JHT Final Report
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Implementation of Advanced Microwave Sounder Unit (AMSU)
Tropical Cyclone Intensity and Size Estimation Algorithms

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Background:

This project is to test algorithms for estimating tropical cyclone (TC) intensity (MSLP) and size (radii of 34, 50 and 64 kt winds) from AMSU data. Two algorithms tested (one from CIRA and one from CIMSS/USAF). The CIRA and CIMSS AMSU-related accomplishments are listed separately for purposes of clarity.

1. Accomplishments

a. CIRA Method

The AMSU TC intensity and size algorithm was run in real time at CIRA beginning with the 2002 hurricane season, using input from the Automated Tropical Cyclone Forecast (ATCF) system. These estimates were obtained from NOAA-15 and –16. At the very end of the 2002 season, the algorithm was generalized to include data from NOAA-17. The results are sent to a TPC server, which forwards hard copy to a TPC printer for use by the hurricane specialists. Evaluations of the performance of the algorithm were provided at the Interdepartmental Hurricane Conferences in the spring of 2002 and 2003. Further details of the algorithm performance are provided below.

The CIRA algorithm was also adapted to run entirely at TPC, using AMSU data obtained from the NCEP IBM in BUFR format. This was accomplished by the beginning of the 2003 hurricane season. Unfortunately, comparisons between the algorithm run at CIRA and TPC, and input from CIMSS/USAFA revealed that the AMSU data obtained from the BUFR files has an additional adjustment applied to it. Thus, the algorithm cannot be run using the BUFR data in its current form. However, arrangements have been made with TPC and EMC to make the raw antenna temperatures (the starting point of the algorithm) to be made available in BUFR format. When this data becomes available, the CIRA AMSU algorithm can then be run completely at TPC.

A comprehensive evaluation was performed of the AMSU estimates of intensity (maximum wind and minimum sea-level pressure (MSLP)) and radii of the 34, 50 and 64 kt winds to the NE, SE, SW and NW of the storm center, for the

NHC best track was used as ground truth for the intensity estimates and the operational NHC forecast/advisories for the wind radii. Two data samples from 2002 were considered. The first one included all east Pacific and Atlantic cases (288 cases, roughly evenly divided between the basins), and the second was restricted to cases with recon data within 6 hours of the AMSU pass (64 cases, mostly from the Atlantic). For comparison, the errors from the 1999-2001 developmental sample were also included. The mean absolute error (MAE), bias, root-mean square error (RMSE) and explained variance were calculated for each of these samples.

Figure 1 shows the MAE for the intensity estimates. These results show that the intensity error characteristics from the 2002 real-time runs were nearly the same as for the developmental sample. Similar to the developmental sample, the method under-estimated the intensity of the most intense systems.

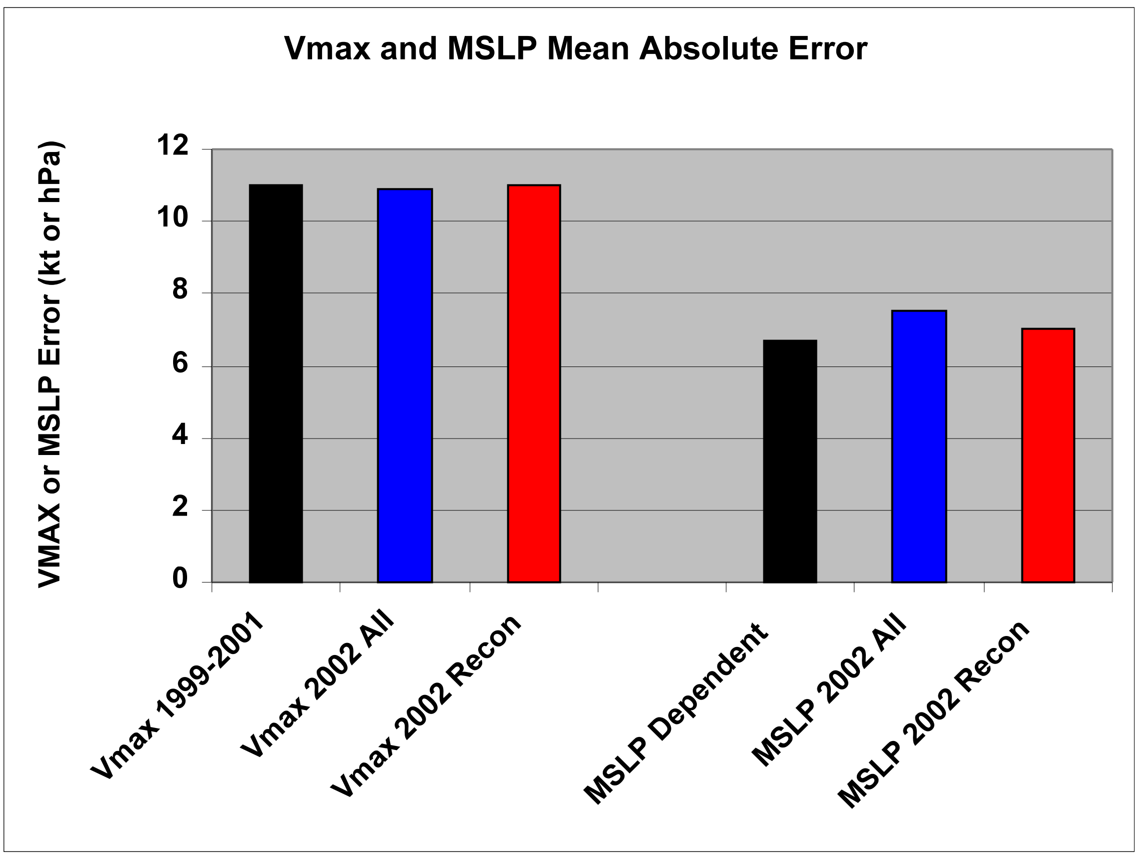

Figure 1. The Mean Absolute Error of the CIRA AMSU intensity estimates from the 2002 real-time runs and from the 1999-2001 developmental sample.

Figure 2 shows the MAE for the AMSU wind radii estimates. Except for the 64 kt radii, the errors of the total 2002 sample are much like those of the developmental dataset. The errors associated with 50- and 64-kt wind radii were smaller for the cases where recon data were available, while the 34-kt wind radii estimates had slightly larger errors for the recon cases.

Table 1 shows all of the error statistics for the 2002 evaluation of the CIRA algorithm. The results are generally similar to the mean absolute errors shown in Figs. 1 and 2 in that the real-time results have characteristics generally similar to the developmental sample results. One exception is that the AMSU 50 and 64 kt wind radii estimates tended to have a high bias. This bias appears to be related to the asymmetry factor included in the method used to determine the asymmetric radii from the symmetric average. The "observed" wind radii tended to be more asymmetric than those predicted by the AMSU algorithm. Generally, there were more cases where the "observed" radii were zero in some quadrants, relative to the AMSU estimates. This is the primary cause for the high bias in the 50- and 64-kt radii estimates. On the other hand, 34-kt radii biases were low, suggesting 34-kt winds from AMSU were less conservative possibly explaining the slightly larger errors associated with the 2002 estimates.

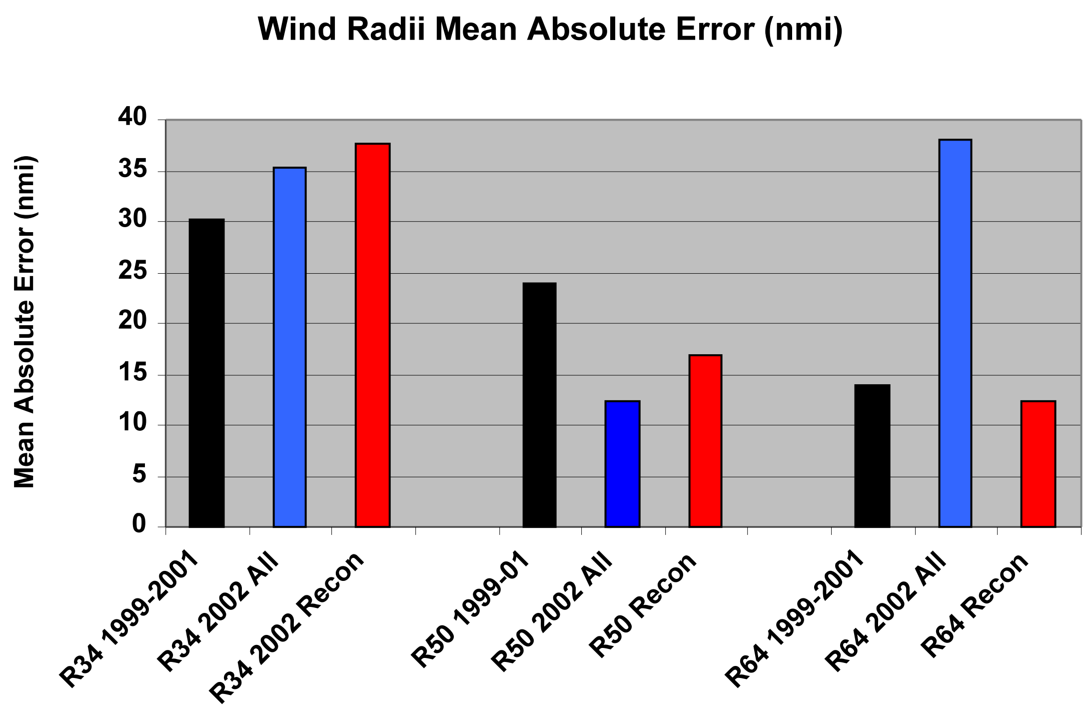

Figure 2. The Mean Absolute Error of the CIRA AMSU 34, 50 and 64 kt wind radii estimates from the 2002 real-time runs and from the 1999-2001 developmental sample.

Table 1. 2002 Validation statistics for the CIRA algorithm (N=sample size, MAE=Mean Absolute Error, RMSE=Root Mean Square Error, Bias=average error, R2=Explained Variance).

	N	MAE	RMSE	BIAS	R^2
R34 1999-2001	129	30.2	40.8	-3.2	59
R34 2002 All	218	12.3	45.9	-16.9	49
R34 2002 Recon	39	37.7	48.1	-15.8	51
R50 1999-2001	92	24.0	34.2	-5.2	44
R50 2002 All	120	12.3	19.2	0.2	59
R50 2002 Recon	24	16.8	28.4	1.7	53
R64 1999-2001	68	14.0	18.7	0.1	55
R64 2002 All	67	38.0	48.9	-15.5	16
R64 2002 Recon	8	12.3	16.9	10.4	60
Vmax 1999-2001	473	11.0	14.1	0	70
Vmax 2002 All	288	10.9	14.1	2.2	69
Vmax 2002 Recon	64	11	14.3	-4.7	72
MSLP 1999-2001	473	6.7	9.3	0	74
MSLP 2002 All	288	7.5	10.5	-1.1	68
MSLP 2002 Recon	64	7.0	10.6	5.3	83

1b. CIMSS/USAF Method

During the 2002 Atlantic basin (ATL) hurricane season, tropical cyclone (TC) intensity estimates (minimum sea level pressure, MSLP) generated by the CIMSS AMSU algorithm were transferred from a CIMSS AMSU processing workstation to TPC in near real-time via file transfer protocol (FTP). The estimates were a result of algorithm developments and the latest upgrades performed in year one of this initiative. The following figures depict two independent analyses from a homogeneous comparison of objective CIMSS AMSU MSLP estimates to equivalent subjective Dvorak estimates, using recon MSLP measurements as validation (see Table 2 and Figure 3 below). Overall, the CIMSS technique performed admirably in comparison to the Dvorak estimates. Several AMSU processing constraints were put into place during the 2002 season based on known limitations in the CIMSS method's ability to estimate MSLP. Mainly, these constraints involved sub-sampling and small eye situations. In these cases meeting our prescribed, empirically based thresholds for eye size and FOV (field of view), AMSU analyses were not performed. As a result, some of the stronger cases in 2002 are not included in the figures below. These cases have since been addressed through research efforts in year two of this initiative, and the constraints have subsequently been lifted (more discussion on this below).

Table 2. CIMSS AMSU results of TC MSLP estimation in the Atlantic basin in 2002, validated against recon MSLP and compared to Dvorak estimates (using values from all 3 satellite analysis centers) for the same storms and analysis times.

Statistical analysis for CIMSS AMSU estimates of TC MSLP (hPa) versus recon MSLP reports (within +/- 3 hrs)

	AMSU	**Dvorak**
Mean Error	3.24	4.52
Std Dev	2.29	3.40
Bias	-0.28	-0.90
RMSE	3.95	5.62

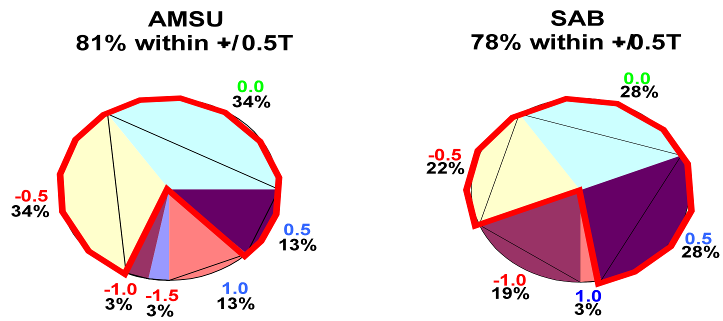

Figure 3. CIMSS AMSU algorithm results compared to Dvorak estimates from the Satellite Analysis Branch (SAB). (compiled by Greg Gallina of NESDIS/SAB)

As mentioned above, due to the limited AMSU-A instrument resolution, storms with eyes smaller than about 30 nm are under-sampled. This problem is aggravated for storms that fall near the edge of the satellite swath (limb). Early in 2003, a bias correction was developed to account for this. Using the 1999-2002 dataset, Radius of Maximum Wind (RMW) values as determined by recon or available microwave satellite data were compared to the resolution of each FOV of the AMSU instrument. Error statistics for storms with an eye size (or core diameter of 2*RMW when no clear eye was observed) smaller than the instrument resolution were determined and compared to recon. The variance explained for this dataset (N=64) was 56%. For real-time estimates, the RMW values are obtained from ATCF messages and used to determine the amount of bias correction needed. The bias is then subtracted from the initial MSLP estimate. As can be seen in Table 3, a significant improvement in skill is obtained using this method. The addition of the bias correction has lead to the removal of earlier constraints, less temporal variance for a given storm, and an increase in the number of estimates for 2003 (especially for stronger systems).

Table 3. Comparison of CIMSS original and bias-corrected MSLP (hPa) estimates. Recon reports of MSLP are used for validation.

	Raw Estimates	Bias Corrected Estimates
Mean ABS Error	7.41	5.54
Bias	2.63	-0.92
RMSE	11.03	7.74
N= 224		

Another correction added to the CIMSS AMSU estimates in 2003 is an adjustment for storms located in a higher or lower than average pressure environment. The developmental dataset used to derive the MSLP estimates includes a broad range of storms whose average environmental pressure (Penv) as determined from the ATCF Outside Closed Isobar (OCI) is 1010.4. However, storms often form in environments that significantly deviate from this value (Danny 2003 for instance). The OCI parameter from the ATCF message is used to adjust the CIMSS AMSU estimate up/down when the OCI value is higher/lower than the 1010.4 hPa average. Fine-tuning of this adjustment is still underway, however initial results for Hurricane Danny and Tropical Storm Erika (for which recon was available) indicate favorable results.

In regards to implementing the CIMSS AMSU algorithm into JHT environment, in early 2003 the algorithm was successfully ported and recompiled to run on the TPC platform (moray.nhc.noaa.gov) under the HPUX UNIX operating environment. In May 2003, several tests were performed using bogus storms initiated by TPC. NCEP BUFR formatted AMSU-A non-limb corrected brightness temperatures were routinely extracted and processed allowing for the appropriate run-time management scripts to be developed and tested. The ported CIMSS AMSU routine successfully navigated NOAA-KLM orbital coverage including the appropriate storm-centered sectorization of AMSU-A non-limb corrected brightness temperature orbit files. CIMSS limb correction routines were successfully tested and validated on the TPC platform; however, residual limb brightening was observed. The residual limb brightening (see Figure 4) posed a significant problem in the sense that the CIMSS AMSU tropical cyclone intensity technique uses a storm-centered AMSU-A limb corrected brightness temperature differencing technique (to determine the upper tropospheric warm anomaly).

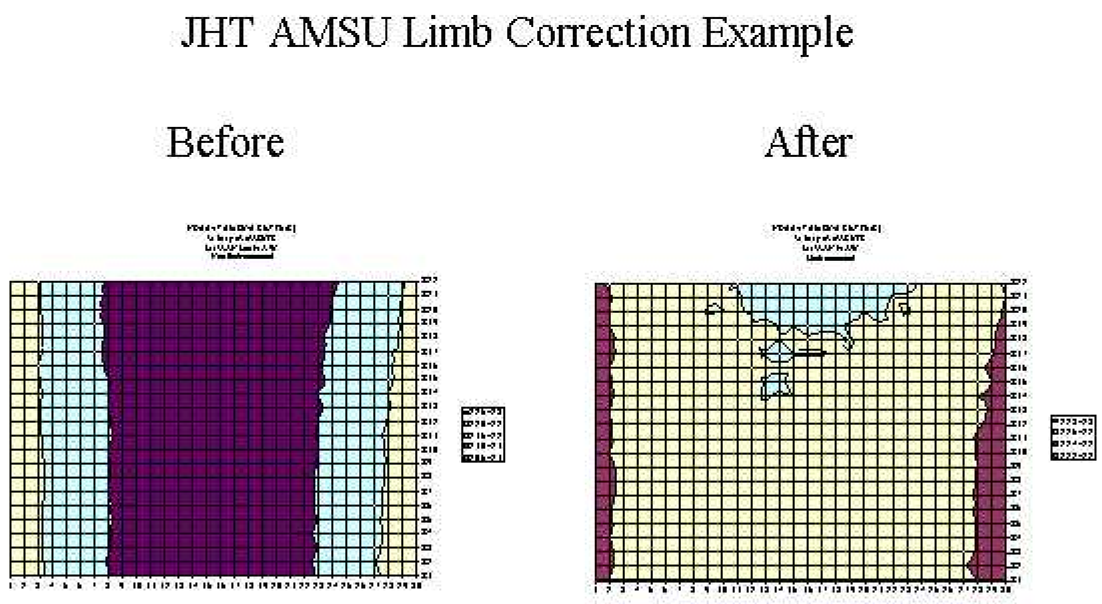

Figure 4. Example of residual limb brightening after limb correction is applied.

The residual limb brightening, if not corrected, potentially introduces considerable error in the estimation of the upper tropospheric warm anomaly magnitude (and MSLP estimation) by virtue of artificially warmer 'non-perturbed' environmental temperatures. CIMSS/USAF personnel inquired whether the CIRA group observed similar limb brightening and confirmed that this problem affected both CIMSS and CIRA AMSU processing and implementation efforts.

At this point in time, both CIMSS and CIRA are waiting for this issue to be resolved by NCEP (as noted by the CIRA summary of activities). Until this problem is resolved by NCEP, CIMSS AMSU tropical cyclone intensity estimates continue to be generated on the CIMSS AMSU processing platform and sent to TPC in near real-time.

2. Things not Completed/Pending Items

While both CIMSS and CIRA evaluated the performance of their algorithms as described above, an independent, homogeneous evaluation is underway by Jack Beven of TPC. Due to other obligations, Jack has not yet completed this work, but is continuing to make progress. As described in the work plan, this evaluation was to be performed only on those AMSU estimates that were made in real-time, and sent to the TPC/JHT workstation. Due to a disk crash on the TPC server (moonfish), all of the real-time AMSU analyses that were sent in real-time in 2002 were lost. Copies of all the CIRA files were saved and provided to Alison Krautkramer and Jack Beven at TPC. The intensity estimates from the CIMSS were regenerated and provided to TPC for evaluation following the season.

In the second year of the proposal, it was suggested that the CIRA and CIMSS algorithms are sufficiently independent, so that it might be possible to combine them in some optimal way. The plan was to use the set of homogeneous cases included in the evaluation sample being prepared by Jack Beven. This possibility can still be investigated once Jack finishes his evaluation. The proposed method is fairly simple, where the combined estimate is a weighted average of the intensity estimates from each algorithm, where the weights are inversely proportional to the error variances of each method. The weights could be developed from the 2002 sample, and then tested on independent cases from the 2003 season.

In the second year of the project, TPC requested that the NASA AMSU algorithm also be included in the comparison. Although obtaining and implementing NASA's algorithm in real-time was beyond the scope of the proposal, it was indicated that a procedure that used a similar technique might be tested on post-season data. However, this did not turn out to be necessary, because Roy Spencer provided the NASA intensity estimates directly to Jack Beven for inclusion in his evaluation of the CIRA and CIMSS algorithms.

As described above, neither JHT sponsored algorithms are currently being run on the JHT computer system due the lack of antenna temperatures in the NCEP BUFR data feed. This problem should be rectified by the end of the 2003 hurricane season.

The final task not completed is to determine future course of action (operational implementation, decide whether to run on TPC HP server or on NCEP IBM, 2nd evaluation, back to drawing board, etc.) This is awaiting a homogeneous evaluation, possible combination of algorithms, and opinion of TPC staff. An evaluation of the results from the 2003 season should help with this decision.

3. Things that did not succeed

None to report.