Synoptic situation associated with the heat wave condition during 17 May to 1 June 2015 over India

Smitha Nair*, P. Chandrasekhara Rao and D. S. Pai

India Meteorological Department, Pune 411 005, India

Heat wave conditions from 17 May to 1 June 2015 caused deaths of over 2000 people, especially in the south Indian states of Andhra Pradesh and neighbouring Telangana. This study comprises the analysis of synoptic features associated with this deadly heat wave. It was found that the presence of large amplitude anticyclonic flow in the upper levels, above normal 500 hPa height values, above normal lower tropospheric temperatures, below normal precipitable water and higher outgoing longwave radiation (OLR) values are major factors associated with the occurrences of heat wave.

Keywords: Air temperature, heat waves, geopotential height, precipitable water.

THE World Meteorological Organization statement on the status of global climate in 2015 (ref. 1) has confirmed that the global surface temperature in 2015 increased by 0.76°C above the 1961–1990 average. A study[2] based on the analysis of multiple indices derived from the latest HadGHCND daily maximum temperature, minimum temperature and average temperature for the period 1950–2011, found increasing global trends in the intensity, frequency and duration of the observed summertime heat waves and annually calculated warm spells. Using observed and model reanalysed data, it is found that during the last century, the atmospheric surface temperature showed an increasing trend with significant variations during different seasons and different regions of India[3,4]. Studies[5–8] also found that there is an increase in intensity, frequency, persistency and areal coverage in warm days, warm nights and heat waves over India. This warming trend continued in 2015 as well.

The present communication examines the conditions associated with two major heat waves during 29 June to 5 July 2012 and 17 May to 1 June 2015. The purpose of this work is to describe the pattern and atmospheric conditions associated with heat waves. The behaviour of specific fields, such as 500 hPa heights, OLR values, lower tropospheric temperatures and precipitable water will be discussed in these cases.

Heat wave over a region refers to a prolonged period of excessively hot weather (above certain threshold temperature value) over the region, which may be accompanied by high humidity. The criteria[9] used by the India Meteorological Department (IMD) for defining the heat wave (HW) and severe heat wave (SHW) conditions over India since 2002 are given in Table 1. It is seen that the HW/SHW conditions signify a certain amount of rise of daily maximum temperature at a station with respect to normal value computed for the period 1971–2000. We have used the criteria given in Table 1 for defining HW/SHW conditions over the stations. The daily maximum temperature data were obtained from Indian Daily Weather records (IDWR), IMD. The maps showing the mean and anomalous wind patterns and mean sea level pressure were obtained from the weather division of IMD Pune. The maps of air temperatures, OLR, precepitable water and geopotential heights were archived from INSAT 3D Imager and Sounder Payload data available at satellite.imd.gov.in.

The 2012 heat wave spanned the months of May, June and July, mostly over northwest, east, north India along the plains of Himalayas, Vidarbha, Costal Andhra Pradesh (CAP), adjoining Telengana and Tamil Nadu. A study of severe heat waves during the period 29 June to 5 July 2012 when maximum districts of India were affected saw temperature anomalies greater than 8° at a few stations of eastern Uttar Pradesh, western Rajasthan and western Madhya Pradesh. Figure 1 shows the maps of daily maximum temperature anomalies associated with this heat wave event. The solid lines in the figure denote the actual onset of SW monsoon 2012 and the dotted lines denote the normal onset dates of SW monsoon. The delay in onset of monsoon by more than a week during the period under study resulted in conditions conducive for extreme HW activities. The conditions during peak heat wave are shown in Figure 2. 1 July is considered as the peak when maximum area was under the grip of this severe heat wave. The heat wave is characterized by the prevalence of a high pressure system in upper winds along a wide region over North and Northwest India. Figure 2 shows the contour map at 00 GMT of 500 hPa heights and OLR image of 1 July. It was observed that higher values of heights (5840 gpm) were centred over

Table 1. Definition of HW/SHW used in this study[9]

Heat wave need not be considered till maximum temperature of the stations reaches at least 40°C for plains and at least 30°C for hilly regions
When normal maximum temperature of a station is less than or equal to 40°C • Heat wave: Departure from normal is 5°C to 6°C • Severe heat wave: Departure from normal is 7°C or more
When normal maximum temperature of a station is more than 40°C • Heat wave: Departure from normal is 4°C to 5°C • Severe heat wave: Departure from normal is 6°C or more
When actual maximum temperature remains 45°C or more irrespective of normal max temperature heat wave should be declared
For coastal stations if the maximum temperature of 40°C is reached heat wave may be declared

*For correspondence. (e-mail: smitha_anil@yahoo.com)

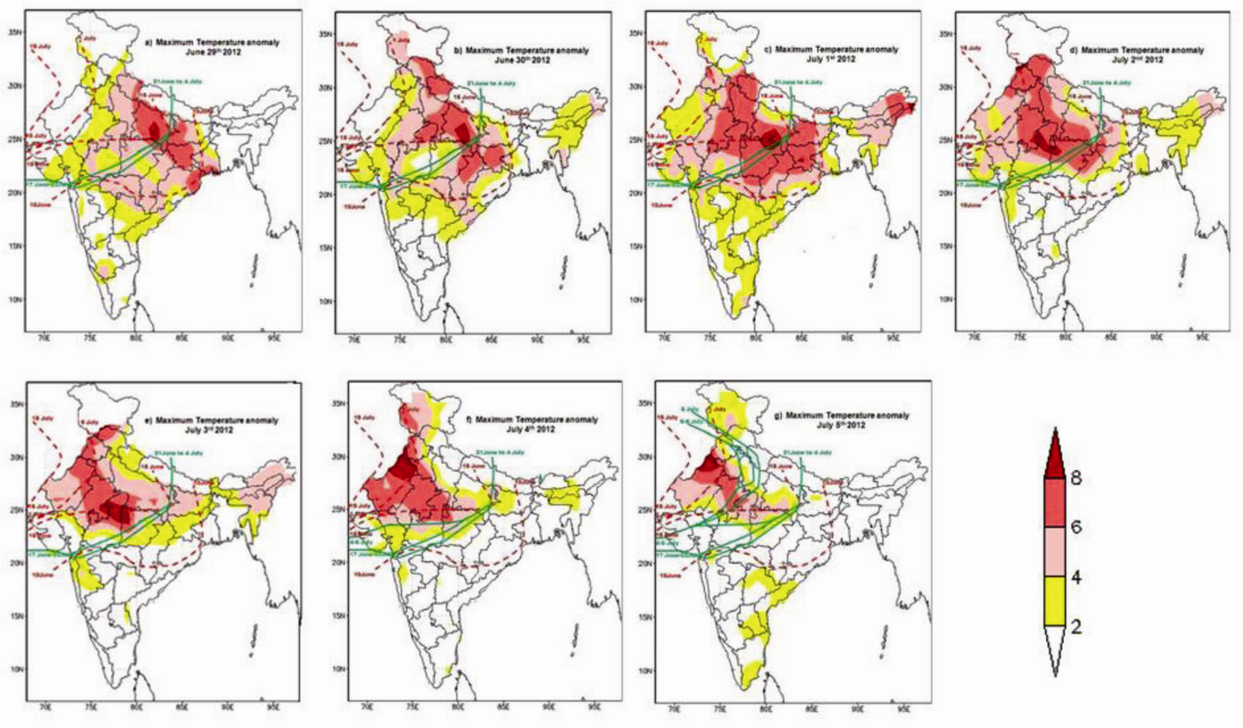

Figure 1. Composite maximum temperature anomaly (°C) map over India for the HW period 29 June to 5 July 2012 based on data from Indian daily weather records. The solid lines denote the actual onset of SW monsoon and the dotted lines denote the normal onset dates of SW monsoon 2012.

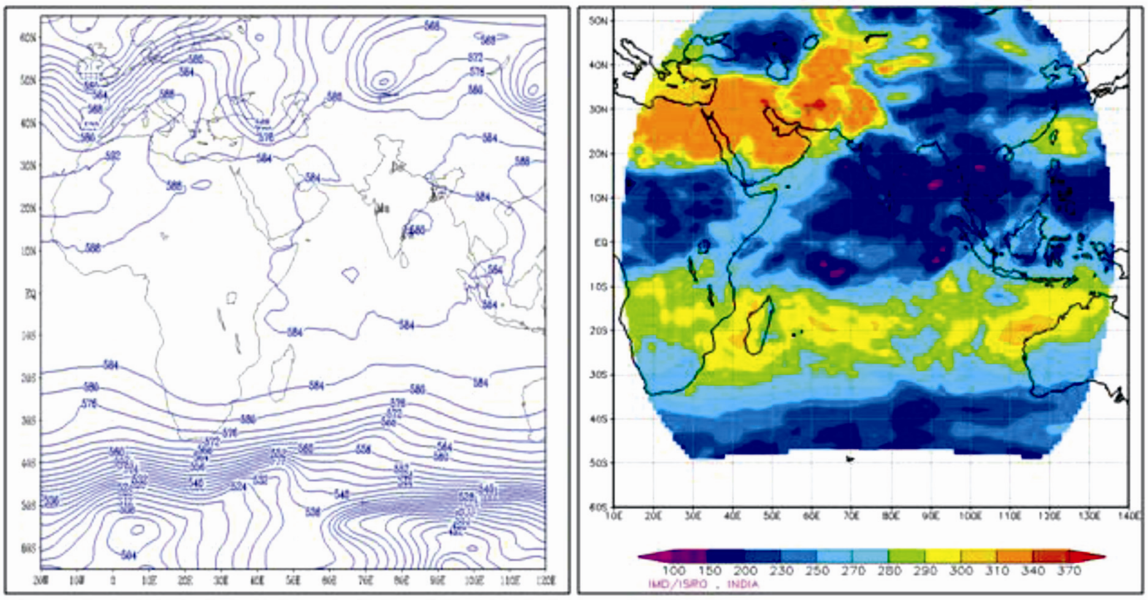

Figure 2. IMD GFS (T574) 500 hPa contour analysis and OLR image from Kalpana 1 at 00 GMT on 1 July 2012.

Northwest, Central and Northeastern region indicating higher average air temperature in the vertical column of air between the ground surface and the 500 hPa height plotted at that point. The prevalence of a high-pressure system was also seen in upper winds along a wide region over North, Northeast and Northwest India. The higher OLR values over Northwest and adjoining areas indicate lack of cloud and high insolation which along with associated subsidence and dry soil led to unrelenting heat.

A heat wave during the period 17 May to 1 June 2015 occurred, making it the fifth deadliest ever in the world and the second deadliest in India[10]. More than 2000 heat

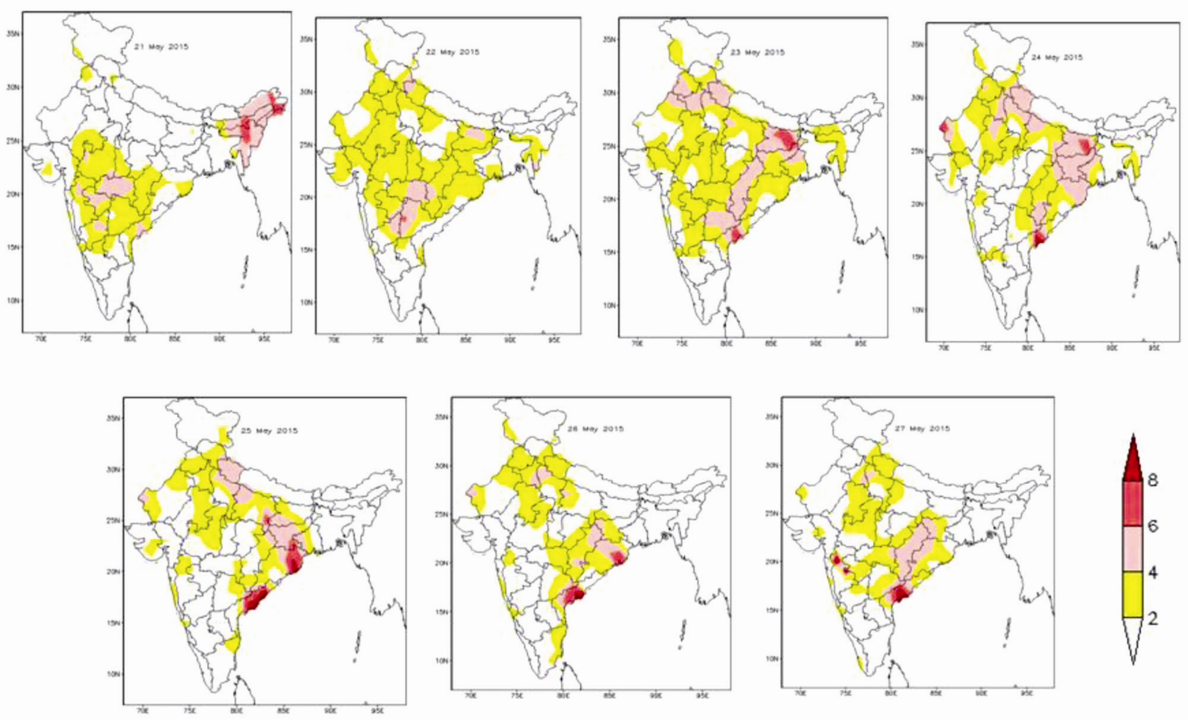

Figure 3. Composite maximum temperature anomaly (°C) map over India for the severe HW period of 21 to 27 May 2015 based on data from Indian daily weather records.

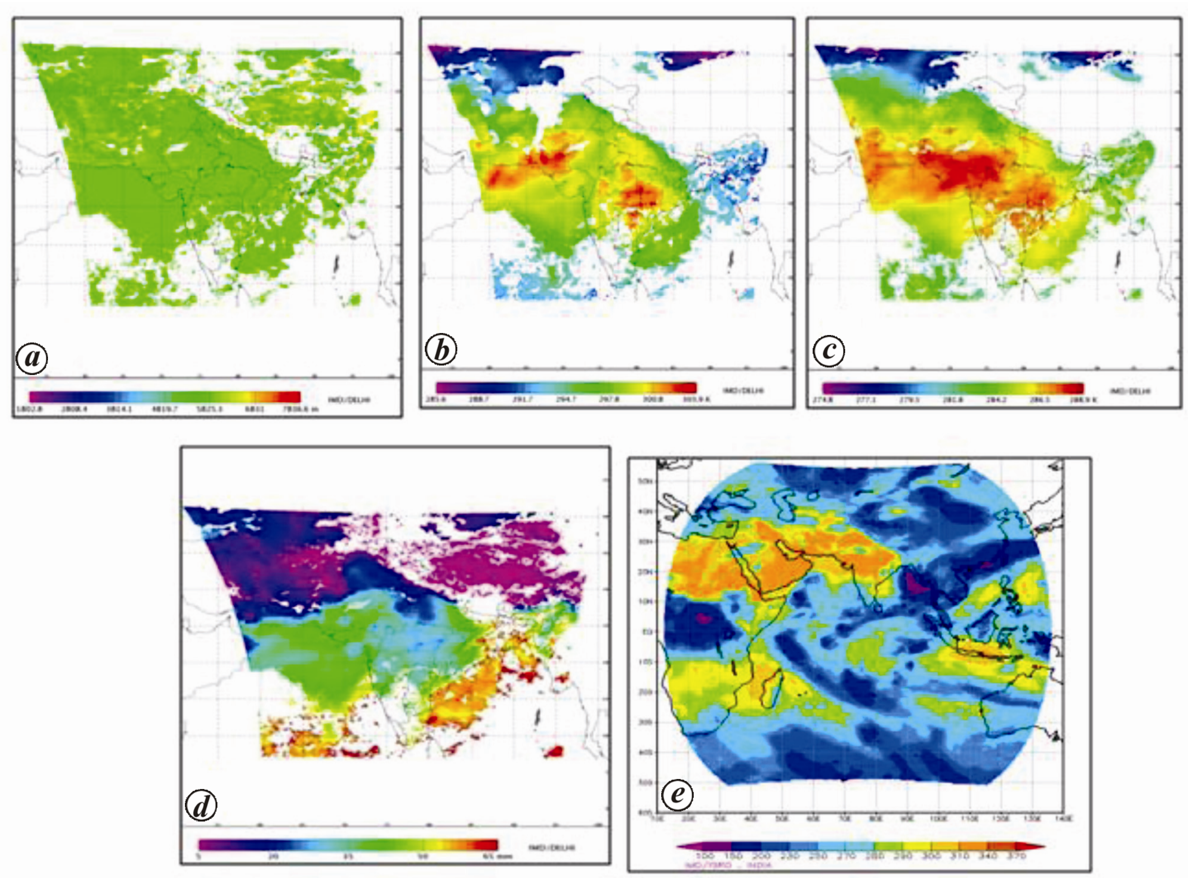

Figure 4. Satellite images at 00 GMT of 20 May 2015 showing: ***a***, 500 hPa heights; ***b***, 850 hPa temperatures; ***c***, 700 hPa temperatures; ***d***, columnar precipitable water; ***e***, OLR values.

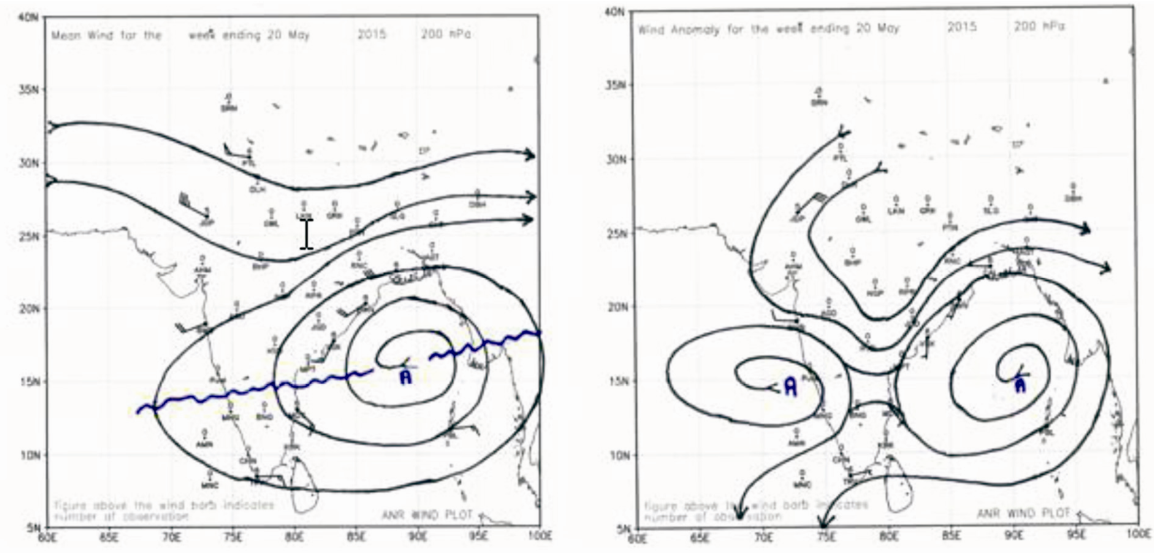

Figure 5. Mean and anomalous wind pattern at 200 hPa for the week ending 20 May 2015.

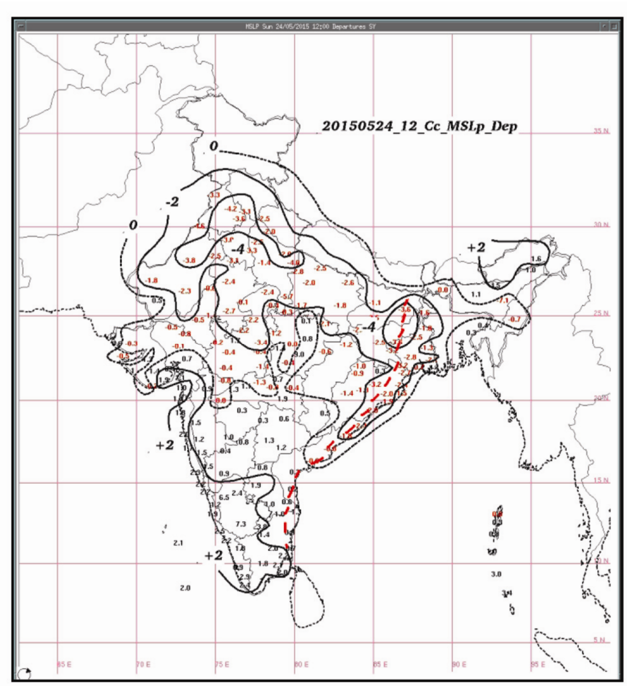

Figure 6. Mean sea level pressure departure at 12 GMT on 24 May 2015.

stress-related fatalities were reported over North India, CAP and Odisha in print and media. The temperatures were above normal during the second fortnight of May and the first week of June over the entire country except at a few places over south Peninsula, North east India and Jammu and Kashmir region. Figure 3 shows the maps of daily maximum temperature anomalies (°C) of days from 21 to 27 May 2015 when severe heat wave conditions prevailed over the country. The HWs experienced during the study period recorded the highest maximum temperature departure of 8°C at a few stations of Odisha and CAP.

From 17 to 18 May, the areas with +4°C maximum temperature anomalies lay concentrated in Gujarat and Madhya Pradesh region. Few stations in Rajasthan experienced maximum temperatures above 45°C. On 17 May, the areas which experienced 2–4°C maximum temperature anomaly covered wide areas of Gujarat, Saurashtra and Kutch and a few places south of Rajasthan, west Madhya Pradesh, Madhya Maharashtra, Bihar and Odisha which increased further northwards and covered many parts of Rajasthan and West Madhya Pradesh on 18 May. On 19 May the areas with maximum temperature anomalies of 2–4°C further spread northwards covering Punjab and Haryana and eastwards covering parts of east Madhya Pradesh, Marathwada, Vidharbha and a few places of Arunachal Pradesh and Nagaland, Manipur, Mizoram and Tripura (NMMT). The temperature anomalies of ≥4°C were experienced at isolated places in eastern Rajasthan, Madhya Pradesh and Madhya Maharashtra. On the 20th, the areas with maximum temperature anomalies of 2–4°C shrunk from Rajasthan and Gujarat and extended eastwards covering many parts of east Madhya Pradesh, Vidharbha, Northeast India and a few parts of Chhattisgarh and southwards covering Telangana and North Interior Karnataka. Maximum temperature anomalies ≥4°C were experienced at a few places of Madhya Pradesh, eastern Rajasthan, Maharashtra and NMMT. On 21 May the maximum temperature anomalies of 2–4°C extended eastwards covering CAP, and a few places of Odisha. The entire North East India experienced temperature anomaly of ≥4°C with few places experiencing temperature anomaly ≥6°C. On 22 and 23 May the entire country except Jammu and Kashmir, Kerala, Tamil Nadu, Arunachal Pradesh, Assam, Sub-Himalayan West Bengal and Sikkim experienced maximum temperature anomalies of 2–6°C and some parts of CAP and Bihar experienced maximum temperature

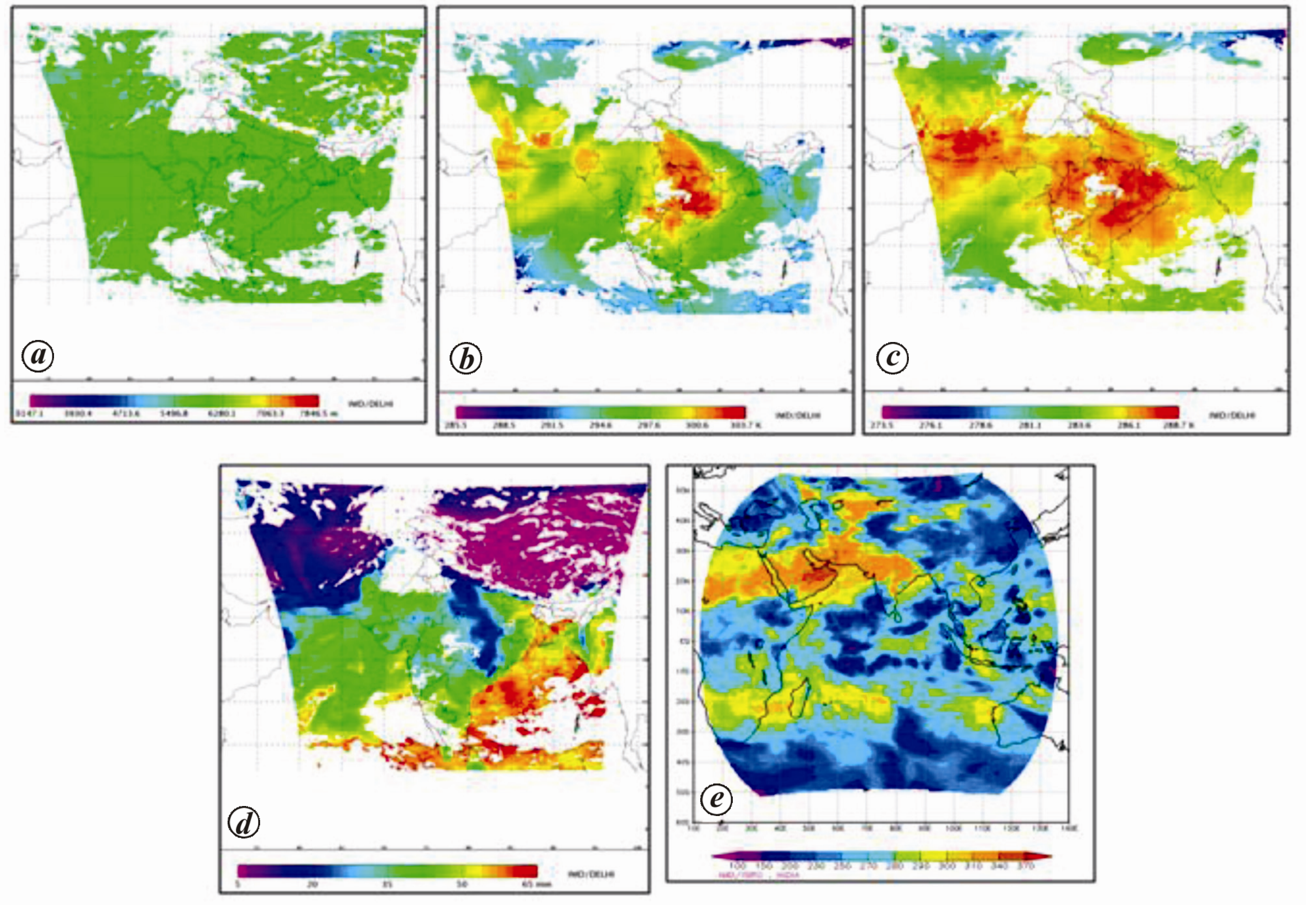

Figure 7. Satellite images at 00 GMT of 29 May 2015 showing: ***a***, 500 hPa heights; ***b***, 850 hPa temperatures; ***c***, 700 hPa temperatures; ***d***, Columnar precipitable water; ***e***, OLR values.

anomalies of ≥6°C. From 24 May onwards the areas with maximum temperature anomalies ≥2°C shrunk from southwards and remained concentrated over north, east and north eastern peninsular region. The minimum temperatures anomalies also ranged between 2°C and 6°C in these areas during this period.

The worst heat wave swept across Telengana and CAP from 25 to 27 May with temperature anomalies ≥6°C, killing over 2000 people in that area as reported in print and media. Machlipattnam, Kakinada and Vishakhapatnam in CAP and Bhubaneswar in Odisha experienced temperature anomaly ≥8°C on 25 and 26 May. The temperatures were above 6°C over some parts of Rajasthan, Bihar, Madhya Maharashtra and east UP also during 25 to 27 May. On 28 May the regions with maximum temperature anomalies 4–6°C shrunk from north and eastern India and moved southwards towards Odisha, Chhattisgarh, Marathwada and Jharkhand. On 29 May it lay concentrated mainly over Chhattisgarh. From 30 May to 1 June the regions with maximum temperature anomalies of 4–6°C were restricted to parts of Vidharbha, Chhattisgarh, Telengana, Jharkhand, Bihar, western Rajasthan, Madhya Pradesh, Gujarat and CAP.

During this period of heat wave the trough was running along the Gangetic plains and a dynamic trough was along 80°E longitude. On 16 May, on 500 hPa chart, there were two highs, one covering the Arabian Sea and the other over Bay of Bengal. As a result, a trough ran along the entire country roughly along 78° longitude. As the trough moved eastwards strong anticyclonic flow blanketed Rajasthan and Gujarat Coast. By 18 May the entire country was in the grip of strong anticyclonic flow with the centre of high pressure over Vidharbha. The 850 hPa and 700 hPa air temperatures were positive except over southern peninsula and parts of eastern India. Figure 4 shows the 500 hPa geopotential heights, 850 hPa and 700 hPa air temperatures, OLR values and precipitable water on 20 May. It is observed that the maximum of heights (5860–5900 gpm) was centred over Northwest, Central and Northeastern peninsular region. This is similar to the 2012 heat wave discussed above where the regions affected with heat waves showed higher values of geopotential height values at 500 hPa. A striking feature is that the largest thermal values of 850 and 700 hPa air temperatures were located around it. This suggests a deep warm boundary layer over the Indian region[11,12]. The outgoing long wave radiation also showed significant positive values over India, indicating cloud-free region with no precipitation as was the case of 2012 heat waves. The region of positive OLR values corresponds to the region of large thermal values. Slightly above normal precipitable water around Andhra Pradesh coast contributed in limited overnight cooling and higher temperature on the following days. By 23 May the centre of high pressure moved southwest and lay over Karnataka. The mean and anomalous flow pattern of winds during the week 14 to 20 May at 200 mb (Figure 5) showed a deep trough across the peninsula indicating subsidence in the upper atmosphere. This high concentration of pressure made it difficult for other weather systems to move into the area, which is why a heat wave can last for several days or weeks. The below normal values of precipitable water over the entire country facilitated a cloud-free sky thus allowing maximum insolation.

On 24 May, on mean sea level pressure chart of 12 GMT (Figure 6), axis of a trough was seen extending from eastern Madhya Pradesh/Odisha to extreme south Peninsula either across CAP or along and off Andhra Coast. This north-south trough was responsible for generating warm, dry, strong northerly or north-westerly winds leading to severe heat wave conditions over many parts of Andhra Pradesh and Odisha. Since the winds are north-westerly to westerly above 20° north, they aid in the eastward transport of warm air and moreover as the flow is completely continental, no moisture could penetrate over the concerned region where heat waves were experienced. This is similar to the case of heat waves of 19 May–10 June 2003 as discussed extensively by Bhadram *et al.*[13]. Figure 7 represents the conditions on 29 May. A strong 500 ridge covered the entire country with maximum 500 hPa heights over north, central, east and north-east peninsular India. Many studies[11,14,15] have pointed out the importance of upper level ridges and heat waves. High 850 and 700 hPa air temperatures values indicated the presence of warm boundary level. However, most of the country showed near normal precipitable water. The 850 and 700 hPa temperature anomalies remained the same till 1 June after which the heat wave conditions weakened. This heat wave shared similar characteristics outlined by 2012 heat waves with higher OLR and 500 hPa height values.

Thus the large scale conditions associated with heat waves and its severity are summarized as follows. Maximum temperature was significantly high over India with some places in Andhra Pradesh experiencing maximum temperature anomaly of greater than 8°C during the study period. The minimum temperature anomalies also ranged between 2°C and 6°C over India during this period. Presence of large amplitude anticyclonic flow over the region along with above normal values of height anomalies at all levels indicated the existence of deep warming of boundary layer which in turn is a good indicator of significant heat waves as summarized by previous studies. Below normal precipitable water over the region also added to the severity of heat wave. The lack of moisture allowed maximum insolation and aided in warming. A north-south trough at sea level along or off Andhra Coast is also often responsible for generating strong northerly or north westerly winds leading to severe heat wave conditions over many parts of Andhra Pradesh.

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