LEDAPS: A Satellite-Based Disturbance Map for North America

Landsat Ecosystem Disturbance Adaptive Processing System

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http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html

Executive Summary

LEDAPS is processing archival Landsat imagery (1975-2000) for North America to generate continental maps of:

- *Surface Reflectance*
- *Forest cover change, disturbance, and recovery*

on a decadal basis, in support of the North American Carbon Program. While this project is concentrating on wall-to-wall analysis of spatial patterns, a related project (Goward et al NACP) is focusing on image time-series analysis to assess disturbance trends for ~25 sample sites across the United States.

Landsat MSS, TM, and ETM+ data centered on 1975, 1990, and 2000 have been assembled and orthorectified as part of the EarthSat GeoCover product. These data are being atmospherically corrected and radiometrically rectified to a consistent surface reflectance (SR) product. Change-detection algorithms are then applied to identify disturbance and recovery trajectories at ~30 meter resolution. To date, ~2200 TM and ETM+ scenes have been processed to reflectance, via reuses of the MODIS MODAPS processing system at NASA GSFC.

Gridded products will be distributed to support carbon modeling, agricultural, and forestry applications. Initial SR products for all North America are available for download, as are "beta" forest disturbance products for the Mid-Atlantic region. The full North America disturbance product will be available during mid-2006.

Reflectance Processing Approach

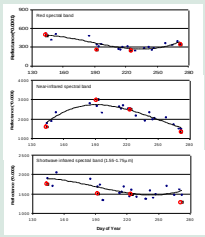
Landsat TM and ETM+ data are calibrated, and then atmospherically corrected to surface reflectance using the MODIS/6S radiative transfer approach. Aerosol optical thickness is estimated from each image using the Kaufman "dark dense vegetation" method, based on the empirical correlation of shortwave (2.2 micron) and blue reflectance for vegetated targets. Ozone and water vapor estimates are taken from TOMS and NCEP reanalysis grids, respectively.

Comparisons with simultaneous MODIS reflectance imagery indicate uncertainties (σ) in the LEDAPS product are of the same magnitude as those of the MODIS reflectance product (σ ~ the greater of 0.8p or 0.005 absolute reflectance). We also note, however, that Landsat-5 TM data show greater frequency of negative reflectance values, possibly resulting from uncertainties in sensor calibration. Older MSS data cannot be atmospherically corrected due to poor calibration and the lack of a shortwave band. Instead we will use the Hall et al (1991) radiometric rectification approach to rectify these data to corresponding Landsat-5 TM reflectance imagery.

Current research is focusing on improvements to the reflectance processing chain, including:

- Corrections for adjacency effect (scattered path radiance derived from outside the IFOV)
- Improved cloud / cloud shadow masking
- Additional validation using vicarious targets (e.g. tarps of known reflectance) coupled with high-resolution imagery (Ikonos, Quickbird)

Example of Landsat-7 ETM+ visible composite imagery before (top) and after (bottom) LEDAPS/6S atmospheric correction.



Time series of surface reflectance data from Saskatchewan, Canada (WRS-2 path 37, row 22), showing correspondence between MODIS (blue) and Landsat-7 (red circle) retrievals for three different wavelengths.

Disturbance Mapping Algorithms

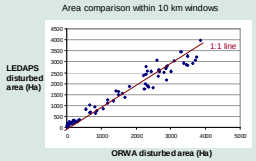
Our goal is to map stand-clearing disturbance events (harvest, crown fires, major mortality events). Two algorithms are being developed through LEDAPS:

- A semi-empirical "Disturbance Index"
- A physically-based approach integrating canopy reflectance modeling

The Disturbance Index (DI) , originally published by Healey et al (2005), is a spectral index recording the distance (in tasseled cap space) between a given observation and a pre-defined "forest" class. Within LEDAPS, the "forest class" is obtained for each scene by using the MODIS VCF %treecover product in combination with Landsat NDVI. For LEDAPS, the per-pixel change in DI value is evaluated using 1990 and 2000 imagery. Strong increases in DI value represent likely disturbance events; strong decreases represent early recover from previous disturbances.

The physically-based approach correlates retrieved Landsat SR values with a "family" of solutions derived from the GeoSail canopy reflectance model. Each solution corresponds to a unique set of canopy properties. Changes in canopy properties (e.g. canopy cover, LAI, etc) can then be interpreted in terms of forest disturbance events.

Mapping harvest patterns, Olympic Peninsula, Washington. Landsat images from 1988 and 2000 were converted to Disturbance Index trends (center right). White represent increased DI values (disturbance); dark colors represent decreased DI values (early regrowth). These values are then thresholded and filtered for non-forest changes to produce a final disturbance/regrowth map (right)



Comparison of LEDAPS decadal disturbance estimate with that prepared from the Oregon-Washington (ORWA) dataset of Cohen et al. (2002), based on semi-annual Landsat image analysis. Evaluated within 10km windows, the LEDAPS estimate is capturing ~90% of the total disturbed area.

Initial Results

Landsat-7 imagery from Olympic Peninsula, Washington, together with LEDAPS disturbance map, showing the preponderance of forest harvest outside of Olympic National Park (dark line). Other State and National Forests are shown in orange and blue, respectively

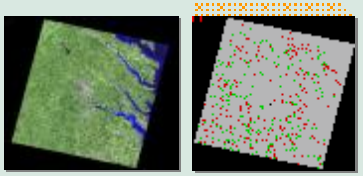
Landsat-7 RGB image of Southern Quebec showing the region near Baie Comeau. In 1991 a complex of large fires burned 2800 km2 to the west of Baie Comeau, and forced the evacuation of the town of Ragueneau. In addition to these fire scars, the LEDAPS map also shows logging along the north coast of the St. Lawrence and in the Notre Dame mountains (southeast part of the image).

A preliminary version of the Disturbance Index algorithm has been run for all 1990-2000 TM/ETM+ pairs in North America – example disturbance/recovery products shown to the right. The results illustrate many "zero order" aspects of North American forest disturbance. High rates of clear-cutting in the U.S. Southeast, St. Lawrence region, and Pacific Northwest stand out. Fire scars across the Boreal zone are captured as localized high rates of disturbance. The algorithm still requires a number of improvements, including:

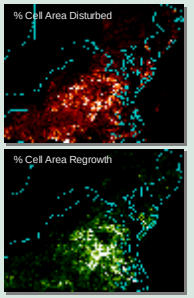
- tuning algorithm thresholds by ecoregion – errors are particularly evident in the Rockies, where disturbance is underrepresented due to sparse canopy cover, and in some areas of the southeast, where seasonal changes in flooded forests may are included erroneously.
- replacement of some "out of season" imagery with alternate sources (e.g. MRLC)
- improved masking of agricultural regions to eliminate errors of commission ("false" disturbance due to cropping patterns)

As products are produced, a separate validation effort is quantifying their accuracy. Three approaches are being used for validation:

- Comparison with FIA data: both county-level and re-measured plot-level data from the US Forest Service Forest Inventory and Analysis (FIA) program are being compared with LEDAPS products.
- Image analysis: visual analysis of temporally-dense Landsat timeseries is being used to quantify the extent to which the decadal LEDAPS maps are missing some disturbance events, and to calibrate the regrowth parameter in terms of stand age. Air photos are used to assess area accuracy
- LTER/Experimental Forests: Local sites with known disturbance history can be compared to the LEDAPS record.



Imagery from Central Virginia, marking the northernmost zone of southeastern "industrial" forestry. Clear cuts occur in naturally regenerated mixed hardwood stands, as well as planted pine.



Preliminary 1/20th degree resolution "modeling grids" showing the percent of each cell mapped as disturbed (top) and regrowing (bottom) during the 1990-2000 interval for the Mid-Atlantic region. LEDAPS gridded products are being produced at resolutions of 30m (UTM projection), 500m (Lambert projection), and 1/20 degree.

Application to Carbon Assessments

LEDAPS will give estimates of the area disturbed per unit time for the 1975-1990 and 1990-2000 epochs, or equivalently, the mean turnover time of forest stands within these periods. This information can assist carbon assessments using multiple approaches:

- Carbon Stocks Accounting: Knowing the mean regional "yield" of stand biomass as a function of age, the disturbance products can be converted to a net change in biomass (change in carbon stocks) by balancing regrowth and disturbance areas.
- Biogeochemical Flux Modeling: The disturbance products can be used to constrain demographic models of stand age. By modeling the specific, regional evolution of NPP and Rh as a function of stand age, net ecosystem productivity may be estimated

LEDAPS Schedule

North American Landsat reflectance products for 1990 and 2000 have been released, and can be downloaded from the LEDAPS web site: http://ledaps.nascom.nasa.gov/ledaps/ledaps_NorthAmerica.html. The 1975-era MSS reflectance data will be available by late-2006

"Beta" disturbance products for the Mid-Atlantic are currently available. The initial continental data set for 1990-2000 will be released in mid-2006. Subsequent releases (2007) will focus on extending the record to 1975-1990, and obtaining direct estimates of canopy changes via integration of canopy reflectance models.

Acknowledgements

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