Tropical Cyclone Induced Cooling Zones: A Geocomputational Hazard

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1. Introduction

Coral reefs are under threat from global climate change (GCC). Rising sea surface temperatures (SST) are expected to cause more frequent and intense bleaching events and an increase in the mean and peak intensities of tropical cyclones (TCs). However, a recent study provided the first evidence that the nearby passage of a TC can reduce the severity of coral bleaching by temporarily lowering high SST. This raises the question: can the increased storminess predicted under future climates partially offset the increased SSTs (and subsequent bleaching) also predicted? To address this, a major GIS modeling study is under way. As a first step, a number of technical issues – primarily related to data quality and large data volumes - must be solved. This paper describes a preliminary investigation of: 1) the scope of the data quality problem and 2) potential ways to address it.

2. Background

In the wake of a TC, upper ocean SST can decrease by as much as 6°C over a distance up to 400 km on either side of the track (Price 1981; Stramma *et al* 1986). The extent of cooling depends primarily upon the intensity of TC-generated winds, the storm's translation speed, and the ocean's mixed layer depth (Price 1981). A recent study demonstrated that periodic TC-induced cooling reduced the severity of bleaching at reefs in the Caribbean by reducing the duration of coral exposure to SSTs above their thermal threshold (Manzello *et al* 2007). GCC models predict SSTs will continue to increase over the next century which may lead to an increase in the mean and peak intensities of TCs (Elsner *et al* 2008). This poses the question of whether the increased storminess predicted by GCC models will partially offset the increased SSTs also predicted by reducing SST-induced bleaching on coral reefs, and how this might vary spatially.

Therefore, a major study is underway to assess: 1) how frequently this interaction likely occurred in the recent past (1985-2007) and 2) under various GCC scenarios, and how this varied spatially for both.

3. The problem

The first step in the project requires a high resolution remotely sensed SST image for each day of the study period. Clouds pose a particular problem for SST estimation using infrared (IR) satellite imagery. Although microwave (MW) SST data, such as that collected by the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) and the Advanced Microwave Scanning Radiometer on the NASA Earth Observing System (AMSR-E), can measure SST through clouds (Jena et al 2006), its spatial resolution is relatively coarse (25-50 km). Further, for MW products the uncertainty of SST observations increases due to rain, sun glint and for any observations within 50 km of land (Reynolds *et al* 2009). Finally, MW SST data did not exist for the early part of the study. Thus, the logical data set to use is the high resolution (4 km) IR Advanced Very High Resolution Radiometer (AVHRR) Pathfinder SST Data, version 5 (http://podaac.jpl.nasa.gov/poet), a product similar to what NOAA uses for their world reef bleaching 'hotspot' analysis. To supplement the AVHRR data, we will utilise the Optimum Interpolation (OI) TMI SST dataset (1998-present) and the recent SST analysis produced by NOAA (ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2) combining in situ, AMSR-E and AVHRR data (OI 1/4 Degree Daily Sea Surface Temperature Analysis). The OI 1/4 Degree Daily SST Analysis offers an AVHRR-only product (1981-present) and an AVHRR + AMSR-E product (2002-present) at a resolution of 25 km.

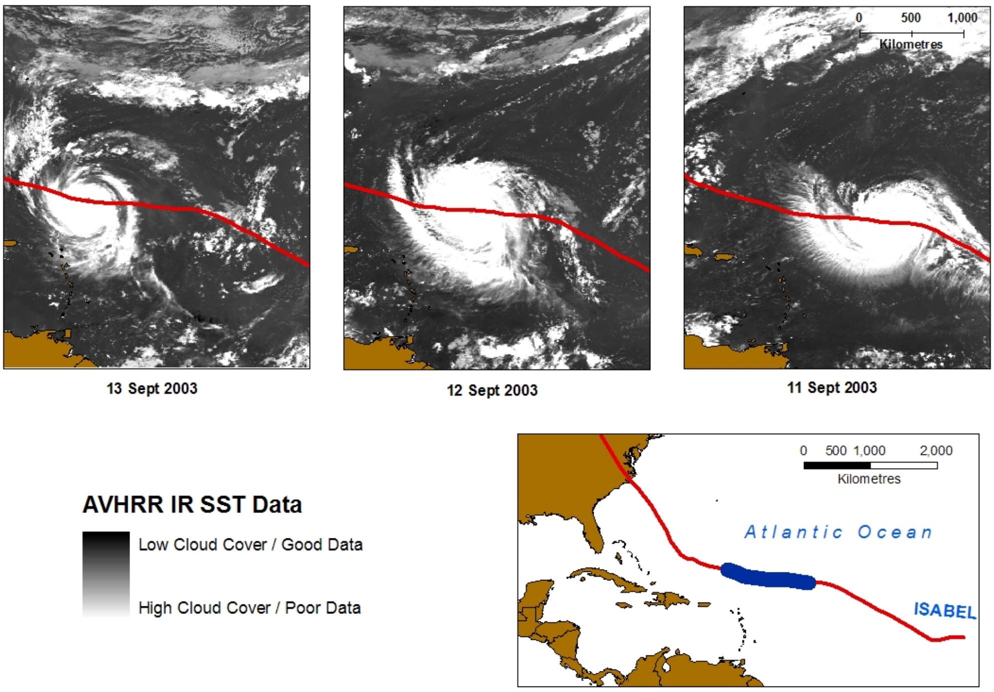

Figure 1. Track of TC Isabel (Sept 2003 - red line) and daily nighttime AVHRR Pathfinder SST V5 data for three days during which Isabel was classified as a severe TC. Extensive areas (white) could not be corrected by NOAA with standard techniques due to clouds.

Techniques used to correct for clouds (estimating values from nearby unaffected pixels or from the same pixel prior to or after the clouded day) have been applied extensively by NOAA to the Pathfinder dataset and data quality images are provided. Unfortunately, during a TC event, cloud can persist for several days over a large area, right in the locations most likely to exhibit the cooling effect. For these areas, the fixes described above were not possible. For example, Figure 1 shows the track of TC Isabel through the Caribbean in September 2003 with AVHRR SST images clearly depicting the outline of the storm. During most TCs, there are a number of pixels for which minimal SST data is available (white areas), and for which some method of SST estimation will be needed.

4. The investigation

So far, we have addressed this issue by:

1. Estimating and documenting the scope of the problem
2. Exploring alternate sources of SST data for the affected pixels.

4.1 Scope of the problem

For each pixel in the study area, we counted:

- The total number of days for which data quality is poor during which a TC passed within 400 km of the pixel (conservative estimate of the maximum distance from which cooling could be observed).
- The number of periods during which the above occurred for more than five consecutive days. Any data gaps greater than this could result in omission of cooling events since the cool wake of a TC can return to pre-TC temperatures in as little as 5 days (Stramma *et al* 1986).
- From this, we assessed the spatial and temporal distribution of the poor quality pixels across the study area and over study period.

4.1 Potential solutions

A range of possible solutions was tested on samples of the poor quality pixels identified above. Many of the original IR and MW datasets have been optimally interpolated (via sensor error corrections, diurnal warming estimation/removal, bias removal using in-situ data) to a daily 25 km grid free of any missing values or data gaps. Since MW data was not available before 1998, two samples of pixels were obtained separately from:

1. 1998-2007, and
2. 1985-1997.

Where possible, samples were chosen for locations for which in situ SST data exists in the NOAA Marine Environmental Buoy Database (http://www.nodc.noaa.gov/BUOY/buoy.html).

For (**1**), two sets of OI MW SST datasets are available with the TMI beginning in 1998 and AMSR-E in June 2002. Daily OI TMI SST data was downloaded from the Remote Sensing Systems website (www.remss.com) and for the AMSR-E data we opted to use the 25 km resolution OI AVHRR + AMSR-E product. MW data is likely to be available at a suitable quality for pixels that are cloud affected in AVHRR because it is unaffected by clouds (coverage in tropical areas typically exceeds 90% - Chelton *et al* 2000).

For (**2**), OI AVHRR-only SST data was used to fill the gaps and, where possible, we tested the resulting SST values against in situ SST data.

Further work includes broadening the sample of poor quality pixels, obtaining more in situ SST data, and where in situ data is reasonably widespread, interpolating it to fill gaps. Once a set of solutions is selected, an estimated level of uncertainty (at least qualitatively) will be recorded to facilitate the creation of uncertainty maps.

5. References

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