Remote Sensing of Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Continuous calibration improvement in solar reflective bands: Landsat 5 through Landsat 8

Nischal Mishra [a,*], Dennis Helder [a], Julia Barsi [b], Brian Markham [c]

[a] Engineering-Office of Research, South Dakota State University (SDSU), Brookings, SD 57007, USA
[b] Science Systems and Applications, Inc., NASA/GSFC Code 618, Greenbelt, MD 20771, USA,
[c] Biospheric Sciences Laboratory, Code 618, National Aeronautics and Space Administration Goddard Space Flight Centre (NASA/GSFC), Greenbelt, MD 20771, USA

ARTICLE INFO

Article history:
Received 13 August 2015
Received in revised form 13 July 2016
Accepted 22 July 2016
Available online xxxx

Keywords:
Landsat
Operation land imager (OLI)
Enhanced thematic mapper plus (ETM+)
Thematic mapper (TM)
Radiometric calibration

ABSTRACT

Launched in February 2013, the Operational Land Imager (OLI) on-board Landsat 8 continues to perform exceedingly well and provides high quality science data globally. Several design enhancements have been made in the OLI instrument relative to prior Landsat instruments: pushbroom imaging which provides substantially improved Signal-to-Noise Ratio (SNR), spectral bandpasses refinement to avoid atmospheric absorption features, 12 bit data resolution to provide a larger dynamic range that limits the saturation level and increases SNR, a set of well-designed onboard calibrators to monitor the stability of the sensor. Some of these changes, such as refinements in spectral bandpasses compared to earlier Landsats and a well-designed on-board calibrator have a direct impact on the improved radiometric calibration performance of the instrument from both the stability of the response and the ability to track the changes. The on-board calibrator lamps and diffusers indicate that the instrument drift is generally <0.1% per year across the bands. The refined bandpasses of the OLI indicate that temporal uncertainty of better than 0.5% is possible when the instrument is trended over vicarious targets such as Pseudo Invariant Calibration Sites (PICS), a level of precision that was never achieved with the earlier Landsat instruments. With three years of data available, the stability measurements indicated by on-board calibrators and PICS agree to 0.5%, which is much better compared to the earlier Landsats, which is very encouraging and bodes well for the future Landsat missions too.

1. Introduction

Landsat 8 (L8) was launched on 11 February 2013 and has two imaging sensors on-board: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). It has now joined the Landsat 7 Enhanced Thematic Mapper (ETM+) on orbit to provide a continued data record of the earth. The Landsat archive contains the longest continuous record of the Earth's surface, as viewed from space, with the Landsat 8 mission extending this record to >42 years (and counting). L8 OLI adopts a pushbroom technology with approximately 70,000 detectors which is a fundamental change (or upgrade) compared to earlier Landsat instruments which all used whiskbroom imagers and contained far fewer (≤136) detectors. Several other enhancements have been made with L8 OLI such as addition of extra spectral bands namely the Coastal Aerosol Band and Cirrus Band, refinements of the bandwidths to avoid some atmospheric absorption features, wider dynamic range that limits saturation that typically occurs at higher radiance, improved temperature stability, and the larger detector integration time and low noise level of the OLI detectors provide superlative Signal-to-Noise Ratio (SNR) compared to earlier Landsat instruments which used whiskbroom imagers and had a shorter integration time. OLI also has three primary on-board calibration devices: a shutter, lamps and diffusers which are employed periodically to track the stability of the instrument. Because of its temporal coverage (eight days with L7 and L8 combined), spatial resolution (30 m) at an appropriate scale for monitoring human activity, as well as the benefit of free access to the public, the Landsat data record is important for land cover change research and global climate change studies. A key precursor for these studies is consistent radiometric calibration and stability of the Landsat sensors.

The primary purpose of this paper is to assess the improved radiometric calibration of Landsat 8 OLI, particularly with respect to spectral bandpasses and its impact on vicarious calibration methods, as compared to on-board calibration systems. This will be done through comparisons with Landsat 5 TM and Landsat 7 ETM+ calibration

* Corresponding author.
E-mail addresses: Nischal.Mishra@sdstate.edu (N. Mishra), Dennis.Helder@sdstate.edu (D. Helder), julia.barsi@nasa.gov (J. Barsi), Brian.L.Markham@nasa.gov (B. Markham).

http://dx.doi.org/10.1016/j.rse.2016.07.032
0034-4257/© 2016 Elsevier Inc. All rights reserved.

performance and through briefly noting the impact that spectral bandpass changes have on common measurements and potential for further refinements in future Landsats.

2. Key OLI design improvements in L8 OLI

As stated earlier, OLI is a pushbroom instrument which essentially increases the integration time for each pixel. It has fourteen overlapping focal plane modules (FPMs) that cover a 185 km swath width (Knight and Kvaran, 2014). The multispectral OLI bands have 494 detectors per module and the panchromatic band has twice as many. Each of the FPMs has its own butcher block assembly of spectral filters. The low noise level of the detectors and a long integration time has significantly improved SNR compared to earlier Landsats which were whiskbroom instruments and had a shorter integration time. Fig. 1 shows the comparison between L7 ETM+ and Landsat 8 OLI SNR at a typical radiance level (Morfitt et al., 2014; Scaramuzza et al., 2004). The figure shows that OLI SNR is 6 to 10 times better than ETM+ SNR for the different spectral bands.

One of the salient features of the OLI instrument is its set of well-designed on-board calibrator systems. OLI has multiple lamps and diffusers as on-board calibration sources to monitor the stability of the sensor system. The diffuser and lamp assemblies in the OLI instrument have been described in detail (Knight and Kvaran, 2014; Markham et al., 2014). The lamps and diffusers have been named as working, backup or pristine depending on the frequency of usage. The three sets of lamps are used daily, bi-monthly and every six months, respectively. The presence of these multiple sources can identify changes in the instrument response as opposed to changes in calibration sources. Similarly, a working diffuser is deployed every week and the pristine diffuser panel is used every 6 months. These diffuser panels are NIST traceable reflectance standards and were characterized prior to launch; trending these ensures that the changes in the OLI instrument are monitored and calibration adjustment can be incorporated in the data processing in the event of potential changes (Knight and Kvaran, 2014).

In general, L8 OLI spectral bands are similar to L7 ETM+ and L5 TM. OLI includes two additional spectral bands: a Coastal/Aerosol Band which allows estimation of the concentration of aerosols in the atmosphere and a Cirrus Band to aid in the detection of clouds. The spectral response function of OLI was well characterized during prelaunch testing and exhibits very minimal out-of-band response and cross-talk among bands (Barsi et al., 2014). Relative to TM and ETM+, enhancements have been made in the position of OLI bands in the electromagnetic spectrum, too. Fig. 2 compares the Relative Spectral Response (RSR) of L8 OLI (blue line), L7 ETM+ (red line) and L5 TM (green line) for matching bands together with a typical atmospheric transmittance profile (black line). It can be seen that, in general, the OLI bands are narrower than ETM+ and TM bands as OLI band edges have been refined to avoid atmospheric absorption features. The most significant change can be noticed in the Near InfraRed (NIR) band where OLI is substantially narrower than the other two to avoid the water vapor absorption features at 817 and 823 nm. Similarly, the SWIR-1 band is considerably narrower in OLI as compared to ETM+ and TM, and placed in a region where atmospheric transmittance is very high. A closer inspection of the SWIR-1 band in TM indicates its proximity to the major water absorption features starting around 1800 nm, where the transmittance is close to zero. A similar explanation holds true for the SWIR-2 band. It should be noted that the spectral resolution and SNR are generally trade-offs in optical system design and narrower bands in OLI were only possible because of the high SNR in OLI as discussed earlier. Atmospheric absorption features are an indication of the composition of the atmosphere and can vary temporally and spatially. This variability can add additional uncertainties in the datasets when vicarious sources such as Pseudo Invariant Calibration Sites (PICS) are trended to monitor the stability of the sensor. The impact of narrower bandpasses on radiometric calibration improvement will be described later explicitly when PICS based stability is discussed.

In contrast to Landsat 8 OLI, Landsat 5 TM and Landsat 7 ETM+ had substantially different on-board calibration systems. Landsat 5 TM only used a set of three lamps for its on-board calibrators (Markham et al., 1998). This system only illuminated a portion of the optical path in the sensor but operated accurately for its design life of three years, but then drifted for the rest of the instrument lifetime. Vicarious methods were then used to calibrate the instruments for its 27 year lifetime (Barsi et al., 2012). Conversely, Landsat 7 had three on-board calibrators – lamps, partial aperture solar calibrator (PASC) and full aperture solar calibrators (FASC). Each of these systems provided only a partial solution to the calibration of the sensor and vicarious methods were needed to perform an accurate calibration (Scaramuzza et al., 2004; Barsi et al., 2012).

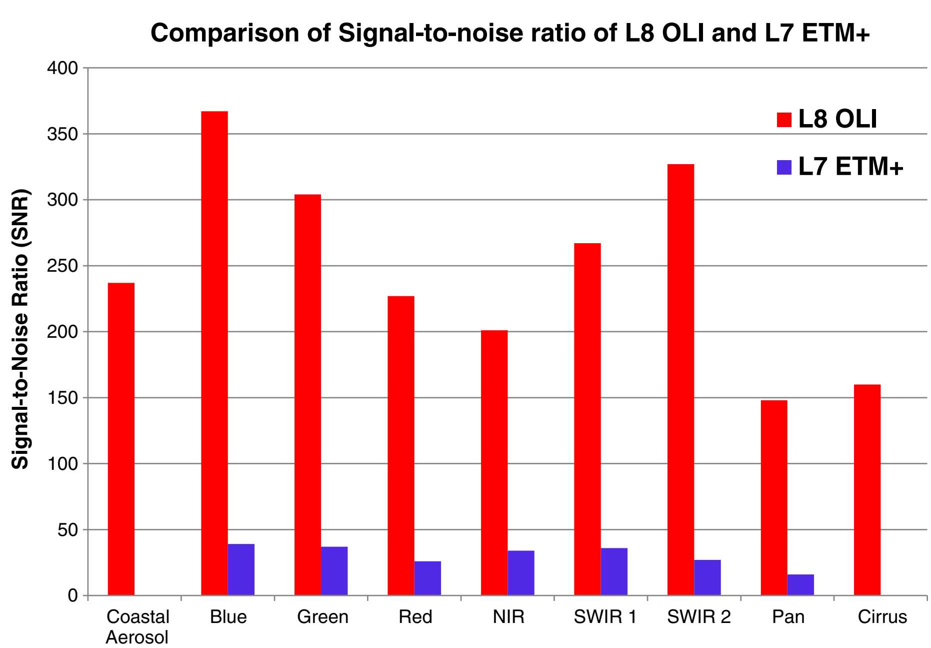

Fig. 1. Signal-to-Noise ratio of L7 ETM+ & L8 OLI at typical radiance levels.

Please cite this article as: Mishra, N., et al., Continuous calibration improvement in solar reflective bands: Landsat 5 through Landsat 8, Remote Sensing of Environment (2016), http://dx.doi.org/10.1016/j.rse.2016.07.032