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THE EFFECT OF SURFACE REFLECTION AND CLOUDS ON THE ESTIMATION OF TOTAL OZONE FROM SATELLITE MEASUREMENTS

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ABSTRACT

The total amount of ozone in a vertical column is being measured by Nimbus 4 and 7 observations of the intensity of ultraviolet sunlight scattered from the earth. The algorithm for deriving the amount of ozone from the observations uses the assumption that the surface reflects the light isotropically and the albedo is independent of wavelength. The effects of anisotropic surfaces and clouds on the estimate of total ozone are computed for models of the earth-atmosphere system.

INTRODUCTION

Nimbus 4 and 7 are making an important series of measurements of the total amount of ozone for most of the world over a period of many years. The amount of ozone is estimated from the intensity of the sunlight scattered from the earth in several bands within the 300 to 400 nm band. Since ozone absorbs light within this band, the intensity of the scattered light decreases as the amount of ozone increases. The algorithm for deriving the amount of ozone is based on a model of the earth-atmosphere system utilizing two assumptions: a) the surface reflects light isotropically according to Lambert's law; and, b) the surface reflectance, or albedo, is independent of wavelength.

Generally, these assumptions are not true, but methods have not been developed for improving the physical reality of the algorithm model. Nevertheless, advanced models of the earth-atmosphere system can be developed for computing the errors caused by these assumptions in estimations of the total amount of ozone. Results of computing the effects for strongly anisotropic surfaces will be discussed first, and then for clouds.

Anisotropic Reflection

The method for estimating the ozone error is to compute the intensity of ultraviolet light scattered by models of the earth-atmosphere system. The total amount of ozone in a vertical column is derived from the intensity by means of the same algorithm used for processing the Backscattered Ultraviolet Instrument measurements.

The effect of rough ocean surfaces is investigated first. The surface is assumed to be an ensemble of randomly oriented, small, reflecting facets. The reflection characteristics are computed according to the Cox-Munk theory (1954). Figure 1 shows how well the computed and measured values compare. The dots represent the intensities measured by Dr. Curran from the NASA Convair 990 aircraft at a height of 10.5 km. The abscissa gives the nadir angle of observation. The intensities are computed for 3 model atmospheres, each with a different aerosol model. The model containing haze L (index of refraction m=1.341-0.0i) agrees best with the measured values over an intensity range of an order of magnitude. The absolute accuracy of the computed intensity is not critical, but good precision is needed for computing changes in intensity associated with model perturbations. The precision of such computations are as good as the measured values -- namely, a few percent.

Table 1 gives the total ozone errors associated with wind speeds of 2 and 10 ms^{-1} and three solar zenith angles. The third column gives the albedo, or hemispherical reflectance for the model. The fourth column gives the albedo that is derived from the ozone algorithm on the assumption that the surface reflects light according to Lambert's law. The albedo is strongly overestimated when the nadir field-of-view is directed towards the bright solar glint. As the solar zenith angle increases and the glint pattern moves away from the nadir field-of-view, the derived albedo approaches the true value.

The total ozone errors in Dobson Units (DU) are given in the last column. They are -2% to -3% -- slightly less than the errors in the satellite values. The errors are small, because the algorithm utilizes the ratio of intensities in moderately and weakly absorbing bands. The effects of surface anisotropy on the reflected intensities is about the same in both bands.

TABLE 1

Model and derived surface albedos for λ380 nm. The last column gives the deviation in the derived amount of ozone from the model value of 240 DU.

Wind Speed (m/s)	Solar Zenith Angle (Degrees)	Surface Albedo		Total Ozone Deviation (DU)	
		Model	Derived		
2	0	0.04	0.23	-5	(-2%)
	28	0.04	0.08	-7	(-3%)
	58	0.08	0.08	-4	(-2%)
10	0	0.040	0.13	-8	(-3%)
	28	0.045	0.09	-6	(-2%)
	58	0.080	0.07	-4	(-2%)

Effects of deviations in the physical state of the atmosphere from the algorithm model tend to cancel in the ratio.

The effect of a snow-ice surface is discussed next. The measured and computed intensities of light reflected from a snow surface are shown for the principal plane containing the sun, the observer, and his zenith in Figure 2. The radial lines give the direction of travel of a photon. The parallel source of light of π units of flux is incident at an angle of 150° from the surface. The circular curves give the intensity of reflected light. The value of isotropic reflection is 1/2, independent of the angle. The values computed for a snow-ice surface are given by the continuous curve labeled as anisotropic. The dashed curve gives measured values. The magnitudes are not important, since they can be adjusted by varying the albedo within a large allowable range (O'Brien, 1977). The measured and anisotropic values are nearly isotropic for backward reflection; but show the strong forward scattering, similar to the solar glint pattern on water.

Table 2 gives the error in the derived amount of ozone, which is 16 DU out of a total of 342 DU. The error is the same when the surface reflects light isotropically, showing that the anisotropic effect is not the cause of the error. The error arises because the Antarctic region is modeled, and the surface is 3.6 km above sea level. When the surface reflectance exceeds 0.8, the algorithm calculates the total amount of ozone for a surface that is 7 km above sea level. The difference between the model and algorithm heights is the reason for the error.

TABLE 2

Surface albedos and total ozone deviations using the intensities at the top of the atmospheres with two surface characteristics. The total amount of ozone in the model is 342 DU. The solar zenith angle θ_0=58°. The surface is 3.6 km above sea level.

Surface Reflectance	Surface Albedo (λ380 nm) Model	Derived	(DU)
Isotropic	0.96	0.96	16 (5%)
Anisotropic	0.95	0.94	16

Clouds

There are no reliable observations of cloud albedo for the λ300 - 400 nm band. We have calculated the reflection and transmission characteristics of a cloud of water drops with an optical thickness τ_c=20 at λ380 nm. Its albedo increases slightly from 0.66 to 0.67 as the wavelength increases from 312 to 380 nm (the solar zenith angle θ_0=48°). Addition of 2 DU of ozone, appropriate for a cloud 1.5 km thick, does not change the albedo appreciably (see Figure 3).

The effect of the atmosphere and a ground surface at sea level on the albedo at the top of cloud is shown in Figure 3. The top of the cloud is placed at the pressure level of 0.4 atm and the base at 0.5 atm. The albedo at the cloud top is weakly dependent on the wavelength, when the surface albedo is small, as for oceans, bare and vegetated lands. On the other hand, when the surface albedo is high, as for snow and ice, the albedo at the cloud top increases significantly with wavelength (Figure 3).

Table 3 shows the deviation in the total amount of ozone in a vertical column caused by clouds. When the surface albedo is small, the error is small. When the surface albedo is large, the ozone errors become significant. The errors decrease with solar zenith angle, because the cloud reflectance increases, and less light is transmitted to interact with the lower atmosphere and ground. These results indicate that high clouds cause a small error in the derived amounts of ozone over surfaces of low reflectivity, but a moderate positive bias over snow surfaces.

TABLE 3

Deviation in the total amount of ozone (DU) caused by a layer of clouds whose upper surface is at pressure of 0.4 atm. The total amount of ozone is 350 DU.

surface albedo \ solar zenith angle	0°	68°
0.07	5 (1.47%)	1 (0.3%)
0.90	27 (7.7%)	11 (3.1%)

Summary

Surface anisotropy causes small errors in the amount of ozone estimated from satellite measurements of the intensity of scattered ultraviolet sunlight. The anisotropic effects for water and snow-ice are nearly independent of wavelength. The algorithm for estimating the total amount of ozone computes the ratio of intensities in moderate and weakly absorbing bands and compares this ratio with values computed for a model with Lambert reflectance. The difference in intensities between the Lambert and anisotropic models tends to cancel in the ratio, resulting in small ozone error.

Since the surface albedo of the algorithm model is independent of wavelength, variations from such a model cause ozone errors. A high cloud above a bright surface causes moderate ozone errors, but small errors above a dark surface.

References

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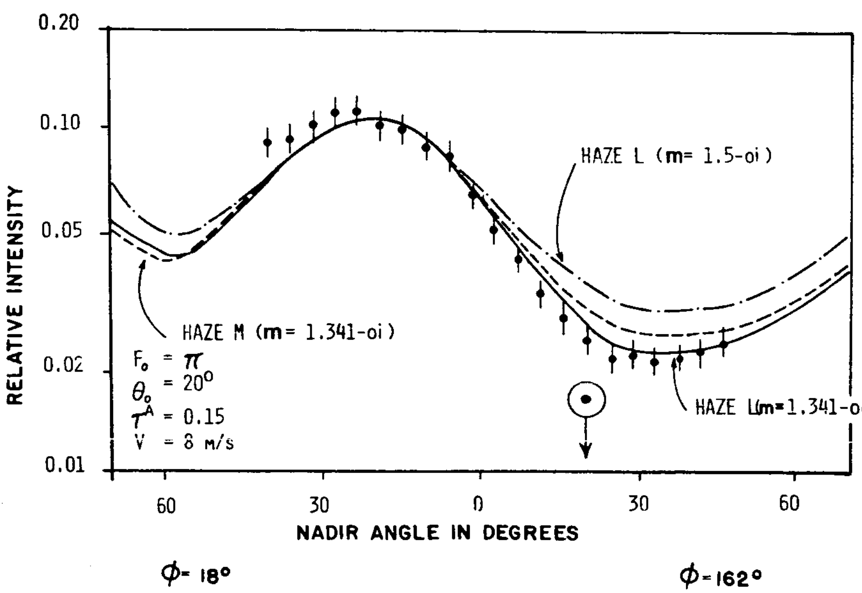

Fig. 1. Upwelling intensities at a height of 10.5 km. The dots give the measured values, and the lines give the values computed for model atmospheres.

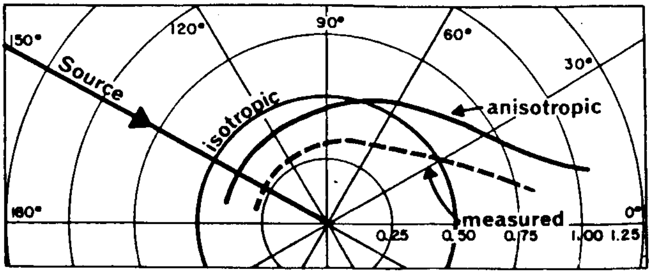

Fig. 2. The computed intensity of light reflected from model snow surfaces compared with values measured by Middleton and Mungall (1952) as a function of the angle from the horizon in the vertical plane containing the source of parallel light, which is located at a zenith angle of θ_0=60°. The source flux is π units. The model isotropic, model anisotropic, and measured intensities are represented respectively by the dot-dashed, continuous and dashed lines; their respective albedos are 1.0, 0.94, and 0.67.

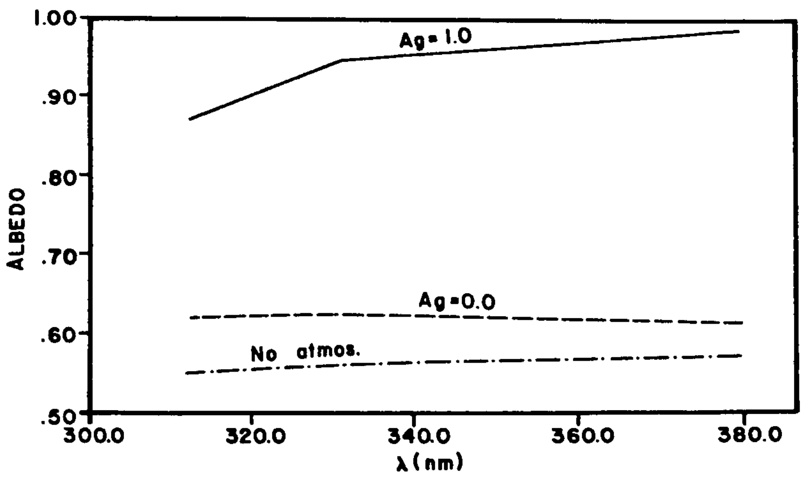

Fig. 3. The albedo at the upper cloud surface as a function of wavelength. The upper two curves are for ground albedos of 0.0 and 1.0. The lowest curve gives the cloud albedo in the absence of the earth's atmosphere and surface. The solar zenith angle is 0°.