DEVELOPMENT AND VALIDATION OF LAND SURFACE TEMPERATURE RETRIEVAL ALGORITHM FROM MTSAT-1R DATA

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ABSTRACT: Land surface Temperature (LST) is a very useful surface parameter for the wide range of applications, such as agriculture, numerical and climate modelling community. Whereas operational observation of LST is far from the needs of application community in the spatial /temporal resolution and accuracy. So, we developed split-window type LST retrieval algorithm to estimate the LST from MTSAT-1R data. The coefficients of split-window algorithm were obtained by means of a statistical regression analysis from the radiative transfer simulations using MODTRAN 4 for wide range of atmospheric profiles, satellite zenith angle and lapse rate conditions including the surface inversions. The sensitivity analysis showed that the LST algorithm reproduces the LST with a reasonable quality. However, the LST algorithm overestimates and underestimates for the strong surface inversion and superadiabatic conditions especially for the warm temperature, respectively. And the performance of LST algorithms is superior when satellite zenith angle is small. The accuracy of the retrieved LST has been evaluated with the Moderate Resolution Imaging Spectroradiometer (MODIS) LST data. The validation results showed that the correlation coefficients and RMSE are about 0.83~0.98 and 1.38~4.06, respectively. And the quality of LST is significantly better during night and winter time than during day and summer. The validation results showed that the LST retrieval algorithm could be used for the operational retrieval of LST from MTSAT-1R and COMS(Communication, Ocean and Meteorological Satellite) data with some modifications.

KEY WORDS: Land surface temperature, MODTRAN 4, MTSAT-1R, MODIS LST

1. INTRODUCTION

KMA (Korea Meteorological Administration) has been developing the COMS (Communication, Ocean and Meteorological Satellite) meteorological data processing system (CMDPS) for the successful operation and efficient use of the satellite data. The COMS is the first geostationary multipurpose satellite of Korea, which will be launched on June 2009. Various meteorological variables, such as clouds, aerosol, sea surface temperature and land surface temperature (LST) will be derived automatically by the CMDPS from the level-1b data.

LST is a key environmental variable in a wide range of applications, such as weather, climate, hydrology, and ecology. But it is one of the most difficult surface variables to observe due to the strong spatio-temporal variations.

Theoretical possibility for the retrieval of LST using split-window method has been shown by Becker and Li (1990), and many others. Numerous works have been made to retrieve the LST from the satellite data, especially polar orbit satellite (NOAA/AVHRR, Terra/MODIS, Landsat/TM (e.g., Kerr et al., 1992; Ulivieri et al., 1994; Wan and Dozier, 1996). However, operational retrieval of LST from the satellite data is very limited due to the poor accuracy of retrieved LST, particularly using geostationary satellite. The lower quality of retrieved LST is mainly caused by the combined effects of spectrally and temporally varying emissivity and atmosphere.

Recently, the various background data (e.g., land cover, vegetation index) and methods (vegetation coverage method: Valor and Caselles, 1996) for the estimation of spectral emissivity are developed. And the quality of geostationary satellite (e.g., MSG/SEVIRI, MTSAT-1R) has been greatly improved recently (e.g., quantization: 8 bits ➔ 10 bits, spatial resolution: 5~10 km ➔ 4 km, observation frequency: 1H ➔ ~ 15 min, navigation accuracy, SNR). As a result, the quality of LST retrieved from geostationary satellite data, such as MSG/SEVIRI, has been significantly improved. As in the MODIS LST group, the LST over Africa and Europe retrieved operationally by the EUMETSAT LSA SAF (Land Surface Analysis Science Application Facility). Nevertheless the investigation of the LST over East Asia region is not thoroughgoing enough.

In this study, we have developed the split-window type LST retrieval algorithm from MTSAT-1R data and validated it with Moderate Resolution Imaging Spectroradiometer (MODIS) LST data for the various conditions. We are plan to use the COMS data when the spectral response functions of COMS are released.

2. METHOD

We developed split-window type LST retrieval algorithm to estimate the LST from MTSAT-1R data. Figure 1 shows a flow chart of this study.

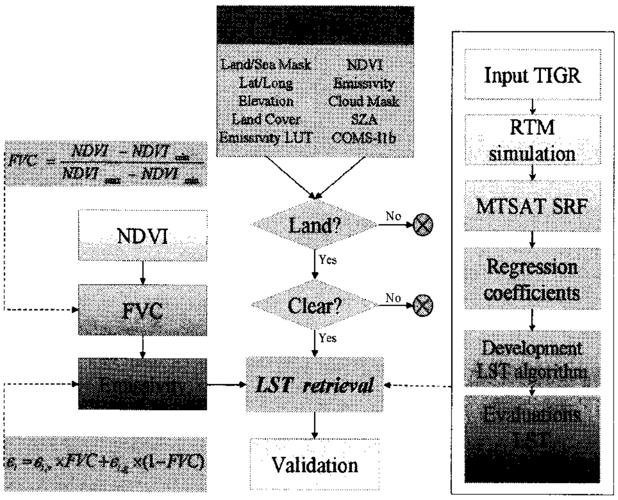

Figure 1. Flow chart for the LST retrieval process using satellite data.

2.1 Radiative transfer model simulation

To retrieve the LST using a split-window method, ground match-up data are needed for the coefficients of regression equation. However, available match-up data are severely limited in LST. So, we performed radiative transfer model simulations using MODTRAN 4 with various atmospheric and satellite viewing conditions. The main factors affecting the retrieved LST using split-window method are atmospheric profiles, spectral emissivity, satellite viewing angle and lapse rate at surface layer. The radiative transfer simulations are designed to include all the impacting factors mentioned above.

- Atmospheric profiles: 535 Thermodynamic Initial Guess Retrieval (TIGR) data sets located at the satellite zenith angle (SZA) less than 60 ° from MTSAT-1R. (see Figure 2)
- SZA: from 0 to 60 according to the relative location of TIGR data to the MTSAT-1R.
- Surface lapse rate: the LST are prescribed as T_a – 6K to T_a + 14K in steps of 2K.
- Band emissivity:
  - IR1 emissivity: from 0.9576 to 0.9890 in step of 0.00314.
  - IR2 emissivity: from 0.9663 to 0.9908 in step of 0.00245

where T_a is the lowest layer air temperature of TIGR data.

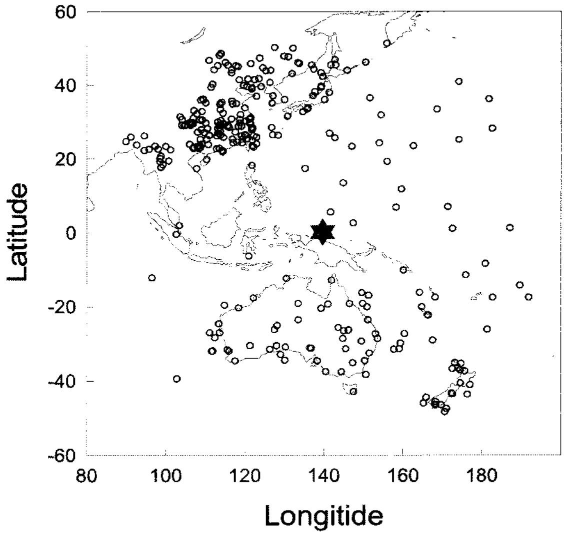

Figure 2. Spatial distribution of TIGR data used in this study.

2.2 Performance test

The LST retrieval algorithm has been developed using a statistical regression method.

$$LST = -1.5418 + 1.00333T_{IR1} + 2.78769\Delta T$$
$$+ 0.31635\Delta T^2 + 1.1552(\sec\theta - 1) + 89.9499(1-\varepsilon)$$

where T_{IR1} = brightness temperature of IR1,
θ = satellite zenith angle,
$\Delta T = T_{IR1} - T_{IR2}$,
$\varepsilon = \frac{\varepsilon_{IR1} + \varepsilon_{IR2}}{2}$

The developed LST algorithm reproduces the LST with a reasonable quality as shown in Figure 3. However, the LST algorithm overestimates and underestimates for the strong surface inversion and superadiabatic conditions especially for the warm temperature, respectively.

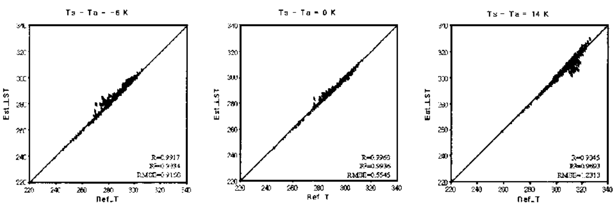

Figure 3. Scatter plots of retrieved LST (ordinate) and prescribed LST (abscissa) according to the surface lapse rate

2.3 FVC and emissivity

To derive the spectral emissivity, vegetation cover method (VCM, Caselles et al., 1997) is used. The effective emissivity of each channel is defined as the weighting sum of the vegetated area and the remaining ground area within a pixel.

$$\varepsilon_i = \varepsilon_{i,g} \times (1 - FVC) + \varepsilon_{i,v} \times FVC$$

Where, $\varepsilon_{i,g}$ and $\varepsilon_{i,v}$ are the vegetation and ground emissivity corresponding to the land cover types. Emissivities of vegetation and ground according to the land cover types were obtained from Peres and DaCamara (2002). FVC is the fraction of vegetation and calculated using the normalized difference vegetation index (NDVI).

$$FVC = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}}$$

Where, $NDVI_{max}$ and $NDVI_{min}$ are the NDVI when the pixel is completely covered with vegetation and ground, respectively.

Figure 4 shows the sample emissivity of IR1 and IR2 over MTSAT-1R observing area in June. The spectral emissivity is generally larger in vegetated area than barren or desert area. And the emissivity of IR2 is slightly larger than IR1, especially in the desert area.

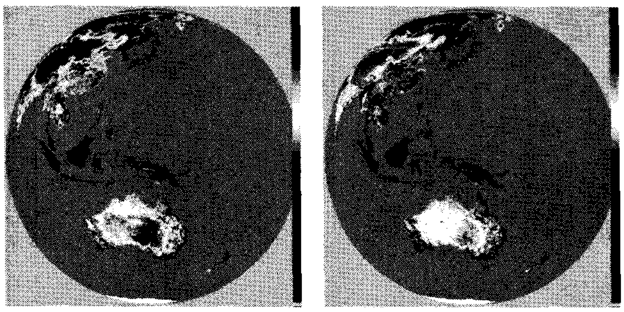

Figure 4. Sample images of spectral emissivity in June_15A. (left: IR1, right: IR2)

3. RESULTS

3.1 LST retrieval

Figure 5 shows the LST of January 2008 derived from MTSAT-1R coverage and prescribed surface emissivity. The cloud (white) is masked by Chung *et al.*(2006)'s multiple dynamic threshold method. Retrieved LST shows a strong spatial variation with the maximum in desert area of Australia, January is peak summer in the Southern hemisphere.

Figure 5. Sample image of LST retrieved from MTSAT-1R data for 0133UTC, 23 Jan. 2008.

3.2 Validation using MODIS LST

To validate the LST estimated in this study, collocated MODIS LST is used. Figure 6 shows the spatial distribution LST derived from MODIS, MTSAT-1R and their differences for the day and night time. Spatial distribution LST between MODIS and MTSAT-1R is very similar and delicate temperature differences. The LST algorithm overestimates and underestimates the LST during day time and night time, respectively.

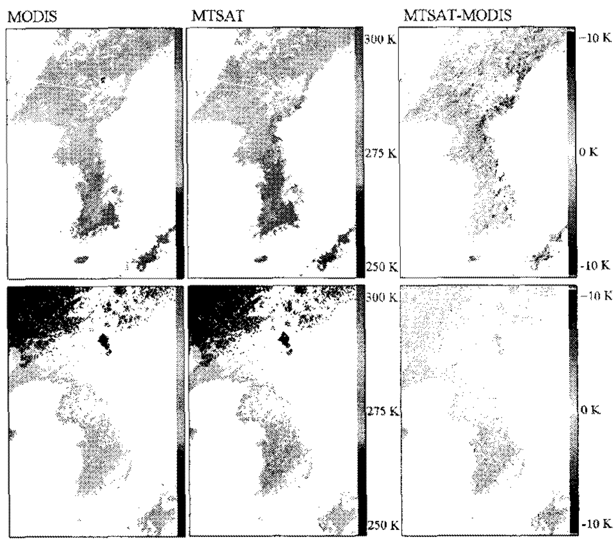

Figure 6. Spatial distribution of LST derived from MODIS, MTSAT-1R and their differences for the day and night time.

And the validation results are shown in Table 1 for the 4 selected cases. Case1 and case3 among 4 selected cases are located over the Korean Peninsula, case2 and case 4 are located over the central China. The validation results with MODIS LST showed that the correlation coefficients and RMSE are about 0.83~0.98 and 1.38~4.06, respectively. The LST estimated in this study is very similar to the MODIS LST, especially at night time (see Figure 7 and Table 1). The correlation coefficients, bias and RMSE showed that the LST retrieval algorithm developed in this study can be used for the LST retrieval in this region.

Table 1. Validation results of LST estimated from MTSAT-1R data for the 4 selected cases.

	MTSAT time	MODIS time	R	Bias	RMSE	Val_P_Num
Case1 /day	0200	0210 0215	0.939	+1.507	2.701	14057
Case2 /day	0400	0350 0355	0.832	+1.976	4.062	23915
Case3 /night	1333	1315 1320	0.989	-0.364	1.389	14729
Case4 /night	1500	1455 1500	0.889	-1.017	1.895	33973

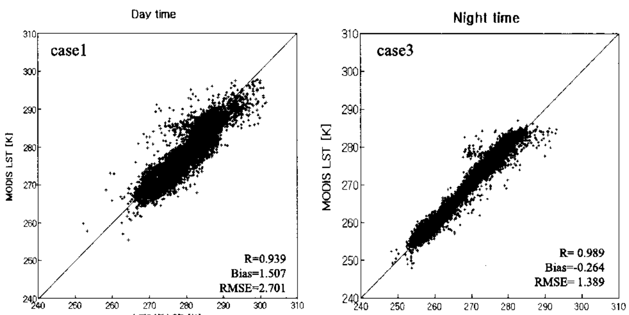

Figure 7. Scatter plots of MODIS LST and MTSAT-1R LST

4. SUMMARY

We have developed the LST retrieval algorithm from MTSAT-1R data using the radiative simulation under the various satellite zenith angles, effective emissivity of land surface and atmospheric profiles.

Sensitivity analysis showed that the algorithm reproduces LST well for the various conditions. However, it has a tendency to overestimate and underestimate when the surface has strong surface inversion and superadiabatic states, respectively. In general, the over and under estimations are significant when the LST is relatively warm. And the performance of LST algorithms is superior when SZA is small.

The validation results with MODIS over the Korean Peninsula and central China showed that the R, bias and RMSE are about 0.83 ~ 0.98, 1.97~ -1.0 and 1.38~4.06, respectively. The performance of LST algorithm is clearly dependent on the retrieval time, land cover and seasons. The quality of retrieved LST is clearly better during night time than day time, and the MTSAT-1R LST is more similar to the MODIS/Aqua LST than MODIS/Terra LST.

The validation results showed that the LST retrieval algorithm developed in this study could be used for the operational retrieval of LST from MTSAT-1R and COMS data with some modifications.

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6. ACKNOWLEDGENENTS

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