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Historical radiometric calibration of Landsat 5

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Historical Radiometric Calibration of Landsat 5

Final Report

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Historical Calibration of Landsat 5's Thermal Band

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Historical Calibration of Landsat 5's Thermal Band

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Abstract

There hasn't been a rigorous study of Landsat 5's thermal band since 1985, the year after its launch. Nevertheless, those who utilize this thermal imagery have been using it under the assumption that the sensor is operating correctly. This research was done to show that the thermal band of Landsat 5, has been radiometrically stable over its lifetime. Also, this research attempted to determine what the calibration of the thermal band has been. This was done using various Landsat 5 images of the thermal bar in the Great Lakes that were taken over the lifetime of the satellite. The focus of this research was to study radiance from the Great Lakes and compare this with the radiance values calculated from the Landsat data. In addition, Landsat 5 was cross calibrated with Landsat 7. These results suggest that Landsat 5's thermal band has remained in nominal specification since launch.

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Introduction

Launched in 1984, Landsat 5 has surpassed its life's expectation. Although Landsat 5 is still functional, Landsat 7 succeeded it in 1999. The last rigorous study of Landsat 5's thermal band, band 6, was in 1985. Since then there has been no rigorous radiometric testing of how well the sensor has been operating. Calibration is important to those who utilize this thermal imagery under the assumption that the sensor is operating correctly. This research attempts to describe the historical behavior of Landsat 5's thermal band and that it has been stable over the 15 year period since the last detailed calibration verification. This was done using various Landsat 5 images of the thermal bar in the Great Lakes taken over the lifetime of the satellite. The focus of this research is to study temperature estimates from the Great Lakes and compare them with the temperature values calculated from the Landsat data. In addition, Landsat 5 was cross-calibrated with Landsat 7 compare the sensors.

Background

Landsat

The Landsat program launched its first satellite in 1972. Its mission was to study the earth's surface features and monitor global change (6). Landsat 5, has been in orbit since March 1,1984 (5). Landsat 5 is an instrument that images using seven different detector arrays which are sensitive in different bands of the electromagnetic spectrum. This research utilized band 6, the thermal-infrared band that is sensitive in the electromagnetic spectrum between 10.40-12.50 micrometers and has a resolution of 120 meters. Images from this band allowed for detecting thermal contrast in the Great Lakes.

Thermal Bar

The thermal bar is a phenomenon relating to temperature that occurs in the Great Lakes in the spring. It is a 4 degree C barrier which separates winter lake water from the warming water that is near to shore. The cold and warm water mix until a 4 degrees C temperature is reached, this temperature is unique because it is water's maximum density. The barrier is a result of the dense water sinking to the bottom of the lake, creating two vertical currents that restrict horizontal motion (4). Figure 1 illustrates this behavior. The surface temperature of the summer stratification region is greater than 4 degrees C and the surface temperature of the winter stratification region is less than 4 degrees C.

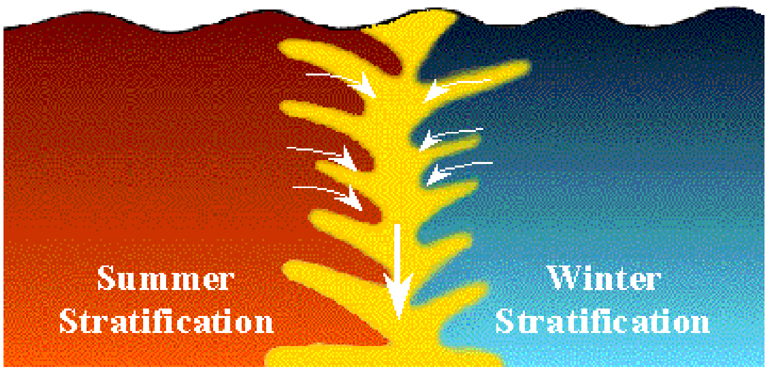

Figure 1: This shows how the thermal bar forms, causing water at 4 degrees C, shown here in yellow, to sink. The surface temperature on the left is greater than 4 degrees C and the surface temperature on the right is less than 4 degrees C(1).

The progression of the thermal bar is different in each of the Great Lakes. This progression will depend on the size and depth of the lake. This results in the selection of images from different lakes during different times in the spring. However the thermal bar forms in all the lakes between March and June. So image selection is restricted to these months. Image selection was also limited to the days where there wasn't any cloud coverage on the lake. The known temperatures surrounding the thermal bar will be the reference to which this research will radiometrically calibrate images.

Theory

Radiance

Radiance is defined by Bukata et. al. (2)
as the radiant flux per unit solid angle lying along a specified direction per unit area lying at right angles to the specified direction at any point in a radiative field (1). Radiance values can be derived from calculations using thermal band image data. The Landsat scenes report data in digital counts, which are converted via a linear transformation into sensor reaching radiance. The gain and bias for this transformation are described in equations 1 and 2. The radiance is scaled between the, maximum, LMAX, and minimum, LMIN, for the band radiance of the thermal band.

Equation 1:

$$\text{gain} = \frac{\text{LMAX}}{254} - \frac{\text{LMIN}}{255}$$

Equation 2: bias = LMIN

Sensor reaching radiance, has to be converted using a linear transformation into ground leaving radiance, Lground, because the atmosphere effects the radiance reaching the sensor and the reference temperatures are on the ground. Once we have ground leaving radiance this is to be converted into planckian radiance, Lplanck, which will mimic a black body radiator. This is important because there is a known relationship, equation 3 between black body radiators and temperature. Since the data is extracted from the lake, the emissivity of water has to be accounted for to convert Lground into Lplanck. Downwelled radiance, Ldownwelled, is backround noise that also contributes to the ground radiance. Equation 4 converts ground radiace to planckian radiance utilizing emissivity of water, a known value of .98, and downwelled radiance.

Equation 3:

$$L_{planck} = \frac{2hc^2}{\lambda^5}\left[\frac{1}{e^{\frac{hc}{Tk\lambda}} - 1}\right]$$

Equation 4:

$$L_{planck} = \frac{L_{ground} - (1 - \varepsilon_{water})L_{downwelled}}{\varepsilon_{water}}$$

Then the radiance values are put through a look up table that utilizes equation 4, to obtain temperatures.

Methods

Historical Calibration

The water temperatures within the thermal bar in the lake are known to be constrained between 4 degrees C and 0 degrees C. Anything less than 0 degrees C would visibly be ice and not selected as data for this study. Regions of interest, were selected in all the Landsat 5 scenes that are were centrally located and considered to be the coldest area within the thermal bar. Since it was apparently the coldest area within the thermal bar this region was estimated to be 1.5 degrees C. These regions of interest were identified and the digital counts were extracted using ENVI. ENVI is a software package that allows the user to analyze and process various types of imagery.

Then this research used various IDL programs written by Julia Barsi (1). Her radiosonde program was used, it inputs radiosonde and weather data and creates a MODTRAN carddeck. Radiosonde data had to be obtained from the closet radiosonde station to each individual lake. Radiosonde and weather information was obtained form stations closest to the scenes that were being examined. This data was needed for each day at the time Landsat 5 was imaging the area. Another program by Julia Barsi (1), make_modtranprofile inputs the carddeck and temperatures, runs MODTRAN and returns a gain and bias. MODTRAN is a radiative transfer, atmospheric propagation model. This gain and bias is applied to sensor reaching radiance and converts it into ground leaving radiance.

Downwelled radiance was obtained by running a Digital Imaging and Remote Sensing Image Generation Model, DIRSIG, component called make_adb. This also ran MODTRAN using the carddeck created previously which is slightly modified, integrates over the visible hemisphere and outputs a spectral array. The carddeck is modifie4d to work with make_adb instead of just Julia's code. This array had to be spectrally integrated across the Landsat 7 bandpass, 10.40-12.50 micrometers, to produce downwelled radiance. The carddeck was modified by filling in the wildcards which were put in using Julia's code that only work when MODTRAN is run using her code. Once the downwelled radiance was determined all the parameters needed for equation 4 were known and planckian radiance was calcuclated. After putting these values through a look up table temperatures were determined. The difference between the planckian temperature and the estimated temperature of the region of interest was considered to be the bias.

Cross Calibration

On June 3, 1999 as Landsat 7 was being flown into orbit it was programmed to line up with Landsat 5's path, resulting in common spatial and temporal coverage. A cross calibration between the two satellites was achieved by comparing the radiance values derived from these overlapping scenes. The same thermal regions were selected in each image. The radiance for Landsat 7 geotif L1g data was calculated the same as the Landsat 5. However, the gain is slightly different in this case. For Landsat 7 the gain is as shown in equation 5. The radiance difference between the calibrated Landsat 7 and Landsat 5 was considered to be the bias.

Equation 5:

$$gain = \frac{LMAX - LMIN}{255}$$

Landsat 7's calibration for that day had to be adjusted because the calibration was done for the sensor just after it was in orbit. However, the cross calibration occurred while the sensor was still achieving orbit and the sensor's shutter had still not completely cooled (which effects the calibration.) The adjustment for the shutter was done by obtaining radiance bias data and temperature for the shutter from a separate calibration effort on various days that the sensor was achieving orbit. The bias versus shutter temperature was plotted and a linear regression, shown by figure 2 was done. Then the equation was applied to the known shutter temperature for the day of the cross calibration, the resulting bias, -0.30841W/(m2 sr um), is the amount that the calibration was off from the orbiting stable Landsat 7 calibration.

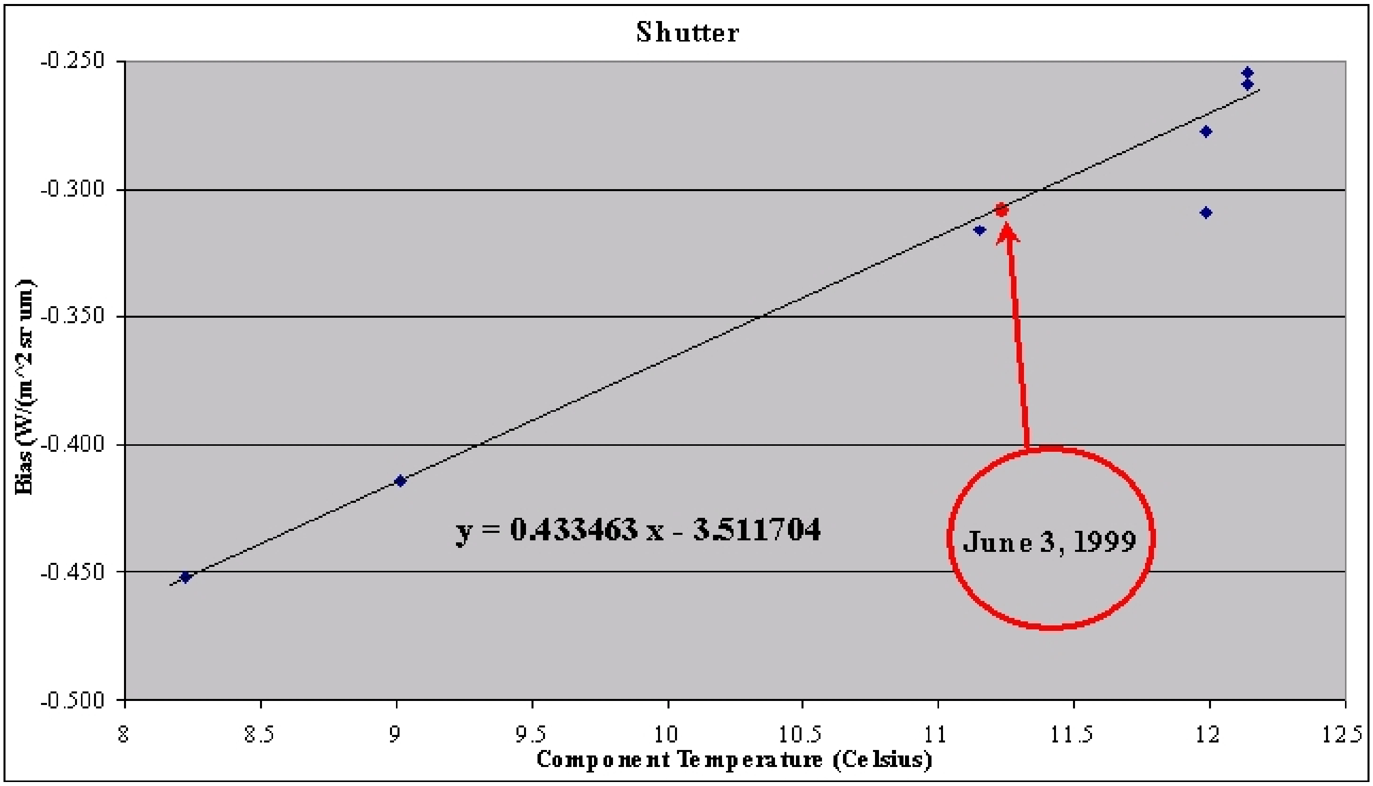

Figure 2: The blue points represent the various days during orbital insertion. The red point is the value derived from the regression for the day of the cross calibration.

Results

Historical Calibration

Images from all of the Great Lakes were utilized for this research. One to two regions of interest were selected from each scene. An example of this is shown in figure 3. Figure 4 shows the result of calibrating various scenes over the years. The error bars are the same value for each scene and represent the total error in this calibration. This accounts for the error inherent in Landsat 5, MODTRAN, Landsat 7, and that due to estimating a temperature of 1.5 degrees C. This research shows that the thermal band on Landsat 5 has been approximately calibrated since its launch.

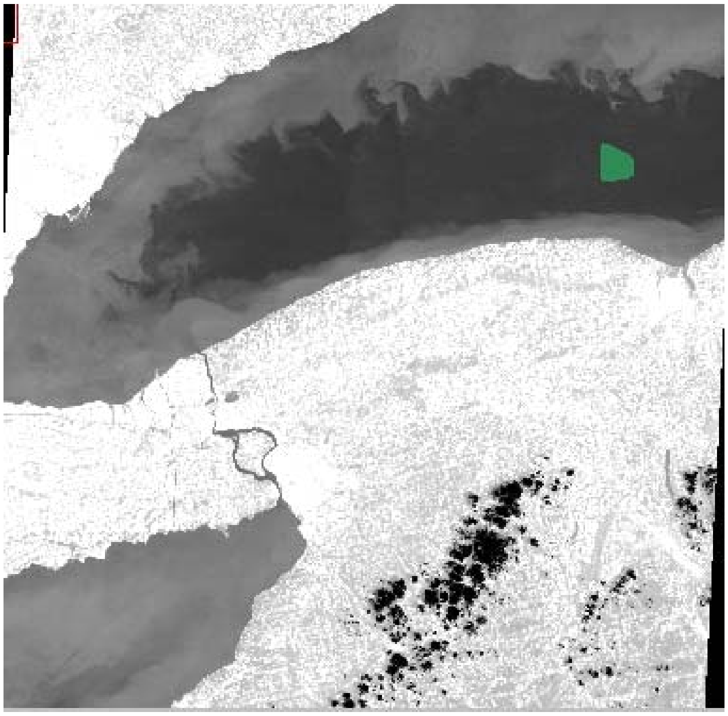

Figure 3: This image of Lake Ontario and a small section of Lake Erie is representative of the scenes selected for this study. The green region of interest was taken in the area appearing to be the coldest on the lake that isn't ice or clouds. This region of interest is similar to those taken for all the scenes used in this study.

Calibration Bias' versus Year

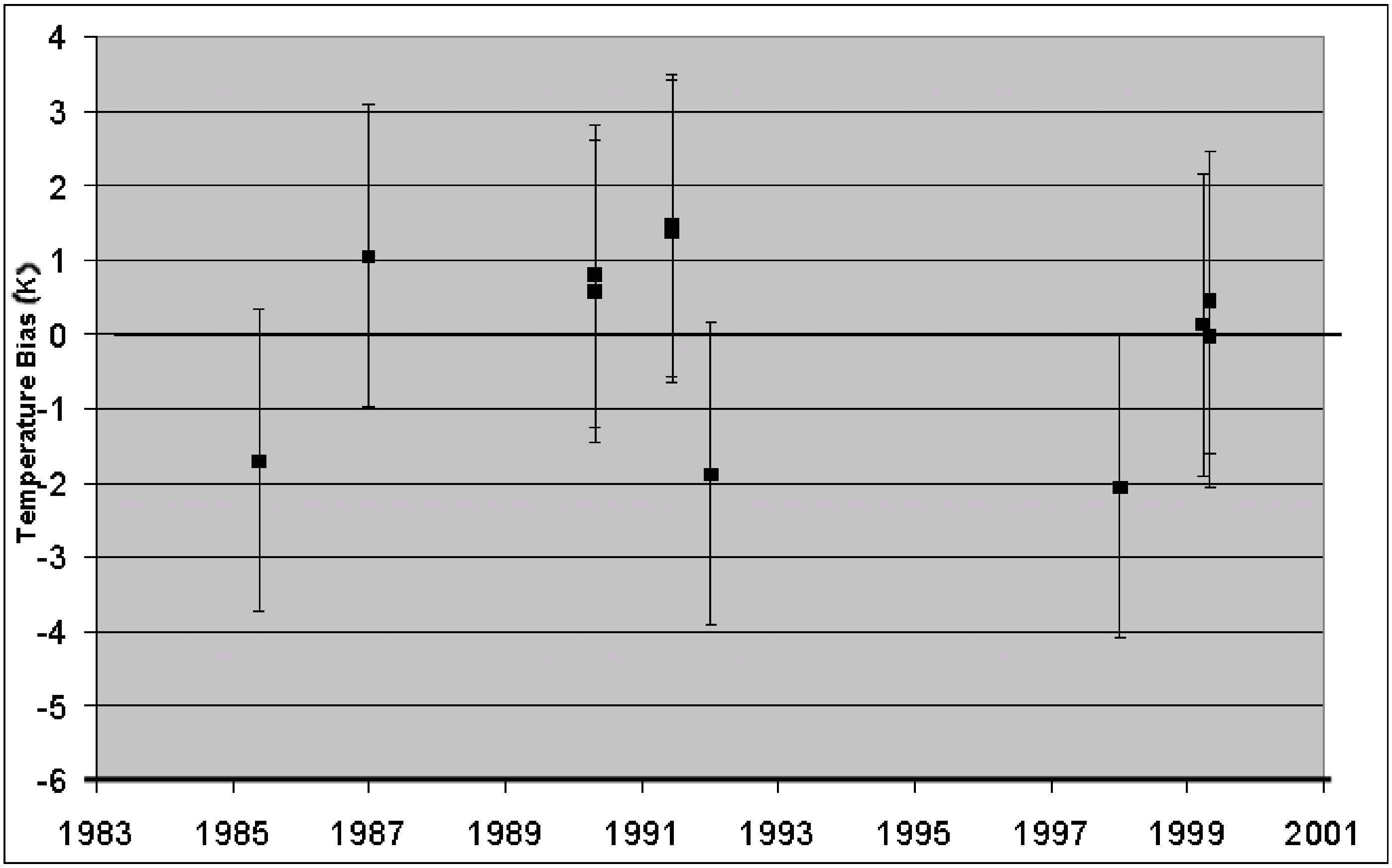

Figure 4: This graph represent the resulting bias determined for the calibration for that particular year.

Cross Calibration

Cross calibration was determined by comparing the resulting radiance values from the common regions that were selected, as shown in figure 5.

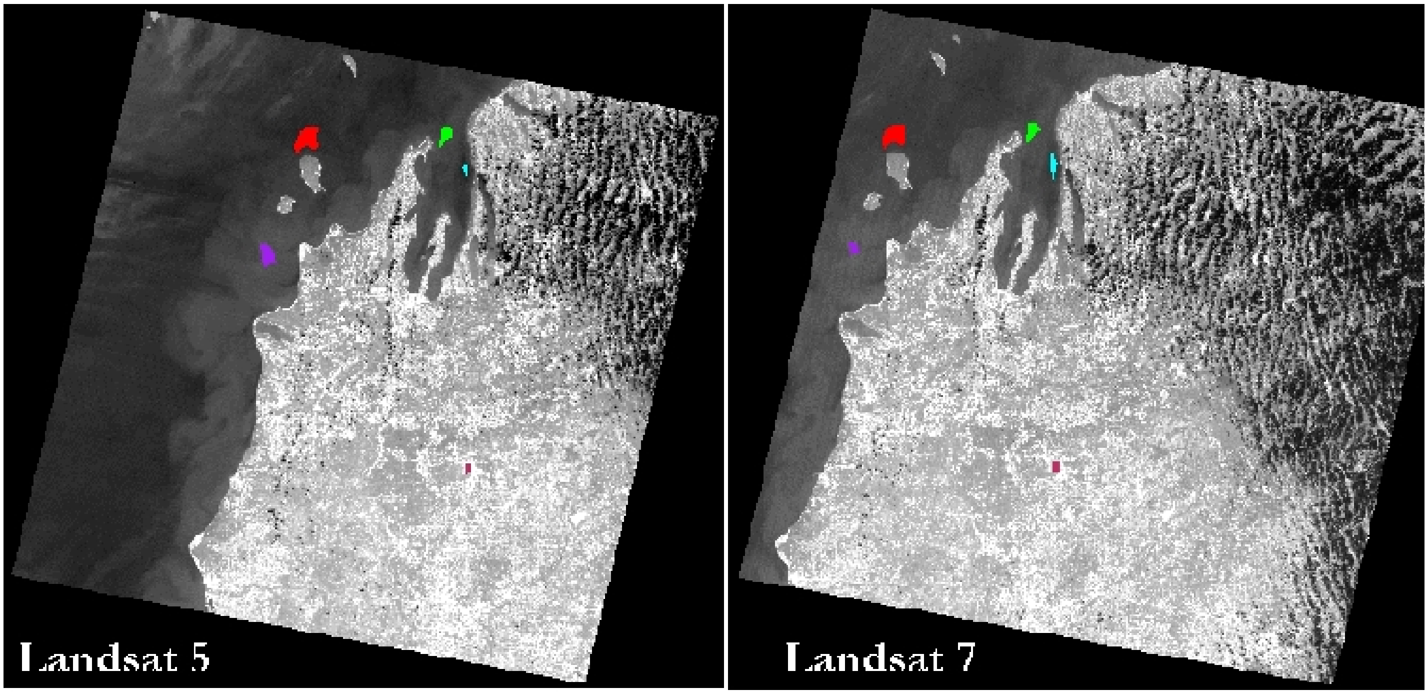

Figure 5: This image of Lake Michigan shows the common coverage of the two sensors on June 3, 1999. The regions shown in color are the common regions selected that were compared for the cross calibration.

The result of this cross calibration is shown in figure 6. This is the bais determined after adjusting the Landsat 7 calibration. The error bars here are the total error representing the intrinsic error Landsat 7 and Landsat 5.

Calibration Bias' versus Year

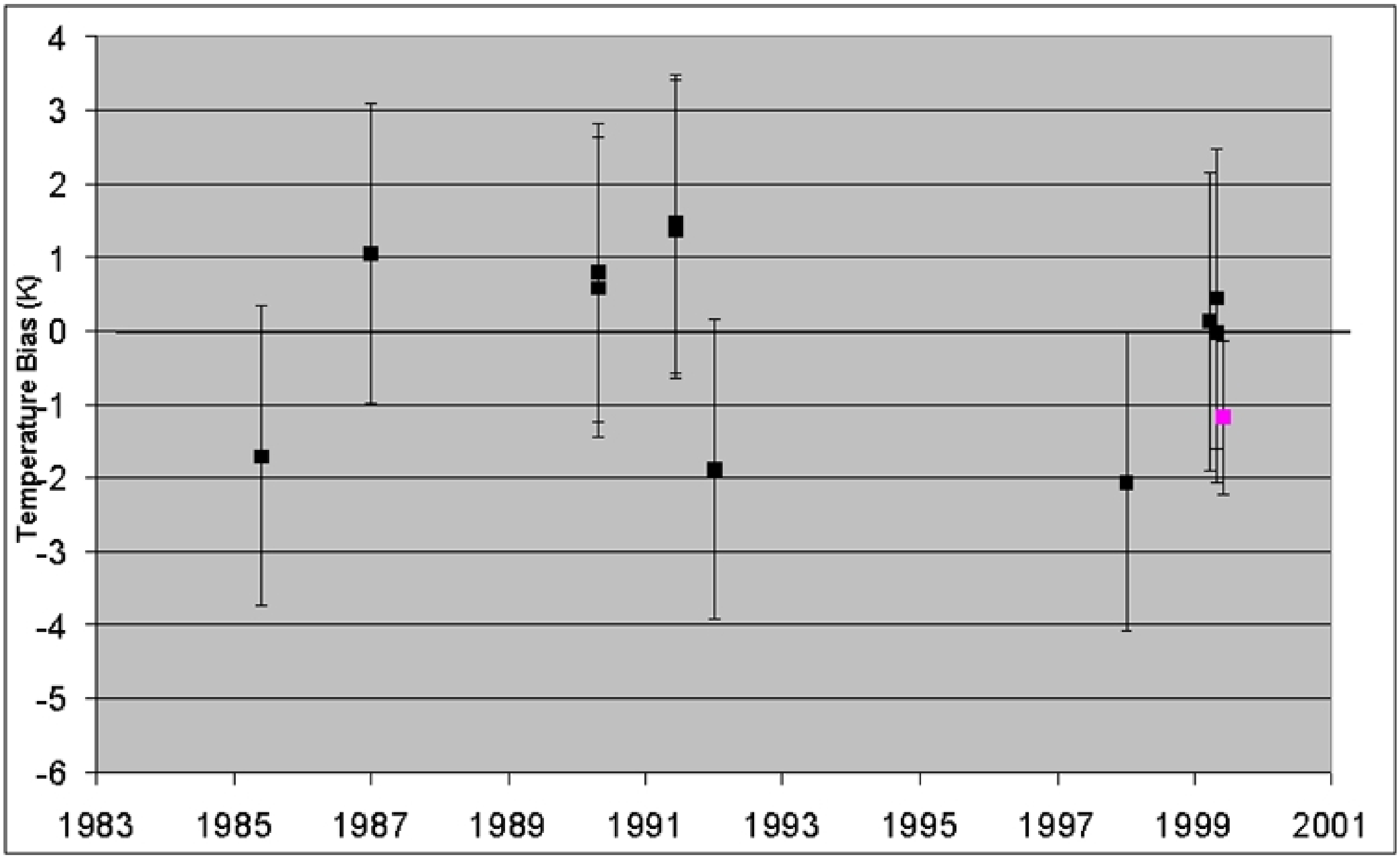

Figure 6: The resultant cross calibration bias is shown here in purple.

Discussion

The calibration done in 1985 (7)
and the cross calibration are the two dates that are the most reliable because of the smaller error. Figure 7 shows the results of these and the errors. Since, these dates are considered to be the best representation of the calibration over the years a line was drawn between these two points. This line was a preliminary assumption of how the thermal band has been behaving over the years.

Calibration Bias' versus Year

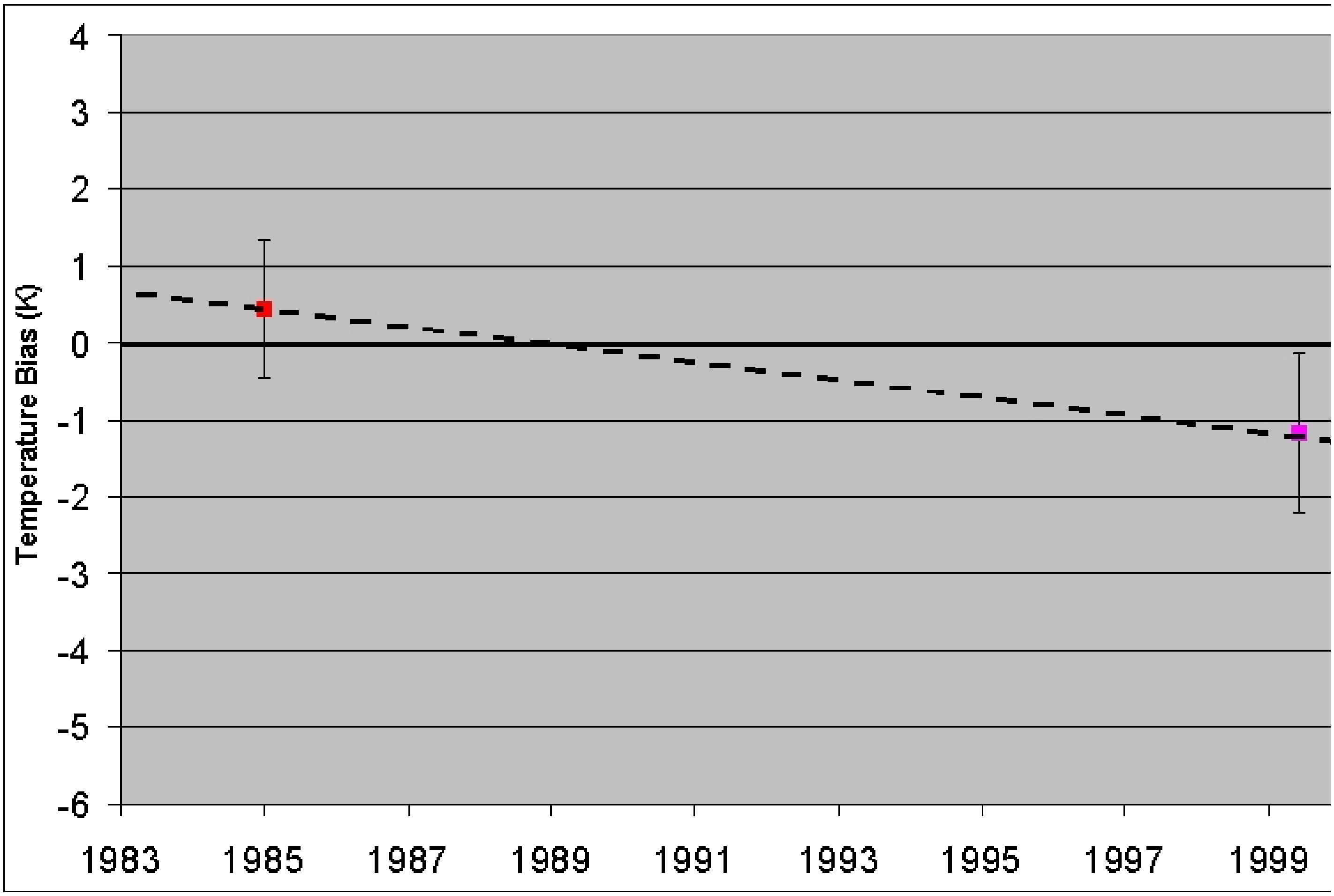

Figure 7: This graph shows the calibration done in 1985 and the cross calibration.
The line represents the assumption of how the sensor has been behaving over the years.

After applying the additional dates to this chart, figure 8, it shows that there is a possibility that this is how the sensor has been behaving because most of the points agree with the line within error. However, two of the data points do not fall near the line. These two points are scenes, shown in figure 9, that are considered to be bad data. After comparing these scenes with an average scene, as shown in figure 10, a difference in the quality of the data was obvious.

Calibration Bias' versus Year

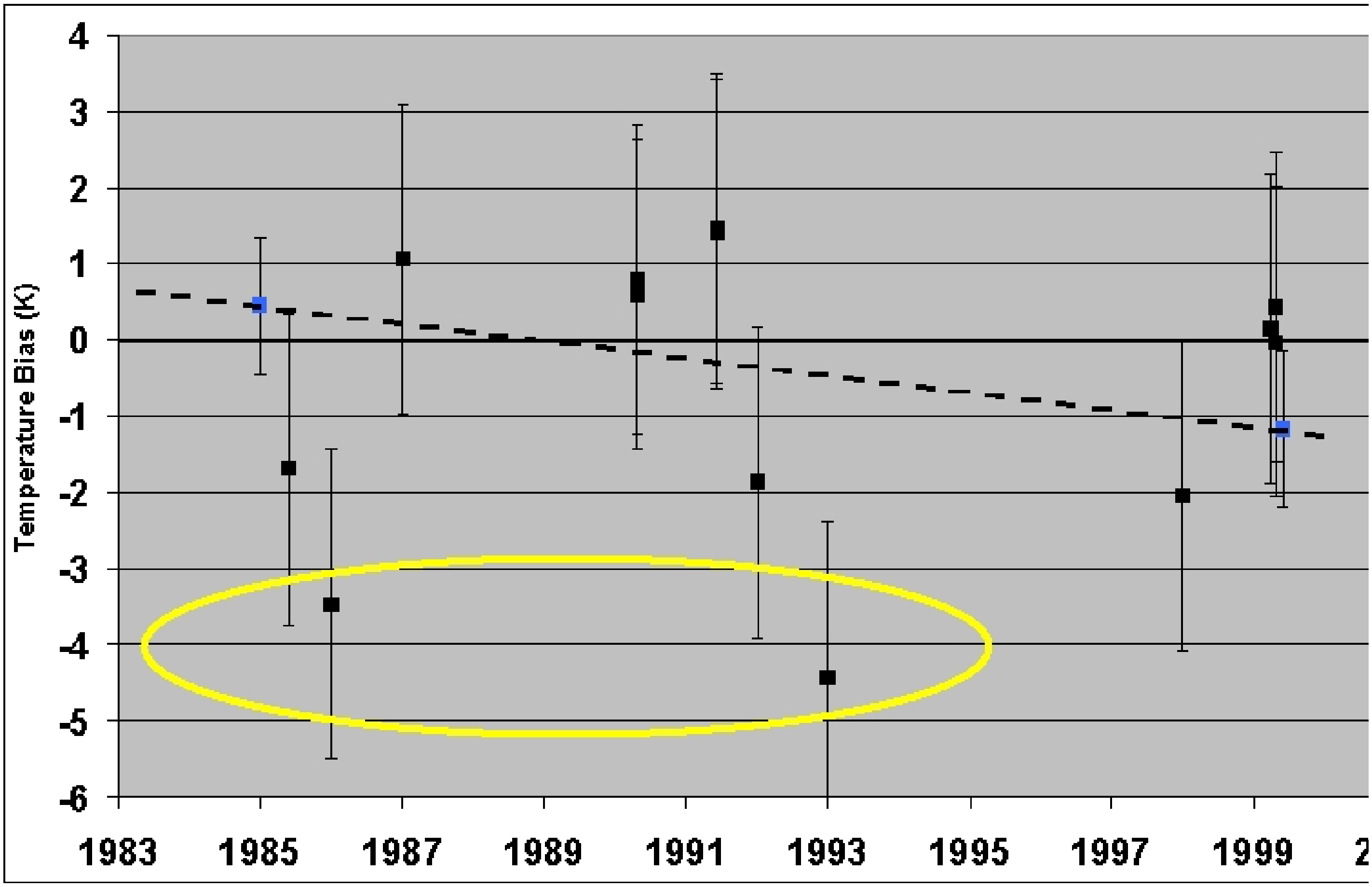

Figure 8: This graph shows all the data points involved in this study. The black points are the historical data points. The two circled in yellow show the two scenes that appear to be bad data.

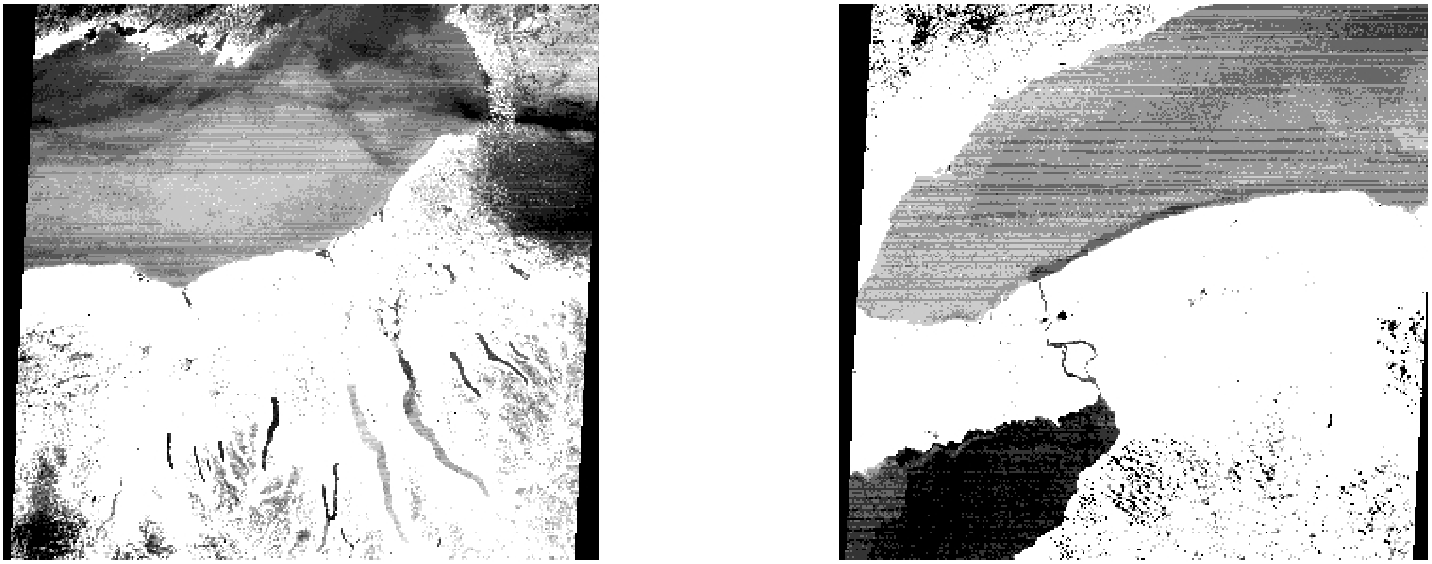

Figure 9: These two images are the scenes that correspond to the two data point that are considered to obtain bad data.

Figure 10: This is an average scene. After comparing this scene to those in figure 9 there is an obvious difference in the quality of the images.

In an attempt to explain why these two scenes had bad data, outgassing data was obtained (3). These scenes were assumed to be collected around an outgassing period. Outgassing is a procedure that burns off the built up ice crystals that form on the sensor. However after looking at the outgassing dates and comparing them to the scenes' dates it was determined that there was no connection between the two.

This research shows that the linear assumption is not the only possible line that can be drawn encompassing this data. To improve the estimated behavior of the sensor more points can now be used to perform a regression on the data. The trustworthy data points can be weighted more to improve the result of the regression.

The historical calibration can be improved by looking at more scenes and improving the estimated temperature of the region of interest. There was one estimate for all the scenes. All that was considered was that it was the coldest spot in the lake. A refined estimate can be made by considering the time of year, the particular lake and the weather conditions for the season. For example, the coldest spot in Lake Superior in June 1987 is probably much different from the coldest spot in Lake Ontario in March 1999. This would also reduce the error associated with the calibration.

Conclusions

This research conducted a historical calibration on the thermal band of Landsat 5. This showed that it has been in nominal calibration since launch. The approximate behavior of the thermal band was investigated. It appears to have been stable and the users of this data have been extracting reasonable temperatures. This was then reinforced by the cross calibration.

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