Using Satellite Imagery to Track Forest Disturbances

Forrest M. Hoffman[†‡], Jitendra Kumar[‡], William W. Hargrove*

[†]University of California - Irvine, [‡]Oak Ridge National Laboratory, and *USDA Forest Service

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Great Smoky Mountains Institute at Tremont Visit to ORNL

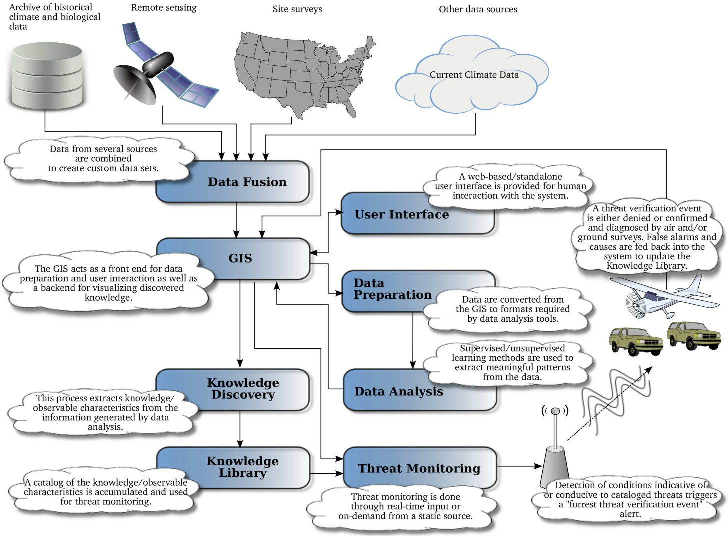
Oak Ridge, Tennessee, USA

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



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.

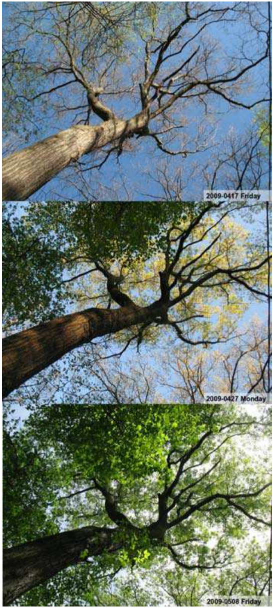
$$\text{NDVI} = \frac{(\sigma_{\text{nir}} - \sigma_{\text{red}})}{(\sigma_{\text{nir}} + \sigma_{\text{red}})} \quad (1)$$

- These spectral reflectances are ratios of reflected over incoming radiation, $\sigma = I_r/I_i$, 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

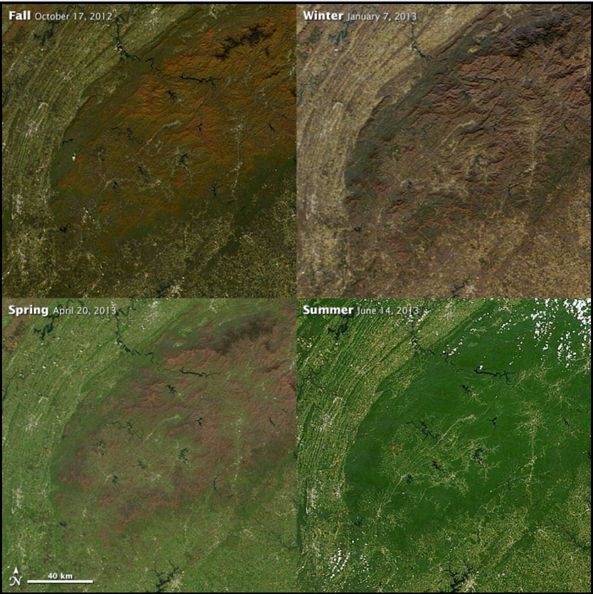
- The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra (EOS AM, N$\rightarrow$S) and Aqua (EOS PM, S$\rightarrow$N) satellites.
- Both view the entire surface of Earth every 1 to 2 days, acquiring data in 36 spectral bands.
- The MOD 13 product provides Gridded 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.

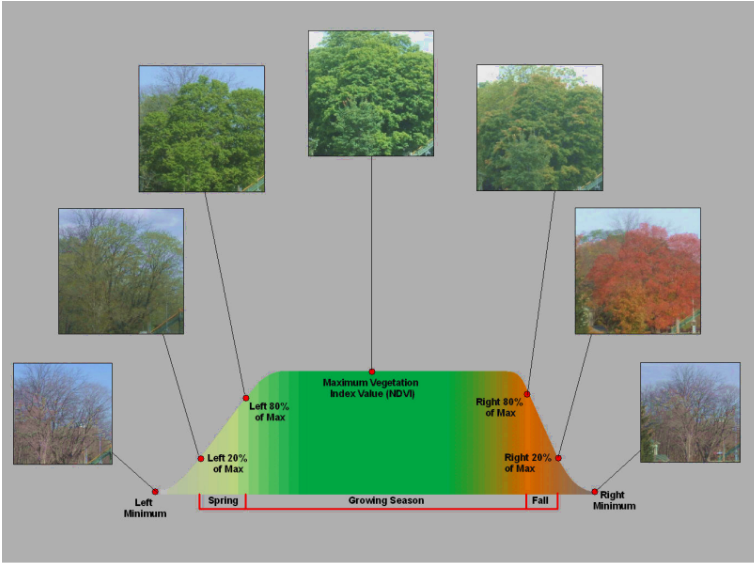


Up-looking photos of a scarlet oak showing the timing of leaf emergence in the spring (Hargrove et al., 2009).

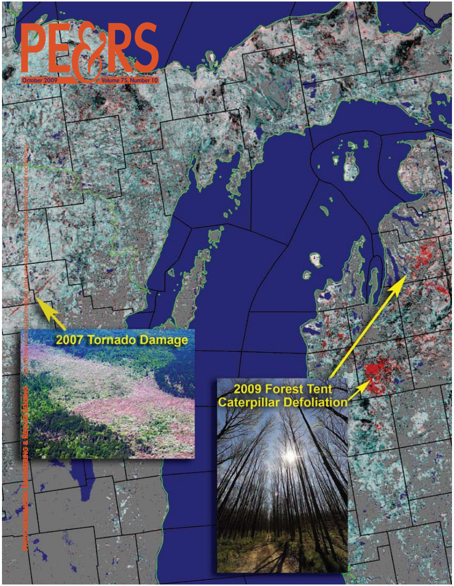
MODIS Snapshots by Season



Annual Greenness Profile Through Time

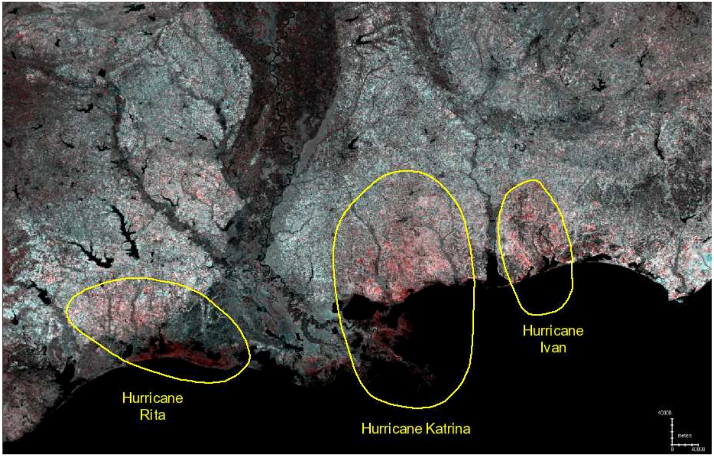


- To detect vegetation disturbances, the current NDVI measurement is compared with the normal, expected baseline for the same location.
- Substantial decreases from the baseline represent potential disturbances.
- Any increases over the baseline may represent vegetation recovery.
- Maximum, mean, or median NDVI may provide a suitable baseline value.



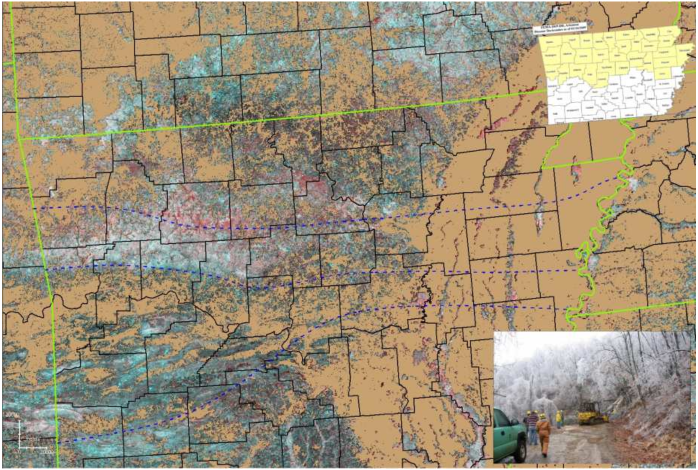
June 10–23, 2009, NDVI is loaded into blue and green; maximum NDVI from 2001–2006 is loaded into red (Hargrove et al., 2009).

Three Hurricanes

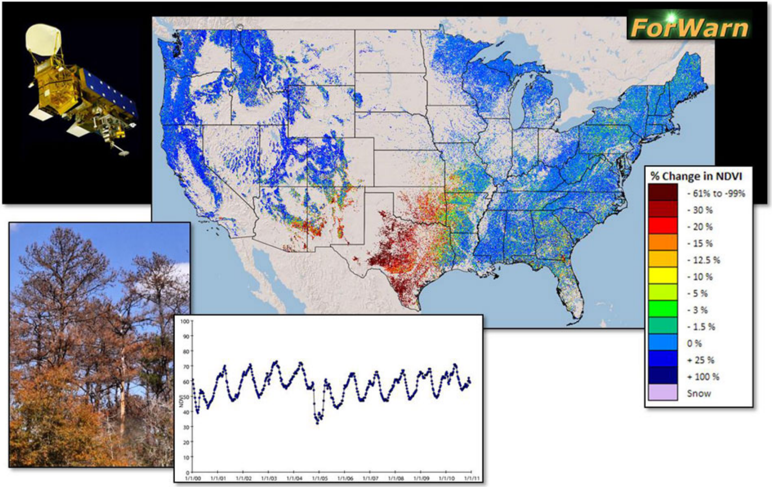


Computed by assigning 2006 20% left value to green & blue, and 20% left from 2004 to red (Hargrove et al., 2009). Red depicts areas of reduced greenness, primarily east of storm tracks and in marshes.

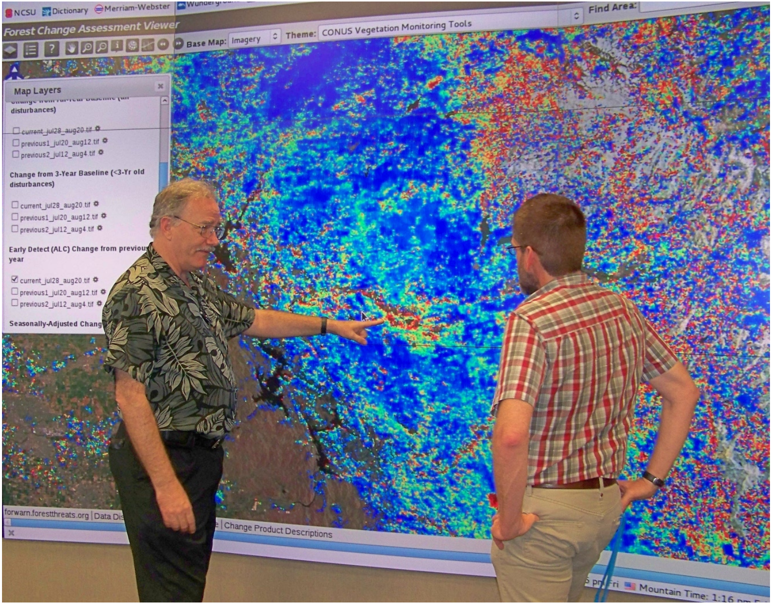
Arkansas Ozarks Ice Storm, Jan. 26–29, 2009



Computed by assigning 2009 max NDVI for June 10–July 15 into blue & green, and 2001–2006 max NDVI for June 10–July 27 into red. Storm resulted in 35,000 without power and 18 fatalities.

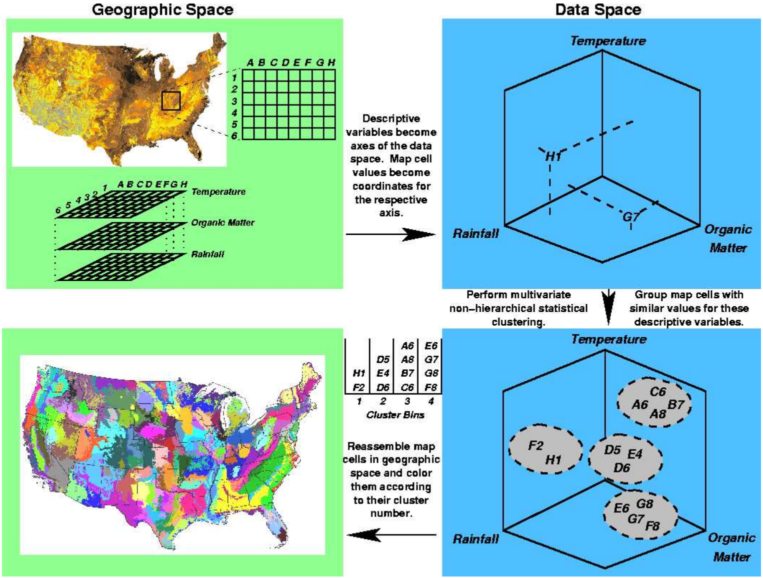


ForWarn is a forest change recognition and tracking system that uses high-frequency, moderate resolution satellite data to provide near real-time forest change maps for the continental United States that are updated every eight days. Maps and data products are available in the **Forest Change Assessment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



ForWarn researchers get EVEREST-sized look at woodland disturbances

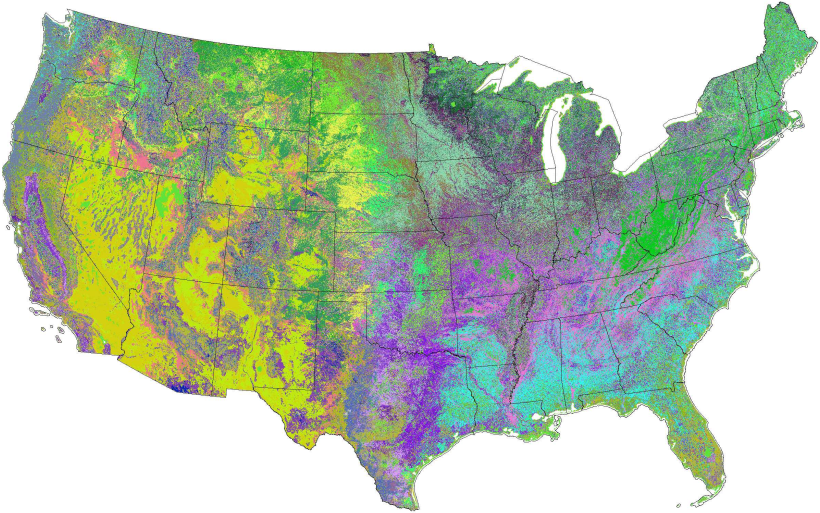
Geospatiotemporal Data Mining



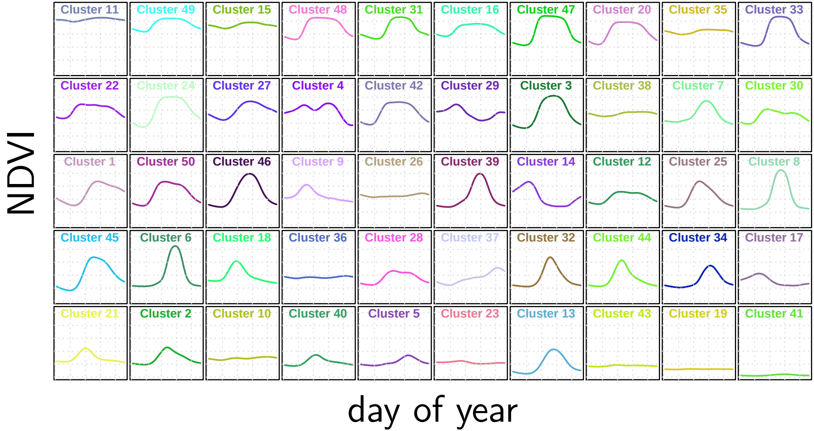
Clustering MODIS NDVI into Phenoregions

- 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.

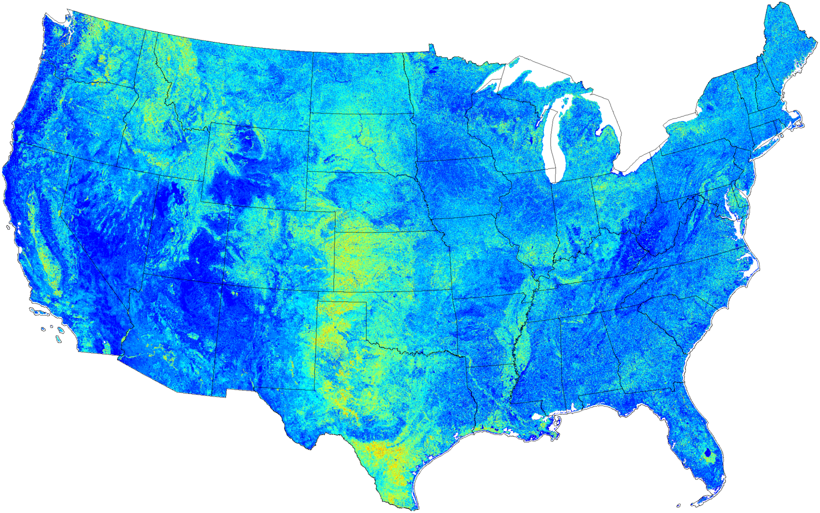
50 Phenoregions for year 2012 (Random Colors)



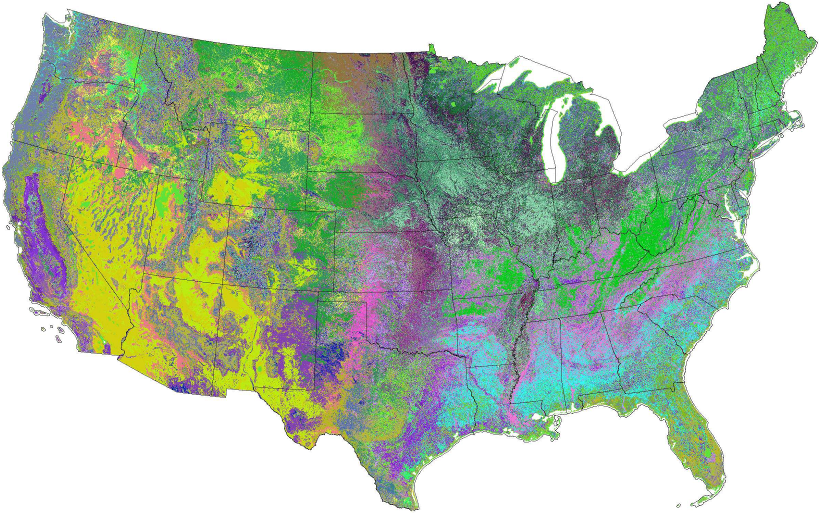
50 Phenoregion Prototypes (Random Colors)



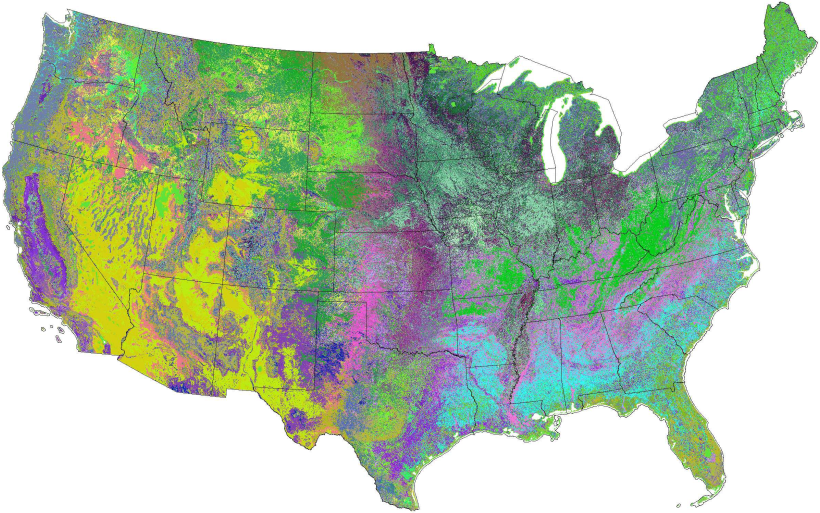
50 Phenoregions Persistence



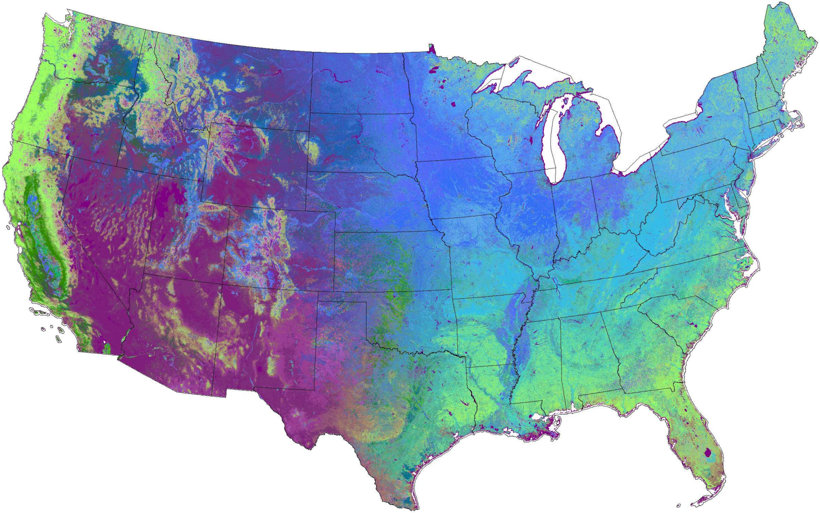
50 Phenoregions Mode (Random Colors)



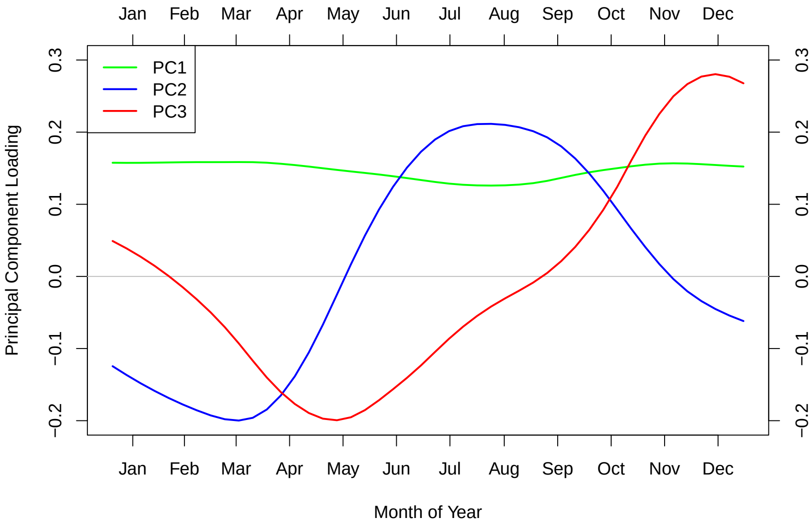
50 Phenoregions Max Mode (Random Colors)



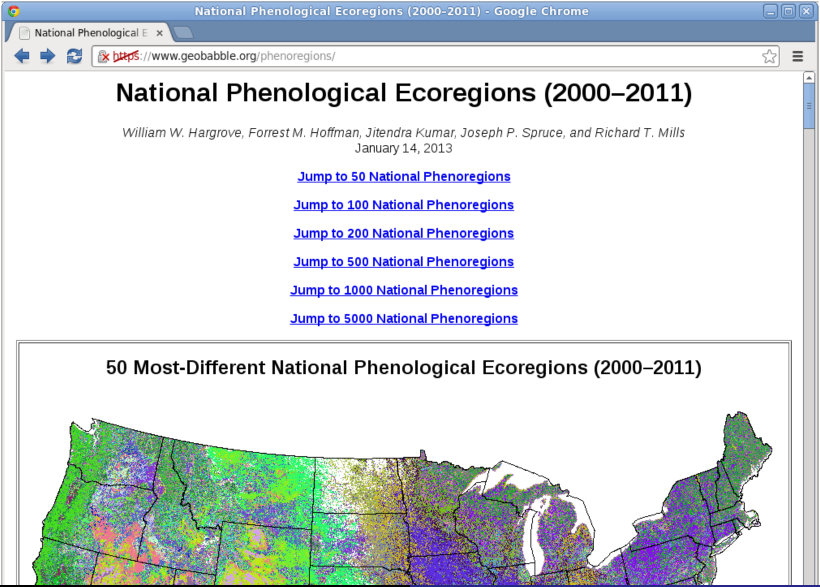
50 Phenoregions Max Mode (Similarity Colors)



50 Phenoregions Max Mode (Similarity Colors Legend)



Phenoregions Clearinghouse



National Phenological Ecoregions (2000–2011)

William W. Hargrove, Forrest M. Hoffman, Jitendra Kumar, Joseph P. Spruce, and Richard T. Mills
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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)

Acknowledgments

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References

William W. Hargrove, Joseph P. Spruce, Gerald E. Gasser, and Forrest M. Hoffman. Toward a national early warning system for forest disturbances using remotely sensed phenology. *Photogramm. Eng. Rem. Sens.*, 75(10): 1150–1156, October 2009.

Forrest M. Hoffman. Analysis of reflected spectral signatures and detection of geophysical disturbance using hyperspectral imagery. Master's thesis, University of Tennessee, Department of Physics and Astronomy, Knoxville, Tennessee, USA, November 2004.

Michael A. White, Forrest Hoffman, William W. Hargrove, and Ramakrishna R. Nemani. A global framework for monitoring phenological responses to climate change. *Geophys. Res. Lett.*, 32(4): L04705, February 2005. doi: 10.1029/2004GL021961.