

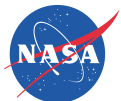
# Geospatiotemporal Data Mining in an Early Warning System for Forest Threats in the United States

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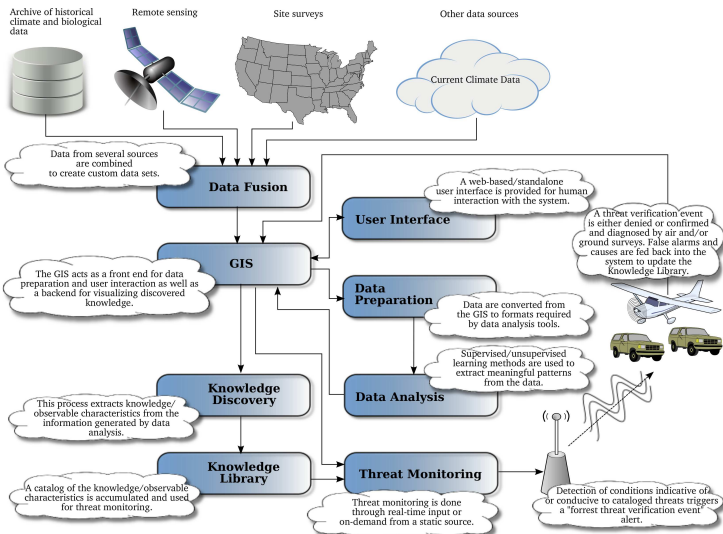


The USDA Forest Service, NASA Stennis Space Center, and DOE Oak Ridge National Laboratory are creating a system to monitor threats to U.S. forests and wildlands at two different scales:

- **Tier 1: Strategic** — An Early Warning System (EWS) 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.

# Overview of the Forest Incidence Recognition and State Tracking (FIRST) 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

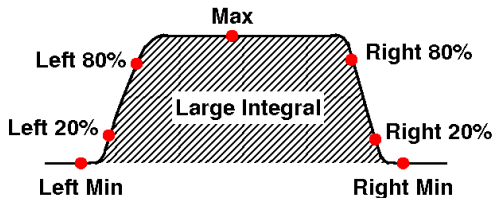
- The Moderate Resolution Imaging Spectroradiometer (MODIS) is a key instrument aboard the Terra (EOS AM, N→S) and Aqua (EOS PM, S→N) satellites.
- Both view the entire surface of Earth every 1 to 2 days, acquiring data in 36 spectral bands.
- The MOD 13 product provides Gridded Vegetation Indices (NDVI 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 16-day Terra 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.
- FIRST 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).



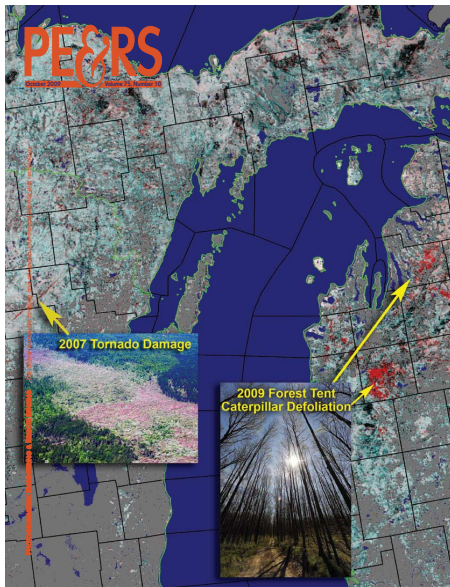
# Idealized Phenology Curve



- An idealized seasonal NDVI curve is fit through data for each MODIS cell, and seven parameters are extracted.
- Each parameter results in two maps: one for the NDVI value and one for the time of the event.
- Cumulative NDVI shows the annual “greening” of the U.S.
- The Large Integral is strongly correlated with annual gross primary production (GPP) of the conterminous U.S. (CONUS).

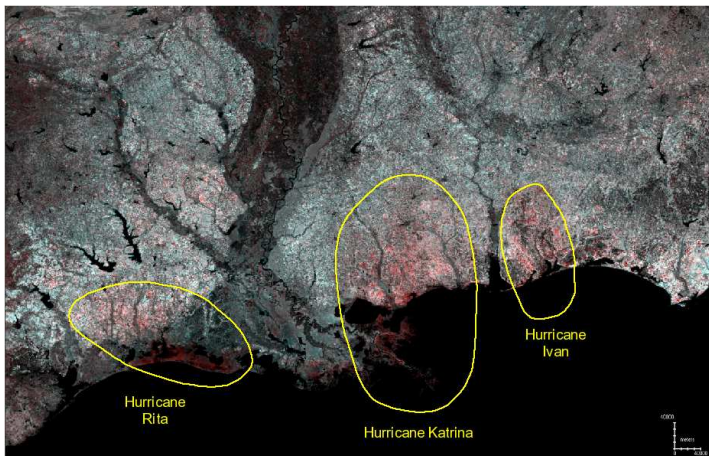
- To detect vegetation disturbances, the current NDVI measurement is compared with the normal, expected baseline for the same location.
- Substantial decreases from the baseline represent potential disturbances.
- Any increases over the baseline may represent vegetation recovery.
- Maximum, mean, or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



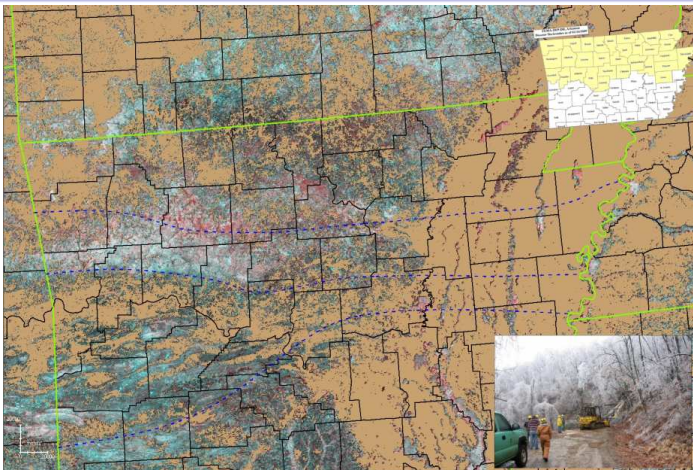


# Three Hurricanes



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

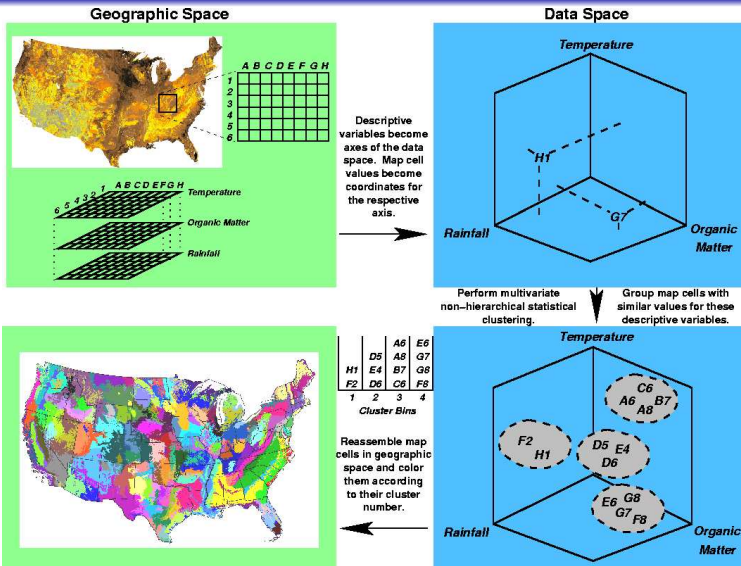


Computed by assigning 2009 max NDVI for June 10–July 15 into blue & green, and 2001–2006 max NDVI for June 10–July 27 into red. Storm resulted in 35,000 without power and 18 fatalities.

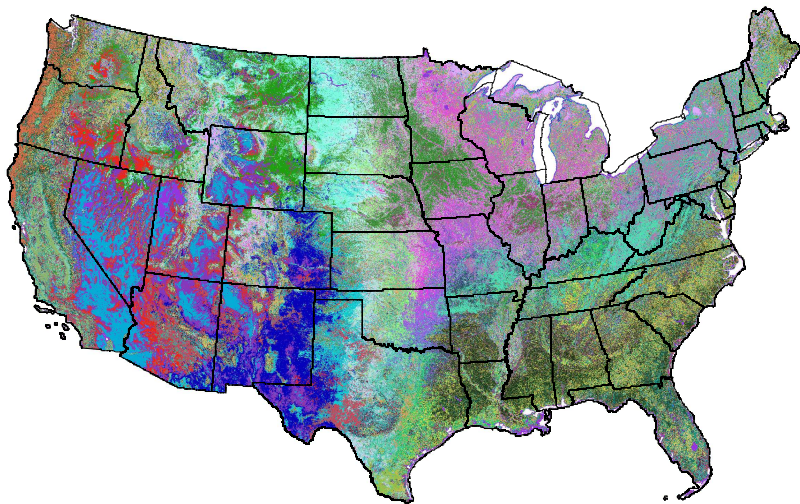
# Data Mining for Change Detection

- Map arithmetic on selected parameters is good for studying the impact of known disturbances, but what is desired is an automated, unsupervised change detection system.
- A data mining approach, utilizing high performance computing (HPC) for the entire body of the very large, high resolution NDVI data history, appears to be the best approach.
- Hoffman and Hargrove previously employed a highly scalable *k*-means algorithm to automatically detect brine scars from hyperspectral remote sensing data (Hoffman, 2004) and for land surface phenology from monthly climatology and 17 years of 8 km NDVI from AVHRR (White et al., 2005).
- For only the current MODIS NDVI data for six years (2003–2008), 22 maps per year, at 250 m over the CONUS, single-precision data exceed 77 GB, requiring HPC resources.

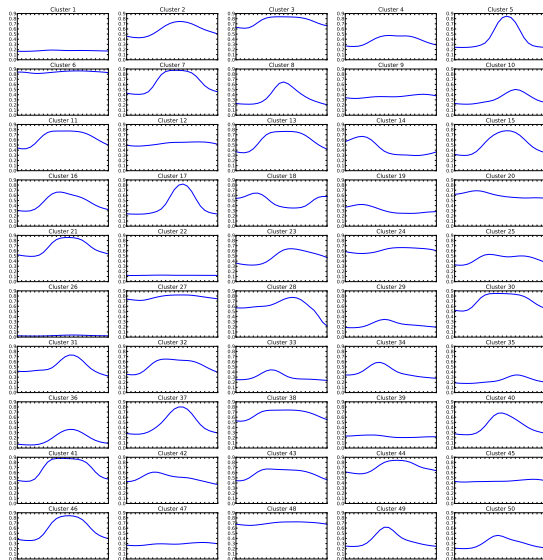
# Geospatiotemporal Data Mining



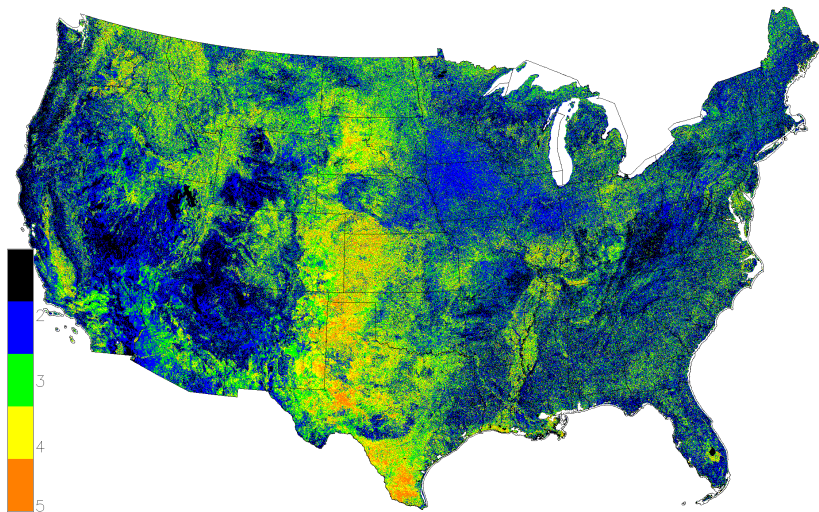
# 50 Phenoregions for Year 2008 (Clustering 2003–2008)



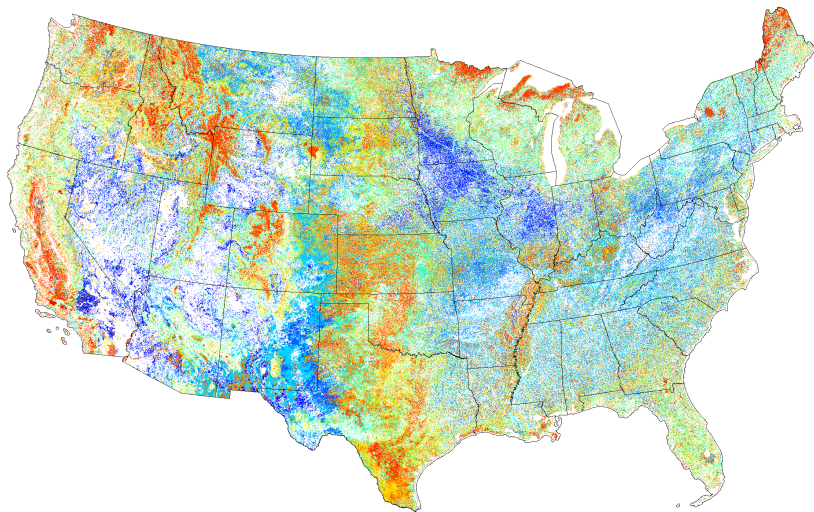
# 50 Phenoregion Prototypes



# Cluster Persistence Map (2003–2008)

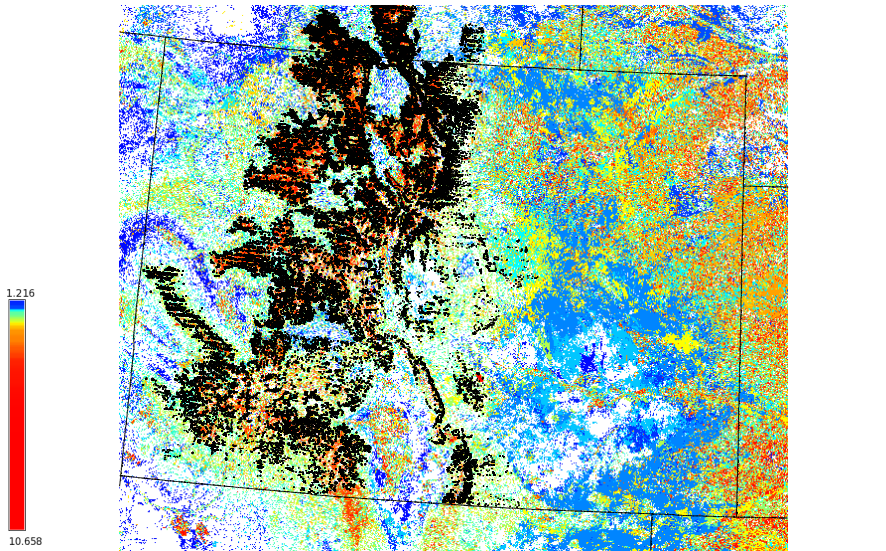


# Cluster Transition Distances for (2008 – 2003)





# Mountain Pine Beetle in Colorado for (2008 – 2003)



# Conclusions and Future Work

- Initial results of geospatiotemporal cluster analysis of phenology from MODIS NDVI are promising, suggesting such analysis will be a key component in the FIRST early warning system.
- The enhanced, accelerated  $k$ -means clustering algorithm enables the analysis of very large, high resolution remote sensing data.
- Determining “normal” phenological patterns is difficult—due to interannual climate variability, spatially variable climate change trend, and relatively short satellite record—mortality events, like progressive Mountain Pine Beetle damage, are easily detected.
- The next step is to establish biome-specific thresholds based on interannual variability, obtain validation from ADS and ground surveys, and track and accumulate both loss and new growth for carbon accounting.
- Future work will build a library of phenostate transitions attributed to pests or pathogens for individual biomes, allowing the system to hypothesize about causes of future disturbances detected.

# Acknowledgments

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