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Landsat cross-calibration based on near simultaneous imaging of common ground targets

P.M. Teillet [a,*], B.L. Markham [b], Richard R. Irish [c]

[a] *Canada Centre for Remote Sensing, 588 Booth Street, Ottawa, Ontario, Canada K1A 0Y7*
[b] *NASA's Goddard Space Flight Center, Code 923, Greenbelt, Maryland 20771, USA*
[c] *Science Systems and Applications, Inc., 5900 Princess Garden Parkway, Lanham, Maryland 20706, USA*

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Abstract

The paper presents the results of an extended analysis of image data sets acquired during the tandem-orbit configuration in 1999 for the purposes of radiometric cross-calibration of the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-5 Thematic Mapper (TM) sensors. Earlier work focused on the tandem pair for the Railroad Valley Playa, Nevada (RVPN) site to tie down the Landsat-5 TM calibration based on the more accurate Landsat-7 ETM+ calibration. This paper describes new results based on as many as eight tandem image pairs. The additional tandem images are of primarily vegetated areas for which little or no ground reference data were available. Increasing the number of tandem pairs yielded results for the Landsat 5 TM gain coefficients within approximately ±1% of the RVPN-based results in spectral bands 1, 2, 3 and 7, and within −2% and −4% of the RVPN-based results for spectral bands 4 and 5, respectively.

Keywords: Landsat; Radiometric calibration; Vicarious calibration

1. Introduction

Earth surfaces with suitable characteristics have long been used to verify the post-launch radiometric calibration performance of satellite sensors. Any associated field measurement campaigns are resource intensive activities and so it is of considerable interest to develop less expensive complementary approaches that can provide more frequent calibration updates, even if they are less accurate. Hence, the use of test sites to check the radiometric calibration of a given satellite sensor without coincident surface measurements or to transfer radiometric calibration between satellite sensors (so-called cross-calibration) without coincident surface measurements has been on the increase.

This paper explores aspects of the radiometric cross-calibration of the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-5 Thematic Mapper (TM) sensors based on near-simultaneous imaging of common ground targets facilitated by a tandem-orbit configuration. The launch of Landsat-7 on April 15, 1999 placed the spacecraft temporarily in an orbit with a ground track very close to that of the Landsat-5 spacecraft. The key period for this tandem configuration was June 1–4, 1999 when the orbital tracks were almost exactly the same, with a temporal offset on the order of 10 to 30 min. This unusual and valuable opportunity was designed to facilitate the establishment of data consistency between Landsat-7 and Landsat-5. During the tandem configuration period when there was useful overlap in coverage between the two sensors, image sequences corresponding to numerous matching scenes were recorded by both the Landsat-7 ETM+ and, in cooperation with Space Imaging EOSAT and international ground stations, the Landsat-5 TM. Subsequently, the Landsat-7 orbit was raised to 705 km for nominal operations. Teillet et al. (2001a, 2004a) focused on the tandem pair for the Railroad Valley Playa,

* Corresponding author.
E-mail address: phil.teillet@nrcan.gc.ca (P.M. Teillet).

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Nevada (RVPN) site to tie down the Landsat-5 TM radiometric calibration with respect to the more accurate Landsat-7 ETM+ calibration.[1] The uncertainty for the calibration transfer method was estimated to be ±3.5 % in the absence of spectral band difference effects (Teillet et al., 2001a).

This short communication describes additional results based on eight tandem image pairs and examines aspects of the common ground-look cross-calibration methodology in greater detail. Although Teillet et al. (2001a) recommended that vegetated surfaces should not be used for cross-calibration, it was deemed worthwhile to check the possibility that the combined use of many tandem image pairs of such surface targets has the potential to yield helpful results for monitoring sensor performance between resource-intensive calibration campaigns.

2. Satellite sensor cross-calibration based on common ground looks

Cross-calibration is one of the various methods used for post-launch satellite sensor calibration. Here, a given sensor is calibrated against another satellite sensor for which the radiometric calibration is better known via near-simultaneous imaging of a common ground target (Teillet et al., 1990). Much of the cross-calibration work over the years has been undertaken because of the significant calibration drift and lack of onboard calibration for the shortwave bands of the NOAA Advanced Very High Resolution Radiometers, a series of sensors that have played an important role in global environmental monitoring. Teillet et al. (1990) used large flat areas at White Sands, New Mexico to update the calibration of the NOAA-9 and NOAA-10 AVHRRs based on Landsat-5 TM and SPOT High Resolution Visible (HRV) image data acquired the same day. Teillet et al. (2001b) generalized the methodology and demonstrated it for multiple sensors over multiple test sites, taking directional reflectance effects and spectral band differences into account.

Cabot et al. (2000) used desert sites in Africa to cross-calibrate sensors such as AVHRR, SeaStar Sea-viewing Wide Field-of-view Sensor (SeaWiFS), and SPOT-4 Vegetation (VGT) with respect to the Polarization and Directionality of the Earth's Reflectances (POLDER) sensor. O'Brien and Mitchell (2001) examined the calibration of AVHRR with respect to the well-calibrated Along Track Scanning Radiometer (ATSR-2) on the European Remote Sensing ERS-2 satellite by comparing reflectances over a bright target in a semi-arid environment. Trishchenko et al. (2002) focused on moderate resolution satellite sensors, including the AVHRRs onboard the NOAA-6, -7, -8, -10, -11, -12, -14, -15, -16 spacecraft, Terra Moderate-resolution Imaging Spectroradiometer (MODIS), VGT, and Global Imager (GLI) on the second Advanced Earth Observing Satellite (ADEOS-2), all with respect to NOAA-9 AVHRR. Rao et al. (2003) presented results on the inter-calibration of Terra MODIS and the ERS-2 ATSR-2 based on desert sites as common targets. Thome et al. (2003) used RVPN to cross-calibrate Earth Observing-1 (EO-1) Advanced Land Imager (ALI), EO-1 Hyperion, MODIS, and Ikonos with respect to ETM+.

3. Methodology

3.1. Landsat tandem image pairs selected for analysis

Table 1 provides information about the eight Landsat tandem image pairs utilized in the study and defines the abbreviations used henceforth to identify the sites. Despite there being hundreds of Landsat tandem image pairs, it proved difficult to find large, reasonably homogeneous areas that were also unaffected by clouds and so only eight pairs were selected. Four of the sites are illustrated in Fig. 1. All sixteen images involved were acquired 1–3 June 1999 during the aforementioned Landsat tandem configuration period. The RVPN tandem pair served as the reference case because it was used for the cross-calibration of Landsat-5 and Landsat-7 sensors. Surface reflectance spectra were only available on image acquisition days for the RVPN and NIOB cases. No ground reference data were available the other six tandem image pairs.

5. Concluding remarks

Increasing the number of Landsat-7–Landsat-5 tandem pairs yielded cross-calibration results for Landsat 5 TM gain coefficients in spectral bands 1, 2, 3 and 7 within approximately ±1% of the RVPN-based results. Results for spectral bands 4 and 5 are within −2% and −4% of the RVPN-based results, respectively. Thus, for Landsat, it is reasonable to use the combination of multiple near-simultaneous ground looks as a supplementary check on radiometric calibration even without coincident surface measurements. Moreover, the new results presented in this paper suggest that the grid-cell image-block approach originally adopted for the Landsat cross-calibration is a reasonable approach for tandem image pairs of primarily vegetated areas for which surface reflectance spectra are not available for use in the radiometric cross-calibration analysis.

Nevertheless, it was found that some of the tandem data sets do not blend well with the others. It is possible but not proven that at least part of the residual differences is attributable to spectral band difference effects. In addition, simulations of at-sensor reflectance indicate that lack of knowledge about atmospheric water vapour content on the days of near-simultaneous image acquisition can, potentially, affect Landsat cross-calibration in spectral bands 4, 5 and 7.

[1] Teillet et al. (2001a) also examined a tandem image pair for the Niobrara grassland site, since ground reference data were available. However, the radiometric cross-calibration between Landsat-5 TM and Landsat-7 ETM+ was based on the RVPN tandem pair only, because the Niobrara grassland is less well understood as a calibration site and the RVPN site is one of the most extensively characterized and used optical calibration test sites in the world.