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A CASE STUDY ON THE IMPACT OF ATMOSPHERIC AEROSOLS IN MODIFYING THE REGIONAL METEOROLOGY

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INTRODUCTION

The role of atmospheric aerosols in modifying the cloud microphysical properties, the radiation balance of the earth-atmosphere system and climate change are well recognized. Atmospheric modeling studies have conclusively shown that the radiative impact of aerosols on the meteorology of a given region/globe could be significant. But the main hindrance in getting the direct observational evidence for the impact of atmospheric aerosols in modulating the meteorological variables is the fact that most often, the effect of atmospheric aerosols will be marred by the variability produced by other meteorological processes.

A large aerosol plume formed over the eastern part of tropical Indian Ocean during the September-November period of 1997 due to the transport of smoke aerosols from the intense forest fires occurred over Indonesia provided an excellent opportunity to study the impact of aerosols in atmospheric radiative forcing. Over the equatorial Indian Ocean, east of ~90°E, the aerosol optical depth (AOD) was larger than 0.7 during September 1997. By October, the smoke aerosol plume started advancing towards west when AOD exceeding 1.0 was observed upto ~80°E in the equatorial region. The decay of the plume started by November, even though AOD exceeding 0.7 was widely observed over the eastern tropical Indian Ocean in this month also, and the AOD resumed its normal value (<0.2) by December. This was an extremely rare and unique opportunity to investigate the aerosol impact on the meteorology over this region because: (a) the observed radiative forcing was immensely large, and (b) this was not a regular phenomena and hence comparison with the same season in other years when AOD was very small (control data) could be possible.

Effect of this plume on the radiation balance of this region is studied using AOD derived from NOAA-AVHRR data and the SBDART radiation transfer model to delineate the modulation on sea surface temperature (SST).

DATA AND METHOD OF ANALYSIS

The values of AOD (at the wavelength 630 nm ± 50 nm) over the tropical Indian Ocean covering a geographical region 20°S to 20°N in latitude and 40°E to 100°E in longitude derived from the clear sky radiance measured by each pixel in Channel 1 of NOAA14-AVHRR on a daily basis during the period of June to December 1997 are used for this study. Method of deriving the AOD from satellite data and the sources of errors are presented elsewhere [*Parameswaran et al*., 2004]. The pixel resolution of AVHRR-Global Area Coverage data is 4 km at nadir. A smoke aerosol model is developed by integrating the insitu observations of aerosol properties during the Indonesian forest fire event reported in the literature, with the properties of different aerosol species obtained from the

OPAC model, for which the Angstrom parameter is 1.15 and aerosol single scattering albedo in the visible region is 0.9. The aerosols are assumed to be externally mixed. The satellite-derived AOD is validated by intercomparing with the sunphotometer measurements over Singapore [Nakagima et al., 1999] and sensitivity analysis indicated that the maximum uncertainty is less than 20% [Parameswaran et al., 2004]. Regional distribution of the clear sky aerosol radiative forcing (ADRF) is estimated by incorporating the AOD values and radiative properties of smoke aerosols in the SBDART radiation transfer model.

RESULTS AND DISCUSSION

Regional distribution of the mean shortwave aerosol direct radiative forcing at the surface over the tropical Indian Ocean during September, October and November 1997 are shown in Fig.1. In October 1997, values of ADRF exceeding -90Wm^{-2} at the surface are observed over the eastern equatorial Indian Ocean, which is about 18% of the total incoming solar flux. Note that the ADRF at the surface was in the range of –30 to –50 Wm^{-2} in September and –30 to –60 Wm^{-2} in November, which decreased to the background level of -8Wm^{-2} by December. Extremely large values of ADRF will substantially reduce the surface heating and hence could reflect in surface temperature (in the present case sea surface temperature). But, as a result of the positive phase of Indian Ocean Dipole (IOD), the sea surface temperature (SST) over the easternmost parts of the Equatorial Indian Ocean was already below its normal value by ~1 K since July 1997. Note that compared to September, a significant decrease in SST (by ~2 K) was observed during October 1997 over the eastern tropical Indian Ocean, which appeared like a ‘cold pool’ extending westward from the coast of Sumatra. Figure 2 shows the change in SST, AOD and surface wind vector from September to October 1997. (The white line shows the contour of an incremental change in AOD of +0.6). The change in surface wind from September to October over the cold pool was insignificant. The spatial pattern of the cold pool matches remarkably well with the contour of change in AOD. Similar agreement is also observed in corresponding difference maps generated for November to December period of 1997. The SST values over this region were comparable during October and November. By December, when smoke plume was almost extinct the cold pool reduced substantially in its spatial extent as well as in the values of SST difference within the pool.

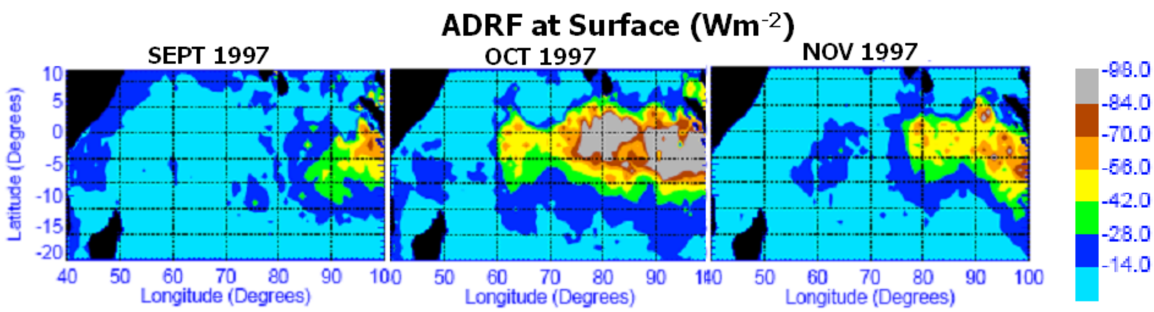

Figure 1: Monthly mean short wave aerosol direct radiative forcing at surface over the Tropical Indian Ocean during September, October, and November 1997.

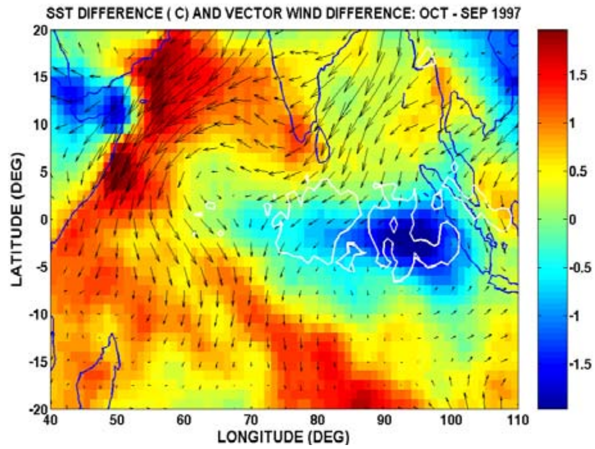

Figure 2. Image of the change in SST from September to October 1997. The white contour lines at the eastern equatorial Indian Ocean represent the contours of +0.6 in the change in AOD from September to October 1997.

In addition to the aerosol radiative forcing, the 'cold pool' could be driven by the changes in surface wind, ocean upwelling, and cloud radiative forcing. All these contributions are to be properly accounted for delineating the aerosol effect. Interestingly, the magnitude and direction of the surface wind in the region of the 'cold pool' was not substantially different during September, October and November, while SST showed significant reduction by about ~2K from September to October and November. This rules out the effect of surface wind. It is also observed that the SST anomaly in the cold pool during October and November did not follow the spatial pattern of surface wind stress curl (an indicator of the surface upwelling/downwelling). Moreover, the change in the surface wind stress curl in the cold pool was negligible from September to October and November and did not follow the spatial pattern of SST difference. These observations indicate that the reduction in SST during October and November of 1997 cannot be completely attributed to IOD. Further to this, because of reduced cloud amount, the anomaly in the net cloud radiative forcing at the surface should be positive over the 'cold pool' during the September-November period, which could have warmed this region. These analyses thus indicate that the observed decrease in SST by ~2K in the cold pool region should be due to the surface cooling caused by the radiative forcing of the aerosol plume.

CONCLUSIONS

The present study suggests that the 'cold pool' observed over the eastern equatorial Indian Ocean was significantly governed by the large aerosol radiative forcing caused by the smoke plume evolved from Indonesia in September – November 1997. It is important to note that under the influence of the IOD, a relatively small 'cold pool' (SST anomaly of ~1K) was present over this region since June 1997, which led to intense drying of the Indonesian region by August –September 1997 leading to large scale forest/peat fires. The intense smoke evolved from this was transported over to the Indian Ocean, which caused a significant increase in the aerosol radiative forcing leading to pronounced cooling of the surface. This has further strengthened the positive phase of IOD (positive feedback) by reducing the SST over eastern equatorial Indian Ocean upto October-November. The situation started reversing by December when the forest fires and smoke completely subsided. The present study provides the first credible observational evidence to illustrate the impact of ADRF in modulating the SST and IOD. It is important to note that this strong positive phase of Indian Ocean Dipole caused huge metrological impact, resulting large-scale dryness over Southeast Asia and increased rainfall over peninsular India, during October-November 1997.

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