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Variability in dynamic and thermodynamic parameters in cyclogenesis over north Indian ocean

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सार – उत्तरी हिंद महासागर (एन. आई. ओ.) के अरब सागर (ए. आर. एस.) और बंगाल की खाड़ी (बी. ओ. बी.) नामक दोनों द्रोणियों में भिन्न-भिन्न प्रकार के गतिक एवं ताप गतिकीय लक्षण होते हैं। इसलिए अरब सागर में बंगाल की खाड़ी की अपेक्षा मन्द चक्रवाती घटनाएँ होती हैं। इन द्रोणियों की भिन्नताओं का पता लगानें के लिए भिन्न – भिन्न मौसम प्राचलों के लिए वर्ष 1971–2005 तक की अवधि की सितम्बर से दिसम्बर महीनों के एन सी. ई पी./एन. सी. ए. आर. पुनः विश्लेषित आँकड़ों का उपयोग करते हुए गतिक एवं तापगतिकीय प्राचलों के वितरण का अध्ययन किया गया है। ऐसा देखा गया है कि अरब सागर में मन्द चक्रवाती घटनाओं के लिए समुद्र सतह तापमान उत्तरदायी नहीं है क्योंकि अरब सागर और बंगाल की खाड़ी में समुद्र सतह तापमान प्रायः न्यूनतम प्रभाव सीमा से अधिक रहता है। पवन अपरूपण के संबंध में देखा गया है कि अक्तूबर के दौरान अरब सागर के 10 डिग्री उत्तर में तूफान बनने के लिए सितम्बर की अपेक्षा अनुकूल स्थिति होती है जबकि संपूर्ण अरब सागर उत्तर क्षेत्र के 20 डिग्री उत्तर क्षेत्र को छोडकर, चक्रवात बनने के लिए निष्क्रिय रहता है। अरब सागर में चक्रवात की रचना को रोकने के लिए आर्द्रता–कारक अपरूपण कारक की तुलना में अधिक सुस्पष्ट रहता है। सभी महीनों में 90 डिग्री पूर्व में स्थैतिक अस्थिरता बहुत कम रहती है इससे वायुमंडल पूरी अवधि के दौरान उदासीन रहता है और इसके निचले स्तर में जब थोड़ी भी हलचल होती है तो सिस्टम सक्रिय होने लगता है। अरब सागर की तुलना में बंगाल की खाड़ी अधिक बैरोट्रापिक है। अरब सागर में अपेक्षाकृत अधिक स्थिर वायुमंडल होने के कारण वर्षा की मात्रा में बंगाल की खाड़ी के सबसे निम्न स्तर की वर्षा की मात्रा से काफी भिन्नता रहती है।

ABSTRACT. The two basins Arabian sea (ARS) and Bay of Bengal (BOB) of the North Indian Ocean (NIO) are having different dynamic and thermodynamic character and therefore ARS has subdued cyclone activity than BOB. In order to examine the difference between these basins in respect of various meteorological parameters, using NCEP/NCAR reanalysis data for the period 1971-2005 during the months of September to December the distribution of the dynamic and thermodynamic parameters are discussed. It is seen that sea surface temperature (SST) is not responsible for subdued activity over ARS as the SST over ARS and BOB is mostly above minimum threshold level. In respect of wind shear, during October in ARS north of 10° N is favourable for storm formation unlike September where the whole of Arabian sea except the region north of 20° N is inert to cyclone formation. The humidity factor is more pronounced in ARS for prohibiting storm formation than shear factor. In all the months static instability at 90° E is least and so the atmosphere is neutral throughout the period and consequence of it any small trigger in the lower level will induce the system to grow further. The BOB is more barotropic than ARS. There is a considerable difference exists in precipitation rate as a consequence of more stable atmosphere over Arabian sea than in Bay of Bengal even at the lower level.

Key words – Vertical wind shear, Static instability, Baroclinicity, Potential vorticity, Precipitation rate and Lapse rate.

1. Introduction

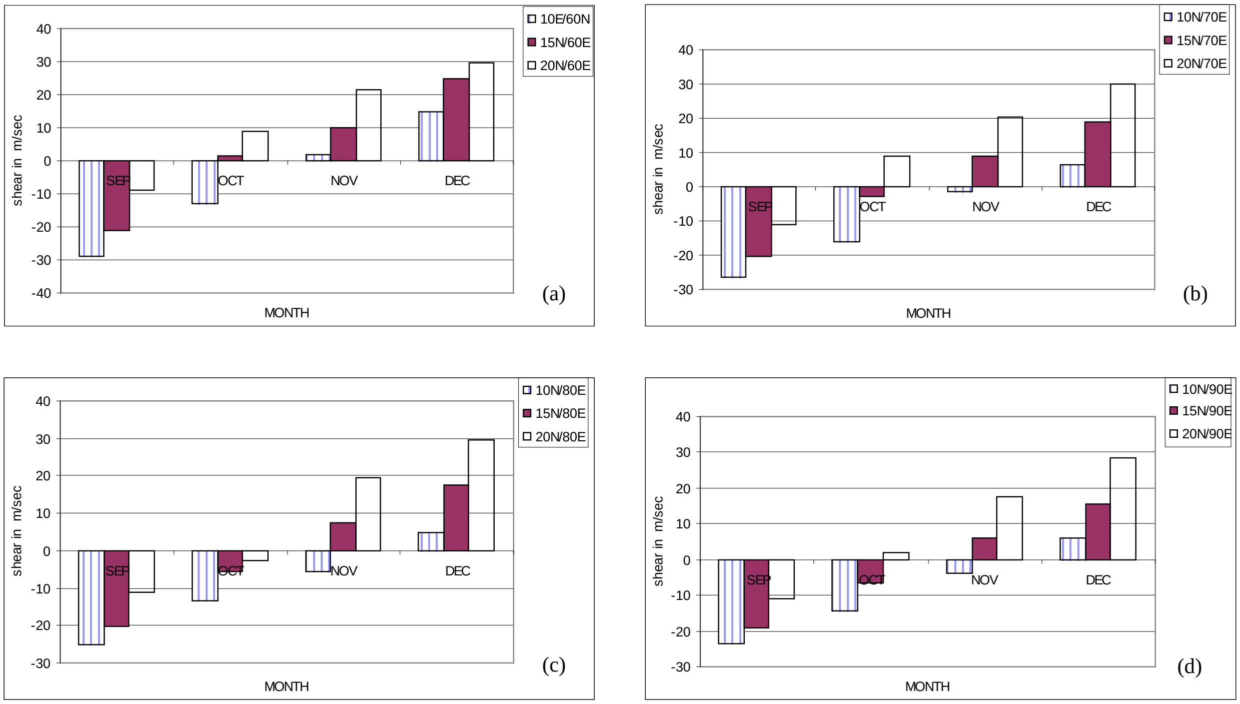
Tropical cyclones are the intense atmospheric vortices, originate over warm tropical Oceans. But it is noticed that not all tropical oceans are conducive for tropical storm formation on various reasons like South Atlantic and South East Pacific. Tropical cyclones play a major role in transporting excess energy received from the sun by the earth from tropical region to the polar region. The energy is derived from condensation in convective clouds concentrated near the cyclone center. Tropical cyclones form from initial convective disturbances known as cloud clusters. They evolve from a loosely organized state into mature intense storms and pass through several characteristic changes. The first global climatology of tropical cyclone genesis by Gray (1968, 1975, 1979) demonstrated that the distribution of genesis may be related to environmental factors such as large value of low level relative vorticity, location of at least few degrees of poleward of equator giving a significant value of planetary vorticity, weak vertical wind shear of horizontal winds, sea surface temperature (SST) exceeding 26° C and a deep thermocline, conditional instability through deep atmospheric layer and large values of relative humidity in the lower and middle troposphere.

Frank (1987) observed that these six parameters are not independent. In the tropics, regions of high sea-surface temperature are inversely correlated with conditional instability due to the weak horizontal temperature gradient in the lower troposphere. High humidity in the middle levels also tend to occur in convective clusters over warm waters, and virtually all areas with widespread deep convection are associated with mean ascending motion. De Maria and Kaplan (1994) remarked that the SST and the outflow temperature are strongly correlated and derived an empirical relation between maximum potential intensity and SST. Schade (2000) concluded that the intensity of tropical cyclone is highly sensitive to a reduction of SST under the eye and such reduction commonly occurs as a response of the ocean to the surface wind field of the cyclone. Cione and Uhlhorn (2003) found that relatively modest changes in inner core SST effectively alter the maximum total enthalpy (sensible and latent heat) flux by 40 % or more. Muthuchami and Sharma (2007) remarked that Higher positive SST anomaly over Arabian sea (ARS) than that of Bay of Bengal (BOB) induce the storms to travel towards west or northwestward and when higher SST anomaly in ARS is below 10° N they mostly cross over Tamil Nadu coast. Muthuchami and Sridharan (2008) seen that in the BOB SST and relative humidity are not responsible for weakening of the storms except in December but wind shear is responsible for weakening of storms. Further the orientation of isotherms of SST over BOB influences the direction motion of the storm. Jadhav and Munot (2007) remarked that SST of north BOB is highly significantly negatively correlated with depression/storms days while SST of south BOB is positively correlated with low pressure days during monsoon months.

Kossin *et al*., (2000) suggested that the primary wind maximum is associated with large vorticity just inside the radius of maximum wind, while the secondary wind maximum is usually associated with relatively enhanced vorticity embedded in the outer ring. Further the instability across the outer ring of enhanced vorticity results in a broader and weaker vorticity ring but still maintains a significant secondary wind maximum and the instability across the moat regions occurs when the radial extent of the moat is sufficiently narrow so that unstable interactions may occur between the central vortex and the inner edge of the ring. Muthuchami and Dhanavanthan (2005) concluded that the intensification of the cyclonic storms depends on the gradient of vertical depletion of mass near RMW and also the low density air near RMW of the system than that of outside the RMW. Over north Indian Ocean in a year about six storms form of which five forms over Bay of Bengal and one over Arabian Sea. Muthuchami and Sridharan (2008) discussed the role of SST over BOB information and intensification of cyclonic storms. But over ARS such study on the role of dynamic and thermodynamic parameters in formation and development of cyclonic storms has not been undertaken. In this paper an attempt is made to understand the distribution of various dynamic and thermodynamic parameters which induce subdued cyclone activity over ARS than over BOB.

2. Data and methodology

The data used in this study has been collected from NCEP/NCAR reanalysis data for the period 1971-2005 during the months September to December. The storm details were collected from the India Met. Dept. (IMD) Publications Tracks of storms and depressions in the Bay of Bengal and Arabian Sea (1979, 1996) and RSMC reports and Annual cyclone Review reports of IMD. The parameters collected are zonal wind speed at 850 and 200 hPa level, surface and upper air temperature, relative humidity and sea surface temperature. From the collected data mean values of various parameters were computed at different latitudes and longitudes at different levels. The vertical wind shear in m/sec is computed between 850 and 200 hPa levels at different latitudes and longitudes over ARS and BOB. The sub-tropical ridge position at 200 hPa level at different longitudes over North Indian Ocean is also extracted. The vertically averaged humidity which is averaged over 925 hPa to 300 hPa also computed separately over North Indian Ocean (NIO), ARS and BOB and its contrast between ARS and BOB are discussed. The thermodynamic parameters such as static stability and baroclinicity are computed by the formulae $\frac{g}{\theta}\frac{\partial\theta}{\partial p}$, $\frac{g}{\theta}\frac{\partial\theta}{\partial y}$ respectively at different levels over ARS and BOB where g is the acceleration due to gravity, θ is the potential temperature of the atmosphere, *p* the atmospheric pressure in vertical component and *y* the usual northerly component of the earths co-ordinate system. The mean precipitation rate at different places is also derived and discussed during September to December over NIO. The average lapse rate between standard levels up to 200 hPa level at different latitudes also have been computed over Arabian Sea and Bay of Bengal and discussed.



Figs. 1(a-d). Vertical wind shear at different places over north Indian Ocean during September to December

3. Results and discussions

3.1. *Vertical wind shear*

(a) *Arabian sea*

Vertical wind shear is one of the major factors which control the cyclone formation and so distribution of wind shear over different locations are discussed here. Figs. 1 (a-d) gives the mean vertical wind shear between 850 and 200 hPa level along 60° E, 70° E , 80° E and 90° E at 10° N and 15° N and 20°N during September, October , November and December. It can be seen that during September along 60° E the wind shear of more than 20 m/sec at 10° N and 15° N is prevailing and it is less than 10m/sec beyond 20° N. But at 70° E the wind shear continue to be at higher values (>10m/sec) at all latitudes south of 20° N. Therefore eastern Arabian Sea is continued to have higher wind shear than in the western Arabian Sea and the whole Arabian Sea is dominated by easterly wind shear during this month. In the month of October pattern changes rapidly over entire North Indian Ocean. In this month at 60° E the vertical wind shear is below 15m/sec at all latitudes, easterly wind shear changed to westerly wind shear in the region north of 15° N and at 20° N and the easterly wind shear of more than 12 m/sec continue to prevail. At 70° E the westerly wind shear at 20° N is similar to 60° E but the easterly wind shear at 70° E near 10° N is much stronger than that of 60° E. Therefore in this month the region north of 10° N is favourable for storm formation unlike September where the whole of Arabian sea except the region north of 20° N is inert to cyclone formation on account of vertical wind shear. In November at 60° E the westerly wind shear increased to more than 20m/sec at 20° N and south of 15° N the westerly wind shear continue to prevail but with less than 10m/sec. In the eastern Arabian Sea the easterly wind shear of very low value continue to prevail at south of 10° N. The westerly wind shear reached upto 20m/sec at 20° N. Therefore the entire Arabian Sea south of 15° N is favourable location for storm formation during this month and the contrast between western Arabian Sea and eastern Arabian Sea is that minimum wind shear is noticed over east Arabian Sea. In December the whole western Arabian sea is not a favourable for storm formation as the wind shear at 60° E is more than 10m/sec at all latitudes. But in eastern Arabian Sea the condition is still favourable for storm formation at lower latitudes south of 12° N as the wind shear is continue to be less than 10m/sec in this region during this month.

(b) *Bay of Bengal*

Bay of Bengal is more active for cyclone formation compared to Arabian Sea. As seen in Figs. 1 (c-d) it can be noted that the easterly vertical wind shear at 80° E in

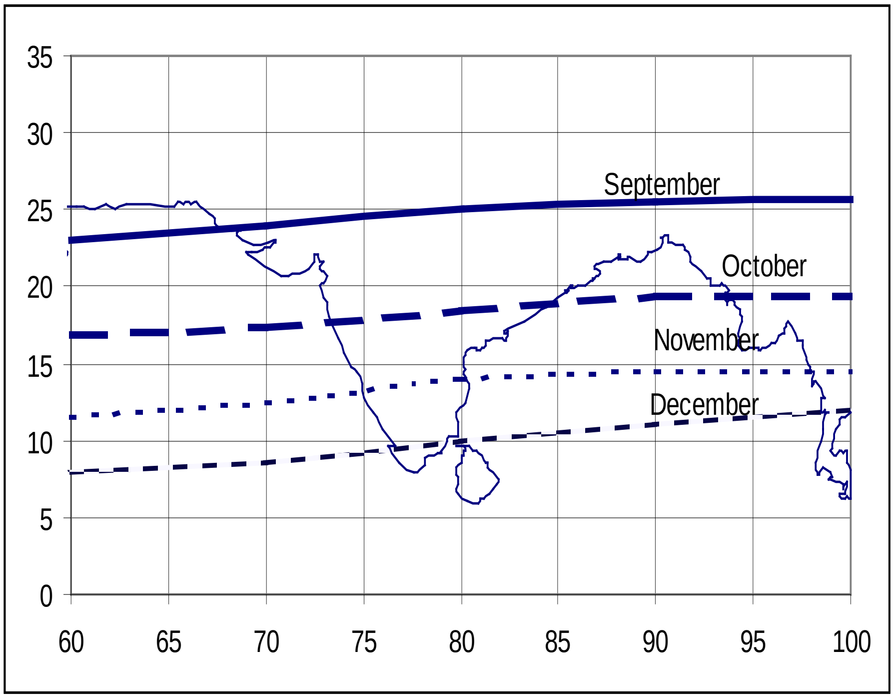
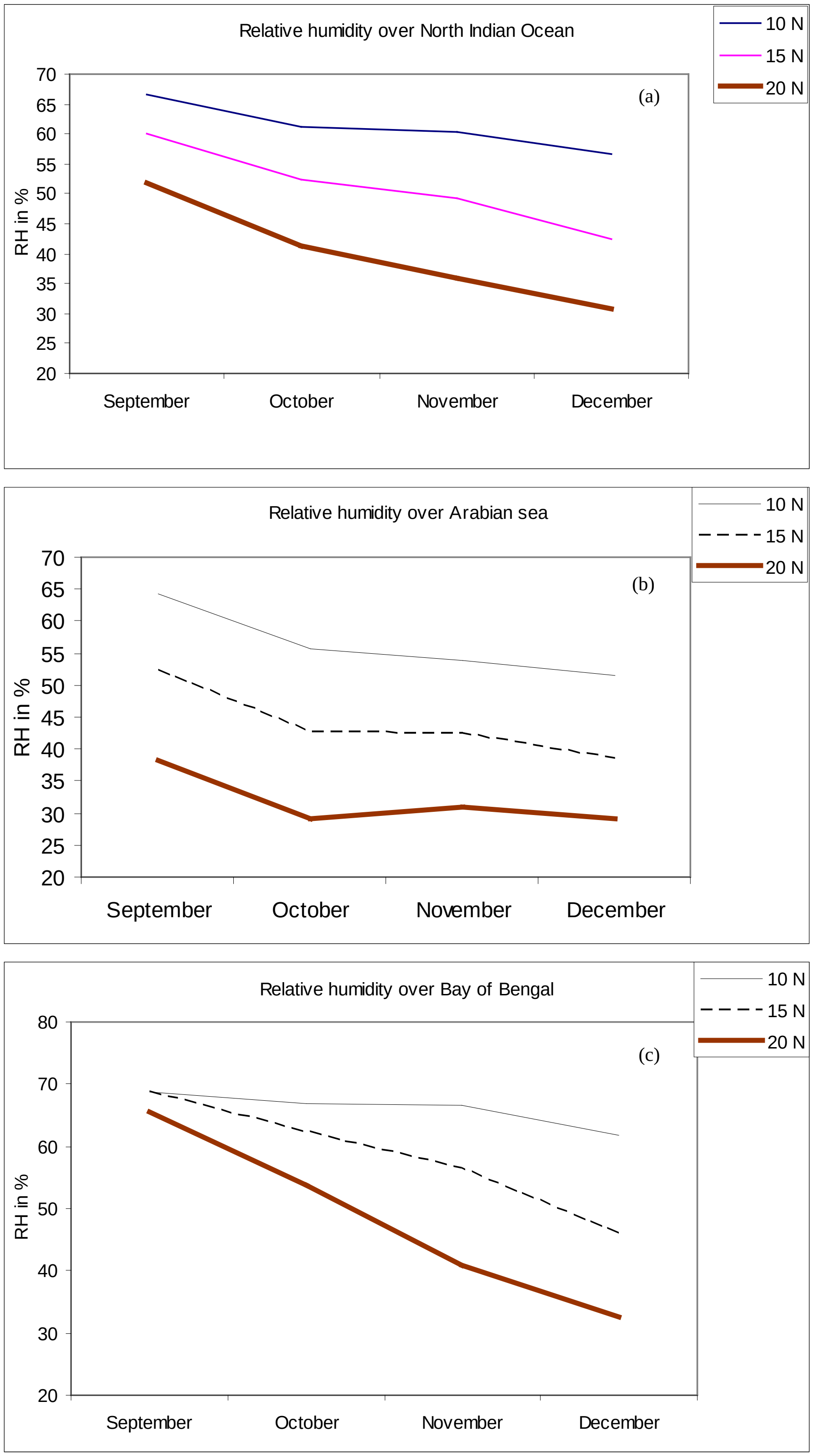


Fig. 2. Mean ridge position at 200 hPa level over North Indian Ocean during September to December

September is more than 10m/sec at all the latitudes south of 20° N particularly it is more than 20 m/sec south of 15° N. Therefore the cyclone formation is inhibited in this region during this month. In 90° E also the same condition prevail over BOB except the fact that the easterly wind shear is comparatively smaller than that of 80° E. In October the easterly vertical wind shear continue to prevail over entire Bay south of 20° N at 80° E but at 90° E the easterly wind shear is prevailed only up18° N. At 90° E north of 18° N the westerly wind shear is noticed but the value of this westerly wind shear is lower compared to easterly wind shear at 15° N and 10° N. hence in this month also the sufficient cyclogenesis in respect of wind shear is prevailing over BOB even at 20° N only lower latitudes of BOB is not fovourable for storm formation during October on account of vertical wind shear. In November over North India north of 20° N the westerly vertical wind shear increased to more than 20m/sec and over the southwest and central Bay the vertical wind shear is below 5m/sec. In east BOB the vertical wind shear is within 5m/sec whereas north Bay is dominated by westerly wind shear of more than 15m/sec. Therefore in this month north Bay is inhibited for cyclone formation on account of vertical wind shear. In December over the Bay of Bengal the region south of 12° N both over eastern and western part is still continue be a favourable location for storm formation on account of vertical wind shear as the vertical wind shear in this region is below 10m/sec and beyond that the vertical wind shear continue to be higher and the values are more than 15 m/sec.

3.2. *Sub tropical ridge position at 200 hPa level*

Though sub-tropical ridge position is considered to be the northern limit of the tropical convective activity but it generally separate the westerly wind regime and easterly wind regime. Fig. 2 gives the ridge position at 200 hPa level over North Indian Ocean and over India at in different months from September to December. From the figure it can be noticed that east of 80° E the sub tropical ridge is north of 25° N and west of that it is between 23° N & 25° N and therefore the easterly wind shear prevailed over entire North Indian ocean in September. This sub tropical ridge shifted southward as season progresses but the rate of shift is slow as it proceeds towards lower latitudes. The reason for slow progress can be attributed to the continued cyclonic activity in the north Indian Ocean. In Arabian Sea the ridge position is much to the south than in Bay of Bengal. This southward shift has some negative influence in the cyclone activity over Arabian Sea compared to Bay of Bengal. Therefore the change of wind from easterly to westerly is much rapid at higher latitudes than at lower latitudes.



Figs. 3(a-c). Vertically averaged humidity over (a) North Indian Ocean (b) Arabian Sea and (c) Bay of Bengal during September to December

TABLE 1

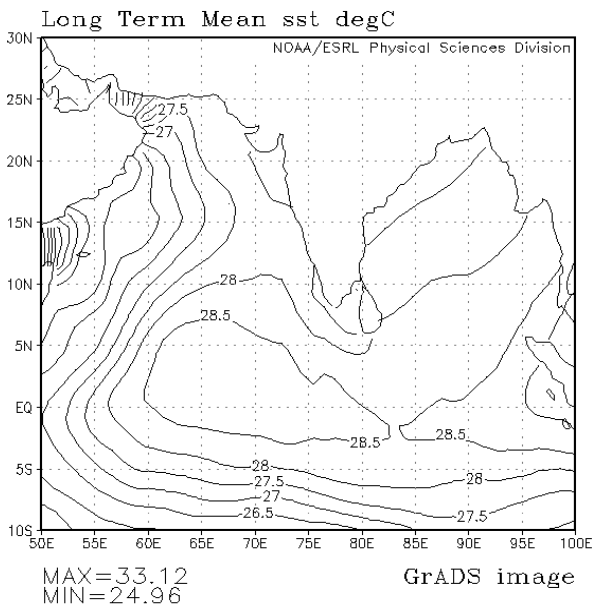
Monthly mean baroclinicity over Arabian Sea and Bay of Bengal during September to December

Month	Level	10-15° N (× 10 $^{-8}$)° K/m				15-20° N (× 10 $^{-8}$)° K/m			
		60°	70°	80°	90°	60°	70°	80°	90°
September	1000	-5.97	-1.78°	0.00	0.00	11.9	0.00	0.00	2.96
	925	1.18	1.18	5.89	1.77	23.4	5.91	0.00	5.89
	850	8.78	2.94	1.75	1.75	29.3	5.86	4.08	5.84
	700	6.86	2.28	-05.7	2.85	5.69	1.71	3.99	5.68
	500	8.17	7.08	3.81	2.72	0.00	5.43	5.16	5.43
	300	8.84	4.16	10.4	7.79	7.76	14.4	9.04	7.75
	200	10.2	10.2	7.61	8.62	7.59	10.0	10.1	9.08
October	1000	-2.98	2.97	0.00	2.97	5.96	7.11	-1.19	-2.97
	925	4.74	5.90	4.72	3.54	18.8	8.81	3.53	0.00
	850	5.88	5.87	5.28	0.00	11.7	4.68	4.09	2.93
	700	-1.72	-4.00	-1.14	0.00	0.00	-5.73	-4.58	0.00
	500	2.72	2.72	1.63	3.27	-1.63	-1.09	0.00	-05.44
	300	5.22	1.04	4.16	4.16	-2.09	-2.08	-1.56	1.04
	200	2.55	4.07	4.07	4.07	1.53	4.06	4.57	2.54
November	1000	-4.77	0.00	-63.03	0.00	-1.19	-8.93	5.70	-11.9
	925	-2.37	5.91	-1.18	0.00	3.56	2.95	5.91	-5.93
	850	0.00	4.40	2.35	1.17	4.12	-2.94	1.18	-5.30
	700	0.00	-1.7	-2.85	0.00	-5.71	-2.86	-5.73	-5.72
	500	0.00	-10.9	0.00	0.00	-8.20	5.48	-4.92	-4.92
	300	-5.24	-4.70	-05.2	0.00	-7.89	-8.39	-5.23	-5.22
	200	-1.27	0.00	0.00	0.00	-5.11	-1.53	0.00	-1.02
December	1000	-12.0	0.00	-2.99	-5.97	-6.02	-11.9	-6.00	-12.0
	925	-8.96	2.96	-05.95	-8.92	-6.00	0.00	5.94	-12.0
	850	-1.18	0.00	-5.31	-2.95	-4.15	-5.90	1.18	-11.8
	700	0.00	0.00	-2.86	0.00	-14.3	-5.72	-8.60	-8.59
	500	-2.73	-2.19	1.64	0.00	-13.3	-11.1	-15.4	-8.22
	300	-5.25	-7.87	-5.23	-5.23	-15.8	-10.05	-10.5	-7.87
	200	-3.58	-4.09	-2.55	-2.55	-4.10	-2.05	-2.56	-1.53

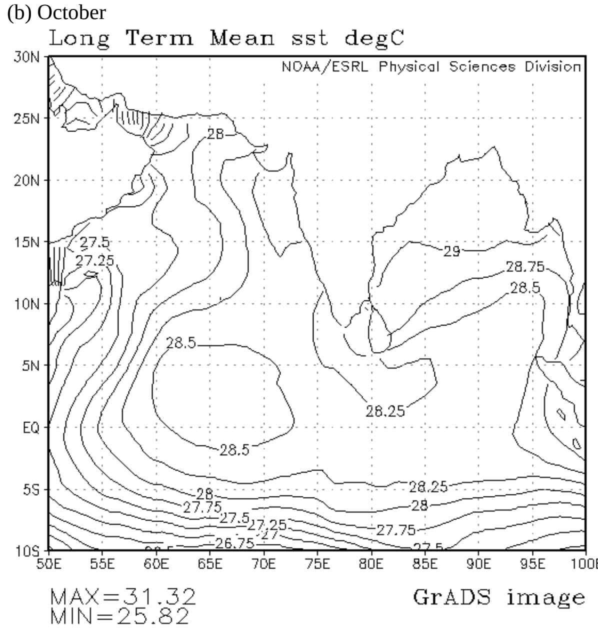
3.3. *Humidity*

Humidity is a controlling factor for cyclogenesis and therefore mean vertically averaged relative humidity (AVRH) from 925 hPa to 300 hPa was computed and discussed. Figs. 3 (a-c) gives the mean AVRH over North Indian ocean, Arabian Sea and Bay of Bengal during September to December. In North Indian Ocean the mean AVRH is 66.5% in September and it decreased to 56.7% in December at 10° N whereas at 15° N it decreased from 60.1% to 42.5 %. At 20° N it decreased rapidly from 51.9 % to 30.8%. Therefore the monthly rate of decrease of AVRH is more in higher latitudes. This is because of not due to land and sea contrast but abundant humidity available in higher latitudes during southwest monsoon period from equatorial and south Indian Ocean continue to

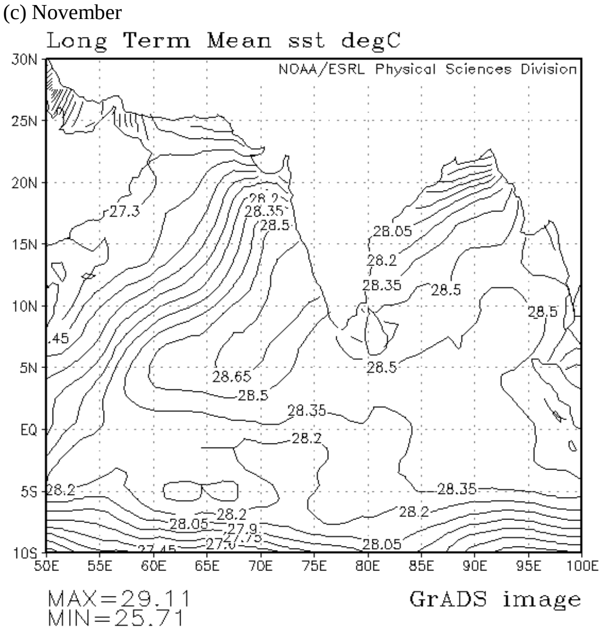
(a) September



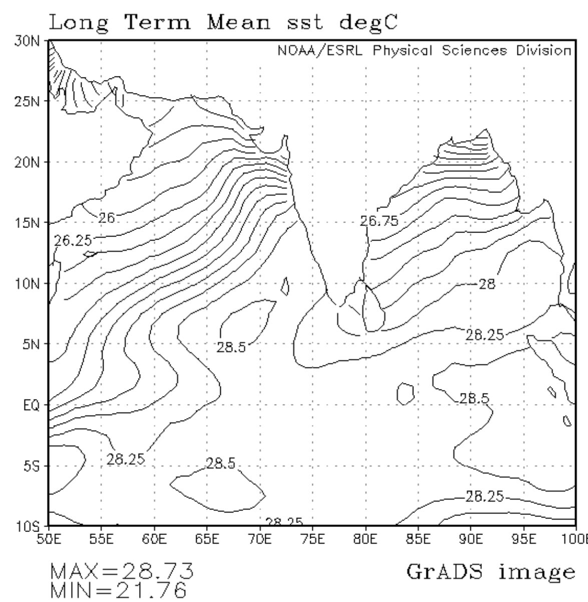
(b) October



(c) November

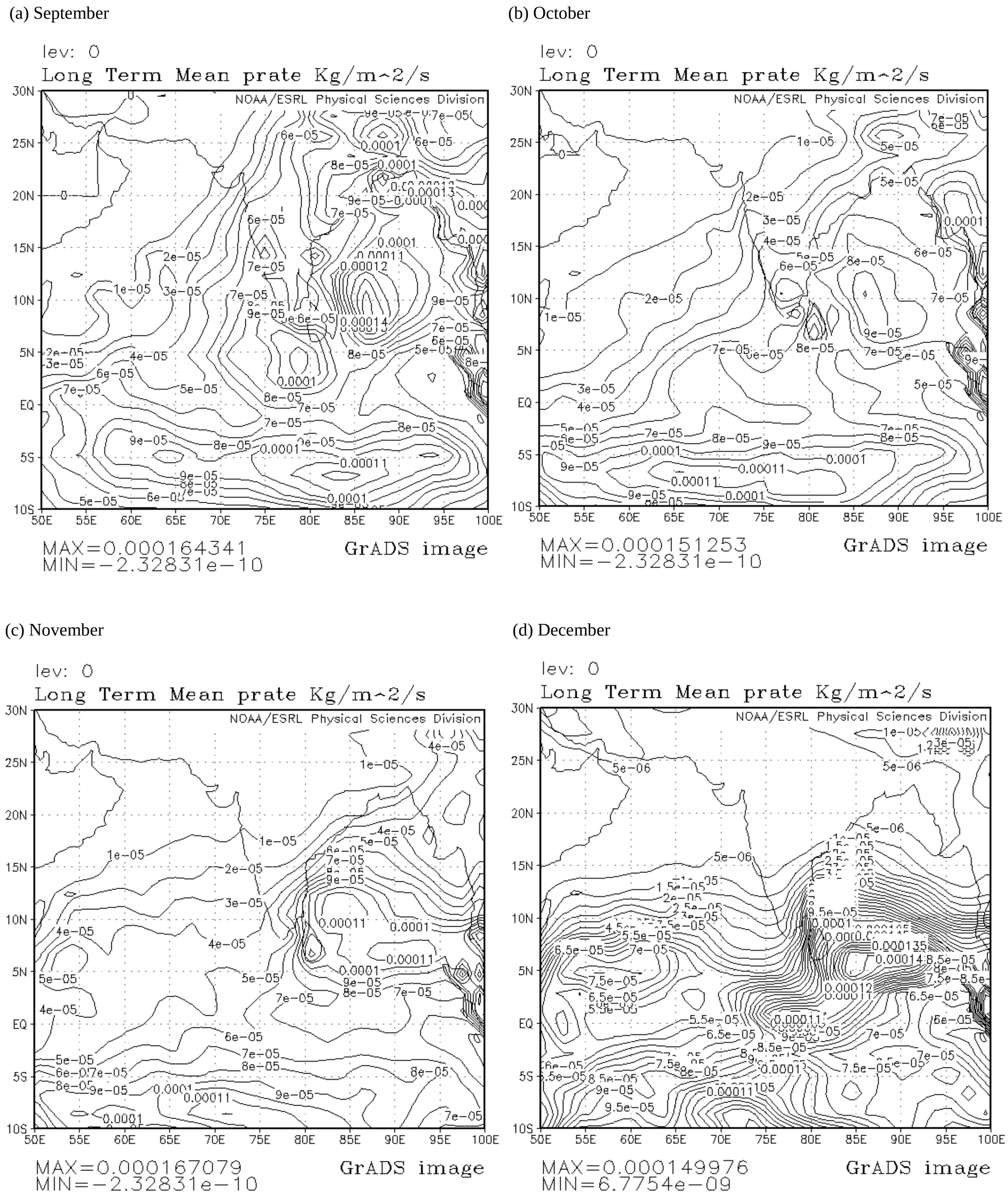


(d) December



Figs. 4(a-d). Monthly mean sea surface temperature over north Indian Ocean during September to December

prevail in lower latitudes during October and November months. The rate decrease of AVRH is about 3.04%, 5.6% and 6.9% respectively at 10° N, 15° N and 20° N. This low rate of decrease of AVRH continues to supply sufficient humidity for formation of cyclones over North Indian Ocean. Fig. 3(b) gives the AVRH over Arabian Sea. It is found that the AVRH is significantly lower north of 15° N compared to over all North Indian oceans AVRH. But the monthly decrease in AVRH is less rapid in ARS than in NIO. This is mainly because the atmosphere is comparatively dry over Arabian Sea than NIO at higher latitudes even during southwest monsoon season. The rate of decreases of AVRH is 4.0%, 4.2%, and 2.6% respectively at 10° N, 15° N and 20° N. Rate of decrease of AVRH at 20° N is very small because the AVRH during September is 38.2%. The AVRH



Figs. 5 (a-d). Mean precipitation rate over the north Indian Ocean during September to December

difference between NIO and ARS is only about 2% in September at 10° N but it is about more than 10 % in other months. Over ARS the region north of 15° N the Gray parameter of RH is mostly 0. If we consider over BOB the AVRH is more in all the months than in ARS and NIO. The monthly rate of decrease of AVRH is as low as 2% at 10° N but it is increased to 11.2% at 20° N. This suggest that the dry sub-tropical westerlies from the

Asian continent contributed rapid dryness at higher latitudes over BOB and the rate of decreases is much higher than of ARS where it is already dry.

3.4. *Static instability*

It is to be noted that in all the months understudy the instability at 90° E is the least and it suggests that the atmosphere is neutral throughout the period and consequence of this any small trigger in the lower level will induce the system to grow further. Therefore the Bay is more active than in Arabian Sea due the difference in distribution of static instability parameter. *i.e.*, upper atmosphere is comparatively conducive for convection in Bay of Bengal than in Arabian Sea.

3.5. *Baroclinicity*

Tropical region is generally barotropic but it does have baroclinicty of small values in certain season or during some occasions. Therefore a study is conducted to find out the distribution of baroclnicity over NIO. The results of the baroclnicity are given in Table 1. It can be seen from the table that in September baroclinicity over ARS is negative only at 1000 hPa level south of 15° N and positive at higher levels over entire NIO. The baroclinicity is comparatively smaller over BOB than in ARS at all levels between 10° to 15° N. North of 15° N, in the lower levels upto 700 hPa the baroclinicity is less in BOB but above 500 hPa level ARS has less baroclinicity than BOB.

In October the baroclinicity is low over BOB than in ARS upto 850 hPa level. At 700 hPa level baroclinicity is negative over ARS and negligible over BOB upto 15° N. Above 700 hPa level in general BOB is more baroclinic than in ARS. North of 15° N the baroclinicty is negative at 1000 hPa level and smaller positive value over BOB. Between 700 to 500 hPa levels entire NIO is with negative baroclinicity. In November upto 15° N the entire region is with small or negligible baroclicity suggests that temperature reversal has been taking place over NIO during this month. But from the distribution of baroclinicty as seen from the Table 1 it can be noticed that in November the warm atmosphere is noticed around 15° N over NIO as the baroclinicity is mostly negative beyond 15° N. Over Bay of Bengal the baroclinicity is zero south of 15° N which is more conducive for formation of cyclonic storms. In December the baroclinicity continue to be negative with higher negative values over ARS beyond 15° N and the Bay is continue to be less baroclinic than ARS.

3.6. *Sea Surface Temperature distribution*

One of the main factor for cyclone formation is the SST over oceanic area which should be above 26° C. Figs. 4 (a-d) gives the monthly mean SST over NIO during September to December. The entire BOB and ARS the SST is normally above 26° C during September, October and November. In September the SST over southwest Arabian sea is found to be below 26° C which is due to the upwelling in the area on account of strong monsoon low level jet whereas in the east ARS the SST is on comparison with the BOB. South of 10° N east Arabian sea is slightly warmer than in same latitude in Bay of Bengal. In October the north Bay become warmer than any other part of the NIO and southwest Arabian SST increases to more than 27° C which is more than the critical value for genesis for cyclonic storm. Therefore the entire NIO has sufficient ocean energy for formation of tropical cyclone in October. In November the north Bay and Arabian Sea started decreasing in SST but continue to have more than threshold value of SST for formation, But the north – south gradient of SST in Arabian Sea is steeper than in the Bay of Bengal. In December not much difference in SST is noticed between ARS and BOB on account rapid decrease in SST over Bay of Bengal than in Arabian sea and in both cases the SST is below 26° C north of 20° N. Therefore subdued cyclone activity over ARS is not due to SST which has a good potential to enhance storm formation.

3.7. *Convective precipitation rate*

Convective precipitation rate gives the measure of convection taking place in a given area which is basic condition for development of cyclonic systems in the tropical ocean basins. Figs. 5 (a-d) gives the mean convective precipitation rate in the NIO during September to December. It can be seen from the Fig. 5(a) that during September there is two parts of active convective zones with highest precipitation of more than $14 \times 10^{-5}/m^2/sec$, one over southwest Bay and another over north Bay of Bengal. The entire Bay of Bengal is found to be active in convection whereas the convection is inhibited in ARS particularly over western part. In ARS, in general precipitation rate is one order less than that of BOB. In October the precipitation rate decreased over BOB compared to September whereas in Arabian Sea not much difference is noticed between September and October. Except in the northwest Arabian Sea the precipitation rate is of equal order in ARS and BOB. In November again the precipitation rate increased over southwest Bay whereas over north Bay it is decreased. The precipitation rate is more than $10 \times 10^{-5}/m^2$ /sec over southwest Bay which is the active zone of convection during northeast monsoon season. In the Arabian sea the precipitation rate

TABLE 2

Monthly mean lapse rate over Arabian Sea and Bay of Bengal during October to December

Month	Level (hPa)	ARS (°C/km)			BOB (°C/km)		
		10° N	15° N	20° N	10° N	15° N	20° N
October	1000-925	-6.5	-5.9	-6.2	-6.8	-6.7	-5.3
	925-850	-7.1	-7.1	-7.8	-6.8	-6.8	-6.8
	850-700	-4.5	-5.4	-6.7	-4.9	-5.1	-5.8
	700-500	-5.0	-4.7	-4.6	-5.1	-5.1	-4.8
	500-300	-6.4	-6.4	-6.4	-6.3	6.3	-6.2
	300-200	10.0	-10.1	-9.8	-10.3	-10.1	-10.1
November	1000-925	-8.0	-7.0	-6.1	-7.0	-6.6	-5.0
	925-850	-7.3	-6.9	-7.0	-6.4	-7.0	-7.5
	850-700	-3.8	-4.7	-5.1	-4.9	-4.8	-5.1
	700-500	-5.2	-5.1	-5.2	-5.1	-5.1	-4.8
	500-300	-6.4	-6.5	-6.6	-6.2	-6.2	-6.4
	300-200	-10.1	-9.9	-9.4	-10.3	-10.4	-9.9
December	1000-925	-8.0	-7.3	-6.0	-7.0	-7.0	-5.0
	925-850	-6.9	-6.1	-6.2	-6.1	-5.9	-7.0
	850-700	-3.7	-3.7	-4.4	-4.2	-4.1	-4.3
	700-500	-5.4	-5.7	-5.7	-5.3	-5.4	-5.3
	500-300	-6.5	-6.4	-6.4	-6.3	-6.3	-6.3
	300-200	-10.0	-9.9	-9.1	-10.1	-10.1	-9.5

ARS - Arabian Sea, BOB - Bay of Bengal

is continue to be with less value and almost zero precipitation rate is noticed in the north Arabian Sea, In December the precipitation rate become very small over Arabian sea and Bay of Bengal north of 15° N. The active precipitation zone shifts to south of 5° N in the southwest Bay of Bengal and it is more than 0.00014 kg/m^2/sec. Even though there is not much change is noticed in SST distribution between Arabian Sea and Bay of Bengal there is a considerable difference exists in precipitation rate and therefore atmosphere over Arabian Sea must be more stable than in Bay of Bengal.

3.8. *Potential vorticity*

Potential vorticity (PV) is the one of the dynamical parameter which controls the formation and intensification of tropical cyclones over tropical oceans. PV anomaly in the core of the cyclonic storm mainly controls the sustenance of the vortex. The interaction of the upper- and lower-level PV anomalies appeared to be important in the initial strengthening of the tropical cyclone. Bosart and Bartlo (1991) concluded that upright ascent associated with the convection short-circuited the slantwise ascent ahead of the advancing PV, triggering warming aloft and the eventual disappearance of the PV anomaly and associated cold dome. Tropical storm development and intensification occurred as the low-level vorticity center (PV maximum) moved northwestward to become situated beneath the midlevel vortex embedded within a local 500–200 hPa warm thickness anomaly. Molinari *et al*. (1998) studied the complexity of interplay between vertical wind-shear, diabatic heating, mutual advection among the vortices at and below the level of outflow anticyclones. The superposition principle is useful to describe the intensification of Tropical cyclones during such interactions. Moller and Montgomery (2000) found that vortex Rossby waves propagate both radially and vertically and higher the wave number weaker the vertical propagation of the PV asymmetries. The lower level PV anomaly intensifies the vortex while symmetrising for wide range of anomaly amplitude. The intensification of tropical cyclones to hurricane strength depends on location and extent of the PV anomaly. A study of PV over NIO reveals that there is not much difference in PV between south ARS and BOB below 15° N during October and December as the isolines of Potential vorticity are mostly parallel over NIO (figures not shown). The potential vorticity over BOB is comparatively lower than in ARS in all the months north of 18° N. The meridional gradient of potential vorticity is increasing from October to December north of 15° N in ARS and in BOB the gradient of it does not change and further the rate of decrease of PV is also small. In November the potential vorticity over BOB is slightly less than that of ARS. Therefore the potential vorticity pattern does not inhibit the formation of storms in October to December in Arabian Sea.

3.9. *Lapse rate over NIO*

From Table 2 which gives the environmental lapse rate of temperature over NIO during October to December it can be seen that during October the lapse rate between 1000 hPa and 925 hPa is less over ARS compared to BOB over central and southern part of NIO. Hence the lower atmosphere is less stable in the BOB than in ARS and so any small amount of low level convergence is sufficient to lift the parcel and produce active convection in BOB. In November and December the lapse rate in the lower level is less in BOB than in ARS and therefore lapse rate is not an inhibitor of cyclone activity in Arabian Sea during November and December. Mostly in higher level also the lapse rate is conducive development of the system over ARS during November and December. The lapse rate is small in the middle atmosphere between 850 hPa to 500 hPa over entire NIO during this season. It is only slightly low in general over ARS than in BOB between 850 and 700 hPa levels in central and southern part of NIO.

4. Conclusions

(*i*) In respect of wind shear in the month of October in ARS north of 10° N is favourable for storm formation unlike September where the whole of Arabian sea except the region north of 20° N is inert to cyclone formation. In December the entire western Arabian Sea is not favourable for storm formation as the wind shear at 60° E is more than 10m/sec at all latitudes. But in eastern Arabian Sea the condition is still favourable for storm formation at lower latitudes south of 12° N. In the BOB in October the sufficient cyclogenesis is prevailing on account of vertical wind shear even at 20° N except in lower latitudes. In November north Bay is inhibited for cyclone formation on account of vertical wind shear. In December over the Bay of Bengal region south of 12° N both over eastern and western part of the Bay is continue to be a favourable location for storm formation on account of vertical wind shear.

(*ii*) Rapid southward shift of subtropical ridge at 200 hPa level have some negative influence in the cyclone activity over Arabian Sea compared to Bay of Bengal.

(*iii*) The atmosphere over NIO is humid only in the low latitudes during the end of southwest monsoon season but relatively dry over ARS and in particular over western part at all levels. The east west gradient of relative humidity is strong between 700 and 500 hPa level north of 10° N over ARS. Therefore humidity factor is more pronounced in ARS for inhibiting storm formation than shear factor as in the BOB.

(*iv*) In November upto 15° N the entire region is with small or negligible baroclinicity and it suggests that temperature reversal has been taking place over NIO during this month. In general BOB is less baroclinic than ARS and therefore Bay is more favourable for tropical convection.

(*v*) The north south gradient of SST in Arabian sea is steeper than in the Bay of Bengal and the SST over Arabian sea is all the time above critical limit of Gray Parameter for storm formation. Therefore the SST is not responsible for subdued activity in ARS.

(*vi*) Even though there is not much change is noticed in SST distribution between Arabian sea and Bay of Bengal there is a considerable difference exists in precipitation rate and therefore the atmosphere over Arabian sea must be stable than in Bay of Bengal.

(*vii*) In November the potential vorticity over BOB is slightly less than that of ARS contrary to October and December and it suggest that the potential vorticity pattern does not inhibit the formation storms in October to December in ARS.

(*viii*) The lapse rate is small in the middle atmosphere between 850 hPa to 500hPa over NIO during this season and it is generally low over ARS than in BOB between 850 and 700 hPa levels in central and southern part of NIO. Therefore the lower atmosphere is less stable in the BOB than in ARS and so any lower amount of low level convergence is sufficient to lift the parcel in BOB than in Arabian Sea.

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