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Monitoring of high temperature weather episodes with Satellite data over the Indian region

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सार – **इन्सैट**-3**डी**/3**आर भू**-**उपग्रह क्रमशः** 74 °E **और** 82 °E **स्थितियों पर कक्षा में हैं और** 6 **चैनल इमेजर डेटा के माध्यम से उच्च स्थानिक क्षेत्र में निरंतर कवरेज प्रदान करते हुए** 15 **मिनट की अस्थायी आवृत्ति के स्टैगरिंग प्रणाली में काम कर रहे हैं। उपग्रह से प्राप्त भूभौतिकीय प्रचाल जैसे आउटगोइंग लॉन्ग वेव रेडिएशन**(OLR), **भूमि सतह तापमान** (LST) **और ऊपरी क्षोभमंडलीय आर्द्रता आदि मार्च**-2022 **के मध्य से शुरू होने वाले लगभग पूरे देश जैसे पंजाब, हरियाणा, राजस्थान, उत्तर प्रदेश** (**यूपी**), **बिहार, मध्य प्रदेश** (**एमपी**), **महाराष्ट्र, आंध्र प्रदेश** (**एपी**), **तेलंगाना, तमिलनाडु उड़ीसा आदि को प्रभावित करने वाले उच्च तापमान के मौसम की निगरानी में बहुत उपयोगी पाए गए हैं। उक्त क्षेत्रों में वास्तविक तापमान मार्च के मध्य से अप्रैल**-2022 **के मध्य तक सामान्य** (~ 4 **से** 7 **डिग्री सेल्सियस**) **से अधिक बना रहता है और देश के अधिकांश भागों में लू की स्थिति उत्पन्न हो जाती है। इस लू की स्थिति न केवल सतह की विशेषताओं से संबंधित है, बल्कि ऊपरी हवा के प्रतिचक्रवाती परिसंचरण और प्रभावित क्षेत्रों में शुष्क हवा के अभिगम से भी संबंधित है। यह शुष्क वायु द्रव्यमान** (**उत्तरी**) **लगभग पूरे उत्तर**-**पश्चिम, मध्य और दक्षिण के कुछ हिस्सों** (**महाराष्ट्र, आंध्रप्रदेश और तेलंगाना**) **के साथ निचले से मध्य क्षोभमंडल तक चलने वाला संपूर्ण प्रतिक्रिया चक्र और क्षेत्रों को गर्म और सामान्य तापमान को सीमा से ऊपर रखता है। पूर्व की ओर बढ़ने वाली प्रणालियाँ भी निचले उत्तरी अक्षांशों तक नहीं पहुँचती और दूर होती हैं और नमी भरी हवाओं को दूर रखती हैं।**

इस शोधपत्र ने ऐसे उच्च तापमान प्रकरणों की निगरानी में इन्सैट-3**डी**/3**आर उपग्रह से व्युत्पन्न उत्पादों की भूमिका को उजागर किया। मौसम की प्रचलित मौसम प्रणालियों की जलवायु संबंधी विशेषताओं के समर्थन के साथ मिश्रित इस प्रकार की मौसमी परिघटनाओं का उपयोग पूर्वानुमान और क्षेत्र पर इसकी अवस्थिति में किया जा सकता है। अध्ययन से यह देखा गया है कि ओएलआर घाटी की प्रभाव सीमा** 330-380 **वाट**/**मी**^{2} **ऊष्ण तापमान या लू चलने वाली स्थितियां होती है। इसी तरह, भूमि की सतह का तापमान और** UTH **का मान क्रमशः** 306-325 ° K **और** 05-25% **होता है। मार्च के मध्य से अप्रैल**-2022 **के मध्य तक** IPWV **का मान भी** 2-12 **मिमी के बीच भिन्न**-**भिन्न होता है।**

इस तरह के उच्च प्रभाव वाली मौसमी परिघटनाओं से अग्रिम में राज्य / जिला स्तर पर समाज और आपदा प्रबंधन अधिकारियों की मदद करने के लिए उपग्रह और जलवायु संबंधी जानकारी को ग्राम स्तर तक एक साथ जोड़ा जा सकता है। यह अध्ययन सीमित डेटा सेट के साथ किया गया है और भविष्य में, इसे विस्तार क्षेत्र में किया जायेगा और पिछला इन्सैट डेटा (**दैनिक, मासिक, ऋतुनिष्ट**) **दीर्घ अवधि औसत** (**एलपीए**) **के लिए उपयुक्त होगा, इससे लगभग पूरे भारतीय क्षेत्र के लिए क्षेत्रवार प्रभाव सीमा निर्धारित की जा सकेगी ।**

ABSTRACT. INSAT-3D/3R Geosatellites are in orbit at 74° E and 82° E positions respectively and operating in staggering mode of 15 minute temporal frequency providing continuous coverage in high spatial domain through 6 channel Imager data. Satellite derived geophysical parameters like Outgoing Long wave Radiation (OLR), L and Surface Temperature (LST) and Upper Tropospheric Humidity etc are found to very useful in monitoring the high temperature weather episodes affecting almost entire country like Punjab, Haryana, Rajasthan, Uttar Pradesh (UP), Bihar, Madhya Pradesh (MP), Maharashtra, Andhra Pradesh (AP), Telengana, Tamilnadu Orissa etc starting from mid of March-2022. The actual temperatures in the above said areas persisting above normal (~ 4 to 7 °C) from Mid March to Mid April-2022 and caused heat wave conditions in most of the places of the country. The persistency of the prevailing heat wave conditions is not only related to surface features but also upper air anticyclonic circulations and sinking of dry air over the affected areas. The entire feedback cycle from lower to middle troposphere operating with dry air mass (Northerly) almost entire Northwest , Central and parts of South (Maharashtra, AP and Telangana) and keep the areas warm and above normal temperature range. The eastward moving systems also not reaching to lower northern latitudes and moving away and keeping away moisture laden winds.

This paper brought out the role of INSAT-3D/3R satellite derived products in monitoring such high temperature episodes. Such type of weather events blended with the support of climatological features of prevailing weather systems of the season can be utilized in forecasting and its persistence over the area. It is seen from the study that, the OLR vales threshold ranges from 330 -380 watt/m^2 in pockets of warmer temperatures or suffering from heat wave conditions. Similarly, the Land surface temperature and UTH values 306 -325 °K & 05-25 % respectively. The IPWV values in mm are also varies from 2-12 mm during mid-March to mid-April-2022.

The satellite and climatological information can be clubbed together up to village level to help the society and disaster management authorities at state /district level in advance of such high impact weather events. This study is done with limited data sets and in future, it will be carried out for larger domain and a suitable the long period average (LPA) of past INSAT data (daily, monthly, seasonal), so that area wise thresholds can be generated from almost for entire Indian domain.

Key words – Outgoing Long wave Radiation (OLR), Land Surface Temperature (LST), INSAT-3D/3R and Heat wave.

1. Introduction

Outgoing Long wave Radiation (OLR) from narrow band radiance to broad band radiances with trained data sets of Genetic algorithm (GA) was developed by Space Applicatioon Centre (SAC), Indian Space Research Organisation (ISRO) with the help of collocated radiances of INSAT-3D and FY-2D.

In the past, developments from both Geostationary and polar satellite was in progess. OLR estimation from Polar orbiting satellite data done by many scientist and researchers in the past like Cross-Track Infrared Sounder (CrIS) hyperspectral infrared sounder radiance measurements (Zhang *et al*., 2017) and widely used as a proxy of convection to understand and diagnose better the tropical convection, precipitation and variability intraseasonal to interannual and monsoon (Chelliah and Arkin 1992; Chiodi and Harrison 2010; Xie and Arkin 1996). Earth Radiation Budget Experiment (ERBE) was designed to produce monthly averages of longwave and shortwave at regional to global scales through Clouds and the Earth's Radiant Energy System (CERES) (Wielicki *et al*., 1996) and later extensive efforts were performed for the High Resolution Infrared Radiation Sounder (HIRS) multispectral OLR estimation technique against broadband observations derived from ERBE and CERES (Ellingson *et al*., 1994; Lee *et al*., 2007). Suomi National Polar-orbiting Partnership (SNPP) utilized improved CERES next generation angular directional model (Loeb *et al*., 2005, 2007) and trends of OLR have been utilized to study climate feedback and mechanisms involved Chu and Wang 1997; Susskind *et al*., 2012). Atmospheric Infrared Sounder (AIRS) algorithm is derived with collocation of CERES observations and psedo channel radiances from AIRS observations and a single IR window channel radiance (10–12 μm) from the Advanced Very High Resolution (AVHRR) was used to estimate the OLR. After the inclusion of water vapour radiance measurement in satelite data remote sensing the algorithms of satellite derived products were modified by the scientists and researchers, Cheruy *et al*. (1991) uses window and water vapour channels observations from Meteosat 2 to calculate OLR from the geostationary satellites. Minnis *et al*. (1991) utilizes imager window and water vapour information for estimating OLR from Geostationary Operational Environmental Satellite (GOES) satellite. Ba *et al*. (2003) validated GOES sounder channels derived OLR with CERES OLR collocated points.

Land Surface Temperature (LST) play an important role in examining the episodes of heat wave which mainly occur March to May every year in Indian domain. INSAT-3D derived LST helps to understand better demarcating the hot spot and vulnerable areas.

A Single Channel (SC) algorithm for retrieving LST from the thermal channel (10.5-12.5 µm) of Kalpana-1 (K1) VHRR sensor was developed over India using a radiative transfer model (Pandya *et al*., 2010, 2011a, 2011b, Pandya *et al*., 2013). In order to exploit the presence of two TIR channels in the INSAT-3D Imager sensor for better estimation of LST, a study has been taken up to develop a method to retrieve LST through a split window (SW) algorithm. Upper Tropospheric Humidity (UTH) is a representative of and it is basically a measure of weighted mean of relative humidity according to the weighting function of the water vapour channel between approximately 600 hPa and 300 hPa. IMD operationally uses the algorithm developed by ISRO based on the work of Schmetz and Turpeinen, 1988; Soden and Bretherton, 1993 for retrieving UTH from water vapour channel measurements. The expected accuracy of the LST as per the INSAT, ATBD of ISRO is 1.5 to 5 K. This parameter is different from air temperature as there is exchange of turbulent heat fluxes through surface air interface. This in turn maintain a balance between surface energy and water balance locally and therefore it varies both temporal and spatial scale as surface equilibrium state also differs with time place.

Present study focus on the customization of INSAT-3D/3R derived products to study the warming or heat wave scenario persisting in India from 9th March 2022 to 3rd Week of Apri-2022, except one or two showers at some places of northeast and southern parts of India. Current heat wave episodes were analysed with the help of OLR, LST and UTH derived daily operationally at IMD. The paper is subsequently divided into different subsections like, data and methodology, results and discussion, concluding remarks and references cited in the work. This study is useful in highlighting the vulnerable areas which were undergone heat wave conditions or likely to be persists in future. Predictability of this customization will depends on the knowledge of the past behaviour of the weather systems, their climatology over the region, speed of movement, global circulation pattern (usual or unusual) experience and of course current monitoring with these satellite derived products. Therefore, this study will really help to the forecasters and end users living at difficult terrain and having sparse ground observation network. Work is in progress to develop suitable threshold for entire Indian domain based on the thresholds with more number of cases. Later on, this will be an important inputs to the disaster managers and heat action plan scheme of government of India running since 2013.

2. Data and methodology

In this work INSAT-3D satellite derived products (Outgoing long wave radiation, Land surface temperature and Upper tropospheric humidity), surface data (temperature), Global Navigation Satellite System (IPWV, temperature, humidity) and rainfall (daily rainfall monitoring network) has been taken from India Meteorological Department, Lodi Road New Delhi. Finally an attempt has been made to decide the optimum thresholds of satellite data during high temperature episodes affecting over Indian domain.

3. Results and discussions

India Meteorological Department (IMD) amd Space Application Centre (SAC), Indian Space Research Organisation (ISRO) both are working in tendom to help and support society by providing weather and climate related information in time. SAC, ISRO has developed the algorithms for all INSAT-3D/3R satellite derived products which are available to the public in real time mode. IMD and even other stake holders utilizing them for weather forecasting, research and disaster managers for their decision making and other stakeholders in many ways. Even during emergency we all utilized the satellite based services of our country as a part of search and rescue operations. The feedback from user agency like IMD and other associated similar agencies of India and abroad is very important to improve further these algorithms (best as per the available channels and payloads). Internationally, in view of the global contribution to the Global Observing Systems (GOS) of World Meteorological Organisation (WMO), ISRO included as a member of Coordination Group on Meteorological Satellites (CGMS) on May 21, 2015 as a 16th Member of CGMS and IMD serves as second member of CGMS since 1979. Therefore, operational weather monitoring and forecasting along with climate monitoring is supported, reviewed globally through CGMS as per the requirement formulated by WMO. These programmes and activities are jointly supported / monitored by WMO and other international agencies. CGMS coordinates and support satellite systems of its members in an end-to-end perspective, including protection of in-orbit assets and support to users as required facilitating and developing shared access to and using of satellite data and products in various applications. The scenario of impact of weather is different at different locations, states, districts, plain area, coastal area, desert area or orographic area and in this change the customization of satellite derived products / images is very essential based on their needs, requirements and future expectations. Therefore, SAC, ISRO has developed a web based (advanced version will also be released soon) data explores tool known as Real Time Analysis of Products and Information Dissemination (RAPID) hosted in IMD website and also available for common man. This software acts as a gateway to Indian Weather Satellite Data providing quick interactive visualization and 4-Dimensional analysis capabilities to various users, students, scientists, forecasters and other stakeholders.

This attempt made in this paper basically a way of utilization of satellite based products in other domains of societal application. Although the satellite derived products utilized in this paper are not directly related to heat wave and they are providing the information related to convection/moisture (OLR, UTH, LST etc). These products can further be utilized to monitor the conditions of prevailing heat waves and can acts as an additional supplement to the forecasters and various other end users. We are all aware that weather activities are modulated by its various components like temperature, humidity, rainfall, winds and weather systems pressure flow patterns (like cyclonic or anti-cyclonic circulation, low, middle and upper troposphere associations etc). This global circulation pattern might be responsible for local or regional weather variations. Even countries like Spain,

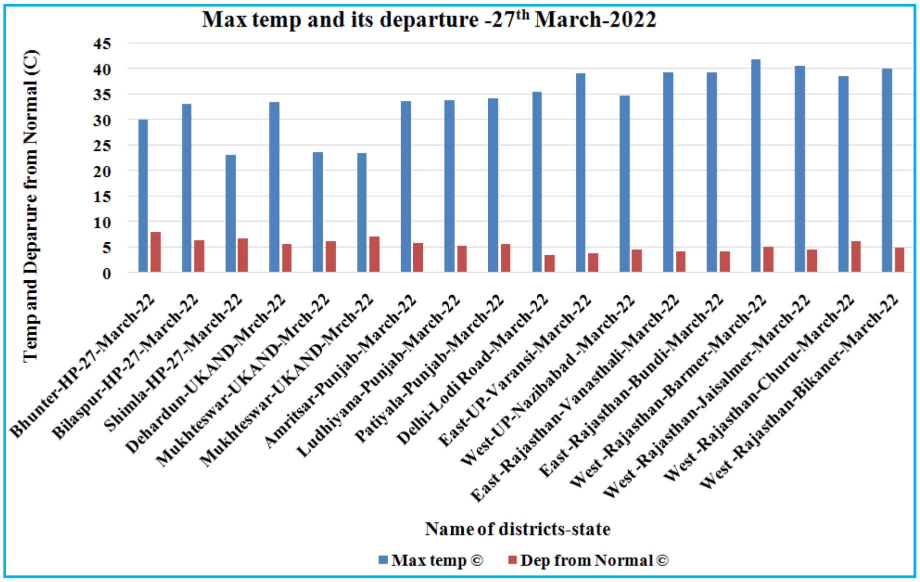


Fig. 1. Actual observed temperature and its departure from Normal (Degree C) on 27th March, 2022 (*Source* : IMD)

Portugal, Western Russia, Kazakhstan, Pakistan and Afghanistan etc. also show abnormal rise of temperature (~ 10 °C more) due to persisting La-Nina conditions. Temperature in almost all parts of the world will likely to rise in March and April despite the cooling influence of the La Nina weather phenomenon said by WMO latest forecasts generated from WMO global producing centres of long range forecasts indicate a moderate likelihood (65 %) that La-Nina event will continue in February and April-2022 (WMO, 2021). Prolonged warmer condition from extreme north can lead to melting of snow can generate lack of fresh water problems and central, west, and peninsular part of India can face drought like conditions. This will again affect the agriculture production and may lead to forest fires which in turn increase the cost of essential commodities. Conventional observations provide and important clue for local and regional weather activities but they are limited and even cannot fill all the data gaps. Therefore, we are dependent on remote sensing platforms like satellite and radar etc. based information and again it depends on the how dense and robust quality controlled data networks (ground as well as upper air) we have. This year (year 2022) pre-monsoon season (March to May) beginning was observed unusual, in the sense that high air temperatures (March to April end) almost all parts of the country, very little or NIL rainfall throughout Indian Domain, very limited thunderstorm or dust storms activities, Very few WDs affecting at lower latitudes of country and made the life more challenging. This type of situations need Government to formulate new strategies, planning and budget allocations accordingly. Therefore, even small information is very important to aware the public in

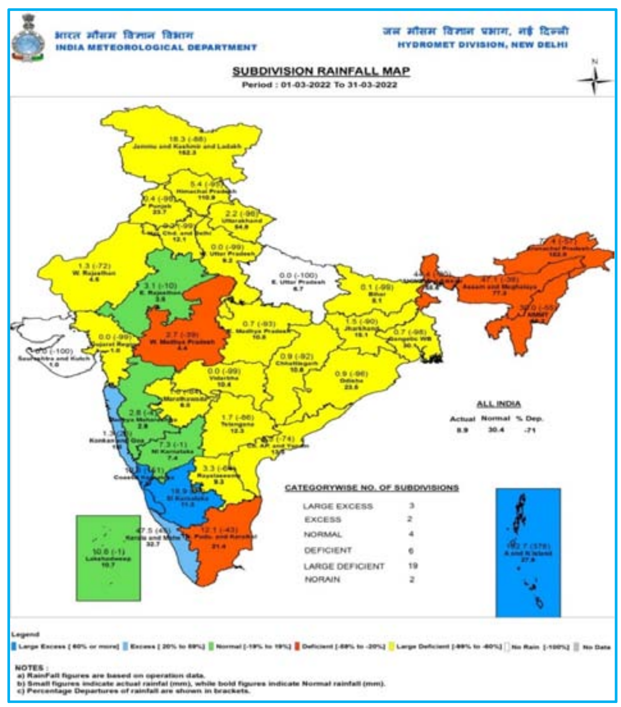
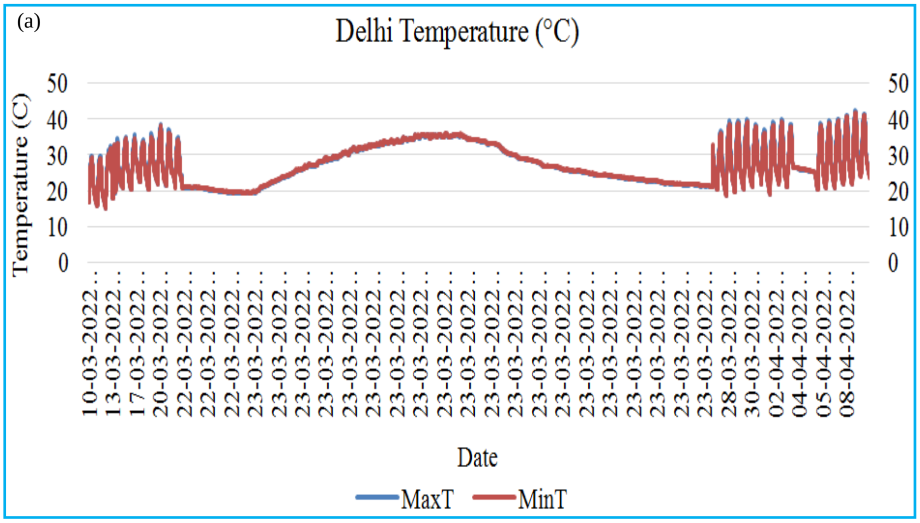
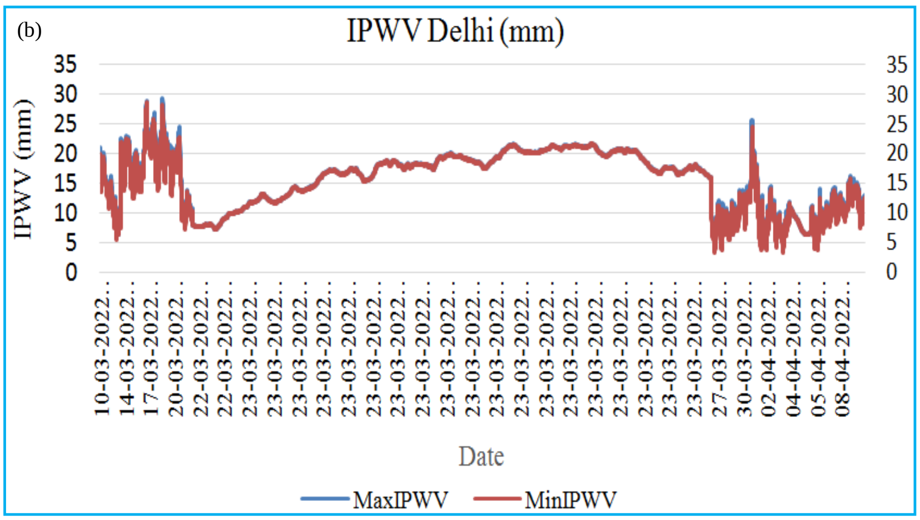
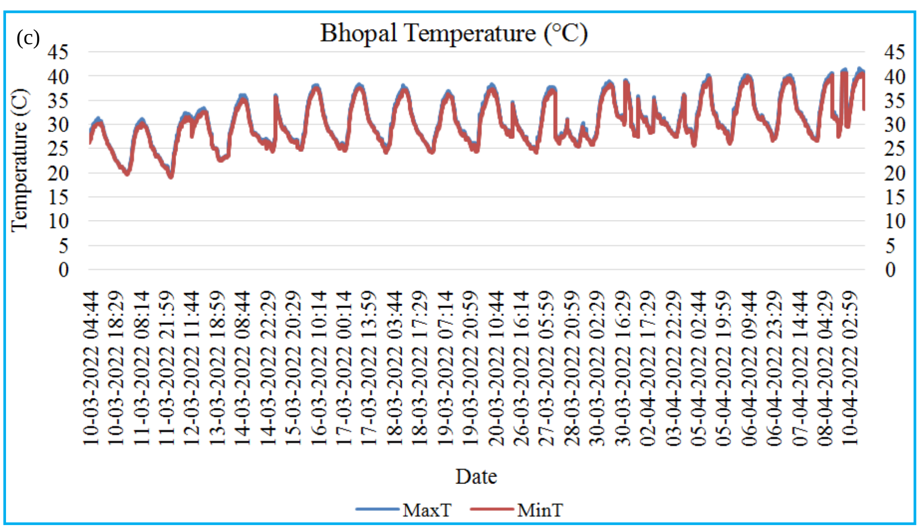


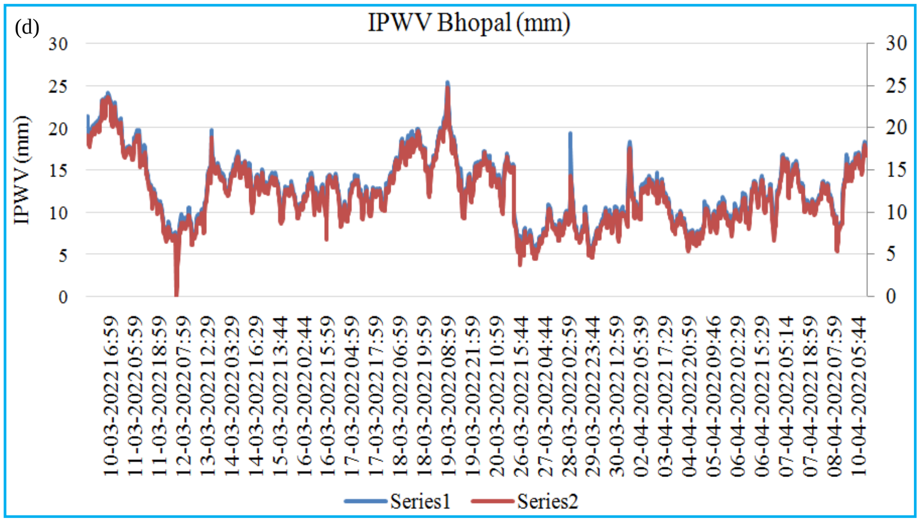
Fig. 2. Actual observed rainfall for the Month of March-2022 (*Source* : IMD)

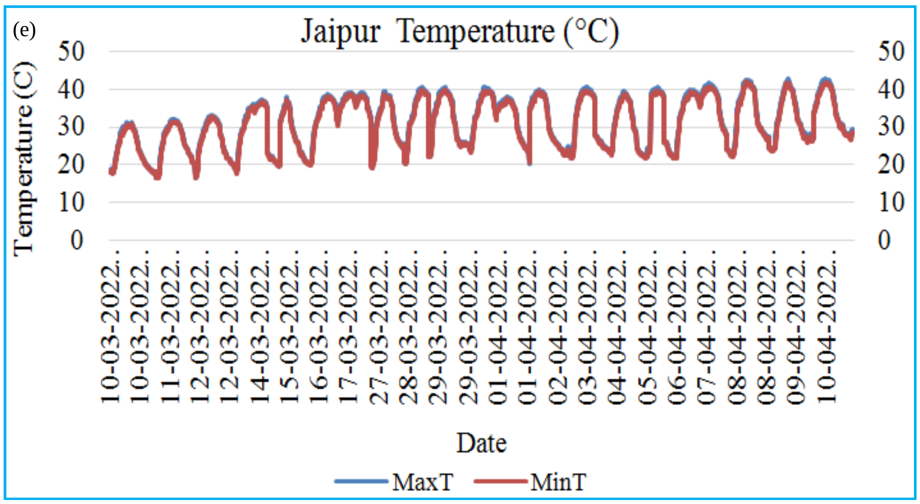
advance, for example, heat wave in this paper to take preventive measures in time. This attempt has done with limited data sets and will be done in future with large data sets. We are working to collect all such recorded heat waves in the last decades and generate the vulnerability pockets throughout the Indian domain so that suitable

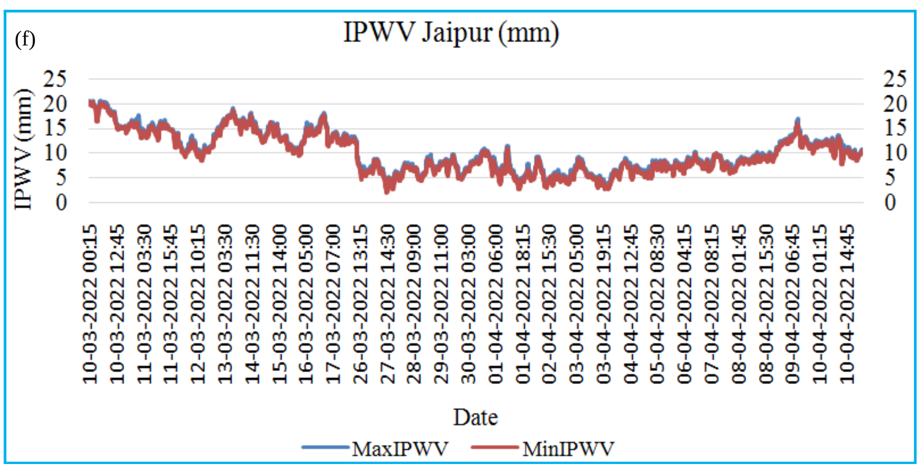

(a)
Delhi Temperature (°C)
Temperature (C)
Date
MaxT
MinT


(b)
IPWV Delhi (mm)
IPWV (mm)
Date
MaxIPWV
MinIPWV


(c)
Bhopal Temperature (°C)
Temperature (C)
Date
MaxT
MinT







Figs. 3(a-f). (a) Daily temperature (Max/Min in °C) Values of Delhi. On 10th March to 10th April -2022 the difference is nearly uniform due to the presence of partial cloudiness, (b) Daily IPWV (Max/Min in mm) Values of Delhi. transition of decrease in IPWV values during hot summer days), (c) Daily temperature (Max/Min in °C) Values of Bhopal, (d) Daily IPWV (Max/Min in mm) Values of Bhopal, (e) Daily Temperature (Max/Min in °C) Values of Jaipur and (f) Daily IPWV (Max /Min in mm) Values of Jaipur (*Source* : GNSS Network IMD) thresholds (OLR, UTH, IST etc) can be made for generated pockets of vulnerability with the support of IMD and ISRO. Change of temperature extremes is of global concern of public health (Buscail *et al*., 2012), agriculture production (Teixeira *et al*., 2013), loss of lives, damages to economy and degradation of people's livelihood (Kim *et al*., 2017). De *et al*., 2005 presents brief review of the extreme weather events that occurred in India during the last 100 years (1991-2004).

3.1. *Inputs from observational surface data of IMD*

Day to day surface data (temperature, pressure, humidity, wind and rainfall) from IMD permanent and part time observatories received at IMD forecasting divisions and processed / analysed to see the current weather condition of the area. Then based on the IMD heat wave criteria (based on the departures of maximum temperature of the station) data processed (Fig. 1) and forecasting information is available for users after due discussion and value additions. The data analysis shows that after 09th of March-2022 almost most of the (northwest, central, northeast, peninsular and south) parts of India the maximum temperature is above the normal (4 to 8 °C). So, in this attempt authors used INSAT-3D /3R satellite operational derived products data (OLR, UTH, LST etc) to monitor the prevailing heat wave conditions throughout the country. This work is important to generate the forecasting potential of the available satellite derived products. Thresholds for alerts based on the composite/customized satellite daily products can be generated after performing the same analysis with larger data sets & its realization with actual occurrences. But this sample study is attempted first time to explore further utilization of available INSAT derived products in examining/monitoring of such heat wave conditions.

3.2. *Inputs daily rainfall monitoring system (DRMS) of IMD*

Rainfall and its measurements are important throughout the year. Almost 75% of the total rainfall occurred during monsoon (June to September) but in other months of the year its distribution and daily measurement is essential to reshape the ongoing and forthcoming activities and recharge the water table along with agriculture activities. Fig. 2, shows the distribution of rainfall for the month of March-2022 and it shows that almost entire Indian domain was facing dry conditions (18 subdivisions large deficient, 6 deficient, 4 normal rainfall). This type of scenario acts as a catalyst for persisting heat wave conditions as the winds approaching from south to north transporting hot air and heat wave conditions prevailing throughout the month. This may be attributed to the absence or few number of western disturbances (WDs) at lower Indian latitudes.

3.3. *Inputs from GNSS Network of IMD*

India Meteorological Department have a network of 25 Global Navigation Satellite System (GNSS) stations for measuring the Integrated Precipitable Water Vapour (IPWV)in mm from ground based receivers retrieved from total delay in zenith direction (Beavis *et al*., 1992 & Duan *et al*., 1996). Each GNSS station is equipped with meteorological sensors for measuring station level, temperature, pressure and humidity at very high sampling rate (10 minute) and then this data is utilised for generating IPWV values in mm operationally by the customized software integrated by Trimble Private Limited. Figs. 3(a-f) are daily generated maps of temperature and IPWV for Delhi, Bhopal and Jaipur stations for operational basis. A sharp transition of temperature and IPWV values for the months of March 2022 (09th March-2022 onward) was seen for these stations. The maximum temperature values for Delhi, Bhopal and Jaipur were found in the range of 34-40 °C with sharp decline of IPWV values in the range of 10-14 mm respectively. These transitions shows warmer temperature than normal over the area and having very less amount of water vapour in the atmosphere. Fig. 1 of actual surface observations on 27th March shows the departure 4-8 °C above the normal in most of the parts of Punjab, East UP, West UP, East Rajasthan and West Rajasthan including Delhi after 10th March-2022 onward. We have shown only one figure of observational data and their temperature departure for brevity. This peculiar behaviour is captured well by GNSS meteorological sensor and derived product data. By examining more number of such cases in future a threshold of temperature & IPWV can be generated and based on the threshold a vulnerability contour maps can be generated over the stations. This will further help in forecasting and in future these thresholds can be further returned based on the ground conditions. Therefore, this preliminary study is an initiation to utilize the present available resources in a better way for forecasting for new emerging scenarios.

3.4. *Outgoing Long wave Radiation (OLR)*

During 25th to 30th March-2022, episode the OLR values in watt/m^2 ranges from (341-370), (351-364), (329-347), (337-360), (334-359), (330-363), (344-362) and (341-364) for West Rajasthan, East Rajasthan, Delhi, Haryana, East Uttar Pradesh, East Madhya Pradesh, West Madhya Pradesh, and Gujarat respectively (Table 1). Work based on the preliminary findings of this work with larger available OLR data sets along with recorded heat occurrences is in progress that will further help to forecasters in demarcating vulnerable areas and threshold of OLR values. The relationship between outgoing longwave radiation (OLR) and the surface

TABLE 1

Outgoing Long Wave Radiation (watt/m^2) and surface temperature (K) from INSAT -3D during the week (25^{th} - 30^{th} March, 2022)

Date OLR (watt/m^2)	West Raj		East Raj		Delhi	Haryana		East UP
25^{th}	356.85	340.67	351.30	350.11	329.31	337.34	346.00	334.80
26^{th}	358.28	364.31	358.43	360.35	337.79	347.04	356.61	349.61
27^{th}	370.20	355.97	360.84	360.24	345.03	359.91	360.49	356.29
28^{th}	365.21	361.45	365.03	364.24	346.97	356.72	359.24	359.32
29^{th}	365.55	359.02	364.78	364.25	343.70	356.73	356.85	358.08
30^{th}	364.42	351.60	361.89	358.19	341.40	349.72	354.42	354.87

Date OLR (watt/m^2)	East MP		West MP		Gujrat	
25^{th}	330.39	335.98	344.08	344.08	340.90	353.34
26^{th}	342.96	349.30	352.17	352.17	352.89	358.79
27^{th}	359.35	357.78	358.70	358.70	360.32	358.17
28^{th}	358.41	360.43	360.55	360.55	364.22	360.41
29^{th}	361.63	362.75	362.07	362.07	364.39	362.19
30^{th}	362.47	362.62	356.32	356.32	363.59	362.09

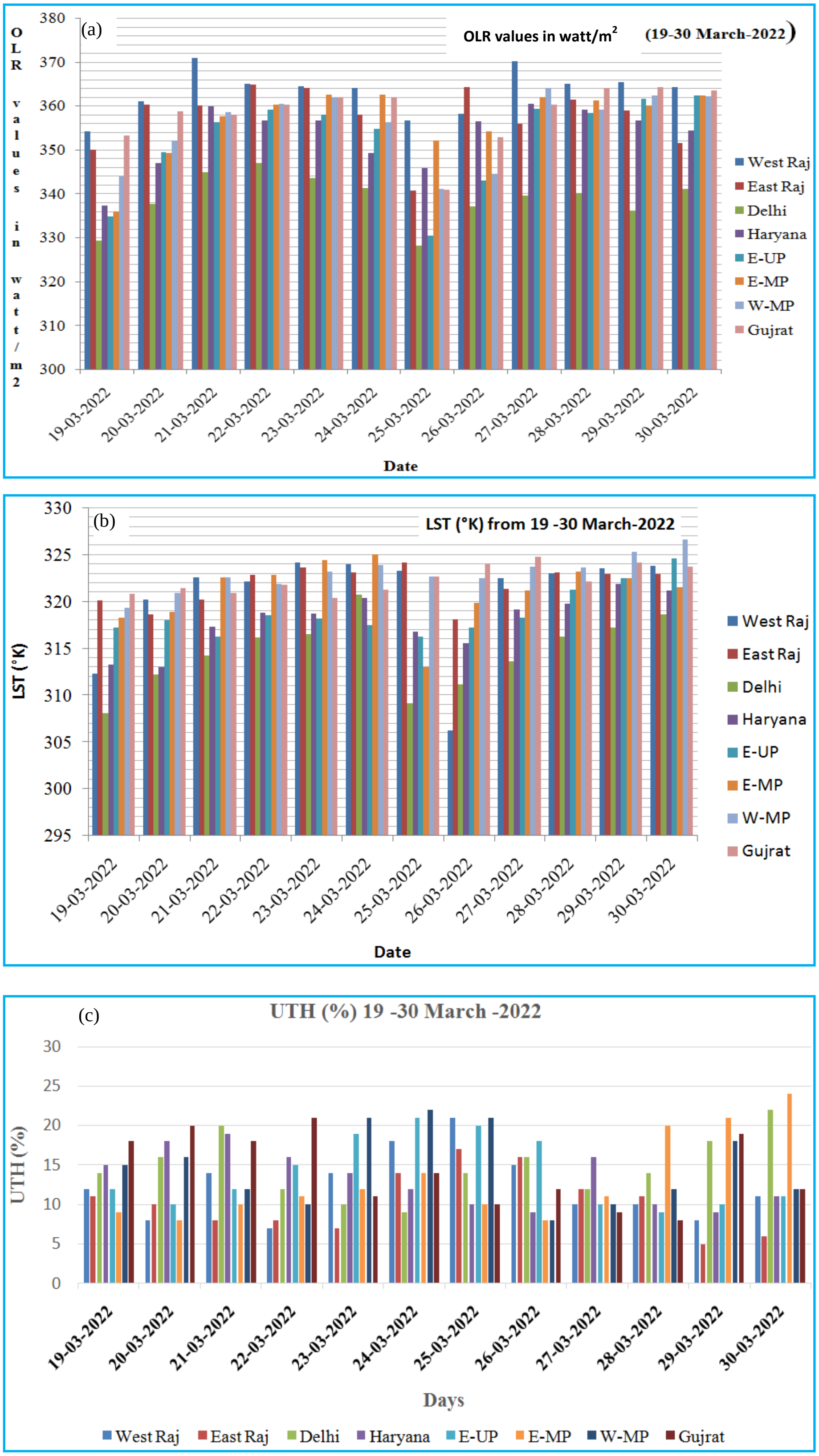
Date LST (°K)	West Raj		East Raj		Delhi	Haryana		East UP
25^{th}	312.28	-	-	-	308.08	313.25	316.78	-
26^{th}	320.15	306.22	318.58	318.07	312.16	312.94	315.56	317.99
27^{th}	322.57	322.48	320.17	321.30	314.19	317.28	319.13	316.27
28^{th}	322.12	322.96	322.79	323.08	316.12	318.80	319.71	318.47
29^{th}	324.08	323.49	323.64	322.92	316.50	318.72	321.87	318.19
30^{th}	323.96	323.80	323.07	322.87	320.72	320.32	321.11	317.48

Date LST (°K)	East MP		West MP		Gujrat	
25^{th}	-	312.94	-	-	-	-
26^{th}	318.85	319.81	320.84	322.50	321.44	323.99
27^{th}	322.51	321.13	322.58	323.65	320.90	324.70
28^{th}	322.77	323.13	321.86	323.62	321.77	322.11
29^{th}	324.37	322.48	323.18	325.22	320.35	324.12
30^{th}	325.04	321.53	323.83	326.54	321.20	323.66

temperature often assume that this relationship is approximately linear, but it is unclear whether the approximation always holds and it enters in "OLR loopiness", that is, how much clear-sky OLR varies between different seasons with the same surface temperature.

Therefore, during clear weather earth surface is warmer and more energy reached to the top of the atmosphere and hence satellite sensors and we get higher values of the OLR and hence surface temperature as discussed.

OLR is a proxy of convection and also widely used as a tool in a variety of other meteorological applications, like monsoon variability, indicator of cloudiness or precipitation etc. We know that radiance in the atmospheric window region is sensitive to thermal emission from the lowest radiation surface, *i.e.*, earth surface or cloud top (Ellingson and Ferraro, 1983). The



Figs. 4(a-c). (a) Daily OLR Values in watt/m^2, (b) Daily OLR Values in watt/m^2 and (c) UTH (%) (*Source* : Satellite division IMD)

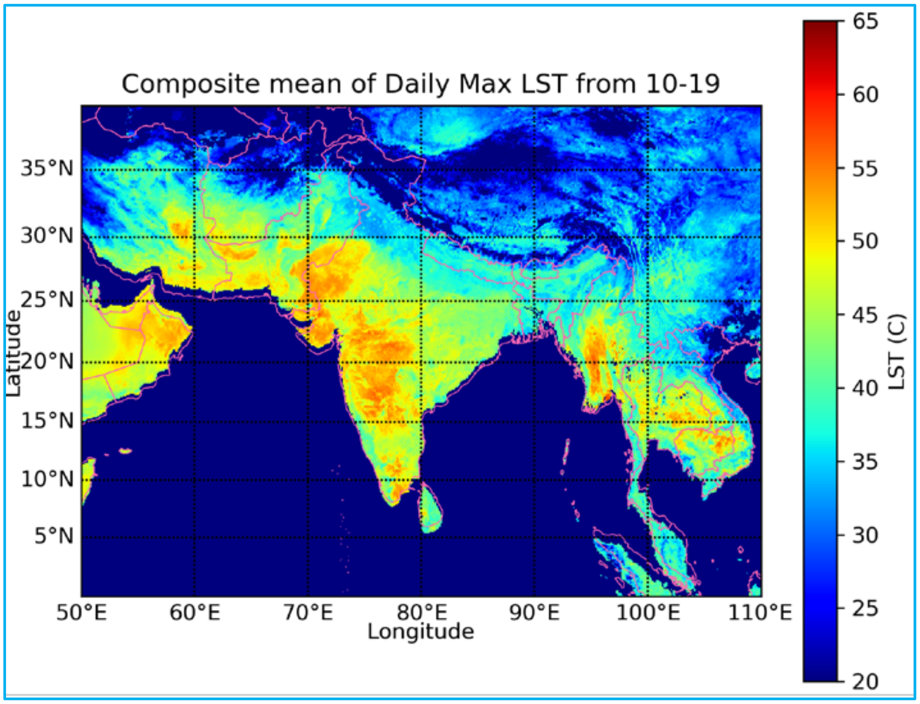


Fig. 5. Composite mean of heat wave episode during 10th to 19th March, 2022

atmospheric water vapor correcting is already mentioned by ATBD development team of ISRO and therefore in dry and clear night atmosphere, this product and be utilized to monitor the heat wave episodes. However, its relation with air temperature will be carried out over the Indian domain with larger data sets.

3.5. *Land Surface Temperature (LST)*

Table 1 represents warmer episodes from 25th to 30th March-2022 in which the LST values are given in °K which ranges from (306-324), (319-324), (313-322), (316-318), (313-322), (312-325), (320-327) and (321-325) for West Rajasthan, East Rajasthan, Delhi, Haryana, East Uttar Pradesh, East Madhya Pradesh, West Madhya Pradesh, and Gujarat respectively (Table 1). Similar trend of LST has been seen in another heat wave episode from 10th march to 19th March, 2022 (Fig. 5). To quantify the LST information in operational basis to the forecasters and end users long term mean of LST data (daily, monthly, seasonal) is in progress and then in the next phase we will process it for all past occurrences and will generate thresholds or contours maps of LST to delineate the vulnerable areas so that a timely alert can be issued after incorporating all necessary value additions.

LST not directly related to air temperature and the spatial scales of the effect of surface temperature on air temperature and the effect of vegetation density on air temperature were related to the mean lapse rate of the atmospheric boundary layer. Therefore, LST depends on location, land surface type, vegetation and elevation of the area. Air temperature was more sensitive to vegetation density when the mean lapse rate of the atmospheric boundary layer was smaller. Accuracy in the estimation of air temperature from satellite-derived surface temperature data can be further improved by multiple regression using the spatially averaged surface temperature and normalized difference vegetation index. The accuracy of the product is further dependent on the emissivity of the surface. However it has the potential to address the warmer temperature episodes during clear nights. Separate study will be carried out to know the biases and RMSE between air temperature and LST over Indian domain.

3.6. *Upper Tropospheric Humidity (UTH)*

The values from 25th to 30th March, 2022, derived from both INSAT-3D/3R are expressed in % ranges from (7-21), (7-16), (9-22), (9-19), (9-21), (10-22), (8-22) and (8-21) for West Rajasthan, East Rajasthan, Delhi, Haryana, East Uttar Pradesh, East Madhya Pradesh, West Madhya Pradesh, and Gujarat respectively [Fig. 4(a-c)]. To blend the UTH information of middle and upper troposphere from INSAT-3D Imager with other data sets like OLR and LST long period average (LPA) values of UTH as per the available satellite data information is required to see the day to day changes and can be made available to the forecasters. Work with old satellite data sets is in progress considering both the temporal and spatial characteristics of past satellite data. Finally a gridded data set will be very useful to delineate the less or more moisture areas and can help to understand better the moisture flow of the weather systems. High values of UTH generally associated convective activities but during the month's mid-March to Mid-April-2022, the UTH values exceed 30% almost all the northwest, central and southern peninsula or subsidence regions. This migration of moisture also not supported by the westward moving systems and therefore we have faced high temperature and dry conditions almost throughout Indian domain.

4. Concluding remarks

This paper is an attempt to blend or customize the available satellite (INSAT-3D/3R) derived products (OLR, LST and UTH) in monitoring the prevailing warmer or heat wave scenario. This will also led an additional supplement of the forecaster's end users to re tune their forecast. These findings will also be useful in identifying vulnerable areas which require heat preparedness plans so that necessary steps can be carried out by the Government. The OLR threshold ranges from 330 to 380 watt/m^2 represents the warmer temperatures zone or an area suffering from heat wave. Similarly, the Land surface temperature and UTH values comes under the ranges 306 to 325 K & 05 to 25 % respectively of the area affected by heat wave. Similarly, the IPWV values in mm are also varies from 2-12 mm during mid-March to mid-April-2022during the time of prevailing heat wave over the region. The outcome of the prevailing heart conditions may lead to scarcity of water as snow will met on high reaches areas and less frequencies of westward moving systems affected India can lead to dry/hot weather conditions throughout Indian domain.

Upper-level humidity helps to investigate the sources and sinks of moisture to particular regions and if this flow is not properly modulated by the mid and upper troposphere weather systems then this moisture will not be transported at lower latitudes and therefore dry conditions will prevails over the area. These conditions were present from mid-March to Mid-April-2022. Hence, to utilize optimally the customized use of UTH along with other satellite derived fields (OLR, LST) work is under progress to develop long-term climatological satellite data from past available INSAT data upper-level for UTH as well as winds so that quantitatively the upper-level water vapour variability and its transport information can be given to the end users.

Forecasters use multiple source inputs as a value addition to modify the model generated forecast. In that case the analysis based on the customization of the above said INSAT-3D/3R satellite products can provide an important input to decide severity and spread of such high temperature events. Therefore, this information could not have forecasting value in isolation but definitely blended with source of information it will improve the forecasting.

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