Diagnostic analysis of future climate scenarios applied to (sub)urban flooding in the Chicago metropolitan area

Momcilo Markus (ISWS/UIUC)

Don Wuebbles (Dept. Atm. Sci./UIUC)

Xin-Zhong Liang (ISWS and Dept. Atm. Sci./UIUC)

Katharine Hayhoe (Dept. Geosc./Texas Tech and UIUC)

David Kristovich (ISWS/UIUC)

Research funded by the Environmental Change Institute (ECI), at the University of Illinois at Urbana-Champaign 2009-2010

Effects of Urban Flooding

- Primary effects of flooding include **damage to buildings, structures**, sewer systems, roadways, **human health hazard, and even human casualties.**

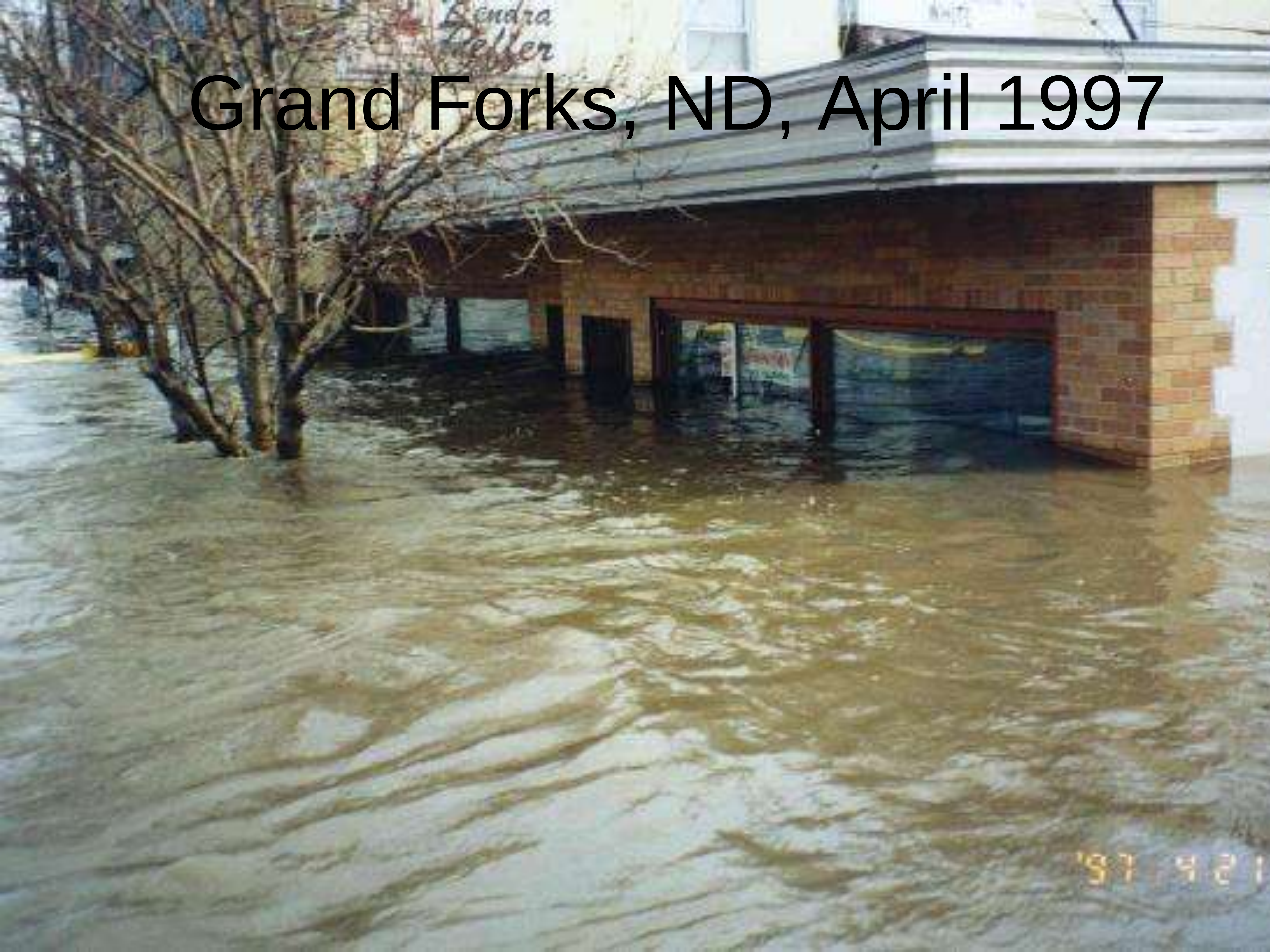
- Flood damage also includes the **contamination of the drinking water supply,** if sewage treatment plants are flooded.

- **Combined sewer outflows** carry not only stormwater, but also untreated municipal and industrial waste, toxic materials, and debris.

- Secondary effects of flood damage include the **disruption of many essential services like gas and electricity**. The **public transportation systems** may also be disrupted during floods, resulting **in shortages of food and other supplies.**

- The flood water carries **increased amounts of sediment and nutrients** causing various water quality problems in the receiving water bodies in a long term.

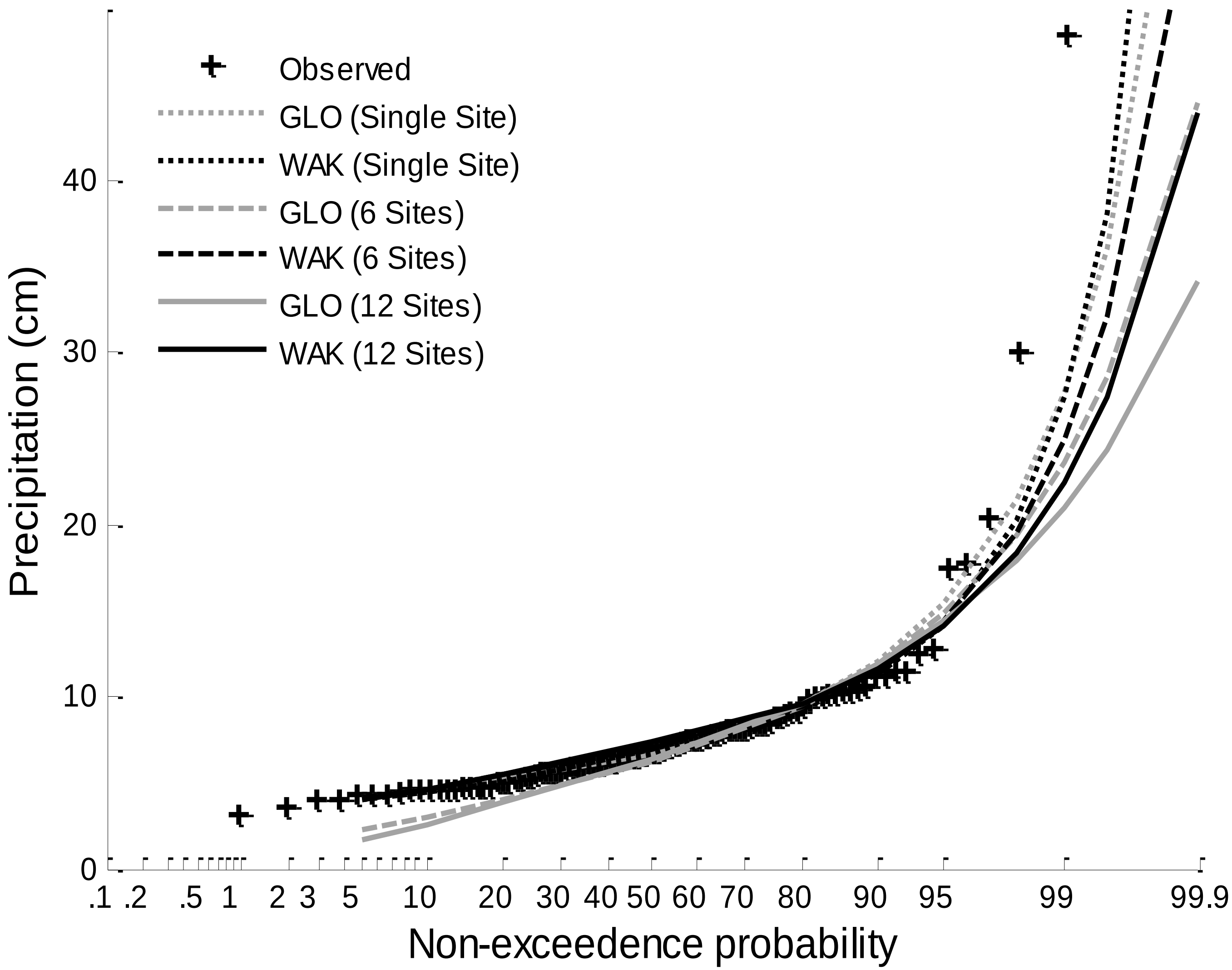
Grand Forks, ND, April 1997



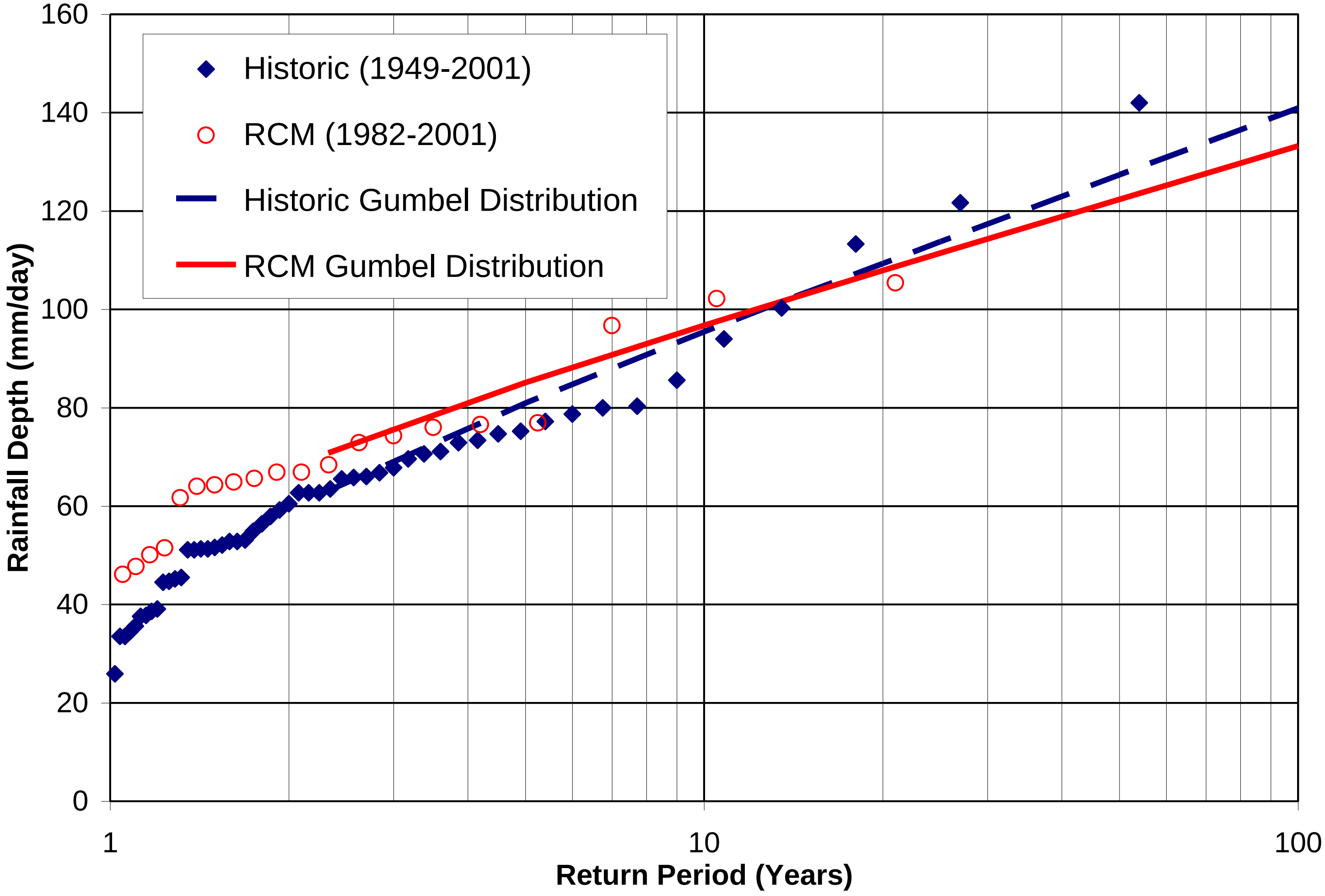
Cedar Rapids, IA, July 2008

Chicago, July 2010

Aurora College (near Chicago)

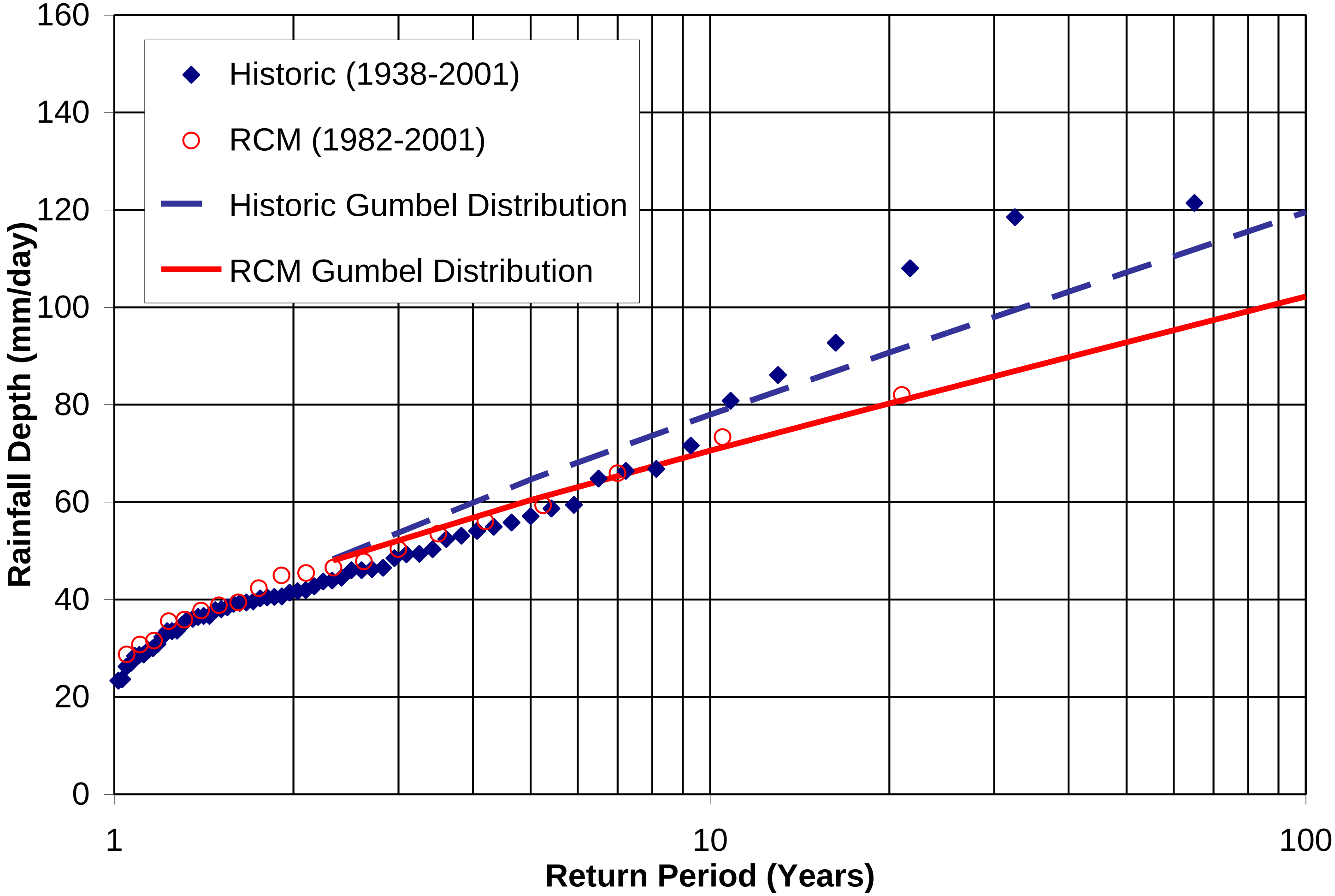


Comparison of 24-Hour Precipitation Annual Maximum Frequency Analysis Results for St. Louis, MO.



Guo, Y, and Senior, M.J., 2006, Climate Model Simulation of Point Rainfall Frequency Characteristics, J. of Hydrologic Eng., 11(6):547-554

Comparison of 24-Hour Precipitation Annual Maximum Frequency Analysis Results for Toronto, ON.



Guo, Y, and Senior, M.J., 2006, Climate Model Simulation of Point Rainfall Frequency Characteristics, J. of Hydrologic Eng., 11(6):547-554

Flood/Rainfall Frequency

By accurately determining the magnitude and frequency of rainfall/floods, we can design preventive measures to reduce the flood damages to a great extent.

RESEARCH QUESTIONS

Will the intensity and frequency of urban storms/floods increase or decrease in the future?

How reliable are the projections of future storms/floods?

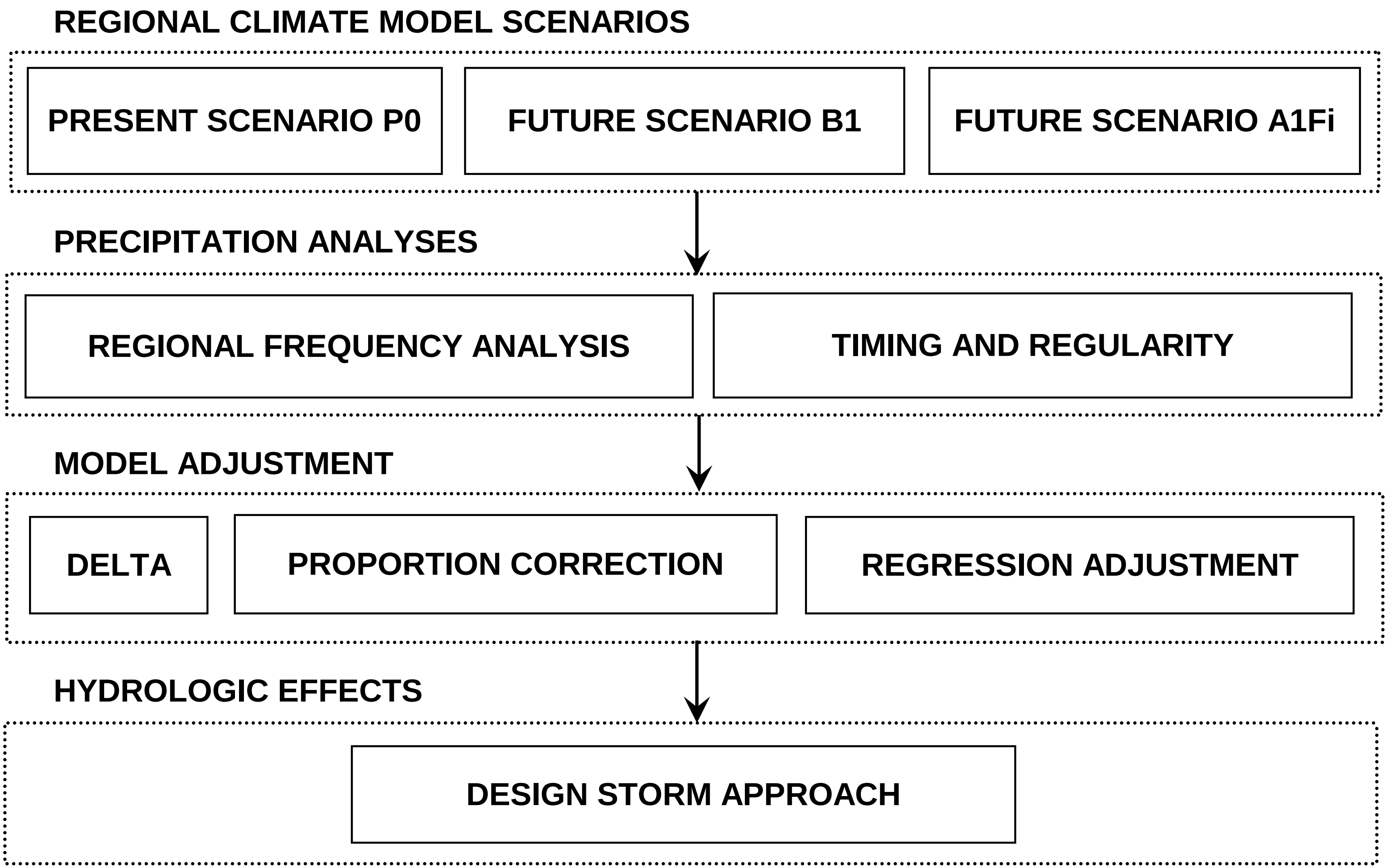
How do we evaluate the capability of climate models to predict future storms?

MODELING ASSUMPTION

Assumption: the models accurately predicting present climate are more likely to accurately predict the future

However, the model's ability to mimic the present climate depends on the selected variable (averages, extremes, distribution, etc.)

Research Schematic



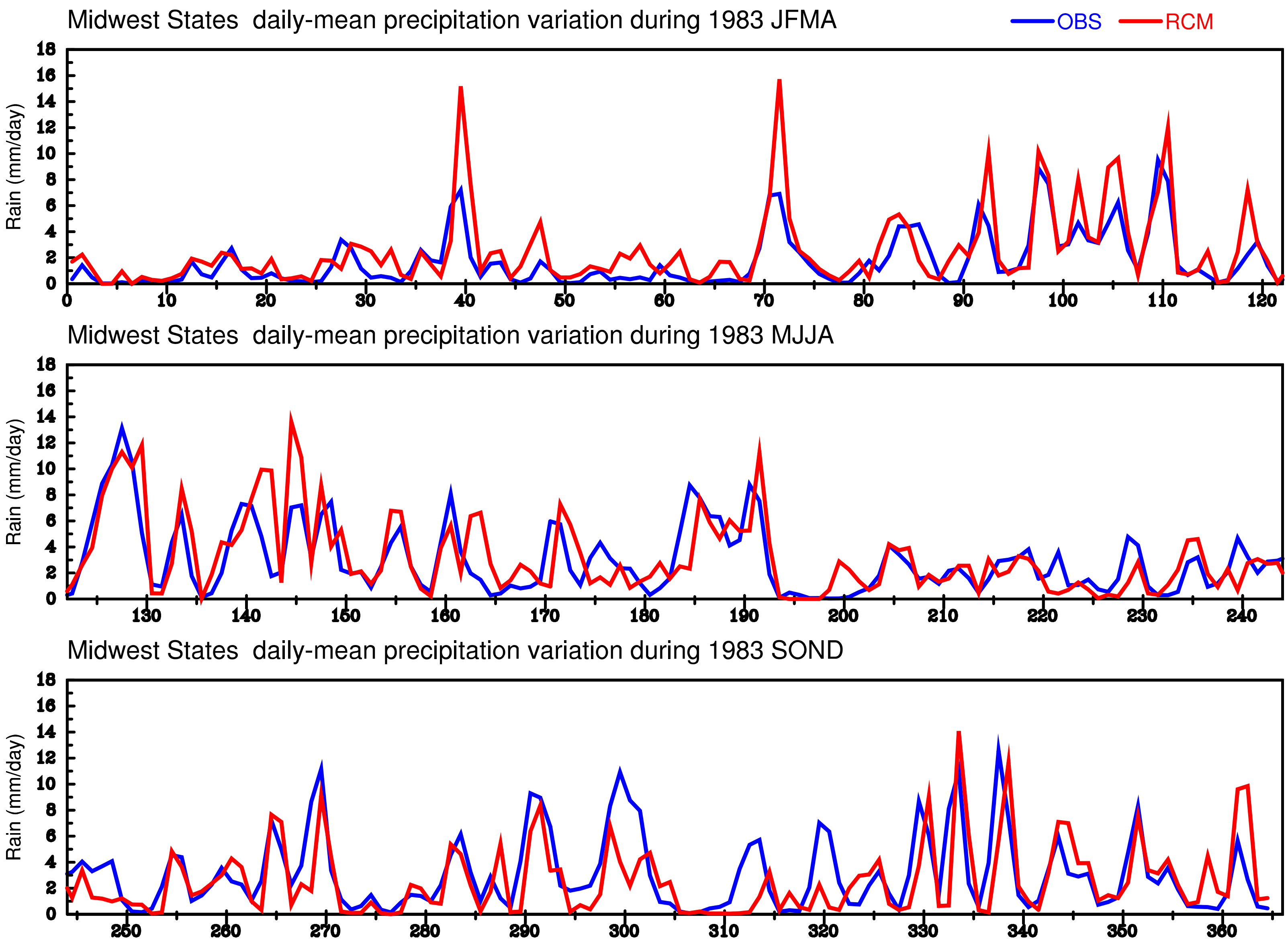
CLIMATE MODEL DATA

This study relies on data generated by a regional climate model (RCM)* downscaling at 30-km spacing from GCM simulations for the following scenarios:

- Present (P0)
- 2050s under the IPCC high (A1Fi) and
- 2050s under low (B1) emissions scenarios

*Liang, X.-Z., Li, L., Kunkel, K. E., Ting, M., and Wang, J. X. L. 2004. “Regional climate model simulation of U.S. precipitation during 1982–2002. I: Annual cycle.” *J. Clim., 1718, 3510–3529.*

CMM5 Daily Precipitation



RESULTS – SPATIAL CORRELATION

Precipitation Gaging Stations and Watersheds

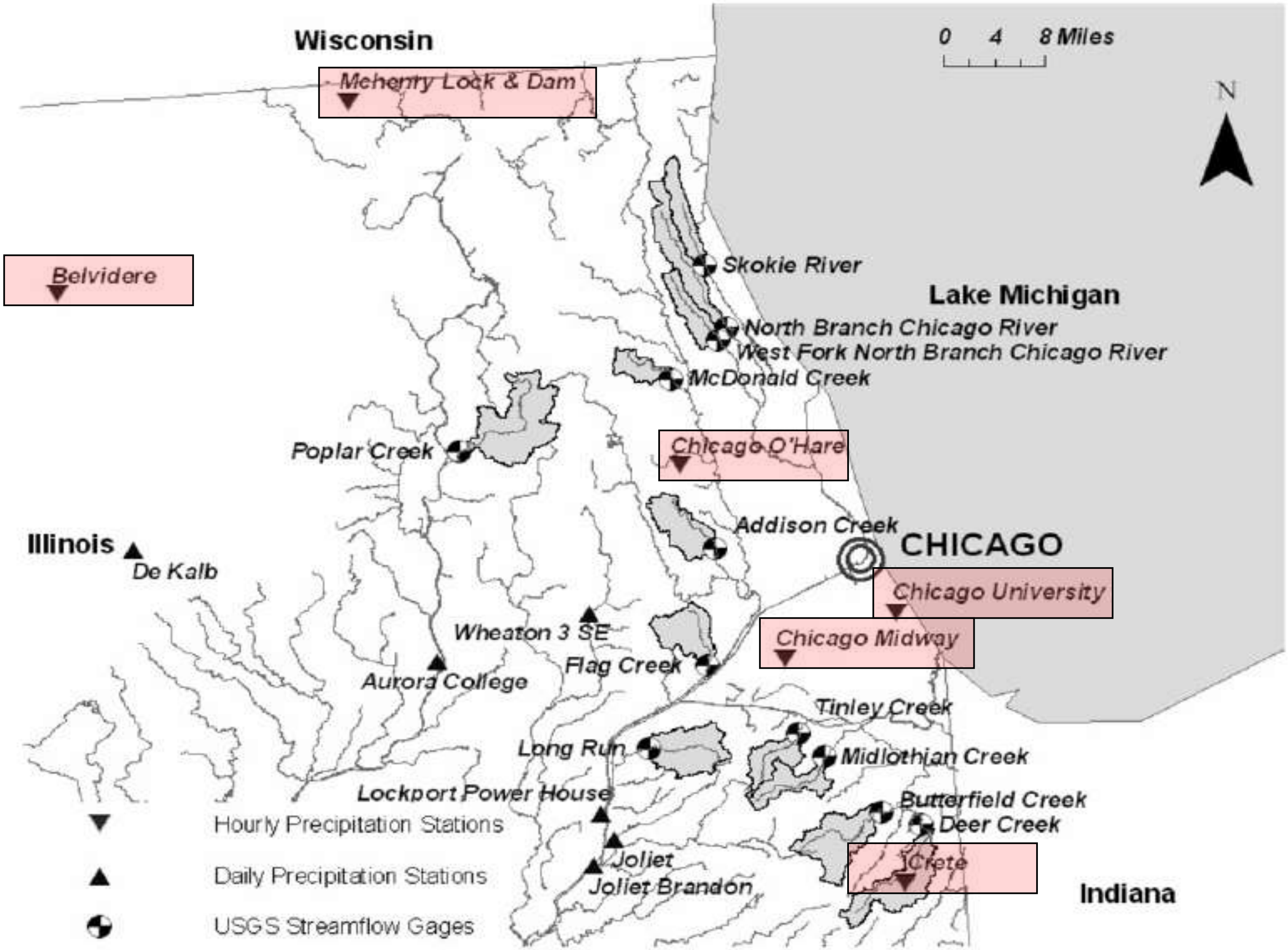
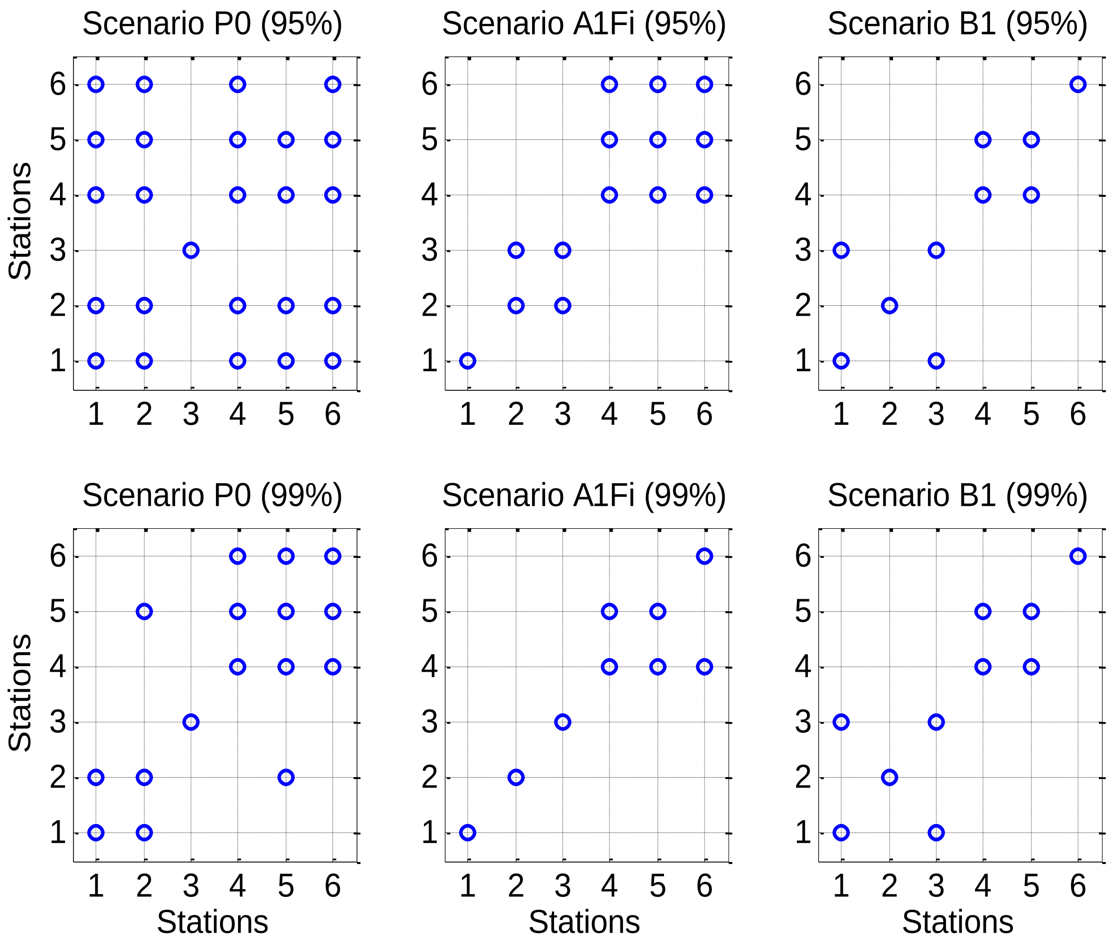


Figure 2 Location of watersheds and raingages.

Spatial Correlations - Serendipity?

P0	Belvidere	OHare	McHenry	University	Midway	Crete
Belvidere	1.000	**0.766**	0.555	**0.676**	**0.702**	**0.663**
OHare		1.000	0.120	**0.753**	**0.886**	**0.674**
McHenry			1.000	0.340	0.183	0.236
University				1.000	**0.943**	**0.871**
Midway					1.000	**0.841**
Crete						1.000
A1Fi	Belvidere	OHare	McHenry	University	Midway	Crete
Belvidere	1.000	0.202	0.615	-0.195	-0.099	0.128
OHare		1.000	**0.683**	-0.249	-0.116	-0.361
McHenry			1.000	-0.140	-0.160	-0.103
University				1.000	**0.894**	**0.873**
Midway					1.000	**0.740**
Crete						1.000
B1	Belvidere	OHare	McHenry	University	Midway	Crete
Belvidere	1.000	0.517	**0.952**	-0.059	-0.026	0.453
OHare		1.000	0.427	0.425	0.508	0.349
McHenry			1.000	-0.070	-0.137	0.427
University				1.000	**0.893**	0.578
Midway					1.000	0.552
Crete						1.000

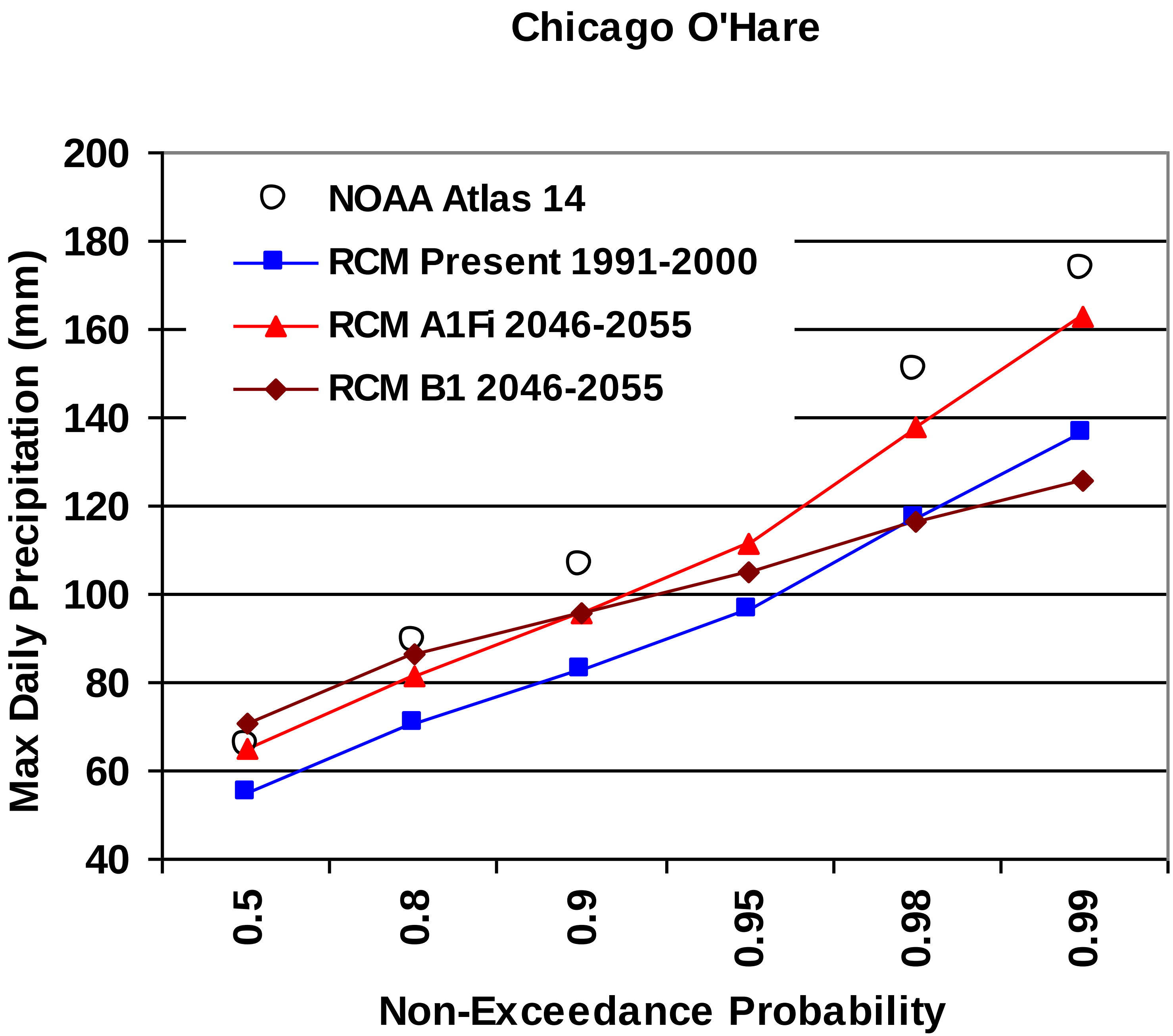
Annual Daily Max Precipitation Spatial Correlations



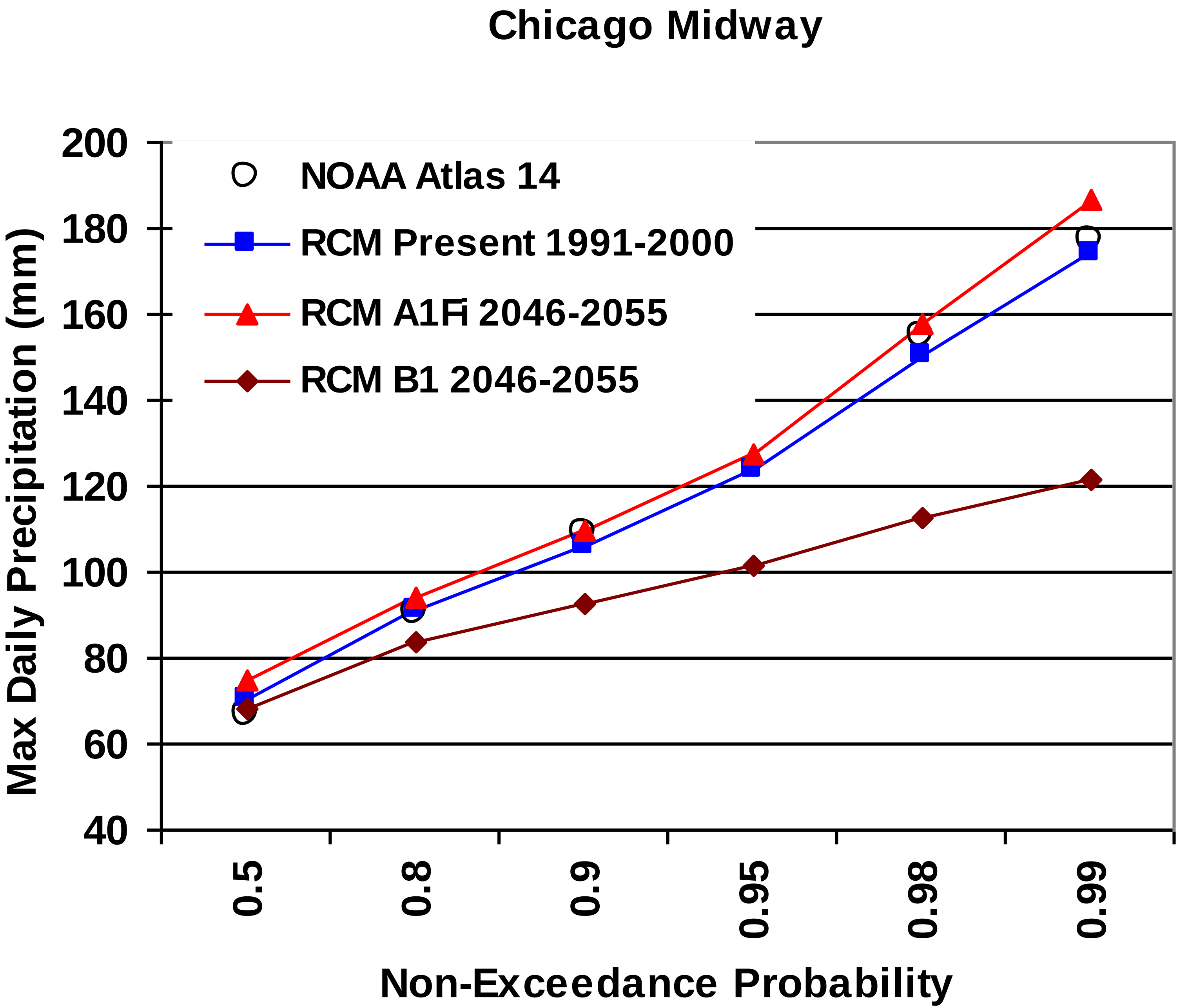
1, 2, 3 = North

4, 5, 6 = South

RESULTS – PRECIPITATION FREQUENCY



Chicago O'Hare
NOAA Atlas 14
RCM Present 1991-2000
RCM A1Fi 2046-2055
RCM B1 2046-2055
Max Daily Precipitation (mm)
200
180
160
140
120
100
80
60
40
0.5
0.8
0.9
0.95
0.98
0.99
Non-Exceedance Probability


Chicago Midway
NOAA Atlas 14
RCM Present 1991-2000
RCM A1Fi 2046-2055
RCM B1 2046-2055
Max Daily Precipitation (mm)
200
180
160
140
120
100
80
60
40
0.5
0.8
0.9
0.95
0.98
0.99
Non-Exceedance Probability

BIAS ADJUSTMENT

- Delta
- Ratio
- Regression Adjustment

$$P_{POBS,T} = aP_{O,T} + b$$

$$_{adj}P_{B1,T} = aP_{B1,T} + b$$

$$_{adj}P_{A1Fi,T} = aP_{A1Fi,T} + b$$

Scenario A1Fi (high emission)

	Return Period in Years	2	5	10	50	100
	Non-Exceedance Probability	0.5	0.8	0.9	0.98	0.99
Belvidere	NOAA Atlas 14	66.50	88.25	104.50	146.75	168.50
	RCM Present 1991-2000	54.88	70.55	82.49	116.50	135.29
	RCM A1Fi 2046-2055	66.97	84.22	98.29	141.81	167.64
	Delta Adjusted	78.59	101.92	120.30	172.05	200.86
	Proportion Adjusted	81.15	105.35	124.51	178.62	208.80
	Regression Adjusted	85.30	105.26	121.53	171.86	201.75
Chicago O'Hare	NOAA Atlas 14	65.50	89.00	106.25	151.00	173.25
	RCM Present 1991-2000	55.20	70.97	82.98	117.19	136.09
	RCM A1Fi 2046-2055	64.99	81.74	95.39	137.62	162.70
	Delta Adjusted	84.17	103.45	119.16	167.78	196.65
	Proportion Adjusted	75.29	99.77	118.66	171.43	199.86
	Regression Adjusted	77.12	102.51	122.14	177.32	207.13
Chicago University	NOAA Atlas 14	66.55	90.68	108.71	154.69	177.29
	RCM Present 1991-2000	70.68	90.87	106.25	150.06	174.26
	RCM A1Fi 2046-2055	74.54	93.75	109.40	157.84	186.60
	Delta Adjusted	78.24	95.76	110.04	154.21	180.44
	Proportion Adjusted	70.40	93.55	111.86	162.46	189.64
	Regression Adjusted	70.18	93.55	111.94	162.70	189.85
Crete	NOAA Atlas 14	70.36	96.52	115.82	165.61	189.99
	RCM Present 1991-2000	69.42	89.25	104.35	147.38	171.14
	RCM A1Fi 2046-2055	71.17	89.51	104.46	150.71	178.17
	Delta Adjusted	80.91	99.33	114.35	160.81	188.39
	Proportion Adjusted	72.11	96.78	115.93	168.94	197.02
	Regression Adjusted	72.13	96.80	115.94	169.35	197.80
Chicago Midway	NOAA Atlas 14	70.00	95.00	114.00	141.00	163.00
	RCM Present 1991-2000	70.68	90.87	106.25	150.06	174.26
	RCM A1Fi 2046-2055	71.17	89.51	104.46	150.71	178.17
	Delta Adjusted	80.91	99.33	114.35	160.81	188.39
	Proportion Adjusted	70.49	93.64	112.21	141.65	166.91
	Regression Adjusted	70.48	93.57	112.08	141.61	166.66
McHenry	NOAA Atlas 14	67.00	89.00	104.00	141.00	158.00
	RCM Present 1991-2000	59.92	77.03	90.07	127.21	147.71
	RCM A1Fi 2046-2055	68.85	86.60	101.06	145.80	172.37
	Delta Adjusted	83.07	98.62	111.30	150.52	173.81
	Proportion Adjusted	75.94	98.57	114.99	159.60	182.66
	Regression Adjusted	76.99	100.05	116.69	161.61	184.37

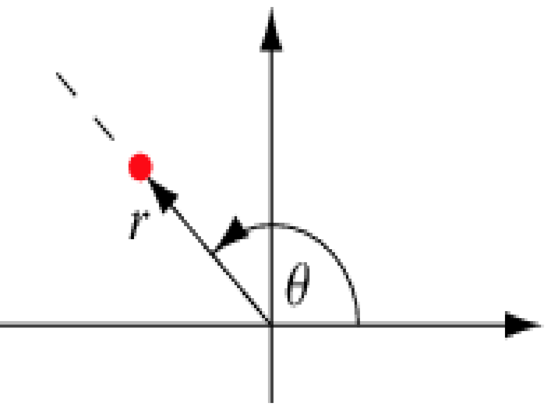
Scenario B1 (low emission)

	Return Period in Years	2	5	10	50	100
	Non-Exceedance Probability	0.5	0.8	0.9	0.98	0.99
Belvidere	NOAA Atlas 14	66.50	88.25	104.50	146.75	168.50
	RCM P0 Present	54.88	70.55	82.49	116.50	135.29
	RCM B1 2046-2055	73.18	89.26	99.06	120.54	129.86
	Delta Adjusted	84.81	106.96	121.07	150.78	163.08
	Proportion Adjusted	88.68	111.65	125.49	151.83	161.75
	Regression Adjusted	92.49	111.08	122.42	147.26	158.05
Chicago O'Hare	NOAA Atlas 14	65.50	89.00	106.25	151.00	173.25
	RCM P0 Present	55.20	70.97	82.98	117.19	136.09
	RCM B1 2046-2055	70.68	86.21	95.67	116.42	125.43
	Delta Adjusted	90.73	108.60	119.50	143.38	153.75
	Proportion Adjusted	80.98	104.24	118.95	150.23	162.59
	Regression Adjusted	83.87	108.11	122.51	150.01	159.68
Chicago University	NOAA Atlas 14	66.55	90.68	108.71	154.69	177.29
	RCM P0 Present	70.68	90.87	106.25	150.06	174.26
	RCM B1 2046-2055	68.40	83.42	92.58	112.65	121.37
	Delta Adjusted	72.64	86.34	94.70	113.00	120.96
	Proportion Adjusted	64.26	83.23	95.04	117.28	124.41
	Regression Adjusted	64.40	83.24	94.72	116.13	123.49
Crete	NOAA Atlas 14	70.36	96.52	115.82	165.61	189.99
	RCM P0 Present	69.42	89.25	104.35	147.38	171.14
	RCM B1 2046-2055	57.66	70.33	78.05	94.97	102.32
	Delta Adjusted	67.34	80.07	87.82	104.82	112.20
	Proportion Adjusted	58.60	77.60	89.52	113.20	121.18
	Regression Adjusted	58.44	76.06	86.63	106.72	113.60
Chicago Midway	NOAA Atlas 14	70.00	95.00	114.00	141.00	163.00
	RCM P0 Present	70.68	90.87	106.25	150.06	174.26
	RCM B1 2046-2055	57.66	70.33	78.05	94.97	102.32
	Delta Adjusted	67.34	80.07	87.82	104.82	112.20
	Proportion Adjusted	56.98	74.45	85.80	85.91	91.07
	Regression Adjusted	57.11	73.52	83.74	89.24	95.71
McHenry	NOAA Atlas 14	67.00	89.00	104.00	141.00	158.00
	RCM P0 Present	59.92	77.03	90.07	127.21	147.71
	RCM B1 2046-2055	71.10	86.71	96.23	117.10	126.16
	Delta Adjusted	85.03	98.72	107.07	125.36	133.30
	Proportion Adjusted	78.18	98.68	110.17	130.90	136.45
	Regression Adjusted	79.50	100.18	111.12	129.80	134.95

RESULTS – SEASONAL TIMING

Circular Statistics - Timing and regularity

Mean Daily Value of occurrence of the maximum rainfall is calculated as:



$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N}\cos(\theta_i)$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N}\sin(\theta_i)$$

$$\bar{\theta} = \tan^{-1}\left(\frac{\bar{y}}{\bar{x}}\right) \qquad 0 \leq \bar{\theta} \leq 2\pi$$

$$\mathrm{MDV} = \bar{\theta}\,\frac{\overline{N}\overline{D}}{2\pi}$$

$$\theta_i = JD_i \frac{2\pi}{ND_i}$$

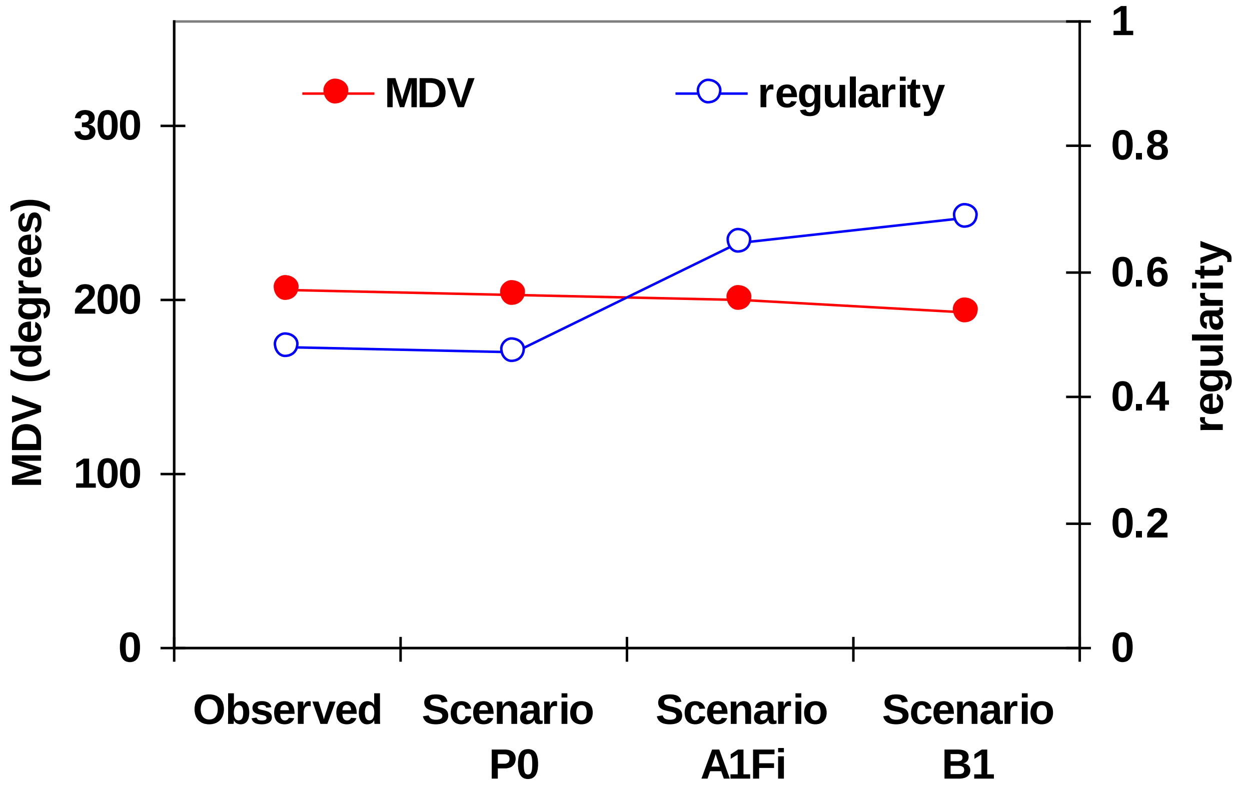
where:
JDi = Julian Date
NDi = number of days in a year

Regularity of the maximum precipitation occurrence is calculated using:

$$\bar{r} = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$0 \leq \bar{r} \leq 1$$

Circular Statistics for Daily Maximum Precipitation: Mean Daily Value and Regularity



RESULTS - SUMMARY

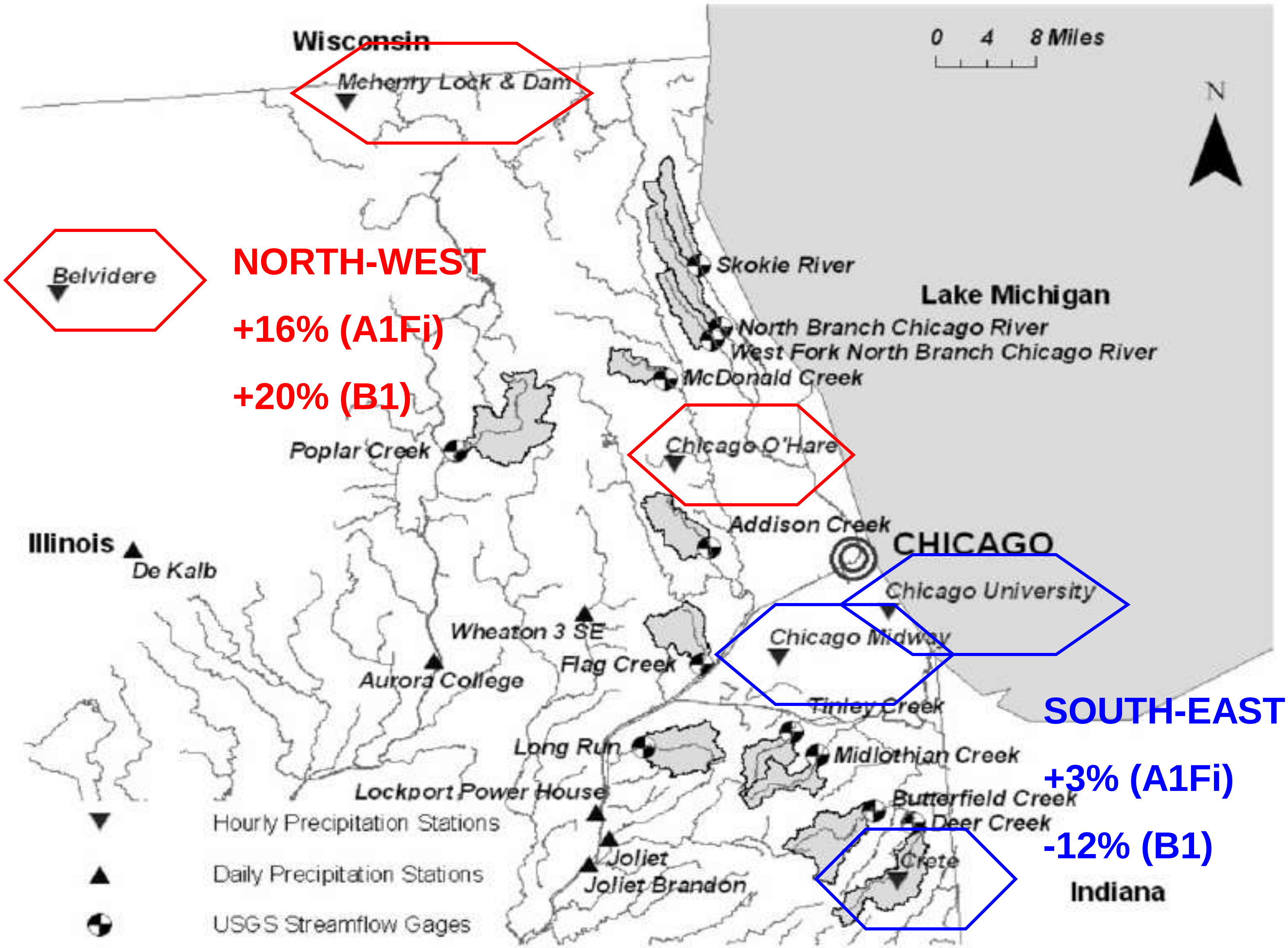


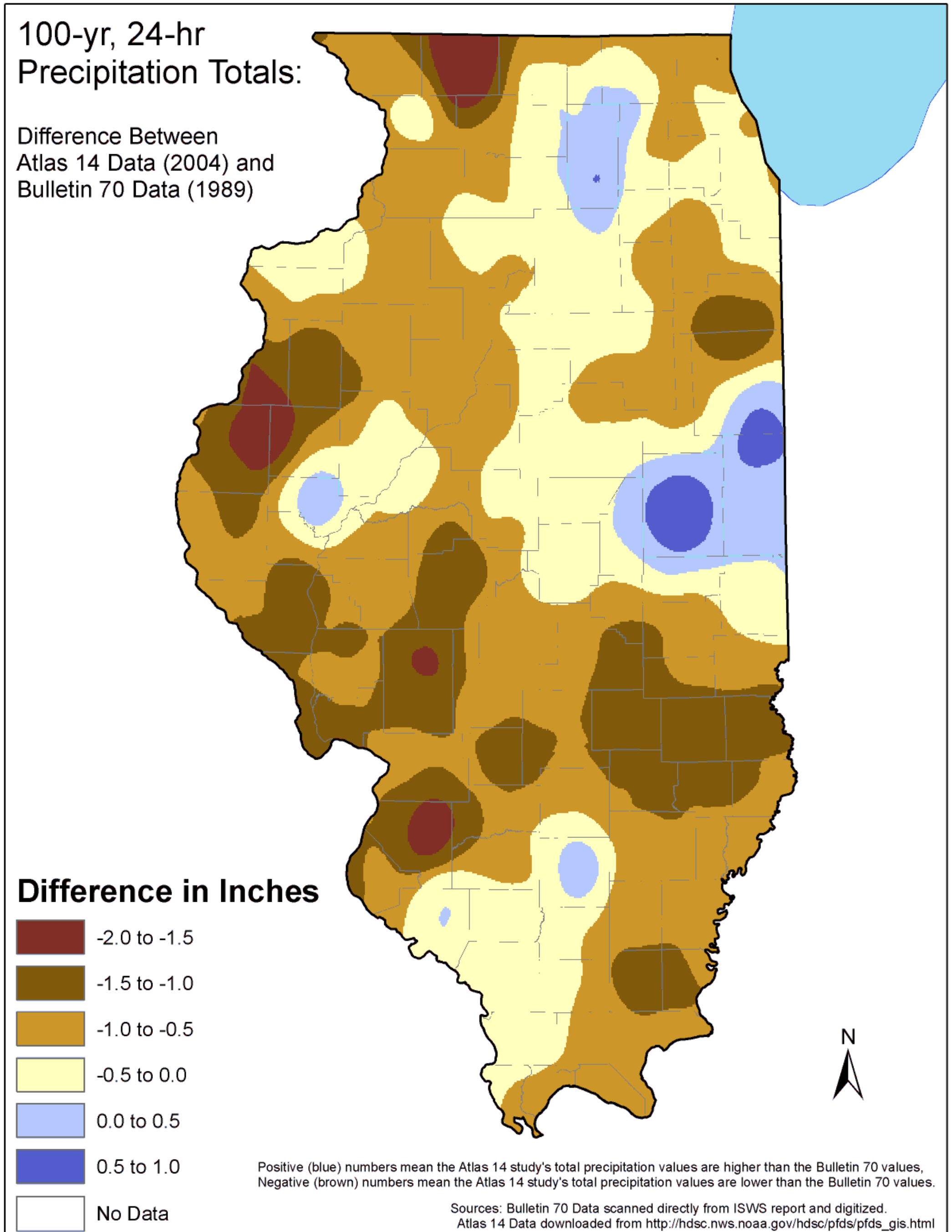
Figure 2 Location of watersheds and raingages.

Dipole

Both the spatial correlation and frequency analysis revealed a distinct separation between the northern and the southern subregions of the Chicago metropolitan area.

UNCERTAINTIES

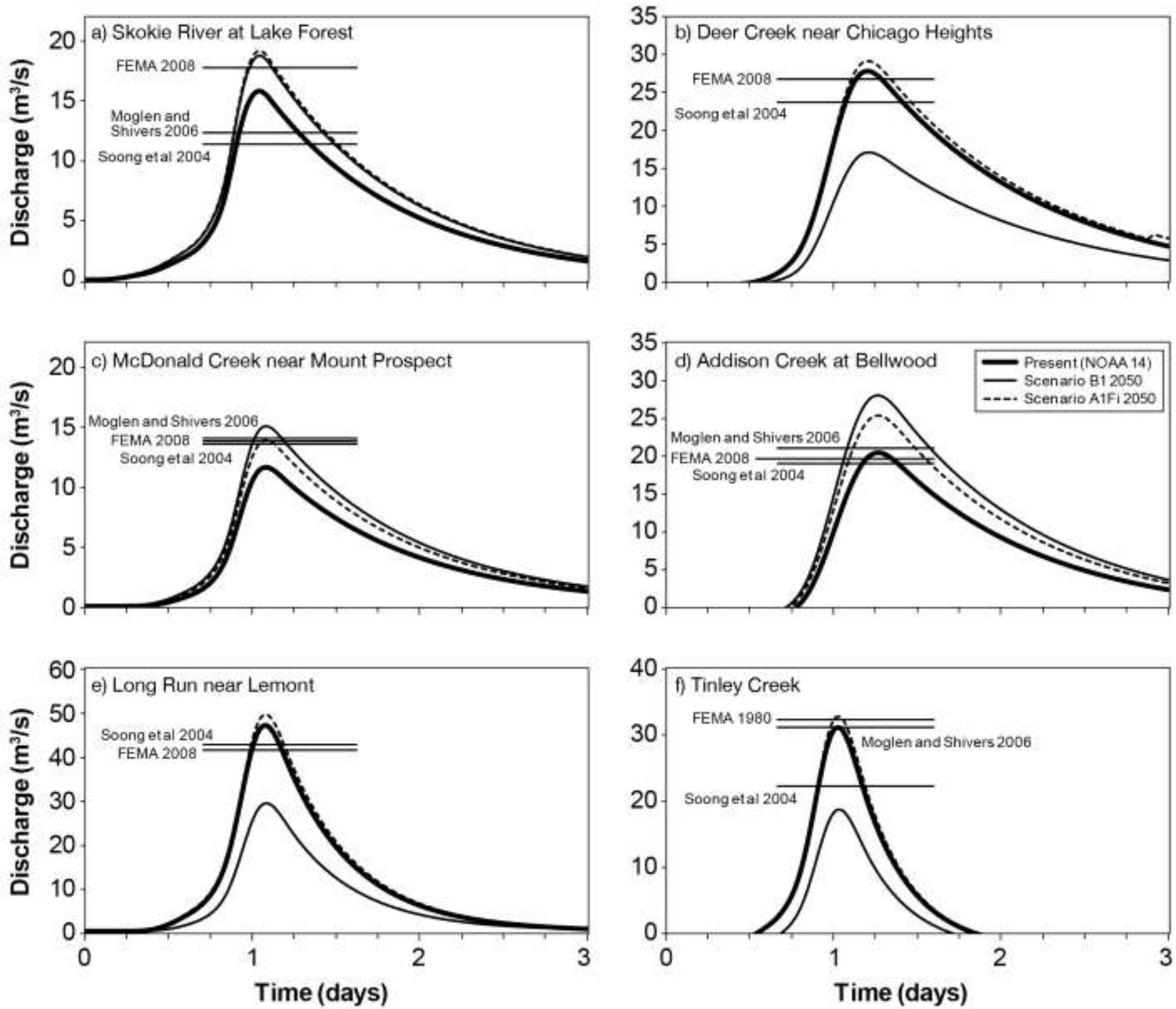
- Data (precipitation and discharge)
- Model (precipitation frequency, flood frequency, design storm approach, hydrologic model, climate models, etc.)
- Future Climate (assumptions)



Illinois State WATER Survey (1895)

RESULTS – HYDROLOGIC EFFECTS

Hydrologic Effects



CONCLUSIONS

- High uncertainty
- The separation in precipitation extremes (flood peaks) needs to be evaluated using longer datasets, and different models
- If the existence of the dipole is confirmed, the present regions used in precipitation frequency analysis might not be found homogeneous. New regional boundaries would have to be determined.
- Relative changes in flood peaks were similar or higher than those of extreme precipitation due to the nonlinear nature of the rainfall-runoff process

FUTURE RESEARCH

- Present precipitation frequency maps (Bulletin 70) need to be updated
- Further develop RCM's and statistical downscaling methods, particularly for smaller increments such as 6-hr, 3-hr and 1-hr
- Validate and finetune the climate models using new observations (monitoring).

Thank you!