Data Continuity of Earth Observation (EO-1) Advanced Land Imager (ALI) and Landsat TM and ETM+

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In the year 2000, NASA launched the Earth Observing-1 (EO-1) Advanced Land Imager (ALI) to test new technologies that could improve the Landsat Thematic Mapper/Enhanced Thematic Mapper Plus (TM/ETM+) sensor series, yet ensure Landsat data continuity. The ALI sensor is characterized by a better signal to noise ratio (SNR) than the Landsat ETM+ and also has three additional bands (Table 1).

Table 1. Spectral and spatial definitions for the 10 EO-1 ALI bands. Bands 1p, 4p, and 5p are bands that are not found on the ETM+. Other bands correspond to ETM+ bands.

Band	Wavelength (μm)	Ground Sampling Distance (m)
Pan	0.48 – 0.69	10
MS-1p	0.433 – 0.453	30
MS-1	0.45 – 0.515	30
MS-2	0.525 – 0.605	30
MS-3	0.633 – 0.69	30
MS-4	0.775 – 0.805	30
MS-4p	0.845 – 0.89	30
MS-5p	1.2 – 1.3	30
MS-5	1.55 – 1.75	30
MS-7	2.08 – 2.35	30

This study quantified the continuity of satellite-retrieved surface reflectance (Δ) for the three most recent Landsat sensors (Landsat 4 TM, Landsat 5 TM, and Landsat 7 ETM+) and the EO-1 ALI sensor. The study was based on ground data verification and, in the case of the ETM+ to ALI comparison, coincident image analysis. Image data was obtained from two locations where extensive ground data was available: the Maricopa Agriculture Center (MAC) southwest of Phoenix, Arizona; and the Walnut Gulch Experimental Watershed in southeastern Arizona, an area that has been studied for nearly 50 years (Figure 1). All comparisons relied on ground measurements of surface reflectance for an independent measure of sensor response.

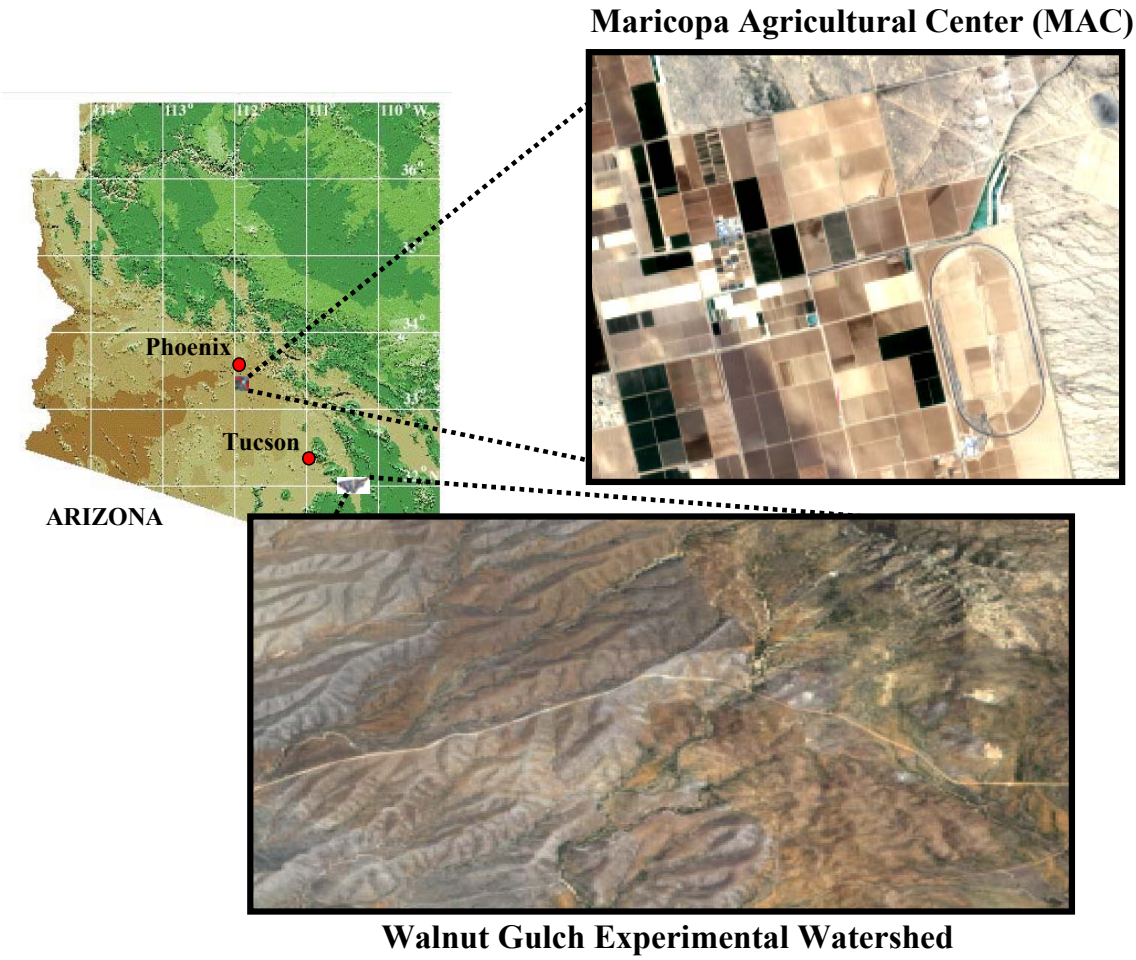

Figure 1. Study Sites

Three separate analyses of data continuity were conducted: (1) Landsat 4 to Landsat 5 TM, (2) Landsat 5 TM to Landsat 7 ETM+, and (3) Landsat 7 ETM+ to EO-1 ALI. For the Landsat 4 – Landsat 5 comparison, data from four Landsat 4 TM images and five Landsat 5 TM images were used. For the Landsat 5 and Landsat 7 comparison, a total of 25 targets were analyzed. In the case of the Landsat ETM+ - ALI comparison, direct sensor-to-sensor comparison was possible because the images from the two sensors were acquired almost simultaneously. For this analysis, 21 data points from five different days at two sites were used. Except for the Landsat 4 – Landsat 5 comparison, atmospherically corrected satellite-based reflectances were compared to ground reflectance.

In all cases, the root mean squared error (RMSE) between satellite-retrieved and ground-measured reflectance were comparable between sensors, and RMSE was generally within the required accuracy for many applications (Tables 2-4). The direct comparison between image pairs of Landsat 7 ETM+ and EO-1 ALI (Table 5) showed good comparability for bands 1-4 and band 7, (RMSE <= 0.02) and moderate results for band 5 (RMSE = 0.03). When the RMSE of all sensors were compared (to minimize the effects of different methodologies), the sensors showed excellent data continuity. The absolute differences in RMSE ranged from 0.00 to 0.02 (Table 6).

Table 2. Root mean square error (RMSE) for ground measured reflectance and reflectance derived using the Refined Empirical Line method for Landsat 4 TM and Landsat 5 TM sensors.

Sensor	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

Table 3. Root mean squared error (RMSE) between ground-measured reflectance and satellite-retrieved reflectances from Landsat 5 TM and Landsat 7 ETM+ sensors.

Sensor	Band 1	Band 2	Band 3	Band 4
Landsat 5 TM	0.017	0.016	0.022	0.027
Landsat 7 ETM+	0.022	0.018	0.022	0.038

Table 4. Root mean squared error (RMSE) between ground-measured reflectance and satellite-retrieved reflectances from Landsat 7 ETM+ and EO-1 ALI.

Sensor	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Landsat 7 ETM+	0.023	0.024	0.027	0.057	0.032	0.013
EO-1 ALI	0.021	0.020	0.023	0.037	0.020	0.020

Table 5. Root mean squared error $RMSE_s$ between satellite-retrieved reflectance for Landsat 7 ETM+ and satellite-retrieved reflectance for EO-1 ALI.

Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
0.003	0.012	0.009	0.018	0.031	0.020

Table 6. Absolute difference in RMSE of ground-measured reflectance and satellite-retrieved reflectance between sensor pairs.

Sensor Pair	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Landsat 4 TM Landsat 5 TM	0.007	0.000	0.000	0.012		
Landsat 5 TM Landsat 7 ETM+	0.005	0.002	0.000	0.011		
Landsat 7 ETM+ EO-1 ALI	0.002	0.004	0.004	0.020	0.012	0.007

A qualitative analysis of the new ALI spectral band 5p (1.20-1.30 μm) showed that ALI band 5p provided information that differed from that provided by the ETM+/ALI SWIR bands 5 and 7 for agricultural targets (Figure 2). Further investigation is warranted to determine what distinctive surface characteristics influenced the reflectance in band 5p.

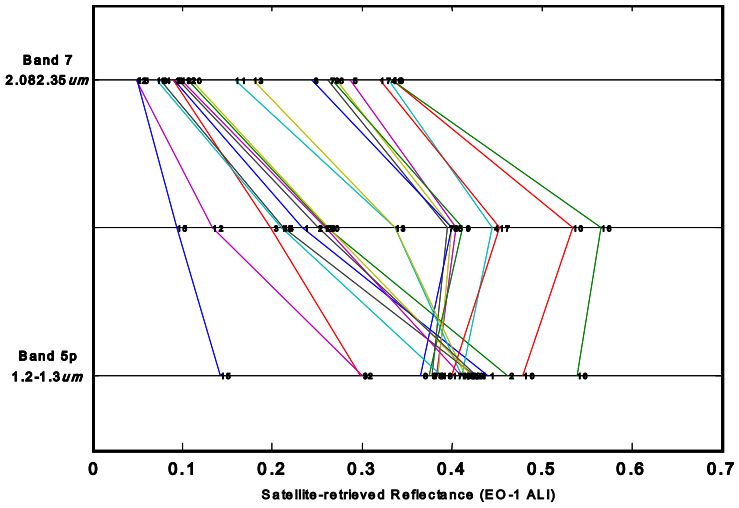

Figure 2. Reflectances retrieved from EO-1 ALI shortwave infrared (SWIR) spectral bands for all 21 targets. Numbers on the graph correspond to target numbers.

ALI band 4p has the advantage over both the ETM+ band 4 and ALI band 4 in that it is relatively insensitive to water vapor absorption (Table 7). Furthermore, since the reflectances retrieved from ETM+ band 4, ALI band 4, and ALI band 4p for 21 agricultural targets were nearly identical, it could be an excellent substitute band for ETM+ band 4 on the next Landsat mission.

Table 7. Root mean squared error (RMSE) reflectance retrieved from Landsat 7 ETM+ band, EO-1 ALI bands 4 and 4p, and associated ground-measured reflectance. Two cases are presented: atmospheric correction without water vapor correction and with water vapor correction.

Band	Without water vapor correction	With water vapor correction
ETM+ Band 4	0.078	0.057
ALI Band 4	0.052	0.041
ALI Band 4p	0.037	0.034

Conclusion:

The four sensors can provide excellent data continuity for temporal studies of natural resources. Furthermore, the new technologies put forward by the EO-1 ALI sensor have had no apparent negative effect on data continuity and should be considered for the next Landsat sensor payload.