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Data Continuity of Landsat-4 TM, Landsat-5 TM, Landsat-7 ETM+, and Advanced Land Imager (ALI) sensors.

R. Bryant[1], M. S. Moran[1], S. McElroy[1], C. Holifield[1], K. Thome[2], and T. Miura[2]

[1]USDA – ARS
Tucson, AZ. 85719

[2]University of Arizona
Tucson, AZ 85721

Introduction

The data from the Landsat program constitutes the longest record of the Earth's surface as seen from space. Landsat 1 was launched in 1972 with the Multi-Spectral Scanner sensor (MSS), which was specifically designed for land remote sensing. This sensor proved so valuable that it was used with four subsequent Landsat missions. In 1982, Landsat 4 was launched with two sensors, MSS and a new sensor called the Thematic Mapper (TM) which had significant improvements in resolution as well as additional bands. The same payload was launched on Landsat 5 in 1984. Landsat 6 was launched in 1993 but failed to reach orbit. Landsat 7 was launched in 1999 with an improved TM sensor called the Enhanced Thematic Mapper (ETM+). The Advanced Land Imager (ALI) was launched in 2000 on the EO-1 (Earth Observer-1) satellite to test technology that will be used for the next Landsat platform, Landsat 8. In comparison to Landsat 7 ETM+, EO-1 ALI provides a greater signal to noise ratio, a pushbroom sensor, greater quantization, and additional wavelength bands.

As technology evolved, newer Landsat sensors were modified slightly while keeping in mind the importance of historical data continuity. There is a keen interest in documenting data continuity over the different Landsat sensors. This study attempts to quantify (within the limits of available information) data continuity over the three most recent Landsat sensors and the EO-1 ALI sensor.

The data set in this analysis includes images from Landsat 4, 5, and 7 TM beginning in 1989 and images from the EO-1-ALI platform acquired in 2001. All the images used were received radiometrically corrected to NASA level 1. Two locations were targeted where extensive ground data were available, the Maricopa Agriculture Center (MAC) southwest of Phoenix, owned and managed by the University of Arizona, and Walnut Gulch Experimental Watershed in southeastern Arizona. This watershed has been instrumented and studied for nearly 50 years by the Southwest Watershed Research Center (SWRC) in Tucson, an entity of the of the Agricultural Research Service (ARS).

Methods

All platform comparisons relied on ground measurements of surface reflectance for an independent measure of sensor response. To compare Landsat 4 TM to Landsat 5 TM imagery, the Refined Empirical Line (REL) approach (Moran, et. al. 2001) was used to predict atmospherically corrected satellite based reflectance. For all other platform comparisons, atmospherically corrected satellite based reflectance was calculated using radiometrically corrected image data. Atmospheric effects were characterized using on ground optical depth measurements and Gauss-Seidel atmospheric modeling code (Thome, 2001). In the case of the Landsat ETM+ - EO1 ALI analysis, we were also able to make direct sensor-to-sensor comparisons because images were acquired within minutes of each other.

Landsat 4 TM - Landsat 5 TM comparison

The data set for this comparison comprised of four Landsat 4 TM images and five Landsat 5 TM images acquired in 1989 at MAC. Reflectances derived from Landsat 4 and 5 TM *dn* (digital number) with the REL method were compared to ground reflectances of a cotton crop throughout the growing season. Root mean square error (RMSE) for the Landsat 4 TM sensor and the Landsat 5 TM sensor were the same for bands 2 and 3. For bands 1 and 4, the RMSE was within 0.025 reflectance value for both sensors (Table 1.) Since the REL approach is based on an average value for the image *dn* at 0 reflectance as well as a target that is assumed to have an invariant reflectance, it contains error in methodology that is not easily quantified.

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TABLE 1.
ROOT MEAN SQUARE ERROR (RMSE) FOR GROUND REFLECTANCE AND REFLECTANCE DERIVED FROM USING THE REFINED EMPIRICAL LINE METHOD. LANDSAT 4 TM AND LANDSAT 5 TM SENSORS.

	Band 1	Band 2	Band 3	Band 4
Landsat 4 TM	0.008	0.006	0.009	0.011
Landsat 5 TM	0.015	0.006	0.009	0.023

Landsat 5 TM - Landsat 7 ETM+ comparison

Nineteen images of Landsat 5 TM and Landsat 7 ETM+ were analyzed; six were Landsat 7 ETM+ images and the remaining were Landsat 5 TM images. More than one target was analyzed for several images for a total of 25 targets. Atmospherically corrected satellite based reflectance compared well with ground reflectance with an RMSE of 0.011 for Landsat 5 TM data and 0.031 for Landsat 7 ETM+ data (bands 1 – 4 aggregated). We also calculated the RMSE for each band separately (Table 2). In comparison to the aggregated data set, there were similar values of uncertainty for Landsat 5 TM and Landsat 7 ETM+ for bands 2 and 3. RMSE for bands 1 and 4 were higher for Landsat 7 ETM+, where the RMSE was 0.017 for TM 5 and 0.056 for Landsat 7 ETM+ in band 1. RMSE for band 4 were 0.019 (Landsat 5 TM) and 0.035 (Landsat 7 ETM+). RMSE for Landsat 5 TM for bands 5 and 7 were not calculated because ground data for these bands were not available. It should be noted that the difference in the number of observations between the two data sets was not taken into account in this comparison.

TABLE 2
ROOT MEAN SQUARED ERROR BETWEEN ATMOSPHERICALLY CORRECTED SATELLITE BASED REFLECTANCE AND GROUND REFLECTANCE FOR LANDSAT 5 TM AND LANDSAT 7 ETM+.

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7	
Landsat 5 TM	0.017	0.017	0.024	0.019			n=19
Landsat 7 ETM+	0.056	0.028	0.029	0.035	0.067	0.088	n=6

Landsat 7 ETM+ - EO-1 ALI comparison

The ground data for the EO-1 ALI – Landsat 7 ETM+ analysis were acquired using an Analytical Spectral Devices Full Spectrum (ASD FS) radiometer. This allowed us to analyze the two shortwave infrared bands along with the visible and NIR bands, which was not possible for the other platform comparisons. Twenty one data points from five different days at two sites were used for our analysis of these two platforms. The procedure for this analysis was similar to our analysis of the Landsat 5 TM and Landsat 7 ETM+ sensors; that is, atmospherically corrected satellite based reflectances were compared to ground reflectance. In this analysis, unlike the Landsat 5 TM – Landsat 7 ETM+ analysis, we accounted for water vapor in our atmospherically corrected satellite based reflectances. RMSE for all bands was 0.027 for EO-1 ALI and 0.028 for Landsat 7 ETM+. Each band of the sensors was also compared and the RMSE statistic calculated (Table 3). The RMSE for band 4 of 0.051 for Landsat 7 ETM+ was substantially higher than for the other bands.

TABLE 3
ROOT MEAN SQUARED ERROR BETWEEN ATMOSPHERICALLY CORRECTED SATELLITE BASED REFLECTANCE AND GROUND REFLECTANCE FOR LANDSAT 7 ETM+ AND ALI.

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
RMSE ALI sensor	0.023	0.025	0.031	0.037	0.033	0.013
RMSE ETM+ sensor	0.020	0.017	0.017	0.051	0.027	0.013

Since our comparison of the Landsat 7 ETM+ - EO-1 ALI sensors was with temporally coincident data at the same location, we were able to make direct sensor comparisons with the atmospherically corrected satellite based reflectances. For all practical purposes, the EO-1 ALI and Landsat 7 ETM+ atmospherically corrected satellite based reflectances were equivalent except in band 5, where EO-1 ALI reflectances were higher. The RMSE (Table 4) for band 5 of 0.088 was significantly greater than for the other bands, which ranged from 0.006 (band 3) to 0.030 (band 7).

TABLE 4
ROOT MEAN SQUARED ERROR BETWEEN ATMOSPHERICALLY CORRECTED SATELLITE BASED REFLECTANCE FOR LANDSAT 7 ETM+ AND ATMOSPHERICALLY CORRECTED SATELLITE BASED REFLECTANCE FOR EO-1 ALI.

	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
ALI_ETM+	0.007	0.008	0.006	0.012	0.088	0.03

The RMSE reported for comparisons of ground reflectance to atmospherically corrected satellite based reflectance are greater than for those reported for comparison of atmospherically corrected satellite based reflectance between sensors. Error in the relationship between the atmospherically corrected satellite based and ground reflectance for both platforms (Table 3) is a result of error inherent in obtaining reliable optical depths for inputs into the atmospheric model, atmospheric modeling code that somewhat simplifies the characterization of the atmosphere, and error in collecting ground reflectance data. By comparing atmospherically corrected satellite based reflectances across platforms, these errors cancel out since they are exactly the same for both platforms. The robust relationship between EO-1 ALI and

Landsat 7 ETM+ atmospherically corrected satellite based reflectances (Table 4) indicates that, with the exception of band 5, data continuity between the platforms is excellent. The similar atmospherically corrected satellite based reflectances for both platforms indicate the relative radiometric stability of the satellites throughout the time of this study.

Analysis across all platforms

Because of the different approaches used to analyze each platform pair, many statistical comparisons would also include error associated with the differences in comparison methodology along with the error we are trying to determine for this project. For example, if we compare the RMSE between the atmospherically corrected satellite based reflectance and the ground reflectance, we are assuming that the error is the same for collecting these data for each platform. Since the methodology is not the same for each comparison, it follows that the error associated with the data collection is not the same.

One way around this problem is to use a 'meta-statistic'. For example, if we use the absolute difference in RMSE for each sensor and compare it to the RMSE for the associated sensor pair dataset, Landsat 4 TM – Landsat 5 TM, Landsat 5 TM – Landsat 7 ETM+, Landsat 7 ETM+ – EO-1 ALI, the error due to differences in methodology would be excluded (Table 5). Although differences in RMSE vary across sensor comparisons for different bands, the highest absolute difference is only 0.020 for band 5 for EO-1 ALI and all other differences are below 0.01 reflectance (Table 5). From previous analysis, we know there is a slight discrepancy between ETM+ band 5 and ALI band 5 sensor response (Table 4). The differences presented in Table 5 are so low that it is appropriate to assume that for this study, after accounting for methodology error, data continuity across all the Landsat and ALI platforms is excellent with the possible exception of the ALI - ETM+ band 5 comparison.

TABLE 5.
ABSOLUTE DIFFERENCE IN RMSE OF ATMOSPHERICALLY CORRECTED SATELLITE BASED REFLECTANCES AND GROUND-BASED REFLECTANCES BETWEEN ONE SENSOR AND ENTIRE DATA SET OF SENSOR PAIRS.

Sensor	Sensor Pair	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
L4	L4–L5	0.005	0.0001	0.0002	0.008		
L5	L4–L5	0.003	0.0001	0.0001	0.004		
L5	L5–L7	0.004	0.0003	0.002	0.007		
L7	L5–L7	0.002	0.001	0.003	0.002		
L7	L7–ALI	0.002	0.001	0.004	0.006	0.010	0.006
ALI	L7–ALI	0.002	0.001	0.004	0.005	0.020	0.008

Conclusion

Overall, the three Landsat sensors and the EO-1 ALI sensor compared in this study exhibited excellent data continuity (Table 5). The only exception was the ALI band 5 which had an RMSE of 0.088 reflectance value when compared to Lansdsat ETM+ band 5. Considering the fact that ALI is a sensor launched for validation of new sensor technologies, the ALI sensor performed extremely well.

References

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