An Alternative Method of Obtaining Direct Aerosol Radiative Forcing From Satellite Observations

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Introduction

Direct aerosol radiative forcing (ARF) is important in understanding the impact of aerosols on earth's climate (Schimel et al. 1996). Global distribution of ARF is usually determined by first inverting satellite measurements to obtain aerosol properties such as optical depths, size distributions, and refractive indices, and then performing radiative transfer calculations. Given the many difficulties and uncertainties in inversion procedures (Twomey 1996), an alternative method is proposed to determine ARF more directly using satellite observations. Some very preliminary results are presented, which are obtained from the use of International Satellite Cloud Climatology Project (ISCCP) Cloud Products, radiation measurements made by the Earth Radiation Budget Experiment (ERBE) instrument on the National Oceanic and Atmospheric Administration (NOAA) satellite, and model calculations.

Method and Results

Direct aerosol radiative forcing is defined as the change in the net radiative flux at a particular level in the atmosphere, such as the top of the atmosphere (TOA), due to the influence of aerosols (Schimel et al. 1996). Radiative transfer models are usually used to estimate the net radiative flux for the system with and without the presence of aerosols. Remotely sensed data sets are used to determine aerosol optical and physical properties, which are used in radiative transfer calculations. We suggest that the net flux for the case with the presence of aerosol can be obtained directly from satellite observations. Radiative transfer models are used only to determine the aerosol-free net fluxes. ARF is simply taken as the difference of these two results.

ERBE broadband shortwave albedo observations for ocean scenes identified as being cloud-free by both ERBE and ISCCP DX level analysis are used. The left panel of Figure 1 shows TOA albedo observations for January 4, 1986, with gray dots. The black dots are calculated cloud- and aerosol-free albedos using the Fu-Liou radiation model (Fu and Liou 1992; Liou et al. 1988), which uses the correlated k-distribution method to model atmospheric transmittance and the delta-four-stream method to solve the radiative transfer equation. The atmospheric profiles stored in ISCCP D1 level data sets are employed. They are derived from the Television Infrared Observation Satellite (TIROS) Observational Vertical Sounder (TOVS). The model of Masuda and Takashima (1996) provides the ocean albedo as a function of solar zenith angle, ocean surface wind speed, and radiation wavelength. This model does not consider the effect of whitecaps, which have different reflective characteristics from those of foamless

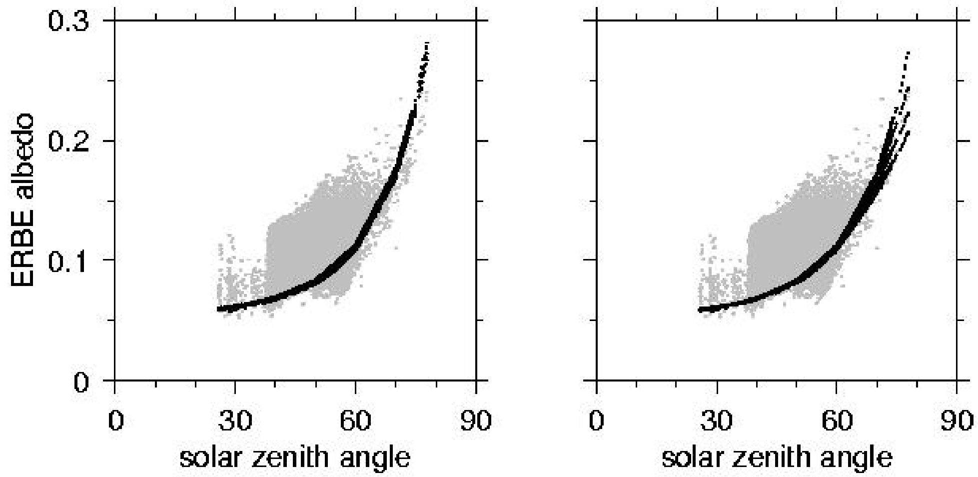

Figure 1. TOA ERBE albedo for January 4, 1986, as a function of solar zenith angle (gray dots). The black dots in the left panel show the sensitivity of the modeled results to water vapor concentrations. The water vapor concentration of the bottom layer of the atmosphere is multiplied by 0.1 and 2.0 factors. Sensitivity to assumed ocean surface wind speed (0, 5, 10, and 15 m/s) is shown by the black dots in the right panel.

waters (Moore et al. 1998). The effect of suspended pigments on ocean reflectance, which is important at certain wavelengths (Gordon 1997), is also not included.

In the left panel of Figure 1, the wind speed is set to zero. To examine the sensitivity of the results to water vapor, the water vapor concentration in the lower atmospheric layers is multiplied by factors of 0.1 and 2.0. The right panel of Figure 1 shows the sensitivity of model calculations to assumed ocean surface wind speed. Speeds of 0.0, 5.0, 10.0, and 15.0 m/s are used, with a lower speed resulting in higher TOA albedo. Comparing the two panels, ARF estimates are more sensitive to the assumed ocean surface wind speed, particularly for situations with high solar zenith angles.

Assuming that the difference between the ERBE data and model calculations is due to the presence of aerosols, then the gray dots that lie above the black dots indicate negative direct radiative forcing. The ERBE data points lying below the model calculations indicate positive radiative forcing, which could be caused by the presence of strong absorbing aerosol, if not noise. Figure 2 shows the ARF obtained by taking the difference between the measured and modeled albedo. Note that the ARF values are instantaneous and not daily averages. In this figure, an ocean surface wind speed of 0 m/s is used. Underestimating or overestimating the ocean surface wind speed can cause a switch of the resulting ARF from positive to negative values.

Monthly maps of instantaneous ARF (not shown) indicate that there are problems that still have to be solved. There is a latitudinal trend where the areas of positive ARF are at high latitudes. This may be due to the solar zenith angle dependence of the ocean albedo model being inadequate for this kind of

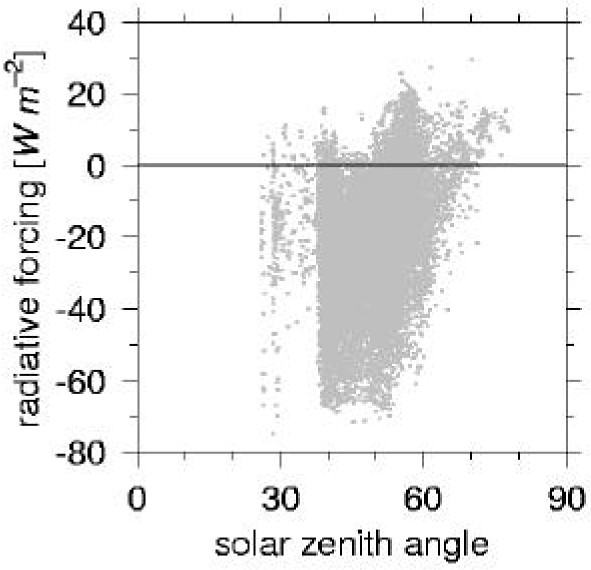

Figure 2. Direct aerosol radiative forcing as a function of solar zenith angle for January 4, 1986, derived using the alternative technique.

study. There is also considerable noise in the results, which may be caused by sub-pixel clouds that are not detected by either ERBE or ISCCP DX analysis. Though there is high ARF to the west of Africa where the optical depth of mineral dust is high (Stowe et al. 1997), high ARF is also seen at locations where aerosol burden is relatively low.

Conclusions

This study proposes a new means of determining direct aerosol radiative forcing from satellite data, which does not require deriving aerosol optical or physical properties. Some very preliminary results are presented. It is found that the results are more sensitive to the ocean surface albedo model than variation in the water vapor concentration. The latitudinal trend in the derived albedo change is likely associated with an inadequate treatment of the dependence of ocean albedo on solar angle. Though the effect of the aerosol plume to the west of Africa is captured by this technique, there is considerable noise in the results. This may be caused by the effect of sub-pixel clouds. This effect is a difficult problem, which requires further investigation.

Acknowledgments

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