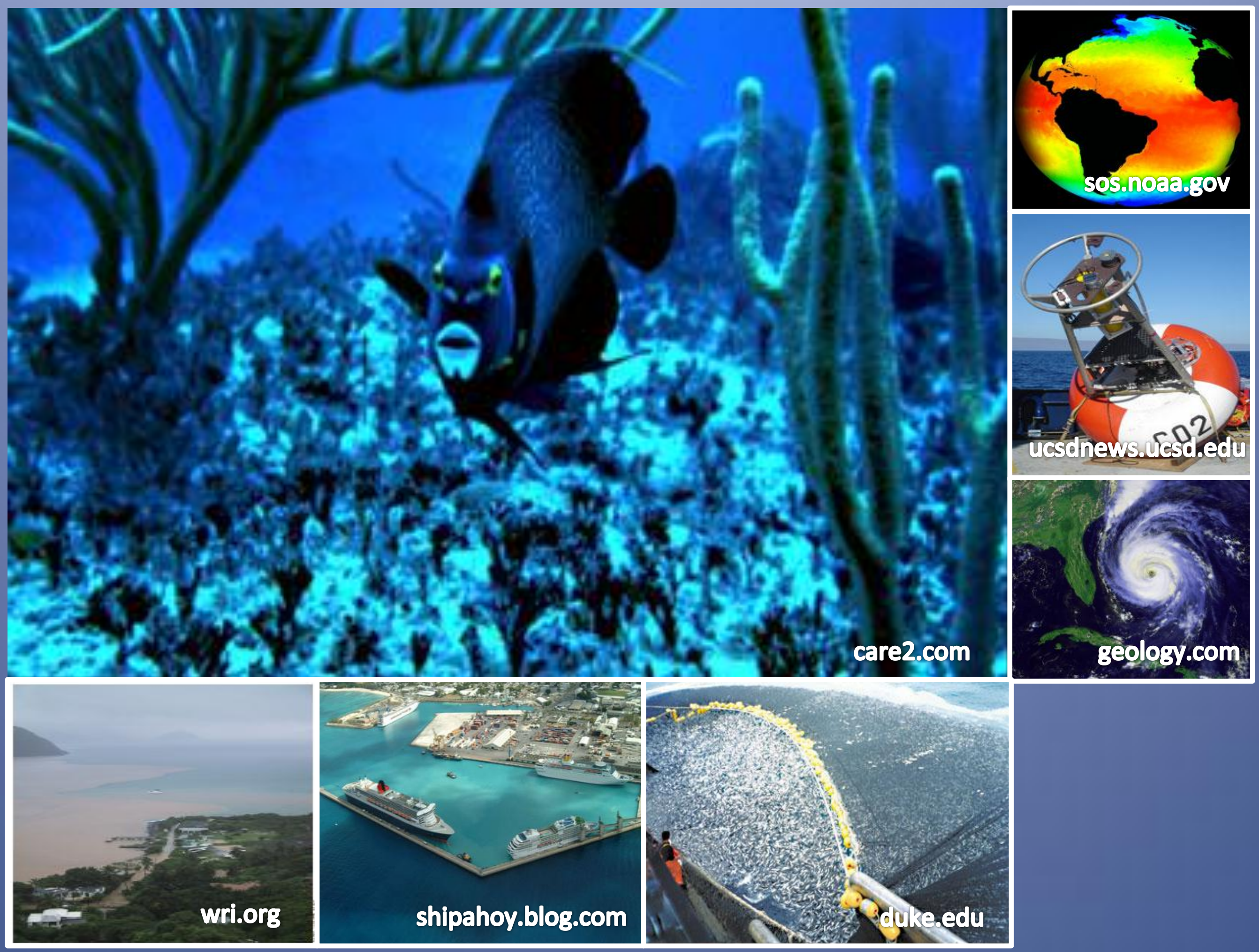

Evaluating Local and Global Stresses on Coral Reefs: A Case Study of Caribbean/Atlantic Reefs

GIS in Water Resources (CE 394K) Term Paper

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December 2, 2011

I. Introduction

A. Background Information

Coral reef communities are seen as “the rainforests of the oceans” [1] due to their biodiversity. Corals are tiny animals that belong to the cnidaria group, which also includes hydras, jelly fish and sea anemones. Coral polyps are sessile and have to use their tentacles to reach out and catch small fish and planktonic animals. Coral reefs are made from the calcium carbonate secretions of the individual polyps; growth rates of 0.3 to 10 cm/yr are typical [5]. *Zooxanthellae* algae have a symbiotic relationship with corals [5]. In exchange for protection and access to light that the algae needs for photosynthesis, the coral gains food. Coral bleaching is the term for when corals lose their zooxanthellae and only their calcium carbonate skeletons remain.

Coral reefs are tolerant over a slight range of temperature, salinity, turbidity, and other water quality parameters; for this reason, coral reefs are found in the sub-tropical or tropical global narrow band from 30° north of the equator to 30° south of the equator at an average depth of 50 m for light access. [2,3,5]

Proper monitoring of coral reefs unlocks many questions surrounding the impacts of terrestrial activities on water quality. Protecting and understanding the value of coral reefs are also important as reefs provide fishery and nursery areas, tourist attractions, coastline erosion protection, and sources of beach sand. Coral bleaching and disease rates are on the rise due to global and local stressors. The reefs are amazingly adaptive to short-term catastrophic events like tropical cyclones. These events are even seen as beneficial as damaged areas can be recolonized with greater biodiversity. On the other hand, coral reefs are not well adapted to survive long-term stresses like influxes of agricultural, sewage, and sediment runoff.

The coral reefs in the Caribbean Sea and Atlantic Ocean comprise 10% of the world's coral reefs [2-3]. Sixty-five species of reef-building corals, 90% of which are unique to the area, are found in the Caribbean Sea and Atlantic Ocean reefs [2]. Sadly, 75% of these reefs are considered threatened with 30% categorized in the high to very high treat levels [2]. Local and global stresses are the cause of coral bleaching and the decline of reefs due to disease. Local stresses include watershed-based pollution, marine-based pollution and physical damage, and overfishing/destructive fishing. Global stresses include changes in temperature (SST), increases in ocean acidity, and the impact of tropical cyclones. An estimate of economic future losses from the stressed coral reefs totals US$350-US$870 million per year based upon the impact to tourism, shoreline protection services, and the fishing industry [2]. A conscientious effort needs to be made in the future to have stringent protection policies for these ecosystems.

B. **Project Objectives**

Thirty-five countries and territories defined the region under analysis for this project. Their watersheds' sediment delivery and erosion potential, port size, and economic dependence on the reefs comprise the local stresses quantified for this project. Global stresses included the intensity and potential location of tropical cyclones, change in temperature from the reef's harmonious temperature of 27°C [3], and change in the concentration of dissolved CO_2 from preindustrial levels. A model of coral reef risk levels based upon the proximity of local and global stresses was created for present day and extrapolated to the year 2100.

The following analyses were completed using ArcGIS to ascertain the impact of local and global stresses on the health of coral reefs and quantifying future risk levels:

(1) Creation of feature layers containing global and local stresses data.

(2) Model created using Map Algebra to compile local and global stress feature layers.

II. Global Stresses

This section examines changes in temperature (SST), increases in ocean acidity, and tropical cyclones as global stresses. Coral reefs are very sensitive to changes in temperature from 27°C. A change of one degree can cause coral bleaching to occur. A temperature raster was created by subtracting 27°C from temperature data measured at 50 m below the sea surface, which is the mean depth of coral reefs. A temperature raster was converted into a point layer that then underwent Natural Neighbor interpolation to create the maps for sea temperatures during 1980, 1990, and 2000 (see Figures 1-3).

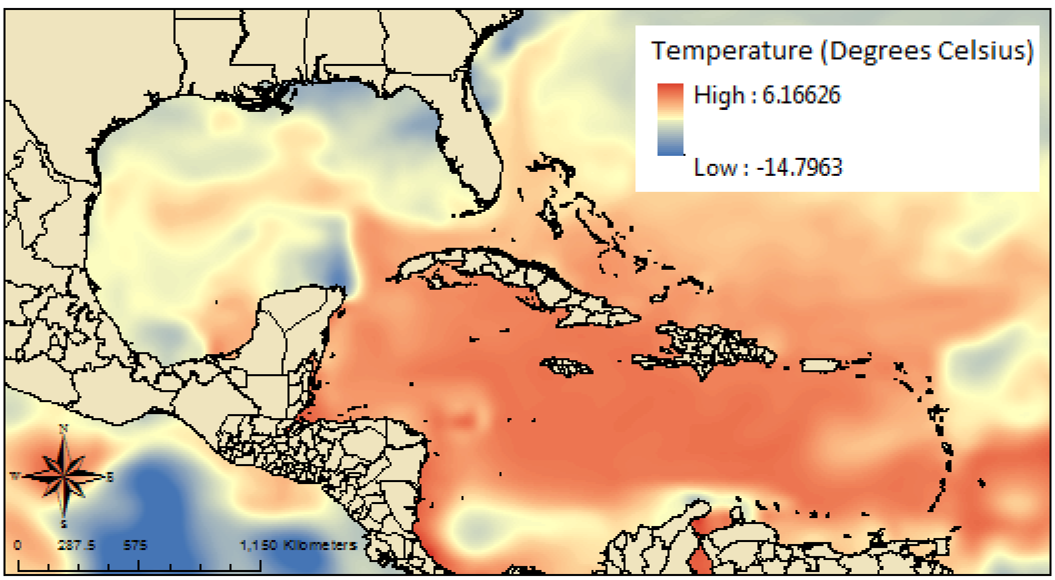

Figure 1. Difference between sea temperatures at 50 m below sea surface in 1980 and the mean temperature that coral reefs thrive (27°C)

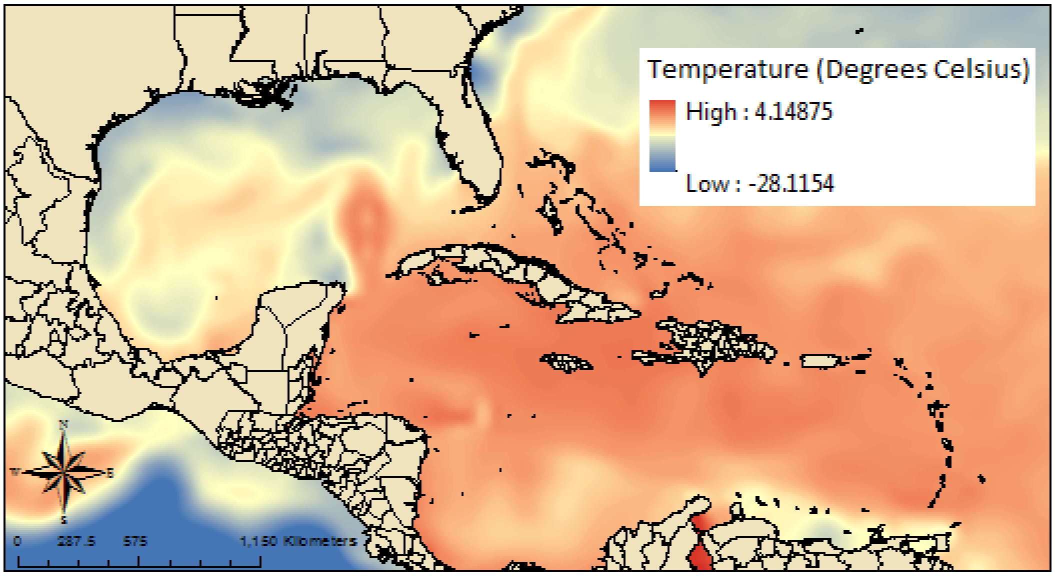

Figure 2. Difference between sea temperatures at 50 m below sea surface in 1990 and the mean temperature that coral reefs thrive (27°C)

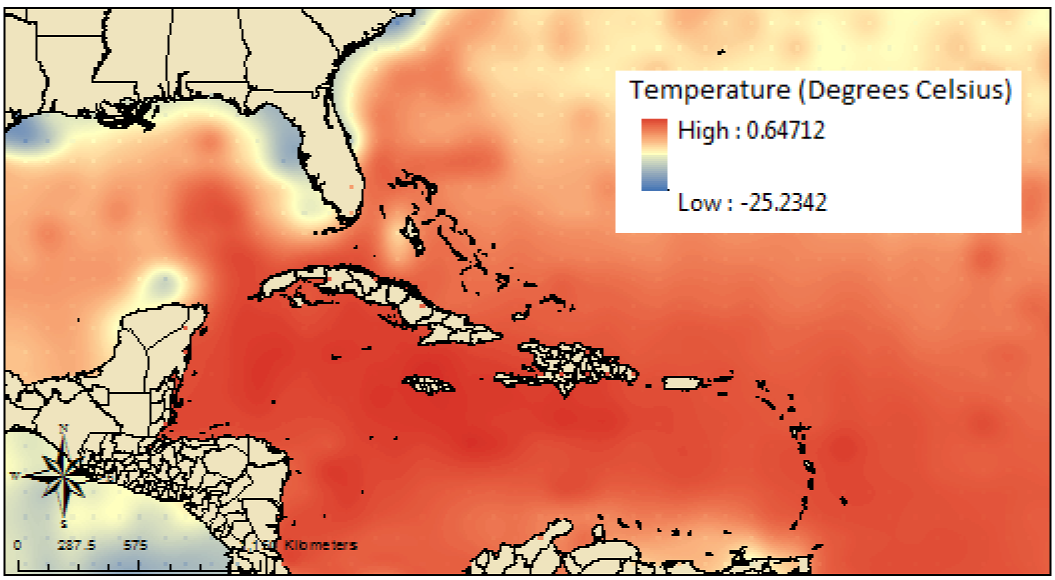

Figure 3. Difference between sea temperatures at 50 m below sea surface in 2000 and the mean temperature that coral reefs thrive (27°C)

Looking at Figures 1-3, the temperature changes from the mean temperature of 27°C are found primarily around the Caribbean islands and Pan American countries where coral reefs are present offshore.

The second global stress investigated during this project was the increasing acidity of the ocean. This increase is due to the rise of anthropogenic carbon dioxide from the atmosphere. Acidification indicates that the concentration of calcium carbonate, vital for coral skeletons and other aquatic organisms' shells, reaches levels considered unsaturated. In parts of the ocean unsaturated with calcium carbonate, new growth of corals is restricted and in extreme cases degenerative. Olsen et al. provided a useful equation relating surface temperature, latitude, longitude, and carbon dioxide concentration [4]:

$$pCO_{2sw} = \left(10.19 * SST + 0.5249 * latitude\ - 0.2921 * longitude + 52.19\right) \qquad \text{(Equation 1)}$$

I amended the above equation by subtracting 270 µatm to model the change between pre-industrial levels (270 µatm) [4] and the current carbon dioxide levels.

$$pCO_{2sw} = \left(10.19 * SST + 0.5249 * latitude\ - 0.2921 * longitude + 52.19\right) - 270 \qquad \text{(Equation 2)}$$

The resulting rasters for years 1980, 1990, and 2000 were converted into point classes and a Natural Neighbor interpolation was applied over the area (see Figures 4-6).

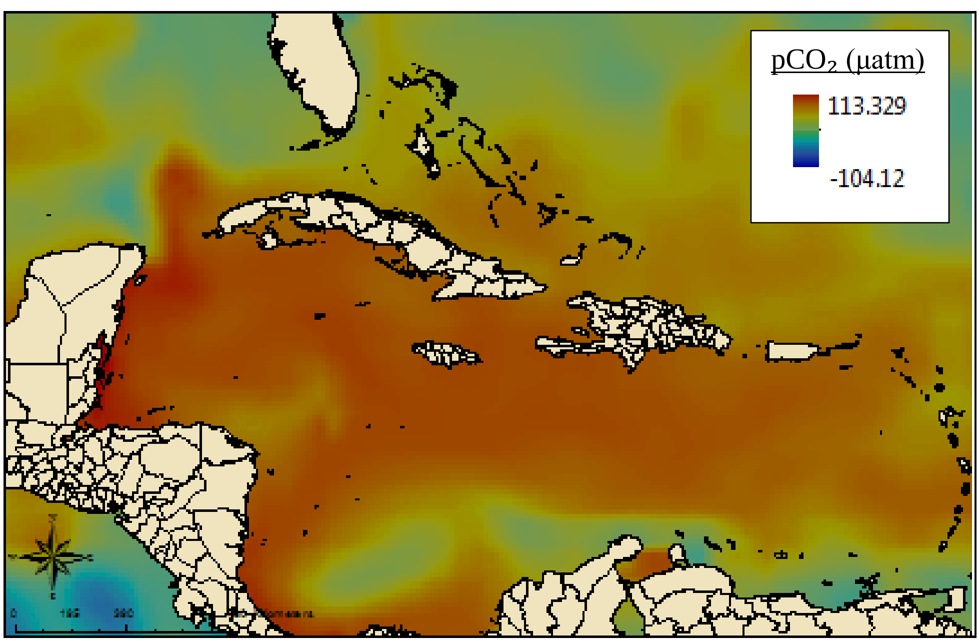

Figure 4. Difference between CO_2 concentration at 50 m below sea surface in 1980 and the pre-industrial CO_2 levels.

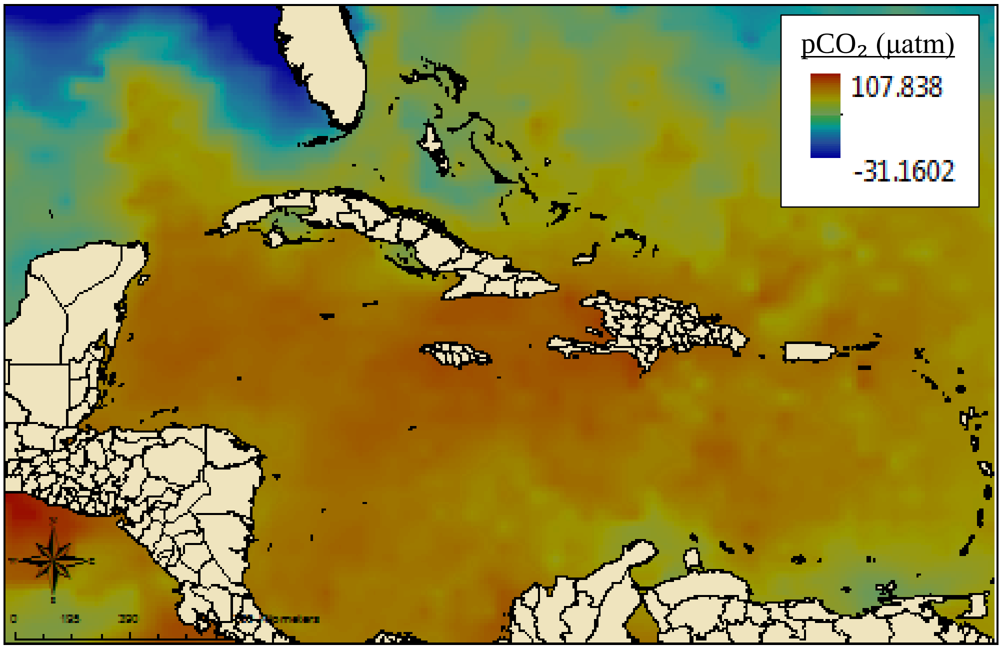

Figure 5. Difference between CO_2 concentration at 50 m below sea surface in 1990 and the pre-industrial CO_2 levels.

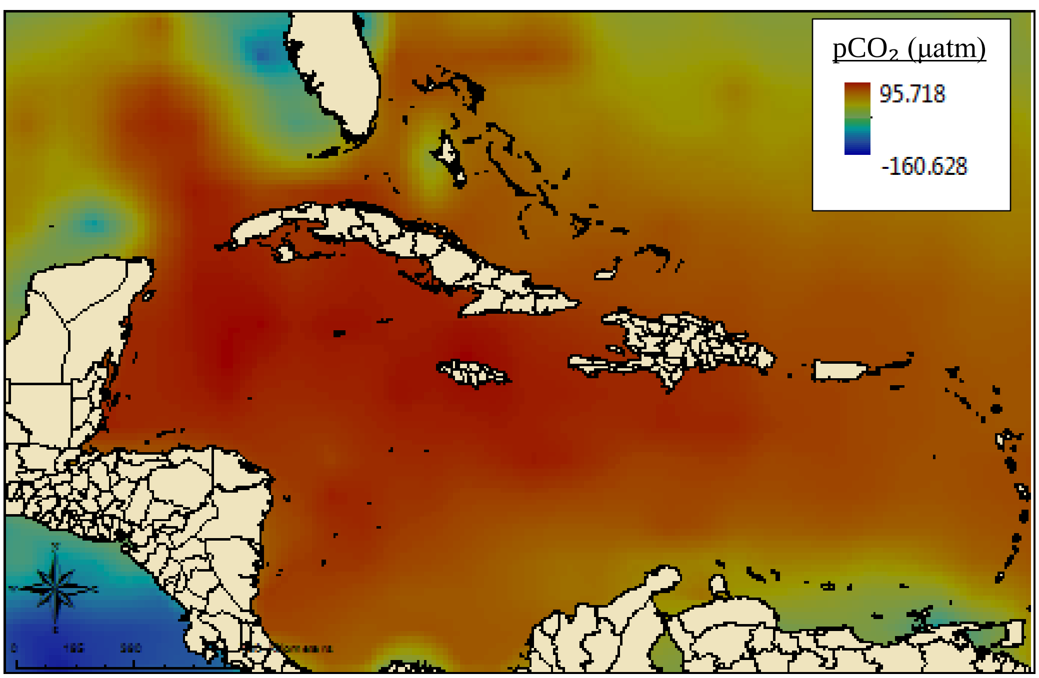

Figure 6. Difference between CO_2 concentration at 50 m below sea surface in 2000 and the pre-industrial CO_2 levels.

Tropical cyclones are another stress to coral reefs as their high winds and waves can cause physical damage. I looked at the intensity of the storms and their paths. The tropical cyclone data from 1848 to 2010 were first manipulated by using the Point Density Tool to determine the likelihood of a tropical cyclone striking a particular location; Figure 7 shows the results.

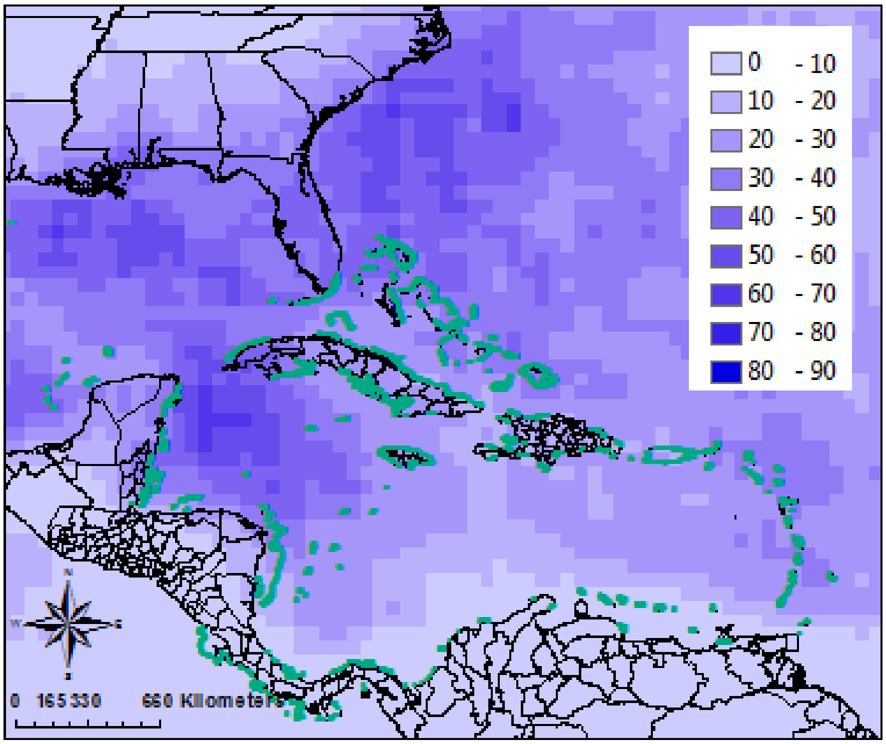

Figure 7. Percent likelihood that a tropical cyclone will strike a location. The teal points indicate the coral reef locations.

The second aspect of tropical cyclones I looked at was the storm intensity. A raster was created based upon the average of the hurricane track polylines. The resulting raster was converted into a point feature class and then subjected the Natural Neighbor interpolation (see Figure 8).

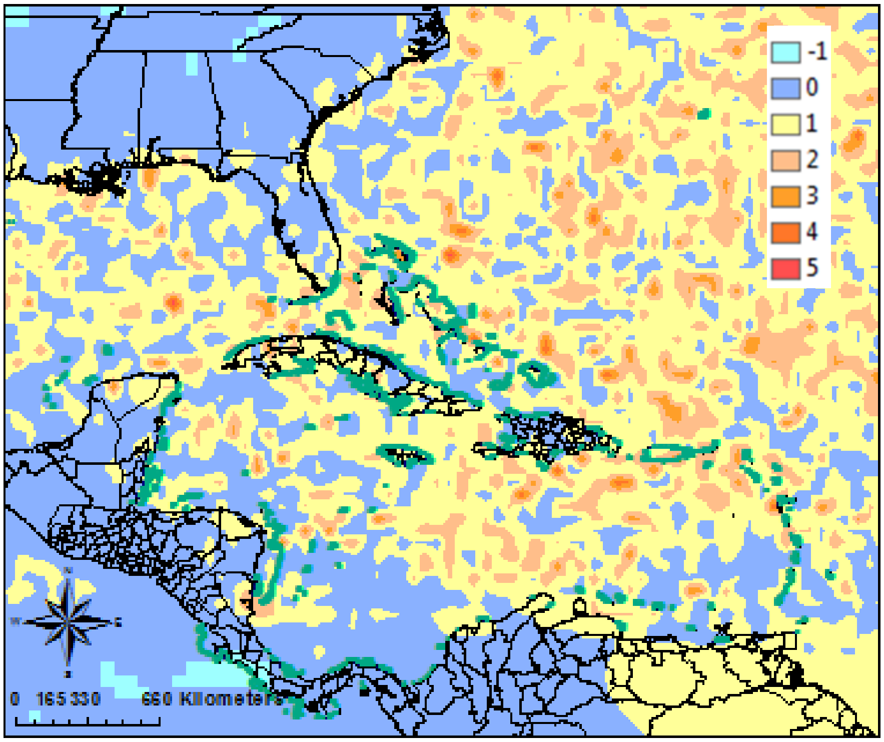

Figure 8. Averaged intensity of tropical cyclones from 1848 to 2010. (-1) indicates Tropical Depression, (0) indicates Tropical Storm, (1-5) indicate Hurricane Categories 1-5. The teal points indicate coral reef locations.

These global stresses were divided into quantified threat levels to create a model of risks to coral reefs that is presented in Section IV.

III. Local Stresses

This section examines the three local stresses that were included in this project's model: watershed pollution, marine-based threats, and the economic dependence on the reef. Watershed pollution was modeled by looking at the relative erosion potential (REP) and the amount of sediment delivered to a pour point annually. Increased sediment delivery is detrimental to coral reefs, especially juvenile coral, due to the loss of light necessary for photosynthesis. Fertilizers and other nutrients are delivered with the sediment. I chose not to model the specific nutrients and focused only on the sediment as a delivery mechanism. The addition of fertilizers and nutrients to the ocean caused extreme eutrophication that can change the aquatic community's biodiversity [3]. Extreme cases of nutrient loading can cause oxygen depleted zones that are devastating to coral reefs. Dead zones were the cause of death for several square kilometers of coral reefs off the coast of Venezuela in 1996 [2]. Figure 9 summarizes the watershed erosion potential and sediment delivery for the region under analysis.

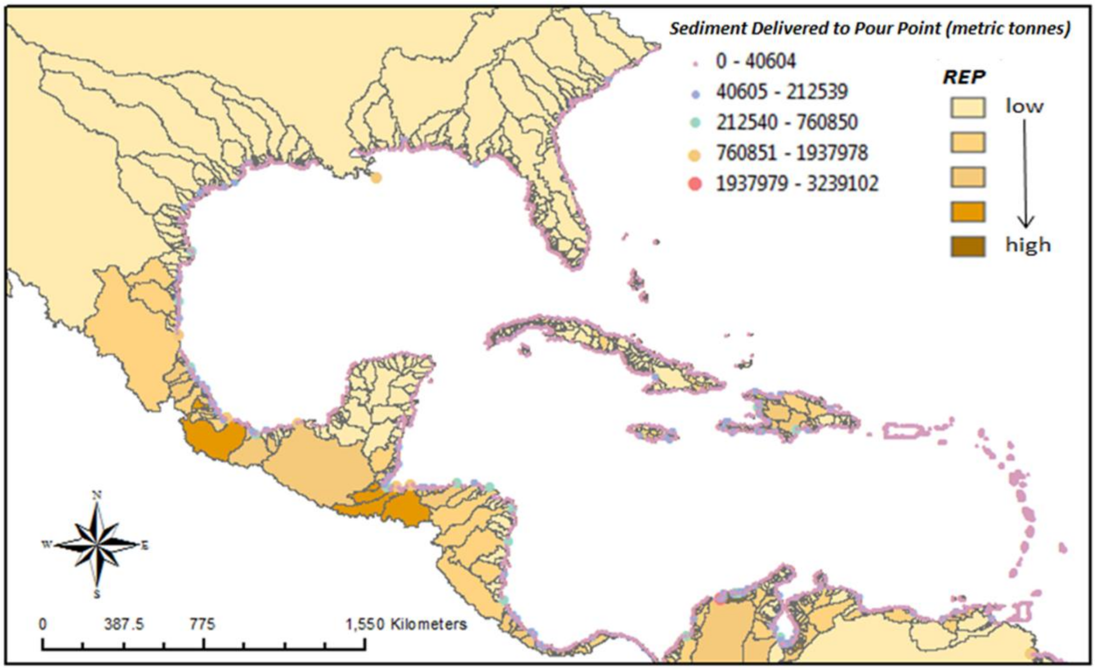

Figure 9. Evaluation of watershed pollution as a local threat for coral reefs. Watersheds are color coded based on their relative erosion potential. The pastel points are the pour point locations where the watersheds empty into the ocean; the pour points are color coded and increase in size to represent the annual sediment delivered to the pour point.

Watersheds within the countries of Mexico, Guatemala, El Salvador, Honduras, Haiti, and the Dominican Republic have the maximum REPs and sediment delivery annual rates in the area under analysis.

The second local stress evaluated was marine-based threats that include physical damage from anchoring and grounding on coral reefs, oil spills, and waste disposal. A chain and anchor weighing up to 4.5 metric tons can cause 200 square meters of damage [2,5]. Grounding of ships (weighing much more than 4.5 metric tons!) can cause irreparable damage to coral reefs.

In addition to the direct physical damage associated with marine activity, the discharge of waste and bilge water causes an influx of nutrients leading to eutrophication and other nutrient-limited issues. I decided to use port size as an indicator of increasing threat to model the effects of marine-based threats since most damage from marine-based activity is around these high-visitation areas. The population of the port was used to reclassify the data into four levels from very small to large. Figure 10 is a map of the ports used in this analysis.

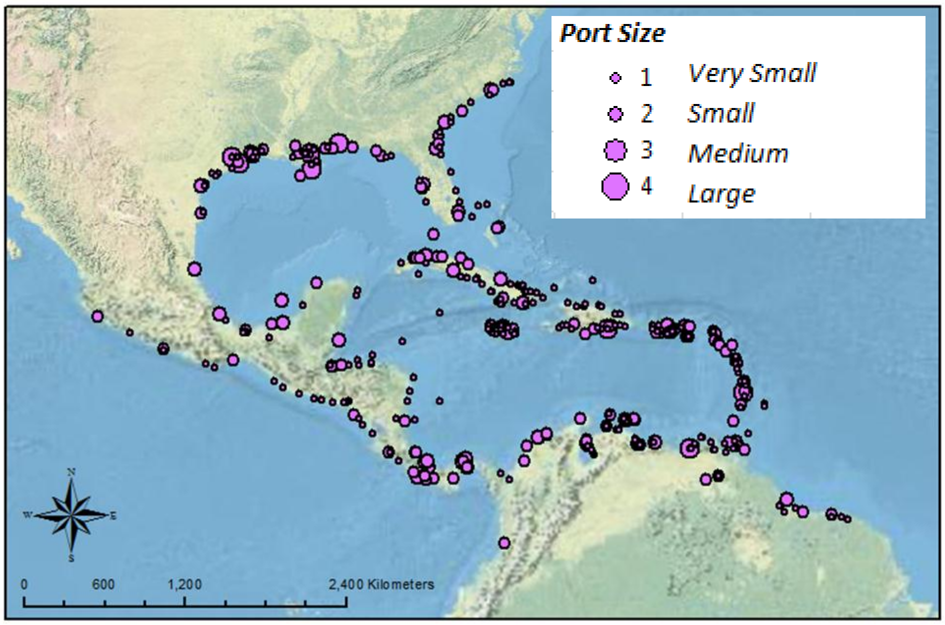

Figure 10. Evaluation of marine activity as a local threat for coral reefs.

Economic dependence on the reefs was the third local stress evaluated. The countries and territories encompassing the Gulf of Mexico and the Caribbean Sea have different socioeconomics leading to different dependence levels on their reefs. To evaluate economic dependence, I looked at data regarding overfishing, destructive fishing, and management of coral reefs. Figure 11 is a map with economic dependence threat levels for the area under analysis.

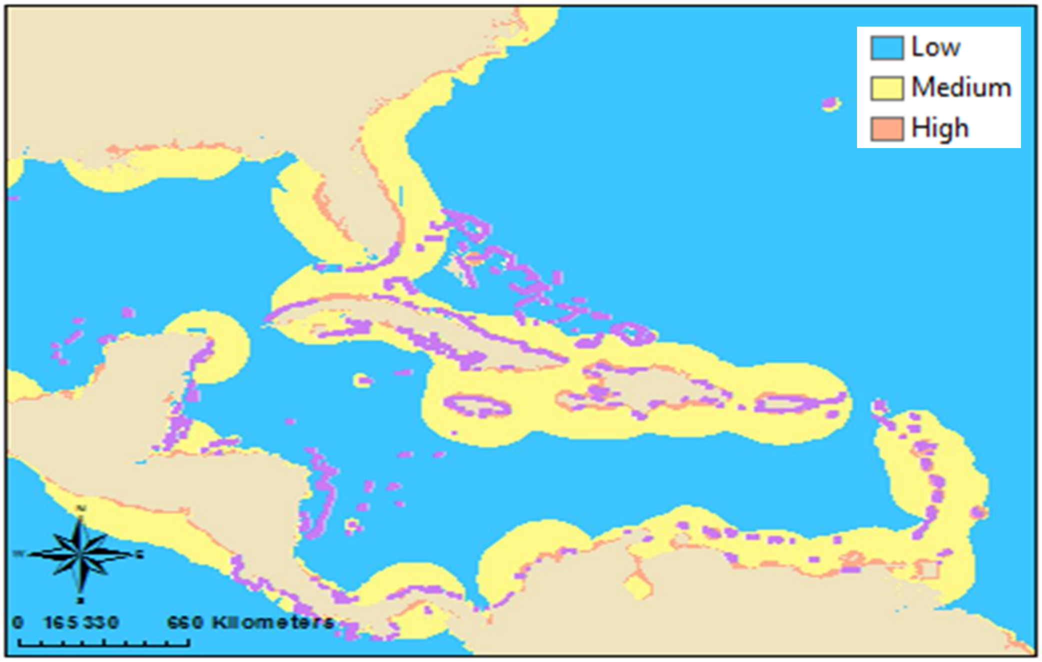

Figure 11. Evaluation of economic dependence on coral reefs as a local threat. Purple points represent location of coral reefs.

These three stresses were incorporated with the global stresses to create a model discussed in the next section.

IV. Model

The final step of the analysis was to create a model of threat levels for present and future years. All of the data layers were reclassified to integer values. Using the reclassified values, the following equation correlated well to observed bleaching points [2]:

$$R = 2 * \left(\frac{Temperature}{27} + \frac{Port\ Size}{4} + \frac{Sediment\ Discharge}{5} + \frac{ErosionPotential}{5} + \frac{Economic\ Dependence}{3} + \frac{Carbon\ Dioxide}{10}\right) + \frac{Storm\ Percentage}{10} + \frac{Storm\ Intensity}{7} \quad \text{(Equation 3)}$$

The reclassified rasters for each stress were divided by the number of reclassified intervals to obtain a normalized value. These values were then summed together to form an intermediate raster layer that was reclassified into risk levels 0 (no bleaching risk) to 3 (high bleaching risk). Figure 12 depicts the current risk level found using the above equation.

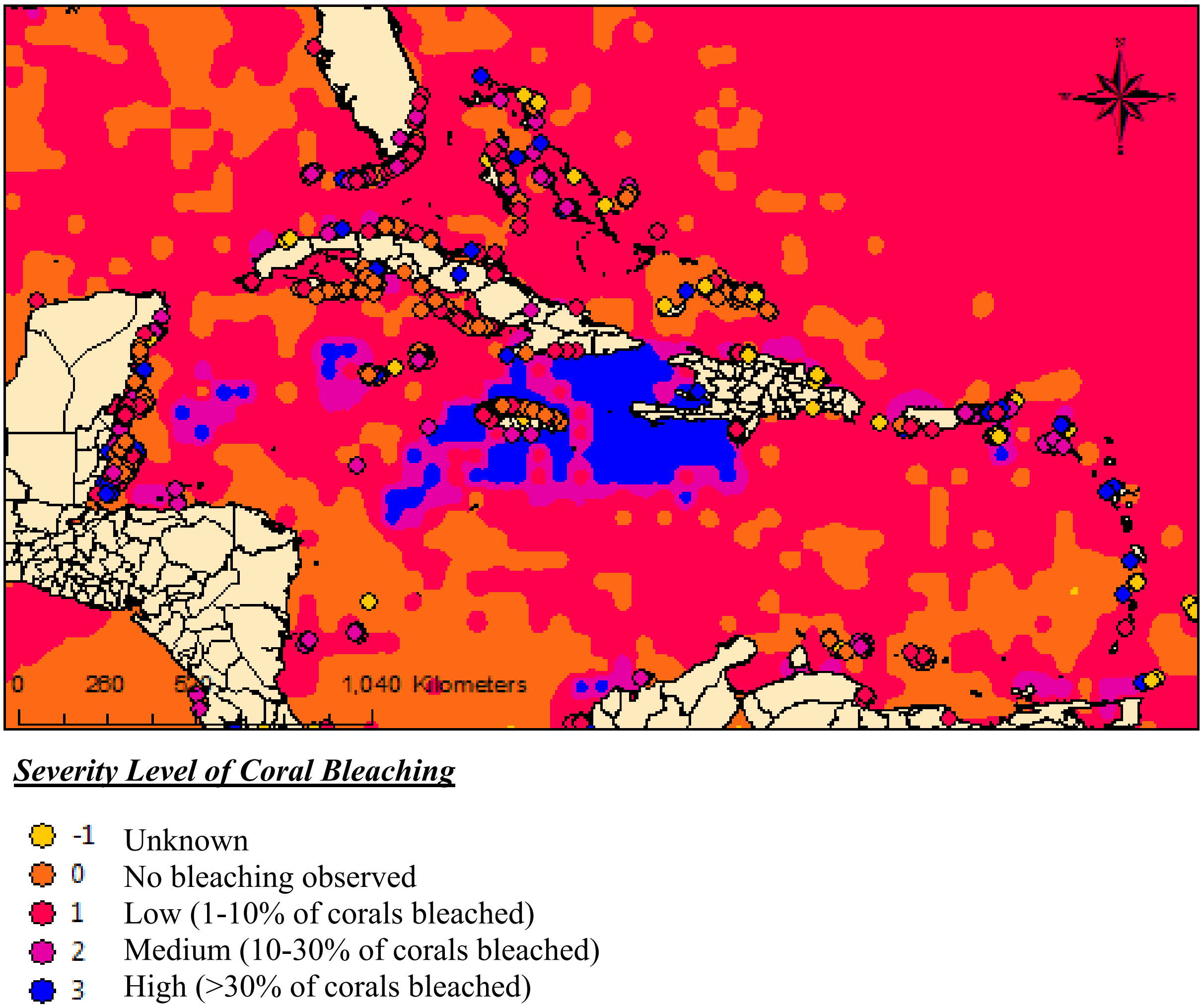

Figure 12. The current risk level found using Equation 1. The points represent qualitative measurements of coral bleaching.

Over the next 90 years, the carbon dioxide of the ocean will increase by 11% [6], the ocean temperature will increase by 6.5°C [7], and storm intensity will increase by 11% [8]. These projected values were inputted into the above equation and the process of reclassification occurred again; Figure 13 shows the outputted risk levels for 2100.

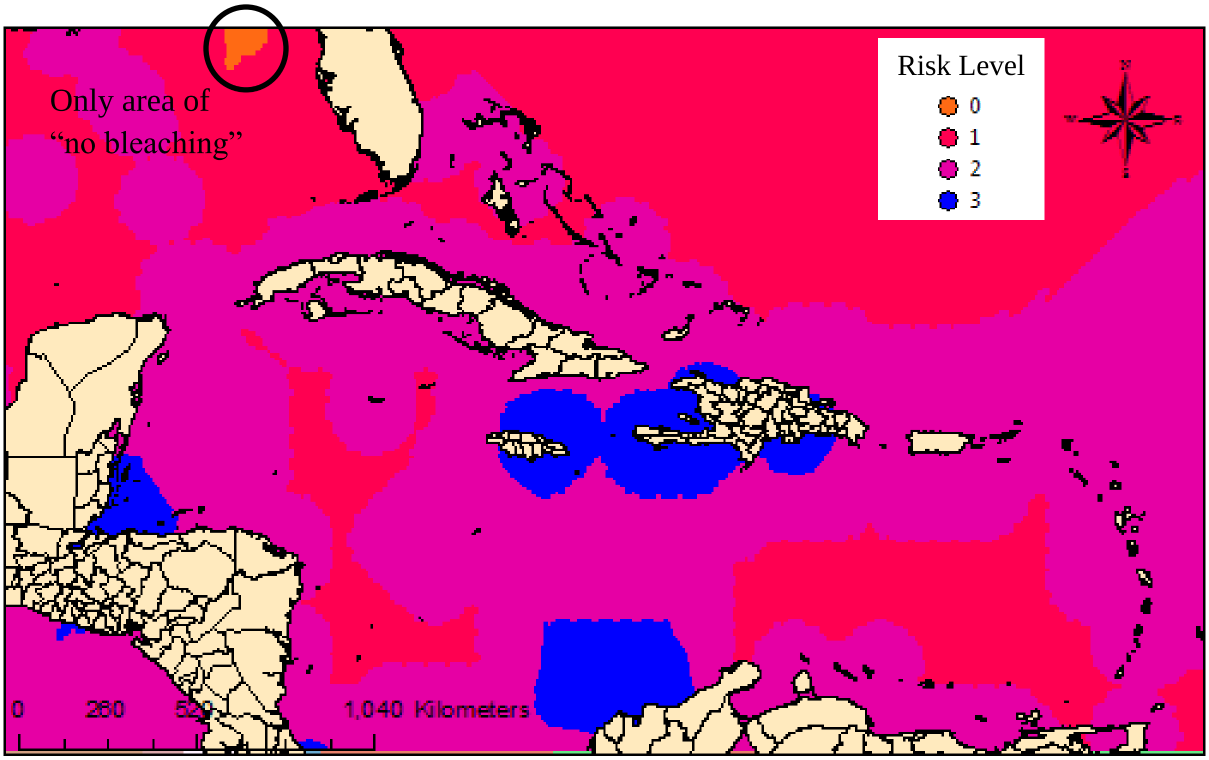

Figure 13. Coral reef risk levels in the year 2100 if protection policies are not implemented and stressors continue to grow as expected.

If stressors continue to grow as expected over the next ninety years and no implementation of stringent protection programs takes place, then the risk level for all of the Caribbean coral reefs will increase. In 2100, the model predicts that 10% to 30% of the coral reefs at a specific location will be bleached. Areas around Jamaica, Haiti, the Dominican Republic, and Belize will have a 30% or greater chance of bleaching.

The last step in the modeling process was completing a sensitivity analysis to determine the effect of halving or doubling the global and local stress inputs on coral bleaching threat levels. Model Builder was used to stream line the process as seen in Figure 14.

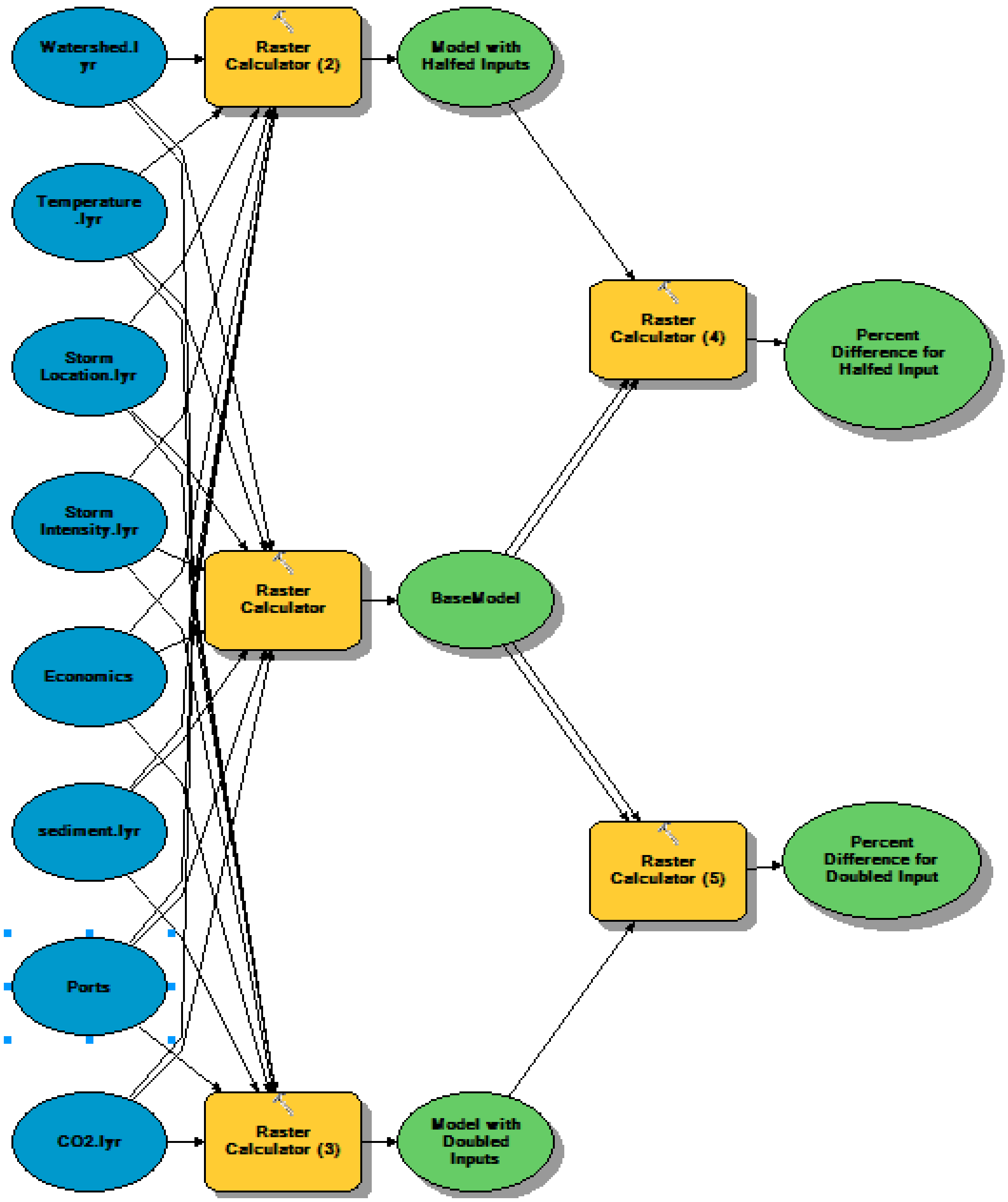

Figure 14. Sensitivity analysis completed through Model Builder.

The results of the sensitivity analysis (see Table 1) indicate that an increase or decrease in the global stresses have similar impact on the coral bleaching threat level, while the acts of increasing or decreasing the local stress inputs has extremely different outcomes.

Table 1. Results of Sensitivity Analysis

Parameter		Mean Percent Difference from Base Model
Global Stresses	Half	70%
	Double	70%
Local Stresses	Half	19%
	Double	227%

The coral reef threat parameter is more resilient to changes in global stresses and more influenced by the changes in local stresses.

V. Conclusions

Coral reefs are a high-risk but high-value ecosystem. While there are many movements to make the human race “green”, the global changes that started with the industrial age still have negative impacts on vulnerable ecosystems. Without the active participation of people, the reefs will no longer exist in their current glory.

The local and global stresses analyzed are just a handful of the stresses that coral reefs face, but are the ones most easily accessible with regards to data. In the future, more quantitative data needs to be collected in regards to specific nutrients and toxics being released into the oceans to thoroughly judge the impact of watershed drainage. Other parameters, like dissolved carbon dioxide, need to be measured over larger spatial ranges to have a complete picture. Overall the data is available but not readily accessible; a fact that needs to change to aid in the preservation of coral reefs for future generations.

VI. Data Sources

Temperature Data Source:

http://apdrc.soest.hawaii.edu/las/v6/constrain?var=1411

Tropical Cyclone Data Source:

http://www.ncdc.noaa.gov/oa/ibtracs/index.php?name=wmo-data

Watershed Pollution Data Source:

http://databasin.org/

Marine Activity Data Source:

http://databasin.org/

Economics Data Source:

http://databasin.org/

VII. Works Cited

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