

# Towards Monitoring Changes at a Global Scale The Global Land Survey

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## Background

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) report calls for the generation of maps documenting global land cover at resolutions between 10m and 30m at least every five years (Townshend *et al.*, in press). Moreover, 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.

Since the 1990s, the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS) have supported development of data sets based on global Landsat observations (Tucker *et al.*, 2004). These land survey data sets, usually referred to as GeoCover™, provide global, orthorectified, typically cloud-free Landsat imagery centered on the years 1975, 1990, and 2000, with a preference for leaf-on conditions. Collectively, these data sets provided a consistent set of observations to assess land-cover changes at a decadal scale. These data are freely available via the Internet from the USGS Center for Earth Resources Observation and Science (EROS) (see <http://earthexplorer.usgs.gov> or <http://glovis.usgs.gov>). This has resulted in unprecedented downloads of data, which are widely used in scientific studies of land-cover change (e.g., Boone *et al.*, 2007; Harris *et al.*, 2005; Hillbert, 2006; Huang *et al.* 2007; Jantz *et al.*, 2005, Kim *et al.*, 2007; Leimgruber, 2005; Masek *et al.*, 2006).

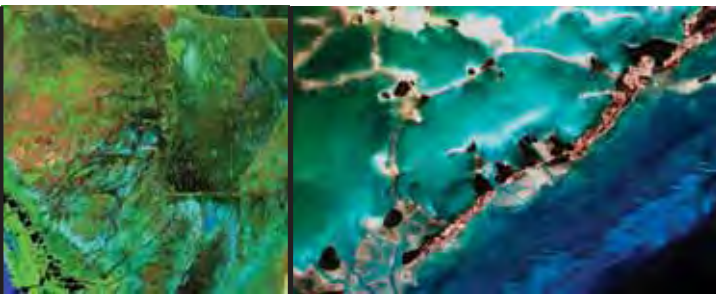
NASA and USGS are continuing to support land-cover change research through the development of GLS2005 - an additional global Landsat assessment circa 2005<sup>1</sup>. Going beyond the earlier initiatives, this data set will establish a baseline for monitoring changes on a 5-year interval and will pave the way toward continuous global land-cover monitoring at Landsat-like resolution in the next decade.

<sup>1</sup> The project described in this report was originally referred to as the Mid-Decadal Global Land Survey (MDGLS) in some documents, but has been renamed Global Land Survey 2005 to establish a consistent naming convention for all of the Landsat global data sets.

Images courtesy of Hassan Parfow, UNEP; Landsat 7 project and EROS Data Center; EROS Data Center; USGS EROS Data Center Satellite Systems Branch; and Scientific Visualization Studio, NASA Goddard Space Flight Center.

# Land-Cover and Land-Use Scale: urvey 2005

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Additionally, with the possibility of a gap in Landsat data continuity before the 2011 launch of the Landsat Data Continuity Mission (LDCM), gathering a global record of current land-cover condition while the Landsat-5 and Landsat-7 observatories are operational is of paramount importance. The project will also provide a prototype for a broader international initiative needed to develop a similar global data set circa 2010 prior to the launch of LDCM.

In this paper we first review the creation of the original Landsat GeoCover™ data sets, and then discuss the activities associated with the current GLS2005 initiative. We conclude by offering a view toward the future, when open access to Landsat and LDCM data will facilitate routine global monitoring of land-cover conditions. Additional information on the project will be made available during the next year on the GLS2005 web site: <http://mdgls.umd.edu/>.

## Heritage Data: the Earthsat GeoCover™ Data Sets

In the late 1990s, NASA's Scientific Data Purchase Program at Stennis Space Center contracted with EarthSat Corporation (now MDA Federal Inc.) to create a global, orthorectified set of Landsat imagery to support mapping of land cover (Tucker *et al.*, 2004). This first Landsat GeoCover™ data set relied on Landsat-4 and Landsat-5 Thematic Mapper (TM) data, and was nominally centered on 1990, but included imagery from the late-1980s to the mid-1990s, in order

to fill 1990 coverage gaps or to provide images with the lowest-available cloud cover. This effort was complicated by the fact that not all Landsat-4 and Landsat-5 data reside within the USGS archive, therefore Landsat International Cooperator (IC) ground receiving stations were contacted to supply Level 1 TM data. A complementary data set centered on 1975 was produced in a similar manner from Landsat Multispectral Scanner (MSS) imagery.

EarthSat Corporation used geodetic control obtained from the National Geospatial-Intelligence Agency (NGA) to orthorectify the 1990-era Landsat TM images. Approximately 600 scenes contained NGA-provided control points to anchor regional "block triangulation solutions" (Dykstra and Storey, 2004). Orthorectification was then performed using the best available digital elevation models (DEMs) from a combination of various sources, including 90-m resolution Digital Terrain Elevation Data (DTED) data and 1-km resolution GTOPO30 data.

A follow-on initiative created a global orthorectified 2000-era GeoCover™ data set using ETM+ data from the first three years of Landsat-7 operations. The USGS selected and pre-processed ETM+ data from the National Satellite Land Remote Sensing Data Archive located at USGS EROS. The 2000 data set was geodetically matched to the 1990 GeoCover™ 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 1990s data set, the 2000 data being registered to

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1990 TM data with relative RMS error of less than 40 m, and an absolute RMS error of less than 64 m.

Several different studies have assessed the accuracy of the 2000 GeoCover™ product. In general, while the 2000 GeoCover™ 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 GTOPO30 DEM was of poor quality.

A Global Land Survey 2000 (GLS2000) dataset is currently being prepared by MDA Federal under contract to the USGS, with funding provided by NASA, USGS, and NGA. The GLS2000 will be processed with terrain correction using Shuttle Radar Topography Mission (SRTM) digital topography supplemented with the best available combination of DTED, National Elevation Dataset (NED), and Canadian Digital Elevation Data (CDED) as required. The original NGA geodetic control will also be supplemented with ~500 Landsat-7 definitive ephemeris scenes to improve accuracy within blocks. The new GLS2000 product, combined with the improved DEMs inputs, will be used to produce new Global Land Surveys for the 1990 and 1975 datasets with improved geometric and topographic properties. This new baseline will be used not only for the GLS2005 products but also for future Landsat products during the next decade.

## GLS2005 Development

### Available Data Sources

The GLS2005 will incorporate data from multiple sensors, principally Landsat-5 TM and Landsat-7 ETM+, but also EO-1 ALI and Terra ASTER as needed. This reflects the diversity of Landsat-like resolution land remote sensing satellites currently in orbit and also represents a necessary accommodation to two major deficiencies in 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) in 2003.

Although Landsat-7 continues to acquire global coverage, post-failure 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, not all researchers agree that these products are suitable for rigorous land-cover change analyses, particularly in regions with persistent cloud cover and rapidly changing seasonal land cover, such as agriculture. Conversely, Landsat-5 TM data have been acquired only via direct downlink to the IC ground receiving stations. Additionally, the radiometric and geometric properties of Landsat-5 TM imagery are inferior compared to Landsat-7 ETM+. The GLS2005 project uses both Landsat-5 and Landsat-7, depending on data availability, cloud cover amount and image quality for any given location.

The GLS2005 working group conducted several studies to evaluate the quality of the gap-filled and radiometrically adjusted ETM+ SLC-off products (USGS, 2003). Only about 60% of the global land can be mapped with relatively cloud-free pairs of Landsat-7 data that can yield good composites. Much of the remaining 40% is being mapped with Landsat-5. In cases where Landsat-5 data are unavailable and ETM+ acquisitions are too cloudy for gap-filling, the best individual Landsat-7 ETM+ SLC-off images are retained without gap filling. During the last two years EO-1/ALI was tasked to collect data over small islands and coral reefs. Terra/ASTER data have been collected over the anticipated gaps in Landsat coverage.

The GLS2005 team was able to cooperate with sites outside of the U.S. to expand our options for GLS2005 scene selection. As with the previous GeoCover™ products, the participation of IC ground stations was solicited. The best Landsat-5 images from IC acquisition regions were added to the pool available for scene selection. Also, during 2006-7 USGS EROS established five additional stations to collect Landsat-5 data over some regions where the IC stations did not exist or were not currently operating. Two ScanEx stations in Russia (in Moscow and Irkutsk) started providing data to USGS in the summer of 2006 and a European Space Agency (ESA) station in Maspalomas, Spain began scene acquisitions that fall. An additional ScanEx station in Magadan, Russia started providing data towards the end of the observational period, i.e. in the end of 2007.

### Scene Selection

The goal of the GLS2005 is to provide one clear image during leaf-on conditions for every location of the global land area between 2004 and 2007, with priority on 2005. In total, some 9,500 Landsat images will be included in the GLS2005 data set, an increase compared to the GLS1990 (~7,000 scenes) and the GLS2000 (~8,200 scenes). This reflects inclusion of Antarctica (to support the International Polar Year) and additional coastal and island areas not represented in the earlier Global Land Surveys.

Out of the nearly 500,000 Landsat images that have been acquired around the globe during 2004-2007, the optimal 9,500 scenes have been selected based on several criteria including acquisition date, cloud cover, gap-fill coverage, sensor choice, and geographic uniformity. The tool used for scene selection – the Large Area Scene Selection Interface (LASSI) developed at NASA Ames Research Center and USGS EROS Center – relies on an innovative global optimization algorithm with a set of user-defined weights for various attributes. With supplied metadata, LASSI can quickly and systematically sort through thousands of scenes to select an optimal set to make an area solution. The details on LASSI are available at <http://lcluc.umd.edu/mdgls/documents.html> and a paper on LASSI for a peer-reviewed journal is being prepared.

### Orthorectification

GLS2005 data are being processed to the highest level of accuracy possible today, with a targeted accuracy of around 30m RMSE relative to the new GLS2000 product evaluated at the per-scene level. The quality of the output scenes depends upon the accuracy of the two major inputs – geometric control and topography. The topographic inputs are vital for correcting the data with respect to features on the Earth. In an effort to match GLS2000 as much as possible, the GLS2005 team uses the same DEM inputs as the GLS2000. Within the United States, NED digital topography will be used, while SRTM data are used for the rest of the globe up to 60 degrees in latitude. In far northern regions ortho-rectification uses either the CDED or DTED topographic data sets. All DEM data used, with the exception of DTED, will be publicly available.

### Gap-filling for Landsat-7

As mentioned earlier, due to the SLC failure, Landsat-7 ETM+ data that will be used for GLS2005 are missing 22% of the scene area. USGS EROS has developed techniques to calculate where these gaps are and which scenes can be combined to provide temporally composited images (see Figure 1). Since selected pairs are acquired from up to three 16-day coverage cycles, the 'fill' scene is radiometrically



Figure 1. Landsat 7 gap-filled scene of Las Vegas, Nevada. Imagery for this scene comes from path 39, row 35 with the Landsat 7 ETM+ base scene acquired June 21st, 2006 and the ETM+ fill scene acquired June 5th, 2006.

adjusted to match the primary scene (Storey *et al.*, 2004). If the scenes are acquired within 1 or 2 16-day cycles, the radiometric correction needed is minimal. For GLS2005, a large majority of the scenes have less than 5 percent residual gap area after filling. After the gap-filling process, a pixel-based raster image - a "gap mask" - is created, so that the user can determine which pixels in the final scene were derived from which input scene.

### Data Format and Distribution

The processing flow of GLS2005 is shown in Figure 2. The GLS2005 scenes will be distributed as uncompressed, individual GEOTIFF band files. In addition, the Landsat-7 ETM+ gap-filled data will be accompanied by the gap mask. The entire data set will be available for FTP distribution via standard USGS EROS distribution portals: Earth Explorer (<http://earthexplorer.usgs.gov>) and the Global Visualization Viewer (GloVis; <http://glovis.usgs.gov>). Batches of scenes will become available to users as they are produced, rather than as regional or continental data sets. Initial Landsat-7 products will be available in early 2008; the complete data set will be finished by the end of 2008.

### Generating Land-Cover Products with GLS Data

Analysis of GLS2005 data will include generation of land-cover and land-cover change products. The NASA 2007 research announcement included a call for the development and prototyping of regional and continental products based on GLS data suite including the newly developed GLS2005. The Food and Agriculture Organization (FAO) Land Cover Classification System (LCCS) was suggested as means for comparison between classifications. Validation using Global Observations of Forest Cover and Land Dynamics (GOF-C-GOLD) regional science networks was also encouraged.

The GLS2005 products will feed into various international regional programs, such as the North American Carbon Project (NACP), the Northern Eurasia Earth Science Partnership Initiative (NEESPI), FAO Forest Resources Assessment (FRA) program 2010, Monsoon Asia Integrated Regional Study (MAIRS) and other regional initiatives. The availability of GLS2005 coverage of all Arctic and Antarctic areas will contribute to the efforts of the International Polar Year.

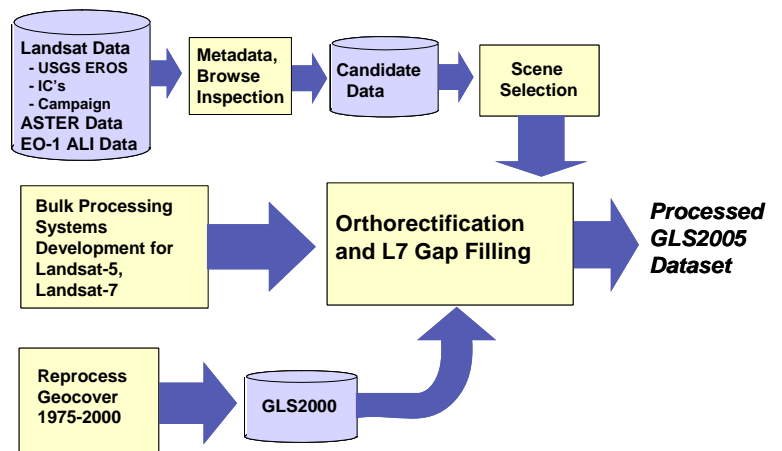


Figure 2. The GLS2005 processing flow.

### Conclusion

The GLS2005 continues the accumulation of a global Landsat-class observation record, following on GLS1975, GLS1990 and GLS2000. These data provide a critical contribution to global monitoring of land-cover change with a spatial resolution of better than 100m and the temporal resolution increasing from decadal to

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5-year interval. These data will permit detailed global and regional assessments of land-cover dynamics including:

- forest-cover change including disturbance and recovery as well as loss through conversion to other cover types such as urban or agriculture;
- agricultural intensification, specifically irrigated agriculture;
- global standing water extent and variability;
- arctic hydrologic changes, including permafrost dynamics, changes in peat lands; and,
- urbanization.

Focusing on these analyses will help meet the needs of society in responding to climate change, food security, and bio-energy availability.

The USGS will provide open and free electronic access to all GLS products. Under a pilot project to prepare for distribution of LDCM data, the USGS is orthorectifying incoming Landsat-7 scenes (beneath a 20% cloud cover threshold) and placing them on servers for user retrieval at no charge. The project began in June 2007 with United States coverage and will expand to global coverage in 2008. In addition, the USGS is working toward a capability wherein users who want historical orthorectified Landsat scenes from the national archive will also be able to select and download them at no charge. This capability will provide a temporally richer data set for future analysis.

A requirement for more frequent than once-in-5-years surveys was stressed at the Annapolis Global Land Survey workshop (Masek, 2007). A continuous global land-imagery survey is anticipated for the LDCM era and beyond, wherein cloud-free or low-cloud-cover images from U.S. and foreign land-imaging satellites will be orthorectified upon receipt by the USGS and posted for electronic retrieval by users at no charge. Also, the Annapolis workshop's conclusion that in some regions multi-season imagery would be preferred for adequate characterization of change is a subject for future improvements in developing a global land monitoring system.

The GLS2005 project paves the way for future international activities to provide improved access to moderate-resolution data. A strategy to improve the interactions between international data providers based on a Land Surface Imaging Constellation concept is currently under development by the Committee on Earth Observation Satellites. The ultimate goal is to develop an ongoing, routine, moderate-resolution global record of land-cover changes, not just intermittent "one time" data sets. Planning for GLS2010 is starting now. Although recent fuel-life projections suggest that Landsat-5 and -7 could operate into 2012 barring failure of any key subsystems, preliminary planning for the 2010 decadal survey is focused on the use of international data sources to provide the necessary coverage, thus setting the stage for a global, integrated, international system for moderate-resolution monitoring.

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