NOAA AWARD NUMBER: NA11OAR4310193 (**FY 11 Joint Hurricane Testbed**)
Florida International University Project Number: 800001149

Progress Report for Year-1 (September 1, 2011 – August 31, 2012)

Project Title: Enhancement of SHIPS Rapid Intensification (RI) Index Using Satellite 37 GHz Microwave Ring Pattern

PI: Haiyan Jiang, Florida International University; haiyan.jiang@fiu.edu
Unfunded Collaborators: Edward J. Zipser, University of Utah; ed.zipser@utah.edu
John Kaplan, NOAA Hurricane Research Division; John.Kaplan@noaa.gov

1. Accomplishments during Year-1

1.1 Real-time testing of the 37 GHz Ring RI Index at NHC

As we have planned in our original proposal, the real-time testing of the automatic 37 GHz ring pattern tropical cyclone (TC) rapid intensification (RI) index is currently running smoothly and is being sent to the National Hurricane Center (NHC) during the current 2012 Atlantic and East Pacific Hurricane season. The testing started on May 15, 2012 and will continue throughout the season. During year 1 (between Sep. 2011 and May 15, 2012), we put a lot of efforts in preparing for the real-time testing. We made contact with various NOAA and NASA agencies about requesting an active account for real-time microwave data access. So far, we have successfully obtained the access for the real-time Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) data from NASA Goddard, and real-time Special Sensor Microwave Imager (SSM/I), Special Sensor Microwave Imager/Sounder (SSMIS), and WindSat data from NOAA NESDIS. The new AMSR-2 data is expected to be available to us through NOAA NESDIS soon after the data is available to NOAA.

To prepare for the real-time testing code, we also met formerly with our NHC points of contact, i.e., Dr. Chris Landsea and Mr. Todd Kimberlain on December 15, 2011. The technical details were discussed about how to obtain the current and forecasted storm track data, and how to better format our output to be better used at NHC. John Kaplan at NOAA HRD has provided the most recent version of real-time SHIPS RI forecasts as input of our automatic algorithm. Dr. Tie Yuan (Postdoc on this project) has been working on making and maintaining the real-time test code. It involves using multiple programming languages including IDL and scripts. Fig. 1 is the flowchart of the real-time testing code. The real-time automatic algorithm is running at FIU servers. Currently for the 2012 hurricane season, after discussing with NHC, we have decided to put three types of outputs online at an ftp site (http://tcpf.fiu.edu/JHT/). These three types of outputs include:

1) TYPE 1: text file of RI forecasts right after each satellite overpass. TYPE 1 forecast files can be access at http://tcpf.fiu.edu/JHT/Txt/ (scroll down to the bottom of the page for the most recent forecast). An example of TYPE 1 real-time forecast for the TRMM overpass on 10:18Z June 15, 20112 for Hurricane Carlotta in the East Pacific basin is shown in Fig. 2, which can also be found online at http://tcpf.fiu.edu/JHT/Txt/1206151018EP0312.TMI.RING.DAT.

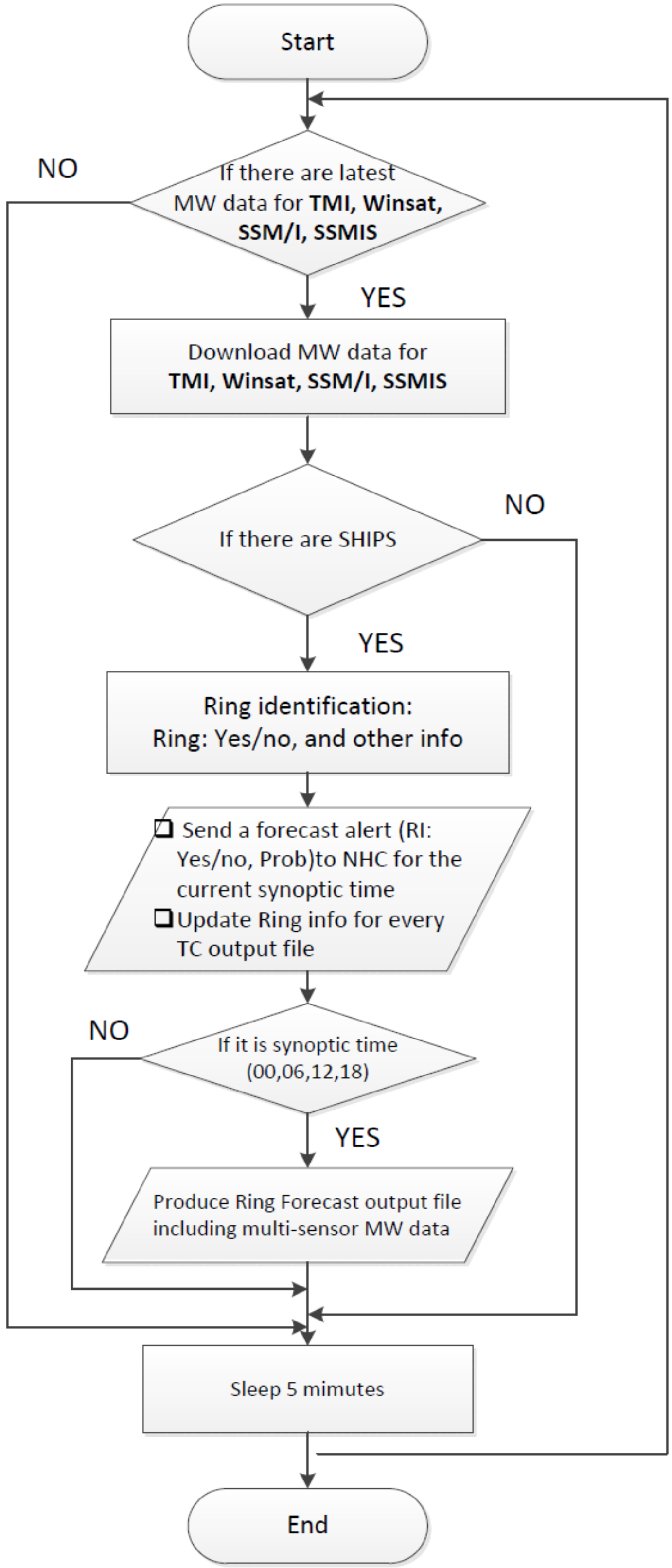

Figure 1. The flowchart of the real-time testing code.

2) TYPE 2: 6 hourly summary text file for each synoptic time T from all individual forecasts from all the available satellite overpasses between T-5 and T+1. TYPE 2 forecast files can be access at http://tcpf.fiu.edu/JHT/Summary/ (scroll down to the bottom of the page for the most recent forecast). The TYPE 2 summary forecast file for the corresponding synoptic time of the TMI Carlotta case shown in Fig. 2 (1200Z June 15, 2012) can be found at http://tcpf.fiu.edu/JHT/Summary/12061512EP0312.DAT.

3) TYPE 3: The 37 GHz color composite (Lee et al. 2002), 37 horizontal and vertical polarized brightness temperatures, and 37 GHz Polarization Corrected brightness Temperature (PCT, Spencer et al. 1989) images for each TC overpass. If a ring pattern is identified, the inner and outer circles of the ring will be indicated in the images. TYPE 3 image files can be access at http://tcpf.fiu.edu/JHT/Figures/ (scroll down to the bottom of the page for the most recent forecast). An example of TYPE 3 real-time 37 GHz images for the TRMM overpass of the Carlotta case shown in Fig. 2 is presented in Fig. 3, which can also be found online at http://tcpf.fiu.edu/JHT/Figures/1206151018EP03.TMI.1B11.2012-06-15T08-56-25Z.7.rt.png.

NHC forecasters can check our ftp site anytime they want. We also send an email alert to NHC whenever there is a positive RI forecast indicated by our automatic method. The Hurricane Carlotta case illustrated in Fig. 2 & 3 was considered as a successful RI forecast case, as confirmed by NHC hurricane specialist Jack Beven.

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       East Pacific 37 GHz RING PATTERN RI INDEX
            TMI  CARLOTTA  EP032012  06/15/12  1018 UTC

===========RI FORECAST BY THE 37 GHZ RING PATTERN RI INDEX==========
FUTURE 24-HOUR INTENSITY INCREASE >= 30 KT (RI)? :        YES

==================MICROWAVE DATA INFORMATION========================
MICROWAVE SENSOR NAME: TMI
RAW DATA FILE: 1B11.2012-06-15T08-56-25Z.7.rt
THE MINIMAL DISTANCE BETWEEN TC CENTER AND THE CENTER LINE OF SATELLITE ORBIT(KM):     158.

===============TC STATUS AT SATELLITE OVERPASS TIME ================
BASIN:                   EP
STORM NAME:          CARLOTTA
TIME:                2012/06/15 10:18
LAT(DEG):               13.37
LON(DEG):              264.60
VMAX(KT):                  60
CURRENT TC CENTER OVER WATER ?:       YES
24-H FUTURE TC CENTER OVER WATER ?:       YES
INTENSITY INCREASE DURING LAST 6 HOUR (KT):        5

============CHARACTERISTICS OF THE 37 GHZ RING=====================
IF THERE IS A RING:                           YES
INNER RADIUS(KM) OF THE RING:                  30
OUTER RADIUS(KM) OF THE RING:                  85
RING THICKNESS(KM):                            55
RATIO OF THE THICKNESS TO OUTER RADIUS(%):      64
% OF CYAN PIXELS IN THE RING:              81
% OF CYAN PIXELS WITHIN 200 KM RADIUS:      31

=============SHIPS RI PROBABILITIES AT CURRENT SYNOPTIC TIME T (THE SATELLITE OBSERVATION FALL INTO T-5H AND T+1H):
PROB OF RI FOR 25 KT RI THRESHOLD=    33%
PROB OF RI FOR 30 KT RI THRESHOLD=    29%
PROB OF RI FOR 35 KT RI THRESHOLD=    23%
PROB OF RI FOR 40 KT RI THRESHOLD=    19%
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Figure 2. An example of TYPE 1 real-time forecast for the TRMM overpass on 10:18Z June 15, 20112 for Hurricane Carlotta in the East Pacific basin. The text file can be found online at http://tcpf.fiu.edu/JHT/Txt/1206151018EP0312.TMI.RING.DAT.

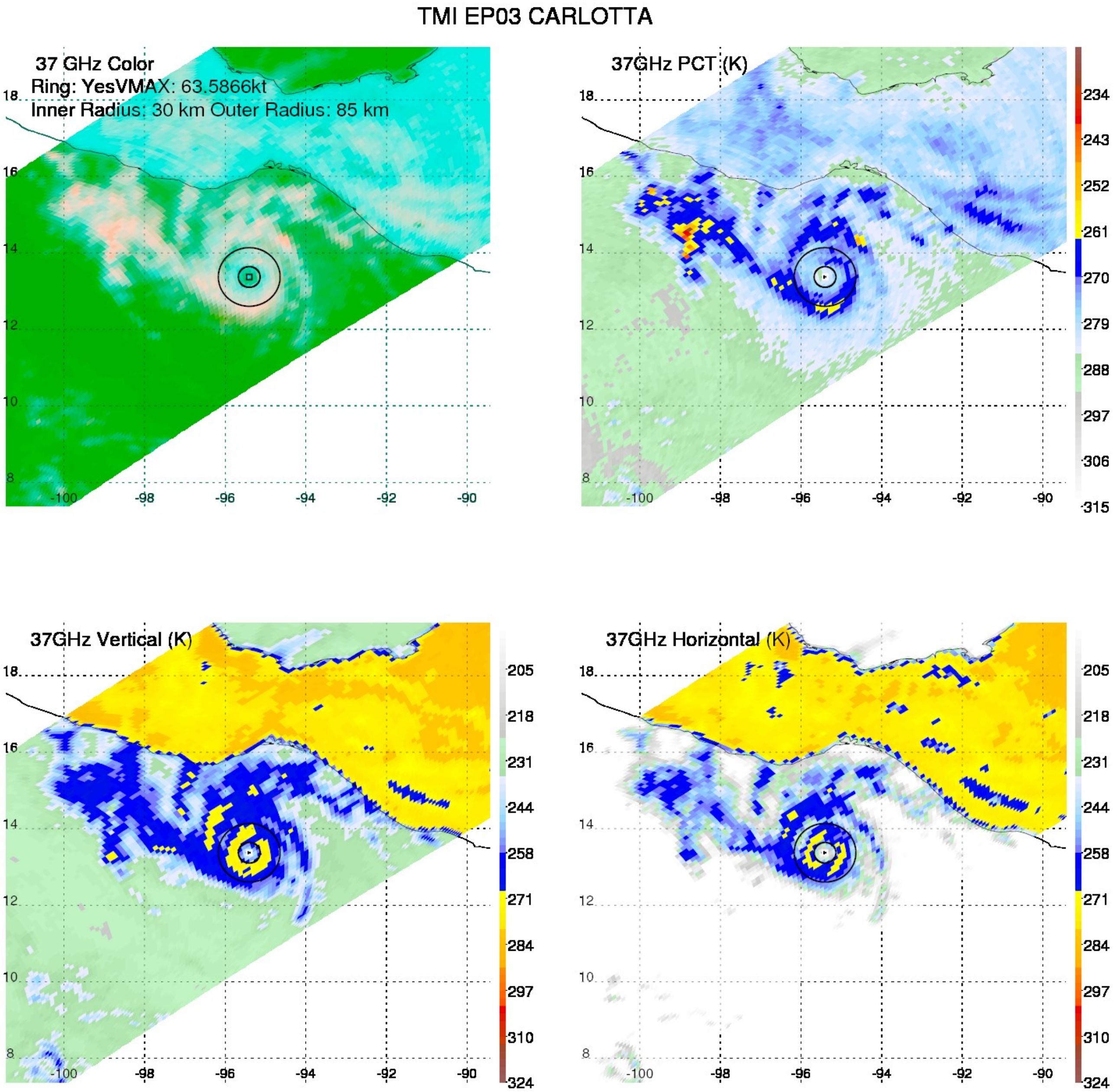

Figure 3. An example of real-time 37 GHz images for the TRMM overpass on 10:18Z June 15, 20112 for Hurricane Carlotta in the East Pacific basin. The file can be found online at http://tcpf.fiu.edu/JHT/Figures/1206151018EP03.TMI.1B11.2012-06-15T08-56-25Z.7.rt.png. The 37 GHz color (top left), Polarization Corrected brightness Temperature (PCT, top right), vertically polarized brightness temperature (bottom left), and horizontally polarized brightness temperature (bottom right) are shown. The storm center derived from 37 GHz observations is indicated as a small dot in each panel. Algorithm-detected inner and outer radii (30 and 85 km respectively) of the ring are indicated in the same panel.

1.2 Evaluation and Refinement of the 37 GHz ring+SHIPS RI index

There are two aspects in term of evaluating and refining the ring+SHIPS RI index. 1) The performance of the index should be evaluated based on a subjective determination of the ring pattern. 2) The evaluation should be done by using the automatic ring identification algorithm, which will be eventually used for the project. Since there are some cases that the automatic algorithm could fail, we should first check the first aspect and refine the RI index based on the subjective determination of the ring. Then the second aspect should follow in order to further refine the index by refining the automatic ring detection algorithm. The first aspect is presented in section 1.2.1 and the second aspect in section 1.2.2.

1.1.1 Evaluation and refinement of the subjective ring+SHIPS RI index

A journal paper (Kieper and Jiang 2012, GLR) has been published this year based on the results discussed in this sub-section. Using a dataset including 84 TCs in the Atlantic basin during 2003-2007, a subjective search has been done in Kieper and Jiang (2012) to find ring patterns from all the available 37 GHz color composite (hereafter 37color, Lee et al. 2002) images for these storms provided by the Navy Research Laboratory (NRL) TC satellite web page (http://www.nrlmry.navy.mil/TC.html, Hawkins et al., 2001, Hawkins and Velden 2011). These images include observations from Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E), WindSat, Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS). From these images, a well-defined cyan-color ring is searched for each satellite overpass. The following criteria are used to define a ring pattern: 1) It is symmetric (round) and should be above 98% closed (not a partial ring); 2) It has to be thick enough. The minimum thickness between the inner and outer edges of the ring should be at least one-fourth of the diameter of the outer edges; 3) The ring should be mostly solid bright cyan; 4) either part of the ring or the whole ring could be pink (intense convection overlaying cyan ring).

From the best track data, each synoptic time, i.e., 0000, 0600, 1200, and 1800UTC, is considered as one case. RI cases are defined as those cases with the following 24-h storm maximum wind speed intensity change equal or greater than 30 kt [Kaplan and DeMaria, 2003]. To be included in the study, the inner core of the TC must be over water at the satellite observations time, and must remain over water for the next 24 hours. The current TC intensity must be equal or less than 100 kt in order to be included in the study (Kieper's original method also required the current TC intensity less than 45 kt, but this criterion is removed after seeing some RI cases with a well-defined ring with current intensity less than 45 kt). The 84 TCs contributed a total of 1735 cases (i.e., 24-h time periods with initial time at the 6 hourly synoptic times). A ring pattern is searched from all the available 37color images with observation times within the previous 6 h of each case's initial time. The Statistical Hurricane Intensity Prediction Scheme (SHIPS) RI index [RII, Kaplan et al., 2010] is used to evaluate the environmental factors for each best track case. The SHIPS RII probability values for a 30 kt intensity increase during 24 h (hereafter RII_30kt) are obtained from the post-time dependent run of the most recent version of SHIPS RII index algorithm for 1995-2010 storms (data provided by J. Kaplan). These values are matched with the 6-hourly best track data. One caveat is that there are 781 out of 1735 total cases with either no 37 GHz microwave observation or SHIPS RII available. Therefore, the final total number of qualified cases used in this study is 954. There are 71 actual RI cases out of these 954 cases.

The ring pattern occurred in 153 out of the 954 cases, in which 39 cases have a ring feature.

Therefore, the probability of RI if using the 37 GHz ring as the sole criterion (the ring RI index) is 25% (39/153, table 1, second column). This represents a factor of 3.5 increases from the climatological mean during the same 5-yr period (table 1, first column). Jiang (2012) indicated that the probability of RI for TCs with hot towers in the inner-core is 9.6%, which is only about a factor of 1.5 increases from the climatological mean (6.3%) using TRMM precipitation radar observed TCs during 1998-2008. Although Jiang (2012)'s results are for global TCs, the substantial difference with this study demonstrates that the ring pattern might be a better inner-core process related indicator for the RI prediction.

The SHIPS RII probability threshold used to forecast RI is about 20% for the Atlantic basin (Kaplan et al. 2010). Here we use this threshold to evaluate the probability of RI for the SHIPS RII. There are 163 cases with RII_30kt ≥ 20%, in which there are 55 actual RI cases. Therefore, the probability of RI is 34% (55/163, table 1, third column), which is a factor of 1.7 higher than the probability of RI for the ring RI index. This indicates that the environmental condition might weigh over the inner-core process in terms of determining RI, although other inner-core processes need to be taken into account as well besides the ring pattern.

Since a favorable environmental condition is necessary for RI, it is optimal to add the SHIPS RII on top of the ring RI index (RII). To do this, a SHIPS RII_30kt threshold is needed. By examining both of the RI and non-RI cases with a ring pattern, it is found that most of actual RI cases with ring have RII_30kt ≥ 5%, while most of the non-RI cases with ring have RII_30kt < 5%. Therefore, it is decided to use RII_30kt ≥ 5% as the additional criterion besides ring. We call this combined RI index as Ring+SHIPS RII. As shown in the last column of table 1, there are 66 (out of 954) cases that satisfy the ring and RII_30kt ≥ 5% criteria, in which there are 38 actual RI cases. This produces a probability of RI of 58% (33/66), which is about of a factor 2 higher than either of the ring or SHIPS RII. This indicates that the 37 GHz ring RII and SHIPS RII are independent predictors.

Based on above results, the ring+SHIPS RII forecast scheme proposed in the original JHT proposal is refined as follow: *1) A thick cyan-color ring pattern (pink-color may be part of the ring) is seen on the NRL 37color images; 2) The inner core of the TC is currently over water and is anticipated to remain over water for the next 24 hours; 3) The current storm intensity is equal or less than 100kt; 4) Environmental conditions are favorable. For the Atlantic basin, this means that the SHIPS RI index for 30 kt increase in 24 hours is 5% or greater.* Further study is needed to determine the SHIPS RII thresholds for other RI thresholds (25 kt and 35 kt intensity increases in 24 hours) in the Atlantic basin and for all three RI thresholds in the Eastern central Pacific basin. This work will be done during year-2.

Table 1: Probability of RI for 2003-2007 Atlantic TCs using the ring, SHIPS RII, and ring+SHIPS RII criteria for the 30-kt RI threshold.

	Climatological mean	Ring	SHIPS RII≥20%	Ring+ SHIPS RII≥5%
# of total forecasts	954	153	163	66
# of correct forecasted cases	71	39	55	38
Probability of RI	7%	25%	34%	58%

There are two more interesting findings presented in Kieper and Jiang (2012): 1) When treating RI as a whole event, which consists of a contiguous period where any 24-hour subset shows at least a

30 kt intensity increase, the probability of RI is even higher. Out of a total of 28 RI events during 2003-2007 Atlantic hurricane seasons, 23 of them have a ring pattern observed in the very early stage of RI. The rest 5 RI events are lack of ring pattern under high environmental shear conditions. 2) For about 70% of cases studied, the 37 GHz ring is associated with the highest 24-h intensity increase during a whole RI event. An example of Hurricane Wilma (2005)'s RI event is shown in Fig. 4, where the 37 GHz ring occurred before a 95 kt intensity increase during 24 hours.

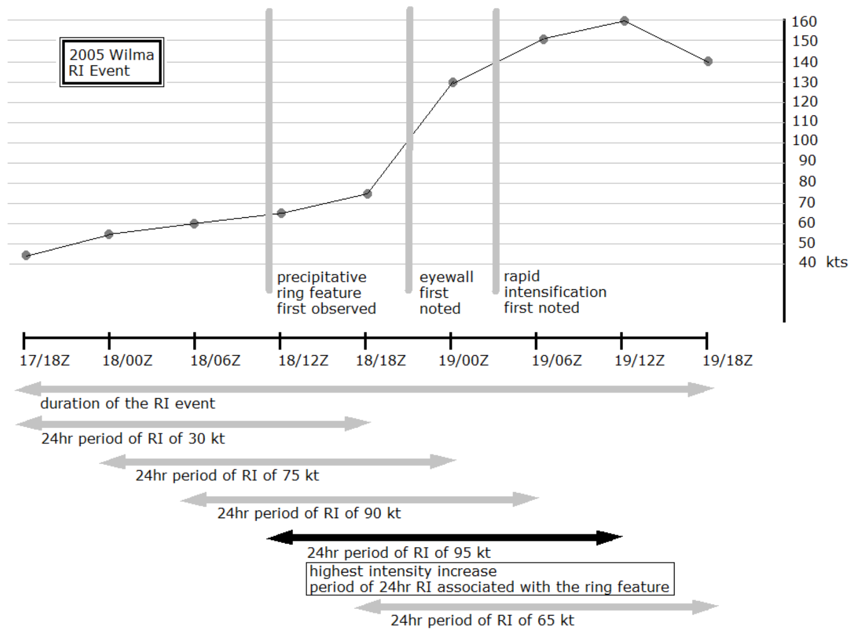

Figure 4. Time series of the 6 hourly best track maximum wind speed (in kts) of Hurricane Wilma (2005) during its 48-h RI event between 18 Z October 17 and 18 Z October 19. The times of the first ring feature seen in the 37color product, eyewall first noted by NHC in the advisory package, and RI first noted by NHC in the advisory package are indicated as vertical lines. Five overlapping 24-h periods of RI are indicated as arrows at the bottom of the figure. The ring was observed about 16 hours prior to the time that NHC first gave the advisory that the hurricane was going through an RI event (from Kieper and Jiang 2012).

1.1.2 Evaluation of the objective version of above refined ring+SHIPS RI index

The objective version of the refined subjective RI index has been developed by using the automatic ring identification algorithm described in our previous proposal. The database for evaluating the automatic RI index consists of all the TRMM TMI observations of tropical cyclones in the Atlantic (ATL) and eastern North Pacific (EPA) basins that developed from 1998 to 2010. At the TMI observation time, the storm must be over water, and will be over water in the following 24 hours. The current storm intensity has to be less than 100 kt. This brings a total sample of 974 and 541 TMI samples for the ATL and EPA basins, respectively. Three RI thresholds are used similar to Kaplan et al. (2010): 25-, 30-, and 35-kt over water intensity changes during 24 hours. Table 2 gives the number of RI and non-RI cases for each RI threshold in each basin.

Since the SHIPS RII thresholds for being used in the refined ring+SHIPS RII have not been determined completely for all three RI thresholds, here the old threshold of the SHIPS RII for 25 kt RI threshold (SHIPS RII_25kt) greater than 20% is used. Probabilities of RI for all samples (climatological mean), and for samples that satisfy 37 GHz ring (ring), SHIPS RII>=20% (SHIPS), and ring+SHIPS criteria are plotted in Fig. 5. For both ATL (Fig. 5a) and EPA (Fig. 5b), we can see that the probability of RI for cases that satisfied the SHIPS criterion is higher than for cases that satisfied the 37 GHz ring criterion. However, when both criteria were satisfied, the probability of RI is about equal to the sum of the two probabilities with only one criterion satisfied. For example, for the ATL basin, the probability of RI for 30-kt intensity change in 24-h is 10% when a 37 GHz ring pattern is detected, and is 22% when the environmental condition is favorable as indicated by SHIPS RII_25kt greater than 20%. The probability increases to 34% when both a ring pattern is seen in the inner core and the SHIPS criterion is satisfied. This indicates that the 37 GHz ring pattern index and the SHIPS index are independent predictors. Also as seen from Fig. 5, the probability of RI decreases as the RI threshold increases. Results for EPA are similar (Fig. 5b).

Table 2: The number of RI and non-RI cases for each set of RI threshold for ATL and EPA basins.

	RI thresholds for 24-h intensity change		
	25 kt	30 kt	35 kt
ATL (974 total)	58 RI/889 non-RI	55 RI/919 non-RI	38 RI/936 non RI
EPA (541 total)	55 RI/486 non-RI	39 RI/502 non-RI	27 RI/514 non RI

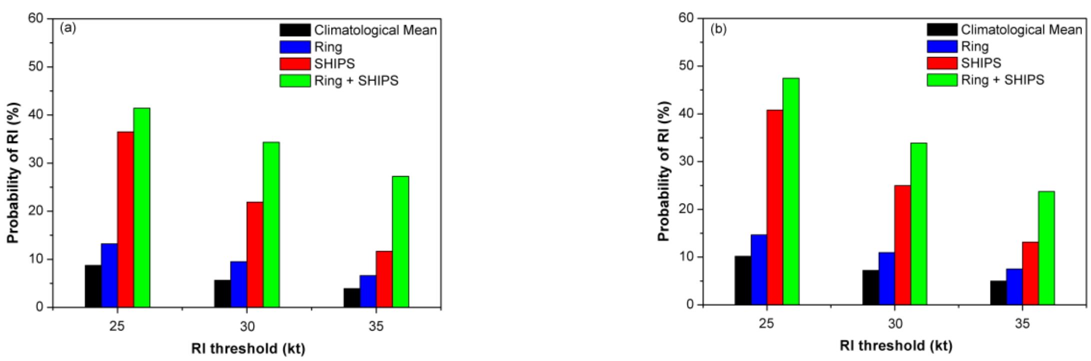

Figure 5. The probability of RI for all samples (climatological mean), and for samples that satisfy 37 GHz ring (ring), SHIPS RII>=20% (SHIPS), and ring+SHIPS criteria for ATL (a) and EPA (b) samples. The probabilities of RI are shown for the 25-, 30-, 35-kt RI thresholds.

1.3 Application of the ring pattern RI index into the Northwest Pacific Basin

Although it is beyond the general tasks for this JHT project, a similar ring pattern RI index is developed and applied to TCs in the Northwest Pacific basin. We have done this for two reasons: 1) It helps our automatic algorithm development, verification, and refinement by using a much larger database. Currently, we only have 13 years of TMI data available. Due to the narrow swath of the TMI, there are only less 2000 good samples in the Atlantic and East pacific basins. This limits our ability to identify reasons for failure of the automatic algorithm. By using the Northwest Pacific storms, the sample size is almost doubled. 2) We would like to compare the performance of the ring index between different basins so that we could better refine the prediction method for the Atlantic and East pacific basins.

The work for the Northwest Pacific basin has been led by Dr. Tie Yuan (postdoc). He presented his preliminary results in 2011 IHC meeting at Miami. Currently he is writing a journal manuscript based on the results.

1.4 Contribution by collaborators and others

J. Kaplan: We have had several meetings with John exclusively for this JHT project. He has been extremely helpful on the algorithm design and how to cooperate with the SHIPS RI index. He has provided the SHIPS RII developmental dataset between 1995-2010, which is crucial for our algorithm development, verification, and refinement. Currently we are using his most recently updated SHIPS RI real-time forecasts as the input of our real-time testing algorithm.

E. Zipser: As an unfunded collaborator, Dr. Zipser has been very helpful on providing insights on the fundamental aspect of the problem, and providing the TRMM database as well.

M. Kieper: Ms. Kieper was listed a private consultant at the proposal writing stage. However, she became a research assistant of the PI in Aug. 2011, and is a PhD student of the PI since Aug. 2012. She has been supported by the JHT grant. She has finished the GRL journal paper writing, and now she is continuing to make great contributions to the project in assisting with the automatic algorithm evaluation and further refinement.

2. **Project deliverables and timeline for year 2 of the project**

Year 2 (September 2012- August 2013): 1) During the current 2012 hurricane season real-time testing, we do find several issues within the automatic ring detection algorithm. Some of the issues are addressed during the test, but some others need more time to solve. For example, the TC center interpolated from NHC track forecasts might be offset from the real center, which causes failure of the ring detection. After the hurricane season, we will assemble all the real-time testing outputs and make a careful evaluation. During yr-2, we will refine the automatic algorithm based on the evaluation results from the real-time testing. 2) Based suggestions by NHC hurricane specialists, e.g., Dr. Chris Landsea, we will extend the RI index from having only one 30 kt RI threshold into four RI thresholds: 25, 30, 35, and 40 kt. We will also work out a strategy to not only provide a “yes” or “no” forecast, but also probabilities. 3) Our critical task during year 2 also includes implementing the final refined version of the 37 GHz RI index into the current version of SHIPS RI index. We will work closely with John Kaplan at NOAA HRD, Ed Zipser at Univ. of Utah, and forecasters at NHC during year 2. 4) We will continue to synthesize our findings into manuscripts and presentations at conferences and workshops.

3. Journal Papers in Preparation, Review, or Revision (wholly or partially supported by this grant)

Jiang, H., T. Yuan, M. Kieper, E. Zipser, and J. Kaplan, 2012: An objective rapid intensification index derived from the 37 GHz microwave ring pattern around the tropical cyclone center. *J. Geophys. Res.*, in preparation.

Jiang, H., and E. M. Ramirez, 2012: Necessary conditions for tropical cyclone rapid intensification as derived from 11 years of TRMM data. *J. Climate*., in review.

Yuan T., and H. Jiang, 2012: Forecasting rapid intensification of tropical cyclones in the Western North Pacific using TRMM 37 GHz microwave observations. *Wea. Forecasting*, in preparation.

Zagrodnik, J., and H. Jiang, 2012: Quantitative Comparison of TRMM Precipitation Algorithms in Tropical Cyclones. *J. Geophys. Res.*, in revision.

4. Journal Publications and Presentations (wholly or partially supported by this grant)

Kieper, M., and H. Jiang, 2012: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. *Geophys. Res. Lett.*, 39, L13804, doi:10.1029/2012GL052115.

Tao, C., and H. Jiang, 2012: Climatology of hot towers in tropical cyclones based on 12-yr TRMM data. *J. Climate*, in press.

Jiang, H., E. M. Ramirez, and D. J. Cecil, 2011: Convective and rainfall properties of tropical cyclone inner cores and rainbands from 11 years of TRMM data. *Mon. Wea. Rew.*, in press.

Jiang, H., 2012: The relationship between tropical cyclone intensity change and the strength of inner core convection. *Mon. Wea. Rev.*, **140**, 1164-1176.

Jiang, H., C. Liu, and E. J. Zipser, 2011: A TRMM-based Tropical Cyclone Cloud and Precipitation Feature Database. *J. Appl. Meteor. Climatol.*, **50**,1255-1274.

Jiang, H., E. M. Ramirez, and D. J. Cecil, 2012: Convective and Rainfall Properties in the Inner Core and Tropical Cyclone Intensity Change Using 11-yr TRMM Data. 30th *Conference on Hurricane and Tropical Meteorology*, Ponte Vedra Beach, FL, April 15-20, 2012.

Kieper, M., and H. Jiang, 2012: The 37 GHz Cyan Ring and Tropical Cyclone Rapid Intensification: What Does the Cyan Color Truly Represent? 30th *Conference on Hurricane and Tropical Meteorology*, Ponte Vedra Beach, FL, April 15-20, 2012.

Tao, C., and H. Jiang, 2012: Climatology of Hot Towers in Tropical Cyclones Based on 12-year TRMM Data. 30th *Conference on Hurricane and Tropical Meteorology*, Ponte Vedra Beach, FL, April 15-20, 2012.

Yuan, T., and H. Jiang, 2012: Evaluation of 37 GHz Microwave Ring Pattern for Forecasting Rapid Intensification of Tropical Cyclones from SSM/I, SSMI/S and AMSR-E data. 30th *Conference on Hurricane and Tropical Meteorology*, Ponte Vedra Beach, FL, April 15-20, 2012.

Zagrodnik, J. P., and H. Jiang, 2012: Quantitative Comparison of TRMM Precipitation Algorithms in Tropical Cyclones. 30th *Conference on Hurricane and Tropical Meteorology*, Ponte Vedra Beach, FL, April 15-20, 2012.

Jiang, H., M. Kieper, T. Yuan, E. Zipser, and J. Kaplan, 2011: The 37-GHz Ring Pattern As An Early Indicator of Tropical Cyclone Rapid Intensification. Oral presentation, *NASA GRIP Science Team Meeting,* Los Angeles, CA, Jun 6-9.

Jiang, H., C. Liu, and E. J. Zipser, 2011: The 13-yr TRMM-based Tropical Cyclone Cloud and Precipitation Feature (TCPF) Database. Poster, *NASA GRIP Science Team Meeting,* Los Angeles, CA, Jun 6-9.

Jiang, H., M. Kieper, T. Yuan, E. Zipser, and J. Kaplan, 2011: Improving SHIPS rapid intensification (RI) index using 37 GHz microwave ring pattern around the center of tropical cyclones. 65th *Interdepartmental Hurricane Conference*, Miami, FL, Feb. 28-Mar. 3.

Yuan, T., Jiang, H., and M. Kieper, 2011: Forecasting rapid intensification of tropical cylones in the Western North Pacific using TRMM/TMI 37 GHz microwave signal. 65th *Interdepartmental Hurricane Conference*, Miami, FL, Feb. 28-Mar. 3.

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mission analysis with satellite digital data and products, *Bull. Amer. Meteor. Soc.*, **92**, 1009-1022.
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