



# Satellite Remote Sensing Imagery Quality and Timeliness: Considerations for Use in Regional Estimation of Crop Production



United States Department of Agriculture  
National Agricultural Statistics Service

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BLS Data Quality Workshop, December 1, 2017  
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# Most popular crop reports from NASS



ISSN: 1949-1522

Released June 28, 2013, by the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA).

**Corn Planted Acreage Up Slightly from 2012**  
**Soybean Acreage Up 1 Percent**  
**All Wheat Acreage Up 1 Percent**  
**All Cotton Acreage Down 17 Percent**

Corn planted area for all purposes in 2013 is estimated at 97.4 million acres, up slightly from the highest planted acreage in the United States since 1936 when an estimated 102 million acres expect to harvest 89.1 million acres for grain, up 2 percent from last year.

**Soybean** planted area for 2013 is estimated at a record high 77.7 million acres, up 1 percent from harvest, at 76.9 million acres, is up 1 percent from 2012 and will be a record high, if realized. It is estimated in New York, Pennsylvania, and South Dakota.

**All wheat** planted area for 2013 is estimated at 56.5 million acres, up 1 percent from 2012. The planted area, at 42.7 million acres, is 3 percent above last year and up 2 percent from the previous year. About 29.4 million acres are Hard Red Winter, 9.96 million acres are Soft Red Winter, and 3.38 million acres are Hard Red Spring wheat. Area planted to other spring wheat for 2013 is estimated at 12.3 million acres, up slightly about 11.7 million acres are Hard Red Spring wheat. The estimated Durum wheat planted area is 1.54 million acres, down 28 percent from the previous year.

**All cotton** planted area for 2013 is estimated at 10.3 million acres, 17 percent below last year, 10.0 million acres, down 17 percent from 2012. American Pima area is estimated at 226,000 acres in 2012.

## Acreage



ISSN: 1936-3737

Released May 9, 2014, by the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA).

**Winter Wheat Production Down 9 Percent from 2013**  
**Orange Production Up Slightly from April Forecast**

Winter wheat production is forecast at 1.40 billion bushels, down 9 percent from 2013. As of yield is forecast at 43.1 bushels per acre, down 4.3 bushels from last year.

Hard Red Winter production, at 746 million bushels, is up slightly from a year ago. Soft Red bushels, is down 21 percent from 2013. White Winter, at 209 million bushels, is down 7 percent. White Winter production, 10.9 million bushels are Hard White and 198 million bushels are Soft White.

The **United States all orange** forecast for the 2013-2014 season is 7.21 million tons, up slightly from the previous forecast but down 13 percent from the 2012-2013 final utilization. The Florida all orange forecast (4.96 million tons), is up slightly from the previous forecast but down 17 percent from last season. Early, midseason, and Navel varieties in Florida are forecast at 53.3 million boxes (2.40 million tons), the previous forecast but down 21 percent from last season. The Florida Valencia orange forecast (2.57 million tons), is unchanged from the previous forecast but down 14 percent from last season. California and Texas production forecasts are carried forward from April.

Florida frozen concentrated orange juice (FCOJ) yield forecast for the 2013-2014 season is 42.0 degrees Brix, down 1 percent from the April forecast and down 1 percent from last season. Yield is projected at 1.59 gallons per box. The early-midseason portion is projected at 1.51 gallons per box, up 1 percent from last year. The Valencia portion is projected at 1.64 gallons per box, down 1 percent from last year. All projections of yield assume the processing relationships this season will be similar to several seasons.

## Crop Production



ISSN: 1948-3007

Released May 12, 2014, by the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA).

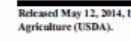
### Corn Planted - Selected States

[These 18 States planted 91% of the 2013 corn acreage]

State	Week ending			2009-2013 Average
	May 11, 2013 (percent)	May 4, 2014 (percent)	May 11, 2014 (percent)	
Colorado	29	36	34	56
Illinois	16	43	78	53
Indiana	27	20	61	45
Iowa	14	23	70	70
Kansas	29	55	72	83
Kentucky	38	38	64	59
Michigan	28	3	20	41
Minnesota	16	8	31	62
Missouri	27	89	89	62
Nebraska	59	44	77	71
North Carolina	92	76	90	96
North Dakota	16	-	3	33
Ohio	49	9	40	46
Pennsylvania	45	8	27	41
South Dakota	33	25	52	43
Tennessee	82	68	87	76
Texas	77	73	80	85
Wisconsin	13	2	20	41
18 States	26	29	59	58

\*Represents zero.

## Crop Progress



Released May 12, 2014, by the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA).

### Corn Planted - Selected States

[These 18 States planted 91% of the 2013 corn acreage]

State	Week ending			2009-2013 Average
	May 11, 2013 (percent)	May 4, 2014 (percent)	May 11, 2014 (percent)	
Colorado	1	-	4	9
Illinois	2	8	38	32
Indiana	3	2	14	28
Iowa	1	1	9	29
Kansas	5	19	35	30
Kentucky	21	15	32	45
Michigan	1	-	1	10
Minnesota	-	-	-	18
Missouri	14	29	53	40
Nebraska	2	7	18	21
North Carolina	85	56	70	84
North Dakota	1	-	1	6
Ohio	2	-	3	21
Pennsylvania	8	-	7	12
South Dakota	1	1	4	9
Tennessee	43	36	53	82
Texas	88	58	85	69
Wisconsin	-	-	-	6
18 States	5	7	18	25

\*Represents zero.

### Corn Emerged - Selected States

[These 18 States planted 91% of the 2013 corn acreage]

State	Week ending			2009-2013 Average
	May 11, 2013 (percent)	May 4, 2014 (percent)	May 11, 2014 (percent)	
Colorado	1	-	4	9
Illinois	2	8	38	32
Indiana	3	2	14	28
Iowa	1	1	9	29
Kansas	5	19	35	30
Kentucky	21	15	32	45
Michigan	1	-	1	10
Minnesota	-	-	-	18
Missouri	14	29	53	40
Nebraska	2	7	18	21
North Carolina	85	56	70	84
North Dakota	1	-	1	6
Ohio	2	-	3	21
Pennsylvania	8	-	7	12
South Dakota	1	1	4	9
Tennessee	43	36	53	82
Texas	88	58	85	69
Wisconsin	-	-	-	6
18 States	5	7	18	25

\*Represents zero.

## Monthly

## Annually

## Weekly

# NASS Research and Development Division

## Spatial Analysis Research Section

**NASS - Research and Science - Windows Internet Explorer**  
http://www.nass.usda.gov/Research\_and\_Science/index.asp

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NASS - Research and Science

USDA United States Department of Agriculture  
National Agricultural Statistics Service

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Statistics by State Select a State

Vegetation Condition Images Cropland Data Layer Image Gallery (2003) available for these states: Arkansas, Illinois, Indiana, Iowa, N. Dakota, Mississippi, Missouri, Nebraska, Wisconsin Land Use Strata for Selected States

Census of Agriculture 2002 Census Map Gallery 2002 Maps: Gallery | Star Tree | List Interact with Data (1997) "Linked Micromap" Plots (1997): Corn | Cotton | Hay | Soybeans | Wheat

Animated Maps Crop Acreage Vegetation Condition Corn | Cotton | Oats | Soybeans | Wheat

Reporters and Presentations State: K307 AD: 00 Crop: Com\_PL Stratum: 12 Version: V1b

Reported Acres Line of LPLs WPL Break Lines 95% Conf Lines Outliers

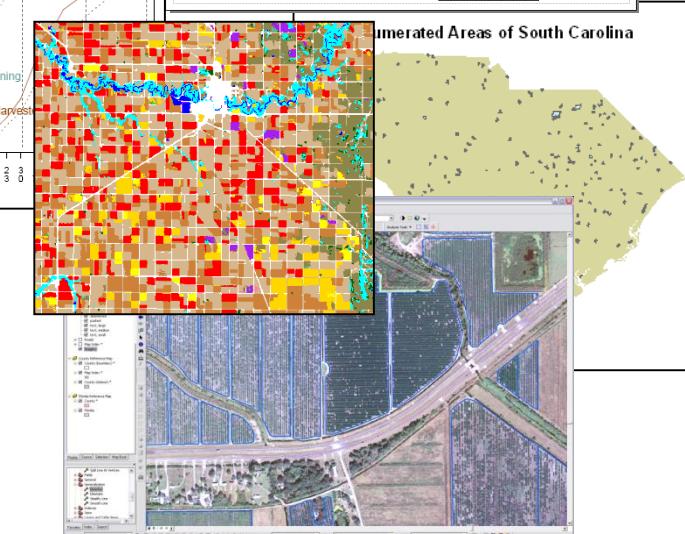
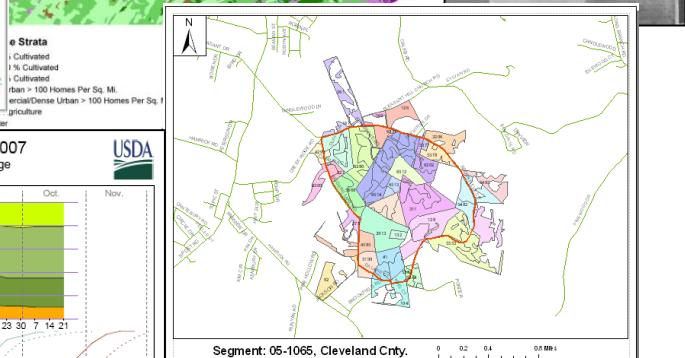
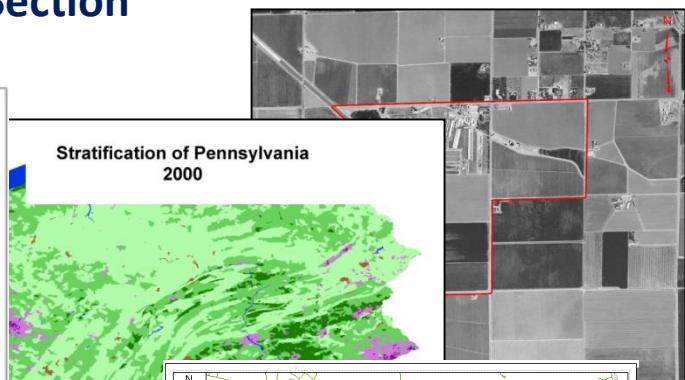
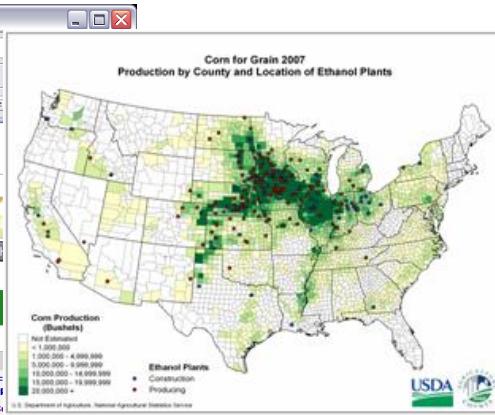
733 archived reports available for download. Area: GIS | Survey | Yield | "Star Tree" Diagram | Presenter Last modified: 8/13/2007

Statistics System (ESS) Site Non-Discrimination Statement

Reported Acres Line of LPLs WPL Break Lines 95% Conf Lines Outliers

733 archived reports available for download. Area: GIS | Survey | Yield | "Star Tree" Diagram | Presenter Last modified: 8/13/2007

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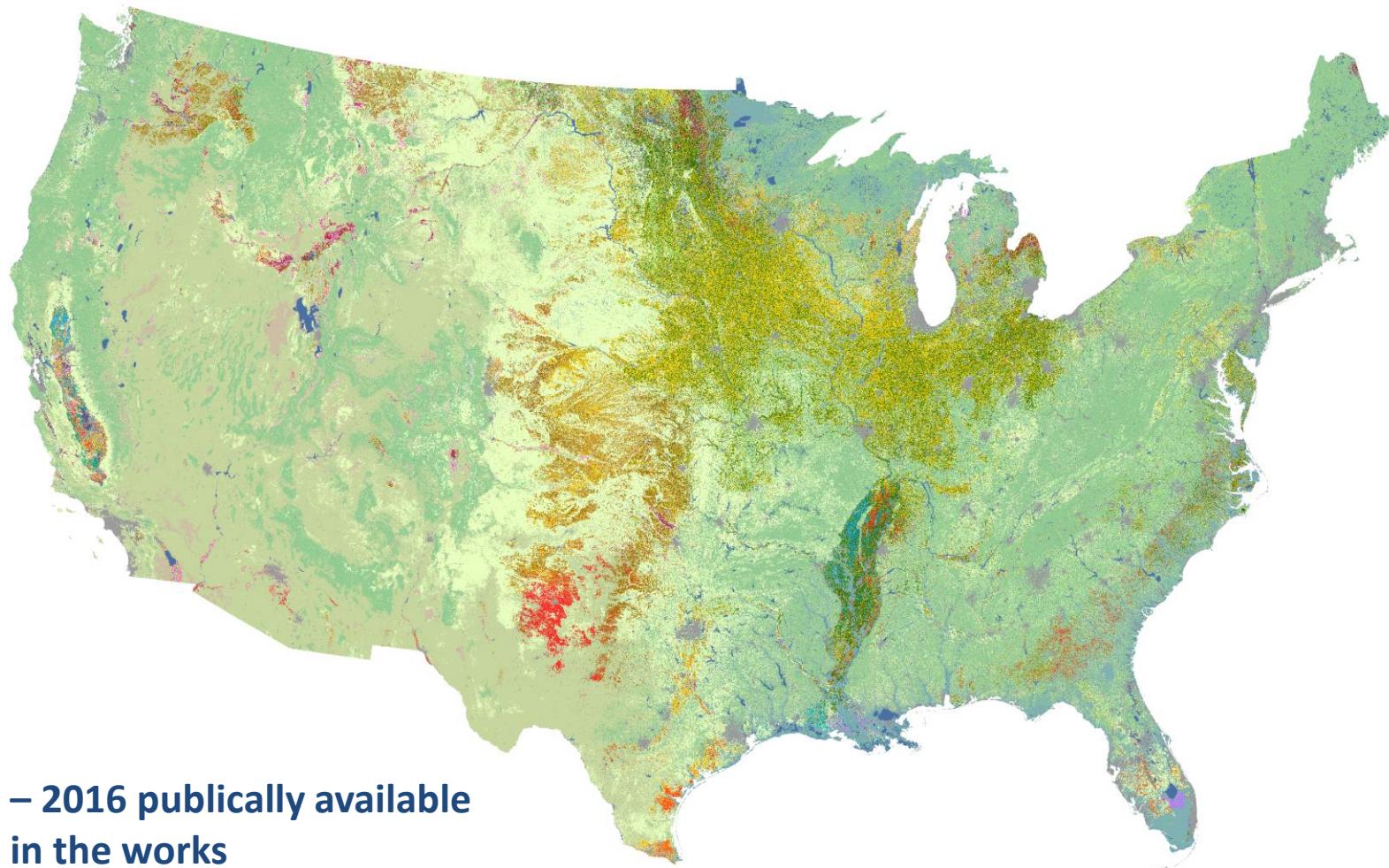
# Land cover mapping - Cropland Data Layer (CDL)

## Agriculture

Pasture/Grass	Fallow/Idle Cropland
Corn	Alfalfa
Soybeans	Cotton
All Wheat	Other Crops
Other Hay	Vegetables/Fruits/Nuts

## Non-Agriculture

Woodland	Barren
Shrubland	Perennial Ice/Snow
Urban/Developed	
Wetlands	
Water	



\* 2008 – 2016 publically available

\* 2017 in the works

\* 2008 and 2009 being reprocessed from 56m to 30m

Landsat Missions | David

Secure | https://landsat.usgs.gov

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**Landsat Headlines**

**November 29, 2017**

**November 21, 2017**

**November 08, 2017**

**November 01, 2017**

**October 30, 2017**

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November 29, 2017 - Delivery changes to Band 4 Solar/Sensor Zenith/Azimuth Angle Bands

A recent software release to the Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA) on-demand interface changes the delivery to users of the Band 4 Solar/Sensor zenith/azimuth angle bands. (Read More)

November 21, 2017 - Landsat Analysis Ready Data for Alaska and Hawaii Available

USGS Landsat Analysis Ready Data (ARD) for Alaska and Hawaii are now available for download from EarthExplorer. This completes the release of U.S. Landsat ARD for all 50 states. (Read More)

November 8, 2017 - New Video Introduces Landsat Analysis Ready Data

A new video introducing Landsat Analysis Ready Data (ARD) has been added to the Landsat ARD webpage, as well as the Landsat Media Library. (Read More)

November 1, 2017 - Upcoming Infrastructure Maintenance

On **Tuesday, November 7, 2017**, the USGS EROS Center in Sioux Falls, South Dakota will **temporarily halt Landsat data processing at 11:00 am CST**, and **all data distribution from EarthExplorer, GloVis, the LandsatLook Viewer, and ESPA at 3:00 pm CST** due to planned required infrastructure maintenance. (Read More)

October 30, 2017 - Landsat Analysis Ready Data Available

USGS Landsat Analysis Ready Data (ARD) for the conterminous United States are now available for download from EarthExplorer. (Read More)

Landsat Missions | GloVis | David

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GloVis

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Interface Controls

Selected Scenes (0)

Lat: 39.5464, Lon: -73.7732

Choose Your Data Set(s)

Data Set Filter

- Landsat 1-5 MSS
- Landsat 4-5 TM C1 Level-1
- Landsat 7 ETM+ C1 Level-1
- Landsat 8 OLI/TIRS C1 Level-1

133 scenes match your criteria.

- OrbView-3
- Sentinel-2

Metadata Filter

Date Range mm/dd/yyyy to mm/dd/yyyy

Cloud Cover 0-100 or empty to 0-100 or empty

Months Jan Feb

APPLY CLEAR

Washington

Selected Scenes (0)

Lat: 39.5464, Lon: -73.7732

30 Km 20 mi

Landsat 8 OLI/TIRS C1 Level-1 LC08\_L1TP\_015033\_20171126\_20171126\_01\_RT Acquired on 2017-11-26

Current Scene Browse Opacity (100%)

PREVIOUS SELECT NEXT

Leaflet | Map data © OpenStreetMap contributors, USGS/EROS

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LandSat Missions | X | GisVis

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Interface Controls

Selected Scenes (0)

Lat: 39.1599, Lon: -77.3780

+ -

Choose Your Data Set(s)

Data Set Filter

- Landsat 1-5 MSS
- Landsat 4-5 TM C1 Level-1
- Landsat 7 ETM+ C1 Level-1
- Landsat 8 OLI/TIRS C1 Level-1 **239 scenes match your criteria.**
- Ortoview-3
- Sentinel-2

Metadata Filter

Date Range

From/To

Cross Cover

0-100 or empty To 0-100 or empty

Months

Jan Feb

APPLY CLEAR

Leaflet Map View Open Close Map Contributors USGS EROS

Landsat 8 OLI/TIRS C1 Level-1 LC08\_L1TP\_015033\_20170822\_20170912\_01\_T1 Acquired on 2017-08-22

Current Scene Browse Opacity (100%)

PREVIOUS SELECT NEXT

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Page Last Modified: 08/18/2017

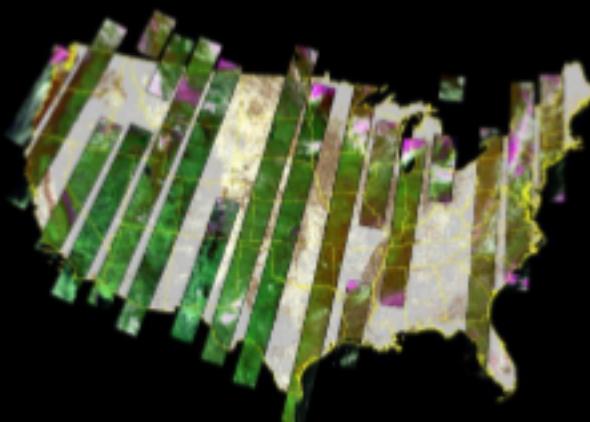
USA.gov

**2017: June 16 – 22**

Agricultural areas



Landsat 8



Sentinel 2a



DMC Deimos



DMC UK2



Resourcesat-2 LISS3

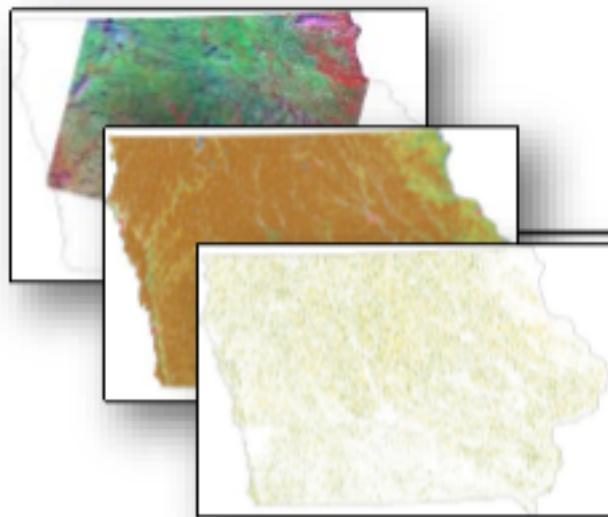


# Available satellite imagery 2017: June 16 – 22



# CDL Processing Flow

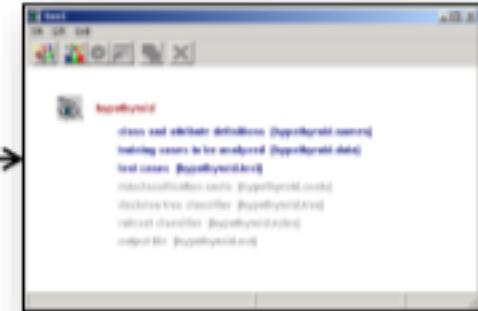
## Input Data



## Sampling



See5



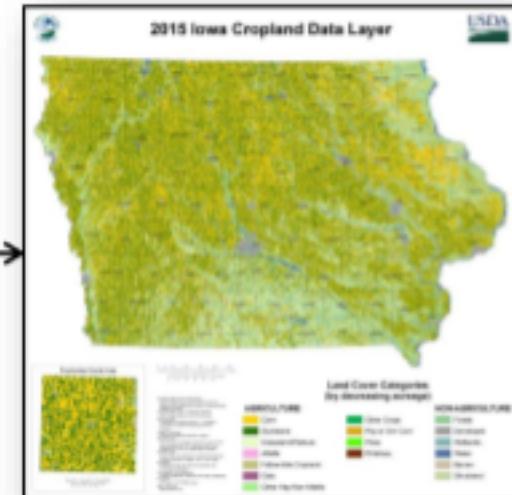
## Decision Tree



## Classification

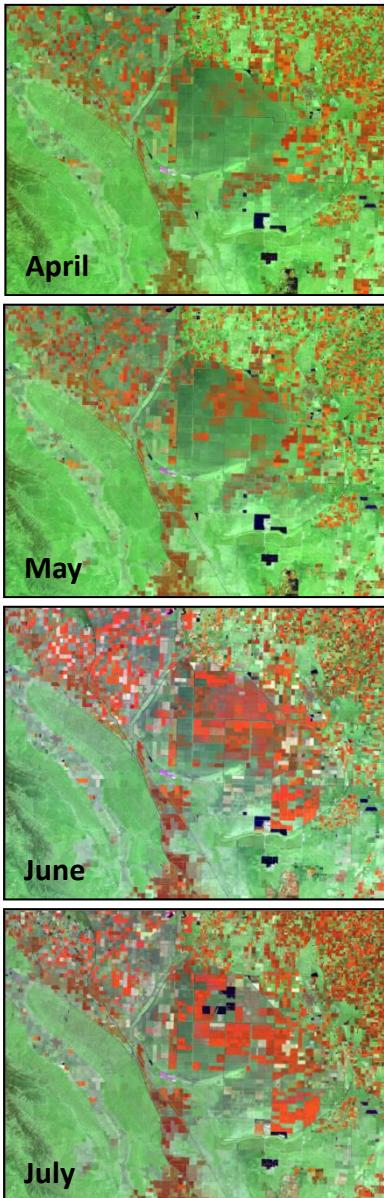


## Output – ArcGIS



# Classification

## False Color IR Imagery

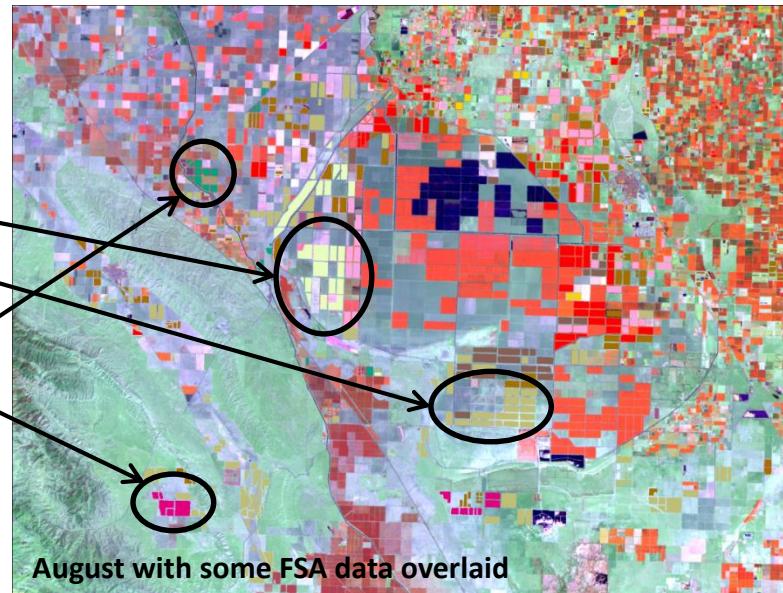


## FSA Ground Truth

### Land Cover Categories

#### Agriculture

- Pasture/Grass
- Alfalfa
- Fallow/Idle Cropland
- Winter Wheat
- Barley
- Cotton
- Almonds
- Corn
- Durum Wheat

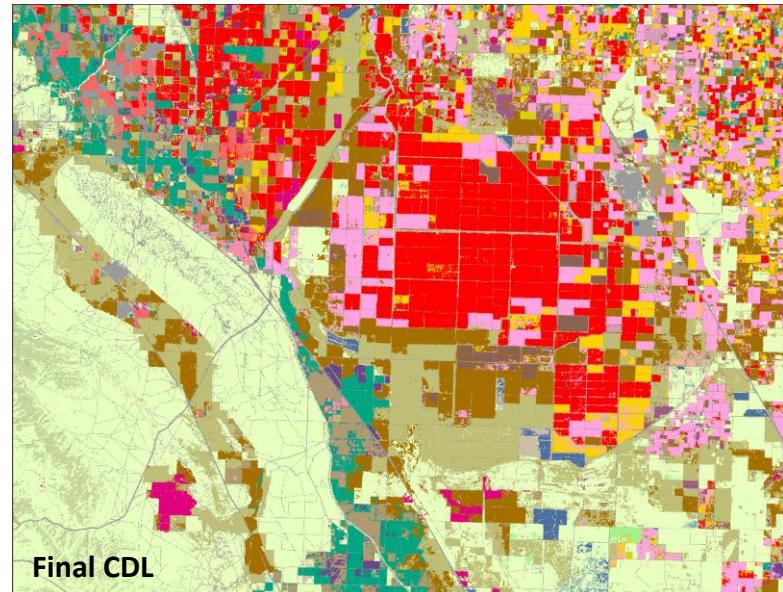


## Final Classification

### Land Cover Categories

#### Agriculture

- Pasture/Grass
- Alfalfa
- Fallow/Idle Cropland
- Winter Wheat
- Barley
- Cotton
- Almonds
- Corn
- Durum Wheat



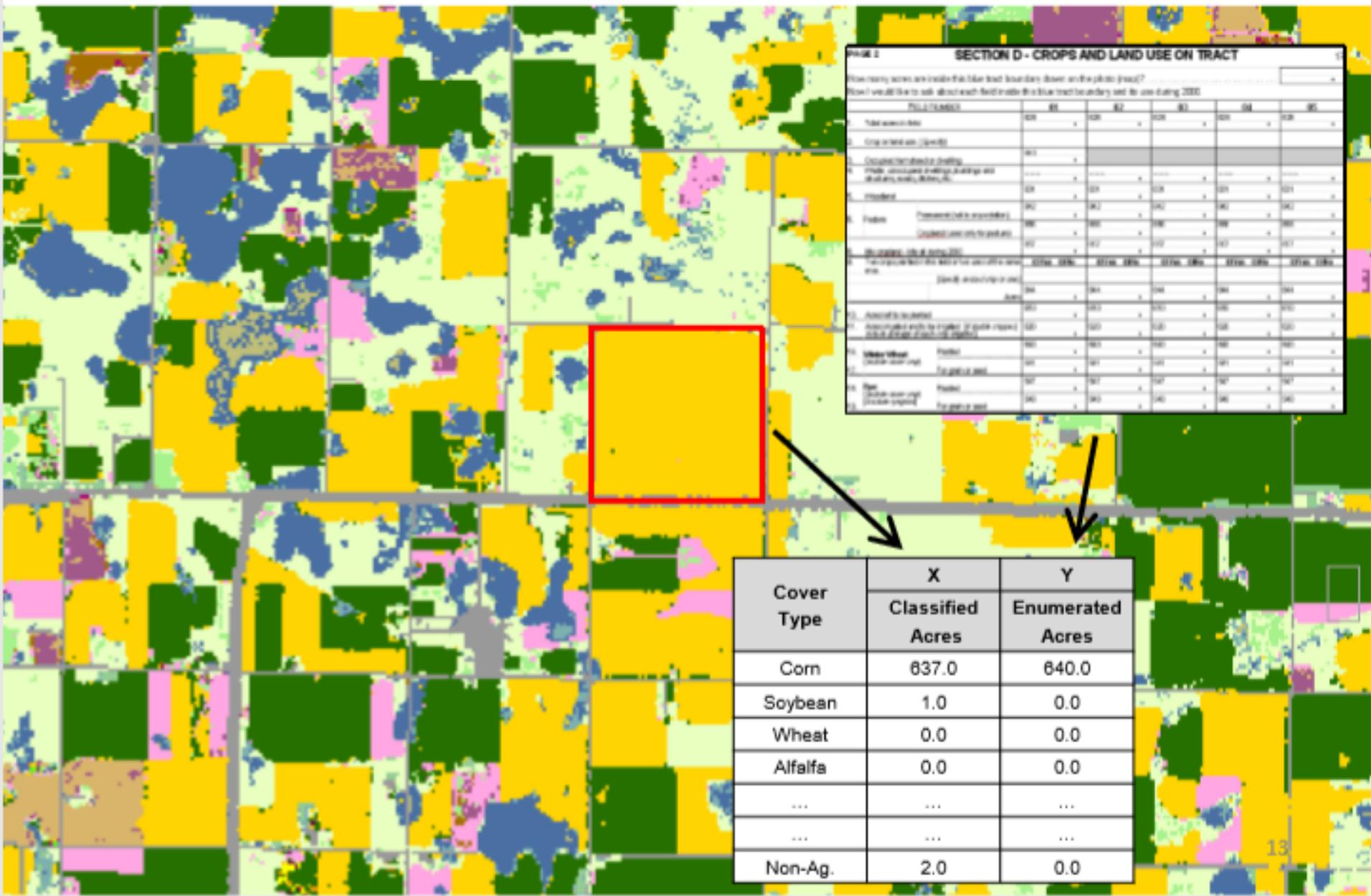
# Accuracy Assessments

USDA, National Agricultural Statistics Service, 2014 Colorado Cropland Data Layer  
STATEWIDE AGRICULTURAL ACCURACY REPORT

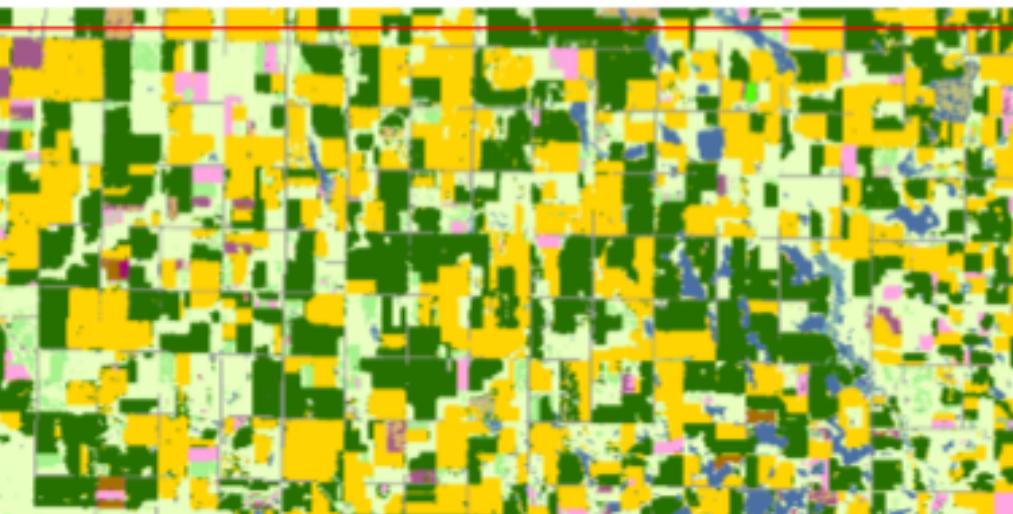
Crop-specific covers only	*Correct	Accuracy	Error	Kappa
OVERALL ACCURACY**	2,630,488	85.5%	14.5%	0.812

Cover Type	Attribute Code	*Correct Pixels	Producer's Accuracy	Omission Error	User's Accuracy	Commission Error	Cond'l Kappa
Corn	1	419737	90.76%	9.24%	0.895	90.22%	9.78% 0.889
Sorghum	4	83214	62.32%	37.68%	0.611	64.72%	35.28% 0.635
Soybeans	5	1058	43.25%	56.75%	0.432	72.47%	27.53% 0.724
Sunflower	6	5760	39.64%	60.36%	0.395	70.61%	29.39% 0.705
Barley	21	7176	71.52%	28.48%	0.715	81.00%	19.00% 0.810
Winter Wheat	24	1100020	93.26%	6.74%	0.905	94.21%	5.79% 0.918
Millet	29	75109	67.86%	32.14%	0.671	76.85%	23.15% 0.762
Alfalfa	36	196153	89.75%	10.25%	0.891	85.60%	14.40% 0.848
Other Hay/Non Alfalfa	37	84626	63.33%	36.67%	0.624	85.92%	14.08% 0.854
Sugarbeets	41	4679	63.13%	36.87%	0.631	90.28%	9.72% 0.903
Dry Beans	42	9406	62.72%	37.28%	0.626	69.54%	30.46% 0.694
Potatoes	43	6104	89.74%	10.26%	0.897	93.79%	6.21% 0.938
Fallow/Idle Cropland	61	625989	88.08%	11.92%	0.855	89.23%	10.77% 0.869

# Classified area vs June enumerated

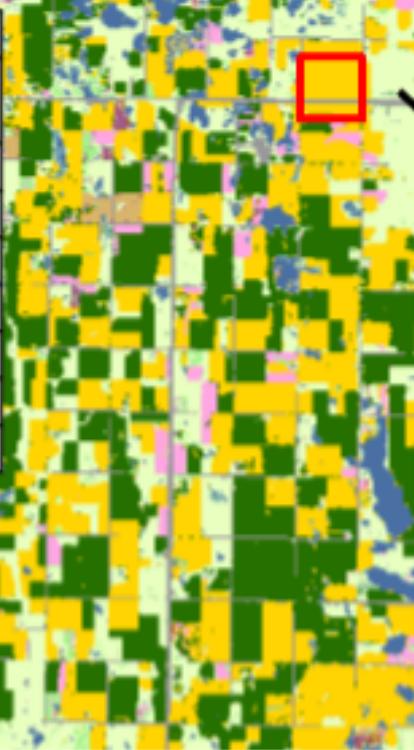


# At three sites



Cover Type	X	Y
	Classified Acres	Enumerated Acres
Corn	178.0	190.0
Soybean	302.0	290.0
Wheat	0.0	0.0
Alfalfa	3.5	0.0
...	...	...
...	...	...
Non-Ag.	158.5	160.0

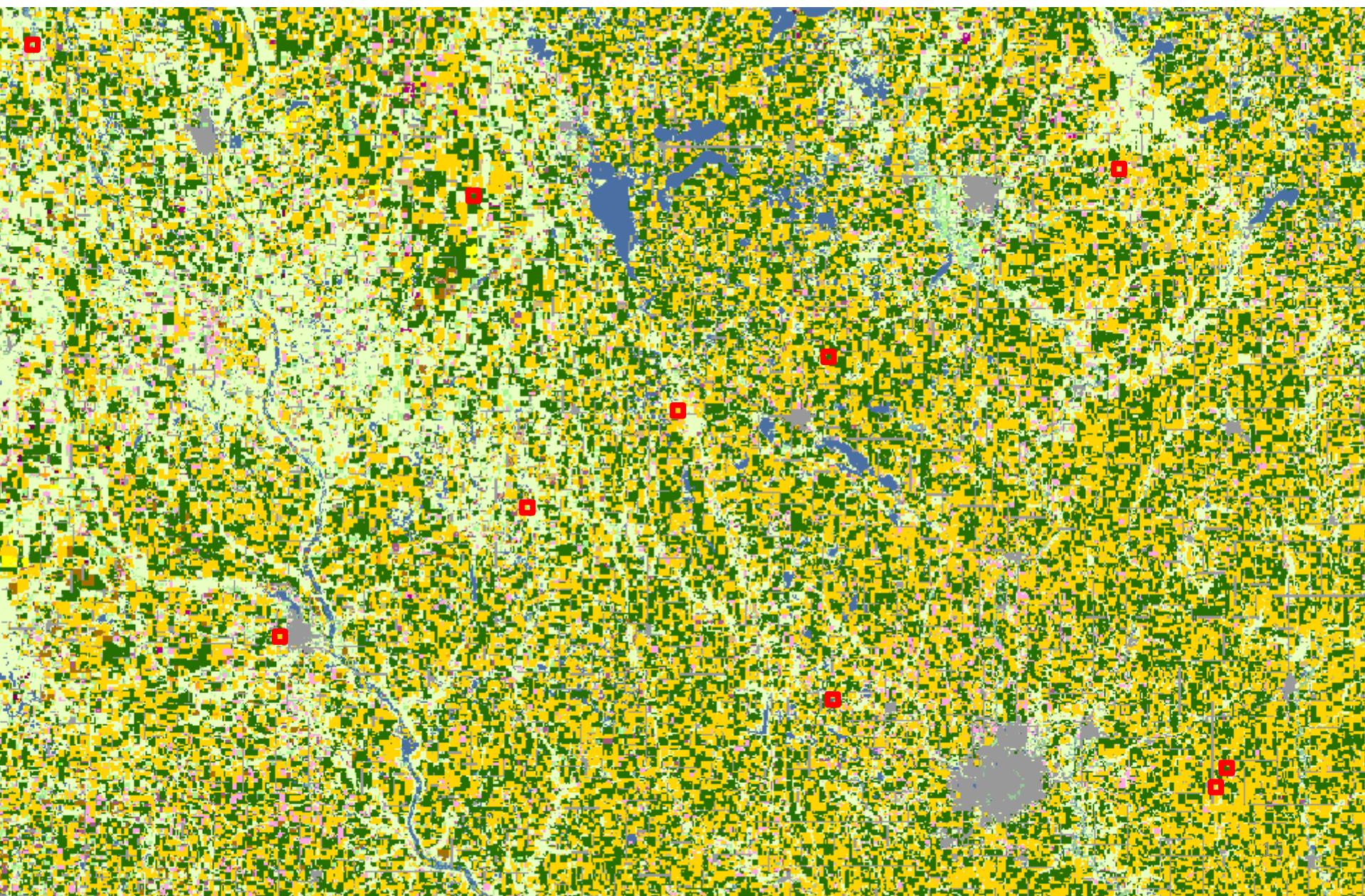
Cover Type	X	Y
	Classified Acres	Enumerated Acres
Corn	34.0	21.0
Soybean	177.0	155.0
Wheat	4.5	0.0
Alfalfa	2.5	0.0
...	...	...
...	...	...
Non-Ag.	422.0	464.0



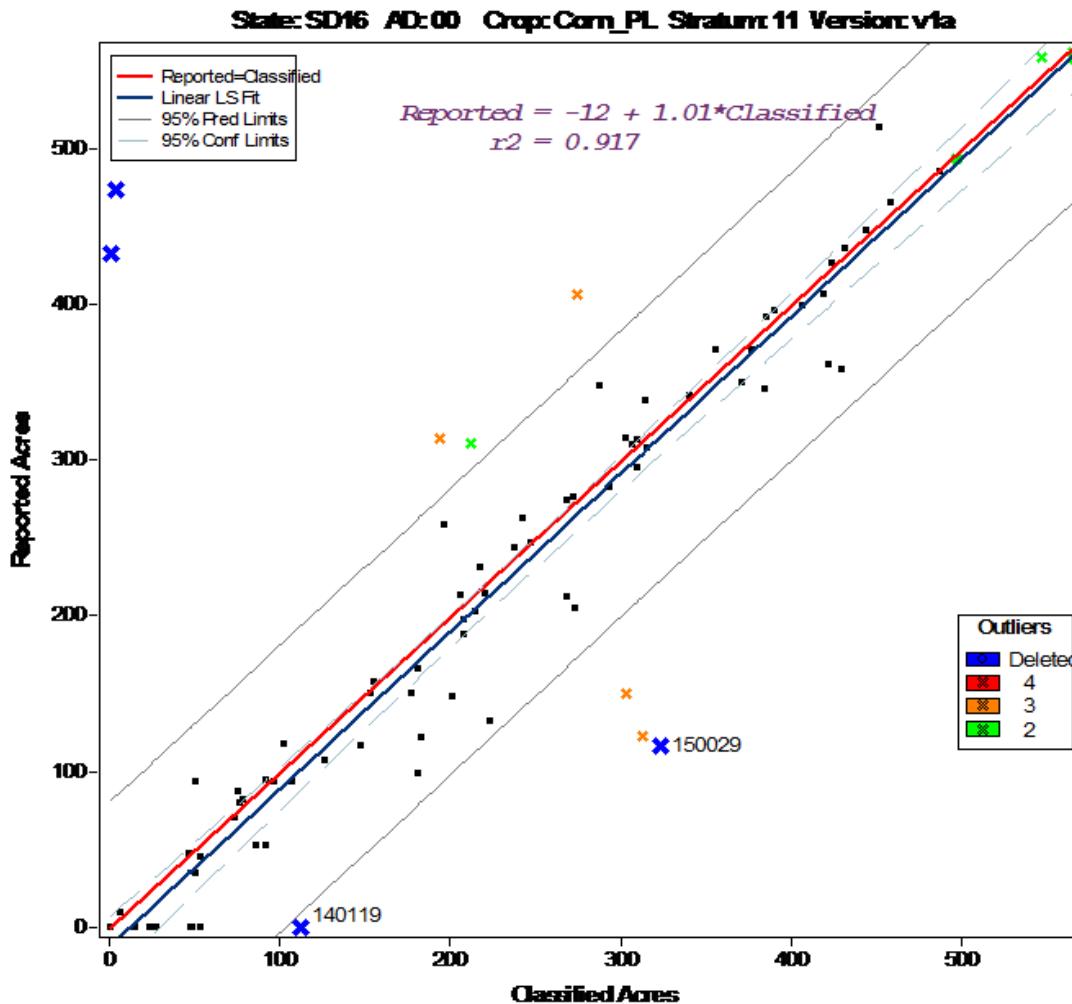
Cover Type	X	Y
	Classified Acres	Enumerated Acres
Corn	637.0	640.0
Soybean	1.0	0.0
Wheat	0.0	0.0
Alfalfa	0.0	0.0
...	...	...
...	...	...
Non-Ag.	2.0	0.0



**10 sites and so forth....**



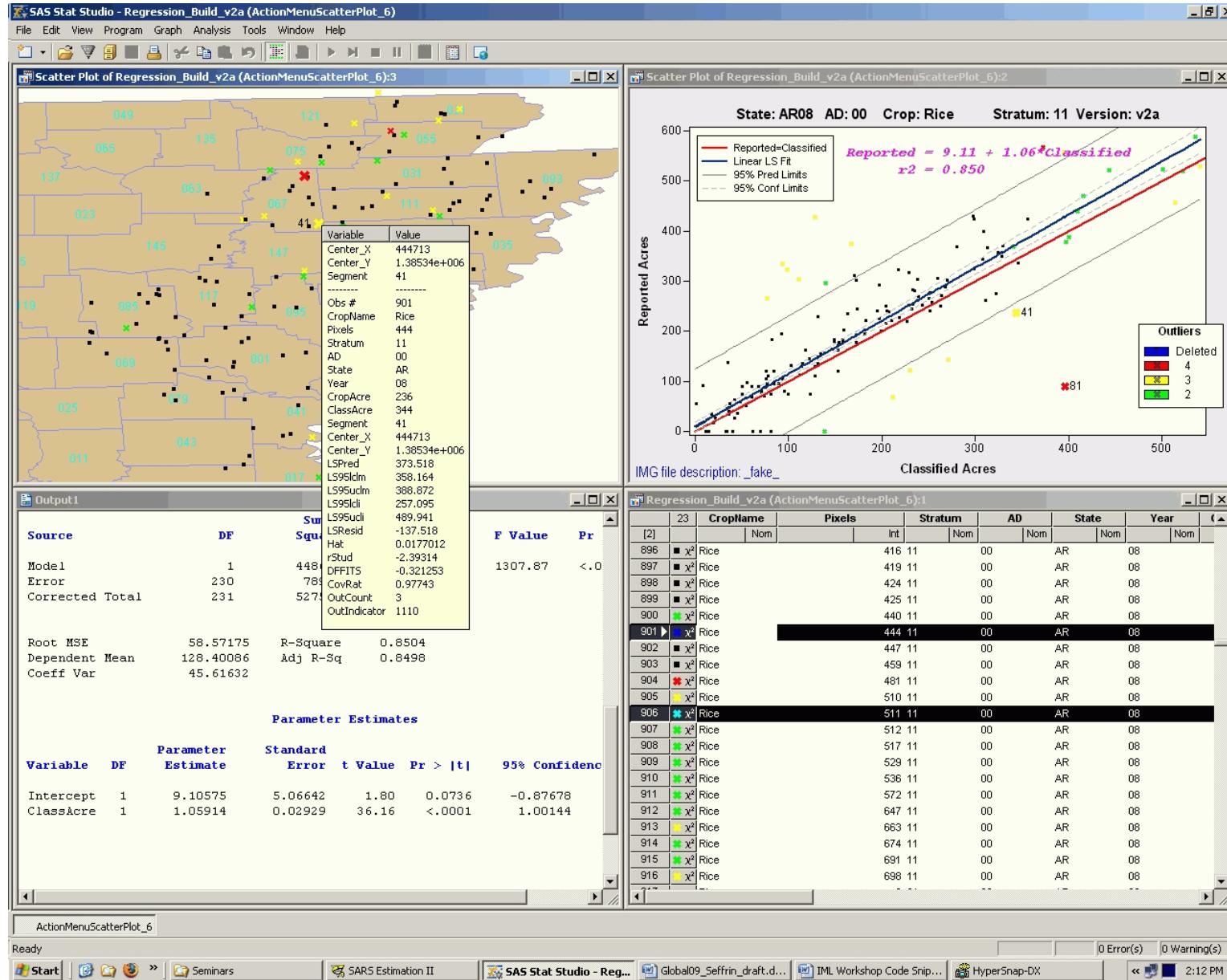
# Acreage Regression Estimation

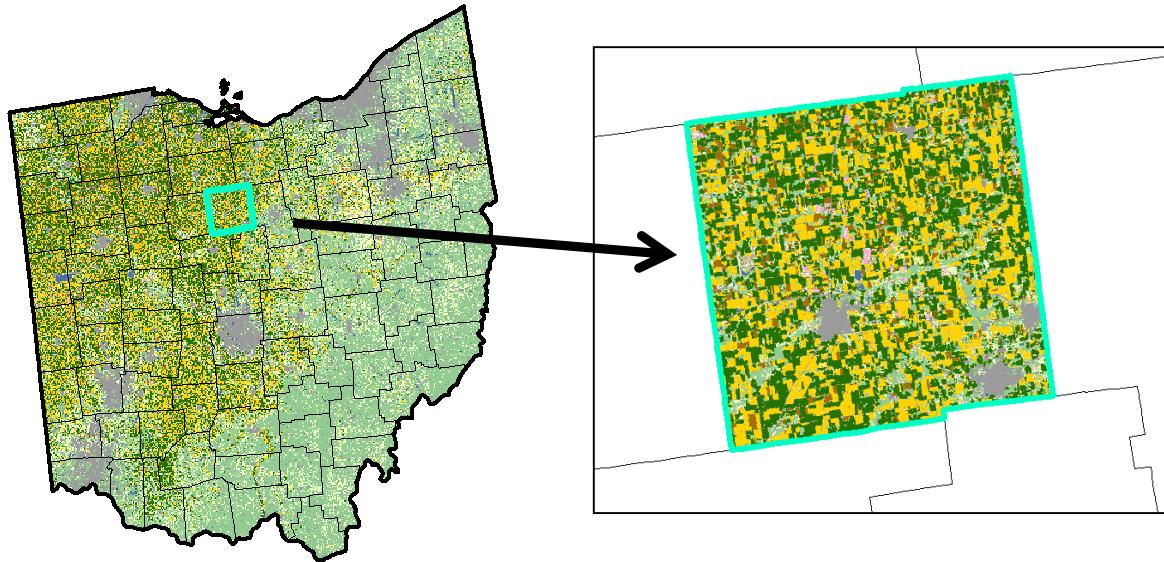


IMG file description: \_oct\_subset\_30m

We don't just “pixel count” from CDL to estimate acreage

# SAS-based Regression Estimate system



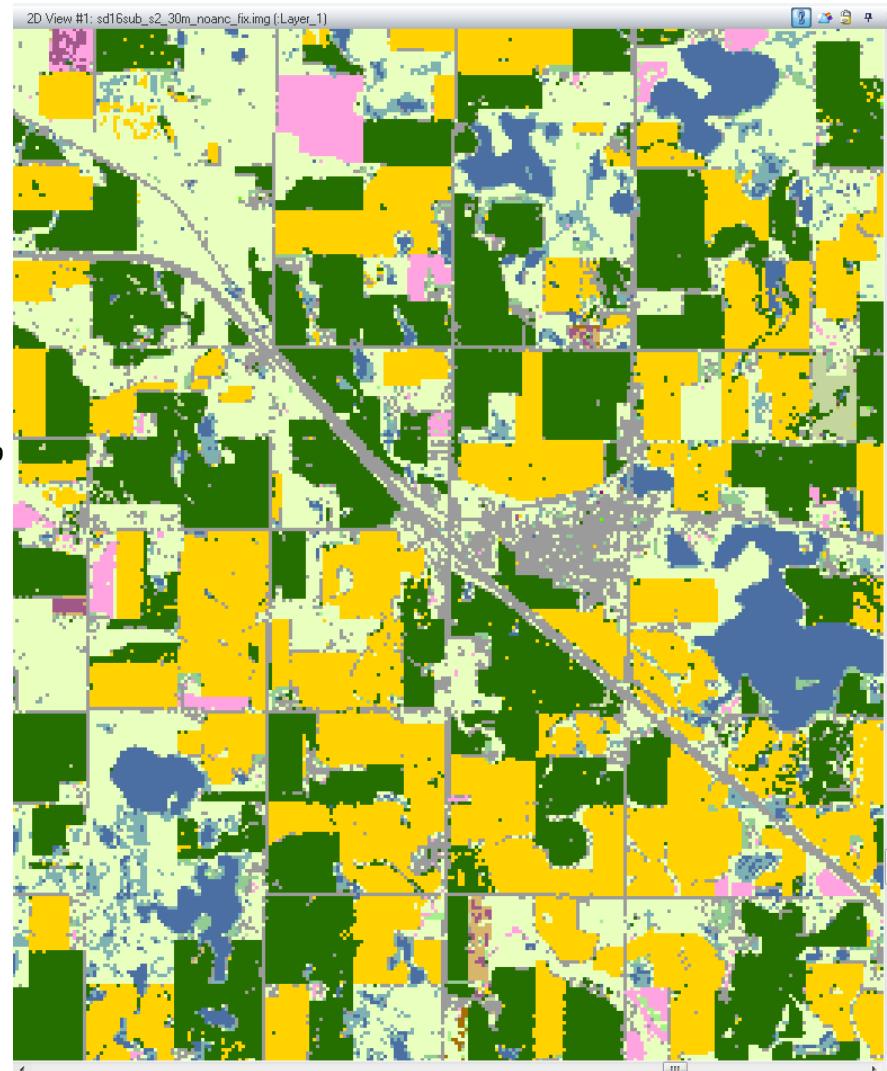


## County Estimates

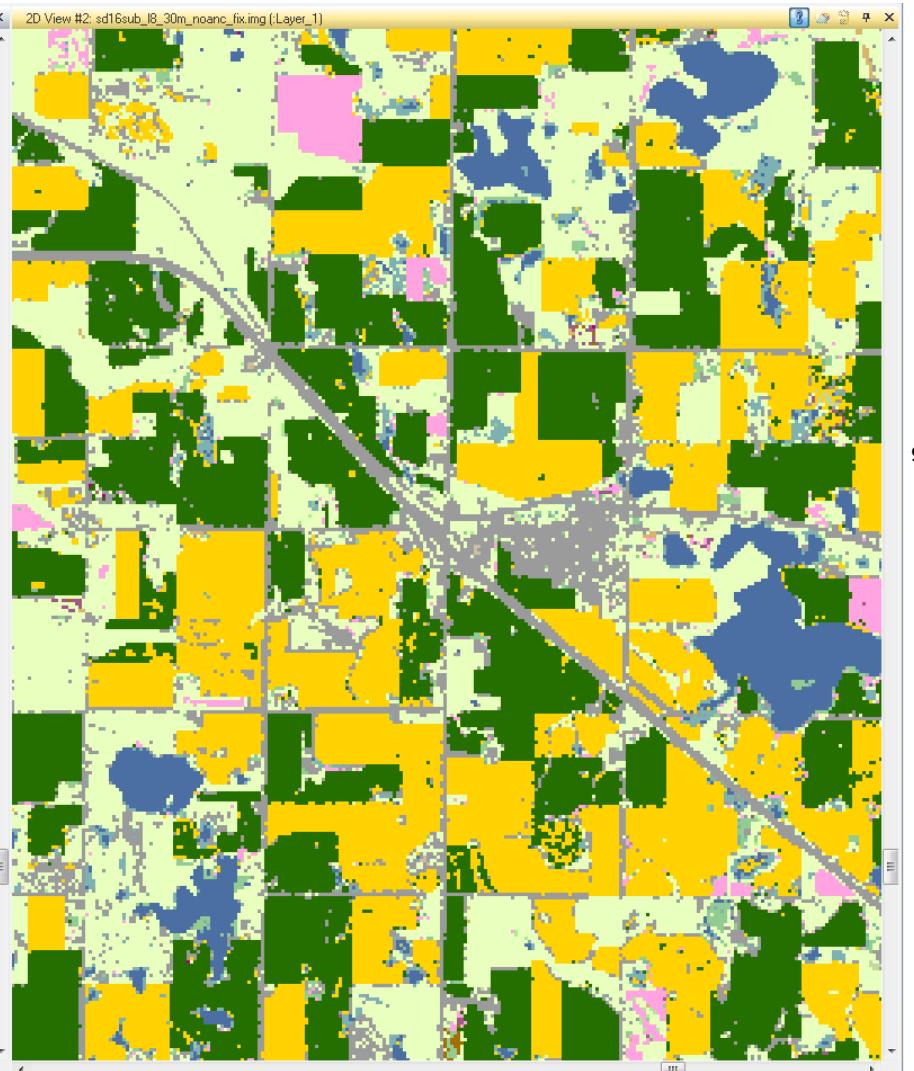
- Use Battese-Fuller estimator with nested design
- Apply state-strata level regression parameters
- Adjust intercept based on segments in county
- Ag Statistics Districts Est = Sum of County Estimates

# Classification comparison #1

30m Sentinel-2a

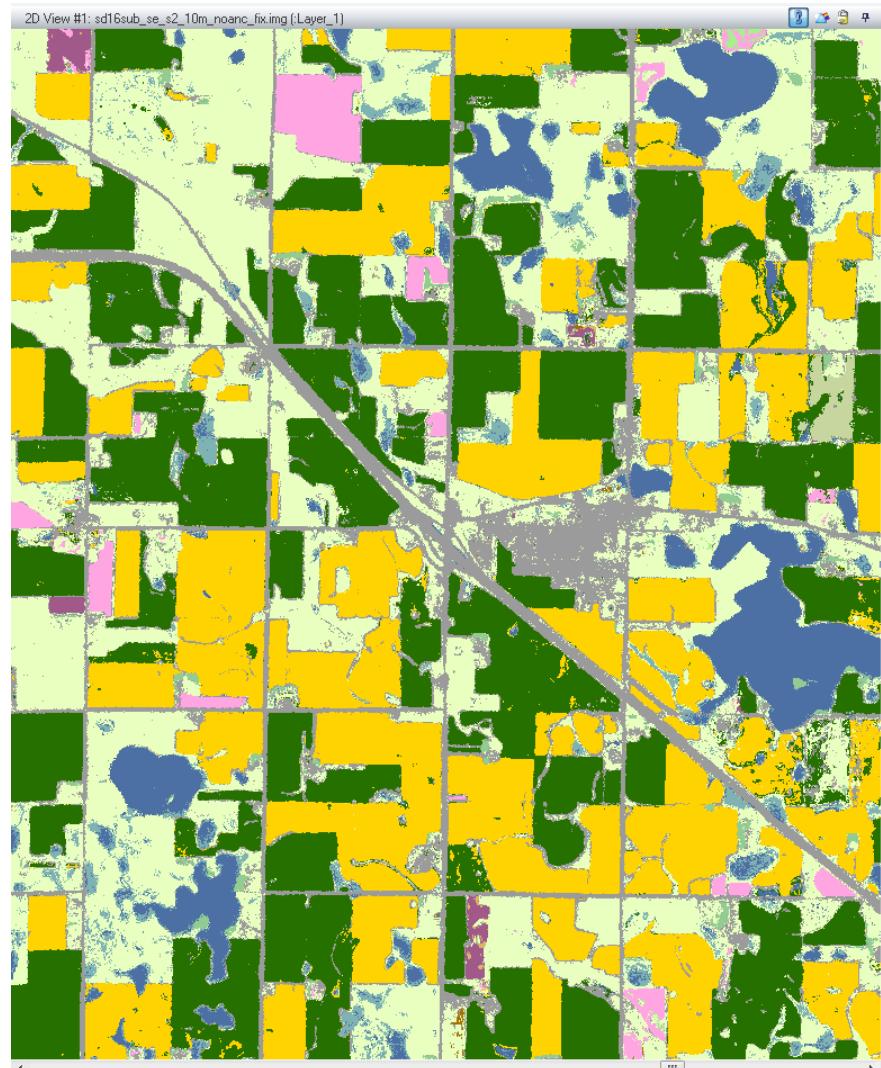


30m Landsat 8

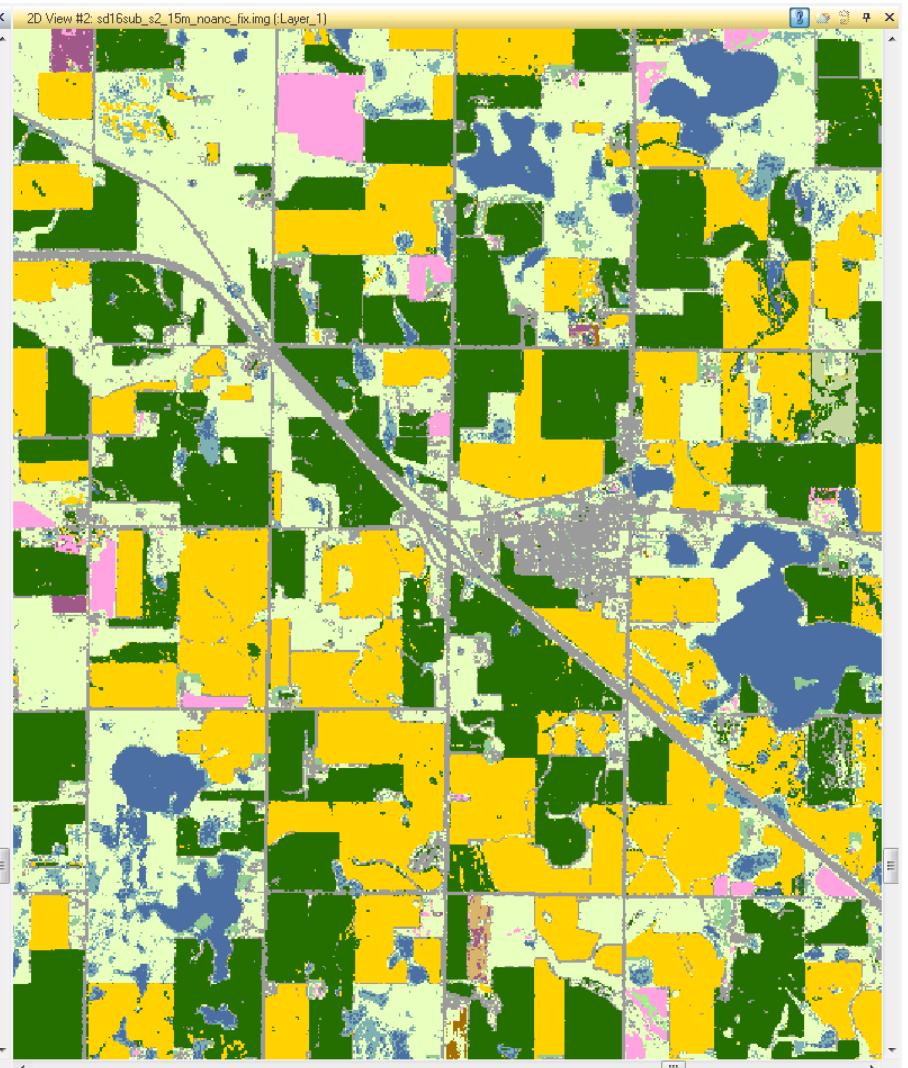


# Classification comparison #2

10m Sentinel-2a

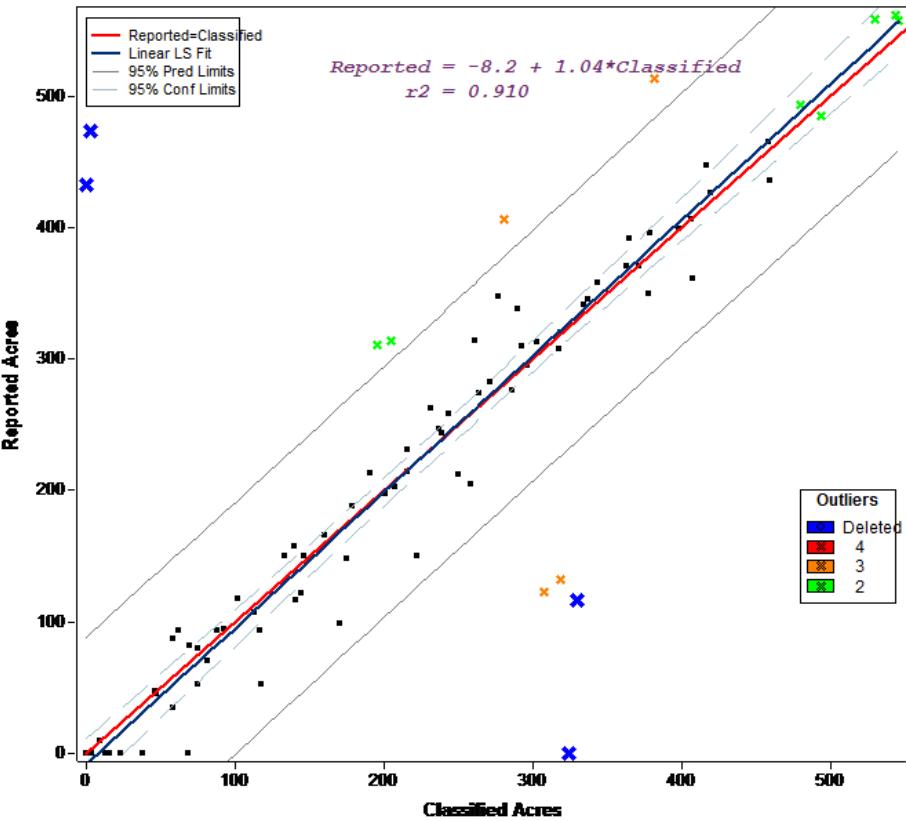


15m Sentinel-2a

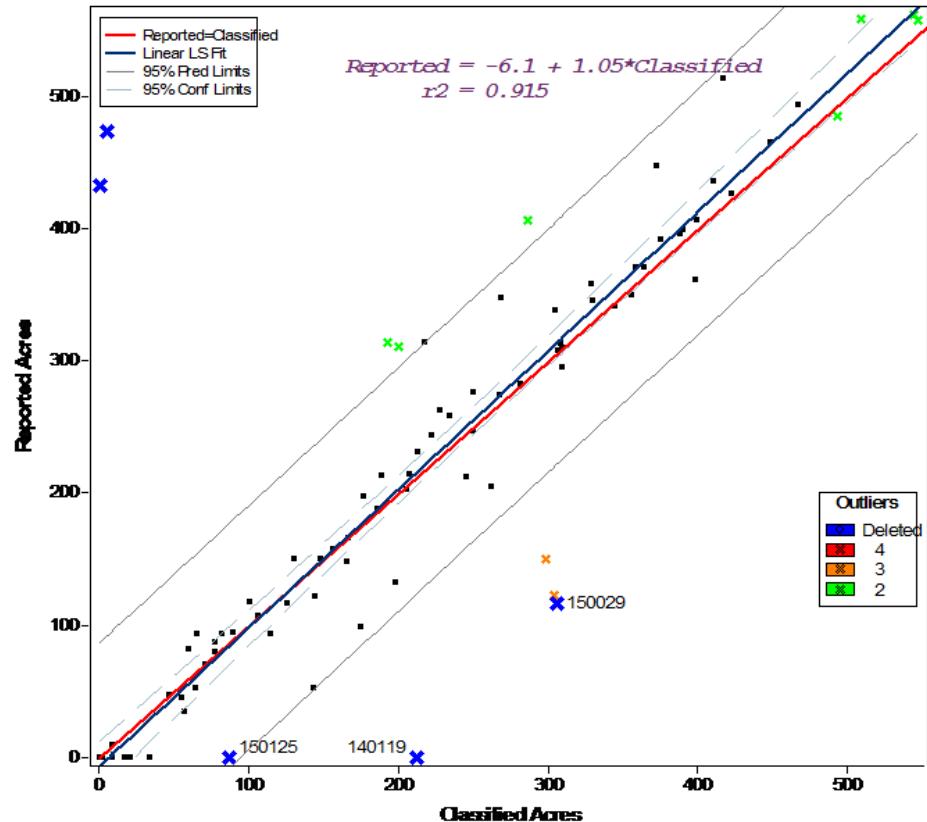


# 60m vs 15m regression analysis - corn

State: SD16 AD: 00 Crop: Corn\_PL Stratum: 11 Version: v1a



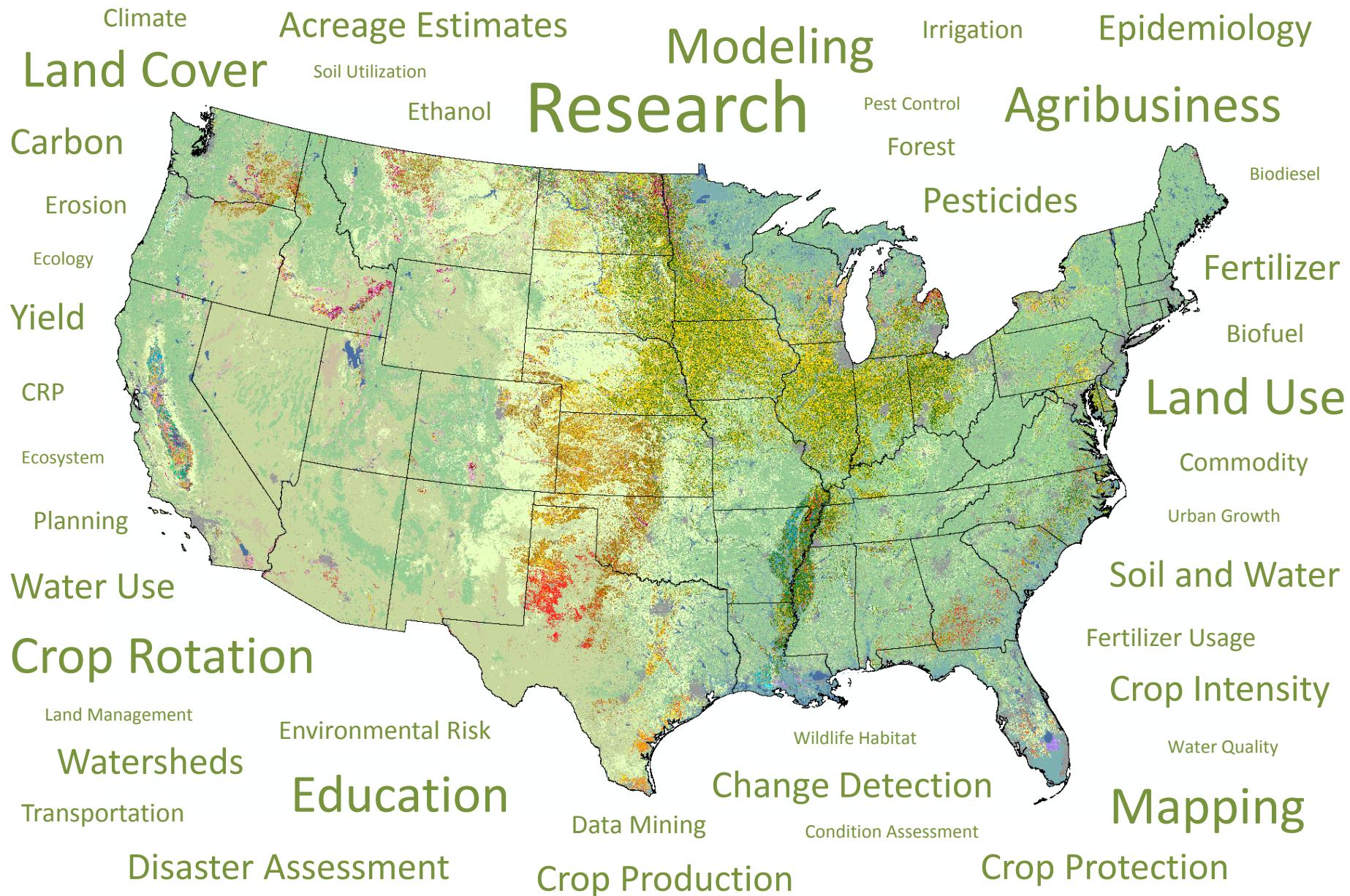
State: SD16 AD: 00 Crop: Corn\_PL Stratum: 11 Version: v3a



IMG file description: \_60m\_fix

VIG file description: \_sub\_s2\_15m\_noan

# CDL Applications





MODIS Web David

https://modis.gsfc.nasa.gov

# MODIS

MODERATE RESOLUTION IMAGING SPECTRORADIOMETER

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---

Release of NASA MEaSUREs CAMEL 5 km Products Announced By LP DAAC

---

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### Tools

The MODIS Tools section has a complete listing of web-based tools that can be used to access a wide variety of MODIS Data, along with an array of links and a summary of each tool.

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### Disciplinary Teams

#### Atmosphere



#### Land



#### Ocean



#### Calibration



24

# <https://worldview.earthdata.nasa.gov/>

The screenshot shows the NASA WorldView interface, a web-based tool for viewing and analyzing satellite imagery. The main view displays a global satellite map of Earth, with a focus on North America and the surrounding oceans. The map includes several types of overlays:

- OVERLAYS:**
  - Place Labels (OpenStreetMap license, Natural Earth)
  - Coastlines / Borders / Roads (OpenStreetMap license, Natural Earth)
  - Coastlines (OpenStreetMap license)
- BASE LAYERS:**
  - Corrected Reflectance (True Color) (Suomi NPP / VIIRS)
  - Corrected Reflectance (True Color) (Aqua / MODIS)
  - Corrected Reflectance (True Color) (Terra / MODIS)

A red button labeled "+ Add Layers" is located at the bottom left of the overlay panel. The interface includes a toolbar at the top right with icons for zoom, refresh, and other functions. At the bottom, there is a timeline and navigation controls. The timeline shows dates from June 26, 2017, to August 2017, with a play button and arrows. A scale bar indicates 500 km. The bottom right corner has buttons for "DAYS", "MONTHS", and "YEARS".

# Hail example

NASA (National Aeronautics and Space Administration) EOSDIS Worldview

File Edit View Favorites Tools Help

NASA WORLDVIEW

Layers Events Data

OVERLAYS

- Place Labels (OpenStreetMap license), Natural Earth
- Coastlines / Borders / Roads (OpenStreetMap license), Natural Earth
- Coastlines (OpenStreetMap license)

BASE LAYERS

- Corrected Reflectance (True Color) (Suomi NPP / VIIRS)
- Corrected Reflectance (True Color) (Aqua / MODIS)
- Corrected Reflectance (True Color) (Terra / MODIS)

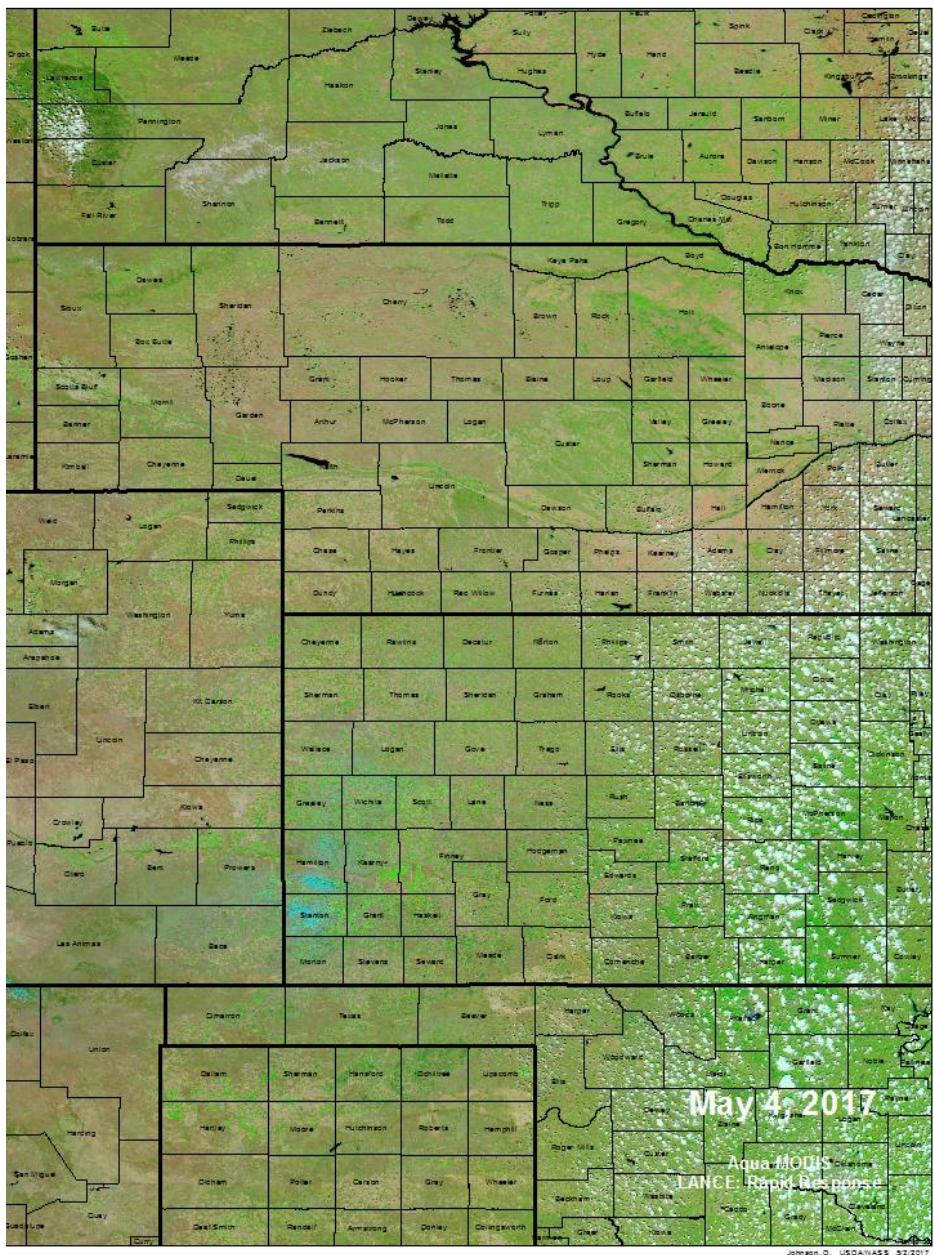
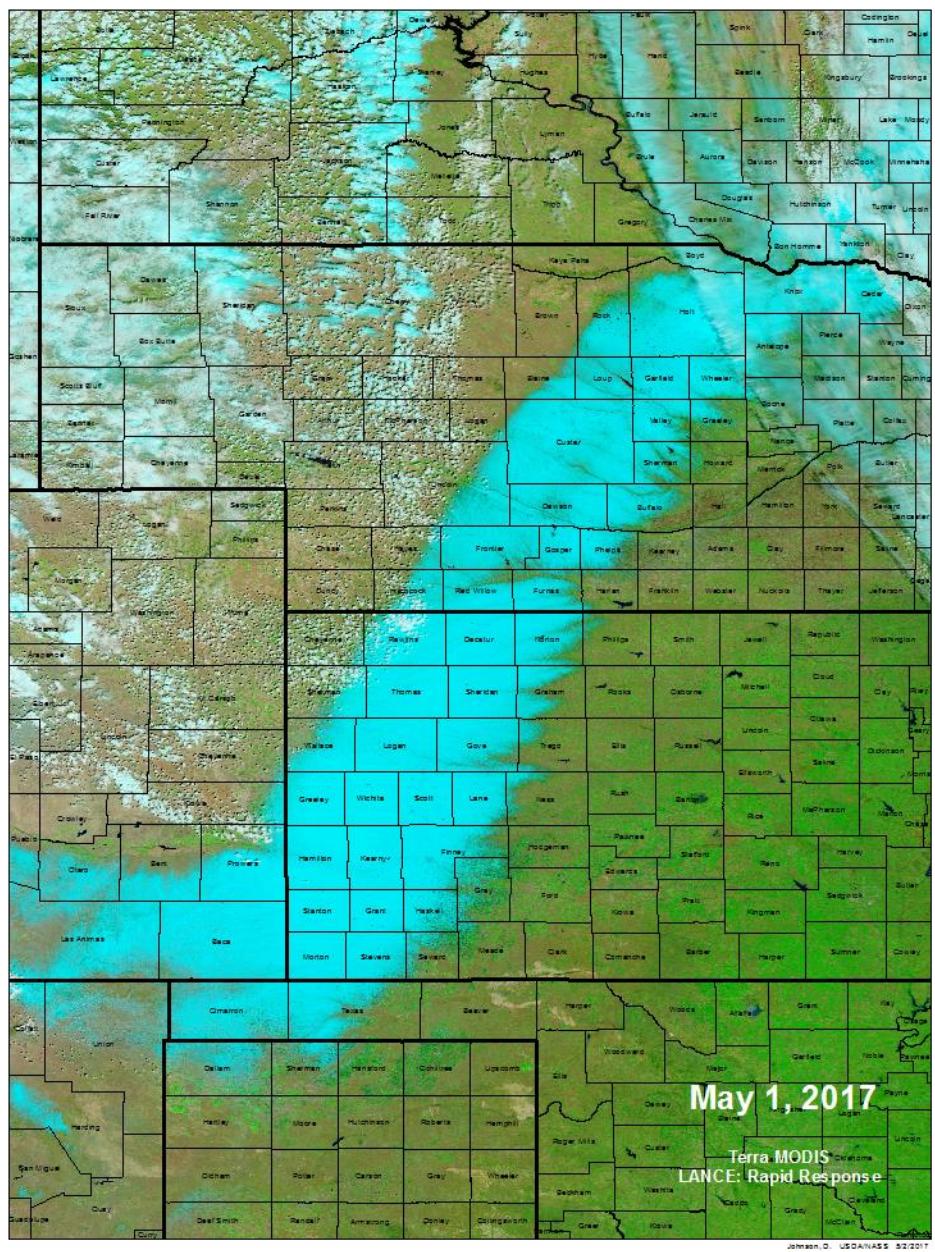
+ Add Layers

50 km | 20 mi

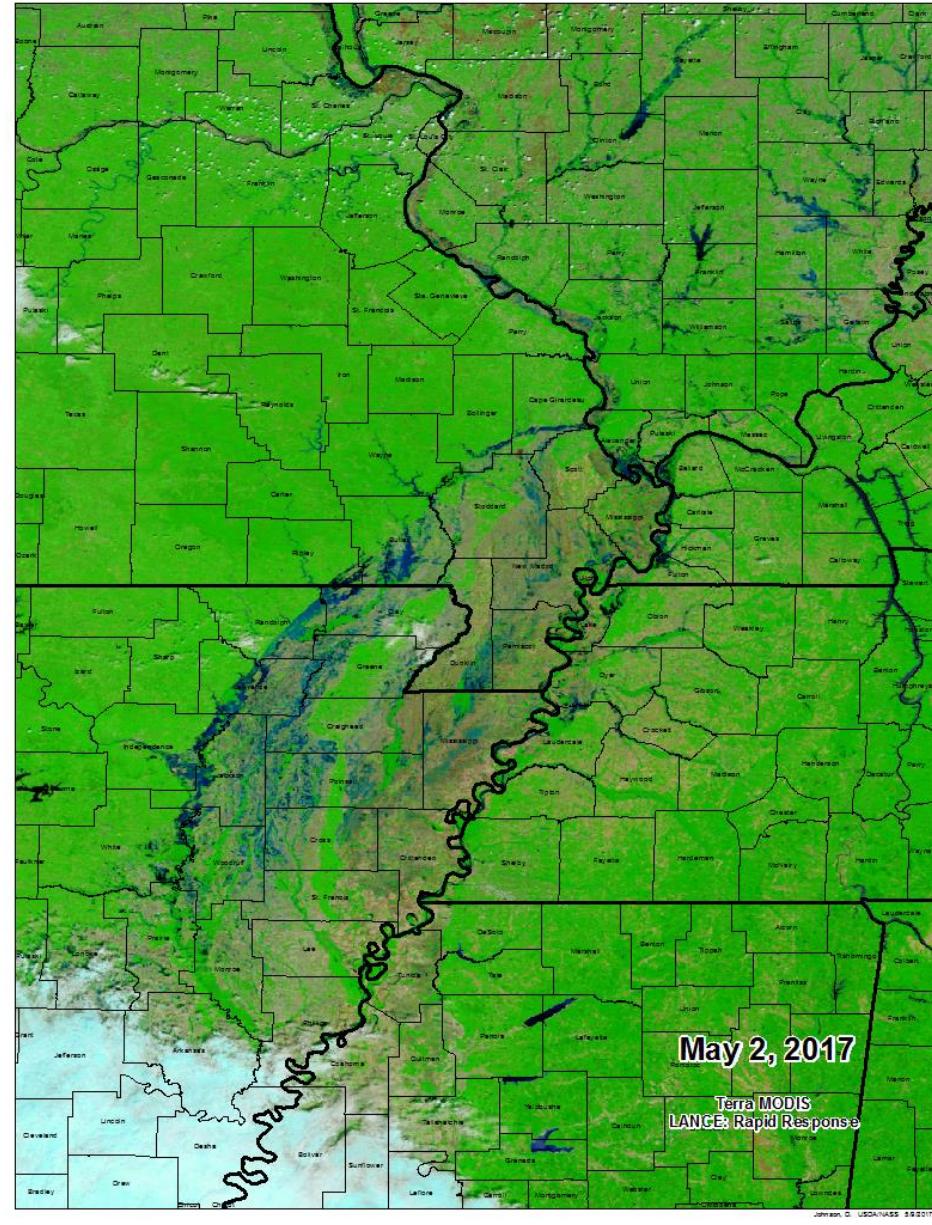
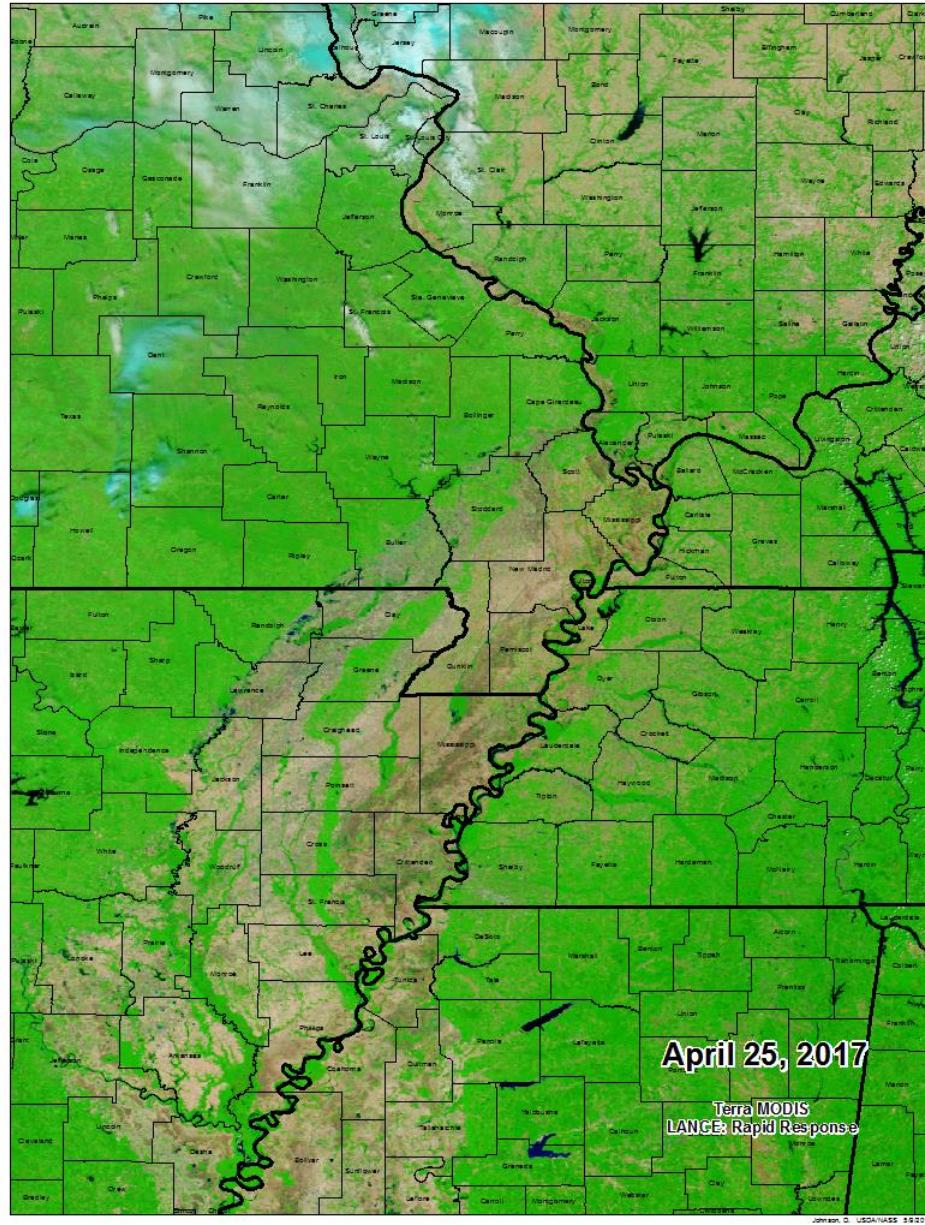
46.6396°, -97.7870° EPSG:4326

2017 JUL 17 < > 🎥 JUN 2017 JUL 2017 AUG 2017 DAYS MONTHS

# MODIS Imagery - Snow event



# MODIS Imagery - Flood event



# Calculation and use of NDVI

WIKIPEDIA  
The Free Encyclopedia

Article Discussion Read Edit View history Search

## Normalized Difference Vegetation Index

From Wikipedia, the free encyclopedia

This article **reads more like a story than an encyclopedia entry**. To meet Wikipedia's [quality standards](#) and conform to the [neutral point of view policy](#), please help to introduce a more formal style and remove any personally invested tone. (July 2011)

The **Normalized Difference Vegetation Index (NDVI)** is a simple graphical indicator that can be used to analyze remote sensing measurements, typically but not necessarily from a space platform, and assess whether the target being observed contains live green vegetation or not.

**Contents**

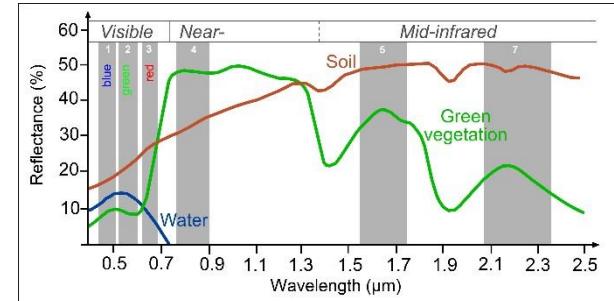
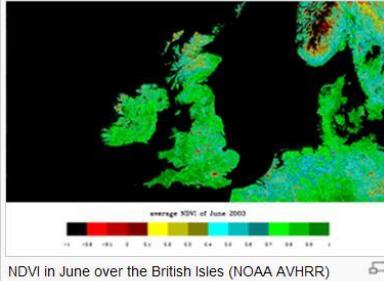
- 1 Brief history
- 2 Rationale
- 3 Performance and limitations
- 4 See also
- 5 References
- 6 External links

### Brief history

[edit]

The exploration of outer space started in earnest with the launch of *Sputnik 1* by the Soviet Union on 4 October 1957. This was the first man-made satellite orbiting the Earth. Subsequent successful launches, both in the Soviet Union (e.g., the *Sputnik* and *Cosmos* programs), and in the U.S. (e.g., the *Explorer* program), quickly led to the design and operation of dedicated meteorological satellites. These are orbiting platforms embarking instruments specially designed to observe the Earth's atmosphere and surface with a view to improve weather forecasting. Starting in 1960, the *TIROS* series of satellites embarked television cameras and radiometers. This was later (from 1964 onwards) followed by the *Nimbus* satellites and the family of Advanced Very High Resolution Radiometer instruments onboard the National Oceanic and Atmospheric Administration (NOAA) platforms. The latter measures the reflectance of the planet in red and near-infrared bands, as well as in the thermal infrared. In parallel, NASA developed the Earth Resources Technology Satellite (ERTS), which became the precursor to the Landsat program. These early sensors had minimal spectral resolution, but tended to include bands

Negative values of NDVI (values approaching -1) correspond to water. Values close to zero (-0.1 to 0.1) generally correspond to barren areas of rock, sand, or snow. Lastly, low, positive values represent shrub and grassland (approximately 0.2 to 0.4), while high values indicate temperate and tropical rainforests (values approaching 1).<sup>[1]</sup>



$$\text{NDVI} = \frac{(\text{NIR} - \text{VIS})}{(\text{NIR} + \text{VIS})}$$

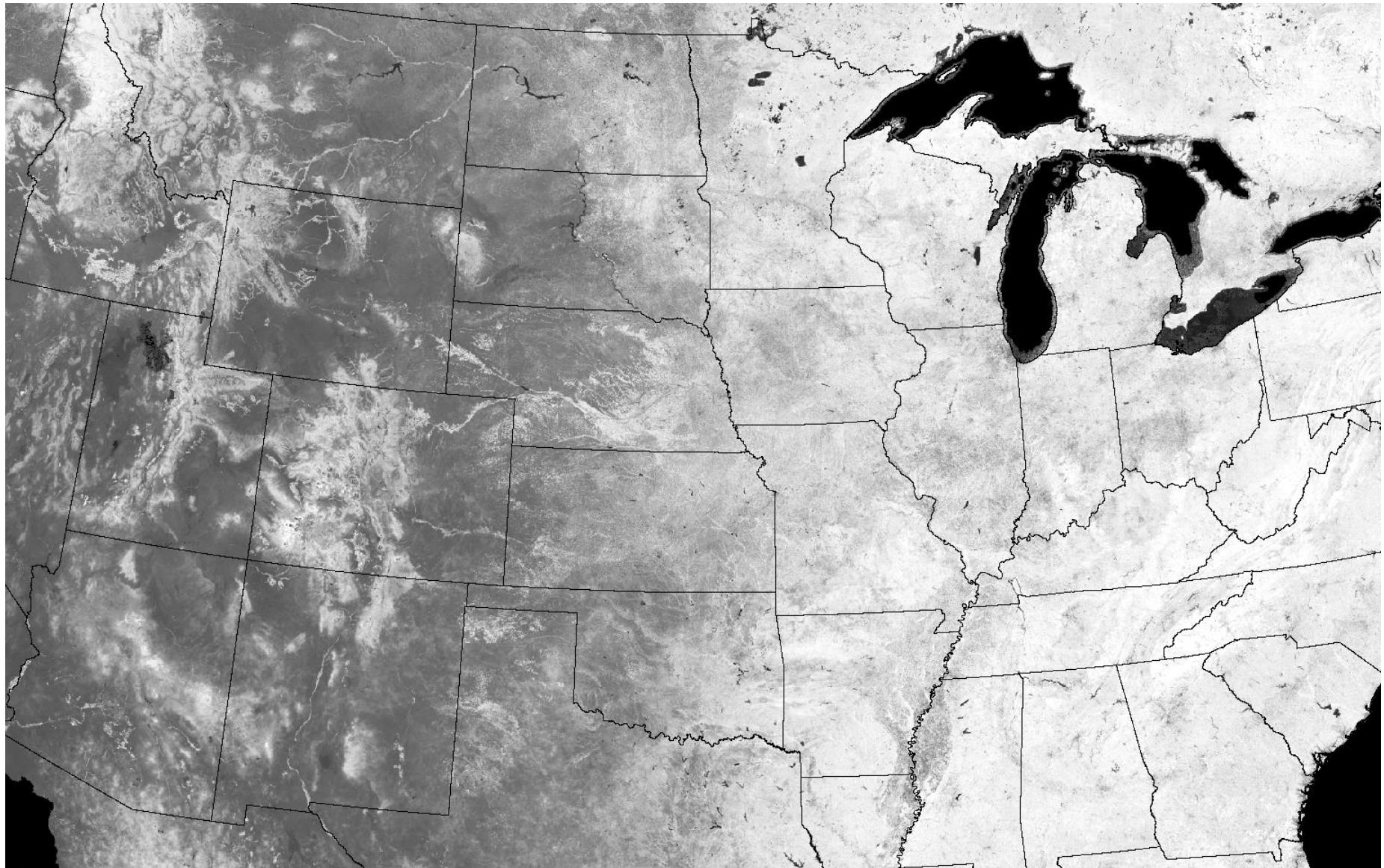
NIR = near-infrared band  
VIS = visible band

Ranges from -1.0 to 1.0

**NDVI is a related to:**

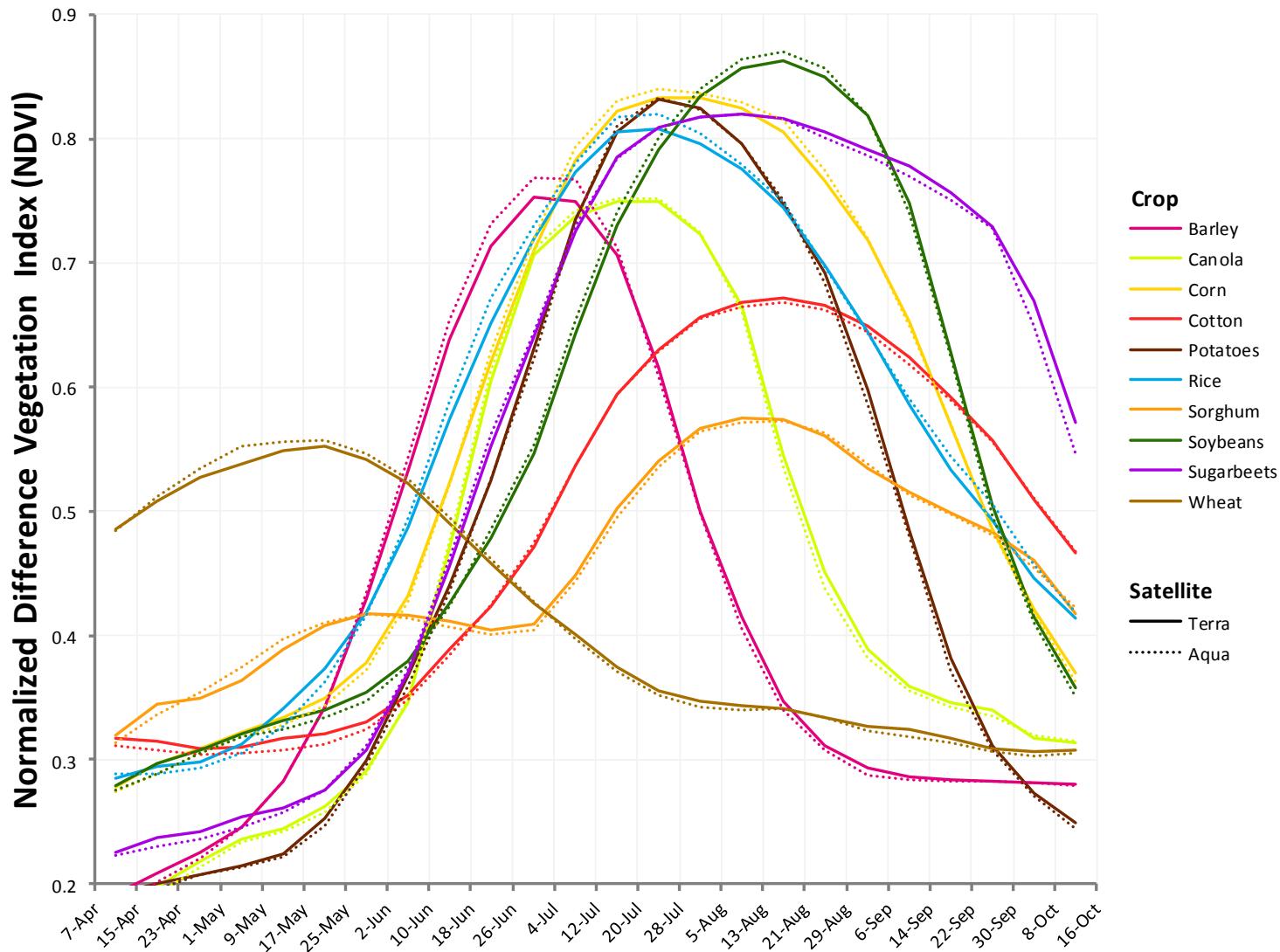
- Plant health
- Chlorophyll content
- “Greenness”
- Amount of Biomass
- Vegetation vigor
- Yield!

# MODIS NDVI 8-day composite imagery example



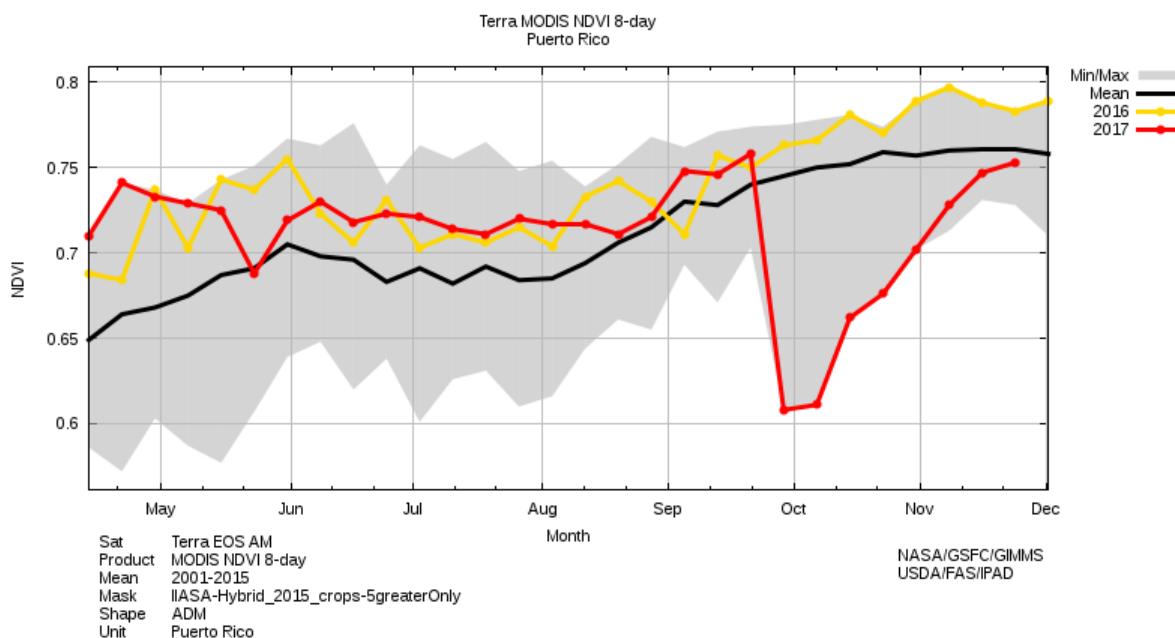
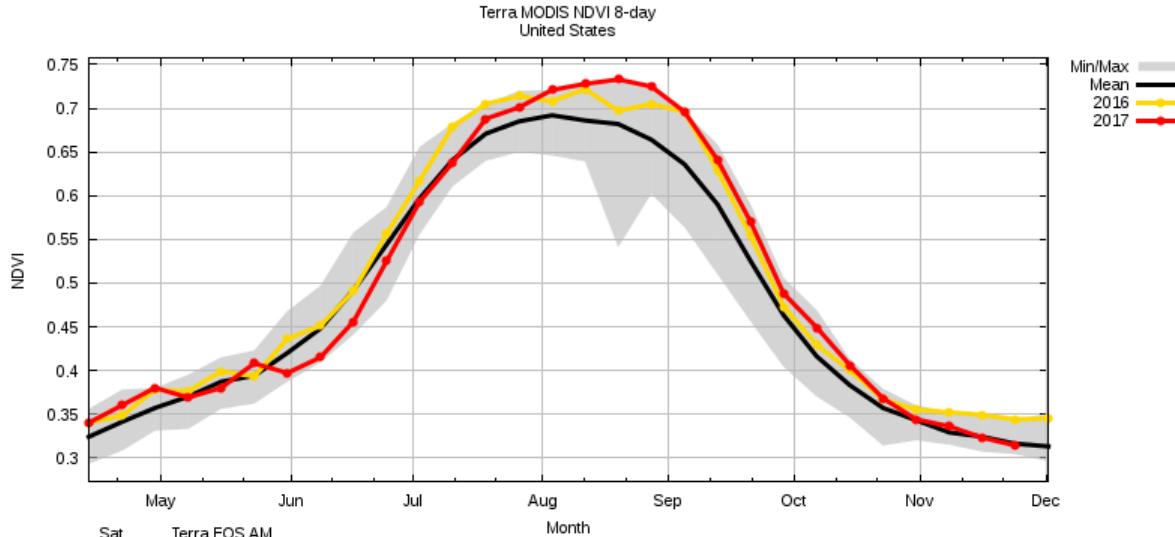
Lighter shades, greater NDVI

# Average NDVI phenologies over United States



Signals isolated using crop specific masks

# Real-time tracking of NDVI



# NASS recent efforts on remote sensing of crop yields

## Premise

- Positive relationship between crop yield and biomass – plant vigor - “greenness” - NDVI
- Negative relationship between crop yield and land surface temperature

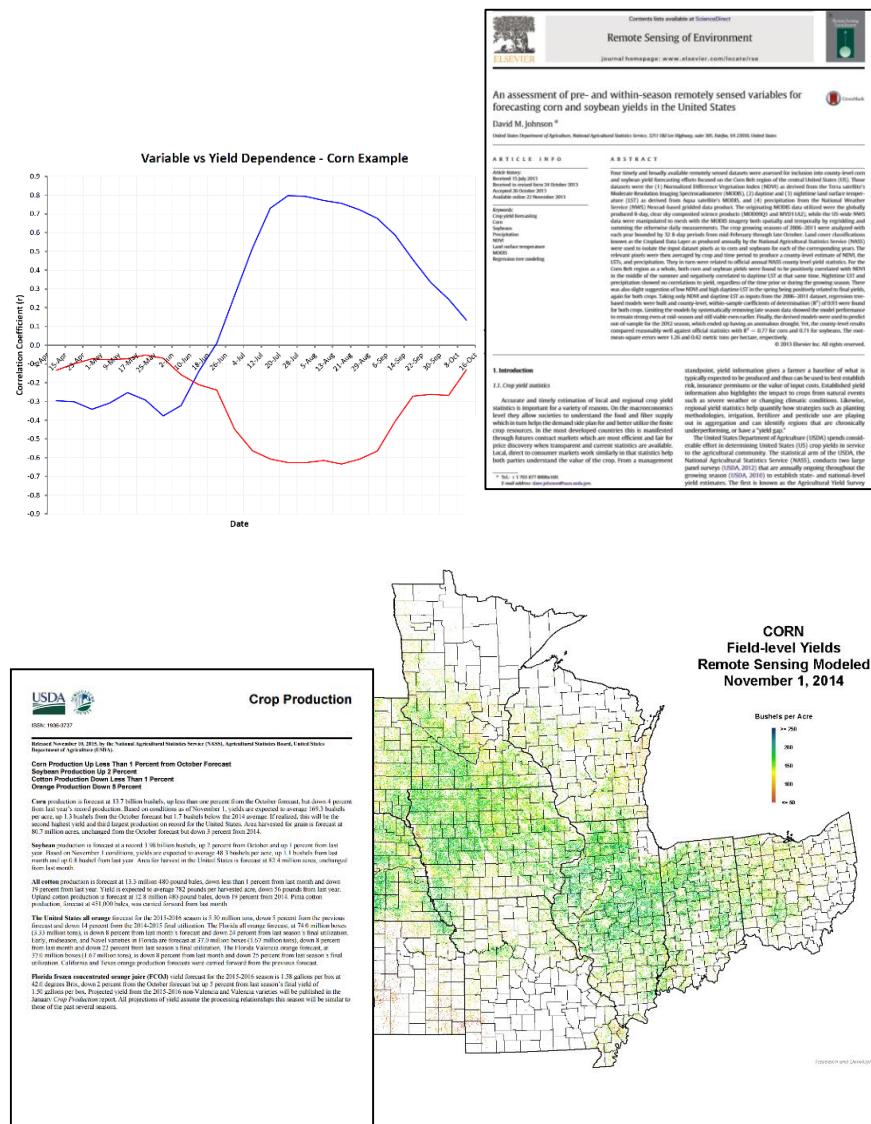
## Utilize time-series MODIS satellite data to obtain biomass and temperature estimates throughout the growing season

- Use Cropland Data Layer to isolate known crop areas
- Then use them in an empirically-based prediction model based on historical imagery and NASS county-level yield statistics

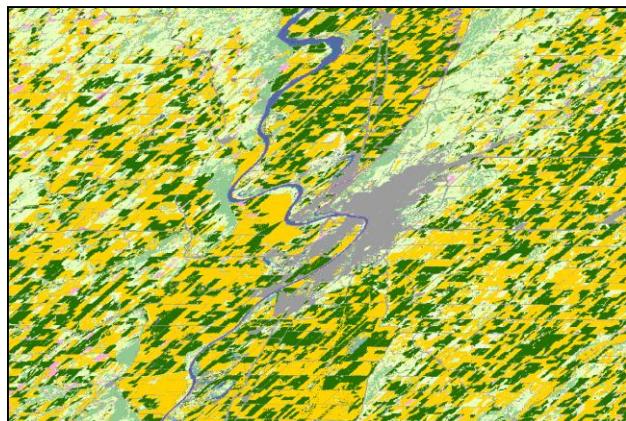
## Run model at National, State, and County levels

- Integrating over season approach
- Using decision trees (Rulequest Cubist)
- Corn and Soybeans operational currently

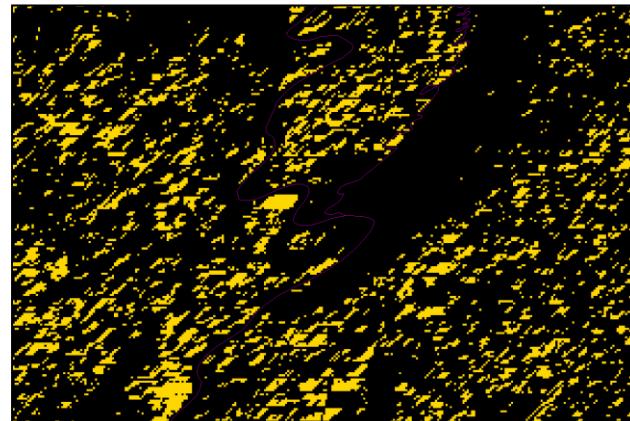
## Perform within crop season at monthly intervals



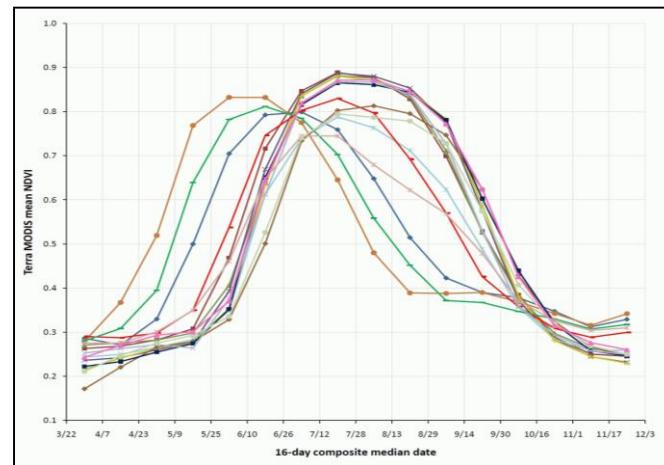
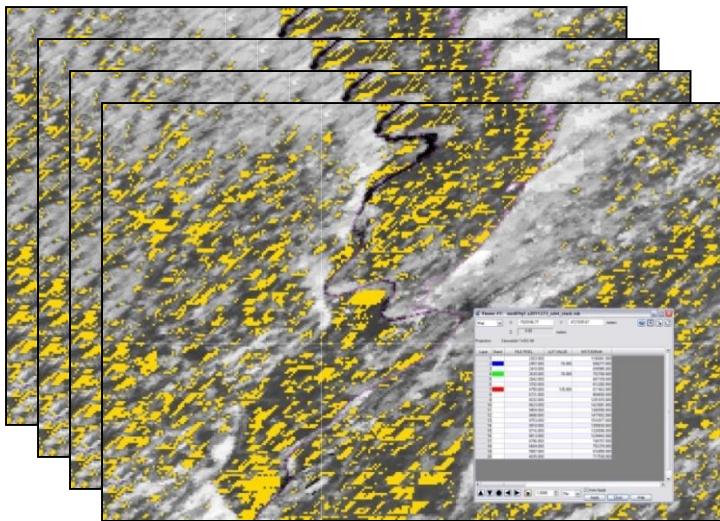
# Intersecting of crop “mask” with time-series of MODIS data



CDL



Isolate crop of interest



Intersect crop mask with MODIS time series and then spatially average those pixels

# County-level time-series database has been built

2006 -> present

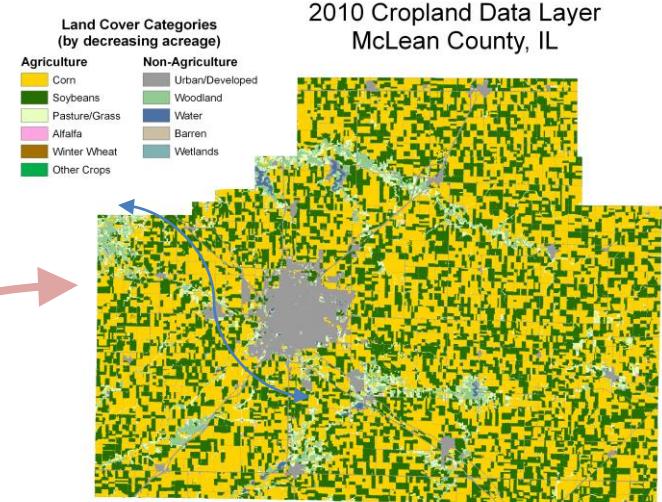
Every eight day “window” through the growing season

- Observed average value of NDVI
- Observed average value of LST

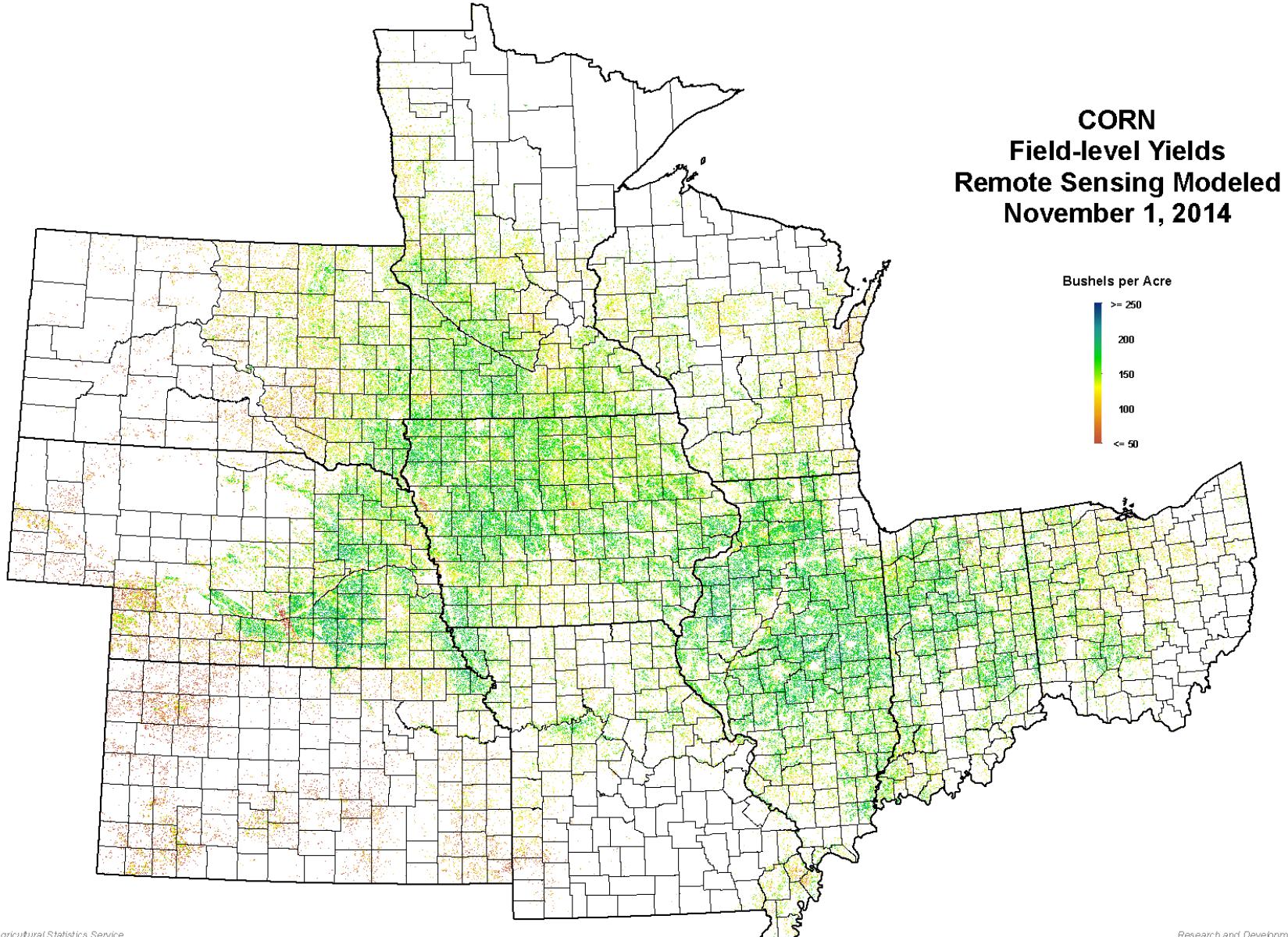
For every county we also know

- NASS published yield

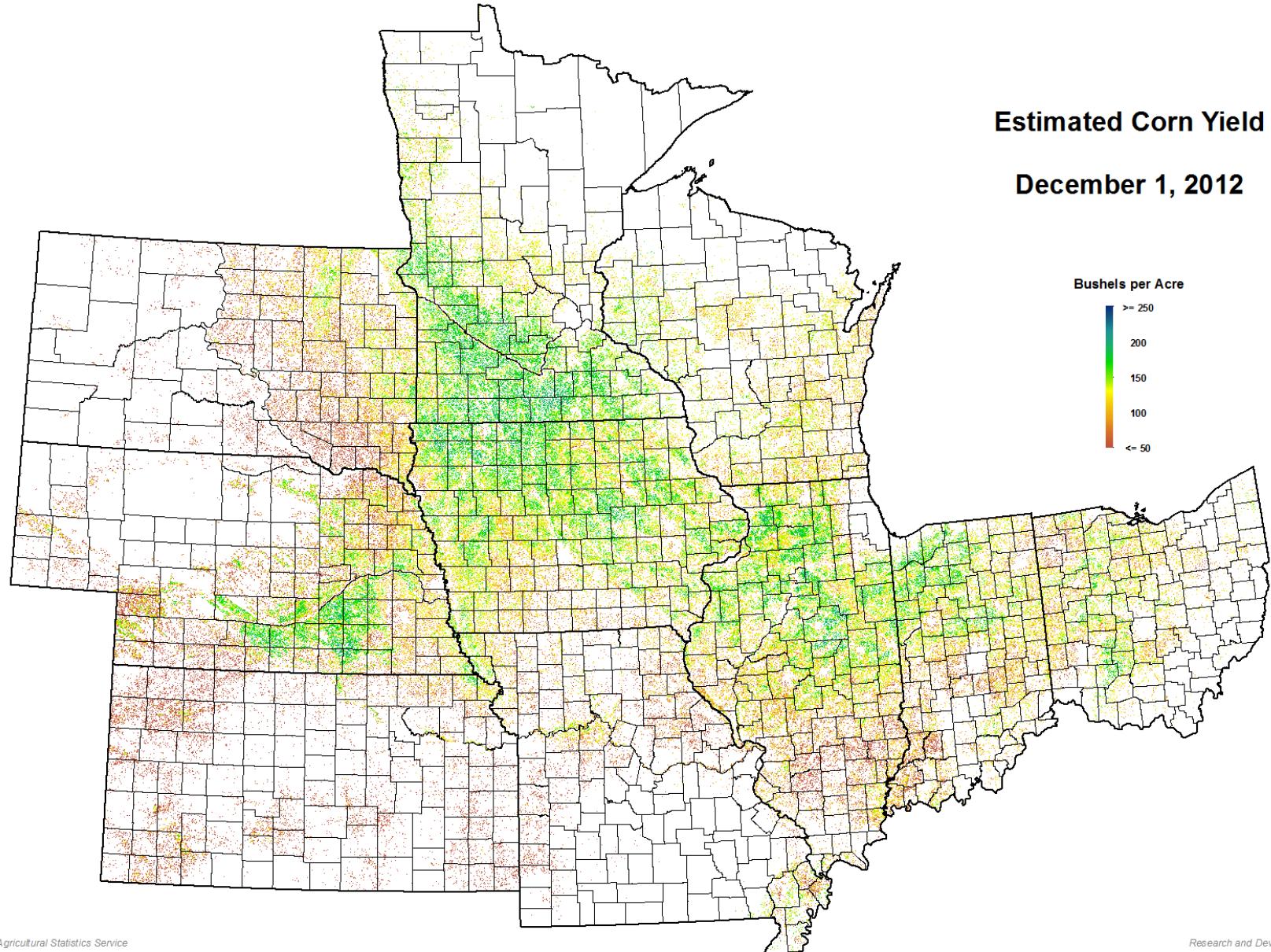
state	county	year	yield	NDVI	DLST	23-Apr	1-May	9-May	17-May	25-May	2-Jun	10-Jun	18-Jun	26-Jun	4-Jul	12-Jul	20-Jul
17	93	2010	168.6			2980.673	3264.547	3862.318	3866.409	3990.153	5893.765	7558.422	8108.906	8559.559	8826.817	8930.85	8935.61
17	95	2010	159.9			2992.195	2977.046	3203.401	3377.778	3848.078	5771.909	7450.655	8012.679	8310.476	8537.081	8645.006	8702.09
17	97	2010	?			3337.864	3836.186	5403.508	4459.949	4311.525	5635.508	7575.966	7776.288	8082.441	8575.966	8689.22	8524.83
17	99	2010	162.9			2844.2	2971.099	3332.757	3486.144	3937.887	6032.626	8059.657	8344.285	8565.456	8784.721	8903.283	8939.18
17	101	2010	156.9			3874.741	3988.952	4349.537	4930.498	5452.197	6205.825	7687.592	8022.794	8396.337	8589.467	8770.097	8827.56
17	103	2010	173.6			2782.144	2805.154	3018.966	3094.823	3512.443	5563.73	7306.284	8102.134	8554.694	8918.413	8949.941	8862.48
17	105	2010	166.6			2816.087	3007.861	3371.65	3608.025	3988.44	6100.426	8236.687	8503.526	8751.071	8872.207	8945.958	8805.10
17	107	2010	155.7			2706.578	2846.325	3249.914	3622.797	4402.778	6661.937	8254.186	8426.524	8515.872	8656.284	8755.741	8782.62
17	109	2010	141.8			3104.659	3240.878	3479.558	3558.215	4056.188	6151.458	7440.174	7913.743	8068.891	8437.704	8697.558	8783.25
17	111	2010	171.4			3079.982	3283.63	3659.725	3626.941	3909.787	5483.311	7163.395	8116.372	8578.756	8844.542	8908.066	8886.72
17	113	2010	169.5			2727.7	2899.42	3316.302	3573.485	4053.523	6484.888	8304.741	8585.89	8846.408	8960.349	8953.985	8860.08
17	115	2010	160.5			2791.229	2943.968	3442.016	3862.389	4880.537	7264.473	8749.776	8793.049	8769.201	8787.036	8828.984	8797.02
17	117	2010	146.9			3213.265	3342.063	3617.414	4030.15	4799.472	6474.308	8021.675	8511.256	8646.314	8885.395	8920.521	9010.37
17	119	2010	166.3			3282.816	3405.388	3712.914	4087.371	4860.512	6581.844	8129.837	8410.098	8587.161	8826.583	8879.477	8854.28
17	121	2010	149.7			3524.353	3534.901	3931.625	4260.018	4856.34	6251.207	7828.069	8242.445	8450.967	8601.465	8853.656	8952.45
17	123	2010	163.3			2748.186	2881.69	3261.708	3448.857	3851.546	5647.397	7541.376	8205.306	8567.037	8799.09	8891.405	8904.80



# Map Output

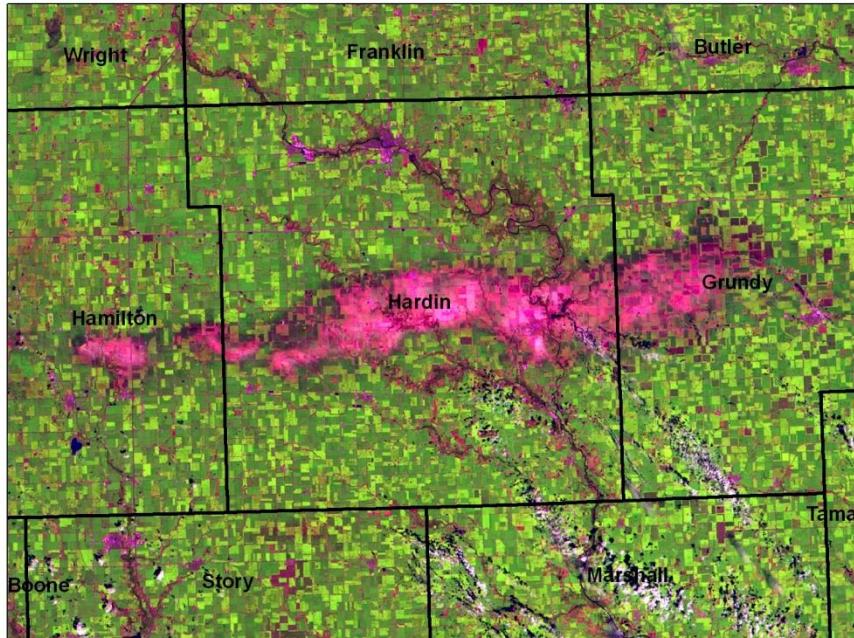


# Map Output

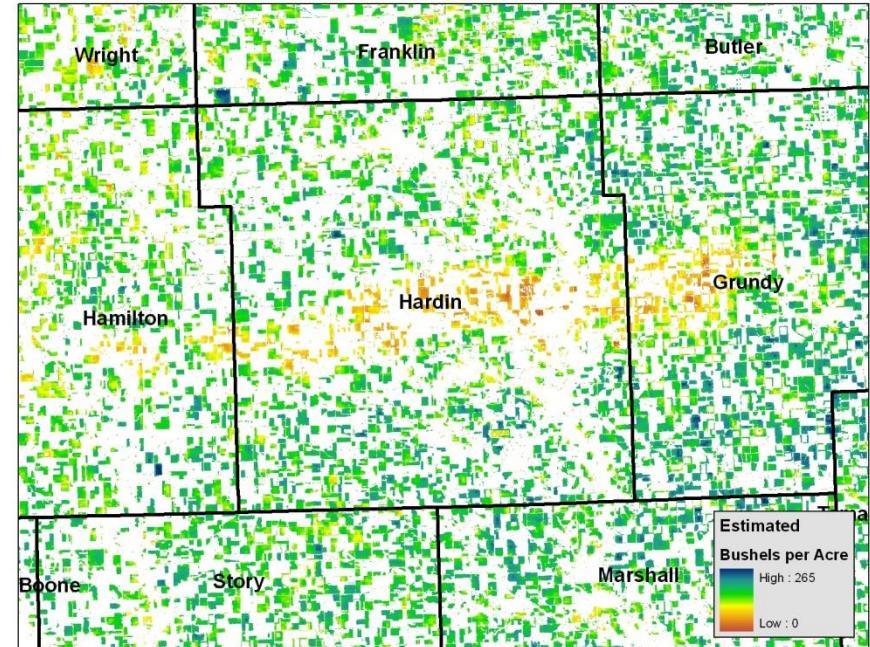


# Localized example of yield map variability

Scene of a large hailstorm



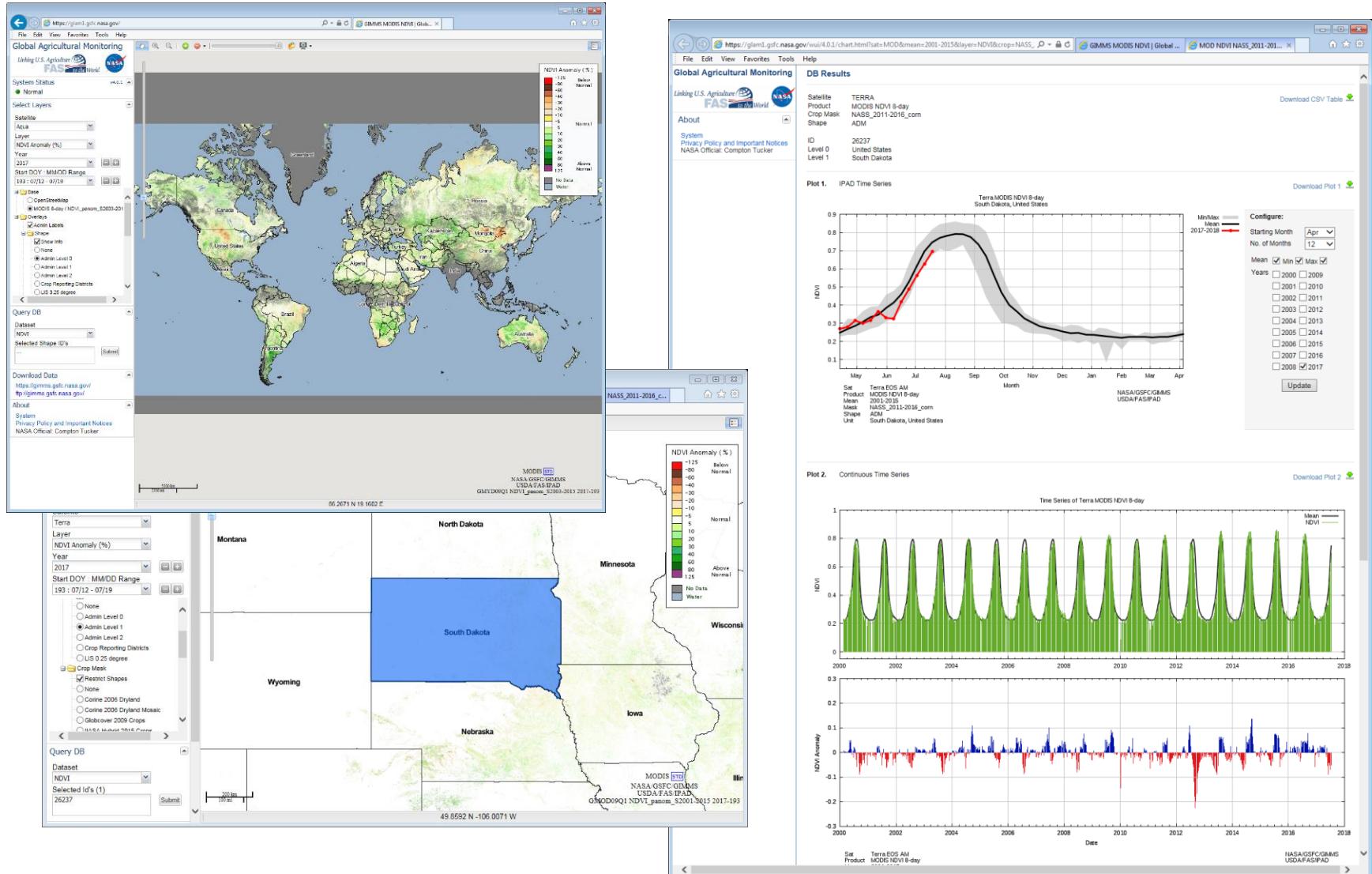
Landsat image



Modeled yields from MODIS

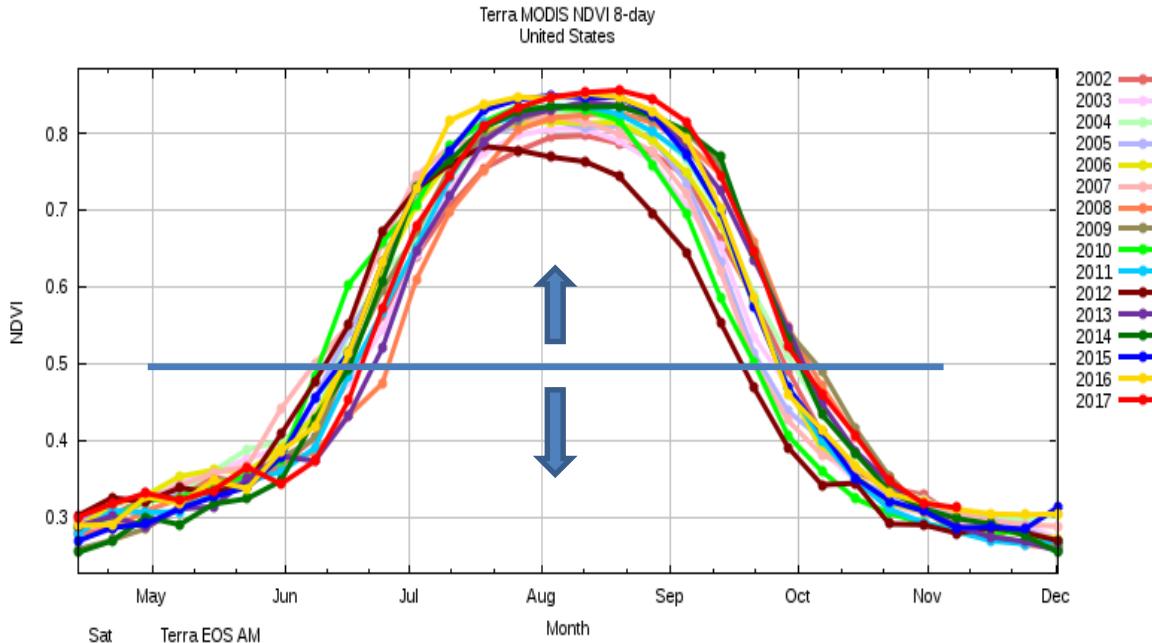
# USDA Foreign Agricultural Service/NASA GLAM

<https://glam1.gsfc.nasa.gov/>



Highly already customized tool for time series analysis and display

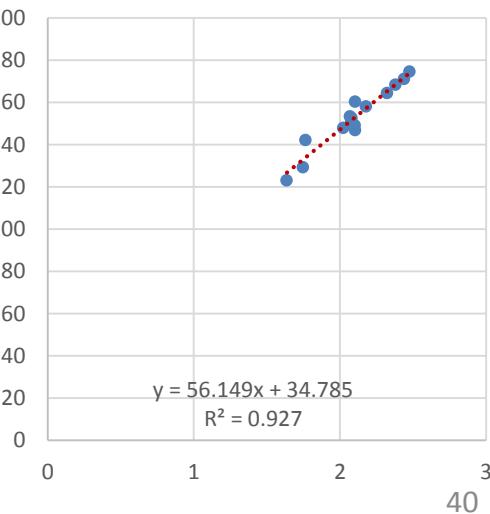
# Also, shifting to a simpler model construction



Calculate area under the curve, over a threshold and relate to past years.

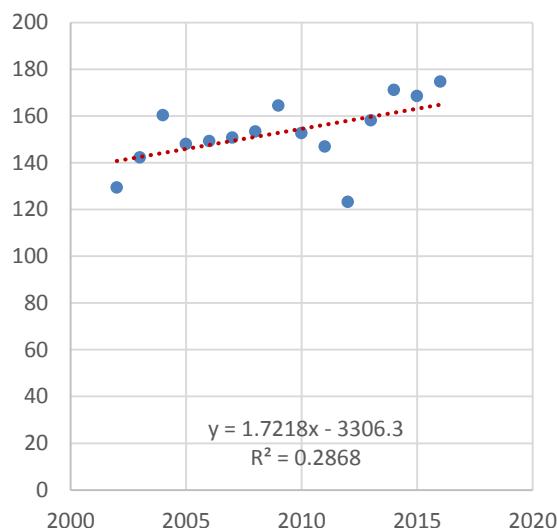


year	yield	andvi
2002	129.3	1.749
2003	142.2	1.765
2004	160.3	2.106
2005	147.9	2.024
2006	149.1	2.104
2007	150.7	2.08
2008	153.3	2.07
2009	164.4	2.324
2010	152.6	2.082
2011	146.8	2.105
2012	123.1	1.637
2013	158.1	2.179
2014	171	2.44
2015	168.4	2.382
2016	174.6	2.477

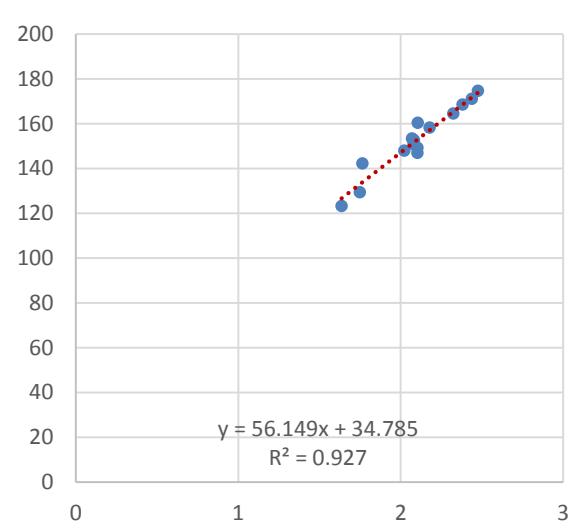


# USA national-level simplistic corn yield model

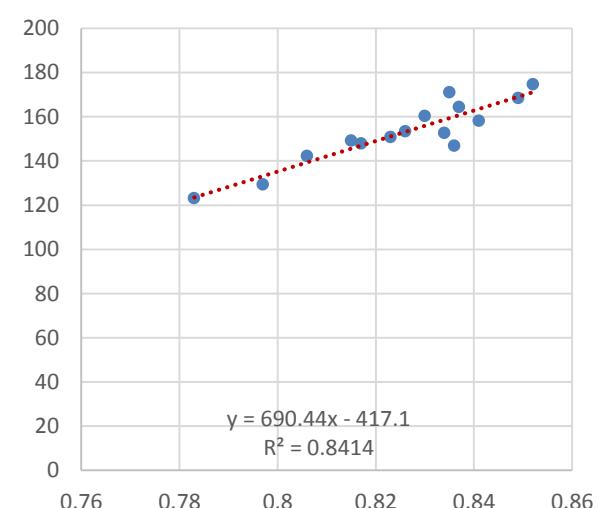
Trend



Integrate



Max



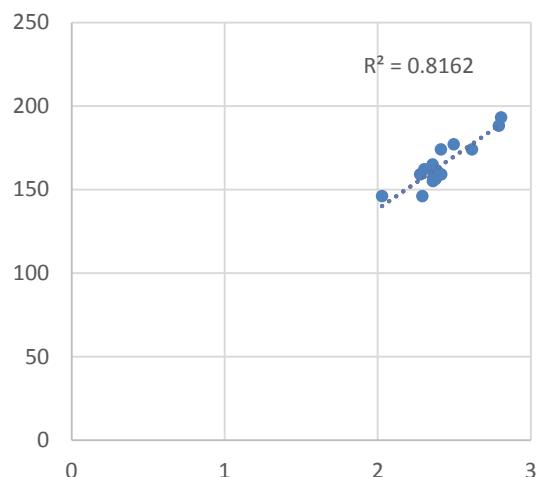
Standard Error 12.5996

Standard Error 4.0309

Standard Error 5.9422

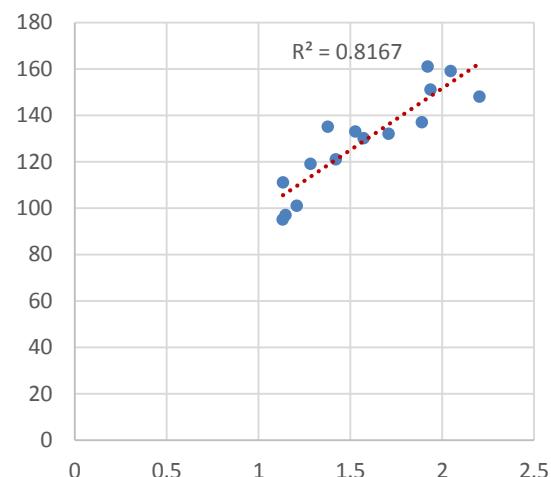
# State-level simplistic yield modeling

Minnesota



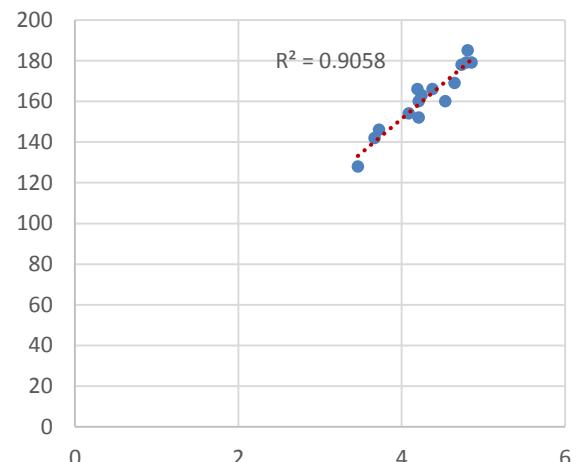
Standard Error 6.1590

South Dakota



Standard Error 9.4601

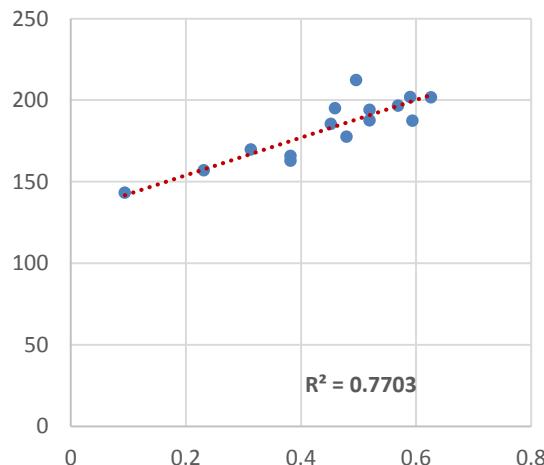
Nebraska



Standard Error 4.9836

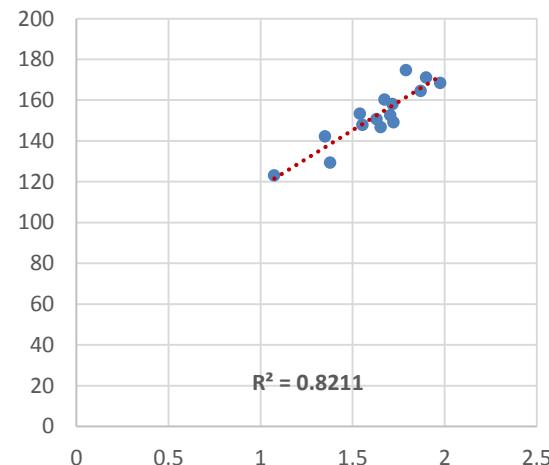
# County-level simplistic yield modeling

Sioux, Iowa



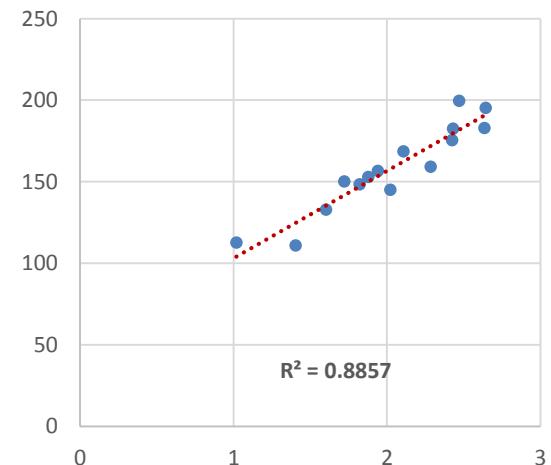
Standard Error 10.41041

Minnehaha, South Dakota



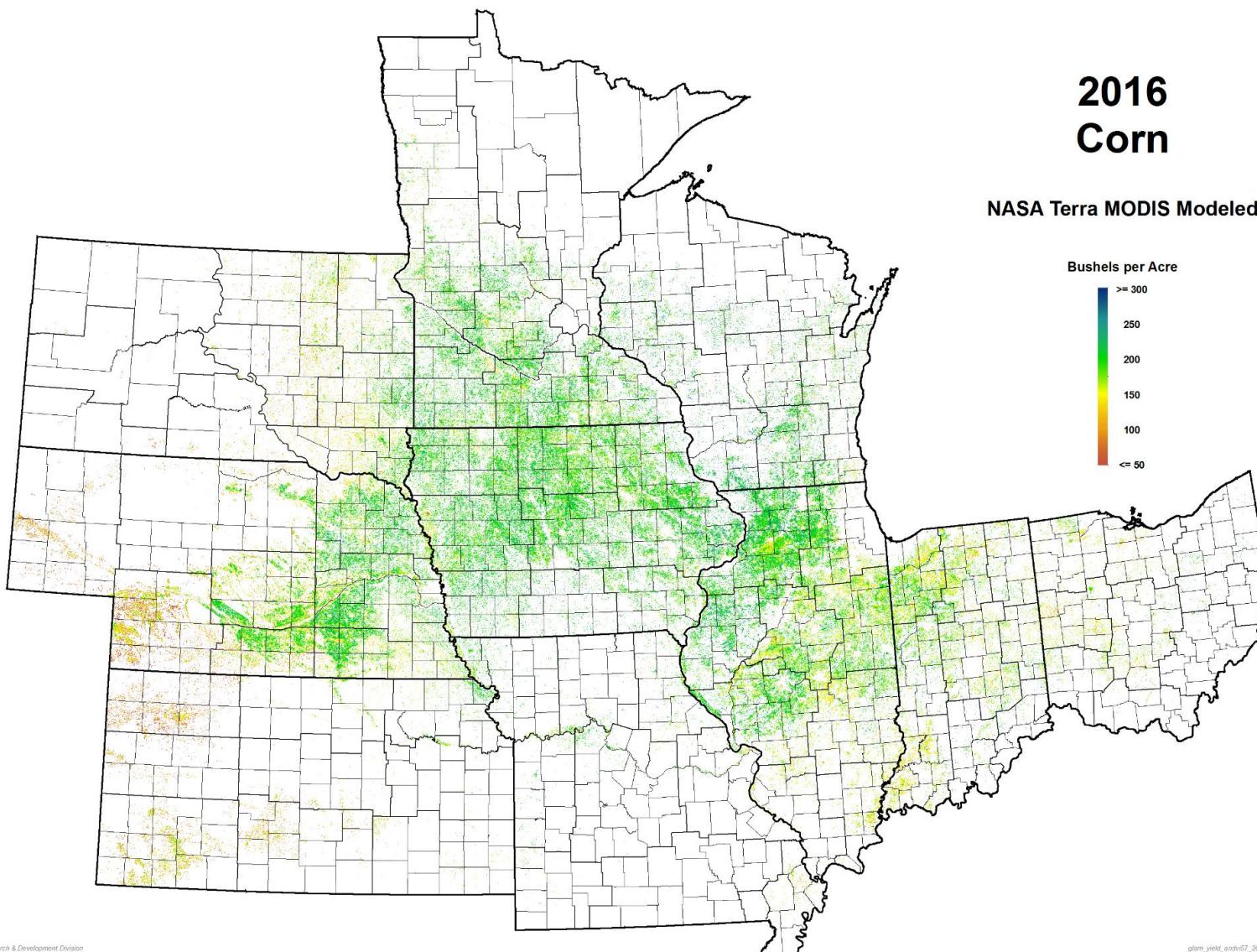
Standard Error 6.31143

Madison, Nebraska

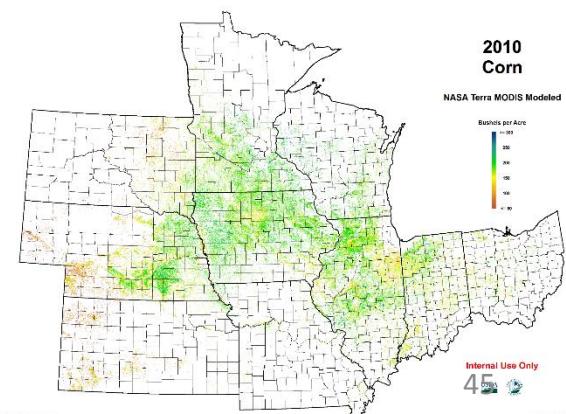
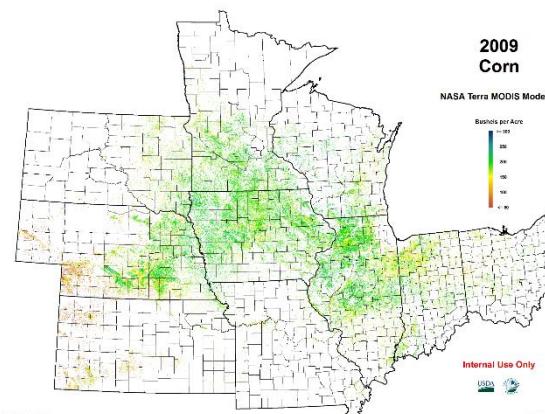
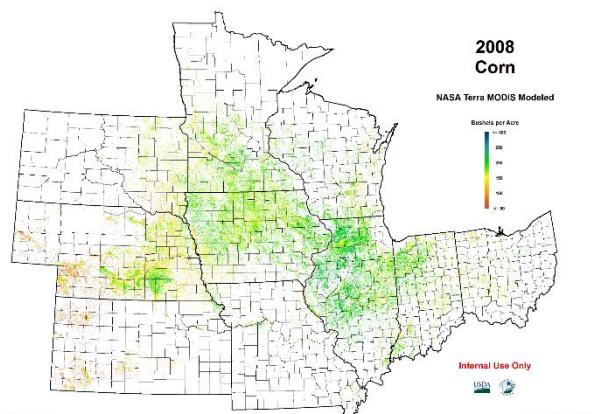
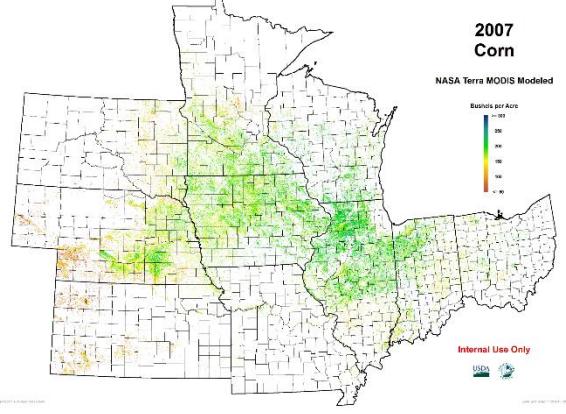
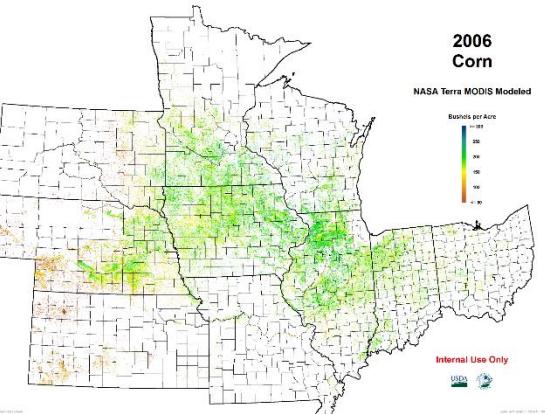
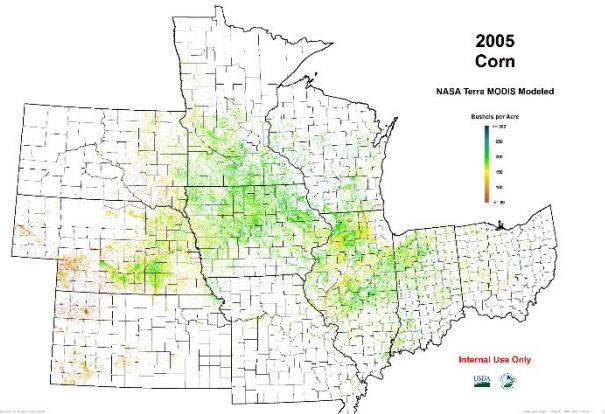
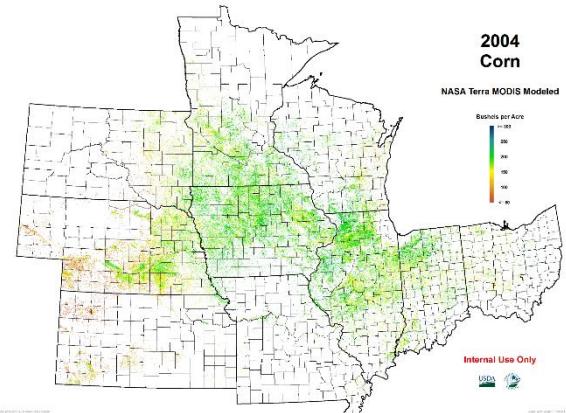
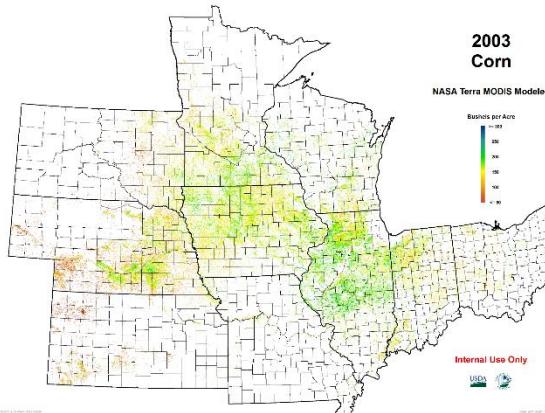
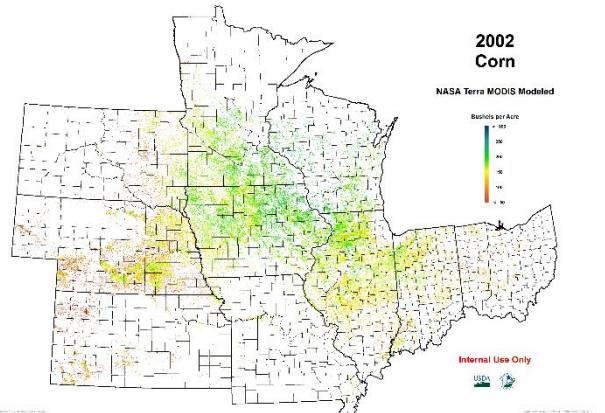


Standard Error 9.377654

# Map output still possible



# And easy to create time series...



# Summary of Remote Sensing for Crop Production Estimation

- **Strengths**

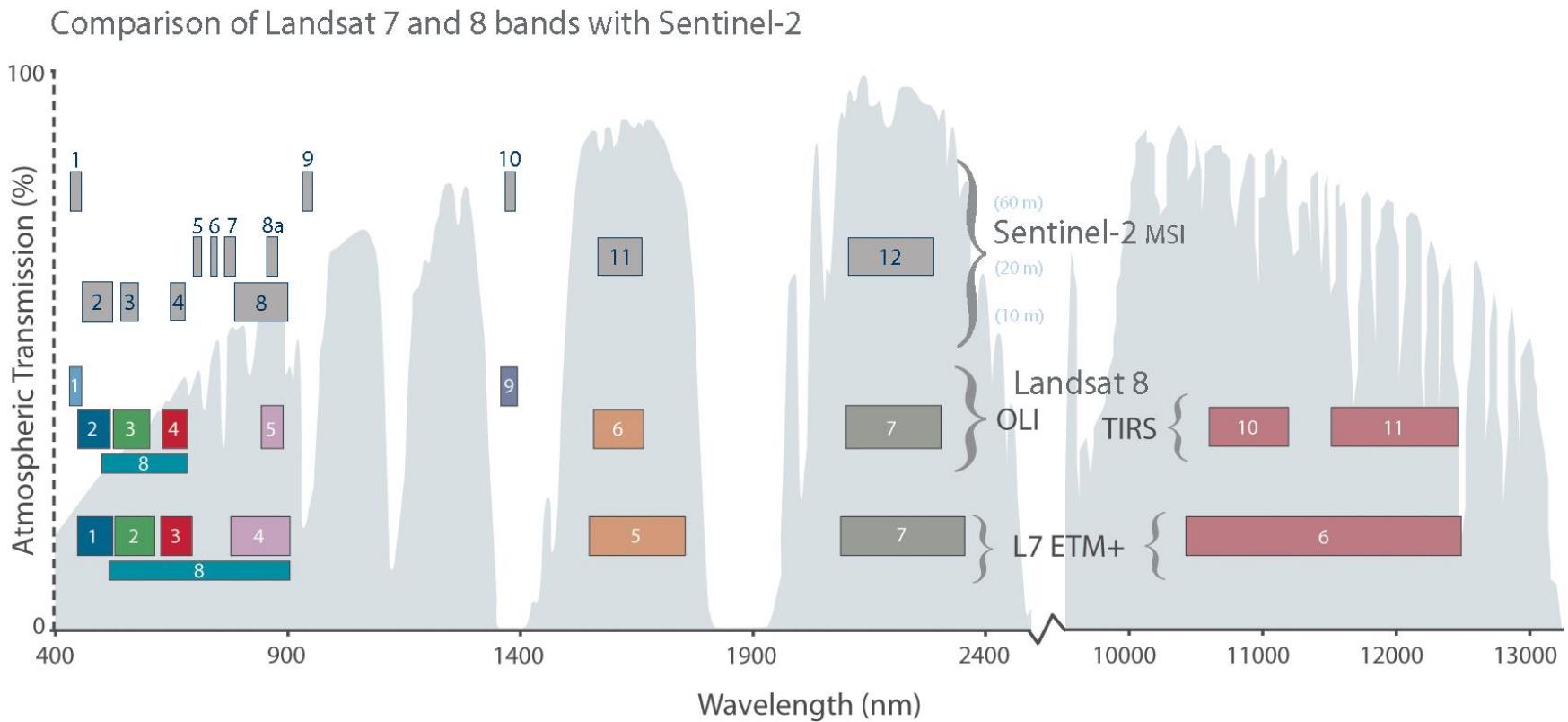
- Good areal coverage
- Solid temporal coverage
- Many free data sources
- Better sensors on the way
- Little data latency
- Fine spatial detail
- Simple statistical models seem to be as good as complicated ones
- Cheap computing and analytics has been a boon

- **Weaknesses**

- Computationally intensive
- Integrative skill set required
- Calibration of datasets always ongoing
- Measurement uncertainties difficult to quantify
- A variety of noise sources are present
- No long-term history
- *In situ* validation lacking
- Past utility was oversold



# Sentinel-2 vs Landsat 7 & 8 spectral bands



# Acreage estimate for a crop in stratum $h$

$$\hat{y}_h = N_h [\bar{y}_h + b_h (\bar{X}_h - \bar{x}_h)]$$

$N_h$  = Number of frame units (segments in frame)

$\bar{y}$  = **sample** mean per segment of reported acres of crop cover

$b_h$  = Slope of the regression of acres in segment on pixel(acres)

$\bar{X}_h$  = **population** mean pixels(acres) in segment

$\bar{x}_h$  = **sample** mean pixels(acres) in segment

# Estimate of county total for a crop, stratum

$$\hat{T}_{(BF)hc.} = N_{hc} \left[ \hat{\beta}_{0h} + \hat{\beta}_{1h} \bar{x}_{hc} + \delta_{hc} \bar{u}_{hc.} \right]$$

$$\bar{u}_{hc.} = \bar{y}_{hc.} - \hat{\beta}_{0h} - \hat{\beta}_{1h} \bar{x}_{hc.} \quad (\text{residual})$$

- 1) if  $\sigma^2_{\text{within}} = 0$ , use  $\delta = 1$ ,
- 2) if  $\sigma^2_{\text{between}} = 0$ , use  $\delta = 0$ ,
- 3) if < 2 segments use  $\delta = 0$ ,
- 4) if  $\sigma^2_{\text{within}} = 1.0$ , use  $\delta = 0$ ,
- 5) otherwise use  $\delta = \gamma$