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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 that converts ResourceSat-1 NDVI values to equivalent Landsat-5 NDVI values was derived thereby enabling direct comparison between the two sensors. Comparisons were made using imagery spanning a 3-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 ($P \geq 0.56$). The intercalibration technique described in this paper represents an easily repeatable process that demonstrates practicable similarity between ResourceSat-1 and Landsat-5 imagery.

Résumé. Le satellite ResourceSat-1 est une alternative désignée dans l'éventualité où les capteurs TM (« Thematic Mapper ») et ETM + (Enhanced Thematic Mapper Plus) de Landsat faisaient défaut avant le lancement prévu de Landsat 8 à la fin de 2012. Cependant, pour permettre l'intégration de ResourceSat-1 dans les nombreux projets actuels à long terme de Landsat autour du monde, on doit démontrer une similarité pratique entre ces données. Pour quantifier le potentiel de ResourceSat-1 à satisfaire certains des besoins de la communauté de la télédétection, les valeurs de NDVI (« Normalized Difference Vegetation Index ») dérivées de Landsat-5 ont été comparées aux valeurs NDVI de ResourceSat-1. Une équation d'interétalonnage a été dérivée permettant de convertir les valeurs de NDVI de ResourceSat-1 en valeurs équivalentes de NDVI de Landsat rendant ainsi possible la comparaison directe entre les deux capteurs. Des comparaisons ont été effectuées à l'aide d'images acquises sur une période de trois ans. Avant l'interétalonnage, les valeurs de NDVI étaient fortement corrélées (moyenne $R^2 > 0.73$) mais statistiquement différentes ($P < 0.001$). Suite à l'interétalonnage, les indices résultants étaient statistiquement inséparables ($P \geq 0.56$). La technique d'interétalonnage décrite dans cet article constitue une procédure facilement renouvelable qui démontre la similarité pratique entre les images de ResourceSat-1 et celles de Landsat-5.
[Traduit par le Rédaction]

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; Miller et al., 2011). 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 existing 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; USGS, 2008). It is this situation that 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 23 July 1972. This, and the subsequent launch of additional Landsat satellites, has 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

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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.

In the joint opinion of NASA and the United States Geological Survey (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) launches 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; hence, it was considered best able to fulfill immediate data needs with minimal complication (Chander, 2007; Teillet and Ren, 2008). It is for this reason that the present study focuses upon ResourceSat-1 and specifically its LISS-III sensor.

Table 1. Landsat-5 Thematic Mapper (TM) (185 km swath width) and ResourceSat-1 LISS III (141 km swath width) spectral characteristics.

	Spectral Resolution (μm)	
Band	Landsat-5[1]	ResourceSat-1[2]
Blue	0.45–0.52	–
Green	0.52–0.60	0.52–0.59
Red	0.63–0.69	0.62–0.68
NIR	0.76–0.90	0.77–0.86
Mid-IR	1.55–1.75	1.55–1.70
Thermal	10.40–12.50	–
SWIR	2.08–2.35	–

Note: The temporal resolution of Landsat-5 = 16 days while ResourceSat-1 = 24 days.

[1]Spatial resolution of Landsat-5 TM = 30 m for all bands, save for the thermal band, which has a spatial resolution of 120 m.

[2]Spatial resolution of ResourceSat-1 = 23.5 m.

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI), derived from the red and near-infrared (NIR) 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; Rahman et al., 2001; Huete et al., 2002). It has been shown that NDVI values are not identical across sensors because of uncertainties related to viewing angle, atmospheric conditions, and spectral band difference effects (Teillet et al., 1997, 2006; Goetz, 1997; van Leeuwen, et al., 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, 1998; Steven et al., 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 greatest similarities are near coincident spectral bandwidths in the red, NIR, and short-wave infrared (SWIR) regions of the electromagnetic spectrum. Because NDVI is derived from red and NIR bands only, much of the potential spectral band difference effects (SBDE) apparent when using the green and blue bands (such as the atmospherically resistant vegetation index (ARVI) and modified triangular vegetation index 2 (MTVI2)) are avoided (Teillet and Ren, 2008). Some SBDE are caused by differences in the red band, further demonstrating the need for intercalibration between sensors.

The effect of the slight differences in swath width and spatial resolution between these sensors was not considered directly in this study as both sensors have a low altitude and moderate spatial resolution that helps avoid geometric distortion and the distinct between-sensor changes in NDVI common to sensors at greater altitude and coarser spatial resolution (Teillet et al., 1997). However, between-sensor differences in swath width, and specifically spatial resolution, may have various practical effects relative to the extent and characteristics of targeted areas of interest. In addition, it should be pointed out that substantial differences in spatial resolution will result in errors when comparisons are made between such sensors. This was demonstrated by Teillet et al. (1997) in an analysis of the effects of spatial resolution differences between 20 AVIRIS data aggregated to 60, 100, 260, 500, and 1100 m spatial resolutions. In these situations, land-cover-specific intercalibrations were necessary (Teillet et al., 1997). No significant errors were anticipated when comparing two moderate spatial resolution sensors such as Landsat-5 TM (30 m) and ResourceSat-1 (23.5 m). The temporal resolution differences (8 days) between these two sensors is also of practical concern as it limits the number of cloud-free scenes available over the course of a growing season.

The objective of this study was to compare Landsat-5 with ResourceSat-1 and determine an intercalibration correction between these sensors for use in the event of a complete Landsat failure prior to a successful launch of Landsat-8 in 2012. Random point sampling across a heterogeneous semiarid landscape 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, the techniques described herein provide a simple yet robust procedure for reliable intercalibration of NDVI between sensors.

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

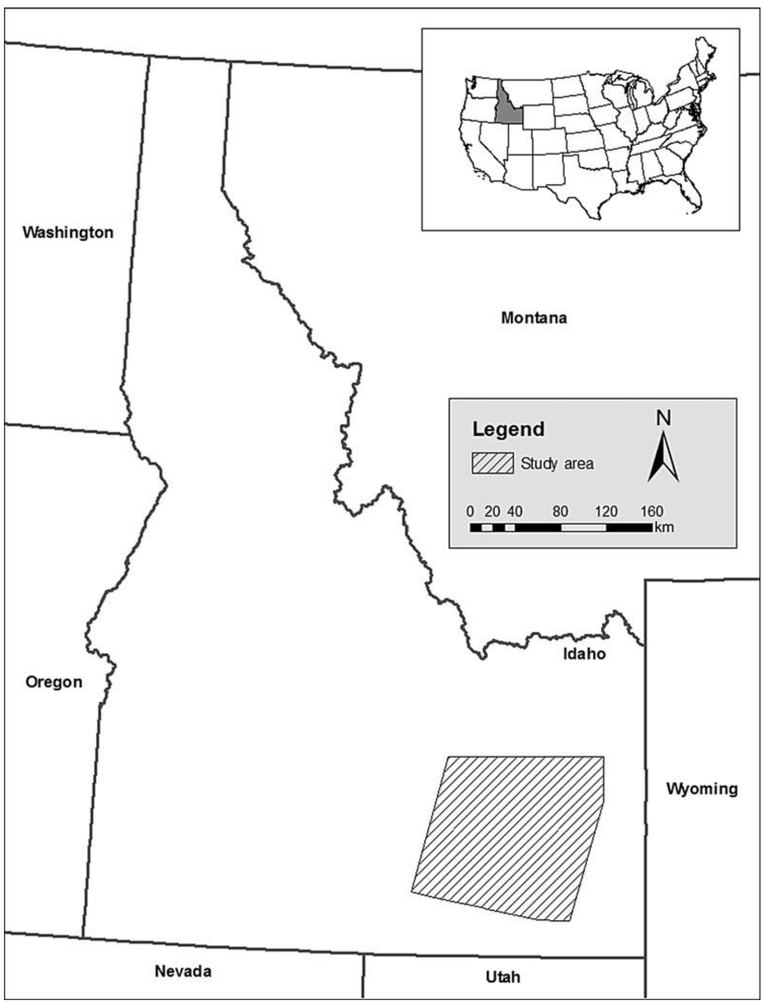

Figure 1. Study area in southeast Idaho, USA used to compare ResourceSat-1 and Landsat-5 NDVI values.

forests, several large reservoirs, lava flows, and various towns and cities, resulting in a highly heterogeneous study area.

Data sources and preparation

Three Landsat-5 scenes were acquired for this study (13 August 2005, 15 July 2006, and 20 September 2007) along with three ResourceSat-1 scenes (20 August 2005, 22 July 2006, and 3 September 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 $\times$ 1 m pixels). Resulting RMSE was $< 1/2$ pixel (Weber, 2006) ($\bar{X}$ RMSE $= 8.2$ 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 a common area of interest (AOI) used throughout this study.

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

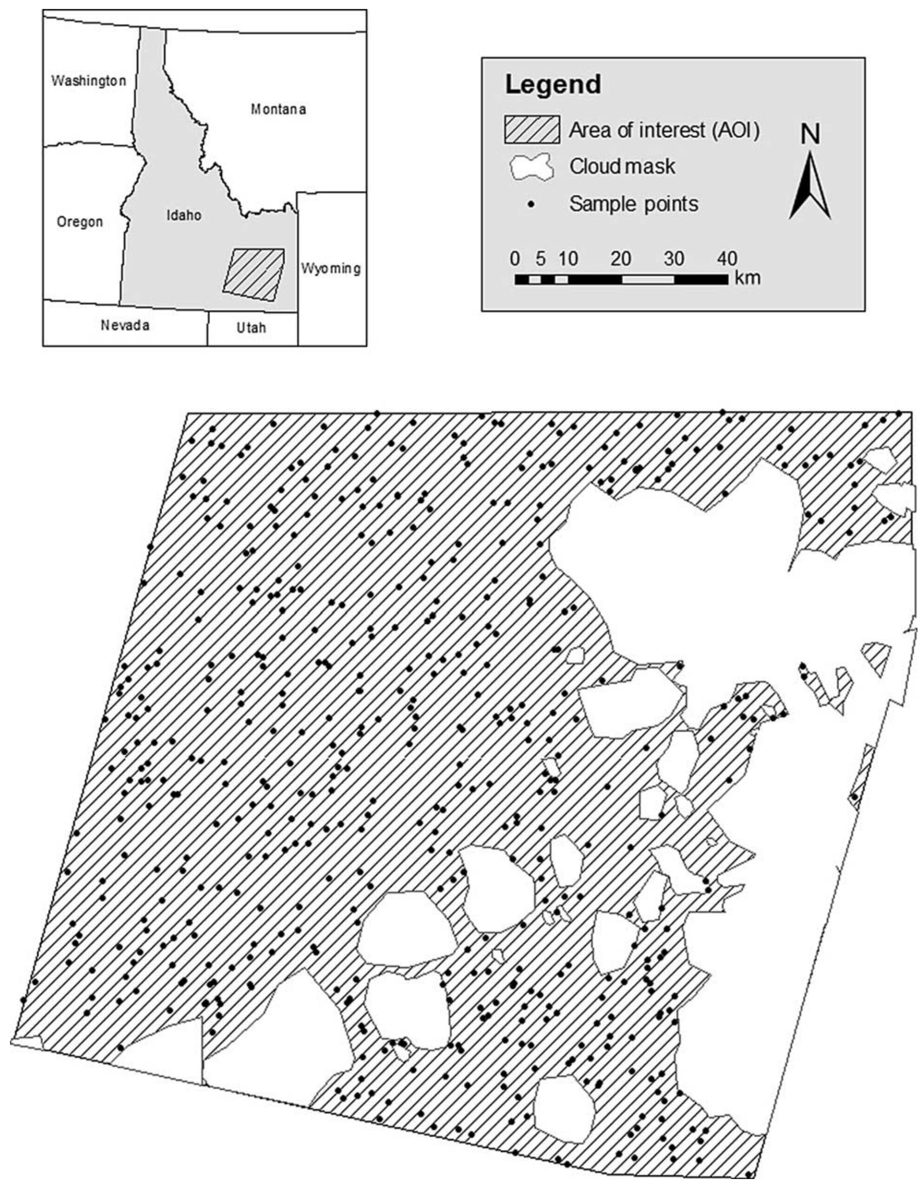

Figure 2. Example of combined cloud mask, sample points, and coincident area of interest between 2005 Landsat-5 and ResourceSat-1 scenes.

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 independent 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). These samples were used for the development of the intercalibration using linear regression analyses to calculate the coefficient of determination (R^2), slope and Y-intercept between NDVI values of 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-1 values to a Landsat-5 equivalent.

To validate 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**). 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) were used to form an intercalibration equation (Equation 1).

$$\text{Intercalibrated NDVI}_{\text{Landsat-5}} = 1.0502 \times \text{NDVI}_{\text{ResourceSat-1}} + 0.177633 \quad (1)$$

Prior to intercalibration, NDVI values from Landsat-5 and ResourceSat-1 were highly correlated ($R^2 \geq 0.56$) 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,

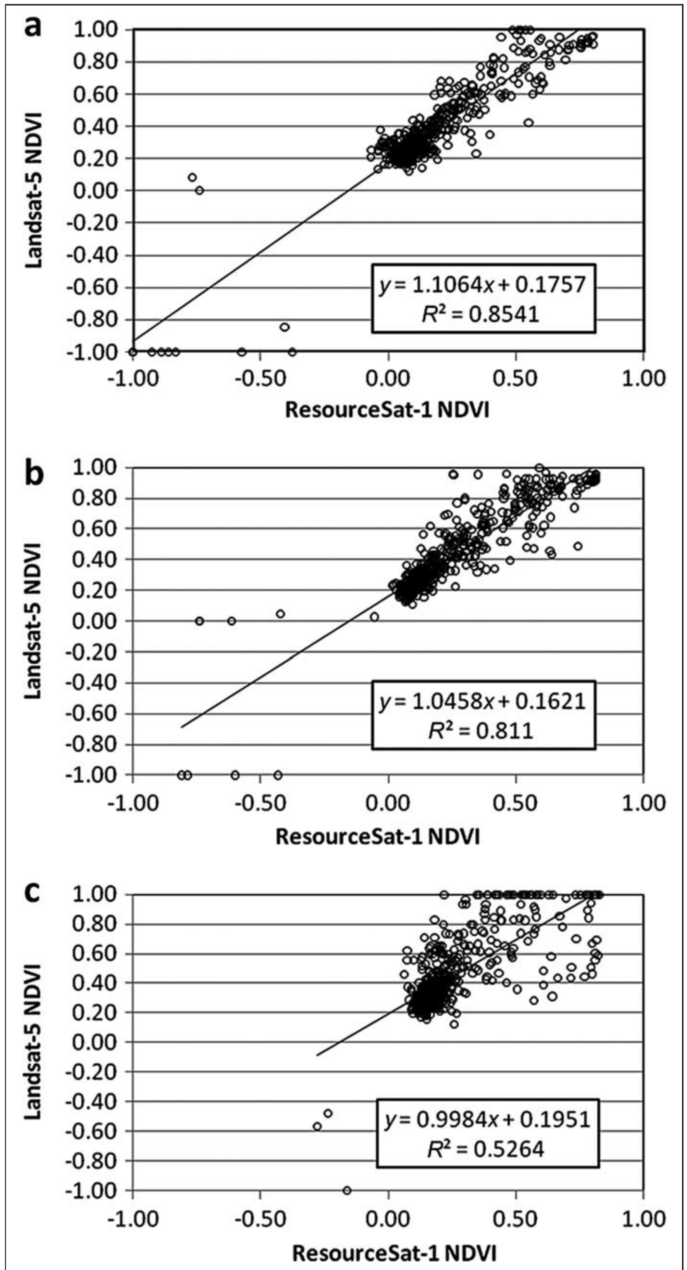

Figure 3. Distribution and correlation of Landsat-5/ResourceSat-1 NDVI values for (a) 2005; (Landsat-5) – (ResourceSat-1) time difference = −7 day, (b) 2006; (Landsat-5) – (ResourceSat-1) time difference = −7 day, and (c) 2007; (Landsat-5) – (ResourceSat-1) time difference = +17 day.

resulting NDVI values were statistically inseparable ($R^2 \geq 0.53$ and $P \geq 0.56$) (**Table 2**).

This study developed an effective intercalibration between Landsat-5 and ResourceSat-1 over a large heterogeneous semiarid landscape 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

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

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 used readily accessible 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). It is important to understand that the specific equation reported in this paper represents a robust intercalibration applicable to one specific study area, and that the intercalibration process will need to be repeated for each new AOI.

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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