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ASSESSMENT OF OCEAN WARMING IN ARABIAN SEA USING SATELLITE REMOTE SENSING FROM 1940-2022

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By

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Abstract:

This research presents a multidimensional assessment of ocean heating in the Arabian Sea from 1940-2022 using satellite remote sensing. The objective of this study is to identify the patterns of ocean heating over time on large scales and predict the Sea surface temperature variations. Several multidimensional rasters were generated to identify the ocean heating patterns across waters of Arabian sea using satellite derived Sea surface temperature as the indicative parameter. The outputs of trend analysis, prediction modelling using harmonic regression, duration of exposure statistics and hotspot mapping indicate that the Arabian sea has undergone significant warming, with a warming trend of approximately 0.085ºC per year which accounts for 0.69ºC warming per decade. The warming trend observed in this study is consistent with global warming patterns and highlights the need for immediate climate action. Additionally, the results can provide insights into the complex oceanographic processes in the Arabian Sea have implications for fisheries, marine ecosystems, and the regional economy.

Keywords: Sea Surface Temperature; Ocean Warming; Multidimension

1. Introduction

Marine heat waves (MHW) are unusual warming phenomena in the oceans, and they have been occurring with increasing frequency over the past few decades, many MHW events have been recorded and are widely distributed over large continents and open oceans. MHW are not just physical a maritime phenomenon; It also has significant impacts on regional coastal ecosystems. The increasing intensity and frequency of MHW has led to increased research interest [1]. As a result of increased ocean heating, according to the 4th Intergovernmental Panel on Climate Change (IPCC 2007), the projected Sea Level Rise (SLR) at the end of the 21st century will be about 0.79 m, including 0.2 m ice sheets melting, while the fifth IPCC report specifies sea level could rise 10 cm over the IPCC 4th report estimate as a result of this sporadic ocean warming. Coastal areas are the most densely populated in the world and this warming will not only have devastating implications on those living in coastal areas with significant social and economic consequences but also will subsequently impact the marine life [2]. Atmospheric heat wave (AHW) frequency has likely increased in Europe, Asia and Australia since about 1950. AHW and MHW are caused by specific atmospheric

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and oceanic sources or a combination of both which are well-studied using ocean remote sensing [3]. Ocean remote sensing has proved to be an efficient resource for mapping large scale patterns of oceanic parameters which helps in identification of increased extreme weather events, such as ocean warming, which have had significant impacts on the environment worldwide. Global warming to the above-mentioned level will lead to negative consequences such as an increase in extreme weather events such as droughts, floods and heat waves than previously estimated [4, 2].

2. Materials and Methods

Traditionally, a raster contains two dimensions, x and y, which describes the location of a pixel but a multidimensional raster includes a 3D or 4D array that contains multispectral satellite imagery of a location across time in case of 3D and depth in case of 4D. It can also contain multiple variables which in this study is specific to Sea Surface Temperature across time in Arabian Sea Region.

Multidimensional raster analysis was performed on ERA5 Sea surface Temperature product monthly averaged from 1940 to 2022 for the Arabian sea region. ERA5 is the fifth generation ECMWF's Integrated Forecast System (IFS). The data was transformed to a uniform lat-lon grid with a resolution of 0.25 degrees for the reanalysis, while the uncertainty estimate was conducted at a resolution of 0.5 degrees (with 0.5 and 1 degree resolutions for ocean waves, respectively).

The Sea Surface Temperature (SST) parameter represents the temperature of the upper layer of seawater. The SST parameter is sourced from two external providers in ERA5. Prior to September 2007, the HadISST2 dataset is utilized, while the OSTIA dataset is used for SST from September 2007 onwards. SST is expressed in Kelvin (K), which can be converted to degrees Celsius (°C) by subtracting 273.15.

Trend analysis was performed to create a multidimensional raster using harmonic regression which estimated the trend for each pixel over the entire time series accounting for changes that happened throughout the year between each month in a cyclical pattern.

$$y = \beta_0 + \beta_1 * t + \beta_2 * \cos\left(\frac{2\pi}{365.25}\omega_i t\right) + \beta_3 * sin\left(\frac{2\pi}{365.25}\omega_i t\right) \quad (1)$$

where β_0 is the intercept of the slope. β_2 and β_3 are the harmonic coefficients for cosine and sine.

$$Amplitude = \sqrt{\beta_3^2 + \beta_3^2} \quad (2)$$

$$Phase = tan^{-1}\frac{\beta_2}{\beta_3} \quad (3)$$

β_2 and β_3 are used to calculate the amplitude, as well as the Phase, which are then used as inputs to the hue saturation and value column model. The amplitude decides the saturation of the color. A larger amplitude means a brighter color, while the Phase decide which color it is, and the value here is a constant. This model is then converted to RGB for display.

Based on the coefficients generated by trend analysis, a multidimensional prediction raster of SST till 2050 was computed using the trend raster with R2 found to be 0.98. The predicted raster was used to generate anomalies to indicate the areas where temperature changed significantly and calculate the duration of changes. Anomalies were generated by computing the difference from mean with mean calculation interval set to be recurring monthly.

Using the predicted anomalies, the regions longest affected by rising temperatures were identified by setting argumentative statistics with time of anomaly raster as Dimension, Duration as the statistics type and Yearly interval as the dimension definition with minimum value set as 1 and maximum value at 5 months.

Table 1: Satellite imagery product description

Product Type	ERA5 Monthly averaged reanalysis
Data Source	cds.climate.copercnicus.eu
Access ID	0cd72f37-dc2d-4405-bb6a-81d4a12b6871
Variable	Sea Surface Temperature
Year	1940-2022
Month	January to December
Time	00:00
Sub-region extraction	North 29.79°, West 56.20°, South 6.12°, East 75.25°
Format	Cloud Raster Format (.crf) and NetCDF

Next an emerging hotspot analysis was performed on a space time cube generated for the limits of Exclusive Economic Zone of Pakistan from the multidimensional raster indicating SST values from 1940-2022. The cubes were generated for the recurring months for 2D and 3D Visualization.

3. Results

Several multidimensional rasters were generated to identify the ocean heating patterns across waters of Arabian sea using satellite derived Sea surface temperature as the indicative parameter. The outputs of trend analysis, prediction modelling using harmonic regression, duration of exposure statistics and hotspot mapping are discussed subsequently.

The output trend raster indicates the direction of change or trend in temperature values between 1940 and 2022. Positive and negative values represent the slope of change in each pixel.

Areas in purple showcase increase in sea surface temperatures over the past 82 years, whereas areas in green having experienced decrease or no significant change in sea surface temperatures during this period. In trend to RGB results, regions with high saturation indicate high amplitude, meaning that they have high variability.

Trend Analysis:

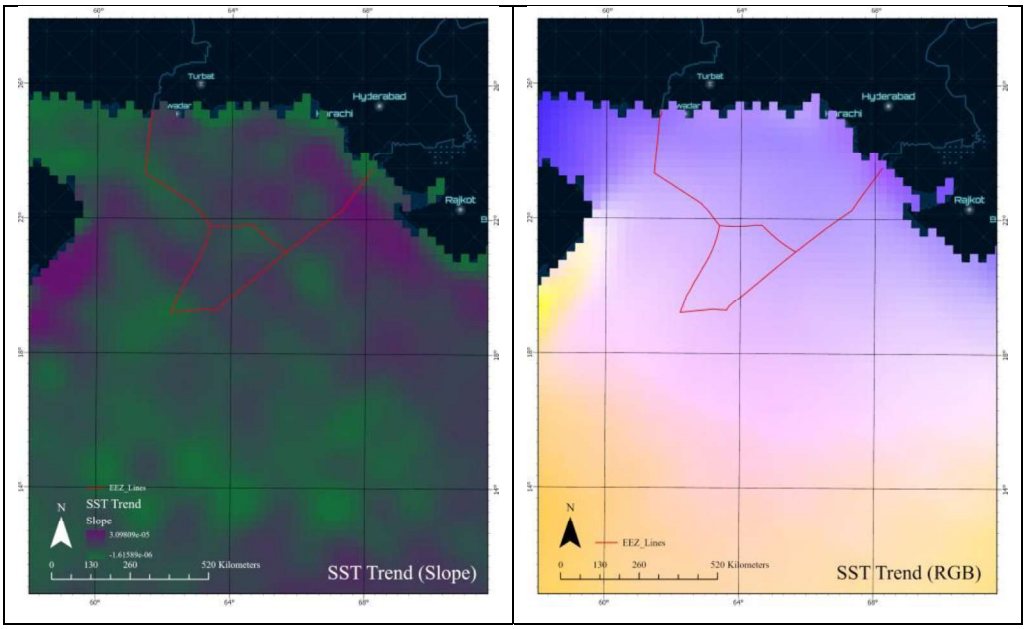


Figure 1: SST Trend Slope and RGB

SST Anomalies:

The anomaly multidimensional raster indicates areas where the pixel value for the selected time slice is subtracted from the mean value over each recurring month.

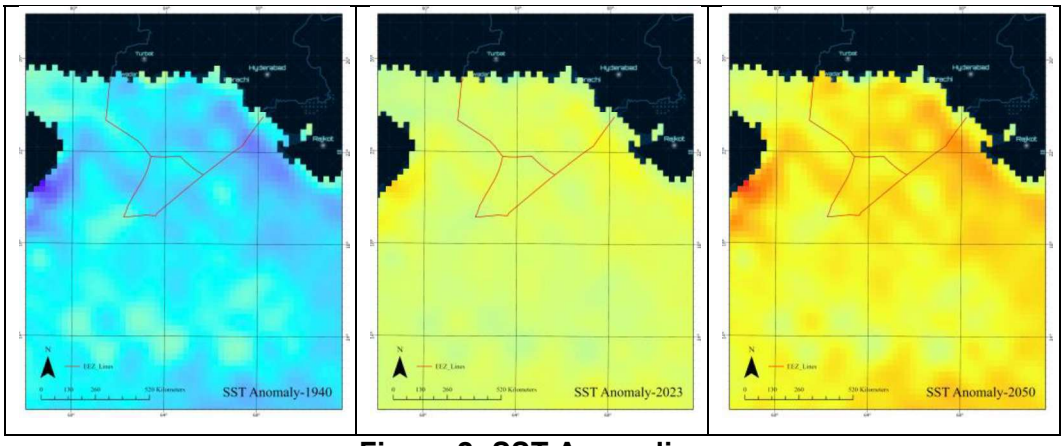


Figure 2: SST Anomalies

Continuous ocean warming is evident from the selected anomalies for 1940, 2023 which is indicative of increasing sea surface temperatures for 2050 as will alarming a sporadic ocean warming.

Duration of Exposure:

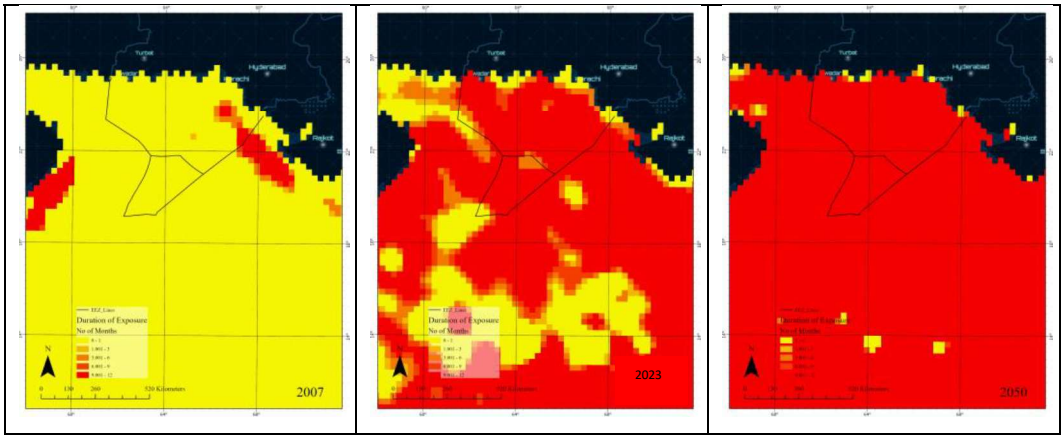


Figure 3: Duration in Months of Contnuous Ocean Warming

The duration of exposure was measured indicating the number of months each pixel will have to adjust to the warmer temperatures. The results indicate increasing duration of warming oceans with time which initially till 2003 highlighted very few regions experiencing persistent heating for 1 month significantly increasing to 9 – 12 months of continuous warming exposure by 2050.

Hotspot Analysis:

The hotspot analysis on the space time pattern mining cube indicates the hot and cold spots with varying ranges of consecutive, intensifying, persistent, diminishing, sporadic, oscillating, historical and new hot and cold spots. It is indicative that the region south east of Murray Ridge is emerging to be intensifying hotspot with increasing SST detected over time, whereas the near shore waters are alarmingly becoming diminishing cold spots which can eventually evolve into new hotspots of high SSTs.

3d Space time pattern mining cubes were generated where each bin represent a month indicating the hot spot patterns with respective colors spanned across 82 years from 1940 to 2022.

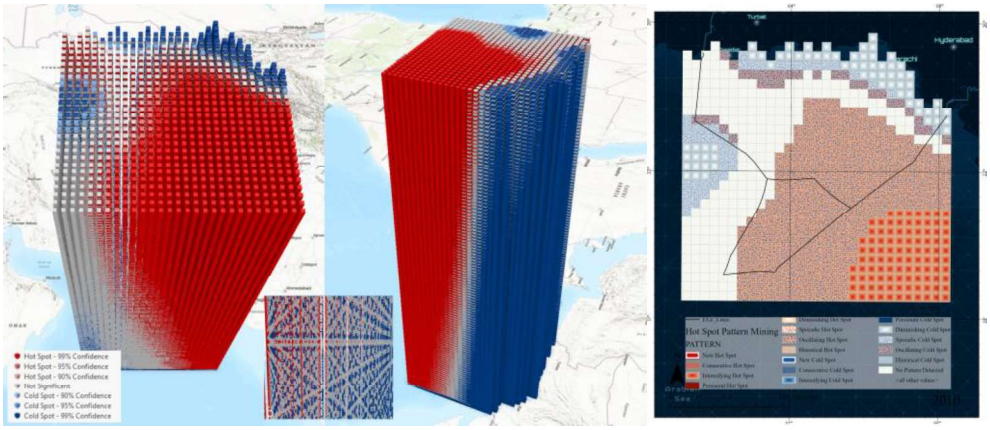
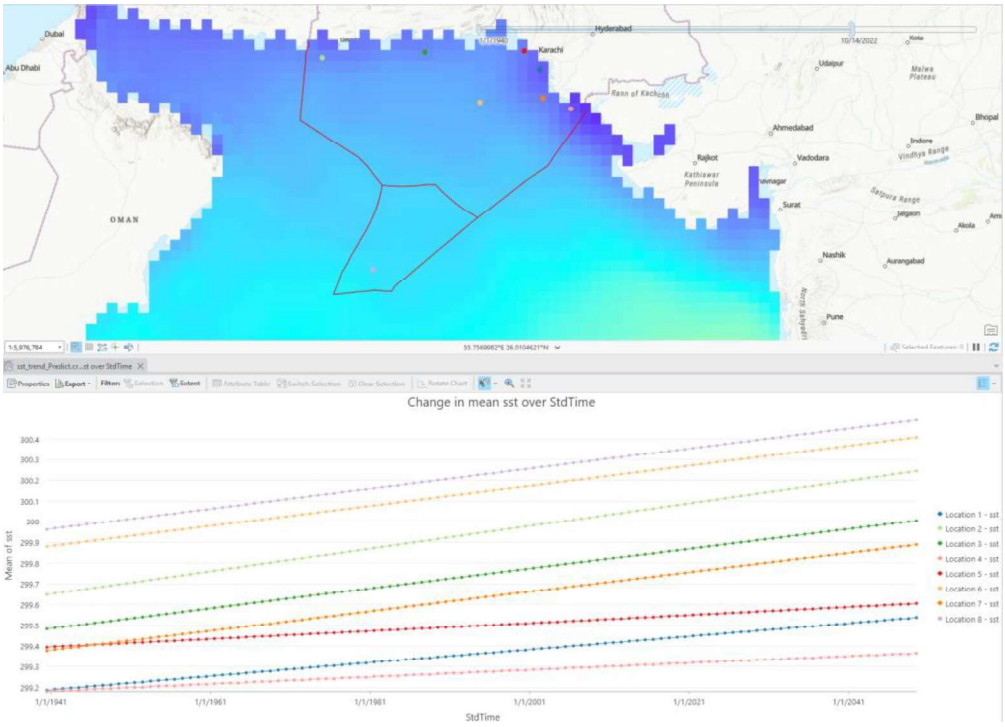
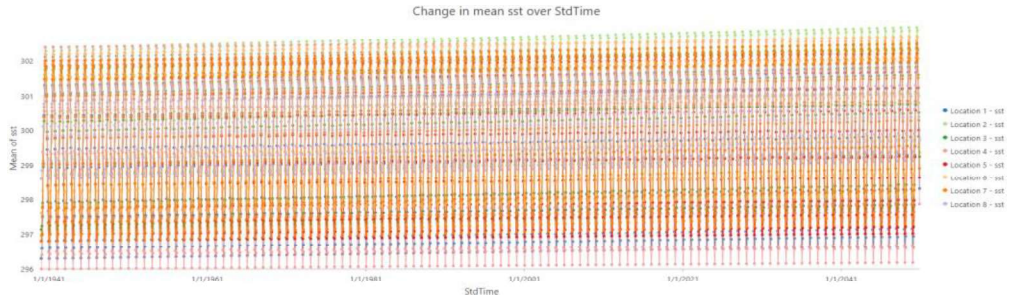


Figure 5: Space-time pattern Mining Cube of SST Hotspots from 1940-2022

SST Variation over Time:



The above figure indicates the change in mean SST aggregated over 1 year for different locations marked with respective pointers in legends. All locations show an increasing trend of SST over the years from 1940 to 2050. The figure below showcase monthly oscillations in SST values indicative of cyclical patterns of temperature over seasons.



4. Discussion

The results with supported literature indicate an alarming ocean heating pattern across Arabian sea, with a warming trend of approximately 0.085ºC per year which accounts for 0.69ºC warming per decade which will certainly have subsequent climate change implications also affecting the seasonal Monsoon Patterns. ERA5 with modelled hindcast raster of SST and satellite derived SST values proved to be an efficient input for temporal assessment of SST patterns across regional scale. The multidimensional raster modelling increases efficacy when coupled with python derived models using ArcGIS API.

References

1. Q. WANG, "Properties and Drivers of Marine Heat Waves in the Northern South China Sea," *JOURNAL OF PHYSICAL OCEANOGRAPHY,* vol. VOLUME 52, p. 917, 28 January 2022).
2. A. Lafta, "Impacts of Potential Sea-Level Rise on Tidal Dynamics in Khor," *Earth Systems and Environment,* 28 January 2020.
3. M. J. Salinger, "The unprecedented coupled ocean-atmosphere summer heatwave in the New Zealand region 2017/18: drivers, mechanisms and impacts," *Environmental Research Letters,* 2019.
4. P. Subraelu, "Global Warming Climate Change and Sea Level Rise: Impact on Land Use Land Cover Features along UAE coast through Remote Sensing and GIS," *Journal of Ecosystem & Ecography,* vol. Volume 12, pp. 4-8, 2022.