Long-Term Agriculture Drought Monitoring using AVHRR NDVI and North American Regional Reanalysis (NARR) from 1981 to 2013 in United States

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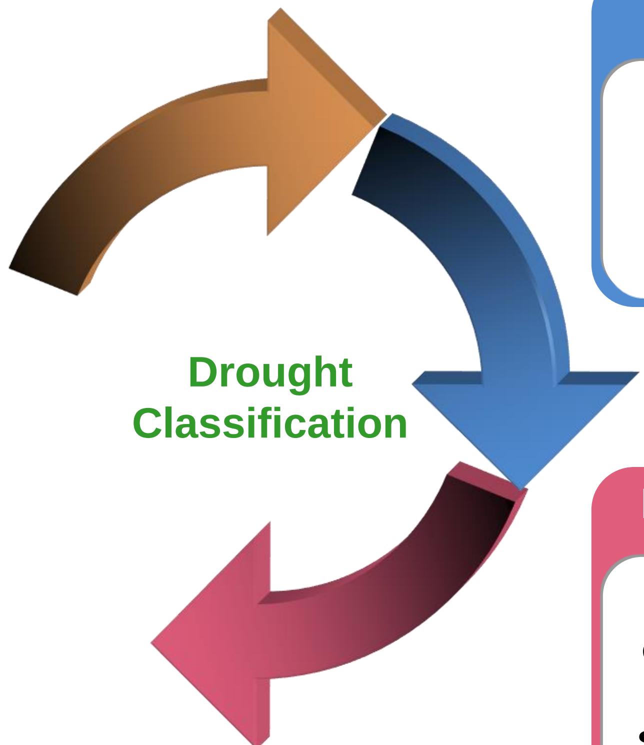
Drought Classification

Meteorological Drought

Absence or reduction of precipitation over a region, precipitation are used commonly as primary indicator

Agricultural drought

Occurs at a critical time during the growing season resulting in declining soil moisture and crop failure



Socio-economic drought

Associated deficits of water resources systems leading to failure to meet the demand of some economic goods and social needs

Hydrological drought

Precipitation deficits over a prolonged period that affect surface or subsurface water supply

Heim 2002, Mishra and Singh 2010

Significance of Soil Moisture

- A deficit in the amount of moisture in the soil defines agricultural drought
- Soil moisture is very critical for healthy plant growth
- Soil moisture plays a very significant role in monitoring agricultural drought

Research objective

- This study aims to expand and extend an agriculturally-based drought index to:
  - Integrate soil moisture
  - Integrate long-term satellite observations of vegetation conditions

Traditional In-situ Drought Indices

- Palmer drought index
  - Palmer Drought Severity Index (PDSI)
  - Palmer Hydrological Drought Index (PHDI)
  - Palmer Modified Drought Index (PMDI)
  - Palmer Z index
- Surface Water Supply index (SWSI)
- Standardized Precipitation Index (SPI)

Remote sensing based drought monitoring

- Normalized Difference Vegetation index (NDVI)
- Ecosystem and drought monitoring
- Good surrogate measures of the physiologically functioning surface greenness level
- NDVI contains both weather related component and ecosystem component

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

- The Vegetation Condition Index (VCI)
- Scaling NDVI values from 0 to 1 can separate the weather related component of NDVI and the ecosystem component.
- Approximate the weather-related component in NDVI

$$VCI = \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})}$$

Remote sensing based drought monitoring

- Temperature Condition Index (TCI)
- Thermal bands based
- High temperature indicate drought condition
- Separate vegetation stress caused by drought or by an excessive wetness

$$TCI = \frac{T_{\max} - T}{T_{\max} - T_{\min}}$$

- Vegetation Health Index (VHI)
- Additive combination of VCI and TCI
- A good tool to monitor drought

$$VHI = \alpha * VCI + \beta * TCI$$

Remote sensing based drought monitoring

- Normalized Difference Water Index (NDWI)
- SWIR channel can reflect change of water content via absorption of water content
- NIR can reflect vigor of vegetation via high optimum reflection by spongy Mesophyll cells
- NDWI is influenced by desiccation and wilting in vegetation canopy
- May be more sensitive than NDVI for drought monitoring, but NDWI is complementary to, not a substitute for NDVI

$$NDWI = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}}$$

Remote sensing based drought monitoring

- Normalized Multi-band Drought Index (NMDI)

- Combine one NIR band and two SWIR bands
- Separate vegetation moisture and soil moisture by amplifying one signal and minimizing the other

$$NMDI = \frac{\rho_{860nm} - (\rho_{1640nm} - \rho_{2130nm})}{\rho_{860nm} + (\rho_{1640nm} + \rho_{2130nm})}$$

Remote sensing based drought monitoring

- Scaled Drought Condition Index (SDCI)
- Combine three standardized scaled remote sensing variables:
  - Land surface temperature (LST) data from MODIS sensor
  - Normalized Difference Vegetation Index (NDVI) data from MODIS sensor
  - Precipitation data from Tropical Rainfall Measuring Mission (TRMM) satellite

$$SDCI = \frac{1}{4} \times scaled\ \ LST + \frac{2}{4} \times scaled\ \ TRMM + \frac{1}{4} \times scaled\ \ NDVI$$

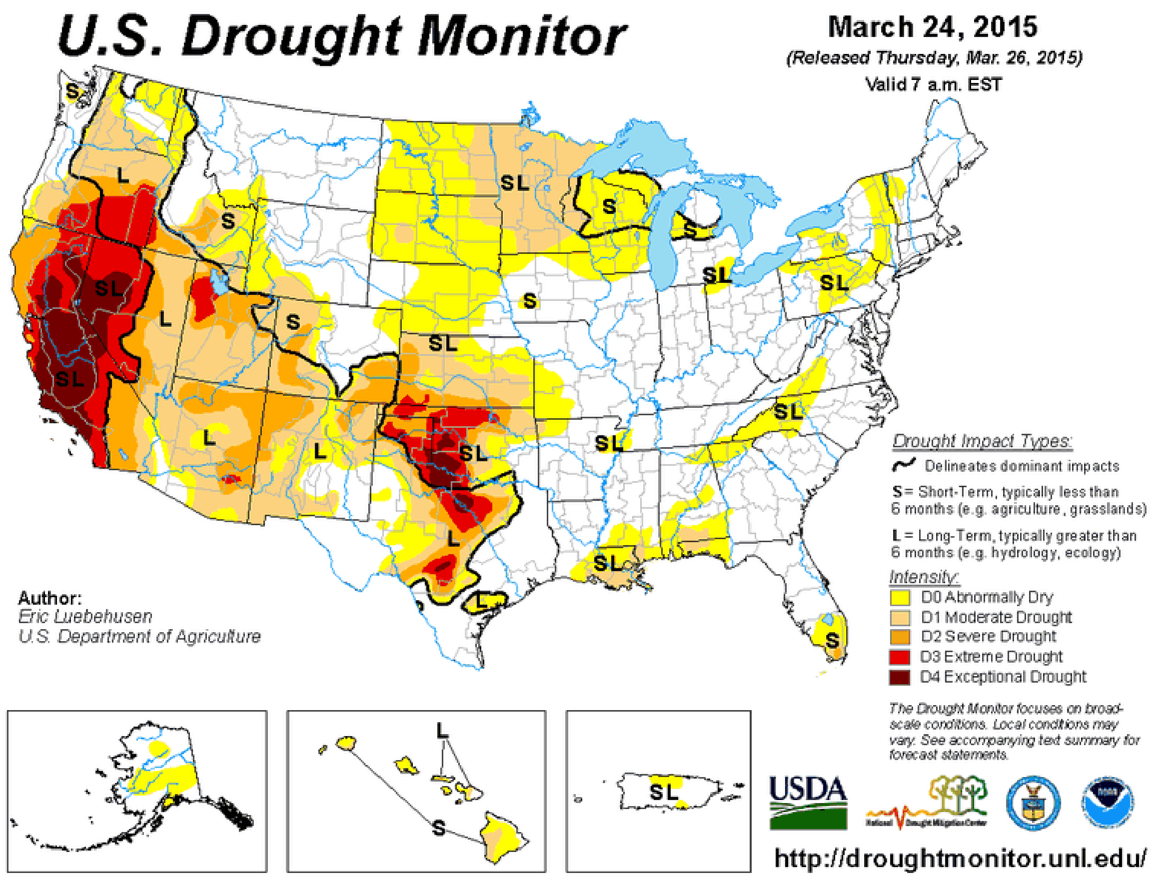
- SDCI outperforms NDVI, NMDI, NDWI, NDDI and VHI in both arid and humid regions to correlate with in-situ drought indices.

- MODIS sensor and TRMM data are available from 2000 to present.

Rhee, Im and Carbone 2010

National wide drought monitoring system

United States Drought Monitor

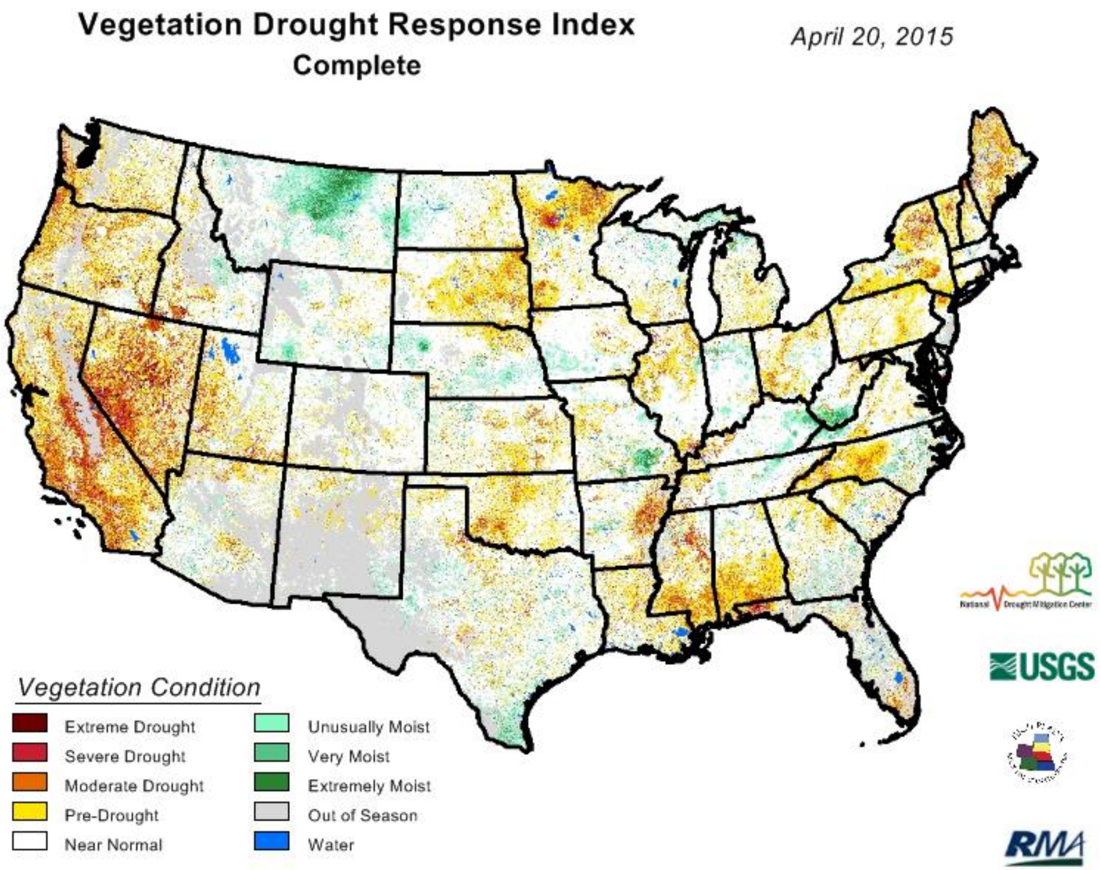


- Time span:
- Jan., 2000-present

- Data:
- Climatic, hydrologic and soil conditions data as well as reported impacts and observations from more than 350 contributors around the country

National wide drought monitoring system

Vegetation Drought Response Index



- Time span:
- May, 2007-present

- Data:
- Remote sensing - typically via satellites, radar or aerial photography as well as climate data (PDSI, SPI, etc.), and other information

Research objective and potential contribution

- This study aims to integrate soil moisture component into SDCI and develop a new drought index, Integrated Scaled Drought Index (ISDI)

- This study will use new data sources to make long-term drought monitoring possible

- The new drought index integrates both climate information and satellite-based observations of vegetation conditions

Data Sources

	Data	Source
Main Data	AVHRR NDVI obtained from Global Inventory Monitoring and Modeling System (GIMMS)	Ecological Forecasting Lab at NASA Ames Research Center <http://ecocast.arc.nasa.gov/>
	LST, Precipitation and soil moisture obtained from North American Regional Reanalysis (NARR)	<http://www.emc.ncep.noaa.gov/mmb/rreanl/>
Auxiliary Data	USGS National Land Cover Dataset (NLCD)	<http://www.mrlc.gov/index.php>
Validation Data	United States Drought Monitor (USDM) Map Vegetation Response Index (VegDRI) Map	<http://droughtmonitor.unl.edu/> <http://vegdri.unl.edu/>
	In-situ drought indices: PDSI, PHDI, Palmer Z index, PMDI, 3 month SPI, 6 month SPI, etc.	<http://www.ncdc.noaa.gov/>
	Agriculture statistics from USDA's National Agricultural Statistics Service (NASS) (Corn yield and Soybean yield)	<http://www.nass.usda.gov/>

Methodology

Table1 Formulas of drought indices

Drought Indices	Formula
ISDI	α * Scaled NDVI + β * Scaled LST + γ * Scaled PCP + λ * Scaled SM
Scaled NDVI (VCI)	$(NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min})$
Scaled LST	$(LST_{max} - LST) / (LST_{max} - LST_{min})$
Scaled PCP	$(PCP - PCP_{min}) / (PCP_{max} - PCP_{min})$
Scaled SM	$(SM - SM_{min}) / (SM_{max} - SM_{min})$

Results

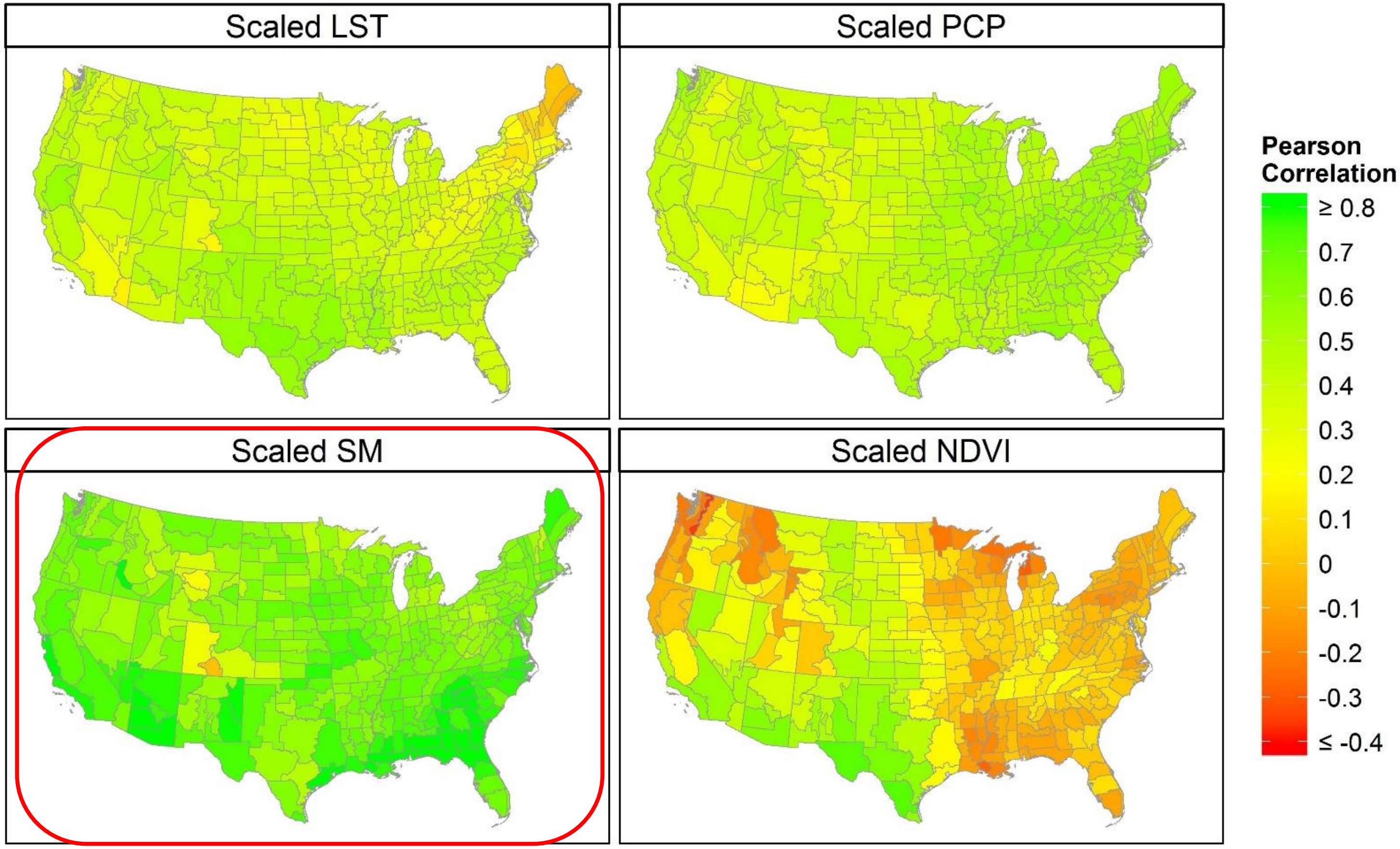
- Correlation with multiple in-situ drought indices

Table. 2 Averaged correlation coefficients between scaled drought indices and in-situ drought indices over 342 climate divisions

	Correlation								
	Z-index	PDSI	PMDI	SPI1	SPI2	SPI3	SPI6	SPI9	SPI12
Scaled NDVI	0.011	0.105	0.118	-0.027	0.068	0.103	0.104	0.132	0.141
Scaled LST	0.373	0.382	0.388	0.217	0.278	0.298	0.306	0.272	0.252
Scaled PCP	**0.850**	0.468	0.446	**0.899**	**0.675**	**0.570**	0.404	0.329	0.291
Scaled SM	0.372	**0.650**	**0.704**	0.256	0.436	0.515	**0.629**	**0.664**	**0.646**

Results

- Spatial variations of correlation coefficients between scaled drought indices and PDSI



Results

- Correlation between ISDI and multiple drought indices

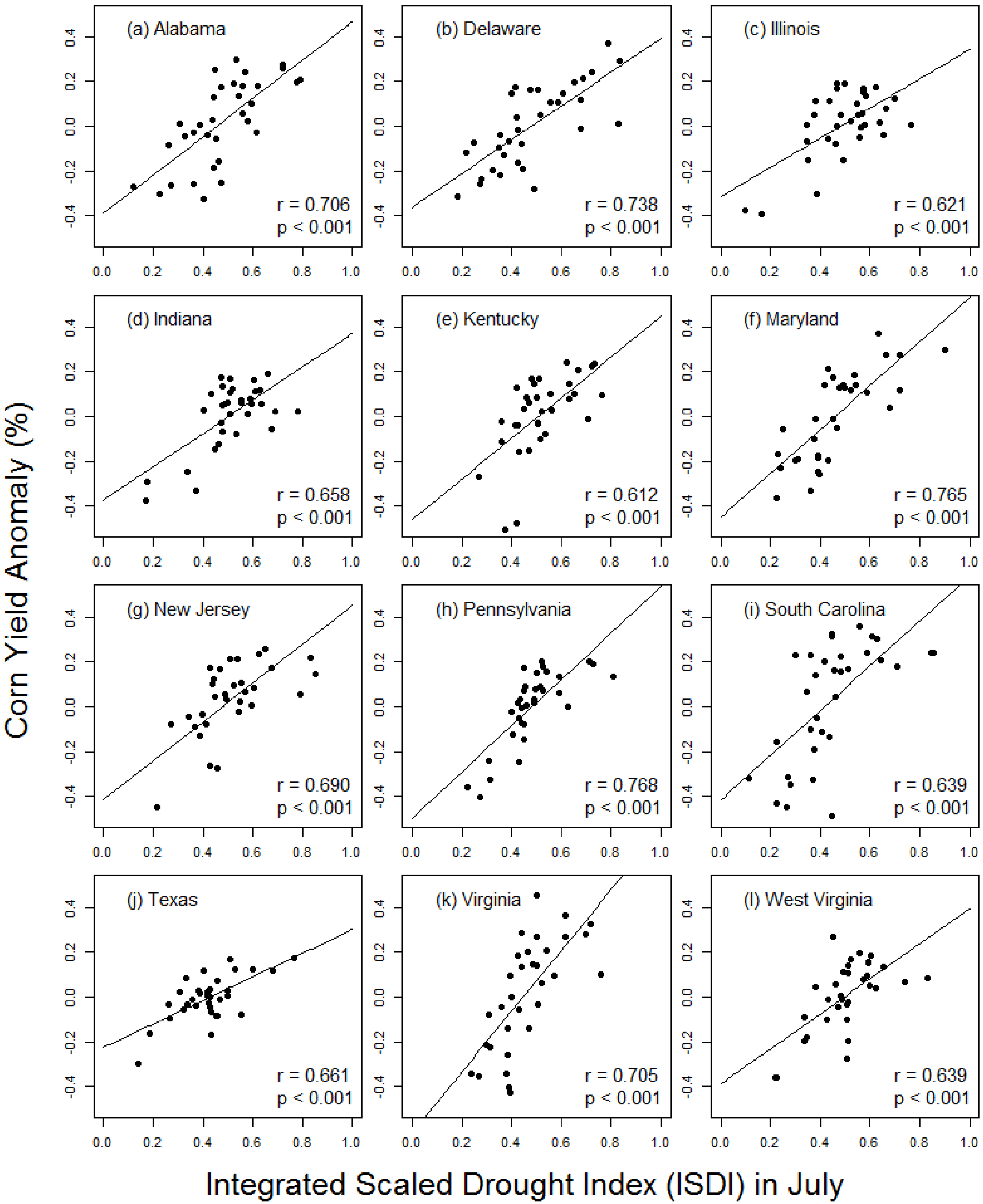
Table.3 Averaged correlation coefficient values between Integrated Scaled Drought Indices and in-situ drought indices over 342 climate divisions

NUM	Weight: Scaled LST	Scaled PCP	Scaled SM	Scaled NDVI	Correlation Coefficient: Z-index	PDSI	PMDI	SPI1	SPI2	SPI3	SPI6	SPI9
1	1/4	1/4	1/4	1/4	0.697	**0.692**	0.714	0.589	0.628	0.637	0.620	0.597
2	2/5	1/5	1/5	1/5	0.642	0.641	0.659	0.509	0.558	0.572	0.561	0.533
3	**1/5**	**2/5**	**1/5**	**1/5**	**0.809**	0.679	0.689	**0.742**	**0.698**	**0.671**	0.603	0.562
4	**1/5**	**1/5**	**2/5**	**1/5**	0.633	**0.720**	**0.754**	0.516	0.604	0.637	**0.662**	**0.657**
5	1/5	1/5	1/5	2/5	0.614	0.633	0.656	0.510	0.569	0.586	0.568	0.557
6	1/3	1/3	1/6	1/6	**0.760**	0.658	0.668	**0.663**	0.644	0.628	0.575	0.531
7	1/3	1/6	1/3	1/6	0.614	0.688	0.717	0.477	0.565	0.597	0.620	0.606
8	1/3	1/6	1/6	1/3	0.597	0.616	0.635	0.467	0.532	0.552	0.540	0.521
9	**1/6**	**1/3**	**1/3**	**1/6**	0.748	**0.720**	**0.743**	0.664	**0.678**	**0.678**	**0.655**	**0.632**
10	1/6	1/3	1/6	1/3	**0.751**	0.650	0.662	**0.683**	**0.661**	0.643	0.578	0.546
11	1/6	1/6	1/3	1/3	0.587	0.688	0.722	0.473	0.573	0.611	0.633	**0.634**
12	2/7	2/7	2/7	1/7	0.723	0.702	0.723	0.615	0.641	0.646	0.628	0.600
13	2/7	2/7	1/7	2/7	0.724	0.643	0.655	0.627	0.624	0.614	0.562	0.527
14	2/7	1/7	2/7	2/7	0.584	0.671	0.702	0.449	0.548	0.585	0.605	0.598
15	1/7	2/7	2/7	2/7	0.711	0.702	0.726	0.626	0.655	0.661	0.639	0.622
VHI	1/2	0	0	1/2	0.308	0.368	0.380	0.161	0.263	0.299	0.303	0.292
SDCI	1/4	1/2	0	1/4	0.833	0.558	0.547	0.798	0.670	0.603	0.472	0.407

15 weight sets

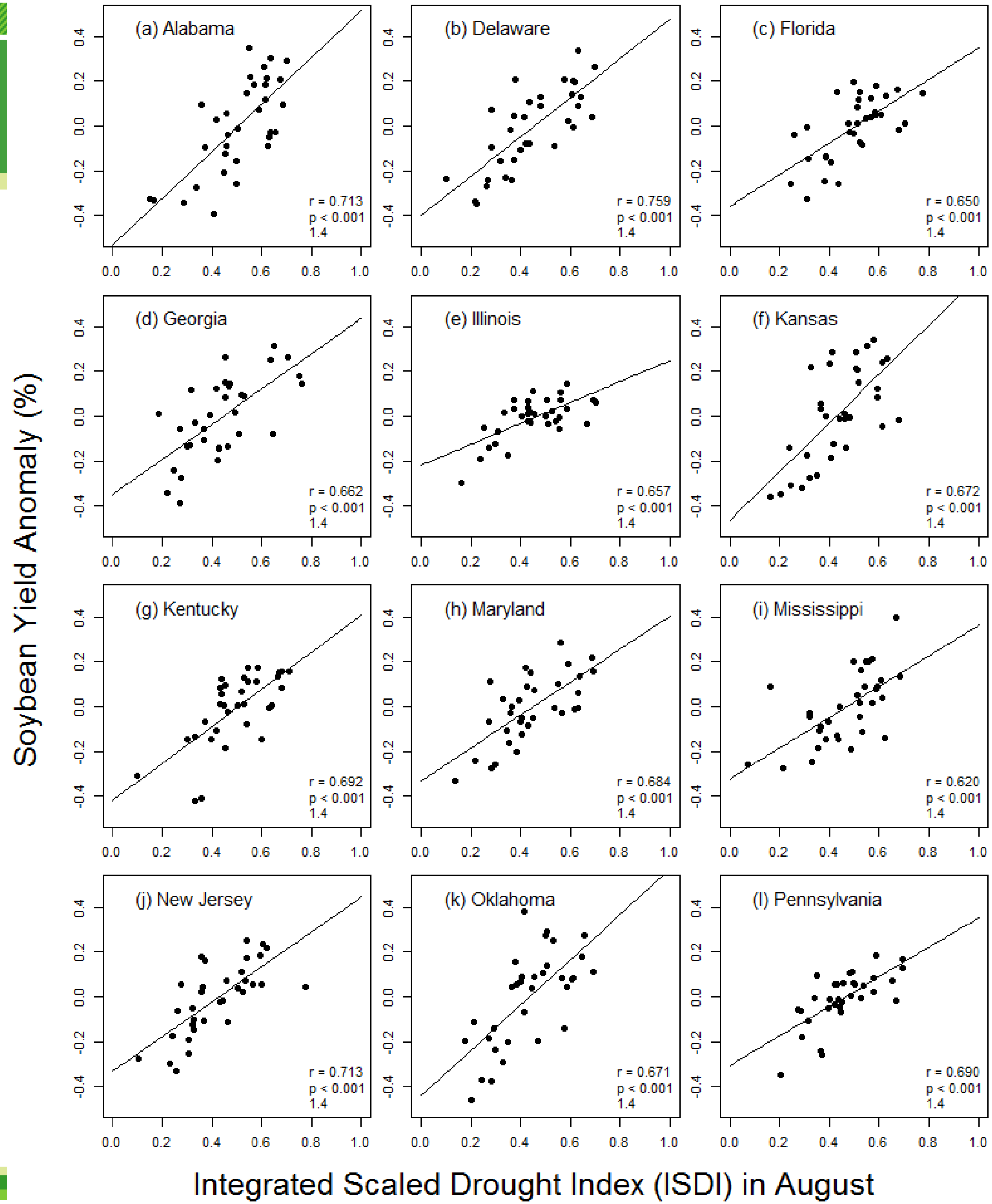
Results

Scatterplots and Correlation between July ISDI and Corn Yield Anomaly

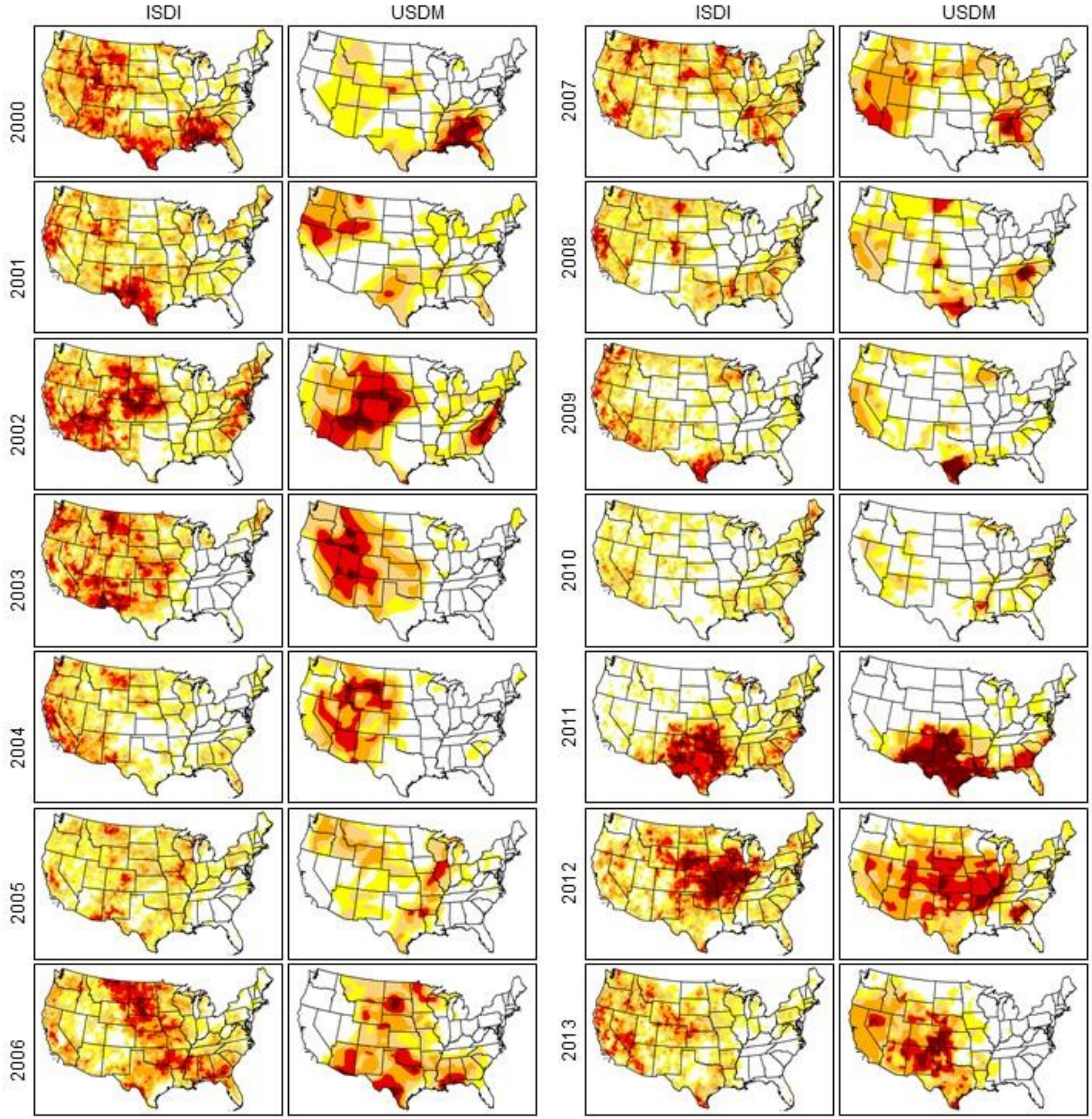


Results

Scatterplots and Correlation between August ISDI and Soybean Yield Anomaly



Results



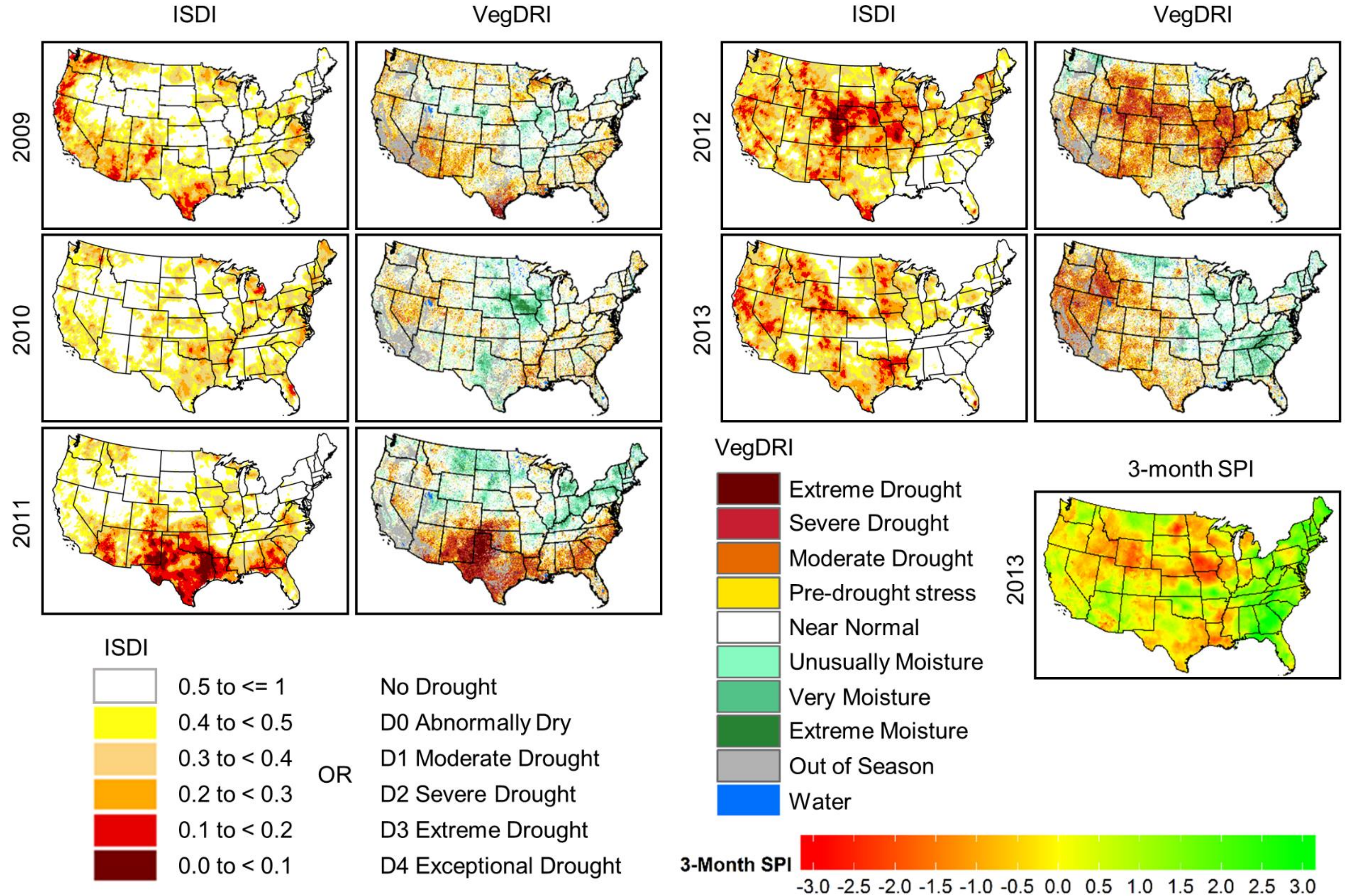
USDM

- No Drought
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

ISDI

ISDI		USDM
0.5 to <= 1	OR	No Drought
0.4 to < 0.5		D0 Abnormally Dry
0.3 to < 0.4		D1 Moderate Drought
0.2 to < 0.3		D2 Severe Drought
0.1 to < 0.2		D3 Extreme Drought
0.0 to < 0.1		D4 Exceptional Drought

Results


ISDI
VegDRI
ISDI
VegDRI
2009
2010
2011
2012
2013
ISDI
0.5 to <= 1
0.4 to < 0.5
0.3 to < 0.4
0.2 to < 0.3
0.1 to < 0.2
0.0 to < 0.1
OR
No Drought
D0 Abnormally Dry
D1 Moderate Drought
D2 Severe Drought
D3 Extreme Drought
D4 Exceptional Drought
VegDRI
Extreme Drought
Severe Drought
Moderate Drought
Pre-drought stress
Near Normal
Unusually Moisture
Very Moisture
Extreme Moisture
Out of Season
Water
3-month SPI
2013
3-Month SPI
-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0.0 0.5 1.0 1.5 2.0 2.5 3.0

Conclusion

- This study successfully integrates soil moisture component into SDCI and form a new agriculturally-based drought index and extend the drought monitoring time back to 1981.
- ISDI shows a very high correlation with in-situ drought index (e.g. PDSI, PMDI, SPI2, SPI3, SPI6 and SPI9).
- ISDI shows a high correlation with corn and soybean yield anomalies.
- ISDI agrees quite well with USDM maps and VegDRI maps and can successfully detect year-to-year change of drought conditions.

Thank you!

Questions or comments?

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