Observability of High-Altitude Atmospheric Scattering Layers

DEREK M. CUNNOLD*
MIT, Charles Stark Draper Laboratory, Cambridge, Mass.

Theme

IN this paper we consider the observability of high-altitude aerosol and atmospheric scattering layers with a satellite-mounted optical detector. In particular, we have examined the detectability of a 50-km layer with a wide-angle receiver of the type that currently is being used to monitor ultraviolet solar energy. We have concluded that a modified instrument of this type has potential for detecting such an aerosol layer and, further, that a narrow field-of-view satellite-mounted telescope used to scan Earth's horizon has general applicability for detecting high-altitude aerosol layers.

Contents

The particular atmospheric scattering layer calculations to be described were the result of an attempt to establish the observability of stratospheric aerosols under various geometrical conditions. These calculations were initiated after Monitor of Ultraviolet Solar Energy (MUSE)[1] observations indicated the presence of anomalous signal enhancements (at approximately 2800 Å) in the solar observations made from the Nimbus 4 satellite. At this wavelength, considerable absorption by atmospheric ozone occurs. Therefore, if an atmospheric scattering layer is to be a significant source of energy, it must be located above approximately 40 km. Evidence for the existence of aerosol layers at such high altitudes has tended to be inconclusive because of the small amplitude of the scattering that such layers would produce. However, we suggest[2] that there is now sufficient observational evidence to believe that an aerosol layer in the region of 50 km exists in the atmosphere—at least on isolated occasions and at particular locations. It has also been suggested[2] that such a layer can affect the measurement of atmospheric ozone concentration profiles by the backscattered ultraviolet (BUV) technique in which nadir satellite observations of backscattered radiance at ultraviolet wavelengths are made,[3] and it was thus concluded that the BUV technique requires that simultaneous determinations of the aerosol extinction function profile be made.

Both the BUV experiment and the MUSE experiment are on the Nimbus 4 satellite. We therefore have investigated the "anomalous" signal enhancements that an aerosol layer at 50 km would produce in the MUSE type of observations for which a wide-angle detector was used.

We have assumed that the sensitivity and orientation of the detector is such that the satellite-mounted instrument always views Earth's horizon and is sensitive to radiation within a 45° half-angle cone as in the MUSE instrument. It is further assumed in this analysis that the optical axis of the instrument line of sight is located in the plane containing the sun and the local vertical through the satellite. The system geometry is given in Fig. 1.

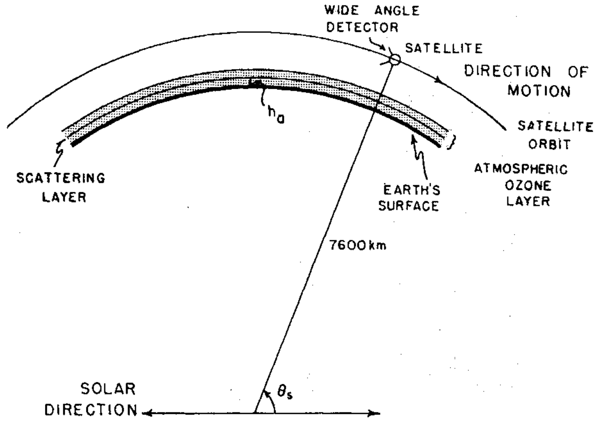

Fig. 1 The geometry of the scattering-layer satellite detector problem.

Consider the scattering produced by a thin atmospheric layer of forward scatterers. In the absence of absorption, the scattering layer produces a signal enhancement which peaks at the solar-occultation angle for the satellite (which for a satellite altitude of 1100 km is approximately 60°). The shape of the enhancement as a function of angle is similar to the shape of the phase function of the scatterers. However, the surface of Earth will prevent the illumination of those scatterers situated on the night side of Earth. For this reason, the maximum enhancement will occur, in fact, for angles θ_s slightly greater than the solar-occultation angle. At the wavelengths of interest (~3000 Å), atmospheric ozone is a powerful absorber. Ozone, therefore, plays an important role in determining the signal enhancement, unless, of course, the layer of scatterers were to be located at a much higher altitude ($\gtrsim$80 km) than the ozone layer. Since the path length of solar radiation through the ozone layer increases rapidly as the satellite angle θ_s approaches the solar-occultation angle, atmospheric ozone tends to reduce the enhancement at angles θ_s in the vicinity of the solar-occultation angle. Our calculations thus show that it is possible for the enhancement to peak at virtually any angle between the day terminator and the satellite-occultation angle, and the actual location will depend upon the height of the scattering layer, its scattering properties, and the particular ultraviolet wavelength used for observation. This suggests the possibility that observations of the scattered energy can yield information on the characteristics of the scattering layer.

The existence of the 50-km aerosol layer discussed earlier has been inferred from observations made at visible wavelengths. The observations suggest an extinction approximately comparable with that for molecular scatterers at the wavelengths used and at 50 km. However, little information is available on the scattering properties of these aerosols and it thus is not possible to deduce the aerosol extinction at ultraviolet wavelengths. On the other hand, it has been estimated[2] that if aerosols are to affect BUV measurements

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* Research Associate, MIT Aeronomy Program, Charles Stark Draper Laboratory, and Department of Meteorology.

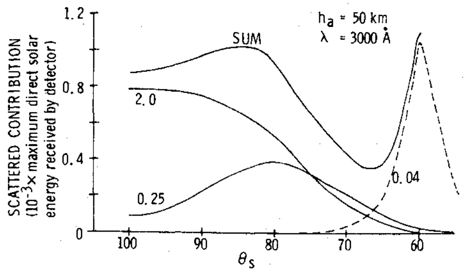

Fig. 2 The total scattering (SUM) produced at 3000 Å by molecular scattering and a 50 km aerosol layer. The contribution from molecular scattering is indicated by the curve denoted 2.0. The aerosol layer contribution is the sum of the curves denoted 0.25 and 0.04.

of ozone, the extinction at 50 km and 2800 Å must be greater than 10% of that for molecular scatterers.

To illustrate the observability of a 50-km aerosol layer we have arbitrarily chosen a 6-km layer with an extinction equal to 1.25 times that for Rayleigh scatterers at 50 km and 3000 Å. For computational purposes we have modeled the aerosol phase function as the sum of two exponentials which decay to $1/e$ of their maxima in 0.04 and 0.25 rad. This model of the phase function is a good approximation to the phase function believed to be appropriate for the stratospheric aerosol layer at 20 km. The total scattered signal, which includes the contribution from Rayleigh scatterers (whose phase function has been approximated by an exponential of width 2.0 rad), is given in Fig. 2. The figure indicates that this aerosol layer is detectable with a wide-angle receiver. Figure 2 also suggests a detectability limit with this instrument of order 0.2 of the extinction for molecular scatterers. It is particularly to be noted however, that the scattered signal is only 0.1% of the directly incident solar energy. Thus, to detect aerosols which may affect BUV observations, a detector of the type considered would have to be sensitive to fluctuations of approximately 10^{-4} against the background of directly incident solar energy and the instrument would have to possess baffling sufficient to prevent signals of this amplitude and scattered by the instrument housing from entering the detector. The MUSE instrument does not possess this capability and is therefore incapable of detecting the 50-km aerosol layer.

We have considered whether the MUSE type of instrument might be modified to detect such a layer, and for detecting other high-altitude aerosol layers. A wide-angle instrument possesses the limitation that it must be operated at approximately 3000 Å so that, by virtue of absorption by ozone, the energy scattered by an aerosol layer may be separated from that produced by molecular scatterers in the lower atmosphere. However, it is reasonable to expect that the wavelength dependence of aerosol scattering is weaker and, in fact, could be considerably weaker than that for molecular scatterers. Thus, if the scattering from 50 km, e.g., can be isolated, high-altitude aerosol layers (including the BUV related layer) would be detected more easily by making measurements at visible wavelengths (e.g., 5000–7000 Å). A narrow-field-of-view telescope may be used for this purpose. A wide-angle detection system also permits only one average atmospheric scattering layer to be derived per orbit whereas a horizon-scanning telescope allows many observations per orbit. A limb-scanning telescope therefore has wider applicability to the detection of high-altitude aerosol layers than a wide-angle MUSE-type instrument. Such a satellite-mounted telescope used to scan Earth's horizon with an altitude resolution of 1 km should yield the extinctions and scattering properties of stratospheric aerosols as a function of both altitude and wavelength.[4,5]

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