Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models

Principal Investigator(s): Galina Chirokova: Galina.Chirokova@colostate.edu
Andrea Schumacher: Andrea.Schumacher@colostate.edu
CIRA/CSU, Fort Collins CO
Collaborator: John Knaff: John.Knaff@noaa.gov
NOAA/NESDIS/StAR, Fort Collins, CO

This Progress Report Period – 09/01/2015 – 03/30/2016
Entire Project Period – 09/01/2015 – 08/31/2017

1. General Description of Progress

Databases of tropical cyclone (TC) size parameters and daily Reynolds Sea Surface Temperature (SST) have been created. The 2015 version of the Statistical Hurricane Intensity Prediction Scheme (SHIPS)/ Logistic Growth Equation Model (LGEM)/ Rapid Intensification Index (RII) code has been modified to work with daily SST and dependent sample testing and retrospective reruns of the modified code have been completed. A statistical-dynamical method for forecasting TC structure and minimum sea level pressure (MSLP) has been developed and tested. The parallel runs of SHIPS/LGEM/RII and TC-size forecasts are planned to be setup at CIRA for the 2016 hurricane season. The modified SHIPS version producing the best forecasts will also be implemented in the quasi-production version of SHIPS on Weather and Climate Operational Supercomputing System (WCOSS) for the 2016 season.

2. Transition to Operations

a. Summary of testbed-related activities and outcomes

The following testbed-related activities are ongoing and planned:

1) TC-size estimates for 2013-2014 were provided to National Hurricane Center (NHC) in December 2015.
2) The possibility of including Decay SHIPS Wind Radii (DSWR) and MSLP estimates in operational Automated Tropical Cyclone Forecast System (ATCF) A-decks is being discussed with NHC points of contact (POCs).
3) SHIPS/LGEM parallel runs with daily SST and constant depth-averaged temperature will be set up at CIRA for the 2016 hurricane season. The modified SHIPS version producing the best forecasts will be also be implemented in the quasi-production version of SHIPS on WCOSS for the 2016 season.

b. What was transitioned?

The transition to operations for this project is scheduled at the end of Year 2 (see item e below). However, some minor computer bugs in the SHIPS/LGEM/RII processing were identified in the course of this work, and will be corrected in the 2016 operational version of the NHC guidance suite on WCOSS.

c. TRL* current vs. start of project

The start of project was TRL3, current level is TRL5.

d. Lessons learned

The project is on schedule and all milestones have been completed as planned. Independent testing on limited number of cases showed larger biases that expected for DSRW TC-size estimates. These biases will be addressed and corrected is possible.

e. Next steps – future plans

i. Has it been approved for transition yet? Plans for future transition?

The transition to operations for this project is scheduled at the end of Year 2, in summer of 2017, if accepted by NHC. The project is on schedule and both the upgraded SHIPS/LGEM/RII code and new TC-structure forecast code will be ready for operational transition by summer 2017. The timing of the final transition will depend on the availability of NHC Technology and Science Branch (TSB) resources.

3. Milestones

a. Completed

1) Create databases of TC size parameters and daily Reynolds SST (Oct 2015)

TC size parameters were calculated from the most recently collected infrared (IR) imagery in the CIRA TC IR image archive. These were used to create an independent variable (the normalized temporal variation of TC size) for the Atlantic, East/Central Pacific, Western North Pacific and Southern Hemisphere TC basins.

The database of daily Reynolds Sea Surface Temperature (DSST) with daily 0.25° resolution (Reynolds at al., 2007) has been created. Data in NetCDF format have been downloaded from ftp://eclipse.ncdc.noaa.gov/pub/OI-daily-v2/NetCDF/. Python and FORTRAN code has been developed for downloading, reading, and interpolating data. Weekly Reynolds SST (RSST) are provided with missing and land values filled. DSST, however have missing values, land, and ice values. These missing values were filled using very simple nearest neighbor interpolation scheme. The purpose of that interpolation is to simplify further processing and to make the dataset independent of the specific land mask used. Finally, interpolated data were converted to the ASCII data format that is currently used for the RSST data used by the operational SHIPS/LGEM models. All available data, from 1981 to 2016 were processed. That allowed for the creation of data for the full time period used by the SHIPS developmental database, currently 1982 - 2015.

2) Modify SHIPS code to use daily, 0.25° Reynolds SST (Nov 2015)

The most current, 2015 version of the SHIPS/LGEM code has been modified to use daily, 0.25° Reynolds SST. The new variable, observed SST, together with the flag to use either weekly or daily SST, has been added to the code. In addition, necessary modifications have been added to the code to make sure SST data are processed in a consistent manner by different pieces of the code. Multiple test runs, including several reruns for the years 2004 - 2015 have been completed to make sure that the code has not been broken by the additions and produces the same results as before while using weekly SST data. It is not possible to make reruns prior to the year 2004 because full model forecast data are not available prior to 2004.

3) Adapt SHIPS statistical code to predict storm structure (Dec 2015)

Using the TC size database, the independent variable (ΔF_{R5}; the change of normalized TC size from the initial time) was used to create separate linear regression models to predict ΔF_{R5} in the Atlantic, East/Central Pacific, Western North Pacific and Southern Hemisphere TC basins. Findings suggest that other than SST, potential intensity and initial intensity, which suggest that storms generally grow over warm and warming SSTs, the most important environmental factors are mid-level moisture (+), initial size (-), and divergence at 200 hPa (+), sign of the relationship provided in the parentheses. Average storm latitude also is important for TC growth.

The FORTRAN code has been written that 1) applies the multiple regression coefficients to predict ΔFR5 from SHIPS large-scale diagnostics and the advisory information and Decay SHIPS/SHIPS (DSHP/DSHA ATCF tech names) track and intensity forecasts, 2) uses the SHIPS intensity forecast, associated track forecast, and the initial wind radii and estimates the parameters associated with a modified Rankine vortex, 3) creates wind radii estimates from the vortex information, and 4) estimates the MSLP based on the intensity, wind radii, motion, and latitude. The methodology of how estimates of TC size (R5) which are created by combining forecasts of ΔFR5 with forecasts of intensity, and the initial TC size (R5(t=0)), can be used to construct the modified Rankine vortex used in the work can be found in Knaff et al. (2016).

Results of independent forecasts for the Atlantic and East Pacific (2013 - 2014) were presented at the Interdepartmental Hurricane Conference (IHC) on 15-17 March in Miami, Florida. An example of the output displayed using the web ATCF and a lot of help from C. R. Sampson (Naval Research Laboratory) is shown in Figure 1. No validation of MSLP has been done at this time.

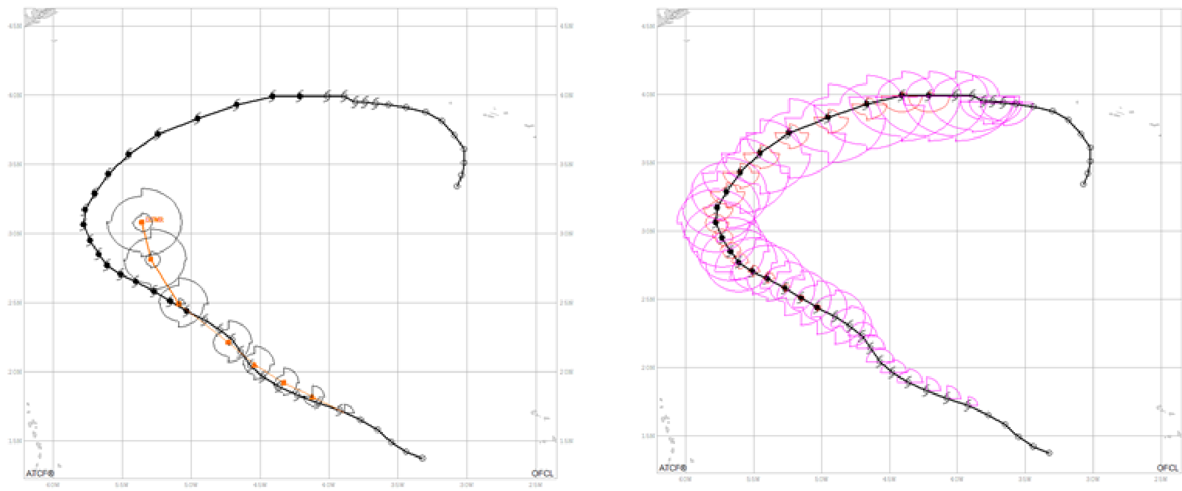

Figure 1: Example of DSWR wind radii forecasts for Hurricane Edouard (2014) initialized on 12 September 00 UTC.

Scripts that collect real-time SHIPS forecasts in the Atlantic, East/Central Pacific, Western North Pacific and Southern Hemisphere TC basins, apply this FORTRAN code, and create forecasts in the ATCF format (ATCF tech name DSWR) have been developed and are running at CIRA. We have begun the coordination with NHC (M. DeMaria, M. Bozeman, C. Mattocks) to get these experimental forecasts in the real time ATCF A-decks.

4) Run SHIPS dependent sample statistics for the years 2005-2013 and complete retrospective SHIPS runs with daily SST (Jan 2016)

1) SHIPS dependent sample statistics runs for the years 1982 - 2014 have been completed. The dependent sample statistic tests are conducted using model analysis rather than forecast fields. The SHIPS diagnostic files for the years 1982 - 2014 for the Atlantic and East Pacific basins have been created, and DSST data for each case have been added to these files. New coefficients for both SHIPS and LGEM for use with DSST were developed from multiple regression. Interestingly, it was found that in approximately 70% of the cases' daily SST along the storm track is colder than weekly SST. One possible explanation is that the SST is cooled by the winds ahead of the storm, and weekly SST are most of the time too old to capture that effect.

2) Retrospective runs of SHIPS/LGEM with new coefficients have been completed for Atlantic (AL) and East and Central Pacific (EP and CP) basins. Figure 2 shows mean absolute errors (MAE) for the results of the run with new coefficients using dependent data for 2004 - 2014. For SHIPS for both AL and EP there are no significant changes in MAE. The same is true for LGEM in the AL. The most interesting result here is the LGEM forecast improvement for the EP, with almost 4% improvement for 108 - 120 hr forecast times. There are only a very small number of CP cases available, but these data are shown for completeness. Biases are slightly improved for SHIPS for both AL and EP, and for LGEM for EP (not shown).

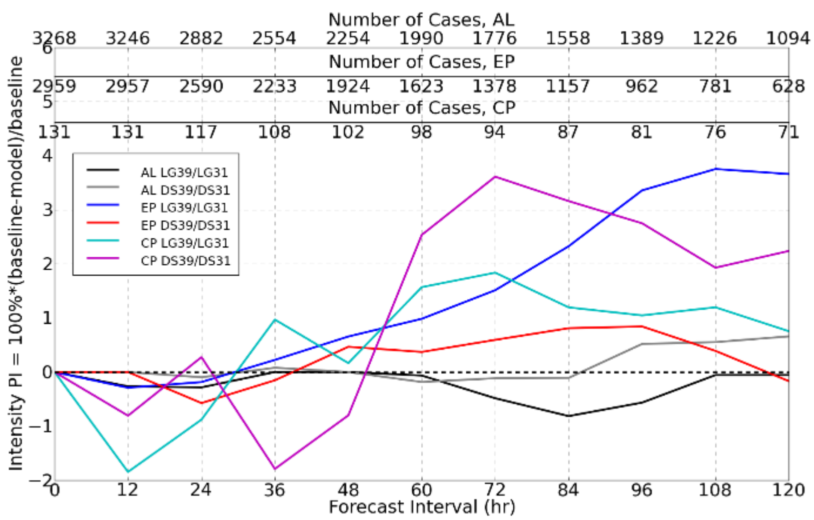

Figure 2. MAE for retrospective SHIPS/LGEM runs for 2004-2014, using coefficients derived for daily SST based on the 1982-2014 dependent sample statistics. Percent improvement is shown for the updated model (Run 39) with daily SST relative to the baseline model with weekly SST and old coefficients (Run 31).

Retrospective runs for the independent 2015 data show similar results, with most significant MAE improvement for LGEM for the EP (Figure 3, upper). Most of the biases are slightly improved for short-time forecasts (up to 72 hours), but AL biases are getting worse after 72-96 hours (Figure 3, lower). The effect of using daily SST has been also evaluated by looking at individual storms from 2015 season. The results were consistent with the overall statistics. For example, it was found, that for Hurricane Blanca, ep022015, there is no significant improvement. Slight improvement in both MAE and biases were found for Hurricane Patricia, ep202015, the strongest AL/EP storm on record. These improvements, however, were relatively small compared to the overall forecast errors for that case.

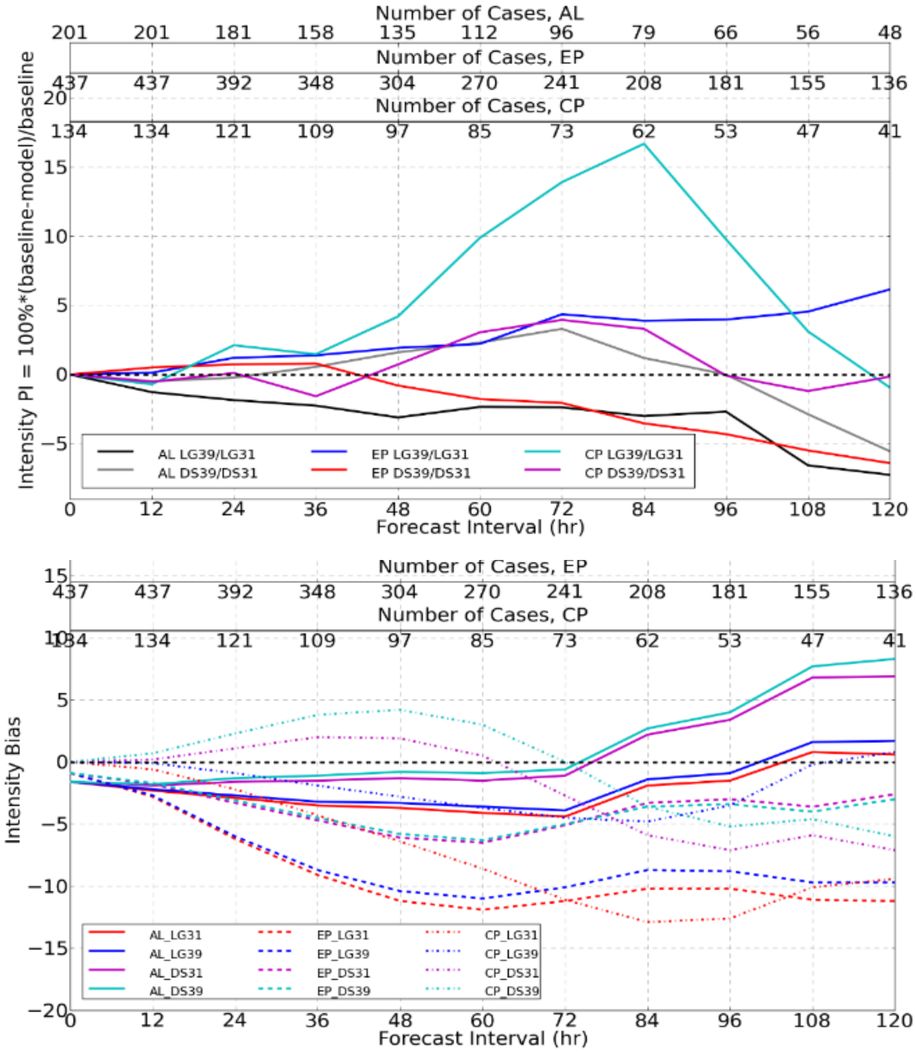

Figure 3. MAE (Left) and bias (Right) for retrospective SHIPS/LGEM runs for independent 2015 data, using coefficients derived for use with daily SST based on the 1982-2014 dependent sample statistics. Percent improvement is shown for the updated model (Run 39) with daily SST relative to the baseline model with weekly SST and old coefficients (Run 31).

3) The next step will be to use daily SST to add ocean depth-averaged temperature to SHIPS/LGEM, which is a better estimate of ocean-TC interaction than ocean heat content (OHC), as described by Lin (2013) and Price (2009). The depth-averaged temperature can be estimated as

$$T_{\bar{d}}(x,\ y) = \frac{1}{d}\int_{-d}^{0} T_i\ (x,\ y, z)dz,$$

where *d* is the depth of vertical mixing caused by TC. Preliminary dependent sample tests using 2005 - 2013 data show that including depth-averaged temperature assuming constant mixing depth should result in up to 3.8 % forecast improvements for SHIPS (see Figure 4). In the second year, the mixing depth for calculating depth-averaged temperature will be parameterized as a function of basic storm parameters such as translational speed and latitude.

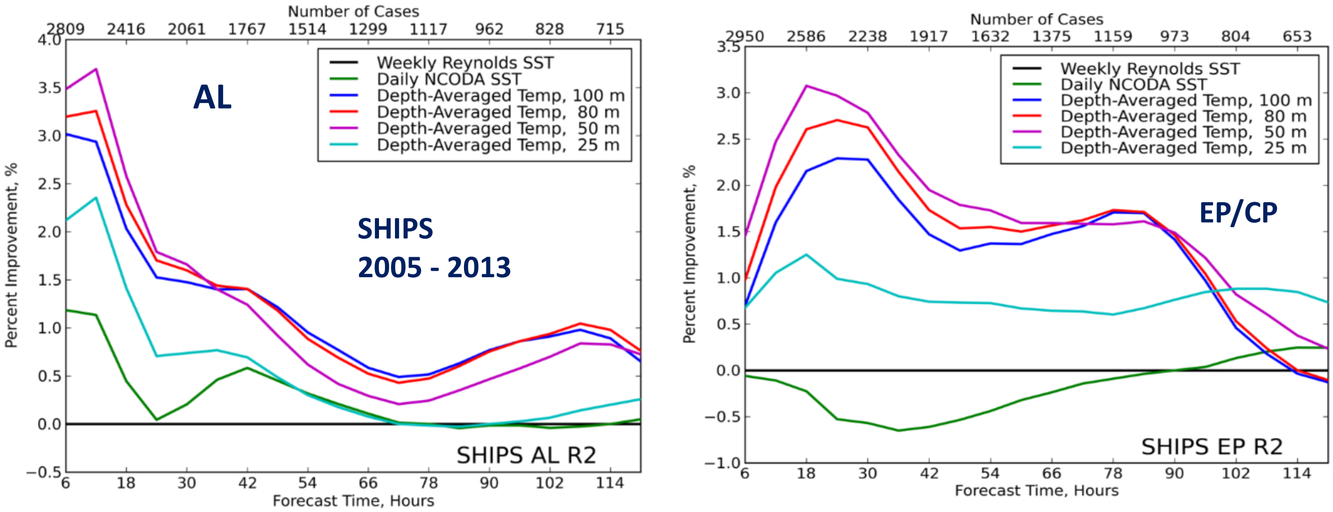

Figure 4. Results of the dependent sample statistics for SHIPS using 2005 - 2013 constant depth depth-averaged temperature for Atlantic (left) and East and Central Pacific (right) basins. These results show that use of temperature averaged over the upper 50 m of the ocean could result in up to 3.8 % MAE improvement for Atlantic and up to 3 % improvement for East Pacific basin.

5) Present year 1 results at IHC and gather feedback (Mar 2016)

G. Chirokova (PI) presented a talk at the IHC (listed in presentations section). In addition, G. Chirokova and J. Knaff discussed project progress with Christopher Landsea and Daniel Brown. It was suggested that the effect of the radius of maximum winds (RMW) on the RII may be investigated to complement the part of the project related to the addition of TC size forecasts to SHIPS/LGEM. This will be investigated if time permits.

b. Not completed

- None -

i. Reasons

ii. Mitigation plan

4. Publications

a. Journal articles published**

Knaff, J.A., C. J. Slocum, K. D. Musgrave, C. R. Sampson, and B. R. Strahl, 2016: Using routinely available information to estimate tropical cyclone wind structure. *Mon. Wea. Rev*., **144**:4, 1233-1247. DOI: http://dx.doi.org/10.1175/MWR-D-15-0267.1

b. Journal articles in process (what stage?)

- None -

c. Other publications/presentations

Chirokova, G., J. Knaff, and A. Schumacher, 2015: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models. Presentation at IHC, March 15 - 17, 2016, Miami, Florida. *This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under Grant No. NA15OAR4590204.*

5. References

I.-I. Lin, P. Black, J. F. Price, C.-Y. Yang, S. S. Chen, C.-C. Lien, P. Harr, N.-H. Chi, C.-C. Wu and E. A. D'Asaro, 2013: An ocean coupling potential intensity index for tropical cyclones. *Geophysical Res. Letters*, **40**, 1878–1882. DOI: 10.1002/grl.50091

Price, J. F., 2009: Metrics of hurricane-ocean interaction: vertically-integrated or vertically-averaged ocean temperature. *Ocean Sci*., **5**, 351-368, doi:10.5194/os-5-351-2009.

Reynolds, R. W., T. M. Smith, C. Liu, D. B. Chelton, K. S. Casey, and M. G. Schlax, 2007: Daily high-resolution blended analyses for sea surface temperature. *J. Climate*, **20**, 5473-5496.

*Technical Readiness Levels (TRLs) are defined below:

TRL 1: Basic principles observed and reported
TRL 2: Technology concept and/or application formulated
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4: Component/subsystem validation in laboratory environment
TRL 5: System/subsystem/component validation in relevant environment
TRL 6: System/subsystem model or prototyping demonstration in a relevant end-to-end environment
TRL 7: System prototyping demonstration in an operational environment
TRL 8: Actual system completed and "mission qualified" through test and demonstration in an operational environment
TRL 9: Actual system "mission proven" through successful mission operations

** Please include full reference and DOI (http://www.apastyle.org/learn/faqs/what-is-doi.aspx). For your publications and presentations, please include language crediting NOAA/OAR and the USWRP for supporting your projects. Suggested language is as follows:

"This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under Grant No. XXXXXXX."

If your project does not have a grant number, then you can exclude that part of the statement.