

Improvements to the SHIPS Rapid Intensification Index: A Year-2 JHT Mid-term report

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## **1. Introduction**

Predicting episodes of tropical cyclone rapid intensification (RI) remains one of the highest forecasting priorities of the National Hurricane Center (NHC). In recent years, a statistically based rapid intensification index (RII) that employs predictors from the SHIPS model has been developed utilizing linear discriminant analysis (Kaplan et al. 2010). The SHIPS-RII provides estimates of the likelihood of RI over the succeeding 24-h for both the Atlantic and eastern North Pacific basins and is currently utilized as an operational forecasting tool by the NHC. Although the current version of the SHIPS-RII has been generally skillful, its utility is somewhat limited since it was developed exclusively for the 24-h lead-time and its skill tends to be limited particularly for the Atlantic basin. Thus, in an effort to improve the overall forecasting utility of the current operational SHIPS-RII, a number of model enhancements are being developed as part of our current Joint Hurricane Testbed (JHT) project. First, ensemble-based (Rozoff and Kossin 2011) versions of the RII that employ both the current SHIPS-discriminant RII as well as the newly developed Bayesian and Logistic versions are being derived for the current operational 24-h forecast lead-time as well as the added lead times of 12-h, 36-h and 48-h to provide additional guidance during the critical watch and warning period that has recently been extended to 48-h by the NHC. Secondly, revised versions of the recently developed deterministic rapid intensity aid (Sampson et al. 2011) are being developed utilizing the newly derived multiple lead-time ensemble-based RII models. Lastly, microwave imagery-based versions of the RII that have been shown to be capable of providing a more accurate measure of the overall inner-core tropical cyclone structure are also being developed for each forecast lead time. In this mid-term report, our year-2 JHT project accomplishments to date as well as our plans for improving the current operational SHIPS-RII during the remainder of the year-2 funding-cycle that were presented at the recently held IHC/TC forum (Kaplan et al. 2013) will be discussed.

## **2. Year-2 mid-term accomplishments**

- a. Multi-lead time RII

Commencing ~ Aug 1, 2012, the new ensemble-based multi-lead time RII that was developed during year-1 of our JHT project was run in real-time (and the output made available to forecasters at the NHC via a web site) for both the Atlantic and eastern North Pacific basins at the Cooperative Institute for Research in the Atmosphere (CIRA) in Fort Collins, CO. Figure 1 provides an example of the output of the new ensemble-based RII for Hurricane Emilia (2012). Section 1 of the output shows the SHIPS-based discriminant RII for the 24-h lead-time that that was adopted for operational implementation by the NHC prior to the 2012 season but that could not be implemented operationally since the total precipitable water (TPW) predictor was not made available on the operational NCEP IBM due to IT limitations. Section 2 is the lightning based version of the RII that was developed as part of the GOES-R Proving Ground while Section 3 shows the output for the new multi-lead time RII for the 20-kt RI threshold at the 12-h lead-time, the 25-kt, 30-kt, 35-kt and 40-kt RI thresholds at the 24-h lead-time, the 45-kt RI threshold at the 36-h lead-time, and the 55-kt RI threshold at the 48-h lead-times, respectively. The RI probabilities are shown for the SHIPS, Logistic, Bayesian, and the three-RII model consensus (i.e. ensemble).

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* EAST PACIFIC RII PARALLEL RUNS FOR JHT/PG *
* GOES AVAILABLE, OHC AVAILABLE *
* EP05 EP052012 07/08/12 00 UTC *

CURRENT MAX WIND (KT): 35. LAT, LON: 10.5 -102.5

+++++++ SECTION 1, 2012 OPERATIONAL RII WITH ++++++
TPW, IRPC, CFLUX ENHANCEMENTS

** 2012 E. PACIFIC RI INDEX EP052012 EP05 07/08/12 00 UTC **
( 30 KT OR MORE MAX WIND INCREASE IN NEXT 24 HR)

12 HR PERSISTENCE (KT): 10.0 Range:-22.0 to 38.5 Scaled/Wgtd Val: 0.5/ 1.1
POT = MPI-VMAX (KT) : 121.6 Range: 40.3 to 144.5 Scaled/Wgtd Val: 0.8/ 1.2
850-200 MB SHEAR (KT) : 2.5 Range: 18.7 to 1.4 Scaled/Wgtd Val: 0.9/ 1.5
HEAT CONTENT (KJ/cm2) : 39.2 Range: 0.0 to 73.7 Scaled/Wgtd Val: 0.5/ 0.8
STD DEV OF IR BR TEMP : 8.2 Range: 38.9 to 2.4 Scaled/Wgtd Val: 0.8/ 1.2
MAXIMUM WIND (KT) : 35.0 Range: 22.5 to 132.0 Scaled/Wgtd Val: 0.3/ 0.4
D200 (10**7s-1) : 66.6 Range:-11.0 to 135.3 Scaled/Wgtd Val: 0.5/ 0.6
BL DRY-AIR FLUX (w/m2) : 68.6 Range:638.0 to -19.8 Scaled/Wgtd Val: 0.9/ 0.0
% AREA WITH TPW <45 mm: 0.0 Range: 82.1 to 0.0 Scaled/Wgtd Val: 1.0/ -0.4
2nd PC OF IR BR TEMP : -0.3 Range: 2.1 to -1.7 Scaled/Wgtd Val: 0.6/ -0.1

Prob of RI for 25 kt RI threshold= 70% is 5.6 times the sample mean(12.5%)
Prob of RI for 30 kt RI threshold= 58% is 7.0 times the sample mean( 8.3%)
Prob of RI for 35 kt RI threshold= 37% is 6.2 times the sample mean( 5.7%)
Prob of RI for 40 kt RI threshold= 36% is 10.6 times the sample mean( 4.0%)

+++++++ SECTION 2, RII WITH LIGHTNING DATA ++++++
FOR GOES-R PROVING GROUND

Prob of RW, Avg IC, RI= 0% 65% 35% no lightning, experimental algorithm
Prob of RW, Avg IC, RI= 0% 61% 39% with lightning, experimental algorithm

Rapid Weakening (RW) = -20 kt or less max wind change in 24 hr
Rapid Intensification (RI) = +30 kt or more max wind change in 24 hr

Recent Lightning Density History (Strikes/km2-year)
Date/Time vmax(kt) Inner core (0-100 km) Rainband (200-300 km)
12 0708 00 35 0.0 12.0
12 0707 18 30 0.0 61.0

Sample mean: 33.0 9.0

Note: Inner core lighting < sample mean favors RI
Rainband lighting > sample mean favors RI
Converse for RW

+++++++ SECTION 3, RII WITH MULTIPLE TIMES ++++++
AND CONSENSUS FOR JHT

** 2012 E. Pacific EXPERIMENTAL RI INDEX EP052012 EP05 07/08/12 00 UTC **

Prob RI for 20kt/ 12hr RI threshold= 23% is 3.7 times sample mean ( 6.2%)
Prob RI for 25kt/ 24hr RI threshold= 70% is 5.6 times sample mean (12.5%)
Prob RI for 30kt/ 24hr RI threshold= 58% is 7.0 times sample mean ( 8.3%)
Prob RI for 35kt/ 24hr RI threshold= 37% is 6.2 times sample mean ( 5.7%)
Prob RI for 40kt/ 24hr RI threshold= 36% is 10.6 times sample mean ( 4.0%)
Prob RI for 45kt/ 36hr RI threshold= 55% is 9.4 times sample mean ( 5.9%)
Prob RI for 55kt/ 48hr RI threshold= 70% is 12.7 times sample mean ( 5.5%)

Matrix of RI probabilities
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RI (kt / h) | 20/12 | 25/24 | 30/24 | 35/24 | 40/24 | 45/36 | 55/48
SHIPS-RII: 22.7% 70.3% 57.9% 37.2% 36.2% 55.3% 69.7%
Logistic: 53.7% 88.6% 81.0% 70.0% 68.8% 80.3% 61.7%
Bayesian: 16.5% 65.0% 54.2% 38.7% 14.1% 22.3% 16.5%
Consensus: 31.0% 74.6% 64.4% 48.6% 39.7% 52.7% 49.3%

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Fig. 1. Sample of the output of the parallel version of the RII that was run in real-time at CIRA during the 2012 Hurricane Season for eastern North Pacific Hurricane Emilia.

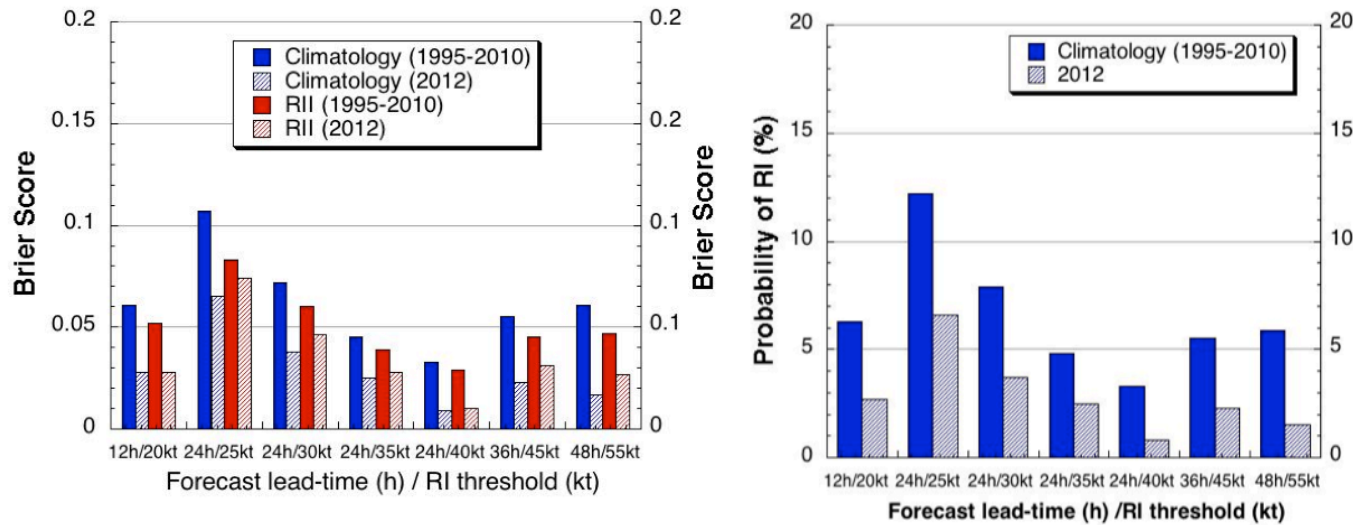
To evaluate the skill of the 2012 multi-lead time real-time RII forecasts, the Brier Score (*BS*) (Wilks 2012) was computed for both the RII as well as climatology using:

$$BS = 1/n \sum_{k=1}^n (y_k - o_k)^2 \quad (1)$$

where  $y_k$  is either the forecasted RII probability or the climatological probability of RI of the 1995-2010 sample for the appropriate lead-time and RI threshold (see Fig. 2) and  $o_k = 0$  when no RI occurred during a given time period and  $o_k = 1$  when RI did occur.

Thus,  $0 \leq BS \leq 1$  with 0 denoting perfect forecast skill.

Figure 2 indicates that while the *BS* values for the ensemble-based 2012 RII forecasts were lower than those that had been obtained previously for the cross-validated 1995-2010 sample the 2012 climatological values were much lower than those that had been previously obtained for the longer term 1995-2010 sample mean. It can be seen that the low climatological *BS* that was observed in 2012 is due in large part to the anomalously low probability of RI in 2012 since inspection of (1) indicates that forecasting a low probability of RI (ranging from 0.03-0.12 depending on lead-time) like those that are used when making a climatological RI forecasts will yield small values of *BS* for years like 2012 when there was an unusually low frequency of RI events.



**Fig. 2. The Brier Score (BS) of the 1995-2010 Atlantic climatological (solid blue bar) and cross-validated RII forecasts (solid red) and the BS of the 2012 climatological (hatched blue) and real-time RII forecasts (hatched red) (left panel). The climatological probability of RI of the 1995-2010 (solid blue) and 2012 real-time (hatched blue) Atlantic basin samples are also provided (right panel).**

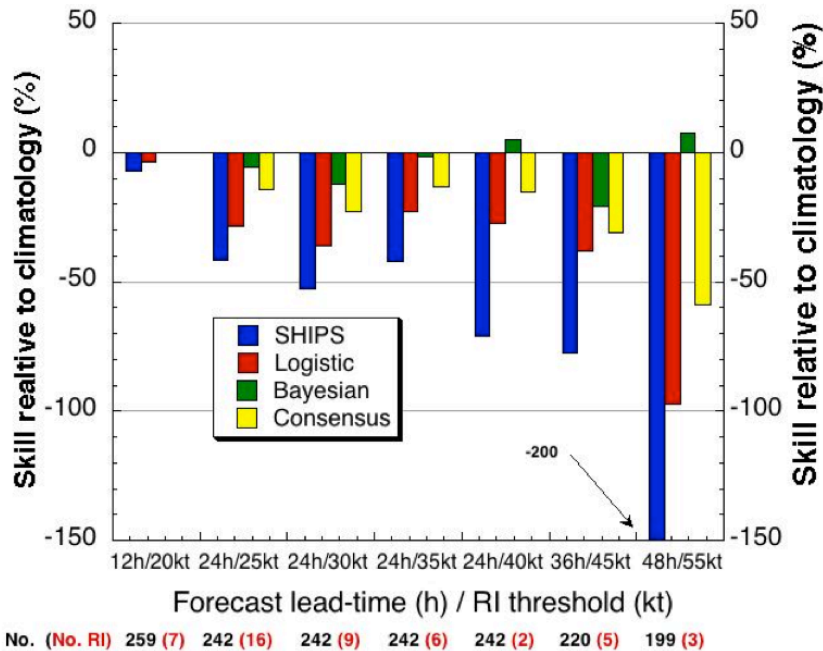
Figure 3 shows the overall skill of the real-time runs of the Atlantic multi-lead time RII for the 2012 Hurricane Season for the SHIPS, Logistic, Bayesian and ensemble-based version of the RII where skill is assessed using:

$$\text{Skill} = (1. - \text{BSM}/\text{BSREF}) * 100. \quad (2)$$

where  $\text{BSM} = \text{BS}$  of the RII forecasts and  $\text{BSREF} = \text{BS}$  of the climatological RI forecasts

and  $-\infty < \text{Skill} < 100$

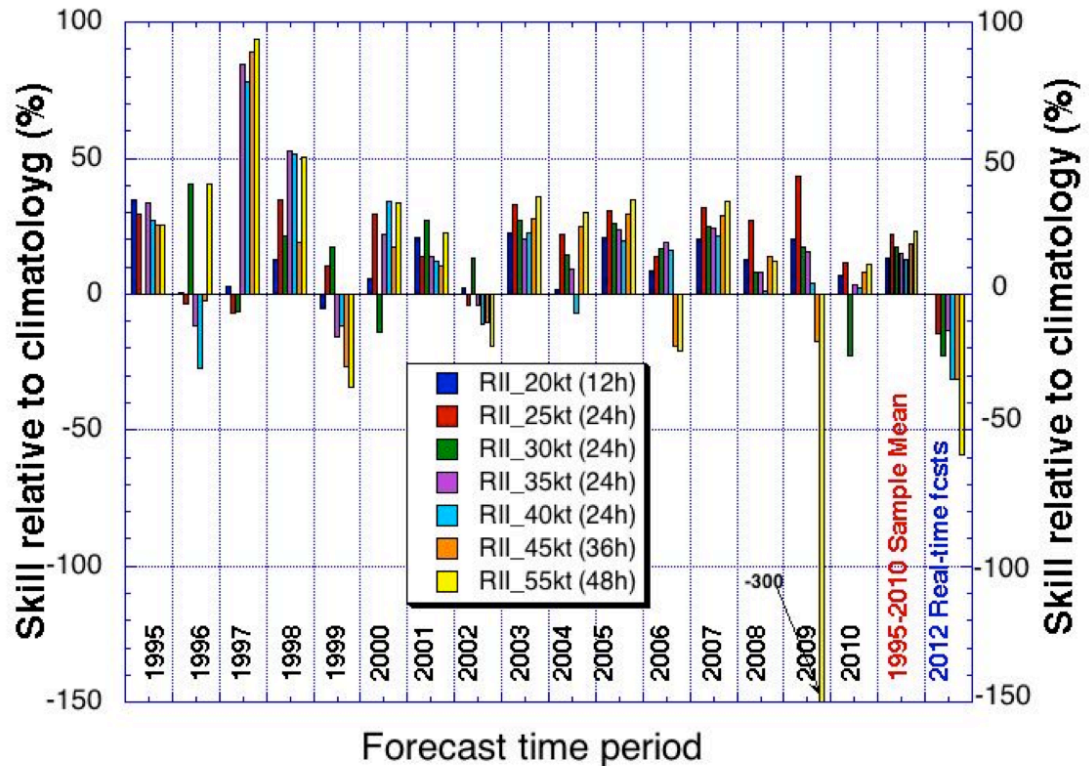
(so perfect skill is 100%)



**Fig. 3. Skill of the 2012 Atlantic real-time multi-lead time RII forecasts. The skill is shown for the SHIPS (blue), Logistic (red), Bayesian (green), and consensus (ensemble-based) (yellow) versions of the RII. The total number of cases (black) and number of RI cases (red) are also provided for each RI lead-time and RI threshold along the x-axis.**

It can be seen that the Atlantic multi-lead time version of the RII did not perform well for the 2012 Atlantic season relative to climatology, which is likely to a large degree the result of the anomalously low  $\text{BS}$  values of the climatological forecasts as was described above. It is worth noting that the ensemble-based RII, that is typically the most skillful of the four versions, was not as skillful relative to the other three versions due mostly to the poor performance of the SHIPS and logistic versions of the RII. Figure 4 indicates that while the new multi-lead time RII did not perform well in the Atlantic in 2012, its performance for each of the various lead times and RI thresholds was generally within the range of the skill that was observed for each of the individual years that comprised the 1995-2010 cross-validated sample. Thus, while Fig. 4 indicates that the Atlantic-based ensemble RII should, on average, prove to be skillful (see 1995-2010 cross-validated sample mean skill) there is considerable year-to-year variability in model

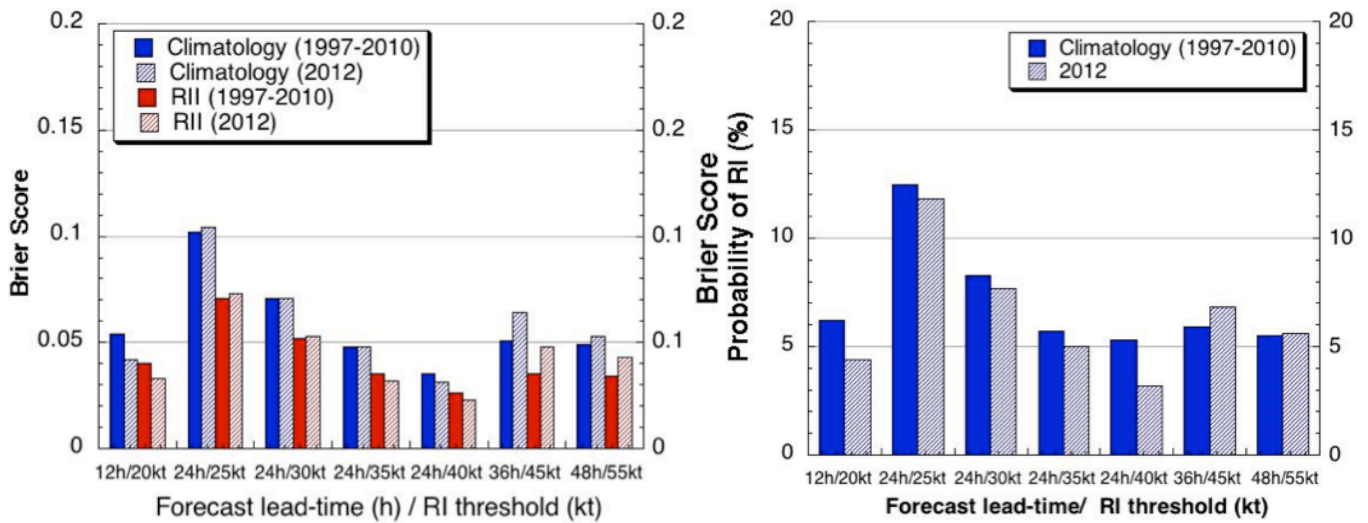
skill and thus there are years (like 2012) in which the RII may not prove to be skillful for a particular (or even multiple) lead-times/RI thresholds.



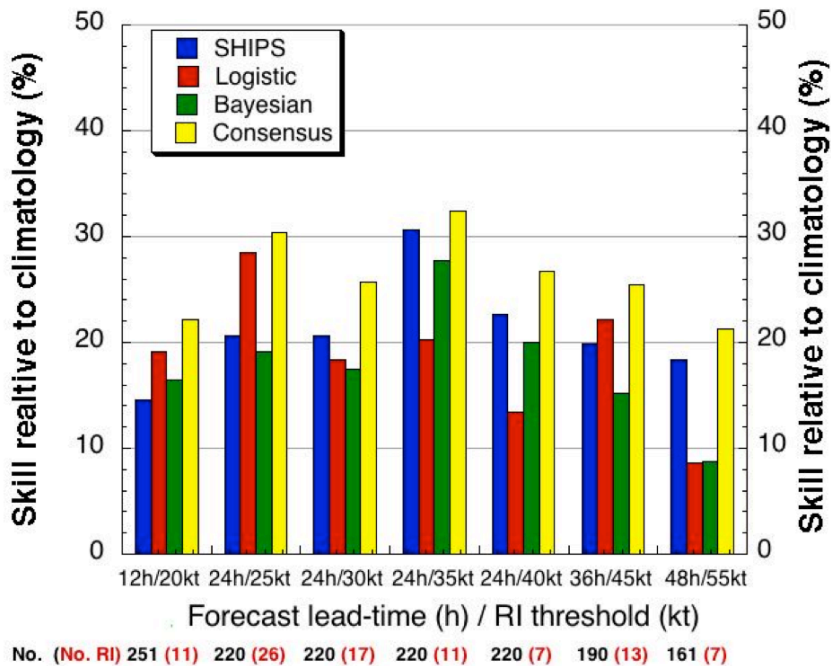
**Fig. 4.** The cross-validated skill of the Atlantic version of the ensemble RII for each of the years that comprised the cross-validated sample as well as the mean skill of the 1995-2010 sample (red label) for each forecast lead-time and RI threshold. The skill of the 2012 Atlantic real-time ensemble RII forecasts for each lead-time and threshold (blue label) are also provided.

Figure 5 shows the *BS* of the eastern North-Pacific basin real-time 2012 RII multi-lead time RII forecasts relative to those made assuming a climatological rate of RII using the same methodology that was employed to verify the Atlantic basin real-time forecasts as was described previously. It can be seen that the *BS* values of the real-time 2012 RII forecasts are less than those for climatology but are close to those that had been previously obtained for the long-term 1995-2010 cross-validated sample. The figure also indicates that that the 2012 eastern North Pacific probability of RI values for the various lead times and thresholds were similar to those that had been observed for the longer-term 1995-2010 sample in contrast to the Atlantic results discussed previously which showed that the 2012 frequency of RI was considerably lower than the Atlantic basin longer term sample mean.

Figure 6 shows the skill of the 2012 real-time eastern North Pacific basin RII forecasts relative to climatology determined using the methods described previously for the Atlantic basin. It can be seen that these RII forecasts were skillful at all lead times and for all RI thresholds and that the ensemble-based version of the RII was more skillful than any of three individual versions of the RII consistent with the results of Rozoff and Kossin (2011).



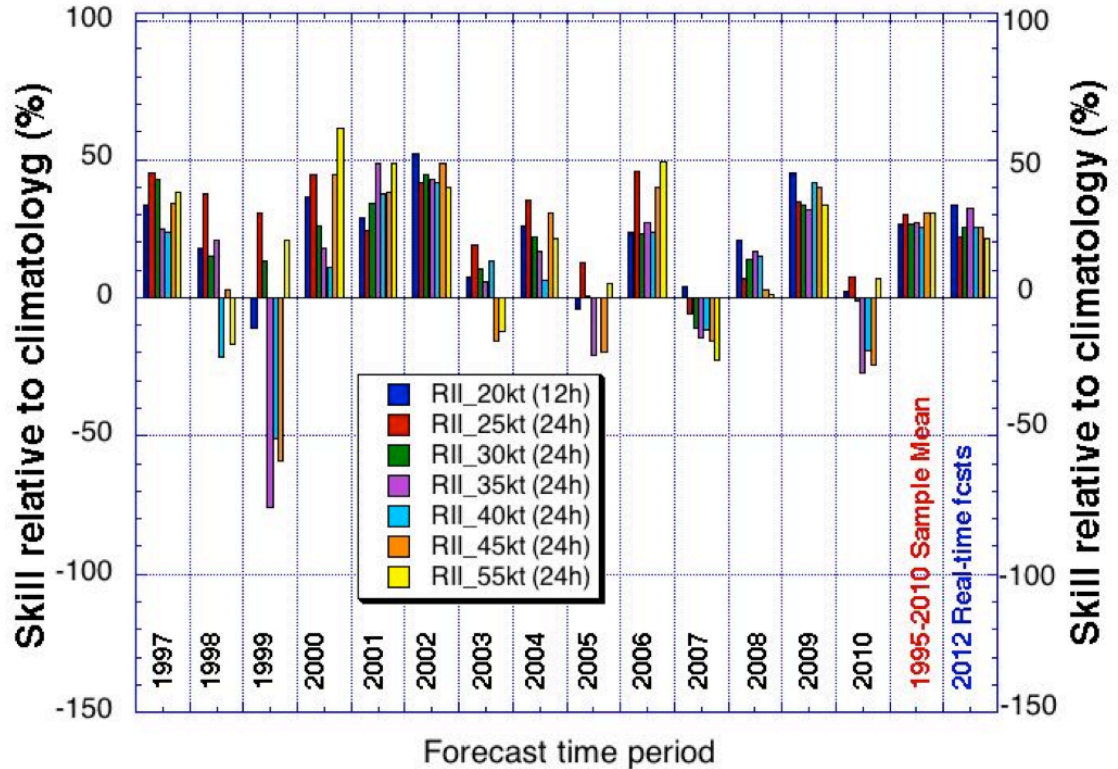
**Fig. 5.** The Brier Score (BS) of the 1995-2010 eastern North Pacific climatological (solid blue bar) and cross-validated RII forecasts (solid red) and the BS of the 2012 climatological (hatched blue) and real-time (hatched red) RII forecasts (left panel). The climatological probability of RI of the 1995-2010 (solid blue) and 2012 real-time (hatched blue) eastern North Pacific samples are also provided (right panel).



**Fig.6.** Skill of the 2012 eastern North Pacific real-time multi-lead time RII forecasts. The skill is shown for the SHIPS (blue), Logistic (red), Bayesian (green), and consensus (ensemble) (yellow) versions of the RII. The total number of cases (black) and number of RI cases (red) are also provided for each RI lead-time and RI threshold along the x-axis.

Figure 7 indicates that the skill of the 2012 ensemble-based eastern North Pacific real-time RII forecasts for the various RI thresholds were similar to that which had been

previously obtained for the 1995-2010 cross-validated sample mean which may reflect, in part, the finding that the 2012 eastern North Pacific Hurricane season was similar (at least in terms of the probability of RI) to that which had been previously observed for that basin for the longer term (1995-2010) sample.



**Fig. 7. The cross-validated skill of the E. Pacific version of the ensemble RII for each of the years that comprised the cross-validated sample as well as the mean skill of the 1995-2010-sample (red label) for each forecast lead-time and RI threshold. The skill of the 2012 E. Pacific real-time ensemble RII forecasts (blue label) for each lead-time and threshold are also provided.**

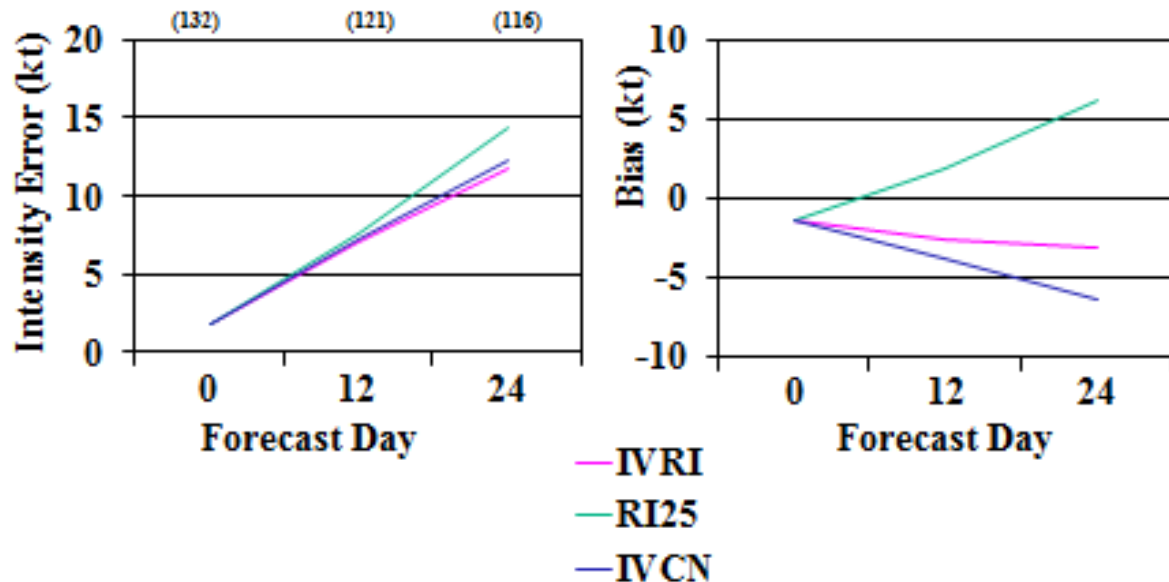
**b. Deterministic RI Aid**

The deterministic rapid intensification aid (RAPID; Sampson et al. 2010) has been developed using the Rapid Intensification Index (RII; Kaplan et al. 2010). The operational RII produces probabilities of intensification rates (25, 30, 35, and 40 knots) through a 24-h period. We use RII thresholds (currently 40%) to trigger whether the deterministic RI (RAPID aids) are produced. We implemented a temporary solution in operations and the resultant output from the IBM is then transmitted back to NHC and ingested into the ATCF in real-time for the 2011 and 2012 seasons. For 2013, we have a more permanent solution where the RAPID aids are computed within SHIPS.

Recently, we recomputed an intensity consensus (see Sampson et al. 2007) using RAPID and the members of IVCN (DSHP, LGEM, GHMI, GFNI and HWFI) for 2011-2012 seasons in order to evaluate its impact on the consensus. As seen in Fig. 8, we found improved forecast errors and reduced biases. The improved forecast errors for

IVRI are about 4-5% and are highly significant. The IVRI bias improvements are approximately 1.2 and 3.2 kt at 12 and 24 h, respectively.

If you evaluate only Atlantic 2011 and 2012 seasons, the errors of the IVRI were worse than the IVCN by 1% and 11% at 12 and 24 h, respectively while the biases were better at 12 h by 1.2 kt and worse by 3.8 kt at 24 h. As was discussed earlier in this report, we suspect that the errors and biases will improve when the rate of RI in the Atlantic basin becomes more typical of the long-term sample mean.

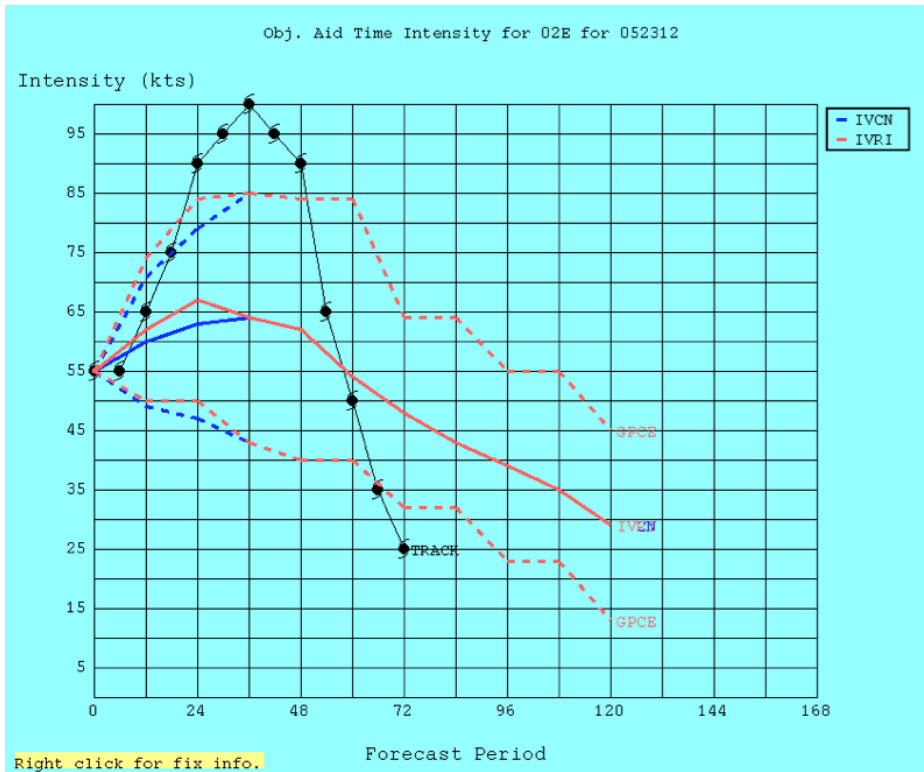


**Fig. 8. Results from 2011-2012 Atlantic and eastern North Pacific seasons for an intensity consensus (IVRI) that includes the deterministic RI aid that was run post-season shows lower mean errors and less bias than IVCN (the operational NHC consensus). RI25 is the deterministic RI guidance for a 25-kt RI event.**

We will continue to run and evaluate RAPID for 2013. In addition, we recently experimented with additional forecast times (36 and 48 h) and RII ensemble probabilities on dependent data. These both show promise with regard to constructing a deterministic RII aid and consensus, so we intend to evaluate what we have constructed on independent data to see if it is worth the effort to implement these in operations.

Finally, we have recently constructed a GPCE for intensity (Goerss and Sampson 2013) and have run experiments using the RAPID aids in the intensity GPCE with success (Fig. 9). We will continue to test out this particular application and will report on its potential forecasting utility in the near future.

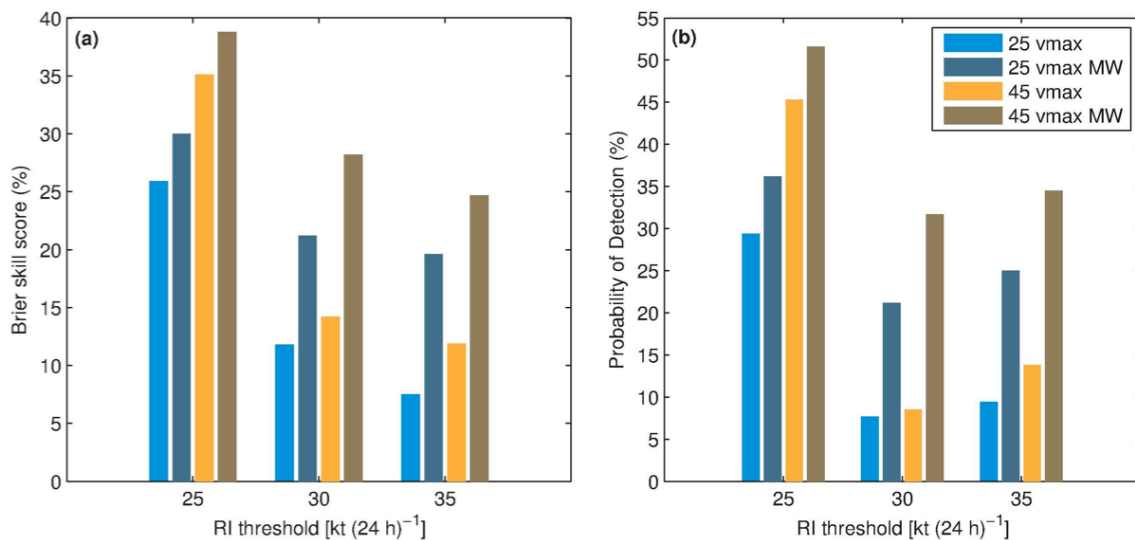




**Fig. 9. Intensity vs. forecast time graph for EP022012 at 2012052312. The solid (dashed) blue line(s) represent the IVCN forecast (GPCE 67<sup>th</sup> percentile) and the solid (dashed) red line(s) represent the same for IVRI (IVCN members + the RAPID aids). Only sold/dashed red lines are depicted beyond 36-h since only the operational and not the new extended range versions of the RII were used to generate these results.**

### c. Microwave-based RII

We have sought to improve the statistical prediction of RI using predictors derived from passive microwave imagery (MI). The MI was used to enhance the RI models described in Rozoff and Kossin (2011). The developmental data included 19.4, 37.0, and 85.5-GHz brightness temperatures from the Special Sensor Microwave/Imager (SSM/I), Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), the Advanced Microwave Scanning Radiometer-EOS (AMSR-E), and WindSat sensors from 1998-2008. The use of MI in statistical models for RI was shown to add appreciable forecast skill (Fig. 10). Recent efforts in this JHT project have consisted of enhancing the developmental dataset for our MI-based structural predictors. Data from 2009-2011 have been added from TMI, AMSR-E, and SSM/I. We have also acquired SSMI/S data from 2005-2011 and have used that to further enhance our developmental dataset. Models were re-derived using this updated data. A real-time MI-based RI model has been designed and will be used and evaluated in real-time for the 2013 Atlantic and Eastern Pacific hurricane seasons. We are in the process of retrospectively testing the performance of the real-time microwave-based RI model for the Atlantic and eastern North Pacific basins for the 2012 Hurricane season.



**Fig. 10.** The impact of adding microwave-based predictors to the logistic regression version of the rapid intensity model on the skill of the 1998-2008 Atlantic basin sample forecasts. Results are shown for versions of the logistic model with (dark blue and brown) and without (light blue and orange) microwave-based predictors. The left panel shows the Brier skill score (relative to climatology) while the probability of detection (based upon 50% cut-off probability threshold) is depicted in the right panel. Results are shown for storms with initial maximum sustained wind intensities of 25 kt and 45 kt, respectively.

## References

- Goerss, J. S. and C. R. Sampson, 2013: Prediction of Consensus Tropical Cyclone Intensity Forecast Error, *Wea. Forecasting*, in prep.
- Kaplan, J., M. DeMaria, and J. A. Knaff, 2010: A revised tropical cyclone rapid intensification for the Atlantic and eastern North Pacific basins. *Wea. Forecasting*, **25**, 220-241.
- \_\_\_\_\_, C. M. Rozoff (CIMSS), C. R. Sampson, J. P. Kossin, C. S. Velden, M. DeMaria, 2013: Improvements to the SHIPS Rapid Intensification Index: A Year-2 JHT Project Update. IHC/TC Forum, Baltimore, MD.
- Rozoff, C. M., and J. P. Kossin, 2011: New probabilistic forecast schemes for the prediction of tropical cyclone rapid intensification. *Wea. Forecasting*, **26**, 677-689.
- Sampson, J. L. Franklin, J. A. Knaff and M. DeMaria, 2008: Experiments with a Simple Tropical Cyclone Intensity Consensus. *Wea. Forecasting*, **23**, 304-312.
- \_\_\_\_\_, J. Kaplan, J. A. Knaff, M. DeMaria, and C. A. Sisko, 2011: A deterministic rapid intensification aid, *Wea. Forecasting*, **26**, 579-585.

Wilks, D.S., 2011: *Statistical Methods in the Atmospheric Sciences*. 3rd ed. Academic Press, 676 pp.

## Appendix

### Year 2 Project timeline

Aug- Dec 2012	Perform real-time testing of new ensemble RII guidance in Atlantic/eastern North Pacific basins
Aug-Dec 2012	Perform real-time testing of new Atlantic/eastern North Pacific Rapid aid guidance
Aug-Dec 2012	Perform in-house testing of new MI-based versions of RII at University of Wisconsin/CIMSS
Sept 2012	Provide year 1 report to the JHT
February 2013	Evaluate performance of new Atlantic/eastern North Pacific RII guidance that was run in real time during the 2012 Hurricane Season
March 2013	Present year 2 results at the IHC
March-Jun 2013	Continue to refine/improve newly developed RI guidance
June 2013	Perform real-time testing of ensemble-based RII, MI-based RII and Rapid intensity aid guidance in both the Atlantic and eastern North Pacific basins
Aug 2013	Provide final code for computing ensemble-based RII, MI-based RII on the IBM as part of operational guidance suite to the NHC
Aug 2013	Implement new Rapid aid guidance into the ATCF as desired by the NHC
Sept 2013	Final report provided to the JHT