GACP 2nd YEAR PROGRESS REPORT[1]

Proposal Title: Top-of-Atmosphere Clear-Sky Broadband Radiative Flux and Direct Aerosol Radiative Forcing from Satellite Measurements

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GOALS

The accuracy of satellite-derived estimates of top-of-atmosphere (TOA) aerosol radiative forcing (natural + anthropogenic) depends critically on the accuracy of shortwave (SW) and longwave (LW) TOA radiative fluxes. Since satellites cannot directly measure flux instantaneously, assumptions are needed to account for the angular and spectral dependence of the radiation field to convert a radiance measurement to a flux estimate. If these assumptions are incorrect, they will lead to errors in TOA radiative flux, and hence, aerosol radiative forcing.

In this investigation, aerosol radiative forcing over ocean from the Clouds and the Earth's Radiant Energy System (CERES) instrument and from theoretical broadband radiative transfer model calculations are compared. The first part of this investigation involves the development of new angular distribution models (ADMs) for converting observed broadband radiances to fluxes over cloud-free oceans. Fluxes obtained using the new ADMs are then compared with fluxes from broadband radiative transfer model calculations initialized using coincident aerosol and sea-state parameters based on imager and microwave retrievals over each CERES footprint.

To determine aerosol radiative forcing from CERES, an approach similar to that outlined in Haywood et al. (1999) is used. The aerosol radiative forcing (or aerosol direct radiative effect) is obtained from the difference between a no-aerosol flux deduced from a radiative transfer model and the diurnally averaged regional flux determined by CERES.

ACCOMPLISHMENTS

- The CERES instrument measures *filtered* broadband radiances in three channels: (i) shortwave (SW) between ≈0.2 to 5 μm; (ii) infrared window (WN) between ≈8 to 12 μm and (iii) total (TOT) between ≈0.2 to 200 μm. For scientific studies, SW, WN and longwave (LW) radiances that are independent of the instrument spectral response function characteristics are really what is needed. These *unfiltered* radiances are determined using a new procedure which significantly improves the accuracy of the unfiltered radiances, particularly for clear ocean scenes. The methodology, together with preliminary results, have been summarized in a paper submitted to *J. Applied Meteorology* (Loeb et al., 2000).
- TOA fluxes are estimated from the unfiltered radiances. This requires bidirectional reflectance models [or Angular Distribution Models (ADMs)] that account for the

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[1] Funding for this study only began at the end of the first year of the GACP, so this report actually covers the 1st year of research.

anisotropy in the measurements. 80 days of CERES-TRMM Rotating Azimuth Plane (RAP) scanner measurements were used to construct an initial set of SW, LW and WN for clear ocean scenes. The SW ADMs were stratified by percentiles of wind speed and percentiles of CERES SW reflectance. The latter is used instead of coincident imager aerosol optical depth retrievals because aerosol retrievals are only available over a limited range of viewing conditions (e.g. outside sunglint), which reduces the number of available CERES measurements for ADM development. The SW ADMs are divided into 12 classes: 3 wind speed percentile classes $\times$ 4 classes of SW reflectance percentiles. A plot of 4 of the 12 SW ADMs is provided in Figure 1. LW ADMs under clear skies have also been developed for 3 classes of precipitable water and 4 classes of the temperature difference between the air-temperature at the surface and the air-temperature at 300 mb above the surface. Directional models, which provide albedo as a function of solar zenith angle, have been derived from the SW ADMs. The directional models are needed for calculating diurnally averaged fluxes.

- Theoretical broadband radiative transfer calculations have been performed using the radiative transfer code of Nakajima and Tanaka (1986). We've incorporated various aerosol types such as the Maritime Tropical and Continental Average models of Hess et al. (1998), and use an ocean surface bidirectional reflectance model based on a subroutine from the 6S code (Vermote et al., 1997) which accounts for specular reflection, reflection emerging from the sea water, and reflection from whitecaps. Look-up tables of reflectance and albedo as a function of aerosol optical depth and viewing geometry were developed for 5 wind speeds and 24 aerosol optical depths.

- Figure 2 shows a preliminary estimate of aerosol radiative forcing from the 80 days of CERES measurements between January and August, 1998. As expected, the maximum forcing occurs near desert regions and coastlines adjacent to anthropogenic sources. By comparison, Figure 3 shows a similar calculation using clear ocean scenes from ERBS. Interestingly, the magnitude of the forcing from ERBS is approximately a factor of 2-3 larger than CERES over open ocean. Near desert regions, the ERBS results lack the sharp increase in aerosol radiative forcing seen in the CERES results. The cause for these discrepancies is due to incorrect cloud screening from ERBS—the ERBS method tends to incorrectly classify many cloudy scenes as cloud-free over the open ocean, whereas near desert regions, clear scenes with heavy aerosol loading are misidentified as cloud.

- To examine the sensitivity to cloud contamination in the CERES results, Figures 4a-b show aerosol radiative forcing for CERES footprints identified as 100% clear (Fig. 4a) and 95% clear (Fig. 4b). Cloud screening within individual CERES footprints is determined from collocated 2-km Visible and Infrared Scanner (VIRS) instrument, which also flies aboard the TRMM spacecraft. Over open ocean, isolated regions that appear to have elevated aerosol radiative forcing show a marked increase in forcing when the clear fraction threshold is relaxed (Figure 4b). Consequently, it is likely that these regions had significant cloud contamination to begin with. Overall, the "aerosol" radiative forcing in Figure 4b is ~25-30% larger than that in Figure 4a. As the CERES cloud mask algorithm evolves, and when CERES-Terra data is used together with a higher-resolution MODIS imager cloud mask, we expect a significant improvement in accuracy.

3rd YEAR STATEMENT OF WORK

- As the CERES cloud mask improves, the CERES ADMs discussed above will be refined and updated.
- We will use MODIS measurements combined with CERES to provide a more rigorous error bound on aerosol radiative forcing due cloud contamination.
- We will perform direct comparisons of aerosol radiative forcing estimates from CERES and theoretical broadband radiative transfer model calculations. Initially, a one-parameter retrieval algorithm for determining aerosol optical depth will be used to initialize the radiative transfer model calculations. This will later be replaced by a two-parameter retrieval approach.
- Wind speed retrievals from TMI will be incorporated in the theoretical model calculations. Aerosol radiative forcing sensitivity to wind speed will be examined.
- We will examine SW, LW and Net aerosol radiative forcing from CERES-Terra near desert regions. We will compare these results with coincident aircraft measurements planned in Autumn, 2000 (Haywood, 2000, private communication).

References

Haywood, J.M., Ramaswamy, V., Soden, B.J., 1999. Tropospheric aerosol climate forcing in clear-sky satellite observations over the oceans. *Science*, **283**, 1299-1303.

Hess, M., P. Koepke, and I. Schult, 1998: Optical properties of aerosols and clouds: The software package OPAC, *Bull. Amer. Meteor. Soc.*, **79**, 831-844.

Nakajima, T., and M. Tanaka, 1986: Matrix formulations for the transfer of solar radiation in a plane-parallel scattering atmosphere. *J. Quant. Spectrosc. Radiat. Transfer*, **35**, 13-21.

Vermote, E., D. Tanré, J.L. Deuzé, M. Herman, and J.J. Morcette, 1997: Second simulation of the satellite signal in the solar spectrum: An overview. *IEEE Transactions on Geoscience and Remote Sensing*, **35**, 675-686.

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Publications:

Loeb, N.G., K.J. Priestley, D.P. Kratz, E.B. Geier, R.N. Green, B.A. Wielicki, P.O'Rawe Hinton and S.K. Nolan, 2000: Determination of unfiltered radiances from the Clouds and the Earth's Radiant Energy System (CERES) Instrument, *J. Appl. Meteor.* (submitted).

Conferences and Seminars:

Loeb, N.G., and Y. Hu, 1999: Top-of-atmosphere clear-sky broadband radiative flux and direct aerosol radiative forcing from satellite measurements. Presented at AGU Fall Meeting, December 13-17, 1999, San Francisco, California.

Loeb, N.G., 2000: New perspectives on top-of-atmosphere aerosol signatures using CERES satellite data. Invited seminar at GFDL, Princeton, NJ, February 7, 2000.

Clear Ocean ADMs (θ_o=60º-70º)

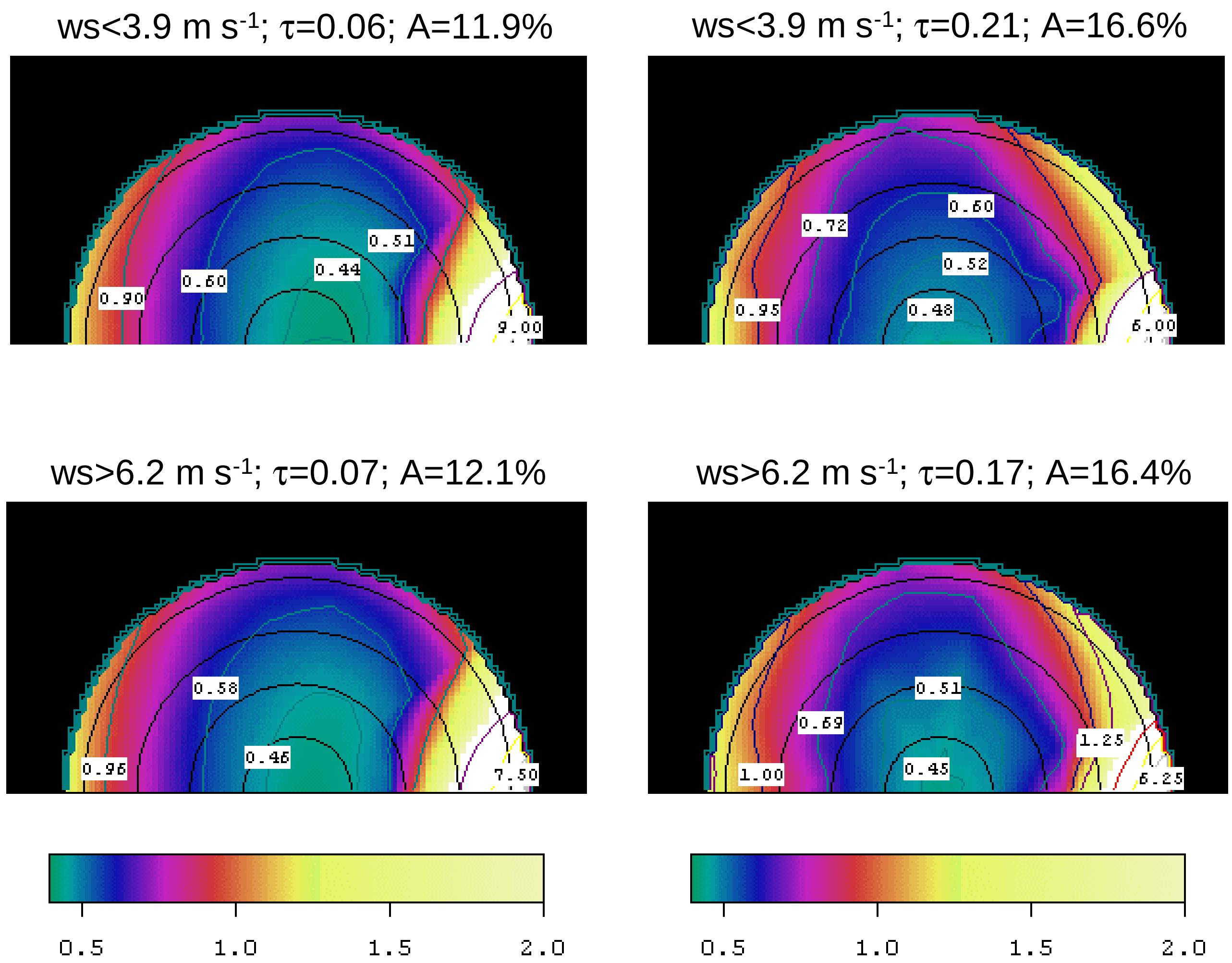
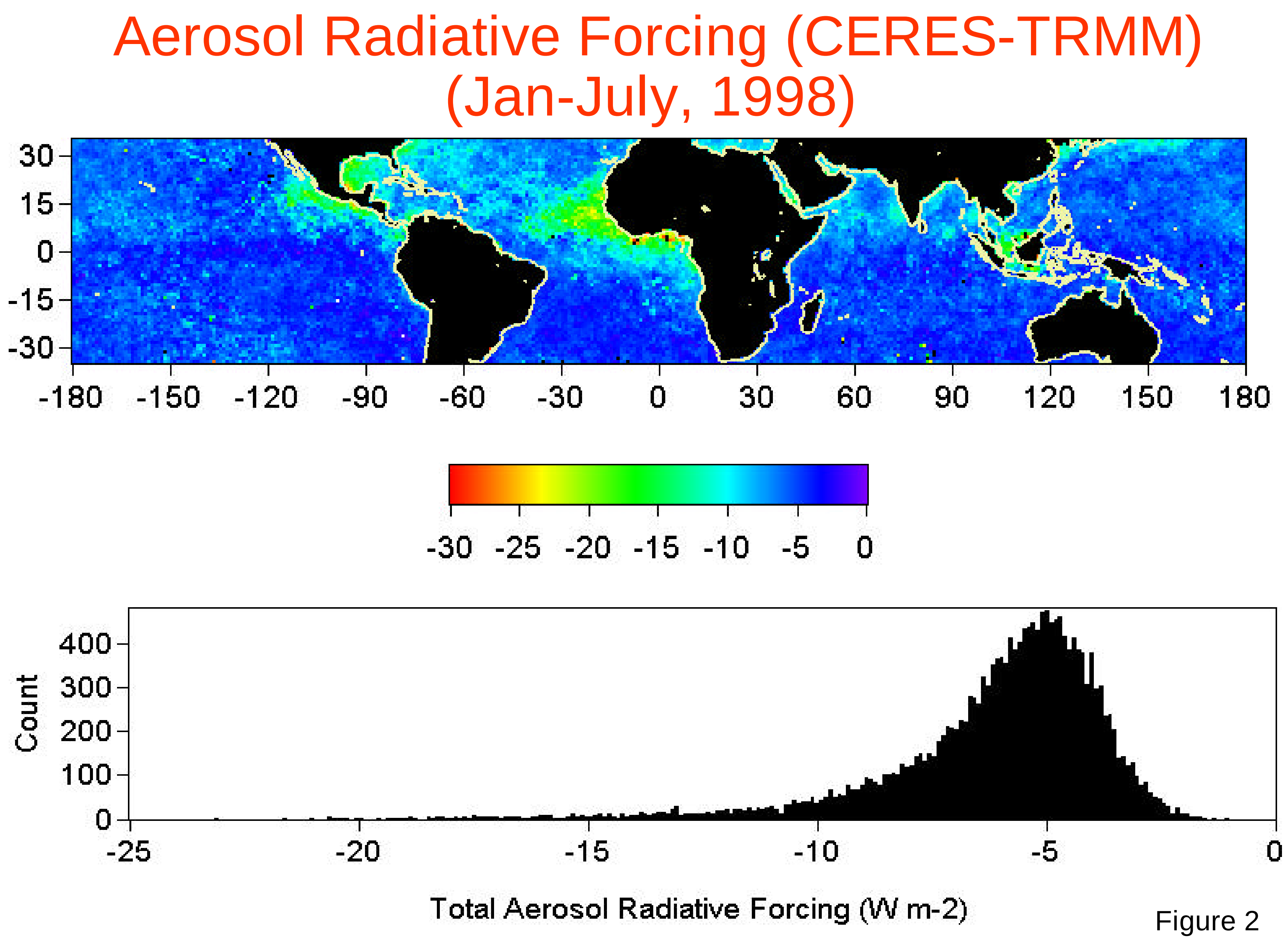


Figure 1



Aerosol Radiative Forcing (CERES-TRMM)
(Jan-July, 1998)
30
15
0
-15
-30
-180 -150 -120 -90 -60 -30 0 30 60 90 120 150 180
-30 -25 -20 -15 -10 -5 0
400
300
200
100
0
Count
-25 -20 -15 -10 -5 0
Total Aerosol Radiative Forcing (W m-2)

Figure 2

Aerosol Radiative Forcing: ERBS (Jan-Aug, 1985)

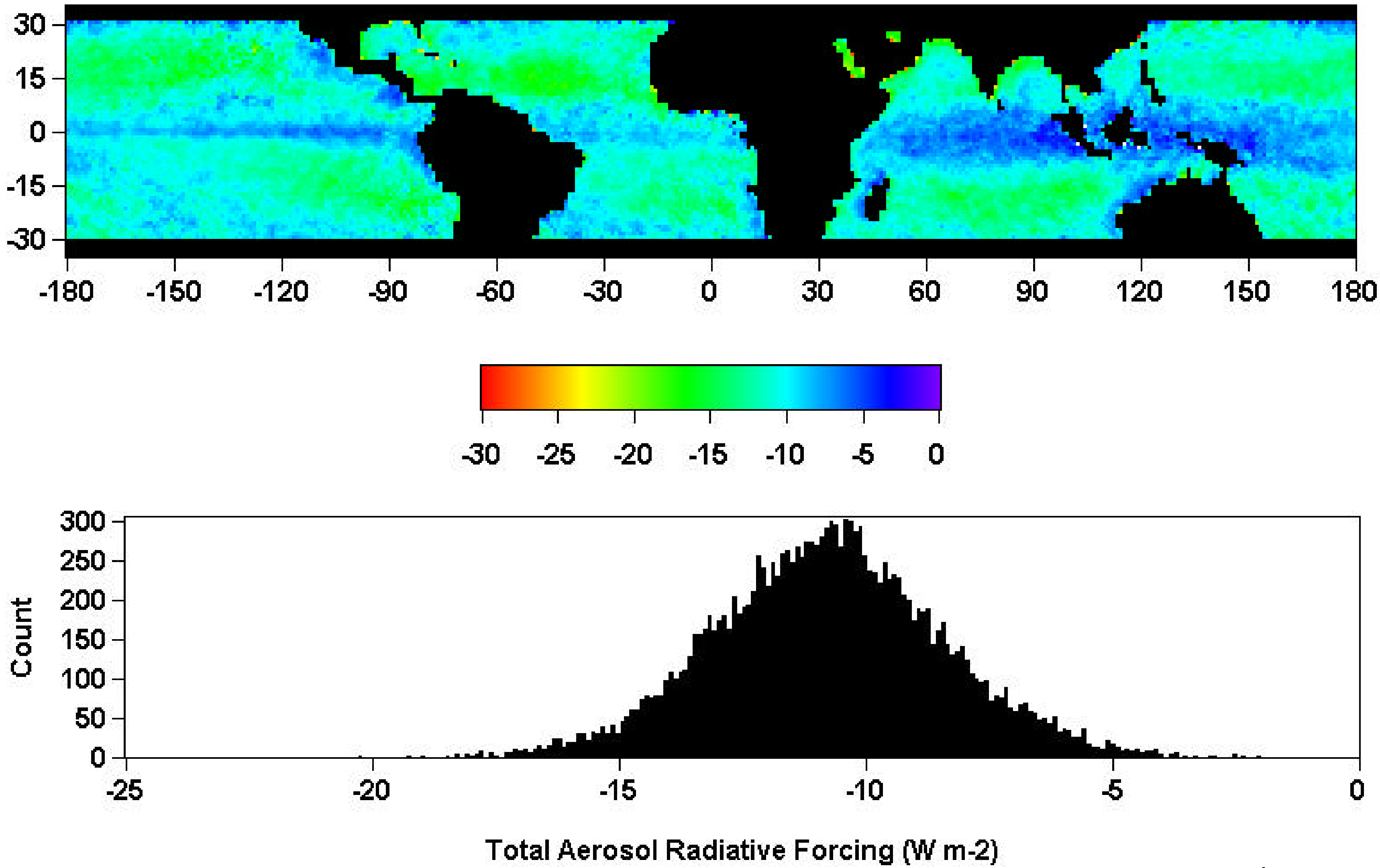


Figure 3

Sensitivity to Cloud Contamination: CERES & VIRS

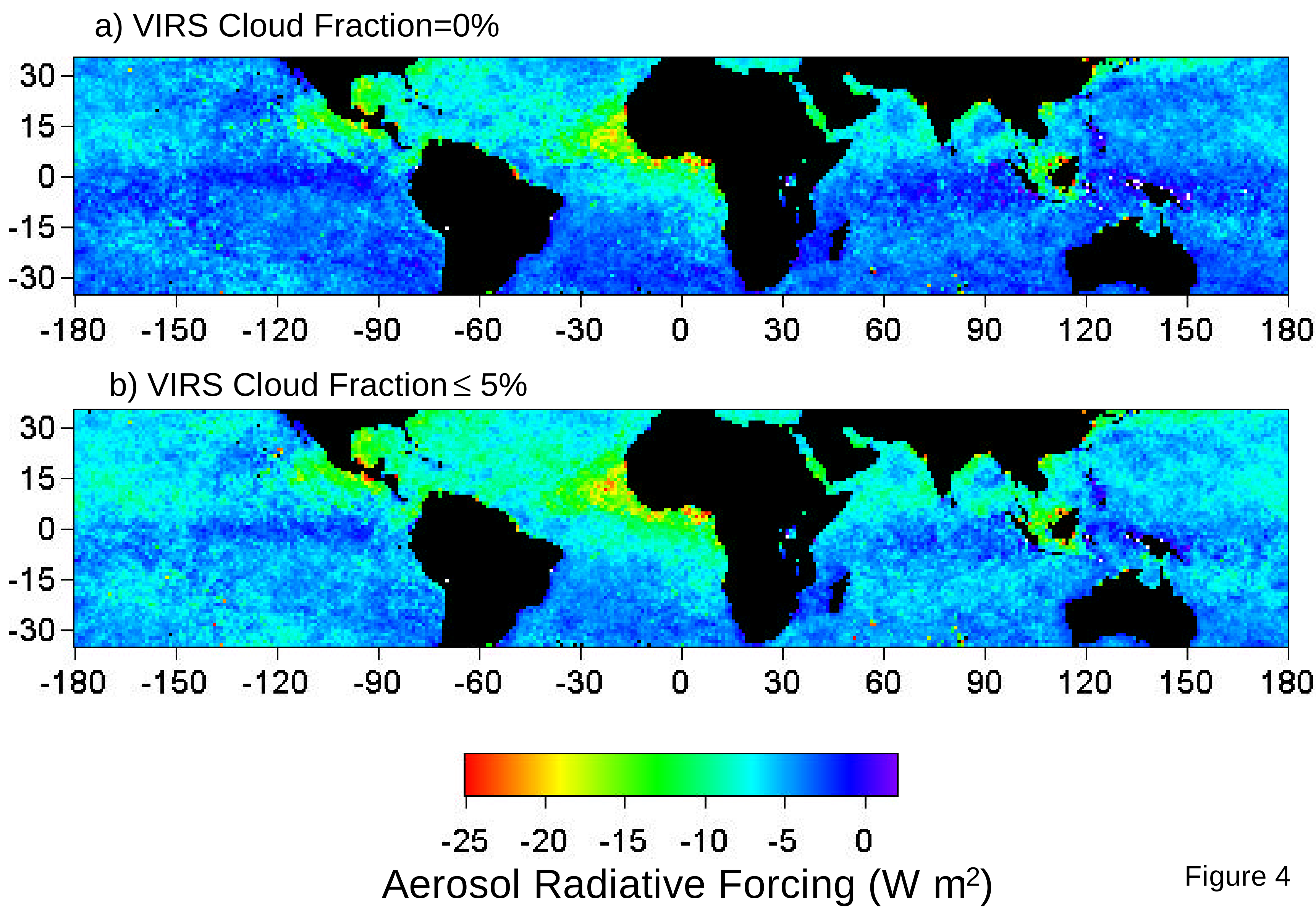


Figure 4