AWRA Wisconsin Section Annual Meeting

Linking Groundwater and Climate to Understand Long-Term Lake Level Fluctuations in Wisconsin

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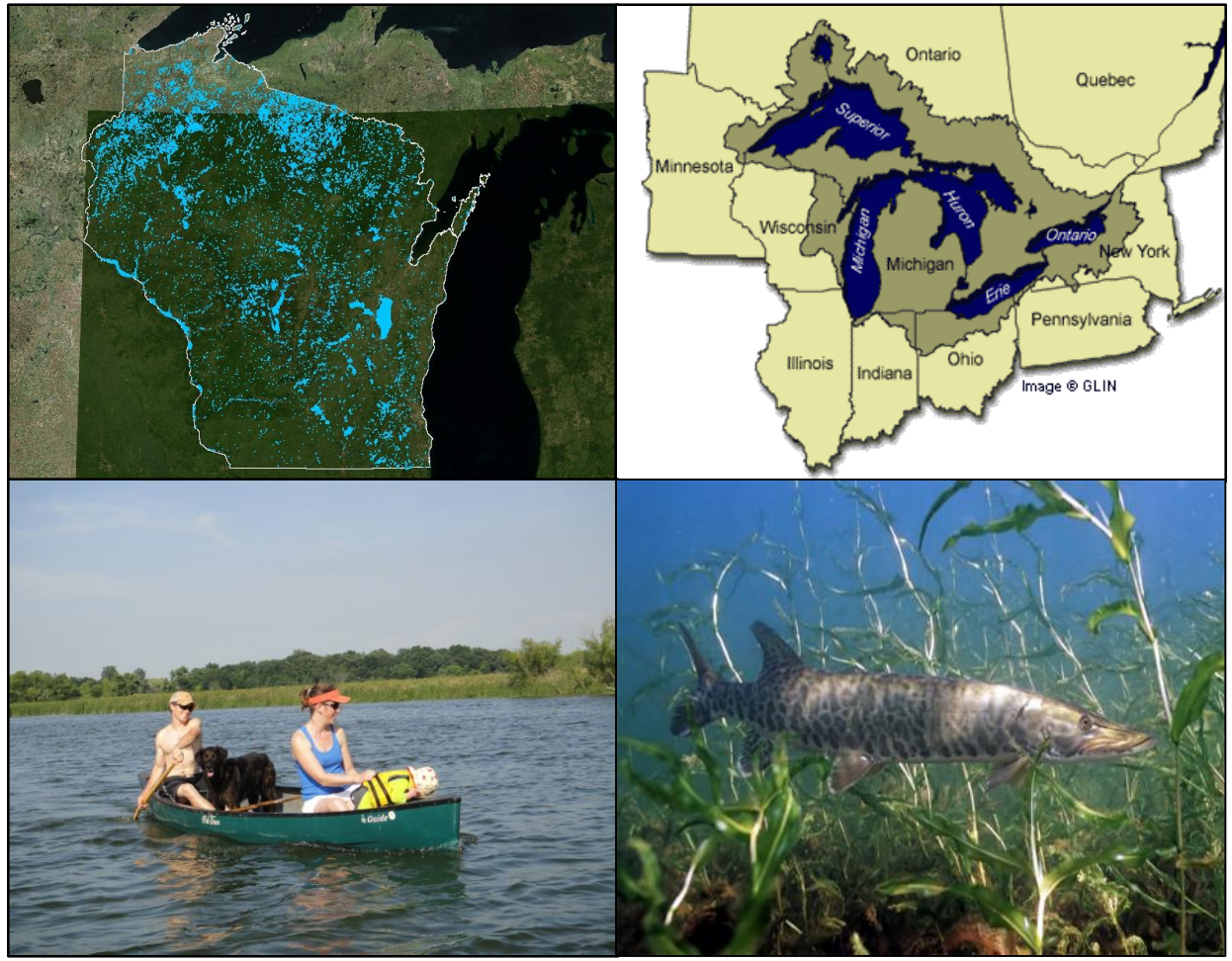
Andrew Rypel, Matt Diebel, Eric Booth, Paul Juckem, Emily Stanley

Wisconsin Groundwater Joint Solicitation

Wisconsin is water rich

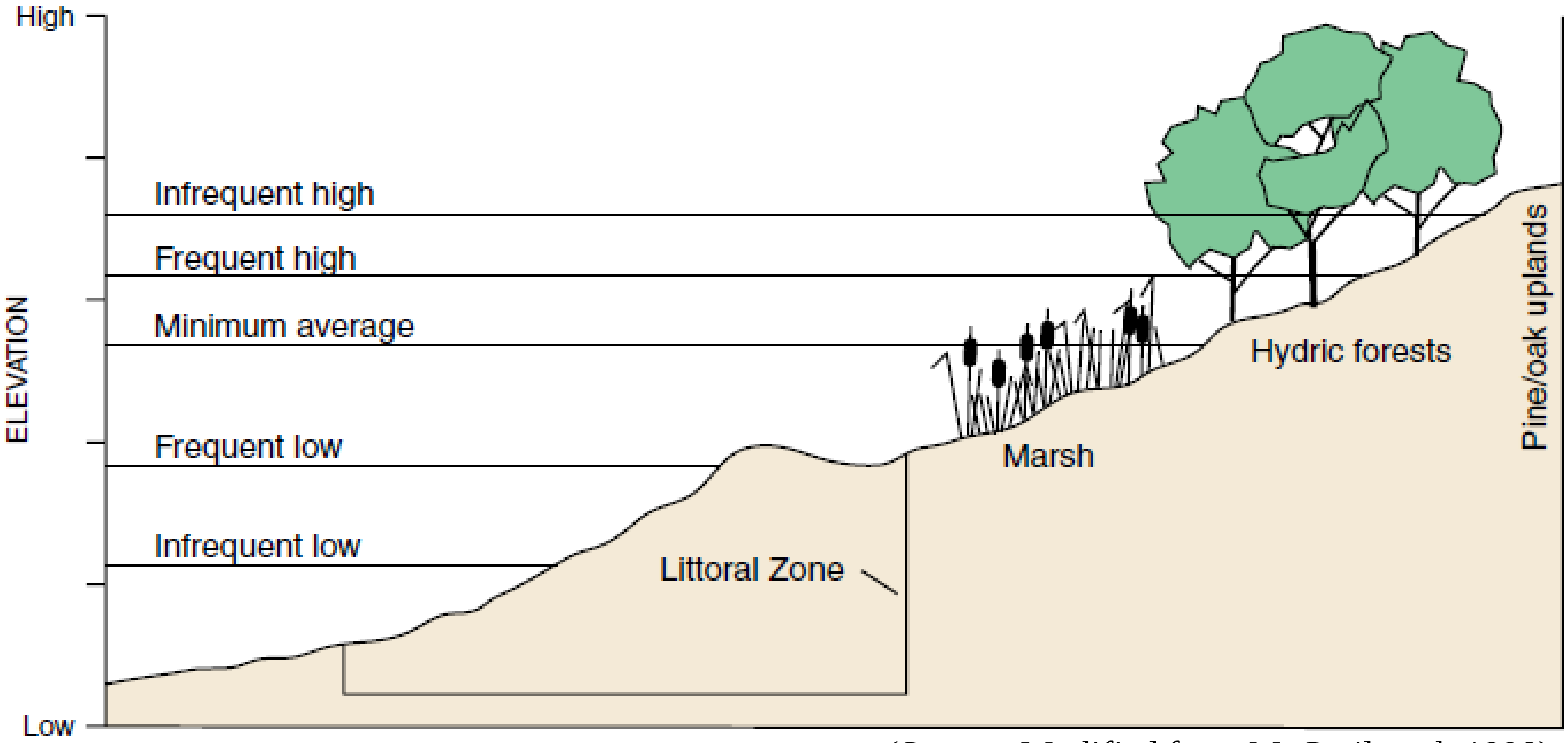


(Source: Fig1 Wisconsin DNR; Fig 2 Great Lake Information Network; Fig 3 Catherine Hein; Fig 4 USFWS)

But, Wisconsin lakes are also facing many challenges

(Source: Fig1 Kate Golden; Fig 2 Dick Lathrop; Fig3-4 USGS)

Compared to streams, lake level regimes are rarely monitored and defined



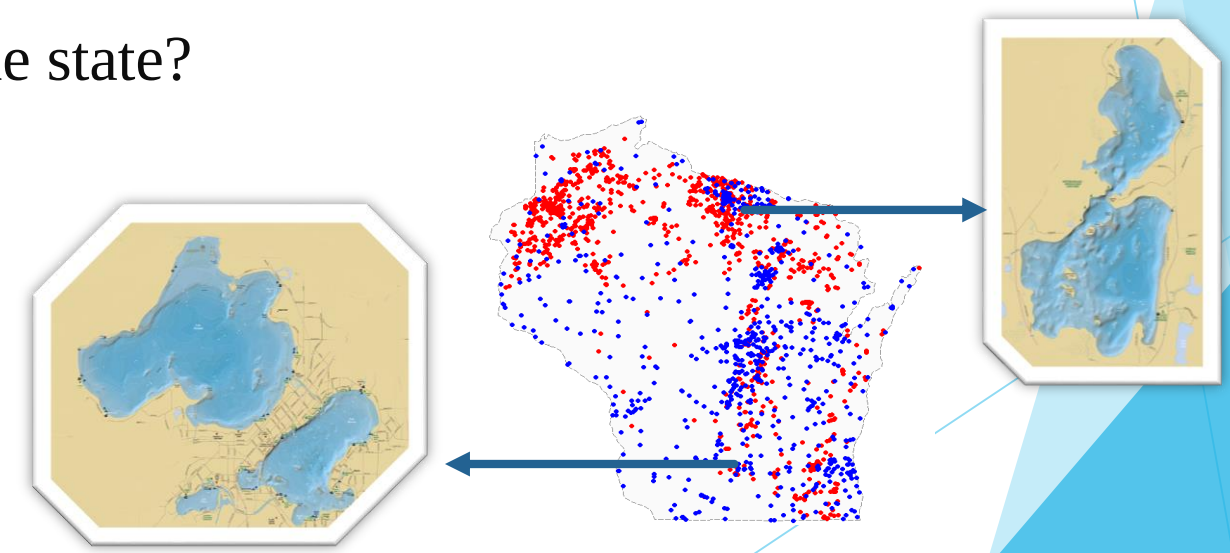
(Source: Modified from McGrail et al. 1998)

Purpose

Understand the drivers of lake level regimes to better manage lakes under a changing climate and increasing demand for groundwater

1) Do water levels across the state behave in the same way?

2) What are the main driver(s) of the spatial and temporal coherence of lakes and groundwater wells across the state?



Purpose

Understand the drivers of lake level regimes to better manage lakes under a changing climate and increasing demand for groundwater

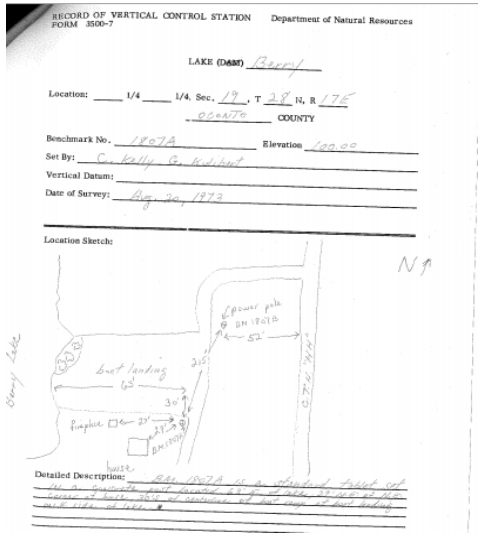
3) Can we predict the historical lake levels with the same driver(s)?

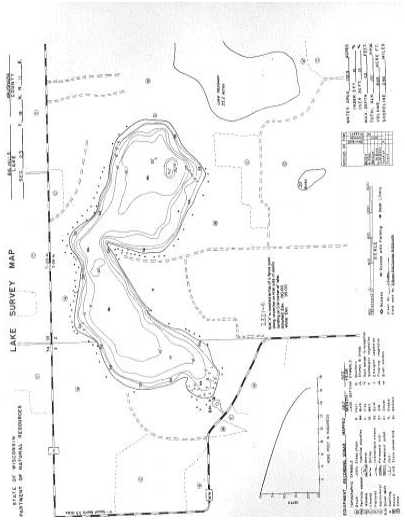
4) What are the hydrologic regimes of lakes in Wisconsin?

Data Compilation

Lake Level and Groundwater Level Data

Digitization





Extraction

Internal Data Cleaning

Merging Datasets

QAQC

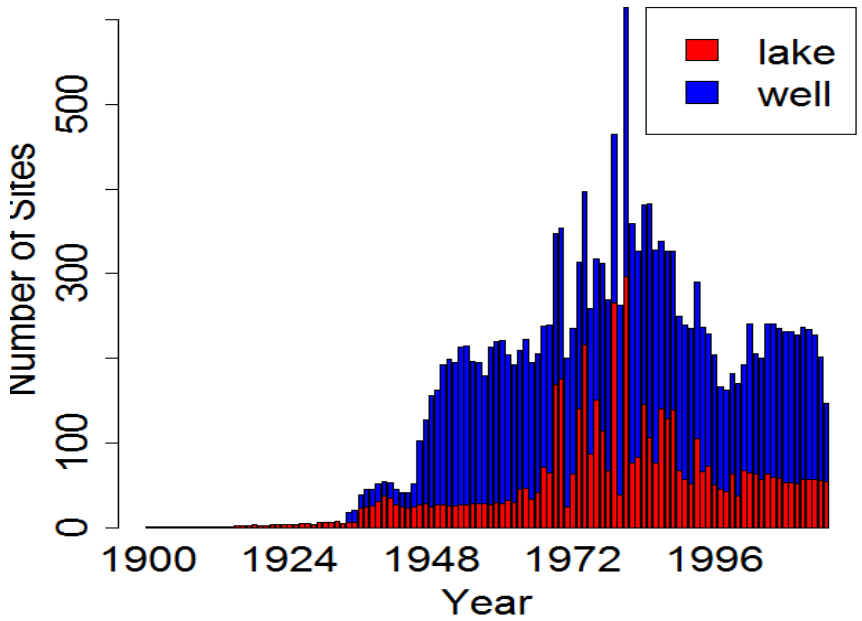
Adding more information

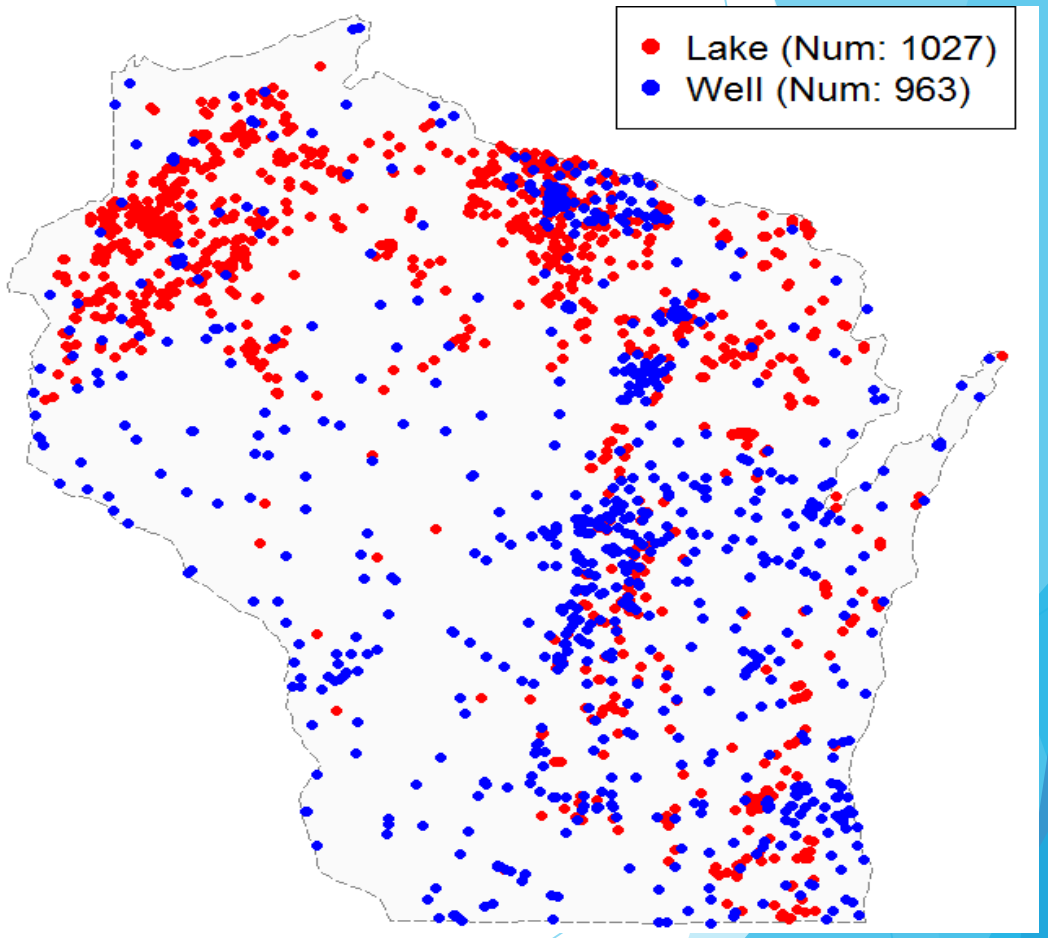
Data input and extracted by Kang Huang, Department of Statistics at UW-Madison

Data Source	Number of Lakes	Number of Lake Level Observations (Accuracy: 1000)	Number of Wells	Number of Groundwater Level Observations (Accuracy: 1000)
USGS	214	330,000	888	393,000
UW NTL-LTER	7	3,000	37	5,000
DNR	752	4,000	-	-
DNR-citizen	22	500	-	-
Central Sands	-	-	38	800
Waushara County	31	800	-	-
North Lake Discovery Center	22	2638	-	-
Shell Lake City	1	800	-	-
Total	**1049**	**342,000**	**963**	**394,000**

The spatial and temporal distribution of the data

- Long term: data spans 1900-2015
- Large scale: data covers all counties

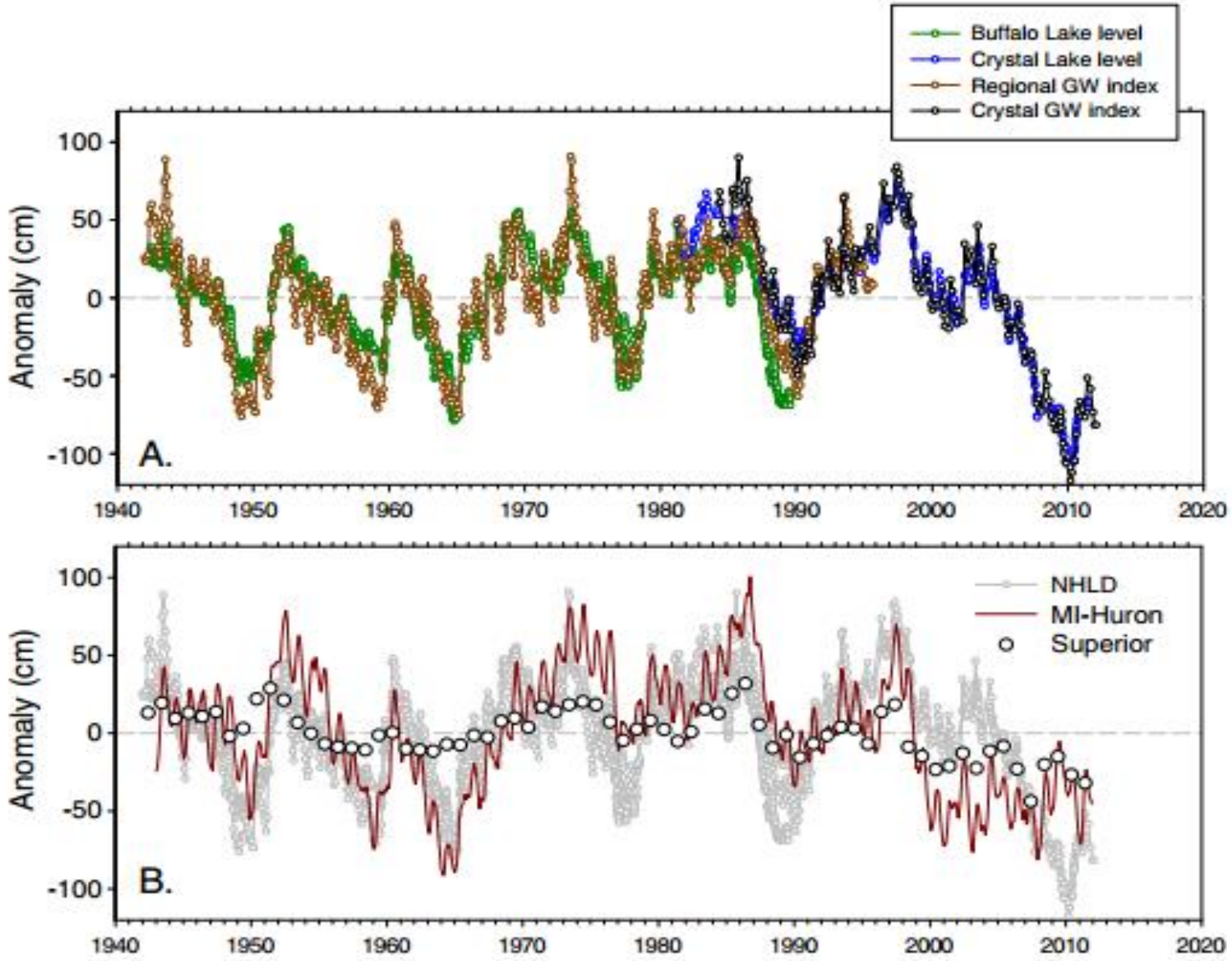




Purpose

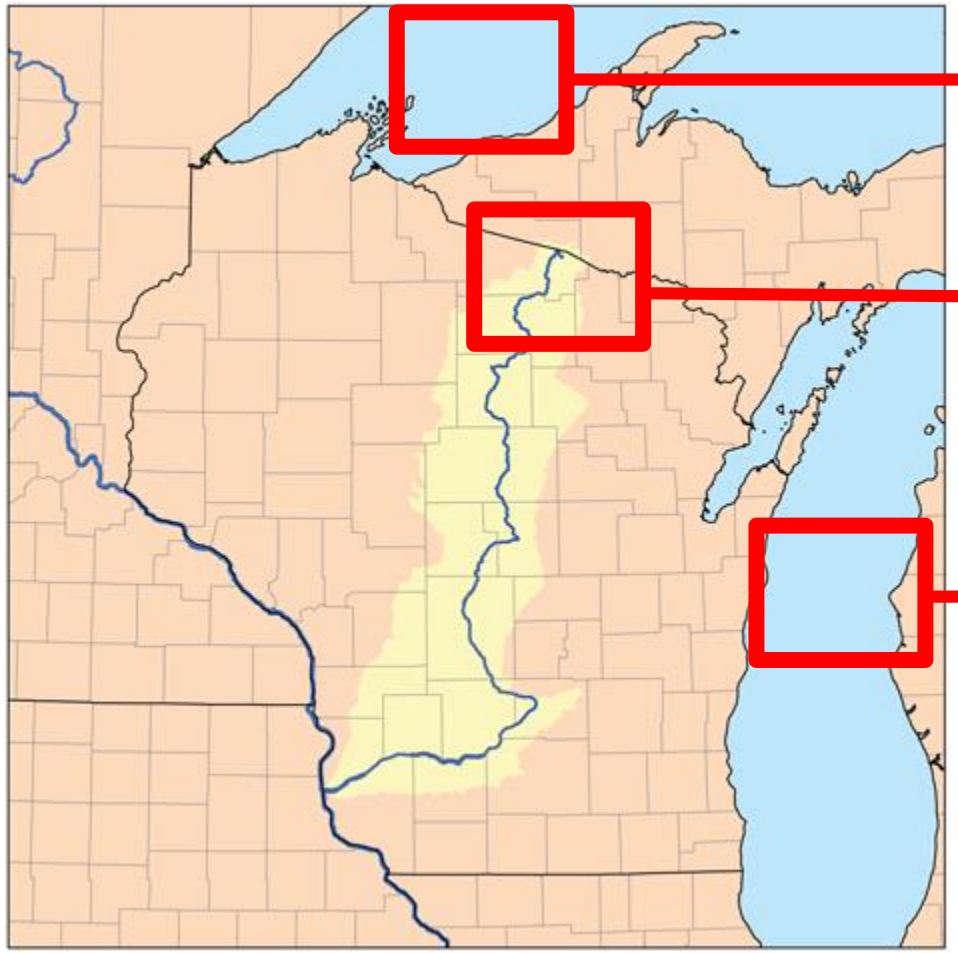
- Do water levels across the state behave in the same way?
- What are the main drivers of the spatial and temporal coherence of lakes and groundwater wells across the state?
- Can we predict the historical lake levels with the same drivers?
- What are the hydrologic regimes of lakes in Wisconsin?

What is the spatial and temporal coherence of lakes and groundwater wells across Wisconsin?



(Source: Carl Watras et al 2013)

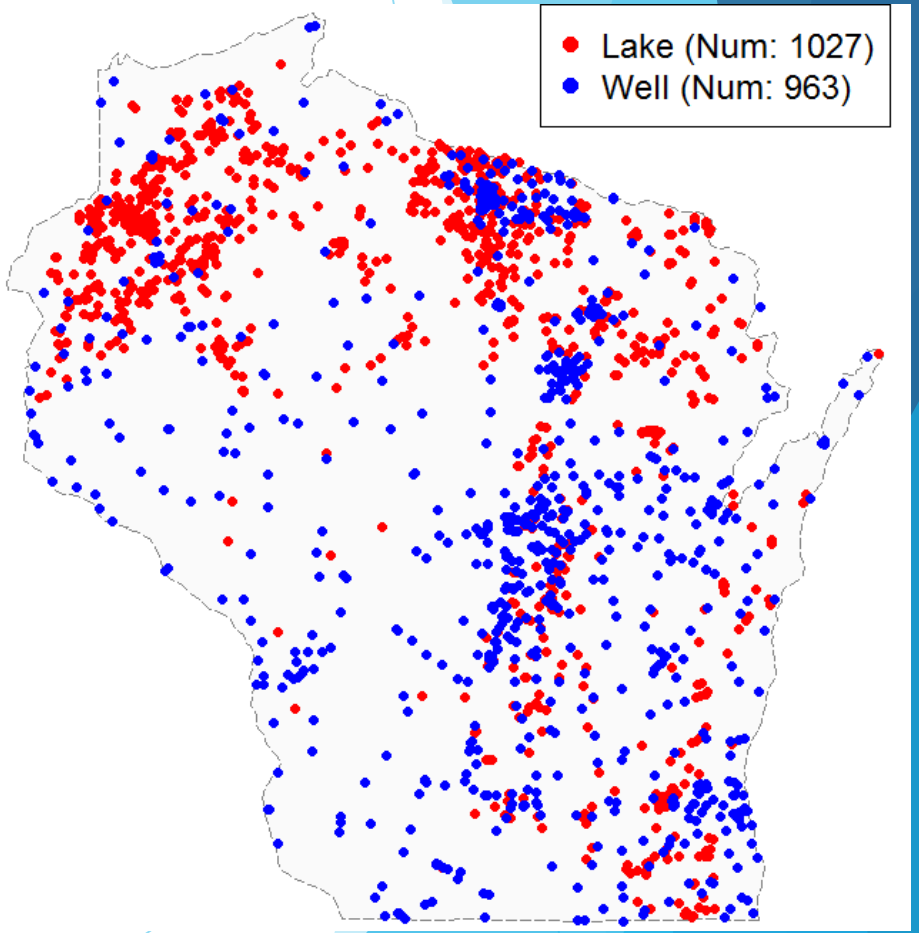
What is the spatial and temporal coherence of lakes and groundwater wells across Wisconsin?



Lake Superior

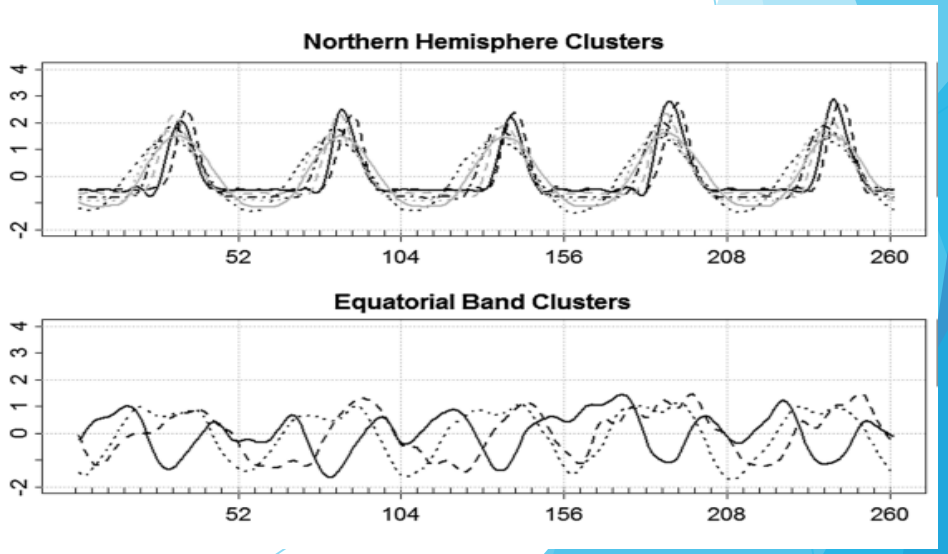
Crystal Lake
Buffalo Lake
Nine Wells

Lake Michigan

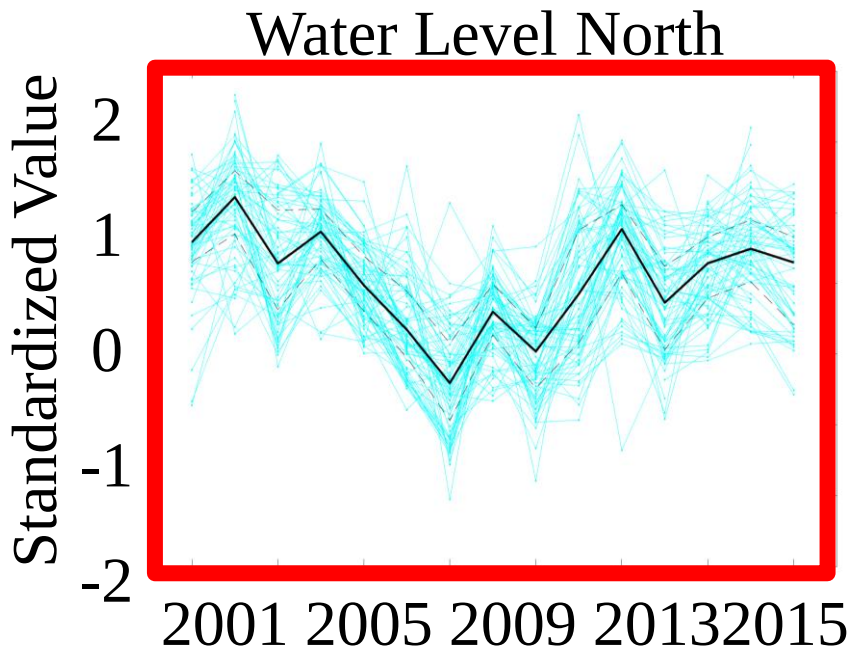


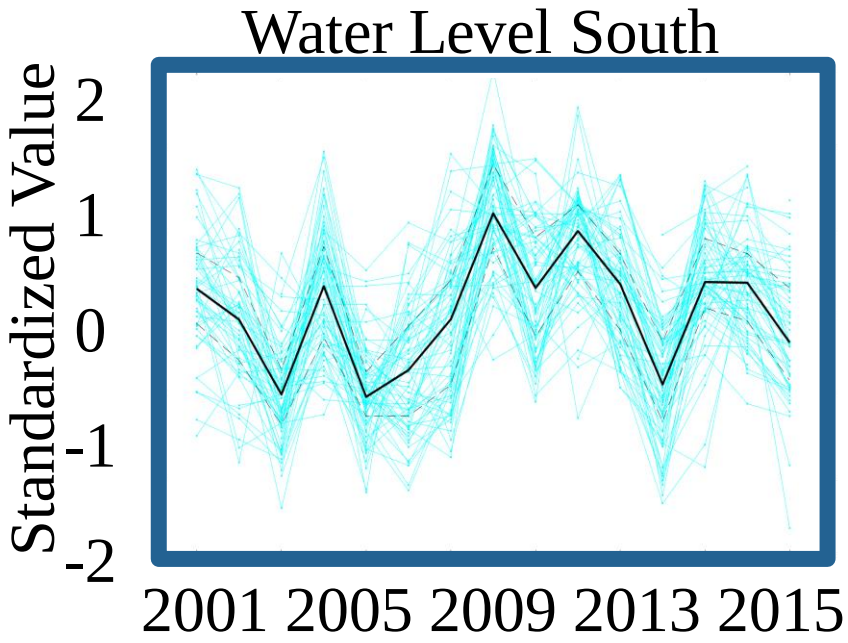
Spatial and Temporal Coherence

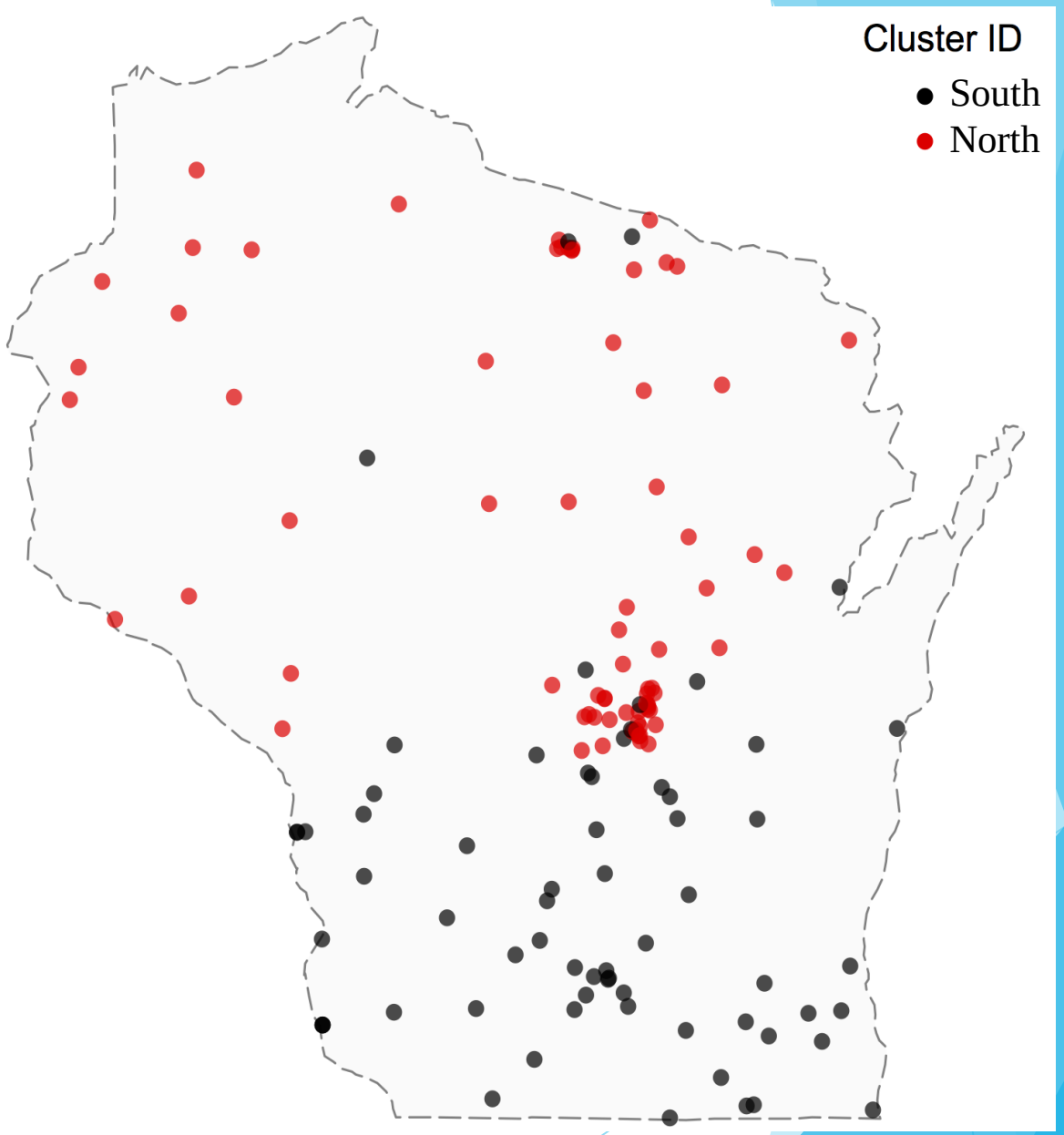
- Method: Dynamic time warping (DTW) and kernel K-means clustering
- Data Input: 167 lakes and wells, 2001-2015, annual summer mean values



(Source: Finazzi et al 2014)


Water Level North
Standardized Value
2
1
0
-1
-2
2001 2005 2009 20132015


Water Level South
Standardized Value
2
1
0
-1
-2
2001 2005 2009 2013 2015


Cluster ID
South
North

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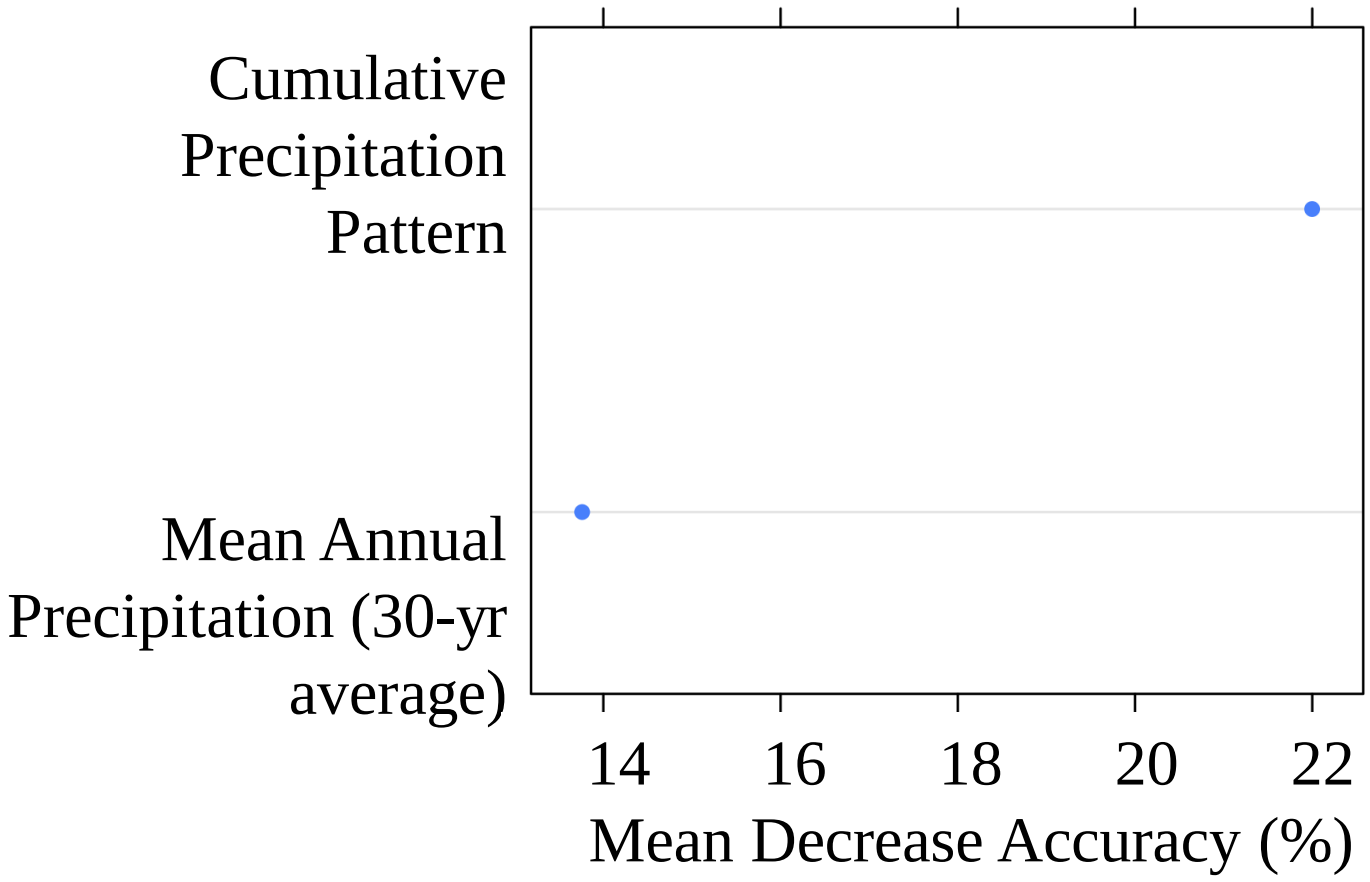
Interpret the result: what influence clusters?

162 Predictors identified

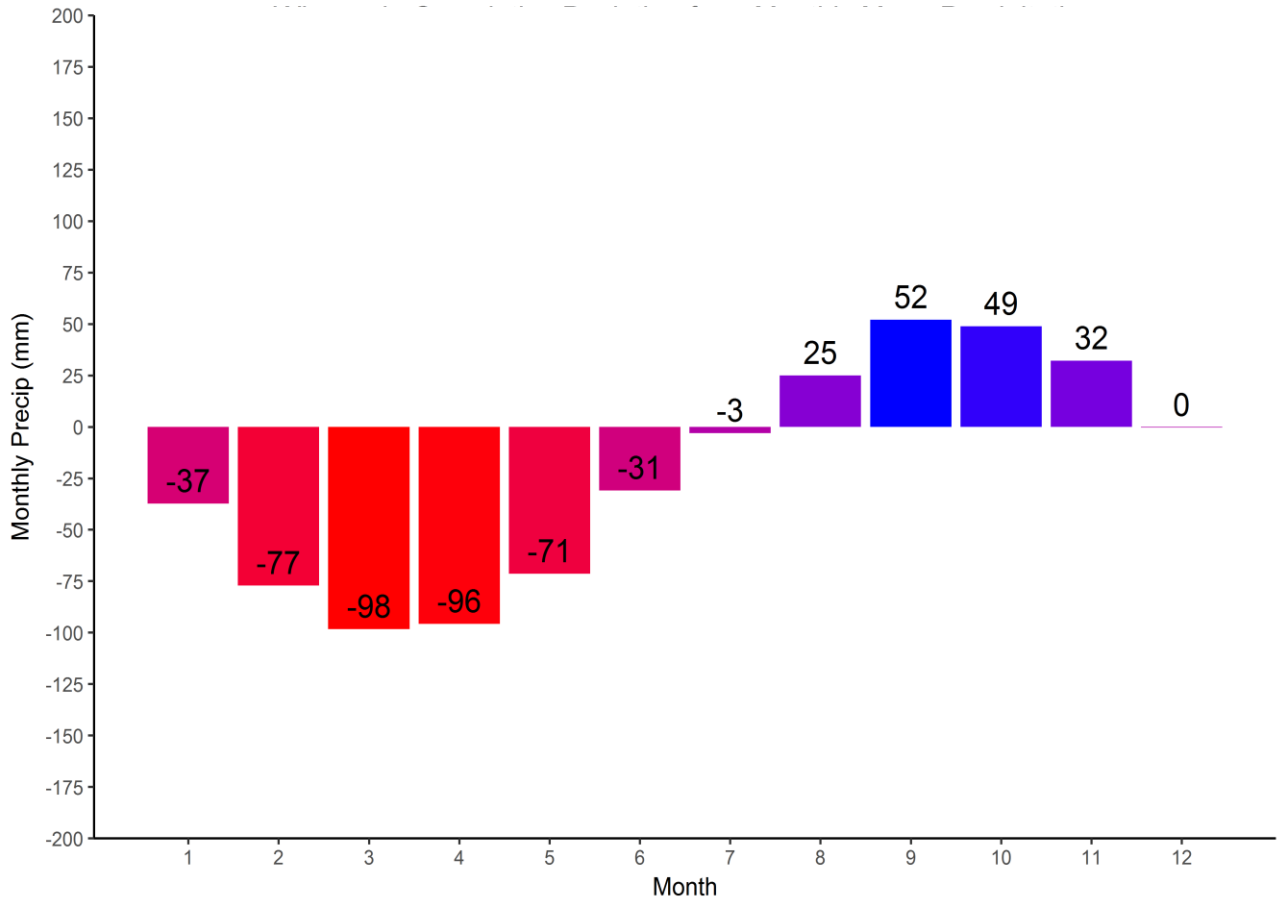
Basic Characteristic	Record Type (Lake vs. Well)	
Parameters at HUC4, HUC8, and HUC12 spatial scale	Landscape:	landcover, land use, …
	Geology:	Sediment type …
	Climate:	precipitation, baseflow, groundwater recharge, …
Other Characteristic	Clusters on cumulative precipitation deviation	

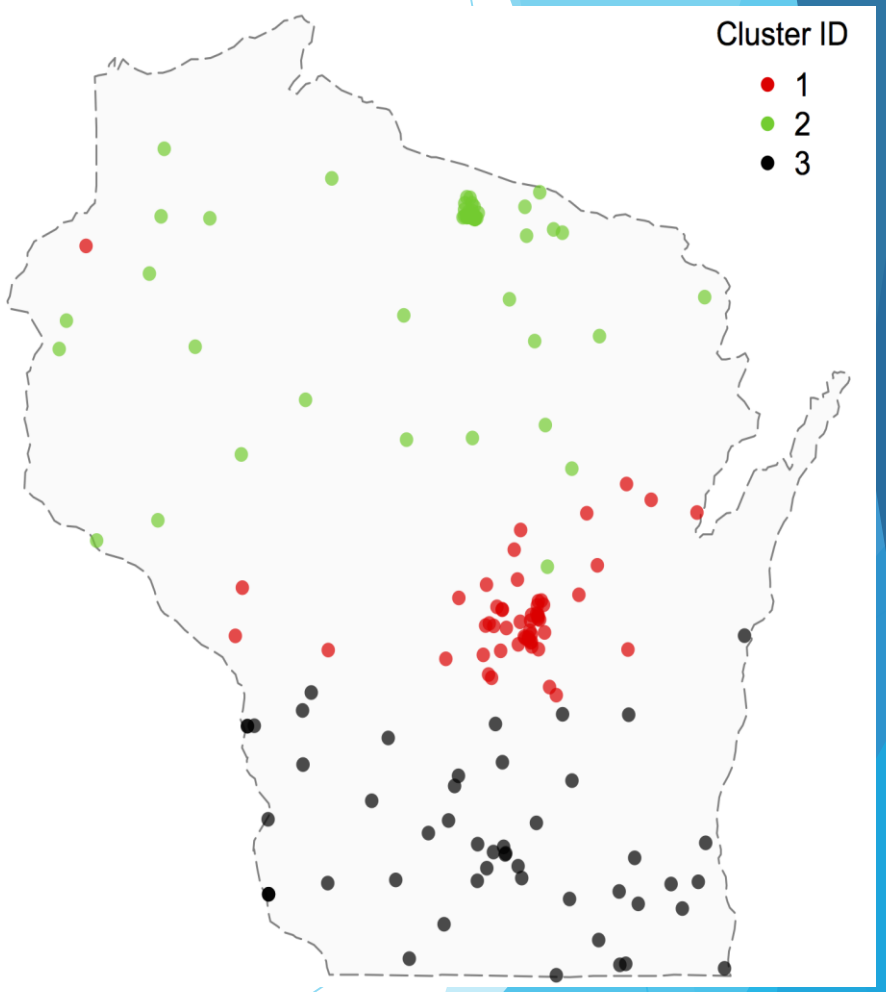
Interpret the result: what influence clusters?

- Random Forest Classification Model
- Correctly classify 89% (83% – 94%) of sites

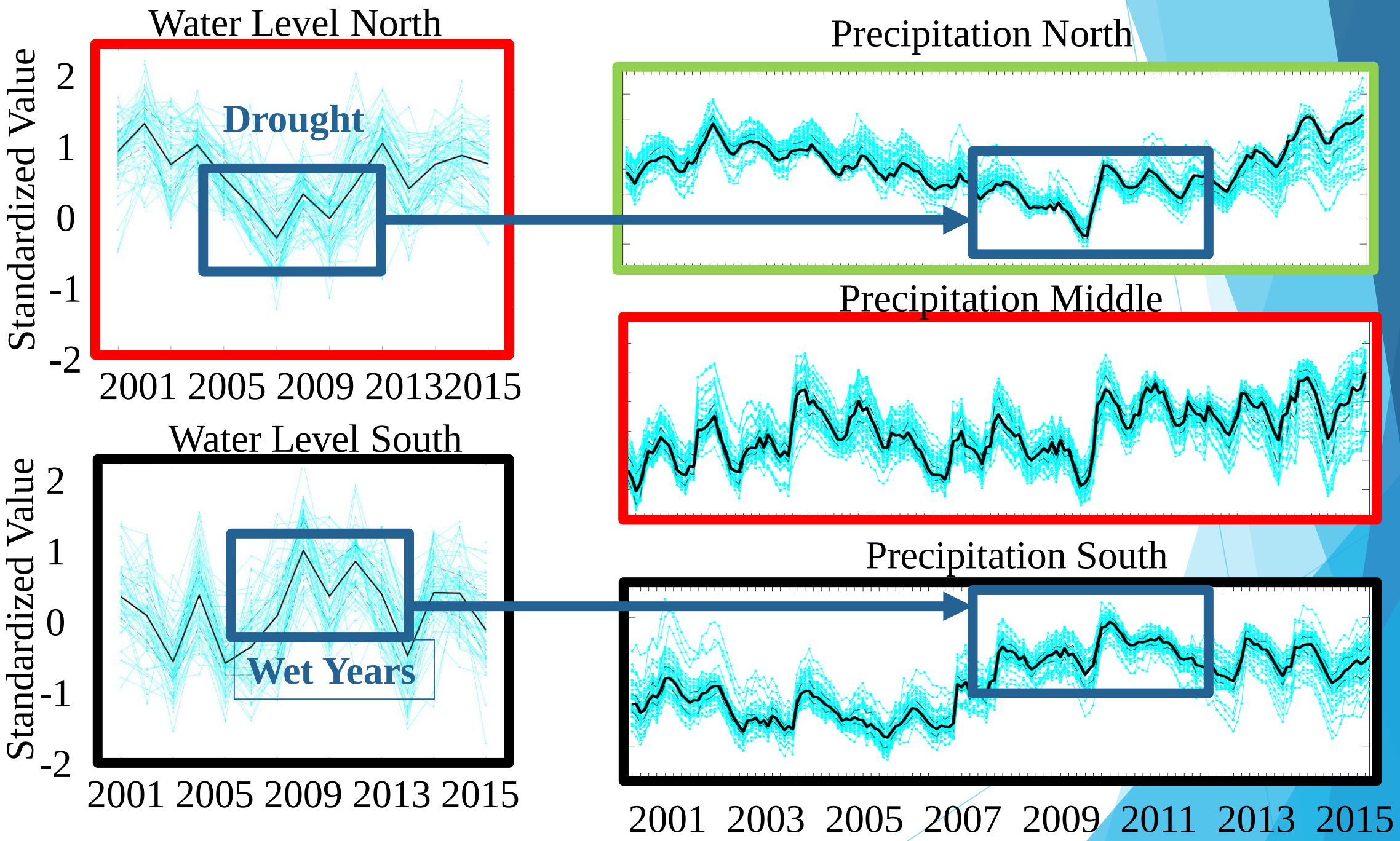


Patterns of Cumulative Deviation Precipitation



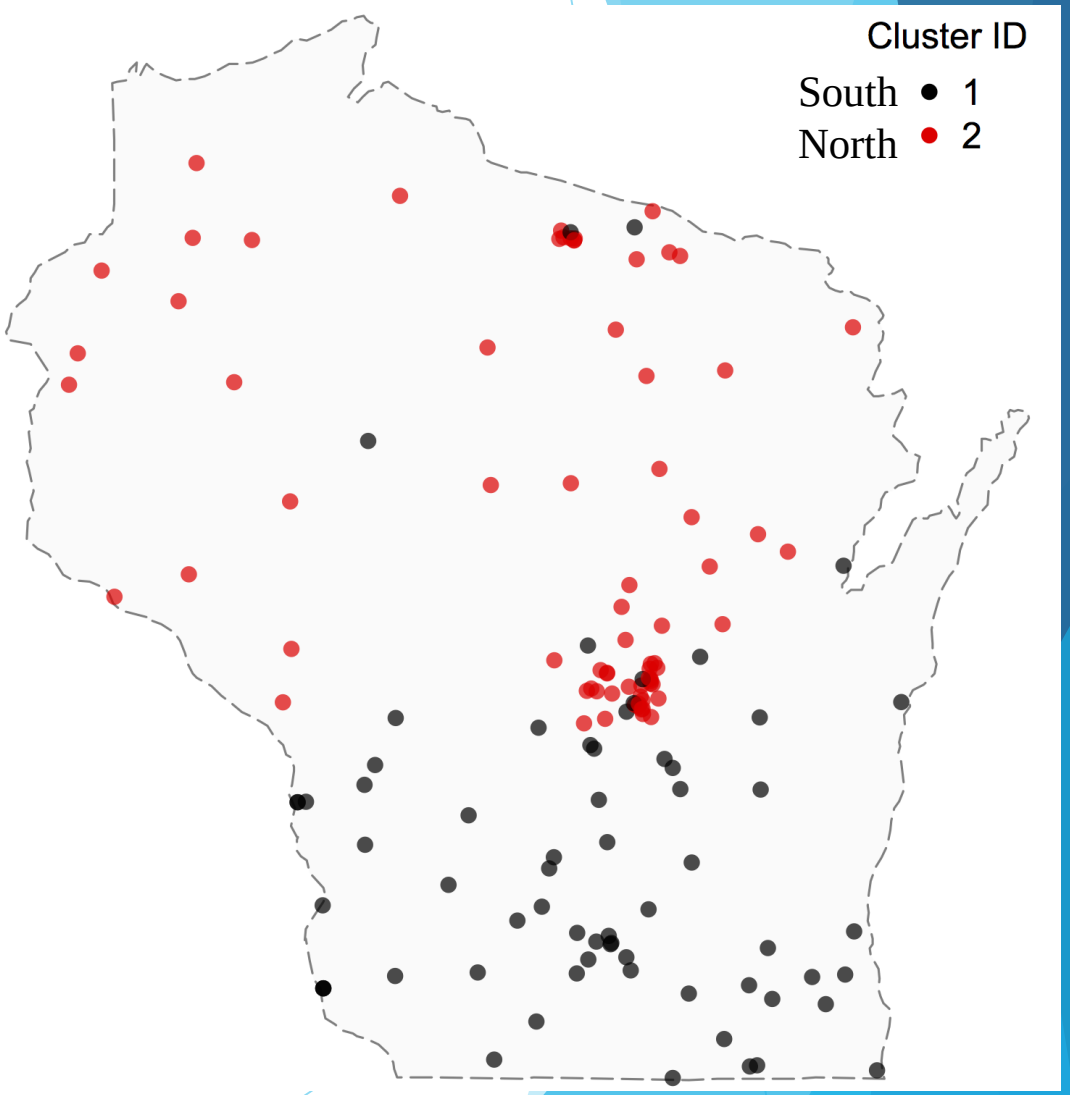


(Source: Bob Smail)

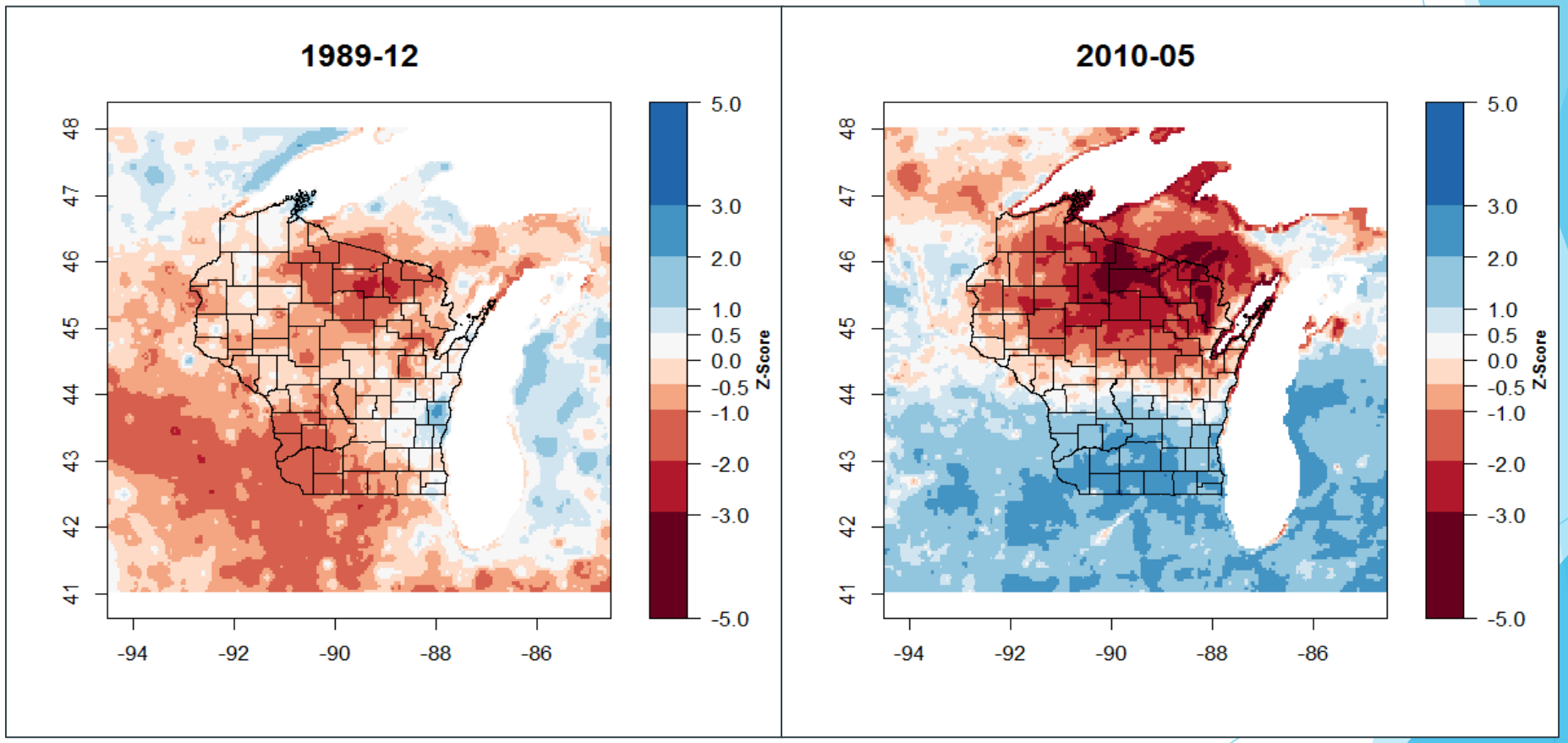

Water Level North
Standardized Value
2
1
0
-1
-2
Drought
2001 2005 2009 20132015
Precipitation North
Precipitation Middle
Water Level South
Standardized Value
2
1
0
-1
-2
Wet Years
2001 2005 2009 2013 2015
Precipitation South
2001 2003 2005 2007 2009 2011 2013 2015

Spatial and Temporal Coherence - Conclusion

- North/South difference in water level patterns
- Dividing line is around the Central Sands area
- Precipitation (amount and long-term pattern) plays an important role in long-term water level patterns



The regional divide may change over time



(Source: Bob Smail)

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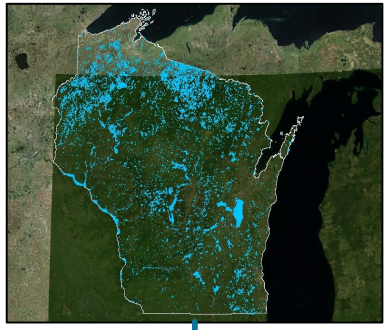
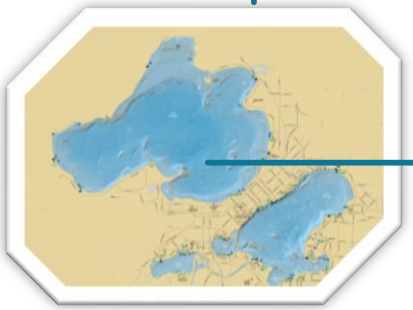
Bayesian Hierarchical Model (BHM)



"Wisconsin Lake"

Lake Level $= \beta \cdot \text{Precipitation} + \alpha$

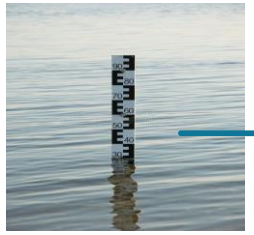
Global Model

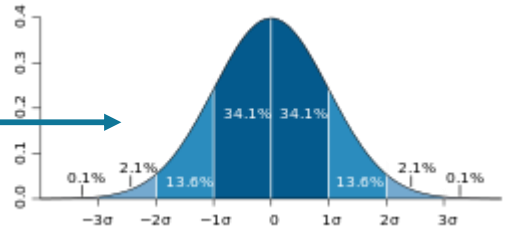


Local Model

Lake Mendota

Lake Level $= \beta_{\text{Mendota}} \cdot \text{Precipitation} + \alpha_{\text{Mendota}}$





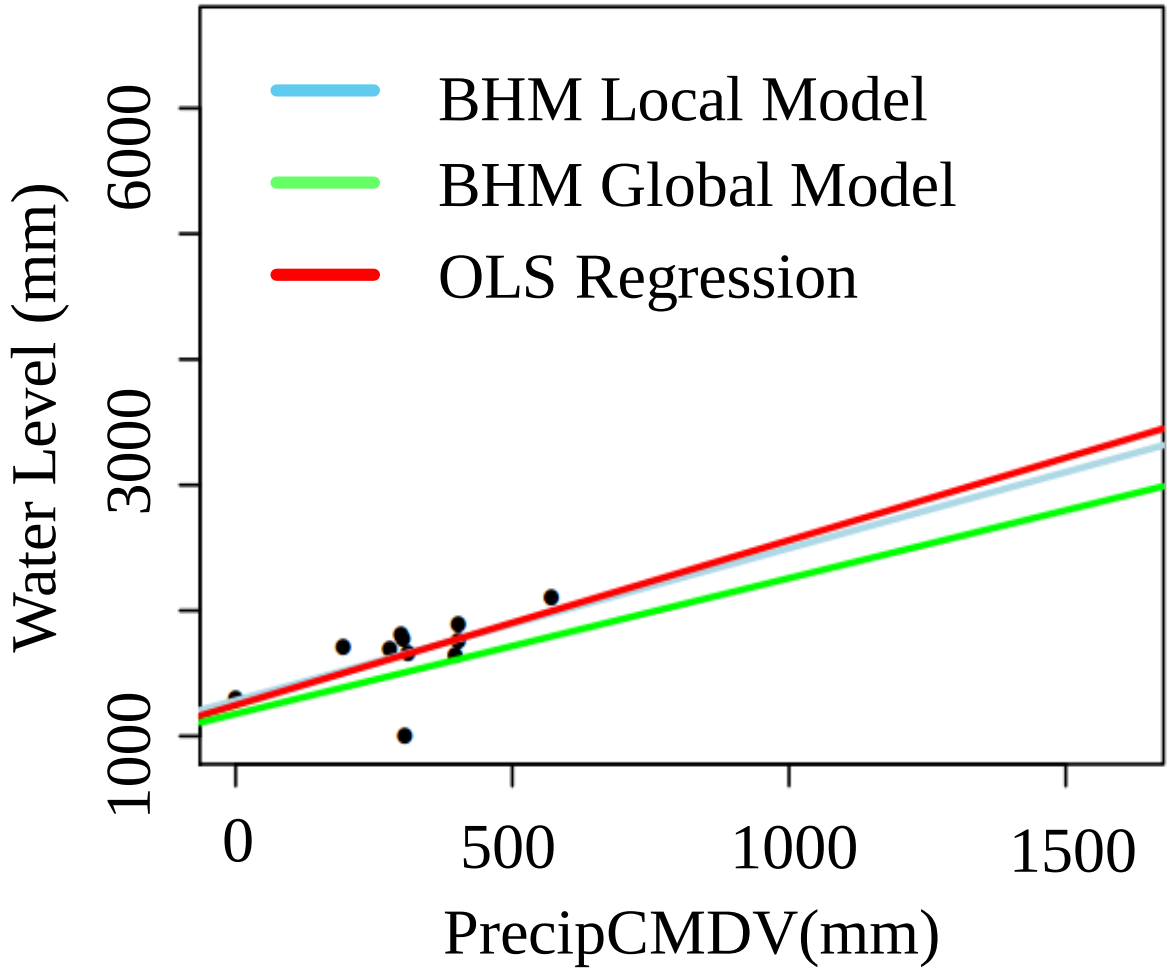
Lake Level Data

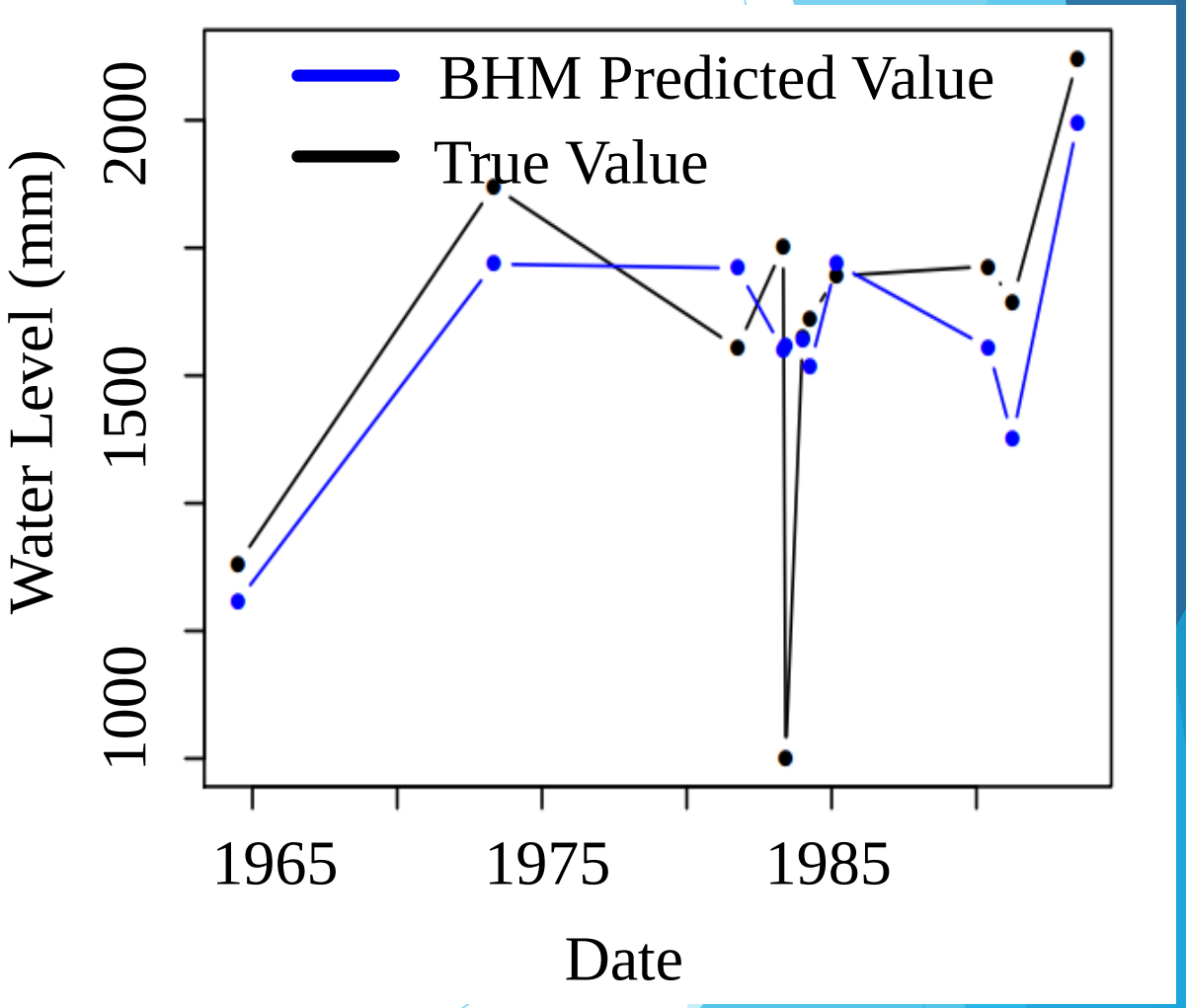
Bayesian Hierarchical Model

Data Input

- 602 seepage lakes
- Seepage lake level : Standardized water level (set the minimum water level as 1000 mm)
- Precipitation : Standardized cumulative deviation from 10-year rolling average (set the minimum cumulative deviation as 0)

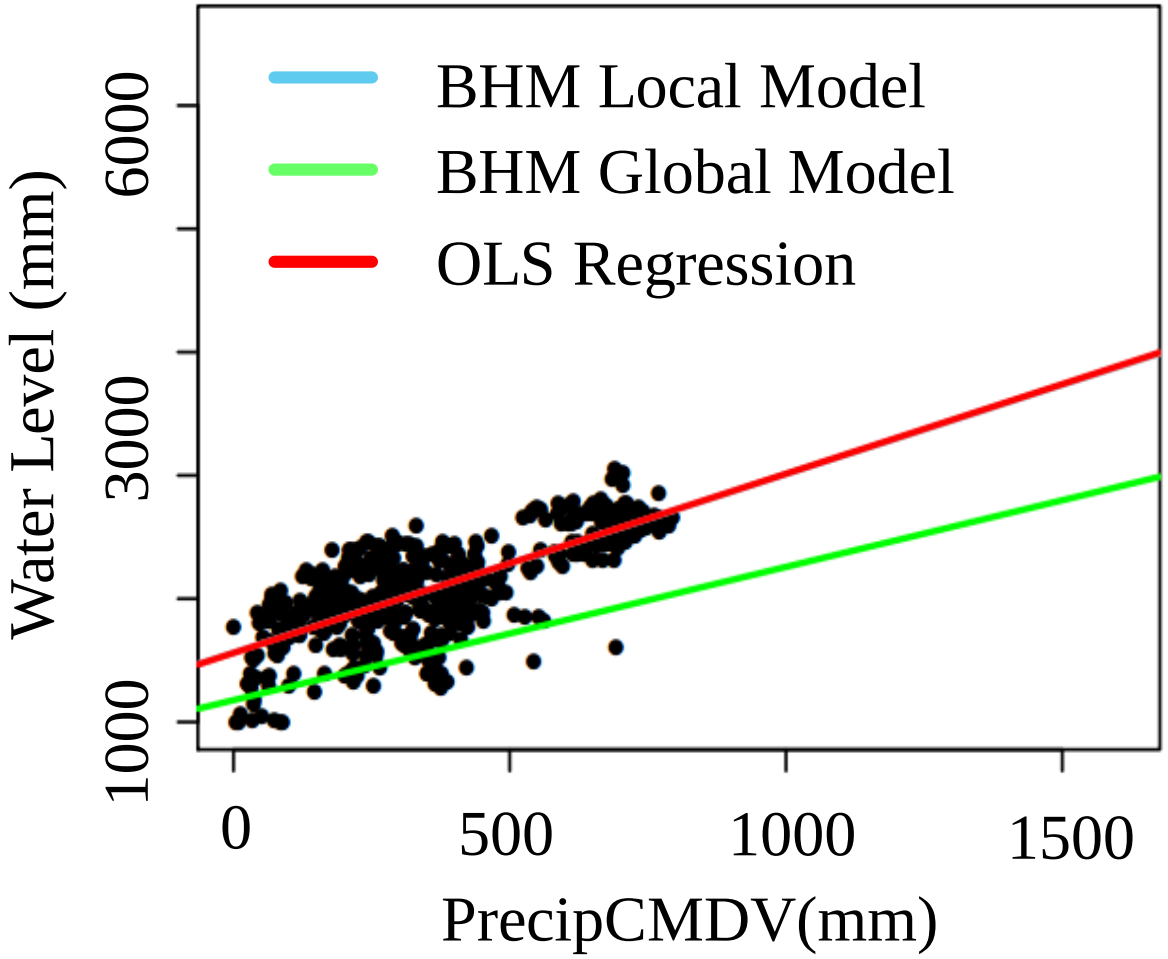
Bayesian Hierarchical Model

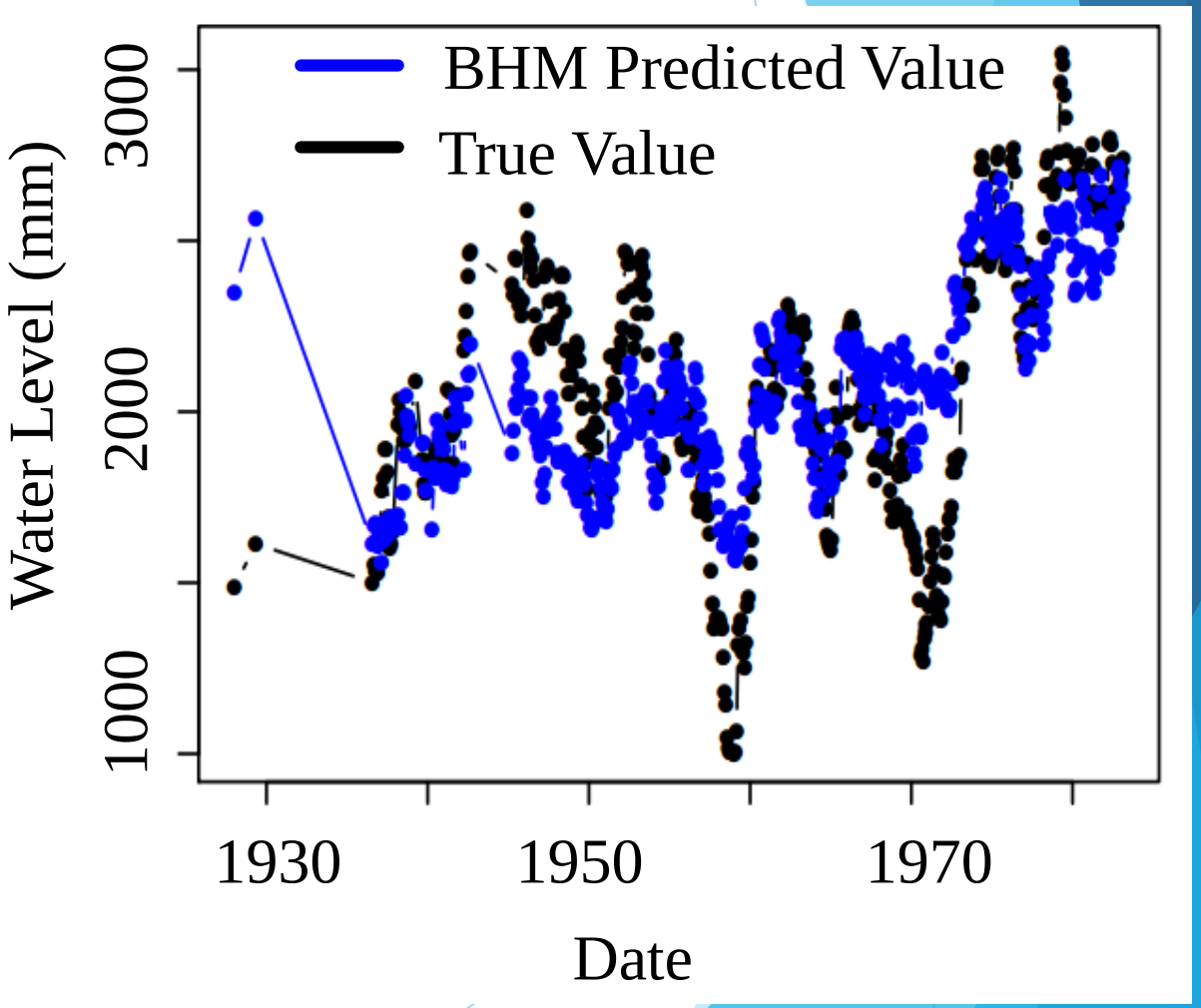




Comstock Lake in Marquette County

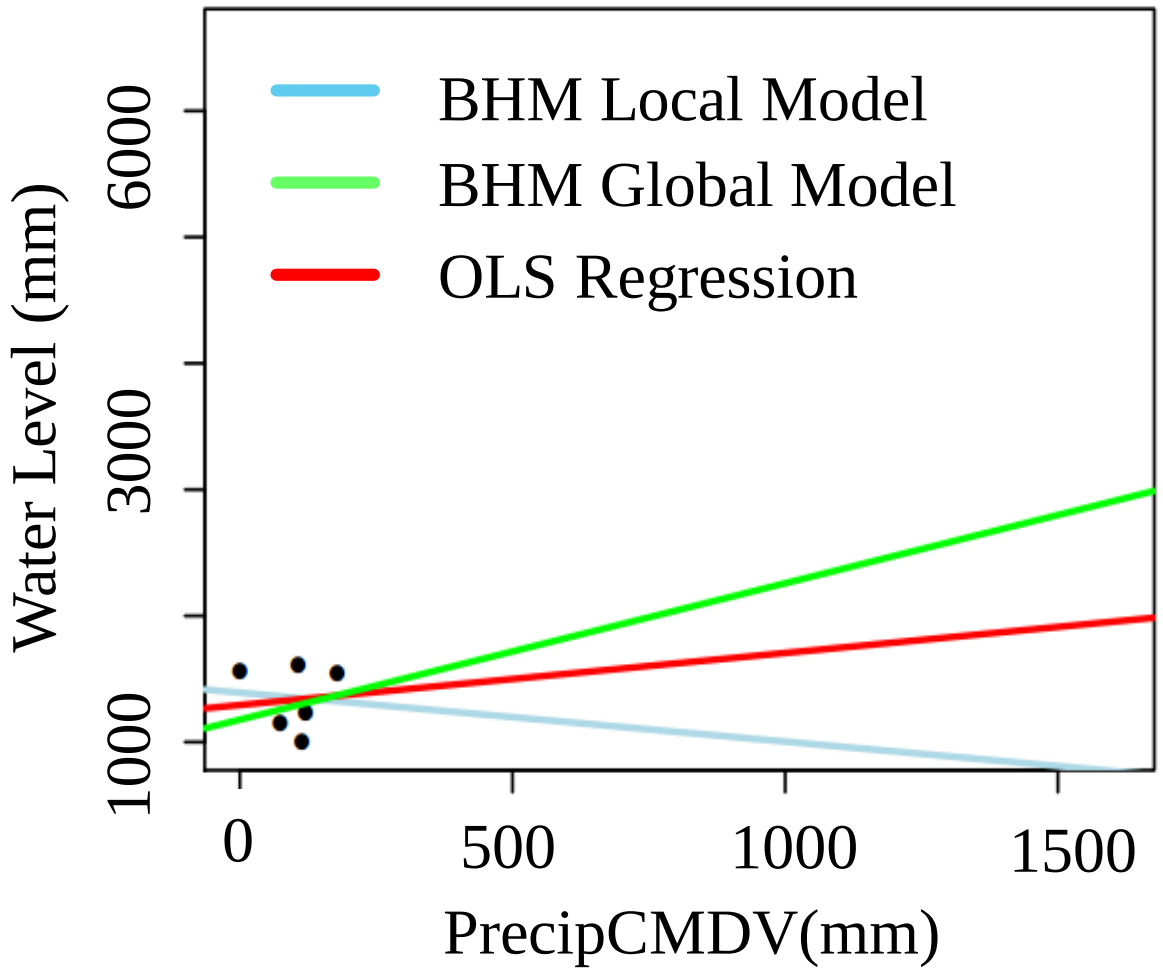
Bayesian Hierarchical Model

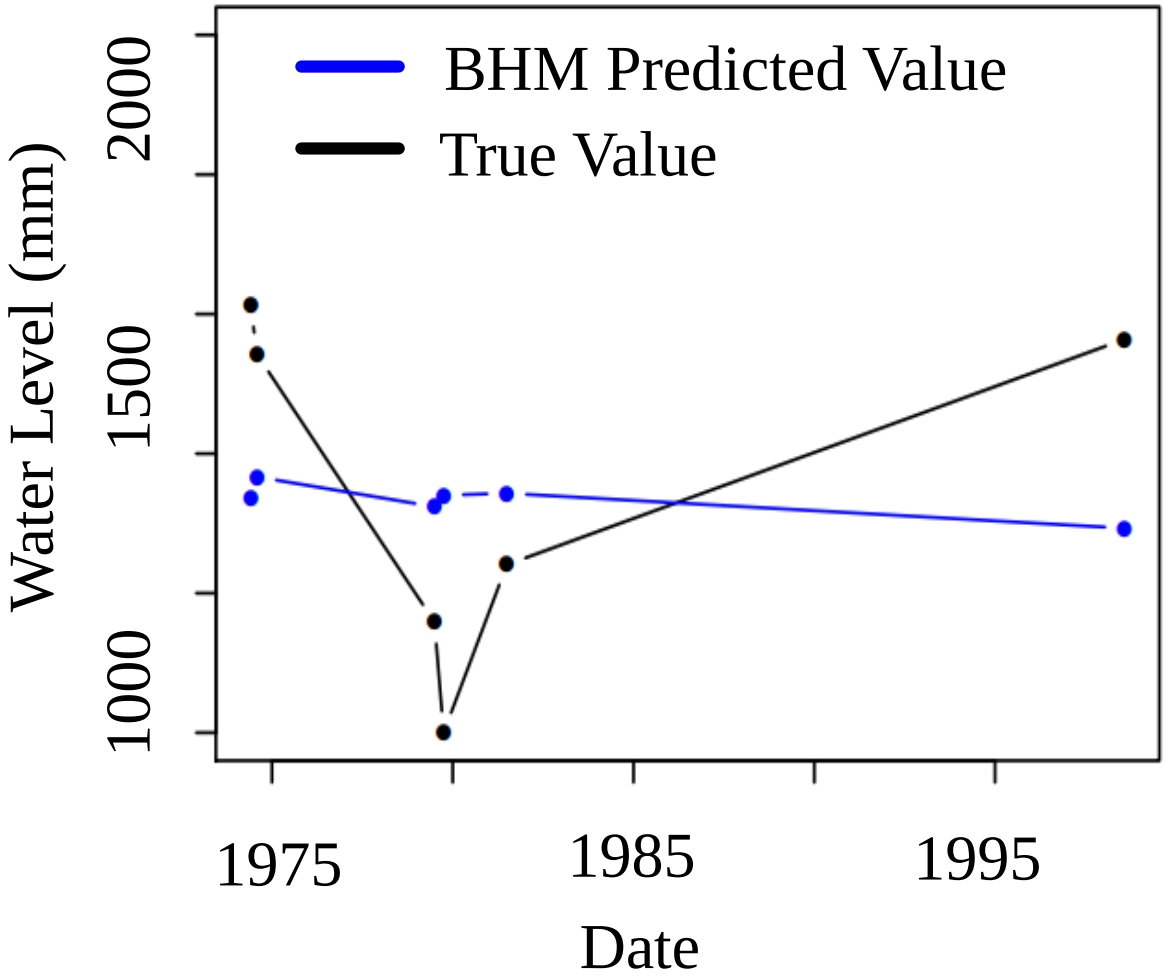




Cedar Lake in Manitowoc County

Bayesian Hierarchical Model





Long Lake in Lincoln County

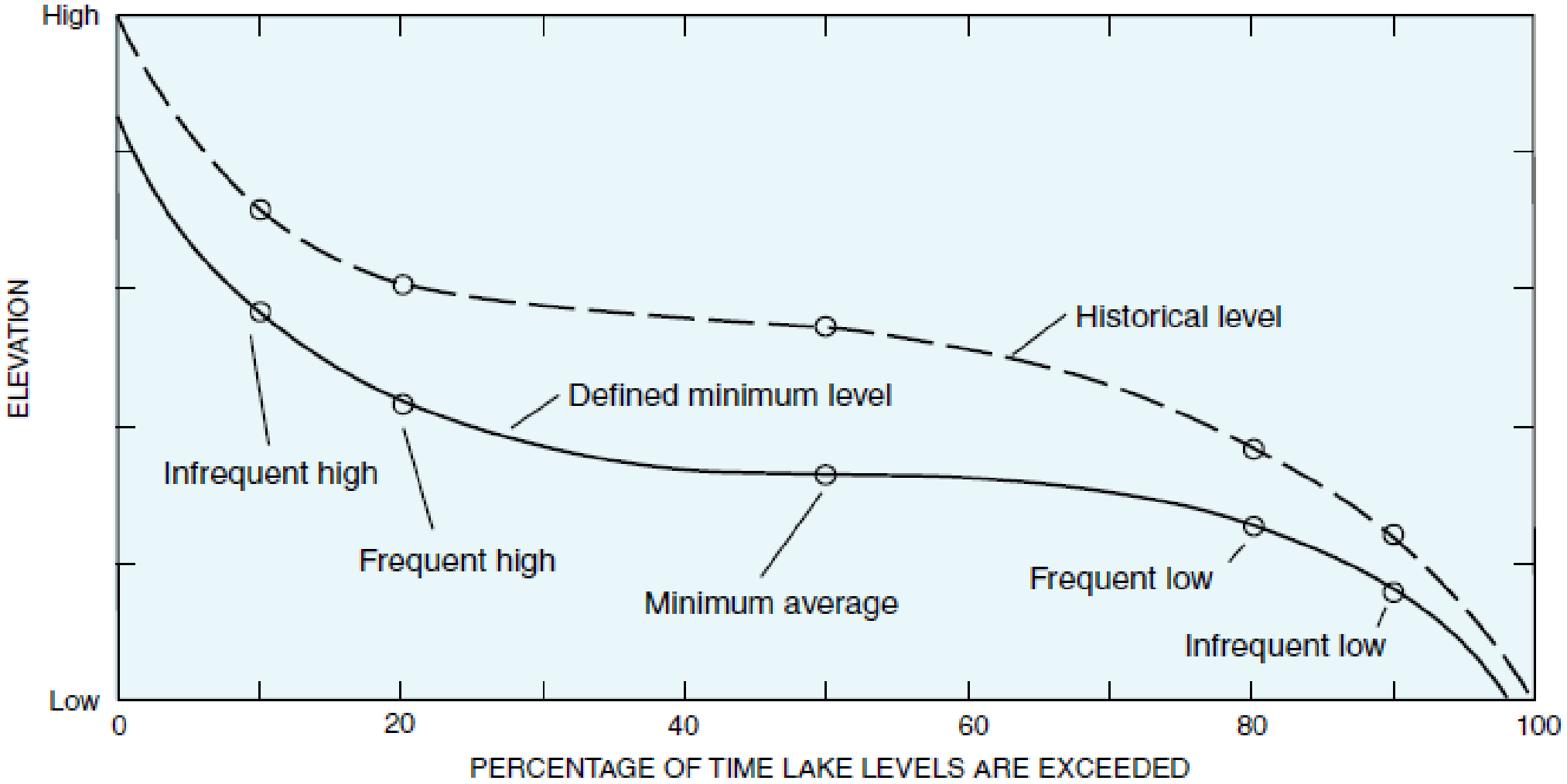
Why do some lakes behave differently?

- Groundwater
  - Soil permeability
  - Depth to bedrock
- Evaporation rate
- Water extraction
- Water regulation
- …

Future work

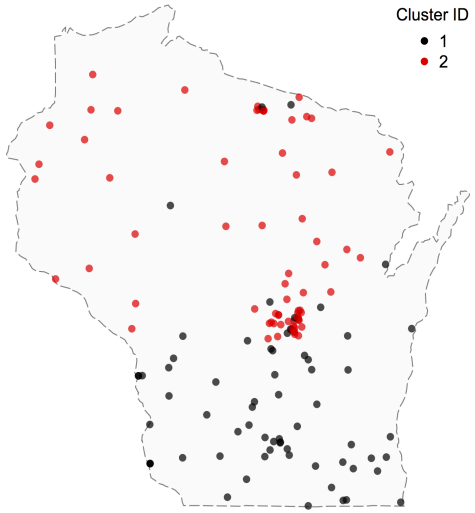
- Do water levels across the state behave in the same way?
- What are the main driver(s) of the spatial and temporal coherence of lakes and groundwater wells across the state?
- Can we predict the historical lake levels with the same driver(s)?
- What are the hydrologic regimes of lakes in Wisconsin?

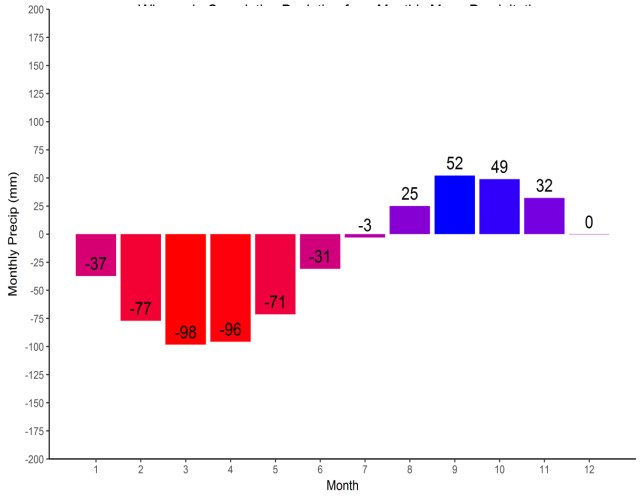
Lake Level Exceedance Probabilities

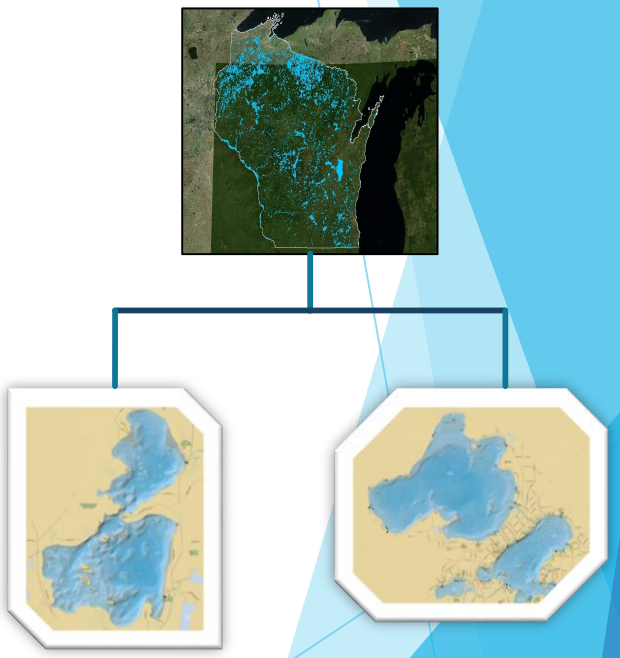


(Source: Modified from McGrail et al. 1998)

Cumulative Deviation of Precipitation is a Good Predictor of Lake Levels







Thank You!

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