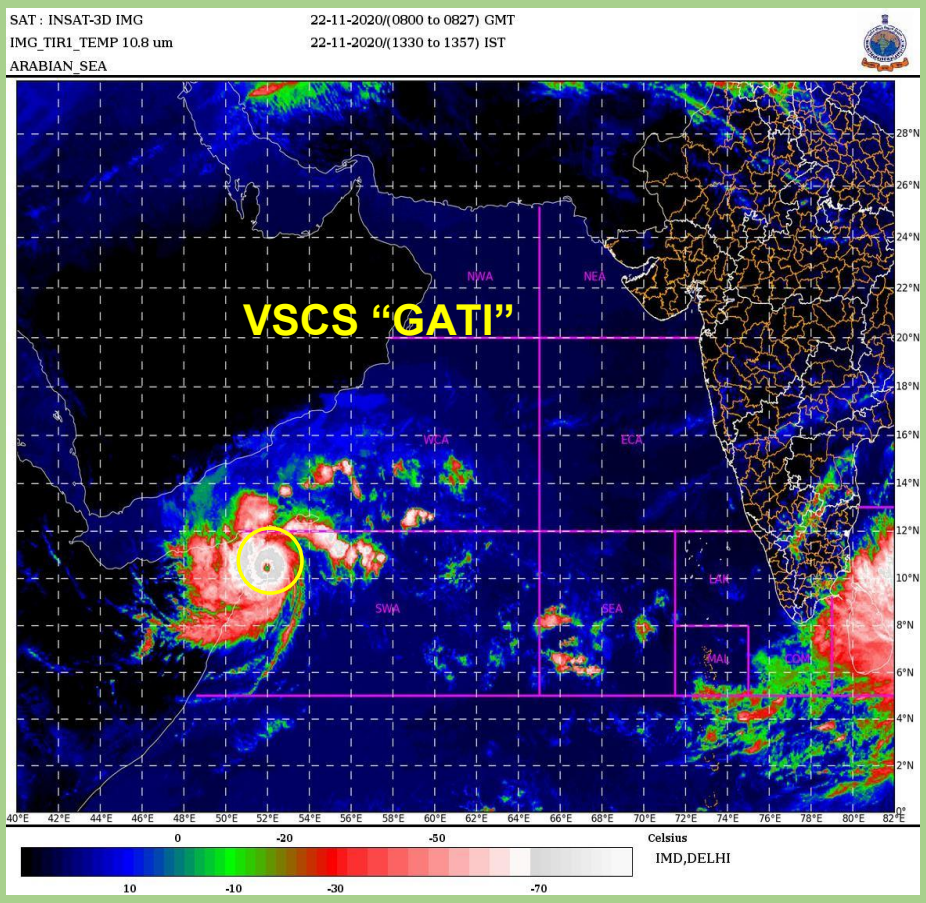
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
INDIA METEOROLOGICAL DEPARTMENT

# Very Severe Cyclonic Storm, 'GATI' over the Arabian Sea (21-24 November 2020): A Report




**INSAT-3D enhanced colored IR imagery of 8 UTC,22nd NOVEMBER, 2020**

## Cyclone Warning Division

## India Meteorological Department

## New Delhi

## December, 2020

# Very Severe Cyclonic Storm "GATI" over the Arabian Sea (21-24 November 2020)

## 1. Introduction

Very Severe Cyclonic Storm (VSCS) "GATI" originated from a low pressure area formed over central parts of south Arabian Sea (AS) in the morning (0300 UTC) 19th November. It lay as a well marked low pressure area over southwest AS & neighborhood in the early morning (0000 UTC) 21st. It concentrated into a depression over the same region in the midnight (1800 UTC) of 21st. Moving west-southwestwards, it explosively intensified into a deep depression in the early morning (0000 UTC) of 22nd, further into the cyclonic storm **"GATI"** in the same morning (0300 UTC), into a severe cyclonic storm in the noon (0600 UTC) and into very severe cyclonic storm in the afternoon (0900 UTC) over southwest AS. It reached it's peak intensity of 75 knots in the same evening (1200 UTC) over the southwest AS. Continuing to move westwards, it crossed Somalia coast near latitude 10.45°N and longitude 51.10°E between 1400 and 1500 UTC of 22nd as a very severe cyclonic storm with estimated wind speed of 130-140 kmph gusting to 155 kmph. Continuing to move nearly westwards, it weakened into a severe cyclonic storm in the early hours (2100 UTC of 22nd) of 23rd, into a cyclonic storm in the early morning (0000 UTC) and into a deep depression in the same noon (0600 UTC) over north Somalia.

Thereafter, it moved west-northwestwards and emerged into Gulf of Aden in the evening (1200 UTC) of 23rd. Continuing to move west-northwestwards, it weakened into a depression in the early morning (0000 UTC) of 24th over Gulf of Aden and adjoining north Somalia and into a well marked low pressure area in the noon (0600 UTC) of 24th over the same region. As per media reports, intense rainfall activity occurred over north Somalia. More than 20 cm rainfall occurred during the period of a day against about 10 cm of annual rainfall over this region. The observed track of the system during 21st to 24th November is presented in Fig. 1.

## 2. Salient Features:

The salient features of the system were as follows:

- GATI was the first very severe cyclonic storm (MSW≥64 KT) crossing Somalia coast during satellite era as per the best track data available with IMD. However it is the second severe cyclonic storm to cross Somalia after 1994. A severe cyclonic storm crossed north Somalia coast during early hours of 20th November 1994 with a wind speed of 101 kmph. Another cyclonic storm (MURJAN) crossed Somalia coast on 26th October 2012. Cyclonic storms, Sagar (in 2018) & Pawan (in 2019) respectively crossed Somalia coast in recent years. Thus though rare, Somalia gets affected by the cyclones from Arabian Sea. Looking at the above statistics, the frequency of cyclones hitting Somalia coast has increased in recent years (2010 onwards).
- Yemen and Somalia also get affected by the cyclones moving into Gulf of Aden. Like the case of cyclone, GATI.

- GATI underwent explosive intensification with an increase in maximum sustained wind speed by 45 knots in 12 hours during 0000 to 1200 UTC of 22nd.
- It moved very fast with a 6 hourly speed of about 20 kmph against the long period average of 13.6 kmph for the period 1990-2013 for cyclonic storms over the Arabian Sea. On 22nd November, it moved with a six hourly speed varying between 36-50 kmph.
- It maintained the intensity of cyclonic storm for about 15 hours after crossing Somalia coast.

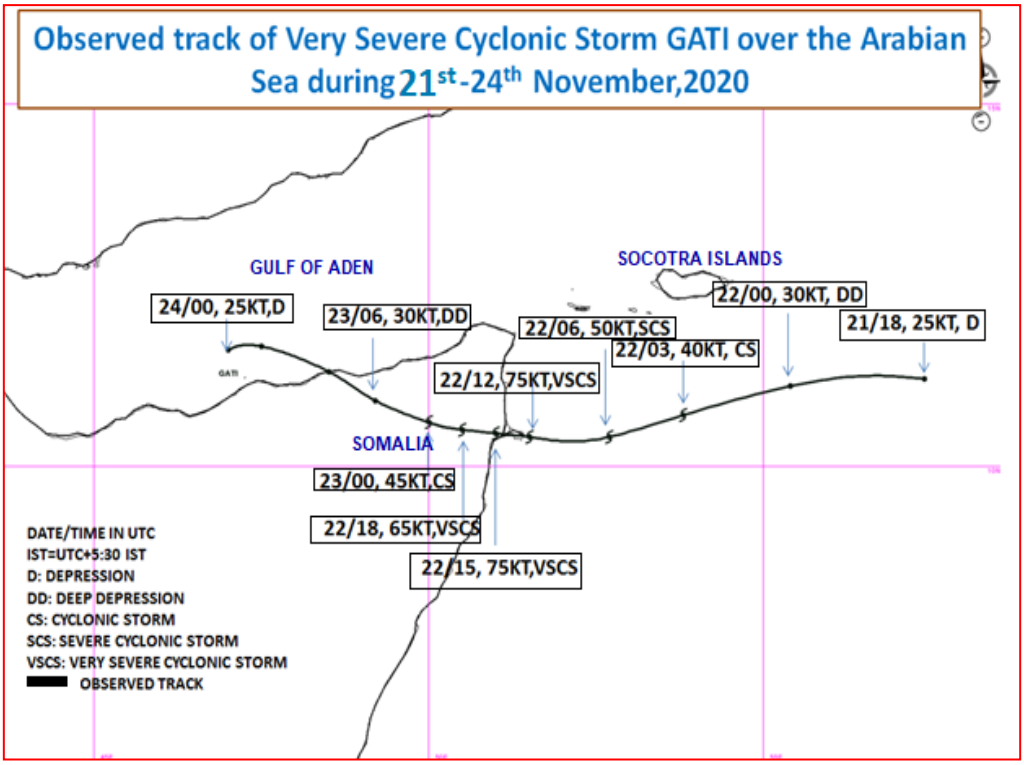



**Fig.1 Observed track of VSCS GATI (21-24 November, 2020) over the Arabian Sea**

**Table 1: Best track positions and other parameters of the Very Severe Cyclonic Storm "GATI" over the Arabian Sea during 21-24 November, 2020**

| Date | Time (UTC) | Centre lat.$^0$ N/ long.$^0$ E. | | C.I. NO | Estimated Central Pressure (hPa) | Estimated Maximum Sustained Surface Wind (kt) | Estimated Pressure drop at the Centre (hPa) | Grade |
|---|---|---|---|---|---|---|---|---|
| 21/11/2020 | 1800 | 11.2 | 57.4 | 1.5 | 1000 | 25 | 04 | **D** |
| 22/11/2020 | 0000 | 11.1 | 55.4 | 2.0 | 998 | 30 | 06 | **DD** |
| | 0300 | 10.7 | 53.8 | 2.5 | 996 | 40 | 08 | **CS** |
| | 0600 | 10.4 | 52.7 | 3.0 | 992 | 50 | 12 | **SCS** |
| | 0900 | 10.4 | 52.0 | 4.0 | 982 | 65 | 22 | **VSCS** |
| | 1200 | 10.4 | 51.5 | 4.5 | 976 | 75 | 26 | VSCS |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Crossed Somalia Coast near lat 10.45$^0$ N and long 51.1$^0$ E between 1400 and 1500 UTC of 22$^{nd}$ Nov. with a maximum sustained wind speed 75 kts gusting to 85 kts | | | | | | |
| | 1500 | 10.4 | 51.0 | - | 976 | 75 | 26 | VSCS |
| | 1800 | 10.4 | 50.5 | - | 982 | 65 | 22 | VSCS |
| | 2100 | 10.4 | 50.1 | - | 986 | 60 | 18 | **SCS** |
| 23/11/2020 | 0000 | 10.5 | 50.0 | - | 994 | 45 | 10 | **CS** |
| | 0300 | 10.7 | 49.7 | - | 997 | 35 | 07 | CS |
| | 0600 | 10.9 | 49.2 | - | 998 | 30 | 06 | **DD** |
| | | Emerged into Gulf of Aden as a Deep Depression around 1200 UTC of 23$^{rd}$ Nov. | | | | | | |
| | 1200 | 11.3 | 48.5 | 2.0 | 999 | 30 | 05 | DD |
| | 1800 | 11.7 | 47.5 | 2.0 | 1000 | 30 | 05 | DD |
| 24/11/2020 | 0000 | 11.6 | 47.0 | 1.5 | 1001 | 25 | 04 | **D** |
| | 0300 | 11.6 | 46.8 | 1.5 | 1002 | 20 | 03 | D |
| | 0600 | Weakened into a well-marked low pressure area over the same region at 0600UTC of 24$^{th}$ Nov. | | | | | | |

## 3. Brief life history

### 3.1. Genesis

A low-pressure area formed over central parts of south Arabian Sea (AS) at 0300 UTC of 19$^{th}$ November. It lay as a well-marked low pressure area over southwest AS & neighborhood at 0000 UTC of 21$^{st}$. It concentrated into a depression over the same region at 1800 UTC of 21$^{st}$.

During 18$^{th}$ – 20$^{th}$ November, the convectively active regime of Madden Julian Oscillation (MJO), represented mathematically by the MJO index, lay in Phase 2 (western Indian Ocean) with amplitude more than 1. It shifted eastwards into Phase 3 (eastern Indian Ocean) with amplitude close to 1, on 21$^{st}$ November, the day of formation of the Depression. Thus, the MJO had favored the genesis of the system.

The Sea Surface Temperature (SST) was around 29-30°C over most parts of south and east-central Arabian Sea (AS). It was slightly less (26-28°C) over west-central & north AS.

High Tropical Cyclone Heat Potential (TCHP), (100-120 KJ/cm$^2$) prevailed over Comorin area and adjoining southwest BOB off south Sri Lanka coast and Kerala coast. TCHP was around 60-80 KJ/cm$^2$ over major parts of south AS except off north Somalia coast. It was less than 50KJ/cm$^2$ to the west of 68°E and north 11°N over the central & north AS and 60 – 80 KJ/cm$^2$ over remaining parts of east-central & northeast AS.

On 18$^{th}$ November, Positive relative vorticity (25-50x10$^{-6}$s$^{-1}$) prevailed over southeast and adjoining southwest & west-central AS with vertical extension upto 200 hPa level. Area of positive divergence (20-30x10$^{-5}$s$^{-1}$) prevailed over southeast AS to the southwest of the potential genesis area. Area of positive convergence zone (05-10 x 10$^{-5}$s$^{-1}$) prevailed over southeast AS to the southeast of this zone. The vertical wind shear (VWS) has been moderate (10-15 KTS) over southeast and adjoining southwest & west-central AS. The upper tropospheric ridge at 200 hPa ran along 15°N over the AS.

On 19$^{th}$ November, Positive relative vorticity (25-50x10$^{-6}$s$^{-1}$) prevailed over southeast and adjoining southwest & west-central AS with vertical extension upto 200 hPa level. Area of positive divergence (30x10$^{-5}$s$^{-1}$) prevailed over southwest AS. Area of positive

convergence zone (05-10 x $10^{-5}s^{-1}$) prevailed over central parts of south AS. The vertical wind shear (VWS) was low to moderate (5-20 kts) over central parts of AS and adjoining south AS. The upper tropospheric ridge at 200 hPa ran along 15°N over the AS.

On 20th November, Positive relative vorticity (25-50x$10^{-6}s^{-1)}$ prevailed over central parts of south AS and adjoining west-central AS with vertical extension upto 200 hPa level. Area of positive divergence (5-20x$10^{-5}s^{-1}$) prevailed over west-central AS to the northwest of the potential genesis area. Area of positive convergence zone (05-10 x $10^{-5}s^{-1}$) prevailed over central parts of south AS and adjoining central AS. The vertical wind shear (VWS) was low to moderate (5-20 kts) over central parts of AS and adjoining south AS. The upper tropospheric ridge at 200 hPa ran along 15°N over the AS.

On 21st November, two fragmented positive relative vorticity zones (25-50x$10^{-6}s^{-1}$) prevailed over southwest AS and another (20-30x$10^{-6}s^{-1}$) prevailed over southwest & adjoining southeast AS with vertical extension upto 500 hPa level. Two areas of positive divergence (10x$10^{-5}s^{-1}$ & 20x$10^{-5}s^{-1}$) prevailed over southwest AS. Another divergence zone of 30x$10^{-5}s^{-1}$ prevailed over southwest AS. Area of positive convergence zone (20 x $10^{-5}s^{-1}$) prevailed over southwest AS. The vertical wind shear (VWS) was low to moderate (5-20 kts) over central parts of AS and adjoining south AS. The upper tropospheric ridge at 200 hPa ran along 15°N over the AS.

Thus, it may be concluded that, under the large scale convective environment, other favourable dynamic & thermodynamic features like, a marginally high TCHP, Low VWS and a vertically coupled low level convergence & upper level divergence zones led to a steady build up of cyclonic vorticity over southwest Arabian Sea leading to the formation of the Depression on 21st Night.

### 3.2 Intensification and movement

The intensification of VSCS GATI was explosive in nature, as the Depression, while moving west-southwestwards, intensified into a deep depression by 0000 UTC of 22nd, further into the cyclonic storm **"GATI"** by 0300 UTC, into a severe cyclonic storm by 0600 UTC and into very severe cyclonic storm by 0900 UTC over southwest AS, all on 22nd November. It reached its peak intensity of 75 knots in the same evening (1200 UTC) over southwest AS. Continuing to move westwards, it crossed Somalia coast between 1400 and 1500 UTC of 22nd as a very severe cyclonic storm. Continuing to move nearly westwards, it weakened into a severe cyclonic storm by 2100 UTC of 22nd, into a cyclonic storm by 0000 UTC of 23rd and into a deep depression by 0600 UTC over north Somalia. Thereafter, it moved west-northwestwards and emerged into Gulf of Aden by 1200 UTC of 23rd. Continuing to move west-northwestwards, it weakened into a depression by 0000 UTC of 24th over Gulf of Aden and adjoining north Somalia and into a well marked low pressure area by 0600 UTC of 24th over the same region.

The environmental features which supported this type of rapid intensification and movement are described below:

All through the life cycle, the MJO index lay in phase 3 with amplitude close to 1, favouring convective environment over the Arabian Sea. Also the SST was around 29-30°C over most parts of south and east-central Arabian Sea (AS). TCHP was around 60-80 KJ/$cm^2$ over major parts of south AS except off north Somalia coast.

At 1800 UTC of 21st November, Relative vorticity zone (100x$10^{-6}s^{-1}$) prevailed over south Arabian Sea to the southwest of the system. An area of positive upper level divergence

$20x10^{-5}s^{-1}$ and an area of positive low level convergence zone ($10 \times 10^{-5}s^{-1}$) prevailed to the southwest of the system. The vertical wind shear (VWS) was low to moderate (10-15 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0000 UTC of 22nd November, Relative vorticity zone ($100x10^{-6}s^{-1}$) prevailed around the system. An area of positive divergence $20x10^{-5}s^{-1}$ and an area of positive convergence zone ($10 \times 10^{-5}s^{-1}$) prevailed over and to the southwest of the system. The vertical wind shear (VWS) was low to moderate (10-15 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0300 UTC of 22nd November, Relative vorticity zone ($100x10^{-6}s^{-1}$) prevailed around the system. An area of positive divergence $20x10^{-5}s^{-1}$ and area of positive convergence zone ($20 \times 10^{-5}s^{-1}$) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0600 UTC of 22nd November, Relative vorticity zone (100x10-6s-1) prevailed around the system. An area of positive divergence 30x10-5s-1 and area of positive convergence zone (40 x 10-5s-1) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0900 UTC of 22nd November, Relative vorticity zone ($100x10^{-6}s^{-1}$) prevailed around the system. An area of positive divergence $30x10^{-5}s^{-1}$ and area of positive convergence zone ($40 \times 10^{-5}s^{-1}$) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

The very severe cyclonic storm "GATI" crossed Somalia coast around 1500 UTC of 22nd November. At 2100 UTC of 22nd November, Relative vorticity zone ($50x10^{-6}s^{-1}$) prevailed around the system. An area of positive divergence ($10x10^{-5}s^{-1}$) and another area of divergence zone ($05 \times 10^{-5}s^{-1}$) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0000 UTC of 23rd November, Relative vorticity zone ($50x10^{-6}s^{-1}$) prevailed around the system. An area of positive convergence ($10x10^{-5}s^{-1}$) and area of divergence zone ($05 \times 10^{-5}s^{-1}$) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 15°N.

At 0600 UTC of 23rd November, Relative vorticity zone ($50x10^{-6}s^{-1}$) prevailed around the system. An area of positive convergence ($10x10^{-5}s^{-1}$) and area of divergence zone ($20 \times 10^{-5}s^{-1}$) prevailed around the system. The vertical wind shear (VWS) was low to moderate (15-20 kts) over and to the west of the system. The upper tropospheric ridge at 200 hPa ran along 16°N. By this time, the system had weakened into a well marked low pressure area over Gulf of Aden and adjoining north Somalia.

Apart from the large scale convective environment provided by the favourable phase of MJO, sufficiently warm SST & TCHP, low level convergence associated with the easterly wave regime, low VWS & enhanced upper level divergence could have aided the

anomalously rapid intensification. Its near westward movement was facilitated by the easterly winds to the south of the sub-tropical Ridge axis.

The Total Precipitable Water vapour (TPW) imageries during 21-24 Nov. 2020 are presented in **Fig.2**. These imageries indicate continuous warm and moist air advection from the near equatorial belt of Inter Tropical convergence Zone across the southeast sector of the system into its core till the night of 22nd November, during the period of its rapid intensification. However, as the system approached coast, there was land interaction and moisture supply also reduced relatively as evident from TPW imageries on 23rd and 24th Nov. The TPW image also indicates relatively cold air advection from Somalia on 23rd and 24th Nov. helping in weakening of the system.

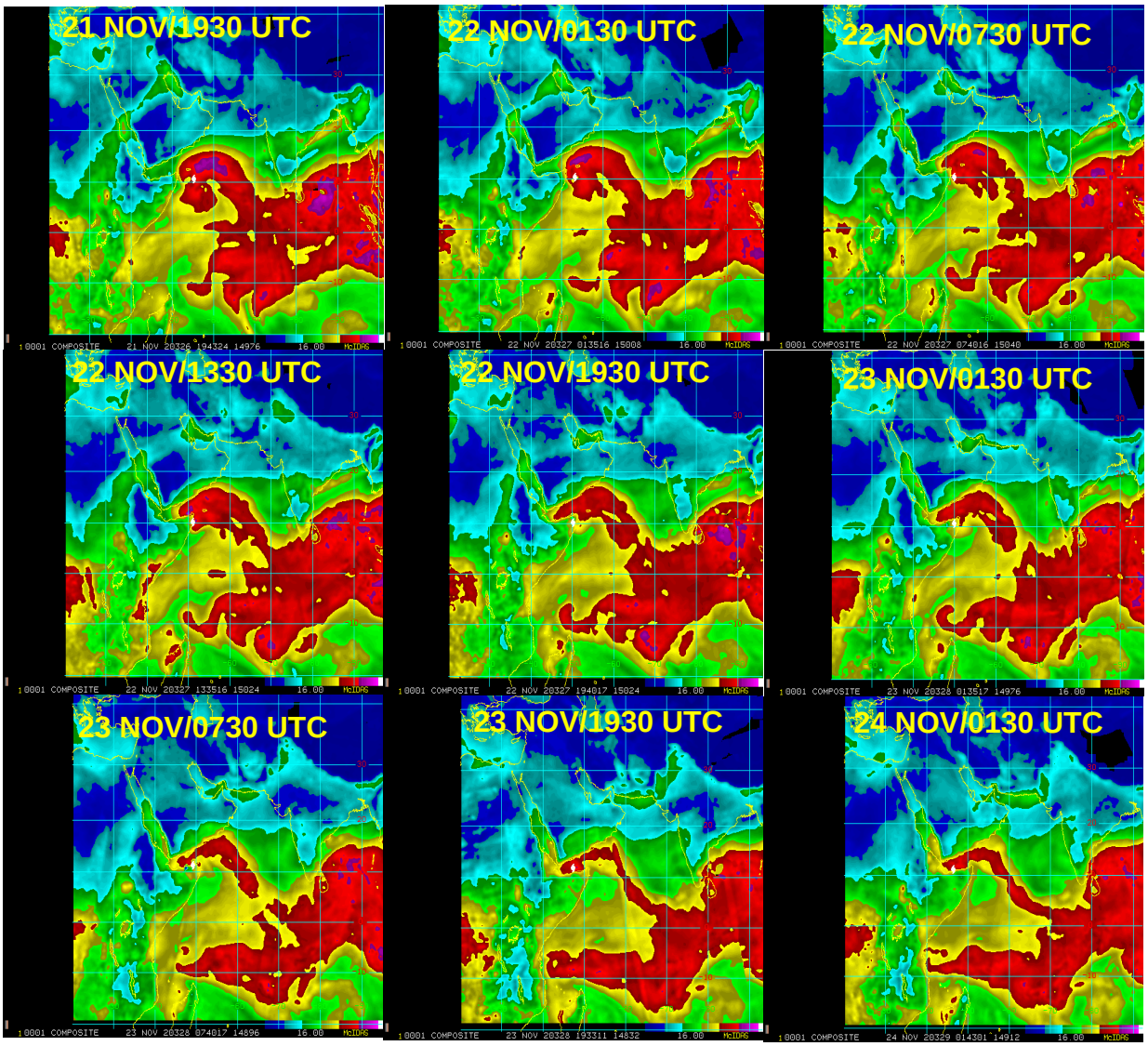



**Fig. 2: Total Precipitable Water vapour (TPW) imageries of VSCS GATI during 21-24 November, 2020**

The wind speed in middle and deep layer around the system centre is presented in **Fig.3**. low to moderate easterly shear (around 15 knots) prevailed during the genesis & mature phase of the system which gradually increased and became High westerly shear during the dissipation stage.

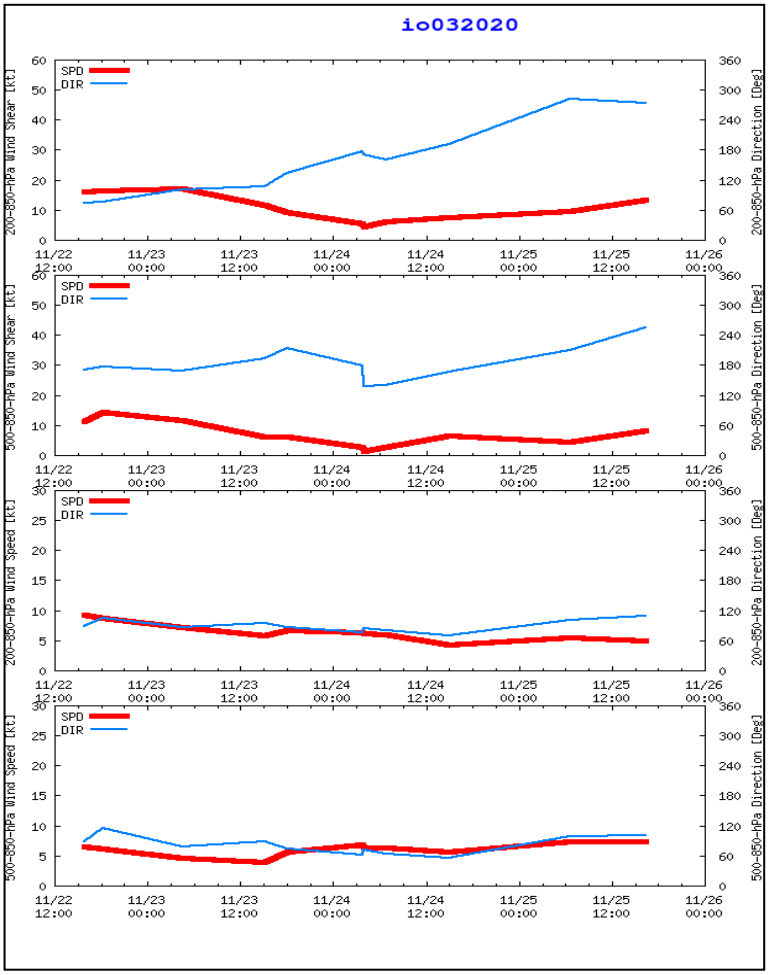



**Fig.3 Wind shear and wind speed in the middle and deep layer around the system VSCS GATI during 21-24 November, 2020**

**Fig.3**, also indicates that from the genesis stage, the mean deep layer winds between 200-850 hPa levels steered the system initially westwards till 15 UTC of 22$^{nd}$ Nov. and west-northwestwards subsequently.

### 3.3. Maximum Sustained Surface Wind speed and estimated central pressure

The lowest estimated central pressure and the maximum sustained wind speed are presented in Fig.4a. There was rapid fall in pressure during the period 1800 UTC of 21$^{st}$ to 1200 UTC of 22$^{nd}$. The lowest estimated central pressure had been 976 hPa during at 1200 UTC of 22nd November. The estimated maximum sustained surface wind speed (MSW) was 75 at 1200 UTC of 22$^{nd}$ with pressure drop of 26 hPa. The pressure rapidly increased during 1200 UTC of 22$^{nd}$ to 0000 UTC of 23$^{rd}$. At the time of landfall, the ECP was 976 hPa and MSW was 75 knots (very severe cyclonic storm) gusting to 85 kts.

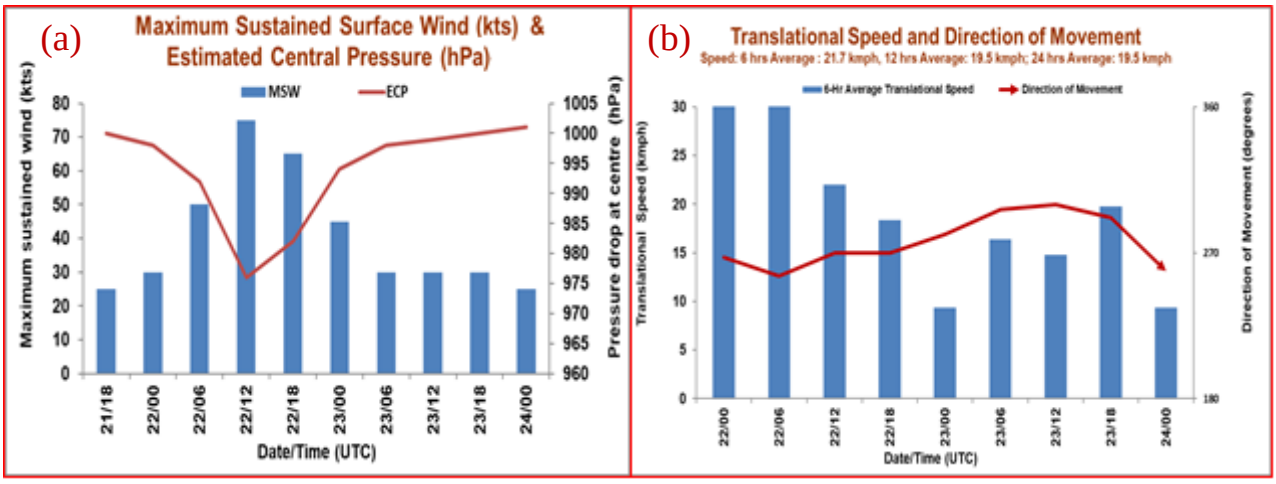



**Fig.4. (a) Maximum sustained surface winds (kts) & (b) Estimated Central Pressure and (b) Mean Translational Speed during life cycle of VSCS GATI**

### 3.4. Translational speed & direction of movement

The twelve hourly movement of VSCS GATI is presented in **Fig.4b**. The 12 hour average translational speed of the cyclone was about 19.5 kmph against the normal speed of 19.3 kmph for VSCS category over AS during post monsoon season. During initial stages of it's development from 1800 UTC of 21$^{st}$ to 0600 UTC of 22$^{nd}$, it moved very fast with an average speed of 35-45 kmph. The east-northeasterly winds in the upper level contributed to this faster movement of the system. The mean wind speed and direction in the deep layer between 850-200 hPa level and the middle layer between 850-500 hPa level is presented in Fig. 3.

## 4. Monitoring of VSCS, 'GATI'

India Meteorological Department (IMD) maintained round the clock watch over the north Indian Ocean and the cyclone was monitored since 12$^{th}$ November, about 10 days prior to the formation of depression over southwest AS on 22$^{nd}$. The cyclone was mainly monitored with the help of available satellite observations from INSAT 3D and 3DR, SCAT SAT, polar orbiting satellites and available ships & buoy observations in the region. Various numerical weather prediction models run by Ministry of Earth Sciences (MoES) institutions (IMD, IITM, NCMRWF, INCOIS), global models and dynamical-statistical models were utilized to predict the genesis, track, landfall and intensity of the cyclone. A digitized forecasting system of IMD was utilized for analysis and comparison of various models' guidance, decision making process and warning products' generation.

#### 4.1 Features observed through satellite

Satellite monitoring of the system was mainly done by using half hourly INSAT-3D and 3DR imageries. Satellite imageries of international geostationary satellites Meteosat-8 & MTSAT and microwave & high-resolution images of polar orbiting satellites DMSP,

NOAA series, TRMM, Metops were also considered. Typical INSAT-3D visible/IR imageries, enhanced colored imageries and cloud top brightness temperature imageries are presented in **Fig.5**. The system showed curved band pattern during genesis and growth stage upto the intensity of CS. It had central dense overcast (CDO) pattern during SCS stage. It showed sheared pattern after landfall.

At 0000 UTC of 22.11.2020 as per satellite imagery, the intensity of the system was T 2.0. Broken low and medium clouds with embedded intense to very intense convection lay over southwest & adjoining west-central Arabian Sea between latitude $7.5^0$N & $12.5^0$N and longitude $50.5^0$E & $57.5\ ^0$E in association with the system. The minimum cloud top temperature has been (Minus) $93^0$C.

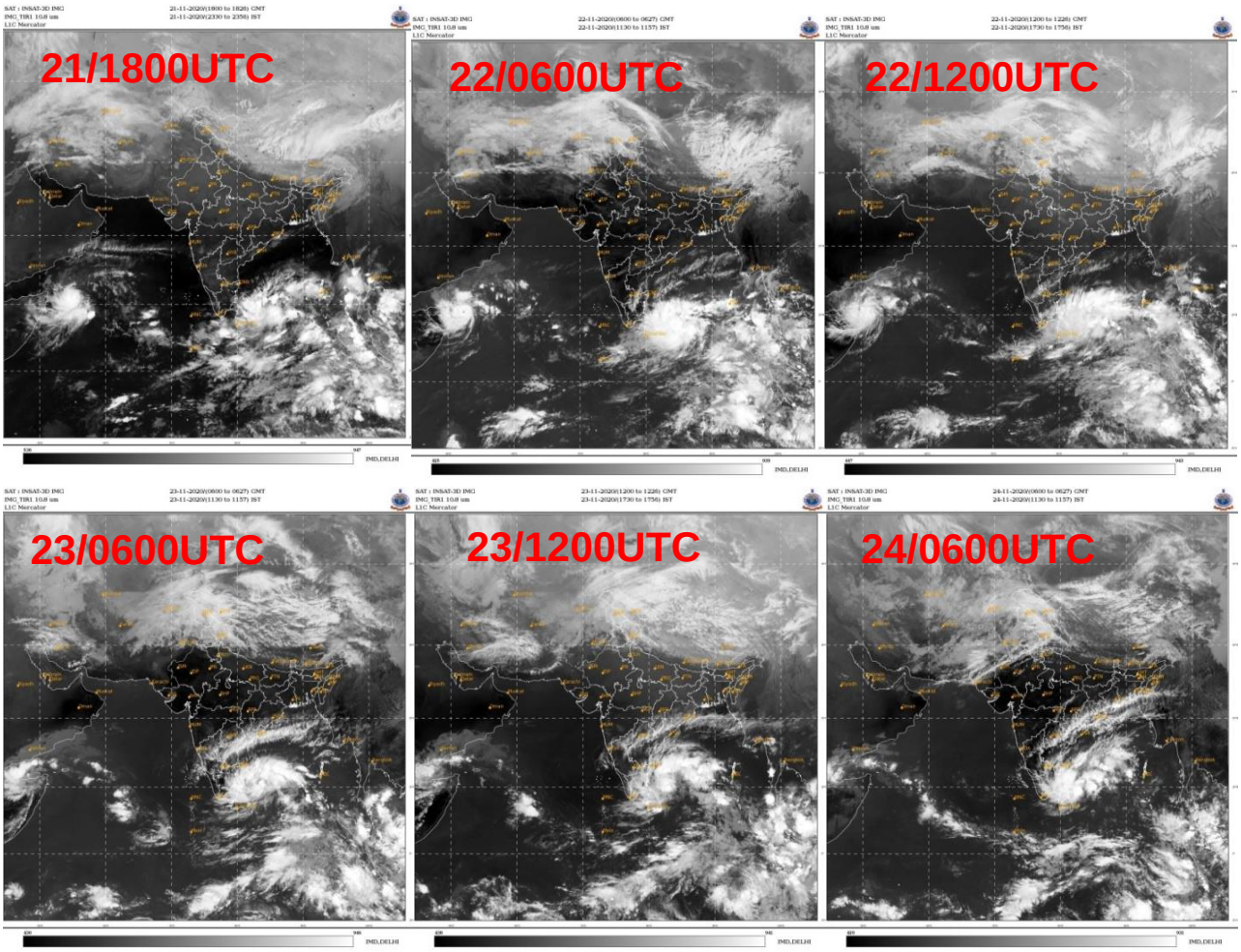



**Fig. 5(a): INSAT-3D IR1 imageries during life cycle of VSCS GATI (21 NOV-24 NOV, 2020)**

At 0300 UTC of 22.11.2020 as per satellite imagery, the intensity of the system was T 2.5. It showed curved band pattern with spiral banding of 0.6. Maximum convection lay in the southern sector of vortex. Broken low and medium clouds with embedded intense to very intense convection lay over southwest & adjoining west-central Arabian Sea between latitude $8^0$N & $12^0$N and longitude $49.5^0$E & $55.5^0$E in association with the system. The minimum cloud top temperature has been (Minus) $93^0$C.

At 0600 UTC of 22.11.2020 as per satellite imagery, the intensity of the system was T 3.0. It showed curved band pattern with spiral banding of 0.75. Satellite imagery indicated rapid organization. Maximum convection lay in the southern sector of vortex. Broken low and medium clouds with embedded intense to very intense convection lay over southwest & adjoining west-central Arabian Sea between latitude 8 $^0$N & 12$^0$N and longitude 49.5$^0$E & 55.5$^0$E in association with the system. The minimum cloud top temperature has been (Minus) 93$^0$C.

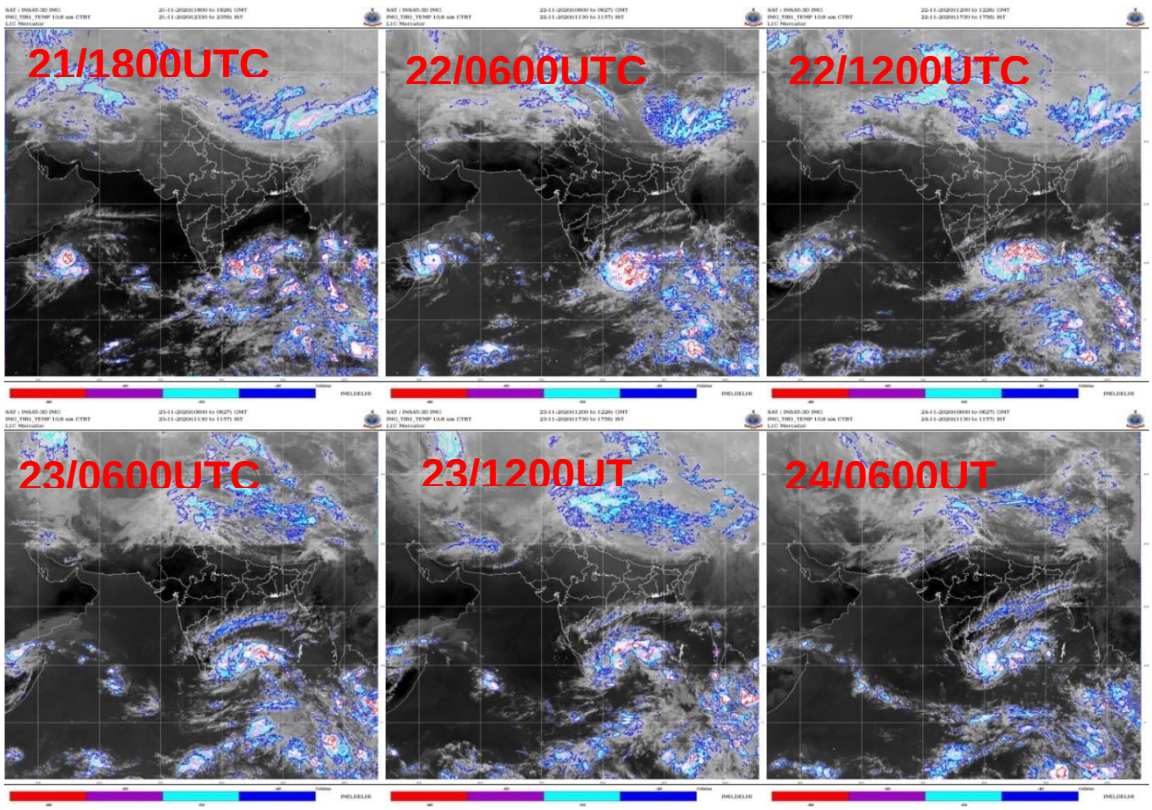



**Fig. 5(b): INSAT-3D CTBT imageries during life cycle of VSCS GATI (21 NOV-24 NOV, 2020)**

At 0900 UTC of 22.11.2020. as per satellite imagery, the intensity of the system was T 4.0. It showed eye pattern with irregular eye. Spiral band had entered into the land indicating interaction of the system with land surface. Maximum convection lay in the southern sector of vortex. Broken low and medium clouds with embedded intense to very intense convection lay over southwest & adjoining west-central Arabian Sea between latitude 8 $^0$N & 12$^0$N and longitude 49.5$^0$E & 55.5$^0$E in association with the system. The minimum cloud top temperature was -93$^0$C

At 1200 UTC of 22.11.2020 as per satellite imagery, the intensity of the system was T 4.5. It showed eye pattern with rugged eye and eye temperature was -37.0 Deg C. Spiral band had entered into the land indicating interaction of the system with land surface. Maximum convection lay in the southern sector of the vortex. Broken low and medium clouds with embedded intense to very intense convection lay over southwest & adjoining west-central Arabian Sea between latitude 8.0º N & 12.0º N and longitude 49.5$^0$E & 55.5$^0$E in association with the system.

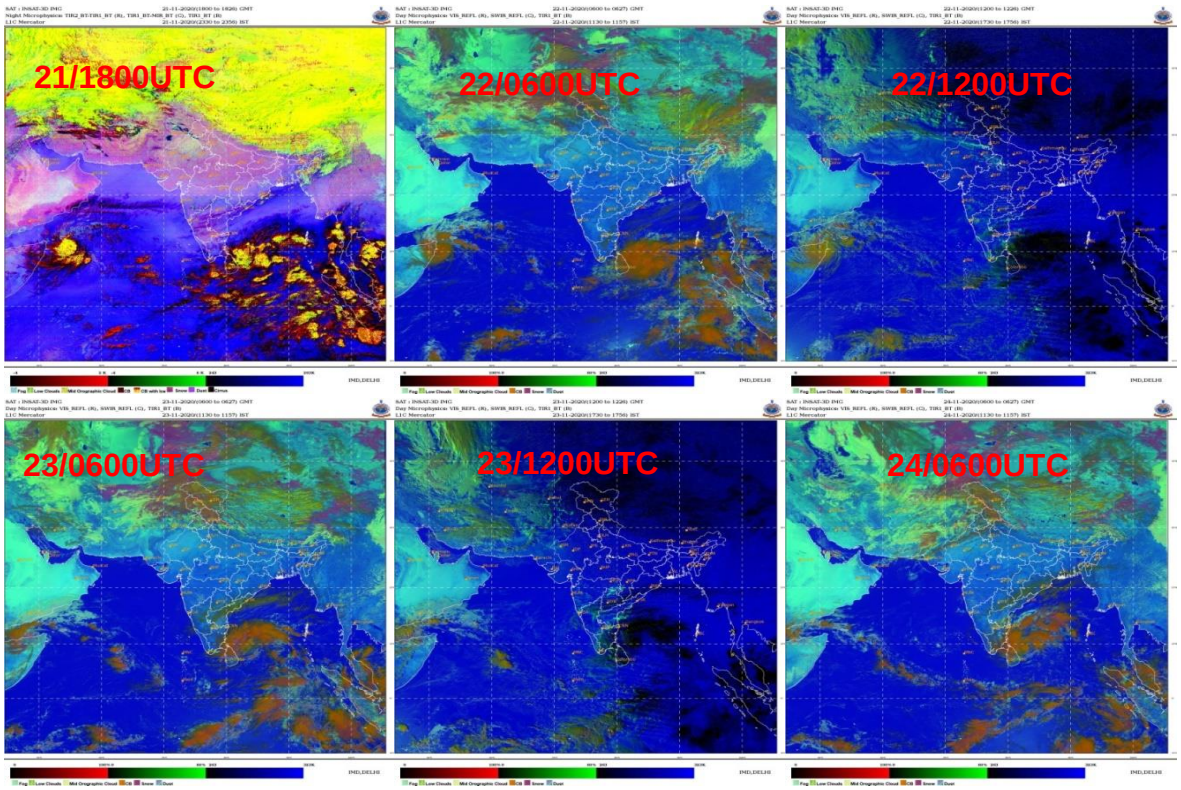



**Fig. 5(c) : INSAT-3D MER_MP imageries during life cycle of VSCS GATI (21 NOV-24 NOV, 2020)**

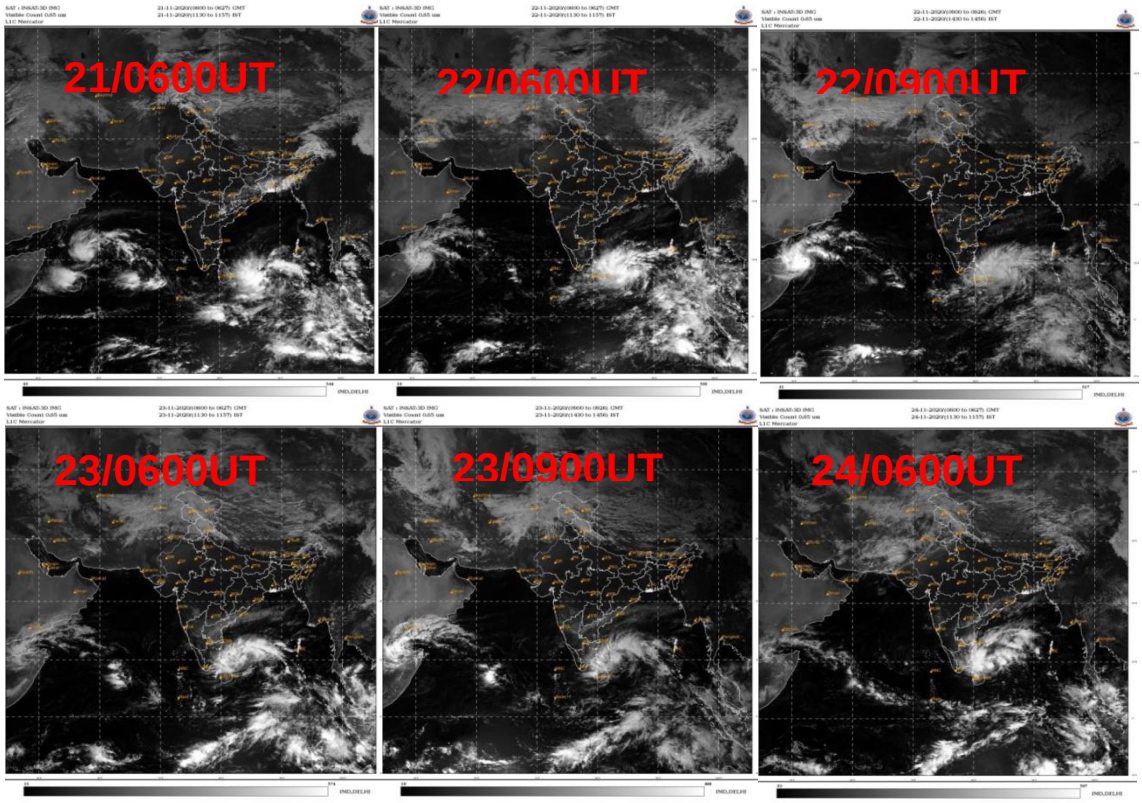



**Fig. 5(d): INSAT-3D Visible imageries during life cycle of VSCS GATI (21 NOV-24 NOV, 2020)**

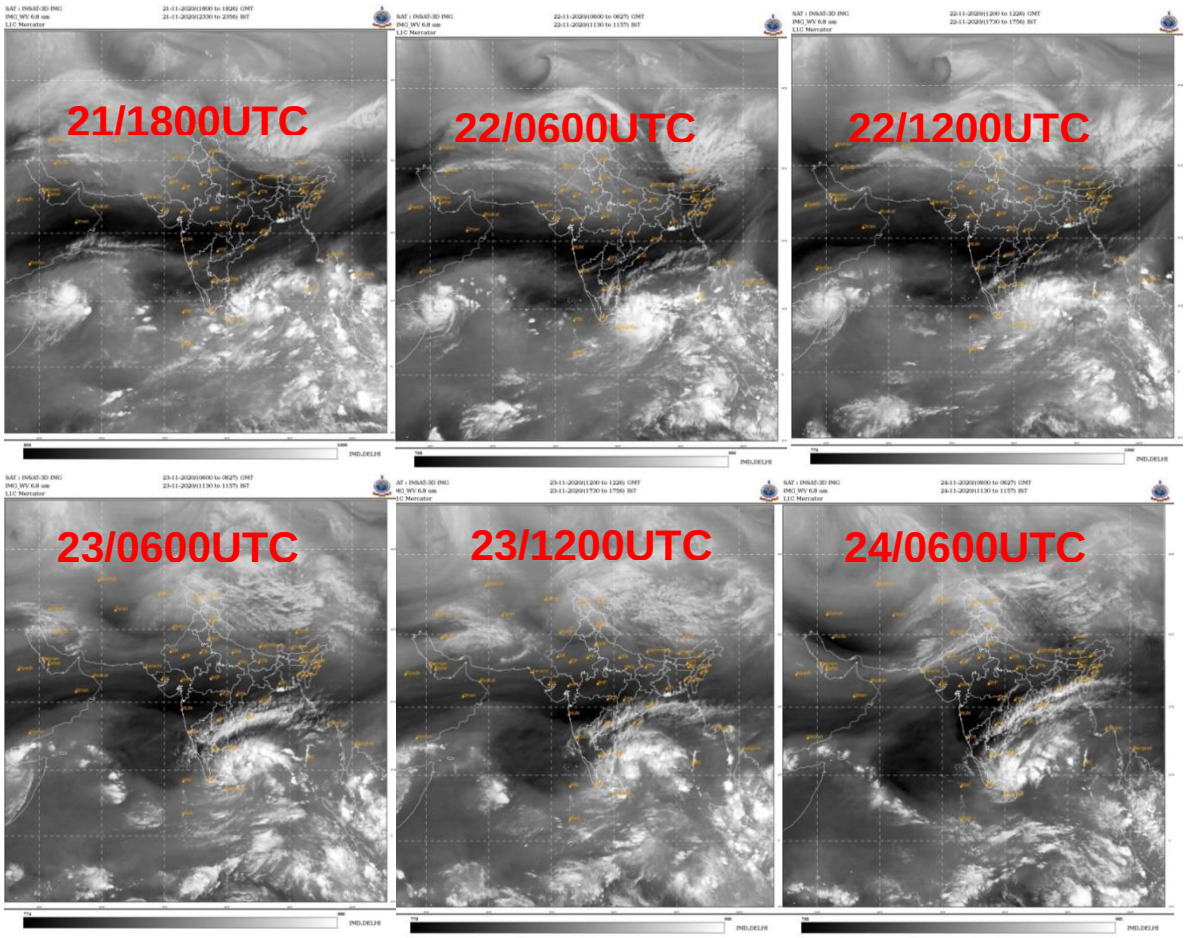



**Fig. 5(e): INSAT-3D Water Vapour imageries during life cycle of VSCS GATI (21-24 NOV, 2020)**

At 2100 UTC of 22.11.2020, as per satellite imagery, associated broken low and medium clouds with embedded moderate to intense convection lay over north Somalia and southwest Arabian Sea between latitude 8.5 $^0$N & 12.5 $^0$N and longitude 40.0$^0$E & 50.5$^0$E in association with the system. Minimum cloud top temperature is - 62.0$^0$C

At 0000 UTC of 23.11.2020 as per satellite imagery, associated broken low and medium clouds with embedded moderate to intense convection lay over north Somalia and southwest Arabian Sea between latitude 8.5 $^0$N & 12.5 $^0$N and longitude 44.0$^0$E & 50.5$^0$E in association with the system. Minimum cloud top temperature was - 62.0$^0$C

At 0600 UTC of 23.11.2020, as per satellite imagery, associated broken low and medium clouds with embedded moderate to intense convection lay over north Somalia coast and adjoining Gulf of Aden. Minimum cloud top temperature was -80.0$^0$C.

At 0000 UTC of 24.11.2020 as per satellite imagery, intensity was T1.5. Convective clouds had sheared away to the north-west of the system. Associated scattered low and medium clouds with embedded intense to very intense convection lay over north Somalia and adjoining Gulf of Aden and neighbourhood. Minimum cloud top temperature was -75.0$^0$C.

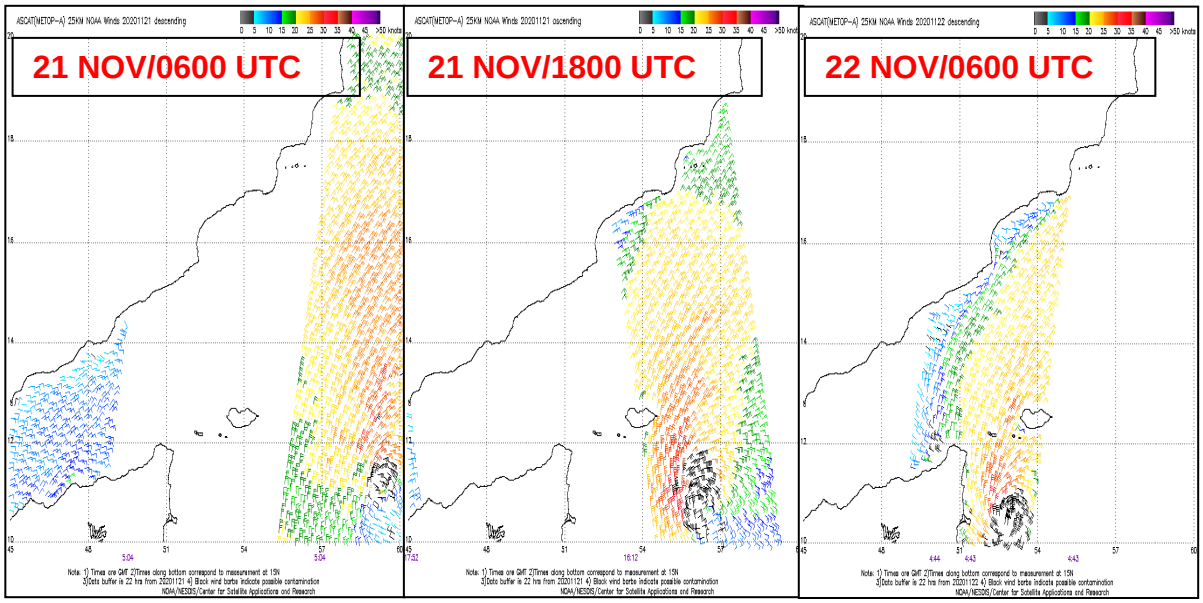



**Fig. 5(f): ASCAT imageries during life cycle of VSCS GATI (21-24 NOV, 2020)**

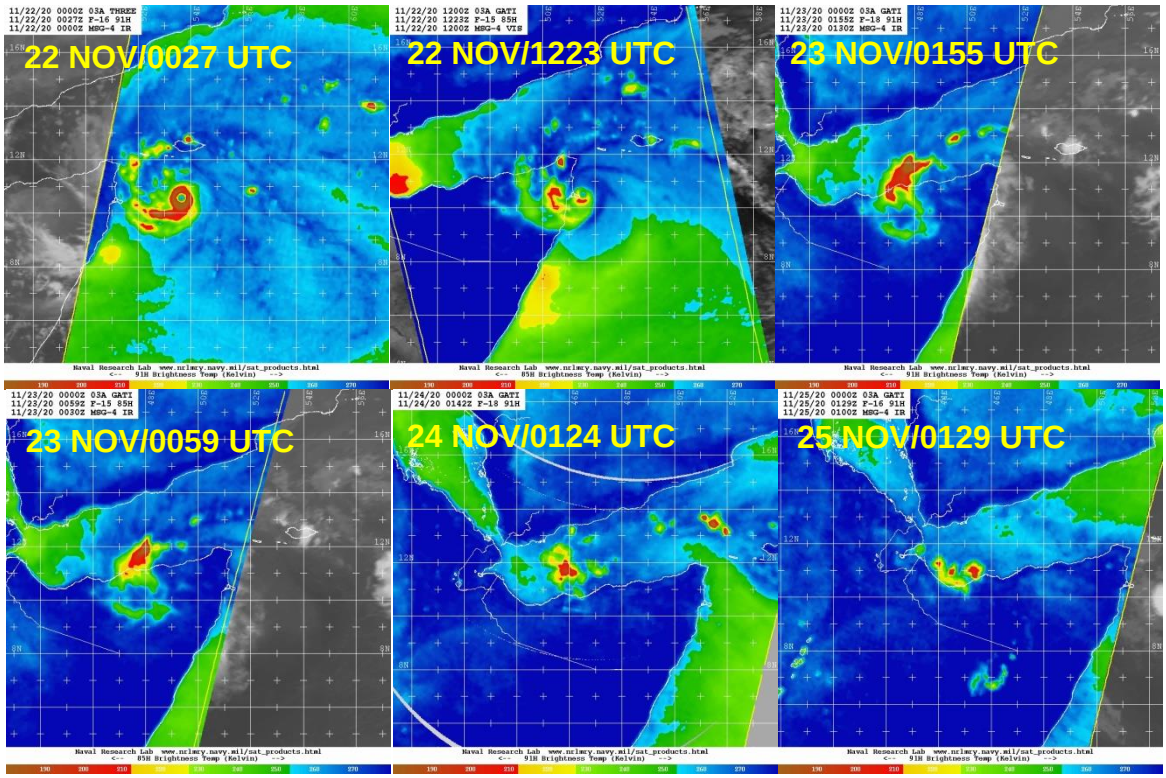



**Fig. 5(g): Microwave imageries during life cycle of VSCS GATI (21-24 NOV, 2020)**

## 5. Dynamical features

IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels during 21st -24th November are presented in **Fig.6.** (The forecast fields are not shown). The analysis of IMD-GFS T-1534 model forecasts based on 0000 UTC of 21st November, 2020 indicated presence of a Well Marked Low (WML) over south AS on 21st. Forecasts were indicating its slight westward movement and weakening in to a Low Pressure Area (LPA) over southwest AS on 23rd, persistence as LPA over southwest AS off Somalia coast on 24th and weakening on 25th.

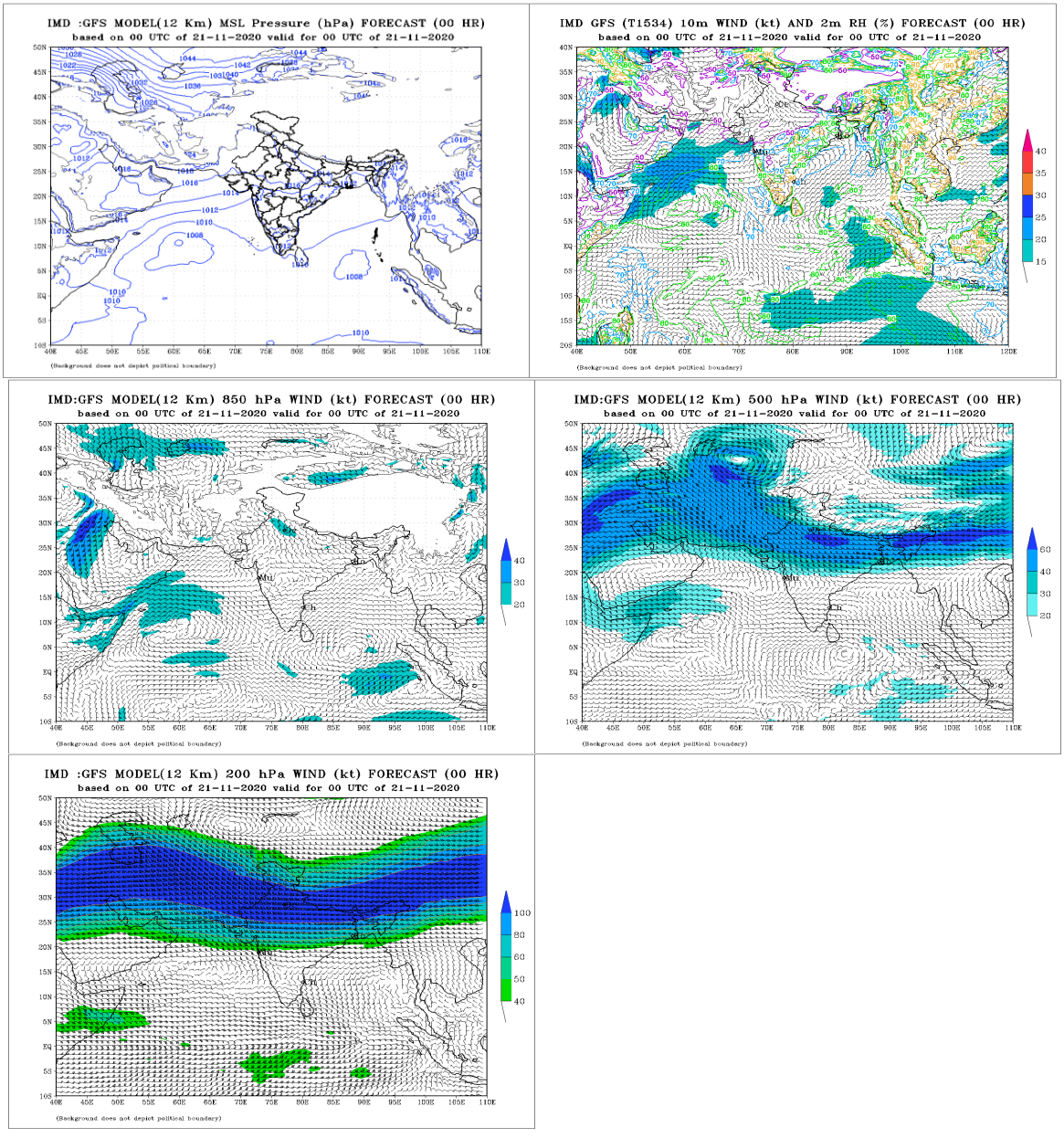



**Fig. 6(a): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 21st November 2020**

The analysis of IMD-GFS T-1534 model based on 0000 UTC of 22nd November, 2020 indicated presence of a CS over southwest AS on 22nd. The forecast fields indicated its slight westward movement and weakening into a D over southwest AS off north Somalia coast on 23rd and weakening on 24th.

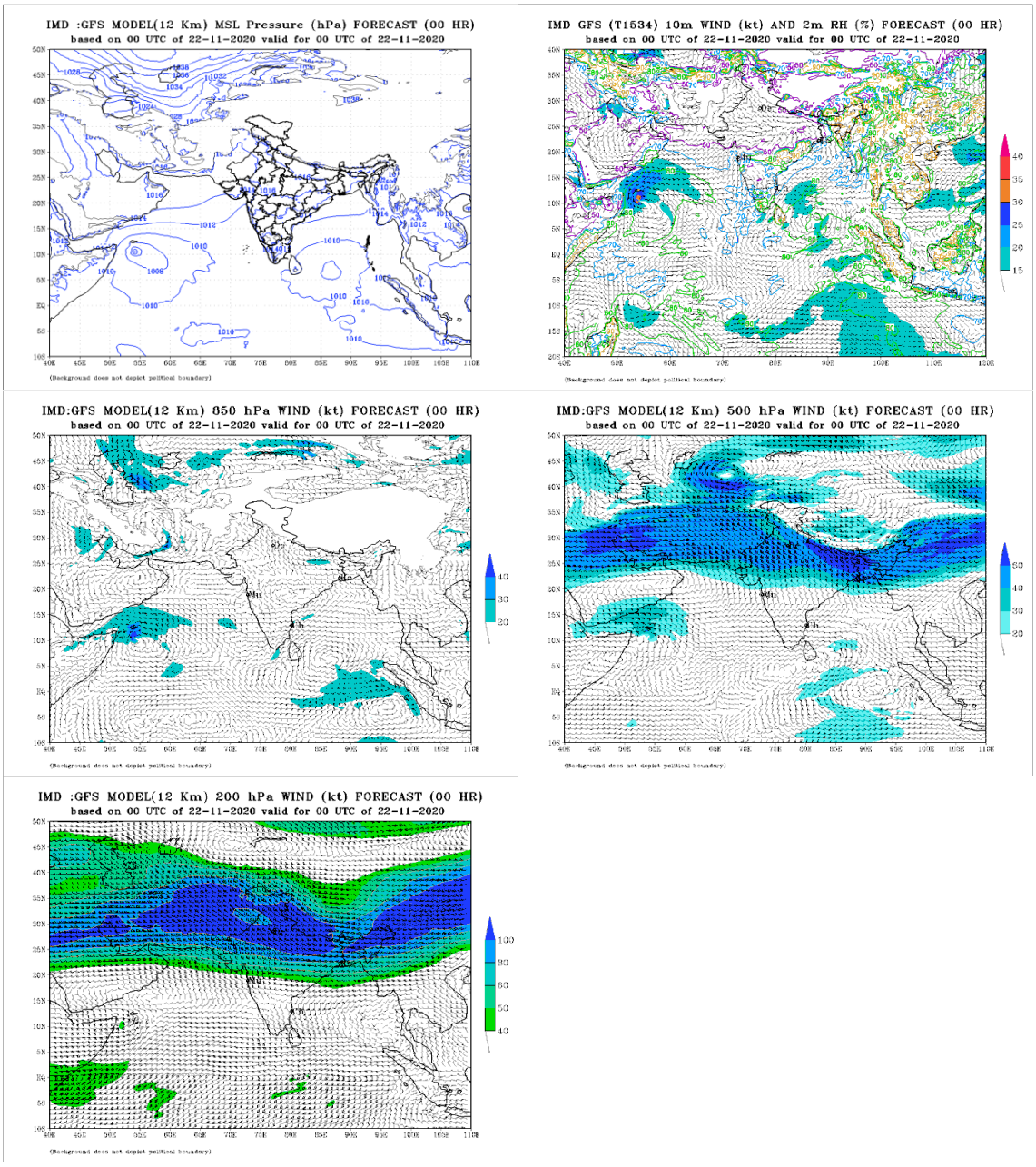



**Fig. 6(b): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 22nd November 2020**

The analysis of IMD-GFS T-1534 model forecasts based on 0000 UTC of 23rd November, 2020 indicated an LPA over north Somalia, though the system lay as a CS over north Somalia.

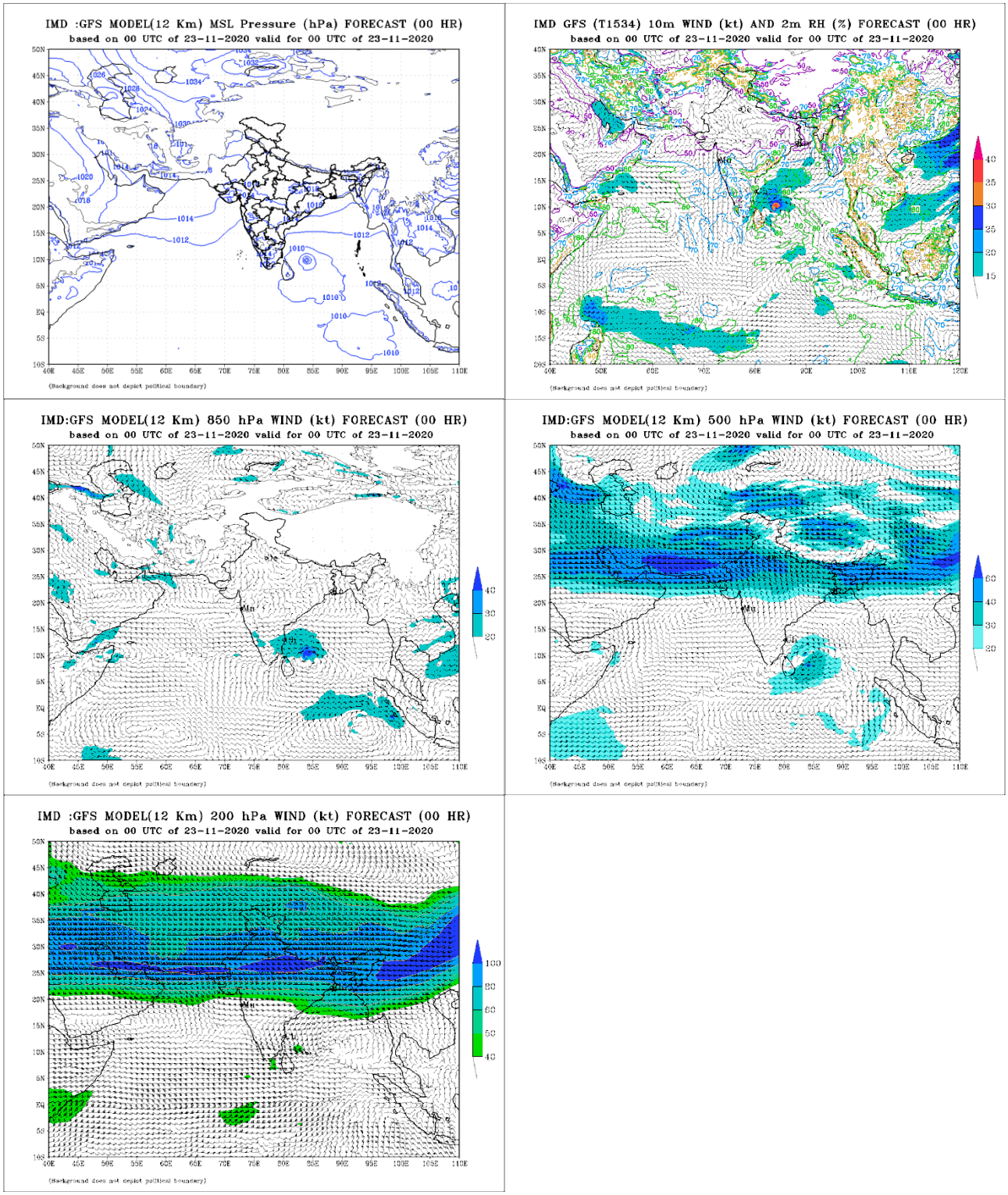



**Fig. 6(c): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 23rd November 2020**

The analysis of IMD-GFS T-1534 model forecasts based on 0000 UTC of 24th November, 2020 indicated a feeble LPA over Gulf of Aden. At that time, the system lay as a depression over Gulf of Aden.

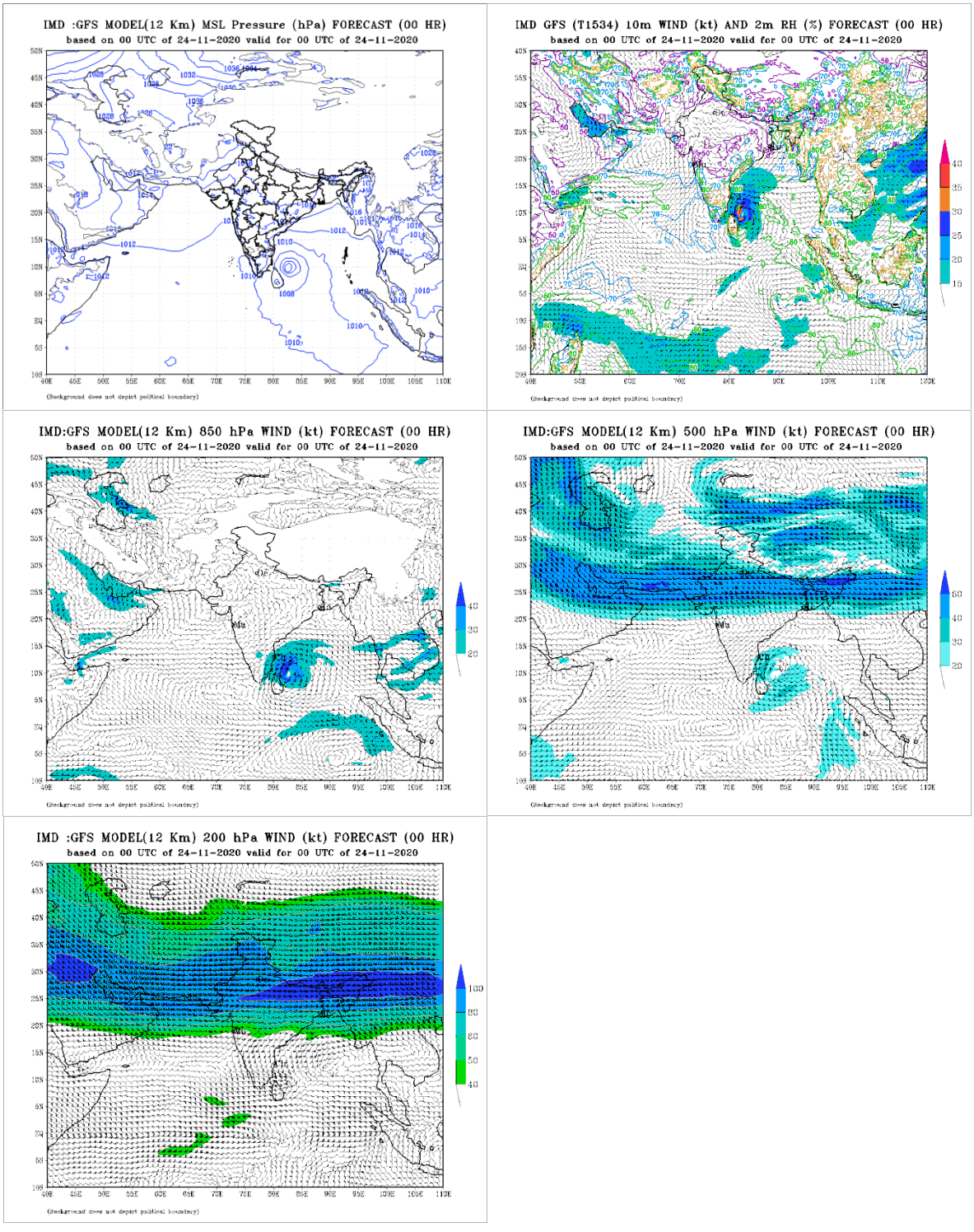



**Fig.6 (d): IMD GFS (T1534) mean sea level pressure (MSLP), winds at 10m, 850, 500 and 200 hPa levels based on 0000 UTC of 24th November 2020**

Thus, IMS GFS couldn't capture the intensity of system correctly. Movement was correctly picked by the model.

## 6. 1 Realized Weather:

Rainfall associated with VSCS GATI based on IMD-NCMRWF GPM merged gauge rainfall data is depicted in **Fig 7**. It indicates heavy rainfall (7-12 cm) over Socotra Islands on 22nd, heavy to very heavy rainfall (7-19 cm) at many places over northeast Somalia with extremely heavy falls (≥20 cm) at a few places on 23rd November, extremely heavy rainfall over Gulf of Aden and adjoining north Somalia on 24th November.

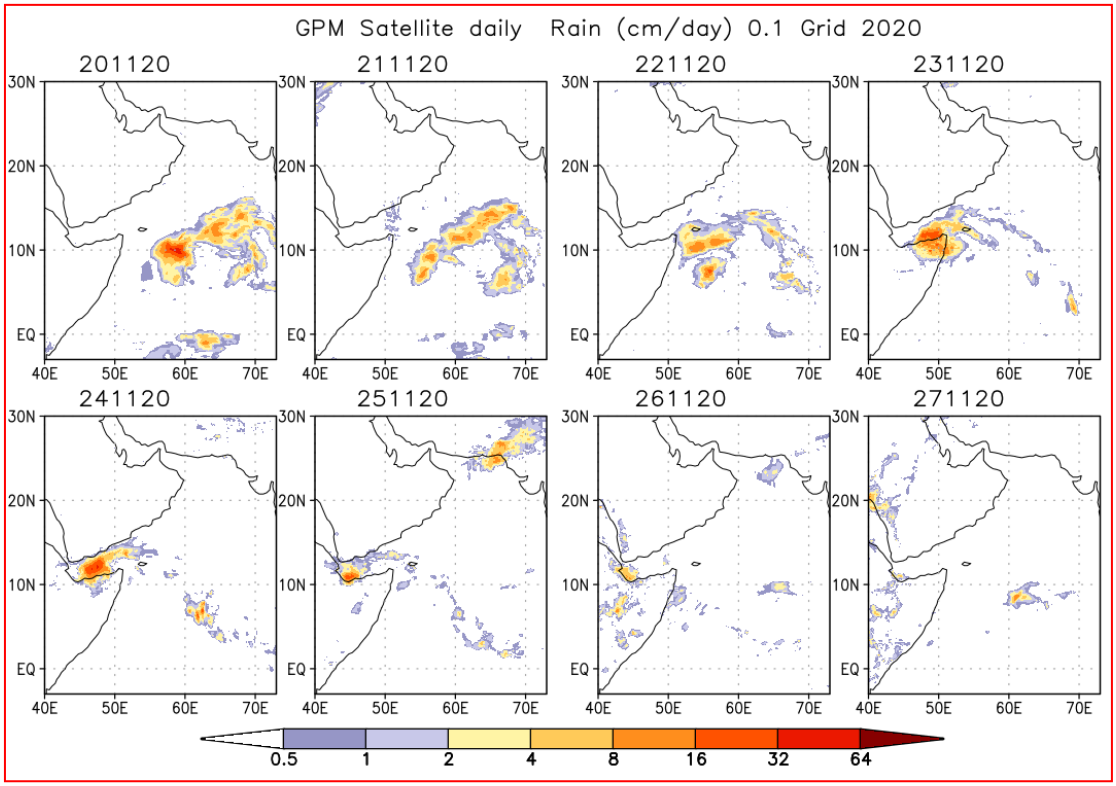



**Fig.7: IMD-NCMRWF GPM merged gauge rainfall during 20th Nov- 27th Nov and 7 days average rainfall (cm/day)**

### 6.2. Wind

The system crossed north Somalia coast with a maximum sustained wind speed 75 kts gusting to 85 kts.

### 6.3 Realized storm surge:

No records are available.

## 7. Damage due to VSCS GATI

Very Severe Cyclonic Storm GATI was the strongest tropical cyclone on record to make landfall in Somalia, and one of few tropical cyclones to do so in the country. GATI caused heavy rainfall over Somalia, peaking at 128 mm in Bosaso. An estimated 10,000 animals were killed by Gati in Ufeyn. The storm killed at least 9 people and displaced approximately 42,000 others in the country and caused millions of dollars in damages. Minor impacts were also observed on the Yemeni island of Socotra and the Ethiopian Highlands. A UN report said, “according to estimates compiled by Puntland authorities, the cyclone has affected about 180,000 people including fishermen, pastoralists, farmers,

traders and other vulnerable groups, such as refugees and IDPs (internally displaced persons)."


**Fig. 8**(a) A house damaged by Cyclone Gati in Xaafuun district. (source: OCHA report dated 25 Nov.).(b) Damaged houses (source: https://www.aa.com.tr, dated 25 Nov.). (c) Fallen electric pole (source: from a twitter user ) . (d) Flood in Puntland's Bari region in Somalia (source : https://newscentral.africa ,dated 25 Nov.) . (e) Gati battered Puntland coastal areas (source: https://guguddetv.com/ dated 23 Nov.) .(f) Flood havoc in the coastal town of Bosaso in northern Somalia (source: https://www.myanmaritv.com/ dated 24 Nov.)

## 8. Performance of operational NWP models

IMD operationally runs a regional model, WRF for short-range prediction and one Global model T1534 for medium range prediction (10 days). The WRF-VAR model is run at the horizontal resolution of 9 km and 3 km with 38 Eta levels in the vertical and the integration is carried up to 72 hours over three domains covering the area between lat. $25^0$S to $45^0$ N long $40^0$ E to $120^0$ E. Initial and boundary conditions are obtained from the IMD Global Forecast System (IMD-GFS) at the resolution of 12 km. The boundary conditions are updated at every six hours interval.

Global models are also run at NCMRWF. These include GFS and unified model adapted from UK Meteorological Office. In addition to the above NWP models, IMD also run operationally dynamical statistical models. The dynamical statistical models have been developed for (a) Cyclone Genesis Potential Parameter (GPP), (b) Multi-Model Ensemble (MME) technique for cyclone track prediction, (c) Cyclone intensity prediction, (d) Rapid intensification and (e) Predicting decay in intensity after the landfall. Genesis potential parameter (GPP) is used for predicting potential of cyclogenesis (T3.0) and forecast for potential cyclogenesis zone. The multi-model ensemble (MME) for predicting the track (at 12h interval up to 120h) of tropical cyclones for the Indian Seas is developed applying multiple linear regression technique using the member models IMD-GFS, IMD-WRF, GFS (NCEP), ECMWF and JMA. The SCIP model is used for 12 hourly intensity predictions up to 72-h and a rapid intensification index (RII) is developed and implemented for the probability forecast of rapid intensification (RI). Decay model is used for prediction of intensity after landfall. In this report performance of the individual models, MME forecasts, SCIP, GPP, RII for the Very Severe cyclonic Storm GATI are presented and discussed.

## 9.1 Prediction of Cyclogenesis [Genesis Potential Parameter (GPP) for GATI]

Grid point analysis and forecast of GPP is used to identify potential zone of cyclogenesis. Fig. 9 (a-h) below shows the predicted zone of cyclogenesis.

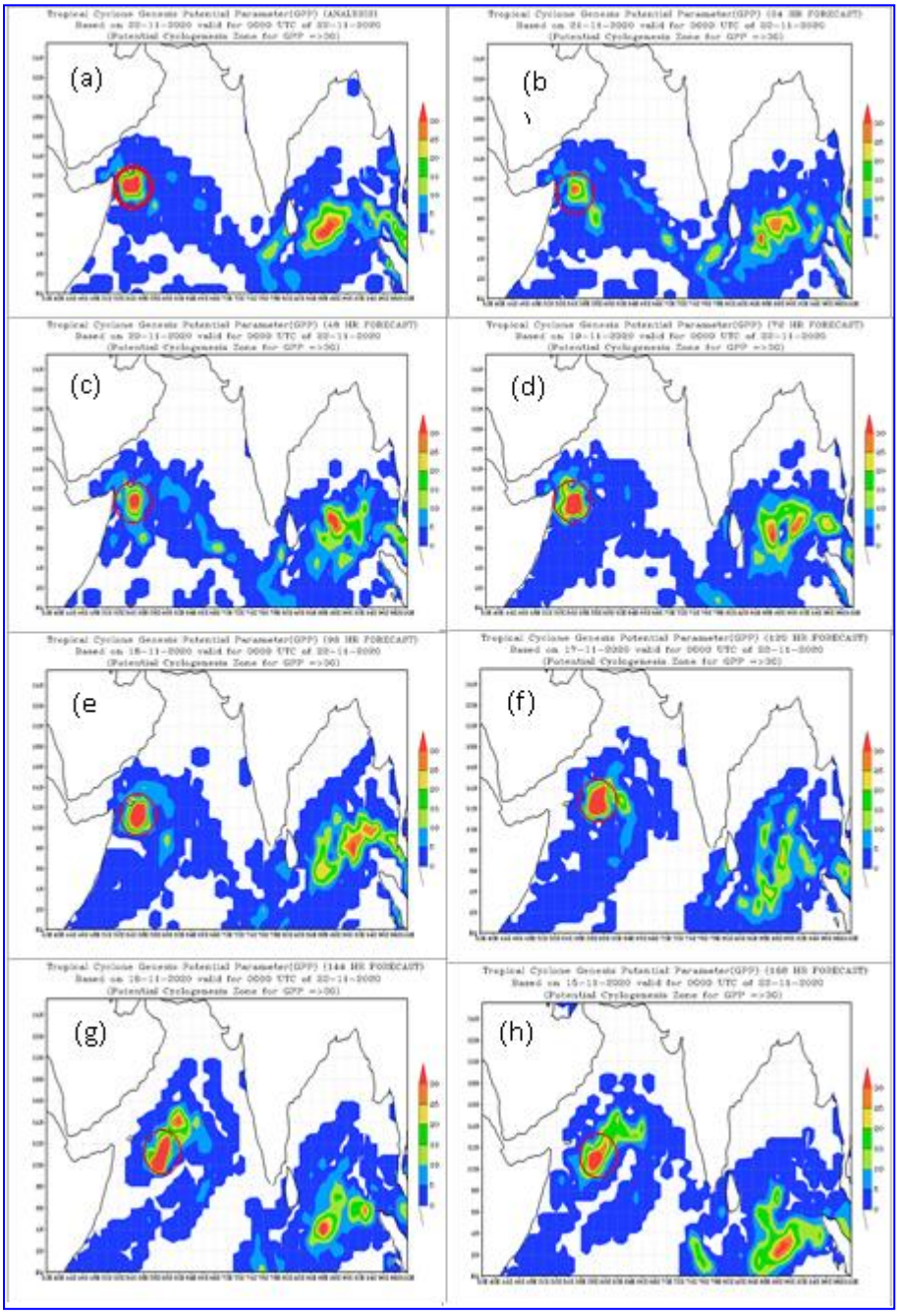



**Fig.9 (a-h): Predicted zone of Cyclogenesis based on 1200 UTC from 15-22 November 2020**

This GPP product predicted Cyclogenesis over the area on 22nd November, 168 hours in advance.

(Product available at http://www.rsmcnewdelhi.imd.gov.in/NWP_CYC/Analysis.htm)

Since all low pressure systems do not intensify into cyclones, it is important to identify the potential of intensification (into cyclone) of a low pressure system at the early stages (T No. 1.0, 1.5, 2.0) of development. For this purpose, an area average analysis of GPP is used. Conditions for (i) Developing system: Threshold value of average GPP ≥ 8.0 and (ii) Non-developing system: Threshold value of GPP < 8.0. From Fig.10, it may be noted that this product also indicated potential for intensification of the system into a Cyclonic storm based on initial condition of 00 UTC of 21st November onwards.

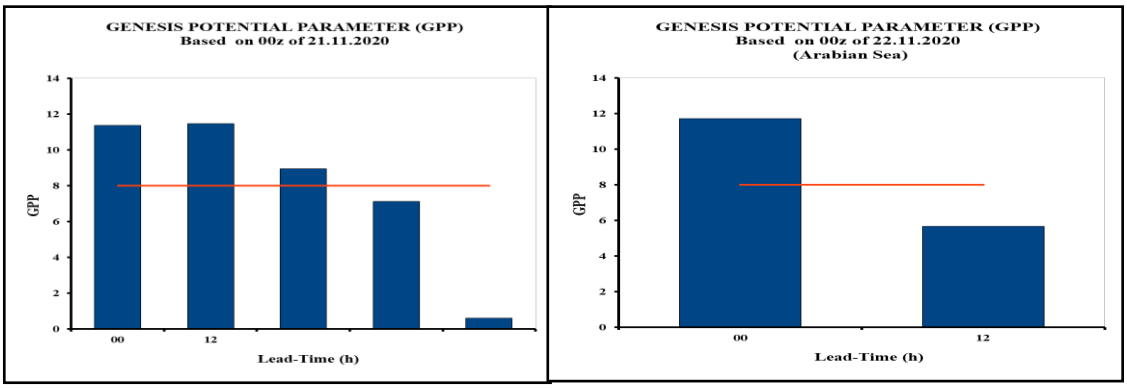



**Fig. 10: Area average analysis and forecasts (a) Area average analysis and forecasts of GPP based on 0000 UTC of 21.11.2020 (b) Area average analysis and forecasts of GPP based on 0000 UTC of 22.11.2020**

## 9.2 Track prediction by NWP models

Track prediction by various NWP models is presented in **Fig.11**. Based on initial conditions of 0000 UTC of 22nd November, most of the models indicated initial west-northwestward movement towards north Somalia coast. However only NCEP GFS and JMA modals did not indicate any landfall and HWRF indicated an initial west-southwestward movement followed by northwestward re-curvature & landfall over north Somalia coast.


**Fig. 11: NWP model track forecast based on 0000 UTC of 22.11.2020**

## 9.3 Track forecast errors by various NWP Models

The average track forecast errors (Direct Position Error) in km at different lead period (hr) of various models are presented in **Table 2**. From the verification of the forecast

guidance available from various NWP models, it is found that the average track forecast errors of HWRF model was minimum for 12 and 24 hours forecast followed by MME.

**Table-2:** Average track forecast errors (Direct Position Error (DPE)) in km (Number of forecasts verified is given in the parentheses)

| LEAD-TIME | 12h | 24h |
|---|---|---|
| **IMD-MME** | 113(1) | 142(1) |
| **ECMWF** | 128(1) | 122(1) |
| **NCEP-GFS** | 142(1) | 279(1) |
| **UKMO** | 114(1) | 167(1) |
| **JMA** | 198(1) | 247(1) |
| **IMD-GFS** | 128(1) | 122(1) |
| **HWRF** | 88(5) | 161(5) |

## 9.4 Landfall forecast error by various NWP Models

Fig.12 shows the landfall errors by the constituent models of MME along with that of MME. Other member models did not provide any landfall forecast.

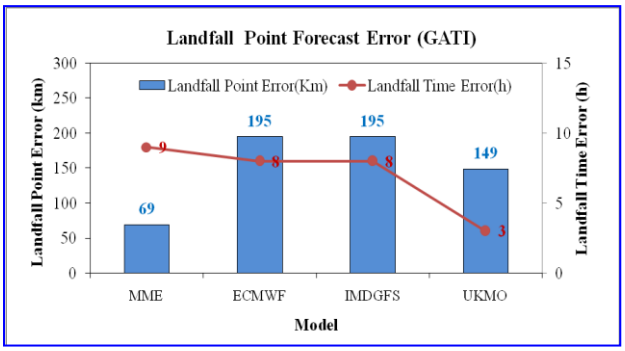



**Fig. 12:** MME Landfall Point and Time Forecast Error of GATI (Forecast based on 00UTC of 22.11.2020; lead time-15h)

## 9.5 Intensity forecast errors by HWRF Model

The intensity forecasts by HWRF model is shown in Table **3(a-b).** The intensity error was high with HWRF model.

**Table-3(c) Average Absolute Error ( INTENSITY ) of IMD-HWRF Model**

(Number of forecasts verified is given in the parentheses) ::

| Lead Time | 12 Hr | 24 Hr | 36 Hr | 48 Hr |
|---|---|---|---|---|
| HWRF | 9.2 (5) | 7.4 (5) | 6.0 (3) | 5.0 (1) |

**Table-3 (d) Root Mean Square (RMSE) ( INTENSITY ) errors of IMD-HWRF Model**

(Number of forecasts verified is given in the parentheses) ::

| Lead Time | 12 Hr | 24 Hr | 36 Hr | 48 Hr |
|---|---|---|---|---|
| HWRF | 10.3 (5) | 9.0 (5) | 8.1 (3) | 5.0 (1) |

To summarise the performance of numerical models it may be noted that though majority of them indicated the genesis and track more or less accurately, the 'explosive' nature of intensification could not be predicted by any of them, due to various limiting factors. SCIP model also could not provide a hint in this case as the 24 hour forecast position predicted by MME based on the initial condition of 0000 UTC of 22$^{nd}$ November, lay over the land and the formula for calculating the Rapid Intensification Index would not perform under the scenario of Post Landfall Characteristics of a Cyclone. Thus the matter to be highlighted here is the limitations by the Dynamical & Statistical models depending on these outputs to correctly prognose the intensity of Cyclonic Storms very close to coast.

## 10. Operational Forecast Performance

### 10.1 Genesis, track, landfall and intensity forecast:

- The extended range outlook issued on 12th November indicated that a depression would form over southwest AS during the week (20-26 November) (about 9 days prior to formation of depression). Actually, depression formed over southwest AS on 21st November.
- The tropical weather outlook issued on 17th November, indicated that a low pressure area would form over south Arabian Sea around 19th with moderate probability of it's intensification into depression (51-75%) around 21st. It was also indicated that the system would move gradually west-northwestwards towards Gulf of Aden by 24th November.

- The first press release issued in association with this system at 1730 hrs IST of 18th November indicated that a depression would form over southwest AS around 21st. It also indicated that, it would move west-northwestwards away from Indian coast (about 3 days and 6 hours prior to formation of depression). Wind warnings for deep sea areas of Arabian Sea were issued in the Press Release along with the advisories for fishermen.
- On 18th November, the detailed daily Report with prognosis and diagnosis issued by IMD under the Forecast Demonstration Project (FDP) indicated that a low pressure area would form over south Arabian Sea around 19th with moderate probability of it's intensification into depression around 21st. It was also indicated that the system would move gradually west-northwestwards towards Gulf of Aden by 24th November. Intense

observation period was declared for Lakshadweep on 18th November and for South Oman and Yemen during 22nd to 25th November. This bulletin is uploaded every day on RSMC website and sent by email to all the beneficiaries of RSMC advisories everyday during FDP Phase (October-December).

- First information that the system would cross north Somalia coast around 10.50N during early morning hours of 23rd was issued at 0900 hrs IST of 22nd November as a severe cyclonic storm with wind speed of 100-110 kmph gusting to 120 kmph. Warnings were further upgraded afterwards. Actually, the system crossed north Somalia coast near 10.50N/51.10E around 1500 UTC with maximum sustained wind speed of 130-140 kmph gusting to 155 kmph.
- Since 18th November onwards, regular updates about the state of Arabian Sea and advisories for fishermen were issued for the states along the west coast of India and Lakshadweep Islands.
- Thus, track and landfall could be predicted well. However, majority of models could not capture the fast movement and rapid intensification of the system over the southwest Arabian Sea leading to higher intensity forecast errors operationally.
- The observed and forecast track based on 0830 hrs IST of 22nd about 12 hrs prior to landfall demonstrating accuracy in track and landfall prediction is presented in Fig. 3. The black and red lines indicate the observed (actual) track and forecast track respectively. The closeness of these two lines indicate very accurate forecast of track (movement) and landfall point of cyclone, GATI.

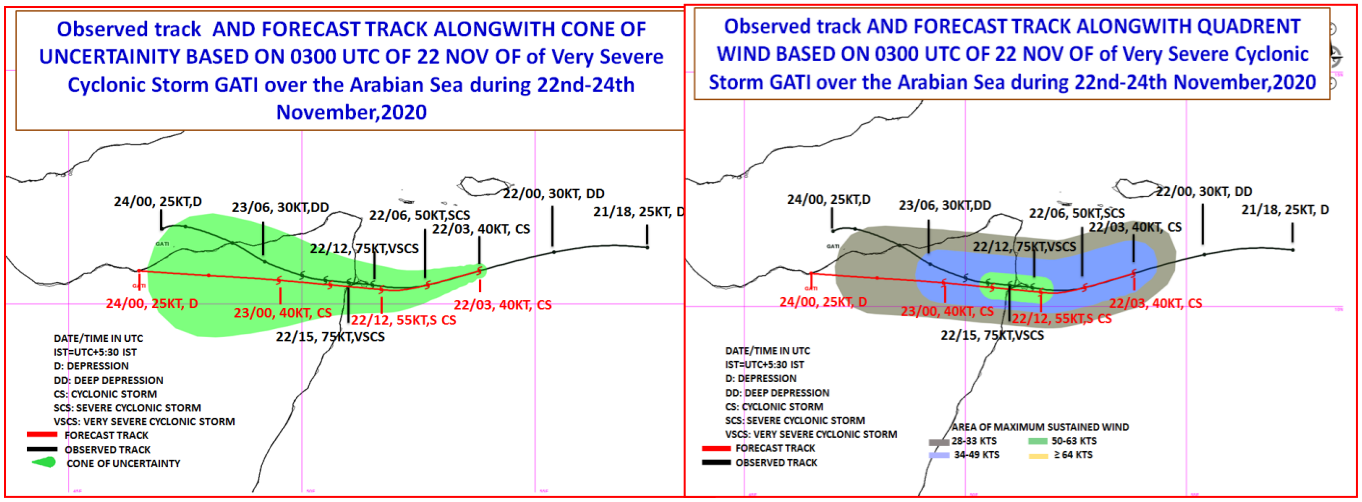



**Fig 13: Observed and forecast track of VSCS GATI based on 0830 hours IST of 22nd November (12hrs in advance of landfall) demonstrating accuracy in track, landfall and intensity forecast**

### 10.2 Landfall forecast error

The 12 hr landfall point forecast error was 7.7km against the long period average (LPA) error of 45 km during 2015-19 respectively. The landfall time forecast error for 12 hrs lead period was 1.5 hours against the LPA (2015-19) error of 2.0 hrs.

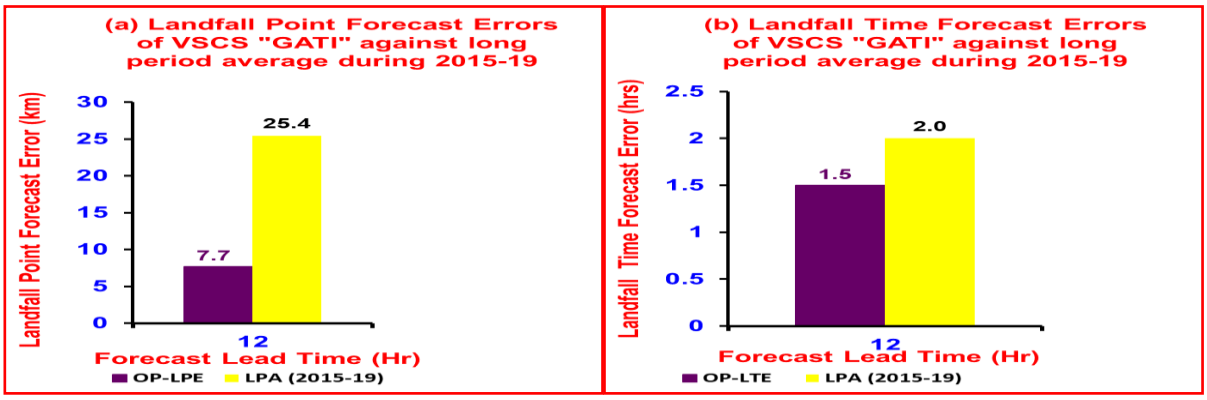



**Fig.14: Landfall (a) point and (b) time forecast errors of VSCS 'GATI" as compared to long period average (2015-19)**

### 10.3 Track forecast error and skill

The track forecast errors (Forecast position – Actual position of Cyclone centre) and skill as compared to Climatological and Persistence forecast are presented in Fig. 5 (a-b). The track forecast errors for 12, 24 and 48 hrs lead period were 61.2, 100.6, and 113.3 km respectively against the LPA errors (2015-19) of 49.6, 80.6 and 125.5 km respectively. (Fig.5a). The track forecast skill was about 63%, 67% and 78% against the LPA skill of 58%, 61%, and 73% for 12, 24 and 48 hrs lead period respectively (Fig.5b).

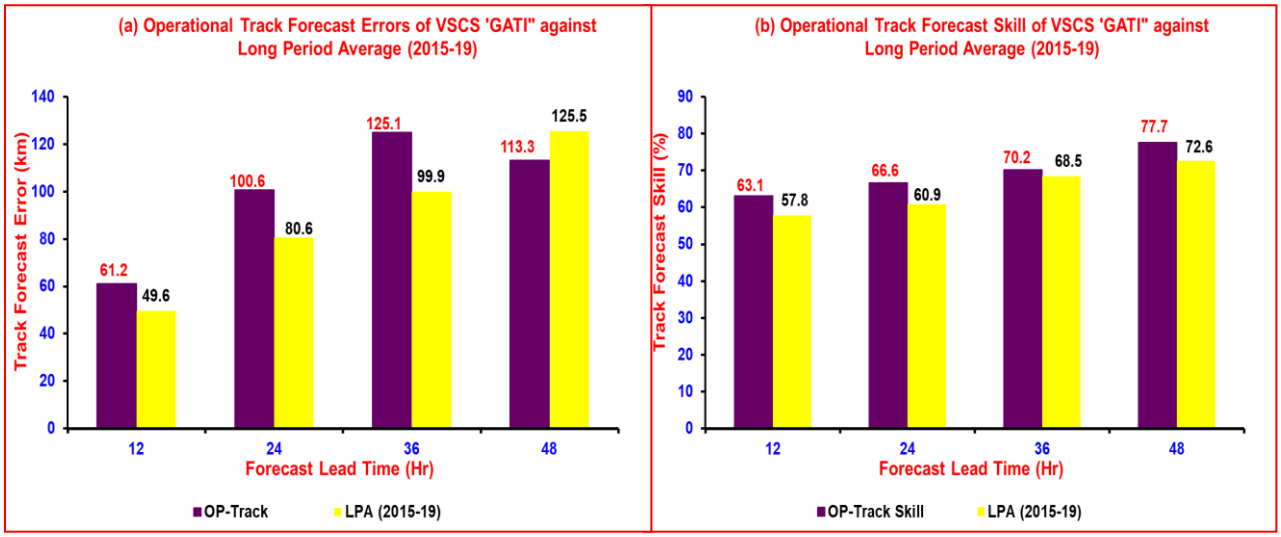



**Fig.15: Track forecast (a) errors and (b) skill of VSCS 'GATI" as compared to long period average (2015-19)**

### 10.4 Intensity forecast error and skill

The intensity forecast errors (Forecast wind – Actual wind) and skill based on absolute errors and root mean square errors are presented in Fig. 6 & 7 respectively.

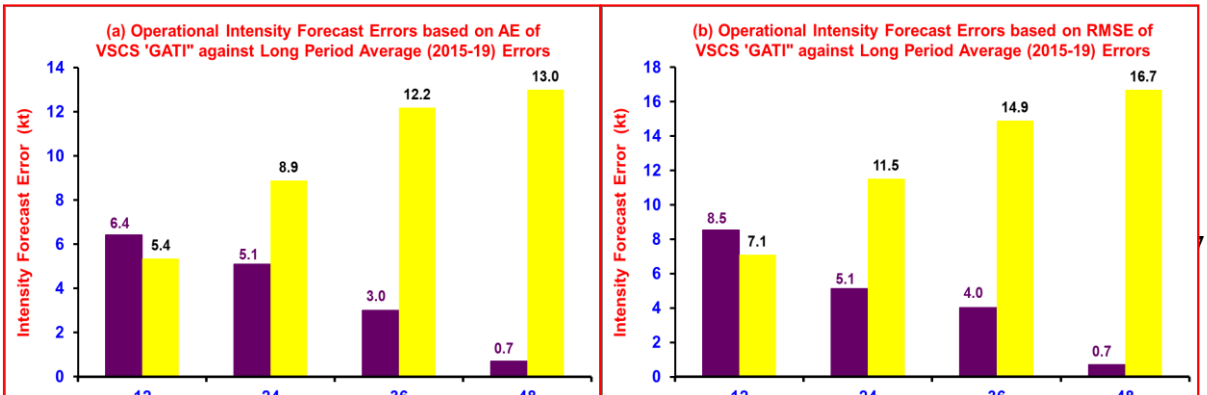


**Fig.16: Absolute errors (AE) and Root Mean Square errors (RMSE) in intensity forecast (winds in knots) of VSCS 'GATI" as compared to long period average (2015-19)**

The absolute error (AE) of intensity (wind) forecast for 12, 24 and 48 hrs lead period were 6.4, 5.1 and 0.7 knots against the LPA errors of 5.4, 8.9 and 13.0 knots during 2015-19 respectively (Fig. 6a). The root mean square error (RMSE) of intensity (wind) forecast for 12, 24 and 48 hrs lead period were 8.5, 5.1 and 0.7 knots against the LPA errors of 7.1, 11.5 and 16.7 knots respectively (Fig. 6b).

The skill (%) in intensity forecast as compared to persistence forecast based on AE for 12, 24 and 48 hrs lead period was 78%, 94% and 99% against the LPA of 29%, 45% and 69% respectively (Fig. 7a). The skill (%) in intensity forecast based on RMSE for 12, 24 and 48 hrs lead period was 78%, 94% and 99% against the LPA of 36%, 49% and 63% respectively (Fig. 7b).

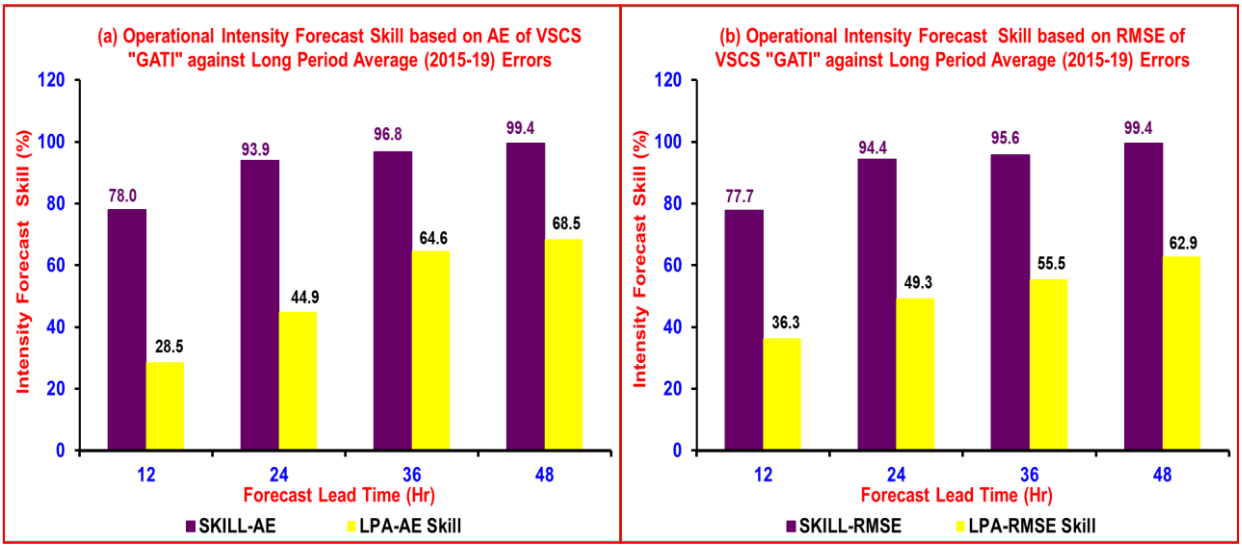



**Fig.17: Skill (%) in intensity forecast based on (a) AE and (b) RMSE of VSCS 'GATI" as compared to long period average (2015-19)**

## 11. Warning Services

### Bulletins issued by Cyclone Warning Division, New Delhi

- **Track, intensity and landfall forecast:** IMD continuously monitored, predicted and issued bulletins containing track, intensity, and landfall forecast for +06, +12, +18, +24, +36 and +48… +72 hrs lead period till the system weakened into a low pressure area. The above forecasts were issued from the stage of depression onwards along with the cone of uncertainty in the track forecast five times a day

and every three hours during the cyclone period. The hourly updates were also provided to Oman on the day of landfall till the system crossed Oman coast. Typical graphical product is presented in **Fig. 6a**.

- **Cyclone structure forecast for shipping and coastal hazard management** The radius of maximum wind and radii of MSW ≥28 knots, ≥34 knots, ≥50 knots and ≥64 knots wind in four quadrants of cyclone was issued every six hourly giving forecast for +06, +12, +18, +24, +36 and +72 hrs lead period. Typical graphical product is presented in **Fig. 6b**.
- **Adverse weather warning bulletins:** The tropical cyclone forecasts alongwith expected adverse weather like heavy rain; gale wind and storm surge was issued with every three hourly update to Somalia. The bulletins also contained the suggested action for disaster managers and general public in particular for fishermen. These bulletins were also issued to Defense including Indian Navy & Indian Air Force.
- **Warning graphics:** The graphical display of the observed and forecast track with cone of uncertainty and the wind forecast for different quadrants were disseminated by email and uploaded in the RSMC, New Delhi website (http://rsmcnewdelhi.imd.gov.in/) regularly. The adverse weather warnings related to gale/squally wind & storm surge were also presented in graphics in the website.
- **Warning and advisory through social media:** Daily updates (every six hourly or whenever there was any significant change in intensity/track/landfall) were uploaded on face book and twitter regularly during the life period of the system. Bulletins were also issued to state level disaster managers through whatsapp. The tropical cyclone advisories were also sent to Oman Meteorological Department through whatsapp.
- **Press release and press briefing:** Press and electronic media were given daily updates since inception of system through press release, e-mail, website and SMS.
- **Warning and advisory for marine community:** The three/six hourly Global Maritime Distress Safety System (GMDSS) bulletins were issued by the Marine Weather Services division at New Delhi and bulletins for maritime interest were issued by Area cyclone warning centres of IMD at Chennai, and Cyclone warning centres at Thiruvananthapuram and Ahmedabad to ports, fishermen, coastal and high sea shipping community.
- **Fishermen Warning:** Regular warnings for fishermen for deep sea of central and north Arabian Sea and the states of Gujarat, Maharashtra & Goa, Karnataka, Kerala and Lakshadweep.
- **Advisory for international Civil Aviation:** The Tropical Cyclone Advisory Centre (TCAC) bulletin for International Civil Aviation were issued every six hourly to all meteorological watch offices in Asia Pacific region for issue of significant meteorological information (SIGMET). It was also sent to Aviation Disaster Risk Reduction (ADRR) centre of WMO at Hong Kong.
- **Diagnostic and prognostic features of cyclone:** The prognosis and diagnosis of the systems were described in the RSMC bulletins.

- **Hourly Bulletin:** Hourly updates on the location, distance from recognised station, intensity and landfall commenced from 0700 UTC of 24th till 1600 UTC on the day of landfall.

**Bulletins issued by RSMC New Delhi, IMD are presented in Table 4(a).**
**Table 4 (a): Bulletins issued by RSMC New Delhi**

| S.N | Bulletin | No. of Bulletins | Issued to |
|---|---|---|---|
| 1 | National Bulletin | 17 | 1. IMD's website, RSMC New Delhi website<br>2. FAX and e-mail to Control Room Ministry of Home Affairs & National Disaster Management Authority, Cabinet Secretariat, Minister of Science & Technology, Headquarter Integrated Defense Staff, Director General Doordarshan, All India Radio, National Disaster Response Force, Chief Secretary- Kerala, Karnataka, Goa, Gujarat and Maharashtra, Administrator- Lakshadweep Islands, Union Territory of Daman and Diu, Union Territory of Dadar and Nagar Haveli. |
| 2 | RSMC Bulletin | 18 | 1. IMD's website<br>2. WMO/ESCAP member countries and WMO through GTS and E-mail including Yemen and Somalia. |
| 3 | GMDSS Bulletins | 7 | 1. IMD website, RSMC New Delhi website<br>2. Transmitted through WMO Information System (WIS) to Joint WMO/IOC Technical Commission for Ocean and Marine Meteorology (JCOMM) |
| 4 | Tropical Cyclone Advisory Centre Bulletin (Text & Graphics) | 08 | 1. Met Watch offices in Asia Pacific regions and middle east through GTS to issue Significant Meteorological information for International Civil Aviation.<br>2. WMO's Aviation Disaster Risk Reduction (ADRR), Hong Kong through ftp<br>3. RSMC website |
| 5 | Tropical Cyclone Vital Statistics | 09 | Modelling group of IMD, National Centre for Medium Range Weather Forecasting Centre (NCMRWF), Indian National Centre for Ocean Information Services (INCOIS), Indian Institute of Technology (IIT) Delhi, IIT Bhubaneswar etc |
| 6 | Warnings through SMS | Daily | SMS to disaster managers at national level and concerned states (every time when there was change in intensity)<br>To general public to users registered with RSMC website from the states of Kerala, Karnataka, Goa, Gujarat and Maharashtra and National level disaster managers.<br>Through INCOIS on Ocean State Forecast |

**Bulletins issued by ACWC Mumbai/CWC Thiruvananthapuram are presented in Table 4(b)**

| S.No. | Type of Bulletin Number | No. of Bulletins issued | |
|---|---|---|---|
| | | ACWC Mumbai | CWC Thiruvananthapuram |
| 1. | Sea Area Bulletins | 14 | - |
| 2. | Coastal Weather Bulletins | 12 | 9 |
| 3. | Fishermen Warnings issued | 21 | 18 |
| 4. | Port Warnings | 8 | 2 |
| 5. | Heavy Rainfall Warning | NIL | 15 |
| 6. | Gale Wind Warning | NIL | - |
| 7. | Storm surge Warning | NIL | - |
| 8. | Information & Warning issued to State Government and other Agencies | NIL | 18 |
| 9. | SMS | 448 | 7 |
| 10. | No. of Press releases | NIL | - |
| 11. | No. of impact based warnings for<br>a. District<br>b. City | NIL | - |
| 12. | No. of whatsapp messages | All bulletins and warning communicated to concerned group | 16 |
| 13. | No. of updates on facebook | 5 | 17 |
| 14. | No. of updates on tweeter | 5 | 17 |
| 15 | No. of warning video released | - | - |
| 16. | No. of Audio bites released | - | - |

## 12. Summary

Very Severe Cyclonic Storm (VSCS) “GATI” originated from a low pressure area that formed over central parts of south Arabian Sea (AS) on 19th November. It concentrated into a depression at 1800 UTC of 21st. Moving west-southwestwards, it explosively intensified into a deep depression in the early morning (0000 UTC) of 22nd and further into the cyclonic storm **“GATI”** in the same morning (0300 UTC), into a severe cyclonic storm in the noon (0600 UTC) and into very severe cyclonic storm in the afternoon (0900 UTC) over southwest AS. It reached its peak intensity of 75 knots in the same evening

(1200 UTC) over the southwest AS. Continuing to move westwards, it crossed Somalia coast near latitude 10.45°N and longitude 51.10°E between 1400 and 1500 UTC of 22nd as a very severe cyclonic storm with estimated wind speed of 130-140 kmph gusting to 155 kmph. Continuing to move nearly westwards, it weakened into a severe cyclonic storm in the early hours (2100 UTC of 22nd) of 23rd, into a cyclonic storm in the early morning (0000 UTC) and into a deep depression in the same noon (0600 UTC) over north Somalia. Thereafter, it moved west-northwestwards and emerged into Gulf of Aden in the evening (1200 UTC) of 23rd. Continuing to move west-northwestwards, it weakened into a depression in the early morning (0000 UTC) of 24th over Gulf of Aden and adjoining north Somalia and into a well marked low pressure area in the noon (0600 UTC) of 24th over the same region.

## 13. Acknowledgement:

India Meteorological Department (IMD) and RSMC New Delhi duly acknowledge contribution from WMO and Oman Meteorological Department in dissemination of bulletins and warnings associated with VSCS GATI.

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