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Long-term simulation of dust distribution with the GOCART model: Correlation with the North Atlantic Oscillation

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Introduction

Long term measurements of surface concentration at Barbados and Miami show a strong year-to-year variability that is apparently linked to various meteorological factors including climate conditions in North Africa (Prospero, 1999). Optical thickness retrieved from Total Ozone Mapping Spectrometer (TOMS) satellite since 1979 presents also a significant inter-annual variation over the North Atlantic (Torres et al., 2002). If one wants to understand the observed inter-annual variability and eventually to predict dust distribution, transport models are useful to determine which processes (e.g. emission, transport, or removal) are driving such variability. The GeorgiaTech/Goddard Ozone Chemistry Aerosol Radiation Transport (GOCART) model is used to simulate dust distribution from 1981 to 1997. The model results are compared with observed surface concentration and TOMS aerosol index, and are correlated with the North Atlantic Oscillation Index, defined by Hurrell (1995).

GOCART Model Description

The GOCART model is a multi-components aerosol transport model which simulates the global distribution of dust, sulfate, carbonaceous and sea-salt aerosols. The detailed description of the model components have been given elsewhere (Chin et al., 2000; Ginoux et al., 2001; Chin et al., 2002), here we give a summary of the dust component. The model has a horizontal resolution of 2^o latitude by 2.5^o longitude and 20-30 vertical sigma layers, and uses the assimilated meteorological fields generated from the Goddard Earth Observing System Data Assimilation System (GEOS DAS). The particle size distribution is discretized into four size bins: 0.1-1, 1-3, 3-6 μm. The continuity equations of mass concentration for each size bins are treated independently. The equations include emission, transport and removal processes. A new approach has been used in GOCART to identify the dust sources. Using Total Ozone Mapping Spectrometer (TOMS) aerosol index, Prospero (2002) have identified and characterized the geo-morphological characterization of the major dust sources. Based on this analysis and the previous work by Herman et al. (1997), Ginoux et al. (2001) have defined a global dust-source function. Figure 1 shows the comparison between the dust source function and climatological TOMS Aerosol Index. The function is constructed as the probability of sediments accumulated in topographic depressions with bare surface. Dust emission depends on the cubic power of the surface winds speed, and the threshold velocity of wind erosion. Transport processes include advection by winds, convection by clouds, and diffusion by turbulent mixing. Removal processes include gravitational settling, surface deposition, and wet deposition (scavenging in convective updrafts and rainout/washout in large scale precipitation).

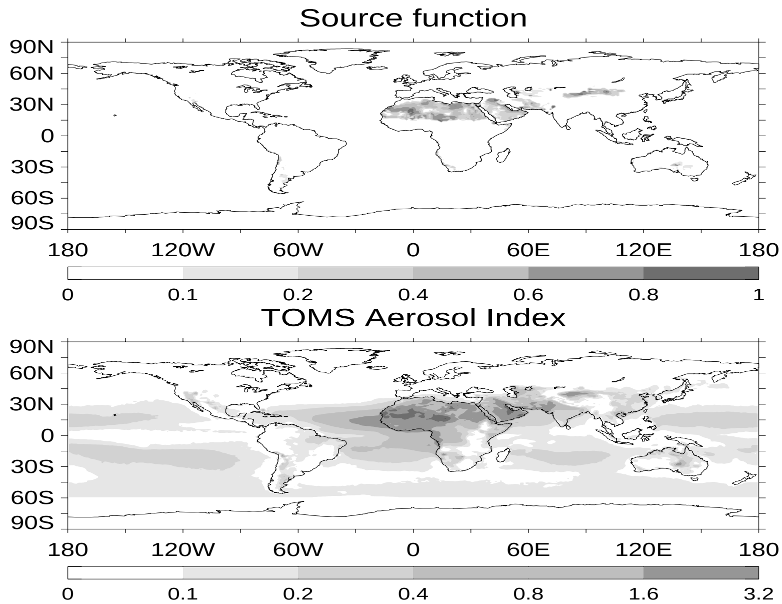

Figure 1. Comparison between GOCART dust sources and the TOMS Aerosol Index.

GOCART Simulation and Comparison with the Observations

The dust distribution has been simulated from January 1981 to 1998. Figure 2 shows the comparison of the monthly dust concentration observed at Barbados (13.17°N, 59.43°W) and simulates with GOCART. The model captures the main seasonal and year-to-year variability.

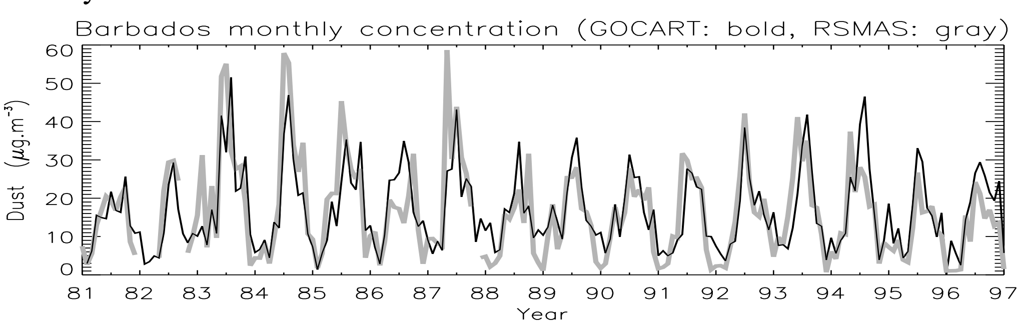

Figure 2. Comparison between observed (dash line) and simulated (bold line) monthly mean surface concentration at Barbados from January 1981 to December 1997.

Torres et al. (2002) have derived optical properties from the backscattered near-ultra-violet from Total Ozone Mapping Spectrometer (TOMS) on board the Nimbus 7 (1979-1992) and the Earth Probe (mid-1996 to present). The advantages of the near-UV technique are the high sensitivity to absorbing aerosol which can be separated from non-absorbing aerosol (e.g. sulfate), and the aerosol retrieval over both land and ocean. In case of dust particle, the optical thickness is a function of the observed radiances, the viewing angles, the altitude of the dust plume and the single scattering, assuming the refractive index. Instead of calculating the dust optical thickness from GOCART and comparing with Torres et al. (2002) data, we calculate an equivalent TOMS AI. The advantage is that there is only one set of assumptions and they are on the model side. The refractive index of dust particles is assumed to be 1.58, for the real part, and 0.0064, for the imaginary part. A detailed description of the TOMS aerosol index (TOMS AI) is given by Herman et al. (1997). Figure 3 shows the correlation coefficient between TOMS AI and the Index calculated with GOCART results. Over all the dusty regions, the correlation is very strong (higher than 0.8). The slope of the correlation (not shown) is around one which suggests that GOCART model reproduces correctly the amplitude of the variability.

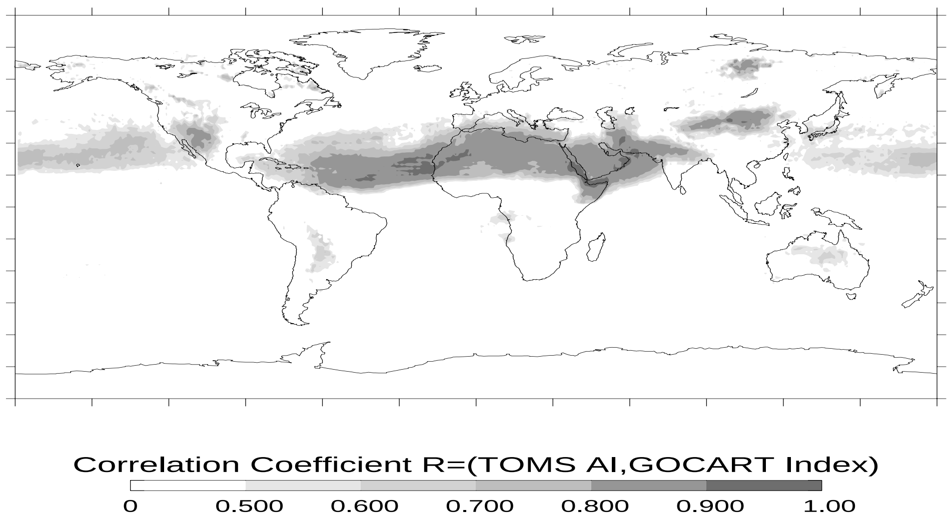

Figure 3. Correlation coefficient between monthly mean TOMS AI and the equivalent index calculated with GOCART, for 1981 to 1992.

Correlation with the North Atlantic Oscillation

The NAO index is defined from the difference between normalized sea-level atmospheric pressures between Lisbon, Portugal, and Stykkisholmur, Iceland (Hurrell, 1995). Winters with high NAO indices are characterized by a deepening of the Icelandic low associated with a stronger Azores anticyclone. This yields to higher surface pressure and drier conditions over Northern Africa. During low NAO conditions, there is an increase of precipitation over the Mediterranean and North Africa. The dust emission, loading, deposition have been correlated with the NAO Index. There are significant correlations in winter, but none in summer. The main reason is that the pressure gradient between Iceland and Portugal is much weaker in summer.

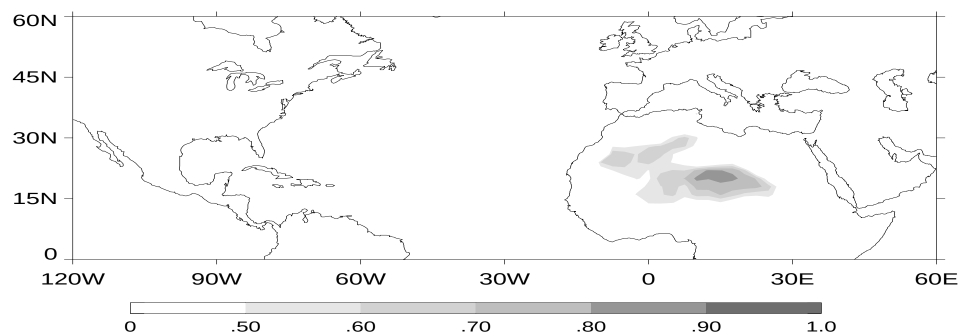

Figure 3. Correlation coefficient between GOCART dust emission and the NAO Index, for winter (1981-1997).

Figure 3 shows the correlation coefficient between dust emission from GOCART and the NAO Index. Over the Bodele depression (Lake Chad region) the correlation is higher than 0.8. The Bodele depression is the most active dust source in winter. Our results suggest that the NAO is a driving force for modulating dust emission in winter. Dust loading is significantly correlated with the NAO Index over the North Atlantic but not over Africa.

Conclusions

Dust size distribution is simulated with the GOCART model which is driven by assimilated meteorology. One major feature of GOCART dust emission is the use of an original dust source inventory based on topography and vegetation. The dust distribution has been simulated from 1981 and compare with surface concentration at Barbados and the TOMS AI. The GOCART results are well correlated with the observations. The simulated inter-annual variability has been correlated with the NAO Index. We find significant correlation with dust emission, loading and deposition, and the NAO Index in winter. Our results suggest that the inter-annual variability of dust over the Atlantic is a combination of variable dust emission and transport, both forced by the NAO.

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