(IJACSA) International Journal of Advanced Computer Science and Applications,
Vol. 13, No. 6, 2022

Merged Dataset Creation Method Between Thermal Infrared and Microwave Radiometers Onboard Satellites

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***Abstract*—Merged dataset creation method between Thermal Infrared (TIR) and Microwave Scanning Radiometer (MSR) onboard remote sensing satellites is proposed. One of the key issues here is the relation between thermal and microwave emissions from the same observation target in particular, Sea Surface Temperature (SST). An example of Tropical Rainfall Measuring Mission (TRMM) satellite based TIR and MSR, Visible Infrared Scanner (VIRS) and TRMM Microwave Imager (TMI) is shown in this paper. SST is estimated, independently, with VIRS or TMI. A method for interpolation of multi-sensor satellite images based on Multi-Resolution Analysis (MRA) is also proposed. The experimental results with TMI/SST image and VIRS/SST image show that Root Mean Square (RMS) error ranges from 0.87 to 0.91-degree C.**

Keywords—Wavelets; VIRS/SST; TMI/SST; MRA; Daubechies; TRMM; TIR; MSR

I. INTRODUCTION

In order to increase observation chances of SST, both of TIR radiometer data and microwave radiometer data are desirable to use with consideration of the difference of radiative transfer processes and interactions between electronic magnetic waves and the sea surfaces. Also, a merged dataset between TIR and microwave radiometer data is also desirable together with a combined SST dataset derived from the TIR and microwave radiometer data.

In general, spatial resolution of TIR is better than that of MSR. TIR data can be acquired in a clear weather condition only. On the other hand, MSR data can be acquired in a cloudy condition as well as rainy condition. If these data can be merged, then fine resolution of microwave and thermal emission of data can be available to use. Also, it becomes possible to increase observation frequency.

Merged dataset creation method between TIR and microwave radiometers onboard remote sensing satellites is proposed. One of the key issues here is the relation between TIR and microwave emissions from the same observation target in particular, SST.

As an example of applying wavelet analysis (expansion, transformation, etc.) to the processing analysis of earth observation satellite images, a method of superimposing multiple visible images after wavelet transform [1], superimposing multiple Synthetic Aperture Radar: SAR images with different off-nadir angles [2], a method of applying the wavelet transform to the pattern of annual fluctuation of the sea surface temperature estimated from satellite data and extracting its characteristics [3], and applying the wavelet transform to the extraction of the surface roughness of sea ice. There are methods [4], methods [5] for extracting spatial features from images extracted from soil moisture, etc. [6].

By the way, in November 1997, the TRMM (Tropical Rainfall Measuring Mission) satellite [Solar Asynchronous Orbit] was launched. The Sea Surface Temperature (SST) is estimated independently by the sensor TMI (TRMM Microwave Imager) and the sensor VIRS (Visible Infrared Scanner) mounted on the TRMM satellite [7]. In this paper, the relationship between SST (TMI / SST) estimated from TMI observation data and SST (VIRS / SST) estimated from VIRS observation data is examined using multi-resolution analysis. That is, the relationship between the actual observation satellite data questions of different types of sensors.

The proposed method considers Multi-Resolution Analysis (MRA). The Daubechies basis (orthonormal basis) is used as the mother wavelet when performing multi-resolution analysis.

The next section describes the related research works in particular SST estimation methodology then the proposed method of merged dataset is created between TIR and microwave radiometer data and theoretical background of fundamentals of wavelet analysis. After that experimental method and results are described followed by conclusion with some discussions.

II. RELATED RESEARCH WORKS

As for the SST estimation method, there are the following related research works.

SST estimation of the pixels partially contaminated with cloud is conducted [8]. A merged dataset for obtaining cloud free Infrared (IR) data and a cloud cover estimation within a pixel for SST retrieval is defined [9]. SST estimation with Advanced Earth Observing Satellite (ADEOS) / Ocean Color and Temperature Scanner (OCTS) data is conducted [10].

Cross validation of OCTS Global Area Coverage (GAC) SST with Multi-Channel SST (MCSST) is conducted [11]. On the other hand, antenna pattern correction and SST estimation algorithms for Advanced Microwave Scanning Radiometer: AMSR is made [12].

SST estimation method with linearized inversion of radiative transfer code for ADEOS/OCTS is proposed [13]. SST estimation accuracy assessment for ASTER/TIR is conducted and also an effectiveness of 8.3μm water vapor absorption band for SST retrieval is investigated [14].

SST estimation with microwave radiometers by means of simulated annealing based on an ocean surface model is conducted [15] together with SST retrieval with microwave radiometer data based on simulated annealing [16].

Estimation of SST, wind speed and water vapor with microwave radiometer data based on simulated annealing is attempted [17] together with estimation of SST, wind speed and water vapor with microwave radiometer data based on simulated annealing [18].

Estimation method of SST with Moderate resolution of Imaging Spectrometer: MODIS data in particular utilizing Band 29 for reducing water vapor influence on SST retrievals is proposed [19]. Nonlinear optimization-based SST estimation methods with remote sensing satellite based Microwave Scanning Radiometer: MSR data are proposed [20].

Comparative study on sea surface temperature estimation with thermal infrared radiometer data among conventional MCSST, split window and conjugate gradient-based methods is conducted [21]. Effectiveness of Noise Equivalent delta Temperature: NEdT and Band 10 (8.3 um) of The Advanced Spaceborne Thermal Emission and Reflection Radiometer: ASTER/ Thermal Infrared Radiometer: TIR on Skin SST: SSST estimation is estimated [22].

Band combination selection method for SST estimation with satellite data is proposed [23]. Artificial Intelligence: AI and remote sensing satellite big data analysis is overviewed [24].

On the other hand, there are the following related research works on the microwave remote sensing.

Data fusion between microwave and thermal infrared radiometer data and its application to skin sea surface temperature, wind speed and salinity retrievals are proposed [25]. Comparative study of optimization methods for estimation of Sea Surface Temperature (SST) and Ocean Wind (OW) with Microwave Radiometer data is conducted [26]. Also, method for rainfall rate estimation with satellite-based microwave radiometer data is proposed [27]. Meanwhile, ice concentration estimation method with satellite-based microwave radiometer by means of inversion theory is proposed [28].

III. PROPOSED METHOD WITH THEORETICAL BACKGROUND

A. Proposed Method

Merged dataset creation method proposed here is to utilize both of TIR and microwave radiometer data together. Therefore, the relation between TIR and microwave radiometer data is a key issue here. Moreover, missing data are another issue. TIR radiometer data does not work in a cloudy condition and rainy condition. Furthermore, spatial resolutions are different between TIR and microwave radiometers. Therefore, some treatments of the missing data as well as spatial resolution difference are needed to use both radiometer data together. In order to take into account the missing data and spatial resolution difference, wavelet Multi-Resolution Analysis (MRA) is featured.

B. Theoretical Background on Wavelet Analysis

Multi-Resolution Analysis (MRA) needs Mother wavelet and is based on Discrete Wavelet Transform: DWT. As a mother wavelet is defined as follows:

The function $\emptyset$ that satisfies the two-scale relationship as follows:

$$\emptyset(x) = \sum_{k \in Z} p_k \emptyset(2x - k) \quad (1)$$

This is called the scaling function.

The sequence $\{p_k \,/\, k \in Z\}$ is called a two-scale sequence, and the scaling function $\emptyset$ is determined by the sequence $\{p_k \,/\, \kappa \in Z\}$. The mother wavelet ψ is determined by equation (2).

$$\psi(x) = \sum_{k \in Z} q_k \, \emptyset(2x - k) \quad (2)$$

Also, Discrete Wavelet Transform: DWT is defined as follows:

The transformation of the discrete wavelet of the function *f (x)* by mother wavelet *ψ (x)* is also given by (3), and its inverse transformation is given by (4).

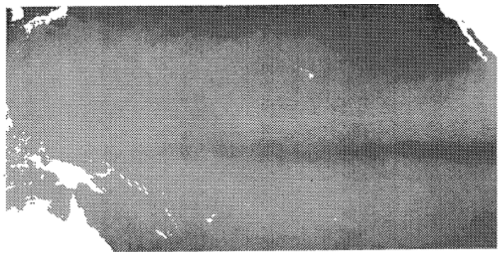
$$d_k^{(j)} = 2^j \int_{-\infty}^{\infty} \overline{\psi(2^j x - k)} f(x) dx \quad (3)$$

$$f(x) \sim \sum_j \sum_k d_k^{(j)} \psi(2^j x - k) \quad (4)$$

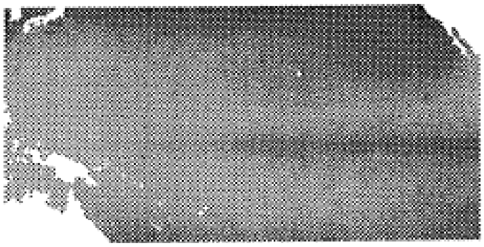
IV. NUMERICAL EXPERIMENT

A. Outline of Experiment

The data used this time are SST estimated images from November 1998 to September 2000 estimated by sensor TMI and sensor VIRS, respectively. Fig. 1(a) shows an example of SST (VIRS / SST) estimated from VIRS observation data, and Fig. 1(b) shows an example of SST (TMI/SST) estimated from TMI observation data.



(a) VIRS.



(b) TMI.

Fig. 1. Examples of SST Images Estimated with VIRS or TMI.

From Fig. 1, it can be seen that the spatial resolution of the VIRS observation data and the TMI observation data are different. The image size of VIRS / SST is 1024 x 512, and the image size of TMI / SST is 512 x 256. The spatial resolution of VIRS observation data is about twice the spatial resolution of TMI observation data.

In this experiment, wavelet decomposition is performed on the VIRS / SST image, and the relationship between the result (LL component) and the TMI / SST image is examined. In addition, consider the impact of differences in support length. By the way, the target VIRS / SST and TMI / SST each include missing data due to the influence of the atmosphere, sensor characteristics, satellite orbit characteristics, and the like. In this experiment, the land data is regarded as missing data. Therefore, the multi-resolution analysis is performed in consideration of the missing data. That is:

1) Data of points where TMI / SST is not missing.

2) All VIRS / SST for generating data corresponding to the points where TMI / SST is not missing by using wavelet decomposition have been observed.

Consider using data that satisfies the two conditions of the data in the region (not missing) [problem of support length during wavelet decomposition]. The above two conditions are called considerable conditions.

First, Z (sup, i, j, t) def is defined as follows:

$$\vartheta(sup,i,j,t) = 1 \ or \ 0 \tag{5}$$

1: Satisfy the conditions for consideration.

0: Does not meet the considerable conditions.

Then, evaluation is performed using the following.

$$J1(sup) = \sqrt{\frac{\sum_{t=1}^{22}\sum_{(i,j)}(\vartheta(sup,i,j,t)\varepsilon_1(i,j,t)}{N}} \tag{6}$$

$$\varepsilon_1(i,j,t) = (G(i,j,t) - H(i,j,t))^2 \tag{7}$$

However, sup represents the support length of the mother wavelet, t represents the time, [i, represents the position, and (i, j, t) represents the TMI / SST, and σ (i, j, t)]. Represents the LL component when VIRS / SST is wavelet-decomposed. Further, N represents the number of Z (sup, i, j, t) = 1.

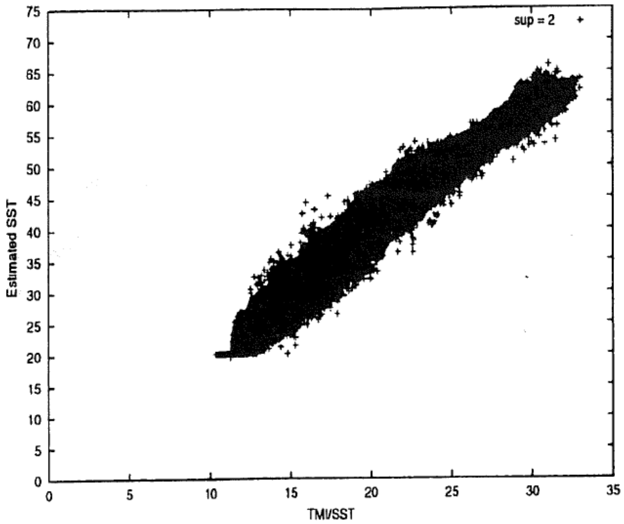
B. Experimental Results

Table I shows the value of J1 (sup) when the support length sup is changed and the number of data N that satisfies the conditions that can be considered for each support length.

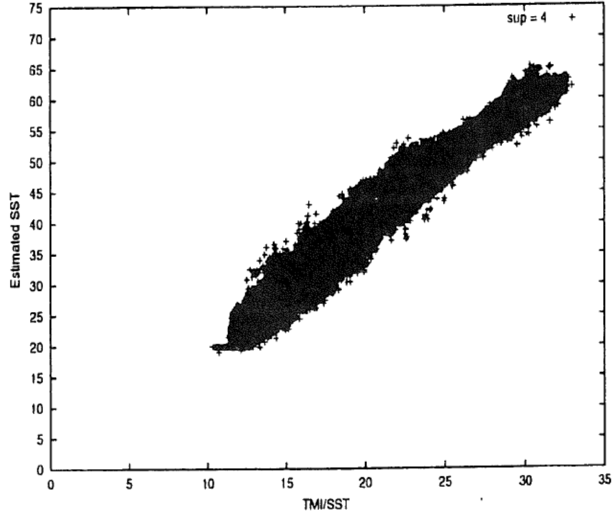
TABLE I. THE ERROR J1(SUP) AND NUMBER OF OBSERVED DATA N FOR THE SUPPORT LENGTH SUP

SUP	J1(SUP)	N
2	25.63	2559974
4	25.644	2537353
6	25.652	2506378
8	25.659	2471573
16	25.676	2331352
20	25.681	2264613

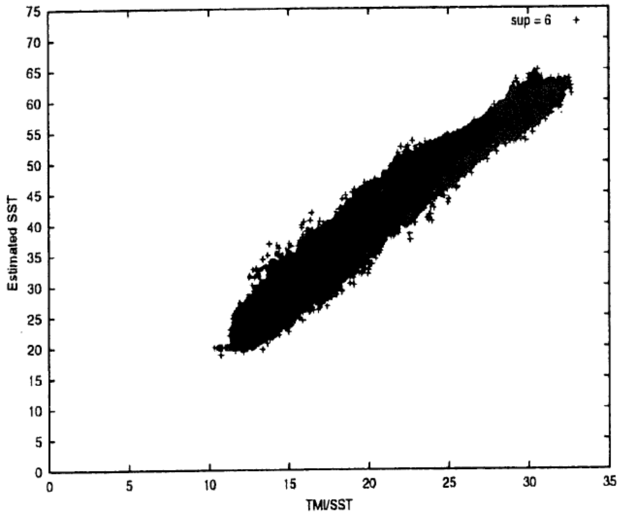
Fig. 2 shows the relationship between the LL component and TMI / SST when the VIRS / SST is wavelet-decomposed when the support length sup is changed [under the conditions that can be considered].



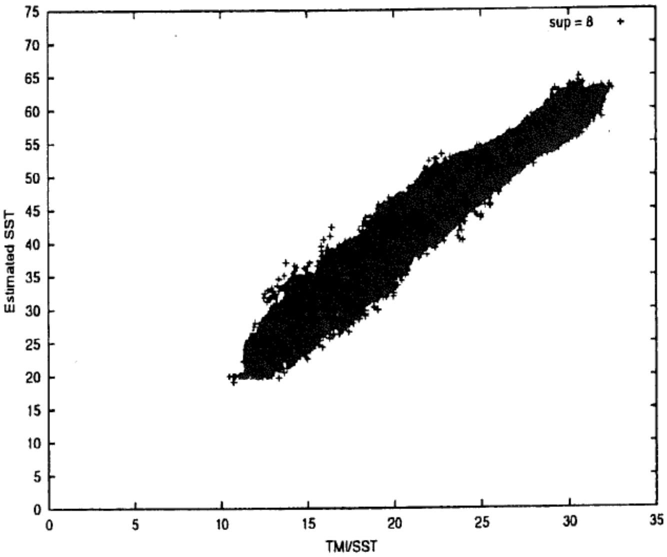
(a) sup=2.



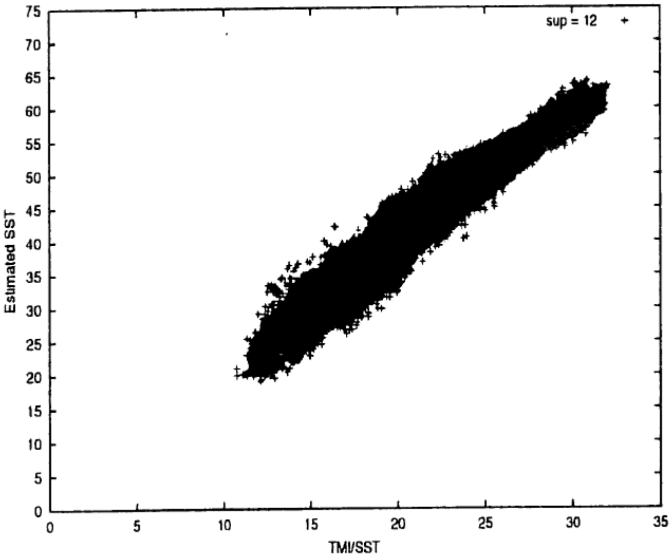
(b) sup=4.



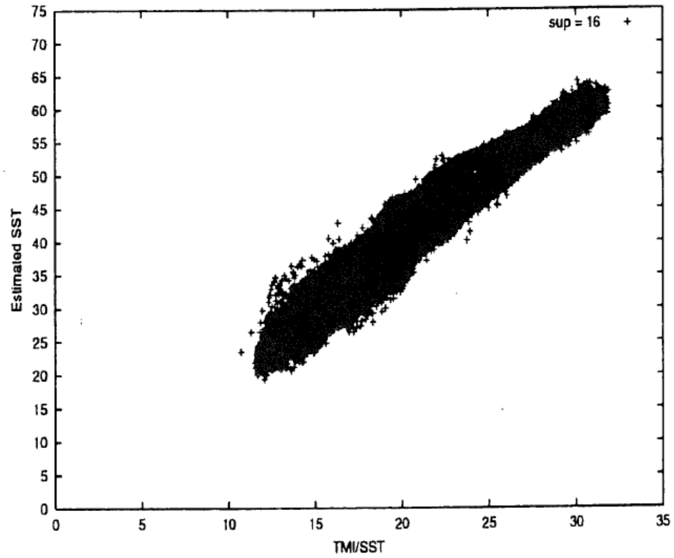
(c) sup=6.



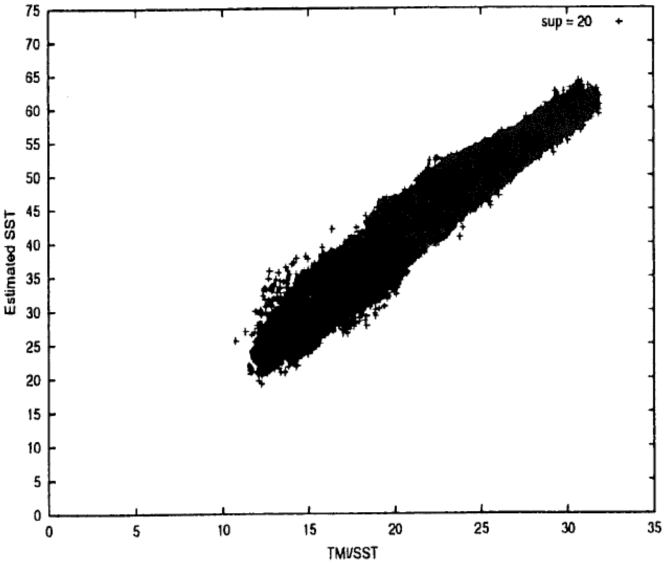
(d) sup=8.



(e) sup=12.



(f) sup=16.



(g) sup = 20.

Fig. 2. Relationship between TMI / SST Data and the Estimated SST through MRA.

The horizontal axis shows TMI / SST, and the vertical axis shows the LL component when VIRS / SST are wave-resolved. Also, physical properties of the ocean surface in thermal emission and microwave emission are different each other so that these effects have to be clarified. For instance, penetration depth of the ocean surface is different between thermal and microwave electric magnetic wave. The divergence shown in the Fig. 2 is caused by the different physical properties of the ocean between thermal and microwave electric magnetic wave.

Table II shows the results of regression analysis on the scatter plots at each support length in Fig. 2, that is, the unknown regression coefficient (a, b) was obtained using the following:

$$J2(sup) = \sqrt{\frac{\sum_{t=1}^{22}\sum_{(i,j)}(\vartheta(sup,i,j,t)\varepsilon_2(i,j,t)}{N}} \tag{8}$$

$$\varepsilon_2(i,j,t) = (G(i,j,t) - H(i,j,t))^2 \tag{9}$$

TABLE II. REGRESSION COEFFICIENTS OF SST ESTIMATION AND THE ERROR J2(SUP) , FOR THE SUPPORT LENGTH SUP

SUP	A	B	J2(SUP)	N
2	1.948	0.873	0.87	2559974
4	1.947	0.927	0.873	2537353
6	1.944	0.997	0.873	2506378
8	1.942	1.07	0.875	241573
12	1.937	1.219	0.883	2400801
16	1.932	1.363	0.895	2331352
20	1.927	1.505	0.909	2264613

V. CONCLUSION

Merged dataset creation method between Thermal Infrared (TIR) and Microwave radiometers onboard remote sensing satellites is proposed. One of the key issues here is the relation between TIR and microwave emissions from the same observation target in particular, Sea Surface Temperature (SST). An example of Tropical Rainfall Measuring Mission (TRMM) satellite based TIR and microwave radiometers, Visible Infrared Scanner (VIRS) and TRMM Microwave Imager (TMI) is shown in this paper. SST is estimated, independently, with VIRS or TMI. A method for interpolation of multi-sensor satellite images based on Multi-Resolution Analysis (MRA) is also proposed.

In this paper, the relationship between the actual observation satellite data questions of different types of sensors including missing data was examined using multiple resolution analysis. From Table I, when examining the relationship between different types of sensors and data questions using multiple resolution analysis, it was confirmed that the shorter the support length, the better the error J1 (sup). From Table II, the regression error J2 (It was confirmed that sup) was 0.87 to 0.91 [C].

VI. FUTURE WORKS

In the future, the author will continue to validate of the proposed method with a variety of TIR and microwave radiometer data. Improvement of observation frequency by the proposed method is another issue. Also, physical properties of the ocean surface in thermal emission and microwave emission are different each other so that these effects have to be clarified. For instance, penetration depth of the ocean surface is different between thermal and microwave electric magnetic wave.

ACKNOWLEDGMENT

This is a report of the research results (or part of it) by the Grant-in-Aid for Scientific Research (Special Researcher Incentive). The author would like to express my gratitude to the Grant provider. The author would like to thank Dr. Kaname Seto of former student of Saga University and Dr. Leland M. Jameson of Naval Research Laboratory for their contribution of this study. The author, also, would like to thank Professor Dr. Hiroshi Okumura and Professor Dr. Osamu Fukuda for their valuable discussions.

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