Statistical approach for detection of natural disturbances in forest ecosystems using remotely sensed phenology

Jitendra Kumar[1], Forrest M. Hoffman[1], William W. Hargrove[2], Richard T. Mills[1], William M. Christie[2], Joseph P. Spruce[3], Steve P. Norman[2]

[1]Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA,
[2]Eastern Forest Environmental Threat Assessment Center, USDA Forest Service, Southern Research Station, Asheville, NC 28804, USA,
[3]Computer Sciences Corp, NASA Stennis Space Center, Stennis, MS 39529, USA

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Disturbances in Forest Ecosystems

- Knowledge of changes in forest cover is essential for sustainable management of forest ecosystems.
- Changes in Forests can be cause by:
  - Natural disturbances: invasive species, diseases/pests, wildfires, extreme weather events (hurricanes, ice storms), climate change etc.
  - Human induced disturbances and management activities: air/water/soil pollution, real estate development, timber harvest etc.
- Our objective is to continuously monitor and track national scale forest vegetation health and status using remote sensing.

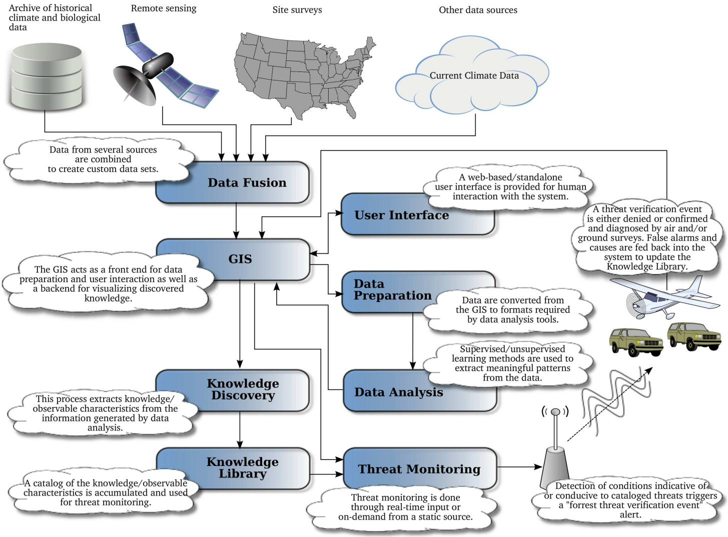
The USDA Forest Service, NASA Stennis Space Center, and DOE Oak Ridge National Laboratory are creating a system to monitor threats to U.S. forests and wildlands at two different scales:

- 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.

ForWarn: Forest Monitoring and Assessment System

http://forwarn.forestthreats.org/



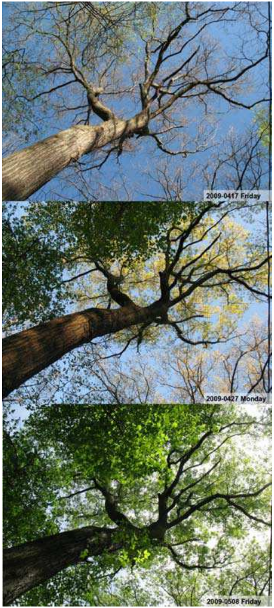
Normalized Difference Vegetation Index (NDVI)

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

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

- 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.

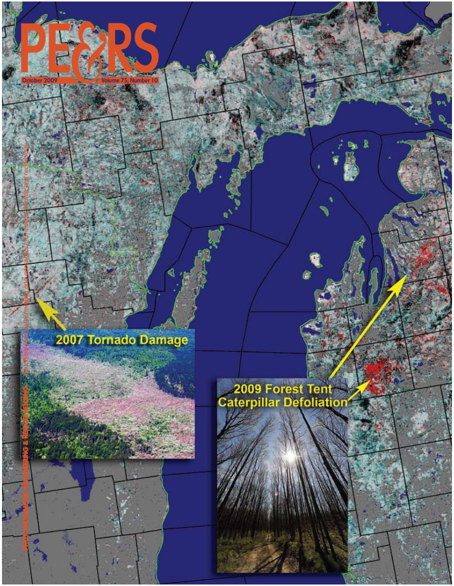
- Phenology is the study of periodic plant and animal life cycle events and how these are influenced by seasonal and interannual variations in climate.
- **ForWarn** is interested in deviations from the "normal" seasonal cycle of vegetation growth and senescence.
- NASA Stennis Space Center has developed 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.



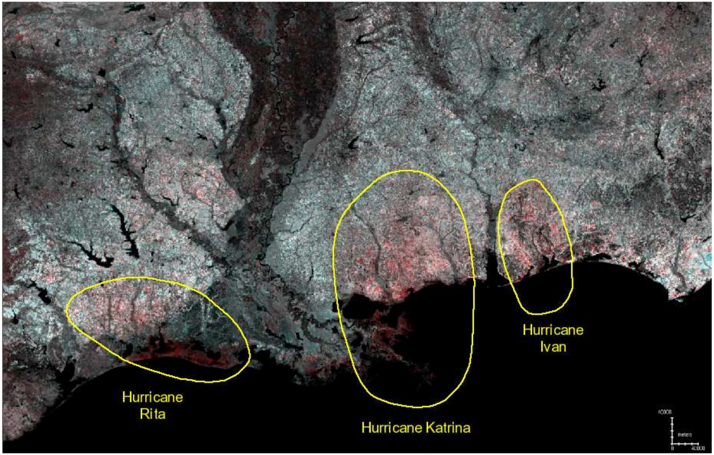
Up-looking photos of a scarlet oak showing the timing of leaf emergence in the spring [Hargrove et al., 2009].

- 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.

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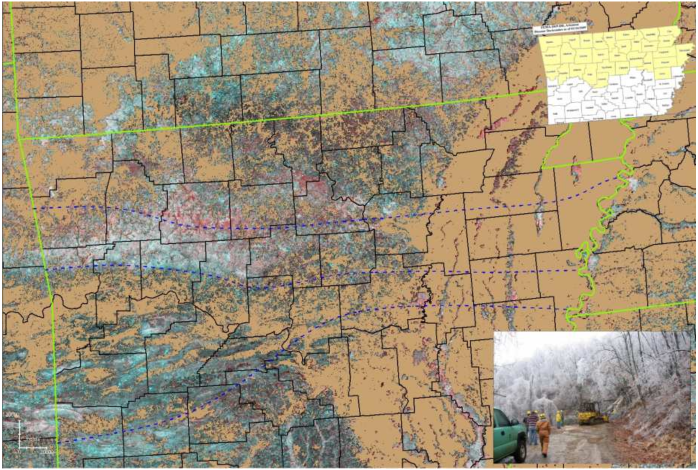
Arkansas Ozarks Ice Storm, Jan. 26–29, 2009

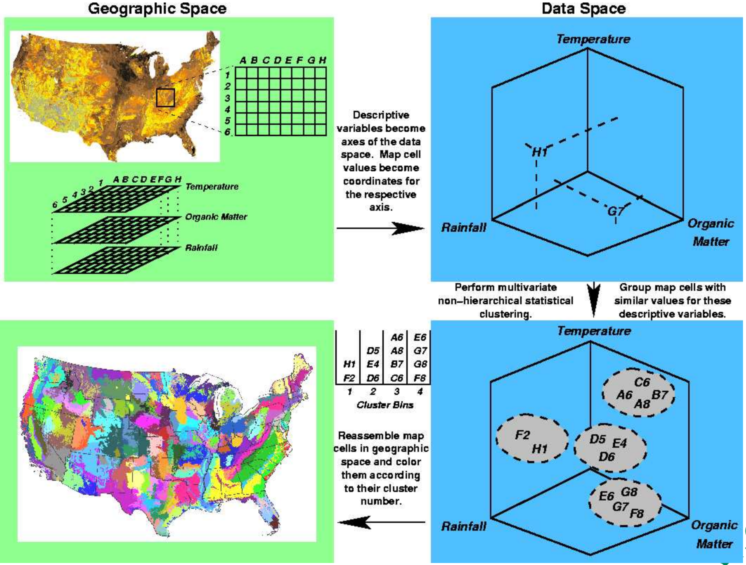


Computed by assigning 2009 max NDVI for June 10–July 15 into blue & green, and 2001–2006 max NDVI for June 10–July 27 into red. Storm resulted in 35,000 without power and 18 fatalities.

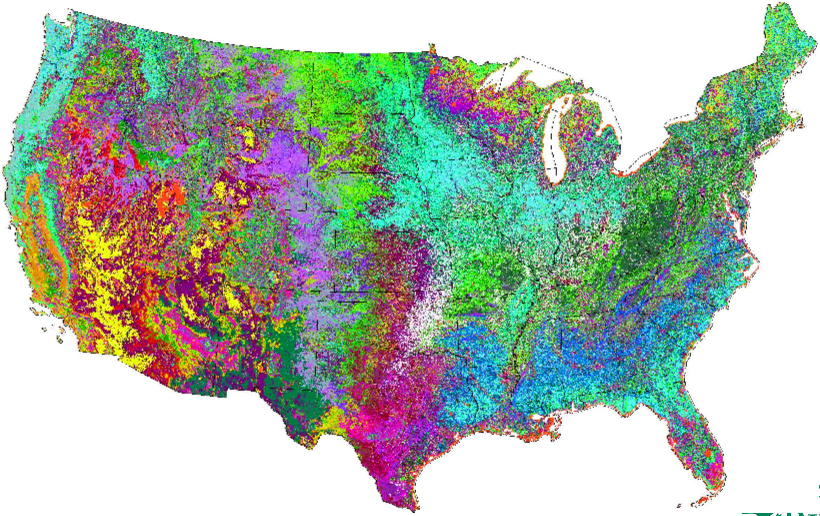
Data Mining for Change Detection

- 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 ([Mills et al., 2011]).
- 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 11 years (2000–2010), 46 maps per year, at 250 m over the CONUS, single-precision data exceed 276 GB, requiring HPC resources ([Kumar et al., 2011]).

Geospatiotemporal Data Mining



50 Phenoregions for Year 2010 (Random Colors)



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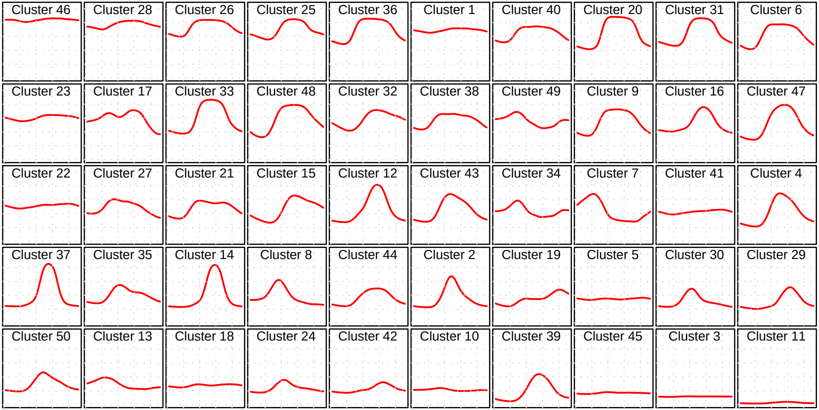
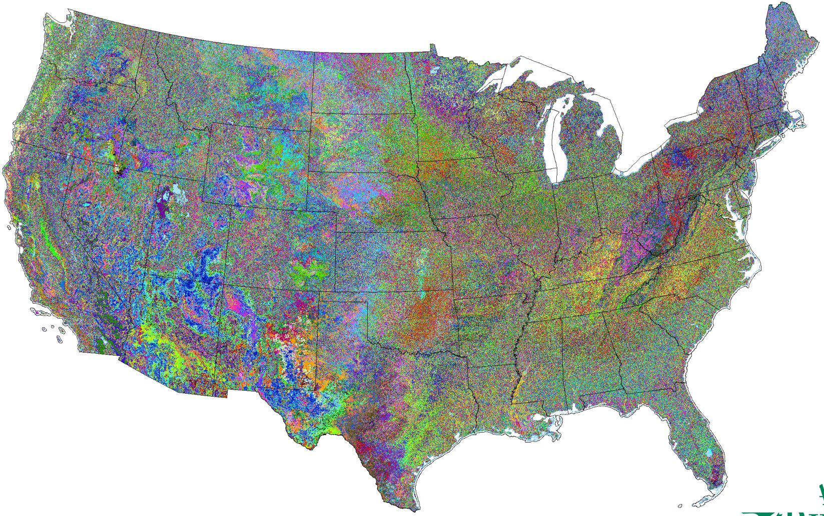
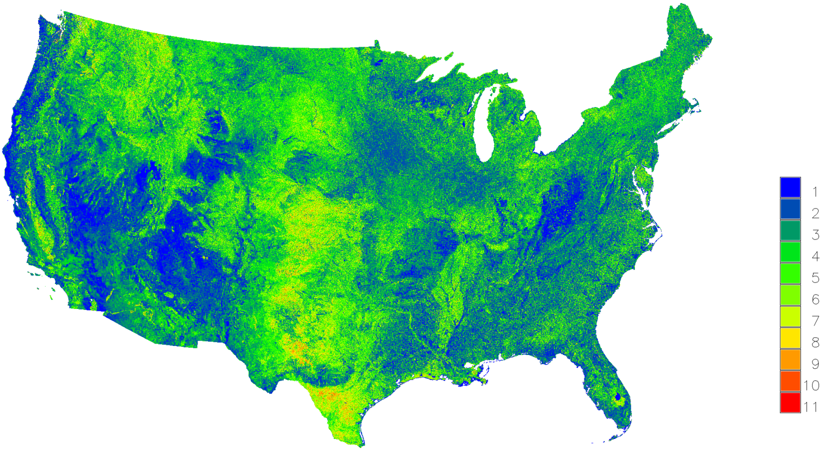
50 Phenoregion Prototypes



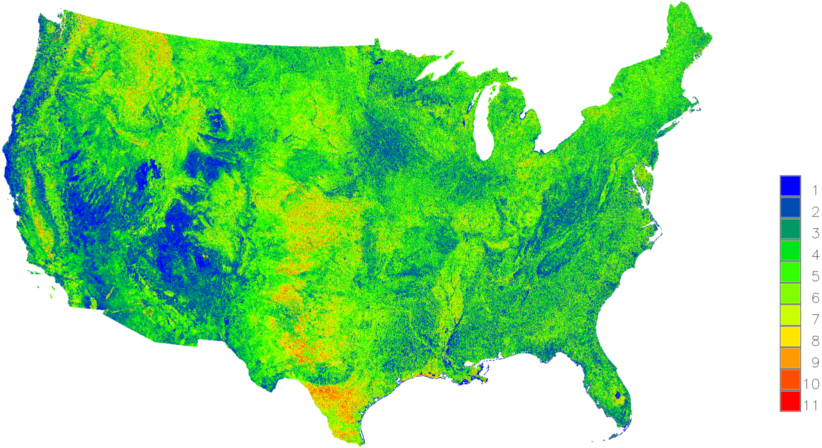
1000 Phenoregions for Year 2010 (Random Colors)



Cluster Persistence Map (2000–2010): k=50



Cluster Persistence Map (2000–2010): k=100



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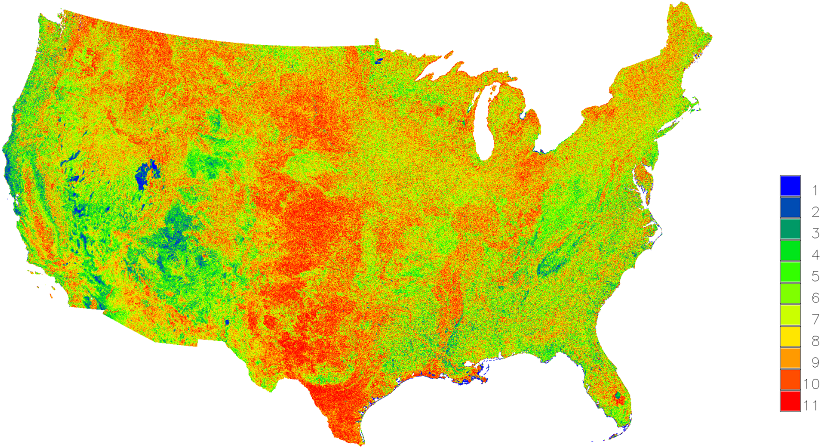
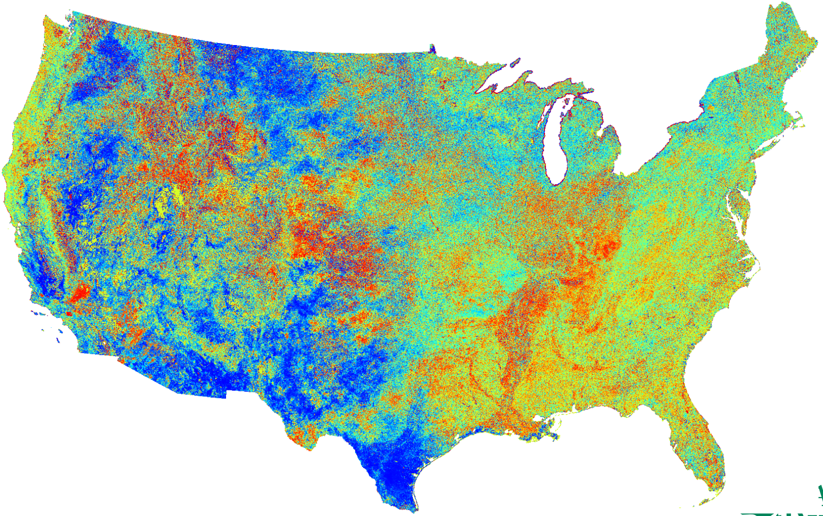
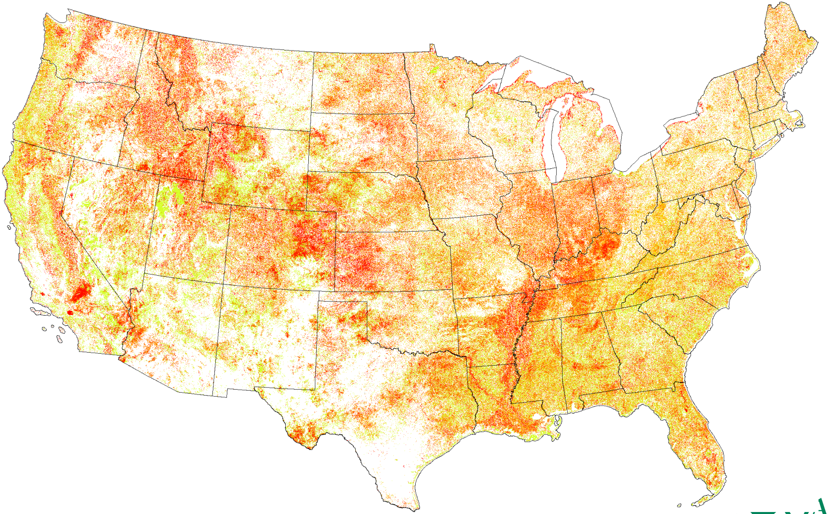
Cluster Persistence Map (2000–2010): k=1000



Disturbance Index (2009-2010): % ΔIntegrated NDVI



Decline map (2009-2010)



Areas of net decline in phenology during 2010-2009 period.

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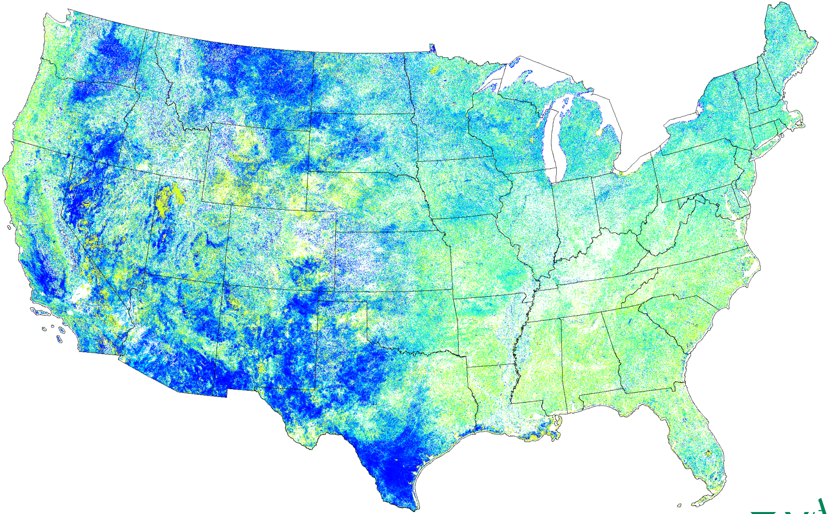
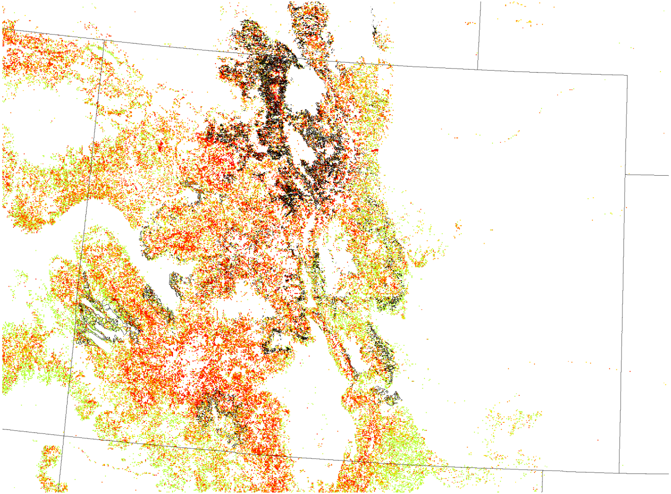
Thrive map (2009-2010)



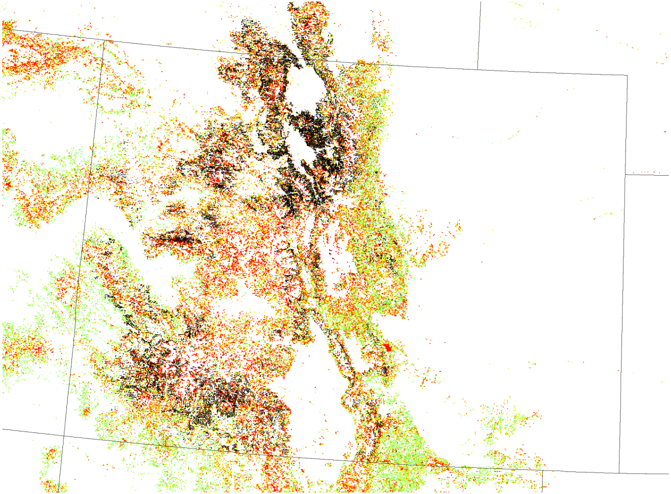
Areas of net thrive in phenology during 2010-2009 period.

Colorado Mountain Pine Beetle (2004-2003)



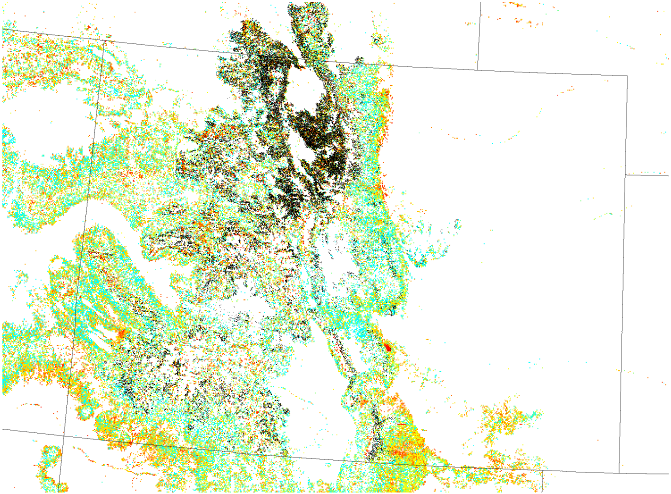
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

Colorado Mountain Pine Beetle (2005-2004)



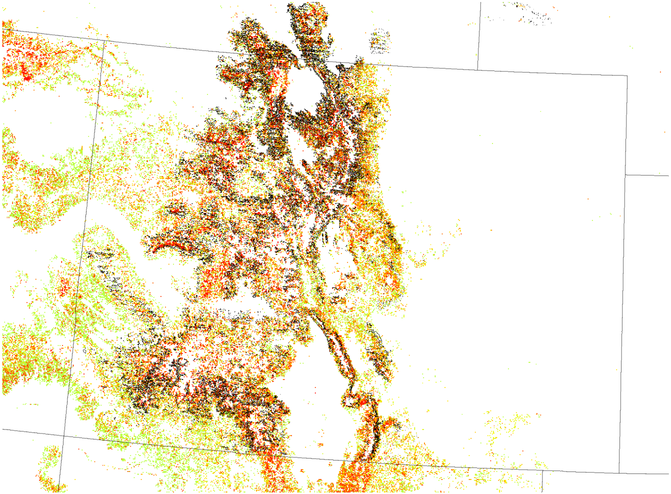
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

Colorado Mountain Pine Beetle (2006-2005)



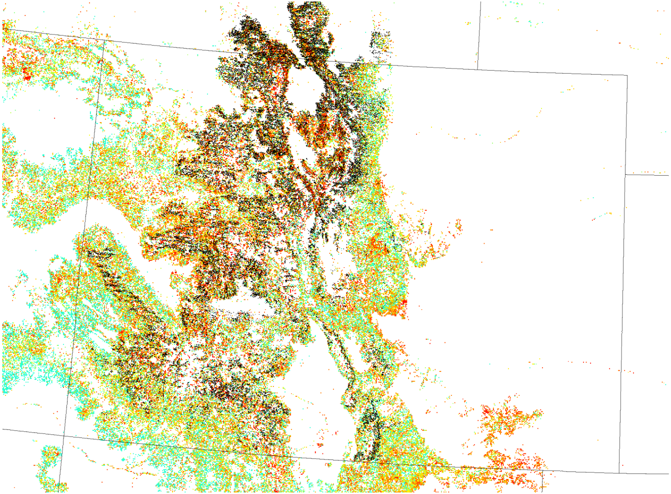
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

Colorado Mountain Pine Beetle (2007-2006)



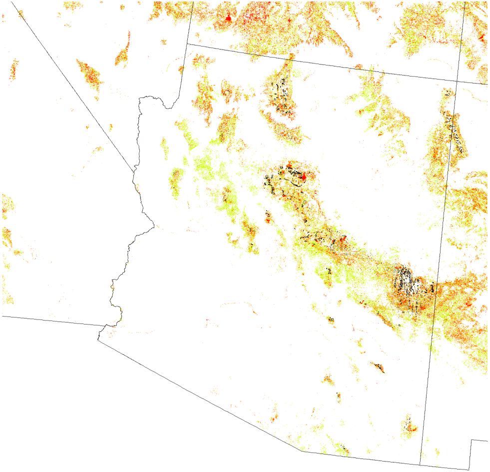
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

Colorado Mountain Pine Beetle (2008-2007)



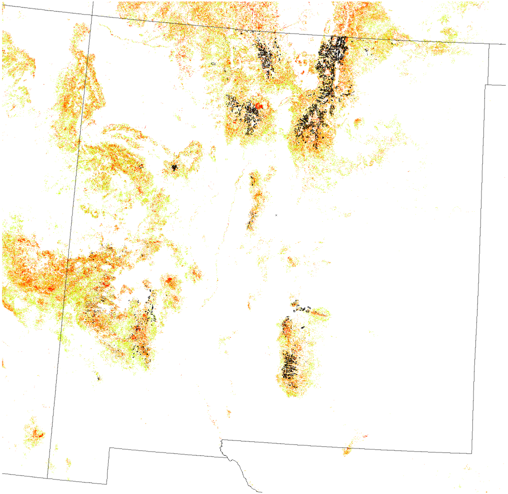
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

Arizona Insect damage (2010-2009)



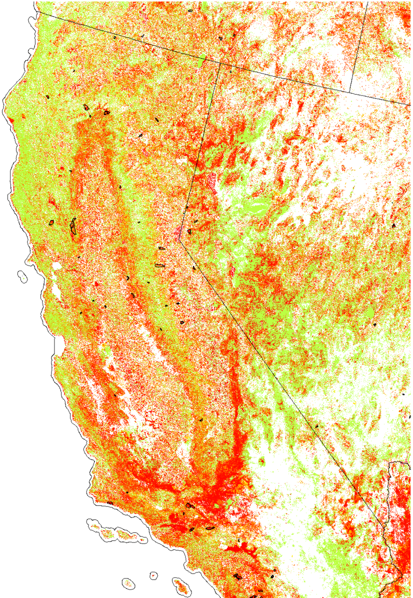
US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

New Mexico Insect damage (2010-2009)

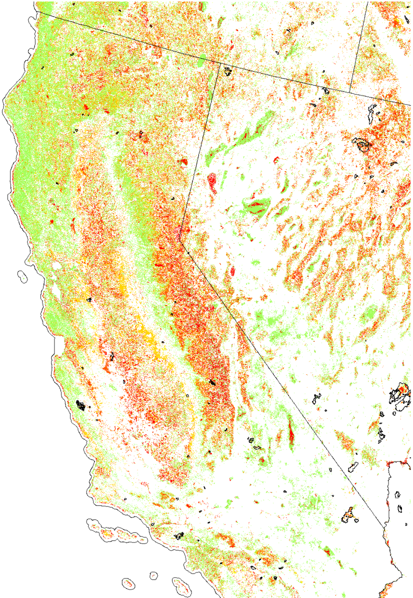


US-FS Sketch map polygons in black overlaid over the disturbance (decline) map.

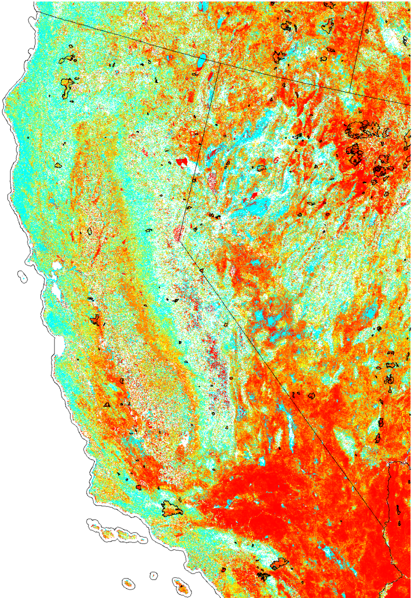
CONUS Wild Fires (2004-2003)



Western US Wild Fires (2005-2004)



Western US Wild Fires (2006-2005)



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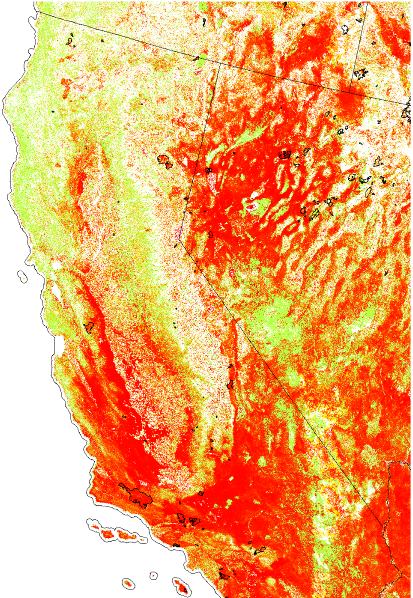
Western US Wild Fires (2007-2006)



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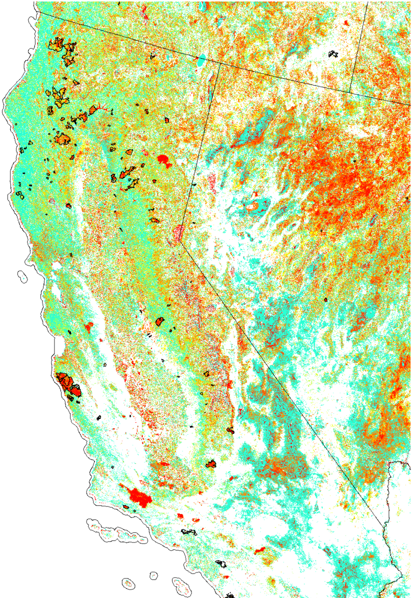
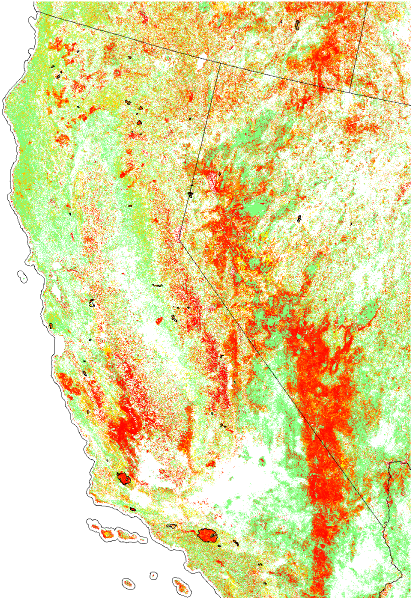
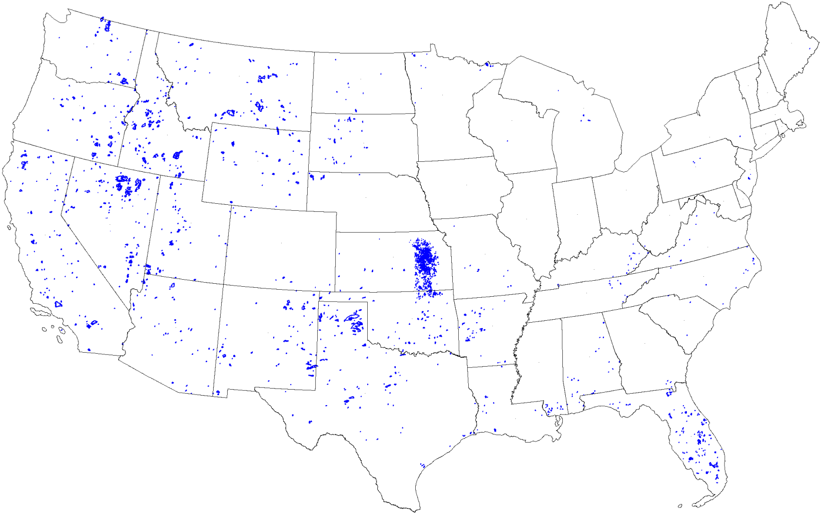
Western US Wild Fires (2008-2007)



Western US Wild Fires (2009-2008)

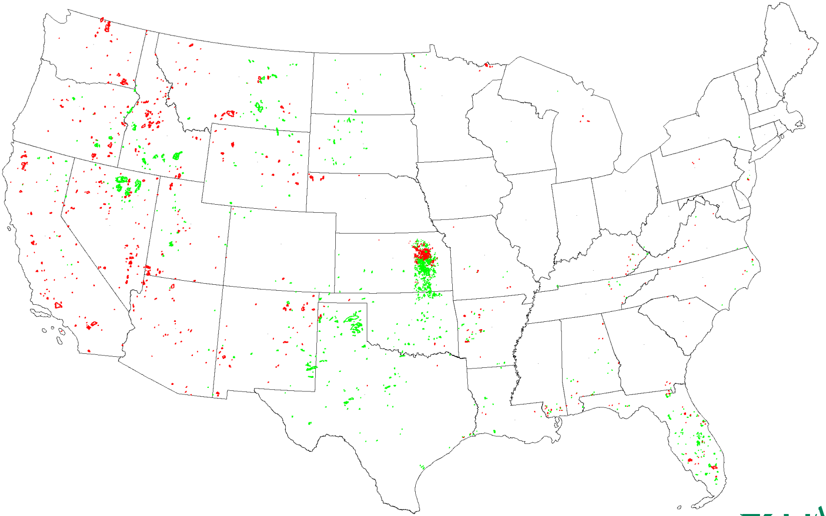


CONUS MTBS 2006



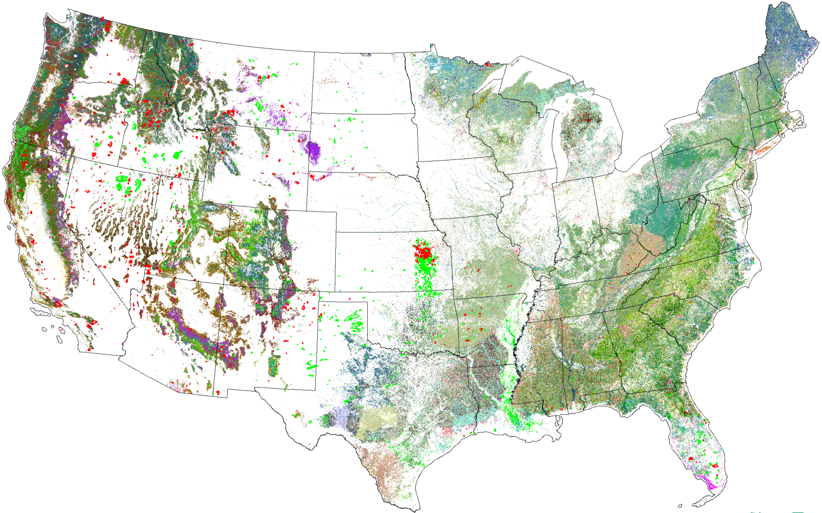
Automated filtering of the distubance/change maps to identify specific events is desired. But high spatio-temporal and biome specific variability in the response of vegetation to disturbance.

CONUS MTBS 2006: Decline and thrive



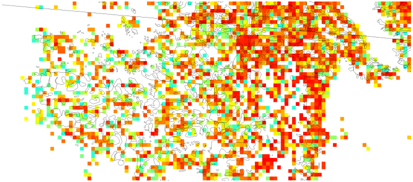
Red areas = net decline; Green area = net thrive

CONUS MTBS 2006: Decline and thrive

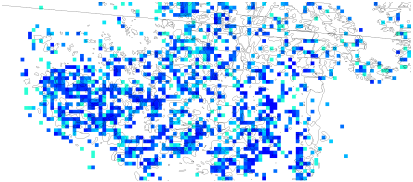


Non-forested area (grasslands, shrublands etc. recovers fast and often have net gain in terms of NDVI.

Tracking forest health decline and recovery: Colorado MPB 2008



(a) Decline



(b) Thrive

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 ForWarn 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.
- However, mortality events, like progressive Mountain Pine Beetle damage and wildfire, are easily detected.
- The next step is to establish generalized or biome-specific or event-specific thresholds based on interannual variability, continue to 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.

Acknowledgements

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