Crop mapping for Continental United States using a remotely sensed phenology metric

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Why Crop Mapping?

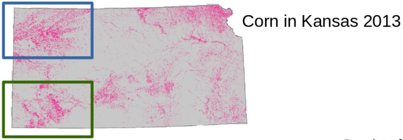
- Recent studies show that the global agricultural production would have to roughly double by 2050.
- These increases would have major environmental impacts.
- Remote sensing data from satellite based sensors provides an objective means to accurately map crop types.
- Use of Phenological metrics (derived from seasonal changes in crop progress like the beginning of green-up or dormancy).

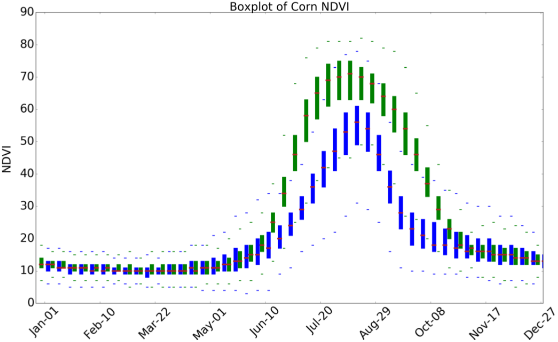
Crop mapping for US

- The United States is a major food producer in the world accounting for about 30% of the world grain exports and crop cultivation accounts for nearly 80% of all water use.
- The Cropland Data Layer (CDL) provided by USDA for CONUS based on extensive ground reference data collected during the mapping year.
- Field data collection for CDL extremely time consuming,expensive and labor-intensive. It is not available for access to the general public.
- The georeferenced raster map is not released until the beginning of the subsequent calendar year for market sensitivity reasons.

Crop mapping for large areas

One of the challenges in using remote sensing data for large area crop mapping is the **variability in ecological zones, which can result in different timing of crop phenological development**.





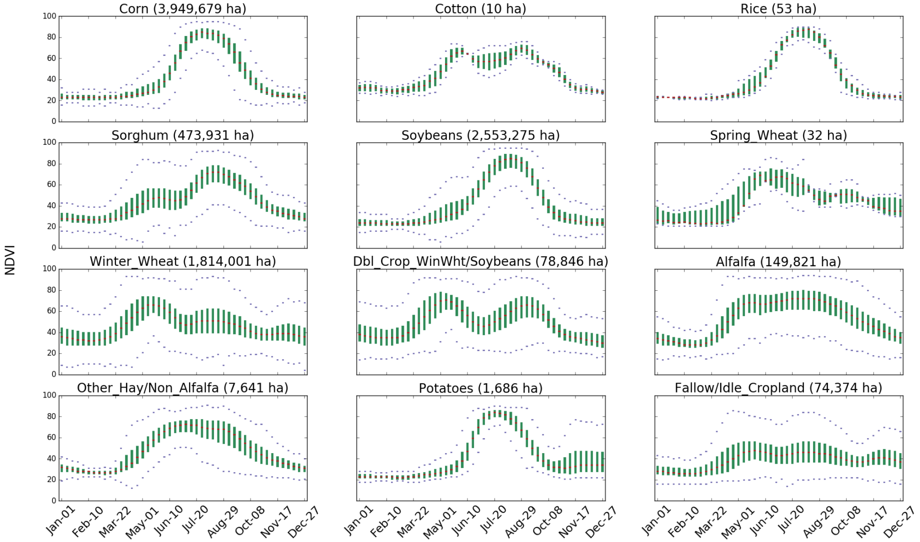
Objectives

1. *Develop a generalized phenology based classification algorithm to map major crops across CONUS*.
2. *Perform the classification at the scale of ecoregions*.
3. *Perform a mid-season crop mapping*.

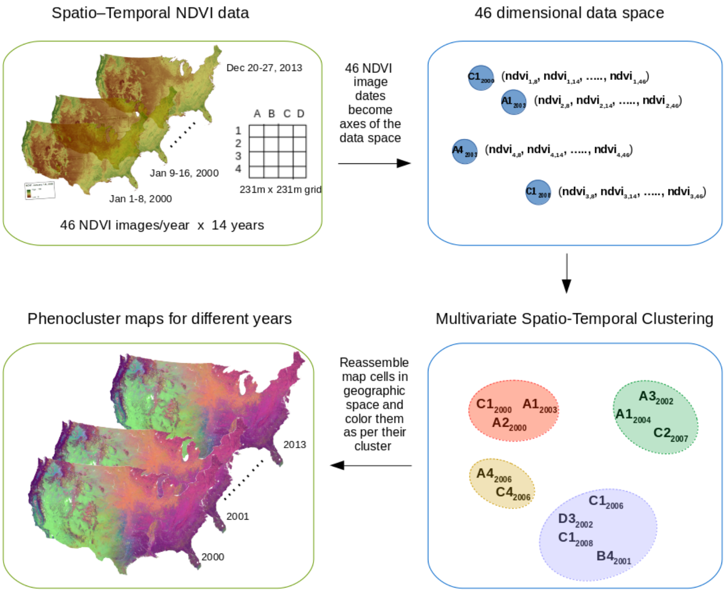
Data

- Remotely Sensed Data
  Smoothed and gap-filled **MODIS Normalized Difference Vegetation Index (NDVI)** data, at **250m spatial resolution and 8-day frequency**, for the entire CONUS was downloaded from the the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center for Biogeochemical Dynamics (DAAC) website for the period 2000-2013.
- Reference Data
  The study was performed for the cropland extent for the CONUS defined by the **USDA Cropland Data Layer (CDL)** for the years 2008-2013 at 30m resolution. To avoid the problem of mixed pixels, the training for the classifier was done only on pure crop pixels from CDL.

Crop specific NDVI profiles for an ecoregion in the US midwest over 2008-12



Classification (Step 1) - Creation of Phenocluster Maps



Classification (Step 2) - Assigning Crop Labels to Phenoclusters

Crop Data Layer

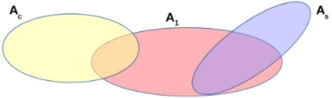
Corn	Corn	Soy	Soy
Corn	Soy	Soy	Soy
Soy	Soy	Soy	Soy
Soy	Soy	Soy	Corn

Assign crop labels to clusters →

Phenocluster map

1	1	1	1
1	1	1	1
1	1	1	2
1	1	2	2

Find Goodness-of-fit (GOF) for every cluster with each crop



GOF for Cluster 1 with Corn = $\frac{A_c \cap A_1}{A_c} * \frac{A_c \cap A_1}{A_1}$

GOF for Cluster 1 with Soy = $\frac{A_s \cap A_1}{A_s} * \frac{A_s \cap A_1}{A_1}$

⋮

For all crops

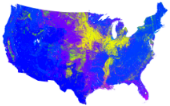
Assign the cluster to the crop with the best fit →

Translate Table

Cluster	Crop
1	Soy
2	Corn
3	Rice
4	Sorghum
⋮	
N	Corn

Reassign the labels geographically →

Phenocluster map reclassed to crop layer categories

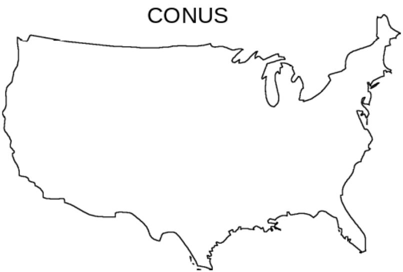


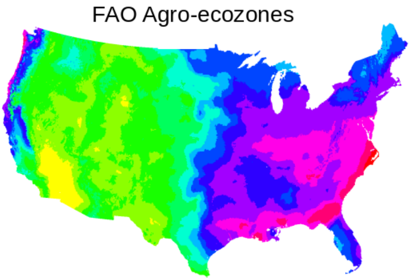
Data used for ecoregion creation

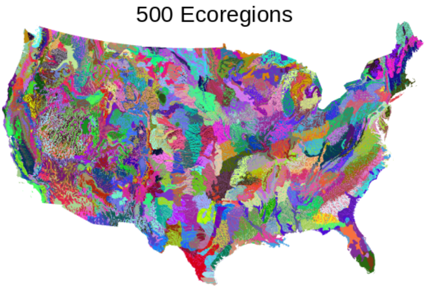
Table: Environmental variables used for ecoregion delineation. These data are in the form of ~1 km raster grids.

Variable Description	Units	Source
Bioclimatic Variables		
Annual mean temperature	°C	Fick and Hijmans (2017)
Mean diurnal range	°C	Fick and Hijmans (2017)
Isothermality	—	Fick and Hijmans (2017)
Temperature seasonality	°C	Fick and Hijmans (2017)
Mean temperature of warmest quarter	°C	Fick and Hijmans (2017)
Mean temperature of coldest quarter	°C	Fick and Hijmans (2017)
Annual precipitation	mm	Fick and Hijmans (2017)
Precipitation seasonality	mm	Fick and Hijmans (2017)
Precipitation during the wettest quarter	mm	Fick and Hijmans (2017)
Precipitation during the driest quarter	mm	Fick and Hijmans (2017)
Edaphic Variables		
Available water holding capacity of soil	mm	Global Soil Data Task Group (2000); Saxon et al. (2005)
Bulk density of soil	g/cm^3	Global Soil Data Task Group (2000); Saxon et al. (2005)
Soil carbon density	g/m^2	Global Soil Data Task Group (2000); Saxon et al. (2005)
Total nitrogen density	g/m^2	Global Soil Data Task Group (2000); Saxon et al. (2005)
Topographic Variables		
Compound topographic index (relative wetness)	–	Saxon et al. (2005)

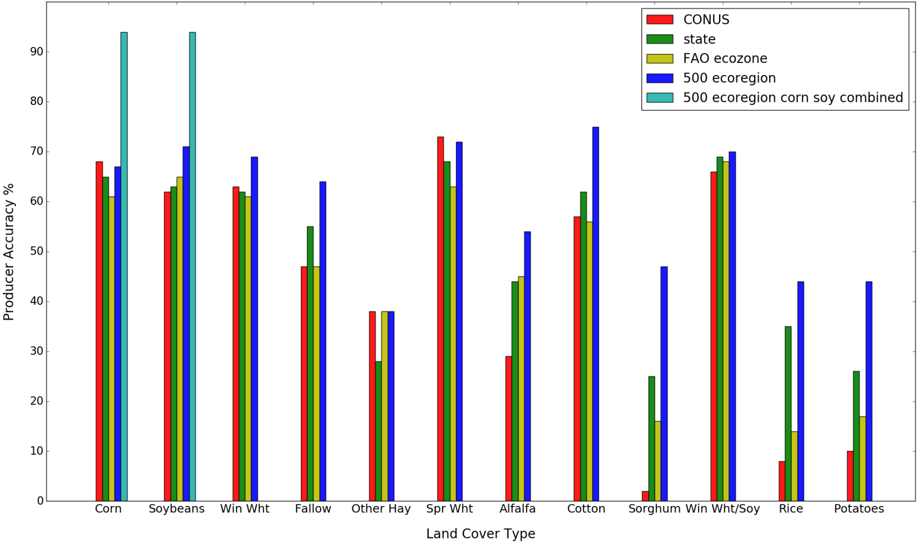
Training the algorithm at different spatial scales



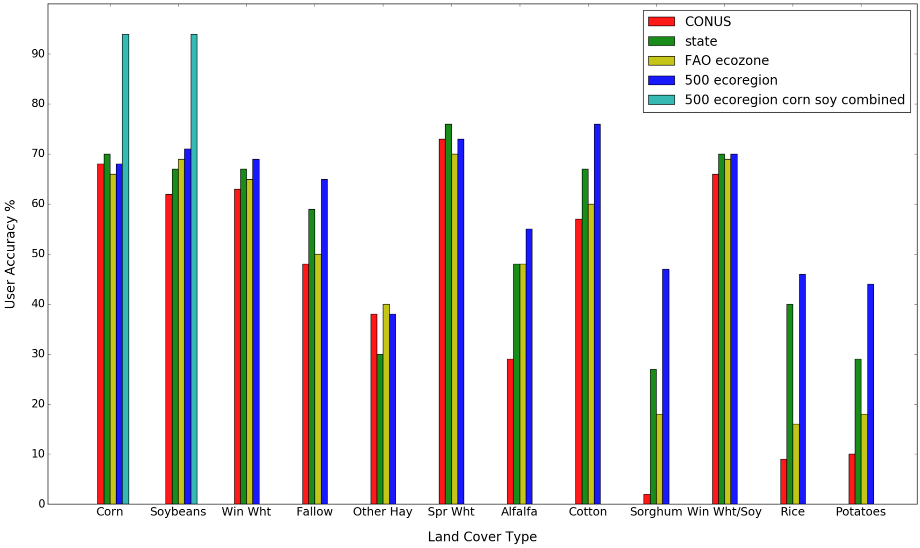




2013 Producer Accuracy (Probability that a CDL pixel will be correctly mapped)



2013 User Accuracy (Probability that a reclassed map pixel matches the CDL)



Crop types getting misclassified

- Corn - Soybeans
- Other Hay with most other crops
- Winter Wheat and Fallow

		Crop Data Layer								User
		Corn	Rice	Sorghum	Soybeans	WinWht	Alfalfa	Other Hay	Fallow	Accuracy (%)
Reclassed Map	Corn	12991	17	173	3174	252	295	522	207	71.14
	Rice	69	233	11	58	0	1	1	24	56.28
	Sorghum	149	0	619	54	154	15	38	92	52.15
	Soybeans	4786	200	87	10099	129	51	359	149	60.68
	WinWht	130	0	114	74	4814	144	245	320	75.00
	Alfalfa	103	0	2	14	79	1279	282	38	64.47
	Other Hay	145	0	1	65	66	281	1357	71	63.83
	Fallow	164	16	87	57	870	56	158	2560	59.36
Producer Accuracy (%)		68.11	47.17	48.25	71.51	70.08	56.07	39.24	65.49	64.11

Table: Confusion Matrix for CONUS

Reasons behind misclassification

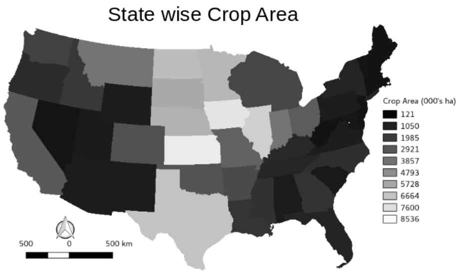
- Similar phenologies for certain crops.
- Poor CDL accuracies for less important crops

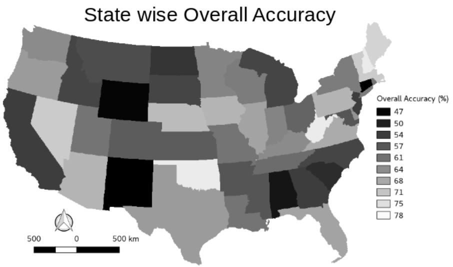
Crop type	Area (x 1000 ha)	Producer Acc (%)	User Acc (%)
Winter Wheat	399	94.4	94.5
Corn	179	93.2	93.6
Soybeans	144	92.9	92.9
Fallow	124	87.5	87.8
Sorghum	124	89.3	89.3
Other Hay/Non Alfalfa	50	**56.1**	90.4
Double Crop WinWht/Soy	35	85.9	85.3
Alfalfa	22	85.9	91.2
Cotton	0.82	**62.7**	**87**
Potatoes	0.13	**75.7**	95.4

Table: Accuracy table for the 2013 CDL for Kansas (Downloaded from the USDA CDL website)

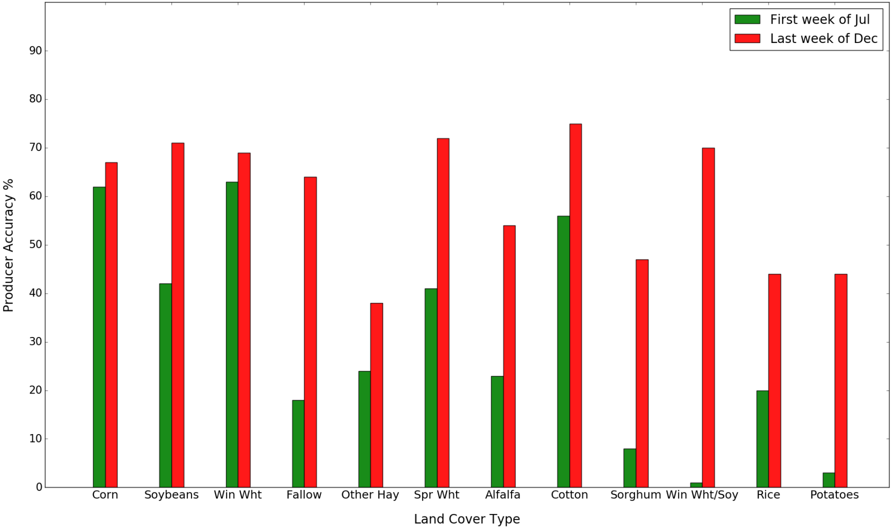
- Mixed pixel effect

State wise Overall Accuracy

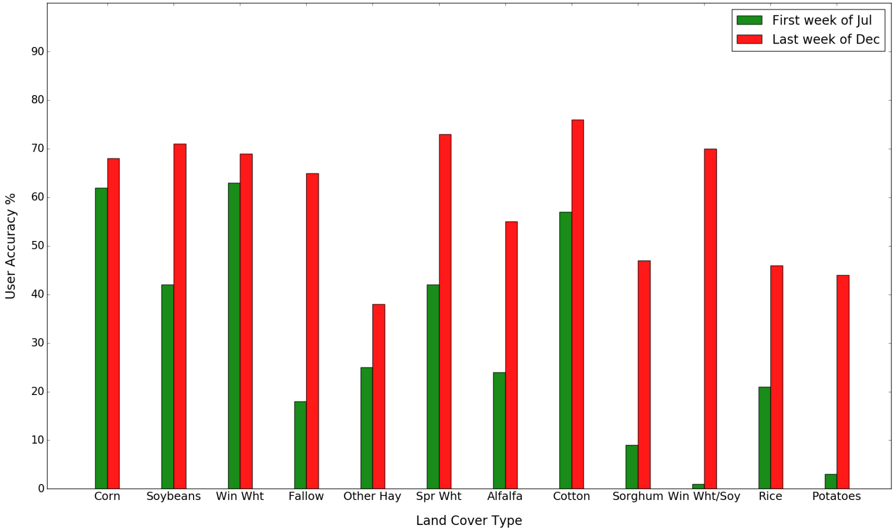




Producer Accuracy for Mid-season Mapping



User Accuracy for Mid-season Mapping



Conclusions

- Land surface phenology metrics can be used to identify and map crops at continental (to global) scale.
- While accuracy are high for dominant crops, they tend to be be lower for less dominant crops (in part due to mixed pixel effect and limited training data).
- Use of ecoregions helps to reduce crop misclassification by addressing spatial variability and allowing for development of more specific models.
- By tracking temporally resolved land surface phenology it's possible to map crops like Corn and Winter wheat mid-way through the season with fair accuracy.

Future Work

- Develop a system for continuous tracking and mapping of agricultural ecosystem using near real time remote sensing (similar to USDA Forest Service ForWarn).
- Estimate crop yield based on phenological trajectory/completion metric through the season.

Acknowledgements

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