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

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सार – मौसम विज्ञानिक आँकड़ों को सामान्यीकृत विसंगतियों के संबंध में बताना प्रायः सहायक रहता है क्योंकि इससे सामान्य बनाम असामान्य मानों को पहचानना सरल हो जाता है। इसके अलावा इससे स्थान के प्रभाव तथा आँकड़ों के प्रसार का प्रभाव दूर होता है और दो भिन्न स्थानों में प्रेक्षणों की तुलना सुविधाजनक हो जाती है। इस प्रकार सामान्यीकृत विसंगति (एन. ए.) पैटर्न अर्थात निर्धारित समय में विसंगतियों का स्थानिक वितरण प्रतिकूल मौसम की घटनाओं में पूर्वानुमानकर्ताओं के लिए एक सशक्त उपकरण बन जाता है।

इस शोध पत्र में उत्तरपूर्वी मॉनसून 2002 की अंतर–मौसमी विशिष्ट प्रकृति पर विचार करते हुए मौसम की प्रतिकूल घटनाओं का विश्लेषण करने के लिए एन. ए. पैटर्न के उपयोग पर कार्य किया गया है। उत्तर पूर्वी मॉनसून 2002 के दौरान सूखे जैसी स्थितियों के बारे में विस्तार से चर्चा की गई है और उनके कारणों की जाँच की गई है। यह भी देखा गया है कि उत्तर पूर्वी मॉनसून 2002 के अंतर मौसमी प्रकृति पैटर्न में प्रेक्षित सूखे जैसे स्थिति का एक कारण 200 एच. पी. ए. ऊपरी तल रिज का होना अथवा सकारात्मक भूविभव ऊँचाई विसंगति, नवम्बर में साइबेरियन हाई में नकारात्मक माध्य समुद्र स्तर दाब विसंगति, 200 एच. पी. ए. पवन विसंगति की तीव्रता हो सकता है। निम्न मेघ मात्रा, शुष्क बल्ब तापमान और सापेक्ष आर्द्रता से उत्तर पूर्वी मॉनसून 2002 में सूखे जैसी स्थितियों का पता चला जबकि औसत पवन गति के एन. ए. से बंगाल की खाड़ी में चक्रवातों के क्षीण होने और प्रायद्वीपीय भारत तक नहीं पहुँचने के बारे में पता चला। उत्तर पूर्वी मॉनसून 2004 के लिए निम्न मेघ मात्रा, सापेक्ष आर्द्रता, शुष्क बल्ब तापमान तथा औसत पवन गति के एन. ए. पैटर्न से उत्तर पूर्वी मॉनसून 2002 के मामले में इन मौसम विज्ञानिक प्राचलों के लिए एन. ए. पैटर्न में सूखे जैसे स्थितियों के प्रेक्षणों की पुष्टि हुई।

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

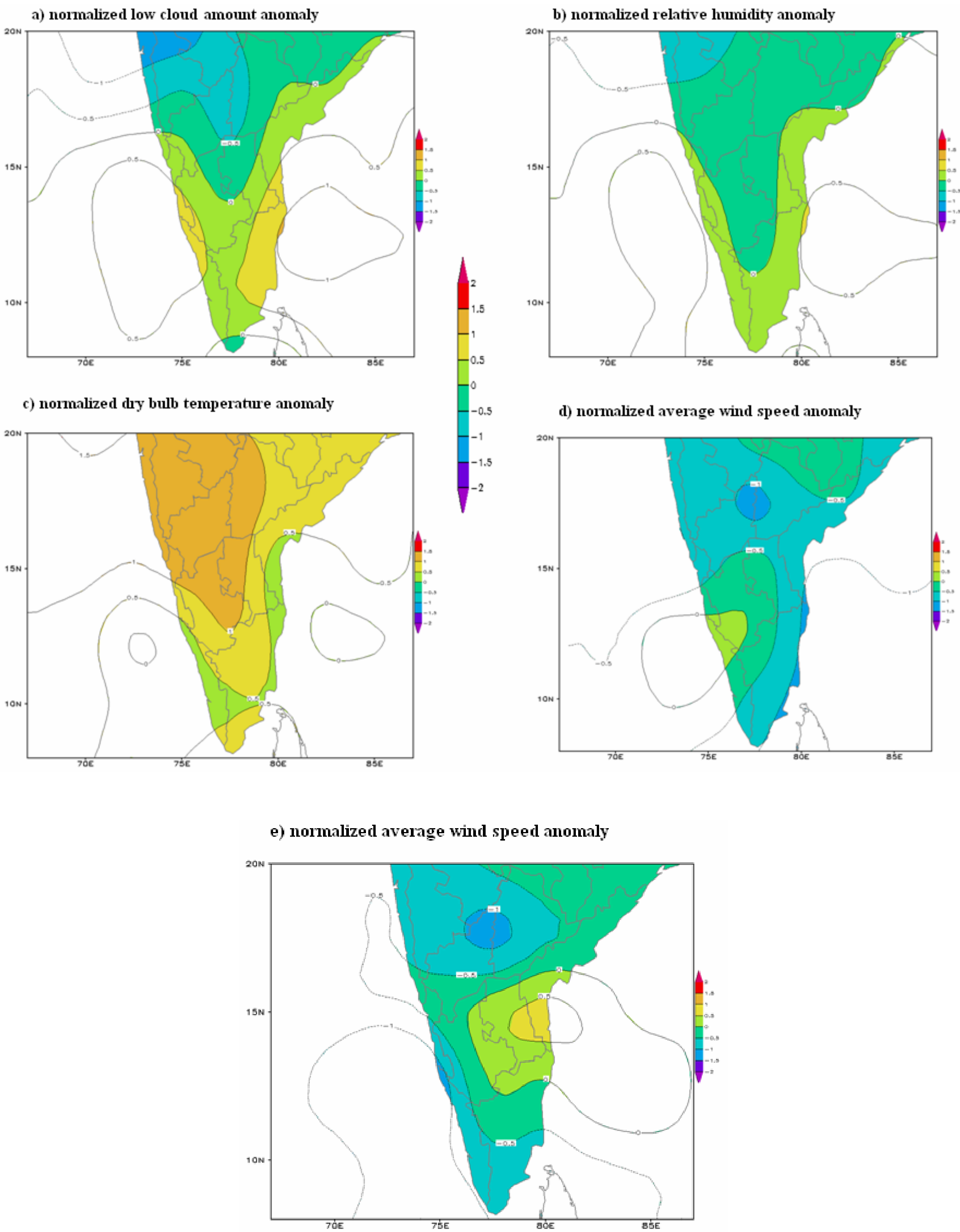
Meteorological Subdivisions	Southwest monsoon 2002			Northeast monsoon 2002		
	Actual (mm)	Normal (mm)	Departure (%)	Actual (mm)	Normal (mm)	Departure (%)
Kerala (KER)	1322	1965	-33	627	475	32
Tamil Nadu and Puducheery (TN)	172	318	-46	396	432	-8
Coastal Karnataka (CK)	2188	3128	-30	457	272	68
South Interior Karnataka (SIK)	522	933	-44	203	208	-2
North Interior Karnataka (NIK)	329	478	-31	141	135	4
Rayalaseema (RYL)	259	386	-33	184	221	-17
Telangana (TEL)	602	773	-22	110	109	0
Coastal Andhra Pradesh (CAP)	436	582	-25	223	323	-31

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.

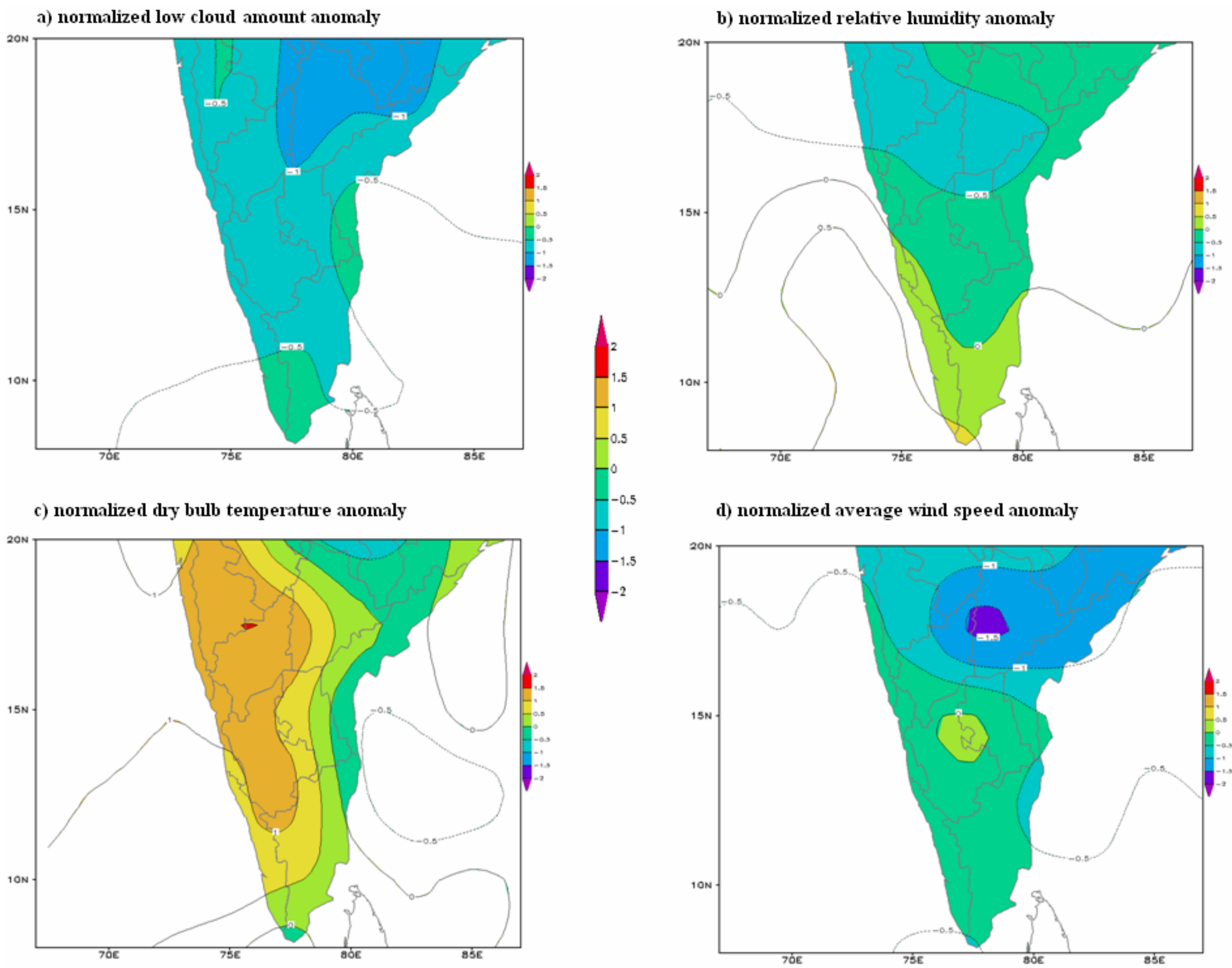
Drought studies indicate that subsidence occurs beneath the ridge of high pressure thereby decreasing relative humidity and making difficult for clouds to form. The increased air temperature that resulted due to subsidence strengthens the upper level ridge warming the ground more. Besides, absence of 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



Figs. 2 (a-d). Anomalies during November 2002 (a) Low cloud amount, (b) Relative humidity, (c) Dry bulb temperature and (d) Average wind speed; at 1200 UTC

observatories over the above sub-divisions for the period 1950-2002 were also used to compute seasonal rainfall of the post-monsoon season. The seasonal rainfall was considered as a meteorological parameter to compute normalized rainfall anomaly.

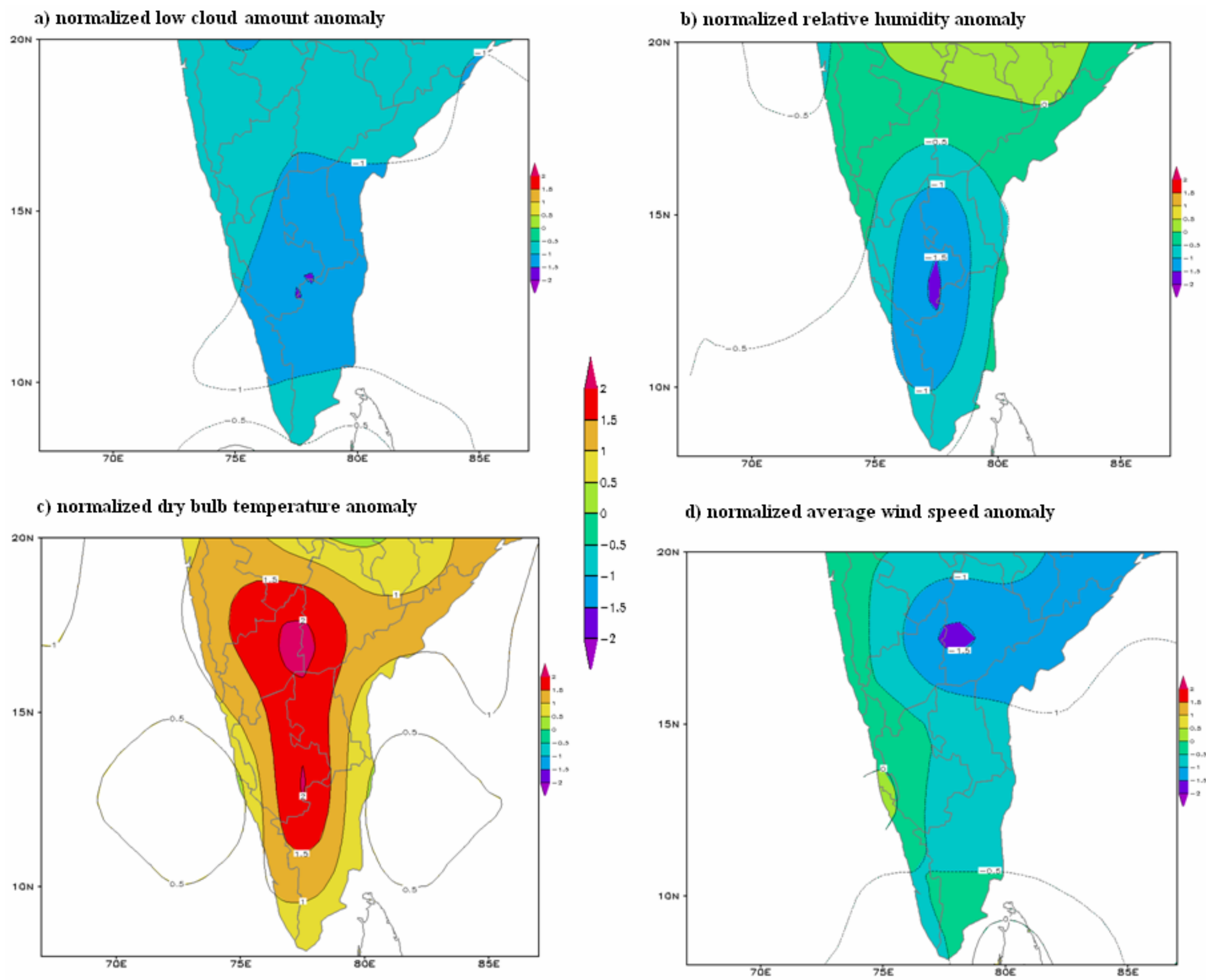
A normalized anomaly of a meteorological parameter is computed using formula:

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

where, P is the meteorological parameter of the station and P_{mean} and σ 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 scanty 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.

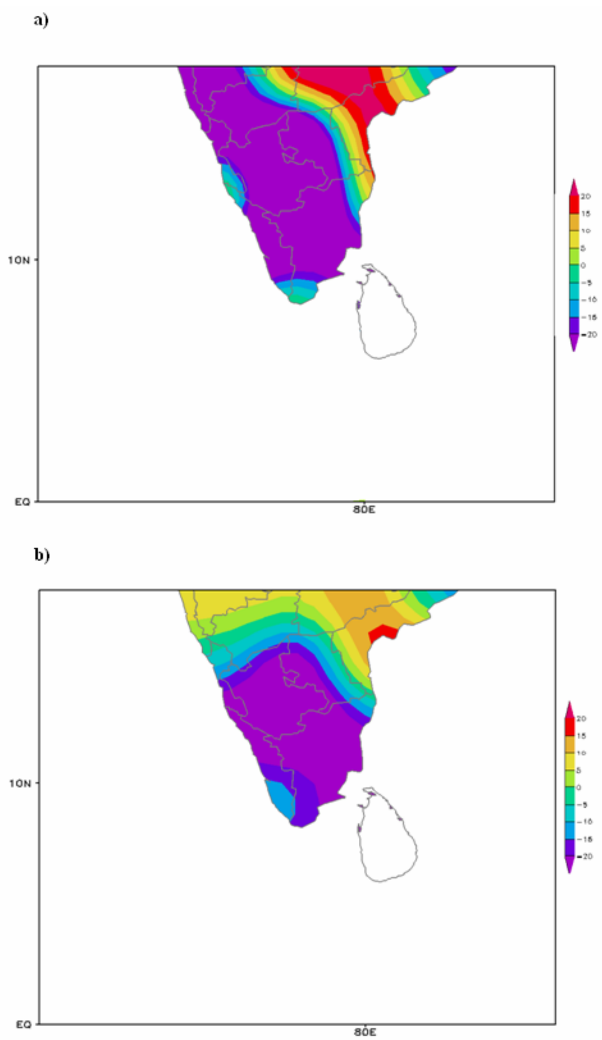
3. Results and discussion

3.1. *Case of northeast monsoon 2002*

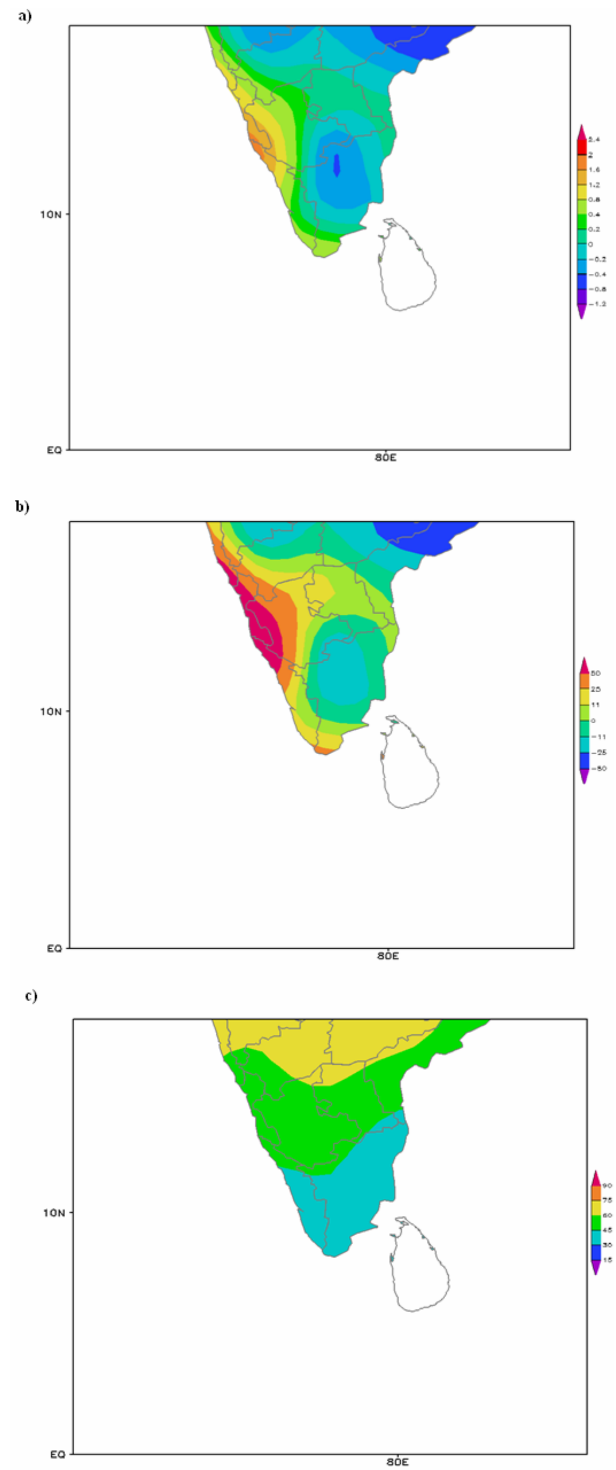
The NA patterns of low cloud amount, dry bulb temperature, relative humidity, average wind speed for the months of October, November and December of Northeast monsoon 2002 are discussed below.

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



Figs. 4(a&b). Normalized 200 hPa geopotential height anomaly for (a) October 2002 and (b) December 2002

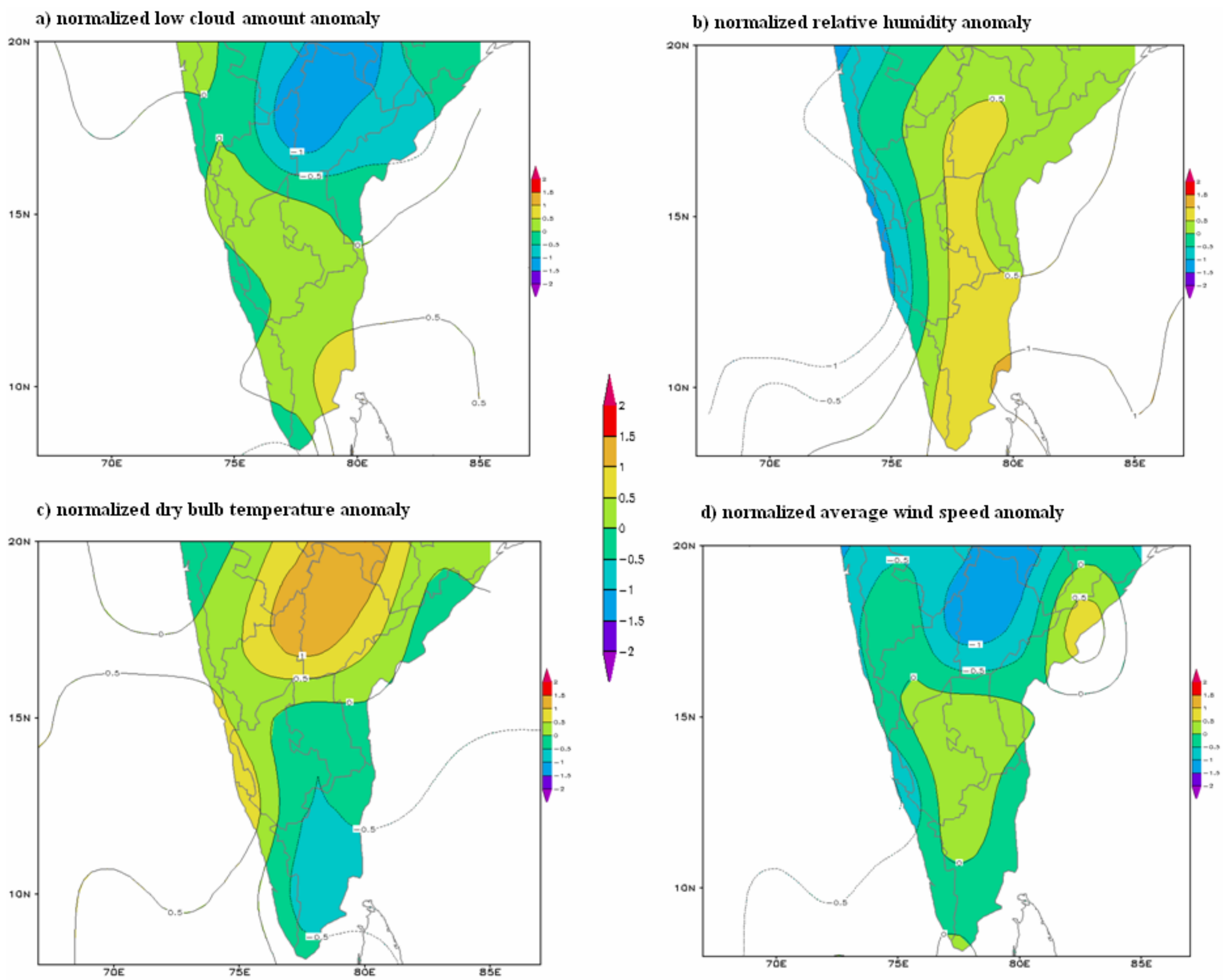


Figs. 5(a-c). Rainfall statistics for northeast monsoon 2002 (a) Normalized rainfall anomaly, (b) Percentage departure of rainfall (mm) and (c) Percentage coefficient of variation of rainfall (%)

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



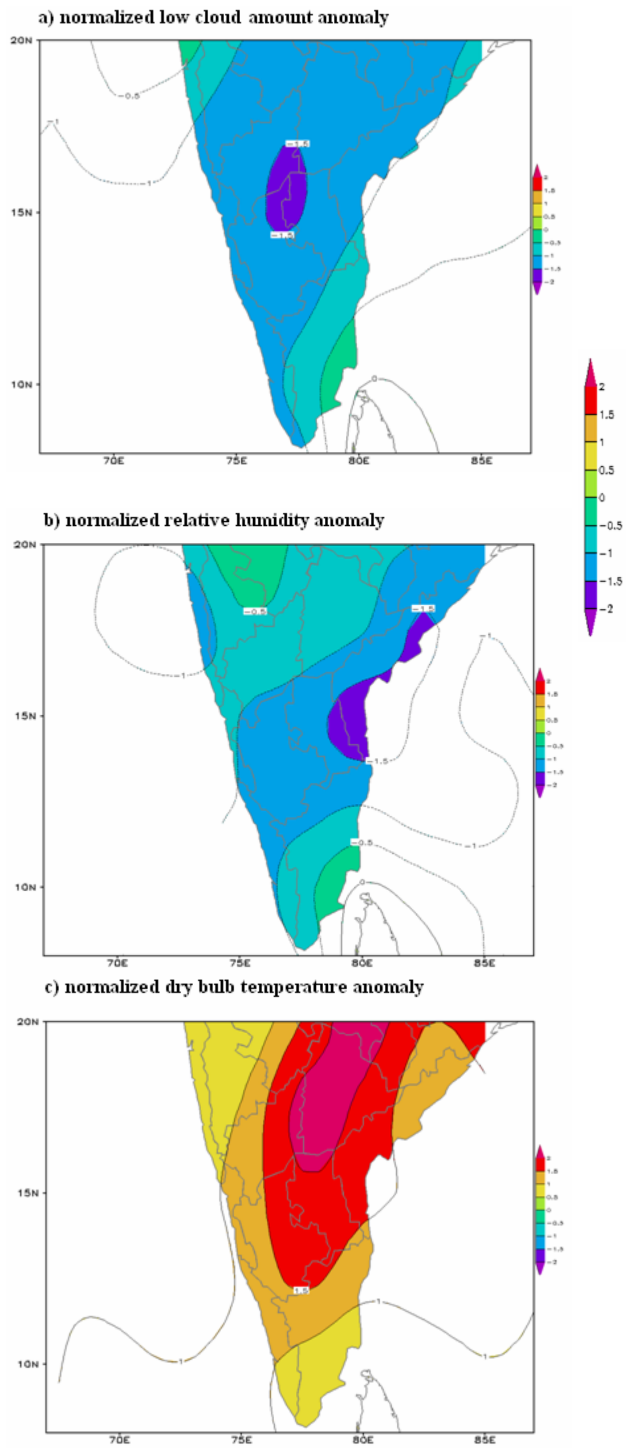
Figs. 6 (a-d). Anomalies during October 2004 (a) Low cloud amount, (b) Relative humidity, (c) Dry bulb temperature and (d) Average wind speed; at 0300 UTC

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 Puducheery, 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

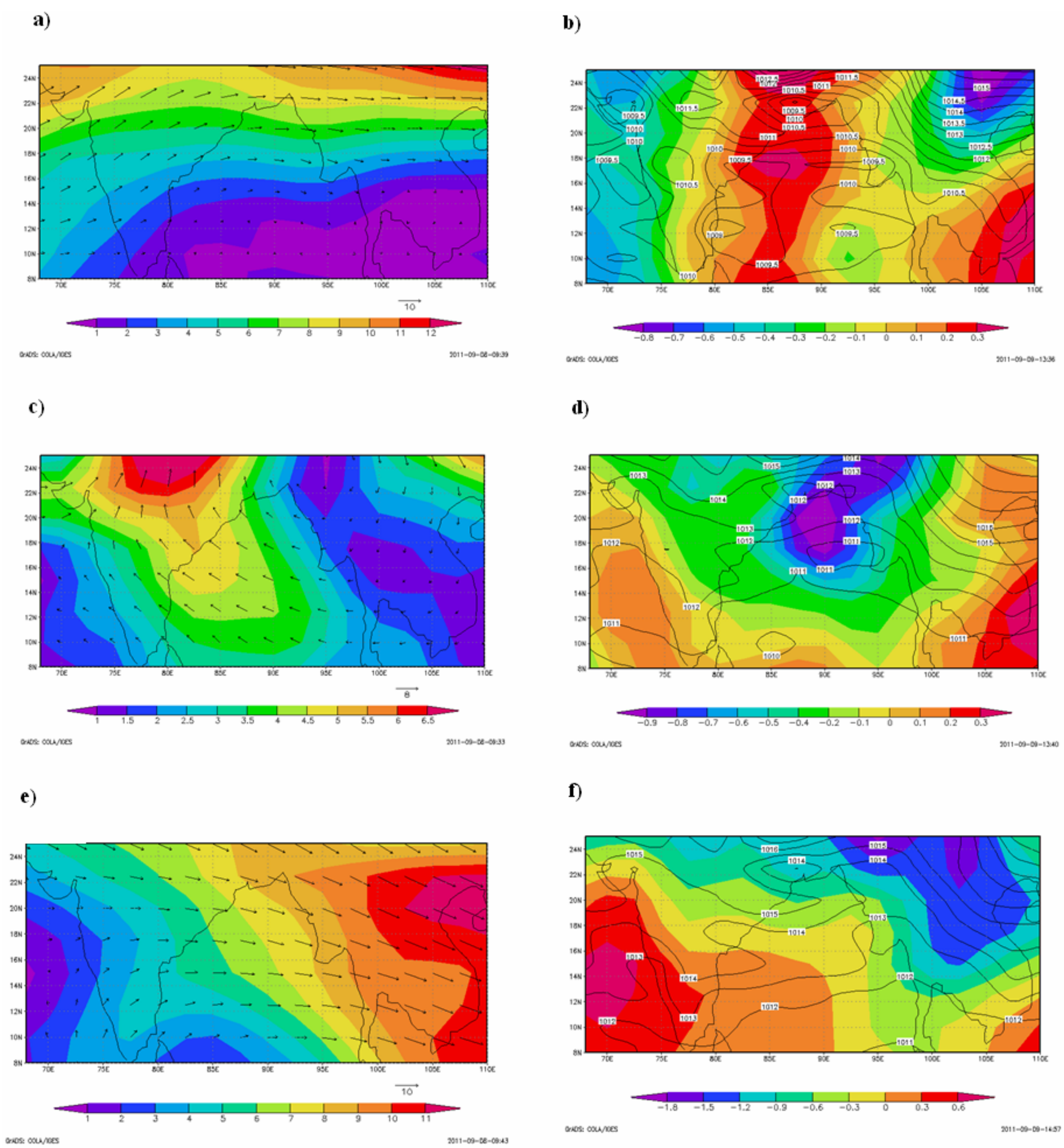


Figs. 7 (a-c). Anomalies during December 2004 (a) Low cloud amount, (b) Relative humidity and (c) Dry bulb temperature

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 conditions at the surface. 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



Figs. 8(a-f). (a) 200 hPa wind anomaly, (b) Mean sea level pressure and anomaly for October 2002, (c) 200 hPa wind anomaly, (d) Mean sea level pressure and anomaly for November 2002, (e) 200 hPa wind anomaly and (f) Mean sea level pressure and anomaly for December 2002

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

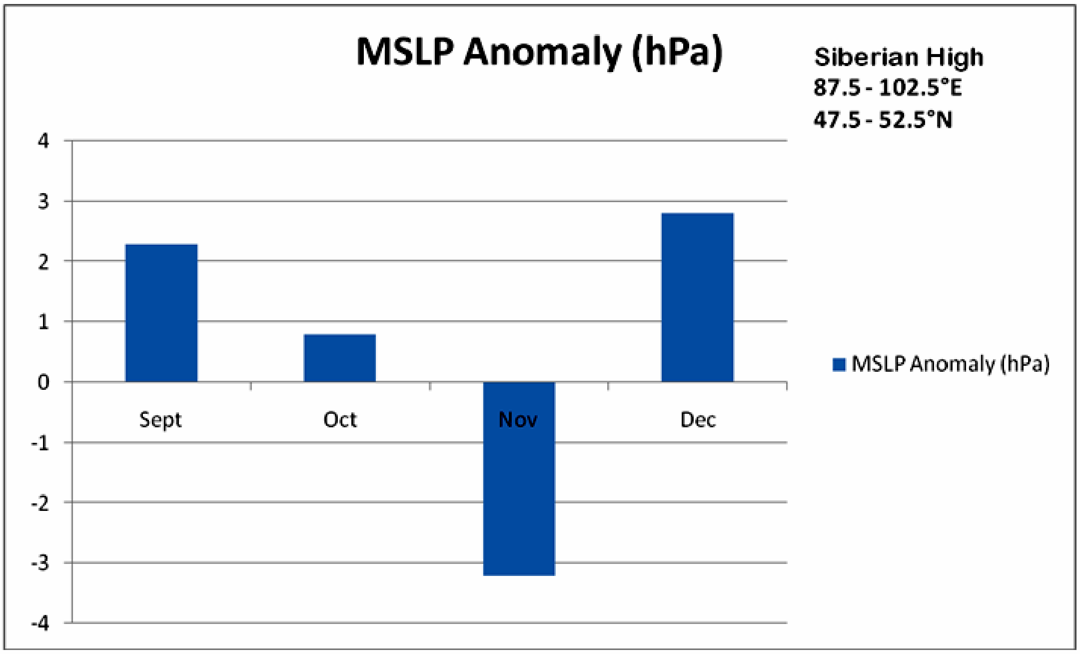


Fig. 9. Mean sea level pressure anomaly (hPa) over Siberian high during 2002

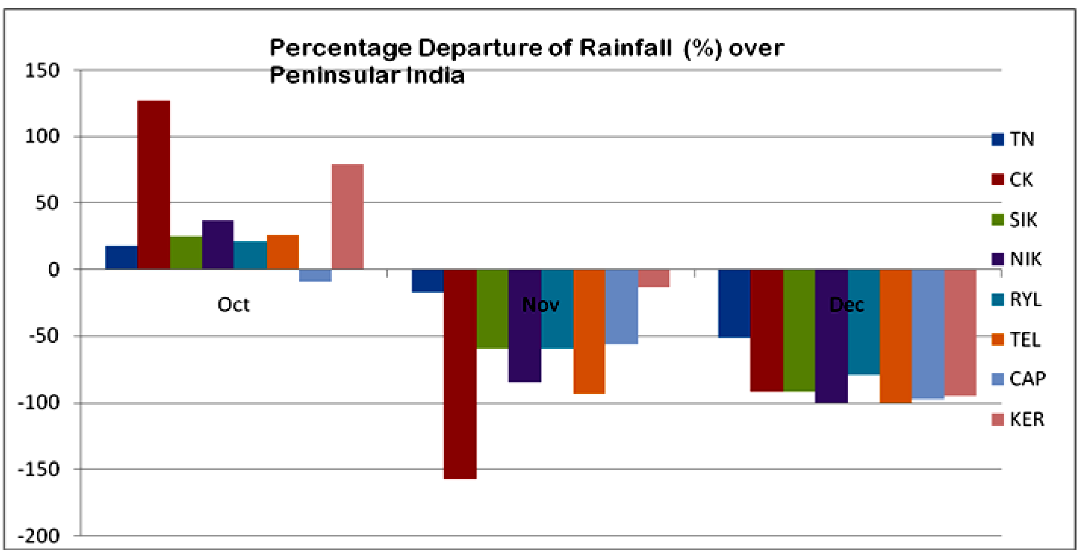
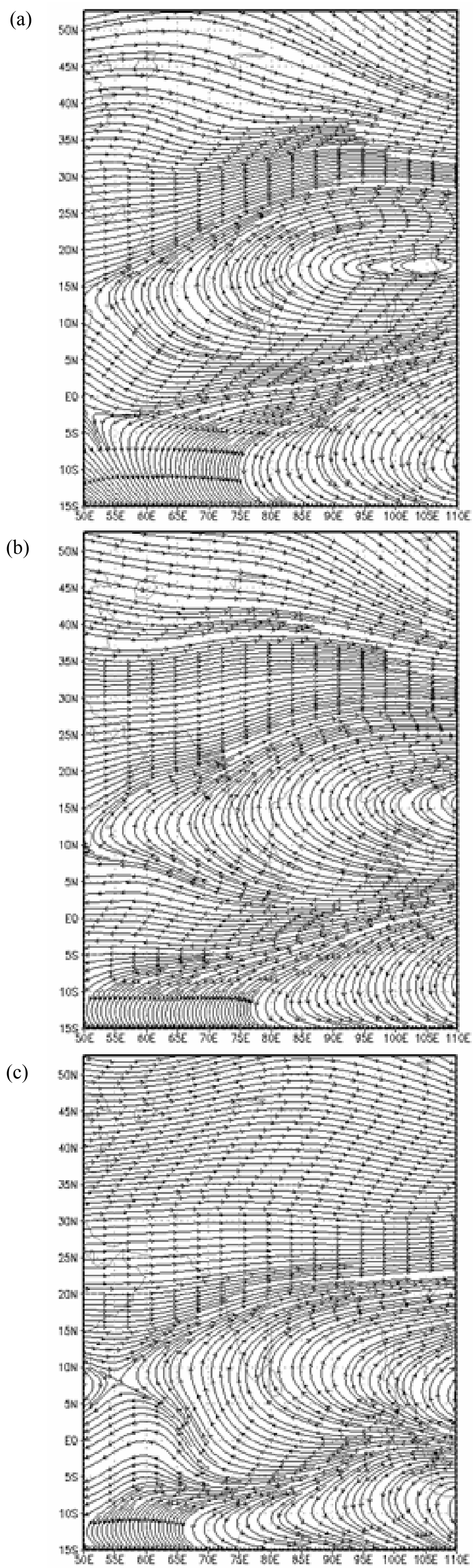


Fig. 10. Interseasonal performance of northeast monsoon over peninsular Indian sub-divisions during 2002

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



Figs. 11(a-c). Stream function of wind during (a) October 2002, (b) November 2002 and (c) December 2002; at 200 hPa level

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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