Spatiotemporal Regime of Climate & Streamflow in the US Great Lakes Basin

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SDSU

the City College of New York

Introduction

Journal of Hydrology (2008) **362**, 69–88

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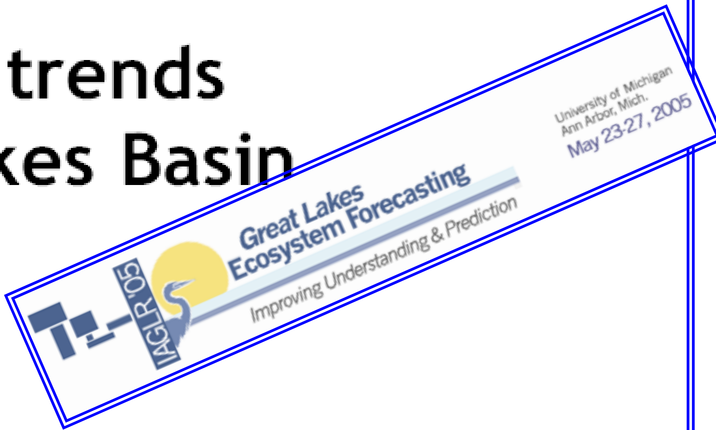
Regionalization, seasonality, and trends of streamflow in the US Great Lakes Basin



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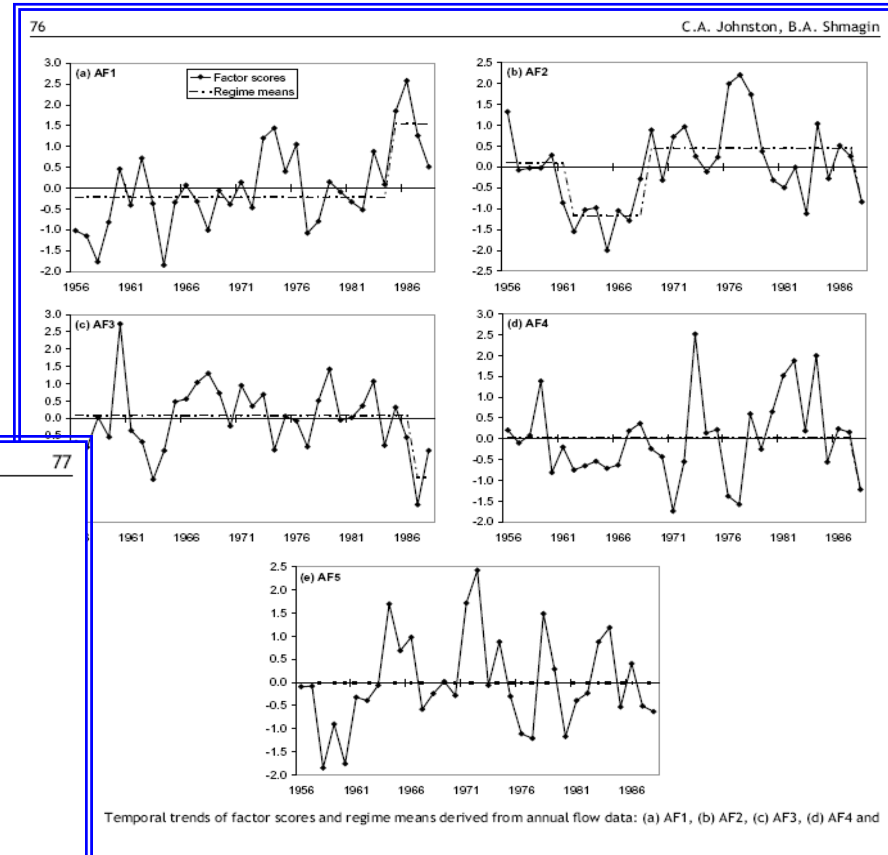
Received 28 February 2008; received in revised form 13 August 2008; accepted 14 August 2008

Five main regions & streamflow regimes



Temporal trends of factor scores and regime means derived from annual flow data: (a) AF1, (b) AF2, (c) AF3, (d) AF4 and

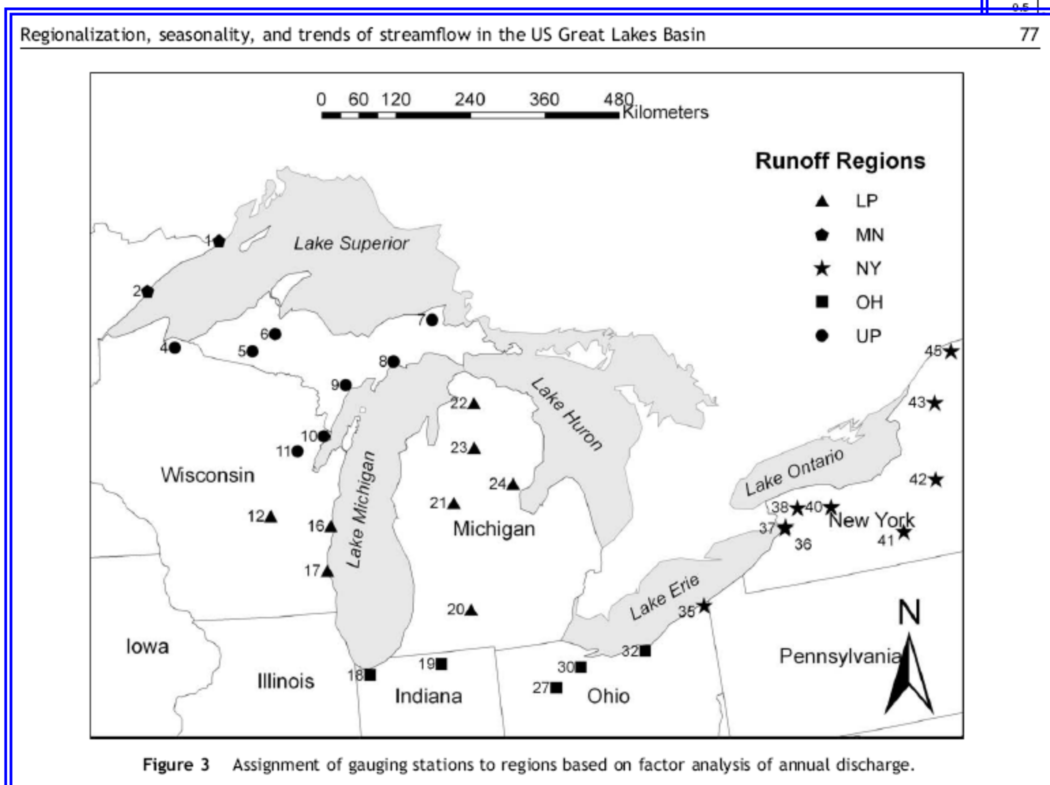


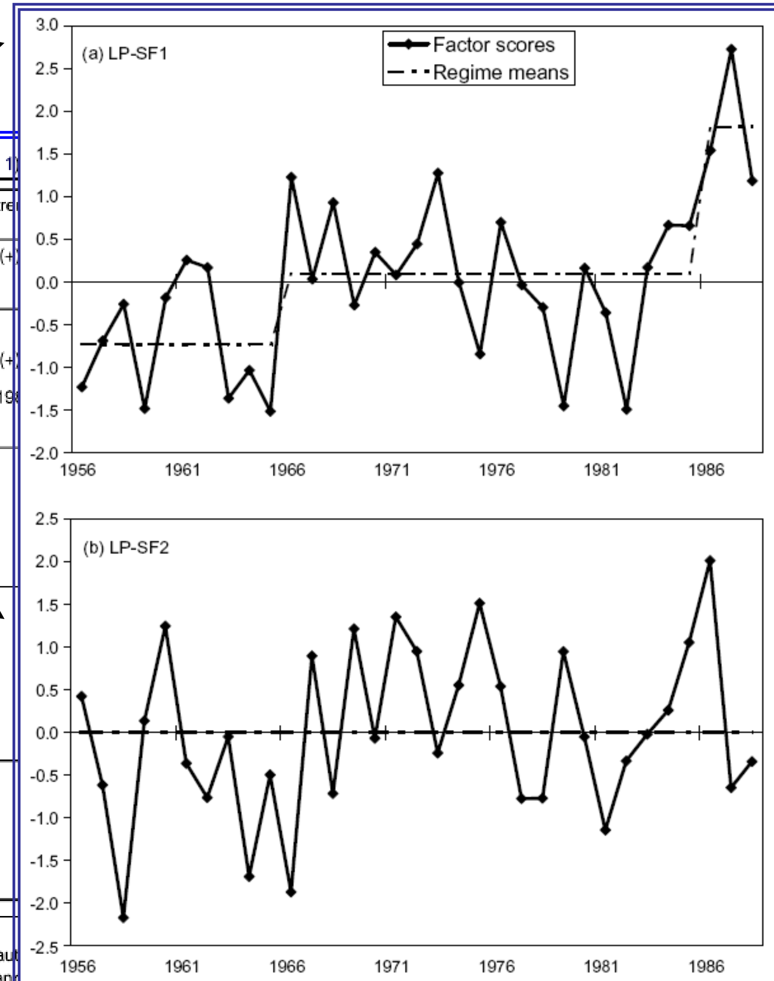
Figure 3 Assignment of gauging stations to regions based on factor analysis of annual discharge.

Introduction

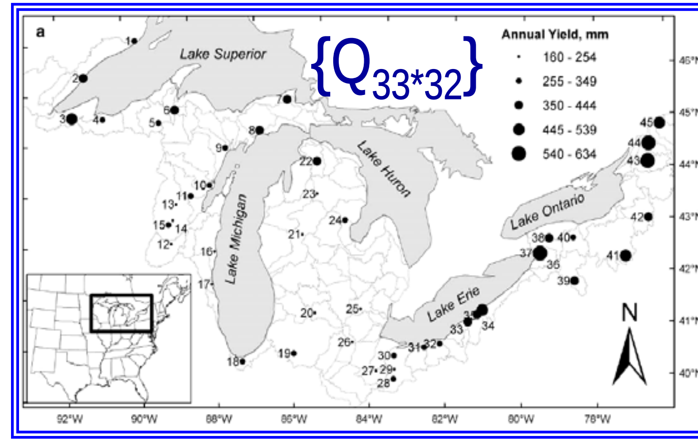
Table 3 Seasonal factors derived from average monthly discharge for five gauging stations representative of AF groups (Table 1)

	Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Var.	% Var.	tau	p	Regime shift year (tre
LP	**1**	0.79	0.90	0.81	0.87	0.91	0.72							4.61	38.4	0.292	**0.018**	1966(+), 1986(+)
	2							0.80	0.83	0.83	0.77	0.69		3.74	31.2	0.114	0.361	none
NY	1											0.91	0.86	2.44	20.3	0.205	0.097	none
	2	0.69	0.68	0.80										1.95	16.3	0.409	**0.001**	1968(+), 1987(+)
	3							0.69	0.82	0.64				1.79	15.0	-0.178	0.150	1962(−), 1969(+), 19
	4					-0.80	0.70							1.31	10.9	0.080	0.525	none
UP	1	0.61	0.87	0.92	0.94	0.73								3.70	30.8	0.083	0.505	none
	2									0.62	0.73	0.84	0.71	2.75	23.0	0.019	0.889	none
	3						0.85							1.48	12.3	0.193	0.118	none
	4							0.79						1.41	11.7	-0.027	0.840	none
OH	1	0.79	0.89	0.80										2.61	21.7	0.159	0.198	none
	2									0.86			0.87	1.76	14.7	0.059	0.642	none
	3				-0.80	-0.88								1.78	14.8	-0.076	0.546	none
	4										-0.79			1.34	11.2	-0.114	0.361	1987(+)
	5											0.82		1.08	9.0	0.165	0.183	none
MN	1	0.88	0.94	0.96	0.92	0.85								4.60	38.3	0.159	0.198	none
	2								0.71	0.93	0.78			2.31	19.2	-0.074	0.556	1987(−)
	3											-0.92		1.32	11.0	-0.288	**0.019**[a]	1987(+)
	4							0.91						1.73	14.4	0.008	0.963	none

[a]Note that the negative factor loading and negative tau value signify an increase in discharge.
Factor loadings > |0.6| shown for individual months. Cell borders within month columns denote season represented: heavy solid line = au
double solid line = late spring, dashed line = mid- to late summer. Regime shift year denotes a significant change in the regime mean, an
discharge. Significant *p*-values for the tau trend statistic shown in bold.



Multivariate empirical data & philosophy of analysis



A **factor** is a portion of a quantity, usually an integer or polynomial that, when multiplied by other factors, gives the entire quantity.

The determination of factors is called factorization (or sometimes "factoring"). It is usually desired to break factors down into the smallest possible pieces so that no factor is itself factorable.

Factor analysis allows the determination of common axes influencing sets of independent measured sets.

It is "the granddaddy" of multivariate techniques (Gould 1996, pp. 42-43) & was invented by Spearman.

The main applications of factor analytic techniques are:

- (1) to ***reduce* the number** of variables and
- (2) to ***detect* structure** in the relationships between variables, that is to ***classify* variables**.

(From: Wolfram *MathWorld*)

The explanation for regime of streamflow has to be found

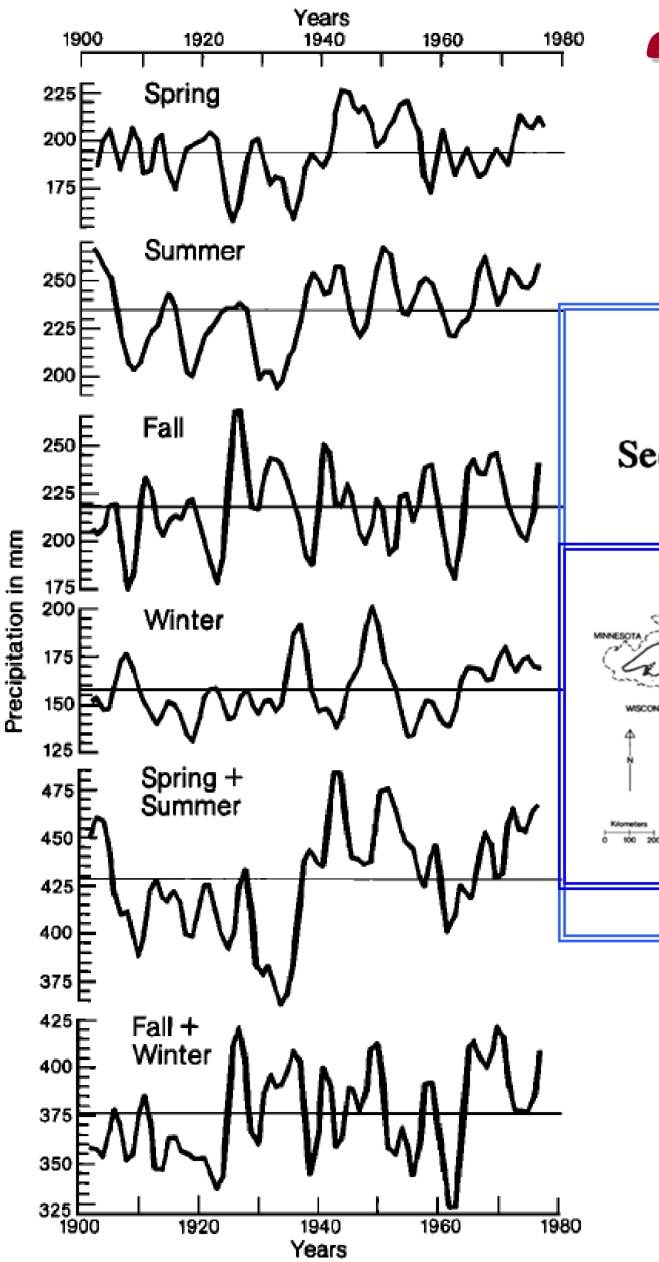


Fig. 4. Great Lakes 5-year weighted average seasonal precipitation. The horizontal solid lines are the 1900–1979 means.

WATER RESOURCES RESEARCH, VOL. 17, NO. 6, PAGES 1619–1624, DECEMBER 1981

Secular Changes in Annual and Seasonal Great Lakes Precipitation, 1854–1979, and Their Implications for Great Lakes Water Resource Studies

Frank H. Quinn

...c Administration, Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan 48104

Fig. 1. Great Lakes Basin.

...ation over the Great Lakes Basin from 1854 to 1979 indicates two ...he first, a relatively dry regime, lasted from the mid-1880's until the ... a relatively wet regime, which continues to the present. The analysis ...ecipitation regime prior to the mid-1880's was similar to the present ...ion appears to be the result of increased precipitation during spring ...e present wet regime will present many challenges for water resource ... management, and

TABLE 1. Summary of the Number of Stations Used in the Data Base Development

Lake Basin	Number of Stations in Year 1918	Number of Stations in Year 1978	Number of 1918 Stations Still Used in 1978
Superior	48	80	19
Michigan	98	141	48
Huron	80	145	44
Erie	89	133	43
Ontario	68	120	29
Total Basin	383	619	183

Secular Trends of Precipitation Amount, Frequency, and Intensity in the United States

Thomas R. Karl and Richard W. Knight
NOAA/NESDIS/National Climatic Data Center, Asheville, North Carolina

Vol. 79, No. 2, February 1998

The boundaries are administrative

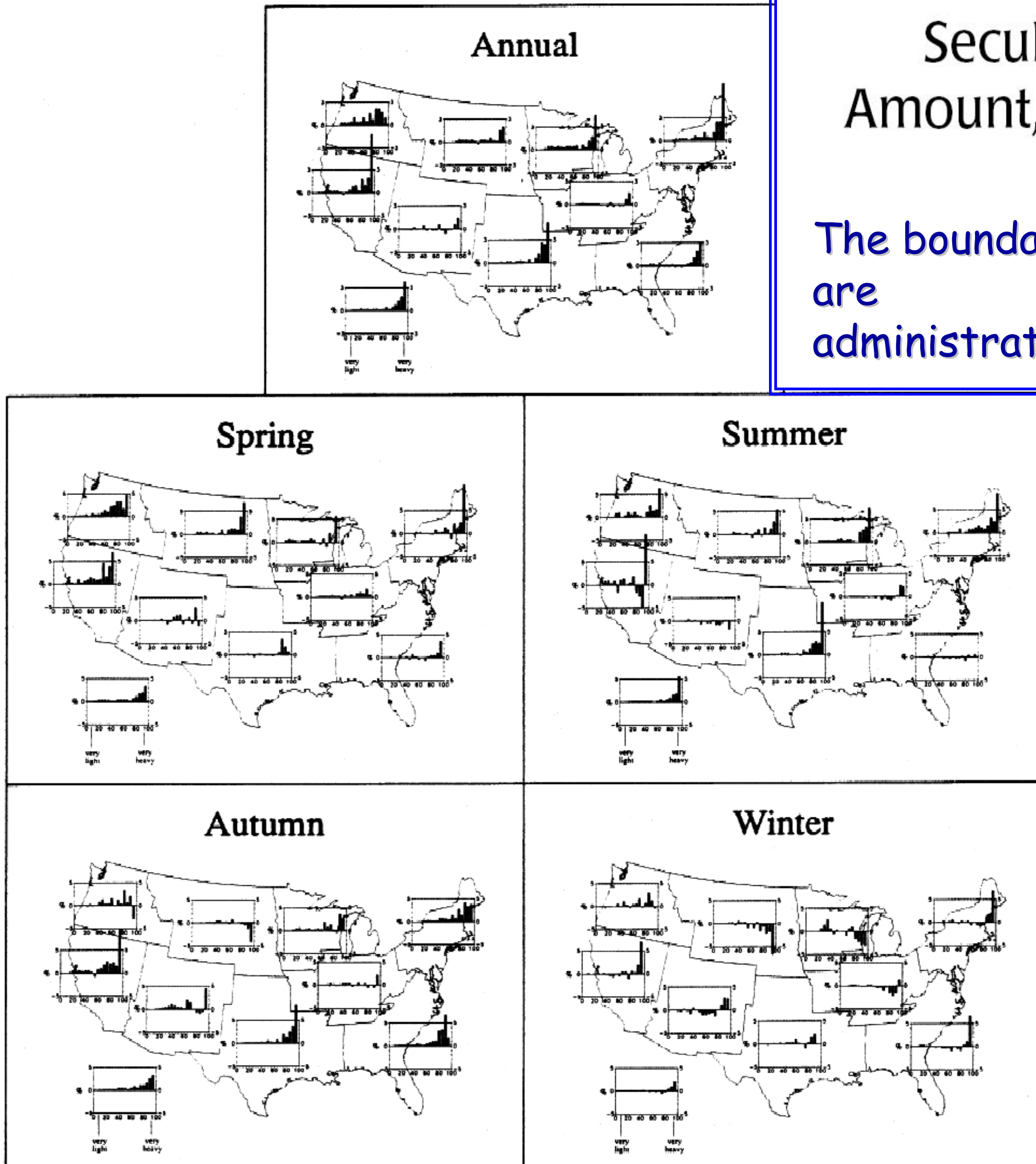


FIG. 1. Trends (1910–96) expressed as percent of mean precipitation per century for various categories of precipitation defined by five percentile class intervals. Value plotted at the 95th percentile represents the trend for the 95th to the highest percentiles, value plotted for the 90th percentile represents the trend for the 90th to the 95th percentile. Value plotted at 5th percentile represents the trend from the lowest percentile to the 5th percentile. The bar chart in the lower left reflects the national average.

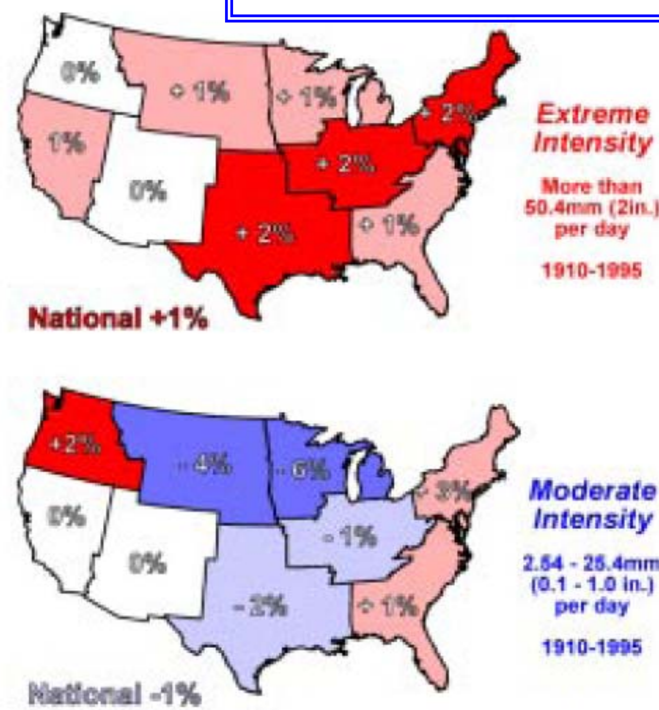


FIG. 7. Trends (1910–95) related to the proportion of total annual precipitation within various categories of precipitation. Trends are expressed as a percent change. Statistically significant trends are highlighted.

The explanation for regime of streamflow has to be found

Consideration of the Great Lakes region as uniform in joint boundaries is the common approach

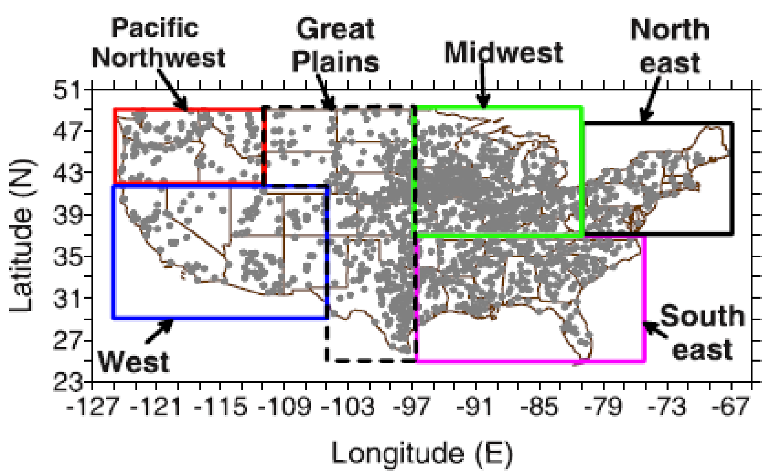


Figure 1. Map of the surface observing stations from which daily precipitation data are presented. Also shown are the regional definitions used which are derived from those used in the US regional climate change assessment [*National Assessment Synthesis Team*, 2000].

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D21108, doi:10.1029/2008JD010251, 2008

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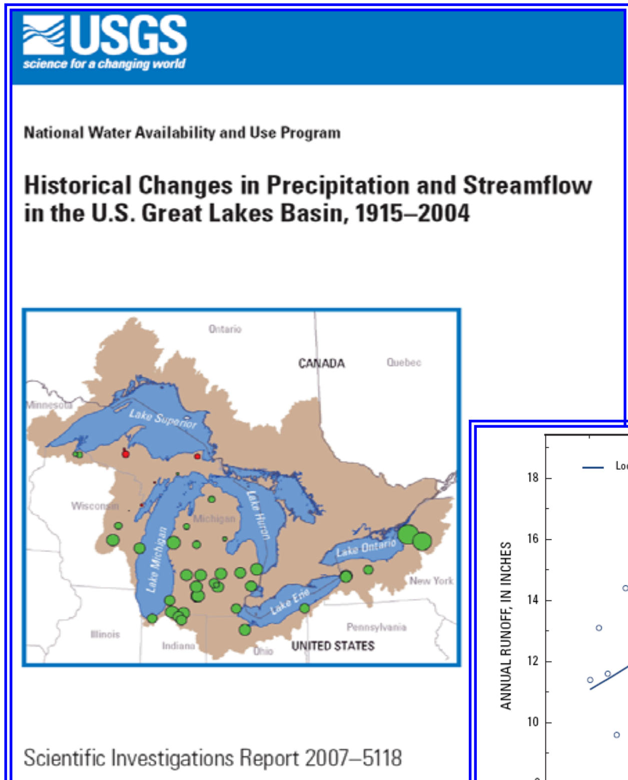
Changes in the seasonality of precipitation over the contiguous USA

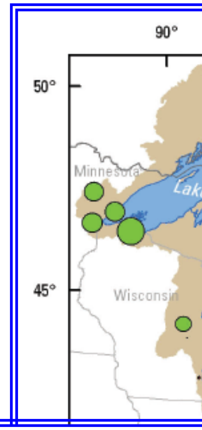
S. C. Pryor[1] and J. T. Schoof[2]

; revised 3 July 2008; accepted 27 August 2008; published 5 November 2008.

es of possible changes in annual total precipitation are dictated, in part,
f precipitation events and changes therein. Herein, we investigated
es in precipitation seasonality over the US using observed station
ords to compute a standard seasonality index (SI) and the day of year
n percentiles of the annual total precipitation were achieved (percentile
he mean SI from the majority of stations exhibited no difference in
tive to 30-year periods earlier in the century. However, analysis of the
which certain percentiles of annual total precipitation were achieved
lly coherent patterns of change. In some regions, the mean day of the
the 50th percentile of annual precipitation was achieved differed by
tween 1971–2000 and both 1911–1940 and 1941–1970. Output from
ere-Ocean General Circulation Models (AOGCM) simulations of
46–2065, and 2081–2100 was used to determine whether AOGCMs
representing the seasonal distribution of precipitation and to examine
hanges. Many of the AOGCMs qualitatively captured spatial patterns of
ng 1971–2000, but there was considerable divergence between
ms of future changes. In both the west and southeast, 7 of 10 AOGCMs
ttainment of the 50th percentile accumulation in 2047–2065, implying a
l of the twentieth-century tendency toward relative increases in
eipt during winter and early spring over the southeast. However, this is
aracterized by considerable interannual variability in the percentile day
the historical period.

. C., and J. T. Schoof (2008), Changes in the seasonality of precipitation over the contiguous USA, *J. Geophys.*
doi:10.1029/2008JD010251.





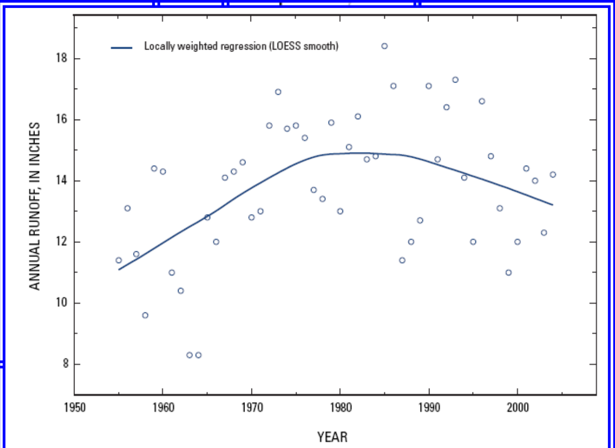


Figure 5. Annual runoff for the average of 43 stations in the U.S. Great Lakes Basin, 1955–2004.

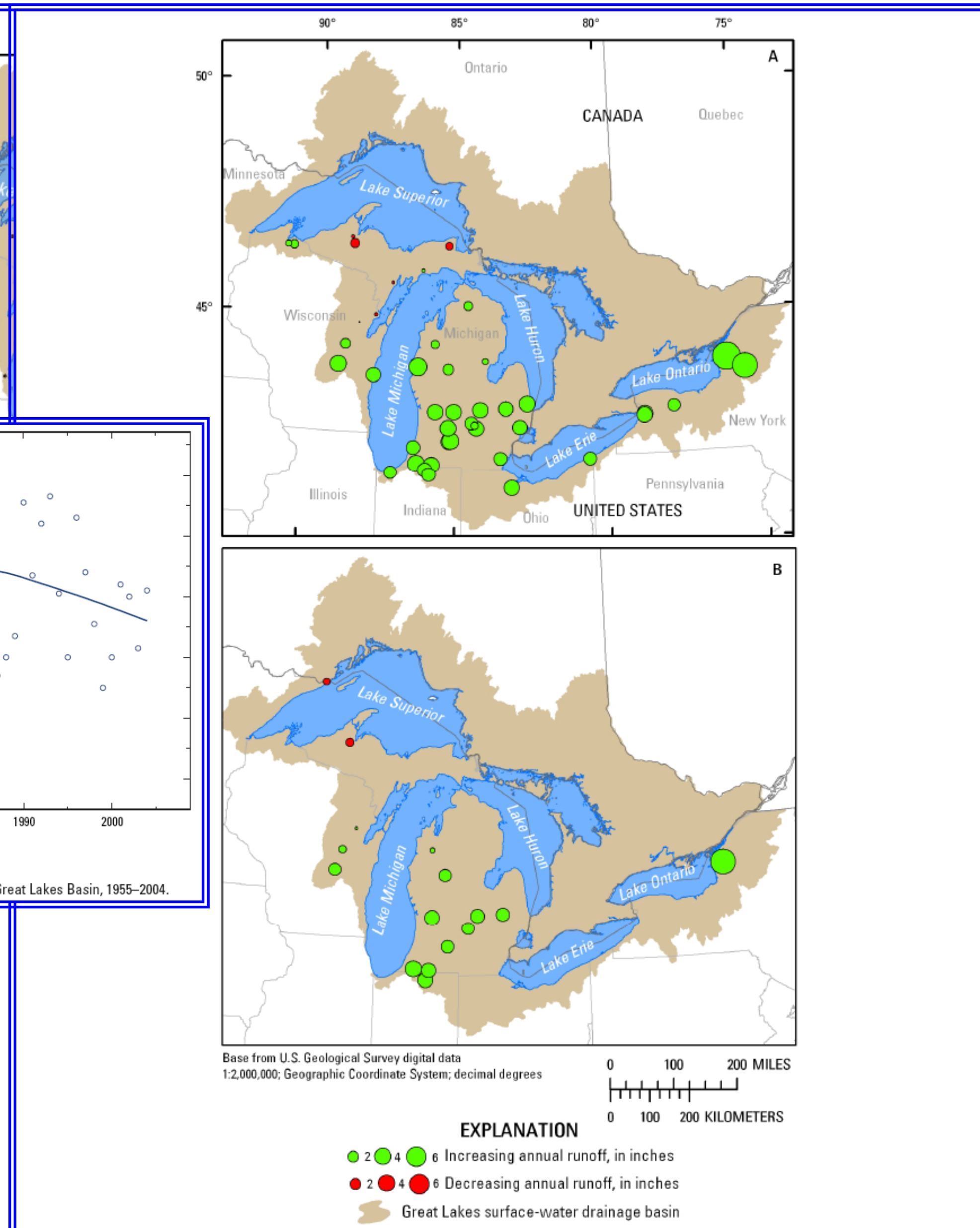


Figure 6. Changes in annual runoff, by station, for (A) 1955–2004 and (B) 1935–2004. Circle sizes proportional to increases or decreases

Figure 3. Changes in annual precipitation, by station, for (A) 1915–2004, (B) 1935–2004, and (C) 1955–2004. Circle sizes proportional to increases or decreases.

Report from USGS

Historical changes were presented month by month

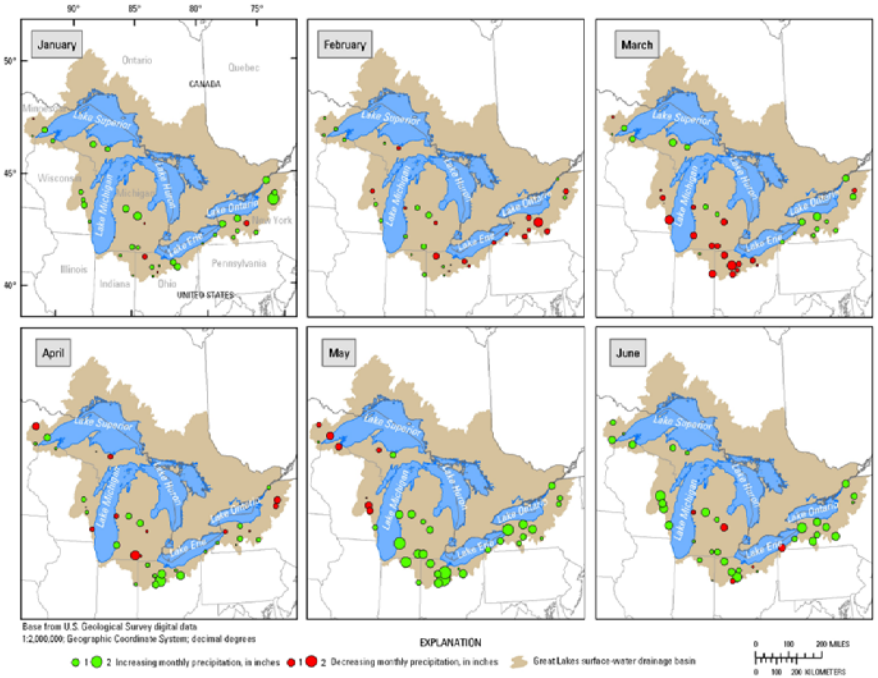


Figure 4a. Changes in monthly precipitation for January through June, by station, 1955–2004. Circle sizes proportional to increases or decreases.

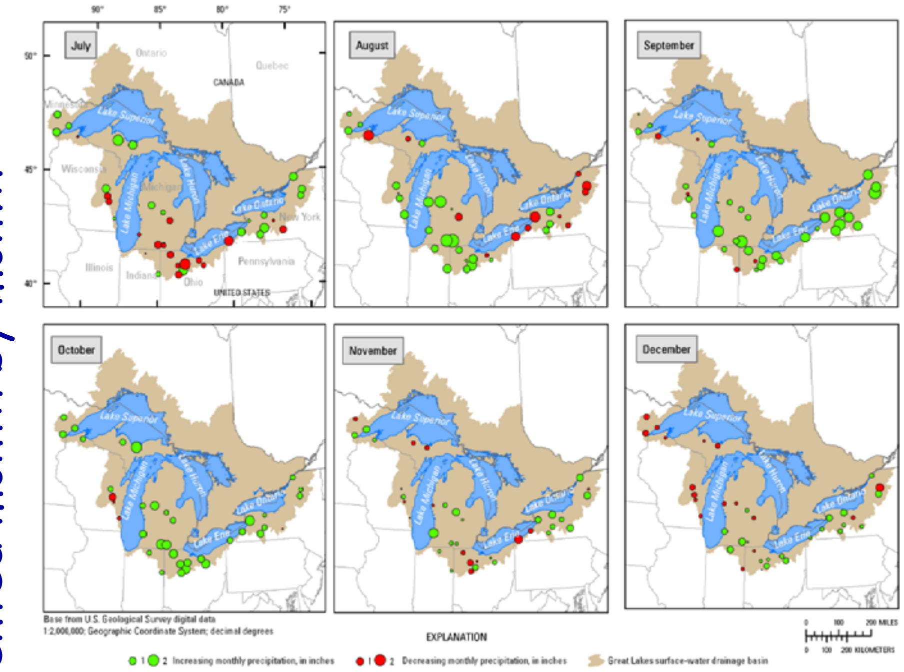


Figure 4b. Changes in monthly precipitation for July through December, by station, 1955–2004. Circle sizes proportional to increases or decreases.

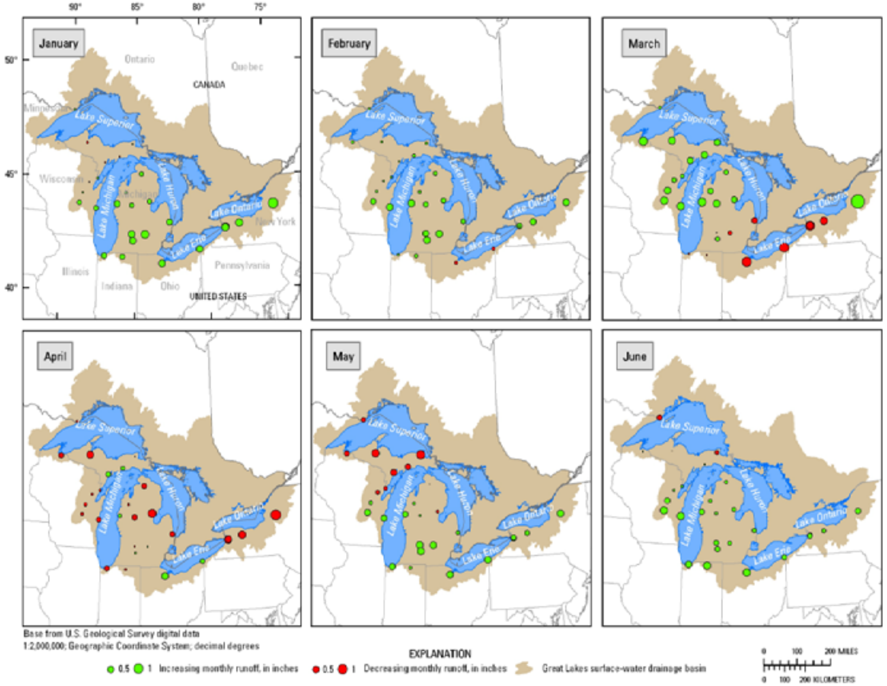


Figure 7a. Changes in monthly runoff for January through June, by station, 1955–2004. Circle sizes proportional to increases or decreases.

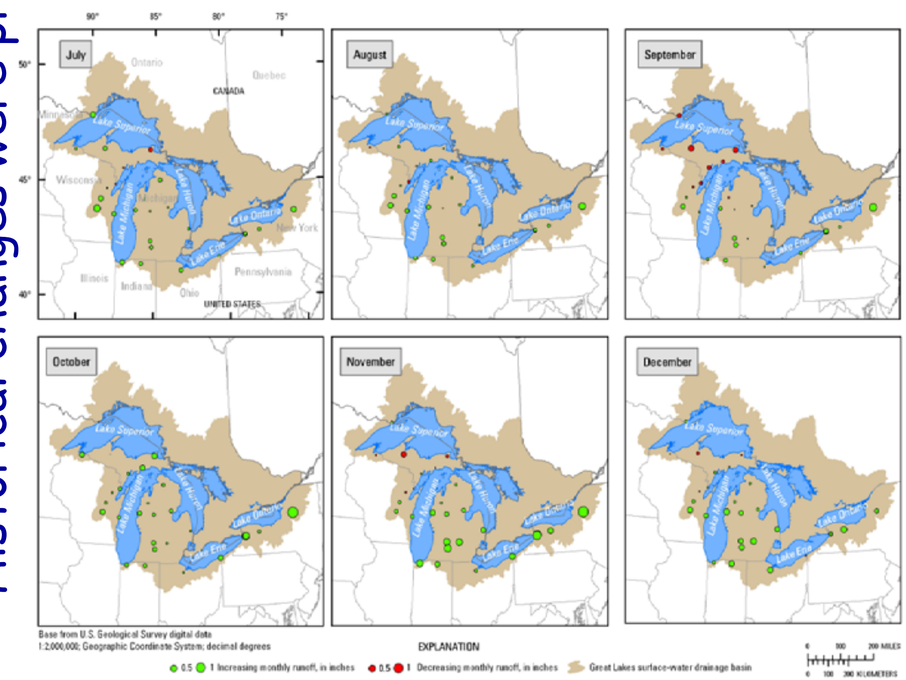


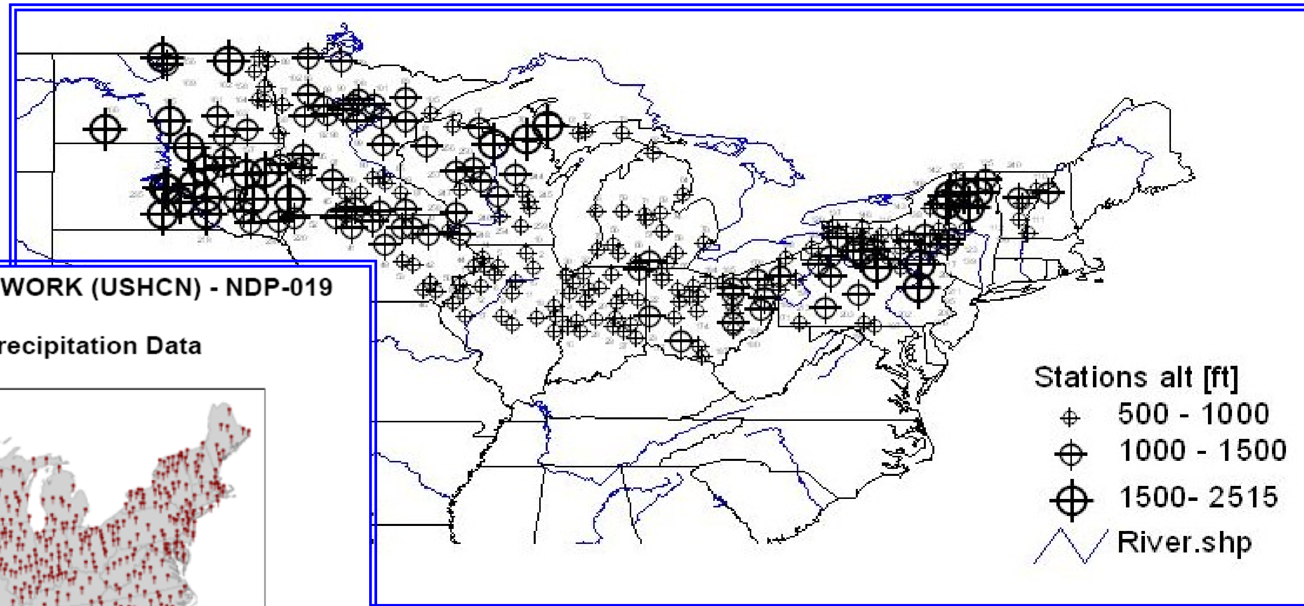
Figure 7b. Changes in monthly runoff for July through December, by station, 1955–2004. Circle sizes proportional to increases or decreases.

Topics

- Introduction:
  The explanation for regime of streamflow has to be found
  (presented earlier)
- Regime of climate characteristics (air temperature & precipitations)
- Scale in Regime – what is it?
- The model
- Results for discussion

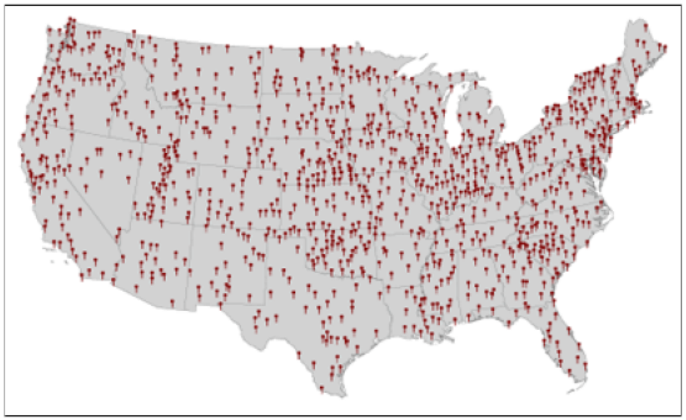
$\{P_{105*165}\}$

$\{T_{105*198}\}$



U.S. HISTORICAL CLIMATOLOGY NETWORK (USHCN) - NDP-019

Monthly Temperature and Precipitation Data



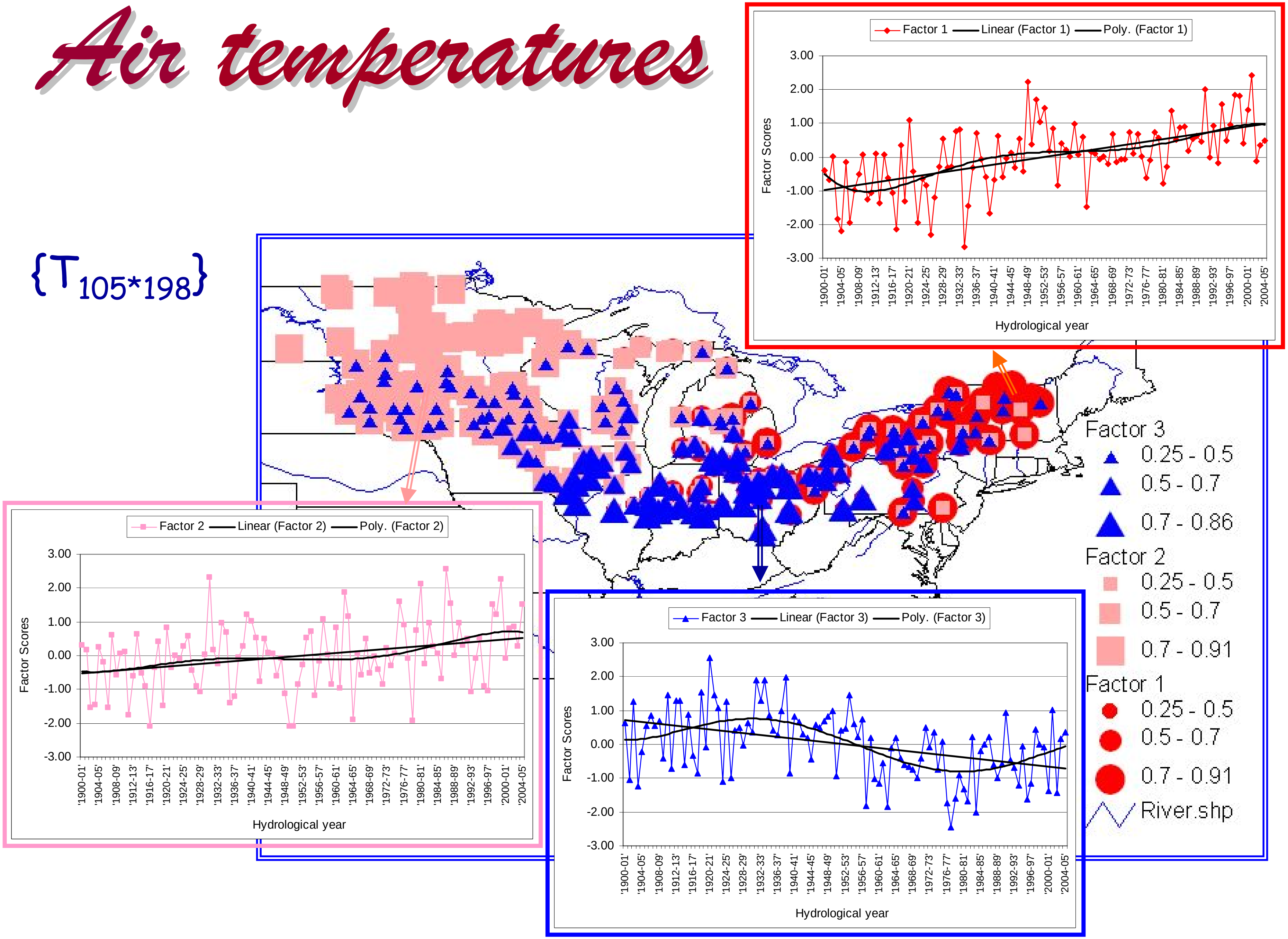
C.N. Williams, Jr., M.J. Menne, R.S. Vose, and D.R. Easterling
National Oceanic and Atmospheric Administration,
National Climatic Data Center,
Asheville, North Carolina

Prepared for on-line distribution by:
B.L. Jackson, L.M. Olsen, D.P. Kaiser, and T.A. Boden
Carbon Dioxide Information Analysis Center
Environmental Sciences Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6335
managed by
University of Tennessee-Battelle, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

Data for characteristics of climate regime

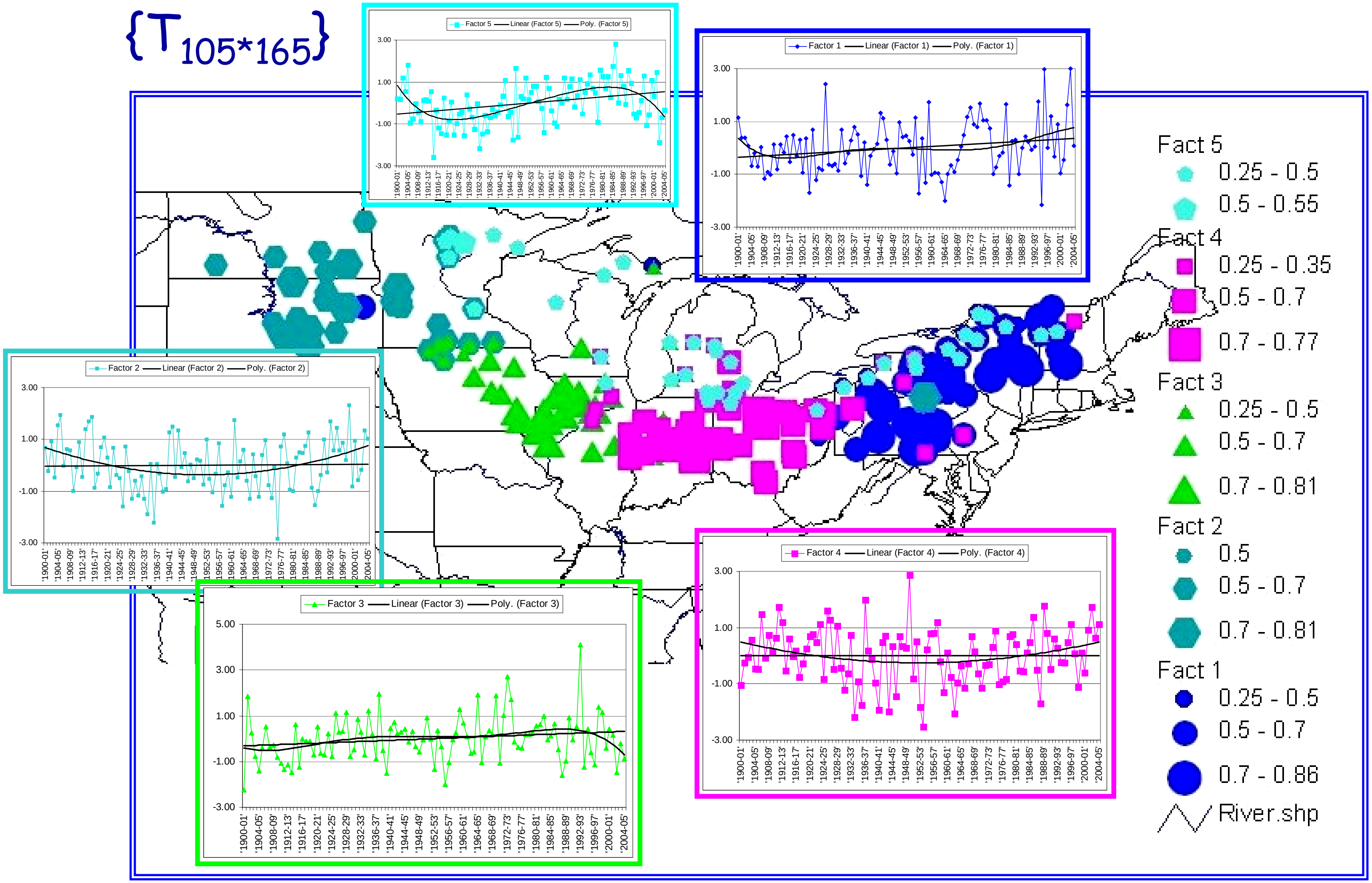
Air temperatures

$\{T_{105*198}\}$

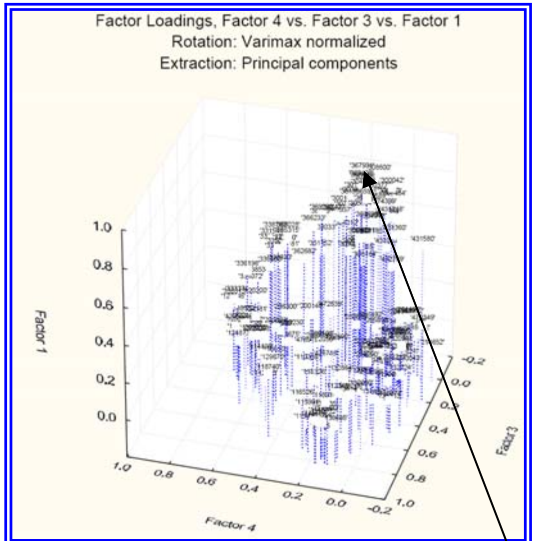


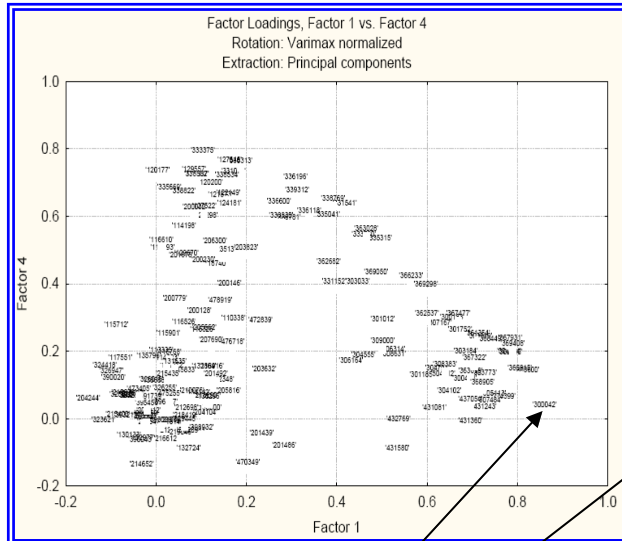
Precipitation, annual sum

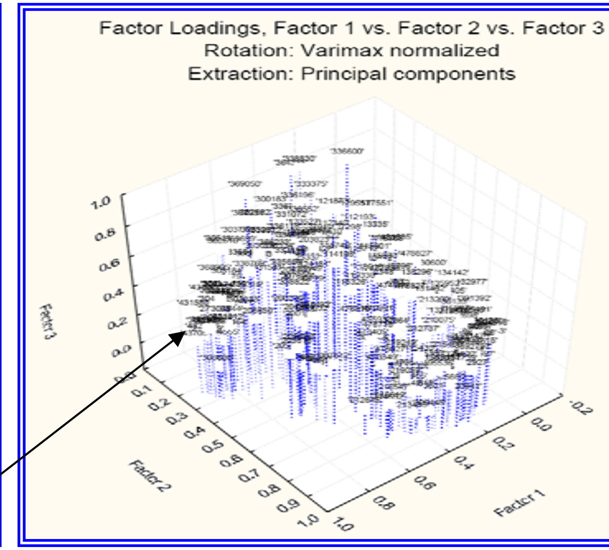
$\{T_{105*165}\}$



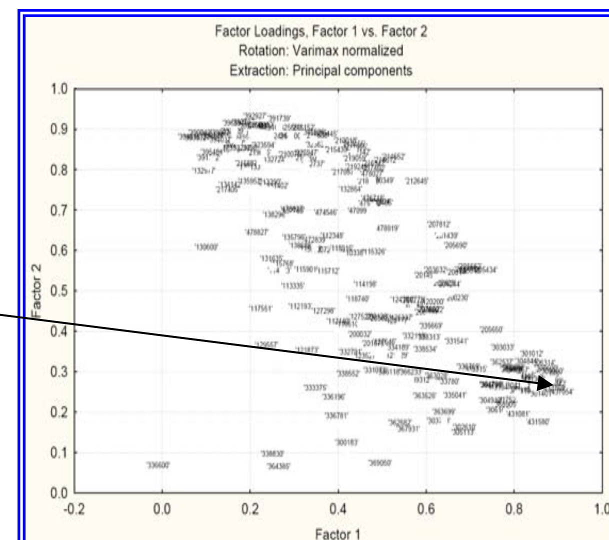
The typical stations



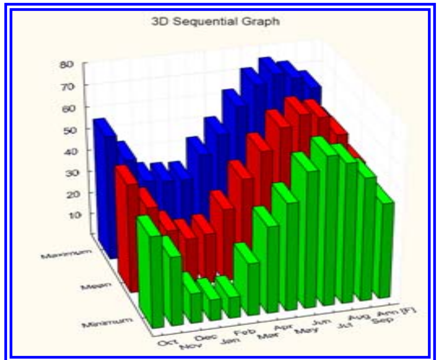




Explained Variability by Factor in "Precip." [%]	Explained Variability by Factor in "Temp." [%]	No of COOP station	Factor Loading of station in "Precip."	Factor Loading of station "Temp."
I - 14	I - 27	300042	I – 0.86	I – 0.89
II - 10	II - 35	391739	II – 0.81	II – 0.91
III - 10		115768	III – 0.81	
IV - 11	III - 25	333373	IV – 0.77	III – 0.86
V - 5		216612	V – 0.55	



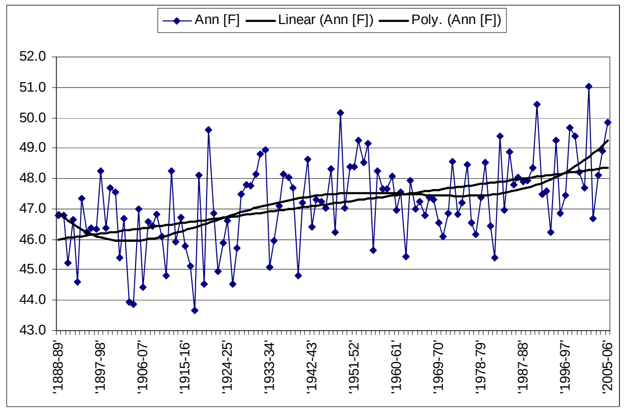
Station 300032, air temperatures

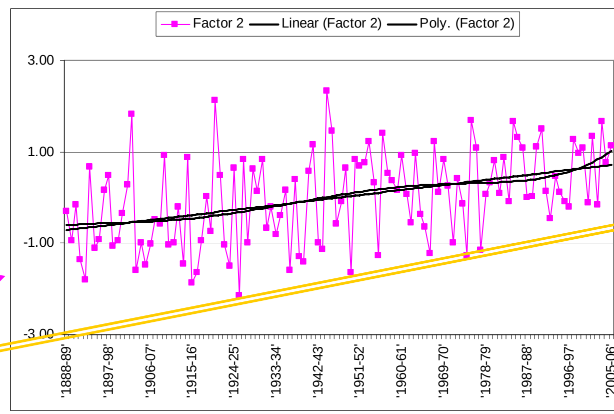


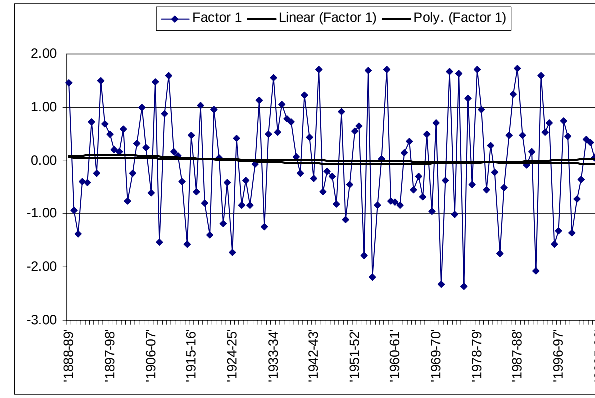
T300042 (118*12,13)

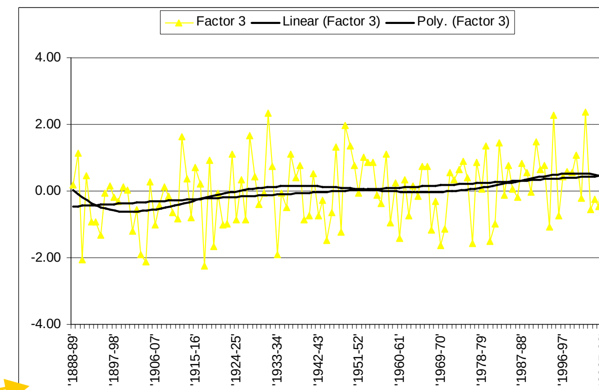
	Factor 1	Factor 2	Factor 3	Factor 4
Jan	**0.74**			
Ann [F]	**0.71**	0.35	***0.59***	
Dec	**0.70**			
Nov	***0.61***		0.33	
Jun		**0.73**		
Aug		***0.64***		
Sep		0.48	0.49	
Mar		-0.34	**0.75**	
Apr			**0.73**	
Feb	0.33		***0.52***	-0.34
Oct	0.27	0.32		-0.40
May				***0.55***
Jul		0.26		**0.76**
Expl.Var	2.24	1.66	2.19	1.33
Prp.Totl	0.17	0.13	0.17	0.10

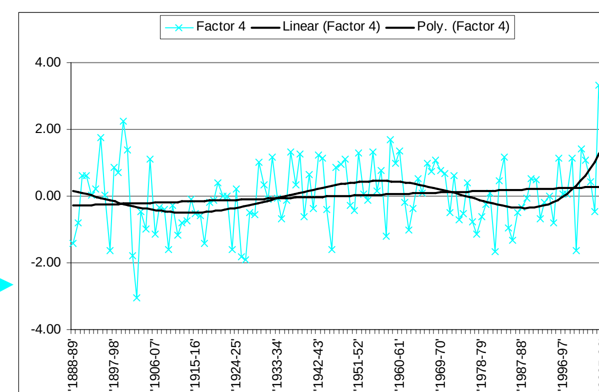
	Factor 1	Factor 2	Factor 3	Factor 4
Jul	0.76			0.26
May	0.54			
Mar		0.77		-0.30
Apr		0.73		
Feb	-0.34	0.51	0.30	0.28
Jan			0.73	
Dec			0.70	
Nov		0.37	0.61	
Aug	0.25		0.30	0.62
Jun				0.73
Sep		0.45		0.50
Oct	-0.40			0.34
Expl.Var	1.31	1.83	1.71	1.57
Prp.Totl	0.11	0.15	0.14	0.13





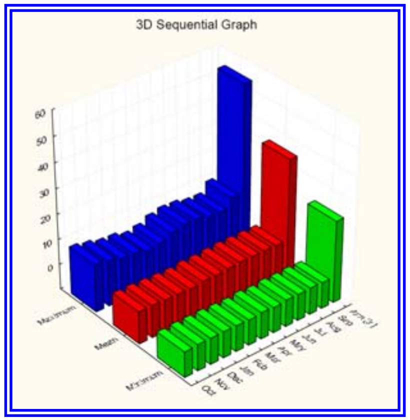


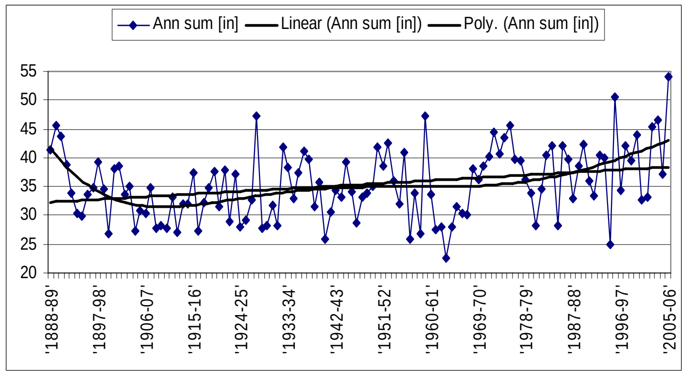




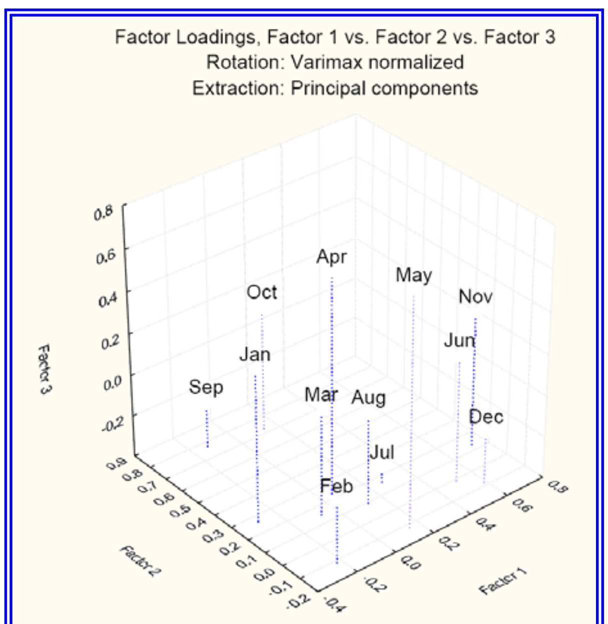
Station 300032, precipitations

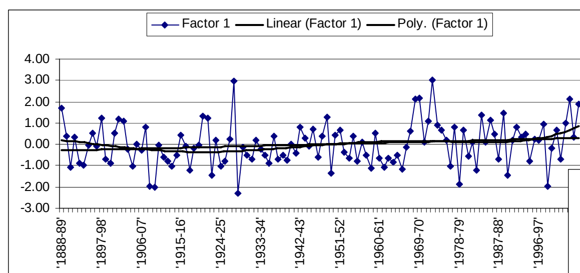
P300042 (118*12,13)

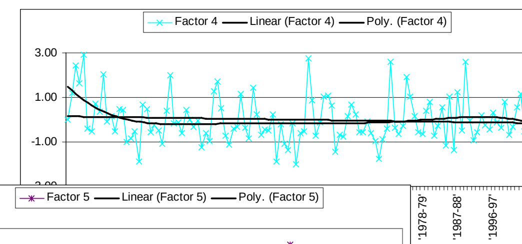


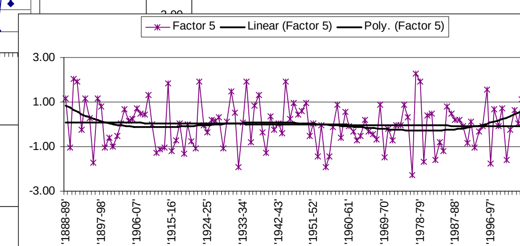


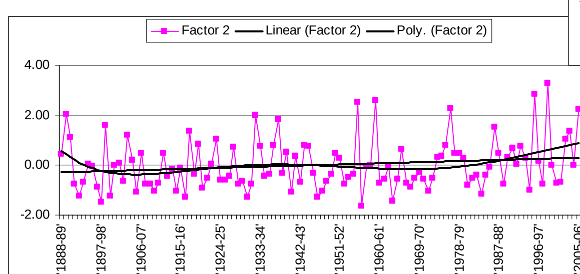
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sep	**0.79**				
Oct	***0.66***				
Ann [in]	***0.64***	***0.53***	0.42	0.33	
Nov		***0.68***	0.28		
Dec		***0.63***			
Jun		***0.52***			-0.33
May			**0.71**		
Apr			**0.70**		
Aug				**0.80**	
Feb				**0.72**	
Mar					**0.73**
Jul	0.26	0.37	-0.36		-0.36
Jan	0.32	-0.25	0.28		***-0.62***
Expl.Var	1.74	1.70	1.64	1.36	1.20
Prp.Totl	0.13	0.13	0.13	0.10	0.09

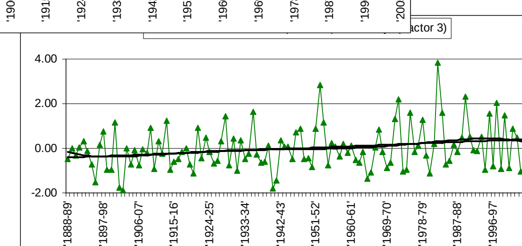






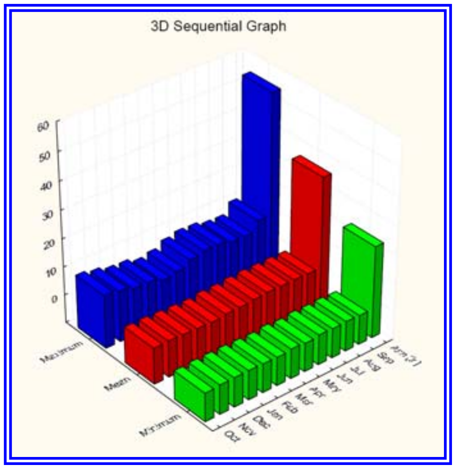




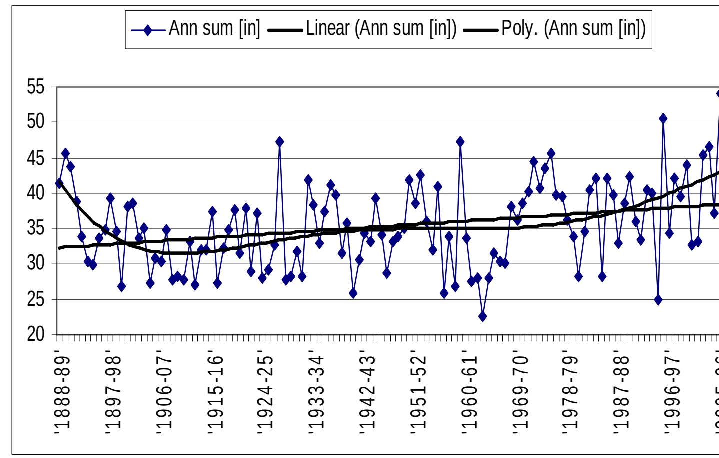


Station 300032, precipitations

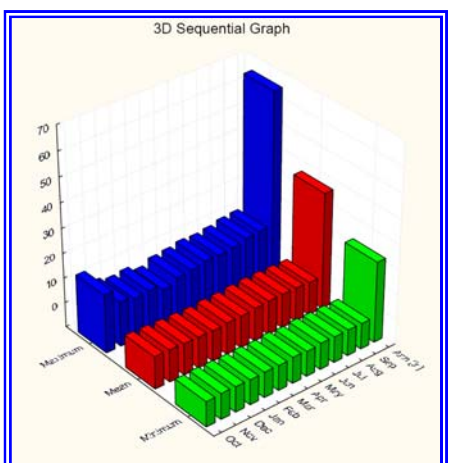
P300042 (118*12,13)

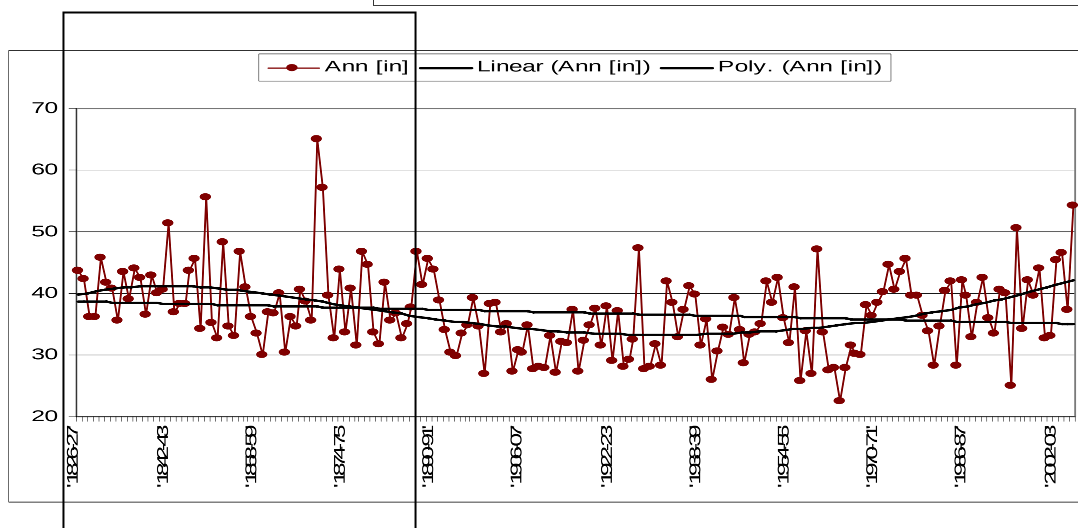


Use of longer time series changes the trend



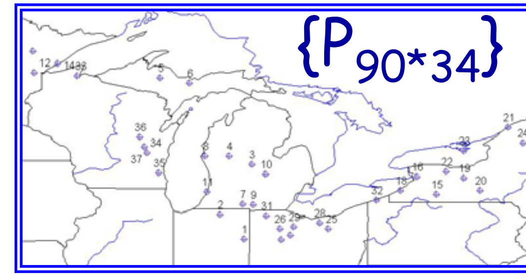
P300042 (180*12,13)

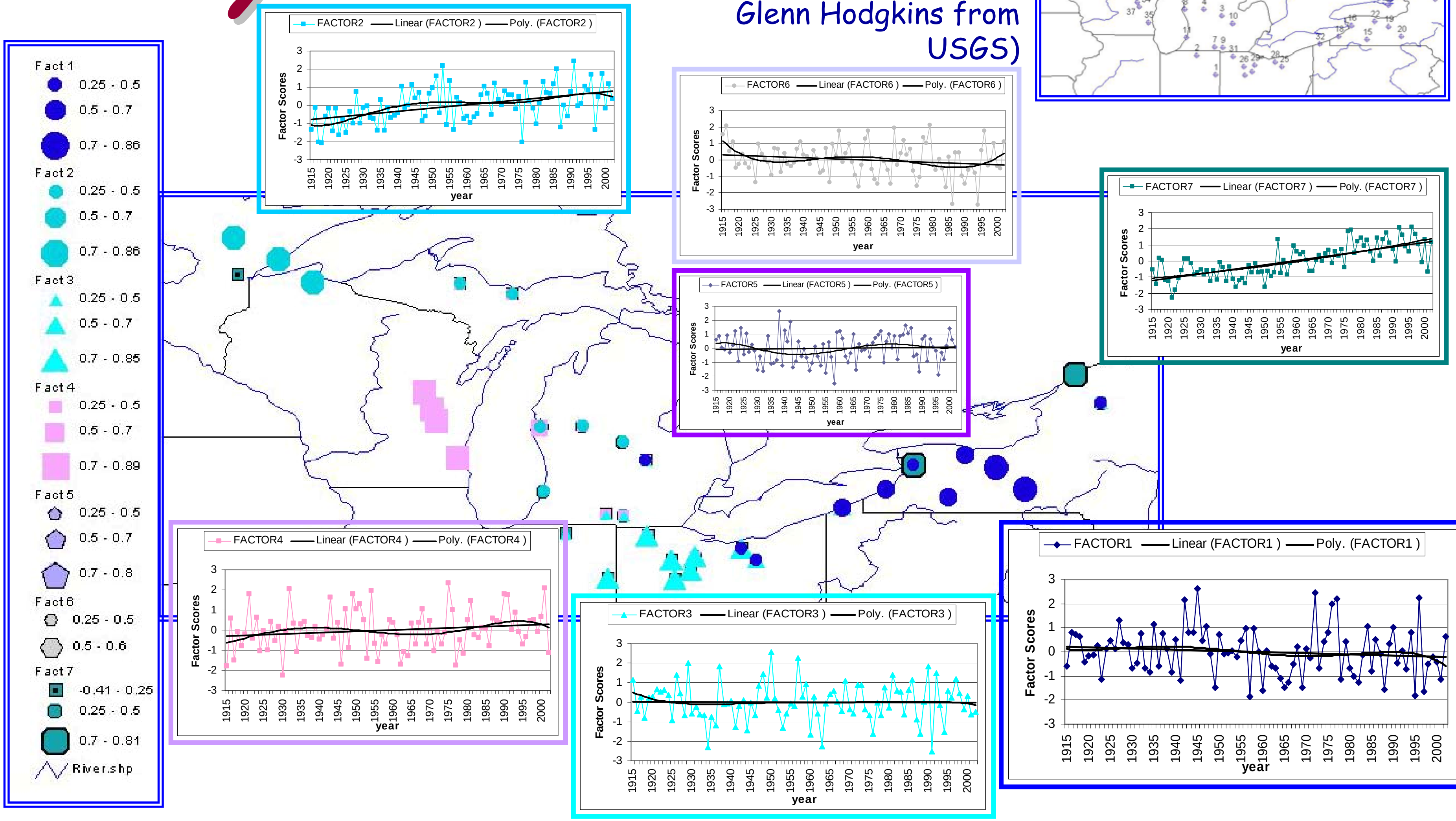




Analyzing precipitation from USGS

Data for 1915 – 2005 were collected & passed for analysis by Glenn Hodgkins from USGS)

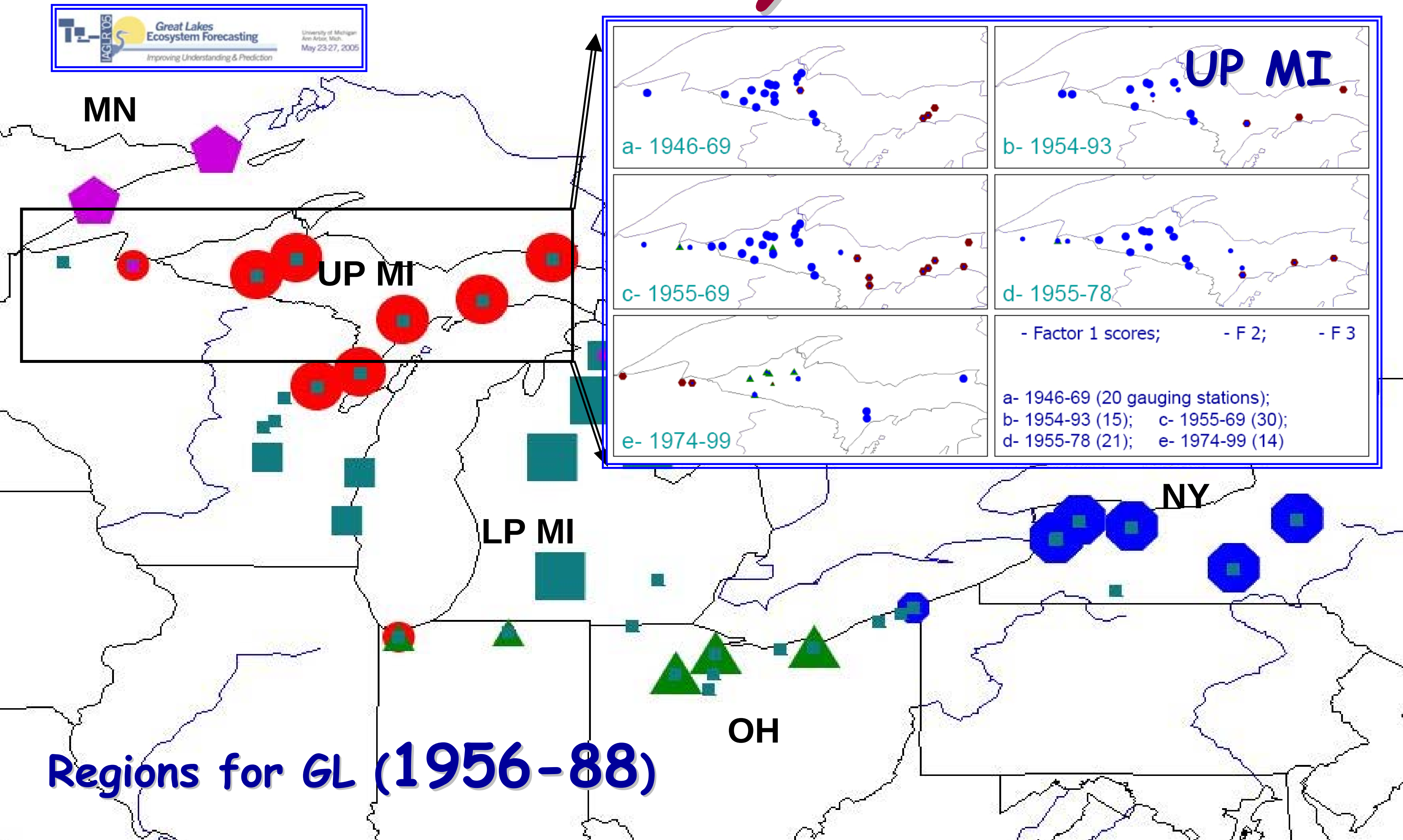




Scale in Regime – what is this?

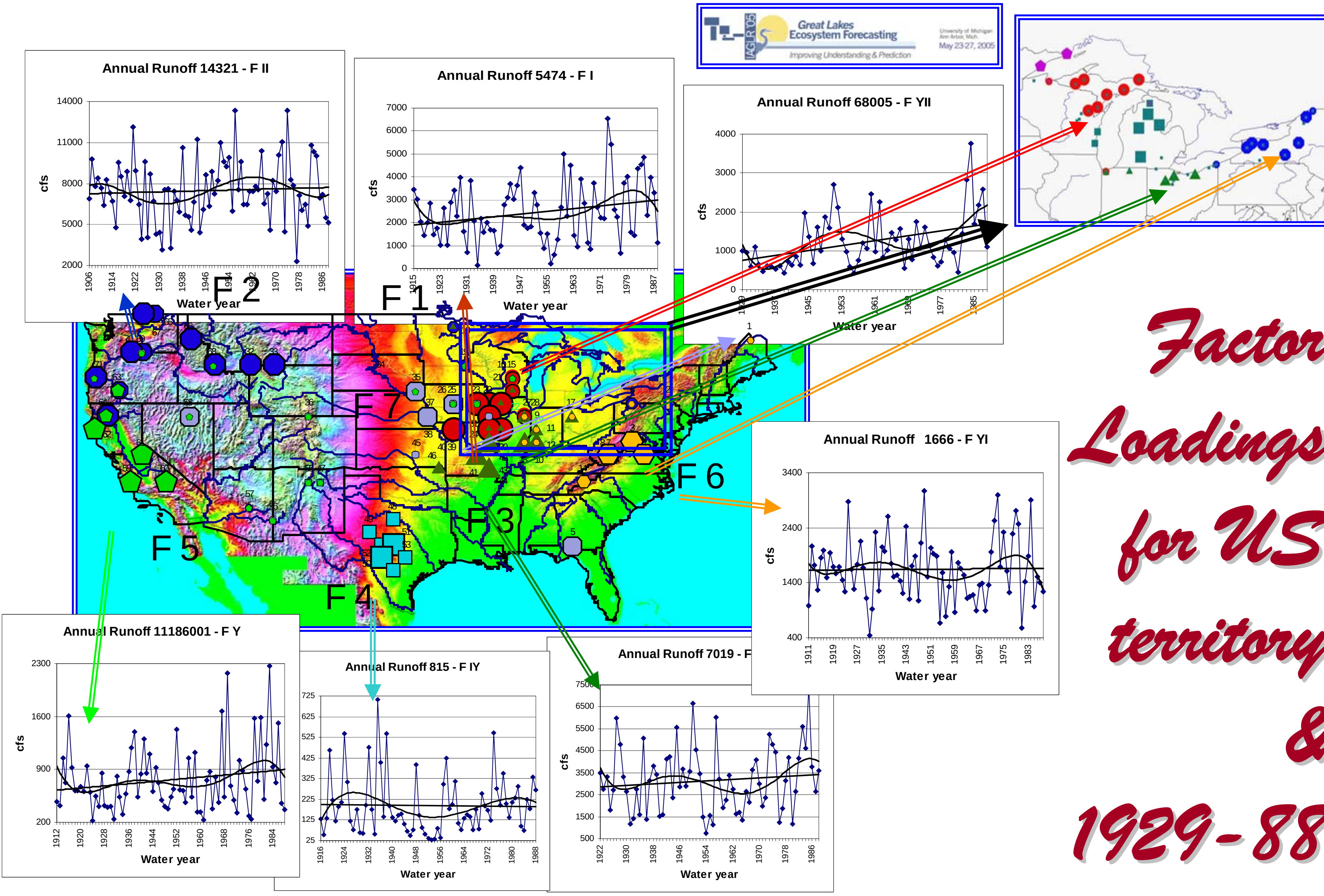
* Streamflow
* Precipitation
* Upper Peninsula (UP) of Michigan

Regimes of annual stream runoff – scale in research: GL & UP MI

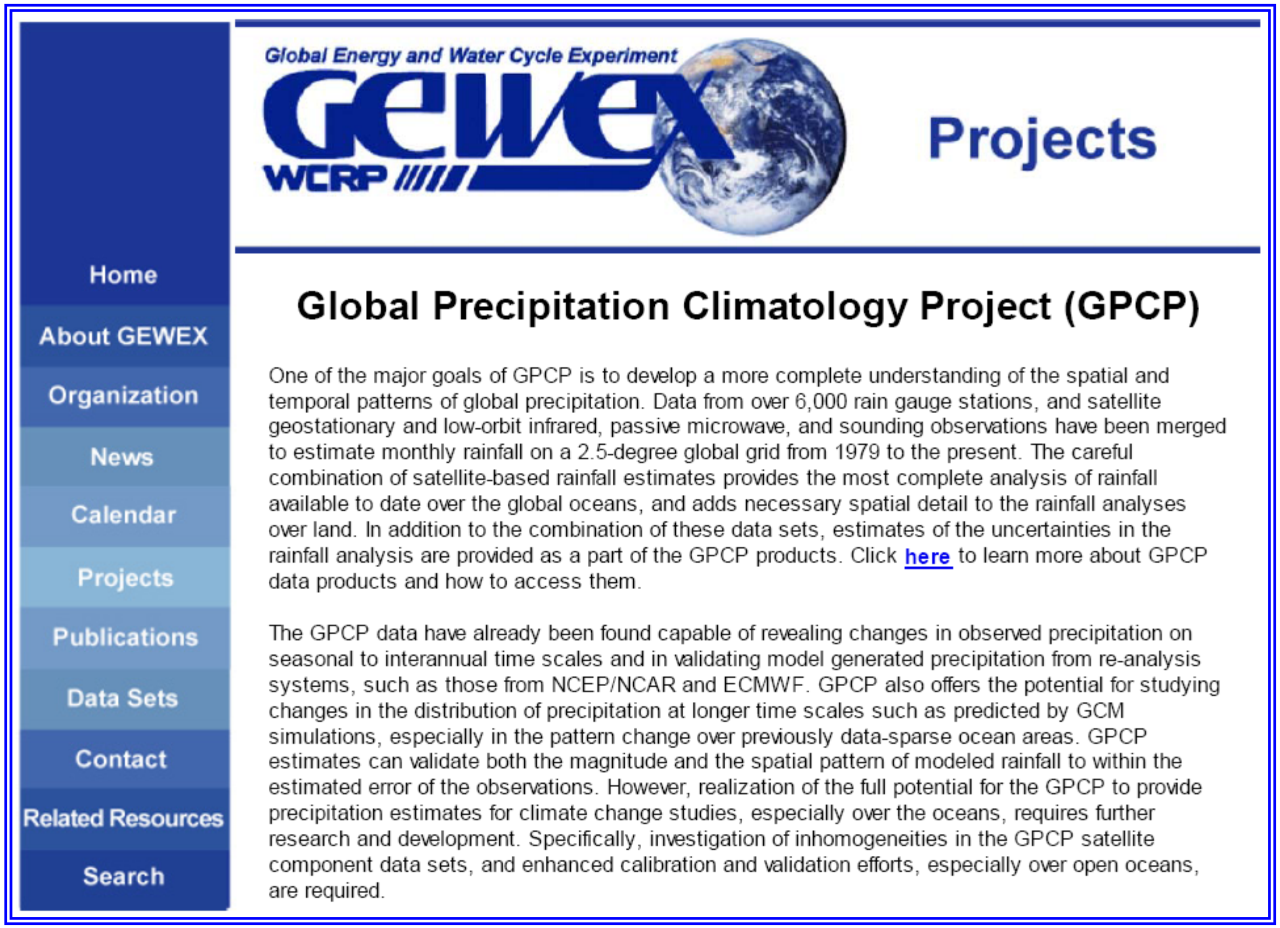


Regions for GL (1956-88)

Factor Loadings for US territory & 1929-88 annual discharge for typical watersheds



Precipitation from Global grid


Global Energy and Water Cycle Experiment

GEWEX

WCRP

Projects

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Global Precipitation Climatology Project (GPCP)

One of the major goals of GPCP is to develop a more complete understanding of the spatial and temporal patterns of global precipitation. Data from over 6,000 rain gauge stations, and satellite geostationary and low-orbit infrared, passive microwave, and sounding observations have been merged to estimate monthly rainfall on a 2.5-degree global grid from 1979 to the present. The careful combination of satellite-based rainfall estimates provides the most complete analysis of rainfall available to date over the global oceans, and adds necessary spatial detail to the rainfall analyses over land. In addition to the combination of these data sets, estimates of the uncertainties in the rainfall analysis are provided as a part of the GPCP products. Click here to learn more about GPCP data products and how to access them.

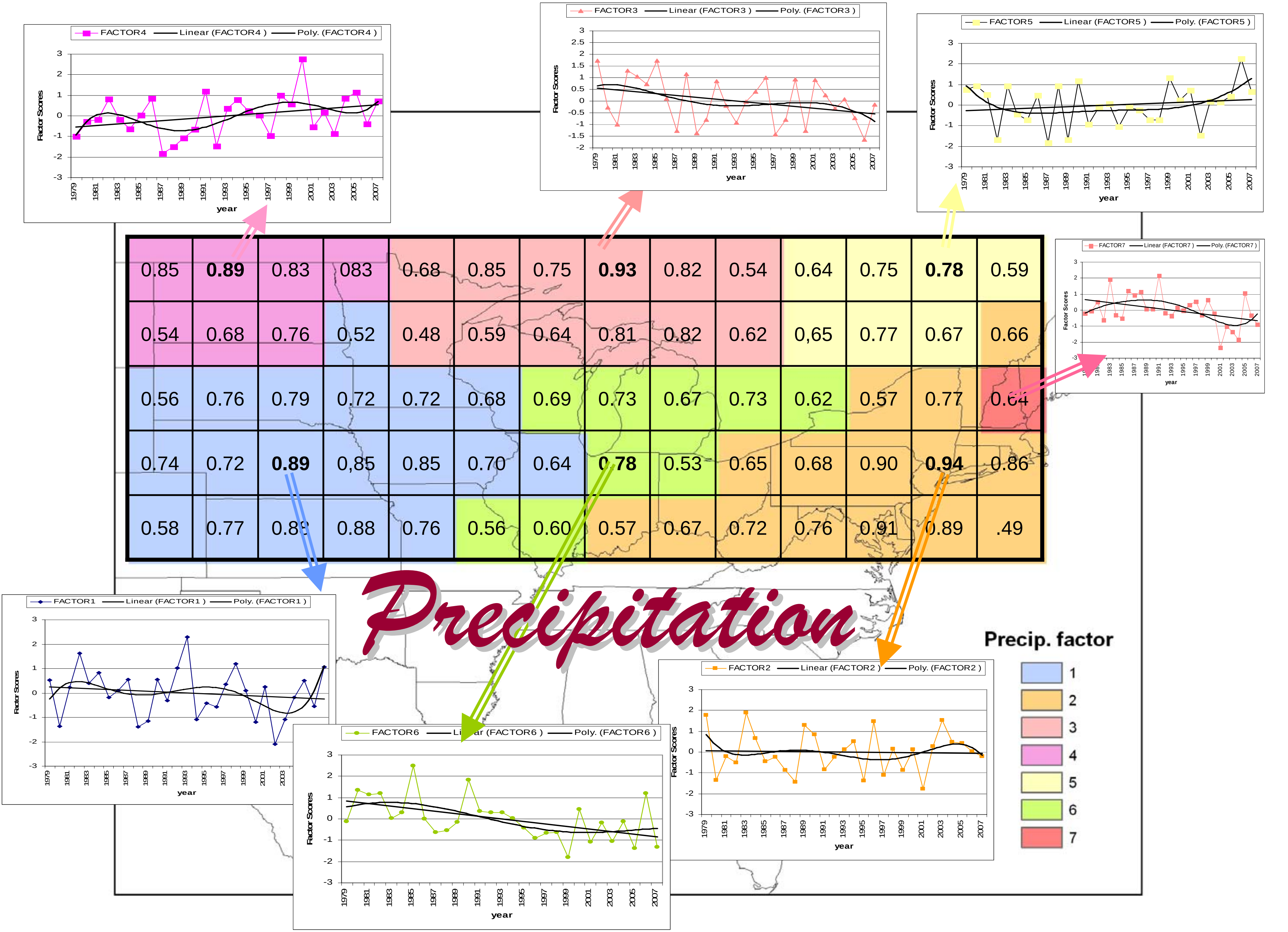
The GPCP data have already been found capable of revealing changes in observed precipitation on seasonal to interannual time scales and in validating model generated precipitation from re-analysis systems, such as those from NCEP/NCAR and ECMWF. GPCP also offers the potential for studying changes in the distribution of precipitation at longer time scales such as predicted by GCM simulations, especially in the pattern change over previously data-sparse ocean areas. GPCP estimates can validate both the magnitude and the spatial pattern of modeled rainfall to within the estimated error of the observations. However, realization of the full potential for the GPCP to provide precipitation estimates for climate change studies, especially over the oceans, requires further research and development. Specifically, investigation of inhomogeneities in the GPCP satellite component data sets, and enhanced calibration and validation efforts, especially over open oceans, are required.

Time series gathered in initial matrix:

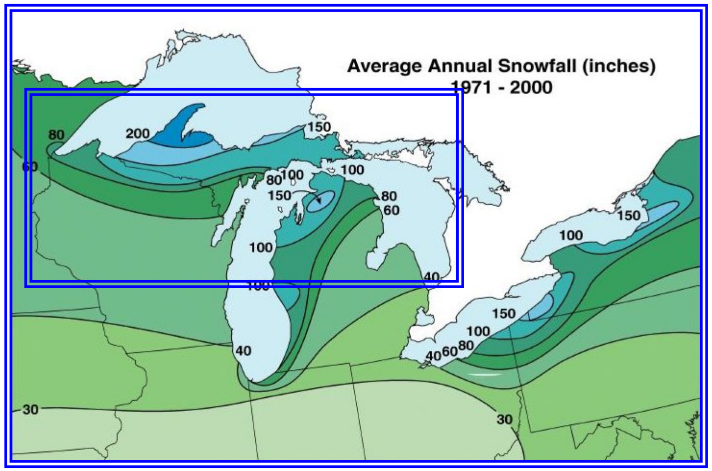
$\{P_{28*90}\}$

$P_{28,i}$

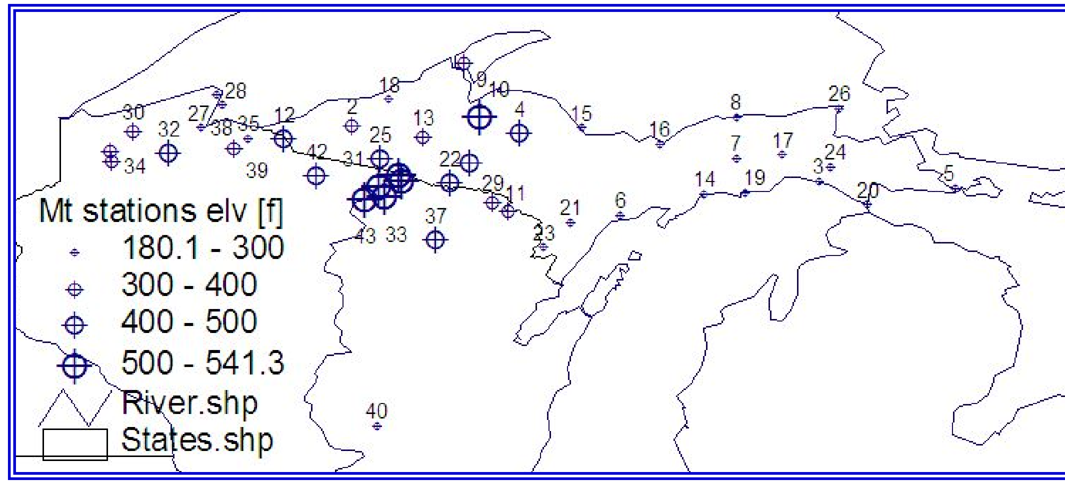
Lat (°N) \ Lon (°W)	103.75	101.25	98.75	96.25	93.75	91.25	88.75	86.25	83.75	81.25	78.75	76.25	73.75	71.25
48.75														
46.25														
43.75														
41.25														
38.75														


Precipitation
Precip. factor
1
2
3
4
5
6
7
0.85 0.89 0.83 083 0.68 0.85 0.75 0.93 0.82 0.54 0.64 0.75 0.78 0.59
0.54 0.68 0.76 0.52 0.48 0.59 0.64 0.81 0.82 0.62 0,65 0.77 0.67 0.66
0.56 0.76 0.79 0.72 0.72 0.68 0.69 0.73 0.67 0.73 0.62 0.57 0.77 0.64
0.74 0.72 0.89 0,85 0.85 0.70 0.64 0.78 0.53 0.65 0.68 0.90 0.94 0.86
0.58 0.77 0.89 0.88 0.76 0.56 0.60 0.57 0.67 0.72 0.76 0.91 0.89 .49
FACTOR4 Linear (FACTOR4) Poly. (FACTOR4)
FACTOR3 Linear (FACTOR3) Poly. (FACTOR3)
FACTOR5 Linear (FACTOR5) Poly. (FACTOR5)
FACTOR7 Linear (FACTOR7) Poly. (FACTOR7)
FACTOR1 Linear (FACTOR1) Poly. (FACTOR1)
FACTOR6 Linear (FACTOR6) Poly. (FACTOR6)
FACTOR2 Linear (FACTOR2) Poly. (FACTOR2)
Factor Scores
year

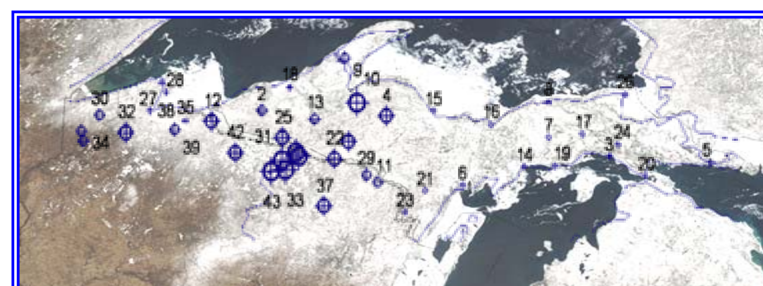
Data from cooperative stations for UP MI



Picture: www.weathermichigan.com



Location & elevation of 44 meteorological cooperative stations with annual sum of total monthly snowfall & monthly air temperature

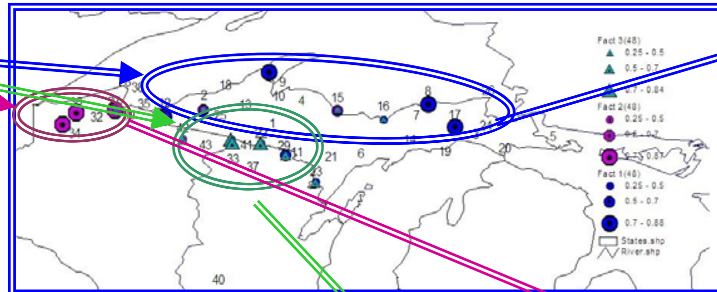


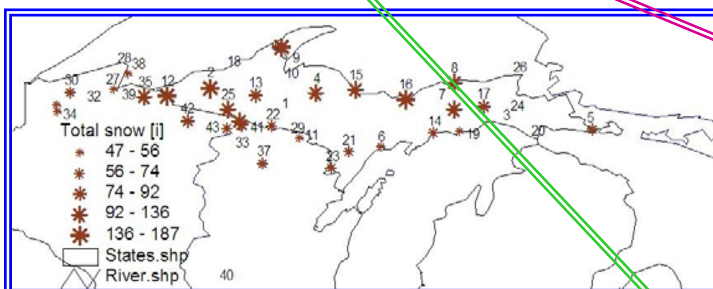
On April 8, 2003

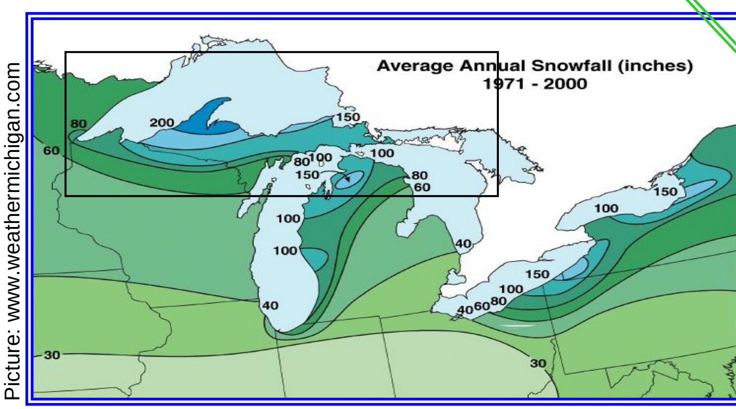
(www.osei.noaa.gov)

Annual snowfall as traditional map & as structure from initial matrix: $T_{(1952-2004*18)}$

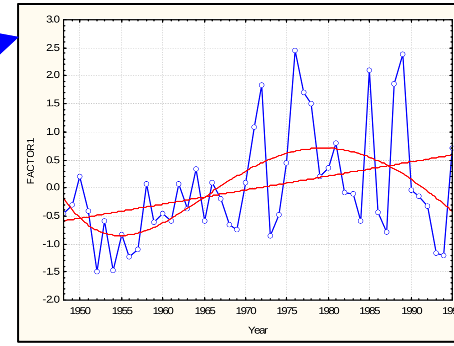
	Fact 1	Fact 2	Fact 3
TS203908	**0.88**		
TS203319	**0.81**		
TS205816	**0.78**		
TS204104	**0.72**	0.30	0.27
TS205178	***0.57***	0.29	0.31
TS200718	***0.56***	0.44	0.32
TS477892		**0.87**	
TS471131		**0.83**	
TS470349		**0.77**	0.39
TS474383	0.25		**0.84**
TS476518			**0.84**
TS207812	0.26	0.36	**0.71**
TS477092		0.45	***0.69***
TS471039	***0.58***		***0.61***
TS207867	***0.50***		***0.59***
TS205690	0.45		0.49
Expl.Var	4.36	2.90	3.95
Prp.Totl	0.27	0.18	0.25

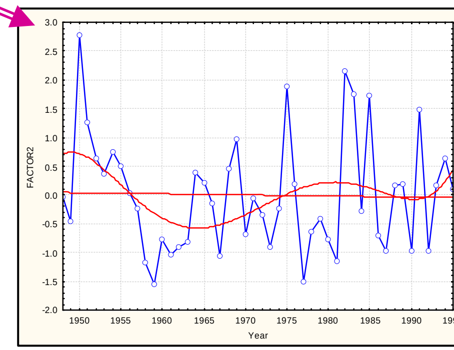


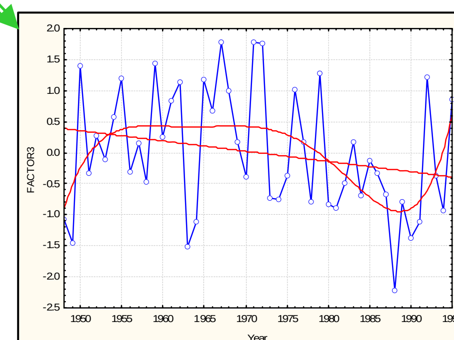




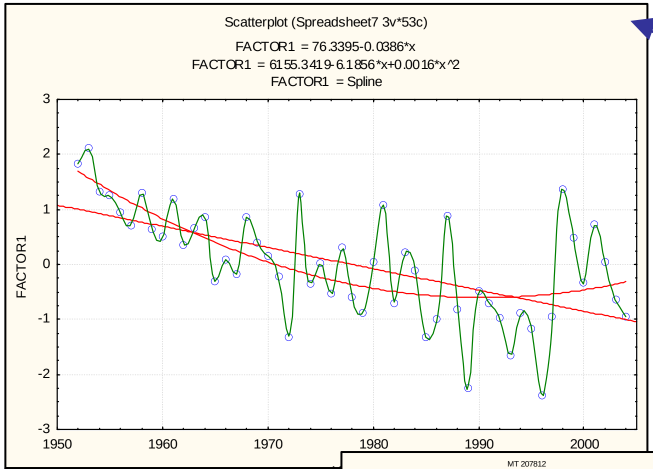
Picture: www.weathermichigan.com

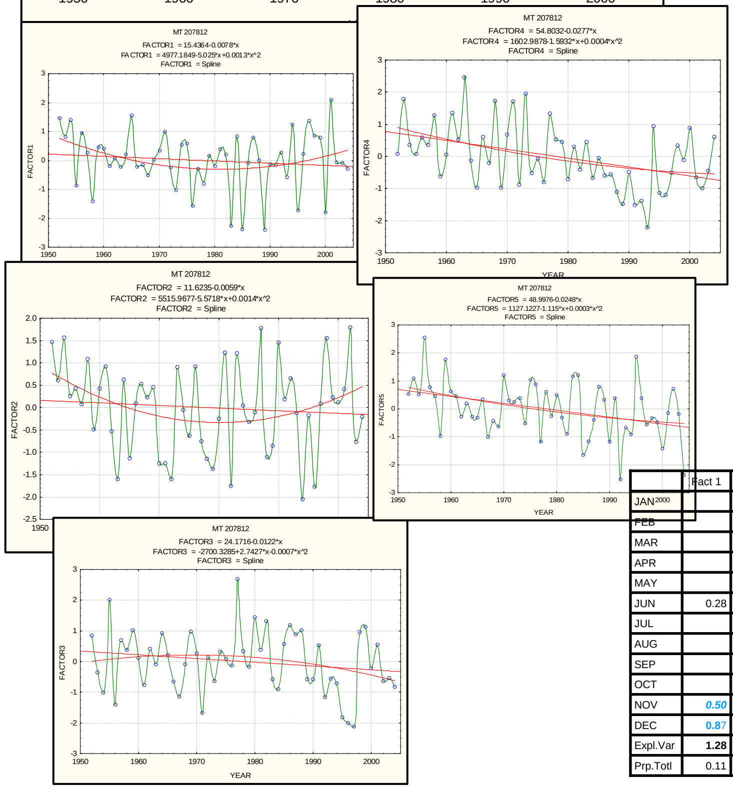


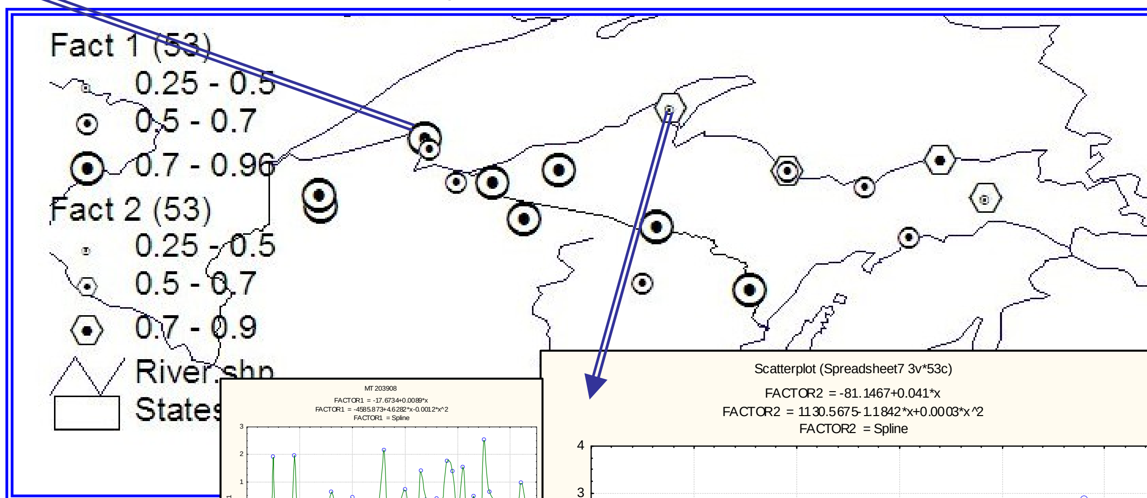


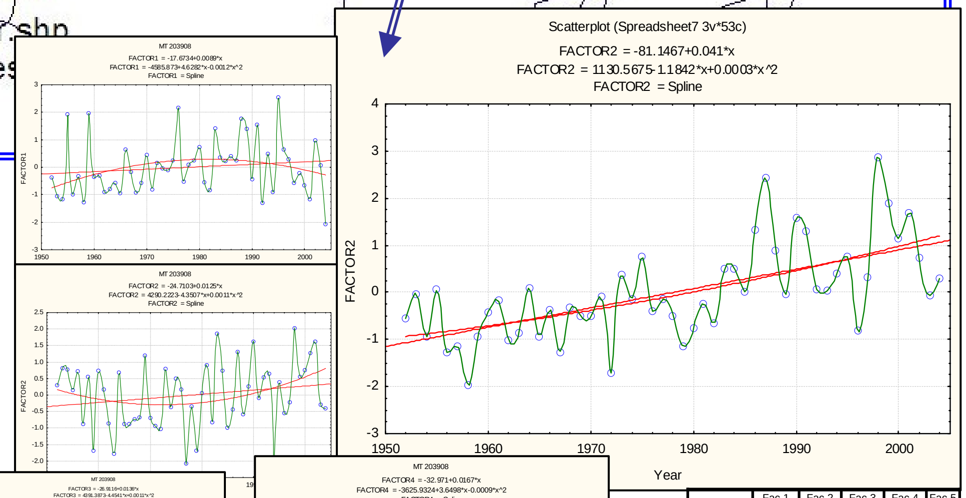


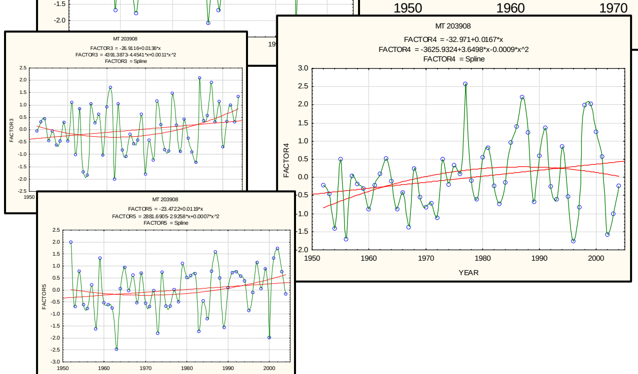
Annual & seasonal regime as a structure for monthly air temperature (UP MI)











	Fact 1	Fact 2	Fact 3	Fact 4	Fact 5
JAN		**0.77**			
FEB		**0.75**			
MAR		0.34		***0.57***	
APR		0.39	***0.64***		
MAY			**0.81**		
JUN	0.28				***0.66***
JUL			***0.52***		***0.53***
AUG					**0.80**
SEP				***0.55***	
OCT				**0.75**	
NOV	***0.50***			***0.54***	
DEC	**0.87**				
Expl.Var	**1.28**	**1.62**	**1.56**	**1.65**	**1.55**
Prp.Totl	0.11	0.14	0.13	0.14	0.13

	Fac 1	Fac 2	Fac 3	Fac 4	Fac 5
JAN		0.86			
FEB		0.75		0.28	
MAR			0.26	0.70	
APR				0.78	
MAY				0.69	
JUN	0.57		0.52		
JUL	0.62			0.41	
AUG	0.59	0.54			
SEP			0.70		
OCT	-0.36				-0.73
NOV	-0.65			0.33	
DEC			0.29		0.80
Expl.Var	**1.71**	**1.79**	**1.32**	**1.98**	**1.29**
Prp.Totl	0.14	0.15	0.11	0.17	0.11

Air temperature – observed values & model

Model for simplified Fourier analysis:

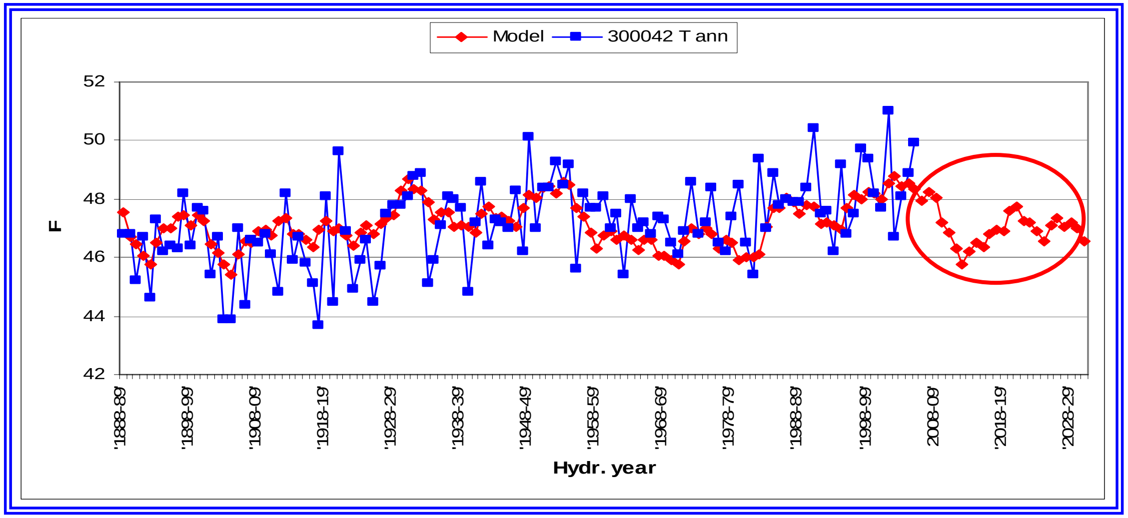
$$X_t = X_0 + \sum_{i=1}^{K} A_i \cos\left(\frac{2\pi}{T_i} t - \varphi_i\right) + Z_t ,$$

Where are:

X_t– observation, X_0 – mean for the interval of observations, A_i – amplitude, Ti – period, φ_i – phase of i-cosinusoid, Z_t – difference between observation & model.

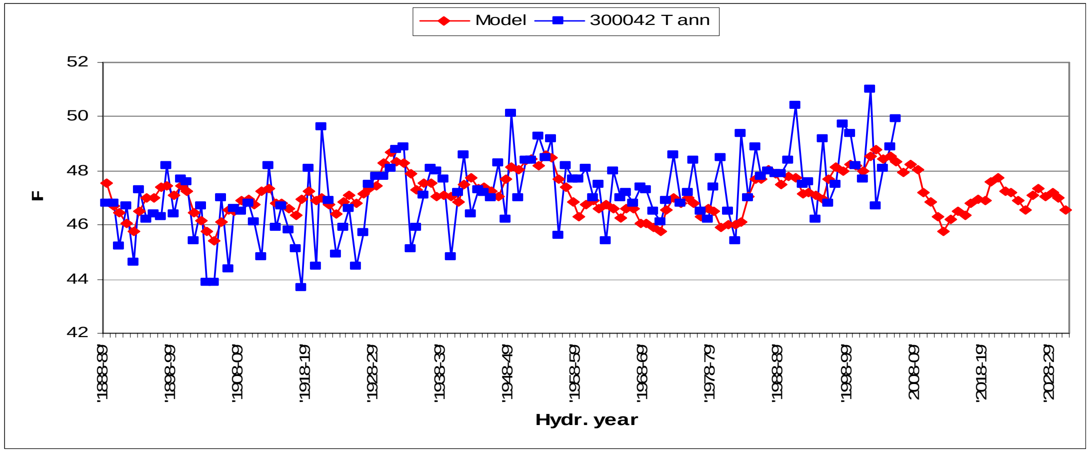
The equation quotients are calculated separately for each selected period & for all periods together under the condition of minimization of the random part

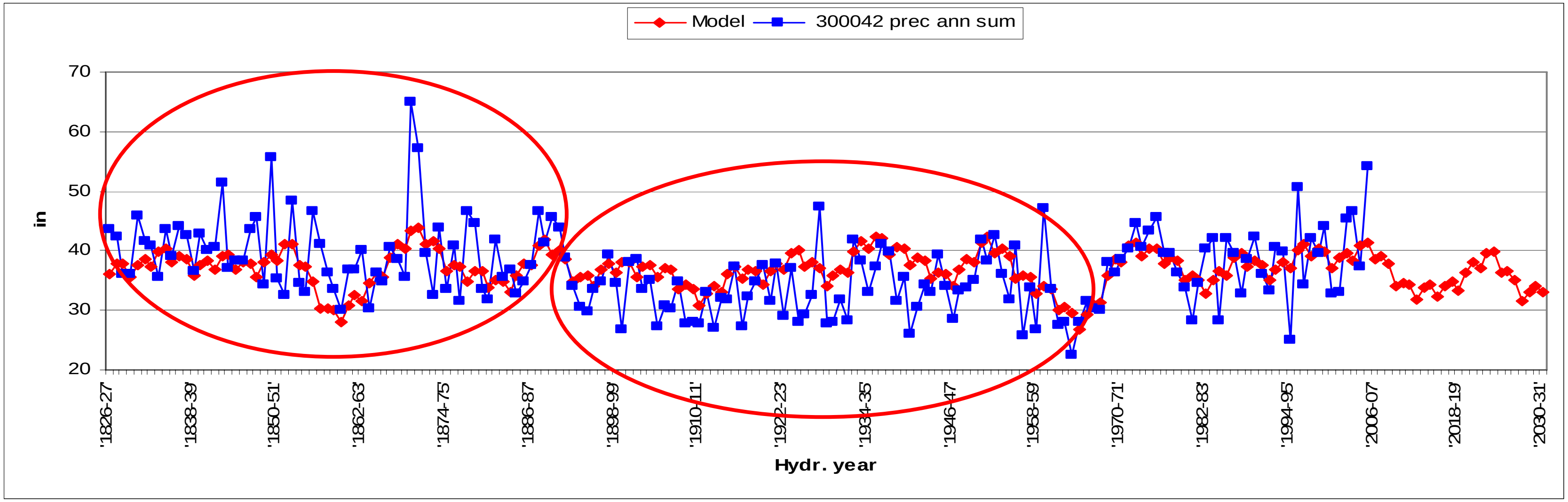
No	T- period [year]	A-amplitude [F]	φ -phase
1	62	0.703	-0896
2	18	0.402	3.325
3	11	0.373	-0.279
4	24	0.338	-1.567
5	39	0.284	-1.450
6	6	0.228	1.352
7	3	0.218	1.108
8	15	0.177	4.604
9	13	0.130	-1.311



Scale for time series

No	T- period [year]	A-amplitude [F]	φ -phase
1	17	2.257	3.684
2	53	1.863	0.761
3	26	1.665	-1.459
4	21	1.504	0.764
5	3	1.353	-0.910
6	9	1.221	0.057
7	12	0.886	1.957
8	34	0.701	2.276
9	76	0.649	2.475





The Model

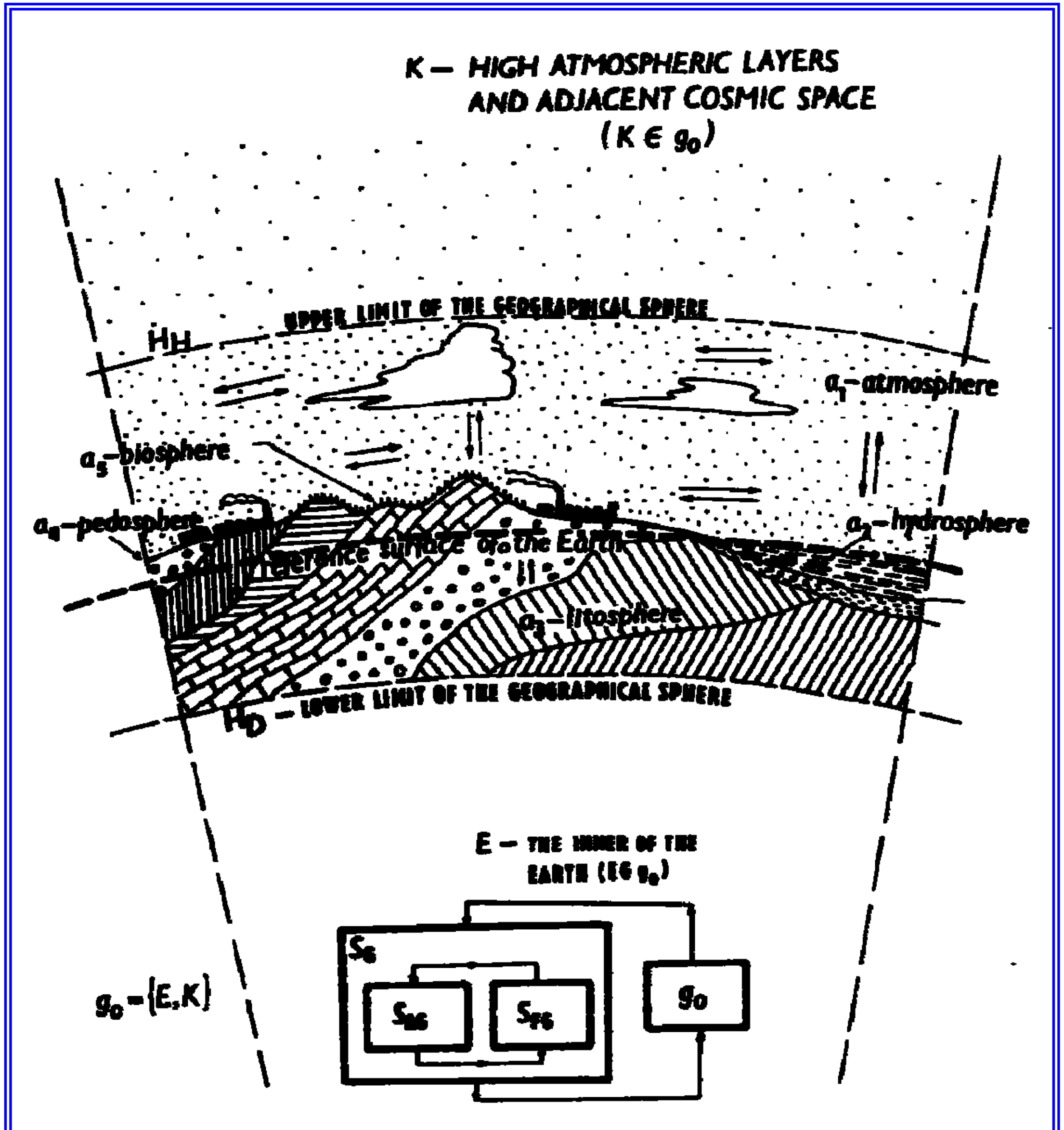
The Gap between Simulation and Understanding in Climate Modeling

BY ISAAC M. HELD

NOVEMBER 2005 BAMS | 1609

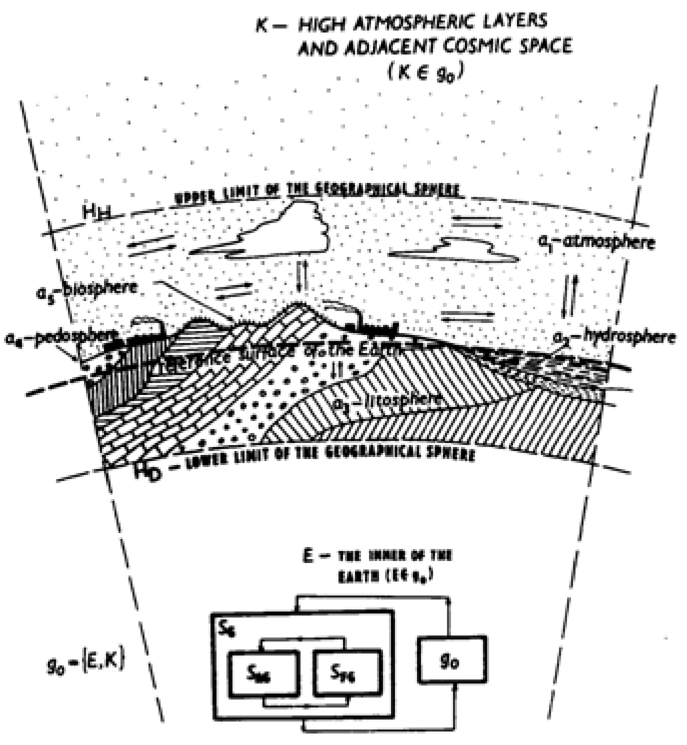
Should we strive to construct climate models of lasting value? Or should we accept as inevitable the obsolescence of our models as computer power increases?

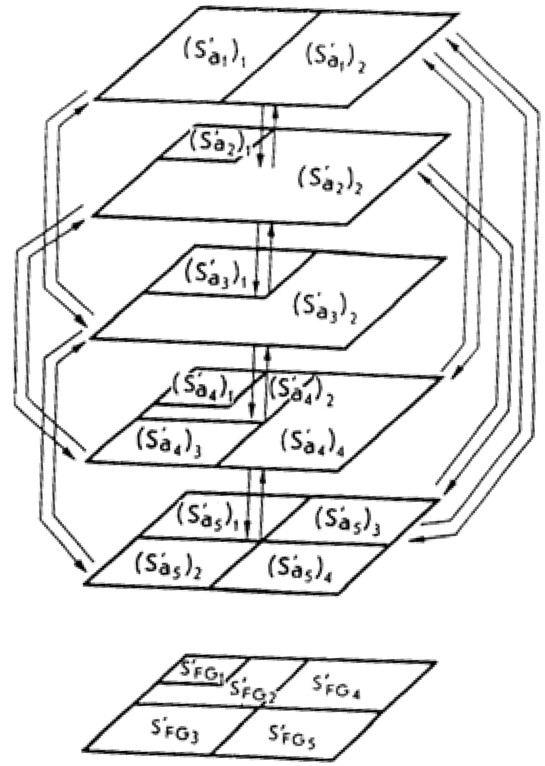
The System Model of Geosphere



Vertical slice of the Geographical Sphere with two independent elements: System of Anthropological Geography (S_{AG}) & System of Physical Geography (S_{FG}). Arrows indicate vertical and horizontal components of matter, energy and information circulating (after Krcho, 1978)

System Model for Landscape

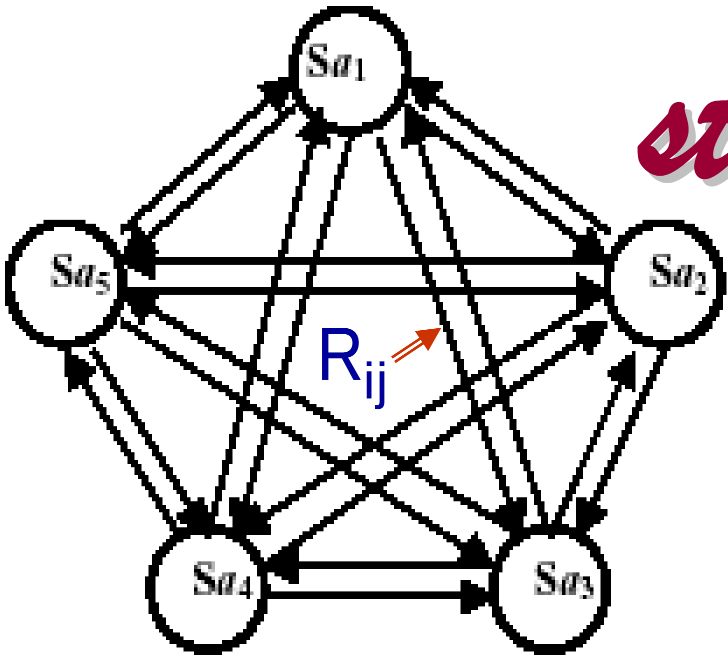




System of Physical Geography Sphere (S_{FG}) with five independent elements:
a_1- atmosphere,
a_2- hydrosphere,
a_3- lithosphere,
a_4- pedosphere,
a_5- biosphere.

Each of these components may be characterized by matrix of input {Wi}, matrix of output {Qi}, & matrix of states {Hi}.

Multidimensional structure of relations



The number of characteristics for elements of landscape and watershed is unlimited but for stable landscape the set of watersheds or stations with data allows to obtain statistical description of connections.

{Ri}
is a matrix of relations between parts of landscape.
Entering the codes and numbers for initial matrix $\{X_{n*p}\}$ we open the way to recovery connections those exist in landscape

Axis for hydrological space – factors (principal components) of initial data matrixes $\{X_{n*p}\}$,
allow consider
{Ri}
as a time spatial structure.

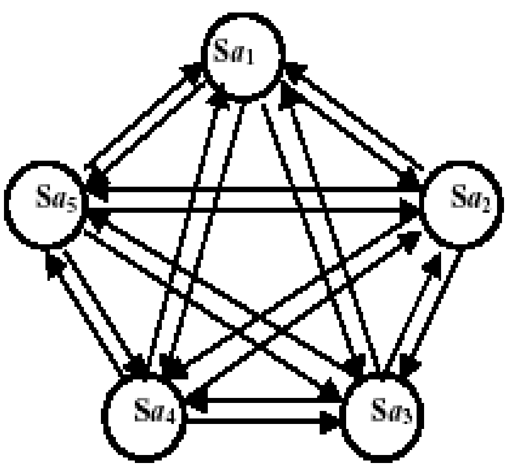
Discover of invisible structure by system analysis

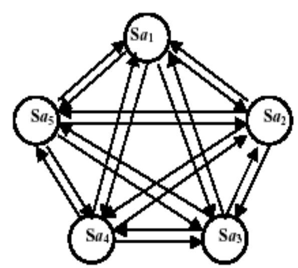
Long-Term Ecological Research and the Invisible Present

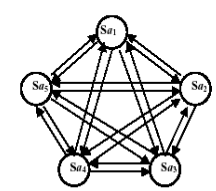
Uncovering the processes hidden because they occur slowly or because effects lag years behind causes

John J. Magnuson

July/August 1990







Results for discussion

- System model applied to landscape allows to formulate research tasks, develop methods of analysis, & present results as a map

- Hydrological object has a scaled time-spatial structure of interaction (straight & feedback connections) with other components of landscape (air, rocks & sediments, soil, plants & animals)

- The complex multidimensional structure of time spatial regime for regional hydrosphere was described for U. S. part of Great Lake watershed

- The entire set of empirical data was used

- Results may be used for improvement of observational net & in applications

Questions?

Scientific research completed on a base of authors donated time