Development of a product based on consensus between Dvorak and AMSU tropical cyclone central pressure estimates at JMA

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1. Introduction

Estimation of tropical cyclone (TC) intensity, such as minimum sea level pressure (MSLP) and maximum sustained wind (MSW), is important for disaster prevention and mitigation. The Japan Meteorological Agency (JMA) uses TC intensity estimates from in-situ and satellite observations to obtain the best-track data, and to create bogus TC vortexes dedicated to the objective analysis in its numerical weather prediction. Since the 1980s, the Dvorak technique (Dvorak 1975, 1984) which is based on TC cloud pattern as observed in geostationary satellite infrared imagery from GMS, MTSAT and Himawari-8 has been used as the standard for estimating TC intensity. Although this technique is known to provide reliable TC intensity estimates in many cases, it is affected by several issues originating from its subjective and empirical approaches (Yoshida et al. 2011).

There is a need to improve satellite-based TC intensity estimates in order to make operational TC analysis more reliable, particularly in situations where in-situ observations are scarce and the accuracy of Dvorak analysis is lower than usual. To support the Dvorak technique, the Meteorological Research Institute (MRI) of JMA developed an objective scheme for the estimation of MSLP from TC warm core intensity as observed by the Advanced Microwave Sounding Unit-A (AMSU-A) of NOAA and MetOp series polar-orbiting satellites (Oyama 2014). In this scheme, which is referred to as the AMSU technique, the positive temperature anomaly of the warm core near the TC center is related to MSLP based on the hydrostatic equilibrium theory. As the warm core intensity determined by AMSU-A is independent of that of the Dvorak technique, the AMSU technique is expected to help improve JMA's operational TC analysis through use in conjunction with Dvorak technique.

This paper describes optimal MSLP estimation using both Dvorak and AMSU MSLPs for TCs in the western North Pacific basin, referred to here as CONSENSUS, and related validation results. Section 2 describes the method used, while Section 3 outlines the validation results of CONSENSUS with reference to JMA best-track data and presents examples of CONSENSUS for several TC cases. Finally, Section 4 summarizes the paper.

2. Method adopted for CONSENSUS with Dvorak and AMSU MSLP estimates

This work involves the use of six-hourly Dvorak MSLP data derived using MTSAT infrared imagery (10.8 μm) and AMSU MSLP data derived using the AMSU-A temperature retrieval channels (55-GHz band) of NOAA and MetOp series polar-orbiting satellites. In the derivation of Dvorak MSLP, the current intensity (CI) number of the TC is determined by analyzing TC cloud pattern in infrared imagery and converted to MSLP by using the lookup table proposed by Koba et al. (1990). Meanwhile, AMSU MSLP is derived from TC warm core intensity, defined as the maximum value of the maximum brightness temperature (TB) anomalies within a radius of 200 km from the TC center for AMSU-A channels 6, 7 and 8, which observe temperatures at around 400, 250 and 180 hPa levels, respectively. NOAA-15, -16, -18, -19 and MetOp-A and -B from 2009 to 2014 are the satellites used for AMSU-A observation. However, each satellite has periods of unavailability due to the equipment defects and periods of non-operation. AMSU-A observation for tropical cyclones is usually obtained twice a day by each satellite. The field of view (FOV) in AMSU-A observation is coarse (about 48 km near the nadir), and observation accuracy is low for warm cores smaller than this.

CONSENSUS is derived as the weighted average of Dvorak MSLP and AMSU MSLP. The weights for CONSENSUS are computed as the reciprocal of the root mean square error (RMSE) against the MSLP of best-track data for TCs in the western North Pacific basin between 2009 and 2011 (Fig. 1). In obtaining the weights for CONSENSUS, linear interpolation was used to produce hourly Dvorak MSLP data and best-track MSLP data for collocation with AMSU-A observation. Consequently, RMSEs of Dvorak and AMSU MSLPs for CONSENSUS are computed for individual TC cloud patterns (Table 1) in consideration of TC intensity estimation error depending on the TC life stage. The Dvorak technique involves the use of different procedures for estimation of CI-number among TC cloud patterns. For example, the value for Eye pattern is derived using TB (IR1) distribution in the central dense overcast (CDO) and the TB value in the Eye, while CI-number for Curved band pattern is derived based on the length of the spiral cloud band. The different procedures of the Dvorak technique among TC cloud patterns could cause life stage-dependent errors. Results from the AMSU technique may also depend on the TC life stage because the reliability of AMSU-A observation could vary with the size and height of the TC warm core (Knaff et al. 2000; Oyama 2014), which relate to TC structural changes associated with the life stage.

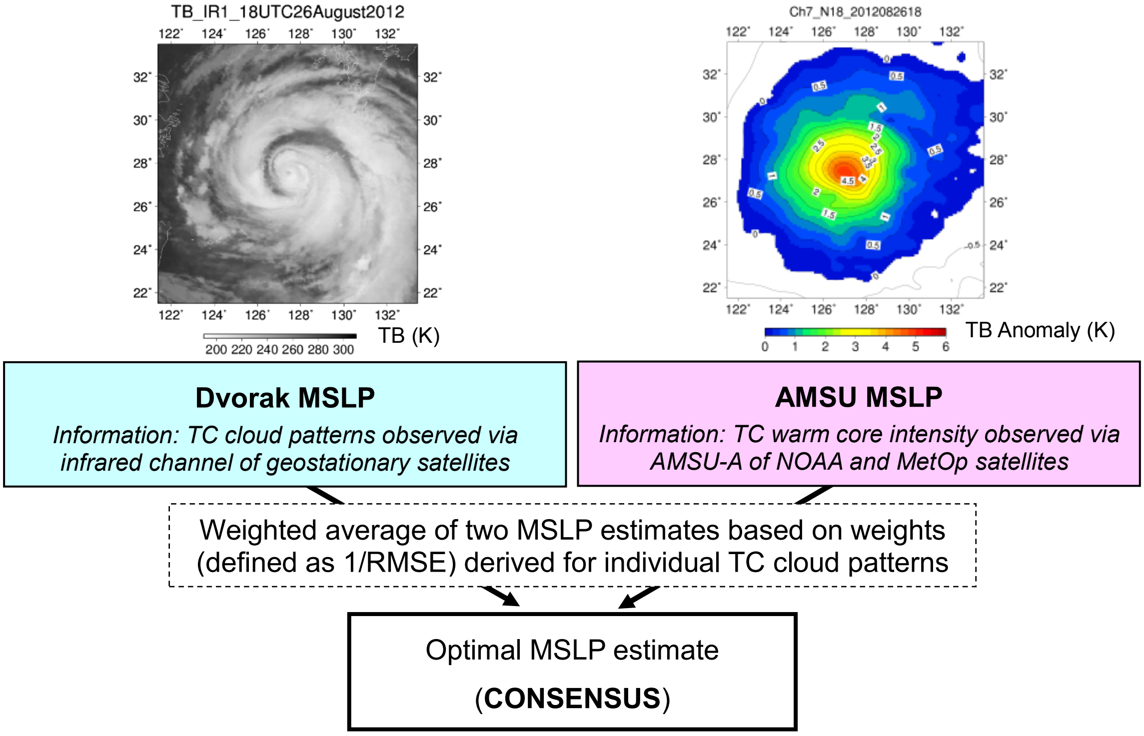


Fig. 1: Outline of CONSENSUS

Table 1: RMSEs of Dvorak and AMSU MSLP estimates relating to best-track MSLP for TCs in 2009−2011 and weights for CONSENSUS.

	RMSE (hPa)		Weight (=1/RMSE)		Number of AMSU-A observations
	Dvorak	AMSU	Dvorak	AMSU	
CB cluster	4.9	7.3	0.20	0.14	142
Curved band	6.9	10.0	0.14	0.10	307
CDO	7.5	23.9	0.13	0.04	30
Eye	7.4	16.1	0.14	0.06	146
Shear/LCV	6.7	6.4	0.15	0.16	147

3. Results

This section details the results of CONSENSUS validation based on 79 TCs in the western North Pacific basin between 2012 and 2014. First, Table 2 shows RMSEs and biases with reference to best-track MSLP for Dvorak MSLP, AMSU MSLP, CONSENSUS and the average of Dvorak and AMSU MSLPs (referred to here as the average). It can be seen that the bias and RMSE of CONSENSUS are smaller than those of Dvorak and AMSU MSLPs, which suggests that the proposed CONSENSUS approach produces better MSLP estimates than Dvorak and AMSU estimates. The

RMSE of CONSENSUS is also smaller than that of the average. This implies that weighting in accordance with TC cloud patterns for CONSENSUS is effective in improving MSLP estimates.

Table 3 shows RMSEs and biases with reference to best-track MSLP for Dvorak MSLP, AMSU MSLP and CONSENSUS for individual TC cloud patterns. It can be seen that the values of CONSENSUS are smaller than those of Dvorak MSLP for all TC cloud patterns. It should be noted that the CONSENSUS approach results in better MSLP estimates than Dvorak estimates even for CDO and Eye patterns where the accuracy of AMSU MSLP is much lower than that of Dvorak MSLP. The superiority of CONSENSUS to Dvorak MSLP in terms of quality for all TC cloud patterns indicates that AMSU MSLP contains information both independent of and complementary to Dvorak MSLP throughout the TC lifetime.

Table 2: RMSE and bias of MSLP estimates with reference to best-track MSLP for TCs in 2012－2014

Dvorak		AMSU		CONSENSUS		AVERAGE	
RMSE	BIAS	RMSE	BIAS	RMSE	BIAS	RMSE	BIAS
7.8	0.1	10.5	0.1	6.3	0.0	6.7	0.1

Table 3: RMSE and bias of MSLP estimates with reference to best-track MSLP for individual TC cloud patterns in 2012－2014

	Dvorak		AMSU		CONSENSUS		Number of data
	RMSE	BIAS	RMSE	BIAS	RMSE	BIAS	
CB cluster	5.4	-1.0	5.1	-0.8	4.4	-0.9	288
Curved band	7.5	-0.8	10.0	0.3	6.1	-0.3	574
CDO	8.7	-1.0	13.8	3.4	7.0	0.1	82
Eye	9.1	3.1	16.5	1.3	8.3	2.6	238
Shear/LCV	9.5	1.0	6.5	-2.0	6.0	-0.5	231

Figure 2 shows RMSE differences between CONSENSUS and Dvorak MSLP for individual TC cases in 2012－2014. It can be seen that the RMSE of CONSENSUS is smaller than that of Dvorak MSLP for 57 TCs (72% of the total). It should also be noted that the RMSE difference between CONSENSUS and Dvorak MSLP is within 3 hPa for TCs where the quality of CONSENSUS is lower than that of Dvorak MSLP, while CONSENSUS often shows estimates that are better than those for Dvorak MSLP by greater than 3 hPa.

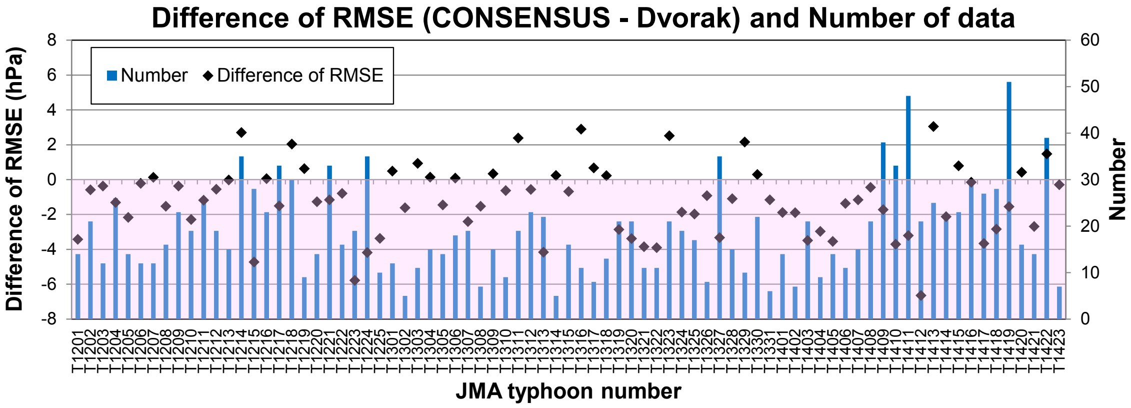
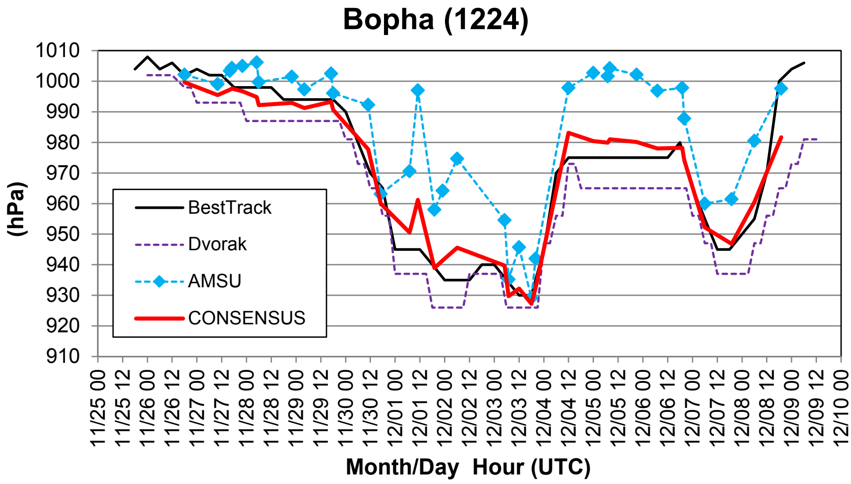


Fig. 2: Comparison of RMSE between CONSENSUS and Dvorak MSLP for individual TC cases in 2012－2014. Each plot denotes the RMSE difference (CONSENSUS minus Dvorak MSLP) with reference to best-track MSLP. Bars denotes the number of data.

In the rest of this section, the characteristics of CONSENSUS for two TC cases are outlined in comparison with Dvorak and AMSU MSLPs. TC Bopha (1224) is a case in which significant improvement of MSLP estimates is observed with CONSENSUS. Figure 3 shows a time series representation of Dvorak MSLP, AMSU MSLP, CONSENSUS and best-track MSLP for this TC. It can be seen that CONSENSUS data are superior to those of Dvorak MSLP throughout the TC's lifetime. Dvorak MSLP tends to be lower than best-track MSLP for the whole period. In contrast, AMSU MSLP tends to be higher than best-track MSLP due to the relatively low TC warm core intensity observed by AMSU-A (Fig. 4). As a result, the CONSENSUS value obtained for this TC is similar to best-track MSLP.

TC Francisco (1327) is another case in which the RMSE of CONSENSUS is smaller than those of Dvorak and AMSU MSLPs. As seen in Fig. 5, particular improvement in MSLP estimation resulting from the introduction of CONSENSUS for this TC is observed in the TC decay stage after 20 October 2013. The superiority of CONSENSUS to Dvorak MSLP may be attributable to the fact that TC Francisco had a relatively large warm core that was well resolved by AMSU-A observation (Fig. 6) and thus the quality of the MSLP estimate can be expected to be relatively high.



T1224, Number of data = 35

	RMSE	BIAS
Dvorak	10.2	-8.8
AMSU	19.3	14.3
CONSENSUS	6.0	0.6

Fig. 3: Time-series representation of Dvorak MSLP, AMSU MSLP, CONSENSUS and the best track MSLP for TC Bopha (1224).

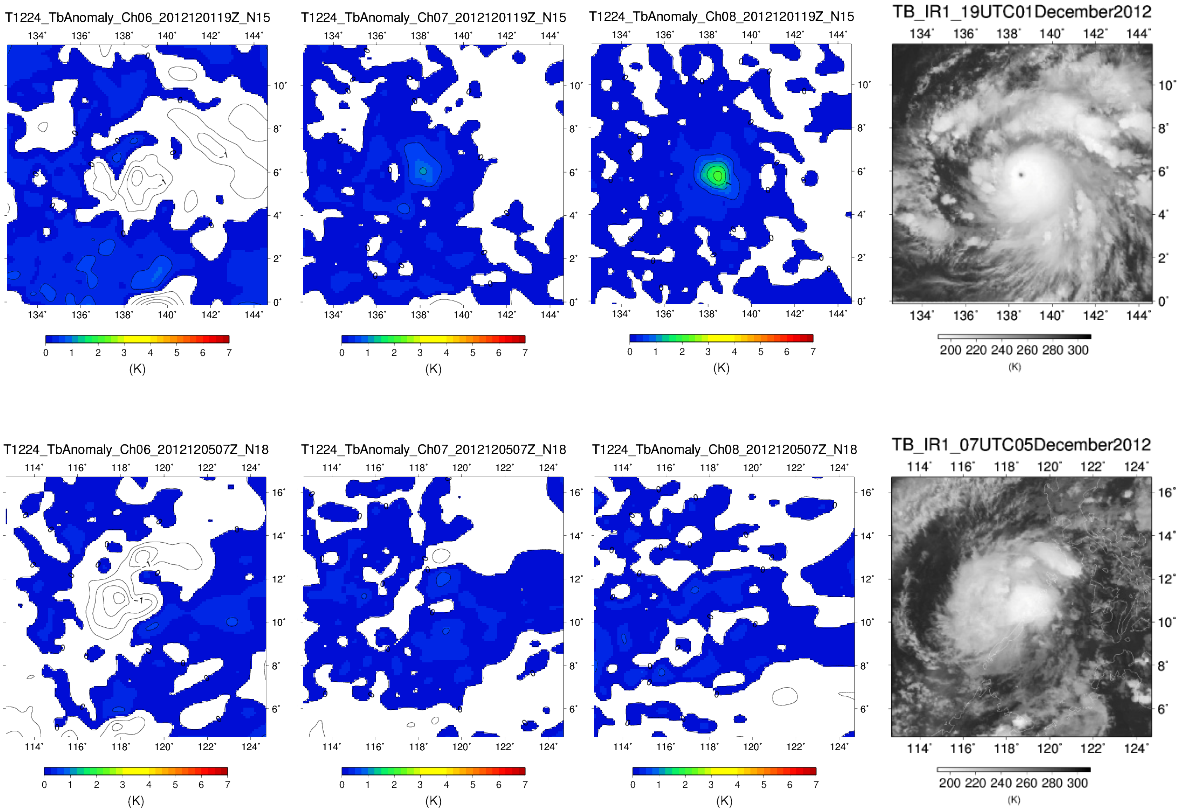
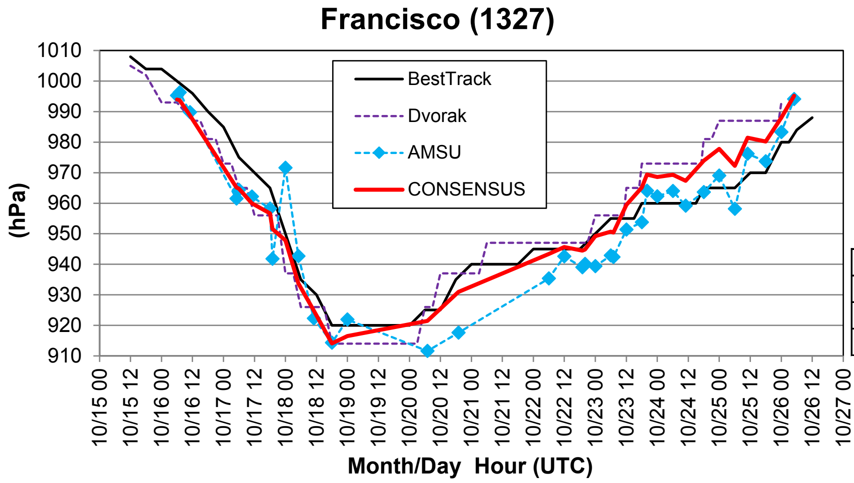


Fig. 4: Spatial distributions of AMSU-A TB anomalies for channels 6, 7 and 8 along with distribution of MTSAT-2 IR1 (10.8 μm) TB values in an area covering 12° longitude × 12° latitude centered on TC Bopha (1224) at 19 UTC on 01 December 2012 (top) and 07 UTC on 05 December 2012 (bottom).



T1327, Number of data = 35

	RMSE	BIAS
Dvorak	10.9	3.0
AMSU	9.4	-3.8
CONSENSUS	7.5	0.0

Fig. 5: As per Fig.3, but for TC Francisco (1327).

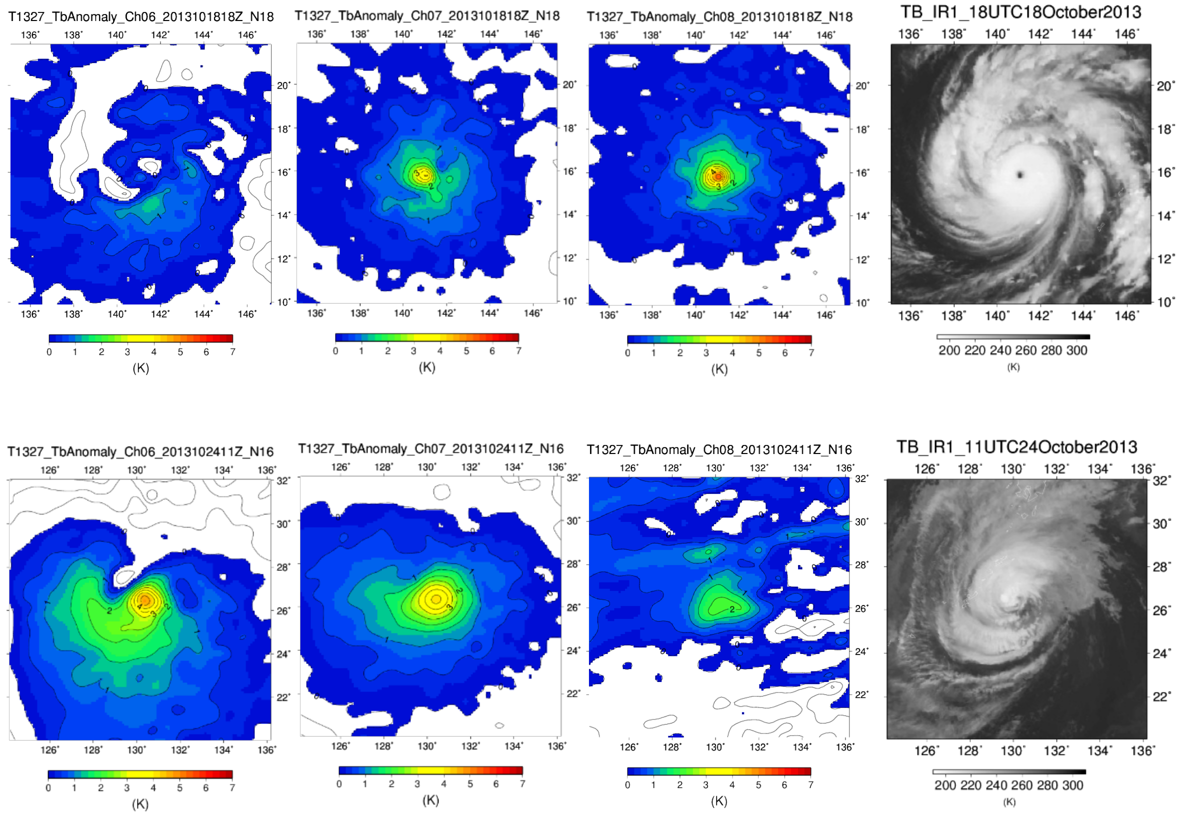


Fig. 6: As per Fig.4, but for TC Francisco (1327) at 18 UTC on 18 October 2013 (top) and 11 UTC on 24 October 2013 (bottom).

4. Summary

This paper describes a JMA method for the derivation of optimal MSLP estimates of Dvorak and AMSU MSLPs (referred to as CONSENSUS) and presents the results of related validation. CONSENSUS was found to be an effective approach for the purpose at hand. The superior quality of CONSENSUS data as compared to that produced by the Dvorak approach is attributed to the beneficial independent information of AMSU MSLP. The advantage of this method indicates that the use of CONSENSUS will contribute to improvement of JMA's operational TC intensity analysis, particularly when in-situ observation data are scarce and operational TC intensity analysis depends largely on the Dvorak technique.

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