Improving GCM aerosol climatology using satellite and ground-based measurements

Li Liu[a,b], Andrew A. Lacis[b], Barbara E. Carlson[b], Michael I. Mishchenko[b], Brian Cairns[b]

[a]Columbia University & [b]NASA Goddard Institute for Space Studies, New York, NY 10025

Abstract :

A physically based aerosol climatology is essential to address the questions of global climate changes. We use available satellite and ground-based measurements, i.e., MODIS, MISR, POLDER, AVHRR, and AERONET data, to characterize the geographic distribution and seasonal variability of aerosol optical depth and size. The Ångström exponent, defined as $A = -\ln(\tau_{\lambda_1}/\tau_{\lambda_2})/\ln(\lambda_1/\lambda_2)$, is used as a measure of aerosol size. Although large discrepancies exist between different datasets, particularly for the Ångström exponent, the measurements point to a need for reducing the aerosol effective radii specified in the GCM from the nearly 1.0 μm average value to about 0.2 or 0.3 μm, as suggested by the observed Ångström exponent. Incorporating this change in aerosol effective radius also improves the agreement for the aerosol optical depth between satellite measurements and the GISS GCM aerosol climatology. As a consequence, the radiative forcing due to aerosol under clear sky conditions is increased by about 30%.
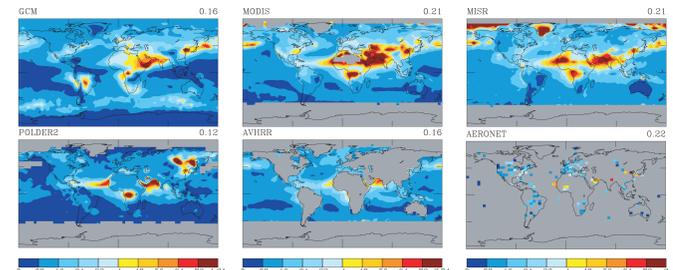
Results and Analyses :

Fig.1: Global distributions of aerosol overall monthly averaged optical depths at 0.55 μm in July compiled from different datasets. The numbers on the top right corners represent global area weighted means.

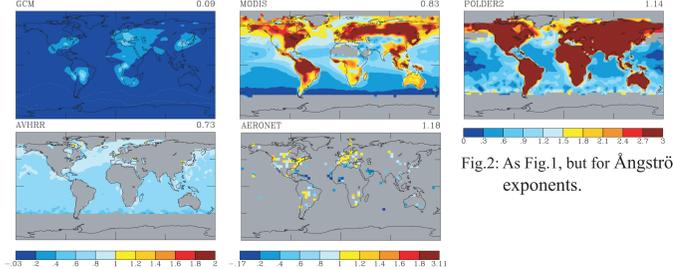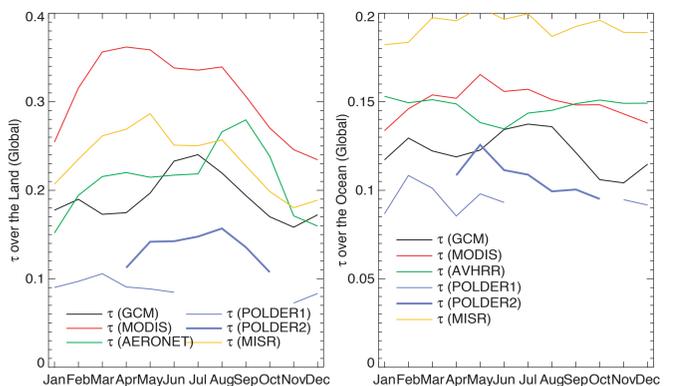Fig.2: As Fig.1, but for Ångström exponents.

Fig.3: Comparisons of GISS GCM and Satellite retrieved aerosol optical depths at 0.55 μm. Note the monthly means are area weighted and calculated from all the data available.
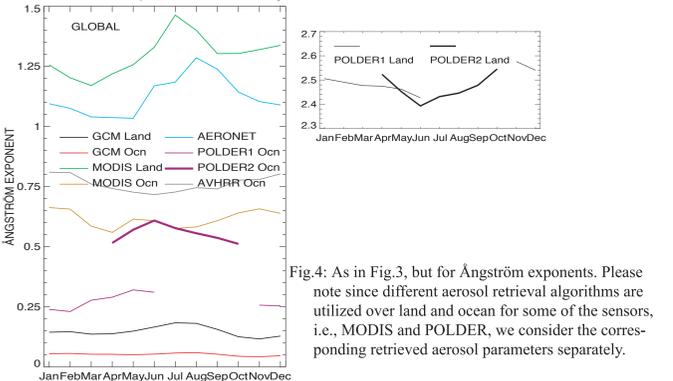

Fig.4: As in Fig.3, but for Ångström exponents. Please note since different aerosol retrieval algorithms are utilized over land and ocean for some of the sensors, i.e., MODIS and POLDER, we consider the corresponding retrieved aerosol parameters separately.
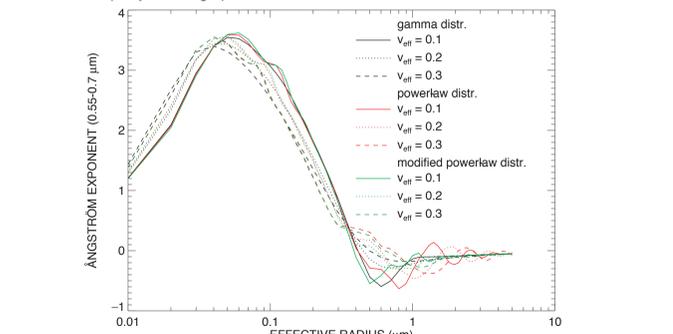

Fig.5: Ångström exponent computed between 0.55 and 0.7 μm versus effective radius for different size distributions.
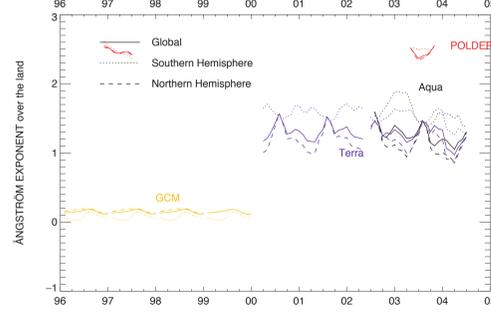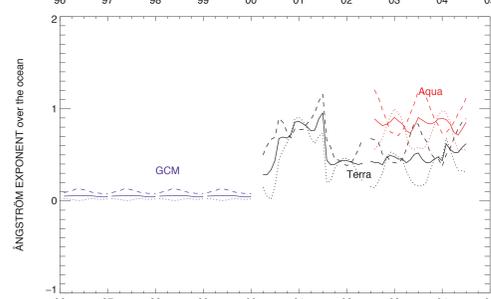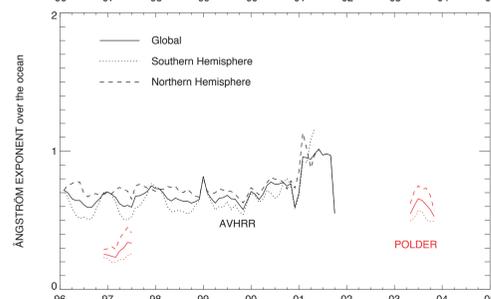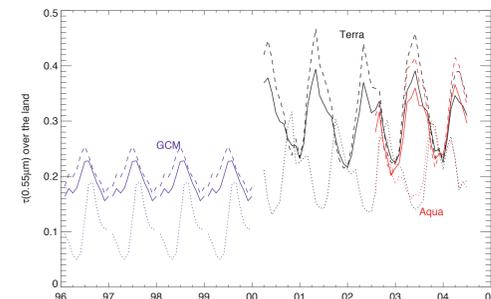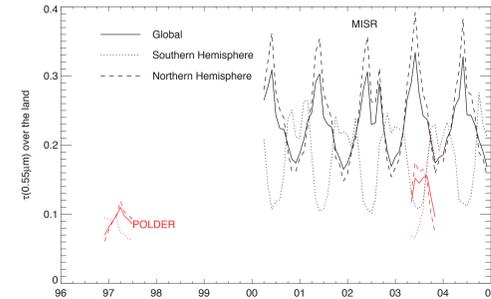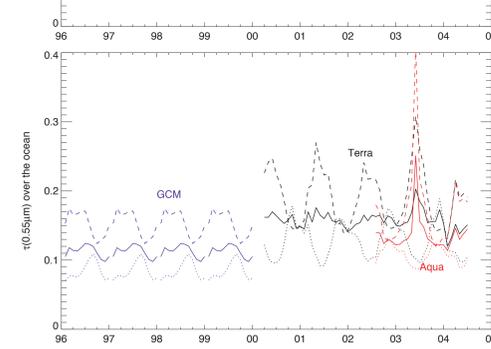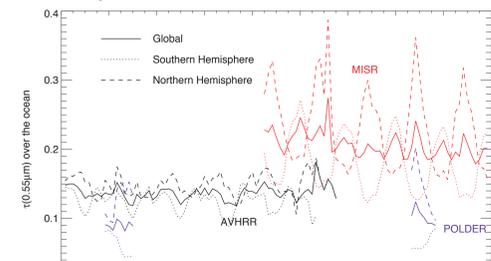

Fig.6: Time series of the satellite retrieved global monthly mean aerosol optical depths and Ångström exponents and GCM aerosol climatology.
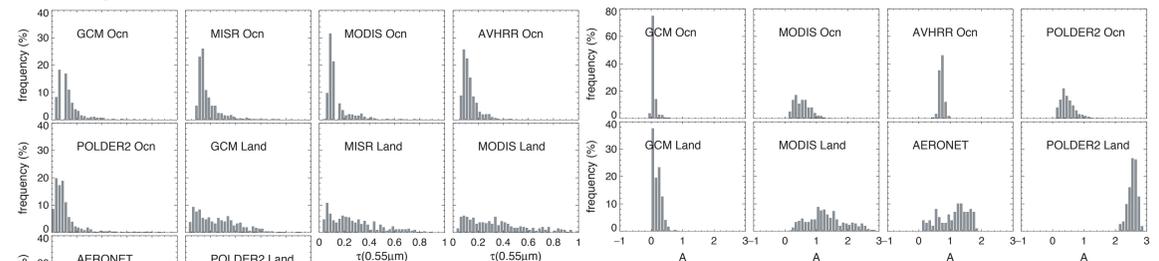

Fig.7 and Fig.8: Frequency distributions of aerosol optical depth and Ångström exponent. The data selected for presentation are overall monthly means in July and are constrained between 45°S - 45°N since satellite retrievals are less reliable in polar regions.

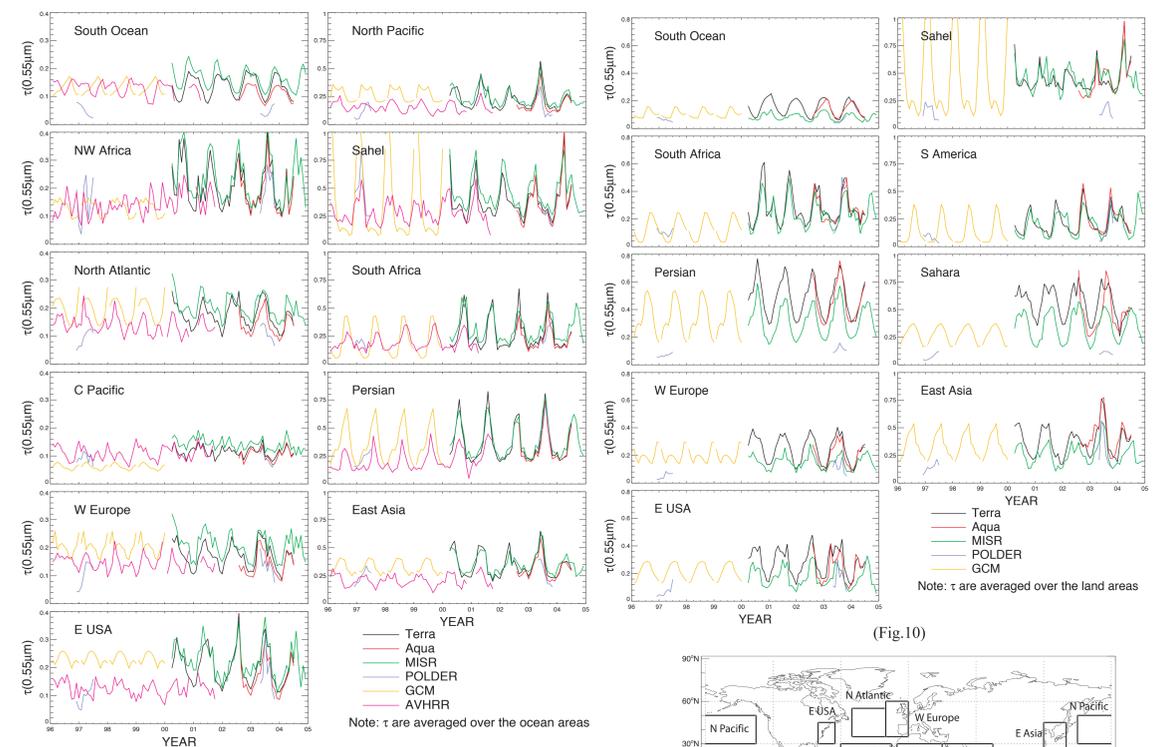Note: τ are averaged over the ocean areas

Fig.9 and Fig.10: Regional analysis of aerosol optical depth averaged over the various areas shown by Fig.11 as a function of time. As mentioned above different retrieval algorithms may be applied to derive aerosol properties over land and ocean, we consider the corresponding retrieved parameters separately (Fig.9 and Fig.10).

Note: τ are averaged over the land areas

(Fig.10)

(Fig.11)

Our goals are, according to their priority, to get the GISS GCM global aerosol optical depth mean right, seasonality right, and regional aerosol distributions right. The intercomparisons reveal that:

(1) Substantial discrepancies exist between different datasets, particularly for Ångström exponent (A). The overall globally averaged aerosol optical depth (AOD) monthly means range from about 0.08 to 0.36 over land and from about 0.08 to 0.2 over ocean, and the A values vary from about 0 to more than 2, representing coarse and fine aerosols respectively. Generally speaking, in terms of aerosol seasonality, MISR and MODIS data agree with each other better than other satellite retrievals and GCM aerosol outputs with the maxima of AODs occurring around May-Jun. and the minima in Dec.-Jan. over ocean. This is not a surprise since the sensors are more advanced and much better calibrated than other old generation instruments. There are appreciable differences between MODIS retrievals onboard Terra and Aqua which well exceed aerosol daily variabilities. The only possible reason is that different algorithms and cloud screening schemes are applied for these two datasets. The big jump between POLDER1 and POLDER2 can also be explained by the different retrieval algorithms. It appears that POLDER2 data are more consistent with other datasets. The POLDER retrieved Ångström exponent over the land is significant higher than others for the reason of that over the land the retrieval technique is only sensitive to small sized aerosols. Due to its limited spectral sampling and the problems with calibration and cloud screening, the AVHRR products are less informative than other more advanced datasets. The AERONET measurements, widely use to validate satellite retrievals and model simulations, reasonably agree with MODIS and MISR data.

(2) Similarities exist between different datasets as well. The average aerosol load is systematically higher in the Northern Hemisphere, and the highest AOD values occur during the summer season and the lowest during the winter. On regional scale, all aerosol products, MODIS and MISR in particular have captured the main aerosol features at the right time, i.e., dust outbreak in Sahara and Persian regions, smoke in South America, mixtures of smoke and dust in Sahel, and pollution downstream of North America, East Asia, and Europe.

(3) It is shown that the GCM aerosol optical depth and Ångström exponent are usually smaller than other datasets except the AODs of POLDER retrievals. Since in our aerosol model, the aerosol effective radii are rather arbitrarily specified to convert mass loadings from transport model simulations into optical depths, by reducing the aerosol effective radii specified in the GCM from the nearly 1.0 micron average value to about 0.2 or 0.3 μm, as suggested by the observed Ångström exponent and Fig.5, we could easily solve the problem. Still we have GCM minimal AOD values occurred in Mar.-Apr. and in Oct.-Nov. which have not been seen in the available satellite observations. How to get the aerosol seasonality right is our ongoing research topic. By bringing up GCM clear sky aerosol optical depth to match that of satellite data would increase aerosol radiative forcing by about 30% following the relationship:

$$\Delta F_R = -\frac{S_0}{4}T_{atm}^2(1-N)(1-a)^2 2\beta\tau$$

where T_{atm} is the transmittance of the atmosphere above the aerosol layer, N is the fraction of sky covered by clouds, a is the albedo of underlying surface, β is the fraction of radiation scattered by aerosol into the upper hemisphere and τ is the aerosol layer scattering optical depth (Charlson et al., 1992)

Reference:

Charlson, R. J., S. E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, Jr., J. E. Hansen, and D. J. Hofmann, Climate forcing by anthropogenic aerosols, *Science*, 255, 423-430, 1992.