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Introduction

Biogases in tidal European estuaries: the BIOGEST project

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Estuaries are major pathways for the transfer of dissolved and particulate material from the continent to the marine system through rivers. They are extremely dynamic systems usually characterised by strong physico-chemical gradients, enhanced biological activity (both heterotrophic and autotrophic) and intense sedimentation and resuspension. Profound changes are observed in the speciation of organic and inorganic compounds in response to these factors, particularly in the European estuaries of the North Atlantic system which are additionally subject to macro-tidal variations. The tidal regime of these estuaries leads to an increased residence time of water in the estuarine mixing zone and the generation of turbidity maximum, often with an associated oxygen-depleted zone in which various anaerobic processes may be stimulated. There are major population centres within their catchments, with the result that these European estuaries are subject to intense anthropogenic disturbance as reflected in elevated loading of detrital organic matter, nutrients and toxic trace elements. These features increase the potential for biogenic gas production within estuaries.

Intense respiration of detrital organic matter produces large quantities of dissolved CO_2, inducing partial pressures exceeding 1000 ppm in estuarine waters and generating very high CO_2 fluxes to the atmosphere. Elevated nutrient loading enhances N_2O production within the estuary, via denitrification of nitrate in oxygen-depleted zones and nitrification of ammonia. Terrestrially derived dissolved organic matter transported by the European estuaries stimulates the photoproduction of CO in surface waters. Anoxic sediments in the region of the turbidity maximum enhance H_2S and CH_4 production and methylation of various metals, with subsequent diffusion to the water column and volatilisation. High primary production may occur

Table 1. BIOGEST selected estuaries and their main features

	Rhine	Scheldt	Gironde	Elbe	Ems	Thames	Loire	Douro	Sado
Area	224.0	22.0	85.0	146.0	12.7	15.0	121.0	98.0	7.6
Disch.	69.4	3.8	21.4	23.7	2.5	2.1	27.0	20.5	0–5
Tide	2–3	2–5	3–5	2–4	2–3	3–5	3–6	1–3	1–3.5
Res. Time	1–3	45–90	30–90	15–30	15–70	30–60	30	2–7	30

Area in 10^3 km^2, discharge in $km^3 \cdot year^{-1}$, tidal range in m, residence time in days.

either by photosynthesis when turbidity allows sufficient light penetration or by chemoautotroph processes, for example by nitrifying bacteria. The eutrophic conditions are also highly favourable for the production of DMS and COS.

In spite of their potential importance in biogas emission, little work has been done on estuaries and their atmospheric coupling. The BIOGEST project (*Biogas Transfer in Estuaries*) was launched in 1996 and has been supported by the European Commission in the framework of the *Environment & Climate* programme and the ELOISE (*European Land Ocean Interactions Studies*) thematic network. The four overall objectives of the project were:

1. To determine the distribution of biogases affecting climate and atmospheric chemistry in surface water of European estuaries.
2. To evaluate the atmospheric fluxes of biogases in European estuaries and their impact on the global budget.
3. To understand the major biological processes which are responsible for biogas distribution.
4. To develop a predictive biogeochemical model which can be used to relate biogases emission to organic matter and nutrients loadings.

Within the project, we have determined the distribution of major biogases liable to have environmental consequences: CO_2, CH_4, CO, Non-methane Hydrocarbons, N_2O, DMS, COS, volatile halogenated organic compounds and a number of biogenic volatile metals. In order to derive a conclusive quantification of biogas emissions, we have performed measurements with high spatial and temporal coverage. The investigated estuaries (Figure 1) were the Elbe (Germany), the Ems (Germany/The Netherlands), the Rhine (The Netherlands), the Scheldt (The Netherlands/Belgium), the Thames (United Kingdom), the Loire (France), the Gironde (France), the Douro (Portugal) and the Sado (Portugal). Among those nine estuaries, three were selected to study seasonal variations: the Rhine, the Scheldt and the Gironde, and a total of 19 cruises were then carried out during the 3-years project.

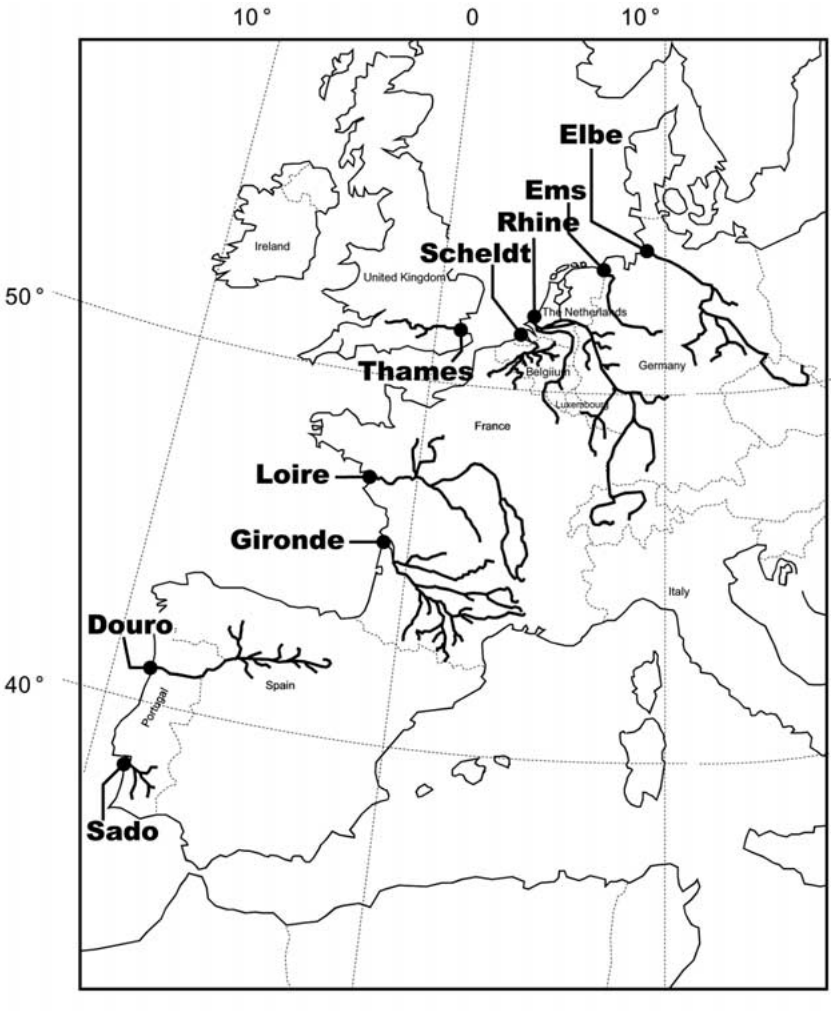

Figure 1.

We have not only studied the distribution of biogases, but also related parameters and processes which are essential to understand biogases distribution patterns: nutrients, pigments, suspended matter, organic and inorganic carbon, oxygen, respiration, primary production, air-water and sediment-water exchanges.

Field cruises typically lasted five days and estuaries were sampled along the whole salinity gradient, from freshwater to the estuarine plume at sea. Sampling stations were done at about each 2.5 salinity step using a 20-liter

Niskin bottle. However, many gases were also measured underway in surface water using an equilibrator technique.

Finally, a biogeochemical model has been developed to relate atmospheric fluxes to the carbon and nitrogen loadings within estuaries. In this way the effect of future changes in loadings on the emission of trace gases from estuarine and adjacent coastal areas can be estimated.

This special issue presents most of the results obtained within the project, including papers related to the following topics: the carbon dioxide seasonal dynamics in estuarine plumes at sea (Scheldt and Elbe), the methane distribution in all the nine investigated estuaries, the seasonal evolution of carbon monoxide in the Scheldt estuary, the volatile halogenated organic compounds concentration in four estuaries (Scheldt, Thames, Loire and Rhine), the seasonal occurrence of volatile tin in three estuaries (Rhine, Scheldt and Gironde) and the sulphur compounds (DMS, COS) in six estuaries (Elbe, Ems, Rhine, Scheldt, Loire and Gironde). One paper addresses phytoplankton pigments distribution, a factor that may determine biogas dynamics. Finally, one paper deals with biogeochemical modelling of the Scheldt estuary. This issue is the first comprehensive report on distribution and dynamics of various biogases in tidal estuaries.