center of the cavity. The early work describing the shear layers as fluid sounding boards was done by Lighthill,[4,5] Phillips,[6] and Landahl.[7] The nonlinear resonance coupling of a quadratic nature leading to resonance of the type indicated in Eq. (3) has been developed by Benney[8] and Bretherton.[9] Recent discussions have been presented by Whitham[10] and Kim et al.[11]

These results indicate that in addition to restrictor spacing and location relative to the acoustic modes of the overall flow system, the presence of amplifying shear layers and reflecting surfaces can produce resonant acoustic energy flows into other frequencies governed by selection rules of the type indicated in Eq. (3).

To determine the source of the primary discrete frequency, such as that indicated in Fig. 2, time-delay cross-correlation measurements were carried out for a single sensor and an X-configuration probe located in the upper shear layer. These results are indicated in Fig. 5. Phillips[6] and Flandro[12] have shown that for vortex production in shear layers, the frequency produced in the acoustic cavity is related to the convective velocity of such vortex structures along the shear layer. From Fig. 5, the convective velocity was determined as approximately 74% of the local shear layer velocity, which resulted in a local convective velocity almost equal to the freestream velocity on the centerline at the forward edge of the cavity. These results yielded a frequency as

$$f = V_c/L = 17.33/0.102 = 170 \text{ Hz} \tag{4}$$

which is the frequency obtained from the spectrum in Fig. 2.

To summarize, these results indicate that significant nonlinear resonant energy transfer of a quadratic nature may be present in internal cavity flows at flow conditions such that the nonlinear frequency selection rules are satisfied. In addition, the primary discrete oscillations produced in such cavity flows have frequencies that are equal in value to the convective velocities of the vortex structures produced in the shear layers divided by the cavity length.

Acknowledgments

The authors wish to gratefully acknowledge support for this project from the University of Utah Research Fund. In addition, many valuable discussions have been held with Prof. Gary A. Flandro, whose assistance is greatly appreciated.

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AIAA 81-0375R

Space Measurements of Tropospheric Aerosols

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Introduction

THE use of satellite radiance measurements to determine the atmospheric aerosol optical thickness has been under investigation for several years.[1-3] It has been shown that, over ocean surfaces, a linear relationship exists between the upwelling radiance in the visible regions and the aerosol content. The aerosol content is defined in terms of the Elterman[4] model vertical aerosol optical thickness, i.e., the aerosol content is given by the ratio (measured aerosol optical thickness at wavelength λ to a model aerosol optical thickness at wavelength λ) $\times N$. That is, a value of $2N$ for the aerosol content indicates that the optical thickness is twice that of the Elterman model. In the results reported here, measurements of the aerosol optical thickness were available only at 0.5 μm, so that all radiances measured by the different radiometers are plotted against aerosol content, where N indicates an aerosol optical thickness of 0.213 (the Elterman model value) measured at 0.5 μm.

Linear relationships between the upwelling radiance and the aerosol content have been determined for Landsat 1,[1] Landsat 2,[2] NOAA-5,[3] GOES-1,[3] and SMS-2. A global-scale ground-truth experiment using NOAA-6 data was conducted in 1980 to investigate the variability of the linear relationship at different sites around the globe; no results are yet available. The possibility of using this ocean technique over inland bodies of water such as rivers, lakes, and reservoirs has been investigated using Landsat 2 data.

Ocean Data

The relationships between radiance and the aerosol content are found to be different for each satellite. This can be due to the aerosol properties being different for each data set or due to uncertainties in the radiometric calibrations of the satellite sensors. The Landsat study[5] found evidence of radiometric calibration differences between Landsat 1 and Landsat 2, and it is believed that similar calibration problems are mainly responsible for the differences in the results given below.

Landsat Results

Data have been obtained at several sites for Landsat overpasses,[5] the largest data set being for the Pacific Ocean at San Diego for Landsat 2 overpasses. These results are shown

Presented as Paper 81-0375 at the AIAA 19th Aerospace Sciences Meeting, St. Louis, Mo., Jan. 12-15, 1981; submitted March 6, 1981; revision received Aug. 3, 1981.

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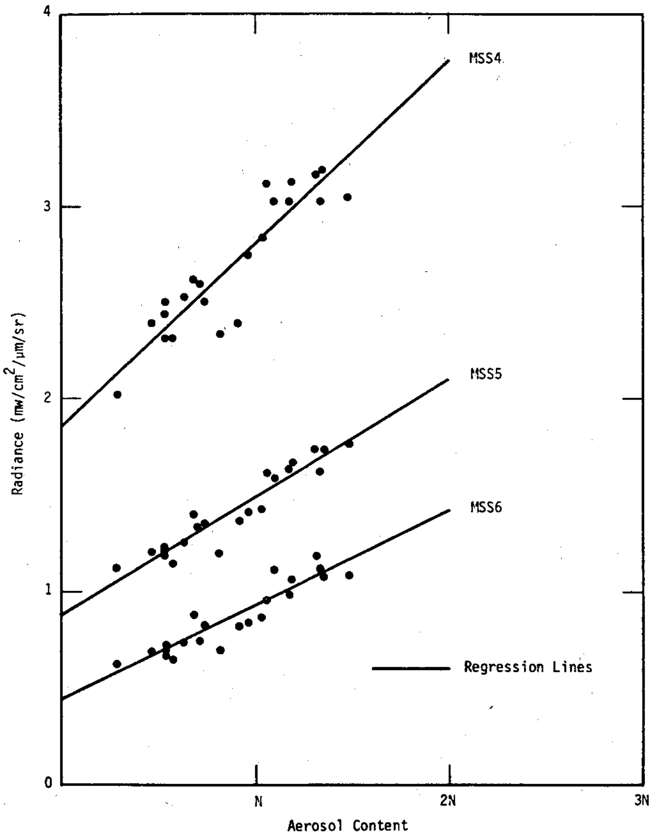

Fig. 1 Landsat 2 ocean radiances vs aerosol content (radiances are for nadir viewing normalized to a sun zenith angle of 63 deg).

in Fig. 1. The radiances are determined from the Landsat digital data (densitometry of the black-and-white imagery is not accurate enough for intercomparison of different images), and the aerosol content values are determined with ground-based sunphotometer measurements at the time of the Landsat overpass. The radiance values are for nadir viewing and are normalized to a sun zenith angle of 63 deg. The normalizing factors used for the measured radiances are based on the theoretical variation of upwelling radiance with sun angle, calculated with the Dave[6] atmospheric scattering code.

GOES-1 and SMS-2 Results

The original GOES-1 results[3] obtained during the 1977 EOMET (electro-optical meteorology) cruise across the North Atlantic have been supplemented by two more data points obtained just off the coast of Panama City, Fla., in December 1978. The results given in Fig. 2 show very good agreement with the Atlantic data obtained 19 months earlier, suggesting that the sensitivity of the GOES-1 sensor is quite stable over long periods.

Data for the SMS-2, the same type of satellite as GOES-1 but positioned over the Pacific Ocean, were obtained for five days at San Nicolas Island in May 1978 and for five days at San Diego in November 1979. At San Nicolas Island, the aerosol content was effectively the same each day and the SMS-2 measured effectively the same radiance each time, thus verifying the repeatability of the technique. The data for San Diego are also given in Fig. 2 and show that the slope of the radiance vs aerosol content relationship for SMS-2 is the same as that found for GOES during the EOMET cruise. The difference between the two lines could be due to a difference in the aerosol properties between the Atlantic and Pacific Oceans, but, as discussed previously,[1] it is most likely due to a difference in the radiometric calibrations of the satellite sensors.

It is noted in Fig. 2 that one of the San Diego data points is significantly higher than expected. However, if the sensor digital count at this time had been just one count less, then the radiance would be 1.07 rather than 1.42 mW/cm^2/μm/Sr, bringing it almost to the expected value. This large change in radiance for a change of one digital count, which is certainly a possible error in the GOES/SMS system, illustrates that the GOES sensor is not really suitable for monitoring small changes in the aerosol content.

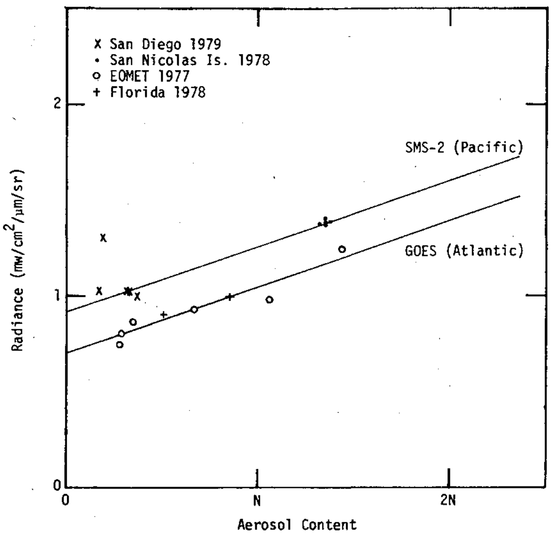

Fig. 2 Satellite radiance vs aerosol content (radiances are normalized to nadir viewing and a sun zenith angle of 63 deg).

NOAA-6 Global Experiment

In order to determine the utility of this technique for measuring aerosols on a global scale, it is necessary to determine the variability of the radiance-aerosol content relationship at different locations. As discussed above, the uncertainties in the radiometric calibrations of different satellites presently prevent any conclusions being reached on aerosol properties. In the summer of 1980, a three-month ground-truth program using a single satellite (NOAA-6) took place. In this experiment, the sunphotometer measurements were made daily at 10 ocean sites around the globe. The ground-truth and satellite data are currently being analyzed. The results at the different sites should provide answers about the global variability of the radiance-aerosol content relationship without being concerned with the satellite radiometric calibration, assuming it does not change during the three-month period.

Measurements over Inland Bodies of Water

It is desirable to extend the aerosol measurements over oceans to over land masses. However, the land measurements are much more difficult since the surface reflectance is high. Thus the upwelling radiance comes mostly from the surface and is quite variable, both spatially and temporally. It was suggested in the Landsat study that the ocean technique might be useful over land masses if the near-infrared (~ 0.9 μm) MSS7 radiance over targets such as rivers, lakes, and reservoirs is used. This near-infrared radiation does not penetrate water as deeply as the visible radiation, so that the upwelling near-infrared radiance seen by the satellite is less influenced by the suspended matter generally found in inland bodies of water. In addition to water turbidity effects, another potential problem for inland sites is the adjacency effect, in which the upwelling radiance above a small body of water is enhanced due to radiation reflected from the adjacent high albedo land. Ground-truth data were obtained for five inland bodies of water during the Landsat study. The MSS7 radiance data were only recently extracted from raw data tapes, instead of calibrated tapes, to insure the accuracy of the low radiance values experienced in MSS7.

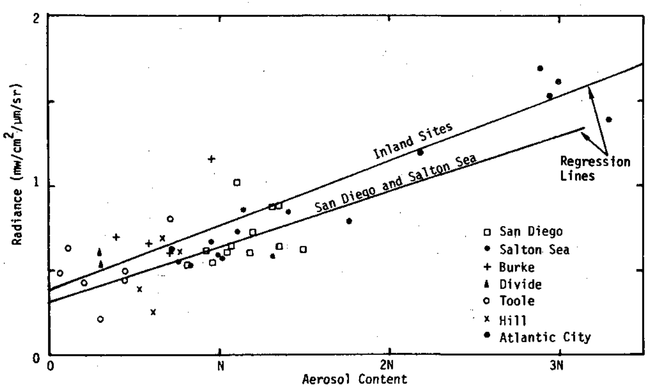

Fig. 3 Radiance vs aerosol content for MSS7 (radiances are normalized to nadir viewing and a sun zenith angle of 63 deg).

Four of the ground-truth sites are located in North Dakota and Montana; the fifth site is at Atlantic City, N.J. The target at Burke, N. Dak., is a river about 500 m wide and 300 m from the sunphotometer location; the Divide, N. Dak., target is a lake 2000×500 m at a distance 500 m from the sunphotometer site; the Toole, Mont., target is a lake 500×500 m at a distance 3000 m from the sunphotometer site; the Hill, Mont., target is a river about 1000 m wide and located about 8000 m from the sunphotometer site; and the Atlantic City target is a reservoir, approximately 300×2000 m, located about 2000 m from the sunphotometer site.

The MSS7 radiance-aerosol content relationship determined for these inland bodies of water is shown in Fig. 3. The San Diego and Salton Sea data for MSS7 are also shown in Fig. 3 (the Salton Sea is very large, being approximately 10×30 km, and is considered equivalent to an ocean target). Raw data tapes were not readily available for these sites, so only radiances for aerosol contents greater than $0.75N$ are shown, since analysis of the inland sites showed the radiance values at these aerosol contents to be about the same on both the calibrated and the raw tapes. The regression line for the inland data shows higher radiance values and more scatter of data than the regression line for the San Diego and Salton Sea data. These differences are mainly attributed to four possible factors, viz., errors in the sunphotometer data, differences in the aerosol properties among the sites, water turbidity effects, and the adjacency effect. These factors and others are discussed in detail by Griggs,[7] who concludes that most of the scatter in the data is caused by water turbidity effects. Little contribution is found from the adjacency effect, in contrast to the large contribution that is theoretically predicted.[8-10] The relationship shown in Fig. 3 can be used to estimate the aerosol content above inland bodies of water with a standard deviation of $0.42N$; this uncertainty is much greater than that found for MSS6 over the ocean ($0.12N$). It appears that the relationship for the inland bodies of water would best be applied to determining an average aerosol content over a period of time at a given target, or an area average at a given time over several targets close together. This averaging could reduce the uncertainty in the measured aerosol content to a useful level.

Conclusions

Linear relationships between the upwelling visible radiance and the aerosol content over the oceans have been found for several satellite sensors, and suggest that satellite monitoring of aerosols on a global basis is possible over the oceans. Use of the same technique for inland bodies of water does not look as promising for accurate measurements with single observations. However, averaging observations over space or time may prove to be useful for quantitative monitoring of pollution episodes over land.

Acknowledgments

This research has been supported by NASA Contracts NAS5-20899 and NAS1-15898, ONR Contract N00014-77-C-0489, and NOAA Contract MO-A01-78-00-4092.

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AIAA 82-4017

A Probe for Low-Speed Measurements in Low-Density Flows

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Introduction

SOME environmental experiments conducted below stratospheric balloons require a determination of wind speed. The wind speed at the scientific package suspended several hundred meters below the balloon is a wind speed relative to the drifting balloon. This relative wind speed seldom exceeds 10 m/s. The aerodynamics of the probe at this low speed and low pressures (P= 1-60 Torr) represent unique conditions that have not been extensively investigated. Consequently, wind-tunnel measurements were recently conducted to determine the flow speed through open pipe probes. With the wind-tunnel calibration, the balloon-borne probe flow speeds are related to the freestream flow.

The calibration was conducted at the NASA Ames Martian Surface Wind Tunnel[1] that duplicated the stratospheric densities and low speeds encountered on a balloon. The tunnel wind speed was measured with a pitot probe. Pitot probe corrections for low Reynolds numbers were made using the data of Bryer and Pankhurst.[2]

Received Feb. 27, 1981. This paper is declared a work of the U. S. Government and therefore is in the public domain.

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