Regional aerosol trends and potential impacts on clouds in the western North Atlantic Ocean

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Introduction and Background

The presence of and changes in the aerosol loading has the direct effect of altering the radiative balance and indirect effect of modifying cloud properties via complex feedbacks (Rosenfeld et al., 2008; Li et al., 2011). Changes in emissions, air quality policies, and socioeconomic factors can ultimately lead to changes in aerosols (e.g. Lin et al., 2013), with cascading effects on clouds and the combined radiative effects. Recent studies have demonstrated a negative trend in the aerosol optical depth (AOD) over the Eastern U.S. and the North Atlantic Ocean (Hsu et al., 2012; Zhao et al., 2008). Occurring concurrently were substantial reductions in anthropogenic emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx; Xing et al., 2013).. Past studies have established a strong correlation between satellite-retrieved AOD and ground-based PM2.5 (particulate matter with aerodynamic diameter < 2.5 µm) observations (Alston et al., 2012).

This study investigates any anthropogenic contribution to the observed aerosol trend and its influence on the direct and indirect effects . We show connections between trends in aerosol loading and in the aerosol SW direct radiative forcing (DRF) and examine the validity of the aerosol first indirect effect (Twomey effect).

Data and Methods

The focus of this work is the western North Atlantic Ocean (-80 < lonE < -30; 20 < latN < 50) from 2000 to 2012. Monthly mean observational data from NASA's MODIS instruments are employed; we specifically investigate the average AOD over ocean and cloud effective radius. The GOCART aerosol model is capable of modeling five individual aerosol species (dust, sulfate, sea-salt, black carbon, and organic carbon) and is used to distinguish anthropogenic from natural contributions to the total aerosol load and trend. Additional evidence for any satellite-observed aerosol trend over the western North Atlantic Ocean is provided by ground-based observations from AERONET and the EPA in 5 Mid-Atlantic States. The trend analysis used here is similar to that of other aerosol trend studies (Hsu et al., 2012; Zhao et al., 2008; Weatherhead et al., 1998).

Conclusions

- There exists a negative AOD trend over much of the northern portion of the domain while a positive AOD trend is reported for the southern portion.
- Using ground observations as evidence, we propose the hypothesis that the observed negative AOD trend is of anthropogenic origin
- GOCART is used to confirm this hypothesis: the negative AOD trend calculated from sulfate matches well spatially to the AOD trend observed from satellite. It is also the only species with significant negative trend in the region.
- GOCART also demonstrates that the positive trend seen from satellites arises from an increase in dust
- SBDART calculations demonstrate the aerosol direct effect: A "cleaning" atmosphere provides less scatterers, reducing the aerosol SW DRF at the TOA and increasing the aerosol SW DRF at the surface. Regions that show positive AOD trend (south of domain) show consistent and opposite results.
- Consistent with Twomey theory, we show the impact of aerosol indirect effects on aerosol-cloud interactions: regions of decreasing AOD demonstrate an increase in the cloud effective radius (Twomey, 1974).

Results

Figure 1 shows the trend analysis of the AOD observed from MODIS over the western North Atlantic Ocean from 2000 to 2012. Two distinct regions with significant trends of opposite sign (magnitude approximately 0.015 to 0.040 per decade) are seen in the western North Atlantic Ocean. Values of the absolute trend, mean value, and relative trend for the GSFC AOD record as well as CEMS SO2 and NOx emissions records for the 5 states are given in Table 1.

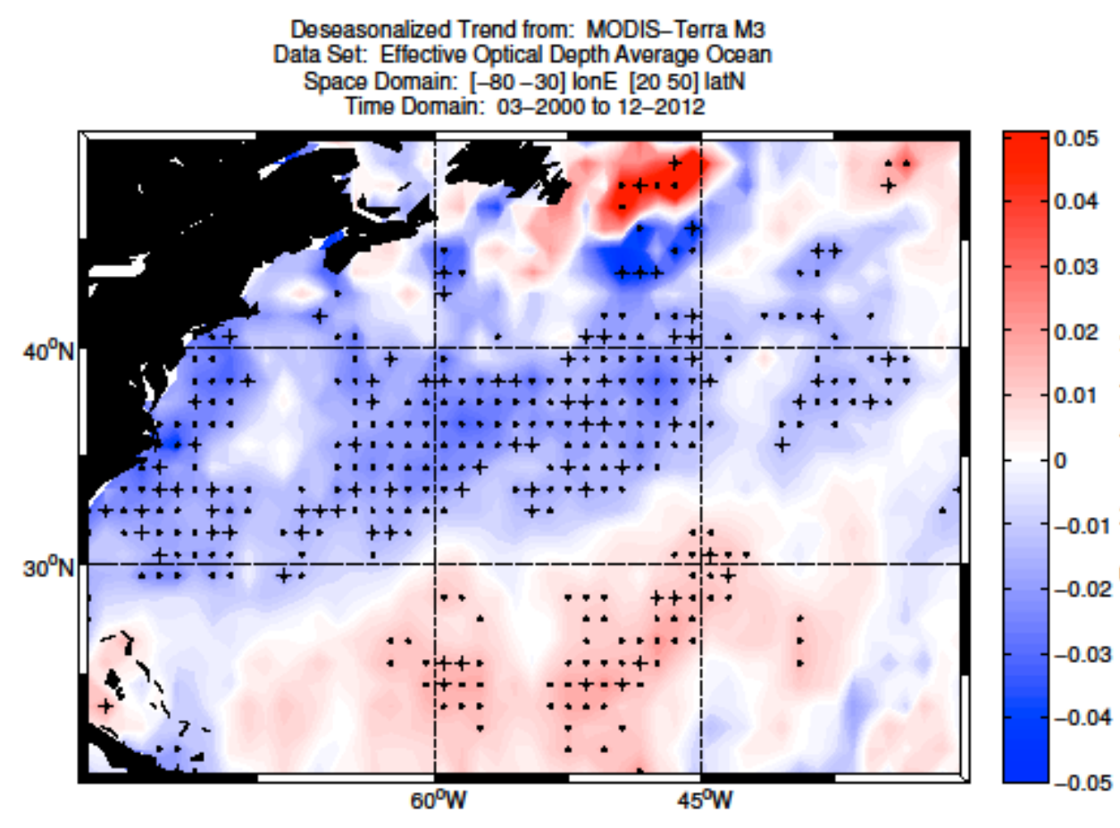

Figure 1: Deseasonalized AOD at 550nm trends from MODIS-Terra over the western North Atlantic Ocean during 03-2000 to 12-2012. Dots and crosses represent statistically significant trends at the 90% and 95% levels, respectively. AOD trends are per decade.

Table 1: Deseasonalized SO2 and NOx emission trends (top), mean emission in 10^3 tons (middle), and relative trend (bottom) from CEMS emissions records from 5 Mid-Atlantic States of the U.S. during 01-2000 to 12-2012. All trends are in 10^3 tons/decade. Mean emission in 10^3 tons. All trends are significant at the 95% level. *GSFC values reported are for AOD.

	MD	VA	WV	OH	PA	GSFC*
SO2	-21.01 21.14 -99.39	-16.55 16.25 -101.87	-46.28 37.21 -124.40	-72.95 91.70 -79.55	-59.09 79.77 -74.07	-0.0552 0.200 -27.49
NOx	-6.16 5.38 -114.38	-4.87 14.78 -127.86	-18.90 14.78 -127.86	-27.21 24.54 -110.89	-8.23 18.54 -44.42	

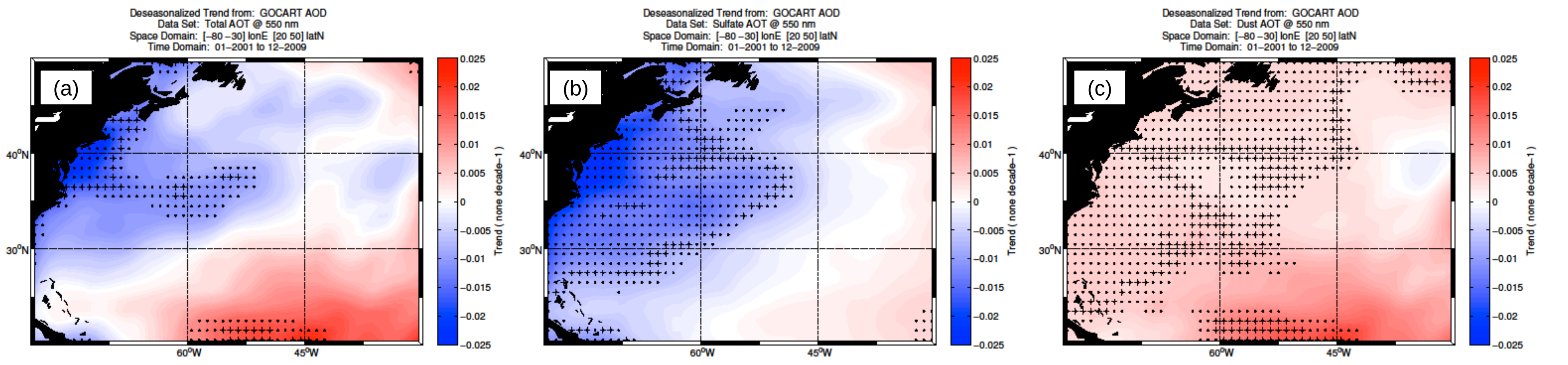

Figure 2: Deseasonalized AOD trends from GOCART for the North Atlantic during 01-2001 to 12-2009: (a) TOT, (b) SU, and (c) DU. Dots and crosses represent trends significant at the 90% and 95% level, respectively. All trends are per decade.

Figure 2 shows the deseasonalized AOD trends calculated from the total (TOT), sulfate (SU), and dust (DU) components from 2001 to 2009.

Figure 3 shows trends in the aerosol SW DRF for top-of-atmosphere (TOA) outgoing, surface downward, Earth-system absorbance, and atmospheric absorbance for the western North Atlantic Ocean from 2000 to 2012 as calculated with SBDART.

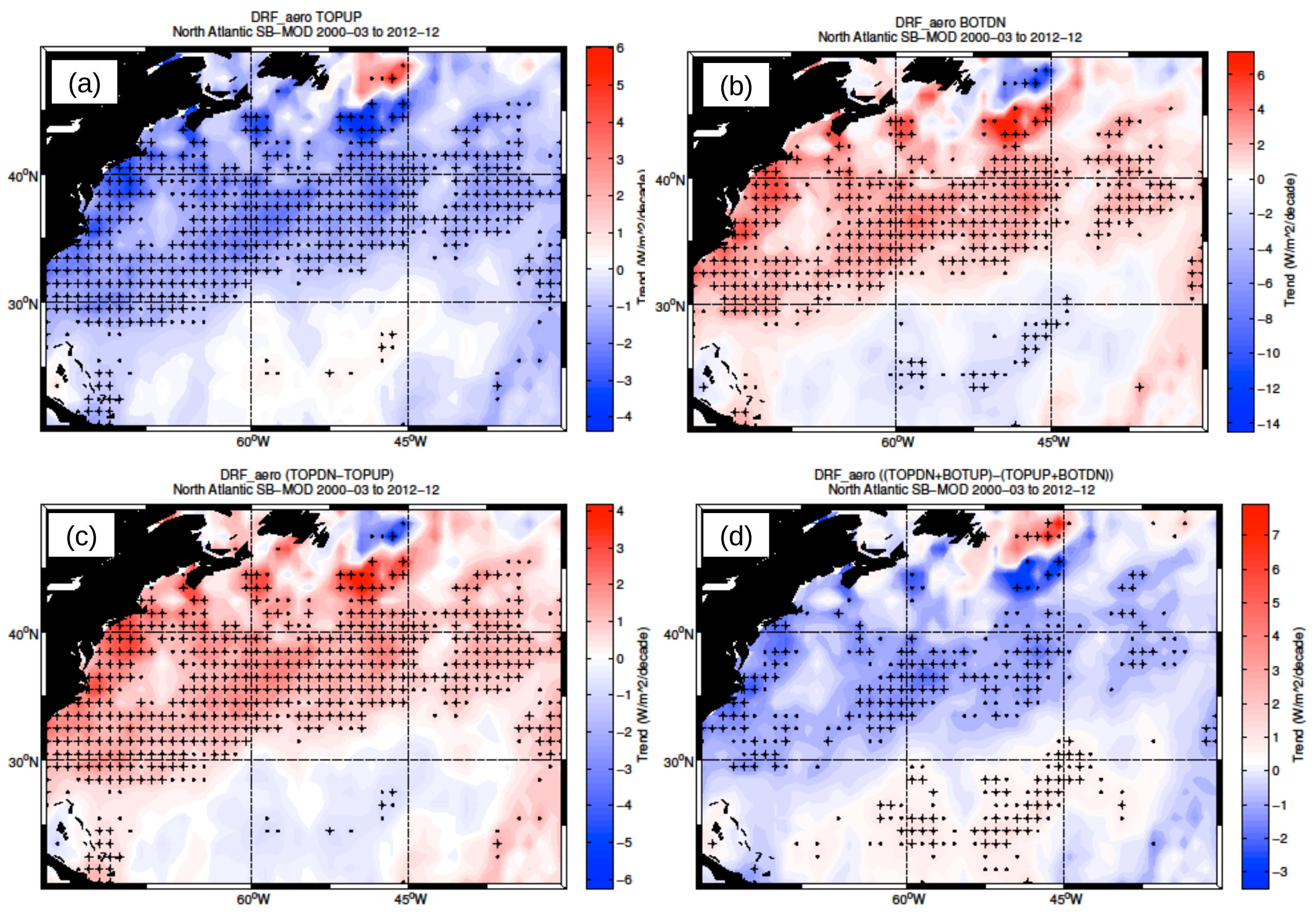

Figure 3: Trends in the calculated aerosol SW DRF from SBDART for (a) TOA outgoing, (b) surface downward, (c) Earth-system absorbance, and (d) atmospheric absorbance. Dots and crosses represent trends significant at the 90% and 95% level, respectively. All trends are in W/m2/decade.

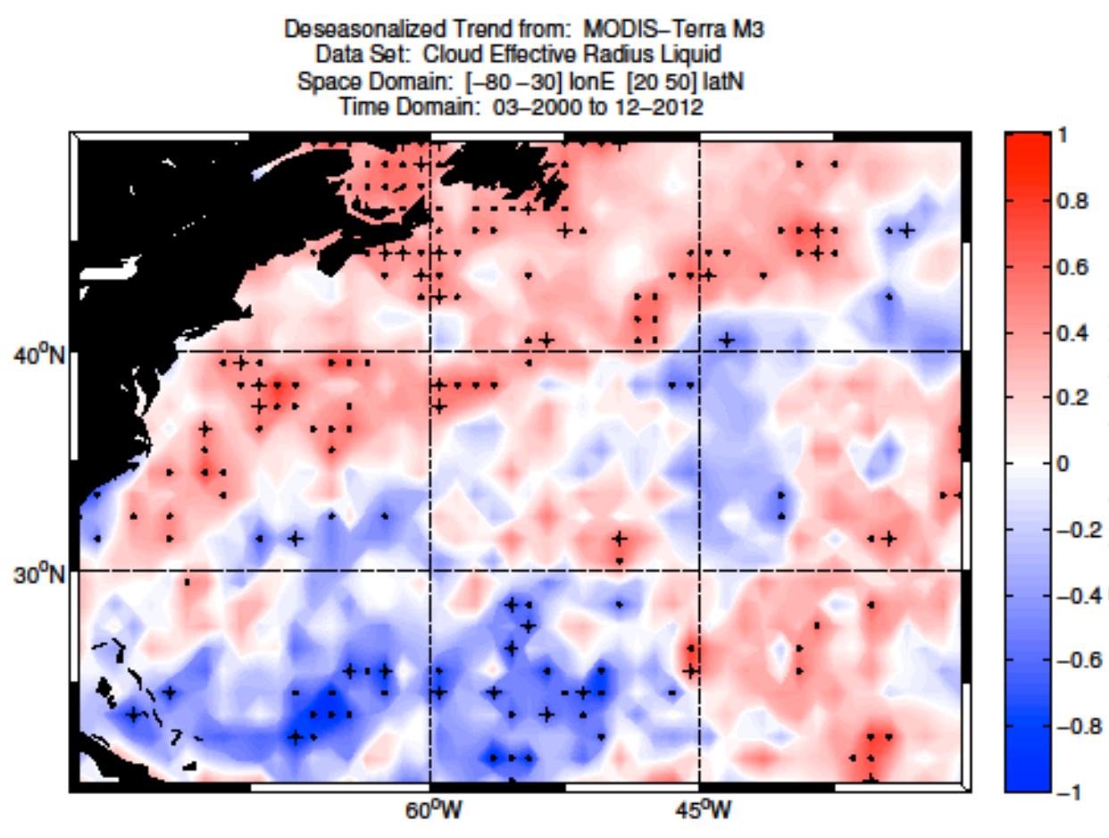

Figure 4: Same as Figure 1 except for cloud effective radius. Dots and crosses represent trends significant at the 90% and 95% level, respectively. Trends are in µm per decade.

Figure 4 shows the deseasonalized trend calculated for the satellite-observed cloud effective radius from MODIS for the western North Atlantic Ocean from 2000 to 2012.

References

Alston, E.J. et al. 2012. Characterization of atmospheric aerosol in the US Southeast from ground- and space-based measurements over the past decade. Atmospheric Measurement Techniques. Vol. 5. Pp. 1667-1682.

Hsu, N.C. et al. 2012. Global and regional trends of aerosol optical depth over land and ocean using SeaWiFS measurements from 1997 to 2012. Atmospheric Chemistry and Physics. Vol. 12. Pp. 8037-8053.

Li, Z. et al. 2011. Long-term impacts of aerosols on the vertical development of clouds and precipitation. Nature Geoscience. Doi: 10.1038/NGEO1313.

Lin, J-.T. et al. 2013. Trend and interannual variability of Chinese air pollution since 2000 in association with socioeconomic development: a brief overview. Atmospheric and Oceanic Science Letters. Vol. 6. Pp. 84-89.

Rosenfeld, D. et al. 2008. Flood or drought: how do aerosols affect precipitation? Science. Vol. 321. Pp. 1309-1313.

Twomey, S. 1974. Pollution and the planetary albedo. Atmospheric Environment. Vol. 8. Pp. 1251-1256.

Weatherhead, E.C. et al. 1998. Factors affecting the detection of trends: statistical considerationsa and applications to environmental data. Journal of Geophysical Research. Vol. 103. Pp. 17149-17161.

Xing, J. et al. 2013. Historical gaseous and primary aerosol emissions in the United States from 1990 to 2010. Atmospheric Chemistry and Physics. Vol. 13. Pp. 7531-7549.

Zhao, T. X. –P. et al. 2008. Study of long-term trend in aerosol optical thickness observed from operational AVHRR satellite instrument. Journal of Geophysical Research. Vol. 113. doi: 10.1029/2007JD009061.

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