On the drought condition of 2002 Indian Summer Monsoon

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Abstract: 2002 Indian Summer Monsoon is charecterised by its extended drought during July. Potential role of the rainfall on the economy and the life of the Indian subcontinent gives motivation to study this extreme drought event. In addition to that, the climate model fails to predict this unusual drought event, not only catching the unprecedented media attention, but also putting a challenge with a case difficult to predict. Moisture convergence and availability from the ocean over the Arabian Sea are studied with a focus on its role in the drought condition of 2002 summer monsoon, and results are compared with the other years. Low level moisture over the Arabian Sea anomalously diverges through out the monsoon season, with a special characteristic in July 2002, while sustained and organized moisture convergence is an indication of a good rainfall. Moisture supply from the Arabian Sea during May and June 2002 was higher compared to that of the other drought years since 1972, however the drought condition rapidly developed in July. Anomalous divergence of wind over the Arabian Sea is found in July 2002, which led to a decrease in surface wind and shallowing moisture transport across the western coast of India. This divergence seems to be the special event which took place in the 2002 summer monsoon and was in coherent with the reduction in rainfall.

1. Introduction

The Indian subcontinent receives about 70% of rain in a summer monsoon season from June to September. Particularly, the 2002 summer monsoon over India is characterised by a wide spread of reduced rainfall. In Fig.1 shown are the daily rain fall of 2002, 2001 and 2000 collected from 100-200 stations spreading throughout the country, and also the daily climatological mean. It is evident that the 2002 mean rainfall is less than the normal, as well as a long drought in July is anomalous. This study concentrates on the estimation of moisture supply from the ocean and its convergence in the lower atmosphere over the Arabian Sea of 2002 and to compare it with (a) two adjacent years (2001, 2000), (b) composite of wet monsoon years and (c) other drought years since 1972. The Low level atmospheric moisture convergence and cloud formations are the fundamental mechanisms for the maintenance of monsoon and rainfall.

2. Method of Study

Evaporation is estimated as Ocean Latent Heat Flux (W/m^2) using bulk formula, $LH = \rho \bullet C_d \bullet L_v \bullet U \bullet (Q_s - Q_a)$, where the terms have usual meteorological meanings. Here sea surface humidity (Qs) is estimated from the model SST derived by using Australian Community Ocean Model (ACOM2.0). This provides the realistic oceanic response to atmospheric forcing in the respective years. An atmospheric Moisture budget is estimated from the sea surface flux and three dimensional advection in the atmosphere by using wind and humidity data derived from NCEP/NCAR. The total moisture budget equation can be written as

$$E-P = \int [\partial q/\partial t + \nabla_{(H)} (q \bullet V) + \partial (wq)/\partial z] \bullet dl \quad (1)$$

where E is the evaporation, P is the precipitation, V is the horizontal wind (u_i ,v_j), z is the altitude and l is the vertical level. The term $\nabla_{(H)}(q \bullet V)$ represents the moisture convergence (divergence). A vertical integration of mositure convergence (divergence) from the sea surface to 750mb is employed for the troposphere.

3. Analysis Results

3a. Comparison of Atmospheric moisture convergence

In Fig.2 is shown the area averaged moisture convergence (divergence) over the Arabian Sea for the monsoon months (May-Sep) of 2002, 2001 and 2000 at 1000mb level. We note from the figure that, during 2002, moisture is relatively diverged at lower level over the Arabian Sea through out the

monsoon season. For the years 2001 and 2000, multiple events of moisture convergence and divergence are evident throughout the monsoon season. A composite of moisture convergence for the wet monsoon years is constructed and shown in Fig.3. Since the area used for averaging is considerably large, a sustained and organized low level moisture convergence over the Arabian Sea is an indication of wet a monsoon year. Moisture convergence (divergence) over the Arabian Sea is highly correlated with the rainfall (Fig.4). The surface moisture convergence (divergence) and its vertical integration from surface to 750mb show that, year 2002 is characterised by the large scale moisture divergence in the tropospheric level compared to the curresponding moisture convergence of the composite of wet monsoon years. A lack of moisture convergence was one major characteristic of 2002 summer monsoon.

3b. Comparison of Latent Heat Flux (W/m^2)

There is no distinct difference between the ocean Latent Heat Flux of 2002, 2001 and 2000, and it is attributed to the relative poor rainfall of these years. A comparison of 2002 ocean Latent Heat Flux with other drought years since 1972 shows that, (we checked five drought years since 1972 (1972,1979,1982,1986 and 1987)), Latent Heat Flux of May 2002 was comparatively larger than the other drought years by a 40 W/m^2, continuing upto June. In July 2002, the ocean Latent Heat Flux was reduced and became similar to the other drought years. Thus until June, 2002 was not as anomalous or dry as the other drought years, whereas a drought-like situation developed in July, and it persisted in August and September. This is in coherent with the relative drought spell in July.

If we imagine that the Latent Heat Flux(W/m^2) itself represents the moisture over the sea surface, its convergence (divergence) could also point to the curresponding moisture convergence (divergence) at the sea surface qualitatively. For the years analysed, we get a close correlation. Thus ocean Latent Heat Flux can be a proxy of moisutre. A close examination tells that, 2002 ocean Latent Heat Flux divergence itself is different from the other drought years (Fig.5). Especially during May, all the other drought years have well strengthened divergence, whereas in May 2002, it is relatively weaker divergence. During July 2002, the Latent Heat Flux divergence is special comparing to the other drought years. This divergence also yielded the moisture divergence in the lower atmosphere.

4. Discussion and Conclusion

A consistent feature of 2002 summer monsoon reveals from the moisture budget analysis is the anomalous divergence (descending motion of the atmosphere) during July. This is in coherent with the drought spell in rainfall over land. The moisture convergence (divergence) is highly correlated with the intraseasonal oscillation of rainfall. More over the moisutre transport across the western coast of the land has been found shallowed during July 2002 (figure not shown). The shallowness corresponds to a smaller vapor flux or low amount of precipitable water vapor entering into the continent. The vertical circulation of the atmosphere during the summer monsoon (Hadley cell-ascending motion over warmer continent and descending motion over the equitorial Indian Ocean) is analysed for 2002. It can be seen than, during July 2002, there is an anomalous divergence over the Arabian Sea, setting up an opposite Hadley cell, weakening the cross equitorial jet at the lower level, or weakening the monsoon. This weakening in wind speed causes a reduction in the ocean Latent Heat Flux (or ocean moisture supply) over the Arabian Sea. The anomalous divergence likely to shallow the vertical moisture transport across the continent and rainfall became weak. The dramatic reversal of Hadley cell could be due to an equitorial ascend, triggering by the warmer ocean than the northern continent. The rapid demise of the rainfall from June to July of 2002 is justifiable with this divergence. The 2002 drought year is the odd one out of last 14 years of normal or above normal rainfalls, and the drought conditions over the Arabian Seas of 2002 is odd one since 1972. This event could be considered as the abrupt changes in the climate, where the tropical regions are always subjected to such changes.

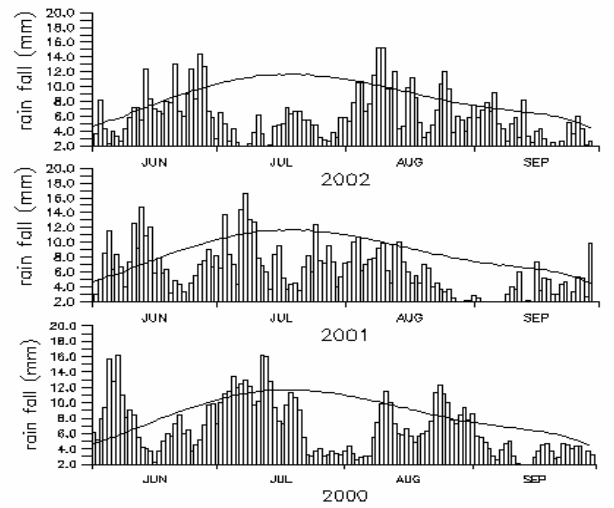

Fig.1. All India Summer Monsoon daily Rainfall (AISMR) collected over 100-200 stations spreading throug out the country (adopted and reproduced from http://www.tropmet.res.in)

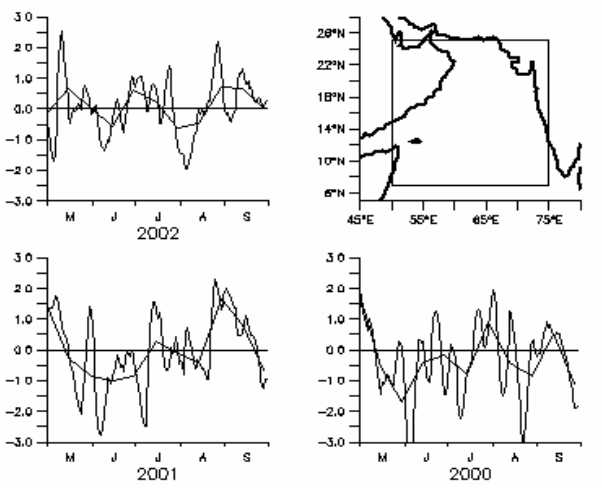

Fig.2. Area averaged moisture convergence (divergence), positive indicates divergence, for 2002, 2001 and 2000 over the Arabian Sea. A divergence during 2002 July is evident. A five day running mean is applied for smoothing. A 15 day average is also shown. (10^{-6} m^2s^{-1})

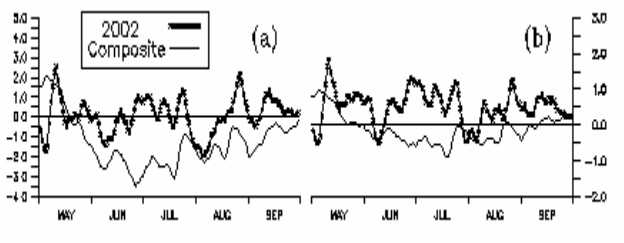

Fig.3. Moisture convergence (divergence) for 2002 (dot line) and composite of wet rainfall years (full line) (a) for 1000mb (b) vertical integrated from 1000mb-750mb

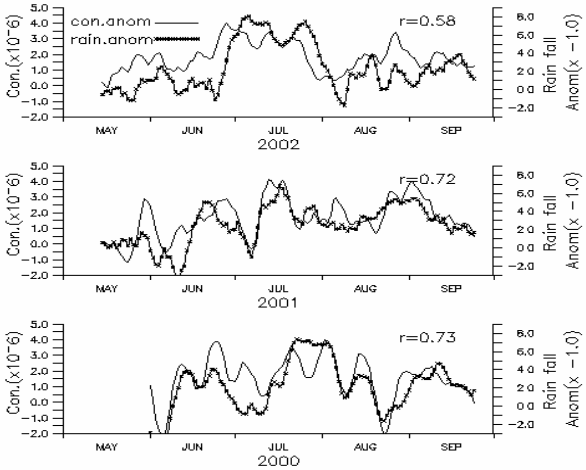

Fig.4. A high correlation is found between moisutre convergence (divergence) anomaly and rainfall anomaly. Correlation is shown inside.

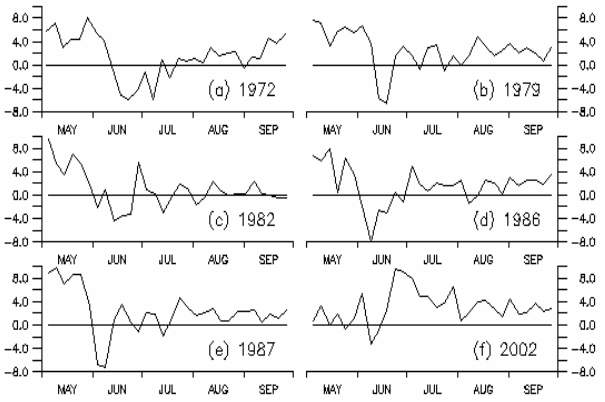

Fig.5.(left). Latent Heat Flux convergence (divergence) over the Arabian sea for 2002 and other drought years since 1972. 2002 Latent Heat Flux divergence is anomalous from other drought years. A specially characterised divergence during July 2002 is coherent with the drought in rainfall over land.