Observed Aerosol Radiative Forcings: Comparison for Natural and Anthropogenic Sources

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Introduction

The modeling of radiative forcing, and aerosol radiative forcing in particular, is one of the largest uncertainties in predicting climate change (Hansen et al. 1998). Addressing this uncertainty first requires an accurate quantification of the existing aerosol radiative effect on the earth's energy balance. Atmospheric Radiation Measurement (ARM) Program observations are used to determine the aerosol forcing in diverse geographical regions for natural and anthropogenic sources. This quantification addresses the two primary ARM objectives by (1) ascertaining the existing variability of the radiative forcing and its relationship to atmospheric composition, and (2) providing strong constraints for testing aerosol models used in climate models.

Methodology

ARM radiometric observations from the Southern Great Plains (SGP) and Tropical Western Pacific (TWP) sites are used to determine the aerosol radiative forcing at the surface. The SGP is dominated by a continental aerosol, and the TWP data are from 1997, when the El Niño suppressed the rainfall in that region and biomass burning was widespread in the area. These observations are compared to those observed during the Indian Ocean Experiment ([INDOEX]; Ramanathan et al. 1996), and to those computed for a set of generic aerosol models representing defaults used in the community for climate modeling and aerosol satellite retrievals. Specifically, the generic models considered here represent maritime ocean, continental, and urban aerosols (Hess et al. 1998).

The metric used for this comparison is the aerosol forcing efficiency at the surface, F(s) (Satheesh and Ramanathan 2000; Conant 2000). F(s) is defined as the slope between the diurnally averaged surface aerosol forcing plotted versus the change in the diurnally averaged aerosol optical depth at 500 nm. The advantages of this metric include (1) it is a bulk property that depends on the radiative character of the aerosol type and is insensitive to the potentially highly variable changes in aerosol optical depth, (2) it is directly obtainable from radiometric observations, and (3) it directly conveys the effects of the aerosol on the surface energy balance.

For this work, F(s) must be "standardized" because F(s) can be affected by changes in parameters unrelated to the aerosol properties. These parameters include the solar geometry, surface albedo, and column water vapor (WV). These parameters are very similar for the TWP and INDOEX, but the standardization is needed to enable comparison to the SGP results. A method has been developed to standardize F(s) at all locations for a "reference day," which is defined here as an equinox day at the equator over an ocean surface. The current method for obtaining F(s) is estimated to be good to within 5 Wm^{-2} (for details, see Vogelmann 2001).

Results

Preliminary results indicate that the surface radiative forcing efficiency at the SGP during August to October 1999, is -66 Wm^{-2} (Figure 1a). That is to say that a unit change in aerosol optical depth at 500 nm reduces the net surface forcing by -66 Wm^{-2}. Analyses for the same period in 1997, 1998, and 2000 yield similar results with a mean of 59 Wm^{-2} (not shown). Overall, these results are in the ballpark of the -55 Wm^{-2} value computed for the generic continental aerosol model.

The shortwave broadband data used in these analyses are constructed from the addition of the direct beam measurements by the Normal Incidence Pyrheliometer (NIP), plus the diffuse beam measurements from a shaded pyranometer: μNIP + Diffuse, where μ is the cosine of the solar zenith angle. As noted by Long et al. (2001), these diffuse measurements, made by a shaded Eppley Precision Spectral Pyranometer (PSP), are known to lose energy via infrared (IR) emission to the sky. This can affect a bias in the diffuse fluxes, particularly at the SGP where the low WV amounts can permit a significant amount of IR loss (contrary to the case for the TWP). A value-added product (VAP) is currently being produced that largely corrects for this bias (SW DIFF CORR 1DUTT VAP), and which will be used for the final data analysis. However, starting in 1999, an Eppley Black & White (B&W) Pyranometer was located at the central facility for making diffuse radiation measurements. This instrument does not have the same significant IR loss problem, and is considered to provide an improved estimate of the diffuse flux (although no absolute standard currently exists for measuring diffuse radiation).

To determine the potential effects of these two different diffuse flux measurements on the determination of the aerosol forcing efficiency, the analysis in Figure 1a was repeated using diffuse fluxes from the B&W pyranometer (Figure 1b). The forcing efficiencies are almost identical, although the data points for the B&W cluster much more tightly about the regression line. Were it not for the large point scattering at larger optical depths (0.2 <), the uncertainty in the slope in Figure 1b would likely be reduced (analysis method improvements pending). The similarity of the results are likely due to the use of the differential method (Conant 2000), which removes the effects of mean biases from the analysis. Finally, it is worth noting that the intercept for the line fits are reduced for the broadband fluxes that use the B&W data. The intercept is -2.6 ± 0.45 Wm^{-2} for the shaded pyranometer broadband data, but is only -0.44 ± 0.59 Wm^{-2} for the B&W.

The analysis for Manus Island in the TWP indicates that the biomass-burning aerosol has a significant impact on the surface radiative budget. The aerosol forcing efficiency for August to October 1997 is -48 Wm^{-2} and the daily average optical depths reached a maximum of one (Figure 2). The particle size, inferred from the Angstrom coefficient, indicates that very small particles are present during 1997, which are characteristic of continental particles—not the large particles expected from an oceanic site (Figure 3). Such large Angstrom coefficients are also common in 1999 and 2000.

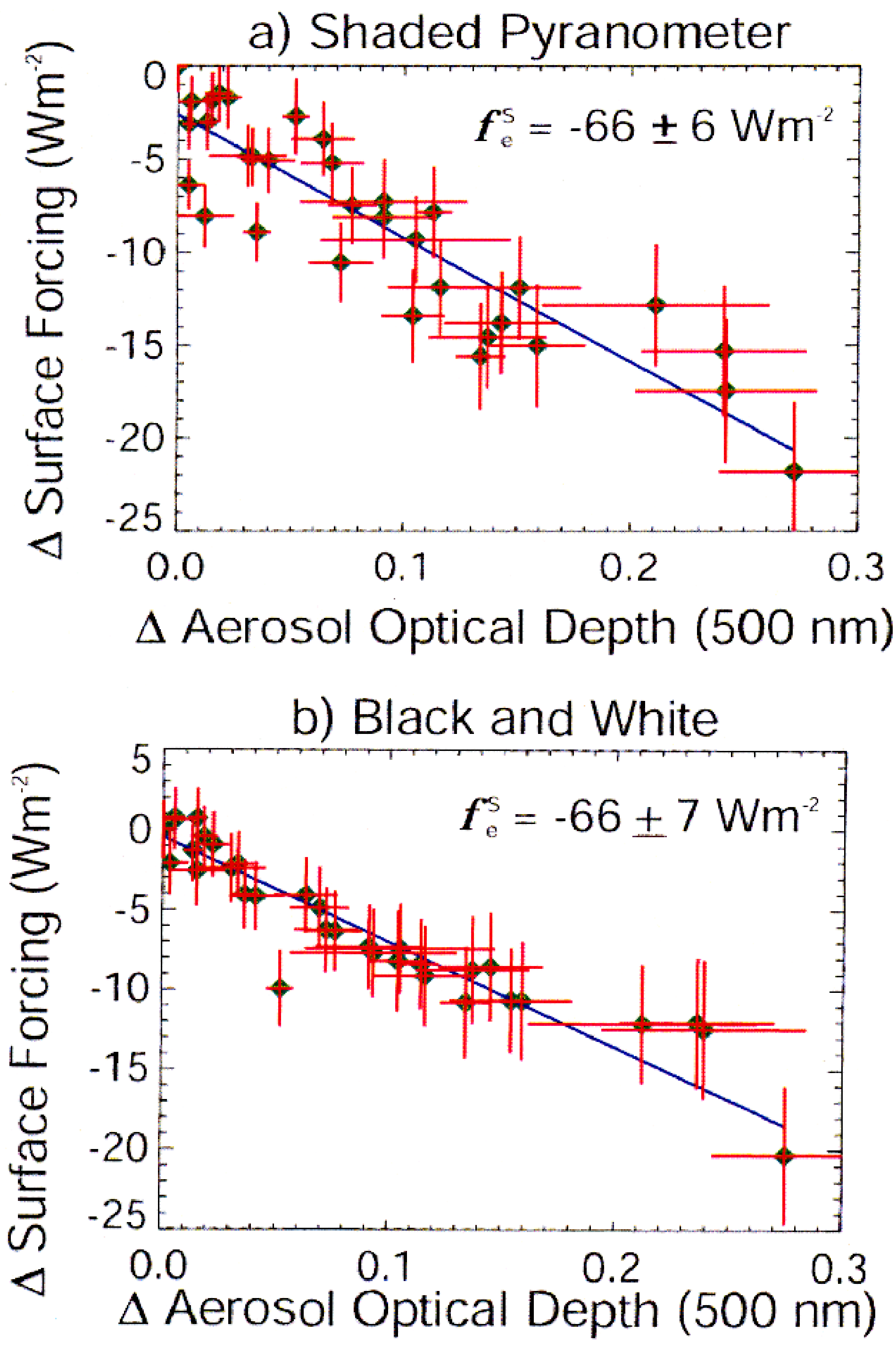

Figure 1. Aerosol forcing efficiencies at the SGP for August to October 1999. Diffuse fluxes from (a) shaded pyranometer, and (b) B&W pyranometer.

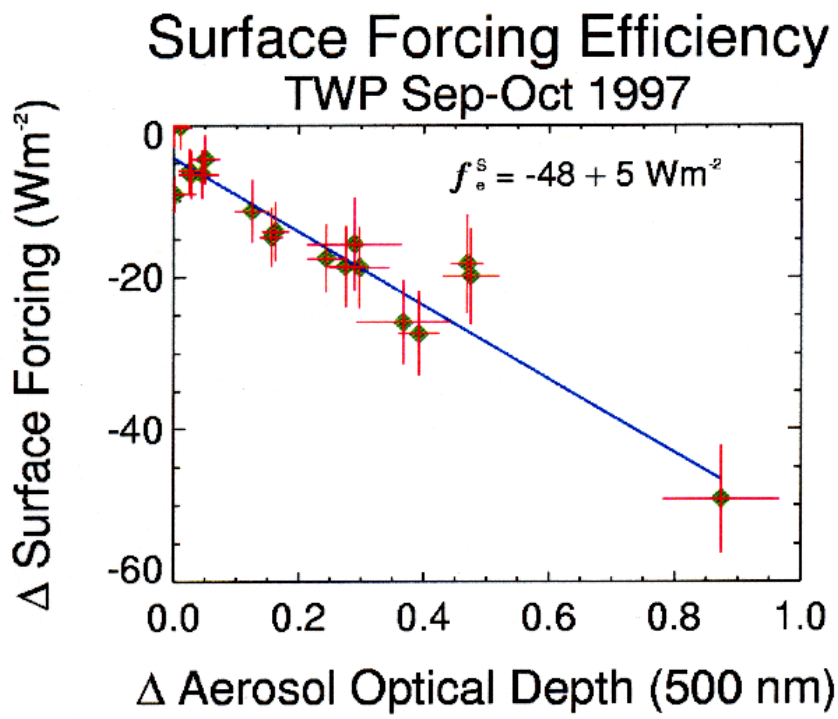

Figure 2. Surface aerosol forcing derived at Manus from Multifilter Rotating Shadowband Radiometer (MFRSR) and pyranometer data. The surface forcing efficiency is -48 Wm^{-2}.

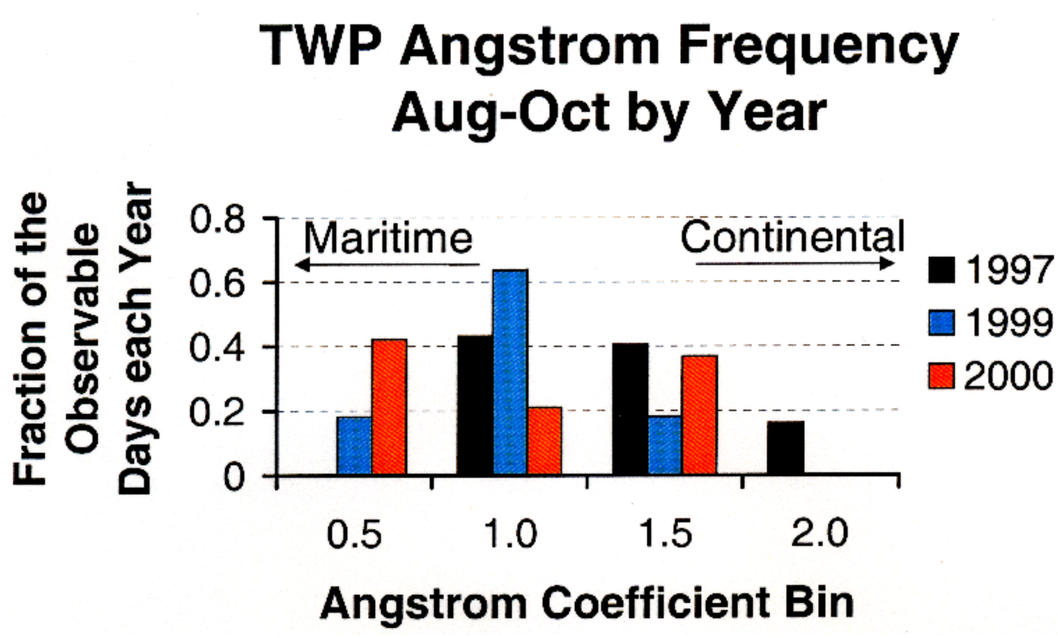

Figure 3. Frequency distribution of Angstrom coefficient occurrences at Manus Island derived from MFRSR data. Large values are indicative of small aerosol particles, vice versa.

Relative to the SGP results, there are considerably greater differences in the forcing efficiency between the generic maritime ocean model (-35 Wm^{-2}), and those observed at the TWP during the biomass burning (-48 Wm^{-2}) and for INDOEX (-70 to -75 Wm^{-2}; Satheesh and Ramanathan, 2000). These results suggest that anthropogenic aerosols, such as biomass burning, can significantly influence the radiative properties of oceanic aerosols. This influence alters their properties considerably from those for generic, pristine ocean aerosol models that may be used in climate models. Further, given the potential long-range transport of these aerosols, these radiative effects can extend to regional and even possibly global scales. This suggests that more attention will be needed to develop methods for ascertaining the properties of oceanic aerosols so that they may be treated properly in models.

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