Intercalibration and Evaluation of ResourceSat-1 and Landsat-5 NDVI

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ABSTRACT

ResourceSat-1 is a designated alternative to Landsat should the existing TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper Plus) sensors fail prior to the successful launch of Landsat 8 in late 2012. However, to enable integration of ResourceSat-1 into the many existing long-term Landsat projects around the world, practicable similarity must be demonstrated. To quantify the potential for ResourceSat-1 to satisfy some of the needs of the remote sensing community, Normalized Difference Vegetation Index (NDVI) values derived from Landsat-5 were compared to NDVI values derived from ResourceSat-1. An intercalibration equation was derived which converts ResourceSat-1 NDVI values to equivalent Landsat-5 NDVI values thereby enabling direct comparison between the two sensors. Comparisons were made using imagery spanning a three-year time period. Prior to intercalibration, NDVI values were highly correlated (mean $R^2 > 0.73$) but statistically different ($P < 0.001$). Following intercalibration, the resulting indices were statistically inseparable (min $P = 0.56$). The intercalibration technique described in this paper represents an easily repeatable process which demonstrates practicable similarity between ResourceSat-1 and Landsat-5 imagery.

INTRODUCTION

Medium resolution earth imaging sensors have become an integral part of land cover analysis and change detection in many land management agencies and research institutions. Landsat imagery in particular has contributed to over 35 years of continuous earth imaging and still plays a prominent role in research and management (Cohen and Goward, 2004; Leimgruber et al., 2005; Williams et al., 2006). However, the National Research Council of the National Academies recently chronicled the dire condition of the United States' earth imaging satellite fleet as well as the political and financial challenges facing current and future earth imaging programs (National Research Council, 2007). An additional concern is the likelihood of the current Landsat satellites failing prior to the launch of Landsat 8, late in 2012 as both Landsat-5 and Landsat-7 have exceeded their mission lifetimes (USGS, 2004 and USGS, 2008). It is this situation which has spurred National Aeronautics and Space Administration (NASA) scientists to identify active earth imaging sensors that are comparable to Landsat, and able to fill the gap in earth imaging capabilities should the need arise (Chander et al., 2008; Wulder et al., 2008).

LANDSAT PROGRAM STATUS

NASA started the Landsat program with the launch of Landsat 1 on July-23, 1972. This and the subsequent launch of additional Landsat satellites have resulted in over 35 years of continuous earth imaging from these sensors. Landsat-5 was launched in 1984 with a design life of 3 years. It carried the Thematic Mapper (TM) sensor, which is comprised of seven operational bands including three in the visible portion of the electromagnetic spectrum (Table 1). Landsat-7 was launched in 1999 with a design life of 5 years. It carried the Enhanced Thematic Mapper Plus (ETM+) sensor, which is comprised of eight operational bands including three in the visible portion of the electromagnetic spectrum.

Table 1. Landsat-5 Thematic Mapper (TM) and ResourceSat-1 LISS III spectral and spatial characteristics. Temporal resolution of Landsat-5 = 16 days, swath width = 185km, and 30 m spatial resolution on bands 1-5 and 7. ResourceSat-1 temporal resolution = 24 days, swath width = 141km, and 23.5 m spatial resolution on all bands.

Band	Landsat-5 Spectral Resolution (µm)	ResourceSat-1 Spectral Resolution (µm)
1	0.45-0.52	-
2	0.52-0.60	0.52-0.59
3	0.63-0.69	0.62-0.68
4	0.76-0.90	0.77-0.86
5	1.55-1.75	1.55-1.70
6	10.40-12.50	-
7	2.08-2.35	-

In the joint opinion of NASA and the USGS, it is "likely and expected" that either Landsat-5 or Landsat-7 could fail at any moment (USGS Remote Sensing Technologies Project: Landsat Data Gap Studies, 2008) as indeed, neither satellite is functioning properly at this time. For example, the batteries on Landsat-5 run too low during its June, July, and August transits over the southern hemisphere resulting in only the far northern portions of Australia being imaged during those months (Geoscience Australia, 2008). In addition, the Enhanced Thematic Mapper Plus (ETM+) instrument onboard Landsat-7 has a Scan Line Corrector (SLC) failure (USGS, 2003) and has operated in "SLC off" mode since May of 2003. The result of this failure is that some areas are imaged twice, while other areas are not imaged at all, leaving up to one fourth of a scene missing (Markham et al., 2004). While the resulting data gaps can be filled using data from other dates, this is not a satisfactory solution for many scientific applications as this introduces temporal inconsistencies (minimum 16 days) into the imagery.

LANDSAT DATA GAP STUDY TEAM

NASA and the USGS have recognized the potential earth imaging data gap and in response, formed the joint Landsat Data Gap Study Team (LDGST) in 2005. The study team identified candidate platforms that would help reduce the impact of a data gap until the Landsat Data Continuity Mission (LDCM) (i.e., Landsat 8) would launch late in 2012 (Chander, 2007). In the LDGST study, two potential gap-fill sensors, the Indian ResourceSat-1 (Linear Imaging Self Scanning III [LISS-III]) and the China-Brazil Earth Resources Satellite (CBERS-2) were selected. Following this selection, an interagency Data Characterization Working Group (DCWG) was formed and tasked with assessing the potential of these sensors to mitigate a possible Landsat data gap.

Of the DCWG's two sensor recommendations, ResourceSat-1 (Table 1), was considered the sensor that provided the best combination of Landsat-5 like data, capabilities, spectral band characteristics, and data accessibility and hence, was considered best able to fulfill immediate data needs with minimal complication (Chander, 2007; Teillet, 2008). It is for this reason that the present study focuses upon ResourceSat-1 and specifically its LISS-III sensor.

NORMALIZED DIFFERENCE VEGETATION INDEX

The Normalized Difference Vegetation Index (NDVI), derived from the red and near-infrared bands common to many sensors, is a widely used numeric indicator of photosynthetically active green vegetation used to estimate biomass, plant productivity, and vegetation cover (Tucker, 1979). It has been shown that NDVI values are not identical across sensors due to uncertainties related to viewing angle, atmospheric conditions, and spectral band difference effects (Teillet et al., 1997, 2006; Goetz, 1997; van Leeuwen, 2006). However, vegetation indices are relatively insensitive to uncertainties in atmospheric corrections and differences in satellite viewing angle and thereby provide the means for direct comparison between sensors (Steven et al, 1998, 2003). This elimination of several potentially confounding factors makes the use of NDVI ideal for intercalibration testing.

Landsat-5 and ResourceSat-1 share many spectral, spatial, and temporal characteristics (Table 1). Among the strongest similarities are near coincident spectral bandwidths in the red, near infrared (NIR), and short-wave infrared (SWIR) regions of the electromagnetic spectrum. Because NDVI is derived from red and near infrared bands only, much of the potential spectral band difference effects caused when using the green and blue bands in other vegetation indices such as atmospherically resistant vegetation index (ARVI) and modified triangular vegetation index 2 (MTVI2) are avoided (Teillet, 2008). The slight differences in swath width and spatial resolution of both sensors were not directly considered in this study, but might have practical effects regarding the extent and characteristics of targeted areas of interest. The eight-day difference in the temporal resolution of these two sensors is of practical concern as it limits the number of cloud free scenes available over the course of a growing season.

The main objective of this study was to compare Landsat-5 with ResourceSat-1 and determine an intercalibration correction between the sensors. Random point sampling of heterogeneous semiarid landscapes allowed for a full range of NDVI values to be used in the development of the intercalibration. In light of potential Landsat program data gaps and given the importance of NDVI in research and land management decisions, these techniques provide a simple but robust procedure for providing reliable intercalibration of NDVI from one sensor to the other.

METHODOLOGY

Study Area

Landsat-5 and ResourceSat-1 imagery was acquired for a study area covering approximately 17,000 km^2 in southeast Idaho, USA (112° 27' 44" W and 43° 00' 12" N) (Figure 1). All Landsat-5 scenes used in this study were acquired for path 39, row 30 with spatially coincident ResourceSat-1 scenes acquired for path 253, row 39. The landscape imaged in these scenes included semiarid sagebrush-steppe, active and fallow agricultural fields, high altitude coniferous forests, several large reservoirs, lava flows, and various towns and cities, resulting in a highly heterogeneous study area.

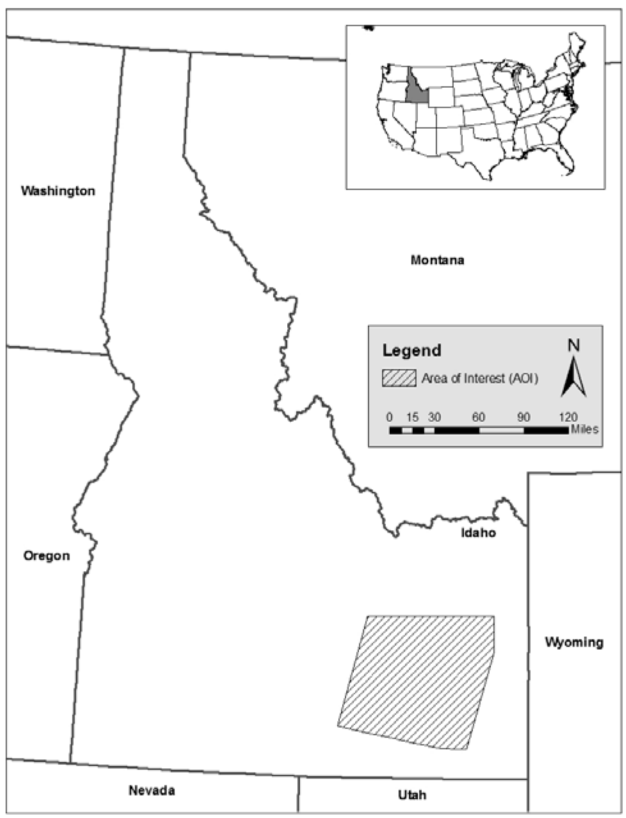


Figure 1. Study area in Southeast Idaho, USA used to compare ResourceSat-1 and Landsat-5 NDVI values.

DATA SOURCES AND PREPARATION

Three Landsat-5 scenes were acquired for this study (August 13, 2005, July 15, 2006, and September 20, 2007) along with three ResourceSat-1 scenes (August 20, 2005, July 22, 2006, and September 3, 2007). These images formed the basis of the three annual cross-sensor comparisons used in this study.

All imagery were atmospherically corrected using the Cos(t) technique (Chavez, 1996) in Idrisi Andes. NDVI layers were created and subsequently georectified against 2004 National Agriculture Imagery Program (NAIP) natural color aerial imagery (1 m x 1 m pixels). Resulting RMSE was < 1/2 pixel (Weber, 2006) ($\underline{x}$ RMSE = 8.2 m and 6.5 m for Landsat-5-derived NDVI layers and ResourceSat-1 derived NDVI layers, respectively). Each of the three image pairs (i.e., NDVI layers from 2005, 2006, and 2007) were then co-registered to each other with a resulting mean RMSE of 7.4 m. Paired Landsat-5/ResourceSat-1 layers were clipped to a coincident area and all cloud cover was removed by manually digitizing a cloud mask layer (Figure 2), resulting in an area of interest (AOI) used throughout this study.

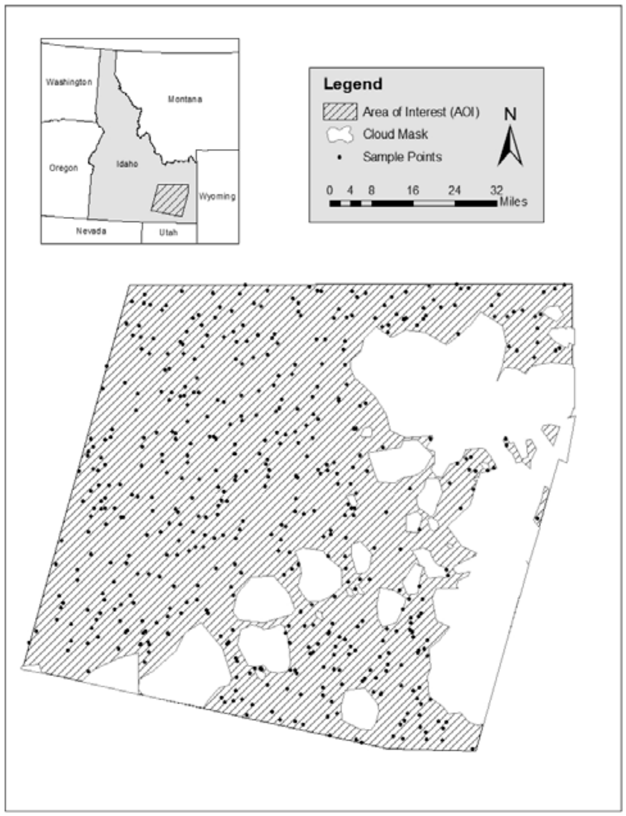


Figure 2. Example of combined cloud mask, sample points and coincident area between 2005 Landsat-5 and ResourceSat-1 scenes.

Weber (2006) reported the importance of identifying the same target pixel when comparing imagery and the need to evaluate co-registration error. Co-registration error between Landsat-5 and ResourceSat-1 image pairs was independently verified using the Georeferencing extension in ArcGIS 9.3. Using 20 well-defined and recognizable features with the image pairs (n = 10 [2005], n = 5 [2006], and n = 5 [2007]), resulting mean RMSE was 8.67 m.

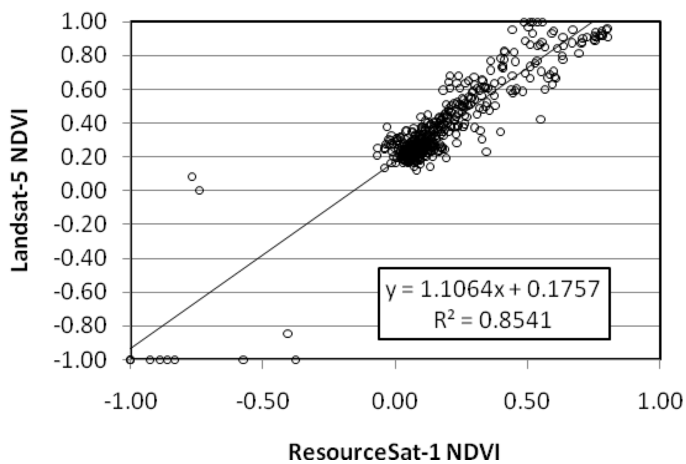
SAMPLING AND STATISTICAL ANALYSIS

For each of the three annual image pairs, 500 development random sample points within the AOI of each image pair were generated using Hawth's Tools for ArcGIS 9.3. The pixel value at each sample point was extracted from both the Landsat-5-derived NDVI layers and the ResourceSat-1 derived NDVI layers using the "Sample" tool in ArcGIS 9.3, creating a table of NDVI values for statistical comparison (*n*=1500 records). Linear regression analyses were used to calculate the coefficient of determination (R^2) between NDVI values and find the slope and Y-intercept between each image pair. Mean slope and intercept of the three image pairs were calculated and the resulting regression equation was then used to intercalibrate ResourceSat-1values to a Landsat-5 equivalent.

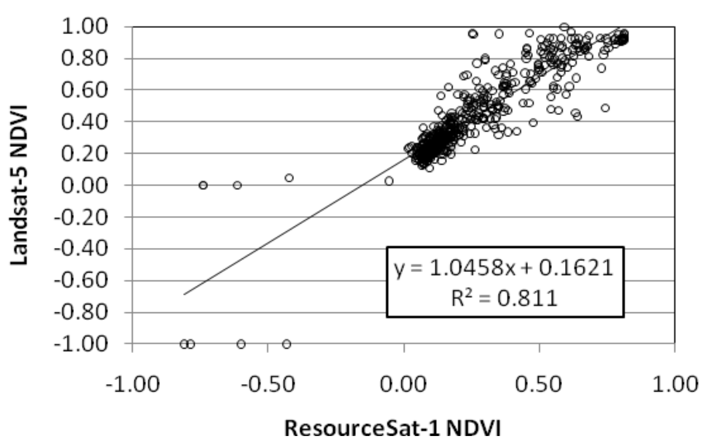
To test the intercalibration equation, NDVI values at 500 independent random sample points were extracted from each image pair using the sample tool in ArcGIS 9.3. The intercalibration equation was applied to ResourceSat-1 NDVI values and then compared to original Landsat-5 derived NDVI values. Linear regression analyses were used to determine the correlation coefficient and Analysis of Variance (ANOVA) was used to test for statistical difference between NDVI values both before and after intercalibration.

RESULTS AND DISCUSSION

Scatter plots with correlation coefficients for 2005, 2006, and 2007 image pair comparisons demonstrate inherent similarity between Landsat-5 and Resource-1 NDVI values even when comparisons included 17-day differences between image acquisitions (Figure 3).



a.



b.

c.

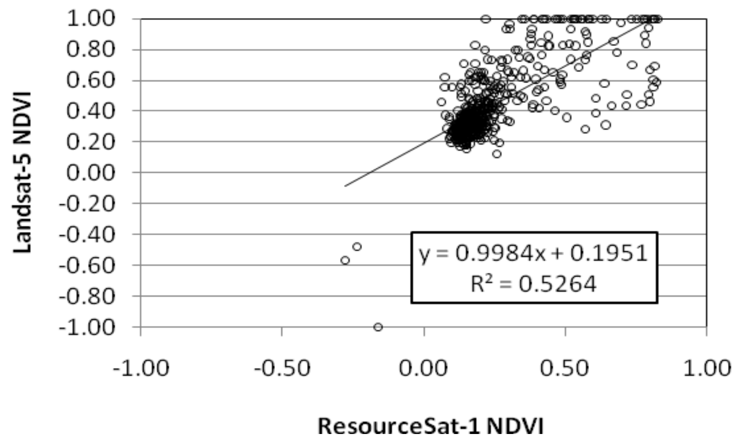


Figure 3. Distribution and correlation of Landsat-5/ResourceSat-1 NDVI values for (a) 2005; (Landsat-5) – (ResourceSat-1) time difference = – 7 day, (b) 2006; (Landsat-5) – (ResourceSat-1) time difference = – 7 day, and (c) 2007; (Landsat-5) – (ResourceSat-1) time difference = + 17 day.

In each, NDVI values extracted from ResourceSat-1 are shown on the X-axis with NDVI values extracted from Landsat-5 given on the Y-axis. Outliers in Figure 3 are largely the result of anthropogenic effects on the environment that occurred between the image pair dates, for example, reservoir drawdown for agricultural irrigation and agricultural harvest. From these data, the mean slope (1.0502; SE = 0.031) and Y-intercept (0.177633; SE = 0.009) and used to form an intercalibration equation (Equation 1).

$$Intercalibrated\ NDVI_{Landsat-5} = 1.0502 * NDVI_{ResourceSat-1} + 0.177633 \tag{1}$$

Prior to intercalibration NDVI values from Landsat-5 and ResourceSat-1 were highly correlated (minimum $R^2 > 0.56$) but statistically different ($P < 0.001$). As a result, the NDVI values from one sensor could not be compared directly to the values from the other sensor. Following intercalibration, the resulting NDVI values were statistically inseparable (minimum $R^2 > 0.53$ and minimum $P = 0.56$) (Table 2).

Table 2. Coefficient of determination and probability values for pre- and post-intercalibrated NDVI values

		P-value	
Year	**R^2**	**Pre-intercalibration**	**Post-intercalibration**
2005	0.83	< 0.001	0.61
2006	0.84	< 0.001	0.66
2007	0.58	< 0.001	0.56

This study demonstrated the ability to develop effective intercalibrations between Landsat-5 and ResourceSat-1 over large heterogeneous regions using imagery acquired over a 17 day interval. This study builds upon and broadens the application of other studies that derived intercalibrations under more homogeneous conditions. For instance, Chander et al. (2008) used near simultaneous image pairs to compare the average of paired homogeneous areas and reported R^2 values between Landsat-5 and ResourceSat-1 of 0.99 for every band, with differences in reflectance across all bands of approximately 13%. The techniques described in this paper use only simple spatial and statistical tools to derive an effective intercalibration equation that is easily repeated and does not require field spectroradiometer data (Steven et al., 2003).

Co-registration errors may lead to erroneous intercalibration of the imagery. Weber et al. (2008) highlight the importance of considering co-registration and independent verification of co-registration error performed in this study revealed the RMSE for 2005, 2006, and 2007 were 6.99, 10.62, and 10.10 m respectively, The weighted mean RMSE was 8.67. Consequently, it is highly probable that the pixel values used this study were extracted from pixels representing the same land features and locations on the earth's surface as the observed RMSE values imply precise co-registration between Landsat-5 and ResourceSat-1 image pairs.

CONCLUSIONS

The importance of medium resolution earth imaging satellites for land cover analysis and change detection, combined with the tenuous status of active Landsat satellites, make studies such as the one presented in this paper timely and valuable. This study produced an easily repeatable and accurate region-specific intercalibration of ResourceSat-1 NDVI to its Landsat-5 equivalent ($R^2 > 0.85$). The process described in this paper illustrates that intercalibrated NDVI is resilient to temporal variations (intercalibrations were based upon 7-17 day differences), as well as spectral band differences. Replication of this technique in other regions will aid scientists contending with the potential Landsat data gap or otherwise needing to compare values from one sensor to another.

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