A Landsat Surface Reflectance Dataset for North America, 1990–2000

Jeffrey G. Masek, Eric F. Vermote, Nazmi E. Saleous, Robert Wolfe, Forrest G. Hall, Karl F. Huemmrich, Feng Gao, Jonathan Kutler, and Teng-Kui Lim

***Abstract*—The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center has processed and released 2100 Landsat Thematic Mapper and Enhanced Thematic Mapper Plus surface reflectance scenes, providing 30-m resolution wall-to-wall reflectance coverage for North America for epochs centered on 1990 and 2000. This dataset can support decadal assessments of environmental and land-cover change, production of reflectance-based biophysical products, and applications that merge reflectance data from multiple sensors [e.g., the Advanced Spaceborne Thermal Emission and Reflection Radiometer, Multiangle Imaging Spectroradiometer, Moderate Resolution Imaging Spectroradiometer (MODIS)]. The raw imagery was obtained from the orthorectified Landsat GeoCover dataset, purchased by NASA from the Earth Satellite Corporation. Through the LEDAPS project, these data were calibrated, converted to top-of-atmosphere reflectance, and then atmospherically corrected using the MODIS/6S methodology. Initial comparisons with ground-based optical thickness measurements and simultaneously acquired MODIS imagery indicate comparable uncertainty in Landsat surface reflectance compared to the standard MODIS reflectance product (the greater of 0.5% absolute reflectance or 5% of the recorded reflectance value). The rapid automated nature of the processing stream also paves the way for routine high-level products from future Landsat sensors.**

***Index Terms*—Atmospheric correction, Landsat, remote sensing.**

I. Introduction

THE analysis of land-cover change and disturbance across large areas remains a central goal for Earth Science research. Changes in vegetation patterns affect Earth's climate, by altering albedo, evapotranspiration, and carbon exchange with the atmosphere [1]–[3]. At the same time, many land-cover changes (such as deforestation and agricultural expansion) directly reflect alteration of ecosystems by human populations, with clear impacts on biodiversity and ecosystem health. It is well known that monitoring land-cover change requires high-resolution imagery ($\sim$ 30-m resolution or better) in order to accurately quantify areas and rates of change [4]. For these reasons, the Global Climate Observing System (GCOS) has called for routine analysis of global land-cover patterns at 30-m resolution every five years.

Such an ambitious goal requires rapid, automated approaches to preprocessing and analyzing high-resolution remote sensing datasets. The National Aeronautics and Space Administration (NASA) has taken the first step toward this goal by procuring the Landsat GeoCover product from Earth Satellite Corporation as part of the Science Data Purchase program. The GeoCover dataset is a global collection of orthorectified, mostly cloud-free Landsat imagery, centered on 1975, 1990, and 2000 epochs [5]. Actual image acquisition dates may vary depending on data availability, but for North America most acquisitions date from 1987–1992 for the 1990-epoch coverage, and 1999–2001 for the 2000-epoch coverage. Since the data have been georegistered and orthorectified (to a geodetic accuracy of $\sim$ 60 m), this product partly supports decadal change-detection applications. However, no radiometric processing was attempted for the GeoCover product beyond normal Landsat Level 1G processing.

The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) project was funded in 2004 to assemble a record of ecosystem disturbance for North America, using the Landsat GeoCover product, in support of the upcoming North American Carbon Program (NACP) [6]. As part of that effort, the LEDAPS team has calibrated and atmospherically corrected the 1990 and 2000 GeoCover product for North America. These data, comprising some 2100 Landsat Thematic Mapper (TM) and Enhanced TM Plus (ETM+) scenes, are available for download from the LEDAPS web site.[1] The new surface reflectance dataset should help researchers more easily use the GeoCover data for tracking land-cover changes in North America, including fire, forest harvest, urbanization, woody encroachment, and changes in agriculture. The purpose of this letter is to document the processing approach used to create the North American surface reflectance product, present initial studies of its accuracy and precision, and illustrate relevant applications of the product.

II. LEDAPS Reflectance Processing Objectives

The processing goals for the LEDAPS surface reflectance product flowed from the overall goal of mapping disturbance across North America. It was decided that radiometric change-detection methods (as opposed to comparisons of classified imagery) would yield best results. To facilitate change detection, it was also decided to correct each image to directional surface reflectance, a physically based measure of land-surface properties that can be compared with similar observations from MODIS and other Earth Observation System (EOS) instruments. Since

Manuscript received May 26, 2005; revised July 5, 2005.

J. G. Masek, N. E. Saleous, R. Wolfe, F. Gao, J. Kutler, and T.-K. Lim are with the Biospheric Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA (e-mail: jeffrey.g.masek@nasa.gov).

E. F. Vermote is with the University of Maryland, College Park, MD 20742 USA and also with the NASA Goddard Space Flight Center, Greenbelt, MD 20771 USA.

F. G. Hall and K. F. Huemmrich are with the University of Maryland Baltimore County, Baltimore, MD 21250 USA.

Digital Object Identifier 10.1109/LGRS.2005.857030

[1]http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html

the Landsat instruments always acquire imagery within $\pm 7.5^\circ$ of nadir, variation in the bidirectional reflectance distribution function (BRDF) from changing view angles was not a concern. However, the GeoCover images were acquired at various points in the growing season, and changes in both phenology and BRDF (from Sun angle variations) do result.

III. Processing Description

The LEDAPS project reused the MODAPS software architecture developed at the NASA Goddard Space Flight Center (GSFC) for producing higher level products from MODIS Level 1B data [7]. In this architecture, low-level data (digital numbers, or DN) are ingested (using HDF-EOS file formats), calibrated to at-sensor radiance, atmospherically corrected to surface reflectance using the 6S approach [8], [9], and then composited, gridded, and/or reprojected as required. Higher level products (such as forest disturbance maps) may then be created from the surface reflectance datasets.

A. Ingest and Calibration

Landsat GeoCover data products were ingested from the University of Maryland Global Land Cover Facility via FTP. Level 1G ETM+ data were calibrated to at-sensor radiance (watts per square meter per steradian per micron) using the published coefficients from the Landsat-7 online Science User's Handbook (http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html; see also [10]). The calibration procedure for Landsat-5 TM GeoCover images was more involved. Landsat-5 TM products produced from the NLAPS processing system at the Canada Centre for Remote Sensing or the U.S. Geological Survey EROS Data Center before May 2003 were calibrated using scene-specific onboard calibrator lamp brightness values. These values, which vary considerably from day to day, probably reflect a long-term degradation in sensor performance superposed on short-term, random variations in lamp output. Immediately after the launch of Landsat-7 in 1999, an underfly experiment allowed both Landsat-7 ETM+ and Landsat-5 TM to simultaneously image the same terrain. With this added control, the Landsat-5 TM historic calibration was revised in 2003 to use a simple exponential decay model [11], [12]. Since the 1990-epoch GeoCover products were processed to Level 1G during 1998–2000, they were originally calibrated using the "old," lamp-based calibration. For LEDAPS, we used the averaged daily lamp brightness history to remove the original, erroneous calibration, and then applied the revised calibration coefficients for the appropriate image acquisition date.

Calibrated images were then corrected to top-of-atmosphere (TOA) reflectance by correcting for solar zenith, Sun–Earth distance, TM or ETM+ bandpass, and solar irradiance (using the MODTRAN solar output model). Landsat TOA reflectance products were output in HDF-EOS format, and may be downloaded from the LEDAPS web site.

B. Atmospheric Correction

Atmospheric correction seeks to compensate for scattering and absorption of radiance by atmospheric constituents, yielding an accurate estimate of surface reflectance. The Landsat surface reflectance product is derived from TOA reflectance by applying an atmospheric correction scheme that assumes that: 1) the target is Lambertian and infinite and 2) the gaseous absorption and particle scattering in the atmosphere can be decoupled. The TOA reflectance can be expressed as

$$\rho_{\mathrm{TOA}} = T_g(\mathrm{O_3}, \mathrm{O_2}, \mathrm{CO_2}, \mathrm{NO_2}, \mathrm{CH_4}) \times \left[\rho_{R+A} + T_{R+A} T_g(\mathrm{H_2O}) \frac{\rho_s}{1 - S_{R+A}\rho_s}\right] \quad (1)$$

where ρ_s is the surface reflectance, T_g is the gaseous transmission due to the gases listed between parentheses, T_{R+A} is Rayleigh and aerosol transmission, ρ_{R+A} is the Rayleigh and aerosols atmospheric intrinsic reflectance, and S_{R+A} is the Rayleigh and aerosols spherical albedo. The transmission, intrinsic reflectance, and spherical albedo terms are computed using the 6S radiative transfer code [8]. Ozone concentrations are derived from Total Ozone Mapping Spectrometer (TOMS) data aboard the Nimbus-7, Meteor-3, and Earth Probe platforms. The gridded TOMS ozone products are available at a resolution of 1.25° longitude and 1.00° latitude from the NASA GSFC Data Active Archive Center (DAAC). In cases where TOMS data are not available (e.g., 1994–1996), NOAA's Tiros Operational Vertical Sounder (TOVS) ozone data are used. Column water vapor is taken from NOAA National Centers for Environmental Prediction (NCEP) reanalysis data available at a resolution of $2.5^\circ \times 2.5^\circ$ (http://dss.ucar.edu/datasets/ds090.0/). Digital topography (1 km GTopo30) and NCEP surface pressure data are used to adjust Rayleigh scattering to local conditions.

V. Discussion: Dataset Applications and Future Directions

The LEDAPS surface reflectance dataset for North America supports multiple uses, including mapping of land-cover, decadal land-cover change, surface water resources, and vegetation biophysics. The conversion to reflectance specifically allows users to cross-compare Landsat observations to laboratory or ground-measured spectral curves, reflectance data from other instruments (ASTER, MODIS, MISR), or the output from canopy reflectance models. None of these techniques was feasible with the original GeoCover dataset. In particular, the cross-comparison between MODIS and Landsat supports scaling studies that seek to understand how radiometric and biophysical properties derived at MODIS resolution (500–1000 m) scale to Landsat resolution (30 m).

In the long term, the LEDAPS exercise points the way toward fully operational atmospheric correction of Landsat-type imagery. Such an approach has already been pioneered by the ASTER science team as part of the EOS program, for a limited set of "on-demand" requests. Since 1972, the Landsat program has never had a standard physical product associated with the mission—only calibrated digital numbers. It is reasonable to expect that data centers, running LEDAPS-like processing systems, could produce a range of standard land science products based on surface reflectance imagery from future Landsat sensors. Such an effort would make routine the seemingly ambitious goal of updating the world's knowledge of land-cover characteristics every five years.