Developing Phenoregion Maps Using Remotely Sensed Imagery

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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, using high performance computing, was applied to the entire body of the high resolution MODIS NDVI record for the continental U.S.

- >80B NDVI values, consisting of ∼146.4M cells for the CONUS at 250 m resolution with 46 maps per year for 12 years (2000–2011), analyzed using *k*-means clustering.

- The annual traces of NDVI for every year and map cell are combined into one 323 GB single-precision binary data set of 46-dimensional observation vectors.

- Clustering yields 12 maps in which each cell is classified into one of *k* phenoclasses, and phenoregions form representative prototype annual NDVI traces.
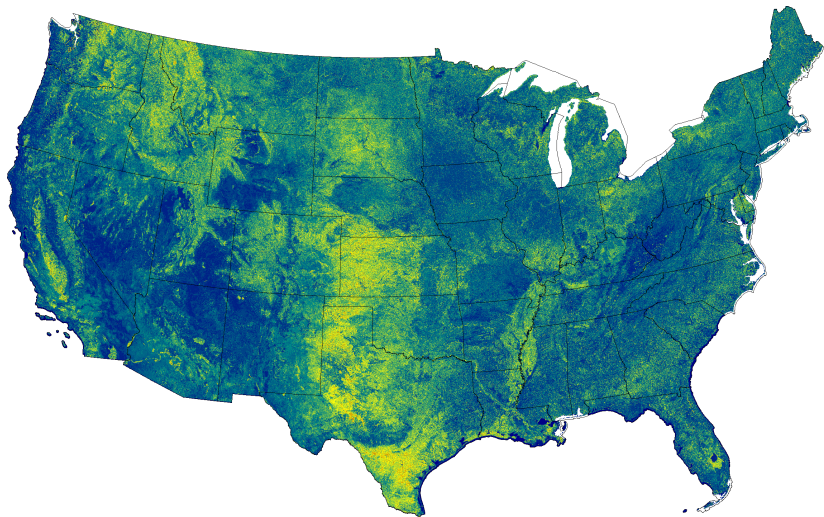
50 Phenoregions for year 2011 (Random Colors)
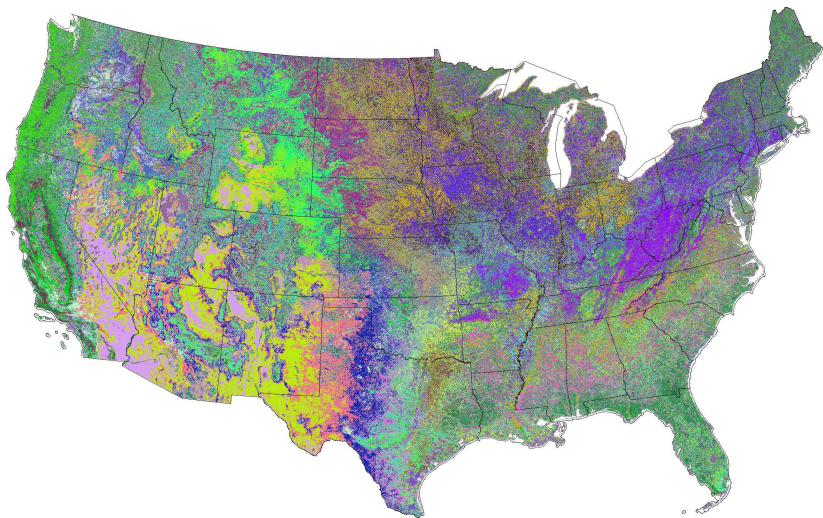
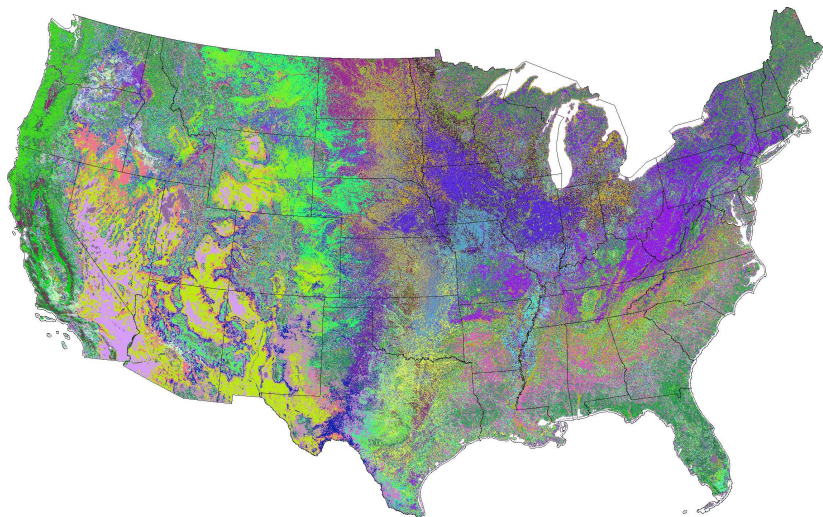# 50 Phenoregion Prototypes (Random Colors)

NDVI

day of year
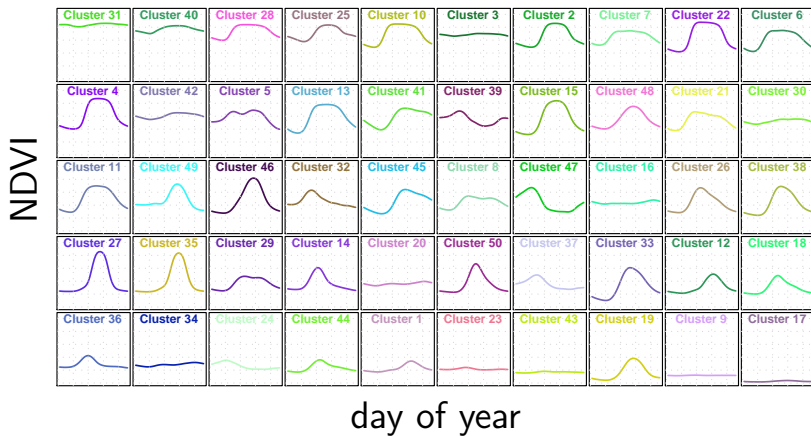
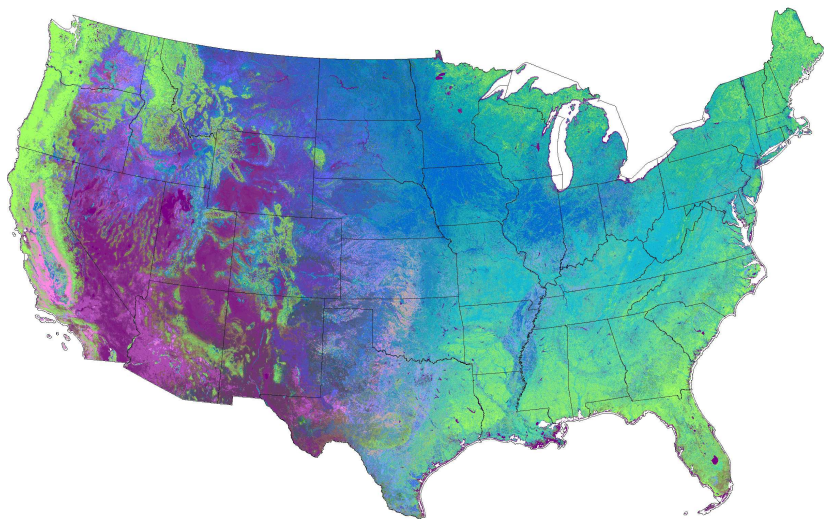# 50 Phenoregions Persistence (Random Colors)
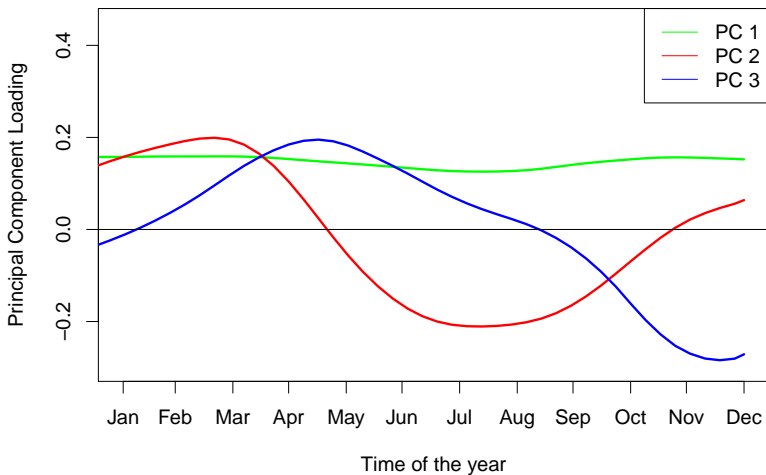
50 Phenoregions Mode (Random Colors)
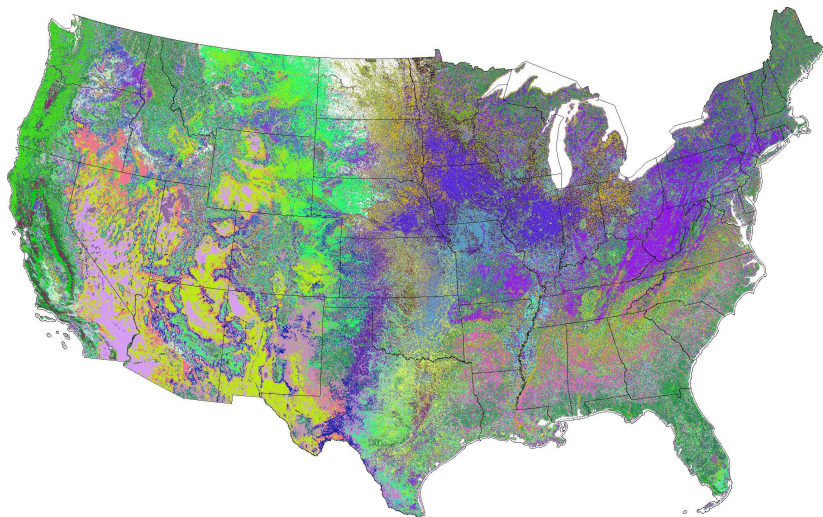
50 Phenoregions Max Mode (Random Colors)

50 Phenoregions Max Mode (Similarity Colors)

50 Phenoregions Max Mode (Similarity Colors Legend)

Phenoregions Clearinghouse

Mapcurves: A Method for Comparing Categorical Maps

- Hargrove et al. (2006) developed a method for quantitatively comparing categorical maps that is
  - independent of differences in resolution,
  - independent of the number of categories in maps, and
  - independent of the directionality of comparison.

Polygon from Map 2 (Reference Map)

Polygon from Map 1 Being Compared

B

C

A
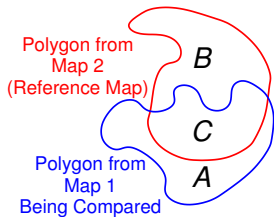
Goodness of Fit (GOF) is a unitless measure of spatial overlap between map categories:

$$\text{GOF} = \sum_{\text{polygons}} \frac{C}{B+C} \times \frac{C}{A+C}$$

- GOF provides "credit" for the area of overlap, but also "debit" for the area of non-overlap.
- Mapcurves comparisons allow us to reclassify any map in terms of any other map (*i.e.*, color Map 2 like Map 1).
- A greyscale GOF map shows the degree of correspondence between two maps based on the highest GOF score.

Two 2-Way Comparisons with Land Cover Maps

Cluster	IGBP Land Cover	Olson's Global Ecoregions
1	Grasslands	cool grasses and shrubs
2	Evergreen Needleleaf Forest	cool conifer forest
3	Croplands	corn and beans cropland
4	Cropland/Natural Vegetation Mosaic	cool forest and field
5	Open Shrublands	semi desert sage
6	Grasslands	cool conifer forest
7	Grasslands	hot and mild grasses and shrubs
8	Cropland/Natural Vegetation Mosaic	cool forest and field
9	Grasslands	hot and mild grasses and shrubs
10	Open Shrublands	semi desert shrubs
11	Croplands	corn and beans cropland
12	Evergreen Needleleaf Forest	conifer forest
13	Open Shrublands	semi desert shrubs
14	Savannas	savanna (woods)
15	Grasslands	hot and mild grasses and shrubs
16	Evergreen Needleleaf Forest	cool conifer forest
17	Evergreen Needleleaf Forest	cool conifer forest
18	Evergreen Needleleaf Forest	cool conifer forest
19	Deciduous Broadleaf Forest	deciduous broadleaf forest
20	Deciduous Broadleaf Forest	deciduous broadleaf forest
21	Deciduous Broadleaf Forest	cool broadleaf forest
22	Open Shrublands	semi desert sage
23	Grasslands	cool grasses and shrubs
24	Grasslands	semi desert sage
25	Croplands	woody savanna

Two 2-Way Comparisons with Land Cover Maps

Cluster	IGBP Land Cover	Olson's Global Ecoregions
26	Evergreen Needleleaf Forest	conifer forest
27	Evergreen Needleleaf Forest	cool conifer forest
28	Water	inland water
29	Croplands	woody savanna
30	Grasslands	cool grasses and shrubs
31	Croplands	cool crops and towns
32	Water	inland water
33	Grasslands	cool grasses and shrubs
34	Open Shrublands	semi desert shrubs
35	Grasslands	hot and mild grasses and shrubs
36	Deciduous Broadleaf Forest	cool broadleaf forest
37	Evergreen Needleleaf Forest	deciduous broadleaf forest
38	Evergreen Needleleaf Forest	cool conifer forest
39	Grasslands	hot and mild grasses and shrubs
40	Croplands	broadleaf crops
41	Cropland/Natural Vegetation Mosaic	cool fields and woods
42	Croplands	corn and beans cropland
43	Mixed Forests	cool broadleaf forest
44	Croplands	deciduous broadleaf forest
45	Cropland/Natural Vegetation Mosaic	cool forest and field
46	Cropland/Natural Vegetation Mosaic	crops, grass, shrubs
47	Evergreen Needleleaf Forest	crops, grass, shrubs
48	Croplands	corn and beans cropland
49	Deciduous Broadleaf Forest	cool broadleaf forest
50	Grasslands	cool grasses and shrubs

Phenoregions Reclassed Using Land Cover Types
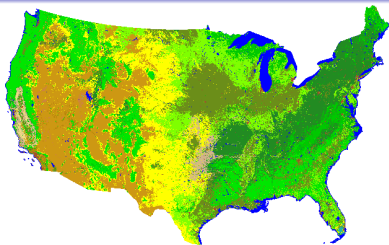
(a) IGBP Land Cover
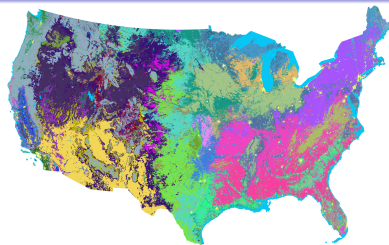
(c) Olson's Global Ecoregions
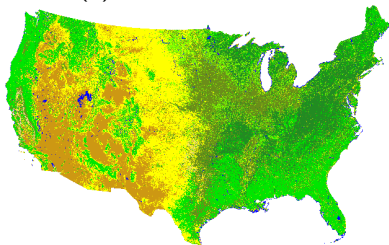
(b) 50 Phenoregions Reclassed
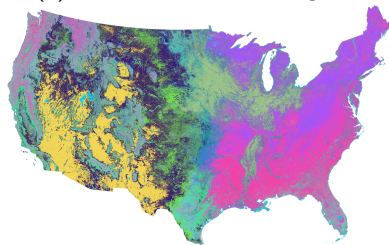
(d) 50 Phenoregions Reclassed

Expert-Derived Land Cover/Vegetation Type Maps
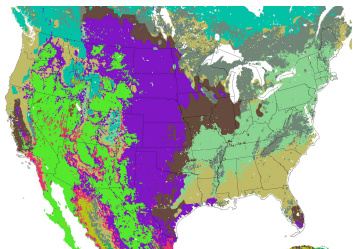
Foley Land Cover
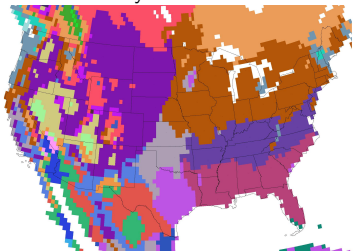
Holdridge Life Zones

	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

Label Stealing: Having your cake and eating it too!

- Clustering is an unsupervised classification technique, so phenoregions have no descriptive labels like **Eastern Deciduous Forest Biome**.

- **Label stealing** 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.

Patchwork Crazy Quilt of Multiple Land Cover Types

5000 Phenoregions Max Mode (Random Colors)
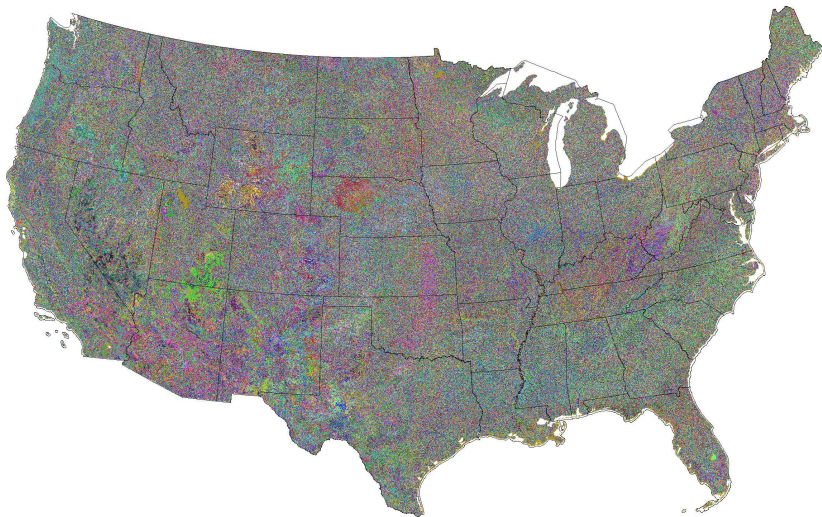
| Cluster	Land Cover Label	Land Cover Map
1	Arable cropland	wilsonhendersonsellersprimaryveg
2	Barren land	NLCD2006
3	Barren or Sparsely Vegetated	landcover.usgs
4	Boreal Evergreen Forest/Woodland	foleylandcover
5	Boreal moist forest	holdridgezonesnormal
6	Cold-deciduous forest, with evergreens	matthewsvegetation
7	Cold-deciduous forest, without evergreens	matthewsvegetation
8	Cool temperate moist forest	holdridgezonesnormal
9	Cool Temperate Moist Forest	leemansholdridgezones
10	Cool temperate steppe	holdridgezonesnormal
11	Cool Temperate Steppe	leemansholdridgezones
12	Cropland	defriesumdvegetation
13	Cropland/Natural Vegetation Mosaic	landcover.igbp
14	Croplands	landcover.igbp
15	Crops, Mixed Farming	landcover.bats
16	Cultivated Cropland	GAP
17	Cultivated crops	NLCD2006
18	Deciduous Broadleaf Trees	landcover.bats
19	Deciduous forest	NLCD2006
20	Evergreen Coniferous Forest	landcover.usgs
21	Evergreen/Deciduous Mixed Forest/Woodland	foleylandcover
22	Evergreen forest	NLCD2006
23	Evergreen Needleleaf Forest	defriesumdvegetation
24	Grassland/herbaceous	NLCD2006
25	Grassland	defriesumdvegetation
26	Grassland/Steppe	foleylandcover
27	Interrupted Forest	landcover.bats
28	Juniper/Pinyon	ktlamb
29	Meadow, short grassland, no woody cover	matthewsvegetation
30	Mixed Forest	defriesumdvegetation
31	Mountains	fvvcode
32	Open Shrubland	foleylandcover

Cluster	Land Cover Label	Land Cover Map
33	Open Shrublands	landcover.igbp
34	Open Water (Fresh)	GAP
35	Open water	NLCD2006
36	Pasture/Hay	GAP
37	Pasture/hay	NLCD2006
38	Pecos-Canadian Plains and Valleys, MLRA 70	mlra
39	Rough grazing + shrub	wilsonhendersonsellersprimaryveg
40	Sacramento and San Joaquin Valleys, MLRA 17	mlra
41	Savanna	landcover.usgs
42	Semidesert	landcover.bats
43	Short Grass	landcover.bats
44	Shrub/scrub	NLCD2006
45	Subboreal	fvvcode
46	Subtropical dry forest	holdridgezonesnormal
47	Subtropical Dry Forest	leemansholdridgezones
48	Subtropical	fvvcode
49	Subtropical moist forest	holdridgezonesnormal
50	Subtropical Moist Forest	leemansholdridgezones
51	Subtropical Thorn Steppe	leemansholdridgezones
52	Subtropical thorn woodland	holdridgezonesnormal
53	Tall/medium/short grassland with 10–40% woody tree cover	matthewsvegetation
54	Tall/medium/short grassland with shrub cover	matthewsvegetation
55	Temperate Deciduous Forest/Woodland	foleylandcover
56	Temperate Needleleaf Evergreen Forest/Woodland	foleylandcover
57	Temperate rough grazing	wilsonhendersonsellersprimaryveg
58	Temperate/subpolar evergreen needleleaved forest	matthewsvegetation
59	Warm temperate dry forest	holdridgezonesnormal
60	Warm Temperate Dry Forest	leemansholdridgezones
61	Warm temperate moist forest	holdridgezonesnormal
62	Warm Temperate Moist Forest	leemansholdridgezones
63	Warm temperate thorn scrub	holdridgezonesnormal
64	Warm Temperate Thorn Steppe	leemansholdridgezones

5000 Phenoregions Reclassed into 64 Land Cover Types
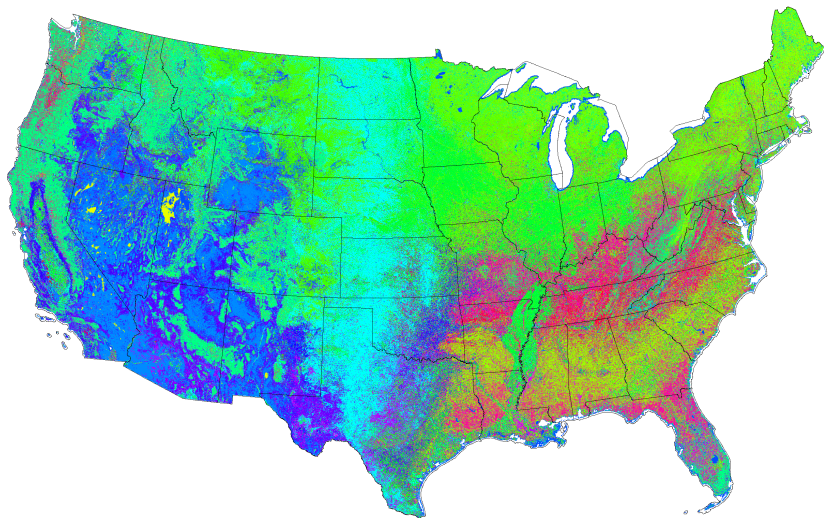
# 5000 Phenoregions Reclassed Goodness of Fit
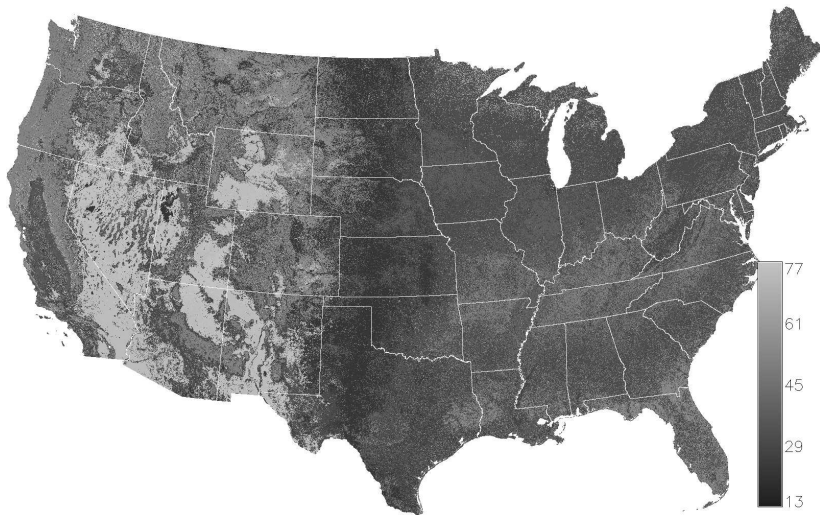
Composition of the 64 Land Cover Types Map

	Map	Cats	WCats	WClusts	%Area
2.	Foley Land Cover	14	6	1456	15.15
5.	Holdridge Life Zones	25	9	495	15.03
7.	BATS Land Cover	17	5	235	14.20
15.	National Land Cover Database 2006	16	8	683	13.91
8.	IGBP Land Cover	16	3	70	9.27
14.	Major Land Resource Areas	197	2	3	8.21
1.	DeFries UMd Vegetation	12	4	272	5.75
12.	Leemans-Holdridge Life Zones	26	8	473	5.27
13.	Matthews Vegetation Types	19	6	288	4.71
4.	GAP National Land Cover	578	3	436	3.63
16.	Wilson, Henderson, & Sellers Primary Vegetation Types	23	3	4	2.33
11.	USGS Land Cover	24	3	450	1.79
6.	Küchler Types	117	1	2	0.38
3.	Fedorova, Volkova, and Varlyguin World Vegetation Cover	31	3	133	0.32
9.	Olson Global Ecoregions	49	0	0	0.00
10.	Seasonal Land Cover Regions	194	0	0	0.00
	TOTAL		64	5000	100%

Cluster	Land Cover Label	Land Cover Map
1	Arable cropland	wilsonhendersonsellersprimaryveg
2	Barren land	NLCD2006
3	Boreal Evergreen Forest/Woodland	foleylandcover
4	Boreal moist forest	holdridgezonesnormal
5	Cold-deciduous forest, with evergreens	matthewsvegetation
6	Cold-deciduous forest, without evergreens	matthewsvegetation
7	Cool temperate moist forest	holdridgezonesnormal
8	Cool temperate steppe	holdridgezonesnormal
9	Cropland/Natural Vegetation Mosaic	landcover.igbp
10	Deciduous Broadleaf Trees	landcover.bats
11	Evergreen Coniferous Forest	landcover.usgs
12	Evergreen/Deciduous Mixed Forest/Woodland	foleylandcover
13	Grassland/herbaceous	NLCD2006
14	Interrupted Forest	landcover.bats
15	Juniper/Pinyon	ktlamb
16	Meadow, short grassland, no woody cover	matthewsvegetation
17	Mixed Forest	defriesumdvegetation
18	Mountains	fvvcode
19	Open Shrubland	foleylandcover
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21	Pasture/Hay	GAP
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24	Sacramento and San Joaquin Valleys, MLRA 17	mlra
25	Savanna	landcover.usgs
26	Semidesert	landcover.bats
27	Short Grass	landcover.bats
28	Shrub/scrub	NLCD2006
29	Subboreal	fvvcode
30	Subtropical dry forest	holdridgezonesnormal
31	Subtropical	fvvcode
32	Subtropical moist forest	holdridgezonesnormal

Cluster	Land Cover Label	Land Cover Map
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35	Tall/medium/short grassland with 10–40% woody tree cover	matthewsvegetation
36	Tall/medium/short grassland with shrub cover	matthewsvegetation
37	Temperate Deciduous Forest/Woodland	foleylandcover
38	Temperate Needleleaf Evergreen Forest/Woodland	foleylandcover
39	Temperate rough grazing	wilsonhendersonsellersprimaryveg
40	Temperate/subpolar evergreen needleleaved forest	matthewsvegetation
41	Warm temperate dry forest	holdridgezonesnormal
42	Warm temperate moist forest	holdridgezonesnormal
43	Warm Temperate Moist Forest	leemansholdridgezones
44	Warm temperate thorn scrub	holdridgezonesnormal
45	Warm Temperate Thorn Steppe	leemansholdridgezones

5000 Phenoregions Reclassed into 45 Land Cover Types
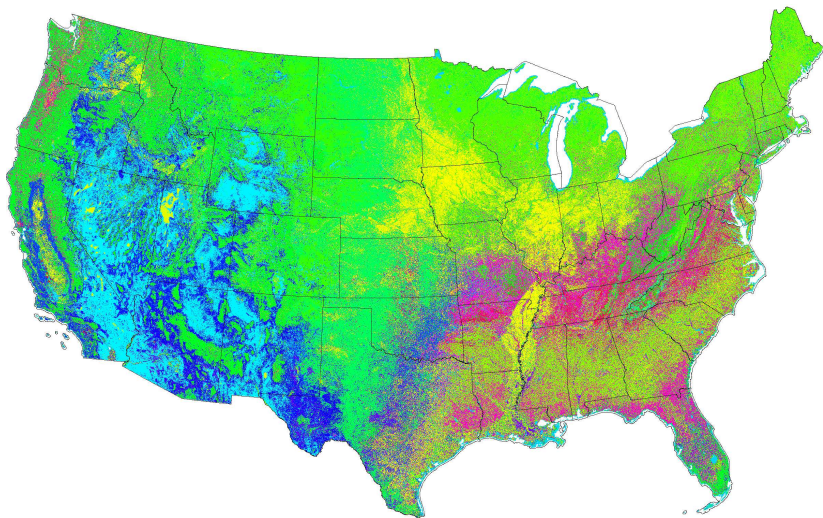
Uses for Label Stealing

- Borrowing ecoregion, land cover, or vegetation type labels for unsupervised classifications.
- Automated attribution of disturbance agents through comparison of a *ForWarn* disturbance map with ADS aerial sketchmaps, wildfire perimeters, tornado track maps, and fuel treatment maps through time.
- Determination of the most important driving variable for phenoregions maps through comparison with separate maps of slope, aspect, solar input, elevation, soil types, etc.
- Automated recognition of species composition of forest vegetation through comparison of a phenoregions map with individual tree species range maps.

See Related Presentations by Collaborators

Next in the **Phenology I** oral session in **Capitol C**:

- **10:20–10:40 a.m.** *Using Land Surface Phenology for National Mapping of the Occurrence and Health of Evergreen and Deciduous Forests* by William W. Hargrove, Joseph P. Spruce, Steven P. Norman, Jitendra Kumar, and Forrest Hoffman

Before lunch in the **Invasives** oral session in **Capitol View Terrace South**:

- **11:40 a.m.–12:00 p.m.** *ForWarn Forest Disturbance Change Detection System Provides a Weekly Snapshot of US Forest Conditions to Aid Forest Managers* by William W. Hargrove, Joseph P. Spruce, Steven P. Norman, and Forrest M. Hoffman

This afternoon in the **Phenology II** oral session in **Capitol C**:

- **1:20–1:40 p.m.** *Recent Efforts to Improve the Near Real Time Forest Disturbance Monitoring Capabilities of the ForWarn System* by Joseph P. Spruce, William W. Hargrove, and Gerald E. Gasser

- **2:40–3:00 p.m.** *Predicting Long-term Wildfire Effects from Multi-seasonal Satellite Data* by Steven P. Norman, William W. Hargrove, Joseph P. Spruce, and William M. Christie

Acknowledgments

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of geophysical disturbance using hyperspectral imagery. Master's thesis,
University of Tennessee, Department of Physics and Astronomy,
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L04705, February 2005. doi: 10.1029/2004GL021961.

William W. Hargrove, Forrest M. Hoffman, and Paul F. Hessburg.
Mapcurves: A quantitative method for comparing categorical maps. *J.
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10.1007/s10109-006-0025-x.