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Paper I 2

DETERMINATION OF AEROSOL CONTENT IN THE ATMOSPHERE

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ABSTRACT

The objective of this investigation is to demonstrate the feasibility of determining the aerosol content in the atmosphere from contrast measurements of ground features, and from radiance measurements. Theoretical relationships between aerosol content and contrast reduction and radiance have been derived for ideal model atmospheres. The preliminary data analysis of the MSS transparencies has shown promising results for the contrast-aerosol content relationship in the Salton Sea/desert region.

1. INTRODUCTION

The apparent increase of particles in the atmosphere is believed to affect the climate of the earth, and has led to the desire to monitor atmospheric aerosols on a global basis.[1,2] The ERTS-1 data present an opportunity to investigate two possible methods of measuring the aerosol content from satellite observations of contrast reduction and of radiance. Demonstration of the feasibility of these techniques will lead to routine satellite monitoring of the atmospheric aerosol content to provide information important in predicting the effect of man's activities on climate. In addition, it will provide input parameters to atmospheric scattering models in algorithms being used to investigate surface properties of the earth's surface from space observations.

2. THEORY OF CONTRAST REDUCTION

Duntley[3] showed that the contrast reduction by the atmosphere of an object relative to the background is given by

$$\frac{C_R}{C_o} = \frac{1}{1 + \frac{B_{a(o)}}{\sigma_o B'_o}\left(e^{\tau} - 1\right)} \qquad (1)$$

where

C_R is the apparent contrast,

C_o is the inherent contrast,

$B_{a(o)}/\sigma_o B'_o$ is the "sky/ground ratio", and

τ is the optical depth of the scattering atmosphere.

To further investigate this relationship, a perfectly arbitrary generalization of Eq. 1 is made:

$$\frac{C_R}{C_o} = \frac{1}{1 + g(\tau, A)} \qquad (2)$$

From values published by Plass and Kattawar[4] for reflected radiance versus albedo, it is concluded that the reflected radiance is well represented by a linear function of A:

$$R_{refl}(\tau, A) = R_{refl}(\tau, 0) + A[R_{refl}(\tau, 1) - R_{refl}(\tau, 0)] . \qquad (3)$$

The apparent contrast is, consequently:

$$C_R = \frac{R_{refl}(\tau, A) - R_{refl}(\tau, A')}{R_{refl}(\tau, A')}$$

$$= \frac{(A-A')[R_{refl}(\tau, 1) - R_{refl}(\tau, 0)]}{R_{refl}(\tau, 0) + A'[R_{refl}(\tau, 1) - R_{refl}(\tau, 0)]} \quad . \tag{4}$$

Since

$$C_o = \frac{A - A'}{A'} \tag{5}$$

we have

$$\frac{C_o}{C_R} = 1 + \frac{R_{refl}(\tau, 0)}{A'[R_{refl}(\tau, 1) - R_{refl}(\tau, 0)]} \tag{6}$$

By identifying with Eq. 2 we find that the unspecified function $g(\tau, A)$ may be separated into τ- and A-dependent parts:

$$g(\tau, A) = f(\tau)/A \tag{7}$$

where

$$f(\tau) = \frac{R_{refl}(\tau, 0)}{R_{refl}(\tau, 1) - R_{refl}(\tau, 0)} \tag{8}$$

Values of $f(\tau)$ using Eq. 8 have been calculated for the center wavelengths of the four MSS channels, based on interpolation of values of $R(\tau, 0)$ and $R(\tau, 1)$ calculated by Plass and Kattawar,[4, 5, 6] for the wavelengths 0.4 μm, 0.7 μm, 0.9 μm and 1.67 μm. The results, for three sun angles, for MSS 6 are shown in Fig. 1. The function $f(\tau)$ is related to the experimentally observable quantities C_o, C_R and A' by Eq. 2 and 7:

$$f(\tau) = A'(C_o/C_R - 1) \quad . \tag{9}$$

Thus, a measurement of the contrast ratio and knowledge of albedo and sun angle yields a value of $f(\tau)$ that determines

3. RELATIONSHIP OF RADIANCE AND AEROSOL CONTENT

Calculations of the radiance backscattered from the earth-atmosphere system, as seen from space have been published by Plass and Kattawar.[4, 5] These calculations, using Monte Carlo techniques, consider multiple scattering of all orders, and take into account aerosol scattering and ozone absorption. Examination of the results of Plass and Kattawar shows that the outgoing radiance varies with aerosol content, and is most sensitive when the underlying surface albedo is low. The ocean, which covers much of the earth, has a low albedo at high sun angles and provides a suitable underlying surface for aerosol measurements. The calculations also indicate that the longer wavelengths ($\geq 0.7\ \mu m$) are more sensitive to aerosol changes. At shorter wavelengths the Rayleigh optical thickness is comparable to, or greater than, the aerosol optical thickness, so that changes in the aerosol content have less effect.

In order to further investigate the effect of aerosols on the upward radiance over a calm water surface, Plass and Kattawar[6] made some calculations for us for several aerosol vertical distributions, and showed a result of great importance for satellite observations of the upward radiance: the upward radiance depends strongly on the total number of aerosols, but <u>not</u> on their vertical distributions. Thus measurements of the upward radiance can be directly related to the total vertical aerosol content and hence the global loading.

The radiance in the MSS channel 6, centered at $0.75\ \mu m$, may be computed by interpolation of the results of Plass and Kattawar at wavelengths $0.4\ \mu m$, $0.7\ \mu m$, $0.9\ \mu m$ and $1.67\ \mu m$, and by assuming a rectangular spectral response $0.1\ \mu m$ wide. The results are plotted in Fig. 2 to show the relationship between the upward radiance and the aerosol content of the atmosphere for various sun angles. A simple linear relationship is shown to exist between radiance and the aerosol content. These straight lines are based on only two values of aerosol content, but a linear relationship may be established by considering the four data points for zero albedo. From these curves a knowledge of the sun angle and the absolute radiance allows the aerosol content of the atmosphere to be determined. It is seen that a 1 percent change in radiance is equivalent to about 1.5 percent change in aerosol content.

4. PROBLEM AREAS

The discussions in Sections 2 and 3 are based on theoretical calculations which use a model atmosphere, a model aerosol distribution, and assume a smooth water surface or a Lambertian surface. In practice, of course, these model conditions are never realized, so that deviations from the theoretical relationships are to be expected. Hence empirical relationships between the satellite data and the aerosol content will be investigated. However, the problem of sun glitter on the ocean still remains.

If the ocean were perfectly smooth, as assumed in the calculations, an image of the sun would be seen at the specular reflection angle, and the only upwelling surface radiation observable at other look angles from space would be the diffuse sky radiation reflected from the ocean surface and the radiation scattered up from below the ocean surface. As the smooth ocean surface is increasingly disturbed, a glitter pattern becomes increasingly larger about the specular point. At sun zenith angles greater than about 30° the glitter effect has been considered negligible (except for very rough seas) at the nadir point. However, recent measurements by Hovis (private communication from R. Fraser) suggest that this assumption is not correct, so that the ocean surface radiance at the nadir is not known accurately.

This problem might be overcome by making observations at two wavelengths, assuming that the spectral variation of the surface radiance is known. The choice of wavelengths must be made carefully since the spectral distribution of the radiance does vary due to ocean properties such as chlorophyll content, suspended matter and depth. If the ratio of reflectivities at two wavelengths remains constant for various surface conditions and sun angles, then the sun glitter problem can be eliminated.

5. PRELIMINARY RESULTS

Two test sites have been used for this investigation. One is the Salton Sea/desert region in the Borrego Desert in Southern California, and the other includes San Diego city and the ocean. Measurements of the vertical aerosol optical thickness have been made with a Volz sun photometer at the times of the satellite overpass when weather conditions permitted. The results of these measurements given, in Fig. 3, show that on all these occasions the aerosol content was lower than the Elterman 1964 model value.[7]

The ERTS-1 data received to date for these test sites have been only in the photographic format, and have been analyzed with a densitometer. Digital data have been requested and will be analyzed on a CDC 6400 computer.

The preliminary analysis of the transparency data received to date has initially shown promising results for the contrast-aerosol content relationship in the Salton Sea/desert region. The measured transparency densities were converted to radiances using the grey scale and preflight calibration data. The radiance of the water across the Salton Sea was found to be almost constant on a given frame, but, as expected, the desert surface was quite variable in radiance. The apparent contrast, C_R, was computed using the brightest portion of the adjacent desert. The inherent contrast, C_o, was calculated by assuming a reflectivity of .30 for the desert and .02 for the Salton Sea (based on albedos measured by Griggs [8]), giving a value of 14.0 for C_o. For this preliminary examination, the same value was assumed for all sets of data, neglecting the variation with wavelength and sun angle. Values of $f(\tau)$ were calculated from Eq. 9, and values of τ determined from plots of $f(\tau)$ vs τ for MSS channels 4, 5 and 6 (e.g. see Fig. 1). MSS 7 is not considered due to the influence of water vapor in this channel. These values of τ were converted to aerosol content assuming that τ is proportional to the number of aerosols.[7] The values of aerosol content in terms of N (Elterman's 1964 model value), obtained in our initial analysis, are given in Table 1. The results, except for one, are reasonable in terms of possible aerosol content, although no ground-truth data are available for comparison. The results for 10-1-72 show excellent agreement among the different channels.

TABLE 1

MSS Channel	Aerosol Content		
	4	5	6
8-26-72	2.5N	1.7N	
10-1-72	.9N	.8N	1.0N
11-6-72	1.8N	.07N*	1.1N

* Low value attributed to calibration or processing problems with this frame.

Analysis of subsequent photographic data has not been so successful due to an apparent calibration problem, at least at the low radiance end of the grey scale. The density of the transparencies for the water surfaces was found to be greater than that of the blackest step of the grey scale, which corresponds to zero radiance. Due to this problem, further analysis of the contrast-aerosol content relationship has been delayed pending the receipt of the digital data which provide more accurate radiance measurements. These tapes are also necessary to investigate the radiance-aerosol content relationship.

6. CONCLUSIONS

The preliminary analysis of the transparency data has shown promising results for the contrast-aerosol content relationship. Further analyses with the digital data, and for more satellite overpasses, are required to clearly demonstrate the feasibility of measuring the atmospheric aerosol content from ERTS measurements.

7. REFERENCES

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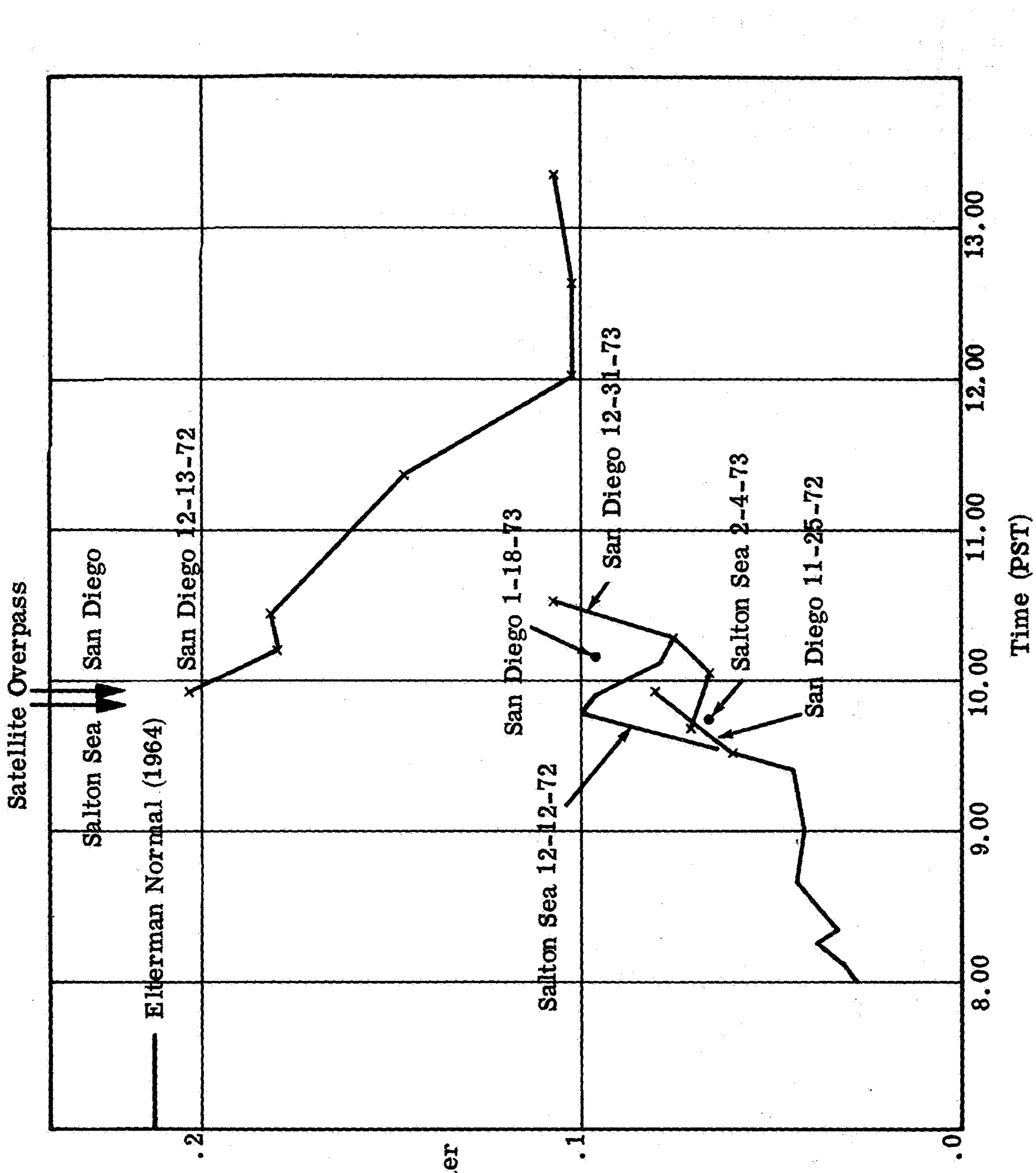

Fig. 1 Volz Data

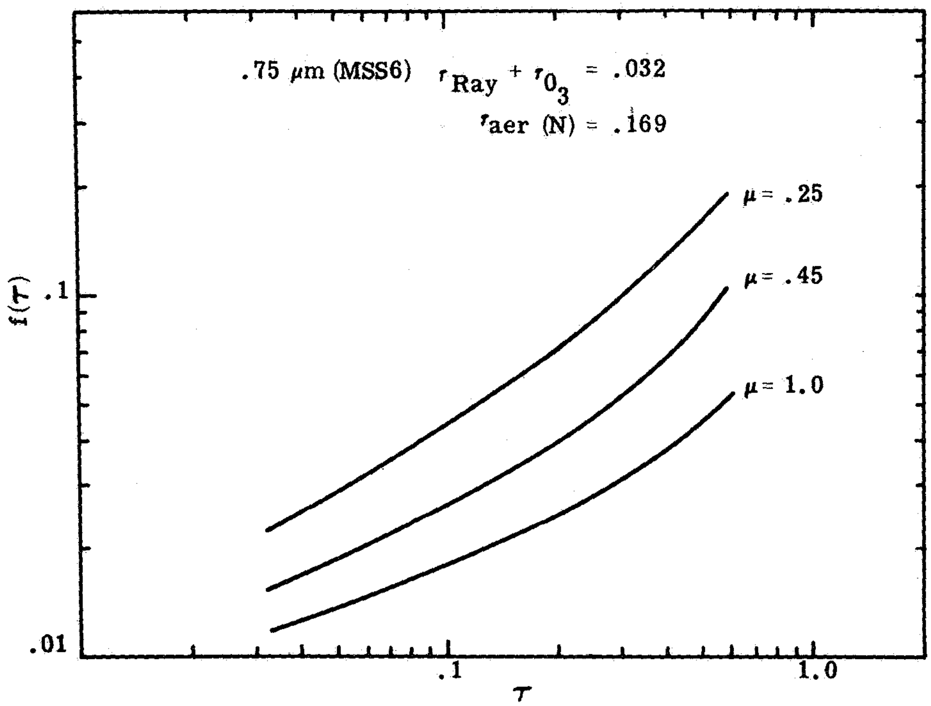

Fig. 2 $f(\tau)$ vs τ for three sun zenith angles, θ, ($\mu = \cos\theta$)

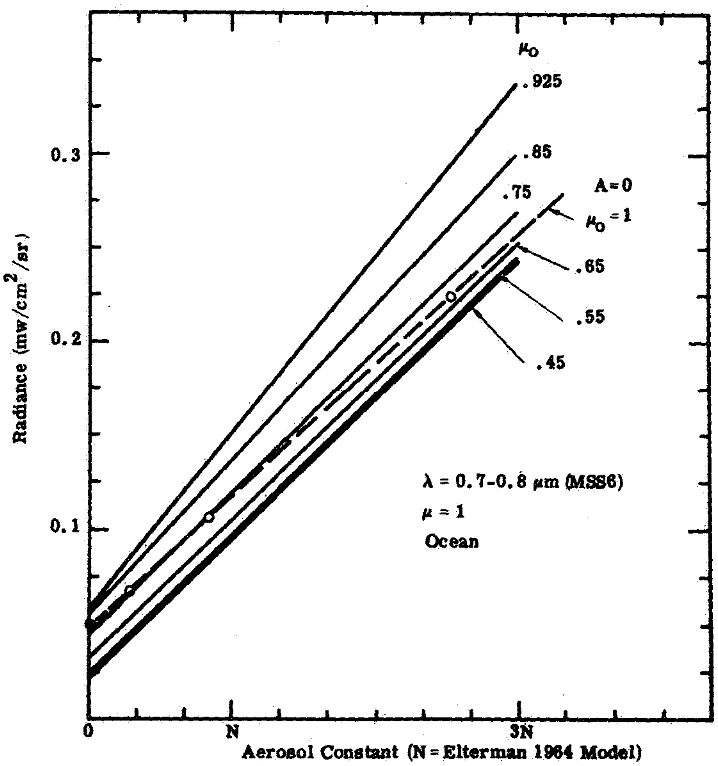

Fig. 3 Radiance vs. Aerosol Content for MSS6