GLOBAL LAND SURVEYS FROM LANDSAT OBSERVATIONS: PAST PRESENT AND FUTURE

G. Gutman[a] and J. Masek[b]

[a]NASA Headquarters, Washington, DC 20546, USA – ggutman@nasa.gov
[b]NASA Goddard Space Flight Center, Greenbelt
MD 20771, USA–Jeffrey.G.Masek@nasa.gov

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ABSTRACT:

Land cover is a critical component of the Earth system, influencing land-atmosphere interactions, greenhouse gas fluxes, ecosystem health, and availability of food, fiber, and energy for human populations. Despite 35 years of Landsat observations, there has not been a unified global analysis of land-cover trends nor has there been a global assessment of land-cover change at Landsat-like resolution. Following the Global Land Surveys (GLS) 1975,1990 and 2000, NASA and USGS jointly support development of GLS-2005 and -2010 -- global 30-m spatial resolution data sets based mostly on Landsat data. The GLS-2000, -2005 and the new GLS-2010, which is under development, represent a system of global land datasets for monitoring changes on a 5-year interval, paving the way toward continuous global land-cover monitoring at Landsat-like resolution in the next decade. The ultimate goal is to develop an ongoing, routine, moderate-resolution global record of land-cover changes.

1. INTRODUCTION

Land cover is a critical component of the Earth system, influencing land-atmosphere interactions, greenhouse gas fluxes, ecosystem health, and availability of food, fiber, and energy for human populations. The recent Integrated Global Observations of Land (IGOL) theme report calls for the generation of maps documenting global land cover at resolutions between 10m and 30m at least every five years. Despite 35 years of Landsat observations, there has not been a unified global analysis of land-cover trends nor has there been a global assessment of land-cover change at Landsat-like resolution. Following the Global Land Surveys (GLS) -1975, -1990 and -2000, NASA and USGS jointly support development of GLS-2005 and -2010 to produce global 30-m spatial resolution data sets for the 2004-2007 and 2009-2010 periods based mostly on Landsat data. Going beyond the earlier initiatives, the GLS-2005 and -2010 together with the previous GLS-2000 establish a solid baseline for monitoring changes on a 5-year interval, paving the way toward continuous global land-cover monitoring at Landsat-like resolution in the next decade.

2. HERITAGE DATA SETS

In the late 1990's, NASA's Scientific Data Purchase Program at Stennis Space Center contracted with EarthSat Corporation (now MDA Federal) to create a global, orthorectified set of Landsat imagery to support mapping of land cover (Tucker et al., 2004). This first Landsat GeoCover[TM] data set relied on Landsat-4 and Landsat-5 Thematic Mapper (TM) data, and was nominally centered on 1990, but included imagery from the mid-1980's to the mid-1990's as required. A complementary data set centered on 1975 was produced from Landsat Multispectral Scanner (MSS) imagery. The 1990-era GeoCover[TM] effort was complicated by the fact that not all Landsat-5 data resides within the U.S. satellite archive at USGS EROS. Since Landsat-5 has no onboard recorder,

the only source for TM data outside the U.S. cone of reception is with the International Cooperator (IC) network. Individual IC ground stations supplied Level 1 TM data for the GeoCover[TM] effort.

Following the launch of Landsat-7 in 1999, a follow-on initiative created GeoCover[TM] 2000, a global orthorectified database using ETM+ data from the first two years of Landsat-7 operation. In this case, all necessary Level 1G data were procured from the USGS EROS archive. At the time it was decided that the GeoCover[TM] 2000 data set would be geodetically matched to the 1990 data set in order to provide a basis for assessing land cover change from 1990 to 2000. This did imply, however, that the absolute geodetic accuracy was slightly worse than the 1990-era data set.

Studies conducted by University of Maryland, NASA and by MDA Federal Inc. have indicated that while the GeoCover[TM] product met specified requirements at the block level, individual scenes may exhibit geodetic errors considerably greater than 40-50m. The problem is more acute over mountainous areas or where the data sources that made up GTOPO30 were of poor quality.

Accordingly the GLS-2005 initiative included a reprocessing of the existing GeoCover[TM] data sets to improve their geodetic accuracy. The new, revised GeoCover[TM] product incorporated SRTM digital topography supplemented with DTED 90-m resolution topography in far northern regions outside of SRTM coverage. The NGA geodetic control was supplemented with ~500 Landsat-7 DE scenes to improve accuracy within blocks. The new product improved the geometric properties of the GeoCover[TM] suite, and is used as a geodetic baseline for the GLS-2010 and other future data sets in the GLS series.

3. GLS DATA SETS DEVELOPMENT

The earlier GeoCover[TM] products were produced using a single sensor, either MSS (GeoCover[TM] 1975), TM (GeoCover[TM] 1990), or ETM+ (GeoCover[TM] 2000). In contrast, the GLS-2005 and -2010 incorporate data from multiple sensors, principally Landsat-5 TM and Landsat-7 ETM+, but also EO-1 ALI and Terra ASTER. In part, this reflects the diversity of moderate-resolution land remote sensing satellites currently in orbit. However, this also reflects a necessary accommodation of two major deficiencies of the current Landsat program: the inability to secure global coverage with Landsat-5 TM, and the failure of the Landsat-7 ETM+ Scan Line Corrector (SLC) mechanism in 2003. Although Landsat-7 continues to acquire global coverage, since 2003 ETM+ imagery has been afflicted with cross-track, wedge-shaped gaps that eliminate 22% of the image area. While USGS EROS has implemented techniques to merge ("gap fill") several ETM+ acquisitions from the same season, it was not clear that these products would be suitable for rigorous land-cover change analyses in regions with rapid land-cover changes, such as agricultural lands, and with frequent clouds. Conversely, although Landsat-5 TM is still in service, it is only acquired via direct downlink to the IC to ground receiving stations. The radiometric and geometric properties of Landsat-5 TM imagery are inferior compared to Landsat-7 ETM+. The GLS-2005 and -2010 initiatives use both Landsat-5 and Landsat-7, depending on data availability, cloud cover amount and image quality for any given location.

The GLS approach aims at providing users with one clear image during leaf-on conditions for every location of the global land area. In total, some 9500 Landsat images are included in the GLS-2005 and -2010 data sets, each -- an increase compared to the 1990 GeoCover[TM] (~7000 scenes) and the 2000 GeoCover[TM] (~8200 scenes). This reflects inclusion of Antarctica and additional coastal and island areas not represented in the earlier GeoCover[TM] initiatives. All images have been acquired during the 2004-2007 measurement epoch for GLS-2005 and are being acquired during 2009-2010 for the GLS-2010. While it is not possible to release seasonal coverage for the globe (i.e. multiple images throughout the growing season), multiple Landsat-7 and Landsat-5 images are released for selected areas in tropics, where it is not generally possible to obtain a single cloud-free image during the growing season. These additional Landsat-7 ETM+ images are not gap-filled, but are released individually.

Deciding which image to include in the final GLS data sets must balance several competing factors including:

- ➢ Acquisition date - preference for acquisitions during maximum local vegetation greenness (NDVI), proximity to the mid-point of the epoch, and proximity to GeoCover[TM] 2000 acquisition data to support change detection.

- ➢ Cloud cover – lower cloud cover scores preferred.

- ➢ Gap-fill coverage – for Landsat-7 images, preference for SLC-off pairs that maximize the area coverage obtained by gap-filling.

- ➢ Sensor choice – bias for Landsat-7 ETM+ over clear regions.

- ➢ Geographic uniformity – preference for adjacent images to be acquired from the same time of year.

During the 2004-2007 measurement period, some 500,000 Landsat images have been acquired around the globe. To automate the process of scene selection, a tool to optimize scene selection was developed -- the Large Area Scene Selection Interface (LASSI) (Franks et al., in press).

The LASSI is an algorithm that balances a user-defined weighting system to various parameters that the user wants to consider in scene selection. With supplied metadata, LASSI can quickly and systematically sort through thousands of scenes to select the best overall set to make an area solution. Weightings are relative to each of the other parameters and for the GLS data sets some examples of the parameters that were used to select the scenes were: NDVI of the candidate images, cloud covers scores, difference in acquisition dates of the Landsat-7 pairs, difference of acquisition dates and day of year of scene neighbors, percent of Landsat-7 gaps filled due to scene overlap, preference for selecting scenes acquired in the center of the observational time period, and preference for selecting scenes that were acquired as close as possible, in date, to the corresponding scenes in the previous GeoCover[TM] 2000 global data set.

4. GLS PROCESSING

Although the preferred sensor for GLS data sets is Landsat-7, there are many places on the globe where it is impossible to obtain a cloud-free composite during the growing season. For example, boreal forests have a short green season that is often cloudy, and other times of the year are limited by climate and sun angle. To increase the chances for cloud-free data, Landsat-5 acquisitions were expanded to include campaign ground stations that were willing to downlink the data for contribution to the U.S. Landsat archive at USGS EROS (normally, these data are archived at ground stations and not available to the U.S. archive). While not as extensive as a campaign as initially hoped, cooperation with sites in Russia, Africa, and Central America has expanded considerably the options for GLS scene selection.

GLS-2005 data have been processed to the highest level of accuracy possible, with a targeted relative accuracy of around 30m. The quality of the output scenes depends upon the accuracy of the two major inputs – geometric control and topography. The geometric control is a new global data product, which uses the same input data as GeoCover[TM], but has a lower RMS error, under 30m. From this data, USGS EROS automatically selects ground control points (GCPs) for each scene and uses these as 'truth.'

The Landsat-7 ETM+ data that have been used for GLS-2005 are missing 22 percent of the scene. The gaps appear as horizontal wedges, where the gaps are widest (14 pixels) at the edge of a scene with no gap in the center. These wedges occur in regular intervals. As mentioned above, this is from the SLC failure in the instrument in May 2003. USGS EROS has developed techniques to calculate where these gaps are, and which scenes can be combined to provide complete, or near-complete, coverage. Due to the possibility of time-distance composite pairs, the 'fill' scene is radiometrically adjusted to match the primary scene. If the scenes are acquired with a cycle or two, the radiometric correction needed

is minimal. For GLS-2005, we have limited the time-distance to a maximum of 3 cycles.

After the gaps in the primary scene are filled by the auxiliary scene, a gap percentage is calculated to determine the success of the gap-filling. Scenes can be filled up to 100 percent; however, minor gaps at the edges of the scenes are possible at lower percentages. For GLS-2005, we are limiting the gap-fill percentage to a minimum of 95 percent. After the gap-filling process, a pixel-based raster image, called a 'gap mask,' is created, so that the user can determine which pixels in the final scene were derived from which input scene. More details on GLS processing (Fig. 1) and on the accuracy of the produced dataset are available in Gutman et al. (2008).
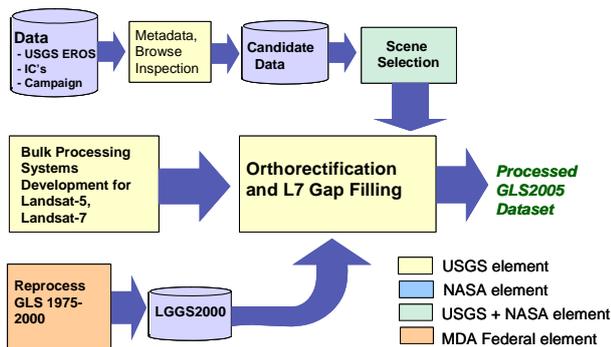
Figure 1. Steps of GLS Processing

In summary, Landsat-5 and Landsat-7 data perform very similarly in the absence of clouds. Gap filling procedure works when cloud cover is not present to impact both the histogram matching procedure and the actual binning of filled pixels. The question is which data source is least affected by undesired atmospheric effects? Since Landsat-5 data are not systematically acquired, an improved compositing procedure with Landsat-7 is considered superior.

CONCLUSION

The GLS-2005 project paved the way for future international activities to provide improved access to moderate-resolution data. The ultimate goal is to develop an ongoing, routine, moderate-resolution global record of land-cover changes. The GLS-2010 initiative includes a strong international component due to a high risk of losing one or both Lansats before the next Landsat (LDCM) is launched. Although recent fuel-life projections suggest that Landsat-5 and -7 could operate beyond 2011 barring failure of any key subsystems, joint international effort under the CEOS Land Surface Imaging Constellation is critical to provide the necessary coverage, thus setting the stage for a global, integrated, international system for moderate-resolution. Finally, as noted above, tremendous opportunities exist for integrating multiple Landsat-type observatories to achieve daily-weekly coverage across broad areas. Sensors, such as the Indian Resourcesat, Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Thailand Earth Observing System (THEOS), Japanese Advanced Visible and Near Infrared Radiometer type (AVNIR), French SPOT-4, China-Brazil Earth Resources Satellite (CBERS-2b) and the upcoming ESA Sentinel-2 missions collectively provide more than enough coverage to establish a routine global monitoring capability. However, to date, only limited progress has been made through CEOS to open access to these data catalogs, and advance data interoperability.

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