7C.2 Update on SATellite-based CONsensus (SATCON) Approach to TC Intensity Estimation

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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 can provide TC forecasters 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 have been provided to NHC, CPHC, BOM and JTWC along with other TC forecast agencies since 2008.

TC forecasters are often faced with the problem of satellite estimates that exhibit a large amount of uncertainty. An example is shown in *Figure 1,* which indicates Dvorak satellite estimates (Maximum Sustained Winds (MSW)) from an experiment conducted during the Tropical Cyclone Structure 2008 (TCS-08) field campaign in the Western Pacific. Intensity estimates were produced by five expert Dvorak analysts who were 'blind' to the available reconnaissance ground truth for Typhoon Sinlaku (15W). Note that the estimates vary by as much as 37 knots. Even taking the mean of the estimates would result in errors as large as 25 knots. Estimate uncertainty of this magnitude is not uncommon. TC forecasters may pick the highest of the available estimates, an average, the lowest of the estimates, or some value in between. The method for establishing the final intensity estimate varies among forecasters and forecast agencies. An objective method which reduces estimate uncertainty is desirable.

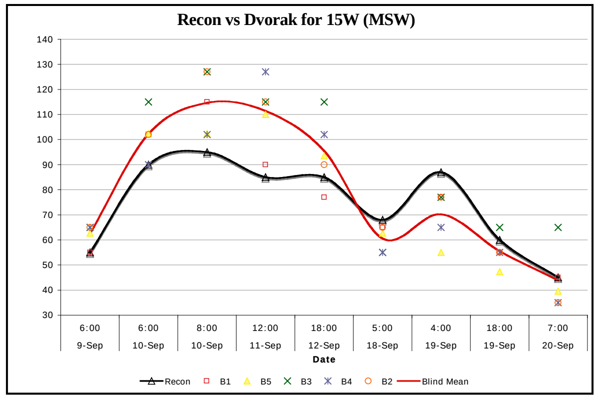

Figure 1. Dvorak estimates of Maximum Sustained Wind (MSW, in Kts) from five expert analysts (B1-B5) for Typhoon Sinlaku (2008) from TCS-08, compared to aircraft reconnaissance.

2.0 Methodology

Each SATCON member is given an empirically-determined weight based on the methods' performance in given situations. Separate weights are used for both Maximum Sustained Wind (MSW) and Minimum Sea Level Pressure (MSLP). The equation used to combine three-member SATCON estimates is:

$$\text{SATCON} = \frac{W_1W_2(W_1+W_2)E_3 + W_1W_3(W_1+W_3)E_2 + W_3W_2(W_3+W_2)E_1}{W_1W_2(W_1+W_2) + W_1W_3(W_1+W_3) + W_3W_2(W_3+W_2)}$$

W_n = weight of method n
E_n = estimate of method n

Equation 1. SATCON three-member weighting

In addition to the three-member estimate of MSW, a fourth estimate of MSW is produced using the highly skillful SATCON MSLP estimate. A pressure-wind relationship similar to Knaff and Zehr (2007) is applied to the SATCON MSLP estimate and includes latitude, the radius to the

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outer closed isobar as a size parameter, and TC translation speed. An average is then taken from this pressure-wind MSW and the SATCON three-member estimate (or two-member if only two satellite members are available).

While not an explicit member of SATCON, the CIMSS Automated Rotational Center Hurricane Eye Retrieval (ARCHER) algorithm provides TC structure information to SATCON. ARCHER produces estimates of TC eye size along with eyewall symmetry and robustness based on passive microwave imagery. These parameters are used to adjust the final SATCON estimate when available (see section 2.2 for further details of ARCHER, along with talk 7C.3 by Tony Wimmers).

2.1 Weighting Structure

The weights used by SATCON are the RMSE errors for the individual members in a given situation. *Figure 2* below shows typical RMSE errors for different scenarios for the three members. As shown in the top panels, the ADT generally performs best in "Eye" scenes. The

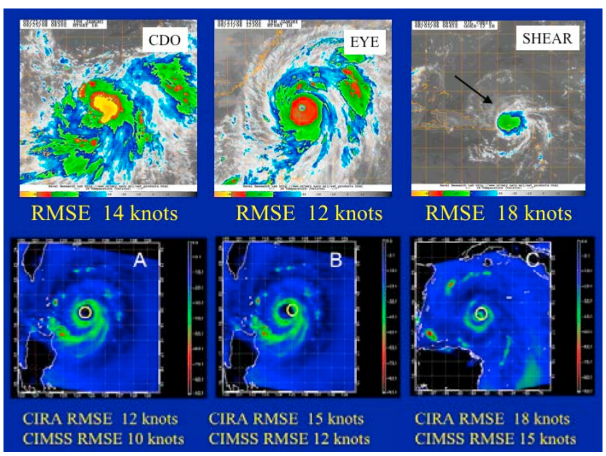

Figure 2. Top panels show IR images and ADT scene types along with their associated ave. RMSE errors. Bottom panels show AMSU-B 89 Ghz imagery. Yellow circles denote the AMSU-A scan position used to produce the intensity estimate. Ave. RMSE errors for the CIMSS and CIRA AMSU methods are noted for each scenario.

bottom panels show AMSU-B 89 Ghz imagery along with the location of the more coarse resolution AMSU-A scan position used to produce the AMSU TC intensity estimates. 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 under-sampling. Finally, panel C represents a "worst case" scenario where the TC eye is small (compared to AMSU-A resolution) and the AMSU-A position is offset from the true TC position. Each of these different RMSE scenarios represents a unique weight for that member. *Figure 3* shows a typical example of how the weighting information is combined to produce a SATCON estimate.

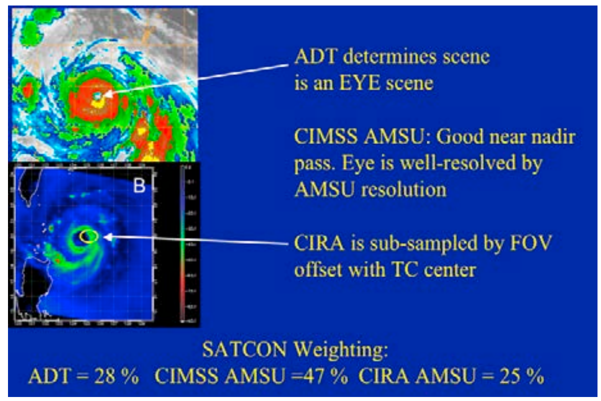

Figure 3. Example of SATCON weighting structure.

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 well-defined eye is present in the infrared imagery (Kossin et. al 2007). Because both AMSU methods suffer from under-sampling issues when the TC eye is less than 50 km, the ADT eye size can be used to adjust the AMSU estimates (AMSU estimate bias is strongly correlated with TC eye size/AMSU scan resolution geometry). The CIMSS AMSU method uses AMSU-B information to determine TC position offset (see bottom panels of *Fig 2*). This 89 Ghz signal is used as a proxy for determining the true TC position relative to the AMSU scan position used for the estimate. When the TC position is not co-located with the AMSU position, a bias correction is applied in the CIMSS AMSU algorithm to account for this source of under-sampling of the TC warm core anomaly. A similar approach is used to adjust the CIRA AMSU estimates within the SATCON algorithm.

The latest version of the ADT (version 8.1) makes use of position and intensity input from passive microwave sensors in the 85-92 Ghz range using ARCHER. ARCHER derives estimates of TC eyewall vigor and completeness, and these parameters are used to create scores that are input into the ADT and applied in cases when the ADT intensity may have a tendency to plateau prior to eye formation in the IR (please see talk 7C.1 by Tim Olander concerning the details on the latest version of the ADT). ARCHER also estimates TC eye size, which can be used by both AMSU methods to account for under-sampling.

Another way in which the eye size from ARCHER is used is as an adjustment to the SATCON pressure-wind (PW) estimate of MSW. The final SATCON PW estimate is adjusted up/down when the TC eye size determined by ARCHER is smaller/larger than the climatologically average eye size. This adjustment is based on the observation that TC MSW values tend to be higher/lower in TCs with small/large eyes given the same MSLP. The correction is only applied when the ARCHER score is greater than 55, signifying a robust well-formed eyewall. This constraint is used to account for TC eye structures that undergo transient changes during initial eyewall formation.

Additional sources of input to SATCON include environmental pressure (from operational centers via ATCF) as well as storm translation speed. ADT and CIRA MSW estimates are adjusted using 50% of the storm motion deviation from the climatological average of 11 knots. After each member estimate is adjusted, the estimates are combined into a single SATCON estimate using the appropriate weights for MSW and MSLP.

3.0 Results

For SATCON validation, cases from 1999-2010 were separated into 2 samples using a "leave every other case out" approach. While the weighting structure used to create the SATCON estimates is totally independent, the cross-algorithm information sharing and pressure-wind pseudo member MSW estimates require the sample to be split into dependent and independent data sets for validation purposes.

Tables 1 and 2 show SATCON performance compared to its individual members (*Table 1*), and operational subjective Dvorak technique estimates (*Table 2*). A homogenous sample of cases including all three members from 1999-2010 makes up an independent sample of N=289. Validation consists of reconnaissance-measured MSLP, and the Best Track MSW values coincident with reconnaissance estimates. It can be seen in *Table 1* that SATCON outperforms all of the individual members. Another measure of skill is that SATCON must perform better than a simple un-weighted average of the three members (*Table 3)*. This is an important result because it indicates that the weighting logic is making an impact.

N=289	CIMSS AMSU	CIMSS ADT	CIRA AMSU	**SATCON**
Bias	0.6	-2.5	-7.1	**-0.5**
Ave err	8.7	10.9	11.7	**7.1**
RMS err	11.1	14.3	15.6	**8.9**

Table 1. Accuracy of Maximum Sustained Wind (MSW) estimates (Kts) derived from satellite-based methods compared to 3-member SATCON and individual members verified against recon-coincident Best Track MSW. Negative method bias indicates underestimate. Cases include Atlantic (263), East Pacific (8) and West Pacific (18).

(hPa) (Knots)	SATCON MSLP	Dvorak MSLP	SATCON MSW	Dvorak MSW
Bias	0.1	-2.0	-0.5	-1.9
Ave err	4.6	6.8	7.1	7.7
RMS err	6.5	9.3	8.9	9.9
N = 289				

Table 2. Comparison of performance between SATCON estimates and coincident operational Dvorak estimates. Verification for MSLP is recon-measured MSLP. MSW verification is Best Track MSW coincident with recon. Dvorak is average of TAFB and SAB estimates. Cases include Atlantic (263), East Pacific (8) and West Pacific (18).

(hPa) (Knots)	SATCON MSLP	Simple MSLP	SATCON MSW	Simple MSW
Bias	0.1	-1.6	-0.5	-3.0
Ave err	4.6	5.0	7.1	8.1
RMS err	6.5	7.5	8.9	10.5
N = 289				

Table 3. Comparison of SATCON with a simple average (no weighting) of the three members. Verification for MSLP is recon-measured MSLP. MSW verification is Best Track MSW coincident with recon.

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 storms 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 available 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. Four additional cases were available from the ITOP-2010 field experiment. While these Dvorak estimates were not double blind estimates, they are included to expand the WPAC sample size and include Typhoon Megi (15W) which reached 165 knots. *Table 4* reveals the results of this experiment, and shows a similar trend to the Atlantic verification where SATCON is slightly more skillful on average than the Dvorak method.

(Knots)	Dvorak MSW	**SATCON MSW**
Bias	-4.9	**-1.5**
Ave err	10.8	**8.4**
RMS err	13.1	**9.9**
N = 18		

Table 4. WPAC 2008 and 2010 validation. Coincident 2008 cases (N=14) includes the double-blind experiment from TCS-08/TPARC project, and 2010 cases (N=4) are from ITOP.

4.0 Future Work

An SSMIS-based sounder method which uses logic similar to the CIMSS AMSU sounder method has been developed at CIMSS and is being evaluated for inclusion in SATCON.

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. This method continues to show promise and could also be used as a member in SATCON in the near future. Temporal variability of the SATCON estimates may be reduced by the inclusion of additional skillful members.

5.0 References

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SATCON web site: tropic.ssec.wisc.edu/real-time/satcon