Progress Report

NASA Headquarters

Earth Science Division

Land Cover/Land Use Change Program

Comparison of the IRS Advanced Wide Field Sensor to Landsat for Supplying General Land Cover Land Use Change Detection Products Needed for NASA LCLUC Program Science

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Project Background and Goals

Dr. Samuel N. Goward is working with Mary Pagnutti and Robert Ryan, Innovative Imaging and Research (I2R)s to support the NASA Land Cover Land Use Change (LCLUC) Program in preparation for a potential Landsat data gap. With the Landsat data gap imminent, NASA's LCLUC Program may require alternative data sources for producing regional to global-scale mapping products depicting land cover/land use distributions and terrestrial environmental changes. One such alternative is the Indian Remote Sensing (IRS) Advanced Wide Field Sensor (AWiFS) on current and future RESOURCESAT satellites. While AWiFS collects data similar to Landsat, system differences including reduced spatial resolution, reduced number of spectral bands, multiple cameras and larger off-axis viewing geometry, may impact LCLUC products.

This study is investigating the scientific utility of the IRS AWiFS for LCLUC research and for its potential to fill Landsat data gaps. We are performing a first-order analysis to examine the potential of using AWIFS data to generate LCLUC products that are normally generated using Landsat data. For over 34 years, the LCLUC community has heavily relied upon Landsat data to perform its scientific activities. The current on-orbit Landsat capability for monitoring the land masses of the world at a 30-meter spatial resolution will likely be lost well before a replacement is available, thus producing a Landsat data gap.

The AWiFS team is also collaborating with the Stennis Space Center Information Technology Services (ITS) technical contracting team and the US Geological Survey (USGS) EROS Data Center (EDC) who are funded separately. These studies will help ascertain the true viability of AWiFs to serve as a Landsat surrogate as well as lay out the methodology for performing trades for future systems. Although AWiFS is similar to Landsat, the sensor has several different characteristics:

- A nominal spatial resolution of 56-meter at nadir compared to 30-meter with Landsat.
- The lack of equivalent Landsat TM/ETM+ band 1 (blue), band 6 (thermal), and band 7 (SWIR-2).
- A 740 km combined ground swath compared to 185 km with Landsat.
- A 5-day revisit time compared to a 16-day revisit with Landsat.
- Multiple pushbroom cameras compared to a single cross-track scanner.
- Lack of onboard calibrators.
- 10-bit data instead of 8-bit.

A key difference between Landsat and AWiFS is the wider swath of AWiFS. Although this wider swath significantly improves the revisit time of the system, it also increases the amount of off-axis imaging. AWiFS acquires imagery up to 24 degrees from nadir as compared to 7.5 degrees for Landsat. This off-axis viewing causes changes in surface reflection and increased atmospheric effects compared to nadir viewing. Artifacts in the Normalized Difference Vegetation Index (NDVI) related to variations in viewing geometry and solar zenith angle at the time of observation may make it difficult to distinguish between expected intra-vegetation type variability (i.e., seasonal or inter-annual variability) and significant land cover change over time (Los et al., 2005; Gutman et al., 1995; Gutman, 1998).

A second major difference between Landsat and AWiFS is the use of multiple pushbroom cameras versus a single cross-track scanner system. The use of multiple pushbroom cameras creates the increased likelihood of several imaging artifacts not seen in historical Landsat imagery. These include camera radiometry differences, relatively large band-to-band mis-registration, increased stray light, and a variable point spread function as a function of band and position in the image. The AWiFS architecture also offers increased revisit time and high signal-to-noise data.

Technical Approach and Methodology

Limited published literature discusses the characteristics of AWiFS reflectance data compared to Landsat data or the potential of AWiFS for generating higher order LCLUC products normally produced from Landsat. Most relevant studies are preliminary. As part of previous remote sensing calibration-validation (cal-val) work, we have performed several key preliminary studies on the characteristics of several commercial imaging systems, including the AWiFS system. We are building upon this cal-val work to explore the scientific utility of AWiFS data.

We are further exploring use of AWiFS imagery in place of Landsat to generate LCLUC products by substituting AWiFS for Landsat within the NAFD (North American Forest Dynamics) disturbance mapping procedures (Fig. 1). The NAFD group developed near-biennial (1984-2007) Landsat time series stacks (LTSS) at ~50 sample locations (Goward, Cohen, Masek and Moisen). Each LTSS image was then processed through the LEDAPS (Landsat Ecosystem Disturbance Adaptive Processing System) processing stream at NASA GSFC (Huang et al. 2009, Masek et al., 2006). This processing stream accepts level 1 Landsat data products and further processes them for consistency and comparability. The processing stream includes: orthorectification using SRTM Digital Terrain Models to achieve subpixel geolocation accuracy; radiometric calibration and conversion to top-of-atmospheric (TOA) reflectance; and adjustment to surface reflectance following the MODIS 6S approach (Masek et al. 2006). The compilation of sample LTSS is described in more detail in Huang et al. (2009).

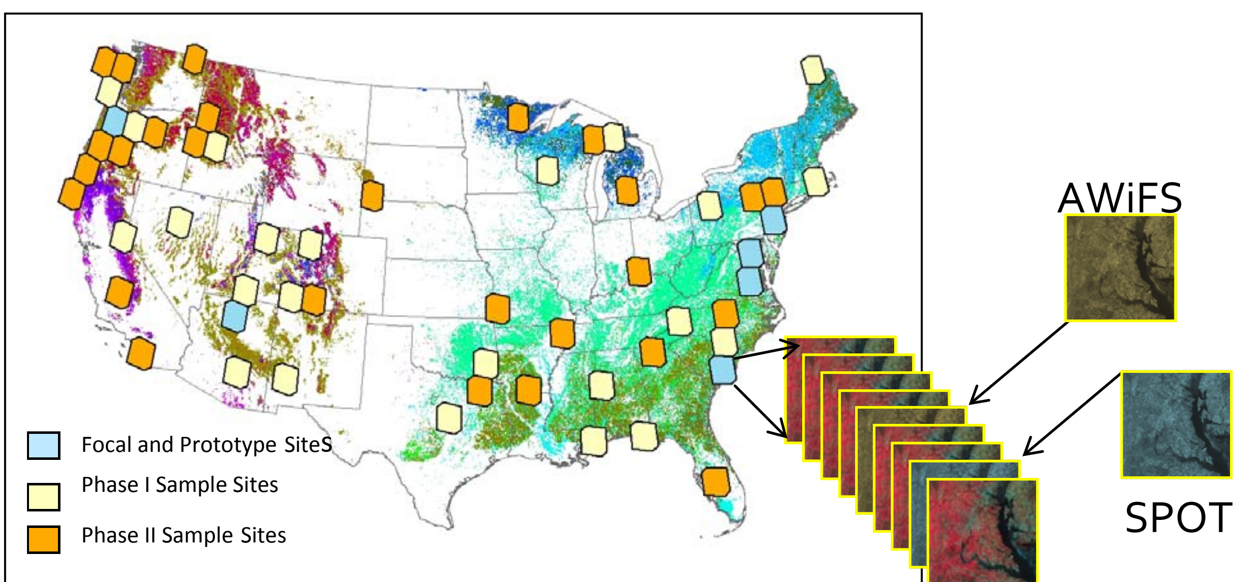


Fig. 1. The NAFD sample LTSS are shown. Each LTSS consists of biennial (Phase I) or annual (Phase II) Landsat data from the 1984 – 2008 time period. We plan to test use of non-Landsat data in creating LCLUC products by substituting AWiFS (and potentially) SPOT images for matching Landsat data within available LTSS and comparing output disturbance maps.

The NAFD project developed a forest disturbance detection methodology using a highly automated vegetation change tracker (VCT) algorithm (Huang et al., 2010). Forest changes are determined from temporal variations in forest signal, where no change from high probability forest location indicates an unchanged forest cover and deviations indicate forest cover changes arising from a variety of disturbance events including harvest, fire, and conversion. Substitution of AWiFS for Landsat scenes within the NAFD LTSS will provide insight into use of alternative image sources for LCLUC products.

Year 1 Objectives: (Focus on viewing geometry and solar zenith angle effect on reflectance)

Objective 1: Order and obtain datasets identified in this project.

For this project, we are primarily using AWiFS datasets obtained from GeoEye through our cal-val work and the USDA Satellite Imagery Archive (http://www.pecad.fas.usda.gov/remote.cfm). The USDA archive contains orthorectified AWiFS imagery that has been shown to have a geolocation accuracy of a pixel or better (Blonski et al., 2005). Much of the data within the archive contains some amount of clouds. We have identified and collected several AWiFS scenes that overlap temporally and spatially with NAFD time series stacks that also contain a wide variety of land cover types appropriate for this type of investigation (Fig. 2). Near-coincident imagery is required to ensure that weather and other temporal land cover changes have minimal impact on the overall results.

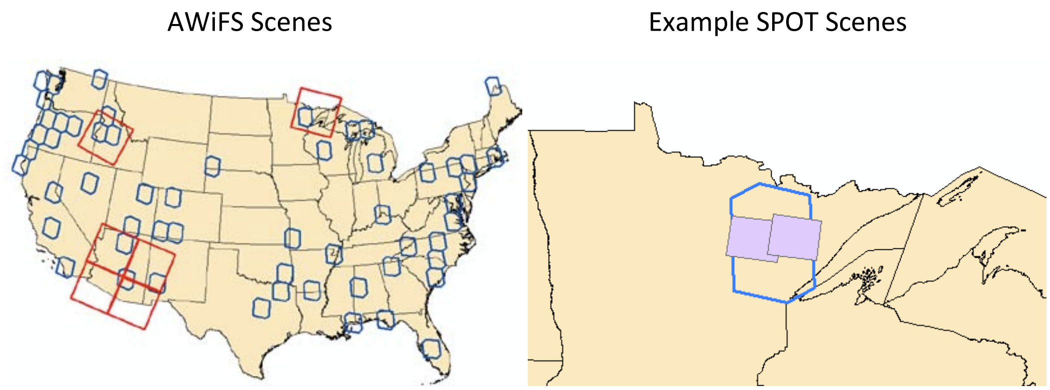


Fig. 2. We began our analysis by locating overlapping temporal and spatial coverage of available AWiFS scenes with the NAFD LTSS sites. NAFD forest disturbance mapping requires nearly cloud-free scenes acquired in the mid-growing season. One of the sites is an AWiFS "super scene", where both Camera A and Camera B cover a portion of the LTSS. Additionally, we are locating a suitable scene in the southeaster U.S. to ensure coverage of a wide variety of land cover types and forest disturbance regimes.

Objective 2: Generate planetary and surface reflectance maps for each data set evaluated

We plan to test both planetary and surface reflectance AWiFS images within the NAFD data stacks. The VCT disturbance mapping code includes 2 versions depending on type of input reflectance data. IR2 is leading the effort to generate surface reflectance maps for the selected sample sites. Image data is first normalized by the cosine of the solar zenith angle and corrected for the Sun-Earth distance to generate planetary reflectance values. On the selected NAFD overlap sites, IR2 is currently modifying existing algorithms and performing a full atmospheric correction using radiative transfer methods. We believe a simple approach for data normalization will detect and quantify viewing and solar zenith angle effects (Pagnutti et al., 2005).

Objective 3: Compare reflectance values of similar land cover types at different viewing geometries and solar zenith angles.

To begin to understand how the characteristics of AWiFS will affect LCLUC issues, this task is focused on detecting variation in reflectance due to off-nadir and solar viewing geometries. We are examining the viewing geometry BRDF (bidirectional reflectance distribution function) effects of the larger field of view of the AWiFS sensor by tracking the apparent brightness/reflectance of land cover features found within a scene over the sensor view angle. (Gutman, 1999; Csiszar and Gutman, 1999). These reflectance values will be compared to determine the effect that viewing geometry has on measured values. Variations in measured values are expected to depend greatly on the feature chosen, so several different land cover classes will be evaluated. The actual features (types and patches) selected will be determined while screening available AWiFS data. The available AWiFS data from the USDA archive covers only about 6 months of the year (i.e., typical growing season) but should be sufficiently long in duration to observe seasonal solar zenith angle effects.

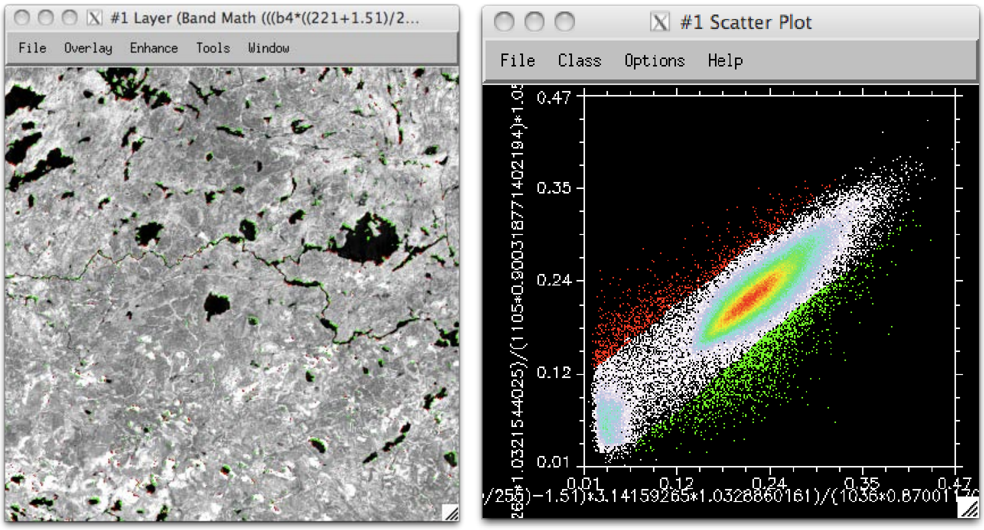
The data will be screened to look for cloud-free regions and attempt to optimize the number of datasets available. To assist with the screening process and selection of AWiFS datasets, near-coincident Terra MODIS (Moderate Resolution Imaging Spectroradiometer) aerosol and water vapor data will be examined for data quality assurance. There is typically less than a 1-hour time difference between MODIS and AWiFS acquisitions. Datasets with optical depths greater than 0.1-0.2 will be discarded if sufficient higher quality datasets are available. We will focus on large uniform areas to minimize any geolocation errors and point spread function effects. We will analyze the reflectance over different viewing geometries and different solar zenith angles. If sufficient data exists, we will fit the data to simple polynomial models for different types of land covers to estimate the BRDF.

Objective 4: Coordinate with EDC and the UMd to perform Landsat-AWiFS comparisons.

We are incorporating the selected AWiFS scenes into existing NAFD data stacks to quantify the uncertainties of substituting AWiFS for Landsat in LCLUC products. Affects of IVOV, BRDF, and radiometric calibration are as yet unquantified, and other sources of error remain to be understood. The NAFD mapping techniques using existing Landsat data stacks to have overall accuracy of > 80%, and we will compare the results using AWiFS substitution of individual time steps to determine the effect on the accuracy of disturbance mapping results.

Initial data exploration of the study site AWiFS and corresponding Landsat scenes are promising. Band to band comparisons show a strong relationship between the data sources (Fig. 3). Thus far we have noted that spatial registration looks reasonable but IFOV differences still need to be addressed in our research. However, we have noted that individual AWiFS bands may not be perfectly registered with each other. We have seen this misregistration most strongly in Band 5. Thus far, our spectral comparisons look reasonable but differences as a result of calibration and atmospheric variations are present.

a) Band 4 Comparison



b) Band 5 Comparison

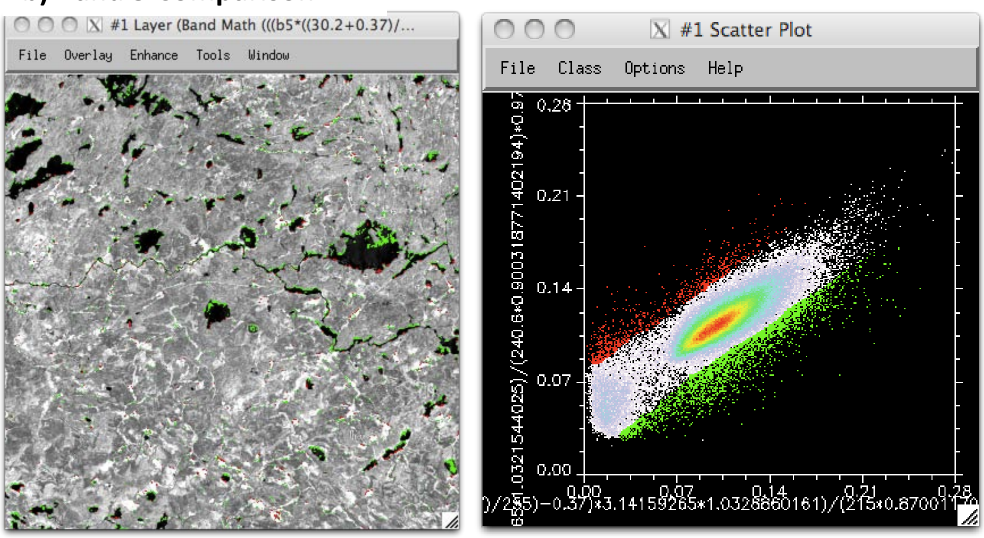


Fig. 3. Comparison of Landsat spectral bands with corresponding AWiFS bands shown here are from WRS2 27/27 (Minnesota). The Landsat image used was acquired on June 22, 2005, and the AWiFS scene is from Jun 17, 2005. Scatterplots show relationship between spectral data for the subsample above. Red and green pixels seen on scatterplots correspond to the colored pixels on the imagery. Similar scatterplots have been created for several subsample regions within each of the NAFD LTSS overlap image pairs.

Currently we are preparing the selected AWiFS scenes for input into the LTSS by creating Landsat-like images that can easily be processed by the current VCT algorithm. The VCT utilizes each Landsat band and therefore we are recreating the Visible Blue (Landsat B1), SWIR2 (Landsat B7), and Thermal bands (Landsat B6) for input into the automated forest disturbance detection procedures. In particular the thermal band is critical for creating cloud masks that minimize commission error in disturbance detection. Methods developed at EROS as well regressions performed at UMD are being tested for an acceptable “pseudo” thermal band creation. The visible and SWIR2 bands are highly correlated with existing AWiFS bands. The final step needed to substitute AWiFS into the NAFD stacks will be to resample the AWiFS to 30 meters to match the LTSS parameters. We also plan to resample at least one of the sample stacks to 56m to test the algorithm and input imagery at different resolutions.

Objective 5: Attend a LCLUC meeting or meet with the LCLUC program manager in the Washington DC area

The project team presented current research and findings at the NASA Land-Cover and Land-Use Change Science Team meeting held in Bethesda, MD on April 20-22, 2010. Dr. Goward presented initial results of comparisons between Landsat and AWiFS scenes corresponding to NAFD sites in "Landsat Data Gap Approach: IRS AWiFS/Spot". Mary Pagnutti of IR2 presented "Assessing and Removing AWiFS Systematic Geometric and Atmospheric Effects to Improve Land Cover Change Detection".

Objective 6: Document results in a brief report

This report documents our research and findings to date.

Year 2 Objectives: (Next steps)

- Order and obtain additional datasets identified in this project.
- Examine differences between AWiFS camera modules.
- Refine and update viewing geometry and solar zenith angle effect on reflectance analysis.
- Coordinate with EDC and the UMd to perform Landsat-AWiFS comparisons.
- Provide briefing materials to NASA headquarters LCLUC program office.
- Attend a LCLUC meeting or meet with the LCLUC program manager in the Washington DC area
- Publish results in a journal paper

Project Staff Interactions

The AWiFS team including UMD, IR2, and US Geological Survey (USGS) EROS Data Center (EDC) has been holding bi-weekly conference calls throughout 2010. This communication allows us to regularly share our research findings and explore different techniques for looking at Landsat and AWiFS comparisons. We will continue these bi-weekly calls throughout Year 2.

Summary

Our research to date suggests that Landsat and AWiFS comparison is promising, but that the potential IFOV differences need to be more fully examined. In addition, there is some evidence that we see a planetary reflectance discrepancy that has been increasing since IRS launch. We are currently exploring the possibility of AWiFS CCD degradation over time. Most research has been done using camera B (B/D quads) as these make up most of the USDA archive. We are currently working with USGS EROS to more fully understand camera A (A/C quads) imagery and to assess radiometry and BRDF analysis for both cameras. We are nearing completion of image pre-processing that will allow substitution of AWiFS imagery into 4 sample NAFD stacks for automated disturbance mapping. We expect initial results for this substitution in early October, which will greatly aid in our understanding of Landsat/AWiFS data comparison.

As the potential Landsat system data gap filler, this type of research is of great interest to NASA and other Federal agencies, such as the USGS, which currently delivers Landsat data and LCLUC products to the nation. In addition, the USDA Foreign Agricultural Service routinely uses AWiFS data in lieu of Landsat data for its agricultural yield predictions. The USDA Forest Service (USFS) is also considering the use of AWiFS data and data from other international systems in a USFS-developed Forest Health Early Warning System to detect forest condition anomalies. The current study may also be of value to NOAA's Coastal Change Analysis Program for assessing coastal LCLUC.

There is also a tie to the Decadal Survey performed by the National Research Council for NASA. International and commercial access to space for terrestrial observations is currently experiencing unprecedented growth. By the year 2010, it is projected that more than 50 imaging satellites with better than 40-m GSD are expected to be operational. Total worldwide investment in new satellite imaging systems easily runs into the billions of dollars. This growth in availability of spaceborne data sources, coupled with U.S. government resource constraints for developing new Earth science missions, will lead to a greater reliance by NASA, NOAA, USDA, USGS, and other agencies on commercial and international data sources.

Many of these new systems are candidates for the Global Earth Observation System of Systems (GEOSS): an international satellite constellation designed to monitor the Earth in a coordinated, comprehensive, and sustained fashion. The GEOSS model intrinsically provides for sharing multisource remote sensing data products within member countries, the European Commission, and participating organizations. Effective use of multisource imagery requires an understanding of both absolute and relative system performance. The need to characterize these data products for use by scientists and high-end users is essential because many systems are not typically calibrated in a manner consistent with or required by the science community. Understanding the data characteristics and operational performance of these systems will be a key component to the success of future remote sensing research using the full array of upcoming systems.

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