NOAA AWARD NUMBER: NA13OAR4590191 (**FY 13 Joint Hurricane Testbed**)
Florida International University Project Number: 800002654

Mid-year Progress Report for Year-1 (Sep. 1, 2013 – Feb. 28, 2014)
& Work Plan for the rest of Year-1 & Year-2 (Mar. 2014 –Aug. 2015)

Project Title: Improvement to the Satellite-based 37 GHz Ring Rapid Intensification Index

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1. Accomplishments during Year-1

1.1 Real-time testing during 2013 hurricane season

This project is a continuation of our JHT FY11 project "automatic 37 GHz ring pattern tropical cyclone (TC) rapid intensification (RI) index" with some improvement proposed. Therefore, we are able to continue the real-time test for the whole 2013 hurricane season. According to the evaluation results based on 2012 hurricane season's real-time test, we proposed to change the SHIPS RI probability threshold to 5% for the Atlantic, while keep the 20% threshold for the East Pacific. However, our NHC point of contact (Chris Landsea) suggested that it is better to use a same threshold of 10% for both basins. This is what we were using for the 2013 season real-time testing.

Another change of the 37 GHz RI index algorithm we made during 2013 is to refine the storm center relocation method. Based on the evaluation results of 2012 real-time testing, most of the false alarms were due to bad storm center fixes. So another important work in order to improve the performance of our automatic ring+SHIPS RI index, especially in the Atlantic basin, is using a better center fixing technique. As suggested by our NHC point of contact, Chris Landsea, the best approach to solve the center fixing problem would be to incorporate the CIMSS ARCHER center fix technique. The good news is that the CIMSS ARCHER project is also funded by JHT FY13. We can expect to adapt their results into our algorithm when they start a real-time testing for ARCHER. However, during 2013 season, CIMSS was not ready for the real-time test. So we made some improvement on top of our original simple storm center relocation method. Originally, our algorithm finds an initial storm center at the microwave observation time based on a linear interpolation from the 6-hourly forecasted storm track data. Then it relocates the center by using a searching technique to search within 60 km around the original center to find the eye region (i.e., sea surface region with H37>=225 K). If a region H37>=225 K is found, then the new center location will be assigned as the center of this H37>=225 K region. This simple method is problematic for cases without any region with H37>=225 K. A more practical strategy has been implemented by searching the coldest H37 and V37, and warmest PCT37 regions around the initial storm center. The final center location is determined as an average center of these 3 regions. This new relocation method has been used in 2013 hurricane season.

The input satellite data for the real-time 37 GHz RI index were obtained from NOAA NESDIS and NASA. They include 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. We used the same output format as we did during 2012 season. A total of 250 microwave overpasses were processed in real-time during 2013 season. All the output and a readme file can be found online at an ftp site (http://tcpf.fiu.edu/JHT/). Whenever there was a positive RI forecast, an email was also sent to NHC points of contact for alert.

1.2 Evaluations of 2013 real-time testing results

1.2.1 Hits & misses during 2013 season real-time testing

The evaluation is done based on RI events. Here each RI event is defined as the whole RI period which usually includes several 24-h overlapping RI periods with each of them having 24-h intensity increase >=25 kts. Note that more than one RI events for each storm is possible. Normally, RI is defined as 24-h intensity increase >= 30 kts. However, the 2013 hurricane season was not active for both Atlantic and East Pacific basins. There was no RI case with 24-h intensity increase >= 30 kts in the Atlantic. Therefore, we use 25 kts as the RI threshold. During the 2013 season, there were two RI events in the Atlantic (AL) basin (table 1) and seven RI events in the East Pacific (EP) basin (table 2).

Table 1: List of storm ID, name, RI start time and max. wind speed (Vmax) at RI start time, RI end time and Vmax at RI end time, the total RI period, and the maximum intensity change of two RI events in the Atlantic 2013 hurricane season.

Storm ID/Name	RI start time (UTC), Vmax	RI end time (UTC), Vmax	RI period	Max. Intensity Change per 24 hr
AL09/Humberto	09/10 18:00, 55 kt	09/12 00:00 80 kt	30 h	25 kt
AL10/Ingrid	09/14 00:00, 50 kt	09/15 00:00, 75 kt	24 h	25 kt

Table 2: List of storm ID, name, RI start time and max. wind speed (Vmax) at RI start time, RI end time and Vmax at RI end time, the total RI period, and the maximum intensity change of seven RI events in the East Pacific 2013 hurricane season.

Storm ID/Name	RI start time (UTC), Vmax	RI end time (UTC), Vmax	RI period	Max. Intensity Change per 24 hr
EP05/Erick	07/05 06:00, 40 kt	07/06 06:00 65 kt	24 h	25 kt
EP07/Gil	07/31 00:00, 40 kt	08/01 06:00, 70 kt	30 h	30 kt
EP08/Henriette	08/05 06:00 45 kt	08/06 18:00, 80 kt	36 h	25 kt
EP11/Kiko	08/31 00:00, 30 kt	09/01 12:00, 65 kt	36 h	30 kt
EP13/Manuel	09/18 00:00, 30 kt	09/19 06:00, 65 kt	30 h	55 kt
EP17/Raymond (1)	10/20 00:00, 30 kt	10/22 00:00, 105 kt	48 h	60 kt
EP17/Raymond (2)	10/27 00:00, 55 kt	10/28 06:00, 90 kt	30 h	35 kt

The table 3 shows hits and misses by the real-time objective 37 GHz ring+SHIPS RI index for these two basins. From this table, for the Atlantic basin, two RI events were all correctly forecasted, and there were no misses. This corresponds to a probability of detection (POD) of 100% (table 4). For both RI storms, the ring pattern was identified within two hours of the onset of RI when 37 GHz microwave data were available (Fig. 1). For the East Pacific basin, there were 4 hits out of 7 RI events, producing a POD of 57% (table 4). Two misses for Hurricane Gil and Henriette were due to no AMSR-2 data available in real-time (Fig. 1, first two images in middle row). The other miss (the first RI event of Hurricane Raymond) was due to missing SHIPS data.

Table 3: The real-time performance of the objective 37 GHz ring+SHIPS RI index for RI events in the Atlantic and East Pacific 2013 hurricane season.

Storm ID/name	37 GHz Ring	SHIPS 25-kt RI Probability	RI forecasted (emailed to NHC)?
AL09/Humberto	Yes	26%	Yes
AL10/Ingrid	Yes	41%	Yes
EP05/Erick	Yes	46%	Yes
EP07/Gil	No (no AMSR2 data)	37%	No
EP08/Henriette	No (no AMSR2 data)	29%	No
EP11/Kiko	Yes	31%	Yes
EP13/Manuel	Yes	40%	Yes
EP17/Raymond (1)	Yes	Missing	No
EP17/Raymond (2)	Yes	28%	Yes

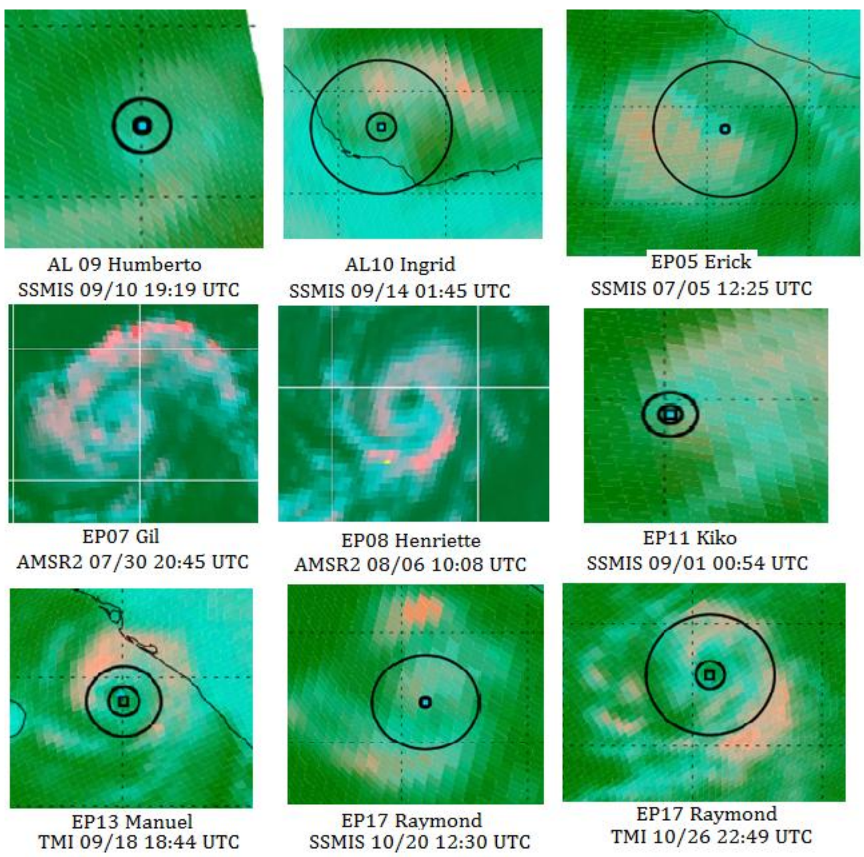

Figure 1. 37color ring images of the RI events in the East Pacific 2013 hurricane season.

1.2.2 False alarms during 2013 season real-time testing

To find out the false alarm ratio (FAR), we need to define the qualified forecasting period. This definition is also event-based. A qualified forecasting period is defined as a non-weakening period with storm initial intensity between 45-100 kt and current and 24-h future storm center over water. In the Atlantic 2013 hurricane season, out of 9 qualified forecasting periods, there was only 1 false alarm. This corresponds to a FAR of 11% (table 4). For the East Pacific 2013 season, out of 14 qualified forecasting periods, there were 3 false alarms. So the FAR is 21%.

Table 4: Probability of Detection (POD) and False Alarm Ratio (FAR) of the objective 37 GHz ring+SHIPS RI index for the Atlantic and East Pacific 2013 hurricane season.

	AL	EP
# of RI events	2	7
# of correct RI forecasts	2	4
POD	100%	57%
# of qualified forecasting periods	9	14
# of false alarms	1	3
FAR	11%	21%

In summary for the 2013 real-time testing, the algorithm worked better in 2013 than last year (2012 season). The possible reasons include: 1) 2013 was a very inactive season, especially in the Atlantic; 2) SHIPS performed better in 2013 than 2012 for both basins. However, problems still exist. First, although high PODs and low FARs were achieved in both basins, our algorithm usually can not capture the early onset of RI. The alert time ranged between 8 and 31 hours before RI ended (the preferred alert time is 24-h before RI ends). Second, bad TC center fixing was the major problem during 2012. In 2013, there were still some false alarms due to bad center fixing.

2. Work plan for the rest of year 1 and year-2

There are four tasks to be completed for this project:

Task 1: Adapting the CIMSS ARCHER product for better TC center fixing

As found in 2012 real-testing, the center –fixing problem was a main factor for poor ring detections during 2012 season, mainly for Atlantic storms. For the 2013 season, the problem was not as bad as in 2012, probably due to the modified center searching technique, or due to the inactive season. At this point, as we are expecting more active seasons in the future, we still need to adapt the CIMSS ARCHER product (PIs: Wimmers and Velden, JHT FY-13 project). As we talked with CIMSS PIs, they plan to do real-time testing in 2014. So we plan to directly use their output as one of the inputs of our algorithm.

Task 2: Adding real-time AMSR2 data as input

We have been contacting with NOAA NESDIS to request for access of the AMSR2 data since the sensor was successfully launched. Recently we were informed that by March 31st, 2014 NOAA expects to provide AMSR2 data from JAXA's GCOM-W1 satellite through the DDS server to authorized users. So we will be able to test the data format and add this sensor into our algorithm at the beginning of 2014 season.

Task 3: Implement, test, and refine the probability-based 37-GHz ring RI index

The current 37 GHz ring RI index is a "yes-and-no" type of forecast. A probability-based forecast is preferable to NHC. As proposed in our original FY-13 proposal, we will add three 85 GHz predictors in order to produce a probability-based RI index. These predictors include areas of 85 GHz polarization corrected brightness temperature (PCT) < 275 K, 250 K, and 225 K, respectively, within the inner core region. A combination of 37 GHz ring, SHIPS, and 85 GHz predictors will be used to generate the probability-based forecast.

The probability-based RI index has been developed using a TMI-based database during 1998-2008 (see section 2c of the original proposal). We plan to finish the implementation code before May 15, 2014 so that we can test the probability-based RI index at NHC during 2014 season. During 2014, we plan to test both the current "yes-and-no" type of forecast and the probability-based forecast in a parallel mode.

After the testing during 2014 season, we will identify successful and failed cases. Based on lessons learned, we'll be able to refine our index to make it better functional. Also during non-hurricane seasons when real-time testing won't take place, we will add microwave data from sensors other than TMI. Our probability-based RI index could be refined based on a larger database. The current plan is to obtain AMSR-E (from http://sharaku.eorc.jaxa.jp/TYP_DB/index_e.shtml) data back to 2002 and SSM/I and SSMIS data back to 1996 (available from Remote Sensing Systems). Real-time testing will also be done during 2015 season. After the real-time testing and algorithm refinement, we plan to implement the final probability-based 37 GHz ring RI index for AL and EA basins. The final RI index will be produced and made available to NHC for operational use.

Task 4: Modifying existing IDL code to make it compatible with NHC environment

All the existing code was written in IDL. IDL is excellent for satellite data processing. But according to NHC TSB branch chief Dr. Mark DeMaria, IDL is not a good language for operational use. We plan to gradually modify our IDL code to make it more compatible with either C or Fortran. The first step as suggested by Dr. DeMaria is to make sure the data input is a separate module, so it can easily be swapped out later for data that comes from an operational data stream. The second step will be to divide the code into several modules based on functions, and try to make the major IDL module executable under Fortran or C.

<u>Project deliverables and timeline</u> based on tasks listed above:

The rest of Year 1 (March 2014- August 2014): The second task (*Adding real-time AMSR2 data as input*) listed above will be completed. We'll also start to work on Task 1 (***Adapting the CIMSS ARCHER product for better TC center fixing***), but again this will depend on the readiness of CIMSS ARCHER product. Real-time testing code of the probability-based 37 GHz ring RI index will be done during year 1, hopefully before the 2014 season starts. All of these will be done by the PI, and graduate students Yongxian Pei and Margie Kieper, in collaboration with forecasters at NHC.

Year 2 (September 2014- August 2015): During year 2, an important task to be completed is to collect more 37 GHz data from AMSR-E, SSM/I, and SSMIS in order to refine the index. We will refine the index by using more microwave data and based on the evaluation results during year-1. Our critical task during year 2 will be implementing the final refined version of the probability-based 37 GHz RI index, and continue to do real-time testing during the hurricane season at year-2. Task 4 will be addressed throughout the coding efforts during both year 1 & 2. We will work closely with forecasters at NHC during both year 1 and 2.

Upon completion of this project, the following deliverables will be provided:

- Code (in IDL) that will produce the "yes and no" type of 37 GHz ring+SHIPS RI index
- Code (in IDL) that will produce the probability-based microwave (37GHz + 85 GHz) RI index
- A detailed document of the guidance for running the code, and predicting RI using the RI index

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

Zagrodnik, J., and H. Jiang, 2014: Rainfall, Convection, and Latent Heating Distributions in Rapidly Intensifying Tropical Cyclones. *J. Atmos. Sci.*, in second review (first major revision decision received in Jan. 2014).

Jiang, H., and C. Tao, 2014: Contribution of tropical cyclones to global very deep convection. *J. Climate*, accepted.

Jiang, H., and E. M. Ramirez, 2013: Necessary conditions for tropical cyclone rapid intensification as derived from 11 years of TRMM data. *J. Climate*., **26**, 6459-6470.

Tao, C., and H. Jiang, 2012: Global distribution of hot towers in tropical cyclones based on 11-year TRMM data. *J. Climate,* **26**, 1371–1386.

Jiang, H., E. M. Ramirez, and D. J. Cecil, 2012: Convective and rainfall properties of tropical cyclone inner cores and rainbands from 11 years of TRMM data. *Mon. Wea. Rew.*, **141**, 431-450.

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.

4. Conference Presentations (wholly or partially supported by this grant)

Jiang, H., M. Kieper, and Y. Pei, 2014: Improvement to the Satellite-based 37 GHz Ring Rapid Intensification Index. 67th *Interdepartmental Hurricane Conference/Tropical Cyclone Research Forum*, Mar 4-7, 2014.

Jiang, H., M. Kieper, T. Yuan, E. Zipser, and J. Kaplan, 2013: Enhancement of SHIPS RI Index Using Satellite 37 GHz Microwave Ring Pattern: A Year-2 Update. 67th *Interdepartmental Hurricane Conference/Tropical Cyclone Research Forum*, Mar 5-7, 2013.

Jiang, H. and E. M. Ramirez 2012, Necessary Conditions for Tropical Cyclone Rapid Intensification as Derived from 11 Years of TRMM Data. *AGU Fall Meeting Session A23K (oral),* San Francisco, CA, December 3-7.

Kieper, M. and H. Jiang, 2012: Quantifying Intensity Forecasts for Rapid Intensification of Tropical Cyclones. *AGU Fall Meeting Session A13L (poster),* San Francisco, CA, December 3-7, 2012.

Tao, C. and H. Jiang, 2012: Contribution of tropical cyclones to global deep convection with overshooting tops. *AGU Fall Meeting Session A13L (poster),* San Francisco, CA, December 3-7, 2012.

Zagrodnik, J. P., and H Jiang, 2012: Comparison of TRMM PR and TMI Version 6 and Version 7 rainfall algorithms in Tropical Cyclones relative to the NEXRAD Stage-IV Multi-sensor

Precipitation Estimate dataset. *AGU Fall Meeting Session H33C (poster)*, San Francisco, CA, December 3-7, 2012.

Jiang, H., M. Kieper, and E. Zipser, 2012: The "Warm Rain" Ring Pattern and Tropical Cyclone Rapid Intensification. *NASA GRIP Science Team Meeting*, Wallops Flight Facility, VA, May 9-10, 2012, 2012.

Jiang, H., and E. M. Ramirez, 2012: Necessary Conditions for Rapid Intensification as Derived from 11 Years of TRMM Tropical Cyclone Precipitation Feature Database (TCPF). *NASA GRIP Science Team Meeting,* Wallops Flight Facility, VA, May 9-10, 2012.

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. AMS 30*th* *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? AMS 30*th* *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. AMS 30*th* *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. AMS 30*th* *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. AMS 30*th* *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, 2012: Enhancement of SHIPS Rapid Intensification Index Using The 37-GHz Ring Pattern. 66*th* *Interdepartmental Hurricane Conference,* Charleston, SC, Mar 5-8, 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. *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. *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. 65*th* *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. 65*th* *Interdepartmental Hurricane Conference*, Miami, FL, Feb. 28-Mar. 3.