

Case Study of the Induced Change in Sea Surface Temperature by Typhoon Haiyan near the Philippines Eastern Waters

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Abstract

Past researches has demonstrated that strong winds associated with a hurricane caused upwelling that eventually result in sea surface cooling. In addition, biological productivity increase and CO₂ emissions are enhanced. During November 5-11, 2013, category 5 typhoon Haiyan devastated the Philippines and caused more than 6,000 deaths. The hurricane's sustained winds were approximately 195 mph. The aims of this research is to identify SST changes using AVHRR after the passage of Haiyan, over a region eastern of the Philippines and within the hurricane's path. At the end of the study SST changes were identified and compared with data from NCDC, in order to validate SST evolution.

Introduction

Tropical cyclones obtain their energy from the warm sea surface, this energy is then released in the form of strong winds that causes ocean mixing (Byju and Prasanna, 2011). This mechanism results in rapid cooling, increase in biological productivity and enhanced emission of CO₂, which Maldonado *et al.* (1997) suggests as evidence that upwelling and turbulent ocean mixing are the dominant factors for the SST cooling observed in the wake of a hurricane.

According to Babin *et al.* (2003), hurricane-force winds, greater than 33 m/s, have dramatic effects on the upper ocean. Surface water cools several degrees Celsius as mixed layer deepens by ten of meters with the most intense changes occurring under the stronger winds on the right-hand side of the storm. The response of the ocean surface layers towards a particular hurricane depends on numerous parameters involving atmospheric and oceanic variables, where some of the important atmospheric parameters include hurricane size (e.g., radius of tropical storm

force winds, radius of hurricane-force winds), strength (wind speed), and transit speed (Babin *et al.*, 2003).

The typhoon Haiyan, which occurred during November 5-11 of 2013, was a super typhoon category 5 that devastated portions of Southern Asia, particularly the Philippines. It is the strongest storm recorded at landfall, with its maximum sustained winds reaching 195 mph and gusts above 220 mph, resulting as and the deadliest in history with more than 6,000 recorded deaths. Monitoring the SST of the Philippines eastern waters before and after the wake of the cyclone can help in interpreting the extent of significant cooling of the sea surface temperature after the passing of typhoon Haiyan. Changes in SST are analyzed using Advanced Very High Definition Resolution Radiometer (AVHRR). This sensor's specifications shows its capability of measuring wavelengths emitted from atmospheric and ocean features, where bands 4 and 5 are combined to remove the effects of the intervening atmosphere to provide estimates of the sea surface temperature (Maldonado et al., 1997). Using ENVI as a software to process the images results convenient as this software has a specific algorithms for computing SST from AVHRR imagery.

The main objective of this study is to make a comparison between the SST obtained from remotely sensed AVHRR imagery taken before and after the passing of the cyclone over Eastern Samar, Philippines (between the 7th and 8th of November) in order to identify changes in SST. We intend to analyzing the changes in SST by preprocessing the images, using an algorithms that ENVI has developed for computing SST in AVHRR imagery in conjunction with the creation of a mask to denote the specific values of interest for the sea surface temperature under study.

Data and Methods

AVHRR imagery for a region of interest enclosed by the coordinates 5N-15N and 125E-145E and valid for November 4, 2013 to November 16, 2013 were employed to analyze SST near the eastern waters of the Philippines. Nonetheless, data regarding the days from November 5, 2013 to November 8, 2013 were excluded from the time range, since images related to the aforementioned days were severely contaminated with clouds associated with the tropical cyclone. Processing of the images was possible using ENVI 's specific utilities for AVHRR; SST maximum values were calculated for every

image on the annotation interface for color ramp, however, the minimum value was set to be 25°C, in order to obtain a color ramp that could display clearly differences in the SST for every image. The last step regarding image processing was to apply a mask for values less than 25°C, which were related to clouds presence in the images.

National Climate Data Center's (NCDC) SST product from the International

Research Institute for Climate and Society was retrieved for the same days assessed on this research, in order to identify SST decreasing over the region of interest and validate the results obtained. Finally, to summarize the results and interpret SST changes, a time series was constructed from each image maximum value and their specific date.

Results

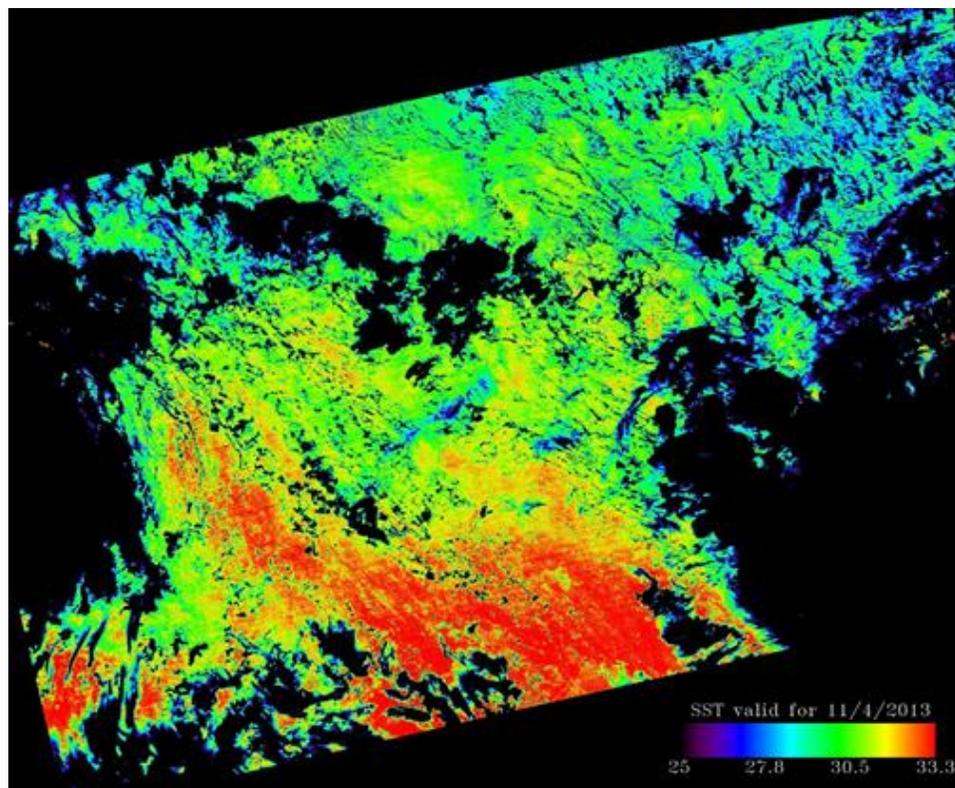


Figure 1. SST valid for November 4, 2013. Region: 5N to 15N and 125E to 145E.

Figure 1. shows a maximum temperature of 33.3°C. It is evident that pixels associated to that temperature value cover a vast area of the image, however, most of the pixels are related to temperatures values of approximately 31°C-32°C; there are regions with temperatures of 27°C as well. Black areas on the images are masked values, which are related to the low temperatures of clouds. Decrease in temperature is observe in Figure 2; maximum temperature value is 29.5°C. Most of the pixels in the image are associated with temperature values ranging from 27°C to 28°C.

Cooler temperatures persist during November 10 (Figure 3.), since the maximum value for temperature is 29.3°C. Pixels associated with this value cover a vast area, even though, the image contains many clouds. Increase in temperature during the 13th of November (Figure 4.) was observed; maximum values are approximately 38.5°C, most of the pixels are related to values of 33°C.

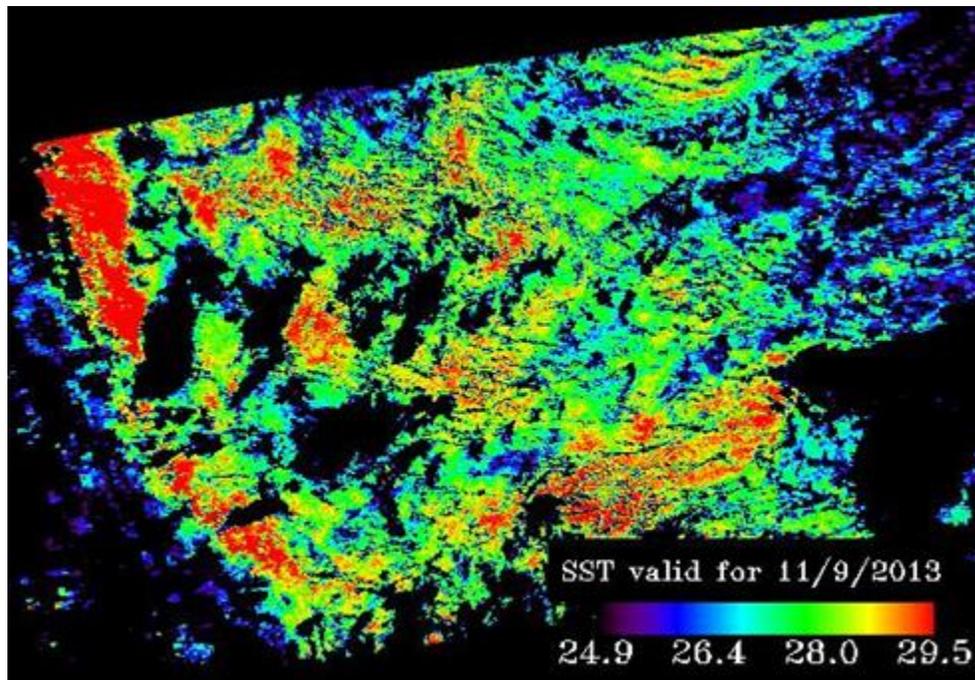


Figure 2. STT valid for November 9, 2013. . Region: 5N to 15N and 125E to 145E.

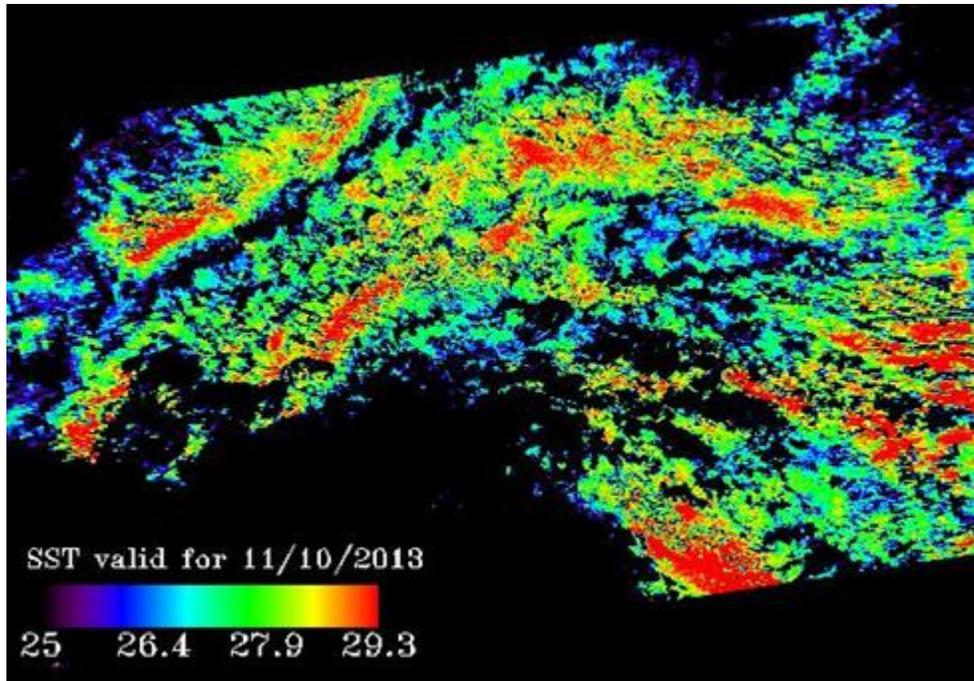


Figure 3. SST valid for November 10, 2013. Region: 5N to 15N and 125E to 145E.

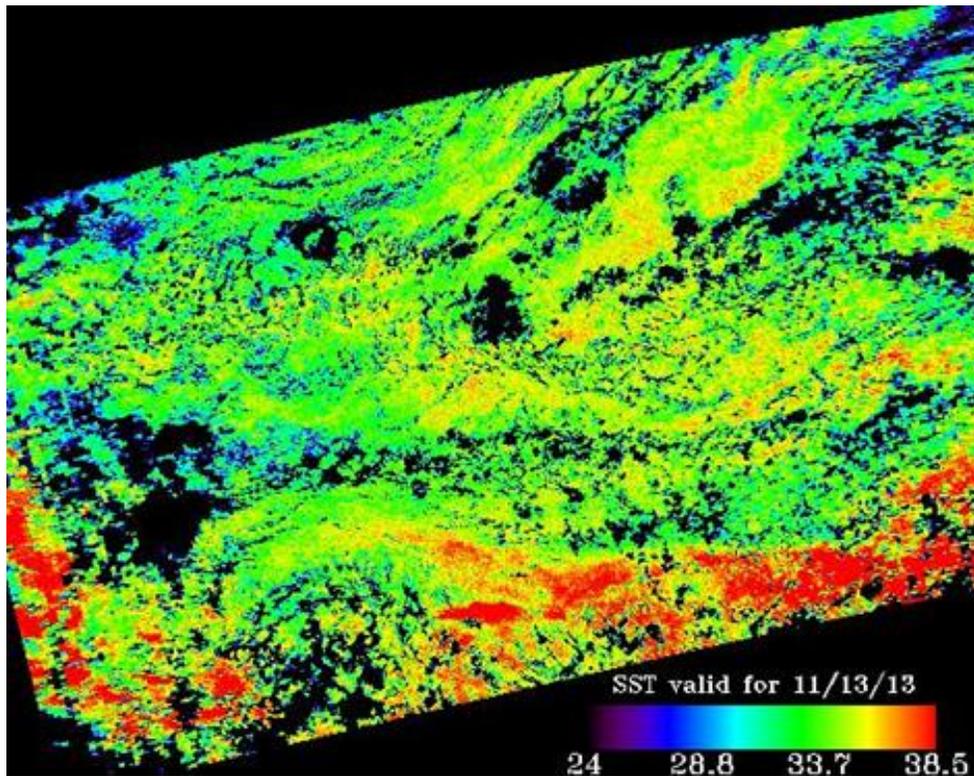


Figure 4. SST valid for November 13, 2013. Region: 5N to 15N and 125E to 145E.

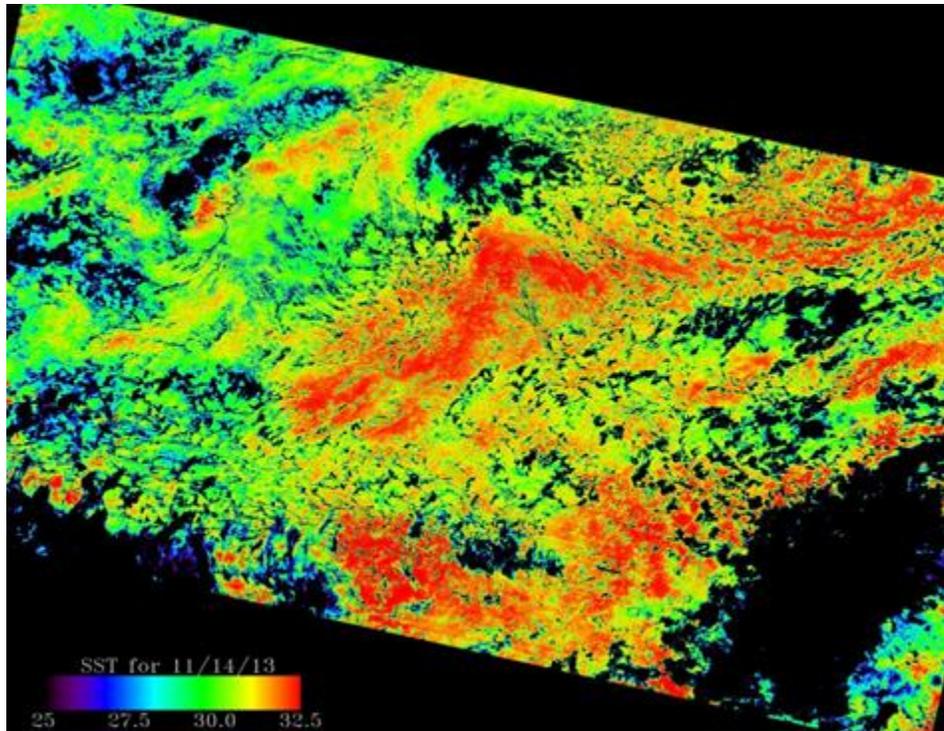


Figure 5. SST valid for November 14, 2013. Region: 5N to 15N and 125E to 145E.

From November 14 and 16, Figure 5. and Figure 6. respectively, temperature seems to be stabilizing, since their maximum values are 32.6°C and 32.7°C respectively. In addition, pixels associated with those temperature values are dispersed over the whole area.

NCDC product showed a decreased in temperature as well (Refer to Appendix), however, there is inconsistency between the results obtained from ENVI and NCDC product, since temperature does not increase

that dramatic in NCDC as on ENVI. The decrease persisted for more days in NCDC product.

From the time series (Figure 7.) it is noticeable a decrease in temperature for two consecutive days after the hurricane has passed. Afterwards the profile shows a dramatic increase towards 38°C. Further day's temperature began to stabilize since, the temperature remained constant for two days.

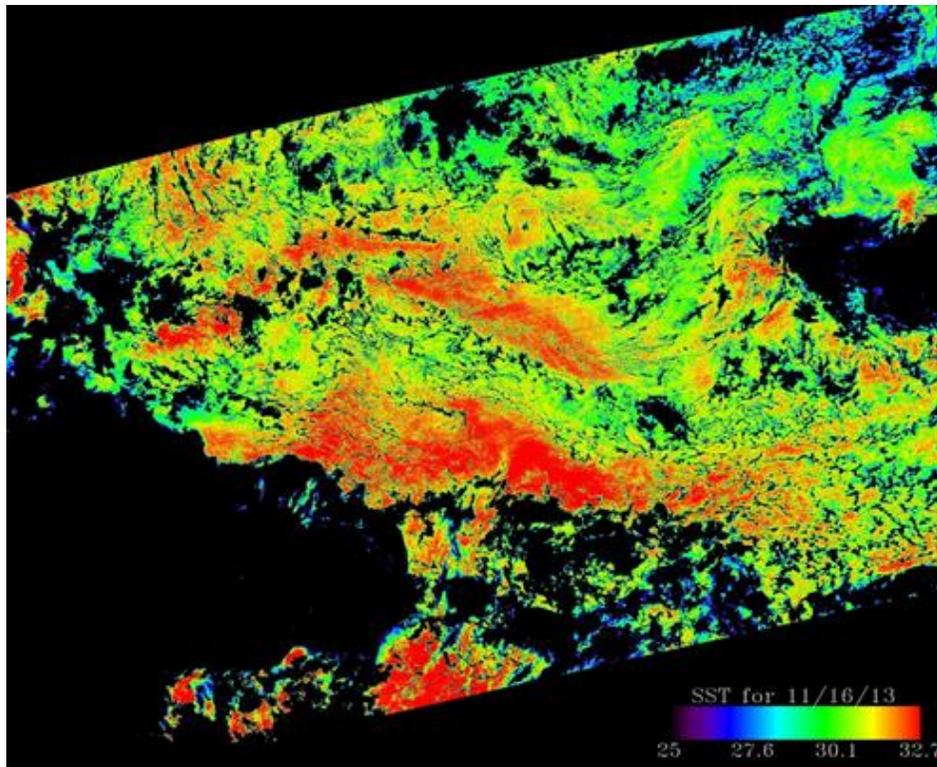


Figure 6. STT valid for November 16, 2013. Region: 5N to 15N and 125E to 145E.

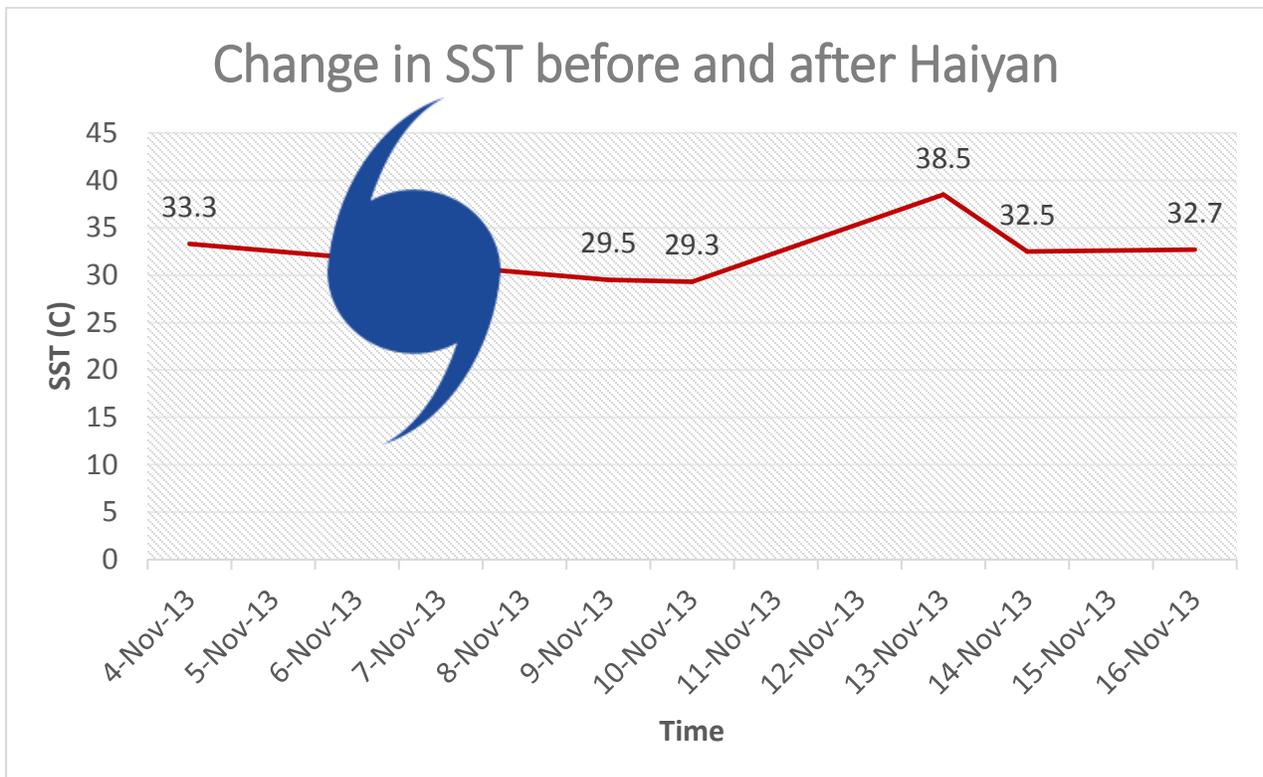


Figure 7. Time series for SST demonstrate cooling during November 9-10. Note that data is not available from November 5-8, since the hurricane passed over the region of interest those days.

Discussion

Decrease in sea surface temperature was appreciable after the passing of the cyclone. The decrease recorded was gradual and consecutive for the two days right after the wake of the storm (9th and 10th of November). From these two dates of appreciable sea surface cooling, the maximum lowest temperature reported from our data was 29.3°C, which occurred on the 10th of November. After this date the sea surface temperature started to rise but it was not until the 14th of November that the SST was restored to its stabilized temperature (approximately 33°C). Meaning that it took about six days for the sea surface temperature to rise back to its normalized temperature.

Due to the large amount of cloud coverage, which did not make possible the calculation of a reliable SST for the images during the wake of the storm, impeded the possibility to obtain an estimate when did the sea surface began to cool. Nevertheless, making use of the available database of AVHRR daily sea surface temperature from NOAA National Climatic Data Center (NCDC), was possible to see that by November 7 the sea surface temperature was beginning to cool and that by the 8th of November the coast of Eastern Samar was

significantly cooled which can suggest the occurrence of coastal upwelling. However, from our data reported before and after the passing of typhoon Haiyan we were able to calculate the maximum lowest SST recorded, which was 29.3°C, 3.7°C less than the average median temperature for the eastern Philippines waters. Our results fall under Maldonado et al.'s (1997) proposal where they state that even a temperature cooling of 2°C in sea surface temperature have a significant impact on the strength of the cyclone. Conversely, this typhoon-induced surface cooling may have influenced the strength of the cyclone which has been previously reported by previous published researches, such as YongQiang and DanLing's (2011) Remote Sensing Analysis of Impact of Typhoon on Environment in the Sea Area South of Hainan Island, where the cooling mechanism of SST strengthens the storms passing through the cool wake.

This study illustrates the value of satellite ocean remote sensing for evaluating the impact of hurricanes on the SST field. The NOAA AVHRR images presented in here clearly depict a cooling of SST along the right side of the track of typhoon Haiyan. In the Northern Hemisphere, the region on the right side of the track of the eye contains the strongest winds (Maldonado et al. 1997).

Therefore, this swath of cooler SST's corresponds to the region of relative strongest winds for this cyclone. The remotely sensed SST measurements shown here are therefore consistent with that of previous in situ and modeling studies.

Recommendations

The biggest challenge for working with SST in AVHRR was the large amount of cloud coverage that gave anomalous calculations of sea surface temperature and thus a suggestion would be the changing of the AVHRR sensor into another one that works best with atmospheric corrections as well as with SST calculations. The Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua platform serves as a spectacular sensor for observing ocean color remote sensing, moreover this sensor provides an "excellent view of SST by using advanced atmospheric correction algorithm for the data processing" (IOCCG, 2010). And so we recommend the use of this sensor instead of AVHRR.

Another recommendation would be to constructing a mosaic that covers a more complete region of Haiyan's trajectory. This would give a greater view over the region of interest and would help in identifying

upwelling, warm/cool pools, and in general as greater view of the sea surface temperature coverage.

References

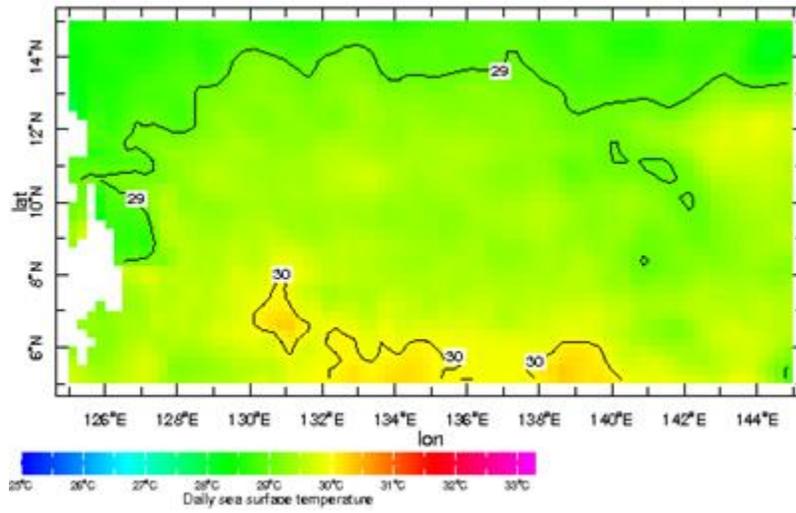
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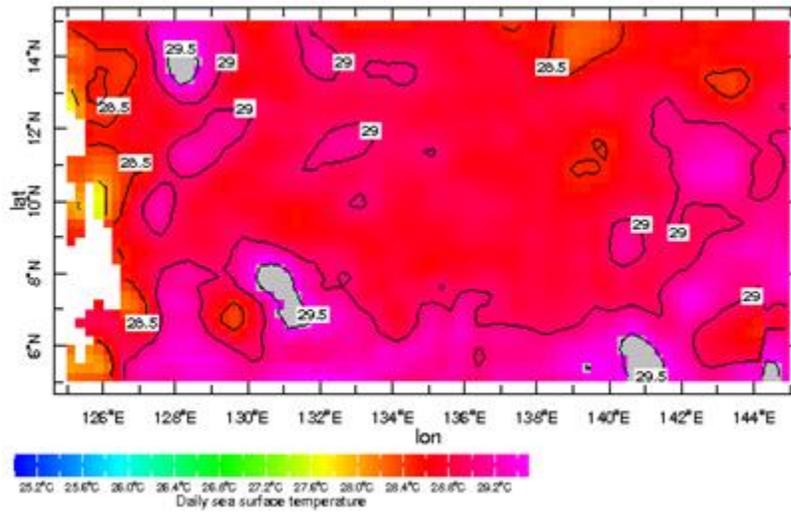
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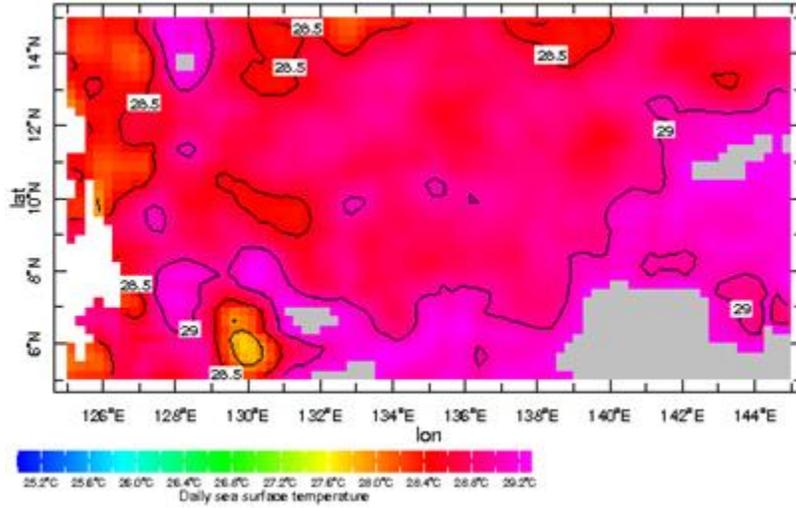
Appendix



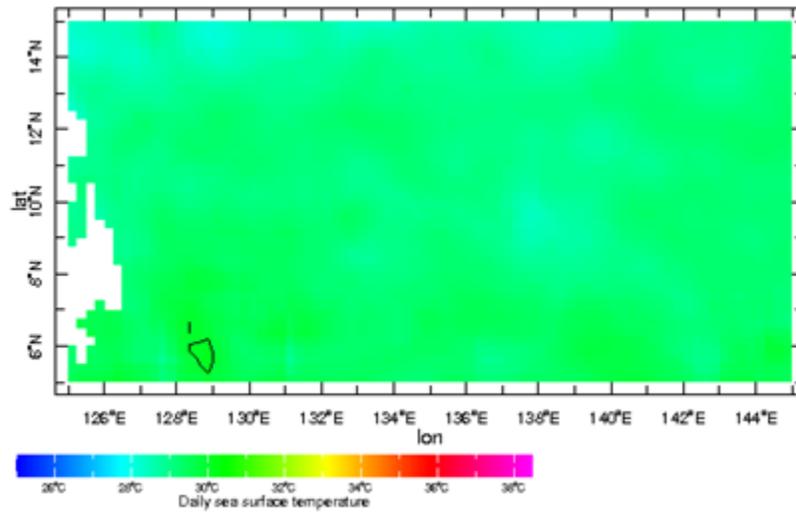
A.1. AVHRR NCDC SST Product valid for November 4, 2013.



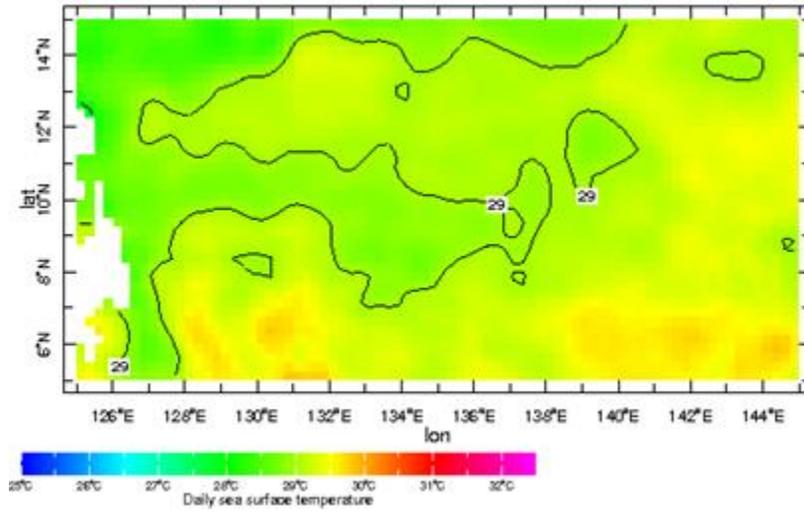
A.2. AVHRR NCDC SST Product valid for November 9, 2013.



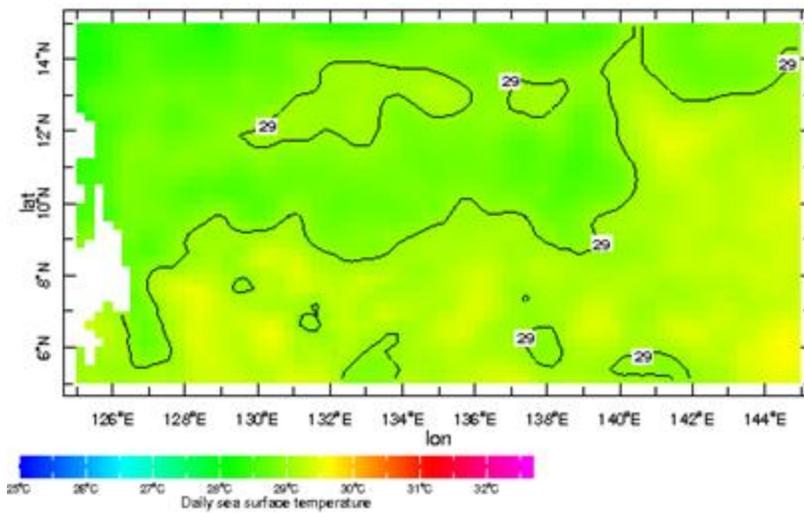
A.3. AVHRR NCDC SST Product valid for November 10, 2013.



A.4. AVHRR NCDC SST Product valid for November 13, 2013.



A.5. AVHRR NCDC SST Product valid for November 14, 2013.



A.5. AVHRR NCDC SST Product valid for November 16, 2013.