4D.2 Evaluation of the Tropical Cyclone SATellite Intensity CONsensus (SATCON)

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1.0 Introduction

The SATellite CONsensus (SATCON) algorithm developed at CIMSS objectively combines Tropical Cyclone (TC) intensity estimates analyzed from satellite infrared and microwave-based methods to produce a consensus estimate which is more skillful than the individual members. Current members of SATCON include the CIMSS ADT along with the CIMSS and CIRA AMSU algorithms. SATCON provides the TC forecaster with the ability to quickly reconcile differences in objective intensity methods thus decreasing the amount of time spent on the analysis of current intensity. Real-time SATCON estimates were provided to NHC during the 2008 and 2009 hurricane seasons.

Getting the current intensity of a TC correct is important for many reasons. 1) The current intensity is the start of the forecast process as it provides information about the short term intensity trend. 2) The current intensity is one of the primary predictors in both dynamic and statistical models. 3) In order to understand TC climatology it is best to have an accurate Best Track.

The forecaster is often faced with the problem of satellite estimates that exhibit a large amount of uncertainty. An example of this can be seen in *Figure 2*. This figure shows Dvorak satellite estimates from an experiment conducted during the Tropical Cyclone Structure 2008 (TCS-08) field campaign in the Western Pacific. Dvorak estimates were produced by five expert Dvorak analysts who were blind to reconnaissance ground truth for Typhoon Sinlaku (15W). Note that the estimates vary by as much as 37 knots. One could take the mean of the estimates however again looking at *Figure 2* doing so would result in errors as large as 25 knots. An objective method which reduces this uncertainty is desirable.

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2.0 Methodology

Each member of SATCON has strengths and weaknesses. For example the ADT method tends to perform best when there is a clear eye present in the IR imagery. However the performance can be degraded when the TC encounters strong wind shear. Both of the AMSU-based methods suffer from varying degrees of sub-sampling and perform best when the TC eye is greater than 50 km in diameter. SATCON makes use of this information to optimally combine the estimates into a single estimate that maximizes the strengths while minimizing the weaknesses.

2.1 Weighting Structure

The actual weights used by SATCON are the RMSE errors for the individual member in a given situation. *Figure 1* below shows RMSE errors for different scenarios for the three members. Again it can be seen that the ADT performs best in "Eye"

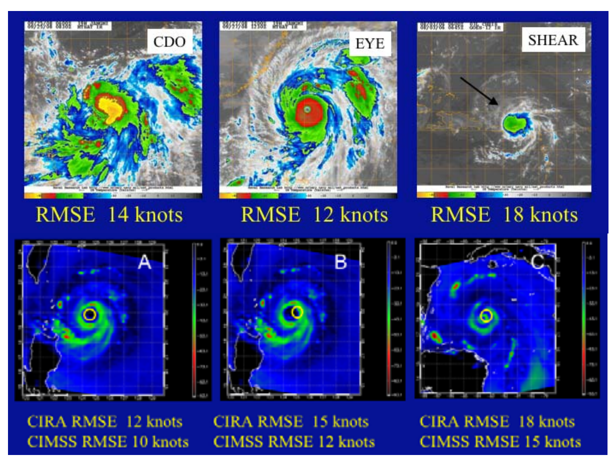

Figure 1. Top panels show IR images and ADT scene types along with the associated RMSE errors. Bottom panels show AMSU-B 89 Ghz imagery. Yellow circles denote the AMSU-A scan position used to produce the intensity estimate. RMSE errors for the CIMSS and CIRA AMSU methods are noted for each scenario.

scenes. The bottom panels of *Figure* 1 show AMSU-B 89 Ghz imagery along with the location of the more coarse resolution AMSU-A scan position used to produce the TC intensity estimate. Three scenarios are shown. In scenario A the eye is large and the AMSU-A scan position coincides with the true TC position. This represents an ideal scenario for both AMSU methods and the RMSE errors reflect this. Panel B shows a scenario where the eye is large however the AMSU-A location is offset from the true TC position resulting in sub-sampling. Finally panel C represents a "worst case" scenario where both the TC eye is small (compared to AMSU-A resolution) and the AMSU-A position is offset from the true TC position. *Figure 3* shows a typical example of how the weighting information is combined to produce a SATCON estimate.

2.2 Information Sharing

Each SATCON member contains parametric information which can be used by the other members. For example the ADT produces estimates of TC eye size when a clear eye is present. Because both AMSU methods suffer from sub-sampling issues when the TC eye is less than 50 km the ADT eye size can be used to adjust the AMSU estimates. The CIMSS AMSU method uses AMSU-B information to determine TC position offset and this can be shared with CIRA AMSU. CIRA AMSU outputs estimates of CLW and max Tb anomaly that can be used to adjust the ADT.

The latest version of the ADT (version 8.1) makes use of input from passive microwave sensors in the 85-92 Ghz range using an algorithm recently developed at CIMSS called ARCHER (see talk 4D.3 by Tony Wimmers as well as poster P1.54 and talk 3D.5a by John Sears). ARCHER creates estimates of TC eyewall vigor and completeness. These parameters are then used to create scores that are used as input to the ADT during cases when the ADT intensity may have a tendency to plateau prior to eye formation in the IR. The latest version of SATCON uses ADT version 8.1. ARCHER also estimates TC eye size and position. TC eye size estimates from ARCHER can be used by both AMSU methods to account for sub-sampling (in the absence of IR eye information).
Additional sources of input to SATCON include environmental pressure (from operational centers via ATCF) as well as storm motion. ADT and CIRA estimates are adjusted using 50% of the storm motions deviation from the climatological average of 11 knots. After each estimate is adjusted the estimates are combined into a single SATCON estimate using the appropriate weights. Separate weights are used for MSLP and MSW.

3.0 Results

Tables 1 and 2 show SATCON performance compared to the individual members (*Table 1*) and the subjective Dvorak technique (*Table 2*). A homogenous sample of cases including all three members from 1999-2009 makes up a sample of N=460. Validation consisted of reconnaissance measured MSLP and Best Track MSW coincident with reconnaissance. It can be seen in Table 1 that SATCON outperforms the individual members. Another measure of skill is that SATCON must perform better than a simple average of the three members. *Table 3* shows this statistic. This is an important result because it indicates that the weighting logic is making an impact.

(Knots)	CIMSS AMSU	CIMSS ADT	CIRA AMSU	SATCON
Bias	-4.0	-5.0	-8.6	-1.0
Ave err	9.1	11.5	12.3	7.2
RMS err	10.2	13.5	14.6	8.3
N = 460				

Table 1. Accuracy of Maximum Sustained Winds (MSW) estimates derived from satellite-based methods compared to 3-member SATCON and individual members verified against reconnaissance-coincident best track MSW. Negative method bias indicates underestimate.

(hPa) (Knots)	SATCON MSLP	Dvorak MSLP	SATCON MSW	Dvorak MSW
Bias	0.3	-2.7	-1.0	-3.0
Ave err	5.2	7.6	7.2	8.1
RMS err	6.4	9.1	8.3	9.0
N = 460				

Table 2. Accuracy of Minimum Sea Lea Level Pressure (MSLP) and Maximum Sustained Wind (MSW) estimates. Verification for MSLP is reconnaissance measured MSLP. MSW verification is best track MSW coincident with reconnaissance. Dvorak is average of TAFB and SAB.

(hPa) (Knots)	SATCON MSLP	Simple MSLP	SATCON MSW	Simple MSW
Bias	0.3	-2.5	-1.0	-4.0
Ave err	5.2	5.7	7.2	8.1
RMS err	6.4	7.7	8.3	9.3
N = 460				

Table 3. Comparison of SATCON with a simple average of the three members

In 2008 the THORPEX TCS-08 project permitted the opportunity to validate satellite-based TC intensity methods in a basin other than the Atlantic. Aircraft reconnaissance was flown into three TC's during the study for the purposes of getting intensity estimates using flight level winds, SFMR and dropsondes. One component of the experiment was to verify the subjective Dvorak technique in a double blind experiment where the Dvorak experts were blind to the aircraft data. This also allowed an unbiased comparison with the objective intensity methods including SATCON. While the number of cases is small the intensities observed during the experiment spanned the range of 35 -140 knots. Table 3 reveals the results of this experiment and shows a similar trend to the Atlantic verification where SATCON is comparable in skill and perhaps more skillful on average than the Dvorak method.

(Knots)	"Blind" MSW	OPer MSW	SATCON MSW
Bias	3.6	2.0	2.9
Ave err	9.3	12.0	8.6
RMS err	11.9	14.9	10.1
N = 14			

Table 4. TCS-08 validation experiment for Typhoons 13W, 15W and 19W. "Blind" is average of five independent Dvorak analysts. OPer is the operational center Dvorak average.

4.0 Future Work

The focus of future work will involve continued evaluation of cross-platform parameter sharing with attention primarily being aimed at improving the MSW estimates. One possible source of improvement is additional input from TC eye size. TC eye size is related to MSW intensity. TC's with smaller eyes tend to have winds that are stronger than TC's of the same MSLP. The ARCHER algorithm outputs TC eye size and therefore those values can be used to derive a unique pressure-wind relationship using the statistically superior SATCON-derived MSLP. One approach would be to use this MSW estimate as an additional "member" in SATCON. Early work with this idea reveals an improvement in the MSW estimates of the 460 case sample. A Knaff-Zehr pressure-wind relationship could also be used. Other SATCON members may join the consensus in the near future. The Naval Research Laboratory has been working on a passive microwave intensity method which uses a pattern matching approach for the 85-92 Ghz imagery. If this method continues to show promise it could also be used as a member in SATCON.

Web Page: http://cimss.ssec.wisc.edu/tropic2/real-time/satcon/

5.0 References

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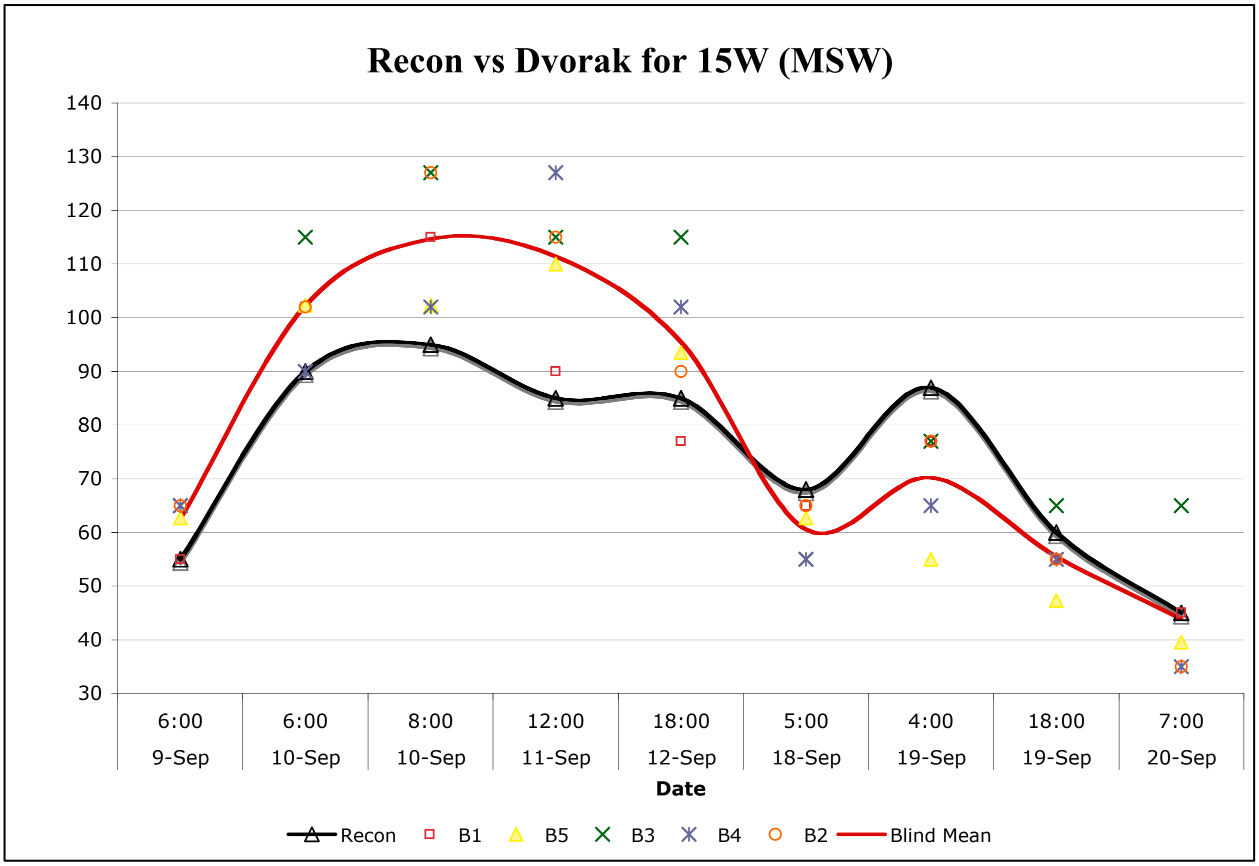

Figure 2. Dvorak estimates for TY Sinlaku (15W) during the TCS-08 experiment. Red line denotes mean of Dvorak estimates while the solid grey line and triangles denote reconnaissance-based ground truth

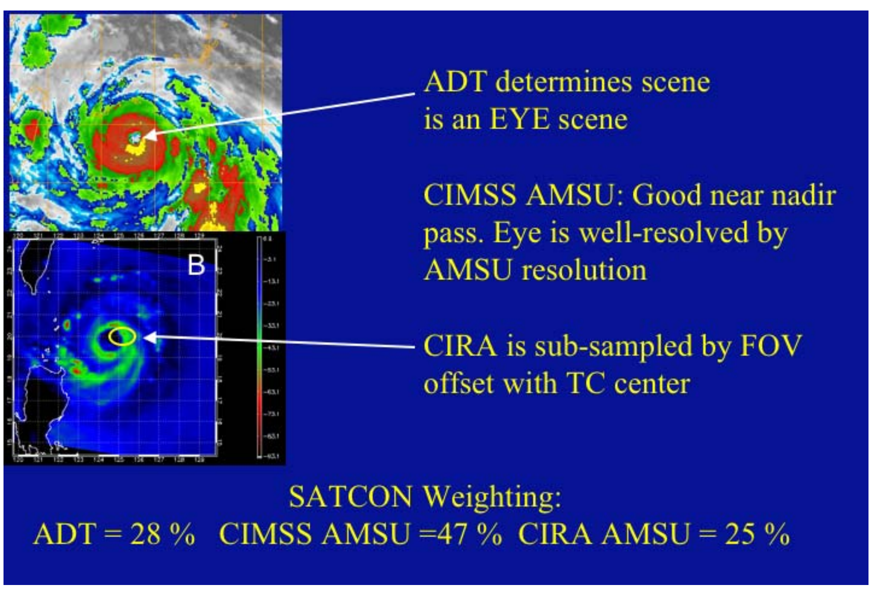

Figure 3. Example of SATCON weighting