

Air Sea Interaction Over the Indian Ocean During the Contrasting Monsoon Years 2002 and 2003

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Abstract

[1] The air sea interaction processes over the Indian Ocean are studied using the satellite data from the Tropical Rainfall Measuring Mission Satellite for two contrasting monsoon years, namely 2002 (deficit) and 2003 (normal). The moisture transport for the two contrasting years was also analyzed using the NCEP/NCAR reanalysis data. Linear correlation coefficient between the convective heating over the Bay of Bengal and the zonal wind at 850 hPa over the peninsular India showed the maximum negative correlation (-0.41) and is statistically significant at 99.9% significance level with a lag of 3 days, with convection leading. The evaporation rates were lower (higher) over the Arabian Sea during active (weak) monsoon conditions, indicating its negligible influence on the ensuing monsoon activity over the subcontinent. Water vapor contents decreased substantially prior to the break over the Arabian Sea and low values prevailed throughout the break period. Further, it was seen that more moisture was transported into the subcontinent (equatorial region) during the active (weak) monsoon conditions.

1. Introduction

[2] The air-sea interaction processes over the Indian Ocean during two recent contrasting monsoon seasons were studied using the data from the Tropical Rainfall Measuring Mission (TRMM). The summer monsoon of 2002 had one of the longest breaks in the recent decades [Ramesh Kumar and Uma Prabhudessai, 2004].

[3] Holt and Raman [1986] using the data from the Monsoon Experiment (MONEX-79) have shown that the evaporation over the Arabian Sea is about two to three times higher during the active conditions as compared to break conditions.

[4] No such study is available for shorter time scales, less than a month, and thus the possible role of various air-sea interaction parameters and evaporation over the Indian Ocean on the summer monsoon remains unknown. The availability of the recently released dataset popularly known as

HOAPS (Hamburg Ocean Atmosphere Parameters and fluxes from Satellite data, for more details please see Grassl *et al.* [2000] has helped in looking at this problem on a better spatial (0.5° X 0.5°) and temporal (5 day mean) scale. The objective of this study is to look into the role of air-sea interaction processes over the Arabian Sea and of evaporation in the Arabian Sea prior to, during and after a recent prolonged break in the monsoon condition July 2002 and contrast it with that of 2003 when monsoon was normal.

2. Monsoon activities of 2002 and 2003

[5] The Indian summer onset of monsoon began on 29th May in the year 2002, 3 days earlier than the normal onset date of 1st June. Even though the onset was in time, it covered the entire subcontinent by only 15th August, a delay of almost one month. In 2003, the monsoon onset was on 8th June, delayed by about one week, but the monsoon covered the entire subcontinent by 5th July, ten days ahead of the normal period. Figure 1 gives the daily all India rainfall for the period 1st June to 30th September for the contrasting years, 2002 and 2003. The seasonal rainfall for the country as a whole was 81% of the long period average in 2002 whereas it was 102% of the long period average in 2003. Further, rainfall for the month of July in 2002 was the lowest (-51%) during past 102 years. Also for the first time in last 133 years there was not even a single depression during the monsoon season of 2002 [Kalsi *et al.* 2004]. The monsoon season of 2003 on the other hand had two depressions in Bay of Bengal.

3. Data

[6] The various air-sea interaction parameters needed for the present study, namely, sea surface temperature, wind speed, cloud liquid water, precipitable water and rainfall have been taken from the TRMM Microwave Imager (TMI) sensor onboard the Tropical Rainfall Measuring Mission (TRMM) (see the website of Remote Sensing Systems <ftp://ftp.ssmi.com/tmi>) for the years 2002 and 2003. They have been further spatially averaged over different study areas namely a) Arabian Sea (45°E – 75°E, 8°N-25°N) and b) Bay of Bengal (80°E-100°E,

8°N-25°N). The evaporation rates for the year 2002 were extracted from the recently available second version of HOAPS dataset – HOAPS II (<http://www.hoaps.zmaw.de>). More details can be had from *Jost et al.*, [2002], *Grassl et al.*, [2000]. The specific humidity and zonal wind were obtained from NCEP/NCAR Reanalysis [*Kalnay et al.*, 1996] website

ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis.daily_avgs. The moisture transport into the three regions a) northern part of the Indian subcontinent (15°N–25°N) b) southern part of the Indian subcontinent (5°N-15°N) and c) equatorial region (5°S – 5° N) along 75°E has been computed by vertically integrating the values of horizontal water vapour flux from 1000 hPa to 300 hPa. The Outgoing Longwave Radiation (OLR) for the study period is taken from the interpolated OLR data provided by the NOAA-CIRES (Cooperative Institute for Research in Environmental Sciences) Climate Diagnostics Center, Boulder, Colorado, from their website <http://www.cdc.noaa.gov> [*Gruber and Krueger*, 1984].

3. Results

[7] *Krishnan et al.* [2003] have studied the influence of positive SST anomalies over the equatorial Indian Ocean and southwest monsoon rainfall in 2000. Their study revealed that the strengthening of the convective activity over the region of the Southern Hemisphere Equatorial Trough (SHET) played a key role in inducing anomalous subsidence over the Indian subcontinent and thereby weakening the monsoon. Further, the warm Indian Ocean SST anomalies influenced the regional intra-seasonal variability in such a manner that it favored prolonged breaks of the monsoon. In our analysis of July SST differences (i.e. difference of 2003 and 2002, figure 2) we found positive ones over most of the eastern equatorial Indian Ocean region in 2002 as compared to 2003, confirming the results of *Krishnan et al.* [2003] on its influence on the prolonged break of the monsoon.

[8] *Gadgil et al.* [2003] have found that convection over the eastern (western) equatorial Indian Ocean is enhanced (suppressed) during the drought years and this difference in convection led to surface zonal wind anomalies from west to east. In the excess years, we have zonal wind anomalies from east to west. An analysis of the Outgoing Longwave Radiation (OLR) differences for July (figure 3) of the contrasting years showed that, the eastern equatorial Indian Ocean was convectively more active in 2002.

[9] *Srinivasan and Nanjundiah* [2002] have shown that the increased convective activity in the Bay of Bengal induces stronger winds in the Arabian Sea

and this in turn enhances the advection of moisture into the Indian subcontinent, leading to increased precipitable water and strength of the monsoon. Using a simple thermodynamic model, they showed that increased precipitable water during July leads to increased rainfall. In our present study we found substantial decrease in the precipitable water content in the month of July over the Arabian Sea for 2002 as compared to 2003 by about 10 to 15 mm (figure 4a). The convective activity over the Bay of Bengal was substantially reduced in July 2002 as compared to 2003 and this could have resulted in weaker moisture transport into the Indian subcontinent (figure 4b).

[10] In order to verify whether such a relationship between convective heating over the Bay of Bengal and zonal wind speed over the Arabian sea holds good in the present case, we have looked at the linear correlation coefficient between the OLR over the region (82.5°E – 92.5°E; 5°N-15°N) and the zonal wind speed at 850 hPa over the peninsular region (70°E-80°E; 10°N-20°N) for the monsoon season of 2002. The linear correlation coefficient between OLR over the Bay of Bengal region and the daily 850 hPa zonal wind over the peninsular India for lags of –10 to + 10 days is given in Figure 5. From the figure it can be seen that the maximum negative correlation (-0.41) occurs between convection over the Bay of Bengal and the zonal wind at 850 hPa over the peninsular India with a lag of 3 days and is statistically significant at 99.9% significance level, with OLR leading. *Jospeh and Sijikumar* [2004] have obtained a similar relationship between the OLR and U index while looking intra-seasonal variability of the low level jet stream of the Asian summer monsoon. They found that the convective heat source over the Bay of Bengal and the strength of the low level Jet stream (zonal component of the wind) at 850 hPa over peninsular India have the highest linear correlation at a lag of 2-3 days.

[11] Figure 6 depicts the vertically integrated moisture transport (VIMT) into the Indian subcontinent. More details of the computation can be taken from *Swapna and Ramesh Kumar* [2002]. More moisture was transported into the equatorial region during the months of June and July in 2002. According to *Joseph and Sijikumar* [2004] the axis of the low level jet stream (LLJ) with its core around 850 hPa is oriented southeastwards over the eastern Arabian Sea and it flows east between Sri Lanka and equator and there is no LLJ over the peninsular India, during the monsoon onset phase and the break in monsoon conditions. This could be the reason why more moisture was transported into the equatorial section during 2002, which agrees with earlier study of *Swapna and Ramesh Kumar*

[2002] that obtained a similar result for the contrasting monsoon years of 1987 (deficit) and 1988 (excess).

[12] *Narayanan et al.* [2004] using the satellite derived parameters, found relatively dry atmosphere west of 65°E, signifying lack of convection and an unstable atmosphere over the southeast Arabian Sea with west-east gradients in precipitable water, cloud liquid water and stability index. We also observed a large west-east gradient in OLR differences during July 2002, which supports the previous results of *Narayanan et al.* [2004].

[13] In order to elucidate the role of the evaporation over the Arabian Sea on the monsoon activity over the Indian subcontinent, we have looked at the evaporation rates over the Arabian Sea during two contrasting monsoon periods, namely active monsoon period (11-15 August, 2002) and weak (6-10 July, 2002). It can be seen that the evaporation rates were in general lower over the Arabian Sea during active conditions (figure 7a) which is in agreement with the previous study of *Ramesh Kumar and Schluessel* [1998] and in contradiction to the result of *Holt and Raman* [1987]. The evaporation rates were larger over the Arabian Sea during the break monsoon conditions (figure 7b).

4. Conclusions:

[14] The evaporation rates were lower (higher) over the Arabian Sea, during active (weak) monsoon conditions over the Indian subcontinent, indicating its insignificant role on the ensuing monsoon activity over the Indian subcontinent for the monsoon 2002. The linear correlation coefficient between the convective heating over the Bay of Bengal and zonal wind at 850 hPa over the peninsular India showed maximum negative correlation (-0.41) and statistically significant at 99.9% significance level with a lag of 3 days, with OLR leading. The unusual prolonged break in the monsoon during July 2002 was due to the combined effect of reduced convective activity over the Bay of Bengal, decreased precipitable water in the Arabian Sea, more vertically integrated moisture being advected into the equatorial Indian Ocean region.

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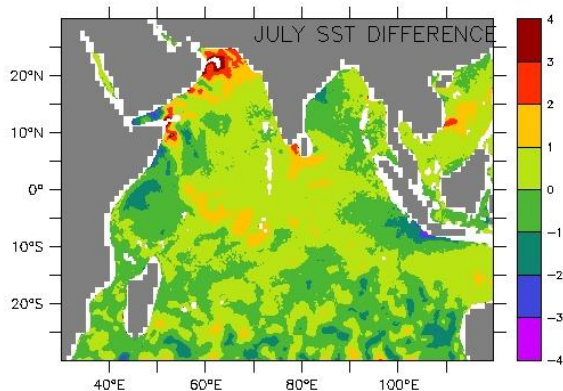


Figure 2. SST differences in degrees celsius (2003 – 2002) for July.

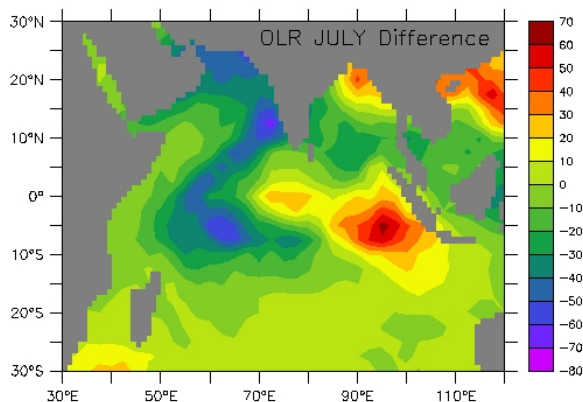


Figure 3. OLR differences in (W/m^2) (2003 – 2002) over the tropical Indian Ocean for July.

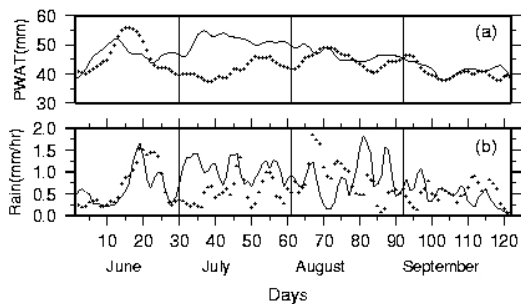


Figure 4a) Daily values of PWAT (mm) over the Arabian Sea for 2002 (dotted line) and 2003 (solid line) from 1st June. 4b) Daily values of rainfall (mm) over the Bay of Bengal for 2002 (dotted line) and 2003 (solid line) from 1st June.

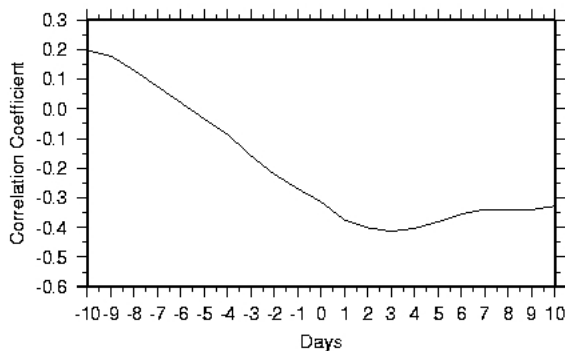


Figure 5: Linear Correlation coefficient between the daily OLR over the Bay of Bengal (area 82.5°E-92.5°E; 5°N-15°N) and the zonal wind speed at 850 hPa over the peninsular India (area 70°E-80°E; 10°N-20°N) for lags –10 days to 10 days. Maximum negative correlation is -0.41 with a lag of 3 days.

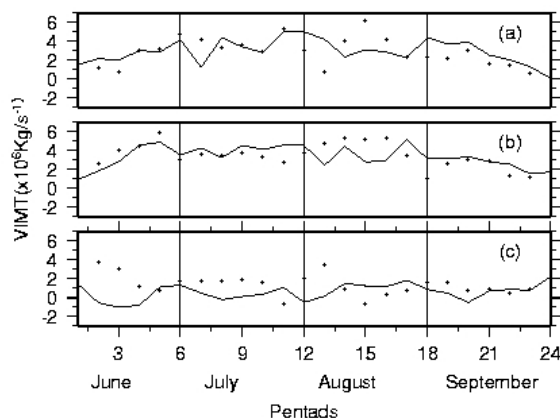


Figure 6. The VIMT into three different regions a) northern part of the Indian subcontinent b) the peninsular region and c) equatorial region for the different pentads starting from 1st June to 30th September for the contrasting monsoon years, 2002 (dotted line) and 2003 (solid line).

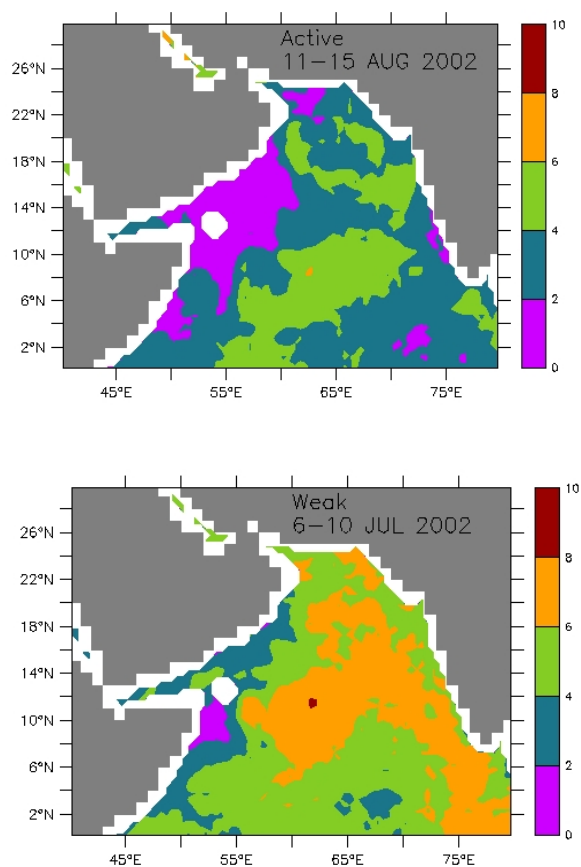


Figure 7. The evaporation rates over the Arabian Sea during two contrasting monsoon activity period over the Indian subcontinent a) Active monsoon conditions (11-15 August, 2002) and b) Weak monsoon conditions (6-10 July 2002).

Figure 1 . All India daily rainfall (mm) for 2002 and 2003 from 1st June. The solid line represents the daily normal.

