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Variations in Atmospheric Structure and Wave Activity in Changing Monsoon Conditions over Mahabubnagar, as observed during Caipeex-2011

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ABSTRACT

Upper-air radiosonde observations, taken during "Cloud Aerosol Interaction and Precipitation Enhancement EXperiment" (CAIPEEX) at Mahabubnagar (16.73°N, 77.98°E) under Integrated Ground Observation Campaign (IGOC) during the second half of southwest monsoon of 2011 have been analysed. Various weather data taken from India Meteorological Department as well as NCEP/NCAR reanalyzed upper-air wind data for the months August and September of 2011 have also been used in the study. Intra-seasonal variation of monsoon, during the period of experiment, has been studied. Using the field observations taken under IGOC, an attempt is made to investigate dynamical and thermal structure and also wave activities in relation to prevailing monsoon conditions over the station. Auto-correlation analysis has been carried out to identify the dominant modes associated with the monsoon variations observed over the station. Various wave characteristics have been extracted. The study has indicated the presence of gravity waves over this tropical station, during monsoon period. It is inferred that the wind shear and tropical convection associated with weather disturbances are possible sources of excitation of such waves over the location.

INTRODUCTION

Radiosonde measurements dominate over other observational techniques in the troposphere and lower stratosphere as they routinely measure these parameters, generally at predetermined pressure levels (Dolas and Kumar 2009). These upper-air observations are very important to meteorologists, particularly to forecasters and climatologists, as they provide a comprehensive picture of the three-dimensional structure and state of the atmosphere. In the data assimilation systems for numerical weather prediction, wind and temperature data from radiosondes and aircrafts have been used as the main source of in- situ information for the last few decades (Amstrup and Huang 1999; Ballish and Kumar 2008). Despite impressive advances in remote sensing techniques, radiosonde observations continue to be an important observational component of most atmospheric research programs and field observational campaigns, world over.

In the recent past, Integrated Ground Observation Campaign (IGOC) was carried out under the project Cloud Aerosol Interaction and Precipitation Enhancement Experiment in 2011 (CAIPEEX-11) over Indian region. Under this experiment, special radiosonde (RS92) observations were taken using Vaisala DigiCORA Sounding System at Mahabubnagar (16.73°N, 77.98°E) during the period 2 August to 31 October 2011. The observations archived through similar sounding system have been used in several studies in the past. Das Gupta et al. (2005) have validated the upper-air observations taken during ARMEX-I (Arabian Sea Monsoon EXperiment) using DigiCORA sounding system. While, Mujumdar et al., (2005) have used upper-air observations taken onboard ORV Sagarkanya under BOBMEX-1999 experiment, using Vaisala RS80 radiosonde equipment. Based on these data, they studied thermodynamic characteristics over North Bay of Bengal during contrasting monsoon conditions (active and weak phases) observed during the period of BOBMEX-1999.

The observation site (Mahabubnagar) of the experiment CAIPEEX-11 lies in the rain shadow region in respect of the southwest monsoon season. This experiment was designed to study atmospheric and thermodynamic parameters in the context with the cloud seeding experiment around and in the southwest sector of Hyderabad over the peninsular Indian region. The availability of these special observations has provided an opportunity to investigate variations in the atmospheric structure over Mahabubnagar station. Accordingly, this study makes an assessment of observed variations, based on CAIPEEX-11 data, in relation to the changing monsoon conditions during the second half of monsoon 2011.

In the past, researchers have also used upper air observations to investigate the wave activities in the troposphere and lower stratosphere. The waves of typical class like gravity waves are known to play an important role in determining large-scale circulation and the thermal structure of the middle atmosphere. These waves propagate from the source region, and finally break or dissipate in other regions and transfer horizontal momentum from the excitation level/latitude to the breaking level/latitude (Yamamori and Sato 2006). They are generated by various sources viz. convection, organized convective systems, topography and spontaneous adjustments. Ogino et al. (2006) mentioned that there is a need to describe the wave characteristics at various locations, especially at places where no observational work has been conducted. Asia is one of the regions. Accordingly, this study makes a preliminary attempt to investigate wave activities over Mahabubnagar station based on the special observations taken during CAIPEEX-11.

The Observational Setup And Data Used

Under CAIPEEX-11, ground observations were taken by using instruments installed at Mahabubnagar site. In addition to this, Radiosonde flights were conducted using Vaisala make DigiCORA Sounding System MW31 GPS upper air sounding system. The instrument is uplifted using 875 gm rubber balloon using hydrogen gas filled in, at ascent rate of about 5 mps. The Ground Check Set GC25 is used with the Radiosonde RS92 and the sounding system introduces a user-friendly radiosonde ground checking procedure. The original sampling interval in each sounding was 2 sec., which corresponds to a height interval of about 3-8 m. The timings of the launching were decided as per the flight schedule of cloud seeding experiment. A total of 97 balloons were launched during the campaign. The performance of the balloons (weight: 875 gm) proved to be good: 72 launches reached the height above 30 km, out of which 17 reached up to 35 km and 18 ascents reached a height of 30 km. Launch was carried out during the daytime. Majority of the balloons reached up to stratosphere. The maximum and minimum heights reached were 35.7 km and 14.9 km, respectively.

Although, the campaign period was from August to October, the present study is based on the radiosonde observations taken under CAIPEEX-11 at Mahabubnagar on a daily basis at 1100/1300 IST (Local time) during the period 02 August to 30 September 2011. Synoptic weather data and reports (like Weekly Weather Reports) are taken from India Meteorological Department's (IMD) website (http://www.imd.gov.in) for the months of August and September during 2011. In addition, rainfall data have been taken from National Data Centre, IMD, Pune for available twenty-one year period during 1972-2005. These data are used to understand the background rainfall climatology of the station. Daily mean reanalyzed upper-air wind data at 2.5° X 2.5° Lat. /Lon. grid point of NCEP/NCAR (Kalnay et al. 1996) over the domain bounded by the latitudes Equator to 30°N and longitudes 60°-100°E for the same period are also utilized.

Summary Of Monsoon Season

During August, four low pressure areas were formed: over land (seen as a low pressure area during 8-11 and 11-17 August). From the remaining two, one formed over Bay of Bengal (29 August-10 September, well-marked during 6-7 September) and the other formed over Arabian Sea (30 August-04 September). Whereas, in September, one depression formed over Bay of Bengal (seen as a low from 20 to 27 September and as a depression during 22-23 September) and two low pressure areas, one over Indian land (6-13 September) and other over Bay of Bengal (13-19 September) were formed. These systems (except the one which formed over Arabian Sea) were initially seen either as an upper-air cyclonic circulation (CyCir) over the eastern part of the monsoon trough, a few days before or they formed over there as a marked system and moved westward across the monsoon trough. The cross equatorial flow maintained its strength all through the month of August and in the first half of September. The withdrawal of monsoon started from 23 September. The systems during the month of September are: low pressure area of 13 to19 and the depression of 22 and 23 remained east of about 80°E. In association with the above synoptic features, all India summer monsoon rainfall was above normal during 4-20 August (except on 5, 12 and 19 August), 24 August to 10 September (except on 31 August) and during 15-19 September. For the Mahabubnagar district, the Southwest monsoon seasonal normal rainfall is 484 mm (Rafiuddin et al., 2007). The actual and percentage departure of rainfall for the months of August and September 2011 are 167.7 mm & 6% and 25.3 mm & - 83 %, respectively.

RESULTS AND DISCUSSION

Daily Rainfall at Mahabubnagar: Fig 1 depicts daily values of rainfall (mm) at Mahabubnagar during August and September-2011. The actual (03 UTC past 24 hrs. accumulated) rainfall (RR) values for the year 2011 are shown by histogram, while the climatology (based on the long term data) rainfall (RN) values are shown by solid line.

It can be seen that the events of above normal RR have mostly occurred around the periods of various systems mentioned above, while RR is below normal or absent from 12 September (Fig. 1). From the plot of RN it can be seen that during August and September, normally, at a very few occasions, the station receives RR > 1 cm. Compared to this, in 2011, it can be seen that the station received RR > 1 cm on 3 August (2.3 cm), 4 August (1.3 cm), 15 August (2.0 cm), 19 August (1.4 cm), 21 August (11.3 cm), 24 August (2.3 cm), 27 August (1.2 cm), 31 August (2.5 cm), 1 September (1.0 cm) and 11 September (1.4 cm). The isolated event of heavy rainfall of 11.3 cm

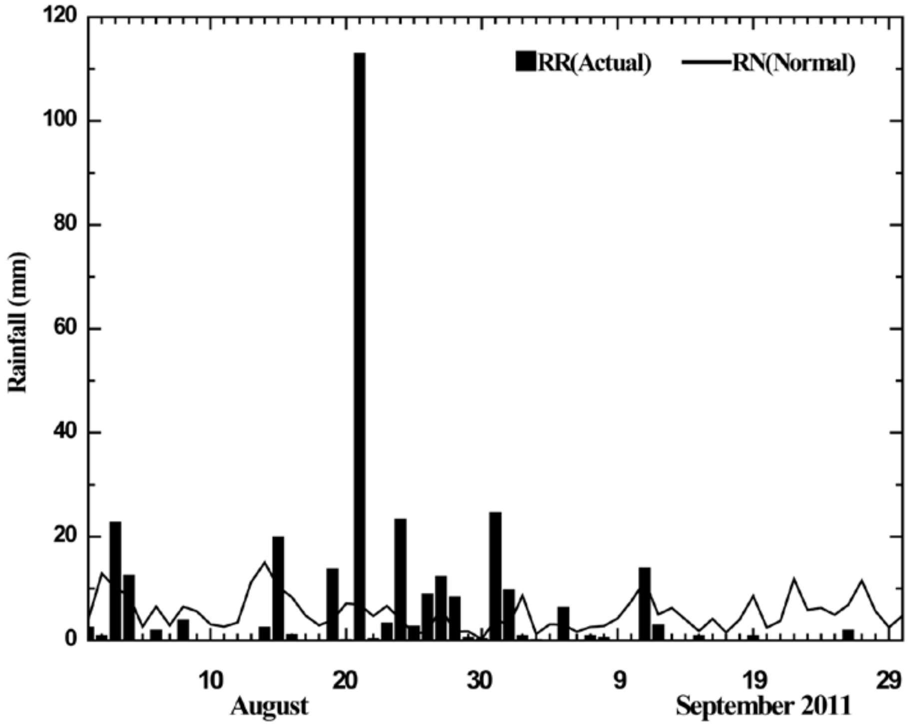

Figure 1. Daily values of rainfall of actual (RR: histogram) and normal (RN: solid line) in mm at Mahabubnagar.

of 21 August occurred in absence of any marked synoptic weather system. Around the period of this event there was a CyCir, which had formed over northwest Bay of Bengal and moved across the monsoon trough during 18-23 August.

Monthly Mean Profiles Of U, V, T And Rh At Mahabubnagar Based On Field Data: Fig 2 (a-d) depict the vertical profiles of monthly averaged zonal (U) and meridional (V) components of wind, temperature (T) and Relative Humidity (RH), respectively at Mahabubnagar for the month of August and Fig.2 (e-h) show that for the month of September. The profiles of monthly-averaged winds and temperature have been investigated to study the dynamic and thermal structure of the atmosphere. The pattern of U is more or less similar in both the months and is dominated by eastward wind component up to mid-tropospheric levels and with strong westward wind components in the upper troposphere and lower stratosphere (Fig. 2a and 2e). The maximum intensity is noticed around tropopause (15-17 km) level. It is seen from Fig 2 (b and f) that V is one order less than U. Also they are southward in the lower troposphere except for August when they are northward in the lower layer up to 900 hPa. While in the layer 650- 450 hPa, they are northward. The average temperature does not show substantial change as season progressed from August to September (Fig. 2c and 2g). Mean tropopause is observed to be located around 100 hPa level in both the months. The profiles of RH exhibit relatively higher values (> 50%) in August up to mid-troposphere (Fig. 2d) than that for September when such high values are noticed to be confined up to lower troposphere (Fig. 2h).

Tropopause Temperature And Height: The daily variation of tropopause temperature and its height over Mahabubnagar are shown in Fig. 3 (a & b), respectively. The minimum and maximum tropopause temperatures during the study period are observed as -84.3°C and -76.7°C, respectively (Fig. 3a). In general the tropopause temperature shows a dominance of 5 to 7 day variation during the study period. The tropopause height is between 16.2 km and 16.4 km (Fig. 3b). Although the tropopause height shows significant day to day variation, it has a dominance of 15-20 day variation. Leena et al., (2012) also found that the cold point tropopause altitude shows significant day-to-day variability within monsoon season with maximum and minimum heights of 16.9 km and 16.2 km, respectively. The present results are more or less match with their findings.

The impact of large scale synoptic features and associated intra-seasonal variation of the monsoon conditions over the station are assessed by using NCEP based U and V data, averaged over the latitude longitude grid box bounded by 16°-17°N and 77°-78°E (representing Mahabubnagar station). The results are discussed by presenting vertical time sections of U and V as well as daily vertical (tropospheric) wind shear over the station. These results are then compared and discussed using the CAPEEX-11 field data.

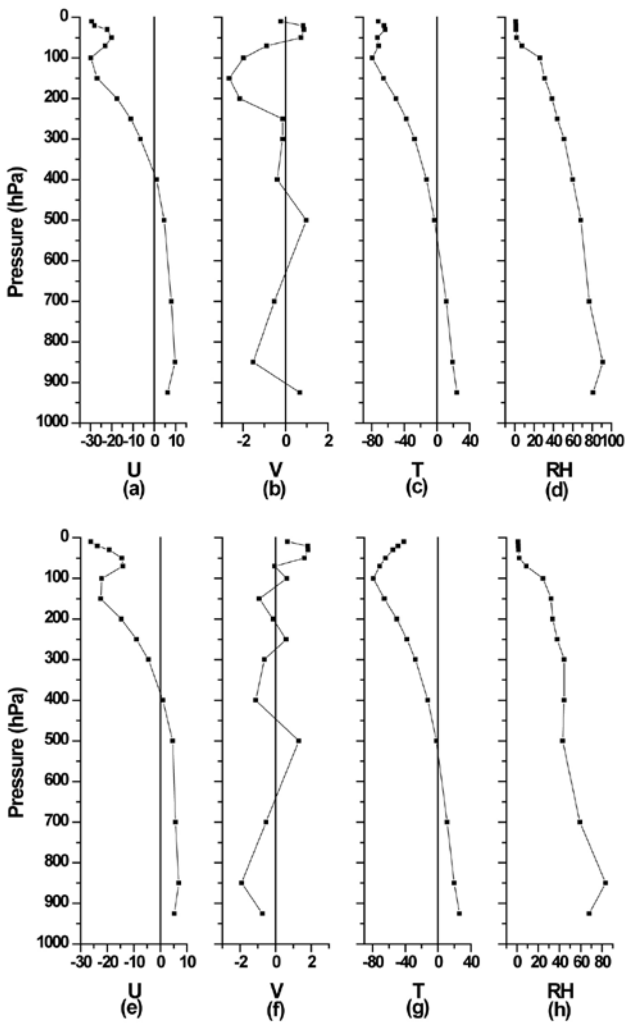

Figure 2. (a-d) Vertical profiles of monthly mean zonal: U and meridional: V components of wind (mps), temperature: T (°C) and Relative Humidity: RH (%) at Mahabubnagar respectively for the month of August and (e-h) that for September 2011.

Vertical Time Section Of Daily U And V Based On Ncep Data: Fig 4 (a and b) present the vertical time sections of mean U and V respectively over the station based on NCEP data for 1000-100 hPa levels during 1 August to 30 September 2011. High values of U (> 10 mps) are noticed from 1 August to about 14 August and from 26 August to 10 September in the lower troposphere (Fig. 4a). Such values are seen even up to mid-tropospheric level around 7-12 August, 28 August, 3 and 6 September. These high values indicate presence of strong monsoon westerlies over the station location in association with the west-northwestward moving transient systems along the monsoon trough, which existed around this period. V is seen to be positive from surface to 900 hPa, from 1 August to 20 September (Fig. 4b). High values of V (> 4 mps) are noticed up to mid-tropospheric level during 2-4 September. Similar high values are noticed in the layer of about 400-500 hPa during 10-11 August and on 16 September and that in 100-200 hPa during 22-30 September. The periods of coexistence of strong positive U and V are indicative of the dominance of strong monsoon winds at the station.

Daily Tropospheric Wind Shear Based On Ncep Data: Daily values of wind shear over the study area are deduced by making subtraction of lower and upper tropospheric zonal wind components (U_{850} - U_{200}) based on NCEP data. Fig 5 shows a plot of these values for the period 01 August to 30 September 2011.

Strong shear (> 25 mps) trends are noticed during 01 to 16 August and 25 August to 11 September on most of the days. These are the periods when monsoon disturbances were formed and good amount of rainfall occurred over the study region. The highest/lowest values of shear are noticed to have repeated after about 30 days. The shear was lowest on 20 August with a value of 11 mps. An isolated event of heavy rainfall was reported on 21 August. The low vertical wind shear around this period is indicative of weaker

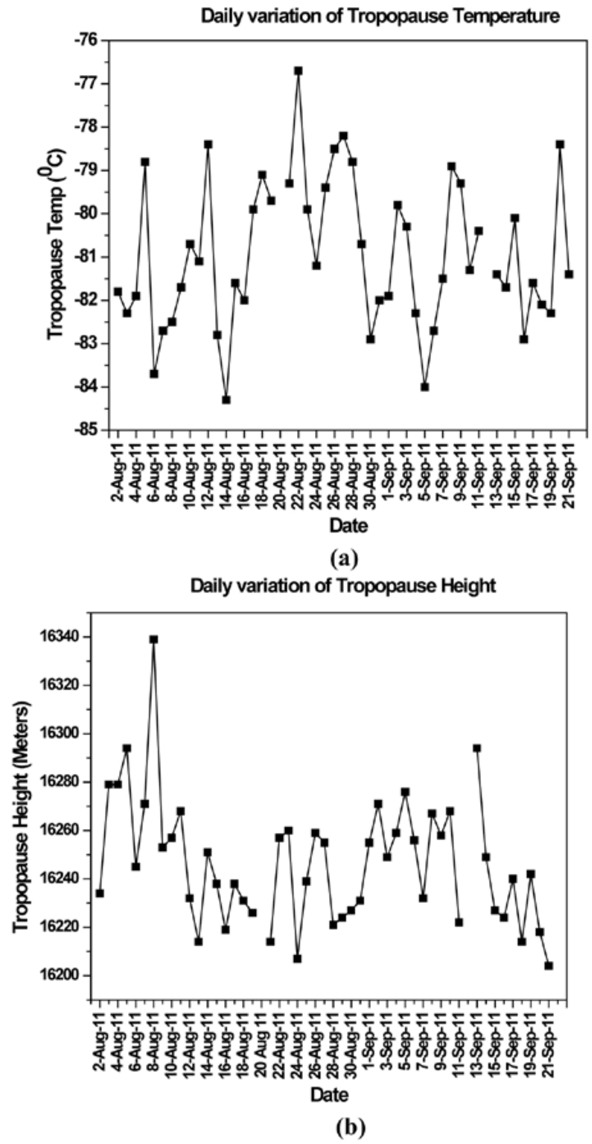

Figure 3. Daily variations of (a) Temperature and (b) Height of Tropopause at Mahabubnagar during 02 August to 20 September 2011.

monsoon conditions. A discussion about the occurrence of such an event under the prevalence of typical wave activities noticed at the station is made in the last section.

Vertical Time Section Of Daily U, V And T Based On Field Data: Fig 6 (a, b and c) show the vertical time sections of observed U, V (both in mps) and T (in °K) respectively at Mahabubnagar for the month of August. Similarly, Fig. 6 (d, e and f) show that for September-2011.

It is evident from the vertical time section of U that below 9 km, the wind is eastward, which turned westward above the same height in the troposphere (Fig. 6a). High positive values of U (> 15 mps) are noticed in the lower troposphere during 2-5 August, 7-12 August, 25-29 August in the presence of marked synoptic systems. The values are seen to be low during 14-23 August. In the upper troposphere, high negative values of U (> |-30| mps) persisting for few days are noticed especially around tropopause height (~16 km), indicating the presence of Tropical Easterly Jet (TEJ). Such high values are seen to reappear after about 10-15 days. Similarly, V also indicates pockets of high positive values up to the mid-troposphere from 3 August reappearing after about 3-7 days up to 23 August (Fig. 6b). Fig 6c gives the vertical time section of T for August. The Figure does not depict much significant changes except for certain perturbations around 7-8, 13 and 24 August, peaking upwards up to 10 km. whereas colder temperatures are noticed near and above tropopause level from 02 to 13 August, which further descends downwards up to 20 August.

It is seen that in September, U shows similar features

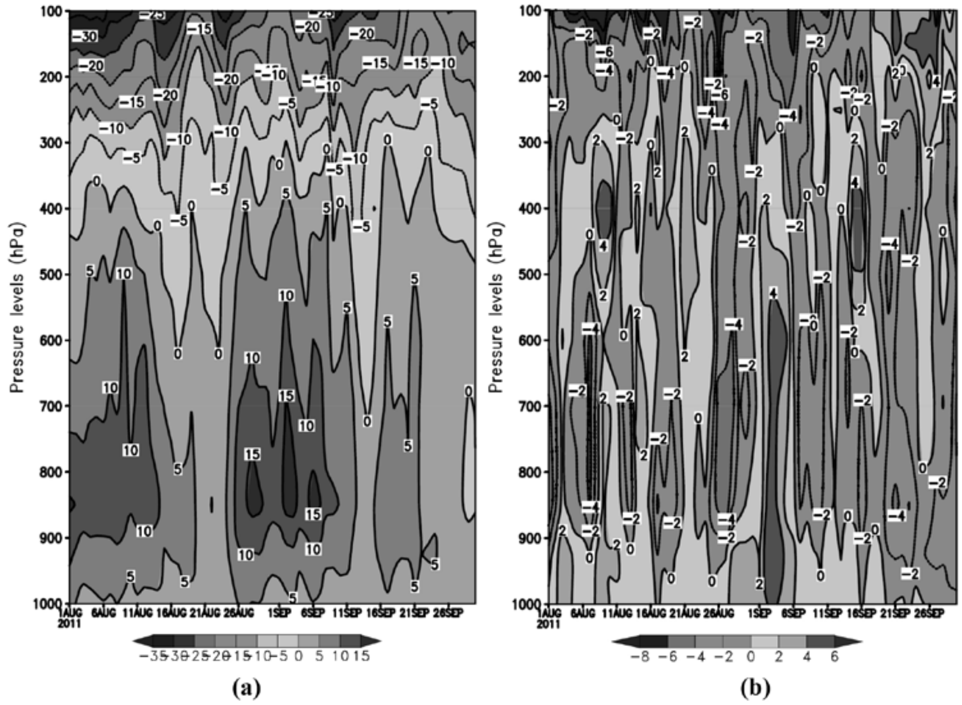

Figure 4. Vertical time section of (a) U and (b) V averaged over the region bounded by 16°- 17°N and 77°-78°E representing Mahabubnagar station location during 1 August to 30 September 2011 based on upper-air NCEP/NCAR winds.

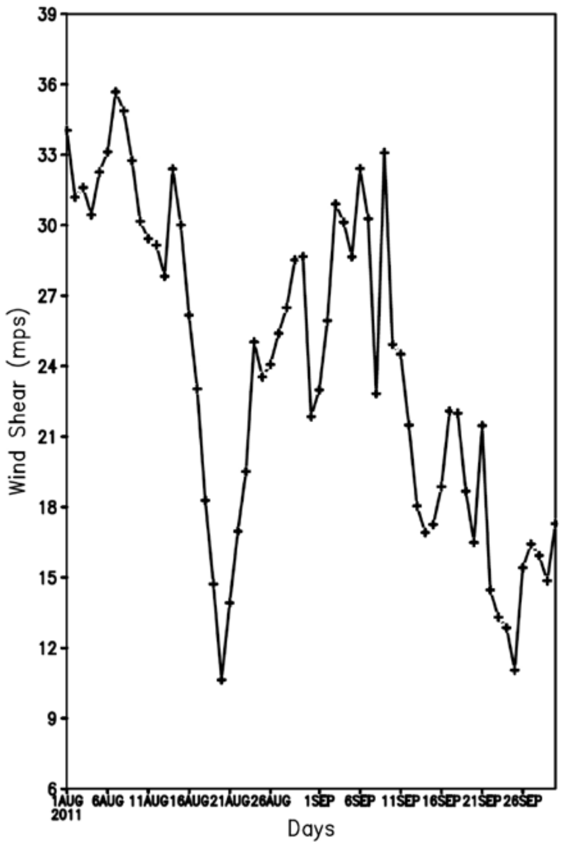

Figure 5. Wind shear over the study domain (16°-17°N and 77°-78°E) between lower and upper troposphere (850-200 hPa) during 1 August to 30 September 2011.

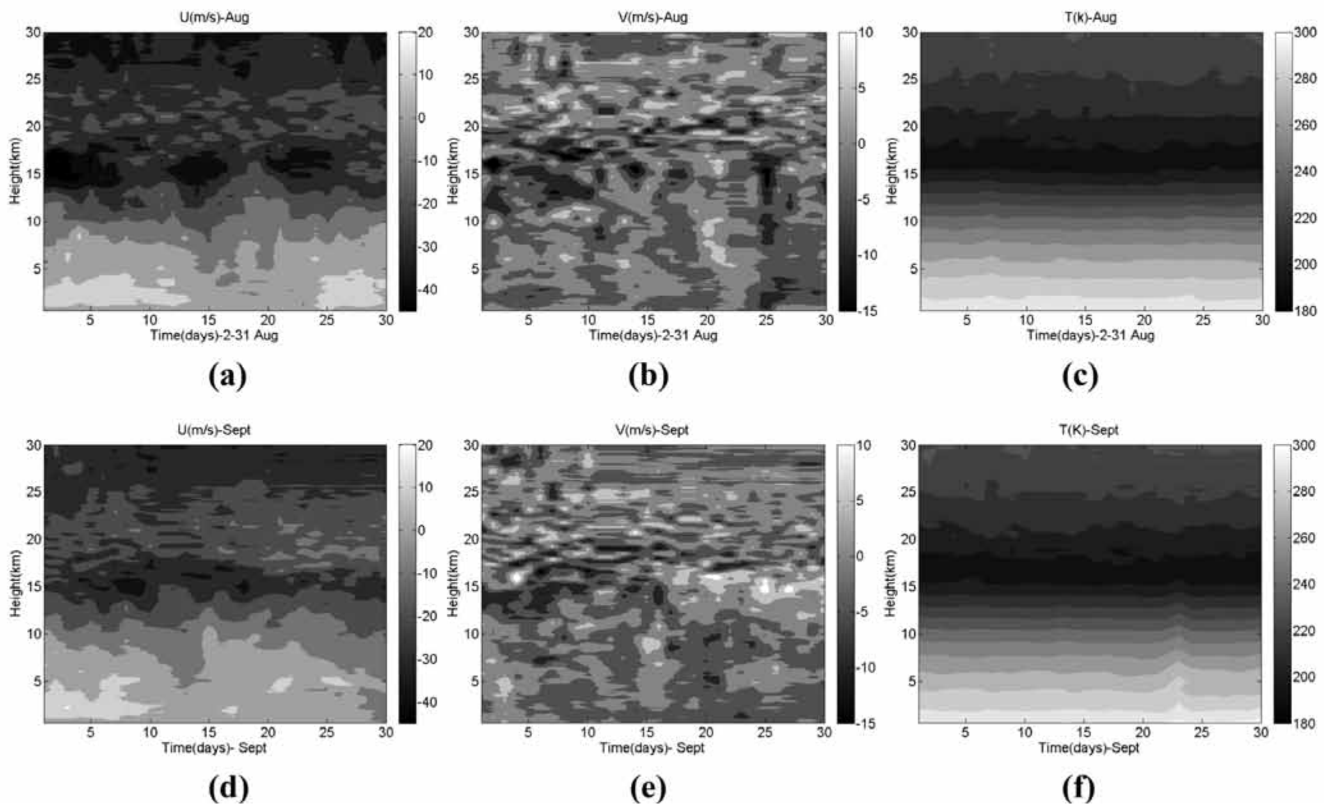

Figure 6. Vertical Time sections of U (a and d), V (b and e) both in mps and T (c and f) in °K for the months of August and September respectively.

as of August i.e. they are eastward up to 10 km and westward above that (Fig. 6d). High positive values (> 15 mps) are noticed in the troposphere during 2-4 and 6-7 September. Vertical time section of V shows high positive values in the troposphere, reappearing after about 10-15 days up to 25 September (Fig. 6e). The vertical time section of T for September shows similar patterns as that of August (Fig. 6f).

Vertical Time Section Of Daily Anomalies Of U, V And T Based On Field Data: Fig 7 (a, b and c) show the vertical time sections of anomalies of U, V (both in mps) and T (in °K) respectively at Mahabubnagar for the month of August and Fig. 7 (d, e and f) for September. The anomalies have been obtained by subtracting the monthly means from individual daily profiles of respective months.

Though the actual values of U show dominance of positive values up to mid-troposphere (Fig. 6a) in August, the anomaly plot of U (Fig. 7a) shows positive anomalies (anomalous westerlies) up to 13 August and then from 25 to 31 August, intercepted by negative anomalies (anomalous easterlies) during 14-25 August. Around tropopause level, alternative pockets of negative/positive anomalies are noticed, showing a tendency to reappear after about 10-15 days. The anomaly plot of V for August (Fig. 7b) shows alternate pockets of positive and negative anomalies up to mid-tropospheric levels, which are seen to reappear after about 3-7 days. The anomaly plot of T (Fig. 7c) shows presence of positive values up to about tropopause level during first fortnight of August, which became negative in the second fortnight except for a day on 24 August.

For the month of September, the anomaly plot for U (Fig. 7d) shows positive anomalies from 1 to 10 September up to mid-tropospheric levels, which further became negative up to 15 September. The values again became positive during 16-25 September. Just above tropopause level, negative anomalies are noticed from 3-18 September followed by positive anomalies up to the end of the section. The anomaly plot of V for September (Fig. 7e) shows alternative pockets of positive and negative anomalies up to mid-tropospheric levels, which are noticed to reappear after about 3-7 days. At tropopause level, negative (positive) values are noticed in the first (second) fortnight of September. The anomaly plot of T (Fig. 7f) shows dominance of positive values up to about tropopause level during 1-17 September. This trend changed to negative thereafter except for the occasions when pockets of positive values are noticed around the mid-tropospheric level, during 22-28 and on 30 September.

The analysis has brought out the features of intra-seasonal variations of the monsoon observed at the study location. The vertical wind shear as discussed above and the anomalies of U and V indicate systematic periodic

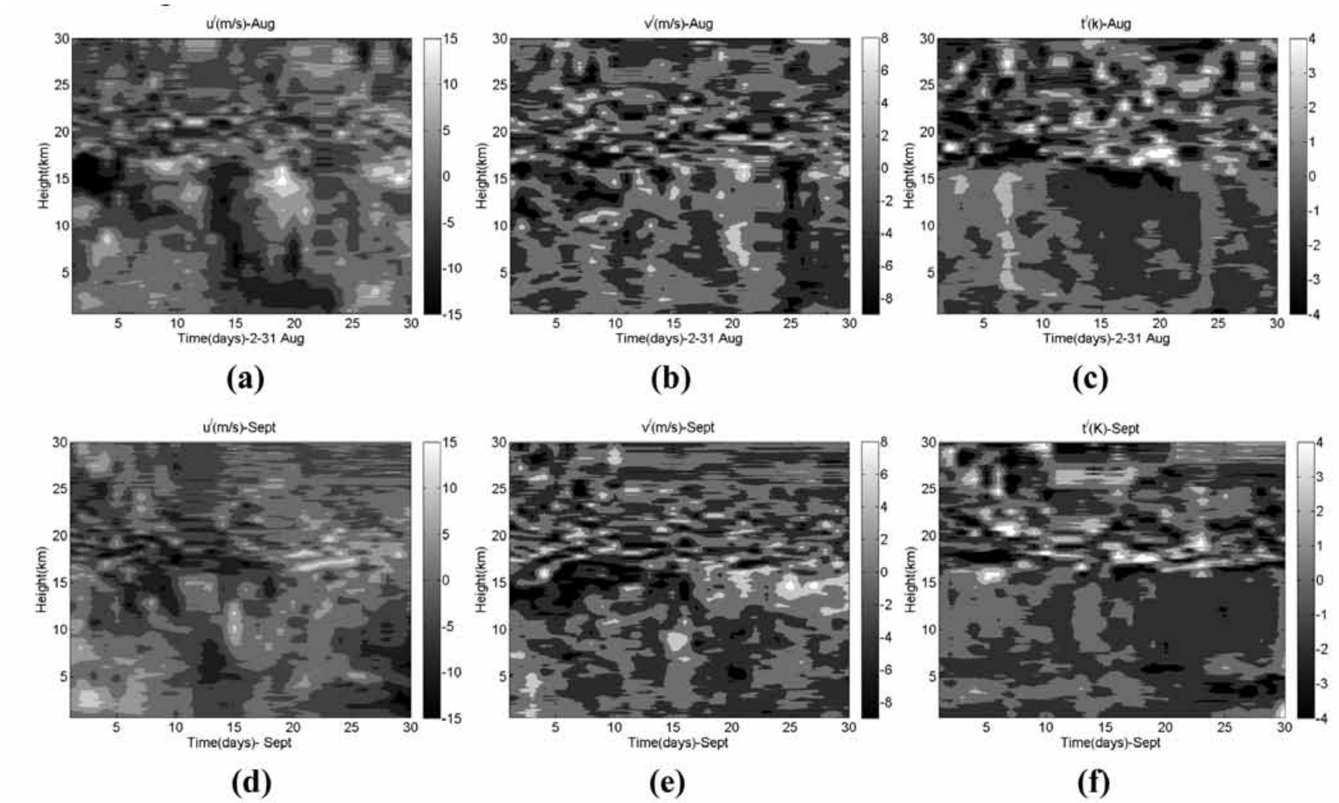

Figure 7. Same as Fig.6 but for the anomalies.

variations. To look for the support to the observed features, statistical analysis has been carried out with the available data.

Statistical Analysis Of Wind Shear, U And V: Intra-seasonal variation of Indian summer monsoon studied by several researchers has brought out the presence of preferred low frequency oscillation associated with the monsoon (Sikka and Gadgil, 1980, Sikka et al., 1986, Paul et al., 1990, Ghanekar et al., 2010). In an effort to examine the presence of intra-seasonal modes, the time series of tropospheric wind shear (U_{850} - U_{200}), deduced using NCEP/NCAR data, for the months of August and September (61 days) and anomalies of U and V at 850 hPa, 500 hPa and 200 hPa levels for the period 2 August to 20 September (50 days), based on experimental data taken at Mahabubnagar have been subjected to statistical analysis.

Wind shear was high during 1 to 16 August and again during 25 August to 11 September. This was the period when good monsoon conditions prevailed over the station. Taking into consideration of this fact, autocorrelation analysis has been carried out. The Auto Correlation Coefficient (**CC**) values for different lags have been worked out in order to identify the recurrence, if any, of positive phase of monsoon during the study period. The results show that with lag of 34 days, maximum positive CC= 0.74 is achieved and is highly significant at 1% level. Hence, it can be inferred that high wind shear and +ve monsoon phase noticed in the beginning of the experiment period have shown a repetition after about 34 days. Similarly, the anomalies of V at 200 hPa level show CC=0.72 for lag of 35 days, which is also significant at 1% level and, hence, supplements the above observation. The anomalies of V except for this case, in general have low correlations as compared to that of anomalies of U. The anomaly of V at 500 hPa exhibits CC of 0.34 with 10 days lag, which is significant at 5 % level indicating variation with 10 days period. The anomalies of U at i) 850 hPa show CC=0.74 with lag of 26 days, ii) 500 hPa show CC=0.72 for lag of 28 days, both highly significant at 1% level and at iii) 200 hPa show CC=0.41 for lag of 24 days, which is significant at 5% level. This pattern indicates that anomalies of U exhibit variation with a dominant period of 24 to 28 days. The daily profiles of U and V based on field data when plotted with successive displacement of 5 m/s indicated systematic wavy patterns during study period (Figs not shown). As the data was available for a limited period, further comprehensive analysis was not possible. Therefore, as a preliminary attempt the perturbations in the fields of U, V and T are investigated, based on anomalies of these fields. The wave characteristics observed based on this analysis has been further investigated in relation to the prevailing weather conditions.

Detection Of Wave Activity: Wave characteristics are mainly investigated from the analysis of wind components.

In order to detect the wave activity, vertical time sections of anomalies of U, V and T based on experimental data have been studied.

The anomaly plots show various wave activities in all parameters and for both the months. The striking feature is that in August, all the three parameters (U, V and T) show generation of waves from tropopause level with certain periodicity. These waves are noticed to propagate either upwards in stratosphere or downwards to surface layer. Leena et al., (2012) observed similar wave patterns originating from tropopause level during monsoon season, based on five years (2006-2011) of high resolution radiosonde data collected from the tropical station, Gadanki (13.5°N, 79.2°E). They showed that such waves are inertia-gravity waves and their sources of generation are strong wind shear and convection. Due to availability of limited period data, the traditional wave analysis has not been carried out. However, the results brought out in this analysis are analogous to what has been observed by Leena et al., (2012), indicating existence of gravity waves at these stations.

The analysis of anomaly of U depicts wave structures propagating from tropopause level (source region). Initially, high negative anomalies (> |-15| mps) are seen around tropopause level where from a wave is noticed to propagate downwards from 15 km to 10 km during 02 to 13 August (Fig 7a). Around this time, good monsoon activity is witnessed through formation of synoptic systems. Also, strong wind shear (Fig. 5) between 850 and 200 hPa levels is seen as an outcome of strong low level monsoon westerlies and very strong upper level easterlies (associated with TEJ) over the study location. From 14 to 25 August, the wave is noticed to descend more and visible up to surface. A wave is also witnessed simultaneously from about 15 to 22 km, during 02 to 23 August propagating upwards in the lower stratosphere and even extending further up to the end of section. Also, during 01-15 September, a wave is seen to propagate downwards, originating from tropopause level and reaching up to surface. This event has occurred under the strong wind shear condition (Fig. 5), similar to the one observed in August (mentioned above) under good monsoon conditions. The conditions are seen to have changed dramatically after 16 September. From this date it is seen that the wind shear has significantly reduced and waves originating from lower troposphere (stratosphere) are noticed to progress upwards (downwards) towards tropopause level. In 2011, monsoon started withdrawing from 23 September and consequently the weakening of TEJ is witnessed through high positive anomalies around tropopause level from 16 September.

In addition to some smaller scale waves, the anomaly plot of V (Fig. 7b) shows, a wave similar to that observed in U field (Fig. 7a), propagating from tropopause to surface during 2-24 August. Also, a wave is noticed from the same source propagating upwards from about 17 to 22 km during 2-23 August and even extending further up to the end of section. In the month of September (Fig. 7e) the wave patterns are of mixed type i.e. ascending and descending. A wave is seen to propagate from lower stratosphere to upper troposphere (just below tropopause level) during 01-30 September.

From the above discussion, it is seen that propagation of waves is noticed from tropopause level. The strong vertical wind shear, resulting from strong easterlies in the upper levels associated with the TEJ and monsoon westerlies in the lower level, has contributed for generation of the waves. Zhang and Yi (2005) made a statistical study of gravity waves at Wuhan (30°N, 114°E) and found that the tropospheric jet is the main excitation source of inertial gravity waves in the troposphere and lower stratosphere. They further concluded that the dynamical instability (strong wind shear) induced by the TEJ acts as the excitation source. The results brought out in the present analysis are consistent with that of Zhang and Yi (2005). Fig. 7 shows the wave patterns. The patterns are clearer and exhibit a systematic trend in the case of U, as compared to other two parameters. Also from the U anomaly field (Fig. 7a and 7d) it is seen that the propagation of tropospheric waves is noticed to follow a near 30 day mode, which is consistent with the statistical results.

The plots of V show some mixed wave characteristics and a 3-7 day periodic variation. During peak monsoon period, disturbances generally form over Head Bay of Bengal and move westward, across the monsoon trough over India. During these periods the monsoon trough becomes active and move to south of its normal position producing good amount of rainfall over the country (Ghanekar et al. 2003 and references therein). The formation and movement of monsoon systems during the study period have caused the occurrences of positive anomalies of V (with an interval of 3 to 7 days). Hence, it can be inferred that the waves associated with these epochs can be correlated with those related to convection caused by the weather systems. Fig 7 (c and f) show the anomaly plots of temperature for the month of August and September, respectively. These plots also show some mixed wave characteristics, similar to that observed in case of V field.

The present study has brought out some preliminary results pertaining to the wave characteristics, based on the data taken under CAIPEEX experiment at Mahabubnagar, during the second half of monsoon 2011. The results are useful as they are based on a new set of data, not available earlier for undertaking such studies.

Un-Precedential Rainfall Event On 21 August: The role of these waves in the changing weather conditions over Mahabubnagar is illustrated here through a case study of heavy rainfall event, reported on 21 August. It was observed that large negative anomalies of U were present around

02 August at tropopause level, which were accompanied by strong vertical wind shear. From this date, a wave is witnessed to descend downward towards the surface as discussed in section "Detection of Wave Activity". Around 20 August, the vertical wind shear was very weak and anomalous colder temperatures were observed over the location, with increased vertical gradient between relatively warmer anomalies at surface layer and colder anomalies in upper layers. On this day when a CyCir was moving across the monsoon trough, heavy rainfall (113 mm) was reported over the location. The unprecedented background conditions, cited above during 20 and 21 August might have caused instability, resulting in such a convective event, over the location. Yamamori and Sato (2006) have observed that wave-wave interaction processes transfer horizontal momentum from the excitation level to the breaking level. The present case suggests that wave originating from tropopause level and breaking out at surface might have exchanged energy and momentum, favoring the convective event.

CONCLUDING REMARKS

The study reveals that over Mahabubnagar, during second half of monsoon 2011, the monthly-averaged zonal component of wind was one order stronger than the meridional component of wind. The tropopause was at a height of about 16.3 km. The variations in tropospheric vertical wind shear exhibited a period of 34 days, while the tropospheric zonal wind component showed a dominance of 24-28 days period.

Vertical time analysis of anomalies of zonal (U) and meridional (V) components of wind as well as temperature (T), depict various wave activities in which anomalies of U gives significant perception of waves. Analysis of the vertical time anomalies of U depict wave propagation originating from around the tropopause height (level of Tropical Easterly Jet: TEJ) and descending (propagating) down (up), up to the surface (lower stratosphere). The tropospheric waves are generated under prevalence of stronger winds associated with TEJ and strong vertical wind shear in the troposphere, which acted as a source for excitation of the waves. These observations are in agreement with earlier studies. From these studies it is evident that these waves are inertia gravity waves. The propagation of these waves seems to have followed a near 30 day oscillation, in accordance with the vertical wind shear and the prevailing monsoon conditions. This is also supported through the results of autocorrelation. Anomalies of V, however, depict a mixed wave structure in the troposphere showing influence of 5-7 day and 10-15 day oscillations over the location.

Availability of a longer time series observations over similar tropical station may further give more insight about the characteristics of the waves mentioned above.

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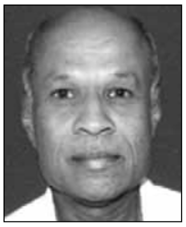

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