

Estimation of Tropical Cyclone Intensity Using Satellite Passive Microwave Observations: Year 1 Update

Haiyan Jiang, Yongxian Pei, and Cheng Tao

Department of Earth & Environment

Florida International University

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2) CHPC Point of Contact: Dave Roberts

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Project Overview

Passive Microwave Intensity Estimation (PMW-IE) Model:

- **Task 1: Model development**
 - **Proof-of-Concept & initial model development using TRMM data**
 - **Model development using current available PMW sensors: GMI, AMSR2, and SSMIS**
- **Task 2: Real time testing during hurricane season & post-season evaluations**
 - **AL basin: 2018 hurricane season**
 - **AL and EP basins: 2019 hurricane season**

Motivation of the Project

- Currently TC intensity is almost exclusively estimated by Dvorak technique (Dvorak 1975, 1984; Objective version ODT: Velden et al. 1998) except when sometime aircraft recon data are available in the AL basin.
- **The Dvorak technique is based on both visible and IR satellite images**, which only show the cloud top structure of a TC and cannot measure the detailed rainfall and convective structure at lower levels, especially in the eyewall: central dense overcast (CDO) scene problem.
- **The advantage of passive microwave** channels is that they allow penetration into precipitating clouds, therefore providing information about precipitation and convective structure at lower levels instead of just the cloud tops.
- In recent years, the number of passive microwave radiometers has increased. **The era has arrived where timely observations from passive microwave sensors can be incorporated into routine TC monitoring and forecasting.**

Past, Current, & Future

Passive Microwave Satellite Sensors

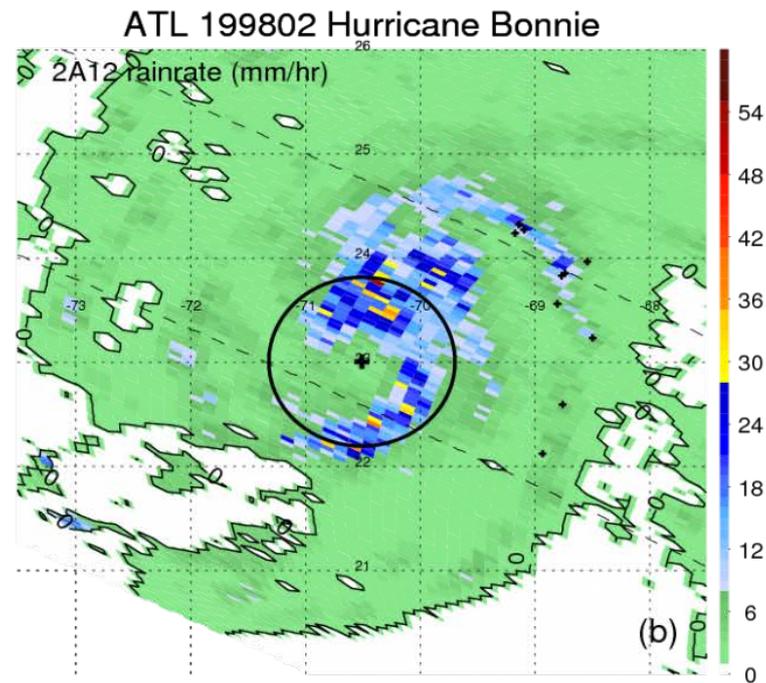
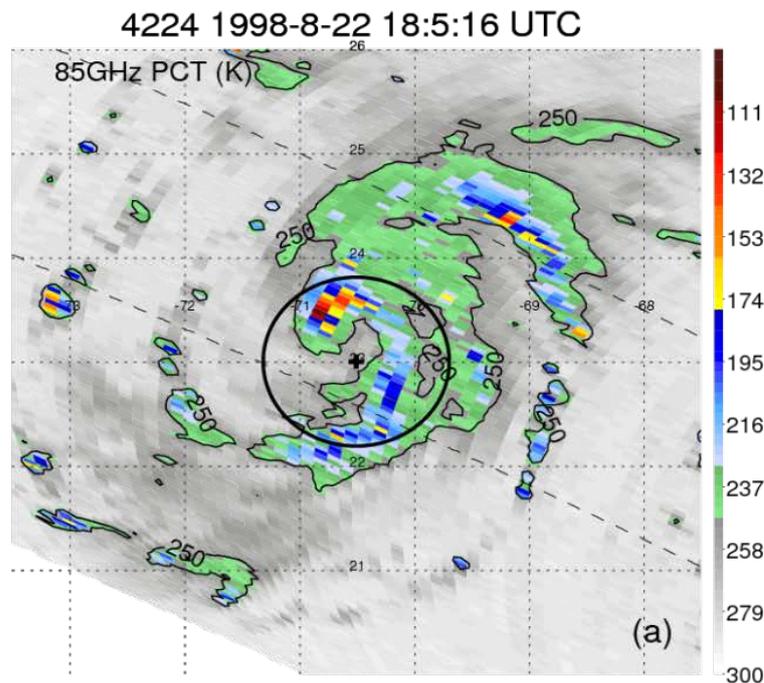
Sensor	85-91 GHz Frequency	Spatial Resolution at 85-91 GHz	Other Frequencies	Year
SSM/I (F15)	85.5 GHz	15 x 13 km ²	19, 22, 37 GHz	1987-
SSMIS (F16, 17,18,19)	91 GHz	14 x 13 km ²	19, 22, 36.5, 50, 60, 183 GHz	2003-
AMSR-E	89 GHz	6 x 4 km ²	6, 10, 18, 23, 36.5 GHz	2002-2011
AMSR2	89 GHz	5 x 3 km ²	6, 10, 18, 23, 36.5 GHz	2012-
TMI	85.5 GHz	7x5 (before boost) / 8x6 (after boost) km ²	10, 19, 22, 37 GHz	1997-2014
GMI	89 GHz	7.2x4.4 km	10, 18, 23, 36.5, 165, 183 GHz	2014-
TROPICS MicroMAS-2	91 GHz	17 x 17 km ²	205, 118, 183 GHz	2020-

Initial Model Development Using TRMM data

- **Previous studies (e.g. Cecil and Zipser 1999) have provided the proof-of-concept** of using microwave brightness temperatures and retrieved rain rates to estimate TC intensity with **small sample sizes & a lower resolution sensor (SSM/I)**.
- We have used a much larger developmental dataset (11-yr TRMM TMI data) to
 - first **re-prove the concept using a higher resolution sensor through the variable selection process,**
 - then **develop a multiple linear regression model (similar to the SHIPS model, DeMaria and Kaplan 1994)** using 1998-2004 (7-yr) cases as the dependent sample,
 - and finally **evaluate the model performance using an independent sample** including 2005-2008 (4-yr) cases.
 - This algorithm will be referred to as the **Passive Microwave Intensity Estimation (PMW-IE) model**.

TRMM Data

- **11-yr TMI data (1998-2008): nearly 1000 TC overpasses in AL/EP basins**
 - Dependent sample for model development: 566 TMI passes from 1998-2004
 - Independent sample for model verification: 383 TMI passes from 2005-2008
- **Observations/retrievals used: 85 GHz PCT; 2A12 rain rate**
- **Inner core radius was manually determined by Jiang et al. (2012)**



Selection of Variables

Table below: List of variables in the inner core having correlation coefficients with Vmax significant at the 99.99% level.

Variables	Description	Units
85 GHz		
1) MEANPCT	Mean 85 GHz PCT	K
2) FRAC275	Fractional area covered by 85 GHz PCT ≤ 275K	%
3) FRAC250	Fractional area covered by 85 GHz PCT ≤ 250K	%
4) FRAC225	Fractional area covered by 85 GHz PCT ≤ 225K	%
5) FRAC200	Fractional area covered by 85 GHz PCT ≤ 200K	%
Rain		
1) U_RR	Unconditional mean rain rate	mm/hr
2) C_RR	Conditional mean rain rate	mm/hr
3) L_RR	Mean light rain (rain rate between 0-5 mm/hr) rate	mm/hr
4) H_RR	Mean heavy rain (rain rate ≥ 5 mm/hr) rate	mm/hr
5) RA	Fractional area covered by rain	%
6) L_RA	Fractional area covered by light rain	%
7) H_RA	Fractional area covered by heavy rain	%

Reproof-of-Concept: Correlation Coefficients

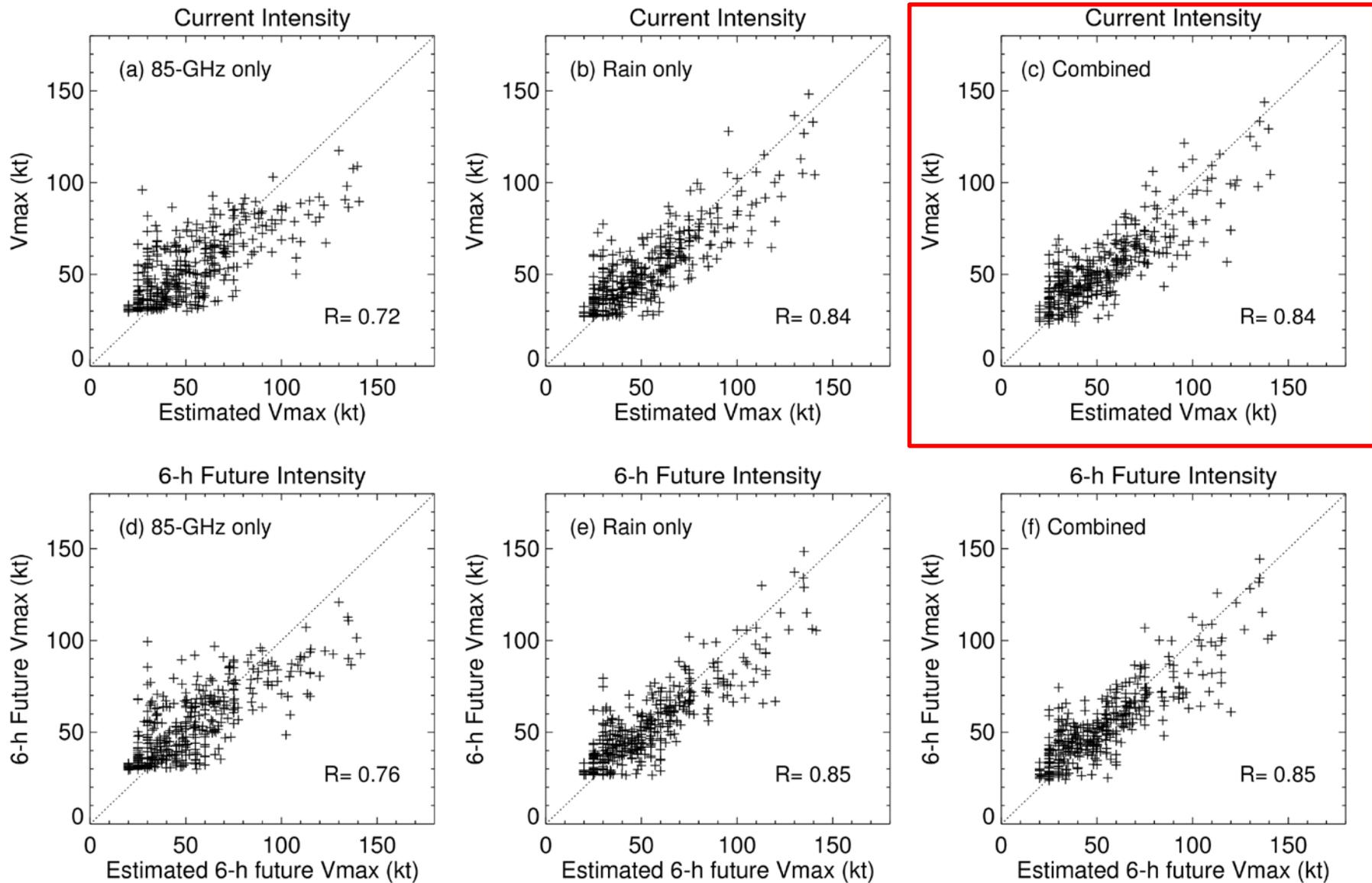
Variables	All AL/EP cases (n=949)		AL cases with aircraft data (n=92)		AL cased without aircraft data (n=406)		EP cases without aircraft data (n=451)	
	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h
MeanPCT	-0.63	-0.68	-0.69	-0.72	-0.62	-0.67	-0.63	-0.69
Frac275	0.64	0.68	0.72	0.73	0.64	0.69	0.63	0.69
FRAC250	0.62	0.68	0.67	0.70	0.62	0.67	0.62	0.68
FRAC225	0.51	0.55	0.54	0.59	0.49	0.53	0.51	0.56
FRAC200	0.25	0.29	0.28	0.34	0.25	0.27	0.22	0.27
All 85-GHz variables	0.67	0.72	0.76	0.76	0.67	0.72	0.67	0.73
U_RR	0.80	0.81	0.82	0.83	0.81	0.83	0.77	0.80
C_RR	0.79	0.80	0.82	0.83	0.79	0.81	0.77	0.79
L_RR	0.73	0.75	0.82	0.82	0.69	0.72	0.74	0.77
H_RR	0.61	0.62	0.64	0.65	0.60	0.61	0.57	0.60
RA	0.48	0.51	0.48	0.49	0.53	0.56	0.46	0.51
L_RA	-0.36	-0.35	-0.50	-0.49	-0.33	-0.33	-0.33	-0.31
H_RA	0.83	0.82	0.85	0.86	0.82	0.84	0.77	0.79
All rain variables	0.82	0.84	0.88	0.89	0.83	0.86	0.79	0.82
Combined 85-GHz and rain variables	0.83	0.85	0.92	0.91	0.85	0.87	0.81	0.83

Multiple-Linear Regression Model (TRMM)

Table below: Regression variables and their corresponding normalized coefficients to estimate Vmax and 6-h future Vmax. r^2 is the percent of total variance explained by each regression.

Variables	85-GHz only		Rain only		Combined	
	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h
MEANPCT	-0.26	-0.25	-	-	0.07	0.09
FRAC275	0.31	0.32	-	-	-0.20	-0.16
FRAC250	0.02	0.08	-	-	-0.08	0.02
FRAC225	0.23	0.21	-	-	-0.21	-0.18
FRAC200	-0.25	-0.23	-	-	0.10	0.09
U_RR	-	-	0.97	1.29	1.30	1.52
C_RR	-	-	-0.65	-1.00	-0.95	-1.20
L_RR	-	-	0.23	0.28	0.40	0.41
H_RR	-	-	0.12	0.15	0.19	0.20
RA	-	-	-0.70	0.41	-2.04	-0.16
L_RA	-	-	0.98	-0.29	2.67	0.48
H_RA	-	-	0.69	-0.42	2.07	0.18
r^2 (%)	40.7	47.5	63.7	68.0	67.5	69.9

Independent Verification (TRMM)



- For the combined algorithm, 78% of the Vmax errors fall with 15 kt compared with 72.5% from the **AMSU TC Intensity Estimate Method** (Demuth et al. 2004). Only 13% of the Vmax errors are more than 20 kt, which is the same as in Demuth et al. (2004).

Independent Verification (TRMM)

Error Analysis

	85-GHz only		Rain only		Combined	
	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h
r^2 (%)	51.6	57.4	70.7	73.0	71.4	72.7
MAE (kt)	13.4	12.8	10.3	10.2	10.3	10.2
RMSE (kt)	17.6	17.0	13.7	13.5	13.6	13.6
Standard deviation of residuals (kt)	17.6	17.0	13.7	13.5	13.6	13.6

- The Mean Absolute Error (MAE) of AMSU-based Vmax estimates is **10.8 kt** as reported by Demuth et al. (2006).
- The AMSU-based TC intensity estimate Root Mean Square Error (RMSE) is **14.0 kt** (Demuth et al. 2006).
- The SSM/I-based Vmax estimate RMSE is **19.7 kt** (Bankert and Tag 2002).

Real-Time Model Development

Using GPM 1C/2A Data

- In real-time, the 85-91 GHz observations will be available through the **GPM 1C-constellation near-real-time product**, which includes the inter-calibrated brightness temperatures from GMI, ASMR2, and SSMIS.
- The microwave rain retrievals will be from the **GPM 2A-GPROF-constellation near-real-time product**, which contains the rain rates retrieved from GMI, AMSR2, and SSMIS using the NASA GPROF algorithm (Kummerow et al. 1996).
- **Latencies:**
 - GPM 1C: **about 20 minutes to 1 hour**
 - GPM 2A: **about 2 to 4 hours**
 - Therefore, in real-time, the rain variables may or may not be available for estimating V_{max} at the current synoptic time. But we can still estimate the current V_{max} using the regression model for the 6-h future V_{max} .

GPM 1C and 2A Data Samples in 2014-2016

AL	GMI	SSMIS	AMSR2	Total
2014	35	90	34	159
2015	36	115	34	185
2016	83	209	68	360
Total	154	414	136	704

- **Dependent sample for model development: 344 overpasses from 2014-2015**
- **Independent sample for model verification: 360 overpasses from 2016**
- **Unlike using the historical TRMM data, in real-time with GPM data, we'll have to use a fixed inner core radius parameter. So our first task is to determine the optimal choice of "inner-core radius" which gives the highest correlation coefficient.**

Sensitivity Tests for Inner Core Radii (GPM/AL)

Correlation Coefficients: t=0 h

Radii (km)	75	100	125	150	175	200	225	250
85-91GHz Predictors	0.54	0.58	0.61	0.62	0.63	0.64	0.64	0.64
Rain Predictors	0.70	0.74	0.75	0.75	0.76	0.76	0.75	0.73
Combined Predictors	0.74	0.77	0.78	0.78	0.78	0.78	0.77	0.76

Correlation Coefficients: t=6 h

Radii (km)	75	100	125	150	175	200	225	250
85-91 GHz Predictors	0.56	0.59	0.61	0.63	0.64	0.65	0.65	0.64
Rain Predictors	0.72	0.75	0.76	0.76	0.77	0.77	0.76	0.74
Combined Predictors	0.75	0.78	0.79	0.79	0.79	0.79	0.78	0.76

Multiple-Linear Regression Model (GPM/AL)

Table below: Regression variables and their corresponding normalized coefficients to estimate Vmax and 6-h future Vmax. r^2 is the percent of total variance explained by each regression.

Variables	85-91 GHz only		Rain only		Combined	
	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h
MEANPCT	-0.14	-0.14	-	-	-0.10	-0.10
FRAC275	0.05	0.04	-	-	-0.16	-0.17
FRAC250	0.63	0.62	-	-	-0.07	-0.07
FRAC225	-0.15	-0.12	-	-	-0.27	-0.24
FRAC200	-0.11	-0.12	-	-	0.06	0.06
U_RR	-	-	0.83	0.82	0.80	0.79
C_RR	-	-	-0.27	-0.23	-0.13	-0.11
L_RR	-	-	-0.02	-0.02	-0.02	-0.01
H_RR	-	-	-0.00	-0.02	0.00	-0.01
RA	-	-	-9.45	-8.27	1.16	1.73
L_RA	-	-	4.19	3.67	-0.18	-0.42
H_RA	-	-	7.23	6.3	-0.78	-1.22
r^2 (%)	35.6	36.0	54.5	55.2	58.6	58.9

Independent Verification: Errors (GPM/AL)

	85-91 GHz only		Rain only		Combined	
	t=0 h	t=6 h	t=0 h	t=6 h	t=0 h	t=6 h
r^2 (%)	44.5	45.5	58.6	60.6	61.1	63.1
MAE (kt)	13.6	13.3	11.6	11.3	10.8	10.4
RMSE (kt)	18.3	18.0	15.8	15.2	15.5	15.1
Standard deviation of residuals (kt)	18.1	17.9	15.7	15.2	15.3	14.9

- The Mean Absolute Error (MAE) of AMSU-based Vmax estimates is **10.8 kt** as reported by Demuth et al. (2006).
- The AMSU-based TC intensity estimate Root Mean Square Error (RMSE) is **14.0 kt** (Demuth et al. 2006).
- The SSM/I-based Vmax estimate RMSE is **19.7 kt** (Bankert and Tag 2002).

Summary

- As demonstrated in Landsea and Franklin (2013), the average best track uncertainty ranges from 5 to 15 kt when both satellite and aircraft data were available.
- **The results here suggest that the PMW-IE can provide TC intensity estimates that are in the same uncertainty ranges as the best track (mainly from the Dvorak method) and the AMSU method.**
- **But the PMW-IE estimates are independent of visible, IR, and microwave sounder observations.** Because of this independence, the PMW-IE method will be able to provide additional information for TC forecasters who can utilize different methods to achieve more accurate intensity estimates.

Next-Step Work

➤ Year 1:

- Mar-May 2018: Real-time Implementation: AL basin 2018 season
- **Potential problem: NOAA NESDIS didn't approve our request for GPM 1C & 2A real-time data access! We'll have to rely on NASA PPS service, which is not always reliable for operational purposes.**

➤ Year 2:

- Jul-Oct 2018: Model development for EP
- Nov-Dec. 2018: Post-season evaluation
- Jan-Jun, 2019: Algorithm refinement; Real-time testing for AL/EP basins in 2019 season

Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index (PMWRing RII) for NHC/JTWC Forecast– Year 3 Update

Presenter: Yongxian Pei¹

PI: Haiyan Jiang¹; Co-PI: Kate Musgrave²

Contributors: Jon Zawislak^{1,3} and Galina Chirokova²

¹*Florida International University*

²*Colorado State University CIRA*

³*NOAA HRD/ UM CIMAS*

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2) JTWC Point of Contact: ***Brian deCicco***

3) This NOAA Joint Hurricane Testbed project was funded by the US Weather Research Program in NOAA/OAR's Office of Weather and Air Quality.



Thanks for your attention!

Previous Studies of TC Intensity Using SSM/I

- **Glass and Felde (1992)** examined the relationship between **the 85-GHz brightness temperature and TC intensity**. They found that the percentage of pixels having brightness temperatures below 220-230 K is highly correlated with TC intensity.
- **Rao and MacArthur (1994)** found that **the microwave-derived rainfall rates in the inner core region** were highly correlated with **24-h future typhoon intensity** (correlation coefficient 0.68). Similar results were found by Rodgers et al. (1994) using the Western North Atlantic TCs.
- **Cecil and Zipser (1999)** examined various ice-scattering signature parameters from the 85-GHz observations. They found high correlations (0.5-0.8) between **the mean 85 GHz polarization corrected brightness temperature (PCT, Spencer et al. 1989) in the inner core and the current and 24-h future TC intensity**.

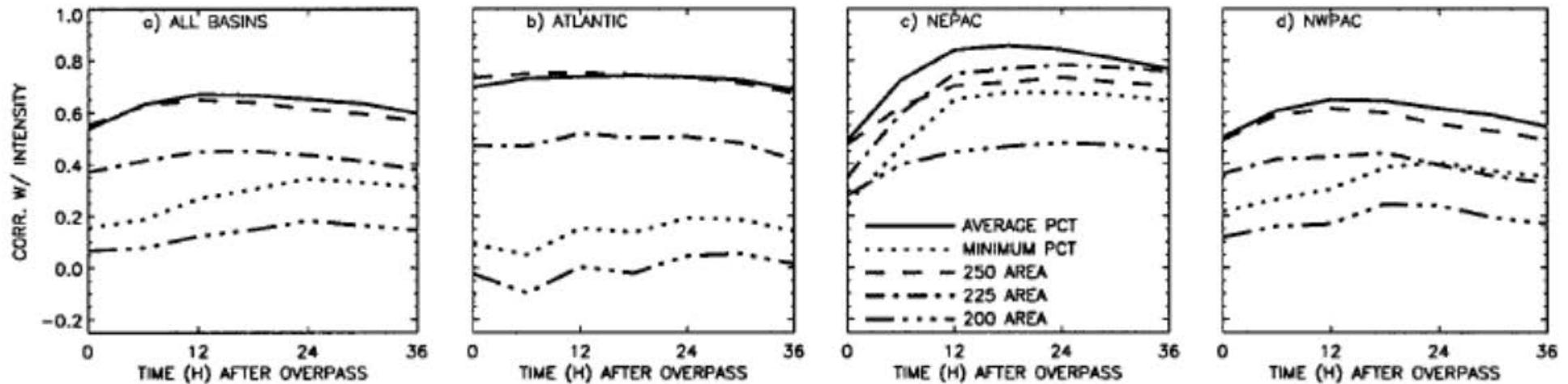


FIG. 2. (a) Correlations between 0° and 1° radius PCT parameters and hurricane/typhoon intensity at the time of SSM/I overpass and 6-h intervals afterward: (b) ATL only, (c) NEPAC only, and (d) NWPAC only.

From Cecil and Zipser (1999): using 2-yr (1995-1996) SSM/I observations (about 270 overpasses) for TCs at hurricane/typhoon strength