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Midyear Progress Report for Year-1 (September 1, 2011 – February 17, 2012)

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

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1. Accomplishments during the first half year of Year-1

1.1 Preparation for real-time testing of the forecast scheme

Based on our plan, real-time testing and evaluation of the 37 GHz ring pattern rapid intensification (RI) index will be done during year 1 (between Sep. 2011 and Aug. 2012). During the past five and half months, we have been preparing for the real-time testing. We have 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. Efforts are still underway to work with NOAA to obtain access for real-time Special Sensor Microwave Imager (SSM/I) and Special Sensor Microwave Imager/Sounder (SSMIS) data. The ring RI index will have a better performance by using the higher resolution TMI data over the lower resolution SSM/I and SSMIS data.

To prepare for the real-time testing code, we have also met 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 SHIPS data, and how to better format our output to be better used at NHC.

Dr. Tie Yuan (Postdoc on this project) has been working on coding the real-time test. It involves using multiple programming languages including IDL and scripts. Fig. 1 is the flowchart of the real-time testing code. The code was run locally at FIU in real-time for Hurricane Kenneth in the East Pacific basin for a TMI overpass at 18:44 Z Nov. 22, 2011. The algorithm identified a ring feature for this case (Fig. 2). Since the probability of RI for 30 kt RI threshold predicted by the SHIPS RII was only 2% (less than our threshold), this case was a correct rejection. Although the code seems working OK for this single case, more testing and refinement are essential.

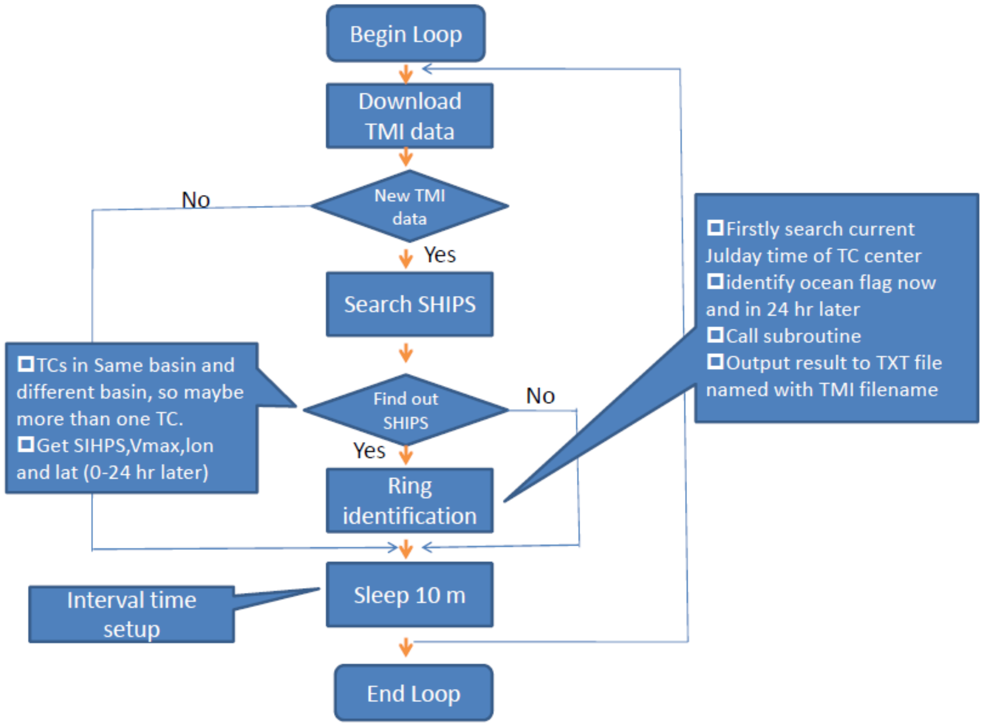

Figure 1. The flowchart of the real-time testing code.

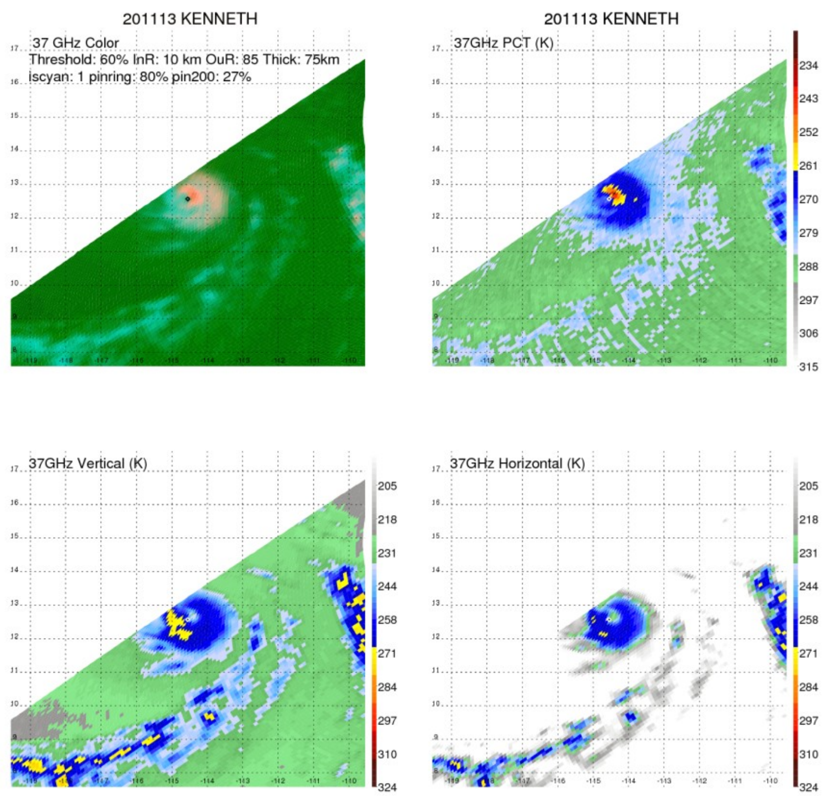

Figure 2. Demonstration of the real-time ring-identification algorithm using the TRMM TMI overpass

of Hurricane Kenneth (2011) at 18:44 Z Nov. 22. 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 black dot in the top left panel. Algorithm-detected inner and outer radii (10 and 85 km respectively) of the ring are indicated in the same panel.

1.2 Refinement and evaluation of the ring pattern RI index for the Atlantic Basin

There are two aspects in term of evaluating and refining the ring pattern 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 has been done and is presented below. The second aspect will be done during the second half year of year-1.

Using a dataset including 84 tropical cyclones (TCs) in the Atlantic basin during 2003-2007, a subjective search has been done to find ring patterns from all the available 37 GHz color 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). 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. 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 threshold for the Eastern central Pacific basin. This work will be done during the second half year of year-1.

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%

A verification of the ring+SHIPS RII forecast scheme refined above is done using 2008 storms in the Atlantic basin for each 6-h synoptic time in the best track data. This verification is essentially post-time because the best track and SHIPS RII data used here are from post-time analyses. Using the data selection criteria described above, there are a total 184 cases with 37 GHz microwave data and SHIPS RII_30kt data available, current intensity ≤ 100kt, and the TC inner core remains over water during the next 24 hours. There are 18 actual RI cases out of these 184 cases.

The skill of the RI forecast for the 2008 season is evaluated using the probability of detection (POD) and the false alarm ratio (FAR). The POD is the percentage of RI cases that are correctly identified. The FAR is the number of times that RI is forecasted but does not occur divided by the total number of times RI is forecasts. As presented in table 2, the PODs for the ring only RII, SHIPS RII, ring+SHIPS RII are 72% (13/18), 50% (9/18), and 72% (13/18), respectively. The POD for the combined RII is 44% higher than that for the SHIPS RII. This increase is apparently from the contribution of the ring criterion. The FARs for the ring only RII, SHIPS RII, ring+SHIPS RII are 52% (14/27), 57% (12/21), and 19% (3/16), respectively. The FAR for the combined RII is 63% lower than that for the SHIPS RII. The verification results show that the combined RII has a potential to increase POD and decrease FAR for the existing operational SHIPS RII.

Table 2: List of probability of detection (POD) and false alarm rate (FAR) of the 2008 Atlantic RI forecast verification using ring, SHIPS RII, and ring+SHIPS RII methods the 30-kt RI threshold.

	Ring	SHIPS RII≥20%	Ring+ SHIPS RII≥5%
# of total forecasts	27	21	16
# of correct forecasted cases	13	9	13
POD	72%	50%	72%
FAR	52%	57%	19%

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 meetings with John twice 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 also provided the SHIPS RII developmental dataset between 1995-2010, which is crucial for our algorithm development, verification, and refinement.

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 since Aug. 2011 and is currently supported by the JHT grant. She is planning to become a PhD student of the PI starting Fall 2012. It is anticipated that she will start to make contributions to the project in the following months when we start the real-time testing.

2. **Project deliverables and timeline for the rest of the project years**

Second half of year 1 (February 2012- August 2012): 1) Real-time testing and evaluation of the 37 GHz ring pattern RI index will be done this half year by the PI, postdoc Dr. Tie Yuan, and research assistant Margie Kieper, in collaboration with forecasters at NHC, and John Kaplan at HRD. We will continue to make every effort possible to get access for real-time SSM/I and SSMIS data and inject them into the real-time tests. 2) Complete the comprehensive verification of the ring index using the complete 14 years (1998-2011) of TMI data for the Atlantic, East Pacific, and North West Pacific basins. 3) Another important task to be completed is to collect more 37 GHz data from the past AMSR-E, SSM/I and SSMIS data in order to refine the algorithm.

Year 2 (September 2012- August 2013): 1) We will refine the index by using more microwave data and based on the evaluation results during year-1. 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. 2) Our critical task during year 2 will be 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.

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

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*, to be submitted.

Jiang, H., T. Yuan, 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.*, to be submitted.

Jiang, H., E. M. Ramirez, and D. J. Cecil, 2012: Convective and rainfall properties in the inner core in relation to tropical cyclone intensity changes from 11 years of TRMM data. *Mon. Wea. Rew*., to be submitted.

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

Tao, C., and H. Jiang, 2012: Climatology of hot towers in tropical cyclones based on 12-yr TRMM data. *J. Geophys. Res.*, to be submitted.

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 review.

Kieper, M., and H. Jiang, 2011: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. *Geophys. Res. Lett.*, in revision.

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

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

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.

5. References (excluding those already cited)

Hawkins, J. D., T. F. Lee, F. J. Turk, C. Sampson, J. Kent, and K. Richardson (2001), Real-time Internet distribution of satellite products for tropical cyclone reconnaissance. *Bull. Am. Meteorol. Soc.,* **82**, 567–578.

Hawkins, J. D. and C. Velden (2011), Supporting meteorological field experiment missions and post-mission analysis with satellite digital data and products, *Bull. Amer. Meteor. Soc.*, **92**, 1009-1022.

Kaplan, J., and M. DeMaria (2003), Large-scale characteristics of rapidly intensifying tropical cyclones in the north Atlantic basin, *Wea. Forecasting*, *18***,** 1093–1108.

Kaplan, J., M. DeMaria, J. A. Knaff (2010), A Revised Tropical Cyclone Rapid Intensification Index for the Atlantic and Eastern North Pacific Basins. *Wea. Forecasting*, **25**, 220–241.