Detecting and Tracking Shifts in National Vegetation Composition Across the MODIS Era

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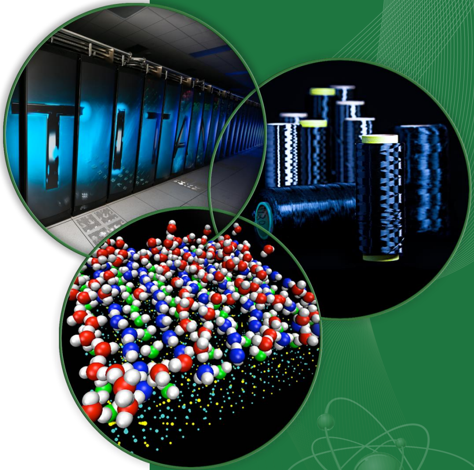

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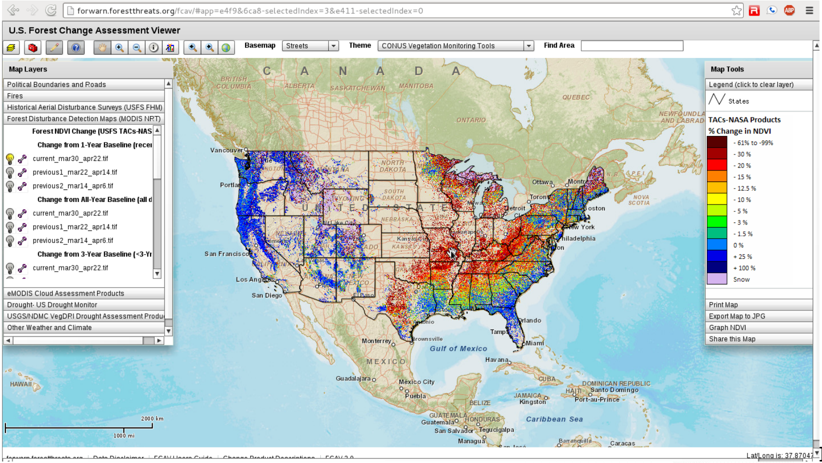
Change in Vegetation Composition

- Land cover maps characterizes the physical land types for any region such as forests, wetlands, impervious surfaces, agriculture, and other land and water types
- Land cover type and chance maps are keys for a range of applications in forestry, hydrology, agriculture, geology etc.
- They are also critically important for management, planning and monitoring of natural resources
- **In this study we aim to develop computational approach and tools for National scale tracking and monitoring of vegetation change**

ForWarn: Near Real-Time Disturbance Monitoring



http://forwarn.forestthreats.org/fcav2

ForWarn has been monitoring changes to vegetation at national scale since 2010. **We want to further understand the impact of these natural and anthropogenic changes on composition and distribution of vegetation (∼ land cover) at national scale**

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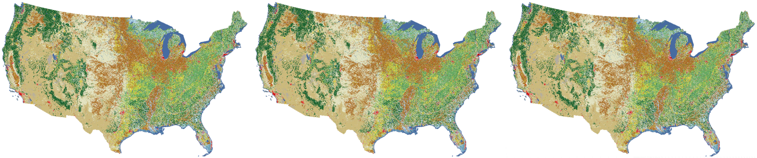
Land Cover Maps

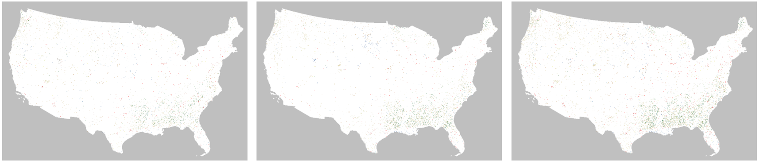
- A number of efforts has been done and are ongoing to develop high resolution maps of land cover at national scale and to monitor changes
- Landcover classes (details and resolution) captured by the land cover mapping efforts have been based on the approach and purpose of the effort and often vary a lot



(a) 2001 (b) 2006 (c) 2011

Figure: National Land Cover Database (NLCD) provides frequently updated landcover map at high resolution

National scale changes in land cover



(a) 2001-2006 (b) 2006-2011 (c) 2001-2011

Figure: NLCD land cover changes

- At the granularity of NLCD types, landcover at national scale appear faily stable
- NLCD maps are updated every 5 years, but a interannual variability and changes are important to understand

National Land Cover Database (NLCD): Changes

Landcover Type	NLCD 2001	NLCD 2006	NLCD 2011
11-Open_Water	103.89	103.33	104.31
12-Perennial_Ice_Snow	0.36	0.36	0.36
21-Developed_Open_Space	64.16	64.79	65.00
22-Developed_Low_Intensity	28.18	28.84	29.27
23-Developed_Medium_Intensity	10.99	12.33	13.22
24-Developed_High_Intensity	3.92	4.41	4.77
31-Barren_Land	23.91	24.44	24.58
41-Deciduous_Forest	220.50	219.12	216.53
42-Evergreen_Forest	240.82	235.90	230.83
43-Mixed_Forest	42.49	41.34	40.00
52-Shrub_Scrub	423.83	427.16	431.53
71-Grassland_Herbaceous	285.31	288.19	290.66
81-Pasture_Hay	135.22	133.65	132.82
82-Cultivated_Crops	310.02	309.45	309.62
90-Woody_Wetlands	77.96	77.85	77.20
95-Emergent_Herbaceous_Wetlands	25.08	25.46	25.95

Area: Million Acres

Objectives

1. Employ historical MODIS NDVI data sets (2000-2012) for continental scale vegetation (landcover) change analysis
2. Track/Quantify changes in land cover annually (routinely)
3. Complete accounting of winners/loosers (donors and receipients)
4. Trajectories of change:
    - trajectory of changes experienced by any location
    - all locations experiencing similary trajectory of changes
5. (Attempt) to translate satellite derived changes to commond land cover definitions

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.

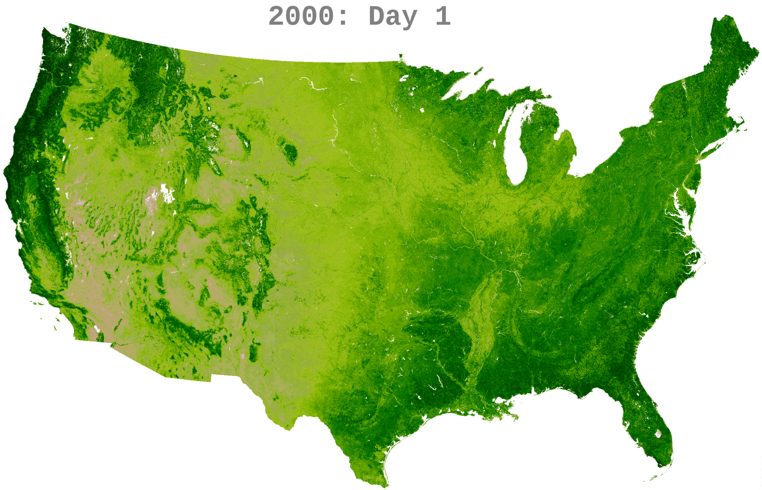
$$\text{NDVI} = \frac{(\sigma_{\text{nir}} - \sigma_{\text{red}})}{(\sigma_{\text{nir}} + \sigma_{\text{red}})} \qquad (1)$$

- 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 produces 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 231 m resolution, processed by NASA Stennis Space Center.

MODIS Normalized Difference Vegetation Index (NDVI)



Number of ∼231m pixels in CONUS = 146,395,381
Times series: 13 × 46 = 598
Data size = 146,395,381 × 4 = 0.585 GB/year 350.177 GB for 13 years (single precision)

Phenoregions

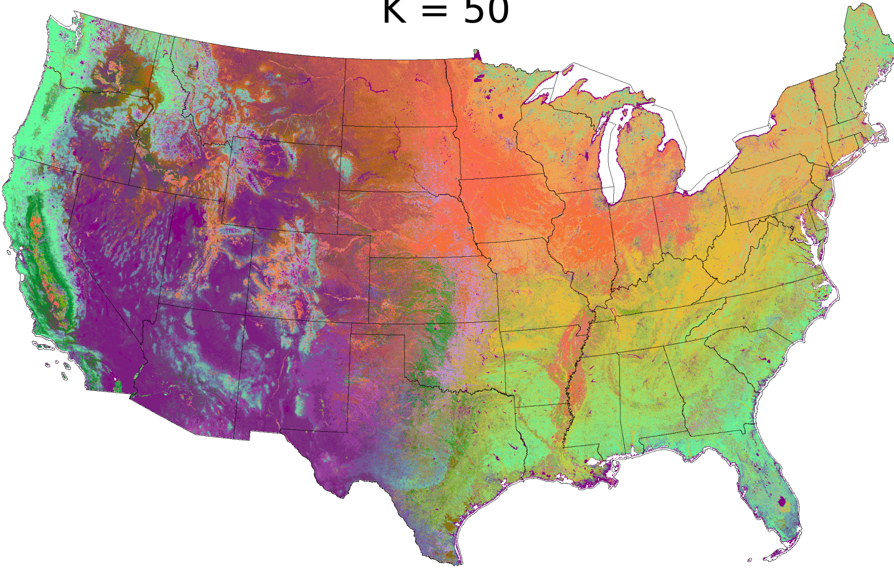
Phenoregions are statistically defined regions with similar phenological characteristics.

We employ a **Multi-variate Spatio Temporal Clustering** algorithm to identify regions with similar landsurface phenology using historical MODIS NDVI data sets. Phenological resolution OR smoothing can controlled by tuning the *k* in the *k*-means algorithm.

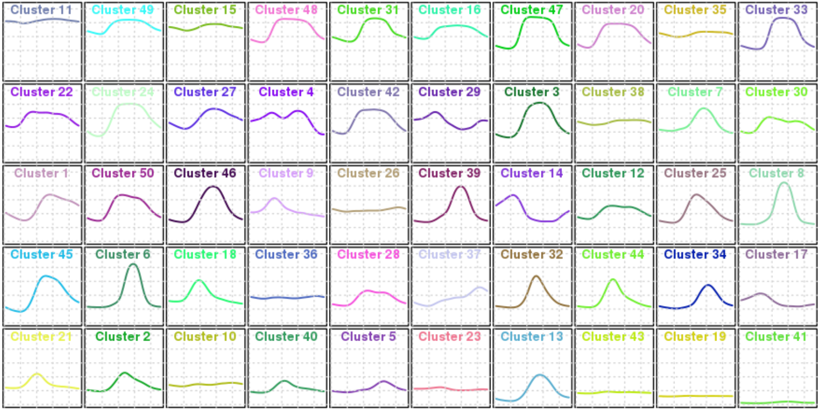
Instead of large volumes distinct land surface phenology associated with every MODIS pixel, Phenoregions provide a handful of smoothed and representative phenological profiles that can be used to represent the landscape.

Phenoregions at various resolution

K = 50

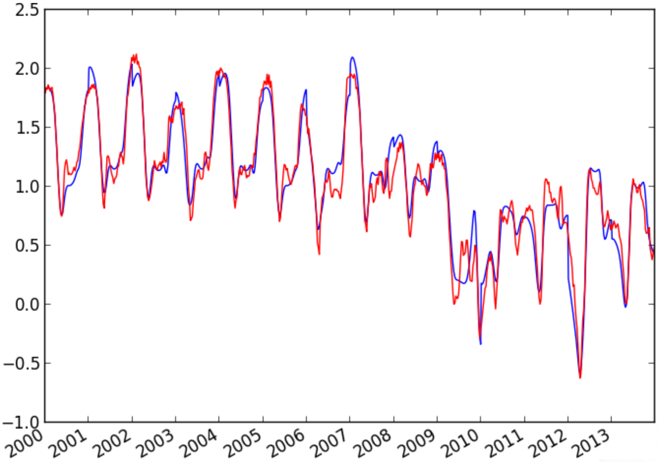


Phenological Signatures



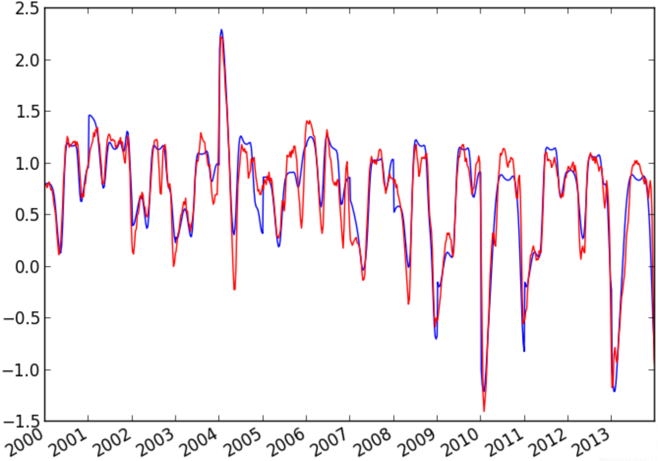
Unlike land cover maps (like NLCD) these signatures define our land cover types (or *Phenoregions*)

Effect of smoothing



MODIS NDVI time series (blue) and smoothed Phenoregion-based trajectory (red) at cell. All regions experiencing similar phenological trajectories of changes can be identified to allow tracking and monitoring of changes to assist with land management, conservation planning and decision making.

Effect of smoothing



MODIS NDVI time series (blue) and smoothed Phenoregion-based trajectory (red) at cell. All regions experiencing similar phenological trajectories of changes can be identified to allow tracking and monitoring of changes to assist with land management, conservation planning and decision making.

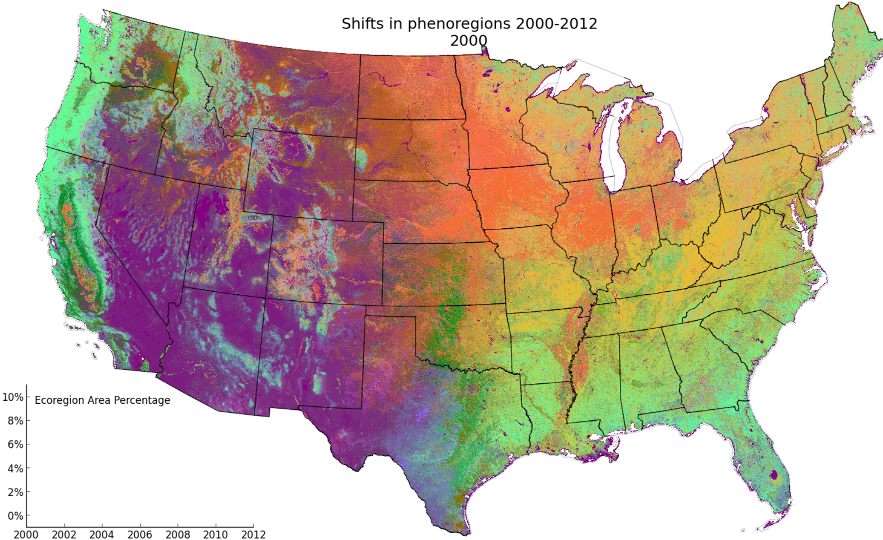
Assumptions

Key Assumptions: Our analysis is based entirely on land surface phenology, without any ground-based validation (intractable at national scale).

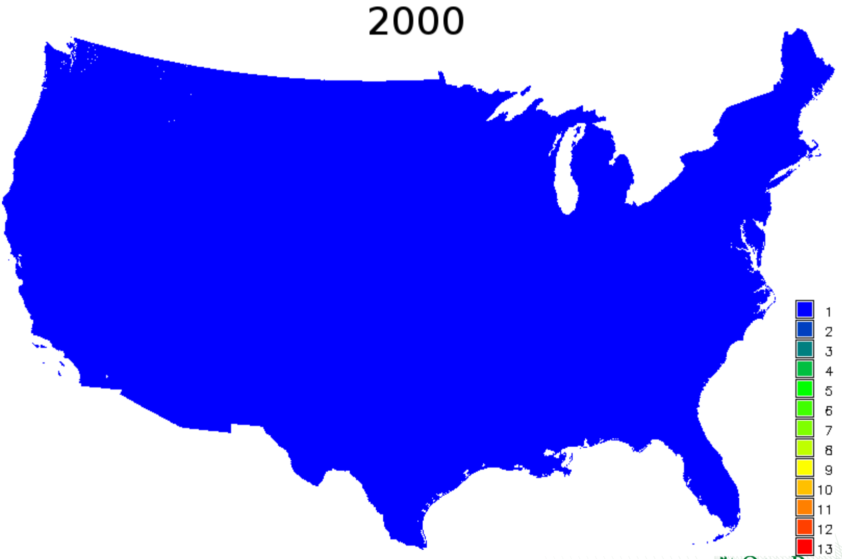
Land cover type = Phenoregions = Phenological signatures

Land cover change = Vegetation change = Landsurface phenology change

Shifts in Phenoregions across time 2000-2012 K=50



Persistence of Phenoregions across time 2000-2012 K=50



Transition Matrix 2000-2001

We develop transition matrix of changes between every pair of land cover types for any two given years. Matrix shows the area exchange between donors and recipients.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	10.84	0.00	2.95	4.58	0.00	0.00	11.32	0.00	2.04	0.00	0.00	3.19	0.00	1.63	0.00	0.00	0.00
2	0.00	36.52	0.00	0.00	1.82	0.00	0.00	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	48.71	0.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	10.53	0.00	1.68	4.10	0.00	0.00	7.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.59	3.02	0.00
5	0.00	20.54	0.00	0.00	14.27	0.00	0.00	0.00	0.00	4.78	0.00	0.00	0.00	0.00	0.00	0.00	2.31
6	0.00	0.00	0.00	0.00	0.00	51.53	0.00	24.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	6.65	0.00	9.84	3.04	0.00	0.00	26.26	0.00	0.00	0.00	0.00	2.45	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	34.14	0.00	31.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	2.57	0.00	0.00	0.00	0.00	0.00	1.35	0.00	18.80	0.00	0.00	10.84	0.00	3.58	0.00	0.00	2.04
10	0.00	5.72	0.00	0.00	1.11	0.00	0.00	0.00	0.00	33.63	0.00	0.00	0.00	0.00	0.00	0.00	6.57
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	81.24	0.00	0.00	0.00	10.34	0.00	0.00
12	1.10	0.00	0.00	0.00	0.00	0.00	3.78	0.00	11.08	0.00	0.00	27.34	0.00	0.00	0.00	0.00	0.00
13	0.00	6.23	0.00	0.00	4.64	1.43	0.00	0.00	0.00	0.00	0.00	0.00	40.18	0.00	0.00	0.00	1.20
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.55	0.00	0.00	0.00	0.00	51.35	0.00	0.00	7.79
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.90	0.00	0.00	0.00	52.99	6.08	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.85	43.55	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.79	10.29	0.00	0.00	0.00	2.96	0.00	0.00	40.45
18	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00	6.76	4.27	0.00	7.51	0.00	0.00	0.00	0.00	3.28
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.02	0.00
21	0.00	5.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.19	0.00	0.00	0.00	0.00	0.00	0.00	11.50
22	0.00	0.00	0.00	1.87	0.00	0.00	1.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.27	0.00

X-Axis: 2000 Y-Axis: 2001

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Adding supervision to unsupervised classification

- Clustering is an unsupervised classification technique, so phenoregions have no descriptive labels like **Eastern Deciduous Forest Biome**.
- **Mapcurves** allows us to perform automated "supervision" to "steal" the best human-created descriptive labels to assign to phenoregions.
- We employ the **Mapcurves GOF** to select the best ecoregion labels from ecoregionalizations drawn by human experts.
- We consider an entire library of ecoregion and land cover maps, and choose the label with the highest GOF score for every phenoregion polygon.

Hargrove, William W., Forrest M. Hoffman, and Paul F. Hessburg. (2006) "Mapcurves: A Quantitative Method for Comparing Categorical Maps." J. Geograph. Syst., 8(2):187208. doi:10.1007/s10109-006-0025-x

Learn from the best!!

	Expert Map	# Cats
1.	DeFries UMd Vegetation	12
2.	Foley Land Cover	14
3.	Fedorova, Volkova, and Varlyguin World Vegetation Cover	31
4.	GAP National Land Cover	578
5.	Holdridge Life Zones	25
6.	Küchler Types	117
7.	BATS Land Cover	17
8.	IGBP Land Cover	16
9.	Olson Global Ecoregions	49
10.	Seasonal Land Cover Regions	194
11.	USGS Land Cover	24
12.	Leemans-Holdridge Life Zones	26
13.	Matthews Vegetation Types	19
14.	Major Land Resource Areas	197
15.	National Land Cover Database 2006	16
16.	Wilson, Henderson, & Sellers Primary Vegetation Types	23
17.	Landfire Vegetation Types	443

Transition Matrix 2000-2001 in terms of NLCD types

We develop transition matrix of changes between every pair of land cover types for any two given years. Matrix shows the area exchange between donors and recipients.

	11:Oper	12:Perer	21:Deve	22:Dev	23:Dev	24:Deve	31:Barr	41:Dec	42:Eve	43:Mix	52:Sh	71:Gr	81:Pas	82:Cr	90:W	95:Emer
11:Open_water	73.66	0.00	0.00	0.00	0.00	0.00	3.24	1.25	3.55	0.00	9.46	3.83	0.00	4.36	0.00	0.00
12:Perennial_ice_snow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21:Developed_open_space	0.00	0.00	5.57	4.48	0.00	0.00	0.00	12.24	28.12	0.00	2.38	0.00	36.28	10.23	0.00	0.00
22:Developed_low_intensi	0.00	0.00	0.00	23.49	0.00	0.00	0.00	3.95	15.90	0.00	6.76	12.36	16.94	19.33	0.00	0.00
23:Developed_medium_int	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24:Developed_high_intens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31:Barren_land	10.08	0.00	0.00	0.00	0.00	0.00	59.69	0.00	0.00	0.00	28.28	1.13	0.00	0.00	0.00	0.00
41:Deciduous_forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	80.41	2.97	0.00	0.00	0.00	7.08	5.62	1.95	0.00
42:Evergreen_forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.45	78.10	0.00	7.25	0.00	3.64	3.59	2.12	0.00
43:Mixed_forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	29.56	35.25	26.36	0.00	0.00	0.00	0.00	7.89	0.00
52:Shrub_scrub	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.73	0.00	79.12	10.49	0.00	4.86	0.00	0.00
71:Grassland_herbaceous	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22	0.00	16.41	66.46	1.90	11.60	0.00	0.00
81:Pasture_hay	0.00	0.00	0.00	1.15	0.00	0.00	0.00	17.32	8.93	0.00	1.53	1.95	54.97	11.25	2.33	0.00
82:Cultivated_crops	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.62	3.79	0.00	8.01	9.33	6.58	67.03	0.00	0.00
90:Woody_wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.08	25.20	1.45	0.00	0.00	6.35	2.73	37.93	0.00
95:Emergent_herbaceous_	0.00	0.00	0.00	3.03	0.00	0.00	0.00	0.00	19.10	0.00	35.86	13.28	3.89	18.03	0.00	6.46

X-Axis: 2000 Y-Axis: 2001

Web-Based Visualization

Historical Trajectorie ×

https://www.climatemodeling.org/veg_trajectories/

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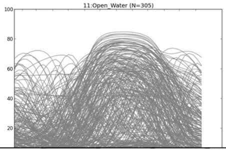
Landcover Changes during period 2000-2012 for CONUS

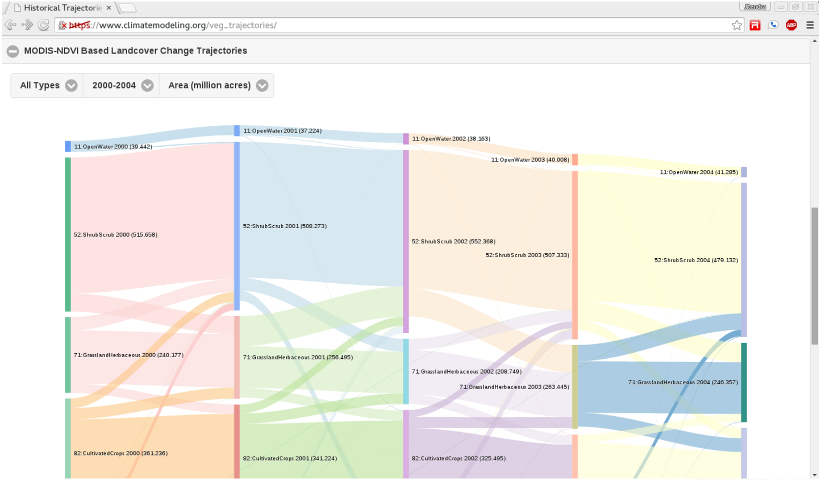
Landcover Type	NLCD 2001	NLCD 2006	NLCD 2011
11-Open_Water	103.8924366637	103.3318902145	104.3058064359
12-Perennial_Ice_Snow	0.3556412751	0.3556386064	0.3556546188
21-Developed_Open_Space	64.1590954749	64.7923740438	64.9951557952
22-Developed_Low_Intensity	28.1783561259	28.8427107679	29.2746389164
23-Developed_Medium_Intensity	10.9866608108	12.3311492069	13.2228323932
24-Developed_High_Intensity	3.9182014548	4.4062150499	4.7651406469
31-Barren_Land	23.9070037696	24.4360598248	24.5762077236
41-Deciduous_Forest	220.5011146234	219.1197236407	216.5272291441
42-Evergreen_Forest	240.8219421413	235.9032999178	230.8259892263
43-Mixed_Forest	42.4916886078	41.3446956459	39.9966544976
52-Shrub_Scrub	423.8279405267	427.1627204789	431.5259277684
71-Grassland_Herbaceous	285.3087898536	288.1886898776	290.6610777782
81-Pasture_Hay	135.221072263	133.6505332013	132.8216840227
82-Cultivated_Crops	310.0210271747	309.4497152749	309.6216573586
90-Woody_Wetlands	77.9578006343	77.847433583	77.2030215006
95-Emergent_Herbaceous_Wetlands	25.0788146234	25.4647366888	25.9489081964

Landcover Type	2000	2001	2002	2003	2004	2005	2006	2007
11-Open_Water	39.6662	37.4362	38.3804	40.2355	41.5196	42.6461	40.7259	42.0071
21-Developed_Open_Space	1.64042	1.51977	2.388	1.52462	1.88714	1.73102	1.62916	1.86888
22-Developed_Low_Intensity	7.22401	10.7781	15.7719	10.6855	13.9149	11.3232	12.797	14.668
31-Barren_Land	10.642	8.82276	11.0497	10.9683	11.5728	7.60548	8.71016	9.65013
41-Deciduous_Forest	264.708	277.896	265.143	271.138	268.974	277.59	278.416	235.186
42-Evergreen_Forest	301.464	308.403	345.454	307.496	303.247	319.194	310.722	304.675
43-Mixed_Forest	6.94342	5.73373	4.37078	4.73162	5.02816	4.51636	3.36365	4.19691
52-Shrub_Scrub	518.593	511.166	555.512	510.22	481.858	476.176	516.918	458.637
71-Grassland_Herbaceous	241.543	257.955	209.937	264.944	247.759	289.363	278.126	320.436
81-Pasture_Hay	142.548	145.212	134.787	152.388	171.279	128.67	117.601	173.502
82-Cultivated_Crops	363.292	343.166	327.347	331.132	355.59	356.091	339.602	338.198
90-Woody_Wetlands	42.1748	32.5782	30.3734	34.8546	37.6667	25.8899	32.1013	37.4758
95-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



https://www.climatemodeling.org/veg_trajectories/

Web-Based Visualization

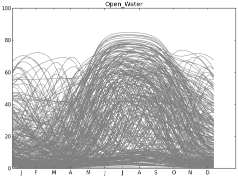


`https://www.climatemodeling.org/veg_trajectories/`

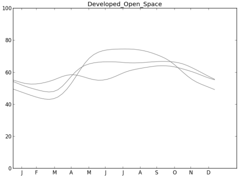
Limitations and Caveats

- We may have introduced some errors due to scale mismatch between NLCD 30m vs MODIS 231m
- Errors may have been introduced by using the existing landcover maps (like NLCD) for training
- Existing landcover maps lacks precision (vs MODIS landsurface phenology based *Phenoregions*)
- Landcover maps are static (*Phenoregions* are dynamic) and often misclassify large area at national scales

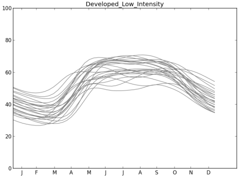
MODIS NDVI signatures associated with NLCD



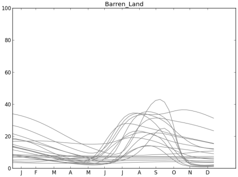
(a) Open Water: 103.33/40.73



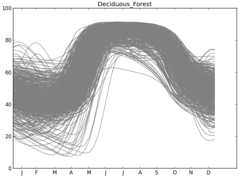
(b) Developed Open: 64.79/1.63



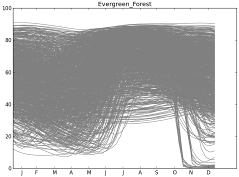
(c) Developed Low Intensity: 28.84/12.80



(d) Barren Land: 24.44/8.71

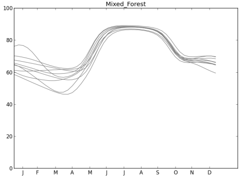


(e) Deciduous Forest: 219.12/278.42

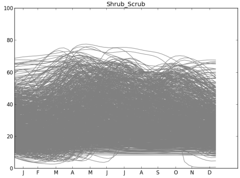


(f) Evergreen Forest: 235.90/310.72

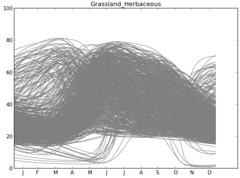
MODIS NDVI signatures associated with NLCD



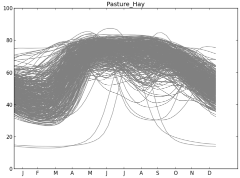
(g) Mixed Forest: 41.34/3.36



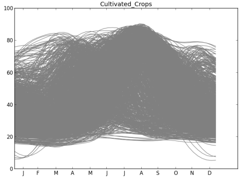
(h) Shrub/Scrub: 427.16/516.92



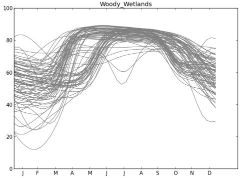
(i) Grassland: 288.19/278.13



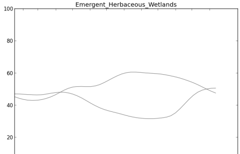
(j) Pasture/Hay: 133.65/117.60



(k) Crops: 309.45/339.60



(l) Woody Wetlands: 77.85/32.10



Summary

What we have done so far

- We have developed apprach to identify and track trajectories of changes using historical MODIS land surface phenology
  - track trajectories of change at any geographic location
  - track all geographic locations experiencing a trajectory of change
- Method allows to choose granularity (in terms of land surface phenology) at which we want to identify and track changes
- We can track donors/recipients (winners/losers) through space and time using the massive MODIS NDVI data set

It's a work in progress

- Translation of MODIS NDVI-based *Phenoregions* to existing land cover maps suffers from several limitations.
- Overlaps calls for a fuzzy/probabilistic analysis of the change
- Visualization of this large and multi-variate spatio-temporal data to allow analysis and understanding is a challenge that we continue to work on