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ANALYSIS OF EXTREME SEVERE CYCLONE STORM 'BIPARJOY' IN THE ARABIAN SEA

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Abstract: In this research, the exceedingly dangerous tropical storm "Biparjoy", which developed over the Southeast Arabian Sea in June 2023, is examined in terms of its development, motion, and dissipation. The Indian Meteorological Department IMD study showed that the cyclone persisted in the oceans for a longer time after it formed, providing a significant amount of strength and moisture to travel a very long trajectory (2525 km) across the Arabian Sea (AS), the Bay of Bengal (BoB), and the North Indian Ocean (NIO), with a total life period of 13 days and 3 hours (depression to depression). The current study evaluates the evolution of the cyclone's Specific and Relative Humidity, Relative Vorticity, Latent Heat Flux and Sea Surface Temperature (SST) using ECMWF reanalysis (ERA5) data. A much higher SST persisted throughout the TC's existence, which maybe the main factor behind the cyclone's sudden intensification, according to an analysis of the satellite data on the TC's SST(Sea Surface Temperature). SST readings and LHF(Latent Heat Flux) measurements were both determined to be high and when the TC neared the beach, an RV value that was both high and positive was discovered. Also seen during intensification were high specific and relative humidity values.

IndexTerms- Tropical Cyclone Storm; Longest Trajectory; Specific Humidity and Relative Humidity.

I. INTRODUCTION

India's coastal regions, tropical cyclones are the most damaging natural catastrophes, resulting in more serious damage than any other calamity (Pendleton et al., 2005; Nicholls, 1995). According to Knutson et al. (2010), these cyclones, which have their origins in the Bay of Bengal and Arabian Sea , have a considerable influence on the overall weather system across the Indian subcontinent. They obtain their energy from the warm water surfaces, contributing significantly to the occurrence of extreme weather in India and seriously interfering with people's lives throughout the nation. The Arabian Sea and the Bay of Bengal are located on India's eastern and western borders, respectively, while the Indian Ocean encircles it on all four sides in the middle and on both of its southern and middle edges. Low-pressure zones frequently emerge in the summer and after a monsoon seasons, creating the ideal environment for the growth of powerful tropical cyclones. These cyclones frequently have an impact on both the west and east coastlines of India (Murali et al., 2017). In the southwest of India, many tropical cyclones have recently caused a considerable number of fatalities and major infrastructural damage. According to several studies, these cyclones have an effect on ocean productivity, oceanic parameters, and atmospheric characteristics (Nguyen et al., Shay et al., 2000; Pandey and Liou, 2020, Kafatos et al., Sarkar et al., 2018c;., Gautam et al., 2005a,b; 2006;). Real-time forecasting is difficult since we still don't fully understand the underlying dynamics and mechanisms of cyclone intensification, migration, and dissipation. These cyclones' abrupt intensification and fury are attributed to a number of physical parameters, including Sea Relative Vorticity, Latent Heat Fluxes, Relative Vorticity, Specific and Relative Humidity, and Sea Surface Temperature (SST) among others. This exploratory study intends to determine the elements influencing the severe intensification, movement, and dissipation of Extremely Severe Cyclonic Storm Biparjoy due to the paucity of studies on the North Indian Ocean basins. The second cyclone storm and third depression of the 2023 North Indian Ocean cyclone season was the powerful tropical cyclone known as Biparjoy, which developed over the eastern central Arabian Sea. It began as a depression that the IMD Indian Meteorological Department initially noticed on June 6 and then became stronger to become a cyclonic storm. Biparjoy fluctuated in power because to shifting convective patterns and wind shear, but it finally quickly became an exceptionally severe cyclonic storm before touching down near Naliya, India, on June 16. After making landfall, Biparjoy deteriorated into a depression before becoming a well-defined low-pressure system on June 19. Notably, Bangladesh picked the name Biparjoy, which in Bengali means "calamity." Biparjoy's observed path is shown in Fig. 1(a), along with a timeline of its evolution, encompassing extreme severe cyclonic storms (ESCS), very severe cyclonic storms (VSCS), severe cyclonic storms (SCS), cyclonic storms (CS) depressions (D) and deep depressions (DD). The IMD analysis demonstrated that Biparjoy stayed in the waters for a lengthy amount of time after creation, gaining strength and moisture as it travelled across the North Indian Ocean over a significant distance (2525 km), engulfing the Arabian Sea(AS) and the Bay of Bengal(BoB). From depression to depression, it lived for a total of 13 days and 3 hours. The goal of this research is to look at the synoptic and dynamical elements that led to the formation, escalation, and final weakening of the Severe Cyclonic Storm (SCS) Biparjoy. It specifically investigates the effects of synoptic-

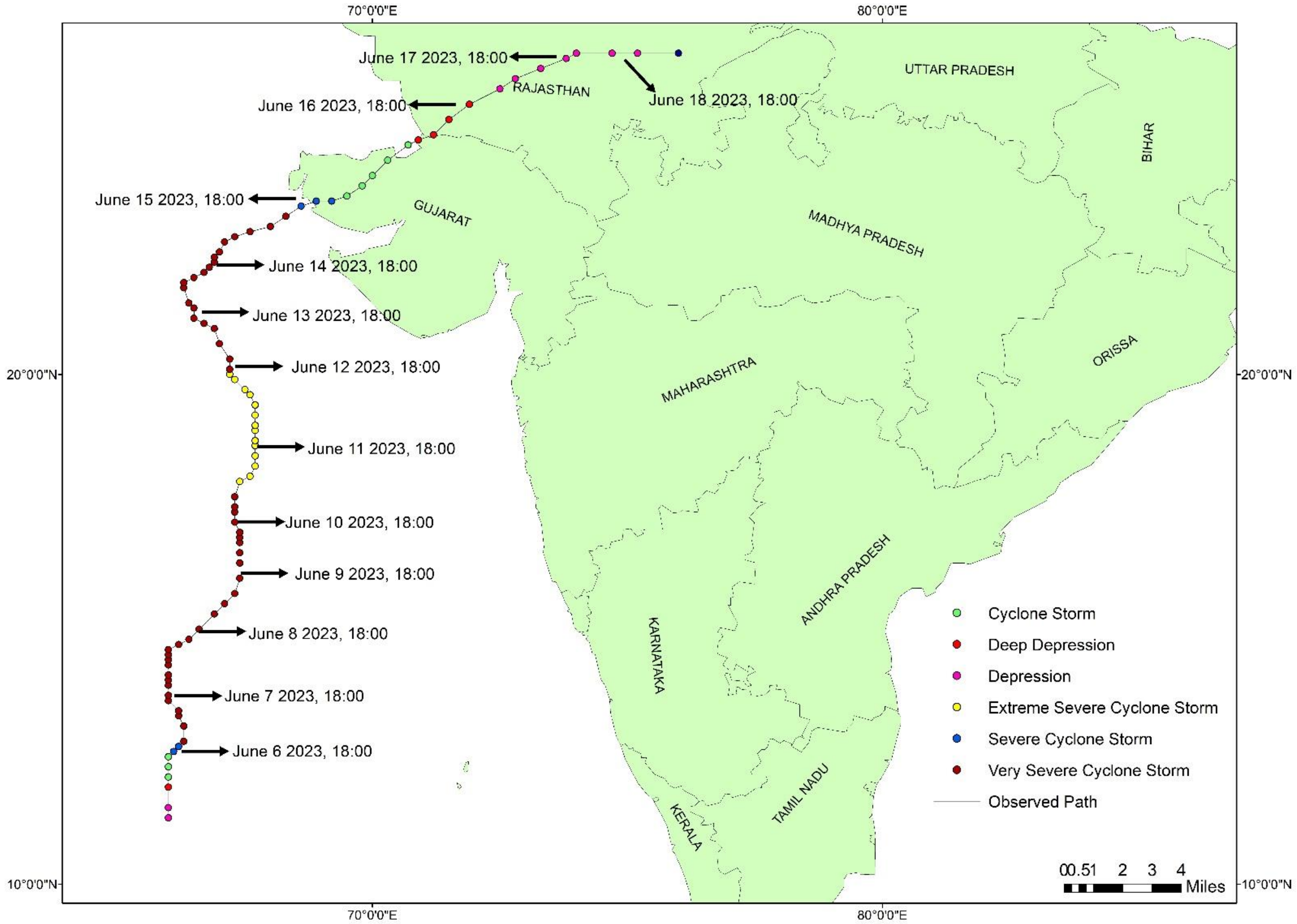

Fig.1. Track observation for ESCS "Biparjoy" in The observed track has been mapped using the best track information available from the India Meteorological Department (IMD).

II. RESEARCH METHODOLOG

1.1. DATA AND SOURCE OF DATA

To examine the cyclone's formidable features, the current analysis uses daily sea surface temperature (SST) readings collected from satellite data and obtained from the ERA5 platform. SST data is a level 4 global data product that integrates information from many sensors. On the ECMWF website, you may get more information on this SST dataset. The research also makes use of data from ERA5 that includes "Latent Heat Fluxes," "Wind Speed and Direction," "Relative Vorticity," "Specific and Relative Humidity," and "Total Column Ozone." Through the linked link, it is possible to acquire ERA5 hourly data at single levels extending from 1959 to the present. On the official website of the IMD, you may get more information on the "Biparjoy" Extreme Severe Cyclonic Storms (ESCS, VSCS, and SCS). ArcMAP 10.8.2 was used to create all of the observed tracks of the cyclone storms. Data from ERA5 were extracted and displayed using GrADS 2.2 and Python 3.11 for Specific and Relative Humidity, Latent Heat Flux, Specific and Relative Humidity, and SST other variables. Using the true-color photos from NASA World View displayed in Fig. 2, the Cyclone Events are confirmed.

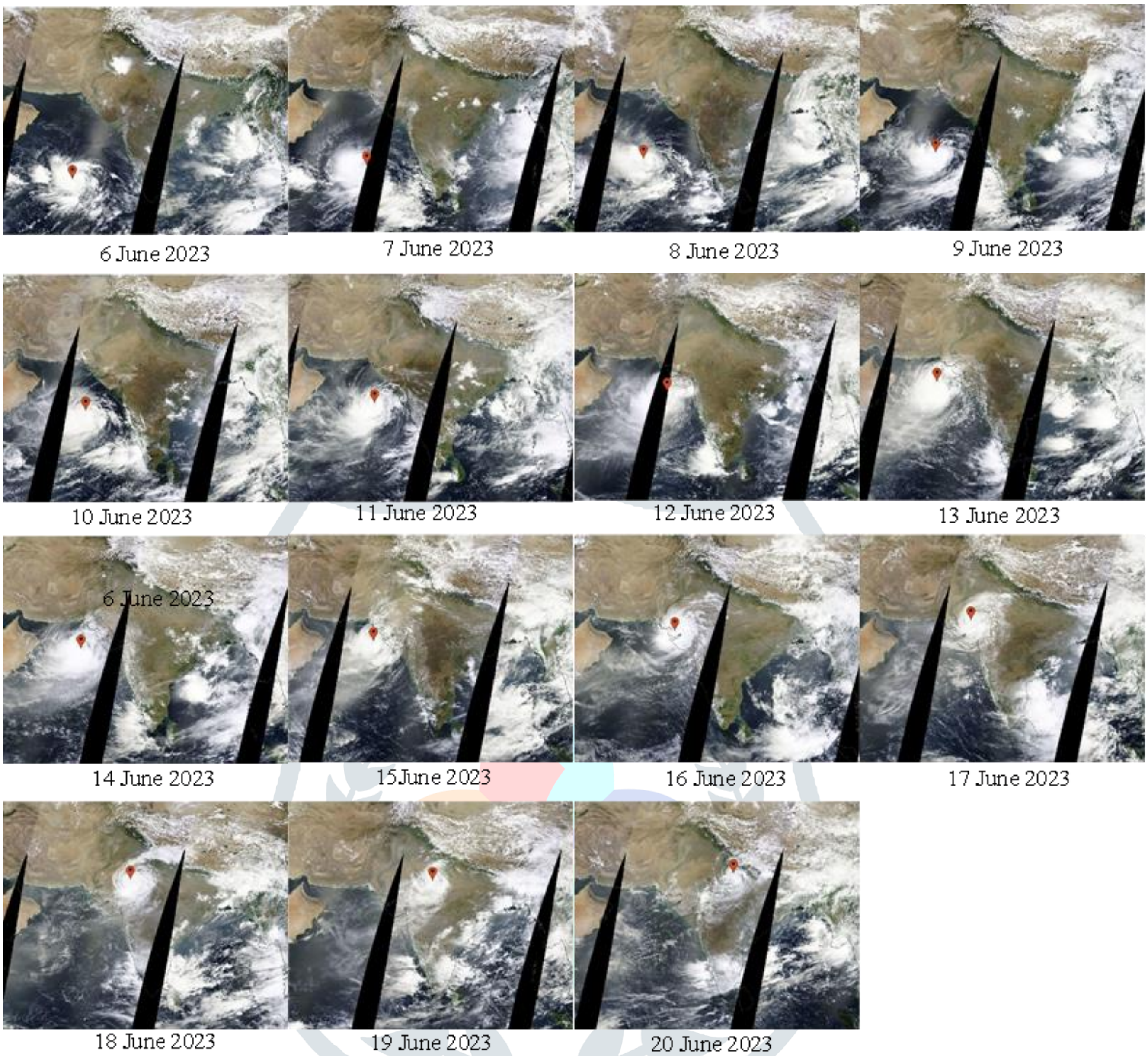

Fig. 2: NASA World View's True Colour Images of Tropical Cyclone "Biparjoy".

III. RESULT AND DISCUSSION

3.1. SEA SURFACE TEMPERATURE

In the literature, it is generally acknowledged that SST is crucial for the growth and intensification of TCs. Tropical cyclones are significantly influenced by SSTs, and vice versa, SSTs are also significantly influenced by cyclones (Strazzo et al. 2016). Dense clouds, Strong winds or Evaporation can have a substantial an effect on the SST, which only extends a few centimeters below the surface of the sea (Singh et al., 2023). According to Lin I. et al. (2008), when SSTs are higher than 25.50 degrees Celsius, about 98.3% of tropical cyclones develop. Additionally, the rapid, rapid strengthening of cyclones is linked to their movement towards warmer SST zones. The SST is briefly cooled by TCs when they pass through after rapidly intensifying (Gao et al. 2010). According to the "SST hypothesis" of quick intensification, the authors of the current study examined the daily SST variations during the ESCS "Biparjoy's" occurrence. The observed SST values over the duration of the VSCS 'Biparjoy' (6th June to 19th June 2023) are shown in Fig. 3(a-m). The chart shows that on June 7-June 10, 2023, a warmer SST pool (around 30 to 31 degrees Celsius) was present over over the east-central Arabian Sea and the nearby north Andaman Sea. Given that the SST in this genesis zone was greater than 2-3 degrees relative to its surrounds, the conditions were optimal for the development of a strong system. It is possible that the SST warm pool helped the ESCS "Biparjoy" grow stronger and advance. A stretch of warmer SSTs can be seen near the Gujarat coast in Fig. 3(g), which is consistent with the IMD's claim that the TC underwent a fast intensification on June 14, 2023, before to making landfall. It's possible that the warmer SST belt along the Gujarat coast helped the storm grow quickly before it made landfall. In the green circular area surrounding impact in the image from October 18th, a much cooler SST (temp 27-28 Degree C) is observed below the reported track after the TC made ashore.

3.2. LATENT HEAT FLUX

There is frequently a correlation between an area where tropical cyclones are fast developing and a region with high surface latent heat fluxes, which represent the heat transfer from the ocean to the atmosphere during a tropical cyclone's strengthening phase (Yang et al. 2007). This heat transfer is due to the Clausius-Clapeyron equation, which describes how adding water vapour to warm, saturated air increases the amount of moisture the air can hold. Condensation occurs as moist air rises in an ascending column, which releases a considerable amount of latent heat, particularly near the cyclone's eye-wall (S. Chen et al. 2014; Y. Wu et al. 2020). The enhanced wind speeds inside tropical storms are caused by this "condensation process," in which a tiny percentage of the energy produced during condensation is converted into mechanical energy. These increased winds then result in higher condensation and evaporation. Condensation (or latent heat) and wind therefore establish a positive feedback loop, transforming the cyclone into a heat engine. But it's important to recognise that this heat engine is reliant on a steady supply of atmospheric moisture,

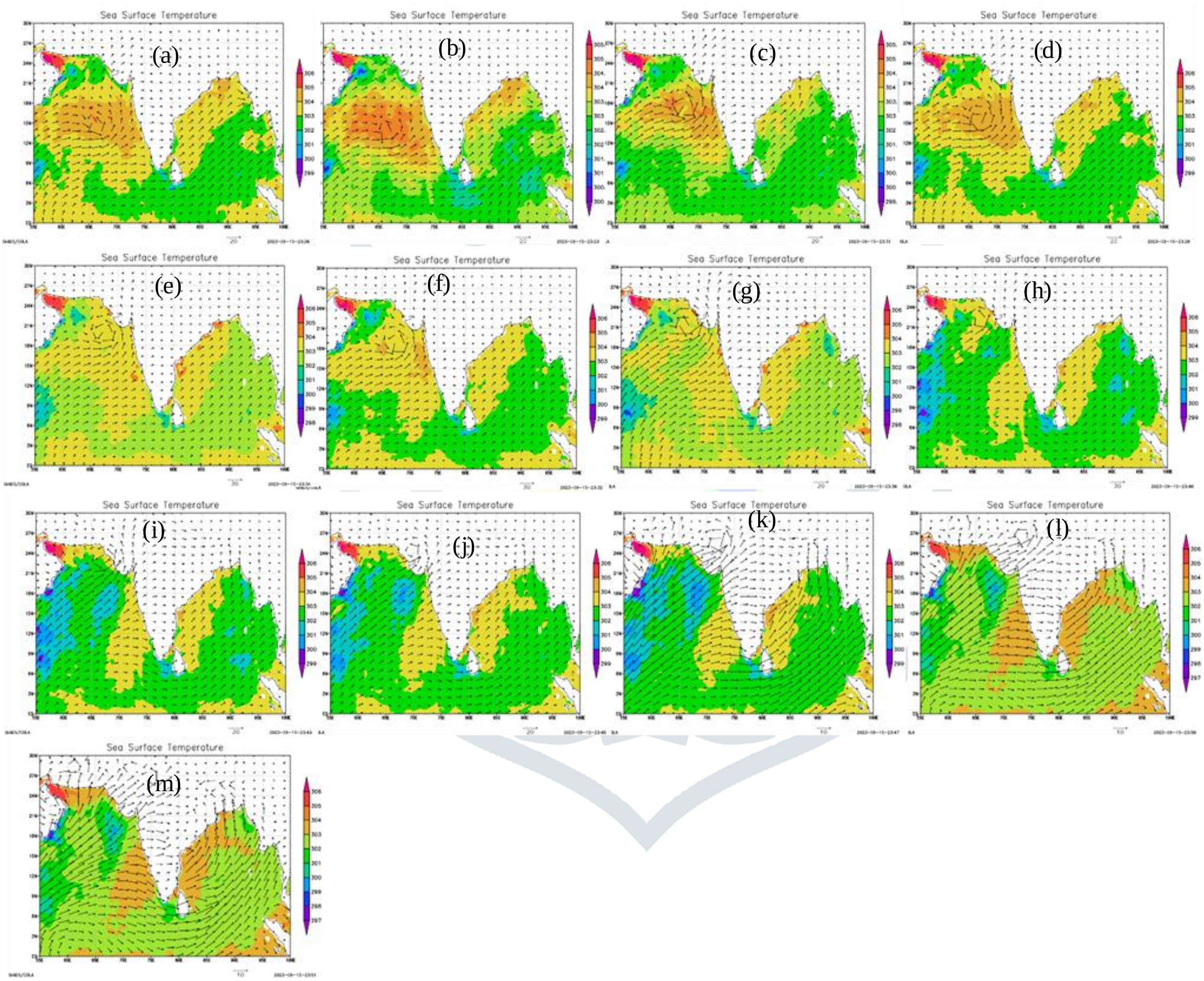

Fig. 3. Daily ESCS "Biparjoy" sea surface temperature charts. The SST data was generated from satellite measurements. The colour bars' values, which are given in Kelvin units, show the observed SSTs. GrADS and Python scripts were used to create the plot.

which makes it reliant on warm ocean waters. As a result, when a tropical storm touches down on land, it loses its fuel and evaporates. Daily changes in the observed latent heat fluxes (measured in Joules per square metre) have been linked to the extreme severe cyclonic storm (ESCS) "Biparjoy." The precursor instability may initially cause a small patch of latent heat to form near to the cyclone's genesis zone (Fig. 4(a)). As the tropical cyclone evolves and systematically develops, the latent heat fluxes increase, reaching values exceeding 3600 Joules per square metre around the area of the eye wall (Fig. 4(b-g)). Story for Mocha on June 13, 2023 (Fig. 4(g)) the tropical cyclone's rapid intensification phase is graphically. This is especially true in the eastern arabian sea region near Pakistan and India's coastal region, where significant amounts of latent heat are released over a wide area. Following landfall, the latent heat flux seems to diminish, as demonstrated in figures Fig. 4(l), highlighting the important contribution of latent heat release to the severe character of Tropical Cyclones "Biparjoy 2023".

3.3. RELATIVE VORTICITY

Relative Vorticity (RV) affects the pace at which TCs form on a global scale. According to Kaplan et al. (2010) and Wang et al. (2015), the interaction of "shear," "curvature," and "Coriolis" causes cyclones to produce vorticity. An RV value that is positive and high in the lower troposphere (up to 850 hPa pressure level) frequently promotes the creation and growth of cyclones. However, the negative RV is a factor in the drop in TCs. RV in TCs is more than 10*10-5 per second at lower levels and in an area between 100 and 200 km. RV establishes the air's horizontal rotation around a vertical axis in reference to a predetermined place on the earth's surface, according to Hoyos et al. (2006). The cyclonic vortex is forced to shift northward when a tropical storm moves in the direction with the highest relative cyclonic vorticity tendency. As the ESCS "Biparjoy" go through their life cycles, the daily variations in RV are depicted in Fig. 5. The RV's magnitude in "sec^{-1}" units is shown on the colour bar. ERA5 data were utilised to plot the RV variances. As shown in Fig. 5(a), "Biparjoy's" genesis occurred at a location where RV was around $3.5042*10^{-5}$ sec^{-1}. Between June 6 and June 7, 2023, there was also a consistent rise in RV (Fig. 5(b-h)). Figure 5(m) shows the curve from June 18th, indicating a decline in RV (ocean cooling at landing). event occurred after ESCS "Biparjoy" had died.

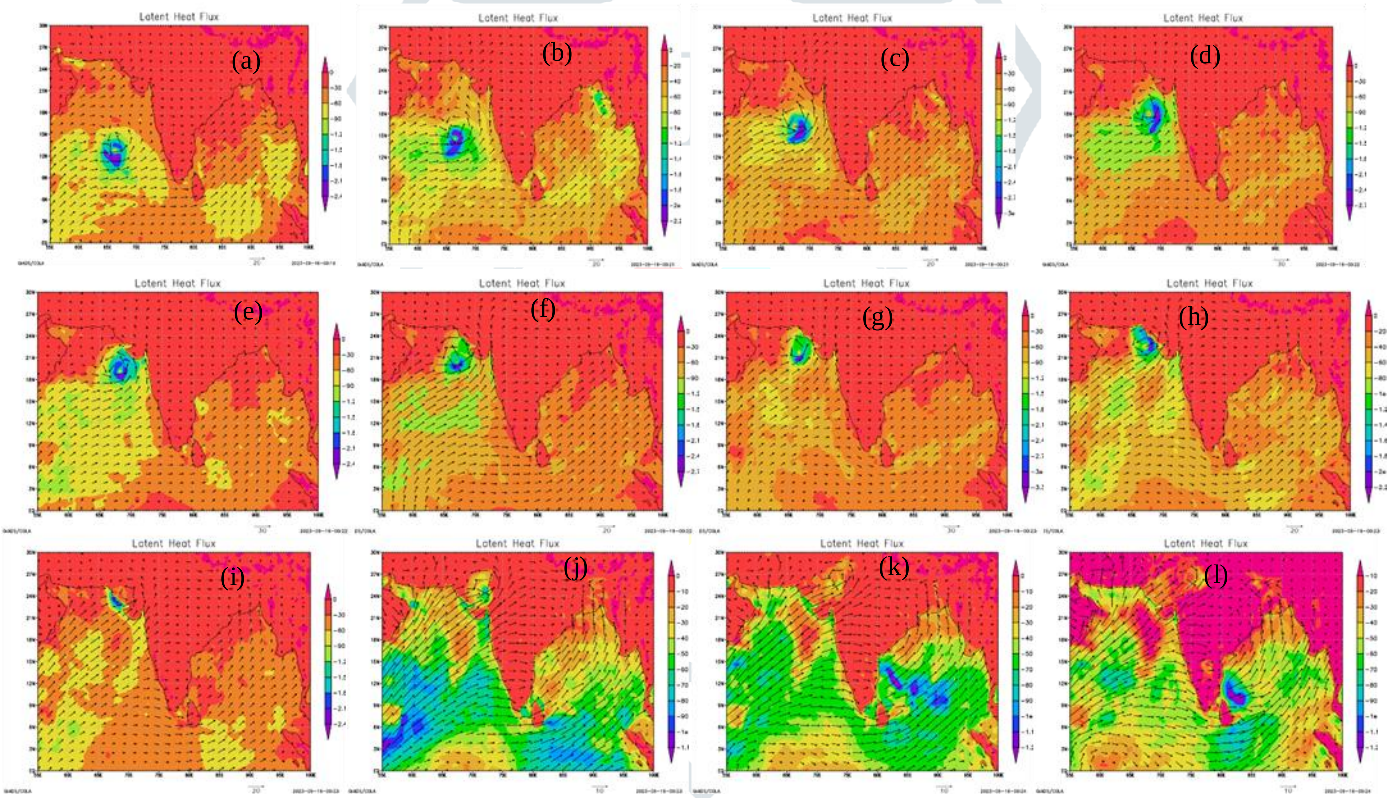

Fig. 4(a-l): Latent heat flow graphs for the ESCS 'Biparjoy' on a daily basis. The latent heat information was collected using the ERA-5 reanalyses. Latent heat concentrations are shown as coloured bars with values in Joules meter-2. Using Python and the GrADS programme, the figure was produced.

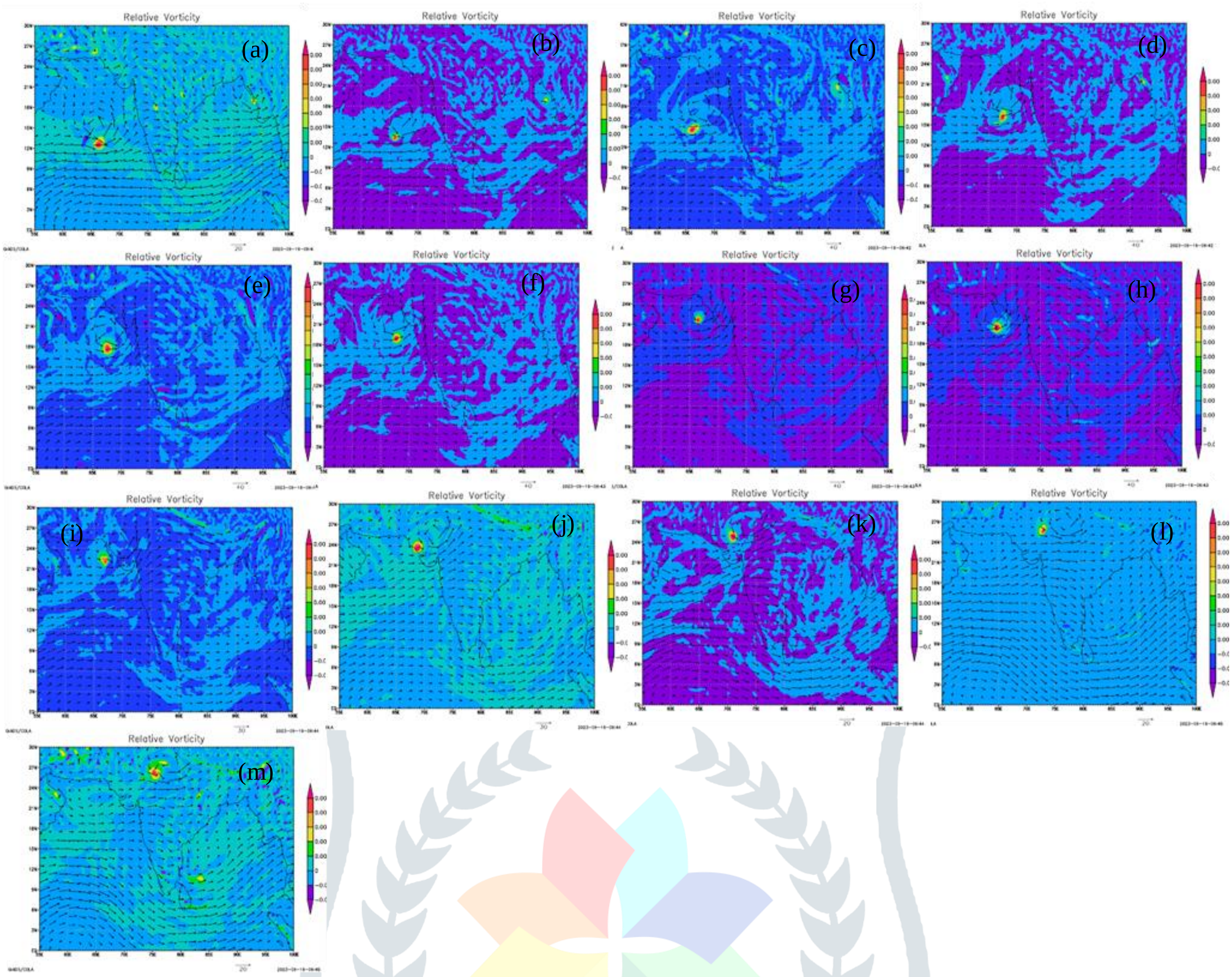

Fig. 5(a-m) Relative Vorticity RV graphs for the ESCS "Biparjoy" on a daily basis. The RV information was gathered using the ERA-5 reanalyses. Color-coded bars with values in sec-1 are used to represent RV levels. Python and GrADS software were used to create the graph.

3.4. SPECIFIC HUMIDITY

Specific humidity, when used to describe a cyclone or tropical storm, refers to the amount of water vapour that is really present in the atmosphere at a certain moment and place. It is often expressed in kilogram of water vapour per kilogram of air and has been an essential feature for understanding the moisture content of the atmosphere inside and near cyclones. The genesis, development, and behaviour of cyclones depend heavily on the quantity of moisture in the air known as specific humidity. This moisture fuels the storm's energy and aids in processes such as condensation, latent heat release, and precipitation. A cyclone can be started by the formation of a low-pressure system brought on by the interaction of two air masses-one warm and wet and the other cold and dry. Cyclones form in warm, tropical regions with high specific humidity, which provides the moisture necessary for the storms to develop and strengthen (Sobel at el. 2016). When water vapour condenses into liquid water inside a cyclone due to rising air, latent heat is generated. This heat release, which drives convective activity and intensification, is the primary energy source for cyclones (Wu, Liguang at el. 2015). Figures 6(a-m) depict the daily variations in latent heat specific humidity associated with the Severe Cyclonic Storms (ESCS) "Biparjoy". One may immediately spot a tiny area of Specific Humidity associated with the antecedent instability close to the cyclone's genesis zone (Fig. 6(a)). As the tropical cyclone grows and strengthens, the Specific Humidity increases, hitting 0.00842 kg/kg of water vapour per kg of air at the eye-wall region for Biparjoy (Fig. 6(b-h)). The storylines for Biparjoy, which takes place on June 10 2023, and Mandous, clearly depict the tropical cyclone's quick intensification phase, during which a substantial quantity of latent heat is produced over a wide region in the middle of the Eastern-central Arabian Sea. According to Fig. 4(m), the specific humidity seems to decrease after impact, emphasising the critical role that the specific humidity played in the strength of Tropical Cyclones "Biparjoy in 2023"

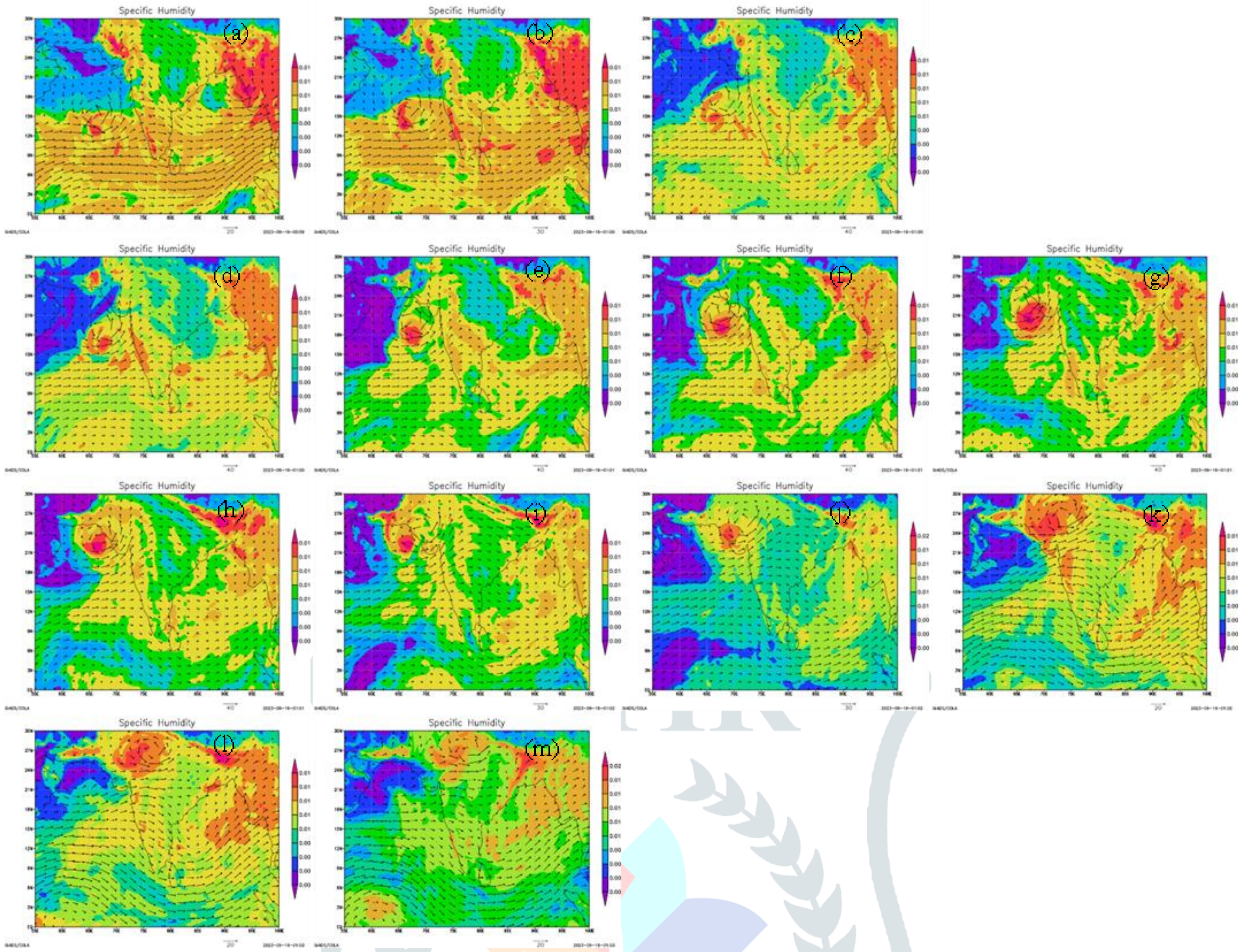

Fig. 6(a-m): Daily graphs of specific humidity for the ESCS "Biparjoy."The Specific Humidity information was gathered using the ERA-5 reanalyses.Color-coded bars with values in kg/kg show certain humidity levels. GrADS and Python were used to build the figure.

3.5. RELATIVE HUMIDITY

Relative humidity in the context of a cyclone or tropical storm refers to the amount of moisture in the air in relation to its capacity to hold moisture at a specific temperature (Wu, Longtao et al. 2012). The amount of moisture in the air is expressed as a percentage and indicates how close to saturation the air is at a certain temperature. The amount of moisture in the air, the likelihood of condensation, the release of latent heat, and the possibility that these weather systems may deliver heavy rain are all provided. Relative humidity is a crucial factor for assessing the stability of the environment. The air is saturated and starts to ascend when the relative humidity in the atmosphere reaches 100% (Pillay et al. 2021). In order for low-pressure systems to emerge at the surface and for cyclones to develop, rising air is required (Kaplan et al. 2010). To develop and strengthen, cyclones require a high relative humidity level near the surface. These storms' moisture requirements are met by warm, moist air coming off the ocean. The air is nearly totally saturated with moisture when the relative humidity is high, which may aid in the intensification of a storm [22]. High relative humidity supports convective flow. Air that is warm and humid cools and condenses at higher altitudes. As a result of the release of latent heat, the storm's updraft is strengthened and boosted. High relative humidity settings, especially those that are close to the surface, can foster the growth and intensification of cyclones (Kaplan et al. 2003). Figure 7 depict the daily variations in relative humidity during the life cycles of the ESCS "Biparjoy". 'Biparjoy's' genesis occurred in a position where Relative Humidity was close to 11% or a little higher, according to Fig. 7(a), which plotted the relative humidity swings using data from the ERA5. As shown in Fig. 7(b-h), there was also a continuous rise in relative humidity from June 8 to June 15, 2023, reaching a maximum of 96%. After ESCS "Biparjoy" passed, there was a decrease in relative humidity (cooling of the waters around the landfall location), as seen on the plot for June 18 (Fig. 7(l)).

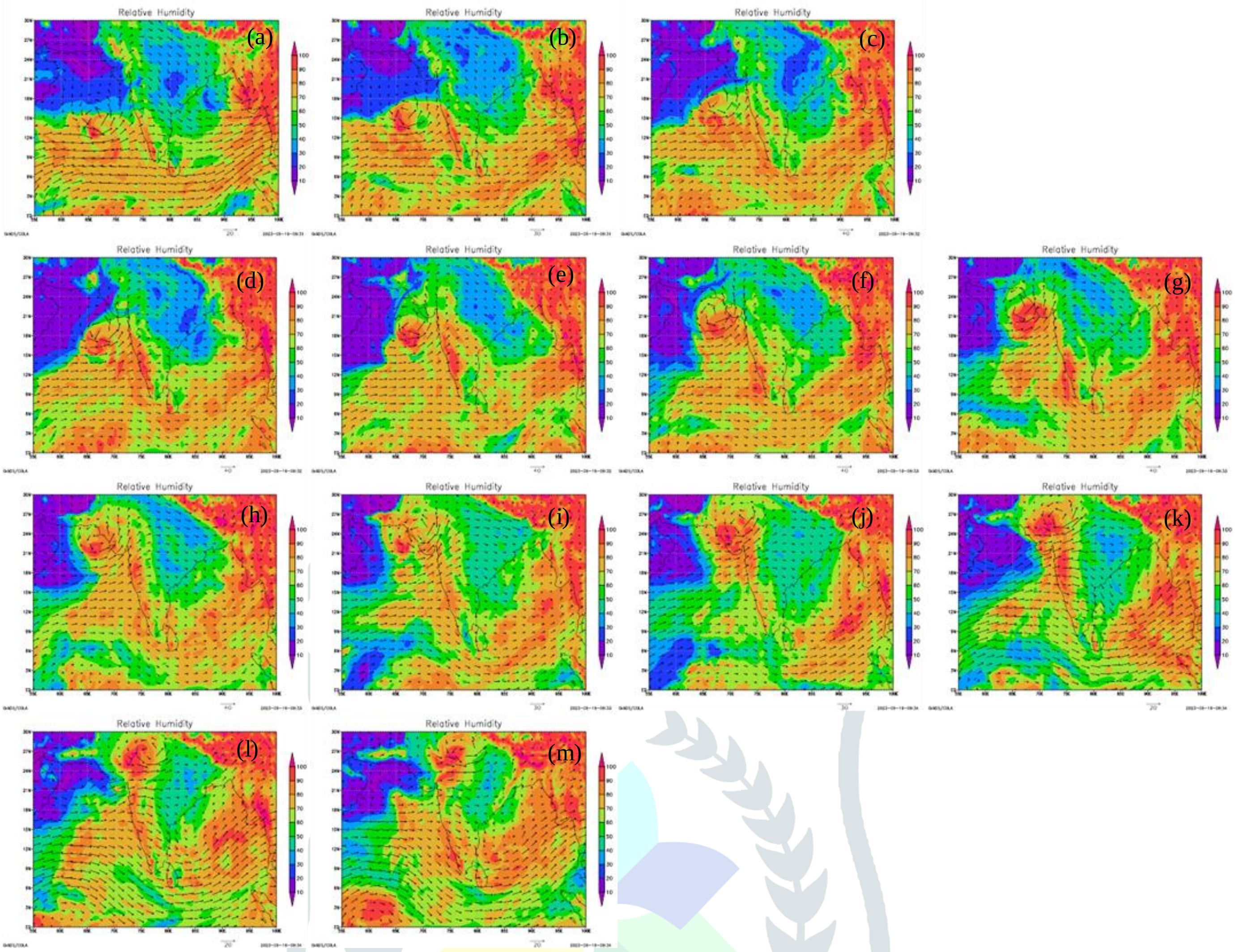

Fig. 7(a-m): Daily relative humidity graphs for the ESCS 'Biparjoy'. The Specific Humidity information was gathered using the ERA-5 reanalyses. Color-coded bars with values in kg/kg show certain humidity levels. Python and the programme GrADS were used to produce the figure.

CONCLUSION

In this study, the ESCS formation was aided by the sea surface temperature's quick rise. A crucial factor in the development and intensification of cyclone storms is latent heat flow, particularly for tropical cyclones. Different latent heat fluxes were present in all of the cyclone storms we observed, including Biparjoy, but substantial latent heat flux release provided them power and drove their intensification. Relative vorticity is a significant component that affects the formation, velocity, and behaviour of cyclone storms. While cyclones can be hindered or weakened by negative relative vorticity, positive relative vorticity is frequently advantageous for cyclone expansion and intensification. Positive relative vorticity aloft (above the cyclone) increases the storm's airflow, which increases its ventilation capacity. Intensification is promoted. Negative relative vorticity aloft might disrupt the storm's organisation and cause it to worsen by preventing outflow and perhaps adding wind shear. Warm, tropical climates with high specific humidity are favourable for the development of cyclones because they provide the necessary moisture for the development and escalation of storms. It provides information on the moisture content of the air, the possibility of condensation, the release of latent heat, and the likelihood that these weather systems may deliver heavy rain. High relative humidity conditions, particularly near the surface, can foster the growth and intensification of cyclones.

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