On-Orbit Measurement of the Effective Focal Length and BBR of MODIS Aqua and Terra

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Introduction

We report here on the measurement of the effective focal length (EFL) and Band-to-Band Registration (BBR) of selected bands of the Aqua and Terra MODIS instruments from on-orbit data. This is achieved by simulating MODIS data with Landsat 7 ETM+ or Landsat 8 OLI data utilizing the MODIS geolocation data generated with varying values of focal length. For each scan of a selected MODIS data set, various subsets of the data are examined to find the subset with the highest spatial correlation between the original and simulated MODIS data using the nominal geolocation information. Then, for this best subset, the focal length value and the spatial shift are varied to find the values that produce the highest spatial correlation between the original and simulated MODIS data. This best focal length value is taken to be the measured instrument EFL and the best spatial shift is taken to be the registration of the MODIS data relative to the Landsat data (from which the MODIS BBR can be inferred).

Overview of the Approach

1. Select pairs of cloud free MODIS and Landsat data sets from the same date over high contrast features visible in the MODIS data.
2. Generate several instances of MODIS geolocation data based on varying values of focal length.
3. For each scan of the MODIS data, over the portion covered by the available Landsat data, simulate several subsets of the MODIS data using the nominal geolocation data and appropriate system point spread function, and select the subset that produces the highest spatial correlation.
4. Visually inspect the Landsat and MODIS subsets to ensure that each subset does not cover a large area of water. Revise the subset selection, if necessary. (Measurements over large areas of water usually give very high spatial correlations but also often give essentially random results for best focal length and spatial shift values.)
5. For the selected subset, measure the spatial correlation between the original and simulated MODIS data for varying values of focal length and spatial shift, and note the spatial shift that produces the highest spatial correlation. Take this best spatial shift as the registration of the MODIS data relative to the Landsat data.
6. For the best spatial shift, fit the plot of spatial correlation values versus focal length values to a 2nd degree polynomial curve and take the focal length that produces the maximum of the curve to be the measured focal length. Note the peak and R^2 fit of this curve as measurement quality factors.
7. Repeat steps 2-6 for the remaining relatively cloud free scans from the MODIS data with coverage by available relatively cloud Landsat data.
8. Tabulate the results from each MODIS data set and report the mean and standard deviation values for the measured focal length and spatial shift values for scan subsets with high spatial correlation and R^2 values (ideally spatial correlation >= 0.99 and R^2 >= 0.995).

Measurement of Spatial Shift and Simulation Quality with Cross Correlation

To maximize the performance of the cross correlation, we scaled the original and simulated MODIS image data to the same range and maintained the data in floating point.

We represent the spatial shift between the original and simulated MODIS image as *r* (row shift) and *c* (column shift) and the shifted simulated image as s_{rc}. Positive column and row shifts move the simulated MODIS image up (south for Aqua and north for Terra) and to the left (east for Aqua and west for Terra).

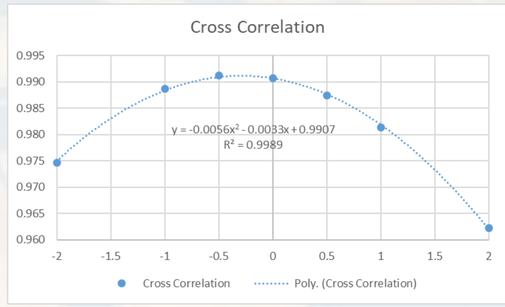
We define the cross correlation (*CC*) between the original MODIS image, *o*, and the shifted simulated image, s_{rc}, as:

$$CC = \max_{rc}\left\{\frac{\sum_x\sum_y[o(x,y)-\bar{o}][s_{rc}(x,y)-\overline{s_{rc}}]}{\sqrt{\sum_x\sum_y[o(x,y)-\bar{o}]^2\sum_x\sum_y[s_{rc}(x,y)-\overline{s_{rc}}]^2}}\right\}$$

The *r* and *c* values correspond to the measured MODIS geolocation offset relative to Landsat.

Measuring the Effective Focal Length

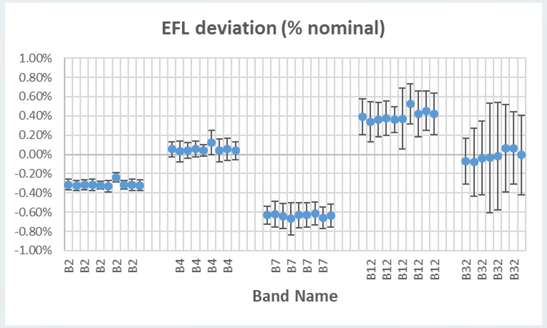
We varied the assumed focal length value for the MODIS geolocation data over the values -2.0%, -1.0%, -0.5%, 0.0%, 0.5%, 1.0%, and 2.0% change from the nominal focal length value, and assumed that the correct EFL corresponds to the focal length that produces the highest value of CC. For the selected subset from scan 0 of the MODIS Terra data set at 1635 UTC on April 30, 2018, we have the plot:

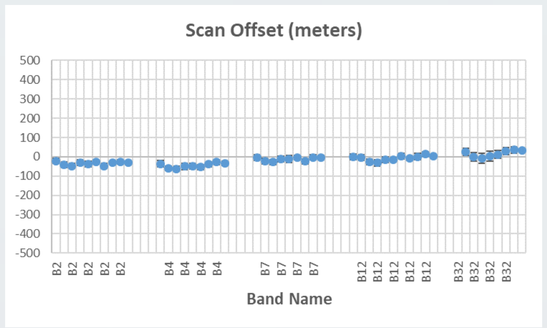


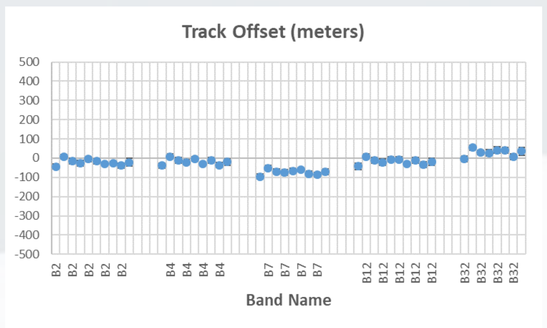
The plot of the measured values forms a very smooth curve that can be fit closely by a 2nd degree polynomial. The first derivative of this curve can be solved to find the location of the peak of the curve: the peak is at -0.294% change.

MODIS Terra Results

Dates of the measured data sets are 5/21/2002, 11/6/2002, 11/22/2002, 12/13/2002, 12/31/2002, 5/25/2013, 9/17/2013, 10/9/2013, 5/7/2017 and 4/30/2018.

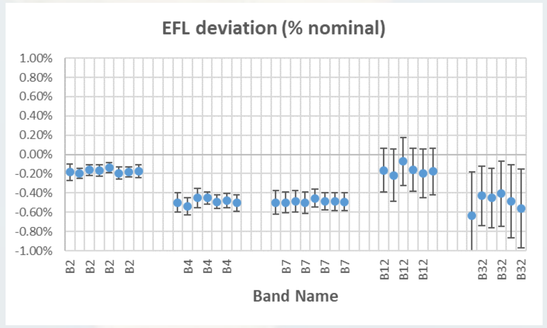


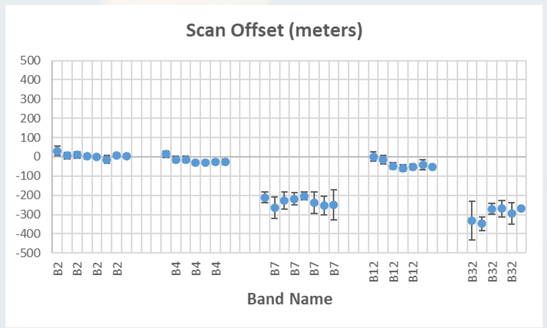


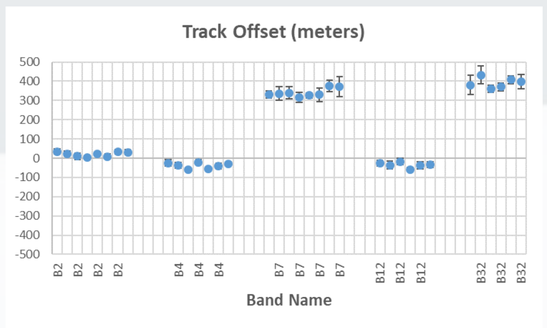


MODIS Aqua Results

Dates of the measured data sets are 11/7/2002, 11/23/2002, 5/24/2013, 5/25/2013, 9/17/2013, 10/8/2013, 5/6/2017 and 4/29/2018.







Conclusions

Using data sets from across the full lifetime of the instruments, we have measured the EFL of the MODIS Terra and Aqua instruments, along with the spatial offset of the geolocation of these instruments versus the Landsat ETM+ or Landsat OLI instruments.

We have found the Terra EFL to be very close to nominal for bands 4 and 32, slightly shorter than nominal for bands 2 and 7, and slightly longer than nominal for band 12. The small measured scan and track offsets for the measured bands indicates that the BBR is very good.

We have found the Aqua EFL to be slightly shorter than nominal for all measured bands, with bands 2 and 12 closer to nominal than bands 4, 7 and 32. While the small measured scan and track offsets for bands 2, 4 and 12 indicate that the BBR is very good for these bands, we find that the BBR is off by some 300 meters for bands 7 and 32.

Reference and Acknowledgment

James C. Tilton, Robert E. Wolfe, Guoqing (Gary) Lin and Zhangshi (Albert) Yin, "On-Orbit Measurement of the Focal Length of the SNPP VIIRS Instrument," in *Proceedings of the IEEE Int'l Geosci. and Remote Sens. Symp.*, Fort Worth, TX, USA, pp. 4056-4059, July 23-28, 2017.

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