Normalized anomaly patterns of meteorological elements: A case study of Northeast monsoon 2002 and 2004

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ABSTRACT. It is often helpful to express the meteorological data in terms of normalized anomalies as they make it easier to discern normal versus unusual values. Also it removes influence of location and spread from data and facilitates the comparison of observations at two different locations. Thus, Normalized Anomaly (NA) patterns i.e., spatial distribution of anomalies at specified time make a powerful tool in hand of forecasters to analyze extreme events.

The present study explores the utilization of NA patterns for the purpose of analyzing extreme events by focusing on the inter-seasonal peculiar behavior of Northeast monsoon 2002. A detailed discussion is given and reasons are explored for droughts like situations during Northeast monsoon 2002. It was also noticed that the persistence of 200 hPa upper level ridge or positive geopotential height anomaly, negative mean sea level pressure anomaly over Siberian High during November, strength of 200 hPa wind anomaly can be one of the reasons for drought-like situation observed in the inter-seasonal behavior pattern of Northeast monsoon 2002. NA patterns of low cloud amount, dry bulb temperature and relative humidity captured drought-like situations during Northeast monsoon 2002 while NA of average wind speed captured the scenario of dissipating cyclones in the Bay of Bengal itself and not reaching to Peninsular India. The NA patterns of low cloud amount, relative humidity, dry bulb temperature and average wind speed for Northeast Monsoon 2004 confirm the observations of drought like situations seen in NA patterns for these meteorological parameters in case of Northeast monsoon 2002.

Key words – Normalized anomaly (NA), Northeast monsoon, Percentage departure of rainfall from normal (PDR).

1. Introduction

Monsoon is a seasonal reversal of winds and the associated rainfall. It is caused due to the annual oscillation in the position of the thermal equator. This is associated with annual oscillation of temperature, pressure, wind, cloudiness and rain. In India during the period October to December the meteorological subdivisions of south coastal Andhra Pradesh, Rayalaseema, Tamil Nadu and some parts of Kerala...
TABLE 1
Percentage departure of seasonal rainfall as per IMD convention in case of Southwest monsoon 2002 and Northeast monsoon 2002

<table>
<thead>
<tr>
<th>Meteorological Subdivisions</th>
<th>Southwest monsoon 2002</th>
<th>Northeast monsoon 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual (mm)</td>
<td>Normal (mm)</td>
</tr>
<tr>
<td>Kerala (KER)</td>
<td>1322</td>
<td>1965</td>
</tr>
<tr>
<td>Tamil Nadu and Puducheery (TN)</td>
<td>172</td>
<td>318</td>
</tr>
<tr>
<td>Coastal Karnataka (CK)</td>
<td>2188</td>
<td>3128</td>
</tr>
<tr>
<td>South Interior Karnataka (SIK)</td>
<td>522</td>
<td>933</td>
</tr>
<tr>
<td>North Interior Karnataka (NIK)</td>
<td>329</td>
<td>478</td>
</tr>
<tr>
<td>Rayalaseema (RYL)</td>
<td>259</td>
<td>386</td>
</tr>
<tr>
<td>Telangana (TEL)</td>
<td>602</td>
<td>773</td>
</tr>
<tr>
<td>Coastal Andhra Pradesh (CAP)</td>
<td>436</td>
<td>582</td>
</tr>
</tbody>
</table>

experience significant precipitation which is known as Northeast Monsoon. The main synoptic situations include formation of low pressure area (LPA) over central and south Bay of Bengal and its subsequent shift towards equator during season, an east west trough from LPA to south Arabian sea with associated upper air trough (3.0 km asl), easterlies in mid and upper troposphere (Forecasting Manual, Part IV, 1973). Dhar and Rakhecha (1983) have studied the association between Southwest and Northeast monsoon rainfall over Tamil Nadu and their study revealed that the Southwest monsoon rainfall is negatively correlated with the Northeast monsoon rainfall. There was Southwest monsoon drought on all India scale both in 2002 and 2004 seasons. In case of Southwest monsoon 2002, the seasonal percentage departure of rainfall indicated deficient rainfall over the meteorological subdivisions of Peninsular India, namely, Kerala, Tamil Nadu and Puducheery, Coastal Karnataka, South Interior Karnataka (SIK), North Interior Karnataka, Rayalaseema, Telangana, Coastal Andhra Pradesh (CAP). However, only CAP had deficient rainfall during Northeast monsoon 2002. This is indicated in Table 1. (Jayanthi et al., 2003). The seasonal variations are present in the data set due to annual oscillations of meteorological elements. It is often helpful to express the data in terms of normalized anomalies as they make it easier to discern normal versus unusual values. Also it removes influence of location and spread from data and facilitates the comparison of observations at two different locations. Thus, Normalized Anomalies (NA) patterns, i.e., spatial distribution of anomalies at specified time make a powerful tool in hand of forecasters to analyze extreme events.

Drought studies indicate that subsidence occurs beneath the ridge of high pressure thereby decreasing relative humidity and making difficult for clouds to form. The increased air temperature that resulted due to subsidence strengthens the upper level ridge warming the ground more. Besides, absence of precipitation causes the ground to dry out. The drop in surface moisture further makes precipitation less likely leading to continuation of drought-like situation. This has to be reflected in NA patterns in case of drought-like situations and exactly opposite for flood-like situations. The present study explores the utilization of NA patterns for the purpose of analyzing extreme events. The year 2002 was a failure in Southwest monsoon and declared as a drought year by India Meteorological Department. This study focuses on the inter-seasonal peculiar behavior of Northeast monsoon 2002. A detailed discussion is given and reasons are explored for drought-like situations during Northeast monsoon 2002. The observations noticed in case of Northeast monsoon 2002 for NA patterns of low cloud amount, relative humidity, dry bulb temperature and average wind speed are tested for yet another deficient monsoon year 2004 for the Northeast monsoon.

2. Data and methodology

For this study, a uniformly distributed 30 class I Meteorological surface observatories of India Meteorological Department located south of 20° N latitude covering Peninsular India comprising of meteorological subdivisions namely Coastal Andhra Pradesh, South Interior Karnataka, Coastal Karnataka, Rayalaseema, Telangana, Tamil Nadu and Puducheery and Kerala were considered. The monthly synoptic hour values of meteorological parameters like low cloud amount, dry bulb temperature, relative humidity and average wind speed for stations over above subdivisions for all available period between the years 1901-2010 were utilized. The monthly rainfall values of 29 surface
Figs. 1 (a-e). Anomalies during October 2002 (a) Low cloud amount, (b) Relative humidity, (c) Dry bulb temperature, (d) Average wind speed; at 0300 UTC and (e) Average wind speed at 1200 UTC
A normalized anomaly of a meteorological parameter is computed using formula:

Normalized Anomaly of meteorological parameter = \( \frac{(P - P_{\text{mean}})}{\sigma} \)

where, \( P \) is the meteorological parameter of the station and \( P_{\text{mean}} \) and \( \sigma \) are the long-term mean and the standard deviation of the meteorological parameter of the station [WMO No. 100]. The normalized anomaly is a dimensionless parameter.

The normalized anomaly of meteorological parameters, namely, low cloud amount, dry bulb temperature, relative humidity, average wind speed and geopotential height were computed. The normalized rainfall anomaly with the percentage departures of rainfall and percentage coefficient of variation of rainfall were also computed for 29 surface observatories over Peninsular India during 2002 and the generated plots were used to derive definition of ‘Drought-like situation’ [Figs. 5(a-c)]. India Meteorological Department (IMD, 1971) classified the drought years into slight, moderate and severe drought as per percentage rainfall deficiency lies between 11% to 25%, 26% to 50% and more than 50% respectively.

We define ‘Drought-like situation’ in terms of negative anomaly of rainfall as that situations which arises...
Figs. 3 (a-d). Anomalies during December 2002 (a) Low cloud amount, (b) Relative humidity, (c) Dry bulb temperature and (d) Average wind speed; at 1200 UTC

when the percentage departure of seasonal rainfall for the station lies between -1 and -11% and percentage coefficient of variation of rainfall is between 30 & 45%. In terms of normalized rainfall anomaly, ‘drought-like situation’ is a situation for station when normalized rainfall anomaly value is negative and below -1.2.

When observed monthly rainfall is deficient or scantly due to the persistence of 200 hPa upper level ridge or positive normalized geopotential height anomaly, a drought-like situation can occur.

NCEP Reanalysis data set were utilized to depict 200 hPa wind anomaly and mean sea level pressure (MSLP) and anomaly over Indian region bounded by Lat. 8° N – Lat. 25° N / Long. 68° E – Long. 110° E during October-December, 2002 to explain the cause and drought like situation. To compute mean sea level pressure anomaly over the Siberian High the area bounded by 87.5 - 102.5° E and 47.5 - 52.5° N is considered for this study.

3. Results and discussion

3.1. Case of northeast monsoon 2002

The NA patterns of low cloud amount, dry bulb temperature, relative humidity, average wind speed for the months of October, November and December of Northeast monsoon 2002 are discussed below.

October

The spatial distribution of NA of low cloud amount showed a negative anomaly over SIK, Telangana, Rayalaseema, part of South Puducheery at 0300 UTC [Fig. 1(a)]. NA of relative humidity showed a negative
anomaly over Northeast CAP, Telangana, parts of Rayalaseema and SIK [Fig. 1(b)] while NA of dry bulb temperature showed positive anomaly over these regions [Fig. 1(c)]. The NA patterns were observed to be same for 1200 UTC observations. Another significant point is that the NA of average wind speed showed negative anomaly at 0300 UTC hours for Telangana, SIK, Tamil Nadu, Kerala while CAP, North parts of Tamil Nadu and Rayalaseema showed positive anomaly at 1200 UTC hours [Figs. 1(d-e)]. Significant rainfall occurred in South CAP under the influence of a depression over the Bay of Bengal.

November

The NA of low cloud amount showed a negative anomaly over south peninsula at 1200 UTC [Fig. 2(a)] followed by NA relative humidity to be negative over CAP, SIK, Telangana, NIK, Rayalaseema [Fig. 2(b)] and
positive NA of dry bulb temperature over these regions [Fig. 2(c)]. A significant observation was that NA of relative humidity showed positive anomaly over South Kerala, Tamil Nadu and Puducherry. NA of dry bulb temperature was negative over east coast of CAP [Fig. 2(b) and Fig. 2(c)] with percentage departure of rainfall from normal to be -17% (normal) and -56% (deficient) respectively (Jayanthi et al., 2003). Heavy rainfall occurred over CAP at isolated places under influence of a severe cyclonic storm over Bay of Bengal for 2 days (10-12 November, 2002). NA of average wind speed showed negative anomaly over peninsular India at 1200 UTC hours [Fig. 2(d)].

**December**

NA of low cloud amount showed negative anomaly over South Peninsula (1200 UTC) followed by negative anomaly of NA of relative humidity (1200 UTC) [Fig. 3(a) & Fig. 3(b)]. Significantly it was observed from Fig. 3(c) that NA of dry bulb temperature showed positive anomaly over peninsular India with percentage of departure of rainfall from normal to be -98% (scanty), -51% (Deficient), 46% (Excess) and -92% (scanty) respectively over CAP, Tamil Nadu, Kerala and SIK during December (Jayanthi et al., 2003). NA of average wind speed showed negative anomaly over peninsular India at 1200 UTC hours [Fig. 3(d)].

Droughts are caused by general climatic fluctuations associated with persistent large scale aberrations of atmospheric circulations which favored subsidence over the region (Pandharinath, 2007). We now present analysis of climatic fluctuations of surface meteorological features associated with drought-like situation of Northeast monsoon 2002. Geopotential height is valuable...
Persistence of 200 hPa upper level ridge can be one of the reasons for drought-like situation observed in the inter-seasonal behaviour pattern of Northeast monsoon 2002. The positive 200 hPa geopotential height anomaly at 0000 UTC for October 2002 and for December 2002 suggests a high over south CAP and adjoining areas indicating persistence of ridge over this area as depicted in Fig. 4 (a) and Fig. 4 (b) respectively. Due to this high the meteorological subdivisions namely CAP, Telangana, SIK and Rayalaseema except Kerala had deficient and scanty rainfall during November and December respectively.

6 intense cyclonic disturbances (4 cyclonic storms and 2 depressions) were observed over North Indian Ocean during 2002 (Jayanthi et al. 2003). Out of this during Northeast monsoon 2002 three cyclonic storms and one depression formed over Bay of Bengal during October 2002. It is noticed that NA of average wind speed showed negative anomaly at 1200 UTC over Telangana, SIK, South Tamil Nadu, Kerala during which period the cyclonic disturbances had formed and dissipated over Sea (22-23 October, 23-28 November and 21-25 December) while Rayalaseema and south CAP showed positive anomaly during October 2002 at 1200 UTC hours. NA patterns captured drought-like situations during Northeast monsoon 2002 while NA of average wind speed captured the scenario of dissipating cyclone in the Bay of Bengal itself and not reaching to Peninsular India.

Studies on general circulation during monsoons indicate that in winter the outflow from the Siberian anticyclone leads to northerly or northeasterly flow across India. The air then moves across the East Indian coast towards the equatorial trough lying south of the equator (Retallack, 1984). During October 2002, all subdivisions of Peninsular India experienced normal or excess rainfall (Fig. 10). It is observed from Fig. 8(a) and Fig. 8(b) that there is westerly wind anomaly over Peninsular India at 200 hPa level indicating westerlies are relatively stronger and a positive MSLP anomaly over Peninsular India. Also Fig. 11 (a) indicates ridge line along Lat. 12° N / Long. 50° E - Lat. 15° N / Long. 110° E. Fig. 9 indicates positive MSLP anomaly over Siberian High during September-October. Studies have shown that an intense pressure over the Siberian High (area bounded by 87.5 - 102.5° E and 47.5 - 52.5° N) during September is associated with the strengthening of surface easterlies over the Bay of Bengal (Geetha and Raj, 2009) which are favourable for good rainfall during October-November which explained good rainfall during October 2002. Negative anomaly of MSLP over Indian and Bay of Bengal region & easterly wind anomalies (i.e., weak westerlies) at 200 hPa level indicated presence of weather systems during November 2002. Also Fig. 11 (b) indicates conditions at the surface.

Figs. 7 (a-c). Anomalies during December 2004 (a) Low cloud amount, (b) Relative humidity and (c) Dry bulb temperature for locating ridges and troughs which are the upper level counterparts of surface cyclones and anticyclones. Strong ridges are accompanied by warm and dry weather
ridge line along Lat. 12° N / Long. 50° E - Lat. 15° N / Long. 110° E. However strong easterly wind anomalies at 200 hPa level (mid and upper troposphere) might have resulted increase in vertical wind shear and entrainment of cold air and dissipation of cyclonic storm (23-28 November) over Sea and not reaching peninsular Indian coast. Also a weaker than normal pressure over Siberian High (negative MSLP anomaly) suggested unfavourable conditions and less rainfall during November 2002. Fig. 8 (e) and Fig. 8 (f) indicates westerly wind anomaly and positive MSLP anomaly over Peninsular India suggesting westerly / southwesterly winds and southward location of
subtropical ridge. Studies have shown that a weaker than normal pressure over Siberian High region during December is associated with northward location of equatorial trough (compared to its normal position near the equator) which becomes conducive for good rainfall during December (Geetha and Raj, 2009). However, it is seen from Fig. 9 that there is positive MSLP anomaly over Siberian High during December 2002 suggesting southward location of Equatorial trough and conditions unfavourable for good rainfall over Peninsular India. Also position of subtropical ridge is southward as depicted in Fig. 11(c). This is confirmed from westerly/Southwesterly wind anomaly from Fig. 8 (e). This explains inter-seasonal behavior of performance of Northeast monsoon 2002 shown in Fig. 10.

Thus for the case of Southwest monsoon 2002, it can be summarized that the meteorological features which can
be linked to drought over CAP are persistence of 200 hPa upper level ridge or positive normalized geopotential height anomaly during months of October and November, negative MSLP anomaly over Siberian High, strength of 200 hPa wind anomaly, negative values of normalized low cloud amount anomaly, normalized relative humidity anomaly and positive values of normalized dry bulb temperature anomaly.

3.2. Case of Northeast monsoon 2004

The NA patterns of low cloud amount, dry bulb temperature, relative humidity, average wind speed for the months of October and December 2004 are discussed below.

October

The NA of low cloud amount showed a negative anomaly over Telangana and CAP and South parts of Kerala with NA of relative humidity anomaly to be positive and positive anomaly of dry bulb temperature over central CAP [Figs. 6(a-c)]. The NA of average wind speed showed a positive anomaly over Rayalaseema, parts of SIK and Tamil Nadu at 0300 UTC [Fig. 6(d)] which reflects the crossing of depression over North Andhra Pradesh coast close to Kalingapatnam in the forenoon of 4th October.

December

The spatial distribution of NA pattern of low cloud amount showed a negative anomaly over all sub-divisions of Peninsular India and NA of relative humidity also showed negative anomaly over these regions while NA of dry bulb temperature showing positive anomaly over above regions [Figs. 7(a-c)]. This suggests a drought like situation during December. The percentage departure of rainfall for this month showed SIK to be -97%, Kerala to be -97% while Rayalaseema, Telangana, Coastal Andhra Pradesh to be -100%, -100% and -99% respectively (Jayanthi et al., 2005).

Thus in case of Northeast monsoon 2004, it can be inferred that the meteorological subdivisions, namely, CAP, Rayalaseema, North Interior Karnataka, South Interior Karnataka, Coastal Karnataka had deficient rainfall due to abnormal behaviour of the meteorological elements.

4. Conclusions

The present case study of Northeast monsoon 2002 revealed that the persistence of 200 hPa upper level ridge
or positive geopotential anomaly, negative MSLP anomaly over Siberian High during November, strength of 200 hPa wind anomaly can be one of the reasons for drought-like situation observed in the inter-seasonal behavior pattern of Northeast monsoon 2002. NA patterns of low cloud amount, dry bulb temperature, and relative humidity captured drought like situations during Northeast monsoon 2002 while NA of average wind speed captured the scenario of dissipating the cyclones in the Bay of Bengal itself and not reaching to Peninsular India. The NA patterns of low cloud amount, relative humidity, dry bulb temperature and average wind speed for Northeast monsoon 2004 confirm the observations of drought like situations seen in NA patterns for these meteorological parameters in case of Northeast monsoon 2002.

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