Developing U.S. Phenoregions from Remote Sensing and the Award-Winning *ForWarn* System

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The USDA Forest Service, NASA Stennis Space Center, DOE Oak Ridge National Laboratory, and DOI Eros Data Center have created a system to monitor threats to U.S. forests and wildlands:

- **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 was in place and managed by the USDA Forest Service, but Tier 1 was 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."
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.

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

- These spectral reflectances are ratios of reflected over incoming radiation, \( \sigma = \frac{I_r}{I_i} \), 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.
MODIS MOD13 NDVI Product

- 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).
Annual Greenness Profile Through Time
MODIS Snapshots by Season – Walker Branch

Fall October 17, 2012

Winter January 7, 2013

Spring April 20, 2013

Summer June 14, 2013
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/
Geospatiotemporal Data Mining

Geographic Space

Data Space

Descriptive variables become axes of the data space. Map cell values become coordinates for the respective axis.

Perform multivariate non-hierarchical statistical clustering.

Group map cells with similar values for these descriptive variables.

Reassemble map cells in geographic space and color them according to their cluster number.
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 $\sim146.4M$ 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)


NDVI

day of year

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50 Phenoregions Persistence
50 Phenoregions Max Mode (Random Colors)
50 Phenoregions Max Mode (Similarity Colors)
50 Phenoregions Max Mode (Similarity Colors Legend)

Month of Year

Principal Component Loading

-0.2 -0.1 0.0 0.1 0.2 0.3

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

PC1

PC2

PC3

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National Phenological Ecoregions (2000–2011)

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Jump to 50 National Phenoregions
Jump to 100 National Phenoregions
Jump to 200 National Phenoregions
Jump to 500 National Phenoregions
Jump to 1000 National Phenoregions
Jump to 5000 National Phenoregions

50 Most-Different National Phenological Ecoregions (2000–2011)
ForWarn researchers get EVEREST-sized look at woodland disturbances

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ForWarn Awards

- **2012 Director's Science Delivery Award** (September 2012)
  Dr. Robert Doudrick, Station Director of the USDA Forest Service Southern Research Station

- **2013 Interagency Partnership Award** (December 2012)
  National Federal Laboratory Consortium (FLC) for Technology Transfer (plus congratulatory letters from Secretary of Energy Ernie Moniz and Secretary of Agriculture Thomas Vilsack)

- **2012 Most Distinguished Scientific or Technical Contribution Award** (December 2012)
  ORNL Computer Science & Mathematics Division (CSMD)

- **2012 Partnership Award** (March 2013)
  Southeast Regional Federal Laboratory Consortium (FLC) for Technology Transfer

- **NASA Group Achievement Award** (August 2013)
  Charles Bolden, NASA Administrator

- **2013 Southern Research Station Director’s Award for Partnerships** (December 2013)
  Dr. Robert Doudrick, Station Director of the USDA Forest Service Southern Research Station

- **Pending: 2013 Chief’s Honor Award** (March 17, 2014 in Washington, DC)
  Thomas L. Tidwell, Chief, USDA Forest Service
New U.S. Forest Change Assessment Viewer (FCAV)

Examples with Phenoregions and Masking:
- Southwest Georgia with Agriculture Mask
- Southwest Georgia
- Urban
- 200 Phenoregions
- 200 Phenoregions with Agriculture Mask
- Northern Mississippi Cropland Data Layer and 50 Phenoregions with Agriculture Mask
- Northern Mississippi 50 Phenoregions with Agriculture Mask
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References

