ANNUAL PROJECT REPORT

NOAA/OAR Joint Hurricane Testbed

Federal Grant Number: NA15OAR4590205

Probabilistic Prediction of Tropical Cyclone Rapid Intensification Using Satellite Passive Microwave Imagery

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Final Annual Report? No

1. ACCOMPLISHMENTS

The primary **goal** of this project is to improve the probabilistic prediction of rapid intensification (RI) in tropical cyclones (TCs). The framework in which we work is probabilistic models. We specifically are innovating upon existing statistical models that use environmental and TC-centric predictors. The statistical models used in this work include the Statistical Hurricane Intensity Prediction System (SHIPS) RI Index (RII) (Kaplan et al. 2010, Kaplan et al. 2015; *Wea. Forecasting*) and the logistic regression and Bayesian models of Rozoff and Kossin (2011; *Wea. Forecasting*) and Rozoff et al. (2015; *Wea. Forecasting*).

The **objectives** of this project are to update the three statistical models to include a new class of predictors derived from passive microwave imagery (MI) evincing aspects of storm structure relevant to RI, using a comprehensive dataset of MI that includes all available relevant sensors, and to develop a skillful consensus model that can be tested and deployed in real-time operations.

Milestones

Before model development, we updated our MI developmental dataset. We already had a dataset of SSM/I, SSMIS, TRMM-TMI, and AMSR-E (Rozoff et al. 2015) for 1998-2013. We updated this data to include the 2014-2015 time period as well, at least for those sensors that were still operational. In addition, we have added AMSR2 and GMI data to this dataset.

We are interested in focusing on predictors derived from three different channels, including the 18.7, 36.5, and 89.0-GHz channels of AMSR-E/2 and GMI. To use predictors from all satellite platforms in a consistent way, we calibrated the 19.35, 37.0, and 85.5/91.7-GHz channels of the other sensors to the AMSR-E/2 and GMI channels. The simple histogram matching technique described in Rozoff et al. (2015) was used for calibration.

With the updated developmental dataset, we have continued to use the simple inner-core MI-based predictors of Rozoff et al. (2015) in our model development, but have also developed new predictors describing aspects of storm structure. The new predictors can be summarized as follows:

a. Asymmetric structure predictors (including predictors describing rainband structure), derived from two-dimensional empirical orthogonal functions (Rozoff and Knaff 2016; *J. Appl. Meteor. Clim.*, to be submitted) and parameters from the Automated Rotational Center Hurricane Eye Retrieval (ARCHER) algorithm (Wimmers and Velden 2010; *J. Appl. Meteor. Clim.*),
b. Inertial stability and latent heating coupling parameters that can be determined from the MI alone. These kinematic and thermodynamic parameter estimates are derived using a developmental dataset of aircraft reconnaissance wind data, attendant HURDAT data, and matching MI (Rozoff and Knaff 2016),
c. Logistic regression, Bayesian, and SHIPS-RII models derived with respect to the stage of RI to better characterize the physical evolution of storm structure during RI.

The (a) and (b) type predictors have been derived but the approach of (c) is in progress.

A model consensus was developed. The logistic regression, Bayesian, and SHIPS-RII models of Kaplan et al. (2015; *Wea. Forecasting*) were updated to include MI-based predictors (1998-2012). So far, the predictors from the Rozoff et al. (2015) paper were the most skillful, although we will continue to refine these models. The consensus produced the highest score in independent testing. For example, the Brier Skill Score is provided below for the three models and their consensus for the Atlantic. Leave-one-year-out cross validation with the developmental data was used to determine the forecast skill, thereby providing an independent measure of forecast skill.

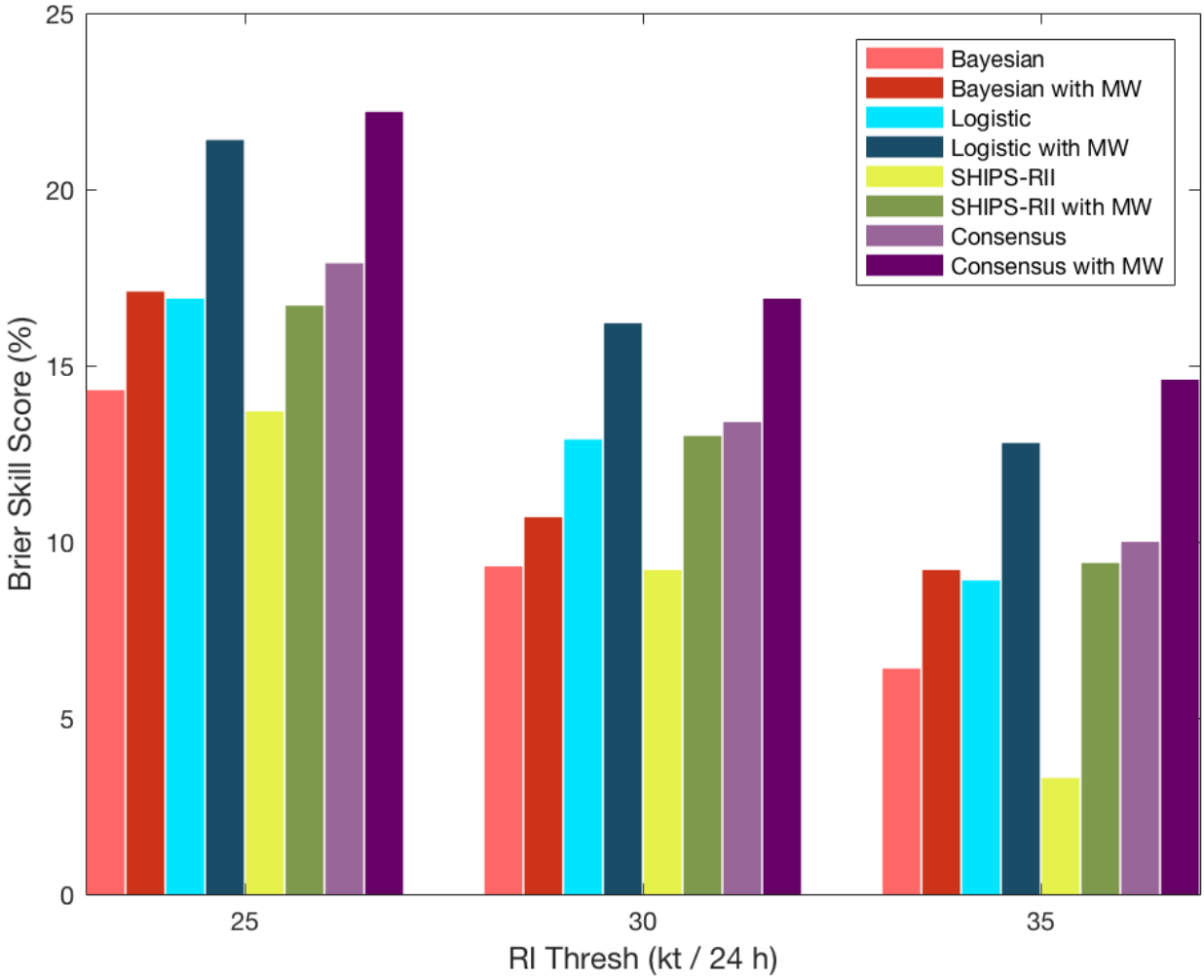

Figure 1. Brier skill scores for the Bayesian, logistic regression, and SHIPS-RII models and their consensus at 25, 30, and 35 kt (24 h)$^{-1}$ RI thresholds without MI-based predictors (light colors) and with MI-based predictors (darker colors) for the Atlantic Ocean.

Status of Project Tasks / Milestones

In the following table, we lay out the tasks that we had originally proposed and the status of these tasks.

Task	Proposed Activity	Status
1	Update developmental dataset to include MI of Atlantic and Eastern Pacific TCs from all available sensors (1998-2016). [September 2015 – January 2017]	Completed (with updates ongoing)
2	Examine and test for significance of new MI-based predictors. [September 2015 – January 2016]	Completed
3	Update logistic regression model to incorporate improved MI predictors and evaluate on retrospective and real-time cases. [January – March 2016]	Completed
4	Enhance the Bayesian and linear discriminant analysis-based SHIPS-RII models with up-to-date MI dataset. [January – March 2016]	Completed
5	Evaluation of updated SHIPS-RII and Bayesian models on retrospective dataset. [March – May 2016]	Completed
6	Convert code from Matlab (development framework) to Fortran and C so that code is portable to NCEP operations. [April 2016 – January 2017]	In progress
7	Real-time testing of models in the Atlantic and Eastern Pacific and continue reforecasts of previous seasons in simulated operational conditions with archived real-time data. [May – November 2016]	Behind Schedule
8	Evaluation of models and model updates, if necessary. [January – June 2017]	Not started
9	Prepare final NCEP-ready code and documentation for running and maintaining models at the conclusion of the project. [February – August 2017]	Not started
10	Operational 2nd real-time (likely first trial now) if resources permit. [June – August 2017]	Not started

As can be seen, significant progress has been made on major tasks. One task that has fallen behind schedule is the real-time product for the 2016 Hurricane Season. While this is unfortunate because it would have provided an opportunity for forecasters and our National Hurricane Center (NHC) contacts to see how our product behaves in real-time, we will still be able to evaluate our product on the 2016 season post-season. These results will be shared with our NHC contacts.

What opportunities for training and professional development has the project provided?
None to report.

How were the results disseminated to communities of interest?
We will provide results on a webpage and share that webpage with our points of contact at NHC. Results have been presented at conferences and a publication will be produced at the project's

completion. We will provide a real-time version of our algorithm to NHC at the end of the project.

What do you plan to do during the next reporting period to accomplish the goals and objectives?
We will complete the real-time implementation of the new models and provide the results on a web page. However, due to the late stage of the 2016 hurricane season at the time of this report, a post-season evaluation of how the models perform on the real-time data will be completed in the next two months and shared with our points-of-contact at the NHC. We will also continue to work on developing a real-time Fortran/C-based algorithm that can operate successfully on NOAA computers.

2. PRODUCTS

Presentations
Rozoff, C. M., C. S. Velden, and J. Kaplan, 2016: JHT Project 7: Probabilistic prediction of tropical cyclone rapid intensification using satellite passive microwave imagery. *Presentation at the 2016 Tropical Cyclone Operations and Research Forum, Miami, FL, 16 March 2016.* [Available online at: http://www.ofcm.gov/ihc16/Presentations/Session%204/07-jht_rozoff.pdf]

Rozoff, C. M., C. S. Velden, and J. Kaplan, 2016: Probabilistic prediction of tropical cyclone rapid intensification using passive microwave imagery. *Poster Presentation at the 32nd AMS Conference on Hurricanes and Tropical Meteorology, San Juan, Puerto Rico, 19 April 2016.* [Available online at: https://ams.confex.com/ams/32Hurr/webprogram/Paper292814.html]

Publications
None to report. However, we will submit a paper on the results of this project at the project's conclusion.

Products
None to report. However, we will submit a Fortran/C-based algorithm of the MI-enhanced RI models to be run on NOAA HPC systems at the conclusion of this project, along with a technical manual and personnel support.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?
Christopher Rozoff, PI, Christopher Velden, Co-PI

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?
No

What other organizations have been involved as partners? Have other collaborators or contacts been involved?
Forecasters and Program Officials (e.g., Shirley Murillo and Christopher Landsea) at the National Hurricane Center/Joint Hurricane Testbed have been in contact with us to find out the status of our real-time products.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?
We anticipate that this project will improve one of the NHC's most reliable forecast tools for predicting RI in TCs, thereby helping NHC improve intensity prediction of TCs. While this project is highly practical, the results of this project may also contribute to increased scientific understanding of intensification processes in TCs.

What was the impact on other disciplines?
While the impact may be minimal, other disciplines use the types of statistical models we have used in this project and therefore researchers may find our research useful.

What was the impact on the development of human resources?
None to report.

What was the impact on teaching and educational experiences?
None to report.

What was the impact on physical, institutional, and information resources that form infrastructure?
None to report.

What was the impact on technology transfer?
None to report.

What was the impact on society beyond science and technology?
Improved TC intensity prediction will be extremely valuable to society, particularly emergency management planning.

What percentage of the award's budget was spent in a foreign country(ies)?
0%.

5. CHANGES/PROBLEMS

The majority of this project has gone as planned. As stated earlier, however, the deployment of a real-time product in the 2016 hurricane season fell behind schedule. We will rectify this delay by providing a post-season analysis of our forecast product's real-time performance on archived real-time data. Also we plan a real-time test during the 2017 hurricane season.

6. SPECIAL REPORTING REQUIREMENTS

We report here on the project's Readiness Level as part of the Joint Hurricane Testbed.

Transition to operations activities
The statistical modeling framework is being developed to run in real-time and also in Fortran/C-based code (as opposed to the Matlab developmental framework) so that it will be readily able to run in an operational environment, including WCOSS high performance computing system.

Summary of testbed-related collaborations, activities, and outcomes
We are working with points of contact (POC) Christopher Landsea, John Beven, Daniel Brown, and Dave Roberts at the NHC for real-time analysis and testing. So far, we have not quite undertaken real-time testing, but will provide our POCs a performance evaluation of the algorithm applied to the 2016 hurricane season and on real-time implementation in 2017.

Has the project been approved for testbed testing yet?
No. 2016 real-time testing is to be performed on CIMSS computing platforms.

What was transitioned to NOAA?
Nothing at this time.

7. BUDGETARY INFORMATION

The project is on budget.

8. PROJECT OUTCOMES

What are the outcomes of the award?
We have developed a multi-model consensus of probabilistic models that predict the likelihood or rapid intensification in tropical cyclones. In particular, we have updated these models to use new predictors from satellite passive microwave imagery. This consensus model improves forecast skill over its constituent models and over the same models not employing microwave data.

Are performance measures defined in the proposal being achieved and to what extent?
Besides the delay in a real-time product, performance measures are being otherwise achieved.

NOAA READINESS LEVELS (RLs)

The NOAA Readiness Levels, according to NOAA Administrative Order 216-105A, can be applied to describe this project. The current project has achieved RL 2, but will have RL 2-9 by the conclusion of this project. The readiness levels that will apply to this project include the following:

- RL 2: Applied research: We have conducted an original investigation of new forecast techniques with the practical goal of developing a useful tool in operational forecasting. However, there are applications to basic research from our results as well. [*In progress*]
- RL 3: Proof-of-concept: While we are behind schedule, we still plan to show how this product performs in real-time. [*In progress*]
- RL 4: We will evaluate the forecast system at our institution, and perhaps in a real-time environment at NHC in 2017 as well, if possible. [*In progress*]
- RL 5: We will evaluate a final algorithm near the end of the project with the goal of having these models deployed in a real-time environment. [*To begin later*]
- RL 6: We will demonstrate the forecast scheme in a real-time environment during the 2017 Hurricane season. [*In progress; to ramp up later*]
- RL 7/8: The overall goal is to implement an improved real-time prediction tool for RI at the NHC (and perhaps the Joint Typhoon Warning Center), including complete documentation and support to implement it in real-time in the operational center. [*To begin later*]
- RL 9: We plan to deploy this system operationally. [*To be being later*]