Probabilistic Prediction of Tropical Cyclone Rapid Intensification Using Passive Microwave Imagery

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Supported by NOAA JHT

Goal of work

- Improve probabilistic prediction of rapid intensification (RI)
  - SHIPS-RII, consensus of multi-model products

- **Approach:** Exploit passive microwave imagery to evince aspects of storm structure for improved statistical models.

Models for Atlantic and E. Pacific RI Prediction

- SHIPS-RII
- Logistic regression model
- Bayesian model
- Unweighted consensus of above three models

More info in Kaplan et al. 2010, Rozoff and Kossin 2011, Kaplan et al. 2015, Rozoff et al. 2015

Datasets

- SHIPS Developmental Dataset (1982 – 2016)
  - Available at CIRA: http://rammb.cira.colostate.edu/research/tropical_cyclones/ships/developmental_data.asp
- Passive microwave imagery-based predictors derived from low-earth orbiting satellites.
  - We choose to focus on 1998 – 2016 for this study

Microwave data

Low-earth orbiting satellites providing passive microwave data 1998 – 2016.

	Low Frequency Channel		**Medium Frequency Channel**		**High Frequency Channel**	
Sensor	**Frequency (GHz)**	**Footprint (km x km)**	**Frequency (GHz)**	**Footprint (km x km)**	**Frequency (GHz)**	**Footprint (km x km)**
SSM/I	19.35	69 x 43	37.0	37 x 28	85.5	15 x 13
SSMI/S	19.35	73 x 47	37.0	41 x 31	91.655	14 x 13
TMI	19.35	30 x 18	37.0	16 x 9	85.5	7 x 5
AMSR-E	18.7	27 x 16	36.5	14 x 8	89.0	6 x 4
AMSR2	18.7	22 x 14	36.5	12 x 7	89.0	5 x 3
GMI	18.7	18 x 11	36.5	15 x 9	89.0	7 x 4

Microwave Data

Data calibration

Match SSMI, SSMIS, and TMI to GMI, AMSRE/2 18.7, 36.5, and 89.0 GHz

Histogram matching technique used (Jones et al. 2006; Rozoff et al. 2015)

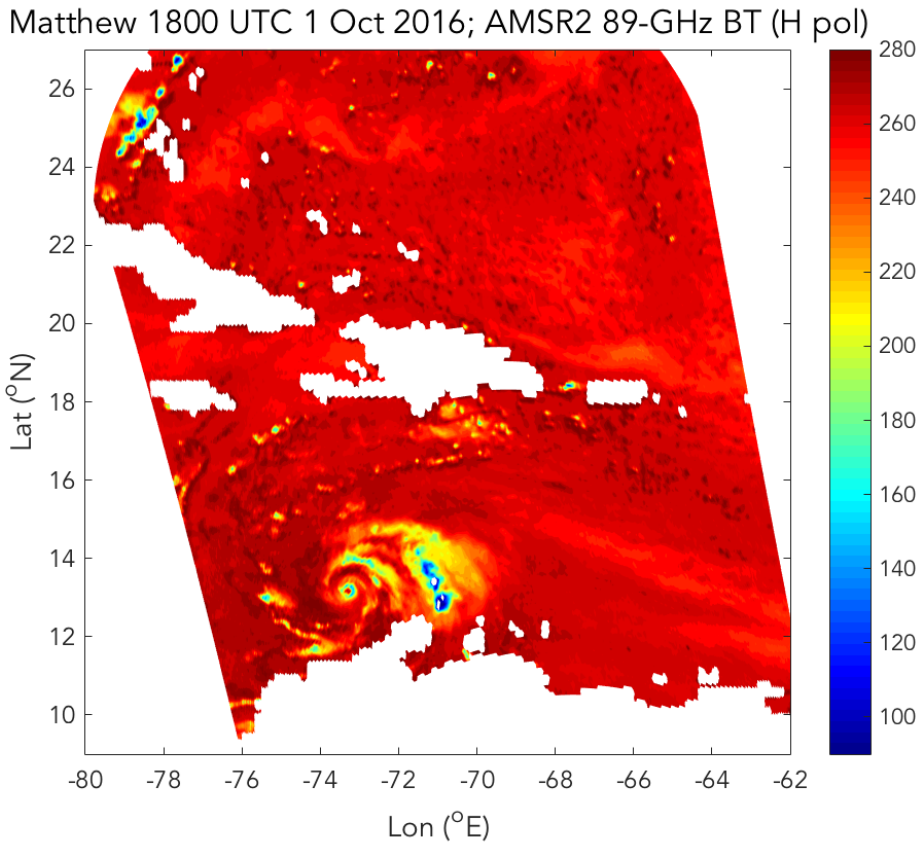
Need matching overpasses

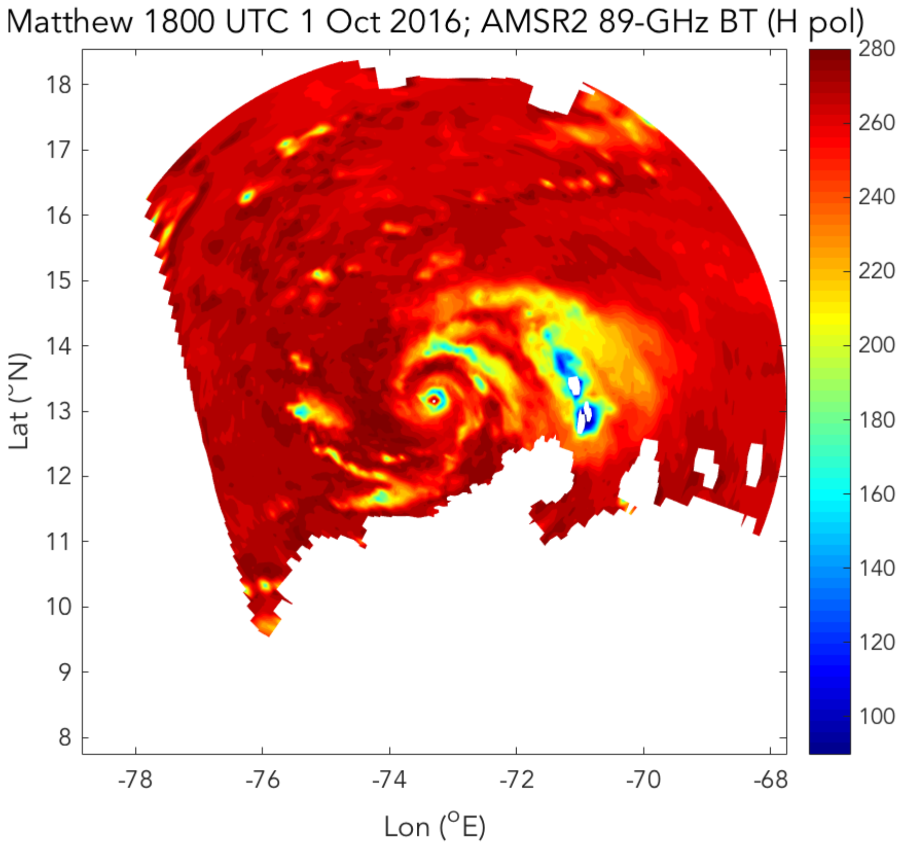
- AMSR-E – TMI: 8 ATL matches within 5 min
- SSMIS – GMI: 29 matches EP/ATL within 30 min
- SSM/I – GMI: 8 EP matches within 30 min

Interpolate to common grid where swaths overlap.
- Common grid is the grid of the lower spatial resolution sensor.

TC-centric grids of MW data (1995-2016) Atlantic and Eastern Pacific basins

- Landmasked calibrated and uncalibrated data (18.7, 36.5, and 89 GHz)
- Native Cartesian grid and common polar grids, both centered on TCs.
  - Polar grids 5-km & 2.5-km Δr and 72/144 azimuthal points for 18.7-36.5 & 89-GHz
- 9489 Atlantic files; 9089 Eastern Pacific files





Choosing microwave data

- We consider microwave data within 6 h of a forecast
- In the case of multiple swaths available at a forecast, we choose data based on the following criteria:
  1. Most complete coverage of storm
  2. Highest spatial resolution sensor chosen
  3. Most recent swath chosen
- Quick stats:
  - Swath is, on average, 2.9-h old
  - Data available ~63% of the time at synoptic forecast times (1998 – 2016)

Microwave-based predictors (Goal: Depict inner core structure)

- **Class 1:** SHIPS-like predictors (basic properties for fixed geometric regions)
- **Class 2:** Brightness temperature properties within an Objective Maximum Inner-Core Precipitation Annulus (MIPA) (defined in Rozoff et al. 2015)
- **Class 3:** ARCHER spiral and ring score properties
  - Comment: Was not found to produce adequate signal for probabilistic models
- **Class 4:** EOF analysis / Principal Components of microwave data
- **Class 5:** inertial stability
  - Comment: Determined not to be sufficiently independent from MW dataset

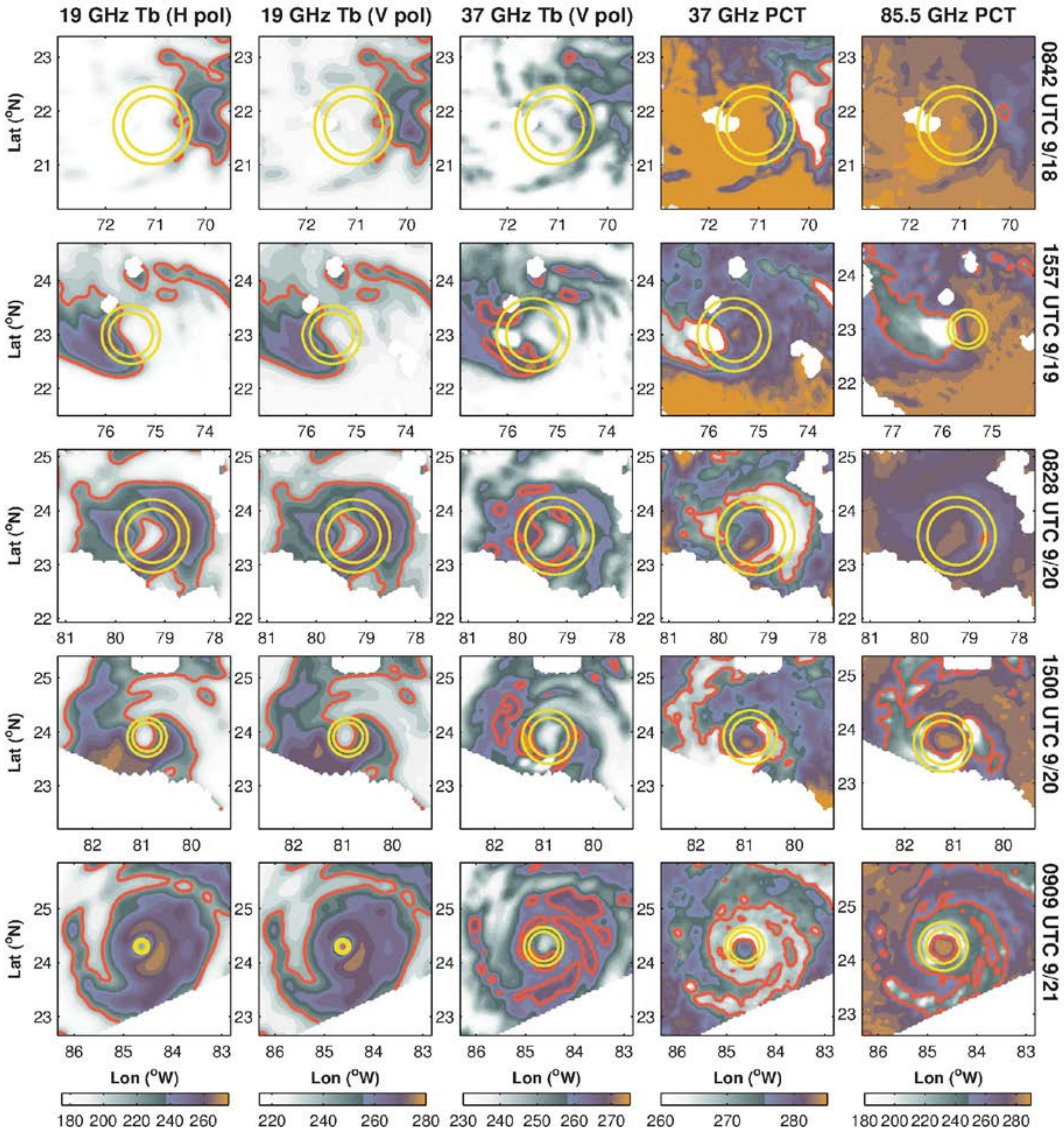
Classes 1, 2, and 4 predictors were found useful in this work.

MIPA-based predictors

A few notes:
1. ARCHER provides center estimate.

2. Inspired by the work Jiang et al. (2011), MIPA criteria are found as follows:
- 36.5 GHz: % area covered by PCT < 270 K or where BT (v) ≥ 265 K and PCT ≥ 270 K maximized.

3. For other channels:
- 18.7 GHz: % area where BT (v) > 245 K and BT (h) > 215 K
- 89 GHz: % area where PCT < 250 K is maximized



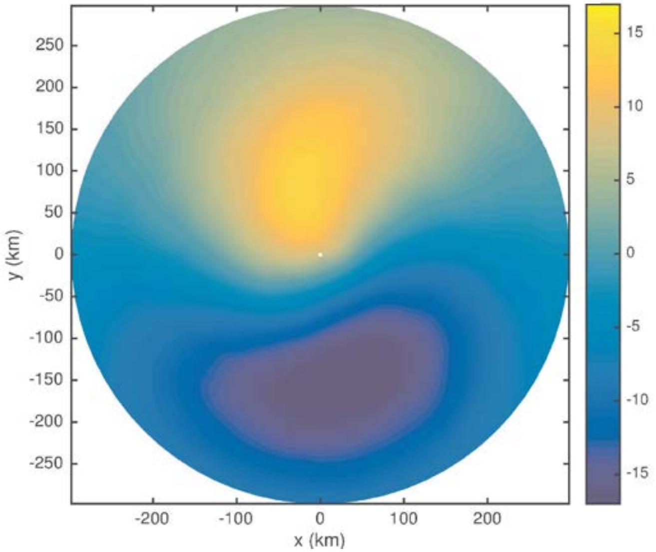
Hurricane Rita (2005) example

Time progresses downward

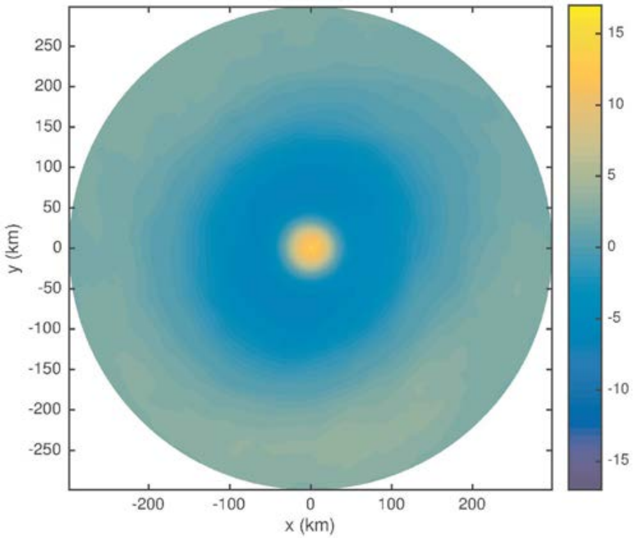
Skillful EOFs/Principal Components

Note:
All microwave images in this analysis were rotated such that the storm motion vector is pointing north prior to conducting the EOF analysis.

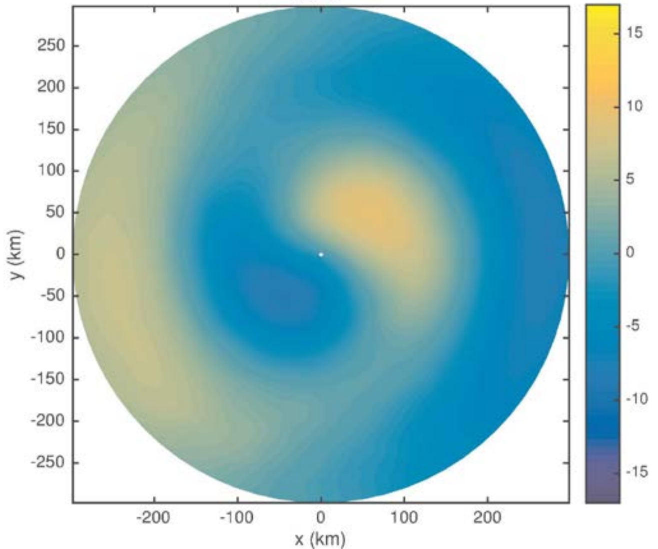
37-GHz (H pol) EOF 3



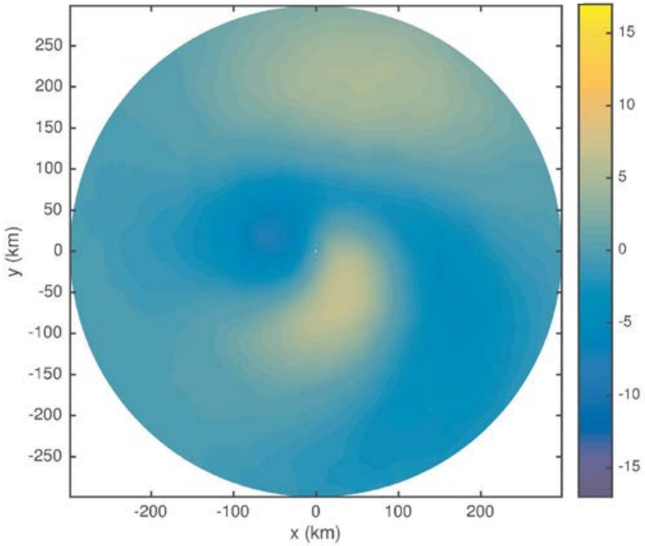
37-GHz (H pol) EOF 5



37-GHz (H pol) EOF 7



89-GHz (H pol) EOF 9



Atlantic Predictors (non-MW)

Predictor	Bayesian	Logistic	SHIPS-RII
PER (12-h intensity change observed for the preceding 12 h)	x	x	x
RSST (Reynolds sea surface temperature)		x	
RHCN (Reynolds heat content)			x
U200 (200-hPa zonal wind, r = 200 – 800 km)	x		
RHLO (850-700-hPa relative humidity, r = 200 – 800 km)			x
RHMD (700-500-hPa relative humidity, r = 200 – 800 km)		x	
D200 (200-hPa divergence, r = 0 – 1000 km)			x
EPSS (The θ_e difference between parcel/environment, r = 200 – 800 km)	x		
POT (Departure from the storm's potential intensity)	x	x	x
SHDC (850-200-hPa vertical shear after vortex removal, r = 0 – 500 km)			x
SHRG (Generalized 850-200-hPa vertical shear, r = 0 – 500 km)	x	x	
SBTIR1 (Stan. Dev. of GOES BT, r = 50– 200 km)	x		x
SBTIR2 (Stan. Dev. of GOES BT, r = 100 - 300 km)		x	
PCT30 (% area from 50-200 radius with GOES IR BT < -30 C)			x
PCT50 (% area from 50-200 radius with GOES IR BT < -50 C)	x		
MXBT (Maximum GOES IR BT from 0-30 km radius)		x	
IR Principal Component 2		x	

Atlantic Predictors (MW)

Predictor	Bayesian	Logistic	SHIPS-RII
Mean MIPA BT (36.5 h)		x	x
Max eye BT (36.5 v)			x
Mean BT (36.5 v) (*r* = 30 – 130 km)	x		
Radius of minimum 36.5-GHz PCT (*r* = 30 – 130 km)	x		
Principal Component 3 (36.5 v)		x	
Principal Component 3 (36.5 PCT)		x	
Principal Component 7 (36.5 h)		x	
Max eye BT (89 h)			x
Max eye BT (89 PCT)		x	
Principal Component 5 (89 h)	x	x	

Eastern Pacific Predictors (non-MW)

Predictor	Bayesian	Logistic	SHIPS-RII
PER (12-h intensity change observed for the preceding 12 h)	x	x	x
RHCN (Reynolds heat content)	x		
EPSS (The pos θ_e difference between parcel/environment, r = 200 – 800 km)	x		
ENSS (The neg θ_e difference between parcel/environment, r = 200 – 800 km)		x	
RHLO (850-700-hPa relative humidity, r = 200 – 800 km)		x	x
D200 (200-hPa divergence, r = 0 – 1000 km)		x	x
POT (Departure from the storm's potential intensity)	x	x	x
SHDC (850-200-hPa vertical shear after vortex removal, r = 0 – 500 km)	x	x	x
SBTIR1 (Stan. Dev. of GOES BT, r = 50– 200 km)			x
SBTIR2 (Stan. Dev. of GOES BT, r = 100 - 300 km)	x	x	
PCT30 (% area from 50-200 radius with GOES IR BT < -30 C)			x
PCT50 (% area from 50-200 radius with GOES IR BT < -50 C)	x	x	
MXBT (Maximum GOES IR BT from 0-30 km radius)		x	

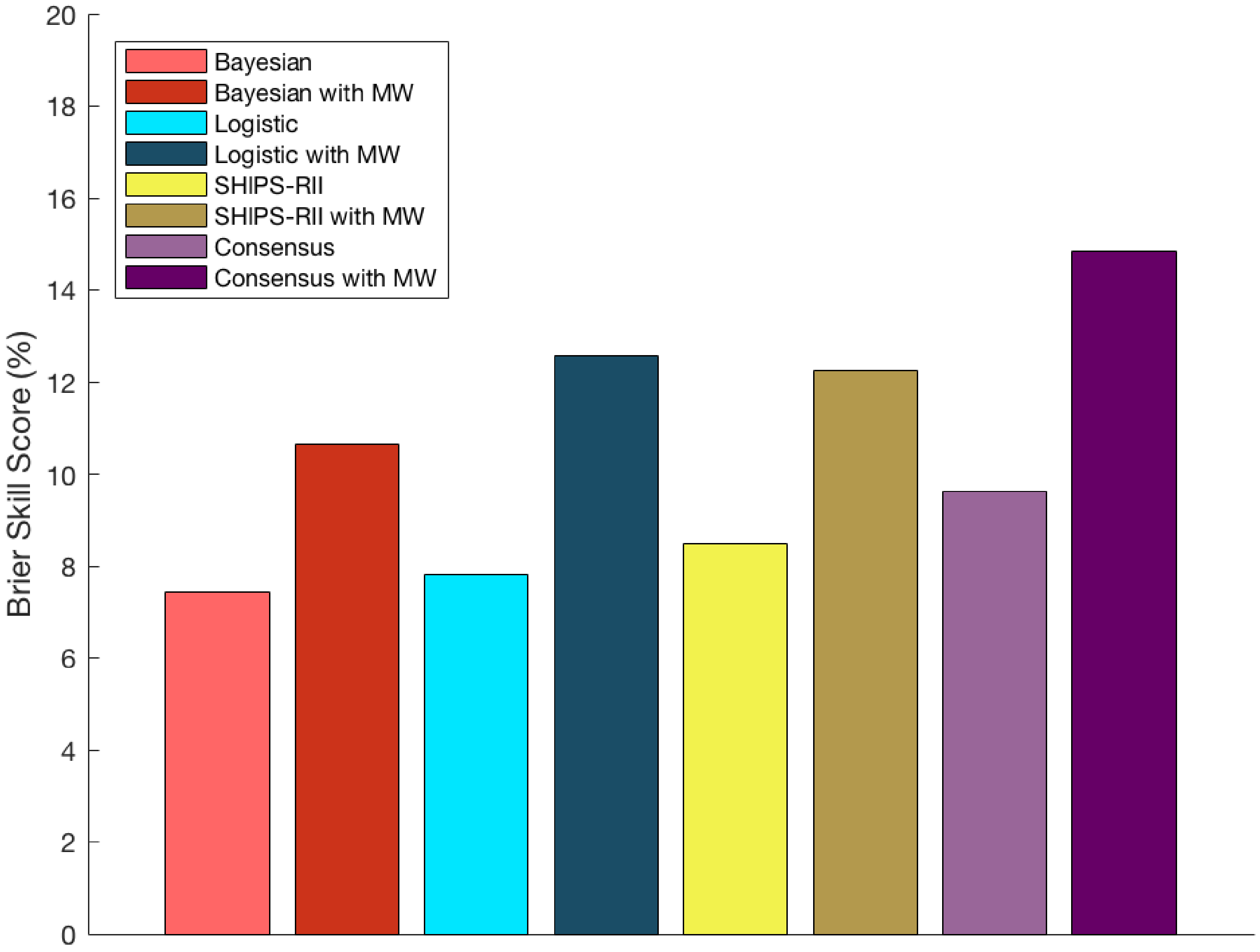
Eastern Pacific Predictors (MW)

Predictor	Bayesian	Logistic	SHIPS-RII
Mean MIPA BT (36.5 h)		x	x
MIPA Criteria: Percentage of MIPA 36.5 PCT < 270 K			x
Mean eye BT (36.5 v)	x		
Mean eye BT (36.5 PCT)			x
Eye Criteria: Percentage of MIPA BT (36.5 v) < 265 K			x
Maximium BT (36.5 v) (r = 30 – 130 km)	x		
Principal Component 3 (36.5 h)		x	x
Principal Component 3 (36.5 PCT)	x		
Mean MIPA BT (89 h)		x	
Max eye BT (89 PCT)		x	
Radius of minimum BT (89 h)	x		
Principal component 9 (89 h)		x	x

Model lead-times

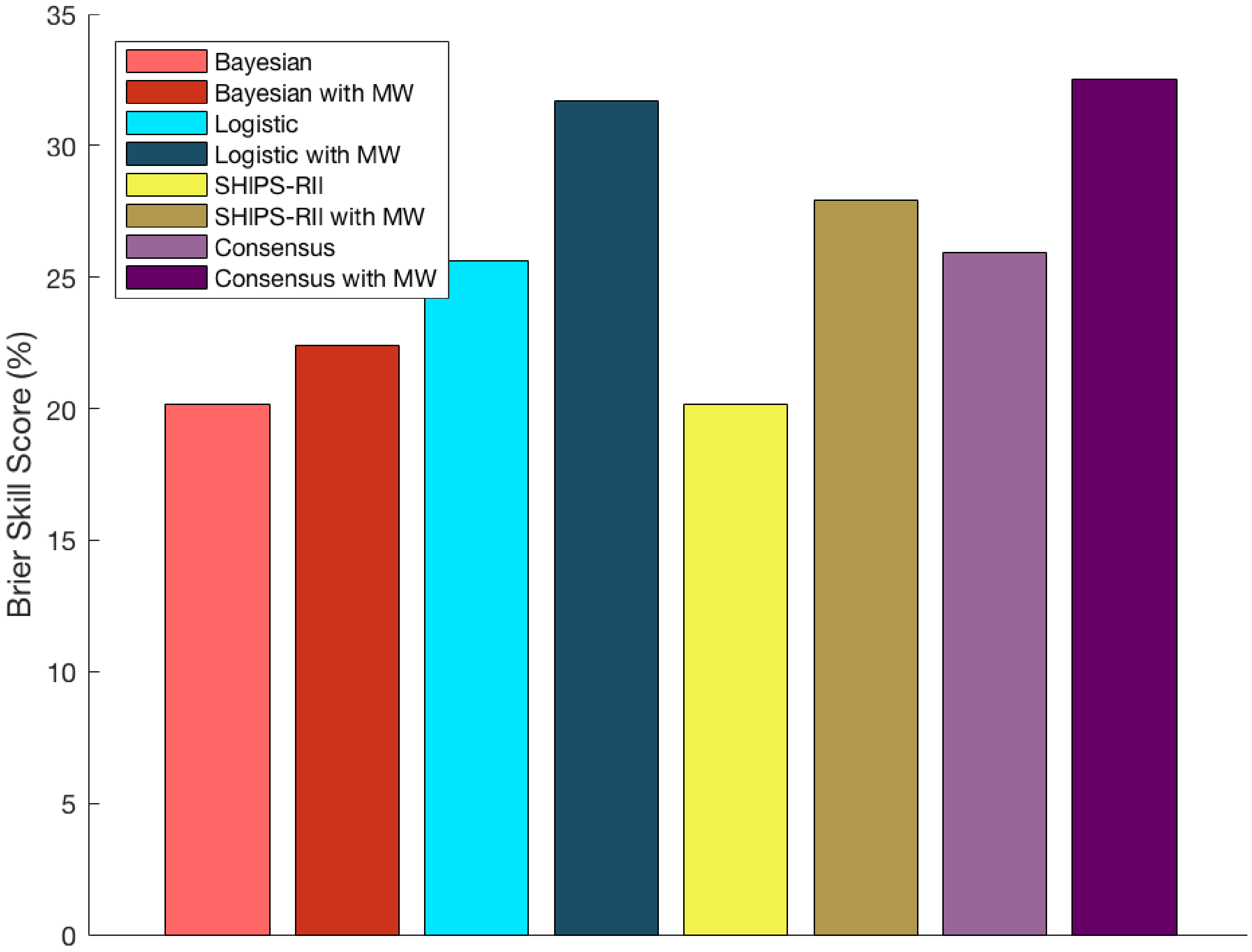
- Follows operational consensus SHIPS-RII
  - 20 kt / 12 h
  - 25, 30, 35, and 40 kt / 24 h
  - 45 kt / 36 h
  - 55 kt / 48 h
  - 65 kt / 72 h

Example: Atlantic Skill Improvements



35 kt / 24 h threshold

Example: Eastern Pacific Skill Improvements



35 kt / 24 h threshold

Project Status

- **Note:** These models were rebuilt in the last few months.
  - To use an improved microwave-based dataset (improved calibration, increased resolution grids)
    - *Result:* large database of TC-centric polar and Cartesian-grid data (calibrated/uncalibrated) that may be of use to the general TC community.
  - An improved selection procedure of MW imagery for each forecast was desired.
  - *Negative side-effect:* Delay in evaluation of 2016 hurricane seasons.
    - Will evaluate after completion and testing of the latest iteration of models.

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  - Leveraging Mark DeMaria et al.'s iships.f code set, including its SHIPS-RII consensus routines supported by previous JHT projects.

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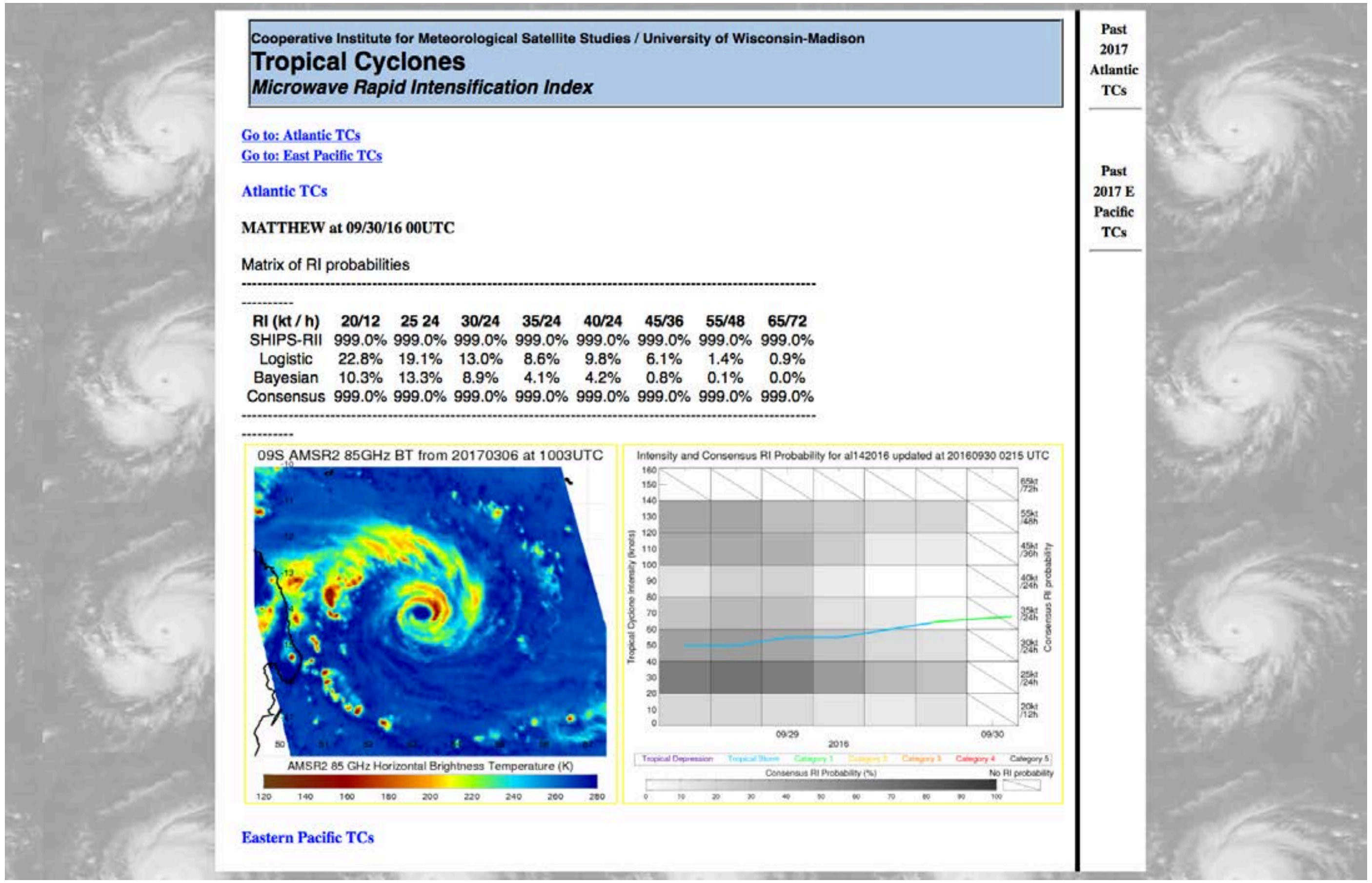
- Websites are being created at CIMSS for providing real-time output during 2017 season. Sarah Griffin (CIMSS) is leading this effort.
  - Mostly just waiting on the completion of scripts and finalized models

Real-time Web Page

- To be hosted at the CIMSS Tropical Cyclones webpages during 2017 Hurricane Season (http://tropic.ssec.wisc.edu)
- Example, Hurricane Matthew (2016) (http://www.ssec.wisc.edu/~sarahm/MW_example)


Cooperative Institute for Meteorological Satellite Studies / University of Wisconsin-Madison

Tropical Cyclones

Microwave Rapid Intensification Index

Go to: Atlantic TCs
Go to: East Pacific TCs

Atlantic TCs

MATTHEW at 09/30/16 00UTC

Matrix of RI probabilities

RI (kt / h)	20/12	25 24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS-RII	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%
Logistic	22.8%	19.1%	13.0%	8.6%	9.8%	6.1%	1.4%	0.9%
Bayesian	10.3%	13.3%	8.9%	4.1%	4.2%	0.8%	0.1%	0.0%
Consensus	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%	999.0%

Eastern Pacific TCs

Past 2017 Atlantic TCs

Past 2017 E Pacific TCs

Sample Products

- Quilt diagrams will help forecaster visualize RI probabilities for all RI thresholds and lead-times very rapidly and also see a time history of previous forecasts along with the storm's intensity evolution.