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Topic :

Increase in cyclone formation in the Arabian Sea

ABSTRACT:

The destructive potential of tropical cyclones (TCs) in reaction to global warming is an unanswered question. Previous studies have overlooked the impact of TC size change in the context of global warming, resulting in a considerable underestimation of TC destructive potential. The lack of reliable and consistent historical data on TC size makes it difficult to make a confident estimate of the relationship between the observed trend in TC size and the trend in sea surface temperature (SST) against the backdrop of global climate change.

The current study employs a linear regression model to evaluate the reaction of TC size and destructive potential to increases in SST from the year 1891 to 2020. Since 2001, researchers have seen a 52 percent increase in storms in the Arabian Sea, which has transformed into an ideal ocean basin for the development of cyclones. Furthermore, cyclones in the Arabian Sea have been observed to move more slowly, absorbing as much energy as possible when at sea before transforming into severe-intensity storms when they reach the coast.

KEYWORDS: Tropical Cyclone, Sea surface temperature, Arabian sea

INTRODUCTION:

The northern Indian ocean consists of two seas: the Bay of Bengal to the east and the Arabian Sea to the west. Tropical Cyclones which form at the north of the equator over the ocean, covering either side of the Indian sub-continent that's the Bay of Bengal, and therefore the Arabian Sea are termed North Indian Ocean (NIO) tropical cyclones. Historically, tropical cyclone activity within the Bay of Bengal is usually more than that of the Arabian Sea.

But the new research showed a shift during this trend. In recent years the frequency of cyclones over the Arabian Sea has also begun to increase. History reveals that the NIO basin has two cyclogenesis favoring seasons per year. One is from April–to May (pre-monsoon season) and the other is from October–to December (post-monsoon season).

It is understood that the evolution of the intensity of cyclones generally depends on the initial intensity of the storm, the thermodynamic profiles of the atmosphere, and also the thermal structure of the upper ocean through which it propagates. Cyclones are characterized by their devastating potential to break structures, the foremost fatalities come from storm surges and also torrential rain flooding the lowland areas of coastal territories.

NIO contributes to over 80% of worldwide fatalities which happens mostly as a result of the coastal flooding arising from the land falling cyclones. Proper analysis and research are needed to prevent large-scale loss of lives and property damage.

What is a tropical cyclone?

(Formation of a cyclone)

(Figure 1)

Cyclones are low-pressure systems that arise over warm tropical waters and are characterized by gale-force winds around the center. Winds can travel hundreds of kilometers (miles) from the storm's eye. Sucking in massive amounts of water frequently results in severe rains and flooding, resulting in significant loss of life and property damage. When they attain persistent winds of at least 119 kilometers per hour, they are also known as hurricanes or typhoons, depending on where they originate in the world. Tropical cyclones (hurricanes) are the most destructive weather occurrences on the planet. Cyclones are low-pressure systems that form over warm tropical waters, with gale-force winds near the center. The winds can extend hundreds of kilometers (miles) from the eye of the storm. Cyclones are low-pressure systems that form over warm tropical waters, with gale-force winds near the center(Figure 1). The winds can extend hundreds of kilometers (miles) from the eye of the storm.

LITERATURE REVIEW AND RESEARCH PROBLEM:

LITERATURE REVIEW:

- **Based on the analyzing the Arabian Sea cyclone Years and Non - Cyclone Years:**

Baburaj, P., Abhilash, S., Abhiram Nirmal, C., Sreenath, A., Mohankumar, K. and Sahai, A., 2022. Increasing incidence of Arabian Sea cyclones during the monsoon onset phase: Its impact on the robustness and advancement of Indian summer monsoon. *Atmospheric Research*, 267, p.105915.

During the beginning phase of the Indian Summer Monsoon, cyclones have been common in the Arabian Sea in recent decades. The impact of these cyclones on the establishment and northward spread of the monsoon system was investigated in this study. The key dynamical components of the monsoon semi-permanent systems, such as wind at 850 and 150 hPa, are studied separately for Arabian Sea Cyclone Years and Non-Cyclone Years. Pentad (5-day average) composites for Arabian Sea Cyclone Years and Non-Cyclone Years are calculated using pentads centered on the start of the Monsoon season in Kerala. To analyze the evolution of the monsoon system over the Indian subcontinent, six pentad composites are created (2 before, 1 during, and 3 after the onset pentad). The data demonstrates that the cyclones produced within 8 days of the monsoon over Kerala influenced the Low-Level Jet and Tropical Easterly Jet. The Low-Level Jet and Tropical Easterly Jet patterns in Arabian Sea Cyclone Years take 10 days to stabilize (acquire) their typical pattern (spatial and intensity) as Non-Cyclone Years. A pentad (similar) study of SST reveals a similar pattern to that of Low-Level Jet. The SST lowers throughout Low-Level Jet as its speed increases. On the day of start and thereafter, Total Precipitable Water indicates a large change over the Arabian Sea rather than the Bay of Bengal. Tropical Easterly Jet variations are caused by changes in the upper tropospheric meridional temperature gradient. Cyclone-induced disturbances are shown to disrupt the thermodynamic and dynamical condition of the background monsoon circulation. Because of strong Low-Level Jet and Tropical Easterly Jet, the high value of vertical wind shear of zonal wind across the Indian Monsoon area during Non-Cyclone Years is optimal for monsoon. The north-south temperature differential is smaller for Arabian Sea Cyclone Years, resulting in a little delay in developing Tropical Easterly Jet following monsoon commencement. Kinetic energy at 925 hPa is greater during Non-Cyclone Years than during Arabian Sea Cyclone Years, which helps to explain rainfall fluctuations.

- **Based on Climatology :**

[3]Evan, A. and Camargo, S. 2011. A Climatology of Arabian Sea Cyclonic Storms. *Journal of Climate*. 24, 1 (2011), 140-158.

Each year, 1–2 tropical cyclones emerge over the Arabian Sea, with just a handful of these storms being strong enough to be categorized as extremely severe or super cyclonic. As a result, few studies have precisely identified the seasonal to interannual variations in environmental variables that are linked with tropical cyclogenesis in the Arabian Sea. However, numerous powerful Arabian storms have formed and made landfall in the previous 30 years, causing significant damage, which drives this new research on the basin.

The findings of previous research are revisited by using recent observational and reanalysis data to discover large-scale factors linked with Arabian tropical cyclone variability during seasonal periods. Then year-to-year changes in environmental conditions that are related to interannual variability in Arabian storms during the pre-and post-monsoon periods are elucidated. The analysis of the relationship between large-scale environmental variables and seasonal storm frequency supports conclusions from work completed more than 40 years prior. Based on the trend in premonsoon storm frequency, we can conclude that may(June) storms are usually associated with an early(late) onset of the southwest monsoon.

The findings also show that November cyclones (the month when the majority of postmonsoon cyclogenesis occurs) form primarily when the Bay of Bengal experiences a broad region of high sea level pressure, implying that November storms form in either the Arabian Sea or the Bay of Bengal but not both at the same time. Finally, an examination of variations in a genesis potential index indicates that long-term variability in the potential for a storm to form is driven by changes in midlevel moisture.

- **Based on A Spatio - Temporal Analysis in Support of Natural Hazard Risk:**

  Suad Al-Manji, Gordon Mitchell and Amna Al Ruheili
  Submitted: October 5th, 2020Reviewed: March 2nd, 2021Published: April 3rd, 2021

Tropical cyclones are a regular natural disaster that has had a significant impact on Oman. Between 1881 and 2019, 41 Tropical cyclones systems made landfall in Oman, each accompanied by high winds, storm surges, and large flash floods, frequently resulting in loss of life and significant damage to infrastructure. Tropical cyclones have an impact on Omani coastal areas ranging from Muscat in the north to Salalah in the south. However, a greater awareness of high-risk areas is required, and this is of particular relevance to disaster risk reduction agencies in Oman. The goal of this research is to locate and map Tropical cyclones' tracks, as well as their spatiotemporal distribution to landfall in Oman, to identify high-risk locations. To further identify the Spatio-temporal distribution of Tropical cyclones tracks and their landfall in Oman, the research employs Kernel Density Estimation and Linear Direction Mean approaches.
The research demonstrates distinct seasonal and monthly trends. This knowledge will aid in disaster preparation for high-risk locations.

- **Based on The increasing frequency of extremely severe cyclonic storms :**

  [4]Murakami, H. et al. 2017. Increasing frequency of extremely severe cyclonic storms over the Arabian Sea. Nature Climate Change. 7, 12 (2017), 885-889.

Initially, post-monsoon extremely severe cyclonic storms erupted over the Arabian Sea in 2014 and 2015, causing significant damage. According to the World Meteorological Organization, extremely severe cyclonic storms are tropical storms with lifetime maximum winds of greater than 46 ms-1. However, it is uncertain if the abrupt increase in post-monsoon extremely severe cyclonic storms is the result of global warming, natural variability, or stochastic behavior. Using a set of high-resolution global coupled model experiments that properly mimic the climatological distribution of extremely severe cyclonic storms, we show that anthropogenic forcing has likely increased the probability of late-season extremely severe cyclonic storms occurring in the Arabian Sea since the preindustrial era. On the other hand, stochastic processes were most likely to blame for the specific timing of identified late-season extremely severe cyclonic storms in 2014 and 2015. Natural variability is also shown to have played a slight role in the reported increase in extremely severe cyclonic storms. As a result, continued anthropogenic forcing will increase the risk of cyclones in the Arabian Sea, with socioeconomic implications.

RESEARCH METHODOLOGY:

RESEARCH DESIGN:

Exploratory research was conducted for this project using Linear Regression Model.
When a problem has not been clearly defined, exploratory research can be used to explore and analyze the situation. This will help researchers to discover research problems.
Exploratory research does not give us an answer but it helps us to understand the situation better. Exploratory research helps determine the data collection method and often relies on secondary research (such as our literature review). The objective of exploratory research is to gather preliminary information that will help define problems.

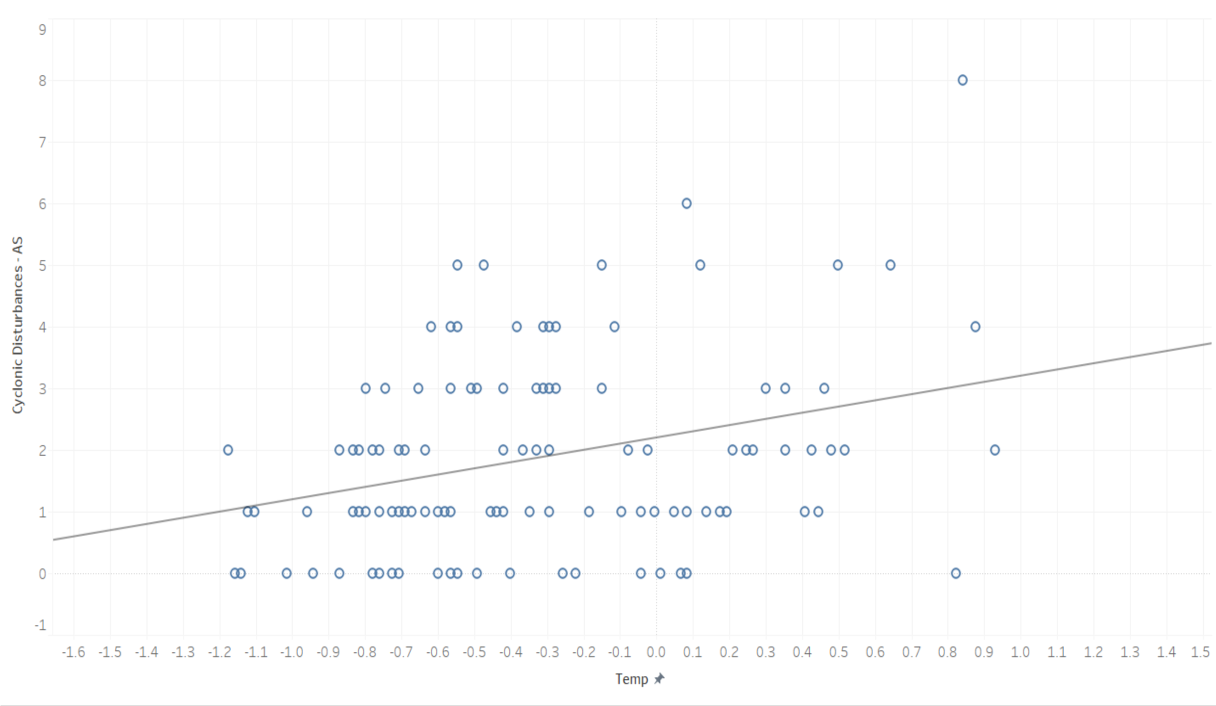
Secondary data analysis was conducted to identify the factors.

Linear regression model:

The LR model is developed using the multiple linear regression techniques:

$\mathbf{Y} = a + b\,\mathbf{X}$

where **Y** is the dependent variable and **X** is the independent variable and a is the intercept and b is the slope.



(regression line showing how the increase of cyclone disturbance concerning the increase in sea surface temperature)
(Figure 2)

The Linear Regression Model was implemented with the number of Cyclonic Disturbance in the Arabian Sea from 1891 to 2019 and the Sea Surface Temperature of the Northern Hemisphere from 1891 to 2020

Model Evaluations:

Best fit values	
slope	0.9522 +- 0.2732
Y-intercept	2.116+-0.1593
x-intercept	-2.222
1/slope	1.050

95% confidence intervals	
slope	0.4187 to 1.488
Y-intercept	1.804 to 2.428
X intercept	-4.672 to -1.512

Goodness of fit	
R square	0.8730
Sy.x	1.467

Is the slope significantly non-zero?	
F	12.15
Dfn.DFd	1.127
P-value	0.0007
Derivation from horizontal	Significant

Data	
Number of XY pairs	129
Equation	Y= 0,9522*X+2.116

The statistical correlations were well correlated squared values bold values $\boldsymbol{r^2}$ values for no change were as high as 0.87. The Slope value is positive as well as 0.95 which also shows a high positive linear relationship between Sea Surface Temperature and the number of cyclone formations in the Arabian Sea.

Linear Regression Analysis concerning P values also signifies that the predictor variables (Sea Surface Temperature & No of cyclone formation) are statistically significant to include in any further final models.

HYPOTHESIS:

1. Why is climate change fuelling Tropical cyclones?

The oceans absorb over 90% of the heat emitted by greenhouse gases, resulting in rising water temperatures. While cyclones get their energy from warm waters, rising temperatures are driving more intense storms to form. What is happening currently is that the Arabian Sea temperatures, the ocean's surface temperatures, are rapidly rising. Cyclone storm surges may be worsened by increasing sea levels, making them even more dangerous and catastrophic.

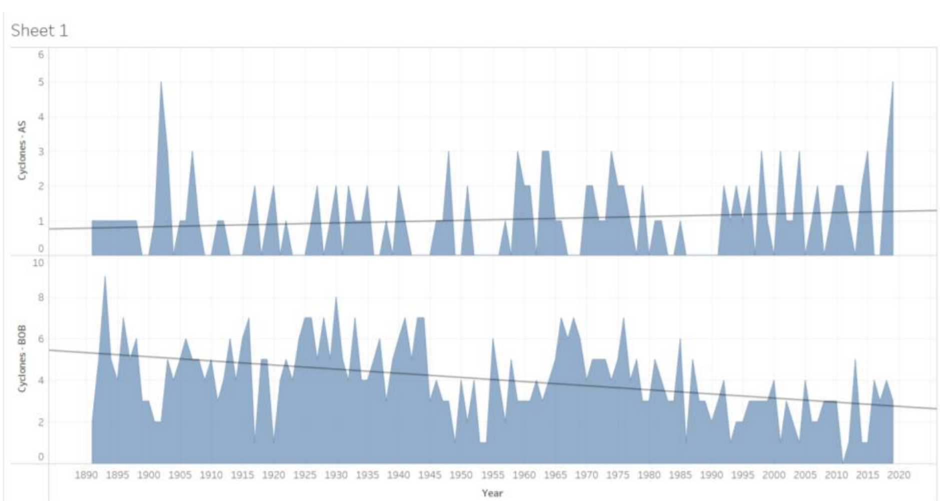
2. What else is making Tropical Cyclones more deadly?

Cyclones can make large storm surges, tsunami-like flood-when they result in landfall. They are the most dangerous component of a cyclone and are only slightly affected by wind velocity. Storm surge refers to rising seas triggered by a storm that forms a wall of water several meters higher than the normal tide level. Large swells move faster than cyclones and can be spotted up to 1,000 km ahead of a strong storm. The surge can reach dozens of kilometers inland, inundating homes and making roadways impassable.

Several factors influence storm surge, including storm strength, forward speed, storm magnitude, and storm approach angle to the shore. The underlying land characteristics of the shore, such as bays and estuaries, are also in play. People failed to leave earlier storms because they did not realize the surge's lethal threat. That was the situation with Super Typhoon Haiyan in 2013, which killed or went missing 7,350 people in the central Philippines, mostly owing to the surge. According to the Indian Meteorological Department, a storm surge of up to four meters (13 feet) is expected to inundate certain coastal regions of Gujarat during Tauktae's landfall.

RESULT AND DATA ANALYSIS:

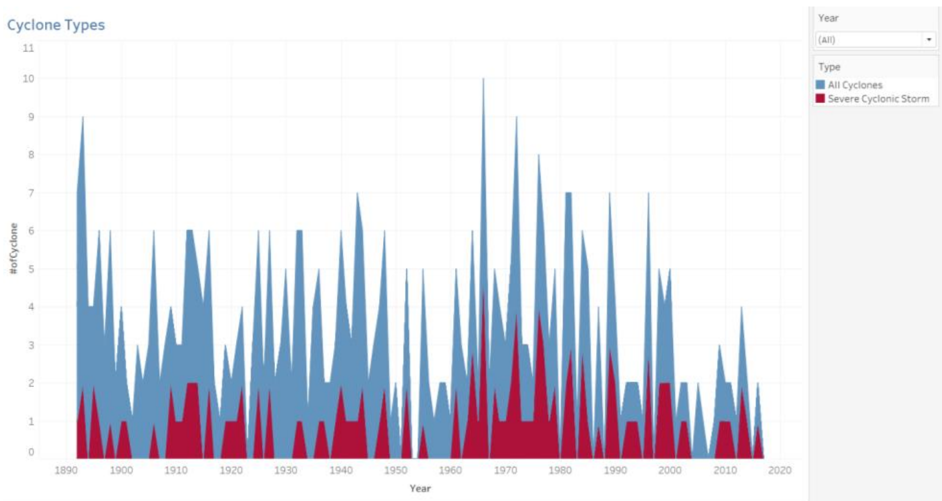
There has been an increase in the frequency and intensity of cyclones developing over the
The Arabian Sea over the past two decades, while the Bay of Bengal has seen fewer such storms. Compared with the 38 years between 1982 and 2020, cyclone frequency over the Arabian Sea increased by 52 percent, and over the Bay of Bengal, it reduced by 8 percent. (Figure 3)



(comparison of the cyclone frequency over the Arabian Sea and Bay of Bengal)
(Figure 3)

On average, about four to five cyclones occur over the north Indian Ocean region (including both the Bay of Bengal and the Arabian Sea) per year, with approximately three-fourths developing over the Bay of Bengal. But this is quickly changing. In 2019, eight cyclones formed in the north Indian Ocean, with five forming in the Arabian Sea. In 2018, there were seven cyclones, including three over the Arabian Sea. In addition to the frequency, intensity, and duration of cyclones over the Arabian Sea are changing.

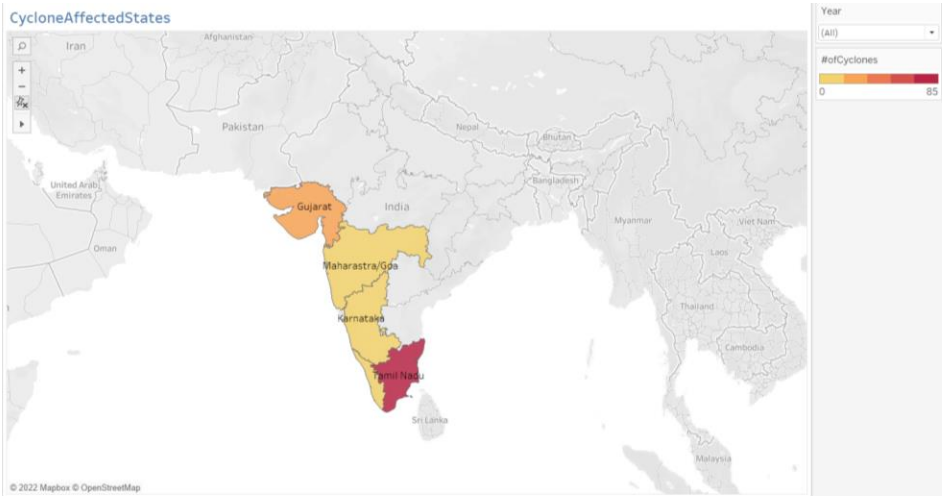
In addition to more cyclones than usual over the Arabian Sea, there also occurred back-to-back "extremely severe-type" cyclonic storms within a month on the Arabian Sea coast in 2015. This trend suggests India's west coast will soon have to contend with stronger storms and more frequent storms.



(Graph depicting cyclone types over the years 1980-2020)
(Figure 4)

The west coast has been the least prepared for severe cyclones until now. In the last two decades, the number of very severe cyclones in the Arabian Sea has increased by 150%. We need to be prepared, not only in terms of forecasts but also in terms of risk assessments.

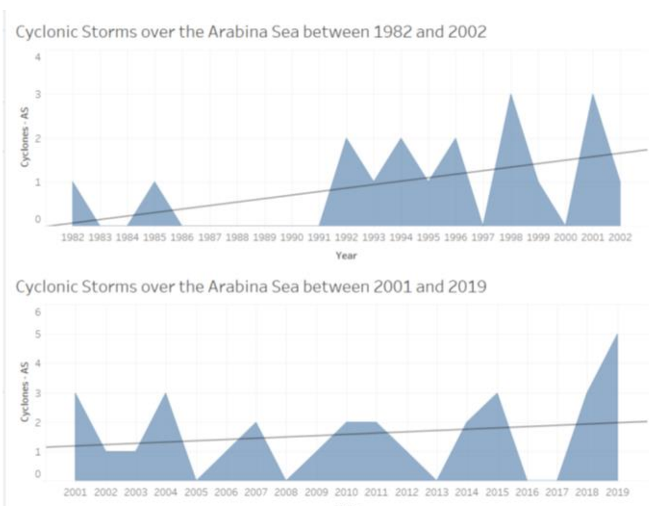
Risk assessment should be performed by considering the overlapping impacts of storm surges, heavy rains, and a rising sea level which can result in prolonged flooding on the west coast. As more cyclones form in the Arabian Sea, the chances of some getting closer to the west coast will increase, as we've seen in the past few years.



(graph showing the states affected by cyclones from the Arabain Sea)
(Figure5)

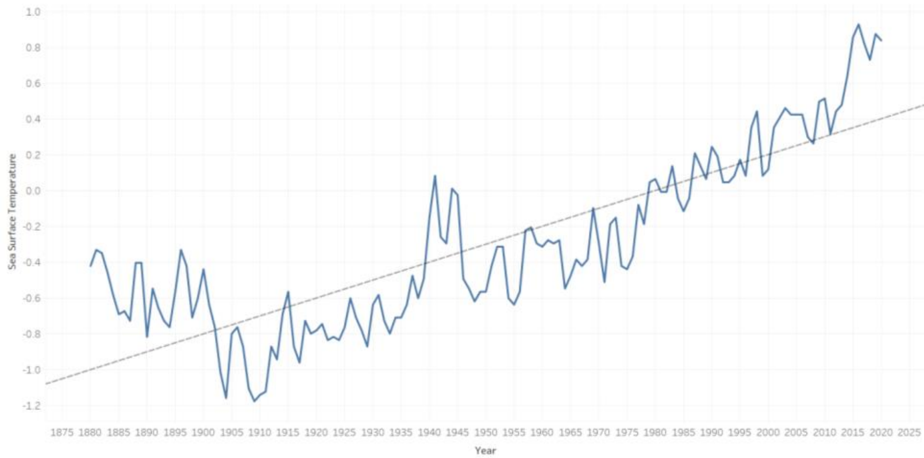
According to the study, cyclones over the Arabian Sea have become increasingly severe in recent decades. The duration of cyclonic storms over the Arabian Sea is also increasing. Compared to 1982 to 2002, the total period of cyclonic storms over the Arabian Sea increased by 80% between 2001 and 2019.

As a result the length of severe cyclonic storms almost tripled during the same period.



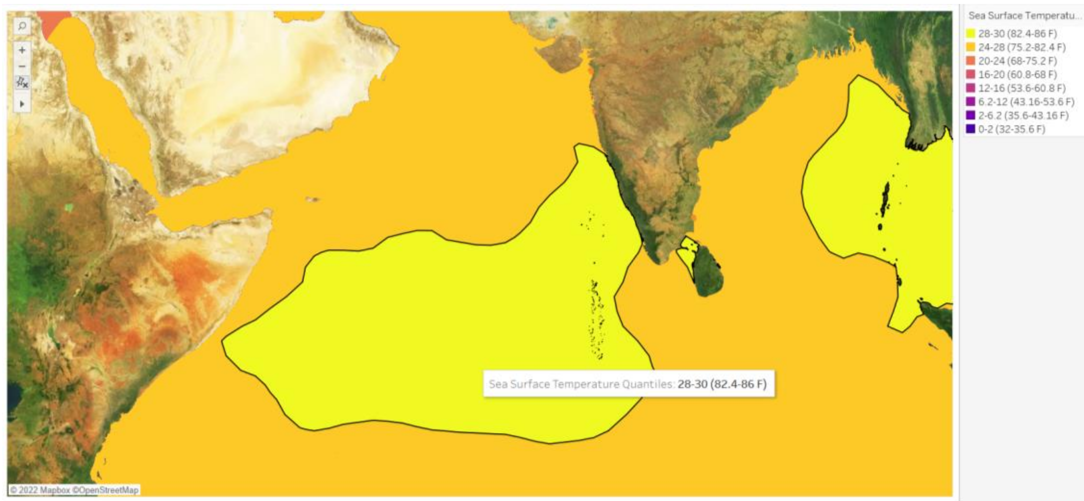
(comparison between the increase in cyclone formation over the two decades)
(Figure 6)

This confirms what has been theorized for a few years: abnormal warming of the Arabian Sea is creating conditions conducive to stronger cyclones than those in the Bay of Bengal, which has been considered to have ocean-atmosphere conditions more conducive to cyclone development.



(graph depicting the increase in sea surface temperature)

(Figure 7)



(sea surface temperature variation over the different oceans)

(Figure 8)

The normal frequency of cyclonic storms in the Arabian Sea :

The average number of observed cyclones (both weak storms and intense storms) is two per year between 1998 and 2019 in the Arabian Sea.

Reason for the increase in the frequency of severe cyclonic storms in the post-monsoon period over the Arabian Sea:

Three factors might be involved with the increase in ESCSs during the post-monsoon season. The first is the rise in sea surface temperature, especially over the Arabian Sea. The warming ocean contributed to more intense cyclones in the Arabian sea, as well as the delay of the winter monsoon, leading to a longer storm season. Lastly, an increase in anthropogenic aerosols, which influence the distribution of sea surface temperatures, contribute to changes in the monsoon circulation, leading to more intense storms.

Impact of climate change on tropical cyclones:

Global warming causes warming in the surface ocean, which is conducive to the intensification of tropical cyclones. However, rising greenhouse gas concentrations also cause warming in the upper atmosphere, which stabilizes the atmosphere.

The stable atmosphere makes it difficult for tropical cyclones to develop. Therefore, cyclone frequency would decrease when global warming continued. However, once a tropical storm starts, it can become an intense storm due to the warmed ocean surface. In general, the above discussion applies to global tropical cyclones. But when we talk about regional tropical cyclones, the picture is more complex. Certain regions get more active storms when the circulation changes and others get less active storms. It is difficult to predict how tropical cyclones will change over time.

CONCLUSION AND SUGGESTIONS

The Indian seas have received relatively little attention compared to other ocean basins of the world when it comes to the interpretation of cyclone seasons. Thus, we used linear regression to support the seasonal Tropical Cyclone activity using Cyclone formation variables in the period from 1891 to 2019. Through correlation analysis, the current study finds the strong co-relation factors between the increase in the number of cyclones in the Arabian Sea concerning the increasing the Sea Surface Temperature in recent years. Even due to the interannual variables of climate in the tropics and the existence of vast ocean basins, there is no guarantee that the seasonal tropical cyclone prediction model developed for the Atlantic and Pacific oceans by several research teams is also applicable to the Indian Ocean.

To overcome this, use genetic algorithms and historical data to generate thousands of 'synthetic tropical cyclones' based on global climate models.

A large dataset of simulations of these computer-generated cyclones, which are similar to natural cyclones, will allow the researchers to project tropical cyclone behavior and occurrence over the next decades despite climate change, even in regions where tropical cyclones rarely occur today. We can obtain results from a global perspective with just a 10km resolution.

Using a statistical model and data from high-resolution climate models, we will see how climate change will affect the frequency of most extreme tropical cyclones. By 2050, global warming will increase the likelihood of strong cyclones in many areas. The result will be more intense tropical cyclones and hurricanes in tropical areas that are already vulnerable to climate change from sea-level rise, which will add to the risk of weather extremes and flooding.