Extreme Hydrological events in January 2022: A Case study over Telangana and Andhra Pradesh state

Abstract: The study is to analyse the extreme rainfall events over Andhra Pradesh and Telangana states, where both monsoon and post monsoon seasons contribute significant rain. Winter season 2022 was highlighted with unusual rainfall in some districts of Andhra Pradesh and Telangana in 2nd week of January 2022, causing significant damage. In this paper to identify the observational aspects, main synoptic system, physical process and thermodynamic features leading to such unusual rainfall during winter season. Observations of the study indicates that Hail storm recorded over Telangana state on 13th. Heavy rainfall in Telangana on 13th due to most active western disturbance as a cyclonic circulation over Rajastan& Pakistan, Heavy to very heavy rainfall which is all time record reported on 14th January 2022 at Vizianagaram was due to confluence of winds from Arabian sea and Bay of Bengal at lower tropospheric levels over East and adjoining central India and a trough from North interior Karnataka to North Interior Odisha.

Keywords: Hail storm, Heavy rainfall, Trough, western disturbances.

1. INTRODUCTION :

Andhra Pradesh is situated on the east coast of Peninsular India. Coastal Andhra Pradesh state which is located 78^0-89^0E and 9^0-22^0N. According to the 2011 census, it has an area of 92,906 km^2 and a population of 34,193,868.This area includes the districts of Andhra Pradesh between the eastern Ghats and the Bay of Bengal. It includes districts of Srikakulam, Vizianagaram, Visakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam and Nellore. The state has the second longest coastline (972km) among all states in India. Coastal Andhra Pradesh has rich agricultural land, owing to the delta of the Godavari and Krishna rivers. The prosperity of coastal Andhra can be attributed to its rich agricultural land and an abundant water supply from these two rivers. Andhra Pradesh The fishing industry is also important to the region. Costal Andhra Pradesh is located to the east of Telangana and Rayalaseema regions share boarder with Odisha to the North and Tamilnadu to the west. It experiences heavy to very heavy Rainfall associated with the meteorological systems during pre-monsoon, southwest monsoon and post monsoon / NE monsoon season. Heavy rains occur over the region due to passage of westerly moving tropical disturbances and due to strong monsoon currents and short period heavy falls occurs with intense convective activities during premonsoon season. In the year 2022 January month recorded heavy rainfall in Vizianagaram District, Moderate to heavy in Visakhapatnamover all Andhra Pradesh recorded rainfall during January 11^{th} to 16^{th} (Fig.1). Monthly Normal rain fall of January month of Vizianagaram and Visakhapatnam is 9.9mm and 10 mm respectively (table -1).

Telangana state is comes under a semi-arid region and has a predominantly hot and dry climate. Summers start in March, and peak temperatures observed in the month of May with average high temperatures is 42 °C (108 °F) range. The monsoon starts from June and to September with about 755 mm (29.7 inches) of precipitation. A dry, mild winter starts in late November and lasts until early February with little humidity and average temperatures in the 22–23 °C (72–73 °F) range (Economic survey of Telangana 2011-12). The Central Deccan Plateau dry deciduous forests ecoregion covers much of the state, including Hyderabad. Over 80% of the original forest cover has been cleared for agriculture, timber harvesting, or cattle grazing, but large blocks of forest can be found in Nagarjunsagar-Srisailam Tiger Reserve and elsewhere. The more humid Eastern Highlands moist deciduous forests cover the Eastern Ghats in the eastern part of the state.

Thunderstorm, Hailstorm, Duststorm: Generally winter season transforms into spring the temperature rises initially in the southern parts of India, giving rise to thunderstorms and squally

weather which are hazardous in nature. While the southernmost part of the country is free from dust storm and hailstorm, such hazardous weather affect the central, Northeastern, north and Northwestern parts of the country. Records indicate that the largest size hailstone occurred in association with a thunderstorm in April, 1888 at Moradabad a town near Delhi. The hailstone measured size of a Pigeon's egg in diameter (IMD 1888). The hailstorm frequencies are highest in the Assam valley, followed by hills as Uttaranchal, South Bihar (now known as Jharkhand) and Vidarbha in the eastern parts of Maharashtra (Philip & Daniel 1976). However, thunderstorms also occur in these areas during the rest of the year as well, for example, Calcutta (Kolkata) has the highest frequency of thunderstorm in September while Delhi, Jaipur and Ahmedabad have the highest frequencies in July. In the year 2022 in the winter season in peninsular and east coast observed Hail storm and Heavy rainfall. What are the factors caused the occurrence of such extreme events was going to discuss in this paper.

The extreme rainfall events were categorized into three categories as per criteria of India Meteorological Department (website : IMD Monsoon Report 2014). These were (a) Heavy Rainfall (64.5- 124.4 mm one-day rainfall), (b) Very Heavy Rainfall (124.5-244.5 mm one-day rainfall) and (c) Extremely Heavy Rainfall (≥244.5 mm one-day rainfall)

Synoptic situations favourable for occurrence of hail storms in general:

Southern region
i. Hailstorm is a combined result of a. passage of western disturbances, b. a stronger than normal and southward located Sub-Tropical Westerly Jet Stream and c. presence of warm & moist easterlies in the lower troposphere.
ii. Upper level divergence provided by the sub-tropical westerly jet stream, in combination with the formation of a feeble north-south wind discontinuity providing convergence in the lower levels along with the temporary establishment of the oceanic highs.
iii. The above listed synoptic features independently or in combination lead to intense convective activity which manifest in the form of damaging hailstorms. (N. Chattopadhyay et al.2017

2. DATA METHODOLOGY

IADP Rainguage stations of state government, Rainfall data of IMD observatories of Telangana state and Andhra Pradesh state are used for the study. In AP RS/RW stations are located only in two places and in Telangana it is only one place, hence to represent entire area Wyoming university upper air sounding data is considered for Thermal indices of Lifted index/K indices and precipitable water. Real time satellite images, S band radar pictures, Forecast products of Total lightining flash count 3km resolution indicated with red colour in fig 6(b), Rainfall probability, Analysis of 850 wind products of IITM are used for the movement and nature of extreme hydrological events.

In addition, all India surface and upper air observations

K Index: The K index is a measure of thunderstorm potential based on the vertical temperature lapse rate, and the amount and vertical extent of low-level moisture in the atmosphere.

K = T(850 mb) + Td(850 mb) - T(500 mb) - DD(700 mb)

in degrees C, where T represents temperature, Td represents dewpoint temperature, and DD represents dewpoint depression at the indicated level.

K below 30:	Thunderstorms with heavy rain or severe weather possible (see note below).
K over 30:	Better potential for thunderstorms with heavy rain.
K = 40:	Best potential for thunderstorms with very heavy rain.

In general, the higher the ambient or inflow K index value, the greater the potential for heavy rain. However, beware of low (less than 30) values of K. Since the K index includes the dewpoint depression (i.e., difference between the temperature and dewpoint temperature) at 700 mb, dry air at this level will cause a low K value. However, given moisture below 700 mb, unstable air, and a lifting mechanism, strong or severe organized thunderstorms, and even heavy rain, can still occur. Scattered diurnal convection occurring in an environment containing high K (and PW) values can cause a quick burst of very heavy rain.(USA NWS).

LIFT Lifted index

LIFT = T500 - Tparcel

T500 = temperature in Celsius of the environment at 500 mb

Tparcel = 500 mb temperature in Celsius of a lifted parcel with the average pressure, temperature, and dewpoint of the layer 500 m above the surface

SWEAT index

SWEAT = 12 * TD850 + 20 * TERM2 + 2 * SKT850 + SKT500 + SHEAR

TD850 = Dewpoint in Celsius at 850 mb

TERM2 = MAX (TOTL - 49, 0)

TOTL = Total totals index

SKT850 = 850 mb wind speed in knots

SKT500 = 500 mb wind speed in knots

SHEAR = 125 * [SIN (DIR500 - DIR850) + .2]

DIR500 = 500 mb wind direction

DIR850 = 850 mb wind direction

KINX K index

KINX = (T850 - T500) + TD850 - (T700 - TD700)

T850 = Temperature in Celsius at 850 mb

T500 = Temperature in Celsius at 500 mb

TD850 = Dewpoint in Celsius at 850 mb

T700 = Temperature in Celsius at 700 mb

TD700 = Dewpoint in Celsius at 700 mb

TTOT Total Totals index

TOTL = (T850 - T500) + (TD850 - T500)

T850 = Temperature in Celsius at 850 mb

TD850 = Dewpoint in Celsius at 850 mb

T500 = Temperature in Celsius at 500 mb

CAPE Convective Available Potential Energy (J/kg)

CAPE = GRAVTY * SUMP (DELZ * (TP - TE) / TE)

SUMP = sum over sounding layers from LFCT to EQLV for which (TP - TE) is greater than zero

DELZ = incremental depth

TP = temperature of a parcel from the lowest 500 m of the atmosphere, raised dry adiabatically to the LCL and moist adiabatically thereafter

TE = temperature of the environment

CINS Convective Inhibition (J/kg)

CINS = GRAVTY * SUMN (DELZ * (TP - TE) / TE)

SUMN = sum over sounding layers from top of the mixed layer to LFCT for which (TP - TE) is less than zero.

DELZ = incremental depth

TP = temperature of a parcel from the lowest 500 m of the atmosphere, raised dry adiabatically to the LCL and moist adiabatically thereafter

TE = temperature of the environment

EQLV Equilibrium level (hPa)

EQLV = level at which a parcel from the lowest 500 m of the atmosphere is raised dry adiabatically to the LCL and moist adiabatically to a level above which the temperature of the parcel is the same as the environment. If more than one Equilibrium Level exists, the highest one is chosen.

BRCH Bulk Richardson number

BRCH = CAPE / (0.5 * U**2)

CAPE = Convective Available Potential Energy

U = magnitude of shear (u2 - u1, v2 - v1)

u1,v1 = average u,v in the lowest 500 m

u2,v2 = average u,v in the lowest 6000 m

3.RESULTS AND DISCUSSION

3.1a Synoptic situation on 11th January 2022 : a) A trough between South interior Karnataka and South Chhattisgarh in lower troposphere levels and a cyclonic circulation over Southwest Bay of Bengal and neighbourhood at 1.5 km above mean sea level was existed. Confluence of winds from Arabian sea and BoB at lower troposphere level over East and Adjoining Central India was forecasted.

Thermal indices of Andhra Pradesh state are calculated here representative district is Visakhapatnam and it was taken as reference. The indices are Showalter index is 5.39, Lifted index -0.72, Sweat index 107.39, K index 11.50, CAPE 72.17, level of free convection 539.70, Bulk Richardson number 1.50, Precipitable water (mm) for entire sounding 28.30. from Table 2. Lifted index/K index value was 33 from fig 1(a), indicating better potential for Thunderstorm with heavy rainfall. Precipitable water is 30 mm in fig 2(a) of 12z, 3hourly TS with lightening, severe weather indicating with red over Telangana region in Fig 5(a).

3.1b Realised weather on 11th January : Heavy rainfall occurred at isolated places in Warangal Rural, Mahabubabad and Yadadri Bhuvanagiri districts and As per media, Hailstorm occurred at isolated places in Hanumakonda,Waranganal, Jangaon and Kumarambheem districts of Telangana.

Rainfall in Telangana in (cm) is Atmakur (dist Warangal_rural) 8, Chennaraopet (dist Warangal_rural) 7, Gudurwrgl (dist Mahabubabad) 7, Bhuvanagiri (dist Y. Bhuvanagiri) 7, Kothaguda (dist Mahabubabad) 6, Khanapur (dist Warangal_rural) 6, Jammikunta (dist Karimnagar) 6, Nallabelly (dist Warangal_rural) 6, Karimnagar (dist Karimnagar) 6, Jangaon (dist Jangaon) 5, Narsampet (dist Warangal_rural) 5, Shayampet (dist Warangal_rural) 5, Karimnagar(a) (dist Karimnagar) 5, Bhongir(arg) (dist Y. Bhuvanagiri) 5, Mogullapalle (dist J. Bhupalpally) 5, Dharmasagar (dist Warangal_urban) 5, Parkal (dist Warangal_rural) 5.

3.2 12th January 2022:

3.2a Synoptic situation: The trough between South interior Karnataka to south Chhattisgarh at 0.9 km above mean sea level and a cyclonic circulation over Southwest Bay of Bengal and neighbourhood persists and it was extended upto 1.5 km above mean sea level. A cyclonic circulation lied over south Tamil Nadu and neighbourhood at 0.9 km above mean sea level also existed. (imd press release 12 Jan 2022)

Thermal indices of K index is 33 from fig1(b), Precipitable water 30 mm from fig 2(b) of 12Z, K index is 30 table 1,indicating Heavy rainfall over Telangana, CAPE value also more during 12th January from table 2, 3hourly lightening threat showed red colour over Telangana region in fig 5(b). Potential areas of severe weather over telangana region showed on 12th January 2022 fig 6(a).

3.2b Realised weather on 12th January : Thunder Storm accompanied with Hail observed in isolated places over EMP VID Chattisgarh, Gangetic West Bengal & Telangana.

11th and 12th JAN : Isolated rain over Telangana :Hailstorm occurred at isolated places in Hanumkonda, Warangal, Janagao and Kumarambheem districts of Telangana. In Coastal Andhra Pradesh: Komarada (Vizianagaram) 3cm.

3.3 13th January 2022

3.3a Synoptic situation: The trough between South interior Karnataka and south Chhattisgarh on 12th January was existed between North Interior Karnataka and north Interior Odisha at 0.9 km above mean sea level on 13th January and a cyclonic circulation over south Konkan and neighbourhood at 1.5 km above mean sea level persists. The cyclonic circulation over Southwest Bay of Bengal and neighbourhood extending upto 1.5 km above mean sea level also persists.

Lifted/K index is 33 from fig1(c), Precipitable value is 40mm fig 2(c)of 12Z, Rainfall probability showed moderate over Telangana and Andhra states fig 4(c). 3hourly lightening on 13th red indicated over Telangana and Coastal Andhra Pradesh fig 5(c), Potential Areas of Severe Weather also indicated over Telangana and North coastal Andhra Pradesh in Fig 6(b) Kindex 32.6 table2 for (fig9), 13 clearly showed confluence of winds from Arabian sea and BOB at lower troposphere level is very likely over East and Adjoining Central India

3.3b Realised Weather on 13th January

The cyclonic circulation over south Tamil Nadu and neighbourhood at 0.9 km above mean sea level persists. Parts of the state have been receiving unseasonal rains over the last two to three days. Hyderabad Meteorological Centre of the India Meteorological Department (IMD) attributed the unseasonal rainfall due to a trough running from north interior Karnataka to north Odisha. Heavy rain and hailstorms in parts of the state have damaged crops and houses during the last two days. Strong winds also uprooted electricity poles at a few places.(News reports on 13 Jan) Parts of Greater Hyderabad also received rain on 13th morning. Areas like Alwal, Rajendranagar, Chilkalguda, Maredpalli, Abids, Sultan Bazar, Himayat Nagar, Basheerbagh, Koti, Liberty, Khairatabad witnessed downpour leading to inundation of roads at a few places. Parvathagiri in Warangal Rural district recorded the highest rainfall 10 cm. Noothankal in Suryapet recorded 8 cm, Kollapur in Nagarkurnool 7 cm, and Garla in Mahabubabad district recorded 7 cm rainfall. 13Th, S kota (Vizianagaram) 5 cm in Andhra Pradesh.

3.4 14th January 2022

3.4a Synoptic situation : The trough between North Interior Karnataka to north Interior Odisha at 0.9 km above mean sea level persists. The cyclonic circulation over south Konkan & neighbourhood at 1.5 km above mean sea level persists. The cyclonic circulation over Southwest Bay of Bengal & neighbourhood was lied over Southwest & adjoining Southeast Bay of Bengal and extends upto 1.5 km above mean sea level. The cyclonic circulation over south Tamil Nadu & neighbourhood at 0.9 km above mean sea level persists. The cyclonic circulation over south Konkan & neighbourhood persists and it was seen between 1.5 km & 2.1 km above mean sea level.

Potential areas of severe weather Thunder storm with 5-10cm Rainfall indicated in fig 6(d). In Radar picture fig7 dbz value is more than 55 indicating severe weather.

3.4b Realised weather on 14th January

Normal Rain fall of Vizianagaram District during January was 9.9 mm from table1 but due to synoptic situation existed in and around Coastal Andhra Pradesh Vizianagaram district recorded highest rain

fall of 16cm which is a very heavy rainfall(IMD). It was a very rare feature of rainfall that was occurred in north Coastal Andhra Pradesh District Vizianagaram in the month of January.

Rain occurred at a few places in Telangana highest rainfall is 6cm in Jajireddigudem (suryapet)

Paravathipuram 16cm, Seethanagaram 9cm, Garugubilli 7cm, Bobbili, Balajipeta 5cm each, Bondapalle, Jiyyamavalsa 4CM each Above all in Vizianagaram district

Amaravati , Teneali, Mangalgiri (GNT) 5 cm each

15/1/2022 Many stations in VZM , VSK Districts recorded 2cm & above rainfall

In this year 2022 hail storms and heavy Rainfalls reported in the month of January in Telangana State and Heavy Rainfall Reported in coastal Andhra Pradesh.

The results reveal that indices associated with convective and potential instabilities perform better for differentiating thunderstorms. The results indicate that the region is showing higher instability for thunderstorm occurrences on Thunderstorm Day, and there is higher moisture availability for the area during the whole pre-monsoon season. The inhibition is higher over Non Thunderstorm Day, limiting the convective activity occurrence on certain days. (Rajesh sahu et al 2020)

FORECAST FOR THE PERIOD

The meteorological situation as depicted above is quite unusual over central and adjoining northern parts of peninsular India during this part of the year. Hence, capturing the very first event in our day-to-day weather forecasts could be accomplished.

The spatial distribution and intensity of rainfall had been predicted well. Also the subsequent events had been warned sufficiently in advance (2 days is the maximum lead time that can be achieved at present, with available resources).

The MeT office has issued a yellow warning for the next three days, including Thursday. It said hailstorms and heavy rain are likely to occur at isolated places in Mulugu, Bhadradri Kothagudem, Khammam, Nalgonda, Suryapet, Mahabubabad, Warangal (Rural), Warangal (Urban), Janagaon, Yadadri Bhuvangiri, Nagarkurnool districts.(Times News paper on 14th Jan 2022.)

4. CONCLUSION

- The southern end of the trough in lower & middle tropospheric levels associated with system was south of 20°N, deep in the Arabian Sea during 5th to 8th January, 2022 and pumped high moisture from the Arabian Sea to the system. In addition there was high moisture feeding from the Bay of Bengal into the system at lower tropospheric levels.

- The diurnal temporal pattern of the hail storm/Heavy rainfall over the states shows that late evenings are most conducive for occurrence of extreme rainfall events due to accumulation of precipitable water.

- High relative Humidity in the lower and upper troposphere and low relative humidity in middle troposhere required for deep convection is observed in these events.

- By continuous rainfall and hailstorm monitoring with availability of radar and lightening products and satellite observations, the nowcasting of hailstorm and heavy rainfall events are possible with a lead time of half to an hour. The lead time of nowcast of heavy rain can be increased by 1-2 hours with availability of reflectivity products of GEFS, the favorable synoptic and thermodynamic conditions in association with NWP model outputs can help much more.

- There is a need for adequate RADAR network in the country to forecast the occurrence of hailstorms over larger areas. Issuing timely warnings and Agromet advisories before and after hailstorm incidence will help the farmers to protect the crop and minimize the loss besides adopting integrated management strategies for early recovery of the crops/trees.

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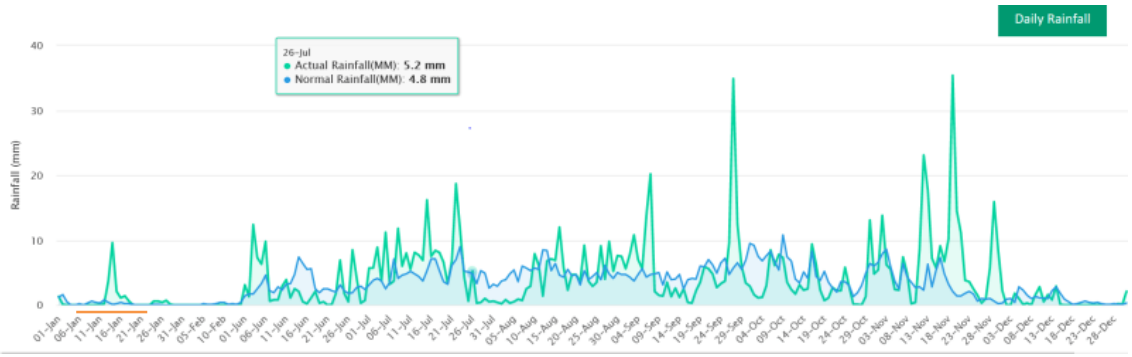


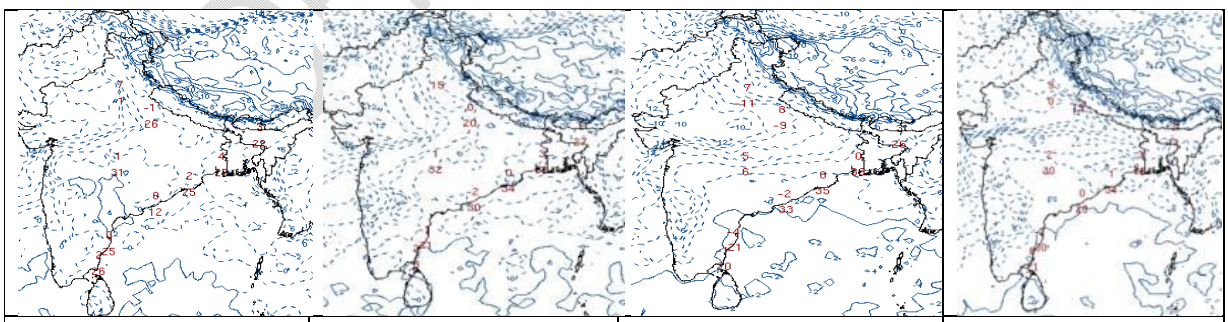
chart:1 Rainfall of Andhra Pradesh from June2021 to Feb14 2022

Districtwise Monthly Seasonal Rainfall (mm) data from 01/06/2020 to 31/05/2021

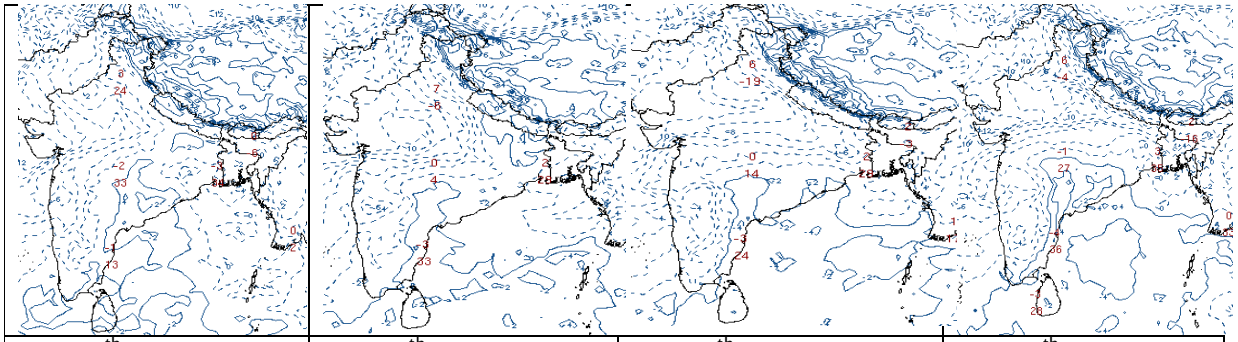
A:Actual N:Normal

District	South-West Monsoon								North-East Monsoon						Winter Period				Hot Weather Period					
	Jun N	Jun A	July N	July A	Aug N	Aug A	Sept N	Sept A	Oct N	Oct A	Nov N	Nov A	Dec N	Dec A	Jan N	Jan A	Feb N	Feb A	Mar N	Mar A	April N	April A	May N	May A
Srikakulam	134.9	129.5	189.4	131.4	185.1	116.3	196.3	135.2	182.8	216.4	90.6	47.3	2.6	0.0	6.1	10.8	19.8	0.0	20.8	0.0	30.5	33.0	102.7	68.7
Vizianagaram	128.4	142.4	178.7	175.5	195.1	92.6	190.5	171.4	167.9	225.0	73.3	53.7	4.6	0.0	9.9	2.9	15.6	0.4	21.8	0.5	30.7	53.0	114.2	92.5
Vishakapatnam	128.8	142.2	197.3	192.8	196.5	181.9	190.0	193.6	205.3	294.8	87.3	103.7	4.6	0.0	10.0	1.8	12.3	1.3	20.7	4.9	35.0	50.6	114.5	110.1
East Godavari	123.7	132.9	239.1	319.2	218.9	239.6	186.3	284.2	206.7	350.7	88.4	152.7	10.3	0.1	8.7	2.0	11.0	1.3	13.5	0.8	17.5	28.4	93.5	67.4
West Godavari	114.7	121.6	250.2	391.5	249.2	229.3	177.8	280.9	165.7	300.2	63.4	121.6	10.3	0.0	10.2	0.0	7.5	1.0	14.4	0.1	18.4	18.5	71.2	78.6
Krishna	97.8	134.4	210.6	306.0	212.8	171.9	163.9	219.5	162.7	243.2	70.7	111.9	16.0	0.6	8.4	0.0	7.4	4.3	10.7	0.0	14.5	17.1	58.0	59.1
Guntur	86.3	103.4	142.1	239.2	152.0	145.0	145.4	210.1	130.5	137.9	82.0	117.6	16.4	0.1	9.2	0.0	9.2	3.2	8.7	0.0	11.4	11.0	59.8	58.3
Prakasham	58.0	81.7	89.7	140.9	107.0	92.2	133.6	233.5	206.5	106.2	143.7	242.4	43.5	9.1	11.8	3.1	4.5	15.9	9.5	0.0	11.8	16.5	51.9	70.4
Nellore	56.8	69.0	86.3	138.3	86.1	125.7	102.1	156.1	239.0	84.9	313.4	487.0	109.0	158.6	14.2	64.0	5.7	21.5	4.0	0.0	10.1	8.8	53.7	12.8
Chittoor	78.7	99.3	101.9	272.1	117.4	128.6	141.4	172.7	162.7	138.0	162.6	255.8	70.1	90.2	2.2	32.1	1.2	8.3	3.7	0.0	17.6	35.2	61.7	56.3
Kadapa	69.2	91.2	96.7	153.2	114.0	139.0	113.7	308.2	131.9	125.6	93.4	229.2	25.7	53.3	2.7	8.9	1.9	8.2	5.7	0.1	11.2	22.6	36.7	72.4
Anantapur	63.9	106.8	67.4	166.8	88.7	56.6	118.4	236.8	110.7	113.0	34.7	48.5	9.9	19.1	1.6	14.4	1.3	12.1	3.3	0.0	12.8	33.4	39.6	79.5
Kurnool	77.2	134.9	117.2	238.1	135.0	117.6	125.7	267.3	114.5	123.2	27.6	38.4	7.5	2.7	7.8	31.1	4.3	11.6	7.7	0.0	17.0	22.3	38.5	77.8
State	**93.7**	**113.1**	**151.3**	**225.1**	**158.3**	**141.8**	**152.7**	**224.8**	**168.2**	**185.9**	**102.4**	**157.7**	**25.4**	**26.7**	**7.9**	**13.3**	**7.8**	**7.3**	**11.1**	**0.4**	**18.3**	**26.2**	**68.9**	**68.7**

Table:1 District wise Monthly Seasonal Rainfall (mm) data from 01/06/2020 to 31/05/2021

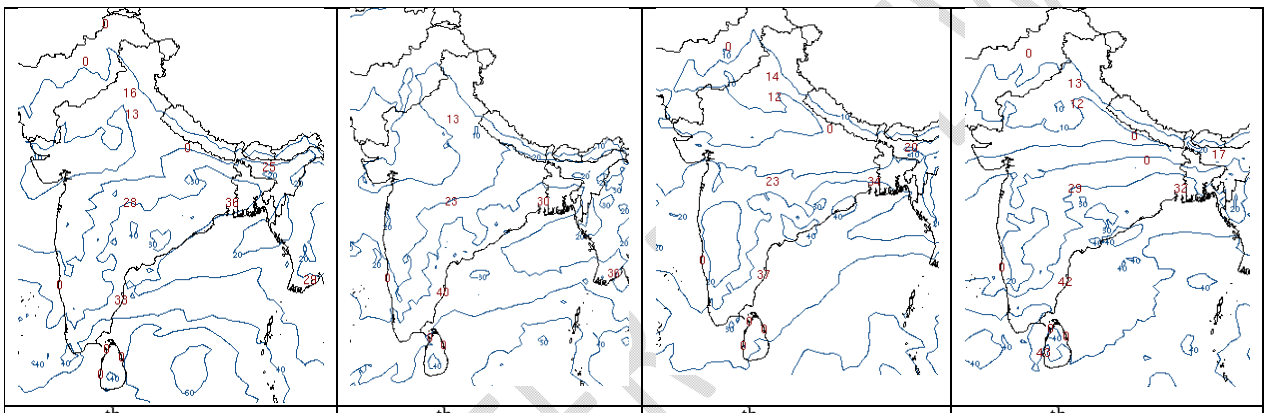


00 Z 11 Jan2022 (a)	00 Z 12 Jan2022 (b)	00 Z 13 Jan2022	00 Z 14 Jan2022



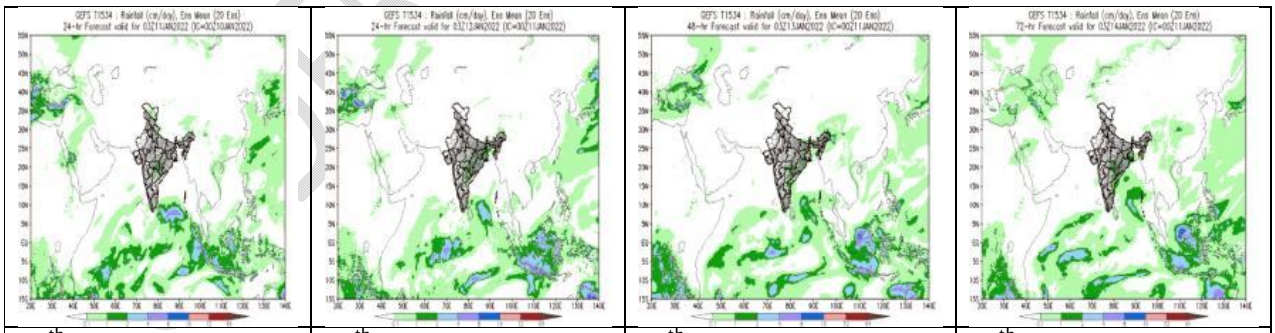
12Z 11th Jan 2022 (a)	12Z 12th Jan 2022 (b)	12Z 13th Jan 2022 (c)	12Z 14th Jan 2022 (d)

Fig :1 Lifted / K Indices over India region from 11th to 14th January 2022



12Z 11th Jan 2022 (a)	12Z 12th Jan 2022 (b)	12Z 13th Jan2022 (c)	12Z 14th Jan 2022 (d)

Fig:2 Precipitable Water analysis over India Region 11th to 14th January 2022



11th Jan 2022 (a)	12th Jan 2022 (b)	13th Jan 2022 (c)	14th Jan 2022 (d)

Fig:3 GEFS forecast products from 11th to 14th January 2022

Fig:4 Rainfall probability based on GEFS Forecast for 13th to 14 January 2022

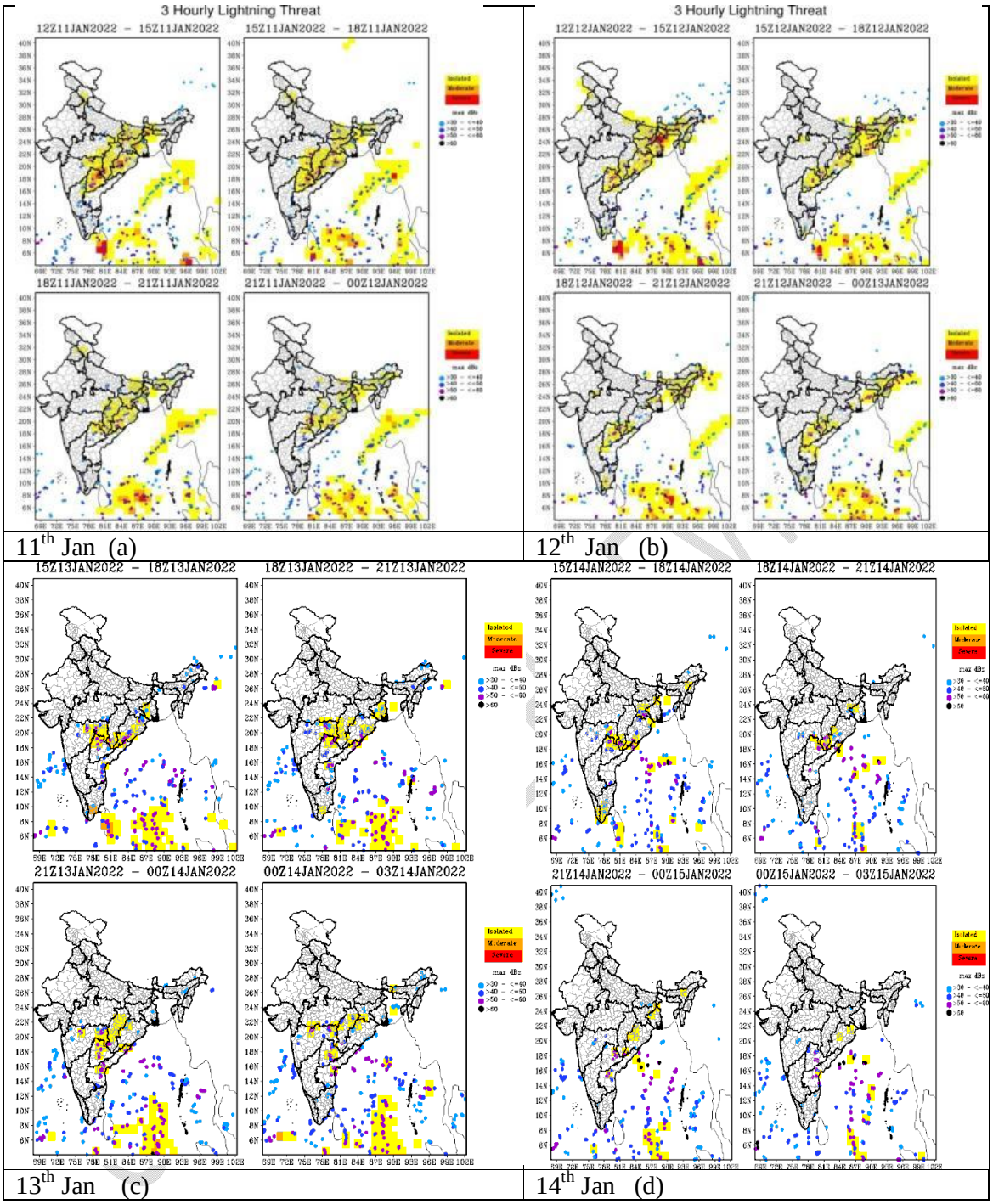


Fig:5 3 hourly Lightning Threat for the study period.

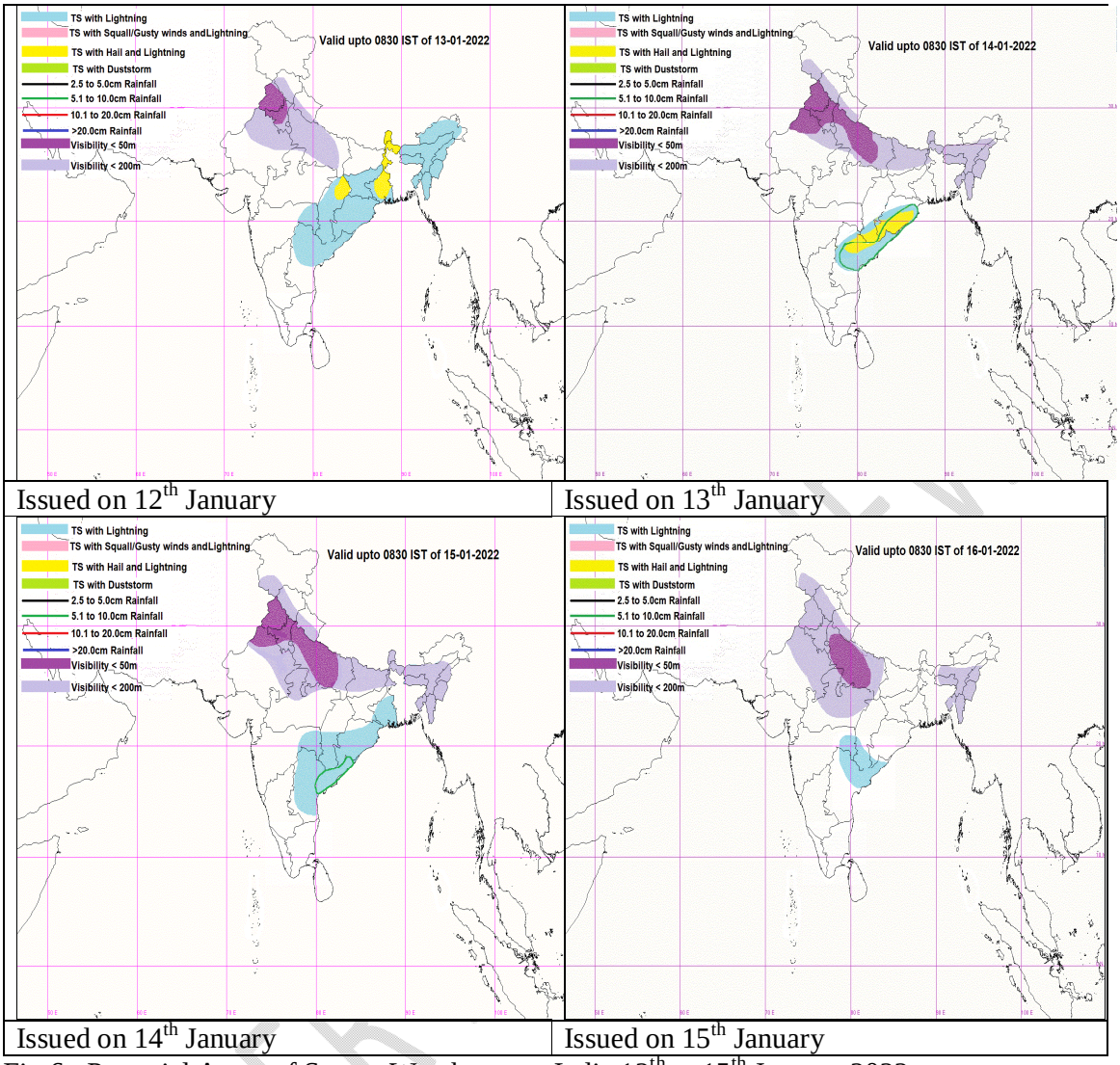
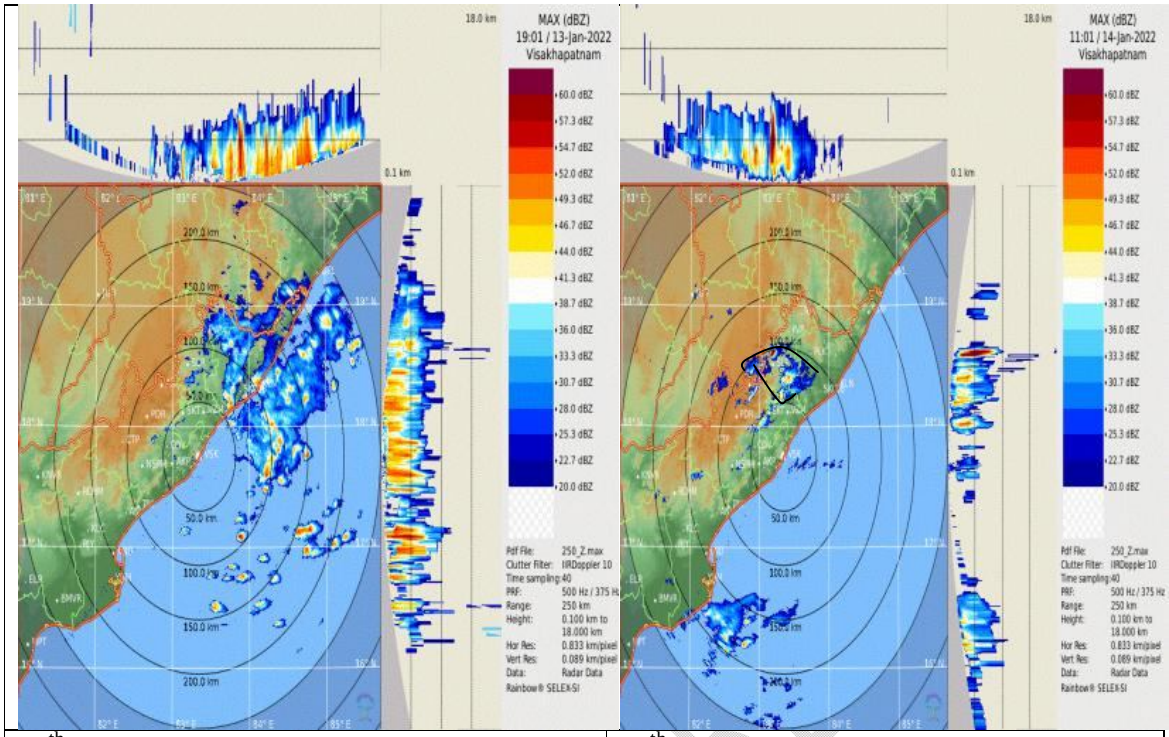


Fig:6 : Potential Areas of Severe Weather over India 12th to 15th January 2022

Parameter	11/00	12/00	13/00	14/00
Lifted index	-0.72	-2.9	-2.9	-0.04
SWEAT Index	107.39	187.2	172.6	191.1
K Index	11.5	30	32.6	28.4
Totals Totals index	40.60	47.3	47.4	44.7
CAPE	72.17	430	386.7	69.8
CI	-217.62	-6.22	-48.96	-91.9
EL	398.89	383.4	408.2	457.4
LFC	539	918.53	768.5	774.9
LCL	927	943	953.3	949.66
Bulk Richardson no	1.50	5.3	10.5	1.59
Precipitable Water mm	28.3	35.98	38.81	35.52

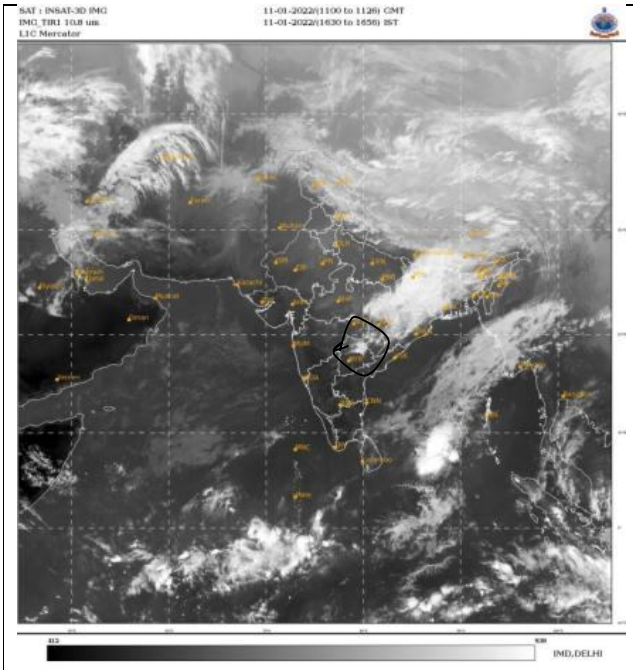
Table :2 Thermodynamic parameters at reference station Visakhapatnam 43150



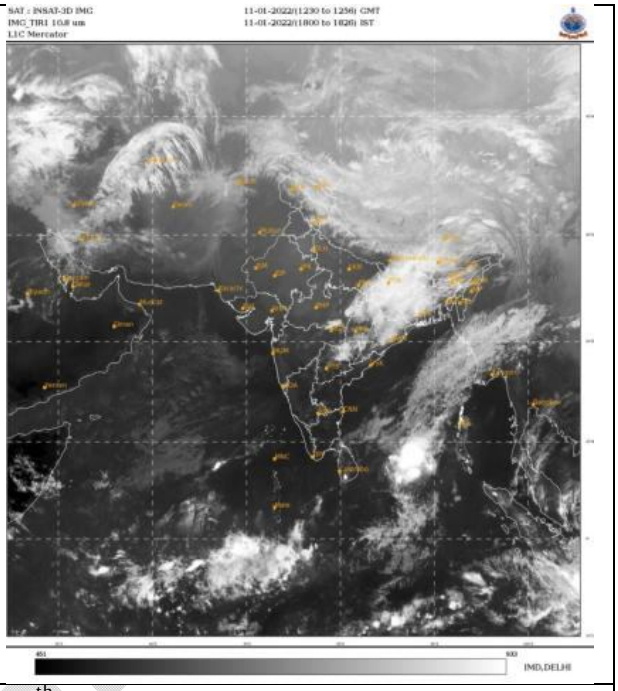
13th January | 14th January

14th January | 15th January

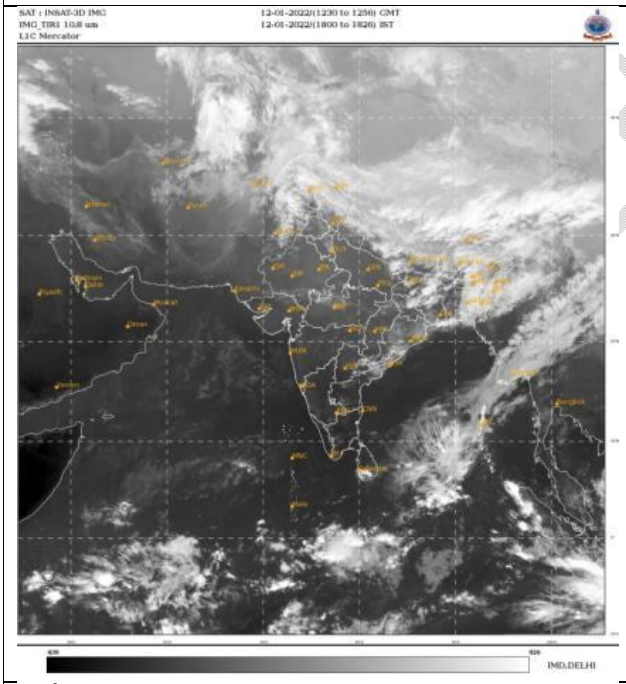
Fig:7 Radar observations over North coastal Andhra Pradesh from 13th to 15th January 2022



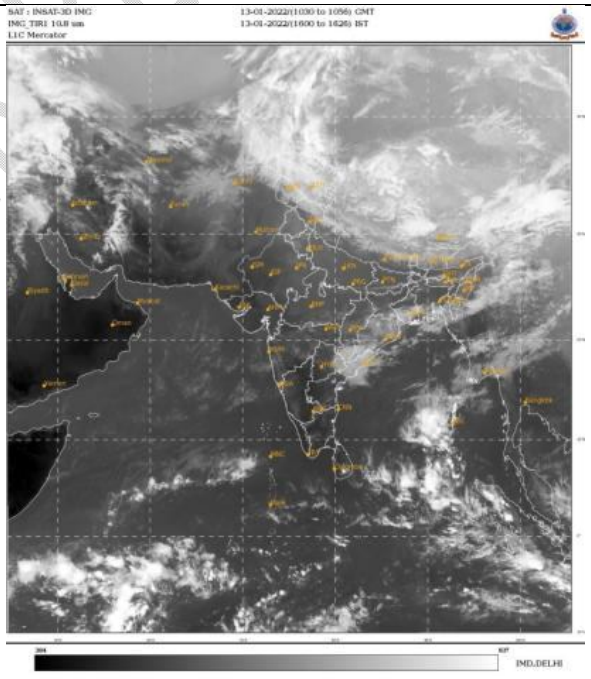
11th Jan 1630 IST



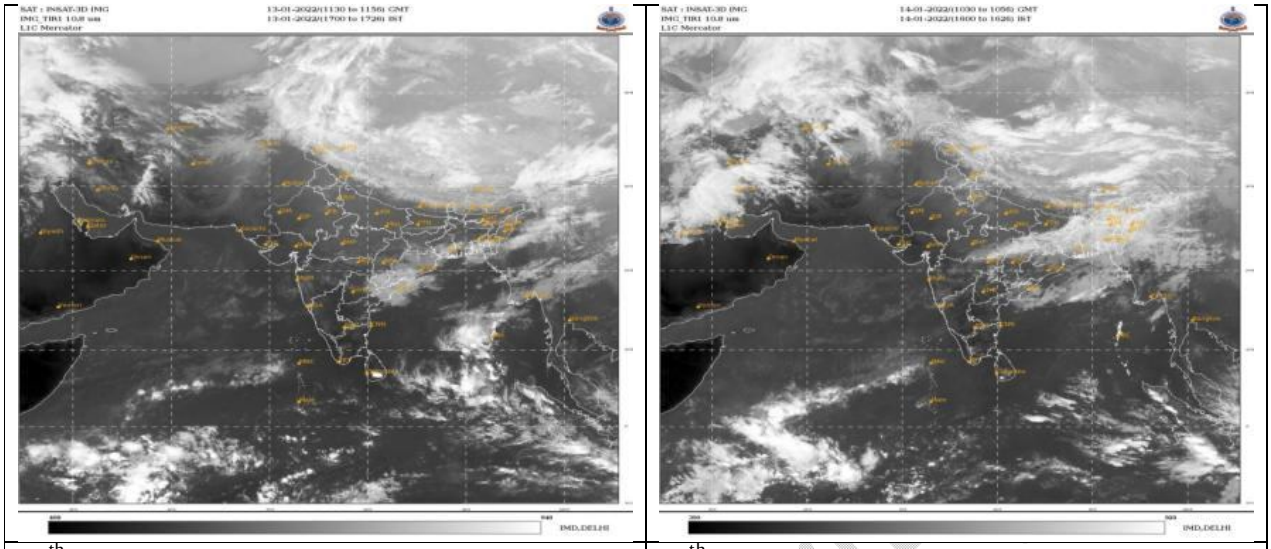
11th Jan 1830 IST



12th Jan 1830 IST

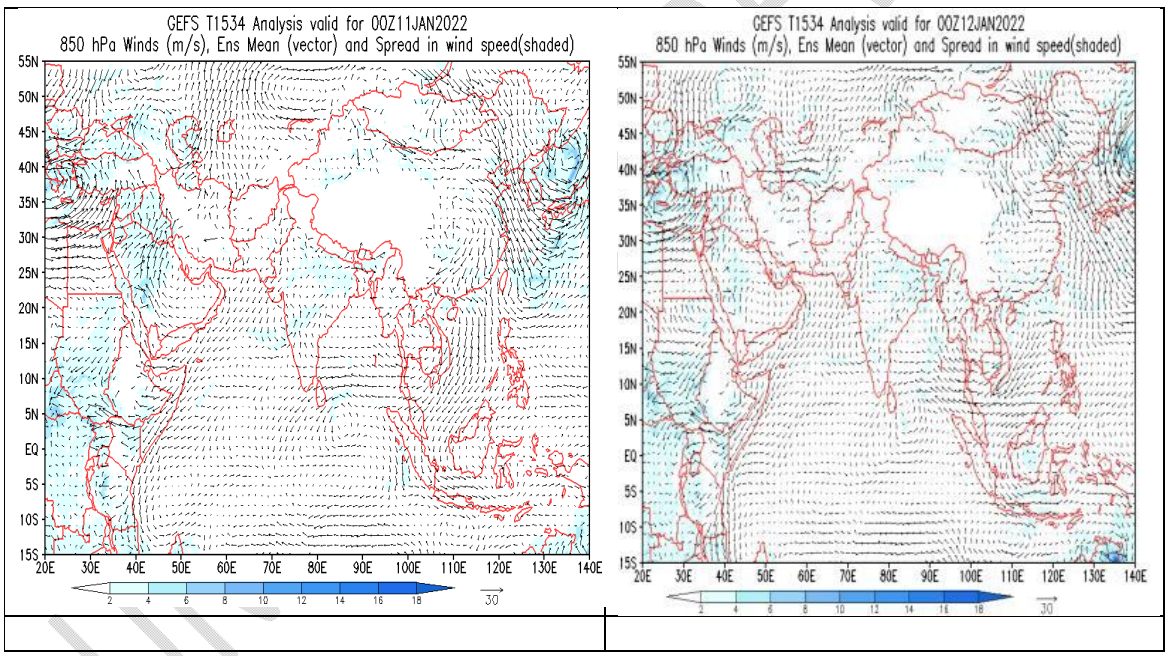


13th Jan 1630 IST



13th Jan 1730 IST | 14th Jan 1630 IST

Fig:8 Insat 3D TIRI Satillite pictures observed during study period from 11th to 14th January 2022



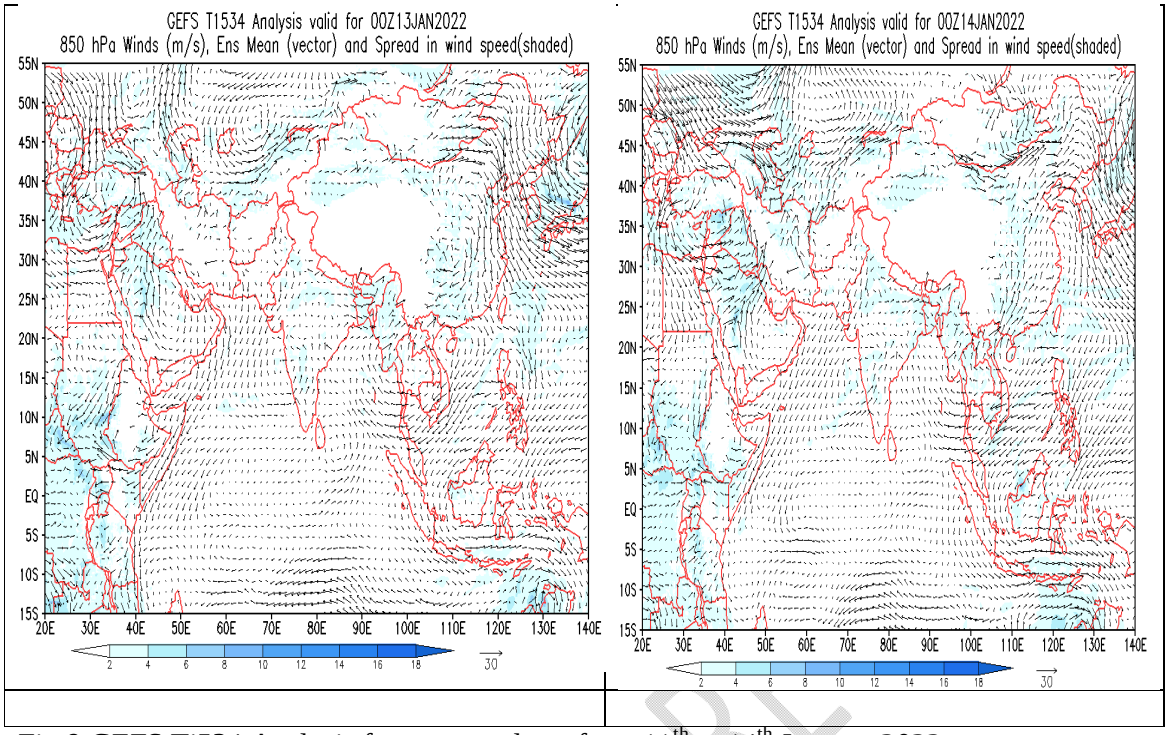


Fig:9 GEFS Ti534 Analysis forecast products from 11th to 14th January 2022