Correlating Radioactive Material to Sea Surface Temperature off the Coast of Japan: The Fukushima Daiichi Nuclear Disaster

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ABSTRACT: On March 11, 2011 a magnitude 9.0 earthquake occurred off the coast of Japan, triggering a 40m tsunami and leading to millions of dollars' worth of structural damage on the island. One of the most devastating results of this was the damage to the Fukushima Daiichi nuclear plant, causing a loss-of-coolant accident which eventually led to nuclear meltdown. Over the course of the following months tons of radioactive material spilled, was intentionally dumped, and carried by groundwater into the Pacific Ocean. The goal of this study was to investigate whether the amount and extent of radioactive material was significant enough to affect sea surface temperature near the location of the plant. A total of six images were produced, showing sea surface temperature off the west coast of Japan every six months since the earthquake. Sea surface temperature was calculated for AVHRR images using the algorithms offered by ENVI. Results were unclear, indicating that sea surface temperature is much more strongly affected by Pacific currents rather than any nuclear material. Further studies in a smaller area should be performed to test for a smaller degree of changing temperature.

KEY WORDS: AVHRR, sea surface temperature, Fukushima

INTRODUCTION

On March 11, 2011, Japan suffered a devastating 9.0 M_w earthquake, now known as the Tohoku Earthquake. The hypocenter of this earthquake was located approximately 373 km northeast of Tokyo, about 32 km below the ocean floor, where the North American tectonic plate subducts westward underneath the Pacific plate. Scientists believe that the earthquake occurred as a thrust fault moved upwards 30-40 m, while slipping over an area about 300 by 150 km. The effects of the earthquake were catastrophic: almost 16,000 people were killed, with close to 10,000 more injured or missing. Deaths and injuries were in part due to structural collapse of many buildings, and also as a result of tsunami waves reaching up to 40 meters in height.

One of the major disasters associated with the Tohoku Earthquake was the damage to the Fukushima Daiichi nuclear plant. The Fukushima plant was powered by boiling water reactors, which use nuclear reactions to constantly boil water; the resulting steam is used to drive turbines and generate electricity. The tsunami associated with the Tohoku earthquake surpassed the 10 m seawall protecting the plant, leading to complications with the nuclear reactors. The floodwaters from the tsunami inhibited the nuclear cooling processes, which led to building pressure, explosions, and leaks of radioactive material.

The first report of radioactive water outside of the reactors took place on March 24, 2011. Pools of highly radioactive water were found near the three nuclear reactors that were affected by the earthquake and tsunami. By April 4, water with low levels of radiation was being dumped into the Pacific Ocean, in order to make room for highly radioactive water in storage tanks. In addition to the intentional dumping of low level radioactive water into the ocean, a leak in one of the nuclear reactors led to further contamination of highly radioactive water. It was later reported that groundwater had also been contaminated by the leaks, which has led to unforeseen levels of radiation in the ocean. The increasing amount of nuclear material in the Pacific has led to a rise in ocean temperatures.

METHODS

Obtaining Images

The images necessary to carry out this project were images from the Advanced Very High Resolution Radiometer (AVHRR), a sensor found on several satellites including NOAA-6 through NOAA-19, TIROS-N, and MetOp-A. Images were obtained from the National Oceanic and Atmospheric Administration (NOAA) Comprehensive Large Array-data Stewardship System (CLASS) website (www.class.noaa.gov). This program offers environmental data including satellite images related to better understand atmospheric and oceanic processes.

Images were obtained by first selecting the sensor necessary for the project (AVHRR), defining a study area (east coast of Japan), and searching for images with the least amount of cloud cover within the given time period. The time period for this study was once every six months, starting on March 11, 2011, the day of the Tohoku earthquake, and continuing until September 2013. Several images were downloaded and the ones with the least cloud cover were selected and processed.

Processing Images

The processing of images was performed using Exelis ENVI software. One of the advantages to using AVHRR images for this study is that ENVI has several algorithms written specifically for working with AVHRR images. The first step was to calculate the sea surface temperature (SST) for each image. ENVI has two different types of algorithms for this process, based on whether the image was obtained at night or during the day. The algorithms used in this study were:

$$SST\ (^{\circ}C) = a*T4 + b*(T4-T5) + c$$
and
$$SST\ (^{\circ}C) = a*T4 + b*(T3-T5) + c$$

for the day-time and night-time passes respectively. T3, T4, and T5 are the brightness temperatures from Bands 3, 4, and 5 respectively, and a, b, and c are coefficients (McCain et al., 1985).

The next step was to create a mask that covered the land and clouds in each image. Ideally this step is performed using Band 2 (near infrared) because water absorbs near infrared radiation significantly enough that water can be distinguished from land and clouds based on pixel value. For some of the downloaded images Band 2 was unavailable, so a mask was created as accurately as possible using the other available bands. Once the mask was applied to the SST image, the entire package was georeferenced using ENVI's program for georeferencing AVHRR images. A color map was applied to the final image to better depict the differences in sea surface temperature. Figure 1 shows a work-flow diagram of this procedure.

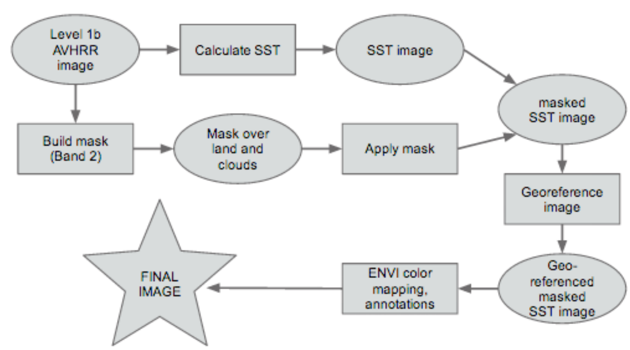

Figure 1: A work-flow diagram showing the steps taken to carry out this project, starting with the level 1b AVHRR satellite images.

RESULTS

Six sea surface temperature images were created by this project, from March and September of the years 2011, 2012, and 2013 (Figures 2-7). Scale bars on the upper left corner of each image indicate the range of temperatures shown in each image. It should be noted that the maximum temperature in the March images is 23ºC whereas the maximum temperature for the September images is 30ºC.

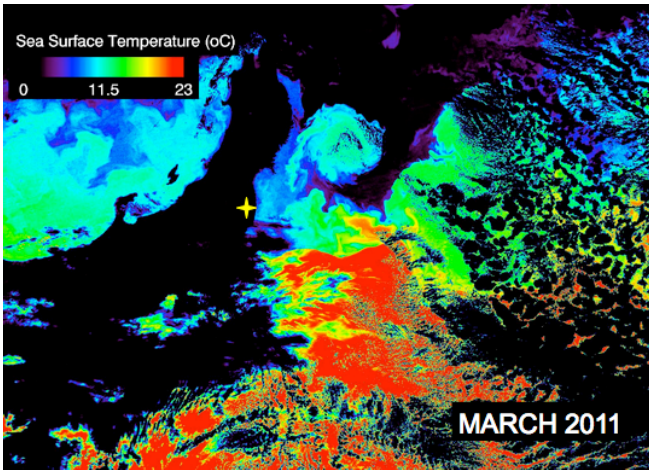

Figure 2: SST image of the east coast of Japan from March 2011. Star indicates location of the Fukushima Daiichi Nuclear Plant.

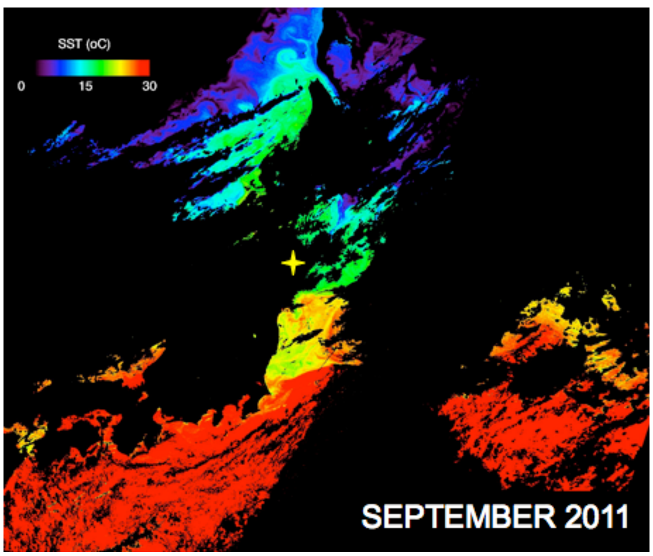

Figure 3: SST image of the east coast of Japan from September, 2011.

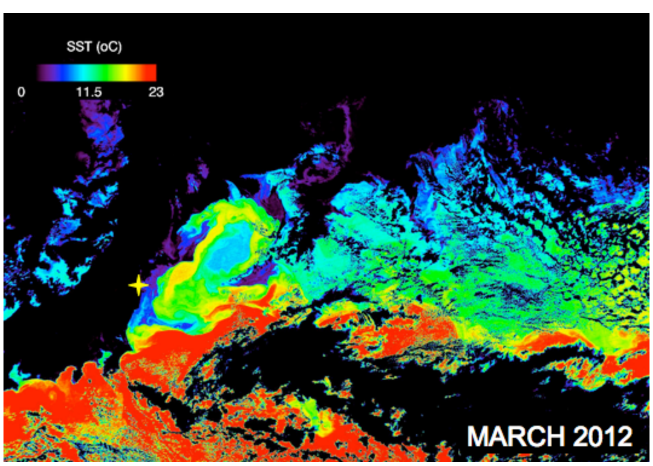

Figure 4: SST image from March, 2012.

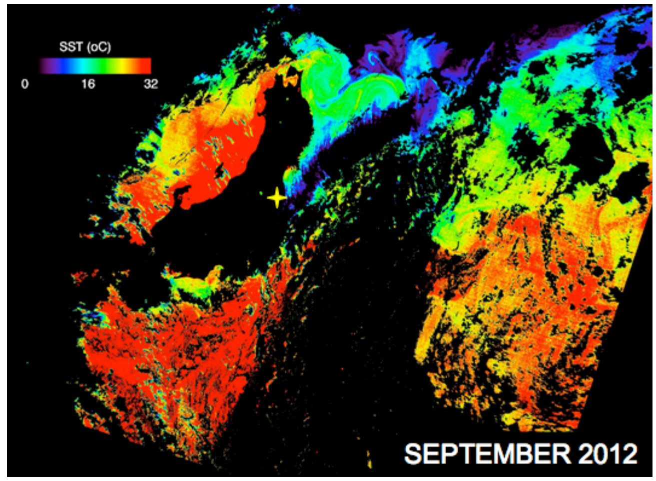

Figure 5: SST image from September, 2012.

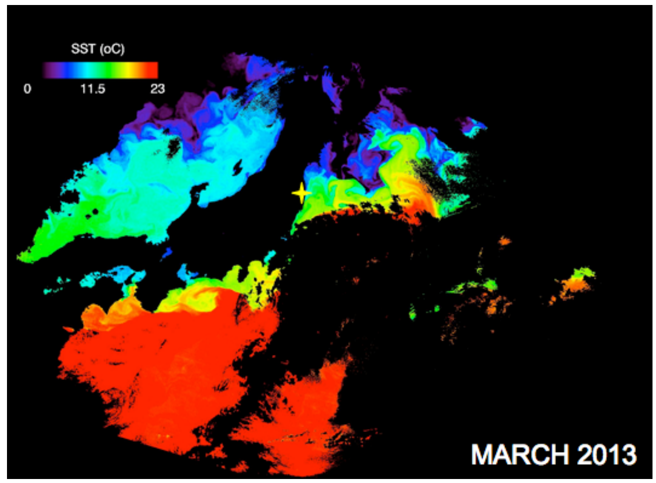

Figure 6: SST image from March, 2013.

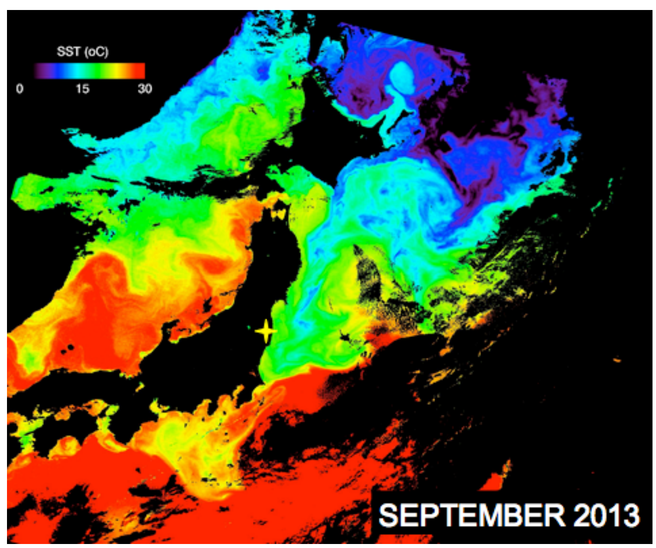

Figure 7: SST image from September, 2013.

DISCUSSION

The six images generated in this study appear to offer no insight into the extent of radioactive contamination in the Pacific. Though the images do appear to present a striking change in surface temperature over time, this can easily be explained by an understanding of Pacific currents (Figure 8). The Pacific is controlled by currents that circle northward from the equator, carrying warmer water north and carrying colder water toward the center of the ocean. The scales on the SST images also indicate that the Pacific is much warmer in September than in March, which can be explained by the fact that throughout the summer months (June-August), water is being warmed significantly more than in the winter.

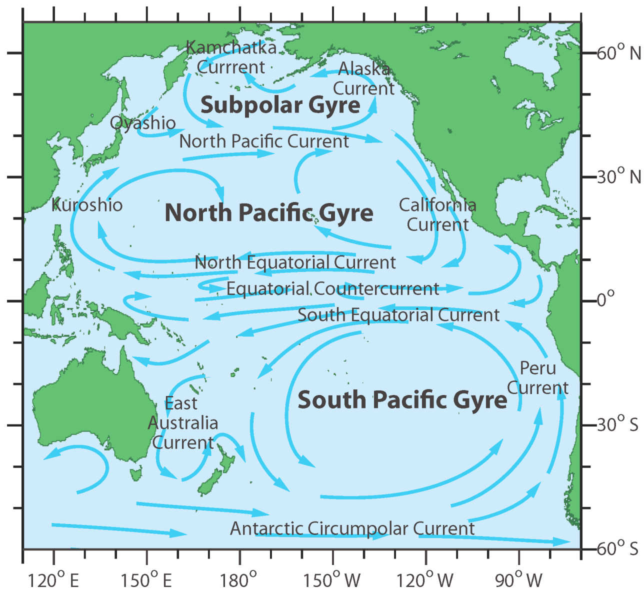

Figure 8: A map of Pacific currents. From www.seos-project.eu.

The lack of results in this project can be explained by a number of flaws related to the development of the project and the methodology used. The most apparent flaw was an issue of the study site. Japan is more than 80% covered by clouds for three-quarters of the year (Figure 9), meaning that satellite images unaffected by clouds were nearly impossible to obtain. A way to correct this would be to create a composite image using data from several days in a given time period to create an image with significantly less cloud cover. This step was not taken due to the investigator's lack of experience with ENVI software. For this reason, the periodicity of this project was required to change from the originally planned four times a year to only two, in order to better avoid cloud obstruction.

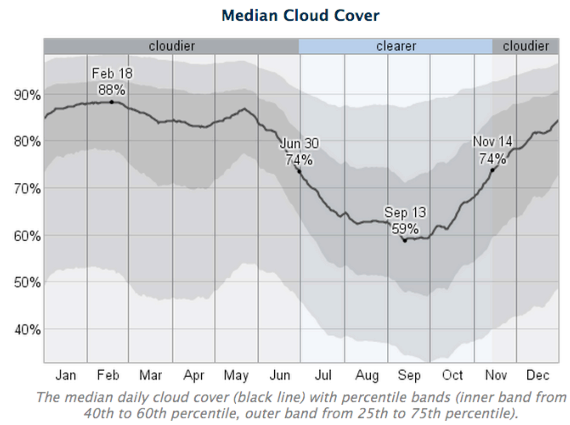

Figure 9: Average cloud cover over Japan. From www.weatherspark.com.

This project was further flawed by its scope. Local AVHRR images (such as those used in this project) have a spatial resolution of 1.1 km. This allowed the project to calculate SST for a large area, the entire east coast of Japan. However, this project would have benefitted from a much smaller scale. The Pacific Ocean is a huge body of water, greatly affected by large-scale processes such as tides and currents. The scale of the nuclear spill, while huge in anthropologic terms, is miniscule compared to the scope of the ocean. Any radioactive material spilled into the Pacific would have dispersed to widely to created any measurable change in ocean temperature. It is possible that a high-resolution study focused at the site of the spill would have yielded some results.

Overall, this project was an excellent means of practicing certain functions available in ENVI. However, it was poorly planned and executed. A project using composite images from a different sensor with a higher spatial resolution could have generated better results.

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