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The impact of improved signal-to-noise ratios on algorithm performance: Case studies for Landsat class instruments

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ABSTRACT

The Landsat Operational Land Imager (OLI) has 5 to 10 times better signal-to-noise ratios (SNRs) in all spectral bands than previous Landsat instruments. SNR performance has long been recognized as a value in instrument design, however, the impact on algorithm performance for earth science applications is poorly documented. Since SNR performance may drive design/cost tradeoffs on future missions, a set of experiments were designed to evaluate the impact of various SNR levels on algorithms applied to different science applications. The application areas studied spanned a wide range including water quality, land cover and forestry. The experiments involved producing data sets with a range of signal-dependent SNR values ranging from Landsat 7 ETM + levels to OLI levels. Algorithms were then run on these otherwise identical data sets and evaluation metrics applied to evaluate the relative performance versus SNR. In all cases, performance was shown to be a strong function of SNR with substantial increase in performance as SNR increased (e.g. constituent retrieval errors reduced by a factor of three). However, in some cases, the rate of increase slowed at higher SNR levels. Regrettably, the point of diminishing returns was not the same for all applications leaving significant burden on design teams to decide which application's needs could be fully met in terms of SNR requirements.

1. Introduction

The Operational Land Imager (OLI) onboard Landsat 8 represents a marked improvement in medium resolution earth imaging (Irons, Dwyer, & Barsi, 2012). Following in the Landsat Worldwide reference system (WRS) II orbit with 30 m ground sample distance (GSD), the data look very similar to Landsat's 5 and 7. However, unlike the TM instruments the OLI is a push-broom instrument with approximately 6000 across-track detectors. As a result the detectors can dwell on each spot on the earth longer, significantly improving signal-to-noise (Schott, 2007, Chapter 6). To take advantage of this improved signal-to-noise ratio (SNR), OLI has an increased bit depth of 12 compared to the Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) which had 8-bit data and the Landsat MSS sensor which had 6-bit data. OLI also has two additional bands and slightly narrower spectral bandwidths as seen in Fig. 1.

The correlation between higher SNR's and image quality is well recognized. In the remote sensing community this is perhaps most clearly expressed in the General Image Quality Equation (GIQE). The GIQE is designed to relate image metrics such as pixel size on the ground, edge sharpness, and SNR to the interpretability of black and white remotely sensed images (Leachtenauer et al., 1997). The GIQE suggests that while image interpretability is a function of SNR it is nowhere near as large a factor as pixel size or image sharpness and that after a point increasing SNR will not have an observed impact for photo interpretation purposes. Fiete and Tantalo (2001) took this further in terms of the noise equivalent change in reflectance (NEΔR), showing that interpretability was linearly related to NEΔR.

There is not as clear a body of literature relating SNR to the utility of multispectral data. In part, this is because it typically requires very high SNR data that can then be degraded so that images, whose only change is in SNR, can be compared through some analytical application algorithm. Williams et al. (1984) did just this after Landsat switched from the 6-bit MSS sensors to the 8-bit TM sensors. They showed that degrading 8-bit TM data to 6-bit data (i.e. roughly a factor of 4 in SNR) resulted in a loss of approximately 5 percentage points in land cover classification accuracy. Other studies have shown that improved SNR can improve preprocessing algorithms for hyper-spectral data. Seidel et al. (2008), showed that aerosol optical depth retrieval improved with higher SNR and Chen (2006) shows that hyperspectral end member selection algorithms perform better at higher SNR. Kruse (2000) looked at AVIRIS imaging spectrometer data and found that the classification accuracy and number of minerals mapped improved with SNR.

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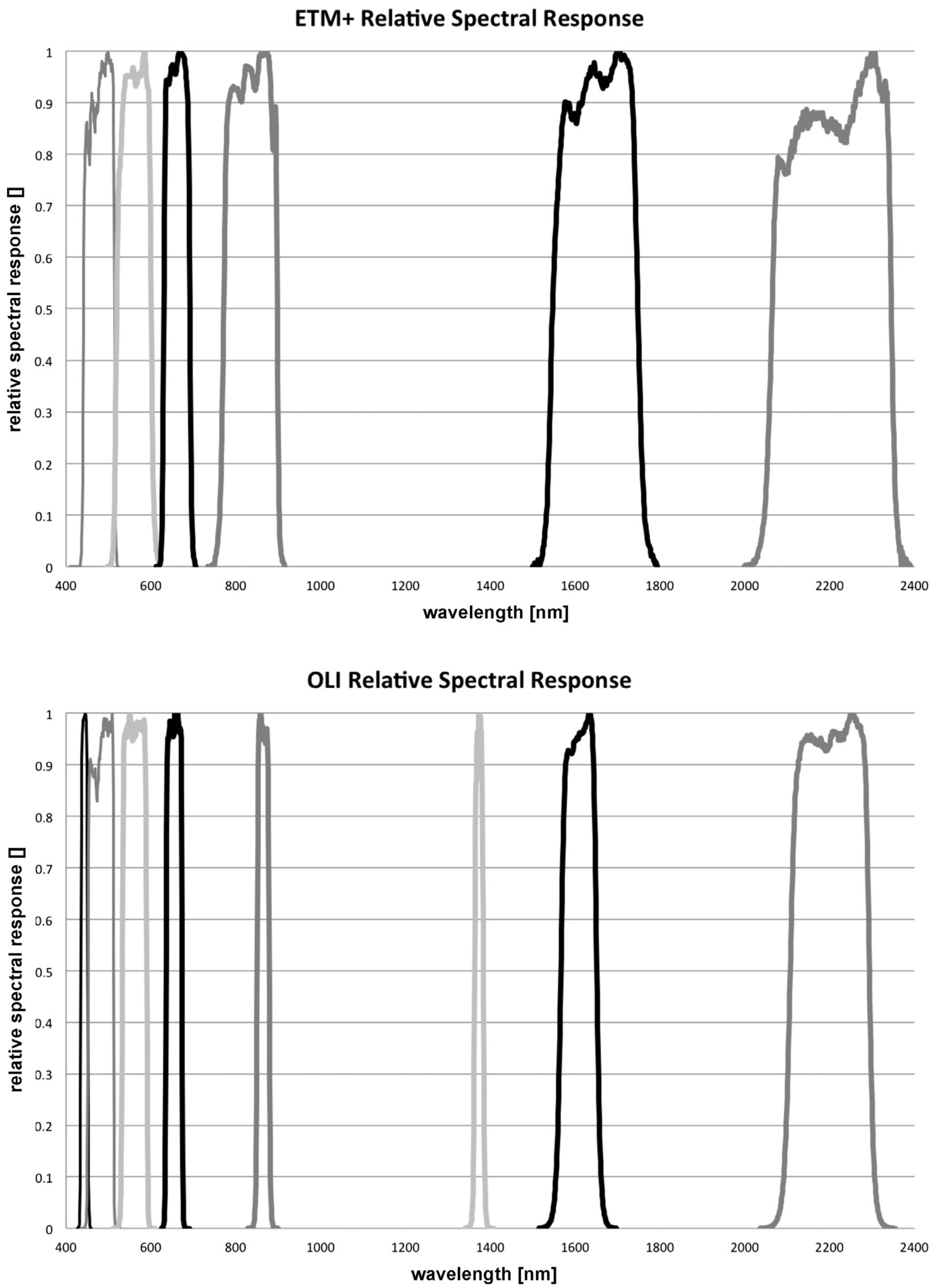

Fig. 1. Landsat ETM + a (top) and OLI b (bottom) spectral response functions.

This was based on the roughly 20-times improvement in AVIRIS SNR due to a number of instrument improvements from 1987 to 1998. However, no quantitative values for the improvements were stated. Green (2000), using AVIRIS data showed that the number of Minimum Noise Fraction (MNF) images with eigen values above a meaningful information threshold was directly related to SNR. However, the implication of this for specific applications was not demonstrated. Swayze, Clark, Goetz, Chrien, and Gorelick (2003) using simulated AVIRIS spectra showed, using the Tetracorder algorithm, that the classification accuracy of individual spectra improved with SNR. The relationship of the improvement to SNR being a function of the absorption spectrum of the mineral. In general for Landsat class instruments (medium resolution–multispectral) there is only limited data relating SNR to algorithm performance across any range of applications. The high SNR achieved by OLI provided a potential source of data to support an investigation of the role SNR plays in algorithm performance.

In prelaunch testing the OLI instrument dramatically exceeded its specified SNR and on orbit testing has verified that these high SNR values are being maintained in operational use (Knight & Kvaran, 2014). SNR or radiometric resolution is almost always an important parameter in instrument design trade studies (Schott, 2007, Chapters 6 & 13). Generally speaking, improved SNR comes at the cost of poorer spatial resolution, lower spectral resolution, less coverage, larger optics (size and weight) and higher data rates. As we look to the next

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