The Influence of Indian Ocean Warming and Soil Moisture Change on the Asian Summer Monsoon

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Tanvir Ahmed1*, F. Kucharski2
1Dept. of Physics, Shahjalal University of Science and Technology, Sylhet, Bangladesh
2Abdus Salam International Center for Theoretical Physics (ICTP), Trieste, Italy
*Email: tanvir_sust@yahoo.com

Abstract

An Atmospheric General Circulation Model (AGCM) is used to examine the influence of Indian Ocean warming and soil moisture change on the Asian summer monsoon. Three numerical experiments have been done for this purpose. The first one is related to the positive Sea Surface Temperature (SST) anomaly related to global warming and its effect on the Asian summer monsoon. The last two are related to the change of soil moisture and its impact on Asian summer monsoon. It has been shown that the Asian summer monsoon is weakening for the positive SST anomalies of the Indian Ocean but a significant increase of precipitation in South Asia, Bay of Bengal and Arabian Sea. There is a positive and negative anomaly precipitation dipole in the meridional direction that is nearly equal in magnitude which is also created in the East Asian region. On the other hand it has been shown that changing the soil moisture has direct impact on precipitation and monsoon circulation and a relatively high impact on the dry or semiarid area on the Indian subcontinent.

Keywords: Monsoon dynamics, Asian Monsoon, soil moisture, SST anomaly, surface energy.

1. Introduction

The Asian monsoon is characterized by a seasonal reversal of the surface winds and a distinct seasonality of precipitation [1]. The climate of Asian region is mostly controlled by the two Asian monsoons. One is called Asian winter monsoon and another Asian summer monsoon [2]. During the boreal summer, winds flow from the southern hemisphere, accumulating moisture and depositing copious amount of precipitation over the south Asian continent. The fundamental driving mechanisms of the monsoon cycle are the cross-equatorial pressure gradients resulting from differential heating of land and ocean, modified by the rotation of the Earth and exchange of moisture between the ocean, atmosphere and land [3]. Radiative heating of the continent gives rise to a continental scale thermal low in the southeast direction, the low level wind flow in from southwest. The monsoon is also manifested as land-atmosphere-ocean interaction between continents and oceans in the seasonal cycle [4]. Some of the recent model studies emphasized the relative importance of the Ocean-Atmosphere-Interaction (OAI) compared to Land-Atmosphere-Interaction (LAI) particularly focusing on the strong impact of large-scale SST anomalies in the tropical Oceans nearby the continents [5].

There are a lot of physical parameters which have influence on the Asian summer monsoon. The most important are Sea-Surface-Temperature (SST), atmospheric circulation, orography, land cover change, snow cover and soil moisture. Ocean SST plays an important role on the Asian summer monsoon. The gradients of SST within the ocean are important in determining the location of precipitation over the tropics, including the monsoon regions [6]. It might be supposed that the distribution of SST in the Indian Ocean plays a role in determining monsoon rainfall variability [7]. The influence of Indian Ocean on the Asian monsoon variability has been suggested by models and empirical evidence. Atmospheric General Circulation Models (AGCM) have been used to address how the regional climate associated with monsoon rainfall and circulation anomalies respond to imposed SST anomalies. Several studies demonstrate the significance of the Indian
ocean SST in influencing the monsoon. AGCM studies in which the solar forcing of the land and ocean are incorporated separately show that the annual cycle of SST in the Indian ocean is crucially important in establishing the monsoon circulation and rainfall [8]. Model simulations also confirm that the Arabian sea SST influence subsequent monsoon rainfall on timescales less than a month. A cool Arabian sea SST leads to reduced Indian rainfall and vice-versa [9]. Yanai et al [10] showed that the strong (weak) Asian summer monsoon years are associated with negative (positive) SST anomalies in the equatorial eastern Pacific, Arabian sea, Bay of Bengal and south China sea, but positive (negative) SST anomalies in the equatorial western Pacific. Clark et al [11] showed that the relationship between Indian ocean SST variability and the variability of the Indian monsoon. In their work they included ENSO which produced Indian Ocean SST variability.

The Indian ocean has undergone a significant warming after 1976 [12]. But the predictive relationship between Indian Ocean SST anomalies and climate remains especially poorly characterized. It is important that to explore the affect of the climate shift on the Asian monsoon region. The physical quantities of the land surface which may be anomalous atmospheric forcing or climate memory effect on can be soil moisture (SM). SM is a key parameter for Land-Atmosphere-Interaction (LAI) in the climate system [13]. The anomaly of surface and near-surface soil moisture is likely to have a persistence of several days to several months, which cause climate memory through anomalous surface energy and moisture fluxes. Manabe et al [14] firstly assessed the climate memory effect of soil moisture in GCMs using the so called bucket model interacting with the atmosphere through a surface water balance. In recent years, realistic land surface models have been developed and many sensitivity experiments with GCMs have been conducted using different types of LSMs under different experimental designs. Douville et al [15] assessed the influence of SM on seasonal and interannual variability of the Asian and African monsoon. They found that the impact of SM anomaly through the LAI process is significant in relatively dry monsoon regions but not in the humid monsoon regions. Kanae et al [16] also performed a set of GCM simulations on the boreal summer hydroclimate for about 40 years (1951-1998) with and without realistic SM anomalies and noticed that only semi-arid regions in the peripheries of monsoon regions showed reasonably good simulated precipitation compared with that observed. In the Asian region the sensitivity of precipitation to SM condition is large. The only relatively dry area [17] the relationship between SM and precipitation variability on daily to seasonal timescales was also emphasized by several studies. Delworth et al [18] analyzed the temporal variability of 50 years GCM simulation. They showed that the spectrum of SM was red but with significant spatial variations. The red nature of the spectrum was more pronounced at higher latitudes due to the lower potential evaporation. They also did second set of GCM integration with prescribed SM and showed that SM variability. Koster and Suarez [19] performed a series of GCM simulations in which the timescale of SM retention was carefully controlled. As this timescale increased, the variance of daily precipitation decreased and the correlation between consecutive monthly precipitations increased. Sud and Smith [20] also did an experiment in which they prescribed a zero evapotranspiration over India. It was found that the rainfall was essentially unaltered because the increased moisture convergence produced by the enhanced sensible heating of the planetary boundary layer largely compensated for the reduction in evapotranspiration. Sikka and Gadgil [21] also did idealized experiments which indicated that the Indian monsoon rainfall was rather sensitive to regional SM. Recently, Meehl [22] compared the relative contributions of external conditions (involved surface albedo) and internal feedbacks (involved SM) in a number of atmospheric GCMs. He concluded that there was a positive feedback between SM and precipitation over south Asia, with increased SM providing a surface moisture source for further monsoon precipitation. While many numerical studies have demonstrated the sensitivity of the Asian monsoon to sea surface temperature (SST) showing significant correlations between SST and precipitation anomalies [23]. But the sensitivity to SM variations has been much less investigated. As more than half of the world population lives in the monsoon Asia. It is a critical and important question for society what kind of changes are likely to occur in future climate. For this purpose the present study aim to investigate the effect of Indian Ocean warming (SST anomalies without forcing ENSO) on the Asian summer monsoon and the response the Asian summer monsoon to change SM of that region.

2. Model and Data

Model:
The Abdus Salam International Center for Theoretical Physics (ICTP) Atmospheric Global Climate Model (AGCM), simplified parameterization, primitive-Equation DYnamics called SPEEDY [24] is used to perform the simulation forced by the observed Hadley center SST dataset for the period 1949-1998. The resolution of the model is 3.75 times 3.75. The model is based on the spectral dynamical core developed at the Geophysical Fluid Dynamics Laboratory. It is a hydrostatic, sigma-coordinate, spectral-transform model in the vorticity-divergence from described by Bouke (1974) with semi-implicit treatment of gravity waves. The basic prognostic variables are
vorticity divergence, absolute temperature and the logarithm of surface pressure. The parameterized process include large scale condensations, convection, short and long wave radiations, surface fluxes of momentum, heat and moisture, and vertical diffusion. Convection is represented by a mass flux scheme that is activated where conditional instability is present (Namely where saturation moist static energy decreases with height between the lowest layer, PBL, and upper-tropospheric layers). The short-wave radiation schemes uses two spectral bands one of which represents the near-infrared portion of the spectrum. long-wave radiation schemes uses four spectral band one of the atmospheric window and the other ones for the spectral regions of absorption by water vapor and carbon dioxide [24]. The model is configured with eight vertical (sigma) levels and with the spectral truncation at total wave number 30. The land and ice temperature anomalies are determined by a simple one-layer thermodynamic model.

Data:
Climate Prediction Center Merged Analysis Precipitation (CMAP) [25] and The National Center for Environmental Prediction (NCEP) [26] reanalysis data were used for different experiments. NCEP reanalysis data was used for wind field from time duration 1949 to 1998 and CMAP data was used for rain fall from time duration 1979 to 1998.

3. Experimental Design and Climatologies:
For this research purpose, four experiments have been done, these are,

CNTRL → 50 years (1949-1998) long control integration with ICTP AGCM forced by climatological SSTs, Fig.1.1 (a)

EXP-1→ A 50 years (1949-1998) integration with ICTP AGCM forced by positive SST anomalies in the Indian Ocean (domain 32S-32N, 30E-150E) Fig.1.1 (b)

EXP-2→ 50 years (1949-1998) integration with ICTP AGCM run by 20 percent decreasing soil moisture in the same domain Fig.1.1 (c)

EXP-3→ 50 years (1949-1998) integration with ICTP AGCM run by 20 percent increasing soil moisture in the same domain Fig.1.1 (d)

Figure 1.1: Show the summer SST (from left to right) of control run, EXP-1, EXP-2, and EXP-3. Unit of SST is K.

Climatologies:
The Asian monsoon region was selected to perform the analysis. The CMAP and NCEP reanalysis data set used to find the influence of Indian Ocean warming and soil moisture on the Asian summer monsoon. The Asian summer monsoon starts from June to September. We analysis the climatic feature June to September. The precipitation and 925 hpa wind climatology from JJAS has been shown in the Fig.1.2.  The Fig.1.2 displays the observation and model climatologies. Fig.1.2 (left) shows that the observed precipitation climatology from the CMAP data set. CMAP data derived from satellite observations are considered more reliable than reanalysis estimates. But are available only from 1979. Here we used the period 1979 to 1998. Fig.1.2 (left) shows precipitation maximum over the Bay of Bengal, Northern India, west coast of India and equatorial and south-equatorial Indian Ocean. On the other hand Fig.1.2 (right) shows precipitation maximum at the center of the Indian Ocean, Bay of Bengal, equatorial and south equatorial Indian Ocean. It has been shown that equatorial flow, the Somali jet, even though weaker than observed.

The summer (JJAS) mean flow (observation and model) patterns at 850 hpa are shown in the Fig.1.3 (left) respectively. It has been shown that flow weakens than observed. Fig.1.3 (right) shows 200 hpa wind field
climatologies for observation and model respectively. At 200 hpa the most outstanding features are the huge anticyclonic circulation centered over the southern edge of the Tibetan plateau. Fig.1.4 (left) shows the horizontal distribution of the surface-temperature at 925 hpa for summer monsoon (JJAS). A huge warm air mass is centered on the north-west and centre part of Asia. There are no significant different between model and observation. Fig.1.4 (right) shows the surface pressure distribution over that region. Generally it has been shown that at summer (JJAS), surface pressure of land area is low compared to the ocean. It also shows that some part of Arabian sea and Bay of Bengal show high pressure during the summer season. It can be said that, overall the ICTP AGCM captures all the climatic feature which are well match with observation.

Figure 1.2: The precipitation and 925 hpa wind climatology for JJAS, Observation (left), Model (right). Unit of Precipitation, mm/day.

Figure 1.3: Summer wind speed at 850hpa of OBS (left-upper) Model (left-bottom) & and 200 hpa of OBS (right-upper) & Model (right-bottom) Unit of wind speed, m/s
4. Results and Discussion

EXP-1: To determine the exact SST anomalies in the Indian Ocean, we subtract the CNTRL simulation SST from EXP-1. It has been shown that positive SST anomalies in the range (0.3 to 0.7) °C. The Arabian sea, Bay of Bengal, and south east Indian ocean experience much warming Fig.1.5 (left). Fig.1.5 (right) display the relative change of precipitation and wind flow at 925 hpa with respect to CNTRL simulation. It has been shown that a reduction of precipitation in the east Asia, Philippine and central Indian ocean. A significant increase in precipitation in the Bay of Bengal, Arabian sea, south India and Indonesian Island. The reduction of precipitation is related to the weakened the Somali jet and divergence of the wind flow. It has been shown that in the Fig.1.6 (left) and Fig.1.6 (right) a strong convergence occur in the Arabian sea for this more precipitation occur in this region. Another explanation is, the positive SST anomalies created a low pressure that produce a convective instability which create more precipitation in this location. There is a positive and negative anomalies precipitation dipole in the meridional direction are nearly equal in magnitude create in the east Asian region. It is think that, the strong impact of the east-west heating contrast on the east Asian regions.

Figure 1.5: The positive SST anomaly of Indian Ocean for EXP-1-CNTRL (left) in JIAS, Relative change of Precipitation & 925 hpa wind climatology (right).

Fig.1.7 (left) shows the relative change of surface temperature difference at 925 hpa at JIAS from EXP-1-CNTRL simulation. It has been shown that, central India experience decreasing temperature which is related to more precipitation during the monsoon period. Distribution of pressure is show in the Fig.1.7 (right) show the relative
change the pressure difference from EXP-1-CNTRL. It has been shown that only pressure decreasing in the Arabian sea, and increasing at central India which is related to the more precipitation of that region.

**Figure 1.6:** Summer wind speed at 850 hpa and 200 hpa of EXP-1-CNTRL (left) aEXP-1-CNTRL (right) respectively.

**Figure 1.7:** Surface temperature difference at JJAS, EXP-1-CNTRL (left), Surface pressure difference at JJAS, EXP-1-CNTRL (right), Unit of temp 7 Pressure is K & hpa respectively.

**EXP-2 and EXP-3:**
Soil water availability that are prescribed over south Asia in the perturbed experiments EXP-2 and EXP-3. SM directly related to the soil water availability. This is show in the Fig.1.8, here the percentage of SWAV decreasing in EXP-2 and increasing EXP-3. The effect of SM on the precipitation has been shown in the Fig.1.9. If we see the Fig.1.9 (bottom left) we see that, a reduction of precipitation occur on the Bay of Bengal and the South Indian region, and increase of precipitation occur north Asia. Fig.1.9 (bottom right) show the opposite feature of precipitation pattern but not symmetric. Two processes are competing in this area. I) increased SM means more evaporation and therefore more precipitation. II) more evaporation also leads to surface cooling which decreases the meridional temperature gradient and there by the monsoon circulation and precipitation. And a relatively high impact of SM anomaly in dry or semiarid regions. For this reason precipitation not increasing as expected in the south Indian region in EXP-3 but increasing in North Indian region. SM also could persist long enough to modify the atmospheric circulation over seasonal to inter annual timescales, this is shown in the Fig.1.10 which is 850 hpa wind field and 200 hpa wind field. It has been shown that the circulation pattern totally different for EXP-2 and EXP-3. So can be said that Dry (wet) SM anomaly is associated with a strengthening (weakening) of the monsoon trough and of the south west monsoon flow.

SM also affects the surface- temperature. Fig.1.11 shown surface-temperature increasing in EXP-2 and decreasing in EXP-3 and that is symmetric. One possible explanation when we changing SM the sensible and latent heat fluxes also change which lead to change the surface-temperature. Fig.1.12 show the pressure distribution of the
The Influence of Indian Ocean Warming and Soil Moisture Change on the Asian Summer Monsoon

EXP-2 (upper left) and EXP-3 (upper right) and the variation with respect to CNTRL are bottom left and right. It has been shown that pressure decreasing in the remote area from area where we decreasing SM and vice versa.

The changing of Asian summer monsoon related to many parameters. We only investigate the positive SST anomaly and SM. It is claim that snow cover melting in the Himalayan region impact on Asian summer monsoon. On the other hand the anomaly of the surface and near-surface SM is likely to have a persistence of several days to several months, which may cause climate memory through anomalous surface energy and moisture fluxes. So I have a plan to research the impact of snow cover melting on the Asian summer monsoon.

Figure 1.8: Soil water availability in percent (SWAW) for EXP-2 (upper left), EXP-3(upper- right) and EXP-2-CNTRL (bottom left), EXP-3 (bottom right).

Figure 1.9: Precipitation and wind speed for EXP-2 (upper left), EXP-3 (upper right) and EXP-2-CNTRL (bottom left), EXP-3 (bottom right), Unit mm/day.
Figure 1.10: Wind speed at 850 hpa for EXP-2 (upper left), EXP-3 (upper right) and EXP-2-CNTRL (bottom left), EXP-3 (bottom right), Unit m/s.

Figure 1.11: Surface temperature for EXP-2 (upper left), EXP-3 (upper right) and EXP-2-CNTRL (bottom left), EXP-3 (bottom right), Unit, K.
The Influence of Indian Ocean Warming and Soil Moisture Change on the Asian Summer Monsoon

5. Conclusion

The present study investigates the influence of a positive SST anomaly on the Indian Ocean (which is produce by consequence of the global warming) and the SM change on the Asian summer monsoon. It has been shown that there is a significant increase of precipitation in the south Asia, Bay of Bengal, Arabian sea and Indonesian Island and reduction of precipitation in the central Indian Ocean and east Asia. There is a positive and negative anomaly precipitation dipole in the meridional direction of nearly equal in magnitude creates in the east Asian region. So it can be conclude that there is a teleconnection between the positive SST anomaly and precipitation of the east Asian region. On the other hand SM plays an important role on the Asian summer monsoon. Mechanisms is compelling in this area, Increase SM means more evaporation and therefore more precipitation. In this study it has been shown that the monsoon precipitation increasing in the north Indian region compare to south Indian region with increasing SM. It also shown that a reduction of precipitation occurs on the Bay of Bengal when decreasing SM. So it can be concluded that SM and precipitation feedback regionally dependent and there is a positive feedback between SM and precipitation over south Asia.
Bibliography


