JP1.4

IMPROVEMENTS IN REAL-TIME STATISTICAL TROPICAL CYCLONE INTENSITY FORECASTS USING SATELLITE DATA

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1. INTRODUCTION

Although some progress has been made in the last few years, the skill of operational intensity forecasts is considerably less than that of the track forecasts (DeMaria et. al., 2002). For track forecasting, there is a suite of skillful global and regional prediction models available as guidance to the forecasters. For intensity, the three primary models for the Atlantic basin are the simple SHIFOR model which uses climatology and persistence to make prediction, the Statistical Hurricane Intensity Prediction Scheme (SHIPS) which includes storm environmental conditions in addition to climatology and persistence, and the NCEP version of the GFDL hurricane model. The SHIFOR model is primarily used as a benchmark for evaluating the skill of the official National Hurricane Center (NHC) intensity forecasts and those from the objective models. SHIFOR was recently updated using a larger developmental sample, and to provide forecasts to five days (Knaff et. al., 2003).

Figure 1 shows the average errors from the operational intensity models and the official NHC forecasts for a 5-year sample (1997-2001). Because the updated SHIFOR was not available until 2001, the results from the old version were used in this comparison. The errors from the GFDL model are larger than those from SHIFOR out to 36 hours, indicating that the short-range intensity forecasts are not skillful. This lack of skill is not too surprising considering the difficulty of initializing a model in the region of a tropical cyclone where convective and boundary layer processes are of first-order importance, but the observational data is usually sparse. The SHIPS and NHC Official forecast errors are somewhat smaller than those of SHIFOR, indicating modest skill.

The predictors for SHIPS include climatology and persistence, parameters for the atmospheric environment (vertical shear, etc), and sea surface temperature, but contain relatively little information about the storm itself or the sub-surface ocean structure. In this paper, the potential for improving SHIPS using predictors from GOES infrared imagery (10.7 μm) and the ocean heat content (OHC) estimated from satellite altimetry data is evaluated for an independent set of cases from real-time runs during the 2002 season. The experimental version of SHIPS with the GOES and OHC predictors is compared with the operational version of SHIPS that does not include the input from the satellite data.

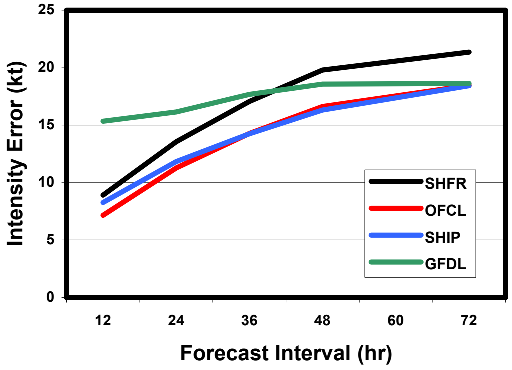

Figure 1. The average intensity errors (kt) from the SHIFOR, Official NHC, SHIPS, and GFDL forecast for 1997-2001. The verification is for a homogeneous sample of cases using the standard selection rules of NHC (storms of tropical storm strength or greater, extra-tropical and subtropical cases excluded). The sample sizes at 12, 24, 36, 48 and 72 h are 898, 803, 716, 638, and 508.

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2. THE OPERATIONAL SHIPS MODEL

DeMaria and Kaplan (1999) described the 1997 operational version of the SHIPS model. That version was developed from all Atlantic storm cases from 1989 to 1996. For each year since 1997, the cases from the previous year were added to the sample, and the prediction coefficients were re-derived. The sample for the 2002 season includes all Atlantic storms from 1989-2001. The sample for each forecast interval is restricted to cases that remained over the water.

Several other changes were made to the model since 1997. Beginning in 2000, the official NHC track forecast was used to determine the SST and atmospheric predictors, rather than the track from the barotropic LBAR model. Also in 2000, the forecasts over land were modified in a post-processing step using a simple empirical decay model. In 2001, the forecasts were extended from 72 to 120 h, and the NCEP global model was used to determine the atmospheric predictors out to 5 days. From 1997-2000, a 48-h forecast from an adiabatic atmospheric model was used for the atmospheric predictors.

Table 1 lists the 16 predictors included in the 2002 operational version of SHIPS. Static predictors (indicated by S) are evaluated only at t=0, and time dependent predictors (indicated by T) are averaged along the storm track from t=0 to the forecast interval. For example, for the 48 h prediction of intensity change, the vertical shear is averaged from 0 to 48 h at 12 h intervals. The effects of SST are included in predictors 8 and 15, since the maximum potential intensity is determined as a function of SST using an empirical formula. The coefficients for the predictors were determined using a standard multiple regression technique, where the dependent variable at each forecast time is the intensity change from the NHC best track (0-12, 0-24, …, 0-120 h). The 1989-2001 sample includes 1849 cases at 12 h, which reduces to 1031 by 72 h. All available tropical cyclones cases at 0000 and 1200 UTC (including unnamed depressions and the depression stages of named tropical cyclones) were included in the developmental sample.

Table1. 2002 Operational SHIPS Model Predictors

1.	Absolute value of (Julian Day – peak season value)	(S)
2.	Initial intensity	(S)
3.	200 hPa eddy momentum flux converge (0-600 km)	(S)
4.	200 hPa divergence (0-1000 km)	(S)
5.	Pressure level of storm steering	(S)
6.	Zonal component of storm motion	(S)
7.	Maximum wind change during the past 12 h	(S)
8.	Maximum potential intensity – current intensity	(T)
9.	850-200 hPa vertical shear (200-800 km)	(T)
10.	200 hPa zonal wind (200-800 km)	(T)
11.	200 hPa temperature (200-800 km)	(T)
12.	850-700 hPa relative humidity (200-800 km)	(T)
13.	850 hPa relative vorticity (0-1000 km)	(T)
14.	Vertical shear times sine of storm latitude	(T)
15.	Square of potential-current intensity	(T)
16.	Initial intensity time shear	(T)

3. GOES AND ALTIMETRY PREDICTORS

The GOES data for the experimental version of SHIPS were obtained from the archive maintained by the Cooperative Institute for Research in the Atmosphere (CIRA). Since 1995, channel 4 infrared imagery (10.7 μm) from GOES-8 for nearly all of the Atlantic tropical cyclones were collected (Zehr 2000). The imagery for each storm was re-mapped to a 4 km Mercator projection. The brightness temperatures (BTs) were then azimuthally averaged on a 4 km, storm-centered radial grid. The BT standard deviations from the azimuthal average were also calculated at each radius. The SHIPS database consists of forecast cases at 0000 and 1200 UTC. The GOES BT data closest in time to each of the SHIPS forecast cases were obtained. In all cases, the GOES data was within one hour of the time from the corresponding SHIPS case.

Many studies have shown that the heat content through some depth of the ocean is important for tropical cyclone intensity change (e.g., Shay et. al., 2000). Through the retrieval and analysis of high resolution blended TOPEX/Poseidon (T/P) and European Research Satellite (ERS-2) radar altimetry data in combination with hydrographic data, the OHC relative to 26^{o}C water was estimated by applying the approach described by Mainelli-Huber (2000). OHC analyses in the pre-storm environments from most cases were available back to 1995 over a domain that extends from 0-40^{o}N and 100-50^{o}W.

If predictors from the GOES and altimetry data were combined with those from the operational SHIPS model, it would be necessary to reduce the sample size, because these new data were only available back to 1995, and only over a limited part of the Atlantic basin. To overcome this problem, a two-step prediction procedure was applied. In the first step, the SHIPS model with full data sample (1989-2001) was derived as before. Then, the difference between the SHIPS predictions and the observed intensity changes were calculated. These differences were then used as the dependent variables in a second multiple regression, where parameters from the GOES and altimetry data are the independent variables. The sample for this second regression includes 578 cases at 12 h, which reduces to 314 cases at 72 h.

The second regression step includes two predictors from the GOES data and one from the altimetry data. The GOES predictors are the percent of the area from 50 to 200 km from the storm center where the GOES BT is colder than -20^{o}C, and the standard deviation of the GOES BT (relative to the azimuthal average) averaged from 100 to 300 km. The altimetry predictor is OHC above 50 kJ/m^2, averaged along the storm track. Using the previous terminology, the GOES parameters are static predictors, and the altimetry parameter is a time dependent predictor. The OHC generally exceeds 50 in the Caribbean, near warm-core eddies in the Gulf of Mexico, and along the Gulf stream (see Fig. 2). Analysis of the results with the dependent data indicates that the satellite data has the potential to reduce the errors by about 5%.

In real time the operational SHIPS uses the predictors from the first regression, and a correction is applied using the second regression to provide the experimental SHIPS forecast. In real-time, the GOES data is obtained from a dataset maintained on the NCEP IBM, and the OHC analyses are run daily at NHC using the previous 10 days of altimetry data, over a domain that includes the entire Atlantic basin to 60°N. Figure 2 shows an example of the OHC content analysis for September 26, 2002 used as input for the experimental version of SHIPS.

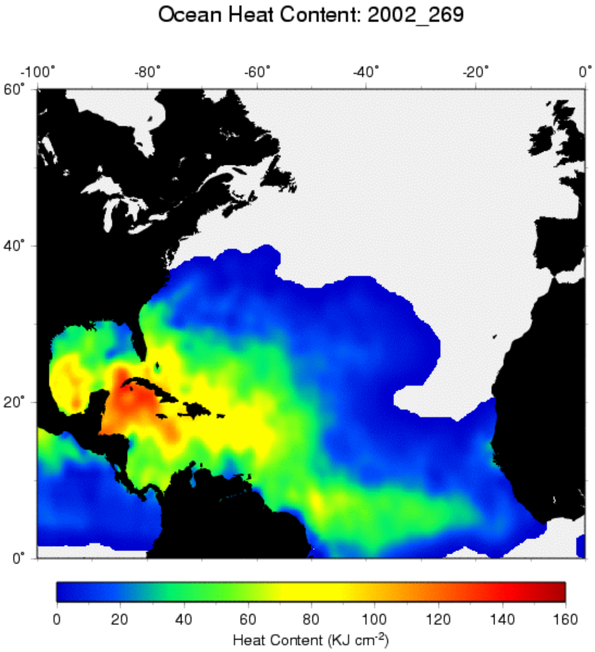

Figure 2: Ocean heat content derived from satellite altimetry data for Sept. 26, 2002.

4. PRELIMINARY RESULTS

The experimental version of SHIPS with the satellite predictors was implemented on the NCEP IBM computer on August 20, 2002 and is run just after the operational SHIPS model. In the following preliminary analysis, all forecast cases through 12 UTC on September 26, 2002 are included. As of this date, the experimental SHIPS was run for all forecasts of nine named tropical cyclones (Dolly-Lili). The intensity forecasts were validated for all cases of tropical storm strength or greater using the NHC working best track.

So far, the 2002 season has proved to be a challenging year for intensity forecasting. Many of the early storms were in highly sheared environments, and failed to develop beyond tropical storm stage. The exception was hurricane Isidore which intensified rapidly until it struck the Yucatan peninsula and rapidly weakened. Figure 3 shows the average errors from SHIFOR (updated version) and the operational and experimental SHIPS models for the 2002 season so far. Comparing Fig. 3 with Fig. 1 shows that the errors from SHIFOR and SHIPS are much larger than the long-term average, and that the errors from SHIPS are larger than those from SHIFOR, indicating no skill. However, the experimental SHIPS errors are smaller than those of the operational SHIPS out to 60 h, indicating that the satellite data do improve the forecasts.

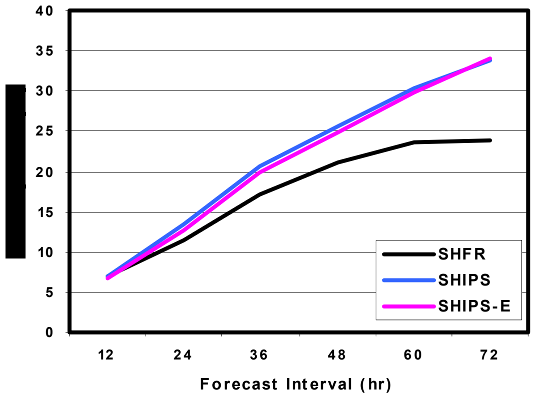

Figure 3. The average intensity errors (kt) from the SHIFOR, operational SHIPS and experimental SHIPS forecasts for the period Aug., 20-Sept. 26, 2002. The verification is for a homogeneous sample of cases using the standard selection rules of NHC (storms of tropical storm strength or greater, extra-tropical and subtropical cases excluded). The sample sizes at 12-72 h are 108, 91, 76, 63, 52 and 42.

The large 2002 forecast errors in Fig. 3 relative to the previous 5-year averages in Fig. 1 are primarily due to the Isidore forecasts. Isidore became a tropical storm to the south of Jamaica in the western Caribbean on September 18, 2002. As seen in Fig. 2, this is an area of very high heat content, and the storm rapidly intensified to a strong category 3 hurricane over the next four days as it moved northward and then westward. The difficulty with the intensity forecasts occurred during the period when Isidore moved westward after crossing the western tip of Cuba. The official track forecasts indicated that the storm would remain just offshore of the Yucatan peninsula, and thus, the statistical forecasts were not adjusted to account for landfall. In reality, the storm moved further south than expected and stalled over Yucatan for about 24 h, before finally moving northward and striking Louisiana as a strong tropical storm. During the time when Isidore was over the Yucatan, it decayed to a weak tropical storm, but for several time periods, the SHIPS forecasts were based upon a storm track over the water, with nearly ideal oceanic and atmospheric conditions, resulting in errors of up to 100 kt.

To help remove the influence of the track forecasts and interaction with land on the ability of the satellite data to improve the SHIPS forecasts, the verification for the 2002 season was repeated, but only for cases where the storms remained over the water. For this comparison, the post-processing step that corrects for land was by-passed to obtain SHIPS forecasts without the influence of land. Figure 4 shows that with the sample restricted to the cases over water, the intensity errors are considerably smaller than for the total sample shown in Fig. 3, and are closer to the longer-term averages in Fig. 1. The SHIPS errors for this sample are closer to those from SHIFOR, but are still slightly larger. The experimental SHIPS errors are again smaller than those from the operational SHIPS, except at 48 h.

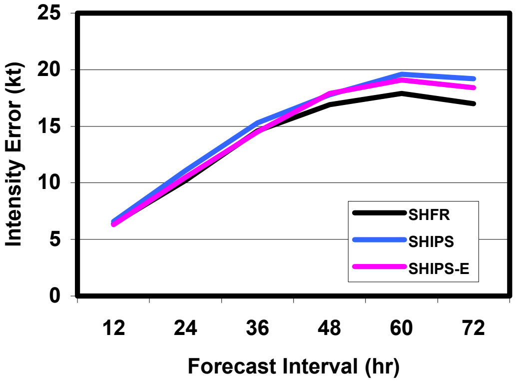

Figure 4. The average intensity errors (kt) from the SHIFOR, operational SHIPS and experimental SHIPS forecasts for the period Aug. 20-Sept. 26, 2002 for those cases that remained over the water. The verification is for a homogeneous sample of cases using the standard selection rules of NHC (storms of tropical storm strength or greater, extra-tropical and subtropical cases excluded). The sample sizes at 12-72 h are 101, 80, 60, 44, 34, 24.

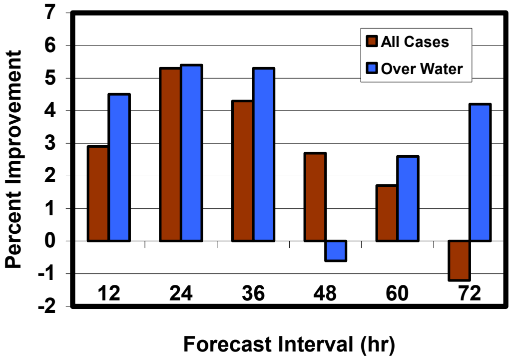

Figure 5. The percent improvement (error reduction) of the experimental SHIPS forecasts relative to the operational version for all available cases of tropical storm strength or greater and for cases that remained over the water.

Figure 5 shows the percent improvement of experimental SHIPS relative to the operational version for the total sample, and for the cases that remained over water. Similar to the results from the dependent data, the satellite predictors improve the forecasts by up to about 5%. For the total sample, the largest improvements occur at 24 h. For the over water sample, there is also some improvement at 60 and 72 h. It is possible that the difficulties due to the interaction of Isidore with land overshadowed any improvements in the longer ranges.

The experimental version of SHIPS will be run during the remainder of the 2002 season, and the verification and comparison with the operational version will be performed after the season with a larger data sample, and using the final NHC best track intensities.

5. CONCLUDING REMARKS

The preliminary results of this study suggest that the parameters from the GOES brightness temperatures and the ocean heat content estimates from satellite altimetry data improve the operational SHIPS model forecasts by about 5%. A more comprehensive evaluation will be performed at the end of the 2002 hurricane season.

Results from this study also illustrate the sensitivity of the intensity forecast to the track forecast. Hurricane Isidore was an extreme example, where the track forecasts for many cases remained just north of Yucatan, but the actual storm stalled over land for about 24 h. Thus, the SHIPS model predicted continued intensification of this category 3 hurricane, but the observed storm rapidly decayed to a weak tropical storm during this period, resulting in forecast errors of up to 100 kt.

Because the SHIPS prediction is linear, the contributions from the GOES and OHC predictors can be evaluated separately. This analysis will be performed after the 2002 season is completed. Work is also underway to modify the operational version of SHIPS for the east Pacific basin to include predictors from GOES. At the present time, the OHC analysis is not available for the east Pacific, so the impact of this factor can not be evaluated. Work is also underway to determine if additional parameters with predictive information can be extracted from the GOES imagery.

This work was performed as part of the Joint Hurricane Test-bed of the U.S. Weather Research Program. If the preliminary results are confirmed at the end of the season, the version of SHIPS with the satellite data will become operational for the 2003 hurricane season.

ACKNOWLEDGMENTS

This work was partially supported by a grant to CIRA from the NOAA U.S. Weather Research Program. L.K. Shay was supported by the National Science Foundation through Grant ATM-01-08218. Tom Cook developed the real-time satellite-derived heat content analyses and Ms. Inger Solheim assisted with the processing of the GOES data.

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