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TROPICAL CYCLONE INTENSITY IN RELATION TO SST AND MOISTURE VARIABILITY: A GLOBAL PERSPECTIVE

Robbie Berg*

RSMAS / University of Miami
Miami, Florida

1. INTRODUCTION

Sea surface temperature (SST) plays an important role in determining the intensity of tropical cyclones (TC). More specifically, the depth of the upper-ocean mixed layer and oceanic heat content dictates the response time for any decreases in SST due to the passage of a TC. Maximum Potential Intensity (MPI), based on models by Emanuel (1986) and Holland (1997), is governed by SST and surface relative humidity. Therefore, a storm's intensity is partly determined by SST and low-level moisture. However, these variables change due to interaction with the TC, and consequently the MPI is never achieved. Cione et al. 2000 noted that upper ocean "cold wakes" are often visible along the tracks of TCs, and these wakes can often be 4-5°C cooler than surrounding SST. These values, however, vary globally according to location and intensity of the TC in part because each of the ocean basins has their own thermal profile to dictate surface heat fluxes. For example, the SST in the wake of Typhoon Shirley in 1965 (maximum winds of 40 ms^{-1}) in the western Pacific decreased by about 2°C while the SST in the wake of weaker Hurricane Ginger in 1972 (maximum winds of 35 ms^{-1}) decreased by 4°C (Wright 1969, Black 1972). This study attempts to acquire a global perspective of TC intensity with respect to SST and moisture availability by comparing SST decreases in the wake of TCs in each of the world's ocean basins according to storm intensity.

2. DATA AND METHODOLOGY

The TRMM (Tropical Rainfall Measuring Mission) Microwave Imager (TMI) has become a key tool in recent years for analyzing precipitation rates and water vapor content in the tropics. Remotely sensed measurements of SST through clouds have been difficult since earlier radiometers such as SSM/I lacked the necessary low frequency channels for retrieval. While the lowest frequency used by SSM/I is 19 GHz, the TMI radiometer employs a 10.7 GHz channel that allows measurement of SST regardless of cloud cover or high concentrations of aerosols and atmospheric water vapor. Sea surface roughness is one major problem for microwave retrievals of SST (since high wind events such as TCs are accompanied by sea surface roughness), but the incorporation of infrared retrievals has smoothed the inconsistencies.

*Corresponding author's address: Robbie Berg, RSMAS, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149. Email: rberg@rsmas.miami.edu

TRMM SST data and columnar water vapor are obtained from Remote Sensing Systems, and a more comprehensive discussion can be found at www.remss.com. A 3-day running mean of the SST is employed to fill in gaps between ascending and descending swath paths and filter out day-to-day fluctuations. Each calendar day has a corresponding 3-day running mean image ending on 00Z that day. Three-day best-track TC data is then superimposed on the image. Since TRMM SST sensing began operation in December 1997, TC activity from 1998-2001 is inspected to monitor SST changes due to interactions with passing storms.

Tropical cyclones of similar intensity are chosen from different ocean basins and characterized by intensity: weak storms (tropical depressions or tropical storms), moderate storms (Category 1 or 2 hurricanes, or the equivalent), and strong storms (Category 3, 4, or 5 storms, or the equivalent). Storms are also classified according to one of six ocean basins: Atlantic (ATL), East Pacific (EPAC), West Pacific (WPAC), Southwest Pacific (SWPAC), North Indian (NIND), or South Indian (SIND). SST variation is then compared between the basins according to intensity. Hurricane Floyd (1999) in the Atlantic Ocean, Supertyphoon Zeb (1998) in the western Pacific Ocean, and Tropical Cyclone Paul (2000) in the southern Indian Ocean are chosen as examples. At the times chosen, each TC is classified as a strong storm.

3. RESULTS

Preliminary analysis of SST cold wakes for each of the mentioned TCs indicates that a significant variation does exist across ocean basins. For example, a significant cold wake along the past track of Hurricane Floyd at 00Z 14 September 1999 (maximum winds 60 ms^{-1}) is evident as SST in the coldest part of the wake are as much as 5°C cooler from the surrounding SST. Figure 1 shows a 3-day track of Hurricane Floyd to the east of the Bahamas superimposed on the 3-day averaged SST. A decrease of SST to the right of the hurricane track agrees well with the conclusions of Jordan (1964). Whereas SST around the storm is near 28°C, SST immediately behind the storm is near 22°C (missing TRMM data possibly hides even lower values).

Similarly, the SST associated with Tropical Cyclone Paul in the southern Indian Ocean at 00Z 17 April 2000 (maximum winds 54 ms^{-1}), as shown in Figure 2, exhibits a decrease in the wake of the storm. Since this storm occurred in the Southern Hemisphere, the largest SST decrease occurs on the left side of the track. The

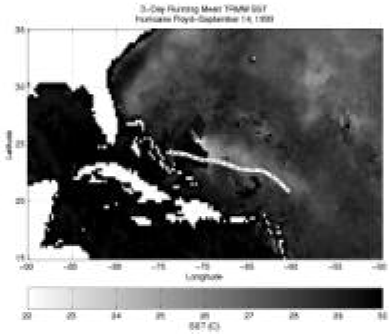

Figure 1. Three-day track of Hurricane Floyd ending on 00Z 14 September 1999 superimposed on a 3-day average of TRMM SST. SST ranges from 22°C to 30°C.

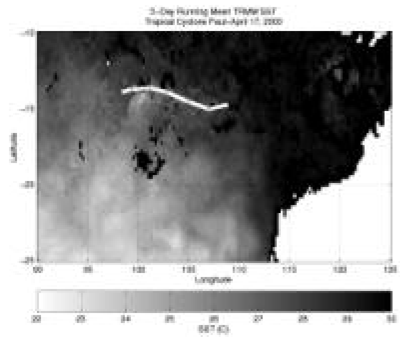

Figure 2. Three-day track of Cyclone Paul ending 00Z 17 April 2000 superimposed on a 3-day average of TRMM SST. SST ranges from 22°C to 30°C.

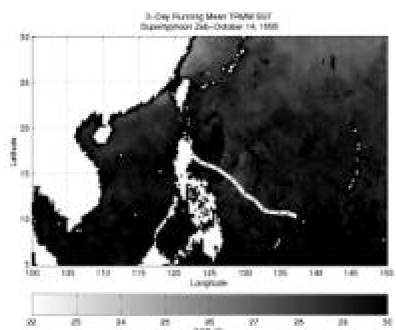

Figure 3. Three-day track of Supertyphoon Zeb ending 00Z 14 October 1998 superimposed on a 3-day average of TRMM SST. SST ranges from 22°C to 30°C.

difference between SST in the wake of the storm and the surrounding environment is approximately 4°C (23°C in the wake and 27°C in the adjacent areas).

Supertyphoon Zeb in the western Pacific Ocean at 00Z 14 October 1998 (maximum winds 69 ms^{-1}) displays a behavior drastically different from that of Floyd and Paul despite the fact that it is a stronger storm. Figure 3 shows the track of Supertyphoon Zeb with a noticeable absence of a cold wake. Even though Zeb is a major TC, SST in the wake of the storm does not vary by more than 1°C.

The preliminary results indicate that variations in SST in the wake of TCs do in fact differ from ocean to ocean. By these examples, it seems apparent that SST in the western North Pacific is not affected by TC interactions as much as in the North Atlantic or South Indian Oceans despite the fact that the chosen Pacific storm is stronger than the Atlantic and Indian storms. These results are also consistent with climatological ocean mixed-layer depths (OMLD), which can be attained from the Navy (www7330.nrlssc.navy.mil). OMLD in the Atlantic Ocean (in September) and the Indian Ocean (in April) range from 25-50 m while the OMLD in the Pacific Ocean (in October) averages between 50 and 75 m. The deeper OMLD in the Pacific Ocean explains the fact that SST associated with Supertyphoon Zeb did not decrease as much as SST associated with Hurricane Floyd and Tropical Cyclone Paul.

4. FUTURE WORK

Future work will attempt to calculate an average SST decrease for each ocean basin (as described in the methodology section) and test for statistical significance. Consecutive 3-day running means of SST will be composited over the lifetime of each storm for a complete view of a particular storm's cold wake. HRD dropsondes will be employed as verification for TRMM measured SST decreases in the wake of a TC. Atmospheric water vapor content will also be studied in a similar manner to SST to determine global variations. TCs in different ocean basins may respond differently to varied concentrations of atmospheric water vapor, and TRMM data can assist in such an assessment.

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