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ANOMALIES IN THE SOUTH AMERICAN MONSOON INDUCED BY AEROSOLS

William K. M. Lau and Kyu-Myong Kim
Laboratory for Atmospheres
NASA Goddard Space Flight Center

1. Introduction

The South American Monsoon System (SAMS) is a major component of the global climate system affecting fresh water supply and distribution for large parts of South America, and is an area of active research by GEWEX and CLIVAR under the WCRP. On the other hand, the region is known to suffer from the influence of aerosols from dust, biomass burning and industrial pollution. Up to now, almost all the research on SAMS by the monsoon community has been focused on the impacts of sea surface temperature, land processes, orographic effects and internal atmospheric dynamics, while the aerosol community has focused on chemistry, radiative forcing and local and microphysical effects of cloud and rain modification, with very little intersect between the two disciplines. Only a handful of very preliminary studies have been conducted on possible impacts of aerosols on the wet seasons. The conventional wisdom is that during the wet season, monsoon dynamics control is dominant, and aerosol forcing is at a minimum due to wet scavenging of pollutants and lack of biomass burning activities. In this study, we will show evidence that this conventional wisdom may be flawed, and that aerosols may have a strong impact on evolution of the SAMS.

The possible impacts of the aerosol on the water cycle are very complex, involving direct and indirect effects. The direct effect refers to the depletion of the surface radiation reaching the earth surface by reflection and/or absorption of solar radiation by the aerosol – the so-called "solar dimming" effect. The indirect effects refers to the increase in cloud condensation nuclei (CCN) due to increased aerosol loading, which increase the population of small cloud drops, making the clouds more reflective and suppresses rainfall by reducing coalescences of smaller cloud drops to form larger rain drops. In addition, some types of aerosols such as dust under suitable environmental conditions may be effective to initiate ice-phase precipitation. More recently, using climate models, Ramanathan et al (2005) showed that the "solar dimming" (SM) effect due to sulfate and black carbon emissions over India, may cause a weakening of the South Asia monsoon. On the other hand, Lau et al (2006) showed that through the "atmospheric heat pump" (EHP) effect due to atmospheric heating of dust and black carbon over the Indo-Gangetic Plain, piling up over the southern slopes of the Tibetan Plateau, the South Asia monsoon may be enhanced. There two scenario does not necessary contradict each other, as they may applied in different spatial and temporal scales. In this paper, we present preliminary results of a numerical model experiments to examine the relative impact of SM vs. EHP in order tease out the possible fundamental signals of aerosols on SAMS.

We use the 2 x2.5 degree GEOS GCM with Microphysics with the Relax Arakawa-Schubert (McRAX) cumulus parameterization. The GCM is forced by global aerosol forcing obtained from the Goddard Chemistry, Aerosol, Radiation Transport (GOCART) model. The GOCART keeps track of atmospheric loading of 5 species of aerosols (dust, black carbon, organic carbon, sulfate, and sea salt), and the radiative forcing are computed from prescribed single scattering albdo, asymmetric factors as a function of the spectra, the species, size distribution, and relative humidity distribution. Experiments will be carried out with and without aerosol forcing. In all the results shown here, only the direct effects of aerosols are included. To keep the aerosol signals clean, all external forcing SST, solar radiation at the top of the atmospheres, greenhouse gases are prescribed to climatological condition. The experiements are designed to allow full water cycle (not aerosol) and land-atmosphere interaction so that the SH and EHP effects are operative. This work is just the beginning.

2. Results

It can be seen that the GEOS GCM control run (without aerosols) shown in Fig. 1a and b, simulate the large scale circulation pattern reasonably well compared to observations (Fig 1 c and d), expect for spurious rain over the Andes, which is due to unrealistic grid-scale convection from the coarse resolution of the model. The model also seems to underestimate the rainfall over Amazonia in the interior of the continent.

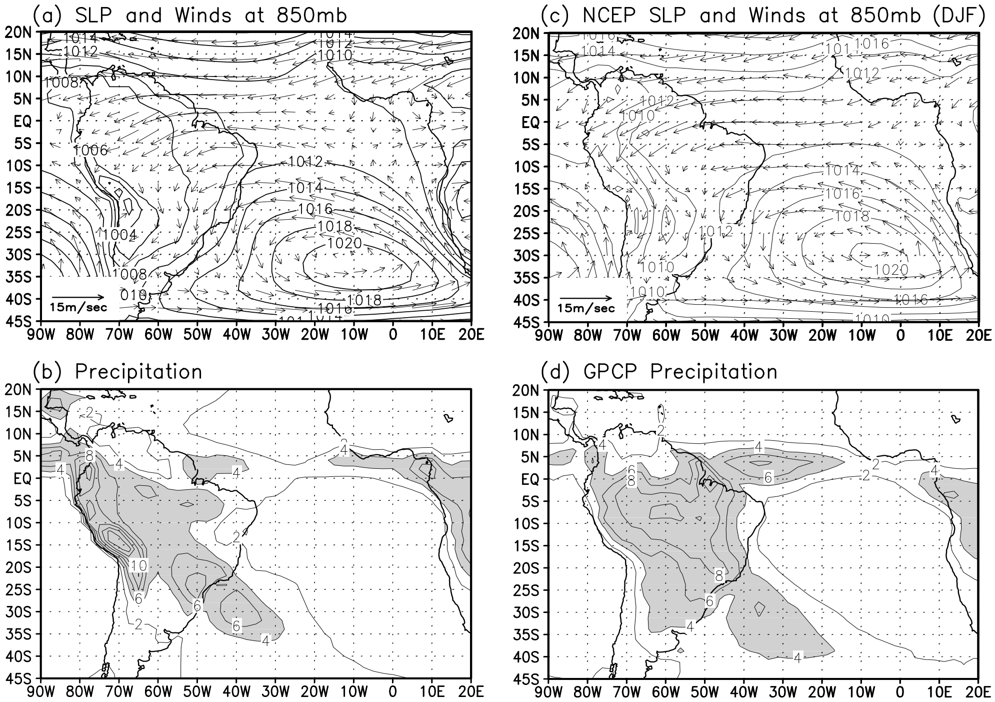

Fig. 1 Model simulated sea-level pressure and 850mb wind (a, b), compared to observations from NCAR/NCEP reanalysis and GPCP (c, d).

Figure 2 shows the aerosol optical thickness (AOT) distribution in the pre-monsoon season (SON), and the monsoon season. In SON, there are three major sources of aerosols. The large aerosol source is due to Sahara dust at 15^{o} N, from

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North Africa to the eastern Atlantic. One secondary AOT maximum, consisting of mostly black carbon from biomass burning and industrial pollution, is found deep in the center of the South America continent, in southwestern Brazil/Bolivia/Paraguay region. The AOT maximum over the east coast of South Africa neare 10-20^{o}E, 15^{o}S is from biomass burning over coast of Angola. In DJF, the dust aerosols center has expanded and shifted coast to the equator, as the trade wind, and the ITCZ move closer to the equator (See Fig. 1c and d). At this time, both secondary maximum due to biomass burning over southwestern Brazil and Angola vanish due to the advent of the wet season.

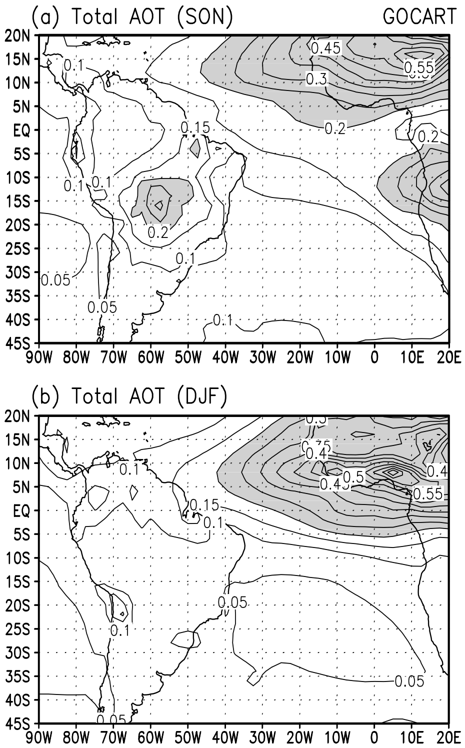

Fig. 2 AOT distribution from GOCART

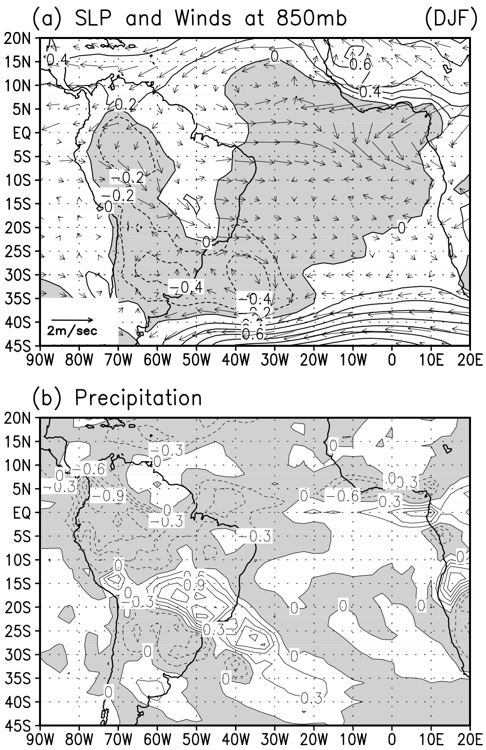

Fig. 3 Aerosol –indcued anomalies in a) SLP And

Figure 3 shows the anomaly of the SAMS in DJF induced by aerosol forcing. There is pronounced increase over the La Plata basin of subtropical SAMS region, and corresponding reduction over northwestern South America. The rainfall anomaly is caused by an increase in the low level jet (LLJ) over the eastern slopes of the Andes in northwestern S. America (Fig. 3a). The increase LLJ appears to be connected to a large scale cyclonic circulation which cover the tropical Atlantic, with convergence flow towards positive rainfall anomalies that develop over the east coast of Africa just south of the climatological position of the ITCZ over the Gulf of Guinea. As a result, a near-equatorial anomalous Walker circulation with rising motion over eastern Atlantic/east Africa, and sinking motion over northeastern S. America is forced primarily due to different absorption of elevated dust across the Atlantic. The cross-equatorial northeasterly flow from the induced cyclonic circulation is deflected by the Andes, and in the process enhances the seasonal LLJ. Further analyses (not shown) show that as a precursor to the rainfall anomalies in DJF, atmospheric heating due to the elevated black carbon from biomass burning, and the SM effect may have caused a delay of SAMS over southwestern Brazil in October-November, which subsequently lead to increase moisture flux into, and resulting in increased rainfall in the southeastern Brazin and the La Plata Basin in November-December. Further experiments with dust aerosol only shows a similar, but weaker rainfall anomaly pattern compared to Fig. 3b. Thus it appears that the EHP effect may have help to precondition the pre-monsoon local environment over southwestern Brazil, so that the monsoon atmosphere-land system is more convectively unstable with respect to to LLJ moisture flux spurred by the dust-induced Walker circulation from the equatorial region.

4. Conclusion

We find that during the pre-monsoon season (September-October-November) Saharan dust contribute to heating of the atmosphere over the central and eastern equatorial Atlantic/Africa region through the "elevated heat pump" mechanism. The heating generates an anomalous Walker circulation with sinking motion, and low level northeasterlies over the Caribbean and northwestern South America. The low level flow is blocked by the Andes, and turn south and southeastward, increasing the low level jet (LLJ) along the eastern slope of the Andes. The increased LLJ transports more moisture from the Atlantic and the Amazon, enhancing the moisture convergence over subtropical land regions of South America. The moisture convergence was further accelerated by atmospheric heating by biomass burning over the Amazon. The net results of the dust and biomass heating on the SAMS are : a) an enhanced LLJ, b) a reduction of monsoon rain season over northwestern South America and western Brazil c) an advance of the monsoon rainy season in southeastern Brazil and La Plata basin.

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