Validation of Landsat 7 ETM+ band 6 radiometric performance

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ABSTRACT

Since shortly after launch the radiometric performance of band 6 of the ETM+ instrument on Landsat 7 has been evaluated using vicarious calibration techniques for both land and water targets. This evaluation indicates the radiometric performance of band 6 has been both highly stable and accurate. Over a range corresponding to a factor of two in radiance (5 to 55 C in kinetic temperature terms) the difference between the in-situ derived radiance and the image derived radiance is on average 0.5% or less. Water targets are the easiest to use but are limited to the temperature range from 0 to about 32 C. Land targets can reach 55 C or more but are far less spatially homogeneous than water targets with respect to both local surface temperature and spectral emissivity. The techniques used and the results are described.

Key Words: Landsat 7, ETM+, radiometric, thermal, TIR, validation, vicarious calibration, calibration

1. INTRODUCTION

The Enhanced Thermal Mapper plus (ETM+) is a 8 band multi-spectral high spatial resolution imaging instrument flying on the Landsat 7 spacecraft since 15 April 1999[1]. One of these bands (band 6) is sensitive to thermal emission from the earth's surface and atmosphere in the 10-13 µm atmospheric window region. Band 6 operates in a wisk broom mode with a ground sample distance of 60 m and a cross-track swath width of 183 km. In this discussion, this band will be called a Thermal InfraRed (TIR) band as effectively all the energy reaching the instrument within the bandpass of band 6 comes from thermal emission from the earth's surface and atmosphere. Additional information on the ETM+ instrument, its operation and how to obtain data can be located through the USGS EROS Data Center web site at: http://edc.usgs.gov/products/satellite/landsat7.html

As part of a Landsat 7 validation effort, vicarious calibration measurements have been made, since the September 1999 through the early summer of 2005, of several water and a land target to establish estimates of the accuracy of the band 6 image radiance product. The Salton Sea, CA, Cold Springs reservoir, NV and Lake Tahoe, CA have been used for water targets and the Railroad Valley playa, NV has been used for the land target.

2. VICARIOUS CALIBRATION PROCEDURE FOR WATER AND LAND TARGETS

Water is a preferred target for satellite thermal emission calibration because it is uniform in composition, changes radiating temperature slowly, has a high and known emissivity and often exhibits low surface temperature variations (usually less than 1 C) over areas as large as several ETM+ pixels. The limitation in using water targets is that the surface radiating temperature range is limited to the freezing point of water on the low end and the low thirties in Centigrade at the high end. Since in some seasons many land targets are much warmer than 30 C, land targets are a valuable adjunct to water targets in the vicarious calibration of TIR bands on satellite instruments as they allow a much larger radiance range to be examined. Targets at higher altitude are preferred as there is less atmosphere between the surface and the instrument and usually the atmospheric column contains less total water vapor. One of the water sites used in this study, Salton Sea, is below sea level and often has over it column water amounts exceeding 3 cm. It was selected as a stringent test of the atmospheric correction procedure used not because it was an ideal vicarious calibration site. In addition, it has been noticed for both water and land targets that short term variations in emission are lower when the surface is not being actively heated (at night) than during the day. Although this is an advantage in terms of radiometry it is offset by the disadvantage of working in the dark.

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2.1 Water targets

The vicarious calibration procedure for water targets is similar to that used with land targets and will be described first. To provide an estimate of bulk water temperature, temperature measuring buoys (5 to 9 buoy) are dispersed over an area covering approximately 4 X 4 ETM+ pixels in area (240 X 240 m). These buoys measure and log the bulk water temperature at about 2-3 cm beneath the water surface. The bulk water temperature is not the radiating or kinetic temperature of the water surface that is sensed by ETM+ but this array of measurements does provide an objective estimate of how uniform the near surface water temperature is across the area of the array. To determine the difference between the bulk water temperature and the water surface radiating temperature, simultaneous measurements of the brightness temperature of the water surface are made with a radiometer near the location of one of the buoys. In addition to these temperature measurements several radiosondes are launched near the time of the expected ETM+ overflight to provide profile estimates of air temperature and relative humidity as a function of atmospheric pressure and sun photometer measurements are used to provide estimates of the time changes in atmospheric opacity and total column water vapor amount.

Using the atmospheric profiles of water vapor and air temperature derived from the radiosondes, the spectral emissivity of water and the spectral response of the radiometer, the water brightness temperature measurements are converted to surface kinetic temperature using a current version of the radiation transfer code MODTRAN[2]. From this derivation the bulk water to surface kinetic temperature difference is determined for the buoy nearest the radiometer and this difference is applied across the array of buoys. This difference has always been between plus/minus 1 C with almost all values being positive, i.e. the bulk water temperature is almost always greater than the derived water surface kinetic temperature as would be expected from the exchange of energy and matter occurring at the air/water interface. With the time of image acquisition known, the average derived water surface kinetic temperature is computed for the area of the array. In addition to deployable buoy arrays a coauthor (Simon Hook) is operating four large buoys on Lake Tahoe, CA that each are equipped with bulk water temperature measuring sensors and radiometers and these are also used to provide estimates of water kinetic temperature at those buoy locations. The Lake Tahoe large buoys are operated continuously and it is from this collection that the difference in variance between day and night brightness temperature measurements can be most clearly seen. Near real-time radiometric and other data from the Lake Tahoe buoys may be viewed at: http://laketahoe.jpl.nasa.gov

With the average surface kinetic temperature established across the array, the surface leaving radiance for band 6 can be computed using the spectral emissivity of water, the spectral irradiance of the sky derived using MODTRAN and the radiosonde profiles and the band 6 spectral response. In tern, the surface leaving radiance can, using MODTRAN and the radiosonde profiles, be projected to the top of the atmosphere through the use of the calculated atmospheric attenuation and path radiance.

2.2 Land target

The procedure for the land playa target used is similar to that for water targets with the exception that there is no equivalent to the bulk water measurements across the array. For the playa target a small array (2-5) of radiometers is used to estimate the average surface temperature across an area of similar size to that used for the water targets. The surface brightness temperature measured by the radiometers may be converted to a surface kinetic temperature in the same way outlined above for water surfaces. The spectral emissivity is separately measured sometimes in the field and always by returning samples (15) for spectral emissivity measurement in the laboratory.

The area on Railroad Valley Playa used for the vicarious calibration of ETM+ was selected based on using the NASA aircraft scanners TIMS and MASTER to locate a large region of low brightness temperature variance when the scanners were operated at relatively high spatial resolution (20 m). The playa surface is nearly flat and has very low local relief (generally less than 1 cm). However, the average spectral emissivity of the surface does change with time and location and only spectral emissivity measurements made at or near the time of the satellite overflight will provide estimates of the surface spectral emissivity appropriate for use with that overflight. In addition, the time history of brightness measurements over especially short (seconds to a few minutes) time periods most often displays very much higher maximum to minimum values than is ever seen with water targets. The most difficult aspect of this playa target for TIR vicarious calibration is the scale difference between the total area being measured by the radiometers (a few hundred centimeters) and that viewed by even a single ETM+ pixel (several thousand meters). It is likely that the biggest source of error lies in the fact that radiometer measurements of the surface emission are not representative of the area being viewed by the satellite instrument.

2.3 Comparing water and land in-situ measurements with ETM+ thermal images

To provide the image based estimate for comparison with the in-situ measurements, ETM+ level 1R or 1G data is registered to a UTM map base and checked with GPS derived locations within the image. The average value of at sensor radiance for the buoy array or radiometer array area is then extracted from the ETM+ band 6 image. At this point the image based average radiance estimate can be converted to an average water or land surface kinetic temperature using the spectral emissivity of water or land, the ETM+ band 6 relative spectral response and the radiosonde based atmospheric profiles. As an alternate the average surface kinetic temperature derived from the in-situ measurements can be projected through the atmosphere allowing an at sensor (or top-of-the atmosphere) comparison of spectral radiance. In practice both are usually done.

3. RESULTS AND DISCUSSION

3.1 Early results

Vicarious calibration for ETM+ began in September 1999 with a field campaign at Lake Tahoe. By the fall and winter of that year it became clear that the at sensor atmosphere radiance derived from in-situ measurements significantly differed from the at sensor atmosphere radiance derived from the band 6 images as illustrated by the lower curve and associated data points of figure 1. The slope of a linear fit to these data was however near unity indicating a constant offset (about 0.3 W/m2/sr/µm) in radiance between the in-situ and image derived radiance across the entire radiance range explored. Fortunately the Landsat validation effort included two investigations of the ETM+ band 6 inflight calibration and the second effort, which used different methods in a different part of the US, and was headed by John Schott reported similar results[3].

The dominant factors in the on board calibration system used for ETM+ are the internal “black body” and an internal shutter whose temperatures are measured and whose emissivity was known. Determining the gain of the system depends on measurement of both the internal black body and the internal shutter. The offset for the system is primarily dependent on measurement of the internal shutter but also depends on assessing the thermal contributions from five other elements of the system (scan line corrector, central baffle, secondary mirror and mask, primary mirror and mask and scan mirror). The coefficients which determine the contribution of each of these five elements to the offset were derived empirically using a least squares fitting procedure on instrument data obtained using two external calibration black bodies in the laboratory. These coefficients account for the internal surfaces “seen” by the detectors other than the internal calibration black body, shutter and scene. In addition they tend to account for emissivity deviation from unity for the shutter and internal calibration black body. Because the laboratory setting and the combination of temperatures used for the various components in the instrument during the laboratory tests can never be expected to perfectly duplicate flight conditions it was assumed that the offset detected in the two vicarious calibration efforts arose from this difference. A decision was made to adjust the calibration equations used in the ground calibration to remove this offset and a revised calibration procedure was implemented in the fall of 2000[4]. More recently (October 2003) it was discovered that the scaling coefficient used to convert data numbers to radiance for the scan line corrector component temperature was incorrect. The effect is to produce an offset like that observed. The implications of this discovery are still being explored.

The upper curve in figure 1. displays the vicarious calibration results using images processed with the new procedure from February of 2001 through May of 2003. For these data no offset is evident and the slope appears near linear

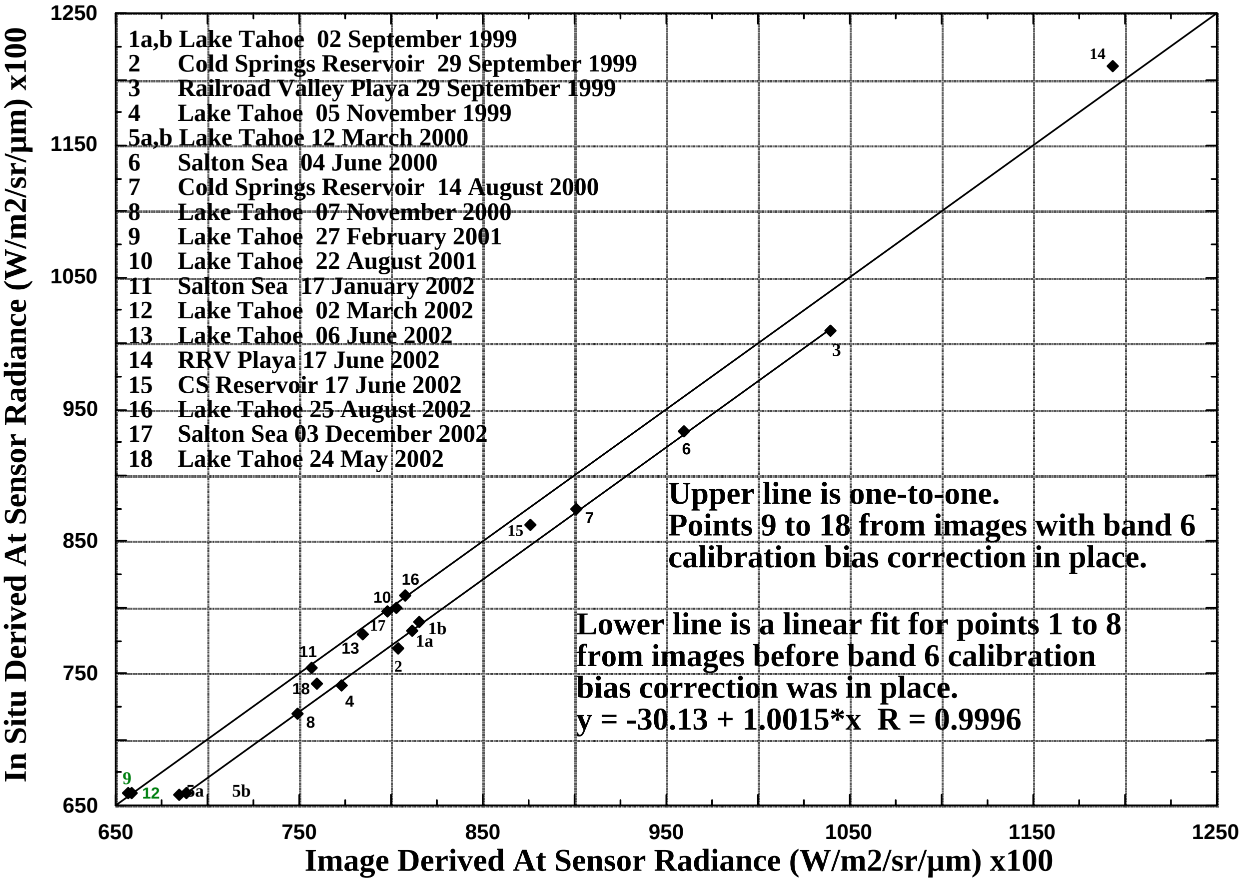

Figure 1: In-situ versus image at sensor radiance at Lake Tahoe, Salton Sea, Cold Springs reservoir and Railroad Valley Playa from September 1999 through May 2002. Data points were taken from band 6 images both before and after the band 6 calibration bias correction was implemented as indicated in figure text.

over nearly a two to one radiance range (~5 to 55 C in kinetic energy terms). When the two data sets are combined (accounting for the offset in the early data) the one sigma measure of deviation for the set is only the equivalent of a few tenths of a degree Centigrade lending confidence that the at sensor radiance in ETM+ images is known to better than 0.5 % for the radiance range and time period monitored.

3.2 Scan line corrector off

On 31 May 2003 the ETM+ experience a failure of its scan line corrector[5]. The scan line corrector consists of two mirrors which are in the optical path from the scene to the detectors. One of the questions associated with this loss of function was would the thermal band calibration be affected. Figure 2. displays data collected over that last eighteen months at Lake Tahoe, Salton Sea and Railroad Valley playa. All the data points below a radiance of 8.5 W/m2/sr/µm were obtained from the large buoys on Lake Tahoe. The two data points near 9.3 W/m2/sr/um are from the Salton Sea and the high radiance points are from Railroad Valley playa. Although the deviations from a one-to-one line are larger for several of the data points than was the case in figure 1. the larger deviations are likely due to the larger uncertainty inherent in using a land target for the high end radiance and the large values of column water vapor encountered at the Salton Sea for the particular field campaigns involve. It appears that the loss of scan line corrector function has not significantly altered the high quality of the band 6 radiances ETM+ is returning.

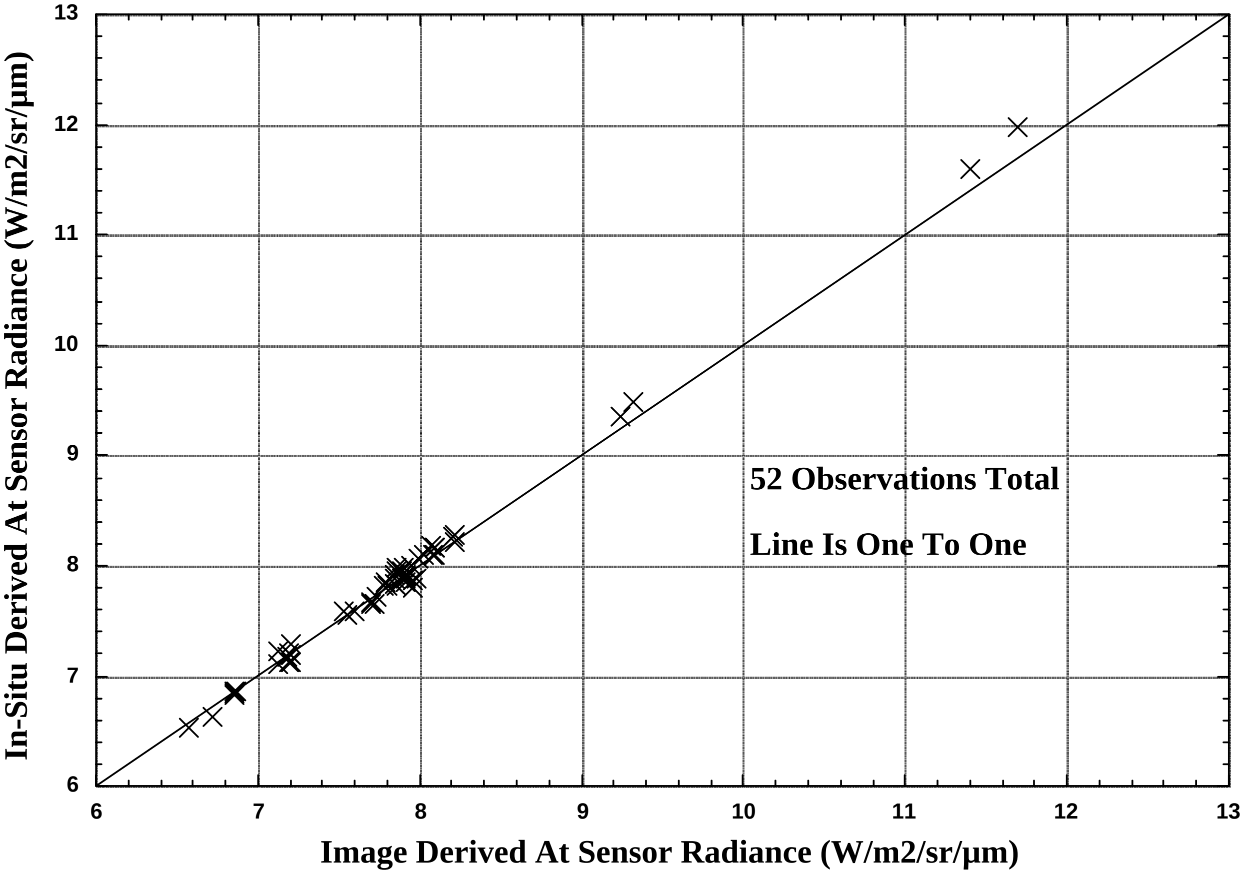

Figure 2: In-situ versus image at sensor radiance at Lake Tahoe, Salton Sea and Railroad Valley Playa from June 2004 through March 2005.

4. CONCLUSIONS

In-situ vicarious calibration techniques have been successfully applied in the validation of the Landsat 7 ETM+ band 6 thermal radiance. In the process, a large radiance offset was discovered and subsequently removed from band 6 image data. The inclusion of two investigators conducting TIR validation on the Landsat 7 Science Team was very helpful in quickly establishing the radiance offset discovered was real. Continued monitoring indicates the ETM+ band 6 operation has been very stable and accurate to better than 1% in terms of the at sensor atmosphere radiance. Although the ETM+ scan line corrector has ceased to function there is no clear evidence the TIR band 6 radiometric performance has been affected.

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