The Abnormal Indian Summer Monsoon of 2002: JRA25 Reanalysis

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INTRODUCTION

Over half the world's population lives within the influence of the Asian monsoon and a further large fraction lives within the monsoon areas of Africa and the Americas. The occurrence of this Asian summer monsoon circulation is one of the most spectacular seasonal phenomena on the globe. The summer monsoon is the single most important weather in India due to its enormous socioeconomic impact. Forecasting monsoon characteristics, including their onsets, advancements, breaks, duration and the withdrawal, remains a challenging scientific problem (WCRP 2005) because of the complexities of the interactions involved in it. In particular the Indian summer monsoon 2002 has drawn the attention of the meteorological community because of various factors. In this paper an attempt is made to analyse this abnormal behaviour of the monsoon 2002 with the Japanese Re-Analysis (Onogi et al 2005) data archives. The 2002 season also coincides with a period of exceptionally dense satellite monitoring .

DATA USED

Data from multiple sources have been employed for this study. The new atmospheric re-analysis, the Japanese 25-year Re-analysis (JRA25) that covers the 26 years 1979 - 2004 is introduced. Generally, reanalysis produces global objective analysis datasets for over a decade in a consistent manner with state-of-the-art data assimilation system. The data assimilation and forecast system of JRA25 is the global spectral model at a Spectral Triangular truncation of 106 (T106) waves with 40 layers. The resolution will be equivalent to a horizontal grid size of around 120 *km*. It is noteworthy to say that the JRA25 has assimilated the following observations during 2002: (i) the brightness temperature from TIROS Operational Vertical Sounder (TOVS) on board National Oceanic and Atmospheric Administration (NOAA)-14 vertical profiles (ii) the Advanced TOVS level 1-c raw data (iii) the Special Sensor Microwave/Imager (SSM/I) precipitable water vapor (iv) the atmospheric motion vectors from European Meteorological Satellites (v) Chinese snow depth (vi) wind profiler (vii) exceptionally dense space-based observations like QuickScat wind, etc. We use monthly mean reanalysis data from National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) for the period 1958-2004. Precipitation data for this study are also obtained from the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) datasets (Xie and Arkin 1997) valid for 1979-2004. The rainfall time series was obtained from the Indian Institute of Tropical Meteorology (IITM) Pune, India.

ONSET OF THE MONSOON

The arrival of the summer monsoon over the Kerala coast is found to be reasonably punctual either towards the end of May or beginning of June (Ramesh et al. 1996; Taniguchi and Koike 2006). Given the relatively small scale of Kerala that is less than 200 *km* in breath, sensitivity of the declaration of onset based solely on the district's rainfall to spatial area in the monsoon transitions is also likely to be large. India Meteorological Department (IMD) declared the observed onset date of the southwest monsoon 2002 over the Kerala on 29 May, which is three days before the normal date. The following characteristics for the evolution of the onset over the Arabian Sea covering the area of 0° - 19.5° N and 55.5 °E - 75 °E: (a) the net tropospheric (1000 - 300 *hPa*) moisture build-up, (b) the mean tropospheric (1000 - 100 *hPa*) temperature increase, (c) sharp rise of the kinetic energy at 850 *hPa*. From JRA25 it is calculated that the mean tropospheric moisture value are at the order of 50 ~ 66 (*mm*) over this Arabian Sea area. The evolution of the monsoon onset process starts with the tropospheric moisture build-up which takes place as a consequence of the intensification of the low level cross equatorial flow with required intensity. As a result of the transient activity, latent heat release takes place in the troposphere leading to an increase of mean tropospheric temperature. The computed value of the mean tropospheirc temperature from 1000 - 100 *hPa* for this period over the above box also shows the indication of the onset. The 850 *hPa* shows the persistent and sharp increase of the kinetic energy over the Arabian Sea at the order of 60-80 (m^2 s^{-2}) during this onset period. From this computation we have convinced that the onset date is 29 May, as declared by IMD.

In 2001 Wang et al. introduced a dynamical index based on horizontal wind (*U*) shear at 850 *hPa* called the circulation index. They recommend that the circulation index computed with the mean difference of the zonal winds (*U*) between the two boxes; one for southern region and the other for the northern region, ie 05° – 15° N, 40°- 80°E and 20°-30° N, 70°-90° E can be used as the criteria for identifying the onset date. In 2002 Syroka and Toumi also defined a similar type of circulation index introduced by taking the box slightly towards east of Wang's case. In both the cases the regions are chosen to be dynamically consistent where the convective heating taking place over the summer Indian subcontinent and also correspond with the common mode of variability. The daily circulation index can be used to define both the dates of onset and withdrawal of the Indian summer monsoon from these regions. From the JRA25 datasets we can infer that, there is a clear asymmetry to the annual cycle with a steep increase in the index at the onset time. More explicitly, the changes of sign of the index in the boreal summer indicate the date of onset.

ADVANCEMENT PHASE

After onset, the northern limit of monsoon usually defined as the northern limit of the continuous belt of precipitation, which moves northward progressively. It is obvious that this movement is not uniform as it has inter-annual variability. The Indian summer monsoon undergoes periods of enhanced and reduced rainfall activity over a large region in central and north India. In the advance phase by 12 June, the monsoon covered peninsular India, northeastern region and some parts of east central India. During this advancement phase there were three stagnation epochs (i) 13-19 June, (ii) 05-18 July, (iii) 20 July – 14 August; observed from IMD daily weather charts as well as from IITM rainfall maps.

The stagnation which occurred in June was of rather shorter duration of seven days from 13 June, but the stagnation occurred in July was for the period of 14 days from 05 July. One more stagnation epoch noticed again during the period 20 July – 14 August. Thus the total number of stagnation days that occurred during 2002 is observed as 43 days. Hence it is clear that the advancement phase of monsoon 2002 was not only most delayed but also the duration of the monsoonal flow pattern over the India was only 78 days out of 122 calendar days. So this monsoon 2002 is abnormal. The monsoon advancement to northwestern parts of India was so late; the whole country came under the influence on monsoon only after 15 August.

During this 2002 season this zonal wind speed 18 $m\ s^{-1}$ is remarkably less than the normal climatological values. From the JRA25 datasets it is seen that for the month of June the jet was having the speed of more than 20 $m\ s^{-1}$ along the latitudinal belt of 10°-15°N at the fixed longitudinal view of 60° E. Subsequently in general it is supposed to intensify in July month, but in this season it was reduced by 4-6 $m\ s^{-1}$. This strength can be correlated with the poor rainfall realized during July. In the month of August it picked up its strength and it reached more than 20 m s^{-1} by keeping almost the same latitudinal position. The cross equatorial flow can be examined by analyzing the meridional component of the wind (*V*) over a suitable latitudinal belt. The strength of meridional wind at the equatorial view over the longitudinal belt of 30 °E -100 °E for the monsoon months (June, July, August) are seen. On an average it has the strength of 10-14 $m\ s^{-1}$ valve ranging from the latitudes 40°E – 50°E at the level 950 – 800 *hPa*. In this monsoon season the August month has the maximum strength, which has brought a good amount of rainfall over India. No remarkable cyclonic storm, depression, deep depression formed during the monsoon 2002. This is also a unique notable history for the past 133 years. The JRA25 datasets says that in this year 2002 many typhoons have seen over the pacific regions especially in July. Hence many days the break condition prevailed over the Indian region during July, which leads to drought condition.

CIRCULATION PATTERN

The JRA25 data are used for studying the seasonal mean characteristics of the flow pattern. The wind anomaly for the year 2002 has been computed from the JRA25 database of 1979-2004. Here we study the wind anomaly pattern of JRA 25 for July month against the wind anomaly pattern of NCEP for the lower and upper levels separately. The Figures (1a, 1b) show the July month circulation anomalies of JRA25 and NCEP reanalysis at 850 *hPa.* The cross equatorial flow at 850 *hPa* in the Arabian Sea was very weak since the easterly anomalies was observed over this region up to Somalia coast. From the figures we noticed that Indo-Gangetic plains, easterlies were not seen. Strong westerly anomalies were observed. Hence we can note that the monsoon trough was very weak. Thus it gives one more clue for the occurrence of break during July. At 200 *hPa* a strong westerly anomaly was seen at the tropo-pause level over northwest India. During July strong mid-latitude westerlies were observed due to the existence of anticyclone over the northern part. The presence of the Tibetan anticyclone can be noticed in the NCEP as well as JRA25 datasets. In the southern region the Tropical Easterly Jet was seen in a much weaker condition than the normal strength. It is also one of the reasons for the poor rainfall over India. In this section we ultimately examined the JRA25 long-term flow charts with the NCEP flow charts. Both JRA25 and NCEP have good scores for the seasonal predictions.

In August the rainfall activity resumed after the record failure of July rainfall. The cross equatorial flow strengthens over the Somalia and Arabian Sea at 850 *hpa* level. Easterlies were stronger as observed over the region from 20°N – 30°N in contrast to July. It leads to rain over this monsoon trough region. This situation is different from July case. The tropical easterly jet also nearly located over the Tamil Nadu and Kerala coast with very weak. Ultimately it brought rainfall in this August month.

RAINFALL DISTRIBUTION

For the Indian region, the summer monsoon season of 2002 was an anomalous one with below normal observed rainfall. Predictability of the monsoon in a model can vary from year to year depending on the synoptic conditions in both the atmosphere and oceans. The European Center for Medium Range weather Forecasting predicted normal rainfall based on 01 May conditions.

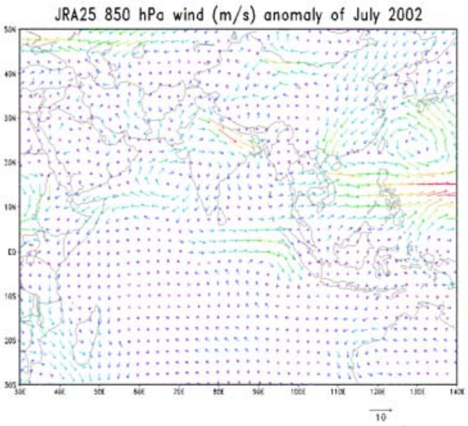

Figure 1a JRA25 Wind (m/s) anomaly at 850 hPa for July 2002

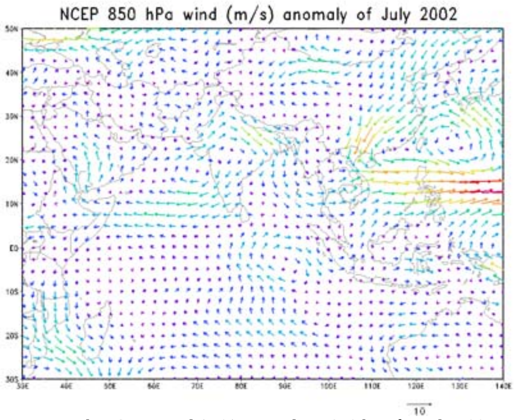

Figure 1b NCEP Wind (m/s) anomaly at 850 hPa for July 2002

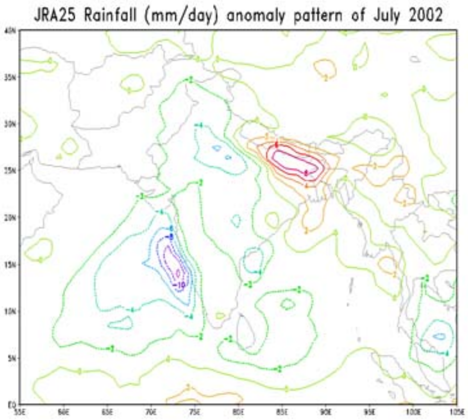

Figure 2a JRA25 rainfall (mm/day) anomaly for July 2002

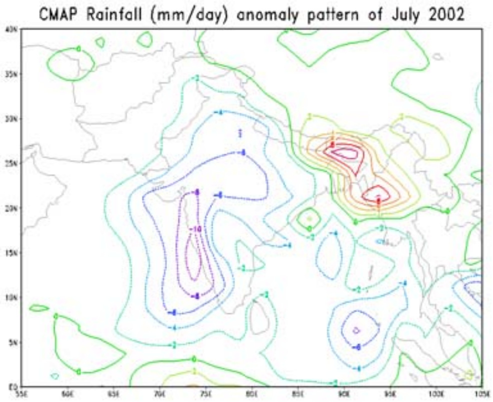

Figure 2b CMAP rainfall (mm/day) anomaly for July 2002

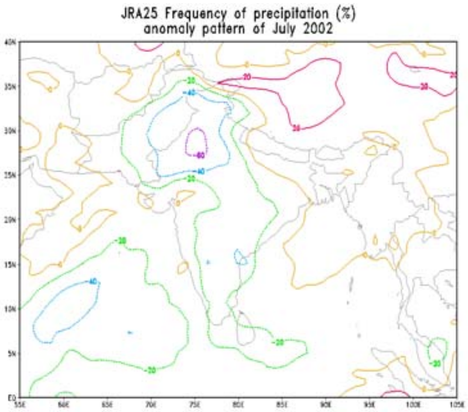

Figure 3c JRA25 frequency (%) of precipitation anomaly for July 2002

But the forecasts for June, July and August by the seasonal forecasts from suggested some deficiency only over the southwestern peninsula, and near-normal conditions over the rest of the country. The International Research Institute also suggested normal rainfall over the entire country. The same conditions noticed for some other model predictions. As per drought criteria, the year 2002 is placed under the phenomenal all-India drought category. During this period the seasonal rainfall over the country as a whole was recorded as 81 % of its long-term average. This rainfall distribution severely impacted the Indian agriculture and the economy as a whole.

RAINFALL DISTRIBUTION AND THEIR ANOMALIES

The monsoon 2002 had a good start in June, thus it amounted to a positive anomaly in this month. The seasonal rainfall for the month of June to September obtained from the JRA25 datasets and the CMAP datasets are studied respectively. From this study it is drawn that the areas that received more than 100 cm of rain during the season JJAS are the west coast strip in the windward side of the north-south oriented hill ranges (Western Ghats), the extreme north-eastern part of the country and a region in the east adjoining the Bay of Bengal. As per the IITM the sub-division observed rainfall it is documented that the northwest and peninsular India indicated deficient rainfall. July recorded deficient and scanty rainfall over almost all parts of India except small pocket covering Bihar, West Bengal and Sikkim. The JRA25 rainfall anomaly patterns for July have plotted (Figures 2a, 2b, 2c) along with the CMAP rainfall anomaly pattern respectively. The negative anomaly for July is caused because of the prolonged break condition.

The JRA25 and CMAP maps shows negative anomaly through out the country except the northeast region. The intensity of negative anomaly observed over the west coast of India is at the order of 10 $mm\ day^{-1}$. The extreme northeast India is having positive anomaly at the order of 6-10 $mm\ day^{-1}$ other regions has the negative anomaly as shown in the maps. In addition the JRA25 is over predicting the rainfall by 10-12 % in the land areas. The JRA25 frequency of precipitation for July is showing negative anomaly more than 50 %. Thus it leads to drought condition over India in 2002. The JRA25 shows positive anomaly over the Orissa region, but the CMAP does not show the same amount. The July 2002 rainfall deficiency did not continue in August and September. When the spatial distribution of rainfall for the recent drought year 1987 is put in juxtaposition with 2002, the results shows that northwest India received deficient rainfall in both the cases, where as the southern India got normal rainfall in the 1987 case.

WITHDRAWAL PHASE

In terms of rainfall, the onset is better defined than the withdrawal, especially over south India. The withdrawal phase of the summer monsoon is also an important aspect, which takes place around early September. It is true that one cannot distinguish the withdrawal of the summer monsoon from the onset of the winter monsoon over southern region of the country. The JRA25 maps show the Tibetan anticyclone at 200 *hPa*, which starts moving southwards which leads to a withdrawal. From this JRA25 dataset it is verified that the values of the circulation index show that there is a slower decrease during the withdrawal/retreat phase of the monsoon than onset. From this study the change of sign of the index in the boreal autumn explicitly indicates the displacement of monsoon air by a continental air mass and the development of anticyclone flow over north and central India.

CONCLUSION

The exceptional weakness of the 2002 Indian summer monsoon has been investigated using JRA25, NCEP/NCAR and CMAP reanalysis datasets. JRA25 is able to reveal most of the different phases of monsoon reasonably well as observed. Comparison of zonal wind fields from different reanalysis reveals generally good agreement in the Indian regions. The rainfall in the 2002 monsoon season reveals the key roles played by break periods during July these periods coincide approximately with their climatological mean dates. This study will be useful for medium range weather forecasting over the Asian summer monsoon region. These results are encouraging to carry out the regional reanalysis data assimilation runs in India.

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