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Radiative Transfer in the Lower Atmosphere Based on TOMS/ADEOS Measurements

Principal Investigator:

John E. Frederick

Department of the Geophysical Sciences

The University of Chicago

5734 South Ellis Avenue

Chicago, IL 60637

Telephone: (312) 702-3237

Facsimile: (312) 702-9505

E-mail: frederic@rainbow.uchicago.edu

I. Objective

The long-term objective of this research is to develop and apply methods to compute the solar ultraviolet (UV) spectral irradiance at the earth's surface using information to be provided by the TOMS/ADEOS data set. The broad philosophy is to view the TOMS measurements as a probe of the radiative transfer properties of the earth's atmosphere. Prior to the launch of ADEOS, we have focused on analysis of the Nimbus 7 TOMS data base as well as the development of numerical models for eventual use with ADEOS measurements. The emphasis of recent work has been on numerical modeling of the radiative effects of cloudy skies in the UV part of the spectrum.

II. Activity During the Reporting Period

Efforts during the final four months of 1995 (under Grant NAG5-1986) and the initial two months of 1996 (under the successor grant NAG5-3140) centered on improving the handling of clouds in the new radiative transfer model developed by graduate student Carynelisa Erlick as part of her Ph.D. research. Our previous studies have shown that the effective reflectivities contained in the Nimbus 7 TOMS data base are valid statistical indicators of the attenuation of UV irradiance provided by cloudy skies. However, our early work did not consider the optical properties of the clouds themselves, specifically the possibility that their attenuation might be dependent on wavelength. Examination of this issue requires a detailed mathematical treatment of the interaction of solar UV radiation with a cloud. This is the focus of Ms. Erlick's work under the current

NASA grant. The goal of this model development is to create a radiative transfer code which simultaneously computes the TOMS measurables (backscattered radiances at specific wavelengths) and the ground-level spectral irradiance over the entire UV-B (290-320 nm) and UV-A (320-400 nm) for clear skies and any type of cloudy conditions.

The radiative transfer model in its present form treats a cloud as a plane parallel layer, of specified optical thickness, which contains a prescribed statistical distribution of cloud drop sizes, air molecules, and absorbing molecules (usually ozone alone, although other absorbers are possible). The liquid cloud drops are allowed to contain dissolved material, being molecular or particulate, which absorbs in the UV. Published data on absorption of UV radiation by cloud-water have been used to estimate the complex part of the refractive index of the clouds, although the magnitude of this quantity varies greatly with geographic location.

Early test calculations have been done to examine the wavelength dependence of the attenuation of sunlight provided by cloudy skies. Here we assumed (1) no liquid-phase absorption inside the cloud drops and (2) a tropospheric ozone profile typical of an unpolluted atmosphere taken from the U. S. Standard Atmosphere 1976. We characterize the effect of a cloudy sky on ground-level irradiance by the ratio:

$$N(w) = E(cloudy,w)/E(clear,w)$$

where w is wavelength, and E refers to irradiance under clear or cloudy skies. If a cloudy sky provides the same attenuation at all wavelengths, then N(w) will be independent of w.

For the situation described above we have obtained the following initial results. As wavelength decreases from w=500 nm into the UV, to approximately 320 nm, N(w) increases monotonically. As an example, consider a cloud which leads to a ground-level irradiance at 500 nm which is 40% of the clear-sky result [N(500 nm) = 0.4]. The corresponding computed value at 340 nm is approximately N(340 nm) = 0.5. That is, cloudy skies provide less attenuation in the UV-A than in the visible. This effect arises from a radiative coupling between the cloud and the Rayleigh scattering atmosphere in which the cloud is imbedded. Downward moving radiation at both 340 nm and 500 nm experiences the same degree of attenuation upon the initial passage through the cloud. However, Rayleigh backscattering beneath the cloud affects the shorter wavelength radiation more than the longer. A larger fraction of the irradiance originally transmitted at 340 nm will upwell and encounter the base of the cloud than is the case at 500 nm. Reflection of the upward-moving scattered light back into the downward direction therefore has a greater influence on ground-level irradiance at 340 nm than at 500 nm. The coupling between wavelength-dependent Rayleigh scattering and the wavelength-independent cloud leads to the effect, as opposed to any wavelength dependence in the optical properties of the cloud itself. This is the origin of the increase in N(w) as w decreases. Note that absorption of radiation is not involved here.

As one proceeds to wavelengths shorter than approximately 320 nm, the effects of absorption by tropospheric ozone located inside the cloud become significant. Both the clear and cloudy atmosphere used in the definition of N(w) contain the same ozone profile. However, ozone located in the air within a cloud has a disproportionately large influence. Clouds tend to trap UV radiation by efficiently scattering it from drop to drop. Therefore sunlight takes a long effective path through a cloud, leading to enhanced absorption in the UV. When this influence is included, N(w) undergoes a maximum around w=310-320 nm and rapidly declines toward shorter wavelengths. At w=300 nm N(w) has declined to a value very similar to that at 500 nm.

III. Plans for the Coming Months

The radiative transfer code including the detailed treatment of clouds will be tested further, with emphasis on studies of absorption of UV radiation within clouds. When model development is completed we will begin to address the question: Exactly what can one infer about the UV optical properties of cloudy scenes using backscattered radiances measured by TOMS on the ADEOS mission?