A STUDY ON THE SEASONAL CHANGE OF DIFFERENCE OF BRIGHTNESS TEMPERATURES OBTAINED FROM LANDSAT-7/ETM+ AND TERRA/MODIS

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ABSTRACT: The brightness temperatures (BTs) around Hotien Oasis of the southwestern part of Taklimakan Desert in XinJiang, China retrieved from the data of Landsat-7/ETM+ band 6 and Terra/MODIS bands 31 and 32, for higher sun elevation observed on June in 2002, indicates following features. (1) Good linear relationship between the BTs of ETM+ and that of MODIS. (2) The observation time adjusted BT of ETM+ is almost equal to that of MODIS. (3) The BT of Terra/MODIS band 31 is slightly higher than that of band 32 over a reservoir while opposite feature is recognized over desert area. (4) The statistical analysis of 225 sample data of ETM+ in one pixel of MODIS for different landcovers indicates that the standard deviation and range of BT of ETM+ corresponding to one pixel of MODIS are 0.45 ℃, 2.25 ℃ for the flat area of desert, while respective values of the oasis farmland and shading side of rocky hill amount to 2.88 ℃, 14.04 ℃, and 2.80 ℃, 16.04 ℃.
On the other hand, in the seasonal changes of difference of BTs retrieved from ETM and MODIS acquired in 2000 to 2003, it is found that the parabola opens upward in the flat area of desert and the oasis reservoir although the parabola opens downward in the oasis farmland. Furthermore, in the difference of ground surface temperature of a black rubber sheet on the roof at Hiroshima, Japan that had been measured in referring, the parabola opens upward and temperature differences on January and June are approximately 2.7 ℃ and 0.6 ℃.

1. INTRODUCTION

The brightness temperatures (BTs) retrieved from the data of thermal infrared (TIR) bands of the sensors onboard Terra, Aqua and meteorological satellites are widely used in the study of global warning including energy flux between land surface and the atmosphere, while there are not a few demands for the BT retrieved from the TIR band of Landsat-7/ETM+ (Enhanced Thematic Mapper Plus). The spatial resolution of the data of the TIR band of Landsat-7/ETM+ is approximately 60 m which is a great advantage for the study of meso and small scale phenomena however it is extremely difficult to get satisfactory data due to long repeat cycle of 16 days (Cahnder, 2004, NASA, 2011a). On the other hand, in case of Terra/MODIS (MODerate resolution Imaging Spectroradiometer) and Aqua/MODIS the TIR band data can be acquired almost in daily basis although the spatial resolution is approximately 1000 m (Wan, 2002, NASA, 2011b).
For the reflective solar bands, the data of the surface reflectance of Terra/MODIS were analyzed together with the data of Landsat-7/ETM+ and confirmed that the absolute error of the land surface products was less than 5 % (Liang, 2002). In addition, the intercalibration between the reflected bands of Landsat-7/ETM+ and those of Terra/MODIS was performed for the vegetation analysis (Rochdi, 2008). Based on these analyses, concluded that the reflectance bands of Landsat-7/ETM+ and Terra/MODIS have good linear relationship.
For TIR bands the level-2 MODIS land surface temperature (LST) product of 1 km spatial resolution (MOD11_L2) obtained from the TIR bands 31 and 32 of Terra/MODIS it was confirmed that the error of LST products ranging from 263 K (-10 ℃) to 322 K (49 ℃) is less than 1 K for the atmospheric column water vapor ranging from 0.4 to 3.0 cm (Wan, 2002). Furthermore it was also confirmed that the error of the daily level-3 MODIS LST product of 1 km spatial resolution (MOD11A1 Version 5 for Terra and MYD11A1 Version 5 for Aqua) obtained from the same bands of both Terra and Aqua/MODIS was less than 1 K in the range from 263 K (-10 ℃) to 331 K (58 ℃) for the atmospheric column water vapor ranging from 0.4 to 3.5 cm (Wan, 2008).
The objective of this paper is to compare the BTs of selected targets of Taklimakan Desert in China observed with the TIR bands of Landsat-7/ETM+ and Terra/MODIS and to clarify the relationship between the BTs obtained from both sensors. Finally, the seasonal change of difference of BTs retrieved from TIR bands of Landsat-7/ETM+ and Terra/MODIS caused by the observation time difference will be also considered.

2. ANALYSIS DATA AND STUDY AREA

2.1 Analysis Data

The specification of Landsat-7 (NASA, 2011a) and Terra (NASA, 2011b) is shown in Table 1, which indicates that the orbits of two satellites are almost same and the observation time difference is within 30 minutes. The specification of TIR band of ETM+ and MODIS is shown in Table 2. The major difference of two sensors is spatial and spectral resolution, swath width and repeating cycle.
The instrument malfunction occurred on the Scan Line Corrector (SLC) of ETM+ on May 31, 2003 subsequently SLC was turned off, and now only SLC-off mode data are acquired (NASA, 2011a, Storey, 2005). In this study, we decided to analyze SLC-on mode data of ETM+ acquired before May 31, 2003. To reduce the shading effects on the BT of the land surface of vegetated area the data of higher sun elevation were selected.

2.2 Study Area

The study area is around Hotien Oasis of the southwestern part of Taklimakan Desert in XinJiang,China. Covering the area between 74°E and 96°E, 36°N and 43°N Taklimakan Desert is the largest sandy desert in Asia with the area of about 270,000 km^2 (Oguro, 2005). The main reasons of having chosen the area are
(1) During a fairly large-scale research project "Japan-China Joint Study on Desertification (1989-1994)", using a hand-held radiometer we have collected abundantly the land surface and underground temperature data of this area together with near surface meteorological data and also radio sounding data.
(2) Surrounded by high mountain ranges with average height of 1200 meter above sea level the area is characterized with extremely dry atmospheric condition resulting in very little effect of water vapor.
(3) Locating between two rivers, the Karakax River and the Yurungkax River, Hotien Oasis is the largest oasis in the southern part of the desert. There is a good weather station equipped with radio sounding facilities, land surface, and underground temperature observing facilities.
The analyzed satellite data of ETM+ and MODIS over and around Hotien Oasis are shown in Table 3. For an example, the false color images of ETM+ and MODIS over the Hotien Oasis in Taklimakan Desert observed on June 8, 2002 are shown in Figure 1. The range of sensor nadir angles of ETM+ is approximately ranging from 7.28° (west) to 7.28° (east) and that of MODIS is approximately ranging from 9.51° (west) to 8.09° (east).

Table 1: Satellite specification of Landsat-7 and Terra.

Satellite	Sensor	Launch date	Altitude km	Inclination Degrees	Swath km	Repeat cycle Days	Crossing time UTC
Landsat-7	ETM+	April 15, 1999	705	98.2	185	16	10:00-10:15 (Descending node)
Terra	MODIS	December 18, 1999	705	98.2	2330	1-2	10:30 (Descending node)

Table 2: Band specification of the TIR bands of Landsat-7/ETM+ and Terra/MODIS.

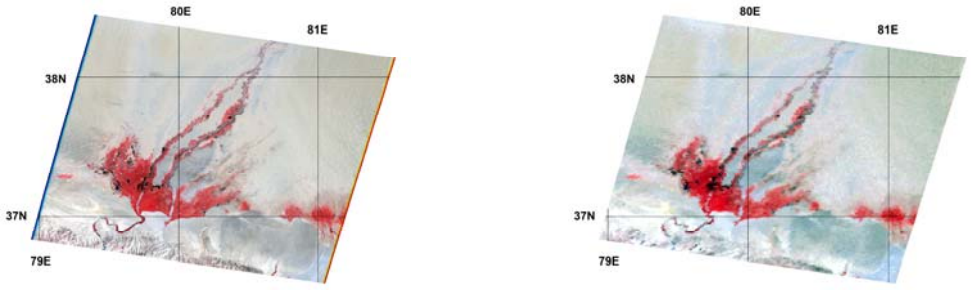
Satellite	Sensor	Band	Spectral range μm	Center wavelength		Spectral radiance $W/(m^2 \cdot sr \cdot \mu m)$	Spatial resolution m
				Spectral range μm	Cumulative histogram at 50% of RSR μm		
Landsat-7	ETM+	6	10.31-12.36	11.335	11.217	8.20 (LG), 1.09 (HG)	60
Terra	MODIS	31	10.78-11.28	11.030	11.011	9.55 (300 K)	1000
		32	11.77-12.27	12.020	12.027	8.94 (300 K)	

Note that LG and HG for Landsat-7/ETM+ indicate the low gain and the high gain, respectively.

Table 3: Analyzed data of Landsat-7/ETM+ and Terra/MODIS around Hotan Oasis in Taklimakan Desert.

Date	J-day	ETM+		MODIS
yyyymmdd	ddd	UTC	Sun_EL degrees	UTC
20010112	012	05:06	26.35	05:45
20020131	031	05:05	29.59	05:35
20030203	034	05:05	30.24	05:30-05:35
20020304	063	05:05	39.60	05:35
20030307	066	05:05	40.60	05:30
20000314	074	05:09	43.97	05:45
20020421	111	05:05	57.00	05:35
20000501	122	05:08	60.47	05:45-05:50

Date	J-day	ETM+		MODIS
yyyymmdd	ddd	UTC	Sun_EL degrees	UTC
20020608	159	05:05	65.23	05:35
20000805	218	05:07	60.29	05:45
20020827	239	05:04	55.10	05:35
20021014	287	05:04	40.66	05:30-05:35
20001024	298	05:06	37.51	05:45
20021201	335	05:04	27.59	05:35
20001211	346	05:06	26.26	05:45
20011230	364	05:05	25.27	05:35



(a) (b)

Figure 1: False color images of Landsat-7/ETM+ (R, B, G: bands 4, 3, and 2) (a) and Terra/MODIS (R, G, B: bands 7, 2, and 1) (b) over the Hotien Oasis in Taklimakan Desert observed on June 8, 2002. The geographic locations of the four corners (clockwise starting at the top left) of the image are UL (38.45°N, 78.87°E), UR (38.47°N, 81.70°E), LR (36.49°N, 78.92°E), and LL (36.50°N, 81.68°E). In the false color images, yellow is sandy desert and sand dunes, gray is desert of stones and pebbles, white is rocks, red is farmlands and grasslands, and black is water of river and reservoir.

3. DATA PROCESSING

The data of the TIR band 6 of ETM+ can be converted from observed spectral radiance (L_λ) to observed BT. The conversion equation (NASA, 2011, Chander, 2009) is

$$T_6 = \frac{K_2}{\ln\left(\frac{\tau\varepsilon K_1}{L_\lambda} + 1\right)} \qquad (1)$$

where T_6 is observed BT in Kelvin, K_1 is calibration constant 1 (666.09 W/(m^2·sr·μm)), K_2 is calibration constant 2 (1282.71 K), L_λ is observed spectral radiance in W/(m^2·sr·μm), τ is adjustment parameter to atmospheric effect, ε is adjustment parameter to emissivity effect.

The data of the TIR bands 31 and 32 of MODIS can be converted from observed spectral radiance (L_λ) to observed BT applying the Planck's law of blackbody radiation. The conversion equation (NASA, 2011b) is

$$T = \frac{\frac{hc}{k\lambda}}{\ln\left(\frac{\tau\varepsilon 2hc^2}{L_\lambda \lambda^5 \times 10^{-6}} + 1\right)} \qquad (2)$$

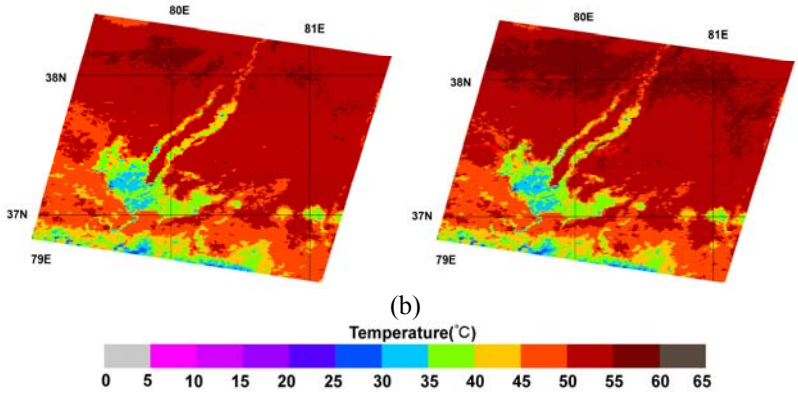
where T is observed BT in Kelvin, h is Planck constant (6.62606896×10^{-34} J·s), c is speed of light ($2.99792458\times10^{+8}$ m/s), k is Boltzmann constant (1.3806504×10^{-23} J/K), λ is center wavelength in meter, L_λ is observed spectral radiance in W/(m^2·sr·μm), τ is adjustment parameter to atmospheric effect, ε is adjustment parameter to emissivity effect.
From Equations (1) and (2), the center wavelengths of the TIR band 6 of ETM+ can be estimated. The estimated center wavelength of the TIR band 6 of ETM+ is nearly equal to the center wavelength obtained from the cumulative histogram at 50% of RSR as shown in Table 2.

4. RESULTS AND DISCUSION

4.1 Linearity's of BTs Retrieved from the Data of ETM+ and MODIS Acquired on June 8, 2002

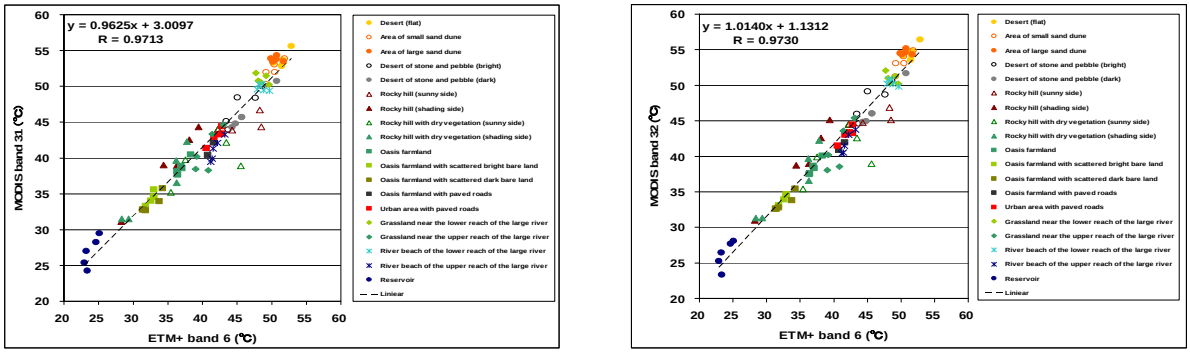
BT images over Hotien Oasis acquired on June 8, 2002 of ETM+ band 6, MODIS bands 31 and 32 are shown in Figure 2. Here, BT of ETM+ band 6 and that of MODIS bands 31 and 32 were computed by Equations (1) and (2), respectively. Furthermore in these Equations, the adjustment parameters of atmospheric effect (τ) and emissivity effect (ε) were assumed to be 1. From Figure 2 it is found that the range of BT is approximately 20-60 ℃. In addition, BT of desert of MODIS band 32 image seems a little higher than the other images.
For accurate comparison of BT's retrieved from the data of band 6 of ETM+ and MODIS bands 31and 32, following data processing was performed. (1) Correction of geometric distortions of the data in reference with the ground control points which had been accumulated during the Japan-China Joint Study of Desertification; (2) Resampling of MODIS data of 1 km×1 km size to make (900 m×900 m) pixels so that each MODIS pixel contains exactly 225 ETM+ (60 m×60 m) pixels; since the difference of the sizes of the original and resampled pixels is small the Nearest Neighborhood Method was adopted for resampling; (3) Five clear pixels of MODIS were selected from each category of landcover within the area of ETM+ image; (4) For each of 20 landcover categories, statistical values such as mean, standard deviation, maximum and minimum values, ranges, and ratios of the number of samples belonging to m (mean) ±1 and 2 σ (standard deviation) of 20 categories were computed for each of 5 ETM+ images corresponding to 5 selected pixels of MODIS image; (5) The average values of the items listed above were computed from the above stated 5 ETM+ image samples.
In here, some noteworthy features of the BTs of ETM+ are pointed out.
(A) Surprisingly large range for specific targets: 16.04 ℃ for shading side of rocky hill and 14.04 ℃ for the oasis farmland, while comparatively small range for the flat area of desert with the value of 2.25 ℃. The reason of large range of the oasis farmland is due to the fact that subdivided farmlands are surrounded with tall wind and sand break forests. The low temperatures of the tree leaves and shadows of the forests contribute to the large range.
(B) Reflecting the large values of ranges, the shading side of rocky hill and the oasis farmland show large standard deviation. The oasis farmland shows the largest value of 2.88 ℃ while for the flat area of desert shows the smallest value of 0.45 ℃. Since number of sample of MODIS is only 5 the standard deviation of MODIS data was not computed.
(C) As to BT the observation time of MODIS is nearer to the local noon than that of ETM+ by about 30 minutes therefore the BTs of MODIS is generally higher than those of ETM+ except sunny side of rocky hills and the beach of the upper reach of the large river which have slightly higher BTs than MODIS. The reason is that the slope of the sunny side of these places with a favorable orientation for the sun received more sun radiation and was warmed up than other places.
(D) Among the BTs of ETM+ for different landcover categories the top 3 ranking BT of the target in the descending order is (1) sandy desert and sand dunes, (2) grassland and river beach of the lower reach of the large river, and (3) desert of stone and pebble, and rocky hill (sunny side) while the top 3 bottom ranking in the ascending order is (1) reservoir, (2) oasis farmland with scattered bare land, and (3) rocky hill with dry vegetation (shading side).
(E) As to the distribution of the samples of ETM+ the distribution of the following categories are very close to the normal distribution: sunny side rocky hills, oasis farmland with scattered bright bare land and grass land near the upper reach of the large river.
The relations between BT of ETM+ band 6 and MODIS bands 31 and 32 are shown in Figure 3. From Figure 3, it can be seen that BT of ETM+ and that of MODIS bands 31 and 32 indicate high correlations, and the correlation coefficients are approximately 0.97. The regression equations between ETM+ band 6 and MODIS band 31 and 32 are

$$\begin{aligned} T_{31} &= 0.9625\times T_6 + 3.0097 \quad \text{(for Terra/MODIS band 31)}, \\ T_{32} &= 1.0140\times T_6 + 1.1312 \quad \text{(for Terra/MODIS band 32)} \end{aligned} \tag{3}$$



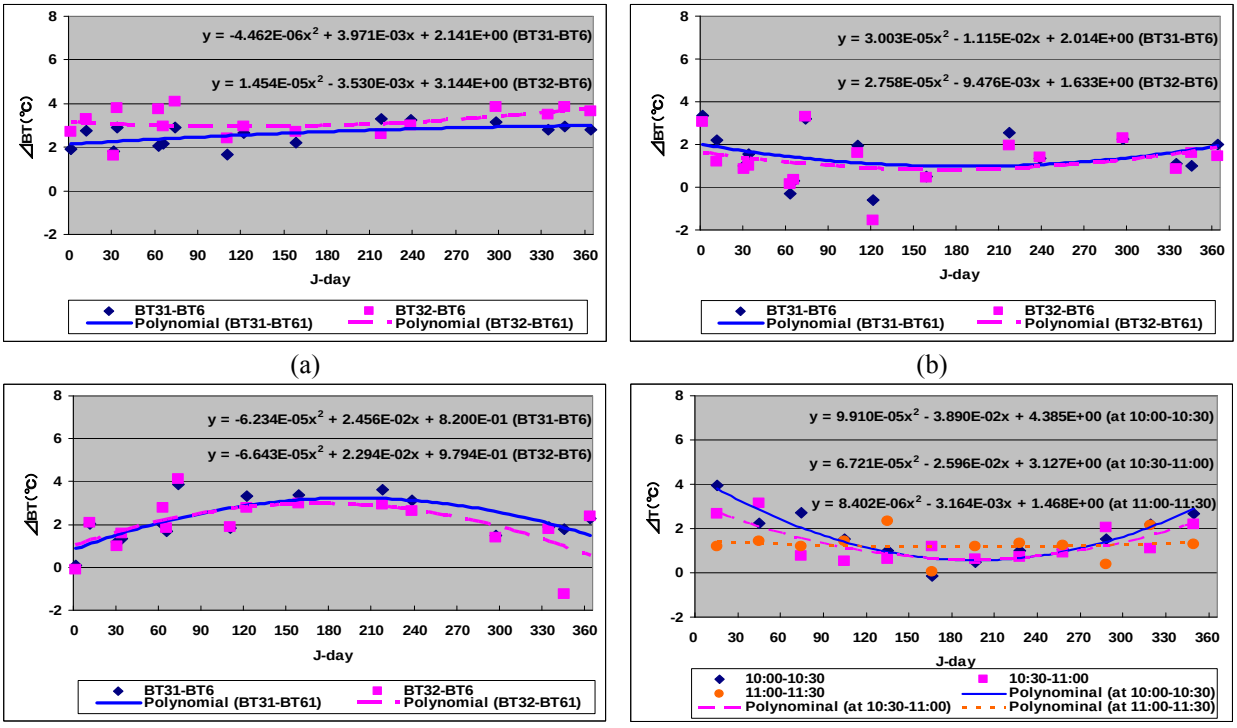
(a) (b) (c)

Figure 2: Brightness temperature images of Landsat-7/ETM+ band 6 (a), Terra/MODIS bands 31 (b), and 32 (c) over the Hotien Oasis in Taklimakan Desert observed on June 8, 2002.



(a) (b)

Figure 3: Comparison between the brightness temperatures obtained from band 6 of Landsat-7/ETM+ and Terra/MODIS bands 31 (a) and 32 (b).



(a) (b)

(c) (d)

Figure 4: Seasonal changes of the difference of brightness temperatures obtained from band 6 of Landsat-7/ETM+ and Terra/MODIS bands 31 and 32 for the flat area of desert (a), the oasis reservoir (b) and the oasis farmland (c), the seasonal change of the difference of ground surface temperature for a black rubber sheet on the roof observed by automatic weather station at Hiroshima, Japan (d).

4.2 Seasonal Changes of the Difference of BTs Retrieved from the Data of ETM+ and MODIS

For the flat area of desert, the oasis reservoir and the oasis farmland, the seasonal changes of the difference of BTs retrieved from ETM+ band 6 and that of MODIS bands 31 and 32 over Hotien Oasis acquired from 16 images listed in Table 3 are shown in Figure 4. Here the adjustment parameter of emissivity effect (ε) was set to be appropriate values (Wan, 2008) although the adjustment parameter of atmospheric effect (τ) was assumed to be 1. As the reference, the seasonal change of the difference of ground surface temperature for a black rubber sheet on the roof observed by automatic weather station at Hiroshima Institute of Technology, Japan is also shown in Figure 4. From Figure 4, in the seasonal changes of difference of BTs, the parabola opens upward in the flat area of desert and the oasis reservoir although the parabola opens downward in the oasis farmland. Furthermore, in the difference of ground surface temperature of a black rubber sheet on the roof, the parabola opens upward and temperature differences on January and June are approximately 2.7 ℃ and 0.6 ℃.

5. CONCLUSION

The result of the analysis lead to the following conclusions
(1) Good linear relationship between the retrieved BTs from the data of Landsat-7/ETM+ band 6 and those of Terra/MODIS bands 31 and 32.
(2) BT retrieved from the data of Terra/MODIS is slightly higher than that of Landsat-7/ETM+, however considering the observation time of Terra/MODIS is approximately 30 minutes nearer to the noon, it can be concluded that the value of BT of MODIS will be equal to that of ETM+ if adjustment for the observation time difference is made.
(3) Comparing of the retrieved BT of the targets from the observed data of Terra/MODIS band 31 and 32, the values of band 31 are slightly higher than that of band 32 over the water while with opposite trend over the desert and vegetated area.
(4) The standard deviation and range of BT of Landsat-7/ETM+ corresponding to one pixel of Terra/MODIS are 0.45 ℃, 2.25 ℃ for the flat area of desert while respective values of the oasis farmland and shading side of rocky hill amount to 2.88 ℃, 14.04 ℃, and 2.80 ℃, 16.04 ℃.
(5) In the seasonal changes of difference of BTs obtained from Landsat-7/ETM+ band 6 and that of Terra/MODIS bands 31 and 32, the parabola opens upward in the flat area of desert and the oasis reservoir although the parabola opens downward in the oasis farmland.

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