SST Retrieval Using AVHRR on Board NOAA-19 in the Seas Around Japan

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Abstrak

Tujuan dari kajian ini adalah untuk memperoleh formula Multi-Channel Sea Surface Temperature (MCSST) baru dari AVHRR/NOAA-19 yang diluncurkan pada bulan February 2009. Karena HRPT data yang ditransmisikan dari satelit diterima di Universitas Tohoku, Jepang maka area kajiannya adalah perairan di sekitar Jepang. Dengan menggunakan pengukuran SST in-situ yang didapat dari drifting buouys , sebanyak 2248 match-up data (1181 untuk siang hari dan 1067 untuk malam hari) diperoleh dari data bulan September-November 2009. Kemudian match-up data tersebut dipisahkan menjadi 2 bagian, separuh digunakan untuk mendapatkan formula dan separuhnya lagi untuk validasi. Koefisien formula MCSST diperoleh menggunakan analisa multi regresi terhadap match-up data yang terdiri dari brightness temperature dari kanal AVHRR split window dan SST in-situ. Validasi menggunakan match-up data independen menunjukkan untuk siang hari nilai SST memiliki bias 0.05^{0}C dan Root mean square differences (RMSD) sebesar 0.61^{0}C sedangkan untuk malam hari sebesar 0.08^{0}C untuk bias dan 0.55^{0}C untuk RMSD.

***Kata kunci** : AVHRR, MCSST, NOAA-19, perairan Jepang*

Abstract

The purpose of this study is to derive new Multi-Channel Sea Surface Temperature (MCSST) equations of AVHRR aboard NOAA-19, which was launched in February 2009. Since the HRPT data transmitted from the satellite are directly received at the Tohoku University in Japan, the study area is the seas surrounding it. Using in situ SSTs measured by drifting buoys, 2248 match-ups (1181 for daytime and 1067 for nighttime) are generated for September – November 2009. The daytime and nighttime match-ups are separated into a half for algorithm tuning and another half for validation. Coefficients of MCSSTs are obtained for daytime and nighttime by applying multiple regression analysis to the match-ups, which consist of brightness temperatures of the AVHRR split-window channels and the in-situ SSTs. Validation using the independent match-ups shows that the retrieved daytime and nighttime SSTs have biases of 0.05 and 0.08^{0}C and root mean square differences of 0.61^{0}C and 0.55^{0}C, respectively.

***Key words** : AVHRR, MCSST, NOAA-19, seas around Japan*

Introduction

Sea Surface Temperature (SST) is one of the important parameters for studying the ocean and atmosphere. SST can be used for a variety of oceanographic studies; for example, current, eddy, upwelling, front in local scale, and ENSO, Dipole Mode, climate change in global scale. Therefore, the availability of SST data is needed by many oceanographers. Though conventional method to collect SST data is in-situ observations by ship and buoy, it is well known that the number of in situ SST measurements is not enough to cover the global ocean (e.g., Kaplan *et al*, 1998; Smith & Reynold, 2004; Kawai *et al*., 2006). Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA series satellites first provided global maps of high-resolution SST in the beginning of 80s. There have been published many papers on the AVHRR SST retrieval for the global oceans (e.g., McClain *et al*, 1985) and the regional seas (e.g., Sakaida & Kawamura, 1992a) .

On February 6th 2009, the newest NOAA series satellite, named NOAA-19, was launched and has been

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operated since June 2nd, 2009. The AVHRR of NOAA-19 has five channels, two visible channels (channels 1 and 2 at 0.58-0.68*μm* and 0.725-1.0*μm,* respectively), one short-wavelength infrared channel (channel 3A and 3B at 1.58-1.64 *μm* and 3.55-3.93*μm),* and two long-wavelength infrared channels, (channels 4 and 5 at 10.3-11.3*μm* and 11.5-12.5*μm*, respectively), which is called split-window channels (http://www.oso.noaa.gov/poesstatus/index.asp). The swath width of AVHRR is about 2800 km and its ground resolution is 1.1 km at nadir (http://www.geo.mtu.edu/rs/avhrr/). In order to retrieve SST from AVHRR, Multi Channel SST (MCSST) algorithm using the split window cannels was proposed by McClain *et al*. (1985). The measuring principle of MCSST is that there is a linear relationship between the difference of the actual SST and a satellite measurement in one channel and the difference of satellite measurements by the split window channels (e.g., McMillin & Crosby, 1984; Li, 2000).

For the seas around Japan, the group of Tohoku University has studied the SST retrieval using AVHRR for more than 20 years. The local receiving station was set up at the university campus in 1988 (Kawamura *et al*., 1993a), and the processing system was gradually established (Kawamura *et al*., 1993b). Table 1 shows several publications on SST retrieval using AVHRR studied by the group of Tohoku University. Kizu & Sakaida (1996) have published the MCSST equation for NOAA-9, and Sakaida & Kawamura (1992a) for NOAA-11 for the seas around Japan. The studies listed in Table 1 have shown that the MCSST algorithms provided by NOAA (http://www.neodaas.ac.uk/faq/sst_equations) for global oceans are sometime not suitable for the regional seas, and a set of MCSST algorithm for a one of the NOAA/AVHRRs cannot be applied for the other AVHRRs. Once a new NOAA satellite is launched, it is better to prepare suitable regional SST retrieval algorithm for its AVHRR. The purpose of this study is to derive a new MCSST equation for AVHRR of NOAA-19 in the seas and the Pacific Ocean around Japan.

Material and Method

HRPT data of NOAA-19 from August 2009 has been received by the Tohoku University's receiving station. In this study, the AVHRR data included in the HRPT data from September 2009 – November 2009 were used. The local passing time of NOAA-19 is at around 11.00 – 15.00 (ascending) and around 22:00 - 02:00 (descending). The AVHRR data of ascending passes are used to derive a daytime MCSST equation and those of descending passes a nighttime MCSST equation. Examples of NOAA-19/AVHRR images for the received area are shown in Figure 1.

In situ SSTs measured by drifting buoys in the study area are used as sea truth data. In general, in order to derive the MCSST equations, it is necessary to make a set of match-up data, which consists of the truth SST and collocated satellite measurements with ancillary data. The in-situ SSTs are generally measured at 1 m depth. They are provided by Data Buoy Cooperation Panel (DBCP) and accessed via Global Telecommunications Service (GTS). The DBCP is an international program coordinating the use of autonomous data buoys to observe atmospheric and oceanographic conditions, over ocean areas where few other measurements are taken (http://www.jcommops.org/dbcp/).

For the SST retrieval from the satellite infrared measurements, the measured sea area should be cloud free. To find the cloud-free SST area around the in situ SST, three steps were taken i.e. less-cloud image selection by eyes, geometric correction, and quality control of the satellite measurements. Since the original AVHRR image has geometric distortion due to the earth shape and the earth rotation, the geometric correction is needed. Ground Control Points (GCPs) are used for the accurate geometric correction (e.g., Kawamura *et al*., 1993b; Sakaida & Kawamura, 1996). Geometric correction is carefully examined by eyes and its accuracy is within 1 pixel.

The third step (quality control process) is to obtain the cloud-free satellite measurements at the in situ SST position, around which sub images of 7 x 7 pixels of AVHRR channels 2 and 4 for daytime (channels 3 and 4 for nighttime) are sampled for following eye examination. Quality of the sampled satellite measurements is categorized into 4 classes, i.e., Bad (the point is covered by cloud), Indecision (the point is located near cloud or land or in sun glitter area), Fine (the point is cloud free but located near front) and Excellent (the point is cloud free and not around fronts).

Surveying the NOAA-19/AVHRR data for September-November 2009, 1181 daytime match-ups from 58 AVHRR scenes and 1067 nighttime match-ups has been obtained from 29 AVHRR scenes of NOAA-19 dataset (Figure 2a and Table 2). Numbers of the match-ups including Indecision, Fine and Excellent data for daytime (nighttime) are 822 (602), 92 (138) and 267 (327), respectively (Figure 2a Table 2). For further analysis, the match-ups (824) including Fine and Excellent data are used. Two match-ups with indecision data are specially generated for covering low SSTs (7.9^{0}C and 10.7^{0}C) for nighttime. The number of daytime (nighttime) match-ups is 359 (467), whose in situ SSTs range from 7.1^{0}C (7.9^{0}C) to 29.7^{0}C (29.3^{0}C). The match-up locations of Fine, Excellent and two Indecisions are plotted in Figure 2b. The match-up data are randomly separated into 2 groups. The first group is for MCSST algorithm tuning and the second group is for validation.

Results and Discussion

Due to atmospheric attenuation of the infrared radiation from the ocean surface, the true SST values are always higher than the brightness temperatures. Using the first group of match-ups, comparison between the brightness temperature of Ch 4 and the in-situ SST is shown in Figure 3a and b for daytime and nighttime, respectively. They show that the higher the in situ SST values, the greater their differences. Sakaida & Kawamura (1992) have found that the maximum difference is about 10^{o}C at around 27 ^{o}C of the buoy SST in the analysis of AVHRR onboard NOAA-11. In this case of AVHRR/NOAA-19, the maximum difference is 8.2 ^{0}C at 27.7^{0}C of the in-situ SST for daytime and 9.4 ^{0}C at 27.4^{0}C for nighttime.

The traditional MCSST equation using the split-window brightness temperatures of AVHRR is written as :

$$MCSST = a + b\,T_4 + c\,(T_4-T_5) + d\,(T_4-T_5)(\sec \varphi-1),$$

where T_4 and T_5 denote the brightness temperatures of channel 4 and 5, respectively, Φ the satellite zenith angle (^{o}) and a, b, c and d are constants. After applying multiple regression analysis to the first group of match-ups, we get the coefficients both for daytime and nighttime. The obtained AVHRR/NOAA-19 new MCSST equations for the seas around Japan (Figure 2) are

for daytime:

$$SST = -0.82029 + 1.073049\,T_4 + 1.391844\,(T_4-T_5) + 0.959019(T_4-T_5)(\sec \varphi-1),$$

for nighttime:

$$SST = -0.2197929 + 1.08664\,T_4 + 1.694175\,(T_4-T_5) + 0.796074(T_4-T_5)(\sec \varphi-1).$$

Performances of the MCSST equations are denoted by small RMSDs and high correlation coefficients of 0.99 (Table 3 and Figure 4). The RMSD values show the satisfactory result for the equation. The RMSD value is only little larger than the result showed by Sakaida & Kawamura (1992). The MCSST equation for AVHRR/NOAA-11, obtained by Sakaida & Kawamura (1992), has 0.43^{0}C value for RMSD and 0.0^{0}C for bias.

The MCSST equations are applied to the second group of match-ups for validation. Figure 5 and Table 3 show validation results of the MCSSTs, which are the bias and RMSD for daytime (nighttime) are 0.01^{0}C (0.01^{0}C) for daytime and 0.61^{0}C (0.55^{0}C), respectively. Figure 5 also demonstrates the smooth graph of both daytime and nighttime data. The data exist axially surrounding the y = x line. It indicates the strong correlation, low bias and low RMSD.

The previous MCSST study of NOAA-9 data done by Kizu & Sakaida (1996) showed the larger bias and RMSD for data validation i.e : -0.01^{0}C (-0.13^{0}C) for daytime (nighttime) bias and 0.78^{0}C (0.77^{0}C) for daytime (nighttime) RMSD respectively. Completely, the satisfactory results are showed when comparing the validation results for the other AVHRRs listed in Table 1. Since the RMSDs of the previous studies range from 0.43 to 0.78^{0}C, those of the present study (0.55-0.61^{0}C) are in its middle.

The NOAA/NESDIS split window equation set for NOAA-19 are given

for daytime:

$$SST = -278.74596 + 1.01922\,T_4 + 1.72270\,(T_4-T_5) + 0.80263\,(T_4-T_5)(\sec \varphi-1),$$ and

for nighttime:

$$SST = -277.71304 + 1.01432\,T_4 + 1.91798\,(T_4-T_5) + 0.72064\,(T_4-T_5)(\sec \varphi-1)$$

(http://www.neodaas.ac.uk/faq/sst_equations).

SST is given in ^{0}C and T_4 and T_5 are in Kelvin. Table 4 shows the validation results of the NOAA's MCSST equations using the match-up data set generated by the present study. Their bias and RMSD for daytime (nighttime) are -0.011^{0}C (-0.096^{0}C) and 0.66^{0}C (0.57^{0}C), which are larger than those of present study.

It is concluded that the new MCSST equations have good performance for estimating SSTs in the seas around Japan. Nevertheless, because the limited

Table 1. Publications on SST retrieval using AVHRR in the seas around Japan studied by the group of Tohoku University

Publications	NOAA	RMSD (^{o}C)
Sakaida & Kawamura (1992a)	NOAA-11	0.43
Sakaida & Kawamura (1992b)	NOAA-11	0.48, 0.56 and 0.43 for nighttime split window, dual window and triple window, respectively
Kizu & Sakaida (1996)	NOAA-9	0.78 and 0.77 for daytime and nighttime, respectively
Sakaida & Kawamura (1996)	NOAA-11 (HIGHERS)	0.51
Lee *et al*. (2005)	NOAA-12-16	0.67 and 0.52 around Taiwan for daytime and nighttime, respectively
Present study	NOAA-19	0.61 and 0.55 for daytime and nighttime, respectively

Table 2. Numbers and categories of the match-ups

		Daytime data				Nighttime data			
		Sep-09	Oct-09	Nov-09	Total	Sep-09	Oct-09	Nov-09	Total
Total Number		340	402	439	1181	7	518	542	1067
Number for each category	Indecision	266	289	267	822	3	272	327	602
	Fine	31	26	35	92	4	62	72	138
	Excellent	43	87	137	267	-	184	143	327

Table 3. Comparison statistics of the match-ups for algorithm tuning and validation

	Daytime data		Nighttime Data	
	Algorithm Tuning	Validation	Algorithm Tuning	Validation
Bias (^{o}C)	0.0	0.005	0.0	0.008
RMSD (^{o}C)	0.59	0.61	0.56	0.55
Correlation	0.99	0.99	0.99	0.99

Table 4. Comparison statistics for validation between new MCSST equation and MCSSTs provided by NOAA

	Daytime data		Nighttime Data	
	New MCSSTs	NOAA's MCSSTs	New MCSSTs	NOAA's MCSSTs
Bias (^{o}C)	0.005	-0.011	0.008	-0.096
RMSD (^{o}C)	0.61	0.66	0.55	0.57

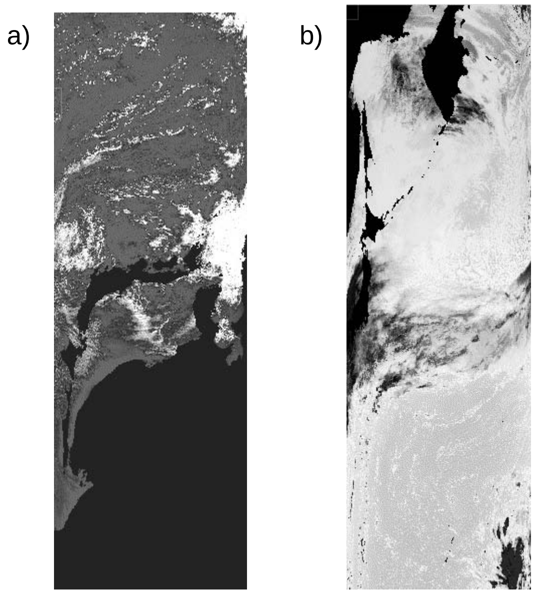

Figure 1. Examples of AVHRR/NOAA-19 images. a) Ascending Image of AVHRR Channel 2 for daytime observation on 20 November 2009, and b) Descending Image of AVHRR Channel 3 for nighttime observation on 25 October 2009.

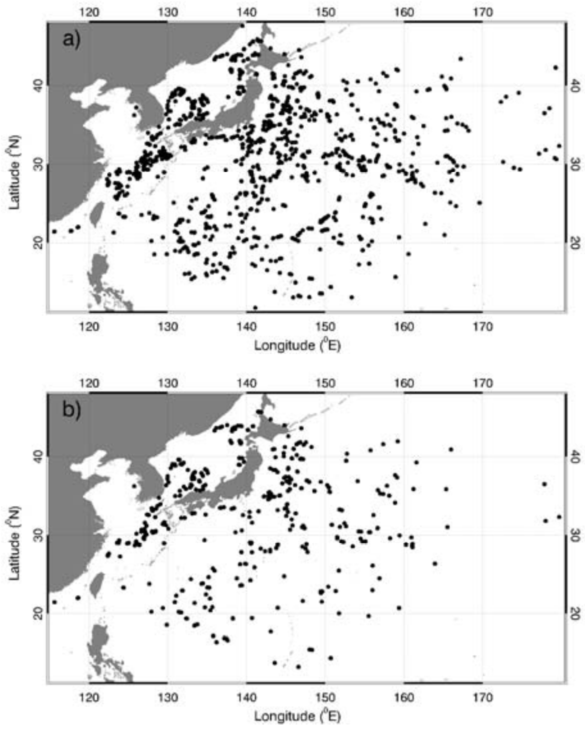

Figure 2. Locations of drifting buoys used for the match-ups in the study area. a) All the match-ups and b) the match-ups of Excellent, Fine and two Indecisions (See the text).

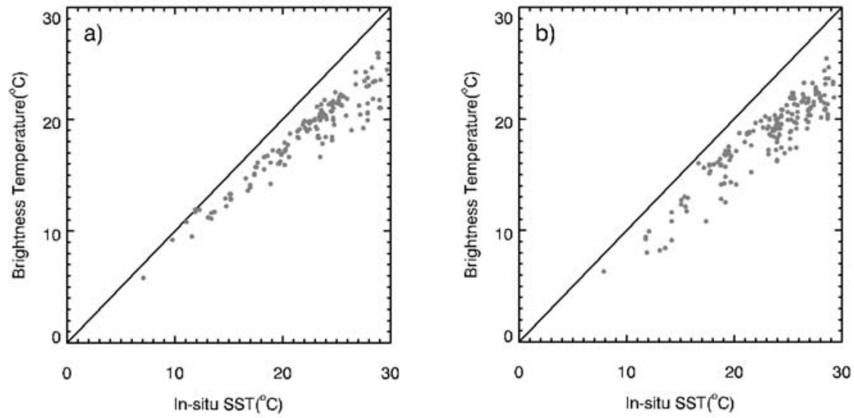

Figure 3. Relationship between the In-situ SSTs and the brightness temperatures of Ch.4.
a) Daytime and b) Nighttime.

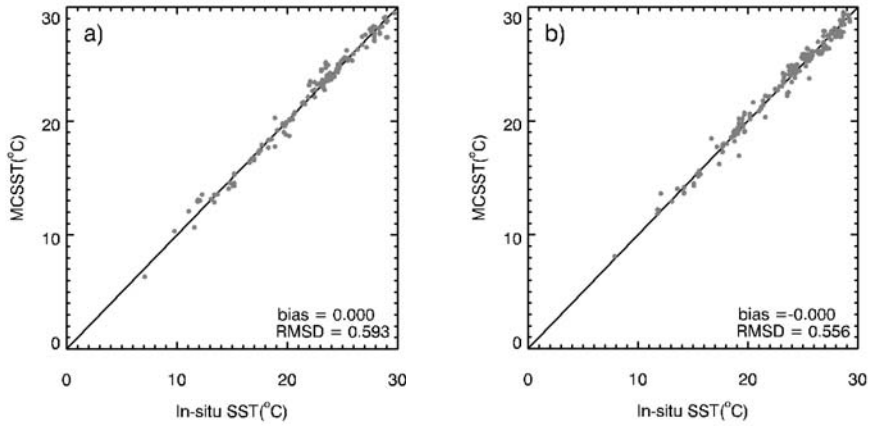

Figure 4. Relationship between MCSSTs and the In-situ SSTs.
a) Daytime and b) Nighttime

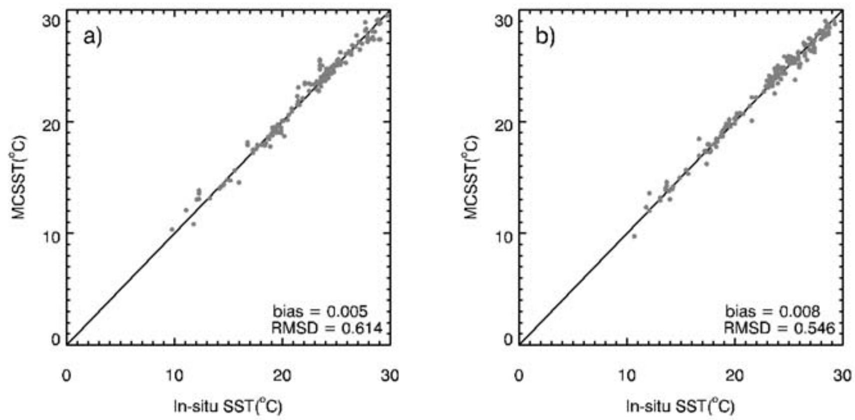

Figure 5. Validation of MCSSTs against the in-situ SSTs.
a) Daytime and b) Nighttime.

period of available AVHRR data for September – November 2009, performance of the MCSST equations for low SST range < 7^0 C is not examined in this study. The MCSST equations should be validated for whole seasons. These tasks are left for future study.

Conclusion

In order to derive new MCSST equations for AVHRR on board NOAA-19, match-ups consisting the split-window brightness temperatures and the collocated in-situ SST are generated. Using the match-ups, the MCSST equations are derived for daytime and nighttime by applying multiple regression analysis. The equations are validated by using the independent match-ups, which demonstrates that the bias and RMSD for daytime (nighttime) are 0.01^0C (0.01^0C) for daytime and 0.61^0C (0.55^0C), respectively. It can be concluded that the new MCSST equations have good performance for estimating SSTs in the seas around Japan.

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