Dust Aerosol Radiative Effects from Terra and Aqua

Thomas A. Jones*,
Sundar A. Christopher,
Jianglong Zhang,
Lorraine Remer

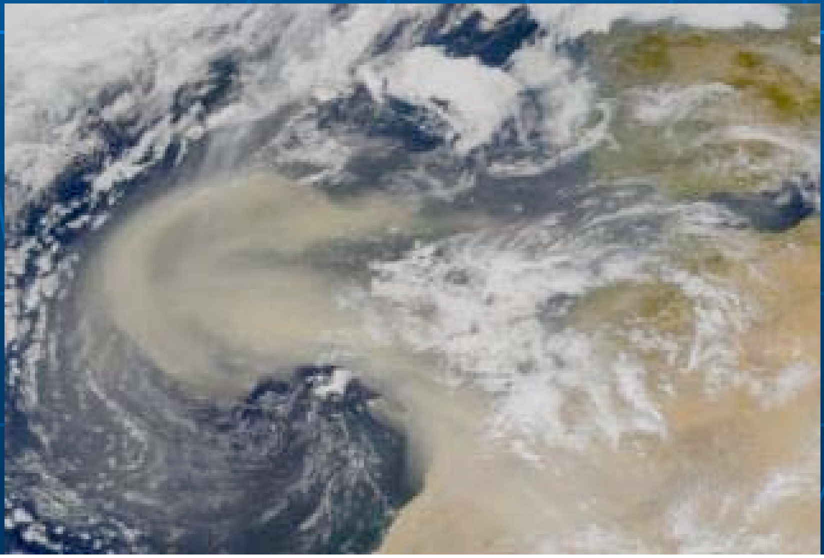
October 31, 2006

Outline

- Why are dust aerosols important?
- Goals of this research
- Data
- Assumptions
- Separation of AOT components
- Dust Radiative Effect
- Terra vs. Aqua differences
- Continuing Research

Importance of Dust Aerosols

- Naturally occurring dust aerosols are major contributors to the Earth-atmosphere system
  - Annual dust aerosol emissions range from 1000-3000 Tg
- Dust aerosols generally originate over desert regions such as the Sahara
  - Atmospheric transport allows dust to spread far away from its source regions
  - Uncertainty exists as to the contribution of land use change and anthropogenic aerosols to overall dust loading.



Effect of Dust Aerosols

- Over open oceans, dust aerosols increase reflectivity, reducing incoming TOA solar (shortwave) flux
  - A cooling effect
- Dust aerosols also absorb and emit outgoing longwave flux, but emit at colder temperatures than the background ocean
  - A warming effect
- Previous research indicates that SW cooling generally exceeds LW warming, but the magnitude of the LW effect is largely unknown

Goals

- Use satellite observations of aerosol optical thickness (AOT) and fine mode fraction (FMF) to determine the proportion of AOT due to dust aerosols
- Use satellite-derived TOA incoming SW and outgoing LW fluxes to determine the effect of dust AOT on the energy budget
- Compare SW and LW effects to produce a net dust radiative effect
  - Does LW warming significantly offset SW cooling?
- Since the greatest concentration of dust aerosols occurs over the Atlantic ocean, west of Africa, this research was initially restricted to that domain.

Data

- CERES Single Satellite Footprint (SSF)
  - Terra FM1, Edition 2B data files
  - CERES reports SW and LW TOA radiance at a ~20 km resolution which are converted to fluxes using ADMs (Zhang et al. 2005a)
  - Data collected for June, July, and August between 2000 and 2005
  - Spatial domain limited to tropical Atlantic (10-60°W, 0-30°N)
- MODIS
  - Reports aerosol optical thickness at 0.55 μm
  - Combined with CERES footprint data using a point spread function
    - Raw MODIS AOT available at higher resolution

Assumptions

- Only over-ocean data considered.
  - Pixels over land or near coast are removed
- Only clear-sky pixels considered
  - MODIS Cloud Fraction < 1.0 %
  - CERES Clear sky percent > 99.0 %
  - Removes ~95% of total data
- Dust Radiative Effect statistics calculated from only data where dust AOT is > 0
  - Dust AOT only valid where $0.3 \leq$ FMF ≤ 0.9

Separation of AOT

- We use Kaufman et al. (2005) technique to separate observed AOT into maritime, anthropogenic, and dust components
  - Simple mathematical function
- Separates AOT components using assumed FMF characteristics of each
  - $F_{mari} = 0.3$, $F_{dust} = 0.5$, $F_{anth} = 0.9$
- Assumes maritime optical thickness is a function of surface wind speed

$$\tau_{ma} = 0.007W + 0.02$$

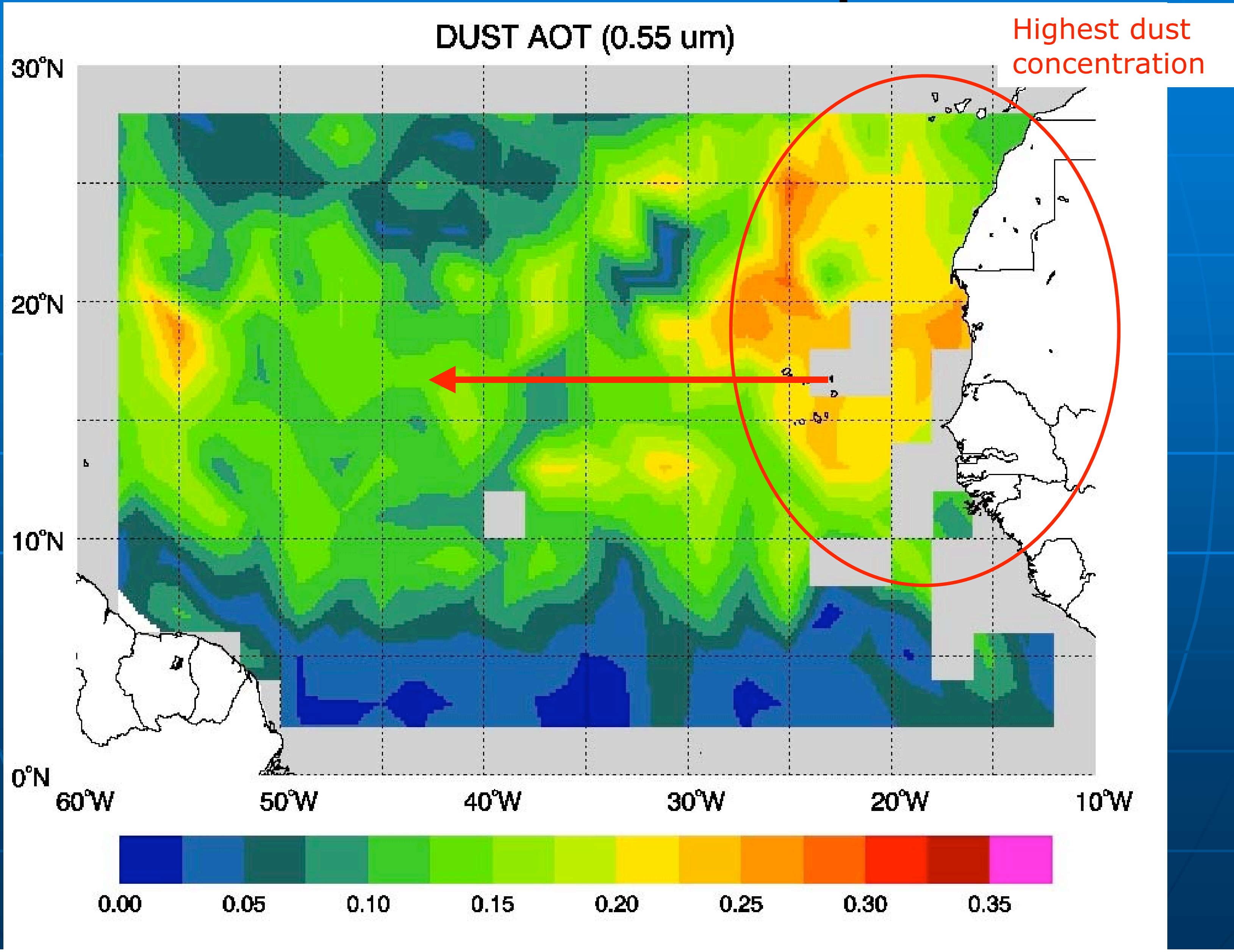
Separation of AOT

- Kaufman et al. Dust AOT Equation:

$$\tau_{du} = [\tau_{0.55}(f_{an} - f) - \tau_{ma}(f_{an} - f_{ma})]/(f_{an} - f_{du})$$

- Uncertainties and limitations:
  - Observed FMF bounded between 0.5 and 0.9
  - For low observed AOT, this equation can return a negative value for dust AOT
    - Dust AOT set equal to 0 in this case
  - Kaufman et al. estimates a 15% uncertainty in component AOT using this technique
    - Has a downstream effect on component radiative effect uncertainty

Dust AOT Map



DUST AOT (0.55 um)
Highest dust concentration
30°N
20°N
10°N
0°N
60°W
50°W
40°W
30°W
20°W
10°W
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35

Calculating Radiative Effect of Dust Aerosols

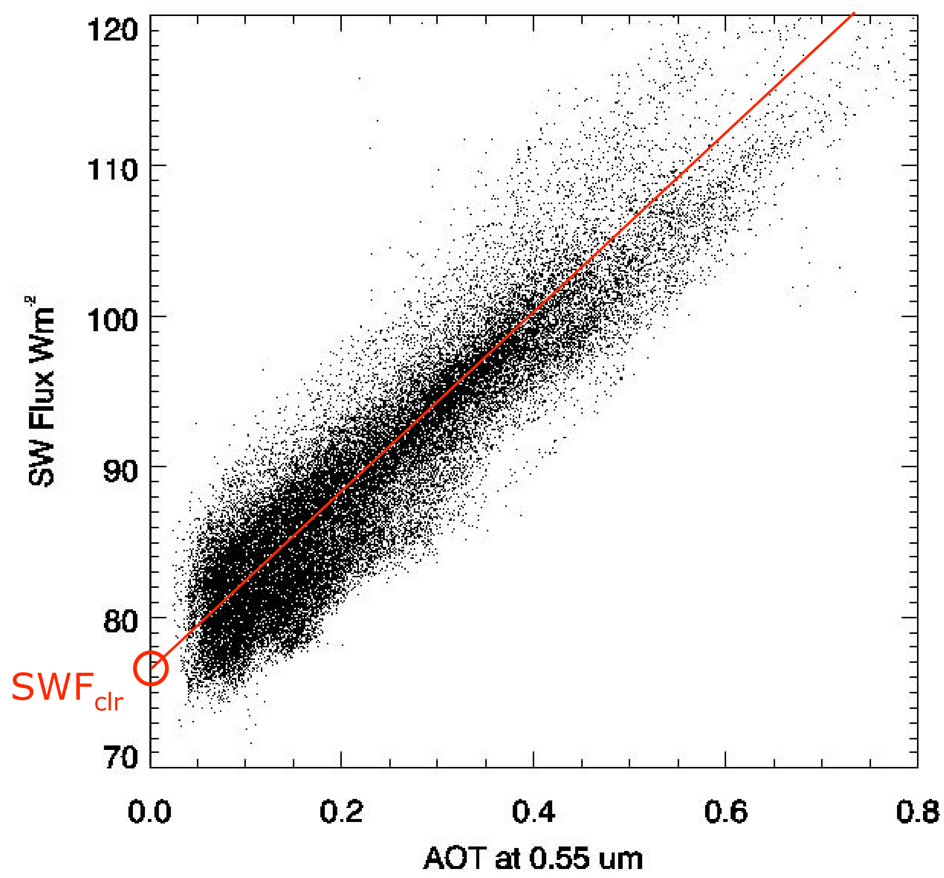
- Dust Radiative Effect is calculated by subtracting SW and LW fluxes containing aerosols (F_{aero}) from a clear-sky, aerosol-free background (F_{clr})
  - This difference is then scaled by the ratio of dust AOT to total AOT to derive the component of forcing from dust

$$DRE = \frac{\tau_{du}}{(\tau_{0.55} - \tau_{ma})} \times (F_{clr} - F_{aero})$$

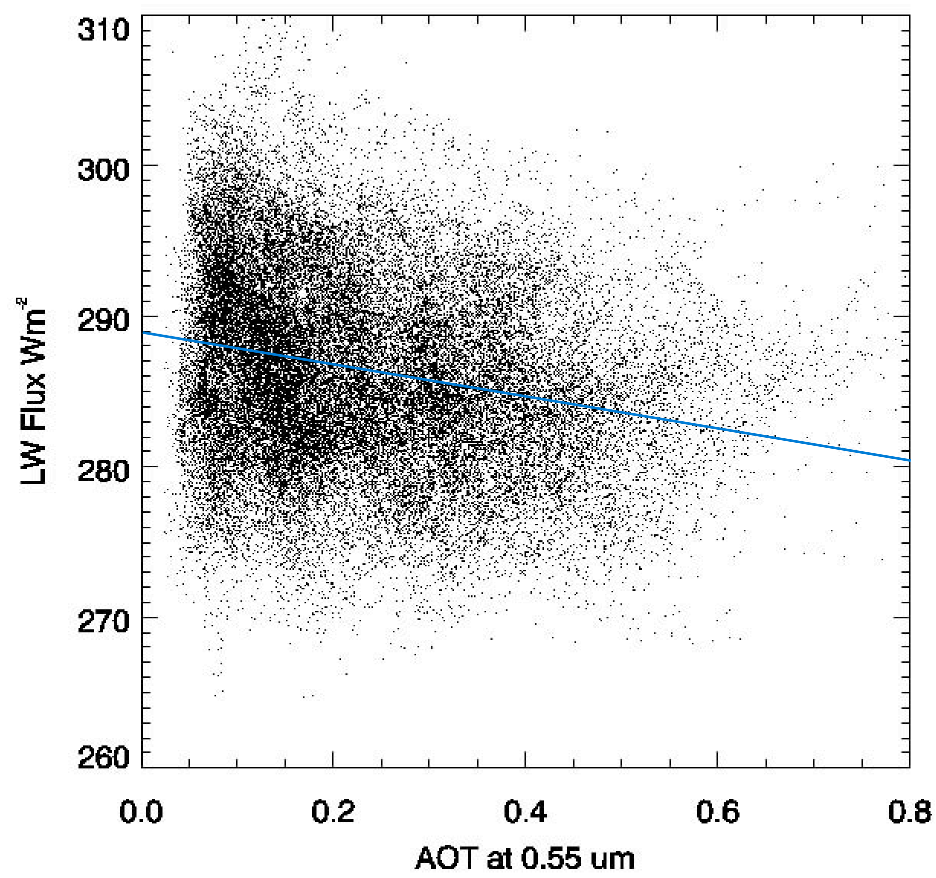
- The clear-sky, aerosol free background is derived by relating pixels where AOT < 0.2 to SW flux and deriving what the AOT=0 flux value should be.
  - No adjustment for LW (Use AOT < 0.1)

AOT-Flux relationship

Shortwave



Longwave



Diurnal and Sample-Bias Adjustments

- Instantaneous radiative effect numbers do not tell the whole story
- Terra only observes AOT and flux at ~10:30 local time
  - Diurnal variability not sampled
  - Use "diurnal adjustment" functions developed by Remer and Kaufman (2005)
  - Diurnal effect ≈ instantaneous effect ÷ 2.0
- The CERES footprint is much larger than the MODIS footprint
  - Due to clear-sky assumption, DRE is biased toward clear-sky regions
  - AOT from the MOD08 data set were used to derive MODIS-only dust AOT, which is higher than the CERES-footprint dust AOT
  - This difference (0.045) is used to adjust DRE upward

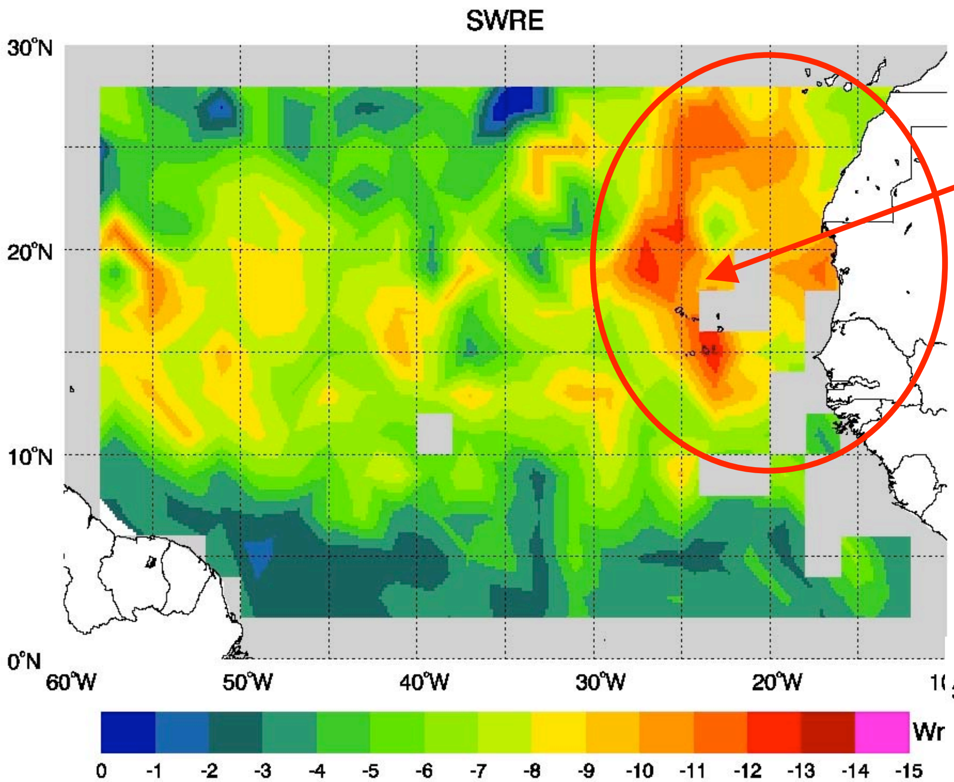
Statistics Table

Radiative effect values include diurnal and sample bias adjustments.

CERES AOT	0.23
DUST AOT	0.15
SWRE (Wm^{-2})	-7.36
LWRE (Wm^{-2})	0.89
NRE (Wm^{-2})	-6.47
CLOUD FRACTION	0.57
Li et al. (2004)	-12.6
Loeb et al. (2005)	-5.99

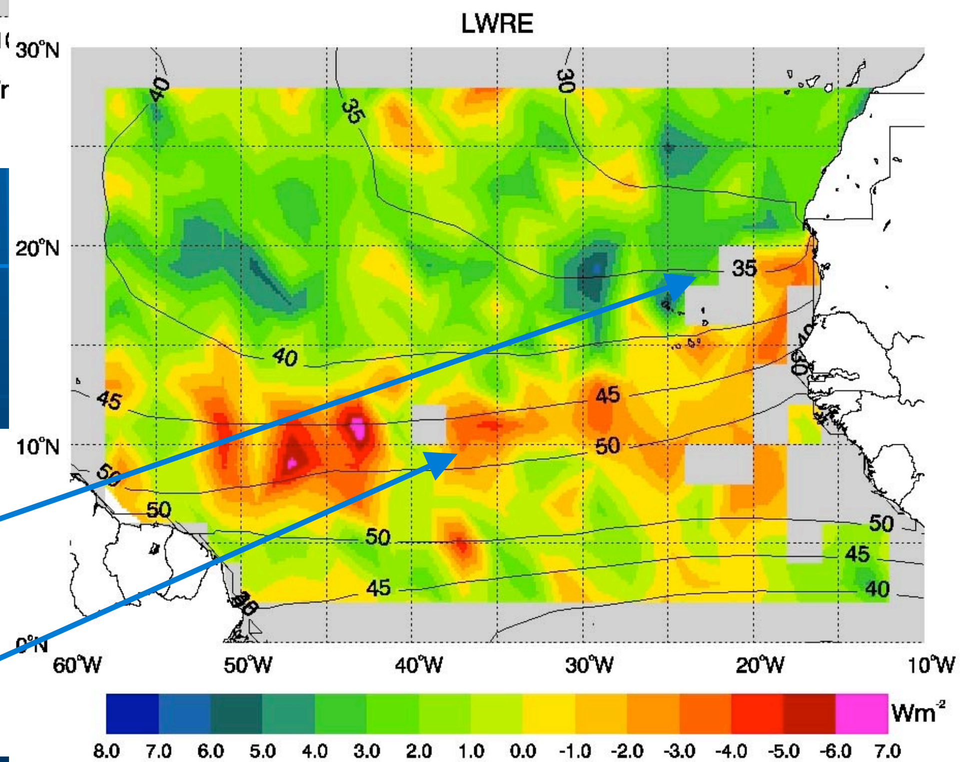
Uncertainty is ~20%

Spatial and temporal domains are not an exact match.



Adjusted SWRE:

Maximum cooling corresponds to location of highest dust aerosol concentration

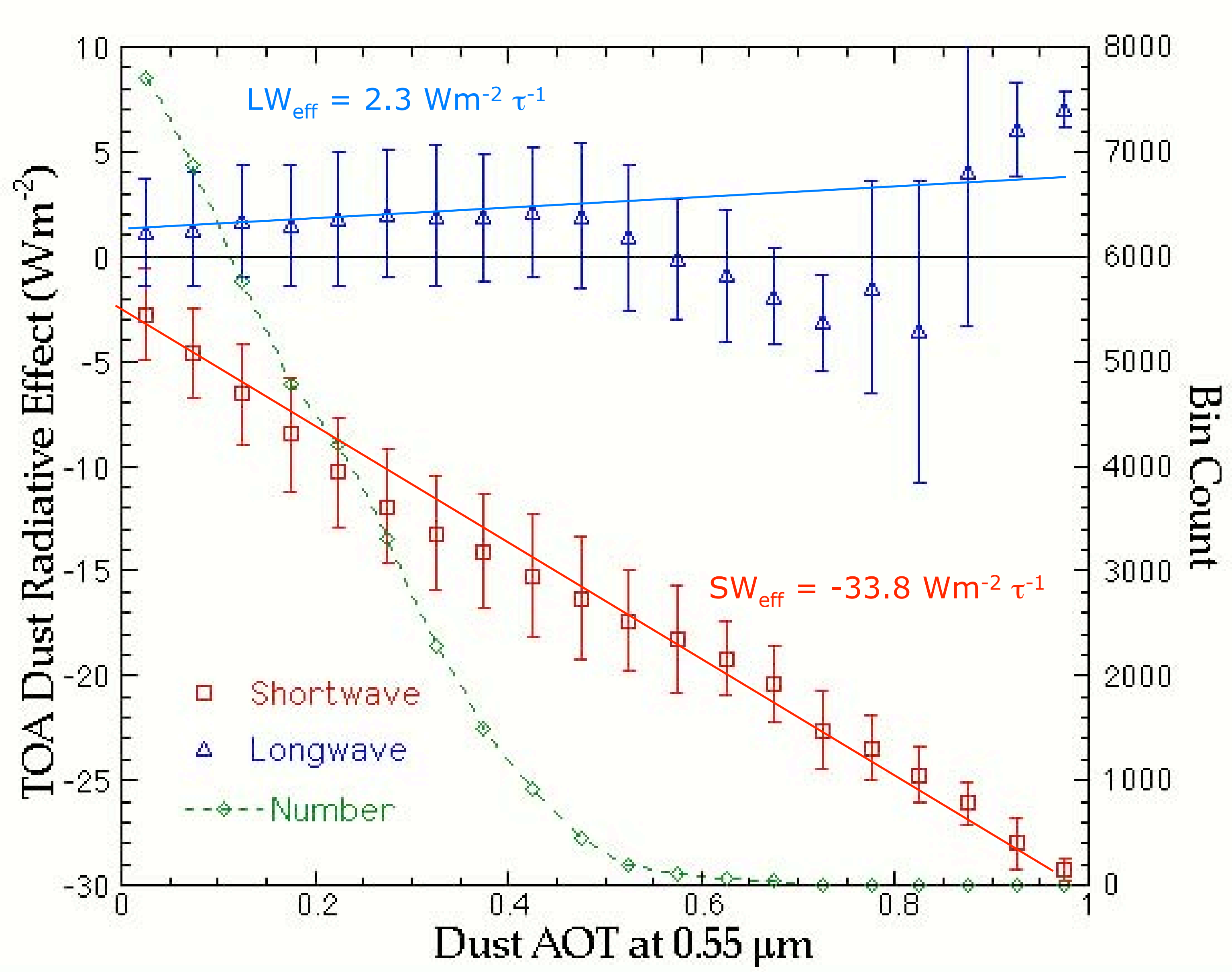


Adjusted LWRE:

Correlation with AOT concentration much less

Cooling along ITCZ

DRE as a Function of Dust AOT



Conclusions

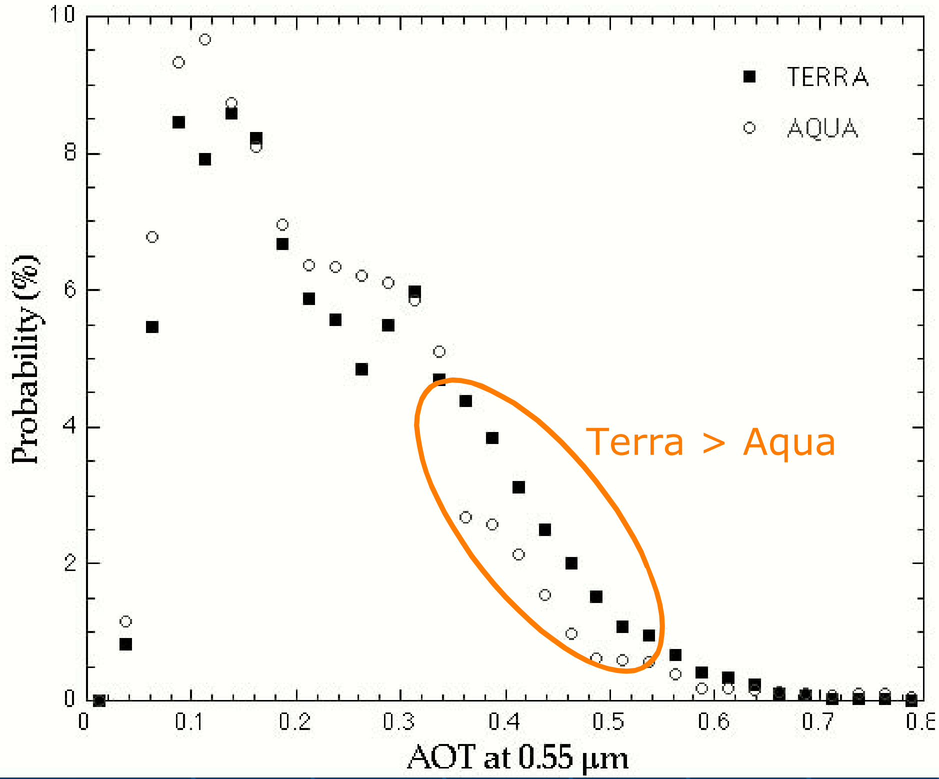
- Dust aerosols have a measurable impact on both SW and LW fluxes
  - For this region, almost all NRE can be attributed to dust aerosols
- The LW warming offsets SW cooling by approximately 15%
  - A significant number
- Provides framework for global analysis

Terra vs. Aqua DRE

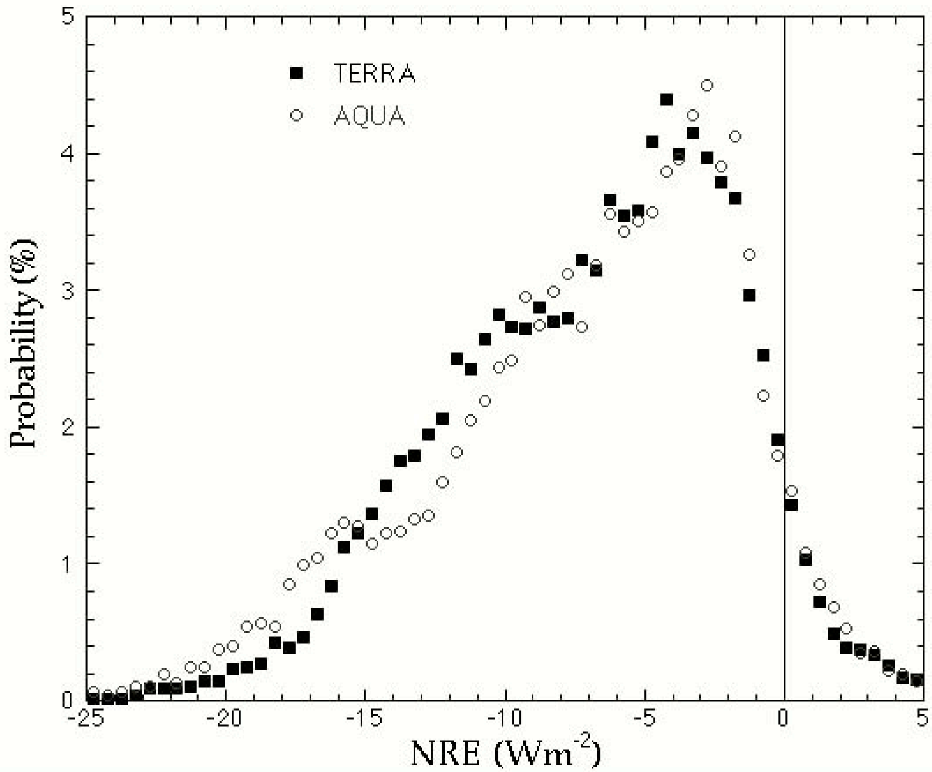
- CERES SSF data from Terra and Aqua satellites were compared to examine the effect of different overpass times on AOT and DRE measurements
  - 2003-2005, June, July, and August
  - FM1 and FM3 instruments used
  - Same Atlantic ocean domain as before
  - Aqua satellite overpass time is approximately 3 hours after Terra (13:30 vs. 10:30 local time)

AOT histogram

Aerosol Optical Thickness

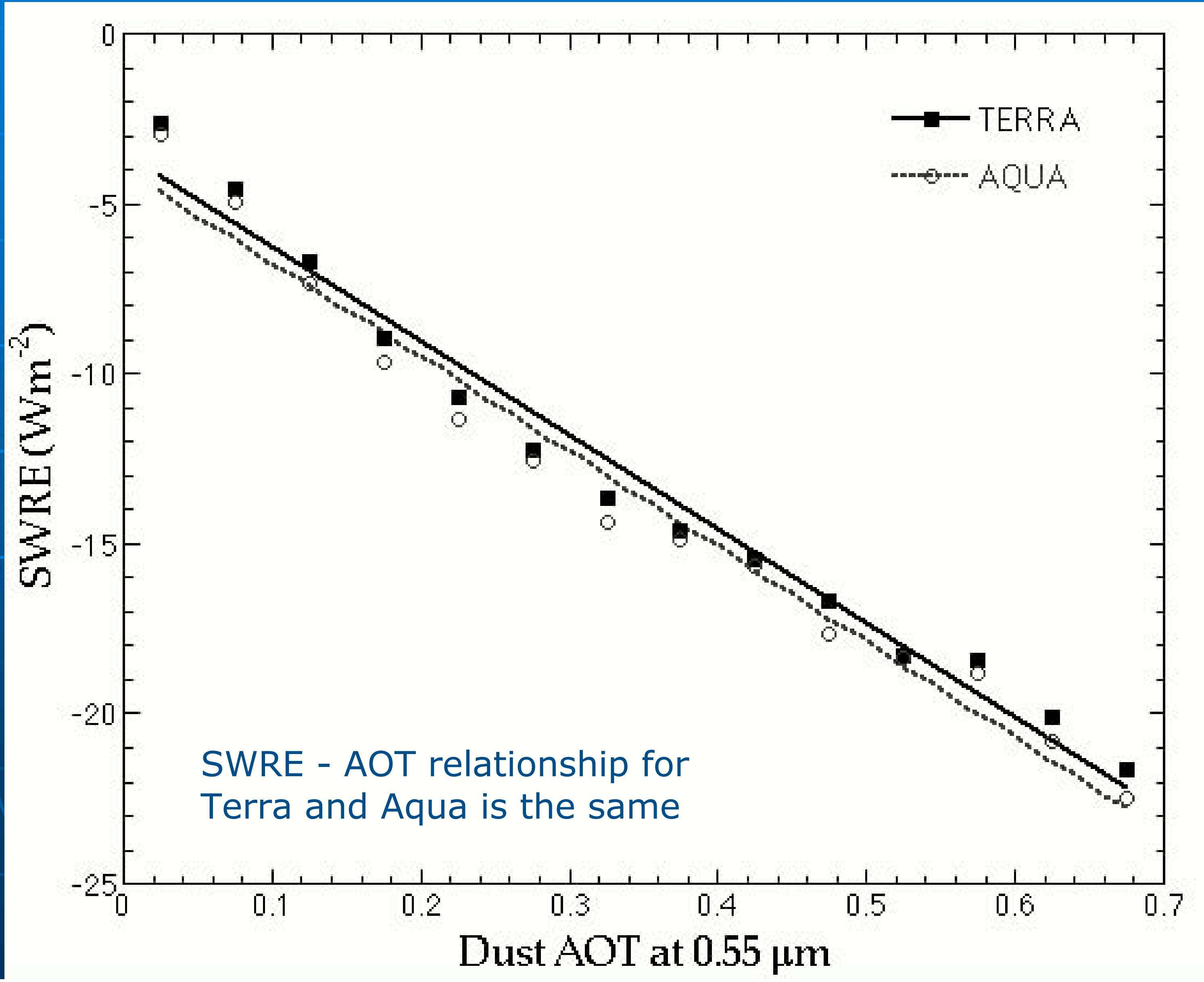


Adjusted NET
Dust Radiative Effect

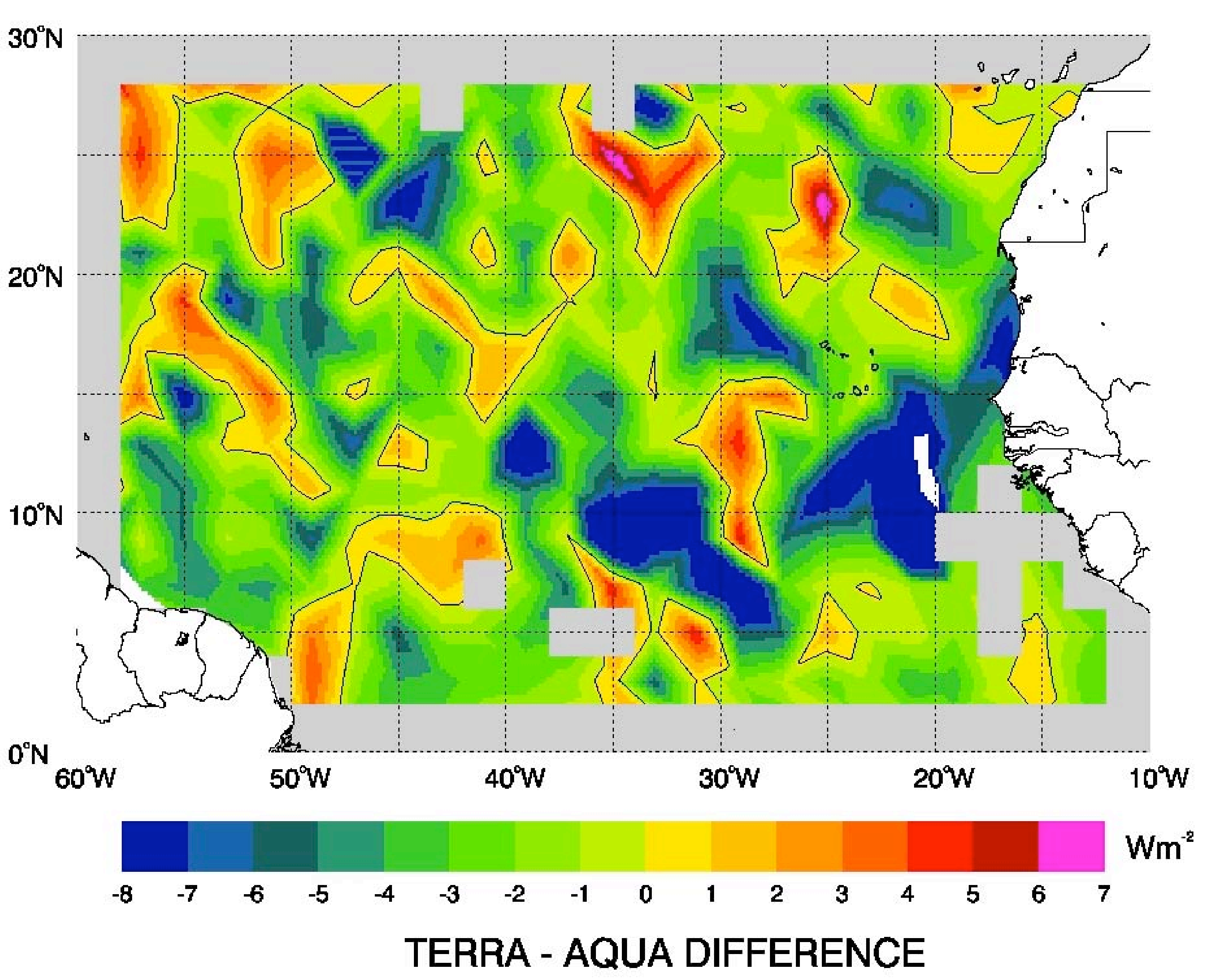


	Terra	Aqua
AOT	0.24	0.22
NRE	-6.90	-7.00

SWRE vs. Dust AOT



Terra – Aqua Net Radiative Effect



Terra-Aqua Conclusions

- Terra AOT are slightly higher than corresponding Aqua AOT throughout this domain
  - Differences are small and randomly distributed
- Differences in adjusted net dust radiative effect are small.
  - AOT-SWRE relationship is the same
  - Sample bias adjustment is larger for Aqua

Ongoing Research

- Global Dust
  - Use 2000-2001 CERES SSF data for global determination of dust radiation effect
  - Also study sensitivity of FMF thresholds on component radiative effect results
- Averaging
  - Performing an analysis of the statistical properties and assumptions inherent reported DRE values.

References

- T.A. Jones and **S.A. Christopher**, Is the top of atmosphere Dust Net Radiative Different Between Terra and Aqua?, Geophysical Research Letters, **submitted, September, 2006**

- **Christopher, S.A.** and T. Jones, Satellite-based Assessment of Cloud-free Net Radiative Effect of Dust Aerosols over the Atlantic Ocean, Geophysical Research Letters,- **revised** September 11, 2006 - 2006GL027783R

- **Christopher, S. A**., J. Zhang, Y. J. Kaufman, and L. A. Remer (2006), Satellite-based assessment of top of atmosphere anthropogenic aerosol radiative forcing over cloud-free oceans, Geophys. Res. Lett., 33, L15816, doi:10.1029/2005GL025535.

- H. Yu, Y. J. Kaufman, M. Chin, G. Feingold, L. A. Remer, T. L. Anderson, Y. Balkanski, N. Bellouin, O. Boucher, **S. A. Christopher**, P. DeCola, R. Kahn, D. Koch, N. Loeb, M. S. Reddy, M. Schulz, T. Takemura, M. Zhou, A review of measurement-based assessment of aerosol direct radiative effect and forcing, Atmos. Chem. Phys. 6, 613-666, 2006.

- Zhang, J., **S.A. Christopher**, L.A. Remer and Y.J. Kaufman, Shortwave Aerosol Cloud-Free Radiative Forcing from Terra, I: Angular Models for Aerosols, Journal of Geophysical Research -Atmospheres, D10, S23, doi:10.1029/2004jd005008, 2005.

- Zhang, J., **S.A. Christopher**, L.A. Remer and Y.J. Kaufman, Shortwave Aerosol Cloud-Free Radiative Forcing from Terra, II: Global and Seasonal Distributions Journal of Geophysical Research -Atmospheres, D10, S24, doi:10.1029/2004jd005009, 2005.

- Anderson, T.L., R.J., Charlson, N. Bellouin, O. Boucher, M. Chin, **S.A. Christopher**, H.J. Haywood, Y.J. Kaufman, S. Kinne, J. Ogren, L.A. Remer, T. Takemura, D. Tanre, O. Torres, C.R.Trepte, B.A. Wielicki, D. Winker, H. Yu, A-Train strategy for quantifying direct aerosol forcing of climate: Step-wise development of an observational basis for aerosol optical depth, aerosol forcing efficiency, and aerosol anthropogenic fraction, Bulletin of the American Meteorological Society, 2005, 1795-1809.

- **Christopher, S. A**., and J. Zhang (2004), Cloud-free shortwave aerosol radiative effect over oceans: Strategies for identifying anthropogenic forcing from Terra satellite measurements, Geophysical Research Letters, 31, L18101, doi:10.1029/2004GL020510.

Questions

The End

- Who am I, and why am I here?