Derivation of SST using MODIS direct broadcast data

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ABSTRACT

MODIS (MODerate-resolution Imaging Spectroradiometer) onboard the first Earth Observing System (EOS) satellite, Terra, was launched successfully at the end of 1999. The direct broadcast MODIS data has been received and utilized in Korea Meteorological Administration (KMA) since February 2001. This study introduces utilizations of this data, especially for the derivation of sea surface temperature (SST). To produce the MODIS SST operationally, we used a simple cloud mask algorithm and MCSST algorithm. By using a simple cloud mask algorithm and by assumption of NOAA daily SST as a true SST, a new set of MCSST coefficients was derived. And we tried to analyze the current NASA's PFSST and new MCSST algorithms by using the collocated buoy observation data. Although the number of collocated data was limited, both algorithms are highly correlated with the buoy SST, but somewhat bigger bias and RMS difference than we expected. And PFSST uniformly underestimated the SST. Through more analyzing the archived and future-received data, we plan to derive better MCSST coefficients and apply to MODIS data of Aqua that is the second EOS satellite. To use the MODIS standard cloud mask algorithm to get better SST coefficients is going to be prepared.

Keywords: MODIS, SST, MCSST, simple cloud mask, PFSST, buoy collocated data

1. Introduction

The first EOS satellite, Terra, was launched at the end of 1999 for the multidisciplinary purposes of comprehensive monitoring of land, ocean, and atmosphere. MODIS, the only direct broadcasting onboard sensor of Terra, is making observations in 36 co-registered spectral bands at moderate resolution (0.25 – 1km). KMA began to receive the MODIS data from February 2001. The raw data are being processed using the IMAPP (International MODIS and AIRS Processing Package) developed by CIMSS (Cooperative Institute of Meteorological Satellite Studies) to generate the level 0 and 1 data set. KMA currently processes level 1 data further to produce the true color composite imagery, sea surface temperature (SST), vegetation index, aerosol optical depth, snow cover information and high resolution (250m) composite imagery for detection of drought or flood area. This study describes the current status of the SST retrieval process using MODIS direct broadcast data and plans for the future improvements.

Estimation of SST using satellite data has advantages over the in-situ observation such as by ship and buoy. The most important advantage would be the continuous production of SST information for large area with a single well-calibrated instrument. However satellite data always have atmospheric interferences that must be considered. First, cloud cover amounting to just a few percent of the instantaneous field of view can introduce large errors in the retrieved SST, because clouds are usually much colder than the sea surface. Radiances from surface also attenuated by atmospheric constituents, mainly by water vapor. In this study, for an operational production of SST using direct broadcast MODIS data, we employed simple cloud screening method and MCSST algorithm for atmospheric correction. Section 2 introduces the procedure for the derivation of SST and new regression coefficients followed by the validation results in Section 3. The paper is summarized and future works are described in Section 4.

2. Retrieval of SST

2.1 Simple Cloud Screening Methodology

The standard MODIS cloud screening procedure is known to perform very well (Heidinger et al., 2002), but it takes much time. For the fast operational derivation of SST from the huge size of MODIS data, we adopted a simple cloud screening procedure, which is consist of single, and dual channel threshold test and comparison test with recent SST. First, for single channel threshold test, pixels are considered as cloud contaminated when the brightness temperature derived from MODIS channel 31 (Tb11, 10.780-11.280 um) is smaller than 270 K. Second test is split window test. Generally, Tb11 is higher than Tb12 (channel 32, 11.770-12.270 um) in clear condition. Because the radiance is more sensitive to water vapor at 12um than at 11um, the difference between Tb11 and Tb12 become larger due to existence of water vapor. Thus we consider the pixels are cloud contaminated when the differences between Tb11 and Tb12 (Tb11-Tb12) are negative. Finally, under consideration that SST does not have a significant change within short term, cloud detection test that are finally executed is temporal uniformity test using comparison with GMS weekly SST (Ahn et al., 2001). For the cloud screening, 3.5°C is assumed as threshold value of temperature difference between MODIS SST and GMS weekly mean composite SST.

2.2 Atmospheric Correction

After the cloud screening procedure, atmospheric correction must be performed. In any spectral interval, thermal radiation emitted by the sea surface is absorbed by atmospheric constituents and reemitted at all levels in the atmosphere. Thus in the SST retrieval, it is important to estimate an amount of atmospheric attenuation. Many efforts have been made to achieve the required accuracy by through developing better atmospheric correction algorithm (Walton et al., 1988; Kilpatrick et al., 2001). One of the most popular methods for the correction of the atmospheric effects is the utilization of differential optical path length first suggested by Saunders (1967). MCSST (McClain et al., 1985), CPSST (Cross Product SST, Walton et al., 1988) and NLSST (Non-Linear SST, Walton et al., 1998) are representative. In this study, we used MCSST retrieval algorithm and it assumes that the amount of atmospheric attenuation of one window channel is linearly proportional to the temperature difference of two window channel measurements. The form of the MCSST retrieval equation is as follows:

$$\begin{aligned}\mathrm{MCSST} &= a\,T11 + b\,(T11-T12)\\ &\quad + c\,(T11-T12)(\sec(SZA)-1) + d \qquad (1)\end{aligned}$$

Where T11 is the brightness temperature of channel 31 of MODIS, T12 is that of channel 32, SZA is satellite zenith angle, and a, b, d and d are constant coefficients.

2.3 Derivation of New MCSST Regression Coefficients

For the MODIS SST estimation, the coefficients of (1) are determined by linear regression method with accurate SST obtained from buoy and/or ship observation. But as the collocated satellite and buoy SST in the region where the direct broadcasted data cover is limited, we assume the NOAA SST as true value. Using the collocated MODIS radiance and NOAA SST, we derive a new set of MCSST coefficients. For the collocation data set, we use NOAA-12, -14, -15, and –16 satellite data. NOAA SST's are calculated using the coefficients provided by NOAA/NESDIS and are known that their accuracy is about 1.2°C RMSE (Kim et al., 2000). SST's retrieved each NOAA satellite have other error characteristics, respectively. Thus, daily mean composite SST data was used in order to reduce random error that was existed in data itself and to minimize the cloud covered area. To prepare the accurate collocated data between MODIS Tb11, Tb12, SZA and NOAA SST, we checked navigation accuracy and select the data only where satellite zenith angle is smaller than 55 degree. Newly derived MCSST regression coefficients in this study are shown in Table 1.

Table 1. MCSST regression coefficients derived from regression with NOAA SST's.

A	B	C	d
1.013560	2.10808	1.249500	-1.68848

Where the unit of Tb11 and Tb12 is Kelvin. The SST imageries produced by using the new regression coefficients are displayed in METRI RSRL website (http://satweb.metri.re.kr/modis_sst_E.htm) and updated in every pass over the Korean peninsula.

3. APPLICATIONS AND VALIDATION

3.1 Buoy SST Data Quality Control (Q/C)

The SST data from drifting and moored buoys are obtained by through the GTS (Global Telecommunication System), which contains erroneous data caused either by the malfunctioning of buoys itself or by problems in data communication. The best approach for the Q/C of the buoy data might be a manual inspection of each station data. However, an objective Q/C procedure is required to avoid the subject of the manual inspection and to handle huge size of the buoy data properly (Hansen and Poulain, 1996). We applied modified Q/C procedure suggested by Ahn et al. (2002). We first remove whole data from buoy station that reported very small number of observations. Also, when a temporal variation of SST at a given buoy is too large, we assumed that the data is erroneous one. When we apply the Q/C procedure to the data obtained East Asia region between January and June, 2002, about 6 % of data is screened as the bad data, total number of buoy data in this period is 71,663, and the number of bad data is 4,054.

3.2 Collocated Data

For the collocation, we make sure that the navigation of MODIS data is done properly by visual inspection of MODIS imagery. The collocated data consists of Tb for MODIS Ch 20, 29, 31, 32, albedo for MODIS Channel 1, buoy SST, GMS weekly mean composite SST, and geographical information. The brightness temperature and albedo are derived from radiance data using inverse Planck function and attribute data included in MODIS data format. When available, we also use the albedo data to eliminate the cloud-contaminated pixel. For the albedo test, if reflectance of MODIS Channel 1 (620-670 um) is larger than 6 %, it is considered as cloud pixel. The time and space window for the collocation is ±1 hour and 3 km radius from the buoy observation. For the validation, we averaged Tb and albedo based on the location of each buoy data. The number of collocated cloud-screened data is 205 for the time period of April to June 2002.

3.3 Validation

The scatter diagram of derived and buoy SST is shown in Figure 1 along with the comparison between buoy SST and PFSST SST (Brown et al., 1999). When PFSST was calculated, GMS weekly mean SST was used as first guess SST instead of Reynolds NCEP OI (Optimal Interpolation) SST. The bias and rms difference between new MCSST and buoy SST is about -0.13° and 1.32° C, respectively, while they are -0.83° C and 1.34° C, respectively for the PFSST SST, which are much larger than expected value. PFSST is evaluated to retrieve SST somewhat colder in this study. Both algorithms have high correlation with the buoy SST, 0.99, and 0.98 for MCSST and PFSST, respectively. For a further validation, Figure 2 shows the bias as a function of Tb11, Tb11-Tb12, satellite zenith angle, and time. It is difficult to make a firm conclusion simply because of the small number of data set, but the magnitudes of bias seem to increase slightly in accordance with the increase of Tb11, Tb11-Tb12, satellite zenith angle. And it is obvious that PFSST has negative biases for the whole cases but scatterness of PFSST is smaller than those of MCSST. Similar RMSE but bigger error of PFSST caused from this.

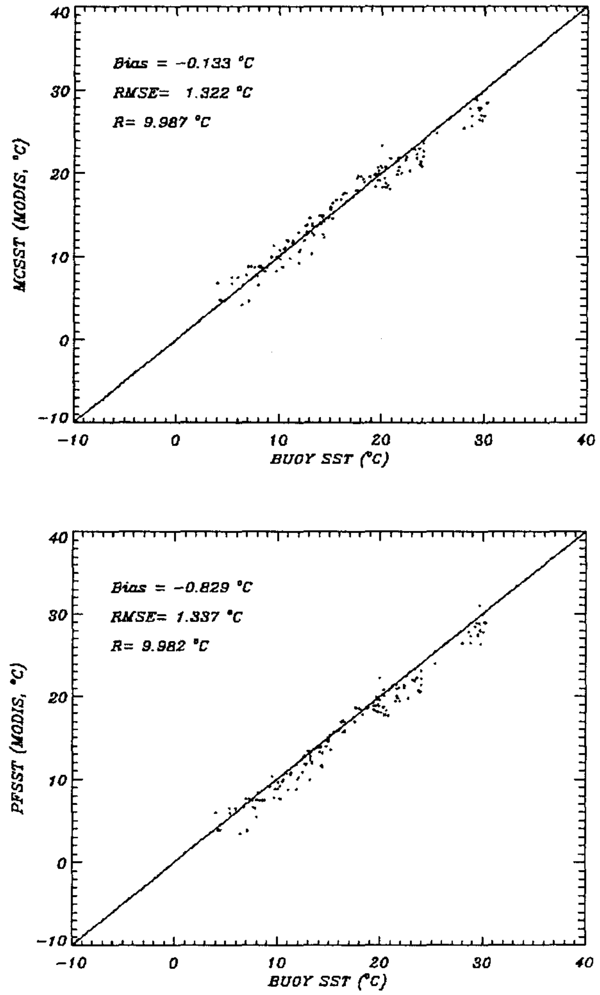

Figure 1. Scatter plots of buoy SST versus a) MODIS MCSST retrieved using new coefficients derived from this study, and b) PFSST suggested by NASA/NESDIS using GMS weekly mean SST instead of NOAA Reynolds SST.

4. SUMMARY AND DISCUSSION

For an operational purpose, we adapted simple cloud screening method and produced SST using MCSST algorithm. Because MODIS direct broadcasting data was first received on February 2001 and it had experienced some problem to process and archive the data, there is not enough data to apply the regression with MODIS and buoy collocated data. In order to derive the MCSST coefficients for a regional application, regression analysis was performed under assumption that NOAA daily mean composite SST is real SST. MODIS SST calculated using the new coefficients derived in this method are produced every MODIS pass and displayed in website.

To validate the accuracy of this MODIS SST, even though it has small number, we make buoy and MODIS collocated data. Now we use data obtained up to 3 months. The total number of collocated data is 205. In the result that the accuracy of MCSST using the coefficients generated in this study was evaluated using these buoy collocated data set, the bias and RMSE are –0.13°C and 1.32°C, respectively, which are somewhat better than those of NASA pre-launch PFSST algorithm. PFSST has bigger cold bias, but has more uniform bias characteristics for the most aspects (Tb11, Tb11-Tb12, satellite zenith angle, and time) than those of MCSST.

In future, we will analyze the archived and future-received data as well, and plan to derive better MCSST coefficients. KMA is preparing to receive the second earth observing satellite, Aqua, now. MODIS was also boarded in this satellite, so we can produce SST maps more frequently and accurately. To use the MODIS cloud mask algorithm that make to manage the cloud effects more detail and can get the regression coefficients better is going to be prepared.

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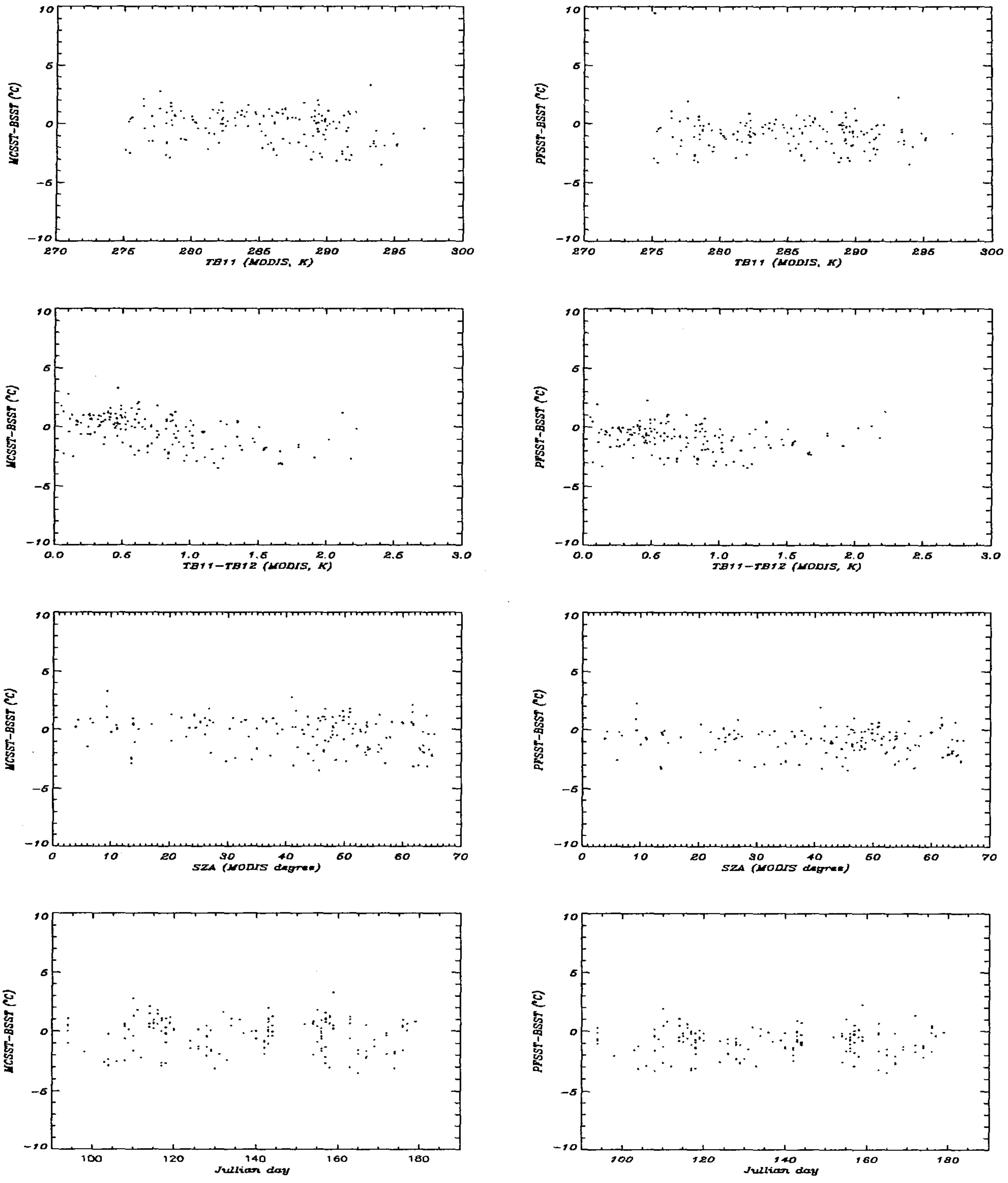

Figure 2. Bias as a function of Tb11, Tb11-Tb12, satellite zenith angle and time.

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