Analysis of the Indian Ocean Tsunami of 2004

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***Abstract*—The Indian Ocean Tsunami was one of the deadliest natural calamities in history. The Tsunami first hit the Sumatra coast of Indonesia on December 26, 2004. Although Indonesia is prone to earthquakes and tsunamis, the calamity was rather unexpected on the Indian Ocean Coastline as such highly devastating tsunamis are more probable along the Pacific Coastline. In this report we investigate the effects of the disaster on vital ocean parameters such as surface salinity, temperature, height anomaly and currents, using 2D scalar and vector visualisation techniques.**

I. Introduction and Initial Hypothesis

The Indian Ocean Tsunami was a result of the Indian Ocean Plate coming under the Burma plate. This movement of the tectonic plates released energy equivalent to twice the total energy released by ammunition used in the entire of World War II. Due to such a high release of energy, the temperature of the ocean surface is hypothesized to increase. Since the temperature of the surface would increase, so would it's salinity. Additionally along the coastline the surface height anomaly would have also increased due to the increase in sea level during the tsunami. This would have also impacted the currents in the Indian Ocean [2].

Hence, we use the INCOIS dataset of the Indian Ocean during the period of December 2003 - December 2005 which has all the parameters required for our study. We use 2D scalar and vector field visualisation methods to visualize the changes in the aforementioned parameters in order to capture the impact of the calamity on the parameters.

II. Data Processing

The dataset contains 5 folders namely:

- sss (Sea Surface Salinity)
- sst (Sea Surface Temperature)
- ssha (Sea Surface Height Anomaly)
- zonal-current
- meridional-current

Each folder contains several files, each file denoting a day when the data was recorded. The filename is the date of day and since the data is captured over a 5-day interval over a period of 2 years, there are a total of 147 files in each folder. Each file contains the following fields of the data along with metadata such as units and bad flags:

- DATE: Date of the observed value in the format (Day-Month-Year)
- TIME: Time in days since 01-JAN-1901 00:00:00
- LON: Longitude
- LAT: Latitude
- DATAPOINT: Such as SSS, SST, SSHA, V (meridional current), U (zonal current)

We process all files sequentially and remove the metadata. The rest of the files have all field data separated by commas. We take the rest of the file and extract the latitude, longitude and data point. We initially create a dictionary to map from longitude value to another dictionary of latitude values which maps from latitude to the corresponding data point. We also collect all latitude and longitude values in two separate lists. Then, we create a 2D grid having the dimensions, (len(latitude list), len(longitude list)). Each value of the 2D grid is the value of the data point at the latitude and longitude at the index, same as that in the grid, in the each of the lists. For finding the magnitude matrix we just find the square root of the sum of squares of each value in the grid in the zonal-current grid and meridional current grid. We then use various plotting techniques to plot this grid.

III. Methods

For both the methods, we have used standard Python packages such as *matplotlib* for visualizing the data and *manimation* for making a video of the timesteps taken from the dataset.

A. Picking Timesteps

We have considered the visualizations over the entire duration of two years. For the time from December 2003 to October 2004 and February 2004 - December 2005 (all 4 months inclusive), we have taken every fourth file. This means that there is approximately one file, i.e. one day, per month for these intervals. While in the interval November 2004 - Jan 2004 (Both inclusive), we take each file, i.e. each day in the dataset for these months. That is, the timestep in this interval is one.

This method was used in order to carefully focus on the minute changes in the ocean parameters in the months nearing the disaster. The visualisation from other months is simply to observe the normal trend in the parameters. Hence, they don't require much detail as compared to the months nearing the disaster.

B. Scalar Field Visualization

Out of the parameters given to us, sea surface salinity, temperature and height anomaly form a scalar field. Hence, we use scalar field visualization techniques in order to visualize change in those variables. Contour Fill is a scalar field visualization Technique which was used for the task. We used the contourf() method from the BaseMap package in matplotlib for the technique.

The following are some questions that were to be answered in this report:

For contours, will you use the same contour values for all the selected time steps?
Yes, as this will help us capture the difference in the value of the parameter for a particular region on the map across different timesteps.

For color mapping, will you use the same min-max values to generate the color palette?
Yes, the minimum and maximum values used to generate the color map are, in fact, the minimum and maximum value of the parameter across all data files respectively.

Type of color spectrum used
The type of the color spectrum used varies from parameter to parameter. Hence, we discuss the details of the color map in the following sub sections.

1) Sea Surface Salinity: We used the *GnBu* colour map for the contour fill. We observed that this colour map adequately highlights the variation in values across regions in a particular timestep as it consists of 2 colours: Green and Blue. Also, this is a *Sequential* colour spectrum. A *Sequential* color spectrum is used to plot distribution that has a certain order, but no value to center to. Since salinity value across all data files is strictly positive and has order since it is a real number, we see that a *Sequential* color spectrum is the best to represent such data [1].

An example for this visualization is shown in figure 1.

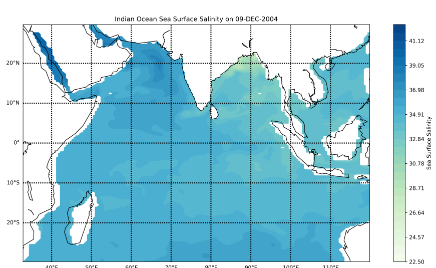

Fig. 1. Sea Surface Salinity for December 9, 2005

2) Sea Surface Temperature: We used the reversed *autumn* colour map for the contour fill. The yellow and orange shade of the colour map signify heat and is, hence, the most apt color to represent temperature. A *Sequential* color spectrum is used to plot distribution that has a certain order, but no value to center to. Since temperature value across all data files is strictly positive and has order since it is a real number, we see that a *Sequential* color spectrum is the best to represent such data [1].

An example for this visualization is shown in figure 2.

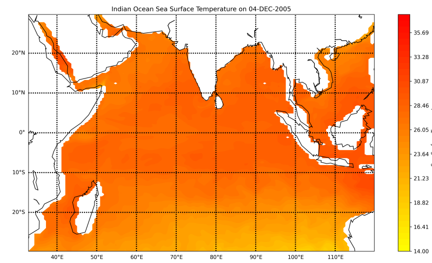

Fig. 2. Sea Surface Temperature for December 4, 2005

3) Sea Surface Height Anomaly: We used the reversed *coolwarm* colour map for the contour fill. The cool warm map is made of 2 colours: red and blue. The colour map centers around white, which denotes 0. The colour contrast shows that if the height anomaly is positive it is blue while if negative it is red. We felt that the red color signifies low lying values while blue color signifies high lying values. This colour map can hence model the texture of the sea surface well too. A *Divergent* color spectrum is used to plot distribution that has a value it centers to. Sea Surface Height Anomaly is the difference between a long time average value of the Sea Surface Height and it's current value. Since this value is centered around zero and is always in the interval $[-0.6, 0.6]$, we see that a *Divergent* color spectrum is the best to represent such data [1].

An example for this visualization is shown in figure 3.

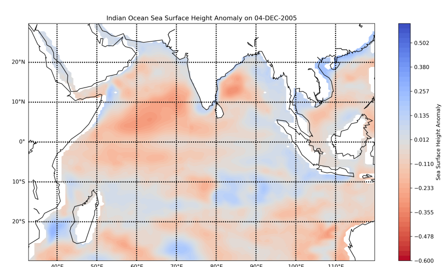

Fig. 3. Sea Surface Height Anomaly for December 4, 2005

C. Vector Field Visualization

The dataset contains 2 current values: zonal current, which denotes the x-component of the current direction and meridional current, which denotes the y-component of the current direction. Hence, ocean currents form a 2D vector field. We employ two visualization methods to visualize the data:

1) Visualization of Current Direction by Quiver plots
2) Visualization of Current Magnitude by Contour Fill
3) Visualization of both Current Magnitude and Direction

These techniques are detailed in the below subsections.

1) Visualisation of Current Magnitude: The current magnitude is plot using the *contourf()* method. This helps us visualise the magnitude of the current at different regions within a timestep as well as across multiple timesteps. We use the magma colour map for the contour fill, which is a perceptually uniform sequential colour map. An example is shown in figure 4.

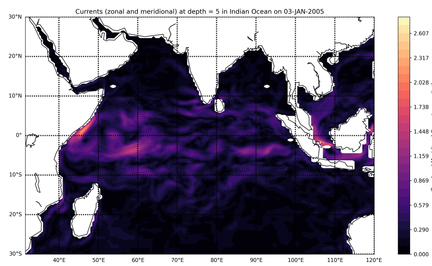

Fig. 4. Magnitude plot for January 3, 2004

2) Visualization of Current Direction: The current direction is plot using the quiver arrow plots. This helps us visualize the direction of the currents. the quiver arrows are shown black in colour. An example is shown in figure 5.

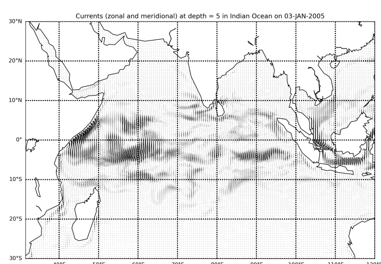

Fig. 5. Quiver plot for January 3, 2004

3) Visualization of both current magnitude and direction: The current direction and magnitude are both plot on one map using quiver plots for direction over which magnitude contour fill is plot. An example is shown in figure 6.

In addition to the above methods, we also tried merging sea surface salinity, temperature and height anomaly with the current direction plot, but we noticed that since there were no common longitudes and latitudes for the values and were hence giving errors. We would try to fix this error in the future release.

IV. Inferences

The above visualizations show a slight version of the hypothesis we made. We believe a more intense version could have been see had we got the data from 26^{th} to 28^{th} of December 2004. This is because the calamity struck on 26^{th}

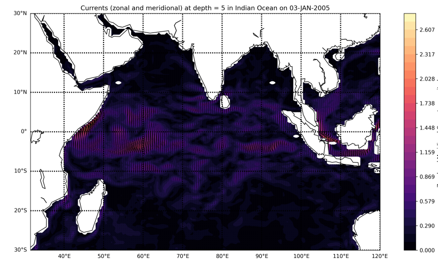

Fig. 6. Both Magnitude and Quiver plot for January 3, 2004

of December 2004 and hence, more changes in values could be observed there.

A. Sea Surface Salinity

The area near the Sumatra coast has a high sea surface temperature as shown in Figure 7.

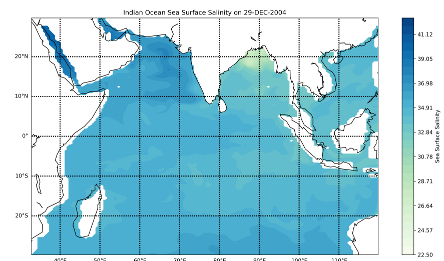

Fig. 7. Sea Surface Salinity on 29th December, 2004

B. Sea Surface Temperature

The area near the Sumatra coast has a high sea surface temperature as shown in Figure 8.

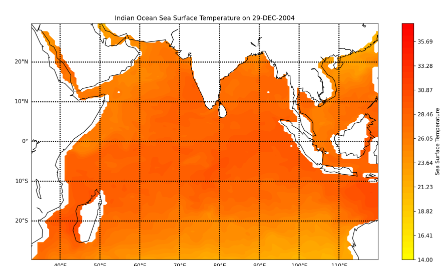

Fig. 8. Sea Surface Temperature on 29th December, 2004

C. Sea Surface Height Anomaly

The sea surface height anomaly seems to have increased near the Indian Coastline, which keeps with the fact that the Tsunami had reached India's Eastern Coastline around that time. This effect is shown in Figure 9.

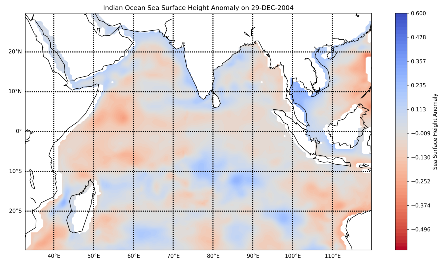

Fig. 9. Sea Surface Height Anomaly on 29th December, 2004

Acknowledgment

We thank Prof. Jaya Nair for providing us the INCOIS Dataset which help us get some insight into an important historical event.

References

[1] John Hunter. Choosing colormaps in matplotlib, 2022.
[2] Maged Merghany. Simulation of tsunami impact on sea surface salinity along banda aceh coastal waters, indonesia, 2014.