AJAE

Open Access

Vol. 15, No. 3, 2020117, September 2021
doi: https://doi.org/10.5572/ajae.2020.117
ISSN (Online) 2287-1160, ISSN (Print) 1976-6912

Research Article

Prediction of Heatwave 2013 over Andhra Pradesh and Telangana, India using WRF Model

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Received: 17 November 2020
Revised: 3 March 2021
Accepted: 5 July 2021

ABSTRACT Heatwaves are acknowledged to be the major meteorological disaster, causing a noticeable impact on humans and animals' lives during the last few decades. The number, frequency, duration, intensity, and areal extent of the heatwaves are on the rise during recent years. The Maximum temperature data of 2013 is analyzed to assess the synoptic nature, intensity, frequency, and various significant facets of the heatwave over the south peninsular states of Andhra Pradesh and Telangana. Indian subcontinent experienced a major heatwave during 2013, which claimed 1216 human lives. Even though the highest intensity of maximum temperatures is observed in May over major areas of India, the increasing (incidence, duration, number of spells, and the sweltering temperatures) number of heatwaves are observed over many parts of the country. The northwest and southeast coastal regions are the two heat wave prone regions. The advection of heat from the northwest with the aid of north-westerly winds causes heatwaves over northwest India to sweep or move towards India's southeast and east coast. The heatwave record over south-eastern India, i.e, Andhra Pradesh and the adjoining Telangana state during May 22–24, 2013 were described in this study. Maximum temperatures above 40°C are observed with a sudden rise by 6 to 7°C over the study region. An attempt is made to predict the maximum temperatures 72 hours before the existence of a heatwave at 3 km horizontal resolution using the Advanced core of the Weather Research and Forecasting (WRF) model. Model predicted temperature values match with observations and the statistical metrics show a high index of the agreement, lower values for root-mean-square error and mean absolute error. Atmospheric circulation patterns associated with this heatwave are also presented. The arrest of sea breeze, the hovering of diabatic heat because of subsidence is the factor that abetted the heatwave blockade over the south-eastern part of the country. The WRF model forecasts could present the occurance of the heat wave over AP and Telangana region with 72 hour lead time with high accuracy.

KEY WORDS Maximum temperature, Weather research and forecasting model, WRF, Heatwave, Statistical metrics

1. INTRODUCTION

With the burgeoning demand for shelter to the growing population, rapid industrialization, and growing urbanization, there has been a drastic reduction in land use and land cover quality. These are major anthropogenic causes of climate change (Fischer *et al.*, 2015). The resultant maximum temperatures aided by the relative humidity during the summer season produce heatwaves that cause sunstrokes, heat stress, other physiological effects, culminating in fatalities. Because of the abnormal rise in temperatures, the human body experiences uneven physiological stress as the optimum temperature of the human body is 37°C, and there is an apparent correlation between heat stress and mortality rate. The escalated temperatures may lead to the loss of human lives and cause financial deprivation that are the major concerns of the disaster managers of every nation, including India. Heatwave episodes are treated as natural disasters in this modern era because of their connection to human health (De Bono *et al.*, 2004) and the environment (Ciais *et al.*, 2005).

Intergovernmental Panel on Climate Change (IPCC, 2007), in its fourth assessment report (AR4) reported that the mean surface air temperature has been increased by 0.7°C during 1961–2000. The changes in the temperature play an essential role in global warming, which is not similar worldwide. India, for instance, experienced multiple severe heat waves associated with increased mortality during the years 1971, 1987, 1997, 2001, 2002, 2013, and 2015 and of late, recorded maximum death rate in recent years (2001–2016) due to heat waves (Mazdiyasni *et al.*, 2017). Pramanik & Jagannathan studied trends in maximum and minimum temperature (1954) by using 30 stations in India for 1880–1950. The number, frequency, duration, intensity, and extent of the heatwaves increased worldwide over three times since the 1960s (Min *et al.*, 2011). Prediction of these heat waves with ample lead time is essential to overcome the impact of heatwaves. The formation of heat waves leans upon some specific maximum temperature threshold values over a particular region, and the value varies from one area to another. For example, India's maximum temperature threshold is 45°C while it is 40°C for Australia; 32°C for the northwestern United States, and 28°C for Denmark. These values depend on atmosphere variables such as humidity and topography (Das and Smith, 2012). Numerous studies of heatwave episodes were carried out all over the world for example, in North America (Lau and Nath, 2012; Gershunov *et al.*, 2009), in Europe (e.g., Dasari *et al.*, 2014; Black *et al.*, 2004; Fink *et al.*, 2004; Schar *et al.*, 2004). In India also many studies were carried out to understand the characteristics of heatwaves (Pai *et al.*, 2017, 2013, 2004; Ratnam *et al.*, 2016; Ray *et al.*, 2013; Mohan and Bhati, 2011) and the synoptic features connected to heatwaves were identified (Desai, 1999; Subbaramayya and SuryanarayanaRao, 1976; Raghavan, 1966). The heatwave definition is different for different regions, and it is generally related to continuous abnormal temperatures (Meehl and Tebaldi, 2004). Several cases of heatwaves were observed all around the world. During the 2003 heatwave in Europe, the loss of human lives is about 70,000 (Robine *et al.*, 2008), and nearly 11,000 in Russia. In Japan, nearly 1718 (Matsuyama and Sato, 2011) lost their lives during 2010, and in Chicago, about 500 died during 1995 (Dematte *et al.*, 1998). In India, the highest intensity of heatwaves occurred during 2015, which led to nearly 2500 deaths, out of which 2320 deaths were registered only in Andhra Pradesh (AP) and Telangana states (Charan Singh and Kumar, 2018; Dodla *et al.*, 2017). The highest maximum temperatures were recorded over southeast coastal states of India, especially over AP and Telangana, and also mortality rate is high over these regions (Naveena *et al.*, 2021a, 2021c, 2020a; Satyanarayana and Dodla, 2020) and atmospheric wind pattern plays a major role for the highest recorded death rate over these regions (Satyanarayana *et al.*, 2021, 2018; Venkata *et al.*, 2017). The frequency and intensity of heatwaves increases significantly for future scenario of heatwaves over the Indian subcontinent up to 21st century (Naveena *et al.*, 2021b, 2020b). Convection and instability in the atmosphere are also high over these regions during the pre-monsoon season (Umakanth *et al.*, 2021, 2020a, 2020b, 2020c, 2020d). According to the World Meteorological Organization, the death rate due to heatwaves will double in the next 20 years (Larsen, 2006).

Heatwave characteristics are different for different regions. It may last from a few days to a few months also. For example, heatwaves that occurred over Europe during 2003 continued for three months, i.e., from June to August (Fink *et al.*, 2004; Schar and Jendritzky, 2004), and the heatwave that occurred over the U.S. during 1995 did last for only a few days in July (Palecki *et al.*, 2001; Kunkel *et al.*, 1996). Generally, heatwaves last for few days only (Khaliq *et al.*, 2005).

Temperatures during summers are increasing, and the intensity and frequency of heatwaves are also rising due to climate change. According to Intergovernmental Panel on Climate Change (third Assessment Report), the increase in temperatures started since last 50 years due to anthropogenic activities and the average temperature of the globe, i.e., both sea surface and land temperature increased $0.6 \pm 0.2°C$ during the 20^{th} century. A detailed analysis of Northern Hemispheric data showed that temperatures have increased at a higher rate during 20^{th} century when compared to the last 10 centuries (Houghton *et al.*, 2001).

It will be useful to analyze the trends of long-term daily maximum temperature to understand the phenomena of heatwaves over a particular geographical location (Li *et al.*, 2015). Several vulnerable zones are at higher risk to heatwaves where huge populations reside. Efforts are, therefore, required to develop the prediction skill of Numerical Weather Prediction (NWP) models to aid in disaster management (De *et al.*, 2005). Many researchers have extensively used WRF, a mesoscale model, in simulating extreme temperature regions, particularly over Europe and North America (Giannaros *et al.*, 2013; Giovannini *et al.*, 2013; Salamanca *et al.*, 2012; Bohnenstengel *et al.*, 2011). Using the downscaled value of maximum temperature and comparing it with North American regional reanalysis (NARR) data, a generalized extreme value is presented and used in the study (Wang *et al.*, 2016). For the progression of a heatwave through regional and global effects, land-atmosphere coupling plays a significant role. While numerical models are extensively used to model extreme events such as heatwaves, land surface schemes (LSSs) are used for weather simulations in some studies. These schemes are also used in the WRF model. This kind of exploration is imperative as the present WRF sensitivities to various physical parameterizations are mainly concentrated on convective precipitation (Fan, 2009). However, the impact on heatwaves in terms of frequency, intensity, and spatial distribution of temperature, is different for different LSSs. One extreme weather heatwave event over East China, LSS induced negative feedback between low-level atmospheric circulation and surface temperature, is sensitive to LSS (Zeng *et al.*, 2011). WRF model simulations over India were carried out for Andhra Pradesh (Dodla *et al.*, 2017), Odisha (Gouda *et al.*, 2017), Delhi (Mohan and Bhati, 2011).

In the present paper, an attempt is made to predict heatwaves 72 hours before their occurrence over Andhra Pradesh and Telangana, with the aid of the WRF model at 3 km horizontal resolution. Forecast of heatwaves with a prior lead time gives essential information and direction to the people to protect themselves from the deadly effects of heatwaves. It helps disaster managers to arrange the contingency measures.

2. DATA AND METHODOLOGY

2.1 Data

a. Daily maximum temperature data from 9 Automatic Weather Stations are taken from India Meteorological Department (IMD) for May 2013 in both the south-eastern coastal states of India, i.e., Andhra Pradesh and Telangana, to identify heatwaves and also to assess the duration of a heatwave over this region.

b. Gridded daily maximum temperature data are obtained from IMD from 1951 to 2019 at one-degree spatial resolution to generate climate means (Srivastava *et al.*, 2008). The data are used for to identify the area of coverage and span of heatwave conditions over Andhra Pradesh and Telangana regions for May 2013. Anomalies or deviations from climate mean normal values are calculated at each grid point.

c. Reanalysis global dataset of European Centre for Medium-Range Weather Forecasts (ECMWF) at 0.125° resolution for May 2013 are used for the most probable time of occurrence of the maximum temperature of the day at 0900 UTC for the region between 12.5–20°N; 76.5–85°E at different pressure levels from 1000 to 700 hPa. Relative humidity, vertical velocity, and wind flow are analyzed to summarize the dynamics linked with the 2013 heatwave (https://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/).

d. National Centre for Medium Range Weather Forecasting (NCMRWF) generated Indian Monsoon Data Assimilation and Analysis (IMDAA) reanalysis data (https://rds.ncmrwf.gov.in/) available at 12 km horizontal resolution is also used to generate the dynamics of the heatwave of 2013.

e. The initial, and time varying boundary conditions for the model are provided from the National Centers for Environmental Prediction Global Forecast System (NCEP GFS) forecasts available at 0.25° spatial resolution and at 3-hour interval (http://www.ftp.ncep.noaa.Gov/data/nccf/com/gfs/prod/).

2.2 Methodology

The basis for characterizing "heatwave" in the present analysis is similar to the definition given by IMD. IMD proclaims a region to be under heatwave when the anomaly of maximum temperature is greater than 4–5°C (5–6°C) where the normal maximum temperature is $\geq$40°C ($<$40°C) and proclaims it to be a region of a severe heatwave when anomalies of maximum temperature are ≥6°C (≥7°C). If the normal maximum temperature is ≥40°C (<40°C) and if the temperature is greater than 45°C heatwave is declared without considering temperature anomaly (IMD, 2015).

Statistical analysis is carried out for correlation coefficient (CC), BIAS, RMSE (root-mean-square error). IOA (Index of agreement) is calculated to estimate the model's performance in predicting the temperatures for the present study period. The equations enlisted herein are adapted from Wilks (2006).

$$Mean = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (1)$$

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}(M_i - O_i) \quad (2)$$

$$\text{Correlation Coffecient (CC)} = \frac{\sum_{i=1}^{n}(M_i-\overline{M})(O_i-\overline{O})}{\sqrt{\sum_{i=1}^{n}(M_i-\overline{M})^2}\sqrt{\sum_{i=1}^{n}(O_i-\overline{O})^2}} \quad (3)$$

$$\text{Mean Absolute Error } (MAE) = \frac{1}{n}\sum_{i=1}^{n}|M_i - O_i| \quad (4)$$

$$\text{Root Mean Square Error } (RMSE) = \sqrt{\frac{\sum_{i=1}^{n}(M_i-O_i)^2}{n}} \quad (5)$$

$$\text{Index of Agreement (IOA)} = 1.0 - \frac{\sum_{i=1}^{n}(M_i-O_i)^2}{\sum_{i=1}^{n}(|M_i-\bar{O}|+|O_i-\bar{O}|)^2} \quad (6)$$

Where O_i and M_i correspond to observations and model values; X_i is the dataset values; n is the number of samples; Σ denotes the summation formula.

2.3 Model Description and Experimentation

In the present study, Advanced Research Weather Research and Forecasting model version 3.6.1 was used. The model was sourced and developed from National Center for Atmospheric Research (NCAR). It is appropriate for predicting real-time weather applications and also for a wide range of atmospheric simulations. In this model, there is flexibility to opt domain of interest, horizontal resolution, and nested domains, and a number of options are available to select different parameterization schemes for the planetary boundary layer, radiation, explicit moisture, and soil processes. A concise explanation of the model was given by Skamarock *et al.* (2008).

In the present study, two interactive nested domains, the outer domain with 9 km resolution and inner domain with 3 km resolution are chosen. The inner domain covers AP and Telangana states, and the neighbouring Bay of

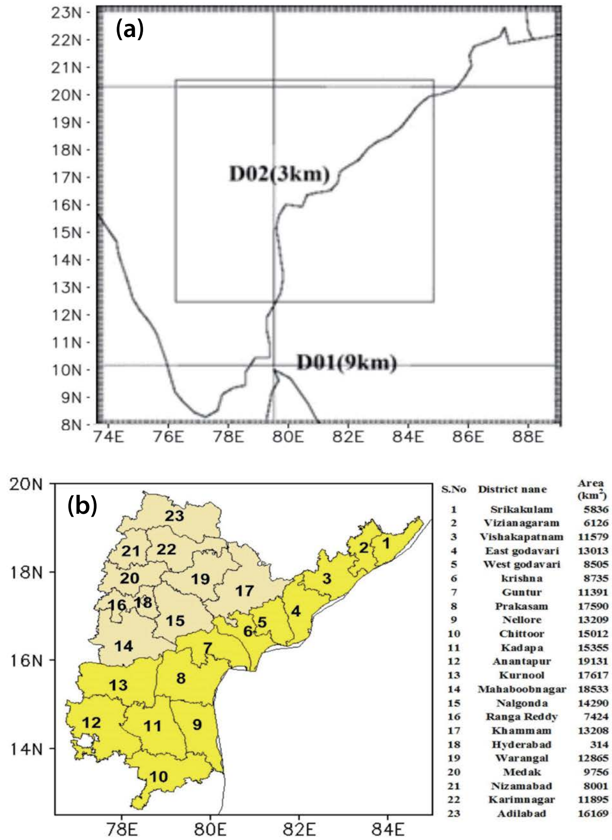

Fig. 1. (a) Model Domains, (b) Spatial map of Andhra Pradesh and Telangana (numbers indicate districts).

Table 1. Model Configuration.

Model	WRF (ARW Core)	
Version	3.6.1	
Dynamics	Primitive equation, non-hydrostatic	
Vertical resolution	42 levels	
Domains	Domain1 8–23°N; 73.5–89°E	Domain2 12.5–20°N; 76.5–85°E
Horizontal resolution	9 km	3 km
Radiation	Dudhia scheme for short wave RRTM scheme for long wave	
Initial and boundary conditions	NCEP GFS Global Forecast	
Cumulus convection	Grell-Freitas old Simplied	
Planetary boundary layer	Mellor-Yamada-Janjic TKE scheme	

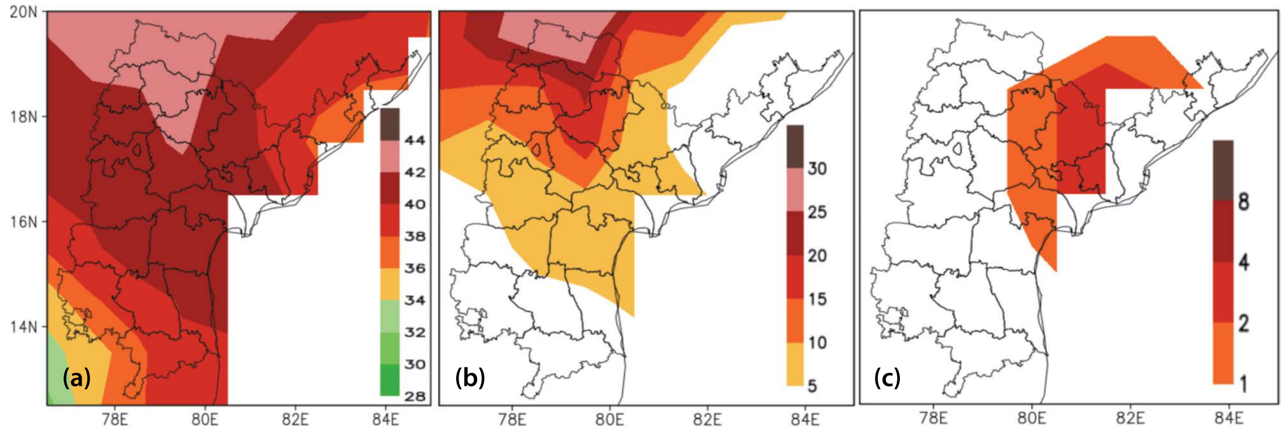

Fig. 2. (a) Mean Maximum Temperature during May, 2013, (b) Maximum Temperature days above 42°C, (c) Heat Wave days Mean + 4°C (37°C) during May, 2013.

Bengal region to some extent. The model is utilized to predict the weather conditions with a prior lead time of 72 hours for each day for May 22–24, 2013. The model domain region represented in Fig. 1, and a details are given in Table 1. Outputs from the model are stored at 3 hr interval. 0900 UTC, equivalent to 1430 IST, is the time of maximum temperature to examine the heatwave. The boundary conditions and the initial conditions for the model were provided from NCEP GFS forecasting files at a time interval of 3 hour and at a horizontal resolution of 0.25°. The model forecasted surface temperatures (2 m) were used to estimate the model accuracy with a prior time of 24, 48, and 72 hours. During May 22–24, 2013, the model forecasted surface temperature, and wind (10 m) is utilized to observe warm air accumulation.

3. RESULTS AND DISCUSSION

The distinct characteristics of May 2013 heatwave event are represented in this section. Mean maximum temperature, the number of heatwave days above 42°C, and mean +4°C days are calculated for May 2013 and forecast of this heatwave event using WRF model with a good lead time of 24, 48 and 72 hours, dynamical characteristics accompanied with this heatwave are also underscored.

3.1 Maximum Temperature over Andhra Pradesh and Telangana during May 2013

The spatial distribution of mean maximum temperature from IMD gridded data for May 2013 is shown in Fig. 2a. The highest temperatures of 42°C to 44°C were recorded for Adilabad, Karimnagar, Warangal, and Nizamabad. North coastal AP exhibited colder temperatures of the order of 36°C to 38°C over Srikakulam, Vizianagaram, Visakhapatnam, and East Godavari (Fig. 2a).

The number of days with maximum temperatures more than 42°C are also high for northern Telangana to the extent of 20 to 30 days during May 2013 (Fig. 2b). In Andhra Pradesh, only west Godavari, Krishna, and Guntur recorded the frequency of about 5 to 10 days during May 2013, and all other districts recorded less than 5-day frequency (Fig. 2b). Mean + 4°C days show 2 to 4 days for West Godavari and Guntur districts of Andhra Pradesh (Fig. 2c).

3.2 Heatwave Event

The time series (1–31 May, 2013) of maximum temperature is depicted in Fig. 3, and climatological mean of daily maximum temperature from IMD gridded data for 9 AWS stations is given in Table 2 and depicted in Fig. 3. A time series plot is utilized to spot the occurrence of heatwave conditions.

In order to comprehend the present heatwave event, spatial distribution plots of maximum temperature and their anomalies from climate mean normal values are plotted for the period 22–24 May, 2013. From the maximum temperature spatial distribution plots, first locales of temperature surpassing 40°C are identified. To find out the regions of heatwaves based on the definition of heatwaves, as mentioned in section 2, maximum temperature anomalies are investigated. Heatwave event over AP and Telangana sustained during May 21–24, 2013.

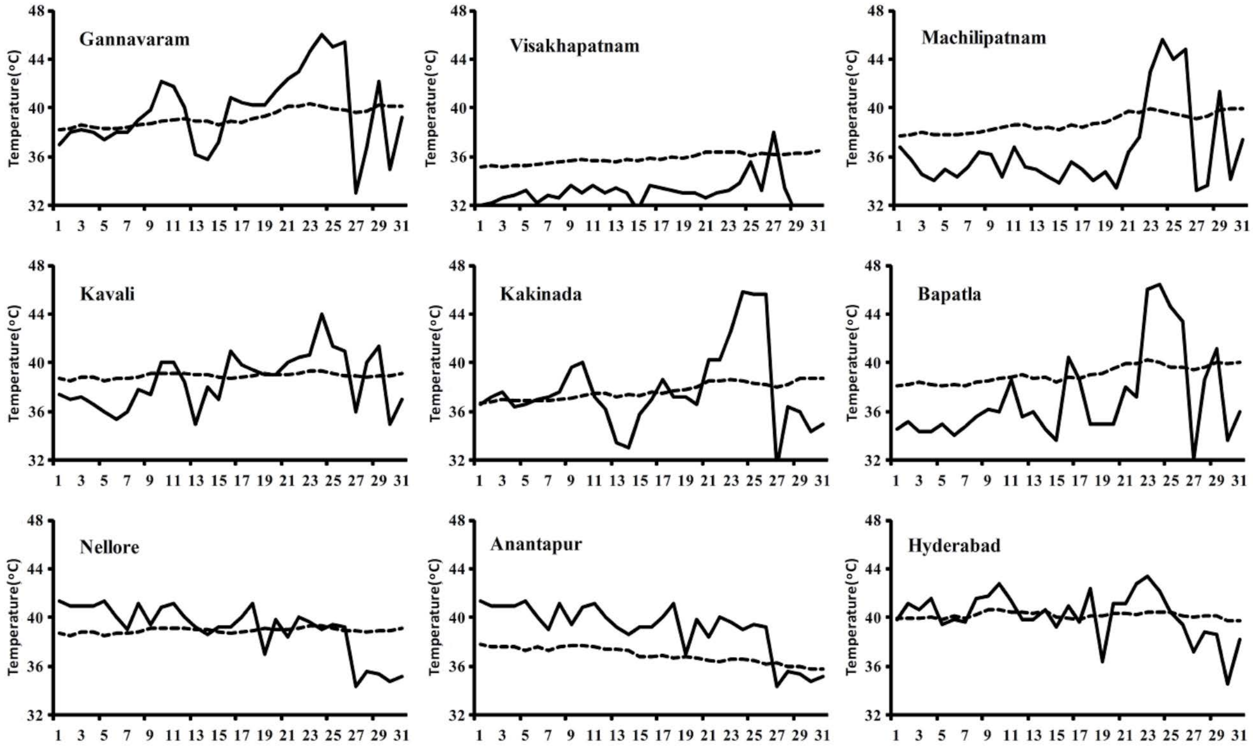

Fig. 3. Time series of daily maximum temperature (°C) at different locations in Andhra Pradesh and Telangana during May 1–31, 2013 (solid line) along with corresponding climatological mean (dotted line).

Table 2. Automatic Weather Stations geographical locations in Andhra Pradesh and Telangana.

S. No.	Station name	Latitude	Longitude
1.	Gannavaram	16.54°N	80.80°E
2.	Visakhapatnam	17.68°N	83.21°E
3.	Machilipatnam	16.18°N	81.13°E
4.	Kavali	14.91°N	79.99°E
5.	Kakinada	16.98°N	82.24°E
6.	Bapatla	15.90°N	80.46°E
7.	Nellore	14.44°N	79.98°E
8.	Ananthpur	14.68°N	77.60°E

Fig. 3 gives a clear delineation and segregation of the regions where maximum temperatures surpass 40°C. The spatial distribution plots of maximum temperature indicate that a heatwave with temperature around 43°C to 45°C is observed over the Telangana region and from 40°C to 44°C over the AP region on 21st May. On 22nd May, the heatwave extends over the northern Telangana region, and from 24th May onwards, it starts dissipating (Fig. 4a–d (upper panel)).

From maximum temperature anomalies (deviation from climate mean normal maximum temperature as given in section 2. 1), it is clear that a heatwave occurred over the northern Telangana region with an anomaly of 4–5°C on 21st May. On 22nd May, it extended and slightly moved southwards and spread up to southern and central AP. On 23rd May, it moved towards northern AP and 24th May it moved further northwards, covering northern AP completely (Fig. 4a–d (lower panel)).

3. 3 Model Prediction

As explained in the model in section 2.3, WRF model has been utilized to make 72 hours forecasts for each of the heatwave periods during 22–24 May, 2013. For the domain covering Telangana and AP region, model forecasts are made at a resolution of 3 km. At 0900 UTC (equivalent to 1430 Indian standard time), i.e., the time when maximum temperature occurs, the temperature distribution of the model predicted values with a lead time of 24, 48, and 72 hours using NCEP GFS analysis and forecasts which is available at 25 km resolution, are presented in Figs. 5–7.

These plots exhibit the existence of heatwave condi-

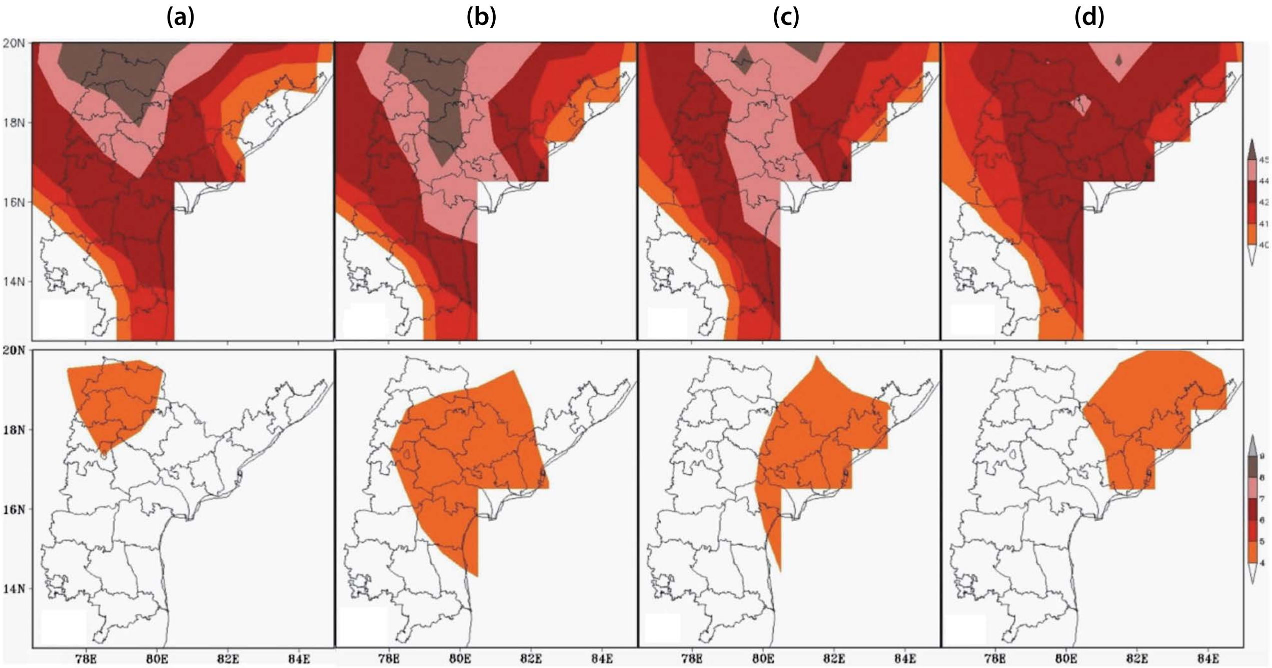

Fig. 4. Maximum temperature (°C, upper panel), and maximum temperature anomalies (°C, lower panel) valid on (a) 21st May, (b) 22nd May, (c) 23rd May and (d) 24th May, 2013.

tions over Telangana and AP with maximum temperature surpassing 44°C. Prediction of maximum temperature with a very good lead time of 72 hours is made using NCEP-GFS forecasts. Firstly, the model predictions with a lead time of 24 h, 48 h, and 72 h are computed by comparing the values of the grid domain with NCEP final analysis and then with the observational data of the IMD.

Statistical metrics such as RMSE, MAE, BIAS, CC, and IOA have been calculated and given in Table 3. NCEP analysis is compared at each grid point over 3 km resolution to calculate statistical metrics over the study domain (12.5–20.5°N; 76.5–85°E). Many data points are considered, and these statistical metrics show a remarkable similarity between the analysis and model prediction for all the lead times. From Table 3, it is quite evident that the values of MAE, RMSE, and BIAS are very less and CC and IOA are high.

During day-1, the predicted temperature with a lead time of 24 hours statistical metrics denote that MAE is 0.49°C, RMSE is 0.80°C, CC is 0.95, BIAS is −0.11°C, and IOA is 0.97 (Table 3a). For day-2, with a lead time of 48 hours, MAE is 0.47°C, RMSE is 1.27°C, CC is 0.90, Bias is −0.20°C, and IOA is 0.93. For day-3, with a lead time of 72 hours, MAE is 0.59°C, RMSE is 1.44°C, CC is 0.85, BIAS is −0.18°C, and IOA is 0.90 (Table 3a). Again,

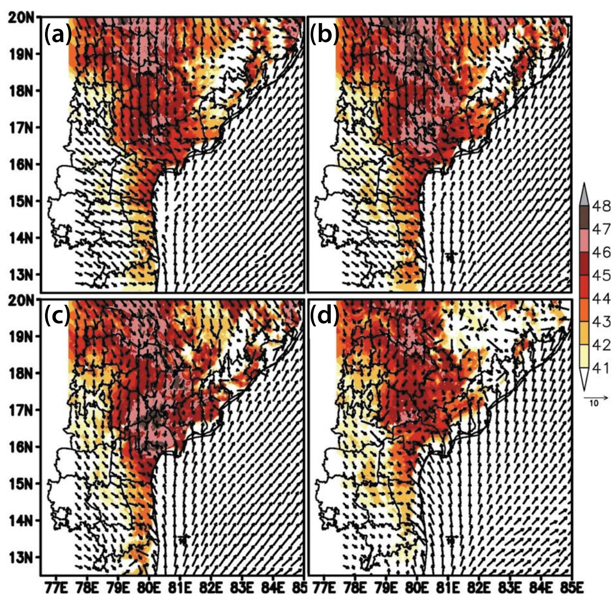

Fig. 5. Maximum temperature (°C) along with surface winds overlayed for (a) Observation, (b) Day-1, (c) Day-2 and (d) Day-3 forecast valid on 22nd May, 2013.

statistical metrics are calculated between the model predicted temperature data point and the nearest station location point (9 locations) during the heatwave event

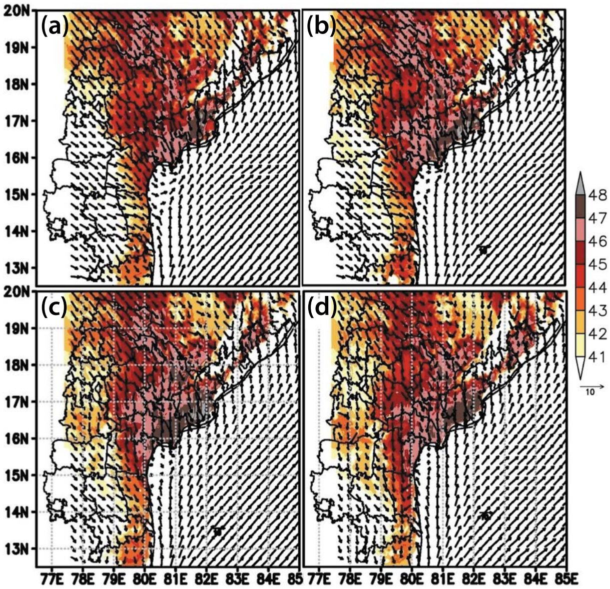

Fig. 6. Maximum temperature (°C) along with surface winds overlayed for (a) Observation, (b) Day-1, (c) Day-2 and (d) Day-3 forecast valid on 23rd May, 2013.

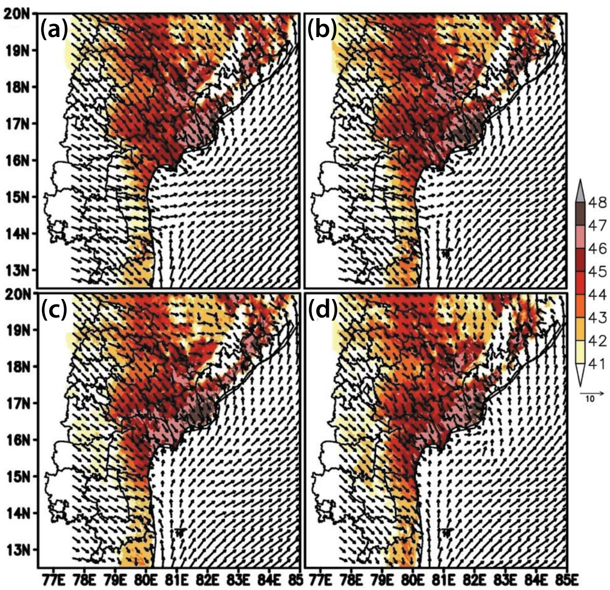

Fig. 7. Maximum temperature (°C) along with surface winds overlayed for (a) Observation, (b) Day-1, (c) Day-2 and (d) Day-3 forecast valid on 24th May, 2013.

from 22nd to 24th May, 2013, as given in Table 3b.

The time series of observed temperatures at the six AWS stations (Ganavaram, Nellore, Ongole, Bapatla, Kakinada, and Hyderabad) and the corresponding WRF model day-1 (24 hr), day-2 (48 hr), and day-3 (72 hr)

Table 3. Statistical metrics of the evaluation of model predictions temperatures over Andhra Pradesh and Telangana during 22–24 May, 2013.

a) Andhra Pradesh and Telangana domain region					
	MAE	RMSE	CC	BIAS	IOA
Day 1	0.49°C	0.80°C	0.95	−0.11°C	0.97
Day 2	0.47°C	1.27°C	0.90	−0.20°C	0.93
Day 3	0.59°C	1.44°C	0.85	−0.18°C	0.90
b) Mean statistics from station observations					
Day 1	0.52°C	1.46°C	0.95	0.09°C	0.97
Day 2	0.44°C	1.94°C	0.90	0.16°C	0.94
Day 3	0.52°C	2.24°C	0.85	−0.02°C	0.92

temperature forecasts at 3-hour interval for the period from 00 UTC of 22 May to 21 UTC of 24 May, 2013 are depicted in Fig. 8. It is clear from Fig. 8 that WRF model forecasted the temperature with 24 hours (day-1), 48 hours (day-2), and 72 hours (day-3) lead times at all these six AWS stations. The model forecasts show the pattern very well agreeing with the observations, but day-3 slighlty underestimes the temperature (Fig. 8). This displays an excellent correlation of about 0.95 for day-1, with very less bias, although RMSE is slightly higher for day-3, i.e. 2.24°C. It gives clear evidence that temperatures can be predicted with a lead time of up to 72 hours, and the WRF model forecasted the heatwave events with greater accuracy. The main reason for the rise of Maximum Temperature over coastal AP is the absence or deflection of sea breeze during day time over south eastern coastal regions, resulting in the accumulation of heat over the regions of AP and Telangana (Dodla *et al.*, 2017).

3.4 Dynamics Associated with a Heatwave

To know the dynamics associated with heatwaves, horizontal wind fields, and relative humidity are plotted for an area-averaged domain between 17 to 17.5°N latitude and 80 to 80.5°E longitude where heatwave event is maximum, as is clear from both the ECMWF and the NCMWF data sets (Fig. 9). The wind fields show that north-westerly flow and westerlies strengthen from surface to 700 hPa pressure level during the heatwave event of 22nd–24th May, 2013. And, low humidity is observed for the heatwave event up to 750 hPa, and advection of heat is seen at the lower levels showing heat accumulation. The time-height section of the vertical velocity (*10 Pa/sec) and

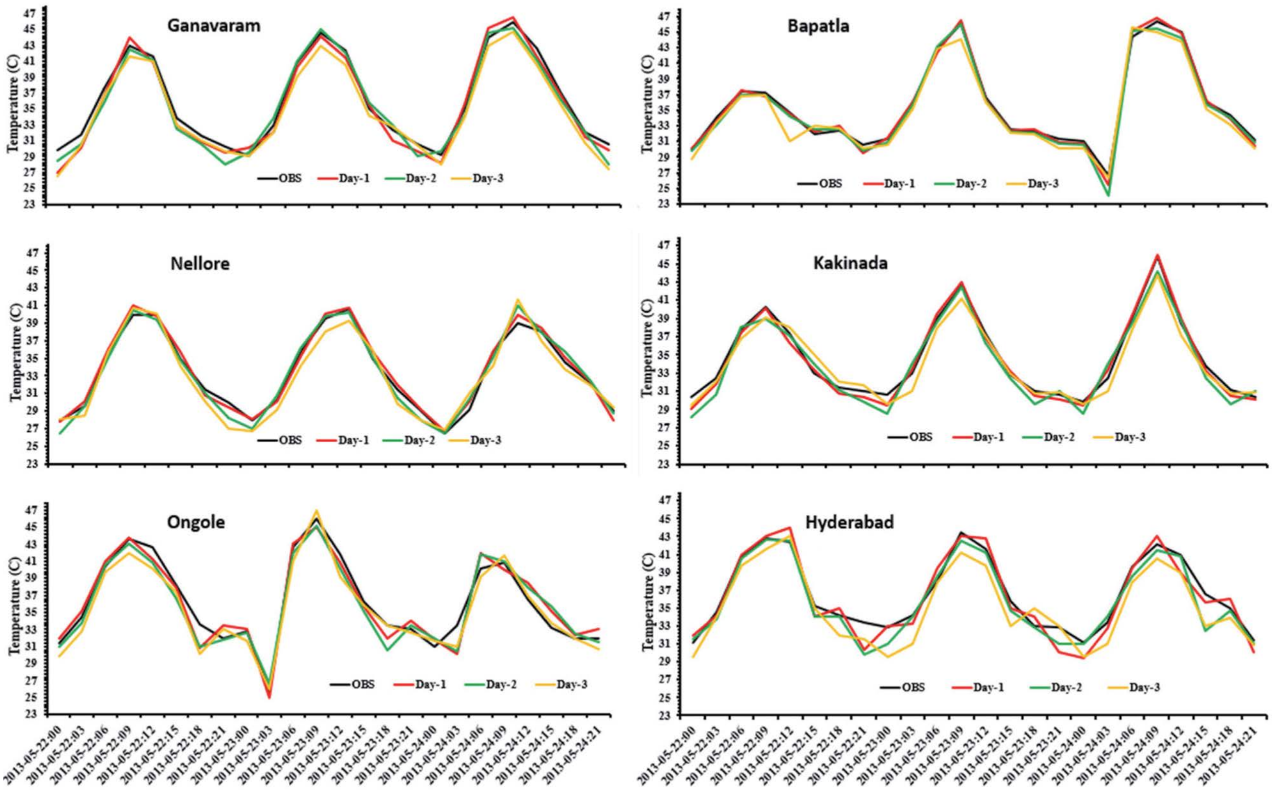

Fig. 8. The time series of temperature (°C) at 3-hour interval from the AWS stations, and corresponding WRF model Day-1, Day-2 and Day-3 forecasts during the period from 00 UTC of 22 May to 21 UTC of 24 May, 2013.

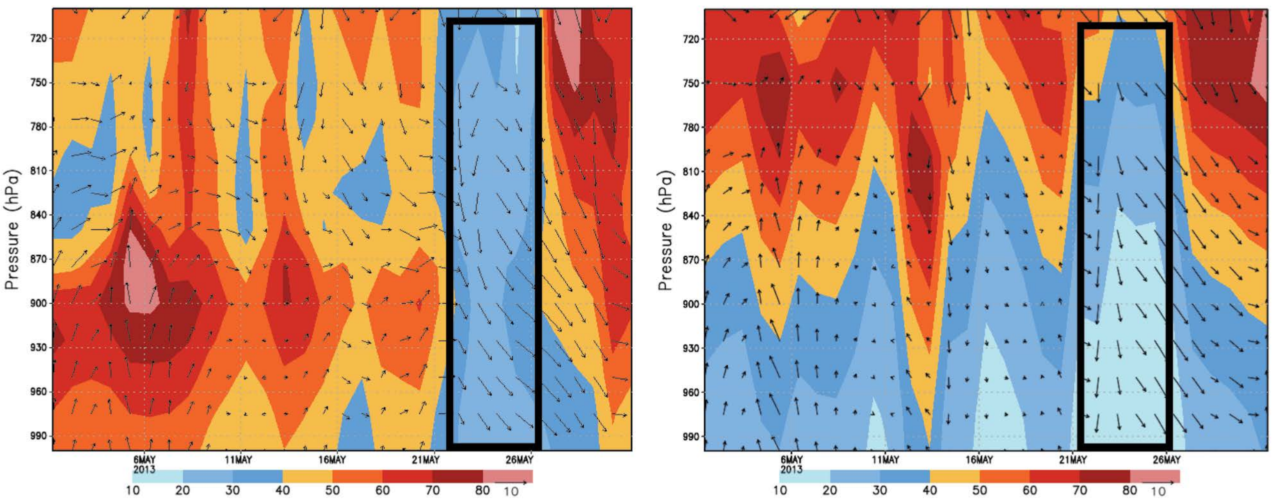

Fig. 9. Time-height sections of a relative humidity (%, shaded) and horizontal wind (m/s, vectors) representing for a region (17.0–17.5°N, 80.0–80.5°E) from May 1–31, 2013 by using ECMWF daily data (left panel), and NCMWRF daily data (right panel).

wind speed (m/sec) are also plotted to know the dynamics associated with this heatwave for the domain mentioned above (from surface to 700 hPa). During the heatwave event, the vertical velocity is −0.5 from 850 hPa to 700 hPa, showing the rising motion leading to heatwaves (Fig. 10).

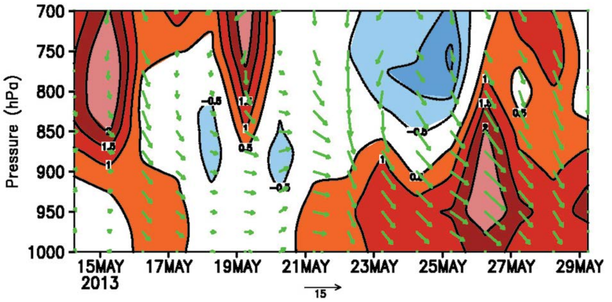

Fig. 10. Time-height sections of a vertical velocity (*10 Pa/sec, shaded) and wind speed (m/s, contours) representing the region of 17.0 to 17.5°N, 80.0 to 80.5°E from May 1 to 31, 2013 by using ECMWF daily Data.

4. CONCLUSIONS

A detailed analysis of the heatwave over AP and Telangana during 21–24 May, 2013 is carried out in this present study. This heatwave could be predicted with a lead time of 24, 48, and 72 hours using WRF with a resolution of 3 km. The features of the present heatwave are studied. Maximum temperatures of 43°C to 45°C are observed over Telangana and 40°C to 44°C over AP region during the starting day of the heatwave.

These results indicate that the model is accurate in predicting the heatwave. However, in calculating the statistical metrics, the model showed minor errors in predicting the surface temperature (2 m) as root-mean-square error and mean absolute error are smaller values, and with higher values for the index of agreement and correlation coefficient values. Heatwaves are one of the major calamities which claim human lives, and predicting these heatwaves with a good lead time will be very useful for managing their impact on humans. The model results were used further to realize the thermodynamical reasons for the heatwave. Analysis of temperature advection has brought out an interesting and important dynamic reason for the coastal region vulnerability for warm air advection. The coastal regions are cooler than inland stations because of the vicinity to the sea and sea breeze effect during daytime. Still, the same sea breeze effect has contributed to the observed heatwave over the coastal AP region during the latter fortnight of May, 2013.

ACKNOWLEDGEMENT

The authors acknowledge free access to GFS data from National Centers for Environmental Prediction (NCEP); National Center for Atmospheric Research NCAR; ERA data from the European Centre for Medium-Range Weather Forecasts (ECMWF), U.K.; AWS data from MOSDAC, Government of India, NCMRWF for providing IMDAA data. This research is supported It supports this research by Early Career Research Award, Science and Engineering Research Board, Government of India through financial support under grant No. ECR/2016/001295.

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