

Comparative Meteorological Assessment of Cyclones Biparjoy and Michaung: Statistical and Spatial Analysis of Dual-Basin Cyclonic Events Over the Indian Subcontinent

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ABSTRACT

Tropical cyclones emerging over the Arabian Sea and Bay of Bengal pose significant threats to coastal India, yet their meteorological characteristics and impacts differ due to contrasting oceanic and atmospheric conditions. This study presents a comparative analysis of two major cyclonic systems that struck India in 2023, cyclone Biparjoy (Arabian Sea) and Cyclone Michaung (Bay of Bengal). A multidisciplinary framework integrating statistical tools, circular distribution modeling, and GIS-based spatial analysis was employed to assess cyclone dynamics, wind behavior, pressure variations, rainfall intensity, and resultant flooding impacts. The study applies Von Mises and Wrapped Normal distributions to model storm directions, Mann-Whitney and regression tests to examine meteorological relationships, and spatial interpolation techniques to visualize precipitation and wind intensity. Results reveal that while Biparjoy exhibited a prolonged lifespan and north-northeast trajectory with moderate inland rainfall, Michaung was shorter-lived but more destructive in urban regions, causing severe flooding in Chennai due to extreme precipitation (530 mm in 72 hours). Comparative findings underscore how regional atmospheric conditions and coastal geomorphology govern cyclone intensity and flood susceptibility across India's east and west coasts. The integrated analysis provides valuable insights for enhancing cyclone forecasting, flood preparedness, and adaptive disaster management in both basins.

KEYWORDS

Sections; Tropical cyclones; Von Mises; Wrapped Normal Distribution

1. Introduction

Around the world, people have long been deeply concerned about tropical cyclones, which are widely recognized as one of the most devastating natural disasters on the planet. Tropical cyclones are considered one of the most detrimental natural disasters that can wreak havoc on coastal regions. With over 50 million people affected across the world, it is a significant concern for all living beings [26]. These fierce storms are characterized by their powerful wind gusts, intense rainfall, and surging ocean waters,

all of which can contribute to significant economic and ecological damage [1]. In recent years, the frequency and severity of tropical storms and cyclones have increased noticeably, a reality that is primarily attributed to the ongoing effects of climate imbalance and global warming. Despite the best efforts of individuals and organizations to prepare for these events, the damage caused by tropical cyclones can be immense, resulting in the tragic loss of human lives and long-term environmental impacts that can be felt for years to come [3]. Tropical cyclones have a specific origin in certain regions of the ocean [16]. These regions are located in the northern hemisphere above latitude 10° N and in the southern hemisphere below latitude 10° S. The impact of these cyclones on offshore areas is primarily characterized by strong and turbulent winds, which can cause significant damage to infrastructure and property. Furthermore, these storms have a profound effect on the ocean, as they cause the cooler and more saline lower layers of water to rise, leading to changes in temperature and salinity that can have far-reaching consequences for marine life. It is essential to understand the mechanics of these storms to prepare for their impact and protect vulnerable populations and ecosystems [13]. The impact of tropical cyclones can vary significantly depending on the force of the storm when it hits land. The degree of devastation can be influenced by various factors, such as the location, population density, and infrastructure of the affected area. It is important to note that even a relatively weak tropical cyclone can still cause significant damage and loss of life, particularly in areas that are not well prepared for such events. Therefore, it is critical to remain vigilant and take appropriate measures to protect oneself and the community in the event of a tropical cyclone [24]. The greater the intensity, the greater the risk of damage and destruction in coastal areas [11]. The havoc wrought by tropical cyclones in tropical coastal regions cannot be overstated. The loss of life, biodiversity, economic instability, and social disruption that they bring about are nothing short of devastating [23]. Countries in South and Southeast Asia, in particular, are at high risk due to their high exposure to these natural disasters, compounded by poverty, poor environmental and socioeconomic conditions, and a limited capacity to adapt [6]. According to projections, the number of people who may potentially face the impact of these catastrophic occurrences is anticipated to increase significantly by the year 2050 [22]. India, with its vast coastline of more than 7000 km, is particularly vulnerable to the impact of tropical cyclones and storm surges. This is because of favourable climatic and marine conditions that are conducive to cyclone formation in the North Indian Ocean (NIO) region, which lies in the proximity to the equator [18]. Despite the relatively low frequency of cyclone formation in NIO, the impact is disproportionately high, particularly in terms of coastal and urban flooding [17]. This is a significant issue for major metropolitan areas, such as Mumbai, Chennai, and Kolkata, which are situated close to the coast. As a result, large populations are affected by these severe hydrometeorological events and associated flooding situations. The Indian subcontinent is a densely populated region that faces an elevated risk of being impacted by tropical storms and severe cyclones [21]. The inhabitants of this area are directly exposed to the potential dangers posed by these weather events, which can cause significant damage to infrastructure, property, and human life. As such, it is crucial that measures are taken to ensure the safety and security of those living in this region during times of extreme weather conditions [5, 20]. The severity of cyclones has been on the rise in recent decades as a result of the increase in sea surface temperature [9, 19].

During the year 2023, events of great significance occurred in the Northern Indian Ocean region. India experienced two major cyclonic storms, Cyclone Biparjoy and Cyclone Michaung, that exemplified this east-west contrast. Biparjoy originated in the

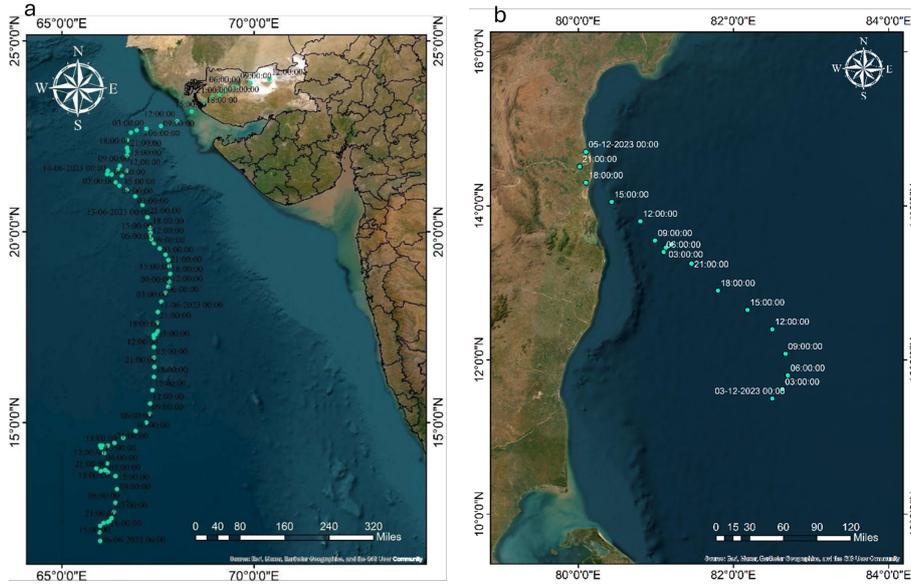


Figure 1. (a) Trajectory of cyclonic storm Biparjoy; (b) Trajectory of cyclonic storm Michaung

Arabian Sea in June 2023, persisting for an unusually long 13 days before making landfall along the Gujarat coast. Michaung, emerging in December 2023 over the Bay of Bengal, moved swiftly towards the east coast, severely affecting the metropolitan city of Chennai and neighboring state of Andhra Pradesh. Together, these events provide a natural experiment for evaluating cyclone dynamics across contrasting oceanic environments. During its life cycle, Cyclone Biparjoy followed a meandering path, predominantly directing its movement towards the North-North-West to North-North-East direction. This trajectory was intricately reliant on the vigour of the anticyclones and the sea surface meteorological parameters it met. Figure 1 visually depicts the track of Cyclone Biparjoy from June 6th to June 16th and of Cyclone Michaung from December 3rd to December 5th. This comprehensive study offers an in-depth examination of the devastating cyclonic storm known as "Biparjoy," which originated in the Arabian Sea during the month of June in the year 2023. Once it made landfall, this fierce storm had a significant impact on the western coast of India, particularly in the state of Gujarat. The southern coast of Pakistan, specifically Karachi, was also affected, as were the inland regions of northwestern India and adjacent Pakistan, including Rajasthan and Sindh. In late November, another such meteorological phenomenon started brewing in the Gulf of Thailand that eventually transformed into a Low-pressure area in the South Andaman Sea and Indian Ocean. This disturbance gradually intensified and crossed the Bay of Bengal, becoming a deep depression on December 2, 2023. As it gained momentum, it transformed into a cyclonic storm which was officially named Michaung. As it progressed, the storm moved towards the eastern coast of India, with sustained winds of 110 km/h (70 mph) and heavy rainfall in north-eastern Tamil Nadu, including Chennai, and south-eastern Andhra Pradesh. Eventually, on December 5, the cyclonic storm made landfall near Bapatla in Andhra Pradesh, causing extensive damage to property as well as life [8]. The objective of this research is to evaluate the various meteorological factors of Cyclone Michaung that lead to flooding in the metropolitan regions of Chennai. Chennai is a sprawl-

ing city located on the eastern coast of India and is known to be highly vulnerable to floods, making it crucial to understand the underlying causes of this phenomenon. Our research aims to explore the trajectory of storms and their related factors with the objective of understanding the impact of cyclones on the environment. To achieve this objective, we conducted a thorough investigation utilizing a comprehensive methodology, statistical analysis, and presentation of our findings, which will be thoroughly discussed in the following sections.

2. Methodology

Our comprehensive study delves into the various factors that led to the formation and impact of the Extremely Severe Cyclonic Storm "Biparjoy" that emerged in the Arabian Sea in June 2023 and Cyclonic storm Michaung, emerged in Bay of Bengal during December 2023.. We conducted extensive research on crucial parameters such as cyclone speed, wind speed below the surface, pressure at the eye's center, sea surface pressure, precipitation dimensions, eye radius, cyclone radius, movement direction, and post-cyclone aftermath effects.

2.1 Cyclone Biparjoy To obtain accurate insights, we used various statistical tools to analyze trends and tendencies. For instance, to assess the direction, we compared two different distribution models: The Circular distribution model of Von Mises and the Wrapped Normal distribution. The Von Mises distribution is a unique type of probability distribution that is specifically designed to operate on a circular plane, where values can range from 0 to 2π . This distribution is sometimes referred to as the circular normal or Tikhonov distribution. Although it shares some similarities with the normal distribution, the Von Mises distribution has the added feature of existing on a circular plane, which sets it apart from other types of distributions. It is important to note that the Von Mises distribution is a specialized version of the Von Mises-Fisher distribution, which can be extended to encompass multi-dimensional spheres.

Overall, the Von Mises distribution is a valuable tool for analyzing data that falls within a circular context [4]. Circular statistics is a field that often utilizes the wrapped normal (WN) distribution. This distribution is obtained by wrapping the normal distribution around the unit circle and consolidating all probability mass that is wrapped around the same point. This is akin to defining a randomly distributed variable X and then examining the wrapped random variable $X \bmod 2\pi$. By using the WN distribution, circular statistics is able to accurately model circular data and provide meaningful insights into the underlying patterns and trends [12].

2.2 Cyclone Michaung For Cyclone Michaung and its analysis, data from several sources were incorporated, and a thorough analysis was conducted [10]. A quantitative analysis and tools for different meteorological parameters of Cyclone Michaung were used for the assessment. Some of these statistical tools include the fitness of the distribution method. These methods are used to analyze extreme events and calculate the probabilities of their occurrence [7].

For the estimation and study purposes, correlational and regression analysis was done for different parameters to understand the relationship between various variables. Additionally, a descriptive statistic of smallest extreme value was used for the parameters of surface wind speed of the Chennai city and maximum observed wind speed of the cyclonic storm Michaung at its different stages of intensity. To some ex-

tent, these tools help in understanding the likelihood of floods and estimating their magnitude and severity.

Furthermore, for modelling the wind direction data, we have used the "von Mises distribution" and "Wrapped Normal distribution" as they are statistical tools used to model circular data and can be employed in flood assessment to analyze the direction and spatial patterns of the cyclone trajectory. When we talk about cyclones, understanding the overall directions of cyclone movement and the extent of damage in a particular direction is crucial. This information helps us to assess the potential impact of floods on communities and infrastructure, determine evacuation routes, and develop effective response plans. By analyzing the data on flooding directions and damage extent, we can identify areas that are more vulnerable to damage and prioritize our efforts to reduce the risk of further damages in the future. This knowledge is also helpful in predicting future flood events, which can help us to prepare better and minimize the impact on people and property. By utilizing statistical methods like the smallest extreme value, Mann-Whitney test, and von Mises distribution, researchers and disaster management professionals are able to analyze and interpret data related to tropical cyclones, assess the severity and impact of flood events, compare different groups or areas affected by floods, and understand patterns and trends in flood occurrences. These statistical tools are crucial in helping to make informed decisions regarding disaster preparedness, response, and mitigation strategies [25]. To collect the necessary data, we relied on a plethora of sources, including the National Centers for Environmental Information, the National Oceanic and Atmospheric Administration's International Best Tracks Archive for Climate Stewardship (IBTrACS) Datasets, and the India Meteorological Department. This study provides a detailed account of the factors that contributed to the formation and impact of the Extremely Severe Cyclonic Storm "Biparjoy." By examining various parameters and using statistical tools, we have gained valuable insights that can help in mitigating the impact of such natural disasters in the future.

3. Results and Discussion

3.1 Biparjoy cyclonic storm:

In the case of the Biparjoy cyclone, the storm direction has a very serious influence on the intensity of occurrence and frequency of events. Hence, the model fitting and assessment from a statistical perspective is warranted before embarking on the environmental impact study. Both objective is realized here by fitting circular distributions on the storm direction as it is available in degree measurements. We consider two well-known circular distributions, viz. Von Mises [14] and wrapped normal distribution [2] are fitted to the data. The angular deviation and angular variance of the storm direction data are respectively 1.348114 and 1.817412. The distribution of data is presented through a circular bar chart, along with a dot plot and a kernel density plot in Figure 2. Based on the chart, it is observed that the majority of the data is concentrated around the north and north-east direction.

The Von Mises distribution is a symmetric unimodal distribution, which is the most common model for unimodal samples of circular data. Its probability density function is given by

$$f(x; \mu, \kappa) = \frac{1}{2\pi I_0(\kappa)} \exp[\kappa \cos(x - \mu)], \quad 0 \leq x < 2\pi, \quad 0 \leq \mu < 2\pi, \quad 0 \leq \kappa < \infty \quad (1)$$

where, $I_0(\kappa) = \frac{1}{2\pi} \int_0^{2\pi} \exp[\kappa \cos(x - \mu)] dx$ which is the modified Bessel function of order zero. The parameter is called the mean direction of the distribution and k is the concentration parameter or the dispersion parameter. When $k = 0$, the distribution reduces to a circular uniform distribution and increases k to an increasing concentration about the reference direction. For $k \geq 2$, this distribution is approximated well by the wrapped normal distribution. The wrapped normal distribution has a probability density function

$$f(x; \mu, \sigma) = \frac{1}{2\pi} \left(1 + 2 \sum_{k=1}^{\infty} \rho^{k^2} \cos[k(x - \mu)] \right), \quad 0 \leq x < 2\pi, \mu \geq 0, 0 < \rho < 1 \quad (2)$$

Where, μ is the mean direction and $\rho = \exp\left(-\frac{\sigma^2}{2}\right)$ is mean resultant strength of the wrapped distribution, respectively. The value of $\rho = 0$ correspond to the circular uniform distribution and as ρ increases to one, the distribution concentrates increasingly around the mean μ . An excellent overview of the properties of the wrapped distributions can be found in [15].

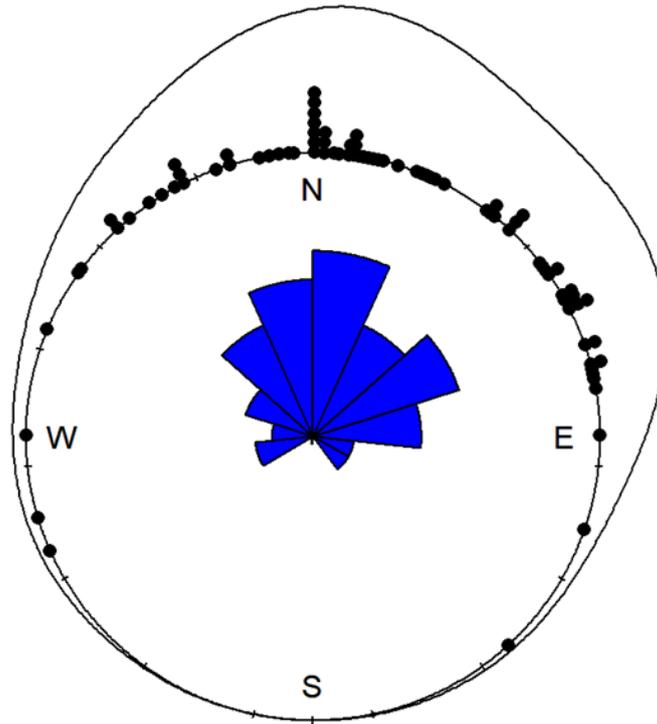


Figure 2. The distribution plots

The goodness-of-fit (GOFT) tests were carried out based on a bootstrapping approach. Table 1 presents the GOFT values and their corresponding p -values.

According to the table, we can conclude that Von Mises distribution fits well as p -value correspond to three out of four tests is greater than 0.05. Whereas, wrapped normal distribution didn't fit well in every case as p -value is less than 0.05 rejecting null hypothesis that the data follows a wrapped normal distribution. The estimated parameters values correspond to Von Mises distribution are $\hat{\mu} = 17.198752$ and $\hat{k} =$

Table 1. Goodness-of-fit test results for circular distributions

Distribution	Kuiper's test	Rayleigh test	Rao's Spacing test	Watson's test
Wrapped Normal	0.0004	0.0002	0.0004	0.0004
Von Mises	0.0710	0.4943	0.0035	0.0604

2.13447 respectively and for the wrapped normal distribution the estimates are $\hat{\mu} = 15.90455$ and $\hat{\rho} = 0.72476$ respectively. Thus, the average mean direction of the storm direction is roughly 17 degrees towards north-east.

3.1.1 Analysis of Storm speed and Direction of storm movement:

The movement of the storm is dependent on the drag forces applied to the storm by external phenomena. In the case of Cyclone Biparjoy, two different anti-cyclones played a significant role in the movement of the cyclone, as well as affecting the speed of the movement of the cyclone inside the Sea. Figure 3 shows the Maximum observed storm speed in kmph along with the Direction of the storm movement in degrees. The drag forces made the cyclone move in the North direction mostly. On the impact day, i.e., 16th June 2023, the direction changed Eastwards and made its landfall between Jakhau port of Kutch (India) and Karachi (Pakistan).

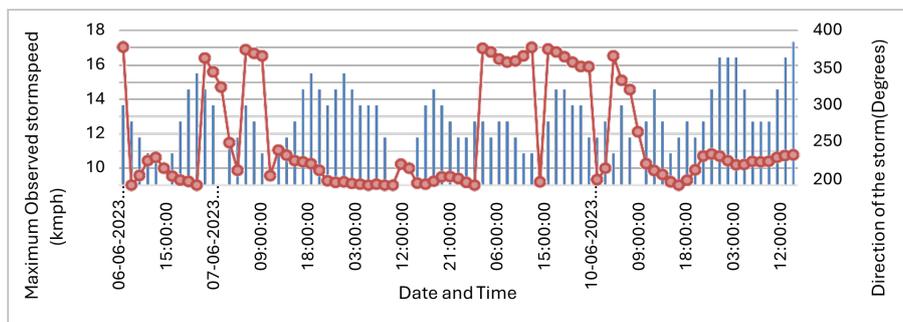


Figure 3. Maximum observed storm speed and direction of cyclone Biparjoy

The path of the storm was impacted by a multitude of atmospheric factors, such as air pressure and wind patterns. Despite its lack of speed, the storm exhibited a significant degree of variability, changing direction a total of 9 times throughout its lifespan.

3.1.2 Analysis of Maximum observed wind speed and Central pressure of the eye

The cyclonic system reached its peak surface wind speed, reaching 194.46 kmph at 0600 IST on 11th June, and sustained this maximum intensity until 12th June at 1200 IST. Concurrently, the central pressure during this period decreased to its lowest level, measuring 945 Mb. The correlation between pressure drop and surface wind speed is depicted in Figure 4, where a discernible trend is evident.

The velocity of a cyclone, which is a large-scale atmospheric disturbance, is closely tied to the level of pressure that is exerted within its core. When the pressure at the core decreases, it causes air to flow more rapidly towards the center, which in turn intensifies the surface wind speed. This heightened wind speed reinforces the cyclone, making it even more powerful and potentially devastating. Due to the complex interplay of atmospheric variables, predicting the behavior of a cyclone can be a challenging task for meteorologists and other experts in the field.

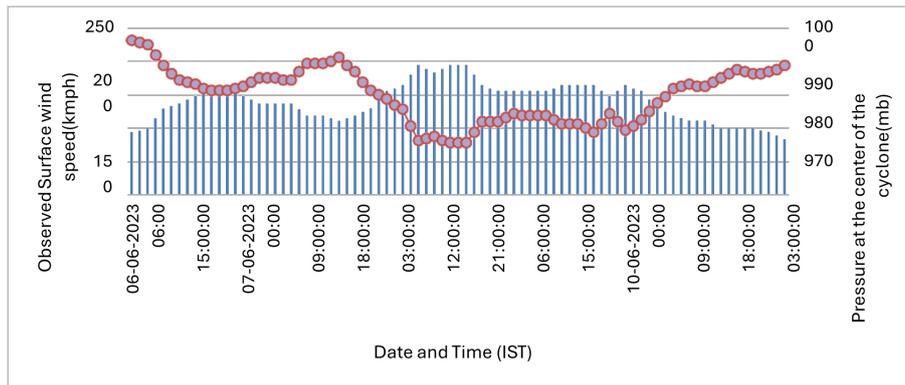


Figure 4. Observed surface wind speed and pressure at the center of the cyclone

3.1.3 Analysis of Precipitation over the Impact Sites:

The cyclonic system resulted in the occurrence of substantial to extremely heavy rainfall in the states of Gujarat and Rajasthan. Particularly, the Saurashtra region, encompassing districts like Devbhoomi Dwarka, Jamnagar, and Kutch, experienced extremely heavy rainfall. In Gujarat, the districts of Banaskantha and regions in Rajasthan, including Sirohi, Barmer, Jalore, and Rajsamand, also encountered intense precipitation. Among the areas affected, the highest recorded rainfall in the Saurashtra and Kutch region was observed in the Devbhoomi Dwarka district (Okha) on June 17th, amounting to 228.1mm. In Rajasthan, the highest 24-hour cumulative rainfall of 360mm was recorded in Mount Abu, Sirohi, on June 18th.

To illustrate the distribution of 24-hour cumulative rainfall across various stations in Gujarat and Rajasthan states during the period from June 13th to June 20th, refer to Figure 5. This figure provides a comprehensive depiction of the rainfall pattern observed during the mentioned time frame in the affected regions.

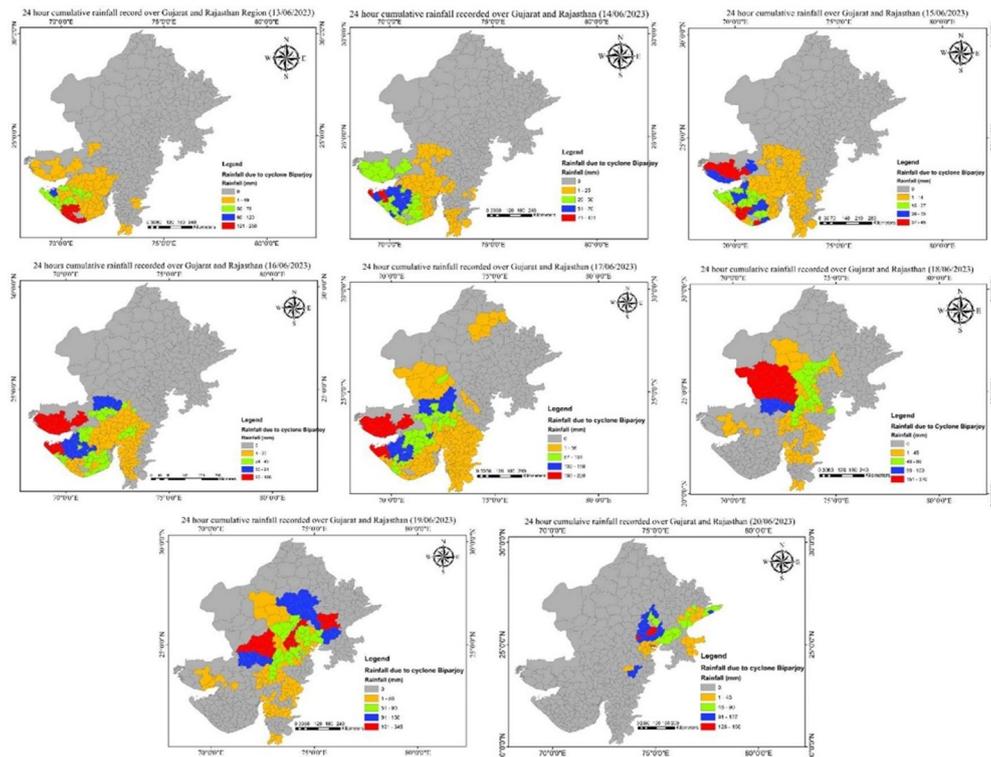


Figure 5. 24 hour cumulative rainfall recorded over Gujarat and Rajasthan from June 13 to June 20

The report published by the disaster management facilities of Gujarat and Rajasthan says, The coastal regions of Gujarat and Maharashtra were dealt a severe blow by the unrelenting downpour and strong winds, which led to significant loss of life and property damage. Among the hardest hit areas were the districts of Kutch and Rajkot, where three fatalities were reported as a result of uprooted trees and a collapsed wall. Although the state government has reported zero fatalities due to the cyclone. In comparing the effects of Cyclone Biparjoy to those of other cyclones that have swept through the region, it is important to acknowledge that Biparjoy cyclone had the lowest number of casualties. This observation highlights the significance of disaster preparedness and response measures that have been implemented in recent years, as they have contributed to mitigating the impact of natural disasters on the affected populations. Nonetheless, it is crucial to remain vigilant and continue to improve upon these efforts to ensure the safety and well-being of those living in areas prone to cyclones and other natural calamities. The situation was exacerbated by the strong waves that swept away tents situated on Mandvi Beach.

As the cyclone approached, high tides were observed in the Dwarka region, which caused extensive damage to the electricity network in Gujarat, estimated to be around 10.13 billion INR as reported by PGVCL. The Indian National Congress estimated that the statewide damage amounted to a staggering 80-100 billion INR. Meanwhile, in Maharashtra, heavy rainfall and high tidal waves were witnessed, and four people in Mumbai were found deceased due to heavy storm surge. A total of 23 people were injured, while 4,600 villages experienced power outages.

Furthermore, in July 2023, the Government of Gujarat announced a relief package of 2.4 billion INR for farmers, as crops and trees spread across 130,000 hectares of land were severely damaged by the cyclone. The situation was dire, and the Government's

response was deemed necessary to provide financial support to the farmers who had been impacted by the disaster.

3.2 Michaung Cyclonic Storm:

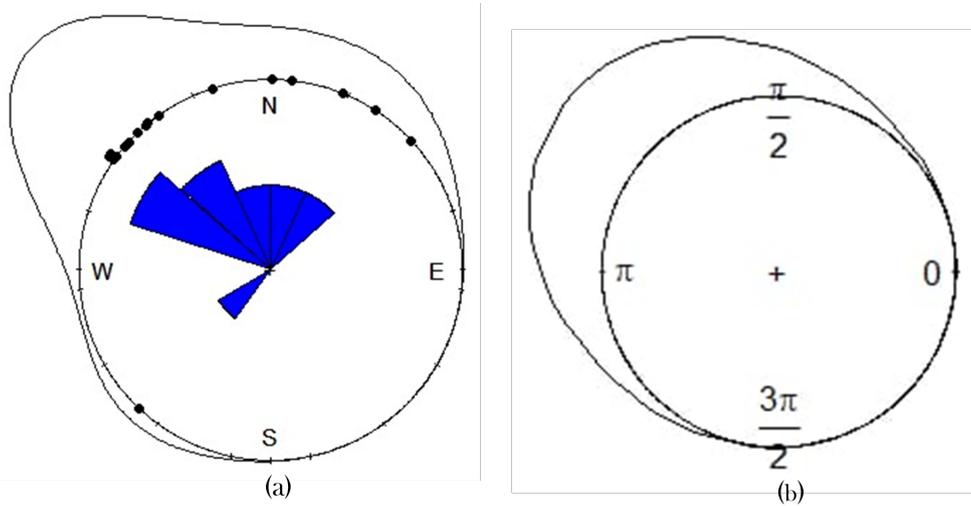


Figure 6. Direction plot for wind direction (a) Von Mises Distribution, (b) Wrapped Normal Distribution

Figure 6 shows the Von Mises distribution and the Wrapped Normal Distribution for Cyclone Michaung. It is observed that the VMS was not a good fit for the data; however, a wrapped normal distribution provides a relatively good fit with a p-value of 0.2036 using the Rayleigh test of Uniformity. The average direction according to VMS is 329.8782 degrees and $k = 2.1229$. If we convert it into directions then it shows North-Westward movement of the cyclone, which is towards the Andhra Pradesh Coast. The Median direction of the wind according to this model is 319 degrees with a standard deviation of 0.7201279. The value of $k > 2$, also supports the fact that the VMS is not a good fit distribution for this data. The parameter estimates of wrapped Normal distribution are $\rho=0.7646$ and $\mu=329.1765$, which agrees with the mean of VMS distribution.

3.2.1 Analysis of Storm speed and Direction of storm movement:

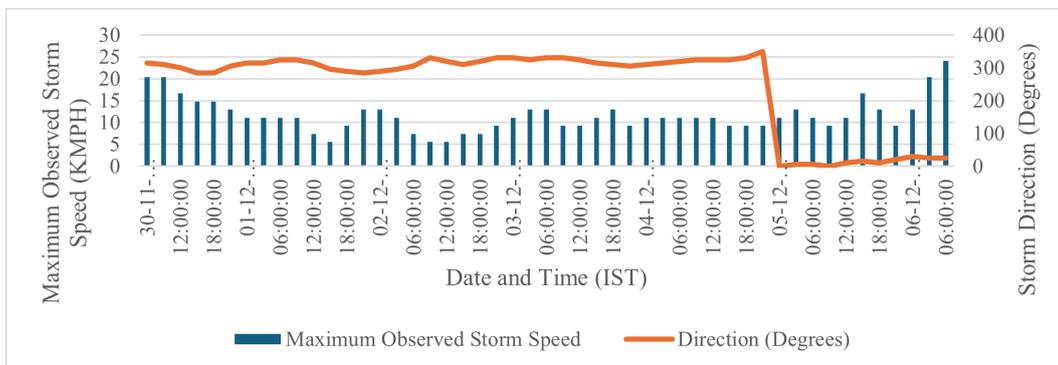


Figure 7. Maximum Observed storm speed and direction of the Cyclone Michaung Distribution

Figure 7 shows the Maximum observed storm speed in kmph along with the Direction of the storm movement in degrees. The storm speed fluctuates as it moves further towards the land. Looking at the direction, due to favorable conditions in the Bay of Bengal, the storm moved in a North-West direction for most of the time, and after making landfall near Chennai, it moved in the North direction towards the state of Andhra Pradesh. After landfall, it became weak and moved further as a low-pressure system.

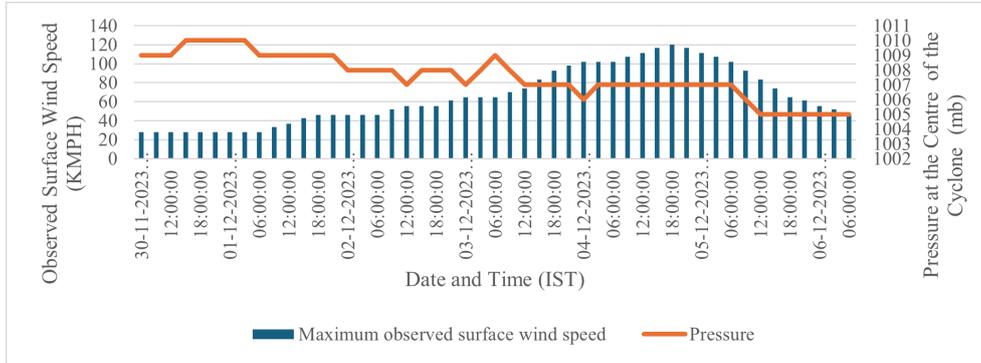


Figure 8. Observed surface wind speed and pressure at the centre of the cyclone Michaung

The surface wind velocity of a cyclone is closely tied to the level of pressure that is exerted within its eye of the storm. When the pressure at the eye or the core decreases, it causes air to flow more rapidly towards the center, which in turn intensifies the surface wind speed. In the case of Michaung, the surface wind speed reached 120 km/h on the evening of December 4th, making it a severe cyclonic storm with decreasing pressure at the centre.

3.2.2 Correlation and Regression Study:

To gain a comprehensive understanding of the relationship between various parameters and their impact on each other, we conducted an initial correlational analysis. We aimed to identify the degree of correlation among different parameters and how each of them is closely related to the other. The results of this analysis are presented in Table 2, which shows the interrelationship between different variables and provides invaluable perspectives on the research. In this analysis, we considered several parameters, including the coordinates of the cyclone, distance from landmass, Wind speed, pressure, and Distance from Chennai. By compiling and analyzing this data, we were able to acquire a basic understanding of the interplay between these parameters and their impact on the overall study.

The study observed that as the cyclone advanced towards the landfall site in coastal Andhra Pradesh, there was a significant increase in rainfall activity in Chennai. This correlation between the distance of the cyclone from Chennai and the amount of rainfall it caused is a noteworthy phenomenon. Moreover, the study reveals that there is a strong relationship between wind speed and distance from Chennai. As the cyclone moves closer to land, the wind speed increases, which explains the high amount of destruction in the coastal districts. The study also revealed that there is a correlation between pressure and distance from land. As the cyclone moves closer to the landfall site, the cyclonic pressure undergoes a positive change. As the distance decreases, the pressure decreases at the coastal sites. In summary, the findings could be useful in

predicting the trajectory of future cyclones and mitigating their impact on coastal communities.

Table 2 Correlation between different meteorological parameters of the cyclone

Table 2. Correlation matrix of cyclone-related parameters

	Latitude	Longitude	Dist2Land	Wind speed	Storm Speed	Pressure	Dist from Chennai	Rainfall	Wind direction
Latitude	1								
Longitude	-0.98	1							
Dist2Land	-0.98	0.99	1						
Wind speed	0.97	-0.97	-0.99	1					
Storm Speed	0	0.10	0.09	-0.06	1				
Pressure	-0.97	0.97	0.98	-1	0.07	1			
Dist from Chennai	0.92	-0.96	-0.93	0.91	-0.10	-0.90	1		
Rainfall	0.79	-0.76	-0.73	0.70	-0.14	-0.69	0.82	1	
Wind direction	0.15	-0.06	-0.14	0.21	0.47	-0.21	-0.09	-0.15	1

We propose the regression models for predicting the trajectory as storm speed = $-45+0.055X$ pressure with $R^2=55\%$ and a model for rainfall as $Rainfall = 3065-0.456Xdistance$ to land $-2.64Xwind$ speed $-2.76Xpressure$ with a $R^2= 59\%$.

3.2.3 Distribution identification and diagnosis:

A thorough inferential analysis on the speed of the cyclone movement (Storm speed) and the rainfall during the touchdown or landfall period was conducted. To achieve this, identification of probability distribution function was utilized. The best probability model identified for the storm speed is Normal distribution (p-value is 0.539), whereas the model identified for rainfall is Lognormal distribution (p-value is 0.903). The descriptive statistics and some point estimates of the storm speed and rainfall are shown in Table 3. It is inferred that the average storm speed is roughly 9.91365 kmph. The corresponding estimated average rainfall is 25.3529 mm, which according to the Lognormal distribution is $(\theta + \beta^2/2)=26.6443$ mm.

Table 3. Distribution identification and diagnosis

Statistics	Storm Speed	Rainfall
Mean	9.91365	25.3529
Median	9.26	20
Standard Deviation	4.24049	21.2219
Skewness	-0.104452	2.05417
Kurtosis	-0.778482	5.58016
Best fit Distribution	Normal	Lognormal
Location (θ)	9.91365	2.93110
Scale (β)	4.24049	0.83842
Anderson–Darling test	0.301	0.178
P-value	0.539	0.903

The probability distribution identification and likelihood estimates are carried out in R software. We have also found a very high significance (p-value = 0.0004) while testing the difference of longitude (median = 14.90) and latitude (median = 81.10). As per the Geo-spatial mapping, it has been identified that the area encompassing 14.900 N, 81.100 E is likely to have witnessed the maximum destruction during the cyclonic storm. Further, upon comparing this finding with the meteorological data, it has been confirmed that these coordinates had the highest recorded wind speed (as high as 111.11 kmph) on December 5, 2023, at 00.00 hours. Chennai is approximately 220 km away from this point and experienced severe destruction and flooding during this time period. Parts of the coastal districts of Nellor, Prakasam, and Thiruvallur also experienced heavy rainfall with extreme wing gusts and flood-like situations in

some parts. This observation provides valuable insights into the areas that were most severely impacted by the storm and can aid in assessing the extent of damage caused in the region

Figure 9 shows investigation of the behaviour of tropical cyclones, specifically the relationship between the speed of cyclone movement and the maximum wind speed of the cyclone, by analyzing the contour plots or interpolation of these variables against the coordinates of the cyclone at different time intervals. The map was developed using the Inverse Distance Weighting (IDW) method of Interpolation in ArcGIS. The findings of the study reveal that the speed of cyclone movement increased mid-ocean near Kanchipuram, suggesting the presence of favorable environmental conditions for the cyclone to intensify. Additionally, the wind speed of the cyclone increased to 111.1 kmph near Chennai, which was the highest recorded wind speed during this time period. The contour plots show the changes in wind speed and storm speed at different locations and at different times, providing insights into the dynamics of tropical cyclones. The use of ArcGIS and the IDW method of Interpolation allowed for a detailed analysis of the cyclone’s behavior, providing precise data on the cyclone’s movement and the associated wind speeds.

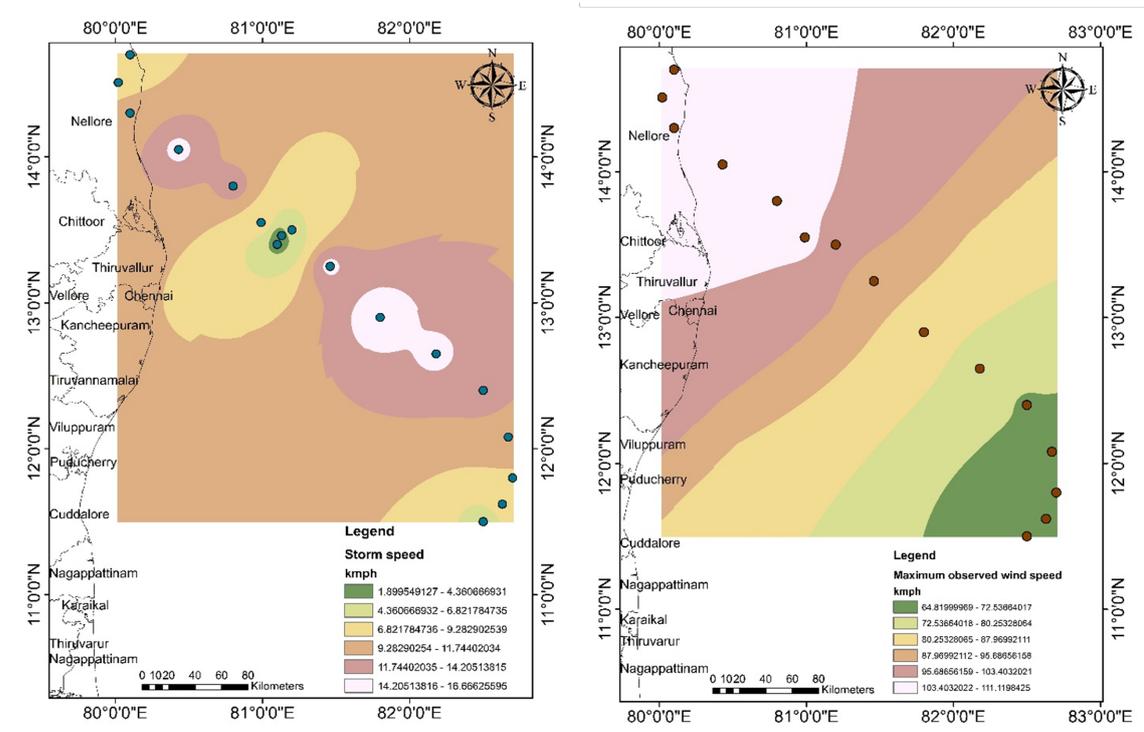


Figure 9. Contour plots of speed of the cyclone movement and maximum wind speed of the cyclone (Speed against Coordinates)

3.2.4 Analysis of Precipitation over the impacted sites:

As per the latest information provided by the India Meteorological Department (IMD), the coastal surface observations from multiple locations along the coast have indicated some alarming patterns. The maximum wind speed was recorded at a remarkable 60 knots (110 km/h; 69 mph), while the minimum sea level pressure was found to be as low as 988 hectopascals (29.2 inHg). These extreme weather conditions

resulted in unusually high levels of precipitation in various regions of the coastal states of Tamilnadu and Andhra Pradesh. The excessive rainfall caused severe flooding in several parts of the metropolitan city of Chennai on December 6, with numerous areas being inundated with water. The situation was exacerbated by the fact that Nungambakkam in Chennai recorded the highest rainfall of 530 mm (21 in) in a three-day period between December 4 and 6. This led to the city’s drainage systems becoming overwhelmed, resulting in additional flooding in low-lying areas. The following figure 10 exhibit a projection of the precipitation that occurred during this time period in Chennai, which helps to provide a more comprehensive view of the situation.

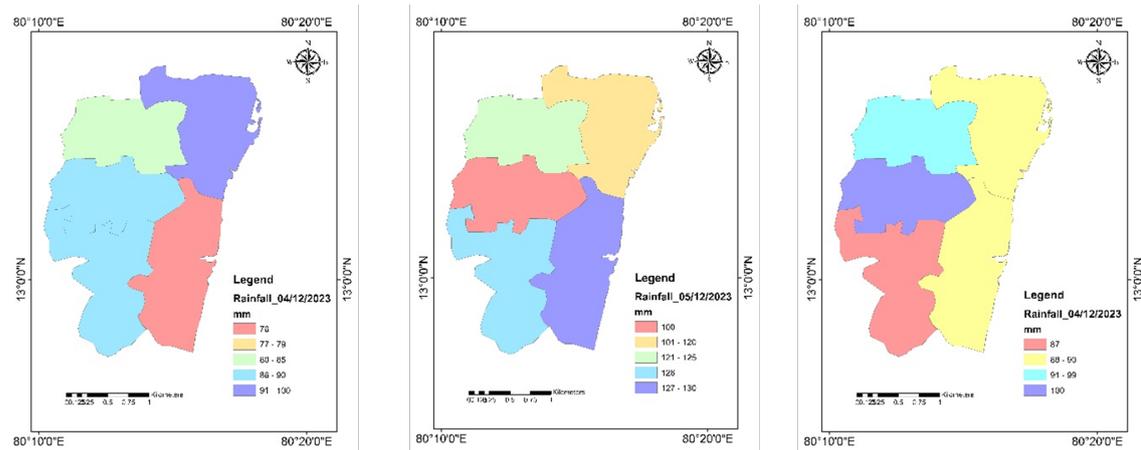


Figure 10. Amount of Rainfall occurred in Chennai during December 4 to 6

4. Conclusion

The study shows that the cyclonic storm Biparjoy caused severe damage across coastal regions of India due to heavy rainfall, strong wind velocities, and storm surges, mostly in the states of Gujarat and Rajasthan. Understanding its information, trajectories, and impacts is crucial for improving future prediction and preparedness. Directional analysis shows that most storm movement was concentrated toward the north and the northeast of the cyclone, affecting Saurashtra, Kutch, and Karachi. Comparing distribution models indicates that the Von Mises distribution fits the cyclone direction of about 17°NE. Notably, Biparjoy resulted in fewer casualties than previous regional cyclones, highlighting the importance of strengthened disaster management practices.

The study also examines meteorological factors influencing urban flooding during Cyclone Michaung in Chennai, using statistical analysis and GIS-based techniques. It provides detailed insights into rainfall, wind patterns, and flooding probabilities, revealing complex relationships such as the inverse link between Chennai rainfall and the cyclone’s proximity to its Andhra Pradesh Landfall. A strong correlation between maximum and surface wind speeds further underscores their combined role in flooding severity. Directional analysis using the Von Mises distribution shows a clear North-Westward movement, identifying high-risk zones along the Andhra Pradesh coast.

Overall, the research enhances understanding of cyclone behavior and cyclone-induced urban flooding, offering valuable guidance for disaster preparedness and climate-resilient planning. It also highlights key differences for differences between cyclones originating in the Arabian Sea and those in the Bay of Bengal, emphasizing their distinct meteorological characteristics.

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Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the authors used Grammarly and ChatGPT to improve clarity and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.