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Meteorological conditions for development of heat wave over Coastal Andhra Pradesh and Telangana

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ABSTRACT
Heat waves are one of the weather hazards affecting different regions of India with varying intensity. Beforehand knowledge of the meteorological conditions favorable for the occurrence of heat wave/severe heat wave conditions over a given region/state is required for issuing warnings. Reasonably accurate meteorological conditions are now available from dynamical models, several days in advance, and the same could be used for issuing warnings about likely development of heat wave/severe heat wave condition. In the recent past, Andhra Pradesh and Telangana had been affected by severe heat wave conditions for several days in continuation. In the present study meteorological conditions associated with the heat waves over coastal Andhra Pradesh and Telangana during May 2015 have been detailed. The analysis of meteorological conditions has shown that the severe heat wave conditions during the year had resulted due to advection of dry air from northwest over a prolonged period of time when skies were cloud-free, soil moisture was low and there was an absence of development of strong sea breeze in the afternoons.

Key words: Meteorological conditions, Heat waves, Sea breeze, Soil moisture, Warnings about heat waves.

INTRODUCTION

WMO statement on the status of the global climate has indicated a rise in temperatures over various parts of the globe (WMO Tech No.1085). According to the 'Synthesis report-climate change 2014' (IPCC- AR5), each of the past 3 decades has been warmer than any other preceding decades since 1850. Over northern hemisphere, the period from 1983 to 2012 was the warmest 30-year period of the past 1400 years (Fifth Assessment Report AR5, 2014). The global averaged combined land and ocean surface temperature data, as calculated by a linear trend, has shown a warming of 0.85 (0.65 to 1.06°C) over the period 1880 to 2012. These reports (Fifth Assessment Report AR5, 2014) have thus indicated an increasing propensity of occurrence of heat waves over different countries of the globe. A heat wave is a condition of excessively hot weather, for a few days or for a prolonged period of time in some cases, which may be accompanied by dry hot winds and high humidity. There is no universal definition of heat wave as temperature ranges have wide variance over different continental and maritime regions. One range of temperature may be easily adaptable in one region, but may cause discomfort in another region, because of different levels of endurance to these climatic conditions. In India, the intense heat days commence in the month of March over the extreme south peninsular India and subsequently affect the central and northern parts of the country till mid-July by which time the southwest monsoon establishes over the entire country. While most parts of the country including Andhra Pradesh and Telangana experience heat waves in the month of April and May, the northern states experience heat waves mainly during May-June. Advection of heat fluxes causes the spread of heat from one area to the neighboring areas. If a heat wave forms over an area and remains confined there only, the heat wave is called an in-situ type of heat wave. If the heat wave conditions spread over the neighboring areas, then this type of heat wave is called an advection type of heat wave. In India, most of the heat waves are of the advection type.

India Meteorological Department (IMD) defined heat wave in terms of the departure of maximum temperature from the normal maximum temperature of a station (Table 1). Subbaramayya and Rao (1976) have described, in detail, the heat and cold wave days in different states of India. Bedekar et al., (1974) and Chaudhary et al., (2000) have analyzed heat and cold waves and their impact. Jenamani (2005) analysed Ocean and atmospheric features associated with extreme temperature variation over east coast of India during 1998. Ray et al., (2013) have analysed the cause of extreme high temperatures over Gujarat state. Pai et al., (2004) concluded that there is a significant increasing trend in the heat wave days over Telangana and Andhra Pradesh. The study by Bhadram et al., (2005) has shown increase in the frequency of severe heat waves and also their duration. The authors noted that the highest maximum temperatures which hitherto used to be recorded over Telangana are shifting to the coastal districts of the state in recent years. Pai et al., (2013) found that both Andhra Pradesh and Telangana experienced 8 or more number of heat wave days during the 5 months period of March-July in the study period of 1961-2010.These studies have addressed some aspects of the heat wave. Analysis of synoptic, dynamic and thermodynamic conditions helps in understanding the

Figure 1. Map of meteorological sub-divisions of India including the shaded sub-divisions Telangana and coastal Andhra Pradesh.

Table 1. IMD criteria of heatwaves, severe heatwaves and hot days

S.No.	Criteria	Departure from normal	Intensity of the Heat wave
1	Heat wave is considered if maximum temperature of a station reaches at least 40.0 °C or more for plains.	Between 4.5 to 6.4 °C	Heat wave
		≥ 6.4 °C	Severe Heat wave
2	When the absolute/actual maximum temperature of the day is 45.0 °C or more.	Absolute/actual maximum temperature of the day is 45.0 ^{0}C or more.	Heat wave
		Absolute/actual maximum temperature of the day is ≥ 47.0 ^{0}C.	Severe Heat Wave
3	Warm night should be considered only when maximum temperature remains 40 °C or more. It may be defined based on departures or actual minimum temperatures.	minimum temperature departure is 4.5 °C to 6.4 °C	Warm night:
		minimum temperature departure is >6.4 °C	Very warm night:
4	When maximum temperature departure is 4.5 °C or more from normal, Heat Wave may be described provided actual maximum temperature is 37 °C or more.	Maximum temperature departure is 4.5 °C or more.	Heat wave for coastal stations

various physical processes involved in the development of heat wave conditions. The heat waves during the summer of 1998, 2002, 2003 and 2015 had a profound impact on the lives of the people over various regions of India. A large number of deaths were reported from different parts of the two states during May-June 2003, more particularly from the coastal districts. According to the state government reports, 3054 persons died in the states of Andhra Pradesh and Telangana in 2003 (Bhadram et al., 2005).The heat wave during May 2015 swept across the states of Andhra Pradesh and Telangana and resulted in a lot of discomfort and the death toll reached an alarmingly high number of 1910 human lives (Press Information Bureau, Govt. of India, 5th August 2014). Meteorological conditions that prevailed over Andhra Pradesh and Telangana during the severe heatwave of May 2015 have been analyzed in this study.

METHOD OF ANALYSIS

Favorable conditions for the occurrence of heat waves:

(a) Synoptic conditions

(i) A large amplitude high / anti-cyclonic flow that promotes subsidence and stagnation over the heat wave region.
(ii) High geo-potential thickness values.
(iii) High positive vertical velocity and
(iv) Warm-air-advection over the region or hot and dry wind flow over the region from northwest.
(v) Jet-streams to prevail over northern parts of the country

(b) Dynamic and thermodynamic conditions

(i) Maximum insolation
(ii) Scanty clouds or cloudless days
(iii) Near dry adiabatic lapse rate over the region and
(iv) Lesser moisture up to a deep layer aloft

DATA USED IN HEAT WAVE ANALYSIS

IMD daily station data for the study period in respect of maximum temperature (Tmax) recorded across the states of Andhra Pradesh and Telangana have been utilized. Analysis using the temperature metrics (the values of Threshold Maximum Temperatures or intensity of temperature) in respect of mean monthly Maximum Temperature, mean diurnal range, Maximum Temperature equal to or above 40°C(T-40) and Maximum Temperature equal to or above 45°C (T-45), heat wave & severe heat wave days are identified and analyzed in this section. Several metrics in respect of temperature are computed and analyzed. The departure of day maximum temperature of May 2015 from the pentad normal maximum temperature for the climatological period 1981-2010 is calculated. The composite mean, climatology and anomaly of the geopotential height thickness on daily and monthly time-scales and the targeted period are plotted and analyzed. The National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis data of daily/ monthly average fields in respect of 500 hPa geo-potential height (Z500), winds at surface, 850 hPa& 200 hPa, temperature at 2-m level is used. The NCEP/NCAR reanalysis data is used to draw graphics for visualization and quick analysis and evaluation of the prevailed conditions during the heat wave period (Kalnay et al., 1996). The National Oceanic and Atmospheric Administration (NOAA) Outgoing Long-wave Radiation (OLR) NOAA data is used to study the OLR & OLR anomalies, sensible and latent heat regimes that affected the region.

RESULTS AND DISCUSSIONS

Analysis of synoptic, physical and dynamical conditions have been carried out to find the meteorological conditions favorable for rise of temperature up to the threshold of heat wave/severe heat wave conditions over Telangana and Andhra Pradesh during May 2015. The results of analysis of different parameters have been discussed, in brief, in the following paragraphs.

Surface air temperature: The area of maximum values of mean air temperature is seen in central India and the contiguous areas of Telangana and Costal Andhra Pradesh. The areal extent of T-40 contour (line passing through mean temperatures of 40^0 C or more) is larger during 15-31 May than during 01-31 May, 2015. It implies that there is an increase in the intensity of air temperature over the areas around Andhra Pradesh and Telangana. The advection of heat from Arabian mainland and Gulf to southeastwards upto Coastal Andhra Pradesh through Afghanistan, Pakistan, Rajasthan, Madhya Pradesh, Vidarbha, Telangana and adjoining area is evident (Figure 2). The intense heat fluxes concentrated over Madhya Pradesh, Chhattisgarh, Odisha, Telangana, and Andhra Pradesh are also shown in Figure 2. The advection of hot dry air does not indicate the area of maximum temperature because the parameter in use here is for mean temperature. The propagation and advection of heat takes place from Arabian area to the interior parts of India. The image clearly indicates that the advection is more pronounced under conducive synoptic conditions during the latter half than during the first half of May 2015. The Figure 3 shows the maximum temperature distribution over the country. The image shows a pronounced change in the areal extent of increased temperatures in the second half of May than in the first half. The figures 2 and 3 indicate a significant change in the intense heat conditions over central and adjoining parts of India. Absolute maximum temperatures alone cannot be construed as heat-waves. The term 'heat-wave' is a relative condition with respect to the normal maximum temperature of an area. The normal maximum temperatures of Andhra Pradesh and Telangana are lower than central parts of the country. This gives an indication that heat-wave conditions did exist in second half of May 2015 over Coastal Andhra Pradesh and Telangana.

Distribution of Prevailing winds

Wind flow pattern at 850 hPa level (Figure 4) shows an anti-cyclonic flow with incursion of northwesterly winds deep to the south upto latitude 5.0^0 N near Java Islands. At 700 hPa level, the anti-cyclone lies over northeast Arabian Sea with the ridge line extending up to Malaysia

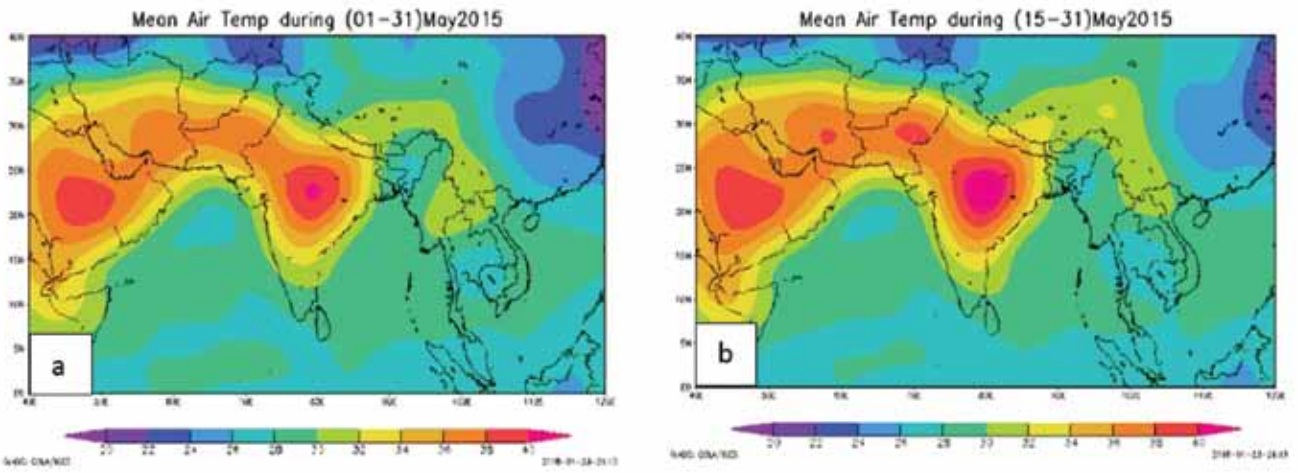

Figure 2. Advection of dry hot air from the Arabian continent and adjoining areas over to parts of the country during (a) May 01-31 and (b) during May 15-31, 2015.

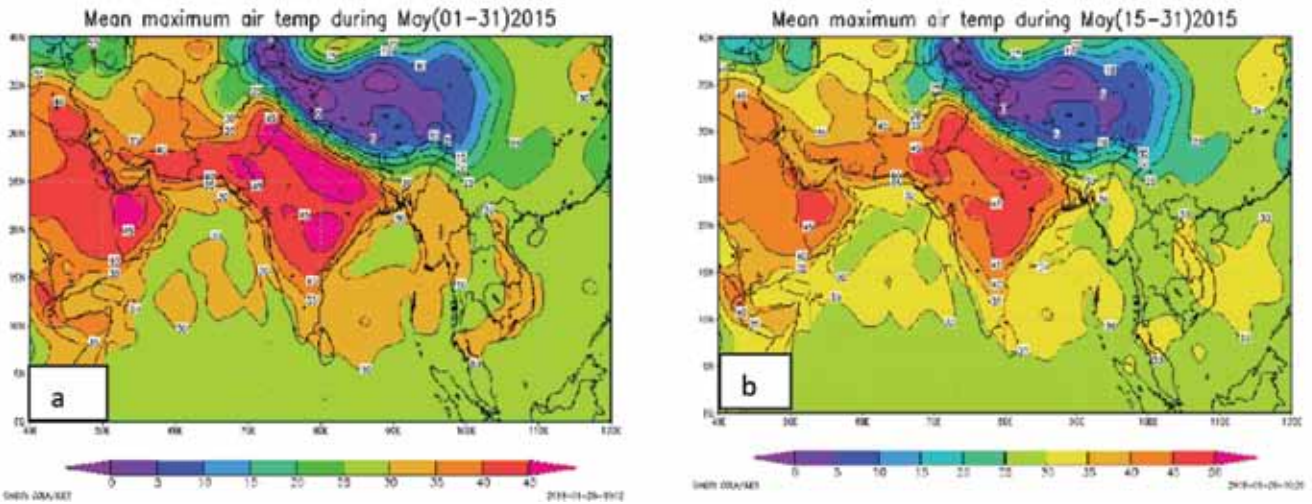

Figure 3. Mean maximum temperature (^{0}C) distribution over the country during (a) May 01-31 and (b) May 15-31, 2015.

with southward tilt. There is a pronounced, strong, sustained, stagnant ridge at 500 hPa level running along latitude 20.0^0 N over the Indian region with an elongated ridge line extended east-southeastwards upto the South China Sea. The composite wind pattern from surface to 500 hPa indicates the position of the ridge line delineating the westerly/ northwesterly flow to the north and north/ northeasterly flow to the south during first half of the May. Westerly to northwesterly winds prevailed over the major parts of the country with an anti-cyclonic flow at around 5.0^0 S in the Sumatra over the surface during the second half of May 2015.The anti-cyclonic flow at 700 hPa and 500 hPa shows reinforcement in the second half of May than in the first half. There is also a strong clock-wise flow of winds over the west central parts of Bay of Bengal and Coastal Andhra Pradesh in the period 15-31 May than during the period 01-31 May.

Position of Sub-Tropical Westerly Jetstream

At 200 hPa level the mean position of Sub-Tropical Westerly Jetstream (STWJ) is located at 25.0^0 N. The STWJ defines northern limit of the Hadley Cell (Chandler, 1979). This STWJ is the place to the south of which maximum subsidence takes place. This contributes to the formation of stagnant high pressure area and hence to the persistence of higher temperature on the surface. The upper tropospheric winds (Figure 5) show strong convergence upto 100 hPa level indicating lower level strong divergence, in concurrence with the Dines Compensation principle.

Geopotential height thickness

The geopotential height thickness analysis as a prognostic tool provides an inkling of an idea as to the probability of

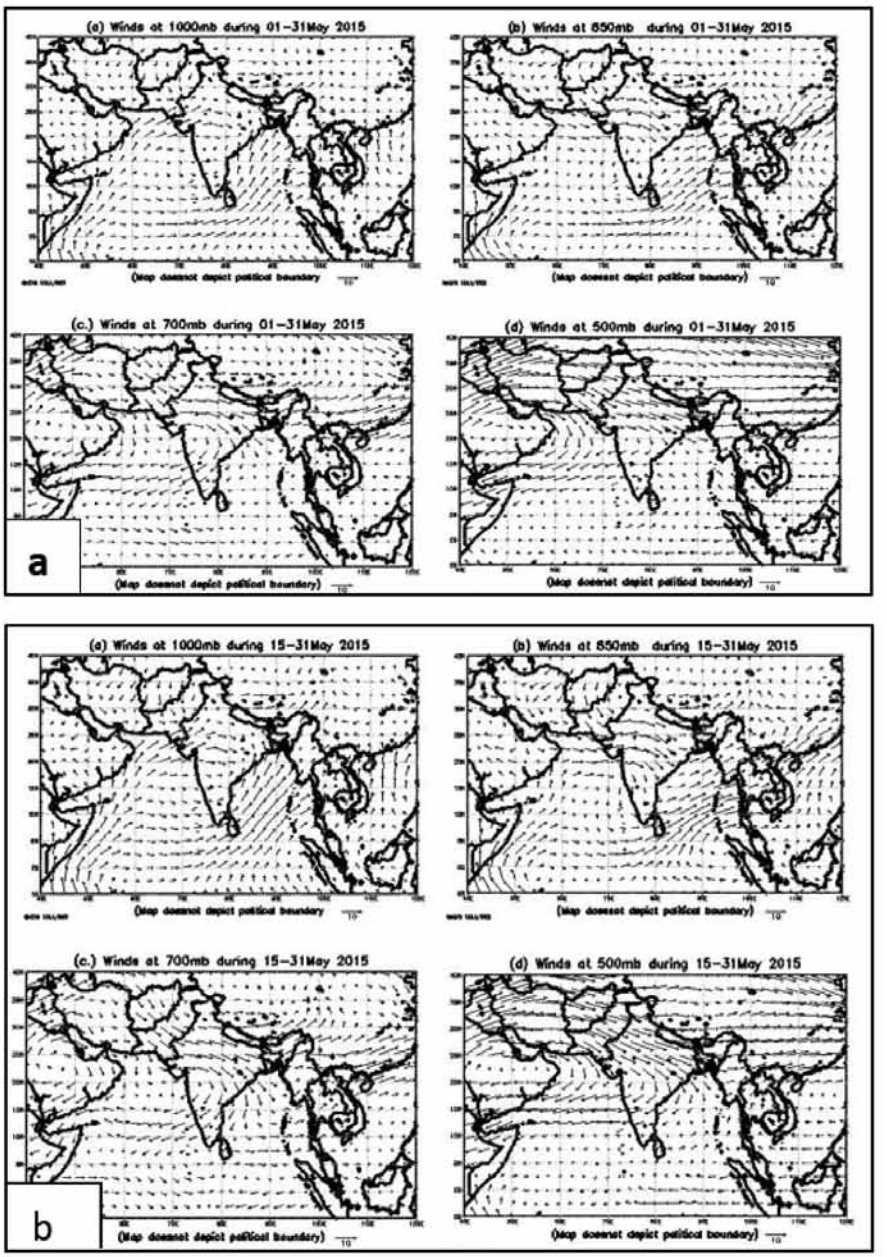

Figure 4. Prevailing winds during (a) May 1-31 May and (b) 15-31 May, 2015 at 1000, 850, 700 and 500 hPa levels.

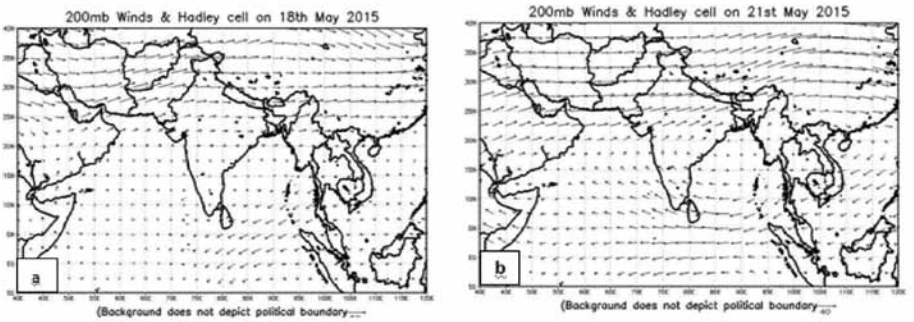

Figure 5. Transition of Upper Tropospheric circulation strengthening in to sub-tropical Westerly Jet stream (a) on May 18 and (b) May 21.

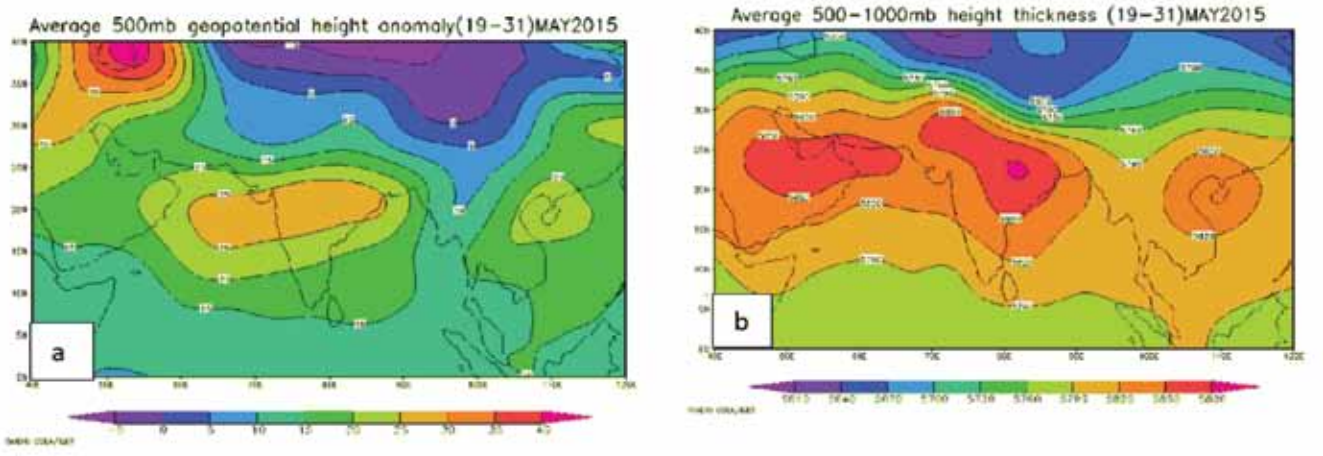

Figure 6. (a) 500 hPa Geopotential anomaly and (b) 500-1000 hPa thickness during 19-31 May, 2015.

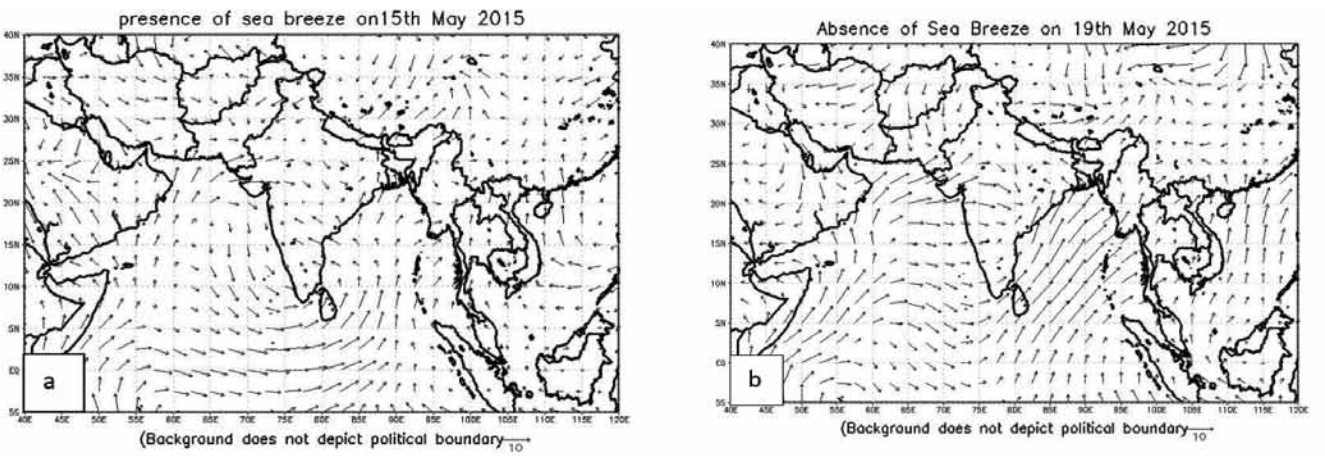

Figure7. Winds indicating (a) presence of Sea Breeze on May 15 and (b) absence of sea breeze on May 19, 2015.

occurrence of heatwaves. The geopotential height thickness (z) is a function of air temperature and moisture between the levels for which the z is computed. The increase in thickness (z) results in warm air advection (WAA) or diabatic heating. This implies that the solar heating is concentrated in to the area where the maximum z is found. Mcqueen and Cadesman (1957) have shown the correlation of heatwaves with thickness of the air-mass between 1000 and 500 hPa levels. It is obvious that the larger average height thickness and positive anomaly of thickness between the levels 1000 and 500 hPa are indicative of the warmer regions (Figure 6(b). Hence, it shows the zone of maximum heatwaves or severe heatwaves.

The contour/ isoline of maximum geo-potential (Z_{500}) thickness is observed around the area of Rajasthan, Haryana, Chandigarh & Delhi, Uttar Pradesh, Madhya Pradesh, Chhattisgarh, Odisha, Coastal Andhra Pradesh, Telangana and Vidarbha(Figure 6(a). This promoted maximum flux over this area and resulted in an intense negative vorticity advection in the mid-troposphere and warm air advection over the surface area enclosed by the maximum Z_{500} contour. The warm air advection is more conspicuous / evident at 700 hPa. The clockwise flow contributes to the incursion of warm, dry air over the larger contour of Z700.

Late onset of sea-breeze

The coastal areas of Andhra Pradesh, generally, experience during the afternoon sea breezes that alleviate the impact of heat. The prevailing wind and synoptic conditions upto 17 May 2015 were supportive of a breeze from the sea along the coastal areas. The southerly and southeasterly winds prevailed over Bay of Bengal on most of the days from May 1-17, 2015 (Figure 7). The anti-clockwise flow was located over southeast peninsula & Comorin till 15 May, produced south easterly flow and sea breeze over the southeast peninsula south of south coastal Andhra Pradesh. The winds over the Bay of Bengal off Coastal Andhra Pradesh were from southeasterly/south-southwesterly direction

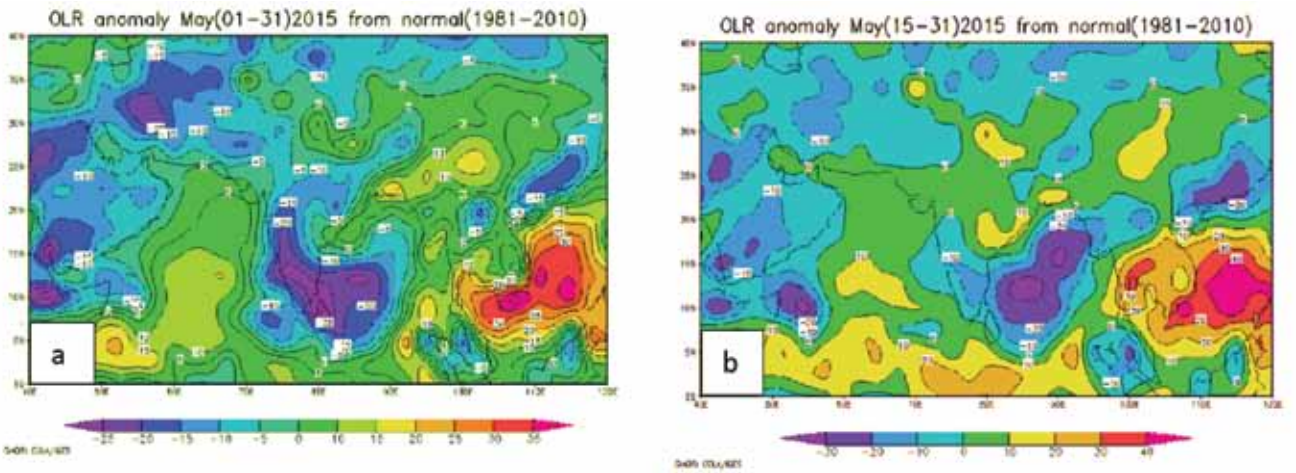

Figure 8. Outgoing Longwave Radiation Anomaly during (a) 1-31 May and (b) 15-31 May 2015.

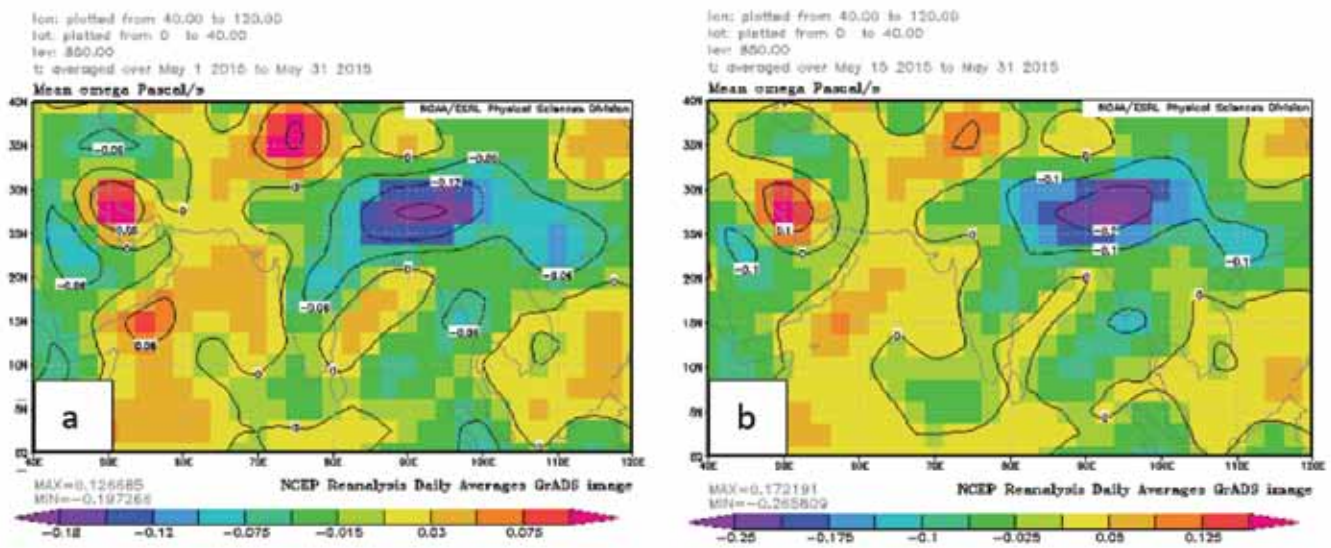

Figure 9. Mean omega indicates the stagnant air and subsidence over the area under study at (a) 850 hPa during May (1-31) and (b) during May (15-31), 2015.

during the middle of May and did become south-westerly from 19thMay and exhibit/delay of sea breeze setting. Resulted dry/hot winds from northwest continued to prevail over Andhra Pradesh. Details pertaining to the prevailing winds and the sea breeze on (a) 15th May and (b) on 19th May are shown in Figure 7 (a & b).

Relative humidity (RH) and moisture

Relative humidity over the northwest, central and adjoining peninsular India was very less. The maximum and minimum RH was of the order of 40-50 and 20-30 in general. Such lesser RH contributes to rapid rise in day temperature as the duration of day is quite longer in the month of May; the night could not cool so much. As a result, the higher temperature cycle was lasting for many days over the study area.

Outgoing long wave radiation and Cloudiness

Outgoing long wave radiation was used as proxy to measure the amount of clouds, particularly over the heat wave region. The Outgoing long wave radiation value during 19-31 May was more than 250 w/m^2.This indicates that the cloud was practically absent over the region. The OLR anomaly is positive over the region. It allows incoming radiation during day time and outgoing during night time. This has resulted in more insolation heating over the region (Figure 8). Resulted increase in temperatures maintained the temperature up to heat wave level.

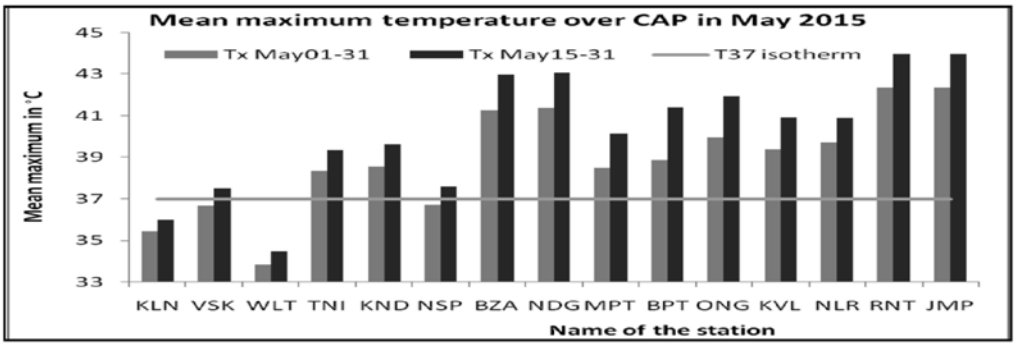

Figure 10(a). Mean maximum temperature over the sub-divisions namely of Coastal Andhra Pradesh during May 1-31 and May 15-31, 2015.

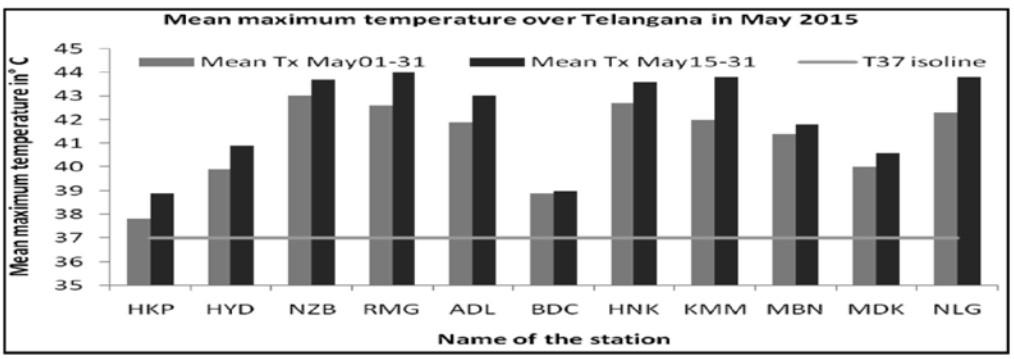

Figure 10(b). Mean maximum temperature over the sub-divisions of Telangana during May 1-31 and May 15-31, 2015.

Observed Temperatures

The metrics derived from the Maximum temperatures and diurnal ranges have been analyzed and the final output is presented. It can be seen that the mean Tx is conspicuously more in May15-31 period than from May 01-31(Figure 10, Red spike is higher than blue spike) over coastal Andhra Pradesh, little higher in Telangana and more or less the same/ lesser in Rayalaseema. Most stations in Telangana and Rayalaseema had experienced more than 19 days of T40 days in May. Whereas, only 50% stations in coastal Andhra Pradesh have recorded 10 or moreT40 days. Station-wise analysis indicates that Rentachintala & Gannavaram (10 days), Bapatla (8 days), Nandigama (7 days), Machilipattanam (6 days), Ongole (5 days) and Kavali (4 days) in south coastal Andhra Pradesh experienced more cumulative heatwave days as compared to north coastal Andhra Pradesh stations, where only Kakinada (4 days) experienced more number of heat wave days.

It is obvious that there is more number of severe heat waves over coastal Andhra Pradesh, with Gannavaram experiencing 8 severe heatwave days. No station in Rayalaseema experienced heatwave days. In Telangana, Ramagundam & Nalgonda (12 days each), Hanumkonda (10 days), Nizamabad & Khammam (9 each) and Adilabad (6 days) experienced cumulative heatwave days. It is also evident that there is less number of Severe Heatwave days over Telangana than over the coastal Andhra Pradesh. This explains the severity of heat wave intensity over coastal Andhra Pradesh compared to Telangana. This also explains the distinctively higher mortality rate over coastal Andhra Pradesh than over the state of Telangana. The continental sub-divisions of Telangana and Rayalaseema have larger normal maximum temperatures than over the coastal Andhra Pradesh where most of the stations have maritime climate (Figures 10, 11&12).

During the climatological span of 50 years from 1961 to 2010, Nellore had experienced 18 years of prolonged, persistent heat wave spells of 15 days or more with an exceptionally long spell of 35 days from 6th May to 9th June, 1996 (Pai et al., 2013). Contrary to the record spells that it experienced, Nellore did not record any heatwave days in May 2015. Ramagundam (1984) and Kakinada (1998), the stations from Telangana and coastal Andhra Pradesh experienced once i.e., the former in 1984 and later in 1998 recorded climatological instances of 16 days (>15 days) of heat wave spells. They also observed that no station in Andhra Pradesh or Telangana experienced spells of Severe Heat Wave (SHW) of 7 days or more during the above climatological period. It is quite noticeable that more stations in coastal Andhra Pradesh recorded SHW days than in Telangana during May 2015. In fact, Machilipatnam and Baptla recorded 5 days each of SHW days. The stations in coastal Andhra Pradesh aggregate

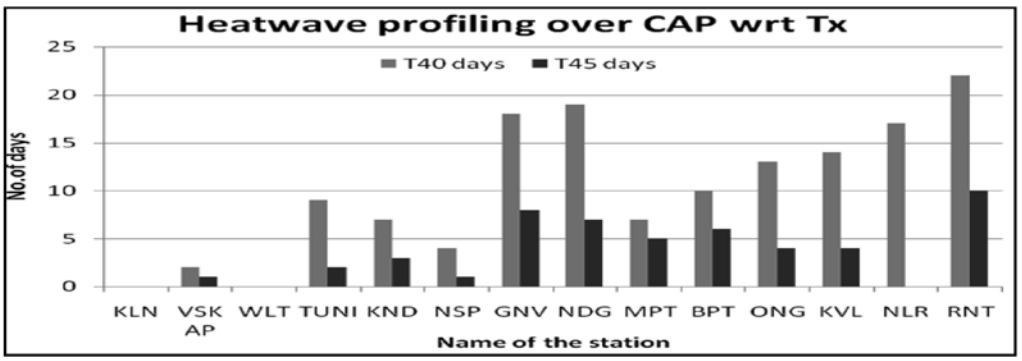

Figure 11(a). Heat wave profiling over the sub-divisions of Coastal Andhra Pradesh during May 2015.

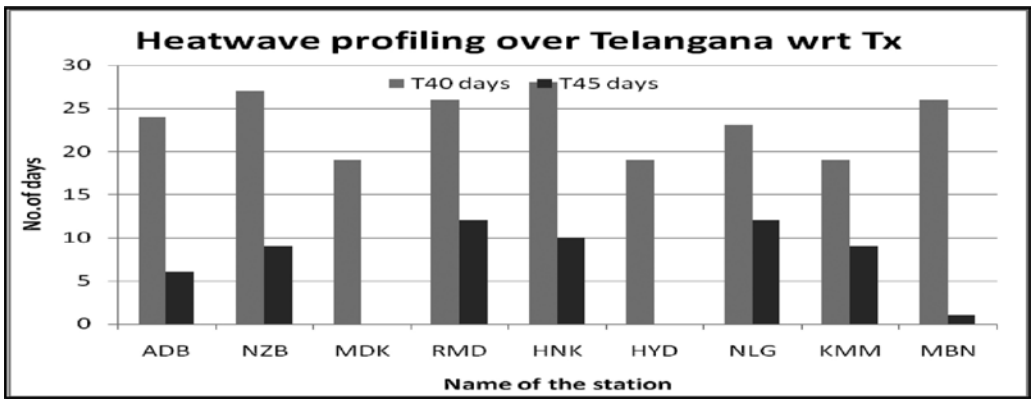

Figure 11(b). Heat wave profiling over the sub-divisions of Telangana during May 2015.

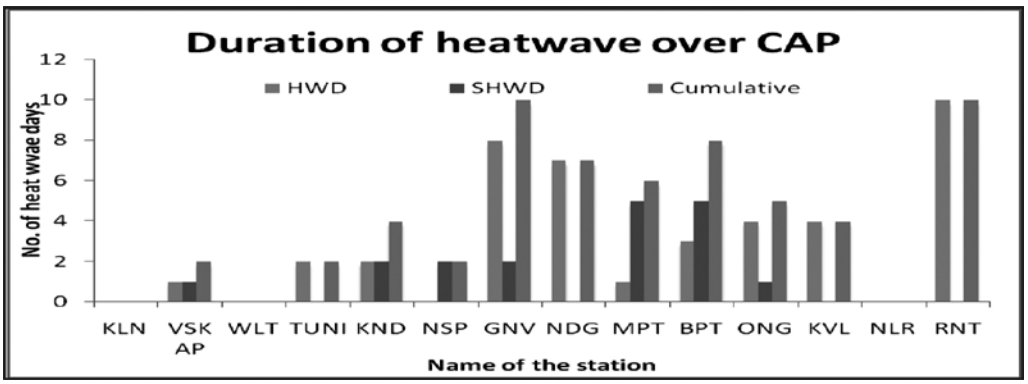

Figure 12(a). Duration of heat-wave over the sub-divisions of Coastal Andhra Pradesh during May 2015.

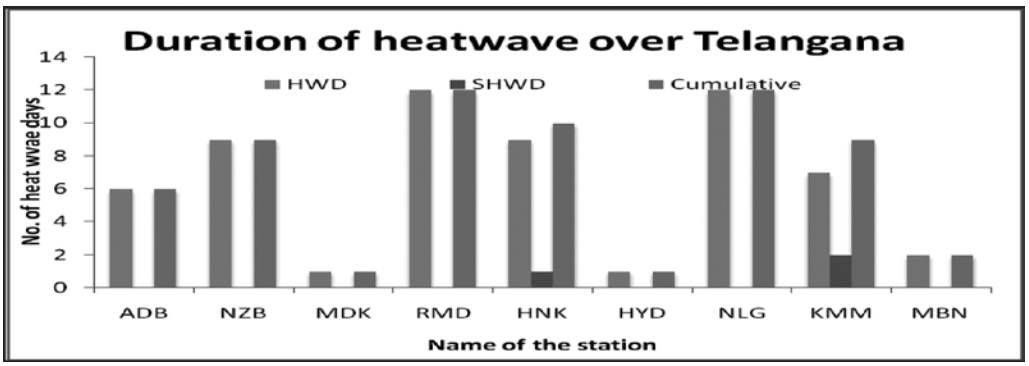

Figure 12(b). Duration of heat-wave over the sub-divisions of Telangana during May 2015.

18 days of SHW days while Telangana stations account for only 3 days of SHW days.

CONCLUSIONS

It is noticed from the study that the heat wave condition developed over Telangana prior to Andhra Pradesh. The period of heat wave over Telangana was 12 days from 19th May onwards; bout of heat wave like conditions was developed from 3rd May 2015 onwards. The heat wave spell continued over coastal Andhra Pradesh for 9 days from 21st to 28th and on 31st after an interruption/hiatus of 2 days. The number of severe heat wave days is more over coastal Andhra Pradesh than over Telangana. Khammam in Telangana recorded the highest maximum temperature of 47.6^0 C on 23rd and it is the highest Tx of the season. Visakhapatnam in coastal Andhra Pradesh recorded the highest ever recorded Tx of 45.0^{0}C on 25th May. There are no heat wave days over Rayalaseema.

On the basis of analysis of synoptic, thermodynamic and dynamic aspects of the heat-waves it is inferred that various parameters like prevailing wind, advection of dry air, absence of sea breeze or late setting of sea breeze, high insolation and cloud- free atmosphere are the causes of such a long spell of heat wave/ severe heat wave over Telangana and Andhra Pradesh during May 2015.

Since heat wave recurrence every summer is expected as a normal feature as suggested by Reddy (Nov, 2017) in his editorial we need to take various precautionary and curative measures, especially by senior citizens and children to lessen the negative impact. Quoting global studies he pointed out that "The 500-hPa height anomalies are most strongly related to positive warm season precipitation anomalies over the Indian monsoon region and associated positive convective heating anomalies that drive mid-latitude teleconnection patterns in response to anomalous tropical convective heating in future climate. Thus, areas already experiencing strong heat waves could experience even more intense heat waves in the future. But other areas could see increases of heat wave intensity that could have more serious ramifications/impacts because these areas are not currently as well adapted to heat waves."So, it is needed to study this phenomenon more closely in the near future.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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