Application of Remotely Sensed Imagery for Detection of Red Tide Algal Blooms and Sea Surface Temperature off the Florida West Coast

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Abstract

Toxic blooms almost occur annually along the west coast of Florida. There have been many suggested parameters that may cause the increase in chlorophyll levels and red tide events but scientists are still unsure of the combination of oceanographic factors that make marine environmental conditions favorable for red tide formation. In this study, growth response of red tide and chlorophyll a levels were examined and compared to temperature changes in the Gulf of Mexico off the west coast of Florida, using remotely sensed imagery derived from Aqua-MODIS SST and Chlorophyll a Products. Statistical analysis along with visual analysis revealed increased temperatures have a linear relationship with growth of chlorophyll a levels and red tide events.

INTRODUCTION

Toxic red tides have been observed in Florida since the 1840s. Since that time, multiple episodes with significant fish kills, as well as cases of NSP (Neurological Shellfish Poisoning) have been reported from the Gulf of Mexico (including the east coast of Mexico), the east coast of Florida, and up to the North Carolina coast; toxic blooms occur almost annually on the west coast of Florida. Recently, these and other red tides appear to be increasing in incidence, duration and geographic spread and it is unclear why (Viviani 1992, Smayda 1990, Van Dolah 2000, Tester 1991, Tester 1997). Anthropogenic influences (such as nutrient run-off) inducing red tide blooms and the transport of dinoflagellate cysts in ballast water of ships have been suggested as possible causes. However, these red tides in Florida occurred even before significant pollution and development by human populations: during 1844- 1971, red tides and their sequellae were noted along the west coast of Florida at least 24 times before the major industrial and agricultural development of that area. Alternative explanations (such as the effects of changing ocean temperatures, currents and weather patterns associated with global warming, as well as atmospheric transport of Sahara dust) are being investigated (Tester 1997, Tester 1991, Viviani 1992, Morris 1991, Ishida 1996, Walsh 2001).

Recent prolonged red tides in the Gulf of Mexico have been associated with significant environmental, human health, and economic impacts. Beaches in Texas and shellfish beds from Florida to Mexico have been closed. Significant die-offs of fish, endangered manatees, and double-crested cormorants, as well as reported adverse human health effects, have resulted annually secondary to the red tide toxin exposure along the coastline of the Gulf of Mexico (Hopkins 1997, Trainer 1999).

The classic causative organism of Florida red tides is *Karenia brevis* (formerly known *as Gymnodinium breve* and *Ptychodiscus brevis*). *K. brevis* is a dinoflagellate which contains the photosynthetically active pigment chlorophyll a and is restricted to the Gulf of Mexico and the Caribbean, but has been carried by ocean currents around Florida and up the east coast of the United States as far as North Carolina (Ishida 1996, MacLean 1979, Hermes 1984 Chang 1998, Temple 1995, Morohashi 1999, Anderson 1994, Anderson 1994, Sierra Beltran 1998, Cortes Altamirano 1995, Tommasi 1983, Horstman 1991, Khan 1997, Steidinger 1983). *K. brevis* usually blooms in the late summer and autumn, almost every year off the west coast of Florida, causing massive fish and bird kills.

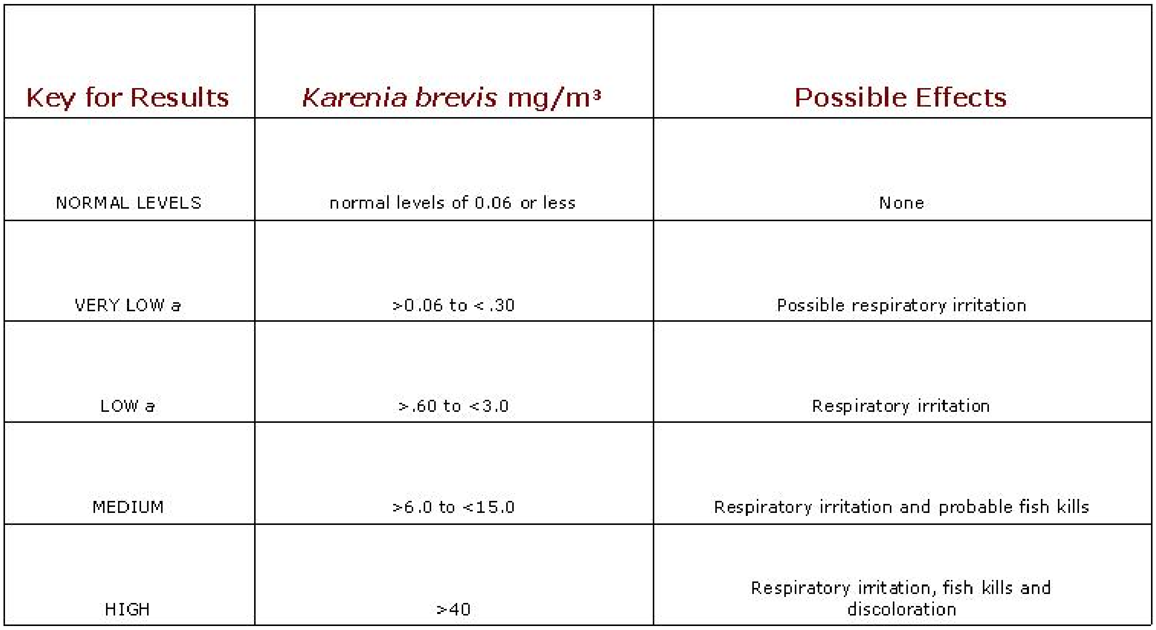
The *K. brevis* organism is relatively fragile because it is unarmored. Therefore, particularly in wave action along beaches, the organism is easily broken open, releasing the toxins. During an active in-shore red tide, the aerosol of contaminated salt spray will contain the toxins and organism fragments, both in the droplets and attached to salt particles; these can be carried inland depending on wind and other environmental conditions (Pierce 1990).

Associated with these algal bloom episodes of *K. brevis,* a variety of phytoplankton-related natural toxins have been identified. The most important group is the neurotoxic brevetoxins (*Ptychodiscus brevis* toxin, i.e., PbTx). As a group, the brevetoxins are lipid soluble, cyclic polyethers with molecular weights around 900. Over 9 different brevetoxins have been isolated in sea water blooms and *K. brevis* cultures, as well as multiple analogs and derivatives from the metabolism of shellfish and other organisms (Morohashi 1999, Baden 1995, Kirkpatrick and Fleming, 2004).

As with many of the known marine toxins, the brevetoxins are tasteless, odorless, and heat and acid stable. These toxins cannot be easily detected, or removed by food preparation procedures (Baden 1982a, Baden 1993, Baden 1995, Sakamoto 1987). As a consequence of their lipid solubility, these toxins are expected to easily pass through cell membranes including the blood brain barrier, as well as buccal mucosa and skin. Fish, birds, and mammals are all susceptible to the brevetoxins (Viviani 1992, Morris 1991, Ishida 1996).

The most effective way to prevent adverse health effects to humans and fish, reduce the economic impact from the red tides (impact on tourism and disposal of literally millions of tons of dead fish on beaches and in canals and rivers) is to prevent exposure to the toxins and organisms (Fleming 1995). In the case of NSP (Neurological Shellfish Poisoning), this means monitoring. Table 1 displays the different levels of *K. brevis* and their respective effects.

Table 1: Possible Effects of Karenia *brevis* (mg/m^3) Concentration Levels



Key for Results	*Karenia brevis* mg/m^3	Possible Effects
NORMAL LEVELS	normal levels of 0.06 or less	None
VERY LOW *a*	>0.06 to < .30	Possible respiratory irritation
LOW *a*	> .60 to <3.0	Respiratory irritation
MEDIUM	>6.0 to <15.0	Respiratory irritation and probable fish kills
HIGH	>40	Respiratory irritation, fish kills and discoloration

Managers can use chlorophyll concentrations provided by MODIS and other imagery to target sampling efforts. This imagery is provided to state and local managers in Florida by a cooperative effort between the NOAA National Ocean Service and Coast Watch programs. The information, including the interpreted image, the last-known position of the red tide bloom, and the speed and direction of local winds, is e-mailed to managers. They can then use this bulletin to direct crews to the appropriate areas to take water samples. Only analyses of the water sample by microscope will determine whether toxic red tide is present.

In this study we will apply remotely sensed imagery for detection of red tide algae/chlorophyll *a* concentrations. Chlorophyll *a* is the predominant type of chlorophyll found in algae and cyanobacteria, and its abundance is a good indicator of the amount of algae present in the waters. The chlorophyll *a* concentrations will be investigated at the surface of the water column off the west coast of Florida from January 2005 through October 2005.

Since satellites detect changes in the way the sea surface reflects light and these changes can be linked to concentrations of chlorophyll, this shows where algae and other ocean plants are concentrated in the ocean. Imagery of the red tide blooms in Gulf of Mexico off west-central Florida will be used to provide visualization of algal events in a tri-monthly time series to determine if temperature is a causative factor in the increase of red tide events.

DATA

The Aqua satellite is a multi-national NASA scientific research satellite in Sun-synchronous orbit roughly 438 miles above the Earth. Aqua Satellite studies the precipitation, evaporation, and cycling of water and carries 6 instruments for studies of water on the earth's surface and in the atmosphere:

- Microwave Scanning Radiometer-EOS - measures cloud properties, sea surface temperature, near-surface wind speed, radiative energy flux, surface water, ice and snow. Furnished by the National Space Development Agency of Japan.
- MODIS - Moderate Resolution Imaging Spectroradiometer, also measures cloud properties & radiative energy flux, also aerosol properties; land cover and land use change, fires and volcanoes. This instrument is also aboard Terra.
- AMSU-A -Advanced Microwave Sounding Unit - measures atmospheric temperature and humidity.
- AIRS - Atmospheric Infrared Sounder - measures atmospheric temperature and humidity, land and sea surface temperatures.
- HSB - Humidity Sounder for Brazil - VHF band equipment measuring atmospheric humidity. Furnished by Instituto Nacional de Pesquisas Espaciais of Brazil.
- CERES - Clouds and the Earth's Radiant Energy System - measures radiative energy flux.

For the purpose of this study MODIS was used to obtain data. MODIS- Moderate Resolution Imaging Spectroradiometer is described as follows:

- Swath Dimension: 2300km at 110° from 705km altitude
- IFOV: 250m (2 bands), 500m (5 bands), 1000m (29 bands)
- Radiometric Sensitivity: 12-bit in 36 spectral Bands .4µm-14.4µm
- Data is processed into 44 distinct data products

The two products from MODIS used in this investigation were Level-3 Aqua-MODIS Chlorophyll Product with a spatial resolution of 4km, radiometric resolution of 8-bits and a monthly composite range and the Level-3 Aqua-MODIS SST [11 µ night] Product with spatial resolution of 4km, radiometric resolution of 8-bits and monthly composite range.

Both of these products provide binned data over a period of time and a mean is used to obtain monthly values. These values are stored as scale real values and the images are representations of binned data products generated from MODIS. The products chosen represent images of the geophysical parameter specified and the binned data over the months of January, March, May, July, and September, which are the months under investigation.

METHODS

For the purpose of this project of determining the relationship between the water surface temperature changes and the algal blooms that produce red tides on the Gulf of Mexico and more precisely off the Florida west coast during the period from January to October, 2005, we compared monthly images from January, March, May, July, September, and October obtained from the Aqua-MODIS SST Product and Chlorophyll Product to analyze the water surface temperature and increased levels of chlorophyll concentrations in the Region of Interest using ENVI 4.2 software for image processing, visualization, analysis, and presentation of digital imagery. (Atmospheric effects were already removed with algorithms from the images used in this study.)

Before proceeding with the temporal comparison of the images we used scaling equations to apply values to the Digital Numbers (DN) according to the Product standard mapped parameter scaling from NASA's Ocean Level 3 Mapped Image Products specifications document. This had to be applied in order to convert the scaled real values (DN) into geophysical values using the global attributes **Scaling, Scaling Equation, Base, Slope, and Intercept**. The following are the scaling equations and variables used for scaling chlorophyll *a* and temperature:

- **Chlorophyll *a***: measure in mg/m^3 with an approximate range of 0-64:
    - **Scaling:** Logarithmic
    - **Scaling Equation:** **"**Base**((Slopel3m_data)+ Intercept) = Parameter value"
    - **Base:** 10.0
    - **Slope:** .015
    - **Intercept:** -2.0

- **Temperature**: measured in C° with an approximate range of -2.0-45:
    - **Scaling:** Linear
    - **Scaling Equation:** "(Slopel3m_data)+ Intercept = Parameter value"
    - **Base:** not included as global attribute
    - **Slope:** 0.188
    - **Intercept:** -2.0

After the scaled real values were converted to geophysical values, these values were assigned colors using density slice (The continuous gray scale of an image is "sliced" into a series of classifications based on ranges of brightness values). The desired minimum and maximum values were entered for the geophysical values and colors were selected for each slice. All the image pixels with data values in the sliced ranges were then displayed as the colors assigned to those ranges. All pixels within a "slice" are considered to be the same information class.

After all values were converted and color assignments were completed, statistics/histograms were calculated and evaluated to determine changes in chlorophyll *a* concentration levels and sea surface temperatures between the months under investigation.

RESULTS

Blooms of autotrophic algae are increasingly frequent in coastal waters around the world. Blooms of these organisms are attributed to two primary factors by current research: natural processes such as circulation, upwelling relaxation, and river flow; and, anthropogenic loadings leading to eutrophication. Unfortunately, the latter is commonly assumed to be the primary cause of all blooms, which may not always be the case in many instances. For example, scientists believe that Florida's very active 2004 hurricane season along with increased sea surface temperatures may have played an important part in the development of extensive and long-lasting red tide conditions that affected its coastal areas in 2005.

In this study we found that temperature did influence the growth of *K. brevis*, or red tide events and overall chlorophyll *a* levels off the west coast of Florida. Below are tri-monthly time series images of chlorophyll *a* detection/changes and sea surface temperature changes.

Image 1: January 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)

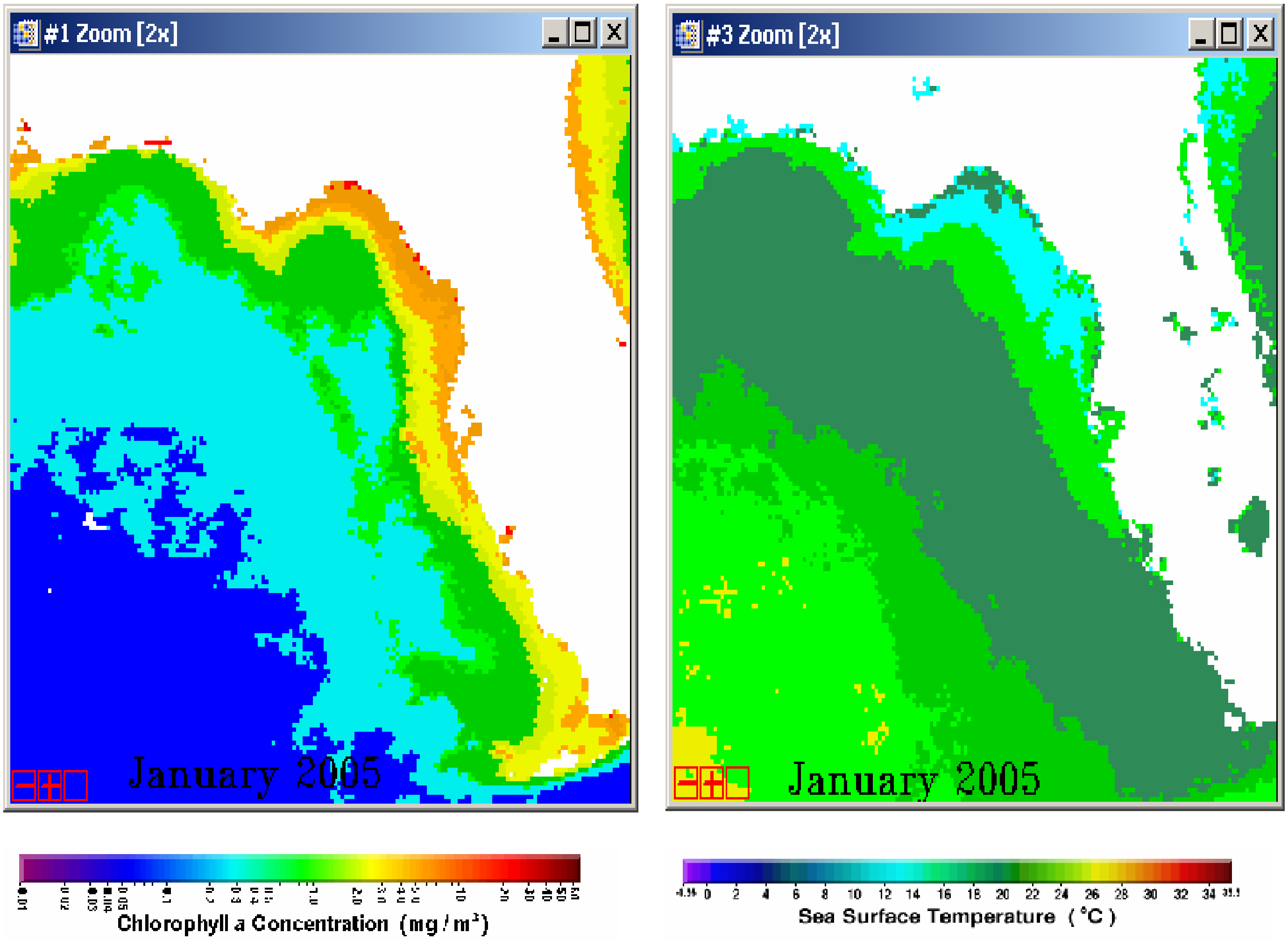


Image 2: March 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)

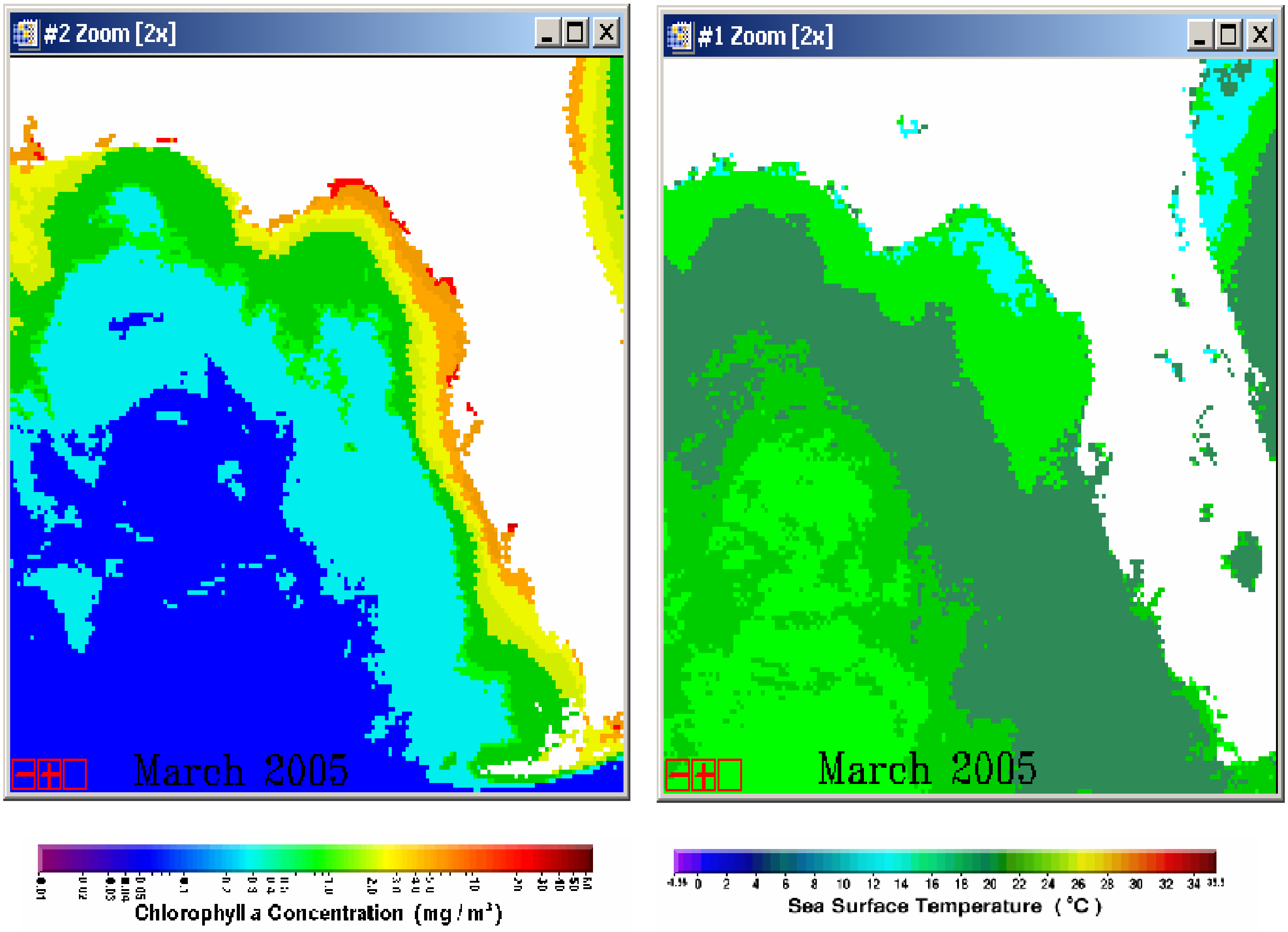


Image 3: May 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)

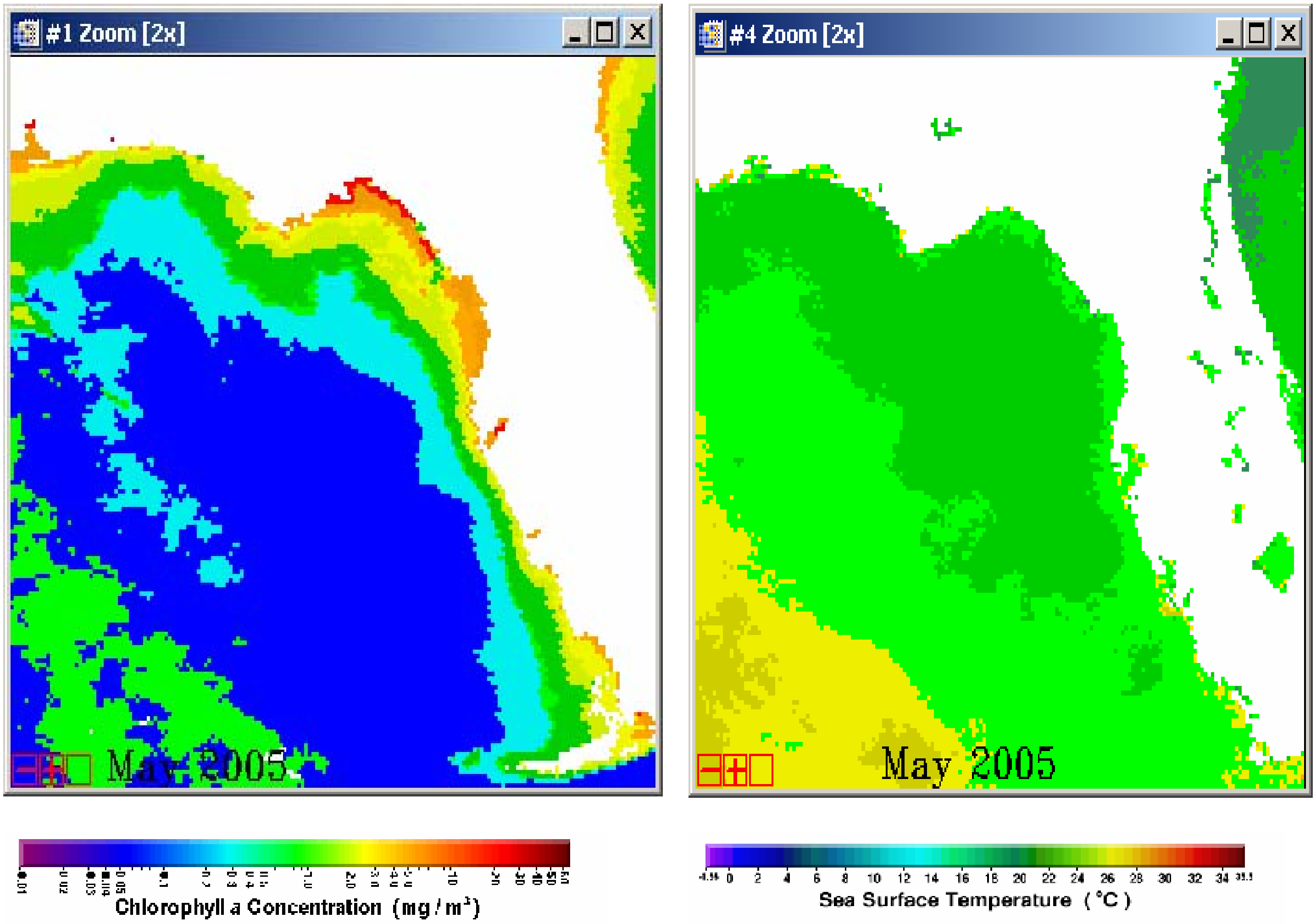


Image 4: July 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)

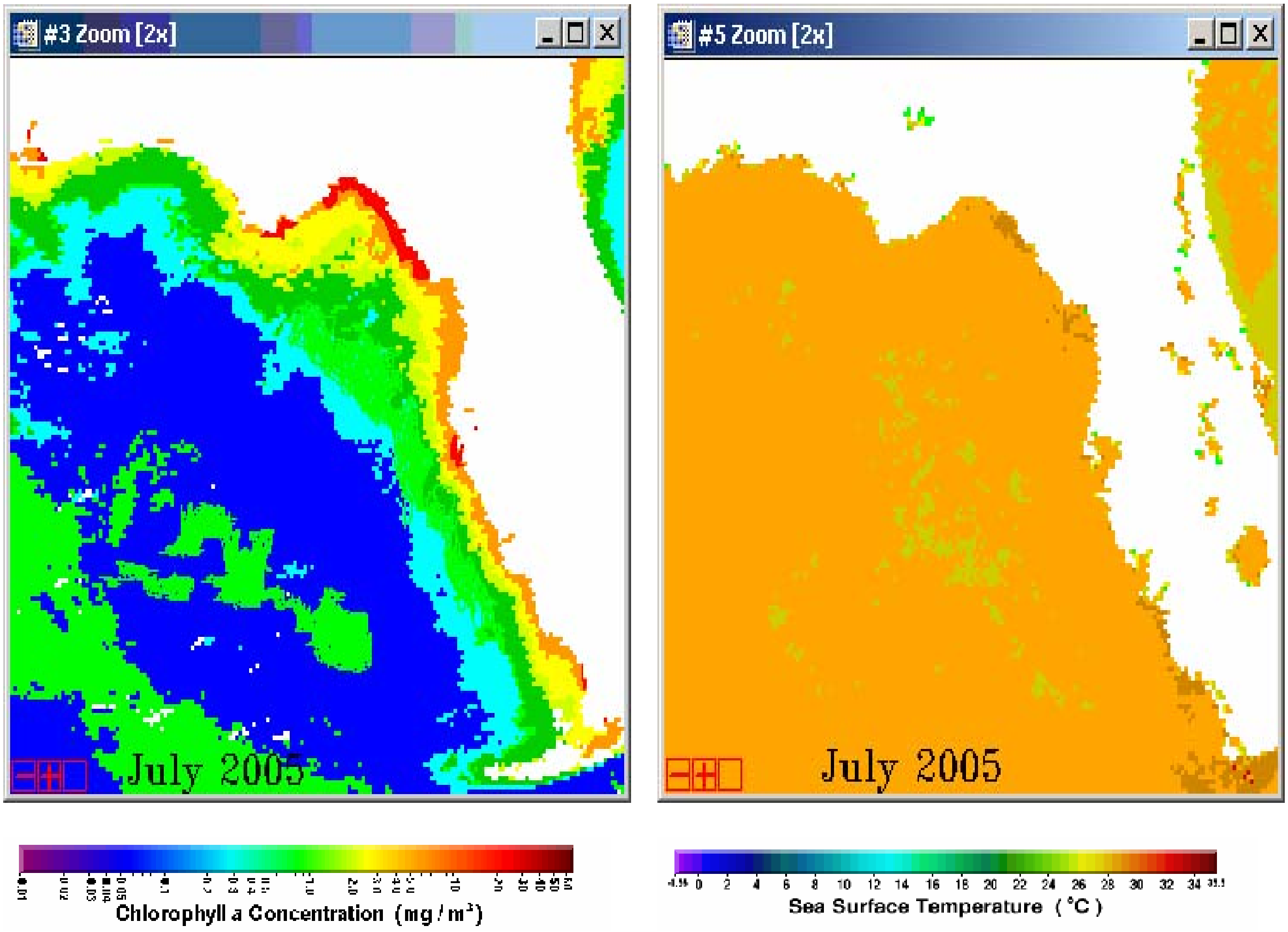


Image 5: September 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)

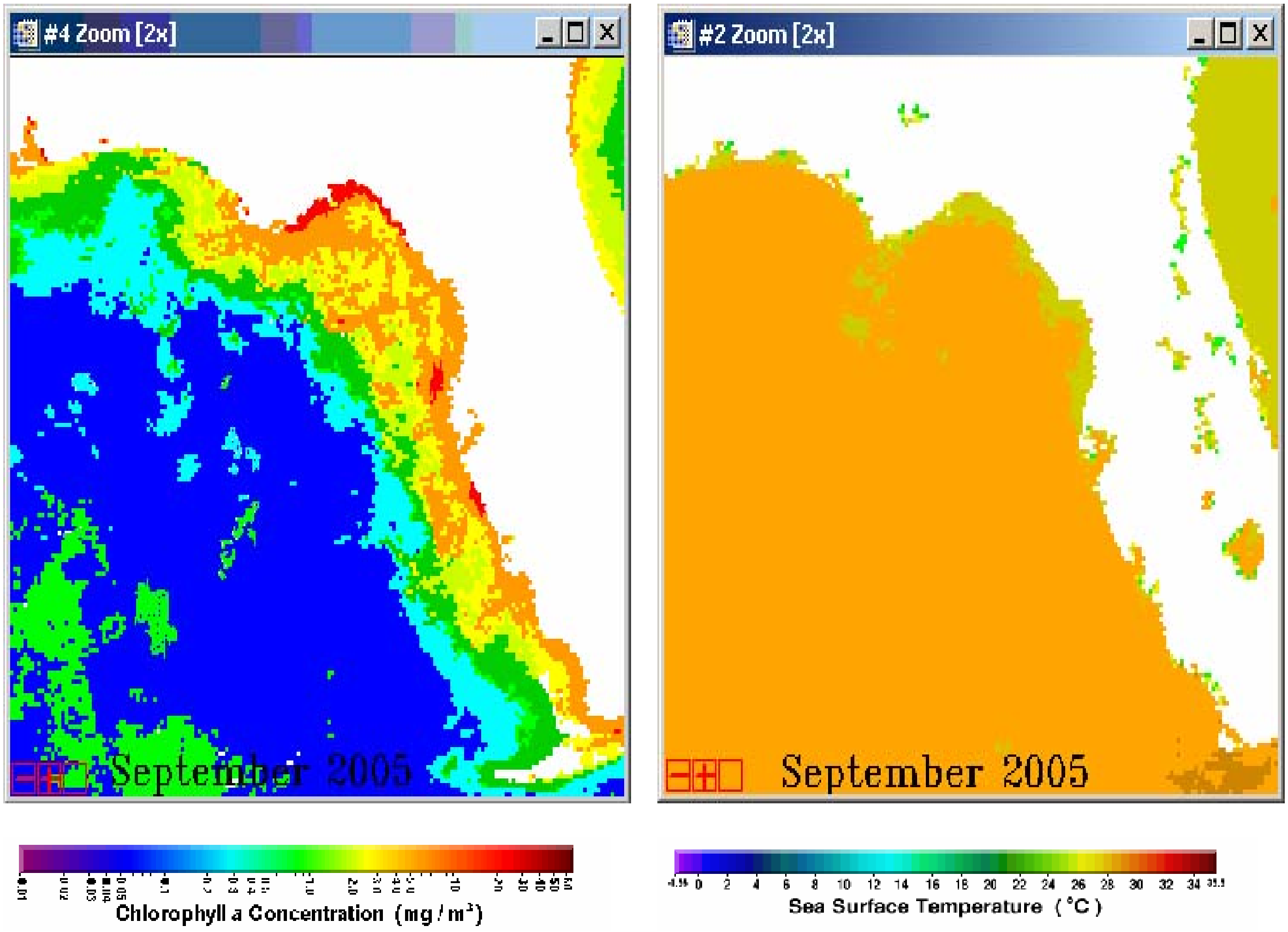
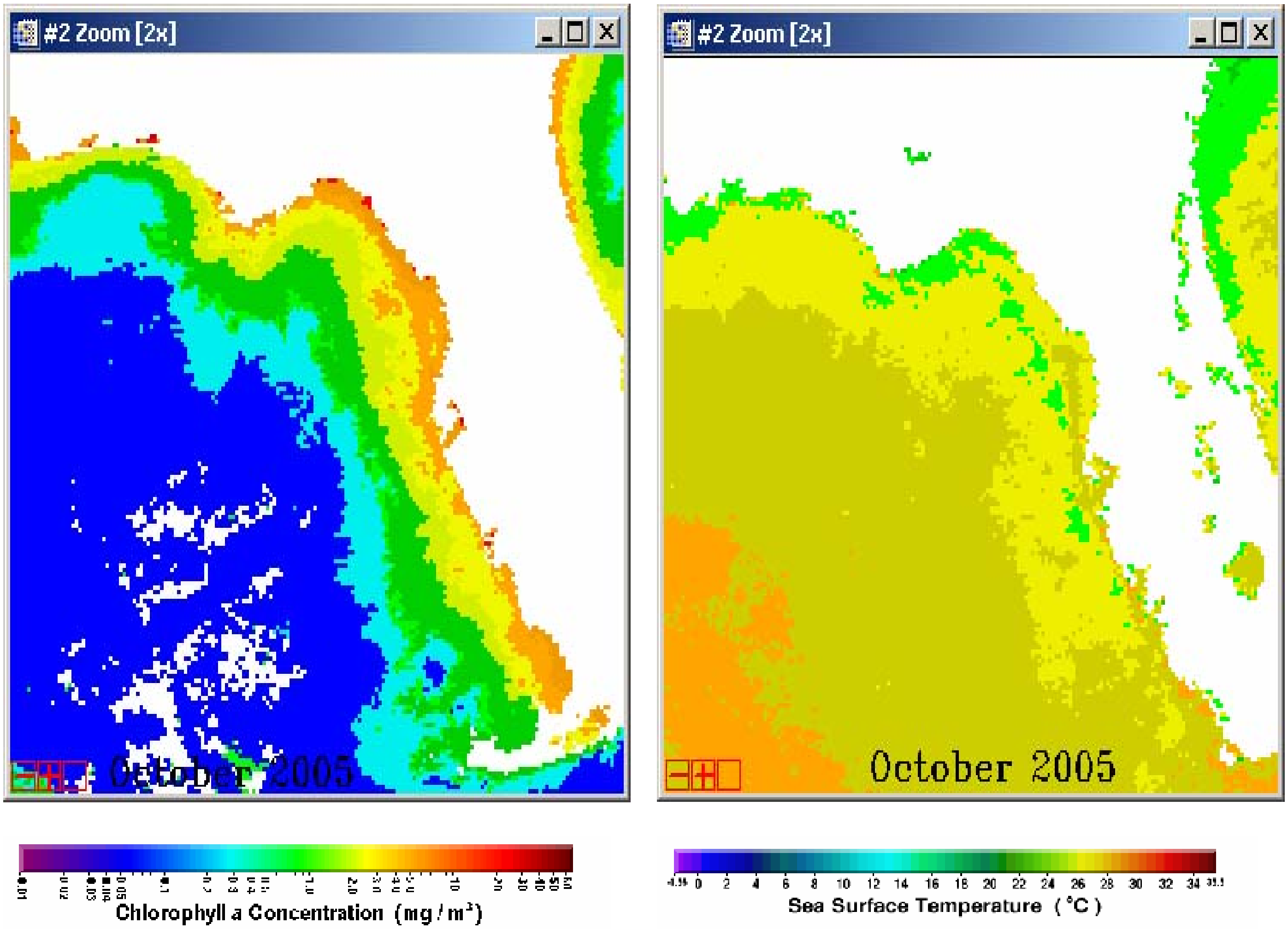


Image 6: October 2005: Chlorophyll *a* (mg/m^3) & Sea Surface Temperature (°C)



For the tri-monthly time series images, image statistics were determined for chlorophyll *a* concentration changes above 0.6 mg/m^3 and chlorophyll *a* concentration changes above 40 mg/m^3 (which is considered toxic/red tide event) for each month along with an average temperature change.

- January to March: Chlorophyll *a* concentrations above 0.6 mg/m^3 increased 5.82%. Chlorophyll *a* concentrations above 40 mg/m^3 increased 63%. Average temperature increased from 25.03 °C to 25.92 °C (+0. 89 °C).

- March to May: Chlorophyll *a* concentrations above 0.6 mg/m^3 increased 11.15%. Chlorophyll *a* concentrations above 40 mg/m^3 increased 108%. Average temperature increased from 25.92 °C to 27.83 °C (+1.19 °C).

- May to July: Chlorophyll *a* concentrations above 0.6 mg/m^3 increased 21.44%. Chlorophyll *a* concentrations above 40 mg/m^3 increased 187%. Average temperature increased from 27.83 °C to 31.55 °C (+3.72 °C).

- July to September: Chlorophyll *a* concentrations above 0.6 mg/m^3 increased 13%. Chlorophyll *a* concentrations above 40 mg/m^3 decreased 36%. Average temperature had no significant change from 31.55 °C to 31.45°C (-0.1 °C).

- September to October: Chlorophyll *a* concentrations above 0.6 mg/m^3 decreased 33.1%. Chlorophyll *a* concentrations above 40 mg/m^3 decreased 71%. Average temperature had no significant change from 31.45°C to 29.20 °C (-2.25 °C).

The total percent increase in Chlorophyll *a* concentrations above 40 mg/m^3 between January and September was 674% with a total average temperature increase of 6.42 °C (25.7%).

CONCLUSION

A challenge scientist's face when interpreting satellite images of red tides is that what may appear to be high levels of chlorophyll could in fact be chlorophyll and *something else.* Shallow coastal areas are rich in sediment and organic matter deposited by rivers and stirred up by tides. So chlorophyll may be present, but it is mixed in with these other substances that influence the color and intensity of the light reflected by the ocean.

One-way to determine whether a satellite has detected sediment and organic matter or chlorophyll is to look at fluorescence signals. When algae absorb light, not all of it is converted to energy; some is converted to heat, and some is released as light. The re-emitted light, called fluorescence is not the same wavelength as sunlight that is simply reflected by the surface.

Chlorophyll imagery is also not sufficient to distinguish harmful from non-harmful algae. Since red tide is a natural phenomenon (not caused by human beings); when temperature, salinity, and nutrients reach certain levels, a massive increase in *K. brevis* algae can occur but it is unsure to what harmful effects.

Another problem scientist's face is that no one knows the exact combination of factors that causes red tide. Though this study does show that high temperatures combined with a possible lack of wind and rainfall is usually at the root of red tide blooms.

However, it is natural for chlorophyll *a* levels to fluctuate over time. Chlorophyll *a* concentrations are often higher after rainfall, particularly if the rain has flushed nutrients into the water. Higher chlorophyll *a* levels are also common during the summer months when water temperatures and light levels are high because these conditions lead to greater phytoplankton numbers.

Changes to systems which decrease (*e.g.* construction of canal estates) or increase (*e.g*. breakwaters, training water and dredging) flushing rates influence chlorophyll *a* concentrations also because flushing dilutes nutrients and moves them away from plants, making them less available. Conversely, slow moving or stagnant waters let nutrients increase and cell numbers grow.

In conclusion, this study itself leaves opportunity for more research to investigate other parameters that may contribute to the increase in red tide events. Many parameters have been studied and are still under constant investigation. This project merely shows how temperature may play a factor in the growth of *K. brevis* but it could also be influenced by a combination of other parameters not studied in this investigation.

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