MODIS-based Modeling of Corn and Soybean Yields in the US

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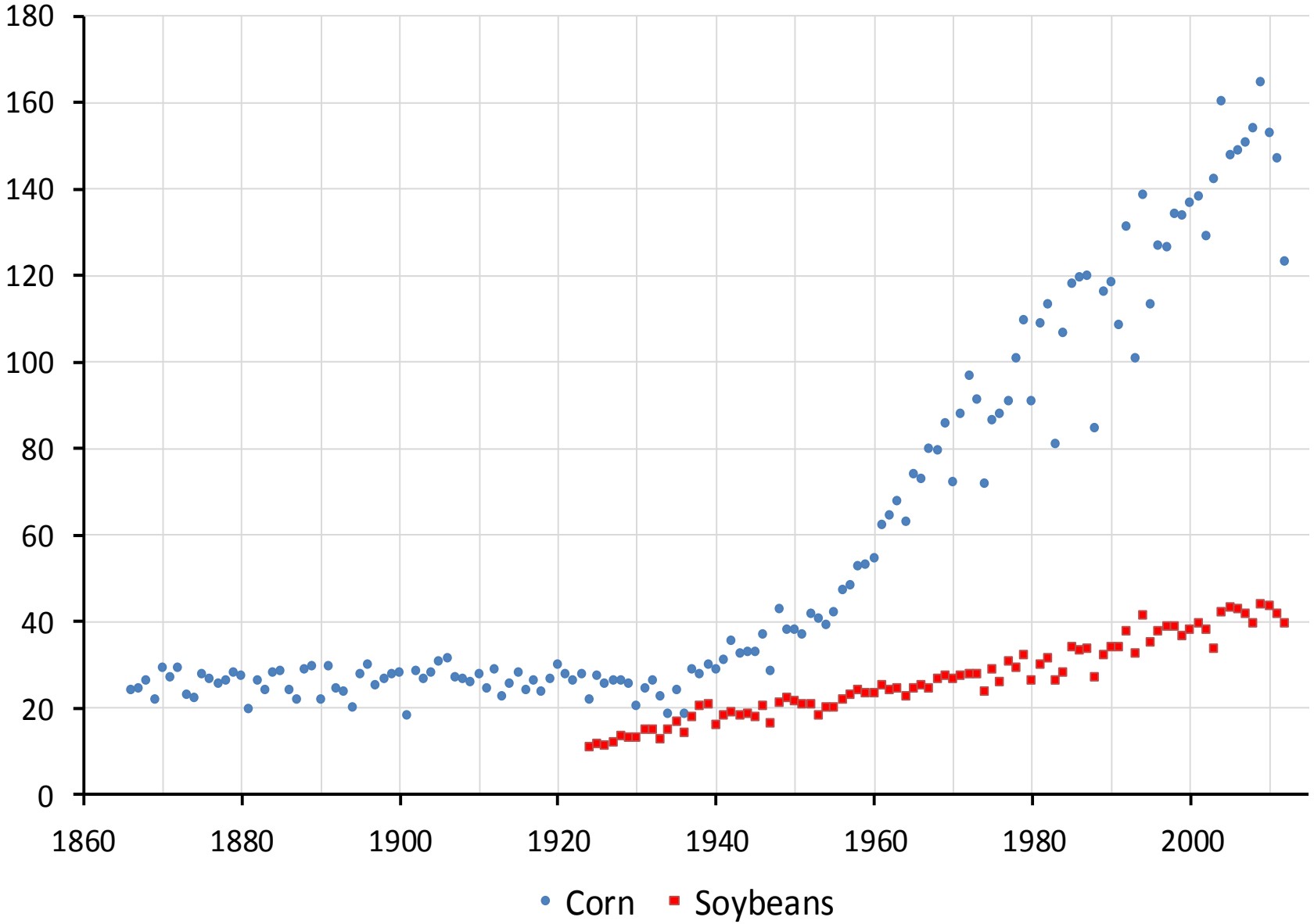
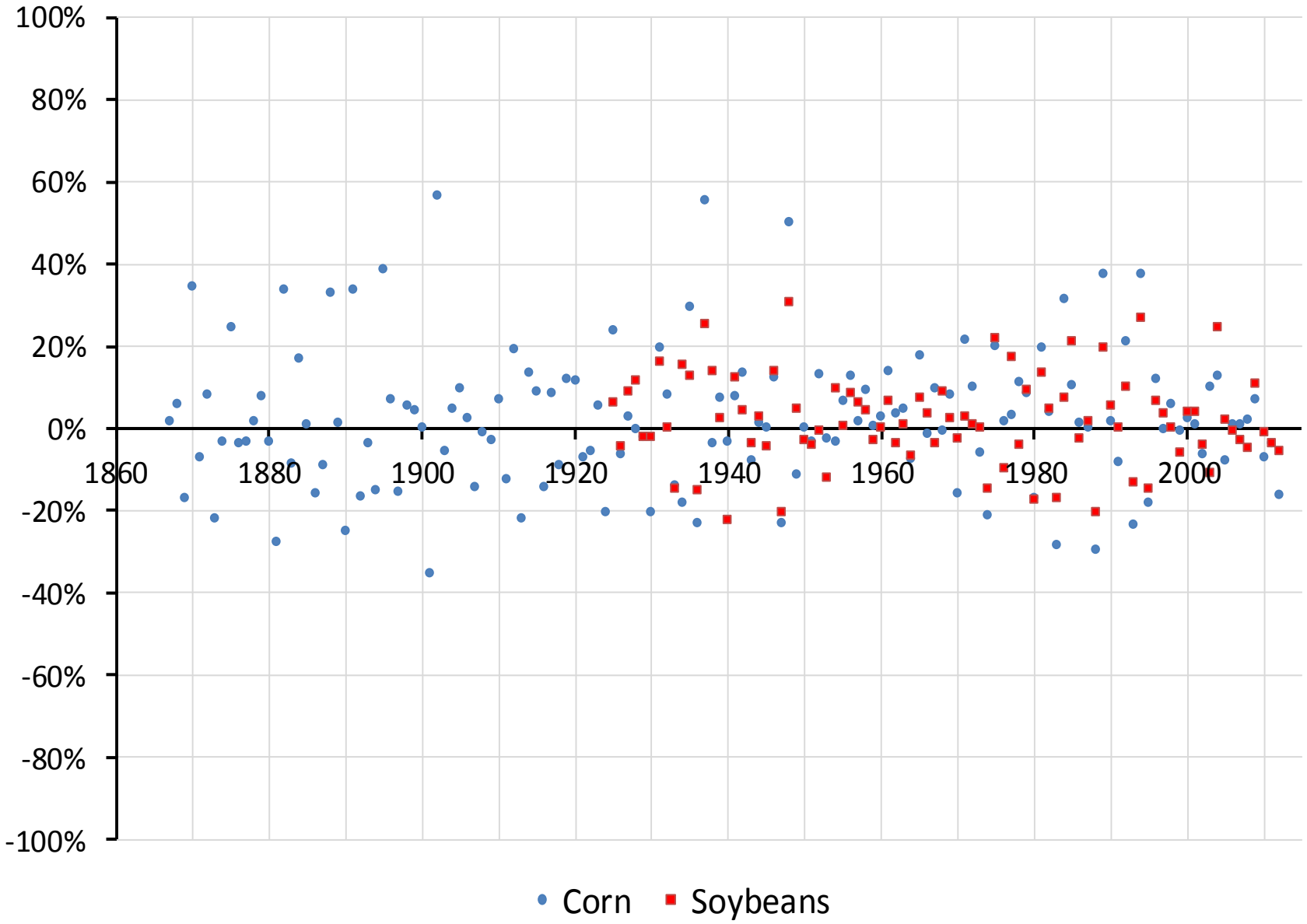
National Agricultural Statistics Service
www.nass.usda.gov

United States Yield (bushel/acre)



United States Yield Year to Year Change %



NASS Crop Production reports

Corn Area Planted for All Purposes and Harvested for Grain, Yield, and Production – States and United States: 2009-2011 (continued)

State	Yield per acre			Production		
	2009	2010	2011	2009	2010	2011
	(bushels)	(bushels)	(bushels)	(1,000 bushels)	(1,000 bushels)	(1,000 bushels)
Alabama	108.0	116.0	114.0	27,000		
Arizona	175.0	210.0	180.0	3,500		
Arkansas	148.0	150.0	142.0	60,680		
California	180.0	195.0	185.0	28,800		
Colorado	153.0	151.0	133.0	151,470		
Connecticut [1]	(NA)	(NA)	(NA)	(NA)		
Delaware	145.0	115.0	130.0	23,635		
Florida	100.0	105.0	100.0	3,700		
Georgia	140.0	145.0	158.0	51,800		
Idaho	180.0	180.0	185.0	14,400		
Illinois	174.0	157.0	157.0	2,053,200		
Indiana	171.0	157.0	146.0	933,660		
Iowa	182.0	165.0	172.0	2,420,600		
Kansas	155.0	125.0	107.0	598,300		
Kentucky	165.0	124.0	139.0	189,750		
Louisiana	132.0	140.0	135.0	80,520		
Maine [1]	(NA)	(NA)	(NA)	(NA)		
Maryland	145.0	106.0	109.0	61,625		
Massachusetts [1]	(NA)	(NA)	(NA)	(NA)		
Michigan	148.0	150.0	153.0	309,320		
Minnesota	174.0	177.0	156.0	1,244,100		
Mississippi	126.0	136.0	128.0	87,570		
Missouri	153.0	123.0	114.0	446,760		
Montana	152.0	135.0	130.0	3,952		
Nebraska	178.0	166.0	160.0	1,575,300		
Nevada [1]	(NA)	(NA)	(NA)	(NA)		
New Hampshire [1]	(NA)	(NA)	(NA)	(NA)		
New Jersey	143.0	114.0	123.0	10,010		
New Mexico	185.0	180.0	180.0	9,250		
New York	134.0	150.0	133.0	79,730		
North Carolina	117.0	91.0	84.0	93,600		
North Dakota	115.0	132.0	105.0	200,100		
Ohio	174.0	163.0	158.0	546,360		
Oklahoma	105.0	130.0	90.0	33,600		
Oregon	215.0	200.0	215.0	6,880		
Pennsylvania	143.0	128.0	111.0	131,560		
Rhode Island [1]	(NA)	(NA)	(NA)	(NA)		
South Carolina	111.0	91.0	65.0	35,520		
South Dakota	151.0	135.0	132.0	706,680		
Tennessee	148.0	117.0	131.0	87,320		
Texas	130.0	145.0	93.0	254,800		
Utah	155.0	172.0	164.0	2,635		
Vermont [1]	(NA)	(NA)	(NA)	(NA)		
Virginia	131.0	67.0	118.0	43,230		
Washington	215.0	205.0	225.0	22,575		
West Virginia	126.0	90.0	114.0	3,780		
Wisconsin	153.0	162.0	156.0	448,290		
Wyoming	140.0	121.0	130.0	6,300		
United States	164.7	152.8	147.2	13,091,862		

(NA) Not available.
[1] Area harvested for grain not estimated.

Crop Production 2011 Summary (January 2012)
USDA, National Agricultural Statistics Service

USDA

Crop Production

ISSN: 1936-3737

Released August 11, 2011, by the National Agricultural Statistics Service (NASS), Agricultural Statistics Board, United States Department of Agriculture (USDA).

Planted Acreage Update

Survey respondents who reported acreage as not yet planted in Minnesota, Montana, North Dakota, and South Dakota during the survey conducted in preparation for the *Acreage* report, released June 30, 2011 were re-contacted in July to determine how many of those acres were planted or still intended to be planted. Acreage estimates in this report reflect this updated information.

Corn Production Up 4 Percent from 2010
Soybean Production Down 8 Percent from 2010
Cotton Production Down 9 Percent from 2010
All Wheat Production Down 1 Percent from July Forecast

Corn production is forecast at 12.9 billion bushels, up 4 percent from 2010. If realized, this will be the third largest production total on record for the United States. Based on conditions as of August 1, yields are expected to average 153.0 bushels per acre, up 0.2 bushel from 2010, and the fourth highest yield on record. Acreage planted for all purposes is estimated at 92.3 million acres, unchanged from the June estimate. Area harvested for grain is forecast at 84.4 million acres, down less than 1 percent from June but up 4 percent from 2010.

Soybean production is forecast at 3.06 billion bushels, down 8 percent from last year. Based on August 1 conditions, yields are expected to average 41.4 bushels per acre, down 2.1 bushels from last year. Area for harvest in the United States is forecast at 73.8 million acres, down less than 1 percent from June and down 4 percent from 2010. Planted area for the Nation is estimated at 75.0 million acres, down fractionally from June.

All cotton production is forecast at 16.6 million 480-pound bales, down 9 percent from last year's 18.1 million bales. Yield is expected to average 822 pounds per harvested acre, up 10 pounds from last year. Upland cotton production is forecast at 15.8 million 480-pound bales, down 10 percent from 2010. American Pima production is forecast at 737,200 bales, up 46 percent from last year. Producers expect to harvest 9.67 million acres of all cotton, down 10 percent from 2010. This harvested total includes 9.38 million acres of Upland cotton and 287,500 acres of Pima cotton.

All wheat production, at 2.08 billion bushels, is down 1 percent from the July forecast and down 6 percent from 2010. Based on August 1 conditions, the United States yield is forecast at 45.2 bushels per acre, up 0.6 bushel from last month but down 1.2 bushels from last year.

USDA
United States Department of Agriculture
National Agricultural Statistics Service

Crop Production
2011 Summary

January 2012

ISSN: 1057-7823

Published no later than the 12th of each month.

Yields results primarily derived from two surveys

Agricultural Yield

- Farmer reported survey data of expected crop yields.
- Data obtained throughout the growing season.
- Conducted in all states except Alaska and Hawaii.
- Sample size in the 1000s per state.
- Farm operator contacts are selected from the March Crops/Stocks survey (small grains) and the June Crops/Stocks survey (late season crops and tobacco).
- Primarily telephone based.

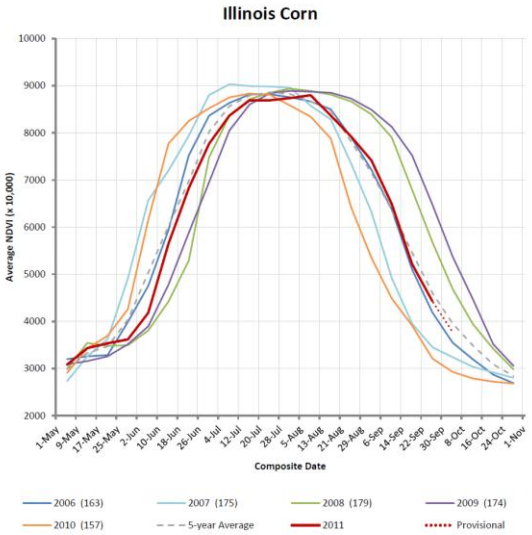
Objective yield

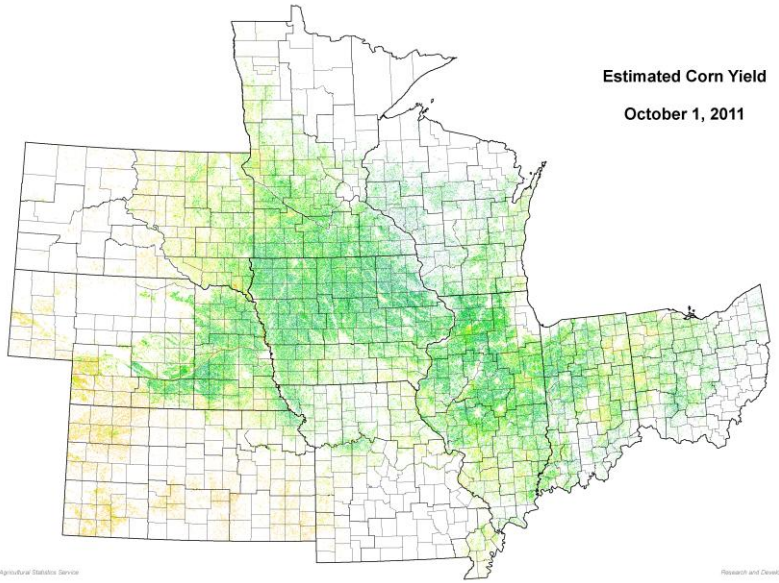
- Corn, Cotton, Soybeans, Wheat, Potatoes.
- Only done in states where the commodities are primarily found.
- Samples selected from areas found in June Area Survey ("Acreage").
- Performed at 100s of sample sites per state.
- Biophysical plant/seed measurements obtained.
- Each plot revisited a few times per season.

Estimating Yield from Remote Sensing

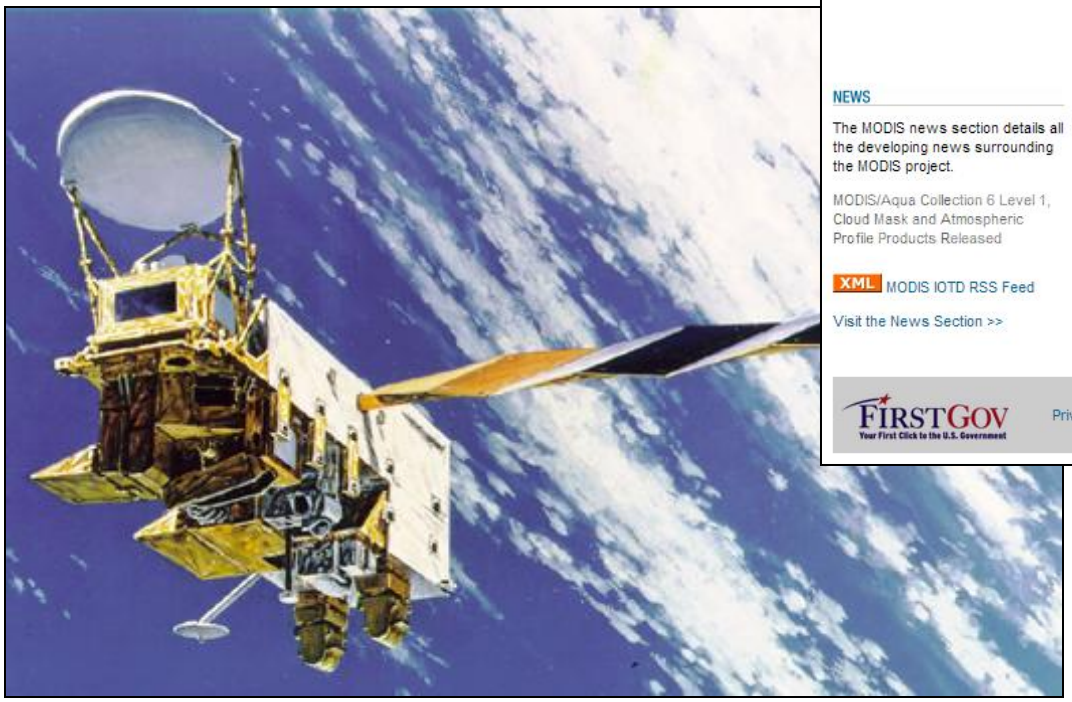
Third method for yield estimates

- There is a relationship between crop
  - Biomass, vigor, “greenness”, NDVI
    - and
  - Daytime land surface temperature
- And the resulting corn or soybean yield
- Utilize MODIS data to obtain biomass and temperature variables
- Do it for
  - National, State, “ASD”, and County levels
  - And map at pixel level





Moderate Resolution Imaging Spectroradiometer (MODIS)



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MODIS Web

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DATA

The MODIS Data section contains everything from ATBDs to Product Descriptions to tutorials on ordering MODIS data from the various DAACs. Peruse the Data section today.

NEWS

The MODIS news section details all the developing news surrounding the MODIS project.

MODIS/Aqua Collection 6 Level 1, Cloud Mask and Atmospheric Profile Products Released

XML MODIS IOTD RSS Feed

Visit the News Section >>

IMAGES

Super Typhoon Jelawat (18W) in the Philippine Sea

DISCIPLINES

Atmosphere

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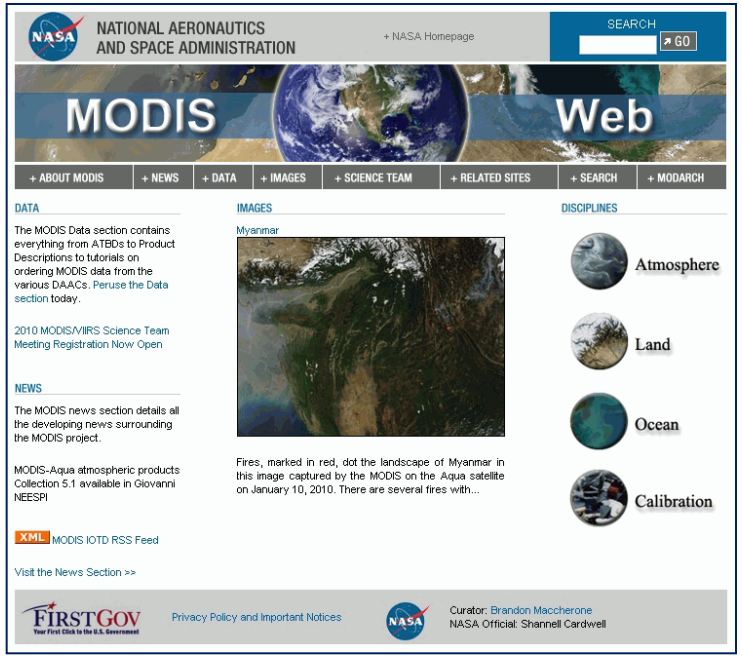
Curator: Brandon Maccherone
NASA Official: Shannell Frazier

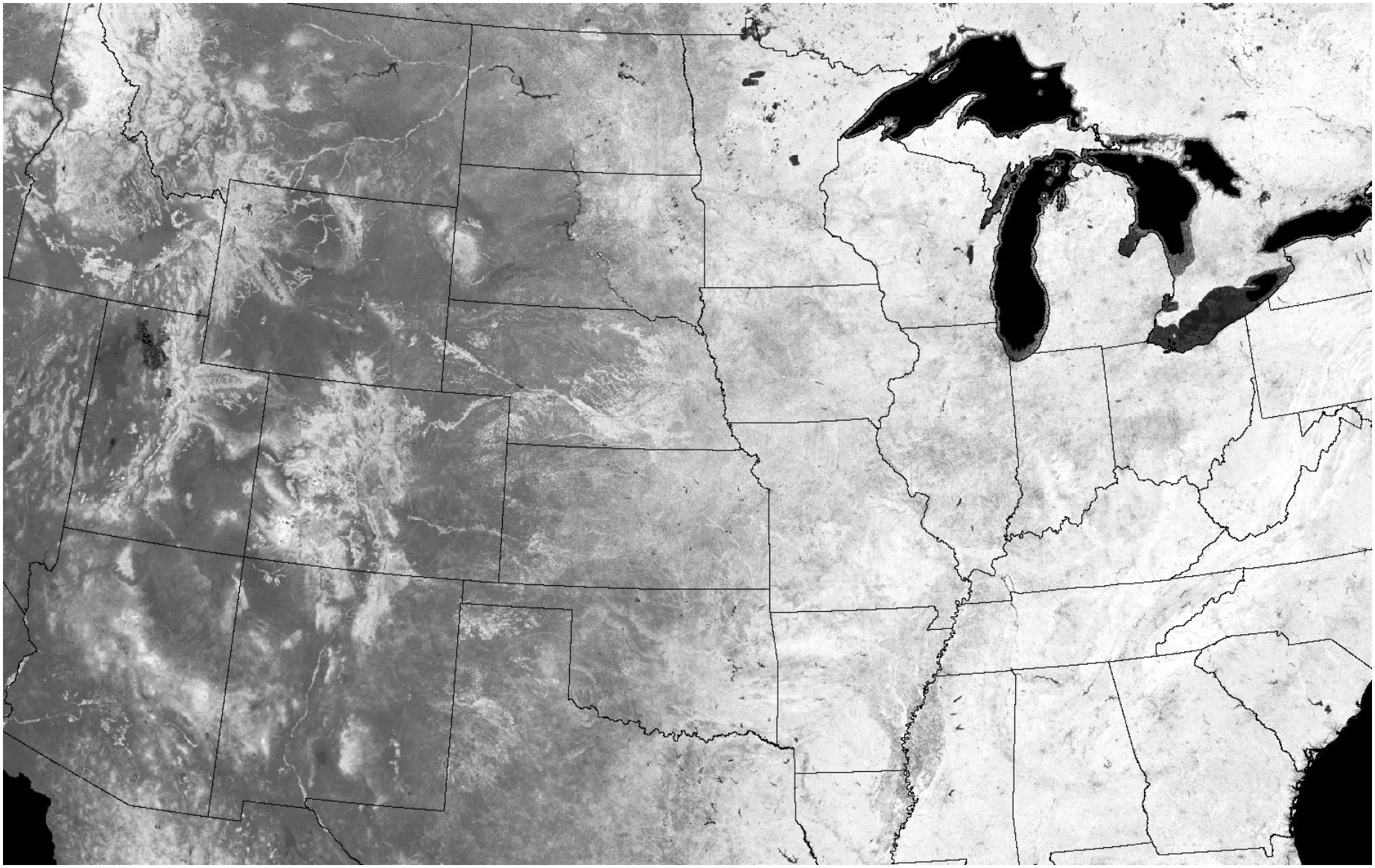
Why MODIS?

- Global coverage
- Daily revisit rate
- 15 acre ground sample resolution
  - from red and near-infrared bands
- “Best of” image mosaics automatically generated
  - 8 and 16-day temporal windows
- Timely
  - data usually available within a couple of days
- Free distribution
  - downloaded via ftp
- Robust user group
  - nearly 20,000 citations so far
- Launched in 1999 and 2002
  - Two of them
  - 10-year plus history
- 6 year design life but still functioning fine
- Similar follow-on mission
  - VIIRS

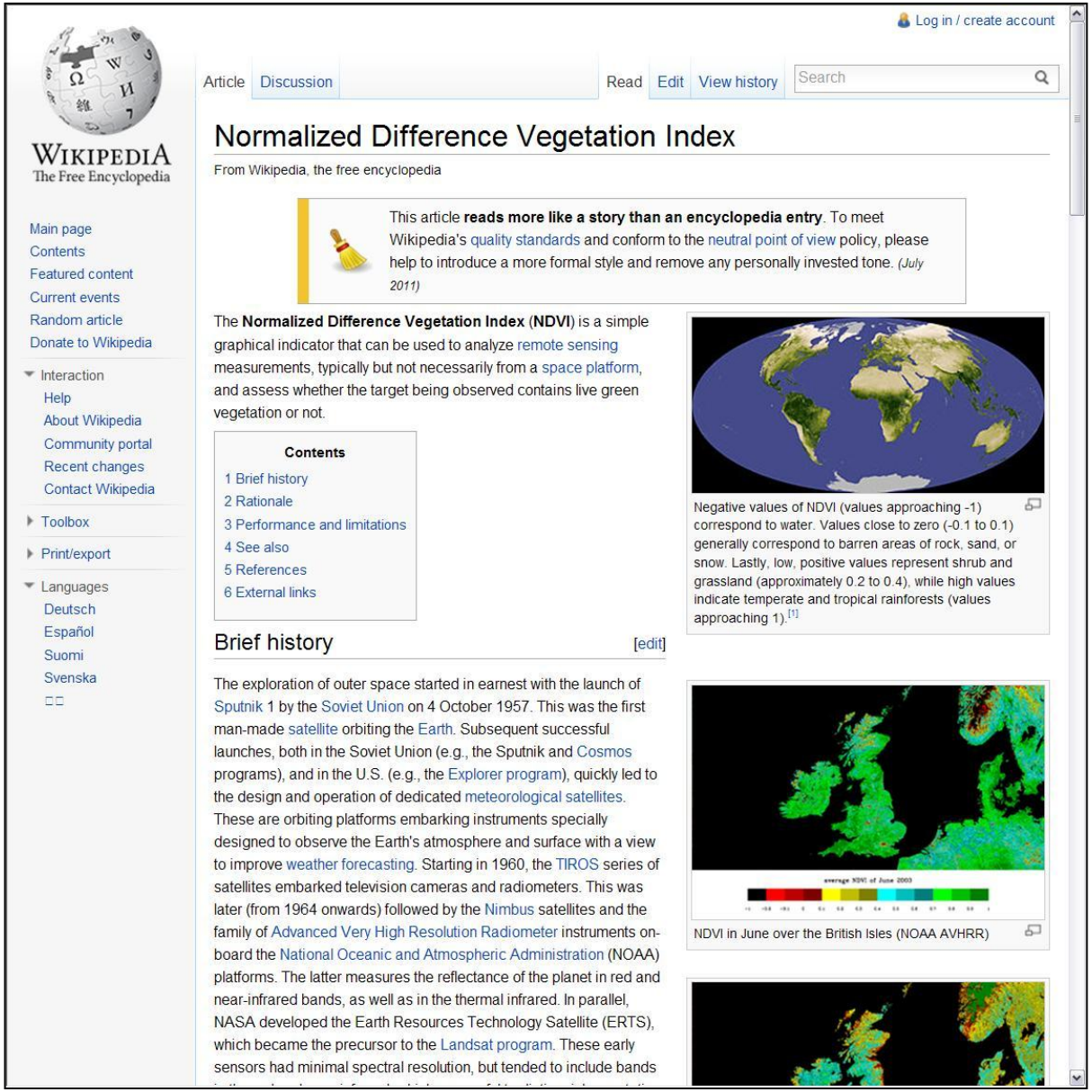


modis.gsfc.nasa.gov

MODIS NDVI data example



Calculation and use of NDVI



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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

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).[1]

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 on-board 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

NDVI in June over the British Isles (NOAA AVHRR)

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

NIR = near-infrared

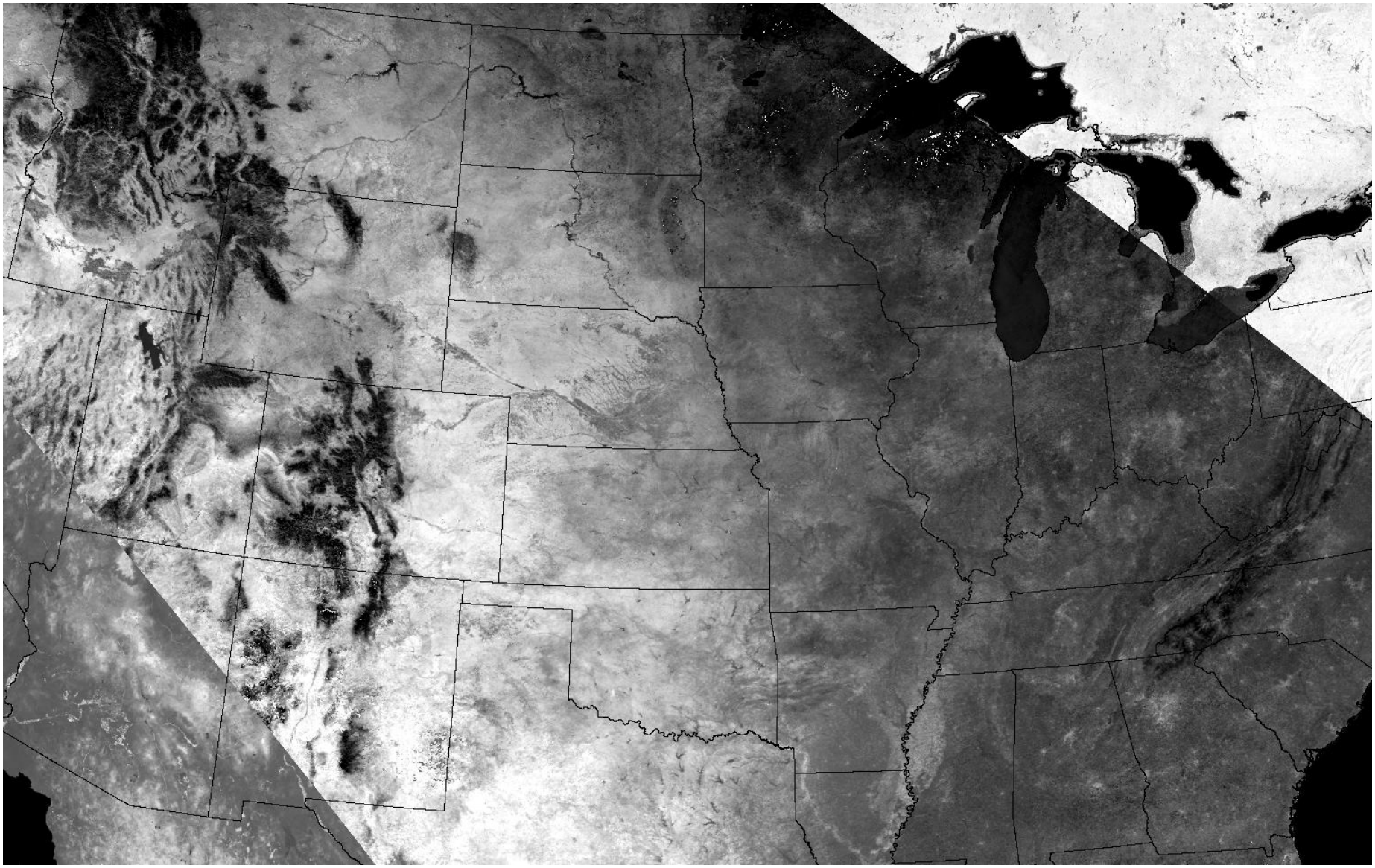
VIS = visible

Ranges from -1.0 to 1.0

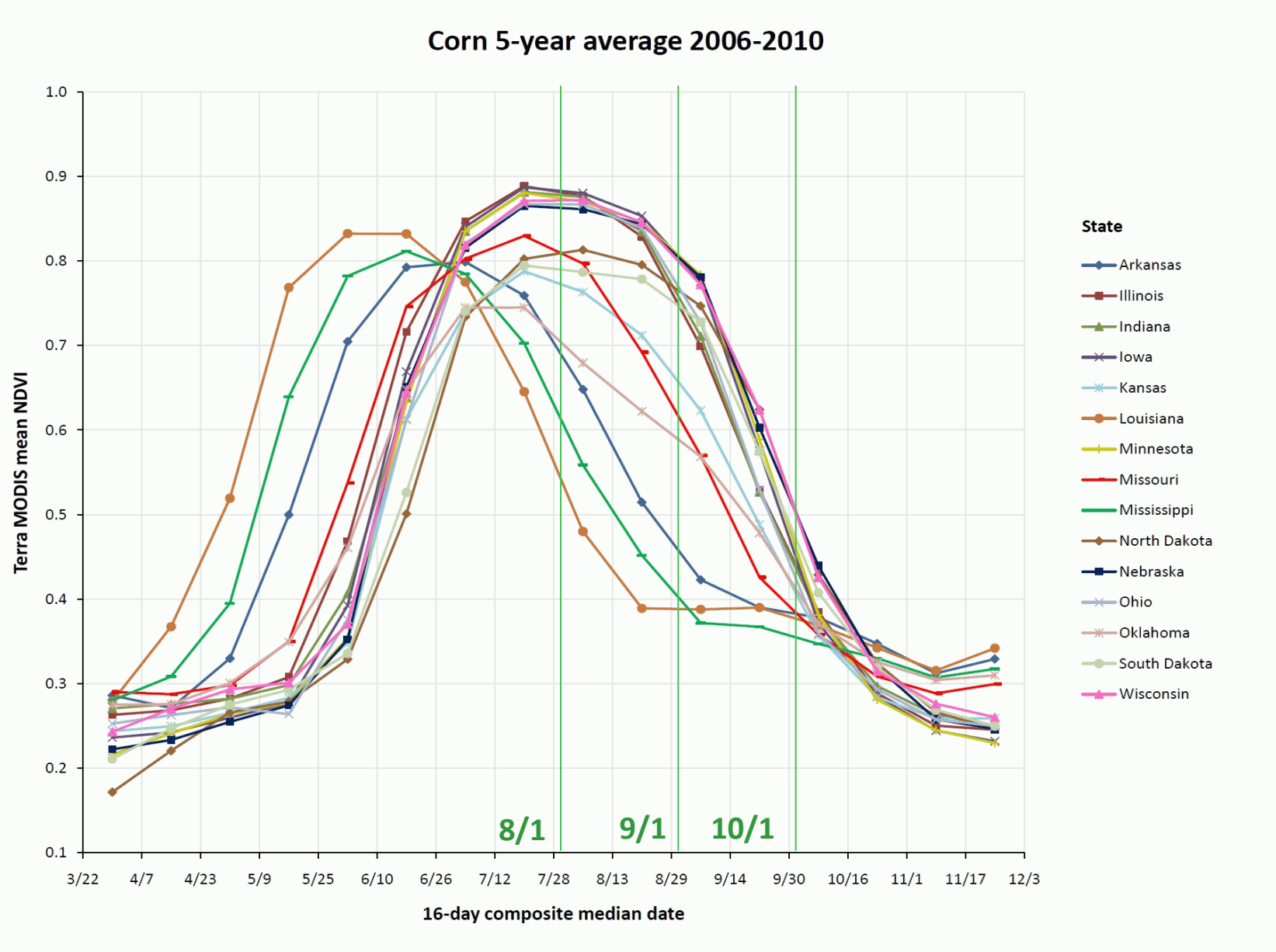
NDVI is a related to

- Plant health
- Cholophyll content
- “Greenness”
- Biomass
- Vegetation vigor

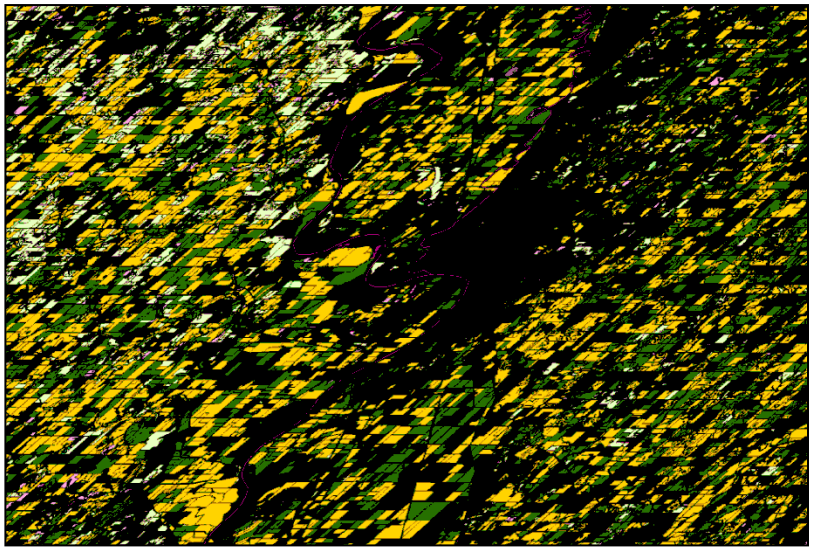
MODIS LST data example



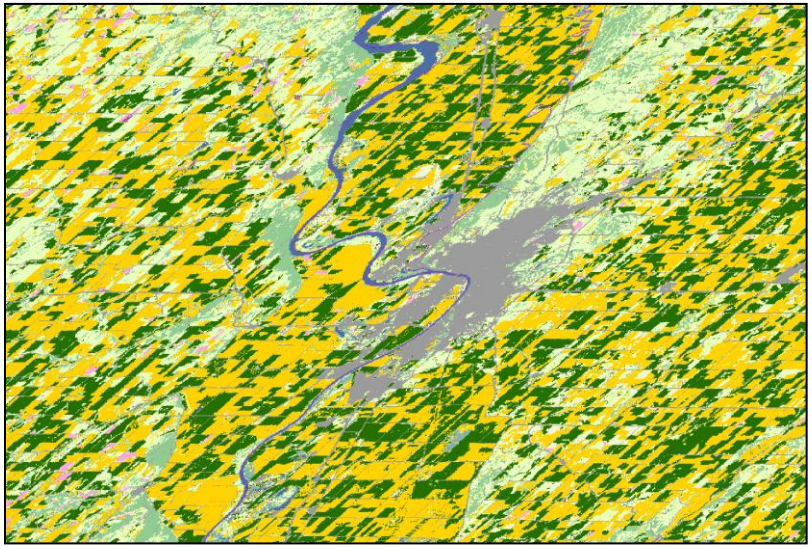
Corn phenology fundamentals



Establishing the pixels that are only corn

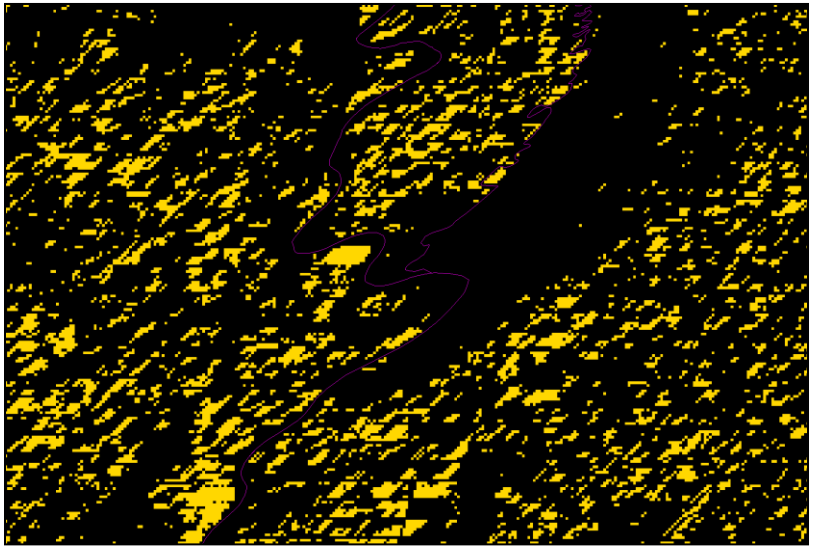


- or -



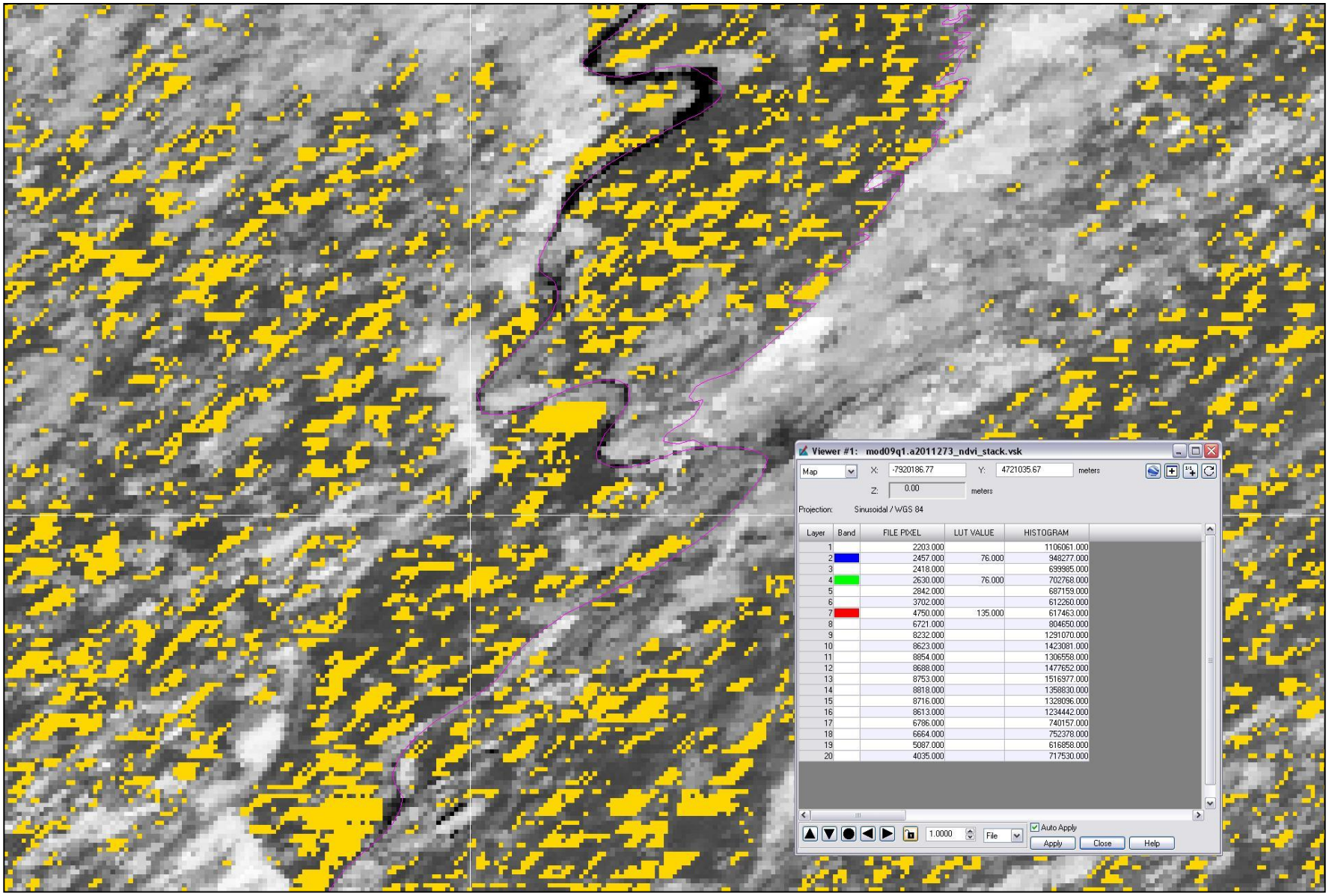
FSA CLU/578
(early season)

NASS CDL
(late season)



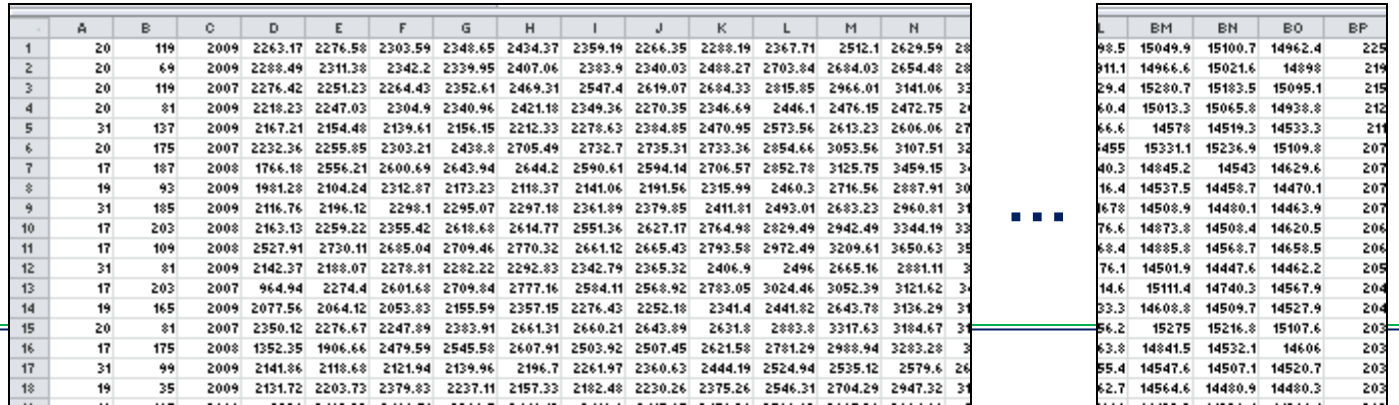
MODIS-scaled
High probability sample
of corn areas

Intersecting corn “mask” with MODIS data



County-level database developed

- Potential predictor variables (independent)
  - State (All major production Corn Belt states)
  - County (for each that had a published estimate, ~1000 of them)
  - Year (2006 – 2011)
  - 32 for each ranging every 8 days from February 18 – October 30
    - NDVI (derived from Terra "MOD09Q1" 250m)
    - Day LST (1:30 PM – from Aqua "MYD11A2" 1000m)
      - Thus 68 in total
- Forecast variable (dependent)
  - NASS published county level yield (available from NASS "Quickstats" webpage)
- Resulting database to evaluate ~5000 records



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	...	BM	BN	BO	BP
1	20	119	2009	2263.17	2276.58	2303.59	2348.65	2434.37	2359.19	2266.35	2288.19	2367.71	2512.1	2629.59		15049.9	15100.7	14962.4	225
2	20	69	2009	2288.49	2311.38	2342.2	2339.95	2407.06	2383.9	2340.03	2488.27	2703.84	2684.03	2654.48		14966.6	15021.6	14898	219
3	20	119	2007	2276.42	2251.23	2264.43	2352.61	2469.31	2547.4	2619.07	2684.33	2815.85	2966.01	3141.06		15280.7	15183.5	15095.1	215
4	20	81	2009	2218.23	2247.03	2304.9	2340.96	2421.18	2349.36	2270.35	2346.69	2446.1	2476.15	2472.75		15013.3	15065.8	14938.8	212
5	31	137	2009	2167.21	2154.48	2139.61	2156.15	2212.33	2278.63	2384.85	2470.95	2573.56	2613.23	2606.06		14578	14519.3	14533.3	211
6	20	175	2007	2232.36	2255.85	2303.21	2438.8	2705.49	2732.7	2735.31	2733.36	2854.66	3053.56	3107.51		15331.1	15236.9	15109.8	207
7	17	187	2008	1766.18	2556.21	2600.69	2643.94	2644.2	2590.61	2594.14	2706.57	2852.78	3125.75	3459.15		14845.2	14543	14629.6	207
8	19	93	2009	1981.28	2104.24	2312.87	2173.23	2118.37	2141.06	2191.56	2315.99	2460.3	2716.56	2887.91		14537.5	14458.7	14470.1	207
9	31	185	2009	2116.76	2196.12	2298.1	2295.07	2297.18	2361.89	2379.85	2411.81	2493.01	2683.23	2960.81		14508.9	14480.1	14463.9	207
10	17	203	2008	2163.13	2259.22	2355.42	2618.68	2614.77	2551.36	2627.17	2764.98	2829.49	2942.49	3344.19		14873.8	14508.4	14620.5	206
11	17	109	2008	2527.91	2730.11	2685.04	2709.46	2770.32	2661.12	2665.43	2793.58	2972.49	3209.61	3650.63		14885.8	14568.7	14658.5	206
12	31	81	2009	2142.37	2188.07	2278.81	2282.22	2292.83	2342.79	2365.32	2406.9	2496	2665.16	2881.11		14501.9	14447.6	14462.2	205
13	17	203	2007	964.94	2274.4	2601.68	2709.84	2777.16	2584.11	2568.92	2783.05	3024.46	3052.39	3121.62		15111.4	14740.3	14567.9	204
14	19	165	2009	2077.56	2064.12	2053.83	2155.59	2357.15	2276.43	2252.18	2341.4	2441.82	2643.78	3136.29		14608.8	14509.7	14527.9	204
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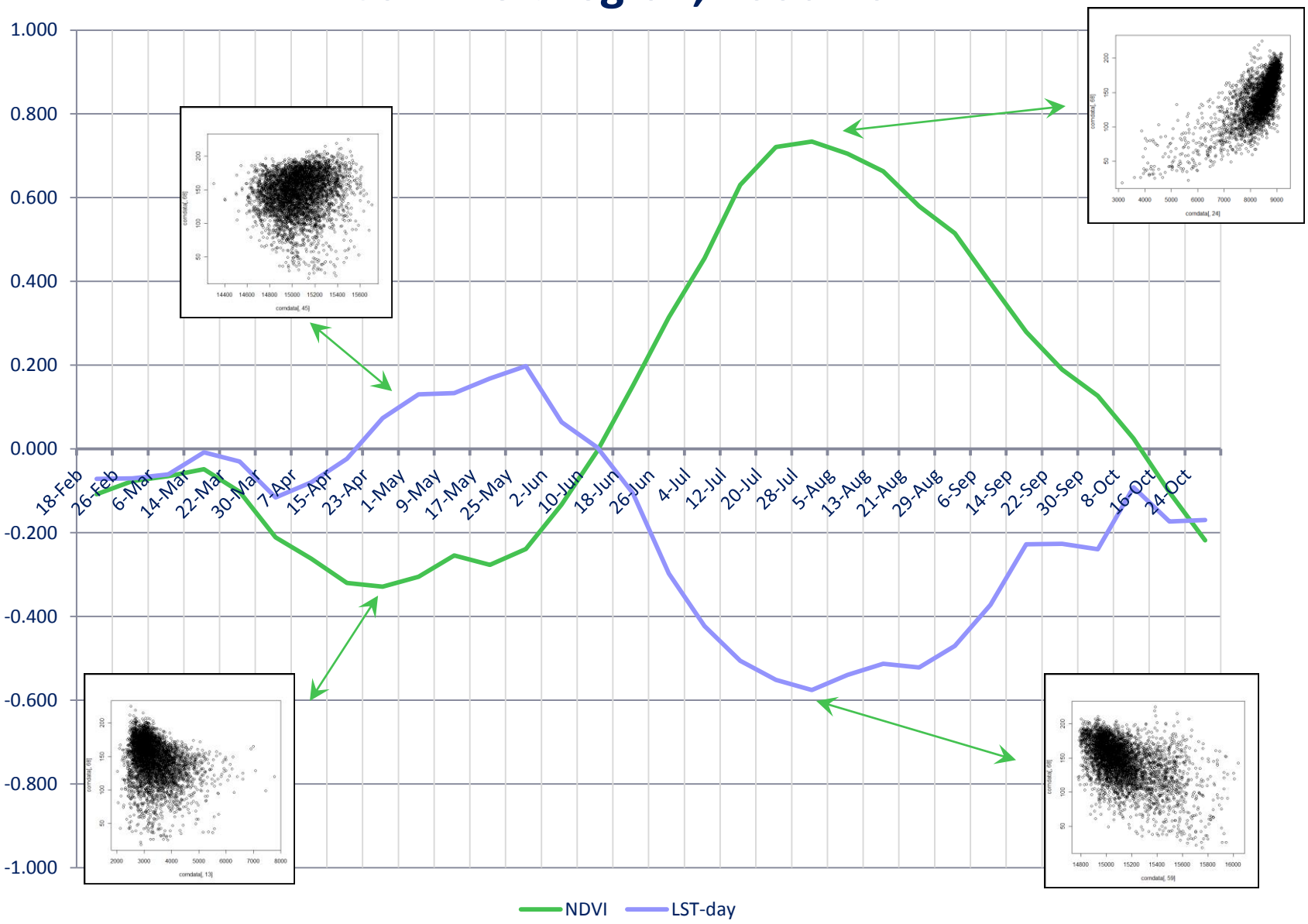
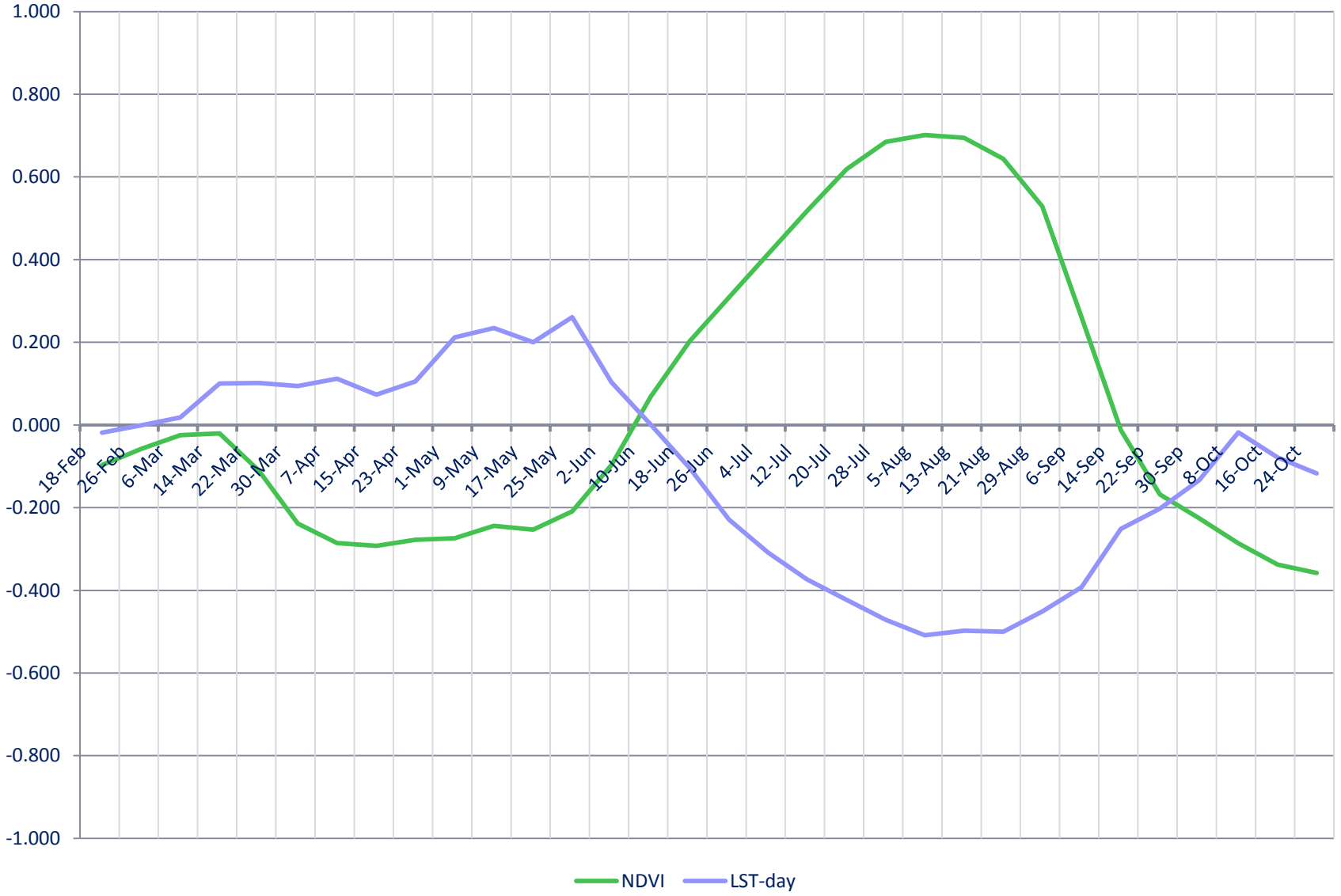
16	17	175	2008	1352.35	1906.66	2479.59	2545.58	2607.91	2503.92	2507.45	2621.58	2781.29	2988.94	3283.28		14841.5	14532.1	14606	203
17	31	99	2009	2141.86	2118.68	2121.94	2139.96	2196.7	2261.97	2360.63	2444.19	2524.94	2535.12	2579.6		14547.6	14507.1	14520.7	203
18	19	35	2009	2131.72	2203.73	2379.83	2237.11	2157.33	2182.48	2230.26	2375.26	2546.31	2704.29	2947.32		14564.6	14480.9	14480.3	203

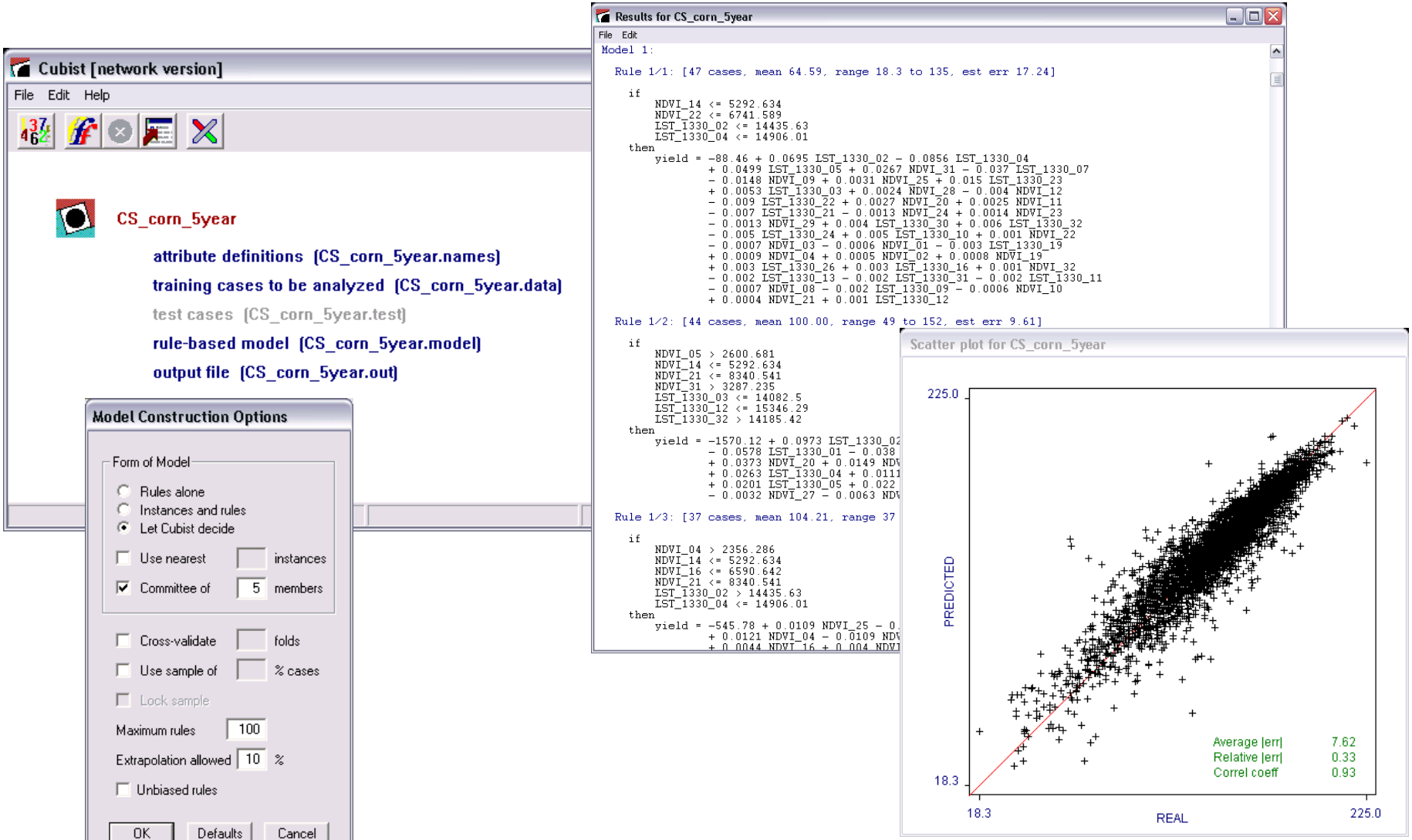
Corn yield dependence at county level
Corn Belt region, 2006-2011



Soybean yield dependence at county level
Corn Belt region, 2006-2011



Rulequest Cubist



Example county-level prediction output

Case No	Given Value	Predicted Value
1	1701.0	92.49 +- 24.78
2	1703.0	138.24 +- 24.78
3	1705.0	64.58 +- 24.78
4	1707.0	129.20 +- 24.78
5	1709.0	106.46 +- 24.78
6	17011.0	132.43 +- 24.78
7	17013.0	104.15 +- 24.78
8	17015.0	150.99 +- 24.78
9	17017.0	127.98 +- 24.78
10	17019.0	123.06 +- 24.78
* 11	17021.0	122.79 +- 24.78
12	17023.0	79.02 +- 24.78
13	17025.0	45.30 +- 24.78
14	17027.0	59.63 +- 24.78
15	17029.0	94.61 +- 24.78
16	17031.0	140.96 +- 24.78
17	17033.0	65.67 +- 24.78
18	17035.0	83.40 +- 24.78
19	17037.0	143.90 +- 24.78
20	17039.0	124.48 +- 24.78
21	17041.0	125.98 +- 24.78
22	17043.0	137.51 +- 24.78
23	17045.0	104.61 +- 24.78
24	17047.0	76.02 +- 24.78
25	17049.0	66.14 +- 24.78
26	17051.0	62.86 +- 24.78
27	17053.0	101.90 +- 24.78
28	17055.0	54.85 +- 24.78
29	17057.0	109.45 +- 24.78
30	17059.0	113.84 +- 24.78
31	17061.0	104.00 +- 24.78
32	17063.0	100.02 +- 24.78
33	17065.0	64.23 +- 24.78
* 34	17067.0	110.53 +- 24.78
35	17069.0	69.21 +- 24.78
36	17071.0	127.78 +- 24.78
37	17073.0	121.29 +- 24.78
38	17075.0	128.79 +- 24.78
39	17077.0	63.20 +- 24.78
40	17079.0	70.46 +- 24.78
41	17081.0	46.99 +- 24.78
42	17083.0	94.22 +- 24.78
43	17085.0	123.96 +- 24.78
44	17087.0	73.05 +- 24.78
45	17089.0	131.46 +- 24.78
46	17091.0	130.11 +- 24.78
47	17093.0	120.26 +- 24.78
48	17095.0	128.95 +- 24.78
49	17097.0	120.66 +- 24.78
50	17099.0	128.53 +- 24.78

Corn

Case No	Given Value	Predicted Value
1	501.0	45.30 +- 7.60
2	503.0	32.20 +- 7.60
* 3	505.0	4.31 +- 9.50
* 4	507.0	4.31 +- 9.50
* 5	509.0	4.31 +- 9.50
* 6	5011.0	4.31 +- 9.50
* 7	5013.0	4.31 +- 9.50
* 8	5015.0	4.31 +- 9.50
9	5017.0	36.80 +- 7.60
10	5019.0	10.88 +- 7.60
11	5021.0	39.92 +- 7.60
* 12	5023.0	4.31 +- 9.50
* 13	5025.0	4.31 +- 9.50
* 14	5027.0	4.31 +- 9.50
15	5029.0	19.68 +- 7.60
16	5031.0	34.14 +- 7.60
17	5033.0	28.26 +- 7.60
18	5035.0	43.82 +- 7.60
19	5037.0	39.48 +- 7.60
* 20	5039.0	4.31 +- 9.50
21	5041.0	39.78 +- 7.60
22	5043.0	38.52 +- 7.60
23	5045.0	11.48 +- 7.60
24	5047.0	4.31 +- 9.50
* 25	5049.0	4.31 +- 9.50
* 26	5051.0	4.31 +- 9.50
* 27	5053.0	4.31 +- 9.50
28	5055.0	33.53 +- 7.60
29	5057.0	28.21 +- 7.60
30	5059.0	12.47 +- 7.60
* 31	5061.0	4.31 +- 9.50
32	5063.0	31.07 +- 7.60
* 33	5065.0	4.31 +- 9.50
34	5067.0	34.07 +- 7.60
35	5069.0	41.76 +- 7.60
* 36	5071.0	4.31 +- 9.50
37	5073.0	36.72 +- 7.60
38	5075.0	34.29 +- 7.60
39	5077.0	41.19 +- 7.60
40	5079.0	42.98 +- 7.60
41	5081.0	26.32 +- 7.60
42	5083.0	10.81 +- 7.60
43	5085.0	34.80 +- 7.60
* 44	5087.0	4.31 +- 9.50
* 45	5089.0	4.31 +- 9.50
46	5091.0	22.51 +- 7.60
* 47	5093.0	43.11 +- 7.60
48	5095.0	36.57 +- 7.60
* 49	5097.0	4.31 +- 9.50
* 50	5099.0	4.31 +- 9.50

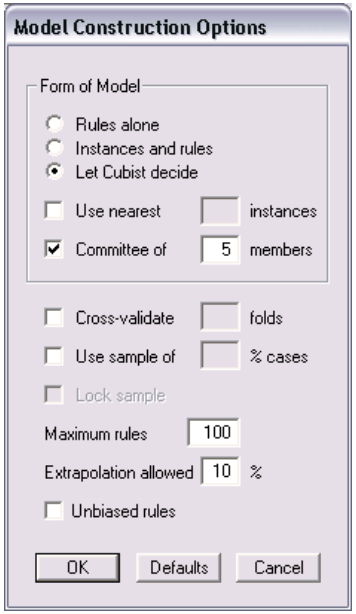
Soybeans

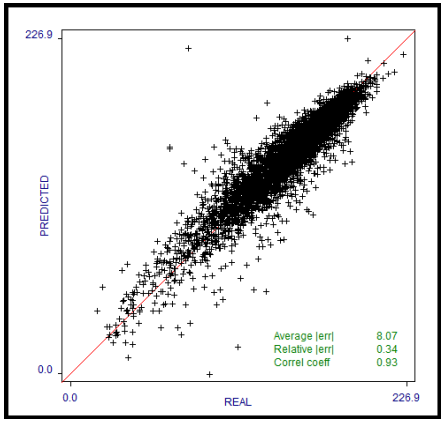
Weight by a 3-year average of harvested acres to derive ASD, state, and region estimates

“Voodoo Modeling”

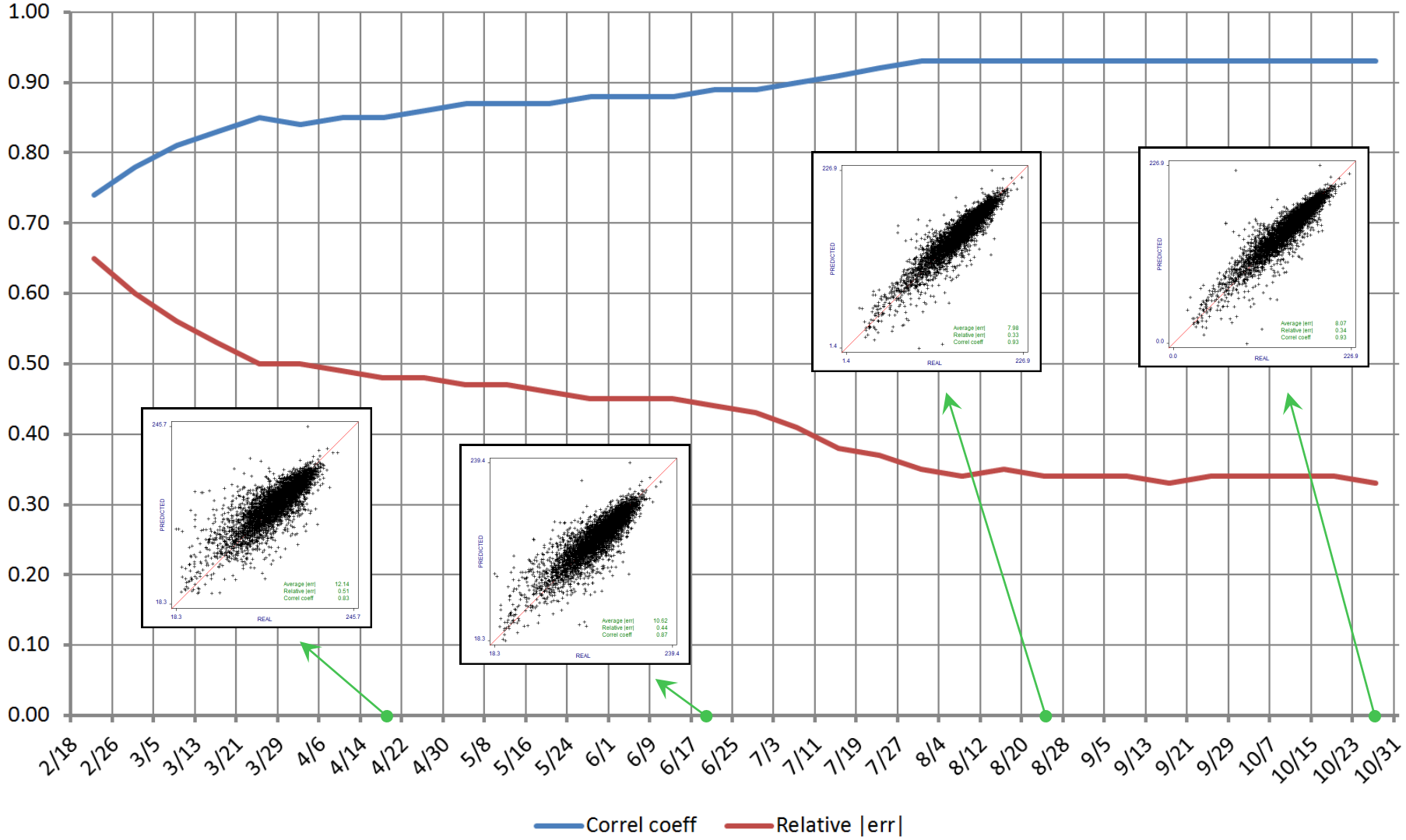
Utilizing **Rulequest Cubist** software

- Learning tool to predict continuous (vs discrete) outcomes
- Allow for “composite” predictions using both
  - Instance-based
    - “Nearest neighbor”
    - Predicts the target value of a new case by finding the **n** most similar cases in the training data, and averaging their target values.
  - Model-based, via decision trees and piecewise linear regression
    - Divide and conquer strategy
    - Recursive splitting of training data to minimize intra-subset variation
  - Thus, for composite of instances and models:
    - Cubist finds the n training cases that are "nearest" (most similar) to the case in question. Then, rather than averaging their target values directly, Cubist first adjusts these values using the rule-based model.
- Also, does “Committee” models
  - made up of several rule-based models. Each member of the committee predicts the target value for a case and the members' predictions are averaged to give a final prediction





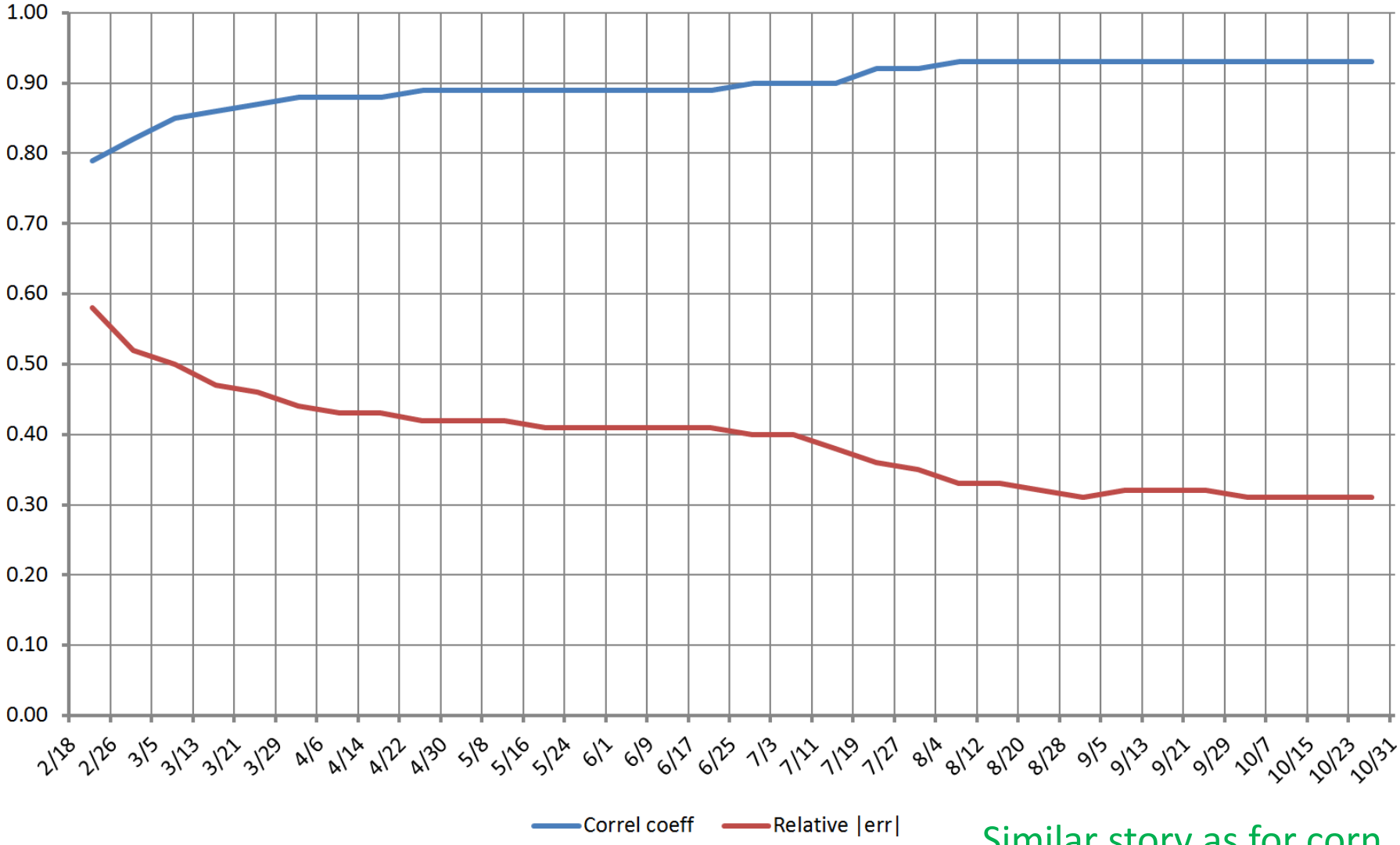
Corn yield regression-tree model performance *v.* data timing
county level, speculative region, 2006-2011



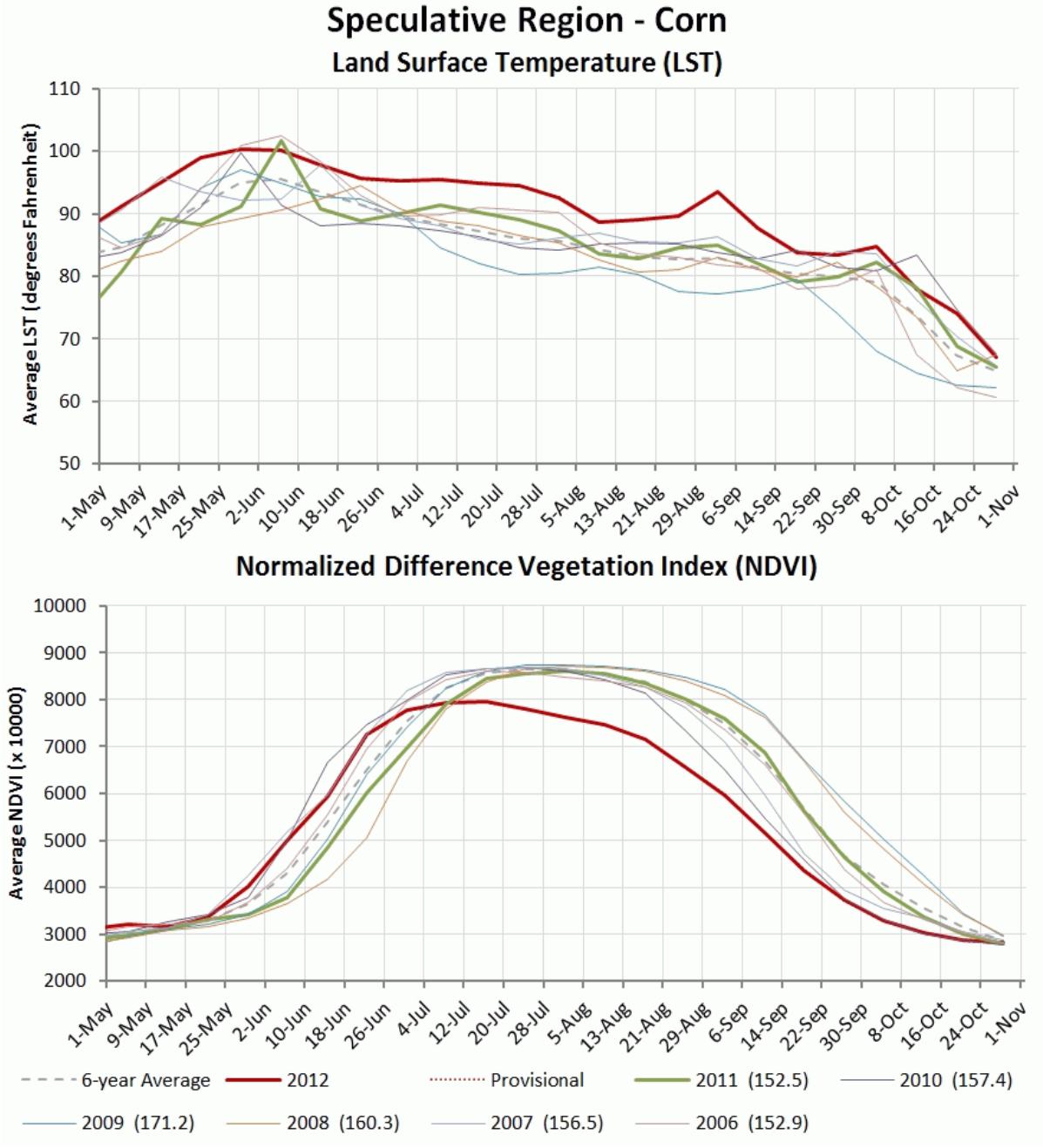
The **relative error magnitude** is the ratio of the average error magnitude to the error magnitude that would result from always predicting the mean value; for useful models, this should be less than 1!

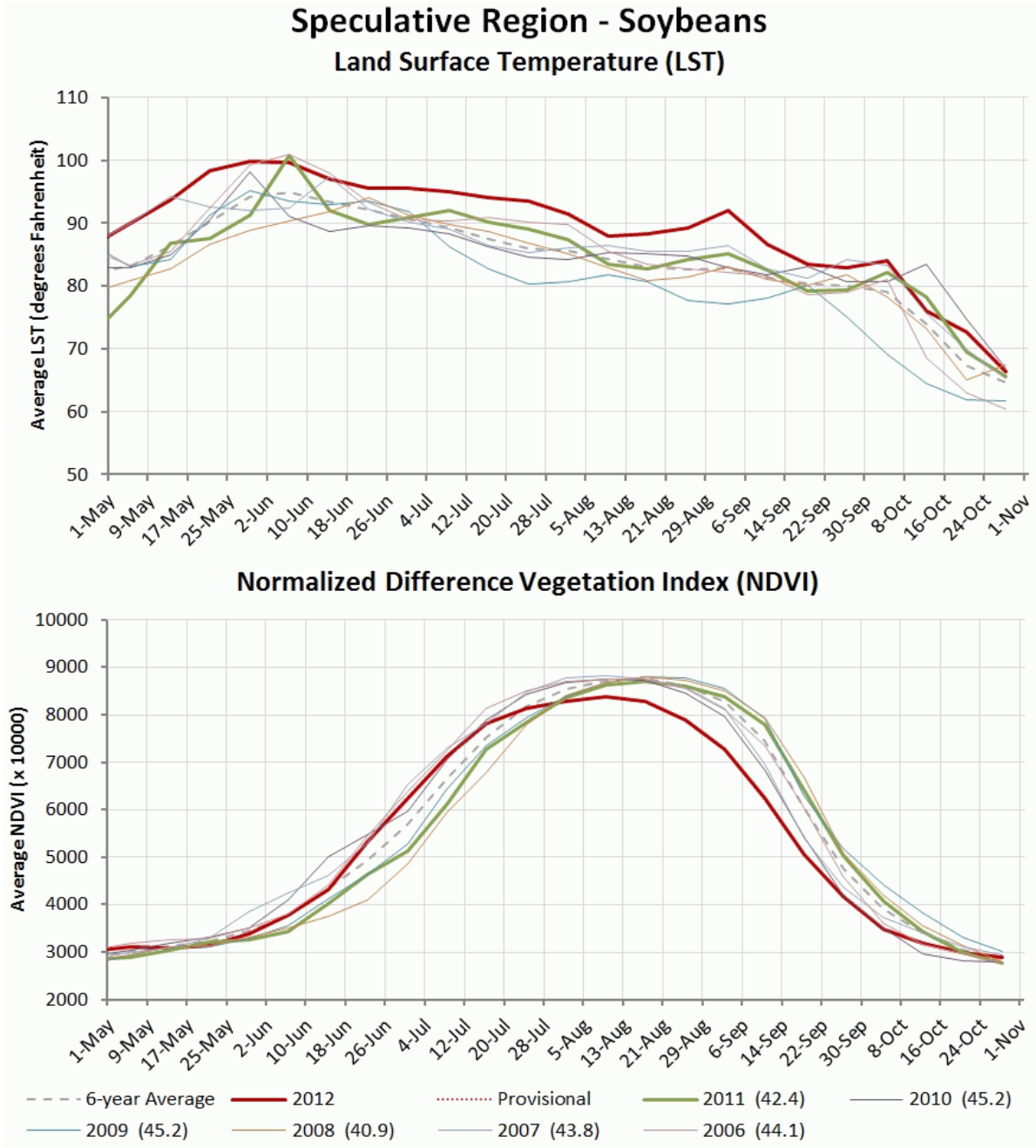
The **correlation coefficient** measures the agreement between the cases' actual values of the target attribute and those values predicted by the model.

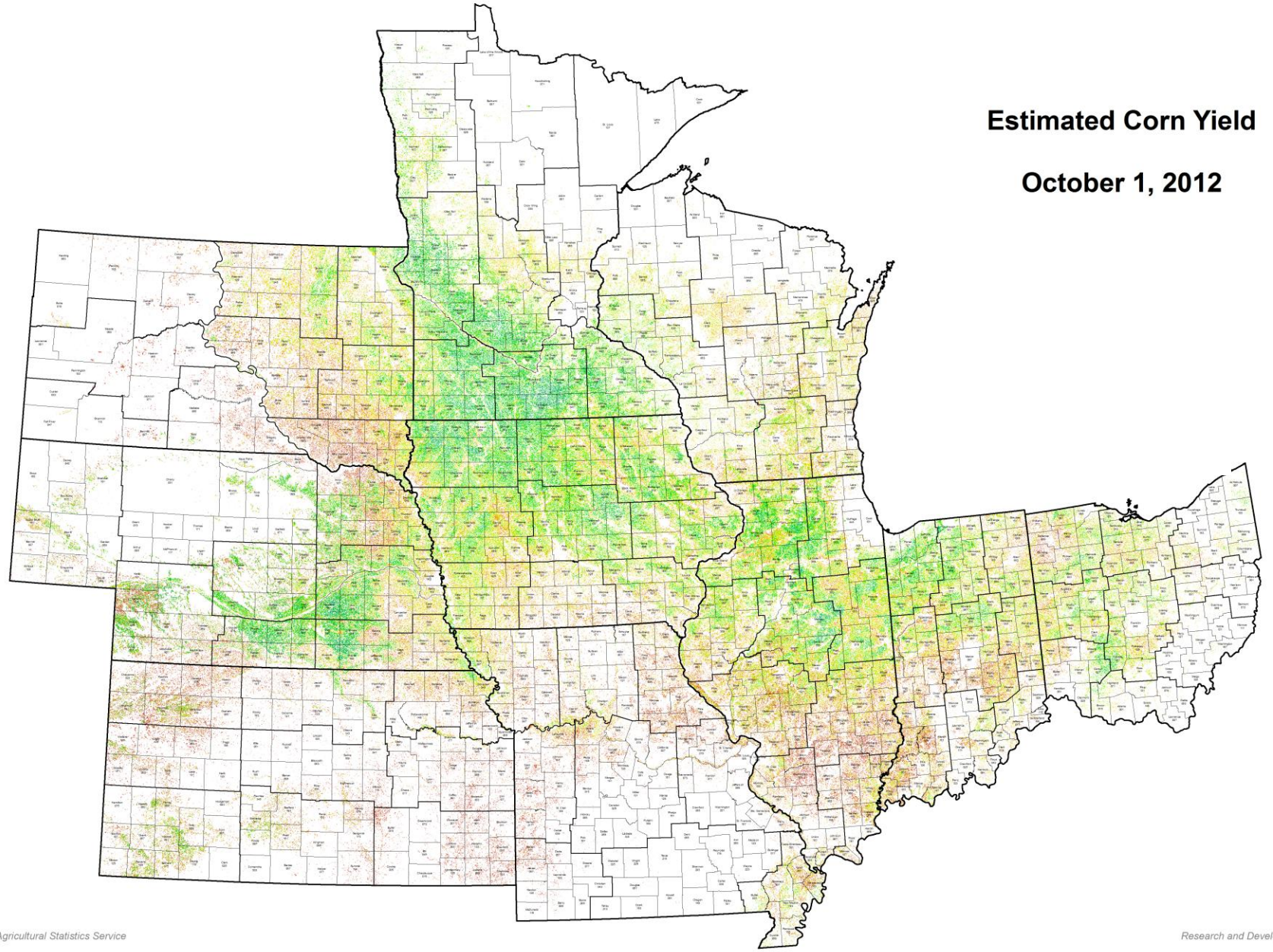
Soybean yield regression-tree model performance *v.* data timing
county level, speculative region, 2006-2011

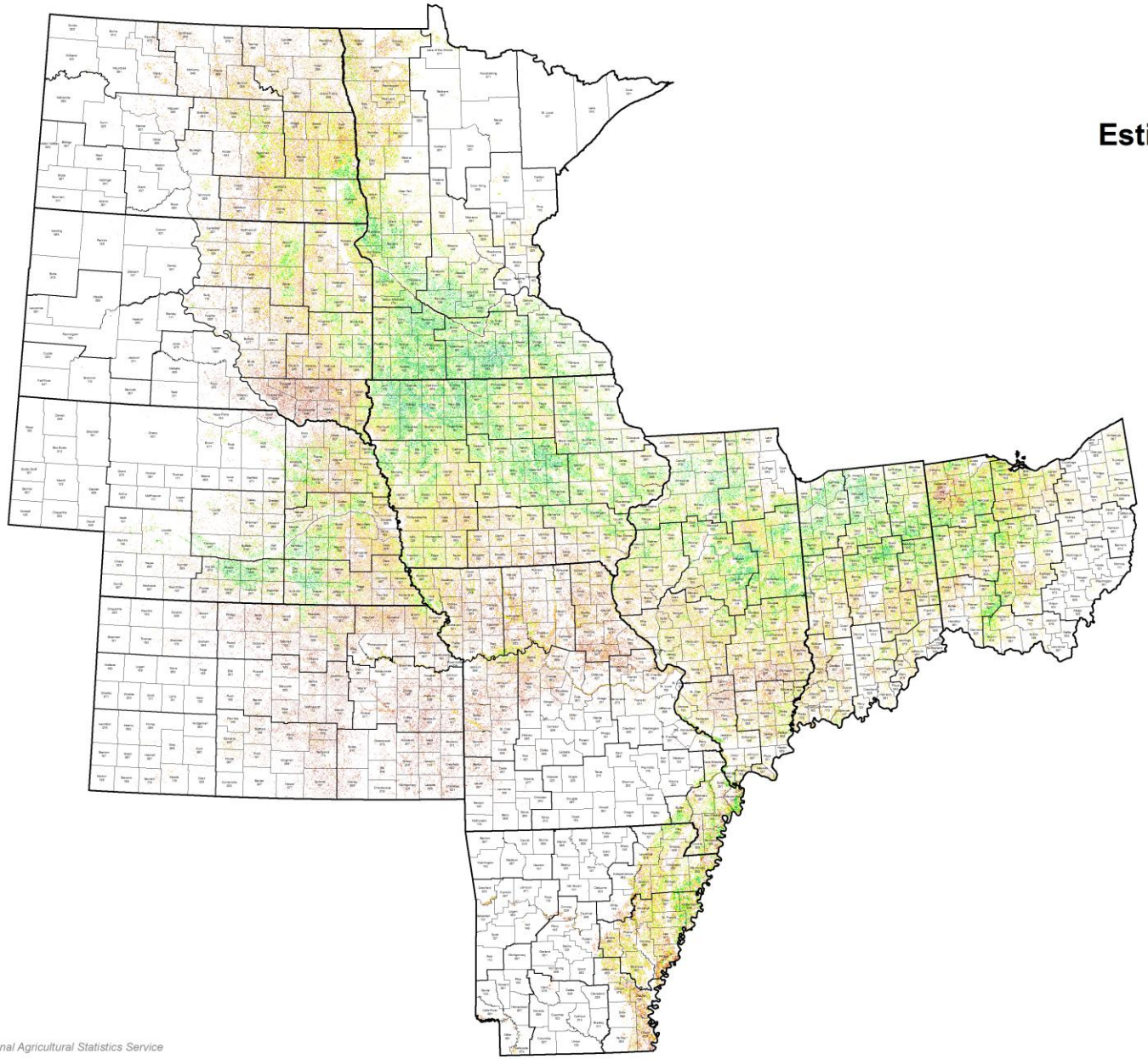


Similar story as for corn


Speculative Region - Corn
Land Surface Temperature (LST)
Average LST (degrees Fahrenheit)
110
100
90
80
70
60
50
1-May
9-May
17-May
25-May
2-Jun
10-Jun
18-Jun
26-Jun
4-Jul
12-Jul
20-Jul
28-Jul
5-Aug
13-Aug
21-Aug
29-Aug
6-Sep
14-Sep
22-Sep
30-Sep
8-Oct
16-Oct
24-Oct
1-Nov
Normalized Difference Vegetation Index (NDVI)
Average NDVI (x 10000)
10000
9000
8000
7000
6000
5000
4000
3000
2000
6-year Average
2012
Provisional
2011 (152.5)
2010 (157.4)
2009 (171.2)
2008 (160.3)
2007 (156.5)
2006 (152.9)


Speculative Region - Soybeans
Land Surface Temperature (LST)
Average LST (degrees Fahrenheit)
110
100
90
80
70
60
50
1-May
9-May
17-May
25-May
2-Jun
10-Jun
18-Jun
26-Jun
4-Jul
12-Jul
20-Jul
28-Jul
5-Aug
13-Aug
21-Aug
29-Aug
6-Sep
14-Sep
22-Sep
30-Sep
8-Oct
16-Oct
24-Oct
1-Nov
Normalized Difference Vegetation Index (NDVI)
Average NDVI (x 10000)
10000
9000
8000
7000
6000
5000
4000
3000
2000
6-year Average
2012
Provisional
2011 (42.4)
2010 (45.2)
2009 (45.2)
2008 (40.9)
2007 (43.8)
2006 (44.1)


Estimated Corn Yield
October 1, 2012
USDA/National Agricultural Statistics Service
Research and Development Division



Estimated Soybean Yield

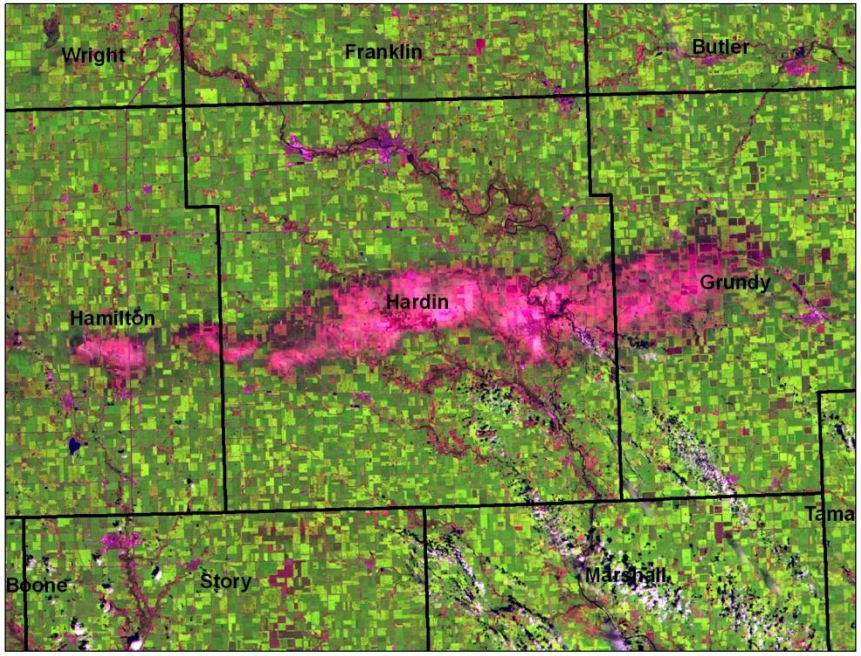
October 1, 2012

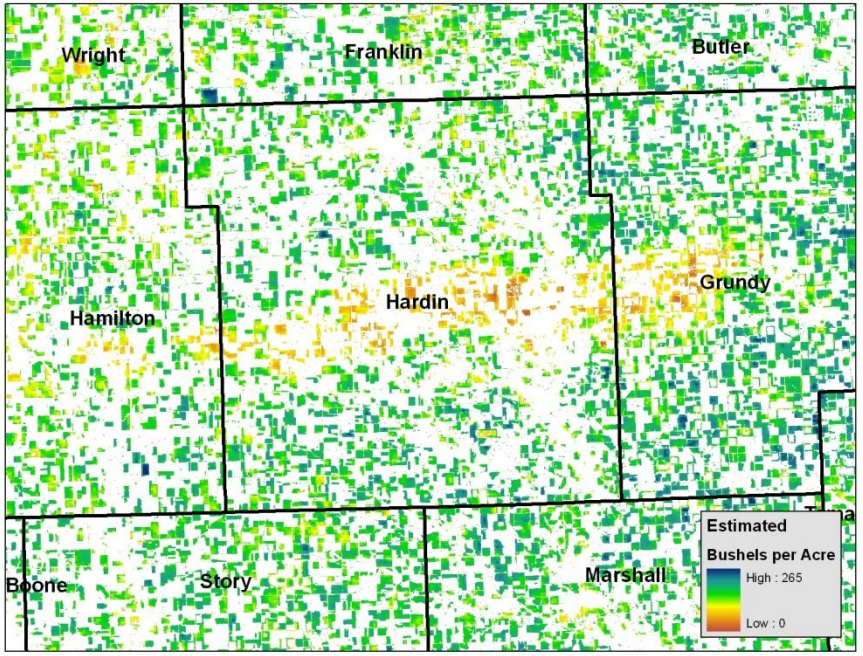
USDA/National Agricultural Statistics Service

Research and Development Division

Reality check

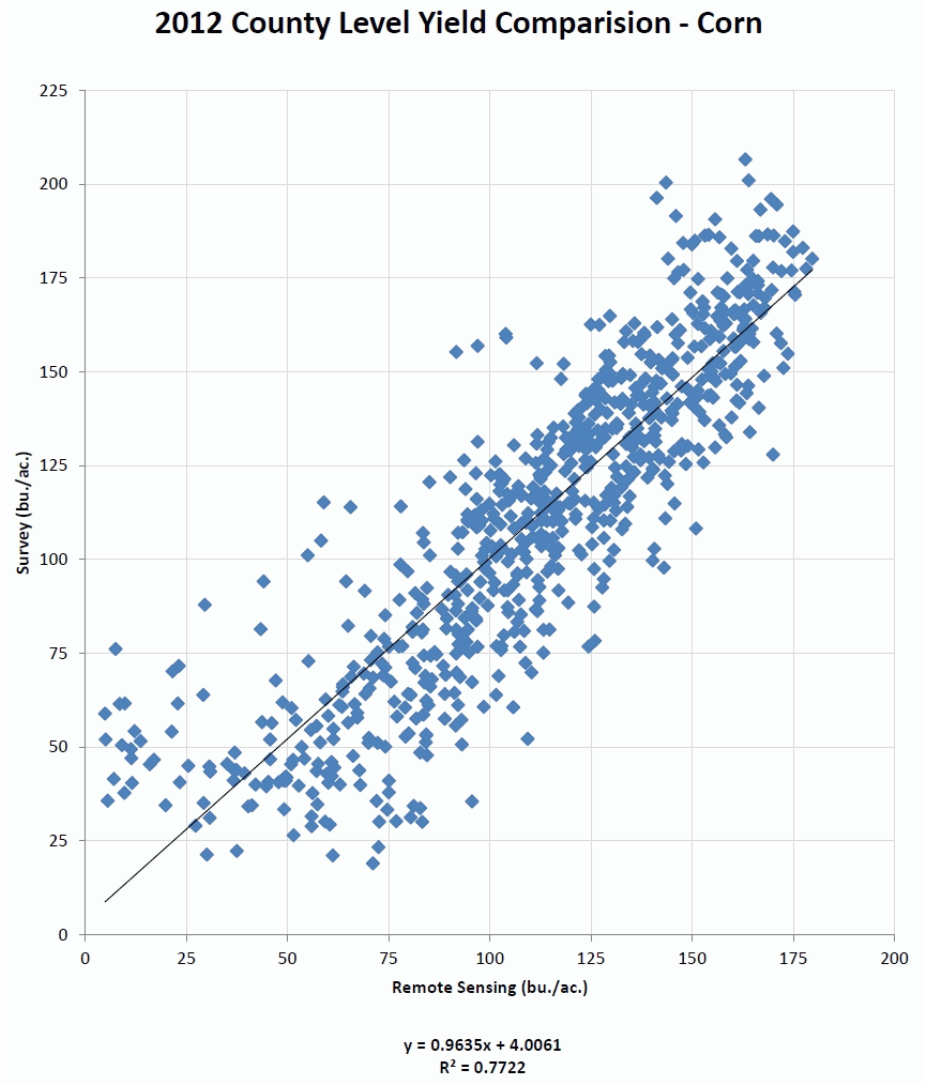
Scene of a large hailstorm

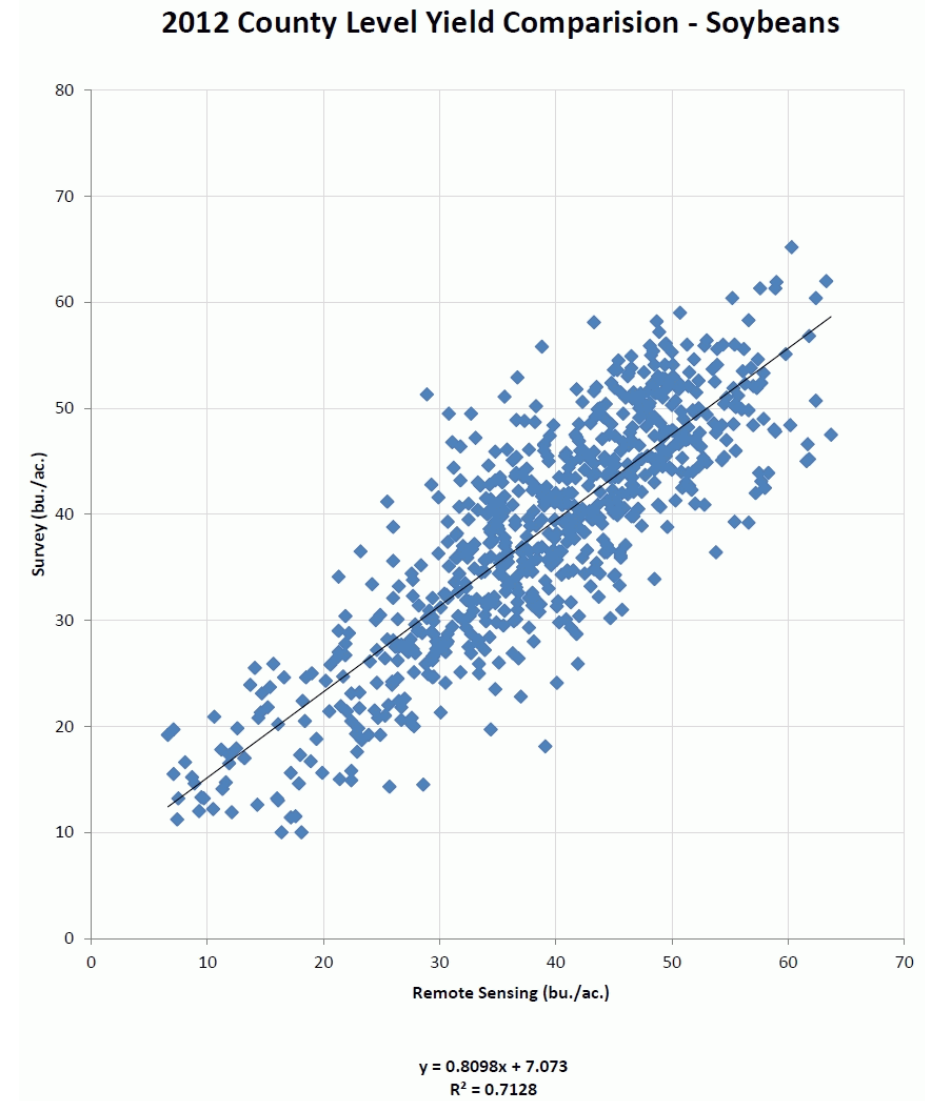




2012 Results: Remote sensing vs NASS yield

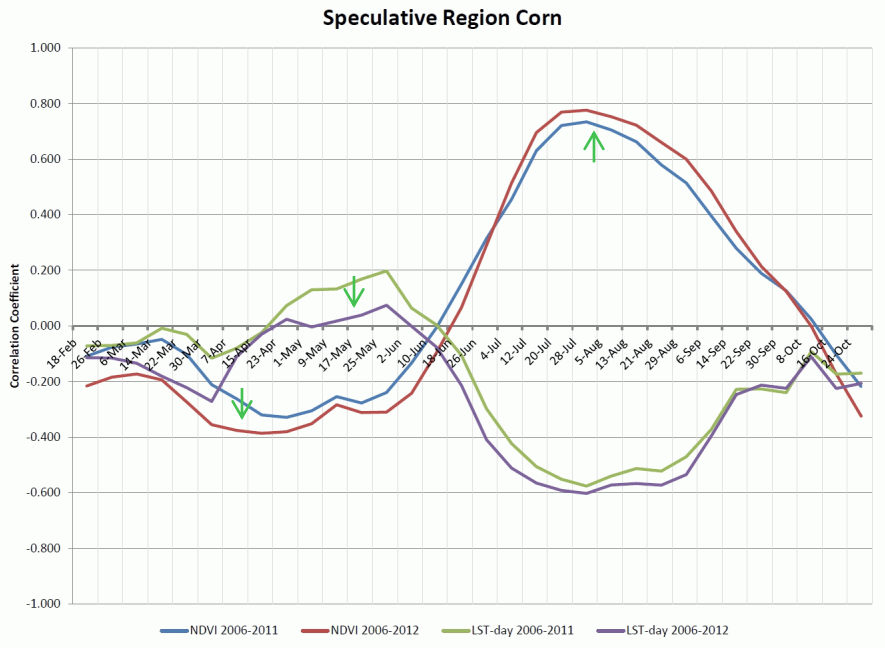
State level average error corn = 5.8 bu./ac. soybeans = 3.1 bu./ac.

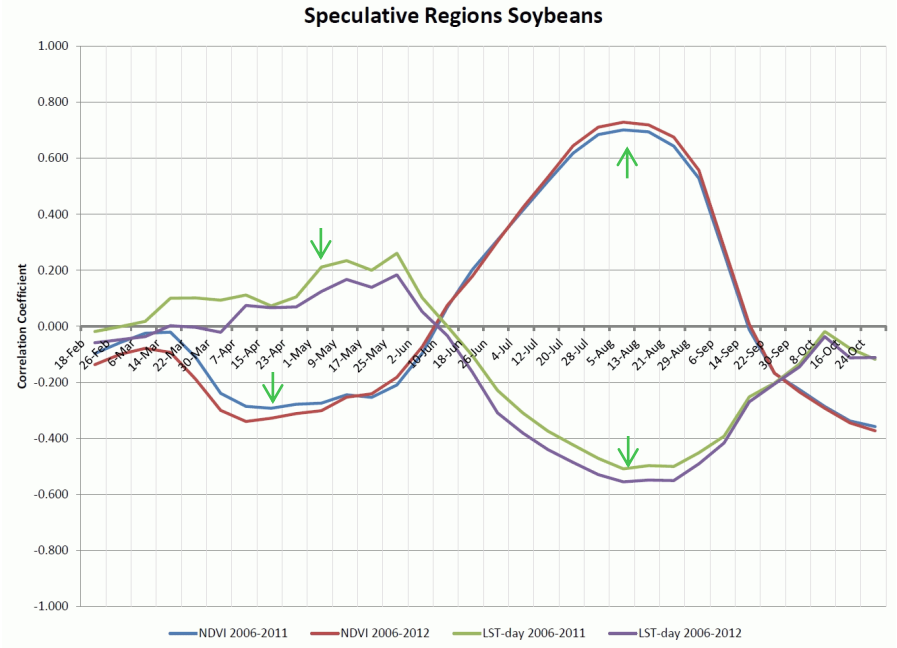




Models improvements for 2013

	2012	2013
• Corn		
– relative |err|	0.33	0.30
– correl coeff	0.93	0.95
• Soybeans		
– relative |err|	0.31	0.30
– correl coeff	0.93	0.94





- Absolute error unchanged
  - ~8.0 bu/ac for corn, ~2.5 for soybeans

The end