A Spatio-Temporal Drought Analysis for the Midwestern US

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Dr. Shih-Chieh Kao

Oak Ridge National Laboratory, CSE

kao@ornl.gov

http://www.ornl.gov/~5v1/

Dr. Rao S. Govindaraju

Purdue University, Civil Engineering

govind@purdue.edu

Dr. Dev Niyogi

Purdue University, Agronomy, EAS

climate@purdue.edu

Drought Overview

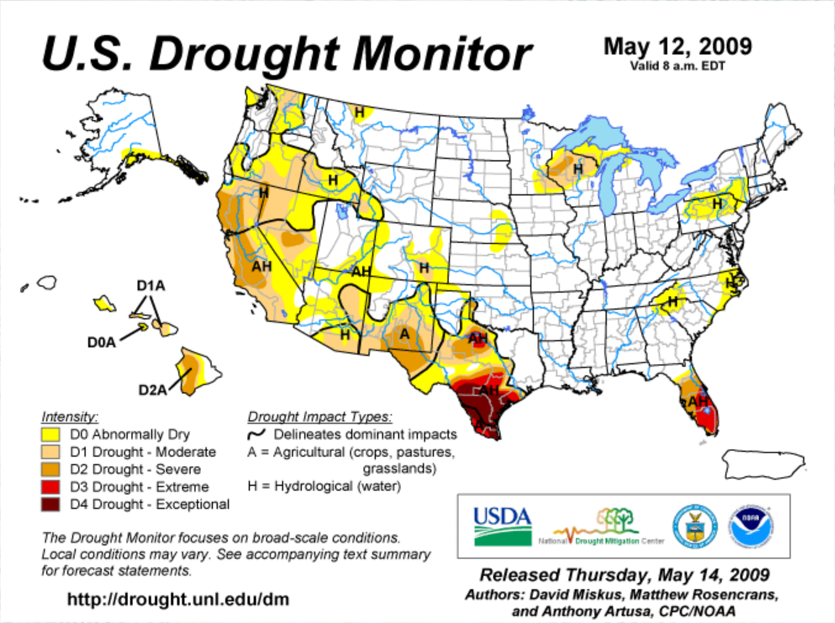
- **Challenges**
  - **No clear (scientific) definition**
  - **Phenomenon dependent in**
    - **Time and space**
    - **Between various variables (e.g. precipitation, streamflow)**
- **Classification of droughts**
  - **Meteorological drought**
  - **Hydrologic drought**
  - **Agricultural drought**
- **Various drought indices**
  - **Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Vegetation Condition Index (VCI), CPC Soil Moisture, Standardized precipitation index (SPI)**

Sept., 2007, George H. Sparks Reservoir
Lithia Springs, Georgia

(Barry Gillis, http://www.drought.unl.edu/gallery/ 2007/Georgia/Sparks1.htm)

US Drought Monitor

- **Overall drought status (D0 ~ D4) determined based on various indices together (Svobada *et al.*, 2002)**
  - **PDSI**
  - **CPC Soil moisture**
  - **USGS weekly**
  - **Percentage of normal**
  - **SPI**
  - **VCI**



http://drought.unl.edu/DM/MONITOR.html

- **Linear combination of selected indices (OBDI, objective blend of drought indicator) was adopted as the preliminary overall drought status**

- **The decision of final drought status relies on subjective judgment**

Research Objectives & Study Area

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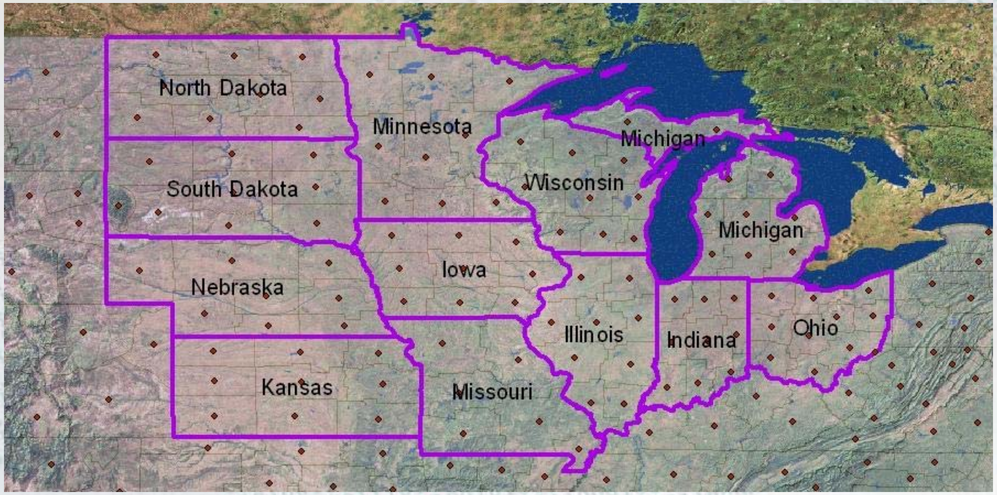
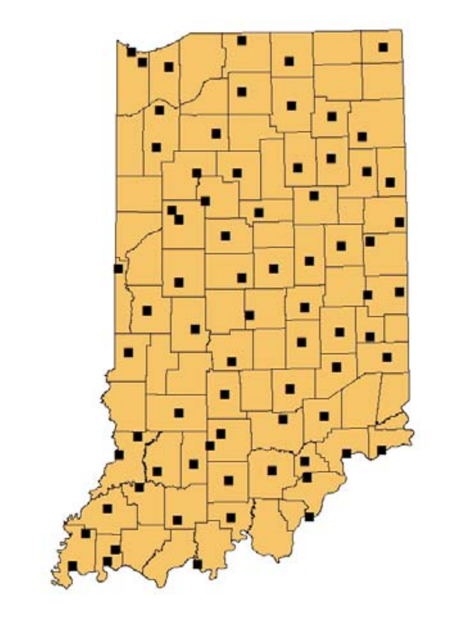
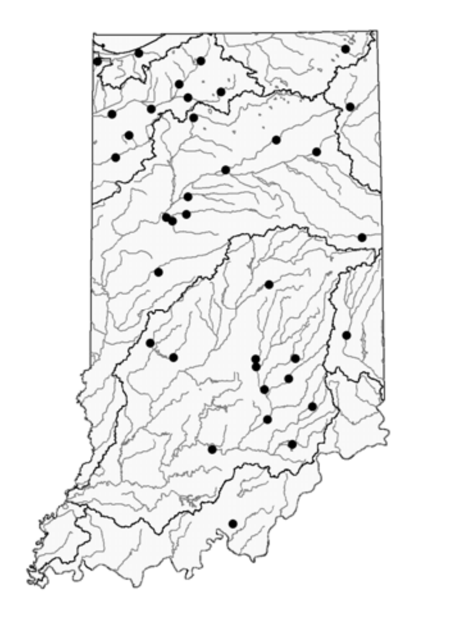
- **Research Objectives**
  - **Exploring the dependence structure between various drought indices**
  - **Develop probability-based joint drought index**
- **NOAA time bias corrected divisional dataset (TD-9640)**
  - **Monthly precipitation, temperature, SPI, PDSI**
  - **1895 ~ present**
- **NOAA daily precipitation dataset (TD-3200)**
  - **73 stations (>80 years)**
- **USGS unregulated daily mean flow**
  - **36 stations (>50 years)**







Standardized Index Method

- **Proposed by McKee *et al.* (1993)**
- **Generalizable to various types of observations**
  - **For precipitation: SPI**
- **For a given window size, the observed precipitation is transformed to a probability measure using Gamma distribution, then expressed in standard normal variable**

Probabilities of Occurrence (%)	SI Values	Drought Monitor Category	Drought Condition
20 ~ 30	-0.84 ~ -0.52	D0	Abnormally dry
10 ~ 20	-1.28 ~ -0.84	D1	Drought - moderate
5 ~ 10	-1.64 ~ -1.28	D2	Drought - severe
2 ~ 5	-2.05 ~ -1.64	D3	Drought - extreme
< 2	< -2.05	D4	Drought - exceptional

- **Though SIs for different windows are dependent, no representative window can be determined**

Co-occurrence of Droughts

- **Precipitation SIs $\{u_1, u_2, \ldots, u_{12}\}$ and streamflow SIs $\{v_1, v_2, \ldots, v_{12}\}$ are selected**
  - **Annual cycle accounts for the seasonal effect naturally**
  - **Allow for a month-by-month assessment for future conditions**
- **Dependence structure**

Upper triangle: Spearman's $r_{i,j}$ between u_i and u_j; lower triangle: Spearman's $r_{i,j}$ between v_i and v_j

j \ i	1	2	3	4	5	6	7	8	9	10	11	12
1		0.71	0.57	0.48	0.41	0.38	0.37	0.36	0.35	0.33	0.31	0.30
2	0.89		0.82	0.70	0.61	0.55	0.53	0.51	0.49	0.47	0.44	0.42
3	0.80	0.93		0.87	0.76	0.69	0.64	0.61	0.59	0.56	0.54	0.51
4	0.73	0.85	0.94		0.90	0.81	0.75	0.70	0.67	0.65	0.62	0.60
5	0.67	0.78	0.87	0.95		0.92	0.85	0.79	0.75	0.72	0.69	0.67
6	0.63	0.72	0.81	0.89	0.96		0.93	0.87	0.82	0.78	0.75	0.73
7	0.59	0.68	0.75	0.83	0.90	0.96		0.94	0.89	0.85	0.81	0.78
8	0.57	0.64	0.72	0.79	0.85	0.91	0.97		0.95	0.90	0.86	0.83
9	0.55	0.62	0.69	0.75	0.81	0.87	0.93	0.97		0.96	0.91	0.88
10	0.53	0.60	0.66	0.72	0.78	0.83	0.89	0.94	0.98		0.96	0.92
11	0.51	0.58	0.64	0.70	0.75	0.81	0.85	0.90	0.94	0.98		0.96
12	0.50	0.56	0.62	0.68	0.73	0.78	0.83	0.87	0.91	0.95	0.98	

Copulas

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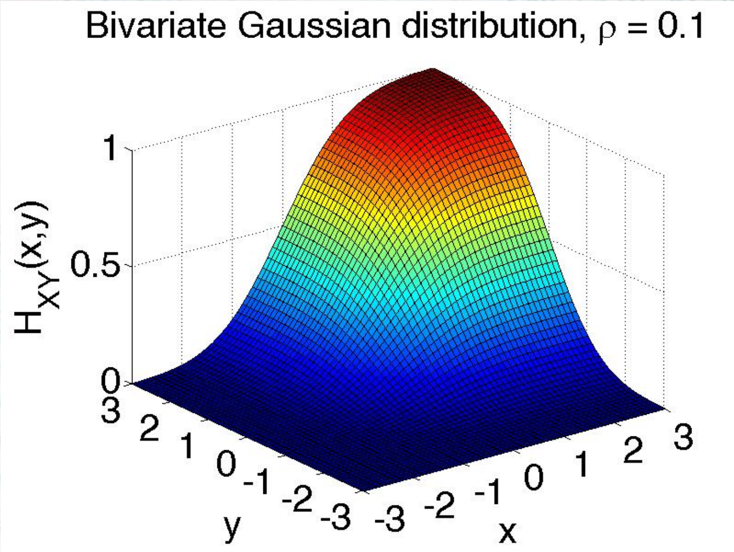
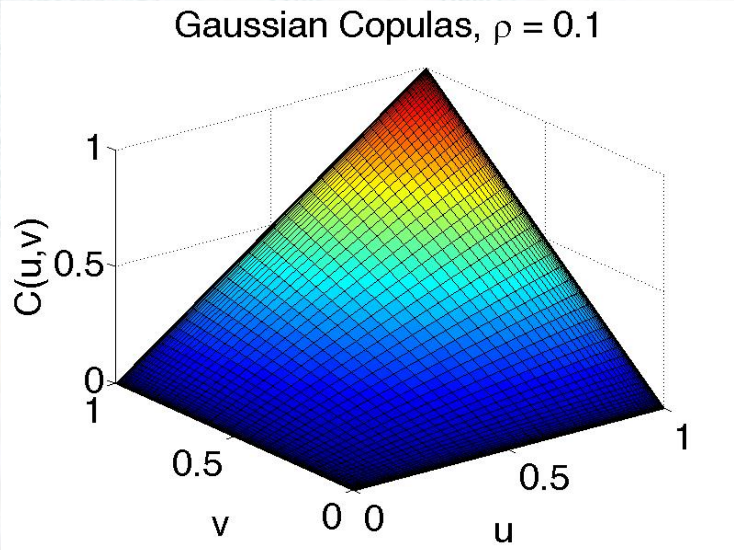
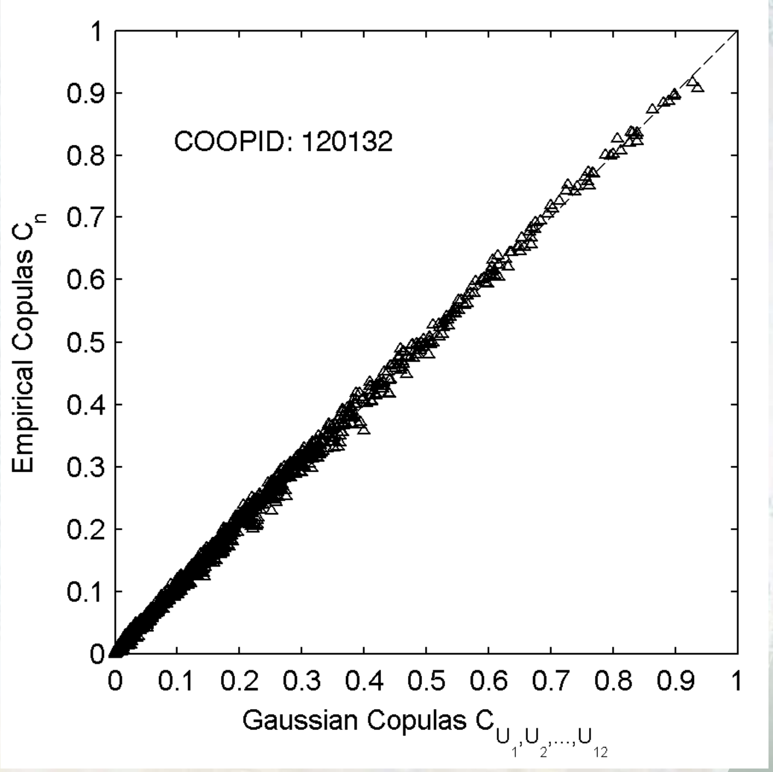
- **Transformation of joint cumulative distribution**
  - **$H_{XY}(x,y) = C_{UV}(u,v)$ marginals: $u = F_X(x)$, $v = F_Y(y)$**
  - **Sklar (1959) proved that the transformation is *unique* for continuous r.v.s**
- **Use copulas to construct joint distributions**
  - **Marginal distributions => selecting suitable PDFs**
  - **Dependence structure => selecting suitable copulas**
  - **Together they form the joint distribution**





Higher Dimensional Copulas

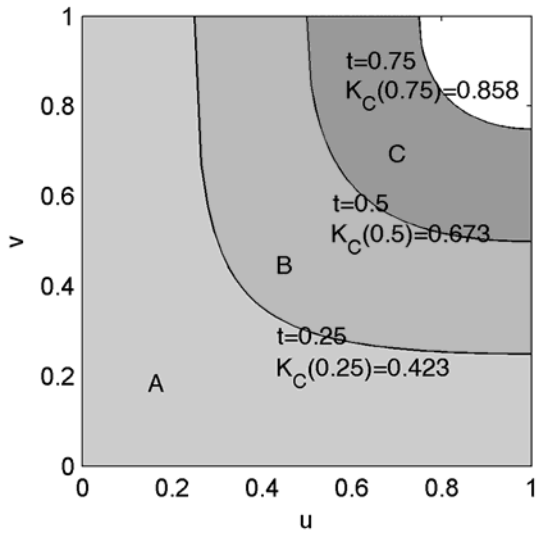
- **Limited choices because of high mathematical complexity**
  - **Gaussian copulas**
    - **Derived from the well-known multivariate normal distribution**
    - **Preserving all bivariate marginal dependencies through the correlation matrix Σ**
  - **Empirical copulas**
    - **Multi-dimensional rank-based probabilities**
    - **Treated as the observed probabilities when performing model verification**

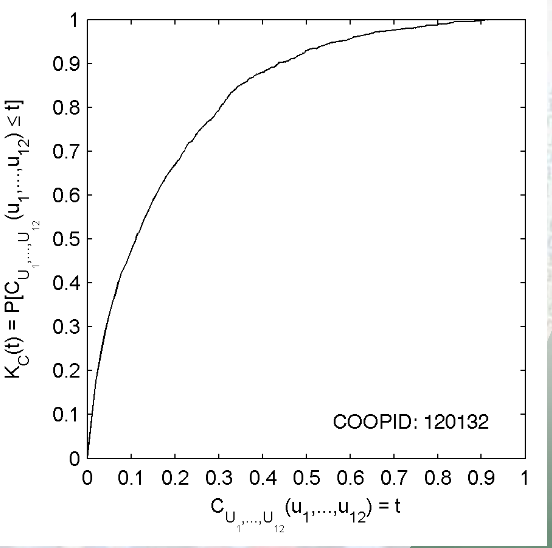


- **Empirical copulas were adopted in this study**

Joint Deficit Index (I)

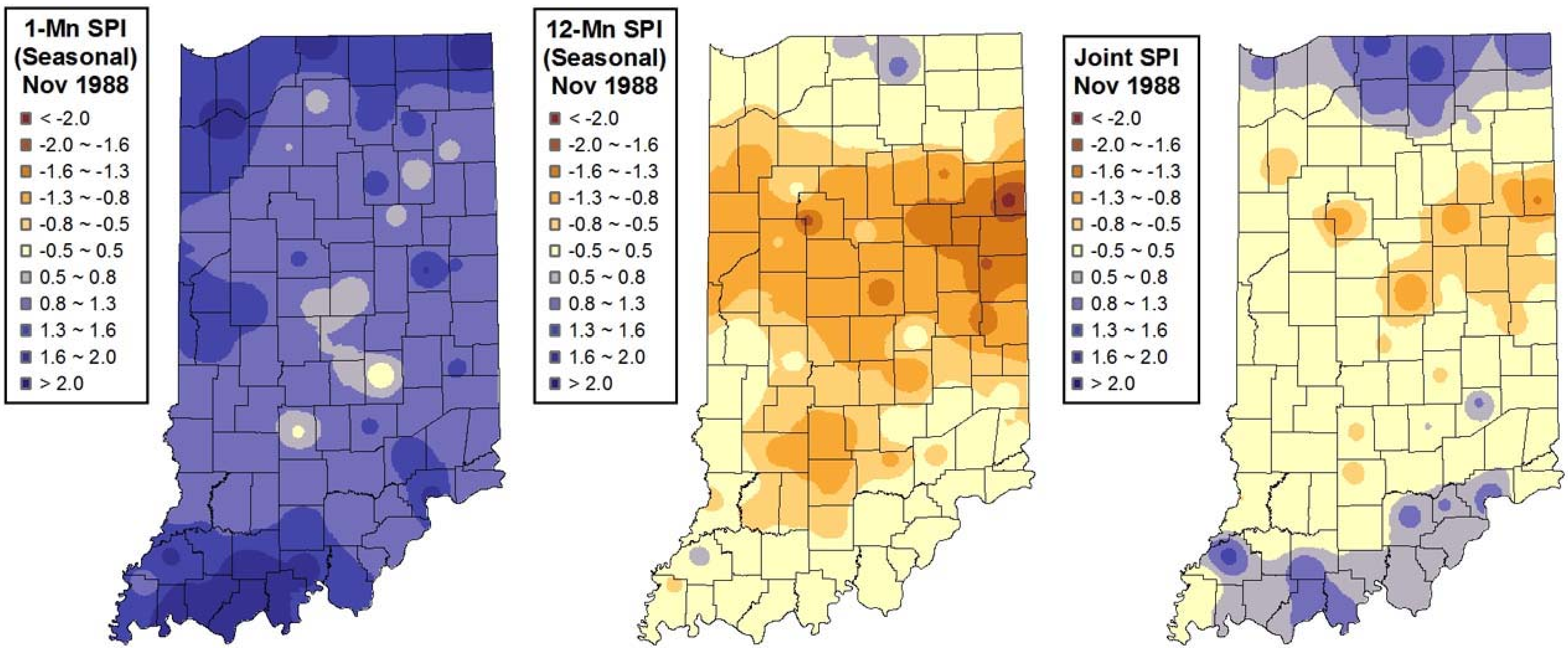
- **Assumption: events with the same value of copulas (joint cumulative probability) have same severity**
  - **Copula values are treated as joint deficit status**
- **Distribution function of copulas $K_C(t)$**
  - **Give probability measure for events with $C(u_1, u_2, \ldots, u_{12}) \le t$**
- **Joint deficit index (JDI)**
  - $JDI = \Phi^{-1}(K_C)$
  - Share the same classification with SI





Joint Deficit Index (II)

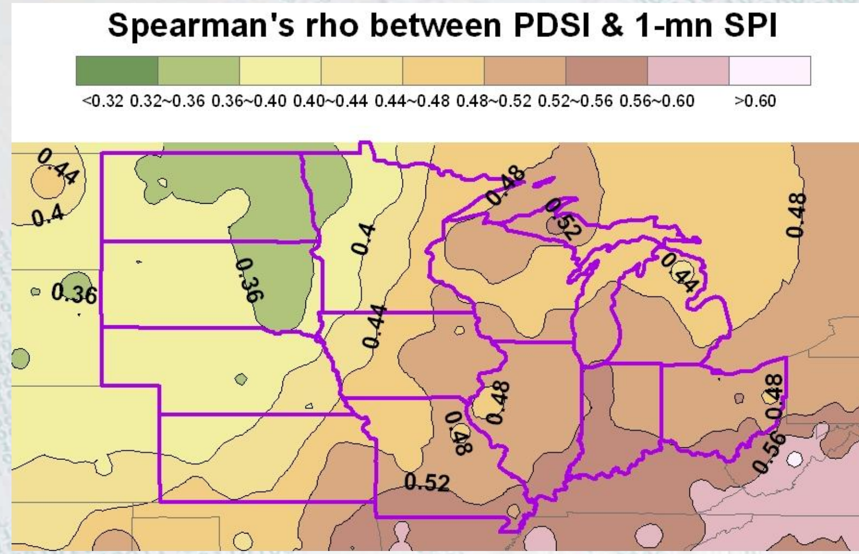
- **Comparison between 1-mn SPI, 12-mn SPI, and JDI**
  - **12-Mn SPI changes slowly, weak in reflecting emerging drought**
  - **1-Mn SPI changes rapidly, weak in reflecting accumulative deficit**
  - **JDI reflects joint deficit**

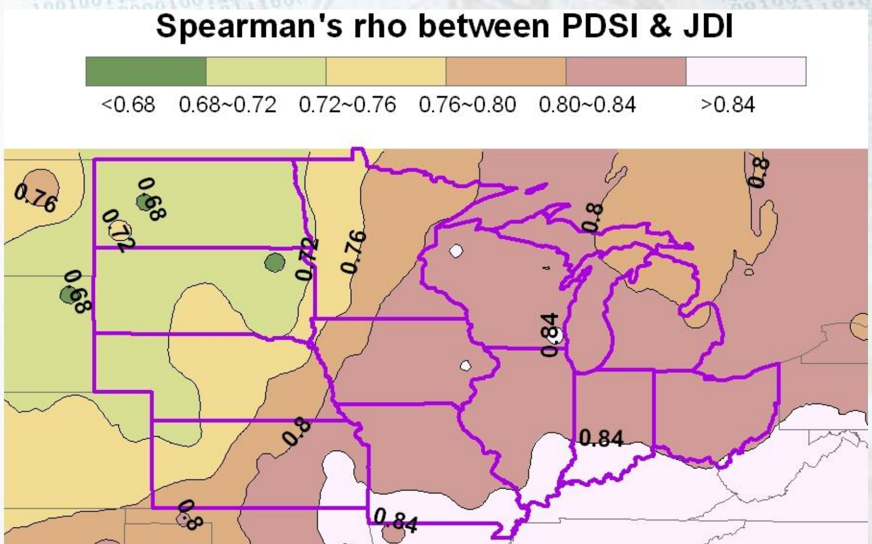


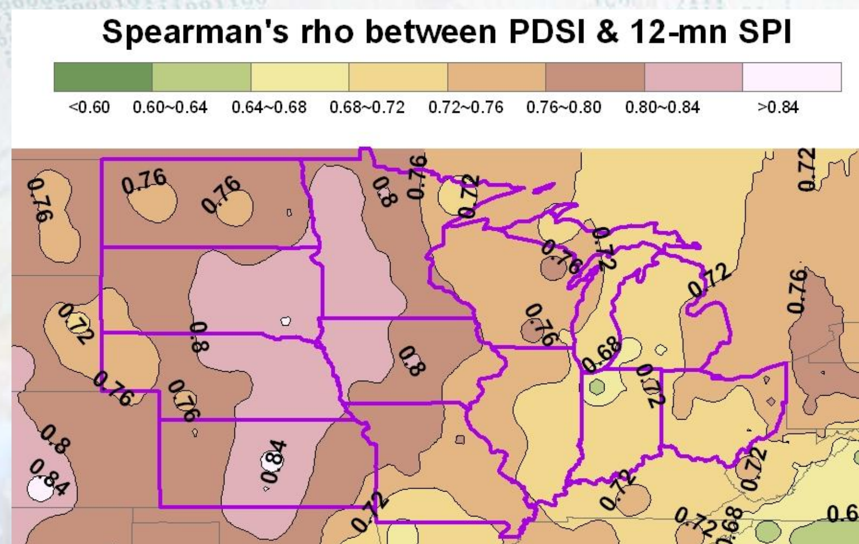
In Comparison with SPI & PDSI

- **PDSI**
  - **Based on both precipitation and temperature**
  - **Highly correlated to JDI**

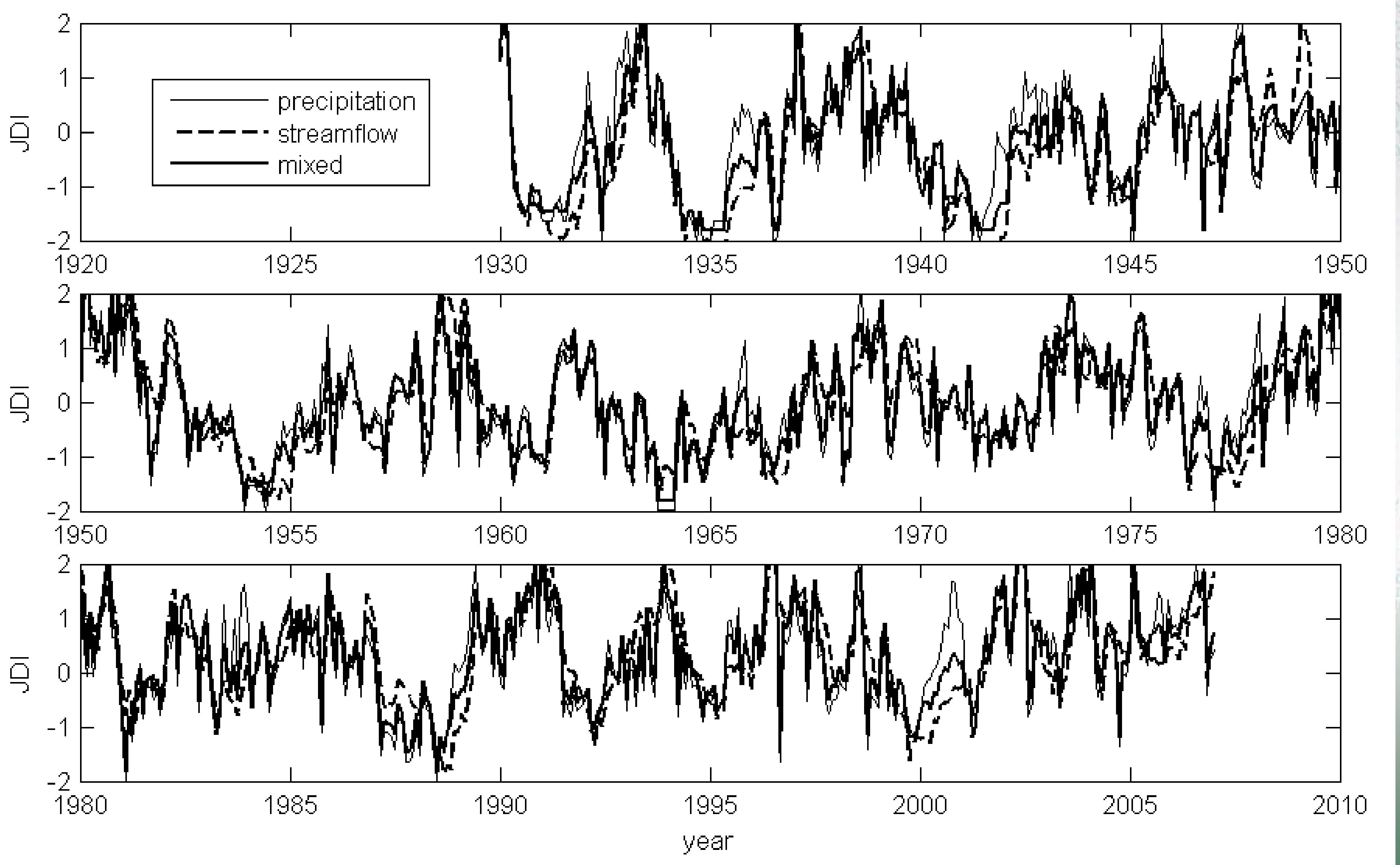
	SPI_1	SPI_3	SPI_6	SPI_9	SPI_{12}	JDI
JDI	0.72	0.80	0.79	0.76	0.70	
PDSI	0.45	0.66	0.75	0.77	0.76	0.79





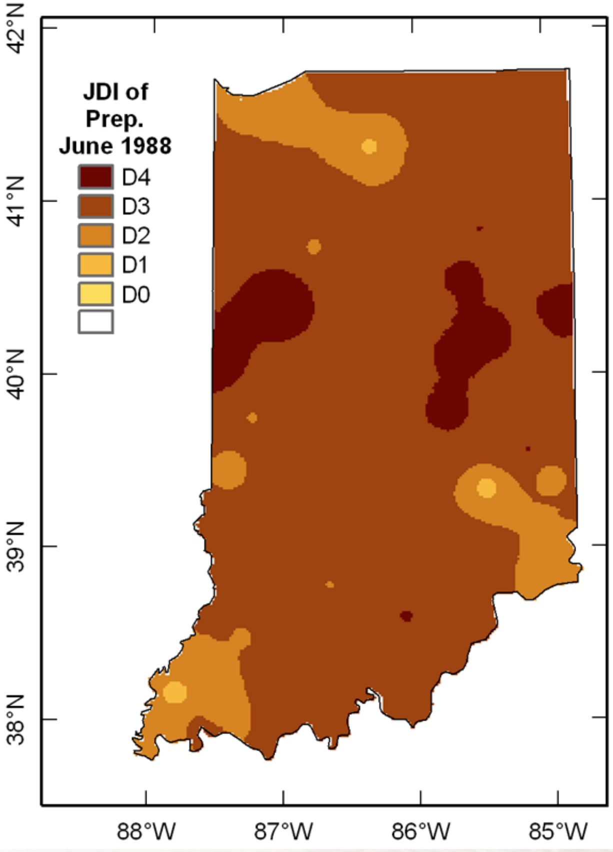


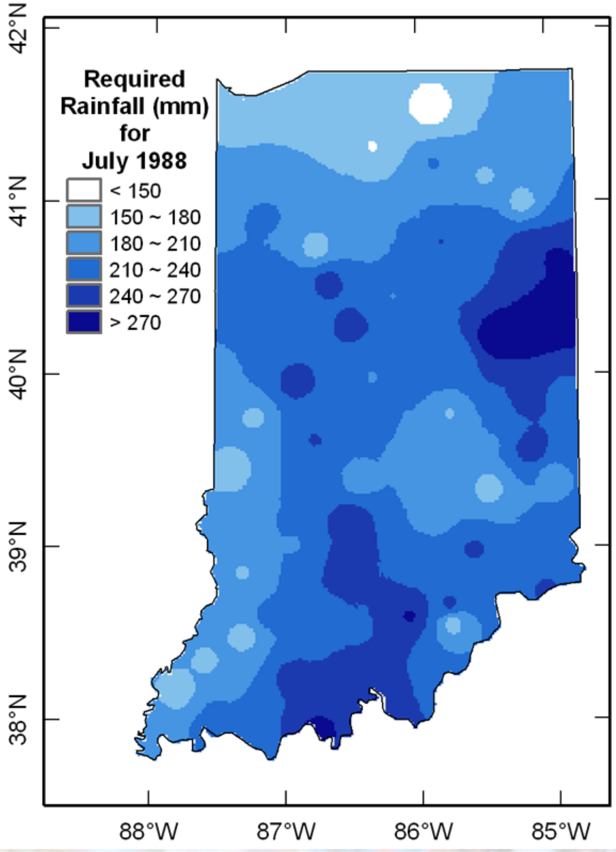
Precipitation vs. Streamflow

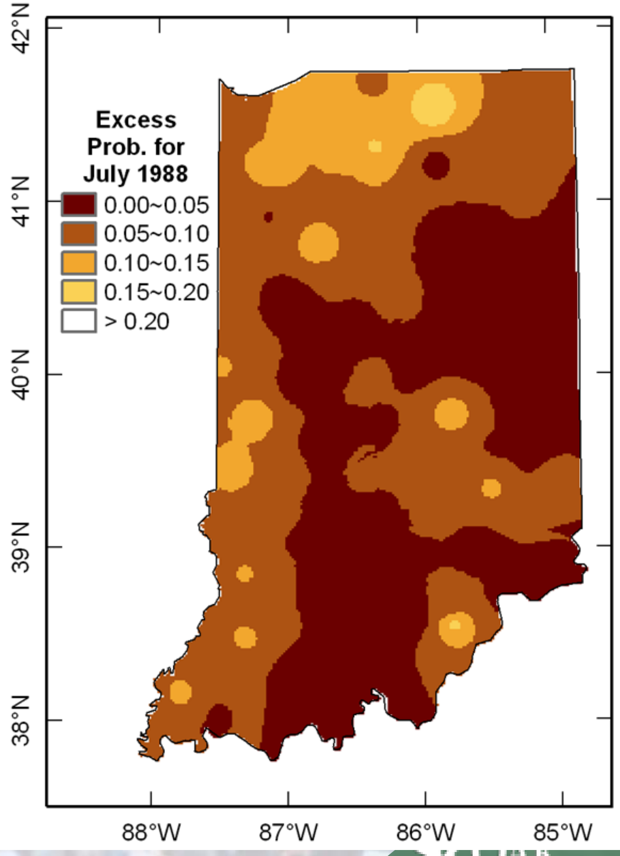


Potential of Future Droughts

- **Required precipitation for reaching joint normal status (K_C = 0.5) in the future**
- **Probability of drought recovery**







Conclusion

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- **JDI can offer an objective and probability-based overall drought description. It is capable of capturing both emerging and prolonged droughts in a timely manner**
- **High correlation was founded between PDSI and JDI, suggesting the applicability of JDI.**
- **JDI has potential to be applied on different types of hydrologic variables, and can be used to derive an inter-variable drought index**
- **Potential of future droughts can be assessed by using JDI, where the required precipitation and its exceedance probability can be determined**

Thank you
Questions?

Dr. Shih-Chieh Kao
kao@ornl.gov; http://www.ornl.gov/~5v1/