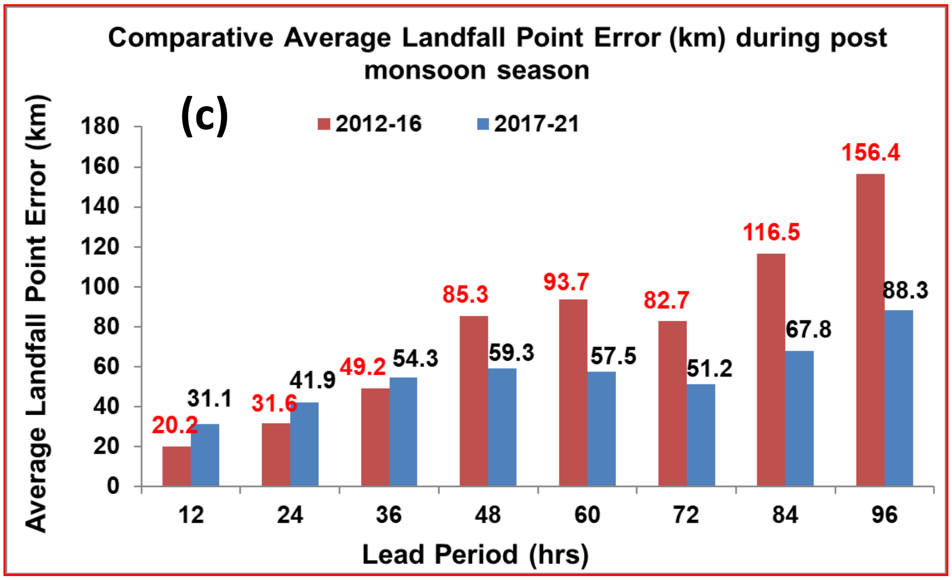


Fig. 4.9. Comparative operational (a) track and (b) intensity and (c) Landfall forecast in the post monsoon season during 2017-21 against 2012-16.

4.5. **A case study of Tropical Cyclone Ockhi**

In this section, the details of the tropical cyclone (TC-OCKHI) are discussed to bring out various forecasting issues and challenges related to the cyclone during the NE monsoon season. The TC- Ockhi was responsible for deaths of over 350 people from southern Tamil Nadu and Kerala, between 30 Nov and 3 Dec 2017. There were also some unidentified fishers from the north-eastern states of India who were lost at sea while working on-board fishing vessels. The full force of the storm was borne by fishermen at sea, unlike the previous cyclones over the Arabian sea (Manas Roshan 2019).

The TC OCKHI formed as a low pressure area over southwest Bay of Bengal (BOB) and adjoining areas of south Sri Lanka on 28th Nov /0300 UTC and became well marked on 29th /0000 UTC over the same region. The vertical wind shear of horizontal wind was moderate to high (15-30 knots) over the southwest Bay of Bengal and adjoining Sri Lanka coast. Under the favourable environmental conditions, it concentrated into a Depression (D) over southwest BOB off southeast Sri Lanka coast on 29th / 0300 UTC.

Moving westwards, it crossed Sri Lanka and emerged into Comorin area by 29th /1200 UTC. It intensified into a Deep Depression (DD) on 29th/2100 UTC. Moving northwestwards it intensified into a Cyclonic Storm (CS) on 30th / 0300 UTC over the Comorin area, into a Severe Cyclonic Storm (SCS) over Lakshadweep area on 01st December / 0000 UTC and further into a Very Severe Cyclonic Storm over southeast Arabian Sea (AS) to the west of Lakshadweep by 01st / 0900 UTC.

Generally, for the North Indian Ocean basin, TCs are considered to have undergone rapid intensification (RI)/ rapid weakening (RW) whenever 30 knots increase/decrease is noted in maximum sustained surface wind speed (MWS; Vmax) in 24 hrs. It is interesting to note that OCKHI underwent RI between 01st /0000 UTC to 02nd 0000 UTC and attained its peak intensity of 150-160 kmph gusting to 180 kmph on 2nd /0900 UTC with lowest central pressure of 976 hPa over the Arabian Sea. It then gradually recurved north-northeastwards, maintained its VSCS intensity till 04th / 1200 UTC and then weakened gradually. It crossed the south Gujarat coast as a well-marked low on 06th Dec/0000 UTC (IMD, 2018). More details of its genesis and tracks are available in Geetha and Balachandran (2020) and the IMD (2018) report on TC-Ockhi (https://rsmcnewdelhi.imd.gov.in/uploads/report/26/26_83ec45_ockhi%20pre.pdf).

The system caused extensive damages over extreme south Tamil Nadu and south Kerala during its developmental stages on 29-30 Nov. The system centre was about 60 km from Kanyakumari, the southern-most tip of peninsular India on 30th Nov/ 0300 UTC when it intensified from DD to CS stage (as per IMD's best track data). Even though the centre of the system did not cross the coast and move inland, Kanyakumari and Thiruvananthapuram (Kerala) bore the brunt of the fury of the eye-wall region of the TC during 29th night-30th Nov morning. The IMD's best track of TC-OCKHi is shown in Fig. 4.10 and spatial pattern of mean sea level pressure on 29th Nov and 30th Nov is shown in Fig. 4.11. These charts show the movement of TC-OCKHI and quick intensification by 30th Nov near the Comorin area.

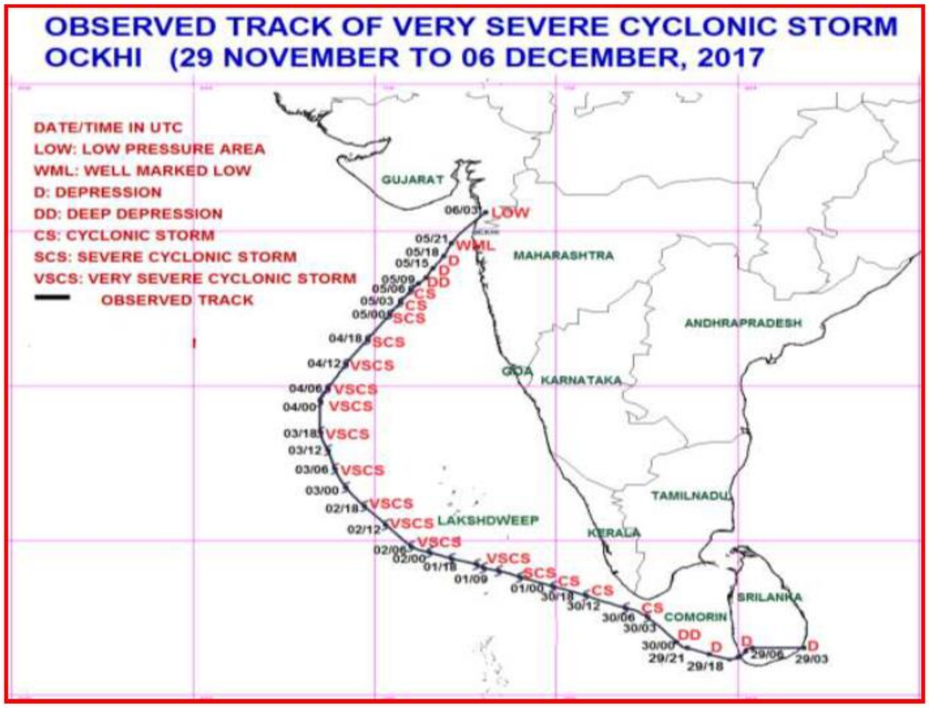
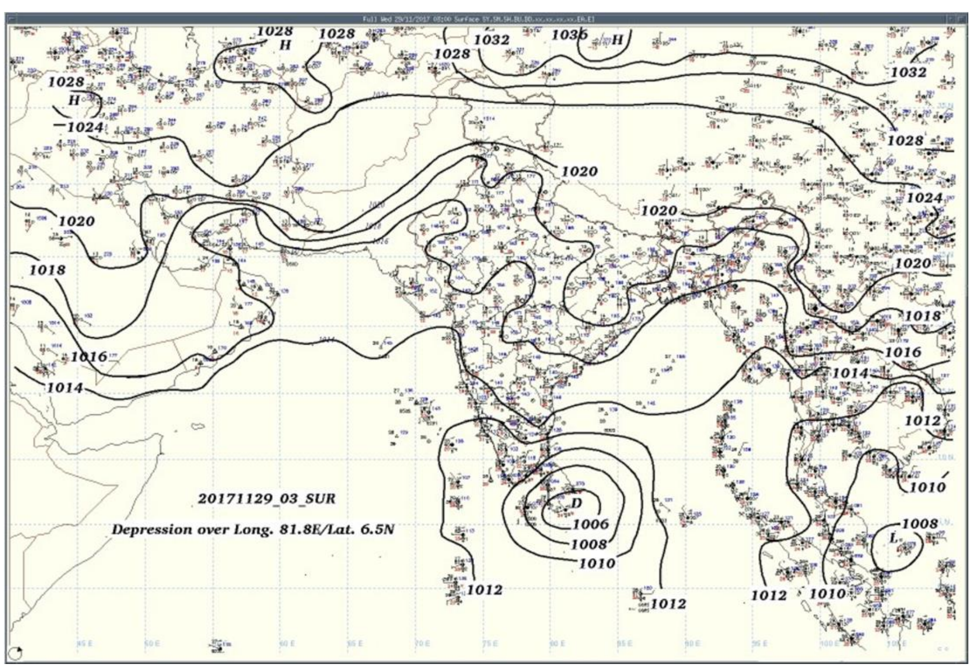
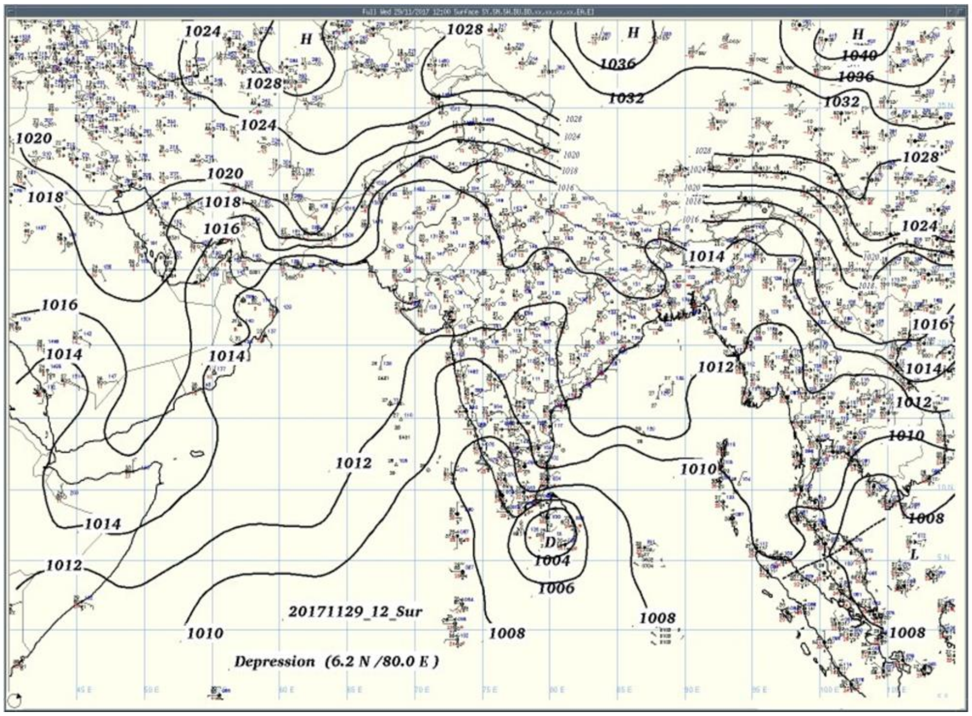


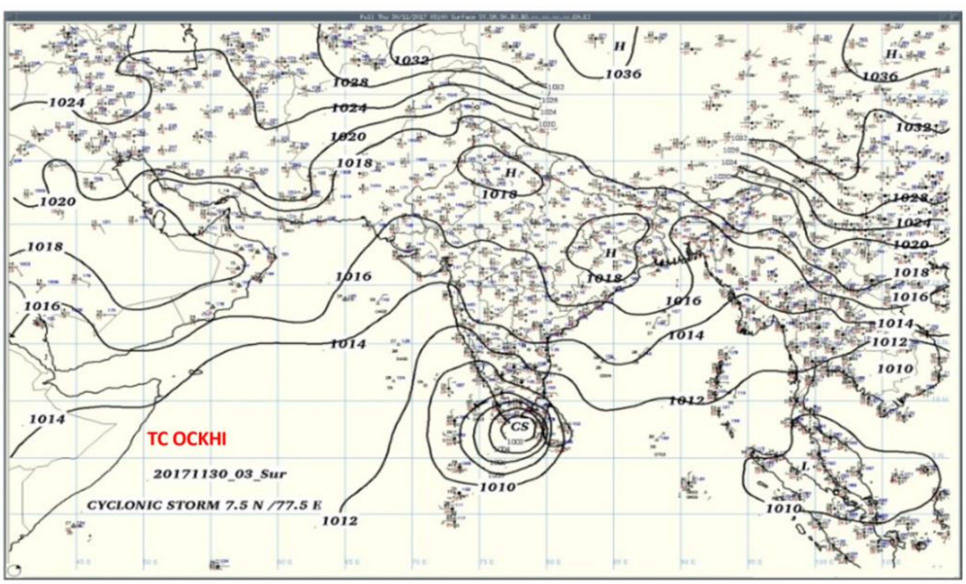
Fig. 4.10. Observed track of very severe cyclonic storm OCKHI, 29 Nov to 06 Dec 2017. Source: India Meteorological Department (IMD).



(a)



(b)



(C)

Fig. 4. 11. Mean Sea Level Pressure Chart on a) 29 Nov 2017, 03 UTC b) 29 Nov 2017 12 UTC and c) 30 Nov 2017 03 UTC. Source: India Meteorological Department.

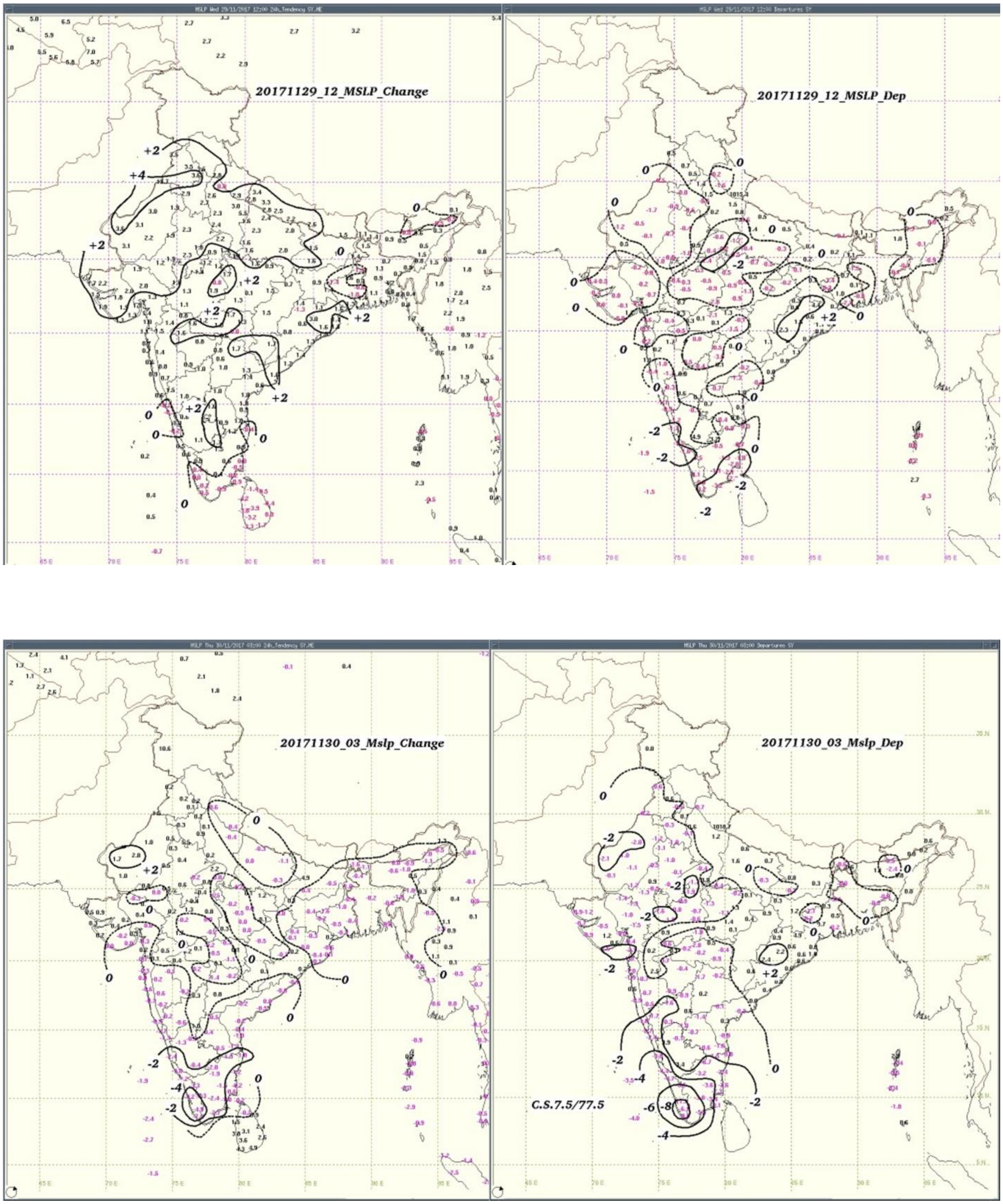


Fig. 4.12. 24 hour change in MSLP (on left) and MSLP departure from normal (right) on a) 29th Nov 2017 12 UTC and b) 30th Nov 2017 03 UTC. Source: IMD Meteorological Department.

Fig. 4.12 above shows the Mean Sea Level Pressure (MSLP) changes in 24 hour and MSLP departures from normal on 29th and 30th Nov 2021. These charts show rapid fall of mean sea level pressure by 30th Nov and large-scale negative departure (of the order of 8 hPa) off the Kerala coast.

Fig. 4.13 shows low level convergence and 850 hPa vorticity patterns at 03 and 12 UTC on 29th Nov, when the system intensified into a cyclonic storm. The low-level convergence pattern shows a rapid increase in the low-level convergence over the region associated with the weather system. The INSAT satellite pictures of TC-Ockhi are shown in Fig. 4.14. These images are provided by the Satellite Directorate of IMD, which shows the westward movement and then north-northeasterly recurvature towards the Gujarat coast.

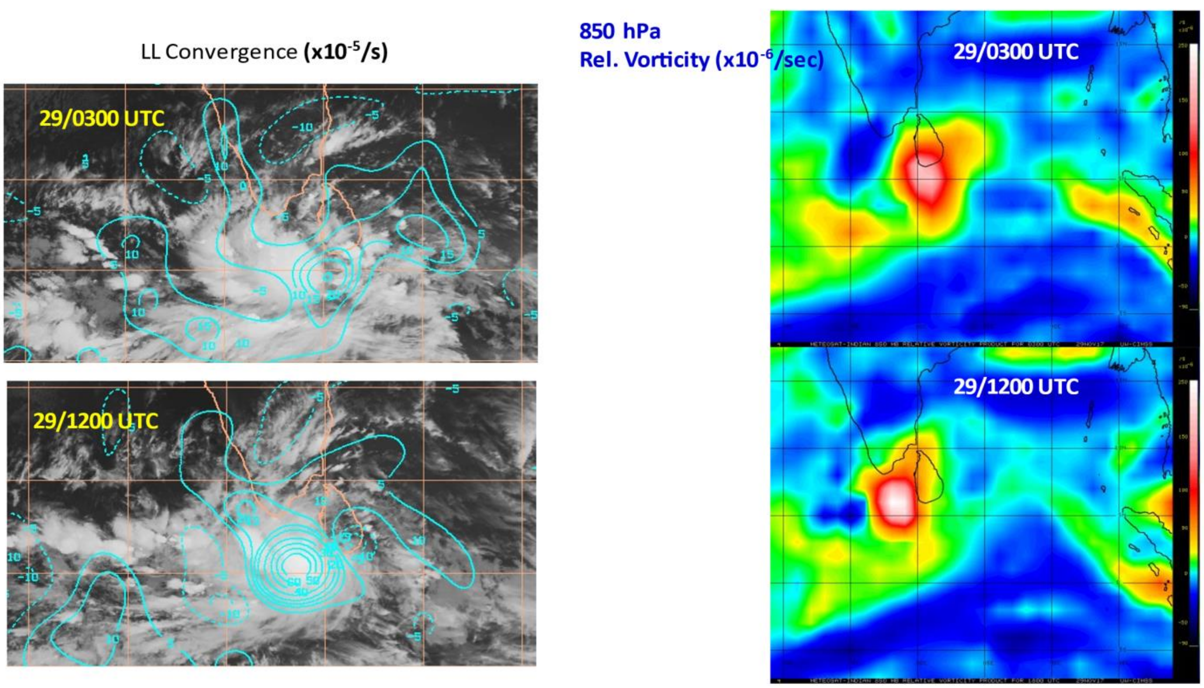
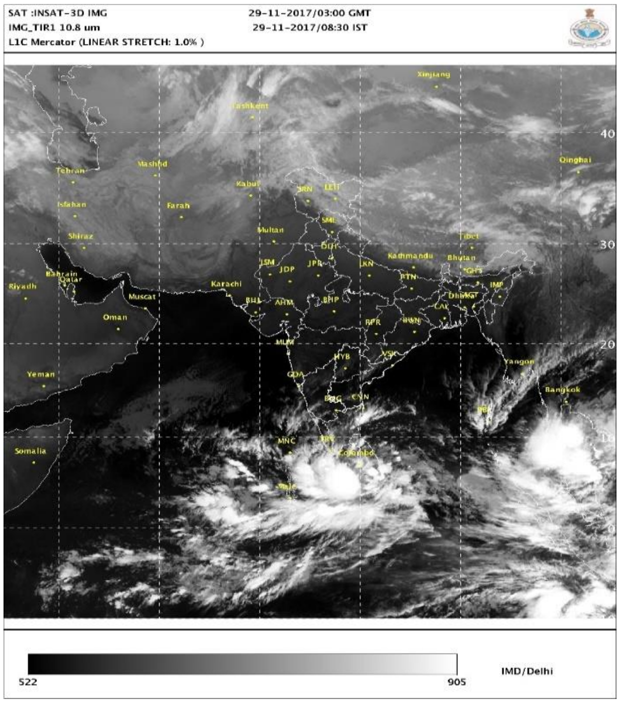
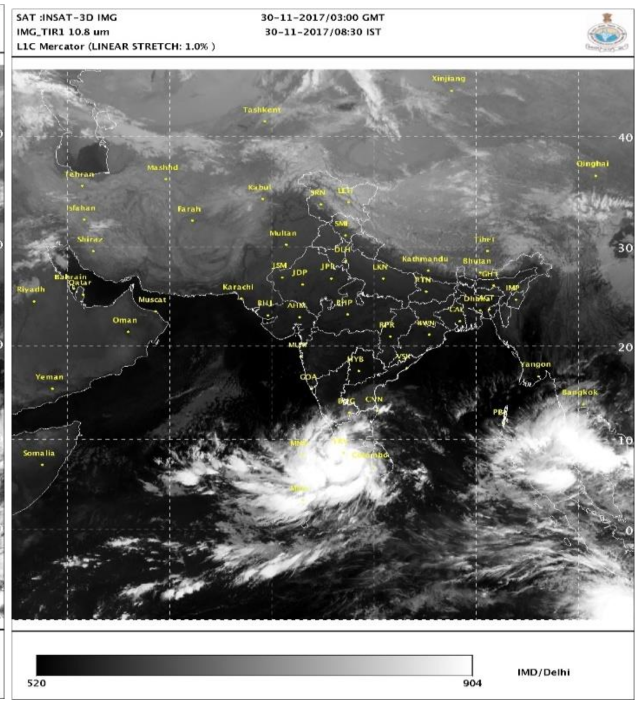


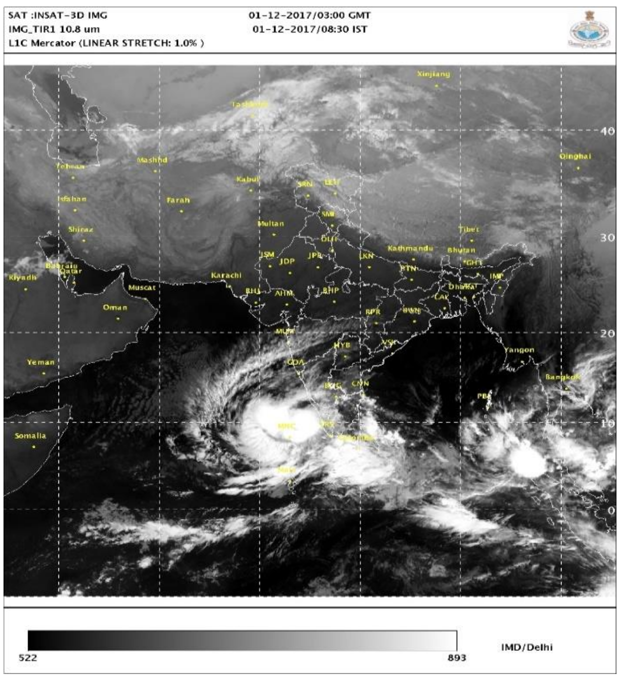
Fig. 4.13. Low-level convergence (10^{-5}/s) (left) and 850 hPa vorticity (10^{-5}/s) (right) at 03 and 12 UTC on 29th Nov 2017. Source: IMD



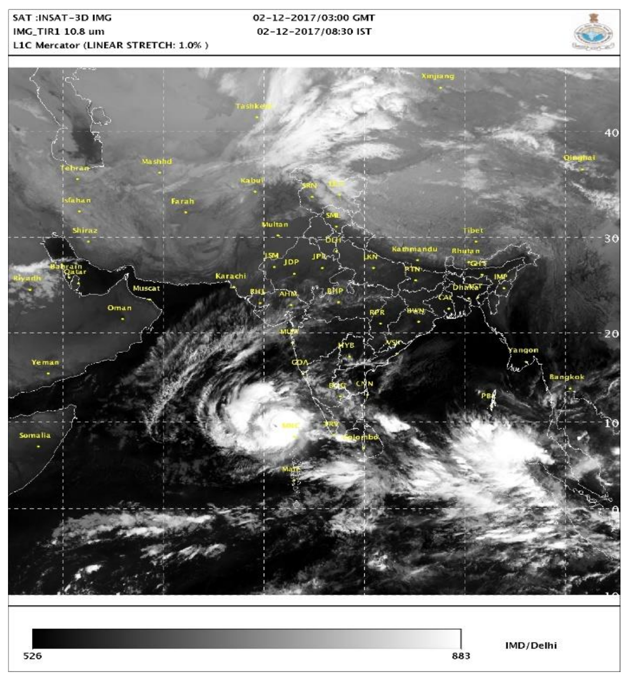
a) 29 Nov 0300 UTC



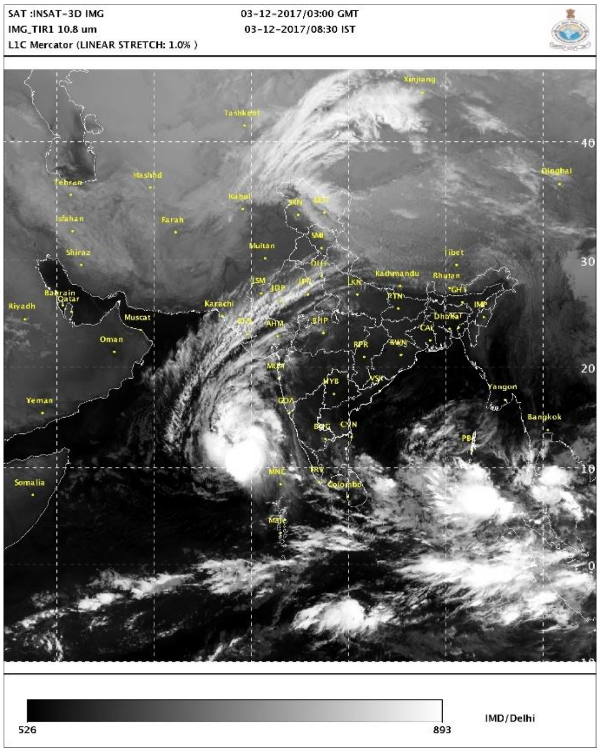
b) 30 Nov 0300 UTC



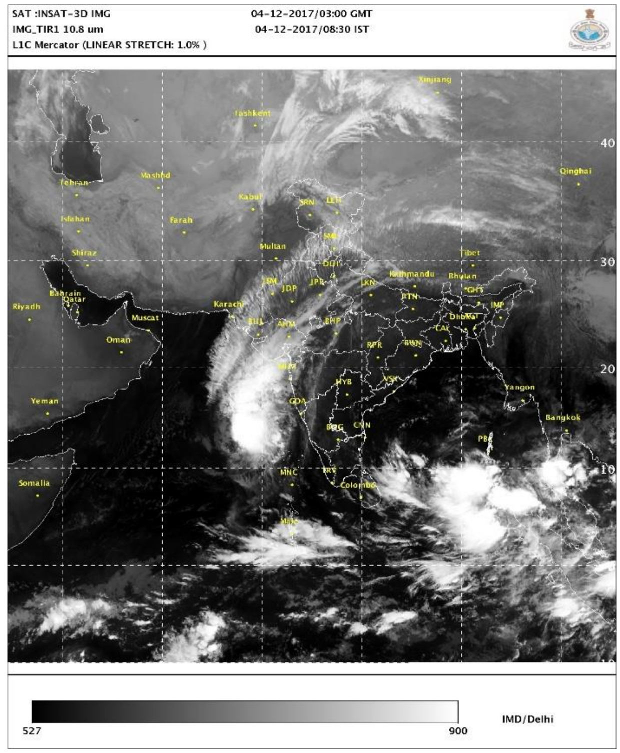
c) 01 Dec 0300 UTC



d) 02 Dec 0300 UTC



e) 03 Dec 0300 UTC

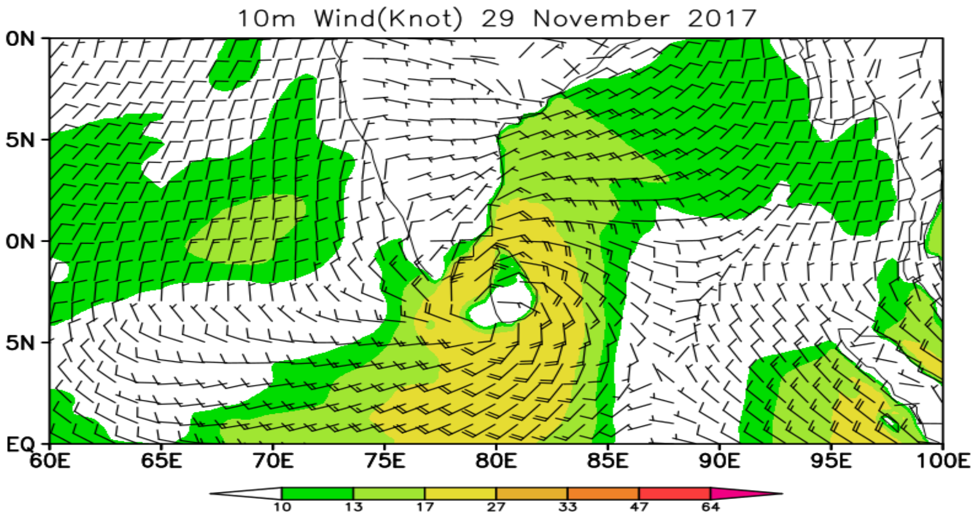


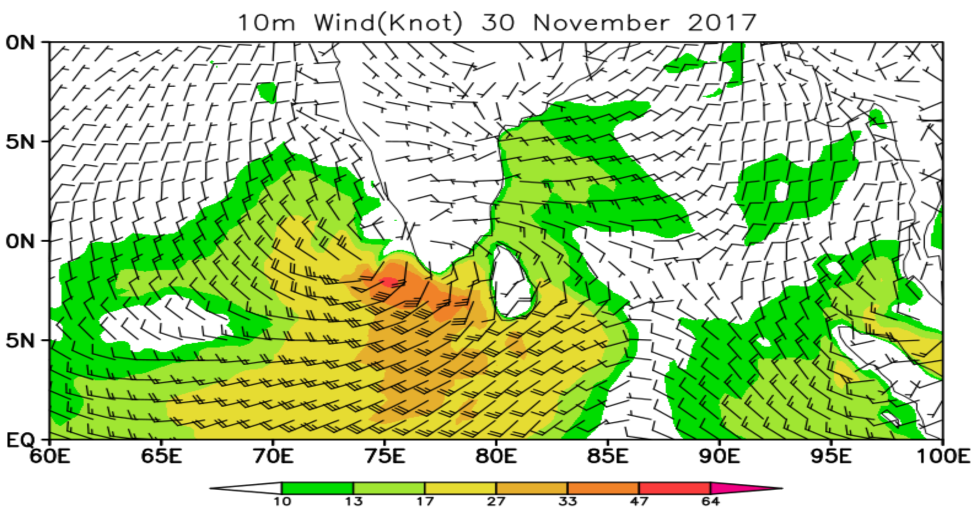
f) 04 Dec 0300 UTC

Fig. 4.14. INSAT IR image at 0300 UTC showing TC-Ockhi during 29 Nov- 04 Dec 2017. Source: IMD Satellite Directorate.

Fig. 4.15 shows the spatial distribution of 10 m wind (in knots) from 29 Nov to 4th Dec showing the intensification and weakening of surface winds associated with TC-Ockhi. These plots are prepared using the ERA5 reanalysis data with 0.25 degree resolution.

It caused heavy to very heavy rainfall over Lakshadweep on 01st and 2nd Dec. There was heavy rainfall over north coastal Maharashtra and adjoining south coastal Gujarat on 5th Dec. Thiruvananthapuram recorded 62 kmph wind in gustiness at 1300 IST of 30th Nov. Storm surge of height 1m over Lakshadweep Islands was observed on 30th Nov.


10m Wind(Knot) 29 November 2017
0N
5N
0N
5N
EQ
60E
65E
70E
75E
80E
85E
90E
95E
100E
10
13
17
27
33
47
64


10m Wind(Knot) 30 November 2017
0N
5N
0N
5N
EQ
60E
65E
70E
75E
80E
85E
90E
95E
100E
10
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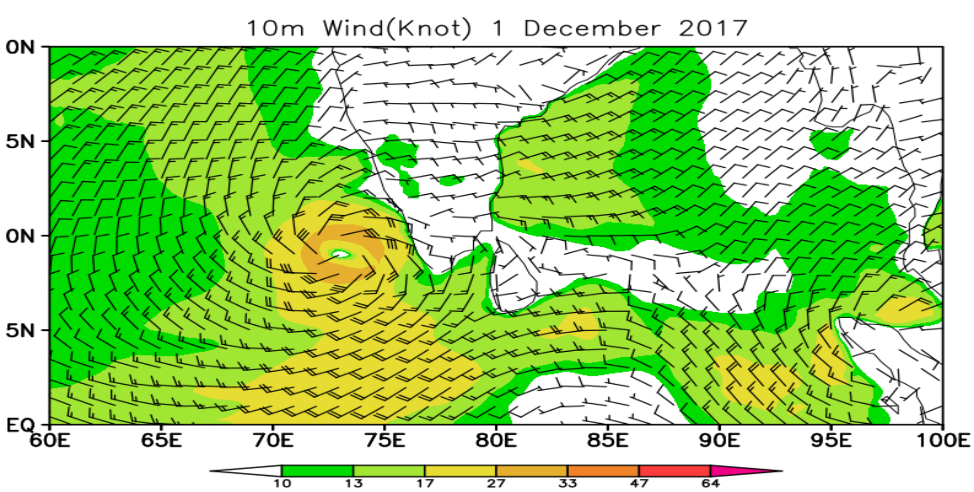
17
27
33
47
64


10m Wind(Knot) 1 December 2017
0N
5N
0N
5N
EQ
60E
65E
70E
75E
80E
85E
90E
95E
100E
10
13
17
27
33
47
64

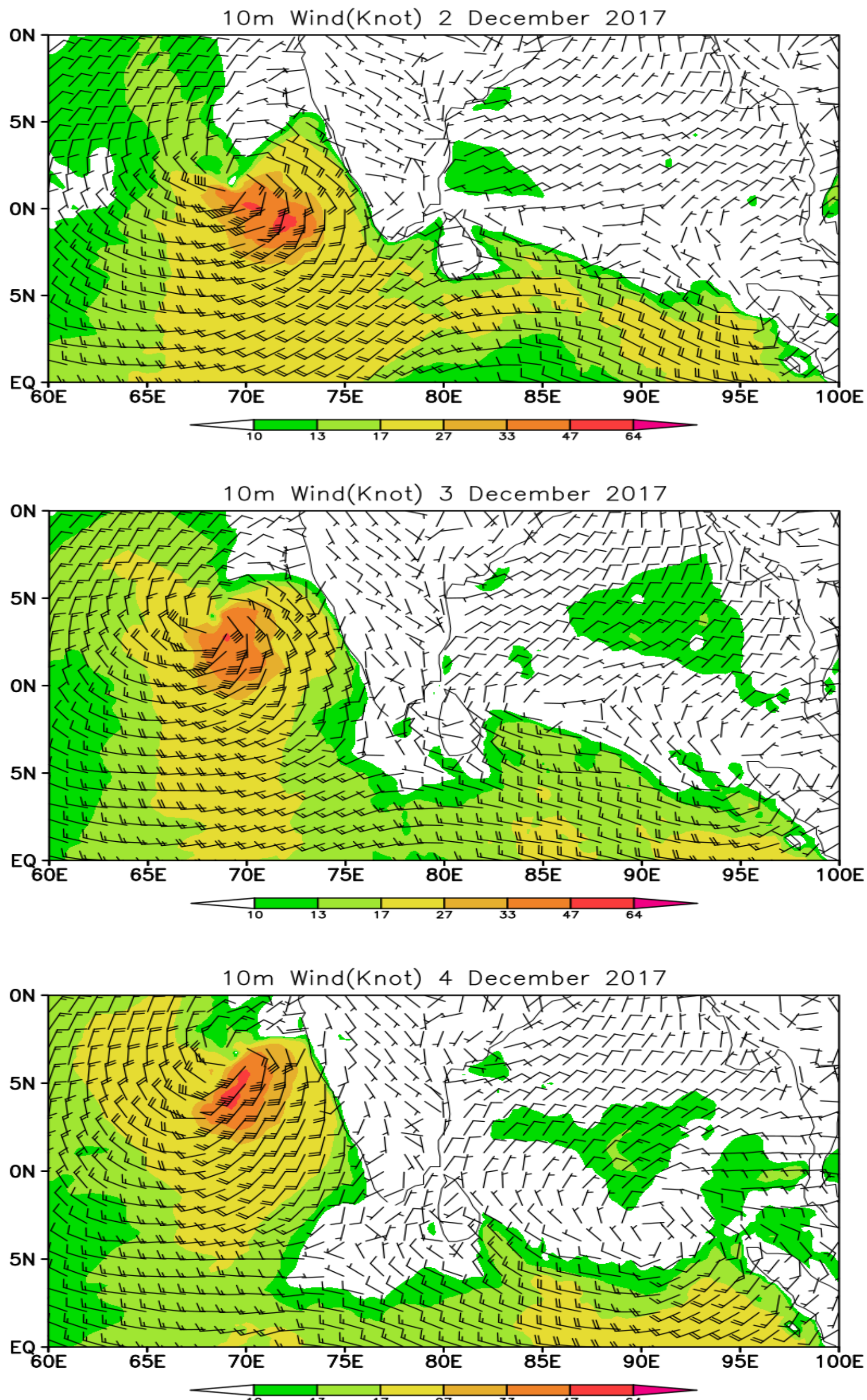


Fig. 4.15. Spatial distribution of 10 m wind in knots from 29 Nov to 4 Dec 2017. Source: ERA reanalysis data

The salient features of TC-Ockhi are given below (IMD, 2018):

- This was the only fourth cyclonic storm developing over the Comorin Sea (south of Kerala and Tamil Nadu and west of Sri Lanka) during the past 120 years. Previously two cyclones (19-22 Nov and 17-19 Dec) in 1912 and another in 1925 (06-10 Nov) developed over the Comorin Area. All these cyclones affected south Kerala and south Tamil Nadu.
- TC-Ockhi was thus a rare cyclone with rapid intensification in genesis stage (from depression to cyclonic storm within 24 hours). The system intensified rapidly from 1800 UTC of 30th to 0000 UTC of 2nd Dec (increase in wind speed by 30 kts in 24 hours) (Fig. 4.16).
- The total track length of the cyclone was 2538 km.
- The 12 hourly average translational speed of the cyclone was 15.0 kmph. However, it moved faster in the genesis stage (29/0830 IST to 30/0830 IST) with 12 hourly average translational speed of 19 kmph.
- The life period of cyclone was 6 days & 18 hours against long period average of 4.7 days for very severe cyclonic storm over north Indian Ocean.
- The peak maximum sustained surface wind speed (MSW) of the cyclone was 150-160 kmph gusting to 175 kmph (85 knots) during 0600 UTC of 2nd to 0000 UTC of 3rd December (Fig. 4.17)
- The lowest estimated central pressure was 976 hPa (from 0300 UTC of 2nd to 0000 UTC of 3rd December) with a pressure drop of 34 hPa (Fig. 4.17).
- The intensification/weakening of TC-Ockhi was largely governed by the Ocean heat content. However, the rapid weakening on 4th and 5th Dec was facilitated by dry and cold air intrusion and high vertical wind shear under the influence of a trough in mid latitude westerlies.

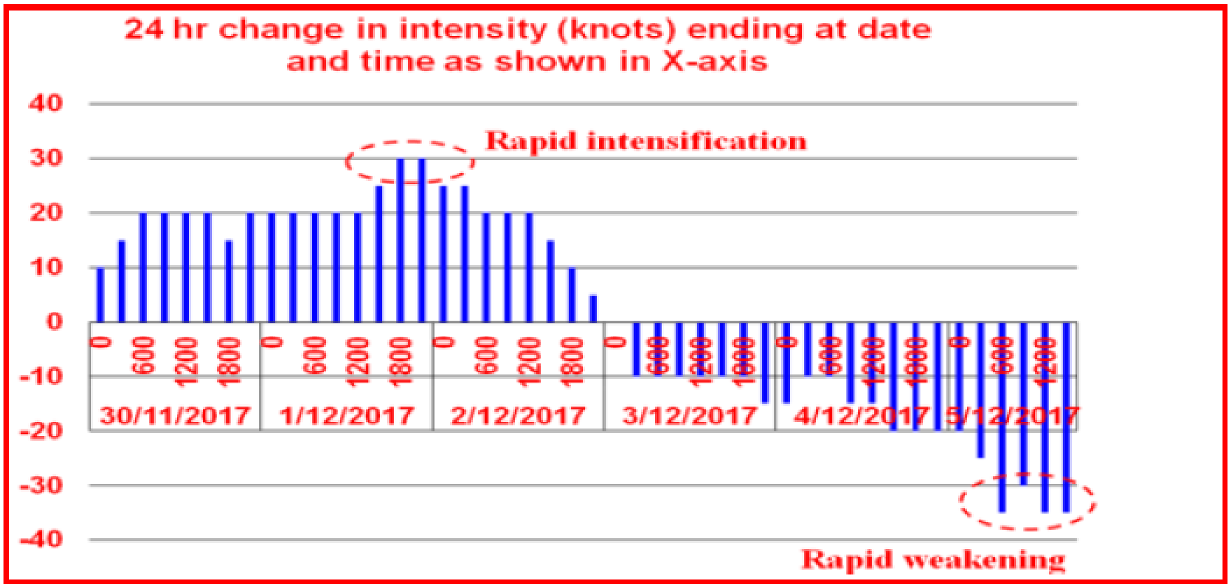


Fig. 4.16. 24-hour change in intensity (knots) ending on different date and time. Rapid intensification and rapid weakening are indicated. Source: IMD 2018 report.

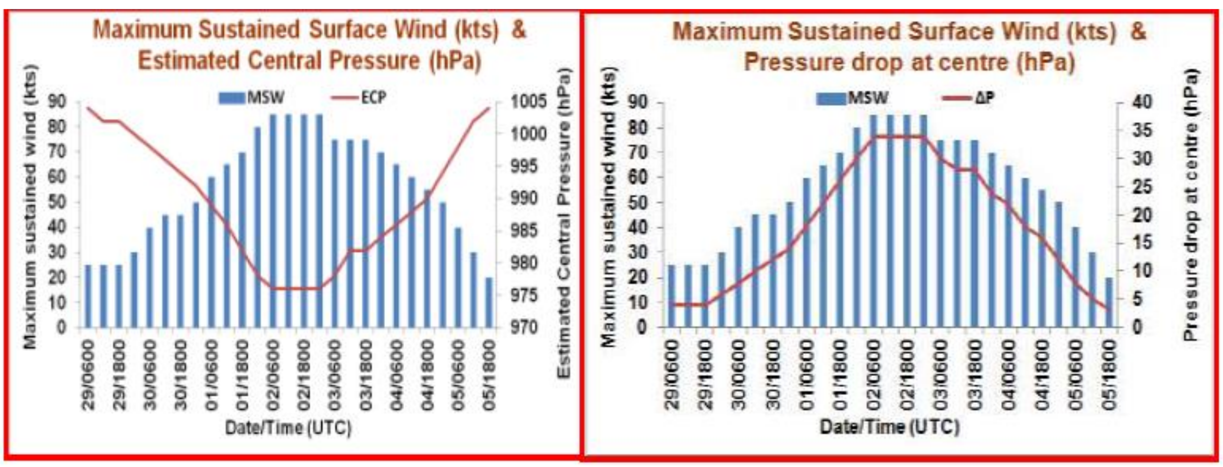


Fig. 4.17. a) Maximum sustained surface wind (kts) and estimated centre pressure (hPa) and b) Maximum sustained surface wind (kts) and pressure drop at centre (hPa). Source: IMD 2018 report.

Genesis and intensification of tropical cyclones are closely related to oceanic conditions like sea surface temperatures (SST) and ocean heat content. Fig. 4.18 shows the spatial distribution of SST during 23-28 Nov, just prior to the formation of TC-Ockhi.

This plot clearly shows sea surface temperatures were more than 28.5^{0}C over the southwest Bay of Bengal (where the TC-Ockhi initially formed), which is much more than the SST threshold for formation of tropical cyclones. Over southeast Arabian sea, SSTs were even more than 29.0^{0}C. Many previous studies (for example, Jangir et al., 2021, Sanap et al., 2020) have documented the relationship between the ocean heat content and intensification of tropical cyclones. Fig. 4.19 shows the Tropical cyclone heat potential (TCHP), which clearly suggests the presence of large ocean heat content over southwest Bay of Bengal (Comorin area) and southeast Arabian sea (over the observed track of TC-Ockhi), TCHP was more than 70 KJ/cm^2. This large amount of heat potential was mainly responsible for the rapid intensification of TC-Ockhi.

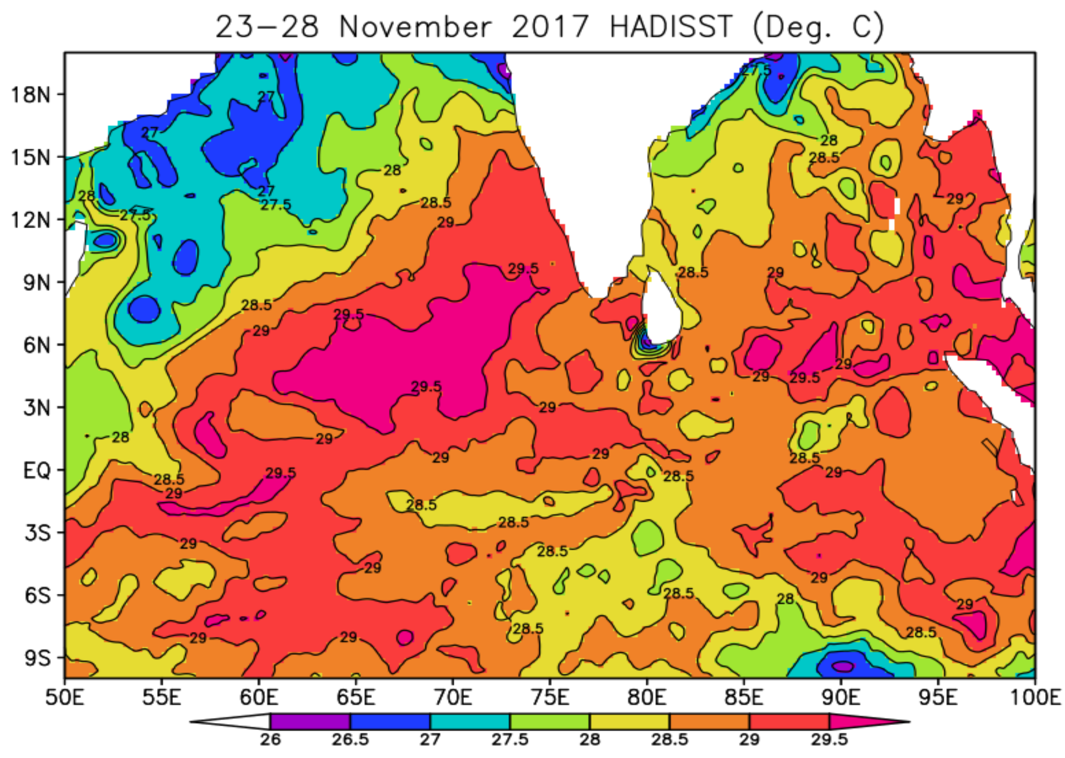


Fig. 4.18. Spatial distribution of Sea Surface Temperatures (SST) in ^{0}C averaged during 23-28 November 2017, just before the TC-OCKHI formed over southwest Bay of Bengal. Source: UK Met office, HADISST.

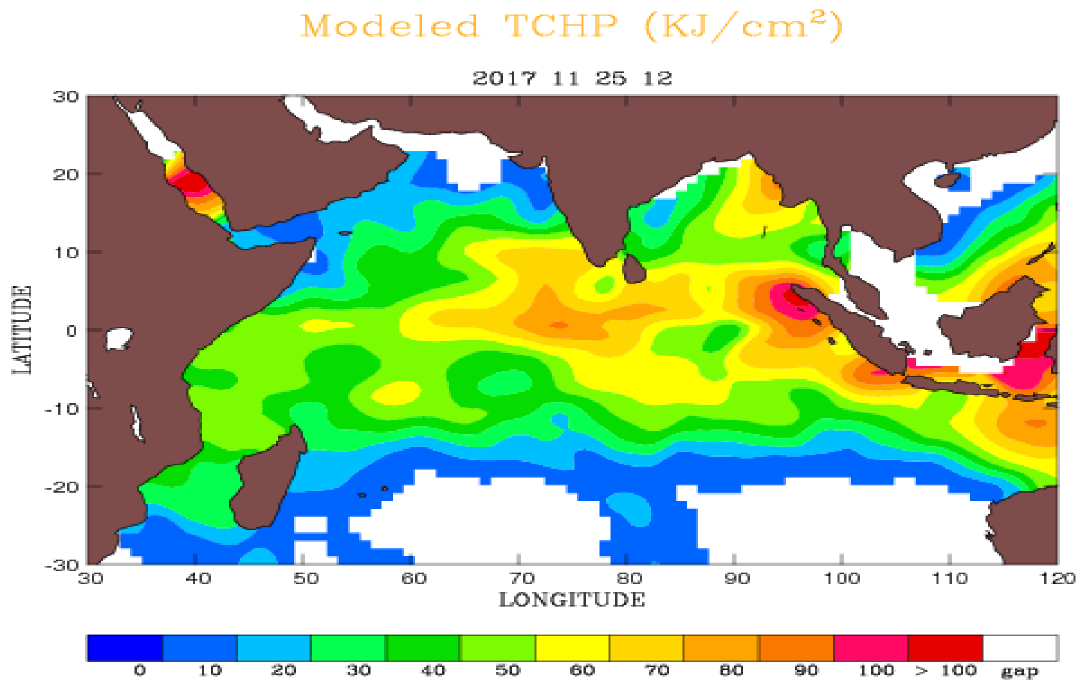


Fig. 4.19. Spatial distribution of Tropical Cyclone Heat Potential (TCHP) in KJ/Cm^2 on 25 November 2017, just prior to the formation of TC-OCKHI. Source: NRSC, ISRO.

Singh et al., (2020) studied the role of eastward moving Madden and Julian Oscillation (MJO) in the genesis of TC-Ockhi. Mohapatra and Adhikary (2011) also studied the role of MJO on tropical cyclone genesis over the Indian Ocean region. MJO is an eastward-moving wave in the tropical belt associated with enhanced convective activity in the regions from which it passes. Previous studies have shown that MJO in phase 4 is conducive for cyclogenesis in the south of Bay of Bengal by ensuing increased vorticity and anomalous cyclonic circulation on the westward side of MJO-induced convective activity. As the MJO propagated from phase 3 to phase 4 in November, 2017, it resulted in anomalous westerlies over the entire south Bay of Bengal (near the equator) in response to the shift in the convection over the maritime continent The anomalous westerlies along with anomalous easterlies over a narrow zone centred near 10°N, caused a strong shear zone and positive vorticity (Singh et al., 2020).

Jyothi et al., (2020) investigated the oceanic and atmospheric processes that have contributed to the Rapid Intensification (RI) and Rapid Weakening (RW) of Cyclone Ockhi using the HYbrid Coordinate Ocean Model (HYCOM) simulations and Global Forecast system (GFS) outputs. The environmental conditions prevailed before RI showed the presence of thick warm and fresh waters, ample supply of mid-tropospheric relative humidity, and moderate wind shear. The intrusion of dry air, strong vertical wind shear, and unfavourable oceanic conditions annihilated the storm intensity during the RW stage. Compared to the ocean temperatures, the vertical structure of salinity showed remarkable differences between the RI and RW locations resulting in contrasting upper-ocean stratification.

NWP Forecast Guidance for TC-Ockhi

India Meteorological Department (IMD) refers to many forecast products for preparing warnings for tropical cyclones over the north Indian Ocean. In this case of TC-Ockhi also, IMD had referred to many NWP products from IMD GFS, NCUM, ECMWF and JMA models. An analysis of inferences drawn from these models suggests that none of the models could provide an early forecast guidance for the genesis of TC-Ockhi as a Low/depression and its further intensification. The first model forecast guidance was available from the ECMWF model based on 28 Nov 0000 UTC in which the model indicated formation of a depression and its intensification into a severe cyclonic storm over the Arabian sea. The other models started indicating the formation of this system and its intensification from 29th Nov only. It is very important to note that none of the models correctly indicated the rapid intensification of TC-Ockhi during the course of its travel around the Comorin area.

However, the track forecasts by some of the models in predicting track of TC-Ockhi have been reasonably accurate as shown in Table-4.3 below. Numbers given in the bracket is number of verified forecasts. It can be seen that the Multi-Model Ensemble (MME) of IMD has the lowest errors compared to other models up to 48