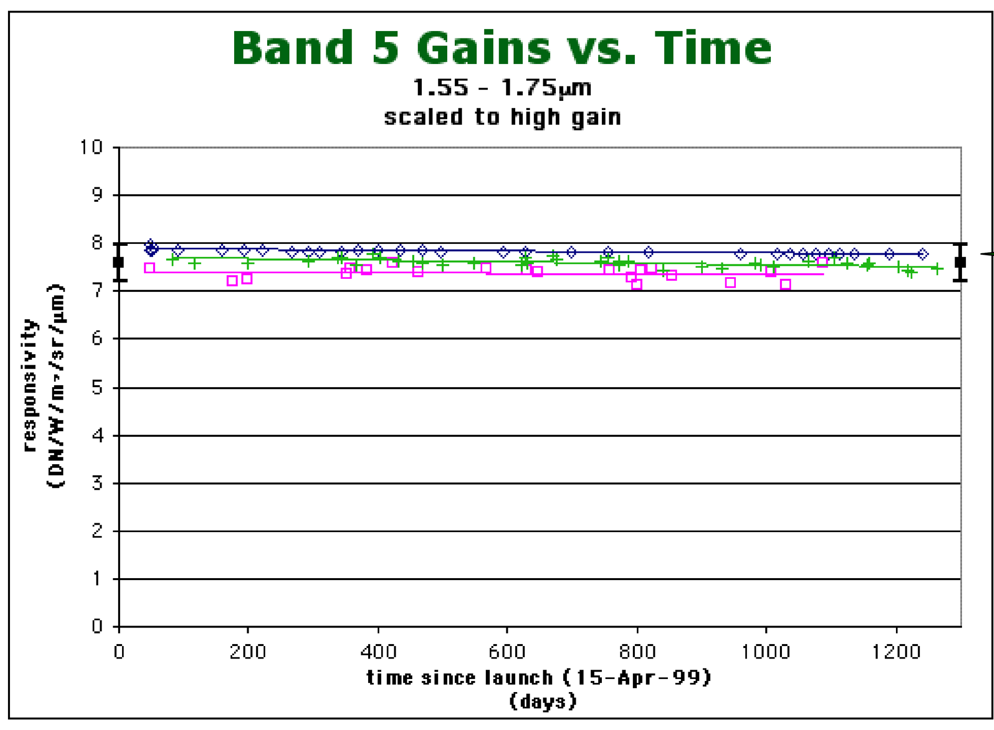
Landsat-7 ETM+ Radiometry: Satellite, Image and Ground Calibration

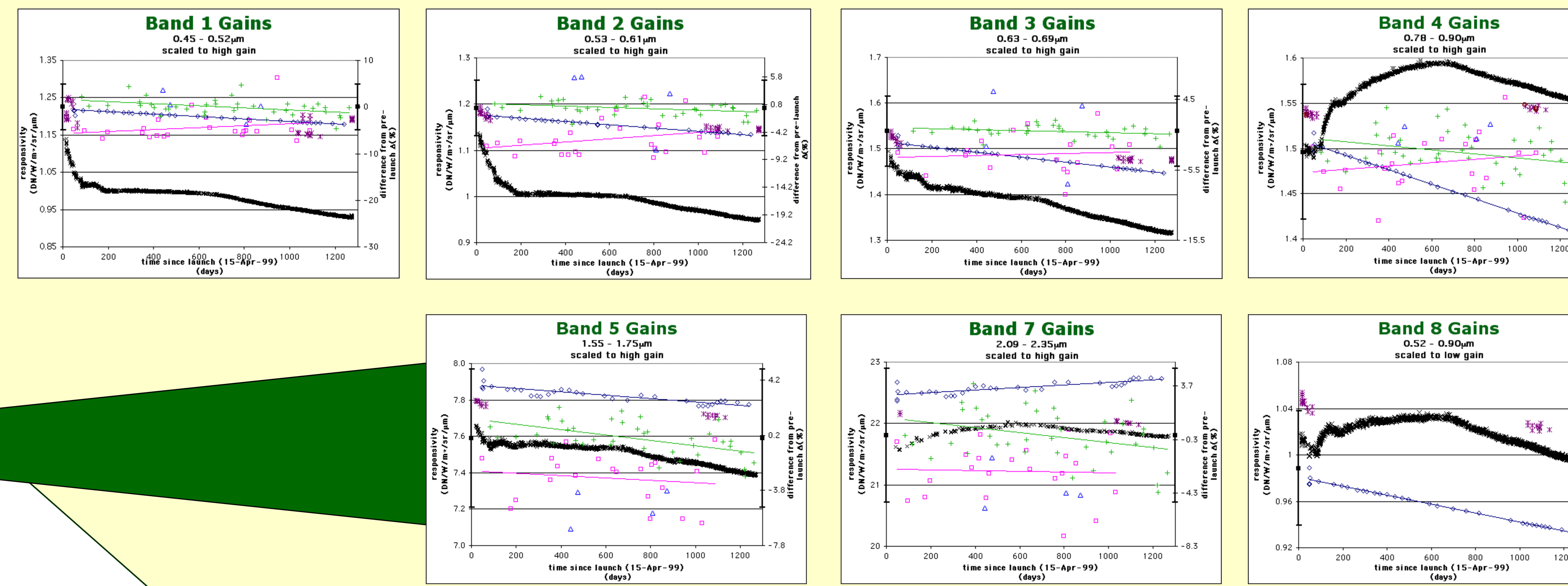
Brian Markham[1], Julia Barsi[1], Ed Kaita[1], Kurt Thome[2], Dennis Helder[3], John Schott[4], Frank Palluconi[5], John Barker[1]

[1]Goddard Space Flight Center, Greenbelt, MD
[2]University of Arizona, Tucson, AZ
[3]South Dakota State University, Brookings, SD
[4]Rochester Institute of Technology, Rochester, NY
[5]NASA/Jet Propulsion Lab, Pasadena, CA

(as of 15-Oct-02)

Reflective Bands 1-5, 7, 8: Stable and Accurate





- **Relative Stability: ±0.1%** (FASC fit uncertainty)
- **Relative Accuracy: <±1%/year** (slope uncertainty)
- **Absolute Accuracy: ±2%** (different methods)

Radiometric Calibration Methods (sampling per year)

Instrument Based Calibration
- × Internal Calibrator, primary lamp, high and low gain state gains merged where available, data from IAS database, USGS/EDC, through 08-Oct-02 (~1500)
- ✳ Internal Calibrator, redundant lamp, high and low gain state gains merged where available, data from IAS database, USGS/EDC, through 08-Oct-02 (0-20)
- ◇ Full Aperture Solar Calibrator (10-12)

Image Based Calibration
- + Relative stability full-scene uniformity sites (scaled to pre-launch) (15-20)

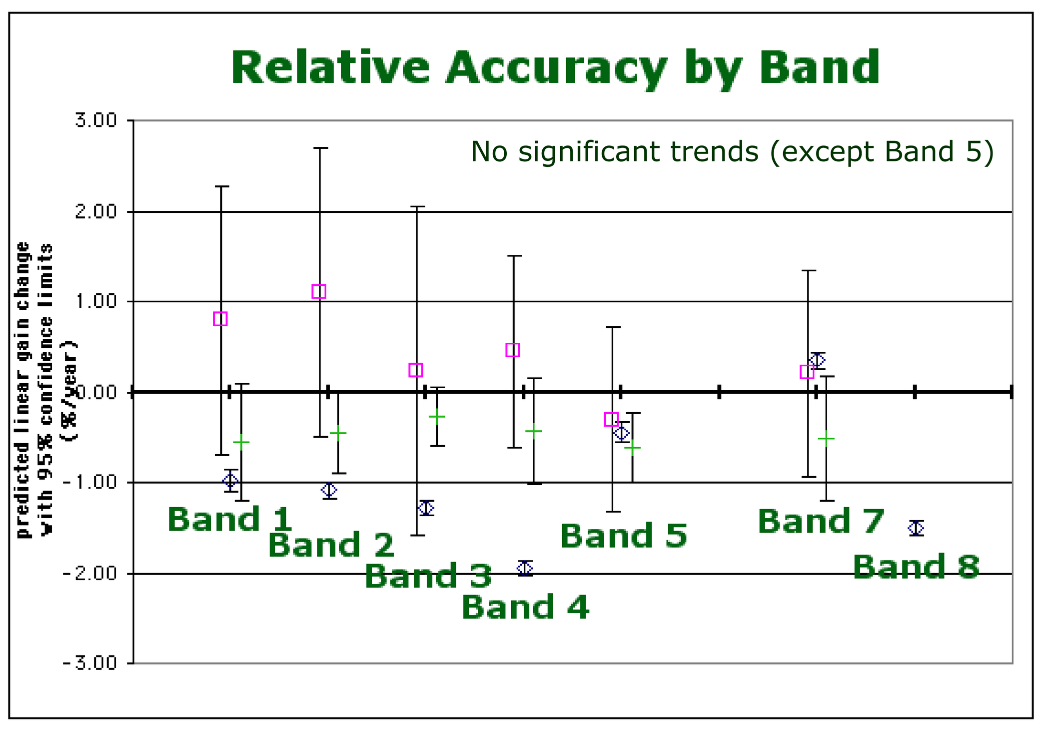
Ground Based Calibration
- □ University of Arizona absolute calibration (5-10)
- △ South Dakota State University absolute calibration (2-4)

Pre-Launch Absolute Calibration
- ■ Pre-launch (1)

The Landsat-7 ETM+ sensor has three on-board calibration devices for tracking radiometric calibration for the reflective bands, the Internal Calibrator (IC) lamps, the Full Aperture Solar Calibrator (FASC) panel and the Partial Aperture Solar Calibrator (PASC) pin-hole mirror. The IC consists of a lamp source and a black background on a shutter, viewed with every scan of the scanning mirror. Though the system has two lamp sources on the shutter, only a single lamp is used operationally. The "redundant" lamp has only been used a few times to date. System gains calculated based on the IC have shown anomalous behavior, thought to be associated with IC-related vacuum shifts, filament flares, instrument temperature and current, and lamp usage, so have not been used for calibration as of yet. The FASC is a solar diffuser panel, located outside of the instrument and deployed in front of the entrance aperture approximately once per month. The gains calculated based on the FASC acquisitions generally show downward trends across the reflective bands (0 to -2% per year), though this is mostly thought to be due to panel degradation. The PASC results have been anomalous and not well understood, so will not be discussed here.

Science team members from University of Arizona (UAz) and South Dakota State University (SDSU) conduct ground look calibration campaigns in the western United States to validate the on-board calibration devices. The gains calculated based on the UAz campaigns may predict upward trends across the reflective bands (0 to 1.5% change per year) though none of the slopes are statistically significant.

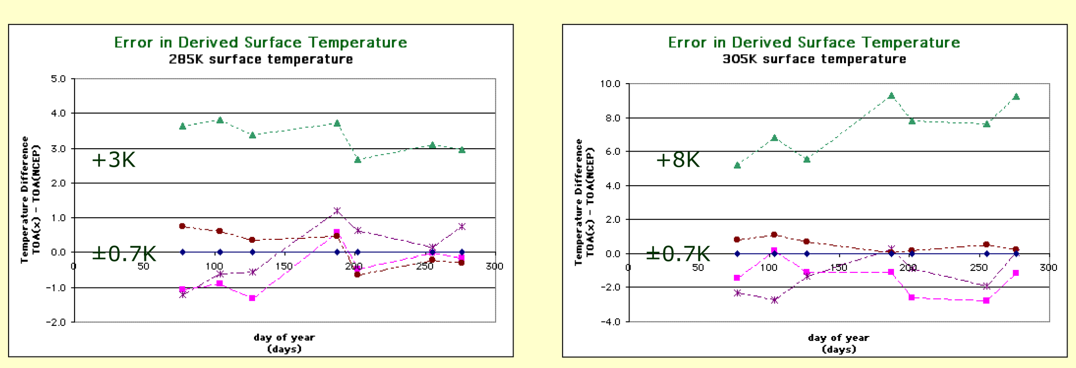
A recent addition to the calibration methods is a full-scene image based method. Though this method was initially incorporated strictly to monitor stability, scaling the relative stability results to the pre-launch gains presents a relative monitor of gain change. Four radiometrically homogeneous scenes (CV = ±3-6%) have been monitored, four times per year since launch. Gains calculated based on this method, referred to as "relative stability full-scene uniformity sites", may show downward trends in all bands (0 to -0.75% change per year), though only the slopes in Band 2 and Band 5 are statistically significant.



- Comparison of instrument change as indicated by %/year and the 95% Confidence Interval on the slope prediction and as predicted by the three most stable calibration methods indicates that the trends exhibited by the FASC are probably due primarily to FASC-related degradation, with the exception of Band 5.
- Band 5, with all three methods predicting a change of ~-0.5%/year, will be considered for updating when the Calibration Team meets in December.
- Otherwise, with no strong indication of change, the processing system continues to use the pre-launch determined gains to calibrate the imagery ordered by users.
- The limits of radiometric change, as shown by the radiometric accuracy, indicate the ETM+ is stable enough to be used as an EOS reference standard.

Derivation of Surface Temperature

- **3-8K high without correction**
- **±0.7K with correction**



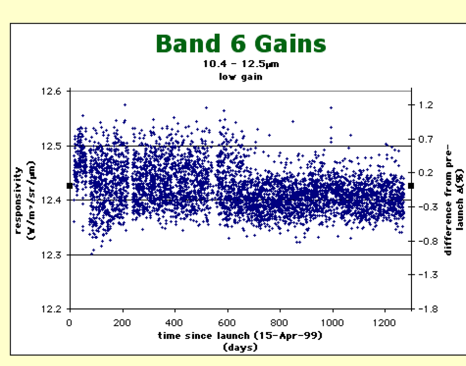
Atmospheric Correction Methods
- ▲ None
- ■ MODTRAN standard atmosphere
- ✳ MODTRAN standard atmosphere corrected for local surface conditions
- ● MODTRAN standard atmosphere corrected for local column water vapor

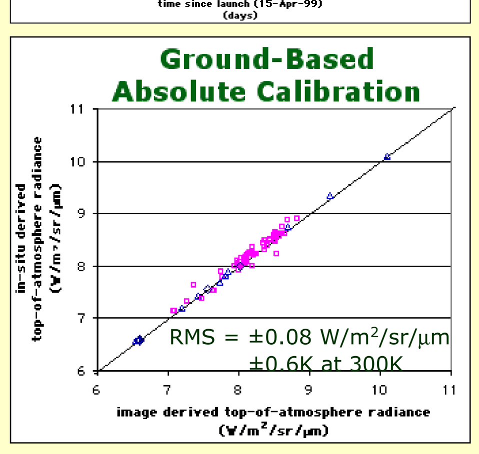
While atmospheric correction for a single band thermal instrument requires more knowledge of the atmosphere than for a multi-band thermal satellite imager, an illustrative error analysis of various methods of atmospheric correction of Landsat-7 thermal data shows that almost any atmospheric correction is adequate, depending on the level of accuracy required. This error analysis compares the top-of-atmosphere (TOA) temperature for two different surface temperatures predicted using a radiative transfer model for an assortment of estimates of the atmosphere and for a localized profile of the atmosphere. While still more complicated than performing a split-window technique, the results show that as long as almost any type of atmospheric correction is performed, the error in TOA temperature will be approximately random and within a standard error of ±0.5 at 285K or ±0.8K at 305K over a representative land surface.

The study made use of MODTRAN 4.0 as the radiative transfer model. The National Centers for Environmental Prediction (NCEP) Global Assimilation Data System provided the local profiles. Atmospheric profiles were chosen for cloud-free dates, once per month over the Washington, DC area, from March through October, 2001. The atmospheric correction results from the NCEP profiles served as truth in this error analysis.

Thermal Band 6: Stable and Accurate

- **Relative Stability: ±0.2%** (fit uncertainty)
- **Relative Accuracy: ±0.1%/year** (slope uncertainty)
- **Absolute Accuracy: ±0.6K at 300K** (different methods)



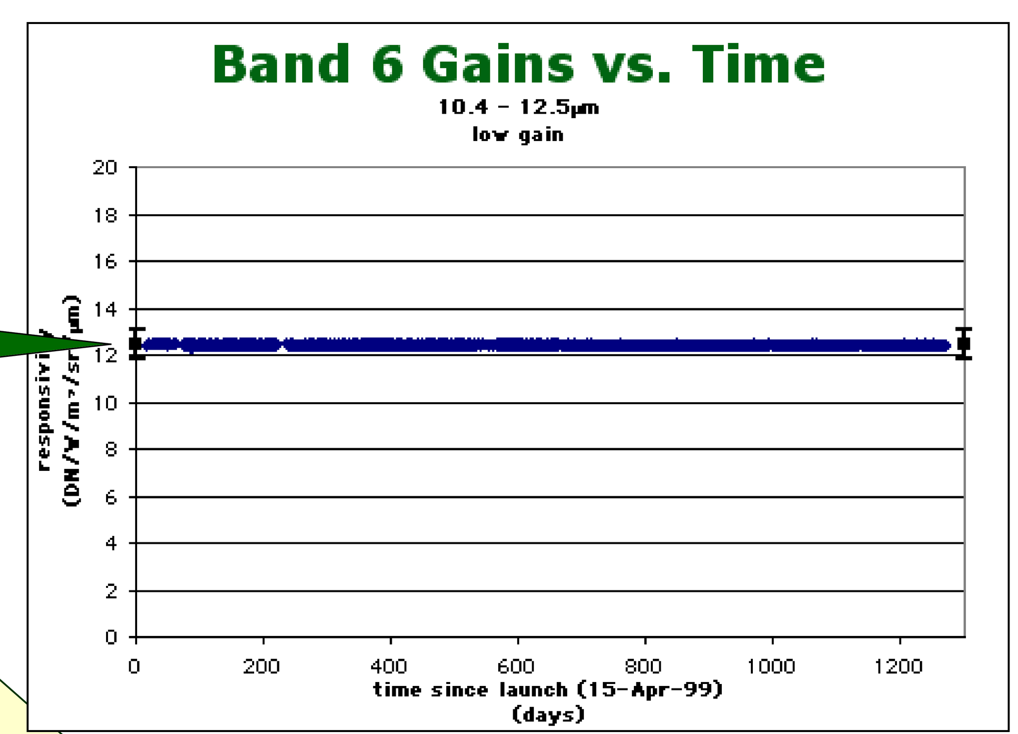


Radiometric Calibration Methods (sampling per year)

Instrument Based Calibration
- ◆ Blackbody Calibrator, low gain state gains, data from IAS database, USGS/EDC, through 08-Oct-02 (~1500)

Ground Based Calibration
- △ NASA/Jet Propulsion Laboratory absolute calibration (5-10)
- □ Rochester Institute of Technology absolute calibration (15-25)

Pre-Launch Absolute Calibration
- ■ Pre-launch (1)



The Landsat-7 ETM+ sensor has a single on-board calibration device for tracking radiometric calibration for the emissive thermal band; the Internal Blackbody Calibrator (BB) which also functions as a reflective band calibration source, consists of a hot blackbody and an ambient temperature background and is viewed with every scan of the scanning mirror. The gains calculated from the BB for the thermal band have been stable to within ±0.2% since launch, with no significant slope.

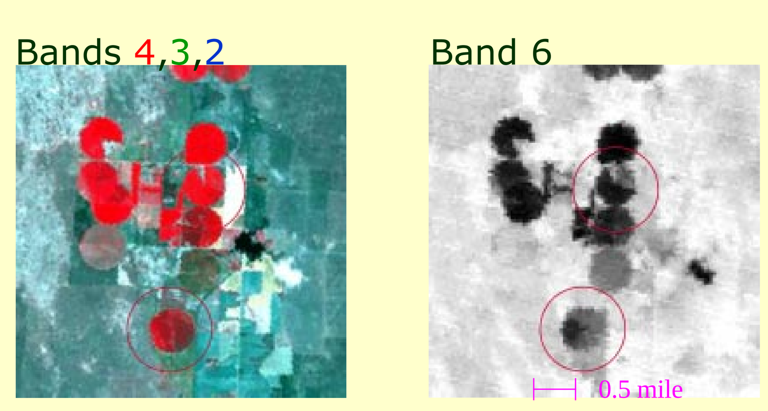
Science team members from NASA/Jet Propulsion Laboratory (JPL) and Rochester Institute of Technology (RIT) conduct ground look calibration campaigns to validate the on-board calibration devices. Neither group has detected an error in gain, though initially they discovered a 0.31 $W/m^2/sr/\mu m$ (~3K at 300K) error in offset. This offset error correction was fully implemented in the processing system by 01-Jan-01. Since then, neither team has detected any residual offset, with an RMS error of ±0.08 $W/m^2/sr/\mu m$ or ±0.6K at 300K.

Thermal Band 6 Irrigated Pivot Fields Sensitivity Example
Landsat Path 33/Row 32, acquired 10-Jul-99

In an example illustrating the sensitivity of the thermal band, these pivots in eastern Colorado are in various stages of irrigation. While the color-infrared image on the left displays the health of the vegetation, the thermal band, on the right, shows the pivots, and fractions of pivots, that are actively being irrigated. This was used as part of a study to investigate the sustainability of the Great Plains aquifers.

Notice the differences between the pivots circled in red. Both are cases where only a portion of the pivot is being irrigated.

Images courtesy of the Center of the Study of Earth from Space (CSES), University of Colorado Boulder.



Related References

The Science Data User's Handbook:
http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html

Markham, B.L, et. al. "Landsat-7 ETM+ Radiometric Stability and Absolute Calibration." SPIE Sensors, Systems, and Next-Generation Satellites, Vol. 4881. Sept 2002.

Barker, J.L., et. al. "Landsat-7 Mission and Early Results." SPIE Sensors, Systems, and Next-Generation Satellites, Vol. 3870, pp. 299-311. Sept 1999..