PROJECT REPORT

ON

Sea Surface Temperature and Wind Analysis of Tropical Cyclone Biparjoy

COURSE NAME :- M.Sc (AGRICULTURE ANALYTICS)

PREPARED BY:

SATYAM KUMBHAR (DAIICT 202319005)

And

ABHAY KUMAR (DAIICT 202319012)

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SUBMITTED TO : - Dr. Sanjeev Kumar Singh
(Marine and Atmospheric Science Department)

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

This study investigates the Analysis of highly hazardous tropical storm "Biparjoy," which originated in the Southeast Arabian Sea from 6th June 2023 to 19th June 2023.The observed intensity and track reveal that the cyclone sustained its intensity over an extended period, thereby accumulating substantial strength and moisture to traverse a considerable distance of 2525 km across the Arabian Sea (AS), the Bay of Bengal (BoB), and the North Indian Ocean (NIO). The cyclone's total lifespan, from its initial formation as a depression to its dissipation, spanned 13 days and 3 hours. During this cyclone wind speed goes up to 30 - 34 m/s.

This present study evaluates Sea Surface Temperature, Wind Velocity and Precipitation during the cyclone period. To study these parameters we did Climatological study of Arabian Sea and Bay of Bengal from 1990 to 2022. In which we studied the trend of Sea Surface Temperature (SST) monthly and yearly for last 32 years. Climatological study shows that area average sea surface temperature of Arabian sea and Bay of Bengal (BOB) shows that the Bay of Bengal (BOB) Sea surface temperature is slightly higher than Arabian sea. To understand the conditions causing genesis SST anamoly has been computed for May June months

The wind velocity of cyclone at different pressure levelslike 850 hPa, 500 hPa and 200 hPa has been also analysed understand cyclone strength, dynamics, and behavior across the vertical atmospheric column. This multi-level approach enhances the accuracy of cyclone forecasting and prediction, aiding in effective disaster management and mitigation efforts.

In this study we also studied precipitation during cyclone period to understand the distribution and intensity of rainfall associated with these weather events. Heavy precipitation during cyclones can lead to flooding, landslides, and other hazards, impacting both human populations and ecosystems. By analyzing precipitation patterns, meteorologists can improve forecasts and provide timely warnings to mitigate potential risks and protect lives and property.

Introduction

India's coastal areas are in fact seriously threatened by tropical cyclones, especially those that are near the Arabian Sea and the Bay of Bengal. The energy required for the genesis and strengthening of these storms is derived from warm ocean waters. They can cause extensive damage to homes, businesses, and infrastructure as they approach landfall by bringing with them strong winds, torrential rains, storm surges, and flooding. These cyclones affect more than just the nearby coastal regions. They can cause fatalities, harm crops, and interfere with transportation networks. Furthermore, tropical cyclones have a significant impact on India's weather system as a whole, frequently causing extreme weather conditions like thunderstorms, intense rain, and in certain areas, drought. (Nitish Raj Rathaur et al.)

The Bay of Bengal and the Arabian sea are located on India's eastern and western borders respectively. The southwest coast of India is in fact very vulnerable to tropical cyclones especially from June to September when the monsoon season is in full swing. The states of Karnataka, Kerala, Gujarat ,Maharashtra and Goa are frequently vulnerable to the effects of cyclones that originate in the Arabian Sea. These cyclones have the potential to cause fatalities and infrastructure damage because to their powerful winds, flooding, storm surges, and heavy rains. Real-time forecasting of cyclones presents significant challenges due to the complex and dynamic nature of these weather systems. While advancements in technology and modeling have improved our ability to predict cyclone behaviour, there are still limitations due to the incomplete understanding of the underlying mechanisms governing their formation, intensification, movement, and dissipation.

Cyclones are influenced by a myriad of factors, including sea surface temperatures, atmospheric pressure systems, wind patterns, and interactions with land masses. However, the exact interplay of these factors and how they contribute to cyclone dynamics is not yet fully understood. This lack of comprehensive understanding makes it challenging to accurately forecast the behaviour of cyclones in real-time, especially as they can quickly change intensity and trajectory in response to various environmental conditions. Numerous elements, such as wind patterns, interactions with land masses, sea surface temperatures, and atmospheric pressure systems, can affect cyclones. It is still unclear how precisely these elements interact and how that affects cyclone dynamics. It is difficult to predict cyclone behaviour precisely in real time due to this lack of thorough understanding, especially as cyclones may swiftly vary in strength and direction in reaction to a variety of environmental circumstances. As a result of rising global temperatures, ocean temperatures rise as well, especially in areas like the Arabian Sea. As a result of the rising sea surface temperatures, cyclone development and expansion are fueled by increased energy and moisture. The number of cyclones developing in the Arabian Sea and other tropical parts of the world has increased as a result.

Bangladesh proposed the term "Biparjoy," which means "disaster" or "calamity" in Bengali.

On June 6, 2023, Cyclone Biparjoy formed in the southeast Arabian Sea, becoming the first cyclone of the year in Arabian sea. It quickly gained strength and by June 7th, it had transformed into a highly intense and dangerous very severe cyclonic storm. On June 11, the sea surface temperature, weak shear wind, and upper air divergence overpowered the negative factor (dry air), helping Biparjoy gain strength.On June 14, the persistent cyclone reached wind speeds of 129 kilometers per hour, or 80 miles per hour, according to the Saffir-Simpson Wind Scale, classifying it as a category 1 storm. Before making a sudden turn to the east on June 14, the storm had been in the Arabian Sea for eight days, mostly traveling steadily north.The cyclone passed Mandvi (Gujarat) and Karachi (Pakistan) and the adjacent beaches of Kutch and Saurashtra before making landfall close to Jakhau Port (Kutch) on June 15. After that, it had turned roughly northeast. For coastal regions in both nations, the storm caused flash floods and severe rainfall. After touching down in Gujarat, it then travelled to Rajasthan. cyclone Biparjay is on course to become the longest-lasting cyclone ever recorded in the Arabian Sea. This highlights the potential impact of climate change on tropical weather systems. Warmer sea surface temperatures can provide more energy for cyclones to maintain their strength and last longer. It is crucial for meteorological agencies and policymakers to continue monitoring and studying these trends.

OBJECTIVES

1. **Climatological study of SST during period of 1990 -2023 of North Indian Ocean**
2. **Analyse the Sea surface temperature of Arabian sea during tropical cyclone Biparjoy (6th June – 19th June, 2023)**
3. **Analyse the Wind Velocity of Arabian sea during tropical cyclone Biparjoy (6th June – 19th June, 2023)**

Literature review

Sea surface temperature

Sea surface temperature (SST) is a critical factor in both the formation and intensity development of tropical cyclones (TCs). Conversely, Tropical Cyclones themselves can influence SST through various mechanisms over their life cycles. This study focuses on the SST changes induced by Tropical Cyclones in the Bay of Bengal (BoB) region and Arabian sea between 1992 and 2023.

Seasonal fluctuations, ocean currents, weather patterns, and climatic phenomena like the Indian Ocean Dipole (IOD) and El Niño-Southern Oscillation (ENSO) can all impact sea surface temperature (SST) in the Bay of Bengal. The mean SST (1990-2023) fig 1 illustrates mean sea surface temperature per year. The Sea Surface Temperature (SST) difference between 2023 and the 1990-2022 average provides information on climatic changes. Positive deviations may indicate ocean warming, which affects marine ecosystems, weather patterns, and climate models. Understanding these distinctions helps policymakers develop strategies to reduce climate change and adapt to its consequences on coastal regions)(Zesheng Chen et. al.)

Tropical cyclones can potentially cause severe harm to coastal areas, including major infrastructural damage, fatalities, and economic disruption. Scientists can more accurately predict the intensity, frequency, and paths of these storms by examining variables such as sea surface temperatures, air pressure, wind patterns, and ocean currents. Research like those of(Suzana J. Camargo et al. 2011) has shown that warm local sea surface temperatures (SSTs) are critical for the development and intensification of tropical cyclones. Nevertheless, it is still unclear how exactly rising SSTs in a warming world would affect the activity of tropical cyclones.

Potential intensity (Suzana J. Camargo et al. 2011) is a theoretical concept that assesses the maximum intensity that a tropical cyclone could reach given the available thermodynamic energy for tropical cyclone intensification in the environment, including the underlying ocean. It is one way to measure the relationship between SST and tropical cyclone activity. Theoretical research indicates that tropical cyclone intensity may increase in response to global warming, mainly due to rising sea surface temperatures (SSTs) and changing atmospheric thermodynamic conditions.

Tropical cyclones (TCs) are amongst the deadliest and costliest natural disasters, affecting people, economies and the environment in coastal areas around the globe.. Wind intensity correlates with the severity of other tropical cyclone-caused dangers such as storm surges, waves, and precipitation. TC-generated waves are an extreme example of wind-wave interactions, and their research is needed to enhance risk assessments and mitigation measures.(Laura Cagigal et al. 2022). Winds can also be measured using remote sensing such as Doppler radar, microwave scatterometers, and microwave radiometers. We have taken windspeed at a height of 800,500,200 to analysis and observe that at 800 and 500 it's converging Convergence often occurs in regions where low-pressure systems are developing. Converging winds at 800 hPa and 500 hPa favor cyclone formation and intensification. and at 200 it's diverging. Diverging winds at 200 hPa act as a limiting factor, preventing further cyclone growth.

Study area

We choose study area over Arabian sea which extend s at 0°–25°N latitude and 55°–75°E longitude and covers approximately 615,000 square kilometers in the Arabian Sea. The Arabian Sea, located in the northern Indian Ocean, is surrounded by several geological features. To the west, it shares borders with the Arabian Peninsula, the Gulf of Aden, and the Guardafui Channel. The Gulf of Oman and Iran are to the northwest, with Pakistan marking its northern border. To the east lies India, while to the southeast are the Maldives and the Laccadive Sea. Finally, Somalia lies to the southwest. The Arabian Sea spans approximately 3,862,000 square kilometers (1,491,130 square miles) in surface area. Its widest point measures around 2,400 kilometers (1,490 miles), while its deepest point reaches depths of 4,652 meters (15,262 feet). Our objective is to gain deeper insights into the role of sea surface temperature in shaping cyclone formation. we will explore various factors including wind patterns, atmospheric pressure, wind velocity, and intensity to gain a comprehensive understanding of the complex dynamics driving cyclone development in this region.

DATA AND SOURCE OF DATA

For explore the formidable characteristics of the cyclone, We are using ERA5 reanalysing model obtained from Copernicus website .

Reanalysis is a process that integrates model data with observations worldwide to create a comprehensive and uniform dataset, adhering to the laws of physics. This method, known as data assimilation, mirrors the approach employed by numerical weather prediction centers. At regular intervals (such as every 12 hours at ECMWF), previous forecasts are merged with recently acquired observations in an optimal manner to generate a fresh, refined estimation of the atmospheric state, referred to as analysis. Subsequently, this updated analysis is utilized to produce an enhanced forecast. Reanalysis operates similarly, albeit at a lower resolution, enabling the compilation of datasets spanning multiple decades. Unlike forecasting, reanalysis isn't bound by time constraints, affording ample time for gathering observations. Moreover, when delving into historical data, there's opportunity to incorporate enhanced versions of original observations, enhancing the quality of the reanalysis output. Data has been regridded to a regular lat-lon grid of 0.25 degrees for the reanalysis and 0.5 degrees for the uncertainty estimate (0.5 and 1 degree respectively for ocean waves)

We have collected Sea surface temperature from 1990 to 2023 which will show trendline how sea surface temperature is increasing or decreasing over time, data for the Month of May, June, July to show how sea surface temperature varies during cyclone period.

Link = https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels-monthly-means?tab=form

To study the wind velocity in cyclone period have also taken U and V component of wind at different pressure levels at 850hPa, 500hPa and 200hPa. The U component denotes the wind's east-west or zonal movement, while the V component signifies its north-south or meridional motion. These components are essential for determining both the direction and intensity of windflow within a given region.

Link = https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form

To study the relationship between intensity and pressure we have taken Estimated Maximum Sustained Wind (kt) and Estimated Centre Pressure (hPa) from IMD report.

Link= https://rsmcnewdelhi.imd.gov.in/archivereport.php?internal_menu=MjY=&year=MjAyMw==

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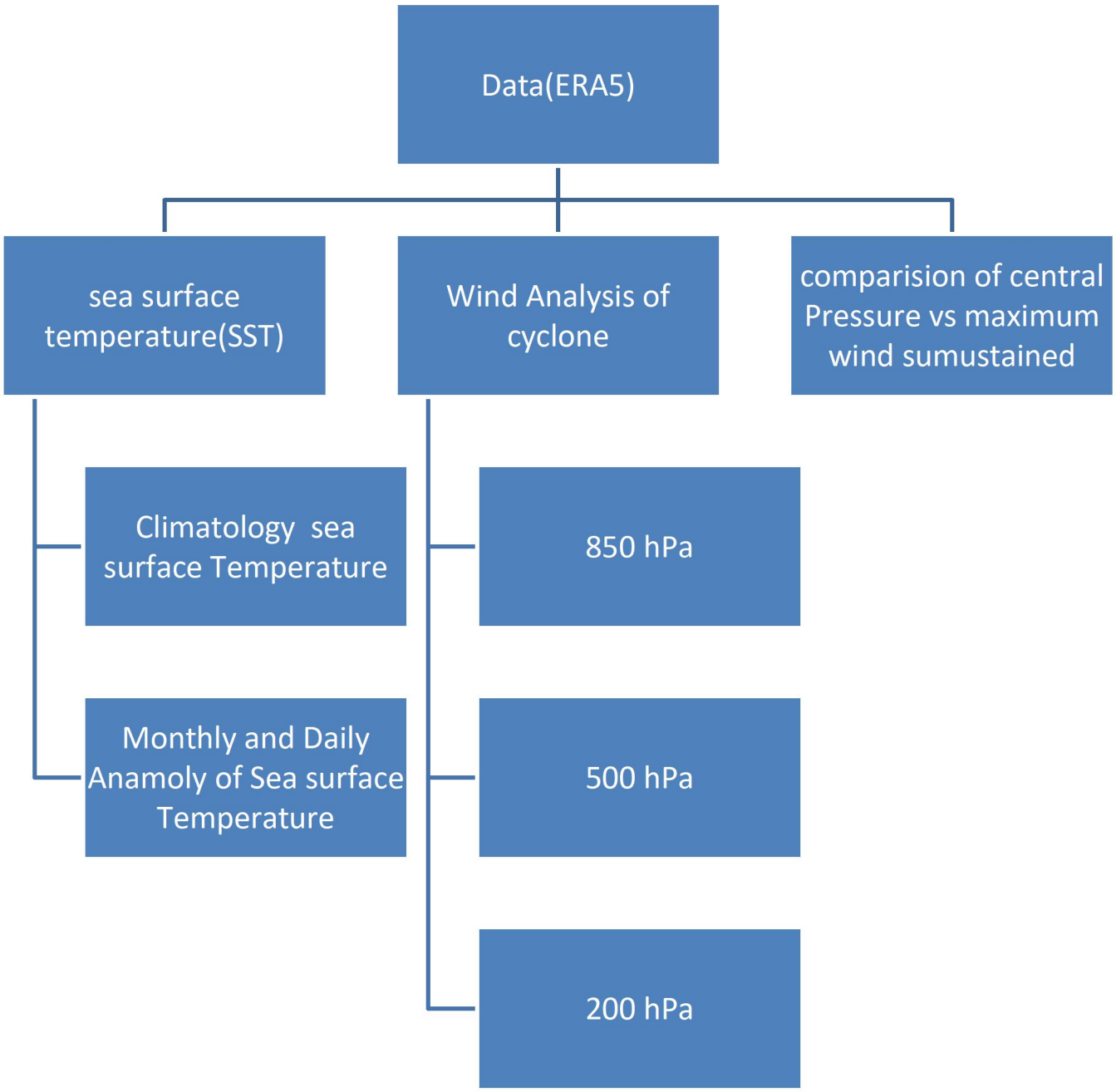
METHODOLOGY



Data -

we analyzed Sea Surface Temperature by using Copernicus ERA5 hourly and monthly averaged data on single levels from 1940 to present datasets and to analyse Wind speed we used Copernicus ERA5 hourly data on pressure levels from 1940 to present. And to study relation between central pressure and wind speed of cyclone Biparjoy we used the Best track positions and other parameters of the Extremely Severe Cyclonic Storm “BIPARJOY” over Arabian Sea during 06th – 19th June, 2023 given by IMD.

Analysis of Sea Surface Temperature :

Cyclones require warm ocean waters with temperatures typically above 26.50°C to provide the necessary energy for their formation and intensification. The warm water evaporates, providing moisture and heat to fuel the storm. To study the formation of cyclone we studied SST in 2 ways:

1) Climatology of Sea Surface Temperature
2) Daily Sea Surface Temperature Anomaly

1) Climatology of Sea Surface Temperature:

To study the cyclone formations in Arabian Sea and Bay of Bengal, understanding the Climatology of Sea surface Temperature of Arabian Sea and Bay of Bengal is important. In this we studied the Mean Sea Surface Temperature (°C) per month and year (1990 - 2023) of Arabian Sea and Bay of Bengal.

To understand atmospheric conditions leads to genesis of Biparjoy we studied Mean Sea Surface Temperature of May and June of Arabian Sea from 1990 to 2023 and the Difference/change in Mean Sea Surface Temperature (May - June) of Arabian Sea between 2023 and 1990 - 2022.

2) Daily Sea Surface Temperature Anomaly

To study the behavior of very saviour cyclonic storm Biporjoy we did the Daily Sea Surface Temperature Anomaly of study area. In which we studied Mean Sea Surface Temperature from 01.06.2023 to 20.06.2023. To understand the movement of Biparjoy we studied the difference between Mean SST of two consecutive days with trajectory of cyclone.

Analysis of Wind Speed :

To study of wind speed at different pressure levels, such as 850 hPa, 500 hPa, and 200 hPa, provides valuable information about the structure and intensity of the cyclone at different altitudes within the atmosphere.

1) Analysis of Wind Speed at 850 hPa pressure level :

This level is often used to assess low-level atmospheric conditions, typically near the surface. By analyzing cyclones at 850 hPa, we can gather information about the low-level circulation, including the strength and direction of surface winds, moisture content, and temperature gradients. This level is particularly useful for understanding the interaction between the cyclone and the underlying surface, such as oceans or land.

2) Analysis of Wind Speed at 500 hPa pressure level :

The 500 hPa level is commonly used as a mid-level indicator of atmospheric conditions. It represents an altitude where the pressure is approximately halfway between the surface and the top of the troposphere. Analysis at this level provides insights into the dynamics of the cyclone's vertical structure, including the strength and position of the jet

stream, upper-level divergence, and the distribution of vorticity. These factors influence the development, track, and intensity of the cyclone.

3) Analysis of Wind Speed at 200 hPa pressure level :

The 200 hPa level is located near the top of the troposphere and is often used to study upper-level atmospheric features. Analysis at this level provides information about the upper-level steering currents that can influence the movement and track of the cyclone. Additionally, features such as upper-level troughs, ridges, and wind shear can be assessed, which impact the intensity and evolution of the cyclone.

relation between central pressure and wind speed in cyclone period :

Studying the relationship between central pressure and wind speed during cyclones informs about storm intensity. A lower central pressure often correlates with stronger winds, aiding in forecasting and understanding cyclone behavior and potential impacts.

RESULT AND DISCUSSION

Climatological Study :

This study investigated the characteristics of tropical cyclone Biparjoy, using the tropical cyclone best-track data, daily sea surface temperature data, pressure data at different pressure levels including 850 hPa, 500 hPa and 200 hPa from Copernicus Era5 data for period 06.06.2023 to 19.06.2023 for the North Indian Ocean. It also includes the analysis of sea surface temperature trends in both Arabian Sea and Bay of Bengal from 1990 to 2023.

A) Analysis of Sea Surface Temperature :

1) Climatology of Sea Surface Temperature

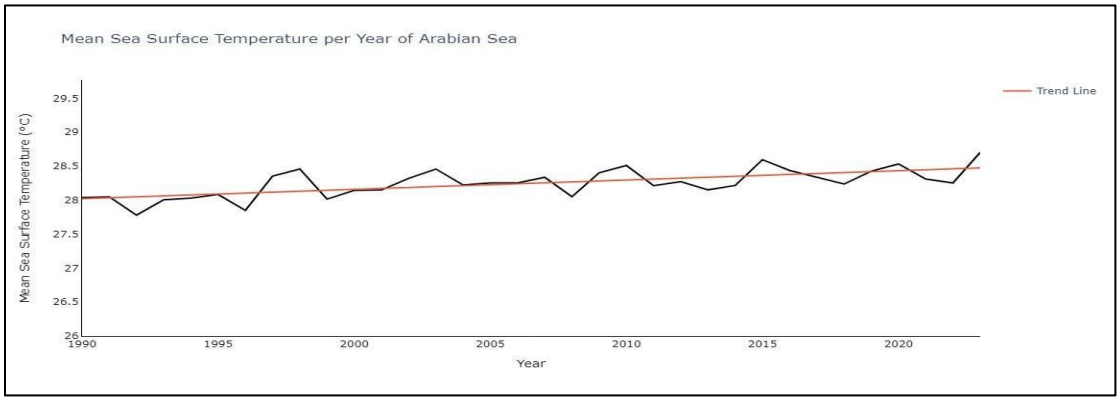


Fig 1- Mean Sea Surface Temperature (°C) per year (1990 - 2023) of Arabian Sea

In Arabian Sea, the sea surface temperature is in increasing trend. It is varied in range 27.70°C - 28.70°C. The lowest yearly mean SST is noted in year 1992 (27.78°C) and the highest yearly mean SST is noted in year 2023 (28.70°C). As SST is increasing year by year it leads to increase in intensity and frequency of cyclones.

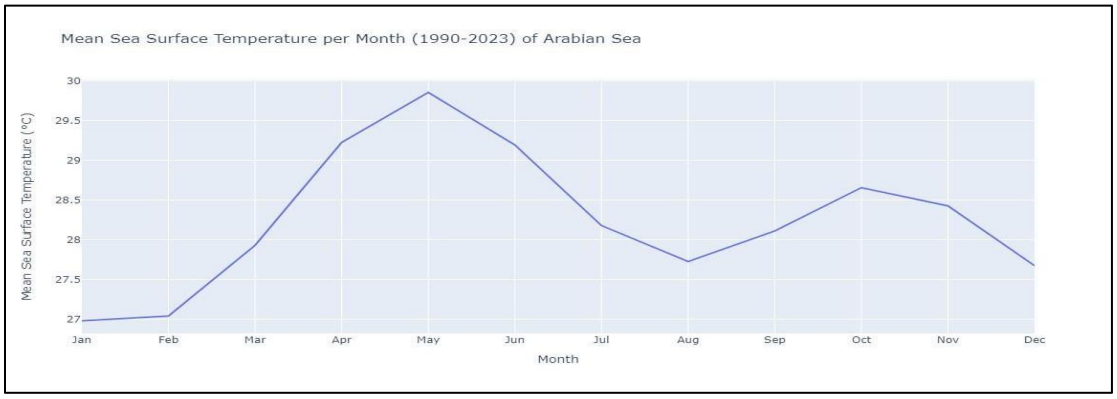


Fig2 - Mean Sea Surface Temperature (°C) per month (1990 - 2023) of Arabian Sea

This plot shows the mean SST of every month from 1990 to 2023 in Arabian Sea. It shows the two peaks in a year in premansoon and post mansoon months i.e May and October respectively.

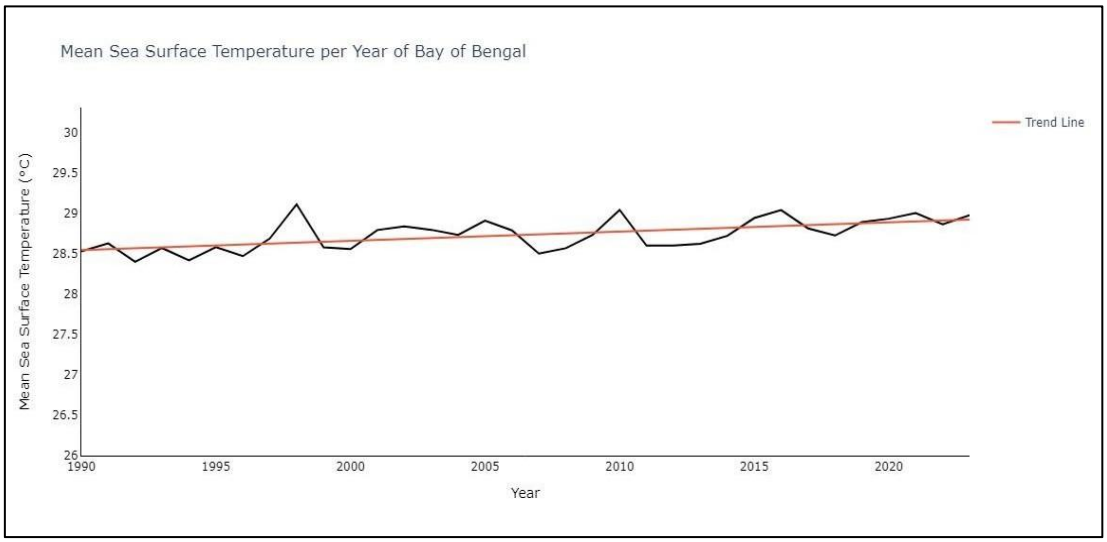


Fig 3- Mean Sea Surface Temperature (°C) per year (1990 - 2023) of Bay of Bengal

In Bay of Bengal, the sea surface temperature is in increasing trend. It is varied in range 28.40°C - 29.11°C. The lowest yearly mean SST is noted in year 1992 (28.40°C) and the highest yearly mean SST is noted in year 1998 (29.11°C). As SST is increasing year by year it leads to increase in intensity and frequency of cyclones.

The mean SST of Bay of Bengal is comparatively more than mean SST of Arabian Sea because, the most of the largest rivers in India ends at Bay of Bengal. The Bay of Bengal receives the annual runoff 1.5 X 10**12 m3 from rivers flowing in it. Therefore, the surface layer in Bay of Bengal is much fresher than that in the Arabian Sea : the average salinity of the top 50 m in the Arabian Sea exceeds that in Bay of Bengal by nearly 3 PSU. The large inflow of freshwater from precipitation and runoff results in strong near-surface stratification in Bay of Bengal. This leads to increase in sea surface temperature constantly. Because of this reason the frequency of cyclones is higher in Bay of Bengal as compared to Arabian sea.(*S.S.C. Shenoi .et .al*)

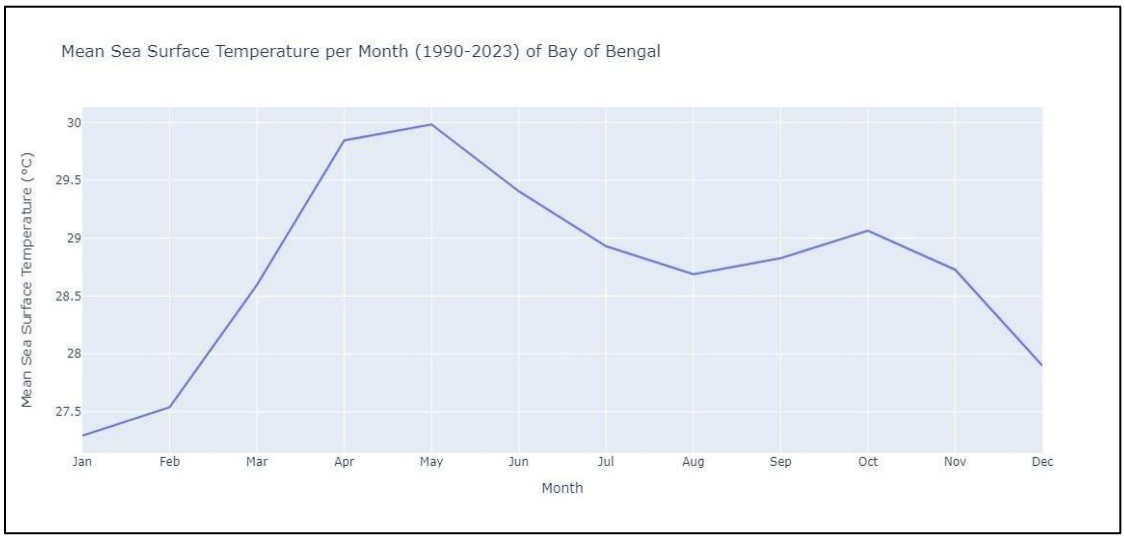


Fig 4 - Mean Sea Surface Temperature (°C) per month (1990 - 2023) of Bay of Bengal

This plot shows the mean SST of every month from 1990 to 2023 in Bay of Bengal. It shows the two peaks in a year in pre-monsoon and post-monsoon months i.e May and October respectively.

2) Monthly Sea Surface Temperature Anomaly from Climatology for May and June

In Arabian Sea the SST goes high in the month of May and June. This causes genesis of cyclones. This study of monthly SST anomaly from climatology for May and June month defines the increasing trend in SST from 1990 to 2023.

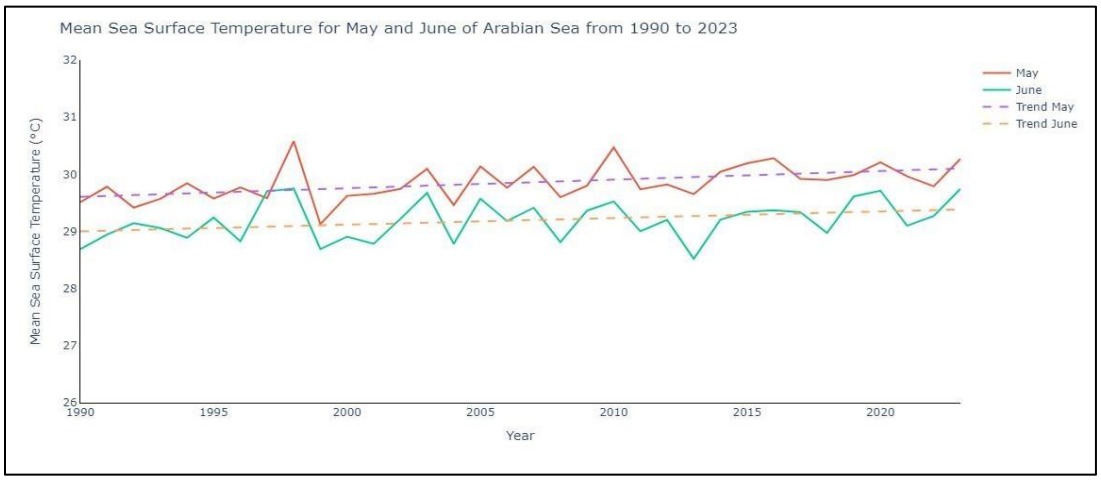
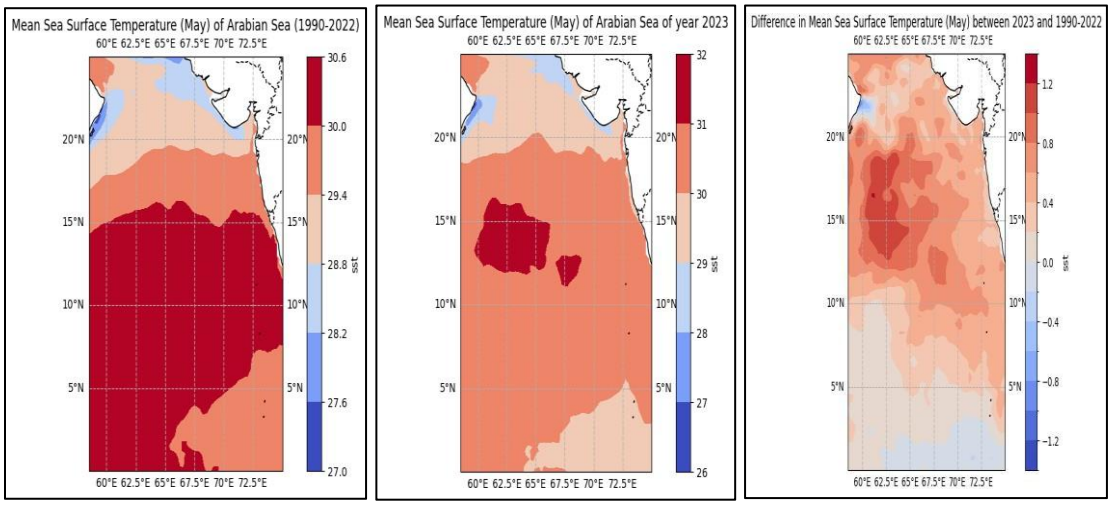


Fig 5 - Mean Sea Surface Temperature of May and June of Arabian Sea from 1990 to 2023

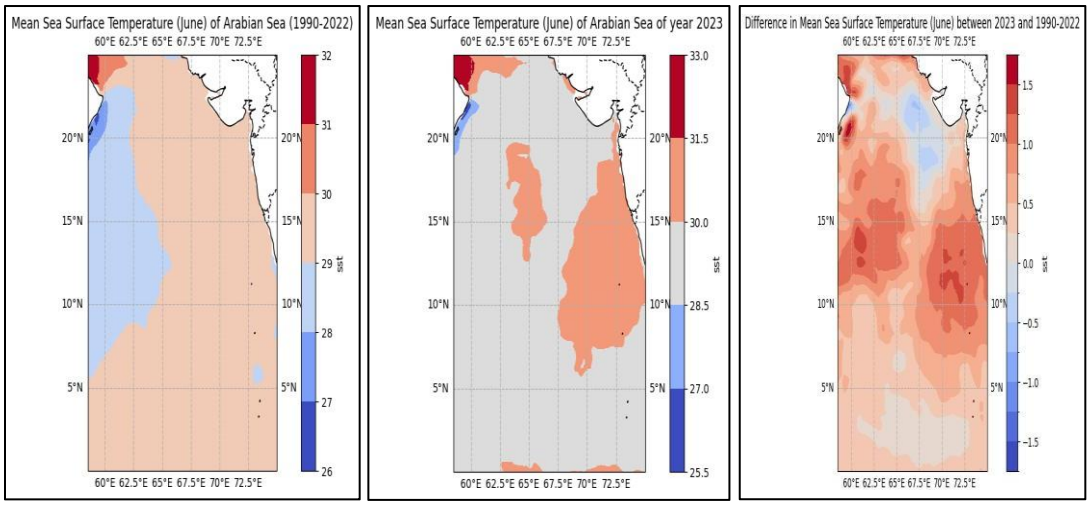
From 1990 to 2023, the SST of month May varies in range 29.12°C to 30.57°C. And in June month SST varies in range 28.51°C to 29.72°C. As SST is very high than 26.5°C, leads to form cyclone generally after mid of May upto mid of June . After cyclone the SST starts to decrease rapidly. Hence, we get comparitively less SST in June month than May month.



(A) (B) (C)

Fig 6 - (A)- Mean Sea Surface Temperature (May) of Arabian Sea from 1990 to 2022
(B)- Mean Sea Surface Temperature (May) of Arabian Sea of year 2023
(C)- Difference/change in Mean Sea Surface Temperature (May) of Arabian Sea between 2023 and 1990 - 2022

In the month of the May, bellow the 15°N the Arabian sea shows very high SST (30°C - 32°C). In 2023 in May month the bellow 20°N SST was in range 30°C - 31°C. The south-east side of Arabian is showing less variation in SST in May. That shows the suitable condition for genesis of cyclones in Arabian Sea.



(A) (B) (C)

Fig 7 - (A)- Mean Sea Surface Temperature (June) of Arabian Sea from 1990 to 2022
(B)- Mean Sea Surface Temperature (June) of Arabian Sea of year 2023
(C)- Difference/change in Mean Sea Surface Temperature (June) of Arabian Sea between 2023 and 1990 - 2022

In the month of the June, the Arabian sea shows SST (28°C - 31°C). In 2023 in June month the bellow 20°N SST was in range 28.5°C - 31.5°C. After the cyclone the SST starts fall down rapidly. The middle-east side of Arabian is showing high variation in SST in June. That shows the rapid cooling of Arabian Sea.

Daily Sea Surface Temperature Anomaly :

As sea surface temperature is the most critical factor to form cyclones. A tropical cyclone is an atmospheric phenomenon that has a system of low air pressure that forms over the oceans in the increase in sea surface temperature. Tropical cyclones can form in oceans with sea surface temperatures above 26.5°C. (*Anendha D. N. et. al.)*

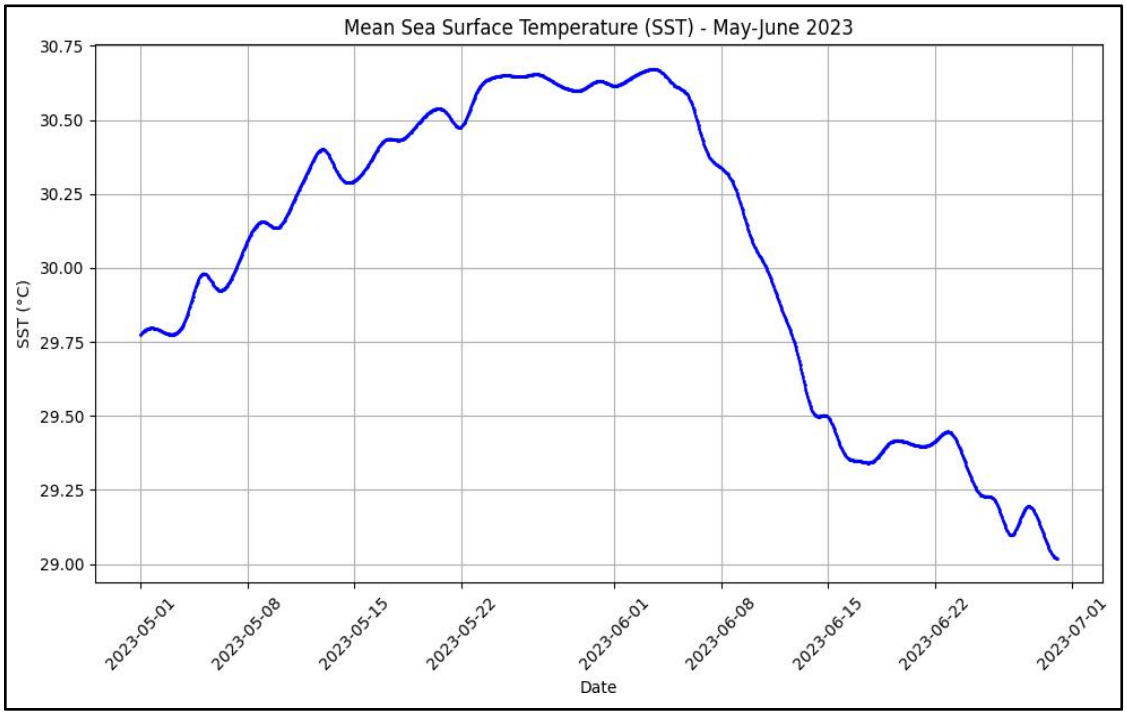


Fig 8 - Mean Sea Surface Temperature from 01.05.2023 to 30.06.2023

In the May and June months, we can see the in May month the SST is gradually increasing. In the June month on dated 04.06.2023 it is showing the highest mean SST (30.66°C). This shows the conditions are created to form a cyclone. On the 06.06.2023 the cyclone get generated. Within the cyclone period (06.06.2023 to 19.06.2023), the mean SST dropped highly. On the last date of cyclone dated 19.06.2023, it is showing SST 29.40°C, which is lowest SST in cyclone period. After cyclone the SST starts to decrease slowly.

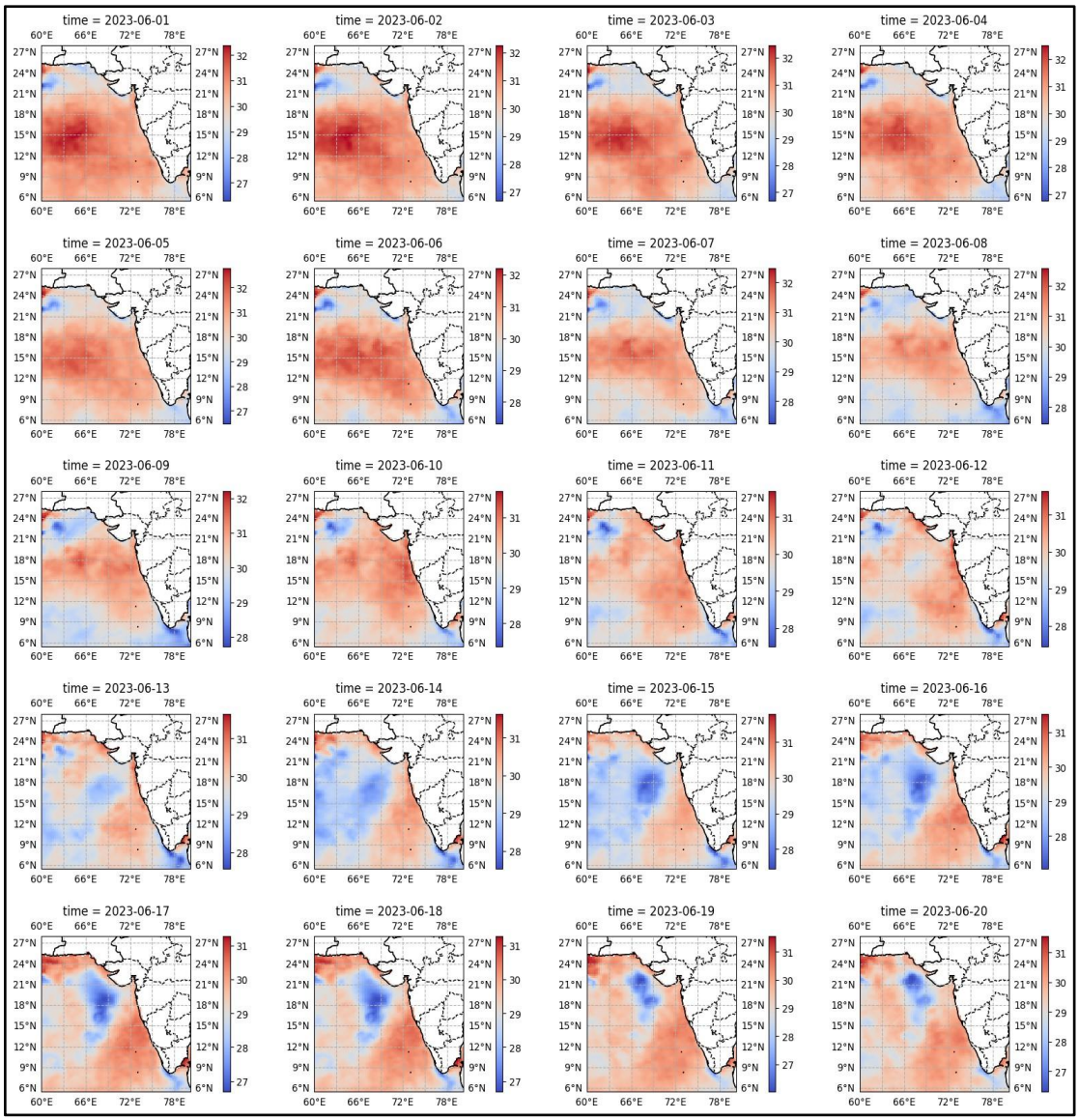


Fig 9 - Spatial representation of Mean Sea Surface Temperature (01.06.2023 to 20.06.2023)

The mean sea surface temperature was highest at the first 4 days of June 2023 is 30.61°C, 30.64°C, 30.66°C, and 30.66°C consecutively. These warm temperatures in the Arabian sea of the tropics are needed as the basis for the intensification of tropical cyclones and fuel to drive tropical cyclones. From date 06.06.2023 to 14.06.2023 the SST starts to decrease fast. As the cyclone moves the SST of ocean behind the cyclone increases gradually.

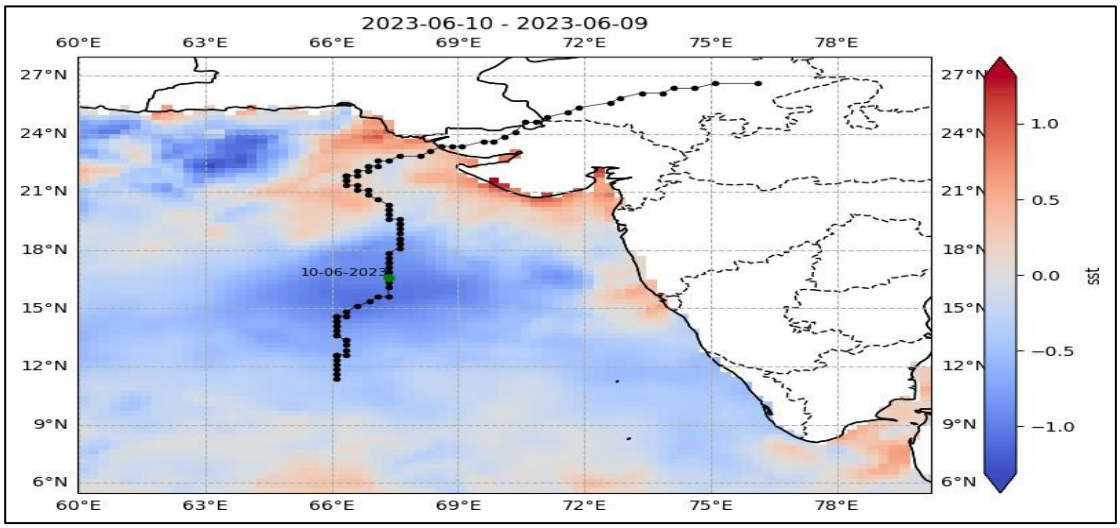


Fig 11 - Change in location of cyclone according to difference in SST of dates 2023.06.09 and 2023.06.10

On 2023.06.09 the cyclone was at point having latitude 14.6°N and longitude 66.35°E. The difference in SST of dates 2023.06.09 and 2023.06.10 is +0.5°C. As cyclones moves towards the maximum SST difference location. It shows +ve anomaly. Now, on date 2023.06.10 the cyclone is at point having latitude 16.6°N and longitude 67.35°E

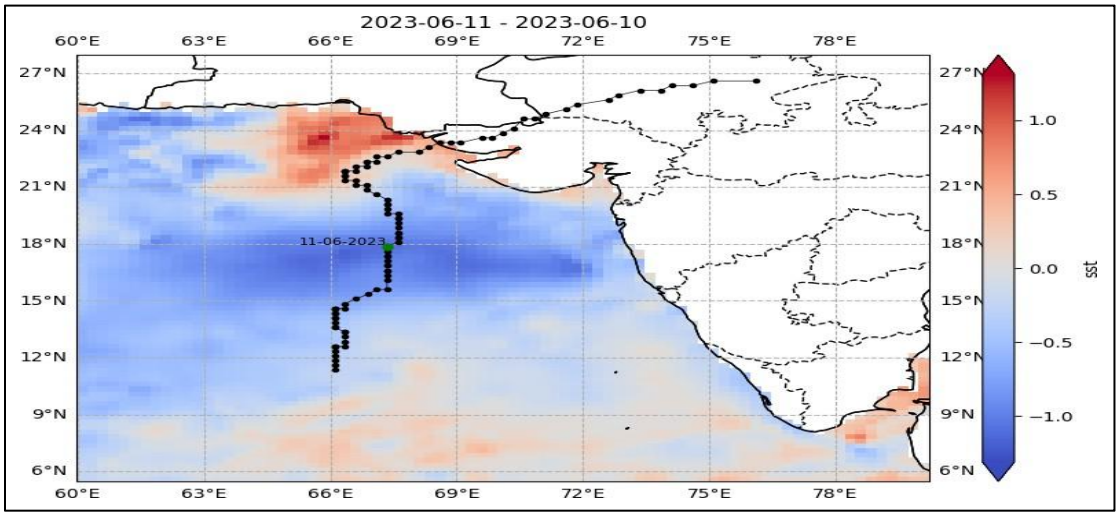


Fig 12 - Change in location of cyclone according to difference in SST of dates 2023.06.10 and 2023.06.11

On 2023.06.09 the cyclone was at point having latitude 16.6°N and longitude 67.35°E. The difference in SST of dates 2023.06.09 and 2023.06.10 is +0.5°C. As cyclones moves towards the maximum SST difference location. It shows +ve anomaly. Now, on date 2023.06.11 the cyclone is at point having latitude 17.85°N and longitude 67.35°E

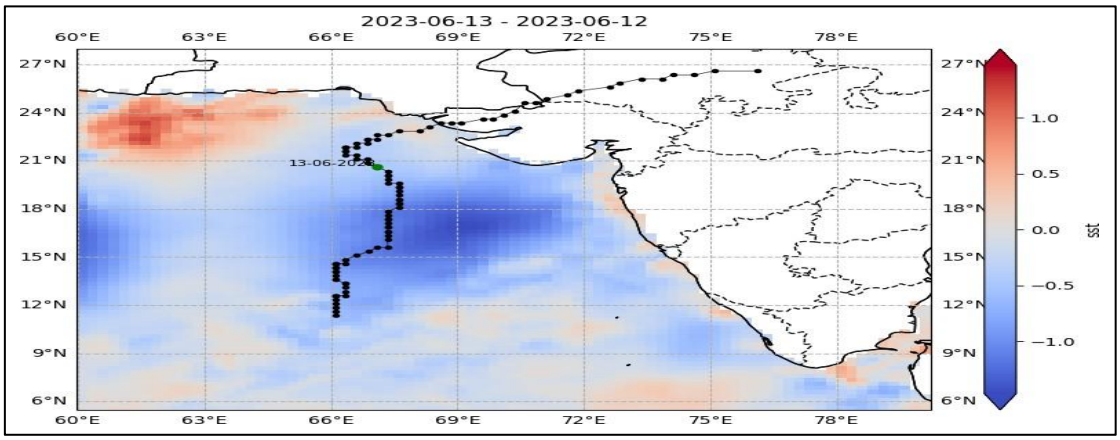


Fig 13 - Change in location of cyclone according to difference in SST of dates 2023.06.12 and 2023.06.13

On 2023.06.12 the cyclone was at point having latitude 19.35°N and longitude 67.6°E. The difference in SST of dates 2023.06.09 and 2023.06.10 is +0.5°C. As cyclones moves towards the maximum SST difference location. It shows +ve anomaly. Now, on date 2023.06.13 the cyclone is at point having latitude 20.6°N and longitude 67.1°E

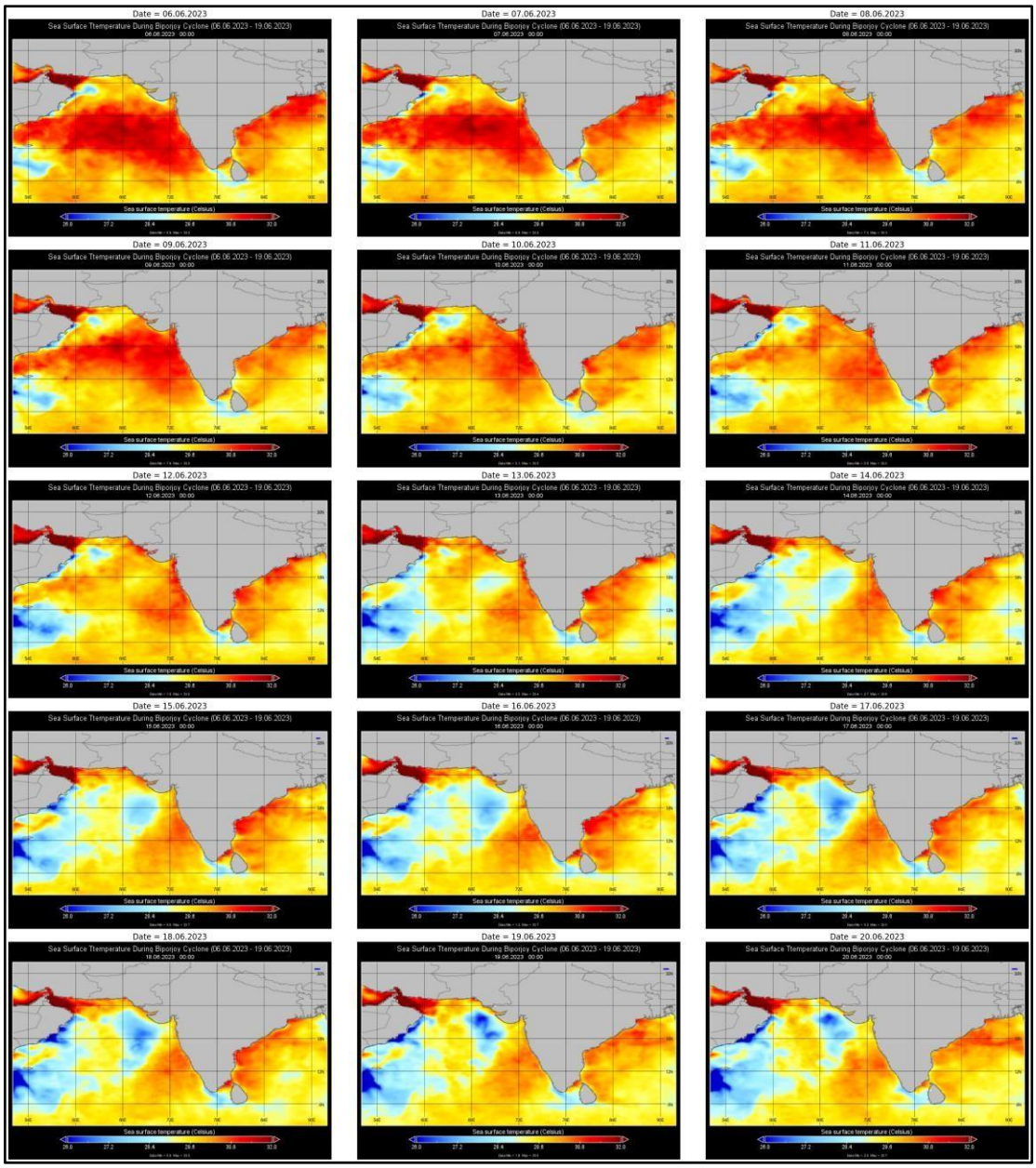


Fig 14 - Mean Sea Surface Temperature variation in cyclone period in both Arabian Sea and Bay of Bengal

At the start of cyclone period the mean SST of Arabian Sea was in range 30°C - 34°C and mean SST of Bay of Bengal was in range 28°C - 30°C. The SST of Bay of Bengal was much less than Arabian Sea during cyclone period. As cyclone moves ahead the mean SST of of Arabian sea decreased rapidly and at the end of the cyclone the SST comes in range 26°C - 30°C, it was showing wide range at different locations. But in case of Bay of Bengal there was no large fluctuations in mean SST throughout the cyclone period.

Analysis of Cyclonic Winds

- **At 850 hPa pressure level**

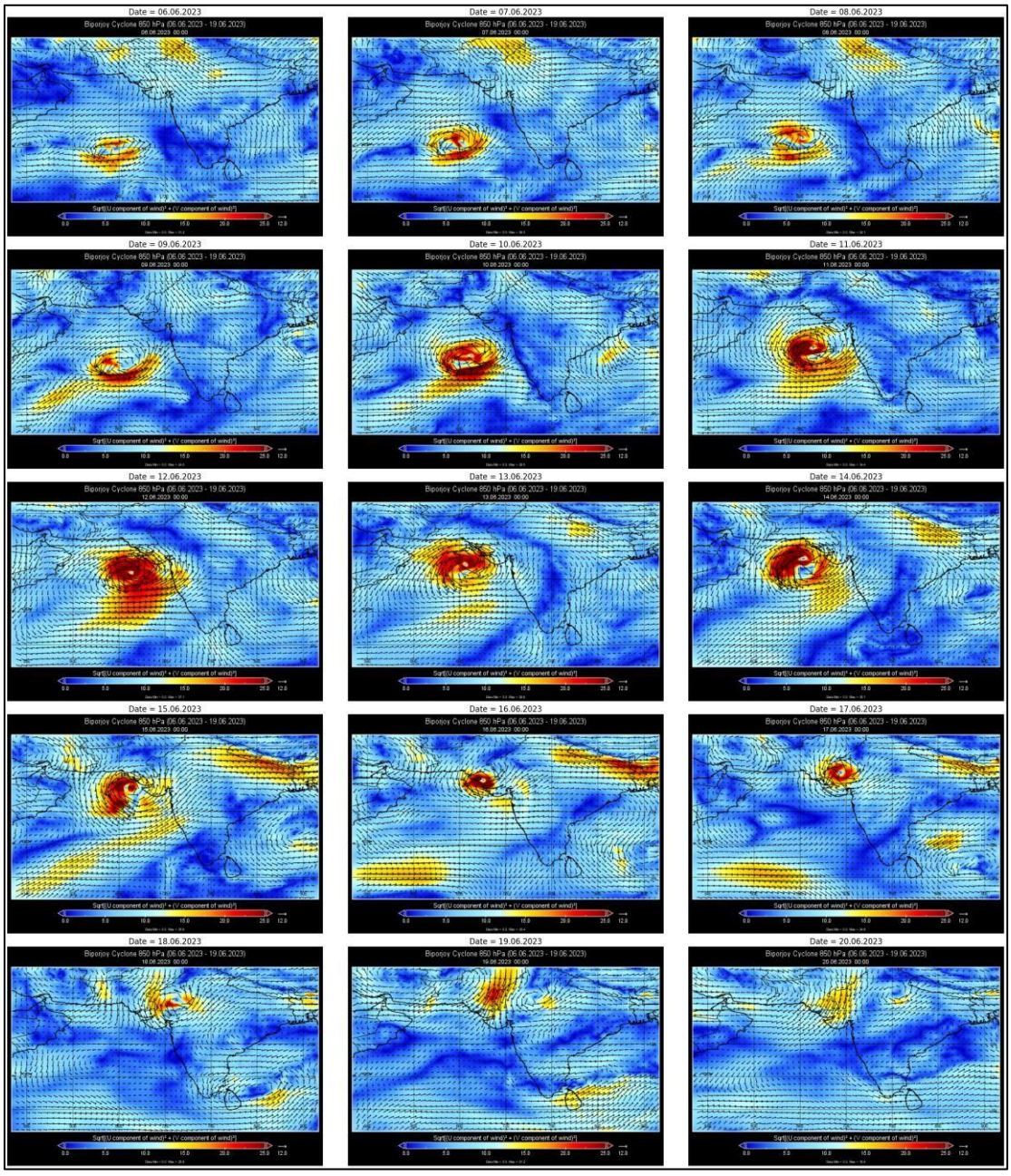


Fig 15 - Spatial representation of wind vectors and wind velocity of Biparjoy Cyclone at 850 hPa pressure level

At 850 hPa pressure level wind vectors shows the convergence. As the cyclone moves ahead the wind velocity goes on increasing. The wind velocity is high around the cyclone eye. At 850 hPa pressure level the high wind speed is in range 25 - 32 m/s.

- **At 500 hPa pressure level**

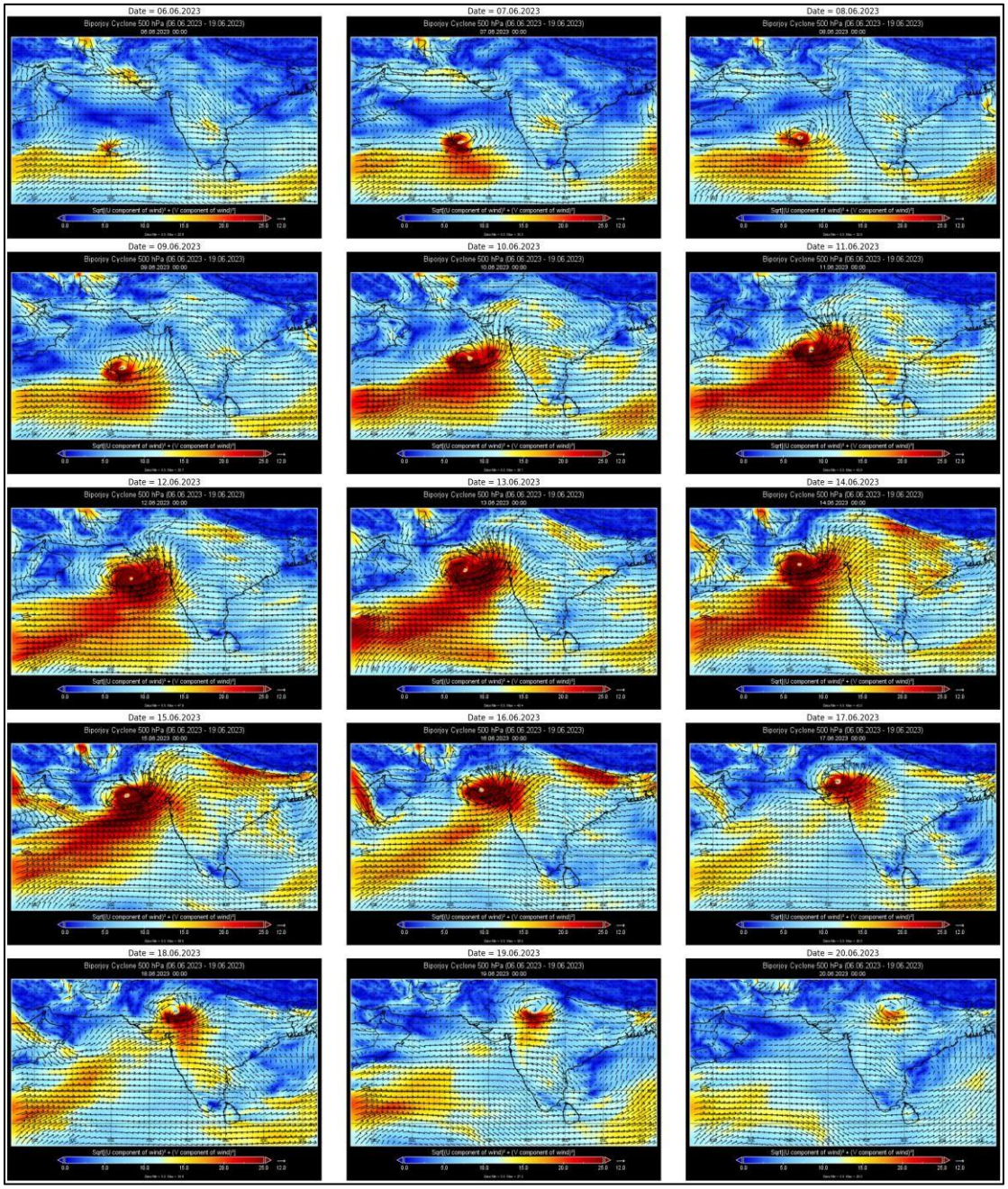


Fig 16 - Spatial representation of wind vectors and wind velocity of Biparjoy cyclone at 500 hPa pressure level

At 500 hPa pressure level wind vectors shows the convergence. As the cyclone moves ahead the wind velocity goes on increasing. The wind velocity is high around the cyclone eye. As compared in terms of coverage of high wind speed at 500 hPa pressure level is large as compared to 850 hPa pressure level. At 500 hPa pressure level the high wind speed is in range 25 - 32 m/s.

- **At 200 hPa pressure level**

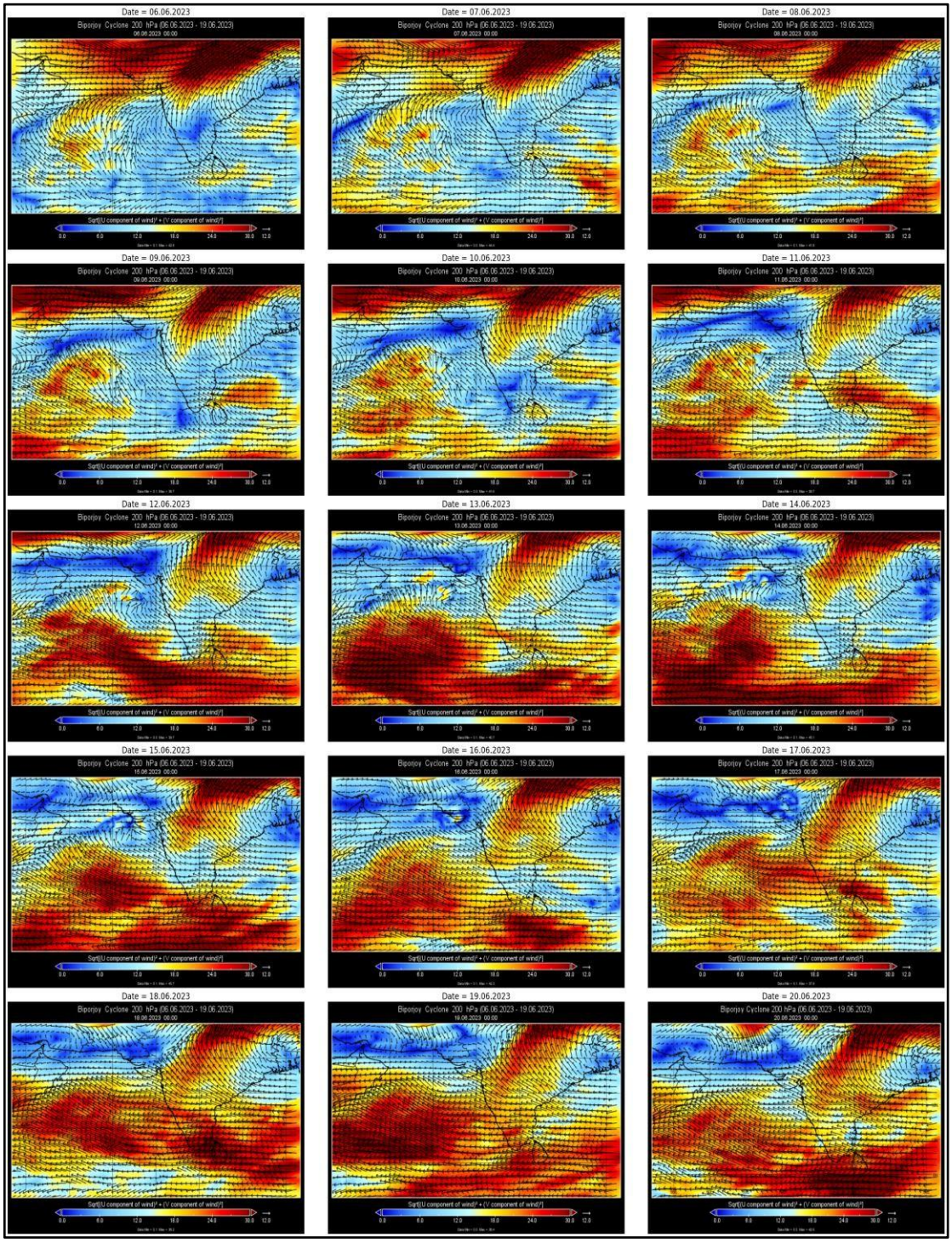


Fig 17 - Spatial representation of wind vectors and wind velocity at 200 hPa pressure level

At 200 hPa pressure level wind vectors shows the divergence. It indicates severity of cyclone. As the cyclone moves ahead the wind velocity goes on increasing. The wind velocity is low at the cyclone eye. As compared in terms of coverage of high wind speed at 200 hPa pressure level is very large as compared to 850 hPa and 500 hPa pressure level. At 200 hPa pressure level the high wind speed is in range 30 - 40 m/s.

Relation between Central Pressure and Maximum Sustained Wind Speed against cyclone duration

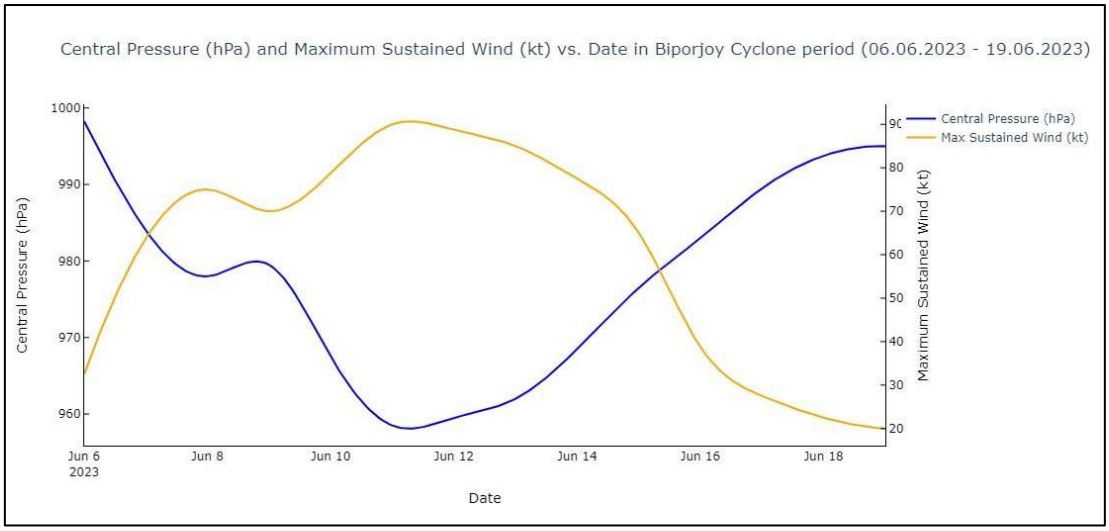


Fig 18- Graph of Central Pressure (hPa) and Maximum Sustained Wind (kt) vs Dates of Biparjoy Cyclone Period (06.06.2023 - 19.06.2023)

The plot depicts the trajectory of Cyclone Biparjoy, showcasing changes in Centre Pressure (hPa) and Maximum Sustained Wind (kt) over time. Initially, the cyclone strengthens, as indicated by decreasing pressure and increasing wind speeds, reaching its peak intensity as a Very Severe Cyclonic Storm (VSCS) on 10.06.2023. Subsequently, it gradually weakens as it moves northward, transitioning to Severe Cyclonic Storm (SCS) and Depression (D) categories. The plot illustrates the dynamic evolution of the cyclone, capturing its intensification, peak, and eventual dissipation, providing insights into its lifecycle and potential impact.

Precipitation Analysis in Cyclone Period

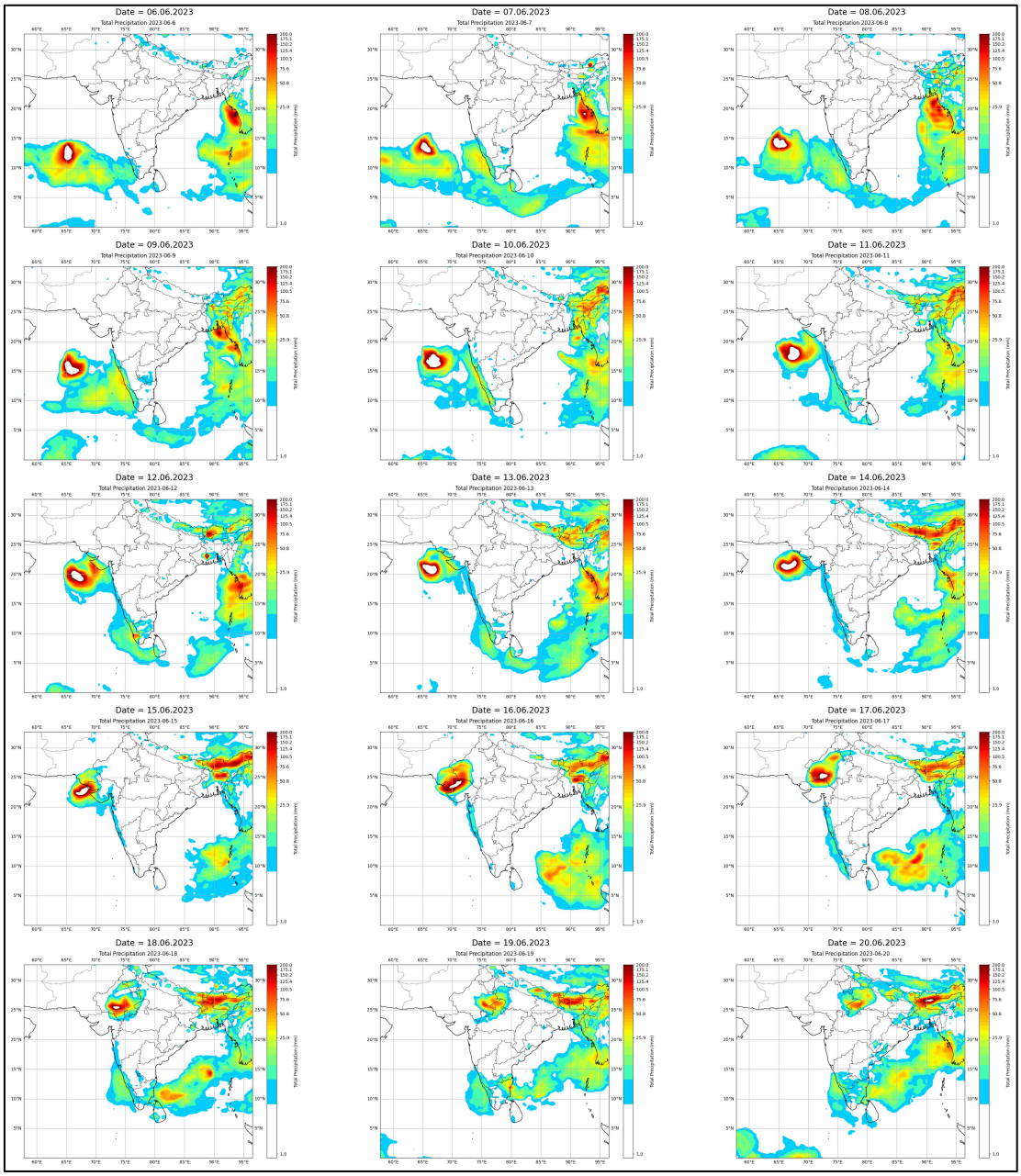


Fig - Spatial representation of precipitation in cyclone period (06.06.2023 - 19.06.2023)

During cyclone period it is observed that the western coastal side is faced heavy rain. The coastal side of Maharashtra faced medium rainfall with high wind speed. Specificly the coastal side of Gujarat is affected seviourly with very high wind speed.

Conclusion

Sea Surface Temperature Climatology:

- In last 30 years the SST of Arabian Sea and Bay of Bengal is increased by 1.0°C and 0.6°C respectively. In recent years SST of Arabian Sea raised rapidly.

- The average cyclone-induced SST cooling is 2–3°C during the pre-monsoon season and 0.5–1 °C during the post-monsoon season. This varying ocean response to cyclones in the two seasons in the Arabian sea , it is due to the difference in cyclone wind power input and ocean thermal stratification.

Biparjoy cyclone

- Biparjoy was the first cyclonic storm over the Arabian Sea in the year 2023.It developed during the onset phase of monsoon over Indian region.It crossed Saurashtra & Kutch coast close to Jakhau Port with maximum sustained wind speed (MSW) of 65 knots (33 m/s) gusting to 75 knots (38 m/s) (115-125 kmph gusting to 140 kmph) on 15th June.

- Biparjoy has been one of the longest duration cyclone over the North Indian Ocean (NIO) including the Bay of Bengal (BoB) and the Arabian Sea (AS) with a total life period of 13 days and 3 hours.

- Biparjoy exhibited a frequently changing track of movement during its life cycle. The movement explicitly depended upon the strength of the driving anticyclones present over central India and Arabian Peninsula. The cyclone changed it's path about 9 times, resulting in relatively higher difficulty in predicting the path of the cyclone.

- The system reached it's peak intensity of 75 - 90 knots (40 - 45 m/s) at 0000 UTC of 13th June and maintained it's peak intensity till of 12th June.

- The central pressure during this period was 958 hPa with pressure drop of about 40 hPa at the centre.

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