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TESTING GLOBAL ESTIMATES OF TROPICAL CYCLONE HEAT POTENTIAL FIELDS TO IMPROVE HURRICANE INTENSIFICATION PREDICTION

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1 INTRODUCTION

This work is part of the hurricane component of CBLAST, and consists in the analysis and investigation of the link between the upper ocean thermal structure and tropical cyclone sudden intensification in tropical regions using remote sensing procedures. Though forecasts of Atlantic hurricane tracks have improved greatly during recent years, large errors in intensity forecasts still remain. . Over the past few years, the intensity forecast statistical models were generally more skillful than the dynamical models. Statistical prediction models attempt to quantify the relationship between TC intensification and variables that can be estimated or observed in real-time. Some examples of these variables, referred as predictors, are the initial maximum wind speed, the wind shear, the latitude of the TC and the sea surface temperature (SST). The subsurface ocean thermal structure is also being considered as a predictor among several other thermodynamic variables that could further enhance our knowledge of the role of the ocean in TC intensification. We provide here results from a novel methodology to estimate the *tropical cyclone heat potential* (TCHP) to aid in the investigation of intensity changes in TCs and to improve current models for scientific research and operational prediction. Global estimates of this parameter are posted daily in:
http://www.aoml.noaa.gov/phod/cyclone/data.

2. UPPER OCEAN THERMAL STRUCTURE

The thickness of the upper ocean layer from the sea surface to the depth of the 26°C isotherm is only a few tens of meters in most of the tropical regions. During the summer months, a stable warm layer above 26°C characterizes the mixed layer. A passing TC draws energy from these warm waters and mixes them with the cooler waters below 26°C. This creates upwelling, raising the depth of the base of the mixed layer, subsequently lowering the temperature of the surface waters. These cooler waters now provide less energy to the TC, most likely slowing the rate of intensification. On the other hand, the depth of the 26°C isotherm in the core of warm currents and warm anticyclonic rings may reach more than a hundred meters. This type of condition has values of thermal energy usually several times larger than those associated with the genesis and sustainability of a TC, and is found in most regions where TCs occur. Understanding the role of these warm features on the intensification of hurricanes in the tropical North Atlantic is an on-going research topic in an early stage. Preliminary results have shown their importance in the sudden intensification of hurricanes in the Gulf of Mexico. Since then, the monitoring of the upper ocean thermal structure has become a key element in understanding and predicting sudden TC intensification.

3. MONITORING THE UPPER OCEAN THERMAL STRUCTURE

There are two key problems that need to be addressed: the location of these warm features and an estimate of their vertical thermal structure. These warm features, such as rings and eddies, have warmer waters than their surroundings with their isotherms deepening towards their centers. Satellite altimetry provides global observations of the sea surface height anomaly (SHA), a parameter that allows the identification of the location and estimation of their vertical thermal structure. Depending on many factors, such as the vertical stratification and the dynamic processes involved, the relationship between selected isotherms (such as the depth of the 20°C isotherm, which usually lies within the thermocline waters in most tropical regions) and the sea surface height can be estimated from the altimeter-derived sea height anomalies, in combination with *in situ* and climatological hydrographic observations. This task is far from being simple. Many factors contribute to the variability of the sea height and they all need to be properly accounted for and incorporated in the computations, including steric and dynamic effects, and the barotropic component of the ocean circulation. In many regions these estimates were confirmed to be adequate for the purpose of describing the main temperature features of the upper ocean, with mean rms errors of 10 m in the estimate of the depth of the 26°C. Methodology and additional information about these fields can be obtained from the Trinanes and Goni abstract.

4. EXAMPLES

Illustrative cases of the link of the upper ocean thermal structure and the sudden intensification of Atlantic hurricanes have previously been reported, as in Opal (1995) and Bret (1999). As a western Pacific example, we show here the upper ocean conditions prior to (July 19) and after (July 23) the passage of Typhoon Imbudo through the northern Philippines (Goni and Trinanes, 2004). This typhoon intensified from a category 2 typhoon (90 kt sustained winds) to a category 4 typhoon (125 kt sustained winds) during a period of only 12 hours on July

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20, when its track crossed a region that increased its oceanic TCHP by almost 100 kJ/cm^2. The SHA fields are evidence of the change in the upper ocean dynamics and thermal conditions due to the passage of the TC. The upper ocean exhibits a cooling (decrease of TCHP values) of 60 to 100 kJ/cm^2, with the sea surface temperature (SST) decreasing by 3 to 4^{o}C, along the track of the TC. Similarly, the depth of the 26^{o}C isotherm decreased by 25 to 100 m, due to the mixing and upwelling of waters, as well as for the uptake of thermal energy by the TC.

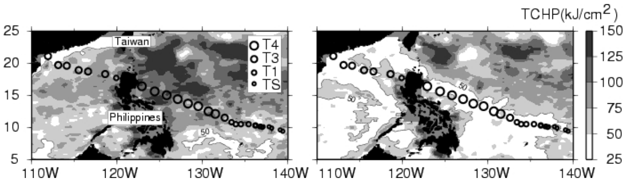

Figure 1. TCHP fields before (July 19, 2003) and after (July 23, 2003) Typhoon Imbudo.

5. TCHP EVALUATION IN THE SHIPS FORECAST MODEL

Over the past several years, the Statistical Hurricane Intensity Prediction Scheme (SHIPS) has been the most skillful intensity forecast model out to about 72 hours. DeMaria et al (2003) showed that the short-term (12-60 h) SHIPS forecasts have the potential to be improved by including the tropical cyclone heat potential (referred also as ocean heat content) data as a predictor. In that study, TCHP data was available for the Atlantic basin from 50-100^{o}W for the period 1995-2001 from the algorithm described by Mainelli (personal communication to Mark DeMaria). Results showed that the SHIPS forecasts were improved by a maximum of about 5% at 36-48 hours with additional TCHP input, in combination with predictors from GOES satellite infrared imagery. Further analysis showed that about half of that improvement was due to the TCHP input (~2.5%). Results also showed that the best statistical relationship between intensity change and TCHP was obtained by including only those TCHP values that exceeded 50 kJ/cm^2. Although this average forecast improvement is not very large, TCHP values exceed 50 kJ/cm^2 over only a small part of the Atlantic basin. Thus, the additional TCHP predictor had only a minor effect on most forecasts, but a much large impact on the few that crossed the high heat content regions.

The TCHP analyses in this study are global and extend back to 1992. This larger sample will be used to determine the potential to improve the SHIPS forecasts over the entire Atlantic and east Pacific basins (a separate version of SHIPS is also run for east Pacific storms). As a first test, the impact on the intensity forecasts was assessed using a dependent data sample. The 2003 operational version of SHIPS included 16 predictors, determined from a multiple regression analysis with all available cases from 1989-2002. For the impact study, this sample is restricted to those for which the TCHP analyses are available. For the TCHP sample, the regression coefficients are re-calculated; along with a measure of model intensity (maximum surface winds, measure in knots) forecast error. Then, the TCHP is added as a 17th predictor, and the reduction of the forecast error is evaluated.

Figure 2 shows the reduction in the intensity forecast error for all TCHP cases from the Atlantic basin, and for the western part of the Atlantic basin (initial storm positions west of 50^{o}W). The TCHP fields used here were obtained using weekly average of SHA and SST fields. These results show that for the total Atlantic basin, the forecast improvement is very small. However, for the western Atlantic sample, the improvements are 1-3%, which is consistent with the results of DeMaria (2003). This result indicates that the TCHP does not provide much information about tropical cyclone intensity change on the eastern side of the Atlantic, but has the potential to improve the forecasts on the western side. This result is not too surprising, since the TCHP gradients are larger on the western side of the basin, and there are more regions with TCHP exceeding 50 kJ/ cm^2. Figure 2 also shows the forecast improvements for the eastern Pacific basin. The improvements are generally smaller than for the Atlantic, but there may be some potential utility for the TCHP analyses on the eastern side of the east Pacific basin. Again, this is not too surprising because the largest values and gradients of TCHP in the east Pacific tend to occur near the west coast of Mexico. We expect that the use of daily instead of weekly SHA and SST fields will improve these estimates.

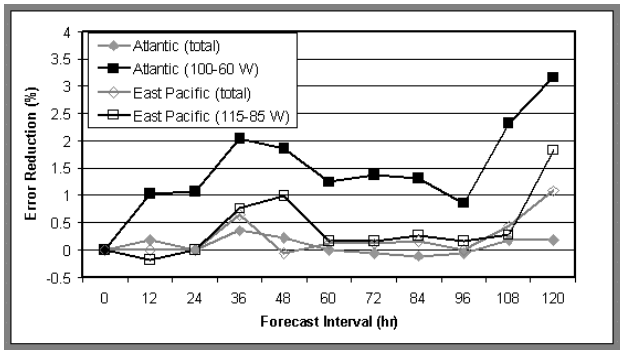

Figure 2. Reduction of intensity forecast in SHIPS using TCHP fields.

6. References

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