Using Satellite Imagery to Track Forest Disturbances

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January 24, 2014

Great Smoky Mountains Institute at Tremont
Visit to ORNL
Oak Ridge, Tennessee, USA
The USDA Forest Service, NASA Stennis Space Center, and DOE Oak Ridge National Laboratory are creating a system to monitor threats to U.S. forests and wildlands at two different scales:

- **Tier 1: Strategic** — The ForWarn system that routinely monitors wide areas at coarser resolution, repeated frequently — a *change detection system* to produce alerts or warnings for particular locations may be of interest.

- **Tier 2: Tactical** — Finer resolution airborne overflights and ground inspections of areas of potential interest — *Aerial Detection Survey (ADS)* monitoring to determine if such warnings become alarms.

Tier 2 is largely in place, but Tier 1 is needed to optimally direct its labor-intensive efforts and discover new threats sooner.
Design Plan for the *ForWarn* Early Warning System

Data Fusion

- Data from several sources are combined to create custom data sets.

GIS

- The GIS acts as a front end for data preparation and user interaction as well as a backend for visualizing discovered knowledge.

Knowledge Discovery

- This process extracts knowledge/observable characteristics from the information generated by data analysis.

Knowledge Library

- A catalog of the knowledge/observable characteristics is accumulated and used for threat monitoring.

Data Preparation

- Data are converted from the GIS to formats required by data analysis tools.

Data Analysis

- Supervised/unsupervised learning methods are used to extract meaningful patterns from the data.

User Interface

- A web-based/standalone user interface is provided for human interaction with the system.

Threat Monitoring

- Detection of conditions indicative of or conducive to cataloged threats triggers a ‘forest threat verification event’ alert.

Archive of historical climate and biological data

Remote sensing

Site surveys

Other data sources

Current Climate Data

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References
Normalized Difference Vegetation Index (NDVI)

- NDVI exploits the strong differences in plant reflectance between red and near-infrared wavelengths to provide a measure of “greenness” from remote sensing measurements.

\[
NDVI = \frac{(\sigma_{\text{nir}} - \sigma_{\text{red}})}{(\sigma_{\text{nir}} + \sigma_{\text{red}})}
\]

- These spectral reflectances are ratios of reflected over incoming radiation, \( \sigma = \frac{l_r}{l_i} \), hence they take on values between 0.0 and 1.0. As a result, NDVI varies between −1.0 and +1.0.

- Dense vegetation cover is 0.3–0.8, soils are about 0.1–0.2, surface water is near 0.0, and clouds and snow are negative.
The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra (EOS AM, N→S) and Aqua (EOS PM, S→N) satellites. Both view the entire surface of Earth every 1 to 2 days, acquiring data in 36 spectral bands. The MOD 13 product provides Gridded Vegetation Indices (NDVI and EVI) to characterize vegetated surfaces. Available are 6 products at varying spatial (250 m, 1 km, 0.05°) and temporal (16-day, monthly) resolutions. The Terra and Aqua products are staggered in time so that a new product is available every 8 days. Results shown here are derived from the 8-day Terra+Aqua MODIS product at 250 m resolution, processed by NASA Stennis Space Center.
Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate.

ForWarn is interested in deviations from the “normal” seasonal cycle of vegetation growth and senescence.

NASA Stennis Space Center has developed a new set of National Phenology Datasets based on MODIS. Outlier/noise removal and temporal smoothing are performed, followed by curve-fitting and estimation of descriptive curve parameters.

Up-looking photos of a scarlet oak showing the timing of leaf emergence in the spring (Hargrove et al., 2009).

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MODIS Snapshots by Season

- **Fall**: October 17, 2012
- **Winter**: January 7, 2013
- **Spring**: April 20, 2013
- **Summer**: June 14, 2013

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Annual Greenness Profile Through Time
To detect vegetation disturbances, the current NDVI measurement is compared with the normal, expected baseline for the same location.

Substantial decreases from the baseline represent potential disturbances.

Any increases over the baseline may represent vegetation recovery.

Maximum, mean, or median NDVI may provide a suitable baseline value.

June 10–23, 2009, NDVI is loaded into blue and green; maximum NDVI from 2001–2006 is loaded into red (Hargrove et al., 2009).
Three Hurricanes

Computed by assigning 2006 20% left value to green & blue, and 20% left from 2004 to red (Hargrove et al., 2009). Red depicts areas of reduced greenness, primarily east of storm tracks and in marshes.
Arkansas Ozarks Ice Storm, Jan. 26–29, 2009

ForWarn is a forest change recognition and tracking system that uses high-frequency, moderate resolution satellite data to provide near real-time forest change maps for the continental United States that are updated every eight days. Maps and data products are available in the Forest Change Assessment Viewer at http://forwarn.forestthreats.org/fcav/
ForWarn researchers get EVEREST-sized look at woodland disturbances

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Geospatiotemporal Data Mining

Geographic Space

Data Space

ForWarn Clustering Phenoregions

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Clustering MODIS NDVI into Phenoregions

- Hoffman and Hargrove previously used $k$-means clustering to detect brine scars from hyperspectral data (Hoffman, 2004) and to classify phenologies from monthly climatology and 17 years of 8 km NDVI from AVHRR (White et al., 2005).

- This data mining approach requires high performance computing to analyze the entire body of the high resolution MODIS NDVI record for the continental U.S.

- >87B NDVI values, consisting of $\sim$146.4M cells for the CONUS at 250 m resolution with 46 maps per year for 13 years (2000–2012), analyzed using $k$-means clustering.

- The annual traces of NDVI for every year and map cell are combined into one 327 GB single-precision binary data set of 46-dimensional observation vectors.

- Clustering yields 13 phenoregion maps in which each cell is classified into one of $k$ phenoclasses that represent prototype annual NDVI traces.
50 Phenoregions for year 2012 (Random Colors)
50 Phenoregion Prototypes (Random Colors)

Phenology Centroid Prototypes (phendump.2000-2012, k = 50)

Cluster 11
Cluster 49
Cluster 15
Cluster 48
Cluster 31
Cluster 16
Cluster 47
Cluster 20
Cluster 35
Cluster 33
Cluster 22
Cluster 24
Cluster 27
Cluster 4
Cluster 42
Cluster 29
Cluster 3
Cluster 38
Cluster 7
Cluster 30
Cluster 21
Cluster 2
Cluster 10
Cluster 40
Cluster 5
Cluster 23
Cluster 13
Cluster 43
Cluster 19
Cluster 41
Cluster 1
Cluster 50
Cluster 46
Cluster 9
Cluster 26
Cluster 39
Cluster 14
Cluster 12
Cluster 25
Cluster 8
Cluster 45
Cluster 6
Cluster 18
Cluster 36
Cluster 28
Cluster 37
Cluster 32
Cluster 44
Cluster 34
Cluster 17
Cluster 2
Cluster 10
Cluster 40
Cluster 5
Cluster 23
Cluster 13
Cluster 43
Cluster 19
Cluster 41

NDVI

day of year

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50 Phenoregions Persistence

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Using Satellite Imagery to Track Forest Disturbances
50 Phenoregions Mode (Random Colors)
50 Phenoregions Max Mode (Similarity Colors)

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This research was sponsored by the U.S. Department of Agriculture Forest Service, Eastern Forest Environmental Threat Assessment Center (EFETAC) and the U.S. Department of Energy Biological and Environmental Research (BER) program. This research used resources of the Oak Ridge Leadership Computing Facility at Oak Ridge National Laboratory, which is managed by UT-Battelle, LLC, for the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.
