Ocean and Atmospheric Characteristics Associated with the Cyclogenesis and Rapid Intensification of NIO Super Cyclonic Storms

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ABSTRACT

An attempt is made to investigate the various atmospheric and oceanic conditions that contributed to the genesis and rapid intensification (RI) of the super cyclonic storms (SUCS) formed over the North Indian Ocean (NIO) basin during 1982-2020. Weak to moderate vertical wind shear values are found in all the cases supporting genesis. The genesis potential parameter was > 30 in four cases, whereas the other two cases, viz., Gonu and Odisha SUCS experienced values ≤ 30. Prior to genesis, Equatorial Rosssby (ER) waves followed by Madden Julian Oscillation (MJO) were dominant, whereas in case of Amphan, all the three convectively coupled equatorial waves viz., MJO, ER, and Kelvin wave were present. The Ocean conditions were more conducive for tropical cyclone (TC) genesis than the atmospheric conditions. Both sea surface temperature and tropical cyclone heat potential (TCHP) supported the cyclogenesis. In most cases, the setting up of the pre-genesis scenario was heavily influenced by the ocean characteristics, whereas the atmospheric conditions were supportive enough. The environmental conditions that prevailed before the starting of RI process, showed the presence of thick warm waters, a sufficient supply of moisture at the middle of the troposphere, and moderate wind shear in all cases. Mid-tropospheric relative humidity, sea surface temperature and low-level relative vorticity, all had a significant role in the RI process of all SUCS storms across the NIO basin. During the RI days, TCHP ≥ 60 $kJ.cm^{-2}$ was observed for Amphan and Gonu, with thick barrier layers for all cases. Gonu encountered a warm core eddy along its track, which provided extra fuel for the RI process. All six TCs are slow to moderate moving ones, which enabled them to spend significant time over the Ocean surface and interact with the warm waters to get positive feedback for the RI process.

Keywords: SUCS, Equatorial Rossby waves, MJO, TCHP, rapid intensification

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INTRODUCTION

- TCs are among the most destructive natural disasters on earth. The North Indian Ocean (NIO), including the Arabian Sea and the Bay of Bengal, accounts for about 7% of the global TCs (Gray,1975).

- Indian Meteorological Department (IMD) has categorized TCs occurring over NIO into 7 categories viz., (i)Depression (17-27 kt), (ii) Deep Depression(DD) (28-33 kt), (iii) Cyclonic Storm(CS) (34-47 kt), (iv) Severe Cyclonic Storm(SCS) (48-63 kt), (v) Very Severe Cyclonic Storm (VSCS) (64-89 kt), (vi) Extremely Severe Cyclonic Storm(ESCS) (90-119 kt), (vii) Super Cyclonic Storm (SUCS) (≥120 knots).

- 6 SUCS have occurred over the NIO considering from 1982-till present.

- Of the 6 SUCS formed so far, two numbers of SUCS have formed over Arabian Sea (AS), and 4 numbers of SUCS have formed over the Bay of Bengal (BOB).

- SUCS to have formed over NIO so far are as follows:

  - ✓ Andhra Super Cyclone (1990)-BOB
  - ✓ Bangladesh Super Cyclone (1991)-BOB
  - ✓ Odisha Super Cyclone (1999)-BOB
  - ✓ Gonu (2007)- AS
  - ✓ Kyarr (2019)-AS
  - ✓ Amphan (2020)-BOB

METHODOLOGY

1

ENSO and IOD phases are computed by following NOAA and Mahala et al. (2015).

2

Kelvin wave band includes (Straub and Kiladis, 2002)

i. periods 2.5-20 days

ii. wave numbers 1-14

ii. depths of 8-90 m

3

ER wave band includes (Kiladis et al. 2009).

i. periods 9-72 days

ii. wave numbers 1-10

iii. depths of 8-90 m

4

MJO wave band includes (Kiladis et al. 2005).

i. periods 20-100days

ii. wave numbers 1-14

5

The identification of warm core eddies (anti-cyclonic) and cold core eddies (cyclonic) are done by following Mason et al. (2014).

6

Tropical Cyclone Heat Potential (TCHP) is calculated using the following equation:

$$Q = c_p \sum_{z=0}^{z26} \rho i \, (Ti - 26)\Delta zi$$

where **Q** is the **TCHP** value (Jcm^{-2}),

cp is **specific heat** at const. pressure,

Ti is **water temperature in °C at the i-th level**,

Δzi is **i-th layer water thickness**,

ρi is the **density of water at the i-th level**.

The parameter **Z26** is the **depth (m) of the 26°C isotherm.**

7

GPP is calculated by following Kotal et.al (2013). It is given by

$$GPP = \begin{cases} \frac{\xi_{850} \times M \times I}{S}, \text{if } \xi_{850} > 0, M > 0 \text{ and } I > 0, \\ = 0, \text{if } \xi_{850} \leq 0, M \leq 0 \text{ or } I \leq 0, \end{cases},$$

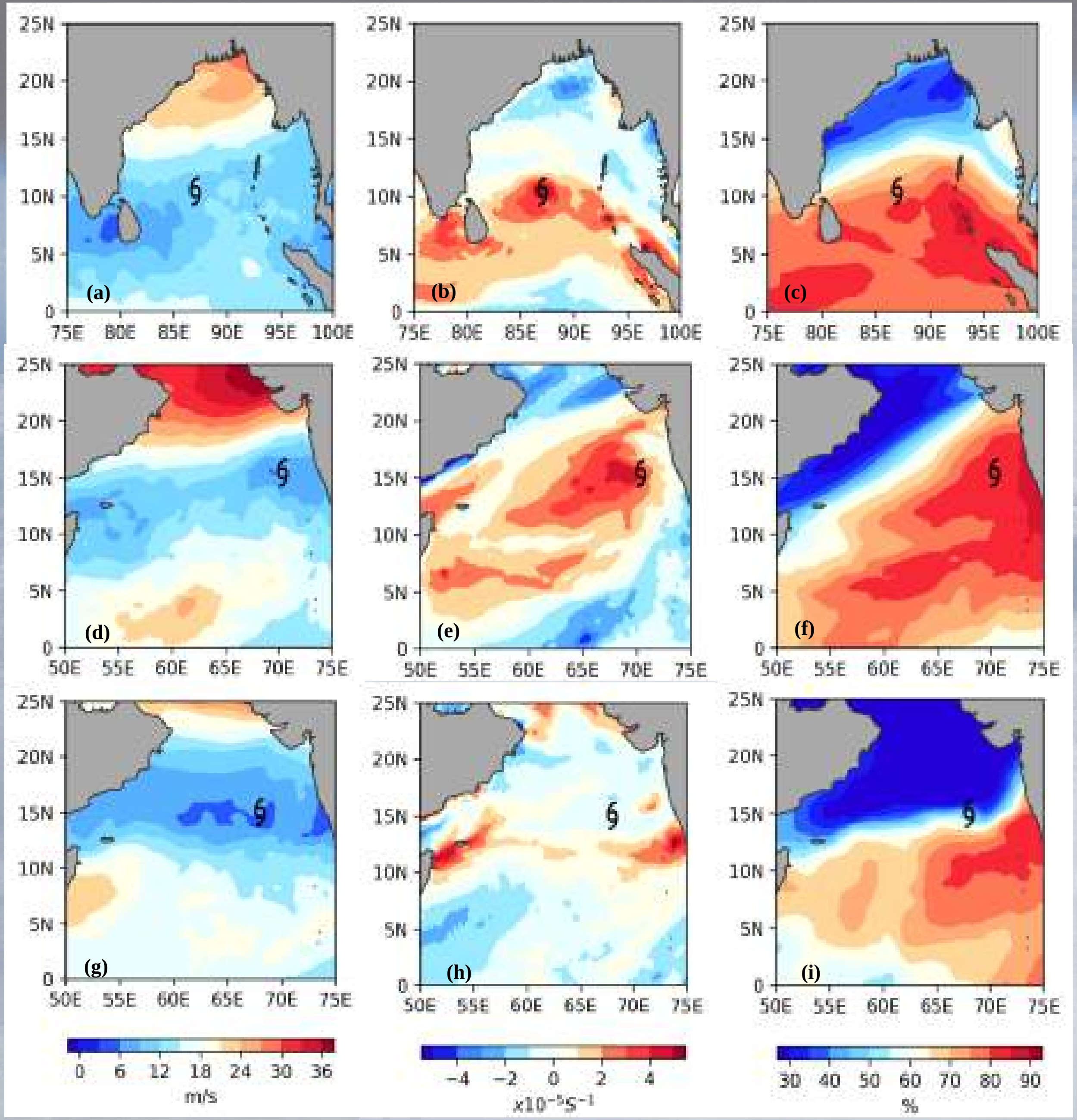

Figure 1.Spatial variation of **vertical wind shear** (m/s; first column), **low level relative vorticity** (sec^{-1}; second column) and **mid-tropospheric relative humidity** (%; third column)over North Indian Ocean (NIO) basin during the pre-genesis period (i.e. 7 days prior to formation) concerning to three tropical cyclones: Amphan (a, b, c), Kyarr (d, e, f) and Gonu (g, h, i). It is overlaid by the approximate genesis location of the corresponding cyclone (as defined by the latitude and longitude of their initial classification at tropical depression stage). All of the parameters considered here are taken from ERA-5 global analyses data set. Here, same color scale is used but for different parameters.

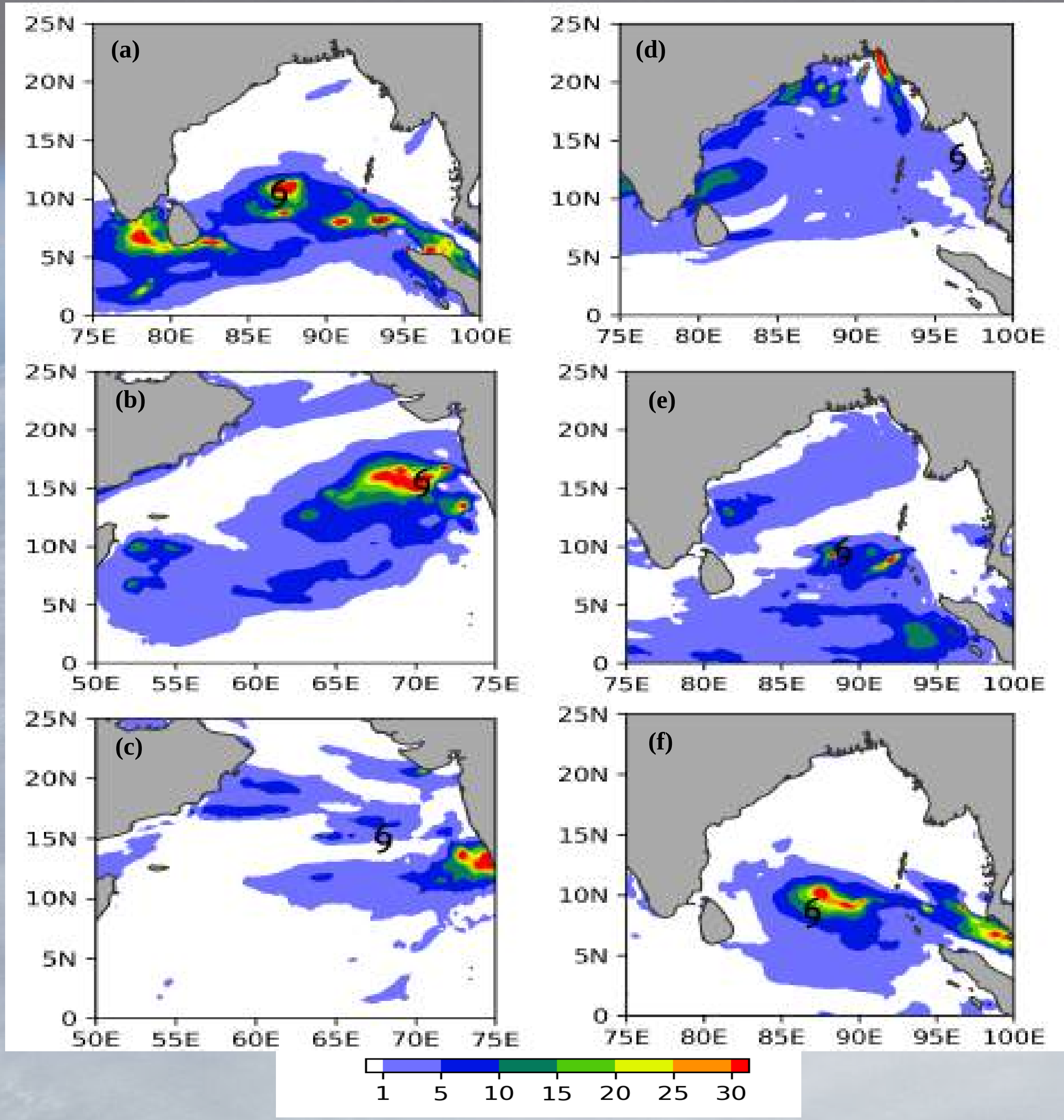

Figure 2. Variation in **genesis potential parameter** (GPP) during pre-genesis period concerning to six cyclones over NIO basin (a) Amphan (TC1), (b) Kyarr (TC2), (c) Gonu (TC3), (d) Odisha super cyclone (TC4), (e) Bangladesh super cyclone (TC5), (f) Machilipatnam super cyclone (TC6). It is overlaid by the approximate genesis location of each TC (as defined by the latitude and longitude of their initial classification at tropical depression stage). The GPP is estimated using ERA-5 global analyses data set.

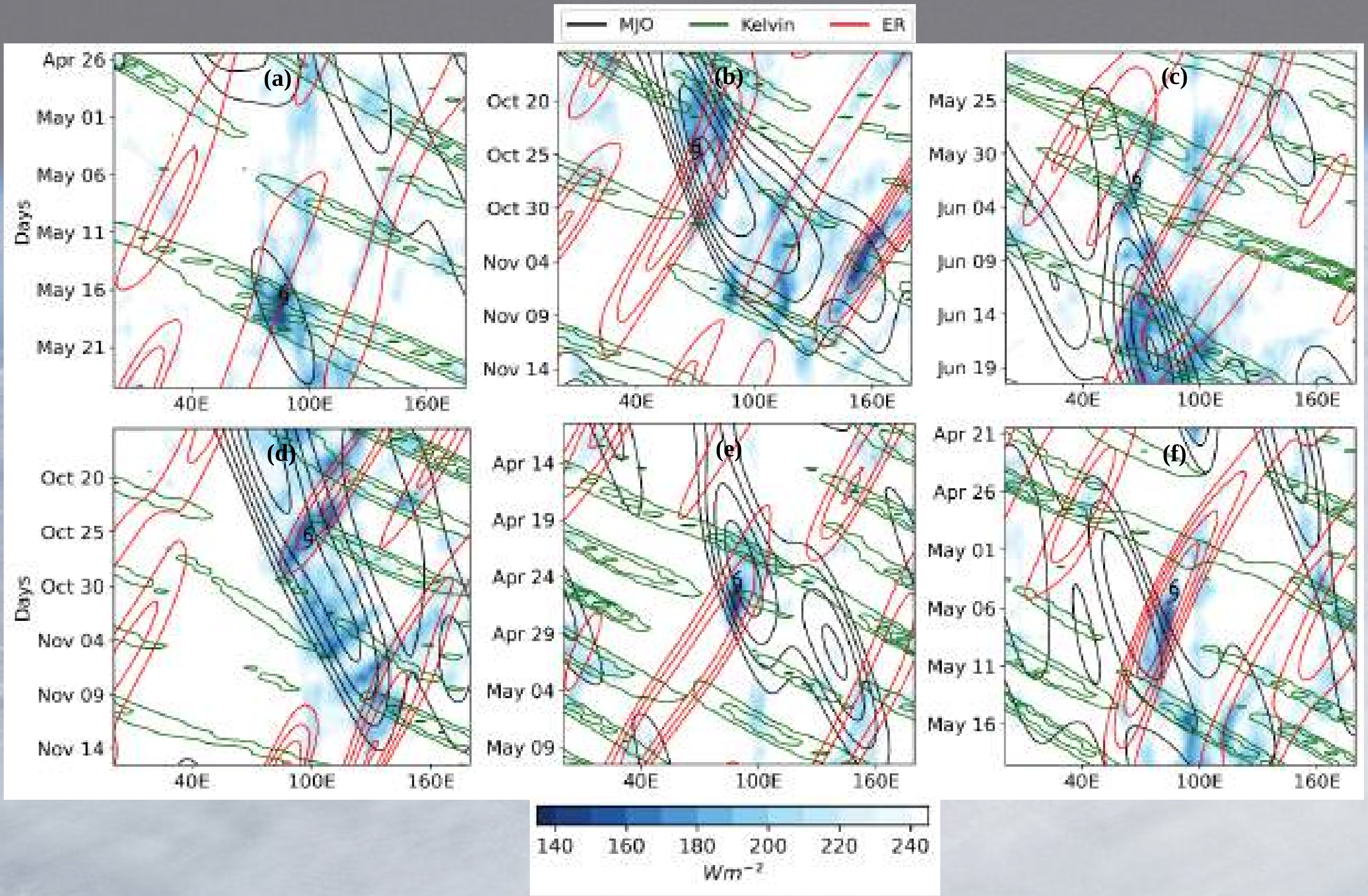

Figure 3.Hovmoller plot of unfiltered OLR (shaded), negative **MJO wave-filtered OLR anomalies** (**black contours**), negative **Kelvin wave-filtered OLR anomalies** (**green contours**), and negative **ER wave-filtered OLR anomalies** (**red contours**) averaged over the region 0°-20°N concerning to the six cyclones TC1-TC6 (Figure 2) for the period (a) 25 April-25 May 2020, (b) 15 Oct-15 Nov 2019, (c) 20 May-20 June 2007, (d) 15 Oct-15 Nov 1999, (e) 10 April-10 May1991, (f) 20 April-20 May 1990. It is overlaid by the approximate genesis location of each TC considered using cyclone symbols. The OLR data is considered from NCEP, USA.

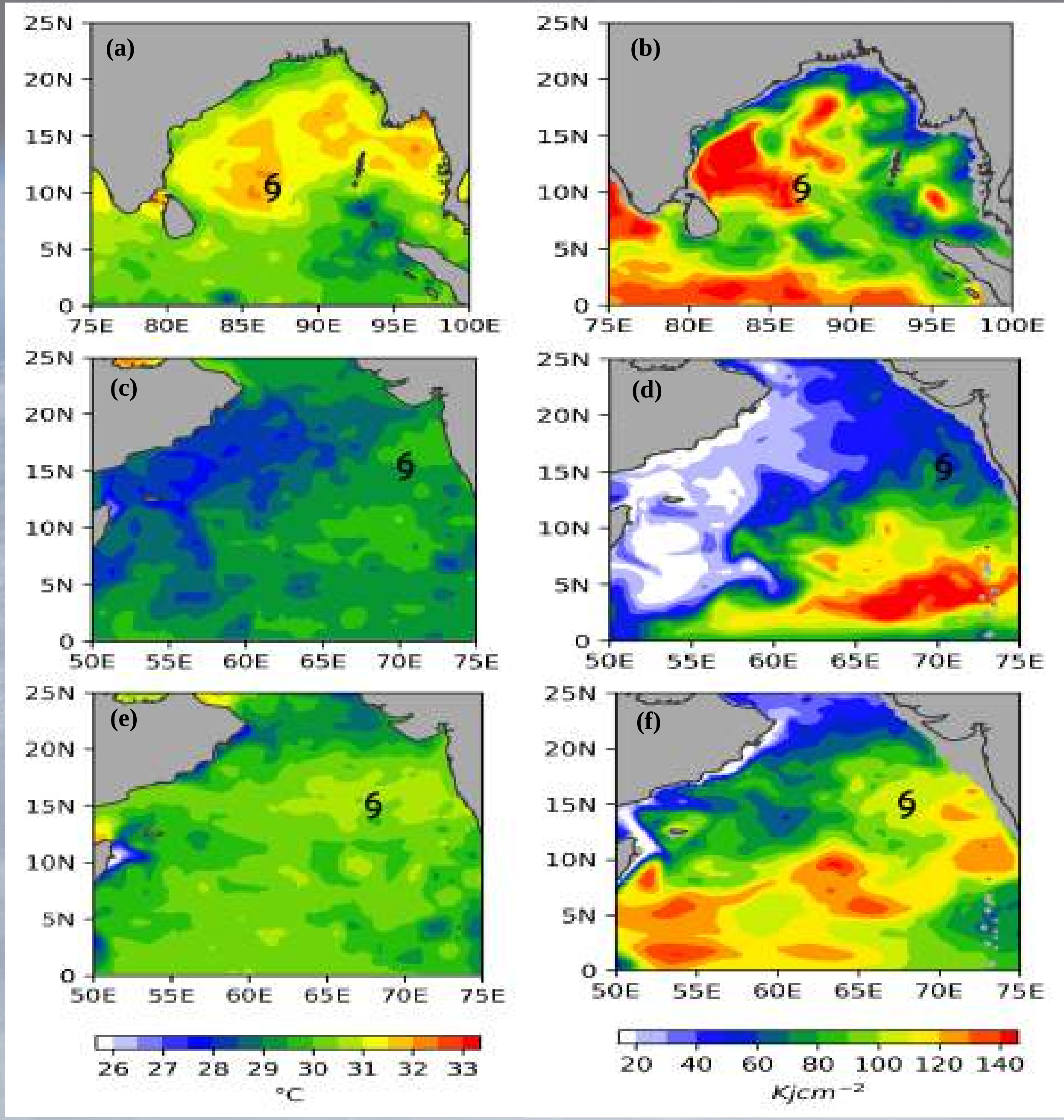

Figure.4.Pre genesis (i.e. 7 days prior to formation) Spatial variation of **SST** (ºC), and **TCHP** ($kJ.cm^{-2}$) during the pre-genesis period concerning to three tropical cyclones: Amphan (**a, b**), Kyarr (**c, d**) and Gonu (**e, f**). It is overlaid by the approximate genesis location of corresponding TC (as defined by the latitude and longitude of the initial classification at tropical depression stage). The left column is for SST and the right column is for TCHP. The SST data is considered from NCEP, USA and TCHP is estimated using potential temperature data from CMEMS, UK.

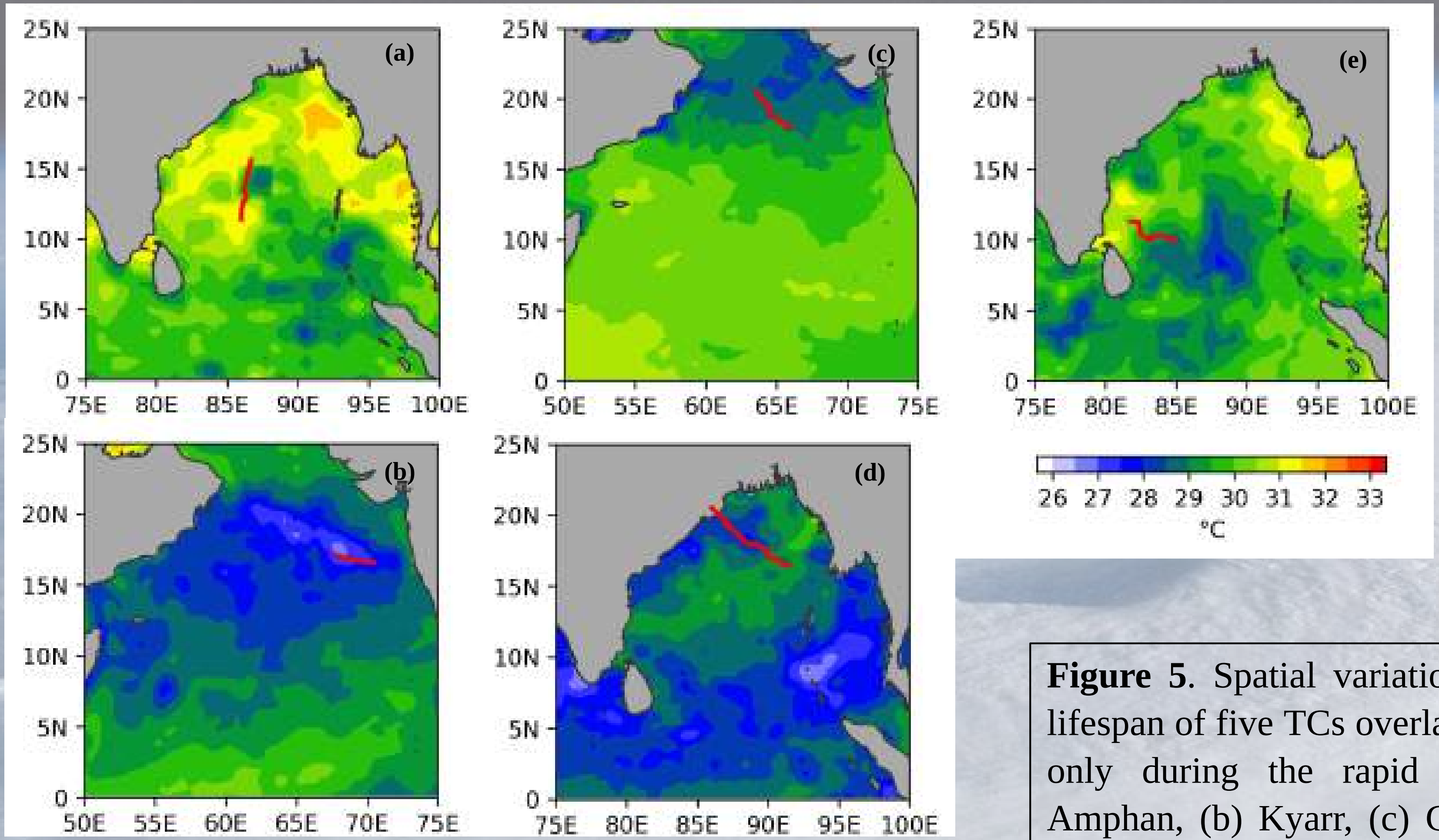

Figure 5. Spatial variation of **SST** (ºC) during the whole lifespan of five TCs overlaid by their track (red colored line) only during the rapid intensification (RI) period: (a) Amphan, (b) Kyarr, (c) Gonu, (d) TC4, and (e) TC6. The SST data is from NCEP, USA. Since TC5 did not undergo RI stage, the SST variation for it is not shown here.

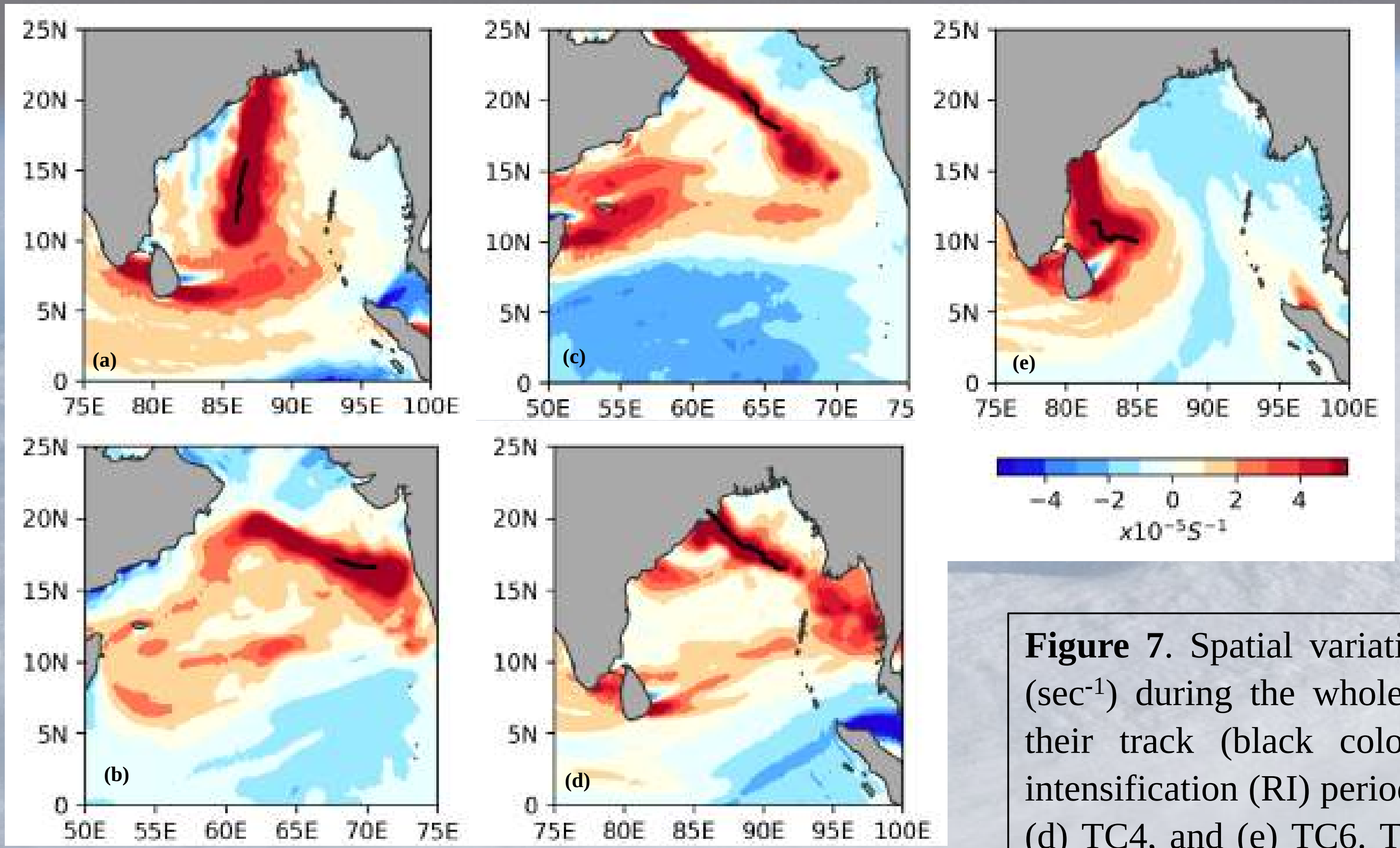

Figure 7. Spatial variation of **low level relative vorticity** (sec^{-1}) during the whole lifespan of five TCs overlaid by their track (black colored line) only during the rapid intensification (RI) period: (a) Amphan, (b) Kyarr, (c) Gonu, (d) TC4, and (e) TC6. The wind data is taken from ERA-5 global analyses. Since TC5 did not undergo RI stage, the relative vorticity variation for it is not shown here.

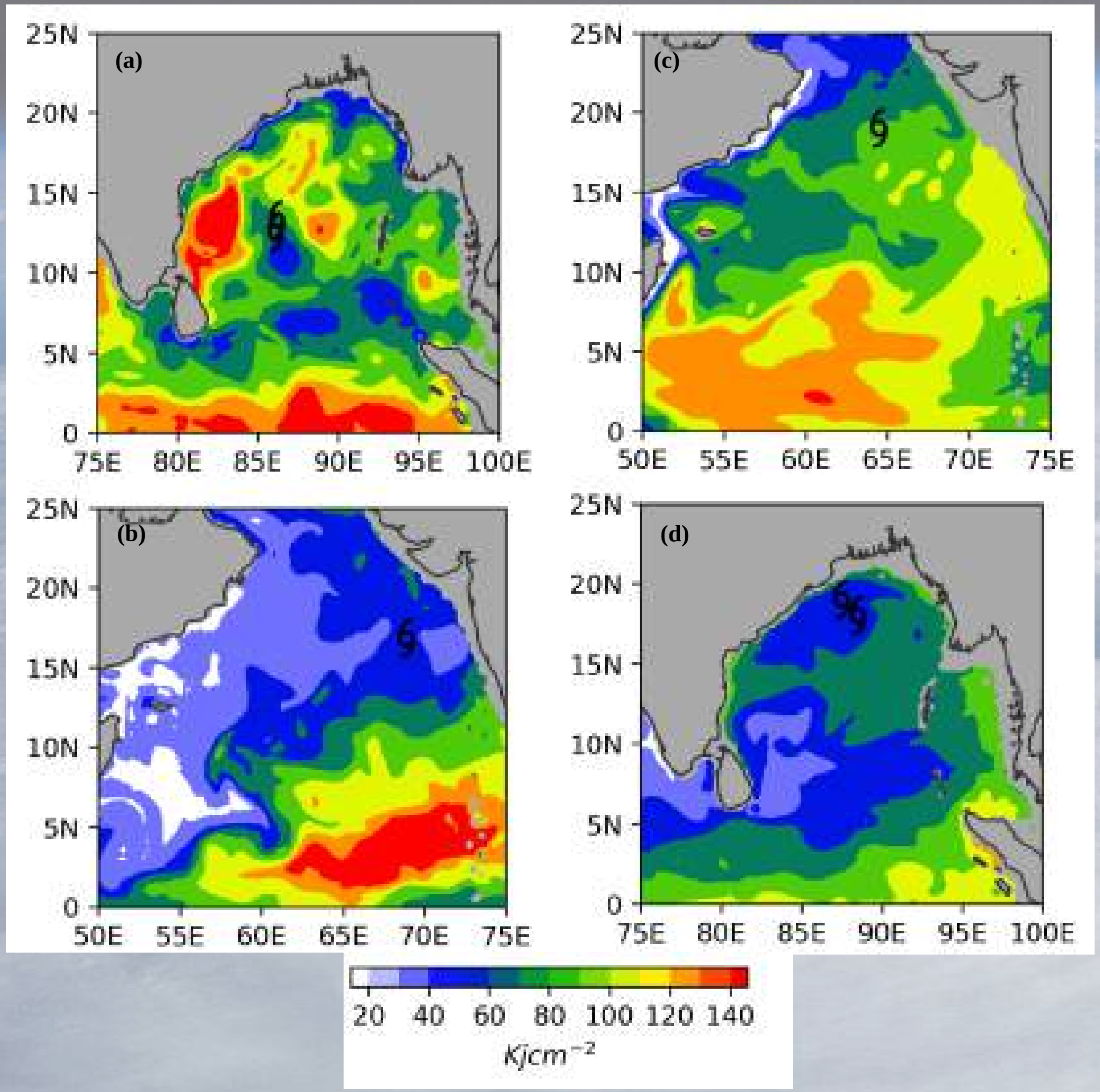

Figure 9. Spatial variation of **TCHP** (kJ.cm^{-2}) during RI days of four NIO super cyclones: (a) Amphan, (b) Kyarr, (c) Gonu, and (d) TC4. The cyclone symbols illustrate the position of a TC when it got rapidly intensified. The TCHP is computed using CMEMS data set. The TCHP variation for TC5 and TC6 is not shown here due to unavailability of data.

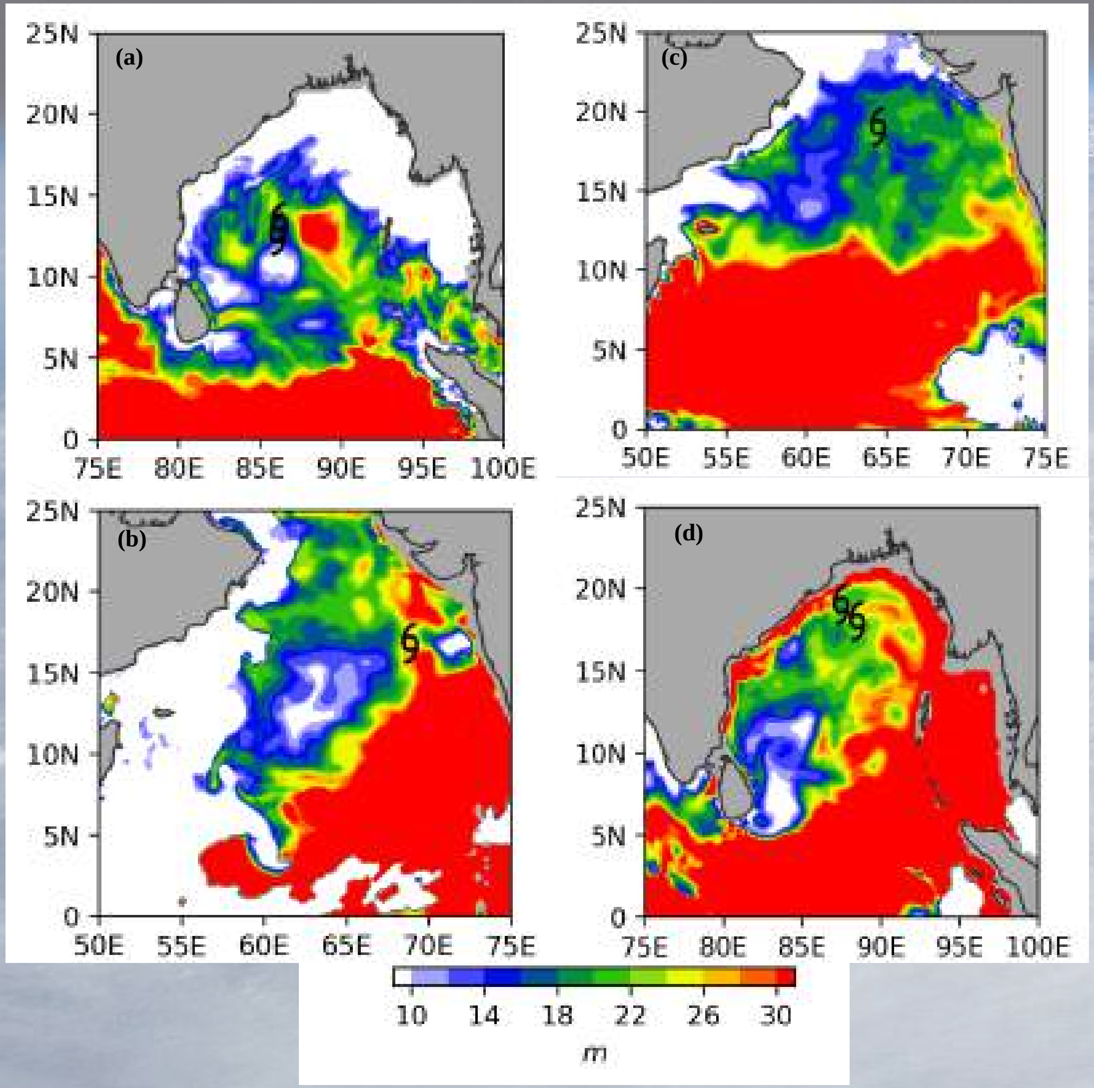

Figure 10. Spatial variation of BLT (m) during RI days of four NIO super cyclones: (a) Amphan, (b) Kyarr, (c) Gonu, and (d) TC4. The cyclone symbols give the position of a TC when it got rapidly intensified. The BLT is computed using CMEMS data set. The BLT variation for TC5 and TC6 is not shown here due to unavailability of data.

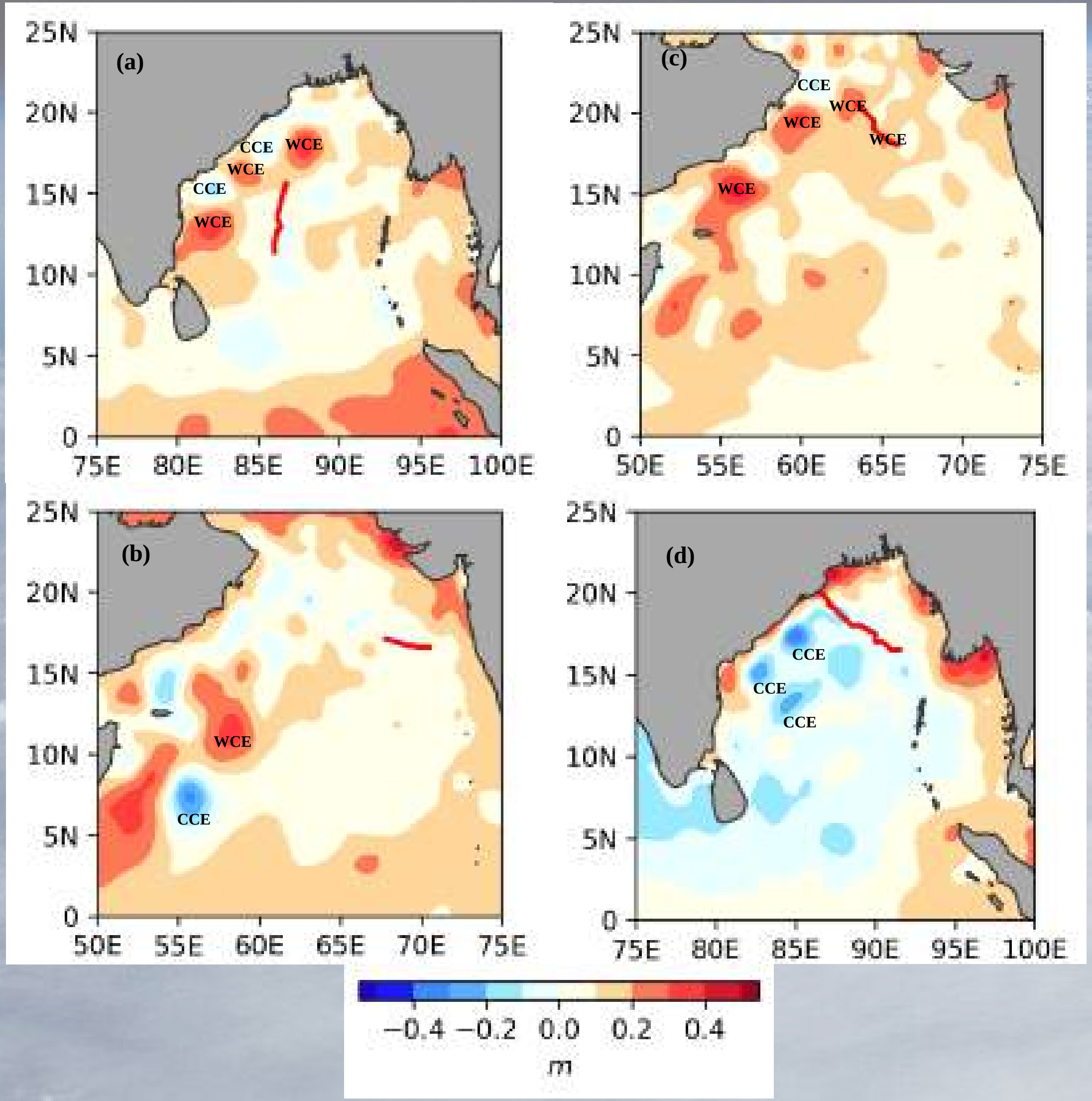

Figure 11. Spatial variation of SLA (m) during the whole lifespan of four super cyclones overlaid by their track (red colored line) only during the RI period: (a) Amphan, (b) Kyarr, (c) Gonu, and (d) TC4. Warm core eddies are denoted as WCE and cold core eddies as CCE. The SLA data is taken from CMEMS, Europe.

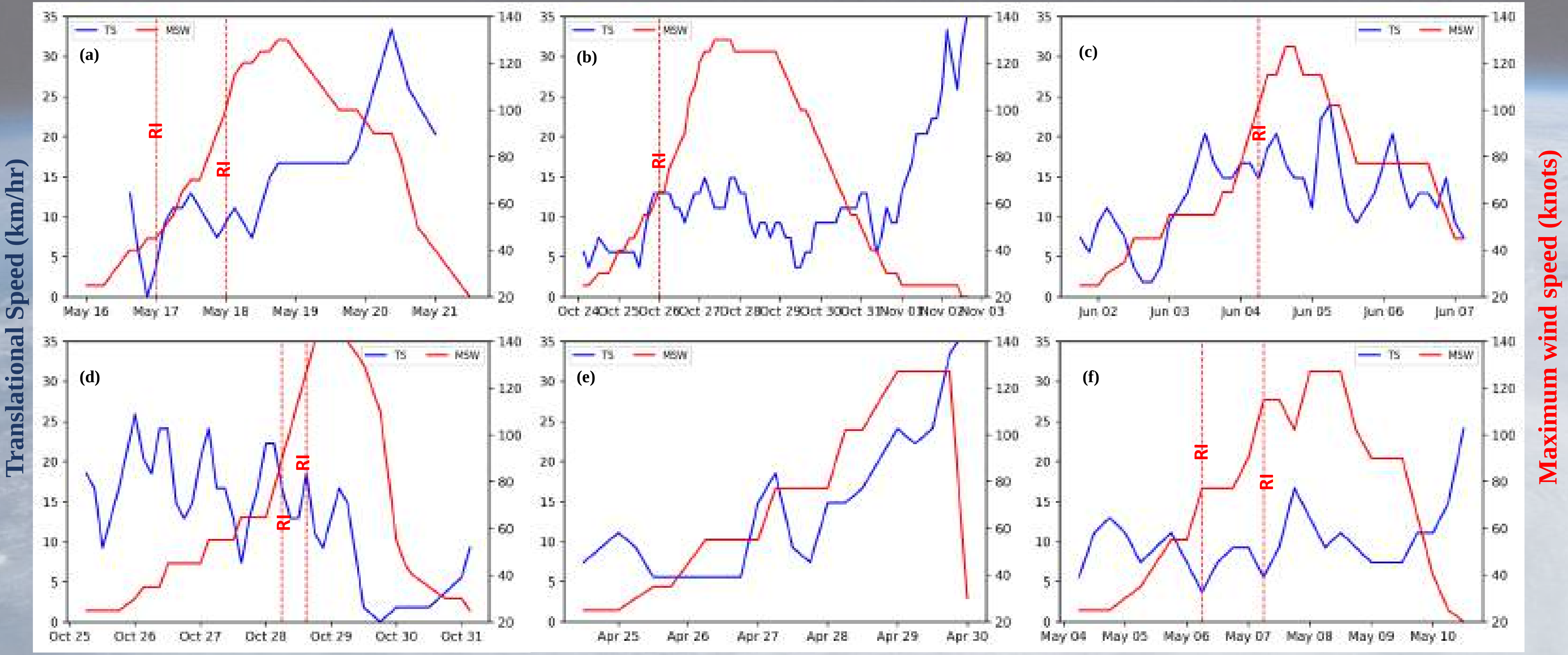

Figure 12. Intensity of the considered six NIO super cyclones in terms of maximum sustained wind or MSW (red line) speed (knots) and translational speed (km/h) or TS (blue line) during their RI phases indicated by the red dotted lines: (a) Amphan, (b) Kyarr, (c) Gonu, (d) TC4, (e) TC5, and (f) TC6.

Summary of the study

- The **vertical wind** shear supported genesis, with values being weak to moderate in all cases.
- The **GPP** was greater than 30 in four out of six cases, whereas Gonu and Odisha SUCS had values less than 30.
- **ER** wave was the dominant of **CCEWs** followed by **MJO** before their genesis. In the case of Amphan, all the three waves were present.
- **Ocean conditions** were more conducive for the TC genesis than the atmospheric conditions.
- Pre-genesis scenario was heavily influenced by the ocean characteristics, whereas the atmospheric conditions were not that supportive.
- **Sea surface temperature**, **mid-tropospheric relative humidity**, and **low-level relative vorticity** all had a substantial role in the RI process of all SUCS storms across the NIO basin.
- During the RI days, **TCHP ≥ 60 kJ.cm^{-2}** was observed for Amphan and Gonu, with thick barrier layers for all cases.
- Gonu encountered a **warm core eddy** along its track, which provided extra fuel for the RI process.
- All six TCs are **slow to moderate** moving ones, which facilitated them to spend sufficient time over the Ocean surface and interact with the warm waters to get **positive feedback** for the RI process.

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Thank you…………

"Earthquakes , cyclones , floods- these are part of the way the earth operates. Although we can't prevent natural hazards from happening, we can learn from them, and use this knowledge to prevent natural hazards from turning into natural disasters"