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

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Introduction

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

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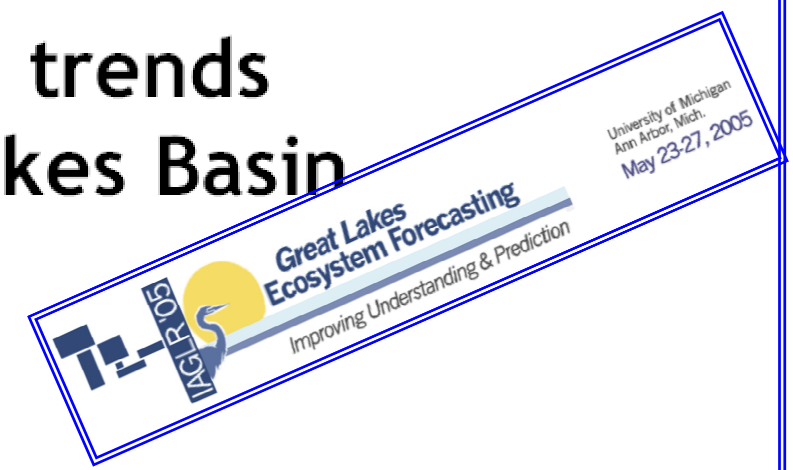

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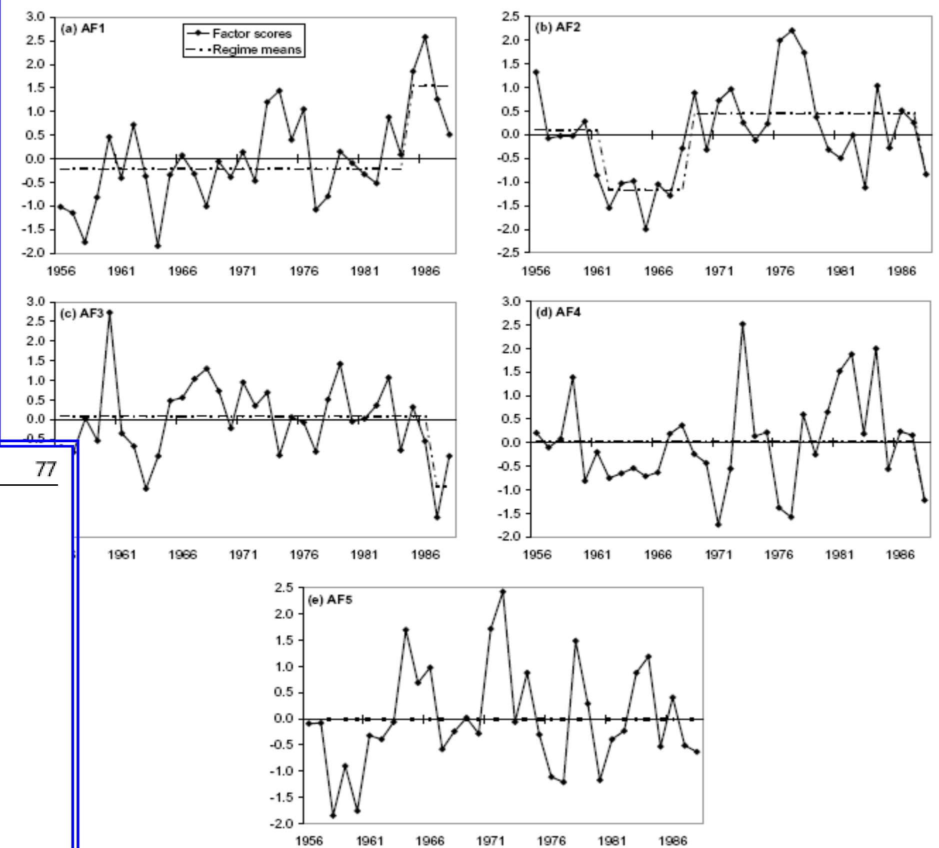
Five main regions & streamflow regimes



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

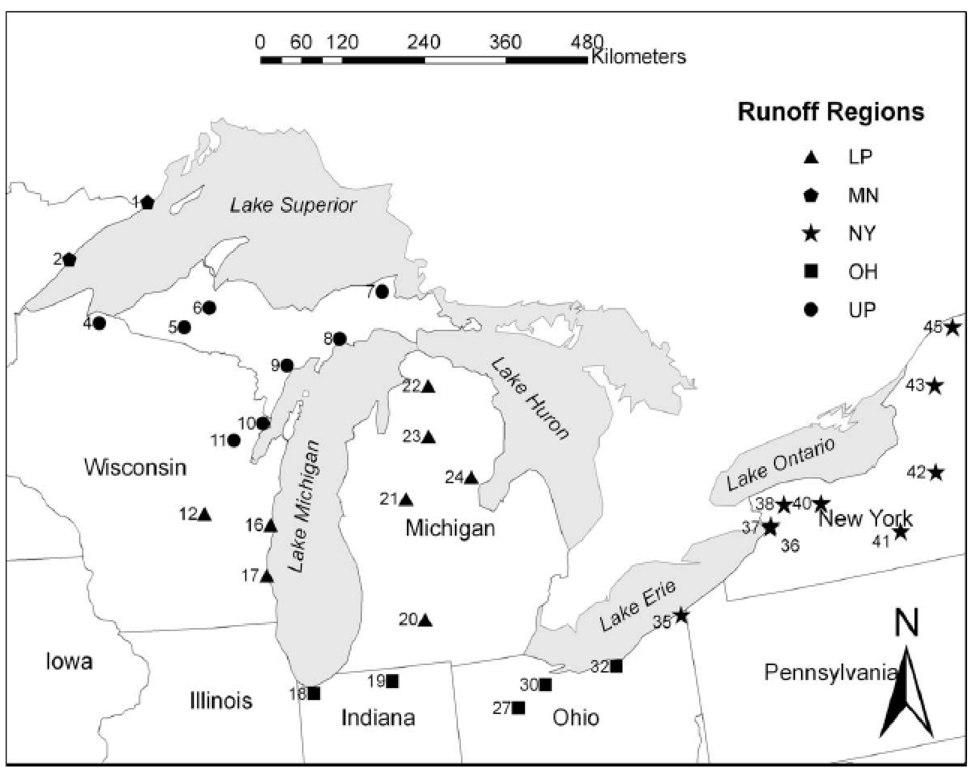


Figure 3 Assignment of gauging stations to regions based on factor analysis of annual discharge.

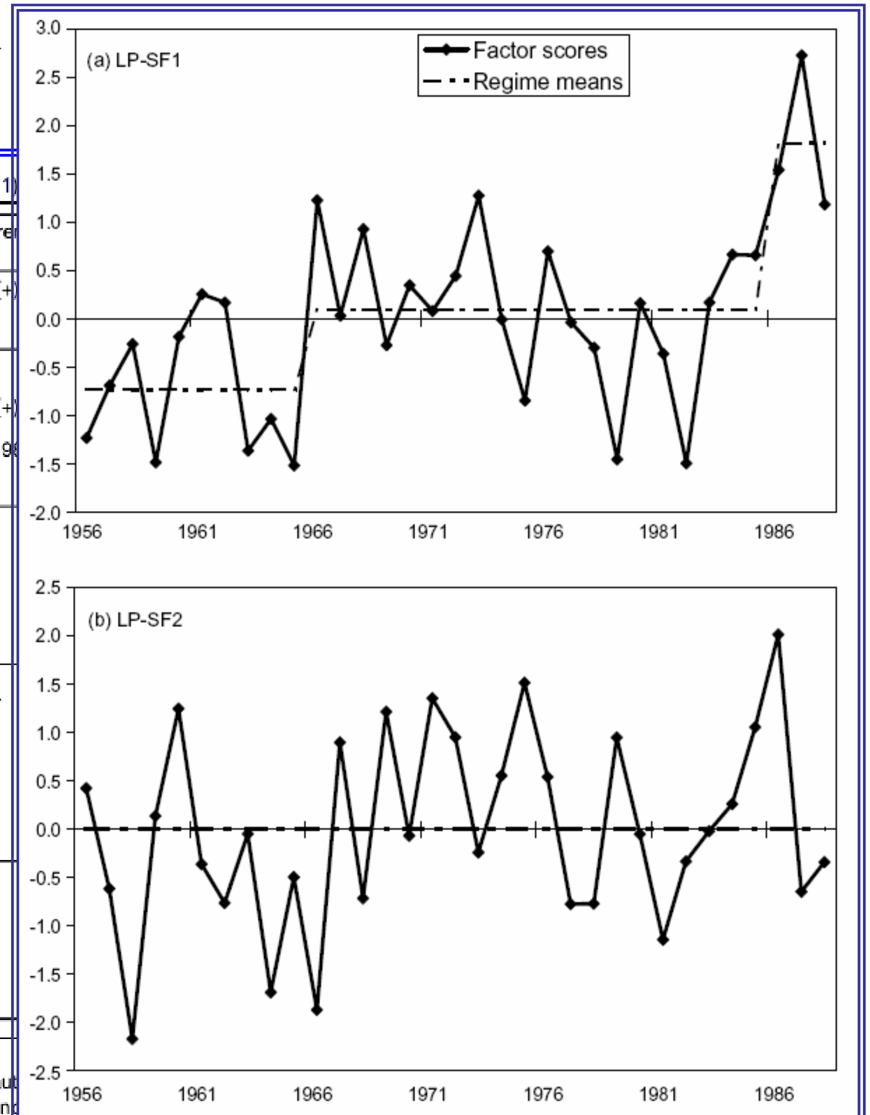
Seasonal regimes for typical watersheds

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

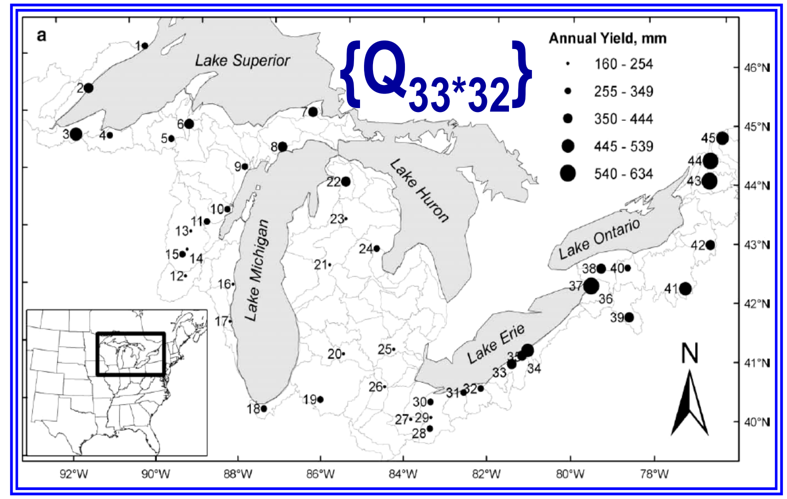
	Factor	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Var.	% Var.	tau	p	Regime shift year (tre
LP	**1**	0.79	0.90	0.81	0.87	0.91	0.72							4.61	38.4	0.292	**0.018**	1966(+), 1986(+
	2							0.80	0.83	0.83	0.77	0.69		3.74	31.2	0.114	0.361	none
NY	1											0.91	0.86	2.44	20.3	0.205	0.097	none
	2	0.69	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*)

Knowledge of new level may come only from analysis of empirical data

The explanation for regime of streamflow has to be found

Consideration of the Great Lakes watershed as uniform in joint boundaries or in administrative boundaries is the common approach for analysis of regime of precipitation

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

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An analysis of annual precipitation over the Great Lakes Basin from 1854 to 1979 indicates two distinct precipitation regimes. The first, a relatively dry regime, lasted from the mid-1880's until the late 1930's. This was followed by a relatively wet regime, which continues to the present. The analysis also indicates that the annual precipitation regime prior to the mid-1880's was similar to the present regime. The change in precipitation appears to be the result of increased precipitation during spring and summer. A continuation of the present wet regime will present many challenges for water resource managers and planners concerned with lake regulation, water supply forecasting, coastal zone mana

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]

Received 9 April 2008; revised 3 July 2008; accepted 27 August 2008; published 5 November 2008.

[1] Consequences of possible changes in annual total precipitation are dictated, in part, by the timing of precipitation events and changes therein. Herein, we investigated historical changes in precipitation seasonality over the US using observed station precipitation records to compute a standard seasonality index (SI) and the day of year on which certain percentiles of the annual total precipitation were achieved (percentile day of year). The mean SI from the majority of stations exhibited no difference in 1971–2000 relative to 30-year periods earlier in the century. However, analysis of the day of year on which certain percentiles of annual total precipitation were achieved indicated spatially coherent patterns of change. In some regions, the mean day of the year on which the 50th percentile of annual precipitation was achieved differed by 20–30 days between 1971–2000 and both 1911–1940 and 1941–1970. Output from the 10-Atmosphere-Ocean General Circulation Models (AOGCM) simulations of 1971–2000, 2046–2065, and 2081–2100 was used to determine whether AOGCMs are capable of representing the seasonal distribution of precipitation and to examine possible future changes. Many of the AOGCMs qualitatively captured spatial patterns of seasonality during 1971–2000, but there was considerable divergence between AOGCMs in terms of future changes. In both the west and southeast, 7 of 10 AOGCMs indicated later attainment of the 50th percentile accumulation in 2047–2065, implying a possible reversal of the twentieth-century tendency toward relative increases in precipitation receipt during winter and early spring over the southeast. However, this is also a region characterized by considerable interannual variability in the percentile day of year during the historical period.

Citation: Pryor, S. C., and J. T. Schoof (2008), Changes in the seasonality of precipitation over the contiguous USA, *J. Geophys. Res.*, *113*, D21108, doi:10.1029/2008JD010251.

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

Thomas R. Karl and Richard W. Knight

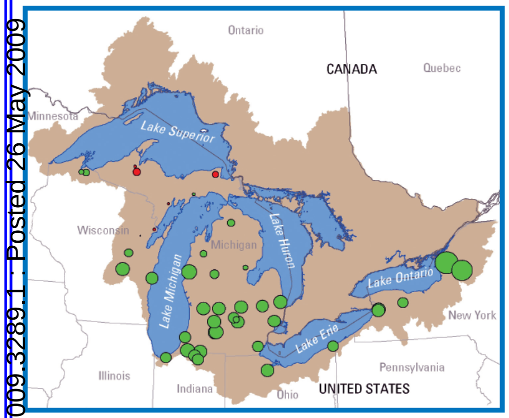
NOAA/NESDIS/National Climatic Data Center, Asheville, North Carolina

Vol. 79, No. 2, February 1998

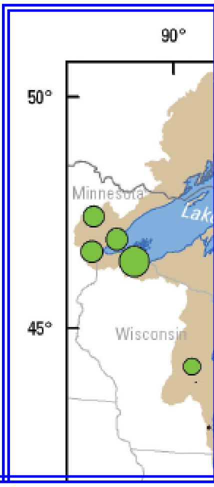
USGS
science for a changing world

National Water Availability and Use Program

Historical Changes in Precipitation and Streamflow in the U.S. Great Lakes Basin, 1915–2004



Scientific Investigations Report 2007–5118



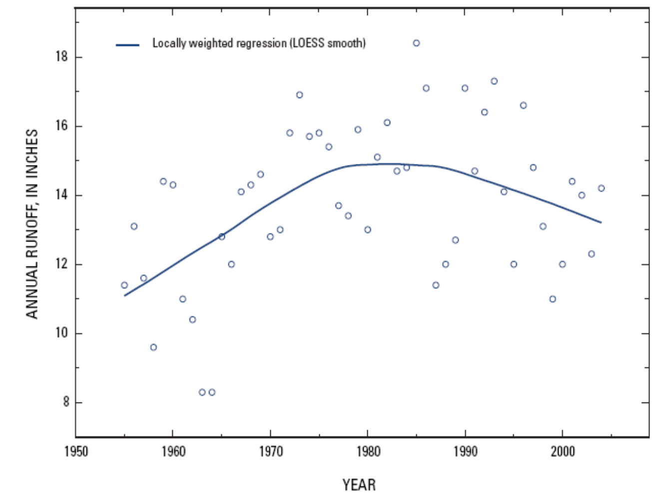


Figure 5. Annual runoff for the average of 43 stations in the U.S. Great Lakes Basin, 1955–2004.

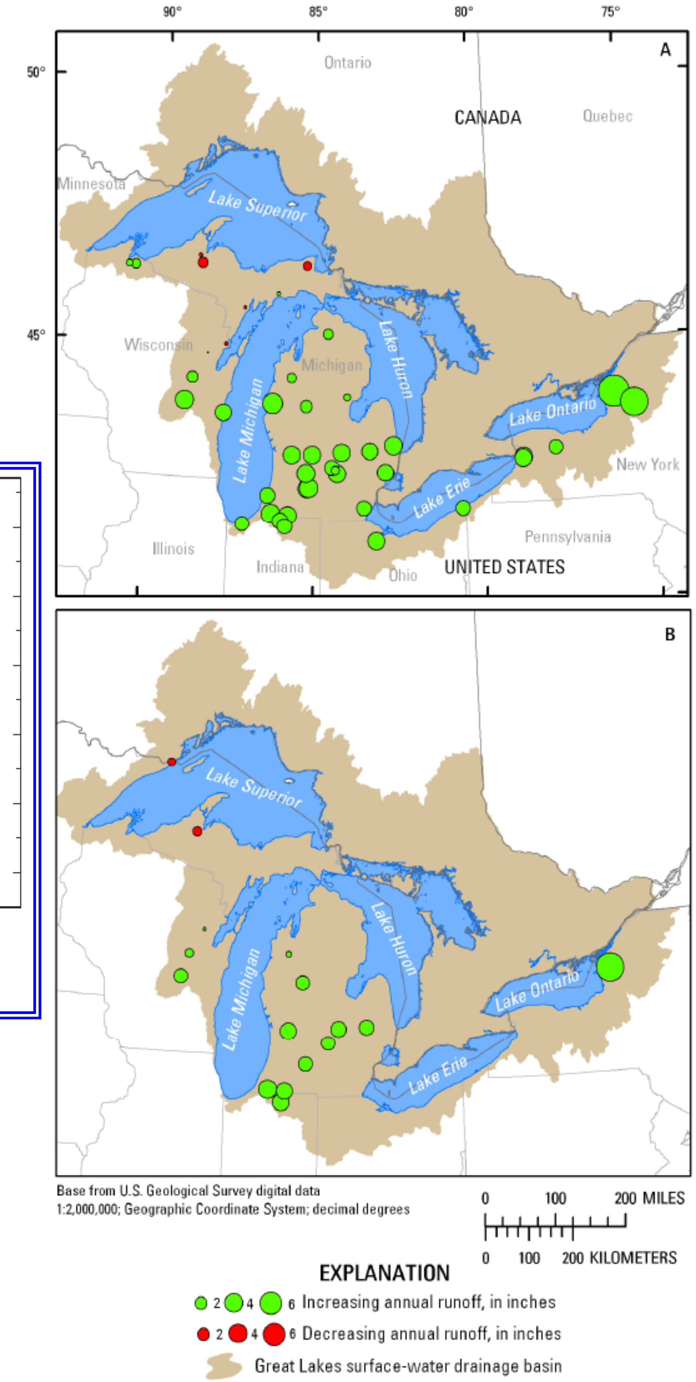
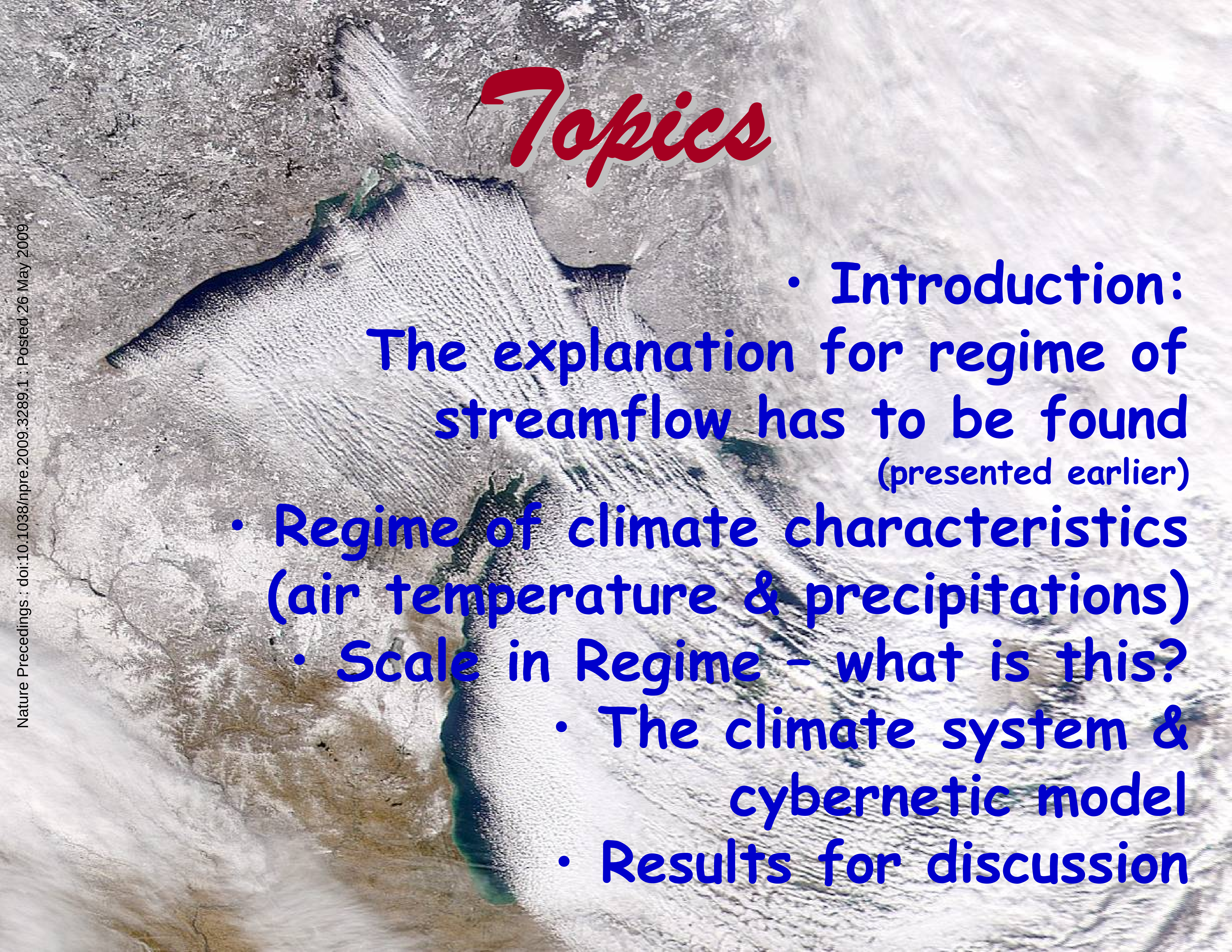


Figure 6. Changes in annual runoff, by station, for (A) 1955–2004 and (B) 1935–2004. Circle sizes proportional to increases or decreases

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

Analysis completed for stations not for region



Topics

• Introduction:
The explanation for regime of streamflow has to be found
(presented earlier)

• Regime of climate characteristics (air temperature & precipitations)

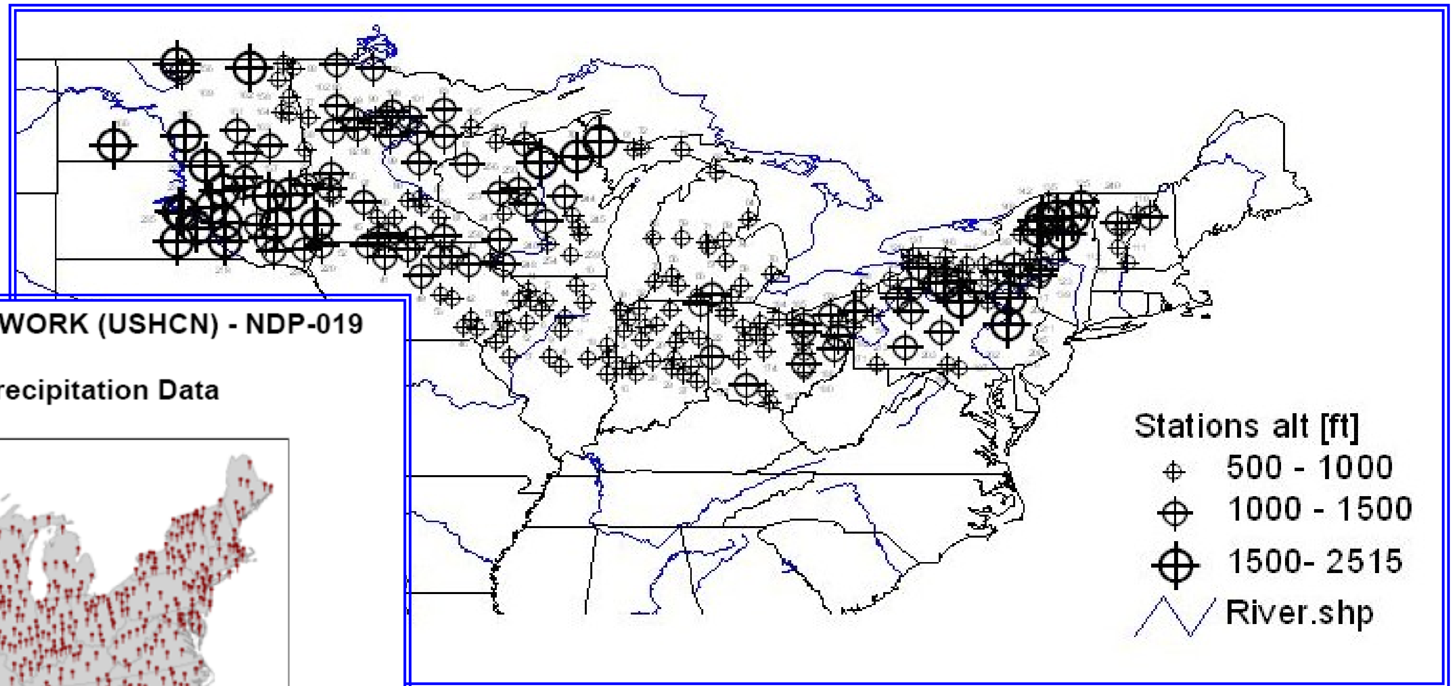
• Scale in Regime – what is this?

• The climate system & cybernetic model

• Results for discussion

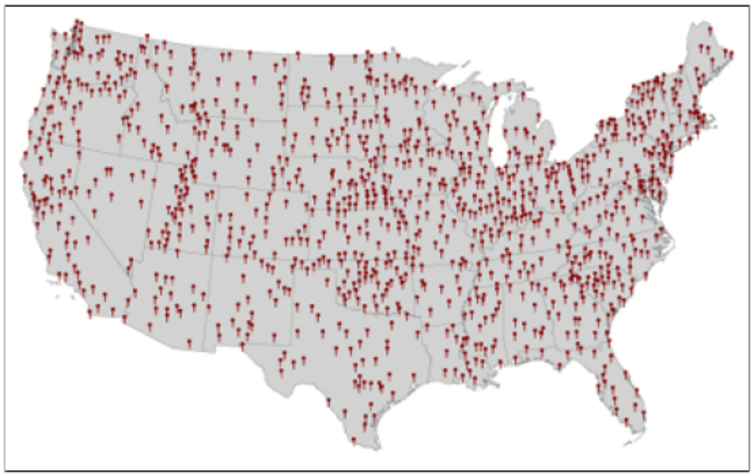
$\{P_{105*165}\}$

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



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
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University of Tennessee-Battelle, LLC
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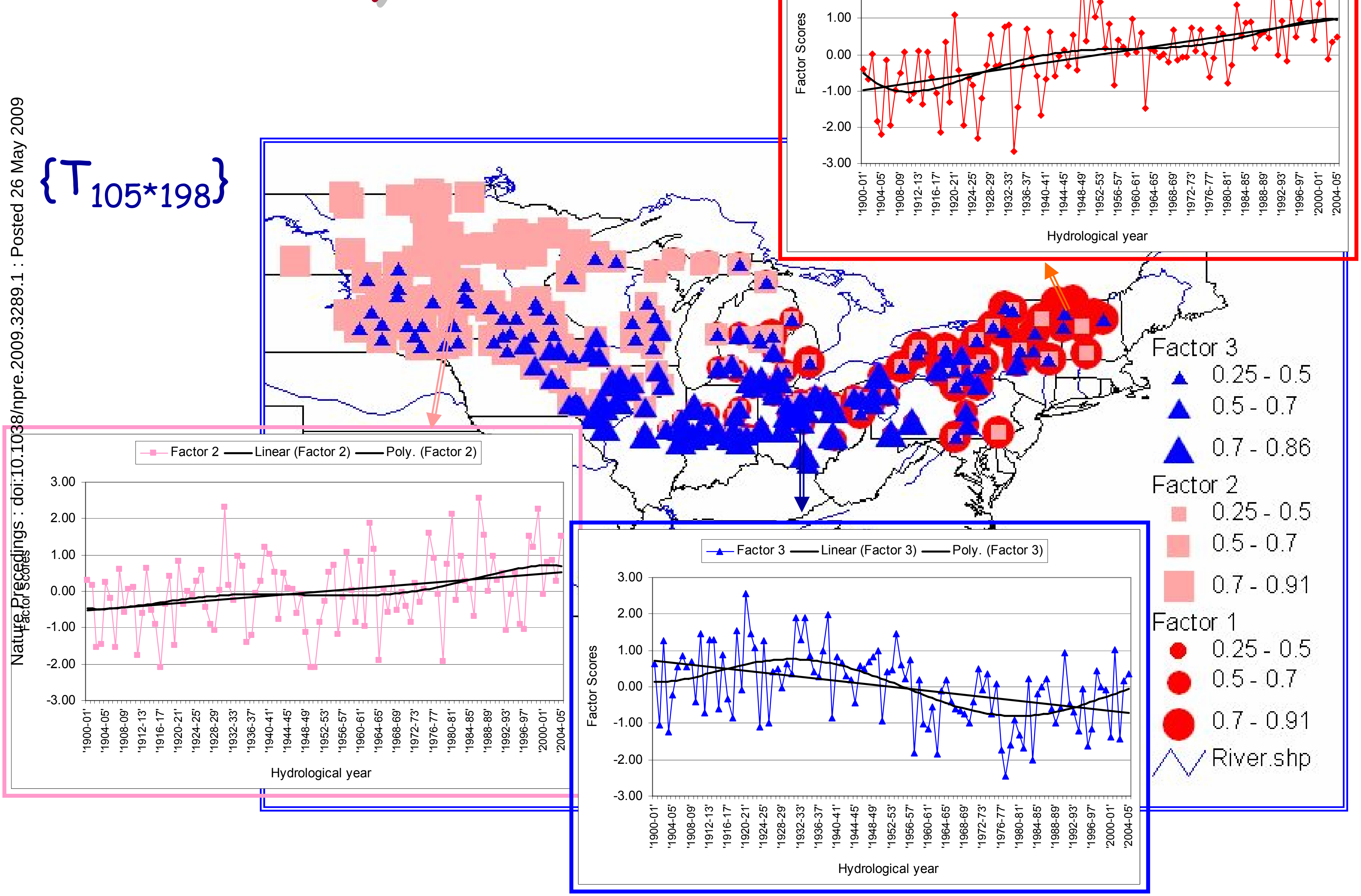
under contract DE-AC05-00OR22725

Data for characteristics of climate regime

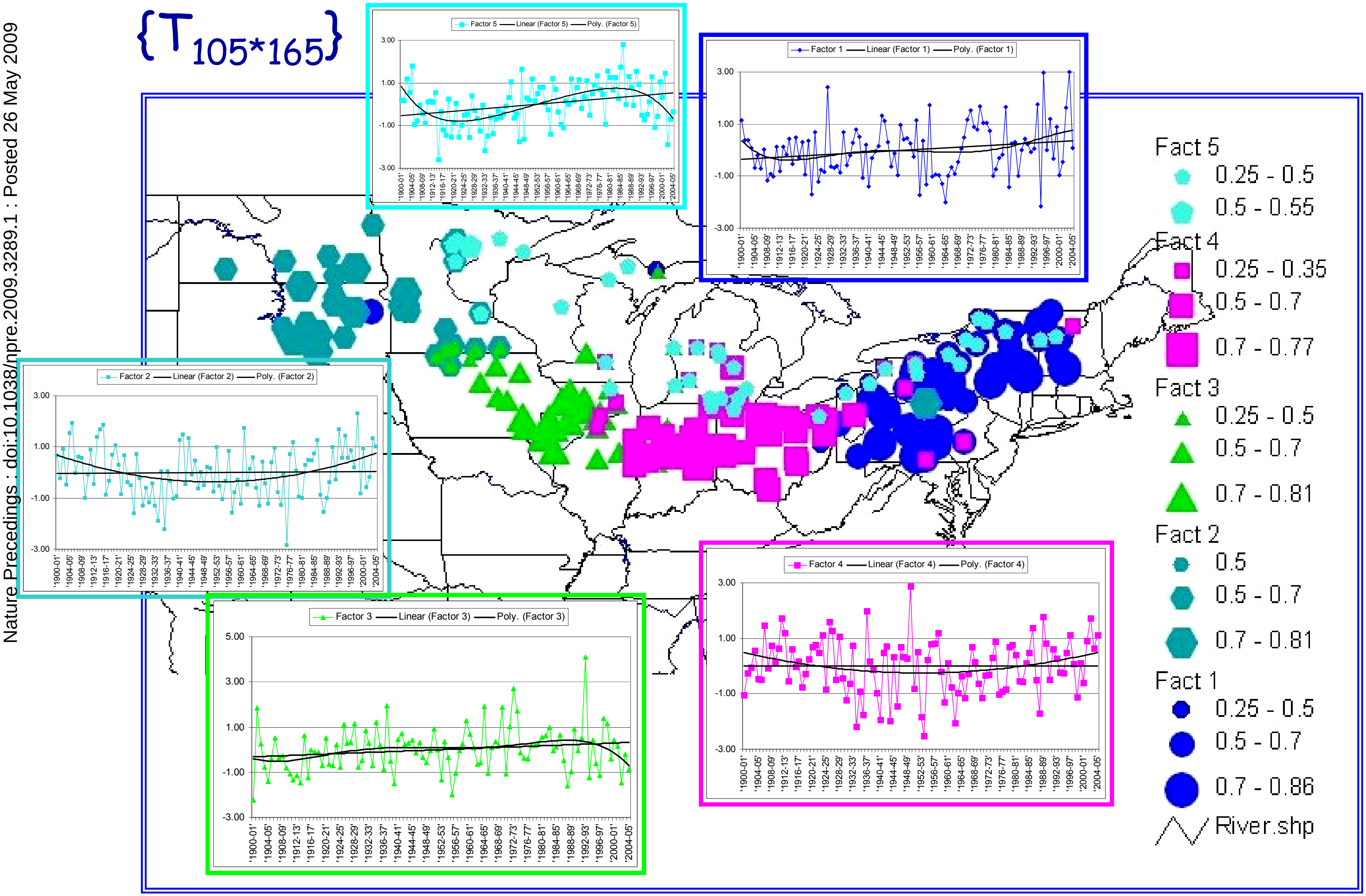
Air temperatures

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

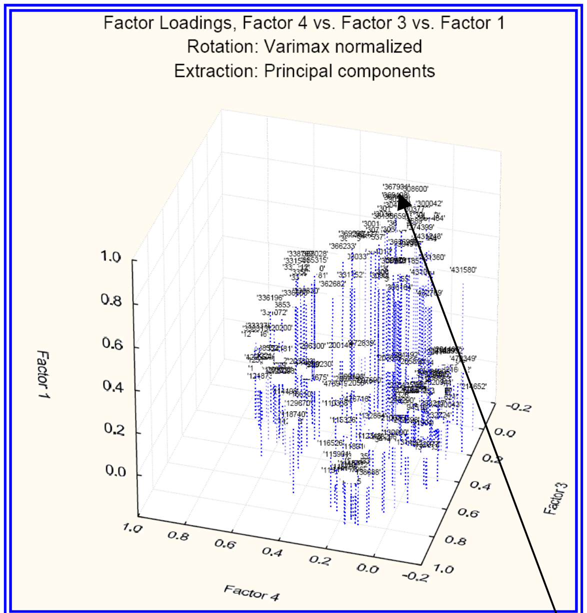


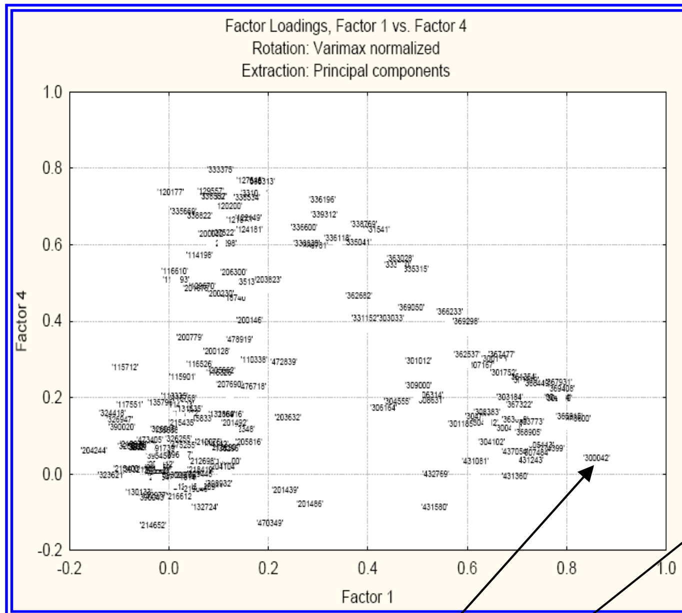
Precipitation, annual sum

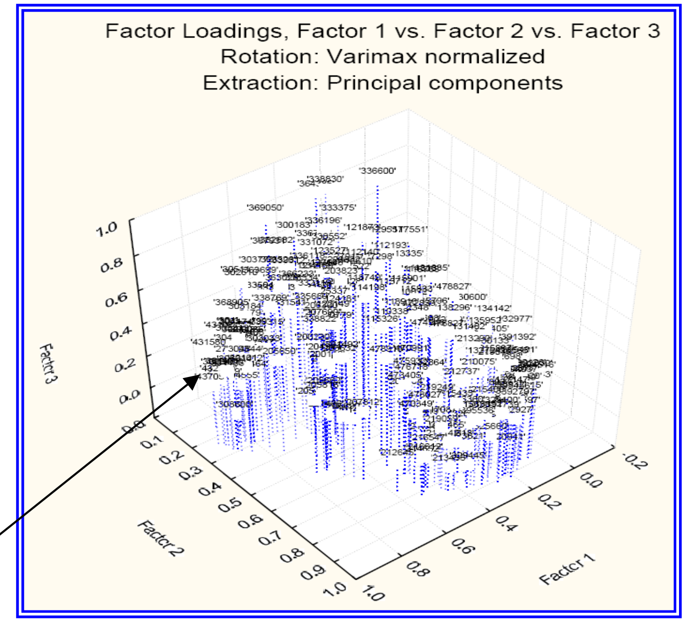
$\{T_{105*165}\}$



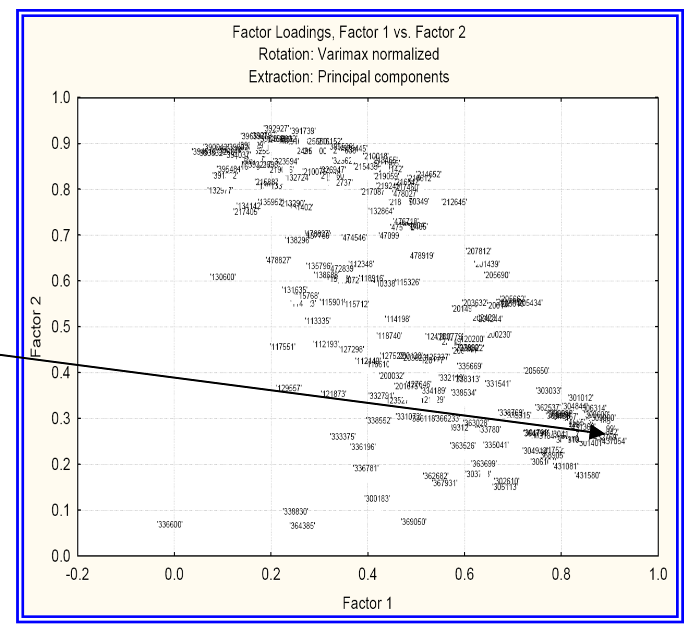
The typical stations





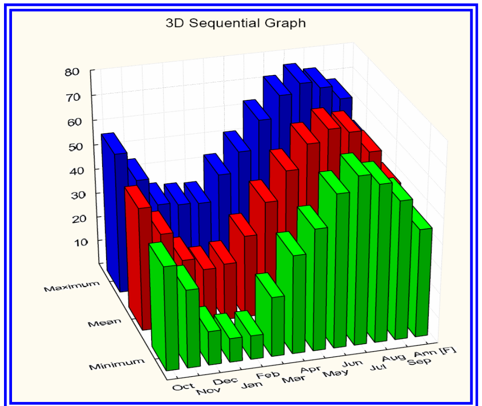


Explained Variability by Factor in "Precip." [%]	Explained Variability by Factor in "Temp." [%]	No of COOP station	Factor Loading of station in "Precip."	Factor Loading of station "Temp."
I - 14	I - 27	300042	I - 0.86	I - 0.89
II - 10	II - 35	391739	II - 0.81	II - 0.91
III - 10		115768	III - 0.81	
IV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



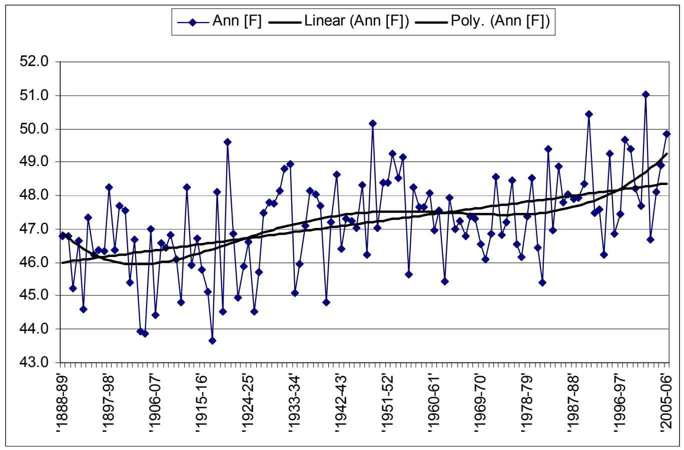
Station 300032, air temperatures

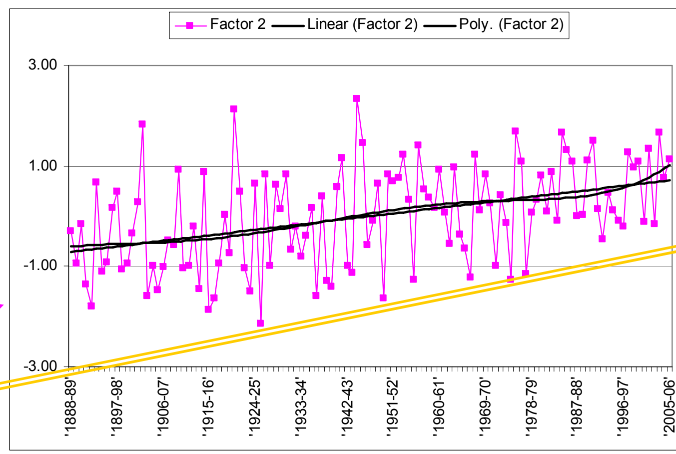
T300042 (118*12,13)

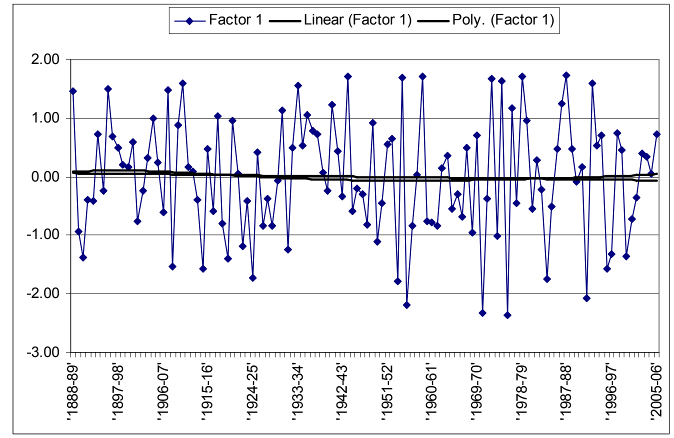


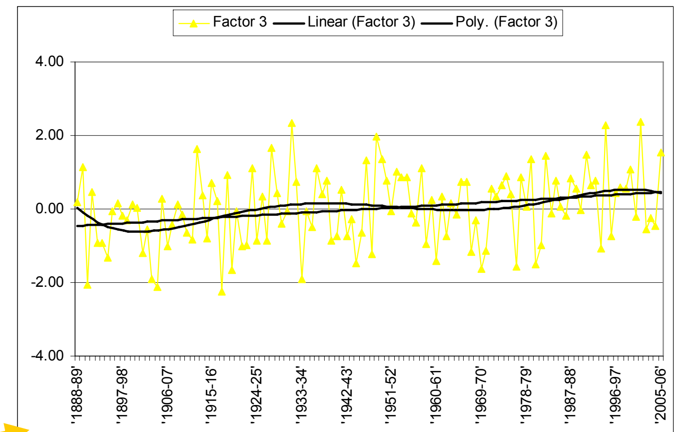
	Factor 1	Factor 2	Factor 3	Factor 4
Jan	**0.74**			
Ann [F]	**0.71**	0.35	***0.59***	
Dec	**0.70**			
Nov	***0.61***		0.33	
Jun		**0.73**		
Aug		***0.64***		
Sep		0.48	0.49	
Mar		-0.34	**0.75**	
Apr			**0.73**	
Feb	0.33		***0.52***	-0.34
Oct	0.27	0.32		-0.40
May				***0.55***
Jul		0.26		**0.76**
Expl.Var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

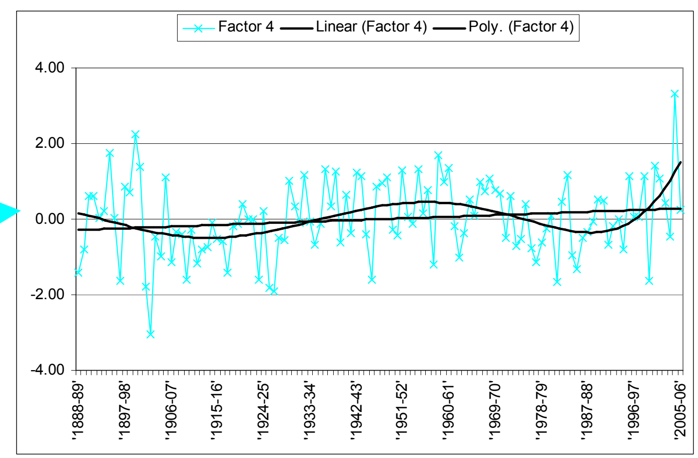
	Factor 1	Factor 2	Factor 3	Factor 4
Jul	0.76			0.26
May	0.54			
Mar		0.77		-0.30
Apr		0.73		
Feb	-0.34	0.51	0.30	0.28
Jan			0.73	
Dec			0.70	
Nov		0.37	0.61	
Aug	0.25		0.30	0.62
Jun				0.73
Sep		0.45		0.50
Oct	-0.40			0.34
Expl.Var	1.31	1.83	1.71	1.57
Prp.Totl	0.11	0.15	0.14	0.13







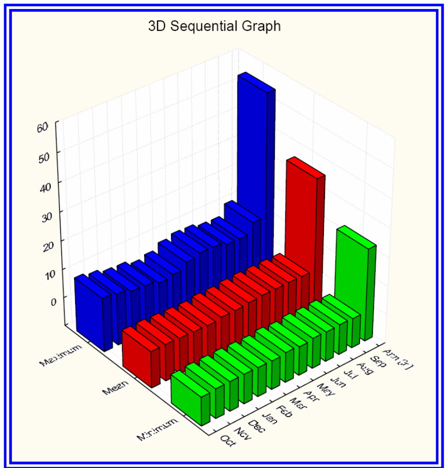


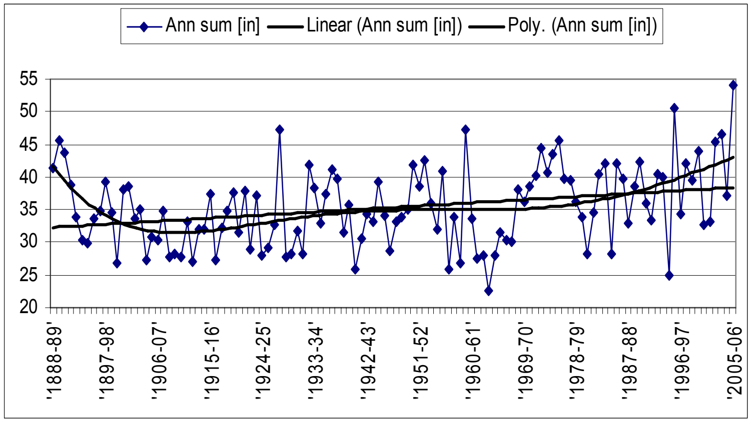


Trend in annual values reflects different trends of seasons

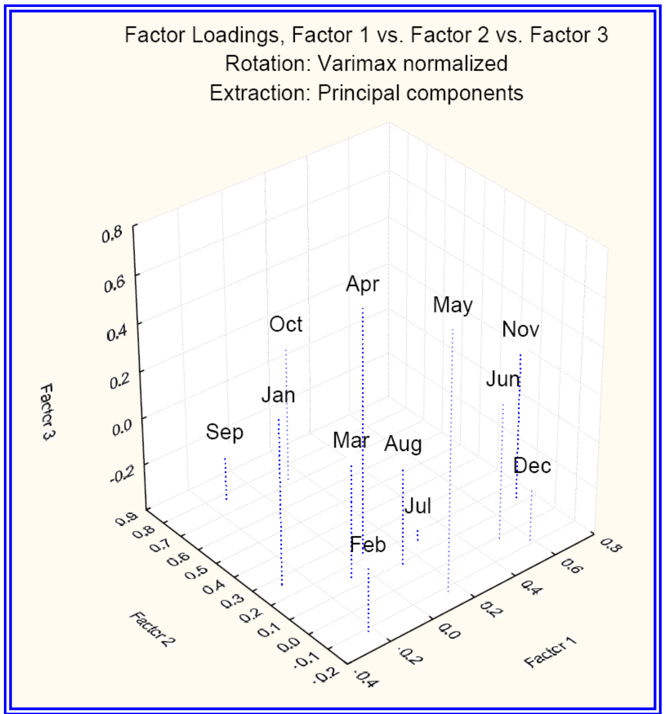
Station 300032, precipitation

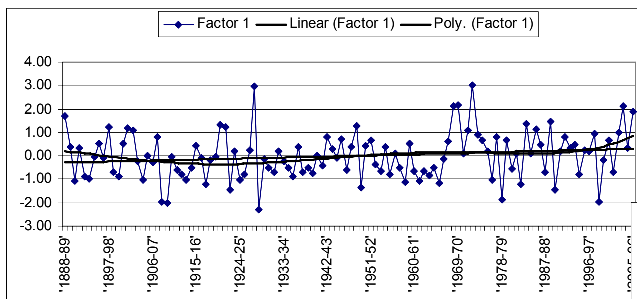
P300042 (118*12,13)

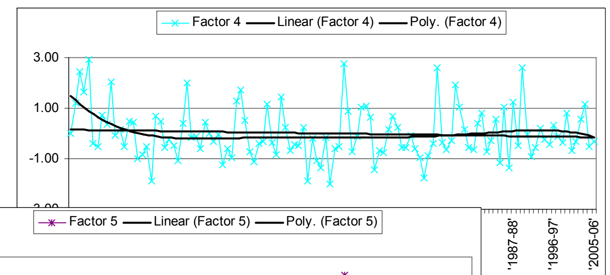


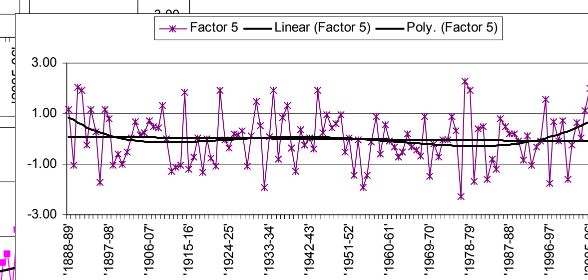


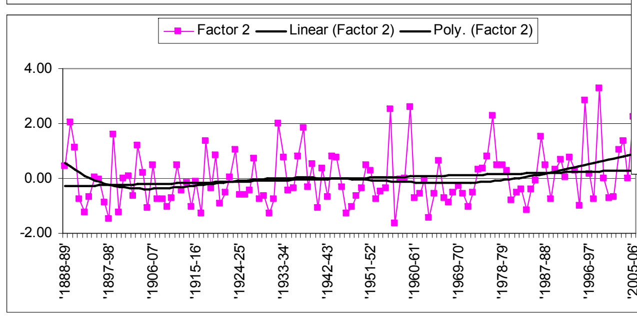
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Sep	**0.79**				
Oct	***0.66***				
Ann [in]	***0.64***	***0.53***	0.42	0.33	
Nov		***0.68***	0.28		
Dec		***0.63***			
Jun		***0.52***			-0.33
May			**0.71**		
Apr			**0.70**		
Aug				**0.80**	
Feb				**0.72**	
Mar					**0.73**
Jul	0.26	0.37	-0.36		-0.36
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

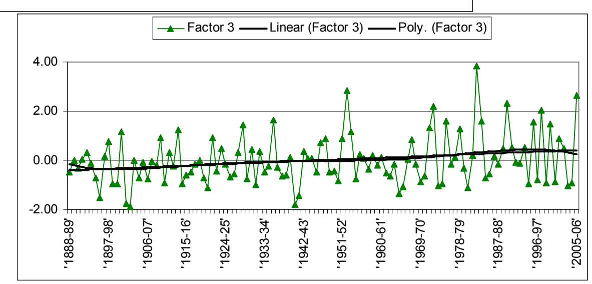








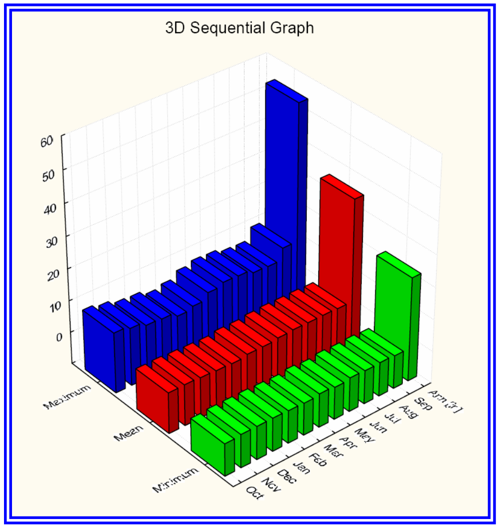




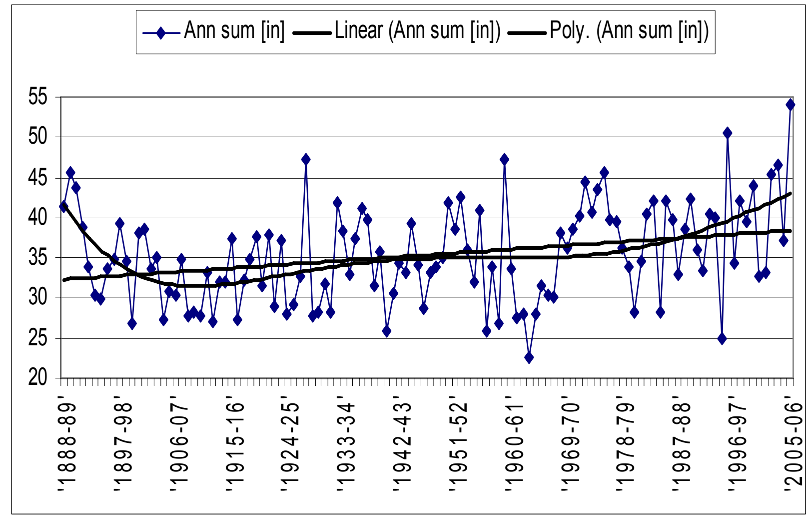
Trend in annual values reflects different trends of seasons

Station 300032, precipitation

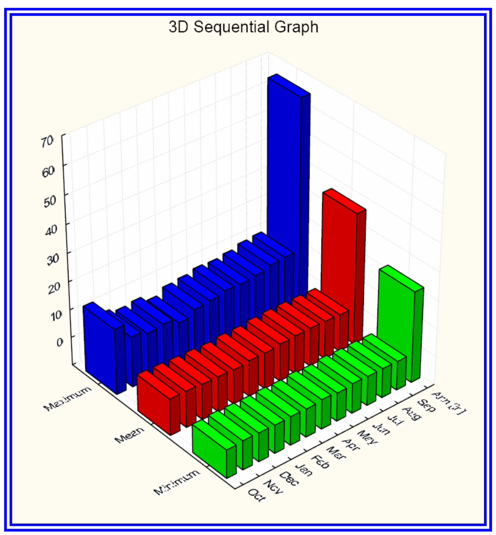
P300042 (118*12,13)

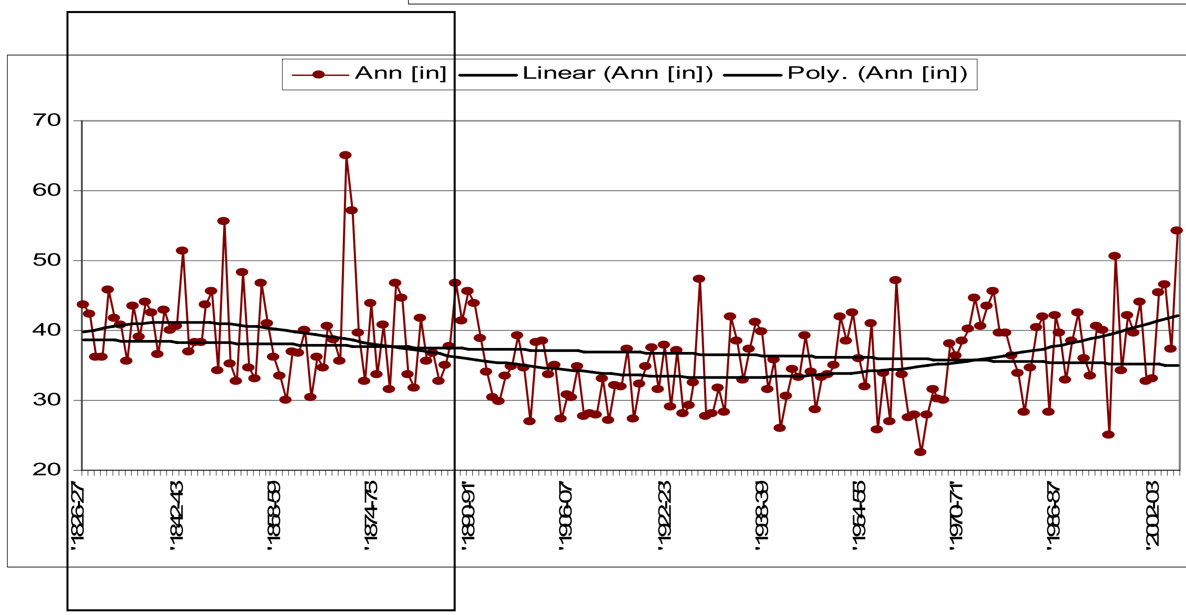


Use of longer time series changes the trend



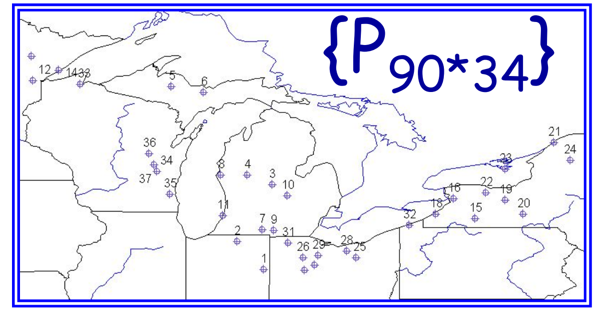
P300042 (180*12,13)

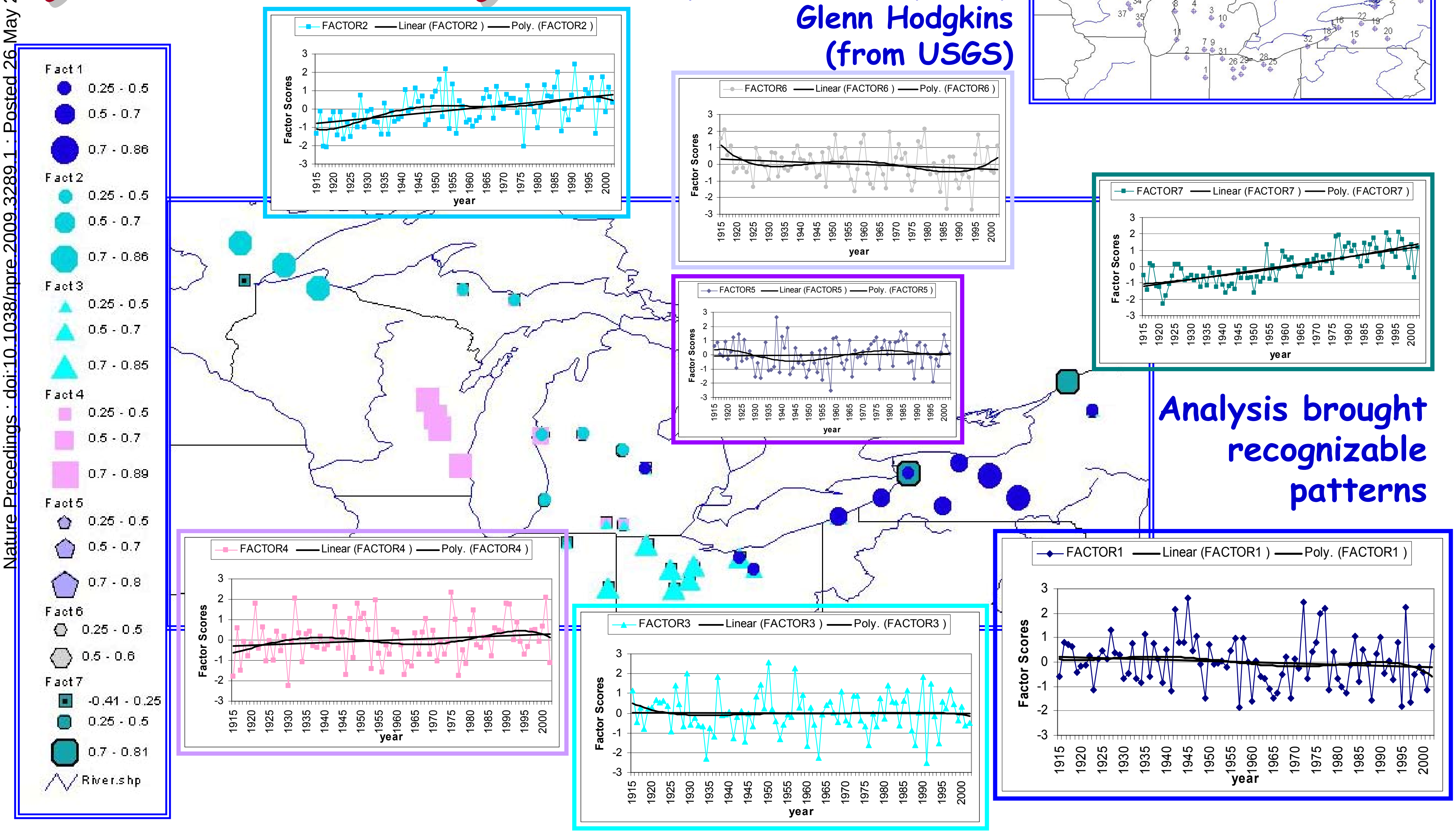




Analyzing precipitation data from USGS

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





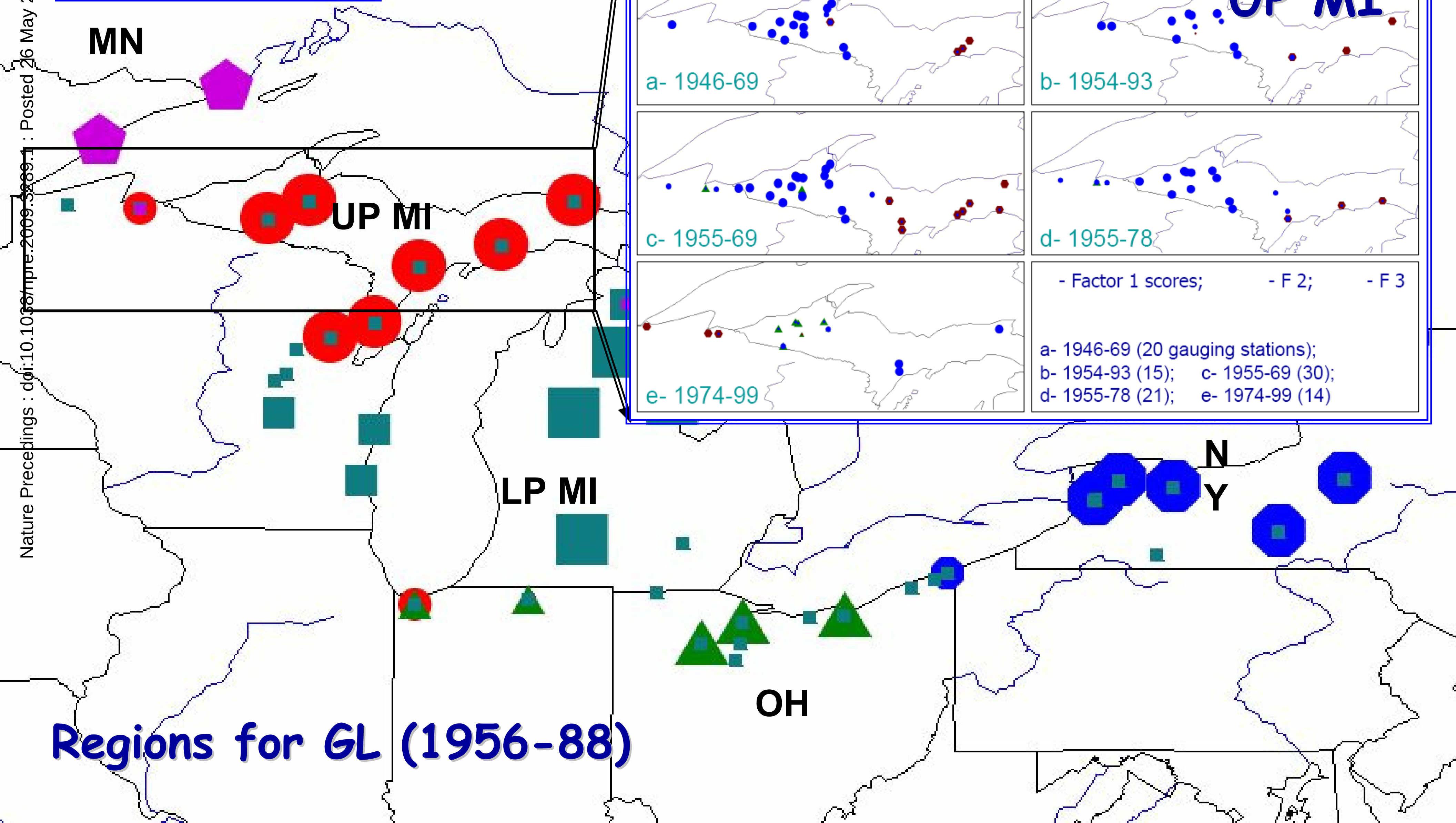
Analysis brought recognizable patterns

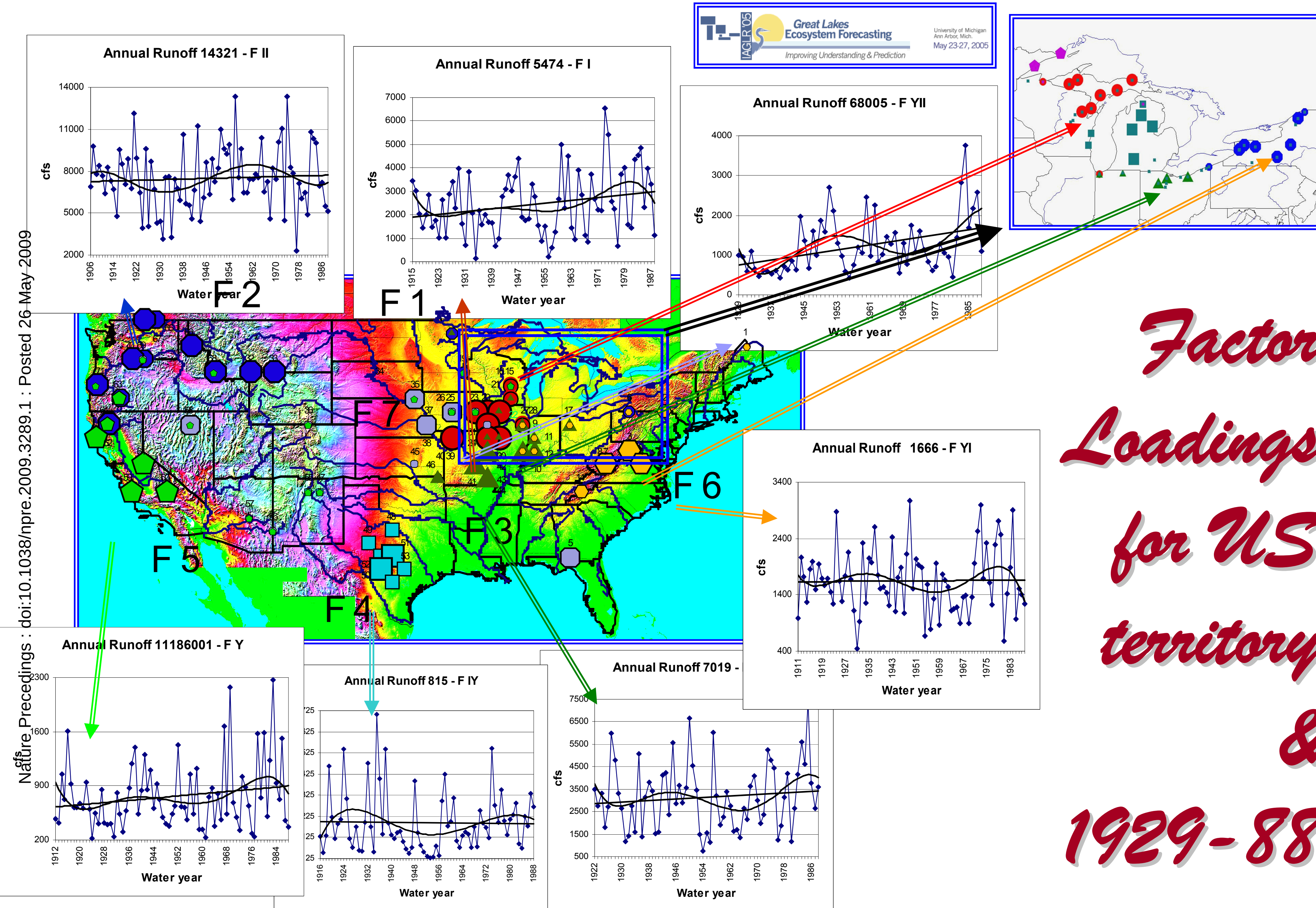
Scale in Regime – what is this?

* Streamflow
* Precipitation
* Upper Peninsula (UP) of Michigan (MI)
    - Snowfall
    - Precipitations
    - Air temperature

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

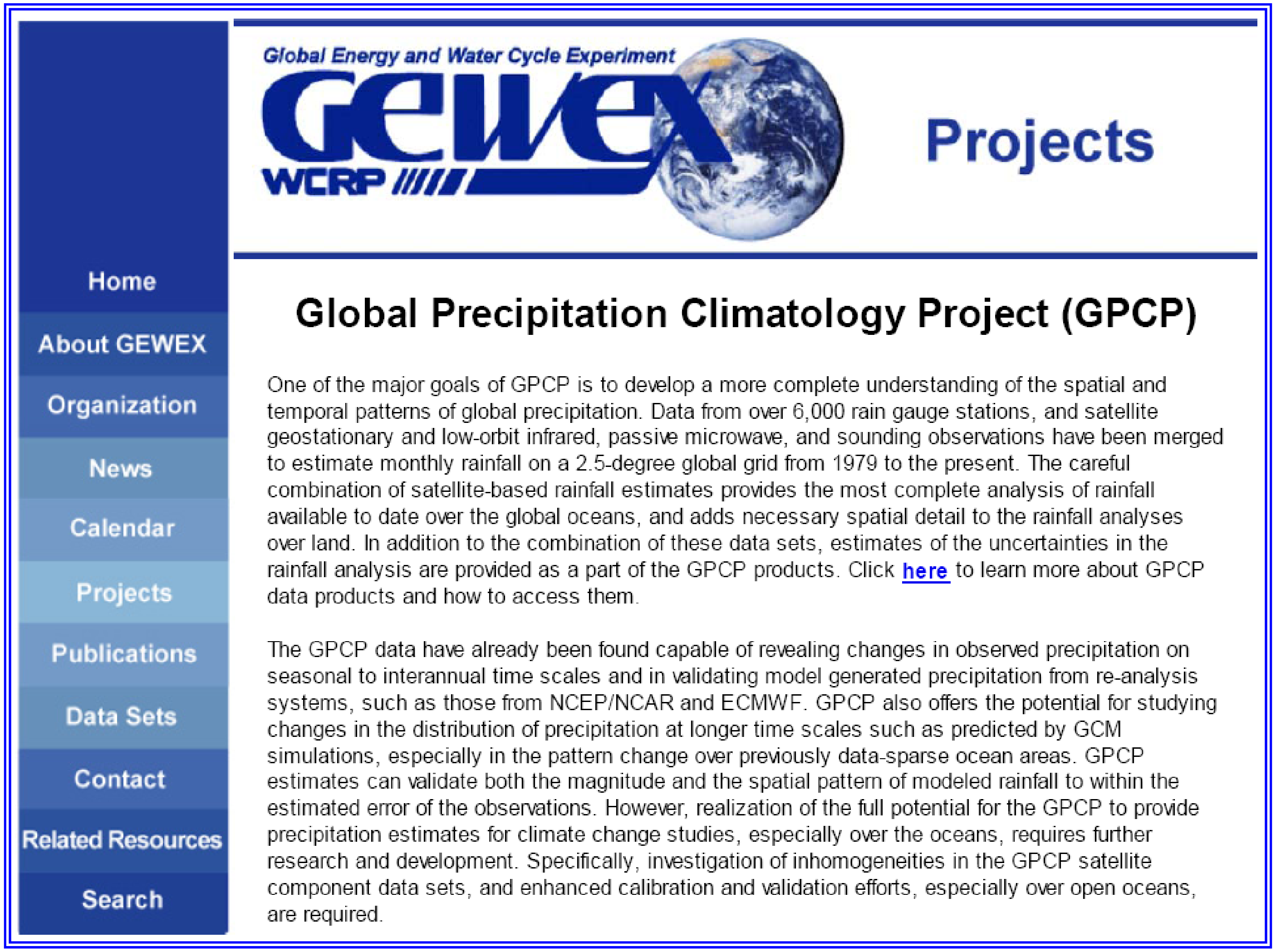
IAGLR '05 Great Lakes Ecosystem Forecasting
Improving Understanding & Prediction
University of Michigan Ann Arbor, Mich. May 23-27, 2005





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.

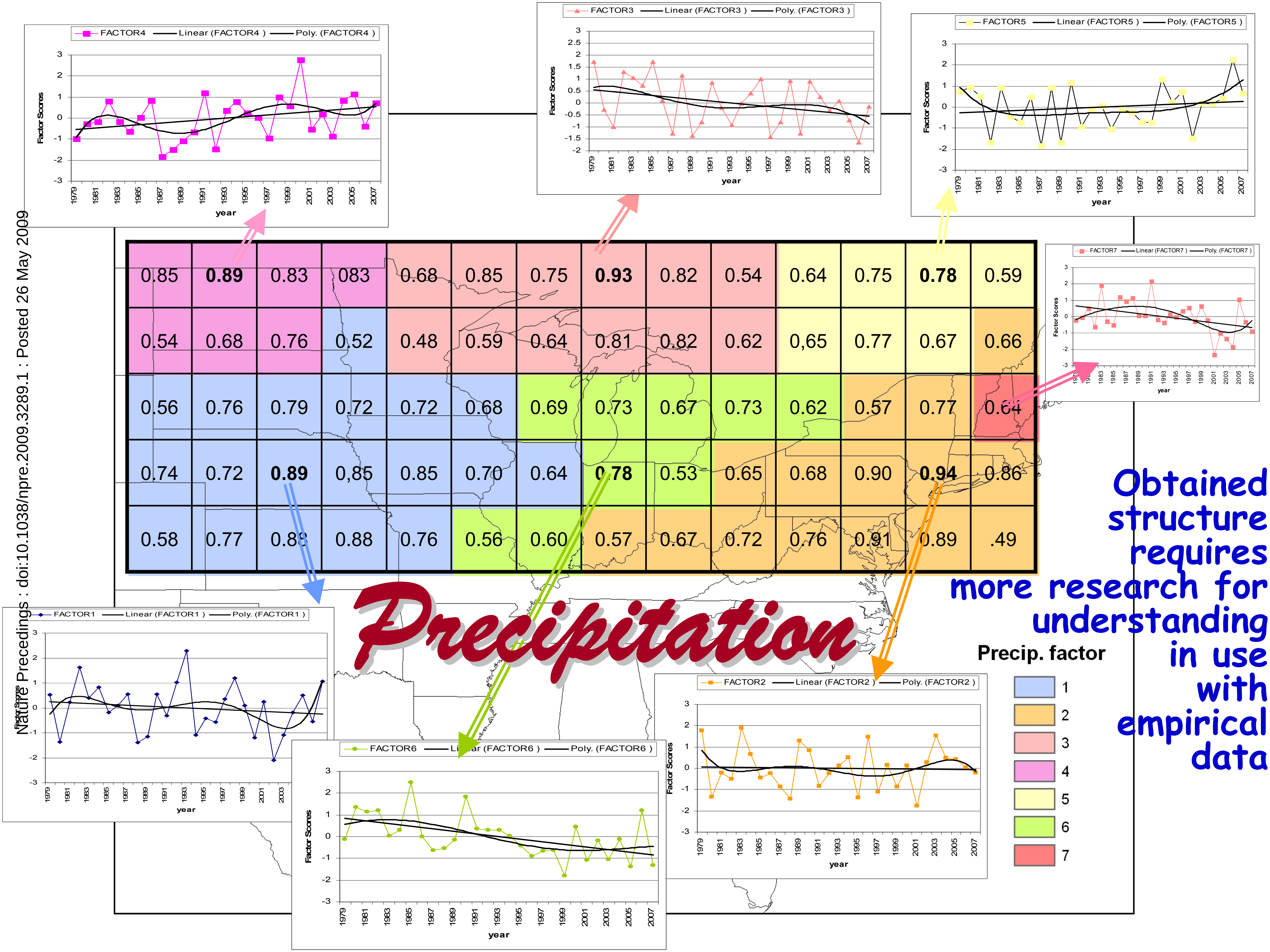
The GPCP data have already been found capable of revealing changes in observed precipitation on seasonal to interannual time scales and in validating model generated precipitation from re-analysis systems, such as those from NCEP/NCAR and ECMWF. GPCP also offers the potential for studying changes in 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:

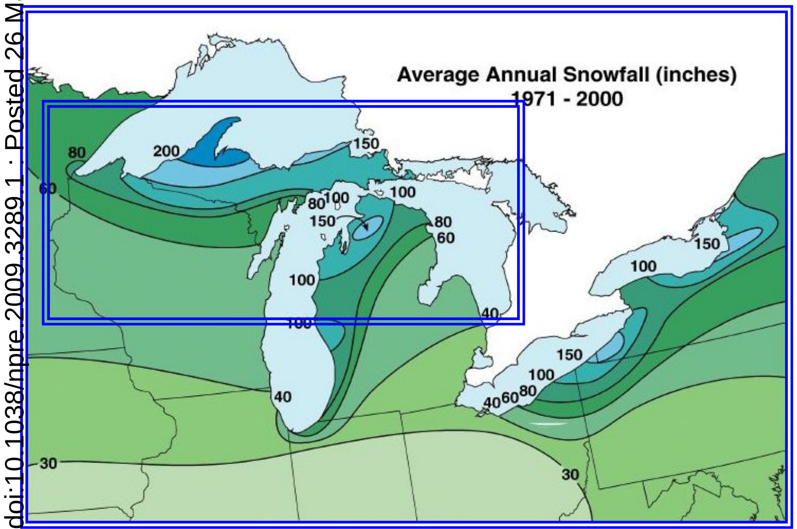
$\{P_{28*90}\}$

$P_{28,i}$

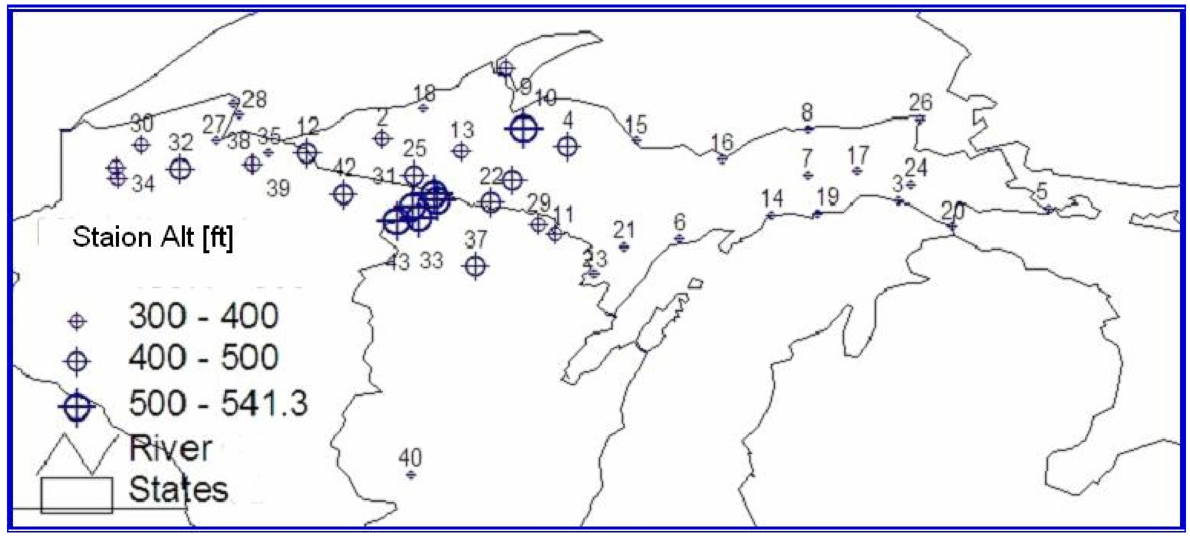
Lat (ºN) \ Lon (ºW)	103.75	101.25	98.75	96.25	93.75	91.25	88.75	86.25	83.75	81.25	78.75	76.25	73.75	71.25
48.75														
46.25														
43.75														
41.25														
38.75														


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
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 0.88 0.88 0.76 0.56 0.60 0.57 0.67 0.72 0.76 0.91 0.89 .49
Precipitation
Precip. factor
1
2
3
4
5
6
7
Obtained structure requires more research for understanding in use with empirical data

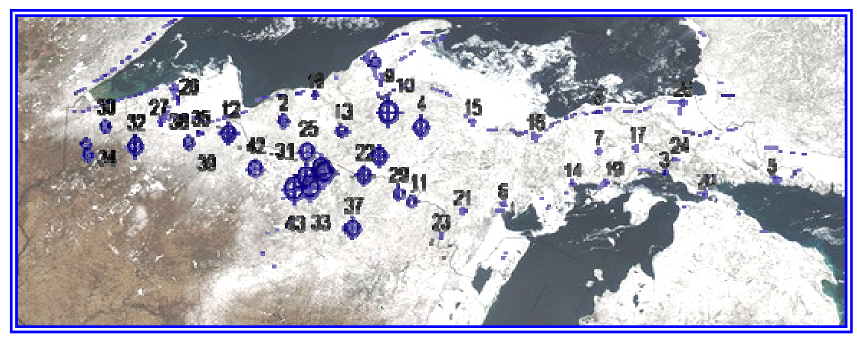
Data from cooperative stations for UP MI



Picture from www.weathermichigan.com



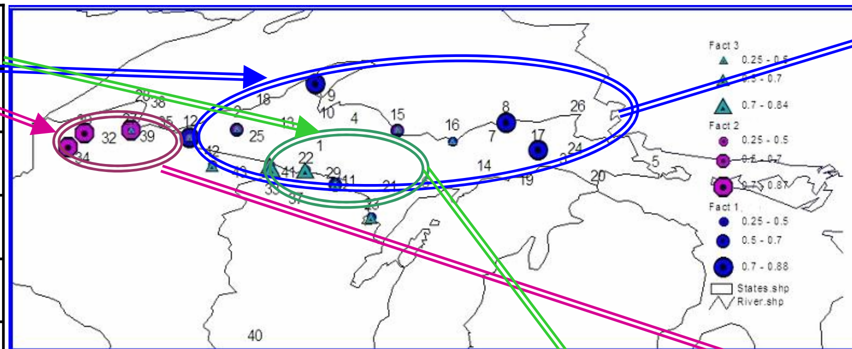
Location & elevation of 44 meteorological cooperative stations with annual sum of total monthly snowfall, precipitations & air temperature

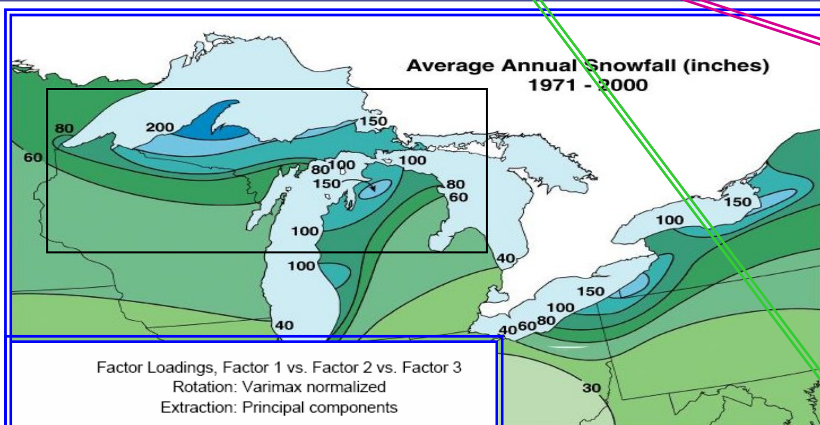


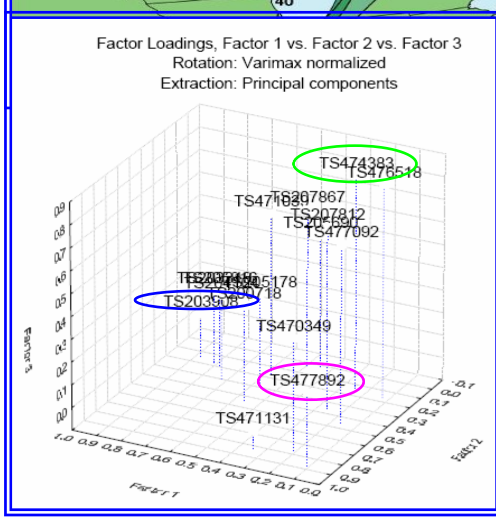
April 8, 2003
(www.osei.noaa.gov)

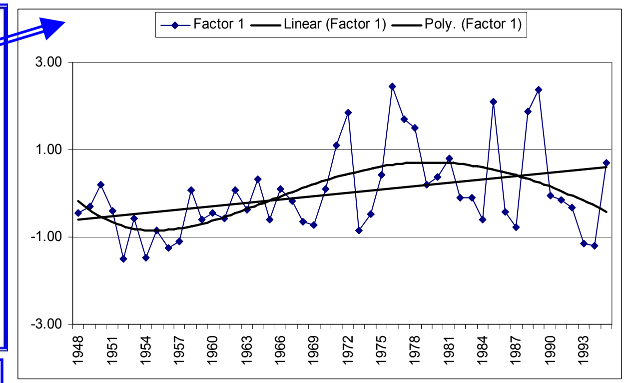
Annual snowfall on traditional map & as structure from initial matrix: S(1948-95*18)

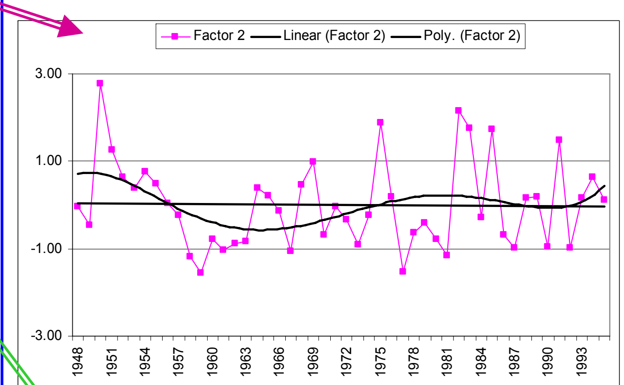
	Fact 1	Fact 2	Fact 3
TS203908	**0.88**		
TS203319	**0.81**		
TS205816	**0.78**		
TS204104	**0.72**	0.30	0.27
TS205178	***0.57***	0.29	0.31
TS200718	***0.56***	0.44	0.32
TS477892		**0.87**	
TS471131		**0.83**	
TS470349		**0.77**	0.39
TS474383	0.25		**0.84**
TS476518			**0.84**
TS207812	0.26	0.36	**0.71**
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

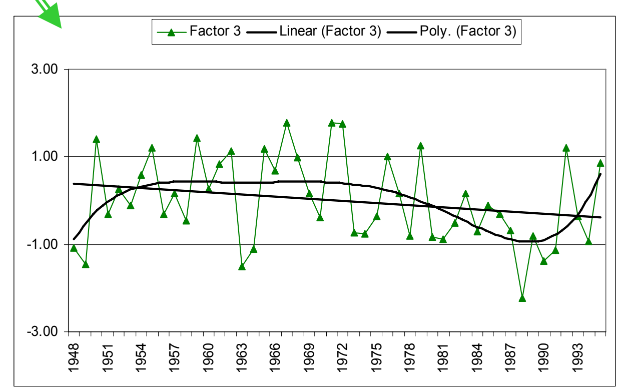








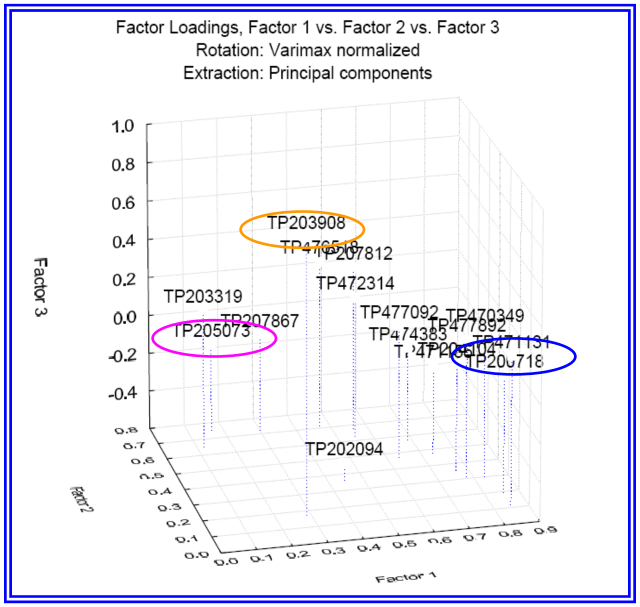


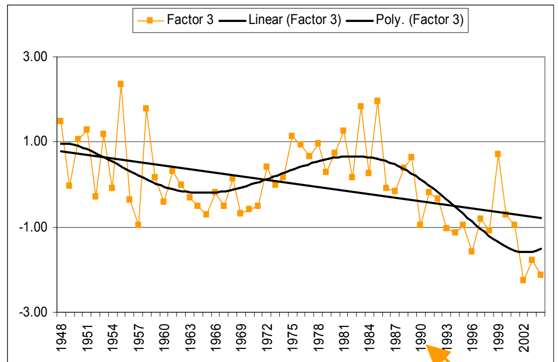


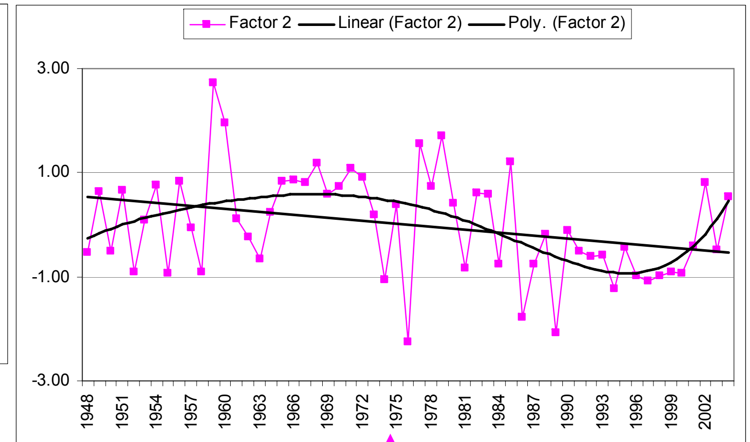
Regime of annual snowfall has three dimensional structure

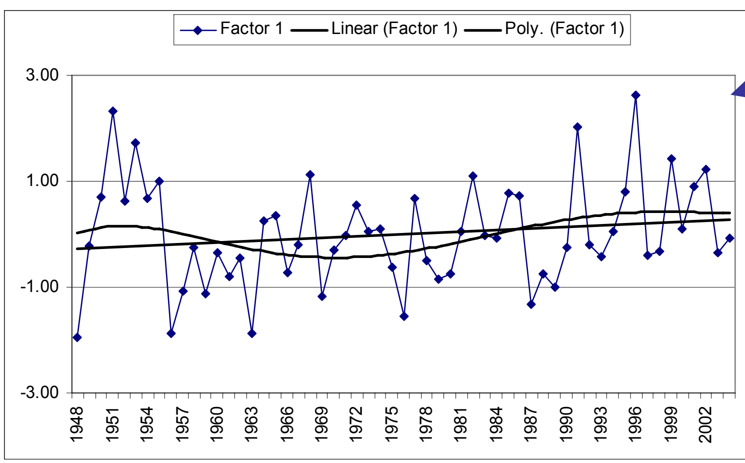
Regime of precipitation as a structure for UP MI

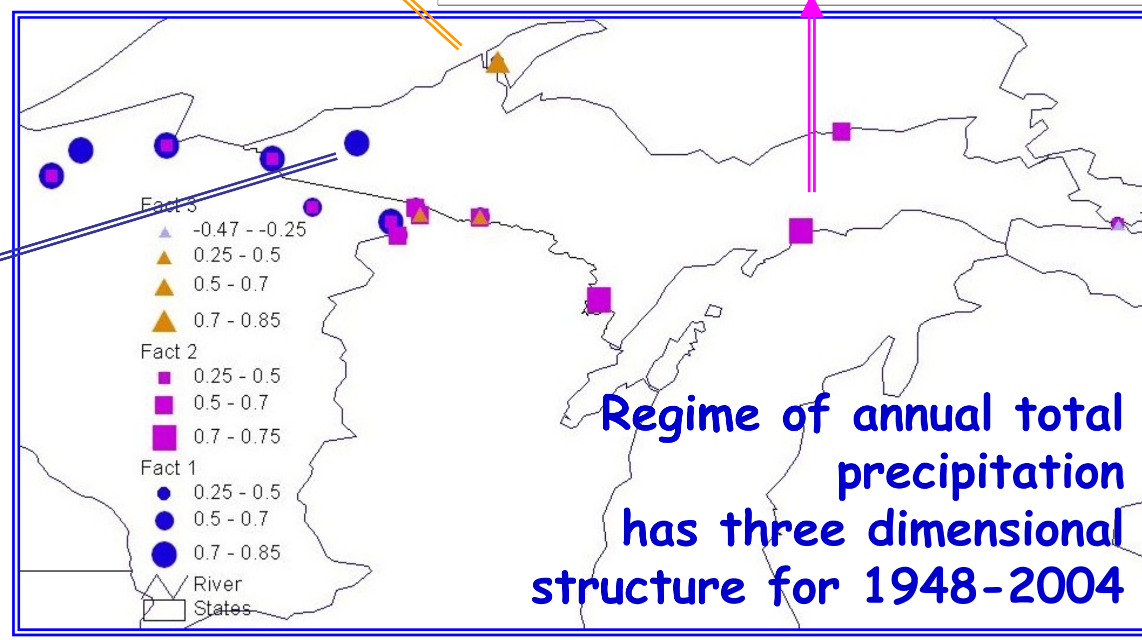
Nature Precedings : doi:10.1038/npre.2009.3289.1 : Posted 26 May 2009



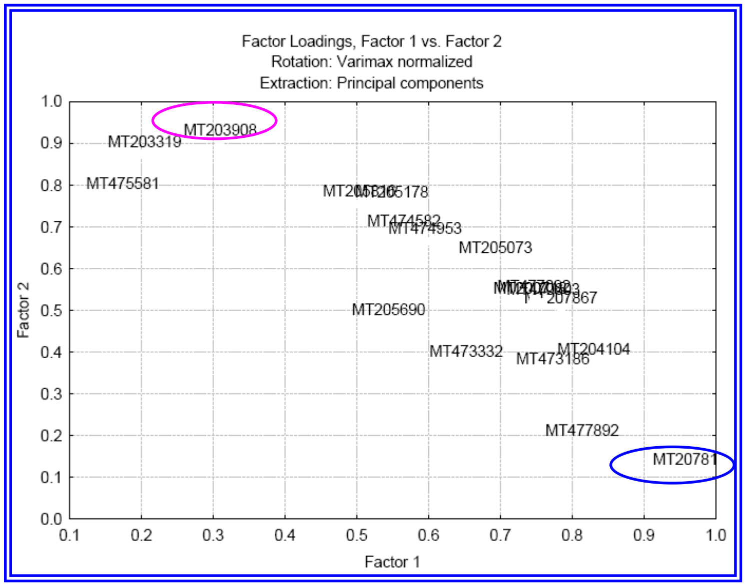


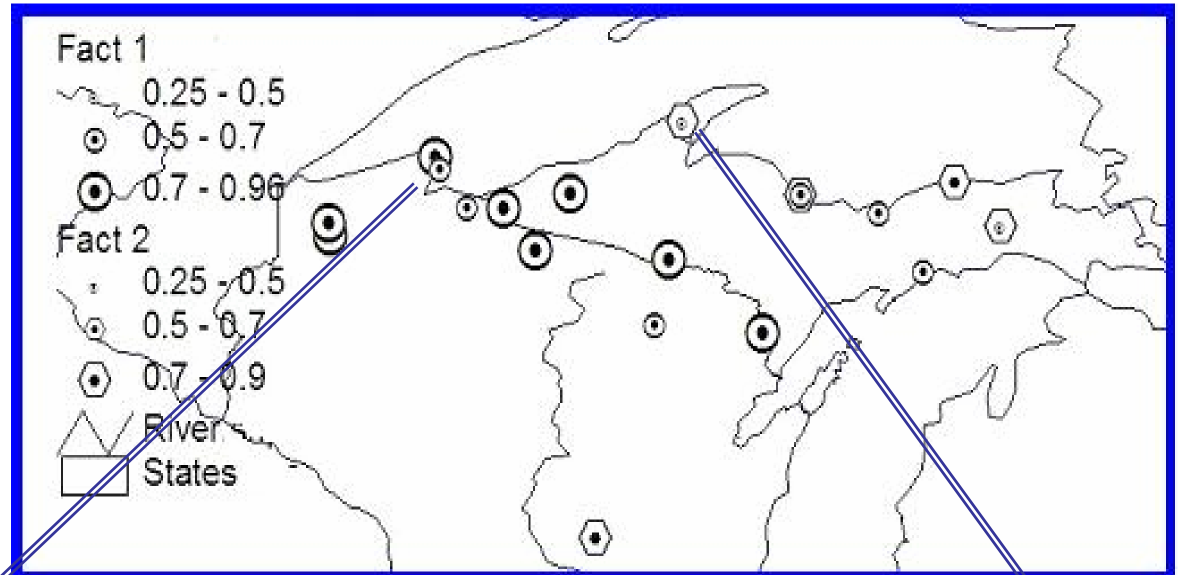


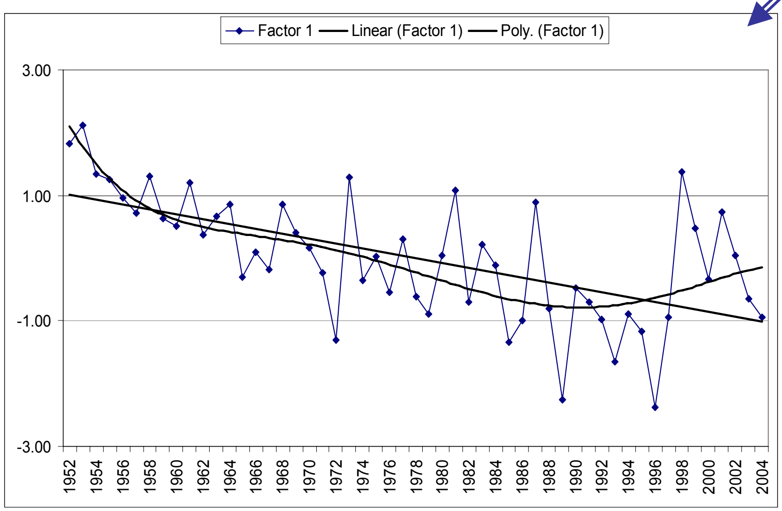




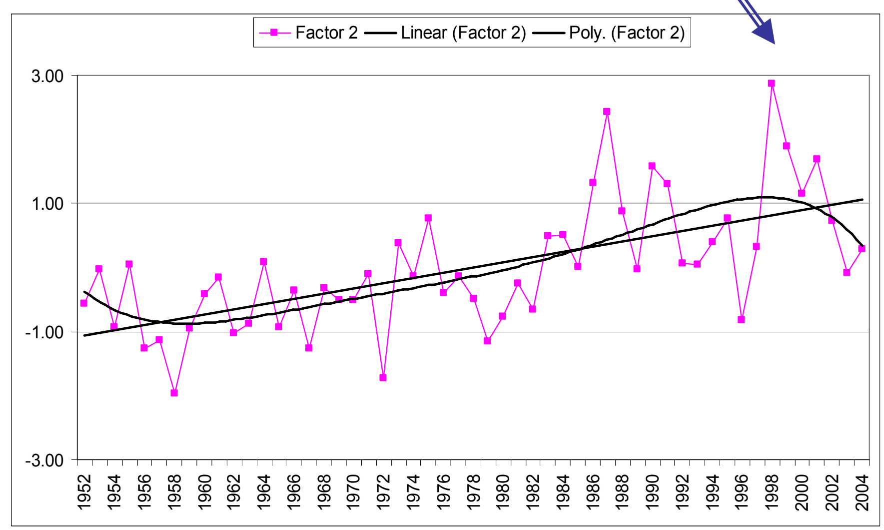
Regime of air temperature as a structure for UP MI



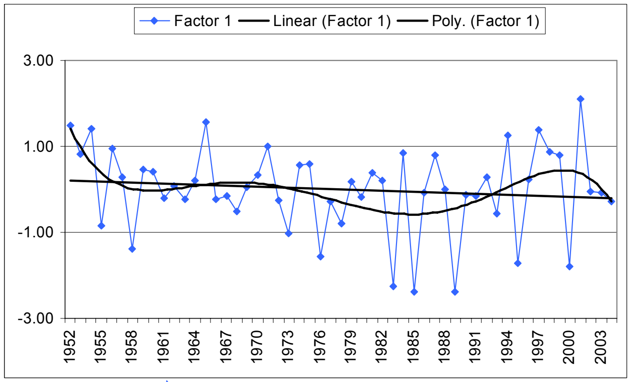


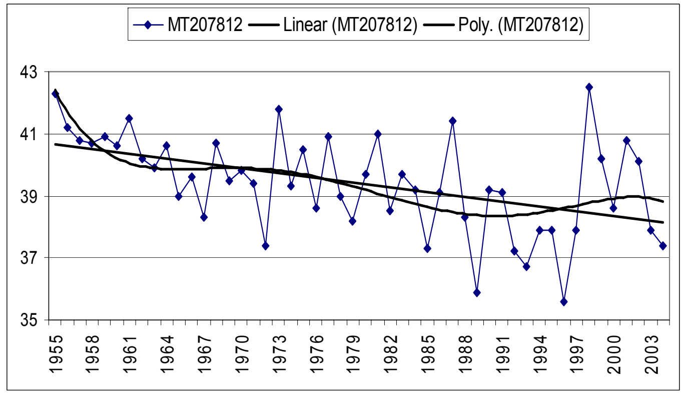


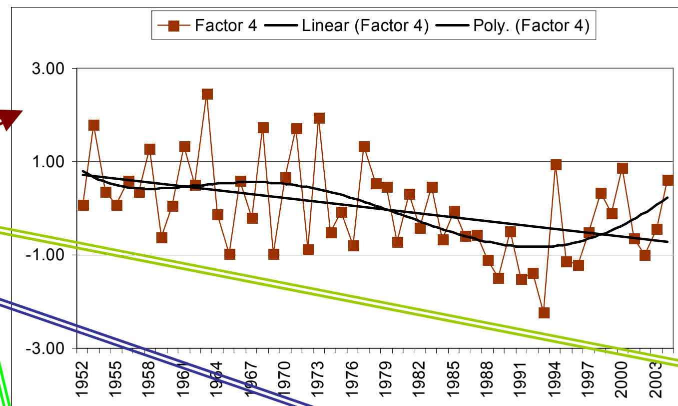
Regime of annual air temperature has two dimensional structure for 1952-2004

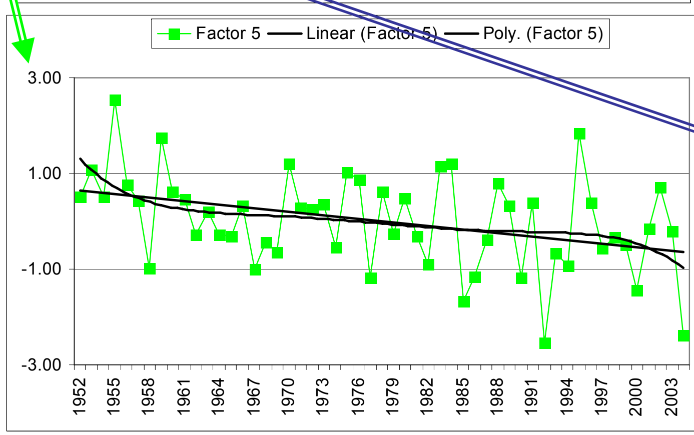


Seasonal regime of air temperature for station 207812 (1952-2004) as a structure

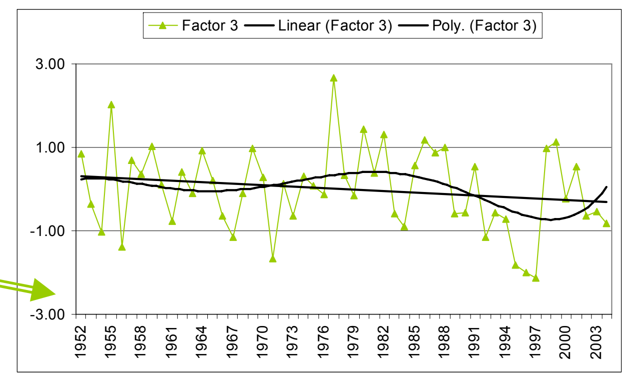


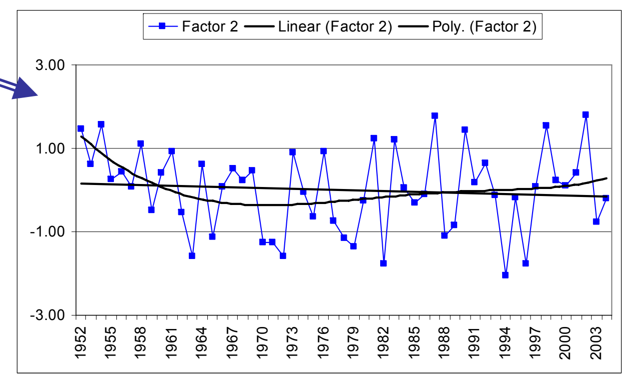






Seasonal regime of air temperature has five dimensional structure for 1952-2004





	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

Air temperature – observed values & model

Model for simplified Fourier analysis:

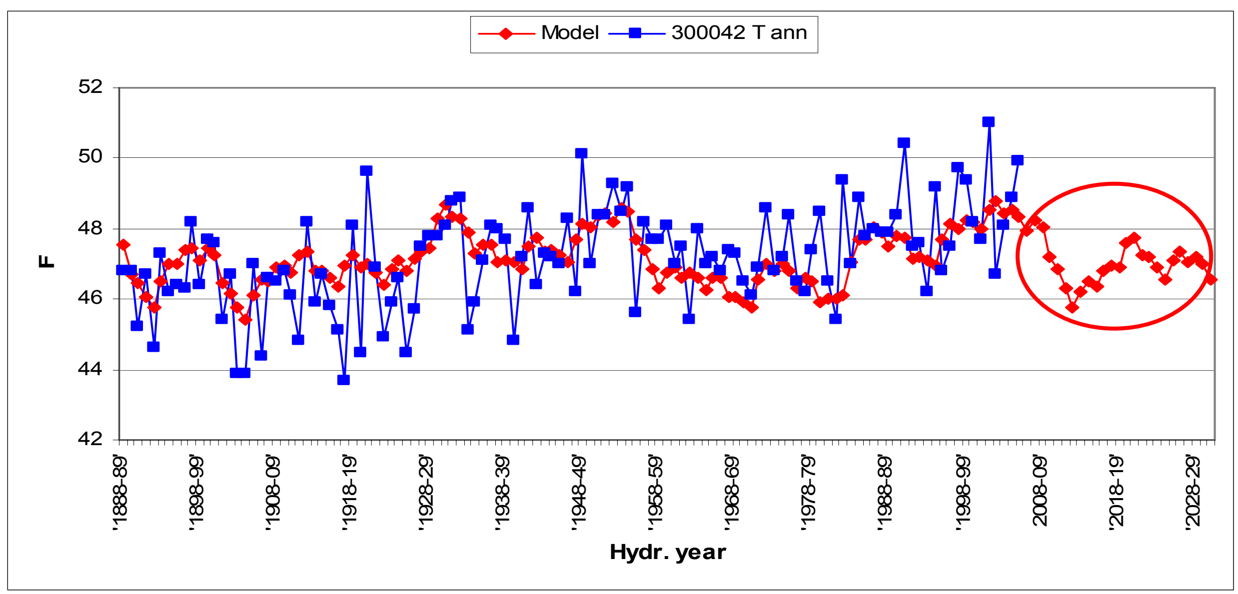
$$X_t = X_0 + \sum_{i=1}^{K} A_i \cos\left(\frac{2\pi}{T_i} t - \varphi_i\right) + Z_t \,,$$

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.

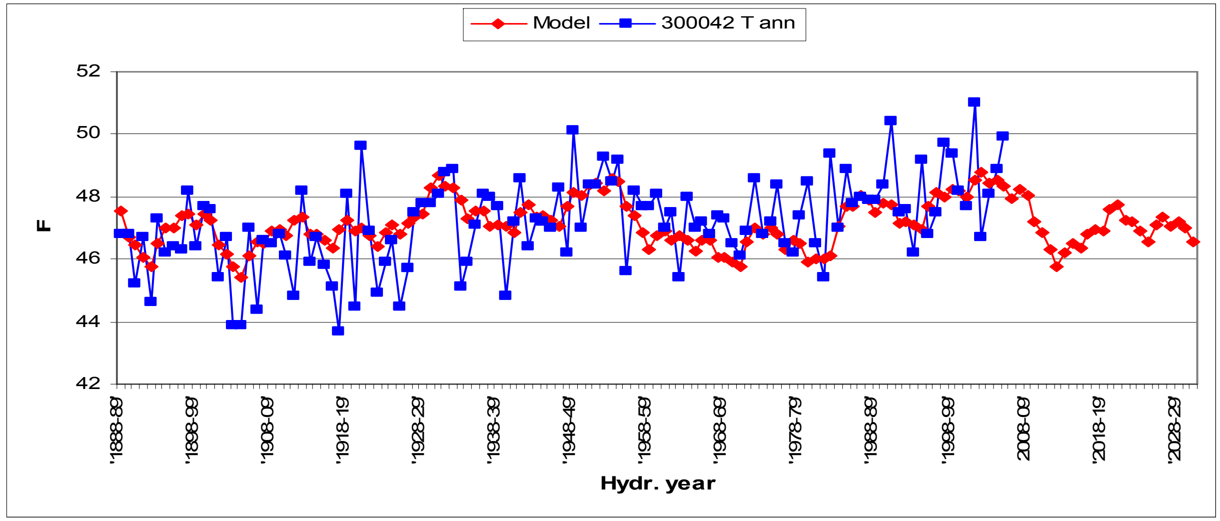
The equation quotients are calculated separately for each selected period & for all periods together under the condition of minimization of the random part

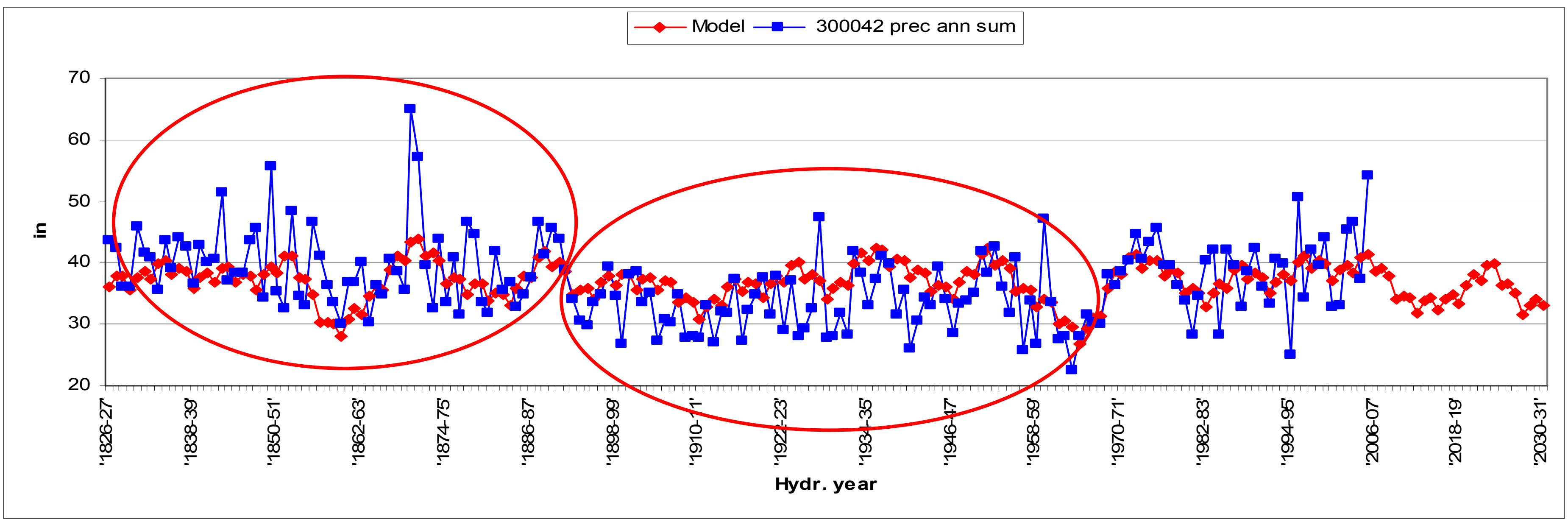
No	T- period [year]	A-amplitude [F]	φ -phase
1	62	0.703	-0896
2	18	0.402	3.325
3	11	0.373	-0.279
4	24	0.338	-1.567
5	39	0.284	-1.450
6	6	0.228	1.352
7	3	0.218	1.108
8	15	0.177	4.604
9	13	0.130	-1.311



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 climate system & cybernetic model

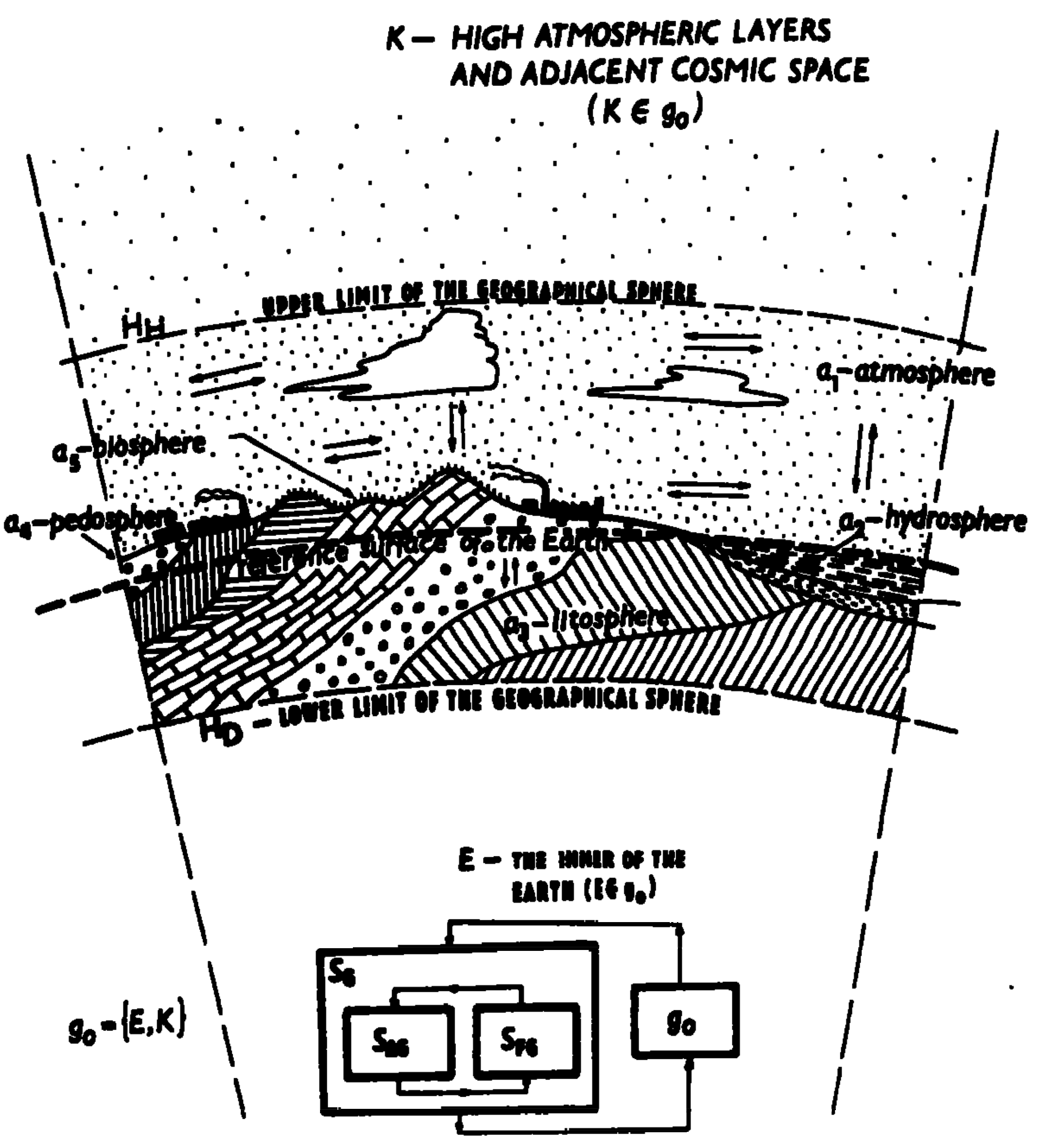
The Gap between Simulation and Understanding in Climate Modeling

BY ISAAC M. HELD

NOVEMBER 2005 BAMS | 1609

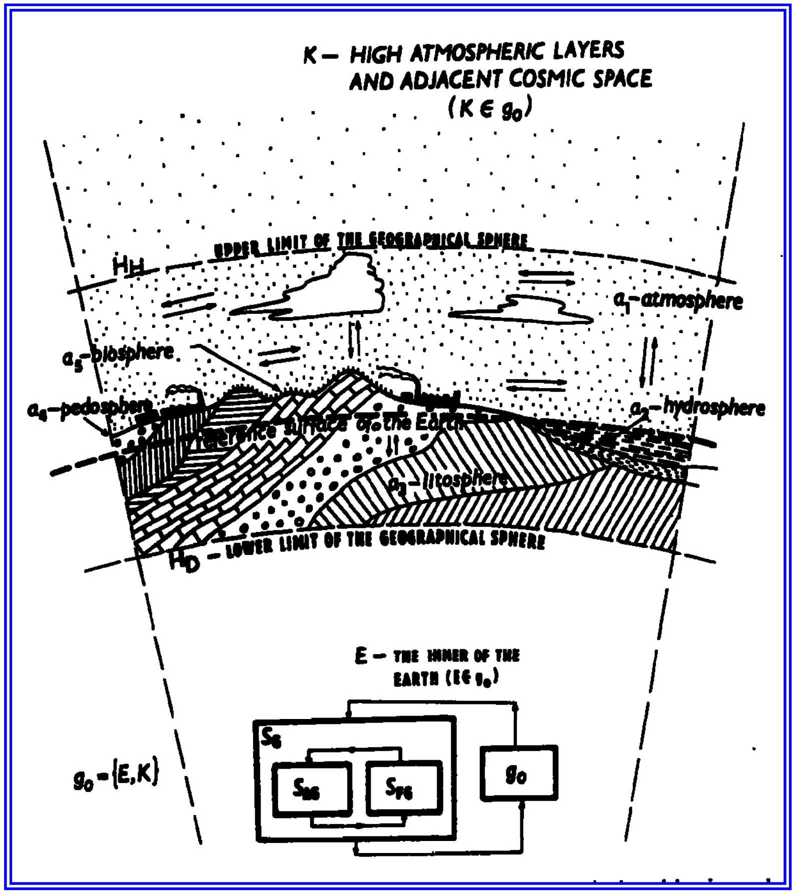
Should we strive to construct climate models of lasting value? Or should we accept as inevitable the obsolescence of our models as computer power increases?

The Cybernetic Model of Geosphere

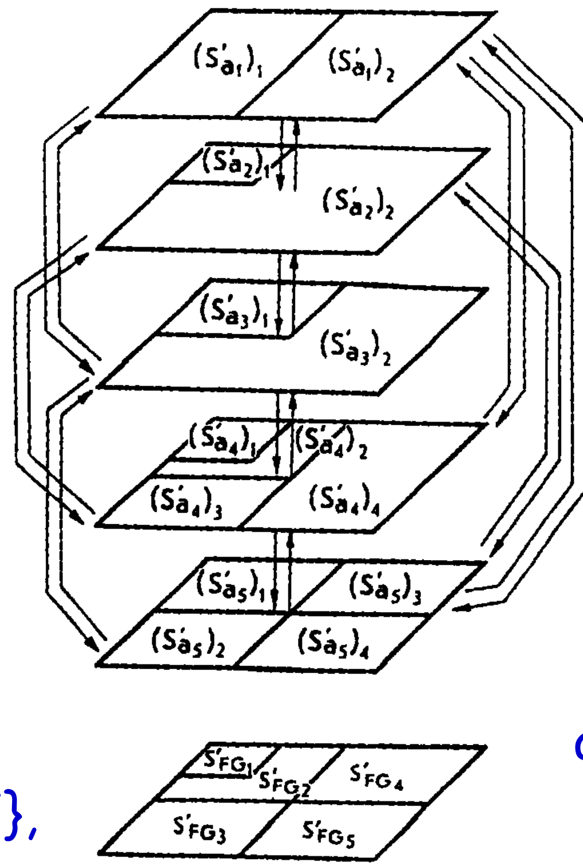


Vertical slice of
the Geographical Sphere with
two independent elements:
System of
Anthropological Geography
(S_{AG}) &
System of Physical Geography
(S_{FG}).
Arrows indicate
vertical & horizontal
components of matter, energy
& information circulation
(after Krcho, 1978)

Cybernetic Model for Landscape



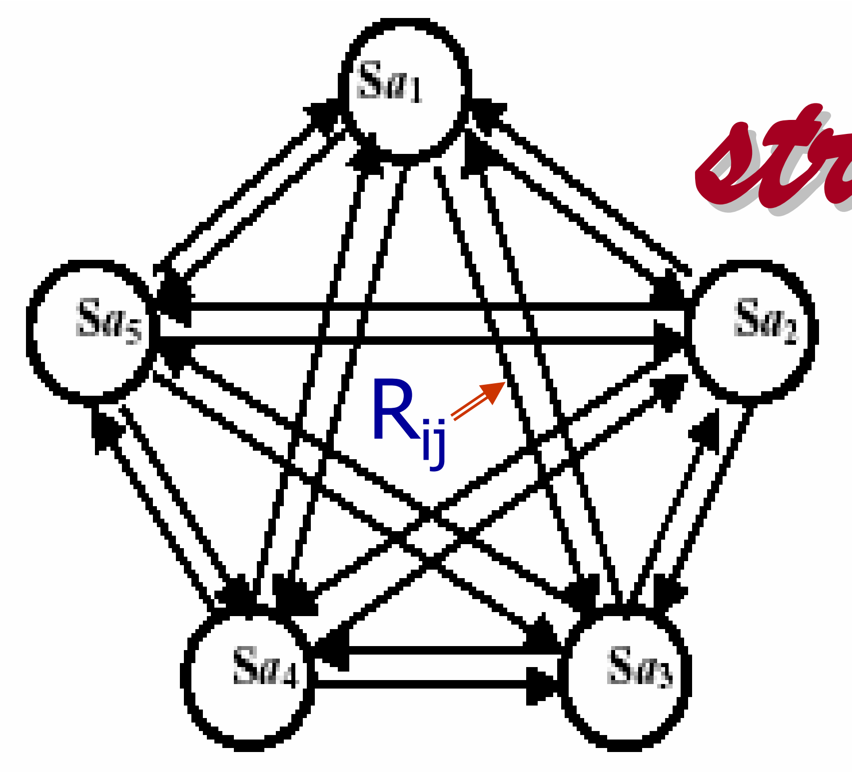
Each of these components may be characterized by matrix of input {Wi}, matrix of output {Qi}, & matrix of states {Hi}.



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.

Multidimensional structure of relations



The number of characteristics for elements of landscape & 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 & 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.

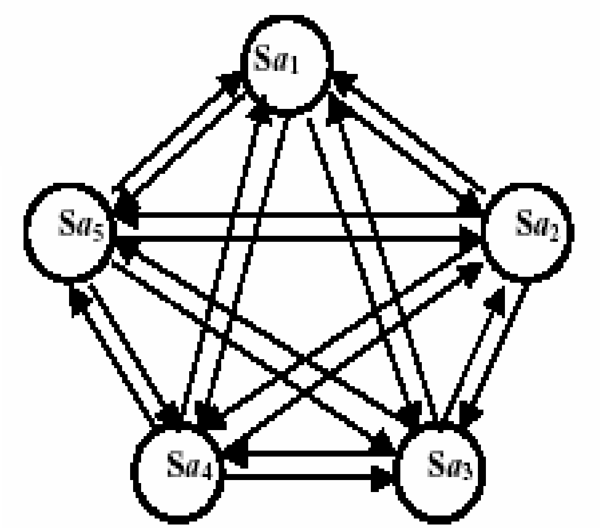
Discovery of invisible structure by system analysis

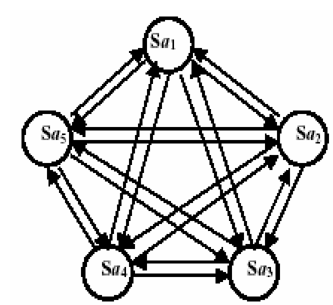
Long-Term Ecological Research and the Invisible Present

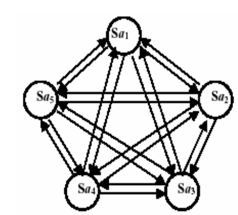
Uncovering the processes hidden because they occur slowly or because effects lag years behind causes

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

Nature Precedings : doi:10.1038/npre.2009.3289.1 : Posted 26 May 2009


Questions?
Lake Superior,
01/18/2009
2:31 pm
CITY OF DULUTH
PUBLIC BEACHES
Conditions are unsafe for swimming.
The designated swimming area is closed.
RIP CURRENTS
Break the Grip of the Rip!
IF CAUGHT IN A RIP CURRENT
SAFETY
Scientific research
completed on a base of
authors donated time