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Complementarity of ResourceSat-1 AWiFS and Landsat TM/ETM+ sensors

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ABSTRACT

Considerable interest has been given to forming an international collaboration to develop a virtual moderate spatial resolution land observation constellation through aggregation of data sets from comparable national observatories such as the US Landsat, the Indian ResourceSat and related systems. This study explores the complementarity of India's ResourceSat-1 Advanced Wide Field Sensor (AWiFS) with the Landsat 5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+). The analysis focuses on the comparative radiometry, geometry, and spectral properties of the two sensors. Two applied assessments of these data are also explored to examine the strengths and limitations of these alternate sources of moderate resolution land imagery with specific application domains. There are significant technical differences in these imaging systems including spectral band response, pixel dimensions, swath width, and radiometric resolution which produce differences in observation data sets. None of these differences was found to strongly limit comparable analyses in agricultural and forestry applications. Overall, we found that the AWiFS and Landsat TM/ETM+ imagery are comparable and in some ways complementary, particularly with respect to temporal repeat frequency. We have found that there are limits to our understanding of the AWiFS performance, for example, multi-camera design and stability of radiometric calibration over time, that leave some uncertainty that has been better addressed for Landsat through the Image Assessment System and related cross-sensor calibration studies. Such work still needs to be undertaken for AWiFS and similar observatories that may play roles in the Global Earth Observation System of Systems Land Surface Imaging Constellation.

1. Introduction

The land science community is increasingly interested in moderate spatial resolution (MODRES: 10–100 m) satellite remotely sensed observations as a primary source of land cover dynamics information (Goward et al., 2009, 2011). Landsat established this type of land observatory when the first satellite was launched in 1972. Landsat to this day continues to acquire systematic, within-year and between-year multispectral observations that support analyses of local to global scale land cover change. Use of Landsat to evaluate and monitor land dynamics has recently been strongly advanced by the US Geological Survey's (USGS) decision to provide no-cost access to the US Landsat archive held at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota.

The aging of current US Landsat observatories, Landsat 5 and Landsat 7, along with painfully slow progress toward deployment of the next-generation Landsat Data Continuity Mission (LDCM) has begun to undermine applied science use of Landsat, particularly in the US. The concerns are whether applied sciences, currently dependent on Landsat data, can continue in the absence of one or more Landsat observatories.

Landsat 5 (L5), originally planned for a 3 year mission life, is now in its 27th year of service. Landsat 7 (L7), currently in its 12th year of operation, suffered a failure of the scanline corrector (SLC) mirror in 2003, which has harmed many uses of these data. Landsat 8 (LDCM) is currently not planned for launch until the 15 January 2013 to 15 February 2013 timeframe. The US Department of Agriculture (USDA) switched to a multi-platform approach in 2008, including the use of ResourceSat-1 AWiFS data because of these concerns.

Several countries have placed in orbit satellite sensors that are at least potentially complementary to the Landsat observatory. These include the French Satellite Pour l'Observation de la Terre (SPOT) and the Indian Remote Sensing (IRS) satellite begun in the 1980s, the Japanese Advanced Land Observing Satellite (ALOS) and the Disaster Monitoring Constellation (DMC) (Goward et al., 2009). Furthermore China, in conjunction with Brazil, has flown the China–Brazil Earth Resources Satellite (CBERS) and has flown a series of Huan jing (HJ) satellites also known as environmental satellites. All of these international activities have led the Committee on Earth Observation Satellites (CEOS) and the Group on Earth Observations (GEO) to formulate a

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working group on Land Surface Imaging (LSI) Constellation (http://www.ceos.org/).

Despite the increasing range of international land observatories, there are in fact few MODRES land observatories that meet the high standards that Landsat established to monitor the Earth's land areas. The combination of:

- a systematic acquisition strategy
- long-term global archive (federally supported),
- visible, near infrared, shortwave infrared and thermal infrared spectral measurements
- well-calibrated geometry and radiometry

converges to meet the fundamental requirements of many land studies including Land Cover Land Use Change (LCLUC), agriculture, forest dynamics, fresh water resources and urbanization.

1.1. Landsat data gap study team

In 2003 – after the L7 SLC failed – the USGS and NASA formed a scientific-technical Data Gap Study Team (DGST) to assess what other international assets would be available to compliment or replace the potentially missing land observations in the US national archive (Chander & Stensaas, 2008). After 2 years of deliberation, this team concluded that only the China–Brazil CBERS mission and the IRS AWiFS sensor might be suited as substitutes for Landsat observations. One of the tightest constraints the team identified was the need for at least one shortwave infrared (SWIR) spectral band in the measurements. One of the largest remaining uncertainties is whether the collection of a systematic global observation set would be possible with either observatory.

Since 2005 only limited progress beyond the DGST findings has been accomplished either technically or internationally, concerning use of the AWiFS or CBERS as a compliment to the Landsat TM/ETM+ (Chander et al., 2008). Recently NASA Earth Science Program managers (LCLUC, Ecosystems and Applied Science) decided to fund a further detailed assessment of AWiFS through the auspices of the USGS EROS, NASA Stennis Space Center, and University of Maryland (UMD) Geography Department. This report summarizes the outcome of these studies.

2. Comparison of ResourceSat-1 AWiFS and Landsat TM/ETM+ technical specifications

While the AWiFS camera modules collect data similar to Landsat, there are several significant differences between the two sensor systems. First, the Landsat TM/ETM+ is a traditional optical–mechanical multispectral scanner in which all spectral bands are acquired nearly simultaneously. The AWiFS sensor package consists of two separate camera modules, each of which has four linear array cameras (Fig. 1). Interestingly, The IRS team selected to use Landsat TM band number nomenclature for both their Linear Imaging Self Scanner (LISS) and AWiFS cameras (National Remote Sensing Agency, 2003) (Table 1). The TM/ETM+ instrument nominally acquires 7 spectral bands versus AWiFS 4 spectral bands. The blue (B1), second SWIR (B7), and thermal infra-red (TIR) bands (B6) are not observed with the AWiFS sensor (Table 2).

2.1. Radiometry

Other differences between the two sensor systems are found primary with geometry and radiometry (Table 2). The AWiFS produces lower ground spatial resolution (56 m at nadir) versus TM's 30 m instantaneous field of view (IFOV) at nadir. However AWiFS radiometry is acquired at 10-bits versus TM's 8-bits (National Remote Sensing Agency, 2003). The Relative spectral response (RSR) functions for the two sensors are similar although the AWiFS bands tend to be narrower than the TM/ETM+, similar to the spectral filters in the Operational Landsat Imager (OLI) to be flown on the LDCM (Fig. 2).

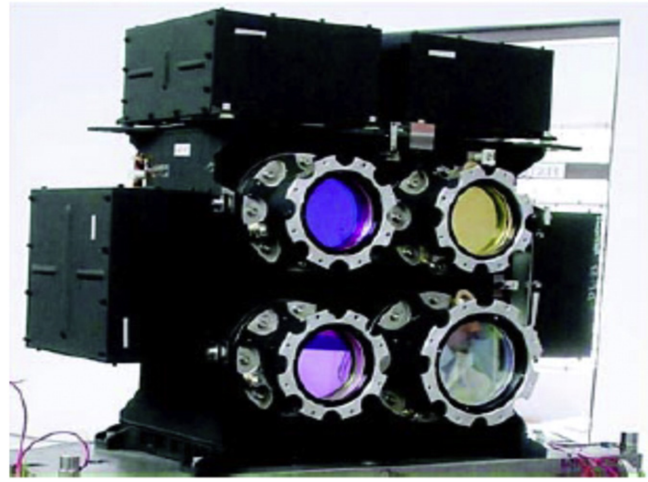

Fig. 1. Single AWiFS camera module. This is one of the two modules used to make up the full AWiFS sensor. Note that the SWIR camera (lower right) uses a larger, longer focal length lens than the other three spectral cameras.

2.2. Geometry

A primary difference between TM/ETM+ and AWiFS is the wider swath of AWiFS (Fig. 3). The full AWiFS sensor consists of two separate electro-optic camera modules (AWiFS-A and AWiFS-B) mounted adjacent to each other. Each AWiFS camera module has a swath slightly more than double the Landsat TM/ETM+ swath (372 km versus 180 km). The full sensor two camera module system is mounted such that each camera is tilted 11.94° with respect to nadir. This provides a full swath of over 730 km or 4 times as great as a Landsat scene. A full AWiFS image consists of four sub-images or Quads noted as A, B, C and D (Fig. 4). The Quads are acquired through forward motion of the sensor assembly in orbit.

This two camera module arrangement results in the AWiFS sensor imaging ±24.3° from nadir versus TM's ±7.5°. This wider AWiFS swath significantly improves the revisit time. However, this also substantially increases off-axis imaging and therefore increases the potential for observing bidirectional reflectance distribution function (BRDF) effects from the surface and the atmosphere (Gutman, 1998; Gutman et al., 1995; Los et al., 2005). Multiple cameras also increase radiometric calibration complexity. Further, AWiFS visible near-infra-red (VNIR) cameras (B2–B4) use rectangular detectors that result in considerably different IFOVS in the across-track versus along-track directions (Table 1, Fig. 5). The SWIR spectral cameras (B5) use larger, square detectors that are compensated for by using a longer focal length lens on the camera (Table 1, Fig. 1).

2.2.1. Orthorectification

Both image data sets were processed to a level 1T — terrain corrected or orthorectified product. Data resampling was conducted using cubic convolution. The Landsat data was resampled to 30 m IFOV versus the 56 m AWiFS (Lutes, 2005, 2006).

Table 1
Differences in the SWIR spectral camera with the visible and near infrared cameras. This difference can also be seen in Fig. 1. (Dave et al., 2006).

	Bands 2, 3, 4	Band 5
Focal length	139.5 mm	181.3 mm
Detector size (cross-track)	10 μm	13 μm
Detector size (along-track)	7 μm	13 μm
Detector material	Silicon	Indium gallium arsenide