ATMOSPHERIC CORRECTION OF LANDSAT SEA SURFACE TEMPERATURE BY USING TERRA MODIS

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Abstract: Thermal infrared images of Landsat-5 TM and Landsat-7 ETM+ sensors have been unrivalled sources of high resolution thermal remote sensing (60m for ETM+, 120m for TM) for more than two decades. Atmospheric effect that degrades the accuracy of Sea Surface Temperature (SST) measurement significantly, however, can not be corrected as the sensors have only one thermal channel. Recently, MODIS sensor onboard Terra satellite is equipped with dual-thermal channels (31 and 32) of which the difference of at-satellite brightness temperature can provide atmospheric correction with 1km resolution. In this study we corrected the atmospheric effect of Landsat SST by using MODIS data obtained almost simultaneously. As a case study, we produced the Landsat SST near the eastern and western coast of Korea. Then we have obtained Terra/MODIS image of the same area taken approximately 30 minutes later. Atmospheric correction term was calculated by the difference between the MODIS SST (Level 2) and the SST calculated from a single channel (31 of Level 1B). This term with 1km resolution was used for Landsat SST atmospheric correction. Comparison of in situ SST measurements and the corrected Landsat SSTs has shown a significant improvement in R^2 from 0.6229 to 0.7779. It is shown that the combination of the high resolution Landsat SST and the Terra/MODIS atmospheric correction can be a routine data production scheme for the thermal remote sensing of ocean.

Keywords: Landsat, Terra, MODIS, sea surface temperature, atmospheric correction

1. INTRODUCTION

Since early 1980s, the thermal sensors of Landsat-5 TM and Landsat-7 ETM+ have provided mid-resolution satellite infrared images, which is one of the highest resolution satellite sensors until now. The thermal infrared remote sensing with 60m-resolution for ETM+ and 120m for TM enabled detailed study of rives and sea surface temperature (SST). The SST is marred significantly by atmospheric condition, especially when the area is under cloud cover, haze or dust. Various algorithms exist to use other channels of Landsat images or statistical comparison with in situ temperature measurements (Lee and Han, 2005) for atmospheric correction. However, without additional thermal channel, it is virtually difficult to operationally eliminate the atmospheric effect that normally results in underestimation of SST.

Recent low-resolution (~1 km) optical sensors such as AVHRR onboard NOAA satellites or MODIS onboard Terra and Aqua satellites are equipped with more than two thermal infrared channels for atmospheric correction by utilizing the different response between different thermal wavelengths to atmospheric condition. MODIS onboard Terra flies within 30 minutes after Landsat pass. It is equipped with dual-thermal channels (31 and 32). At-satellite brightness temperature difference between two adjacent thermal channels can provide atmospheric correction capability with 1km resolution.

In this study we corrected the atmospheric effect of Landsat SST by using MODIS data obtained almost simultaneously. We then compared the atmospheric-corrected Landsat SST with in situ measurement for quality assessment of this novel method.

2. STUDY AREA AND DATA

The study area covers three frames of Landsat data with path-row of 115-34 (east part, 2 scenes), 116-34(west-north part, 7 scenes), and 116-035 (west-south part, 6 scenes) as shown in Fig. 1.

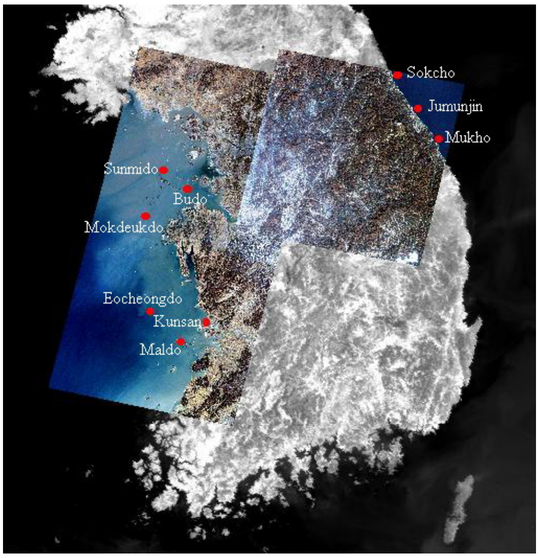

Fig. 1. The study area. Three frames of Landsat data are overlying a Terra/MODIS image. The dots indicate the locations of coastal stationary observation posts.

The Landsat data acquired after the launch of Terra satellite in 1999 was chosen, as listed in Table 1. MODIS data taken approximately 30 minutes after the Landsat pass (total 11 days) was also retrieved from DAAC, NASA.

The in situ SST data was acquired from the coastal stationary observation posts. They include Sokcho, Jumunjin, Mookho along the east coast, and Sunmi-do, Bu-do, Mokduk-do, Eocheong-do, Gunsan, Maldo along the west coast of Korean peninsula. We retrieved the daily in situ SST measured at 10am from 1999 to recent.

3. ATMOSPHERIC CORRECTION METHOD

The DN values of Landsat thermal channel is converted to radiance and thus to water surface temperature (Kelvin) by the following NASA equation:

$$T_{Landsat} = K_2/\ln\{K_1/[(Lmax-Lmin)/(QCALmax - QCALmin)*(DN - QCALmin)+ Lmin]+1\} \quad (1)$$

Here all parameters are satellite and/or acquisition-date dependent and are fully discussed in Chander and Markham 2003.

Fig. 2 shows the relationship between Landsat SST and in situ SST of which R^2 is 0.6229. The regression shows that Landsat SST is generally underestimated when compared with in situ data. This is a typical case of atmospheric error of Landsat SST. For some data points with minus SST was eliminated due to heavy cloud cover that MODIS can not give atmospheric correction either.

The atmospheric-corrected MODIS SST is calculated by the following equation (Brown and Minnett, 1999):

$$T_{MODIS} = a_1 + a_2T_{31} + a_3*(T_{31}-T_{32})*Bsst + a_4*(T_{31}-T_{32})*(sec(theta)-1) \quad (2)$$

where the brightness temperature of band 31 and 32 can be calculated by:

$$T_{31} = c2/[wavelength * \ln (c1 / (wavelength^5 * radiance) + 1)]$$
$$c1=1.1911x10^8 WM^{-2}sr^{-1}(\mu m^{-1})^{-4}$$
$$c2 = 1.439x10^4 \text{ K } \mu m \quad (3)$$

Table 1. Landsat (TM or ETM+) and Terra MODIS dataset.

PATH-ROW	Acquisition Date (yyyy.mm.dd)
115-034	2000.04.06
	2000.05.08
	2000.09.29
116-034	2000.09.04
	2001.09.23
	2004.03.23
	2004.04.24
	2004.06.11
	2004.07.29
	2004.08.30
116-035	2000.11.23
	2004.03.23
	2004.04.24
	2004.06.11
	2004.07.29
	2004.08.30

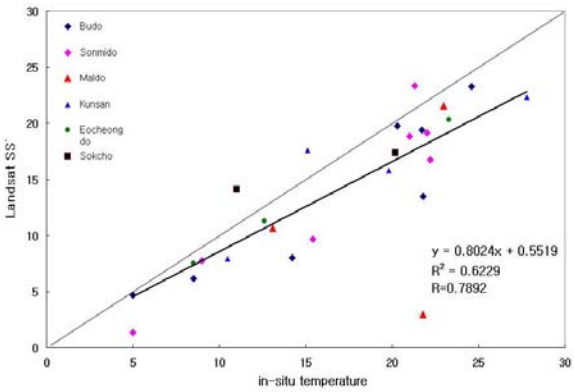

Fig. 2. Relationship between Landsat SST and in-situ temperature before the atmospheric correction

The parameters for MODIS SST algorithm depend on the acquisition period, day or night, and mostly importantly, whether the amount of (T_{31}-T_{32}) is greater than or less than 0.7K.

Now we need to consider the spectral coverage of Landsat TM/ETM+ and MODIS thermal bands. Landsat thermal channel (10.4–12.5um) encompasses both MODIS 31 (10.78 - 11.28um) and 32 (11.77-12.27um) channels. In theory, T_{32} suffers more severely when the atmospheric effect increases than T_{31}, as depicted in Fig. 3, but the difference is usually smaller than 0.7K when cloud or haze are not severe. If we assume that the response trend of Landsat thermal bands to atmospheric absorption are in between the two MODIS thermal bands, then we can get the atmospheric correction term for Landsat thermal bands with errors recognizable by MODIS algorithms.

Therefore, by substituting the brightness temperature of MODIS band 31 from MODIS SST, we can get Landsat atmospheric correction term by

$$\Delta T = T_{MODIS} - T_{31}, \quad (4)$$

with possible error ranges of roughly (T_{31}-T_{32})/2 (>0). For the areas of (T_{31}-T_{32}) <0.7K, the error can be less than 0.35K. The Landsat SST with atmospheric correction of 1km resolution would be:

$$T_{Landsat-atm} = T_{Landsat} + \Delta T. \quad (5)$$

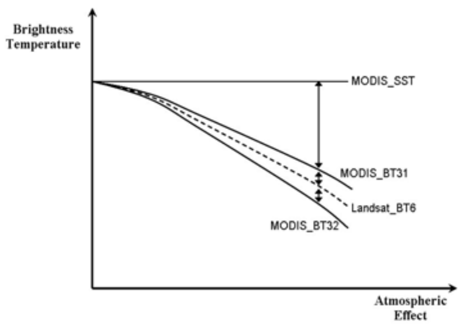

Fig. 3. Schematic diagram of the responses of brightness temperature to atmospheric absorption. Note MODIS band 32 suffers more than 31, while Landsat thermal bands lies in between.

The data processing is now straightforward. From MODIS Level 2 (MOD28L) dataset we can extract T_{MODIS} directly. For T_{31}, we can use MODIS Level 1B (MOD021KM) dataset and (3). Then Landsat SST can be atmospherically corrected by (4) and (5).

4. RESULTS AND DISCUSSIONS

To evaluate the assumptions on the response curve of Landsat TM(ETM+) and Terra MODIS as shown in Fig. 3, we have compared the brightness temperature of MODIS 31 (T_{31}) and Landsat SST ($T_{Landsat}$) in Fig. 4. It shows relatively good agreement with R^2 of 0.7864, implying the difference between two bands is not very significant. Several erroneous points may have occurred due to 30 minutes difference of two satellite pass and fast-varying atmospheric condition, or difference of spatial resolution.

Fig. 5 compares the atmospheric-corrected MODIS SST (T_{MODIS}) and Landsat SST. T_{MODIS} clearly shows higher value than $T_{Landsat}$, due to the atmospheric correction of MODIS SST.

Finally, we compared the atmospheric-corrected Landsat SST with in situ data as shown in Fig. 6. R^2 was improved significantly from 0.6229 (Fig. 2) to 0.7779 after atmospheric correction. Table 2 shows the SST data according to each data processing step.

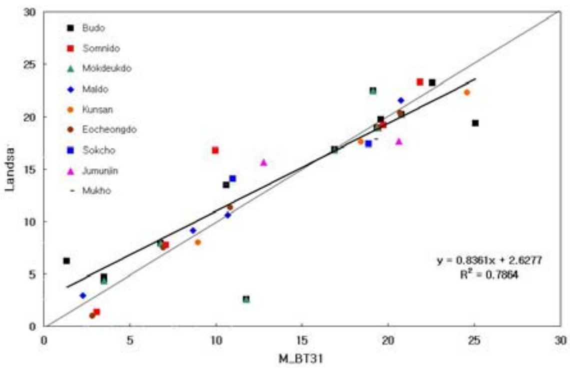

Fig. 4. Relationship between Landsat SST and MODIS BT31.

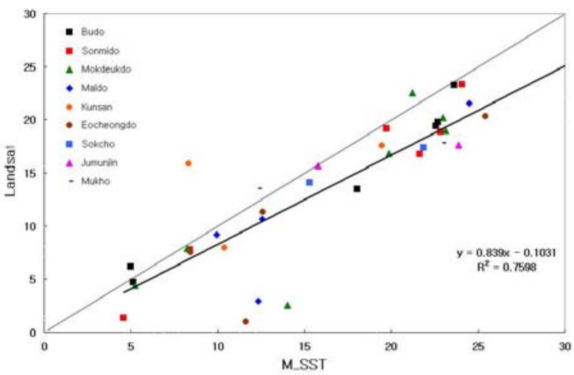

Fig. 5. Relationship between Landsat SST and MODIS SST.

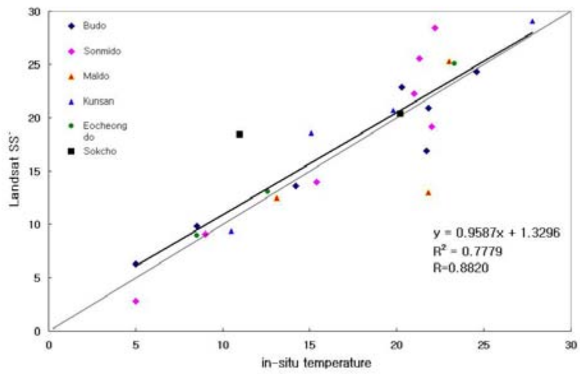

Fig. 6. Relationship between the atmospheric-corrected Landsat SST and in-situ SST. Note the improvement of R^2 compared to that of Fig. 2.

5. CONCLUSION

The atmospheric correction of Landsat SST by using Terra MODIS data was successfully applied and tested along the Korean coastal area. Comparison of atmospheric-corrected Landsat SST with in situ SST data has shown an improvement of R^2 from 0.6229 (before) to 0.7779 after the correction. It is shown that the combination of the high resolution Landsat SST and the Terra/MODIS atmospheric correction can be a routine data production scheme for the thermal remote sensing of ocean. This method will improve the high-resolution SST measurement from Landsat-5 and Landsat-7 until or even after the new LDCM (Landsat Data Continuity Mission) with the proposed 120m-resolution, dual-thermal channels become available.

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Table 2. Landsat TM/ETM+, Terra MODIS and in situ SST (℃). Data in gray cell are not used.

DATE	In situ coastal observation posts	$T_{Landsat}$	T_{MODIS}	T_{31}	ΔT (= T_{MODIS} - T_{31})	$T_{Landsat-Atm}$ (=$T_{Landsat}$ +ΔT)	In situ SST
2000.09.04	Budo	23.27	23.64	22.56	1.08	24.35	24.60
	Sonmido	23.32	24.07	21.86	2.21	25.54	21.30
2001.09.23	Budo	19.39	22.56	25.08	-2.51	16.88	21.70
	Sonmido	19.16	19.72	19.74	-0.02	19.14	22.00
2004.03.23	Budo	4.70	5.12	3.52	1.61	6.31	5.00
	Sonmido	1.33	4.59	3.10	1.49	2.82	5.00
2004.04.24	Budo	6.18	4.98	1.33	3.65	9.83	8.50
	Sonmido	7.77	8.41	7.09	1.32	9.09	9.00
2004.06.11	Budo	8.04	-4.12	-9.69	5.58	13.61	14.20
	Sonmido	9.65	-41.93	-46.23	4.30	13.95	15.40
2004.07.29	Budo	19.75	22.70	19.58	3.13	22.87	20.30
	Sonmido	18.85	22.84	19.45	3.39	22.24	21.00
2004.08.30	Budo	13.49	18.05	10.60	7.45	20.94	21.80
	Sonmido	16.77	21.65	9.99	11.66	28.43	22.20
2000.11.23	Maldo	10.63	12.55	10.68	1.87	12.50	13.10
	Kunsan	7.97	10.39	8.98	1.41	9.39	10.50
	Eocheongdo	11.30	12.61	10.84	1.77	13.07	12.60
2004.03.23	Maldo	-6.96	4.54	2.63	1.90	-5.05	5.70
	Kunsan	-3.86	9.47	6.71	2.76	-1.10	9.80
	Eocheongdo	-1.52	3.85	1.47	2.38	0.86	5.70
2004.06.11	Maldo	-21.15	-27.57	-31.07	3.50	-17.65	15.60
	Kunsan	15.84	8.33	3.42	4.91	20.74	19.80
	Eocheongdo	-15.77	1.88	-2.35	4.23	-11.54	14.20
2004.07.29	Maldo	21.55	24.49	20.74	3.75	25.30	23.00
	Kunsan	22.34	31.34	24.60	6.74	29.09	27.80
	Eocheongdo	20.34	25.44	20.70	4.74	25.08	23.30
2000.05.08	Mukho	13.51	12.35	10.51	1.83	15.35	0.28
	Jumunjin	15.69	15.78	12.79	2.98	18.67	12.90
	Sokcho	14.11	15.29	11.00	4.29	18.40	11.00
2000.09.29	Mukho	17.81	22.94	19.19	3.75	21.56	0.24
	Jumunjin	17.64	23.88	20.60	3.28	20.92	20.80
	Sokcho	17.38	21.88	18.88	3.00	20.38	20.20