URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

Deciphering the weakening of the Indian summer monsoon circulation using a regional climate model RegCM 4.5

B. Abish * (1) and Arun .K (1) (2)
(1) Nansen Environmental Research Centre India, Kochi, India
(2) Department of Atmospheric Sciences, Cochin University of Science and Technology, Kochi, India

Abstract

In this study, the weakening of the Indian summer monsoon circulation is analyzed using the regional climate model RegCM 4.5. It is seen that the when sulfate aerosol component is included in the model run, the simulated temperature shows a cooling at 925 hPa during the 2000 -2011 period for the JJA season. Almost similar pattern is shown when compared with the JRA-55 reanalysis data. At the same time, the Indian Ocean warming has caused an increase in the temperature of the surface waters. Concurrently, the steep temperature that is essential for the strength of the summer monsoon circulation has weakened, resulting in the reduction of the monsoon rainfall over India.

1. Introduction

The Indian summer monsoon is a major component of the global climate system affecting fresh water supply and distribution over large parts of the Indian subcontinent[1]. During the summer monsoon season, the north Indian region is meteorologically sensitive due to the apparent position of monsoon trough and the inter-tropical convergence zone. However, the weather pattern of the region is severely affected recently by the enhanced concentration of atmospheric aerosols such as dust from natural sources, carbonaceous and sulfate aerosols from anthropogenic emissions[2]. The large scale equatorial upper tropospheric heating associated with the excessive warming of the Indian Ocean is reported to have resulted in the weakening of the steep temperature gradient that is essential for the sustained strength of the monsoon winds[3]. They suggested that the tropospheric cooling of the continental region and the rapid warming of the Indian Ocean had resulted in the relaxation of monsoon circulation and in the consequent reduction of rainfall. However, the reason for the continental cooling of the troposphere is not well understood.

From a global perspective, any change in the monsoon circulation, would cause a shift in the large scale heating and hence on the pressure gradient. Ultimately this will induce a change in the atmospheric general circulation pattern affecting the global hydrological cycle[4].Analysis using climate models that accounts for major aerosol types (e.g. sulfates, black carbon etc.), have provided further insight into the importance of sea surface temperature (SST) and aerosol forcing in the dynamics of the monsoon circulations[5,6,7]. In this context, the combined feedback by the rapid warming of the Indian Ocean and the subcontinental aerosol cooling due to sulfate aerosols on the Indian summer monsoon is an intriguing aspect in atmospheric science. Here we investigate the possible role of sulfate aerosols in controlling the large scale monsoon circulation over the Indian region.

2. Data and methodology

The RegCM version 4.5 developed by the Earth Systems Physics (ESP) group of the Abdus Salam International Centre for Theoretical Physics (ICTP) has been employed to examine the dynamic impacts of large aerosol radiative forcing on the atmospheric temperature and circulation during the summer monsoon season. The model has a horizontal resolution of 60 km and σ vertical coordinate system. Simulations are done over the Indian Ocean domain (Figure. 1) with centre 16.93 latitudes and 67.18 longitudes, having 160 grid points in the y-direction, 192 grid points in the x-direction and 18 vertical sigma levels with the model top at 50 hPa defined by the international programme named the Coordinated Regional Climate Downscaling Experiment (CORDEX)[8]. RegCM4.5, with its high resolution and the coupled aerosol modules that are included, considers both anthropogenic and natural type of aerosols. Therefore, RegCM4.5 is optimally suited for modeling studies on aerosols at a regional level and it is extensively used for conducting various experiments by including the sulfate aerosol component in the model runs (Hereafter, SULF).

The simulated temperature is compared with the air temperature data obtained from the JRA-55 reanalysis datasets[9]. Monthly mean sea surface temperature (SST) for the period 1980 - 2011 is taken from Hadley Centre Global Sea Ice and Sea Surface Temperature (HadISST) datasets[10]. The anomaly for the period 2000-2011 is computed from the climatology of 1980-2011. Daily rainfall data is obtained from Global Precipitation Climatology Project (GPCP)[11] which contains observations and satellite precipitation data merged into global grids.

3. Results and Discussions

During the monsoon season, the Western Ghats (WG) along the south western coast of India receives maximum amount rainfall as the moisture laden south westerly winds undergoes forced ascend along the steep mountainous range that contributes to cloud formation and heavy rainfall.

However, the presence of atmospheric aerosols in large quantities over the subcontinent modifies the cloud properties altering their radiative properties leading to an increase in the cloud reflectance and consequently the planetary albedo. The resultant aerosol indirect effect act to cool the Earth-atmosphere system by increasing the cloud optical depth and cloud cover respectively. This reduces the net solar radiation at the top of the atmosphere as well as at the surface. The vertical thermal stability in the lower tropospheric level in turn gets modified thereby influencing the large-scale atmospheric circulations.

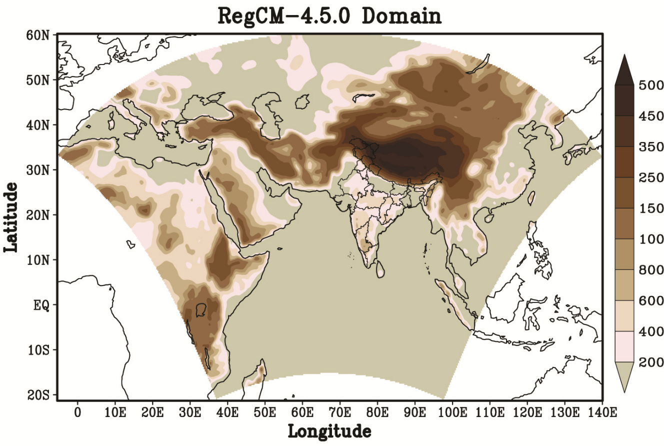

Figure 1. CORDEX Indian Ocean domain used in the model run.

Figure 2 shows the temperature anomaly at 925 hPa for the JJA for the period 2000 to 2011. Here the anomalies for the period 2000 - 2011 are computed from the 30-year climatology (1980 - 2011). From the JRA-55 reanalysis data, it is seen that cold anomaly prevails over the most parts of north Indian region including Indo-Gangetic Plain (IGP). Studies have documented that this region is affected by a large concentration of anthropogenic aerosols from local emissions. A similar pattern is seen in the SULF run where anomalous cooling has occurred over most parts of northern India. Here the simulated 925 hPa temperature also shows cooling over the peninsular India, which is not observed in the JRA-55 data. During the time, the peninsular India has cooled by about 0.2 °C, while that over central and northern India is about 0.1 °C. The almost similar pattern shown by JRA-55 reanalysis data and the SULF run indicates the possible role of sulfate aerosols in the surface cooling of the region. The surface cooling during JJA reduces the steep temperature gradient that is essential for the sustained strength of the summer monsoon circulation.

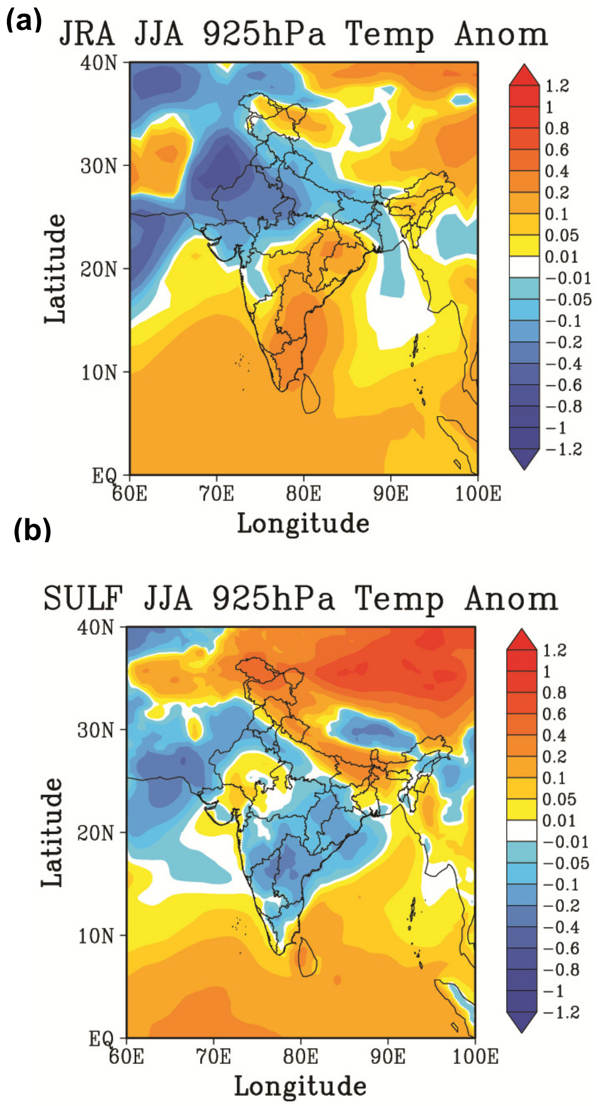

Figure 2. Temperature anomaly at 925 hPa during JJA in (a) JRA (b) SULF run

The Indian Ocean has been experiencing severe warming since nearly three decades. It is reported that normally cold waters during La Nina events were replaced by warm waters with SST exceeding 0.2 °C over large areas of the Indian Ocean[12]. During the recent decades (2000-2011), when compared with the climatology (Figure 3a) the Indian Ocean SST has shown an increase of more than 0.1 °C (Figure 3b) over most parts of the basin. The intense warming of the Indian Ocean and the associated enhanced deep convection caused an increased release of latent heat into the atmosphere. The consequent heating of the upper troposphere affected the large-scale circulation leading to a decline in the moisture advection towards subcontinent leading to a reduction in summer monsoon over India. As a consequence, the rainfall reduces over the Indian region particularly over WG, which is dominated by orographic rainfall.

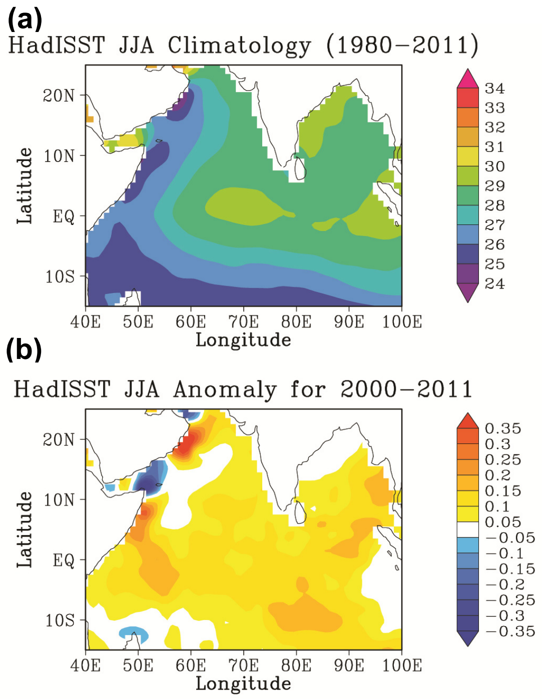

Figure 3. The SST climatology for the period 1980-2011 (b) SST anomalies are computed from the above base year for 2000 to 2011.

Figure 4 depicts the time series of the monthly mean rainfall (mm/day) in the JJA season. From the figure, it is seen that the when sulphate aerosol component is included in the model, it follows almost similar pattern as in the GPCP observations. The rainfall follows a slightly decreasing trend during the last 3 decades over the Indian region. From the figure, it is seen that the simulated rainfall is overestimated in 1983, 1998 and 2000, while it is underestimated in 1987, 1993 and 2004.

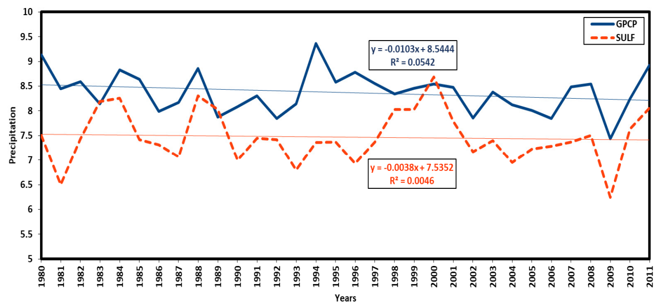

Figure 4. Time series of the JJA monthly mean rainfall (mm/day) over the Indian region in RegCM4.5 simulations and JRA-55 reanalysis.

4. Conclusion

The simulated temperature in the RegCM 4.5 model run, when sulphate aerosol component is included shows a cooling of the atmosphere at 925 hPa, which is comparable from the JRA-55 reanalysis datasets. In the last decade 2000-2011 alone, the surface has cooled by about 0.2 °C over most part of India. The intense warming of the Indian Ocean and the cooling of the continental region has resulted in the decline of the thermal gradient and on the advection of moisture from the ocean. The simulations indicate that the excessive concentration of sulphate aerosols may have an influence on the weakening of the summer monsoon circulation over India. This is evident in the declining trend in the monsoon rainfall in the model simulation as well as in the GPCP reanalysis datasets.

5. Acknowledgements

This research has received funding from the grant (No. ECR/2016/000905) provided by the Science and Engineering Research Board (SERB), Department of Science and Technology (DST), Govt. of India

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