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Evaluation and Comparison of the IRS-P6 and the Landsat Sensors

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Abstract

The Indian Remote Sensing Satellite (IRS-P6), also called ResourceSat-1 was launched in a polar Sun-synchronous orbit on Oct 17, 2003. It carries three sensors: the high resolution Linear Imaging Self-Scanner (LISS-IV), the medium resolution Linear Imaging Self-Scanner (LISS-III), and the Advanced Wide Field Sensor (AWiFS). These three sensors provide images of different resolutions and coverage. To understand the absolute radiometric calibration accuracy of IRS-P6 AWiFS and LISS-III sensors, image pairs from these sensors were compared to images from the Landsat 5 (L5) Thematic Mapper (TM) and Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+) sensors. The approach involves calibration of surface observations based on image statistics from areas observed nearly simultaneously by the two sensors. This paper also evaluated the viability of data from these next-generation imagers for use in creating three National Land Cover Dataset (NLCD) products: Land Cover, Percent Tree Canopy, and Percent Impervious Surface. Individual products were consistent with previous studies but had slightly lower overall accuracies compared to data from the Landsat sensors.

Keywords: Landsat, Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+), Indian Remote Sensing Satellite (IRS-P6), ResourceSat-1, Advanced Wide Field Sensor (AWiFS), Linear Imaging Self-Scanner (LISS-III), Calibration, Characterization, Spectral bands, Reflectance, Land cover, Canopy, Impervious

I. INTRODUCTION

Detection and quantification of change in the Earth's environment depends on satellites that can provide calibrated, consistent measurements of the Earth's surface features. The Landsat Program began in 1972 and since then has provided continuous, consistent measurements of the Earth's surface features over seven mission generations. To date, the Landsat suite of satellites has collected the longest continuous archive of multispectral data of any space program. Landsat 5 (L5) and Landsat 7 (L7) are the two currently operational satellites in the Landsat series. The Indian Remote Sensing Satellites (IRS) constellation program consists of three currently operating satellites: IRS-P6 (ResourceSat-1), IRS-1C, and IRS-1D. Section B provides an overview of these sensors.

A. Purpose of This Paper

This paper evaluates and compares the IRS-P6 and the Landsat sensors, and includes: 1) an overview of the sensors; 2) a comparison of the Relative Spectral Response (RSR) profiles; 3) calibration by near-simultaneous surface observations; and 4) preliminary assessments of the utility of IRS-P6 imagery for production of National Land Cover Dataset (NLCD) products.

B. Sensor Overview

The section below provides an overview of the sensors that were used in this study.

1) *Landsat 5 (L5) Thematic Mapper (TM)*: The L5 TM is an Earth-imaging sensor that was launched on March 1, 1984. It incorporated advancements in spectral, radiometric, and geometric capabilities relative to the Multispectral Scanner (MSS) flown on previous Landsat satellites. L5 TM Bands 1-5 and 7 have 16 detectors with center wavelengths of approximately 0.49, 0.56, 0.66, 0.83, 1.67, and 2.24 μm , respectively [1]. The detectors for Bands 1-4 are located at the Primary Focal Plane (PFP), where the temperature is not controlled but normally varies between 292 and 300 K. The detectors for Bands 5, 6, and 7 are located at the Cold Focal Plane (CFP). Because of their relatively long wavelengths, high noise signals result from the internal thermal excitation of the detector materials. To minimize this noise and allow adequate detection of scene energy, a radiative cooler maintains the CFP temperature at set points between 95 and 105 K. The Internal Calibrator (IC) is incorporated as an onboard radiometric calibration system for the L5 TM. Onboard calibration of the TM uses lamps to calibrate the reflective bands and a blackbody source to calibrate the thermal band.

2) *Landsat 7 (L7) Enhanced Thematic Mapper Plus (ETM+)*: The ETM+ sensor was launched on April 15, 1999, on the L7 platform; it is based on the TM sensors onboard the Landsat 4 (L4) and L5 satellites. The L7 ETM+ sensor added a new panchromatic band, improved spatial resolution of the thermal band to 60 m, and added two calibration devices to help improve the radiometric calibration. L7 ETM+ has three on-board calibration devices: a Full Aperture Solar Calibrator (FASC), which is a white painted diffuser panel; a Partial Aperture Solar Calibrator (PASC), which is a set of optics that allows the L7 ETM+ to image the Sun through small holes; and an IC, which consists of two lamps, a black body, a shutter, and optics to transfer the energy from the calibration sources to the focal plane. One of the requirements of the L7 mission is to achieve radiometric calibration accuracy of the ETM+ data with an uncertainty of less than five percent in at-sensor radiance [1], a requirement more stringent than in the past for the Landsat Program.

Another significant improvement in the L7 system is the incorporation of an Image Assessment System (IAS) as part of the ground processing system at the U.S. Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) in Sioux Falls, South Dakota. IAS analysts work with their counterparts at the Landsat Project Science Office of the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) to analyze the calibration information and update the algorithms used within the IAS. The IAS is responsible for offline assessment of image quality to ensure compliance with the radiometric and geometric requirements of the L7 spacecraft and the ETM+ sensor throughout the Landsat mission. One of the most important roles of the IAS is the generation of the Calibration Parameter File (CPF), which contains all of the necessary parameters for generating a geometrically and radiometrically calibrated product. In early 2002, the IAS also became responsible for the routine radiometric and geometric calibration of the L5 TM following its transition to bumper mode operations.

3) ResourceSat-1 Advanced Wide Field Sensor (AWiFS) and Linear Imaging Self-Scanner (LISS-III): The IRS-P6 is a three-axis body-stabilized satellite. Launched in October 17, 2003, it has an operational life of five years, with a near-polar, Sun-synchronous orbit at a mean altitude of 817 km. The IRS-P6 payload consists of three sensors: LISS-III, AWiFS, and a high-resolution multispectral sensor (LISS-IV). All three sensors work on the ‘push-broom scanning’ concept, using linear arrays of detectors. In this mode of operation, each line of image data is electronically scanned and contiguous lines are imaged by the forward motion of the satellite. Unique to IRS-P6 is that three sensors with different resolutions and swath widths are on the same platform as shown in Fig.1. [2], [3], [4].

LISS-III: The P6 LISS-III is a multispectral sensor operating in four spectral bands, three in the Visible and Near Infrared (VNIR) bands and one in the Short Wavelength Infrared (SWIR) region, with 23.5 m spatial resolution and a ground swath of 141 km. The P6 LISS-III sensor is a nadir-looking sensor with a 24-day revisit cycle [2]. A field of light-emitting diodes (LEDs) – four in the visible bands and six for the SWIR bands – are used as calibration sources, allowing a cycle of six non-zero intensity levels during the acquisition of dark data.

AWiFS: The P6 AWiFS camera operates in four spectral bands similar to P6 LISS-III, providing a spatial resolution of 56 m at nadir and covering a ground swath of 740 km. To cover this wide swath, the P6 AWiFS camera is split into two separate electro-optic modules, AWiFS-A and AWiFS-B as shown in Fig. 2. [2]. P6 AWiFS has an LED-based calibration source similar to P6 LISS-III, but with six LEDs and 16 non-zero intensity levels available.

C. Relative Spectral Response (RSR) Profiles

Figs. 3 and 4 show the RSR profiles between corresponding L7 ETM+, L5 TM, and P6 AWiFS and LISS-III spectral bands. Table I summarizes the spectral range of these sensors. The L7 ETM+ bands were based on the seven L5 TM spectral bands. The P6 AWiFS and LISS-III Bands 2, 3, 4, and 5 are similar to the corresponding L5 TM and L7 ETM+ spectral bands.

D. L7 ETM+, L5 TM and P6 AWiFS, P6 LISS-III Quantization

The data quantization for L7 ETM+ and L5 TM is 8 bits. L7 employs two alternate gains that permit enhanced radiometric resolution in the high-gain mode and expanded dynamic range in the low-gain mode. Geometrically and radiometrically calibrated products, known as Level 1G (L1G) products, are only available as 8-bit images for Landsat sensors.

The radiometric resolution of the IRS-P6 sensors varies:

P6 AWiFS has 10 bits

P6 LISS-III (VNIR) has 7 bits with four gain settings

P6 LISS-III (SWIR) has 7 out of 10 bits (sliding)

The Analog-to-digital (A/D) converter is 12 bits for P6 AWiFS and P6 LISS-III SWIR. The data are captured as 12 bits and the two least significant bits are ignored. The P6 AWiFS data corresponding to all four bands are received as 10-bit parallel data. For the P6 LISS-III SWIR bands, the selected 7 consecutive bits out of 10 bits generated at payload end are transmitted. The selection of 7 bits for the SWIR band is done by bit sliding in the base Band Data Handling (BDH) system formatter. In the formatter, any consecutive 7 bits out of 10 bits are selected by a data command before multiplexing the data. The A/D converter is 7 bits for P6 LISS-III VNIR bands. The data are captured and transmitted as 7 bits with four pre-gain settings options.

The level 1 product for P6 LISS-III is available as 8-bit images. P6 AWiFS data products are available as 8-bit and 10-bit images.

II. DATA SETS AND TEST SITE EVALUATIONS

A. Sun-synchronous Orbits

The L5 and L7 satellites operate in a repetitive, circular, Sun-synchronous, and near-polar orbit, with an inclination of 98.2 degrees, at a nominal altitude of 705 km (438 miles) at the Equator. The Sun-synchronous orbit means that all acquisitions over a given area occur at the same time of the day. The equatorial crossing time during descending passes (descending passes are on the Sunlit side of the Earth and ascending passes are on the dark side of the orbit) is nominally between 9:30 and 10:00 a.m. local time for all Landsat missions. Circling the Earth at 7.5 km/sec, each orbit takes nearly 99 minutes. The spacecraft completes just over 14 orbits per day, covering the entire Earth between 81 degrees north and south latitude every 16 days, completing 233 orbits per cycle on the World Reference System-2 (WRS-2).

The IRS-P6 satellite operates in a circular, Sun-synchronous, near-polar orbit with an inclination of 98.69 degrees, at an altitude of 817 km. The satellite takes 101.35 minutes to complete one revolution around the Earth and completes about 14 orbits per day with a ground track velocity of 6.65 km/sec. The entire Earth is covered by 341 orbits during a 24 day cycle.

B. Test Site Descriptions

Because the number of coincident image pairs between these sensors is limited, the scene selection for these studies proved to be a challenge. Owing to the lack of near-simultaneous images available over the well-characterized and traditionally used calibration and application evaluation sites, alternate sites were investigated that have high reflectance, large dynamic range, high spatial uniformity, high Sun elevation, and minimal cloud cover. The final scenes selected for the current work were over Mesa, Arizona and Salt Lake City, Utah.

1) Mesa, Arizona: A cloud-free L7 ETM+ scene was acquired on June 29, 2005. Thirty-one minutes later, P6 AWiFS and LISS-III scenes covering part of the same footprint were acquired. Because of the scan-gap issue, the prior and post L7 scenes (June 13 and July 15) were also acquired, completing the L7-based data set for the NLCD validation. Mesa is a desert site with little vegetation. The L7 ETM+ scenes are referenced in the WRS-2 with path 36, rows 35-39. The P6 reference is path 257, row 47.

2) Salt Lake City, Utah: A cloud-free L5 TM scene was acquired on June 19, 2005. Thirty-one minutes later, a P6 AWiFS and LISS-III scene of the same region was acquired. The L5 TM

6

scenes are referenced in the WRS-2 system with path 38, rows 30-32. The P6 reference is path 255, row 41.

In both test sites and for each available image source, the area common to all images was evaluated for its ability to duplicate existing NLCD products. Table II lists the coincident P6 and Landsat scenes selected for the study along with the location, product ID number, path, row, date of acquisition, and the sun elevation angle for the scenes. Figs. 5 and 6 show the approximate image boundaries of the scenes used.

C. Data Processing System

Orthorectified scenes were used for this study. Terrain Correction includes radiometric, geometric, and precision correction, as well as the use of a Digital Elevation Model (DEM) to correct relief displacement caused by local topography. The accuracy of the terrain-corrected product depends on the availability of local Ground Control Points (GCPs), as well as the quality and resolution of the best available DEM. The absolute radiance values are then scaled to calibrated digital numbers before being output to the distribution media.

The following processing parameters were used to generate the Landsat products, and were chosen to replicate the processing parameters for the P6 AWiFS and LISS-III products as closely as possible:

Map Projection:	Albers
Standard Parallel 1:	29.5
Standard Parallel 2:	45.5
Central Meridian:	-96
Latitude of Origin:	23
False Northing:	0
False Easting:	0
Horizontal Datum:	WGS84
Resampling method:	Cubic Convolution (CC)
Image orientation:	Map (north up)

E. Conversion to Reflectance

Remote sensing satellite detectors exhibit a linear response to incoming radiance, whether from the Earth's surface radiance or internal calibration sources. This response is quantized into 8-bit

7
or 10-bit values that represent brightness values commonly called Digital Numbers (DN). To convert the calibrated digital numbers to at-aperture radiance, rescaling gains and biases are created from the known dynamic range limits of the sensor [5], [6]. This radiance is then converted to Top of Atmosphere (TOA) reflectance by normalizing for solar elevation and solar spectral irradiance. When comparing images from different sensors, there are two advantages to using reflectance instead of radiances. First, the cosine effect of different solar zenith angles due to the time difference between data acquisitions can be removed, and second, it compensates for different values of the exoatmospheric solar irradiances arising from spectral band differences. Table II lists the Solar Elevation angles and Table III summarizes the Solar Exoatmospheric Spectral Irradiances (ESUN) values used in this study. To maintain consistency with the ETM+, this paper uses spectral radiance units of $W/m^2 sr \mu m$.

III. CALIBRATION BY NEAR-SIMULTANEOUS SURFACE OBSERVATIONS

Data continuity requires consistency in the interpretation of image data acquired by different imaging sensors. This section describes the comparisons of the reflectance measurements obtained from the L7 ETM+, L5 TM, and P6 AWiFS and LISS-III sensors.

Cross-calibration was performed with image statistics based on large common areas observed near-simultaneously by the two sensors. Because the image acquisitions occurred 31 minutes apart, it was assumed that the surface and atmospheric conditions did not change during that time. Changes in sun angle were corrected for with the conversion to TOA reflectance. A more detailed treatment of the calibration methodology is provided in [7], [8] and [9].

A. Region of Interest

The L7, L5, and P6 sensors differ in their along-track and across-track pixel sampling. A feature simultaneously observed by these sensors is represented by slightly different numbers of image pixels because of the differences in viewing geometry and sensor scanning times. This makes it very difficult to establish sufficient geometric control to facilitate radiometric comparisons on a point-by-point and/or detector-by-detector basis. Therefore, the analysis approach made use of image statistics based on large homogenous areas common in the image pairs. These large areas were carefully selected using distinct features common to both of the images. Both bright and dark regions were selected to obtain maximum coverage over each sensor's dynamic range, but areas with clouds or cloud shadows were excluded. Regions of interest (ROI) were defined within these areas for each image triplet (L5 TM or L7 ETM+, P6 AWiFS, and LISS-III). Gaps in the L7 ETM+ data caused by the scan-line corrector anomaly were discarded. Homogeneity of

each region was then tested by rejecting any region with a standard deviation of more than 10 DN in any Landsat band. This left 27 regions for the Mesa, Arizona collection and 34 regions for the Salt Lake City, Utah collection.

Fig. 7 shows a pair of regions of interest from the Mesa test site, with AWiFS data on the left and L7 ETM+ data on the right. Fig. 8 shows a pair of regions of interest from the Salt Lake City test site, with P6 AWiFS data on the left and L5 TM data on the right.

Once all area regions of interest were selected, image statistics were computed to obtain mean and standard deviation target values on a band-by-band basis. The mean target statistics were then converted to absolute units of radiance and then to TOA reflectances, taking into account the RSR of the sensor bands and the sun angle during the acquisitions. These reflectance values were then plotted for each sensor pair, and a linear fit calculated, giving a relative gain and bias between each sensor pair.

B. Cross-Calibration Results and Discussions

Figs. 9 and 10 show the cross-calibration plots for the Mesa, Arizona collection, and Figs. 11 and 12 show the cross-calibration plots for the Salt Lake City, Utah collection.

As a check of the consistency of the satellite calibrations and the methodology used, a cross-calibration was also calculated between the AWiFS and LISS-III sensors. Figs. 13 and 14 show the cross-calibration plots comparing AWiFS reflectances to LISS-III reflectances for the Mesa, AZ and Salt Lake City, UT collections respectively.

In each set of plots, the reflectance from the Landsat sensor is compared against the reflectance of the AWiFS and LISS-III sensors. The expected 1:1 reflectance line is also plotted for reference. A least-squares fit has been made to the data in each band, giving the cross-calibration gain and biases as the coefficients of the linear fit.

These preliminary results indicate that the IRS-P6 sensors can be cross-calibrated to the Landsat sensors to within an accuracy of 13 percent. The IRS-P6 AWiFS and LISS-III sensors are within 5.5 percent of each other in all bands except Band 2, which has a 16.4 percent difference.

Because the AWiFS image was present in both collections, and because the calibration of the AWiFS sensor is generally closer to the Landsat sensors than to LISS-III, it is instructive to look at the cross-calibration results as a function of difference from AWiFS. Table IV shows the cross-

calibration gains of all four sensors normalized to AWiFS. The cross-calibration of AWiFS to the L5 TM produced the best result, with consistent differences in absolute calibration of approximately six percent in all bands of the TM and the AWiFS sensor.

These cross-calibration accuracies should be considered the difference between the Landsat and P6 sensor reflectance data when used for scientific applications. The expected difference in results from those applications – including the NLCD product generation described below – should be similar to the cross-calibration accuracies. This is therefore a preliminary measure of the viability of using non-Landsat sensors for Landsat data continuity in scientific applications.

A source of error in these results may be in the assumption that the TOA reflectance of all terrain in the study scenes underwent minimal changes between passes of the satellites – a timescale of 30 minutes. This may not be true for some regions of interest, including water regions, croplands in changing wind conditions, and areas near clouds that may have had drastic changes in humidity between satellite passes. As the Landsat TM and ETM+ sensors are known to be calibrated to within six percent of each other [10], [11], the normalized results appear to have a systematic error in the calibration to the ETM+, indicating possible problems in the Mesa, Arizona scene, most likely caused by transient changes in reflectance or aerosol loading.

The RSR of the sensors is also a likely cause of error. Although measured in detail pre-launch, spectral filters are known to degrade post-launch and are difficult to characterize in orbit. This is the most likely cause of the discrepancy in the cross-calibration between AWiFS and LISS-III in Band 2, although it may affect other bands as well. Additional work is in progress to characterize the IRS-P6 sensors over the entire mission.

IV. VIABILITY OF IRS-P6 FOR NLCD PRODUCTS

A. National Land Cover Dataset (NLCD) Background

The Multi-Resolution Land Characteristics (MRLC) Consortium is a group of Federal agencies who first joined together in 1993 to purchase L5 imagery for the conterminous United States and to develop the National Land Cover Dataset (NLCD 1992). In 1999, a second-generation MRLC consortium was formed to purchase three phenologic dates of L7 ETM+ imagery for the entire United States (MRLC 2001) and to coordinate the production of a comprehensive land cover database for the nation called the NLCD 2001.

10

The MRLC consortium is designed to meet the current needs of Federal agencies for nationally consistent satellite remote sensing and land cover data. The consortium also provides imagery and land cover data as public domain information, all of which can be accessed through the MRLC website [12].

The NLCD products are raster data layers at 30 m resolution, generated from at least three dates (leaf-off, leaf-on, and spring) of L5 TM and L7 ETM+ imagery. All Landsat imagery is preprocessed with precision terrain corrections, and normalized to at-satellite reflectance. The three NLCD 2001 products are land cover, percent tree canopy, and percent impervious surface [13]. Currently, NLCD 2001 has been compiled across all 48 conterminous states. Alaska, Guam, Hawaii, and Puerto Rico, are scheduled for completion by December 31, 2007. Methodology and data sources for the next generation NLCD are being planned (NLCD '06/'07). Alternative data platforms and providers are being considered to replace the aging L5 and to avoid the current scan-gap problems of L7 ETM+ data.

B. Experimental Design and Procedures

For the NLCD test, the same data were used as in the cross-calibration test, except that only one Landsat scene was used for each collection – Path 38, Row 31 for Salt Lake City, Utah and Path 36, Row 37 for Mesa, Arizona. For the Mesa scene, both the prior and post scenes (June 13, July 15) were acquired to make a complete L7-based gap-filled data set.

NLCD classification procedures normally use mosaics of L5 TM and L7 ETM+ imagery from three dates (leaf-off, leaf-on, and spring), capturing phenologic characteristics of the area. Along with ancillary information, the imagery is used in a series of decision-tree regressions [10]. Classifications used standard NLCD tools (ERDAS Imagine, NLCD Mapping Tool, See5, and Cubist) to generate classification logic and map the results. A more detailed explanation of the NLCD products is in [13], [14].

In both test sites and for each available image source, the area common to all images was evaluated for its ability to duplicate existing NLCD products. Artificial products were constructed by massively sampling existing products and assessing each image source's ability to generate a duplicate by comparing its version to the source. In contrast to the usual NLCD procedures, no ancillary information (e.g., DEM or Slope) was used in the classification. The intent was to generate results based solely on the spectral information unique to each data set.

Owing to different areas of common extent between sensors (P6 AWiFS / Landsat and P6 LISS-III / Landsat) on each test site, two results are reported per available product, per site.

C. Land Cover Estimation

Land cover is a discrete label based on classification of the Earth’s surface as it is represented in imagery. At the time of the experiment, the NLCD 2001 land cover product for the Salt Lake City site was available, but not for the Mesa site. For this reason, land cover estimations were made only over the Salt Lake City site.

To generate the land cover training data, 10,000 random points per land cover class were extracted from the existing land cover classification, yielding 110,000 points for 11 NLCD classes. Urban classes were excluded, because they are derived from the percent impervious surface data layer. Points common to all image pairs were used for classification in decision trees, with cross-validation and boosting options in See5.

The cross-validations of land cover indicated that a consistently more complex decision tree was generated with L5 data than with P6 AWiFS and LISS-III. This is likely caused by the presence of more spectral content (Bands 1 and 7) in the Landsat data, and thus more information available for decision tree training.

Table V summarizes the mean error estimates of each classification. The difference values show that L5 has lower estimated error than P6 AWiFS and LISS-III, most likely because of the presence of more spectral content in the L5 data. The large magnitudes of estimated error are not representative of the normal NLCD procedures, for reasons stated above, but the magnitudes of the estimated error differences between the two sensors range from two to six percent.

Table VI summarizes the 11 NLCD classes mapped by decision tree methods. Overall, there are strong agreements in the ability to determine most classes, with differences of less than five percent.

For some classes (bolded text in the table), L5 was typically five percent or more accurate than P6 AWiFS and LISS-III. These occur on the classification of evergreen, shrub/scrub, woody wetlands, and emergent wetlands. Historically, L5 TM Bands 1 and 7 have been widely used for vegetation and moisture discrimination, so increased difficulty with P6 AWiFS and LISS-III to classify moist and dry vegetation can be explained [15].

D. Canopy Density Estimation

Tree canopy density estimates are a continuous estimate of the percentage of tree cover, on a per pixel basis. In this study, they were generated by massively sampling approximately 1,000 points per value, from 1 to 100 (totaling approximately 100,000) out of existing canopy products of both the Salt Lake City and Mesa sites. Points common to all image pairs were used for multiple regressions, using cross-validation and committee model options.

Table VII summarizes the percent tree canopy cross-validation results for both the Salt Lake City and Mesa test sites. The results typically show very slight (one to two percent) differences in average absolute error between L5 TM in Salt Lake City and L7 ETM+ in Mesa, versus P6 AWiFS and LISS-III. Fig. 15 contains graphs of each percent tree canopy difference from the current NLCD 2001 standard product, where narrower bases and taller peaks imply closer agreement with the source. For the purpose of computing percent tree canopy, P6 AWiFS and LISS-III appear quite useful.

E. Impervious Surface Estimation

Impervious surface estimates are a continuous estimate of the percentage of impervious surface, on a per pixel basis. In this study, they were generated by massively sampling approximately 1000 points per value, from 1 to 100 (total approximately 100,000) out of existing impervious surface products of both the Salt Lake City and Mesa sites. Points common to all image pairs were used for multiple regressions, using cross-validation and committee model options.

Table VIII summarizes the impervious surface cross-validation results for both the Salt Lake City and Mesa test sites. Similar to the canopy estimates, the results typically show very slight (one to two percent) differences in average absolute error between L5 TM in Salt Lake City and L7 ETM+ in Mesa, versus P6 AWiFS and LISS-III. Fig. 16 contains graphs of each impervious estimate difference from the current NLCD standard product, where narrower bases and taller peaks imply closer agreement with the source. For the purpose of computing percent impervious surface, P6 AWiFS and LISS-III appear quite useful.

F. Further Discussions

Some anomalies were noted for both percent tree canopy and percent impervious surface data layers. For the Mesa site, the P6 AWiFS data were composed of all four quadrants, and intensity artifacts can be seen that were a result of the various quadrant overlaps (example in Fig. 17). A

similar situation can be found in the L7 ETM+ mosaic of scan-gap data, with low intensity “stripes” (example in Fig. 18). Further work would be needed to identify an optimum method of using these data sets without generating these artifacts. The P6 LISS-III impervious estimate did not contain any artifacts, and therefore may potentially outperform the L7 ETM+ scan-gap mosaic as a basis for tree canopy and impervious surface estimates.

V. SUMMARY AND CONCLUSION

To understand the absolute radiometric calibration accuracy of the P6 AWiFS and LISS-III sensors, image pairs from these sensors were compared to images from the L5 TM and L7 ETM+ sensors. The approach involved calibration of surface observations based on image statistics from areas observed nearly simultaneously by the two sensors. The average reflectance estimates obtained from these sensors agree within 13 percent.

This paper also provides an initial evaluation of the viability of the P6 platform for providing images suitable for generating three NLCD Products: land cover, percent tree canopy, and percent impervious surface. Individual P6 AWiFS and LISS-III products were slightly less accurate in classifying particular land cover classes, but provided a very useful approximation to L5 TM and L7 ETM+ for percent tree canopy and percent impervious surface. Artifacts were noted in the areas of overlap, both of the P6 AWiFS quadrants, and of the scan-gap L7 ETM+ mosaic. These drawbacks may be addressed by potential five-day revisits of the P6. More image acquisitions would be needed to investigate these issues.

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Table I. SPECTRAL COVERAGE [1] and [2]

Spectral Range (µm)			
Band	L5 TM	L7 ETM+	P6 AWiFS/LISS-III
1	0.450-0.520	0.450-0.515	
2	0.520-0.600	0.525-0.605	0.52-0.59
3	0.630-0.690	0.630-0.690	0.62-0.68
4	0.760-0.900	0.775-0.900	0.77-0.86
5	1.550-1.750	1.550-1.750	1.55-1.70
6	10.40-12.50	10.40-12.50	
7	2.080-2.350	2.090-2.350	
Pan		0.520-0.900	

Table II: COINCIDENT P6 & LANDSAT SCENES USED FOR THIS STUDY

Sensor	Product ID	Path	Row	Time (GMT)	Solar Elevation
Location: Mesa, AZ (June 29, 2005)					
Landsat 7 ETM+	L71036035_03520050629	36	35	17:46:25	65.21 °
Landsat 7 ETM+	L71036036_03620050629	36	36	17:46:49	65.53 °
Landsat 7 ETM+	L71036037_03720050629	36	37	17:47:13	65.77 °
Landsat 7 ETM+	L71036038_03820050629	36	38	17:47:37	65.94 °
Landsat 7 ETM+	L71036039_03920050629	36	39	17:48:01	66.02 °
AWiFS Quad A	AW257047A001	257	47	18:17:35	69.50 °
AWiFS Quad B	AW257047B001	257	47	18:17:35	72.60 °
AWiFS Quad C	AW257047C001	257	47	18:18:23	70.30 °
AWiFS Quad D	AW257047D001	257	47	18:18:23	73.60 °
LISS-III	L32570470101	257	47	18:18:14	71.48 °
Location: Salt Lake City, UT (June 19, 2005)					
Landsat 5 TM	LT5038030000517010	38	30	17:54:58	62.95 °
Landsat 5 TM	LT5038031000517010	38	31	17:55:22	63.59 °
Landsat 5 TM	LT5038032000517010	38	32	17:55:46	64.18 °
AWiFS Quad A	000010491201	255	40	18:23:45	65.50 °
AWiFS Quad B	000010491301	255	40	18:23:45	68.10 °
AWiFS Quad C	000010491401	255	40	18:24:39	67.50 °
AWiFS Quad D	000010491501	255	40	18:24:39	70.30 °
LISS-III	000010491601	255	41	18:24:51	68.64 °

16

Table III: SOLAR EXOATMOSPHERIC SPECTRAL IRRADIANCES (ESUN) VALUES USING CHKUR MODTRAN 4.0 SPECTRUM. (UNITS = W/M² μM)

Bands	L5 TM	L7 ETM+	P6 LISS-III	P6 AWiFS
2	1826.000	1840.000	1846.770	1849.820
3	1554.000	1551.000	1575.500	1579.370
4	1036.000	1044.000	1087.340	1075.110
5	215.000	225.700	236.651	235.831

Table IV: CROSS-CALIBRATION RESULTS NORMALIZED TO THE AWiFS SENSOR

Sensor	Band			
	2	3	4	5
L5 TM	1.00	1.06	1.05	1.04
L7 ETM+	1.11	1.08	1.13	1.12
P6 AWiFS	1.00	1.00	1.00	1.00
P6 LISS-III (Mesa)	0.90	0.96	0.97	1.00
P6 LISS-III (SLC)	0.86	0.95	0.97	0.97

Table V: MEAN ERROR ESTIMATES OF LAND COVER CLASSIFICATIONS

Mean Error Estimates	
P6 AWiFS	44.9%
L5 TM	42.8%
Difference	2.1%
P6 LISS-III	50.7%
L5 TM	44.8%
Difference	5.9%

Table VI: LANDCOVER CLASSIFICATION TEST

		P6 AWiFS	L5 TM	L5 TM –P6 AWiFS	P6 LISS-III	L5 TM	L5 TM –P6 LISS-III
	LC Class Name	% Correct	% Correct	delta %	% Correct	% Correct	delta %
1	open water	87.2	87.3	0.1	92.7	92.6	-0.2
2	barren land	86.3	87.1	0.7	76.2	81.9	5.7
3	deciduous forest	65.7	70.6	4.9	66.0	68.9	2.9
4	evergreen forest	37.4	52.3	14.9	40.4	50.5	10.1
5	mixed forest	69.4	68.8	-0.6	62.2	66.0	3.7
6	shrub/scrub	39.7	46.6	6.9	36.0	44.5	8.4
7	grassland	63.1	64.0	0.8	52.0	59.6	7.6
8	pasture/hay	29.6	30.6	0.9	22.5	26.4	3.9
9	cultivated crops	48.6	53.3	4.7	44.7	46.7	2.1
10	woody wetlands	37.6	43.6	6.0	29.8	40.2	10.4
11	emergent wetlands	54.9	62.8	7.9	41.0	58.2	17.2

Table VII: CROSS-VALIDATION STATISTICS FOR PERCENT CANOPY TESTS

Canopy Estimates				
SLC, UT (L5 TM)	P6 AWiFS	P6 LISS-III	L5 TM (vs. P6 AWiFS)	L5 TM (vs. P6 LISS-III)
Average error	14.6	14.7	13.9	14.1
Relative error	0.58	0.58	0.55	0.56
Correlation coefficient	0.75	0.75	0.77	0.77
Mesa, AZ (L7 ETM+)	P6 AWiFS	P6 LISS-III	L7 ETM+ (vs. P6 AWiFS)	L7 ETM+ (vs. P6 LISS-III)
Average error	12.0	12.1	11.8	11.5
Relative error	0.70	0.67	0.69	0.64
Correlation coefficient	0.67	0.68	0.68	0.71

Table VIII: CROSS-VALIDATION STATISTICS FOR PERCENT IMPERVIOUS SURFACE TESTS

Impervious Estimates				
SLC, UT (L5 TM)	P6 AWiFS	P6 LISS-III	L5 TM (vs. P6 AWiFS)	L5 TM (vs. P6 LISS-III)
Average error	14.8	15.5	14.5	14.1
Relative error	0.59	0.61	0.58	0.56
Correlation coefficient	0.75	0.72	0.75	0.77
Mesa, AZ (L7 ETM+)	P6 AWiFS	P6 LISS-III	L7 ETM+ (vs. P6 AWiFS)	L7 ETM+ (vs. P6 LISS-III)
Average error	15.6	16.9	15.4	15.0
Relative error	0.65	0.78	0.64	0.70
Correlation coefficient	0.70	0.57	0.70	0.68

IRS-P6 THREE TIER IMAGING

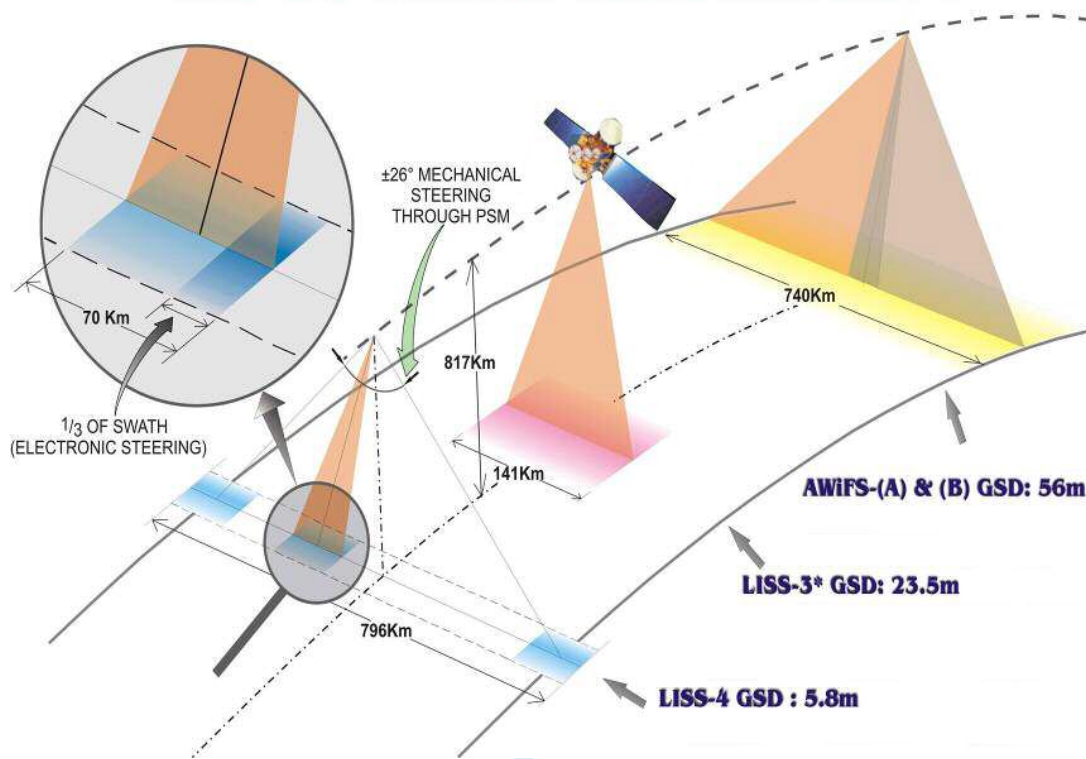


Fig. 1. P6 sensors swath covered on the ground [4]

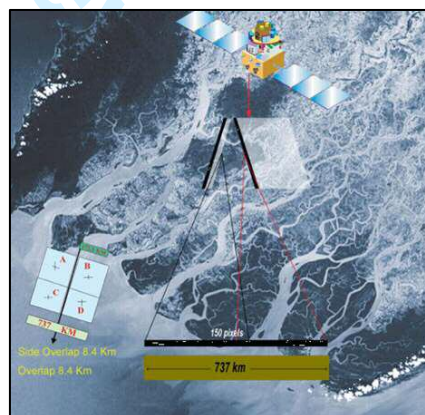
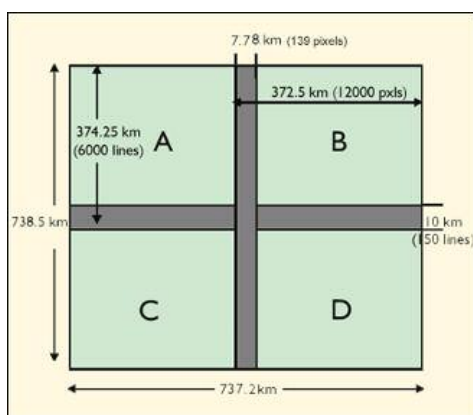


Fig. 2. P6 AWiFS Twin Cameras [2]

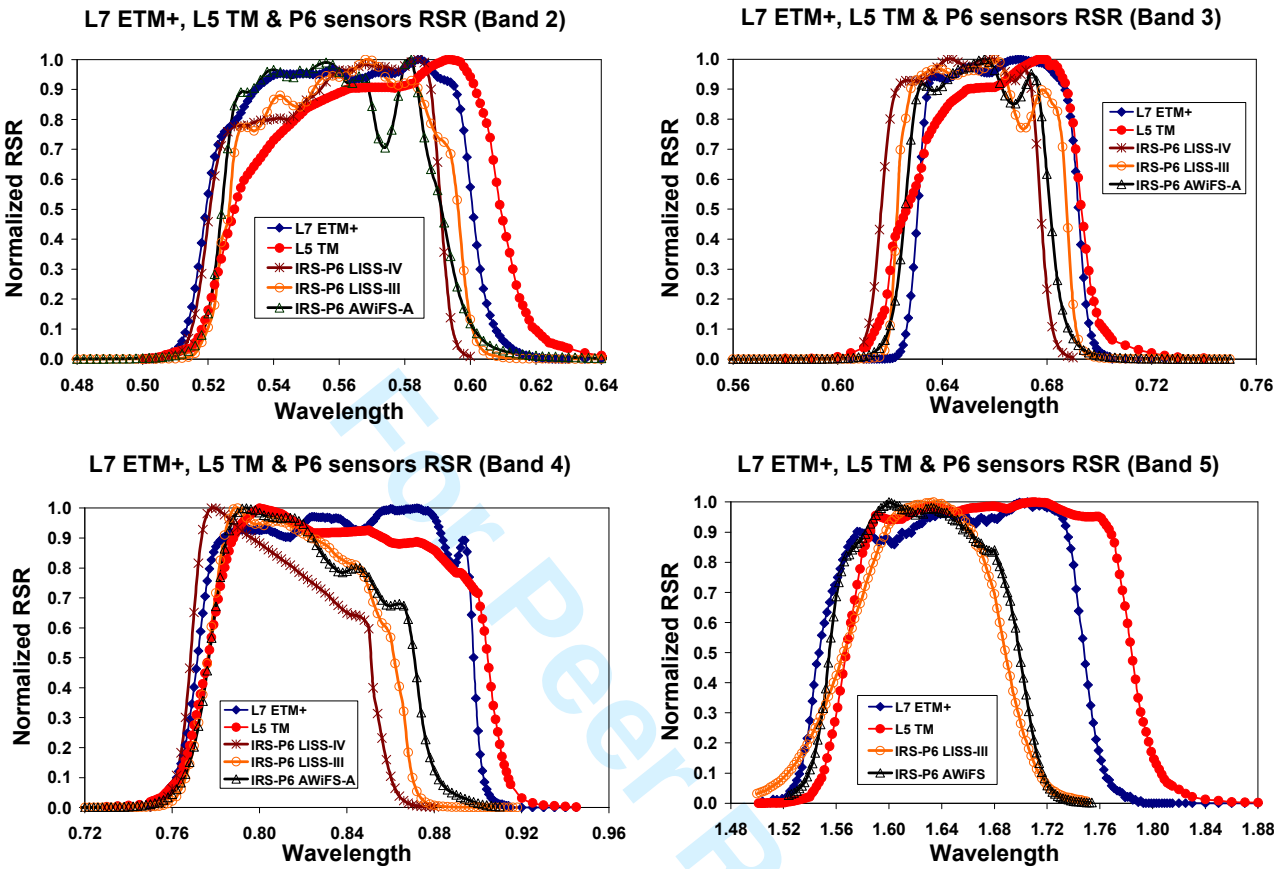


Fig. 3. Relative Spectral Responses profiles of L7 ETM+, L5 TM, P6 AWiFS, and P6 LISS-III sensors.

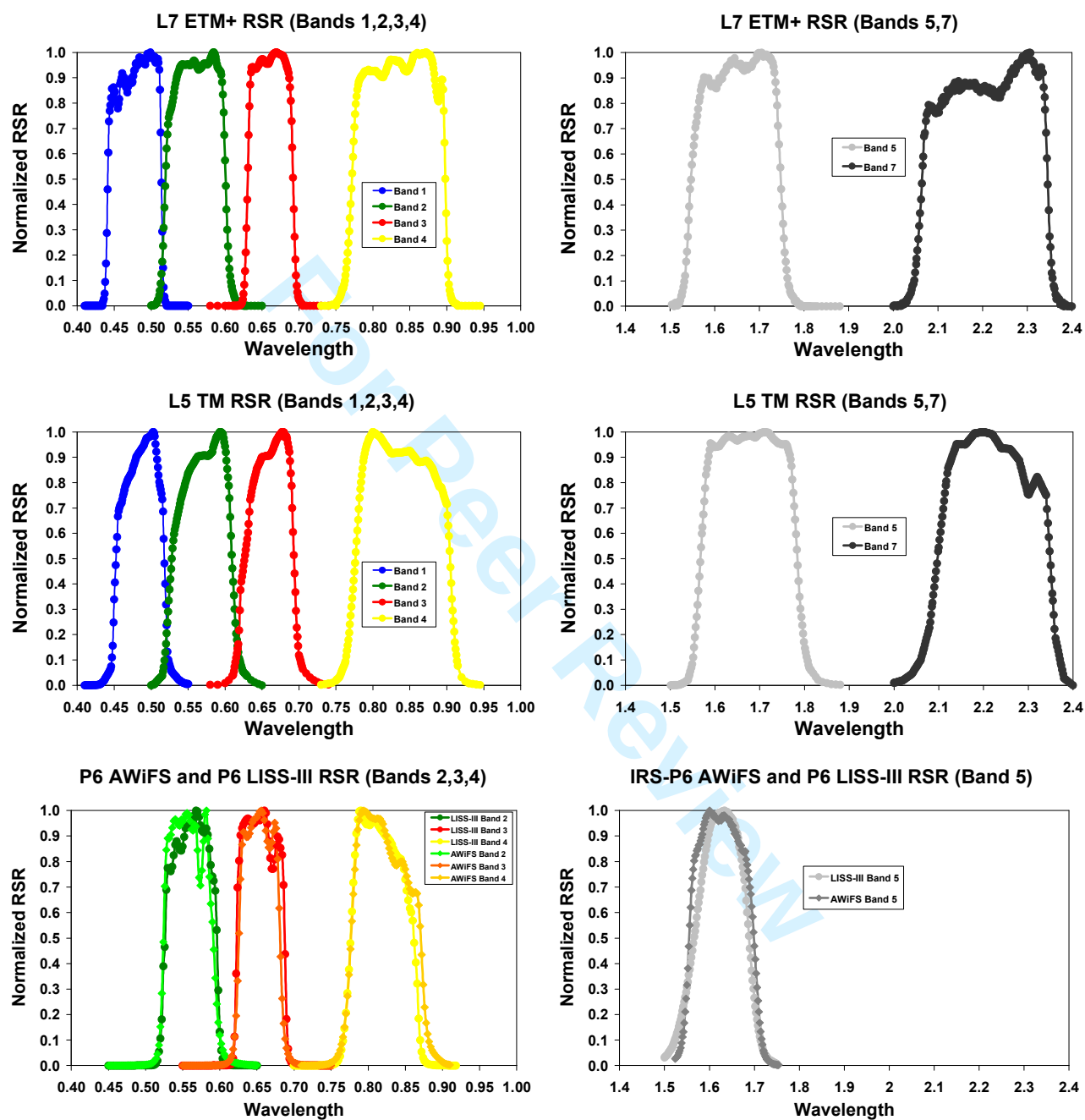


Fig. 4. Comparison of the Relative Spectral Responses profiles of L7 ETM+, L5 TM, P6 AWiFS, and P6 LISS-III sensors.

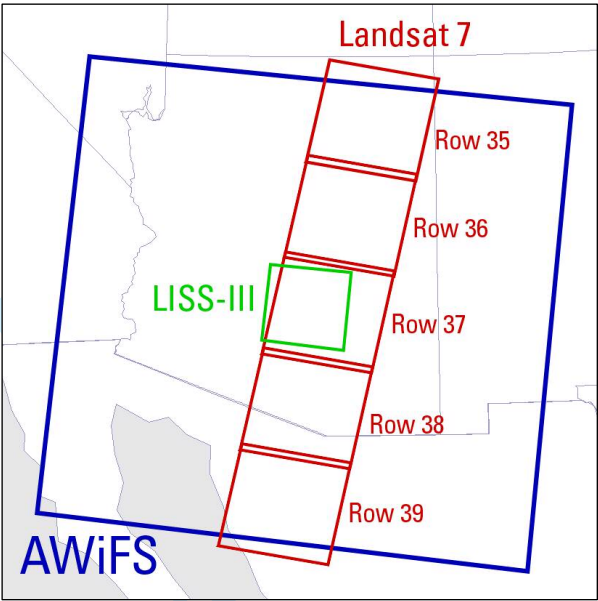


Fig. 5. – Image boundaries of scenes used in Mesa, Arizona collection.

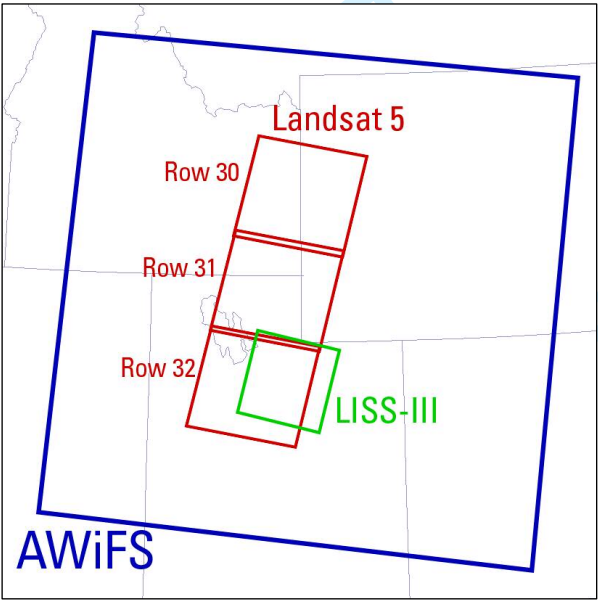


Fig. 6. – Image boundaries of scenes used in Salt Lake City, Utah collection.

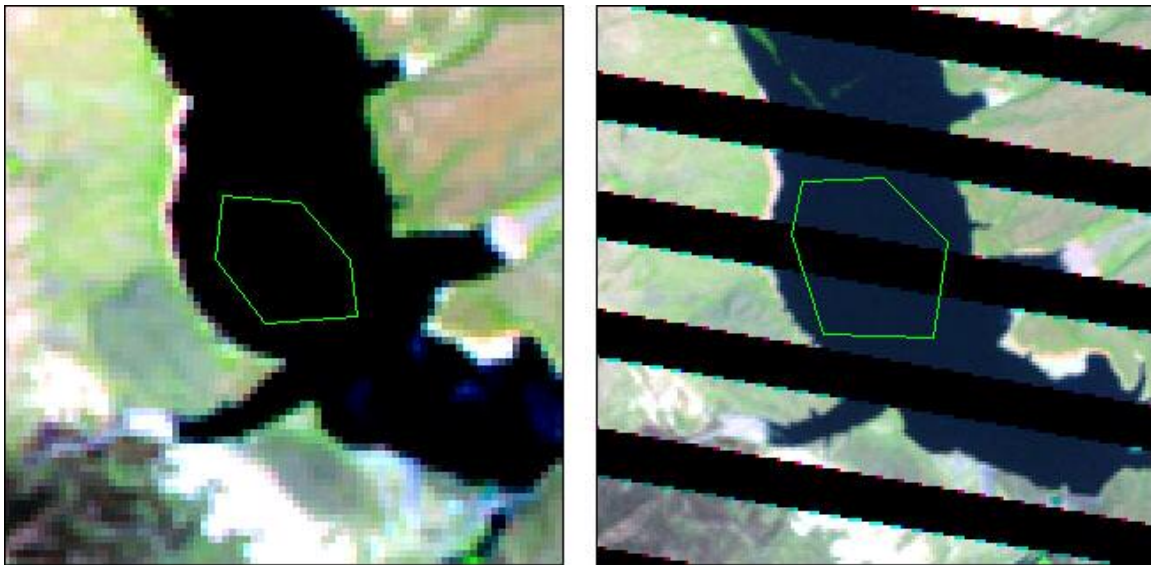


Fig. 7. Paired homogenous regions of interest.
Data from Mesa, Arizona collection, with P6 AWiFS (left) and L7 ETM+ (right).

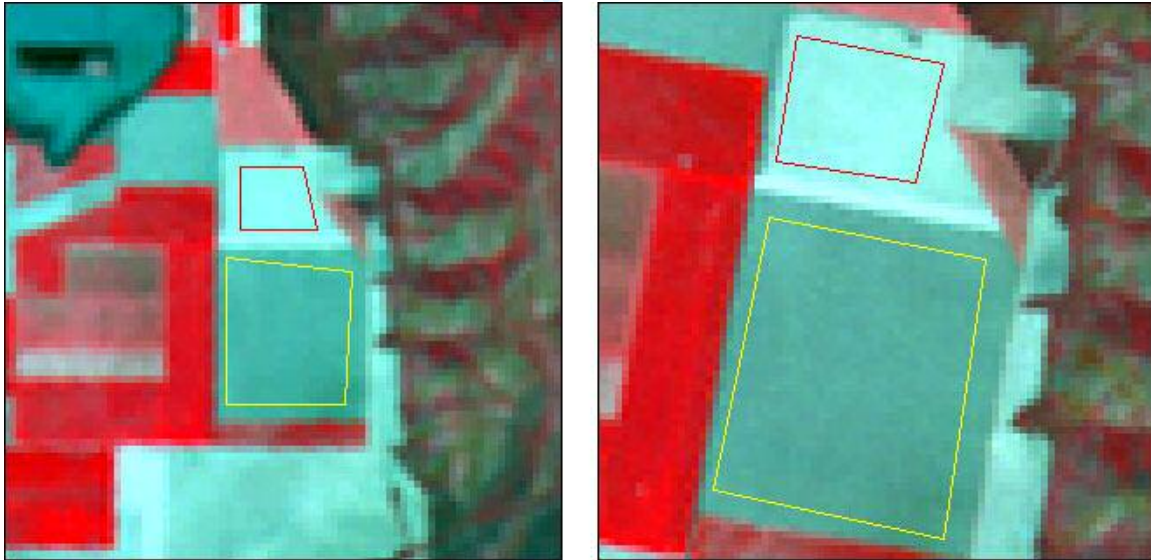


Fig. 8. Paired homogenous regions of interest.
Data from Salt Lake City, Utah collection, with P6 AWiFS (left) and L5 TM (right).

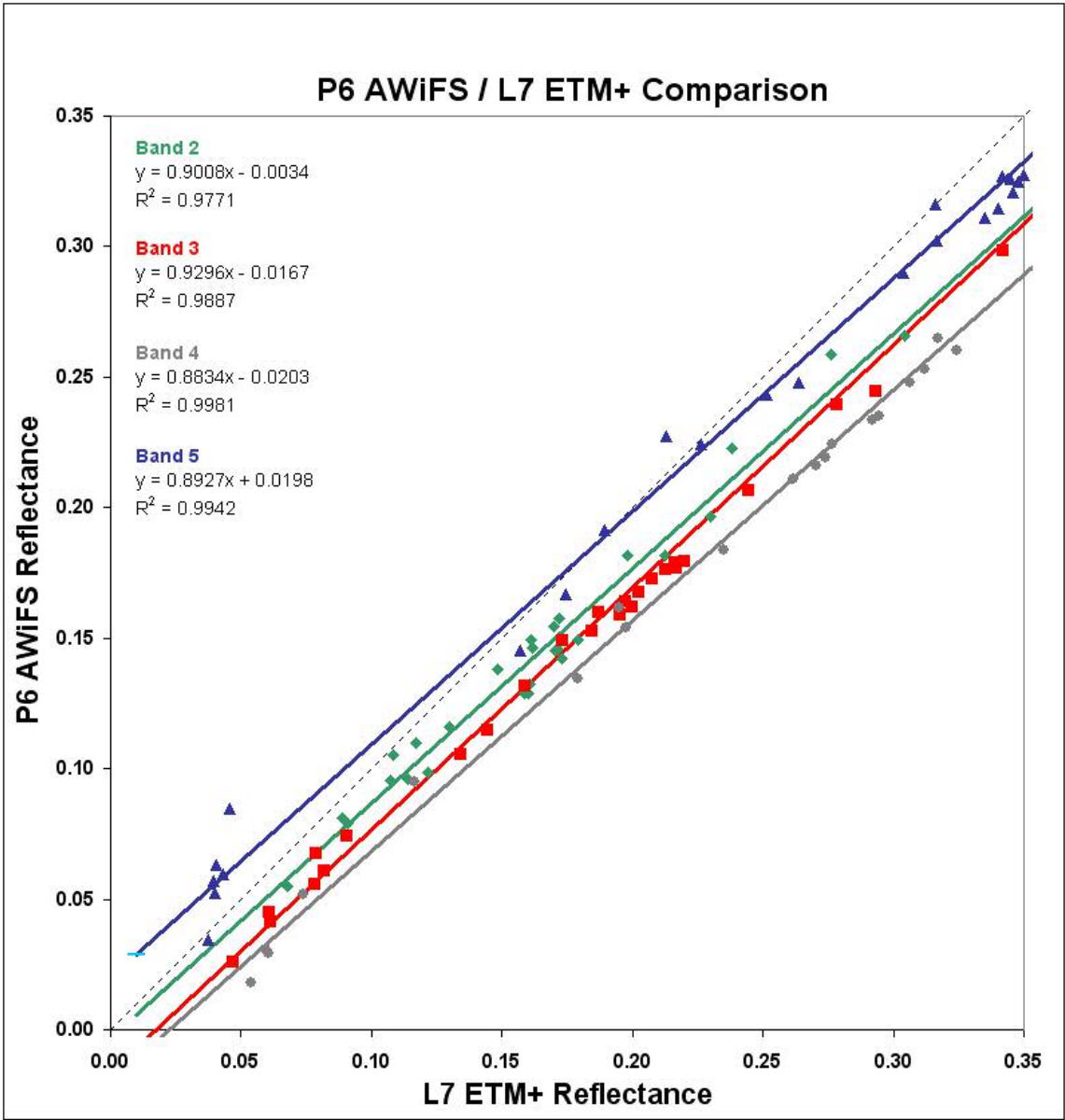


Fig. 9. Reflectance of homogenous regions viewed by the L7 ETM+ plotted against the same regions viewed by P6 AWiFS.

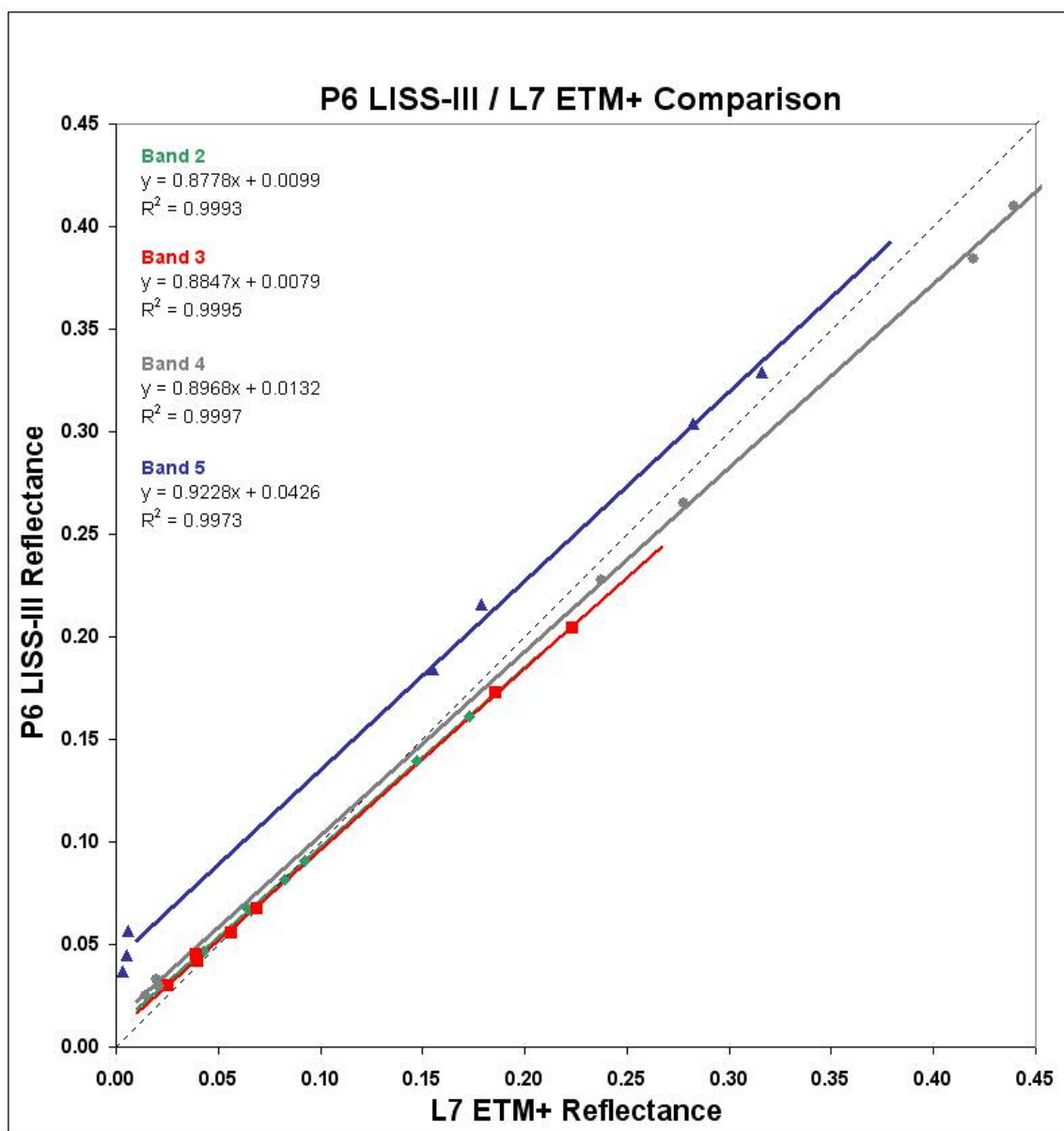


Fig. 10. Reflectance of homogenous regions viewed by the L7 ETM+ plotted against the same regions viewed by P6 LISS-III.

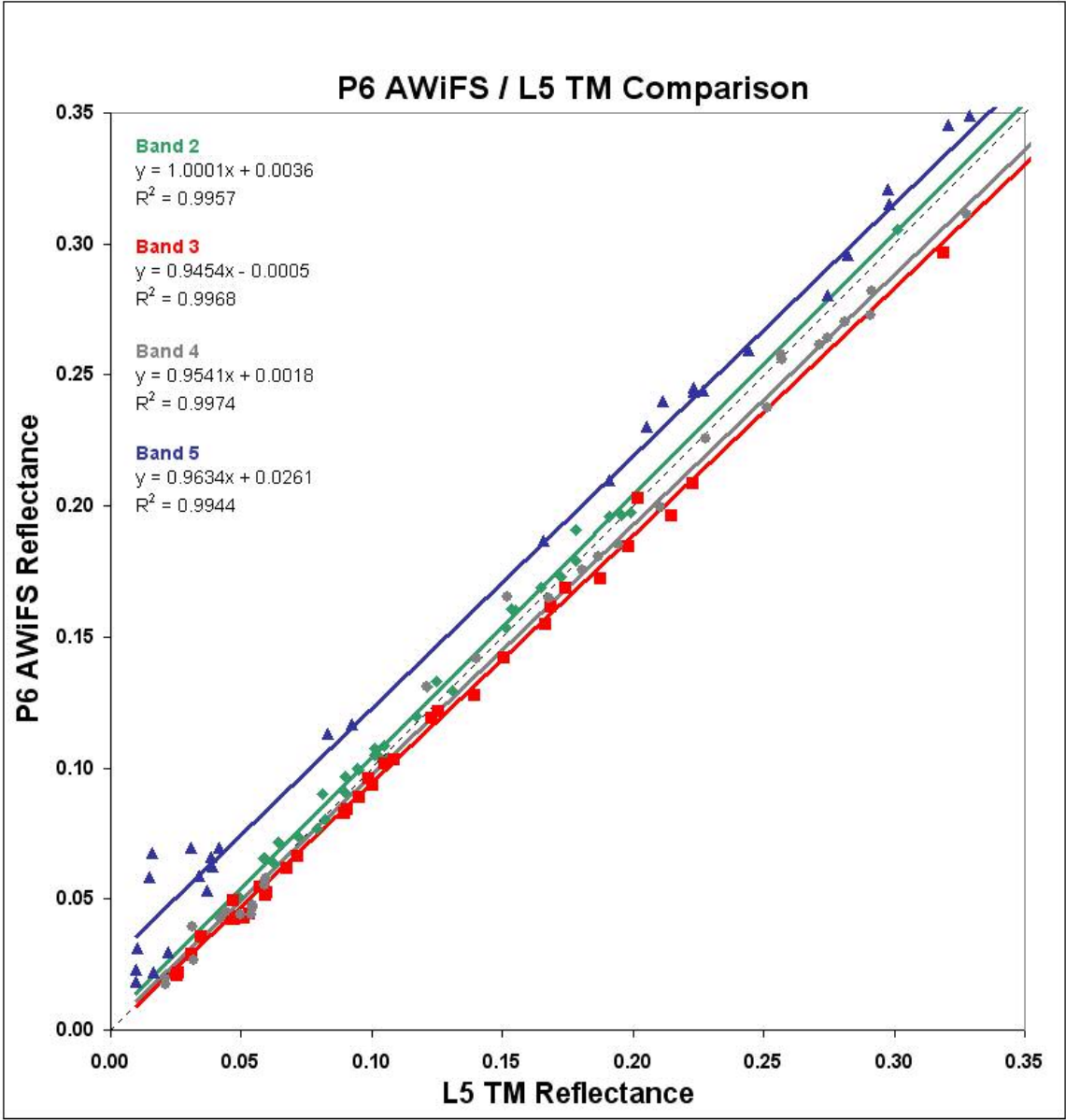


Fig. 11. Reflectance of homogenous regions viewed by the L5 TM plotted against the same regions viewed by P6 AWiFS.

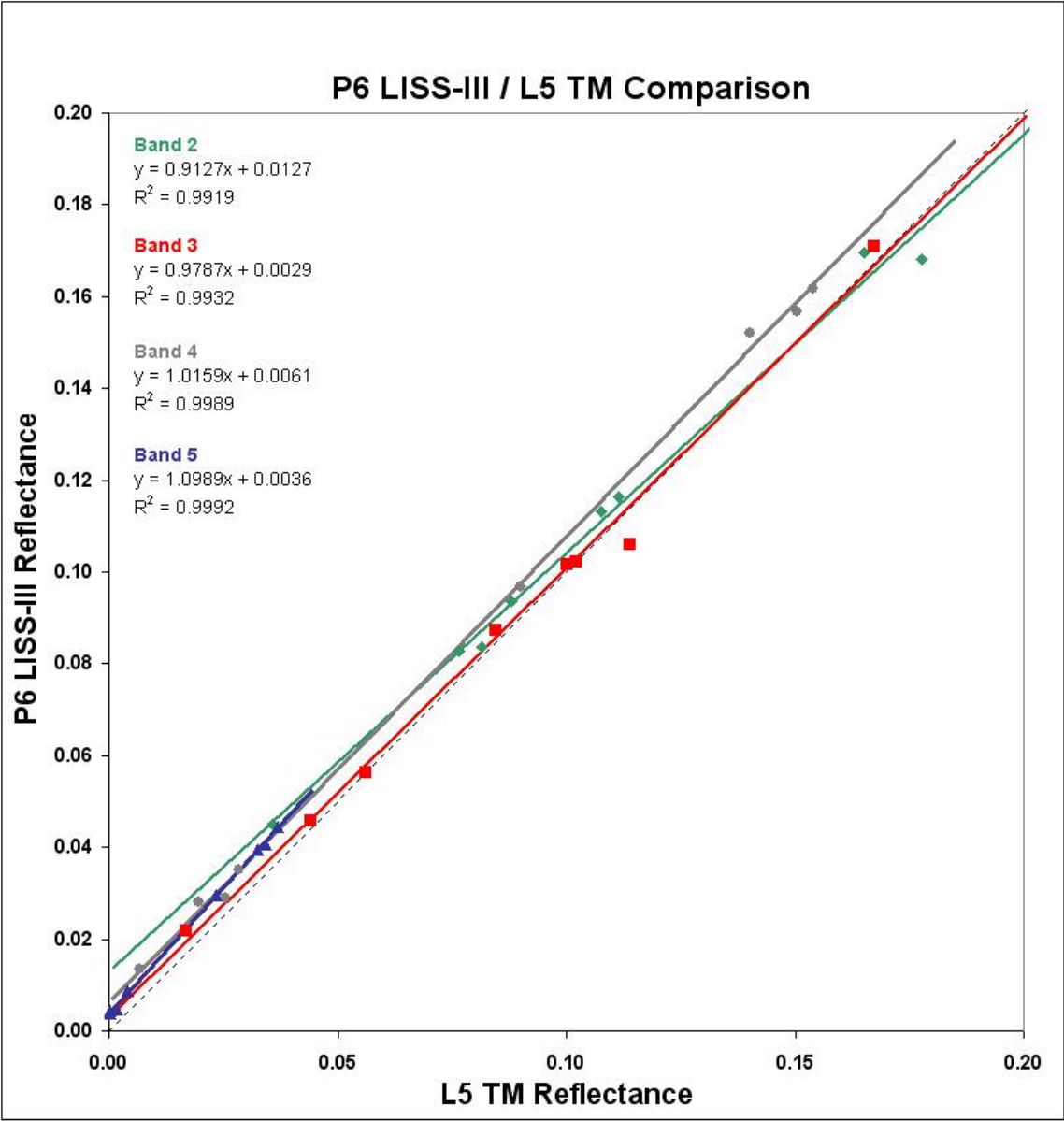


Fig. 12. Reflectance of homogenous regions viewed by the L5 TM plotted against the same regions viewed by P6 LISS-III.

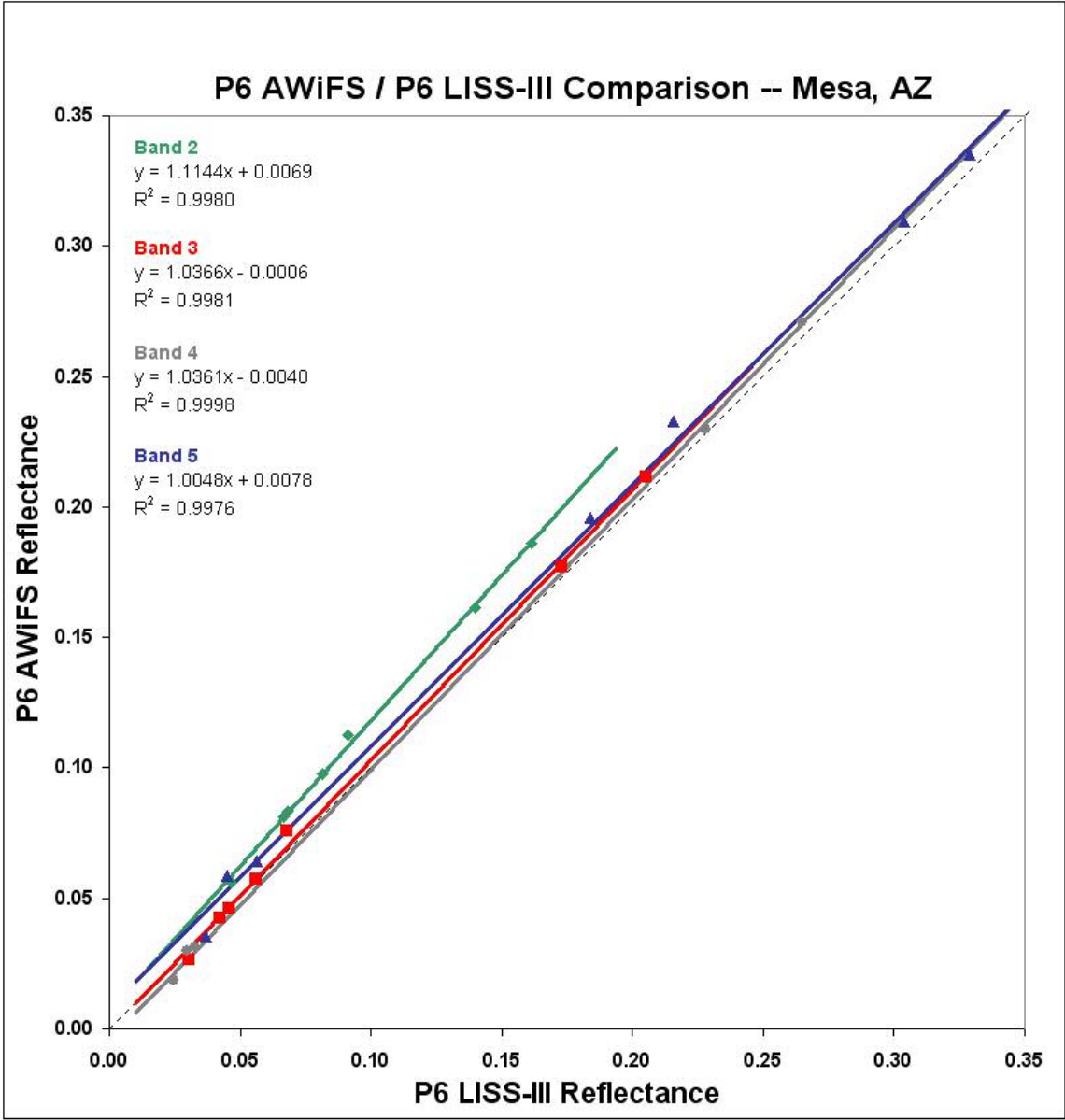


Fig. 13. Reflectance of homogenous regions viewed by both the P6 AWiFS and the P6 LISS-III sensors for the Mesa, Arizona collection.

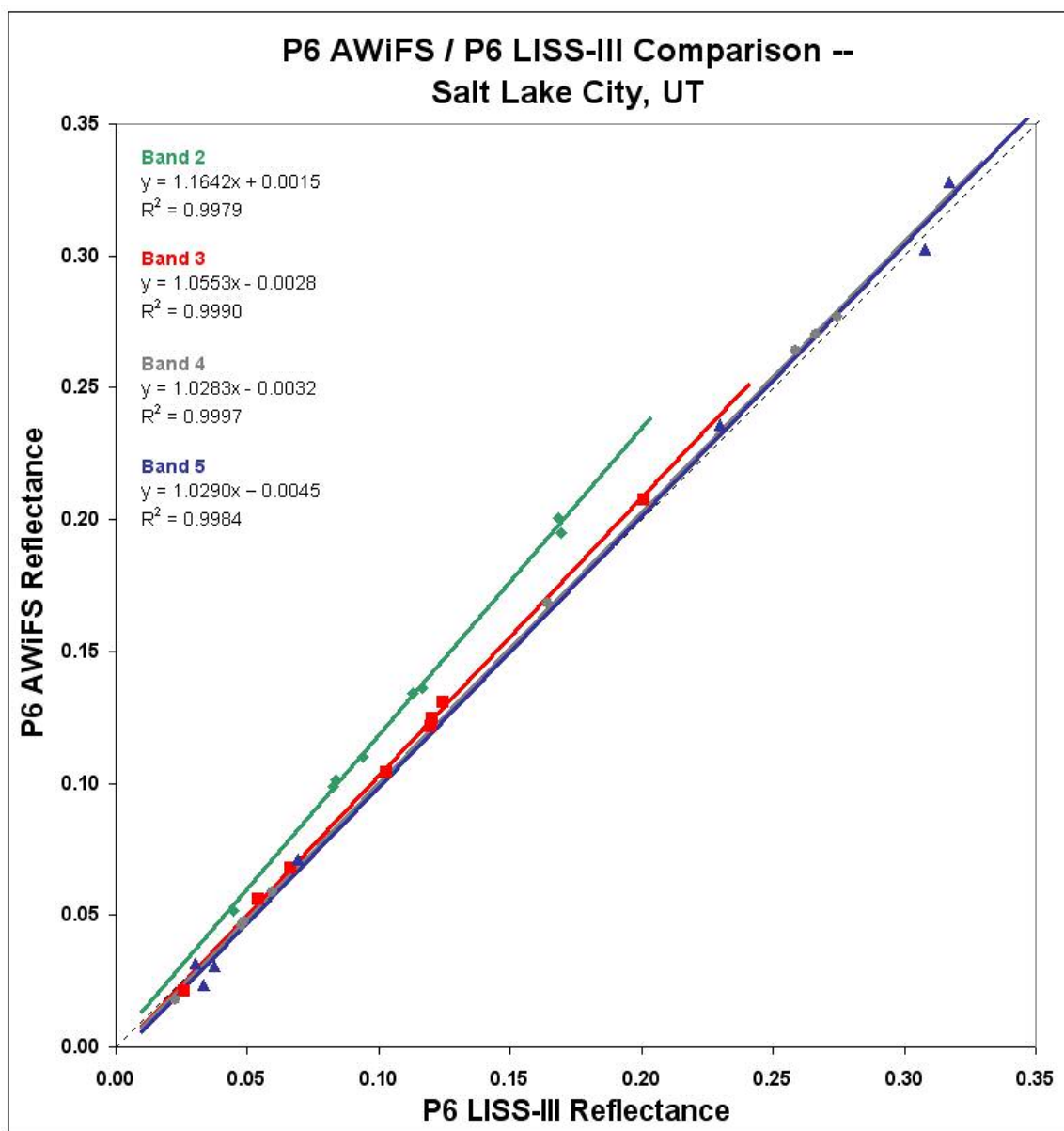


Fig. 14. Reflectance of homogenous regions viewed by both the P6 AWiFS and the P6 LISS-III sensors for the Salt Lake City, Utah collection.

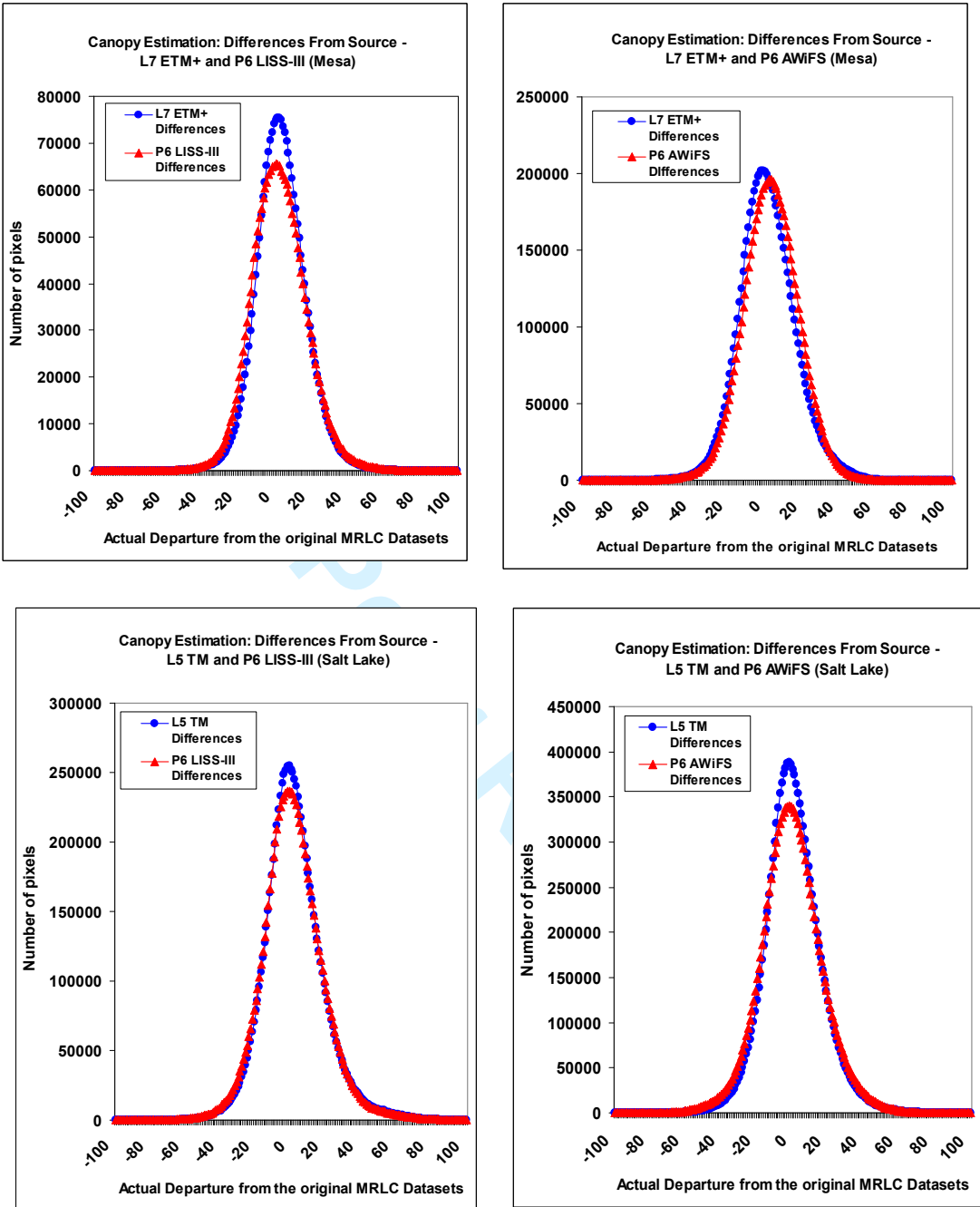


Fig. 15. Difference of percent tree canopy calculated from test imagery and NLCD 2001.

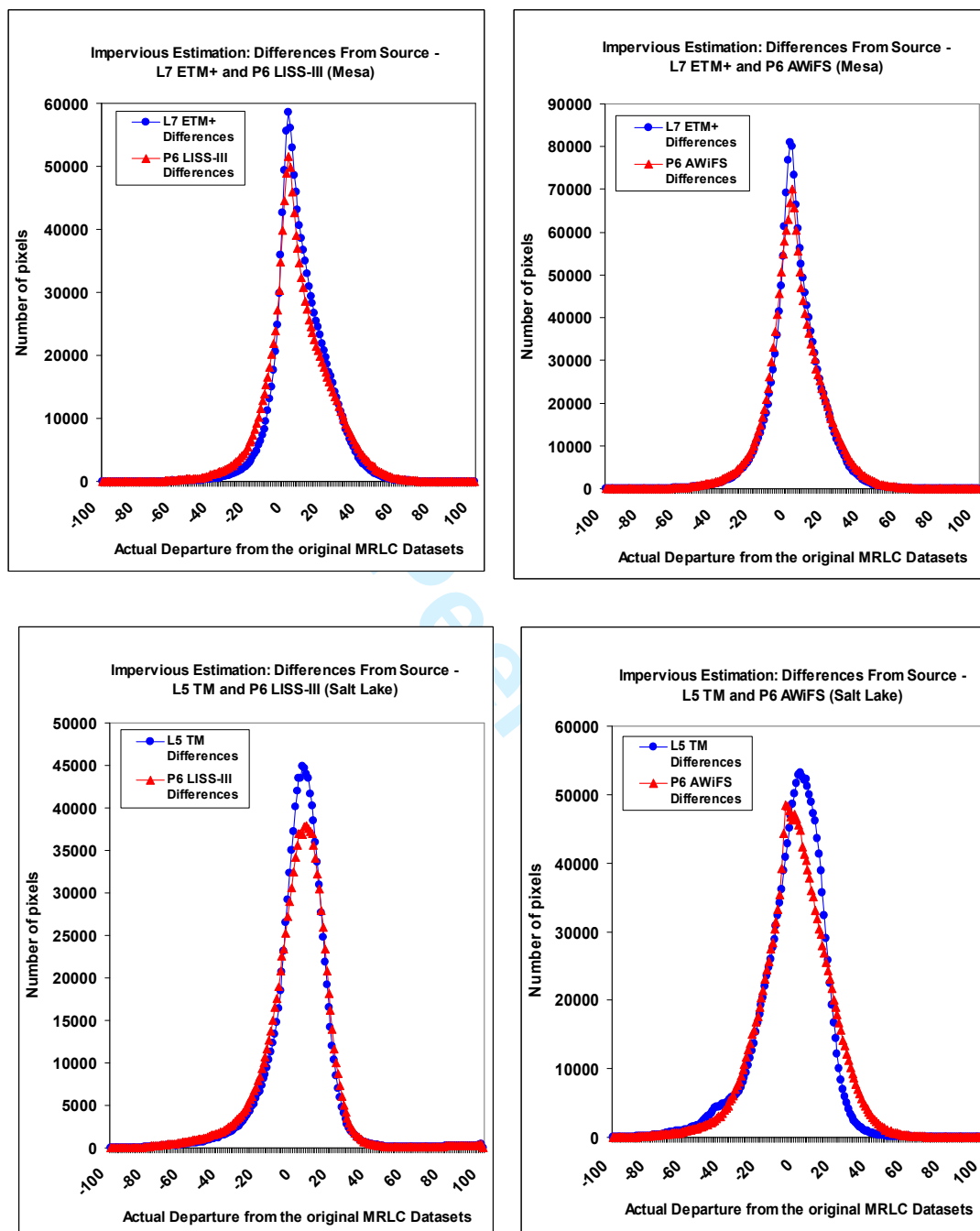


Fig. 16. Difference of percent impervious surface calculated from test imagery and NLCD 2001.

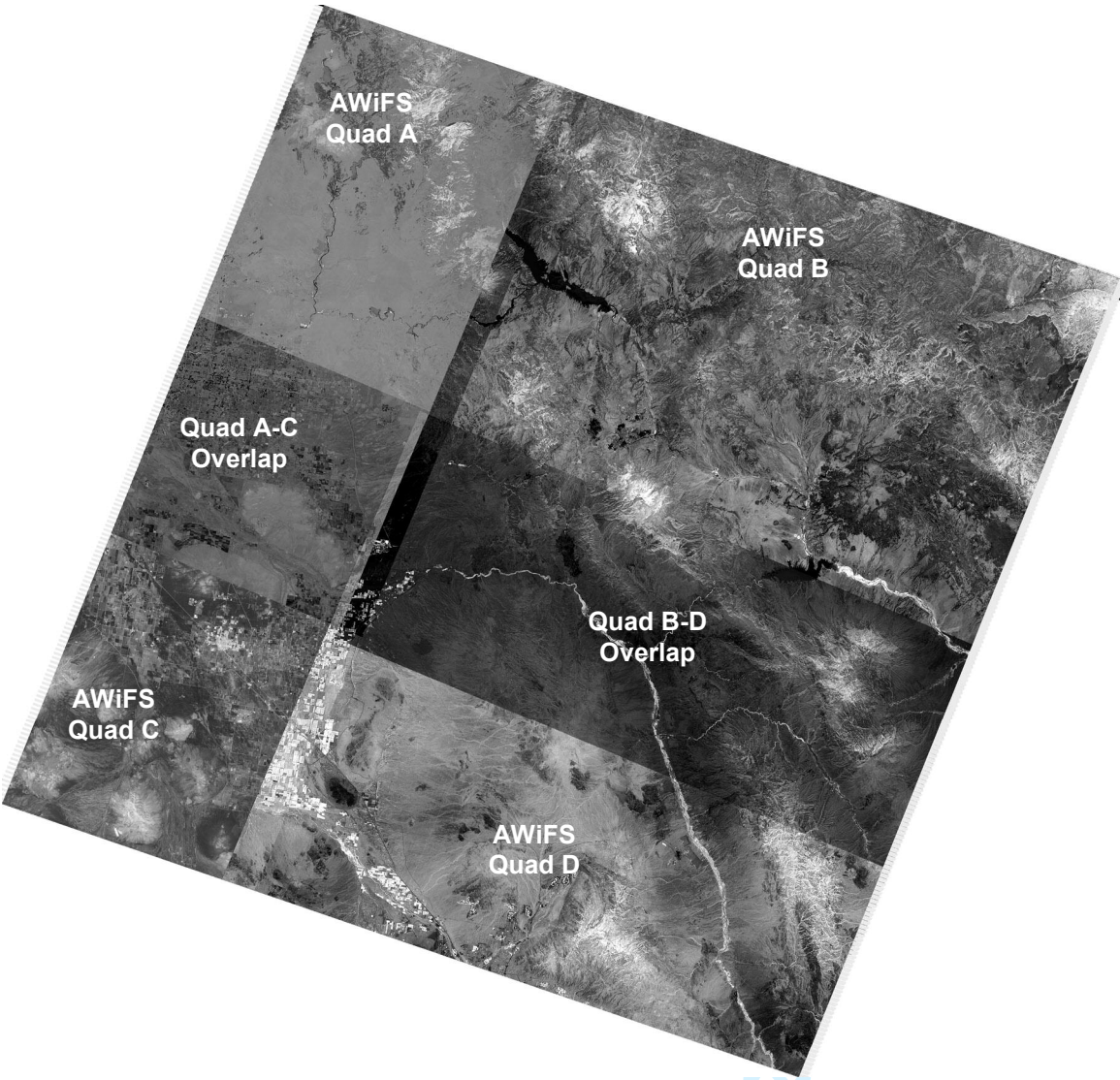


Fig. 17. Percent tree canopy map of AWiFS data over the extent of the Mesa, Arizona L7 ETM+ scene, showing the classification errors due to overlaps in the P6 AWiFS quadrants

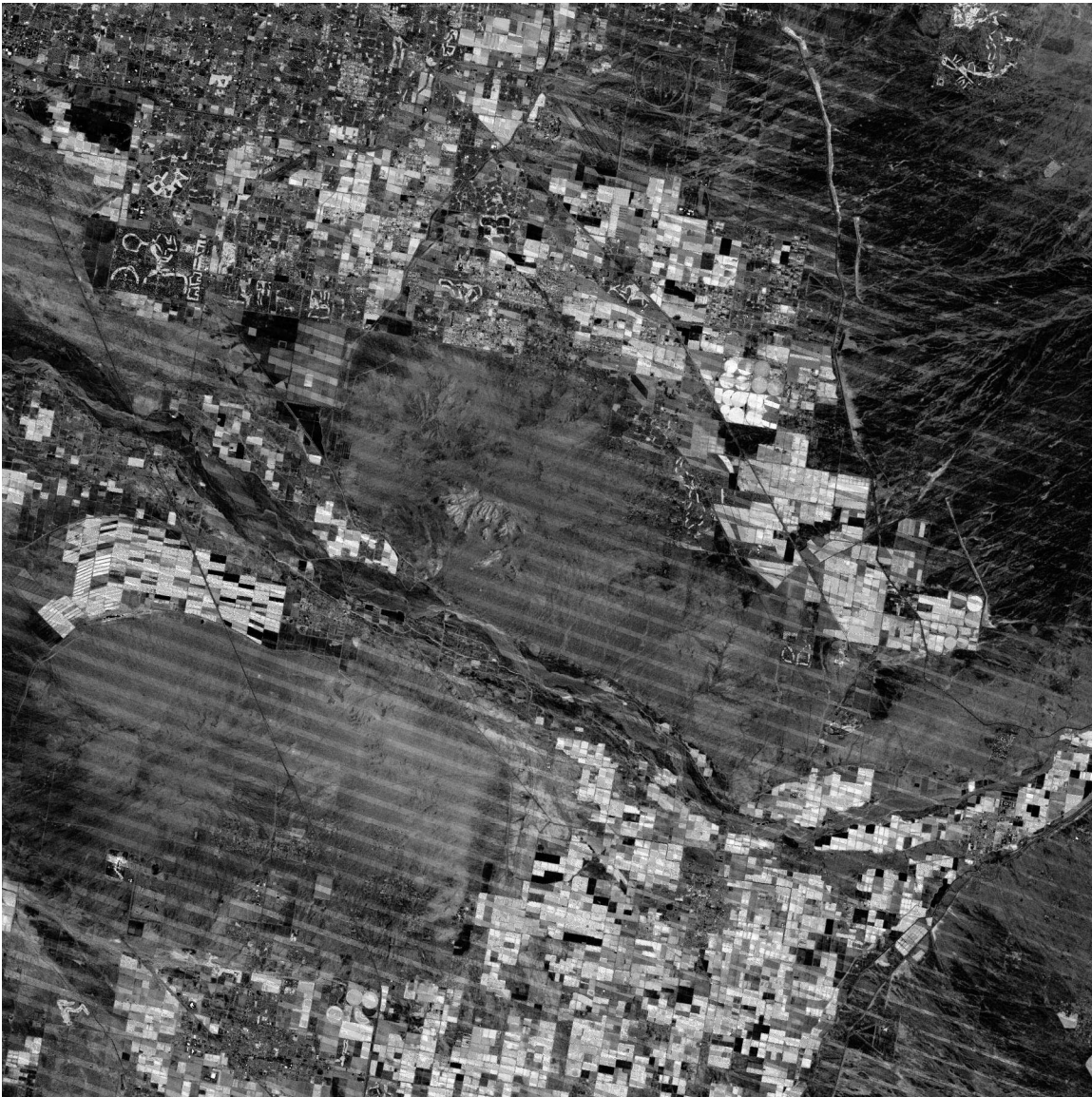


Fig. 18. Percent tree canopy map of L7 ETM+ data in part of the Mesa, Arizona scene, showing classification errors due to gap-filling