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EOS ASTER Thermal Infrared Band Vicarious Calibration

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ABSTRACT

Calibration of the five EOS ASTER instrument emission bands (90 m pixels at surface) is being checked during the operational life of the mission using field measurements simultaneous with the image acquisition. For water targets, radiometers, temperature measuring buoys and local radiosonde atmospheric profiles are used to determine the average water surface kinetic temperature over areas roughly 3 X 3 pixels in size. The in-band surface leaving radiance is then projected through the atmosphere using the MODTRAN radiation transfer code allowing an at sensor radiance comparison. The instrument at sensor radiance is also projected to the water surface allowing a comparison in terms of water surface kinetic temperature. Over the first year of operation, the field measurement derived at sensor radiance agrees with the image derived radiance to better than ±1% for all five bands indicating both stable and accurate operation.

1. INTRODUCTION

ASTER (Advanced Spaceborne Thermal Emission and reflectance Radiometer) is a 14 band multi-spectral high spatial resolution imaging instrument[1] flying on the Earth Observing System (EOS) platform TERRA which was launched in December of 1999. Five of the 14 bands (bands 10-14) are wholly contained within the spectral region 8-12μm which is a window region for the earth's atmosphere as shown in Figure 1. These channels were included in order to provide estimates of surface kinetic temperature and surface spectral emissivity. In this discussion these bands will be called Thermal InfraRed (TIR) bands as effectively all the energy reaching the instrument at these wavelengths comes from thermal emission from the earth's surface and atmosphere. The TIR band positions were selected to maximize emissivity information from surface minerals, rocks and soils and the bandwidth was selected to provide a noise equivalent delta temperature (NEΔT) ≤ 0.3 C. The ground sample distance is 90 m and the cross-track swath width is 60 km. ASTER operates with an 8% duty cycle and has a goal of providing nearly cloud free images of the entire land area of the earth over the course of the planned six year mission. Additional information on the ASTER instrument, its operation and how to obtain data can be located through the U.S. ASTER science team Web site at: http://asterweb/.

ASTER images are acquired in a wisk broom mode using ten detectors in each band. In flight, the scanning mirror may be rotated to provide all detectors with a full aperture view of an on board temperature controlled blackbody. This blackbody may be stepped through four different temperatures. The response characteristics of each of the fifty detectors were determined before flight and are represented by a second order polynomial of the form $L = a_{0i} + a_{1i}*DN + a_{2i}*DN^2$. Where: L is the at sensor radiance, a_{0i} is the constant term for detector i, a_{1i} is the linear term for detector i and a_{2i} is the quadratic term for detector i. These 150 coefficients are provided in the meta data which accompanies each ASTER level 1A scene and are applied in ASTER level 1B scenes. In flight, for each group of scenes, the scan mirror is commanded to view the blackbody at ambient temperature (i.e. no heat applied) and this single measurement is used to set the a_0 coefficient for each detector for these scenes. Periodically at intervals of about a month the scan mirror is commanded to view the blackbody which is run and held at four different temperatures. temperatures. These measurements are use in a least squares procedure to provide an estimate of all three coefficients ~~for each detector~~.

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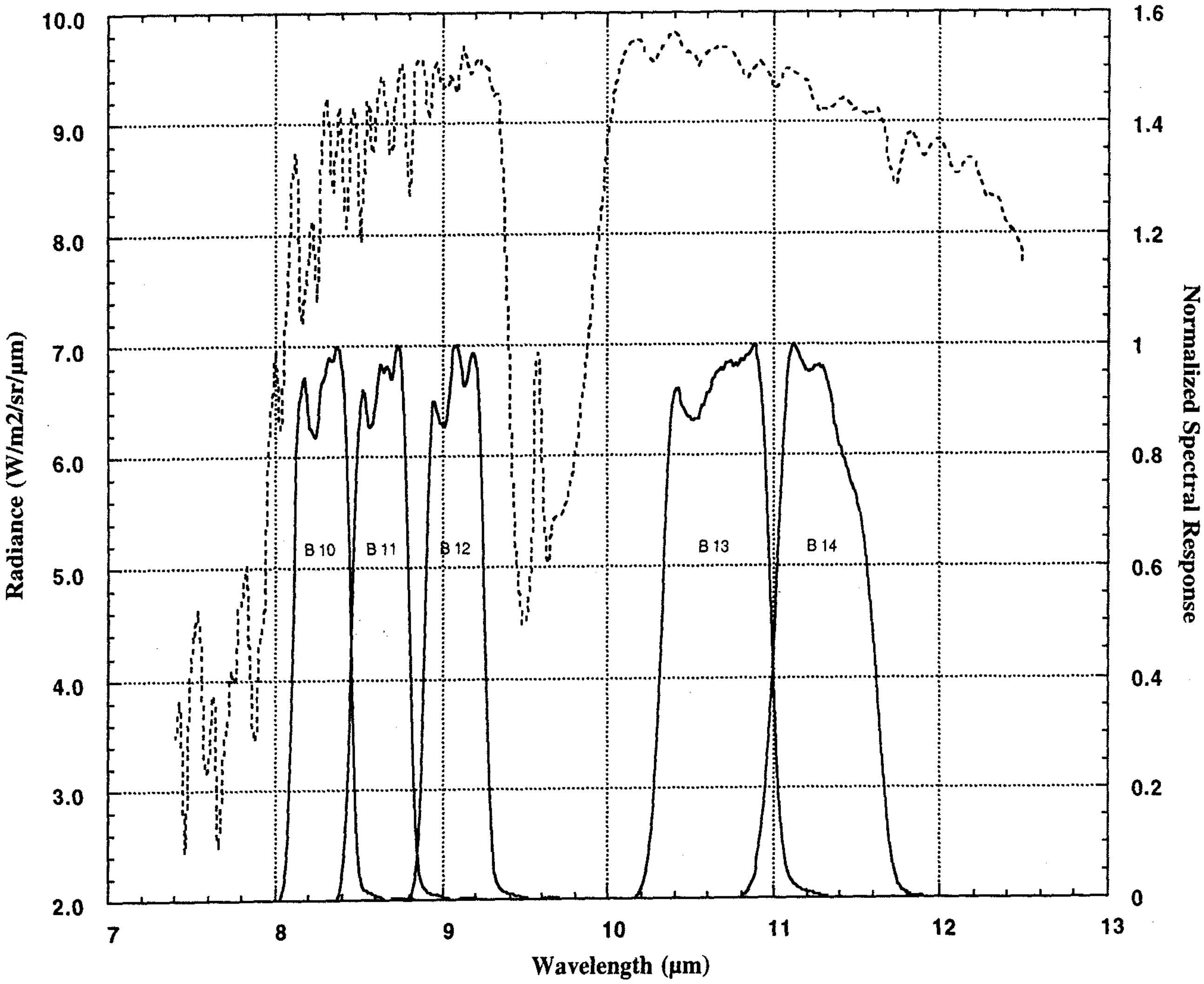

Figure 1 ASTER Thermal infrared band (B10-B12) normalized spectral response (solid curves) and typical at sensor radiance (dashed curve) for this spectral region..

In practice it has been found the constant term, as determined from the view of the blackbody at instrument ambient temperature, does not change significantly. The quadratic term is very small and it was decided before launch that, although it could be determined in flight, its values would not be changed. The linear term may change but for the results presented here a single set of values has been used for all reductions. These values were determine from an onboard calibration conducted in March 2000 and the database version for these coefficients is designated 1.01.

2. VICARIOUS CALIBRATION PROCEDURE FOR WATER TARGETS

Water is used as a target because it is uniform in composition, has a high and known emissivity, and often exhibits low surface temperature variation (≤ 1 C) over large areas. To provide an estimate of bulk water temperature we use temperature measuring buoys (5 to 9 buoys) dispersed over an area covering 3 X 3 ASTER pixels in area (270 X 270 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 which is sensed by ASTER. To determine the difference between the bulk water temperature and the water surface radiating temperature we simultaneously measure the brightness temperature of the water surface with a radiometer near the location of one of the buoys. In addition to these temperature measurements we also launch several radiosondes near the time of the expected ASTER overflight to provide an estimate of air temperature and relative humidity, sun photometer measurements are used to provide a measure of changes in atmospheric opacity and total column water vapor and near surface measurements are made of wind velocity, air temperature and relative humidity.

Using 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 the radiation transfer code MODTRAN. 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 ±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. With the time of image acquisition known, the average derived water surface kinetic temperature is computed from the buoys in the array. In addition to buoy arrays one of the authors (Hook) is operating four rafts on Lake Tahoe, CA which each are equipped with bulk water temperature measuring sensors and radiometers and these are also used to provide estimates of water kinetic temperature at the raft locations.

To provide the image based estimate for comparison, ASTER level 1B 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 area is then extracted for each of the five ASTER TIR bands. ASTER level 1B TIR image data contains 16 bit scaled radiance and the scaling factor is applied providing the average at sensor radiance for each band. At this point the image based average radiance estimate can be converted to average water surface kinetic temperature using the spectral emissivity of water, the ASTER band relative spectral response, the radiosonde based atmospheric profiles or the average water surface kinetic temperature can be projected through the atmosphere allowing an at sensor comparison of spectral radiance. In practice both are usually done.

3. RESULTS AND DISCUSSION

Two California Lakes have been used as targets. Lake Tahoe (1898 m elevation) and Salton Sea (-70 m elevation). These lakes provide a range in surface temperature from about 5 C for Lake Tahoe in the winter to 32 C for Salton Sea in the summer. This range in surface temperature provides about a factor of two change in radiance at the top of the atmosphere. Figure 2 contains the results of five discrete comparisons for each of the five ASTER thermal bands conducted over the first year and one-half of ASTER operation. On this plot perfect agreement for any band would be a straight line at 45 degrees.

Each band is well fit by a straight line with the maximum standard deviation being for band 10 at 0.68%. This indicates that instrument operation and calibration knowledge has been stable for the year and one half covered. In addition, no unexpected non linear behavior has been observed. Taking the best fit lines as representative of the instrument behavior indicates that the maximum deviation for any band is less than one percent in at sensor radiance over the range shown and the standard deviation for all five bands as a group is 0.36%. In the lower radiance range (5- 8 $W/m^2/sr/\mu m$) all five bands are similar while at the upper end of the range (9- 10 $W/m^2/sr/\mu m$) the behavior of band 10 and 12 are beginning to deviate from the other three though this deviation is in opposite directions for these two bands.

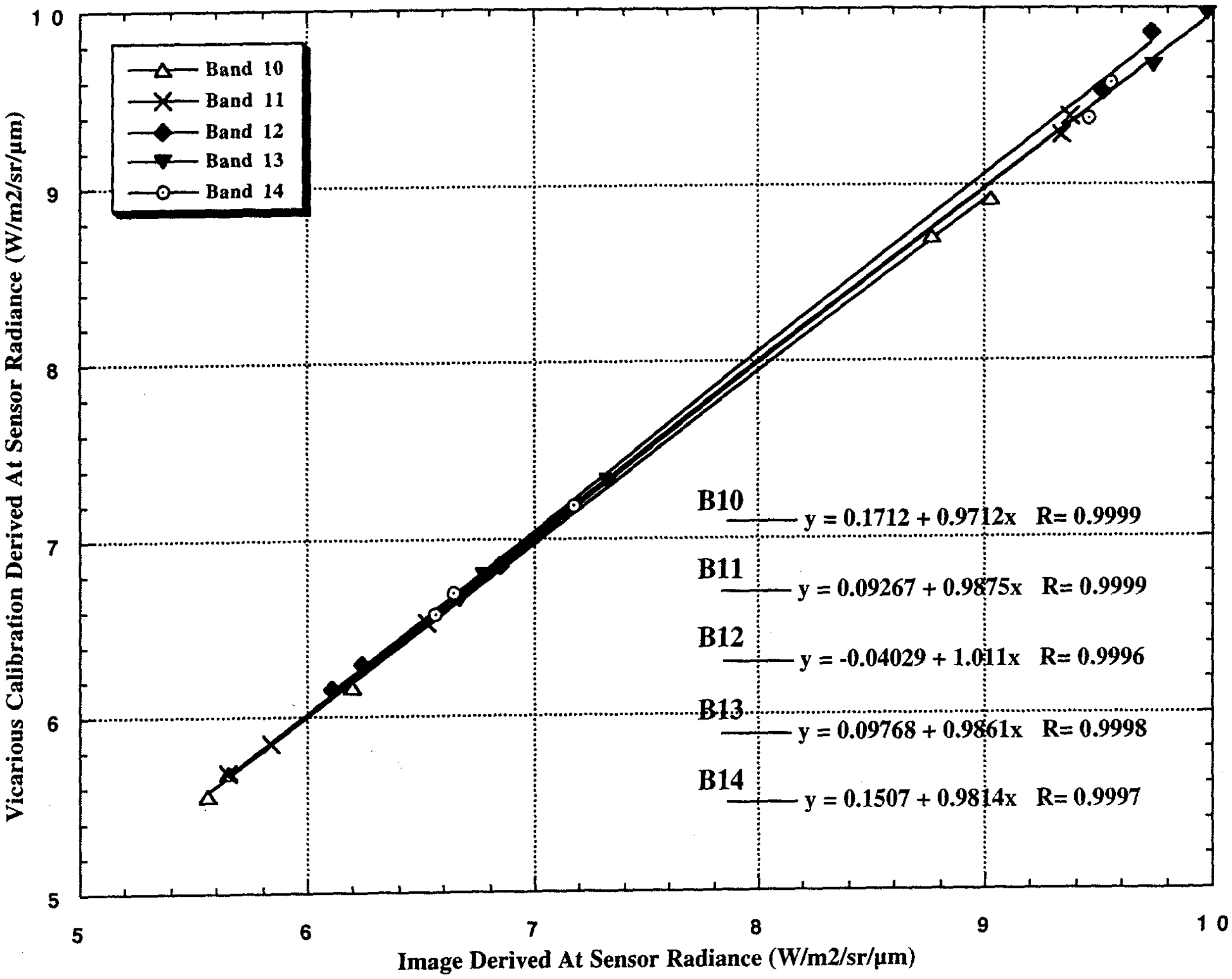

Figure 2 An at sensor radiance comparison. The ordinate marks the at sensor radiance derived from surface measurements and the abscissa the corresponding quantity obtained from a registered level 1B image. The data were obtained from Lake Tahoe on 12 March/07 November 2000 and 27 February 2001 and Salton Sea on 04 June/07 August 2000.

An idea of the precision of the vicarious calibration can be obtained from Figure 3 where the deviations from the linear fits for each band are displayed. The largest deviations are 0.6%. In considering error sources, they likely lie with aspects of the procedure which are dependent on a single device type such as the absolute accuracy of the radiosonde measurements of air temperature and relative humidity. Both the thermistors used for bulk water temperature measurements and the radiometers are calibrated against laboratory standards and the equipment in use by three groups of ASTER investigators (Tonooka, Hook and Palluconi) have been compared in the field on multiple occasions with agreement at the 0.1 C level for the bulk water temperature measuring thermistors and the 0.2-0.3 C level for the radiometers. The benefit of having three groups making independent measurements is substantial, both at leading to equipment improvements and improvements in procedures.

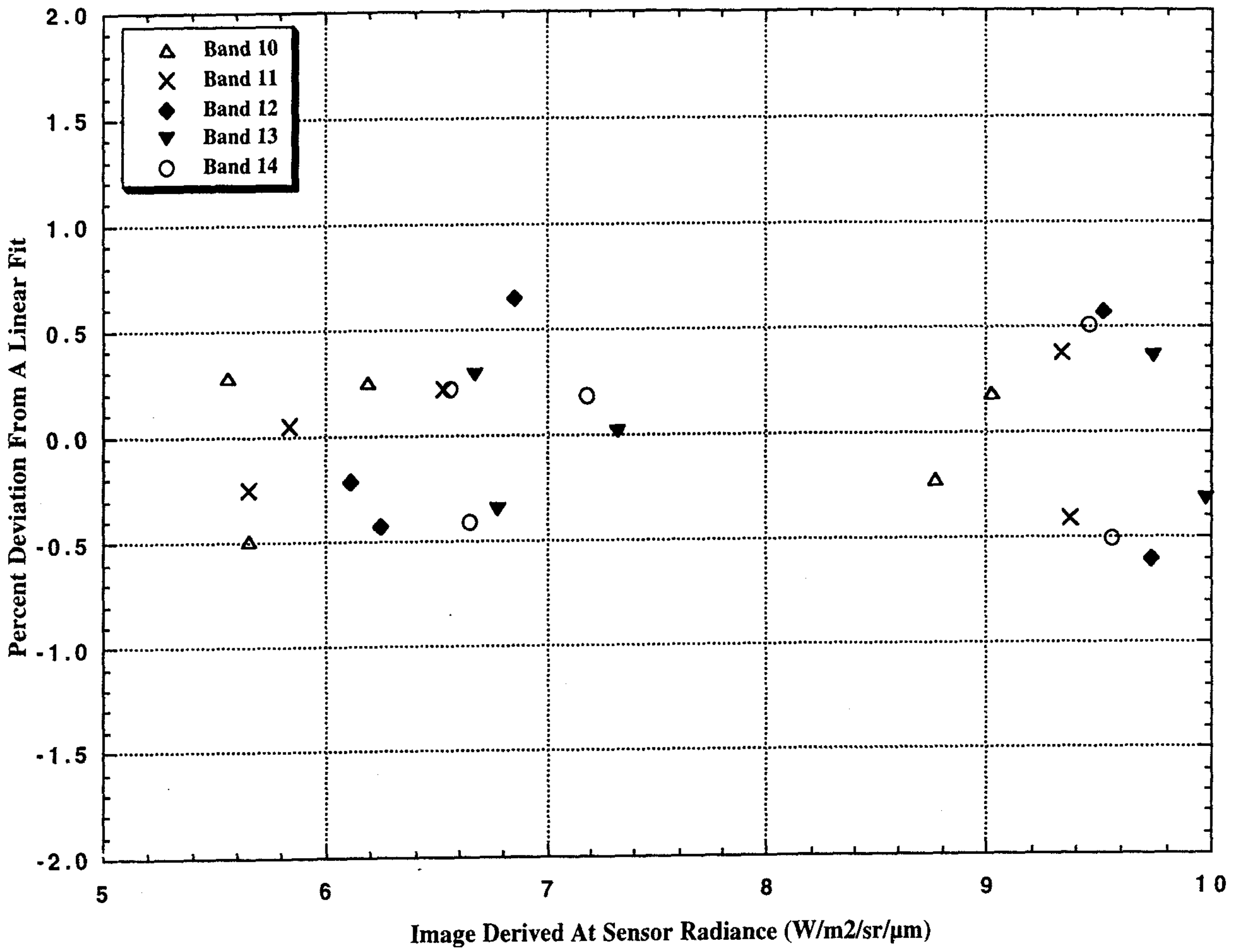

Figure 3 Deviation of the at sensor radiance from the linear fits of Figure 2 for each of the five ASTER TIR bands.

4. CONCLUSIONS

Using water targets the inflight calibration of the five ASTER TIR bands has been shown to be stable for the first 1.5 years of operation and its accuracy is know to ±1% or better over the 5-10 $W/m^2/sr/\mu m$ at sensor radiance range.

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REFERENCE

1. Kahle, A. B., F. D. Palluconi, S. J. Hook, V. J. Realmuto, AND G. Bothwell, "The Advanced Spaceborne Thermal Emission AND Reflectance Radiometer (ASTER)", *Int. J. Imag. Sys. Tech.*, **3**, pp. 144-156, 1991.