TWENTY-FIVE YEARS OF LANDSAT THERMAL BAND CALIBRATION

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1. INTRODUCTION

Landsat-7 Enhanced Thematic Mapper+ (ETM+), launched in April 1999, and Landsat-5 Thematic Mapper (TM), launched in 1984, both have a single thermal band. Both instruments' thermal band calibrations have been updated: ETM+ in 2001 for a pre-launch calibration error [1] and TM in 2007 for data acquired since the current era of vicarious calibration has been in place (1999) [2]. In the past two years, the vicarious calibration teams have made regular collects of very hot targets, and have been able to make use of archived buoy data to extend the TM calibration back in time. The new data has made it clear that both instruments require adjustments in their thermal calibration coefficients. These new coefficients will be generated and put into the operational processing system to remove the calibration errors.

The JPL vicarious calibration team has long operated automated buoys on Lake Tahoe for the purpose of vicarious calibration [3]. In 2008, the Salton Sea station became operational. Salton Sea, located in southern California, gets far hotter than Lake Tahoe. Vicarious calibration results of the Salton Sea for both instruments added to the understanding of a small gain error that the Tahoe data had suggested. With the Salton Sea data, an ETM+ gain error became statistically significant. Though it causes errors as large as 1.2K at high temperatures (35C), at more usual earth temperatures (4-20C) the calibration error is within the noise of the calibration methodology (+/-0.6K). With an ETM+ calibration update, the RMSE will be +/-0.6K for all temperatures.

The RIT vicarious calibration team mined the archive of the NOAA National Data Buoy Center for sites on the Great Lakes and in the Atlantic Ocean where buoy data was regularly available between 1984 and 2007 and there were radiosonde data within close proximity to allow for atmospheric correction [4]. Four Landsat scenes were chosen and the study made use of almost 200 separate acquisitions of these scenes. The technique was first tested with Landsat-7 data, and was shown to be as reliable as the standard RIT vicarious calibration methods. The TM calibration was largely unmonitored for most if it's lifetime. The RIT buoy results suggest a lifetime error in gain and a change in the bias after 1997. The 2007 TM calibration update accounted for much of the offset error but was only implemented for data acquired after 1999. With the additional buoy data, the calibration will be corrected for the earlier time period and the result will be a consistent calibration to within +/-0.6K for the lifetime of the TM.

2. ETM+ CALIBRATION ERROR

The compiled data from JPL and RIT are shown in Figure 1. If the data were perfectly calibrated, the data would be scattered about the 1:1 line. These data are tilted with respect to the 1:1 line, indicating the error is dependent on target temperature. The two RIT data sets are separated into two series: RITG is their traditional Ground truth method involving deploying people out on the lakes [5]; RITB is the new Buoy method which makes use of NDBC water temperature data and associated meteorological data to predict space-reaching radiance. The results of the teams' compiled vicarious calibration data indicate 5.8% gain error in the ETM+ thermal band calibration for the life of the mission. As a result of the 2001 calibration correction, the calibration error is smallest at the center of the temperature range, which happens to be the range of "normal" earth temperatures (4-20C). The errors get larger as one moves away from center of the range. Since the noise in the process is ±0.6K, this error was difficult to detect until the Salton Sea data were added to the collection. The Salton Sea data are all at the high end of the range; all of the JPL data shown in Figure 1 above 8.5 W/m2 sr um are Salton Sea acquisitions. These new data made the slope of the regression statistically different than 1, indicating a lifetime gain error. The gain error results in a variable calibration error that is dependent on target temperature. It is zero for a target at about 285K (~7.5 W/m^2 sr um). However at 273K (~6.0 W/m^2 sr um), the instrument is predicting about 0.8K too hot and at 300K (~9.0 W/m^2 sr um), it is predicting about 0.7K too cold. This calibration error was corrected in the processing system by changing several calibration coefficients. These changes were made in the system on Jan 1, 2010. Analysis of the corrected data indicates no residual gain or offset error.

3. TM CALIBRATION ERROR

The compiled calibration data for the TM thermal band are shown in Figures 2 and 3. With the indication of the bias error from past analysis, the data naturally fell into two populations. Figure 2 contains only data from between 1984 and 1997 (only RITB); Figure 3 shows all data from after 1999 (JPL, RITG and RITB). In both figures a gain error of about 4% is apparent, similar to that of the ETM+ thermal band, of about 4%, but the data in Figure 3 also indicate a statistically significant bias error. After extensive statistical analysis, it was determined that the calibration bias most likely occurred sometime in the first six months of 1997. It is still hoped that a cause can be found for the change, perhaps a satellite anomaly during that time period, but without a definite correlation, the correction for the offset error will been moved from April 1999 (the 2007 correction) to April 1997. Once this change is made in the processing system, all data acquired after April 1997 will be corrected for the offset error. The offset correction will be adjusted based on the new analysis from 0.091 W/m^2 sr um (the 2007 correction) to 0.12 W/m^2 sr um (0.9K at 300K), for all data acquired after April 1997. For the period before 1997, the gain error will result in calibration errors similar to that of the ETM+. Since the bias change in 1997, the combined error of the system would be within 0 and 2K for the same temperature ranges.

An update to the processing system will be made within the next six months for all TM data since launch. The resulting RMS error after the correction will be within +/-0.6K.

4. CONCLUSIONS

The Landsat TM and ETM+ thermal bands have been surprisingly stable over their lifetime. Though there was a lifetime gain error, the magnitude of the error was small enough such that it took years of rigorous monitoring to uncover in ETM+. The Salton Sea has proven to be an extremely useful site due to it's higher temperature range. For TM, a system with little monitoring for the first 15 years of life, this novel method of using the NCDC buoy archive has let the RIT take vicarious calibration back in time to a period where no one was actually monitoring the instrument. The teams' data are in agreement for both instruments, both have a lifetime gain error and TM has a bias error since 1997. The errors have already been corrected for the ETM+ thermal by modifying parameters in the processing system. The errors will be corrected shortly for the TM thermal band. Once the corrections are complete, both instruments will be calibrated to within +/-0.6K.

5. REFERENCES

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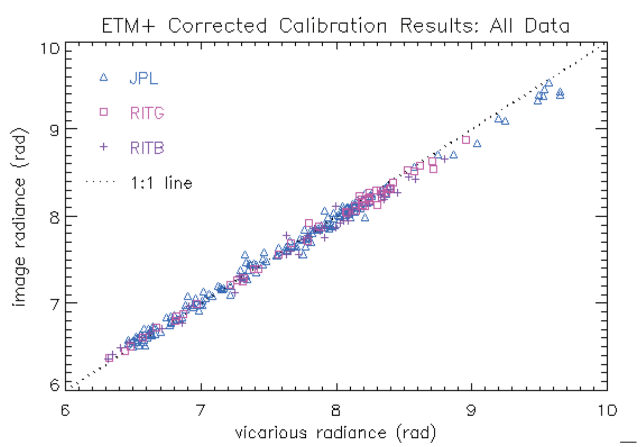

Figure 1. The collected vicarious calibration data for Landsat ETM+ thermal band for the lifetime of the mission. The recent JPL Salton Sea

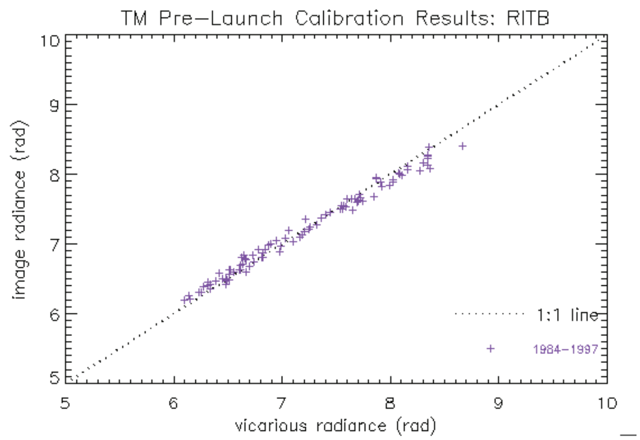

Figure 2. The vicarious calibration data for Landsat-5 TM from 1984 through 1996 (inclusive). During this time, there is only data available from RITB. The data are slightly tilted with respect to the 1:1 line but don't show any significant bias.

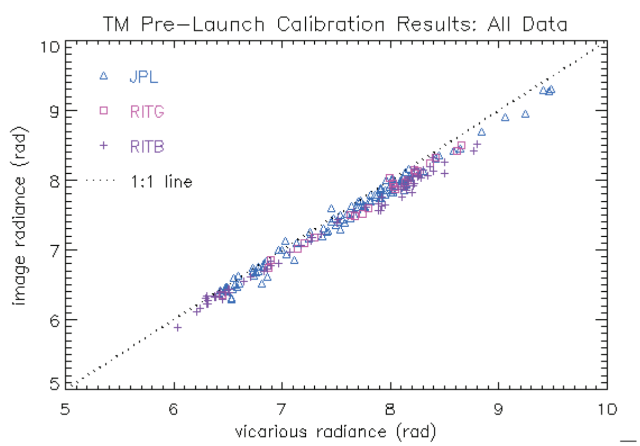

Figure 2. The collected vicarious calibration data for Landsat-5 TM after 1997. All three data sets indicate a gain error of about 4% through the tilt off the 1:1 line and a bias error of about 1K by their shift off the 1:1 line.