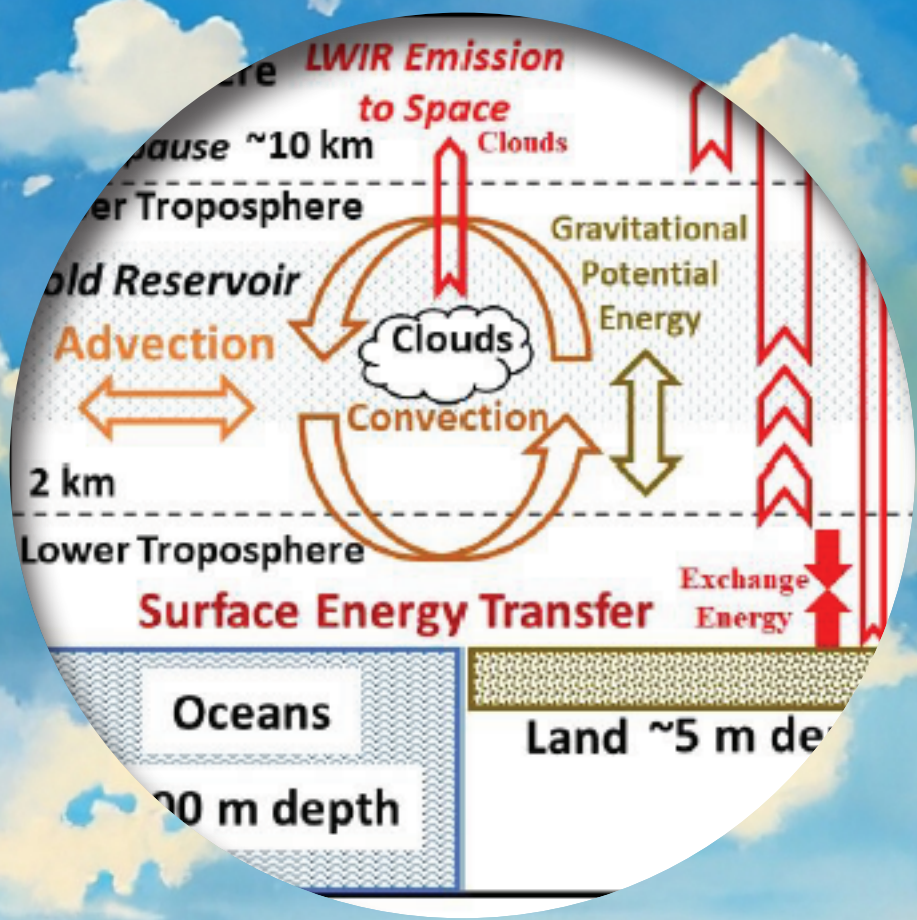
Science of Climate Change

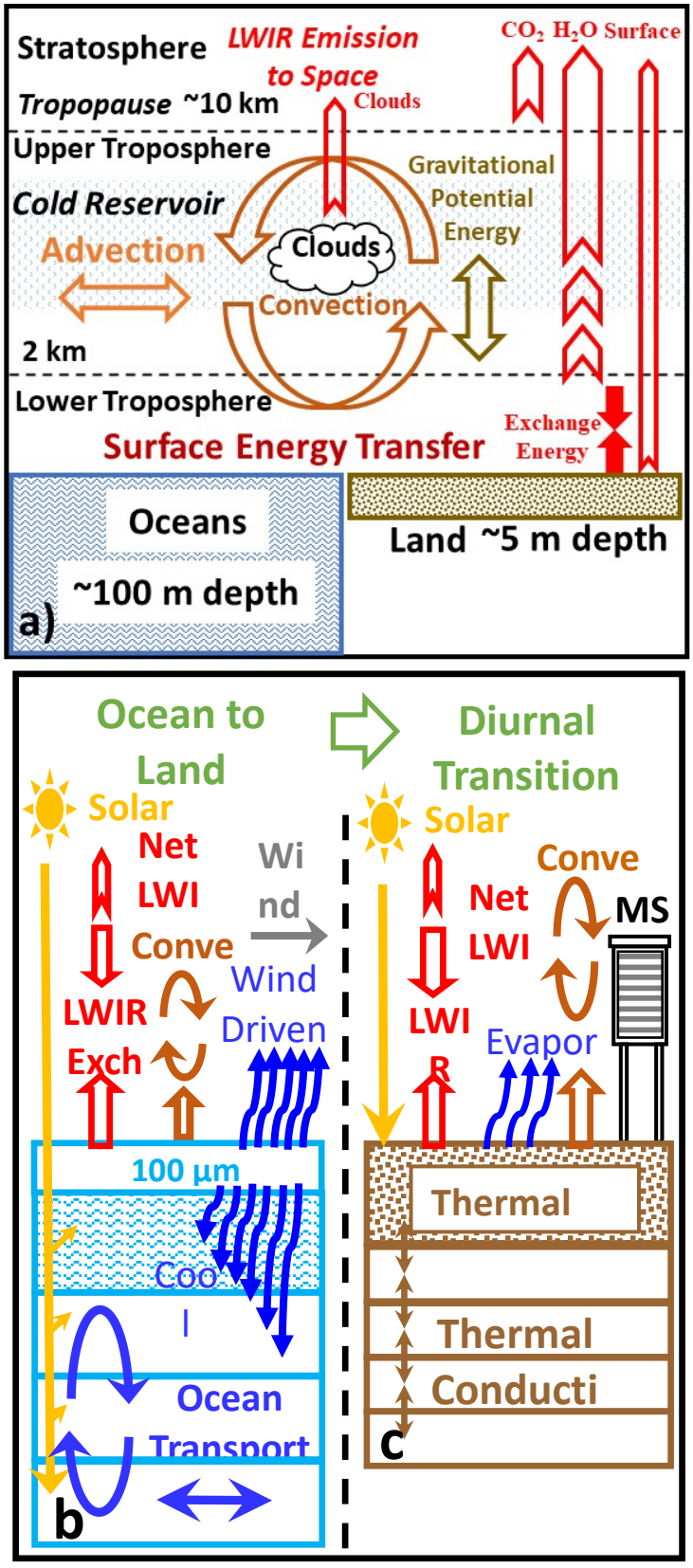
Volume 3.5
2023

https://scienceofclimatechange.org



Published by: Klimarealistene (Org. no. 995 314 592)

ISSN 2703-9080 (print) ISNN 2703-9072 (online)



Basic climate energy transfer processes for the earth, a) atmospheric energy transfer showing the tropospheric heat engine, b) ocean energy transfer and c) land energy transfer (schematic).

From an article by Roy Clark: *Time Dependent Climate Energy Transfer: The Forgotten Legacy of Joseph Fourier.* Figure 1, page 435 - 4

SCIENCE OF CLIMATE CHANGE

Volume 3.5

December 2023

ISSN 2703-9072

Klimarealistene, P.O. Box 33, 3901 Porsgrunn, Norway

Table of Content

Editorial

With this issue of SSC, we finish the 3rd year for this journal. Our goal was to produce quarterly issues. A special issue with proceedings from the Copenhagen Climate Conference in September 2013 was published in the first part of December 2023 as volume 3.4. To our surprise we had interesting papers to fill another issue – which then became this volume 3.5. For the Editorial Board this is important because the Chief-Editor has served his term, and we are uncertain when a new Chief-Editor and Editorial Board will take over.

The first article in this issue is written by Roy Clark who points out that the climate modelers have forgotten what Joseph Fourier wrote already in 1825 in his theory of heat: that we have seasonal delays between peak solar flux and the subsurface temperature response. This is clear evidence of a non-equilibrium thermal response, while the models assume thermal equilibrium.

Michael Schnell and Hermann Harde present a Model-Experiment which shows that the temperature of a heated body depends on the infrared radiation of its colder surrounding, and that this does not contradict physical laws.

The statement in the latest IPCC-reports that all increased carbon in the atmosphere is due to anthropogenic emission, is challenged by Antero Ollila, who shows that this cannot be true, in particular if we study the $^{13}C/^{12}C$ ratio.

The question of origin of the increase of atmospheric CO_2 is also discussed by Eike Roth, who argues, based on elementary physics and logic, that the increase in CO_2 is most likely due to emissions from natural sources with only a minor contribution from anthropogenic sources.

Finally, the importance of CO_2 for the life on Earth is demonstrated by Forrest Frantz, who shows as an example, that the increase in CO_2 has resulted in a 13% increase in the leaf-index for the Scandinavian Peninsula the last 23 years. This has resulted in increased greening, increased crops and cooling the ground in the summer. For a healthy planet we need more CO_2 in the atmosphere - not less!

Another eye-opener is the essay by Richard Mackey who compares the difficulties for the scientific community to accept the theory of continental drift with the extraordinary antiscientific attitude shown by a large number of established scientists supporting the IPCC doctrine.

We are pleased to realize one of our goals which is to provide good science which challenge the established views. This is what brings science forward. We welcome contributors to a lively debate in future issues under a new editor.

Good reading

Jan-Erik Solheim
Editor

A digital version of this volume can be found here: https://doi.org/10.53234/scc202310/34

OPEN ACCESS

Klimarealistene
P.O. Box 33,
3901 Porsgrunn
Norway
ISSN: 2703-9072

Correspondence:
roy.clark@ventu-raphotonics.com

Vol. 3.5 (2023)

pp. 421-444

Time Dependent Climate Energy Transfer: The Forgotten Legacy of Joseph Fourier

Roy Clark

Ventura Photonics,
Thousand Oaks, CA, USA

Abstract

Joseph Fourier discussed the temperature of the earth in two similar memoires (reviews) in 1824 and 1827. An important and long neglected part of this work is his description of the time dependence of the surface energy transfer. In particular, he was able to explain the seasonal time delays or phase shifts between the peak solar flux and the subsurface temperature response using his theory of heat published in 1822. This is clear evidence for a non-equilibrium thermal response to the solar flux. Diurnal and seasonal phase shifts occur in both the ocean and land temperature records. These phase shifts provide important additional information about the time dependent energy transfer processes that determine the surface temperature. Unfortunately, starting with the work of Pouillet in 1836, this time dependence was neglected and replaced by an equilibrium average climate. It was assumed, incorrectly, that the surface temperature could be determined using average values for just the solar and IR flux terms. This approach created CO_2 induced global warming as a mathematical artifact in the simplistic equilibrium air column model used by Arrhenius in 1896. Physical reality was abandoned in favor of mathematical simplicity. The equilibrium assumption is still the foundation of the fraudulent climate models in use today. In order to move beyond the pseudoscience of radiative forcings, feedbacks and climate sensitivity to CO_2 it is necessary to follow Fourier and restore the time dependence to the surface energy transfer. A change in flux produces a change in the rate of cooling (or heating) of a thermal reservoir, not a change in temperature.

Keywords: Convection Transition Temperature; Diurnal Phase Shift; Exchange Energy; Joseph Fourier; Ocean-Land Temperature Coupling; Phase Shift; Seasonal Phase Shift; Thermal Equilibrium; Time Dependent Energy Transfer.

Submitted 2023-11-20, Accepted 2023-12-02. https://doi.org/10.53234/scc202310/25

1. Introduction

The term ‘equilibrium’ is often used incorrectly in climate science. The concept of radiative equilibrium was introduced by Kirchoff (1860):

At thermal equilibrium, the power radiated by an object must be equal to the power absorbed.

The lunar surface under solar illumination is close to thermal equilibrium. The absorbed solar flux is emitted back to space as LWIR radiation with almost no time delay. At the lunar equator, the maximum surface temperature at lunar noon is near 390 K (117 °C). As the solar flux changes, the surface temperature changes so that the emitted LWIR flux matches the absorbed solar flux, Clark and Rörsch (2023). The term equilibrium as used by Arrhenius, (1896) was not a radiative equilibrium, it was simply a mathematical equality between an average absorbed solar flux and an average emitted LWIR flux. Similarly, the term equilibrium used by Manabe and Wetherald, (1967) was a steady state condition. The average solar and LWIR fluxes in and out of the model were equal and the internal air layer and surface temperatures were stable. The temperature change during each model time step was very small. Such a condition is not found in the earth’s atmosphere.

An important property of a non-equilibrium thermal system is the time delay or phase shift between the time varying heat source and the temperature response of the thermal reservoir. Joseph Fourier discussed the temperature of the earth in two similar memoires in 1824 and 1827, Fourier (1824; 1827). He correctly described the time dependent heating of the earth's land surface by the solar flux using his theory of heat, Fourier (1822). He also described ocean solar heating and atmospheric cooling by convection. However, he did not use the term 'greenhouse effect'. Instead, he described a solar calorimeter with glass windows. An important part of his work was the description of the seasonal time delay or phase shift in the subsurface heat transfer.

> *At a moderate depth; as three or four meters, the temperature observed does not vary during each day, but the change is very perceptible in the course of a year, it varies and falls alternately. The extent of these variations, that is, the difference between the maximum and minimum of temperature, is not the same at all depths, it is inversely as the distance from the surface. The different points of the same vertical line do not arrive at the same time at the extreme temperatures. ..... The results observed are in accordance with those furnished by the theory, no phenomenon is more completely explained.* *Fourier 1824, p. 144.*

This is indisputable evidence for a non-equilibrium thermal response to the solar flux. There is a time delay as heat flows in and out of the ground or the oceans. Such seasonal and diurnal phase shifts have been ignored in climate science for almost 200 years. Similar phase shifts occur in other energy storage devices including capacitors in AC electronic circuits and in optical passive cavity resonators (cavity ringdown), Clark (1993).

The phase shifts provide important additional information about the time dependent energy transfer processes that determine the surface temperature. Unfortunately, starting with the work of Pouillet (1836), this time dependence was neglected and it was incorrectly assumed the surface temperature could be determined using average values for just the solar and IR flux terms. Physical reality was abandoned in favor of mathematical simplicity. Arrhenius (1896) stated:

> *III.* ***Thermal Equilibrium*** *on the Surface and in the Atmosphere of the Earth*
>
> *All authors agree in the view that there prevails an* ***equilibrium*** *in the temperature of the earth and of its atmosphere.* *Arrhenius 1896, p. 254.*

Manabe and Wetherald (1967) set out to answer the following questions:

> *1) How long does it take to reach a state of* ***thermal equilibrium*** *when the atmosphere maintains a realistic distribution of relative humidity that is invariant with time?*
>
> *2) What is the influence of various factors such as the solar constant, cloudiness, surface albedo and the distributions of various atmospheric absorbers on the* ***equilibrium temperature*** *of the atmosphere with a realistic distribution of relative humidity?*
>
> *3) What is the* ***equilibrium temperature*** *of the earth's surface corresponding to realistic values of these factors?* *Manabe and Wetherald, 1967, p. 242.*

Knutti and Hegerl, (2008) stated:

> *When the radiation balance of the Earth is perturbed, the global surface temperature will warm and adjust to a* ***new equilibrium state****.* *Knutti and Hegerl, 2008, p. 735.*

Manabe and Wetherald, (1967) copied Arrhenius and created the equilibrium climate fantasy land in which the climate modelers play their computer games with radiative forcings, feedbacks and a climate sensitivity to CO_2. This fantasy land is described in Chapter 7 of the Working Group 1 IPCC Climate Assessment Report (2021):

> *This chapter assesses the present state of knowledge of Earth's energy budget, that is, the main flows of energy into and out of the Earth system, and how these energy flows govern the climate response to a radiative forcing. Changes in atmospheric composition and land use, like those caused by anthropogenic greenhouse gas emissions and emissions of aerosols and their precursors, affect climate through perturbations to Earth's top-of-atmosphere energy budget. The effective radiative forcings (ERFs) quantify these perturbations, including any consequent adjustment to the climate system (but excluding surface temperature response). How the climate system responds to a given forcing is determined by climate feedbacks associated with physical, biogeophysical and biogeochemical processes. These feedback processes are assessed, as are useful measures of global climate response, namely* ***equilibrium climate sensitivity*** *(ECS) and the transient climate response (TCR).*

There is no climate equilibrium state that can be perturbed by an increase in the atmospheric concentration of CO_2 or other greenhouse gases. In the time step integration algorithm used by Manabe and Wetherald in 1967, the change in temperature produced by a 'CO_2 doubling' during each time step is too small to measure in the normal diurnal and seasonal changes in surface temperature. The warming signal created by the 1967 model cannot accumulate in the real atmosphere.

Phase shifts, such as those described by Fourier, are observed in the diurnal and seasonal temperature cycles for both ocean and land temperatures. However, before considering these phase shifts in more detail, a brief review of time dependent energy transfer processes will be provided. Additional information is provided by Clark and Rörsch (2023).

2. Climate Energy Transfer

The earth is an isolated planet that is heated by the absorption of short wave (SW) electromagnetic radiation from the sun and cooled by the emission of longwave IR (LWIR) radiation back to space. The earth's climate has been sufficiently stable over several billion years for life to evolve into its present forms. This requires an approximate planetary energy balance between the absorbed solar flux and the outgoing LWIR radiation (OLR) returned to space so that the surface temperature over most of the planet remains within the relatively narrow range needed to sustain life. Unfortunately, this has led to the misconception that there is an exact energy balance between the absorbed solar flux and the OLR that controls the surface temperature.

The earth is also a rotating water planet with an atmosphere that has an IR radiation field. Approximately 71% of the surface area is ocean. At the surface, the downward LWIR flux from the lower troposphere interacts with the upward LWIR flux from the surface to establish an exchange energy. This limits the net cooling LWIR flux (upward minus downward LWIR flux) to the emission into the atmospheric LWIR transmission window, mainly in the 800 to 1200 cm^{-1} spectral range. Within the main spectral regions of the atmospheric IR absorption and emission bands, when the surface and surface air temperatures are similar, photons are exchanged without any significant transfer of heat. In order to dissipate the absorbed solar heat, the surface must warm up so that the excess heat is removed by moist convection (evapotranspiration). This requires a thermal and/or humidity gradient at the surface-air interface. The requirement for climate stability is set by the Second Law of Thermodynamics, not the First. There is no 'magic thermostat' at the top of the atmosphere (TOA) that controls the surface temperature. The surface gradients adjust as the temperatures change and this maintains the overall energy balance.

Convection is also a mass transport process. It is coupled to both the gravitational field and the rotation (angular momentum) of the earth. As the warm air rises through the troposphere, it cools as it expands and internal energy is converted to gravitational potential energy. For dry air, the lapse rate, or change in temperature with altitude, is -9.8 °C km^{-1}. As moist air rises above the saturation level, water condenses to form clouds with the release of latent heat. This reduces the

lapse rate. The US standard atmosphere uses an average lapse rate of -6.5 °C km^{-1}. The coupling of the convection to the rotation leads to the formation of the Hadley, Ferrel and polar cell convective structure, the trade winds, the mid latitude cyclones/anticyclones and the ocean gyre circulation. In addition, the troposphere functions as an open cycle heat engine that transports part of the absorbed solar heat from the surface to the middle and upper troposphere by moist convection. From here it is radiated back to space, mainly by LWIR emission from the water bands. The upward and downward LWIR flux terms are decoupled by molecular line broadening effects, Clark and Rörsch (2023). When the atmospheric concentration of a greenhouse gas such as CO_2 is increased, there is a slight decrease in the LWIR flux at TOA produced by absorption in the atmopshere below. A small amount of additional heat is released into the tropopshere. This is dissipated by wideband LWIR emission to space and does not produce a measurable change in surface temperature. A change in flux at TOA is called a radiative forcing by the IPCC, Ramaswamy et al, (2019). Such a forcing by greenhouse gases does not change the energy balance of the earth, nor does it produce a measurable change in surface temperature.

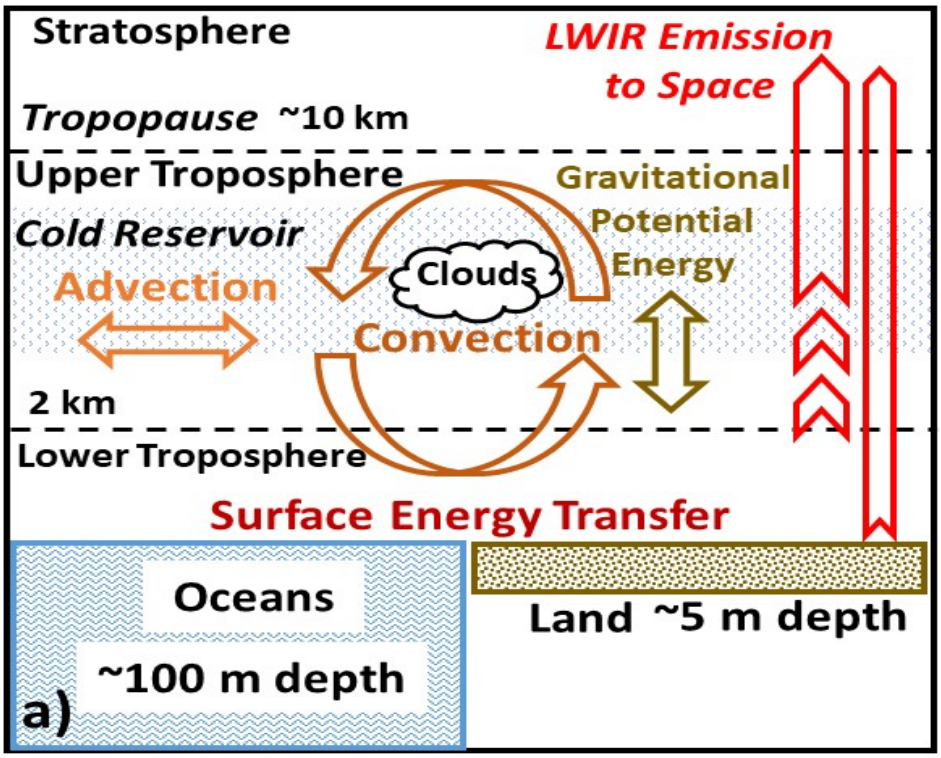
A change in surface temperature is produced by a change in the heat content or enthalpy of the surface reservoir or thin layer of ocean or land at the surface-air interface. There are four main, time dependent, interactive flux terms that are coupled to this reservoir. These are the absorbed solar flux, the net LWIR emission, the moist convection (evapotranspiration) and the subsurface transport (precipitation and freeze/thaw effects are not included here). The net LWIR flux increases with decreasing humidity and decreases with increasing cloud cover. The convection depends on the temperature difference between the surface and the surface air layer. The energy transfer processes are different at the land-air and ocean-air interfaces and have to be considered separately. In addition, the ocean surface temperatures are coupled to the land surface temperatures by weather systems that form over the oceans and move overland.

Over the oceans, the surface is almost transparent to the solar flux. Approximately half of the flux is absorbed within the first meter layer and 90% is absorbed within the first 10 m layer, Clark (2013a, 2013b). The diurnal temperature rise at the surface is quite small, typically 2 °C or less. The dominant cooling term is the wind driven evaporation or latent heat flux. The LWIR flux is absorbed within the first 100 micron layer, Hale and Querry (1973). Here it is fully coupled to the wind driven evaporation or latent heat flux. The sensible heat flux term is usually small, less than 10 W m^{-2}. The cooling terms are fully coupled at the surface and should not be separated and analyzed independently of each other. The cooler water produced at the surface then sinks and is replaced by warmer water from below. This is a Rayleigh-Benard type of convective flow with columns of warmer and cooler water moving in opposite directions. It is not a simple diffusion process. The convective flow and therefore the evaporative cooling continue over the full 24 hour diurnal cycle. As the cooler water sinks, it carries the surface momentum to lower depths. This drives the ocean currents that form the ocean gyre circulation. Outside of the tropics there is a seasonal time delay or phase shift between the peak solar flux at solstice and the surface temperature response that may reach 6 to 8 weeks. In addition, there is no requirement for an exact flux balance between the solar heating and the surface cooling terms. There are natural variations or quasi-periodic oscillations in ocean surface temperatures that may extend to depths of 100 m or more. This also means that there is no exact planetary flux balance at TOA between the absorbed solar flux and the OLR.

Over land, all of the flux terms are absorbed by a thin surface layer. The surface temperature increases in the morning after sunrise as the solar flux is absorbed. This establishes a thermal gradient with both the cooler air above and the subsurface ground layers below. The surface-air gradient drives the evapotranspiration and the subsurface gradient conducts heat below the surface during the first part of the day. Later in the day, as the surface cools, the subsurface gradient reverses and the stored heat is returned to the surface. As the land and air temperatures equalize in the evening, the convection stops and the surface cools more slowly by net LWIR emission. This convection transition temperature is reset each day by the local weather system passing through. Almost all of the absorbed solar heat is dissipated within the same diurnal cycle.

The surface or skin temperature is the temperature at the surface-air interface. The weather station temperature or meteorological surface air temperature (MSAT) is the temperature measured by a thermometer installed in a ventilated enclosure located for convenience near eye level, 1.5 to 2 m above the ground, Oke (2016). Historically in the US, the daily minimum and maximum MSATs were recorded using Six's thermometer mounted in a white painted wooden enclosure (Stevenson screen or cotton region shelter). Temeratures are now recorded electronically using a smaller 'beehive' enclosure. The minimum and maximum MSAT are produced by different physical processes. The minimum MSAT is usually a measure of the surface air temperature of the local weather system passing through. The change in temperature or ΔT from minimum to maximum is determined by the mixing of the warm air rising from the solar heated surface with the cooler air at the level of the MSAT thermometer. The minimum and maximum readings are often averaged to give an 'average daily temperature'. This has little physical meaning.

The energy transfer processes associated with the surface energy transfer and the tropospheric heat engine are shown schematically in Fig. 1.



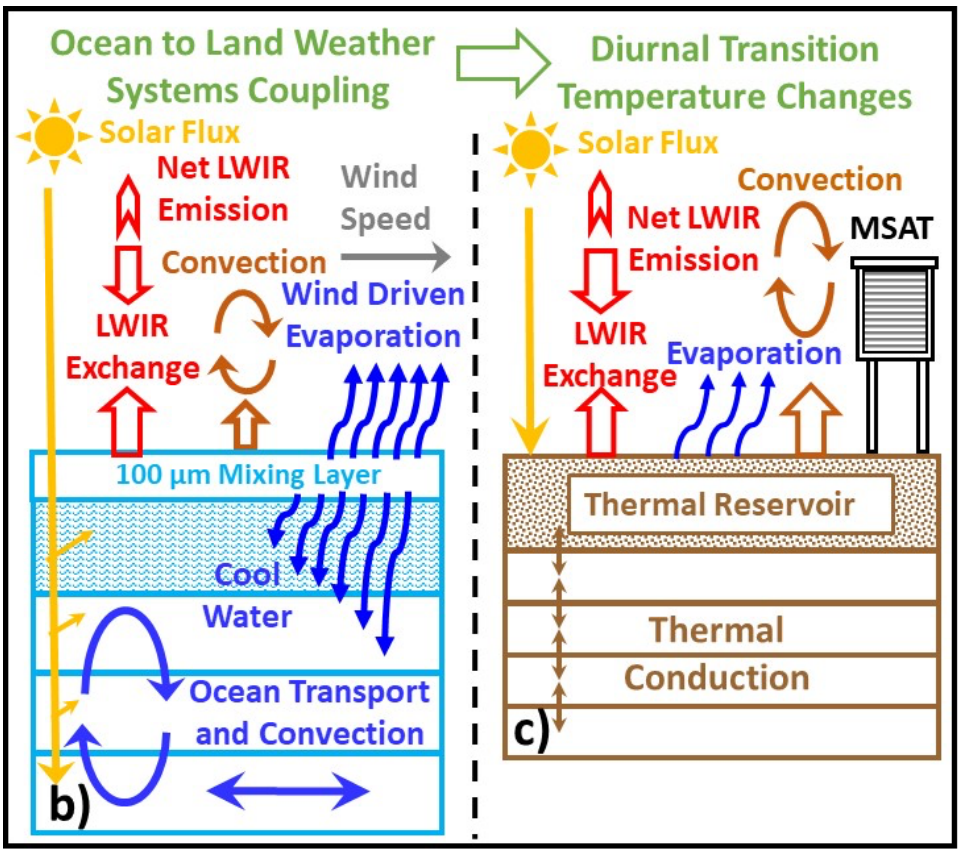


Figure 1: Basic climate energy transfer processes for the earth, a) atmospheric energy transfer showing the tropospheric heat engine, b) ocean energy transfer and c) land energy transfer (schematic).

The focus of this article is on the null hypothesis that changes in the atmosperhic concentration of greenhouse gases do not cause climate change. Short term climate change is related to quasi-periodic ocean oscillations with periods in the 1 to 7 and 10 to 70 year range. Longer term climate changes in the 100 to 1000 year time frame are related to variations in the solar activity as measured by sunspot cycles and other solar pameters. Ice age cycles with periods near 100,0000 years are caused by changes to the earth's orbital and axial rotation known as Milankovitch cycles. Over longer geological time scales, climate change is produced by plate tectonics that alter the continental boundaries that determine ocean circulation, Clark and Rörsch (2023). Natural climate drivers were recently considered by Ollila (2023). The detailed energy transfer processes related to climate change are both subtle and complex. The first step is to abandon the pseudoscience of radiative forcings, feedbacks and climate sensitivity and consider instead the time dependence of the climate energy tranfer processes that determine the surface temperature, including the phase shifts that were described by Fourier almost 200 years ago.

3. The Diurnal Ocean Phase Shift

When the solar flux warms the ocean during the day, there is a time delay or phase shift between the peak solar flux at local noon and the surface temperature response. The magnitude of both the temperature increase and the time delay are dependent on the wind speed.

Fig. 2 shows selected TRITON buoy data for location 156° E, 0° lat. (equator) in the Pacific warm pool, TRITON (2021). Hourly average data are shown for July 1 to 15, 2010. Fig. 2a shows the

air temperature and the ocean temperatures at 1.5 and 25 m depth (SST 1.5 and SST 25). Fig. 2b shows the wind speed and the solar flux. Over the period shown, the average air temperature was 301.2 K (28.2 °C), the averge SST was 301.8 K (28.8 °C) for SST 1.5 and 301.6 K (28.6 °C) for SST 25. Both the air and the SST 1.5 temperatures exhibit a diurnal variation. The maximum daily excursion was 1.5 K for the air temperature and 1 K for SST 1.5. The SST 1.5 data show a strong dependence on the wind speed. The maximum increase in daily temperature of 1 K on day 10 occurred with the wind speed near 1 m s^{-1}. The minimum increase in temperature of 0.1 K occurred on day 14 when the wind speed was in the 6 to 7 m s^{-1} range. These maxima and minima are indicated by the arrows in Fig. 2. There was a gradual drift in SST 25, but there was no significant diurnal variation at these depths.

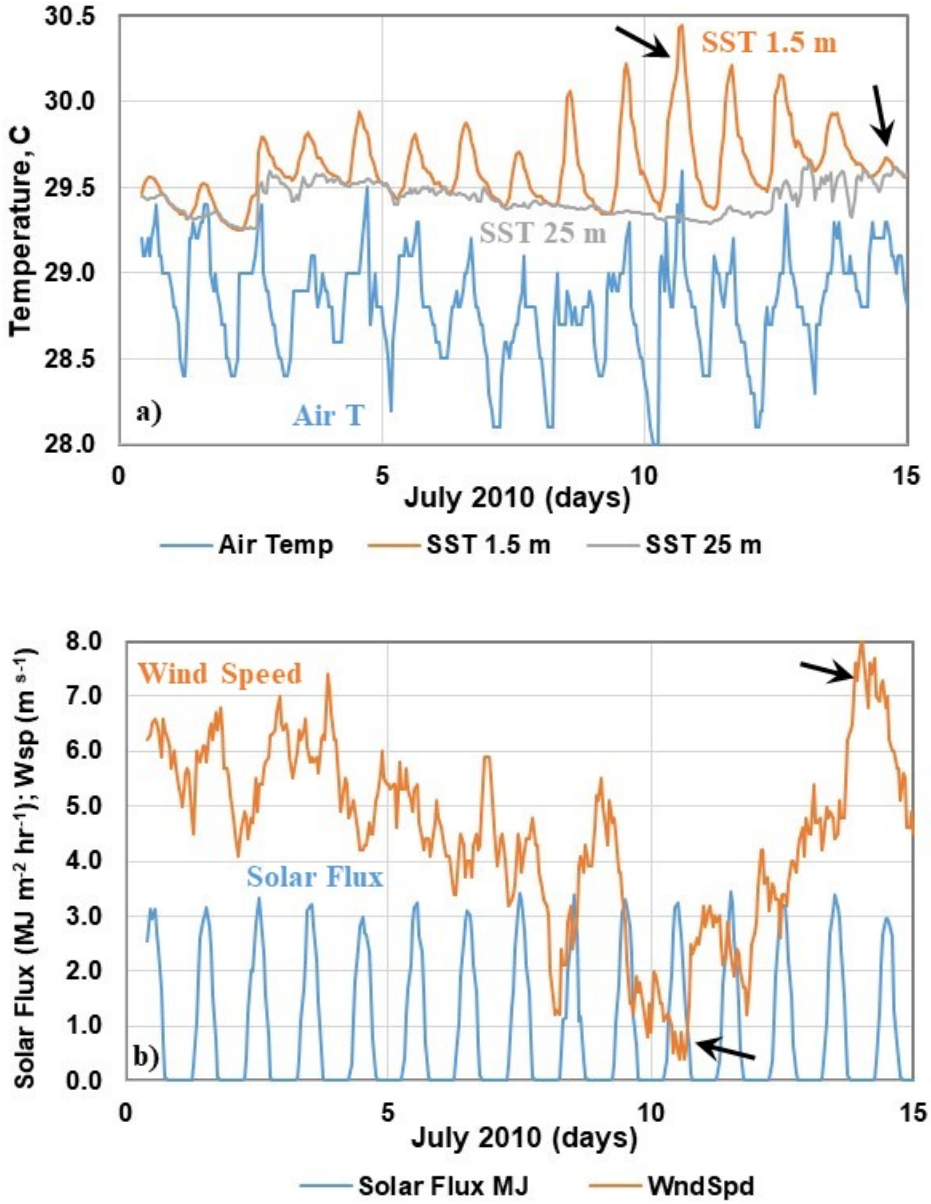


Figure 2: July 2010 TRITON buoy hourly data, 156° E, 0° lat., a) air and ocean temperatures (1.5 and 25 m), b) wind speed and solar flux.

The magnitude of the phase shift is also dependent on the wind speed. This is shown in Fig. 3 for days 10 to 15. The approximate phase shift in hours and the total daily solar flux in MJ m^{-2} day^{-1} are shown for each of the 5 days. The phase shift decreases as the wind speed increases. This increases the surface evaporation and there is more downward convection of cooler water from the surface. The sensitivity of the latent heat flux to the wind speed is approximately 15 W m^{-2}/m s^{-1}, Clark and Rörsch (2023). In addition, the 1 to 2 MJ m^{-2}.day^{-1} variations in the total daily solar flux have no observable effect on the SST 1.5 diurnal temperature changes. The increase in downward LWIR flux to the surface produced by an increase of 140 ppm in the atmospheric CO_2 concentration is approximately 2 W m^{-2} or 0.17 MJ m^{-2}.day^{-1}. This can have no measurable effect on ocean temperatures. It is simply absorbed within the first 100 micron ocean layer and dissipated as an insignificant part of the total surface cooling flux. The absorbed solar flux is decoupled from the wind speed driven latent heat flux. There is no 'equilibrium average flux balance' at the ocean surface on any time scale. The amount of heat stored in the ocean thermal reservoir depends on the accumulated net flux balance, including ocean transport effects. There can be no 'climate sensitivity' to CO_2.

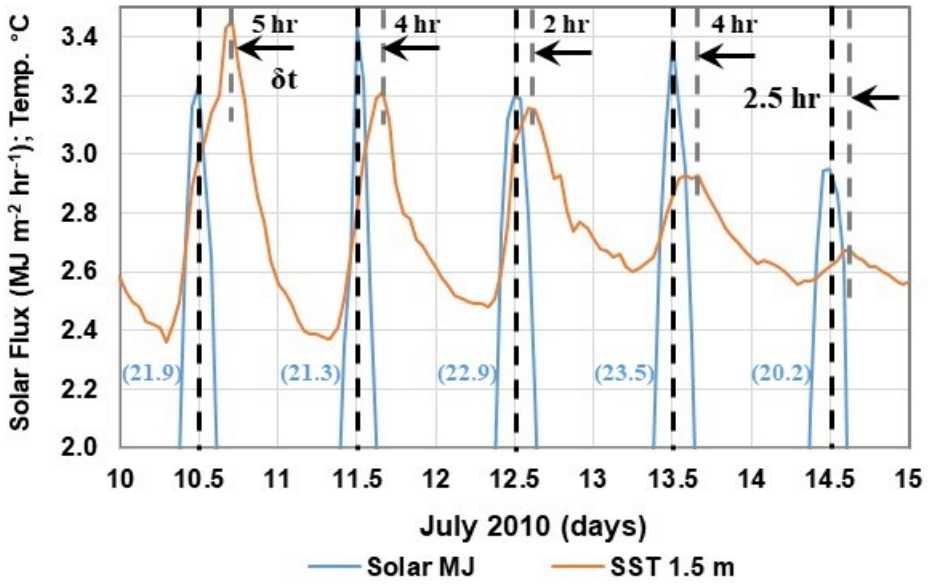
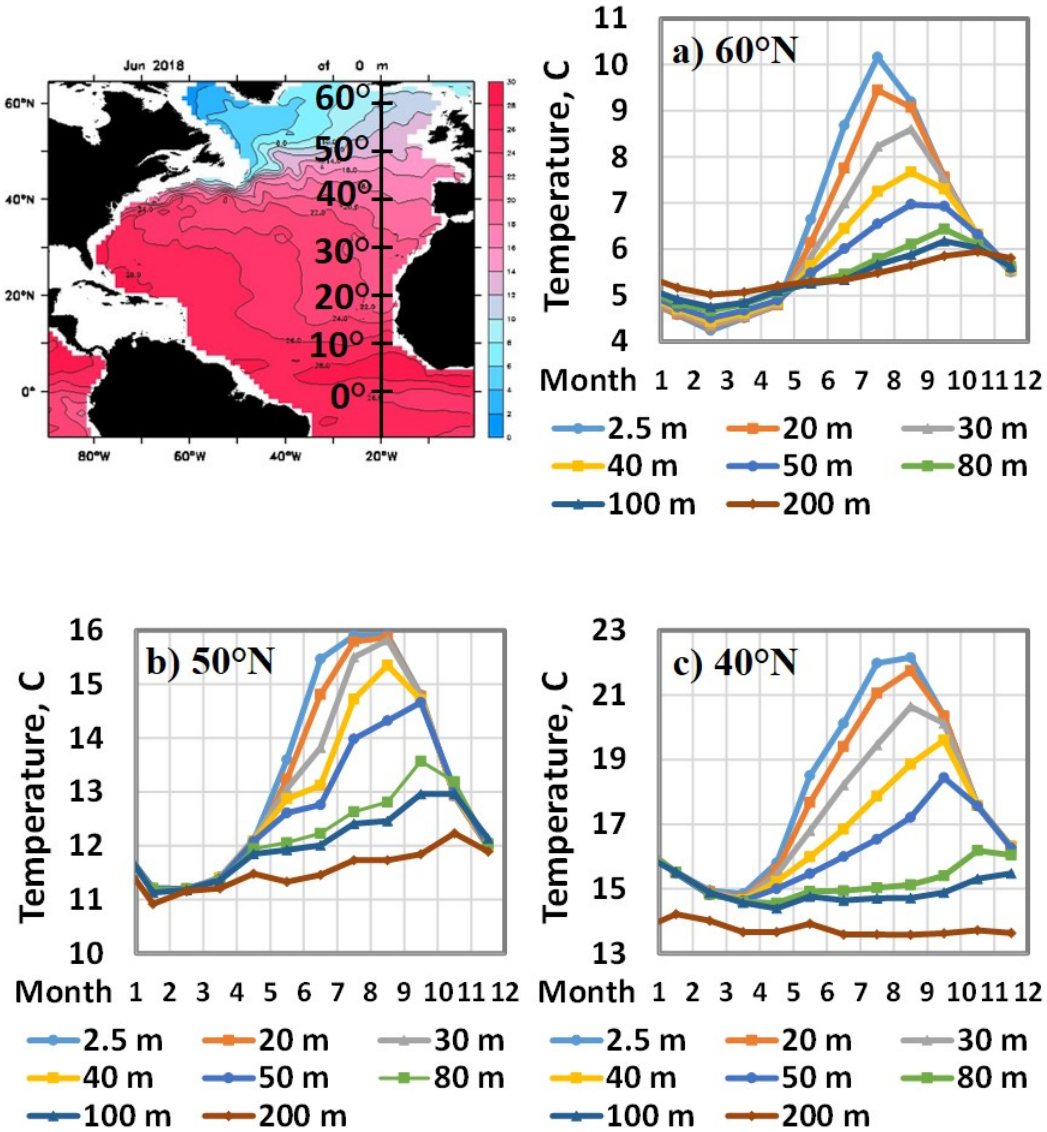


Figure 3: Phase shift between the 1.5 m ocean temperature and the solar flux, July 10 to 15, 2010. The values for the total daily solar flux (MJ m^{-2} day^{-1}) are also shown in parenthesis.

4. The Seasonal Ocean Phase Shift

Fig. 4 shows the monthly ocean temperatures for 2018 at selected depths from 2.5 to 200 m for a 5° x 1° (latitude x longitude) strip at 10° intervals from 60° N to the equator, 0° N along the 20° longitude transect in the N. Atlantic Ocean. This extends from south of Iceland to the equator off the coast of Africa as shown on the location map. The data were downloaded from the Argo Marine Atlas, Argo (2021). For latitudes from 20° to 60° N, the data show a winter surface temperature minimum in March or April. Summer solar heating then produces a stable stratified thermal layer structure with a surface temperature peak in August or September. The peak temperatures increase from 10 °C at 60° N to 25 °C at 20° N. There is a time delay or phase shift of approximately 8 weeks after summer solstice. The phase shift increases and temperature rise decreases at lower depths. The subsurface thermal layer structure then collapses as the wind driven evaporative cooling in winter exceeds the solar heating. The heat stored and released during the

course of a year may easily reach 1000 MJ m^{-2}. This is a major factor in stabilizing the earth's climate. At low latitudes, 0° and 10° N, there is no obvious summer temperature peak. These locations are influenced by the S. Atlantic Equatorial Current. The cooler water from the Benguela Current that flows northwards along the west coast of Africa, changes direction and flows westwards towards S. America. For 0° N, the surface temperature increases from approximately 27 to 29 °C for the first five months of the year. It then decreases to approximately 24 °C over the next three months and gradually warms up during the rest of the year. The April peak is produced by the summer solar heating in the S. Hemisphere.



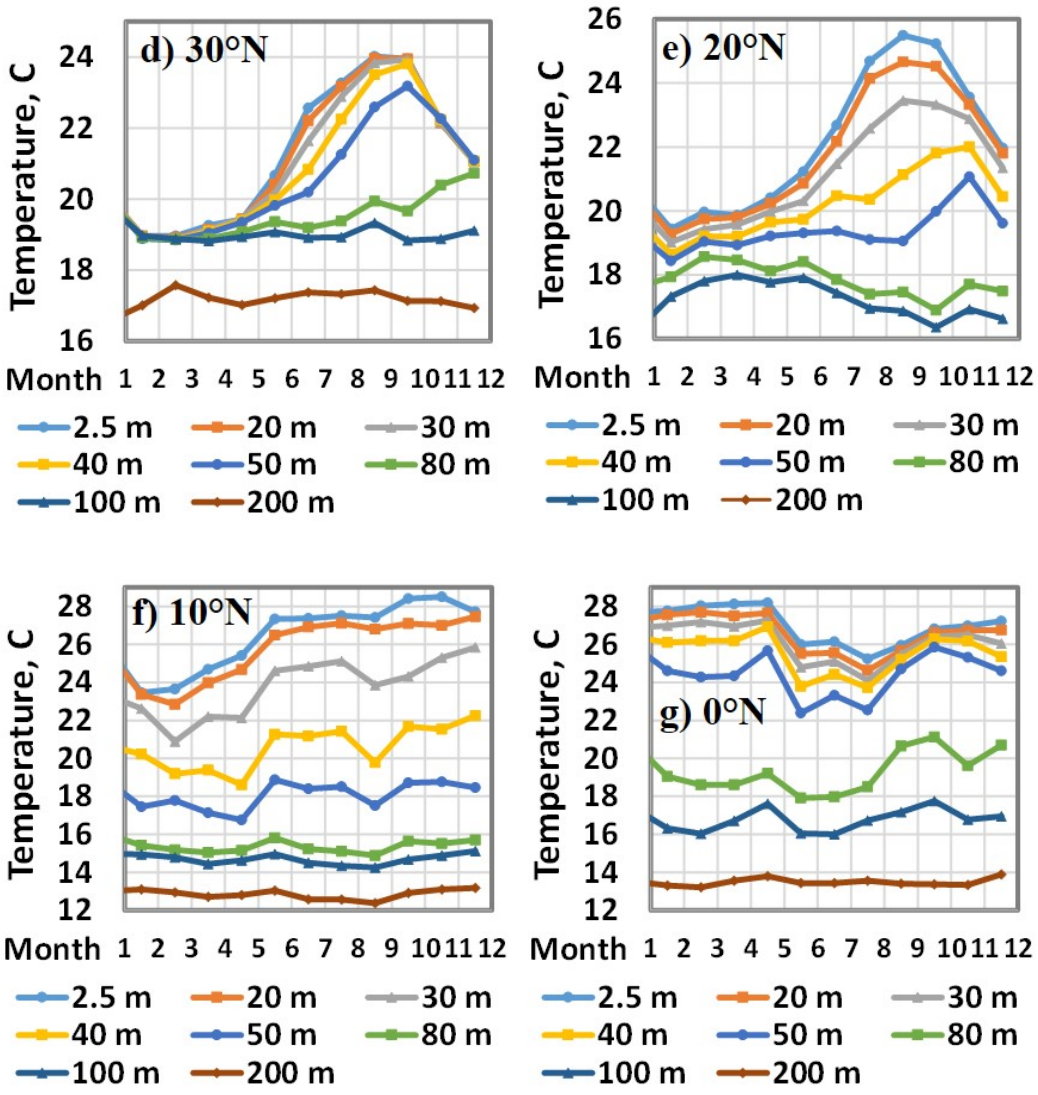


Figure 4: Monthly Argo float data for 2018 for selected depths from 2.5 to 200 m at 10° intervals from 60° N to the equator along the 20° W longitude transect. The locations are indicated on the map, inset.

5. The Diurnal Phase Shift Over Land

Historically in many countries, the maximum and minimum MSATs were recorded using Six's thermometer. The diurnal phase shift was only recorded during specialized measurement programs. It was recorded in 1953 as part of the Great Plains Turbulence Field Program conducted in O'Neill, Nebraska, (Letteau and Davidson 1957; Clark and Rörsch 2023). Subsurface temperature data and the 2 m air temperature recorded for August 13-14, 1953, are shown in Fig. 5. The phase shift for the surface (0.5 cm) temperature is indicated. The measurement site latitude and longitude are 42° 26' N and 98° 32' W. Local solar noon occurs approximately 30 minutes after Central Standard Time (CST) noon. The minimum surface temperature of 18.7 °C was recorded at 06:30 and the maximum surface temperature of 40.9 °C was recorded at 14:30. At the end of the observation period at 02:30 on August 14, the temperature was 20.6 °C. The temperature may be expected to continue to cool until after sunrise. The diurnal temperature rise decreased with increasing depth and the phase shift increased with depth. The diurnal temperature variations were not detectable at 80 cm depth. The surface and air temperatures equalized near 6.30 pm. The convection transition temperaure was near 31 °C.

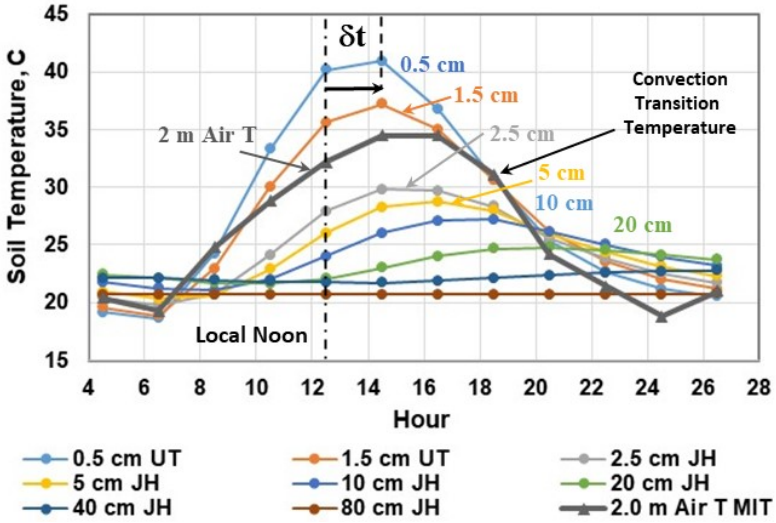


Figure 5: Subsurface temperature data and the 2 m air temperature recorded at O'Neill, Neb. on August 13-14, 1953.

The parameters recorded during this test period also included humidity and solar, total and net flux data. The absolute humidity (mb) and the relative humidity (RH %) are shown in Fig. 6. As the air temperature increased during the first part of the day after sunrise, the absolute humidity increased from 14 to 20 mb. This was caused by increased evaporation from the solar heated surface. However, the relative humidity decreased from 70 to 30%, because the saturated water vapor pressure used to determine the relative humidity increased with the air temperature. The assumption of a fixed RH used in the climate models is incorrect near the surface, Manabe and Wetherald (1967). This also invalidates the water vapor feedback used equilibrium climate models to amplify the initial temperature increase produced by an increase in CO_2 concentration, IPCC AR6 (2021). The O'Neill field data would have been available to Manabe and Wetherald before 1967.

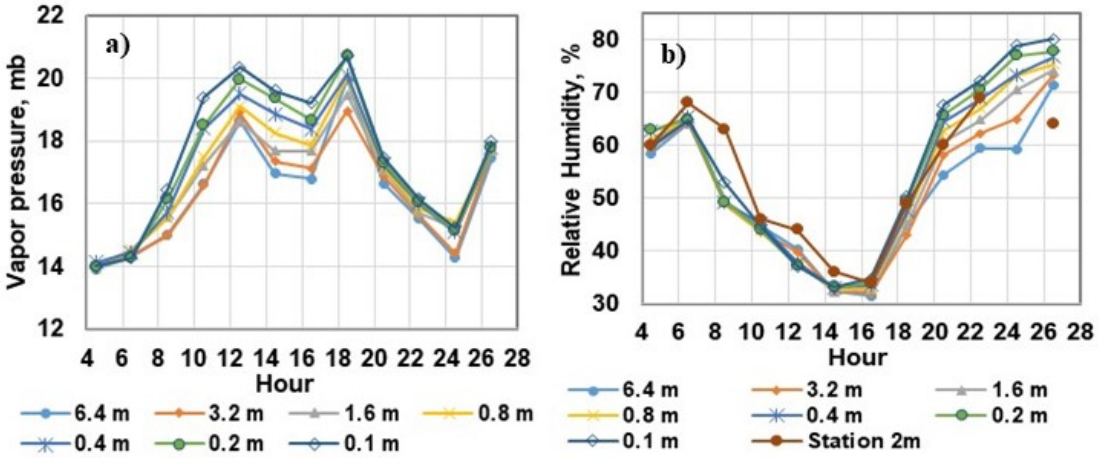


Figure 6: a) Humidity (mb) and b) relative humidity (%) at seven monitoring locations, 0.1 to 6.4 m above the surface. The weather station RH measurement is also included in b). Recorded at O'Neill, Neb. on August 13-14, 1953.

The recorded flux data is summarized in Fig. 7. The peak solar flux was 957 W m^{-2}. At night, the measured net flux is the difference between the upward LWIR flux emitted by the surface and the downward LWIR flux emitted by the lower troposphere to the surface. The average value was -59 W m^{-2}. A negative flux indicates a surface cooling. During the day, the net flux also includes the net solar flux (downward minus reflected solar flux). The total flux includes both the downward solar flux and the downward LWIR flux. There was insufficient data for a more detailed analysis.

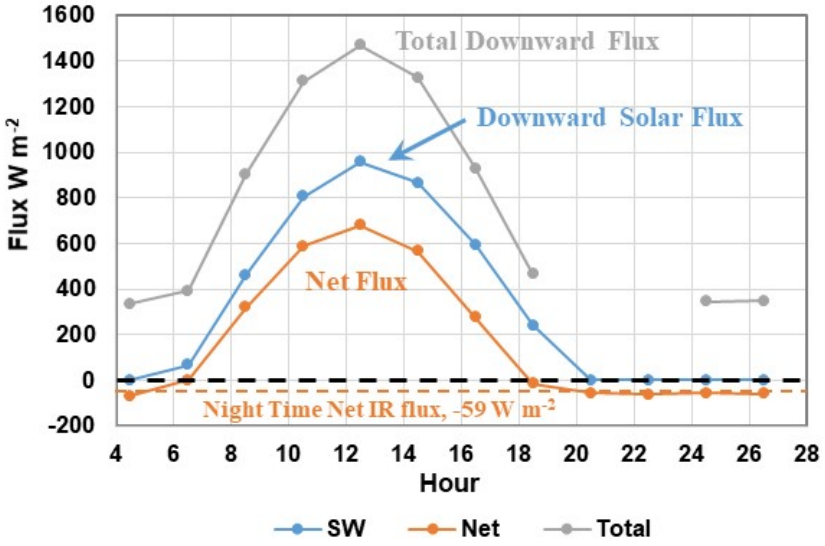


Figure 7: Total, solar and net flux data recorded at O'Neill, Neb. on August 13-14, 1953.

6. The Seasonal Phase Shift Over Land

In addition to the diurnal phase shift, there is also a seasonal phase shift. The peak temperatures occur after the summer solstice. This may be investigated by using the 1981 to 2010 30 year daily climate averages for the O'Neill, Neb. weather station #256290, WRCC, (2021). The maximum and minimum daily temperatures, the 1σ standard deviations and the ΔT (T_{max} - T_{min}) values are shown in Fig. 8. There is a phase shift of approximately 30 days between the peak solar flux at summer solstice, day 172 and the peak seasonal temperature response. In addition, the ΔT values remain within the approximate range 13.4 ±2 °C for the entire year while the temperature variation is ±10 °C. The change in temperature from one day to the next, ΔT_n, for the maximum and minimum temperatures are shown in Fig. 9. The day to day temperature changes are small, below 0.4 °C. The phase shift is indicated by the zero crossing point after the summer solstice. There are three features in Fig. 8 that require further consideration. First, the 1σ standard deviations are quite large. Second, the variation in ΔT is smaller than the changes in the max and min temperatures. Third, the seasonal phase shift is not produced locally.

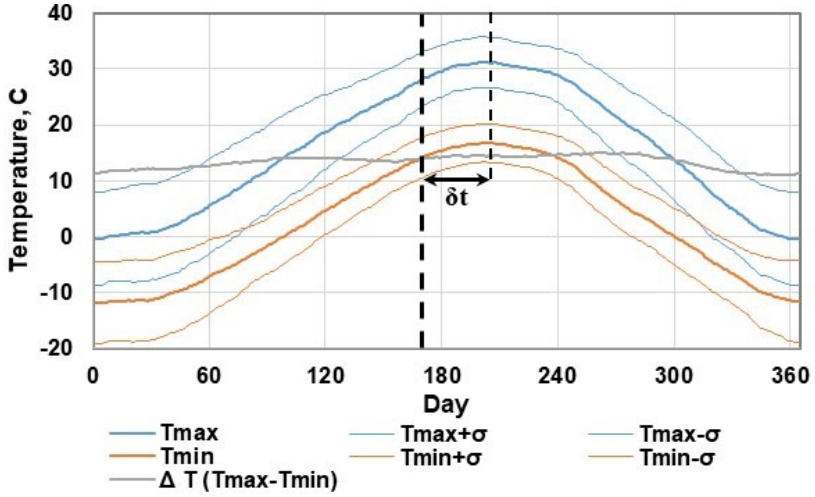


Figure 8: 1981-2010 daily climate averages for O'Neill, Neb., station #256290. The 1σ standard deviations and the ΔT (T_{max} -T_{min}) are also shown. The seasonal phase shift, δt is indicated.

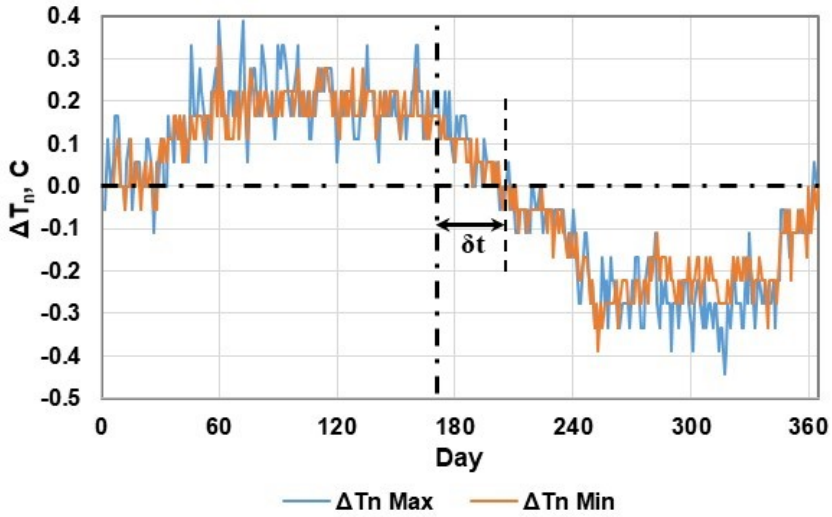


Figure 9: The change in temperature from one day to the next, ΔT_n for the maximum and minimum temperatures shown in Fig. 8. The seasonal phase shift here is the zero-crossing point after the summer solstice. The time delay is approximately 30 days.

The 1σ standard deviation range in the daily average temperatures is from ±3.4 to ±8.7 °C. The larger values occur at the beginning and end of the year when the temperatures are lower. Convective cooling of the surface occurs during the day when the solar heated surface is warmer than the surface air temperature. Each evening there is a convective transition temperature at which the surface and surface air temperatures approximately equalize and the dominant cooling term becomes the net LWIR flux emitted into the LWIR transmission window. This transition temperature is reset each day by the local weather system passing through. The variation in transition temperature is similar to the variation in the minimum temperatures. The measured maximum and minimum temperatures and ΔT values from the 1953 O'Neill observation site weather station data are plotted in Fig. 10 with the climate data from Fig. 8 over the same time period. The differences from the climate means are plotted in Fig. 11. The maximum difference is +8.8 °C for Sept 8. The day to day temperature variations related to the convection transition temperature are sufficiently

large that any change in surface temperautre produced by an increase in the downward LWIR flux to the surface related to an increase in the CO_2 concentration are too small to measure, Clark and Rörsch (2023).

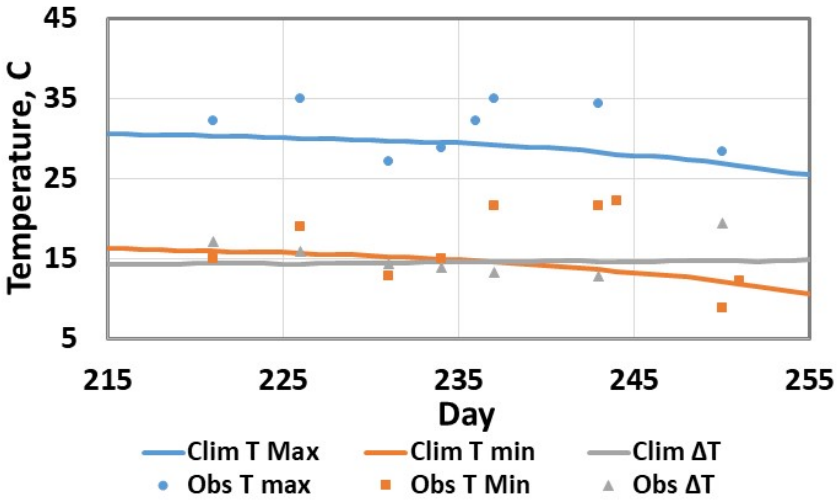


Figure 10: The maximum and minimum air temperatures and ΔT values from the O'Neill Test Site weather station data, plotted with the 1981-2010 30-year climate average data for O'Neill.

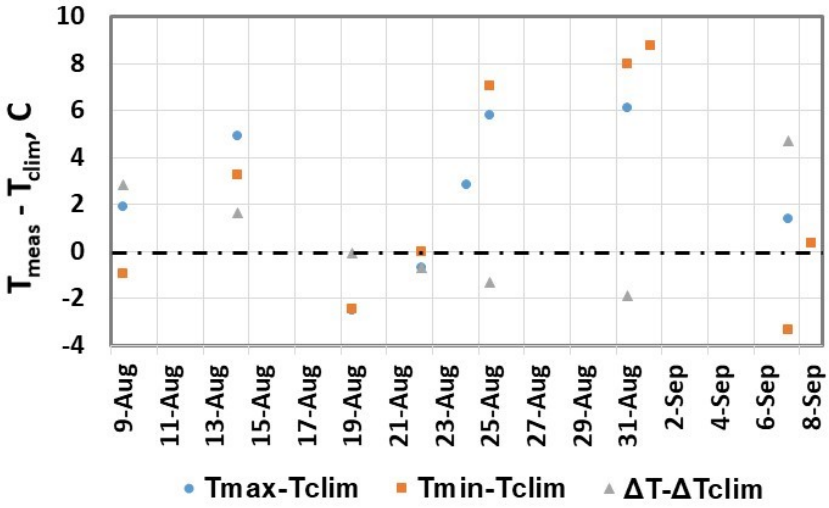


Figure 11: Deviations of the measured temperatures and delta temperatures from the climate averages shown in Figure 8.

The smaller variation in ΔT compared to the min and max temperatures shows that there is a control mechanism that regulates the daily temperature increase. The moist convection (evapotranspiration) or sensible and latent heat fluxes increase with the solar flux and the rate of surface cooling increases. The latent heat flux also depends on the available surface moisture. This is discussed in more detail by Clark and Rörsch (2023).

Over land, almost all of the absorbed solar flux is dissipated within the same diurnal cycle. The heat capacity of the surface layer is too small to produce any large seasonal phase shifts. These are caused by changes in the convective transition temperature related to the weather systems passing through. In many regions of the world, these weather systems are formed over the ocean and the bulk air temperature is influenced by the ocean temperature along the path of the weather system. The source of the seasonal phase shift is the ocean temperature response to the solar flux. There may also be longer term temperature fluctuations related to ocean oscillations.

7. The Coupling of the Ocean and Land Surface Temperatures

The ocean to land coupling of the surface temperatures may be investigated by comparing Pacific Ocean surface temperatures off the coast of California to land surface temperatures measured at the Ameriflux 'Grasslands' monitoring site near Irvine, CA and the daily 1981-2010 climate record from the nearby Santa Ana weather station. Fig. 12 shows the 2.5 m depth ocean temperatures for 2017 derived from Argo float data. The data are for rectangular areas centered at 35° and 45° N, 127.5° W. The angular block size is 2° latitude and 5° longitude. The size was selected to provide an average of at least 10 Argo buoy readings per month near the coast along the path of the prevailing weather systems approaching California from the Gulf of Alaska. The Argo data consists of monthly averages. These were fit to 5th order polynomials that were used to generate the daily trends. In addition, the 30 year average MSAT minimum data for Santa Ana, WRCC, (2021) and the MSAT minimum data for the Grasslands site (Clark and Rörsch 2023; Clark, 2013a; 2013b) are also shown. The seasonal phase shift and the temperature range are consistent with ocean temperatures near 45° N. The temperature spikes in the Grasslands data are produced by the transition from onshore ocean air flow to offshore flow. As the air flows from the inland desert plateau to the ocean it descends by approximately 1 km in altitude and is warmed by air compression.

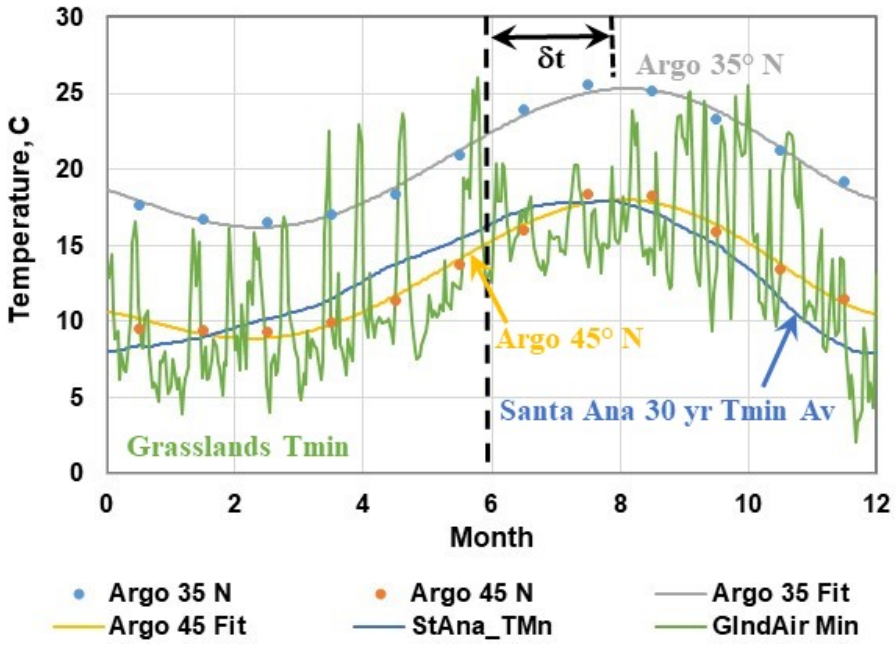


Figure 12: Comparison of Argo 2.5 m ocean surface temperatures at 35° and 45° N with the 30 year 1981-2010 daily minimum MSAT from Santa Ana and the Grasslands 2008 minimum MSAT data.

The seasonal phase shifts observed for Santa Ana are not limited to coastal weather stations. They are observed in weather stations across the continental US and in many other regions of the world. Fig. 13a and 13b shows the 1981-2010 30 year daily T_{min} and T_{max} climate data for eight S. California weather stations, WRCC (2021). The locations are indicated on the map. Los Angeles (LA) and Los Angeles Airport (LAX) are located near or at the coast. The maximum temperatures here are lower because of the influence of the ocean marine layer. The nighttime cooling is also less. Redlands (Rdl), Riverside (Rvsd) and San Bernardino (SnBno) are located approximately 80 km (50 miles) inland, Indio (Ino) and Mecca (Mca) are approximately 150 km (94 miles) inland and Blythe (Bly) is approximately 250 km (156 miles) inland near the Colorado River. The approximate phase shift is indicated. The ΔT temperature rises from min to max are shown in Fig. 13c.

These stay in a narrower range than the measured temperatures. The seasonal phase shifts are shown in Fig. 13d. These vary from approximately 60 to 30 days. The values generally decrease with increasing distance from the coast. Fig. 14 shows the 30 year daily 1981-2010 climate data, ΔT temperature rise and seasonal phase shifts for 11 US stations near 40° latitude.

In addition to the seasonal phase shift, longer term temperature changes related to ocean oscillations are also coupled to the weather station temperatures through the convection transition temperature. For California stations, the Pacific Decadal Oscillation (PDO) can be detected and for UK stations it is the Atlantic Multi-decadal Oscillation (AMO). This is discussed in more detail in Clark and Rörsch (2023).

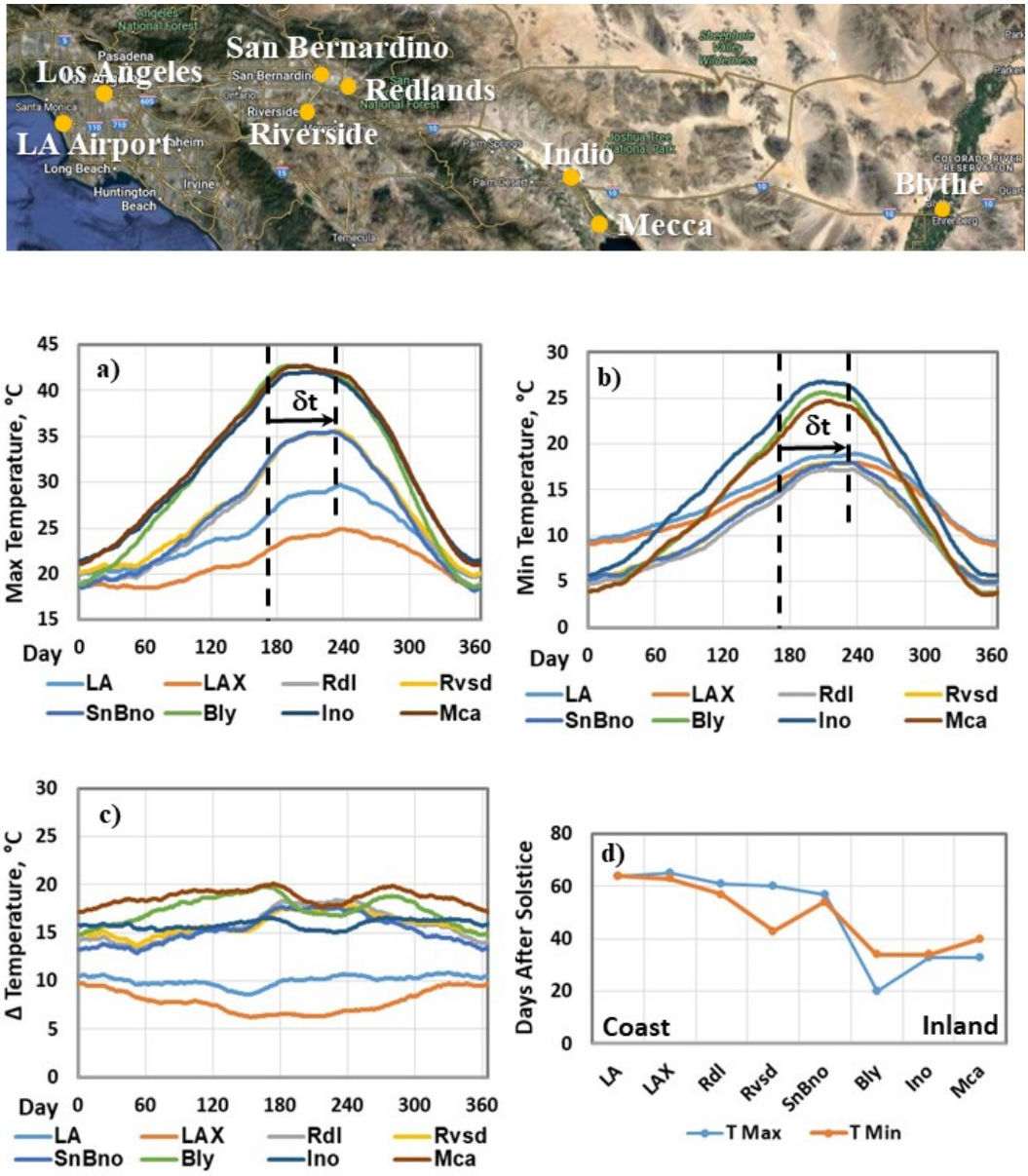


Figure 13: Daily climate averages for a) minimum, b) maximum, c) ΔT (max-min) temperatures and d) the seasonal phase shifts for eight weather stations in S. California, Los Angeles (LA), Los Angeles Airport (LAX), Redlands (Rdl), Riverside (Rvsd), San Bernardino (SnBno), Blythe (Bly), Indio (Ino) and Mecca (Mca).

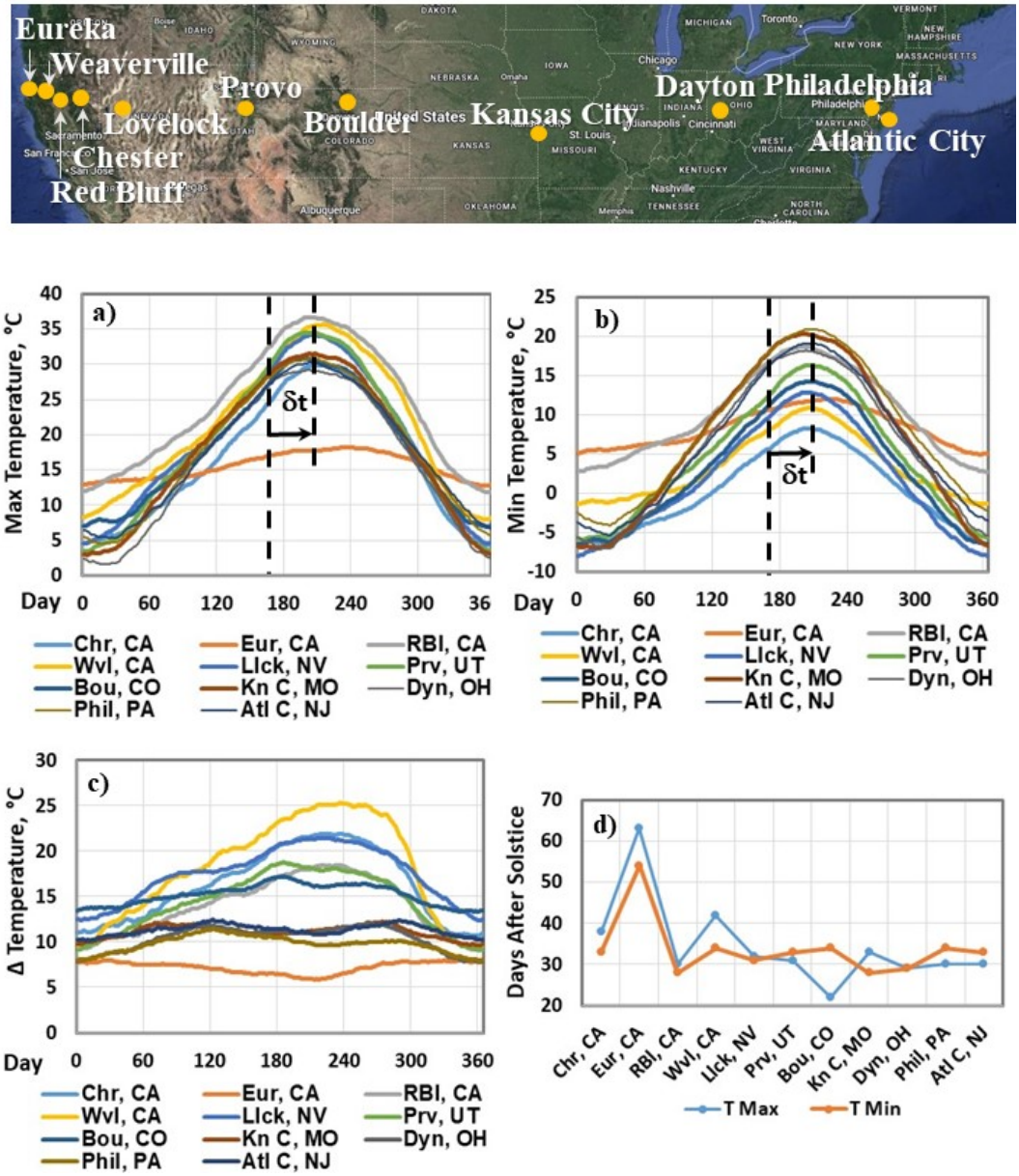


Figure 14: 30 year climate data and seasonal phase shifts for 11 weather stations near 40° latitude, Chester (Chr), CA, Eureka (Eur), CA, Red Bluff (RBl) CA, Weaverville (Wvl), CA, Lovelock (Llck), NV, Provo (Prv), UT, Boulder (Bou), CO, Kansas City (Kn C), MO, Dayton (Dyn), OH, Philadelphia (Phil), PA and Atlantic City (Atl C), NJ.

The global temperature change record is an area weighted average of the weather station data after it has been extensively processed or 'homogenized' and the mean has been subtracted. When the climate anomaly record, such as the HadCRUT4 data set is evaluated, the dominant term is found to be the Atlantic Multi-decadal Oscillation (AMO). The correlation coefficient between the two data sets is 0.8. This is illustrated in Fig. 15a (AMO, 2022; HadCRUT4, 2022; Morice et al, 2012). The AMO consists of a quasi-periodic oscillation superimposed on an underlying linear trend. A least squares fit to the data from 1900 gives a sinusoidal oscillation with an amplitude of 0.2 °C and a period of 61 years with a long term linear trend near 0.3 °C per century. The linear trend is attributed to the temperature recovery from the Maunder minimum or Little Ice Age, Akasofu (2010). Both the period and the slope may change with time. There is a 0.3 °C offset

between the AMO and the HadCRUT data after 1970. This requires further investigation of the 'homogenization' process and bias effects related to changes in the number and location of the weather stations used to generate the HadCRUT averages (Andrews, 2017a; 2017b; 2017c; D'Aleo and Watts, 2010). The influence of the AMO extends over large areas of N. America, Western Europe and parts of Africa. The weather systems that form over the oceans and move overland couple the ocean surface temperature to the weather station data through the diurnal convection transition temperature. The contributions of the other ocean oscillations to the global temperature anomaly are smaller. The IOD and the PDO are dipoles that tend to cancel and the ENSO is limited to a relatively small area of the tropical Pacific Ocean. However, small surface temperature variations in the tropical oceans have a major impact on ocean evaporation and rainfall. Fig. 15b shows a tree ring construction of the AMO from 1567 (Gray, 2004; Gray.NOAA, 2004). The modern instrument record is also indicated in green.

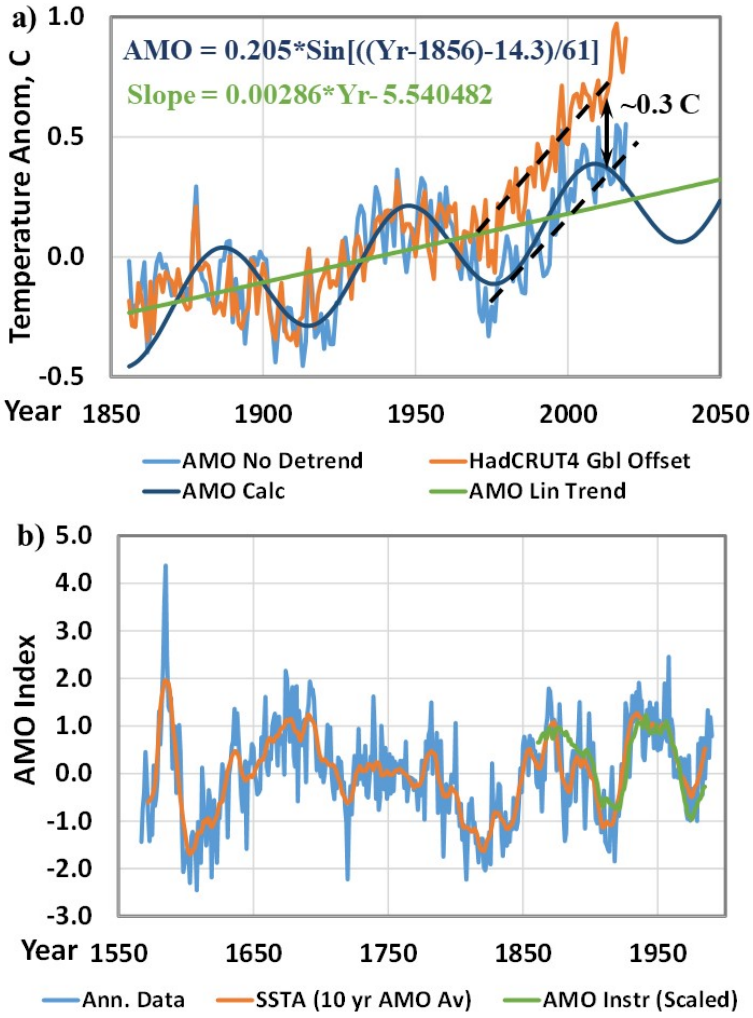


Figure 15: a) Plots of the HadCRUT4 and AMO temperature anomalies overlapped to show the similarities. Both the long term 60 year oscillation and the shorter term 'fingerprint' details can be seen in both plots. b) Tree ring reconstruction of the AMO from 1567. The modern instrument record is shown in green.

The role of the AMO in setting the surface air temperature has been misunderstood or ignored for a long time. The first person to claim a measurable warming from an increase in CO_2 concentration was Callendar (1938). The warming that he observed was from the 1910 to 1940 warming phase of the AMO not from CO_2. This was coupled to the land-based weather stations through changes to the convection transition temperature. During the 1970s there was a 'global cooling'

scare that was based on the cooling phase of the AMO from 1940 to 1970 (McFarlane, 2018; Peterson et al, 2008; Douglas, 1975; Bryson and Dittberner, 1976). In their 1981 paper Hansen et al chose to ignore the 1940 AMO peak in their analysis of the effects of CO_2 on the weather station record, Hansen et al (1981). Similarly, Jones et al conveniently overlooked the 1940 AMO peak when they started to ramp up the modern global warming scare in (Jones et al, 1986; 1988). The IPCC also ignored the AMO peak in its First Assessment Report in 1990, IPCC FAR WG1 fig. 11 SPM p. 29, IPCC FAR (1990) and it has continued to ignore it as shown in IPCC AR6 WG1 TS CS Box 1 fig. 1c p. 61, IPCC, AR6, (2021). This is illustrated in Fig. 16. The AMO, the HadCRUT4 global data and the periods of record used are shown in Fig. 16a. The AMO consists of a long period oscillation near 60 years superimposed on a linear temperature recovery from the Little Ice Age (LIA), Akasofu (2010). The temperature records used by Callendar, Douglas, Jones et al, Hansen et al and IPCC 1990 and 2021are shown in Figs. 16b through 16g. The Keeling curve showing the increase in atmospheric CO_2 concentration is also shown in Figs. 16d through 16g, Keeling (2023).

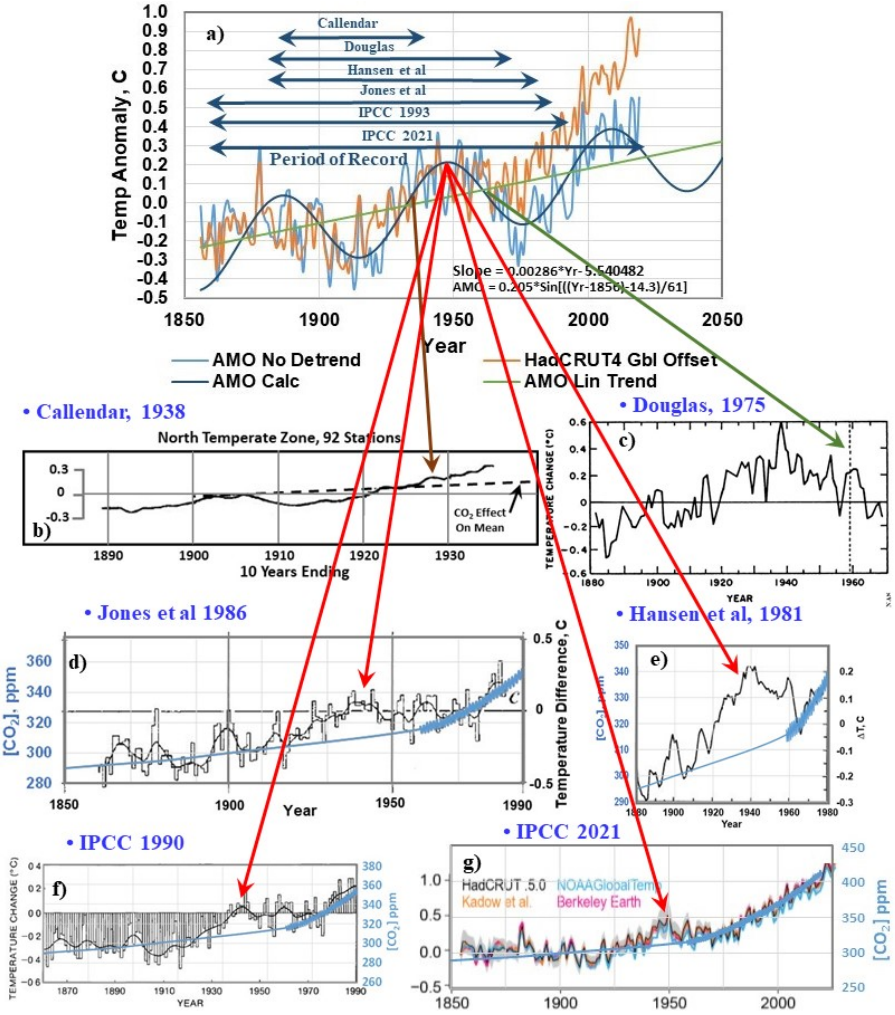


Figure 15: a) AMO anomaly and HadCRUT4 global temperature anomaly, aligned from 1860 to 1970, b) temperature anomaly for N. temperate stations from Callendar (1938), c) global cooling from Douglas (1975), d) global temperature anomaly from Jones et al (1986), e) global temperature anomaly from Hansen et al (1981), f) and g) global temperature anomaly from IPCC (1990) and IPCC (2021). The changes in CO_2 concentration (Keeling curve) are also shown in d) through g). The periods of record for the weather station data are also indicated.

8. Conclusions

The time delays or phase shifts between the peak solar flux and the surface temperature response are an important and long neglected part of the time dependent surface energy transfer processes that determine the surface temperature. The subsurface seasonal land temperature phase shift was described by Fourier in 1824 and 1827. Diurnal and seasonal phase shifts occur in both the ocean and land temperature records. Such phase shifts are clear evidence for a non-equilibrium thermal response to the solar flux. Starting with the work of Pouillet in 1836, this time dependence was neglected and replaced by an equilibrium average 'climate'. It was assumed, incorrectly, that the surface temperature could be determined using average values for just the solar and IR flux terms. Physical reality was abandoned in favor of mathematical simplicity. The scientific process of hypothesis based on available evidence was not applied. The equilibrium climate assumption became accepted as scientific dogma that provided foundation for the pseudoscience of radiaitve forcings, feedbacks and climate sensitivity still used by the IPCC today.

Over the oceans there is a diurnal phase shift where both the temperature rise and the time delay are dependent on the wind speed. This is because the dominant surface cooling term is usually the wind driven evaporation or latent heat flux. Outside of the tropics there is also a significant seasonal phase shift that may easily reach 6 to 8 weeks. There is no requirement for an exact flux balance between the absorbed solar heat and the surface cooling. Any thermal imbalance is accounted for by a change in ocean heat content or enthalpy. The penetration depth of the LWIR radaition into the surface is 100 micron or less. Here it is fully coupled to the wind driven evaporation. Any small increase in downward LWIR flux to the surface is overwhelmed by the much larger and more variable latent heat flux. Small increases in the downward LWIRflux to the surface produced by a 'greenhouse gas forcing' cannot produce a measurable incease in ocean surface temperature.

Over land, the excess absorbed solar heat is removed during the day by moist convection. Almost all of the absorbed solar flux is dissipated within the same diurnal cycle. The surface temperature is reset each day as the bulk air temperature of the local weather system changes the diurnal transition temperature. In many parts of the world, the prevailing weather systems are formed over the oceans and then move overland. This explains the observed coupling of the seasonal phase shift in the ocean surface temperature to the weather station record. On a longer timescale, the ocean oscillations may also be coupled to the weather station record.

There can be no 'CO_2 signal' in the global mean temperature record. The dominant term is the AMO. There are also contributions from urban heat island effects and changes to the number and urban/rural mix of the weather stations used in the averaging. The raw data is also adjusted for bias using homogenization techniques that generally add warming to the raw data. The 1940 AMO peak in the temperature record has been conveniently ignored.

The equilibrium assumption is still the foundation of the fraudulent climate models in use today. When the time dependent surface temperature changes related to the diurnal and seasonal cycles are analyzed in more detail, it is found that there can be no 'climate sensitivity' to CO_2. The changes in LWIR flux related to a 'radiative forcing' by greenhouse gases do not change the energy balance or the surface temperature of the earth. Nor can there be a 'water vapor feedback' that amplifies a nonexistent warming. This is a mathematical artifact created by the equilibrium assumption, the fixed RH distribution and the time step integration algorithm introduced by Manabe and Wetherald in 1967.

Guest-Editor: Stein Storlie Bergsmark; Reviewers: anonymous.

Acknowledgements

This work was performed as independent research by the author. It was not supported by any grant awards and none of the work was conducted as a part of employment duties for any employer. The views expressed are those of the author.

References

Akasofu, S.-I., 2010: *On the recovery from the Little Ice Age*, Natural Science, v. 2, no. 11, pp. 1211-1224. http://dx.doi.org/10.4236/ns.2010.211149

AMO, 2022: *Atlantic Multidecadal Oscillation*. https://www.esrl.noaa.gov/psd/data/correlation/amon.us.long.mean.data

Andrews, R., 2017a: *Adjusting Measurements to Match the Models – Part 3: Lower Troposphere Satellite Temperatures*, Energy Matters, Sept 14. http://euanmearns.com/adjusting-measurements-to-match-the-models-part-3-lower-troposphere-satellite-temperatures/#more-19464

Andrews, R., 2017b: *Making the Measurements Match the Models – Part 2: Sea Surface Temperatures*, Energy Matters, Aug 2. http://euanmearns.com/making-the-measurements-match-the-models-part-2-sea-surface-temperatures/

Andrews, R., 2017c: *Adjusting Measurements to Match the Models – Part 1: Surface Air Temperatures*, Energy Matters, July 27. http://euanmearns.com/adjusting-measurements-to-match-the-models-part-1-surface-air-temperatures/

Argo, 2021: *Global Argo Marine Atlas*. https://argo.ucsd.edu/data/data-visualizations/marine-atlas/

Arrhenius, S., 1896: *On the influence of carbonic acid in the air upon the temperature of the ground*, The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, v. 41, pp. 237-276. https://doi.org/10.1080/14786449608620846

Bryson, R. A. and G. J. Dittberner, 1976: *A non-equilibrium model of hemispheric mean surface temperature*, J. Atmos. Sci., v. 33, no. 11, pp. 2094-2106. https://journals.ametsoc.org/view/journals/atsc/33/11/1520-0469_1976_033_2094_anemoh_2_0_co_2.xml

Callendar, G. S., 1938: *The artificial production of carbon dioxide and its influence on temperature*, J. Roy. Met. Soc., v. 64, pp. 223-240. https://doi.org/10.1002/qj.49706427503 Available at: http://www.met.reading.ac.uk/~ed/callendar_1938.pdf

Clark, R., 2013a: *A dynamic, coupled thermal reservoir approach to atmospheric energy transfer Part I: Concepts,* Energy and Environment, v. 24, nos. 3-4, pp. 319-340. https://doi.org/10.1260/0958-305X.24.3-4.319

Clark, R., 2013b: *A dynamic, coupled thermal reservoir approach to atmospheric energy transfer Part II: Applications*, Energy and Environment, v. 24, nos. 3-4 pp. 341-359. https://doi.org/10.1260/0958-305X.24.3-4.341

Clark, R., 1993, *Optical measurement with direct traceability to the primary standards of length and time: toward a system of metrology based entirely on the properties of the photon*, Optical Engineering, v. 32, no. 3, pp. 571-584. [https://doi.org/10.1117/12.61045]

Clark, R. and A. Rörsch, 2023: *Finding Simplicity in a Complex World - The Role of the Diurnal Temperature Cycle in Climate Energy Transfer and Climate Change*, Clark Rörsch Publications, Thousand Oaks, CA. https://clarkrorschpublication.com/

D'Aleo J. and A. Watts, 2010: *Surface temperature records: policy driven deception?* Aug. 27, http://scienceandpublicpolicy.org/images/stories/papers/originals/surface_temp.pdf (Link not working) Available at: https://venturaphotonics.com/files/6.0_D'Aaleo.Watts.Surface_temp.SPPC%202010.pdf

Douglas, J. H., 1975: *Climate change: chilling possibilities*, Science News, March 1, v. 107, pp.

138-140. https://www.sciencenews.org/wp-content/uploads/2008/10/8983.pdf

Fourier, J.-B. J., 1824: *Remarques générales sur les températures du globe terrestre et des espaces planétaires*, Annales de Chimie et de Physique, v, 27, pp. 136–167. https://gallica.bnf.fr/ark:/12148/bpt6k65708960/f142.image# English translation: http://fourier1824.geologist-1011.mobi/

Fourier, J.-B. J., 1827: *Mémoire sur les températures du globe terrestre et des espaces planétaires*, Mém. Acad. R. Sci. Inst. Fr., v. 7, pp. 527-604. https://www.academie-sciences.fr/pdf/dossiers/Fourier/Fourier_pdf/Mem1827_p569_604.pdf English translation: http://www.wmconnolley.org.uk/sci/fourier_1827/

Fourier, J. -B. J., 1822: *Theorie Analytique de la Chaleur*, Didot, Paris. https://gallica.bnf.fr/ark:/12148/bpt6k29061r/f7.item

Gray, S. T., L. J. Graumlich, J. L. Betancourt and G. T. Pederson, 2004: *A tree-ring based reconstruction of the Atlantic Multi-decadal Oscillation since 1567 A.D.*, Geophys. Res. Letts., v. 31, L12205, pp. 1-4. https://doi.org/10.1029/2004GL019932

Gray, S. T., L. J. Graumlich, J. L. Betancourt and G. T. Pederson, 2004: *Atlantic Multi-decadal Oscillation (AMO) Index Reconstruction,* IGBP PAGES/World Data, Center for Paleoclimatology, Data Contribution Series #2004-062, NOAA/NGDC Paleoclimatology Program, Boulder CO, USA. https://www.ncei.noaa.gov/pub/data/paleo/treering/reconstructions/amo-gray2004.txt

HadCRUT4, 2022: *HadCRUT4 Data Series*, https://www.metoffice.gov.uk/hadobs/hadcrut4/data/current/time_series/HadCRUT.4.6.0.0.annual_ns_avg.txt

Hale, G. M. and M. R. Querry, 1973: *Optical constants of water in the 200 nm to 200 μm wavelength region*, Applied Optics, v. 12, no. 3, pp. 555-563. https://doi.org/10.1364/AO.12.000555

Hansen, J., D. Johnson, A. Lacis, S. Lebedeff, P. Lee, D. Rind and G. Russell, 1981: *Climate impact of increasing carbon dioxide*, Science, v. 213, pp. 957-956. https://pubs.giss.nasa.gov/docs/1981/1981_Hansen_ha04600x.pdf

IPCC AR6, 2021: Forster, P., T. Storelvmo, K. Armour, W. Collins, J.-L. Dufresne, D. Frame, D.J. Lunt, T. Mauritsen, M.D. Palmer, M. Watanabe, M. Wild, and H. Zhang, *The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity*. In: Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.), *Climate Change 2021: The Physical Science Basis*. *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Chapter 7, pp. 923-1054. doi: 10.1017/9781009157896.009, https://www.ipcc.ch/report/ar6/wg1/

IPCC FAR, (1990), Houghton, J. T., G. J. Jenkins and J. J. Ephraums (Eds.), *Climate Change, The IPCC Scientific Assessment*, Cambridge University Press, New York. [https://www.ipcc.ch/site/assets/uploads/2018/03/ipcc_far_wg_I_full_report.pdf]

Jones, P. D., T. M. L. Wigley, C. K. Foland, D. E. Parker, J. K. Angell, S. Lebedeff and J. E. Hansen, 1988: *Evidence for global warming in the past decade*, Nature, v. 332, p. 790. https://doi.org/10.1038/332790b0

Jones, P. D., T. M. Wigley and P. B Wright, 1986: *Global temperature variations between 1861 and 1984*, Nature, v. 323 no.31, pp. 430-434. https://www.nature.com/articles/322430a0

Keeling, 2023: *The Keeling Curve*. https://scripps.ucsd.edu/programs/keelingcurve/

Kirchoff, G., (1860), *On the relation between the radiating and absorbing powers of different bodies for light and heat*, Philosophical Magazine Series 4, v. 20 pp. 1-21, (Translation by F.

Guthrie) https://archive.org/details/londonedinburghd20lond/page/n15

Original publication: *Ueber das Verhältniss zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Körper für Wärme en Licht*, Annalen der Physik en Chemie, v. 109 no. 2 pp. 275-301. http://www.bio-physics.at/wiki/images/Kirchhoff_Emissions_und_Absorptions-vermoegen.pdf

Knutti, R. and G. C. Hegerl, 2008: *The equilibrium sensitivity of the Earth's temperature to radiation changes*, Nature Geoscience, v. 1 pp. 735-743. https://www.nature.com/articles/ngeo337

Lettau, H. H. and B. Davidson (1957), *Exploring the Atmosphere's First Mile. Proceedings of the Great Plains Turbulence Field Program, 1 August to 8 September 1953* Volume II, Site Description and Data Tabulation, Oxford, Pergamon Press.

Available at:
https://books.google.com/books?hl=en&lr=&id=5bcJAQAAIAAJ&oi=fnd&pg=PA377&dq=Lettau,+H.H.+and+B.+Davidson,+Exploring+the+atmosphere%E2%80%99s+first+mile.+Oxford:+Pergamon+Press,+1957.&ots=N0vbpjURx3&sig=sSTz9EMWpwi0XysXHTcWcLNxWv0#v=onepage&q&f=false

Manabe, S. and R. T. Wetherald, 1967: *Thermal equilibrium of the atmosphere with a given distribution of relative humidity*, J. Atmos. Sci., v. 24 pp. 241-249. http://www.gfdl.noaa.gov/bibliography/related_files/sm6701.pdf

McFarlane, F., 2018: *The 1970s Global Cooling Consensus was not a Myth*, Watts Up with That, Nov. 19. https://wattsupwiththat.com/2018/11/19/the-1970s-global-cooling-consensus-was-not-a-myth/

Morice, C. P., J. J. Kennedy,N. A. Rayner and P. D. Jones, 2012: *Quantifying uncertainties in global and regional temperature change using an ensemble of observational estimates: The HadCRUT4 data set*, J. Geophysical Res. Atmospheres, v. 117, D08101, pp. 1-22. https://doi.org/10.1029/2011JD017187

Oke T. R., 2006: *Initial guidance to obtain representative meteorological observations at urban sites*, Instruments and Observing Methods, Report No. 81, WMO/TD-No. 1250, World Meteorological Association, pp. 47.

https://www.researchgate.net/publication/265347633_Initial_guidance_to_obtain_representative_meteorological_observations_at_urban_sites

Ollila, A., 2023: *Natural Climate Drivers Dominate in the Current Warming*, Science of Climate Change, v. 3, no.3, pp. 290-326. https://doi.org/10.53234/scc202304/03

Peterson, T. C., W. M. Connolley and J. Fleck, 2008: *The myth of the 1970's global cooling consensus*, Bull. Amer. Meteor. Soc., v. 86, pp. 1325-1337. [https://doi.org/10.1175/2008BAMS2370.1]

Pouillet, M., 1837: *Memoir on the solar heat, on the radiating and absorbing powers of the atmospheric air and on the temperature of space.* In: Scientific Memoirs selected from the Transactions of Foreign Academies of Science and Learned Societies, edited by Richard Taylor, v. 4, pp. 44-90.

http://nsdl.library.cornell.edu/websites/wiki/index.php/PALE_ClassicArticles/archives/classic_articles/issue1_global_warming/n2-Poulliet_1837corrected.pdf

Original publication, 1836: *Mémoire sur la chaleur solaire: sur les pouvoirs rayonnants et absorbants de l'air atmosphérique et sur la température de l'espace,* Comptes Rendus des Séances de l'Académie des Sciences, Paris. v. 7, pp. 24-65.

Ramaswamy, V., W. Collins, J. Haywood, J. Lean, N. Mahowald, G. Myhre, V. Naik, K. P.

Shine, B. Soden, G. Stenchikov and T. Storelvmo, 2019: *Radiative Forcing of Climate: The Historical Evolution of the Radiative Forcing Concept, the Forcing Agents and their Quantification, and Applications* Meteorological Monographs v. 59, Chapter 14. https://doi.org/10.1175/AMSMONOGRAPHS-D-19-0001.1

TRITON, 2021: *TRITON Buoy Data*. https://www.pmel.noaa.gov/tao/drupal/disdel/

WRCC, 2021: *Western Region Climate Center*. https://wrcc.dri.edu/sod/arch/hbF.html

OPEN ACCESS

Klimarealistene
P.O. Box 33,
3901 Porsgrunn
Norway
ISSN: 2703-9072

Correspondence:
harde@hsu-hh.de

Vol. 3.5 (2023)

pp. 445-462

Model-Experiment of the Greenhouse Effect

Michael Schnell[1], *Hermann Harde* [2]

[1]*Ex Academy of Science, Berlin, Germany*

[2]*Helmut-Schmidt-University, Hamburg, Germany*

Abstract

Radiation exchange of infrared-active gases with their environment is the basis of the atmospheric greenhouse effect (GHE). While the theoretical principles for the energy and heat exchange by infrared radiation were already refined at the end of the penultimate and beginning of the last century, experimental verifications in the laboratory showed quite contradictory results, on the one hand excluding any influence of greenhouse gases, on the other hand indicating a significantly greater impact than theoretically expected.

This study presents a simple experimental set-up, by which the infrared active gases are replaced by a broadband absorber and emitter plate in a Styrofoam hollow cylinder and by which the principles of the GHE can be demonstrated. In particular, we show that the temperature of a heated body depends on the infrared radiation of its colder surrounding and does not contradict physical laws.

Parallel heat fluxes in form of heat conduction and radiation with their mutual influence are extensively investigated, and it is shown, when the inside of the set-up is coated with an aluminum foil, up to 73% of the supplied power to a heated plate is dissipated through infrared radiation. Transferring these relationships to the heat transport in the atmosphere suggests that the CO_2 greenhouse effect not only depends on its concentration, but also on the mechanical heat flows, mainly evaporation.

Keywords: Greenhouse effect; back-radiation; radiation exchange, heat conduction

Submitted 2023-11-06, Accepted 2023-12-10; https://doi.org/10.53234/scc202310/27

1. Introduction

The so-called atmospheric greenhouse-effect (GHE) is largely controlled by the energy transfer processes in the atmosphere. While convection and heat conduction are easy to understand, the third form of energy transport, infrared (IR) radiation, is more difficult to convey. In particular, quite controversially disputed is the thesis that a heated body can further be heated up by the radiation of a colder body or gas. This is seen as a violation of the second law of thermodynamics, although Clausius [1] as one of the inventors of this law never questioned a mutual exchange of heat by radiation.

Nevertheless, a refutation of the GHE was deduced from some laboratory experiments, which demonstrated that in a compartment with a non-transparent window for IR-radiation or filled with carbon dioxide (CO_2), this gives no different temperature compared to a housing with transparent window and without CO_2 (Wood [2]; Allmendinger [3]; Nahle [4]; Seim & Olsen [5, 6]). On the other hand, there exist some deceptive demonstrations in the Internet, partially with a temperature incline of more than 10°C (e.g., v. Ditfurth [7]), which, however, have to be explained as a CO_2 stratification effect and not as GHE (Schnell [8]). Also, an unreproducible video experiment is spreading awareness for a climate crisis (Al Gore [9]), which meanwhile has also been falsified

by several revisions (Watts [10]; Solheim [11]).

It is fundamentally problematic trying to refute or prove the GHE based on just a single temperature measurement. This overlooks the fact that a higher temperature in a compartment - as in a real greenhouse - is mainly caused by suppressed convection and not by radiation exchange (Wood [2]). At best it can be shown that CO_2 is an IR-active gas that absorbs IR-radiation. The actual GHE, however, is the result of a temperature gradient in the atmosphere. For further explanations on the theory and experimental studies of the greenhouse gases CO_2, methane and nitrous oxide (with a similar experimental setup as described here) see Harde & Schnell [12].

To shed some light on this confusion, we present here some principal investigations to show what is really important when simulating the GHE in the laboratory. In Section 2 we refer to the basics of energy transport by IR-radiation and what measures have to be taken, to avoid or to determine the individual fractions of competing heat flows.

The experimental setup that is comparatively easy to implement, is explained in Section 3. It is aimed at interested people who want to demonstrate the GHE by simple means. It also addresses sceptics, who can check their reservations using the experimentally derived data.

Section 4 presents measurements of the radiation exchange between a cooler and a warmer plate, in particular the back-radiation on the heated plate. In Section 5 is the GHE simulated by placing an intermediate absorber-emitter plate between the cooled and heated plate and measuring the temperature increase of the warm plate.

To clarify what amount of heat is transferred by conductivity and by radiation, the heat losses of the set-up are investigated in detail in Section 6, and finally it is shown in Section 7 that, depending on the internal wall of the radiation channel, up to 73% of the supplied heating power to the warm plate can be dissipated through infrared radiation.

2. Some Basics of the Radiation Exchange

Calculating the energy, dissipated from a body by IR radiation, can be complicated, if more than two bodies with different geometries and emissivities are involved in the radiation exchange. In practice, however, the calculations can be simplified with sufficient accuracy by making certain assumptions.

Ideally, for two black bodies with an emissivity $\varepsilon = 1$ and temperatures T_W and T_C, the net radiation balance ΔS_{WC} is the difference of the IR radiation between two plane-parallel, closely opposed surfaces A, with $\sigma = 5.67 \cdot 10^{-8}$ W /(m^2·K^4) as the Stefan-Boltzmann constant[1]:

$$\Delta S_{WC} = S_{BW}(T_W) - S_{BC}(T_C) = \sigma \cdot A \cdot T_W^4 - \sigma \cdot A \cdot T_C^4 = \sigma \cdot A \cdot (T_W^4 - T_C^4)\,. \quad (1)$$

Real bodies do not completely absorb the incident radiation, but rather reflect part of the radiation, which reduces the radiation balance ΔS_{WC} through reflection. From laboratory experiments Stefan [13] empirically derived the radiation balance of reflecting surfaces, which is the precursor of the well-known Stefan-Boltzmann law [14]:

$$\Delta S_{WC} = \sigma \cdot E \cdot A \cdot (T_W^4 - T_C^4)\,. \quad (2)$$

The radiation exchange efficiency E of plane-parallel surfaces is calculated from the emissivities ε_W and ε_C of the warm and cold plates as:

$$E = \left(\frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_c} - 1\right)^{-1}. \quad (3)$$

[1] S_B stands for the radiation power of a body as a function of its temperature according to Stefan-Boltzmann with the additional subscripts indicating the location of this emission (Fig. 2).

For blackened, rough surfaces with emissivities $\varepsilon_{W,C} = 1$, $E = 1$, and (2) changes to (1).

A transfer of radiation and thus power between two bodies is always characterized by radiation and back-radiation. In order to replicate this process experimentally, two surfaces of different temperatures are required, which should be positioned at short distance and, if possible, parallel to each other for optimal radiation exchange.

Dulong & Petit [15] were able to realize a quite smart arrangement for the radiation exchange, when studying the cooling rate of a thermometer, heated to 200 °C in an evacuated copper vessel. The vacuum excludes mechanical heat flows and the concentrically arranged surfaces enable unhindered exchange without contact of the IR radiation with other surfaces (Fig.1).

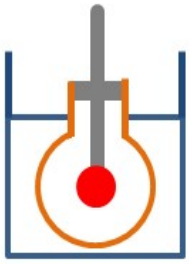


Figure 1: Set-up of the Dulong-Petit experiment.

Experimental set-ups that are easier to implement, consist of two parallel plates, which oppose each other in an elongated compartment at normal pressure, where one plate can be heated and the other cooled. The compartment enables a radiation exchange between the two plates in form of a radiation channel that directs the IR radiation from one plate to the other through multiple reflections. Due to the size and inner surface of the housing (also as potential container for IR-active gases) total reflection is excluded, while part of the radiation is absorbed by the container walls and dissipated as heat to the outside or returned to the original plate by re-emission. In such a radiation channel, there are unavoidable transmission losses, so that less heat than expected by (1), is transferred by IR radiation. This is taken into account by a transfer factor $f_T < 1$.

In previous experiments on the GHE with a similar experimental setup, a transfer factor of $f_T = 0.75$ was found. This shows that despite a larger plate distance, up to 75% of the diffusely emitted radiation can be predominantly reflected and directed to the other plate (Harde & Schnell [12]).

This article presents a simple experimental setup for investigating the joint heat transport through heat conduction and infrared radiation. In this way, the basics of the greenhouse effect can be presented in a particularly retraceable way. However, also complex studies on the propagation and superposition of parallel heat flows can be performed, which can simulate the competing heat transport in the atmosphere and the only incompletely understood role of clouds. Parallel heat flows such as convection and evaporation reduce the radiation transport and thus the greenhouse effect of the IR-active gases, as reflected by different influences in dry or wet areas.

3. Experimental Set-Up

Fig. 2 shows the schematic of the experimental set-up, a vertical hollow cylinder made of Styrofoam, which is located in the laboratory with a constant room temperature T_R (for technical details, see Appendix). The apparatus, designed as a modular set-up, can be easily converted and therefore be used for different experiments.

The temperature T_W and the heating power H_W of the warm plate P_W give the most important information for an investigation. With these data, the back-radiation and the greenhouse effect can be determined, but also the parallel heat flows via conduction and radiation can be tracked and quantified.

The circular ring P_S (sensor plate) plays a special role. This unheated surface is a sensor for back-radiation and horizontal heat propagation, but also takes part in the radiation exchange with the cooled plate and must be taken into account when analysing and evaluating the heat flows.

Additional temperature sensors along the radiation channel are recording the mechanical heat flows at the respective positions. At the bottom the radiation channel contains the cooled plate, either with a blackened (P_C) or polished (P_{CP}) surface (Appendix, Fig. 9). Its temperature is 1°C colder than the room temperature T_R. When starting an experiment, all other temperature sensors are approximately at room temperature, while the warm plate P_W and also the sensor plate P_S in the upper position of the radiation channel will attain significantly higher temperatures after switching on the heating. This results in air stratification with a temperature gradient from top to bottom, which excludes convection as a possible heat transport. A digital laboratory power supply with a constant voltage of 4.0 volts is used for the electrical heating of the plate P_W, supplying a power of H_W = 1.2 W.

The greenhouse effect is simulated by placing an additional blackened aluminum disk P_I into the radiation channel. Such an intermediate plate, like greenhouse gases, can absorb infrared radiation and re-emit it according to its own temperature. This property is the core of the greenhouse theory, which leads to an increase in the temperature T_W of the warm plate P_W. This plate acts as heat source and sensor at the same time.

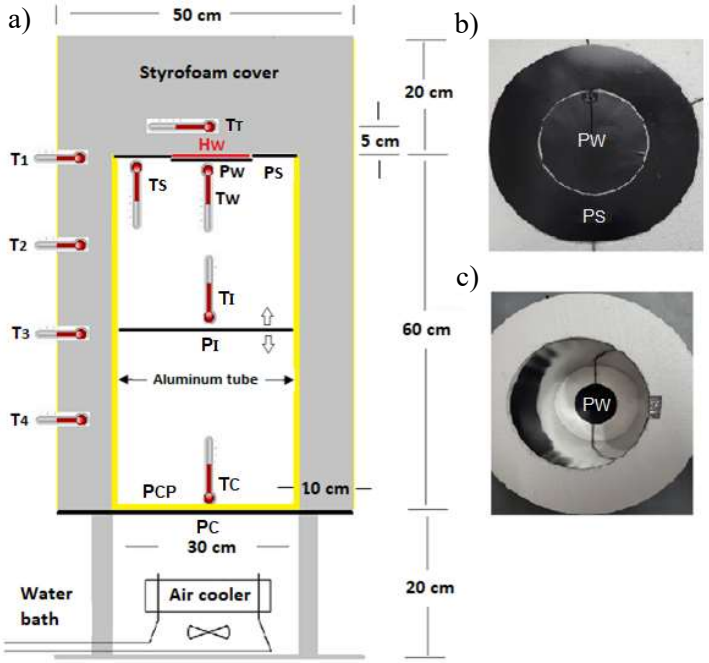


Figure 2: a) Experimental set-up of the Styrofoam radiation channel with internal aluminum tube, temperature sensors T *and plates* P *(subscripts: T-top, W-warm, S-sensor, I-intermediate, C-cold, CP-cold polished). b) Top of radiation channel with warm plate* P_W *and sensor plate* P_S. *c) Radiation channel with polished aluminum tube before installing the sensor plate* P_S.

4. Evidence of Back-Radiation

The P_W and P_S plate release part of their heat through radiation exchange with their surroundings. While the IR-emission of these plates is clearly defined by their temperatures T_W and T_S and their emissivities $\varepsilon_{W,S}$ = 1, the radiation from the environment, the so-called back-radiation, is inherently much more complex. This radiation results from a superposition of emissions and reflections that emanate from the cooled plate and the channel wall of the hollow cylinder. This will be demonstrated for the base plate by varying its surface and temperature.

Even the word back-radiation is questioned by critics of the greenhouse effect, who claim that the laws of physics do not allow such radiation or that an observation according to (1) or (2) would only be possible in vacuum.

The IR emission of the cold plate P_C is undoubtedly self-sufficient radiation, which, according to the Stefan-Boltzmann law, only depends on the plate temperature T_C and the emissivity ε_C:

$$S_{BC}(T_C) = \sigma \cdot \varepsilon_C \cdot A_C \cdot T_C^4 \,. \tag{4}$$

Fig. 3 shows two examples illustrating how the temperature of the constantly heated plate P_W is influenced by the back-radiation[2]. After having reached thermal equilibrium (~ 100 minutes), the black coated base plate P_C is further cooled down from 17 to 11°C (Fig. 3a). Due to (2) the radiation exchange between the plates increases and the temperature T_W decreases accordingly. In Fig. 3b, the base plate is replaced by a polished disc P_{CP} under otherwise same conditions as in Fig. 3a. Owing to the significantly reduced absorptivity, respectively emissivity (α_C resp. ε_C), the radiation transfer is reduced accordingly and the temperature T_W increases till thermal equilibrium is established. In contrast to the blackened plate, there is hardly any reaction to T_W, when the P_{CP} plate cools down. This is explained by the fact that with reduced emissivity, the reflectivity r_C = 1 - ε_C increases and the emission from the cooled plate is largely replaced by the reflected radiation from the warm plate. Their radiation losses are reduced accordingly[3]. A change in thermal conductivity, as a possible cause of these effects, can be ruled out in these experiments (see Sec. 6).

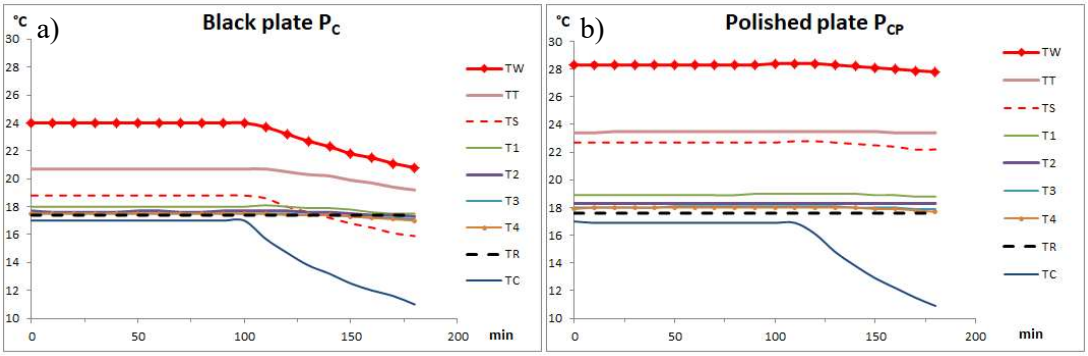


Figure 3: Impact of the back-radiation on the temperature T_W of the warm plate P_W, a) with blackened plate P_C and b) with polished plate P_{CP}.

The heat loss of a body to its colder environment, in this case the heated plate, is determined by the temperature difference ΔT_W with and without heating[4] as:

$$\Delta T_W = T_W(H_W) - T_W(0) = \vartheta_T \cdot H_W \,. \tag{5}$$

H_W is the dissipated heat, which in equilibrium is equal to the heating power supplied, and ϑ_T (°C/W) represents the total thermal resistance of the experimental setup, which includes all heat flows. According to (5), even with a constant supply of heat, a body experiences a temperature increase when the thermal resistance ϑ_T increases. In the same way, the greenhouse effect can be described by a respective resistance ϑ_G (Section 5).

Therefore, the results are in full agreement with (1) and (2), according to which the temperature T_W of a heated body also depends on the intensity of the back-radiation of its surrounding, even when the surrounding is colder than the considered body.

---

[2] In analogy to the back-radiated and back-scattered radiation in the atmosphere we use this term here, too.

[3] The radiation exchange E explicitly takes into account that radiation is not only absorbed by surfaces, but also reflected.

[4] ΔT_W is the temperature increase of plate P_W from a lower to a higher thermal equilibrium, which establishes after switching on the heating H_W (Fig. 4).

Transferred to the Earth this means, the Earth's surface is heating up stronger, when the intensity of the atmospheric back-radiation increases. Back-radiation is not a privilege of greenhouse gases, because aerosols or clouds also produce infrared radiation in the atmosphere. At the same temperature, their radiation intensity would even be higher than that of the gases, since all IR wavelengths of a Planckian radiator are contributing to this radiation. The effect of low clouds, which is noticeable at mild night temperatures, is particularly impressive. In comparison, CO_2 has only a small influence and cannot come close to keeping up with clouds, as shown by the strong nighttime cooling in arid deserts despite high daytime temperatures (and despite rising CO_2 concentrations).

5. Simulation of the Greenhouse Effect

When modeling the greenhouse effect, the question is, what effects an unheated IR-active body in the radiation channel on the heat transport. When planning the corresponding experiment, it is important to ensure that such a body must have an absorption coefficient ε close to 1 and a high thermal conductivity λ, not to build up an additional thermal resistance in the radiation channel. A 0.5 mm thin aluminum disk, blackened on both sides, called as intermediate plate P_I, meets both conditions (Fig. 2a). A thin layer thickness and thermal conductivity λ_{Al} = 220 W/(m·°C) ensure a high heat flow in the aluminum disc.

In the radiation channel, disk P_I interrupts the radiation exchange through an absorption-emission cycle, whereby the energy supplied, is released again on both sides by infrared radiation. This process, in principle, corresponds to the effect of greenhouse gases in the atmosphere, with the difference that in the black disk all available wavelengths of a Planck radiator are affected by the absorption-emission interruption. In this model experiment, the cooled plate P_C is the energy sink, the place where the net energy transmitted by IR radiation is dissipated.

The model experiment can also be viewed as a simulation of the impact of clouds on the radiation exchange. In this sense, the disk P_I simulates a complete cloud cover and P_W the earth's surface.

Another sensor on the disk P_I provides information about the temperature T_I that occurs at this location, which would correspond to the temperature of the gases or clouds.

By definition, the measure of the greenhouse effect is the temperature increase ΔT_G of the warm plate compared to a measurement without a plate P_I but the same heating H_W. The respective resistance can be defined as $\vartheta_G = \Delta\vartheta_T = \vartheta_T$ (with disc) - ϑ_T (no disc). In three experimental setups, that differ only in the distance between the disk P_I and the warm plate, the existence of this plate in the beam path causes well observable temperature differences of up to 2.0 °C (Table 1).

Table 1: Greenhouse effect of a blackened disc for a constant heating output H_W = 1.2 W.

Intermediate plate P_I distance to P_W (cm)	T_W (0) °C	$T_W(H_W)$ °C	T_I °C	ΔT_W °C	ΔT_G °C	H_W W	ϑ_T °C/W	ϑ_G °C/W
5	16.9	26.1	19.8	9.2	2.0	1.20	7.7	1.7
30	16.9	25.7	19.0	8.8	1.6	1.20	7.4	1.4
55	16.9	25.3	18.5	8.4	1.2	1.20	7.0	1.0
no disc	16.8	24.0	-	7.2	-	1.20	6.0	-

For the plates P_W and P_S, the source of the back-radiation is no longer plate P_C, but the warmer plate P_I with the temperature T_I (Fig. 4, Dashed Red). This is recorded accordingly as an increase in the temperature T_W (Red) and T_S (Light Green). For comparison are shown the temperatures T_W and T_S without disk P_I (Blue lines). Once again, this confirms what was already proven in Sec. 4:

The temperature of a heated body clearly depends on the intensity of the back-radiation of its surrounding, even when this is colder, and it experiences an increase ΔT_G when ϑ_T increases.

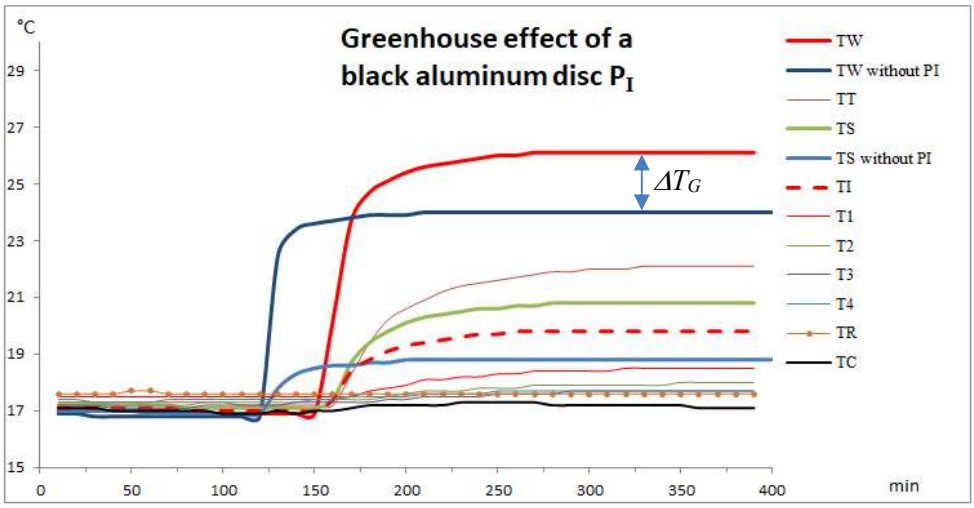


Figure 4: Temperatures in the radiation channel with intermediate plate P_I *(5 cm below plate* P_W*) before and after switching on the heating* H_W*. For comparison, the temperatures* T_W *and* T_S *without disk* P_I *(blue lines).*

The simulated greenhouse effect is also reflected in the trend of the thermal resistance ϑ_G, which characterizes this impact and which increases, the closer disk P_I comes to the warm plates P_W and P_S, and thus causes a temperature increase of T_W in analogy to (5) (Table 1).

Applied to the atmosphere this means, low clouds with their comparatively high temperatures and broad emission generate such a strong back-radiation that contributions from greenhouse gases are strongly masked and only show a minor effect. Accordingly, under a higher cloud cover with lower temperature, the fraction of IR-active gases to the GHE is increasing (Harde [16]).

6. Heat Losses at Radiation Transfer

In order to check how far the above measurements really reveal an exchange of radiation between the plates and not heat conduction, some additional investigations are required. For this purpose, the disk P_I is again removed.

6.1 Preliminary Theoretical Considerations

Without external heating, all surfaces in the radiation channel have approximately the room temperature (Fig. 4, up to minute 120). When energy is supplied to the plate P_W in form of a constant electrical heating power H_W, its temperature increases until an equilibrium of supplied and dissipated power is reached.

This power is dissipated through radiation exchange ΔS_{BW} between the heated and cold plate, a parallel exchange ΔS_{BS} between the unheated sensor plate and the cold plate, as well as a mechanical heat flow J_Q to the laboratory room with temperature T_R (Fig. 5a).

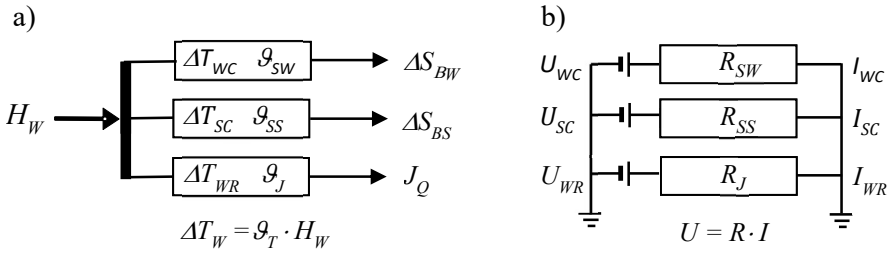


Figure 5: a) Heat fluxes of radiation and conductivity, b) equivalent electrical circuit diagram.

However, these heat flows only occur when there is a temperature difference to their surrounding inside and outside the experimental set-up. For ΔS_{BW} and ΔS_{BS} these are the differences ΔT_{WC} and ΔT_{SC} to the cooled plate, for J_Q it is the difference ΔT_{WR} to the room air. They form the drive for these flows and, in equilibrium, are also determined by the power H_W and these flows.

For smaller powers and corresponding temperature changes the net radiation exchange can be expressed in good approximation by differentiating (1):

$$\begin{aligned} \Delta S_{Bi} &= \sigma \cdot \left(\varepsilon_i \cdot A_i \cdot T_i^4 - \varepsilon_C \cdot A_C \cdot T_C^4\right) \\ &\approx 4 \cdot \sigma \cdot \varepsilon_i \cdot A_i \cdot T_i^3 \cdot \Delta T_{iC} = 4\frac{S_{Bi}(T_i)}{T_i}\Delta T_{iC}\ ;\ \ i = w,s \\ &= q_{Si} \cdot \Delta T_{iC} = \frac{1}{\vartheta_{Si}} \cdot \Delta T_{iC}\ , \end{aligned} \tag{6a}$$

with

$$q_{Si} = \frac{1}{\vartheta_{Si}} = 4\frac{S_{Bi}(T_i)}{T_i} \tag{6b}$$

as specific heat transfer by radiation and ϑ_{Si} as radiation resistance.

Since due to multiple scattering and reflection losses occur in a radiation channel with side walls, compared to the theoretically expected radiation exchange according to (6), this must be taken into account by a transfer factor f_T. The total radiation balance ΔS_{BT}, which is only of further interest, is therefore given as:

$$\Delta S_{BT} = f_T \cdot (\Delta S_{BW} + \Delta S_{BS}) = \frac{1}{\vartheta_{ST}} \cdot \Delta T_{WS}\ . \tag{6c}$$

ϑ_{ST} is the total radiation resistance and ΔT_{WS} a weighted temperature difference of the two top plates to the cold plate.

According to Fourier, the mechanical heat flow J_Q can be calculated in good approximation from the thermal conductivity λ_{St} of the Styrofoam insulation, its thickness d and its surface A_{St} as:

$$\begin{aligned} J_Q &= \lambda_{St} \cdot \frac{A_{St}}{d}\Delta T_{WR} \\ &= q_J \cdot \Delta T_{WR} = \frac{1}{\vartheta_J} \cdot \Delta T_{WR} \end{aligned} \tag{7a}$$

with

$$q_J = \frac{1}{\vartheta_J} = \lambda_{St} \cdot \frac{A_{St}}{d} \tag{7b}$$

as conductivity and ϑ_J as resistance of the mechanical heat flow.

Since in thermal equilibrium not more heat can be dissipated than supplied, the heat flows add up to the electric heating H_W with

$$H_W = \Delta S_{BT} + J_Q\ . \tag{8}$$

The addition of the heat flows can be directly compared with the parallel connection of resistors in an electrical circuit (Fig. 5b), in which the temperature differences correspond to the applied voltages and the heat fluxes correspond to the electric currents, which add up to the total current according to Kirchhoff's rule and Ohm's law.

Applied to the atmosphere, this also means: The overall balance between the Earth's surface and the atmosphere is always determined by the parallel heat transfer channels such as radiation, heat conduction, convection and evaporation. With the same total power supplied, an increase in one process has the opposite effect on the other channels.

The heat flow J_Q can be determined experimentally by the heating power H_W, when the radiation exchange is prevented by a special experimental setup, the so-called Styrofoam block, where $\Delta S_{BT} = 0$ and (8) transitions to

$$J_Q = H_W \ . \tag{9}$$

The thermal conductivity λ_{St}, thickness d and surface area A_{St} are fixed design features of the apparatus that define the thermal conduction resistance ϑ_J and, as the reciprocal, the specific heat conduction q_J. Thus, via (7) and (9), q_J can be determined from the heating H_W and the difference between the inside and outside temperature ΔT_{WR}, this for different configurations of the radiation channel, which differ in their wall lining.

For "radiation experiments", the inner Styrofoam disks are removed from the Styrofoam block to get the radiation channel. This change has no influence on the external thermal insulation, so that the competing heat flow J_Q of the hollow cylinder now can be calculated by means of the known specific heat conduction q_J according to (7) (see Section 7).

When the heat flow J_Q is known, the total radiation balance ΔS_{BT}, i.e., that part of the heating output H_W, which is dissipated by IR radiation, can also be calculated:

$$\Delta S_{BT} = H_{SB} = \ H_W - J_Q \ . \tag{10}$$

H_{SB} is the heating power H_W minus the heat flow J_Q, i.e., that part of the heating output H_W that is available for radiation exchange.

6.2 Determination of the Heat Flow J_Q in a Styrofoam Block

To determine the heat flow J_Q of the experimental set-up, the radiation exchange ΔS_{BT} must be prevented. In this case, all supplied power flows exclusively as heat current J_Q outwards according to (7). For this measurement the aluminum tube is removed from the hollow cylinder and the exposed channel is completely filled with 12 polystyrene disks (Fig. 6).

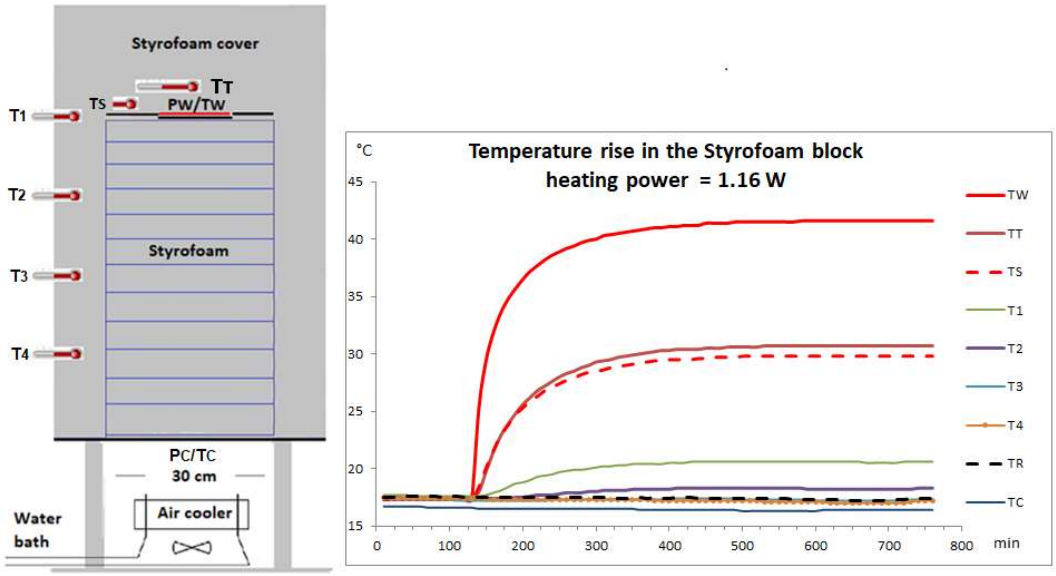


Figure 6: Determination of the insulation loss J_Q of the Styrofoam compartment.

When the heating is switched on, the plate P_W heats up to a temperature of 41.6 °C within around 500 minutes and holds this temperature for the next 200 minutes. The constant T_W temperature proves thermal equilibrium, in which heat input (H_W) and heat removal (J_Q) according to (9) are the same (Fig. 6, right).

The heat from plate P_W mainly flows outwards via the upper Styrofoam cover, as can be seen

from the temperatures T_T = 30.9 °C (Brown Line) and T_S = 29.9 °C (Red Dashed). This is in agreement with the expectation, since the warm plate P_W is located in the upper quarter of the set-up and has physical contact with the Styrofoam lid.

A downward spread towards the cold plate P_C is hindered by the simultaneous lateral heat flow, so that the temperatures of the Styrofoam wall T_1 = 20.6 °C and T_2 = 18.4 °C are only slightly higher than the room temperature T_R = 17.4 °C.

From the difference between the inside and outside temperature ΔT_{WR} and the heating output $H_W = J_Q$, the thermal resistance ϑ_J or the heat conduction q_J for mechanical heat dissipation is calculated according to (7a).

The measurements are repeated for a larger temperature range with two additional heating levels H_W = 0.66 W and H_W = 0.30 W. Only small deviations in the thermal resistance and heat conduction are found. Their averages are listed in Table 2.

Table 2: Specific resistance ϑ_J and heat conduction q_J for different configurations.

Channel wall	T_W °C	T_R °C	ΔT_{WR} °C	$H_W (J_Q)$ W	ϑ_J °C/W	q_J W/°C
Styrofoam	41.6	17.4	24.2	1.16	20.95	0.048
Al-foil	40.5	17.6	22.9	1.15	19.98	0.050
Al-tube	38.0	17.5	20.5	1.16	17.67	0.057

The internal channel is then covered with an aluminum foil or an aluminum tube and filled again with 12 Styrofoam discs. As before, thermal resistance ϑ_J and heat conduction q_J are determined for these experimental configurations using three heating stages.

6.3 Heat Diffusion in a Styrofoam Channel

To control how far the heat conduction expands to the lower plate P_C and could overlap with the radiation transport, the lowest discs from the Styrofoam block (see Subsection 6.2) are gradually removed from the radiation channel. This creates a partial channel (BRC = bottom radiation channel) above the cold plate P_C with the variable length L_{BRC} (Fig. 7).

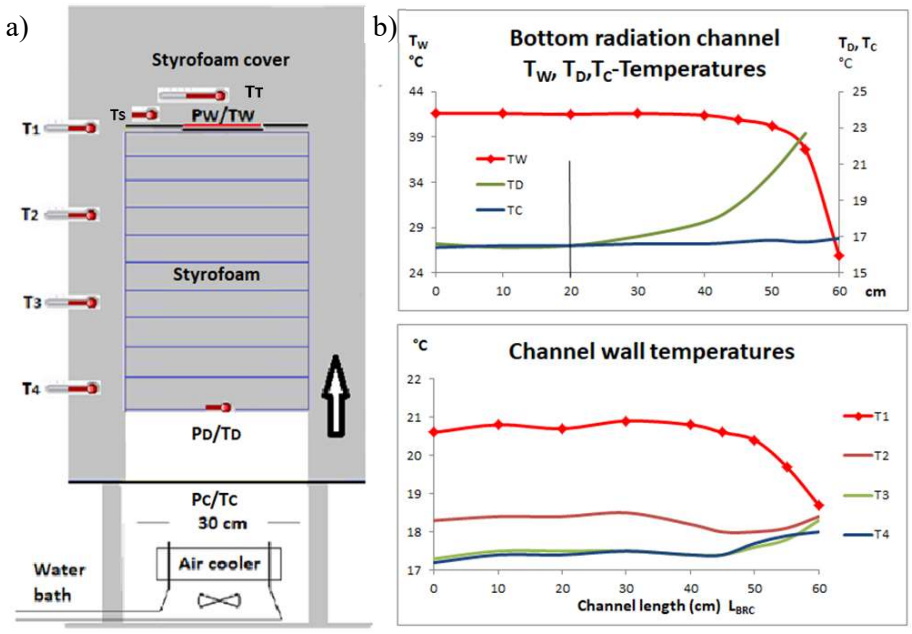


Figure 7: a) Bottom radiation channel BRC above plate P_C*, b) Temperatures via channel length* L_{BRC}.

For our further considerations, not the channel formed, is of interest, only the layer thickness of the Styrofoam disks still present under the warm plate P_W and the temperature T_D of the lowest Styrofoam disk[5].

As long as no heat from the plate P_W reaches the lowest Styrofoam disk, the radiation exchange between the plates P_C and P_D leads to the same temperatures $T_C = T_D$. Indeed, this is observed, when removing the first 4 Styrofoam disks (Fig. 7b). Only when additional polystyrene disks are taken away and the channel length L_{BRC} gets longer than 20 cm, the temperature T_D (Green line) is initially slightly and then significantly higher than T_C (Blue line). From these temperature measurements it can be concluded that the heat from the plate P_W flowing laterally and also downwards, is completely dissipated to the outside after around 40 cm. Mechanical heat conduction through the channel jacket to the cooled plate can therefore be ruled out, and heat conduction via air in the radiation channel plays no role, as has already been demonstrated in previous studies with noble gases of different thermal conductivities [12].

Of particular interest is the removal of the last disk (L_{BRC} = 60 cm), when radiation exchange between the plates P_W and P_C is possible. It is reflected as significant drop of T_W by 11.7 °C (Fig. 7b, top image). This temperature effect demonstrates that heat is transported over larger distances primarily through infrared radiation and not through heat conduction.

6.4 Heat Dissipation in a Styrofoam Channel with Internal Aluminum Cladding

To optimize the radiation exchange, the radiation channel can be lined with a polished 0.5 mm thick aluminum sheet (Fig. 2, without plate P_I), which should have a positive effect on the radiation exchange (Section 7.2).

However, aluminum has a very high thermal conductivity λ_{Al} = 220 W/(m·°C), also changing the thermal conduction J_Q of the set-up. The heat conduction of a Styrofoam block with an aluminum tube increases by 19% to q_{Al} = 0.057 W/°C, compared to the pure Styrofoam lining, and the thermal resistance drops to ϑ_J = 17.67 °C/W (Table 2).

As before, when the lowest polystyrene discs are gradually removed, a maximum spread of 40 cm below the plate P_W (Fig. 8, L_{BRC} = 20 cm) is detected. A mechanical heat flow between the P_W and P_C plates can therefore also be excluded with an internal aluminum tube (Fig. 8).

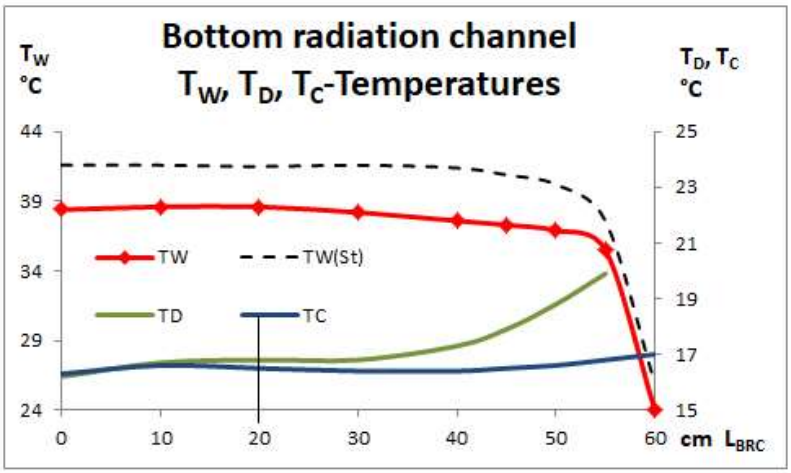


Figure 8: Heat spread towards the P_C plate. Comparison with temperature $T_W(St)$) for the Styrofoam duct without aluminum tube (Black Dashed).

[5] The thickness of the Styrofoam discs is 60 – L_{BRC} cm. Since the conductivity of air λ_L = 0.026 W/(m·°C) is slightly lower than that of Styrofoam with λ_{St} = 0.035 W/(m·°C), we can be sure that the new channel of length L_{BRC} does not elevate mechanical heat conduction downwards.

The only notable difference to the Styrofoam channel $T_W(St)$ is the lower T_W temperature for the same heating output, which is explained in more detail in Subsection 7.2.

The heat conduction of an aluminum layer also depends, among others, on its layer thickness. So, it makes sense to replace the aluminum sheet by a thin aluminum foil as internal coating.

The measurements for the specific heat conduction give q_J = 0.050 W/°C, which is only slightly higher than the hollow Styrofoam cylinder with 0.048 W/°C, and thus represents a good alternative to the aluminum tube for a duct surface with a high degree of reflection (Table 2).

7. Share of Infrared Radiation to the Total Heat Dissipation

Hollow cylinders with end plates of different temperatures dissipate the released heat through both, infrared radiation and heat conduction, according to (8). The ratio of the two heat flows depends on the thermal insulation, the diameter and length of the channel and in particular on its surface. The latter will be demonstrated using three examples with different surfaces in the radiation channel.

At first glance, such an investigation is very special and should only be of interest to specialists who are thinking about experiments on the greenhouse effect. However, we have to remind that the Earth's surface also has various transport mechanisms for dissipating heat from the surface. Understanding the different heat flows and their interdependence also enables a deeper insight into the greenhouse effect and its real or perceived impact on climate change.

a) Radiation Transfer in a Styrofoam Hollow Cylinder

According to (10), with the knowledge of J_Q, the total radiation balance ΔS_{BT} is found as difference of H_W and J_Q. Table 3 shows the temperatures measured in a hollow cylinder of Styrofoam with a heating output of H_W = 1.2 W, and the share of infrared radiation of the total heat flow that is derived from this.

The calculation of the power balances starts with the mechanical flow J_Q = 0.39 W, which, according to (7a), results from the temperature difference $\Delta T_{WR} = T_W - T_R$ and the specific heat conduction q_J = 0.048 W/°C (Table 2). Based on the 1.2 W heating, 32.8% is conducted outwards through J_Q. The power $H_{SB} = H_W - J_Q$ = 0.81 W corresponds to the radiation exchange ΔS_{BT}, which transfers the heat from the two plates P_W and P_S to the plate P_C. Accordingly, 67.2% of the heat is dissipated directly or indirectly through infrared radiation (Table 3).

Table 3: Styrofoam hollow cylinder: Temperatures and power balance.

T_R °C	T_C °C	T_W °C	T_S °C	T_T °C	T_1 °C	T_2 °C	T_3 °C	T_4 °C
17.7	16.9	25.9	20.9	22.1	18.7	18.4	18.3	18.0
P_W/P_S m²	S_{BC} W	S_{BW} W	S_{BS} W	ΔS_{BW} W	ΔS_{BS} W	$\Delta S_{BW}+\Delta S_{BS}$ W	H_{SB} W	f_T
0.019	7.63	8.62	-	0.99	-	2.16	0.81	0.37
0.052	20.79	-	21.96	-	1.17			
H_W W	ΔT_W °C	ΔT_{WR} °C	ϑ_T °C/W	ϑ_{ST} °C/W	ϑ_J °C/W	q_J W/°C	ΔS_{BT} W	J_Q W
1.20	8.8	8.2	7.3	10.9	20.8	0.048	0.81	0.39
							67.2%	32.8%

In order to determine the radiation losses in the Styrofoam cylinder, the theoretical radiation for all three plates P_C, P_W and P_S (S_{BC}, S_{BW}, S_{BS}) is calculated according to the Stefan-Boltzmann law

for $\varepsilon = 1$ and their respective areas. The net radiation exchange between P_W and P_C or between P_S and P_C as defined by (6a), is given as ΔS_{BW} and ΔS_{BS}. The ratio $H_{SB}/(\Delta S_{BW} + \Delta S_{BS})$ defines the transmission factor f_T accordingly (6c).

It turns out that even with a simple radiation channel made of Styrofoam with a transmission factor $f_T = 37\%$, the heating power H_W is mainly (67%) dissipated by infrared radiation from the warm plates P_W and P_S.

Due to the parallel heat flows with the resistances ϑ_{Si} ($i = w, s$) for radiation and ϑ_J for mechanical heat transport, the total resistance ϑ_T is always smaller than the individual resistances.

b) Radiation Transfer in a Styrofoam Hollow Cylinder with an Aluminum Tube

To optimize the radiation exchange, the radiation channel is lined with a polished 0.5 mm thick aluminum sheet. The IR radiation is mainly reflected on this smooth surface and less scattered or absorbed, which should reduce radiation losses in the channel and thus promote radiation exchange. Table 4 shows the temperatures and power balances that arise with a heater output H_W = 1.2 W for a radiation channel with an aluminum tube. The calculation of the energy balances is carried out as described above.

Overall, the heat dissipated by radiation is only slightly increased to 69.1% vs. 67.2% without aluminum pipe. The reason is the higher heat conduction of the aluminum tube, which contributes to an increase in the heat flow J_Q and partially compensates the advantage of better reflection.

Table 4: Styrofoam hollow cylinder with aluminum tube: Temperatures and power balance.

T_R °C	T_C °C	T_W °C	T_S °C	T_T °C	T_1 °C	T_2 °C	T_3 °C	T_4 °C
17.5	17.0	24.0	18.8	20.7	17.9	17.6	17.4	17.4
P_W/P_S m²	S_{BC} W	S_{BW} W	S_{BS} W	ΔS_{BW} W	ΔS_{BS} W	$\Delta S_{BW}+\Delta S_{BS}$ W	H_{SB} W	f_T
0.019	7.64	8.40	-	0.76	-	1.29	0.83	0.65
0.052	20.82	-	21.34	-	0.52			
H_W W	ΔT_W °C	ΔT_{WR} °C	ϑ_T °C/W	ϑ_{ST} °C/W	ϑ_J °C/W	q_J W/°C	ΔS_{BT} W	J_Q W
1.20	7.2	6.5	6.0	8.7	17.5	0.057	0.83	0.37
							69.1%	30.9%

c) Radiation Transfer in a Styrofoam Hollow Cylinder with an Aluminum Foil

An aluminum foil causes a lower specific heat conduction of $q_J = 0.050$ W/°C in the Styrofoam block compared to 0.057 W/°C for the aluminum tube (Table 2) at comparable reflection properties in the hollow cylinder. This also affects the radiation transfer ΔS_{BG}, whereby around 73% of the H_W power is dissipated through IR radiation with an aluminum foil (Table 5).

In summary, coating the Styrofoam channel with an aluminum sheet or aluminum foil improves the reflection properties of the radiation channel, and thereby, increases significantly the transmission factor from $f_T = 0.37$ to $f_T = 0.65$ (Tables 4 and 5).

A channel without coating shows also the direct consequences for the greenhouse effect: When the radiation transport decreases (the respective resistance increases, in this case due to the lower transfer factor $f_T = 0.37$), the temperature T_W of the warm plate inclines, in this case from 24.0 °C to 25 .9 °C to overcome the bottleneck. On the other hand, when the parallel heat flow J_Q increases from 0.33 to 0.37 W (a sheet of metal dissipates more heat than an aluminum foil), the radiation transport ΔS_{BT} must decrease from 0.88 to 0.83 W.

Table 5: Styrofoam hollow cylinder with aluminum foil: Temperatures and power balance.

T_R °C	T_C °C	T_W °C	T_S °C	T_T °C	T_1 °C	T_2 °C	T_3 °C	T_4 °C
17.5	16.9	24.0	18.9	20.8	18.2	17.9	17.6	17.4
P_W/P_S m²	S_{BC} W	S_{BW} W	S_{BS} W	ΔS_{BW} W	ΔS_{BS} W	$\Delta S_{BW}+\Delta S_{BS}$ W	H_{SB} W	f_T
0.019	7.63	8.40	-	0.77	-	1.35	0.88	0.65
0.052	20.79	-	21.37	-	0.58			
H_W W	ΔT_W °C	ΔT_{WR} °C	ϑ_T °C/W	ϑ_{ST} °C/W	ϑ_J °C/W	q_J W/°C	ΔS_{BT} W	J_Q W
1.20	7.2	6.5	6.0	8.2	20.0	0.050	0.88	0.33
							72.9%	27.1%

This finding also contributes to a deeper understanding, how parallel heat fluxes affect the CO_2 GHE. In the Earth-Atmosphere System, mechanical heat flows occur only to a small extent through heat conduction, but mainly through convection and evaporation, whereby heat is removed from the Earth's surface, in addition to radiation transport (Trenberth et al. [17]). On one side this reduces the fraction of the radiation transfer, on the other side the warming of the Earth's surface, caused by increasing greenhouse gases, simultaneously leads to increased convection and evaporation, which overall manifests itself as clear negative feedback for the GHE. Cloud cover has another significant influence on the size of the GHE, as the absorption and emission bands of the GHG are superimposed by the broadband radiation emitted by clouds. Therefore, the effect of GHG under a cloud cover can significantly be reduced (see Harde [16]).

Unfortunately, the impact of evaporation on the GHE, the influence of the cloud cover and a largely saturated water vapor feedback are not taken into account in publications, to which the IPCC refers. This leads to significantly higher estimates of the equilibrium climate sensitivity *ECS* (temperature increase at doubled CO_2 concentration). So, within the Coupled Model Intercomparison Project Phase 6 (CMIP6), e.g., the climate sensitivity is specified as $ECS = 3.78°C$ (IPCC, AR6-WG1-Table7.SM.5 [18]). This is more than a factor of 5 higher than this follows from own calculations with $ECS = 0.68°C$, when taking into account the mentioned impacts, which altogether are contributing to total negative feedback (Harde [16], [19]).

8. Conclusion

Based on the physical principles, there can be no serious doubts that an IR-active body emits infrared radiation, when its temperature is > 0 K, nor about the knowledge that energy can be transported with this radiation. Only controversially discussed is, whether infrared radiation causes warming from cold to warm. This doubt contains a misleading assumption. Thermally induced radiation exchange is not about the direction of energy transfer between two surfaces of different temperatures, which here too always only occurs from warm to cold, but rather about the net radiation balance ΔS_B, which is transferred as energy per time and what effect this has on the warmer body.

To dispel these doubts, heat propagation was studied in a hollow cylinder made of Styrofoam, which is closed at both ends with aluminum plates, so that the two plates can exchange heat through infrared radiation. The upper cover consists of a heatable plate P_W and a passive sensor ring P_S, at the other end is installed an air-cooled plate P_C. In order to demonstrate the radiation transport, the plate P_W is heated with a constant heating power H_W, and the resulting temperature increase ΔT_W of the plate P_W is measured.

In a first demonstration experiment it is shown that the cooled plate controls the radiation exchange either through self-emission or even more effectively through reflection of the incident radiation, which explains the term "back-radiation" and its meaning.

In the next step, the greenhouse effect is simulated in a model set-up. A thin, blackened metal plate P_I is attached inside the hollow cylinder, which influences the radiation transport through an absorption-emission process, similar to IR-active gases, aerosols and clouds in the atmosphere. This hindrance for the exchange of radiation leads to a significant increase in back-radiation and thus, also to an increase in the temperature of the warm plate P_W.

This model experiment and the analog measurements with greenhouse gases (Harde & Schnell [12]) refute the thesis that such warming is not physically possible. The laws of physics apply universally; what is possible in the laboratory also applies to the atmosphere.

Since heat can be transported both by thermal conduction J_Q and by infrared radiation S_B, the focus of the study was to determine, which transport processes dominate at which location and how they influence each other.

Filling the radiation channel with Styrofoam discs leads to a Styrofoam block that dissipates the heat exclusively through heat conduction outwards, from which the specific heat conduction of the Styrofoam insulation q_J is determined, and from which the heat flux J_Q can be calculated. By gradually removing the Styrofoam discs, it can be shown that the mechanical heat flux is restricted mainly to the upper insulation and the upper channel and does not reach the lower part.

With known heat flow J_Q the radiation flux ΔS_{BT} is found as the difference to the heating output H_W (eq. 10), since at thermal equilibrium both flows add up to the supplied power H_W.

The radiation losses caused by the radiation channel are taken into account by a transfer factor f_T, which follows from the ratio of measured to theoretical radiation transport.

The radiation losses can be reduced by coating the radiation channel, either with an aluminum sheet or aluminum foil, so that up to 73% of the heating output H_W is dissipated by infrared radiation. During these tests it was found that the aluminum foil causes a smaller heat loss J_Q than the sheet, which results in a slightly increasing radiation exchange.

Since in thermal equilibrium only as much heat can be dissipated as is supplied, any changes in the mechanical heat flows have a counterbalancing effect on the radiation balance. This also largely applies to the Earth-Atmosphere System, and thus, has a direct impact on the size of the greenhouse effect.

Still controversially discussed is, how the various IR-active components of the atmosphere interact and impact each other, and how great their respective influence is. Larger discrepancies can be found for the estimated feedbacks, which within the CMIP6 studies, e.g., give an average amplification of the basic equilibrium climate sensitivity by a factor of 3.1 and a final $ECS = 3.78°C$. Other studies show negative feedback with an attenuation of 36% and an ECS of only 0.68°C (Harde [16], [19]; Lindzen [20]).

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Editors: Prof. S. S. Bergsmark and Prof. J.-E. Solheim; **Reviewers**: anonymous.

Acknowledgements

We thank the Editors and Reviewers for their comments and for continuously supporting the publication process.

Appendix

A1. Description of the Experimental Set-Up

The cylindrical compartment is made of 16 round Styrofoam plates (Ø: 50, H: 5 cm), which are available as cake dummies (Fig. 2). A hole (Ø: 30 cm) is cut out of the middle of 12 of the Styrofoam panels. These 12 plates form the 60 cm long radiation channel. The 4 remaining plates (without hole) are required for the top cover of the radiation channel (H: 20 cm). The entire construction is hold together by three threaded rods, creating a radiation channel with a Styrofoam surface. The apparatus can be converted relatively easily by loosening the screw connections. From the outside, the cylinder jacket is covered with an aluminum-coated Styrofoam wallpaper

To optimize the radiation exchange, the channel is lined with a 0.5 mm thick, highly polished aluminum plate. The aluminum plate is bent to a tube and the overlap is covered with a 5 cm aluminum tape (Fig. 2). Similarly, to further minimize heat losses, the radiation channel can be lined with an aluminum-paper foil.

The warm plate P_W (Ø: 15.5 cm H: 0.5 mm, area: 0.0189 m^2) is covered with a commercially available heating foil (Thermo TECH, polyester heating foil, self-adhesive 12 V/DC, 12 V/AC 14 W, Ø = 174 mm, the plastic edges are cut to Ø = 15.5 cm) and heated electrically. The electrical power is supplied by a digital power supply (Korad KA3005D DC 30 V, 5 A) with a resolution of 0.01 V at a constant voltage of 4.00 V, unless otherwise specified. The heating output H_W, which is calculated from the voltage and measured current, shows slight deviations, caused by the ohmic resistance of the heating foil with the temperature T_W. The sensor plate P_S (Ø: 30 cm H: 0.5 mm, area: 0.052 m^2) has a hole in the middle (Ø: 15.6 cm), which is occupied by the warm plate.

The cooled plate is a 0.5 mm thick aluminum disc (Ø: 50 cm), which can be either blackened on both sides (P_C) or polished on the inside (P_{CP}). It closes the Styrofoam hollow cylinder at the bottom (Fig. 9a).

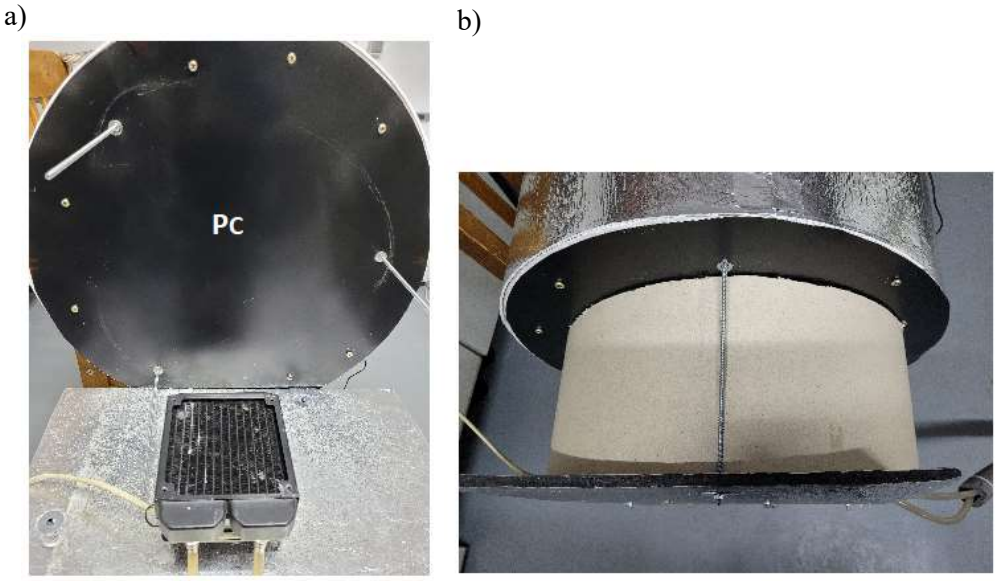


Figure 9: a) Plate P_C with air cooler b) Isolation of cooling unit.

The cold plate is cooled by a constant air flow (fan: Sunon, 120 mm Axial Panel Fan, 230 VAC, DP200A-2123XBT.GN, connected to 150 V = 8 W power consumption) and a heat exchanger (120 mm, 10 pipe, CPU cooler), so that its temperature is around 1°C below the room temperature. The fan and heat exchanger are located in an aluminum tube (H: 20 cm, Ø: 35 cm) that is wrapped with a 5 cm thick layer of polystyrene wallpaper (Fig. 9b).

The cooling water is circulated from a cool box with compressor cooling, filled with 7 liter of water. To ensure a constant water temperature, the compressor is periodically switched on and off. In the case of the cooling experiments, the compressor runs continuously.

The temperatures T_W, T_C, T_T, T_S, T_I, T_D and $T_{1\text{-}4}$ are recorded with data loggers (Elitech, RC4HC series) at intervals of 10 minutes with a resolution of 0.1°C. An 11th data logger measures the room temperature T_R at a distance of 1 m from the apparatus at a height of 80 cm above the floor.

A constant room temperature is a prerequisite for the measurements and is set to 17.5 ± 0.2 °C by thermostating the laboratory, for which a Nanyo mobile air conditioning unit is controlled by an ESCO, ES-10 temperature controller.

References

1. R. Clausius, 1887: Die Mechanische Wärmetheorie, Band I, https://archive.org/details/diemechanischewr00clau/page/n5/mode/2up?view=theater
2. R. W. Wood, 1909: *Note on the Theory of the Greenhouse*, London, Edinborough and Dublin Philosophical Magazine, Vol. 17, pp. 319-320. https://zenodo.org/record/1430650#.Yoo9kPTP1EY
3. T. Allmendinger, 2006: *The thermal behaviour of gases under the influence of infrared-radiation,* Int. J. Phys. Sci. 11: pp. 183-205. https://academicjournals.org/journal/IJPS/article-full-text-pdf/E00ABBF60017
4. N. S. Nahle, 2011: *Repeatability of Professor Robert W. Wood's 1909 experiment on the Theory of the Greenhouse*, Biology Cabinet Online-Academic Resources and Principia Scientific International, Monterrey, N. L.
5. T. O. Seim, B. T. Olsen, 2020: *The Influence of IR Absorption and Backscatter Radiation from CO_2 on Air Temperature during Heating in a Simulated Earth/Atmosphere Experiment*, Atmospheric and Climate Sciences, 10, pp. 168-185, https://doi.org/10.4236/acs.2020.102009.
6. T. O. Seim, B. T. Olsen, 2023: *The Influence of Heat Source IR Radiation on Black-Body Heating/Cooling with Increased CO_2 Concentration*, Atmospheric and Climate Sciences, Atmospheric and Climate Sciences, 13, pp. 240-254. https://doi.org/10.4236/acs.2023.132014
7. H. v. Ditfurth, 1978: Studio-Demonstration im ZDF, TV-Serie "Querschnitte".
8. M. Schnell, 2020: *Die falschen Klimaexperimente*, https://www.eike-klima-energie.eu/2020/11/06/die-falschen-klima-experimente.
9. A. Gore, D. Guggenheim, 2006: *An Inconvenient Truth*, Movie, https://www.imdb.com/title/tt0497116/, Oct.21
10. A. Watts, 2011: *Replicating Al Gore's Climate 101 video experiment shows that his "high school physics" could never work as advertised*, https://wattsupwiththat.com/2011/10/18/replicating-al-gores-climate-101-video-experiment-shows-that-his-high-school-physics-could-never-work-as-advertised/?cn-reloaded=1, Oct.21
11. J.-E. Solheim, 2016: *Start des zweitägigen „Al Gore-Experiments"*, 10. Internationale Klima- und Energie-Konferenz (10. IKEK), EIKE, Berlin, https://www.eike-klima-energie.eu/2017/02/04/10-ikek-prof-em-jan-erik-solheim-start-des-zweitaegigen-al-gore-experiments/,
12. H. Harde, M. Schnell, 2022: *Verification of the Greenhouse Effect in the Laboratory*, Science of Climate Change, Vol. 1.2, pp. N4 1-32, https://doi.org/10.53234/scc202112/213.
13. J. Stefan, 1879: *Über die Beziehung zwischen der Wärmestrahlung und der Temperatur*, in: Sitzungsberichte der mathematisch-naturwissenschaftlichen Classe der kaiserlichen Akade-

mie der Wissenschaften, Bd. 79 (Wien 1879), pp. 391-428.

14. L. Boltzmann, 1884: *Ableitung des Stefan'schen Gesetzes, betreffend die Abhängigkeit der Wärmestrahlung von der Temperatur aus der electromagnetischen Lichttheorie*, Annalen der Physik und Chemie. Bd. 22, pp. 291–294, https://doi.org/10.1002/andp.18842580616.
15. P. L. Dulong, A. Petit, 1817: Annales de Chim. de Phys. VII, pp. 225 – 264 und 337 -36
16. H. Harde, 2017: *Radiation Transfer Calculations and Assessment of Global Warming by CO_2,* International Journal of Atmospheric Sciences, Volume 2017, Article ID 9251034, pp. 1-30, https://doi.org/10.1155/2017/9251034.
17. K. E. Trenberth, J. T. Fasullo, and J. Kiehl, 2009: *Earth's global energy budget*, Bulletin of the American Meteorological Society, vol. 90, no. 3, pp. 311–323.
18. Sixth Assessment Report (AR6) of the IPCC, 2021: *Summary for Policymakers*. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V. et al. (eds.)]. Cambridge University Press.
19. H. Harde, 2022: *How Much CO_2 and the Sun Contribute to Global Warming: Comparison of Simulated Temperature Trends with Last Century Observations*, Science of Climate Change, Vol. 2.2, pp. 105-133, https://doi.org/10.53234/scc202206/10.
20. R. S. Lindzen, Y.-S. Choi, 2011: *On the observational determination of climate sensitivity and its implications*, Asia-Pacific Journal of Atmospheric Sciences, Vol. 47(4), pp. 377–390, https://doi.org/10.1007/s13143-011-0023-x

Testing Carbon Cycle Models and Budgets

Antero Ollila

School of Engineering (Emer.)
Aalto University, Espoo, Finland

OPEN ACCESS
Klimarealistene
P.O. Box 33,
3901 Porsgrunn
Norway
ISSN: 2703-9072

Correspondence to
aveollila@yahoo.com

Vol 3.5
pp. 463-486

Abstract

All carbon cycle models referenced by the IPCC have a common feature: Increased carbon dioxide in the atmosphere originates from anthropogenic emissions. It is also generally known that the CO_2 concentration observations show that about 44 – 46 % of yearly CO_2 emissions seem to have accumulated in the atmosphere; the ocean and biosphere take up the rest. Therefore, this straightforward conclusion that the increased atmospheric CO_2 is anthropogenic may seem correct, but there are profound physical problems. An unusual feature is among carbon budget presentations, that they do not calculate the isotopic composition of the atmospheric CO_2 nor refer to the observed global $\delta^{13}C$ used as a measure of isotopes $^{13}C/^{12}C$ ratio from 1750 to the present time. The analyses of this study show that the current $\delta^{13}C$ value of -8.6 ‰ in the atmosphere conflicts with physical processes and applied recycling flux values meaning that the increased atmospheric CO_2 since 1750 cannot be exclusively anthropogenic. This study's atmospheric anthropogenic CO_2 amount of 70 GtC is much smaller than the 279 GtC reported by the IPCC for 2019. Also, the removal rate of anthropogenic CO_2 from the atmosphere can be approximated to be about 64 years — the same as the radiocarbon ^{14}C removal rate after the 1964 nuclear tests corresponding to the e-folding time of 11 years. The total CO_2 removal rate would be about 220 years meaning an e-folding time of 38 years.

Keywords: $^{13}C/^{12}C$ ratio; $\delta^{13}C$; carbon cycle; permille; anthropogenic carbon dioxide; atmospheric CO_2 composition

Submitted 2023-07-20, Accepted 2023-12-26. https://doi.org/10.53234/scc202310/44

1. Introduction

1.1 General features of the carbon cycle

The carbon cycle's governing feature is the recycling fluxes, which yearly remove about 26 % of the atmospheric CO_2 into the oceans and biosphere, Fig. 1. A fundamental issue is in which way the carbon cycling fluxes (CCFs) remove different CO_2 molecules from the atmosphere, and what is the composition of recycle fluxes from the oceans and the land plans (later land or biosphere) acting as sinks for the anthropogenic CO_2.

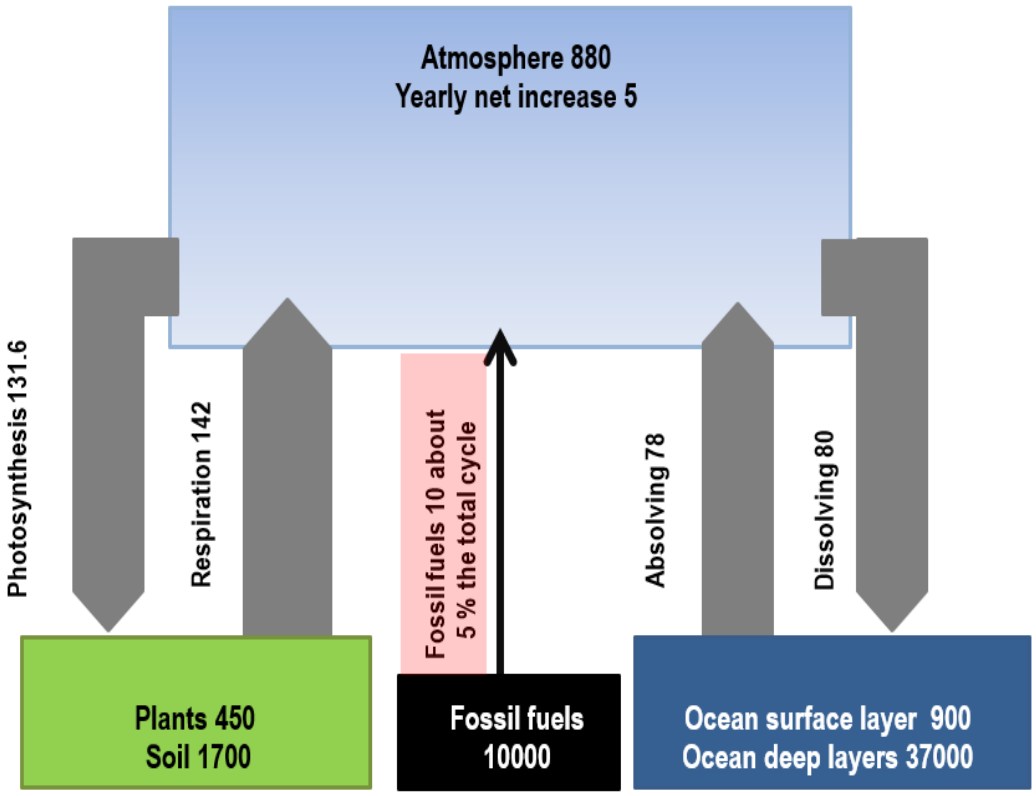


Figure 1: The carbon cycle presentation shows the recycling flux values of the IPCC (2021, Figure 5.12). The numerical values are reservoir amounts in gigatons of carbon (GtC); the flux values are in GtC yr^{-1}.

It is an outstanding feature of global carbon budget presentations like Friedlingstein et al. (2021) that no presentation exists about the fundamental nature of the carbon cycle by introducing the carbon cycle fluxes between the atmosphere and ocean and between the atmosphere and biosphere: no figure and no magnitude estimates. In the latest Assessment Report 6 (AR6) of the IPCC (2021) there is a schematic Figure 5.12 (here Figure 1) depicting the overall presentation of the carbon cycle.

Two permanent isotopes of carbon molecules exist. The most common is ^{12}C, having 6 protons and 6 neutrons; however, ^{13}C has one extra neutron. Isotope ^{12}C is the most common, being 98.9 % of all carbon; the rest is ^{13}C. An exceedingly small concentration of unstable isotope ^{14}C, which is radioactive, also exists.

The measurement unit of ^{13}C (marked as δ^{13}C) is a fraction of carbon isotope ^{13}C expressed as ‰, and it is called also permille value. This unit is linearly dependent (Srivastava et al., 2018) on the relationship ^{13}C/^{12}C:

$$\delta^{13}C = (S/N-1) * 1000\ [‰] \quad (1)$$

where S = ^{13}C/^{12}C being a sample and N = $(^{13}C/^{12}C)_{standard}$ = 0,0112372. The value of this standard comes from a sea fossil "Belemnitella Americana.". This original fossil sample is no longer available, and its value can be back-calculated from a carbonate standard NBS-19, which has a δ^{13}C value of +1.95 ‰ (Brand et al., 2014). Many climate researchers have never heard about this measurement unit. It looks like the IPCC does not want to report on permille values since in the AR6 (IPCC, 2021) there is only one figure, namely Fig. 5-6 and its panel c, where there is a short permille trend of the atmospheric CO_2. The same applies to the main referred research study

(Friedlingstein et al., 2020), which is the basis for the carbon cycle description in the AR6: no reference to the permille values.

Anthropogenic CO_2 means CO_2 originating from fossil fuels and land use (NOAA, 2022a) as a result of human actions. Fossil fuels have the same permille value ($\delta^{13}C$) as plants from the Carboniferous era (359 – 299 million years ago); this value is -28 ‰. The permille values of anthropogenic CO_2 differ from the atmospheric values today (-8.6 ‰), and it can be used to test the fraction of anthropogenic CO_2 in the atmosphere by applying carbon circulation models.

The composition difference between the anthropogenic CO_2 and the natural CO_2 is minimal despite large differences in $\delta^{13}C$ values. One ton of anthropogenic carbon (-28 ‰) contains 10.92 kg of isotope ^{13}C, and one ton of the present atmospheric carbon ($\delta^{13}C$ = -8.6 ‰) contains 11.14 kg of ^{13}C. The difference is 220 grams, which is only 0.022 % of 1 GtC. The atmospheric CO_2 is extremely well-mixed; therefore, CCFs leaving the atmosphere have essentially the same composition, on average, as the atmospheric CO_2. The atmosphere is the mixture of natural CO_2 from the ocean and plants and the fraction of anthropogenic emissions remaining there.

This study aims to show that the IPCC's carbon budget figures contradict the atmospheric CO_2 composition measurements ($\delta^{13}C$). Another objective is to show that annual carbon cycle fluxes changing about 24 - 26 % of the atmospheric CO_2 do not match the IPCC's carbon budget values for different CO_2 fractions. The author developed a new version of the carbon cycle model, DAOBM-4, for calculating the atmospheric $\delta^{13}C$ by improving the fractionation calculation of the air-to-sea and sea-to-air interfaces. When the atmospheric permille value calculations are totally missing in the AR6, a new way to estimate the atmospheric permille value is a part of the DAOBM-4. Fractionation between reservoirs is not known very well, but new equations have been developed starting from 1750 onward.

The atmosphere was divided into three compartments according to the origin of the CO_2: the ocean, biosphere, and anthropogenic emissions. According to the sources of recycling CO_2, this division was applied to the anthropogenic fraction and the natural fraction of CO_2. An essential result is that the atmospheric CO_2 increase since 1750 is only partially anthropogenic. This result means that the decay timescales would be different for anthropogenic and total CO_2 fractions if the CO_2 emissions were ceased. Also, land-use emissions were included based on the CO_2 concentration information.

2. Analyses of carbon cycle models of the IPCC

The IPCC's global warming theory is the enhanced greenhouse effect due to increased GH gas concentrations and carbon dioxide being the leading cause of warming. Another troublesome feature of anthropogenic CO_2 is the long adjustment time of this fraction, as reported by the IPCC (2021): Part of the CO_2 human emitted CO_2 remains in the atmosphere for centuries to millennia, meaning its concentration is exceedingly difficult to reduce once it has entered the atmosphere.

Hellevang and Aagard (2015) have stated that "*The total amount of excess carbon taken up by the two systems was estimated using an airborne fraction of 0.46, implying that a residual of 54 % of the anthropogenic carbon emissions each year has been taken up by the two sinks*." They used this assumption to calculate the atmospheric $\delta^{13}C$. Joos et al. (2013) state that "*Currently, only about half of the anthropogenic CO_2 emission stays airborne*." In AR5 p. 467-469, the IPCC (2013) writes: "*About half of the emissions remained in the atmosphere 240 PgC±10 PgC since 1750.*" In AR6, the IPCC (2021) used the expressions "remained" and "accumulated." The latter

expression leaves the possibility that at least part of anthropogenic CO_2 was recycled from the oceans and biosphere, which may have changed the permille value of the anthropogenic CO_2.

So, without further analysis, it looks like the CO_2 increase since 1750 originates mainly from fossil fuels, which is caused by human actions, meaning the reason is anthropogenic.

The IPCC (2013) introduces another piece of evidence about the real CO_2 composition and its origins: *"An independent line of evidence for the anthropogenic origin of the observed atmospheric CO_2 increase comes from the observed consistent decrease in atmospheric oxygen (O_2) content and a decrease in the stable isotopic ratio of CO_2 ($^{13}C/^{12}C$) in the atmosphere (Figure TS.5)."* This conclusion can be criticized, since all fossil fuel carbon has reacted with atmospheric oxygen, but all fossil fuel carbon has not stayed in the atmosphere but it is divided between the reservoirs. This evidence refers to the isotopic ratio of $^{13}C/^{12}C$, which shows it has been decreasing. This evidence is insufficient since it is only qualitative but not quantified evidence about CO_2 origin.

The IPCC, p. 50-52 (2013) shows evidence about the real CO_2 composition and its origin: *"The distribution of observed atmospheric CO_2 increases with latitude clearly shows that the increases are driven by anthropogenic emissions that occur primarily in the industrialized countries north of the equator.*" This fact cannot be used as univocal evidence about the origin of CO_2. The CO_2 concentration increase does not show anything about the final atmospheric isotopic composition due to continuous recycling fluxes between the reservoirs, which are about 10–12 times greater than yearly CO_2 emissions.

The total CO_2 mass in 2020 was 880 GtC according to the observed CO_2 concentration; in 1750, the total mass was 591 GtC (IPCC, 2021). If all the increase were anthropogenic CO_2, its amount would be 292 GtC, meaning a fraction of 33.4 %. The rest (66.6 %) could be assumed to be natural CO_2 with an unknown permille value. If we use the value of -6.35‰ observed in the atmosphere in 1750, the atmospheric CO_2 mixture of the present atmosphere would be

$$\delta^{13}C = 0.334 * (-28\ ‰) + 0.666 * (-6.35\ ‰) = -13.6\ [‰] \quad (2)$$

This calculation result shows that the result differs greatly from the observed value of -8.6 ‰. If Eq. (2) would give the permille value of -8.6 ‰, the permille value of the natural CO_2 in the atmosphere should be about +1.0 ‰. Since the plants have not been a sink according to AR6, (IPCC 2021, p. 5-22), the land has not changed the atmospheric permille value. The ocean has been the major sink but the fractionation from air to sea and from sea to air are close to each other. Keeling and Graven (2021) have concluded that atmospheric $\delta^{13}C$ is not strongly influenced by net exchanges of CO_2 across the air-sea interface. The permille values of NOAA (2022a) show the same: permille from air to sea -10.5 ‰, and from sea to air -9.5 ‰. Fig. 2 depicts the observed permille value as a function of the anthropogenic CO_2 percentage in the atmosphere up to 2020.

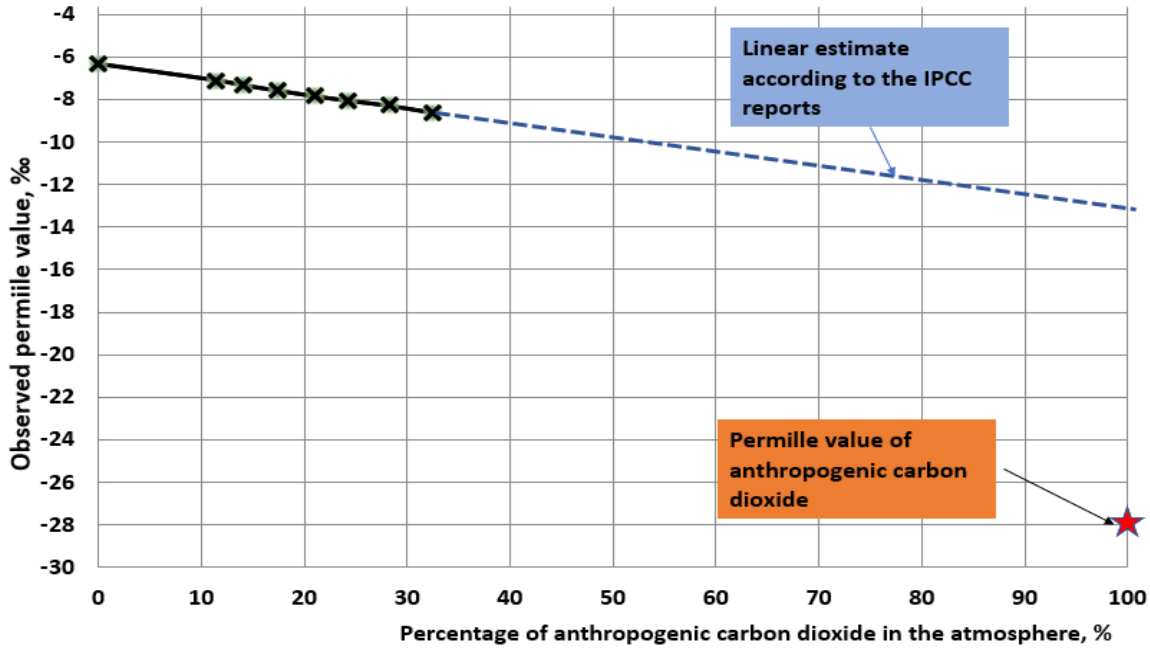


Figure 2: The observed permille value in the atmosphere versus the anthropogenic percentage according to the IPCC. The relationship is linear, and it has been continued to a theoretical situation that the atmospheric CO_2 is totally anthropogenic.

The permille value of the atmosphere would be about -13‰ even though it would be totally anthropogenic to stay in the atmosphere. These two analyses show that the increased atmospheric mass from 1750 cannot be exclusively anthropogenic since the currently observed $\delta^{13}C$ is about -8.6‰.

The total average CCF in the period from 2010 to 2019 from the atmosphere according to Fig. 5.12 (IPCC, 2021) into the sinks has been 221.5 GtC, and the average CO_2 mass has been 851.5 GtC according to CO_2 concentration measurements. It means that 26.0 % of the average atmospheric mass has changed every year during this period. If there were no mechanism controlling the composition of CCF fluxes, the amount of the original atmospheric mass of 828.6 GtC in 2010 would have decreased to 55.1 GtC in 2019. The statement of AR5 and AR6 by the IPCC (2021) and Friedlingstein et al. (2020) means that the anthropogenic CO_2 amount of 239.6 GtC in 2010 has remained in the atmosphere and it has increased to 285.4 GtC in 2019 due to anthropogenic emissions, but they do not show any real evidence in which way this would happen. This analysis shows that the claim that anthropogenic CO_2 has *remained or stayed* in the atmosphere is impossible. Further analysis is needed to show if it is possible that anthropogenic CO_2 could be accumulated – i.e. at least part of 285.4 GtC of anthropogenic CO_2 could have been recycled back from the ocean and from the plants.

There is a fractionation phenomenon from air to sea, sea to air, and vegetation CO_2 exchange. The question is if this fractionation can cause the effect that about 54 - 56 % of the ^{12}C and ^{13}C molecules of yearly anthropogenic emissions would be sequestrated from the atmosphere and the rest of 44 % - 46 % would stay. The ^{12}C and ^{13}C molecules in the atmosphere are mixed almost perfectly and the CCFs cannot separate ^{12}C and ^{13}C according to their origins or if they have been in the atmosphere for 10 years or just arrived. Although the ^{13}C fraction of anthropogenic CO_2 would differ in different reservoirs, over 99 % is the same composition, which must still be labelled anthropogenic if it originates from human actions despite its $\delta^{13}C$ value. The actual $\delta^{13}C$ value of an anthropogenic CO_2 amount in the reservoirs does not change the anthropogenic origin since it is just a consequence of the fractionation of the carbon cycle process and it varies continuously.

The statement that the increased atmospheric CO_2 from 1750 onward is fully anthropogenic, means that there was a physical identification mechanism for ^{12}C and ^{13}C molecules with anthropogenic origin. A simple calculation can be carried out based on the numbers of Fig. 5.12 of AR6 (IPCC, 2021). The average CCFs during the period 2010-2019 sequestrate 26 % of the atmospheric CO_2 into sinks, which means 57.3 GtC of anthropogenic CO_2. According to Fig. 5.12, the same amount is 54.5 GtC. This situation is presented in Table 1 offering another perspective.

Table 1. The average CCFs (GtC yr^{-1}) from 2010 to 2017, according to IPPC (2021, Fig. 5.12), and the percentage fraction of the anthropogenic CO_2 from the total oceanic or terrestrial CCF.

CO_2 quantity/flux	Total CO_2	Anthropogenic CO_2	
	GtC / GtC yr^{-1}	*GtC*	*%*
In the atmosphere	870	279	32.1
From the atmosphere to the ocean	79.5	25.5	32.0
From the atmosphere to the land	142.0	29.0	20.4

Table 1's figures mean the ocean-atmosphere flux would not favour the atmosphere's anthropogenic fraction since it contains 32.0 % of this fraction, and in the atmosphere, its fraction is 32.1 %. Oppositely, the gross photosynthesis flux has only 20.4 % of anthropogenic CO_2. Does a physical explanation for these figures exist? The percentage of the ocean flux is close enough to the atmospheric composition but the percentage of the land plants figure is far too low. The plants prefer anthropogenic CO_2 for its higher ^{12}C isotope concentration. Also, the ocean's surface mixing layer favours anthropogenic CO_2 since phytoplankton and plants in the euphotic surface layer prefer the ^{12}C isotope.

According to Fig. 5.12 of AR6 (IPCC, 2021), the average yearly anthropogenic fluxes from the land plants and the ocean are 25.6 GtC yr^{-1} and 23.0 GtC yr^{-1} respectively. There is no natural process, that can control that from a yearly emission of about 10 GtC, about 5.4 GtC will remain in the atmosphere, and at the same time about 48.6 GtC entering the atmosphere would leave the atmosphere without a single molecule remaining in the atmosphere. This is evidence that the IPCC has used wrong terminology and misleading wording by writing that 44 – 46 % of yearly anthropogenic emissions *remain* in the atmosphere. Their figures and data show that there are strong recycling anthropogenic CO_2 fluxes from the sinks, which are in direct conflict with this claim. The correct wording would be that anthropogenic CO_2 accumulates in the atmosphere.

The simple analyses above show that the general statement of the carbon cycle figures of the IPCC (2021) and Friedlingstein et al. (2020) are against physical processes appearing in the carbon cycle. The essential question remains open: Is the amount of atmospheric CO_2 increase since 1750 solely anthropogenic by nature anyway? Considering the huge natural recycling fluxes changing about 24 % of the atmospheric CO_2 amount each year, it is highly unlikely that each year the increased amount would be only anthropogenic. This claim can be abandoned just by considering that the composition of natural and anthropogenic CO_2 fluxes have a practically similar isotopic composition (99 % of isotope ^{12}C).

Many partitioning research studies show in which way the uptake rates of anthropogenic CO_2 fluxes and storages are divided with the oceans and biosphere. Sabine et al. (2004) found that the global oceanic anthropogenic CO_2 sink from 1800 to 1994 was 118±19 GtC, and Waugh et al.'s (2006) was 134 GtC for the same period. Khatiwala et al. (2009) valued the inventory at 140±25 GtC. Sabine and Tanhua (2009) summarized that the most common estimate of the oceanic anthropogenic CO_2 inventory in the mid-1990s was about 120 GtC. DeVries (2014) estimated the same sink value to be 160–165 GtC in 2012. It should be noted that the anthropogenic CO_2 amounts are not based on direct observations but the methods always include assumptions and models.

Some research studies have used so-called isotope models, which simulate the atmospheric $\delta^{13}C$ values using carbon cycle fluxes like Raynar et al. (2008), Hellevang and Aagard (2015), and Keeling et al. (2017). These simulated $\delta^{13}C$ values are usually close to the observed atmospheric $\delta^{13}C$ values, but the absolute anthropogenic amount in the atmosphere has not been reported.

There is only Figure 5.6 in the latest (IPCC, 2021), where the IPCC shows the acronym $\delta^{13}C$ — the trend of $\delta^{13}C$. The IPCC does not explain this acronym nor show any calculations or explanation for the trend. One purpose of this study is to reveal why this measurement result gets no attention from the IPCC.

According to AR6 (IPCC, 2021), "*the ocean uptake of anthropogenic carbon is a two-step set of abiotic processes that involves the exchange of CO_2, first across the air-sea boundary into the surface mixed layer, followed by its transport into the ocean interior where it is stored for decades to millennia, depending on the depth of storage (Gruber et al., 2019)*." This adiabatic process means that the atmospheric CO_2 dissolves in the surface ocean according to Henry's law, or according to "buffer-factor"-mechanism.

The AR6 (IPCC, 2021) does not report, in which way the anthropogenic CO_2 is divided between the ocean mixing layer and the intermediate & deep ocean. Gruber et al. (2019) reported that 50 % of the anthropogenic CO_2 is in the layer above 400 meters depth. The total anthropogenic CO_2 in the ocean was 160 GtC in 2019 (IPCC, 2021). Since the surface mixed layer depth is 75-100 meters, the anthropogenic CO_2 in this layer can be estimated to be about (80/400)*0.5*160 GtC = 25 GtC. According to IPCC (2021), the annual average recycled 2008-2017 flux of anthropogenic CO_2 was 25.5 GtC. These figures would mean that the recycling flux would return into the atmosphere all the anthropogenic CO_2, which was absorbed by the surface mixed layer.

Two schools of thought exist about the ocean's capacity to dissolve the atmospheric CO_2 and at which rate this dissolution can happen. The most common approach could be called the "buffer factor"-based estimation, or the buffering of the CO_2 exchange from air to seawater, also known as the "Revelle factor" (Revelle and Suess, 1957). The Revelle factor value is about 14 in the high latitude waters and 10 in equatorial waters. A buffer factor 10 means a 10 % increase of partial CO_2 pressure can increase only 1 % of the ocean's total carbon amount. This approach has led to the net dissolving rate of 3.1 GtC yr^{-1} by Ciais et al. (1995), 2.2 GtCyr^{-1} by Gruber et al. (2009), 2.3 GtC yr^{-1} by Graven et al. (2012), 2.6 GtC for the period 2000–2010 by DeVries (2014), 2.6 ± 0.5 GtC yr^{-1} by Goto et al. (2017), and 3.0 GtC yr^{-1} by Woolf et al. (2019). The CO_2 circulation models referred to by the IPCC apply the buffer capacity restriction.

Some studies do not accept the ocean's almost constant buffer capacity. The increased atmospheric CO_2 concentration can increase the buffer capacity by 2.5 to 6 times (Butler, 1982). Other minerals like borate, kaolinite, and clay minerals can increase the storage capacity of CO_2 (Stumm and Morgan, 1970; Meier-Reiner and Hasselman, 1987); in the latter study, the researchers concluded that these buffers together mean an infinite buffer capacity.

Two aspects challenge the buffer capacity approach. Firstly, the ocean can absorb CO_2 yearly at about 90 GtC. Before the year 1750, the dissolving and absolving rates were equal. The increased atmospheric CO_2 concentration has caused an imbalance in these fluxes. If a real buffer mechanism exists, there cannot be two different processes for CO_2 absorption by the surface ocean. Secondly, the recycled flux from the ocean into the atmosphere can compensate for the absorption rate of the anthropogenic CO_2 flux by bringing the net total CO_2 absorption rate closer to zero as depicted in Fig. 1. The simulation results of the author's model DAOBM show this fact for 2020.

A general observation from different types of carbon cycle models is that no research paper shows

exact numerical values from 1750 to the present while including all three essential elements: 1) the carbon budget values of anthropogenic, natural, and total CO_2 amounts in different reservoirs, 2) the carbon cycle fluxes, and 3) the atmospheric $\delta^{13}C$ values. Van der Velde et al. (2012) tested their model for closing a ^{13}C budget, but could not report good results. This may be a symptom of the underlying assumption, which can be found in all CO_2 circulation models: that the increased atmospheric CO_2 amount since 1750 is fully anthropogenic. The budget values in different reservoirs do not fit, or ^{13}C does not fit.

3. Analyses of bomb carbon impulse

Adjustment time (marked with T_{adj}) or relaxation time is a time decay of an instantaneous pulse input in a system to return to zero. It is also a time needed for a system to reach a new balance after a stepwise change of input. Lifetime has been sometimes used to mean adjustment time. In many cases, a carbon cycle system has been approximated by a dynamic process model with a single time constant called the first-order system. Residence time is the same as the time constant of the first-order system, and it is also called e-folding time. It means that after the e-folding time, the output of a step change has happened to 63.2 %, and 36.8 % (=100/e) of the change is still left. Because theoretically, T_{adj} would be infinitely long, in practice T_{adj} is approximated by multiplying the e-folding time T by four: $T_{adj} = 4$ T. At this time moment, a step change has reached the level of 98.2 % from the final equilibrium value. Sometimes a half lifetime has also been used, which means the time when 50 % of the change has happened which is mathematically defined in a first-order linear system = 0.693 * T. Confusion about these time terms happens sometimes but these terms have been specified in the proper way in the Glossary of AR5 (IPCC, 2013).

Radiocarbon isotope ^{14}C from the nuclear bomb tests in the atmosphere accidentally created a global test for the carbon cycle system, and it can be considered the only full-scale climate test by humans, Fig. 3.

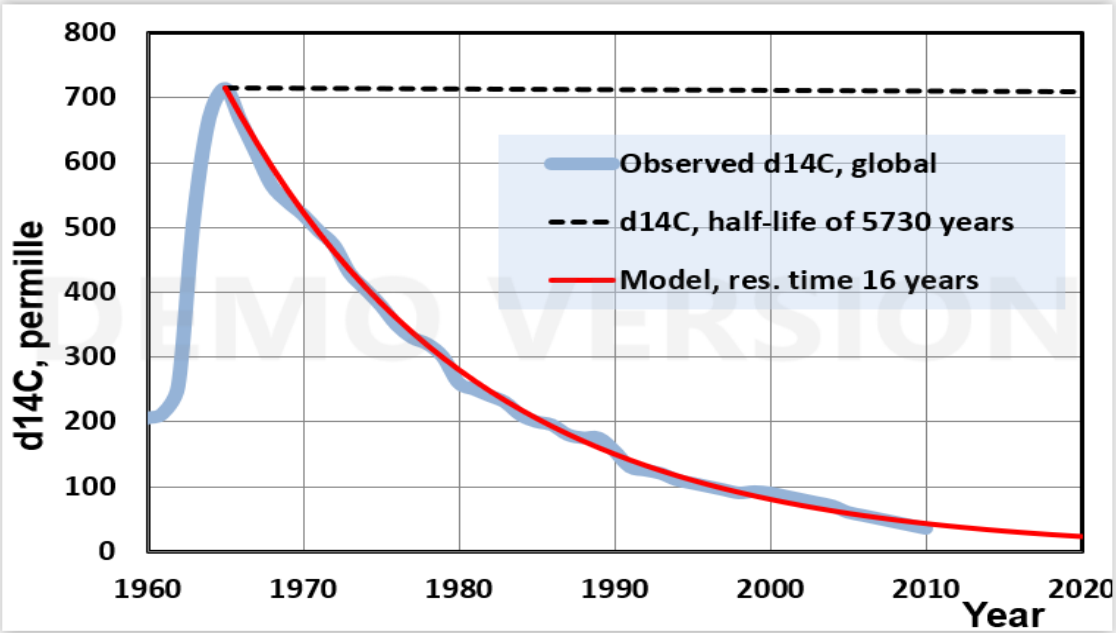


Figure 3: The observed decaying rate of ^{14}C (blue curve) (LLNL, 2022), the simulation result of (Ollila, 2016) (red curve) for anthropogenic CO_2, and the theoretical decaying rate of ^{14}C without recycling fluxes in the carbon circulation system (black dashed curve).

Fig. 2 depicts the observed d^{14}C values, including a peak in 1964. Since nuclear bomb tests ceased in 1964, this measurement is a test of carbon circulation. The curve fitting of these observations gives the best fit with 16 years of e-folding time, meaning 64 years of adjustment time. If no CCFs in the climate system existed, the ^{14}C would have decreased only 0.7 % by 2022 since the half-life time of ^{14}C is 5730 years. It is imminent that the major role in the rapidly decaying rate of ^{14}C is the circulation of CO_2 between the reservoirs, which removes ^{14}C very quickly from the atmosphere: about 26 % annually!

Terrestrial and oceanic plants play a crucial role in anthropogenic CO_2 recycling in explaining fractionation between reservoirs since they discriminate ^{13}C molecules. ^{14}C is heavier than ^{13}C; therefore, plants should discriminate ^{14}C molecules even more than ^{13}C molecules. Nevertheless, the decaying rate of ^{14}C is surprisingly short, hinting that the anthropogenic emissions decay rate should be about the same.

Revelle and Suess (1957) concluded in the 1950s that the average lifetime of a CO_2 molecule in the atmosphere before the ocean absorbs it is about 10 years. This estimate was based on the analyses of cosmogenic isotope ^{14}C lifetime, which is not identical but is related to atmospheric CO_2 molecules according to Revelle and Suess. In the first-order dynamic system, the average lifetime is 0.693 * residence time, which means that the observed residence time of bomb carbon of 16 years corresponds to 11 years average lifetime. The average lifetime value of 10 years by Suess and Revelle corresponds to 14.4 years of residence time. This value calculated from cosmogenic ^{14}C data is surprisingly close to 16 years of T confirmed by the empirical nuclear bomb tracer test years later.

4. DAOBM-4 improvements and results

4.1 Fractionation between the carbon reservoirs

The δ^{13}C value differs in the carbon reservoirs. When carbon dioxide fluxes move from one reservoir to another, the δ^{13}C value does not remain the same as in the reservoir from where a flux flows. This phenomenon of partitioning isotopes between substances with different isotopic compositions was coined “fractionation.”

Photosynthesis of C3 and C4 plants convert inorganic CO_2 to carbohydrates in different ways; therefore, the δ^{13}C of these plants differ. The permille value of plants today varies closely from -25.7 ‰ (NOAA, 2022a), -25.9 ‰ Battle et al. (2000), -27.2 ‰ Tans et al. (1993), and -28.1 ‰ (Quay et al., 2003). However, the -28 ‰ value will be used in this study.

Many researchers have concluded that the preindustrial surface ocean δ^{13}C was at equilibrium with the atmospheric δ^{13}C, and its value was around -6.35‰ (Francey et al., 1999), from -6.35‰ to -6.45‰ (Böhm et al., 2002), or -6.35‰ (Rubino et., 2013) based on ice core samples and coralline sponge samples of Caribbean shallow waters. The author used the δ^{13}C value of -6.35 ‰ for surface water and atmosphere in 1750.

The current observational research studies on the fractionation of air-to-sea and sea-to-air started in about 1970. All these studies have not been carried out on a global scale; however, the results are still close to each other.

Inoue et al. (1987) carried out their experiments in 1982; their air to sea δ^{13}C value was -10 ‰, sea to air -8 ‰, and the surface water δ^{13}C for four years was +1.33 ‰. Marino and McElroy (1991) also reported -8 ‰ for the sea-to-air fractionation. Some researchers have only reported the difference between the δ^{13}C of the atmosphere and the surface water. Siegenthaler and Munnich (1981) found that the air-to-sea fractionation decreases the δ^{13}C value by -1.8 to -2.3 ‰.

Battle et al. (2000) and Alden et al. (2010) have estimated that the same fractionation effect is -2.0 ‰.

The $\delta^{13}C$ value varies for surface water CO_2, according to research studies. Gruber et al. (1999) found that surface water $\delta^{13}C$ varies from 1.6 ‰ to 2.2 ‰, according to latitudes from the database of the 1980s. Schmittner et al. (2013) calculated the value of +2.3 ‰ for 1990–2005. The surface water's high $\delta^{13}C$ value can be explained: Photosynthesis occurs within the euphotic surface layer where phytoplankton and plants live to a depth of 200 meters. The biological pump removes the CO_2 from the surface layer to the deeper part of the ocean almost with the same magnitude fluxes as CO_2 moves into it (Sarmiento and Gruber, 2006). Since photosynthesis also prefers the ^{12}C isotope, the dissolved carbon in surface waters becomes strongly enriched in the ^{13}C isotope.

These studies conclude that the exact knowledge of the numerical values of air-to-sea and sea-to-air fractionation numbers still varies among different research studies. However, general trends from 1750 to now, with accuracies of about ± 0.5‰, can be estimated. The author has constructed simple equations for calculating yearly values for air-to-sea and sea-to-air fractionation trends. The curves based on these equations are explained in the attachment and the permille values according to these equations are depicted in Fig. 4.

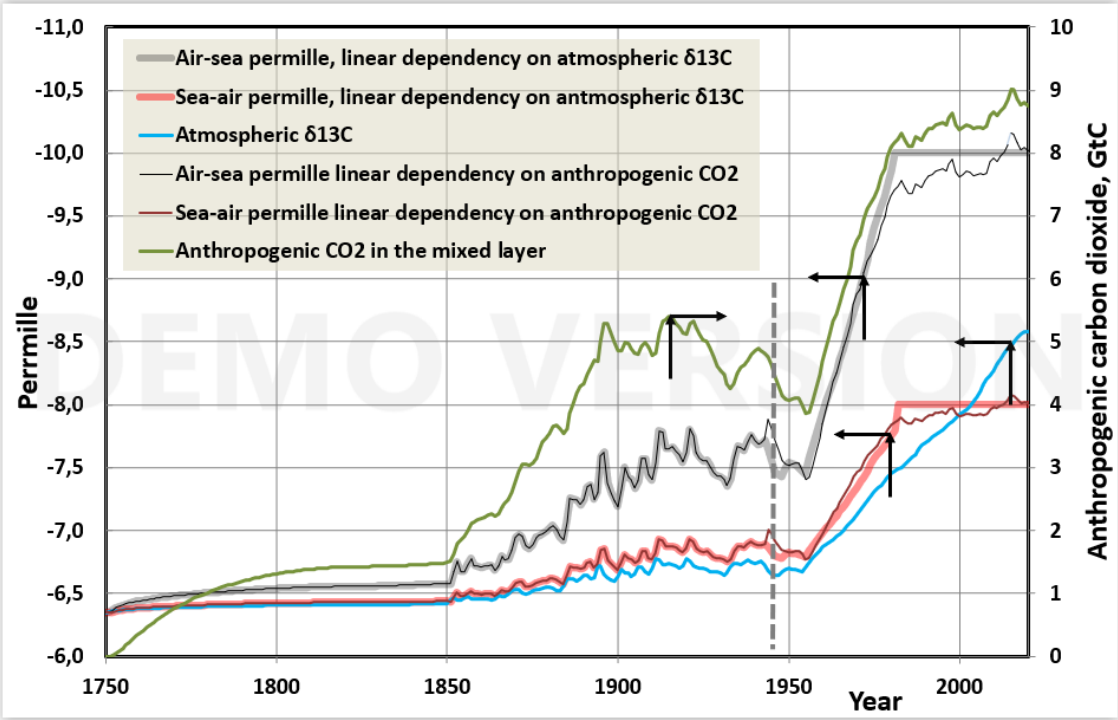


Figure 4: Permille trends from 1750 to 2020 for air to sea and sea to air. The observed atmospheric $\delta^{13}C$ (blue curve) and anthropogenic CO_2 (green curve) trends in the surface ocean water (mixed layer) have been presented.

The air to sea $\delta^{13}C$ trend (grey curve) starts from -6.35 ‰ and increases in a linear relationship to atmospheric $\delta^{13}C$ to the value of -10 ‰ in 1980; thereafter, this value stays the same. In the same way, the sea-to- air $\delta^{13}C$ trend (red curve) starts from -6.35 ‰ and increases in a linear relationship to atmospheric $\delta^{13}C$ to the value of -8 ‰ in 1980; thereafter, this value does not change. The simulation runs with the author's updated CO_2 circulations model DAOBM-4, producing the trend of the anthropogenic CO_2 amount in the surface layer (green curve). This curve's similarity to the air-to-sea and sea-to-air curves is obvious from 1940 onward.

The author changed the linear dependencies of the $\delta^{13}C$ curves after this observation of the anthropogenic amount in the mixed layer from 1940 onward. A noteworthy feature of these $\delta^{13}C$ curves is that air-to-sea and sea-to-air $\delta^{13}C$ values stopped increasing around 1980, according to the research studies, following the behaviour of the anthropogenic amount in the surface layer. The linear dependency of $\delta^{13}C$ offers a practical presentation for these variables for the last 80 years.

It can be criticised that there is no ocean chemistry description of the processes transporting the dissolved carbon into the deep sea and finally to the ocean floor. These descriptions have not been included since the net dissolved total CO_2 amounts never exceed the maximum limits of the buffer-factor approach as will be analyzed later.

4.2 Simulation results by the carbon cycle model DAOBM

The author updated his carbon cycle model; the latest version is number 4: DAOBM-4. The basic construction is still the same as 1DAOBM-3 (Ollila, 2020), which includes 26 equations. The major change is in how to calculate the atmospheric $\delta^{13}C$ and the addition of land-use emissions.

The CCFs dominate the CO_2 composition in the atmosphere. Before 1750, the CCFs were almost constant, and also during the 1800s due to small fossil fuel emissions. Let us use concrete numbers to illustrate: the CO_2 mass at 600 GtC, cycle flux from and into the ocean at 75 GtC yr^{-1}, and the same from the terrestrial biosphere at 120 GtC yr^{-1}. The atmospheric mass can be divided into two compartments, whose magnitudes are (75/195)* 600 = 231 GtC, and (120/195)*600 = 369 GtC. The changes in CCFs and the formation of the third compartment of the anthropogenic CO_2 must be included. The $\delta^{13}C$ values can be calculated for each compartment. According to common mixture calculations, the actual atmospheric $\delta^{13}C$ is the mixture of these compartments. This same approach was applied for calculating the composition of the atmospheric anthropogenic CO_2 amount since it also originates from the same three sources: the fossil fuel emissions remaining in the atmosphere, the fluxes cycling back from the ocean, and the biosphere. All the equations were detailed in the Appendix, encompassing 45 equations.

The DAOBM-4 model uses the yearly fossil fuel usage based on CDIAC's (2022a) bookkeeping method. CO_2 concentration measurements are from NOAA (2022b) as well as sea temperature from NOAA (2022c). The analysis of these two data sources reveals that before the year 1956, the atmospheric CO_2 concentration was higher than the accumulated CO_2 emissions. The difference was assumed to be caused by land-use CO_2 emissions, calculated as the difference between the observed CO_2 measurement and fossil fuel emissions. This calculation method was used until 1956; thereafter, the biosphere turned into a net sink. This method does not separate the current land-use emissions since the biosphere's absorbed CO_2 amount is on a net basis.

Some basic features of DAOBM-4 can be summarized. There are no dynamic time constants applied, but the model simulates the CO_2 fraction changes in the reservoirs and CCFs based on the yearly CO_2 emission and ocean temperature changes. DAOBM-4 keeps the anthropogenic and natural CO_2 fluxes and reservoir quantities separate all the time. The CCFs remove anthropogenic and natural CO_2 quantities from the atmosphere, the surface ocean and the plants exactly in the same relationship as they are momentarily in these reservoirs – no discriminations. The permille calculations have been carried out based on the actual CO_2 concentrations in the atmosphere and considering the fractionation as described above. The magnitudes of CCFs depend linearly on the total CO_2 amounts in the reservoirs and therefore they increase from 1750 up to date. Henry's law has been applied in the dissolution of atmospheric CO_2 into the ocean considering the ocean's temperature. The details have been described in the Appendix. The simulation results are depicted in Fig. 5.

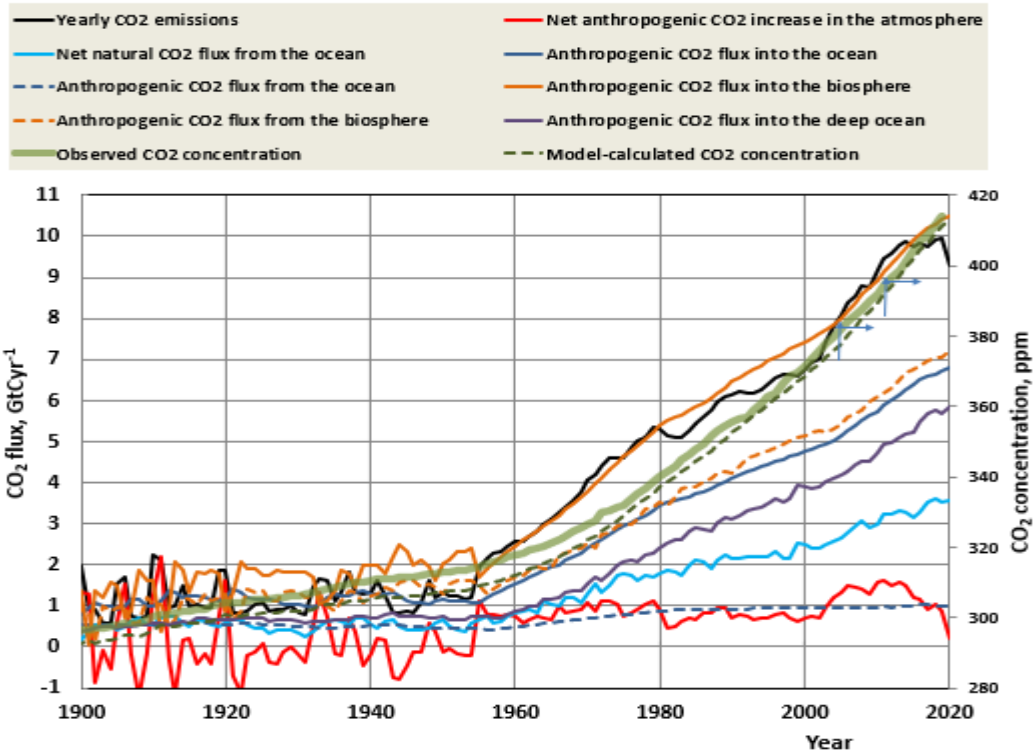


Figure 5: The simulation results by DAOBM-4 from 1750 to 2020.

The carbon budget values starting from 1750 can be calculated using the DAOBM-4 model; the essential values are collected in Fig. 6.

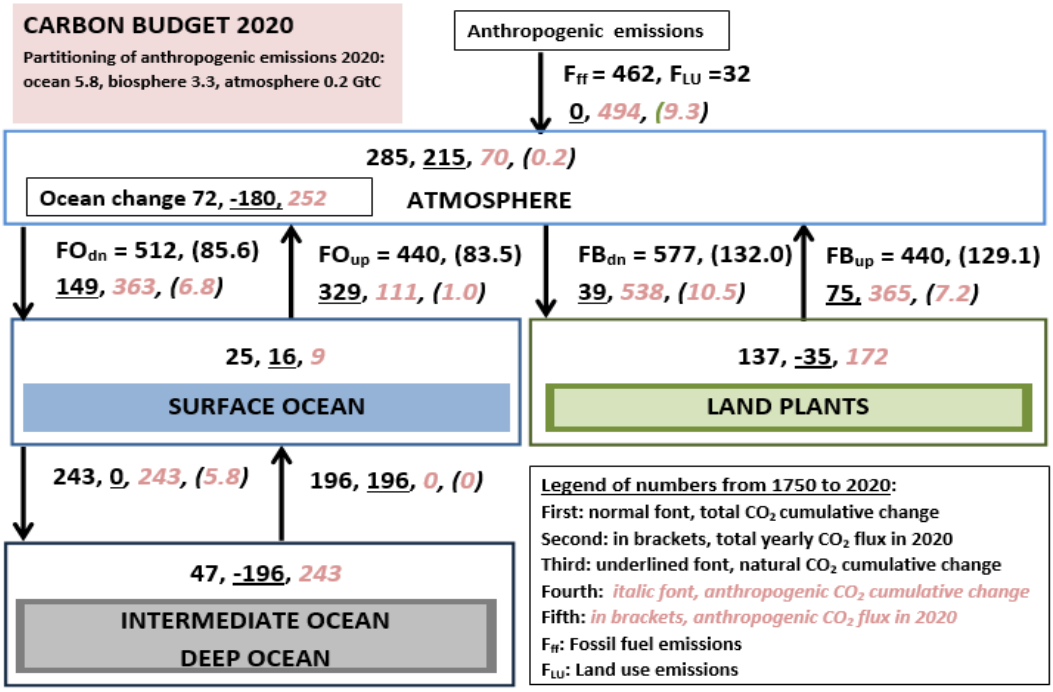


Figure 6: The carbon budget from 1750 to 2020.

Some key figures of the carbon budget should be noticed. The anthropogenic CO_2 emissions are the fossil fuel and land-use emissions, totalling 494 GtC, which is the sum of fossil emissions of 462 GtC and 32 GtC of land use. The total emissions are divided between reservoirs in 2020: biosphere 172 GtC, atmosphere 70 GtC, and the oceans 252 GtC. The small amount of 72 GtC of

the total CO_2 absorbed by the ocean, can be explained by the great amount of 180 GtC of natural CO_2 moving into the atmosphere, and at the same time 252 GtC of anthropogenic CO_2 absorbed by the sea. The atmospheric anthropogenic CO_2 amount is only 70 GtC, which is 8 % of the total atmospheric CO_2 mass originating from the direct fossil fuel emissions at 39 GtC, recycled from the biosphere at 27 GtC, and recycled from the ocean at 4 GtC in 2020. The basic reason for this is the continuous recycling of CO_2 fluxes between reservoirs, which removes and add anthropogenic CO_2 into the atmosphere even without increasing sink values. The plants start releasing anthropogenic CO_2 according to different delay times, as the Appendix equation (23) describes. Another important feature is that the major fraction of the increased atmospheric CO_2 increase is natural CO_2 originating from the oceans at 180 GtC and the biosphere at 35 GtC, totalling 215 GtC.

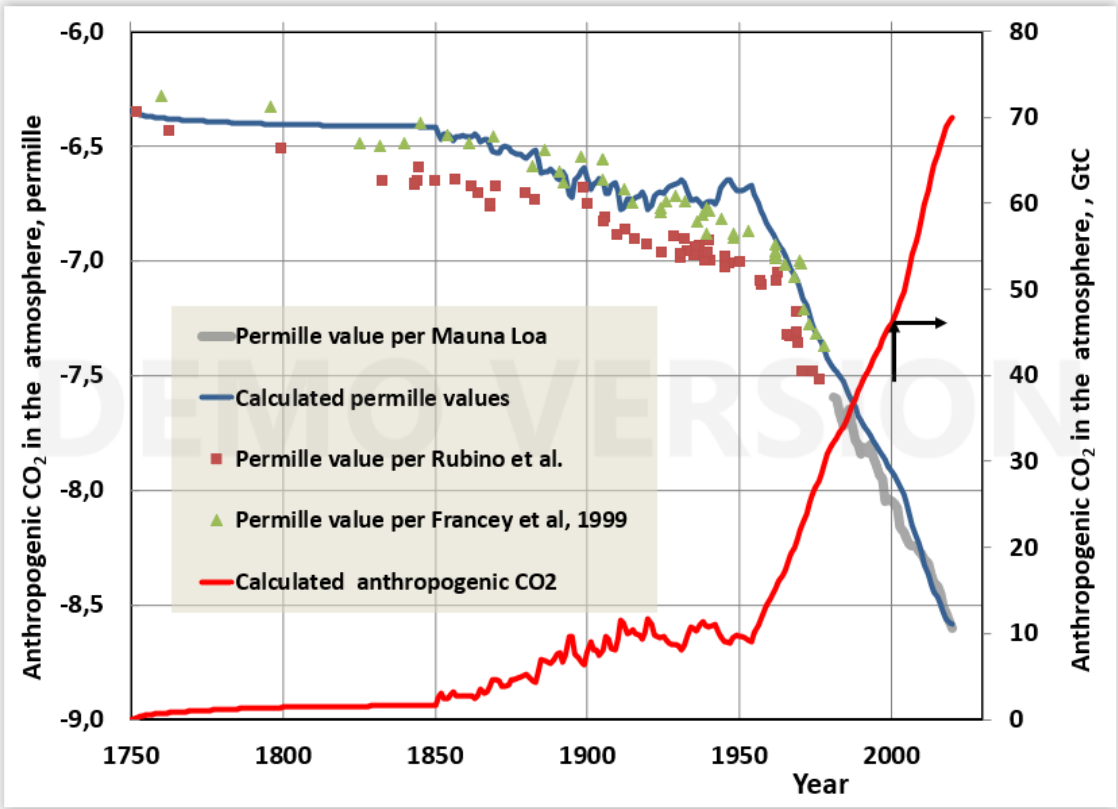


Figure 7: The observed $\delta^{13}C$ values of Mauna Loa are from CDIAC (2022b), and the reference $\delta^{13}C$ values are from Francey et al. (1999) and Rubino et al. 2013). The calculated $\delta^{13}C$ values and the anthropogenic CO_2 in the atmosphere are calculated by the model DAOBM-4.

The calculated and observed $\delta^{13}C$ values are depicted in Fig. 7. As references, the $\delta^{13}C$ values of Francey et al. (1999) and Rubino et al. (2013) are also shown. The model-calculated $\delta^{13}C$ values deviate from the reference values around 1950, possibly because of missing land-use emissions. It looks like there was a discontinuation point around 1950. Fig. 5.5 (b) of the AR6 (IPCC, 2021) depicts six different trends of land-use CO_2 emissions from 1850 to 2019. They all show the same general pattern of increasing emissions from about 0.5 GtC yr^{-1} to about 1.7 GtC yr^{-1} in 1960, thereafter a descent to about 1.3 GtC yr^{-1} in 1990 and thereafter a slightly increasing trend. There is a discontinuation point like in $\delta^{13}C$ trends of Fig. 7. A significant spread can be noticed among these trends from 1940 to 1960 from 0.7 GtC yr^{-1} to 2.7 GtC yr^{-1}. This uncertainty is a probable reason for the spread of calculated $\delta^{13}C$ trends during this period as shown in Fig. 7.

It can be estimated that after 1850, the model-calculated $\delta^{13}C$ values very accurately follow the atmospheric anthropogenic CO_2 growth rate considering the opposite changes of these curves: These curves are like mirror images. Since the $\delta^{13}C$ value -28 ‰ of anthropogenic emissions dramatically differs from the ocean's recycling flux, it dominates the atmosphere's $\delta^{13}C$ value. Fig. 8 depicts the simulation results of DAOBM-4 for the anthropogenic CO_2 and total CO_2 in the atmosphere when the fossil fuel emissions drop to zero after 2020.

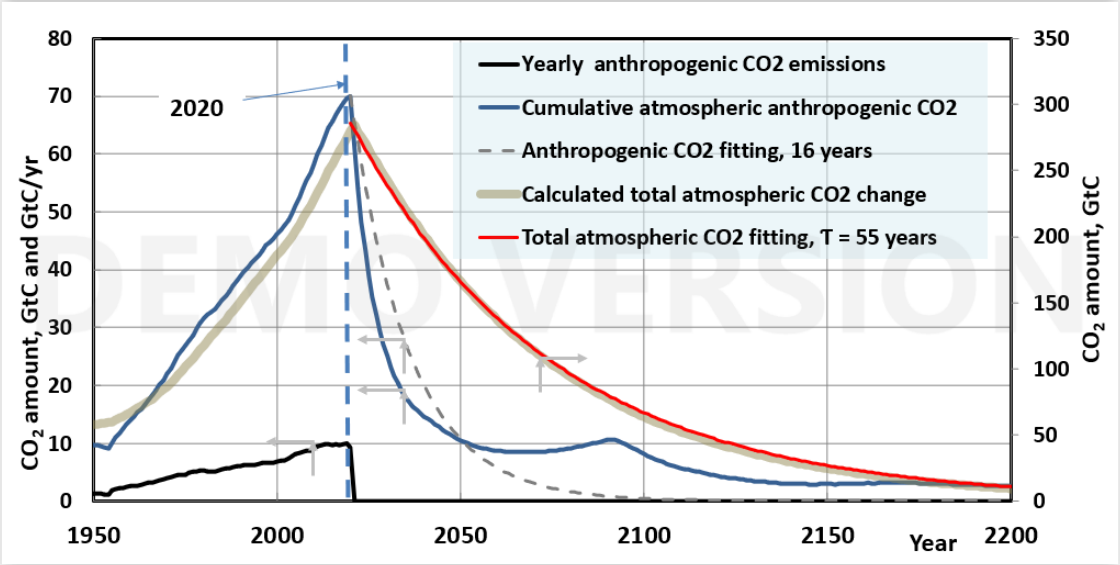


Figure 8: Decay rates of anthropogenic CO_2 and total CO_2 when fossil fuel emissions drop to zero after 2020.

The total CO_2 decay rate follows perfectly a simple dynamic model with a single time constant (residence time) of 55 years. The adjustment (relaxation) time is 220 years. The decay rate of anthropogenic CO_2 does not perfectly follow a dynamic model with a 16-year residence time, but it is a relatively good approximation. The decay curve of anthropogenic CO_2 starts to slightly increase just before 2100 since land plants recycle back this fraction into the atmosphere. We will see in the coming 10 - 30 years if the ^{14}C concentration starts to slightly increase due to this effect. It should be noticed that finally, about 5 % of land-sequestrated CO_2 remains in the land sink.

O'Neill et al. (1994) analyzed why there are so many different timescales and results for anthropogenic CO_2 decay times. They concluded that the empirical turnover time of 30-60 years should be explained. Anyway, they calculated that if emissions would cease in 1990, the adjustment time would be 175 years for anthropogenic CO_2. Berry (2021) concluded that the anthropogenic CO_2 amount in 2020 was 70 GtC and it would fall to 21 GtC in 2100 meaning a longer adjustment time than a bomb carbon test. Some researchers like Lashof and Ahusja (1990) have concluded that the adjustment time for the total CO_2 excess removal from the atmosphere is different from the anthropogenic removal rate, and it would take 230 years which is close to the value of 220 years of this study.

5. Validation

Some key figures of the DAOBM-4 simulation can be used as validation evidence. The observed CO_2 concentration values were not used in the model calculations except for estimating the net land-use emissions. The medium absolute error of the model-calculated CO_2 concentration for 1750–2020 is 1.6 ppm; with the same accuracy, the model calculates the total atmospheric CO_2 mass increase: The difference in 2020 is 2 GtC.

Most carbon cycle models apply the buffer-factor restriction, keeping the yearly ocean absorption rate at a maximum of 2.3–3.0 GtC yr^{-1}. According to Table 5.1 (IPCC, 2021) the average

absorption rate into the ocean is 2.5 ± 0.6 GtC yr^{-1} 2010-2019. The buffer-factor restriction was unapplied in the DAOBM-4 model. However, the maximum net annual absorption rate is 2.2 GtC yr^{-1} in 2020 since the anthropogenic absorption rate is 5.8 GtC yr^{-1}, while the oceans release natural CO_2 of 3.6 GtC yr^{-1} into the atmosphere. A noteworthy property of the DAOBM-4 model is that it does not violate the buffer-factor restriction even though it has not been applied in calculations. On the other hand, a fundamental feature of the DAOBM-4 model is that the carbon cycle fluxes between the atmosphere and ocean vary from 75 to 86 GtC yr^{-1}.

According to the ocean research surveys, the anthropogenic CO_2 amount in the oceans was about 118–165 GtC in 1994, as referred to in the earlier section. The DAOBM-4 model calculates the same amount to be 144 GtC. Khatiwala et al. (2013) have estimated that the best estimate for the year 2010 is 155 GtC. The result of DAOBM-4 is 201 GtC. As noticed before, the anthropogenic CO_2 amounts in the oceans have high uncertainties.

The strong fluctuations in the net yearly anthropogenic CO_2 fluxes into the atmosphere, are depicted in Fig. 9.

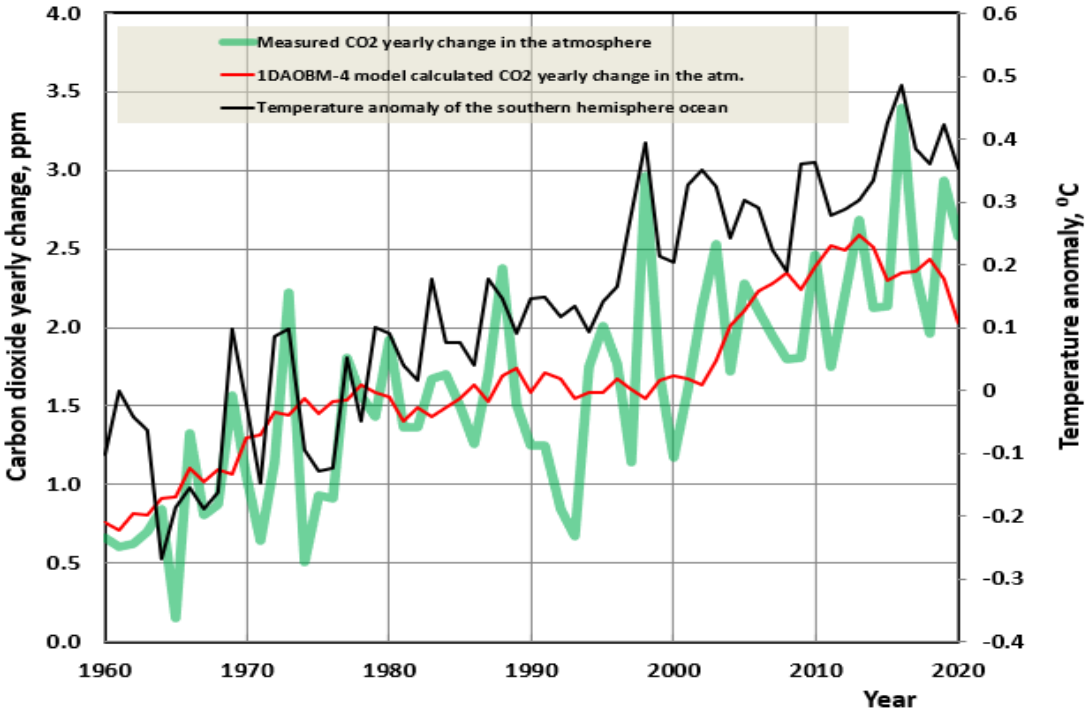


Figure 9: The correlation of yearly atmospheric CO_2 changes (NOAA, 2022b) to the temperature changes of the southern oceans (NOAA, 2022c).

The yearly CO_2 fluctuations relate to the southern oceans' temperature changes since these warm ocean areas absolve CO_2, and the high-latitude ocean areas (mainly NH) dissolve CO_2. There is an anomaly from 1991 to 1995 during the Mt. Pinatubo eruption. Different explanations were proposed, but the real reason is that during the eruption, the plants could photosynthesize more effectively in the diffuse sunlight from various directions (NASA, 2001); therefore, there is an anomaly downwards in the CO_2 concentration. The model-calculated CO_2 concentration trend follows the observed CO_2 ppm values.

The DAOBM-4 model's most prominent feature is its capability to calculate all essential elements of the carbon cycle: yearly budget values, different isotopic CO_2 flux values, yearly CO_2 concentration values, and yearly $\delta^{13}C$ values. Keeling et al. (2017) summarized one of the major problems of carbon cycle models: "*A further difficulty is that the global $\delta^{13}C$ budget does not balance*

convincingly." This problem was also called the "missing" carbon problem" (Siegenthaler and Sarmiento (1993); Field, 2001). DAOBM-4 does not have this problem.

The missing carbon problem can be partly explained by the Earth's strong greening, which is not included in its full magnitude in the carbon cycle models. Bastin et al. (2017) estimated that the biosphere sink value increased to 158.3 GtC by 2017. The DAOBM-4's calculated sink value is 137 GtC.

The earlier simulation results using the 1DAOBM-3 version showed that the residence time of the anthropogenic CO_2 is about 16 years — the same as the radiocarbon from the nuclear tests. Physically, radiocarbon's decay rate is a perfect tracer test for anthropogenic CO_2 since its concentration has been also very low in the atmosphere, and it started to increase notably after 1950. It also means that the anthropogenic CO_2 recirculation fluxes from the sea and plants started from a very low level in comparison to natural CO_2.

6. Conclusions and discussion

The conclusion about the IPCC's carbon budget is that its numerical values conflict with the physical facts. It is physically impossible that the increased CO_2 amount after 1750, which is at 292 GtC in 2020, is solely anthropogenic by nature. The carbon flux cycles remove annually about 26 % of the atmospheric CO_2, and the same applies to the anthropogenic fraction. Carbon fluxes cycle back annually into the atmosphere with almost the same total amount of CO_2; the difference is the yearly sequestration rate. The return fluxes from the sinks have lower anthropogenic amounts than the entering fluxes and this feature dilutes the anthropogenic CO_2 from the atmosphere. The common idea that about 44 - 46 % of annual anthropogenic emissions will stay in the atmosphere since the growth rate of total atmospheric CO_2 amount indicates this figure, does not consider the complicated nature of recycling fluxes of the carbon cycle. It is impossible for natural processes to control the atmospheric CO_2 increase to be exactly only anthropogenic by nature.

Fractionation has an insignificant role in calculating the anthropogenic CO_2 amount in the atmosphere. If the increased CO_2 amount of 292 GtC from 1750 to 2020 would be anthropogenic (permille -28 ‰), its ^{13}C amount would be 3.19 GtC and if it would be the average composition of today (permille -8.6 ‰), its ^{13}C amount would be 3.25 GtC.

The carbon cycle fluxes remove all CO_2 isotopic amounts according to their fractions in the atmosphere. Although the fractionation happens during the absorption and photosynthesis, over 99 % is the isotope ^{12}C, and fractionation processes cannot control if a ^{12}C molecule originates from natural CO_2 or anthropogenic CO_2 emissions. The DAOBM-4 model treats all the isotopic fractions equally in carbon cycle fluxes except for a very small amount of ^{13}C molecules. This is justified, based on the empirical observation that the adjustment time of radiocarbon is only 64 years even though ^{14}C is the least wanted isotope in the sinks. Fractionation calculations consider how $\delta^{13}C$ changes in the carbon cycle fluxes pass the interfaces of air to sea, sea to air, and photosynthesis and respiration of terrestrial plants. Using this physical principle, the anthropogenic CO_2 in the atmosphere is only 70 GtC in 2020; its adjustment time of 64 years is about the same as the radiocarbon's adjustment time.

According to greening studies of the Earth, the major results of DAOBM-4 can be validated against the observed values like CO_2 concentration, $\delta^{13}C$ values, the ocean-absorbed anthropogenic CO_2 amount, and the biosphere sink.

The results of DAOBM have been reviewed many times since this article is not the first publication of the model. Some general observations can be noticed. A concern has been raised that this kind of carbon cycle model makes bold claims about the amount of atmospheric anthropogenic CO_2, and therefore the cause of the recent CO_2 rise and further global warming is different from the presentation of the IPCC.

This paper has questioned the IPCC-calculated composition of the atmospheric CO_2 from 1750 up to date, but it keeps the total atmospheric CO_2 amount as the observed-based fact. It has not been in the scope of this study to consider a theoretical case, what would be the total amount and composition of atmospheric CO2 if there were no anthropogenic emissions.

Natural emissions could also increase the amount of atmospheric CO_2, and DAOBM considers the warming impact on the sequestration rate of the oceans. Anyway, this effect is not significant in the long run but it explains very well yearly CO_2 variations in the atmosphere, see Fig. 7.

Another simple fact is that the CO_2 composition, anthropogenic or natural, has no impact on the warming impact of CO_2. The third fact is that the amount of anthropogenic CO_2 does not affect global warming since the total amount of atmospheric CO_2 defines the warming impact of CO_2. Therefore, it is unprofessional to claim that the idea of this carbon cycle model is to question anthropogenic global warming. They are two different issues. Coupling these things together raises questions about the integrity of reviewers if they have to defend the IPCC's approach with this kind of review comments. There is a direct connection to scenarios of global warming since the future atmospheric CO_2 levels are based on the carbon cycle models. Also, in scenarios, the total atmospheric CO_2 amount defines the warming impact of CO_2 – not the anthropogenic CO_2 amount.

An observation can be drawn that in many cases reviewers have not commented on the discrepancies and violations of physical laws in the IPCC's carbon cycle models like those presented in Table 1. A conclusion will be that there is no explanation. Eq. (2) has been generally doomed to be wrong. Something is indeed wrong since it gives a wrong atmospheric $\delta^{13}C$ value but no physical explanation or a reference has been given of what is wrong according to simple physical facts. Since this study challenges the IPCC's carbon cycle, the results of this paper can be used as an explanation for differences.

Statements and Declarations

This work has not received any funding. The author declares that he has no conflict of interest.

Guest-Editor: Stein Storlie Bergsmark; Reviewers: anonymous.

References

Alden CB, Miller JB, White JWC, 2020*: Can bottom-up ocean CO2 fluxes be reconciled with atmospheric 13C observations?* Tellus B: Chem Phys Meteorol, 62(5), 369-388. https://doi.org/10.1111/j.1600-0889.2010.00481.x

Battle M, 2000: *Global Carbon Sinks and Their Variability Inferred from Atmospheric O_2 and ^{13}C*. Science 287(5462), 2467–2470. https://www.science.org/doi/abs/10.1126/science.287.5462.2467

Bastin J-F, Berrahmouni N, Grainger A, Maniatis D, Mollicone D, et al. 2017: *The extent of forest in dryland biomes.* Science (356), 635-638. https://www.science.org/doi/abs/10.1126/science.aam6527

Berry EX, 2021: *The Impact of Human CO2 on Atmospheric CO_2*. Sc Clim Ch 1.2, 213-249. https://scienceofclimatechange.org/wp-content/uploads/Berry-2021-Impact-of-human-CO2.pdf

Brand W, Coplen T, Vogl J, Rosner M, Prohaska T, 2014: *Assessment of international reference materials for isotope-ratio analysis (IUPAC Technical Report.* Pure Appl Chem, 86 (3), 425–467. https://doi.org/10.1515/pac-2013-1023

Butler JN 1982: *Carbon dioxide equilibria and their applications*. Addison-Wesley Publishing Company, New York:259.

Böhm F, Haase-Schramm A, Eisenhauer A, Dullo W-C, Joachimski MM et al., 2002: *Evidence for preindustrial variations in the marine surface water carbonate system from coralline sponges.* Geochem Geophys Geosyst 3(3). https://doi.org/10.1029/2001GC000264

CDIAC, 2022a: *Carbon emission from 1750 to 2013.* http://cdiac.ornl.gov/ftp/ndp030/global.1751_2010.ems

CDIAC, 2022b: *Isotopic ratio of atmospheric $^{13}CO2/^{12}CO2$*. https://cdiac.ess-dive.lbl.gov/ftp/trends/co2/iso-sio/SIO_Mauna_Loa_13CO2.txt

Ciais P, Tans PP, White JWC, Trolier M, Francey RJ, Berry JA, Randall DR, Sellers PJ, Collatz JG, Schimel DS, 1995: *Partitioning of ocean and land uptake of CO_2 as inferred by $\delta^{13}C$ measurements from the NOAA Climate Monitoring and Diagnostics Laboratory Global Air Sampling Network*. J Geophys Res 00(D3), 5051. https://doi.org/10.1029/94JD02847

DeVries T, 2014: *The oceanic anthropogenic CO_2 sink: Storage, air-sea fluxes, and transports over the industrial era*. Global Biogeochem Cycles 28, 631–647. https://doi.org/10.1002/2013GB004739

Field CB, 2001: *Plant Physiology of the "Missing" Carbon Sink. Plant Physiol* 125(1), 25-28. https://doi.org/10.1104/pp.125.1.25

Francey CE, Allison CE, Etheridge DM, Trudinger CM, Enting IG, Leuenberger M, Langenfelds EM, Steele LP, 1999: *A 1000-year high precision record of δ13C in atmospheric CO_2*. Tellus 51(2), 170-193. https://b.tellusjournals.se/articles/10.3402/tellusb.v51i2.16269

Friedlingstein P, Jones MW, O'Sullivan M, Andrew RM, Bakker DCE et al., (2022) *Global Carbon Budget 2021*. Earth Syst Sci Data 14, 1917–2005. https://essd.copernicus.org/articles/14/1917/2022/

Goto D, Morimoto S, Ishidoya S, Aoki S, Nakazawa T, 2017: *Terrestrial biospheric and oceanic CO_2 uptakes estimated from long-term measurements of atmospheric CO_2 mole fraction, δ13C, and $\delta(O_2/N_2)$ at Ny-Ålesund, Svalbard*. J Geophys Res Biogeosci 122, 1192-1202. https://doi.org/10.1002/2017JG003845

Graven HD, Gruber N, Key R, Khatiwala S, Giraud X, 2012: *Changing controls on oceanic radiocarbon: New insights on shallow-to-deep ocean exchange and anthropogenic CO_2 uptake*. J Geophys Res 117, C10005. https://doi.org/10.1029/2012JC008074

Gruber N, Keeling CD, Bacastow RB, Guenther PR, Lueker TJ, Wahlen M, Meijer HAJ, Mook WG, Stocker TF, 1999: *Spatiotemporal patterns of carbon-13 in the global surface oceans and the oceanic* Suess effect. Global Biogeochem Cycles 13(2), 307–335. https://doi.org/10.1029/1999GB900019

Gruber N, Gloor M, Mikaloff Fletcher SE, Doney SC, Dutkiewicz ML et al., 2009: *Oceanic sources, sinks, and transport of atmospheric CO_2.* Glob. Biogeochem Cycles 23, GB1005. DOI:10.1029/2008GB003349

Hellevang H, Aagaard P, 2015: *Constraints on natural global atmospheric CO_2 fluxes from 1860 to 2010 using a simplified explicit forward model.* Sci Rep 5, 1735. https://doi.org/10.1038/srep17352.

Inoue H, Sugimura Y, Fushimi K, 1987: *$pC0_2$ and $^{13}\delta C$ in the air and surface sea water in the western North Pacific.* Tellus 39B, 228-242. https://doi.org/10.1111/j.1600-0889.1987.tb00285.x

IPCC, 2013: Fifth Assessment Report (AR5). *The Physical Science Basis. Working Group I Contribution to the IPCC Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge. https://www.ipcc.ch/report/ar5/wg1/

IPCC, 2021: Sixth Assessment Report (AR6). *The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press. https://www.ipcc.ch/report/sixth-assessment-report-working-group-i/

Joos F, Roth R, Fuglestvedt JS, Peters GP, Enting IG et al., 2013: *Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multi-model analysis.* Atmos Chem Phys 13, 2793–2825. https://doi.org/10.5194/acp-13-2793-2013

Khatiwala S, Primeau F, Hall T, 2009:Reconstruction of the history of anthropogenic CO_2 concentrations in the ocean. Nature 462, 346–349. https://doi.org/10.1038/nature08526

Khatiwala S, Tanhua T, Mikaloff Fletcher S, Gerber M, Doney SC, Graven HD, Gruber N, McKinley GA, Murata A, Ríos AF, Sabine CL, 2013: *Global Ocean storage of anthropogenic carbon.* Biogeosciences, 10(4), 2169–2191. https://doi.org/10.5194/bg-10-2169-2013

Keeling RF, Graven HD, Welp LR, Resplandy L, Bi J et al., 2017: *Atmospheric evidence for a global secular increase in carbon isotopic discrimination of land photosynthesis*. PNAS 114:10361-10366. https://doi.org/10.1073/pnas.1619240114

Keeling RF, Graven HD, 2021: *Insights from time series of atmospheric carbon dioxide and related tracers*. Annu Rev Environ Resour 46, 85-110. https://www.annualreviews.org/doi/abs/10.1146/annurev-environ-012220-125406

Lashof DA, Ahuja DR, 1990: *Relative Contributions of greenhouse gas emissions to global warming*. Nature 344, 529-531. https://www.nature.com/articles/344529a0

LLNL, Lawrence Livermore National Laboratory, 2022: *^{14}C "Bomb Pulse" Pulse Forensics*. https://cams.llnl.gov/cams-competencies/forensics/14c-bomb-pulse-forensics

Maier-Reiner E, Hasselmann K, 1987: Transport and storage of CO_2 in the ocean – an inorganic ocean-circulation carbon cycle model. Clim Dyn 1987(2):63-90. https://doi.org/10.1007/BF01054491

Marino B, McElroy M, 1991: *Isotopic composition of atmospheric CO_2 inferred from carbon in C4 plant cellulose*. Nature 349, 127–131. https://doi.org/10.1038/349127a0

NASA, 2001: *Large volcanic eruptions help plants absorb more carbon dioxide from the atmosphere.* EurekAlert News, peer-reviewed, https://www.eurekalert.org/news-releases/872996

NOAA, 2022a: *The data: What ^{13}C tells us. The global view.* http://www.esrl.noaa.gov/gmd/outreach/isotopes/c13tellsus.html

NOAA, 2022b: *Global yearly CO_2 concentration.* *https://gml.noaa.gov/webdata/ccgg/trends/co2/co2_annmean_mlo.txt*

NOAA, 2022c: *Ocean temperature database*. ftp://ftp.ncdc.noaa.gov/pub/data/mlost/operational/products/

Ollila A, 2016: *Timescales of anthropogenic and total carbon dioxide (CO_2) in the atmosphere.* Phys Sc Int J 11(3), 1-19. DOI: 10.9734/PSIJ/2016/27004

Ollila A, 2020: *Analysis of the simulation results of three carbon dioxide (CO_2) cycle models.* Phys Sc Int J 23(4), 1-19. DOI: 10.9734/PSIJ/2019/v23i430168

O'Neil BC, Gaffin SR. Tubiello FN, Oppenheimer M, 1994: *Reservoir timescales for anthropogenic CO_2 in the atmosphere*. Tellus, 46(5), 378–389. https://onlinelibrary.wiley.com/doi/abs/10.1034/j.1600-0889.1994.t01-4-00004.x

Quay P, Sonnerup R, Westby T, Stutsman J, McNichol A, 2003: *Changes in the $^{13}C/^{12}C$ of dissolved inorganic carbon in the ocean as a tracer of anthropogenic CO_2 uptake*. Global Biogeochem Cycles 17(1), 4-1-4-20. https://doi.org/10.1029/2001GB001817

Rayner PJ, Law RM, Allison CE, Francey RJ, Trudinger CM, Pickett-Heaps C, 2008: *Interannual variability of the global carbon cycle (1992–2005) inferred by inversion of atmospheric CO_2 and $\delta^{13}CO_2$ measurements*, Global Biogeochem Cycles 22, GB3008. https://doi.org/10.1029/2007GB003068

Revelle R, Suess H, 1957: *Carbon dioxide exchange between atmosphere and ocean and the question of an increase of atmospheric CO_2 during past decades*. Tellus 9, 18-27. https://doi.org/10.3402/tellusa.v9i1.9075

Rubino M, Etheridge DM, Trudinger CM, Allison CE, Battle MO et al., 2013: *A revised 1000 year atmospheric $\delta^{13}C$ record from Law Dome and South Pole, Antarctica.* J Geophys Res: Atm 118(15), 8482–8499. 10.1002/jgrd.50668

Sabine CL, Feely RA, Gruber N, Key RM, Lee K et al., 2004: *The oceanic sink for the anthropogenic CO_2*. Science 305(5682), 367–371. DOI: 10.1126/science.1097403

Sabine CL, Tanhua T, 2009: *Estimation of anthropogenic CO_2 inventories in the ocean*, Annual Rev Mar Sci 2, 175–198. DOI:10.1146/annurev-marine-120308-080947

Sarmiento JL, Gruber N, 2006: *Ocean Biogeochemical Dynamics*. Princeton University Press, Princeton, NJ, USA.

Schmittner A, Gruber N, Mix AC, Key RM, Tagliabue A, Westberry TK, 2013: *Biology and air-sea gas exchange controls on the distribution of carbon isotope ratios $\delta^{13}C$ in the ocean*. Biogeosciences 10(9), 5793–5816. doi:10.5194/bg-10-5793-2013 doi:10.5194/bg-10-5793-2013

Siegenthaler U, Münnich KO, 1989: *$^{13}C/^{12}$ C fractionation during CO 2 transfer from air to sea*. Carbon Cycle Modelling. Bolin B.(ed) Wiley, New York (13): 249-257.

Siegenthaler U, Sarmiento JL, 1993: *Atmospheric carbon dioxide and the ocean*. Nature 365,119-125. https://doi.org/10.1038/365119a0

Srivastava A, Verkouteren M, 2018: *Metrology for stable isotope reference materials: $^{13}C/^{12}C$ and $^{18}O/^{16}O$ isotope ratio value assignment of pure carbon dioxide gas samples on the Vienna PeeDee Belemnite-CO_2 scale using dual-inlet mass spectrometry*. Anal Bioanal Chem 410,4153–4163. https://doi.org/10.1007/s00216-018-1064-0

Stumm W, Morgan JJ, 1970: *Aquatic chemistry. An introduction emphasizing chemical equilibria in natural waters*. John Wiley & Sons, New York.

Tans PP, Berry AB, Keeling RF, 1994: *Oceanic $^{13}C/^{12}C$ observations: A new window on ocean CO_2 uptake.* Global Biogeochem Cycles 7(2), 353-368. https://doi.org/10.1029/93GB00053

van der Velde IR, Miller JB, Schaefer K, Masaryk KA, Denning S, White JWC, Tans PP, Krol MC, Peters W, 2013: *Biosphere model simulations of interannual variability in terrestrial $^{13}C/^{12}C$ exchange.* Global Biogeochem Cycles 27(3), 637–649. https://doi.org/10.1002/gbc.20048

Waugh DW, Hall TM, McNeil BI, Key R, Matear RJ, 2006: *Anthropogenic CO_2 in the oceans estimated using transit time distributions*. Tellus Ser. B 58, 376–389. DOI: 10.1111/j.1600-0889.2006.00222.x

Woolf DK, Shutler JD, Goddijn-Murphy L, Watson AJ, Chapron B et al., 2019: *Key Uncertainties in the Recent Air-Sea CO_2*. Global Biogeochem Cycles, 2018GB006041. https://doi.org/10.1029/2018GB006041

Appendix.

The calculation bases and changes in DAOBM-4.

Table A-1. The calculation bases for variables and coefficients of the DAOBM-4. The changes of version DAOBM-4 are written *in italic font*. The amounts are in GtC and fluxes are in GtC yr^{-1}. The present-day values are updated for the year 2020. Acronyms: n means an individual year, tot means total, nat means natural, ant means anthropogenic, ff means fossil fuel, and lu means land use.

Variable	Variable name	Calculation formula
$FO_{tot,dn}$	Total dissolution carbon pump flux from the atmosphere into the ocean	$75.0 + K_{dn}*(CIA - CIA_{1750})$; $K_{dn} = 0.0378$; CIA is the total atmospheric carbon (1)
$FLUSH_{AO}$-%	Flush-% of the dissolution pump from the atmosphere into the ocean	$100 * FO_{tot,dn} / CIA$ (2)
$FO_{ant,dn}$	Anthropogenic dissolution carbon pump flux from the atmosphere into the ocean	$FLUSH_{AO}$-% * $CIA_{ant,n-1}$ / 100 (3)
$FO_{nat,dn}$	Natural dissolution carbon pump flux from the atmosphere into the ocean	$FO_{tot,dn} - FO_{ant,dn}$ (4)
$FO_{tot,up}$	Total dissolution carbon pump flux from the ocean into the atmosphere	$75.0 + K_{up}* (CSO_{tot} - CSO_{1750})$; $K_{up}=0.333$ (5)
$FLUSH_{OA}$-%	Flush-% of the dissolution pump from the ocean into the atmosphere	$100 * FO_{tot,up} / CSO_{tot,n}$ (6)
$FO_{ant,up}$	Anthropogenic dissolution carbon pump flux from the ocean into the atmosphere	$FLUSH_{OA}$-% *$CSO_{ant,n-1}$ / 100 (7)
$FO_{nat,up}$	Natural dissolution carbon pump flux from the ocean into the atmosphere	$FO_{tot,up} - FO_{ant,up}$ (8)
ΔCIA_{nat}	Natural net CO_2 flux change from the ocean into the atmosphere	$FO_{nat,up} - FO_{nat,dn}$ (9)
CSO_{tot}	Dissolved organic carbon in the ocean in the range of 280 ppm – 430 ppm	$2.2 - 5.5774*10^{-3}*T - 8.631*10^{-5}*T^2 + 6*10^{-4}*$ (C-350); T is ocean temperature (ºC), C is $CO_{2,tot}$ concentration in CSO (10)
CSO_{tot}	Dissolved organic carbon in the ocean in the range of 430 ppm – 600 ppm	$2.255 – 5.114*10^{-3}*T – 6.84*10^{-5}*T^2 + 3*10^{-4}*$ (C-500); T is ocean temperature (ºC), C is $CO_{2,tot}$ concentration in CSO (11)
$FN_{ant,deep}$	Anthropogenic net CO_2 flux from the surface ocean into the intermediate & deep ocean	$K_{ant} * (CSO_{tot,n} - CSO_{tot,1750}) * (CSO_{ant,n-1} / CSO_{tot,n})$; $K_{ant} = 19.0$ (12)
ΔCSO_{tot}	Total CO_2 change in the surface ocean	$CSO_{tot} - CSO_{tot,1750}$ (13)
ΔCSO_{ant}	Anthropogenic CO_2 change in the surface ocean	$FO_{ant,down} - FO_{ant,up} - FN_{ant,deep}$ (14)
ΔCSO_{nat}	Natural CO_2 change in the surface ocean	$\Delta CSO_{tot} - \Delta CSO_{ant}$ (15)
$FN_{ant,ocean}$	Anthropogenic CO_2 flux into the ocean	$FN_{ant,deep} + \Delta CSO_{ant}$ (16)
$FN_{nat,deep}$	Net natural CO_2 flux from the deep ocean	$FO_{nat,atm} - \Delta CSO_{nat}$ (17)
$FN_{tot,deep}$	Total net CO_2 flux into the deep ocean	$FN_{ant,deep} + FN_{nat,deep}$ (18)
ΔCDO_{ant}	Anthrop. CO_2 change in the deep ocean	$F_{deep,n} - F_{deep,n-1}$ (19)
$FB_{tot,dn}$	Total biosphere carbon cycle flux from the atmosphere into the biosphere	$120 + KB_{dn}* (CIA - CIA_{1750})$; $KB_{dn}=0.0426$ (20)
$FB_{tot,up}$	Total biosphere carbon cycle flux from the biosphere into the atmosphere	$120 + KB_{up}* (\Delta CIB_{ant} - \Delta CIB_{ant,1750})$; $KB_{up}=0.03246$ (21)
$FB_{ant,dn}$	Anthropogenic carbon cycle flux from the atmosphere into the biosphere	$(FB_{tot,dn}/CIA)* \Delta CIA_{ant} - F_{lu}$ (22)
$FB_{ant,up}$	Anthropogenic carbon cycle flux from the biosphere into the atmosphere	$0.5*FB_{ant,dn,n} + 0.1*FB_{ant,dn,n-7} + 0.1*FB_{ant,dn,\ n-20} + 0.15 * FB_{ant,dn,,n-70} + 0.05*FB_{ant,db,\ n-250}$ (23)
FLUSH-%	Total-% of the carbon cycle from the atmosphere into the ocean and the biosphere	$100 * (FO_{tot,dn} + FB_{tot,dn}) / CIA$ (24)
ΔCIB_{ant}	Anthropogenic CO_2 change in the biosphere	$FB_{ant,down} - FB_{ant,up}$ (25)

	from 1750 onward	
ΔF_{ff}	*Anthropogenic CO_2 emission flux from fossil fuel combustion*	*Based on the booking-keeping data*
ΔF_{lu}	*Anthropogenic CO_2 emission flux from land-use changes*	ΔCIA_{obs} - ΔCIA_{ff} *from 1750 to 1956* *(26)*
ΔCIA_{ant}	Anthropogenic CO_2 change in the atmosphere from 1750 onward	$\Delta F_{ff} + \Delta F_{lu} - \Delta CSO_{ant} - \Delta CDO_{ant} - \Delta CIB_{ant}$ (27)
ΔCIA_{tot}	Total calculated CO_2 change in the atmosphere from 1750 onward	$\Delta CIA_{nat} + \Delta CIA_{ant}$ (28)
CIA_{tot}	Total atmospheric CO_2	$CIA_{1750} + \Delta CIA_{tot}$ (29)
ΔCIA_{obs}	Observed total CO_2 change in the atmosphere	2.1313 * CO_2 (ppm) (30)
CIA_O	*Total atmospheric CO_2 originating from the ocean*	$((FO_{tot,up}/(FO_{tot,up} + FB_{tot,up} - \Delta CIB_{ant})) * (\Delta CIA_{obs} + \Delta CIA_{1750} - \Delta CIA_{ant})$ *(31)*
CIA_B	*Total atmospheric CO_2 originating from the biosphere*	$(FB_{tot,up} - \Delta CIB_{ant})/(FB_{tot,up} - FO_{tot,up} + \Delta CIB_{ant})) *(CIA_{obs} + \Delta CIA_{1750} - \Delta CIA_{ant})$ *(32)*
CIA_E	*Total anthropogenic CO_2 in the atmosphere*	$CA_E + CA_O + CA_B$ *(33)*
CA_E	*The amount of anthropogenic CO_2 in the atmosphere originating from emissions*	$CA_{E,n-1} + FF_{ff} + FF_{lu} - (FLUSH-\%) * CA_{E,n-1} /100$ *(34)*
CA_O	*The amount of anthropogenic CO_2 in the atmosphere originating from the ocean*	$CA_{O,n-1} + FO_{ant,up} - (FLUSH-\%) * CA_{O,n-1} /100$ *(35)*
CA_B	*The amount of anthropogenic CO_2 in the atmosphere origin. from the biosphere*	$CA_{B,n-1} + FB_{ant,up} - (FLUSH-\%) * CB_{B,n-1} /100$ *(36)*
p_{as}	*Permille fractionation air to sea*	*1750 – 1944: 15.05 + 3.3704 * P_{n-1}* *(37)* *1944 - 2020: -5.34351-0.534 * ΔCSO_{ant}* *(38)*
p_{sa}	*Permille fractionation sea to air*	*1750 – 1944: 2.24 + 1.3525 * P_{n-1}* *(39)* *1944 - 2020: -5.80256-0.252 * ΔCSO_{ant}* *(40)*
$p_{A,n}$	*Permille value of the anthropogenic amount in the atmosphere in the year n*	$(CA_E * (-28) + CA_B * (-28) + CA_O * (-28 - P_{as} + P_{sa})) / CIA_E$ *(41)*
$P_{O,n}$	*Permille portion of the CIA_O in the year n*	$(CIA_O * P_{n-1} - p_{as} * FO_{tot,dn} + p_{sa} * FO_{tot,up}) / CIA$ *(42)*
$P_{B,n}$	*Permille portion of the CIA_B in the year n*	$((-6.35) * CIA_B + (-28.0 - p_{n-1}) * (FB_{ant,up} - FB_{ant,dn}))/ CIA$ *(43)*
$P_{A,n}$	*Permille portion of the anthropogenic CO_2 amount CIA_E in the year n*	$p_{A,n} * CIA_E / CIA$ *(44)*
P_n	*Permille value of the atmospheric CO_2 mixture in the year n*	$P_{O,n} + P_{B,n} + P_{A,n}$ *(45)*

Total carbon pump flux $FO_{tot,dn}$ from the atmosphere into the ocean depends linearly on the difference of the atmospheric CO_2 amount minus the same in 1750 per eq. (1).

Therefore, $FO_{tot,dn}$ increases from *75.0 GtCyr^{-1} in 1750 to 85.6 GtCyr^{-1} in 2020*. Total dissolution carbon pump flux $FO_{tot,up}$ from the ocean into the atmosphere depends linearly on the surface ocean's total CO_2 concentration minus the same in 1750 per eq. (5). Therefore, $FO_{tot,up}$ increased from *75.0 GtCyr^{-1} in 1750 to 83.5 GtCyr^{-1} in 2020*. The linear dependencies of eq. (1) and eq. (5) means both fluxes increase as the total atmospheric CO_2 increases. Both fluxes diminish into the 1750 value if the actual CO_2 concentration values in the atmosphere or the surface ocean approach the values of 1750.

The coefficient K_{ant} is 19.0 in eq. (12) and is calibrated, so the amount of atmospheric anthropogenic CO_2 gave permille values of *-8.60 for $\delta^{13}C$ in 2020*. The coefficient KB_{dn} in eq. (20) was calibrated, so the net natural CO_2 flux from the biosphere is 32 GtC in 2020—the same as the net land-use flux ΔF_{lu}. Therefore, $FB_{tot,dn}$ increases from *120 GtCyr^{-1} in 1750 to 132.0 GtCyr^{-1} in 2020.* The coefficient KB_{up} was calibrated, so the anthropogenic absorption ΔCIB_{ant} is 169 GtC closing the anthropogenic CO_2 budget in reservoirs. Therefore, $FB_{tot,up}$ increases from *120 GtCyr^{-1} in 1750 to 129.1 GtCyr^{-1} in 2020.* Coefficients K_{dn} and K_{up} were calibrated, so the natural

cumulative CO_2 flux from the ocean is 180 GtC from 1750 to 2019, closing the total CO_2 amount in the atmosphere in 2020.

The impacts of respiration and photosynthesis rates on the biosphere's mass CO_2 changes were analyzed in the Appendix (Ollila, 2020). The atmospheric CO_2 mass can be divided into three portions—from the ocean CIA_O, biosphere CIA_B, and anthropogenic CO_2 emissions CIA_E—which relate to the corresponding flux values according to eq. (31), (32), and (33) based on the incoming and outgoing flux values.

The anthropogenic CO_2 amount is the sum of three origins: the anthropogenic emissions CA_E, ocean CA_O, and biosphere CA_B. CA_E, CA_O, and CA_B can also be calculated from the incoming and outgoing anthropogenic fluxes according to equations (34), (35), and (36).

The fractionation across the air-sea P_{as} is linear from 1750 to 1944 according to eq. (37): -6.35‰ in 1750 and -7.71‰ in 1944. From 1944 onward, the P_{as} depends linearly on the anthropogenic CO_2 in the surface ocean according to eq. (38). The fractionation across the sea-air P_{sa} is linear from 1750 to 1944 according to eq. (39): -6.35‰ in 1750 and -6.89‰ in 1944. From 1944 onward, the P_{as} depends linearly on the anthropogenic CO_2 in the surface ocean according to eq. (40).

The permille value $p_{A,n}$ of the atmospheric anthropogenic CO_2 combines the permille values of anthropogenic emissions (-28‰), the permille value (-28‰) of the biosphere CO_2 portion, and the permille value of the anthropogenic CO_2 cycled back from the ocean. The permille value of this latter portion is -28‰, corrected by the difference between the fractionation air-sea and sea-air as formulated by eq. (41).

The yearly permille portion $P_{O,n}$ of the atmospheric mass CIA_O originating from the ocean is calculated according to eq. (42): multiplying the mass value by the earlier year's permille value of the total atmospheric mass and adding the yearly permille change of this mass—the difference between the recycled total CO_2 flux into the ocean and the ocean applying the air-sea and sea-air permille values.

The yearly permille change $P_{B,n}$ of the CIA_B mass originating from the biosphere is based on two terms according to eq. (43). The first is the cumulative increase of the anthropogenic biospheric mass in the atmosphere multiplied by the permille value of -6.35‰. Since the atmospheric permille value has been changing from 1750 onward, this change is calculated by multiplying the difference of recycling fluxes $FB_{ant,up}$, and $FB_{ant,dn}$, and the fractionation across the air to the biosphere is $(-26 + p_{,n-1})$.

The yearly permille change of anthropogenic mass $P_{A,n}$ is calculated according to eq. (44) by multiplying the mass CIA_E by the permille value $p_{A,n}$. The yearly permille value P_n of the total atmospheric CO_2 is the sum of the three mass portions of $P_{O,n}$, $P_{B,n}$, and $P_{A,n}$ according to eq. (45).

OPEN ACCESS

Klimarealistene
P.O. Box 33,
3901 Porsgrunn
Norway
ISSN: 2703-9072

Correspondence:
epitro-choidkjx@gmail.com

Volume 3.5
pp. 487-520

Lessons from the Continental Drift controversy for the IPCC debacle

Richard Mackey

Independent Scholar, Australia

Abstract

This essay examines how in the twentieth century established scientists blocked the development of scientific work about the theory of continental drift. There are many similarities between this blocking behaviour and the manner in which the IPCC and the scientists who believe the IPCC, block scientific work that is not consistent with the IPCC doctrine.

Until the mid-1960s, most geologists believed that the surface structure of planet Earth had been fixed for many hundreds of millions of years. This outlook is also known as 'fixism'. The leading scientists of the period had pronounced this to be true; it was set out as a scientific truth in many standard geology textbooks of that period.

The theory of continental drift ('mobilism') held that the dominant theory was false and that the land masses had been drifting for hundreds of millions of years, were still drifting and would continue to drift. They would collide and split apart resulting in earthquakes and volcanoes.

The established scientists opposed this with a distinctly unscientific vehemence.

Reasons advanced for the extraordinary unscientific behaviour of hundreds of scientists, include tunnel-vision, groupthink, herd-like behaviour, persistent bullying by senior scientists, personal jealousies, empire building, loyalty to colleagues and institutions, arrogance, vicious pettiness ignorance, lack of moral courage, a visceral reluctance of some very senior scientists to acknowledge they were wrong.

There were cover-ups, including keeping the main geology textbooks free of evidence indicating fixism to be false.

The extraordinary antiscientific vehemence shown by hundreds of established scientists is characteristic of proponents of the IPCC doctrine.

In relation to the theory of continental drift, inevitably scientific breakthroughs – plate tectonics - outside of the scientific outlook of the established scientists, demonstrated that the theories of the established scientists were false. This suggests a pathway out of the IPCC debacle.

Keywords:

Wegener, continental drift; IPCC; plate tectonics; carbon dioxide;

Submitted 2023-10-28, Accepted 2023-11-16. https://doi.org/10.53234/scc202310/24

1. Introduction

The four volumes of *The Continental Drift Controversy*, over 3,300 pages, are the life's work of Professor Henry Frankel (1944 – 2019) (Frankel 2012). It is the culmination of a distinguished forty-year research. Professor Frankel received his PhD from Ohio State University in 1974. He was appointed to a teaching position in the Philosophy Department at the University of Missouri, Kansas City (UMKC) shortly after. In 1999, he was appointed Professor of Philosophy and Chair of the Philosophy Department. At the time he retired in 2014, he was professor emeritus in the Department of Philosophy at UMKC.

He researched the combination of geology, physics, history, and philosophy in relation to the scientific controversy over continental drift and its evolution into plate tectonics. His interest in the continental drift controversy and the plate tectonics revolution began while teaching a course on conceptual issues in science during the late 1970s. The controversy provided him with an example of a recent and major scientific revolution to test philosophical accounts of scientific growth and change.

In 2014, Professor Frankel received the Mary Rabbitt History of Geology Award, which the Geological Society of America's History and Philosophy of Geology Division presents annually to an individual for exceptional scholarly contributions of fundamental importance to our understanding of the history of the geological sciences. In 2013, the Geological Society of London, the oldest and most prestigious geological society in the world, recognized his contributions to the history and philosophy of the Earth sciences by awarding him the Sue Tyler Friedman Medal, a medal awarded for distinguished contributions to History of Geoscience. In 2015, the UMKC awarded him the Thomas Jefferson Award. The award recognizes faculty who rise above excellence and demonstrate clear distinction in teaching, research, writing, creative activities and service to the University of Missouri and humankind.

In 2009, 2011, 2014, Dr Allan Krill, a retired professor of geology at the Norwegian University of Science and Technology (NTNU), published a thoroughly researched, desktop published book, *Not Getting the Drift - A Hard Look at the Early History of Plate-Tectonic Ideas* (which he has also named, *Fixists vs. Mobilists*) (Krill 2009, 2011, 2014). In his 2014 edition, Professor Krill states

> *Having just passed the 100-year anniversary of Wegener's first paper, it is time to confront the main reason why the anniversary was not celebrated: the long denial of continental drift is an embarrassment to earth scientists. We don't even know some of the important parts of this history. Maybe we have not wanted to know. The purpose of this book is to draw attention to these parts, not to embarrass us further, but to encourage healthy scientific debate. The history of the continental drift hypothesis reminds us that scientific consensus can be wrong. Even the best scientists can err. Unorthodox hypotheses should be encouraged and treated fairly. To be against a scientific consensus is not the same as being against science.*

His book consists of a detailed compilation of historical data - the works of leading geology textbook authors. In his 2011 edition, Professor Krill states the following about these authors:

> *These authors are especially important, because their textbooks teach students the principles of the science. The theory of continental drift involved a new scientific paradigm, of mobile, not fixed, continents. The textbooks used in introductory geology courses defined the fixist paradigm and influenced the likelihood of a paradigm shift. I have thus paid extra attention to what the main English-language textbook authors wrote and tried to understand in depth how these highly respected scientists thought. I know from long experience that scientists think just the way other people do.*

In the same edition, he comments:

> *I began this project with the feeling that the rejection of continental drift was a scandal for geology and for science. Scientists should not reject a correct interpretation for so*

long. In more familiar scandals, such as recent ones in finance, politics, sports, and religion, one naturally looks for cover-ups. If there were cover-ups here, what was being hidden and who was being protected? I collected all the important historical literature, and I found what I was looking for.

2. The continental drift controversy

The *Continental Drift Controversy* is based upon critical analysis of the entire primary literature and Professor Frankel's 35 years of active correspondence with the leading figures during the revolution's climactic final quarter. Professor Frankel drew on his extensive oral historical work with the key players in the development of plate tectonics. Because of that, his account can never be repeated in terms of its proximity to the events narrated, so many of those key players now being deceased. The four volumes are the definitive work on continental drift and plate tectonics in the field of Earth science. The books won awards including the journal Choice's designation as an outstanding academic title, the Friedman award of the Geological Society of London, and the Geoscience Information Society's 2013 Best Reference Book Award for his first volume.

2.1 The Continental Drift Controversy Volume 1, Wegener and the Early Debate

In this Chapter, Professor Frankel introduces the reader to the work of Frank Taylor and Alfred Wegener. In 1905 Alfred Wegener (1880 -1930) obtained a doctorate in astronomy at Friedrich Wilhelms University (today Humboldt University), Berlin.[1] Wegener's thesis, "The Alfonsine Tables for the use by a modern computer"[2] involved conversion of a thirteenth-century set of astronomical tables in sexagesimal numbers into decimal numbers (see Appendix A); thereafter he abandoned astronomy in favour of meteorology. Alfred Wegener first presented his hypothesis of continental drift in a public lecture in Frankfurt in 1912. After this, he published two short papers in German, and then in 1915 his first book on the subject. He revised this in 1920, 1922 and 1929. The third edition, published in 1922, was translated into several languages, including English, having the title *The origin of continents and oceans*. (Wegener 1922). Wegener postulated that the present-day landmasses had been one huge supercontinent, which he called Pangaea, in the Mesozoic era (252-66 million years ago).

Professor Frankel presents a detailed analysis of Wegener's account, pointing out that it had many flaws as well as some strengths. A significant shortcoming was Wegner's inability to give a plausible explanation of any process that would enable the landmasses to drift apart. Professor Frankel explained that Geology at that time was a significantly underdeveloped science, awaiting the discovery of considerable evidence about the formation, structure, and development of the planet. Nevertheless, he details the dogmatism and outright hostility of those opposed to Wegener's principal hypothesis of continental drift. A dogmatism and hostility that had no scientific basis being essentially irrational. Professor Frankel provides extensive detail about those who supported continental drift and who published many papers providing new evidence in support of continental drift and against the prevailing orthodoxy. After Wegener's death, several scientists kept his drift theory simmering on the back burners of the science kitchen, including Professor Alexander du Toit, (For. Mem. RS) (1878 – 1948), Professor Arthur Holmes (FRS) (1890 – 1965), Professor Reginald Daly (1871 – 1957), and three distinguished Swiss geologists, Professor Émile Argand (1879 – 1940), Professor Eugéne Wegmann, (1896-1982), and Professor Rudolf Staub (1890 – 1961).

The prevailing orthodoxy was that the surface structure of the planet was fixed and that the planet

[1] Frankel incorrectly reports the date on which the Friedrich Wilhelms University awarded Dr Wegener his PhD as November 1904. It was March 1905 – see Appendix A.

[2] Note that in 1904 the word "computer" referred to a person whose job was mostly doing calculations.

had been slowly contracting for hundreds of millions of years. The oceans resulted from landmasses sinking because they contained heavier elements than the landmasses above the water. Furthermore, because the Earth contracted, the mountains resulted from the crumpling up of landmasses as the Earth contracted. The mountains also came about because the sinking of the heavier landmasses - that now formed the bottom of the oceans - squeezed the lighter landmasses. The irregular structure of the Earth's surface was the result of the original structure being irregular by the way the Earth formed from material dragged out of the Sun irregularly by-passing stars. This prevailing orthodoxy was necessarily seriously flawed. Professor Frankel outlines and discusses these flaws. He compares the arguments of the orthodox with the evidence, showing the vast gap between orthodoxy and reality. He details the tunnel vision and groupthink as well as the irrationality, hostility, bigotry and pig-headed prejudice that kept the orthodox view of the world dominant until the late 1960s.

2.2 The Continental Drift Controversy Volume II, Paleomagnetic Support for Shifting Continents

In this Chapter, Professor Frankel explains that the development of continental paleomagnetism formed the evidential basis for seafloor spreading and plate tectonics. Palaeomagnetism, the study of ancient magnetism preserved in rocks, depends on the finding that the magnetisation of magnetic material is always parallel to the magnetic field in which it was magnetised, and the intensity of magnetisation was proportional to the intensity of that field. The magma oozing up from the viscous Asthenosphere and solidifies, the mineral magnetite (Fe3O4) in the magma crystallizes. As it does so, it is magnetized with an orientation parallel to that of Earth's magnetic field at that time, similar to the way a compass needle aligns with the magnetic field to point north. This magnetic record in the rock is called remnant magnetism. The study of remnant magnetism shows that the Earth's magnetic poles changed place several times over the many hundreds of millions of years during which life evolved on the planet. For example, here have been at least 183 reversals over the last 83 million years (on average once every ~450,000 years). The latest occurred 780,000 years ago. As the magma oozes up spreading the sea floor, the new sea floor is magnetized in the direction of the then-current field. Thus, sea floor spreading from a central ridge will produce pairs of magnetic stripes parallel to the ridge. Research showed that the same magnetic records were found over most of the world's ocean floors, which permitted estimates of the times that most of the oceanic crust had developed. As seafloor spreading results in continental drift and plate tectonics, palaeomagnetism provided hard evidence for continental drift.

Professor Frankel provides a detailed account of the development of paleomagnetism and of the realisation that it supported continental drift. He reports that almost all the prominent advocates of the orthodox view of the surface structure of the planet did not read the published paleomagnetism papers. Those who did, rejected the science of palaeomagnetism because they were convinced it must be wrong as it tended to undermine the orthodox view.

2.3 The Continental Drift Controversy Volume III, Initiation of Seafloor Spreading

In this Chapter, Professor Frankel provides a detailed account of the findings showing that the seafloor has been slowly spreading since more than 200 million years ago. Professor Frankel shows the obdurate refusal and tunnel vision of the scientists leading the orthodox view to the considerable evidence being published about the spreading of the seafloor. He also reports that in 1963 two leading scientific journals, *Nature* and the *Journal of Geophysical Research*, refused to publish work demonstrating that seafloor spreading would result in magnetic stripes parallel to the central ridge. He shows how dominant persons leading scientific institutions would enforce a groupthink in their institutions.

2.4 The Continental Drift Controversy Volume IV, Evolution into Plate Tectonics

In this Chapter, Professor Frankel shows that plate tectonics was discovered almost simultaneously and independently by Dr Jason Morgan (1935 – 2023) early in 1967 and Dr Dan Peter McKenzie CH FRS (1942 to present) later in 1967. Both built on the substantial foundations of seafloor spreading, palaeomagnetism and the integration of these principally by John Tuzo Wilson, Drummond Matthews, Frederick Vine, Lawrence Morley, Sir Edward Bullard FRS, and Jim Everett.

Dr. Morgan, a 32-year-old post-doctoral research assistant in the Department of Geology at Princeton University, gave a paper on April 17 at the 1967 meeting of the American Geophysical Union. He was scheduled to deliver a paper on the Puerto Rico Trench, but instead read a paper he called "Rises, Trenches, Great Faults, and Crustal Blocks," and revealed to the geological profession the existence of plate tectonics. The *Journal of Geophysical Research* published his paper, having the same title as his address to the 1967 meeting of the American Geophysical Union, on March 15, 1968 (Morgan 1968).

According to Dr. Le Pichon (Le Pichon 1991), who attended Dr. Morgan's talk and got inspired to verify or falsify Dr. Morgan's new theory,

> *On the basis of this document [the paper Dr. Morgan circulated to a few senior colleagues], it seems extraordinary that, in this hall packed with the best geophysicists and geologists in the United States, nobody got excited or even interested by the implications of Morgan's ideas.*
>
> *They were too new, too different from anything that had been done.*
>
> *Even among those who received the extended outline and had time to digest these new concepts, I apparently was the only one to have considered it sufficiently important to drop everything else and start working along these new lines.*

Professor Frankel reported that Dr. Jason Morgan began to develop his account of plate tectonics from the beginning of 1967. Significantly, Dr Jason Morgan was not a geologist. He was not a geophysicist. He was a physicist. The title of his PhD Thesis was *An astronomical and geophysical search for scalar gravitational waves*. He wrote this thesis while attached to the Palmer Physical Laboratory at Princeton University under the direction of Professor Robert Dicke (1916 – 1997), who held the Cyrus Fogg Brackett Professorship of Physics from 1957 until he was named the first Albert Einstein University Professor of Science in 1975, becoming emeritus in 1984. Professor Dicke suggested this topic to Jason Morgan. In his thesis, he searched for evidence that gravitational waves would affect any or all of: (i) the Earth's rotation; (ii) the Moon's motions; (iii) the planets' motions; (iv) earthquakes; and (v) the data from a gravimeter. Jason Morgan found no evidence. However, using data sets covering the period 1850 to 1962, he found a significant negative correlation between the Length of Day and large, shallow earthquakes, and a significant positive correlation between Length of Day and large, intermediate, and deep earthquakes.[3]

Dr. Morgan developed the first global-scale predictable quantitative model of plate motion that accounted for most of the seismicity at plate boundaries. He presented an outline of his ideas to a large audience on April 17, 1967, and published a more detailed account in 1968. Dr. Morgan was the first to demonstrate the validity of spherical plate kinematics. He constructed great circles perpendicular to the motion that should intersect at the pole of rotation. He did that between two plates on each side of the Africa/North America portion of the Mid-Atlantic Ridge. He obtained

[3] This relationship (between the Earth's rotation and tectonic activity) has been corroborated many times since 1964. Recently published research shows that the decadal variations (speeding up and slowing down) give rise to earthquakes. It is a significant relationship that can improve the prediction of earthquakes. This research is summarised in Mackey (2023). See also Bostrom, R C (2000) *Tectonic consequences of the Earth's rotation*; Oxford University Press.

the rotation rates through the spreading rates on the ridge. George Backus (1930 to present) proposed in Backus (1964) to use the Euler rotation theorem, also known as Euler's Point Theorem, (see Appendix B), to analyse the width - and rate of increase of the width - of the magnetic stripes on the seafloor. He thus tested the rigidity of involved plates, obtained vectors of motion, and could quantify the motion throughout the boundary. In the 1968 version, he added the treatment of the Pacific-Antarctic Ridge. He also determined the North America/North Pacific motion using the continental transform faults and the rate of motion along the San Andreas Fault. He finally obtained the Antarctica/Africa motion through closure of the three previous ones. All this was discussed within the framework of a 20-plate model presented at the beginning of the paper. Backus (1964) acknowledged that Creer, Irving, Nairn and Runcorn (1958) had suggested this. Professor Frankel reports that Dr. Backus applied to the National Science Foundation (NSF) to obtain the needed data. The NSF rejected his request, judging it "too speculative", an attitude indicative of the institutional dismissal of continental drift. However, some 20 years later geologists recognised Dr. Backus' paper to be visionary!

Dr. Morgan and Dr. McKenzie independently discovered, developed, and tested their versions of plate tectonics. Dr. Morgan discovered plate tectonics approximately five months before Dr. McKenzie, and worked on refining and testing it for six months before submitting his paper to the *Journal of Geophysics Research*. Dr. McKenzie and Dr. Parker's paper, "The North Pacific: An Example of Tectonics on a Sphere", appeared at the end of December 1967 in the journal, *Nature* (McKenzie and Parker 1967); Dr. Morgan's paper appeared in April 1968. At the time, Dr. McKenzie was a 25-year-old post-doctoral student at Cambridge University and Robert Ladislav Parker, also was a post-doctoral student at Cambridge University and of the same age as Dr McKenzie.

Professor Frankel explains (Frankel (2012) Vol IV, page 527) the similarities and differences between Morgan's and McKenzie and Parker's papers as follows:

Morgan's testing of plate tectonics was more extensive than McKenzie's: McKenzie's presentation of plate tectonics was conceptually cleaner. Despite the differences between their presentations, both made essentially the same monumental discovery: a precisely formulated kinematic theory that subsumes the kinematics of continental drift and seafloor spreading, the Vine-Matthews[4] hypothesis and the idea of transform faults, the two key corollaries of seafloor spreading. By dividing Earth's outer surface into plates, most comprising both oceanic and continental lithosphere, and of sufficient rigidity to apply Euler's Point Theorem, they could explain the movements of the Earth's outer surface in terms of relative rotational velocities, why almost all earthquakes occur in typically long and narrow seismic zones, why most earthquakes in the same type of seismic zones have the same mechanism, and why slip directions of earthquakes along the common boundary of two plates are roughly parallel to each other. There was simply no competing theory that solved so many important problems without creating serious difficulties. Despite differences in presentations, both made a monumental discovery.

According to Dr. Le Pichon,[5]

> *McKenzie had arrived in Scripps Institution of Oceanography in June 1967 (Menard, 1986). Cox (1973) wrote that "in June, 1967 he got the idea of using rigid-body rotations*

[4] The Vine-Matthews hypothesis, which is referred to more correctly as the Vine–Matthews–Morley hypothesis, describes the magnetic reversals of oceanic crust. The hypothesis correlates the symmetric magnetic patterns seen on the seafloor with geomagnetic field reversals. At mid-ocean ridges, the injection, extrusion, and solidification of magma creates new crust. After the magma has cooled through the point above which certain materials lose their permanent magnetic properties, ferromagnetism becomes possible and the magnetization direction of magnetic minerals in the newly formed crust orients parallel to the current background geomagnetic field vector. Once fully cooled, these directions are locked into the crust and it becomes permanently magnetized. The hypothesis links seafloor spreading and geomagnetic reversals in a powerful manner, with each expanding knowledge of the other.

[5] Le Pichon, X (1991) ibid., page 3

> *to describe plate motions while re-reading the paper by Bullard, Everett and Smith (1965) on fitting the continents together. Robert Parker had just completed a general computer program called SUPERMAP for plotting worldwide geophysical data using any conceivable projection. Parker introduced the idea of using a Mercator projection in plate tectonics...". As noted above, I independently started using oblique Mercator projection in late May early June 1967 and presented the first oblique Mercator maps with the Eulerian pole of rotation as pole of projection at the early September Woods Hole meeting.*
>
> *My main contribution was to dare computing a simplified global kinematic model (six plates instead of the twenty of Morgan) and to show that it could still be considered realistic. In other words, I demonstrated the validity of the plate tectonic concept for a global quantitative description of the tectonics of the Earth. I also did use the oblique Mercator test simultaneously and independently of McKenzie and Parker (1967) and made the first plate kinematic constructions of past oceans, pointing out the geodynamic implications of finite rotations around triple junctions. On the other hand, the elegant discussion made by McKenzie and Parker of the kinematics of the Pacific plate was original and first outlined in a correct way the significance of fault plane solutions for plate kinematics. Their paper shows no evidence of any direct filiation from J. Morgan's paper, substantiating MC Kenzie's claim that it was developed independently.*

According to Professor Frankel, Dr. Xavier Le Pichon (1937 to present) was most likely the only person in Dr. Morgan's audience in April 1967 who appreciated the significance of Dr. Morgan's discovery of plate tectonics. At the time Dr. Le Pichon was a junior research assistant at the University Columbia, New York City. Dr. Morgan's talk inspired Dr. Le Pichon to stop work on everything he was doing and concentrate on corroborating or falsifying Dr. Morgan's theory. To do this, he had to develop Dr. Morgan's theory for the entire surface of the Earth. He found that six plates would be sufficient. Amongst other things, he had to verify that each of the planet's rift openings behaved according to spherical geometry and Euler's rotation on a sphere theorem. Dr. Le Pichon proved that the plates formed an integrated system where the sum of all crust generated at oceanic ridges is balanced by the cumulative amount destroyed in all subduction zones. He started on the new work towards the end of April 1967 and finished it by the end of August 1967, when he submitted his 36-page paper to the *Journal of Geophysics Research*. Reviewers of his paper, including Dr. Morgan, suggested several revisions that Dr. Le Pichon took into account. He waited until Dr. Morgan's paper, "Rises, Trenches, Great Faults, and Crustal Blocks," was published in the *Journal of Geophysics Research* in April 1968. Dr. Le Pichon's paper, "Sea-Floor Spreading and Continental Drift", was published on June 15, 1968 in the *Journal of Geophysics Research* (Le Pichon 1968).

Drs. Bryan Isacks, Jack Oliver and Lynn Sykes published the next major paper, "Seismology and the New Global Tectonics" in the *Journal of Geophysics Research* on September 1968. It was a 44-page defence of the new global tectonics, showing how it was so strongly supported by seismology (Isacks et al.1968). According to Professor Frankel, "it helped tremendously in conveying what later became known more or less as plate tectonics to Earth scientists who did not work in areas that played a significant role in establishing seafloor spreading, V-M,[6] and plate tectonics".

Plate Tectonics (Appendix C) is the grand unifying theory of the solid earth sciences.

Plate Tectonics allows describing consistently and within one logical framework many geological processes that were until then perceived as being unrelated. According to the modern conception of plate tectonics, the surface of the Earth is composed of rigid lithospheric plates that incorporate the crust and the upper (strong) portion of the mantle and move coherently relative to one another over the asthenosphere through geological time, such that deformation, seismicity, and volcanism occur at their boundaries. Some of the most destructive natural hazards that occur on Earth —

[6] Professor Frankel uses "V-M" to refer to the "Vine-Matthews" hypothesis; see footnote 4.

earthquakes, tsunamis and volcanic eruptions — are associated with tectonic plate boundaries.

According to Dr. Le Pichon (Le Pichon 2019): *Knowing that Morgan had already demonstrated the validity of spherical plate kinematics, I could not simply repeat what he had done. I progressively realized that I could have an original contribution in three domains: demonstrating the impossibility of pure expansion of the Earth, obtaining the first global kinematic model, producing the first finite reconstructions based on magnetic anomalies.*

Professor Krill (Krill 2009, 2011, 2014) concluded that mobilism displaced fixism officially in 1969 as a result of the above-mentioned papers as well as three further publications. These were the proceedings of the *Gander International Conference on Stratigraphy and Structure Bearing on the Origin of the North Atlantic Ocean*, held in 1967 (Kay 1967); and new editions of the leading North American textbooks, Longwell Flint and Sanders (1969) and Dunbar and Waage (1969).

In 1967, Dr. Marshall Kay, Newberry Professor of Geology, Columbia University, organised the Gander International Conference, held in Gander, Newfoundland (Kay 1967). The conference gave geologists familiar with the areas bordering the North Atlantic Ocean with an opportunity to present their knowledge and ideas about continental drift, especially as it related to the North Atlantic Ocean. This publication contains most of the papers that were presented at that conference and a few others that were prepared for the sessions. Dr Kay's summation, *Continental Drift in the North Atlantic Ocean*, (Kay 1967) is a most carefully reasoned, evidence-based account of the formation of the North Atlantic continents, islands and oceans of the current era. He summarised several tectonic epochs relating to the North Atlantic area over the past one billion plus years that geologists and others have documented.

Geophysicists now have strong evidence that on several occasions in Planet Earth's long history when the land masses formed one huge supercontinent. See the ***Geologic time spiral—A path to the past*** at Appendix D.

3. Issues Arising for the IPCC debacle

There are significant parallels between the debate over continental drift, and eventually plate tectonics, and the on-going IPCC debacle

3.1 Don't debate – humiliate

The continental drift controversy reveals that most of the leading scientists who rejected Alfred Wegener's continental drift theory did so in a highly pejorative way. They mocked the theory as absolute nonsense; Alfred Wegner was mocked for being quite devoid of critical faculty. The scientific establishment joined ranks and tore holes in his theories, mocked his evidence and maligned his character. They scorned him for writing "delirious ravings" and introducing "moving crust disease and wandering pole plague." The British ridiculed him for distorting the continents to make them fit and, more damningly, for not describing a credible mechanism powerful enough to move continents. At a Royal Geographical Society meeting, an audience member thanked the speaker for having blown Wegener's theory to bits—then thanked the absent "Professor Wegener for offering himself for the explosion." One prominent American Geologist commented, "If we are to believe Wegener's hypothesis, we must forget everything which has been learned in the last 70 years and start all over again." Others referred to continental drift as "Germanic pseudo-science" and accused Wegener of toying with the evidence to spin himself into "a state of auto-intoxication." Wegener's lack of geological credentials troubled another critic, who declared that it was "wrong for a stranger to the facts he handles to generalize from them."

Sir Harold Jeffreys FRS (1891 to 1989) was the leading geophysicist of the early 20th century, and in 1924, published a book that became the bible of geophysics, *The Earth: Its Origin, History, and Physical Constitution* (Jeffreys 1924). He was reader in geophysics at Cambridge (1932–46)

and was the Plumian chair of Astronomy and Experimental Philosophy (1945–58). Harold Jeffreys was knighted in 1953.

He made significant contributions to mathematics and statistics. His books, *Logic and Scientific Inference*, first published in 1931, and *Theory of Probability*, first published in 1939, played an important role in the revival of the objective Bayesian view of probability. Both became definitive texts. In 1940, he married fellow mathematician and physicist, Bertha Swirles, (1903–1999) and together they wrote *Methods of Mathematical Physics*, first published in 1946.

Sir Harold Jeffreys was unshakably opposed the theory of continental drift. He considered the hypothesis "impossible".

According to Professor Frankel:

> *After election to the Plumian Chair of Astronomy and Experimental Philosophy at Cambridge in 1946, Jeffreys occasionally visited his old department of Geodesy and Geophysics), where he learned intermittently of the new work in paleomagnetism and its support for continental drift to which he was adamantly opposed. In the fourth edition of* The Earth: Its Origin, History, and Physical Constitution *(1959), he argued that the mechanism difficulties against polar wandering were bad enough, but those against drift were insurmountable. Hence, the paleomagnetic method must be flawed because the continents could not have drifted.*

Sir Harold Jeffreys was especially unyielding, certain that the crust's rigidity made continental drift impossible. His influence was enormous. His disciples denounced Wegener's hypothesis for decades and lugged Sir Harold Jeffreys' animosity into fifty years of future debates against plate tectonics. Sir Harold Jeffreys lived to 1989, dying at age 98, long after plate tectonics was mainstream – but still opposed the idea.

According to Professor Frankel, Sir Harold Jeffreys was so opposed to anything to do with continental drift that he refused to go to presentations of work-in-progress that gave support, however remote, to continental drift. Professor Frankel shows that because of Sir Harold Jeffreys standing as one of the world's leading scientists in the fields of Physics, Astronomy, Geophysics, the scientific method and the theory of probability, students and university staff mimicked his attitudes to continental drift and ignored and dismissed the topic as unworthy of serious study.

David Attenborough, who studied geology and zoology at Cambridge University in the second half of the 1940s, recounted an incident illustrating its lack of acceptance then:[7]

> *I once asked one of my lecturers why he was not talking to us about continental drift and I was told, sneeringly, that if I could prove there was a force that could move continents, then he might think about it. The idea was moonshine, I was informed.*

The distinguished Australian geologist, Rhodes Fairbridge (1914 – 2006), was an early champion of Wegener's theories. When Rhodes was a boy of seven living with his family at Fairbridge Village, Pinjarra in Western Australia, Professor G E Nichols, the Professor of Zoology at the University of Western Australia at the time, visited the Fairbridge family at their new village. Whilst showing the young Rhodes about the differences between millipedes and centipedes, he also excited Rhodes' imagination by telling him about Alfred Wegener and his exciting ideas of continental drift. This explained how closely related species that could not swim are found all across the Southern Hemisphere: they had been passengers on landmass life rafts that drifted around the globe. The idea stayed with Rhodes. Later in 1928 as a fourteen-year-old, he read J. G. A. Skerl's translation of Wegener, (Wegener 1922) which made a great deal of sense to him. Rhodes became an enthusiast of Wegner's theories. Rhodes was immune to the hostile consensus that derided Wegener's ideas. According to Dr Charles Finkl: "In the 1940s, the distinguished economic geologist Blanchard once told Rhodes that his thoughts about continental drift should be kept to himself else he would never see a full professorship with tenure." Dr Finkl added: "At

[7] David Attenborough: force of nature | David Attenborough | The Guardian

that time Rhodes had not made any discoveries that justified expressing these opinions, so the moral dilemma never arose." As mentioned above, Rhodes publicly championed Wegner's continental drift hypothesis long before it became an integral part of the scientific canon, albeit modified by subsequent evidence and analysis.[8]

In the United States, (Newman (1995)) where opposition to continental drift was stronger and more deeply entrenched than in England and Europe, several prominent scientists ridiculed the theory of continental drift and forcefully opposed any mention of it. These scientists included Walter Munk FRS, (1917 – 2019),[9] Maurice Ewing FRS (1906 – 1974), Thomas C. Chamberlin (1843-1928), Rollin Thomas Chamberlin (1881-1948), Bailey Willis (1857–1949), Charles Schuchert (1858 – 1942) Professor Emeritus at Yale University, President of the Geological Society of America, associate editor of the *American Journal of Science*, and author of the leading American textbook of historical geology.

Bailey Willis was professor and chairman of the geology department at Stanford University from 1915 to 1922. He was president of the Seismological Society of America from 1921 to 1926 and was president of the Geological Society of America in 1928.

Professor Bailey Willis called Wegener's theory a fairy tale (Willis 1944). He says it seems impossible that the continents could move.

Gordon Macdonald (1929 – 2002) was opposed to continental drift. He held various significant positions at the University of California, Santa Barbara. These included Professor of Geophysics in the Department of Earth Science; Professor of Physics in the Department of Physics; and Vice Chancellor, Research and Graduate Affairs. He was a member of the US President's Science Advisory Committee and a member of the Committee's Panel on Atmospheric Sciences.

According to Professor Macdonald (Macdonald 2003):

> *In all science, there is a strong 'herd instinct.' Members of the herd find congeniality in interacting with other members who hold the same view of the world. Before the 1950s, the North American herd of geologists found it comforting and amusing to ridicule those foreign geologists who advocated continental drift. In the early 1960s (several) respected leaders decided to shift directions and the herd soon followed.*

In Europe, geologists were reserved in their criticism, but in America, Wegener was most severely berated. "Utter damned rot," said William Scott, (1858 – 1947) geology professor at Princeton (and President of the American Philosophical Society) in 1923, describing the theory of continental drift. Edward Berry, an American palaeobotanist, called Wegener's theory "a selective search through the literature for corroborative evidence, ignoring most of the facts that are opposed to the idea, and ending in a state of auto-intoxication." According to Professor Bailey Willis (Willis 1944), a renowned earthquake seismologist and geologist for the US Geological Survey, "further discussion of it [continental drift] merely encumbers the literature and befogs the minds of fellow students. [It is] as antiquated as pre-Curie physics. It is a fairy tale." Willis also claimed Wegener was more "an advocate rather than an impartial investigator."

America was the hotbed of anti-continental drift hostility. Ralph Chaney, (1890 – 1971) an American expert on plant fossils and ancient climates, wrote "It is amusing to note that in taking care of their Tertiary forests, certain Europeans [Wegener] have condemned our forests to freezing." Chaney dismissed Wegener's palaeoclimatology as amateurish, apparently unaware that Wegener, with his father-in-law, Wladimir Köppen, wrote the world's primary textbook on the subject. Others, such as Chester Longwell (1887 – 1975) of Yale University, rejected the concept of mobile continents in the 1920s and stayed opposed into the 1960s, even as the evidence became overwhelming. In 1968, Longwell commented, "Although partisans favouring drift may have

---

[8] Further information about Rhodes Fairbridge can be found in Mackey (2007).

[9] For most of his career, Walter Munk was a professor of geophysics at Scripps at the University of California in La Jolla.

been right, they based most of their case on the wrong reasons and were unable to visualize a mechanism." His statement rings of revisionist history with a touch of sour grapes. The most powerful opponent to Wegener's idea was Rollin T. Chamberlin, Professor of Geology at the University of Chicago. He was also editor of *Science* and a fellow of the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. Chamberlin wrote about the theory of continental drift, "Can geology still be considered a science if it is possible for such a theory as this to run wild?"

Lawrence Morley (1920 – 2013) was a Canadian geophysicist and remote sensing pioneer. He was the Director of the Geophysics Branch of the Geological Survey of Canada in Ottawa (1950–1969). In 1970, he established the Canada Centre for Remote Sensing and served as its Director General from 1971 to 1980.

Dr Morley was the first to suggest that repeated reversals of the Earth's magnetic field resulted in magnetic striping in the Earth's crust. He explained that a record of the direction and intensity of the Earth's magnetic field was imprinted on the rocks on the ocean floor. He pointed out that because of the planet's magnetic polarity reversed direction every half-million years, iron-rich rocks and ridges on the sea floor provided a record of field reversals by locking into place their magnetic properties at the time of formation.

In 1963, Dr Morley submitted a letter to *Nature* reporting these findings in February 1963. The editor of *Nature* rejected his letter. Dr Morley revised his letter and in April 1963 submitted it to the *Journal of Geophysical Research*. The editor of that journal refused to publish it, writing to Dr Morley, that a referee's assessment was: "Such speculations make interesting talk at cocktail parties, but it is not the sort of thing that ought to be published under serious scientific aegis."

In 1974, Professor Norman Watkins (1934 to 1977) at the time Director of the Division of Earth Sciences of the National Science Foundation, described Dr Morley's paper as "probably the most significant paper in the earth sciences ever to be denied publication." (Watkins, (1974)). Dr Watkins' 1974 letter is at Appendix E.

At virtually the same time, two geologists at Cambridge University, Drummond Matthews FRS (1931 to 1997), at the time a research fellow at King's College, Cambridge, and Frederick Vine FRS (1939 - present), at the time his research student, developed the same ideas. *Nature* published their paper "Magnetic Anomalies Over Oceanic Ridges" on September 7th, 1963 (Vine and Matthews (1963)).

Even now, there are strange comments. For example, Professor Robert Merrill, Professor Emeritus of Earth and Space Sciences at the University of Washington, writes in his recent book, *Our Magnetic Earth*, (Merrill, (2010)) that:

"I am sometimes asked, "Who discovered plate tectonics?" I reply that many scientists were involved and no one or two individuals should be given credit for the discovery." Page 199.

He does not mention anywhere in his book that Dr. Morgan and Dr. McKenzie have been universally recognised for discovering plate tectonics in 1967. Both have received international prizes for their discovery.

4. Common features between the impact of the IPCC debacle and the continental drift controversy

Professor Frankel gives an analysis of the extraordinary unscientific behaviour of those scientists who opposed Wegener's theory of continental drift. His main points are that the key blockages to the acceptance of continental drift were groupthink and tunnel vision. In saying this, he documents the many shortcomings in Wegener's theory. These include the absence of any plausible account to explain how or why the continents drifted; the use of unreliable, in some cases invalid, data; having an unsatisfactory timetable for continental drift; internal inconsistencies within Wegener's theory, especially in relation to the formation of mountains and landmasses ploughed

through the sea floor in the way Wegener speculated. Nevertheless, science progresses by analysis, new evidence and debate because rarely can one scientist propose a theory that is without shortcomings. Even the brilliant theories of Isaac Newton, James Clerk Maxwell and Albert Einstein had shortcomings!

4.1 Tunnel vision and groupthink rule

Professor Frankel ((2012) Vol 1 pp. 1-37, 488-553, 545-55; Vol IV pp. 421-424) provides considerable detail about the tunnel vision (see Appendix F) and groupthink in the various communities of geophysicists and geologists in the Western world. He considers that these two factors are the key to understanding why the scientific community took so long to reject the dominant theory that the geological structure of the lithosphere were fixed and discover plate tectonics. He documents in detail the narrowness and narrowmindedness of the leading scientists opposed to continental drift. Even so, those two factors do not help much to understand the rancorous nature of those opposed to continental drift, the dominance of prejudice, hubris, and outright hostility of those opposed to continental drift, and the pig-headed refusal of most of those against continental drift to engage in constructive debate.

The scientists opposed also showed limited or no recognition or understanding of how little the phenomena under study was described or understood or even the vast data problems in geology and geophysics at that time.

Eventually, evidence from outside the field of the main focus of geologists overturned the attitudes of those opposed to continental drift. The evidence came from Palaeomagnetism.

4.2 Cover-up

Professor Krill's forensic analysis of geology textbooks within the span of the climate drift controversy led him to these findings (Krill 2009, 2011, 2014):

> *It was Charles Schuchert – professor emeritus at Yale University, President of the Geological Society of America (in 1922), associate editor of the American Journal of Science, and author of the leading American textbook of historical geology – who headed the campaign against mobilism. Wegener's theory would have been taken as a working hypothesis in 1924, were it not for Schuchert's conscious decision to hide and discredit evidence in support of it. Schuchert's tactical moves began with his second edition of the textbook, Historical Geology. He understood that the directions of Permian glacial ice-flow proved mobilism, so he removed arrows from his map that showed those directions. He carefully worded his explanations to sidestep other evidence for mobilism. His efforts continued in his 1928 publications, where he misquoted and ridiculed Du Toit, Daly, and others. He decided not to update and correct key maps and paragraphs of his textbooks. He succeeded in keeping Holmes' breakthrough article on mantle convection-currents out of the American Journal of Science.*

And

> *Established scientists find it difficult to disavow their previous opinions, especially if those opinions appeared in print. I think we might call this the constancy of published scientific opinion. It has to do with the nature of a publication record, and the nature of a scientist. Highly respected scientists are mostly characterized as authoritative, committed, reliable, and stable. It is far less likely for reputable scientists to be adaptable, amenable, flexible, and persuadable. Scientists are people. They like to correct others, but do not like to stand corrected. An ambitious scientist might hope to "rewrite the book" on his science, but not if the book that needs rewriting is his own. If circumstances are right, a scientist will gladly correct his own work. If he is personally involved in making new discoveries, he will be happy to publish a new paper that announces the developments and corrects his earlier conclusions. If his competitor makes new discoveries, he will usually accept them and adopt the new results*

in his next published paper on this topic. But if it is apparent that the evidence was available all along, and that he got it wrong the first time, he will probably not publish again on that particular topic. I know this from personal experience, having myself made an embarrassingly incorrect geological interpretation of this type.

5. The impact of the IPCC debacle is much worse than the impact of the continental drift controversy

5.1 The IPCC structure is one of the worst ways of doing science

The IPCC consists of a political/ideological group that oversights a bureaucratic group that oversights the scientists. The effect of this is stifled debate amongst the scientists and the tunnel vision and group think - that was a dominant feature of the continental drift controversy – that is endemic in the community of scientists that the IPCC oversights. The conduct of science depends on the freedom to debate, the freedom to challenge, the freedom to be wrong; the freedom to publish evidence, analysis and theories that challenge, undermine, contradict long held, established theories. The conduct of science is an open process, whereas the IPCC process is not only closed, but closed tightly.

Dr Xavier Le Pichon noted, "that science that is completely regulated top-down is not efficient".[10]

Professor Richard Feynman (1918 – 1980) explained the conduct of science in this way (Feynman (1965))

Now I'm going to discuss how we would look for a new law. In general, we look for a new law by the following process. First, we guess it (audience laughter), no, don't laugh, that's the truth. Then we compute the consequences of the guess, to see what, if this is right, if this law we guess is right, to see what it would imply and then we compare the computation results to nature or we say compare to experiment or experience, compare it directly with observations to see if it works.

If it disagrees with experiment, it's wrong. In that simple statement is the key to science. It doesn't make any difference how beautiful your guess is, it doesn't matter how smart you are who made the guess, or what his name is … If it disagrees with experiment, it's wrong. That's all there is to it. [11]

That is not the way of the IPCC.

[10] Meeting Plate Tectonics – Xavier Le Pichon; the *Blog* of the Tectonics and Structural Geology Division of the European Geosciences Union; David Fernández-Blanco November 6, 2018; See Tectonics and Structural Geology | Meeting Plate Tectonics – Xavier Le Pichon (egu.eu)

[11] This is an extract from Professor Feynman's speech that he delivered as part of the Messenger Lectures on "The Character of Physical Law" at Cornell University on November 9, 1964. Feynman's Messenger Lectures. It is from Chapter 7, Seeking new laws. See The Feynman Messenger Lectures Video Viewer (caltech.edu)

5.2 There is no direct evidence to support the IPCC hypothesis

Using the established framework of independent and dependent variables[12] in which an independent variable is a cause and a dependent variable is the effect, the climate system is the dependent variable and the variables that cause the climate system to change are the independent variables. Historically, the ideas of independent and dependent variable developed in Mathematics as the concept of a mathematical function became defined systematically in the work of Descartes in 1637, Newton in 1670 and Leibnitz in 1673. It was Leibnitz who defined the concept of "function" as it is used now throughout mathematics and science in 1673 (Youschkevitch 1976).

The alleged evidence for the IPCC hypothesis consists of hypothetical projections of a handful of climate indices (including average global temperature, global sea levels) derived from computer simulations based on a radically simplified theory of climate dynamics from which has been excluded key independent variables. In addition, the computer simulations ignore non-linear, non-stationary functional relationships between the independent and dependent variables; the interaction effects of all relevant independent variables on the behaviour of the independent variables and on the dependent variables; the time gaps between changes in the values of independent variables and changes in the values of dependent variables of which the climate system is composed; and the interaction effects of the dependent variables in aggregate and on the behaviour of the dependent variables Accordingly, the IPCC provides no evidence to support the advocated hypothesis.

The set of independent variables include the Sun's output of radiation and matter; electromagnetic and gravitational fields; shape; and the topological structure of the heliosphere.

The set of dependent variables, that is the climate system, includes the Earth's: atmospheric systems; ocean systems; coupled atmospheric-oceanic systems; clouds; Rossby and Kelvin waves; rotation of the planet; atmospheric angular momentum; dynamo; electromagnetic field; and global electric circuit.

There are other factors relevant to our understanding of the Earth's climate dynamics:

a) climate system's internal variability.
b) Earth's albedo.
c) cosmic rays.
d) Earth's orbital geometry, including Milankovitch processes.
e) planets' gravitational effects on the Earth's and Moon's orbital geometry and,
f) Sun's epitrochoid-shaped barycentric motion.

It is well-known that the relationships between the independent variables (the causes) and the dependent variables - climate system (the effect) - are not simple linear relationships (Rial et al 2004). Four non-linear, non-stationary processes relating the set of independent variables (including those of the Sun mentioned above) to the set of dependent variables (the climate system) have been identified. They are: strange attractors; resonant amplification; phase synchronisation; complexity matching. See, for example, Tsonis et al. (2007), Cohn and Lins (2005), Scafetta, (2023), Paluš and Novotná (2009), Tobias and Weiss (2000)[13].

---

[12] It is customary in all areas of science to make graphs with the independent variable on the horizontal axis and the dependent variable on the vertical axis. In the teaching of science from elementary levels onwards this helps show hypothesised relationships between the cause (the independent variable) and the effect (the dependent variable). In the fields of health and pharmacy, the graphs are called dose-response curves. Anyone who has done experimental science at secondary or tertiary level would have made similar graphs. See also Youschkevitch (1976), Winston and Blais (1996), and Dependent and independent variables - Wikipedia.

[13] The authors' findings are best stated in their own words: "It is clear that the resonance provides a powerful

The IPCC prevents the development and testing of a comprehensive theory of climate. The IPCC prevents the derivation of quantitative predictions about the climate system from a comprehensive theory of climate that includes all relevant independent variables. The IPCC prevents the application to climate science, hence to the IPCC hypothesis, of the approach to science described by Professor Feynman and universally recognised as the way to do science.

As a result, the IPCC is anti-science.

5.3 Outsiders keep out, stay out!

Almost all the leading scientists connected with the IPCC refuse to debate, discuss, read, and/or publish, any scientific paper that provides evidence that does not support the IPCC hypothesis. The climate scientists devoted to the IPCC's doctrine refuse to recognise any work about the Earth's climate dynamics if they regard the authors of that work as being other than climate scientists just like themselves. In this manner, they imitate the behaviour of many geologists, especially American geologists, who rejected the continental drift hypothesis because Wegener and several prominent advocates of his theories were not geologists. And yet the correct geological theory about the movement of the lithosphere's landmasses was discovered by physicists not geologists. Furthermore, throughout the history of science and mathematics, persons outside a particular discipline have made significant contributions to that discipline.

One famous example is that of the mathematician, Dr. Paul Cohen (1934 – 2007).[14] Without any formal background in Logic, in 1963, Dr. Cohen proved that neither the continuum hypothesis nor the axiom of choice can be proved from the standard Zermelo–Fraenkel axioms (ZF) of set theory (Cohen 1966). In conjunction with the earlier work of Kurt Gödel (1906 – 1978), this showed that both of these statements are logically independent of the ZF axioms: these statements can be neither proved nor disproved from these axioms. In this sense, the continuum hypothesis is undecidable; it is the most widely known example of a natural statement that is independent from the standard ZF axioms. Dr. Cohen discovered a new methodology to use in Logic, which he called forcing, to prove the undecidability of the continuum hypothesis.

For his result in the theory of logic, namely proof of the undecidability of the continuum hypothesis, in 1966, the mathematician, Dr. Cohen, won the Fields Medal[15] in mathematics and in 1967, the National Medal of Science.

In 1963, Dr Cohen invited Kurt Gödel to examine his proof before submitting it for publication in the *Proceedings of the National Academy of Sciences USA*.

Kurt Gödel found the proof to be satisfactory and in 1963[16] wrote to Dr. Cohen saying, amongst other things,

> *Let me repeat that it is really a delight to read your proof of the independence of the continuum hypothesis. I think that in all essential respects, you have given the best pos-*

---

mechanism for amplifying climate forcing by solar activity." Hence, there need no longer be any reluctance to accept as fact the observation that the many correlations that have been documented between solar variability and the time histories of various climatic phenomena do indeed have a cause that is of extraterrestrial origin.

[14] This account of Dr Cohen, including the quotation of Kurt Gödel is based on, and derives from, Paul Cohen (1934 - 2007) - Biography - MacTutor History of Mathematics (st-andrews.ac.uk)

[15] The Fields Medal, which is often considered the mathematical equivalent of the Nobel Prize, is granted every four years. In accordance with the prize's statutes, it is given to mathematicians under the age of 40. The Fields Medal that Dr Cohen won continues to be the only Fields Medal to be awarded for a work in mathematical logic, as of 2022, the last year in which the Fields medal was awarded.

[16] At the time (1963) that Professor Gödel received Dr Cohen's draft, he had devoted more than 30 years trying to prove what Dr Cohen had proved in about six months!

> *sible proof & this does not happen frequently. Reading your proof had a similarly pleasant effect on me as seeing a really good play.*

Dr. Cohen was an outsider to the discipline of Logic.

He was not a logician; he was a mathematician who had specialised in several areas of pure mathematics, including Analysis, Topology and Algebra.

The title of his 1958 doctoral thesis was *Topics in the Theory of Uniqueness of Trigonometrical Series*.

In 1959 and 1960, he published two papers *Factorization in group algebras* and *On a conjecture of Littlewood and idempotent measures* that established him as an emerging leader in the areas of Analysis, Topology and Algebra.

The history of science and mathematics shows that a person outside a particular discipline can solve problems in the discipline of which they are an outsider because they bring new expertise, new methods, new knowledge, new ways of understanding to the problem and thereby solve it.

The phenomena that humans try to understand does not come neatly pre-packaged in discipline wrappers ready for humans to unwrap.

The geologists and other scientists opposed to continental drift would not accept the findings and theories of paleomagnetism. Professor Frankel describes the uncompromising determination of Walter Munk FRS, jointly with his then junior colleague, Gordon MacDonald, to debunk palaeomagnetism. According to Professor Frankel, "Their assessment of paleomagnetism carried great weight with many Earth scientists, often, with the latter, I suspect, regardless of whether they had taken the trouble to understand the palaeomagnetic arguments."[17] Nevertheless, the findings and theories of palaeomagnetism were crucial to the discovery of plate tectonics.

Dr. Paul Cohen was able to prove the undecidability of the continuum hypothesis because he could frame it as a mathematical problem rather than a problem in the theory of Logic. This enabled him to develop the idea of forcing inspired by analogies with parts of modern algebra including that part which deals with adjoining mathematical entities to algebraic fields and a lemma in Topology about the structure of particular types of topological spaces.[18]

5.4 The IPCC is circular by design

At core, the IPCC is inherently, unavoidably, and by design, circular.[19]

The IPCC is required to assess human-induced climate change and provide advice about the likelihood of human-induced climate change and strategies to deal with adaptation to, and mitigation of, human-induced climate change. It is prevented from assessing and reporting evidence that conflicts with the theory of human-induced climate change. The IPCC therefore begins with the assumption that human-induced climate change is changing the planet's climate. The IPCC then sets about assembling any evidence of the planet's warming climate, claiming that that this is evidence for what has been assumed. The IPCC has consistently ignored well-established evidence reported by scientists in the world's leading scientific journals and in textbooks that the planet experiences regular cycles of global warming and cooling arising from geophysical phenomena (Mackey 2023).

The computer simulations that the IPCC uses to project the impact of hypothetical human-induced climate change likewise assume that the only form of climate change to take into account in the

---

[17] Frankel Vol II pp 389 – 390; op. cit. page 1

[18] The Discovery of Forcing (projecteuclid.org) and Pages from letter-2011-fall-2.pdf (ias.edu)

[19] Paper: Circular Reasoning in Climate Change Research • Watts Up With That?; See also Spencer, Roy W (2012), especially page XXVII and pp 99 to 100.

algorithmic simulations is human-induced climate change (Pindyck 2015; Munshi 2018).[20]

In a breath-taking example of circularity within circularity, the IPCC asserts that the computer simulations with their built-in circular reasoning are evidence for the circularly reasoned IPCC hypothesis!

The United Nations Framework Convention on Climate Change (UNFCC 1992) defines (in its Article 1) ′climate change′ as: *a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*.

According to the website of the IPCC, (IPCC 1998) the role of the IPCC is *to assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation. IPCC reports should be neutral with respect to policy, although they may need to deal objectively with scientific, technical, and socio-economic factors relevant to the application of particular policies.*

The IPCC definition of climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer) arising only from human activity.

And yet in all of the IPCC's reports, no evidence, independent of the assumption of human-induced climate change, has been published that corroborates the theory of human-induced climate change.

The scientific examination of climate change that considered climate dynamics in totality, would inquire into all reasons for the Earth's climate dynamics. These include theories that explain the Earth's climate dynamics in terms of solar variability; in terms of the natural internal variability of the climate system; and/or in terms of the consequences of the massive re-engineering of the planet by human beings over the last 300 years or so (Cotton and Pielke 2007).

The disinterested approach of science formulates theories and proceeds to produce evidence and analysis that corroborates or refutes existing theories. Science thrives on doubt, debate, the production of conflicting evidence and analysis and the advancement of theories of greater and greater explanatory power, covering broader classes of phenomena and longer periods. Science is forever uncertain, rarely settled. In an area as complex and as young as the science of climate dynamics, the statement that "the science is settled" will always be false.

Had the IPCC been established to understand the planet's climate dynamics scientifically, its role would have been defined in relation to climate dynamics as such without a qualifier limiting 'climate dynamics' to a particular cause.

5.5 The anti-science IPCC is ideological

In contrast, and in an entirely anti-scientific, as against, non-scientific, manner, the IPCC has denigrated alternative explanations, has sought to vilify valid scientific explanations, and personally attack with a view to silencing scientists and others who present valid scientific explanations that are contrary to the IPCC hypothesis. Is this the hallmark of a disinterested scientific inquiry into the truth about climate change? No! It is the distinctive sign of an uncompromising ideological agenda.

An example of the ideological, rather than scientific, *modus operandi* of the IPCC, is the highly political and dismissive way in which the IPCC, in 2003, responded to the advice offered to it by

[20] See, for example, Circular reasoning with climate models - CFACT; Structural errors in global climate models | Climate Etc. (judithcurry.com); Gerry Browning: In Memory of Professor Heinz Kreiss « Climate Audit .

two distinguished (and retired) experts, Ian Castles AO OBE (1935 – 2010) and David Henderson (1927 – 2018). At the time, Dr Castles was a Visiting Fellow at the Asia Pacific School of Economics and Government at the Australian National University, an economist and statistician, a former head of Australia's Bureau of Statistics and former Secretary of the Australian Government Department of Finance (1979–86). Between 1995 and 2000, Ian Castles was Executive Director and Vice President and of the Academy of the Social Sciences in Australia and he was also President of the International Association of Official Statistics. David Henderson (1927 – 2018), was a former Chief Economist of the Organisation for Economic Co-operation and Development and a former visiting professor at Westminster Business School.[21]

The scientists, devoted to the circular anti-science reasoning of the IPCC, have succeeded in closing down debate that questions the IPCC hypothesis. They have succeeded in the sanctioning of individuals who question the IPCC's self-asserted infallibility.[22]

On February 24, 2023 the editors of the EGU journal, *Earth Systems Dynamics*, published by Copernicus Publications, published an extraordinary editorial that stated, amongst other things, that it will no longer accept papers to be considered for publication that examine scientifically whether *global warming, or at least a significant part of it, is caused by factors other than the direct and indirect effect of anthropogenic greenhouse gas emissions.*

The reason for this clear rejection policy is not a lack of scientific openness of the journal and its editors but rather the extremely well-established scientific basis of how the Earth's atmospheric greenhouse effect works, how it affects surface temperatures, and how it is altered by anthropogenic emissions of greenhouse gases.[23]

This statement is an absurd mockery of the publisher's name and of the scientific method.

It reveals a stunning ignorance of the nature of the IPCC's *modus operandi* and of the design of the computer simulations used by the IPCC.

The IPCC's use of a poorly educated, photogenic, messianic, and bigoted teenage girl, to be throughout the world, a key champion of the IPCC hypothesis, is a further sign of the anti-science nature of the IPCC.

IPCC has created a secular religion that has overtaken governments, bureaucracies, scientific academies and many large, including multi-national corporates, just like the Catholic religion had in medieval Europe. The IPCC chair is equivalent to the Pope (Joffe 2019).

Richard Feynman observed: *Religion is a culture of faith; science is a culture of fact*.

And

The only way to have real success in science, the field I'm familiar with, is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what's good and what's bad about it equally. In science, you learn a kind of standard integrity and honesty.

The IPCC has imposed and continues to impose a monstrous expense on the World.

Governments throughout the World have spent many billions of dollars dealing with the IPCC's chimerical theory; they have committed many billions more.

The European Commission has instructed EU members to adopt complex strategies, costing many

---

[21] An account of this can be found on the websites http://www.onlineopinion.com.au/view.asp?article=2147 and http://www.lavoisier.com.au/papers/articles/IPPCissues.html. See also - Bishop Hill blog - Henderson on Castles (bishop-hill.net).

[22] There are many examples- eg - Institutional Bias (bishop-hill.net) ; here is but one recent one Climate censorship is worse than you think | Financial Post

[23] ESD - Editorial: Global warming is due to an enhanced greenhouse effect, and anthropogenic heat emissions currently play a negligible role at the global scale (copernicus.org)

billions of dollars, designed to adapt to and/or mitigate against hypothetical consequences of the chimerical theory. The strategies have done, are doing, and will do significant damage to the economies of member states and the European Union.

Even more damaging is the role central bankers, financiers, IMF, World Bank, global conglomerates, World Economic Forum, the bureaucracies, and bureaucrats of the sovereign states in NATO, the EU, and the OECD in the quixotic devotion to the IPCC's chimerical hypothesis. This disparate assembly is supporting governments in closing down all forms of use of carbon-based compounds, including coal and natural gas, diverting extraordinary volumes of money (many billions of US dollar equivalents) to the development of energy sources that do not use carbon-based compounds.

5.6 The IPCC ignores established science of climate dynamics

The causes of the variations in global temperatures and sea levels over the past few decades that the IPCC has falsely attributed to Carbon Dioxide generated by humans' use of carbon-based fuels are well known. These causes have been documented in the scientific literature and in text-books for over forty years. The causes are of geophysical origin and involve interaction of geophysical phenomena with the Sun's variable output and the intrinsic dynamics of the atmosphere and oceans (Mackey 2007, 2023; Kilifarska et al. 2021; Kilifarska et al. 2020; Sidorenkov 2009; Yndestad et al. 2008; Yndestad 2009; Zharkova, Valentina 2023. The anti-science, ideological IPCC ignores this substantial body of substantial science, and, in consequence engages in scientific misconduct on a grand scale.

5.7 A pathway out of the debacle

The pathway has ten steps.

The **first** step is to more thoroughly detail the geophysical basis for the sixty-year cycles of global warming and cooling.

> Over the past fifty years, geophysicists have established that the planet experiences cycles of global warming and cooling episodes that are repeated about every 60 years; that these cycles are driven by decadal variations in the rate of rotation of the Earth; that these variations result from oscillations of the Earth's inner core; and that these oscillations have their origins in the celestial mechanics of the solar system documented by LaPlace in 1799.[24]

The **second** step is to bring together all the science of solar physics and celestial mechanics that show how variations in the Sun's output and solar system celestial mechanics contribute to the regulation of the Earth's climate.

> Over the last several decades, scientists from several disciplines have published in many of the world's leading scientific journals abundant evidence about the key determinants of climate dynamics. The most significant determinant is the Sun.[25]

The **third** step is to consolidate and test the findings of Humlum et al. (2013) and the recent findings of Koutsoyiannis and Kundzewicz (2020), and Koutsoyiannis et al. (2022a, 2022b) that variations in global temperature give rise to variations in quantities of Carbon Dioxide in the atmosphere rather than the obverse as is asserted (without evidence) in the IPCC doctrine.

The **fourth** step is to consolidate in one place the many flaws in the IPCC's computer simulations and provide a critical analysis of them.

The **fifth** step is to consolidate in one place the many flaws in the IPCC processes and provide a critical analysis of them.

The **sixth** step is to consolidate in one place the many flaws in the quality of data used by the IPCC

---

[24] This is summarised in the publications mentioned in footnote 8. See also Cazenave et al. (2023)

[25] See publications mentioned in the preceeding Paragraph 5.6, and, amongst many others, Kilifarska (2021) and Zharkova et al. (2023).

and weather/climate agencies and provide a critical analysis of them.

The **seventh** step is to document the evidence of scientific misconduct practiced by the IPCC since 1990.

> According to the U.S. Office of Science and Technology Policy (National Academy of Sciences (US), National Academy of Engineering (US) and Institute of Medicine (US) Committee on Science, Engineering, and Public Policy (National Academy of Sciences 2009), and endorsed by the Organisation for Economic Co-operation and Development (OECD Secretariat (2022)), not representing in the research record accurately by the deliberate omission of scientific results, constitutes the falsification of science and is scientific misconduct.
>
> The IPCC does not mention in any of its many reports the vast body of research published over the last 50 years about the regulation of the Earth's climate by variations in the Earth's decadal rotation; it does not mention the well-documented dominant role in the regulation of the Earth's climate of the Sun's output of matter, of the Sun's electromagnetic and gravitational fields, of the Sun's shape; and of the topological structure of the heliosphere; it does not mention the well-documented dominant role of the Lunar Nodal Cycle in the regulation of the Earth's climate. The IPCC has deliberately omitted reporting these scientific results for over thirty years, since the publication of its *First Assessment Report* in 1990. In relation to the role of the Sun in the regulation of the Earth's climate, the IPCC presents a partial and biased account of the published science of only the impact of the Sun's irradiance on the climate system in order to reduce the role of the Sun to a minimum. The IPCC deliberately omits the other ways in which the Sun influences the climate system, including interactions between these ways.
>
> Accordingly, the US and OECD scientific authorities would find the IPCC guilty of egregious scientific misconduct.

The **eighth** step is to document that administratively the IPCC changes data and continues to mislead the public with the deceit that the actual tropospheric temperatures measured throughout the world are the same as the tropospheric temperatures projected by the IPCC's computer simulations when the actual measured tropospheric temperatures are significantly lower and the trends noticeably different.

The **ninth** step is to enable the public to recognize that the IPCC's computer simulations are erroneous since they project temperatures that are too high, with the consequence that the computer simulations are falsified routinely, including since 1990.

The **tenth** step is to terminate use of the IPCC computer simulations and use, and develop, the science of climate dynamics based on observation, analysis, and testable theory.

The results of these ten steps should be presented to an international conference at which the IPCC would be invited to respond to the findings and analysis of each of the ten steps.

Following the conference, the IPCC should be dismantled.

Funding

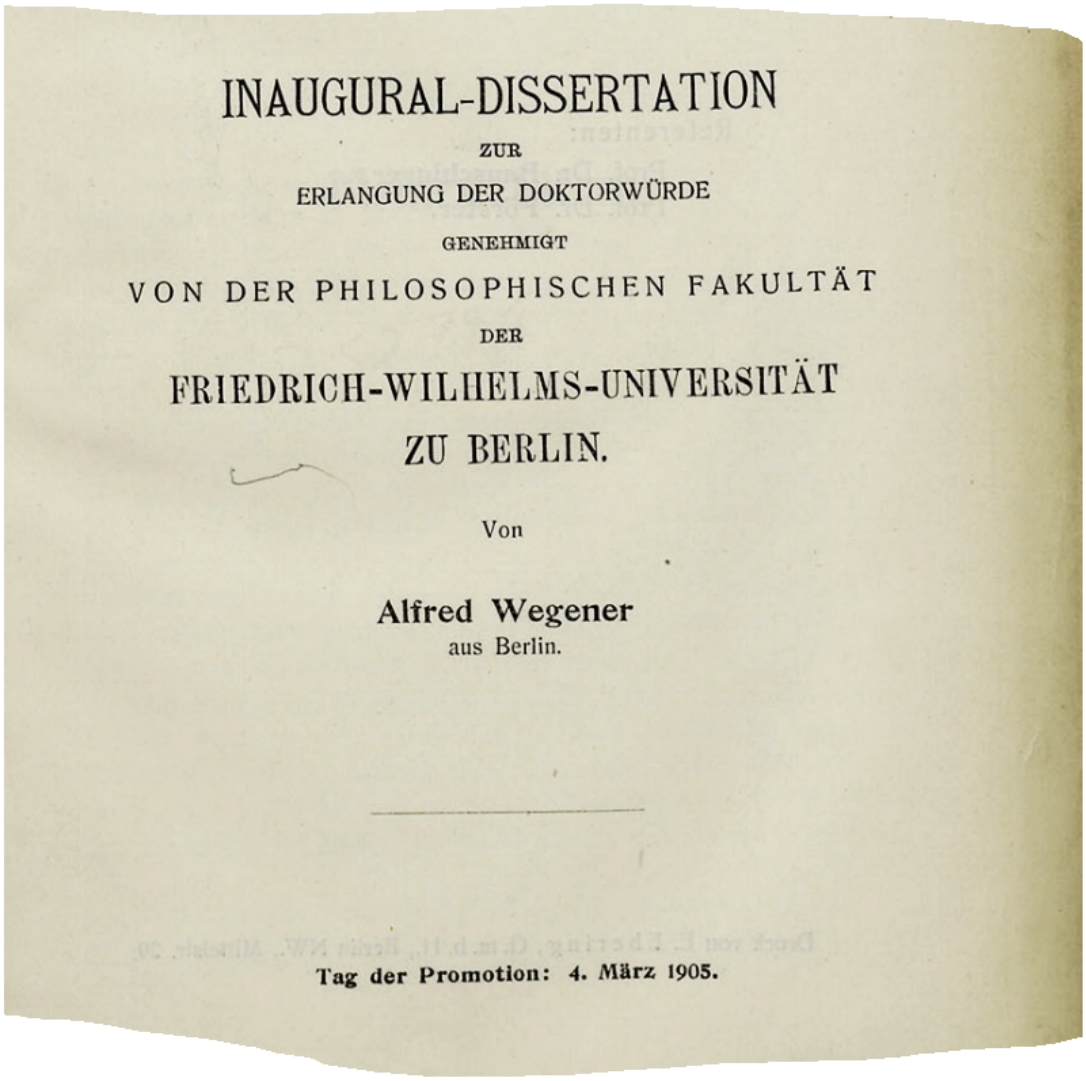
No funding

Guest-Editor: Stein Storlie Bergsmark; Reviewers: anonymous.

Acknowledgements: I would like to acknowledge the encouragement I received from Stein Storlie Bergsmark

Appendix A

Alfred Wegener's PhD thesis, *The Alfonsine Tables for the use by a modern computer*



INAUGURAL-DISSERTATION

ZUR

ERLANGUNG DER DOKTORWÜRDE

GENEHMIGT

VON DER PHILOSOPHISCHEN FAKULTÄT

DER

FRIEDRICH-WILHELMS-UNIVERSITÄT

ZU BERLIN.

Von

Alfred Wegener

aus Berlin.

Tag der Promotion: 4. März 1905.

From: Wielen, Roland and Ute Wielen, Ute (2017) WegenerSup.pdf (uni-heidelberg.de)

The Alfonsine Tables

According to Dr Mott Greene (2015), Professor Julius Bauschinger (1860 – 1934) Director of the Astronomisches Rechen-Institut and Professor of Theoretical Astronomy in Berlin, and Alfred Wegener's dissertation advisor, directed Wegener to do the thesis about the Alfonsine tables.

Dr Greene explained the background.

According to DR Greene, (Greene (2015)), the distinguished American Astronomer, Professor Simon Newcomb (1835 - 1909), Director of the Nautical Almanac Office as well as Professor of Mathematics and Astronomy at Johns Hopkins University in Baltimore, had approached Professor Julius Bauschinger, Alfred Wegener's supervior, to examine the Alfonsine Tables to obtain a lengthy time series of the Moon's positions. In 1870 Professor Newcomb found evidence showing that that the Moon's actual positions deviated from the Moon's predicted positions, using

tables of the Moon's predicted positions (the Hansen Tables) prepared by the German astronomer Peter Hansen (1795 -1874).

These tables, known as Hansen's Tables, were regarded at the time as being the most accurate data about the Moon's position. Established astronomical doctrine of the time was that the theory of the Moon's orbit was complete and the position of the Moon at any time was known with great accuracy. For example, *The Nautical Almanac and Astronomical Ephemeris*, published by the Royal Greenwich Observatory in England used Hansen's Tables as did the United States Nautical Almanac Office.

Dr Greene explained that Professor Newcomb was so concerned about the discrepancy he found between the data in Hansen's tables and his observations that he travelled to Germany to study tables older than the Hansen Tables. He found that the further he went back before 1750 the greater the discrepancy became. He found a potential source of invaluable data in the Alfonsine Tables covering the period from 1252, the date of the coronation of King Alfonso, to sometime in the first half of the sixteenth century.

However, the Alfonsine Tables were not readily accesible to a 19th Century astronomer. They were in rare books held only by a few universities; they were written in a difficult form of Medieval Latin using obsure phraseology of Ptolemic (Earth-centered) solar system with its immense geometrical complexities and obscure terminology. Professor Newcomb found them inaccessible.

Furthermore, Professor Newcomb was coming to the view that the very small discrepancies he found were most likey real, and if so, most likely arose from variations in the Earth's rotation. At the time Professor Newcomb was forming this view (1880s onward), the established astronomical doctrine was that the Earth's rotation was constant. It was the standard for time, thereby placing the rotation of the Earth as the standard clock in the same category as the physical standards for length and weight. As a result, astronomers used the presumed fixed constant of the Earth's rotation to determine all astronomical attributes of the Sun and the solar system.

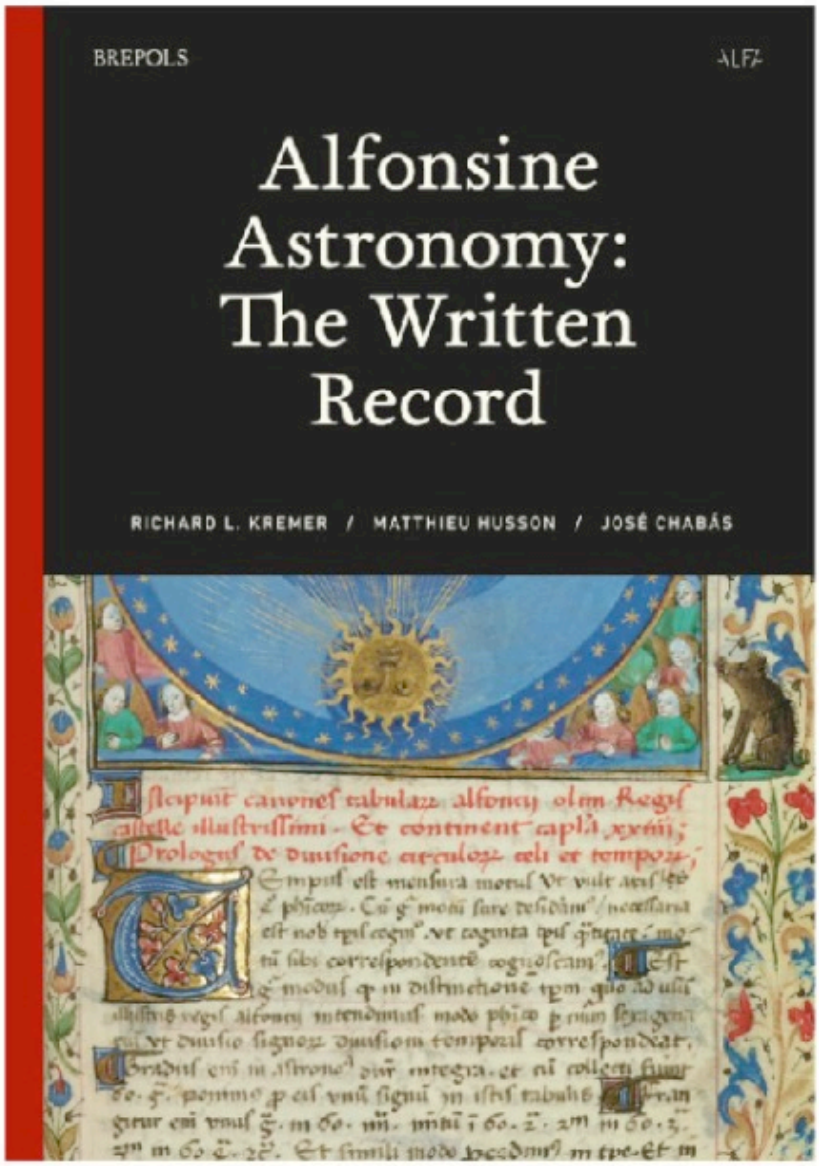
As a careful, honest scientist dedicated to discovering truth, Professor Newcomb wanted to assemble the longest record possible record, back to preclassical antiquity if possible, in order to determine the best possible pattern of the Moon's behaviour. The Alfonsine Tables, covering a period of about 300 years, and containing high quality data, was a crucial source of the data Professor Newcomb required.

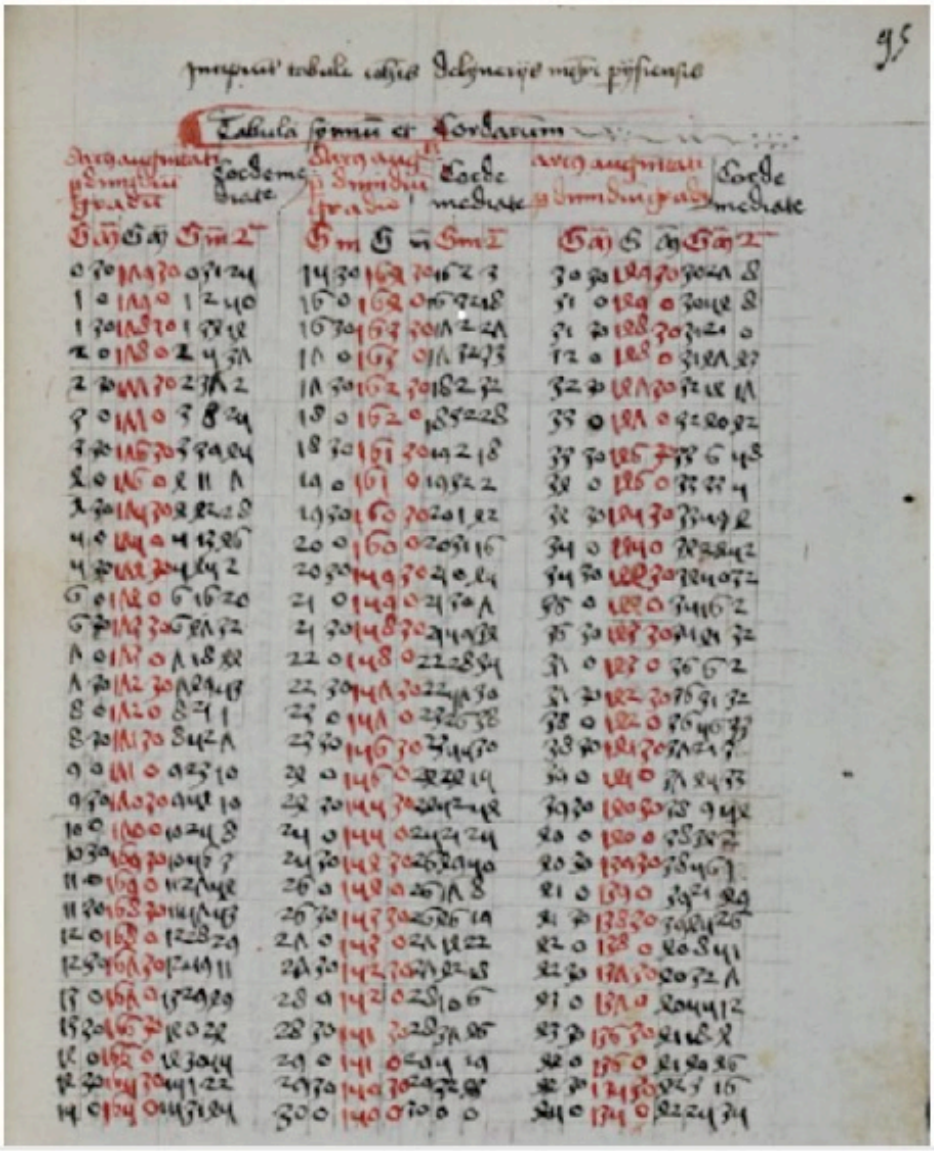
Professor Julius Bauschinger considered Alfred Wegener a suitable scholar to present the Alfonesine Tables in a way accessible to astronomers of the late 19th Century.

Professor Greene describes how Alfred Wegener went about his task, starting in September 1904. He examined six manuscripts to eliminate printer errors; translated the Medieval Latin into German; converted the sexagesimal tables into decimal tables, a task involving about 9,000 hand calculations. He provided extensive notes to explain how to use the tables, including worked examples; a detailed glossary of Medieval Latin technical terms for which there was no German equivalent; and diagrams to show how Ptolemic earth-centric ideas translated into heliocentric ideas.

The Alfonsine Tables were named after Alfonso X King of Castile, León and Galicia from 30 May 1252 until his death on 4 April 1284) who sponsored their creation. They provided data in the form of sexagesimal numbers for computing the position of the Sun, Moon and planets relative to the fixed stars. The positions of a planet are not given directly in the Alfonsine Tables as in modern tables, but the mean longitude is given for the epoch of the tables, which is the beginning of the Christian era (*radix incarnationis*), to which has to be added the change of mean longitude in the interval between the epoch and the time for which the position of the planet is required. It is this quantity, which the tables supplies. The interval elapsed since the epoch is not expressed in years and parts of a year, but in a The sexagesimal system. The unit of time is a day, which is divided into 60 minutes, and these again are divided into 60 seconds, and so on. On the other hand, the unit above a day is 60 days. The computer has therefore, first of all, to express the date

in this peculiar system, which is done by a small auxiliary table, so that additional work is hereby thrown on his shoulders. But, on the other hand, the use of the sexagesimal system reduces the number of tables required for the mean longitude of each planet to one, if only we change the name of the tabular quantity each time. (In the same way we only want one table for converting hours, minutes, and seconds into arc, or vice versa.) This reduced the work of copying a set of tables a good deal, and in the days before the invention of printing, this was an advantage worth considering. It is most likely that the introduction of the sexagesimal system was simply made in imitation of Ptolemy, who had also divided the day into sixty minutes. This account is based on Dreyer (1920).





Appendix B

Euler's rotation theorem, also known as Euler's point theorem and Euler's fixed point theorem

Euler's rotation theorem describes the motion of rigid bodies on the surface of a sphere. Considering the Earth a sphere, the movement of the rigid geological structures of which the Earth's lithosphere is composed can be thought of as movements of rigid elements of the surface of a sphere. The genius mathematician, Leonard Euler (1707 – 1783), examined this purely mathematical idea in 1776. He proved that the displacement of a rigid element on the surface of a sphere is equivalent to a rotation of that element around a suitable axis that passes through the centre of that sphere. That is to say, a rigid element on the surface of a sphere can be moved anywhere else on that sphere by a single rotation around a given axis. Applied to the lithosphere, Euler's rotation theorem means that all plate motions can be described by a rotation axis, which passes through the centre of the Earth and cuts the surface at two points, called the poles of rotation. The relative motion of two plates then needs a pole of rotation and an angular velocity to be defined. It means that the land masses could move on the surface of the Earth by a single rotation by a properly chosen axis. Euler's theorem meant that the composition of two rotations could be expressed as a single rotation about an axis known as the Euler axis.

According to Professor Frankel (Vol II Section 5.16 **Attempts at paleogeographies by Newcastle and Canberra groups**), in 1958, Creer, Irving, Nairne and Runcorn (1958) were the first to consider the possible movement of the continents by means of the geometry of a spherical surface and apply Euler's point theorem to solve the problem of continental reconstructions. Professor Frankel attributes the application of Euler's theorem in this way to Dr. Irving, at the time a Research Fellow in the Department of Geophysics at the Australian National University

Creer et al. (1958) reported[26]

> *The problem of continental reconstructions is clarified by considering the geometry of a spherical surface. A displacement of a continent to any other position on the Earth's surface may be obtained by a finite rotation about a fixed pole on the Earth's surface, which is convenient to call a pivot point. It is required to determine what relative continental displacements have to be assumed to satisfy the palaeomagnetic data…*
>
> *If pole positions for any two continents are available for more than one geological epoch, then a set of pivot points can be found; one for each pair of poles of the same age. In general, they will not coincide. If no relative movement between the continents has taken place between the earliest and latest geological periods under discussion, then the loci of the pivot points for the separate periods should all intersect in one point. In this case, continental drift took place since the latest geological period, by rotation of one continent with respect to the other about this point.*

[26] Frankel, Vol II pp 252 – 253; op. cit. page 1.

The chronology after this is:

> Backus (1964). Dr. Backus refers to the work of Dr. Irving and the paper by Sir Edward Bullard et al, in preparation at the time Dr. Backus wrote his short Letter to *Nature*, published on 8 February, 1964.
>
> Bullard, Everett, and Smith (1965).
>
> Morgan (1967), (1968).
>
> McKenzie and Parker (1967). Professor Frankel quotes Dr. McKenzie explaining that Dr. Backus told him about Euler's theorem over morning tea at Department of Geodesy and Geophysics, Cambridge University.[27]
>
> Le Pichon (1968).

According to Bullard et al. (1965):

> *A contour line at the edge of a continent can be defined by the latitudes and longitudes of a set of points along it, spaced at small enough intervals for the form of the contour to be interpolated between them. If the two contours on opposite sides of an ocean are defined in this way, one may be considered to be moved over the surface of the Earth until it fits as well as may be to the other. By the fixed point theorem, usually called Euler's theorem in this application, any displacement of a spherical surface over itself leaves one point fixed; that is any displacement of a contour line or of a continent may be considered as a rigid rotation about a vertical axis through some point on the surface of the Earth. We call this point the 'centre of rotation'. The problem is to find its latitude and longitude and the rotation about it that gives as good a fit as possible between the two contour lines.*

Professor Frankel confirmed that Dr. James Everett did not know of Euler's theorem at the time he was a junior scientist working with Sir Edward Bullard on the Bullard, Everett and Smith paper of 1965. Dr. Everett developed an equivalent method to calculate the movement of continents on the spherical Earth. Sir Edward Bullard explained to him that he was using Euler's theorem when he, Dr. Everett, discussed his work with Sir Edward.[28]

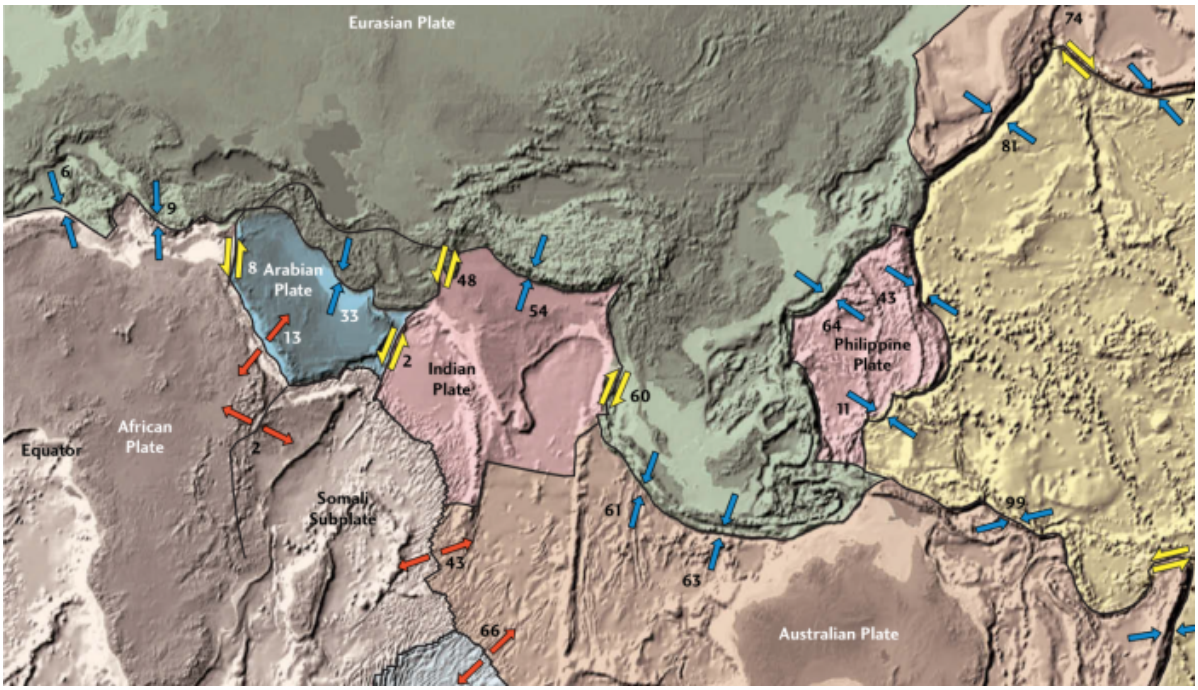
[27] Frankel, Vol IV p 510; op. cit. page 1.

[28] Frankel, Vol IV pp 170 – 186; op. cit. page 1.

Appendix C

Plate Tectonics

This shows the plates of the landmasses including those under the oceans and their boundaries.

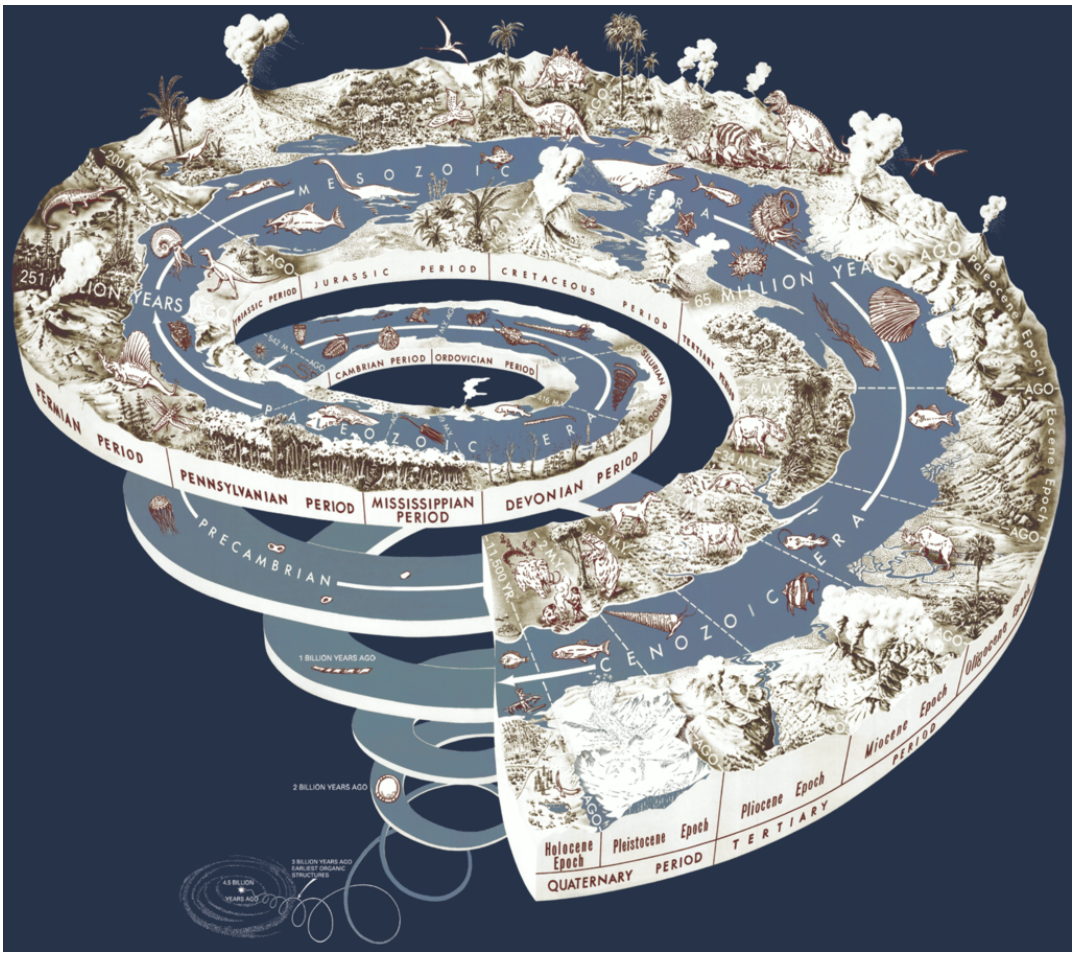


Credit: Grotzinger and Jordan (2014). *Understanding Earth*. [Plate boundaries by Peter Bird, UCLA]
Tectonics and Structural Geology | Meeting Plate Tectonics (egu.eu)

Appendix D

The geologic time spiral—A path to the past

Geologists have evidence that the formation of the continent into one landmass followed by dispersal into several is cyclical. This means that the process identifed a continental drift in which the unitary landmass of Pangea becomes the continental landmasses of today has occurred several times in the planet's 4.5 billion year history. This diagram shows the spiral of landmass development over the 4.5 billion years.



By United States Geological Survey - Graham, Joseph, Newman, William, and Stacy, John, 2008, The geologic time spiral—A path to the past (ver. 1.1): U.S. Geological Survey General Information Product 58, poster, 1 sheet. Available online at http://pubs.usgs.gov/gip/2008/58/, Public Domain, https://commons.wikimedia.org/w/index.php?curid=5597404

Appendix E

Professor Watkins' Letter

L. W. Morley and Sea-Floor Spreading

I have been asked by several geologists for details about the **Saturday Review** article to which I referred in my recent review of Anthony Hallam's book (**Geology**, v. 1, no. 4, 1973, p. 162). A series of articles were included in the magazine under the general heading "Canada's Unappreciated Role as Scientific Innovator." These were written by John Lear, J. Tuzo Wilson, E. T. Degens and D. A. Ross, and Dyson Rose and John Marier. The issue was that of September 2, 1967, p. 45–57.

I recommend the reading of these articles to earth scientists, if only for the partial reproduction (on p. 47 and 48) of L. W. Morley's paper on the interpretation of linear magnetic anomalies, polarity reversals, and his suggested 3- to 5-cm yr^{-1} separation rate for mid-oceanic ridges. Submitted for publication twice in early 1963, and rejected on both occasions because (in one reviewer's opinion), "Such speculation makes interesting talk at cocktail parties, but is not the sort of thing that ought to be published under serious scientific aegis," the manuscript certainly has substantial historical interest, ranking as probably the most significant paper in the earth sciences to ever be denied publication.

N. D. Watkins
Graduate School of Oceanography
University of Rhode Island
Kingston, Rhode Island 02881

Appendix F

Tunnel vision in science

Professor Frankel found that tunnel vision, the capacity to look only at one's area of academic study and nothing else, was one of the social dynamics that kept the theory of continental drift in the backwaters of science for about 50 years. Tunnel vision is the obsession with a scientist's singular field coupled with the inability to find merit in anything outside that field.

Frankel (2012): *The Continental Drift Controversy* (4 volumes), Vol. I, *Wegener and the Early Debate* page 550; Cambridge University Press; 2012.

References

Backus, George (1964) *Magnetic anomalies over oceanic ridges* Nature Vol 201 pp 591-592 (published on 8 February, 1964).

Bostrom, R C (2000) *Tectonic consequences of the Earth's rotation*; Oxford University Press

Bullard, Edward, Everett, J E and Smith, A G (1965) *The fit of the continents around the Atlantic*; Philosophical Transactions of the Royal Society of London. Series A, Mathematical and Physical Sciences Vol 258, pp 41–51 (Manuscript received 23/11/1964)

Cazenave, Anny *et al* (2023) *A 6-year cycle in the Earth system*; Global and Planetary Change Vol 229, October 2023, 104245 (A 6-year cycle in the Earth system - ScienceDirect).

Cohen, Paul J (1966) *Set Theory and the Continuum Hypothesis*; Published by W. A. Benjamin, Inc., New York

Cotton, W.R., and Pielke, R. A., (2007) *Human Impacts on Weather and Climate*, 2nd Edition. Cambridge Univ. Press.

Cox, A., (1973). *PIate Tectonics and Geomagnetic Reversals*. Freeman, San Francisco, Calif., 702 pp.

Creer, K.M., Irving, E., Nairn, A.E.M., and Runcorn, S.K. (1958). *Palaeomagnetic results from different continents and their relation to the problem of continental drift*. Annales de Géophysique, 14: 492–501.

Dreyer (1920) *On the Original Form of the Alfonsine Tables*. Monthly Notices of the Royal Astronomical Society, Volume 80, Issue 3, January 1920, Pages 243–262, https://doi.org/10.1093/mnras/80.3.243a Published: 09 January 1920

Dunbar, C.O. and Waage, K.M., 1969, *Historical Geology* 3rd edition: NY, John Wiley and Sons, 556 p.

Frankel, H R (2012)*The Continental Drift Controversy* (4 volumes), Cambridge University Press; 2012; Vol. I, *Wegener and the Early Debate*; xvii + 604 pp.; Vol. II, *Paleomagnetic Support for Shifting Continents*, xviii + 525 pp.; Vol. III, *Initiation of Seafloor Spreading*; xvi + 476 pp.; Vol. IV, *Evolution into Plate Tectonics*.; xix + 675 pp.; ISBN 978- 0 -521- 875-9

Feynman, Richard (1965) *The Character of Physical Law with new forward by Frank Wilczek* MIT Press, 2017

Grotzinger, J. and Jordan, T (2014) *Understanding Earth. Seventh Edition* W.H. Freeman and Company, a Macmillan Higher Education Company, New York.

Greene, Mott T (2015) *Alfred Wegener: Science, Exploration, and the Theory of Continental Drift*. Baltimore: Johns Hopkins University Press.

Hausfather, Zeke et al (2022) *Climate simulations: recognize the 'hot model' problem* Nature Vol 605 5 May 2022 pp 26 to 29

Isacks, B, Oliver, J and Sykes, L (1968) *Seismology and the New Global Tectonics*; Journal of Geophysical Research, Vol 75, No 18 pp 5855 to 5899, September 15, 1968

IPCC (1998) Intergovernmental Panel on Climate Change - *Principles Governing IPCC Work* ANNEX 7 (ipcc.ch)

Jeffreys, H (1924), *The Earth: Its Origin, History, and Physical Constitution*; Cambridge University Press; 5th edn. 1970; 6th edn. 1976

Joffe, Josef (2019) *The Religion of Climatism A new faith emerges*; Commentary Magazine November 2019 Media; The Religion of Climatism - Josef Joffe, Commentary Magazine

Kay, Marshall (ed) (1967) *North Atlantic—Geology and Continental Drift; The Gander Conference, an International Conference of the American Association of Petroleum Geologists on Stratigraphy and Structure* held in August 1967 and published on January 01, 1969 as the American Association of Petroleum Geologists Memoir Vol 12 DOI: https://doi.org/10.1306/M12367;

ISBN electronic: 9781629812274; ISBN print: 0891812873 North Atlantic—Geology and Continental Drift | GeoScienceWorld Books | GeoScienceWorld

Kilifarska, Natalya (2021) *Impact of Decadal Variations of Galactic Cosmic Rays on Earth's Climate Variability*; *Bulgarian Journal of Physics* vol 48 no 1, pp 004-013 (Bulgarian Journal of Physics (bjp-bg.com))

Kilifarska, N.A., Bakmutov, V.G. and Melnyk, G.V., (2020) *The hidden link between Earth's magnetic field and climate*. Elsevier

Koutsoyiannis, D, and Kundzewicz, Z, (2020) *Atmospheric Temperature and CO2: Hen-Or-Egg Causality?* Sci MDPI, Vol 2, No 83 Special Issue Feature Papers 2020 Editors' Collection Edited by Prof. Dr. Claus Jacob

Koutsoyiannis, D, Onof, C, Christofidis, A and Kundzewicz, Z, (2022a) *Revisiting causality using stochastics: 1. Theory* Proceedings of the Royal Society A~Mathematical, Physical and Engineering Sciences; Vol 478, Issue 2261; 25 May 2022

Koutsoyiannis, D, Onof, C, Christofidis, A and Kundzewicz, Z, (2022b) *Revisiting causality using stochastics: 2. Applications*; Proceedings of the Royal Society A~Mathematical, Physical and Engineering Sciences; Vol 478, Issue 2261; 25 May 2022

Krill, Allan (2009, 2011, 2014) *Not Getting the Drift - A Hard Look at the Early History of Plate-Tectonic Ideas* (which he has also named *Fixists vs. Mobilists*) Microsoft Word - 20110227.doc (ntnu.no) and Microsoft Word - krilldrift1.docx (ntnu.no); published on-line in 2009 and updated in 2011 and 2014.

Le Pichon, Xavier (1968) *Sea-Floor Spreading and Continental Drift*, Journal of Geophysics Research Vol 73, pp 3661-3697; June 15, 1968

Le Pichon, Xavier (1991) *Introduction to the publication of the extended outline of Jason Morgan's April 17, 1967 American Geophysical Union Paper on "Rises, Trenches, Great Faults and Crustal Blocks* Tectonophysics, Vol 187 pp l-22 (PII: 0040-1951(91)90407-J (sciencedirectassets.com)

Le Pichon, Xavier. (2019). *Fifty years of plate tectonics: afterthoughts of a witness*; Tectonics, 38, 2919–2933, https://doi.org/10.1029/2018TC005350 Received 1 OCT 2018 Accepted 23 APR 2019 Accepted article online 16 JUL 2019 Published online 14 AUG 2019

Longwell, C. R, and Flint, R.F., and Sanders, J.E., (1969), *Physical geology*: New York, John Wiley and Sons, 685 p

Macdonald, G J (2003) *How mobile is the earth?*. In: Oreski N (ed). *Plate Tectonics*. Westview Press: Boulder, CO, 2003 pp 111–127

Mackey, R., (2007). *Rhodes Fairbridge and the idea that the solar system regulates the Earth's climate*. *Journal of Coastal Research, Special Issue 50 (Proceedings of the 9th International Coastal Symposium)*, 955 – 968. Gold Coast, Australia. Available here: (PDF) Rhodes Fairbridge and the idea that the solar system regulates the Earth's climate (researchgate.net)

Mackey, R (2023) *The Earth's Decadal Rotation and Climate Change*, Science of Climate Change, Vol 3.2, 119-172. https://doi.org/10.53234/SCC202304/06

McKenzie, D., Parker, R. (1967) *The North Pacific: an Example of Tectonics on a Sphere*. Nature Vol 216, pp1276–1280 (30 December 1967). https://doi.org/10.1038/2161276a0

Menard, H.W., (1986) *The Ocean of Truth, a Personal History of Global Tectonics*. Princeton University Press, Princeton, N.J., 352 pp.

Merrill, R. C. (2010) *Our Magnetic Earth* The University of Chicago Press.

Morgan, W.J. (1968) *Rises, trenches, great faults, and crustal blocks*; J. Geophysical Research, Vol 73, No. 6 pp 1959 to 1982, March 15, 1968.

Munshi, Jamal, (2018) *Circular Reasoning in Climate Change Research* (February 26, 2018). Available at SSRN:https://ssrn.com/abstract=3130131 or http://dx.doi.org/10.2139/ssrn.3130131

National Academy of Sciences (2009): National Academy of Sciences, National Academy of Engineering (US) and Institute of Medicine (US) Committee on Science, Engineering, and Public Policy. *On Being a Scientist: A Guide to Responsible Conduct in Research: Third Edition*. Washington (DC): National Academies Press (US); 2009. Research Misconduct. Available from: https://www.ncbi.nlm.nih.gov/books/NBK214564. See also *Federal Policy on Research Misconduct* Office of Science and Technology Policy | ORI - The Office of Research Integrity (hhs.gov)

Newman, Robert P (1995) *American Intransigence: the rejection of continental drift in the great debates of the 1920s*; Earth Sciences History Vol 14, No 1, pp 62 – 83

OECD Secretariat (2022) *Integrity and Security in the Global Research Ecosystem*; OECD Science, Technology and Industry Policy Papers June 2022 No. 130; Authorised by the OECD Committee on Scientific and Technological Policy on 15/05/2022

Otto, Alexander; Otto Friederike E L; Boucher, Olivier; Church, John; Heger, Gabi; Forster, Piers M; Gillett, Bathan P; Gregory, Johnathan; Gregory, Johnson, C; Knutt, Reto; Lewis, Nicholas, Lohmann, Ulrike; Marotzke, Jochem; Myhre, Gunnar; Shindell, Drew; Stevens, Bjorn; and Allen, Myles R (2013) *Energy budget constraints on climate response* Nature Geoscience Vol6 June 2013 pages 415 & 416

Paluš, Milan, and Novotná, Dagmar (2009) *Phase-coherent oscillatory modes in solar and geomagnetic activity and climate variability*; Journal of Atmospheric and Solar-Terrestrial Physics, Vol 71, Issues 8–9, pp 923-930, https://doi.org/10.1016/j.jastp.2009.03.012.

Pindyck, Robert S (2015) *The use and misuse of models for climate policy* NBER Working Paper Series; Working Paper No 21097 April 2015 JEL No D81, Q51, Q54 National Bureau of Economic Research USA

Po-Chedley, Stephen, Santer, Benjamin D, Fueglistaler, Stephan, Zelinka, Mark D, Cameron-Smith, Philip J, Painter, Jeffrey F, and Qiang Fu (2021) *Natural variability contributes to model–satellite differences in tropical tropospheric warming* Proceedings of the National Academy of Sciences of the United States of America (PNAS) 2021 Vol 118 No 13

Rial, J A et al (2004) *Nonlinearities, Feedbacks and critical thresholds within the Earth's climate system* Climatic Change Vol 65, pp 11–38

Scafetta, Nicola (2023) *Empirical assessment of the role of the Sun in climate change using balanced multi-proxy solar records*; Geoscience Frontiers Vol 14, Issue 6, November 2023, 101650

Schmidt, Gavin A, Shindell, Drew T and Tsigaridis, Kostas (2014) *Reconciling warming trends* Nature Geoscience Vol 7 March 2014

Sidorenkov, N. (2009) *The Interaction Between Earth's Rotation and Geophysical Processes* Wiley VCH, p 247

Spencer, Roy W (2012) *The Great Global Warming Blunder: How Mother Nature Fooled the World's Top Climate Scientists*. Encounter Books, United States of America.

Steiner, A K et al (2020) *Observed Temperature Changes in the Troposphere and Stratosphere from 1979 to 2018* Journal of Climate Vol 33 1 October 2020 pp 8165–8194

Thorne, Peter W, Lanzante, John R, Peterson, Thomas C, Seidel, Dian and Shine, Keith P, (2010) *Tropospheric temperature trends~history of an ongoing controversy* Wiley Interdisciplinary Reviews (WIREs): Climate Change 2010

Tobias, S. M. and Weiss, N. O., 2000. *Resonant Interactions between Solar Activity and Climate*. Journal of Climate, 13, 3745 – 3759.

Tsonis, A A et al (2007) *A new dynamical mechanism for major climate shifts*; Geophysical Research Letters Vol 34, L13705

UNFCC (1992) United Nations Framework Convention on Climate Change (1992) conveng.pdf (unfccc.int)

Vine, F and Matthews, D (1963) *Magnetic Anomalies Over Oceanic Ridges*; Nature Vol 199, pp 947–949 (1963); https://doi.org/10.1038/199947a0

Watkins, N D (1974) *L W Morley and sea floor spreading* LETTERS; Geology Vol 2, No 4 p 170, April, 1974.

Wegener, Alfred (1922) *The Origin of Continents and Oceans*. Translated from the Third German Edition by J. G. A. Skerl, New York, 1924, E. P. Dutton and Co.

Wielen, Roland and Ute Wielen, Ute (2017) *Alfred Wegener and the Astronomisches Rechen-Institut. With an application of his converted Alfonsine Tables to the 'Astronomischer Kalender' for 1448*. Astronomisches Rechen-Institut Zentrum für Astronomie Universität Heidelberg Heidelberg 2017. See also: New book: Alfred Wegener and the Astronomisches Rechen-Institut: Zentrum für Astronomie (uni-heidelberg.de) and Wegener.pdf (uni-heidelberg.de)

Willis, B. (1944). *Continental drift, ein Maerchen*; American Journal of Science, *242*(9), 509–513. https://doi.org/10.2475/ajs.242.9.509 Continental Drift, Ein Maerchen | Published in American Journal of Science (scholasticahq.com). NB: "ein Maerchen" is German for "a fairy tale".

Winston, Andrew S and Blais, Daniel J (1996) *What Counts as an Experiment?: A Transdisciplinary Analysis of Textbooks, 1930-1970*; The American Journal of Psychology, Vol. 109, No. 4 (Winter, 1996), pp. 599-616 (18 pages) https://doi.org/10.2307/1423397

Yndestad, Harald; Turrell, William R; Ozhigin, Vladimir (2008) *Lunar nodal tide effects on variability of sea level, temperature, and salinity in the Faroe-Shetland Channel and the Barents Sea. Deep Sea Research Part I* Oceanographic Research Papers 2008; Volum 55.(10) s.1201-1217

Yndestad, Harald (2009) *The influence of long tides on ecosystem dynamics in the Barents Sea. Deep-sea research. Part II*, Topical studies in oceanography 2009 ; Volume 56.(21-22) s.2108-2116

Youschkevitch, A P (1976) *The Concept of Function up to the Middle of the 19th Century*; Archive for History of Exact Sciences, 27IX1976, Vol 16, No 1, pp 37-85

Zharkova, Valentina et al (2023) *Periodicities in Solar Activity, Solar Radiation and Their Links with Terrestrial Environment*; Natural Science, Vol 15, (No 3), pp: 111-147

OPEN ACCESS

Klimarealistene
P.O. Box 33,
3901 Porsgrunn
Norway
ISSN: 2703-9072

Correspondence:
eike.roth@chello.at

Vol. 3.5 (2023)

pp. 521-542

Climate: Man or Nature?

A Contribution to the Discussion

Eike Roth

Klagenfurt, Austria

Abstract

From a purely logical perspective, humans can only be the main cause of the ongoing warming if two preconditions are met: CO_2 must have a strong climate impact and the large amount of CO_2 in the atmosphere must primarily be anthropogenic. However, the fulfillment of both preconditions is scientifically controversial.

Controversy regarding the strength of the climate impact of CO_2 stems primarily from this being a quantitative question with many uncertain assumptions that everyone makes differently. This leads to results and consequences ranging from "harmlessly small" to "catastrophically large". A resolution of this dissent is not in sight.

Controversy regarding the primary origin of CO_2 is less about quantitative aspects but more about the fundamental assessment of the behavior of CO_2.

In this paper, an assessment of the behavior of CO_2 is made, based on elementary physical quantities and principles. Different viewpoints are taken into consideration, but results stay the same: The increase in atmospheric CO_2 is most likely predominantly due to increased emissions from natural sources with only a minor contribution from anthropogenic emissions. The popular thesis "It's all man-made" is challenged and a careful review is urgently required.

If the predominantly natural origin of the large amount of CO_2 is confirmed, then there are logically only two possibilities left: Either climate is primarily dependent on CO_2, then it is primarily dependent on natural CO_2. Or, other climate influences predominate, then CO_2 only plays a minor role, regardless of its origin. In both cases, nature is stronger than man and it makes no sense to reduce or even stop anthropogenic CO_2 emissions for climate protection reasons! We could concentrate on more urgent tasks. That is why the question of the origin of all the CO_2 is so important. The intention of this paper is to contribute to an in-depth discussion.

Keywords: Carbon cycle; global warming; CO_2-budget; CO_2 residence time; anthropogenic emissions.

Submitted: 2023-12-15, Accepted 2023-12-31 https://doi.org/10.53234/scc202310/40

1. Introduction

Climate has always changed, and it will continue to do so. Nowadays, temperatures are rising again. This climate change differs from previous ones in that this time humankind could be the cause through its CO_2 releases. Whether this is the case is examined in this paper.

For this purpose, Fig. 1 shows the development of the CO_2 concentration in the atmosphere and the globally averaged air temperature close to the ground from 1880 to the present day. The scales are chosen so that the curves can be compared as easily as possible. Superficially, there seems to be a relatively good agreement, which might justify a cause/effect relationship (CO_2 determines the temperature - or vice versa?). In detail, however, there are also considerable deviations, which rather speak against such a relationship. The roughly similar course of the curves could also just be a coincidence (or the result of a completely different common cause). What applies? This paper attempts to clarify the issue.

But prior to that an important comment on the CO_2 concentration in Fig. 1 is necessary: This figure shows the "usual" CO_2 curve, as it can be found in almost all publications on the climate

problem, with a continuous increase since 1880 (and before that, not shown here, a constant value of approx. 280 ppm for thousands of years). However, the course of this curve is largely undisputed only from 1958 onwards, when a new spectroscopic measurement method with considerably improved accuracy was introduced. Prior to that there is controversy: In this period, the curve shown in Fig. 1 is based exclusively on proxy data, particularly reconstructions from ice cores. Direct measurements using chemical methods, which show a completely different picture, are not considered. Among others, Beck (2022) analyzed almost 100000 individual measurements in detail and found strong fluctuations, with values in the 19th century and around 1940 similarly high as today. Engelbeen (2023) criticizes this evaluation as erroneous and cherry-picking, Harde (2023) confirms particularly the high values around 1940, and Fiedler (2023) shows that around the midst of the 19th century values around 400 ppm were the generally accepted state of knowledge. An end of the controversy is not in sight. This paper conservatively uses the "usual" curve as shown in Fig. 1. However, it should be explicitly pointed out that if the chemical measurements of that time were more accurate than the reconstructions from proxy data, the climate problem would differ strongly.

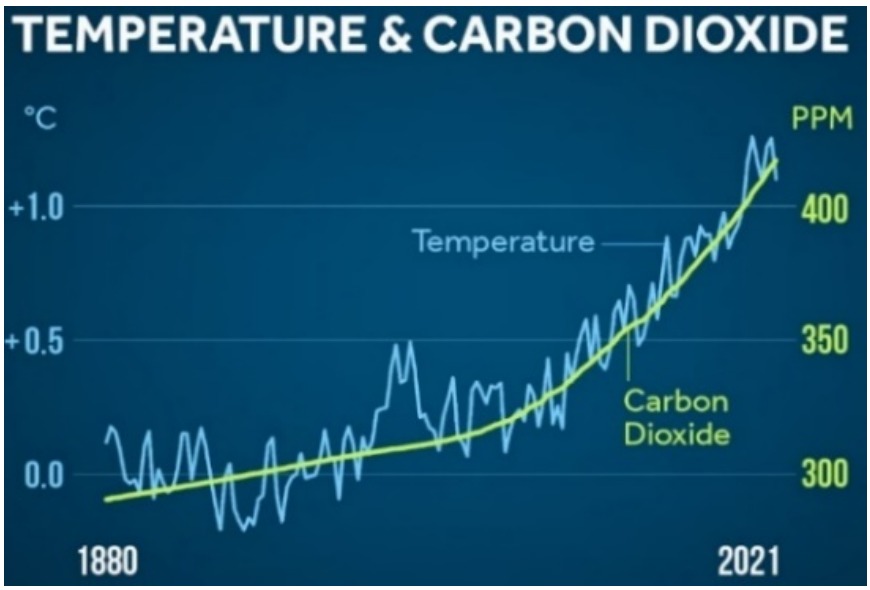


Fig. 1: CO_2 and temperature in the atmosphere from 1880 to 2021:Green: CO_2 concentration in parts per million (ppm), blue: Globally averaged air temperature near the ground in °C (anomalies to the initial value, more precisely to the average of the years 1881-1910). Source: Climate Central, Climate Matters, May 4, 2022, "Peak CO_2 & Heat Trapping Emissions".

Since the start of the Industrial Revolution, *three changes* have undeniably taken place:

- Humans have started to release *large amounts* of CO_2.
- The concentration of CO_2 in the atmosphere has *increased significantly*.
- The temperature has *increased* by a little more than 1 °C.

Thank God, some say, because in their opinion life has become much more comfortable as a result of warming, and because the global food supply has been improved substantially, not least due to the large amount of CO_2 in the atmosphere ("CO_2 fertilization", e. g. Scinexx 2016; Zhu et al. 2016).

Bad, say others, because they think they can already see more extreme weather events and they expect truly catastrophic climate changes in the future if we don't completely stop our CO_2 emissions as soon as possible ("net zero").

These different opinions are only mentioned here because they contribute to the overall picture of "scientifically open ", but they will not be discussed further. Rather, the central topic here is the

elementary question of the entire climate discussion: What is the definitive cause of the warming that has already occurred and could possibly still be expected? **Is it mankind, or rather nature?**

Commonly, this is regarded to have been clarified at length: it is clearly mankind with its CO_2 releases, so they say. Of these releases, half would remain in the atmosphere long-term, increasing the concentration and, consequently, the temperature. However, this can only be true if two *essential preconditions* are met:

- First: CO_2 must have a *strong impact* on climate!
- Second: The large amount of CO_2 in the atmosphere must have been *released by humankind!*

Even if only one of these two preconditions is not met, humankind cannot be predominantly responsible for the climate! Are they met or not? Contrary to popular belief, this is *scientifically open* in both cases! If one takes a closer look, dissent exists and is plausible in many cases.

Regarding the climate impact of CO_2, there is a very large and constantly growing number of scientific papers that only attribute a minor role to CO_2 in climate events. Instead, other influences would be more significant. The sun is typically cited for this, but often also internal variabilities and other factors are quoted.

In the opinion of the author of this paper, however, nothing has been decided yet, *the science is clearly at odds!* Only to the general public is it presented differently: the science is said to be settled, even though *science never really settles*. And in the case of the climate impact of CO_2, it gets increasingly difficult to hide the existing dissent, because of the increasing number of opposing statements. But it doesn't matter, whether this dispute is held publicly or only within the sciences. Because the question of "climate impact" of CO_2 is a very complex question that can only be answered with complicated calculations and on the basis of uncertain assumptions (e.g. about the effects of water vapor and clouds), a timely end to the dispute is uncertain. Opinions don't tell much (everyone has their own!), only time will tell which one is more correct. Only the existing dissent is certain!

Regarding the large amount of CO_2 in the atmosphere, the essence of the debate differs: Doubts about the anthropogenic origin are raised only rarely and have therefore only been discussed very little up to now. Publicly, this dissent almost does not exist at all, but in science, it clearly does exist (e.g. Andrews 2023; Andrews 2023A; Berry 2019; Berry 2021; Berry 2023; Berry 2023A; Harde 2019; Harde et al. 2021; Mueller 2023; Pollard 2022; Roth 2023; Salby et al. 2021A; Salby et al. 2021B; Schrijver 2022; Stallinga 2023). And because "skeptics" very well quote physically plausible arguments (see below), and because the subject is factually not quite as complex and untransparent as that of the climate impact of CO_2, an agreement is perhaps easier to achieve here. Only time will tell. In any case, this paper aims to make a contribution to an in-depth discussion.

2. The Origin of the Large Amount of CO_2 in the Atmosphere

To make the scientific dispute more understandable, the main reasons for the doubts about the anthropogenic origin of the large amount of CO_2 in the atmosphere should be explained and discussed in more detail:

2.1 Basics

2.1.1. Inert gas

CO_2 within the atmosphere behaves like an inert gas. Except for minimal amounts, no CO_2 is produced or lost in the atmosphere. The concentration in it therefore only ever changes according to the (momentary) difference between release and removal (each calculated as the sum of all sources, or, accordingly, all sinks): If more CO_2 is released into the atmosphere than is removed from it, the concentration rises precisely by the difference, if less is released than removed, concentration sinks precisely by the difference.

2.1.2. Removal increases with concentration

The removal of CO_2 from the atmosphere (number of molecules per second) principally increases with increasing concentration in it (and decreases with decreasing concentration) and it is generally independent of whether and how much CO_2 is released into the atmosphere simultaneously. That's just required by physics. (Caution: Often there is no clear distinction between "removal", which is the absolute number of CO_2 molecules removed per second, and "net removal", which only gives the difference to the CO_2 molecules released at the same time; unless otherwise stated, the “removal” is generally meant here in this paper).

2.1.3. Stabilization

As a result of item 2.1.2, whenever the release occurs at a constant value, the concentration adjusts itself to *that* level, where removal *is the same* as release. Then, there is equilibrium. Fig. 2 illustrates this.

That concentration adjusts itself to the value at which outflow equals inflow is not only required by physics (as a consequence of the removal increasing with concentration!), but it is probably also a necessary requirement for all life on earth: otherwise, there would probably not be a stable atmosphere, because CO_2 concentration would run away after the slightest disturbance! The self-stabilization of the atmosphere (decoupling of concentration from emissions via adjusting outflow to inflow) can therefore be regarded as sufficiently proven.

2.1.4. Historical data

Before the beginning of the industrial revolution, such a situation prevailed. Input and output were approximately 80 ppm/y and concentration settled at 280 ppm/y (e.g. IPCC 2021; ppm = parts per million, 280 ppm are 0.028%).

Since then, anthropogenic releases have been added. These have grown from initially very low values up to about 5 ppm/y today (this is about 5% of natural releases; Fig. 4). In this period, concentration has increased to about 420 ppm (e.g. IPCC 2021).

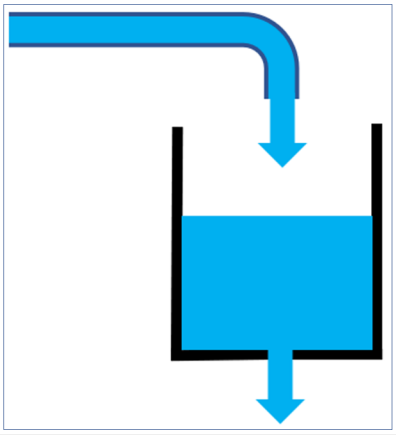


Fig. 2: For illustration: In a water tank with inflow from above and outflow through a hole in the bottom, the water level always adjusts itself to the one value, where outflow equals inflow. And the atmosphere behaves analogous: The CO_2-concentration adjusts itself to the one value, where outflow equals inflow.

2.1.5. Interim findings

Items 2.1.1 to 2.1.4 appear to be clearly correct and are probably not seriously questioned. However, it follows logically mandatory from item 2.1.3 that a reduction of anthropogenic releases to *zero is not necessary*. Not necessary, because, if anthropogenic releases are frozen at a fixed value (e. g. today's), concentration tends towards a stable value, that value, where outflow equals inflow. This is correct at least, when only anthropogenic releases are responsible for the

increase in concentration, as the IPCC assumes. This state would be stationary and theoretically it could be maintained indefinitely without concentration (and potentially also temperature) continuing to rise, despite ongoing releases.

However, this poses serious consequences: IPCC claims that a "fixed CO_2 budget" exists, which is „the maximum amount of cumulative net global anthropogenic CO_2 emissions that would result in limiting global warming to a given level" (IPCC 2021, Glossary). The "fixed CO_2 budget" is often used as the basis for far-reaching assessments and decisions in the field of climate protection. But due to the described effect of self-stabilization of the atmosphere, **a "fixed CO_2 budget" cannot exist**, and all these assessments and decisions lack justification.

This result alone *sets the entire climate problem in a completely different light:* supposedly reliable findings suddenly hang in the air without any justification!

2.2 Core arguments

2.2.1. All molecules are the same

Because all CO_2 molecules *are the same* regardless of their origin, they must all *behave the same way*. And because removal of CO_2 from the atmosphere does not remain constant, but increases with increasing concentration (item 2.1.2), all sources contribute to the concentration according to their respective strength of releases. If the anthropogenic releases account for only about 5% of natural releases (item 2.1.4), then they can only have increased the concentration by about 5% (at equilibrium, less before; but see also section 2.4). *There can be no disproportionately higher contribution from any source!*

2.2.2. Increased releases from natural sources

In reality, concentration has increased by 50%, from 280 ppm in the past to 420 ppm today. In order to reach and maintain this value, the total releases into the atmosphere *must have increased by 50% too!* This means that releases from natural sources must have increased *almost 10 times* more than anthropogenic releases have been added! If natural releases were constant and anthropogenic releases increased the way they have, concentration wouldn't even have reached 300 ppm. For possible sources of increased natural releases, see section 2.4.

The same result of a significantly increased release from natural sources can also be obtained by a slightly different approach: The concentration in the atmosphere (the only value that is really *measured!*) can be used to calculate the level of removal (see below). From the change in the concentration, then it can be calculated which release must have taken place simultaneously, so that the concentration could have developed in exactly the way it did. In detail:

The rules of physics not only require that gross removal (not net removal!) of CO_2 from the atmosphere *depends on the concentration* in the atmosphere (item 2.1.2), but they also make it possible to *quantify the amount* of removal: Because removal takes place primarily via diffusion processes, in principle it must be *proportional* to the absolute concentration. In reality, however, this is probably only an approximation, because only "primarily" diffusion processes work (counterexample: CO_2 removal from the atmosphere through rain, but this could also be approximately proportional to the concentration), and because even in diffusion processes other influences may have some influence.

So, for example, in the case of biomass as a sink, the growth of plants not only depends on CO_2 concentration in the atmosphere (photosynthesis is executed via diffusion processes!), but also on the availability of water and nutrients. However, since plants grow well where they have enough water and nutrients (and therefore also remove a lot of CO_2 from the atmosphere there!), and since they also need less water when the CO_2 concentration is high (because their evaporation losses are smaller as a result of narrowed stomata), this dependency on availability of water and nutrients should not result in a major deviation from proportionality in the real world. Furthermore, proportionality to concentration probably also applies where other parameters already exert some influence, if these other parameters are kept constant. In addition, it must also be taken into account that the biomass has *significantly increased* (Scinexx 2016; Zhu et al. 2016), and therefore

it also removes more CO_2 (and then inevitably it returns more CO_2 too). Regarding biomass, proportionality should therefore be at least a reasonable approximation.

The situation is similar with the second major sink, the ocean: In principle, the number of CO_2 molecules that go into solution per second is proportional to the concentration in the atmosphere (diffusion process!), but because of chemical transformations of the dissolved CO_2 this is valid only approximately in this case too: most of the CO_2 dissolved is converted into carbonate and bicarbonate, which do not contribute to the CO_2 partial pressure (the so-called "Revelle effect"). If the ratio between these chemical forms were constant, it would not have any further influence on the proportionality. But in reality, it is not constant, rather it changes slightly with concentration. Therefore, the proportionality between concentration and removal is only approximate for the ocean too. (To clarify: the Revelle effect has a very significant influence on the *amount* of carbon that is stored in the ocean water (in different chemical forms), but it only slightly influences the proportionality of the *CO_2 exchange rate* to the concentration, which is what matters here).

At least approximate proportionality therefore applies to *both* sinks, the removal by dissolution in ocean water and by photosynthesis in plants. But the question here is not proportionality per se, but rather whether the 5% anthropogenic releases alone are sufficient to increase the concentration by 50%, or whether considerable *additional sources* are required for this. And because both sinks are so strong, it is clearly sufficient for the latter if even only one of the two sinks is approximately proportional. However, since these two processes are physically completely different, and since they occur independently of one another (the only interconnection between the two is the atmosphere as a part of both processes), there must be a substantial error in *both* assessments for the releases from natural sources to have remained constant or increased only slightly, which is extremely unlikely. In any case, a deviation large enough to fully compensate for the above-mentioned factor of 10 is hardly imaginable. If no physical process can be defined that explains a significantly disproportionate effect of the anthropogenic releases under realistic conditions, significantly increased releases from natural sources are *logically mandatory* (see also section 2.4)!

2.2.3. Interim findings

Items 2.2.1 and 2.2.2 show very clearly the **necessity of significantly increased releases** from natural sources in order to explain the high concentration observed in the atmosphere. Therefore, almost certainly, *the climate problem is very different from how it is usually perceived!*

2.3 Supporting arguments

2.3.1. Continuously high increase

Another strong argument for significantly increased releases of CO_2 from natural sources (item 2.2.2) is the continuously high increase in the atmospheric concentration (Figs. 1 and 3). If the atmosphere were a closed reservoir with only anthropogenic releases as a connection to the outside, then these releases would remain in the atmosphere completely, and the concentration would correspondingly increase faster than observed (and it would also, contrary to item 2.1.5, continue to increase as long as there are anthropogenic releases!). However, since the concentration is growing slower than would be expected as a direct result of the anthropogenic releases, CO_2 must be removed from the atmosphere. Thus, the atmosphere is not a closed reservoir! And because removal is greater the higher the concentration is (items 2.1.2 and 2.2.2), concentration cannot continually increase faster than releases increase! The additional supply of CO_2 would simply *not be sufficient* for that.

In more detail: In the last 60 years, concentration in the atmosphere has grown ever more rapidly. From year to year, it has grown a good 2 % faster than in the previous year: the slope has increased from approx. 0.7 ppm/y in 1960 to approx. 2.5 ppm/y in 2020 (Fig. 3). In contrast, the anthropogenic releases have grown considerably slower over a similar period. Their growth increased only under 1 % annually: the slope has increased from approx. 0.048 ppm/y in 1950 to approx. 0.085 ppm/y in 2010, and in the last decade, they have grown even slower (Fig. 4, note

the different scales)! Such *slowly growing* releases cannot explain the *much faster* growth of atmospheric concentration, as long as removal is concentration-dependent! The mass balance just wouldn't add up otherwise. And since no CO_2 is produced in the atmosphere (item 2.1.1), there must be *another source* emitting CO_2 into the atmosphere, which in turn is growing rapidly, even much faster than anthropogenic releases. Releases from natural sources must therefore not only *be larger* than anthropogenic releases (section 2.2), but they must also *grow faster* than them! The anthropogenic releases alone just *do not suffice*.

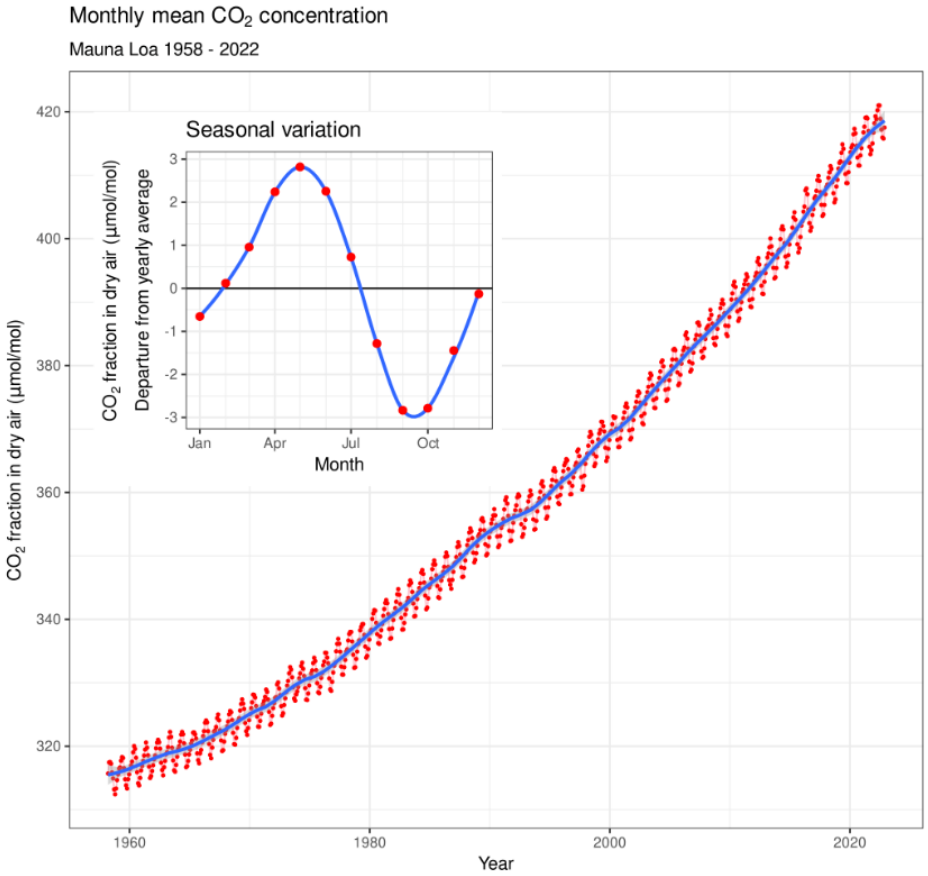


Fig. 3: Monthly CO_2 concentration, Mauna Loa, Hawaii, 1958-2022; Source: Wikipedia, Data: Dr. Pieter Tans, NOAA/ESRL (https://gml.noaa.gov/cogg/trends/) and Dr. Ralph Keeling, Scripps Institution of Oceanography (https://scrippsco2.uscd.edu). Accessed 2023-12-15 https://w.wiki/4ZWn.

This is often contradicted by arguing that the anthropogenic releases have been and are continuously *twice as large* as the CO_2 inventory in the atmosphere is growing, so they could very well be solely responsible for the increase. However, this argument overlooks the dependence of removal on concentration (item 2.1.2): Because removal increases with increasing concentration, *concentration cannot continuously rise faster* than releases rise, because the additional supply of CO_2 will not be sufficient. If concentration were to rise faster, **another source must contribute!**

2.3.2. Seasonal cycles

Another supporting observation are the seasonal cycles of concentration. These cycles are caused by seasonally fluctuating photosynthetic performance and decay of plants with significantly larger land areas in the northern hemisphere than in the southern hemisphere. Figure 3 shows the seasonal cycles superimposed on the long-term increase of concentration. The seasonal cycles show an amplitude of approximately 6 ppm. These cycles contradict the possibility that the increase in the concentration was caused by a limited capacity of the sinks, as the IPCC sees it

(IPCC assumes that the sinks can absorb only half the amount of anthropogenic releases). In reality, the sinks simply take CO_2, from wherever it had entered the atmosphere, and if they are offered more, then they take more! All sinks must *treat* each CO_2 molecule the same since all CO_2 molecules *are* the same, and therefore they *behave* the same! There can be no different treatment depending on the origin of the CO_2. Saturation of the sinks can be ruled out, because otherwise atmospheric concentration, which is increased every seasonal cycle, *could not be lowered again!* The overall greatly increased concentration is therefore probably not the result of small additional releases together with limited sinks (as IPCC sees it), but rather the result of greatly increased releases together with well-acting sinks!

Supplement: According to the IPCC, the sinks have been removing more and more CO_2 from the atmosphere over time: In addition to the previous (and according to the IPCC unchanged) 80 ppm/y (item 2.1.4) comes half of the anthropogenic releases. Today, this equals an additional removal of 2.5 ppm/y. Therefore, the IPCC attributes the sinks the potential to *easily take up that much*. Consequently, at least as long as anthropogenic releases still were below 2.5 ppm/y (until around 1970, Fig. 4), the concentration should only have increased *minimally* because the sinks were not yet saturated. However, even in those days' concentration increased *considerably* (Fig. 1), so the IPCC's view *cannot be correct.* The introduction of a much stronger source easily solves the problem.

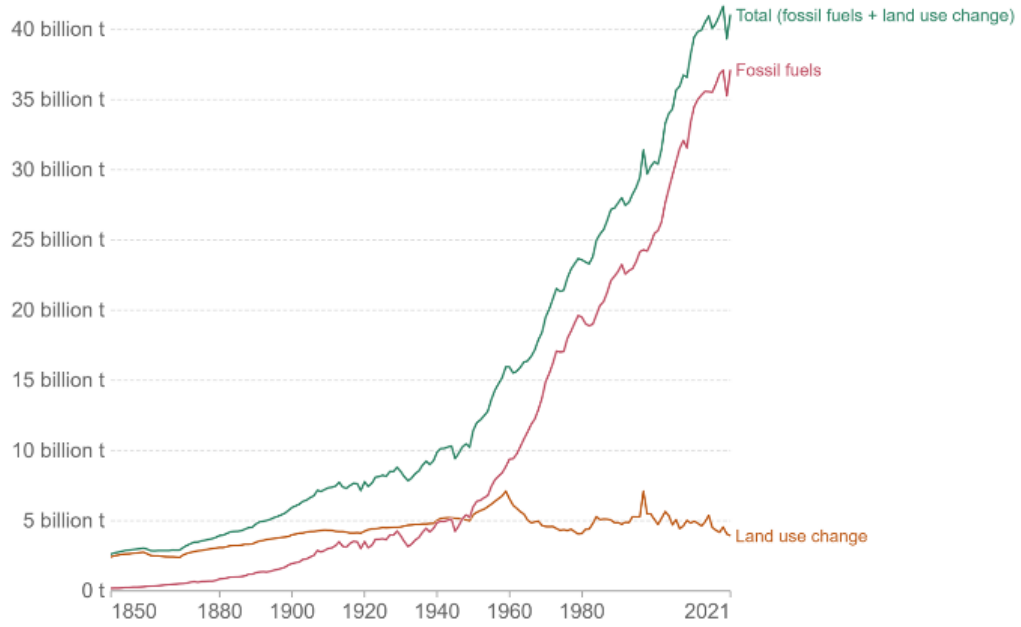


Fig. 4: Global anthropogenic CO_2 emissions 1850-2021 (conversion: 7.8 billion t CO_2 per year = 1 ppm CO_2 per year). Source: Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource].

Supplement to the allegedly constant "natural 80 ppm/y": IPCC apparently assumes that the pre-industrial equilibrium of fluxes has remained unchanged, and that it is only superimposed by the anthropogenic releases, which can be considered separately (and which, according to the IPCC, alone caused all the changes!). But that can't be correct, because the pre-industrial equilibrium came about just because *removal is dependent on concentration* (item 2.1.2). If the concentration changes, then the balance *necessarily shifts!* But not because of the anthropogenic releases, but because of the increased concentration! Rationale: If other releases had decreased to the same extent simultaneously, then anthropogenic releases would have only just compensated for that, without any overall effects arising! As long as the concentration is increased, there is *no return to the previous equilibrium*, not even if the anthropogenic releases were reduced to zero, because the boundary conditions have changed and simply would not allow such a return. And it is not

only the enhanced concentration, but also the *general warming*, whatever the reason, that have *shifted the equilibrium explicitly*. And finally, the atmosphere has *no memory* for any previous equilibrium, it only knows the current boundary conditions. All of this proves that the idea of a constant natural equilibrium **cannot be true!**

2.3.3. The last 10 years and COVID

For about 10 years, the anthropogenic releases have been growing noticeably slower than before (Fig. 4), perhaps a consequence of global efforts to reduce CO_2. If these releases were to determine concentration, a slowdown should also be evident in the concentration curve. However, this is clearly *not the case*, see Fig. 3. Likewise: Due to the COVID lockdown, the anthropogenic CO_2 releases temporarily even fell sharply in 2020 (Fig. 4, by 17% at peak!). That should be noticeable as a clear dent in the concentration curve. However, this *is not the case*, see Fig. 3. This also *contradicts* the view that the anthropogenic releases dominate the concentration.

2.3.4. IPCC's numbers

A confirmation of significantly increased CO_2 releases from natural sources can also be found in IPCC's own numbers: According to Fig. 5.12 in IPCC (2021), releases from natural sources into the atmosphere have increased by (converted) approx. 23 ppm/y, *almost 5 times as much* as anthropogenic sources amount to! Sadly, IPCC ignores its own numbers in their text and explains the concentration increase solely by long-term retention of half of the anthropogenic releases (not the individual molecules, but the corresponding amount of CO_2). According to the IPCC, this separation of anthropogenic CO_2 into two halves always occurs (*constant "airborne fraction"!*), regardless of the level of the anthropogenic releases and regardless of the concentration that has already been reached (for the future, however, the IPCC fears that the airborne fraction will increase due to a possible overburdening of the sinks). However, the IPCC does not give a physical explanation for this behavior of CO_2, nor does the IPCC discuss the discrepancy to its own numbers. There is **great need for clarification!**

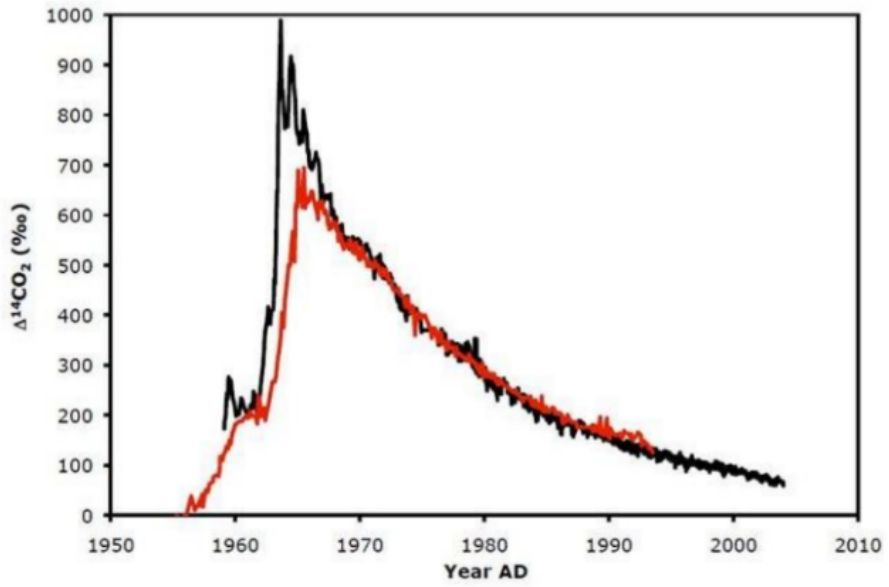


Fig. 5: The $^{14}CO_2$ concentration in the atmosphere: measurements at Vermuntsee (Black), Austria and at Jungfraujoch, Switzerland, at Baring Head, New Zealand (Red); Source: NASA. After the test ban agreement, the concentration fell very quickly and almost completely back to the starting level. The same must apply to any increased concentration if the increased release responsible for it is terminated again.

Supplementary remark: The numbers in Fig. 5.12 in AR 6 also confirm in principle the proportionality between concentration and removal from the atmosphere as it is claimed in this

paper. This proves proportionality to be the correct interpretation of physics. IPCC does not elaborate this in AR 6 either.

2.3.5. $^{14}CO_2$

There has not been a sustained decline in CO_2 concentration for many millennia. Therefore, there are no corresponding observations. But there are such observations with a special form of CO_2: $^{14}CO_2$. Its specialty is radioactivity with a half-life of approximately 6000 years, which allows it to be distinguished from "normal CO_2". Chemically, both forms behave in the same way. $^{14}CO_2$ occurs in a very small percentage in the atmosphere naturally. It was produced anthropogenically by the above-ground atomic bomb tests in such quantities as to increase the concentration significantly (Fig. 5). After the test ban agreement in 1963, anthropogenic releases were largely stopped. Subsequently, the $^{14}CO_2$ concentration has *almost completely* returned to its natural starting level with a constant time constant of only approx. 15 years (Fig. 5).

Clearly, the long-term remainder of $^{14}CO_2$ in the atmosphere is not half of the anthropogenic releases! Rather, practically all of it has been removed by now. Chemically, "normal CO_2" cannot behave differently than $^{14}CO_2$. This means, that the high increase in concentration of 50 % (Figs. 1 and 3) **cannot be reached without substantial additional releases!**

The strikingly large fluctuations in the concentration of $^{14}CO_2$ in the first years after the test ban agreement, see Fig. 5, are due to subsequent seasonal delivery of $^{14}CO_2$ from the stratosphere, where it was predominantly produced, to the troposphere, where it was measured. Only after these subsequent deliveries are largely completed does "undisturbed" dilution occur, particularly by storage in the deep ocean. For more detail on the time response, see the discussions in section 2.4. Here, just the hint that the same dilution must apply to any pulse-elevated concentration in the atmosphere, regardless of its isotopic composition.

2.3.6. Interim findings

The argumentations in items 2.3.1 through 2.3.5 strongly support the central statement that the releases from natural sources **must have increased considerably** for the concentration to have been able to increase as much as was measured (and that these releases *still have to be strong* now, because otherwise the concentration would have dropped again for a long time). It remains to be investigated where this increase comes from or could come from. This is done in section 2.4.

A small note beforehand: In section 1 it was pointed out that, according to some researchers, the CO_2 concentration was already fluctuating strongly before human intervention and was similarly high in the middle of the 19th century and around 1940 as it is today. Even if this is confirmed, it only confirms the variability of natural sources and does not eliminate the need to consider how this variability can be explained. This is the purpose of section 2.4.

2.4 Possible sources

2.4.1. General considerations

The *global warming* has indisputably contributed to the increase of CO_2 in the atmosphere, whatever its source: As a result of the temperature-dependent solubility of gases in liquids, more CO_2 has inevitably been outgassed from the ocean, and biomass has also undoubtedly increased its CO_2 exchange with the atmosphere with increasing temperature. In addition, biomass has increased its mass considerably as a result of *fertilization* with CO_2 (Scinexx 2016; Zhu et al. 2016), which further increases CO_2 exchange with the atmosphere. By how much this has increased the total release is difficult to say, also because this depends not only on the average temperature, but also on its areal distribution, and also on many other influencing variables. But at least a *considerable contribution* from warming is probably undeniable.

Other candidates for the cause of increased atmospheric concentration are e. g. *relocations of ocean currents* with different carbon content and *volcanic outgassing*. Since these processes are only superficially scientifically known, quantifications are hardly possible here.

An interesting observation was put forward for discussion in Pollard (2022): *Freshwater ecosystems* could release up to *six times* as much CO_2 into the atmosphere as humans do by burning fossil fuels. This paper was retracted by the Chief Editor of Frontiers in Environmental Science and the Editor-in-Chief of Frontiers due to suspected methodological errors and limitations. The author did not agree to the retraction. It remains to be seen how the discussion will continue.

2.4.2. Feedbacks in the Carbon Cycle

Other possibilities for increased releases from natural sources are feedbacks, i.e. consequences of releasing additional CO_2 into the atmosphere on other carbon fluxes in the system. In climate science, a distinction is made between the "long-term" (or "geological") and the "short-term" (or "biological") carbon cycle. The "long-term" cycle also includes processes such as sedimentation and weathering of rocks and plate tectonic processes, which occur on time scales of millions of years and longer and therefore do not play a role in current climate discussions. In contrast, the "short-term" cycle describes exchange processes between the atmosphere and the biosphere or the ocean that occur on time scales of days to several millennia. These are relevant for climate discussions.

However, to discuss the development of the CO_2 concentration in the atmosphere in more detail, it is proposed in Roth (2021) to divide the "short-term" carbon cycle even further: into *fast-running processes* with time scales of days to decades, summarized in this paper as the *"small cycle"*, and into *longer-term processes*, called in this paper the *"large cycle"* (see Fig. 6). The rapid processes include all intensive CO_2-exchanges between the atmosphere and the near-surface ocean layer (about 50 to 100 m thick, well mixed by wind and waves, including all living organisms in it, sunlit (photosynthesis!), carbon exchange with the atmosphere on the one hand and with the deep ocean on the other hand), and all similarly intensive exchanges between the atmosphere and short-lived terrestrial biomass, such as annual plants, leaves, needles, etc. The "large cycle" then includes the slower exchanges with the deep ocean and with long-lived terrestrial biomass, such as long-lived woods, humus, peat, etc., and with permafrost.

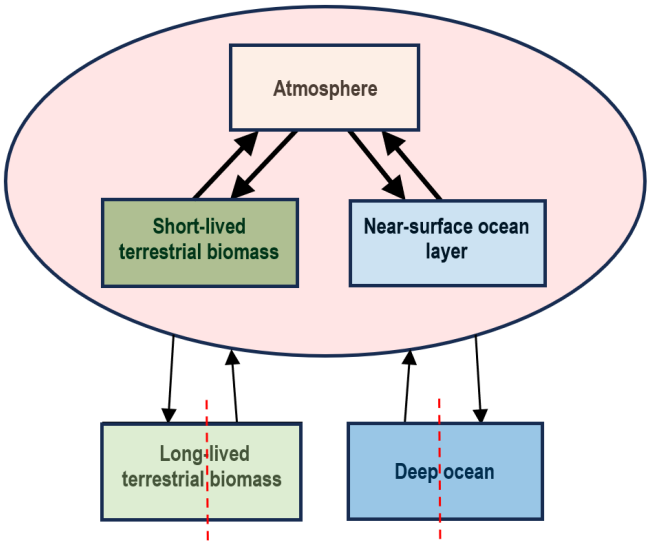


Fig. 6: Schematic diagram of the carbon cycle. In the first stage, all CO_2 released into the atmosphere is rapidly distributed evenly in the "small cycle" (summarized in the ellipse). Then, in the second stage, carbon is more slowly removed from this "small cycle" into the long-lived terrestrial biomass and into the deep ocean ("large cycle"). As a result of the long storage time in the last two reservoirs mentioned, absorption in them and return from them are decoupled for long periods of time (indicated by the dashed red lines).

When CO_2 is released into the atmosphere, it is very quickly (within a few months!) *evenly distributed* within the atmosphere by wind and weather. The atmosphere therefore practically always and everywhere shows the *same concentration* (the same CO_2 partial pressure). Only this well-mixed atmosphere reacts with its partners.

Note: This is generally true, but there are considerable local and temporal deviations in concentration, e. g. depending on the time of day, on wind- and weather-conditions, etc. This is not important for the considerations here, here only the so-called “background concentration” plays a role, which balances these local/temporal fluctuations, but it is very important for the interpretation of punctual measurements of the concentration, see the statement to corresponding discussions on the historical course of the CO_2 concentration in section 1.

CO_2 is removed from the (well-mixed) atmosphere in a *two-stage process*: First, equal distribution is established within the "small cycle". Second, this "small cycle" interacts, like a united larger reservoir, within the "large cycle" with the deep ocean and the long-lived terrestrial biomass (Fig. 6). Let us start with the first stage: the most important characteristic in it is the *intensive exchange* of CO_2 between the atmosphere and its partners: about a quarter of the CO_2 inventory of the atmosphere is exchanged annually (item 2.1.4), in first approximation in equal parts towards the terrestrial biomass and towards the near-surface ocean layer. This high exchange forces the near-surface ocean layer to match the CO_2 partial pressure of the atmosphere everywhere! And this partial pressure is the same everywhere on earth, see above. The temperature-dependent solubility of gases in liquids leads to areas of high concentration in cold water and areas of low concentration in warm water all at the same partial pressure! Roughly speaking, the cold ocean water near the poles *absorbs* CO_2 from the atmosphere and the warm ocean water near the equator *releases* CO_2 into the atmosphere.

Terrestrial biomass behaves similarly. However, because biomass strictly speaking has no CO_2 concentration, as it stores carbon exclusively in other chemical compounds, its behavior is very complicated. A sufficient approximation is that of a reservoir with a given CO_2 concentration, which, at equilibrium, must be the same as that in the atmosphere. During the growing season in spring and summer, much CO_2 is *taken* from the atmosphere, and in fall and winter, much CO_2 is *returned* by decaying leaves, needles, and grasses. In equilibrium, the two effects balance each other out over the year.

In order to better quantify the exchange processes within the "small cycle" and then also those between it and the deep ocean or the long-lived biomass, a *stepwise approach* is chosen: First, the processes within the “small cycle”: When the assumption is made that the two reservoirs "short-lived terrestrial biomass" and "near-surface ocean layer" are much smaller than the atmosphere, even very small amounts of CO_2 taken from the atmosphere would increase the concentration in them considerably. Subsequently, the *same amount* of CO_2 received would be emitted back to the atmosphere after a short time! With increased concentration in the atmosphere, they would take out more, but they would also give back more, to the same extent and only minimally delayed. Such small reservoirs can be practically neglected. With them, the "small cycle" would simply behave as if it consisted of the atmosphere alone. Practically all additionally released CO_2 would remain in the atmosphere and increase the concentration in it accordingly (the interactions in the "large cycle" are not considered at first)!

If the two reservoirs “short-lived terrestrial biomass” and “near-surface ocean layer” were larger, they would play an independent role. If, for example, they had the *same size* as the atmosphere, then they would absorb *half as much* CO_2 as is released additionally into the atmosphere (whatever its origin), and the same amount would remain in the atmosphere. This is exactly the scenario IPCC assumes for anthropogenic releases. As a result of the high exchange rates this distribution would proceed very fast, equilibrium would be reached at the latest within a few years (the "small cycle" always moves *very close to equilibrium!*).

But equally sized reservoirs are rather unlikely under real earth conditions. The actual size of the reservoirs can only be given under arbitrary assumptions: Regarding the near-surface ocean layer, what is the best choice of its thickness? 50 m, 100 m, or 200 m? IPCC (2021) gives an inventory

of 900 Gt C for this layer. However, because of chemical transformations in seawater, most of this carbon is in the form of carbonate and bicarbonate, which do not contribute to the CO_2 partial pressure (see also item 2.2.2). Therefore, the CO_2 content in this layer is much smaller than in the atmosphere, but the total carbon content in the layer is large.

Regarding the terrestrial biomass, there is a different problem: IPCC (2021) does not distinguish between short-lived and long-lived but gives values only for both combined: 1200 Gt C for “permafrost”, 450 Gt C for "vegetation" and 1700 Gt C for "soil" (essentially humus). These values, according to IPCC (2021), have not changed since 1750. What fraction of vegetation do long-lived woods make up? How much carbon do permafrost and soil exchange "rapidly" with the atmosphere? The author of this paper has found no data on this in the literature. For the atmosphere, IPCC (2021) gives 591 Gt C (before the beginning of industrialization, today it is 870 Gt C).

All together the "equal size" of reservoirs in the "small cycle" seems possible but would be *pure coincidence*. However, the exact value of these sizes is not important, as carbon is also removed from the “small cycle” into the deep ocean and into the long-lived terrestrial biomass (see below) in any case. Therefore, even with the same storage size in the "small cycle" a *completely different result* emerges altogether than assumed by IPCC.

The *second step* is the transfer of carbon from the "small cycle" into the deep ocean and into the long-lived terrestrial biomass. Even when taking the correct size of the reservoirs in the "small cycle", there is a *quantitative* problem: the amount of exchange between the "small cycle" (more precisely, the near-surface ocean layer) and the deep ocean is given *inconsistently* by IPCC: For many years, IPCC gave numbers close to 50 ppm/y (IPCC 2007, IPCC 2013, latest draft "Final Government Distribution" of IPCC 2021). However, in the final report IPCC (2021), Fig 5.12, numbers close to 130 ppm/y are given, which is *more than twice as much* as before (in each case converted with 2.13 PgC/y = 1 ppm CO_2 per year)! There is no reasonable explanation for this surprising jump (at least the author of this paper could not find one). However, the tremendous change makes it clear that *we still do not know everything for sure in the carbon cycle!* And concerning transport into the terrestrial biomass, IPCC (2021) does not distinguish between short-lived and long-lived biomass, but only gives a total of 52 ppm/y (before the industrial age, for today, IPCC gives 64 ppm/y). Presumably, the vast majority of this is attributable to the "small cycle", but data on this is lacking. But for the question, whether the anthropogenic releases alone are responsible for the large increase in the concentration, this is of minor importance, because they are *not large enough in any case*, as will be shown later. In item 2.4.4, however, the value will play a role once more.

Prior to that, however, a special feature of the carbon exchange between the "small cycle" and the "large cycle" should be explained: **removal and return diverge** (at least in relevant time scales)! The removal of carbon from the near-surface ocean layer into the deep ocean grows at least approximately proportionally with the concentration in the near-surface ocean layer (and thus in the entire "small cycle"), but the return of carbon from the deep ocean to the near-surface ocean layer takes place *practically unchanged* for some 500 to 1000 years due to the sheer size of the deep ocean and the slow currents in it. It simply *takes this long* for the deep ocean to respond to a change in the atmospheric concentration (and even then, most of the additional carbon released remains in the deep ocean because it is so huge).

According to items 2.1.2 and 2.2.2, the proportionality of removal to concentration applies generally. In the special case of removal by the deep ocean, this is fully confirmed by the two pathways of removal effective here, the "biological pump" and the "physical pump", and their mode of operation - sinking calcareous shells of dead biomass and sinking water packs with their contents, respectively.

Regarding the long-lived terrestrial biomass, detailed numbers are not available, as already stated. But here, too, the CO_2 absorbed is only released back into the atmosphere after a *considerable delay*.

However, a *growing withdrawal* from the "small cycle" and a return to it that is *constant for a long time* enforce that the concentration in the "small cycle" *can increase only very slowly*, unless a considerable *additional source* helps! Therefore, the small anthropogenic releases are *by far not sufficient* for a 50 % increase of concentration (as a reminder: that they cannot contribute disproportionately to the increase of the concentration has already been said in item 2.2.1). So, that the 50 % could come about at all, *a much larger additional source must have been added!*

This necessary additional source could be the deep ocean or the long-lived terrestrial biomass. But it cannot be caused by the anthropogenic releases, but only *by other causes* (e.g. rearrangement of ocean currents, whose cause we do not know yet, or enhanced temperatures, or volcanic outgassing into the ocean or into the atmosphere, or something else). We do not know this source, but it *must exist*, because the course of the concentration *cannot be explained otherwise!* Considering mass balance, the *size* of this additional release can be calculated retrospectively from the course of the curve of concentration.

2.4.3. Some more details to the difference between the atmosphere and the "small cycle"

Because of its importance, the crucial difference between the atmosphere and the "small cycle" should be discussed in more detail: Although in both cases the concentration could only increase by 50 % because the releases from natural sources have increased much more than the anthropogenic releases have added, the *possibilities* for this heavy increase in natural sources are *crucially different*:

In the case of the atmosphere, part of the increase in the strength of the natural sources is due to the small inventory in them. Because of this small inventory, the concentration in them increases rather quickly, and they then return a large fraction of the CO_2 stored back into the atmosphere relatively short term (not the individual molecules, but anyhow in quantity). It still is natural sources that must have become stronger, but in part they have become stronger *as a result of the anthropogenic releases!* (Supplement: Another part of the increased releases from natural sources definitely comes from the global warming, and other causes are also possible, e. g. increased volcanic outgassing, see item 2.4.1).

However, if one considers the "small cycle" in total instead of just the atmosphere as a single reservoir, then the relevant sinks here, the "deep ocean" and the "long-lived terrestrial biomass", are *very large*. Therefore, they respond to the enhanced carbon uptake into them (which is itself a consequence of the increased concentration in the atmosphere) only *after a delay of several 100 years!* However, the release from the natural sources *must already be increased now*, because, only with the anthropogenic releases alone, the concentration in the atmosphere (and thus in the "small cycle") could have increased only very little. This need for a strong source to significantly increase the concentration always exists when the outflow into the sinks (here into the deep ocean and into the long-lived terrestrial biomass) increases with the concentration. The situation is: The answer to the enhanced concentration in the atmosphere *has not yet been received*, but the increase of sources *must already have occurred*. Therefore, the increase in the strength of the natural sources must have come about almost entirely from some cause *other than the increased concentration* in the atmosphere!

To say it again quite clearly: In the case of the *atmosphere*, part of the increased release into it comes as a *response to the increased concentration* in it (and thus also as a response to the anthropogenic releases!), but in the case of the *"small cycle"* this is *not possible* in the relevant period of time! The reason for this is the *large size* of the deep ocean and the long-lived terrestrial biomass! It is ultimately this special feature of the interactions within the "large cycle" that makes a strong additional source truly *unavoidable*.

A somewhat different attempt to quantify: Let us again briefly consider the theoretical borderline case with infinitesimally small reservoirs of the short-lived terrestrial biomass and the near-surface ocean layer as in item 2.4.2: The "small cycle" then degenerates virtually entirely to the atmosphere alone, and without the deep ocean and the long-lived biomass, all anthropogenically released CO_2 would accumulate *exclusively* in the atmosphere, increasing the concentration further and further. However, with these long-term sinks operating, they *remove* almost all

additionally released CO_2, with the consequence that the concentration in the atmosphere (and thus in the degenerated "small cycle") could increase only minimally without a *substantial* additional source. More precisely: This source must be increased to *fully close* the gap between the anthropogenic releases and proportionality to the concentration. Now, instead of the "degenerated small cycle", let's take its real size: Then the near-surface ocean layer and the short-lived terrestrial biomass *store a considerable part* of the anthropogenically released CO_2 within themself (instead of giving it back to the atmosphere) and, as a consequence, the concentration in the atmosphere can only grow *even less* than it does in the “degenerated small cycle", which requires an even stronger additional source! Therefore, it is again the imbalanced CO_2-exchange in the “large cycle” that makes a strong additional source truly *inevitable!*

2.4.4. To quantify the additional source

For the "small cycle" as a whole, of course, the same laws apply as for the atmosphere as a smaller reservoir. Therefore, all arguments put forward for the atmosphere are equally valid for the “small cycle”. Especially, if the concentration in the "small cycle" has increased by 50 %, then the releases into it must also have increased by 50 %! This is where the *jump in IPCC's data* for CO_2 exchange with the deep ocean, described in item 2.4.2, comes into play: 50 % of the new value 130 ppm/y are 65 ppm/y. Subtracting from this the 5 ppm/y anthropogenic releases, shows that the releases from natural sources must have increased by about 60 ppm/y, about *12 times the anthropogenic releases!* But even with the old value of about 50 ppm/y, 50 % of it is 25 ppm/y, so in that case the releases from natural sources must have increased by 20 ppm/y. That is still about *4 times the anthropogenic releases!* The anthropogenic releases therefore play in any case only a *minor role*, with the new IPCC value still much more pronounced than with the old one. For clarification: Because there are no relevant numbers for the long-lived terrestrial biomass available, these calculations only consider the deep ocean. This is conservative, because the total releases must be increased by 50 % and not just those from the deep ocean.

2.4.5. Interim findings

It was shown in item 2.2.2 that the releases from natural sources *into the atmosphere* must be about **10 times greater** than the anthropogenic releases are. A (not well known) part of this increase is due to the increased releases from the short-lived terrestrial biomass and the near-surface ocean layer as a consequence of the relatively small size of these reservoirs (item 2.4.2). In item 2.4.4 it was shown that for the releases from natural sources *into the "small cycle"* only a lower limit of **4 times greater** than the anthropogenic releases can be specified, because of the great uncertainty in the exchange rates with the deep ocean and unknown exchange rates with the long-lived terrestrial biomass. But here, due to the large size of the reservoirs involved, *all enhancement* must come from another cause, independent of the anthropogenic releases. But whatever value applies, it is definitely a **multiple** of anthropogenic releases, these only play a minor role.

Assessment: If all arguments above in section 2 are true, then the climate can be influenced only to a minor extent by anthropogenic CO_2 releases! **The main cause of the observed climate change must be nature!**

2.5 Some more counterarguments

2.5.1. A sink cannot be a source

It is often said that ocean and biomass *could not* have contributed to the increase in the atmospheric concentration, because they have always been and still are a sink. It is further said that *a sink simply cannot be a source*. However, this argument overlooks the fact that ocean and biomass are always *source and sink simultaneously* (they cannot do otherwise!), and that every increased release into the atmosphere increases the concentration in it, and that every increased concentration in the atmosphere increases the removal from it by ocean and biomass.

A distinction should also be made, whether the increase in the concentration in the atmosphere is due to releases *from the outside* (from the outside into the "short-term” carbon cycle (item 2.4.2),

e. g. from fossil fuel burning or from volcanism), or *from the inside* (internal releases due to relocations within the "short-term" carbon cycle, e. g. as a result of warming, or of changes in ocean currents, or some other internal cause). External releases increase the amount of carbon in the "short-term" carbon cycle and are therefore *irreversible*. If the cause is terminated, there is *no return* to the previous equilibrium; rather, the system strives towards a *new* equilibrium. In contrast, releases from the inside leave the amount of carbon in the "short-term" carbon cycle unchanged and are therefore *reversible*. If the cause is terminated, the *previous* equilibrium is re-established.

Whether releases into the atmosphere come "from the inside" or "from the outside" also determines, whether ocean and biomass *act as a net source or as a net sink:* When releases come from the outside, a part of them remains in the atmosphere and the rest is transferred to the ocean and the biomass. Ocean and biomass therefore inevitably and always act as a *net sink* in the case of releases from the outside. If we look at the flows, releases from the ocean and from the biomass initially remain unchanged, but removals by them out of the atmosphere increase directly with the increasing concentration in the atmosphere. Higher removal and lower return signify a net sink! In contrast, releases from the inside are enhanced releases from the ocean and from the biomass through relocations between them and the atmosphere, and therefore the ocean and the biomass are inevitably and always a *net source* in the case of releases from the inside. If we look at the flows, releases from the ocean and from the biomass increase first, before removals by them increase with increasing concentration. Higher releases and lower removal signify a net source.

When the two processes *coexist*, two things matter: their relative strength and the atmospheric CO_2 exchange rate. It is exactly this coexistence, which we have in the real atmosphere: Releases from natural sources are predominantly internal releases, e. g. as a result of warming or of changes in ocean currents. They have been increased by approximately 50 %, which has also allowed the concentration in the atmosphere to increase by approximately 50 %. As a consequence, and somewhat delayed in time, removals by ocean and biomass have also increased. *Because of this lag,* the ocean and the biomass have always been a *net source*. This lag, and with it the strength as a persistent net source, are the smaller the higher the atmospheric CO_2 exchange rate is.

As a *second process*, anthropogenic releases have been added. These are essentially based on the burning of fossil fuels and are therefore largely releases from the outside. They are much smaller than the releases from natural sources, and they have increased the concentration just a tiny bit in addition, but still enough so that the removals by ocean and biomass *have now become larger* than the releases from them. Ocean and the biomass have thus become a *persistent net sink*, despite their increased releases!

Generally: Even if the ocean and biomass are a net source of CO_2 on their own, external releases make them a net sink if they increase the concentration to such an extent that the removal by the ocean and biomass now exceeds their release. Being a net sink and contributing to the concentration increase are therefore clearly **not mutually exclusive!**

2.5.2. Extremely unlikely

It is also sometimes said that it would be extremely unlikely for natural releases into the atmosphere and removals from the atmosphere both to *increase tremendously* over 150 years and to increase *exactly that much* as to accumulate net half of the amount of CO_2 released anthropogenically. However, firstly, releases and removals do not grow independently of each other (the latter rather follow the former relatively closely, being linked over the concentration) and secondly, any following relationship to the anthropogenic releases would be *just as unlikely!* It's similar to pebbles on a beach: It's extremely unlikely that you'll pick one up with exactly those properties as the one you're holding, but you've still picked one up. Any other pebble would be just as unlikely. This probability simply does not signify anything.

2.5.3. Time constant

Often (e. g. in Vahrenholt et al. 2020) climatologists calculate a time constant for the removal of "excess" CO_2 from the atmosphere using the difference between the present concentration and

that at the pre-industrial equilibrium (420 - 280 = 140 ppm) as the driving force and the present net removal rate from the atmosphere (2.5 ppm/y) as the flow rate. This time constant is then approx. 50 years, considerably longer than the few years resulting from the considerations made in this paper (removal proportional to the absolute concentration). However, this linking of the 140 ppm and the 2.5 ppm/y is *pure mathematics*, without any physical basis, and therefore the time constant calculated in this way has *no value*. According to the laws of physics, the atmosphere has *no memory* of a previous equilibrium and the driving force for the net removal of CO_2 can only be the distance to the *new* equilibrium, as it is determined by the *current* boundary conditions (e. g. temperature). This distance to the actual equilibrium *can never be very large* in a homogeneous (well-mixed) medium, where removal increases with increasing concentration. In any case, 140 ppm surplus can definitely be ruled out due to the slow nature of the occurring changes (the annual anthropogenic releases are only about 1% of the atmospheric inventory even today!). The real time constant for reducing an increased CO_2 concentration is **only a few years** and not 50 years!

2.5.4. Decreasing oxygen concentration

It is also often cited as "proof" for the predominantly anthropogenic origin of the large amount of CO_2 in the atmosphere that the oxygen concentration in the atmosphere has decreased correspondingly to the increase in the CO_2 concentration (exactly to that extent, as is expected according to the amount of fossil fuels burned). However, this oxygen decrease only proves that the amount of fossil fuels burned is estimated correctly. It *signifies nothing* about whether or how much CO_2 has been released into the atmosphere from additional sources without oxygen consumption!

2.5.5. Saturation of sinks

IPCC believes that half of the anthropogenic releases have always remained in the atmosphere (constant "airborne fraction"). IPCC gives no physical explanation for this, but fears that the "airborne fraction" could increase considerably in the future due to saturation of the sinks (see item 2.3.4). Due to the rapid equilibration in the "small cycle", saturation is only possible of those sinks, which have a slow exchange rate. Namely, the long-lived terrestrial biomass and the deep ocean. There is no obvious reason why the long-lived terrestrial biomass should become saturated in the relevant range, and saturation of the deep ocean can definitely be ruled out due to its huge volume and to the high pressure and the low temperatures in it. Even if the "50 % model" were to apply at all, deterioration due to potential saturation **can be ruled out.**

2.5.6. Bern Carbon Cycle Model

It is also often argued that IPCC does not simply assume that 50% of the anthropogenic CO_2 releases remain in the atmosphere permanently (constant "airborne fraction", item 2.3.2), but uses the "Bern Carbon Cycle Model" for more precise calculations. This model, named after a group of researchers in Bern, assumes that "excess" CO_2 in the atmosphere is removed according to a formula as it is used for the *radioactive decay* of a mixture of unstable isotopes. This should account for the different *time responses of the various sinks* for CO_2 (e. g. UNFCCC 2002). With an appropriate choice of parameters in the model, the historical course of the CO_2 concentration can thus be calculated from the course of the anthropogenic releases, and with this, it is said, future courses can then also be calculated under assumed emission scenarios. However, this overlooks a *fundamental difference*: The individual unstable isotopes are different and decay according to *their* respective specific properties, whereas the CO_2 molecules are all the same and are removed from the atmosphere by different sinks according to the respective specific properties *of the sinks*. Thus, in radioactive decay, the *decaying substances* determine how fast they disappear, whilst in CO_2 removal, the *sinks* determine how fast the CO_2 disappears. In the case of radioactive decay, the strongest sinks (shortest half-life) are *the first to fade away*, afterwards only the smaller sinks work; in the case of CO_2-removal from the atmosphere, the strongest sinks remain *fully active* until the end. Therefore, the "Bern Carbon Cycle Model" **does not obey the physical conditions in the atmosphere!** For a more detailed critique, see e. g. Roth 2022.

2.5.7. Interim findings

All these counterarguments **do not hold**. Of course, there are many other counterarguments, but the author of this paper has not found any that would be better than those rejected here.

3. Appraisal of the Results

Every single argument presented here seems to strongly support the statement that the fast increase in the atmospheric CO_2 concentration is *primarily fed from natural sources*. All arguments together make this statement even *more stringent*. And all the counterarguments seem to be *baseless*. As long as no convincing counterargument is presented - at least in the opinion of the author of this paper - the rules of physics *exclude* a disproportionate contribution of anthropogenic releases to the concentration of CO_2 in the atmosphere! The lion's share of the increase that has occurred *must therefore come from natural sources*, which must have grown faster (much faster!) than the anthropogenic releases! As always, all of this is much more complicated in detail, but the result is basically the same as shown in this brief description here: **Nature is most likely stronger than humans** when it comes to CO_2 too! In any case, this view must be seriously discussed.

For information: Some more information is given in Roth (2022) (in German). So far, no viable counterarguments have been put forward, at least none have been revealed to the author of this paper. To put it gently, the question of the origin of all the CO_2 in the atmosphere is *scientifically open!* Just as is the question of the climate impact of CO_2, and just as some other questions about the climate. A more detailed discussion of most climate problems can be found in Roth (2019) (in German).

4. Conclusion

If all of this is principally correct, i.e. if the strong increase of CO_2 in the atmosphere is mainly due to *releases from natural sources* (and that is most likely true!), then there are, logically binding, *only two possibilities* left:

- Either *naturally released* CO_2 determines earth's climate, or
- Earth's climate *is not determined by CO_2 at all*, but other influencing factors predominate.

In both cases, **climate change is not man-made** (at least not predominantly)! Therefore, it *does not make any sense* to call for a reduction in the anthropogenic CO_2 emissions for reasons of climate protection. These emissions do not have a key influence (“if all of this is correct”) on the CO_2 concentration and therefore they *cannot* have a key influence on the climate the more. Therefore, the question of wherefrom all the CO_2 in the atmosphere comes *directly affects the foundation of all climate considerations*. If this CO_2 comes mainly from natural sources, *humans cannot be responsible for the climate* (at least not through their CO_2 releases)! It is therefore *necessary above all to demand* that science discusses and clarifies the question of the *origin* of the large amount of CO_2 as quickly as possible without any bias. This question is at least as important as that of the climate impact of CO_2. Only when *both questions* have been clarified can decisions about climate protection measures be made responsibly! And the media and the public should at last acknowledge that the science of climate is still *divided* in many cases, including important issues. Not wanting to admit this or even intentionally wanting to keep it under cover does not solve a single problem, it only creates new ones.

5. Addendum: Actions

However, it is not only the *cause* of climate change that is scientifically open, the *actions* we should take on the basis of the assumption "man-made" are controversial too: Usually, it is demanded to completely transfer our whole energy supply to "renewable energies" as quickly as

possible, primarily to wind and sun. But there are *two fundamental questions* scientifically open: Are these actions really *necessary* or not, and are they *useful and cost-effective* or not? Regarding the first, see above, there is *no necessity*. Regarding the latter, there is still no carefully carried out comparison of costs and benefits of these actions. Some experts say that the costs that *certainly* arise when implementing the demanded climate protection actions very probably exceed the costs that otherwise *debatably* might result from climate change, others contradict fiercely. There is no agreement in sight.

But irrespective of these two open questions, the above-mentioned demand clearly *violates the principles of "technological openness" and "modest use of the landscape"*.

Regarding the first, because there may very well be *better solutions* (many people consider nuclear energy to be one!), and regarding the second, because wind and sun will probably *never* be the backbone of our energy supply! As long as there are no suitable (and affordable!) storage systems to compensate for their erratic energy availability, it simply *doesn't add up* in terms of numbers! For this reason alone, *other solutions must be found*.

But the need for other solutions probably applies even if the storage problem could be solved one day (which in the opinion of the author of this paper is not foreseeable). This is, because the solar radiation reaching the earth is simply *concentrated far too little!* So little that its large-scale use (in whatever way, e. g. directly using the radiation, or converted into the kinetic energy of the wind, or converted into biomass via photosynthesis) *inevitably* involves large-scale land use! With more and more people on earth, however, "area" is becoming more and more of a precious commodity (*we only have one planet!*). We need this precious commodity for everything, from our food supply, to our homes, to shops, to schools, etc., up to ensuring an appropriate living environment for people and nature. To satisfy our energy needs, we should *use it as efficiently as possible!* Wind and solar parks instead of forests, fields and natural landscapes are not a desirable alternative (even if one does not initially consider the possible environmental impacts of the large-scale use of wind and sun, the extent of these environmental impacts is disputed). Mankind *can do better*; it must not blindly follow what people feel to be “good” without analyzing impartially whether or not it is actually “good”. With climate, that *seems to be the case* at the moment!

And one last argument: As long as trading in *CO_2 certificates* applies in the EU (it has only just been expanded!), special additional requirements, such as the expansion of renewable energies in Germany up to x% in year y, are basically *without any effect* on the climate: if they are successful at all, they not only reduce CO_2, but also the consumption of certificates. The certificates that are not consumed in this way are traded, and *exactly the same amount* of CO_2 that was initially saved is then released elsewhere! That's what the buyer bought the certificates for. *The climate doesn't care!* Politicians *must decide* whether they want to achieve the CO_2 reduction (if it is necessary at all) through specially defined measures *or* through general certificate trading. Pursuing both strategies side by side makes little sense because they *work against each other* and thus only *increase costs unnecessarily!*

6. Summary

Logically binding, the observed climate change can only be caused by anthropogenic releases of CO_2, if CO_2 has a *strong impact* on climate *and* if most of the CO_2 in the atmosphere has been brought there *by humans!* Both are *scientifically controversial*, even if this is usually presented differently in public. While the climate impact is primarily a *quantitative* question that can only be answered with highly sophisticated calculations based on unsecured physical assumptions, the origin of the large amount of CO_2 can also be checked very well by means of *fundamental physical considerations.* That is the central theme of this paper here.

Essential starting points are the equality of all CO_2 molecules, the dependence of the (total) number of CO_2 molecules removed from a storage facility per second on the concentration in that storage facility, and the consideration of the fate of CO_2 released into the atmosphere in several

stages (thorough mixing in atmosphere, approximate equal distribution within the three reservoirs atmosphere, short-lived terrestrial biomass and near-surface ocean layer, exchange with the deep ocean and long-lived terrestrial biomass). It turns out that under the real conditions on earth in relevant time periods **no source can contribute disproportionately** to the concentration in the atmosphere. For the concentration to have increased by 50% at all, the 5% anthropogenic releases are *much too small*, the releases from natural sources **must have increased substantially** in addition!

Therefore, on the real earth, *two processes* go on simultaneously: Firstly, nature increases its CO_2 releases into the atmosphere quite substantially. This increases the concentration and with it the removals by ocean and biomass also increase, but delayed, so that ocean and biomass insofar act as a *net source*. Secondly, anthropogenic releases. These are much smaller, but they increase the concentration sufficiently for the removals by ocean and biomass to *become stronger* than the releases from them. Ocean and biomass thus become a *net sink*, despite greatly increased releases from them.

This result is supported by considerations regarding the steepness of the increase in the concentration compared to the growth of the anthropogenic releases, regarding the comparability of these two curves in the COVID period and generally over the last decade, regarding the seasonal cycles of the CO_2 concentration, regarding the saturation or not of the sinks, and regarding the course the concentration of $^{14}CO_2$ in the atmosphere, as well as by showing the invalidity of the usual counter-arguments. The result is always the same: Physics requires that the **releases from natural sources must have increased significantly** in order to be able to explain the observations.

Exactly the *same result* is shown by some of IPCC's numbers as well: Even according to these numbers, the releases from natural sources *have increased much more* than the anthropogenic releases! IPCC just ignores its own numbers in its further text and says something clearly different in words.

A final clarification of the question of the *origin* of the large amount of CO_2 should therefore have the *highest priority* in all climate discussions! This contribution to the discussion here aims to give a boosted impetus to this.

Complementary to the investigation of the origin of the large amount of CO_2, this paper also shows that and why the climate *counteractions*, which are demanded on the basis of the assumption "man-made", *cannot bring the desired result*.

More or less as a by-product of the considerations here, it becomes evident that the assumption put forward by the IPCC that there is a *"fixed CO_2 budget"* for the anthropogenic releases in order to comply with a certain warming limit, which must not be exceeded**, cannot be justified physically.** For all decisions and demands based on such a "fixed CO_2 budget", there is no objective justification. *The climate problem must therefore be reconsidered also for this reason!*

Funding:

The author expressly declares that he has not received any money or otherwise funding from anyone for this work and that there are no other conflicts of interest.

Editor: Jan-Erik Solheim; Reviewers: anonymous.

References

Andrews, D., 2023: *Clear Thinking about Atmospheric CO_2*, Science of Climate Change, Vol. 3.1 (2023), pp. 33-43. https://doi.org/10.53234/scc202301/20.

Andrews, D., 2023A: *The Root Cause of Atmospheric CO_2 Rise*, Science of Climate Change, Vol. 3.2 (2023), pp. 223-226. https://doi.org/10.53234/scc202304/10.

Beck, E.-G., 2022: *Reconstruction of Atmospheric CO_2 Background Levels since 1826 from Direct Measurements near Ground*, Science of Climate Change, Vol 2.2 (2022), pp 148-211. https://doi.org/10.53234/scc202112/16.

Berry, E., 2019: *Human CO_2-Emissions Have Little Effect on Atmospheric CO_2*, International Journal of Atmospheric and Oceanic Sciences, Vol. 3, No. 1, 2019, pp. 13–26. https://doi.org/10.11648/j.ijaos.20190301.13.

Berry, E., 2021: *The Impact of Human CO_2 on Atmospheric CO_2*, Science of Climate Change, Vol. 1.2 (2021), pp. 213-249. https://doi.org/10.53234/scc202112/13.

Berry, E., 2023: *Nature Controls CO_2 Increase*, Science of Climate Change, Vol. 3.1 (2023), pp. 68 – 91. https://doi.org/10.53234/scc202301/21.

Berry, E., 2023A: *Nature Controls CO_2 Increase II*, Science of Climate Change, Vol. 3.2 (2023), pp. 227 – 231. https://doi.org/10.53234/scc202304/11.

Engelbeen, F., 2023: *About Historical CO_2 Levels – Discussion of Direct Measurements near Ground since 1826 by E.-G. Beck*, Science of Climate Change, Vol 3.2 (2023), pp 190-208. https://doi.org/10.53234/SCC202301/33.

Fiedler, M., 2023: *Kohlenstoffdioxidkonzentration vor 1900 und heute*. https://apolut.net/kohlenstoffdioxidkonzentration-vor-1900-und-heute-von-markus-fiedler/, posted Jun. 19, 2013.

Harde, H., 2019: *What Humans Contribute to Atmospheric CO_2: Comparison of Carbon Cycle Models with Observations*, Earth Sciences, Vol. 8, No. 3, 2019, pp. 139–159. https://doi.org/10.11648/j.earth.20190803.13.

Harde, H., Salby, N., 2021: *What Controls the Atmospheric CO_2 Level*?, Science of Climate Change, Vol. 1.1 (2021), pp. 54 – 69. https://doi.org/10.53234/scc202106/22.

Harde, H., 2023: *About Historical CO2-Data since 1826 - Explanation of the Peak around 1940*, Science of Climate Change, Vol. 3.2 (2023), pp. 211-218. https://doi.org/10.53234/scc202304/21.

IPCC 2007, AR 4: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

IPCC 2013, AR 5: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, [Stocker, TF, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC 2021, AR 6: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, MI. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. https://doi.org/10.1017/9781009157896.

Mueller, R., 2023: „Estimation of e-Time for CO_2 and Revelle Factor“, Science of Climate Change, Vol. 3.3 (2023), pp. 327-345. https://doi.org/10.53234/scc202308/06.

Pollard, PC., 2022: *Globally, Freshwater Ecosystems Emit More CO_2 Than the Burning of Fossil Fuels.* Front. Environ. Sci. 10:904955. https://doi.org/10.3389/fenvs.2022.904955.

Roth, E., 2019: *Probleme beim Klimaproblem – Ein Mythos zerbricht*, BoD-Verlag Norderstedt 2019, ISBN 978-3-7481-8275-7, E-Book 978-3-7494-0328-8.

Roth, E., 2022: *Das große Klimarätsel: Woher kommt das viele CO_2?*, BoD-Verlag Norderstedt 2022, ISBN 978-3-7562-2033-5, E-Book 978-3-7562-5347-0.

Salby, M., Harde, H., 2021A: *Control of atmospheric CO_2 - Part I: Relation of carbon 14 to the removal of CO_2*, Science Climate Change, Vol. 1.2 (2021), pp. 177-195. https://doi.org/10.53234/scc202112/30.

Salby, M., Harde, H., 2021B: *Control of atmospheric CO_2 - Part II: Influence of Tropical Warming*, Science Climate Change, Vol. 1.2 (2021), pp. 196-212. https://doi.org/10.53234/scc202112/12.

Scinexx, 2016: *Unser blauer Planet wird grüner – Steigender Kohlendioxidgehalt der Luft fördert das Pflanzenwachstum*, https://www.scinexx.de/news/geowissen/unser-blauer-planet-wird-gruener/.

Schrijver, F., 2022: *Why is the CO_2 Concentration Rising?*, : https://wattsupwiththat.com/2022/04/22/why-is-the-co%e2%82%82-concentration-rising/.

Stallinga, P., 2023: *Residence Time vs. Adjustment Time of Carbon Dioxide in the Atmosphere*, Entropy 2023, 25(2), 384; https://doi.org/10.3390/e25020384.

Vahrenholt, F., Lüning S., 2020: *Unerwünschte Wahrheiten, was Sie über den Klimawandel wissen sollten*, 2. Auflage, Langen Müller Verlag GmbH, München, 2020, ISBN 978-3-7844-3553-4.

Zhu, Z., Piao, S., Myneni, R. et al., 2016: *Greening of the Earth and its drivers*. Nature Clim Change 6, 7 –795 (2016). https://doi.org/10.1038/nclimate3004.

OPEN ACCESS
Klimarealistene
P,O,box 33
3901 Porsgrunn
Norway
ISSN:2703-9072
Correspondence:
forrestfrantz@gmail.com
Vol. 3.5 (2023).
pp. 543-600

The Greening of Scandinavia

Is CO_2 a pollutant?

Forrest Frantz

Biospheric Scientist/Engineer
Washington, United States

Abstract

The four tenets of consensus climate theory are: (1) CO_2 is a pollutant that causes harm to the environment. (2) Increasing CO_2 causes global warming. (3) Increasing CO_2 destabilizes climate. And (4) Those harmful effects last hundreds of years so, we must act now. In science, there are four roles for people: theoretician, scientist, technician/engineer, and philosopher. Many in science take on multiple roles, which have nothing to do with job titles. It is the role of theoreticians to develop theory (sometimes via consensus) so that it can be tested. It is the role of the scientist to apply the ***scientific method*** to test theories imagined by theoreticians. The ***scientific method*** must be based on confirmation via "***observations of the natural universe***." Here, the first tenet of climate theory, "CO_2 is a pollutant that causes harm to the environment", is ***tested using observations*** of changes in environmental quality. The purpose was to use the scientific method that complies with USA criteria of reliable principles and methods for expert testimony (Federal Rule 702 or the Daubert Standard). As such, a scientific hypothesis was tested using preferred processes and real-time climate records from respected sources (NASA, NOAA and the Hadley Met Centre).

Keywords: CO_2; Leaf Area Index; theoretician; scientist; Oxygen-of-Life; scientific method.

Submitted 2023-12-15, Accepted 2023-12-30, Revised 2024-03-13.
https://doi.org/10.53234/scc202310/37

1. Introduction

This paper pulls from experience that includes biospheric science and engineering, including over twenty international patents that are flying on advance lift systems like Elon Musk's Starship. But why biospheric science? And what does that have to do with climate change?

Biospheric science in academia can be limited to the physics and biologic processes found in the air, sea, and land of Earth that contain life. But in industry, such limitations are invalid. Life is in the upper atmosphere and in space on ships and orbiting platforms. That life is affected by the Sun, other planets, and beyond. Biospheric scientists and engineers in industry need to understand the total picture affecting a variety of biospheres (commonly the land, seas, and air, along with space, the moon, and Mars). As such, in industry, all processes associated with climate science are a subset of the broader view—biospheric science. It also includes extreme climate change. Picture a capsule launched from a sub. It shoots through a saltwater biosphere. Then it transitions into a biosphere of

super-heated salty air. Where it is propelled up through the troposphere onward to the cold of charged galactic ionizing space. And then upon reentry, it encounters blistering heat.

It is the job of the biospheric engineer/scientist to understand and design systems to protect payloads from all biospheres encountered on missions. The most precious payloads are astronauts in space and people on aircraft. That is why in aerospace, *theory is always tested*. Or, people will die. Climate-change theory is no different. As such, between 2010 and 2023, climate-change theory has been tested six times. All resulted in the same conclusion. [1-6] Why were those tests ignored? Politicians successfully pushed theory over observation. They used tax dollars to censor research, scientific journals, media, and industry—giving birth to Climate Lysenkoism. [7]

Theory vs ***observation***? ***Theorist*** vs ***Scientist***? Here, theorist and scientists are not used in terms of job title. They are used to describe the **role** people play in science. ***Theorists*** or ***theoreticians imagine***. Whereas ***scientists use scientific methods to test*** that imagination. Consider Einstein.

Theoreticians are critical to science. Like a lot people in science, Einstein wore several hats: theorist (general relativity), scientist (how to test relativity), and engineer (refrigeration). But his forte was imagination. He said: *I am enough of the artist to draw freely upon my imagination* [8]. He was not impressed by the word "theory"—the adult word for imagination. But no matter which word is preferred, testing one's imagination/theory via the scientific method is required. All of Einstein theories were tested. And even with Einstein, 3 of 11 were found to be false.[1] [9,10,11]

Between 1907 and 1915, Einstein worked on getting a consensus on the general theory of relativity to explain the observed orbit of the planet Mercury. His consensus team was engineer Besso, mathematicians Grossmann and Fokker, and theorist Kottler. Besso warned Einstein that his equations were wrong. Einstein ignored him. Just like climate theorists that ***continue to ignore*** two ways that Oxygen-of-Life, CO2, cools the climate. Ignoring Besso hit Einstein hard in 1915 when mathematician Hilbert proved Einstein wrong. This put Einstein in a depressed funk. Did Einstein wave his arms or double down on his errors? No. Einstein admitted he was wrong (told Besso) and started correcting his theory. The result? A stable consensus.

- His 1915 paper, *Explanation of the Perihelion Motion of Mercury from the General Theory of Relativity*, fully accounted for the difference between Newtonian theory and observation. The paper explained that Mercury, in close proximity to the Sun, would follow space displaced by the mass of the Sun. ***But math does not prove theory.*** *Math, just like climate* ***models, can be fit to derive a specific answer.*** *A new* ***test using experimental observation was needed.***
- Einstein's joint preliminary paper in 1911 had suggested measuring the amount that starlight bends inward when going past the sun. Using the 1915 mathematics, the amount was predicted to be twice the bending that was predicted from Newtonian Physics.

All that was needed was for a ***scientist to use the scientific method to test theory versus observation***. Several tried. But weather and World War I intervened. Then Eddington stepped forward. He was a leading astronomer, mathematician (he understood the symbolic math that Einstein used) and he was also a practiced scientist in the scientific method. He used the 1919 total solar eclipse to show that starlight bent inward around the Sun and the moon in the exact amount predicted. He compared photos

[1] Einstein batting score. Eight correct theories were: Detail on Avogadro's number, Quantum Theory of Light, General Theory of Relativity, Special Theory of Relativity (mass-energy relationship), The Photoelectric Effect, Wave-Particle Duality, Brownian Movement, Bose-Einstein Condensate. Three theories that were wrong: Capillary Action, Cosmological constant and Quantum Determinism. While the universe has been shown to be expanding as an accelerating rate (what Einstein called his biggest mistake), it could one day be found that Einstein was correct about Quantum Determinism.

of the same starlight during a total eclipse to that at night without interference from the Sun's gravity (see Figure 1). That is how a theory is ***tested using observation. That is how theory is accepted***.

But isn't climate-change theory also accepted? Something about a 95% consensus? Some people complain about the ***95% consensus among climate theoreticians***. Many claim it's a lie. But it isn't. And furthermore, ***that consensus should be embraced***. Consensus (agreement) on a theory is required

Figure 1: How the scientific method of observation proved Einstein's theory

Even Einstein needed consensus. It is necessary so that scientists know what theory to test. A final test is impossible for a moving target. Here, the consensus on the theory regarding the first tenet of climate-change is stable enough to test. As such, the null hypothesis: *Increases in CO_2 have <u>not</u> caused harm to the environment*. was tested. If climate theory is supported by Official Biospheric Records, then ***the null hypothesis will be rejected*** in favor of the theory.

2. Using Observation to Test If Increasing CO_2 Causes Harm to the Environment

Satellites used by NASA[12] and Copernicus[13] see more than what we see in normal satellite photos of the Scandinavian Peninsula (see Figure 2, left pane from 3-D Earth View). NASA satellites can also see what is on the right. The right image shows the basis for all life in Scandinavia—***flora***.

Knowing how **Leaf Area images** are made and what they mean is critical in saving our biosphere. The Leaf Area Index is the single most important basis for measuring not only the quantity of photosynthetic life (flora), but also the <u>potential</u> for all animal life on Earth—it's food and habitat!

2.1. Technology

NASA-MODIS[14]/Copernicus images are produced from satellite sensors that see visible and near-infrared radiation reflected by vegetation. That allows canopies of flora to be mapped into layers covering the ground. The coverage of canopy layers is converted into a Leaf Area Index (LAI). [15]

2.2. Data Availability

The program to map changes in flora started in 1981. Part of the program included on-ground physical measurements to calibrate satellite readings. The Leaf Area Index is available to the public, 8/10-day or monthly, going back to March 2000 (NASA NEO) or Jan 1999 (Copernicus).

2.3. Leaf Area Index (LAI) Numbers

The LAI index represents the area of all leaves and needles relative to its area of land. An LAI of 0.5 means that on average half of the area is covered by leaves/needles and 2.0 means that on average there are two complete canopies of coverage over that area. LAI varies from 0 to 7 layers.

2.4. Leaf Area Index (LAI) Colors

See Figure 2 (right pane) or Figure 3 (left and right panes). Black (LAI = zero) means no data (e.g., water, glacier, desert, or no flora). Brown means the area is mostly rock, mostly covered by snow, or sparce grasses (LAI 0.1 to 0.2). Yellow (LAI 0.5 – 2) means seasonal grasses/bushes and some trees. And dark green (LAI 2.5 – 7) is a thick, mostly seasonal to non-seasonal canopy of trees. The maximum 1-degree square average NASA Leaf Area Index is currently seven complete canopy layers (mostly nonseasonal) and is found in the Amazon jungle (FYI, the Congo comes close).

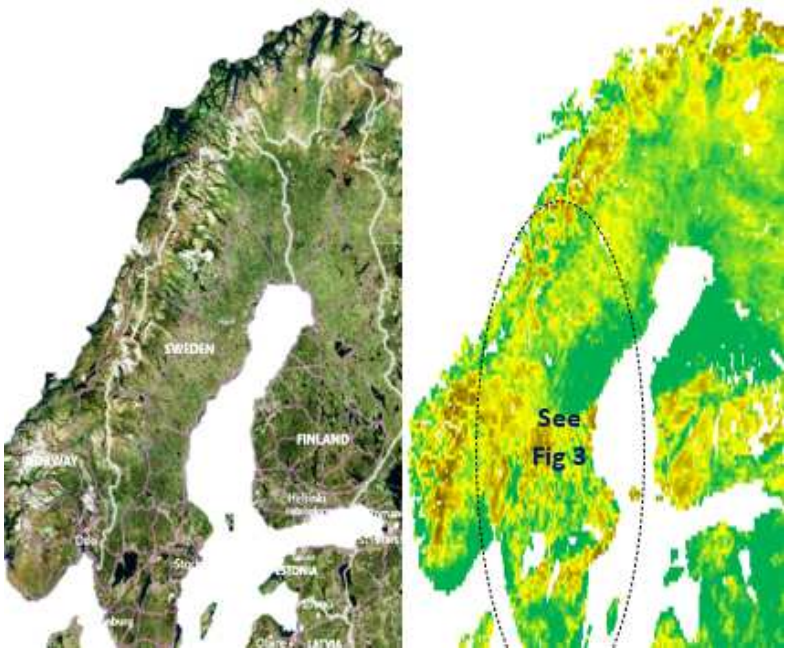


Figure 2: Satellite images of the Scandinavian Peninsula (random visual examples)
(the ellipse in the right pane is the area zoomed into in Figure 3)

2.5. Why Leaf Area Is Important

Oxygen-of-Life (CO_2), water, and sunlight are the three ingredients used by photosynthesis to create all life on Earth. And the IPCC admits that Oxygen-of-Life (CO_2) is limited. "With increased photosynthesis, plants can develop faster, attaining the same final size in less time, or can increase their final mass." [16]

Oxygen-of-Life (CO_2) at 425 ppm is about half to a third of where it needs to be for life in our biosphere to flourish (see Figure 5). The equivalent is us trying to live on the level of oxygen experienced on Mt. Everest. Our growth would be stunted. We would easily succumb to stresses (e.g., a lack of water/food, disease, etc.). Just as trees today easily succumb to disease and wildfire.

Maslow's hierarchy of needs includes **water**, **food**, and **shelter**. [17] All three of these needs are met with adequate flora and are measured by the Leaf Area Index (LAI).

- Leaves/roots contain/retain **water** and flora evapotranspiration creates clouds.
- Leaves (and in some cases the associated plant structure) are the **foundation for all food**. Even carnivores. Carnivores eat animals that somewhere down the food-chain eat herbivores.
- Leaves provide **shelter** for most all animals. Without flora, there isn't enough earth to allow digging animals to burrow. And for the rest of all animals? They find homes in the cover of flora derivatives (e.g., algae/lichen, moss, seaweed/grass, coral/bushes, and kelp/trees).

An increasing leaf area means more food and habitat for wildlife—the potential for an increase in the quality (e.g., health and security) and quantity of wildlife. A decreasing leaf area means less food and habitat—the starvation of established wildlife and less habitat for security. The destruction of endangered species.

The Leaf Area Index, while certainly not the only measure of environmental health, it is inarguably the single most important measure of environmental health. Leaf Area reflects the entire Plantae kingdom (flora) and the potential for the entire Animalia kingdom (fauna).

2.6. Has the rise in Oxygen-of-Life Harmed or Benefitted the Scandinavian Biosphere?

Seeing is believing, so see Figure 3. It zooms into the Leaf Area images that show the peak of flora in 2000 (left pane) and 2023 (right pane) between latitudes 55N and 65N of the Scandinavian Peninsula (see Figure 2 for that location). Note the following in the 2023 image:

- Less brown.
- The light-greens have darkened.
- The dark greens have spread outward and to higher elevations.
- Development has decreased the LAI in some areas.
- But development is overwhelmed by the greening that was mostly caused by the increase in Oxygen-of-Life (CO_2). In the journal Nature (Nature Climate Change), more than thirty authors from around the globe worked with NASA satellite data to calibrate and document the level of and drivers of the greening of Earth. They then wrote the peer reviewed article, *Greening of the Earth and its Drivers* (2016). To quote, ***"CO_2 fertilization effects explain 70% of the observed greening trend."***

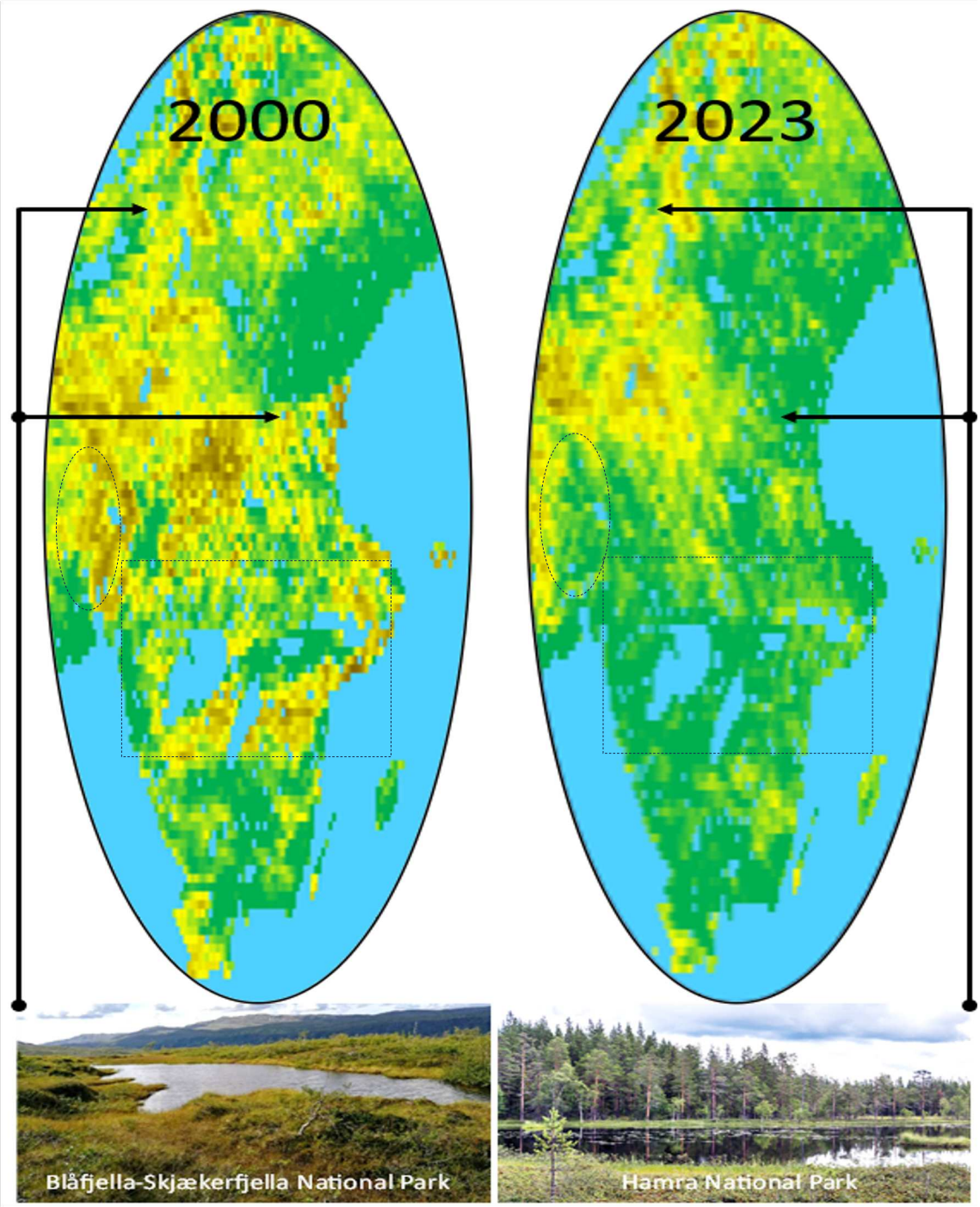


Figure 3: Zooming into a 10º x 10º lat/lon map of peak leaf-area (July) for the Scandinavian Peninsula (NASA)

Note the two parks: a mountainous region in Norway (with areas over 1300 m in elevation) and a lower lying region in Sweden (mostly less than 500 m elevation). In parks, development is nonexistent or limited. What has been happening are three important natural changes caused by the rising of Oxygen-of-Life levels in the air: (1) Flora is growing thicker (horizontal) and in more layers (vertical); (2) Flora is growing at higher elevations; and (3) Those expansions are making more food, clean water, and habitat for wildlife to prosper. The slow but steady effects of Oxygen-of-Life north of Oslo (inner-oblong) and southern Sweden (rectangle) are so remarkable (from brown to green) that even observant humans have noticed the change.

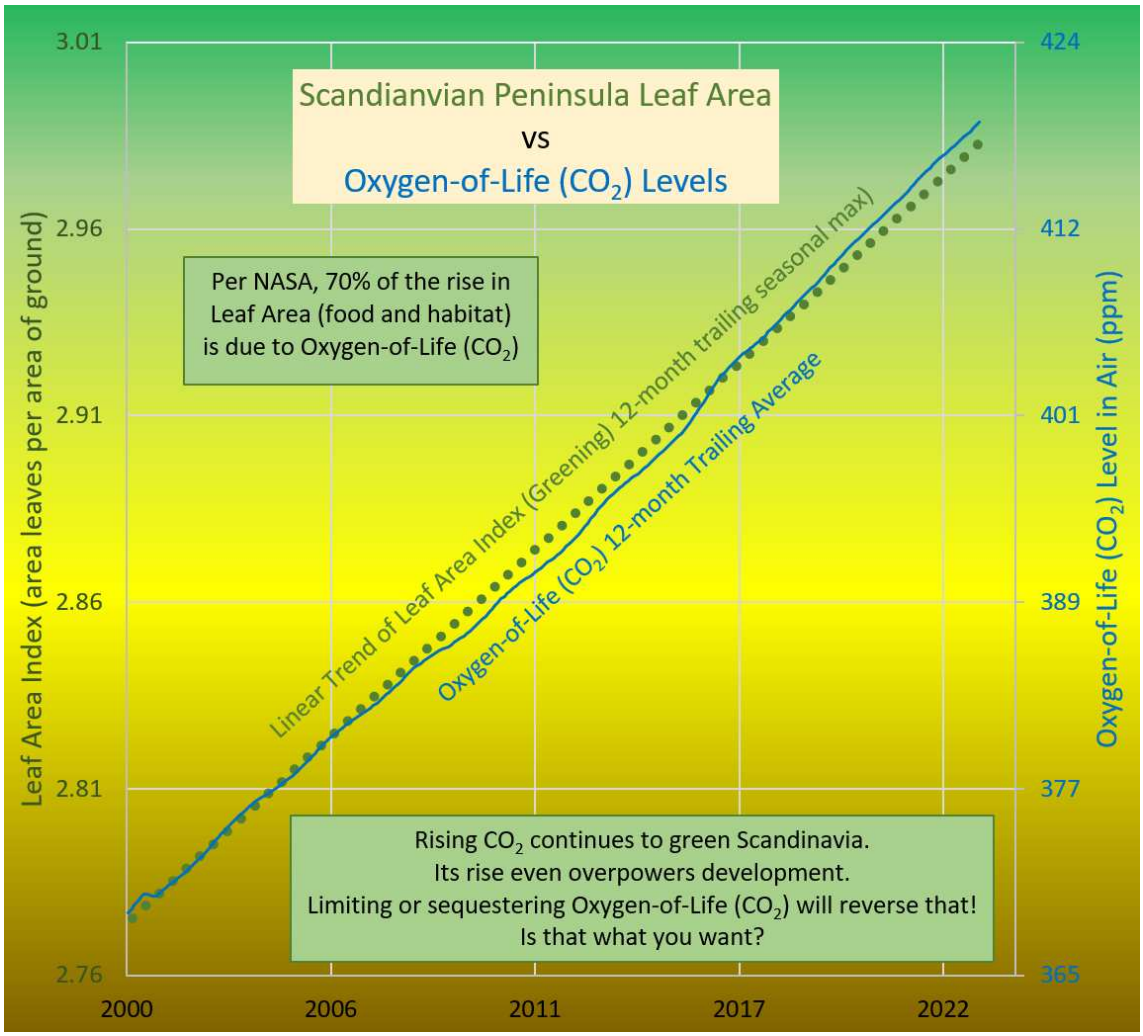


Figure 4: The Leaf Area Index vs Oxygen-of-Life (CO_2) for the Scandinavian Peninsula

Figure 4 shows how the 8% rise in Leaf Area Index (LAI) rose with the 13% rise in Oxygen-of-Life (CO_2) from 2000 through 2023. The left green vertical scale is the LAI for the Scandinavian Peninsula (NASA NEO). The right blue scale is atmospheric CO_2 levels (NOAA). The horizontal scale is all available years: 2000 – 2023. To minimize weather effects, the green line is an area-weighted, regression through the complete 12-month trailing NASA/NEO, Scandinavian Peninsula seasonal maximums LAI time series.

The rise in LAI is likely between 8% and 16% because of the end point, 2023. 2023 had a harsh spring and summer that occurs every 2 to 9 years (characterized by a cold/frosty May and rains pushed to late summer). On a global basis, that cycle occurs about every 3 to 5 years. If 2023 is ignored, the rise would have been 16%. A good rule of thumb is that a 1% rise in Oxygen-of-Life (CO_2) causes a 1% rise in the Leaf Area for the Scandinavian Peninsula.

Imagine how even an 8% increase of the Leaf Area Index helped all wildlife. Imagine how that helped endangered species find more food and more security from predators. Imagine how that helped our crops and our gardens grow more bountiful. Imagine the beauty that created in greener mountains and handfuls of yummy berries as you hike along a woodland trail.

And that 13% rise in the Leaf Area Index is despite development in Norway and Sweden that may convert grass and trees to parking lots, roads, and buildings. That says a lot for the power of Oxygen-of-Life (CO_2) to improve the environment. It also poses an interesting question for development. ***When development occurs, should that be offset by restoring Oxygen-of-Life back to the air so that Oxygen-of-Life can compensate for the loss of green space? This can be easily achieved by passing laws that require the structure to use clean Natural Organic Energy (e.g., natural gas) or electricity generated by clean oil, gas, or coal power stations.*** Do you want policy based on scientific observation or policy based on a theory tailored to support a political narrative proven time after time to brown Earth and kill endangered species?

2.7. Using the Scientific Method to Test the Climate Theory Hypothesis—Tenet One

The tests of hypothesis for the first tenet of climate-change theory used experimental observation as required by the scientific method.

- Earth's biosphere was the laboratory (Eddington's lab to test relativity was the night sky).
- NASA NEO/MODIS satellites took the measurements of the environment—the Leaf Area by time that covered the Scandinavian Peninsula (Eddington/Relativity used cameras to photograph star light). Leaf Area was used because leaves/needles are the basis for all food and habitat used by wild and domestic life. Leaf area is a direct measurement of all flora and directly impacts the potential for all fauna. See Figure 4, dark green line.
- Anthropogenic restoration of Oxygen-of-Life (CO_2) back to the air from where it came was the causal (also called independent) variable (Eddington/Relativity variable was an eclipse). Levels of CO_2 were monitored by NOAA at forty or so marine surface observatories around Earth since 1979 and averaged into a global level. Global CO_2 levels compare quite well with the observations from Mauna Loa Observatory (the famous Keeling curve). See Figure 4, dark blue line.

A regression line was fit (least squares) through 1057 eight-day averages of twelve-month trailing seasonal maximums of leaf coverage; area weighted from a grid of the Scandinavian Peninsula land area represented by 12633 cells (each 40 to 70 square kilometers depending mostly on latitude).

- **Test of null hypothesis (H_0) that CO_2 did <u>not</u> harm the environment.** Rejection would be a t-statistic more negative than **-1.96** to show environmental degradation (a negative slope). But the t-statistic was **+15.9** with a statistically **zero p-value**. Thus, **H_0 not rejected at 100% confidence.**
- **Test of null hypothesis (H_0) that Oxygen-of-Life (CO_2) did not benefit the environment.** Rejection would be a t-statistic more positive than **+1.96** to show environmental improvement. The t-statistic was **+15.9** with a statistically **zero p-value**. Thus, **H_0 rejected at 100% confidence.**

It is impossible for Oxygen-of-Life (CO_2) to have caused harm to the environment when in fact, the environment kept improving as CO_2 levels increased. This conclusion is supported by hundreds of scientific experiments where Oxygen-of-Life (CO_2) levels were varied while measuring the response of about 50 dependent variables that indicate the health of botanic life. The list of those variables is shown in Section 3.1 along with references to about 500 of those scientific experimental studies.

There is ample evidence that Oxygen-of-Life (CO_2) benefits the environment. And no evidence that CO_2 is the cause of harm that even begins to negate its environmental benefit. Oxygen-of-Life also, amazingly enough, more than negated harm to the environment from widespread responsible development. And the evidence suggests that policy should encourage the use of natural organic energy (oil, gas, and coal) as one tool to negate that harm so that humans live in harmony with nature.

3. Discussion

3.1. Why Does Oxygen-of-Life (CO_2) Improve the Environment?

Dr. Sherwood Idso was a pioneer in collecting natural experimental evidence on how Oxygen-of-Life (CO_2) was critical to the growth of grasses, vegetation, and trees. His sons, Dr. Craig Idso and Dr. Keith Idso followed in his footsteps. Sherwood and his sons wrote many books. One in 2011, The Many Benefits of Atmospheric CO_2 Enrichment [238], was a meta study where ***references were deeply discussed in detail*** concerning the benefits and harms of Oxygen-of-Life (CO_2) on flora. Here, that list is summarized, increased, and organized by six types of benefits.

3.1.1. More Oxygen-of-Life Increases Biomass & Leaf Area

- Increases **Net Primary Productivity** of all flora (Figures 5, 6, 8-11)**:** seabed/ground-cover, grasslands, vegetation, sea-kelp, & trees. See references to 60 independent studies. [18-77]
- Increases over-winter **storage proteins** for next-season for a **faster start in growth**. [78-81]
- Raises flora **hormones--stimulates cell division**, **elongation**, **protein synthesis**. [82-87]
- Increases **carbohydrates, denser wood** for **taller/broader structure**. [88-98]
- Increases **Phosphorus** [99-107] and **Nitrogen** [108-125] **nutrient uptake** via enhanced **tap root length**, **lateral root number/size,** and **fine root mass** (Figure 6). 37 studies. [126-162]
- Roots put nutrients/carbon into soils increasing availability of **mineral nutrients**. [163-168]
- Increases the **photosynthesis** rate (Figures 5, 6, 8-11). [169,170,171]

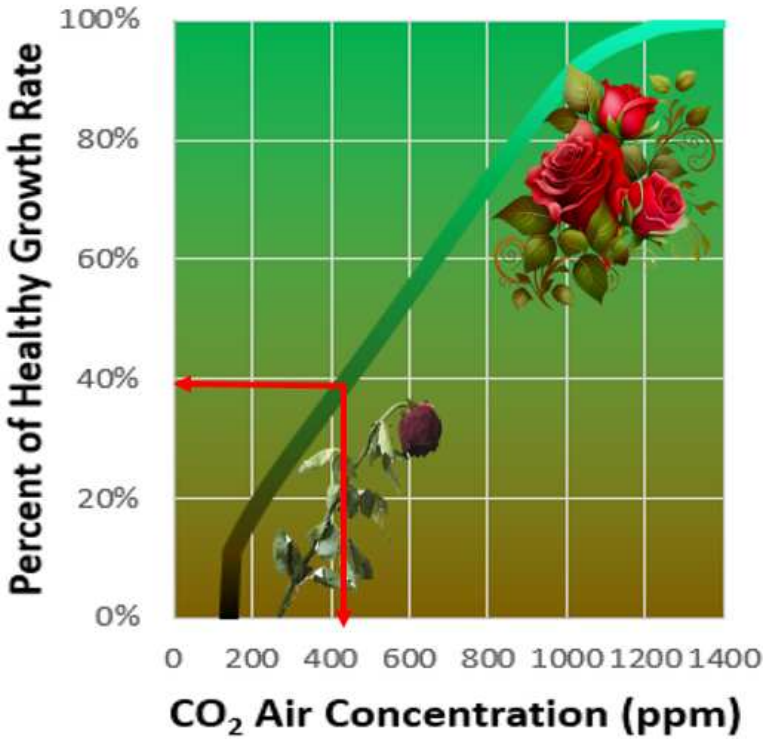


Figure 5: Plots the growth potential plants can reach a various Oxygen-of-Life levels

C3 Type Flora (95% of all biomass) is severely stressed at current CO_2 famine levels (~425 ppm). 100% growth rate occurs at 800 - 2200 ppm (evolutionary CO_2 levels) when plants grew 3x faster. Creating dense canopies for wildlife and endangered species: bountiful food and a secure habitat.

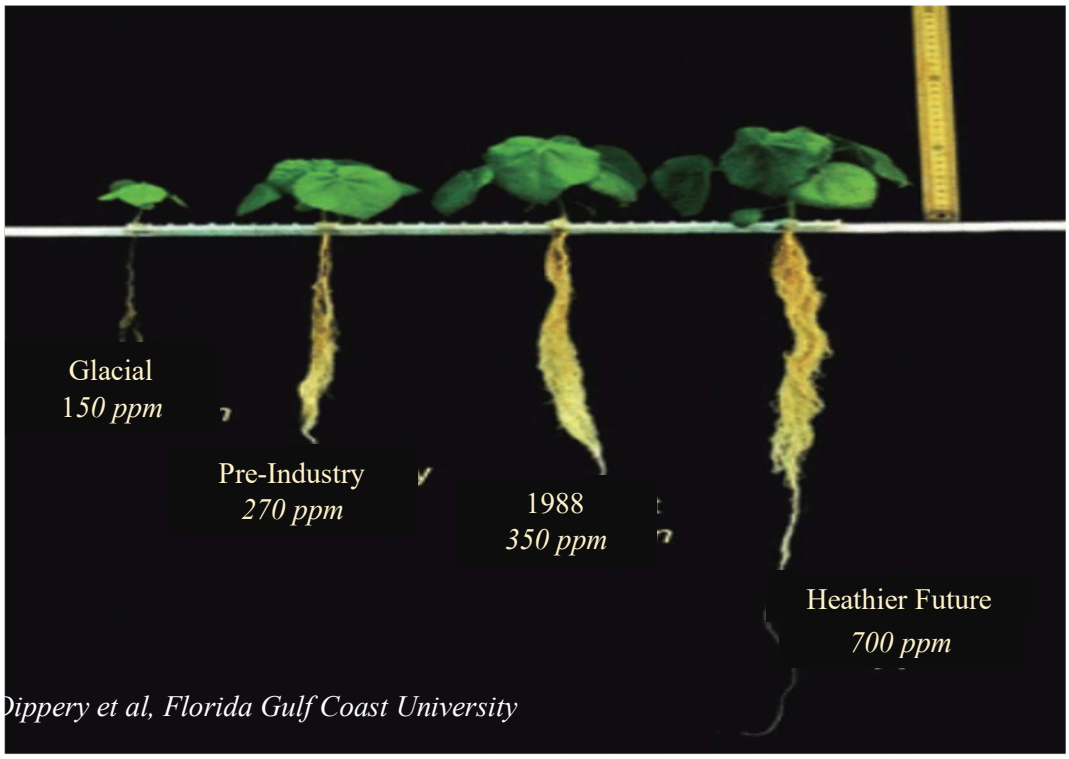


Figure 6: CO_2 Effect on plant and root structure

- Less **erosion** of biologic matter from robust **root & soil structure**. [172-177]
- Enhances **organic matter** in soil for **Earthworms** that aerate soil, provide water drainage, spread nutrients through root networks increasing **enzyme activity** that mitigates toxic soil effects, creates a more **neutral pH** that aids in nutrient uptake. [178-188]
- Increases in some species **Biologic Organic Matter** enhances soil (Figure 7). [189, 190,191]
- Increases **habitat** via beneficial **soils** and anaerobic water **bacteria** (Figure 7). [192-202]
- **Legumes/soil bacteria** symbiotic relationship. Stimulates **nitrogen** fixation (fertilizer) in soils. [203-225]

Figure 7: Oxygen-of-Life Creates Healthy Soil & Soil Organisms Like Earthworms

- **All canopy layers benefit**. Makes the photosynthesis process more efficient. Lower-level plant canopies in less light are able to compensate. [226-237]
- All adding up to a huge increase in **biomass** (Figures 5, 6, 8-11). And read, The Many Benefits of Atmospheric CO_2 Enrichment, by Craig Idso and Sherwood Idso. [238]
- And adding up to increased **biodiversity**. [239-244]
  - Biodiverse relationships are strengthened. [245,246,247]
  - Increased nutrients make room for **niche lifeforms** (some dormant). [248,249]
  - Restores genetic biodiversity that couldn't compete at unhealthy CO_2 levels. [250-257]

Figure 8: How Famine Levels of Oxygen-of-Life Affect the Growth of Life

This timelapse video shows the effect of healthy levels of Oxygen-of-Life on all life—showing flora growth timelapse on land and in saltwater. All conditions were identical except the Oxygen-of-Life (CO_2) levels. One was at existing Oxygen-of-Life levels and the other was at much-higher and healthier levels. Each timelapse shows daily growth of plants at low and healthy Oxygen-of-Life levels over a span of a few weeks. We've grown up with no appreciation of what Oxygen-of-Life does. We assume that what we see in nature is normal. But these timelapse comparisons are a wakeup call. They show the unbelievable effects Oxygen-of-Life has on both land and marine plant growth when those levels are restored to where they used to be and need to be. They clearly show that Oxygen-of-Life is currently at famine conditions. It also shows the huge effect that Oxygen-of-Life has on the growth of trees. ***A must-see shocking video.***

https://youtu.be/_rDeAO-BcE8

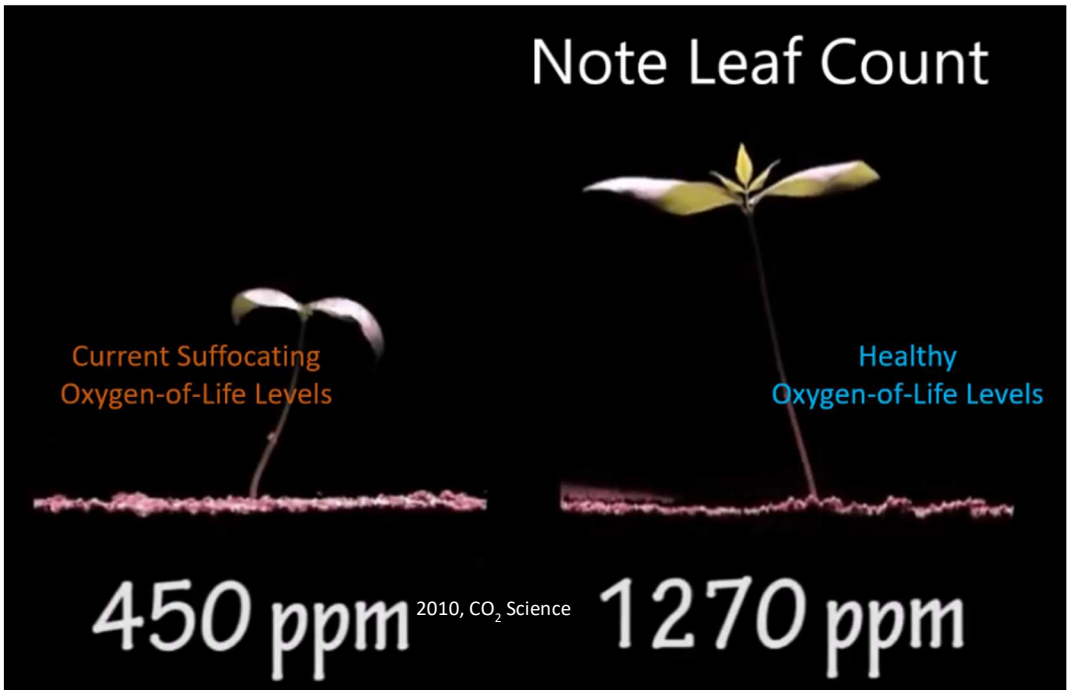


Figure 9: How famine levels of Oxygen-of-Life affect terrestrial growth

The left pane shows a Chick Pea grown near existing levels of Oxygen-of-Life (CO_2). On the right, stem/leaf structure doubles/triples at healthy Oxygen-of-Life levels. On the left is a plant susceptible to attack from pests and stresses. A small attack is more likely to result in death.

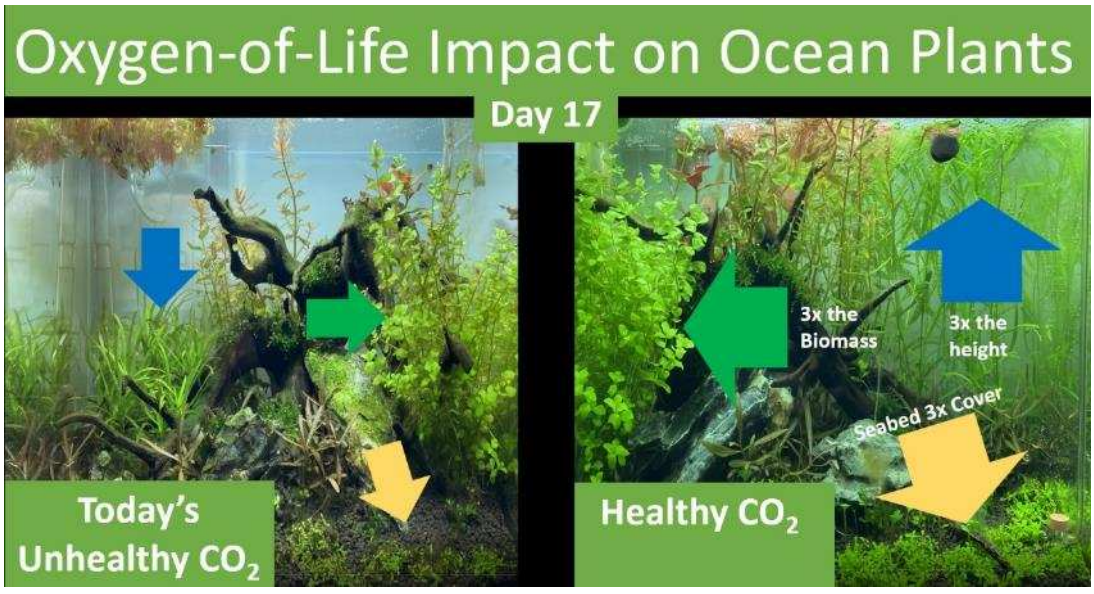


Figure 10: How Famine Levels of Oxygen-of-Life (CO_2) Affect Marine Food for Sea Life

The left is a saltwater tank at existing Oxygen-of-Life (CO_2) levels after 17-days of growth. The right started out exactly like the left tank, but at healthy levels of Oxygen-of-Life. The tank at higher Oxygen-of-Life levels ended up with three times the biomass. Imagine all the sea life cut short by climate activists cutting back on Oxygen-of-Life (CO_2). Murdering billions of marine animals. Unimaginable devastation. They are worse than whale hunters.

Figure 11: How famine levels of Oxygen-of-Life affect tree growth

The left shows a Pine tree near existing levels of Oxygen-of-Life. Because we don't know any better, we think that it's normal for a Pine tree to grow three feet in a year. But at healthy levels of Oxygen-of-Life, a Pine tree grows six feet in one year! Can you imagine living in a time where such miracles are normal?

Think of the billions of animals that Climate Activism has killed from limiting Oxygen-of-Life. Think about how that reduced the habitat for endangered species. First agricultural Lysenkoism killed over 30 million people (they starved to death) between 1925 and 1965. [258,259] Now, Lysenkoism has turned a science where questions can't be answered into a science where answers can't be questioned (Feynman). As a result, Climate Lysenkoism has quietly killed wildlife in the billions. ***Compassionate people find that sickening and sad!***

Thanks to Dr. Sherwood Idso, some paid attention to his work
and are doing everything possible to stop the killing.
What side are you on?

3.1.2. More Oxygen-of-Life Makes Flora More Stress Resistant

- Because the stomata are fewer, smaller, and with less open area (narrower) over time:
  - There is **less water loss** (Figure 12). Thus, plants flourish in dry regions. [260-320]
  - **Pollutant** [321-324] and **ozone** [325,326] stress is less (Figure 12) [327-344]
  - There is less access for the **germ tubes of fungal pathogens** (Figure 12). [345]
- Enhances plant physiology, anatomy, morphology—resists/counters **disease effects**. [346-358]
- Decreases fluctuating **asymmetry** making plants less susceptible to **herbivore attack**. [359-362]
- Increased **glomalin** enhances **soil stability**, decreasing **toxic soil** elements. [363-367]

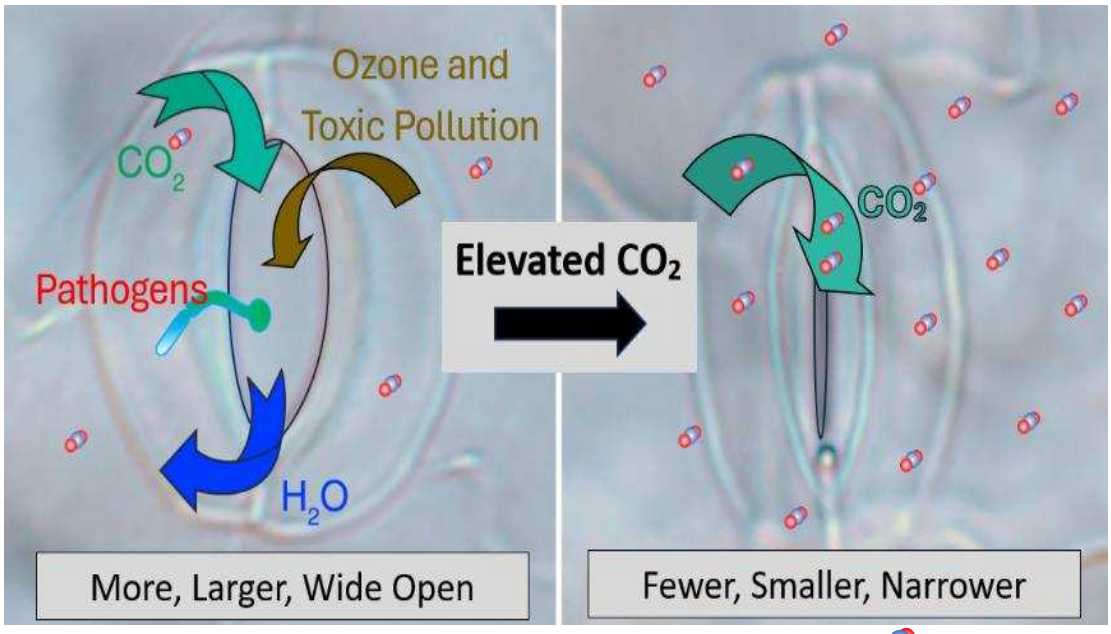


Figure 12: Stomata, the mouth of plants at normal and elevated CO_2 ( ) levels

*Flora uses small openings (stomata), usually under a leaf, to breathe in Oxygen-of-Life (CO_2). **When CO_2 levels fall, stomata numbers must increase and stay open longer.** Thus, (1) Water vapor escapes, making the plant less tolerant to drought, wildfires, and quasi-desert conditions. (2) Pathogens, like fungal germ tubes, can enter through the larger openings. (3) More airflow through the stomata lets in more ozone and pollutants.*

- Helps plants withstand **natural toxins** in the soil. [368,369,370]
- Likely reduces **isoprene** that creates tropospheric **ozone** that stresses flora. [371-381]
- More **monoterpenes** are dispersed in forests: counters **heat stress**, aids in plant healing from **herbivore** (plant eater) damage, and attracts **predators of herbivores**. [382-388]
- More resistant to **high-salinity** (salt) soil. [389-405]
- A powerful treatment for stress-induced problems in **thylakoid membranes** of chloroplasts (the photon/sunlight-to-electron transport tissue). [406-410]
- Increases **tannins** in leaf and fine-roots that protect from predation by voracious **insect herbivores** and from **soil-borne pathogens/herbivores**. [411-425]
- It can more than compensate for **heat** and **UV stress**. [426-438]
- **Biologic Organic Compounds** can aerially spread deterrents against pathogens/herbivores. [439]

3.1.3. More Oxygen-of-Life Increases Flora Reproduction

- Most plants generally produce more and larger **flowers**, attracting more pollinators. [440,441]
- **Nectar** production increase raises the attractiveness of flowers to **bees/pollinators**. [442,443,444]
- Increases **seed** biomass, yield, and germination. [445-458]

3.1.4. More Oxygen-of-Life Enhances Life and Prevents Extinction

- Creates **oxygen** for animals. Phytoplankton creates oxygen for marine life. Terra-flora creates oxygen for land animals (Figures 13 and 14). The relationship between Oxygen-of-Life (CO_2) and life was found by Joseph Priestley. [459] One experiment used a glass bell (Figure 13). He surmised that plants restore oxygen consumed by a burning candle. Unfortunately, he became too religious about theory and was left behind. A lesson for climate theorists? Jan Ingenhousz, in 1796, furthered the discoveries of Priestley and discovered photosynthesis. [460] He saw bubbles form on aquatic plants in sunshine but not at night (Figure 14).
- Means longer **lifespan.** An extended growing season and food production rate benefits flora, bacteria, wildlife, endangered species, the poor, and people subsisting off the land. [461,462]
- Creates more **food for herbivores** (aphids to elephants) for faster **animal growth**. [463-469]
- Enriches the quantity and potency of **food benefits**. [470-482]
- Enriches the quantity and quality of healthy **fatty acids** called lipids. [483-490]
- Increases plant **medicinal qualities** [491-504] to fight tumors, cancers, fevers, and heart disease.
- Avoids **extinction.** Keeps Oxygen-of-Life above the extinction threat level of 150 ppm. [512]

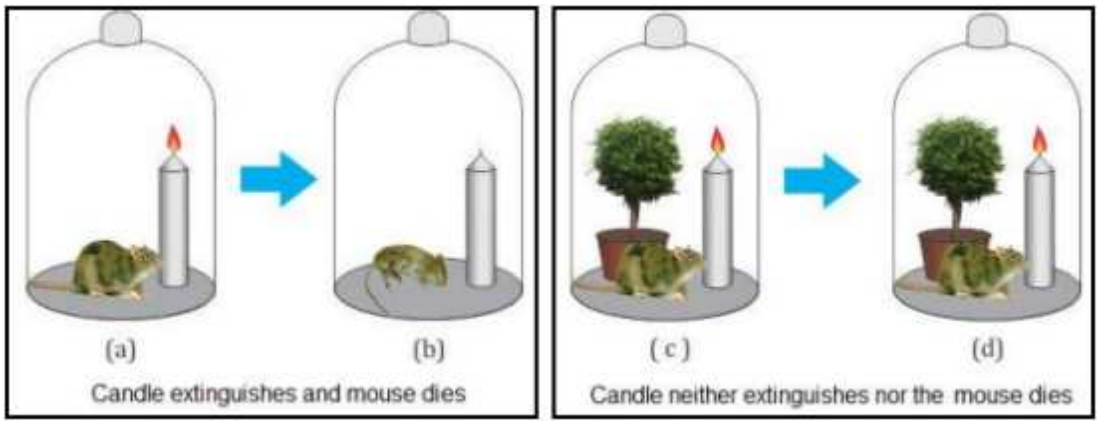


Figure 13: The mouse that died (Topper Learning)

(a) Joseph Priestley found that a burning candle would get extinguished in a closed bell jar.
(b) Similarly, a mouse kept in a closed bell jar would soon suffocate and die.
(c) However, if a mint plant was placed in the jar,
(d) neither the candle would get extinguished nor the mouse died. The plant also grows.

Joseph concluded that the plant restores the air removed or consumed by the candle or the mouse. Another great example of using the scientific method to verify theory via experimental observation of nature.

No other experiment more clearly showed the importance of the critical relationship between flora and fauna. We … all animal life depends on flora! So why are we killing flora? The insanity of such misguided logic baffles healthy minds. Are they doing to themselves what they are doing to plants—breathing less oxygen?

Figure 14: Oxygen being produced by an aquatic plant

Later, Jan Ingenhousz demonstrated that in bright sunlight, small bubbles formed around the green parts of an aquatic plant. In the dark, no such bubbles were formed. The bubbles were found to be oxygen. Plants with Oxygen-of-Life (CO_2), water, and sunlight is what produces the foundation for all life on Earth! More ***food and Oxygen*** *for us (Figure 15).*

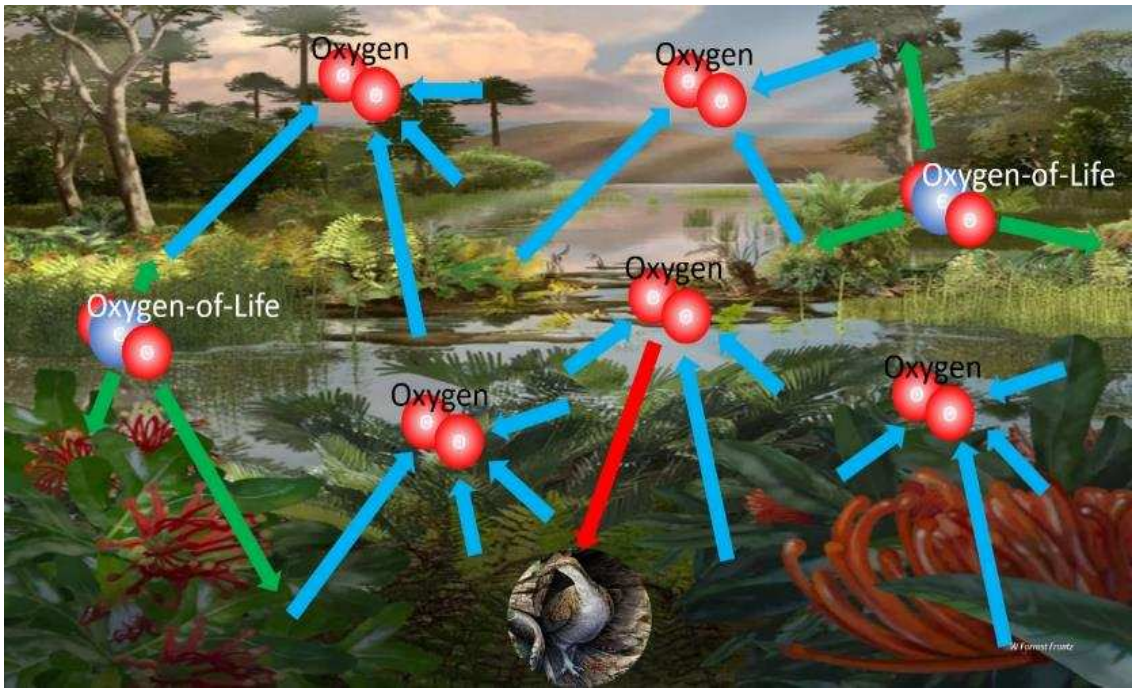


Figure 15: More Oxygen-of-Life means more Oxygen for us

Evolution was strongest when Oxygen-of-Life exceeded 1200 ppm—3x times today's level.

3.1.5. More Oxygen-of-Life Increases the Negative Thermal-Feedback Caused by Flora

- The increased area of leaves shades more ground area (Figure 16 and 17). This lowers ground temperatures. Figure 17 shows normal vs infrared light where leaf and needle shading can massively reduce the temperature of the ground. The result is much less longwave radiation emitted by the ground that would have heated the air. [507] Shade cools! Are you even remotely surprised by that? And if not, ask yourself why don't climate activists account for this in their models? And is this why their models are notoriously inaccurate?
- Photosynthesis **converts hot solar photons to sugars**–a cooling reaction that prevents photons from heating the air. See Figure 16 of the sun, leaf, shade, and sugars below. When earth gets too warm, plants grow and cool. Thus, a **negative-feedback when it's too warm.**
- If too cold, flora levels drop. But Active-IR effects still warm. Thus, a **negative-feedback when it's too cold.** When both negative feedbacks are considered, CO_2 stabilizes climate change.
- Anthropogenic Oxygen-of-Life is created along with **invisible** and **odorless aerosols** that **reflect** incoming solar **photons** or help form **clouds** that reflect incoming solar photons.
- **Iodocompounds** from marine flora help create **clouds** that reflect solar photons. [508-510]

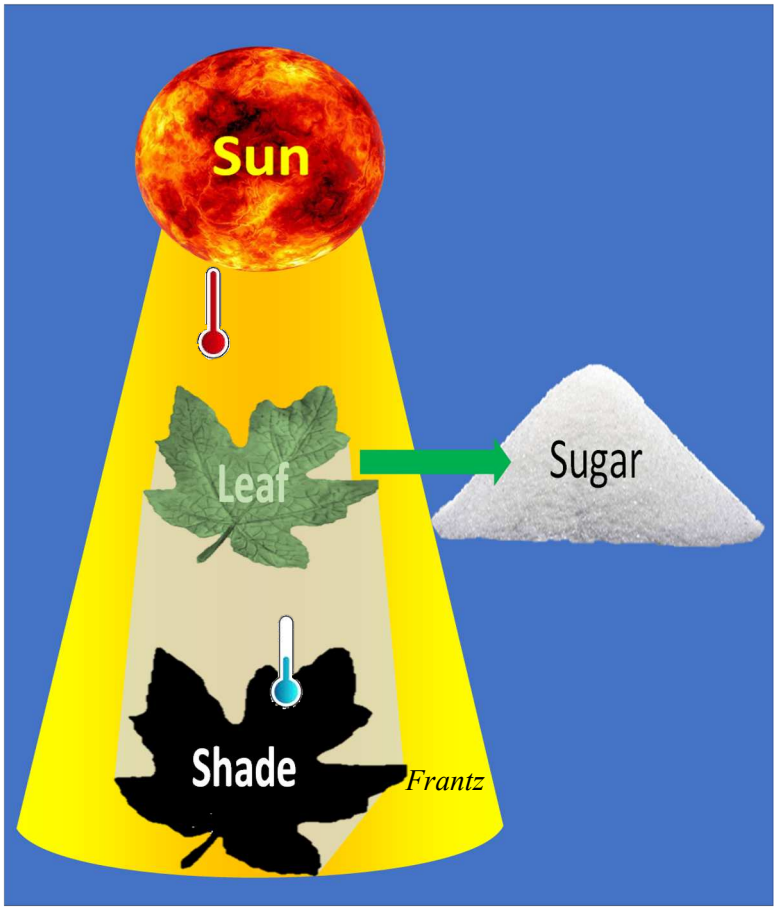


Figure 16: One theory on why leaves cool

Solar irradiation (photons) normally hits and heats up earth. That heat is emitted as longwave IR that heats the air. ***But the leaves of flora intercept incoming hot solar irradiation****. The ground no longer heats up. And the photons are used up in an endothermic (cooling) reaction—photosynthesis. Some of the lost heat returns later when plants decompose (but the delay still causes net cooling). And not all heat is returned. Some ends up as soil or seabeds.*

Albedo used extensively in climate models does not take photon absorption by photosynthesis into account! This author imagines (theorizes) that photon absorption delays heat transfer (just like its Active-IR effect, but in reverse). And when powerful enough, the climate cools to reach a new equilibrium. Now observed more intensely and more often as Oxygen-of-Life levels have risen.

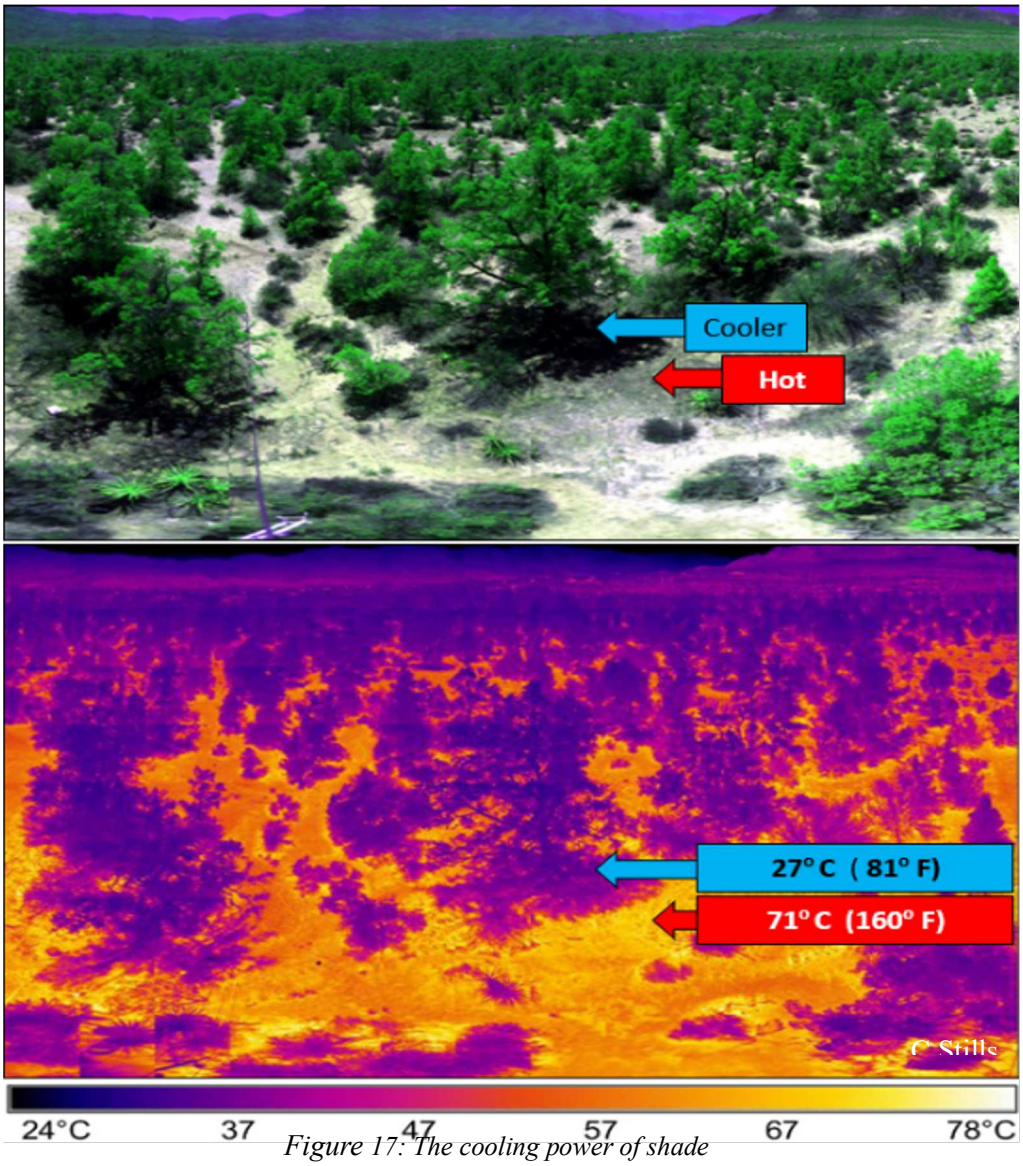


Figure 17: The cooling power of shade

In a desert pine forest, the power of shade to cool is shown in the lower panel of an infra-red image. ***A 44º C difference*** *(nearly 80º F) in soil temperature only one meter away!*

Others imagine (theorize) that cooling is from flora transpiration or cloud formation. It is the opinion of this author that those mostly affect regional climates by causing a quasi-permanent change in regional ***latent, convection, and sensible*** heat transfers. But global climate only changes with a change in heat transfer, via ***radiation***, between space and the atmosphere. Photon absorption during photosynthesis does that. In addition, when Earth has enough Leaf Area, that Green Effect counters and then overturns its Active-IR effect. An ultimate negative-feedback needed for a stable climate. As will be shown when testing the 2nd tenet of climate-change theory, that switch occurred in 1974.

3.1.6. More Oxygen-of-Life Counters the Harm of Sequestering Oxygen-of-Life (CO_2)

- Plants naturally remove Oxygen-of-Life from the air and that process can return CO_2 to the air. Permanent removal of CO_2 from the air is harmful because it's the source of all life.
- In many cases CO_2 is removed from the air, stored in tissue, then in the soil, and ultimately in the depths of the seas, where it turns into natural organic material. Some of which can be returned to the air by using that natural organic material as a source of energy.
- Is one role of humans to restore CO_2 back to the air that was buried in the depths of the seas and lakes? Environmentalists in the energy sector were extremely good at making gas cars and coal and gas powerplant clean (basically zero sulfurs, carbon monoxide, and nitrates). So good that environmental attorney Michael Buschbacher said in March 2024, "Today's cars are so clean that … net particulate matter, in general, is significantly higher for EVs [electric vehicles]." Climate protagonists are doing the opposite. They route your tax dollars to open pit mining of metals required to put in new infrastructure when those funds should be used to upgrade utility plants to the extraordinarily clean systems now available to eliminate real pollution.
- Why are we doing this to our green leafy friends? Imagine reversing roles. Humans breathe in oxygen. Through the respiration process, oxygen breaks down (oxidizes) food (glucose), which is converted to energy. As a result, we exhale CO_2. If sealed in an airtight room (like Earth), we'd soon run out of oxygen and die like the mouse in Figure 13. Fortunately, our beautiful green leafy friends breathe that Oxygen-of-Life and exhale Oxygen. So ***how would you feel if plants banned together and decided to sequester oxygen in the soil instead of breathing it out to the air?*** Based on the imagination of theoreticians, why are politicians endorsing policy that kills flora and wildlife and can even exterminate all life on Earth?

3.1.7. Oxygen-of-Life Increases Flora—the Cornerstone of Biological Diversity

- Flora grows faster/bigger/healthier increasing food/water/shelter for wildlife. [511-518]
- Plants that grow taller or thicker increase wildlife reproduction. [519-536]
- Plants that grow faster increase wildlife reproduction and security after wildfires. [537]

3.1.8. More Oxygen-of-Life Reverses Harms of Deforestation that Endangers Wildlife

- Oxygen-of-Life greens Earth making more habitat for wildlife. Section 2.6.
- Deforestation harms wildlife. [538-552]

3.2. Net-zero and The Great Green Collapse

Net-zero is when humans sequester (store) as much Oxygen-of-Life (CO_2) as they generate. Contrary to what media says about CO_2 lasting in the air for hundreds of years, the IPCC's own formula and more accurate formulas for CO_2 lifetime-in-the-air are clear. [553] Without humans restoring CO_2 to the atmosphere, in less than half a human lifetime, CO_2 will revert to 350 to 370 ppm. Combine that with the coming glacial maximum and CO_2 could drop to 150 ppm where photosynthesis stops and all terrestrial life goes extinct. [554] This is how natural processes remove Oxygen-of-Life from air:

- Cooling seas absorb CO_2. 99% of that CO_2 is converted to bicarbonate and carbonate ions. [555] CO_2 partial pressure effects between sea and air are small because only 1% of CO_2 in the ocean remains as CO_2. Thus, sea temperature remains the dominant factor in dissolved CO_2. If sea temperatures drop, CO_2 will be absorbed despite dropping CO_2 air levels. [556]
- Creation of soil and peat is nearly permanent in removing CO_2 from the air. [557]
- Less outgassing from less flora, wildlife, and forest fires will further reduce CO_2. [558]
- Declining trees and flora will compete to use the remaining CO_2, causing further decline.

The IPCC formula accounts for those factors plus the ways CO_2 would be naturally added to the air. Raising atmospheric CO_2 levels is like riding a bike up a hill. Stop peddling and the return trip back down is rapid. A century of good works that greened the world, undone in half of our lifetime!

Have natural levels of CO_2 in the past million years been healthy? Hell no. 200 million years ago the biosphere CO_2 levels were healthy (far more than twice the unhealthy levels of today). Even the IPCC knows that current Oxygen-of-Life (CO_2) levels are low and are not healthy. This is a quote from the IPCC official report on the CO_2 Cycle. "On land, experiments have repeatedly shown that current CO_2 concentrations are limiting to plant growth". [559] Figures 8/10 also prove that for marine flora.

So apparently, net zero is mankind's goal to create an atmospheric famine by stopping the restoration of Oxygen-of-Life (CO_2) back to healthy levels. The restoration of Oxygen-of-Life (CO_2) back to the air from where it came is hard and heroic work. But it is also brilliant. It is using natural organic energy as the least expensive source of all heating, cooling, and transportation when doing so also results in the greatest environmental benefit. If we stop the hard and heroic *uphill* push of restoring Oxygen-of-Life (CO_2) back to the air, "***The Great Green Collapse"*** will be quick and devastating. In just half a lifetime of net zero policy, Oxygen-of-Life could crash to 350 to 370 ppm and the green index of Scandinavia would revert to looking like the right pane in Figure 18.

The habitat and food supply for all wildlife we've worked so hard to *create would be destroyed*. The toll on flora and animal life *would be devastating*. Please fight for the restoration of Oxygen-of-Life (CO_2). Back to the air. From where it came. To where it belongs. To where it's needed.

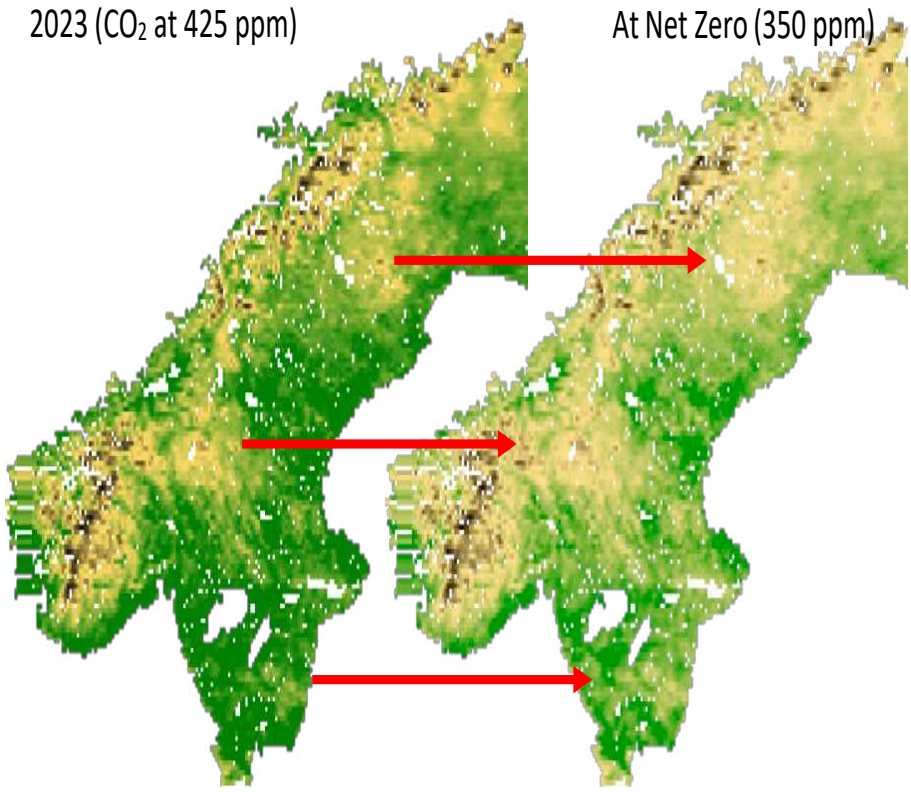


Figure 18: Most likely result if net-zero plunges Oxygen-of-Life to ~360 ppm

If net-zero is achieved, a century of environmental gains made by restoring Oxygen-of-Life back to the air will disappear in what will seem like a few quick years. The wildlife death toll will exceed billions upon billions. A painful death from ***starvation****!*

Figure 19: "This is what starvation looks like."
National Geographic

In 2017, National Geographic published this image. And blamed the cause on CO_2. But the National Geogrphic, an outstanding science journal that isn't immune to human error, set an example and admonished itself. It explained that the real cause of the immense pain seen in this horrific photo of a suffering polar bear barely able to drag itself on its knees, was ***starvation****. Please. Stop limiting and removing Oxygen-of-Life from the air. It is what creates all food for wildlife. Stop the suffering. Don't let wildlife starve! Help restore Oxygen-of-Life back to healthy levels. Stop this insality. Help us green the Earth and support wildlife.*

4. Conclusion

Oxygen-of-Life (CO_2) greened the Scandinavian Peninsula and the World. Without doubt, rising Oxygen-of-Life improves the environment. [560-566] See Section 2.7 for the hypothesis tests. The first tenet of Climate-Change theory is proven to be inconsistent with observation of the natural world.

Newtonian Theorists (pre-Einstein)	Climate-Change Theorists
Physicists correctly theorized that light could be bent by gravity.	Climate physicists correctly theorized that CO_2 could warm the air.
But they failed to take into account an indirect effect that gravity had on light—that Gravity also displaces space itself that light follows. That error lasted about 150 years.	But they failed to take into account an indirect photosynthesis effect—that cools Earth by using up "hot" sunrays, water, and Oxygen-of-Life (CO_2) to make sugars for the food and habitat of wildlife.
Thus, they could never explain the perceived orbit of Mercury that was also affected by the sun's gravitational displacement of space.	Thus, they could never explain why Earth greened and cooled after large increases in Oxygen-of-Life (CO_2).
Proven wrong when Eddington used natural observation during a solar eclipse.	Proven wrong [1-6,12-15] by observing CO_2 changes and the greening/cooling that followed.

Figure 20: The mistake of climate physicists was the same that was made by Newtonian physicists

***NASA & NOAA**: "Scientists say the world would be even warmer if not for a surge in plant growth."[567] "… cooling effect would be -0.3 degrees Celsius (-0.5 F) globally and -0.6 degrees C (-1.1 F) over land."[568] "… significant greening over the last 35 years [70% is] due to rising levels of atmospheric CO_2."[569] "Has plant growth increased alongside rising levels of CO_2 in the atmosphere? It turns out the answer is Yes – in a big way."[570]*

Scandinavian and worldwide greening (also a 6% rise) are the result of a wise human legacy of raising Oxygen-of-Life levels to cause vast increases in food/shelter for wildlife. Climate theorists are trying to force us back into the Little Ice Age, while the increase in Oxygen-of-Life and natural warming since then has greatly benefitted all flora and fauna. The evidence? Greening has strongly continued in the past two decades in Scandinavia and worldwide. In a bit over two decades, Oxygen-of-Life rose 13%. That was the primary cause of the Leaf area of the Scandinavian Peninsula to rise 8% to 16%.

Use your vote to help end misguided politics. Send a message. "While I love much of what you do, I'm withholding my vote until you drop this misguided attack on our biosphere." They don't think you have the guts. They think they own your vote. Are they right? Our trees and wildlife need you to have courage because you are their voice.

***Note on Ending Climate Lysenkoism:** Not once in this report was the common term for CO_2 that infers "die from sooty rust" used. Instead, a new name for CO_2 was declared, "Oxygen-of-Life". It was repeated and repeated. If used enough by everyone trying to prevent the browning of Earth, maybe these ecoterrorist acts against life will stop and never again recur. Please join me in repeating and repeating Oxygen-of-Life. If nothing else, you'll get a good rise out of climate protagonists. And maybe even get them to pause and reflect.*

Acknowledgements

I thank a STEM ambassador (an astro-geobiologist) for asking me to apply the scientific method (comparing theory against natural experimental observation) to each of the four climate-change tenets. I also thank all twenty plus climate centers for open access to their data: NOAA, NASA, Hadley Met Centre, Tokyo Climate Center, China, Berkeley Earth, Remote Sensing Systems, University of Alabama Huntsville, NASA Earth Observatory, Copernicus, Woods Hole Oceanographic Institute, Mauna Loa Observatory, Scripps, South Pole Observatory, American Samoa Observatory, Barrow Alaska Observatory, NOAA STAR, Naval Research Lab, University of Colorado, National Centers for Environmental Information, and the Environmental Protection Agency. ***Not one of those institutes had observations of the natural environment that supported any of the four climate-change tenets.*** When Einstein's theories were tested, 73% were found to be correct. Climate-change theoreticians are zero for four. One of my goals is to put together a $10M USD award for anyone that can find observations that support any of the four tenets proposed by climate theoreticians. It's time for climate protagonists to put their money where their mouth is.

Funding. No external funding for the work.

Figures. The source of the public information is referenced or is art from the author.

Editor: Jan-Erik Solheim Reviewers: Anonymous.

Citation. Forrest Frantz, 2023, Science of Climate Change, Vol..3.5, *The Greening of Scandinavia,* https://www.doi.org/10.53234/scc202310/37

References

1 Soares, PC, 2010: *Warming Power of CO2 and H2O: Correlations with Temperature Changes.* International Journal of Geosciences, 1(03):102-112. doi:10.4236/ijg.2010.13014. https://www.scirp.org/journal/paperinformation?paperid=3447

2 Humlum, O, Stordahl, K, and Solheim, J-E, 2013: *The phase relation between atmospheric carbon dioxide and global temperature.* Global and Planetary Change, 100, 51-69. http://dx.doi.org/10.1016/j.gloplacha.2012.08.008

3 Ruzmaikin, A, Byalko, A, 2015: *On the Relationship between Atmospheric Carbon Dioxide and Global Temperature.* American Journal of Climate Change, 4, 1181-186. http://dx.doi.org/10.4236/ajcc.2015.43014

4 Jackson Davis, W, 2017: *The Relationship between Atmospheric Carbon Dioxide Concentration and Global Temperature for the Last 425 Million Years*. Climate 5(4), 76 https://doi.org/10.3390/cli5040076

5 Frantz, WF, 2023: *Climate Change Theory Versus Reality.* ASIN: B0C2NLLVMH. https://www.amazon.com/dp/B0C2NLLVMH

6 Koutsoyiannis, D, Kundzewicz, ZW, 2020: *Atmospheric Temperature and CO2: Hen-Or-Egg Causality?* Sci 2020, 2(4), 83. https://doi.org/10.3390/sci2040083

7 Carnegie Mellon Encyclopedia of the History of Science: *Lysenkoism.* https://ethos.lps.library.cmu.edu/article/id/560/

8 Quote Investigator. https://quoteinvestigator.com/2013/01/01/einstein-imagination/

9 Brittanica: *Albert Einstein German - American Physisist, From graduation to the miracle year of scientific theories of Albert Einstein*. https://www.britannica.com/biography/Albert-Einstein

10 Ball, P, 2005: *Claiming Einstein for Chemistry.* Chemistry World, Aug 24. https://www.chemistryworld.com/news/claiming-einstein-for-chemistry/3001015.article

11 Krauss, L, 2015: *What Einstein Got Wrong.* Scientific American, Sept. https://www.scientificamerican.com/article/what-einstein-got-wrong/

12 NASA Earth Observation 2023: *Leaf Area Index.* https://neo.gsfc.nasa.gov/view.php?datasetId=MOD15A2_M_LAI

13 Copernicus Global Land Service 2023: *Leaf Area Index.* https://land.copernicus.eu/global/products/lai

14 NASA MODIS, R Myneni, 2023: *MODIS Leaf Area Index/FPAR.* https://modis.gsfc.nasa.gov/data/dataprod/mod15.php

15 NASA Explore, 2023: *Planetary Defense, Supporting Documents.* https://science.nasa.gov/planetary-defense-supporting-documents/

16 Prentic, IC, et al., 2018: *The Carbon Cycle and Atmospheric Carbon Dioxide.* IPCC AR3 Section 3.2.2.4. https://www.ipcc.ch/site/assets/uploads/2018/02/TAR-03.pdf

17 Stroke Symptoms, 2023: *Maslov's Hierarchy of Needs.* https://www.stroke.org/en/stroke-connection/stroke-onward/rebuilding-identity--a-critical-step-in-recovery/maslows-hierarchy-of-needs

18 Johnston, MC, 1963: *Past and Present Grassland of Southern Texas and Northeastern Mexico.* Ecology, Vol. 44, No3, 456

19 Scifres, CJ, 1980: *Brush management: principles and practices for Texas and the Southwest. Brush management: principles and practices for Texas and the Southwest.*

20 LaMarche, VC, Graybill, DA, Fritts, HC, Rose, MR, 1984: *Increasing Atmospheric Carbon Dioxide: Tree Ring Evidence for Growth Enhancement in Natural Vegetation.* Science 225, 1019–1021. https://doi.org/10.1126/science.225.4666.1019

21 Graumlich, LJ, Brubaker, LB, Grier, CC, 1989: *Long-Term Trends in Forest Net Primary Productivity: Cascade Mountains, Washington.* Ecology 70, 405–410. https://doi.org/10.2307/1937545

22 Abrams, MD, Orwig, DA, 1995: *Structure, radial growth dynamics and recent climatic variations of a 320-year-old Pinus rigida rock outcrop community.* Oecologia 101, 353–360. https://doi.org/10.1007/BF00328822

23 Hornbeck, JW, Smith, RB, Federer, CA, 1988: *Growth trends in 10 species of trees in New England, 1950–1980.* Can. J. For. Res. 18, 1337–1340. https://doi.org/10.1139/x88-206

24 West, DC, 1988: *Detection of forest response to increased atmospheric carbon dioxide. Carbon dioxide and climate: Summaries of research in FY 57.*

25 Busing, RT, 1989: *A Half Century of Change in a Great Smoky Mountains Cove Forest.* Bulletin of the Torrey Botanical Club 116, 283–288. https://doi.org/10.2307/2996817

26 Kienast, F, Luxmoore R, 1988: Tree-Ring Analysis and Conifer Growth Responses to Increased Atmospheric CO_2 Levels. Oecologia, vol. 76, no. 4, 1988, pp. 487–95. JSTOR, http://www.jstor.org/stable/4218704

27 Jacoby, GC, 1986: *Long-term temperature trends and a positive departure from the climate-growth response since the 1950s in high elevation lodgepole pine from California.* Proceedings of the NASA Conference on Climate-Vegetation Interactions (Boulder, CO: University Corporation for Atmospheric Research), pp. 81–83.

28 Graybill, DA, 1986: A network of high elevation conifers in the western US for detection of tree-ring growth response to increasing atmospheric carbon dioxide.

29 Jozsa, LA, Powell, JM, 1987: *Some climatic aspects of biomass productivity of white spruce stem wood.* Can. J. For. Res. 17, 1075–1079. https://doi.org/10.1139/x87-165

30 Hornbeck, JW. 1987: *Growth patterns of red oak and red sugar maple relative to atmospheric deposition*. EPA Publications of the Forest Response Program, pp. 277-282

31 Graybill, DA, Idso, SB, 1993: *Detecting the aerial fertilization effect of atmospheric CO2 enrichment in tree-ring chronologies.* Global Biogeochemical Cycles 7, 81–95. https://doi.org/10.1029/92GB02533

32 Becker, M, 1989: *The role of climate on present and past vitality of silver fir forests in the Vosges mountains of northeastern France.* Can. J. For. Res. 19, 1110–1117. https://doi.org/10.1139/x89-168

33 Björkdahl, G, Eriksson, H, 1993: *Effects of crown decline on increment in Norway spruce (Picea abies (L.) Karst) in southern Sweden.*

34 Falkengren-Grerup, U, Eriksson, H, 1990: *Changes in soil, vegetation and forest yield between 1947 and 1988 in beech and oak sites of southern Sweden.* Forest Ecology and Management 38, 37–53. https://doi.org/10.1016/0378-1127(90)90084-O

35 Hari, P, Arovaara, H, Raunemaa, T, Hautojärvi, A, 1984: *Forest growth and the effects of energy production: a method for detecting trends in the growth potential of trees.* Can. J. For. Res. 14, 437–440. https://doi.org/10.1139/x84-077

36 Hari, P, Arovaara, H, 1988: *Detecting CO2 induced enhancement in the radial increment of trees. evidence from northern timber line.* Scandinavian Journal of Forest Research 3, 67–74. https://doi.org/10.1080/02827588809382496

37 Eichkorn, T, 1986: *Growth analyzes on spruce trees in southwest Germany.* Allgemeine Forstzeitschrift, 13: 711-717.

38 Glatzel, G, et al, 1987: *Nutritional disorders in spruce as a complex effect of needle damage and increased nitrogen deposition - a mechanism of forest dieback?* Allgemeine Forst - Jagdztg, 158: 91-97.

39 Spelsberg, G, 1987: *On the problem of assessing the growth in damaged areas.* Allgemeine Forst - Jagdztg, 158: 205-2210.

40 Kenk, G, 1989: *Additional investigations in connection with the current forest damage in Baken-Wurttemberg.* In: Bucher, J.B. and Busher, W.I. (Eds), Air Pollution and Forest Decline, pp. 263-269.

41 Spiecker, H, 1990: *Growth variation and environmental stresses: Long-term observations on permanent research plots in Southwestern Germany.* Water Air Soil Pollut 54, 247–256. https://doi.org/10.1007/BF00298669

42 Kenk, G, Fischer, H, 1988: *Evidence from nitrogen fertilisation in the forests of Germany.* Environmental Pollution, Excess Nitrogen Deposition 54, 199–218. https://doi.org/10.1016/0269-7491(88)90112-1

43 Pretzsch, H, 1985: *Growth characteristics of southern German pine stands in the last 25 years.* Forschungsbericht der Forstlichen Forschungs-Anstalt Munchen, 65.

44 Innes, JL, Cook, ER, 1989: *Tree-ring analysis as an aid to evaluating the effects of pollution on tree growth.* Can. J. For. Res. 19, 1174–1189. https://doi.org/10.1139/x89-177

45 Kauppi, PE, Mielikäinen, K, Kuusela, K, 1992: *Biomass and Carbon Budget of European Forests, 1971 to 1990*. Science https://www.science.org/doi/abs/10.1126/science.256.5053.70

46 Weidenbach, P, 1992: *Silvicultural goals and results.* Allgemeine Forst - Jagdztg, 158: 205-2210.

47 Phillips, OL, Gentry, AH, 1994: *Increasing Turnover Through Time in Tropical Forests.* Science. https://www.science.org/doi/abs/10.1126/science.263.5149.954

48 Pimm, SL, Sugden, AM, 1994: *Tropical Diversity and Global Change.* Science 263, 933–934. https://doi.org/10.1126/science.263.5149.933

49 Phillips, OL, Malhi, Y, Higuchi, N, Laurance, WF, Núñez, PV, Vásquez, RM, Laurance, SG, Ferreira, LV, Stern, M, Brown, S, Grace, J, 1998: *Changes in the Carbon Balance of Tropical Forests: Evidence from Long-Term Plots.* Science 282, 439–442. https://doi.org/10.1126/science.282.5388.439

50 Laurance, William F., Oliveira, AA, Laurance, SG, Condit, R, Nascimento, HEM, Sanchez-Thorin, AC, Lovejoy, TE, Andrade, A, D'Angelo, S, Ribeiro, JE, Dick, CW, 2004: *Pervasive alteration of tree communities in undisturbed Amazonian forests.* Nature 428, 171–175. https://doi.org/10.1038/nature02383

51 Laurance, William F, Nascimento, HEM, Laurance, SG, Condit, R, D'Angelo, S, Andrade, A, 2004: *Inferred longevity of Amazonian rainforest trees based on a long-term demographic study.* Forest Ecology and Management 190, 131–143. https://doi.org/10.1016/j.foreco.2003.09.011

52 Laurance, WF, Oliveira, AA, Laurance, SG, Condit, R, Dick, CW, Andrade, A, Nascimento, HEM, Lovejoy, TE, Ribeiro, JELS, 2005: *Altered Tree Communities in Undisturbed Amazonian Forests: A Consequence of Global Change?* Biotropica 37, 160–162.

53 Lewis, SL, 2005: *Tropical forests and the changing earth system.* Philosophical Transactions of the Royal Society B: Biological Sciences 361, 195–210. https://doi.org/10.1098/rstb.2005.1711

54 Ainsworth, EA, Long, SP, 2005: *What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2.* New Phytologist 165, 351–372. https://doi.org/10.1111/j.1469-8137.2004.01224.x

55 Zhou, L, Tucker, CJ, Kaufmann, RK, Slayback, D, Shabanov, NV, Myneni, RB, 2001: *Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999.* Journal of Geophysical Research: Atmospheres 106, 20069–20083. https://doi.org/10.1029/2000JD000115

56 Hicke, JA, Asner, GP, Randerson, JT, Tucker, C, Los, S, Birdsey, R, Jenkins, JC, Field, C, 2002: *Trends in North American net primary productivity derived from satellite observations, 1982–1998.* Global Biogeochemical Cycles 16, 2-1-2–14. https://doi.org/10.1029/2001GB001550

57 Eklundh, L, Olsson, L, 2003: *Vegetation index trends for the African Sahel 1982–1999. Geophysical Research Letters 30.* https://doi.org/10.1029/2002GL016772

58 Nemani, RR, Keeling, CD, Hashimoto, H, Jolly, WM, Piper, SC, Tucker, CJ, Myneni, RB, Running, SW, 2003: Climate-Driven Increases in Global Terrestrial Net Primary Production from 1982 to 1999. Science 300, 1560–1563. https://doi.org/10.1126/science.1082750

59 Cao, M, Prince, SD, Small, J, Goetz, SJ, 2004: *Remotely Sensed Interannual Variations and Trends in Terrestrial Net Primary Productivity 1981–2000.* Ecosystems 7, 233–242. https://doi.org/10.1007/s10021-003-0189-x

60 Lim, C, Kafatos, M, Megonigal, P, 2004: *Correlation between atmospheric CO2 concentration and vegetation greenness in North America: CO2 fertilization effect. Climate Research*. Climate Research 28, 11–22. https://doi.org/10.3354/cr028011

61 Anyamba, A, Tucker, CJ, 2005: *Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003.* Journal of Arid Environments, Special Issue on The Greening of the Sahel 63, 596–614. https://doi.org/10.1016/j.jaridenv.2005.03.007

62 Olsson, L, Eklundh, L, Ardö, J, 2005: *A recent greening of the Sahel—trends, patterns and potential causes. Journal of Arid Environments, Special Issue on The Greening of the Sahel*. Journal of Arid Environments, Volume 63, Issue 3, November 2005, Pages 556-566. https://doi.org/10.1016/j.jaridenv.2005.03.008

63 Herrmann, SM, Anyamba, A, Tucker, CJ, 2005: *Recent trends in vegetation dynamics in the African Sahel and their relationship to climate.* Global Environmental Change 15, 394–404. https://doi.org/10.1016/j.gloenvcha.2005.08.004

64 Young, SS, Harris, R, 2005: *Changing patterns of global-scale vegetation photosynthesis, 1982–1999.* International Journal of Remote Sensing 26, 4537–4563. https://doi.org/10.1080/01431160500239198

65 Piao et al, 2006: *Variations in Vegetation Net Primary Production in the Qinghai-Xizang Plateau, China, from 1982 to 1999*. Climatic Change. https://link.springer.com/article/10.1007/s10584-005-6339-8

66 Josette Masle, 2000: *The Effects of Elevated CO2 Concentrations on Cell Division Rates, Growth Patterns, and Blade Anatomy in Young Wheat Plants Are Modulated by Factors Related to Leaf Position, Vernalization, and Genotype.* Plant Physiology, 2000 April, 122(4), 1399-1416, DOI 10.1104/pp.122.4.1399

67 Gardner, S, Taylor, G, Bosac, C, 1995: *Leaf growth of hybrid poplar following exposure to elevated CO2.* New Phytologist, 1995 Sep;131(1):81-90. doi: 10.1111/j.1469-8137.1995.tb03057.x.

68 Radoglou, K, Jarvis, P, 1992: *The Effects of CO2 Enrichment and Nutrient Supply on Growth Morphology and Anatomy of Phaseolus vulgaris L. Seedlings.* Annals of Botany, Volume 70, Issue 3, September 1992, Pages 245–256. https://doi.org/10.1093/oxfordjournals.aob.a088466

69 Rogers et al, 1984: *Influence of elevated CO2 on growth of soybean plants.* United States Department of Agriculture (USDA). https://www.ars.usda.gov/ARSUserFiles/60100500/csr/researchpubs/rogers/rogers_84a.pdf

70 Vu, J, Allen, L, Bowes, G, 1989: *Leaf ultrastructure, carbohydrates and protein of soybeans grown under CO2 enrichment.* Environmental and Experimental Botany, Volume 29, Issue 2, April 1989, Pages 141-14

71 Koch, G, Mooney, H, 1996: *Carbon Dioxide and Terrestrial Ecosystems - A Synthesis and Summary.* Carbon Dioxide and Terrestrial Ecosystems (a volume in Physiological Ecology), Chapter 22, pages 415-429. ISBN: 9780125052955.

72 Wand, S, Midgley, G, Jones, M, Curtis, P, 1999: *Responses of wild C4 and C3 grass (Poaceae) species to elevated atmospheric CO2 concentration: a meta-analytic test of current theories and perceptions*. Global Change Biology, 24 December 2001, https://doi.org/10.1046/j.1365-2486.1999.00265.x

73 Drake, B, Gonzàlez-Meler, M, 1997: *More efficient plants: a consequence of rising atmospheric CO2?* Annual Review of Plant Physiology and Plant Molecular Biology, Vol. 48:609-639 (Volume publication date June 1997). https://doi.org/10.1146/annurev.arplant.48.1.609

74 Curtis, P, Wang, X, 1998: *A meta-analysis of elevated CO2 effects on woody plant mass, form, and physiology.* Oecologia 113, 299–313 (1998). https://doi.org/10.1007/s004420050381

75 Norby et al, 2002: *Tree responses to rising CO2 in field experiments.* Plant Cell and Environment, 01 March 2002. https://doi.org/10.1046/j.1365-3040.1999.00391.x

76 DeLucia EH, Hamilton JG, Naidu SL, Thomas RB, Andrews JA, Finzi A, Lavine M, Matamala R, Mohan JE, Hendrey GR, Schlesinger WH, 1999: *Net primary production of a forest ecosystem with experimental CO2 enrichment.* Science, 1999 May 14, 284(5417), 1177-9. doi: 10.1126/science.284.5417.1177. PMID: 10325230.

77 Roleda, M, Morris, J, McGraw, C, Hurd, C, 2011: *Ocean acidification and seaweed reproduction: increased CO2 ameliorates the negative effect of lowered pH on meiospore germination in the giant kelp Macrocystis pyrifera (Laminariales, Phaeophyceae).* Global Change Biology, 04 November 2011 https://doi.org/10.1111/j.1365-2486.2011.02594.x

78 Erice, G, Irigoyen, JJ, Sánchez-Díaz, M, Avice, J-C, Ourry, A, 2007: *Effect of drought, elevated CO2 and temperature on accumulation of N and vegetative storage proteins (VSP) in taproot of nodulated alfalfa before and after cutting.* Plant Science 172, 903–912. https://doi.org/10.1016/j.plantsci.2006.12.013

79 Idso, CD, Idso, SB, Kimball, BA, Park, H-S, Hoober, JK, Balling, RC, 2000: *Ultra-enhanced spring branch growth in CO2-enriched trees: can it alter the phase of the atmosphere's seasonal CO2 cycle?* Environmental and Experimental Botany 43, 91–100. https://doi.org/10.1016/S0098-8472(99)00054-4

80 Idso, KE, Hoober, JK, Idso, SB, Wall, GW, Kimball, BA, 2002: *Atmospheric CO2 enrichment influences the synthesis and mobilization of putative vacuolar storage proteins in sour orange tree leaves.* Environmental and Experimental Botany 48, 199–211. https://doi.org/10.1016/S0098-8472(02)00017-5

81 Maier, CA, Palmroth, S, Ward, E, 2008: *Short-term effects of fertilization on photosynthesis and leaf morphology of field-grown loblolly pine following long-term exposure to elevated CO2 concentration.* Tree Physiology 28, 597–606. https://doi.org/10.1093/treephys/28.4.597

82 Teng, N, Wang, J, Chen, T, Wu, X, Wang, Y, Lin, J, 2006: *Elevated CO2 induces physiological, biochemical and structural changes in leaves of Arabidopsis thaliana.* New Phytol 172, 92–103. https://doi.org/10.1111/j.1469-8137.2006.01818.x

83 Yong, JWH, Wong, SC, Letham, DS, Hocart, CH, Farquhar, GD, 2000: *Effects of Elevated [CO2] and Nitrogen Nutrition on Cytokinins in the Xylem Sap and Leaves of Cotton*. Plant Physiology 124, 767–780. https://doi.org/10.1104/pp.124.2.767

84 Lazar, Thomas, 2003: *Taiz, L. and Zeiger, E. Plant physiology.* 3rd edn. Annals of Botany 91, 750–751. https://doi.org/10.1093/aob/mcg079

85 Jitla, DS, Rogers, GS, Seneweera, SP, Basra, AS, Oldfield, RJ, Conroy, JP, 1997: *Accelerated Early Growth of Rice at Elevated CO2 (Is It Related to Developmental Changes in the Shoot Apex?).* Plant Physiology 115, 15–22. https://doi.org/10.1104/pp.115.1.15

86 Li, CR, Gan, LJ, Xia, K, Zhou, X, Hew, CS, 2002: *Responses of carboxylating enzymes, sucrose metabolizing enzymes and plant hormones in a tropical epiphytic CAM orchid to CO2 enrichment.* Plant, Cell & Environment 25, 369–377. https://doi.org/10.1046/j.0016-8025.2001.00818.x

87 Li, X-M, He, X-Y, Zhang, L-H, Chen, W, Chen, Q, 2009: *Influence of elevated CO2 and O3 on IAA, IAA oxidase and peroxidase in the leaves of ginkgo trees.* Biol Plant 53, 339–342. https://doi.org/10.1007/s10535-009-0062-7

88 Janssens, IvanA, Crookshanks, Meg, Taylor, Gail, Ceulemans, R, 1998: *Elevated atmospheric CO2 increases fine root production, respiration, rhizosphere respiration and soil CO2 efflux in Scots pine seedlings.* Global Change Biology 4, 871–878. https://doi.org/10.1046/j.1365-2486.1998.00199.x

89 Kainulainen, P, Holopainen, JK, Holopainen, T, 1998: *The influence of elevated CO2 and O3 concentrations on Scots pine needles: changes in starch and secondary metabolites over three exposure years.* Oecologia 114, 455–460. https://doi.org/10.1007/s004420050469

90 Kostiainen, K, Jalkanen, H, Kaakinen, S, Saranpää, P, Vapaavuori, E, 2006: *Wood properties of two silver birch clones exposed to elevated CO2 and O3.* Global Change Biology 12, 1230–1240. https://doi.org/10.1111/j.1365-2486.2006.01165.x

91 Liu, X-P, Grams, TEE, Matyssek, R, Rennenberg, H, 2005: *Effects of elevated pCO2 and/or pO3 on C-, N-, and S-metabolites in the leaves of juvenile beech and spruce differ between trees grown in monoculture and mixed culture.* Plant Physiology and Biochemistry 43, 147–154. https://doi.org/10.1016/j.plaphy.2005.01.010

92 Lovelock, CE, Winter, K, Mersits, R, Popp, M, 1998: *Responses of communities of tropical tree species to elevated CO2 in a forest clearing.* Oecologia 116, 207–218. https://doi.org/10.1007/s004420050581

93 Ludewig, F, Sonnewald, U, Kauder, F, Heineke, D, Geiger, M, Stitt, M, Müller-Röber, BT, Gillissen, B, Kühn, C, Frommer, WB, 1998: *The role of transient starch in acclimation to elevated atmospheric CO2.* FEBS Letters 429, 147–151. https://doi.org/10.1016/S0014-5793(98)00580-8

94 Pan, Q, Wang, Z, Quebedeaux, B, 1998: *Responses of the apple plant to CO2 enrichment: changes in photosynthesis, sorbitol, other soluble sugars, and starch.* Functional Plant Biol. 25, 293–297. https://doi.org/10.1071/pp97097

95 Rey, A, Jarvis, PG, 1998: *Long-term photosynthetic acclimation to increased atmospheric CO2 concentration in young birch (Betula pendula) trees.* Tree Physiology 18, 441–450. https://doi.org/10.1093/treephys/18.7.441

96 Reid, CD, Fiscus, EL, Burkey, KO, 1998: *Combined effects of chronic ozone and elevated CO2 on Rubisco activity and leaf components in soybean (Glycine max).* Journal of Experimental Botany 49, 1999–2011. https://doi.org/10.1093/jxb/49.329.1999

97 Riikonen, J, Lindsberg, M-M, Holopainen, T, Oksanen, E, Lappi, J, Peltonen, P, Vapaavuori, E, 2004: *Silver birch and climate change: variable growth and carbon allocation responses to elevated concentrations of carbon dioxide and ozone.* Tree Physiology 24, 1227–1237. https://doi.org/10.1093/treephys/24.11.1227

98 Würth, MKR, Winter, K, Körner, C, 1998: *Leaf carbohydrate responses to CO2 enrichment at the top of a tropical forest.* Oecologia 116, 18–25. https://doi.org/10.1007/PL00013821

99 Barrett, DJ, Richardson, AE, Gifford, RM, 1998a: Elevated atmospheric CO2 concentrations increase wheat root phosphatase activity when growth is limited by phosphorus. Functional Plant Biol. 25, 87–94. https://doi.org/10.1071/pp97045

100 Nguyen, NT, Mohapatra, PK, Fujita, K, 2006: *Elevated CO2 alleviates the effects of low P on the growth of N2-fixing Acacia auriculiformis and Acacia mangium.* Plant Soil 285, 369–379. https://doi.org/10.1007/s11104-006-9022-6

101 Khan, FN, Lukac, M, Turner, G, Godbold, DL, 2008: *Elevated atmospheric CO2 changes phosphorus fractions in soils under a short rotation poplar plantation (EuroFACE).* Soil Biology and Biochemistry 40, 1716–1723. https://doi.org/10.1016/j.soilbio.2008.02.008

102 Niklaus, PA, Leadley, PW, Stöcklin, J, Körner, C, 1998: Nutrient relations in calcareous grassland under elevated CO2. Oecologia 116, 67–75. https://doi.org/10.1007/s004420050564

103 Norby, RJ, DeLucia, EH, Gielen, B, Calfapietra, C, Giardina, CP, King, JS, Ledford, J, McCarthy, HR, Moore, DJP, Ceulemans, R, De Angelis, P, Finzi, AC, Karnosky, DF, Kubiske, ME, Lukac, M, Pregitzer, KS, Scarascia-Mugnozza, GE, Schlesinger, WH, Oren, R, 2005: *Forest response to elevated CO2 is conserved across a broad range of productivity.* Proceedings of the National Academy of Sciences 102, 18052–18056. https://doi.org/10.1073/pnas.0509478102

104 Staddon, PL, Fitter, AH, Graves, JD, 1999: *Effect of elevated atmospheric CO2 on mycorrhizal colonization, external mycorrhizal hyphal production and phosphorus inflow in Plantago lanceolata and Trifolium repens in association with the arbuscular mycorrhizal fungus Glomus mosseae.* Global Change Biology 5, 347–358. https://doi.org/10.1046/j.1365-2486.1999.00230.x

105 Stöcklin, J, Körner, Ch, 1999: *Interactive effects of elevated CO2, P availability and legume presence on calcareous grassland: results of a glasshouse experiment.* Functional Ecology 13, 200–209. https://doi.org/10.1046/j.1365-2435.1999.00308.x

106 Walker, RF, Johnson, DW, Geisinger, DR, Ball, JT, 1998: *Growth and ectomycorrhizal colonization of ponderosa pine seedlings supplied different levels of atmospheric CO2 and soil N and P.* Forest Ecology and Management 109, 9–20. https://doi.org/10.1016/S0378-1127(98)00262-X

107 DELUCIA, EH, CALLAWAY, RM, THOMAS, EM, SCHLESINGER, WH, 1997: Mechanisms of Phosphorus Acquisition for Ponderosa Pine Seedlings under High CO 2 and Temperature. Annals of Botany 79, 111–120. https://doi.org/10.1006/anbo.1996.0320

108 Barrett, DJ, Richardson, AE, Gifford, RM, 1998b: *Elevated atmospheric CO2 concentrations increase wheat root phosphatase activity when growth is limited by phosphorus.* Functional Plant Biol. 25, 87–94. https://doi.org/10.1071/pp97045

109 BassiriRad, H, Reynolds, JF, Virginia, RA, Brunelle, MH, 1997: Growth and Root NO3- and PO43- Uptake Capacity of Three Desert Species in Response to Atmospheric CO2 Enrichment. Functional Plant Biol. 24, 353–358. https://doi.org/10.1071/pp96109

110 Finzi, AC, DeLucia, EH, Hamilton, JG, Richter, DD, Schlesinger, WH, 2002: *The nitrogen budget of a pine forest under free air CO2 enrichment.* Oecologia 132, 567–578. https://doi.org/10.1007/s00442-002-0996-3

111 Haase, S, Rothe, A, Kania, A, Wasaki, J, Römheld, V, Engels, C, Kandeler, E, Neumann, G, 2008: *Responses to Iron Limitation in Hordeum vulgare L. as Affected by the Atmospheric CO2 Concentration.* Journal of Environmental Quality 37, 1254–1262. https://doi.org/10.2134/jeq2006.0136

112 Jin, CW, Du, ST, Chen, WW, Li, GX, Zhang, YS, Zheng, SJ, 2009: *Elevated Carbon Dioxide Improves Plant Iron Nutrition through Enhancing the Iron-Deficiency-Induced Responses under Iron-Limited Conditions in Tomato.* Plant Physiology 150, 272–280. https://doi.org/10.1104/pp.109.136721

113 Kim, H-Y, Lieffering, M, Kobayashi, K, Okada, M, Miura, S, 2003: *Seasonal changes in the effects of elevated CO2 on rice at three levels of nitrogen supply: a free air CO2 enrichment (FACE) experiment.* Global Change Biology 9, 826–837. https://doi.org/10.1046/j.1365-2486.2003.00641.x

114 Kim, H-Y, Lieffering, M, Kobayashi, K, Okada, M, Mitchell, MW, Gumpertz, M, 2003: *Effects of free-air CO2 enrichment and nitrogen supply on the yield of temperate paddy rice crops.* Field Crops Research 83, 261–270. https://doi.org/10.1016/S0378-4290(03)00076-5

115 Lieffering, M, Kim, H-Y, Kobayashi, K, Okada, M, 2004: *The impact of elevated CO2 on the elemental concentrations of field-grown rice grains.* Field Crops Research 88, 279–286. https://doi.org/10.1016/j.fcr.2004.01.004

116 Natali, SM, Sañudo-Wilhelmy, SA, Lerdau, MT, 2009: *Plant and Soil Mediation of Elevated CO2 Impacts on Trace Metals.* Ecosystems 12, 715–727. https://doi.org/10.1007/s10021-009-9251-7

117 Norby, RJ, Ledford, J, Reilly, CD, Miller, NE, O'Neill, EG, 2004: *Fine-root production dominates response of a deciduous forest to atmospheric CO2 enrichment.* Proceedings of the National Academy of Sciences 101, 9689–9693. https://doi.org/10.1073/pnas.0403491101

118 Okada, M, Lieffering, M, Nakamura, H, Yoshimoto, M, Kim, HY, Kobayashi, K, 2001: *Free-air CO2 enrichment (FACE) using pure CO2 injection: system description.* New Phytologist 150, 251–260. https://doi.org/10.1046/j.1469-8137.2001.00097.x

119 Pritchard, Seth G., Strand, AE, McCORMACK, ML, Davis, MA, Finzi, AC, Jackson, RB, Matamala, R, Rogers, HH, Oren, R, 2008a: *Fine root dynamics in a loblolly pine forest are influenced by free-air-CO2-enrichment: a six-year-minirhizotron study.* Global Change Biology 14, 588–602. https://doi.org/10.1111/j.1365-2486.2007.01523.x

120 Rouhier, H, Read, DJ, 1998: *The role of mycorrhiza in determining the response of Plantago lanceolata to CO2 enrichment.* The New Phytologist 139, 367–373. https://doi.org/10.1046/j.1469-8137.1998.00200.x

121 Sasaki, T, Kurano, N, Miyachi, S, 1998: *Induction of Ferric Reductase Activity and of Iron Uptake Capacity in Chlorococcum littorale Cells under Extremely High-CO2 and Iron-Deficient Conditions.* Plant and Cell Physiology 39, 405–410. https://doi.org/10.1093/oxfordjournals.pcp.a029383

122 Smart, DR, Ritchie, K, Bloom, AJ, Bugbee, BB, 1998: *Nitrogen balance for wheat canopies (Triticum aestivum cv. Veery 10) grown under elevated and ambient CO2 concentrations.* Plant, Cell & Environment 21, 753–763. https://doi.org/10.1046/j.1365-3040.1998.00315.x

123 Staddon, PL, Fitter, AH, Graves, JD, 1999: *Effect of elevated atmospheric CO2 on mycorrhizal colonization, external mycorrhizal hyphal production and phosphorus inflow in Plantago lanceolata and Trifolium repens in association with the arbuscular mycorrhizal fungus Glomus mosseae.* Global Change Biology 5, 347–358. https://doi.org/10.1046/j.1365-2486.1999.00230.x

124 Wong, SC, Kriedemann, PE, Farquhar, GD, 1992: *CO2 × Nitrogen Interaction on Seedling Growth of Four Species of Eucalypt.* Australian Journal of Botany, 40(5) 457 - 472.

125 Hungate et al, 1999: *Elevated CO2 increases nitrogen fixation and decreases soil nitrogen mineralization in Florida scrub oak.* Global Change Biology (1999) 5, 781-789

126 Haase, S, Rothe, A, Kania, A, Wasaki, J, Römheld, V, Engels, C, Kandeler, E, Neumann, G, 2008: *Responses to Iron Limitation in Hordeum vulgare L. as Affected by the Atmospheric CO2 Concentration.* Journal of Environmental Quality 37, 1254–1262. https://doi.org/10.2134/jeq2006.0136

127 Berntson, GM, Bazzaz, FA, 1996: *The allometry of root production and loss in seedlings of Acer rubrum (Aceraceae) and Betula papyrifera (Betulaceae): implications for root dynamics in elevated CO2.* American Journal of Botany 83, 608–616. https://doi.org/10.1002/j.1537-2197.1996.tb12746.x

128 Arnone, JA, 1997: *Temporal responses of community fine root populations to long-term elevated atmospheric CO2 and soil nutrient patches in model tropicalecosystems.* Acta Oecologica, From alpine grassland to tropical forest: Biological consequences of elevated atmospheric CO (a sysnthesis of Swiss research) 18, 367–376. https://doi.org/10.1016/S1146-609X(97)80027-6

129 Berntson, GM, Bazzaz, FA, 1997: *Regenerating temperate forest mesocosms in elevated CO2: belowground growth and nitrogen cycling.* Oecologia 113, 115–125. https://doi.org/10.1007/s004420050359

130 Del Castillo, D, Acock, B, Reddy, VR, Acock, MC, 1989: *Elongation and Branching of Roots on Soybean Plants in a Carbon Dioxide-Enriched Aerial Environment.* Agronomy Journal 81, 692–695. https://doi.org/10.2134/agronj1989.00021962008100040026x

131 Ceulemans, R, Mousseau, M, 1994: *Tansley Review No. 71 Effects of elevated atmospheric CO2on woody plants.* New Phytologist 127, 425–446. https://doi.org/10.1111/j.1469-8137.1994.tb03961.x

132 Crookshanks, M, Taylor, G, Dolan, L, 1998: *A model system to study the effects of elevated CO2 on the developmental physiology of roots: the use of Arabidopsis thaliana.* Journal of Experimental Botany 49, 593–597. https://doi.org/10.1093/jxb/49.320.593

133 Curtis, PS, Balduman, LM, Drake, BG, Whigham, DF, 1990: *Elevated Atmospheric CO2 Effects on Belowground Processes in C3 and C4 Estuarine Marsh Communities.* Ecology 71, 2001–2006. https://doi.org/10.2307/1937608

134 Day, FP, Weber, EP, Hinkle, CR, Drake, BG, 1996: *Effects of elevated atmospheric CO2 on fine root length and distribution in an oak-palmetto scrub ecosystem in central Florida.* Global Change Biology 2, 143–148. https://doi.org/10.1111/j.1365-2486.1996.tb00059.x

135 Entry, JA, Runion, GB, Prior, SA, Mitchell, RJ, Rogers, HH, 1998: *Influence of CO2 enrichment and nitrogen fertilization on tissue chemistry and carbon allocation in longleaf pine seedlings*. Box, J.E. (Ed.), Root Demographics and Their Efficiencies in Sustainable Agriculture, Grasslands and Forest Ecosystems: Proceedings of the 5th Symposium of the International Society of Root Research, Held 14–18 July 1996 at Madren Conference Center, Clemson University, Clemson, South Carolina, USA, Developments in Plant and Soil Sciences. Springer Netherlands, Dordrecht, pp. 3–18. https://doi.org/10.1007/978-94-011-5270-9_1

136 Finzi, AC, Schlesinger, WH, 2003: *Soil–Nitrogen Cycling in a Pine Forest Exposed to 5 Years of Elevated Carbon Dioxide.* Ecosystems 6, 444–456. https://doi.org/10.1007/s10021-003-0205-1

137 Gleadow, RM, Foley, WJ, Woodrow, IE, 1998: *Enhanced CO2 alters the relationship between photosynthesis and defence in cyanogenic Eucalyptus cladocalyx F. Muell.* Plant, Cell & Environment 21, 12–22. https://doi.org/10.1046/j.1365-3040.1998.00258.x

138 Hodge, A, Millard, P, 1998: *Effect of elevated CO2 on carbon partitioning and exudate release from Plantago lanceolata seedlings.* Physiologia Plantarum 103, 280–286. https://doi.org/10.1034/j.1399-3054.1998.1030216.x

139 Idso, SB, Kimball, BA, 1991: *Effects of two and a half years of atmospheric CO2 enrichment on the root density distribution of three-year-old sour orange trees.* Agricultural and Forest Meteorology 55, 345–349. https://doi.org/10.1016/0168-1923(91)90070-7

140 Idso, SB, Kimball, BA, Mauney, JR, 1988: *Effects of atmospheric CO2 enrichment on root: Shoot ratios of carrot, radish, cotton and soybean.* Agriculture, Ecosystems & Environment 21, 293–299. https://doi.org/10.1016/0167-8809(88)90095-3

141 Iversen, CM, 2010: *Digging deeper: fine-root responses to rising atmospheric CO2 concentration in forested ecosystems.* New Phytologist 186, 346–357. https://doi.org/10.1111/j.1469-8137.2009.03122.x

142 Iversen, CM, Ledford, J, Norby, RJ, 2008: *CO2 enrichment increases carbon and nitrogen input from fine roots in a deciduous forest.* New Phytologist 179, 837–847. https://doi.org/10.1111/j.1469-8137.2008.02516.x

143 Janssens, IvanA, Crookshanks, Meg, Taylor, Gail, Ceulemans, R, 1998: *Elevated atmospheric CO2 increases fine root production, respiration, rhizosphere respiration and soil CO2 efflux in Scots pine seedlings.* Global Change Biology 4, 871–878. https://doi.org/10.1046/j.1365-2486.1998.00199.x

144 Johnson, DW, Hoylman, AM, Ball, JT, Walker, RF, 2006: *Ponderosa Pine Responses to Elevated CO2and Nitrogen Fertilization.* Biogeochemistry 77, 157–175. https://doi.org/10.1007/s10533-005-5235-7

145 Johnson, MG, Phillips, DL, Tingey, DT, Storm, MJ, 2000: *Effects of elevated CO2, N-fertilization, and season on survival of ponderosa pine fine roots.* Can. J. For. Res. 30, 220–228. https://doi.org/10.1139/x99-199

146 Kimball, BA, Kobayashi, K, Bindi, M, 2002: *Responses of Agricultural Crops to Free-Air CO2 Enrichment*. Sparks, D.L. (Ed.), Advances in Agronomy, Advances in Agronomy. Academic Press, pp. 293–368. https://doi.org/10.1016/S0065-2113(02)77017-X

147 King, J, Pregitzer, K, Zak, D, Sober, J, Isebrands, J, Dickson, R, Hendrey, G, Karnosky, D, 2001: *Fine-root biomass and fluxes of soil carbon in young stands of paper birch and trembling aspen as affected by elevated atmospheric CO2 and tropospheric O3.* Oecologia 128, 237–250. https://doi.org/10.1007/s004420100656

148 Phillips, DL, Johnson, MG, Tingey, DT, Storm, MJ, 2009: *Elevated CO2 and O3 effects on fine-root survivorship in ponderosa pine mesocosms.* Oecologia 160, 827–837. https://doi.org/10.1007/s00442-009-1339-4

149 Phillips, DL, Johnson, MG, Tingey, DT, Storm, MJ, Ball, JT, Johnson, DW, 2006: *CO2 and N-fertilization effects on fine-root length, production, and mortality: a 4-year ponderosa pine study.* Oecologia 148, 517–525. https://doi.org/10.1007/s00442-006-0392-5

150 Pritchard, Seth G, Davis, MA, Mitchell, RJ, Prior, SA, Boykin, DL, Rogers, HH, Runion, GB, 2001: *Root dynamics in an artificially constructed regenerating longleaf pine ecosystem are affected by atmospheric CO2 enrichment.* Environmental and Experimental Botany 46, 55–69. https://doi.org/10.1016/S0098-8472(01)00084-3

151 Pritchard, Seth G., Rogers, HH, Davis, MA, Van Santen, E, Prior, SA, Schlesinger, WH, 2001: *The influence of elevated atmospheric CO2 on fine root dynamics in an intact temperate forest.* Global Change Biology 7, 829–837. https://doi.org/10.1046/j.1354-1013.2001.00457.x

152 Pritchard, Seth G., Strand, AE, McCORMACK, ML, Davis, MA, Finzi, AC, Jackson, RB, Matamala, R, Rogers, HH, Oren, R, 2008b: *Fine root dynamics in a loblolly pine forest are influenced by free-air-CO2-enrichment: a six-year-minirhizotron study.* Global Change Biology 14, 588–602. https://doi.org/10.1111/j.1365-2486.2007.01523.x

153 Pritchard, S. G., Strand, AE, McCORMACK, ML, Davis, MA, Oren, R, 2008: *Mycorrhizal and rhizomorph dynamics in a loblolly pine forest during 5 years of free-air-CO2-enrichment.* Global Change Biology 14, 1252–1264. https://doi.org/10.1111/j.1365-2486.2008.01567.x

154 Rogers, HH, Runion, GB, Krupa, SV, 1994: *Plant responses to atmospheric CO2 enrichment with emphasis on roots and the rhizosphere.* Environmental Pollution 83, 155–189. https://doi.org/10.1016/0269-7491(94)90034-5

155 Runion, GB, Mitchell, RJ, Rogers, HH, Prior, SA, Counts, TK, 1997: *Effects of nitrogen and water limitation and elevated atmospheric CO2 on ectomycorrhiza of longleaf pine.* The New Phytologist 137, 681–689. https://doi.org/10.1046/j.1469-8137.1997.00865.x

156 Tingey, DT, Johnson, MG, Lee, EH, Wise, C, Waschmann, R, Olszyk, DM, Watrud, LS, Donegan, KK, 2006: *Effects of elevated CO2 and O3 on soil respiration under ponderosa pine.* Soil Biology and Biochemistry 38, 1764–1778. https://doi.org/10.1016/j.soilbio.2005.12.003

157 Tingey, DT, Johnson, MG, Phillips, DL, 2005: *Independent and contrasting effects of elevated CO2 and N-fertilization on root architecture in Pinus ponderosa.* Trees 19, 43–50. https://doi.org/10.1007/s00468-004-0361-8

158 Wechsung, G, Wechsung, F, Wall, GW, Adamsen, FJ, Kimball, BA, Pinter JR., PJ, Lamorte, RL, Garcia, RL, Kartschall, Th, 1999: *The effects of free-air CO2 enrichment and soil water availability on spatial and seasonal patterns of wheat root growth.* Global Change Biology 5, 519–529. https://doi.org/10.1046/j.1365-2486.1999.00243.x

159 Weihong, L., Zhang, F, Bai, K, 2000: *Responses of plant rhizosphere to atmospheric CO2 enrichment.* Chin. Sci. Bull. 45, 97–101. https://doi.org/10.1007/BF02884650

160 Wiemken, V, Ineichen, K, Boller, T, 2001: *Development of ectomycorrhizas in model beech–spruce ecosystems on siliceous and calcareous soil: a 4-year experiment with atmospheric CO2 enrichment and nitrogen fertilization.* Plant and Soil 234, 99–108. https://doi.org/10.1023/A:1010500400263

161 Caporn, SJM, Brooks, AL, Press, MC, Lee, JA, 1999: *Effects of long-term exposure to elevated CO2 and increased nutrient supply on bracken (Pteridium aquilinum).* Functional Ecology 13, 107–115. https://doi.org/10.1046/j.1365-2435.1999.00013.x

162 Zhang et al, 2020: Elevated CO2 affects kelp nutrient quality: *A case study of Saccharina japonica from CO2-enriched coastal mesocosm systems.* Journal of Phycology, https://doi.org/10.1111/jpy.13097

163 de Graaff, M-A, Van Kessel, C, Six, J, 2009: *Rhizodeposition-induced decomposition increases N availability to wild and cultivated wheat genotypes under elevated CO2.* Soil Biology and Biochemistry 41, 1094–1103. https://doi.org/10.1016/j.soilbio.2009.02.015

164 Johansson, EM, Fransson, PMA, Finlay, RD, van Hees, PAW, 2009: *Quantitative analysis of soluble exudates produced by ectomycorrhizal roots as a response to ambient and elevated CO2.* Soil Biology and Biochemistry 41, 1111–1116. https://doi.org/10.1016/j.soilbio.2009.02.016

165 Marilley, L, Hartwig, UA, Aragno, M, 1999: *Influence of an Elevated Atmospheric CO2 Content on Soil and Rhizosphere Bacterial Communities Beneath Lolium perenne and Trifolium repens under Field Conditions.* Microb Ecol 38, 39–49. https://doi.org/10.1007/s002489900155

166 Uselman, SM, Qualls, RG, Thomas, RB, 1999: *A test of a potential short cut in the nitrogen cycle: The role of exudation of symbiotically fixed nitrogen from the roots of a N-fixing tree and the effects of increased atmospheric CO2 and temperature.* Plant and Soil, 210, 21–32. https://doi.org/10.1023/A:1004619509878

167 Zhao, X, Misaghi, IJ, Hawes, MC, 2000: *Stimulation of Border Cell Production in Response to Increased Carbon Dioxide Levels*. Plant Physiology 122, 181–188. https://doi.org/10.1104/pp.122.1.181

168 Dippery, JK, Tissue, DT, Thomas, RB, Strain, BR, 1995: Effects of low and elevated CO2 on C3 and C4 annuals. Oecologia 101, 13–20. https://doi.org/10.1007/BF00328894

169 Gunderson, CA, Wullschleger, SD, 1994: *Photosynthetic acclimation in trees to rising atmospheric CO2: A broader perspective.* Photosynth Res 39, 369–388. https://doi.org/10.1007/BF00014592

170 Idso, KE, Idso, SB, 1994: *Plant responses to atmospheric CO2 enrichment in the face of environmental constraints: a review of the past 10 years' research.* Agricultural and Forest Meteorology 69, 153–203. https://doi.org/10.1016/0168-1923(94)90025-6

171 Saxe, H, Ellsworth, DS, Heath, J, 1998: *Tree and forest functioning in an enriched CO2 atmosphere.* The New Phytologist 139, 395–436. https://doi.org/10.1046/j.1469-8137.1998.00221.x

172 Newton, PCD, Carran, RA, Lawrence, EJ, 2004: *Reduced water repellency of a grassland soil under elevated atmospheric CO2.* Global Change Biology 10, 1–4. https://doi.org/10.1111/j.1365-2486.2003.00715.x

173 Prior, SA, Rogers, HH, Runion, GB, Torbert, HA, Reicosky, DC, 1997: *Carbon Dioxide-Enriched Agroecosystems: Influence of Tillage on Short-Term Soil Carbon Dioxide Efflux.* Journal of Environmental Quality 26, 244–252. https://doi.org/10.2134/jeq1997.00472425002600010034x

174 Prior, SA, Runion, GB, Torbert, HA, Rogers, HH, 2004: *Elevated Atmospheric CO_2 in Agroecosystems: Soil Physical Properties.* Soil Science, 169, 434. https://doi.org/10.1097/01.ss.0000131228.51226.8c

175 Prior, SA, Torbert, HA, Runion, GB, Rogers, HH, 2003: *Implications of Elevated CO2-Induced Changes in Agroecosystem Productivity.* Journal of Crop Production 8, 217–244. https://doi.org/10.1300/J144v08n01_09

176 Rillig, M c., Hernández, G y., Newton, P c. d., 2000: *Arbuscular mycorrhizae respond to elevated atmospheric CO2 after long-term exposure: evidence from a CO2 spring in New Zealand supports the resource balance model.* Ecology Letters 3, 475–478. https://doi.org/10.1111/j.1461-0248.2000.00178.x

177 Rillig, MC, Wright, SF, Kimball, BA, Pinter, PJ, Wall, GW, Ottman, MJ, Leavitt, SW, 2001: *Elevated carbon dioxide and irrigation effects on water stable aggregates in a Sorghum field: a possible role for arbuscular mycorrhizal fungi.* Global Change Biology 7, 333–337. https://doi.org/10.1046/j.1365-2486.2001.00404.x

178 Edwards, CA, Fletcher, KE, 1988: Interactions between earthworms and microorganisms in organic-matter breakdown. *Agriculture, Ecosystems & Environment, Proceedings of a Workshop on Interactions Between Soil-Inhabiting Invertebrates and Microorganisms in Relation to Plant Growth.* Agriculture, Ecosystems & Environment, 24, 235–247. https://doi.org/10.1016/0167-8809(88)90069-2

179 Sharpley, AN, Syers, JK, Springett, J, 1988: *Earthworm Effects on the Cycling of Organic Matter and Nutrients.* Agronomy Abstracts 80: 285.

180 Bertsch, PM, Peters, RA, Luce, HD, Claude, D, 1988: *Comparison of earthworm activity in long-term no-tillage and conventionally tilled corn systems*. Agronomy Abstracts. p. 271.

181 McCabe, D, Protz, R, Tomlin, AD, 1988: *Earthworm influence on soil quality in native sites of southern Ontario*. Agronomy Abstracts, p. 281.

182 Zachmann, JE, Molina, JA, 1988: *Earthworm-Microbe Interactions in Soil.* Agronomy Abstracts, 80:289.

183 Kemper, WD, 1988: *Earthworm Burrowing and Effects on Soil Structure and Transmissivity.* Agronomy Abstracts, 80:280.

184 Logsdon, SD, Lindon, DL, 1988: *Earthworm Effects on Root Growth and Function, and on Crop Growth.* Agronomy Abstracts, 80:280.

185 Arnone III, JA, Zaller, JG, Johann G Zaller, 1997: *Activity of surface-casting earthworms in a calcareous grassland under elevated atmospheric CO2.* Oecologia 111, 249–254. https://doi.org/10.1007/PL00008817

186 Zaller, JG, Arnone III, JA, 1999: *Interactions Between Plant Species and Earthworm Casts in a Calcareous Grassland Under Elevated CO_2.* Ecology 80, 873–881. https://doi.org/10.1890/0012-9658(1999)080[0873:IBPSAE]2.0.CO;2

187 Jongmans, AG, Pulleman, MM, Balabane, M, van Oort, F, Marinissen, JCY, 2003: *Soil structure and characteristics of organic matter in two orchards differing in earthworm activity.* Applied Soil Ecology 24, 219–232. https://doi.org/10.1016/S0929-1393(03)00072-6

188 Cole, L, Bardgett, RD, Ineson, P, Hobbs, PJ, 2002: *Enchytraeid worm (Oligochaeta) influences on microbial community structure, nutrient dynamics and plant growth in blanket peat subjected to warming.* Soil Biology and Biochemistry 34, 83–92. https://doi.org/10.1016/S0038-0717(01)00159-6

189 Peñuelas, J, Llusià, J, 2003: BVOCs: *Plant defense against climate warming?* Trends in Plant Science 8, 105–109. https://doi.org/10.1016/S1360-1385(03)00008-6

190 Staudt, M, Joffre, R, Rambal, S, Kesselmeier, J, 2001: *Effect of elevated CO2 on monoterpene emission of young Quercus ilex trees and its relation to structural and ecophysiological parameters.* Tree Physiology 21, 437–445. https://doi.org/10.1093/treephys/21.7.437

191 Jasoni, R, Kane, C, Green, C, Peffley, E, Tissue, D, Thompson, L, Payton, P, Paré, PW, 2004: *Altered leaf and root emissions from onion (Allium cepa L.) grown under elevated CO2 conditions.* Environmental and Experimental Botany 51, 273–280. https://doi.org/10.1016/j.envexpbot.2003.11.006

192 Rønn, R, Ekelund, F, Christensen, S, 2003: *Effects of elevated atmospheric CO2 on protozoan abundance in soil planted with wheat and on decomposition of wheat roots.* Plant and Soil 251, 13–21. https://doi.org/10.1023/A:1022931830078

193 Montealegre, CM, van Kessel, C, Russelle, MP, Sadowsky, MJ, 2002: *Changes in microbial activity and composition in a pasture ecosystem exposed to elevated atmospheric carbon dioxide.* Plant and Soil 243, 197–207. https://doi.org/10.1023/A:1019901828483

194 Montealegre, CM, Van Kessel, C, Blumenthal, JM, Hur, H-G, Hartwig, UA, Sadowsky, MJ, 2000: *Elevated atmospheric CO2 alters microbial population structure in a pasture ecosystem.* Global Change Biology 6, 475–482. https://doi.org/10.1046/j.1365-2486.2000.00326.x

195 Fu, F-X, Mulholland, MR, Garcia, NS, Beck, A, Bernhardt, PW, Warner, ME, Sañudo-Wilhelmy, SA, Hutchins, DA, 2008: *Interactions between changing pCO2, N2 fixation, and Fe limitation in the marine unicellular cyanobacterium Crocosphaera.* Limnology and Oceanography 53, 2472–2484. https://doi.org/10.4319/lo.2008.53.6.2472

196 Hutchins, DA, Fu, F-X, Zhang, Y, Warner, ME, Feng, Y, Portune, K, Bernhardt, PW, Mulholland, MR, 2007: *CO2 control of Trichodesmium N2 fixation, photosynthesis, growth rates, and elemental ratios: Implications for past, present, and future ocean biogeochemistry.* Limnology and Oceanography 52, 1293–1304. https://doi.org/10.4319/lo.2007.52.4.1293

197 Levitan, O, Rosenberg, G, Setlik, I, Setlikova, E, Grigel, J, Klepetar, J, Prasil, O, Berman-Frank, I, 2007a: *Elevated CO2 enhances nitrogen fixation and growth in the marine cyanobacterium Trichodesmium.* Global Change Biology 13, 531–538. https://doi.org/10.1111/j.1365-2486.2006.01314.x

198 Rønn, R, Ekelund, F, & Christensen, S, 2003: *Effects of elevated atmospheric CO 2 on protozoan abundance in soil planted with wheat and on decomposition of wheat roots.* Plant and soil, 251, 13-21.

199 Montoya et al, 2004: *High rates of N2 fixation by unicellular diazotrophs in the oligotrophic Pacific Ocean*. Nature. https://www.nature.com/articles/nature02824

200 Feng, Y, Lin, X, Wang, Y, Zhang, J, Mao, T, Yin, R, Zhu, J, 2009: Free-air CO2 enrichment (FACE) enhances the biodiversity of purple phototrophic bacteria in flooded paddy soil. Plant Soil 324, 317–328. https://doi.org/10.1007/s11104-009-9959-3

201 Elbadry, M, Gamal-Eldin, H, Elbanna, Kh, 1999: *Effects of Rhodobacter capsulatus inoculation in combination with graded levels of nitrogen fertilizer on growth and yield of rice in pots and lysimeter experiments.* World Journal of Microbiology and Biotechnology 15, 393–395. https://doi.org/10.1023/A:1008958832402

202 Harada, N, Nishiyama, M, Otsuka, S, Matsumoto, S, 2005: *Effects of Inoculation of Phototrophic Purple Bacteria on Grain Yield of Rice and Nitrogenase Activity of Paddy Soil in a Pot Experiment.* Soil Science & Plant Nutrition 51, 361–367. https://doi.org/10.1111/j.1747-0765.2005.tb00041.x

203 Arnone Iii, JA, Gordon, JC, 1990: *Effect of nodulation, nitrogen fixation and CO2 enrichment on the physiology, growth and dry mass allocation of seedlings of Alnus rubra Bong.* New Phytologist 116, 55–66. https://doi.org/10.1111/j.1469-8137.1990.tb00510.x

204 Barcelos e Ramos, J, Biswas, H, Schulz, KG, LaRoche, J, Riebesell, U, 2007: *Effect of rising atmospheric carbon dioxide on the marine nitrogen fixer Trichodesmium.* Global Biogeochemical Cycles 21. https://doi.org/10.1029/2006GB002898

205 Dakora, FD, Drake, BG, 2000: *Elevated CO2 stimulates associative N2 fixation in a C3 plant of the Chesapeake Bay wetland.* Plant, Cell & Environment 23, 943–953. https://doi.org/10.1046/j.1365-3040.2000.00610.x

206 De Luis, I, Irigoyen, JJ, Sánchez-Díaz, M, 1999: *Elevated CO2 enhances plant growth in droughted N2-fixing alfalfa without improving water status.* Physiologia Plantarum 107, 84–89. https://doi.org/10.1034/j.1399-3054.1999.100112.x

207 Hartwig, UA, Lüscher, A, Nösberger, J, Van Kessel, C, 2002: *Nitrogen-15 budget in model ecosystems of white clover and perennial ryegrass exposed for four years at elevated atmospheric pCO2.* Global Change Biology 8, 194–202. https://doi.org/10.1046/j.1354-1013.2001.00465.x

208 Koike, T, Izuta, T, Lei, TT, Kitao, M, Asanuma, S, 1997: *Effects of high CO2 on nodule formation in roots of Japanese mountain alder seedlings grown under two nutrient levels, in: Ando, T., Fujita, K., Mae, T., Matsumoto, H., Mori, S., Sekiya, J. (Eds.)*. Plant Nutrition for Sustainable Food Production and Environment: Proceedings of the XIII International Plant Nutrition Colloquium, 13–19 September 1997, Tokyo, Japan, Developments in Plant and Soil Sciences. Springer Netherlands, Dordrecht, pp. 887–888. https://doi.org/10.1007/978-94-009-0047-9_285

209 Lee, TD, Tjoelker, MG, Reich, PB, Russelle, MP, 2003: *Contrasting growth response of an N2-fixing and non-fixing forb to elevated CO2: dependence on soil N supply.* Plant and Soil 255, 475–486. https://doi.org/10.1023/A:1026072130269

210 Levitan, O, Rosenberg, G, Setlik, I, Setlikova, E, Grigel, J, Klepetar, J, Prasil, O, Berman-Frank, I, 2007b: *Elevated CO2 enhances nitrogen fixation and growth in the marine cyanobacterium Trichodesmium.* Global Change Biology 13, 531–538. https://doi.org/10.1111/j.1365-2486.2006.01314.x

211 Lüscher, A, Hendrey, GR, Nösberger, J, 1997: *Long-term responsiveness to free air CO2 enrichment of functional types, species and genotypes of plants from fertile permanent grassland.* Oecologia 113, 37–45. https://doi.org/10.1007/s004420050351

212 Lüscher, A, Hartwig, UA, Suter, D, Nösberger, J, 2000: *Direct evidence that symbiotic N2 fixation in fertile grassland is an important trait for a strong response of plants to elevated atmospheric CO2.* Global Change Biology 6, 655–662. https://doi.org/10.1046/j.1365-2486.2000.00345.x

213 Niklaus, PA, Leadley, PW, Stöcklin, J, Körner, C, 1998a: *Nutrient relations in calcareous grassland under elevated CO2.* Oecologia 116, 67–75. https://doi.org/10.1007/s004420050564

214 Norby, RJ, 1987: *Nodulation and nitrogenase activity in nitrogen-fixing woody plants stimulated by CO2 enrichment of the atmosphere.* Physiologia Plantarum 71, 77–82. https://doi.org/10.1111/j.1399-3054.1987.tb04620.x

215 Olesniewicz, KS, Thomas, RB, 1999: *Effects of mycorrhizal colonization on biomass production and nitrogen fixation of black locust (Robinia pseudoacacia) seedlings grown under elevated atmospheric carbon dioxide.* The New Phytologist 142, 133–140. https://doi.org/10.1046/j.1469-8137.1999.00372.x

216 Niklaus, PA, Leadley, PW, Stöcklin, J, Körner, C, 1998b: *Nutrient relations in calcareous grassland under elevated CO2.* Oecologia 116, 67–75. https://doi.org/10.1007/s004420050564

217 Norby, RJ, 1987: *Nodulation and nitrogenase activity in nitrogen-fixing woody plants stimulated by CO2 enrichment of the atmosphere.* Physiologia Plantarum 71, 77–82. https://doi.org/10.1111/j.1399-3054.1987.tb04620.x

218 Olesniewicz, KS, Thomas, RB, 1999: *Effects of mycorrhizal colonization on biomass production and nitrogen fixation of black locust (Robinia pseudoacacia) seedlings grown under elevated atmospheric carbon dioxide.* The New Phytologist 142, 133–140. https://doi.org/10.1046/j.1469-8137.1999.00372.x

219 Marilley, L, Hartwig, UA, Aragno, M, 1999: *Influence of an Elevated Atmospheric CO2 Content on Soil and Rhizosphere Bacterial Communities Beneath Lolium perenne and Trifolium repens under Field Conditions.* Microb Ecol 38, 39–49. https://doi.org/10.1007/s002489900155

220 Schortemeyer, M, Atkin, OK, McFarlane, N, Evans, JR, 2002: *N2 fixation by Acacia species increases under elevated atmospheric CO2.* Plant, Cell & Environment 25, 567–579. https://doi.org/10.1046/j.1365-3040.2002.00831.x

221 Temperton, VM, Grayston, SJ, Jackson, G, Barton, CVM, Millard, P, Jarvis, PG, 2003: *Effects of elevated carbon dioxide concentration on growth and nitrogen fixation in Alnus glutinosa in a long-term field experiment.* Tree Physiology 23, 1051–1059. https://doi.org/10.1093/treephys/23.15.1051

222 H, T, 2005: *Effects of elevated CO_2 and nitrogen availability on nodulation of Alnus hirsuta (Turcz).* Phyton.
223 Uselman, SM, Qualls, RG, Thomas, RB, 1999: *A test of a potential short cut in the nitrogen cycle: The role of exudation of symbiotically fixed nitrogen from the roots of a N-fixing tree and the effects of increased atmospheric CO2 and temperature.* Plant and Soil 210, 21–32. https://doi.org/10.1023/A:1004619509878
224 Vogel, CS, Curtis, PS, 1995: *Leaf gas exchange and nitrogen dynamics of N2-fixing, field-grown Alnus glutinosa under elevated atmospheric CO2.* Global Change Biology 1, 55–61. https://doi.org/10.1111/j.1365-2486.1995.tb00006.x
225 Vogel, CS, Curtis, PS, Thomas, RB, 1997: *Growth and nitrogen accretion of dinitrogen-fixing Alnus glutinosa (L.) Gaertn.* under elevated carbon dioxide. Plant Ecology 130, 63–70. https://doi.org/10.1023/A:1009783625188
226 Kerstiens, G, 1998a: *Shade-tolerance as a predictor of responses to elevated CO2 in trees.* Physiologia Plantarum 102, 472–480. https://doi.org/10.1034/j.1399-3054.1998.1020316.x
227 Granados, J, Körner, C, 2002: *In deep shade, elevated CO2 increases the vigor of tropical climbing plants.* Global Change Biology 8, 1109–1117. https://doi.org/10.1046/j.1365-2486.2002.00533.x
228 Hättenschwiler, S, 2001: *Tree seedling growth in natural deep shade: functional traits related to interspecific variation in response to elevated CO2.* Oecologia 129, 31–42. https://doi.org/10.1007/s004420100699
229 Herrick, JD, Thomas, RB, 1999: *Effects of CO2 enrichment on the photosynthetic light response of sun and shade leaves of canopy sweetgum trees (Liquidambar styraciflua) in a forest ecosystem.* Tree Physiology 19, 779–786. https://doi.org/10.1093/treephys/19.12.779
230 Kerstiens, G, 1998b: Shade-tolerance as a predictor of responses to elevated CO2 in trees. Physiologia Plantarum 102, 472–480. https://doi.org/10.1034/j.1399-3054.1998.1020316.x
231 Kerstiens, G, 2001: Meta-analysis of the interaction between shade-tolerance,light environment and growth response of woody species to elevated CO2. Acta Oecologica 22, 61–69. https://doi.org/10.1016/S1146-609X(00)01096-1
232 Kubiske, ME, Pregitzer, KS, 1996: *Effects of elevated CO2 and light availability on the photosynthetic light response of trees of contrasting shade tolerance.* Tree Physiology 16, 351–358. https://doi.org/10.1093/treephys/16.3.351
233 Kubiske, ME, Zak, DR, Pregitzer, KS, Takeuchi, Y, 2002: *Photosynthetic acclimation of overstory Populus tremuloides and understory Acer saccharum to elevated atmospheric CO2 concentration: interactions with shade and soil nitrogen.* Tree Physiology 22, 321–329. https://doi.org/10.1093/treephys/22.5.321
234 Osborne, CP, Drake, BG, LaRoche, J, Long, SP, 1997: *Does Long-Term Elevation of CO2 Concentration Increase Photosynthesis in Forest Floor Vegetation? (Indiana Strawberry in a Maryland Forest).* Plant Physiology 114, 337–344. https://doi.org/10.1104/pp.114.1.337
235 Poorter, H, Pérez-Soba, M, 2001: *The growth response of plants to elevated CO2 under non-optimal environmental conditions.* Oecologia, 129, 1–20. https://doi.org/10.1007/s004420100736
236 Sefcik, LT, Zak, DR, Ellsworth, DS, 2006: *Photosynthetic responses to understory shade and elevated carbon dioxide concentration in four northern hardwood tree species.* Tree Physiology 26, 1589–1599. https://doi.org/10.1093/treephys/26.12.1589
237 Zimmerman, RC, Kohrs, DG, Steller, DL, Alberte, RS, 1997: *Impacts of CO2 Enrichment on Productivity and Light Requirements of Eelgrass.* Plant Physiology 115, 599–607. https://doi.org/10.1104/pp.115.2.599
238 Idso, CD, Idso, SB, 2011: *The Many Benefits of Atmospheric CO2 Enrichment: How Humanity and the Rest of the Biosphere Will Prosper from this Amazing Trace Gas that So Many Have Wrongfully Characterized as a Dangerous Air Pollutant!* Vales Lake Publishing.

239 Wilson, GWT, Hartnett, DC, 1998: *Interspecific variation in plant responses to mycorrhizal colonization in tallgrass prairie.* American Journal of Botany 85, 1732–1738. https://doi.org/10.2307/2446507
240 Campbell, BD, Stafford Smith, DM, 2000: *A synthesis of recent global change research on pasture and rangeland production: reduced uncertainties and their management implications.* Agriculture, Ecosystems & Environment 82, 39–55. https://doi.org/10.1016/S0167-8809(00)00215-2
241 Arnone Iii, JA, 1999: *Symbiotic N2 fixation in a high Alpine grassland: effects of four growing seasons of elevated CO2.* Functional Ecology 13, 383–387. https://doi.org/10.1046/j.1365-2435.1999.00325.x
242 Matthies, D, Egli, P, 1999: *Response of a root hemiparasite to elevated CO2 depends on host type and soil nutrients.* Oecologia 120, 156–161. https://doi.org/10.1007/s004420050844
243 Wayne, PM, Carnelli, AL, Connolly, J, Bazzaz, FA, 1999: *The density dependence of plant responses to elevated CO2.* Journal of Ecology 87, 183–192. https://doi.org/10.1046/j.1365-2745.1999.00357.x
244 Taylor, K, Potvin, C, 1997: *Understanding the long-term effect of CO2 enrichment on a pasture: the importance of disturbance*. Canadian Science Publishing, October, 1987. https://cdnsciencepub.com/doi/abs/10.1139/b97-874
245 Griffiths, BS, Ritz, K, Ebblewhite, N, Paterson, E, Killham, K, 1998: *Ryegrass rhizosphere microbial community structure under elevated carbon dioxide concentrations, with observations on wheat rhizosphere.* Soil Biology and Biochemistry 30, 315–321. https://doi.org/10.1016/S0038-0717(97)00133-8
246 Catovsky, S, Bazzaz, FA, 1999: *Elevated CO2 influences the responses of two birch species to soil moisture: implications for forest community structure.* Global Change Biology 5, 507–518. https://doi.org/10.1046/j.1365-2486.1999.00247.x
247 Leadley, PW, Niklaus, PA, Stocker, R, Körner, C, 1999: *A field study of the effects of elevated CO2 on plant biomass and community structure in a calcareous grassland.* Oecologia 118, 39–49. https://doi.org/10.1007/s004420050701
248 van der Heijden, MGA, Boller, T, Wiemken, A, Sanders, IR, 1998a: *Different Arbuscular Mycorrhizal Fungal Species Are Potential Determinants of Plant Community Structure.* Ecology 79, 2082–2091. https://doi.org/10.1890/0012-9658(1998)079[2082:DAMFSA]2.0.CO;2
249 van der Heijden, MGA, Klironomos, JN, Ursic, M, Moutoglis, P, Streitwolf-Engel, R, Boller, T, Wiemken, A, Sanders, IR, 1998b: *Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity.* Nature 396, 69–72. https://doi.org/10.1038/23932
250 Schaffer, B, Whiley, AW, Searle, C, Nissen, R, 1997: *Leaf gas exchange, dry matter partitioning, and mineral element concentrations in mango as influenced by elevated atmospheric carbon dioxide and root restriction.* Journal of the American Society for Horticultural Science. https://journals.ashs.org/jashs/view/journals/jashs/122/6/article-p849.xml
251 Case, AL, Curtis, PS, Snow, AA, 1998: *Heritable variation in stomatal responses to elevated CO2 in wild radish, Raphanus raphanistrum (Brassicaceae).* American Journal of Botany 85, 253–258. https://doi.org/10.2307/2446313
252 Egli, P, Maurer, S, Günthardt-Goerg, MS, Körner, C, 1998: *Effects of elevated CO2 and soil quality on leaf gas exchange and above-ground growth in beech–spruce model ecosystems.* The New Phytologist 140, 185–196. https://doi.org/10.1046/j.1469-8137.1998.00276.x
253 Kubiske, ME, Pregitzer, KS, Zak, DR, Mikan, CJ, 1998: *Growth and C allocation of Populus tremuloides genotypes in response to atmospheric CO2 and soil N availability.* The New Phytologist 140, 251–260. https://doi.org/10.1046/j.1469-8137.1998.00264.x

254 Lüscher, A, Hendrey, GR, Nösberger, J, 1997: *Long-term responsiveness to free air CO2 enrichment of functional types, species and genotypes of plants from fertile permanent grassland.* Oecologia 113, 37–45. https://doi.org/10.1007/s004420050351

255 Midgley, GF, Wand, SJE, Pammenter, NW, 1999: *Nutrient and genotypic effects on CO2-responsiveness: photosynthetic regulation in Leucadendron species of a nutrient-poor environment.* Journal of Experimental Botany 50, 533–542. https://doi.org/10.1093/jxb/50.333.533

256 Norton, LR, Firbank, LG, Gray, AJ, Watkinson, AR, 1999: *Responses to elevated temperature and CO2 in the perennial grass Agrostis curtisii in relation to population origin.* Functional Ecology 13, 29–37. https://doi.org/10.1046/j.1365-2435.1999.00005.x

257 Polley, HW, Tischler, CR, Johnson, HB, Pennington, RE, 1999: *Growth, water relations, and survival of drought-exposed seedlings from six maternal families of honey mesquite (Prosopis glandulosa): responses to CO2 enrichment.* Tree Physiology 19, 359–366. https://doi.org/10.1093/treephys/19.6.359

258 Gordin, MD, 2022: *Lysenkoism.* Encyclopedia of the History of Science 4. https://doi.org/10.34758/d5bq-k368

259 2017: *List of Famines*. Wikipedia. https://en.wikipedia.org/wiki/List_of_famines

260 Centritto, M, Lee, HSJ, Jarvis, PG, 1999: *Interactive effects of elevated [CO2] and drought on cherry (Prunus avium) seedlings I. Growth, whole-plant water use efficiency and water loss.* The New Phytologist 141, 129–140. https://doi.org/10.1046/j.1469-8137.1999.00326.x

261 Ansley, RJ, Wu, XB, Kramp, BA, 2001: *Observation: Long-term increases in mesquite canopy cover in a north Texas savanna.* Journal of Range Management, 2001-03-01, https://doi.org/10.2458/azu_jrm_v54i2_ansley

262 Apple et al, 2000: *Morphology and Stomatal Function of Douglas Fir Needles Exposed to Climate Change: Elevated CO2 and Temperature.* International Journal of Plant Sciences: Vol 161, No 1. https://www.journals.uchicago.edu/doi/abs/10.1086/314237

263 Bahre, CJ, Shelton, ML, 1993: Historic Vegetation Change, Mesquite Increases, and Climate in Southeastern Arizona. Journal of Biogeography 20, 489–504. https://doi.org/10.2307/2845722

264 Biggs, TH, Quade, J, Webb, RH, 2002: *$\delta^{13}C$ values of soil organic matter in semiarid grassland with mesquite (Prosopis) encroachment in southeastern Arizona.* Geoderma 110, 109–130. https://doi.org/10.1016/S0016-7061(02)00227-6

265 Cech, PG, Pepin, S, Körner, C, 2003: *Elevated CO2 reduces sap flux in mature deciduous forest trees.* Oecologia 137, 258–268. https://doi.org/10.1007/s00442-003-1348-7

266 De Costa, W a. JM, Weerakoon, WMW, Abeywardena, RMI, Herath, HMLK, 2003: *Response of Photosynthesis and Water Relations of Rice (Oryza sativa) to Elevated Atmospheric Carbon Dioxide in the Subhumid Zone of Sri Lanka.* Journal of Agronomy and Crop Science 189, 71–82. https://doi.org/10.1046/j.1439-037X.2003.00012.x

267 Wu, D, Wang, G-X, Bai, Y, Liao廖建雄, J, Ren, H-X, 2002: *Response of growth and water use efficiency of spring wheat to whole season CO2 enrichment and drought.* Acta Botanica Sinica 44, 1477–1483.

268 Dugas, WA, Polley, HW, Mayeux, HS, Johnson, HB, 2001: *Acclimation of whole-plant Acacia farnesiana transpiration to carbon dioxide concentration.* Tree Physiology 21, 771–773. https://doi.org/10.1093/treephys/21.11.771

269 Engloner, AI, Kovács, D, Balogh, J, Tuba, Z, 2003: *Anatomical and Eco-Physiological Changes in Leaves of Couch-Grass (Elymus repens L.), a Temperate Loess Grassland Species, after 7 Years Growth Under Elevated CO2 Concentration.* Photosynthetica 41, 185–189. https://doi.org/10.1023/B:PHOT.0000011950.80843.79

270 Gibbins, RP, Beck, RF, McNeely, RP, Herbel, CH, 1992: *Recent Rates of Mesquite Establishment in the Northern Chihuahuan Desert.* USDA-ARS. Jornada Experimental Range, 45:585-588, November 1992. https://typeset.io/pdf/recent-rates-of-mesquite-establishment-in-the-northern-2j40n2ip11.pdf

271 Kellomäki, S, Wang, K-Y, 1998: *Sap flow in Scots pines growing under conditions of year-round carbon dioxide enrichment and temperature elevation.* Plant, Cell & Environment 21, 969–981. https://doi.org/10.1046/j.1365-3040.1998.00352.x

272 Lewis, JD, Lucash, M, Olszyk, DM, Tingey, DT, 2002: *Stomatal responses of Douglas-fir seedlings to elevated carbon dioxide and temperature during the third and fourth years of exposure.* Plant, Cell & Environment 25, 1411–1421. https://doi.org/10.1046/j.1365-3040.2002.00923.x

273 Lloyd, AH, Fastie, CL, 2002: *Spatial and Temporal Variability in the Growth and Climate Response of Treeline Trees in Alaska.* Climatic Change 52, 481–509. https://doi.org/10.1023/A:1014278819094

274 Malmström, CM, Field, CB, 1997: *Virus-induced differences in the response of oat plants to elevated carbon dioxide.* Plant, Cell & Environment 20, 178–188. https://doi.org/10.1046/j.1365-3040.1997.d01-63.x

275 Peterson, AG, Neofotis, PG, 2004: *A hierarchical analysis of the interactive effects of elevated CO2 and water availability on the nitrogen and transpiration productivities of velvet mesquite seedlings.* Oecologia 141, 629–640. https://doi.org/10.1007/s00442-004-1688-y

276 Polley, HW, Johnson, HB, Mayeux, HS, 1994: *Increasing CO2: Comparative Responses of the C4 Grass Schizachyrium and Grassland Invader Prosopis.* Ecology 75, 976–988. https://doi.org/10.2307/1939421

277 Wayne Polley, H, Johnson, HB, Tischler, CR, 2003: *Woody invasion of grasslands: evidence that CO2 enrichment indirectly promotes establishment of Prosopis glandulosa.* Plant Ecology 164, 85–94. https://doi.org/10.1023/A:1021271226866

278 Roberts, SW, Oechel, WC, Bryant, PJ, Hastings, SJ, Major, J, Nosov, V, 1998: *A field fumigation system for elevated carbon dioxide exposure in chaparral shrubs.* Functional Ecology 12, 708–719. https://doi.org/10.1046/j.1365-2435.1998.00241.x

279 Saurer, M, Siegwolf, RTW, Schweingruber, FH, 2004: *Carbon isotope discrimination indicates improving water-use efficiency of trees in northern Eurasia over the last 100 years.* Global Change Biology 10, 2109–2120. https://doi.org/10.1111/j.1365-2486.2004.00869.x

280 Seneweera, S, Ghannoum, O, Conroy, JP, 2001: *Root and shoot factors contribute to the effect of drought on photosynthesis and growth of the C4 grass Panicum coloratum at elevated CO2 partial pressures.* Functional Plant Biol. 28, 451–460. https://doi.org/10.1071/pp01007

281 Szente, K, Nagy, Z, Tuba, Z, 1998: *Enhanced Water Use Efficiency in Dry Loess Grassland Species Grown at Elevated Air CO2 Concentration.* Photosynthetica 35, 637–640. https://doi.org/10.1023/A:1006951628745

282 Tognetti, R, Longobucco, A, Miglietta, F, Raschi, A, 1998: *Transpiration and stomatal behaviour of Quercus ilex plants during the summer in a Mediterranean carbon dioxide spring.* Plant, Cell & Environment 21, 613–622. https://doi.org/10.1046/j.1365-3040.1998.00301.x

283 Tuba, Z, Szente, K, Koch, J, 1994: *Response of Photosynthesis, Stomatal Conductance, Water Use Efficiency and Production to Long-Term Elevated CO2 in Winter Wheat.* Journal of Plant Physiology 144, 661–668. https://doi.org/10.1016/S0176-1617(11)80657-7

284 Tuba, Z, Szente, K, Nagy, Z, Csintalan, Z, Koch, J, 1996: Responses of CO2 Assimilation, Transpiration and Water Use Efficiency to Long-Term Elevated CO2 in Perennial C3 Xeric Loess Steppe Species. Journal of Plant Physiology 148, 356–361. https://doi.org/10.1016/S0176-1617(96)80265-3

285 Vu, JCV, 2005: *Acclimation of peanut (Arachis hypogaea L.) leaf photosynthesis to elevated growth CO2 and temperature.* Environmental and Experimental Botany 53, 85–95. https://doi.org/10.1016/j.envexpbot.2004.03.006

286 Wullschleger, SD, Norby, RJ, 2001: *Sap velocity and canopy transpiration in a sweetgum stand exposed to free-air CO2 enrichment (FACE).* New Phytologist 150, 489–498. https://doi.org/10.1046/j.1469-8137.2001.00094.x
287 Wullschleger, SD, Gunderson, CA, Hanson, PJ, Wilson, KB, Norby, RJ, 2002: *Sensitivity of stomatal and canopy conductance to elevated CO2 concentration – interacting variables and perspectives of scale.* New Phytologist 153, 485–496. https://doi.org/10.1046/j.0028-646X.2001.00333.x
288 Anderson, PD, Tomlinson, PT, 1998: *Ontogeny affects response of northern red oak seedlings to elevated CO2 and water stress: I. Carbon assimilation and biomass production.* The New Phytologist 140, 477–491. https://doi.org/10.1046/j.1469-8137.1998.00296.x
289 Arp, WJ, Van Mierlo, JEM, Berendse, F, Snijders, W, 1998: *Interactions between elevated CO2 concentration, nitrogen and water: effects on growth and water use of six perennial plant species*. Plant, Cell & Environment 21, 1–11. https://doi.org/10.1046/j.1365-3040.1998.00257.x
290 Centritto, M, Lee, HSJ, Jarvis, PG, 1999: *Interactive effects of elevated [CO2] and drought on cherry (Prunus avium) seedlings I. Growth, whole-plant water use efficiency and water loss.* The New Phytologist 141, 129–140. https://doi.org/10.1046/j.1469-8137.1999.00326.x
291 Clark, H, Newton, PCD, Barker, DJ, 1999: *Physiological and morphological responses to elevated CO2 and a soil moisture deficit of temperate pasture species growing in an established plant community.* Journal of Experimental Botany 50, 233–242. https://doi.org/10.1093/jxb/50.331.233
292 Conley, MM, Kimball, BA, Brooks, TJ, Pinter Jr., PJ, Hunsaker, DJ, Wall, GW, Adam, NR, LaMorte, RL, Matthias, AD, Thompson, TL, Leavitt, SW, Ottman, MJ, Cousins, AB, Triggs, JM, 2001: *CO2 enrichment increases water-use efficiency in sorghum.* New Phytologist 151, 407–412. https://doi.org/10.1046/j.1469-8137.2001.00184.x
293 Derner, JD, Polley, HW, Johnson, HB, Tischler, CR, 2001: *Root system response of C4 grass seedlings to CO2 and soil water.* Plant and Soil 231, 97–104. https://doi.org/10.1023/A:1010306720328
294 Fernández, MD, Pieters, A, Azkue, M, Rengifo, E, Tezara, W, Woodward, FI, Herrera, A, 2000: *Photosynthesis in Plants of Four Tropical Species Growing under Elevated CO2.* Photosynthetica 37, 587–599. https://doi.org/10.1023/A:1007175609368
295 Fernández, MD, Pieters, A, Donoso, C, Tezara, W, Azkue, M, Herrera, C, Rengifo, E, Herrera, A, 1998: *Effects of a natural source of very high CO2 concentration on the leaf gas exchange, xylem water potential and stomatal characteristics of plants of Spatiphylum cannifolium and Bauhinia multinervia.* The New Phytologist 138, 689–697. https://doi.org/10.1046/j.1469-8137.1998.00161.x
296 Ferris, R, Wheeler, TR, Hadley, P, Ellis, RH, 1998: *Recovery of Photosynthesis after Environmental Stress in Soybean Grown under Elevated CO2.* Crop Science 38, cropsci1998.0011183X003800040012x. https://doi.org/10.2135/cropsci1998.0011183X003800040012x
297 Ferris, R, Wheeler, TR, Ellis, RH, Hadley, P, 1999: *Seed Yield after Environmental Stress in Soybean Grown under Elevated CO2.* Crop Science 39, cropsci1999.0011183X003900030018x. https://doi.org/10.2135/cropsci1999.0011183X003900030018x
298 Hamerlynck, EP, Huxman, TE, Loik, ME, Smith, SD, 2000: *Effects of extreme high temperature, drought and elevated CO2 on photosynthesis of the Mojave Desert evergreen shrub, Larrea tridentata.* Plant Ecology 148, 183–193. https://doi.org/10.1023/A:1009896111405
299 Leymarie, J, Lascève, G, Vavasseur, A, 1999: *Elevated CO2 enhances stomatal responses to osmotic stress and abscisic acid in Arabidopsis thaliana.* Plant, Cell & Environment 22, 301–308. https://doi.org/10.1046/j.1365-3040.1999.00403.x

300 Li, A-G, Hou, Y-S, Wall, GW, Trent, A, Kimball, BA, Pinter Jr., PJ, 2000: *Free-Air CO2 Enrichment and Drought Stress Effects on Grain Filling Rate and Duration in Spring Wheat.* Crop Science 40, 1263–1270. https://doi.org/10.2135/cropsci2000.4051263x

301 Lin, J-S, Wang, G-X, 2002: *Doubled CO2 could improve the drought tolerance better in sensitive cultivars than in tolerant cultivars in spring wheat.* Plant Science 163, 627–637. https://doi.org/10.1016/S0168-9452(02)00173-5

302 Ottman, MJ, Kimball, BA, Pinter, PJ, Wall, GW, Vanderlip, RL, Leavitt, SW, LaMorte, RL, Matthias, AD, Brooks, TJ, 2001: *Elevated CO2 increases sorghum biomass under drought conditions.* New Phytologist 150, 261–273. https://doi.org/10.1046/j.1469-8137.2001.00110.x

303 Owensby, CE, Ham, JayM, Knapp, AlanK, Auen, LisaM, 1999: *Biomass production and species composition change in a tallgrass prairie ecosystem after long-term exposure to elevated atmospheric CO2.* Global Change Biology 5, 497–506. https://doi.org/10.1046/j.1365-2486.1999.00245.x

304 Palanisamy, K, 2000: *Interactions of Elevated CO2 Concentration and Drought Stress on Photosynthesis in Eucalyptus Cladocalyx F. Muell.* Photosynthetica 36, 635–638. https://doi.org/10.1023/A:1007068826872

305 Polley, HW, Tischler, CR, Johnson, HB, Derner, JD, 2002: *Growth rate and survivorship of drought: CO2 effects on the presumed tradeoff in seedlings of five woody legumes.* Tree Physiology 22, 383–391. https://doi.org/10.1093/treephys/22.6.383

306 Rabha, BK, Uprety, DC, 1998: *Effects of Elevated CO2 and Moisture Stress on Brassica Juncea.* Photosynthetica 35, 597–602. https://doi.org/10.1023/A:1006991210089

307 Runion, GB, Mitchell, RJ, Green, TH, Prior, SA, Rogers, HH, Gjerstad, DH, 1999: *Longleaf Pine Photosynthetic Response to Soil Resource Availability and Elevated Atmospheric Carbon Dioxide.* Journal of Environmental Quality 28, 880–887. https://doi.org/10.2134/jeq1999.00472425002800030020x

308 Schulte, M, Herschbach, C, Rennenberg, H, 1998: *Interactive effects of elevated atmospheric CO2, mycorrhization and drought on long-distance transport of reduced sulphur in young pedunculate oak trees (Quercus robur L.).* Plant, Cell & Environment 21, 917–926. https://doi.org/10.1046/j.1365-3040.1998.00337.x

309 Seneweera, SP, Ghannoum, O, Conroy, J, 1998: *High vapour pressure deficit and low soil water availability enhance shoot growth responses of a C4 grass (Panicum coloratum cv. Bambatsi) to CO2 enrichment.* Functional Plant Biol. 25, 287–292. https://doi.org/10.1071/pp97054

310 Serraj, R, Allen, LH, Sinclair, TR, 1999: *Soybean leaf growth and gas exchange response to drought under carbon dioxide enrichment.* Global Change Biology 5, 283–291. https://doi.org/10.1046/j.1365-2486.1999.00222.x

311 Sgherri, CLM, Quartacci, MF, Menconi, M, Raschi, A, Navari-Izzo, F, 1998: *Interactions between drought and elevated CO2 on alfalfa plants.* Journal of Plant Physiology 152, 118–124. https://doi.org/10.1016/S0176-1617(98)80110-7

312 Tognetti, R, Raschi, A, Jones, MB, 2002: *Seasonal changes in tissue elasticity and water transport efficiency in three co-occurring Mediterranean shrubs under natural long-term CO2 enrichment.* Functional Plant Biol. 29, 1097–1106. https://doi.org/10.1071/pp01220

313 Tomlinson, PT, Anderson, PD, 1998: *Ontogeny affects response of northern red oak seedlings to elevated CO2 and water stress: II. Recent photosynthate distribution and growth.* The New Phytologist 140, 493–504. https://doi.org/10.1046/j.1469-8137.1998.00291.x

314 Volk, M, Niklaus, PA, Körner, C, 2000: *Soil moisture effects determine CO2 responses of grassland species.* Oecologia 125, 380–388. https://doi.org/10.1007/s004420000454

315 Wall, GW, 2001: Elevated atmospheric CO2 alleviates drought stress in wheat. Agriculture, Ecosystems & Environment 87, 261–271. https://doi.org/10.1016/S0167-8809(01)00170-0

316 Ward, JoYK, Tissue, DT, Thomas, RB, Strain, BoyDR, 1999: *Comparative responses of model C3 and C4 plants to drought in low and elevated CO2.* Global Change Biology 5, 857–867. https://doi.org/10.1046/j.1365-2486.1999.00270.x
317 Idso, SB, Kimball, BA, Anderson, MG, 1985: *Atmospheric CO2 Enrichment of Water Hyacinths: Effects on Transpiration and Water Use Efficiency.* Water Resources Research 21, 1787–1790. https://doi.org/10.1029/WR021i011p01787
318 Rogers, HH, Bingham, GE, Cure, JD, Smith, JM, Surano, KA, 1983: *Responses of Selected Plant Species to Elevated Carbon Dioxide in the Field.* Journal of Environmental Quality 12, 569–574. https://doi.org/10.2134/jeq1983.00472425001200040028x
319 Valle, R, Mishoe, JW, Jones, JW, Allen Jr., LH, 1985: *Transpiration Rate and Water Use Effeciency of Soybean Leaves Adapted to Different CO2 Environments*. 1. Crop Science 25, cropsci1985.0011183X002500030011x https://doi.org/10.2135/cropsci1985.0011183X002500030011x
320 Field, CB, Jackson, RB, Mooney, HA, 1995: *Stomatal responses to increased CO2: implications from the plant to the global scale.* Plant, Cell, & Environment, https://doi.org/10.1111/j.1365-3040.1995.tb00630.x
321 Allen Jr., LH, 1990: *Plant Responses to Rising Carbon Dioxide and Potential Interactions with Air Pollutants.* Journal of Environmental Quality 19, 15–34. https://doi.org/10.2134/jeq1990.00472425001900010002x
322 Kellomäki, S, Wang, K-Y, 1997: *Effects of elevated O3 and CO2 on chlorophyll fluorescence and gas exchange in Scots pine during the third growing season.* Environmental Pollution 97, 17–27. https://doi.org/10.1016/S0269-7491(97)00084-5
323 Reid, CD, Fiscus, EL, 1998: *Effects of elevated [CO2] and/or ozone on limitations to CO2 assimilation in soybean (Glycine max).* Journal of Experimental Botany 49, 885–895. https://doi.org/10.1093/jxb/49.322.885
324 Volin, JC, Reich, PB, Givnish, TJ, 1998: *Elevated carbon dioxide ameliorates the effects of ozone on photosynthesis and growth: species respond similarly regardless of photosynthetic pathway or plant functional group.* The New Phytologist 138, 315–325. https://doi.org/10.1046/j.1469-8137.1998.00100.x
325 Heagle, AS, Miller, JE, Pursley, WA, 2000: *Growth and Yield Responses of Winter Wheat to Mixtures of Ozone and Carbon Dioxide.* Crop Science 40, 1656–1664. https://doi.org/10.2135/cropsci2000.4061656x
326 Mishra, S, Heckathorn, SA, Barua, D, Wang, D, Joshi, P, Hamilton III, EW, Frantz, J, 2008: *Interactive Effects of Elevated CO2 and Ozone on Leaf Thermotolerance in Field-grown Glycine max.* Journal of Integrative Plant Biology 50, 1396–1405. https://doi.org/10.1111/j.1744-7909.2008.00745.x
327 Deepak, SS, Agrawal, M, 2001: *Influence of elevated CO2 on the sensitivity of two soybean cultivars to sulphur dioxide.* Environmental and Experimental Botany 46, 81–91. https://doi.org/10.1016/S0098-8472(01)00086-7
328 Agrawal, M, Deepak, SS, 2003: *Physiological and biochemical responses of two cultivars of wheat to elevated levels of CO2 and SO2, singly and in combination.* Environmental Pollution 121, 189–197. https://doi.org/10.1016/S0269-7491(02)00222-1
329 Carlson, RW, 1983: *The effect of SO2 on photosynthesis and leaf resistance at varying concentrations of CO2.* Environmental Pollution Series A, Ecological and Biological 30, 309–321. https://doi.org/10.1016/0143-1471(83)90057-0
330 Hallgren, JE, 1984: *Photosynthetic gas exchange in leaves affected by air pollutants. Gaseous air pollutants and plant metabolism*. 147–159.
331 Grill, D, Müller, M, Tausz, M, Strnad, B, Wonisch, A, Raschi, A, 2004: *Effects of sulphurous gases in two CO2 springs on total sulphur and thiols in acorns and oak seedlings.* Atmospheric Environment 38, 3775–3780. https://doi.org/10.1016/j.atmosenv.2004.04.005

332 Blaschke, L, Schulte, M, Raschi, A, Slee, N, Rennenberg, H, Polle, A, 2001: *Photosynthesis, Soluble and Structural Carbon Compounds in Two Mediterranean Oak Species (Quercus pubescens and Q. ilex) after Lifetime Growth at Naturally Elevated CO2 Concentrations.* Plant Biol (Stuttg) 3, 288–298. https://doi.org/10.1055/s-2001-15203

333 Stylinski, CD, Oechel, WC, Gamon, JA, Tissue, DT, Miglietta, F, Raschi, A, 2000: *Effects of lifelong [CO2] enrichment on carboxylation and light utilization of Quercus pubescens Willd. examined with gas exchange, biochemistry and optical techniques.* Plant, Cell & Environment 23, 1353–1362. https://doi.org/10.1046/j.1365-3040.2000.00638.x

334 Tognetti, R, Johnson, JD, Michelozzi, M, Raschi, A, 1998: *Response of foliar metabolism in mature trees of Quercus pubescens and Quercus ilex to long-term elevated CO2.* Environmental and Experimental Botany 39, 233–245. https://doi.org/10.1016/S0098-8472(98)00013-6

335 Booker, FL, Miller, JE, Fiscus, EL, Pursley, WA, Stefanski, LA, 2005: *Comparative Responses of Container- versus Ground-Grown Soybean to Elevated Carbon Dioxide and Ozone.* Crop Science 45, 883–895. https://doi.org/10.2135/cropsci2004.0198

336 Hudak, C, Bender, J, Weigel, H-J, Miller, J, 1999: *Interactive effects of elevated CO2, O3, and soil water deficit on spring wheat (Triticum aestivum L. cv. Nandu).* Agronomie 19, 677–687.

337 Heagle, AS, Miller, JE, Pursley, WA, 1998: *Influence of Ozone Stress on Soybean Response to Carbon Dioxide Enrichment: III. Yield and Seed Quality.* Crop Science 38, cropsci1998.0011183X003800010022x. https://doi.org/10.2135/cropsci1998.0011183X003800010022x

338 Tiedemann, A v, Firsching, KH, 2000a: *Interactive effects of elevated ozone and carbon dioxide on growth and yield of leaf rust-infected versus non-infected wheat.* Environmental Pollution 108, 357–363. https://doi.org/10.1016/S0269-7491(99)00214-6

339 Miller, JE, Heagle, AS, Pursley, WA, 1998: *Influence of Ozone Stress on Soybean Response to Carbon Dioxide Enrichment: II. Biomass and Development.* Crop Science 38, cropsci1998.0011183X003800010021x. https://doi.org/10.2135/cropsci1998.0011183X003800010021x

340 Cardoso-Vilhena, J, Barnes, J, 2001: *Does nitrogen supply affect the response of wheat (Triticum aestivum cv. Hanno) to the combination of elevated CO2 and O3?* Journal of Experimental Botany 52, 1901–1911. https://doi.org/10.1093/jexbot/52.362.1901

341 Donnelly, A, Finnan, J, Jones, MB, Burke, JI, 2005: *A Note on the Effect of Elevated Concentrations of Greenhouse Gases on Spring Wheat Yield in Ireland.* Irish Journal of Agricultural and Food Research 44, 141–145.

342 Riikonen, J, Kets, K, Darbah, J, Oksanen, E, Sober, A, Vapaavuori, E, Kubiske, ME, Nelson, N, Karnosky, DF, 2008: *Carbon gain and bud physiology in Populus tremuloides and Betula papyrifera grown under long-term exposure to elevated concentrations of CO2 and O3.* Tree Physiology 28, 243–254. https://doi.org/10.1093/treephys/28.2.243

343 Pregitzer, KS, Burton, AJ, King, JS, Zak, DR, 2008: *Soil respiration, root biomass, and root turnover following long-term exposure of northern forests to elevated atmospheric CO2 and tropospheric O3.* New Phytologist 180, 153–161. https://doi.org/10.1111/j.1469-8137.2008.02564.x

344 Kostiainen, K, Kaakinen, S, Warsta, E, Kubiske, ME, Nelson, ND, Sober, J, Karnosky, DF, Saranpää, P, Vapaavuori, E, 2008: *Wood properties of trembling aspen and paper birch after 5 years of exposure to elevated concentrations of CO2 and O3.* Tree Physiology 28, 805–813. https://doi.org/10.1093/treephys/28.5.805

345 Hibberd, JM, Whitbread, R, Farrar, JF, 1996a: *Effect of 700 µmol mol −1CO2 and infection with powdery mildew on the growth and carbon partitioning of barley.* New Phytologist 134, 309–315. https://doi.org/10.1111/j.1469-8137.1996.tb04635.x

346 Hibberd, JM, Whitbread, R, Farrar, JF, 1996b: *Effect of elevated concentrations of CO2on infection of barley byErysiphe graminis.* Physiological and Molecular Plant Pathology 48, 37–53. https://doi.org/10.1006/pmpp.1996.0004
347 Owensby, CE, 1995: *Climate change and grasslands; ecosystem-level responses to elevated carbon dioxide.*
348 Bowes, G, 1993: Facing the Inevitable: Plants and Increasing Atmospheric CO2. Annual Review of Plant Physiology and Plant Molecular Biology 44, 309–332. https://doi.org/10.1146/annurev.pp.44.060193.001521
349 Hartley, SE, Jones, CG, Couper, GC, Jones, TH, 2000: *Biosynthesis of plant phenolic compounds in elevated atmospheric CO2.* Global Change Biology 6, 497–506. https://doi.org/10.1046/j.1365-2486.2000.00333.x
350 Smith, SE, Read, D, 2008 (3rd Edition): *Mycorrhizal Symbioses.* ISBN 978-0-12-370526-6
351 Malmström, CM, Field, CB, 1997: *Virus-induced differences in the response of oat plants to elevated carbon dioxide.* Plant, Cell & Environment 20, 178–188. https://doi.org/10.1046/j.1365-3040.1997.d01-63.x
352 Tiedemann, A v, Firsching, KH, 2000b: *Interactive effects of elevated ozone and carbon dioxide on growth and yield of leaf rust-infected versus non-infected wheat.* Environmental Pollution 108, 357–363. https://doi.org/10.1016/S0269-7491(99)00214-6
353 Jwa, N-S, Walling, LL, 2001: *Influence of elevated CO2 concentration on disease development in tomato.* New Phytologist 149, 509–518. https://doi.org/10.1046/j.1469-8137.2001.00063.x
354 Pangga, IB, Chakraborty, S, Yates, D, 2004: *Canopy Size and Induced Resistance in Stylosanthes scabra Determine Anthracnose Severity at High CO2.* Phytopathology® 94, 221–227. https://doi.org/10.1094/PHYTO.2004.94.3.221
355 Mcelrone, AJ, Reid, CD, Hoye, KA, Hart, E, Jackson, RB, 2005: *Elevated CO2 reduces disease incidence and severity of a red maple fungal pathogen via changes in host physiology and leaf chemistry.* Global Change Biology 11, 1828–1836. https://doi.org/10.1111/j.1365-2486.2005.001015.x
356 Matros, A, Amme, S, Kettig, B, Buck-Sorlin, GH, Sonnewald, U, Mock, H-P, 2006: *Growth at elevated CO2 concentrations leads to modified profiles of secondary metabolites in tobacco cv. SamsunNN and to increased resistance against infection with potato virus Y.* Plant, Cell & Environment 29, 126–137. https://doi.org/10.1111/j.1365-3040.2005.01406.x
357 Braga, MR, Aidar, MPM, Marabesi, MA, de Godoy, JRL, 2006: *Effects of elevated CO2 on the phytoalexin production of two soybean cultivars differing in the resistance to stem canker disease.* Environmental and Experimental Botany 58, 85–92. https://doi.org/10.1016/j.envexpbot.2005.06.018
358 Strengbom, J, Reich, PB, 2006: *Elevated [CO2] and increased N supply reduce leaf disease and related photosynthetic impacts on Solidago rigida.* Oecologia 149, 519–525. https://doi.org/10.1007/s00442-006-0458-4
359 Moller, Shykoff, 1999: *Morphological Developmental Stability in Plants: Patterns and Causes.* International Journal of Plant Sciences: Vol 160, No S6. https://www.journals.uchicago.edu/doi/abs/10.1086/314219
360 Cornelissen, T, Stiling, P, Drake, B, 2004: *Elevated CO2 decreases leaf fluctuating asymmetry and herbivory by leaf miners on two oak species.* Global Change Biology 10, 27–36. https://doi.org/10.1111/j.1365-2486.2003.00712.x
361 Stiling, P, Moon, DC, Hunter, MD, Colson, J, Rossi, AM, Hymus, GJ, Drake, BG, 2003: *Elevated CO2 lowers relative and absolute herbivore density across all species of a scrub-oak forest.* Oecologia 134, 82–87. https://doi.org/10.1007/s00442-002-1075-5
362 Cornelissen, T, Stiling, P, 2005: *Perfect is best: low leaf fluctuating asymmetry reduces herbivory by leaf miners.* Oecologia 142, 46–56. https://doi.org/10.1007/s00442-004-1724-y
363 Treseder, KK, Turner, KM, 2007: *Glomalin in Ecosystems.* Soil Science Society of America Journal 71, 1257–1266. https://doi.org/10.2136/sssaj2006.0377

364 Rilig et al, 1999: *Rise in carbon dioxide changes soil structure.* Nature. https://www.nature.com/articles/23168
365 Ross, DJ, Tate, KR, Newton, PCD, Wilde, RH, Clark, H, 2000: *Carbon and nitrogen pools and mineralization in a grassland gley soil under elevated carbon dioxide at a natural CO2 spring.* Global Change Biology 6, 779–790. https://doi.org/10.1046/j.1365-2486.2000.00357.x
366 Rillig, M c., Hernández, G y., Newton, P c. d., 2000: *Arbuscular mycorrhizae respond to elevated atmospheric CO2 after long-term exposure: evidence from a CO2 spring in New Zealand supports the resource balance model.* Ecology Letters 3, 475–478. https://doi.org/10.1111/j.1461-0248.2000.00178.x
367 González-Chávez, MC, Carrillo-González, R, Wright, SF, Nichols, KA, 2004: *The role of glomalin, a protein produced by arbuscular mycorrhizal fungi, in sequestering potentially toxic elements.* Environmental Pollution 130, 317–323. https://doi.org/10.1016/j.envpol.2004.01.004
368 Jia, H, Guo, H, Yin, Y, Wang, Q, Sun, Q, Wang, X, Zhu, J, 2007: Responses of rice growth to copper stress under free-air CO2 enrichment (FACE). CHINESE SCI BULL 52, 2636–2641. https://doi.org/10.1007/s11434-007-0362-2
369 Sanità di Toppi, L, Gabbrielli, R, 1999: *Response to cadmium in higher plants.* Environmental and Experimental Botany 41, 105–130. https://doi.org/10.1016/S0098-8472(98)00058-6
370 Tukaj, Z, Baścik-Remisiewicz, A, Skowroński, T, Tukaj, C, 2007: *Cadmium effect on the growth, photosynthesis, ultrastructure and phytochelatin content of green microalga Scenedesmus armatus: A study at low and elevated CO2 concentration.* Environmental and Experimental Botany 60, 291–299. https://doi.org/10.1016/j.envexpbot.2006.12.002
371 Arneth, A, Schurgers, G, Hickler, T, Miller, PA, 2007: *Effects of Species Composition, Land Surface Cover, CO2 Concentration and Climate on Isoprene Emissions from European Forests.* Plant Biol (Stuttg) 9, e87–e98. https://doi.org/10.1055/s-2007-965247
372 Baraldi, R, Rapparini, F, Oechel, WC, Hastings, SJ, Bryant, P, Cheng, Y, Miglietta, F, 2004a: *Monoterpene Emission Responses to Elevated CO2 in a Mediterranean-Type Ecosystem.* The New Phytologist 161, 17–21.
373 Lathière, J, Hewitt, CN, Beerling, DJ, 2010: *Sensitivity of isoprene emissions from the terrestrial biosphere to 20th century changes in atmospheric CO2 concentration, climate, and land use.* Global Biogeochemical Cycles 24. https://doi.org/10.1029/2009GB003548
374 Loreto, F, Sharkey, TD, 1990: *A gas-exchange study of photosynthesis and isoprene emission in Quercus rubra L.* Planta 182, 523–531. https://doi.org/10.1007/BF02341027
375 Monson, RK, Fall, R, 1989: *Isoprene Emission from Aspen Leaves 1: Influence of Environment and Relation to Photosynthesis and Photorespiration.* Plant Physiology 90, 267–274. https://doi.org/10.1104/pp.90.1.267
376 Possell, M, Heath, J, Nicholas Hewitt, C, Ayres, E, Kerstiens, G, 2004: *Interactive effects of elevated CO2 and soil fertility on isoprene emissions from Quercus robur.* Global Change Biology 10, 1835–1843. https://doi.org/10.1111/j.1365-2486.2004.00845.x
377 Possell, M, Nicholas Hewitt, C, Beerling, DJ, 2005: *The effects of glacial atmospheric CO2 concentrations and climate on isoprene emissions by vascular plants.* Global Change Biology 11, 60–69. https://doi.org/10.1111/j.1365-2486.2004.00889.x
378 Rapparini, F, Baraldi, R, Miglietta, F, Loreto, F, 2004a: *Isoprenoid emission in trees of Quercus pubescens and Quercus ilex with lifetime exposure to naturally high CO2 environment.* Plant, Cell & Environment 27, 381–391. https://doi.org/10.1111/j.1365-3040.2003.01151.x
379 Rosentiel et al, 2003: *Increased CO2 uncouples growth from isoprene emission in an agriforest ecosystem.* Nature. https://www.nature.com/articles/nature01312

380 Scholefield, PA, Doick, KJ, Herbert, BMJ, Hewitt, CNS, Schnitzler, J-P, Pinelli, P, Loreto, F, 2004: *Impact of rising CO2 on emissions of volatile organic compounds: isoprene emission from Phragmites australis growing at elevated CO2 in a natural carbon dioxide spring.* Plant, Cell & Environment 27, 393–401. https://doi.org/10.1111/j.1365-3040.2003.01155.x

381 Young, PJ, Arneth, A, Schurgers, G, Zeng, G, Pyle, JA, 2009: *The CO2 inhibition of terrestrial isoprene emission significantly affects future ozone projections.* Atmospheric Chemistry and Physics 9, 2793–2803. https://doi.org/10.5194/acp-9-2793-2009

382 Baraldi, R, Rapparini, F, Oechel, WC, Hastings, SJ, Bryant, P, Cheng, Y, Miglietta, F, 2004b: *Monoterpene Emission Responses to Elevated CO2 in a Mediterranean-Type Ecosystem.* The New Phytologist 161, 17–21.

383 Constable, JohNVH, Litvak, ME, Greenberg, JP, Monson, RK, 1999: *Monoterpene emission from coniferous trees in response to elevated CO2 concentration and climate warming.* Global Change Biology 5, 252–267. https://doi.org/10.1046/j.1365-2486.1999.00212.x

384 Loreto, F, Fischbach, RJ, Schnitzler, J-P, Ciccioli, P, Brancaleoni, E, Calfapietra, C, Seufert, G, 2001: *Monoterpene emission and monoterpene synthase activities in the Mediterranean evergreen oak Quercus ilex L. grown at elevated CO2 concentrations.* Global Change Biology 7, 709–717. https://doi.org/10.1046/j.1354-1013.2001.00442.x

385 Peñuelas, J, Llusià, J, 2003: *BVOCs: plant defense against climate warming?* Trends in Plant Science 8, 105–109. https://doi.org/10.1016/S1360-1385(03)00008-6

386 Räisänen, T, Ryyppö, A, Kellomäki, S, 2008: *Effects of elevated CO2 and temperature on monoterpene emission of Scots pine (Pinus sylvestris L.).* Atmospheric Environment 42, 4160–4171. https://doi.org/10.1016/j.atmosenv.2008.01.023

387 Rapparini, F, Baraldi, R, Miglietta, F, Loreto, F, 2004b: *Isoprenoid emission in trees of Quercus pubescens and Quercus ilex with lifetime exposure to naturally high CO2 environment.* Plant, Cell & Environment 27, 381–391. https://doi.org/10.1111/j.1365-3040.2003.01151.x

388 Staudt, M, Joffre, R, Rambal, S, Kesselmeier, J, 2001: *Effect of elevated CO2 on monoterpene emission of young Quercus ilex trees and its relation to structural and ecophysiological parameters.* Tree Physiology 21, 437–445. https://doi.org/10.1093/treephys/21.7.437

389 Ball, MC, Cochrane, MJ, Rawson, HM, 1997: *Growth and water use of the mangroves Rhizophora apiculata and R. stylosa in response to salinity and humidity under ambient and elevated concentrations of atmospheric CO2.* Plant, Cell & Environment 20, 1158–1166. https://doi.org/10.1046/j.1365-3040.1997.d01-144.x

390 Ball, MC, Munns, R, 1992: *Plant Responses to Salinity Under Elevated Atmospheric Concentrations of CO2.* Aust. J. Bot. 40, 515–525. https://doi.org/10.1071/bt9920515

391 Curtis, PS, Balduman, LM, Drake, BG, Whigham, DF, 1990: *Elevated Atmospheric CO2 Effects on Belowground Processes in C3 and C4 Estuarine Marsh Communities.* Ecology 71, 2001–2006. https://doi.org/10.2307/1937608

392 Farnsworth, EJ, Ellison, AM, Gong, WK, 1996: *Elevated CO2 alters anatomy, physiology, growth, and reproduction of red mangrove (Rhizophora mangle L.).* Oecologia 108, 599–609. https://doi.org/10.1007/BF00329032

393 García-Sánchez, F, Syvertsen, JP, 2006: *Salinity Tolerance of Cleopatra Mandarin and Carrizo Citrange Citrus Rootstock Seedlings Is Affected by CO2 Enrichment during Growth.* Journal of the American Society for Horticultural Science 131, 24–31. https://doi.org/10.21273/JASHS.131.1.24

394 Geissler, Nicole, Hussin, S, Koyro, H-W, 2009: *Elevated atmospheric CO2 concentration ameliorates effects of NaCl salinity on photosynthesis and leaf structure of Aster tripolium L.* Journal of Experimental Botany 60, 137–151. https://doi.org/10.1093/jxb/ern271

395 Geissler, N., Hussin, S, Koyro, H-W, 2009: *Interactive effects of NaCl salinity and elevated atmospheric CO2 concentration on growth, photosynthesis, water relations and chemical composition of the potential cash crop halophyte Aster tripolium* L. Environmental and Experimental Botany 65, 220–231. https://doi.org/10.1016/j.envexpbot.2008.11.001

396 Idso, KE, Idso, SB, 1994: *Plant responses to atmospheric CO2 enrichment in the face of environmental constraints: a review of the past 10 years' research.* Agricultural and Forest Meteorology 69, 153–203. https://doi.org/10.1016/0168-1923(94)90025-6

397 Maggio, A, Dalton, FN, Piccinni, G, 2002: *The effects of elevated carbon dioxide on static and dynamic indices for tomato salt tolerance.* European Journal of Agronomy 16, 197–206. https://doi.org/10.1016/S1161-0301(01)00128-9

398 Mavrogianopoulos, GN, Spanakis, J, Tsikalas, P, 1999: *Effect of carbon dioxide enrichment and salinity on photosynthesis and yield in melon.* Scientia Horticulturae 79, 51–63. https://doi.org/10.1016/S0304-4238(98)00178-2

399 Pérez-López, U, Robredo, A, Lacuesta, M, Mena-Petite, A, Muñoz-Rueda, A, 2009: *The impact of salt stress on the water status of barley plants is partially mitigated by elevated CO2*. Environmental and Experimental Botany 66, 463–470. https://doi.org/10.1016/j.envexpbot.2009.03.007

400 Pérez-López, U, Robredo, A, Lacuesta, M, Muñoz-Rueda, A, Mena-Petite, A, 2010: *Atmospheric CO2 concentration influences the contributions of osmolyte accumulation and cell wall elasticity to salt tolerance in barley cultivars.* Journal of Plant Physiology 167, 15–22. https://doi.org/10.1016/j.jplph.2009.06.019

401 Pérez-López, 2009: *The oxidative stress caused by salinity in two barley cultivars is mitigated by elevated CO2*. Physiologia Plantarum - Wiley Online Library [WWW Document]. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1399-3054.2008.01174.x

402 Poorter, H, Pérez-Soba, M, 2001: *The growth response of plants to elevated CO2 under non-optimal environmental conditions.* Oecologia 129, 1–20. https://doi.org/10.1007/s004420100736

403 Rasse, DP, Peresta, G, Drake, BG, 2005: *Seventeen years of elevated CO2 exposure in a Chesapeake Bay Wetland: sustained but contrasting responses of plant growth and CO2 uptake.* Global Change Biology 11, 369–377. https://doi.org/10.1111/j.1365-2486.2005.00913.x

404 Takagi, M, El-Shemy, HA, Sasaki, S, Toyama, S, Kanai, S, Saneoka, H, Fujita, K, 2009: *Elevated CO2 concentration alleviates salinity stress in tomato plant.* Acta Agriculturae Scandinavica, Section B — Soil & Plant Science 59, 87–96. https://doi.org/10.1080/09064710801932425

405 Nicolas, ME, Munns, R, Samarakoo, AB, Gifford, RM, 1993: *Elevated CO2 Improves the Growth of Wheat Under Salinity.* CiNii, https://cir.nii.ac.jp/crid/1363388844084236160

406 Oksanen, E, Sober, J, Karnosky, DF, 2001: *Impacts of elevated CO2 and/or O3 on leaf ultrastructure of aspen (Populus tremuloides) and birch (Betula papyrifera) in the Aspen FACE experiment.* Environmental Pollution 115, 437–446. https://doi.org/10.1016/S0269-7491(01)00233-0

407 Sgherri, CLM, Quartacci, MF, Menconi, M, Raschi, A, Navari-Izzo, F, 1998: *Interactions between drought and elevated CO2 on alfalfa plants.* Journal of Plant Physiology 152, 118–124. https://doi.org/10.1016/S0176-1617(98)80110-7

408 Taub, DR, Seemann, JR, Coleman, JS, 2000: *Growth in elevated CO2 protects photosynthesis against high-temperature damage.* Plant, Cell & Environment 23, 649–656. https://doi.org/10.1046/j.1365-3040.2000.00574.x

409 Tuba, Z, Csintalan, Z, Szente, K, Nagy, Z, Grace, J, 1998: *Carbon gains by desiccation-tolerant plants at elevated CO2.* Functional Ecology 12, 39–44. https://doi.org/10.1046/j.1365-2435.1998.00173.x

410 Wallace, JS, 2000: I*ncreasing agricultural water use efficiency to meet future food production.* Agriculture, Ecosystems & Environment 82, 105–119. https://doi.org/10.1016/S0167-8809(00)00220-6
411 Parsons, WF, Kopper, BJ, Lindroth, RL, 2003: *Altered growth and fine root chemistry of Betula papyrifera and Acer saccharum under elevated CO2.* Can. J. For. Res. 33, 842–846. https://doi.org/10.1139/x03-021
412 Bezemer, TM, Jones, TH, 1998: *Plant-Insect Herbivore Interactions in Elevated Atmospheric CO2: Quantitative Analyses and Guild Effects.* Oikos 82, 212–222. https://doi.org/10.2307/3546961
413 Cornelissen, T, Stiling, P, Drake, B, 2004: *Elevated CO2 decreases leaf fluctuating asymmetry and herbivory by leaf miners on two oak species.* Global Change Biology 10, 27–36. https://doi.org/10.1111/j.1365-2486.2003.00712.x
414 Fajer, ED, Bowers, MD, Bazzaz, FA, 1991: *The Effects of Enriched CO_2 Atmospheres on the Buckeye Butterfly, Junonia Coenia.* Ecology 72, 751–754. https://doi.org/10.2307/2937217
415 Hall, MC, Stiling, P, Hungate, BA, Drake, BG, Hunter, MD, 2005a: *Effects of Elevated CO2 and Herbivore Damage on Litter Quality in a Scrub Oak Ecosystem.* J Chem Ecol 31, 2343–2356. https://doi.org/10.1007/s10886-005-7105-0
416 Hall, MC, Stiling, P, Moon, DC, Drake, BG, Hunter, MD, 2005b: *Effects of elevated CO2 on foliar quality and herbivore damage in a scrub oak ecosystem.* J Chem Ecol 31, 267–286. https://doi.org/10.1007/s10886-005-1340-2
417 Kinney, KK, Lindroth, RL, Jung, SM, Nordheim, EV, 1997: *Effects of CO2 and No3− Availability on Deciduous Trees: Phytochemistry and Insect Performance.* Ecology 78, 215–230. https://doi.org/10.1890/0012-9658(1997)078[0215:EOCANA]2.0.CO;2
418 Kuokkanen, K, Yan, S, Niemelä, P, 2003: *Effects of elevated CO2 and temperature on the leaf chemistry of birch Betula pendula (Roth) and the feeding behaviour of the weevil Phyllobius maculicornis.* Agricultural and Forest Entomology 5, 209–217. https://doi.org/10.1046/j.1461-9563.2003.00177.x
419 Lavola, A, Julkunen-Tiitto, R, 1994: *The effect of elevated carbon dioxide and fertilization on primary and secondary metabolites in birch, Betula pendula (Roth).* Oecologia 99, 315–321. https://doi.org/10.1007/BF00627744
420 Lindroth, RL, 1996: *CO2-mediated changes in tree chemistry and tree-Lepidoptera interactions.* Carbon dioxide and terrestrial ecosystems 105–120.
421 McDonald, EP, Agrell, J, Lindroth, RL, 1999: *CO2 and light effects on deciduous trees: growth, foliar chemistry, and insect performance.* Oecologia 119, 389–399. https://doi.org/10.1007/PL00008822
422 Parsons, WFJ, Lindroth, RL, Bockheim, JG, 2004: *Decomposition of Betula papyrifera leaf litter under the independent and interactive effects of elevated CO2 and O3. Global Change.* Biology 10, 1666–1677. https://doi.org/10.1111/j.1365-2486.2004.00851.x
423 Peltonen, PA, Vapaavuori, E, Julkunen-tiitto, R, 2005: *Accumulation of phenolic compounds in birch leaves is changed by elevated carbon dioxide and ozone.* Global Change Biology 11, 1305–1324. https://doi.org/10.1111/j.1365-2486.2005.00979.x
424 Stiling, P, Cattell, M, Moon, DC, Rossi, A, Hungate, BA, Hymus, G, Drake, B, 2002: *Elevated atmospheric CO2 lowers herbivore abundance, but increases leaf abscission rates.* Global Change Biology 8, 658–667. https://doi.org/10.1046/j.1365-2486.2002.00501.x
425 Williams, RS, Lincoln, DE, Thomas, RB, 1994: *Loblolly pine grown under elevated CO2 affects early instar pine sawfly performance.* Oecologia 98, 64–71. https://doi.org/10.1007/BF00326091
426 Idso, SB, Idso, KE, Garcia, RL, Kimball, BA, Hoober, JK, 1995: *Effects of atmospheric CO2 enrichment and foliar methanol application on net photosynthesis of sour orange tree (Citrus aurantium; Rutaceae) leaves.* American Journal of Botany 82, 26–30. https://doi.org/10.1002/j.1537-2197.1995.tb15644.x

427 Nilsen, S, Hovland, K, Dons, C, Sletten, SP, 1983: *Effect of CO2 enrichment on photosynthesis, growth and yield of tomato.* Scientia Horticulturae 20, 1–14. https://doi.org/10.1016/0304-4238(83)90106-1

428 Seemann, JR, Berry, JA, Downton, WJS, 1984: *Photosynthetic Response and Adaptation to High Temperature in Desert Plants 1: A Comparison of Gas Exchange and Fluorescence Methods for Studies of Thermal Tolerance.* Plant Physiology 75, 364–368. https://doi.org/10.1104/pp.75.2.364

429 Veres, JS, Williams Iii, GJ, 1984: *Time course of photosynthetic temperature acclimation in Carex eleocharis Bailey.* Plant, Cell & Environment 7, 545–547. https://doi.org/10.1111/1365-3040.ep11616231

430 Deckmyn, G, Caeyenberghs, E, Ceulemans, R, 2001: *Reduced UV-B in greenhouses decreases white clover response to enhance CO2.* Environmental and Experimental Botany 46, 109–117. https://doi.org/10.1016/S0098-8472(01)00087-9

431 Estiarte, M, Peñuelas, J, Kimball, BA, Hendrix, DL, Pinter Jr, PJ, Wall, GW, LaMorte, RL, Hunsaker, DJ, 1999: *Free-air CO2 enrichment of wheat: leaf flavonoid concentration throughout the growth cycle.* Physiologia Plantarum 105, 423–433. https://doi.org/10.1034/j.1399-3054.1999.105306.x

432 Johnson, D, Campbell, CD, Lee, JA, Callaghan, TV, Gwynn-Jones, D, 2002: *Arctic microorganisms respond more to elevated UV-B radiation than CO2.* Nature 416, 82–83. https://doi.org/10.1038/416082a

433 Koti, S, Reddy, KR, Kakani, VG, Zhao, D, Gao, W, 2007: *Effects of carbon dioxide, temperature and ultraviolet-B radiation and their interactions on soybean (Glycine max L.) growth and development.* Environmental and Experimental Botany 60, 1–10. https://doi.org/10.1016/j.envexpbot.2006.05.001

434 Qaderi, MM, Reid, DM, 2005: *Growth and physiological responses of canola (Brassica napus) to UV-B and CO2 under controlled environment conditions.* Physiologia Plantarum 125, 247–259. https://doi.org/10.1111/j.1399-3054.2005.00566.x

435 Qaderi, MM, Reid, DM, Yeung, EC, 2007: *Morphological and physiological responses of canola (Brassica napus) siliquas and seeds to UVB and CO2 under controlled environment conditions.* Environmental and Experimental Botany 60, 428–437. https://doi.org/10.1016/j.envexpbot.2006.12.019

436 Rozema, J, Lenssen, GM, van de Staaij, JWM, Tosserams, M, Visser, AJ, Broekman, RA, 1997: *Effects of UV-B radiation on terrestrial plants and ecosystems: interaction with CO2 enrichment.* Plant Ecology 128, 183–191. https://doi.org/10.1023/A:1009762924174

437 Zhao, D, Reddy, KR, Kakani, VG, Mohammed, AR, Read, JJ, Gao, W e. i., 2004: *Leaf and canopy photosynthetic characteristics of cotton (Gossypium hirsutum) under elevated CO2 concentration and UV-B radiation*. Journal of Plant Physiology 161, 581–590. https://doi.org/10.1078/0176-1617-01229

438 Zhao, D, Reddy, KR, Kakani, VG, Read, JJ, Sullivan, JH, 2003: *Growth and physiological responses of cotton (Gossypium hirsutum L.) to elevated carbon dioxide and ultraviolet-B radiation under controlled environmental conditions.* Plant, Cell & Environment 26, 771–782. https://doi.org/10.1046/j.1365-3040.2003.01019.x

439 Pichersky, E, Gershenzon, J, 2002: *The formation and function of plant volatiles: perfumes for pollinator attraction and defense.* Current Opinion in Plant Biology 5, 237–243. https://doi.org/10.1016/S1369-5266(02)00251-0

440 Niu et al, 2000: *Day and Night Temperatures, Daily Light Integral, and CO2 Enrichment Affect Growth and Flower Development of Pansy (Viola x Wittrockiana).*

441 Johnson, SL, Lincoln, DE, 2000: *Allocation responses to CO2 enrichment and defoliation by a native annual plant Heterotheca subaxillaris.* Global Change Biology 6, 767–778. https://doi.org/10.1046/j.1365-2486.2000.00355.x

442 LAKE, JC, HUGHES, L, 1999: N*ectar Production and Floral Characteristics of Tropaeolum majus L. Grown in Ambient and Elevated Carbon Dioxide.* Annals of Botany 84, 535–541. https://doi.org/10.1006/anbo.1999.0949

443 Dag, A, Eisikowitch, D, 2000: *The Effect of Carbon Dioxide Enrichment on Nectar Production in Melons Under Greenhouse Conditions.* Journal of Apicultural Research.

444 Erhardt, A, Rusterholz, H-P, Stöcklin, J, 2005: *Elevated carbon dioxide increases nectar production in Epilobium angustifolium.* L. Oecologia 146, 311–317. https://doi.org/10.1007/s00442-005-0182-5

445 Kooij, TAW, De Kok, L, 1996: *Impact of elevated CO2 on growth and development of Arabidopsis thaliana L. Phyton*. Annales rei botanicae 36, 173–184.

446 Jitla, DS, Rogers, GS, Seneweera, SP, Basra, AS, Oldfield, RJ, Conroy, JP, 1997: *Accelerated Early Growth of Rice at Elevated CO2 (Is It Related to Developmental Changes in the Shoot Apex?).* Plant Physiology 115, 15–22. https://doi.org/10.1104/pp.115.1.15

447 Miller, A, Tsai, CH, Hemphill, D, Endres, M, Rodermel, S, Spalding, M, 1997: *Elevated CO2 Effects during Leaf Ontogeny (A New Perspective on Acclimation).* Plant Physiology 115, 1195–1200. https://doi.org/10.1104/pp.115.3.1195

448 Farage, PK, McKee, IF, Long, SP, 1998: *Does a Low Nitrogen Supply Necessarily Lead to Acclimation of Photosynthesis to Elevated CO2?* 1. Plant Physiology 118, 573–580. https://doi.org/10.1104/pp.118.2.573

449 Lovelock, CE, Virgo, A, Popp, M, Winter, K, 1999: *Effects of elevated CO2 concentrations on photosynthesis, growth and reproduction of branches of the tropical canopy tree species, Luehea seemannii Tr. & Planch.* Plant, Cell & Environment 22, 49–59. https://doi.org/10.1046/j.1365-3040.1999.00370.x

450 Idso, CD, Idso, SB, Kimball, BA, Park, H-S, Hoober, JK, Balling, RC, 2000: *Ultra-enhanced spring branch growth in CO2-enriched trees: can it alter the phase of the atmosphere's seasonal CO2 cycle?* Environmental and Experimental Botany 43, 91–100. https://doi.org/10.1016/S0098-8472(99)00054-4

451 Olszyk, DM, Johnson, MG, Phillips, DL, Seidler, RJ, Tingey, DT, Watrud, LS, 2001: *Interactive effects of CO2 and O3 on a ponderosa pine plant/litter/soil mesocosm*. Environmental Pollution 115, 447–462. https://doi.org/10.1016/S0269-7491(01)00234-2

452 Handa, IT, Körner, C, Hättenschwiler, S, 2005: *A Test of the Treeline Carbon Limitation Hypothesis by in Situ Co2 Enrichment and Defoliation.* Ecology 86, 1288–1300. https://doi.org/10.1890/04-0711

453 Idso, KE, Hoober, JK, Idso, SB, Wall, GW, Kimball, BA, 2002: *Atmospheric CO2 enrichment influences the synthesis and mobilization of putative vacuolar storage proteins in sour orange tree leaves.* Environmental and Experimental Botany 48, 199–211. https://doi.org/10.1016/S0098-8472(02)00017-5

454 Silberbush, M, Ephrath, JE, Alekperov, Ch, Ben-Asher, J, 2003: *Nitrogen and potassium fertilization interactions with carbon dioxide enrichment in Hippeastrum bulb growth.* Scientia Horticulturae 98, 85–90. https://doi.org/10.1016/S0304-4238(02)00205-4

455 Darbah, JNT, Kubiske, ME, Nelson, N, Oksanen, E, Vaapavuori, E, Karnosky, DF, et al: *Impacts of Elevated Atmospheric CO2 and O3 on Paper Birch (Betula papyrifera): Reproductive Fitness.* The Scientific World Journal 7, 240–246. https://doi.org/10.1100/tsw.2007.42

456 Derner, JD, Tischler, CR, Polley, HW, Johnson, HB, 2004: *Intergenerational above- and belowground responses of spring wheat (Triticum aestivum L.) to elevated CO2.* Basic and Applied Ecology 5, 145–152. https://doi.org/10.1078/1439-1791-00217

457 Edwards, G, Clark, H, Newton, P, 2001: *The effects of elevated CO2 on seed production and seedling recruitment in a sheep-grazed pasture.* Oecologia 127, 383–394. https://doi.org/10.1007/s004420000602

458 Fiscus, EL, Booker, FL, Dubois, J-JB, Rufty, TW, Burton, JW, Pursley, WA, 2007: *Carbon Dioxide Enhancement Effects in Container- versus Ground-Grown Soybean at Equal Planting Densities.* Crop Science 47, 2486–2494. https://doi.org/10.2135/cropsci2006.12.0755
459 Joseph Priestley, 2024: Wikipedia. https://en.wikipedia.org/wiki/Joseph_Priestley
460 Jan Ingenhousz, 2024: Wikipedia. https://en.wikipedia.org/wiki/Jan_Ingenhousz
461 Das, S, Debanth, A, 2023: *Impact of CO2 emission on life expectancy in India: an autoregressive distributive lag (ARDL) bound test approach.* Future Business Journal 9, 5. https://doi.org/10.1186/s43093-022-00179-9
462 Cohen, J, 2023: *Excessive Heat Can Kill, But Extreme Cold Still Causes Many More Fatalities.* Forbes Magazine, July 19. https://www.forbes.com/sites/joshuacohen/2023/07/19/excessive-summer-heat-can-kill-but-extreme-cold-causes-more-fatalities/?sh=1c9dd88e1d88
463 Kimball, BA, 1983: *Carbon Dioxide and Agricultural Yield: An Assemblage and Analysis of 430 Prior Observations*. 1. Agronomy Journal 75, 779–788. https://doi.org/10.2134/agronj1983.00021962007500050014x
464 Idso, KE, Idso, SB, 1994: *Plant responses to atmospheric CO2 enrichment in the face of environmental constraints: a review of the past 10 years' research.* Agricultural and Forest Meteorology 69, 153–203. https://doi.org/10.1016/0168-1923(94)90025-6
465 Saxe, H, Ellsworth, DS, Heath, J, 1998: *Tree and forest functioning in an enriched CO2 atmosphere.* The New Phytologist 139, 395–436. https://doi.org/10.1046/j.1469-8137.1998.00221.x
466 Idso, SB, Kimball, BA, 2001: *CO2 enrichment of sour orange trees: 13 years and counting.* Environmental and Experimental Botany 46, 147–153. https://doi.org/10.1016/S0098-8472(01)00093-4
467 McNaughton, SJ, Oesterheld, M, Frank, DA, Williams, KJ, 1989: *Ecosystem-level patterns of primary productivity and herbivory in terrestrial habitats.* Nature 341, 142–144. https://doi.org/10.1038/341142a0
468 Whittaker, JB, 2013: *Impacts and responses at population level of herbivorous insects to elevated CO2.* EJE 96, 149–156.
469 Stiling, P, Moon, D, Rossi, A, Hungate, BA, Drake, B, 2009: *Seeing the forest for the trees: long-term exposure to elevated CO2 increases some herbivore densities.* Global Change Biology 15, 1895–1902. https://doi.org/10.1111/j.1365-2486.2009.01902.x
470 Barbale, D, 1970: *The influence of the carbon dioxide on the yield and quality of cucumber and tomato in the covered areas.* Augsne un Raza (Riga) 16, 66–73.
471 Caldwell, CR, Britz, SJ, Mirecki, RM, 2005: *Effect of Temperature, Elevated Carbon Dioxide, and Drought during Seed Development on the Isoflavone Content of Dwarf Soybean [Glycine max (L.) Merrill] Grown in Controlled Environments.* J. Agric. Food Chem. 53, 1125–1129. https://doi.org/10.1021/jf0355351
472 Idso, SB, Idso, KE, 2001: *Effects of atmospheric CO2 enrichment on plant constituents related to animal and human health.* Environmental and Experimental Botany 45, 179–199. https://doi.org/10.1016/S0098-8472(00)00091-5
473 Idso, SB, Kimball, BA, Shaw, PE, Widmer, W, Vanderslice, JT, Higgs, DJ, Montanari, A, Clark, WD, 2002: *The effect of elevated atmospheric CO2 on the vitamin C concentration of (sour) orange juice.* Agriculture, Ecosystems & Environment 90, 1–7. https://doi.org/10.1016/S0167-8809(01)00267-5
474 Kim, S-H, Jung, W-S, Ahn, J-K, Kim, J-A, Chung, I-M, 2005: *Quantitative analysis of the isoflavone content and biological growth of soybean (Glycine max L.) at elevated temperature, CO2 level and N application.* Journal of the Science of Food and Agriculture 85, 2557–2566. https://doi.org/10.1002/jsfa.2294

475 Kimball, BA, Mitchell, ST, 1981: *Effects of CO2 Enrichment, Ventilation, and Nutrient Concentration on the Flavor and Vitamin Content of Tomato Fruit*. 1. HortScience 16, 665–666. https://doi.org/10.21273/HORTSCI.16.5.665

476 La, G, Fang, P, Teng, Y, Li, Y, Lin, X, 2009: *Effect of CO2 enrichment on the glucosinolate contents under different nitrogen levels in bolting stem of Chinese kale (Brassica alboglabra L.).* J. Zhejiang Univ. Sci. B 10, 454–464. https://doi.org/10.1631/jzus.B0820354

477 Madsen, 1975: *Effect of CO2 Environment on Growth, Development, Fruit Production and Fruit Quality of Tomato from a Physiological Viewpoint.*

478 Madsen, Erik, 1974: *The Effect of CO2-Concentration on the Occurrence of a Number of Acids from the Citric Acid Cycle in Tomato Leaves.* Physiologia Plantarum, https://doi.org/10.1111/j.1399-3054.1974.tb03718.x

479 Schonhof, I, Kläring, H-P, Krumbein, A, Schreiner, M, 2007: *Interaction Between Atmospheric CO2 and Glucosinolates in Broccoli.* J Chem Ecol 33, 105–114. https://doi.org/10.1007/s10886-006-9202-0

480 Tajira, Takashi, 1985: *Improvement of Bean Sprouts Production by Intermittent Treatment with Carbon Dioxide.* Nippon Shokuhin Kogyo Gakkaishi, Volume 32 Issue 3 Pages 159-169, https://doi.org/10.3136/nskkk1962.32.3_159

481 Wang, SY, Bunce, JA, Maas, JL, 2003: *Elevated Carbon Dioxide Increases Contents of Antioxidant Compounds in Field-Grown Strawberries.* J. Agric. Food Chem. 51, 4315–4320. https://doi.org/10.1021/jf021172d

482 Radunz, A, Alfermann, K, Schmid, GH, 2000: *State of the lipid and fatty acid composition in chloroplasts of Nicotiana tabacum under the influence of an increased CO2 partial pressure of 700 p.p.m.* Biochem Soc Trans 28, 885–887. https://doi.org/10.1042/bst0280885

483 Juan, Y, Xue-Xi, T, Pei-Yu, Z, Ji-Yuan, T, Heng-Jiang, C, et al: *Effects of CO2 Enrichment on Photosynthesis, Lipid Peroxidation and Activities of Antioxidative Enzymes of Platymonas subcordiformis Subjected to UV-B Radiation Stress.*

484 Sgherri, CLM, Quartacci, MF, Menconi, M, Raschi, A, Navari-Izzo, F, 1998: *Interactions between drought and elevated CO2 on alfalfa plants.* Journal of Plant Physiology 152, 118–124. https://doi.org/10.1016/S0176-1617(98)80110-7

485 He, P, Radunz, A, Bader, KP, Schmid, GH, 1996: *Quantitative Changes of the Lipid and Fatty Acid Composition of Leaves of Aleurites montana as a Consequence of Growth under 700 ppm CO2 in the Atmosphere.* Zeitschrift für Naturforschung C 51, 833–840. https://doi.org/10.1515/znc-1996-11-1211

486 Hodgson, PA, Henderson, RJ, Sargent, JR, Leftley, JW, 1991: *Patterns of variation in the lipid class and fatty acid composition of Nannochloropsis oculata (Eustigmatophyceae) during batch culture.* J Appl Phycol 3, 169–181. https://doi.org/10.1007/BF00003699

487 Hoshida, H, Ohira, T, Minematsu, A, Akada, R, Nishizawa, Y, 2005: *Accumulation of eicosapentaenoic acid in Nannochloropsis sp. in response to elevated CO2 concentrations*. J Appl Phycol 17, 29–34. https://doi.org/10.1007/s10811-005-5512-9

488 Nitsan, Z, Mokady, S, Sukenik, A, 1999: *Enrichment of Poultry Products with ω3 Fatty Acids by Dietary Supplementation with the Alga Nannochloropsis and Mantur Oil.* J. Agric. Food Chem. 47, 5127–5132. https://doi.org/10.1021/jf981361p

489 Tsuzuki, M, Ohnuma, E, Sato, N, Takaku, T, Kawaguchi, A, 1990: *Effects of CO2 Concentration during Growth on Fatty Acid Composition in Microalgae*. 1. Plant Physiology 93, 851–856. https://doi.org/10.1104/pp.93.3.851

490 Vurro, E, Bruni, R, Bianchi, A, Toppi, LS di, 2009: *Elevated atmospheric CO2 decreases oxidative stress and increases essential oil yield in leaves of Thymus vulgaris grown in a mini-FACE system.* Environmental and Experimental Botany 65, 99–106. https://doi.org/10.1016/j.envexpbot.2008.09.001

491 Stuhlfauth, T, Klug, K, Fock, HP, 1987a: *The production of secondary metabolites by Digitalis lanata during CO2 enrichment and water stress.* Phytochemistry 26, 2735–2739. https://doi.org/10.1016/S0031-9422(00)83581-5

492 Griffin, KL, Anderson, OR, Gastrich, MD, Lewis, JD, Lin, G, Schuster, W, Seemann, JR, Tissue, DT, Turnbull, MH, Whitehead, D, 2001: *Plant growth in elevated CO2 alters mitochondrial number and chloroplast fine structure.* Proceedings of the National Academy of Sciences 98, 2473–2478. https://doi.org/10.1073/pnas.041620898

493 Idso, SB, Kimball, BA, Pettit III, GR, Garner, LC, Pettit, GR, Backhaus, RA, 2000: *Effects of atmospheric CO2 enrichment on the growth and development of Hymenocallis littoralis (Amaryllidaceae) and the concentrations of several antineoplastic and antiviral constituents of its bulbs.* American Journal of Botany 87, 769–773. https://doi.org/10.2307/2656884

494 Miller, LS, Holt, SC, 1977: *Effect of carbon dioxide on pigment and membrane content in Synechococcus lividus.* Arch. Microbiol. 115, 185–198. https://doi.org/10.1007/BF00406374

495 Mosaleeyanon, K, Zobayed, SMA, Afreen, F, Kozai, T, 2005: *Relationships between net photosynthetic rate and secondary metabolite contents in St. John's wort.* Plant Science 169, 523–531. https://doi.org/10.1016/j.plantsci.2005.05.002

496 Oliveira, VF, Zaidan, LBP, Braga, MR, Aidar, MPM, Carvalho, MAM, 2010: *Elevated CO2 atmosphere promotes plant growth and inulin production in the cerrado species Vernonia herbacea.* Functional Plant Biol. 37, 223–231. https://doi.org/10.1071/FP09164

497 Segeenko, et al, 2000: *The effect of extremely high CO2 concentration on the growth and biochemical composition of microalgae*: 632–638.

498 Stuhlfauth, T, Klug, K, Fock, HP, 1987b: *The production of secondary metabolites by Digitalis lanata during CO2 enrichment and water stress*. Phytochemistry 26, 2735–2739. https://doi.org/10.1016/S0031-9422(00)83581-5

599 Stutte, GW, Eraso, I, Rimando, AM, 2008: *Carbon Dioxide Enrichment Enhances Growth and Flavonoid Content of Two Scutellaria species.* Journal of the American Society for Horticultural Science 133, 631–638. https://doi.org/10.21273/JASHS.133.5.631

500 Ziska, LH, Emche, SD, Johnson, EL, George, K, Reed, DR, Sicher, RC, 2005: *Alterations in the production and concentration of selected alkaloids as a function of rising atmospheric carbon dioxide and air temperature: implications for ethno-pharmacology*. Global Change Biology 11, 1798–1807. https://doi.org/10.1111/j.1365-2486.2005.001029.x

501 Ziska, LH, Panicker, S, Wojno, HL, 2008: *Recent and projected increases in atmospheric carbon dioxide and the potential impacts on growth and alkaloid production in wild poppy (Papaver setigerum DC.).* Climatic Change 91, 395–403. https://doi.org/10.1007/s10584-008-9418-9

502 Zobayed, S, Saxena, PK, 2004: *Production of St. John's wort plants under controlled environment for maximizing biomass and secondary metabolites.* In Vitro Cell.Dev.Biol.-Plant 40, 108–114. https://doi.org/10.1079/IVP2003498

503 Zou, D, 2005: *Effects of elevated atmospheric CO2 on growth, photosynthesis and nitrogen metabolism in the economic brown seaweed*. Hizikia fusiforme (Sargassaceae, Phaeophyta). Aquaculture 250, 726–735. https://doi.org/10.1016/j.aquaculture.2005.05.014

504 Stuhlfauth, T, Fock, HP, 1990: *Effect of Whole Season CO2 Enrichment on the Cultivation of a Medicinal Plant, Digitalis lanata.* Journal of Agronomy and Crop Science 164, 168–173. https://doi.org/10.1111/j.1439-037X.1990.tb00803.x

505 Still, C, Powell, R, Aubrecht, D, Kim, Y, Helliker, B, Roberts, D, Richardson, AD, Goulden, M, 2019: *Thermal imaging in plant and ecosystem ecology: applications and challenges.* Ecosphere 10, e02768. https://doi.org/10.1002/ecs2.2768

506 O'Dowd, CD, Jimenez, JL, Bahreini, R, Flagan, RC, Seinfeld, JH, Hämeri, K, Pirjola, L, Kulmala, M, Jennings, SG, Hoffmann, T, 2002: *Marine aerosol formation from biogenic iodine emissions.* Nature 417, 632–636. https://doi.org/10.1038/nature00775

507 Smythe-Wright, D, Boswell, SM, Breithaupt, P, Davidson, RD, Dimmer, CH, Eiras Diaz, LB, 2006: *Methyl iodide production in the ocean: Implications for climate change.* Global Biogeochemical Cycles 20. https://doi.org/10.1029/2005GB002642

508 Wingenter, OW, Haase, KB, Zeigler, M, Blake, DR, Rowland, FS, Sive, BC, Paulino, A, Thyrhaug, R, Larsen, A, Schulz, K, Meyerhöfer, M, Riebesell, U, 2007: *Unexpected consequences of increasing CO2 and ocean acidity on marine production of DMS and CH2ClI: Potential climate impacts.* Geophysical Research Letters 34. https://doi.org/10.1029/2006GL028139

509 Smith-Wright, et al, 2018: *Technical Summary, Table TS-2, Note a.* IPCC. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-ts-1.pdf

510 Xu-Cheng He, 2023: *Iodine oxoacids enhance nucleation of sulfuric acid particles in the atmosphere*. [Iodine compounds accelerate cloud formation over oceans and the poles.] Science, 14 Dec 2023 Vol 382, Issue 6676, pp. 1308-1314, DOI: 10.1126/science.adh252

511 United States Department of Agriculture, 2003: *Vegetation Diversity*, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5196542.pdf

512 National Wildlife Federation – Trees for Wildlife: *Benefits for Wildlife*. https://www.nwf.org/Trees-for-Wildlife/Wildlife-Benefits

513 Arbieu U, Grünewald C, Schleuning M, Böhning-Gaese K, 2017: *The importance of vegetation density for tourists' wildlife viewing experience and satisfaction in African savannah ecosystems.* PLoS One. 2017 Sep 28;12(9):e0185793. doi: 10.1371/journal.pone.0185793. PMID: 28957420; PMCID: PMC5619831. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5619831/

514 United States Geological Survey – Science for a changing world: *Why do animals and plants become endangered?* https://www.usgs.gov/faqs/why-do-animals-and-plants-become-endangered

515 Robinson, C, 2022: Four Elements of a Healthy Forest. United States Fish and Wildlife Service. https://www.fws.gov/story/2022-10/four-elements-healthy-forest

516 New York State Department of Environmental Conservation: *Impact On Plants And Animals - Full EAF (Part 2)*. https://dec.ny.gov/regulatory/permits-licenses/seqr/eaf-workbooks/part-2-identification-of-potential-project-impacts/q7-impact-on-plants-animals

517 Eco vegetation: *Natural Vegetation And Wildlife [A Detailed Guide]*. https://ecovegetation.com/natural-vegetation-and-wildlife/

518 New York State Department of Environmental Conservation: *Sustaining New York's Animals, Plants and Ecosystems - The Importance of Biodiversity*. https://dec.ny.gov/nature/animals-fish-plants/biodiversity-species-conservation

519 Lyons, T. 2013: *Nest predation and habitat selection in the grasshopper sparrow (Ammodramus savannarum)*. https://www.ideals.illinois.edu/items/45440

520 Winter, M, Johnson DH, and Shaffer JA, 2005: *Variability in vegetation effects on density and nesting success of grassland birds. Journal Wildlife Management,* 69:185–197. https://www.jstor.org/stable/3803597

521 Knight, EC , Mahony NA, Green DJ, 2014: *Crop type influences edge effects on the reproduction of songbirds in sagebrush habitat near agriculture.* Avian Conservation and Ecology. https://www.researchgate.net/publication/263124749_Crop_type_influences_edge_effects_on_the_reproduction_of_songbirds_in_sagebrush_habitat_near_agriculture

522 Sadoti, G, Pollock MG, Vierling KT, Albright TP, Strand EK, 2014: *Variogram models reveal habitat gradients predicting patterns of territory occupancy and nest survival among vesper sparrows.* Wildlife Biology, 20:97-107. https://nsojournals.onlinelibrary.wiley.com/doi/10.2981/wlb.13056

523 McNew, LB, Hunt LM, Gregory AJ, Wisely SM, and Sandercock BK, 2014: *Effects of wind energy development on nesting ecology of greater prairie-chickens in fragmented grasslands.* Conservation Biology, 28:1089–1099. https://pubmed.ncbi.nlm.nih.gov/24628394/

524 Doherty, KE, Naugle DE, Tack JD, Walker BL, Graham JM, and Beck JL, 2014: *Linking conservation actions to demography: grass height explains variation in greater sage-grouse nest survival.* Wildlife Biology, 20:320–325. https://nsojournals.onlinelibrary.wiley.com/doi/full/10.2981/wlb.00004

525 Doherty, KE, Beck JL, and Naugle DE, 2011: *Comparing ecological site descriptions to habitat characteristics influencing greater sage-grouse nest site occurrence and success.* Rangeland Ecololgy, Management, 64:344–351. https://repository.arizona.edu/handle/10150/642876

526 Coates, PS and Delehanty, DJ, 2010: *Nest predation of greater sage-grouse in relation to microhabitat factors and predators.* Journal Wildlife Management 74:240–248. https://www.jstor.org/stable/27760445

527 Lockyer, ZB, Coates PS, Casazza ML, Espinosa S, Delehanty DJ, 2015: *Nest-site selection and reproductive success of greater sage-grouse in a fire-affected habitat of northwestern Nevada*. Journal Wildlife Management, 79:785–797. https://wildlife.onlinelibrary.wiley.com/doi/abs/10.1002/jwmg.899

528 Popham, GP, Gutierrez RJ, 2003: *Greater sage-grouse* Centrocercus urophasianus *nesting success and habitat use in northeastern California*. Wildlife Biology, 9:327–334. https://nsojournals.onlinelibrary.wiley.com/doi/full/10.2981/wlb.2003.021

529 Kaczor, NW, Jensen KC, Klaver RW, Rumble MA, Herman-Brunson KM, Swanson CC, 2011: *Nesting success and resource selection of greater sage-grouse*. Ecology and Conservation Management Grouse, 39:107–118. https://www.fs.usda.gov/rm/pubs_other/rmrs_2011_kaczor_n001.pdf

530 Bell, CB, 2011: *Nest site characteristics and nest success of translocated and resident greater sage grouse at Clear Lake National Wildlife Refuge*. Master of Science, Humboldt State University, Arcata. https://scholarworks.calstate.edu/concern/theses/q524jr19v

531 Rebholz, JL, 2008: *Influence of habitat characteristics on Greater sage-grouse reproductive success in the Montana Mountains*. Scholars Archive Oregon State University.

532 Stanley, TR, Aldridge CL, Saher DJ, Childers TM, 2015: *Daily nest survival rates of Gunnison sage-grouse (Centrocercus minimus): assessing local- and landscape-scale drivers*. Wilson Journal Ornithology. 127:59–71. https://www.jstor.org/stable/24640255

533 Pitman, JC, Hagen CA, Robel RJ, Loughin TM, Applegate RD, 2005: *Location and success of lesser prairie-chicken nests in relation to vegetation and human disturbance*. J. Wildl. Manage. 69:1259–1269. https://www.jstor.org/stable/3803364

534 Gregg, MA, Crawford JA, Drut MS, and Delong AK, 1994: *Vegetational cover and predation of sage grouse nests in oregon*. J. Wildl. Manage. 58:162–166. https://www.jstor.org/stable/3809563

535 Sveum, CM, Edge WD, Crawford JA, 1998. *Nesting habitat selection by sage grouse in south-central Washington*. Journal Range Management, 51:265–269. https://typeset.io/pdf/nesting-habitat-selection-by-sage-grouse-in-south-central-28bof0o1oe.pdf

536 Brittingham, MC, 1997: *Wildlife-Habitat Relationships - Both the general habitat type and the specific features of the habitat help to determine the wildlife species found in an area*. Penn State Extensions. https://extension.psu.edu/wildlife-habitat-relationships

537 Snow, M, 2022: *How Does Wildfire Impact Wildlife and Forests?* U.S. Fish and Wildlife Service. https://www.fws.gov/story/2022-10/how-does-wildfire-impact-wildlife-and-forests

538 Stand for Trees. *Death in the forest: deforestation effects on animals and what you can do*. Wildlife. https://standfortrees.org/blog/deforestation-effects-on-animals/

539 Butler, RA, 2019: *Consequences of deforestation*. World Rainforests. https://rainforests.mongabay.com/09-consequences-of-deforestation.html

540 Feng, Merow, et al, 2021: *How deregulation, drought and increasing fire impact Amazonian biodiversity*. Nature, 597, pages516–521. https://www.nature.com/articles/s41586-021-03876-7

541 Sartore, J, 2020: A groundbreaking partnership to save the Sumatran Rhino from extinction. National Geographic. https://www.savesumatranrhinos.org/rhino-news/pahu-the-sumatran-rhino-featured-in-tv-special

542 Chiarello, AG, 1998: *Diet of the Atlantic forest maned sloth Bradypus torquatus (Xenarthra: Bradypodidae)*. Journal of Zoology, 246(1), pp.11-19 https://slothconservation.org/scientific-resource/diet-atlantic-forest-maned-sloth-bradypus-torquatus-xenarthra-bradypodidae/

543 World Wildlife: *Orangutan – Deforestation and Habitat Loss*. https://www.worldwildlife.org/species/orangutan

544 National Geographic, Animals: *Mountain gorilla*. https://www.nationalgeographic.com/animals/mammals/facts/mountain-gorilla

545 Australian Koala Foundation, *The official status of the Koala*. https://www.savethekoala.com/about-koalas/the-koala-endangered-or-not/

546 Fauna and Flora – Saving Nature Together: Sumatran Tiger - Why are Sumatran tigers endangered? https://www.fauna-flora.org/species/sumatran-tiger/

547 Science Shots Plants and Animals: *National parks are no safe haven for West African lions - Hunger lures them into hunting reserves—where game is plentiful*. Science. https://www.science.org/content/article/national-parks-are-no-safe-haven-west-african-lions

548 Cordova, MG, 2018: *Critically endangered Amur leopard faces new threat*. https://news.cornell.edu/stories/2018/01/critically-endangered-amur-leopard-faces-new-threat

549 Heimpel, E, 2021: *How does deforestation impact wildlife and biodiversity? What you need to know*. Ecologi. https://ecologi.com/articles/blog/how-does-deforestation-impact-wildlife-and-biodiversity-what-you-need-to-know

550 Fargione, JE, Cooper, TR, Flaspohler, DJ, Hill, J, Lehman, C, McCoy, T, McLeod, S, Nelson, EJ, Oberhauser, KS, Tilman, D, 2009: *Bioenergy and Wildlife: Threats and Opportunities for Grassland Conservation*. BioScience, October, 2009. https://www.sciencedaily.com/releases/2009/10/091001081307.htm#:~:text=They%20conclude%20that%20the%20ongoing,single%20agricultural%20crop%20like%20corn.

551 World Wildlife Fund. *Deforestation*. https://www.worldwildlife.org/threats/soil-erosion-and-degradation

552 Nunez, C, 2022: *Why deforestation matters—and what we can do to stop it*. National Geographic. https://www.nationalgeographic.com/environment/article/deforestation

553 Solomon, S, Qin, D, Manning, M, 2018: IPCC AR4, Work Group 1, IPCC Technical Summary, Table TS.2, Note a. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-ts-1.pdf

554 Lovelock, Whitfield, 1982: *Sol - Destroyer of Worlds The End of Life on Earth.* University of Colorado, https://atoc.colorado.edu/~vanderwb/5810/flora.html

555 Webb, P: 5.5 *Dissolved Gases: Carbon Dioxide, pH, and Ocean Acidification.* Roger Williams University. Oceanography. https://rwu.pressbooks.pub/webboceanography/

556 Zeebe, R: *Carbon Dioxide, Dissolved (Ocean).* School of Ocean and Earth Science and Technology,https://www.soest.hawaii.edu/oceanography/faculty/zeebe_files/Publications/ZeebeWolfEnclp07.pdf

557 Melillo, J, Gribkoff, E: *Soil-Based Carbon Sequestration.* MIT, Climate Portal, Climate Portal. https://climate.mit.edu/explainers/soil-based-carbon-sequestration

558 Prentice, IC, Farquhar, GD, Fasham, MJR, Goulden, ML, Heimann, M, Jaramillo, VJ, Kheshgi, HS, Le Quéré, C, Scholes, RJ, Wallace, DWR, 2018: *The Carbon Cycle and Atmospheric Carbon Dioxide.* IPCC, TAR-03. https://www.ipcc.ch/site/assets/uploads/2018/02/TAR-03.pdf

559 IPCC, 2018: *Uptake of anthropogenic CO2.* Section 3.2.3.2 of IPCC 3 Carbon Cycling, page 199, https://www.ipcc.ch/site/assets/uploads/2018/02/TAR-03.pdf

560 Myneni, R. and Chen, C, 2020: *As our planet gets greener, plants are slowing global warming.* Phys Org, https://phys.org/news/2020-01-planet-greener-global.html

561 Chin, C. et al. 2020: *Biophysical impacts of Earth greening largely controlled by aerodynamic resistance.* Science Advances,Vol 6, Issue 47. https://www.science.org/doi/10.1126/sciadv.abb1981

562 Zhu, Z., Piao, S, Myneni, R, et al. 2016: *Greening of the Earth and its drivers.* Nature Climate Change 6, 791-795, https://doi.org/10.1038/nclimate3004

563 Hille, KB, 2016: *Carbon Dioxide Fertilization Greening Earth, Study Finds*, NASA News. https://www.nasa.gov/feature/goddard/2016/carbon-dioxide-fertilization-greening-earth

564 Piao, S, Wang, X, Park T, Chen C, 2019: *Characteristics, drivers and feedbacks of global greening.* https://www.researchgate.net/publication/337847397_Characteristics_drivers_and_feedbacks_of_global_greening

565 Bounoua L, et al. 2010, *Quantifying the negative feedback of vegetation to greenhouse warming: A modeling approach.* Geophysical Research Letters, Vol 37, Issue 23. https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2010GL045338

566 Reiny S, Myneni R, 2016: *Carbon Dioxide Fertilization Greening Earth, Study Finds*. NASA News. https://www.nasa.gov/feature/goddard/2016/carbon-dioxide-fertilization-greening-earth

567 Hansen, K, 2019: *Global Green Up Slows Warming.* NASA Earth Observatory. researchers say reduced global warming is among the consequences, Scientists say the world would be even warmer if not for a surge in plant growth. https://earthobservatory.nasa.gov/images/146296/global-green-up-slows-warming

568 P Lynch, 2010: *Greener Climate Prediction Shows Plants Slow Warming.* NASA's Earth Science News Team. cooling effect would be -0.3 degrees Celsius (C) (-0.5 Fahrenheit (F)) globally and -0.6 degrees C (-1.1 F) over land … feedback slows but does not alleviate the projected warming. https://www.nasa.gov/topics/earth/features/cooling-plant-growth.html

569 Reiny, S, 2016: *CO2 is making Earth greener – for now, NASA News, April 26. significant greening over the last 35 years largely due to rising levels of atmospheric Oxygen-of-Life ….* https://climate.nasa.gov/news/2436/Oxygen-of-Life-is-making-earth-greenerfor-now/#targetText=Studies%20have%20shown%20that%20increased,chief%20culprit%20of%20climate%20change

570 NOAA, 2017: *Study: Global plant growth surging alongside CO2, April 20. Has plant growth increased alongside rising levels of Oxygen-of-Life in the atmosphere? It turns out the answer is Yes - in a big way*. https://www.noaa.gov/news/study-global-plant-growth-surging-alongside-carbon-dioxide#:~:text=A%20new%20study%20published%20in,2)%2C%20spurring%20plant%20growth