Snow Melt Runoff Events in the Eastern and Central United States: Connections to Global Forcings Through Synoptic Frequencies

Daniel J. Leathers
Department of Geography
Delaware State Climatologist
University of Delaware

Zachary Suriano
Department of Geography
University of Delaware

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Susquehanna River - Harrisburg, PA January 22, 1996

Red River - Grand Forks, ND March 21 − April 1, 2009

Research Questions:

It's All About Snowmelt Flooding!

- Quantify the global-scale forcings associated with significant snow cover ablation events, with particular attention to the role of major atmospheric teleconnections and oceanic and land-surface conditions.

- Ascertain the "pathways" from global-scale forcings to ablation within a basin, with special emphasis on the role of synoptic-scale weather patterns.

NOAA Funded Project

"Toward Improved Understanding of Extreme Snow Melt Runoff Events Under Past, Present, and Future Climate"

University of Delaware and….

Gina Henderson

U.S. Naval Academy

Tom Mote

Univ. of Georgia

Dave Robinson

Rutgers Univ.

Some things to discuss…

- the basins
- data and methods
- 2.54+ cm ablation events; synoptic patterns
- ablation case studies
- connections to global forcings
- long-term trends

Ablation Defined

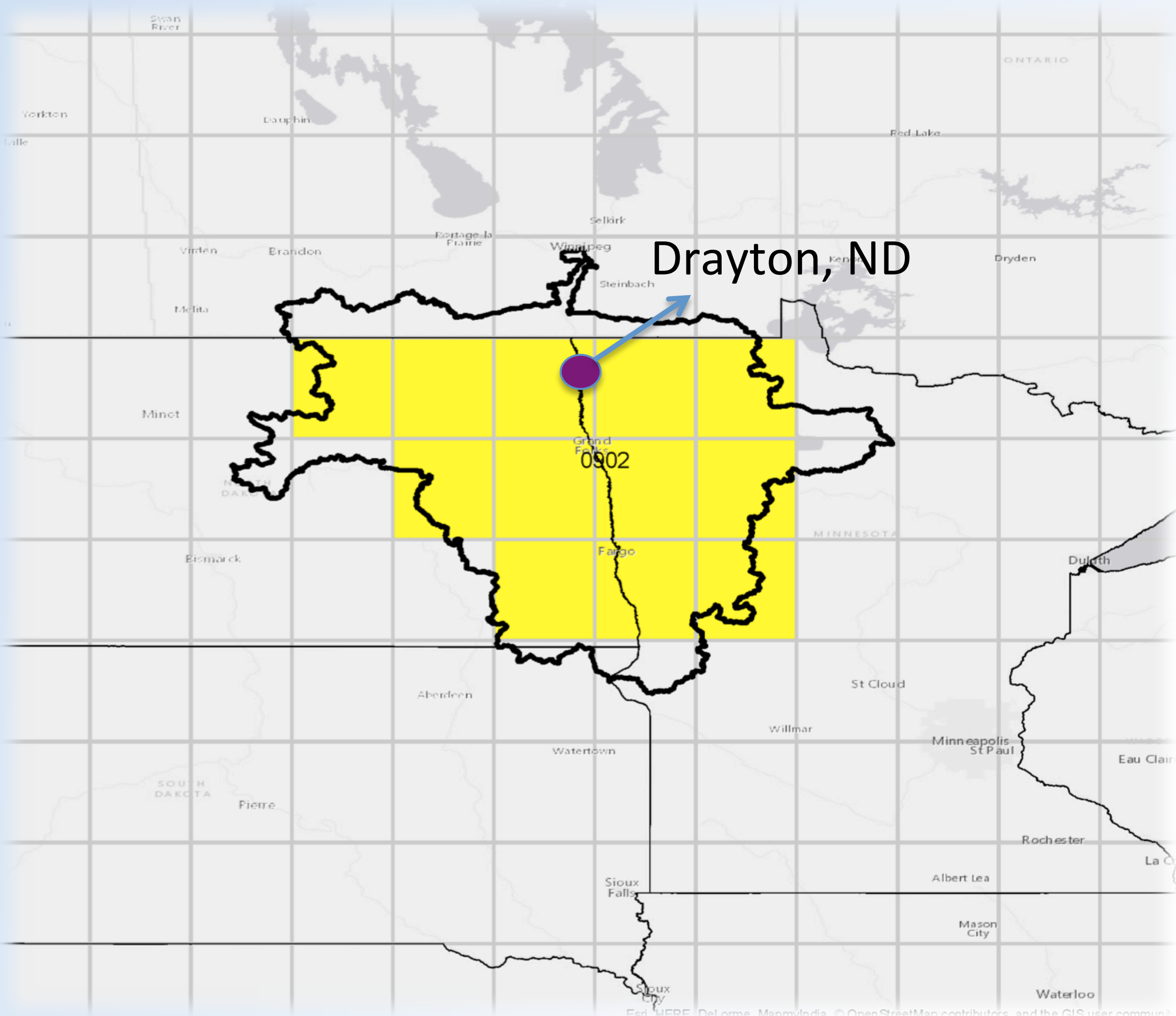
All processes that remove snow including melting, sublimation, wind erosion, and avalanche*…*

We use snow depth change as a surrogate for ablation. Snow depth changes are extensively quality controlled using temperature and snowfall data to make sure they are associated with melting. Suspicious snow depth changes are flagged and excluded from analysis.

We assume that sublimation and wind erosion are small in comparison to melt on a daily basis.

The Basins

Red River of the North



Basin Area – 111,004 km^2

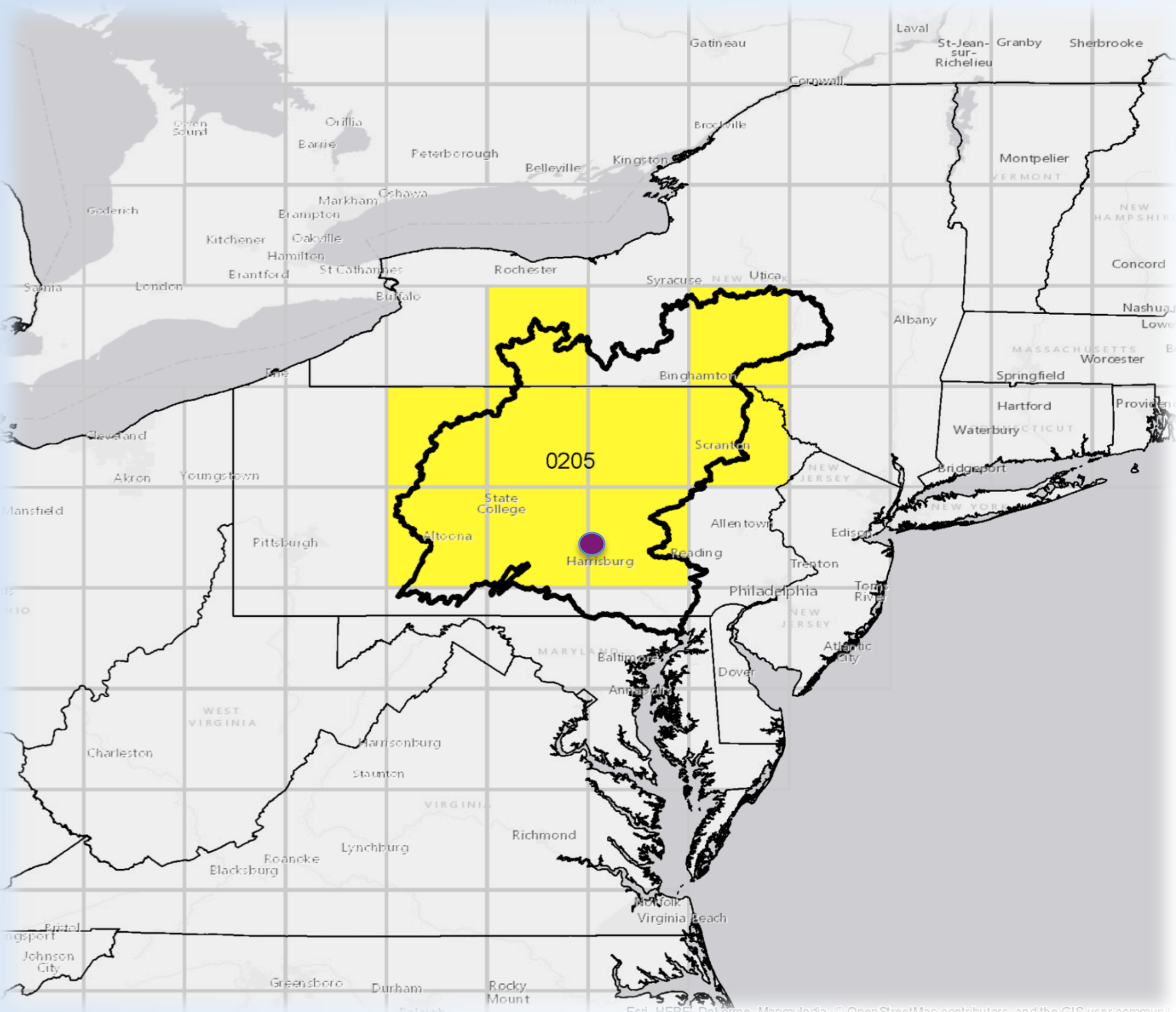
Length – 550 miles

Mean Discharge – 8617 cfs

2.54 cm ablation gives: 7.4×10^{10} gallons

Nearly 13 times the mean daily flow.

Susquehanna River



Basin Area – 71, 224 km^2

Length – 464 miles

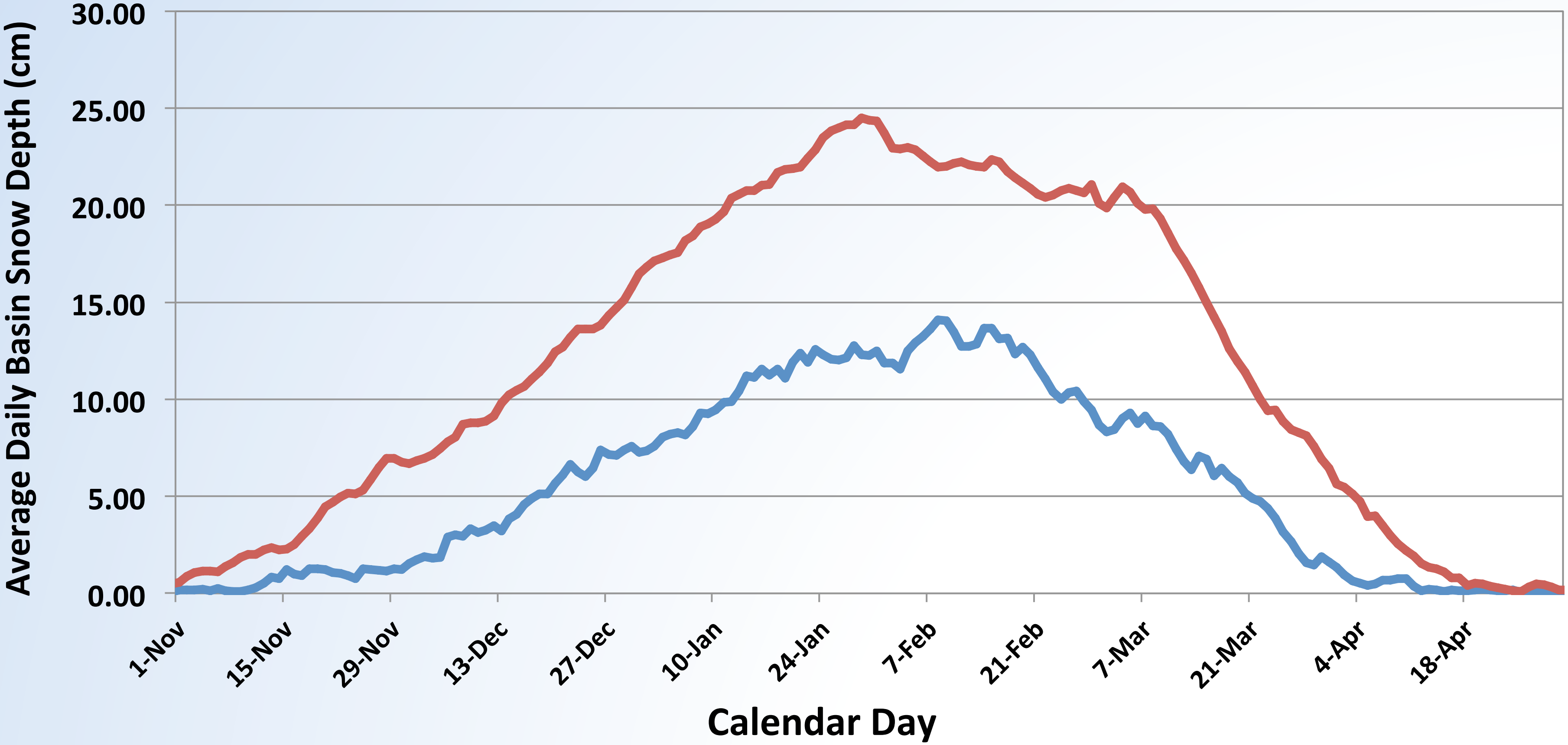
Mean Discharge – 40080 cfs

2.54 cm ablation gives:
4.75 X 10^{10} gallons

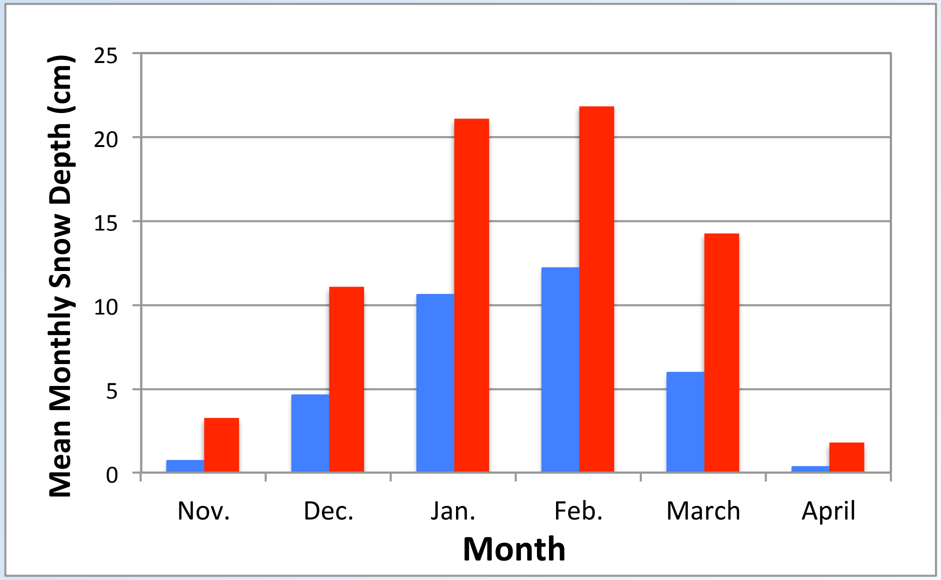
Nearly twice the mean daily flow.

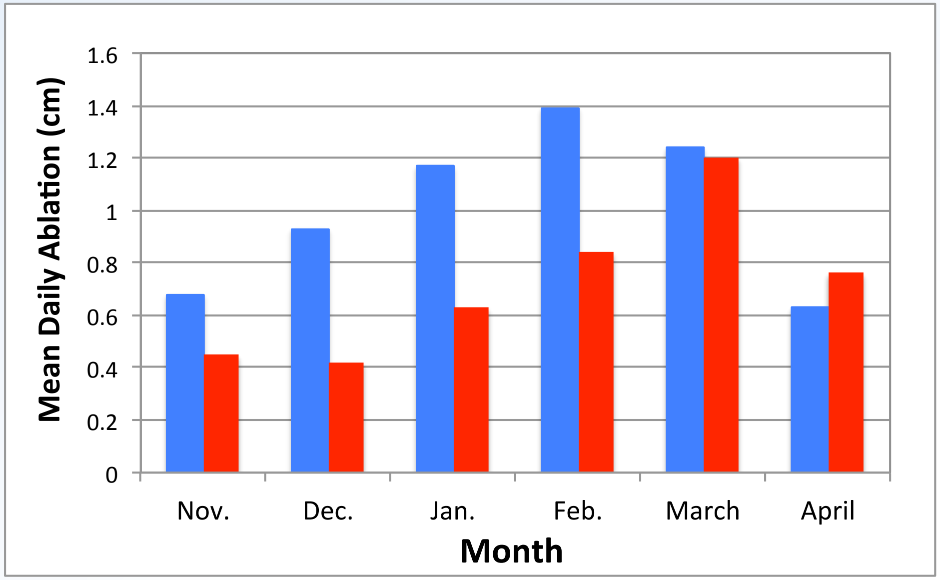
Mean Daily Basin Snow Depth 1960 – 2009

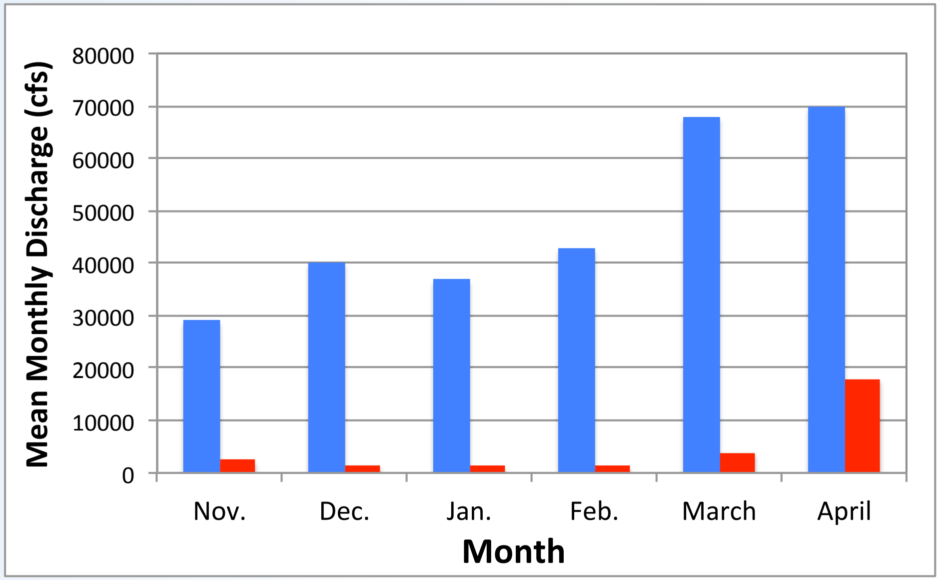
Red line – Red River, Blue line – Susquehanna River



Some Basin Comparisons

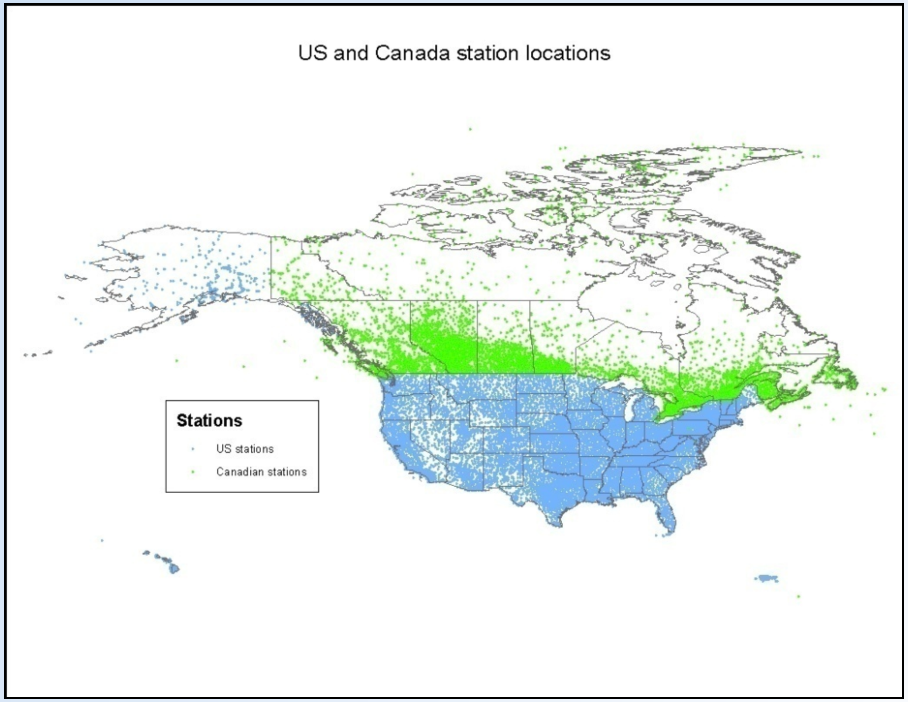






Data and Methods

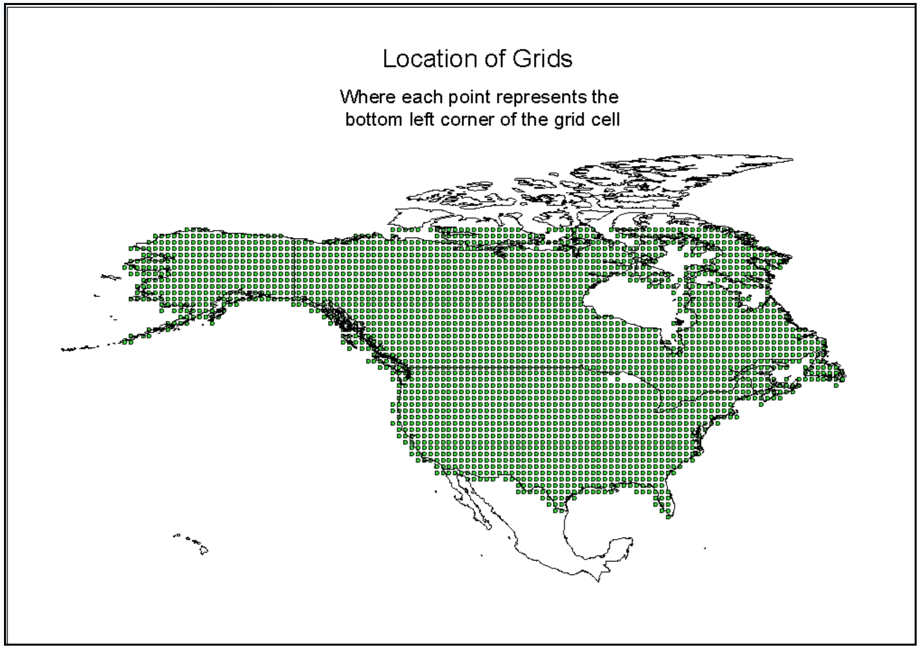
Snow Depth Data



1^o X 1^o gridded daily snow depth data set developed at the University of Georgia. Archived at Rutgers University

Utilizes U.S. COOP and Canadian daily surface observations

Extensive quality control routines



Gridded snow cover data used to identify basin-wide ablation episodes.

Dyer and Mote, 2006, Geophysical Res. Letters

Kluver et al., 2016, J. of Atmos. And Oceanic Tech.

Temporal Synoptic Index (TSI)

Data

Daily Synoptic Weather Data
1946 – 2016
Minneapolis and Philadelphia

4X Daily Temperature, Dew Point Temperature, Cloud Cover, Vector Wind Speed, Atmospheric Pressure

Statistical Treatment

Temporal Synoptic Indexing
Principle Component Analysis with Cluster Analysis

Result

Daily Synoptic Type Calendar
Each Day is Classified as a Specific Synoptic Type
~ 15 Types Per Season

Kalkstein and Corrigan, Annals of AAG, 1986

Global-Scale Forcings Investigated

Atmospheric Teleconnections

Arctic Oscillation (AO)
North Atlantic Oscillation (NAO)
East Atlantic (EA)
East Atlantic/Western Russia (EA-WR)
Scandinavia (SCAND)
Polar/Eurasia (POL)
West Pacific (WP)
East Pacific-North Pacific (EP-NP)
Pacific/North American (PNA)
Tropical/Northern Hemisphere (TNH)

Land-Surface Conditions

Northern Hemisphere Snow Cover Extent
Eurasia Snow Cover Extent
North American Snow Cover Extent

Ocean Conditions

Nino 3.4 Region SSTs
Oceanic Nino Index
Pacific Decadal Oscillation
Atlantic Multi-Decadal Oscillation

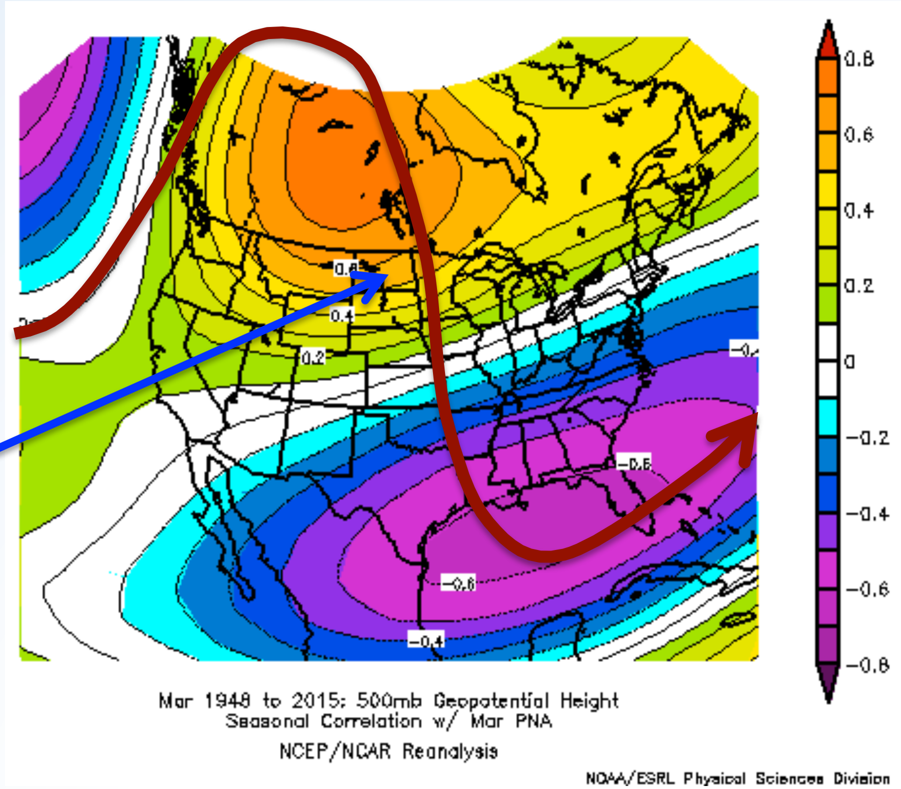
Atmospheric Teleconnections − NOAA Climate Prediction Center
Ocean Conditions - NOAA Climate Prediction Center
Land-Surface Conditions − Rutgers Global Snow Lab

What we could do…

March - Red River

2.54+ cm Ablation Frequency

East Atlantic	-0.321
PNA	-0.285
Polar – Eurasia	-0.284
PDO	-0.311



Why the negative correlation with the PNA?

What are the physical processes that are associated with this correlation?

We want to know the pathways by which global-scale forcings manifest themselves in ablation events!

Global-Scale Forcing

↓

Synoptic-Scale Patterns

↓

Surface Energy Fluxes

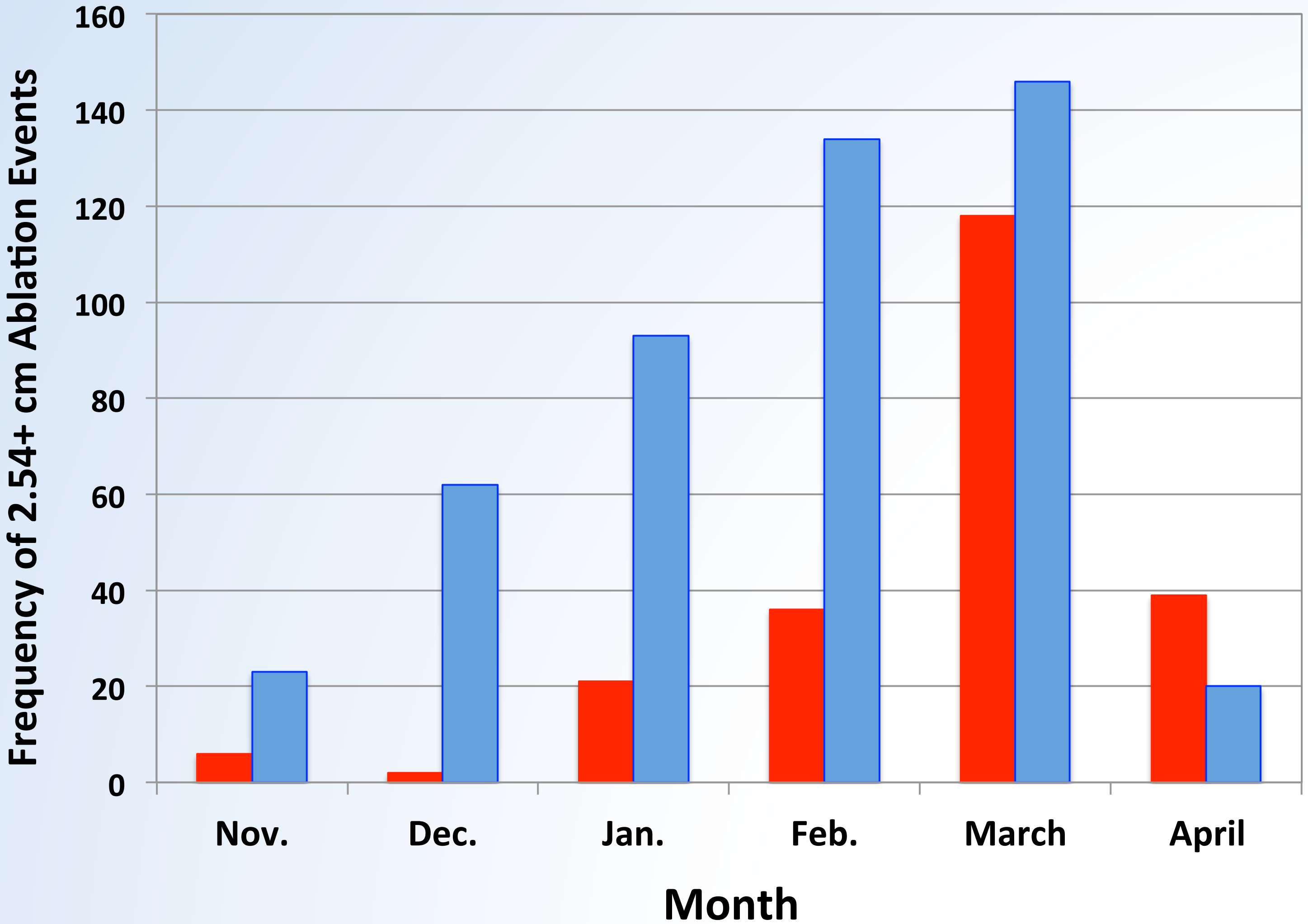
2.54+ cm Ablation Events

Red River Basin and Susquehanna River Basin

Synoptic Patterns

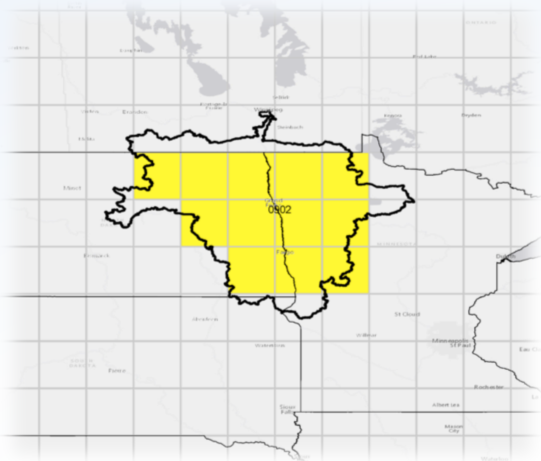
Monthly 2.54+ cm Ablation Frequency

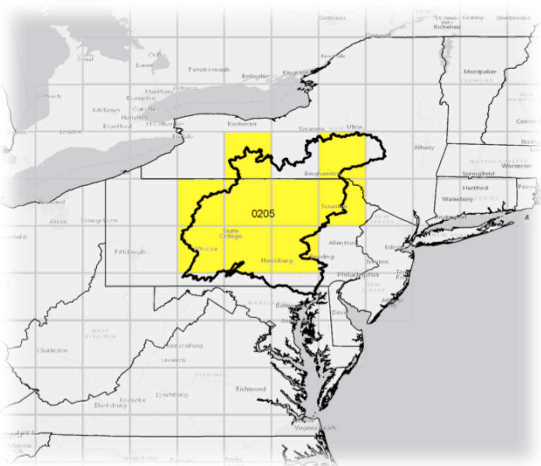
Red bars – Red River, Blue bars – Susquehanna River



More ephemeral snow cover in the Susquehanna expressed by more ablation episodes.

1 inch ablation





50,000,000,000 gallons of water!!

Assuming 10:1 Snow to Water Ratio

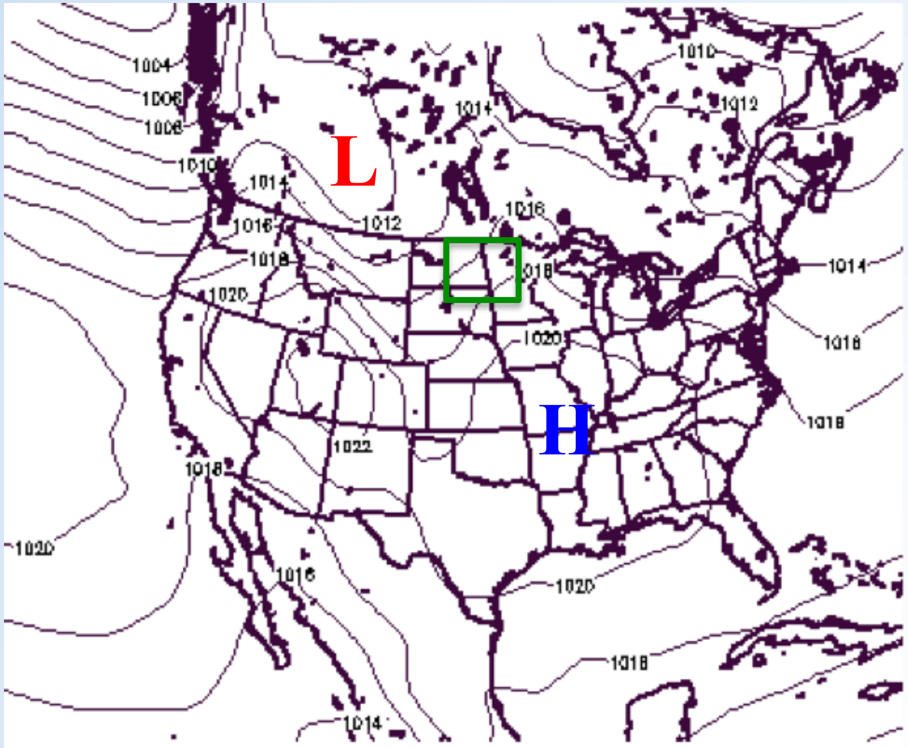
Red River Synoptic Patterns

2.54+ cm ablation events (175) 1960 - 2009

7.4 X 10^{10} gallons

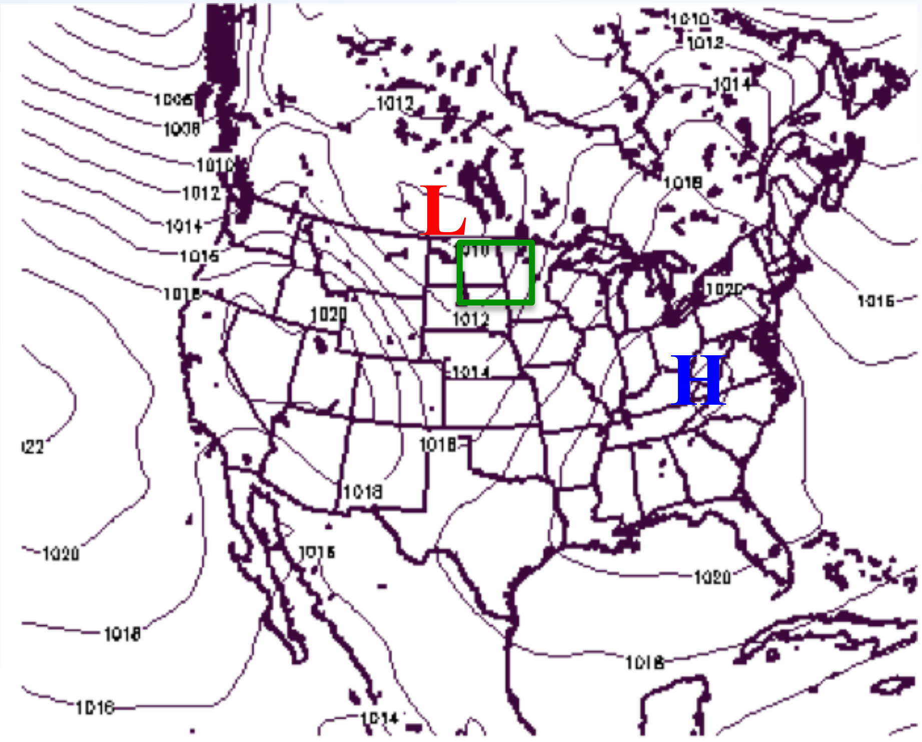
January (21)	**1032 (6)**	**1035 (6)**	**1033 (6)**	
February (36)	**1033 (16)**	**1032 (7)**	**1031 (4)**	**1034 (3)**
March (118)	**2031 (27)**	**2036 (26)**	**2003 (17)**	**2005 (9)**

Red River January



Sea Level Pressure (mb) Composite Mean
Synoptic Type 1033

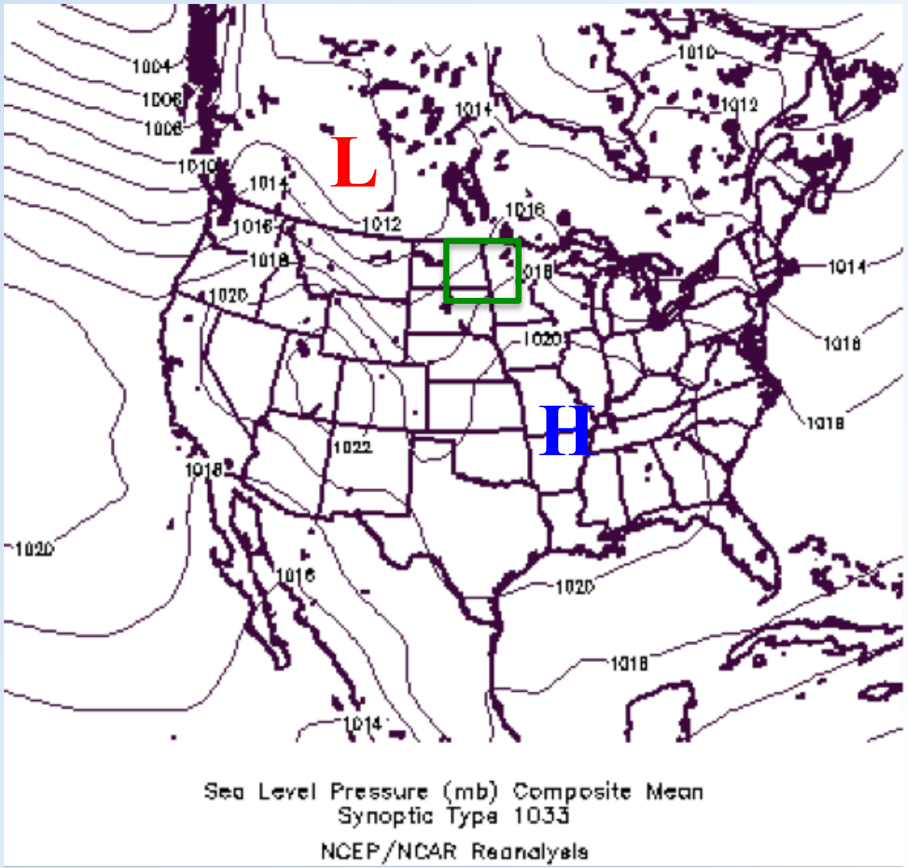
NCEP/NCAR Reanalysis

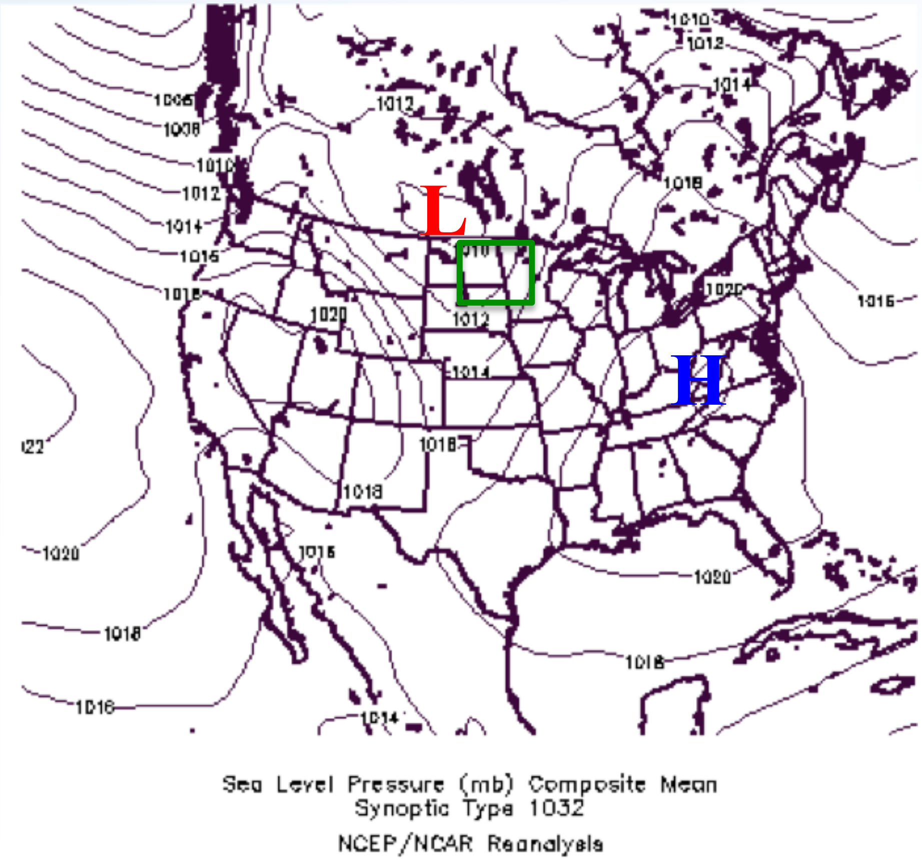


Sea Level Pressure (mb) Composite Mean
Synoptic Type 1032

NCEP/NCAR Reanalysis

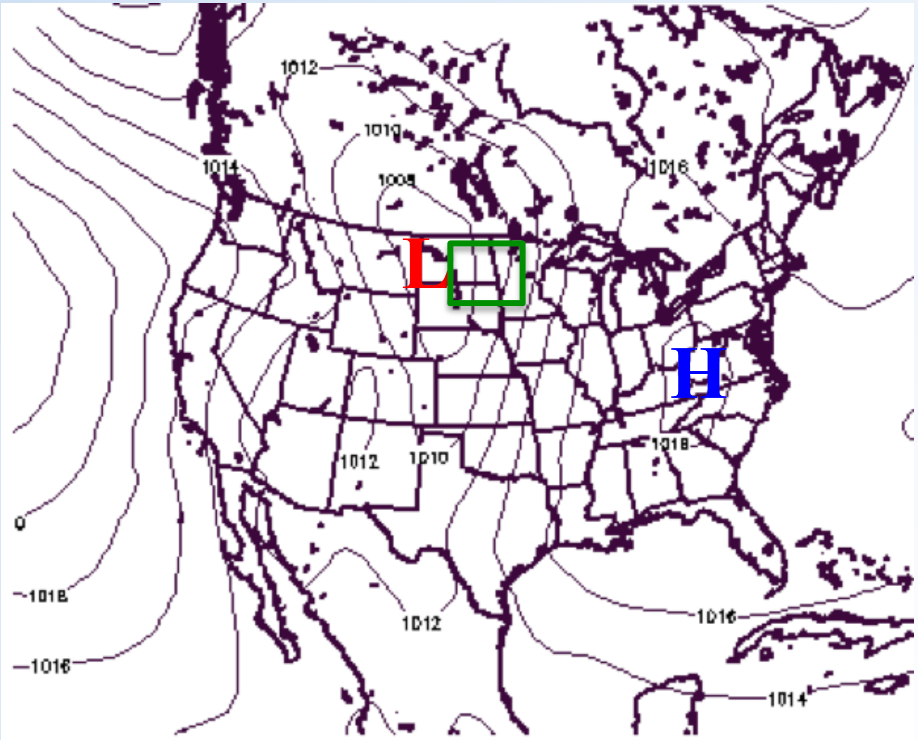
Red River February



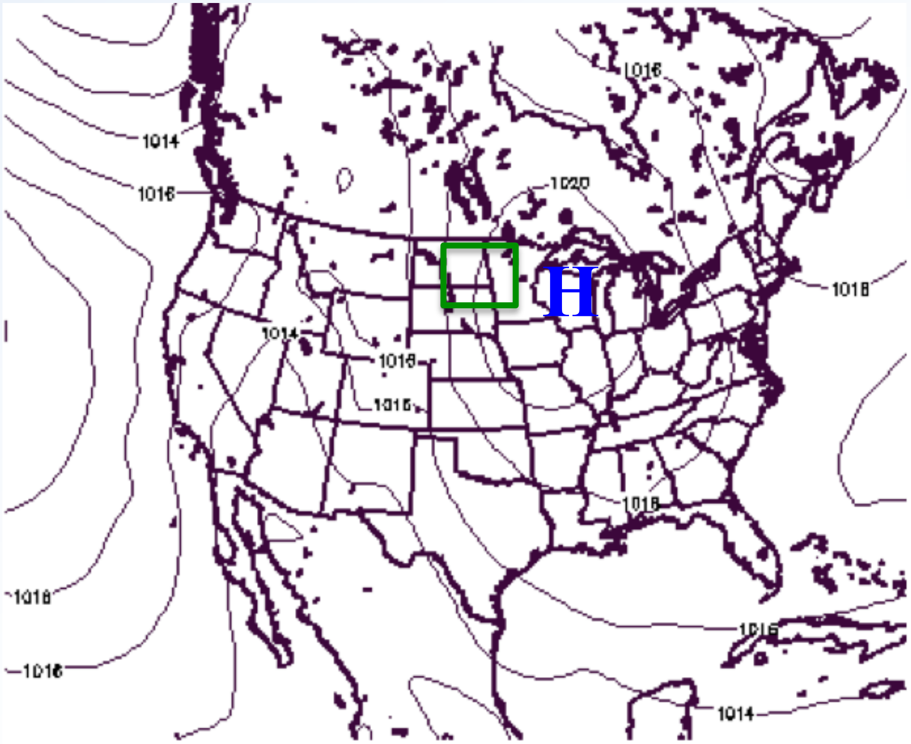


Same synoptic types as January…

Red River March



Sea Level Pressure (mb) Composite Mean
Synoptic Type 2036
NCEP/NCAR Reanalysis



Sea Level Pressure (mb) Composite Mean
Synoptic Type 2031
NCEP/NCAR Reanalysis

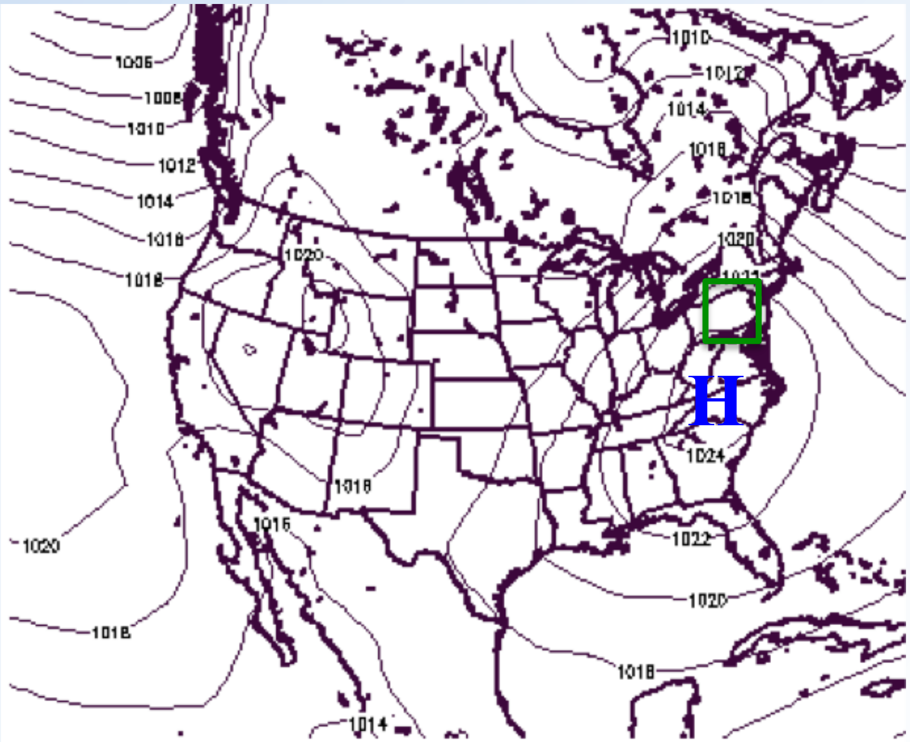
Susquehanna River Synoptic Patterns

2.54+ cm ablation events (373) 1960 - 2009

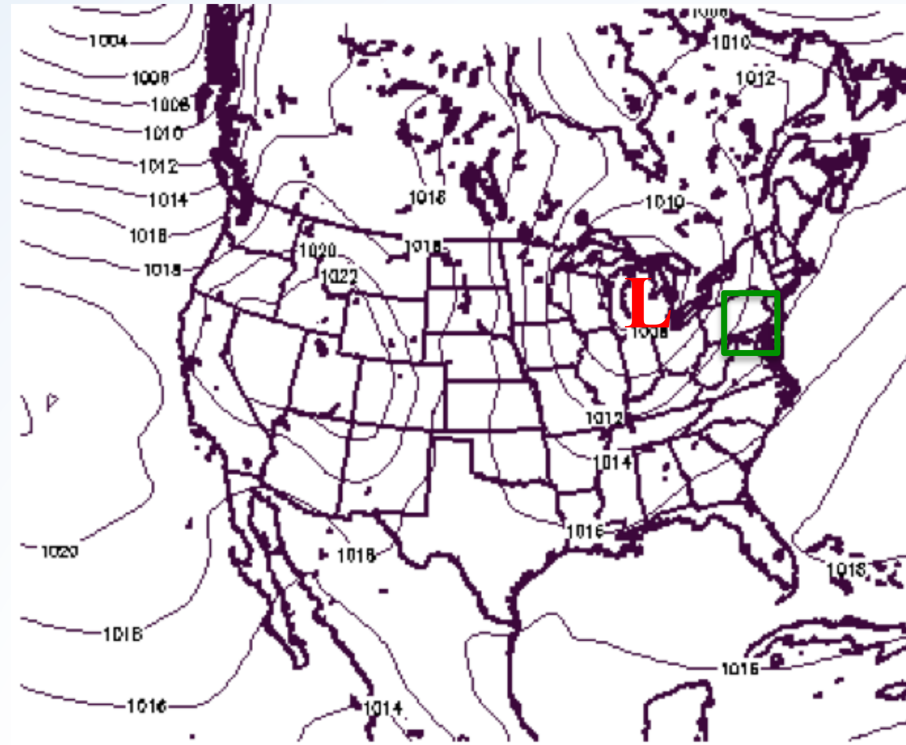
4.75 X 10^{10} gallons

January (93)	**1035 (19)**	**1031 (16)**	**1034 (12)**	**1005 (11)**
February (134)	**1035 (24)**	**1031 (19)**	**1034 (17)**	**1016 (15)**
March (146)	**2036 (26)**	**2031 (21)**	**2034 (16)**	**2035 (16)**

Susquehanna River January



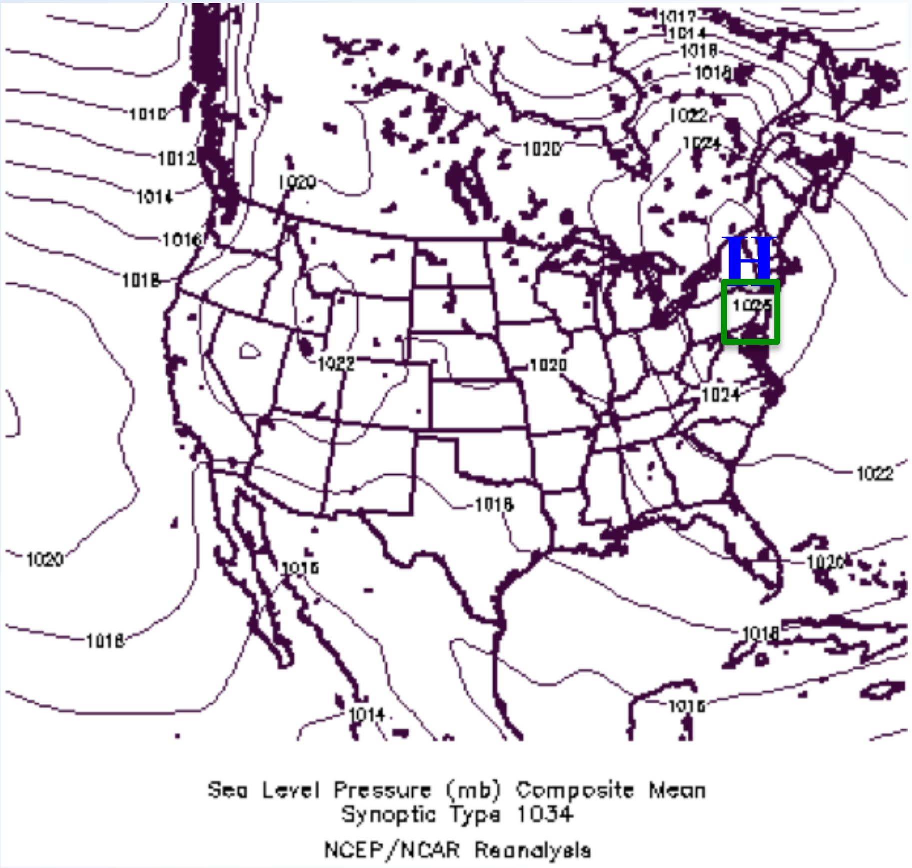
Sea Level Pressure (mb) Composite Mean
Synoptic Type 1035
NCEP/NCAR Reanalysis



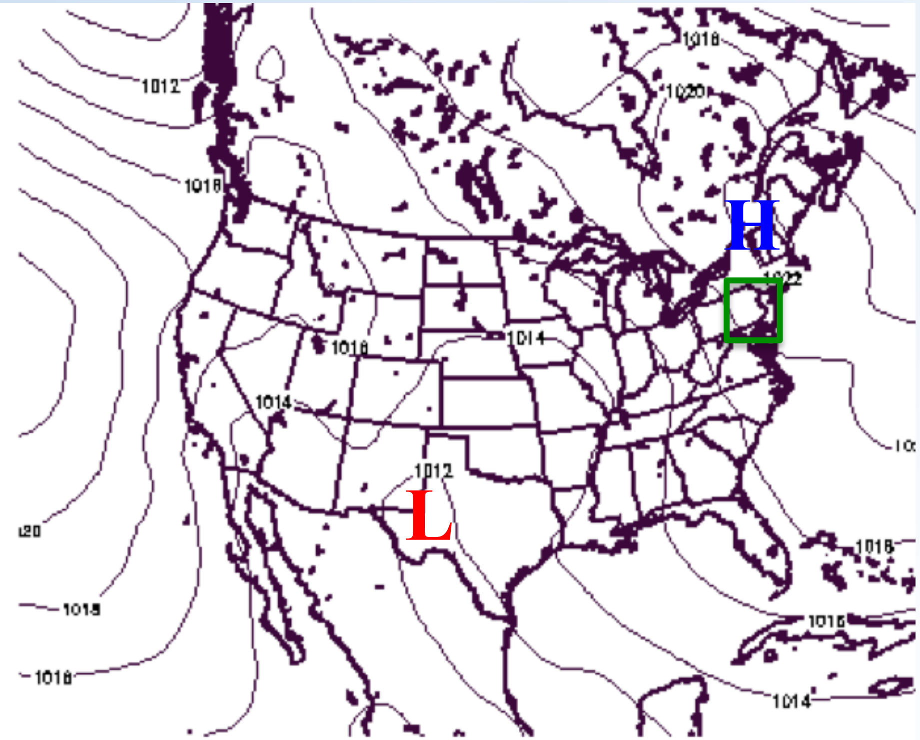
Sea Level Pressure (mb) Composite Mean
Synoptic Type 1031
NCEP/NCAR Reanalysis

Susquehanna River February

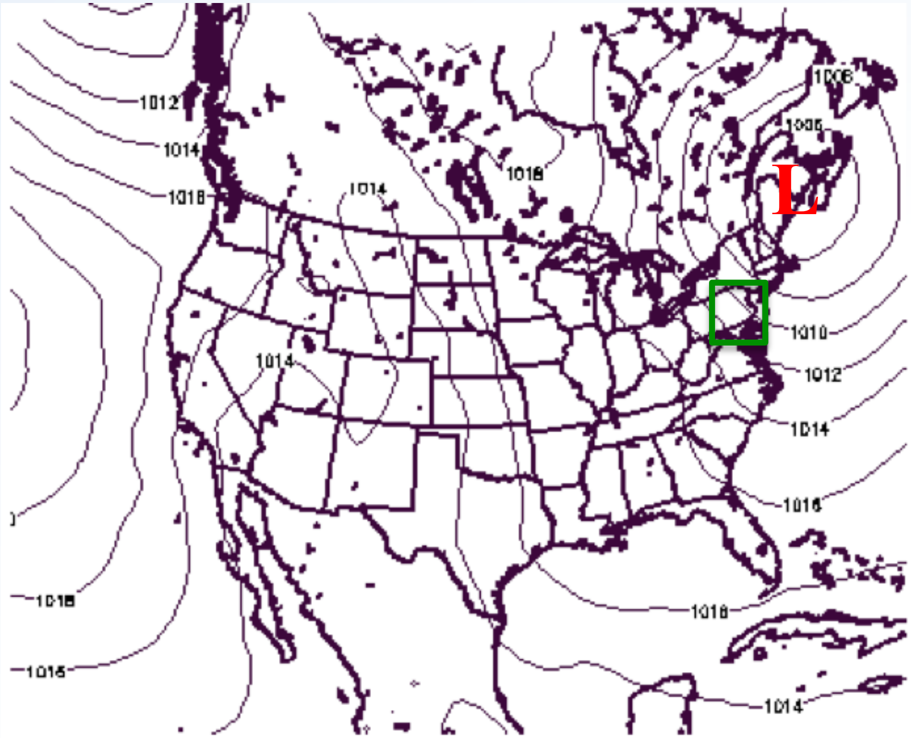
Same as January in addition too...



Susquehanna River March



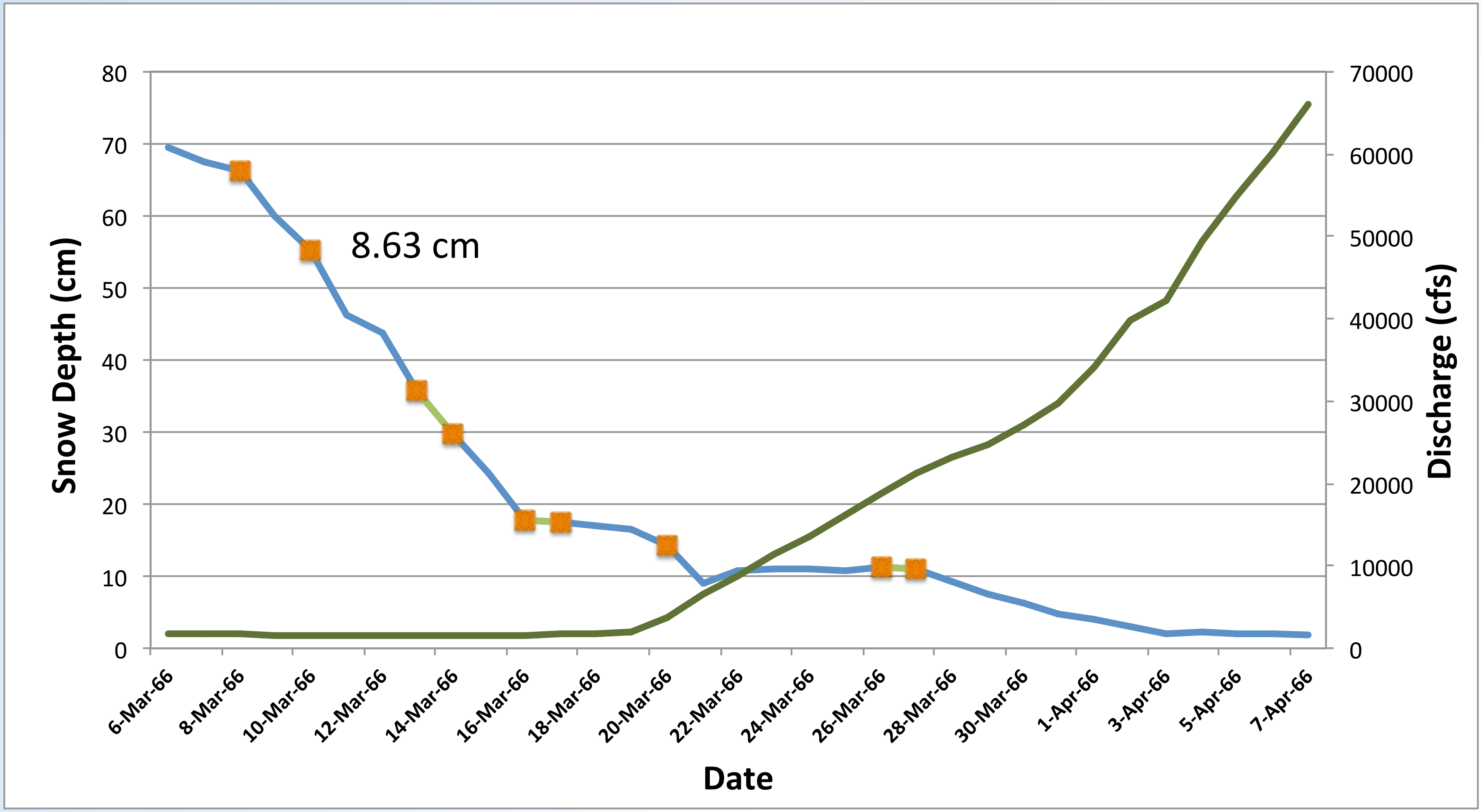
Sea Level Pressure (mb) Composite Mean
Synoptic Type 2036
NCEP/NCAR Reanalysis



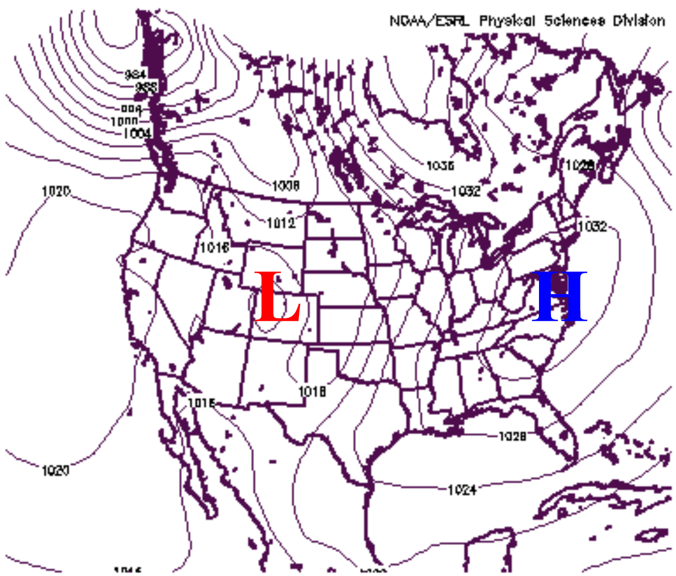
Sea Level Pressure (mb) Composite Mean
Synoptic Type 2031
NCEP/NCAR Reanalysis

Two Brief Case Studies

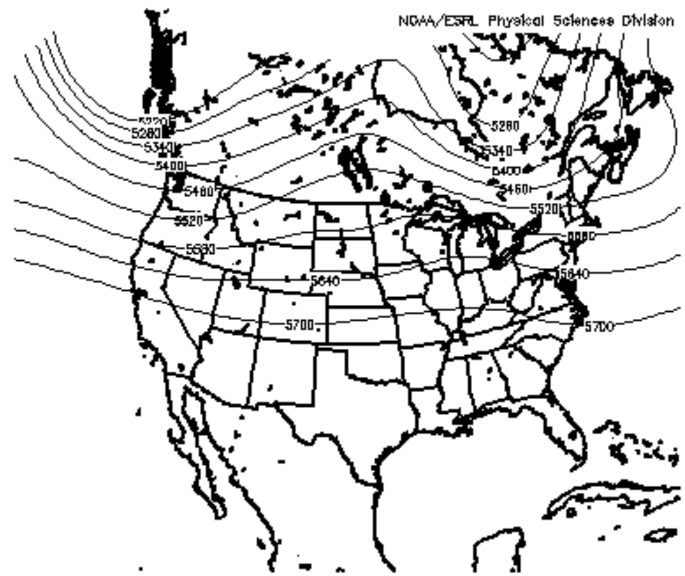
Red River example, March 6 – April 1, 1966. Snow depth (blue), discharge (green), and ablation synoptic type days (orange squares).



March 10, 1966 – ablation 8.63 cm



Sea Level Pressure (mb) Composite Mean
03/10/66
NCEP/NCAR Reanalysis

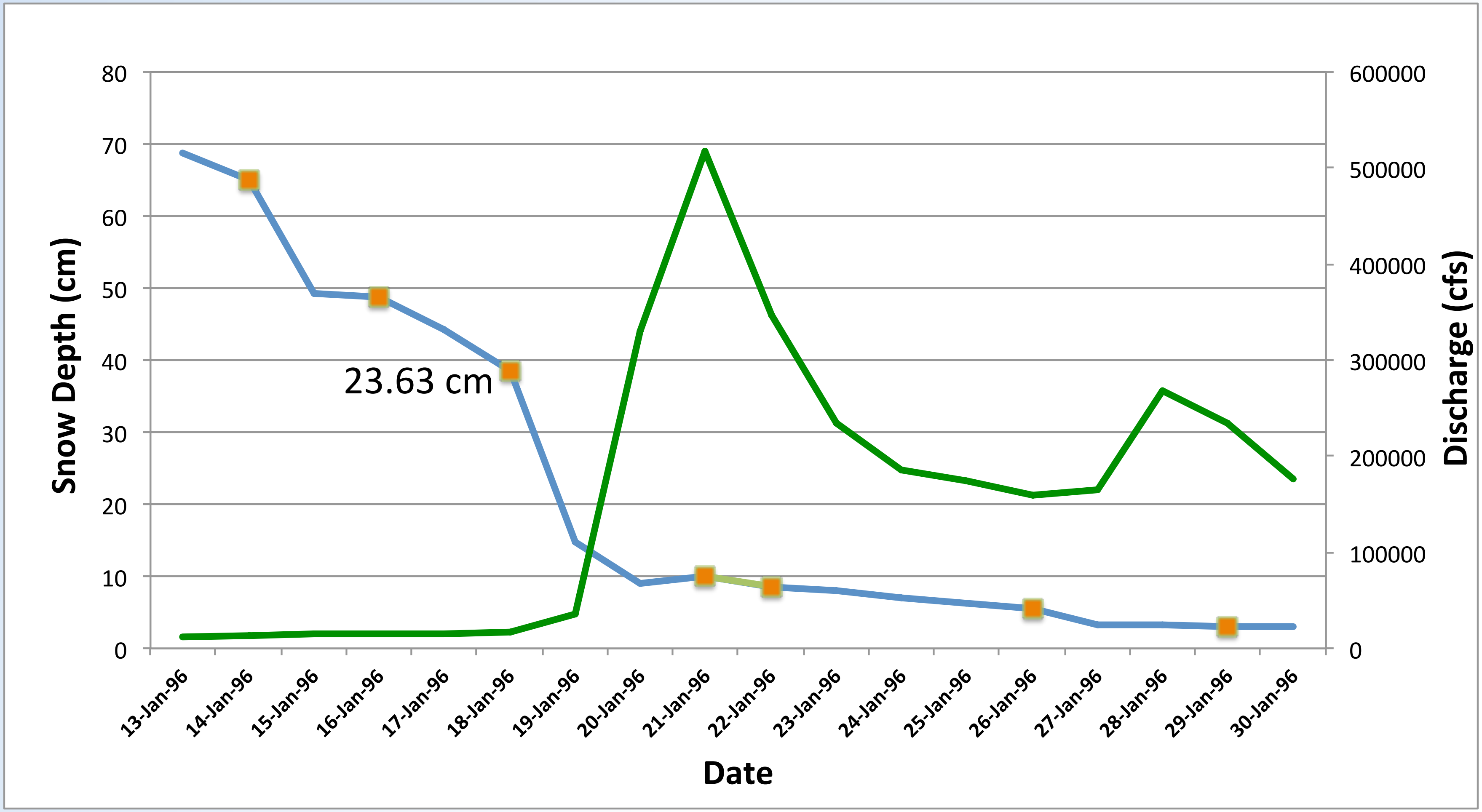


500mb Geopotential Height (m) Composite Mean
03/10/66
NCEP/NCAR Reanalysis

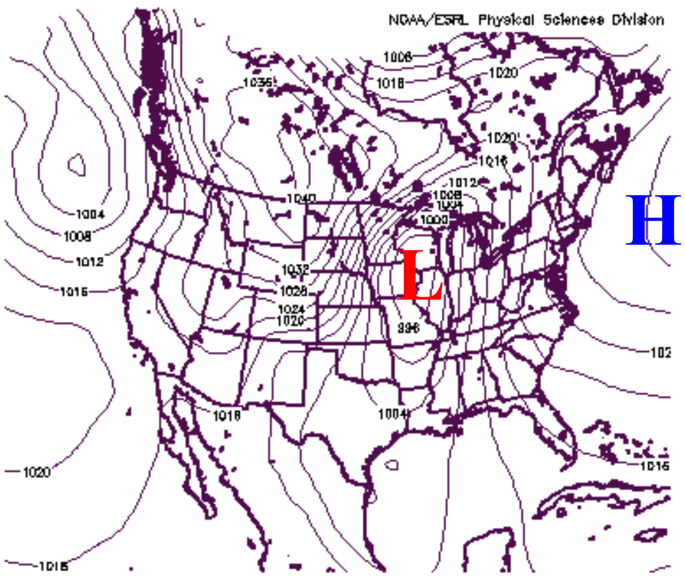
Strong southerly flow over the basin. Temps and dew points significantly above freezing, along with moderate winds. Large sensible and latent heat fluxes into the snow pack.

T-15z	Td-15z	SLP-15z	U-15z	V-15z	CC-15z	T-21z	Td-21z	SLP-21z	U-21z	V-21z	CC-21z	T-3z	Td-3z	SLP-3z	U-3z	V-3z	CC-3z
6.1	3.3	1017.1	-2.6	3.2	10	12.8	6.1	1014.5	4.4	1.6	9	3.3	2.2	1015.9	0.4	-2	10

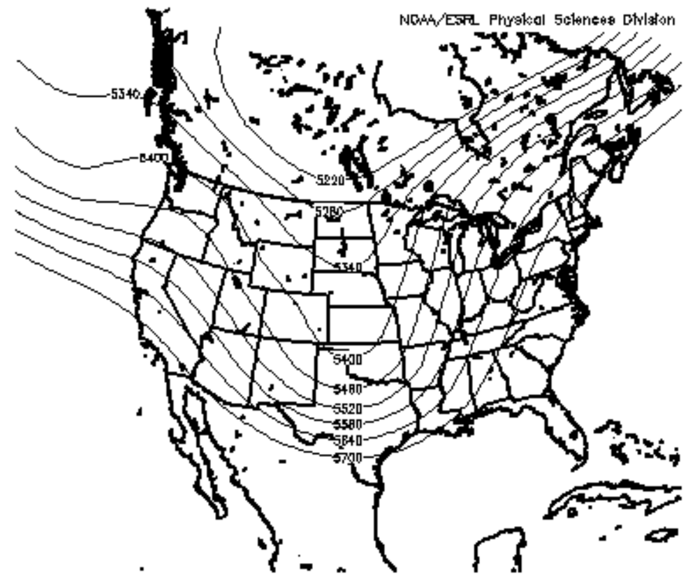
Susquehanna River example, January 13 – 30, 1996. Snow depth (blue), discharge (green), and ablation synoptic type days (orange squares).



January 18, 1996 – ablation 23.72 cm



Sea Level Pressure (mb) Composite Mean
01/18/96
NCEP/NCAR Reanalysis



500mb Geopotential Height (m) Composite Mean
01/18/96
NCEP/NCAR Reanalysis

Strong southerly flow over the basin. Temps and dew points far above freezing and high wind speeds. Extreme sensible and latent heat fluxes into the snow pack. Heavy rainfall adds more energy and water to the melting pack.

T-15z	Td-15z	SLP-15z	U-15z	V-15z	CC-15z	T-21z	Td-21z	SLP-21z	U-21z	V-21z	CC-21z	T-3z	Td-3z	SLP-3z	U-3z	V-3z	CC-3z
16.1	15	1001.7	0	10.8	10	10	8.3	997.7	11.6	-6.7	10	-3.9	-5	1017	12.1	-4.4	0

The largest ablation events in both basins are associated with very large turbulent fluxes, both sensible and latent heat fluxes. In some cases, rain-on-snow events add additional energy to the pack from the warm rainfall.

Dew point temperatures above freezing are very important to rapid ablation. Condensation takes place on the pack releasing large amounts of latent heat!

Synoptic Type Frequencies and Global Forcings

Red River - Pearson Correlation Coefficients

2.54+ Synoptic Type Frequencies and Global Forcings

	Synoptic Type	EP / NP	AO						
January	1032	-0.454	0.324						
	1033	-0.438	0.103						
	1035	-0.056	-0.04						
	Synoptic Type	NAO	EP/NP	EA/WR	SCA	POL	NH Snwd	Eur Snwd	NA Snwd
	1031	-0.328	-0.251	-0.357	0.073	0.037	-0.067	0.054	-0.258
February	1032	0.216	-0.261	0.016	-0.398	-0.314	-0.356	-0.327	-0.239
	1033	0.154	-0.281	0.075	-0.183	-0.109	-0.371	-0.277	-0.369
	1034	-0.031	-0.174	0.114	-0.195	-0.002	-0.254	-0.155	-0.316
	Synoptic Type	WP	EP/NP	EA/WR	POL	NA Snwd	AMO		
	2003	-0.287	-0.042	-0.061	0.138	0.173	-0.252		
March	2005	-0.331	0.304	0.036	0.218	0.498	0.047		
	2031	-0.116	-0.002	0.03	-0.279	-0.216	0.299		
	2036	0.251	0.072	0.34	0.021	-0.227	0.047		

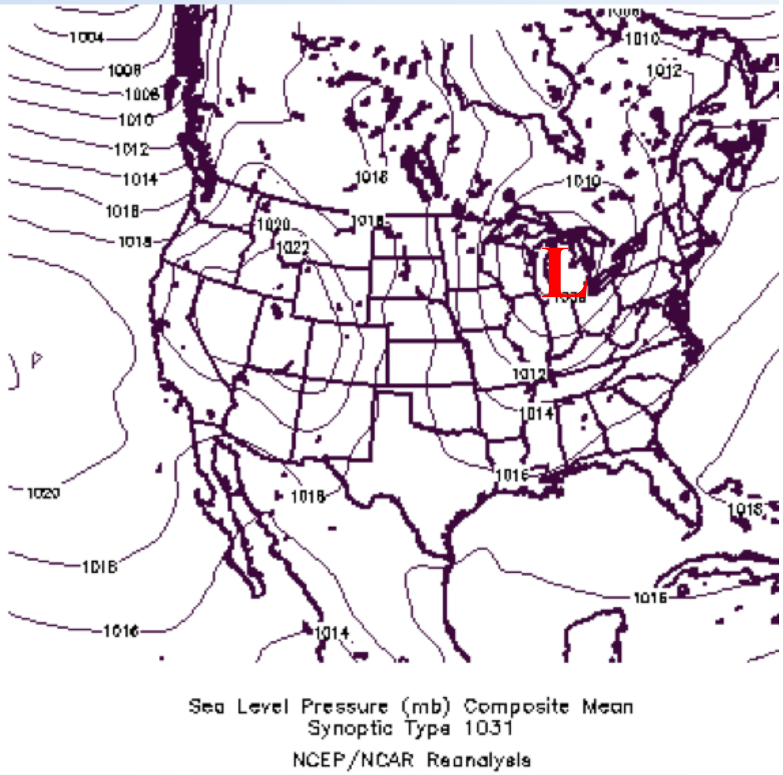
Susquehanna - Pearson Correlation Coefficients
2.54+ Synoptic Type Frequencies and Global Forcings

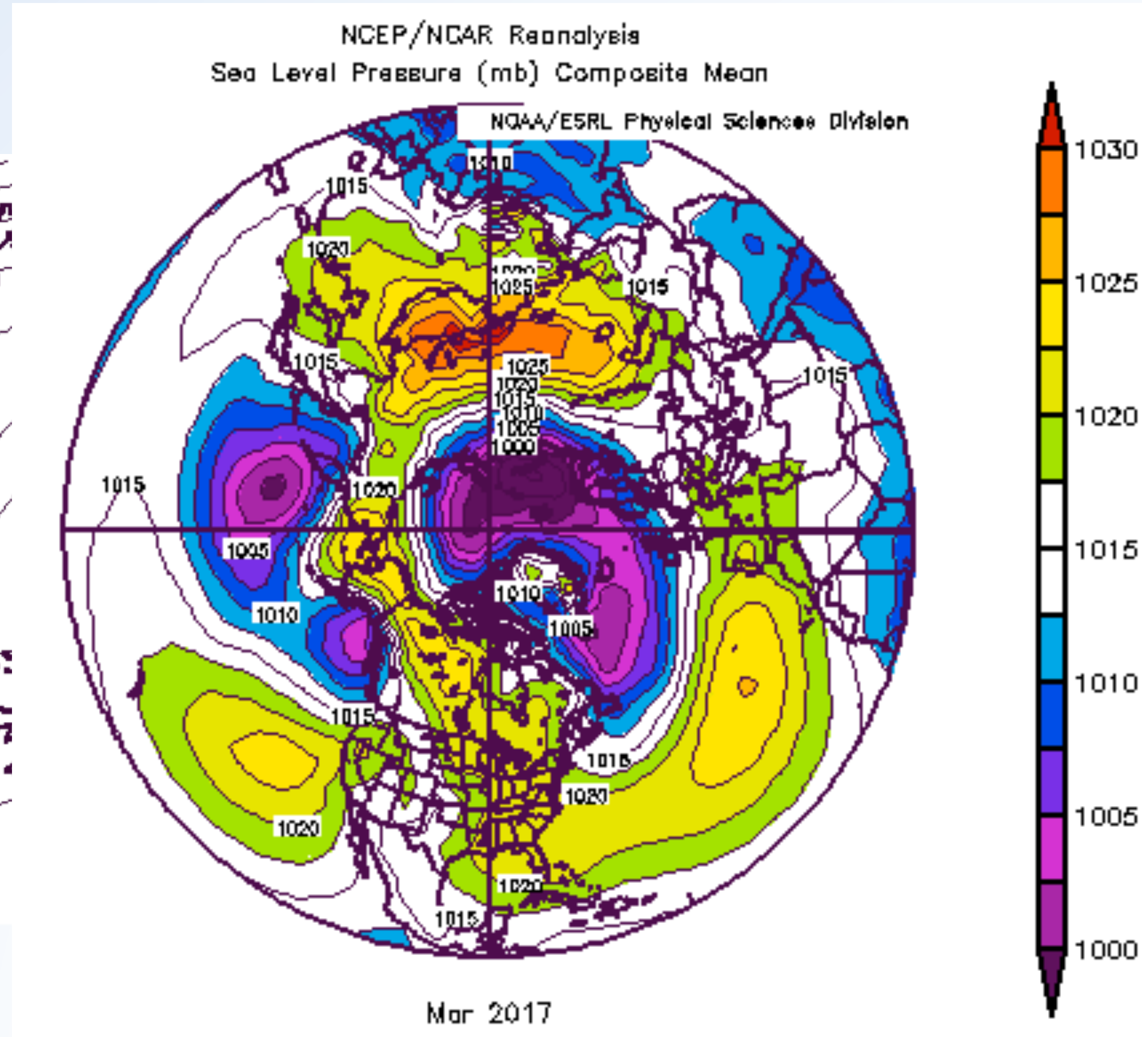
	Synoptic Type	NAO	WP	EP/NP	PNA	EA/WR	AO	NA Snwd
January	1005	-0.421	0.399	0.19	0.247	-0.24	-0.302	0.276
	1031	0.189	0.253	-0.264	-0.054	0.294	0.305	-0.437
	1034	0.319	-0.118	0.179	-0.307	-0.229	0.186	0.316
	1035	0.05	-0.043	-0.441	-0.088	0.301	0.208	-0.304

	Synoptic Type	NAO	EP/NP	POL	AO	NH Snwd	NA Snwd
	1016	0.225	-0.338	-0.187	0.294	-0.331	-0.299
February	1031	0.129	-0.416	-0.146	0.216	-0.394	-0.517
	1034	0.218	0.197	-0.148	0.081	0.258	0.453
	1035	0.324	-0.312	-0.406	0.227	-0.367	-0.456

	Synoptic Type	NAO	WP	PNA	Nino3.4	AO	ONI	PDO
	2031	-0.573	0.127	0.387	0.082	-0.584	0.096	0.092
March	2034	0.373	0.137	-0.146	-0.131	0.396	-0.13	-0.081
	2035	0.11	0.118	-0.363	-0.379	0.192	-0.374	-0.133
	2036	0.242	-0.385	-0.205	-0.093	0.344	-0.089	-0.31
	2037	0.198	0.135	-0.168	0.138	0.272	0.115	-0.025

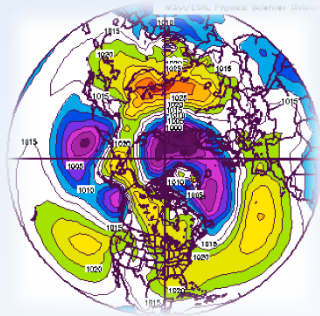
Susquehanna - March
Correlation of -0.573 between Type 1031 and NAO





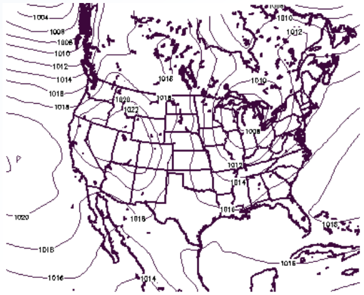
East coast trough and added baroclinicity leads to more cyclogenesis and more frequent ablation episodes.

Strong negative NAO / AO



Increased snow depth, increased probability of significant ablation events.

Changes in the frequency of ablation patterns over Mid-Atlantic



Sea Level Pressure (mb) Composite Mean
Synoptic Type 1031
NCEP/NCAR Reanalysis

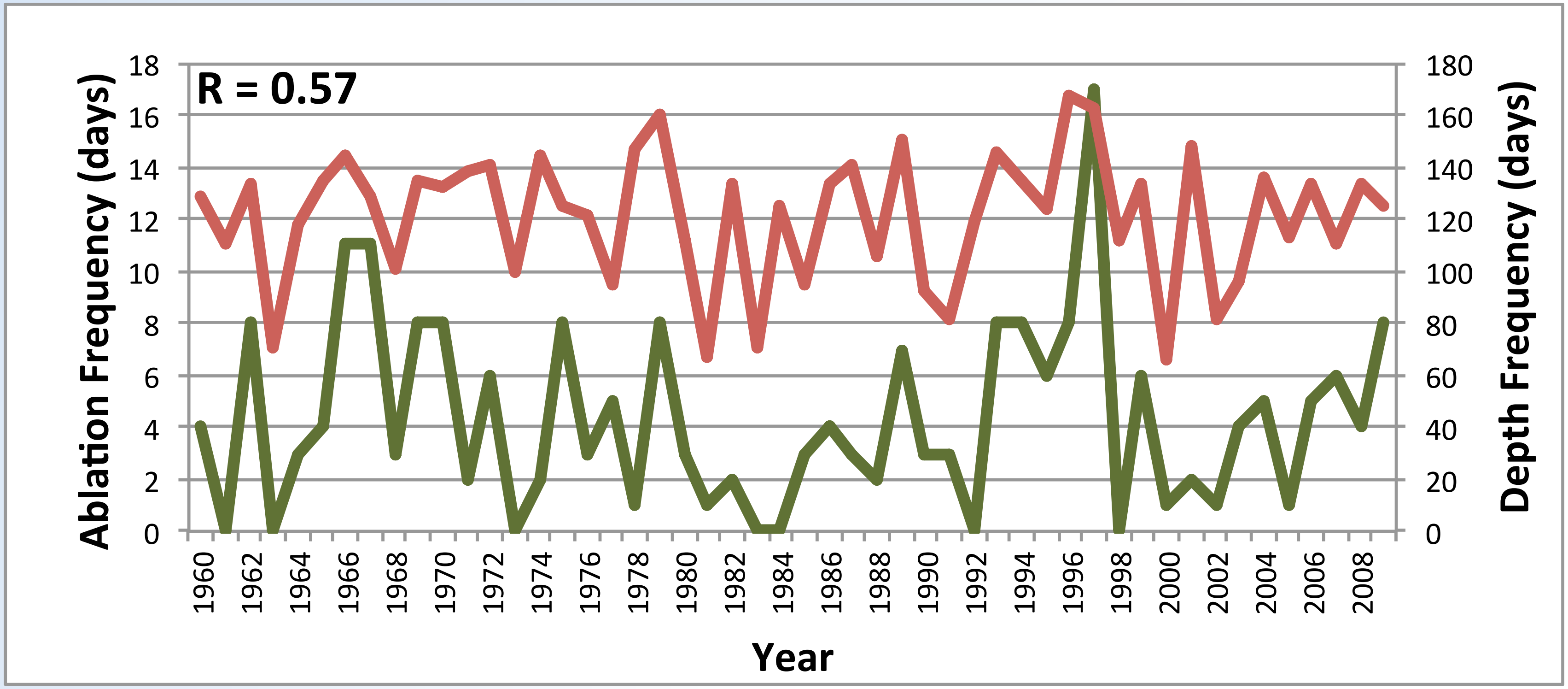
Increased probability of large flooding events.

Long-Term Trends

Red River Basin

Seasonal (Nov. – April) 2.54 cm snow depth (red) and 2.54 cm ablation (green)

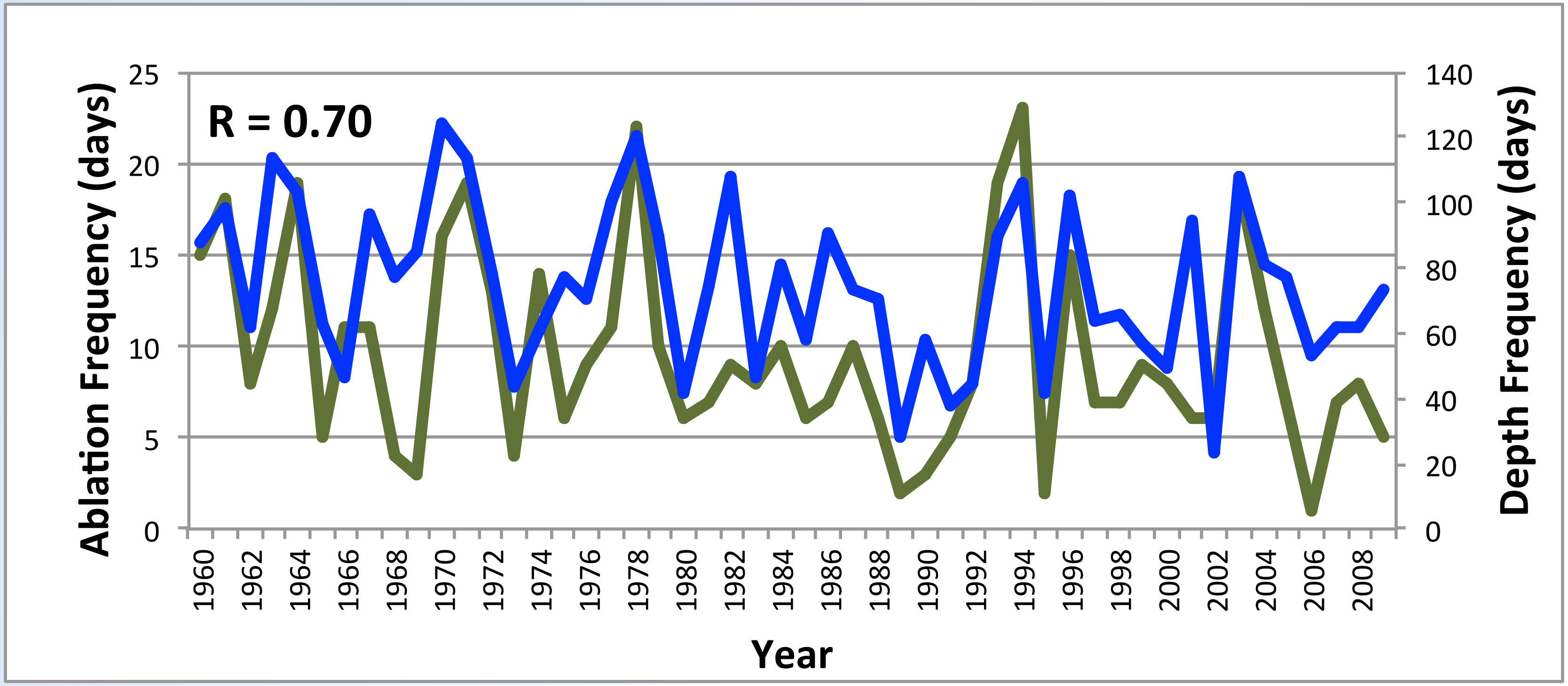
January 2.54 cm ablation events are significantly increasing



Susquehanna River Basin

Seasonal (Nov. – April) 2.54 cm snow depth (blue) and 2.54 cm ablation (green)

February 2.54 cm ablation events are significantly decreasing



Summary…

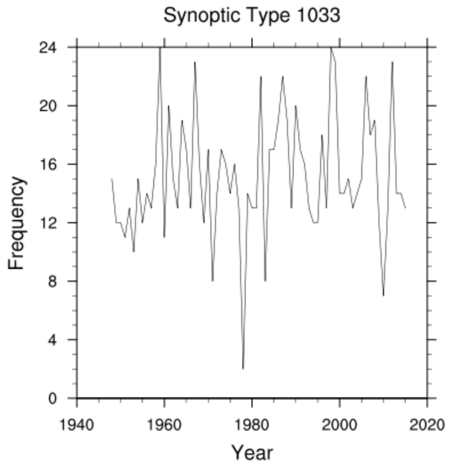
- distinct synoptic types are associated with the largest (2.54 cm) ablation events in both the Red and Susquehanna River basins

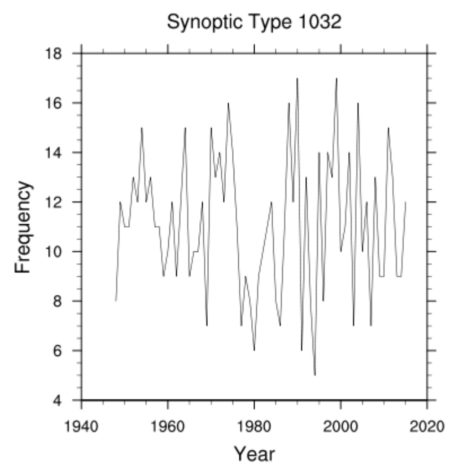
- these synoptic types are in many cases significantly related to global-scale forcing mechanisms (teleconnections and land and ocean surface conditions)

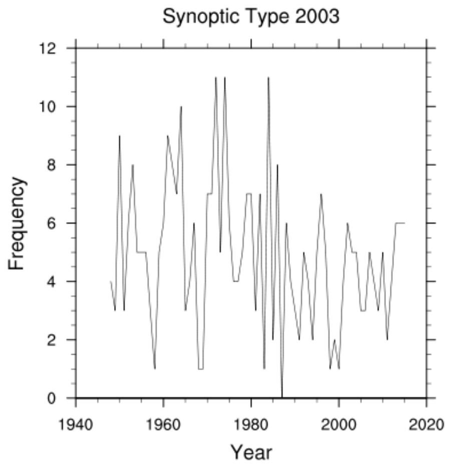
- a “pathway” can be traced from global forcings, through synoptic patterns, to local surface energy fluxes (latent and sensible heat) to explain ablation episodes

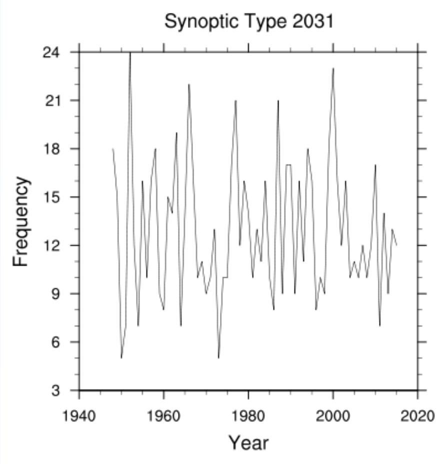

Questions or Comments?

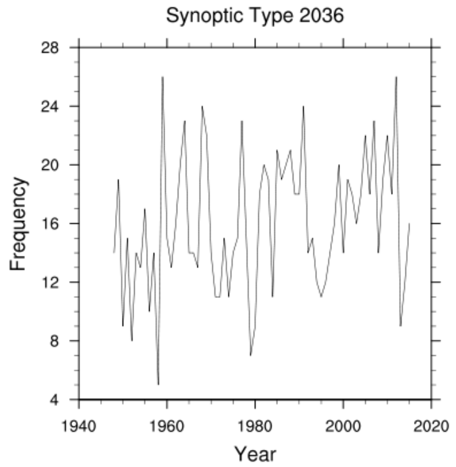
Red River Synoptic Types











Susquehanna River Synoptic Types