PROJECT REPORT

NOAA/OAR Joint Hurricane Testbed

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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 Since Last Project Report

a. **Baseline and New Models**

Using SHIPS developmental data and new microwave developmental datasets, we have revised the new Bayesian, logistic regression, and SHIPS-RII models described in the last report. The previous models seemed to suffer from overfitting in real-time testing, so we reduced the number of new MI-based predictors. Conforming with the operational SHIPS-RII consensus model, we have derived models for the following RI thresholds: 20 kt / 12 h; 25, 30, 35, and 40 kt / 24 h; 45 kt / 36 h; 55 kt / 48 h; and 65 kt / 72 h.

Tables 1 and 2 show the baseline SHIPS predictors and new microwave-based predictors for the Atlantic models, respectively, while Tables 3 and 4 show the same for the Eastern Pacific models. Note, while the list of predictors below is large, any given model (including the MI-enhanced models) has anywhere from 5 to 11 predictors total.

Table 1. Baseline SHIPS predictors used in the Atlantic models. Note that the models may contain different predictors at various RI thresholds, so the thresholds for which a predictor is used is indicated below. Thresholds here are expressed as: (intensity increase in knots, period of time in hours).

Predictor	Bayesian	Logistic	SHIPS-RII
PER (12-h intensity change observed for the preceding 12 h)	**All thresholds**	**All thresholds**	**All thresholds**
RSST (Reynolds sea surface temperature)		**(45,36)**	
RHCN (Reynolds heat content)			**(35,24), (40,24), (55,48), (65,72)**
U200 (200-hPa zonal wind, *r* = 200 – 800 km)	**(30,24), (35,24), (55,48), (65,72)**		
RHLO (850-700-hPa relative humidity, *r* = 200 – 800 km)	**(25,24), (45,36), (55,48), (65,72)**	**(55,48), (65,72)**	

D200 (200-hPa divergence, *r* = 0 – 1000 km)	**(20,12), (25,24), (30,24), (55,48), (65,72)**	**(25,24), (30,24), (35,24), (40,24)**	**All thresholds**
EPSS (The q_e difference between parcel/environ, *r* = 200 – 800 km)	**(35,24), (40,24), (45,36), (55,48), (65,72)**		
POT (Departure from the storm's potential intensity)	**All thresholds**	**All thresholds**	**All thresholds**
SHDC (850-200-hPa vertical shear after vortex removal, *r* = 0 – 500 km)	**(20, 12)**		
SHGC (Generalized 850-200-hPa vertical shear, *r* = 0 – 500 km after vortex removal)	**(40,24)**	**(20,12), (25,24), (30,24), (45,36), (40,24), (55,48)**	**All thresholds**
SHRG (Generalized 850-200-hPa vertical shear, *r* = 0 – 500 km)	**(25,24), (30,24), (35,24), (45,36), (55,48), (65,72)**	**(45,36), (65,72)**	
BTA1 (Ave. GOES BT, *r* = 0 – 200 km)		**(65,72)**	
SBTIR1 (Stan. Dev. of GOES BT, *r* = 50–200 km)	**(25,24), (30,24), (35,24), (40,24)**		**(20,12), (25,24), (30,24), (35,24), (40,24), (55,48)**
SBTIR2 (Stan. Dev. of GOES BT, *r* = 100 - 300 km)		**(20,12), (25,24), (30,24), (35,24), (40,24)**	
PCT40 (% area from 50-200 radius with GOES IR BT < -40 C)	**(20,12)**		
PCT50 (% area from 50-200 radius with GOES IR BT < -50 C)	**(25,24), (30,24), (35,24), (40,24), (45,36)**	**(20,12)**	
MXBT (Maximum GOES IR BT from 0-30 km radius)	**(45,36)**	**(25,24), (30,24), (35,24), (40,24), (45,36)**	
MXRA (Radius of maximum GOES IR BT from 0-30 km radius)	**(65,72)**	**(55,48), (65,72)**	
CFLX (Dry air predictor based on the difference in moisture flux between the air with the observed (GFS) RH)			**(25,24), (30,24), (35,24), (45,36), (55,48), (65, 72)**
200-400 km GFS TPW standard deviation		**(25,24), (30,24)**	
400-600 km GFS TPW standard deviation		**(55,48), (65,72)**	
600-800 km average GFS TPW	**(30,24)**		
IR PC 2	**(65,72)**	**(20,12), (25,24), (30,24), (45,36), (55,48)**	**(20,12), (25,24), (30,24), (45,36), (55,48)**

Table 2. Same as Table 1, but for microwave-based predictors

Predictor	Bayesian	Logistic	SHIPS-RII
Max. eyewall brightness temperature (BT) [36.5-GHz horizontal polarization (h)]			**(40,24)**
Mean eyewall BT (36.5 h)		**(20,12), (25,24), (30,24), (35,24)**	**(20,12), (25,24), (30,24), (35,24), (45,36)**
Max. eye BT [36.5 vertical polarization (v)]	**(40,24)**	**(40,24)**	**(35,24)**
Mean eye BT (36.5 v)	**(30,24)**	**(55,48)**	**(55,48)**
Mean eye 36.5 PCT		**(35,24)**	
Percent of eye with 36.5 polarization corrected temperature (PCT) ≥ 270 K and BT (36.5 v) < 265 K	**(25,24)**		
Mean BT (36.5 h) (r = 0 – 30 km)	**(55,48)**		
Radius of min. BT (36.5 h) (r = 0 – 30 km)	**(40,24)**	**(40,24)**	
Radius of min. BT (36.5 v) (r = 0 – 30 km)	**(55,48)**		
Mean BT (36.5 h) (r = 30 – 130 km)	**(45,36)**	**(45,36)**	
Mean BT (36.5 v) (r = 30 – 130 km)	**(25,24)**		
Max BT (36.5 h) (r = 30 – 130 km)	**(30,24), (45,36)**		**(30,24)**
Max BT (36.5 v) (r = 30 – 130 km)	**(20,12), (35,24), (40,24)**	**(20,12), (45,36)**	**(20,12), (40,24), (45,36)**
Min 36.5 PCT (r = 30 – 130 km)	**(40,24)**		
Radius of max BT (36.5 h) (r = 30–130 km)			**(40,24)**
Radius of max BT (36.5 v) (r = 30–130 km)		**(40,24)**	
Radius of min 36.5 PCT (r = 30 – 130 km)	**(25,24)**		
Mean eyewall BT (89 h)	**(30,24)**		
Min eye BT (89 h)	**(45,36)**	**(25,24), (30,24), (35,24)**	
Max eye BT (89 h)			**(20,12), (35,24)**
Eye radius (89-GHz)			**(30,24)**
Eyewall width (89-GHz)			**(25,24)**
Radius of min BT (89 h) (r = 30 – 130 km)		**(20,12), (40,24), (45,36)**	**(45,36)**
Principal Component (PC) 2 (89 v)	**(65,72)**		

Table 3. Same as Table 1, but for the Eastern Pacific.

Predictor	Bayesian	Logistic	SHIPS-RII
PER (12-h intensity change observed for the preceding 12 h)	**All thresholds**	**All thresholds**	**All thresholds**
RHCN (Reynolds heat content)	**All thresholds**		**(20,12)**
U200 (200-hPa zonal wind, *r* = 200 – 800 km)			**(25,24), (30,24)**
EPSS (The pos q_e difference between parcel/environment, *r* = 200 – 800 km)	**(25,24), (30,24), (35,24), (40,24), (45,36), (55,48)**		
ENSS (The neg q_e difference between parcel/environment, *r* = 200 – 800 km)		**(25,24), (65,72)**	
RHLO (850-700-hPa relative humidity, *r* = 200 – 800 km)		**(20,12), (35,24), (40,24), (45,36), (55,48), (65,72)**	
RHMD (700-500-hPa relative humidity, *r* = 200 – 800 km)		**(30,24)**	
RHHI (500-250-hPa relative humidity, *r* = 200 – 800 km)	**(55,48), (65,72)**		
D200 (200-hPa divergence, *r* = 0 – 1000 km)	**(20,12), (65,72)**	**(25,24), (30,24), (35,24), (40,24), (45,36), (55,48)**	**All thresholds**
POT (Departure from the storm’s potential intensity)	**All thresholds**	**All thresholds**	**All thresholds**
VMAX (Current maximum wind speed)			**(25,24)**
SHDC (850-200-hPa vertical shear after vortex removal, *r* = 0 – 500 km)	**All thresholds**	**All thresholds**	**(55,48), (65,72)**
SHGC (Generalized 850-200-hPa vertical shear, *r* = 0 – 500 km after vortex removal)			**(20,12), (25,24), (30,24), (35,24), (40,24), (45,36)**
SBTIR1 (Stan. Dev. of GOES BT, *r* = 50–200 km)			**(20,12), (25,24), (30,24), (35,24), (40,24)**
SBTIR2 (Stan. Dev. of GOES BT, *r* = 100 - 300 km)	**(25,24), (30,24), (35,24), (40,24), (45,36)**	**(20,12), (25,24), (30,24), (35,24), (40,24), (45,36)**	**(45,36)**
PCT10 (% area from 50-200 radius with GOES IR BT < -10 C)		**(55,48), (65,72)**	**(65,72)**
PCT40 (% area from 50-200 radius with	**(20,12)**		

GOES IR BT < -40 C)			
PCT50 (% area from 50-200 radius with GOES IR BT < -50 C)		**(20,12)**	
PCT60 (% area from 50-200 radius with GOES IR BT < -60 C)	**(25,24), (30,24), (35,24), (40,24)**		**(20,12)**
MXBT (Maximum GOES IR BT from 0-30 km radius)		**(25,24), (30,24), (35,24), (40,24)**	
CFLX (Dry air predictor based on the difference in moisture flux between the air with the observed (GFS) RH)			**(20,12), (30,24), (35,24), (40,24), (45,36), (55,48)**

Table 4. Same as Table 2 but for the Eastern Pacific

Predictor	**Bayesian**	**Logistic**	**SHIPS-RII**
Mean eyewall BT (36.5 h)	**(25,24)**	**(20,12), (25,24), (30,24), (35,24), (45, 36)**	**(20,12), (25,24), (30,24), (35,24), (40,24), (45,36)**
Mean eyewall BT (36.5 v)		**(40,24)**	
Min eye 36.5 PCT		**(20,12)**	
Max eye 36.5 PCT		**(40,24)**	**(25,24), (35,24), (40,24)**
Mean eye BT (36.5 v)	**(30,24), (35,24)**		
Percent of eye with BT (36.5 v) < 265 K	**(45,36)**		**(30,24), (35,24)**
Max BT (36.5 v) (*r* = 30 – 130 km)	**(40,24), (45,36)**		
Mean BT (36.5 h) (*r* = 30 – 130 km)	**(55,48)**		
Mean eyewall BT (89 h)		**(40,24)**	
Min eye BT (89 h)	**(20,12), (25,24)**	**(25,24), (30,24) (35,24), (45,36)**	**(45,36)**
Radius of min BT (89 v) (*r* = 0 – 30 km)		**(20,12), (55,48)**	
Radius of min BT (89 h) (*r* = 30 – 130 km)	**(30,24), (35,24), (40,24)**	**(20,12)**	
Mean BT (89 h) (*r* = 100 – 300 km)	**(55,48)**	**(55,48)**	
PC 2 (89 h)	**(25,24)**	**(25,24), (30,24), (35,24), (45,36)**	

The Brier skill score improvements to the consensus of the RI models by including microwave-based predictors are shown in Fig. 1. The Brier skill score with respect to a climatological baseline is used to evaluate the model skill. The models with and without microwave-based predictors are evaluated for the exact same forecasts over the period 1998-2016 in both the Atlantic and Eastern Pacific using leave-one-year-out cross validation. In both basins, and for all models, skill is substantially improved by the inclusion of the microwave-based predictors listed in Tables 2 and 4, although the relative improvements become small or zero at the 65 kt / 72-h RI threshold due to the lack of MI-based predictors. We note that all consensus member models also experience enhanced skill by including MI-based predictors except at the 65 kt / 72-h threshold, where the improvements are small or zero due to few or no MI-based predictors used. The consensus produces the highest skill, consistent with the results of the non-microwave-based models in Kaplan et al. (2015; *Wea. Forecasting*).

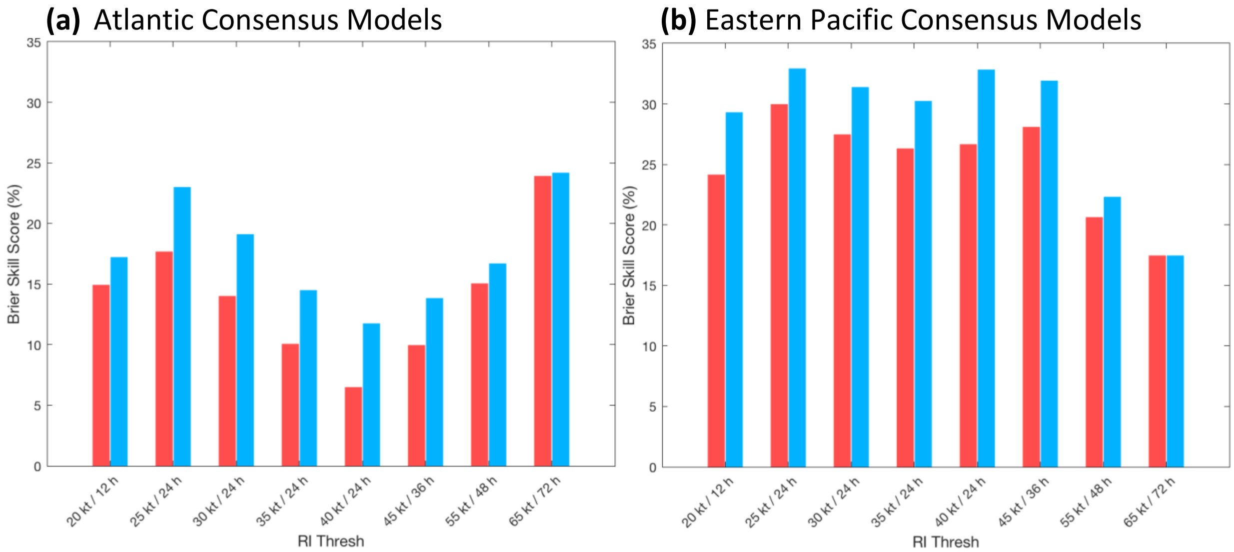

Figure 1. The Brier skill scores of the consensus RI model with (blue) and without (red) microwave-based predictors for the (a) Atlantic and (b) Eastern Pacific using leave-one-year-out cross-validation for the years 1998-2016.

b. **Real-time testing of models during 2017 Atlantic and Eastern Pacific hurricane seasons**

An experimental website was developed to demonstrate and allow a quick assessment of the probabilities of RI with the updated models and the inclusion of satellite microwave data in real-time. The site can be found at http://tropic.ssec.wisc.edu/real-time/mw-ri-prob/. Four different microwave sensors are being used in this real-time demonstration:

1) Special Sensor Microwave Imager (SSM/I) from the Defense Meteorological Satellite Program (DMSP) F15 satellite
2) Special Sensor Microwave Imager/Sounder (SSMI/S) from the DMSP F16, F17, and F18 satellites
3) Advanced Microwave Scanning Radiometer 2 (AMSR2)
4) Global Precipitation Measurement (GPM) Microwave Imager (GMI)

An example of the real-time website from 2240 UTC 24 August 2017 during Hurricane Harvey is illustrated in Fig. 2. The probabilities of RI with microwave predictors are displayed in the left table, and the concurrent operational RI model probabilities are displayed in the right table. Both probabilities are shaded based on percentages. Past probabilities can be viewed in the chart below the left table. Boxes are shaded based on consensus RI probabilities using microwave data. White boxes indicate probabilities were not available due to the lack of MW data in that analysis cycle, which has an occurrence rate of about 39% in the Atlantic Basin. In addition, no RI probabilities are calculated using microwave data if the TC center is too close to land.

Past RI probability tables for a particular storm can also be viewed by clicking on the "History" link or the TC name in the right column. An example of the RI probabilities history for TC Katia (2017) is shown in Fig. 3. The intensity of the TC and the maximum potential intensity (MPI) are listed. (In the SHIPS-RII model, the model probabilities are set to zero if the RI thresholds exceeds the MPI.) Between 0600 UTC 6 September 0600 UTC 7 September 2017, Katia rapidly intensified by 35 kts, and 30kts between 1200 UTC 6 September and 1200 UTC 7 September. In both of these cases, higher RI probabilities were predicted with the microwave-enhanced models.

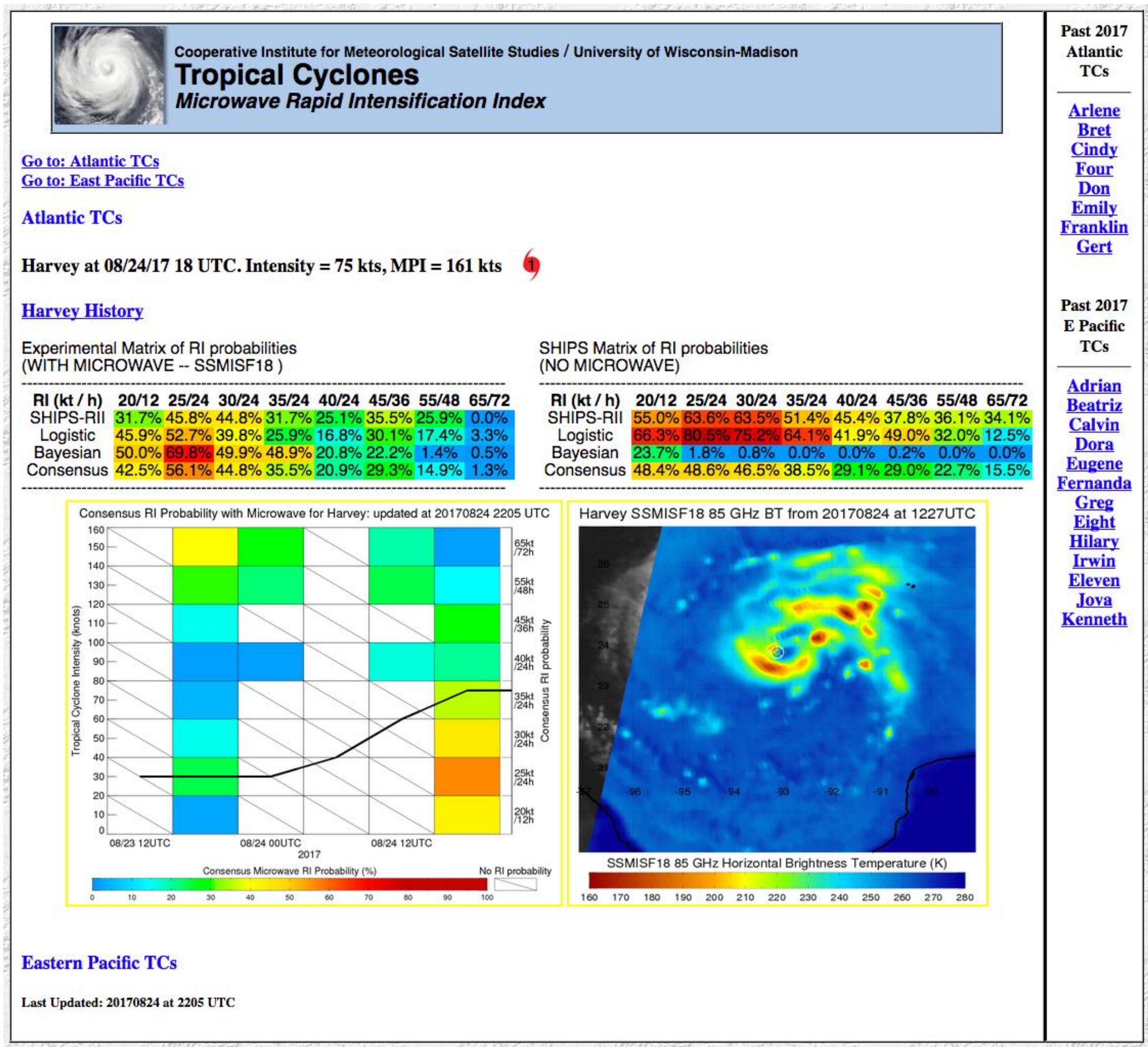

Figure 2. Example of the real-time TC RI prediction site designed to demonstrate the upgraded RI models using microwave data.

Katia at 09/06/17 18 UTC. Intensity = 65 kts, MPI = 162 kts

Experimental Matrix of RI probabilities
(WITH MICROWAVE -- SSMISF18)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	34.4%	50.0%	50.0%	31.7%	14.4%	34.0%	35.6%	57.5%
Logistic	38.4%	71.2%	64.2%	39.3%	16.7%	51.7%	55.8%	67.0%
Bayesian	30.0%	49.9%	10.7%	3.1%	0.5%	5.1%	0.6%	3.1%
Consensus	34.3%	57.0%	41.6%	24.7%	10.5%	30.3%	30.7%	42.5%

SHIPS Matrix of RI probabilities
(NO MICROWAVE)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	46.8%	64.8%	63.4%	54.3%	44.3%	51.4%	41.0%	59.5%
Logistic	55.8%	85.1%	80.1%	70.7%	42.6%	65.9%	51.8%	41.8%
Bayesian	29.8%	13.8%	13.4%	6.4%	5.4%	2.7%	0.3%	0.5%
Consensus	44.1%	54.6%	52.3%	43.8%	30.8%	40.0%	31.1%	33.9%

Katia at 09/06/17 12 UTC. Intensity = 40 kts, MPI = 170 kts

Experimental Matrix of RI probabilities
(WITH MICROWAVE -- AMSR2)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	31.8%	50.1%	50.1%	32.2%	6.4%	39.0%	28.8%	51.3%
Logistic	36.7%	82.0%	70.6%	50.4%	12.5%	52.4%	56.0%	74.9%
Bayesian	12.3%	71.6%	24.7%	4.2%	0.8%	17.1%	5.1%	23.7%
Consensus	26.9%	67.9%	48.5%	28.9%	6.6%	36.2%	30.0%	50.0%

SHIPS Matrix of RI probabilities
(NO MICROWAVE)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	18.5%	50.0%	38.3%	23.2%	12.7%	31.9%	38.7%	60.0%
Logistic	34.1%	69.9%	59.8%	43.2%	21.1%	54.1%	51.2%	51.2%
Bayesian	11.8%	41.6%	28.7%	6.3%	5.3%	5.2%	2.0%	12.1%
Consensus	21.5%	53.9%	42.3%	24.2%	13.0%	30.4%	30.6%	41.1%

Katia at 09/06/17 06 UTC. Intensity = 35 kts, MPI = 164 kts

Experimental Matrix of RI probabilities
(WITH MICROWAVE -- SSMISF18)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	22.6%	45.5%	39.1%	7.7%	4.2%	38.6%	24.4%	44.9%
Logistic	48.8%	54.7%	43.6%	23.8%	17.1%	60.8%	40.1%	64.3%
Bayesian	12.5%	11.6%	11.6%	0.9%	0.9%	15.5%	1.9%	6.6%
Consensus	28.0%	37.3%	31.4%	10.8%	7.4%	38.3%	22.1%	38.6%

SHIPS Matrix of RI probabilities
(NO MICROWAVE)

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	9.1%	37.3%	21.6%	10.2%	8.8%	15.4%	24.4%	50.3%
Logistic	20.0%	46.2%	34.1%	19.7%	13.2%	43.7%	30.6%	37.5%
Bayesian	4.8%	27.7%	18.1%	4.2%	2.6%	4.8%	1.2%	3.8%
Consensus	11.3%	37.1%	24.6%	11.4%	8.2%	21.3%	18.7%	30.5%

Figure 3. Example of RI probabilities from Atlantic TC Katia (2017).

Status of Project Tasks / Milestones

The following table summarizes the tasks originally proposed with some updated dates due to a NCE, 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 – December 2017]	In Progress

7	In-house 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. [June – November 2016]	Completed
8	Evaluation of models and model updates. [January – December 2017]	In Progress
9	Prepare final NCEP-ready code and documentation for running and maintaining models at the conclusion of the project. [February – December 2017]	In Progress
10	Operational demo real-time test. [June – November 2017]	In Progress

What opportunities for training and professional development has the project provided?
This project will provide training for forecasters for the use of MI-based probabilistic RI models in operations.

How were the results disseminated to communities of interest?
We are providing the real-time results on a shared webpage with our points of contact at NHC. Prior results have been presented at conferences and a publication will be produced at the project's completion. We will provide a real-time-capable version of our algorithm code 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 plan to finish the work on developing a real-time Fortran/C-based algorithm that can operate successfully on NOAA computers.

2. PRODUCTS

Presentations in this reporting period
Rozoff, C. M., and C. S. Velden, 2017: JHT Project 4: Probabilistic prediction of tropical cyclone rapid intensification using satellite passive microwave imagery. *Presentation at the 2017 Tropical Cyclone Operations and Research Forum, Miami, FL, 16 March 2016.* [Available online at: http://www.ofcm.gov/meetings/TCORF/ihc17/Session_09/9-4-rozoff_jht_web.pdf]

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 Velden (PI), Christopher Rozoff (Co-PI), Sarah Griffin (CIMSS/UW-Madison research assistant)

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?
Velden is now the listed institutional PI for UW-CIMSS, as Rozoff is now at NCAR

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 briefed on the project progress.

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 often use the types of statistical models we have used in this project, and therefore researchers may find our project methodology 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, especially RI, 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 project fell behind schedule (particularly in completing conversion of code from Matlab to more portable Fortran/UNIX based scripting) as the original PI changed institutions.

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 the 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 during the 2017 hurricane season.

Has the project been approved for testbed testing yet?
The 2017 real-time testing is being performed on CIMSS computing platforms.

What was transitioned to NOAA?
Nothing at this time.

7. BUDGETARY INFORMATION

The project is on budget. A NCE was granted to extend the project through December, 2017.

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 demonstrating 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 4, but plan to also have RL 5-9 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. [*Completed*]
- RL 3: Proof-of-concept: We showed how this product performs in real-time. [*Completed*]
- RL 4: We evaluated the forecast system at our institution in a real-time environment [*Completed*]
- RL 5: We will evaluate a final algorithm near the end of the project with the goal of having these models deployed into an operational environment. [*In progress*]
- RL 6: We will demonstrate the forecast scheme in a real-time environment during the 2017 Hurricane season. [*Not tested on NOAA computers*]
- RL 7/8: The overall goal is to implement an improved real-time prediction tool for RI at the NHC, including complete documentation and support to implement it in an operational center. [*In progress*]
- RL 9: We plan to deploy this system operationally. [*Implementation to be determined by NHC/JHT*]