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Evaluation of Temperature Anomalies and Ocean Productivity during the 2004 Sumatra-Andaman Earthquake

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Introduction

On December 26th 2004, a 9.3 magnitude (M_W) earthquake occurred off the coast of Sumatra, Indonesia, producing a tsunami of devastating impact (Giest *et al.* 2007, Lay *et al.* 2005, Park *et al.* 2005). The propagation of water posed a significant human and environmental impact (Giest *et al.* 2006). Most of the existing research conducted by the National Oceanic and Atmospheric Administration (NOAA) on the impacts of the Sumatra-Andaman earthquake focuses on the human impact and tsunami prediction and warning methods (Arcas *et al.* 2006, Giest and Bilek *et al.* 2006), with environmental studies limited to sediments and bathymetry. The impact of natural disasters (earthquakes and tsunamis) on marine life is largely ignored. However, oceanic water is hypothesized to have experienced turbidity, phytoplankton removal and nutrient upwelling as a result of the earthquake (Halder *et al.* 2013, Sarangi 2012, Tang *et al.* 2009); therefore, it is proposed that the before and after effects of the earthquake be determined and analyzed to study oceanic water quality and productivity.

Remote sensing of chlorophyll *a* serves as the main indicator of the total phytoplankton population. Using the Moderate-resolution Imaging Spectroradiometer (MODIS-AQUA) the absorption coefficient of phytoplankton (solar radiation absorbed) is obtained, and produces a rough estimation of phytoplankton abundance (high absorption coefficient indicates a high population of phytoplankton). By observing the changes in the above parameters; in addition, to monitoring the concentrations of phytoplankton (coccolithophores, cyanobacteria, chlorophytes, diatoms) over time the effects of the 2004 earthquake on oceanic water quality can be determined.

Smaller earthquakes, the 2005 Nias earthquake (8.7 M_W) and 2006 Java earthquake (7.7 M_W), occurred in the vicinity of the 2004 Sumatra-Andaman earthquake (off the west coast of Sumatra) and produced less destructive tsunamis (USGS *et al*. 2005, Ammon *et al.* 2006, Mori *et al.* 2010). Due to lack of research and information regarding the 2005 Nias earthquake and its occurrence during March 2005 directly following the 2004 Sumatra earthquake, the 2006 Java earthquake was selected as a point of comparison.

Literature suggests that an earthquake in 2002, of magnitude 7.2 served as a foreshock (Vallée 2007); however, foreshocks do not consistently occur with every earthquake and cannot be utilized as an accurate method of prediction. In order to minimize human loss due to natural hazards, indicators of natural hazards (anomalies) are sought to predict regions at risk. In addition to oceanic implications, this study seeks to determine an atmospheric precursor to the 2004 Sumatra earthquake for the production of an earthquake prediction model, and determine the overall effects of the earthquake on Sumatra's phytoplankton population.

This earthquake was caused by a release of stress as a result of the subduction of the Indian plate beneath the Burma plate 30 km below sea level (USGS et al 2015). Currently there are no tsunami earthquake prediction models. Deep-Ocean Assessment and Reporting Tsunami (DART), and Indian Ocean Tsunami Warning System (IWOTS) has invested more than $450 million dollars in equipment to detect tsunamis. After an earthquake has occurred, scientist forecast tsunami-induced currents, gage the height of the waves, and project wave arrival time on shorelines (Oskin 2014). However predicting tsunami damage after the earthquake has already caused, it doesn't give enough evacuation time. That is why currently, scientists are working to explore new atmospheric parameters to predict earthquakes before they happen.

Atmospheric parameters that have been tested in earthquake prediction modeling include: radon concentration, ionosphere modifications with increased electron density (Pulinets et al., 1997), outgoing longwave radiation (OLR), Low-Earth orbit tomography, critical plasma frequency in the ionospheric F2-region, foF2, (Ouzounov et al., 2011., Chuo, Y., 2002), total electron content (TEC) (Astafyeva and Heki 2011) and surface latent heat flux (SLHF) (Qin et. al 2009). Studying atmospheric anomalies show promise in developing earthquake prediction method.

Using 5 GPS stations in Central Italy Nenovski *et al.* (2015) studied the Ionospheric TEC variations six days before and fifteen days after the Abruzzo earthquake. This research showed a local disturbance in the lower ionosphere (160km). Dimitar Ouzounov's *et al.* (2011) research revealed similar disturbances, more than 100 earthquakes in Asia and Taiwan whose magnitudes were bigger than 5.5 and depths less than 50 km showed electron concentrations in the ionosphere increases substantially. It was also noted that charged particles, ions, attract condensed water and release heat (Ouzounov *et al.* 2011). The release of heat could be measured through cloud top temperature and that increase in condensation of water. One measure of increase condensation is relative humidity index, RHI (%), which will be used in this experiment.

Research Questions

How is ocean productivity (phytoplankton population) impacted by this natural disasters (tsunami/earthquake)?

Does a similar quake and tsunami disaster in the region illustrate similar trends (comparison to the 2006 Pangandaran earthquake and tsunami)?

Increased surface latent heat index (Qin 2009) and total electron content in the ionosphere is hypothesized to occur 2-7 days before the earthquake (Ouzounov 2011), is this trend visible during the 2004 Sumatra- Andaman earthquake?

The following research seeks to answer the above questions by studying the indicators of earthquake events and the after effects of 2004 hazard on the Indian Ocean productivity.

Study Site and Methods

Analyses and visualizations used in this paper were produced with the Giovanni online data system, developed and maintained by the National Aeronautics and Space Administration Goddard Earth Sciences Data and Information Services Center (NASA GES DISC). NASA's Giovanni program was used to compile data from Aura (EOS CH-1, MODIS-Terra (EOS AM-1), MODIS-Aqua (EOS PM-1), GLDAS-2 (NOAH10), and NOBM. We also would like to acknowledge the mission scientists and associated NASA personnel for the production of the data utilized in this research effort.

NOBM provides assimilated daily global oceanic products (chlorophyll *a*, phytoplankton, iron, nitrates and mixed layer depth) related to oceanic productivity. MODIS-Aqua provides spectral data to determine chlorophyll *a* concentration and calculate the absorption coefficient of phytoplankton.
GLDAS - 2 is the global version of LDAS, both have a high resolution of (2.5 degrees to 1 km) and a temporal resolution of 3-hours. MODIS- Terra and Aqua high spatial resolution provides high temporal resolution of global coverage every day. Aura has a Microwave Limb Sounder instrument with seven microwave receivers using limb viewing geometry, whereby the signal intensities and vertical resolution are maximized (Livesey 2015).

To observe the atmospheric effects before the Indian Ocean Earthquake and Tsunami three parameters were evaluated. (1) Cloud top temperature (1) Vertical temperature profile at the epicenter (2) RHI % at the epicenter (3) Surface latent heat flux. Each of these parameters were chosen to observe the possible correlation between these atmospheric conditions and earthquake prediction methods.

First, cloud top temperature was measured globally using Modis-Terra & Aqua between the days of Dec. 5, 2004 - Jan 10, 2005 (Figure 11). The purpose of this measurement was to determine if any large fluctuations of temperature occurred over the epicenter during the month prior to the earthquake. Secondly, the vertical temperature profile was collected from Aura, for three coordinates that were closest to latitude 3.3 and longitude 95 on the dates of December 18 - 19, 22 - 27 2004 (Figure 12). These temperature profiles were then used to further examine temperature anomalies possibly associated with the seismic activity. Thirdly, RHI (%) vertical profiles were observed utilizing Aura from December 18 - 19, 22 - 27 2004 compiling information for three coordinate points closest to latitude 3.3 and longitude 95 (Figure 13). RHI (%) was used in this experiment as a measure for the increase in humidity directly proportional to the increase in TEC in the atmosphere reported as an indicator of earthquake development (Ouzounov *et al.* 2011). Figure 14 utilized the same parameter, RHI (%) but observed the atmospheric changes on December 26 2007, 2008, 2009. This figure was created to compare the information in figure 13. If the results of these years were similar to the result in 2004, it would have been concluded that the RHI (%) change could have been an outcome of seasonal variability and an earthquake related factor. Lastly, the latent heat index parameter of GLDAS-2 was utilized December 19-26 for the years 2003-2006. Recent research has discussed the increase in surface latent heat preceding earthquakes (Qin et. al., 2009) and this was the only sensor on Giovanni that covered that parameter. This observation showed the latent heat flux changes between each year during December. The purpose of these changes was to discover if there usually was in increase in latent heat flux around that area every year or if the increase could be recorded as an anomaly. All data were considered in relation to seasonal changes and the limitations of the satellite information.

Time series (June 1-May 30th) from NOBM were produced for the concentrations of chlorophyll *a* (mg/m^3), coccolithophores (mg/m^3), cyanobacteria (mg/m^3), chlorophytes (mg/m^3), and diatoms (mg/m^3) for years 2003-2006. Time series (June 1-May 30th) from MODIA-Aqua were produced for the concentration of chlorophyll *a* (mg/m^3) with 4 km and 9 km spatial resolution and absorption coefficient of phytoplankton (1/m) with 4 km and 9 km spatial resolution. NOBM has high temporal resolution (1-day) and low spatial resolution (roughly 8000 km); whereas, MODIS-Aqua has a lower temporal resolution (8-day) and a high spatial resolution (4 km and 9 km).

Graphs/figures

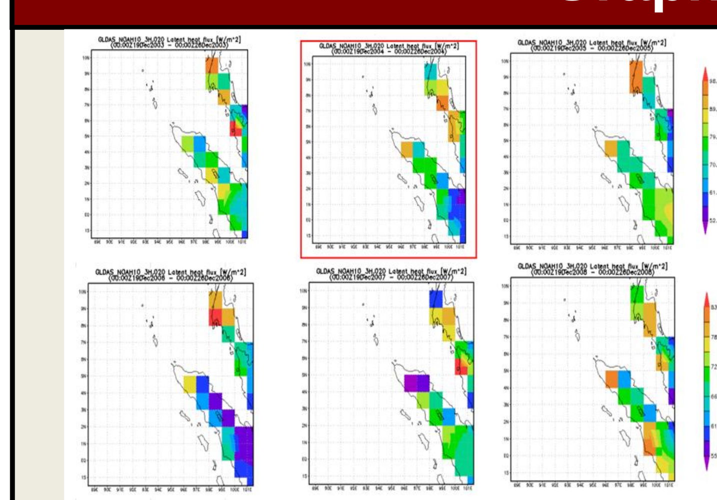

Figure 14: Latent Heat Flux in (W/m^2) within the coordinates (88.598 West, 9.683° North, -0.817° South, 100.998° East) collected hourly (3 hours temporal resolution). All data was retrieved from via Giovanni.

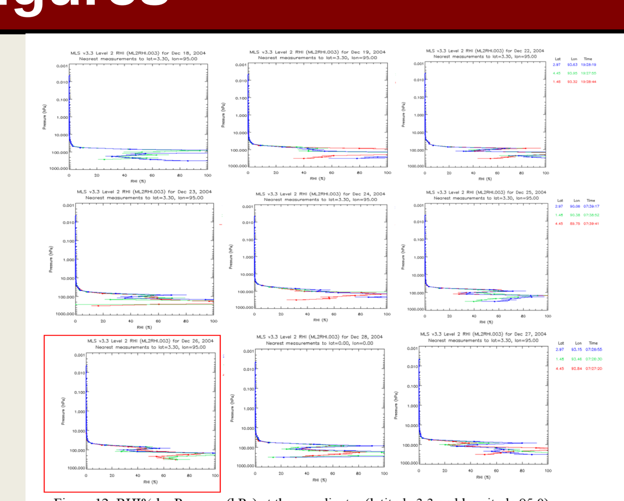

Figure 12: RHI% by Pressure (hPa) at the coordinates (latitude 3.3 and longitude 95.0) With spectral resolution at 5km at 261-100 hPa, 4km at 56.2 – 3.16 hPa, 7.2k at 1 – 0.316 hPa, 10 km at .1 - .001 hPa. All data was retrieved from MLS/Aura via Giovanni.

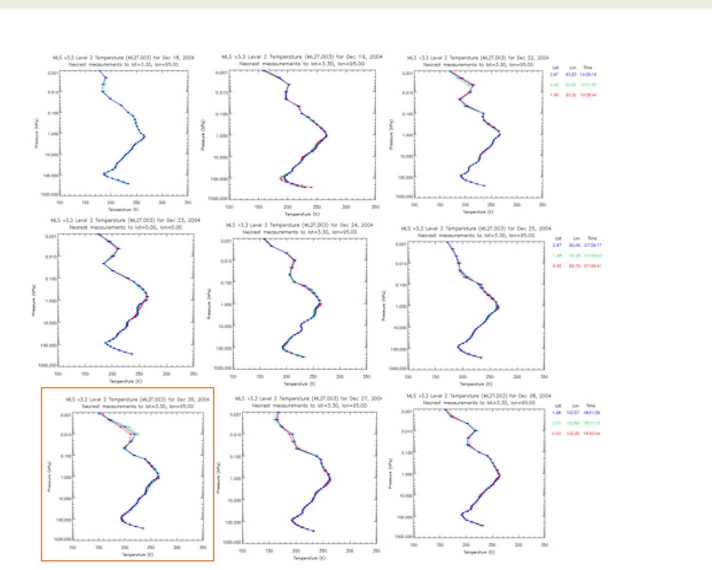

Figure 11: Temperature Profile at the coordinates (latitude 3.3 and longitude 95.0) With spectral resolution at 5km at 261-100 hPa, 4km at 56.2 – 3.16 hPa, 7.2k at 1 – 0.316 hPa, 10 km at .1 - .001 hPa. All data was retrieved from MLS/Aura via Giovanni.

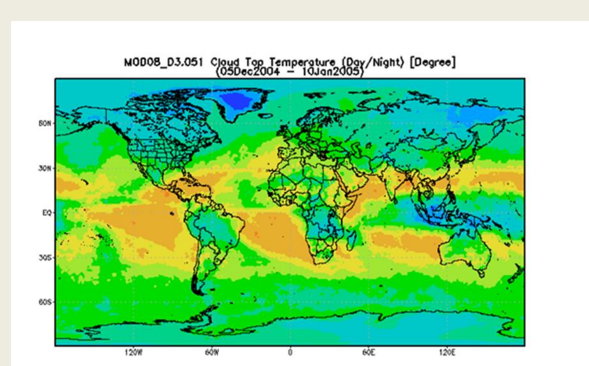

Figure 11: Cloud Top Temperature (Day/Night) within the coordinates (-180° West, 90 North, -0.90° South, 180° East) collected twice daily 1km spatial resolution. All data was retrieved from Modis -Terra and Aqua via Giovanni for Dec. 5, 2004 - Jan 10, 2005.

Graphs/figures

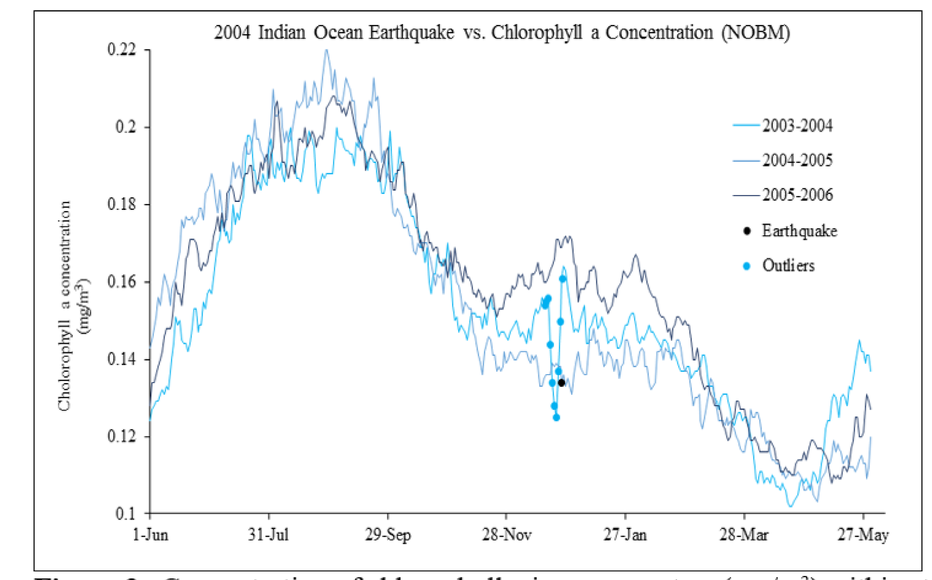

Figure 3. Concentration of chlorophyll a in ocean waters (mg/m^3) within stated coordinates (45.552° West, 24.222° North, -23.778° South, 115.152° East) collected yearly (daily) with a spectral resolution of 0.667° (latitude) and 1.25° (longitude). Earthquake occurred Dec, 26th 2004. All data was retrieved from NOBM via Giovanni and tabulated.

Graphs/figures

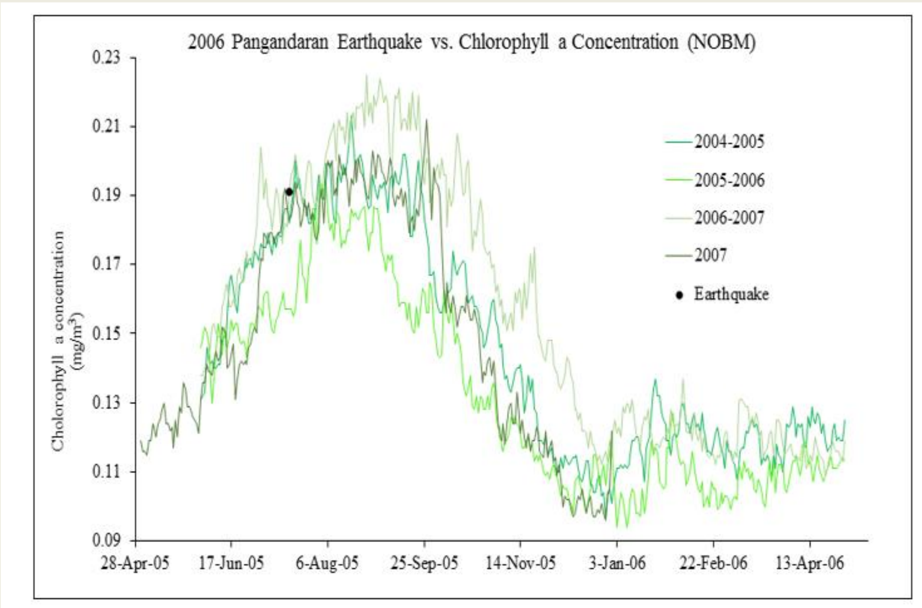

Figure 10. Concentration of chlorophyll a in ocean waters (mg/m^3) within stated coordinates (94.71° West, 5.19° North, -25.71° South, 141.51° East) collected yearly (daily) with a spectral resolution of 0.667° (latitude) and 1.25° (longitude). Earthquake occurred July, 17th 2006. All data was retrieved from NOBM via Giovanni and tabulated.

Conclusions

The oceanic productivity of the Indian Ocean and temperature anomalies prior to the Sumatra-Andaman earthquake (M_W =9.3) and tsunami (December 26th 2004) were studied. Data was obtained via NASA's Giovanni program to determine the effect on phytoplankton (primary producers) and temperature changes over the region of the earthquake. Seasonal trends were visible in the concentrations of chlorophyll a, coccolithophores, cyanobacteria, chlorophytes, diatoms and absorption coefficient, in addition to storm trends. Further study on the Sumatra fault is necessary. Phytoplankton in the Indian Ocean appears to vary more with season and ENSO rather than natural disasters. Additionally, continuous storms and the common occurrence of earthquakes, makes determining the significance of events difficult. Earthquake prediction models such as the "Lithosphere-Atmosphere-Ionosphere Coupling mechanism," still requires significant investigation and cannot be applied to all earthquakes (Ouzounov *et al.* 2011). This experiment neither supports nor refutes the hypothesis that earthquakes can be predicted using atmospheric parameters. More parameters, such as longwave radiation, thermal radiation and TEC/GPS, need to be studied over the epicenter and consistent atmospheric conditions need to be articulated for that region.