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JMA'S ACTIVITIES FOR THE DEVELOPMENT OF A NEW MULTI-CHANNEL SEA SURFACE TEMPERATURE (SST) ALGORITHM

This document reports on JMA's activities for the development of a new sea surface temperature (SST) algorithm and its application to MTSAT data.

JMA has operationally retrieved SSTs from GEO data since GMS-5 was launched in 1995. These SSTs indicate good performance for ocean monitoring status, but additional efforts to reduce bias are necessary.

JMA has now developed a new algorithm as a theoretical extension of the traditional multi-channel sea surface temperature method (MCSST). Its application to MTSAT-2 data is expected to improve the calculation of water vapor absorption and sea surface emissivity. The cloud screening method used has also been improved.

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1 INTRODUCTION

Sea surface temperature (SST) is an important parameter in ocean monitoring, environmental monitoring, long-term forecasting and other activities. To meet the related requirements, JMA has operationally retrieved SSTs from GEO data since GMS-5 was launched in 1995. These SSTs indicate good performance for ocean monitoring status.

Daily averaged SSTs have generally been used so far, but recently there has been increased demand for SSTs with higher temporal resolution to be used in short-term weather forecasting. To meet such demand, JMA needs to evaluate whether hourly data from MTSAT can be used for objective SST analysis. Before performing such evaluation, however, it is necessary to reduce the large negative bias of current MTSAT SSTs for satellite zenith angles exceeding 50 degrees (Figure 1).

JMA developed a new algorithm to reduce this bias last year. It involves mathematically deriving SSTs from an infrared radiation transfer equation that takes into account the dependence of water vapor absorption on the length of the radiation path and variations in emissivity with respect to the radiation angle from the ocean surface. The algorithm's application to MTSAT data is expected to improve the quality of SSTs recorded in sea areas far from the subsatellite point.

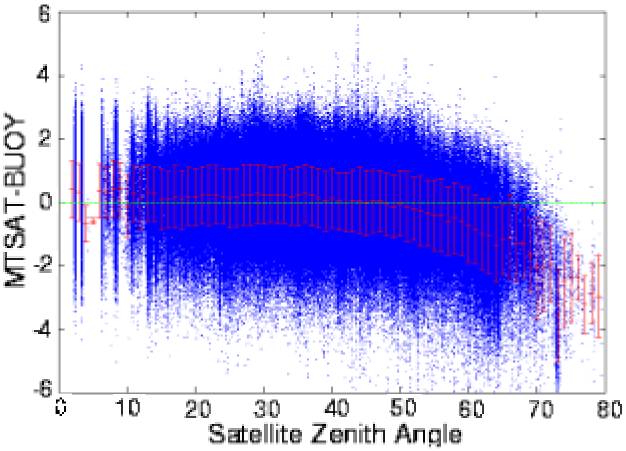


Figure 1 Departure of current MTSAT SSTs from BUOY observations as a function of the satellite zenith angle

2 SST ALGORITHM

The new algorithm developed by JMA is mathematically derived from a simplified infrared radiation transfer equation:

$$I \quad B(T_s) \quad B(\overline{T})(1 \quad), \qquad (1)$$

where is the wavelength, I is the radiation intensity, is the emissivity, B is the Planck function, T_s is the sea surface temperature, $\exp(\quad)$ is the transmittance (: an extinction coefficient) and $\overline{T}$ is the mean air temperature.

If we presume that

$$\overline{T}_{10.8} \quad \overline{T}_{12}, \qquad (2)$$

$$_{10.8} \quad const \quad _{12}, \qquad (3)$$

then estimations of sea surface temperature (T_s), transmittance ( ) and mean air temperature ($\overline{T}$) can be derived to minimize the cost function:

$$J(x) \quad (x \quad x_0)^T B^{\ 1}(x \quad x_0) \quad (H(x) \quad y_0)^T R^{\ 1}(H(x) \quad y_0), \qquad (4)$$

where $x_0 \quad (T_s^0, \ {}^{0}_{10.8}, \overline{T^0})$ and $y_0 \quad (I_{10.8}, I_{12})$ are the background and observation vectors, respectively, B and R are the background variability and observation error covariance matrixes, respectively, and $H(x)$ is an observation operator that transforms x to y.

Regarding the traditional MCSST method developed for LEO data by NOAA, the equation is also derived from the transfer equation. However, the two algorithms involve different assumptions (Table 1).

In the MCSST method, emissivity and water vapor absorption are assumed to be constant or approximated as a simple linear function for every satellite zenith angle. Such assumptions are practical in seas where the satellite zenith angle is within around 45 degrees, but the coverage of MTSAT spreads above 45 degrees up to about 80 degrees, and includes seas where the value is 50 degrees. In these areas with high zenith angles, the assumptions are no longer appropriate.

To solve these problems, current MTSAT SSTs are retrieved using an algorithm empirically extended from the MCSST method at JMA. However, as shown in Figure 1, SSTs still have the problem of negative bias in areas with higher satellite zenith angles.

In the new algorithm, the effects of emissivity are theoretically expressed as functions of the satellite zenith angle. Water vapor absorption is calculated by modifying its background, which is given by an empirical function of brightness temperature and the satellite zenith angle. Application of this algorithm to MTSAT data is expected to improve the quality of MTSAT SSTs. Figure 2 shows differences between *in-situ* data (BUOY) and draft SSTs retrieved using the new algorithm (MTSAT minus *in-situ*). The draft versions are calculated using temporally fixed coefficients with a match-up data set of satellite data and *in-situ* data spanning the period from July 2010 to February 2011. It is clear that the negative bias tendency seen in Figure 1 is remarkably reduced.

An example of a daily map is shown in Figure 3. As expected from comparison between Figure 1 and Figure 2, SSTs estimated with the new algorithm are higher than current SSTs on both the eastern and western sides.

Table 1 List of SST algorithm assumptions

	MCSST	NEW ALGORITHM
Air temperatures	Constant along the radiation path	Constant along the radiation path
Emissivity	Approximated by a constant function for all over the satellite zenith angle	Function of satellite zenith angle
Water vapour	Constant along the radiation path, but cancelled in the process of derivation because of the approximation of the water vapour absorption	This will be included in background water vapor absorption which will be empirically derived
Radiation path length	Approximated by the inverse of cosine of satellite zenith angle	This will be included in background water vapor absorption which will be empirically derived
Water vapor absorption	Constant	Background will be given by an empiricall function of difference of brightness temperatures at 10.8 micron and 12 micron channels
Transmittance	A linear function of water vapor, radiation path length and water vapor absorption	Exponential function of water vapor absorption
Plank function	Approximated by a linear function of brightness temperature	No approximation

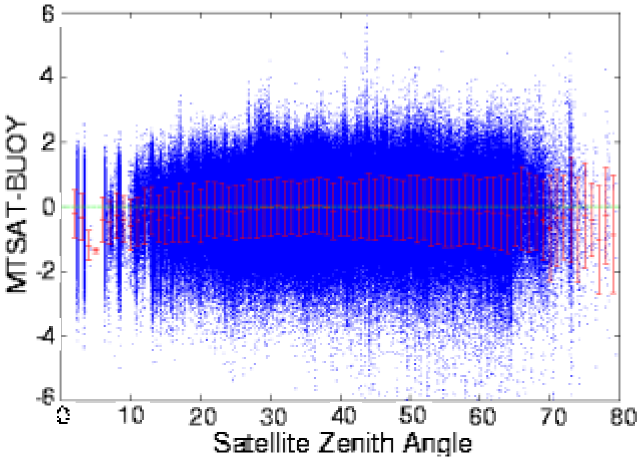


Figure 2 Departure of new MTSAT SST draft versions from BUOY observations as a function of the satellite zenith angle

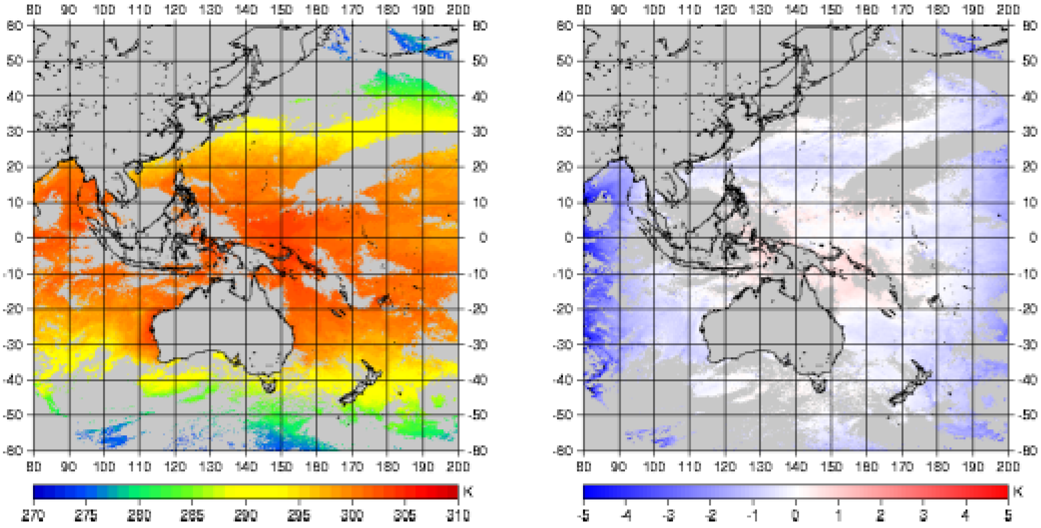


Figure 3 Example of a daily map of new MTSAT SSTs (left) and its difference from current MTSAT SSTs (current minus new) for 1 March, 2011

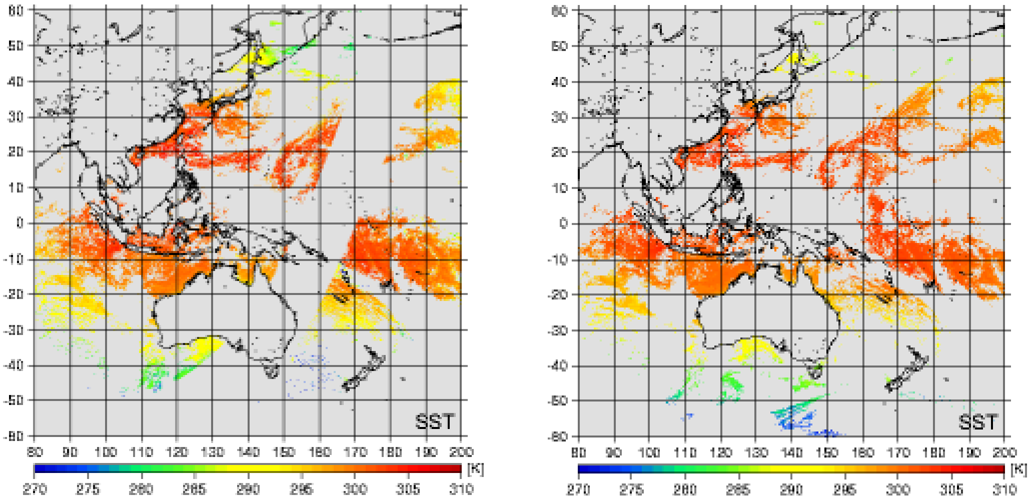
3 CLOUD SCREENING

In the new retrieval, the cloud screening algorithm is also refined. It is based on the tests shown in Table 2, to which two comparison tests have been added. In these comparisons, each brightness temperature value for the 10.8-micron channel is compared with its maximum for the most recent 10-day period and daily SSTs objectively analyzed by JMA.

Table 2 Table of tests for cloud screening

TEST	DATA FOR THE TEST	CURRENT CLOUD SCREENING	CLOUD SCREENING UNDER DEVELOPMENT
THERMAL GROSS TEST	brightness temperature at 10.8 microns (BT10.8)	○	○
REFRECTANCE TEST	visible data	○	○
SPLIT WINDOW TEST	BT10.8, BT12	○	○
SPLIT WINDOW TEST NIGHTTIME	BT10.8, BT12, BT3.8	○	○
THERMAL UNIFORMITY TEST	BT10.8	○	○
REFRECTANCE UNIFORMITY TEST	visible data	○	○
COMPARISON TEST (MAXIMUM BRIGHTNESS TEMPERATURE)	BT10.8, maximum BT10.8 in the last 10 days	-	○
COMPARISON TEST (ANALYZED SST)	BT10.8, analyzed daily SST	-	○

In the current cloud screening tests, thresholds are constant for the direction of the satellite zenith angle, the sun zenith angle, the sun glint angle, and latitude. In subsequent tests, the dependence of thresholds on these parameters will be taken into account if necessary. The thresholds utilized in the present analysis enable the retrieval of SSTs in the twilight region (Figure 4).



Current product

Product under development

Figure 4 Comparison of samples (07 UTC, 23 July, 2011) of the current product (left) and that derived using the new algorithm (right). Note that data are available with the new version in the area between 150°E and 170°E longitude where data are lacking in the current version due to the difficulty of current cloud screening in the twilight region.

4 CONCLUSIONS AND FUTURE PLANS

Table 3 shows statistical estimations from current SST products and draft versions of the new SSTs. Although the mean errors of the new SSTs show large negative values compared to the current ones for satellite zenith angles smaller than 40 degrees, the values are improved when the satellite zenith angle is greater than or equal to 40 degrees. It should be noted that the new algorithm has no bias correction term, while the current algorithm has an empirically appended one. The large negative mean errors of the new SSTs for lower zenith angles will be improved through further tuning of the algorithm and the introduction of a bias correction term. Meanwhile, the standard deviations are improved up to 0.97 K for the whole range of satellite zenith angles. This seems to be because of the new algorithm’s superior expression of infrared radiation transmission.

Additionally, the total number of match-ups shows a remarkable increase due to the renewal of the cloud screening tests.

Table 3 Statistical estimations from current SST products (top) and draft versions of SSTs (bottom) based on comparison with *in-situ* (BUOY) data for June 2011

satellite zenith angle (degrees)	<20	<40	<60	<80
Number of match-ups	50	2856	1874	848
mean error (K)	0.0266	0.026534	0.359333	1.971073
standard deviation (K)	0.68019	0.687082	0.929145	1.544053

satellite zenith angle (degrees)	<20	<40	<60	<80
Number of match-ups	428	10809	8011	2260
mean error (K)	0.272968	0.097477	0.111845	0.224823
standard deviation (K)	0.441018	0.565183	0.717906	0.972863

Although progress remains in the development phase, it is seen that the new algorithm and cloud screening tests improve the quality of SSTs retrieved from MTSAT-2 data. The RMSE of draft SSTs calculated from the mean error and the standard deviation given in Table 3 for satellite zenith angles from 60 to 80 degrees was about 0.99 K. This is between the qualities of microwave SSTs and AVHRR SSTs.

JMA is now in the final step of tuning the algorithm, which is expected to be finished by the end of 2011. An SST product based on the new algorithm is scheduled for launch by the end of March 2012.

Although the quality of SSTs retrieved with the new algorithm is practical, there is still room for improvement based on the assumptions involved. JMA plans such improvement for data from the next-generation GEOs (Himawari-8 and -9).