

Wintertime Climate Variability in the Lake Michigan Region:

Sensitivity of Snowfall to Temperature and Northern Hemisphere Teleconnection Patterns

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March 15, 2012

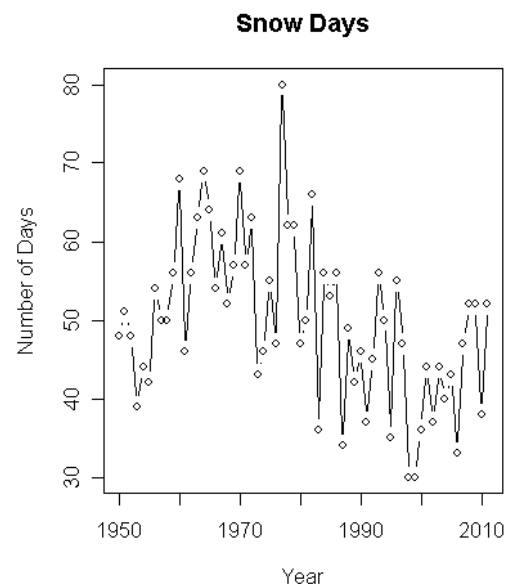
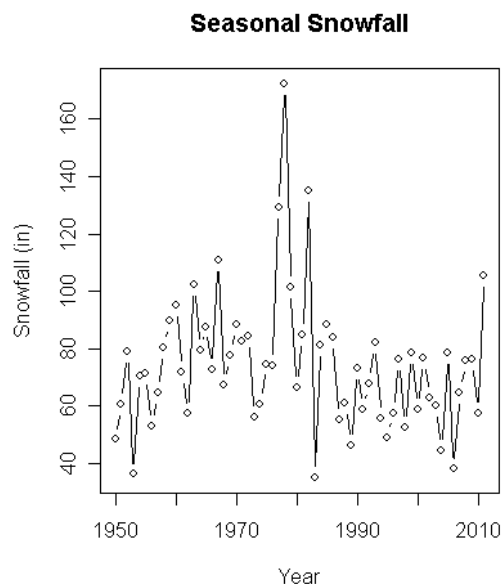
Outline

- Introduction
- Adventures with Data
 - Regions and station selection
 - Temperature and snowfall
 - Comparison of sub-regions
 - Sensitivity of snowfall to temperature
 - Sensitivity to tele-connection patterns
- Daily Data Winter Stew: PC1 and PC2
- Conclusions



Introduction

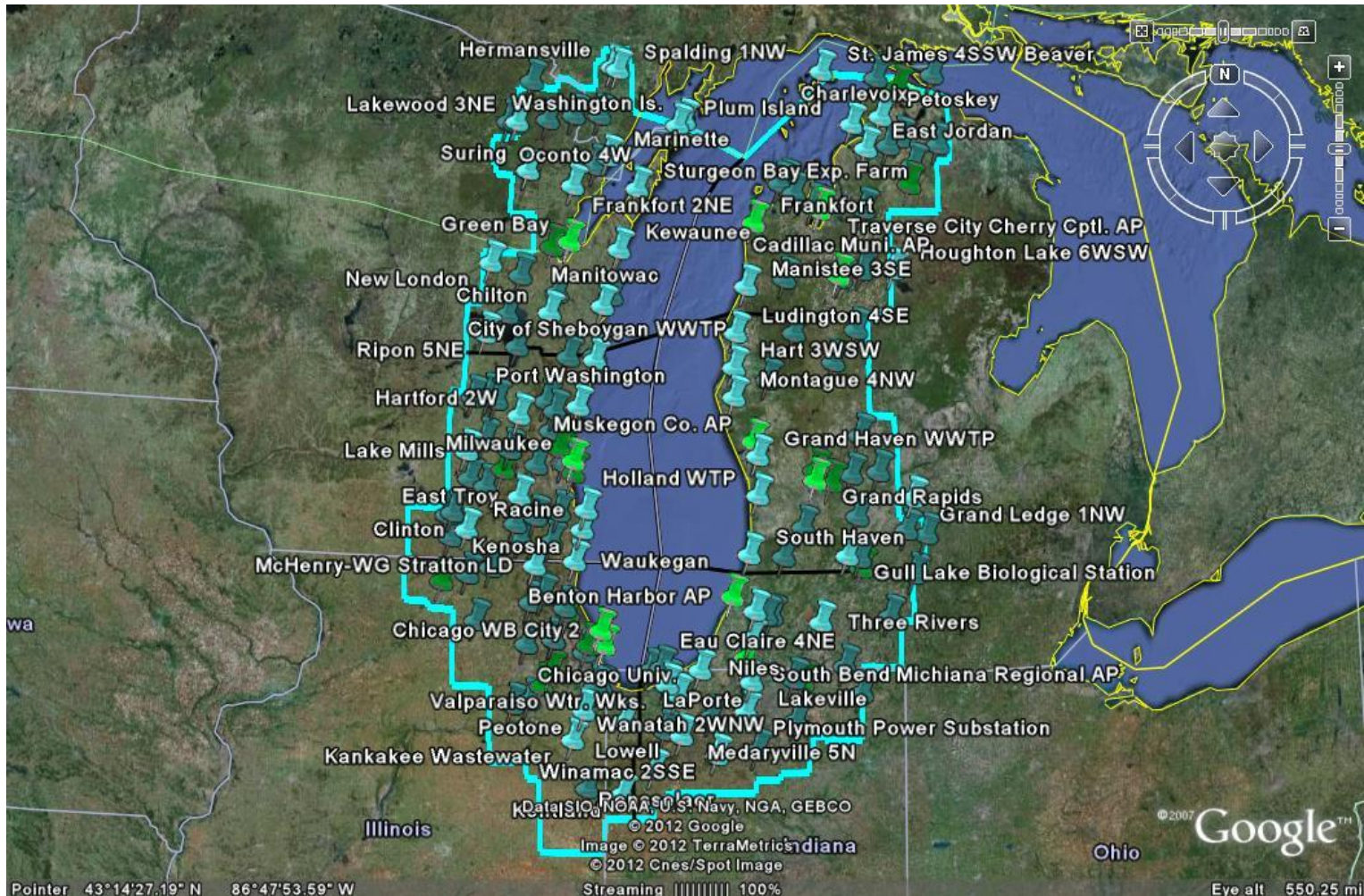
- Wintertime data in northern Indiana and the adjacent southern Lake Michigan region reveals:
 - Tremendous year-to-year noise, with a super-imposed warming trend
 - Strong relationship between snowfall and temperature and tele-connection patterns
 - Decrease of seasonal snowfall at locations like South Bend, which is not obvious at locations with little or no LES
- How localized is this?
 - South Bend ->



Questions and Charge to the Students

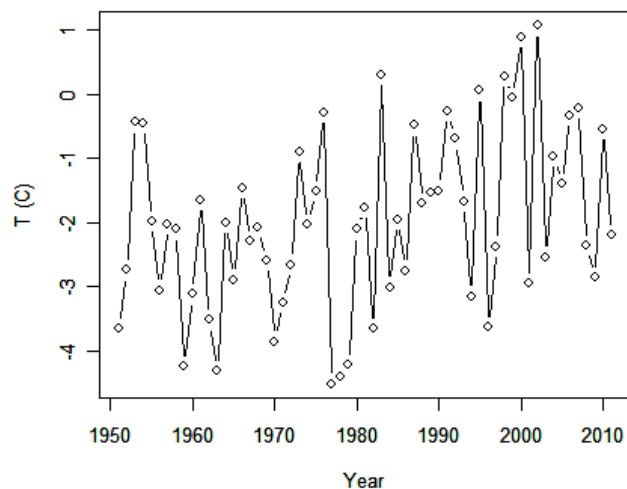
- How should we characterize the snowfall and temperature variability?
- How does the sensitivity of snowfall to temperature vary spatially?
- How do the temperature and snowfall vary with large-scale patterns?
- Charge to the students
 - Design regions, pick stations, download from NCDC, and explore, plot, etc.
 - Compare results with another student group, which is examining November data
 - Experience the joys of working with snowfall data
 - Changes in observer, observation type, distribution shape, and NAs

Map of Regions and Stations

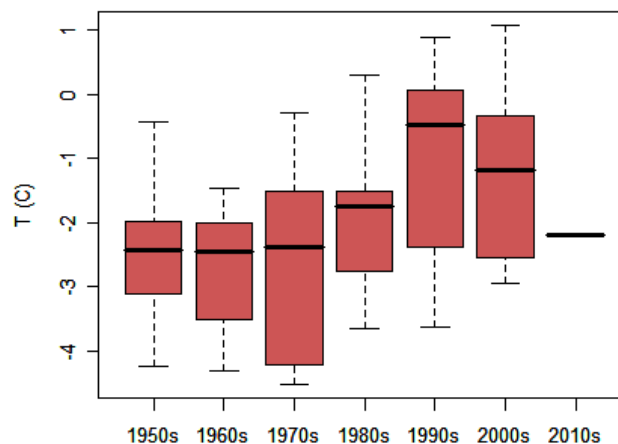


Regional Temperature Composite

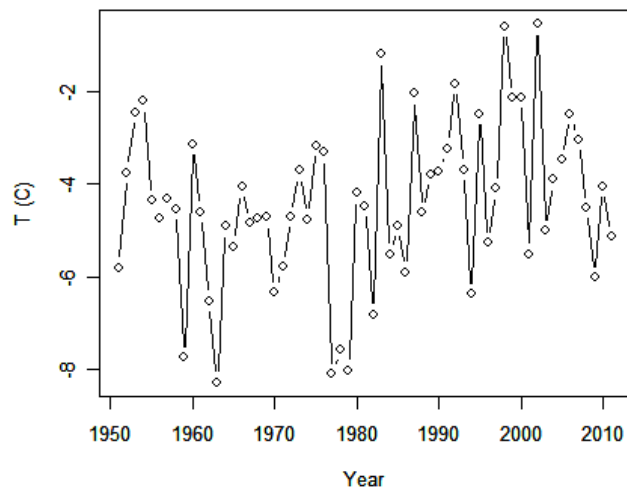
NOV to MAR Regional Temperature



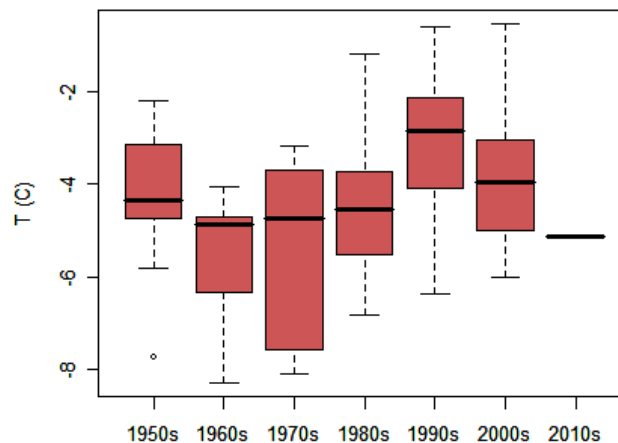
NOV to MAR Regional Temperature



DEC to FEB Regional Temperature

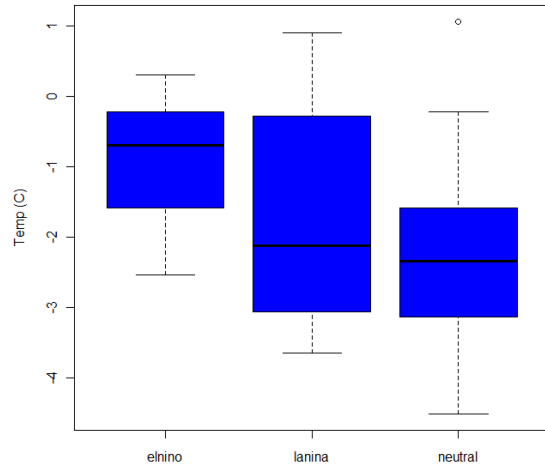


DEC to FEB Regional Temperature

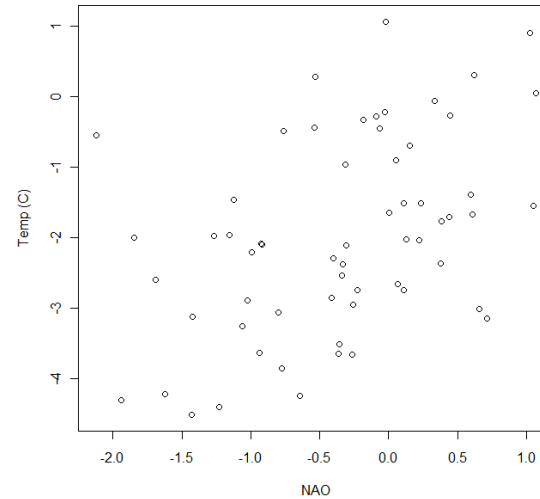


Sensitivity of Temperature to Teleconnection Patterns

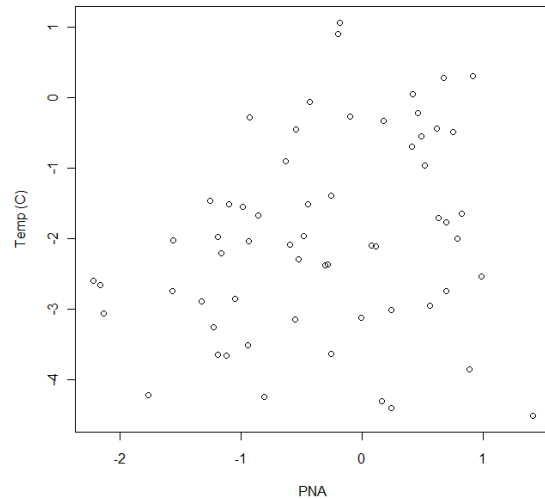
ENSO vs Lake Michigan Regional Composite Temperature



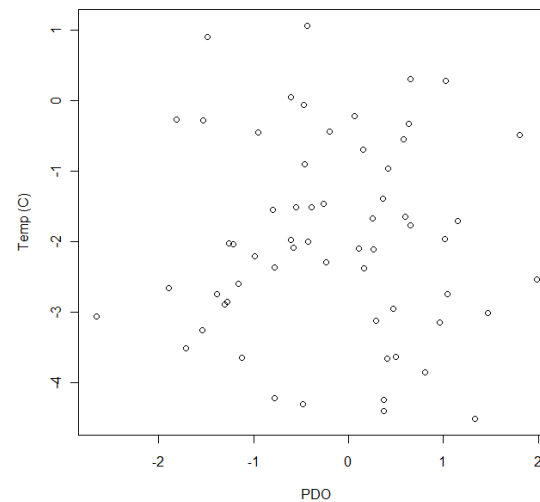
NAO vs Lake Michigan Regional Composite Temperature



PNA vs Lake Michigan Regional Composite Temperature

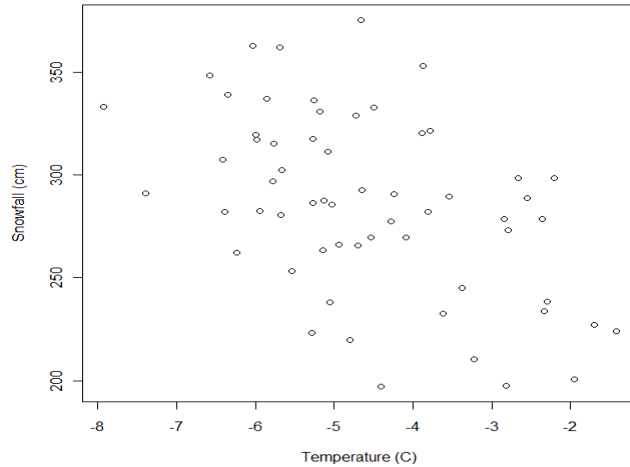


PDO vs Lake Michigan Regional Composite Temperature

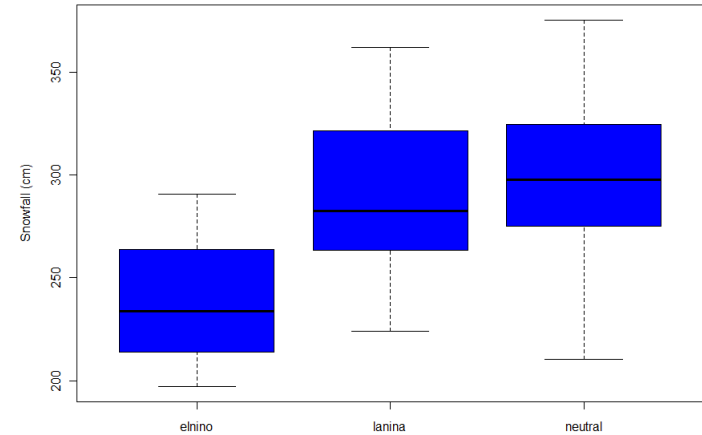


Northeast Region

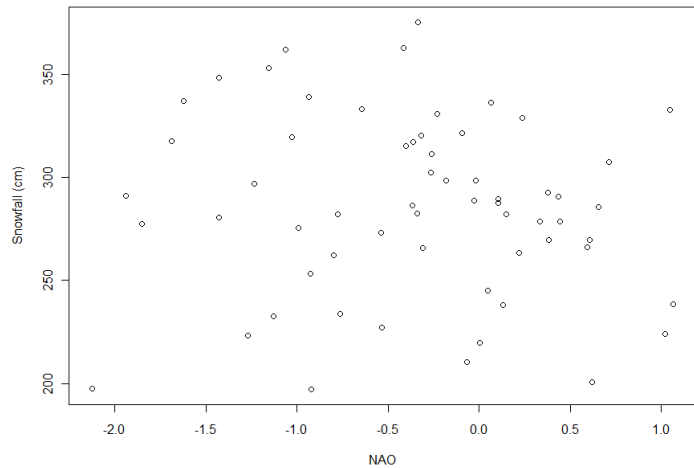
Northeast Lake Michigan Temperature vs Composite Snowfall



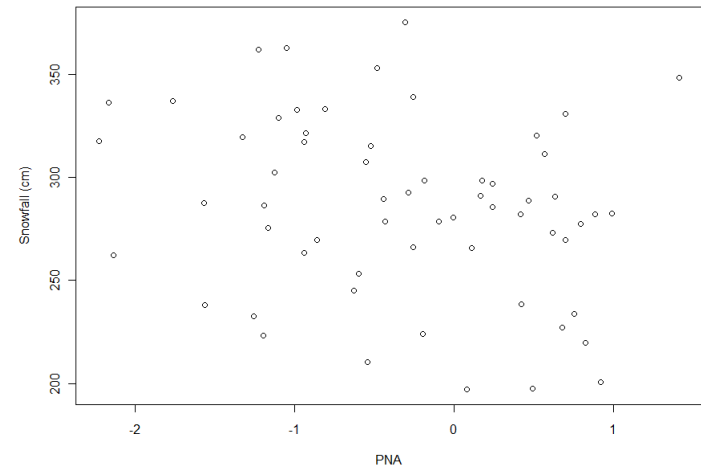
ENSO vs Northeast Lake Michigan Composite Snowfall



NAO vs Northeast Lake Michigan Composite Snowfall

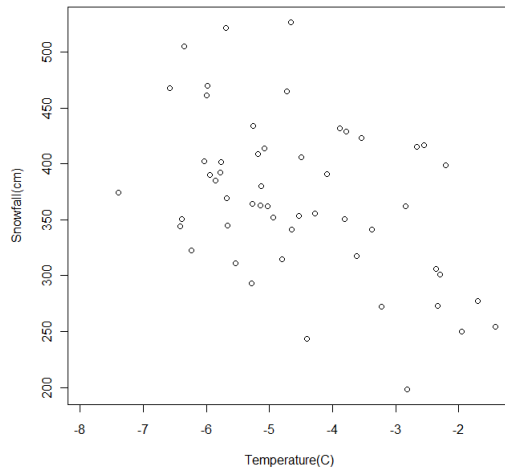


PNA vs Northeast Lake Michigan Composite Snowfall

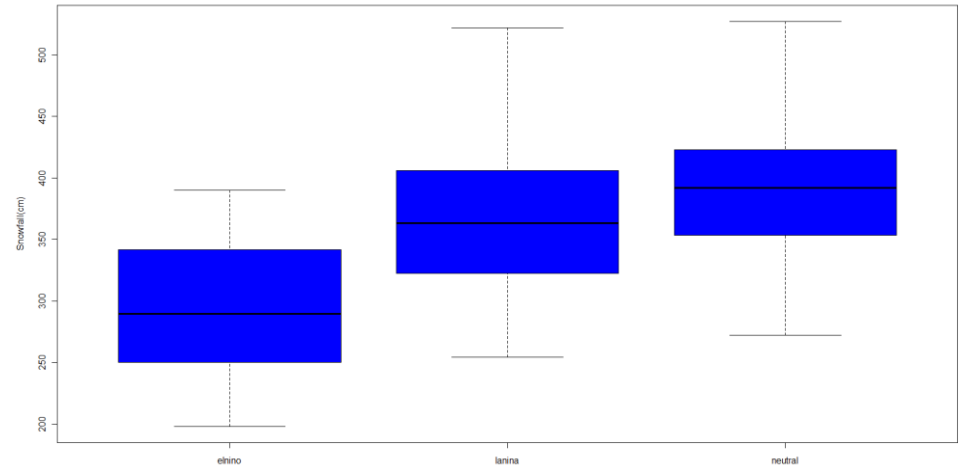


Northeast Region

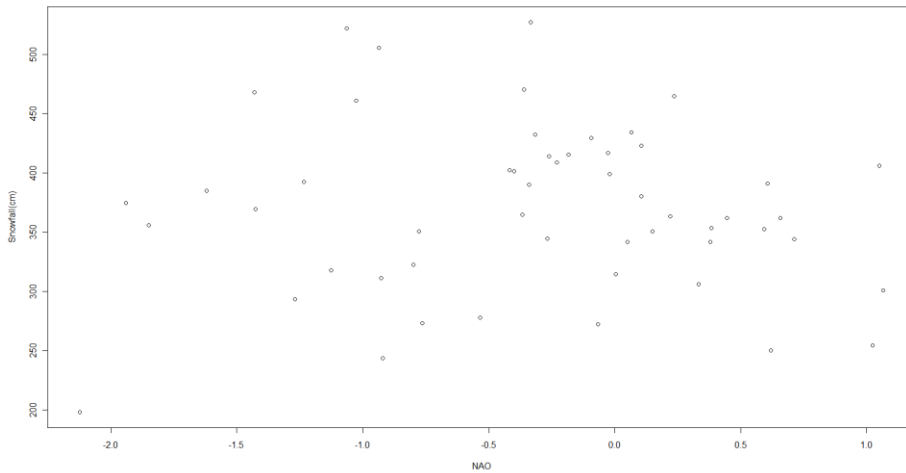
Gaylord Seasonal Temperature and Snowfall



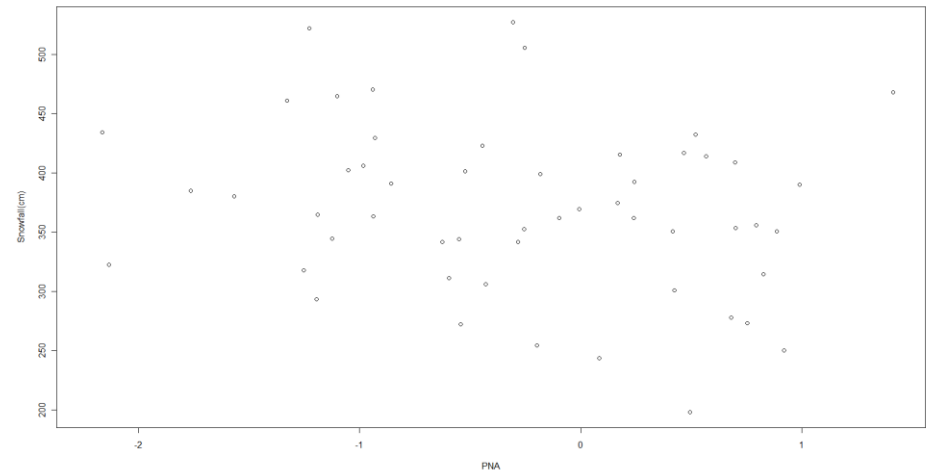
Gaylord ENSO and Snowfall



Gaylord NAO and Snowfall

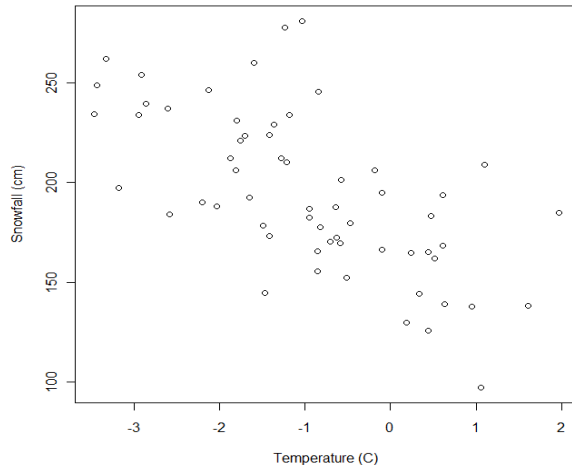


Gaylord PNA and Snowfall

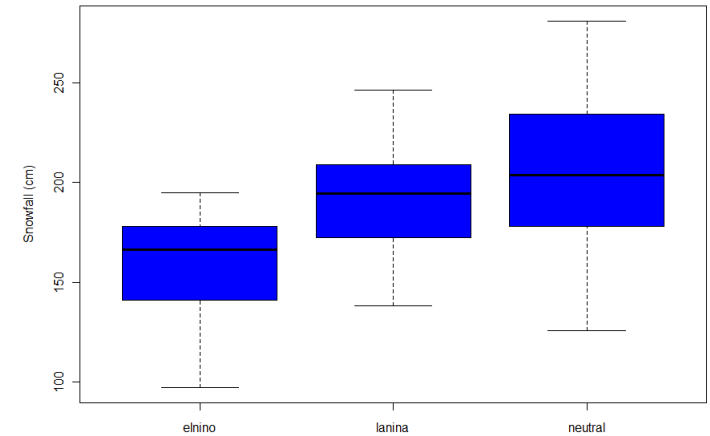


Eastern Region

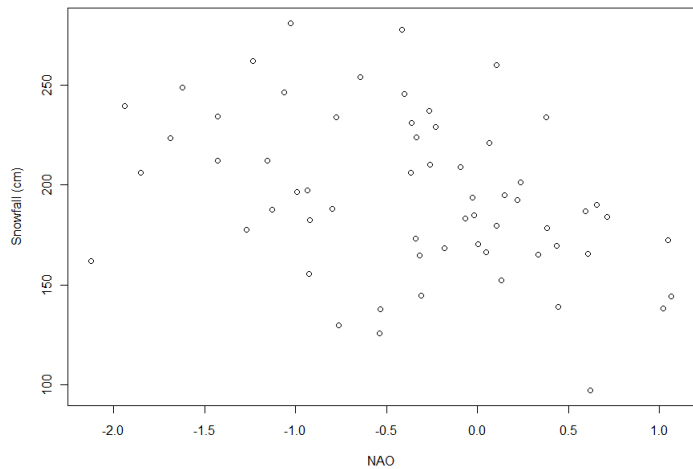
East Central Lake Michigan Temperature vs Composite Snowfall



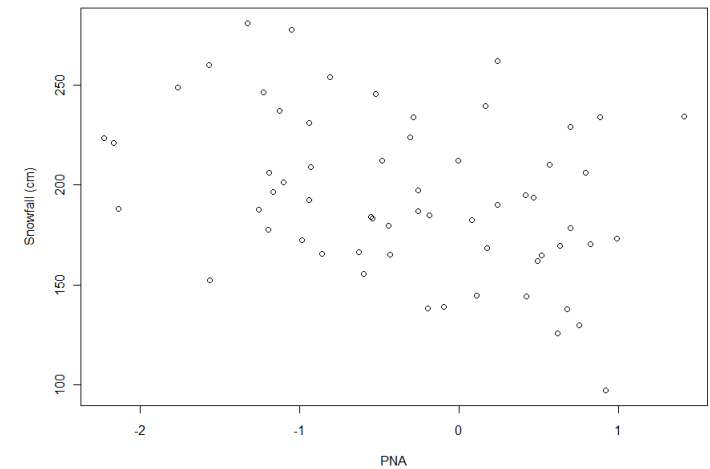
ENSO vs East Central Lake Michigan Composite Snowfall



NAO vs East Central Lake Michigan Composite Snowfall

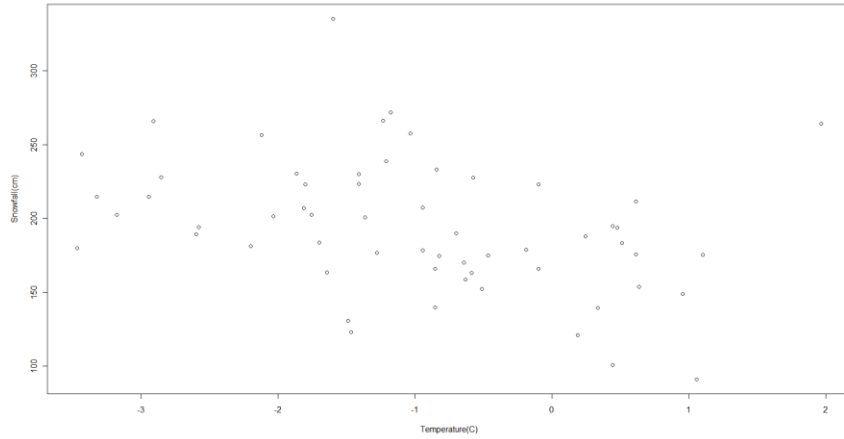


PNA vs East Central Lake Michigan Composite Snowfall

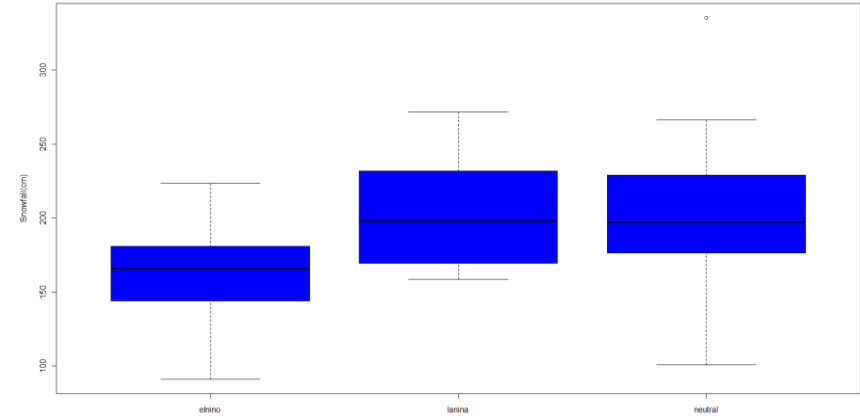


Eastern Region

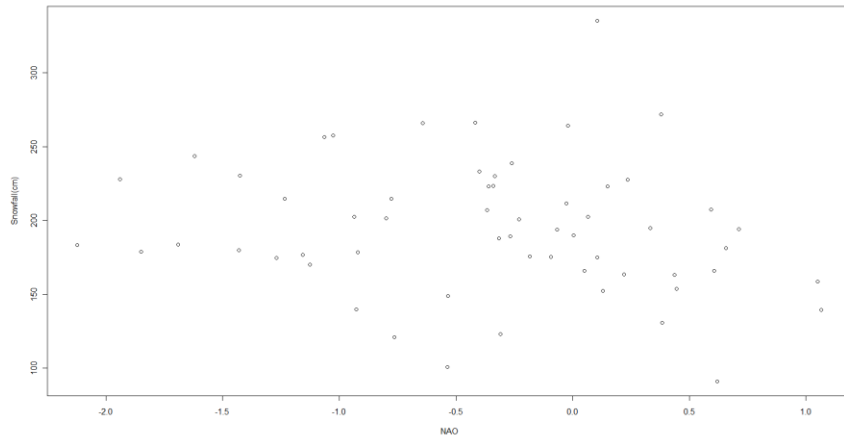
Grand Rapids Seasonal Temperature and Snowfall



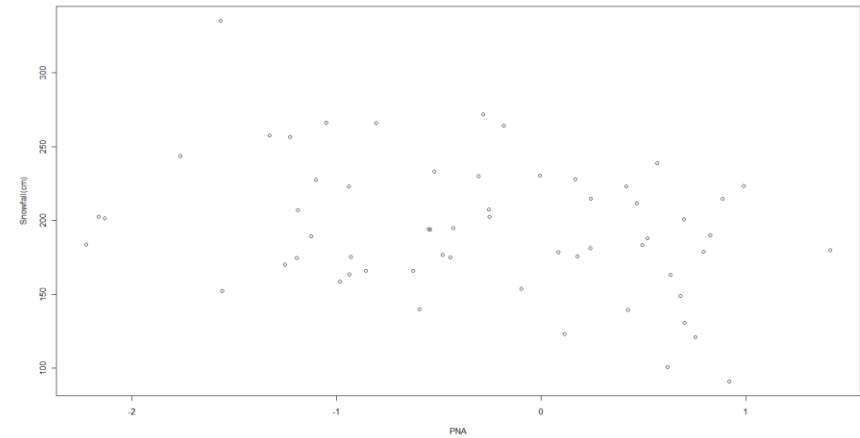
Grand Rapids ENSO and Snowfall



Grand Rapids NAO and Snowfall

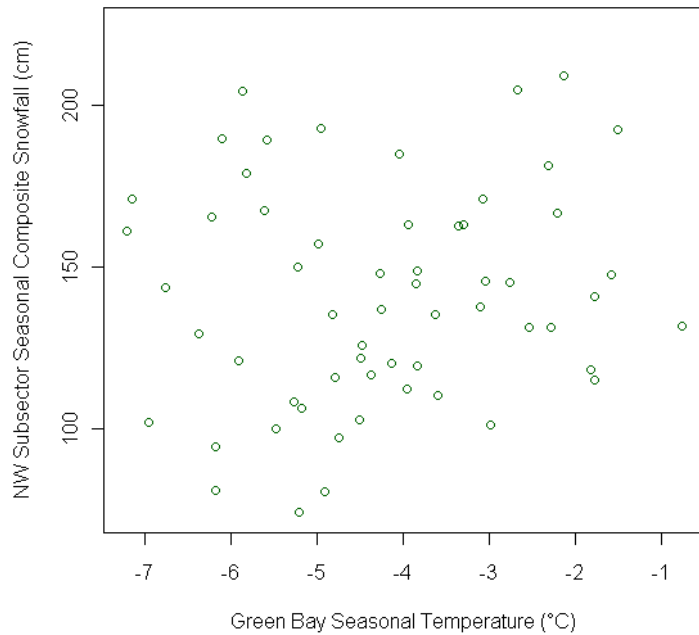


Grand Rapids PNA and Snowfall

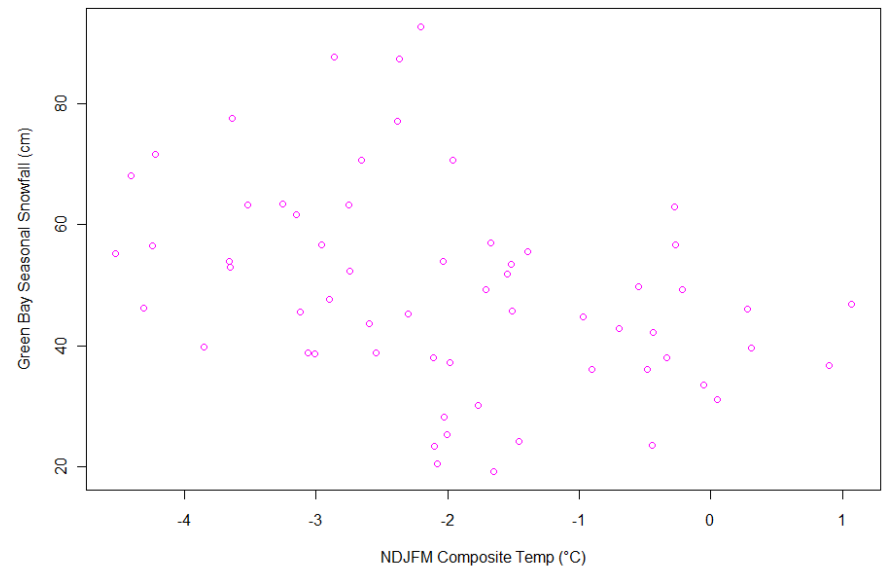


Northwest Region

NW Sector Seasonal Composite Snowfall and Temperature

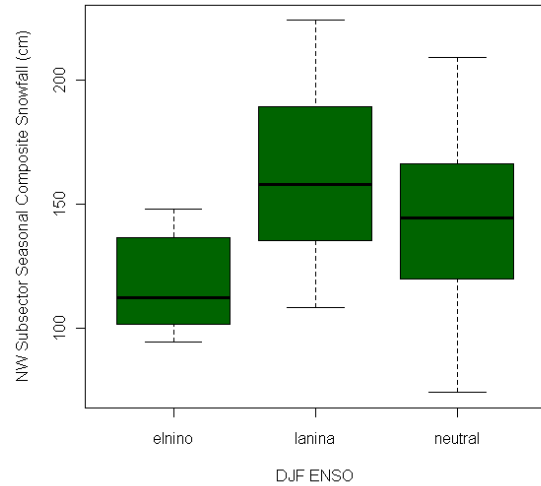


Green Bay, WI Seasonal Snowfall and November-March Composite Temperature

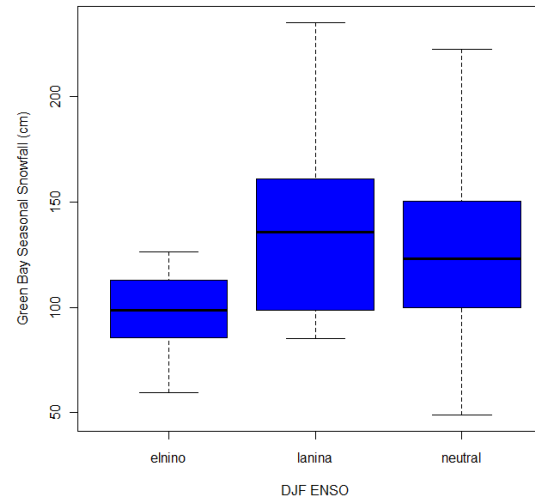


Northwest Region

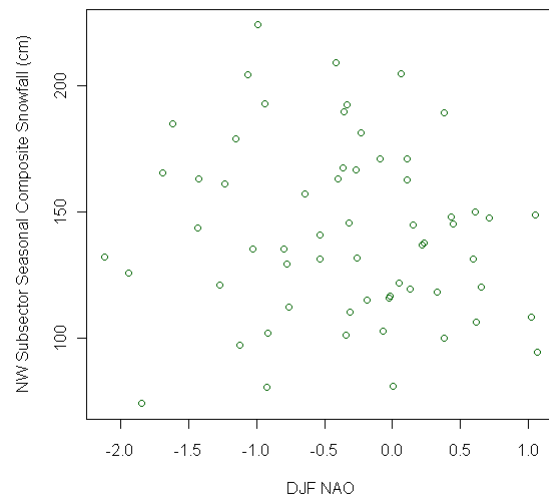
NW Sector Seasonal Composite Snowfall and ENSO



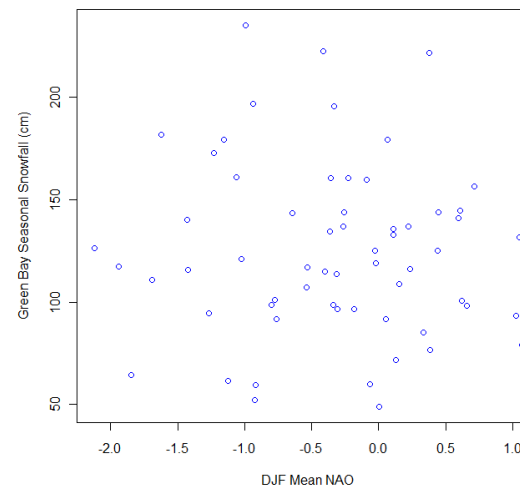
Green Bay, WI Seasonal Snowfall and DJF ENSO



NW Sector Seasonal Composite Snowfall and NAO

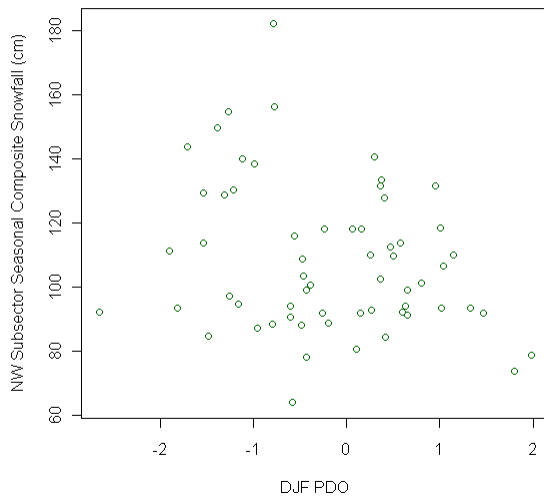


Green Bay, WI Seasonal Snowfall and DJF Mean NAO

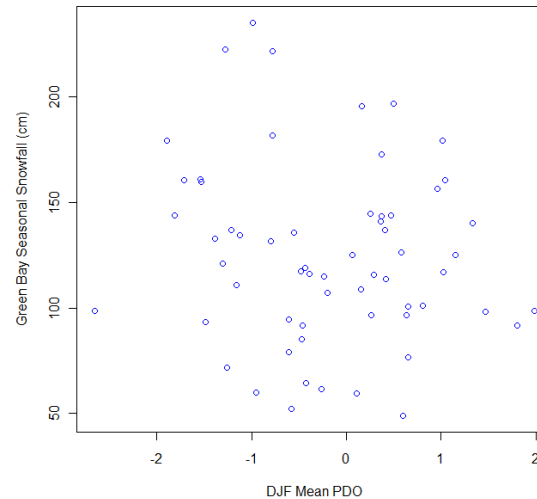


Northwest Region

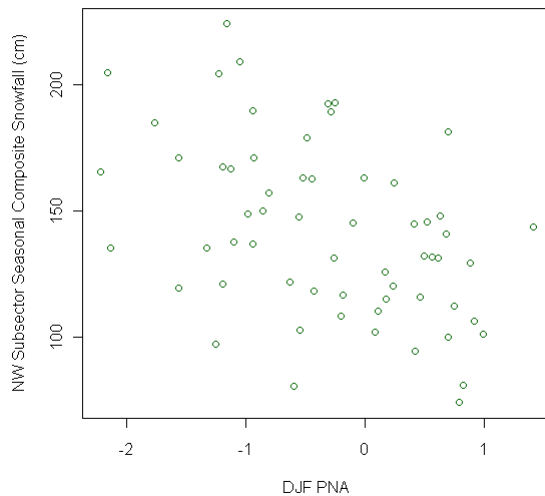
NW Sector Seasonal Composite Snowfall and PDO



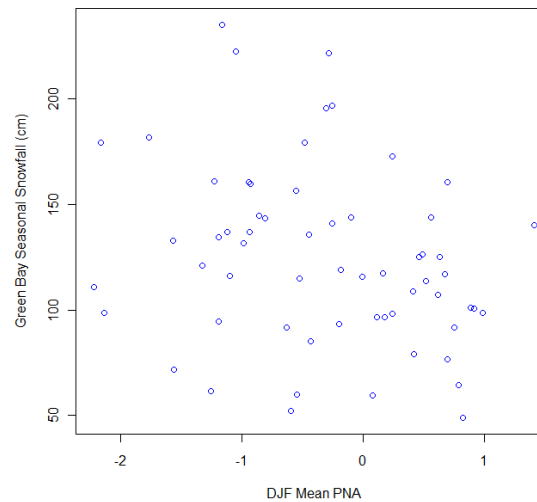
Green Bay, WI Seasonal Snowfall and DJF Mean PDO



NW Sector Seasonal Composite Snowfall and PNA

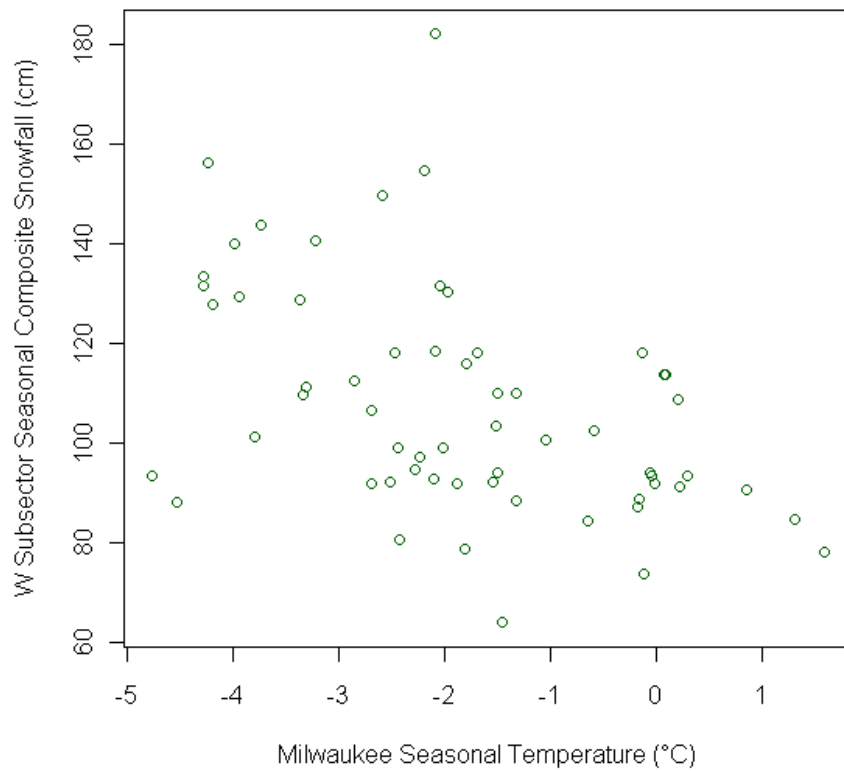


Green Bay, WI Seasonal Snowfall and DJF Mean PNA

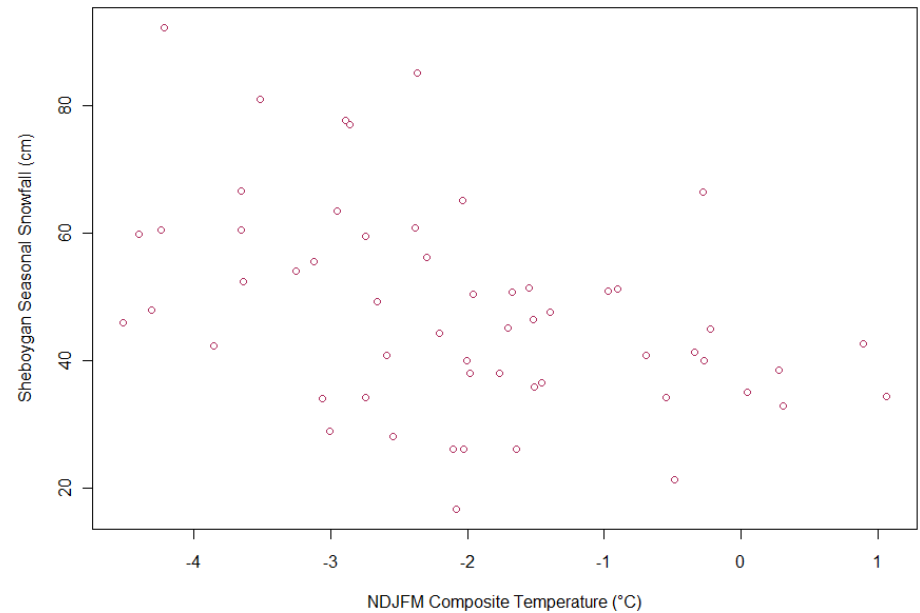


Western Region

W Sector Seasonal Composite Snowfall and Temperature

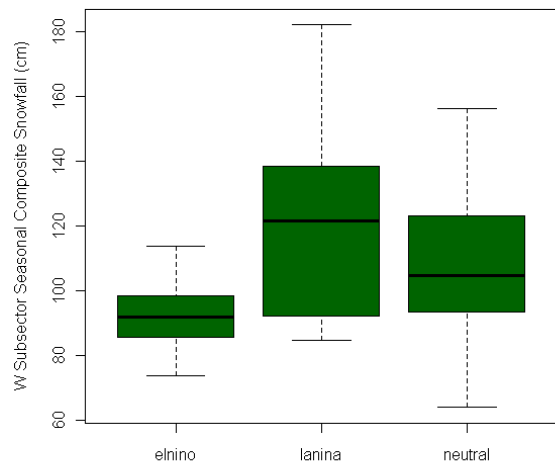


Sheboygan, WI Seasonal Snowfall and November-March Composite Temperature

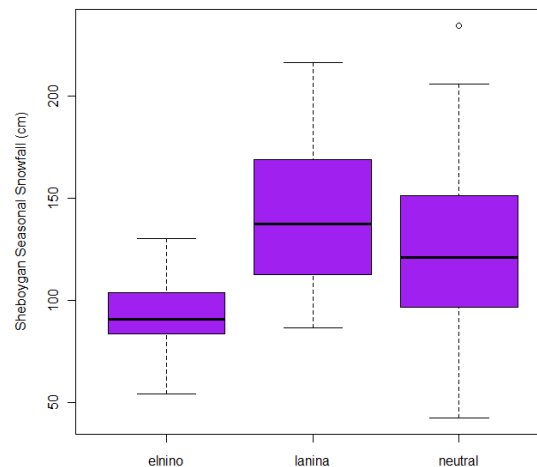


Western Region

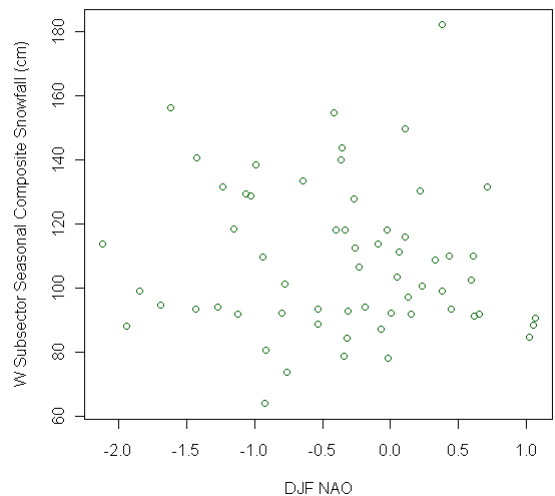
W Sector Seasonal Composite Snowfall and ENSO



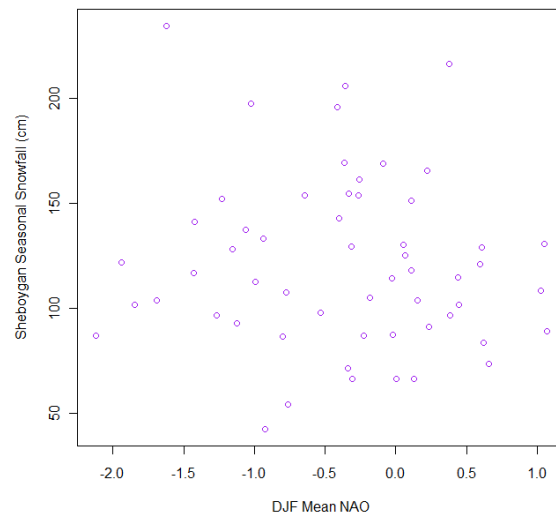
Sheboygan, WI Seasonal Snowfall and DJF ENSO



W Sector Seasonal Composite Snowfall and NAO

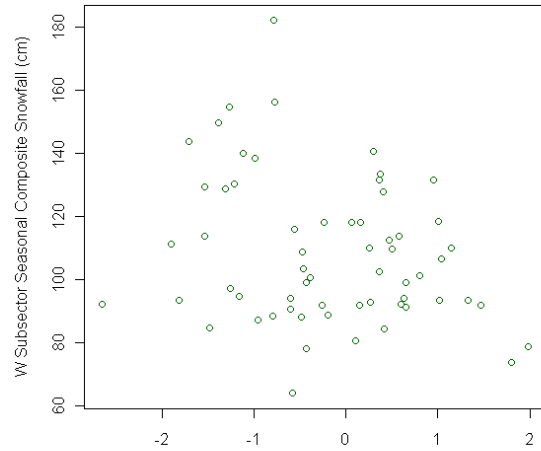


Sheboygan, WI Seasonal Snowfall and Mean DJF NAO

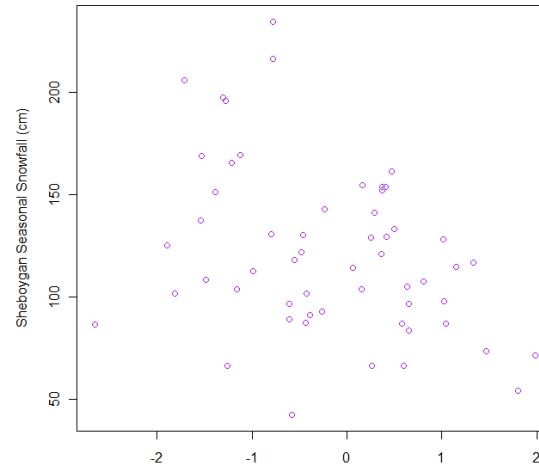


Western Region

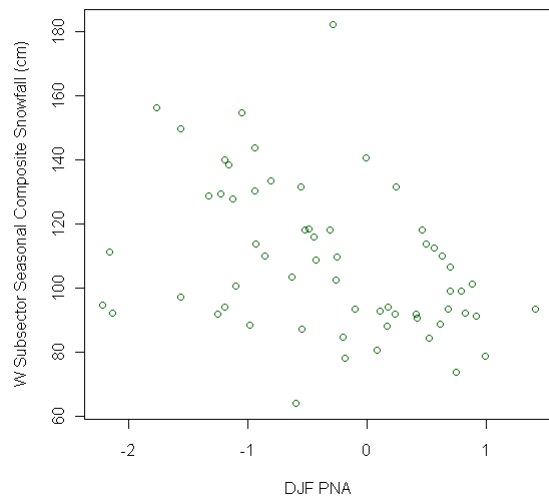
W Sector Seasonal Composite Snowfall and PDO



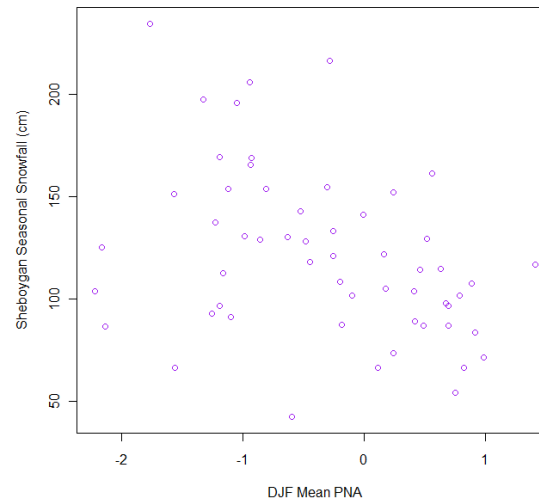
Sheboygan, WI Seasonal Snowfall and Mean DJF PDO



W Sector Seasonal Composite Snowfall and PNA

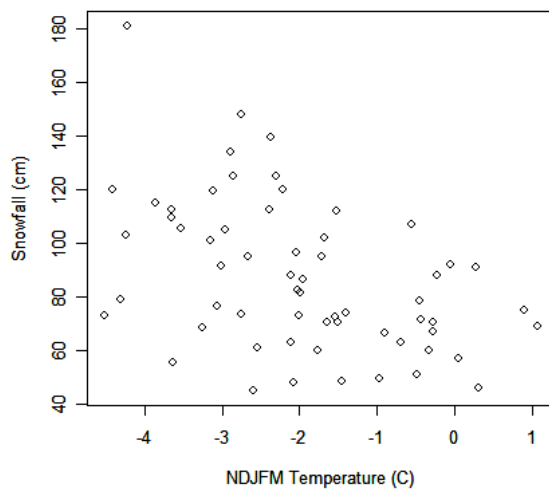


Sheboygan, WI Seasonal Snowfall and Mean DJF PNA

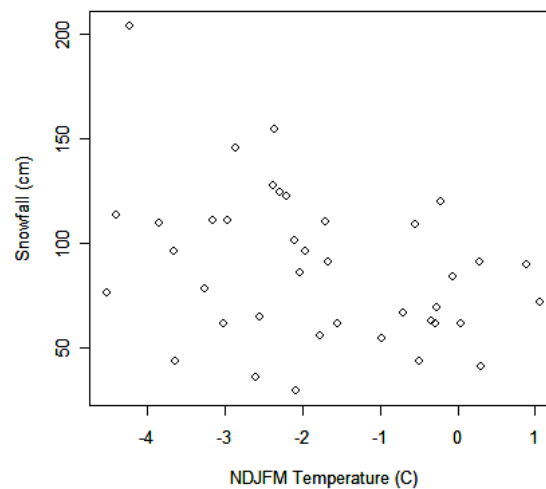


Southwest Region

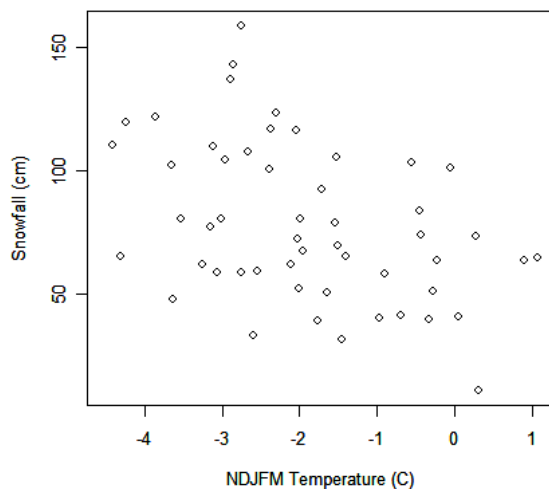
Regional Temperature and SW Composite Snowfall



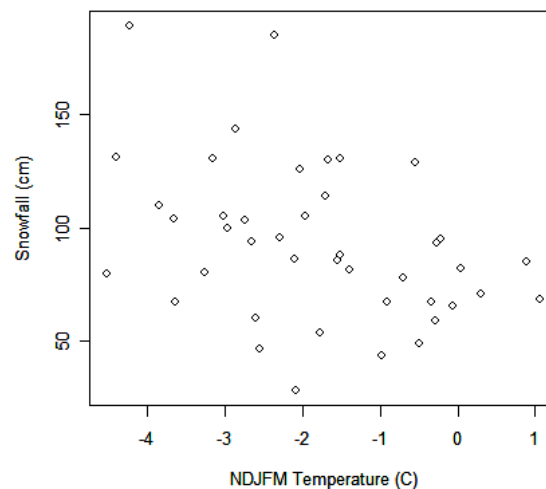
Regional Temperature and Chicago Midway IL Snowfall



Regional Temperature and Aurora IL Snowfall

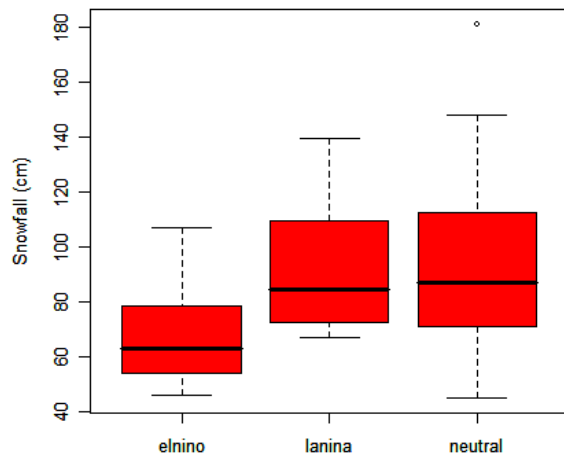


Regional Temperature and Rockford IL Snowfall

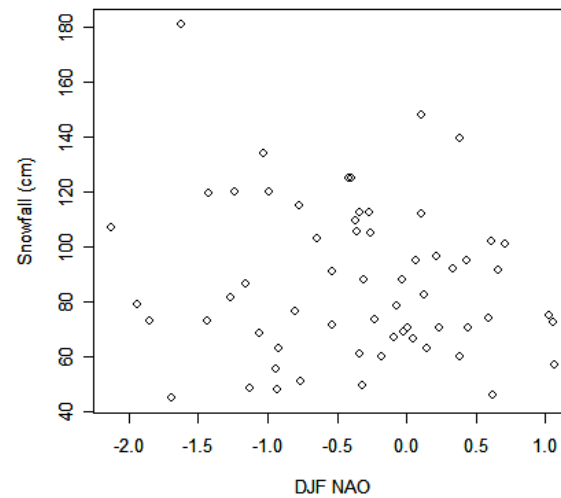


Southwest Region

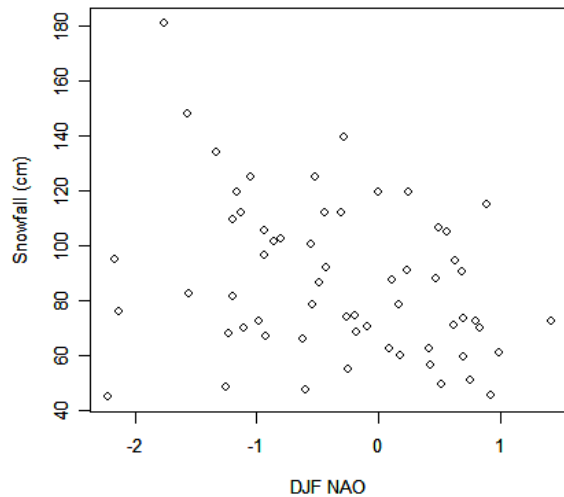
ENSO and SW Composite Snowfall



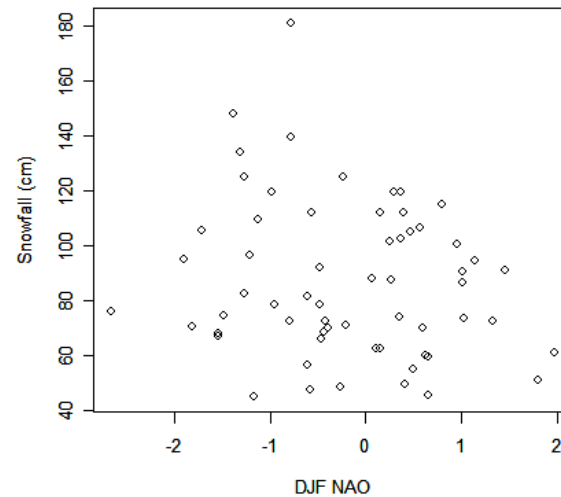
NAO and SW Composite Snowfall



PNA and SW Composite Snowfall

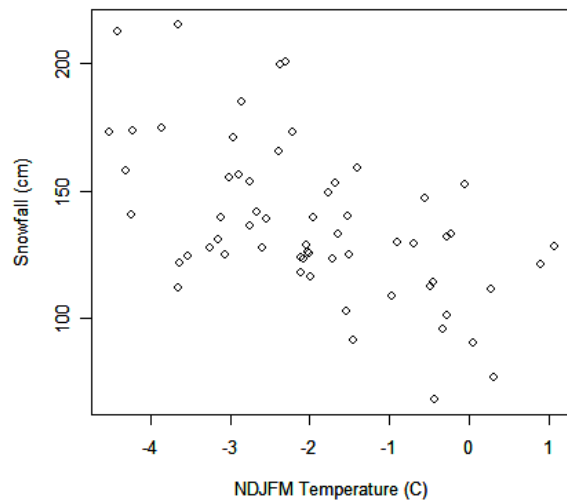


PDO and SW Composite Snowfall

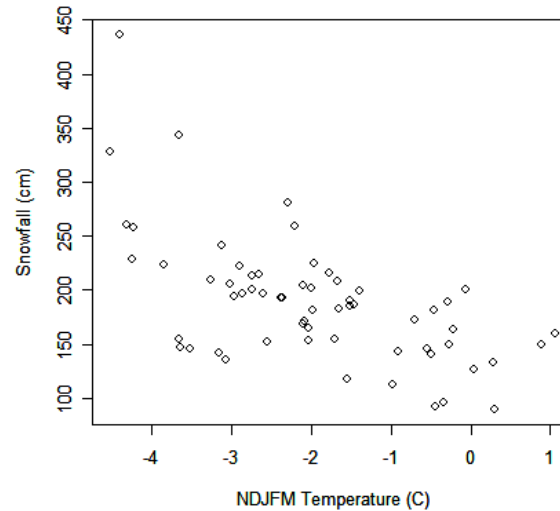


Southeast Region

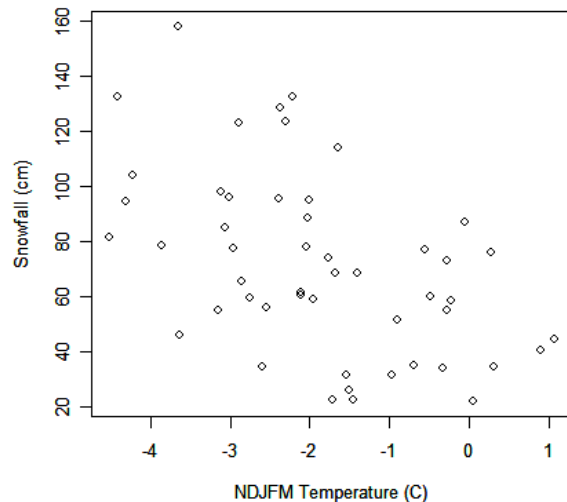
Regional Temperature and SE Composite Snowfall



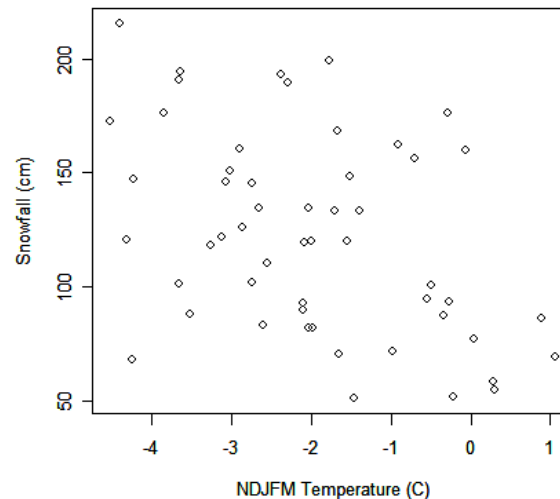
Regional Temperature and South Bend IN Snowfall



Regional Temperature and Winamac IN Snowfall

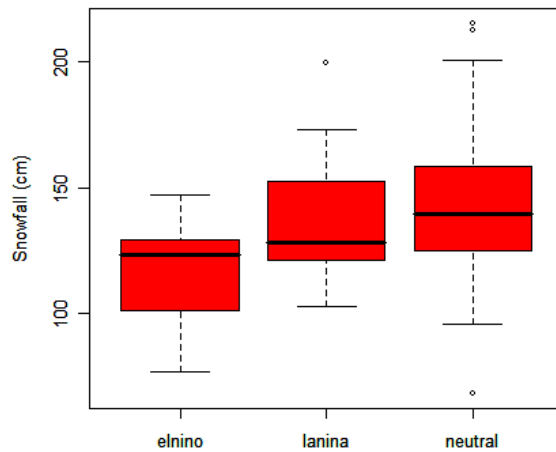


Regional Temperature and Cold Water MI Snowfall

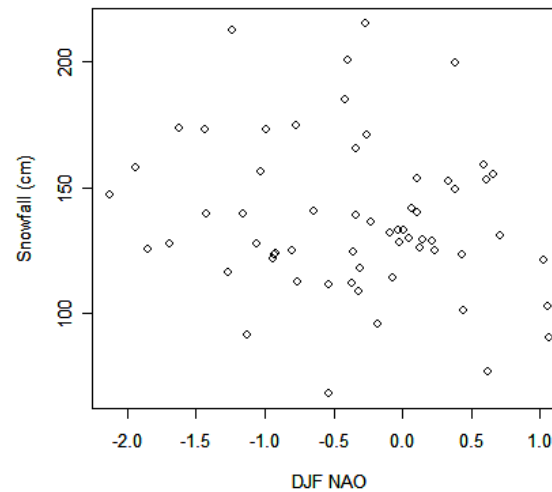


Southeast Region

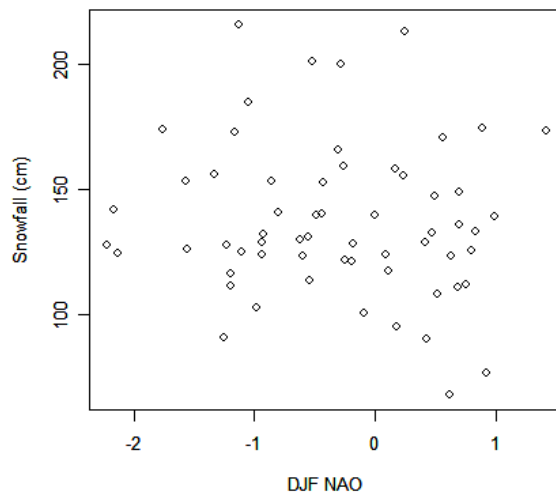
ENSO and SE Composite Snowfall



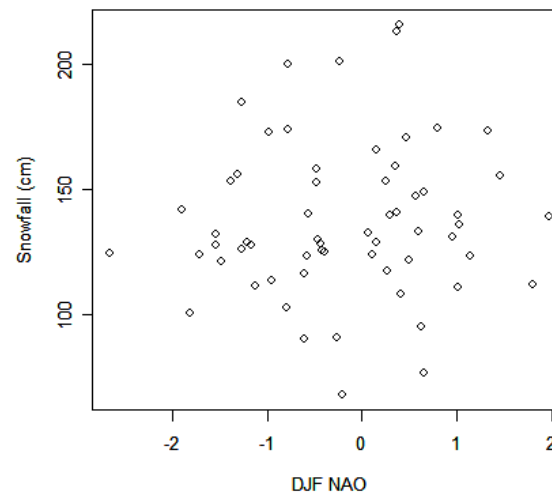
NAO and SE Composite Snowfall



PNA and SE Composite Snowfall

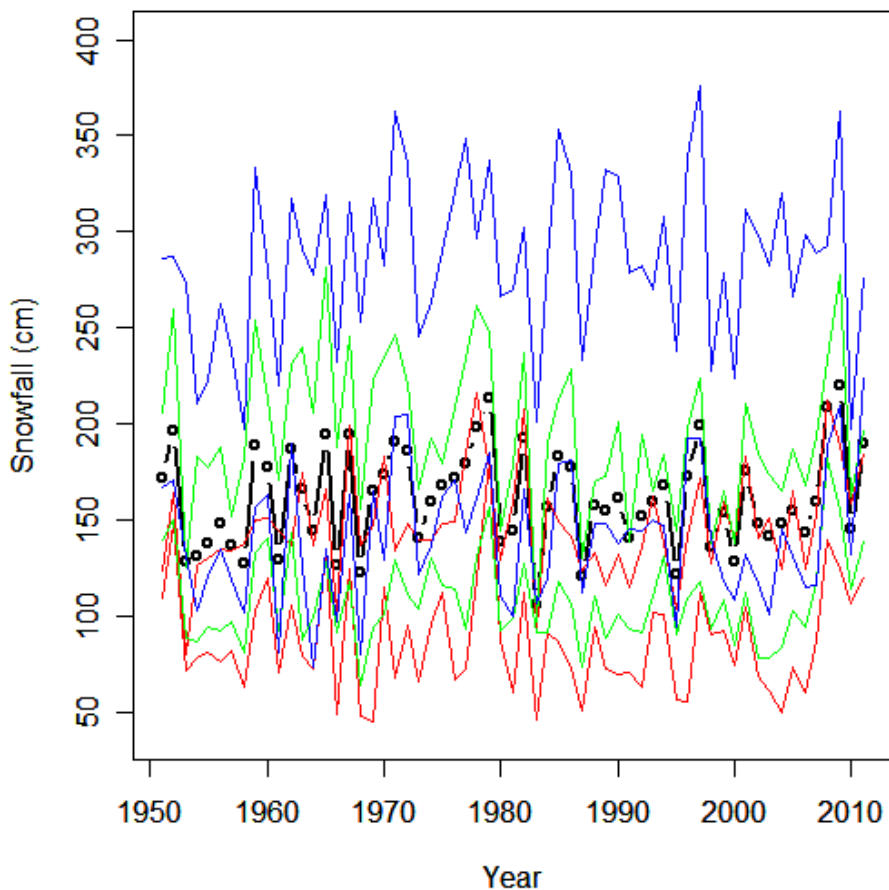


PDO and SE Composite Snowfall

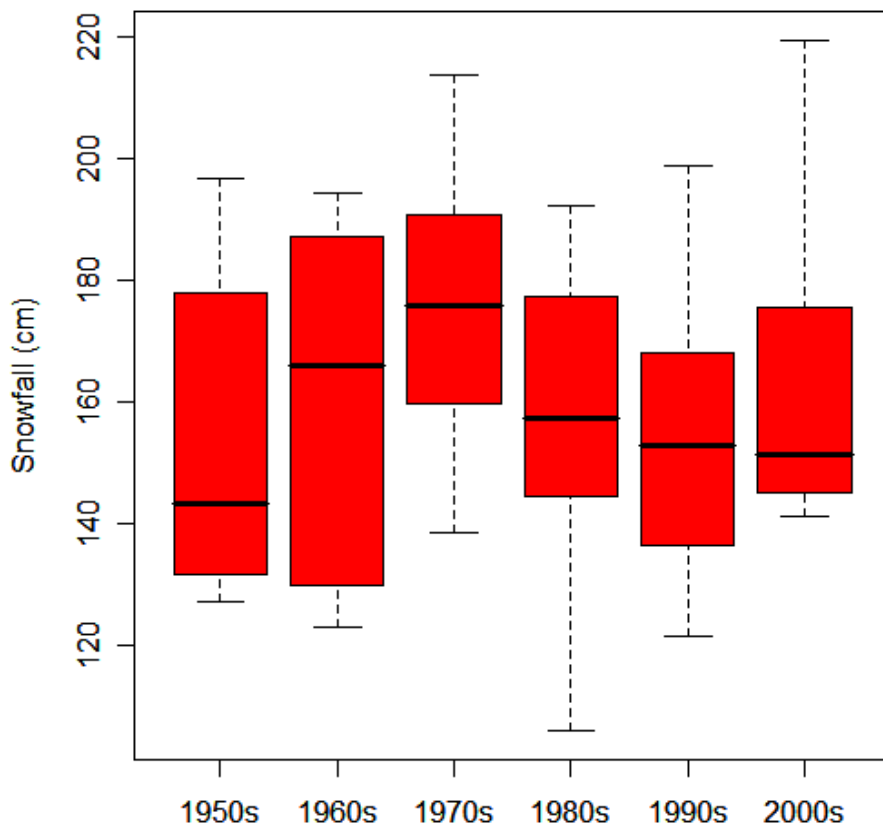


Regional Snowfall Composite

Composite Seasonal Snowfall



Composite Seasonal Snowfall

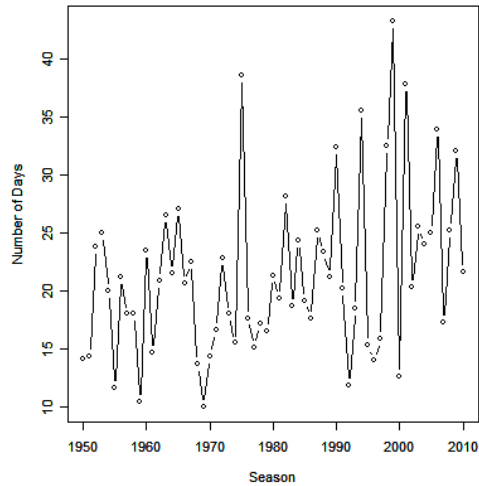


Daily Threshold Data

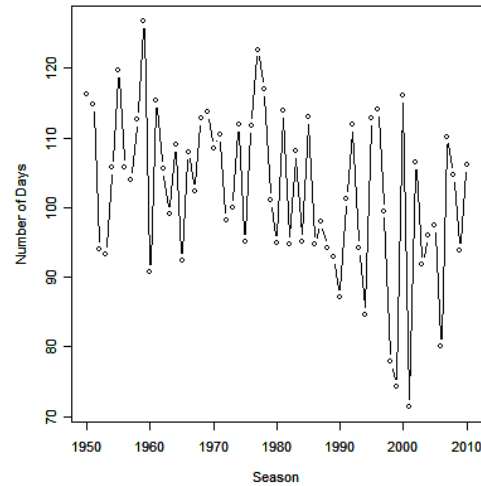
- Using their stations, regional composites were calculated for the seasonal number of days with:
 - High temperature
 - Thresholds of 10, 4.5, 0, -6.5 °C
 - Low temperature
 - Thresholds of -12, -17.5 °C
 - Snowfall
 - Thresholds of >T, 2.5 cm, 5 cm, 15 cm
 - Snow cover
 - Thresholds of 2.5 cm, 5 cm, 15 cm
 - Precipitation Days
- NAs are fairly common with daily data:
 - Used standardized anomalies per station for each month to compute the regional composite – this reduces the NA bias relative to a simple average

Composite Temperature Thresholds

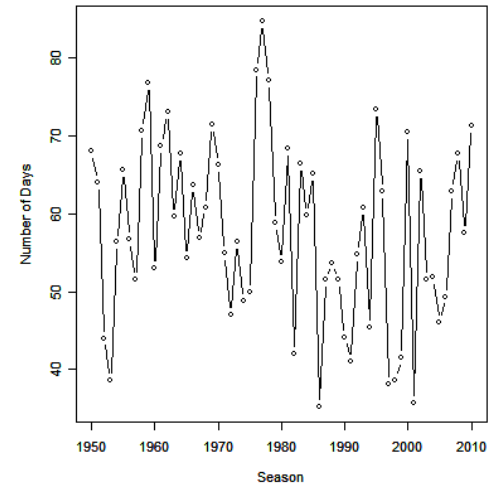
Composite Days 10 C or Warmer



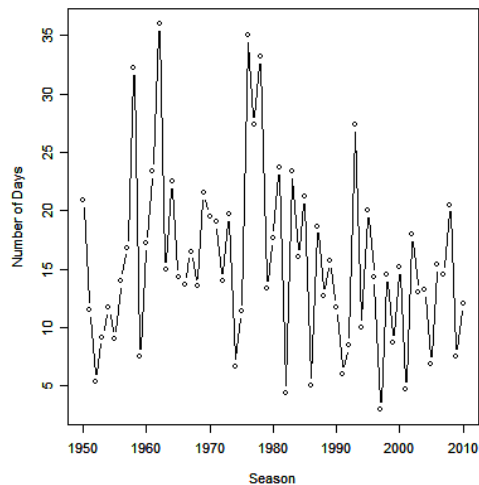
Composite Days Below 4.5 C



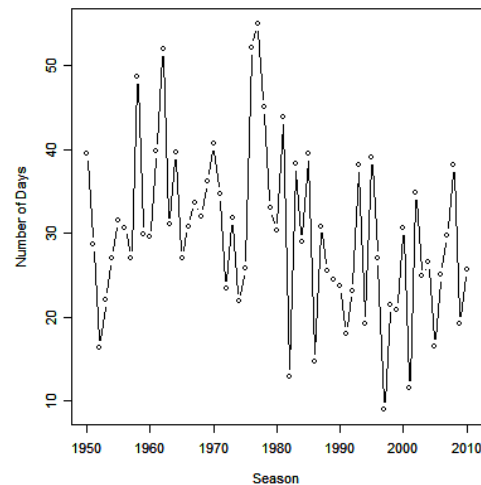
Composite Days 0 C or Below



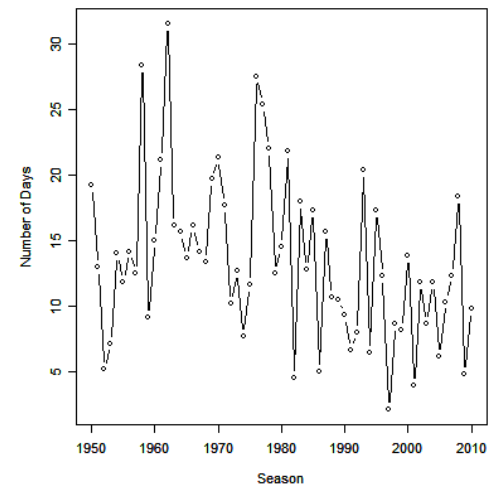
Composite Days Below -6.5 C



Composite Lows Below -12 C

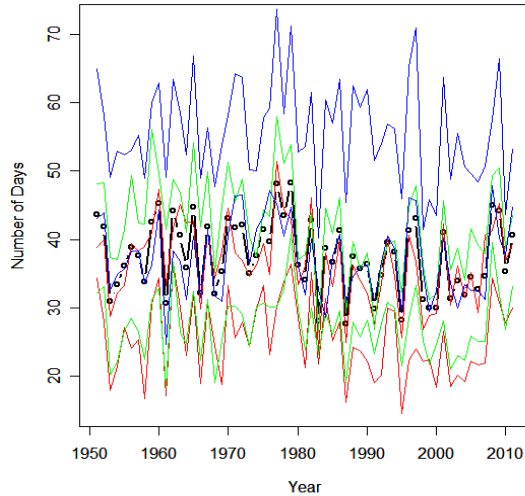


Composite Lows -17.5 C or Below

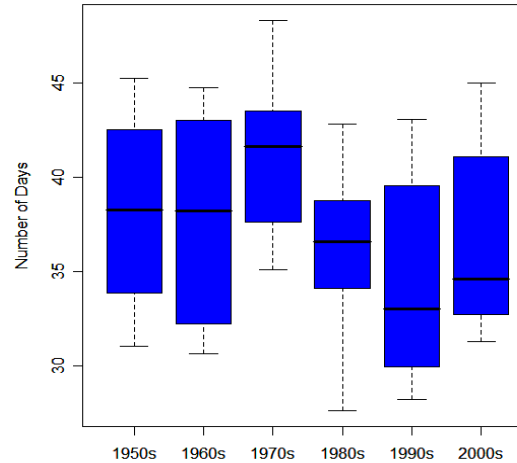


Composite Snow Days and Days with Snow Cover

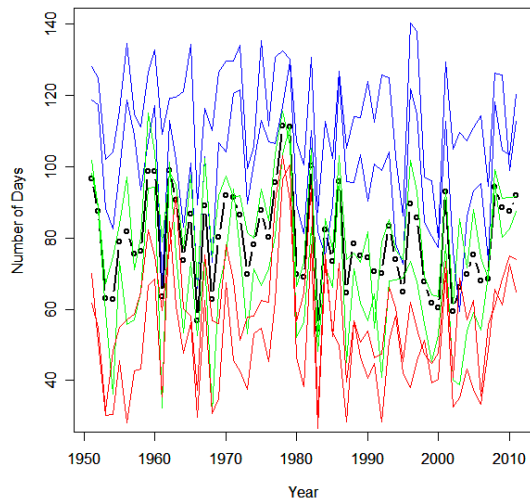
Composite Snow Days



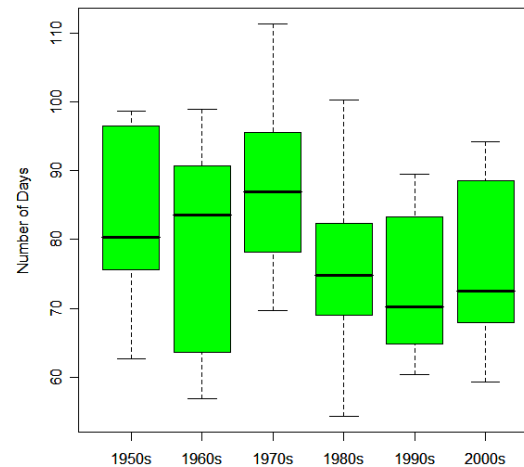
Composite Snow Days



Seasonal Snow Cover Days



Seasonal Snow Cover Days

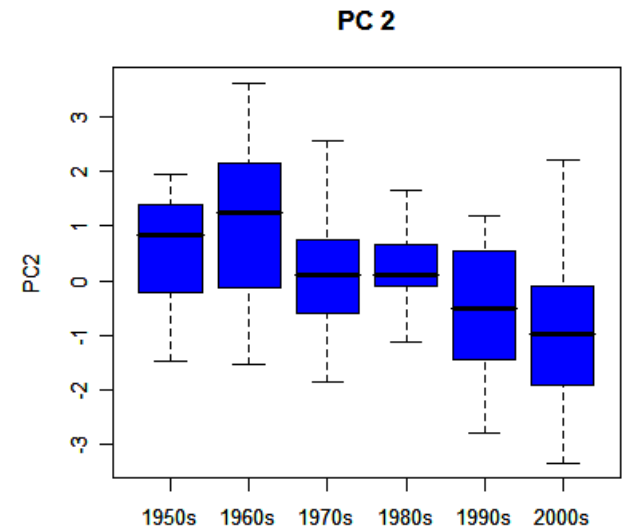
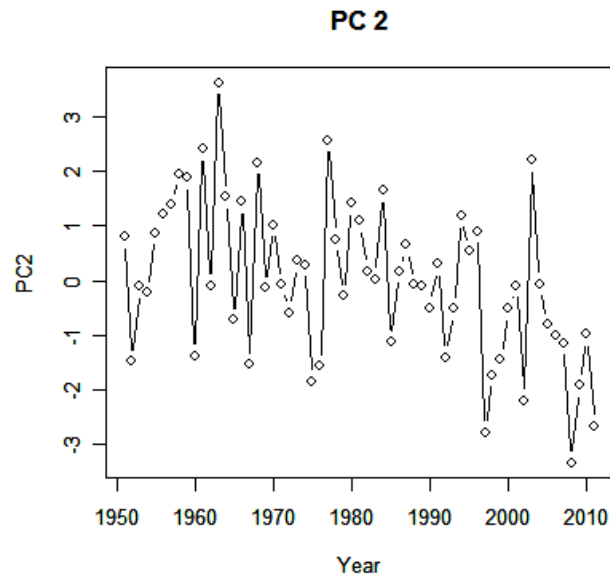
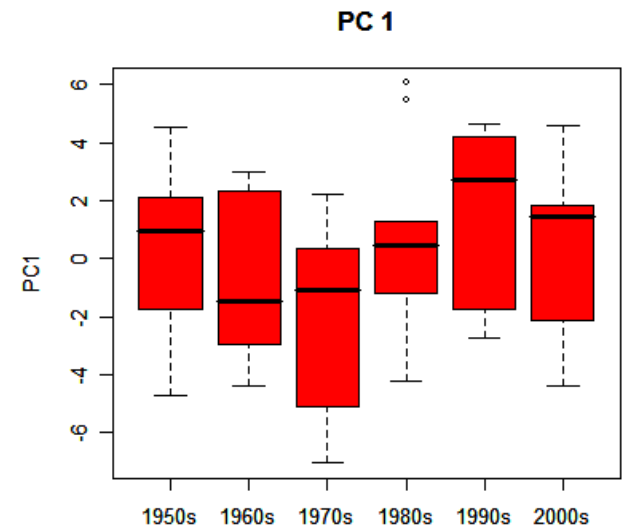
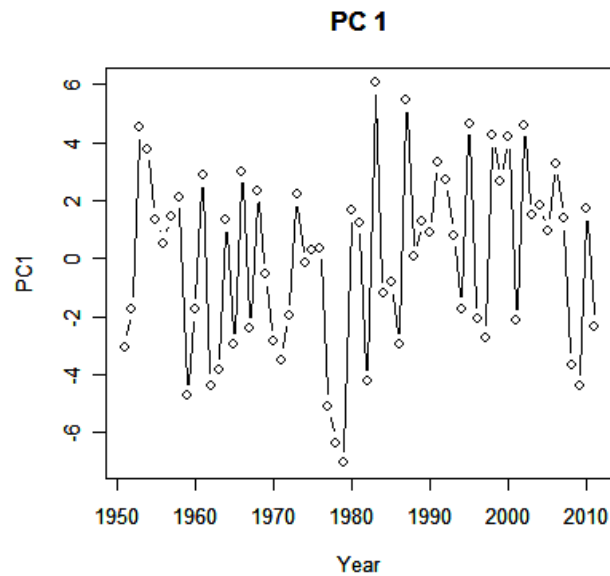


Numerical Approaches

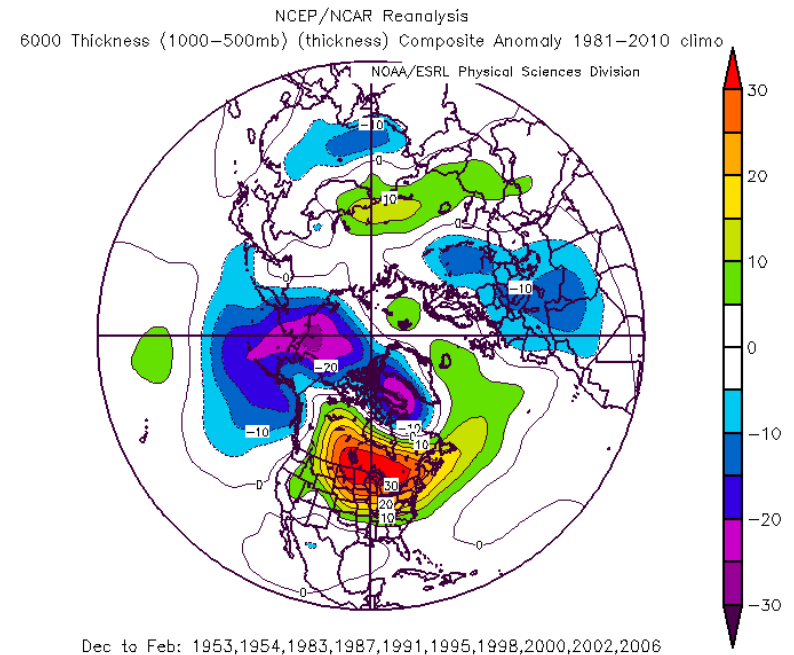
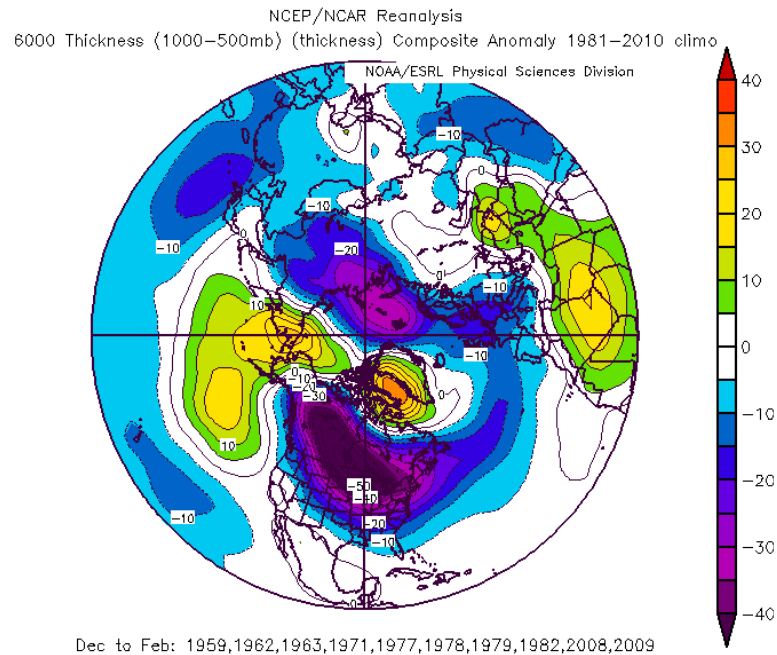
- Regression
 - Regression for most of the variables suggests that the tele-connection patterns together explain ~35% or more of the variance
- Classification
 - Supervised, unsupervised
- Trend Assessment
 - Trends are significant in most of the regional temperature variables, and some of the snow-related metrics in the more southern zones (especially on the tails of the season)
 - The residuals are mostly auto-correlation free, and thus independent
- Principal Component Analysis

PCA Fever

Loadings	PC1	PC2
DJF T	0.28	-0.32
Snowfall	-0.29	-0.27
Days \geq 50	0.17	-0.10
Days \leq 32	-0.29	0.16
Days < 20	-0.25	0.35
Lows < 10	-0.28	0.33
Lows \leq 0	-0.26	0.35
Snow Days	-0.30	-0.08
SnowD 2.5	-0.30	-0.23
SnowD 5	-0.28	-0.28
SnowD 15	-0.19	-0.40
Snow Cover	-0.30	-0.05
Snow C 15	-0.30	-0.02
PrecipD DJF	-0.20	-0.37



1000-500 hPa Thickness Top and Bottom 10 PC1



Conclusions

- Substantial wintertime variability, along with a trend toward milder winters (with a later start to the snow season in the southern zones)
- Snowfall dependence on temperature is robust, but varies with latitude and local role of LES
 - For the NW sector, some of the least-snowy winters are actually some of their coldest!
- Clear dependence on tele-connection patterns, but snowfall data is quite noisy.
 - ENSO warm events have clearest statistical impact.
 - The NAO/snowfall correlation is fairly weak, but there is a notable dearth of snowy winters in positive NAO-dominant winters
- Number of snowfall and snow cover days are helpful metrics, and they correlate well with temperature
- Future work: more statistical analysis, comparison with November group, trying to separate LES from non-les seasonal snow.

Extra slides

- May be useful if people have questions

Basic Regression with Winter T

(if someone asks - not using interaction terms, for simplicity)

Coefficients:

	Estimate	Pr(> t)
(Intercept)	-2.6433	6.06e-07 ***
nao\$DJF	0.9201	0.000597 ***
pna\$DJF	0.5515	0.091981 .
mei\$DJF lanina	-1.8166	0.021844 *
mei\$DJF neutral	-1.6765	0.002483 **
pdo\$DJF	-0.6301	0.043793 *

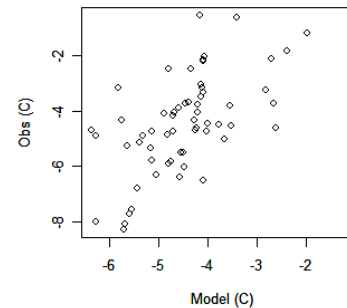
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.469 on 55 degrees of freedom

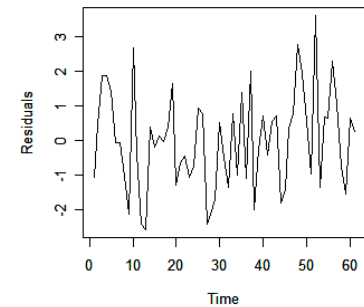
Multiple R-Squared: 0.3588, Adjusted R-squared: 0.3005

F-statistic: 6.154 on 5 and 55 DF, p-value: 0.0001348

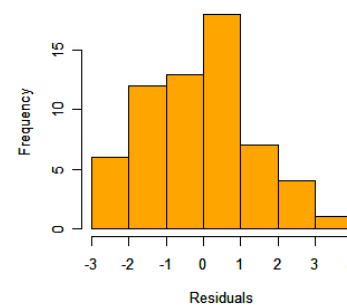
Model Predictions and Observations



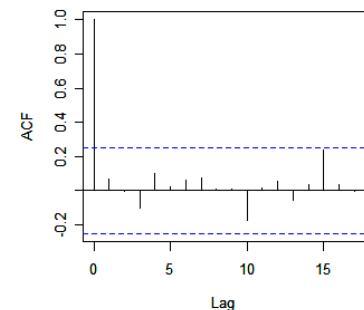
Model Residuals



Model Residuals



ACF of Model Residuals



Basic Regression with LN (Winter Snowfall)

(if someone asks - not using interaction terms, for simplicity)

Coefficients:

	Estimate	Pr(> t)
(Intercept)	4.87357	< 2e-16 ***
nao\$DJF	0.04106	0.081807 .
pna\$DJF	-0.07816	0.010499 *
mei\$ensolanina	0.23292	0.001704 **
mei\$neutral	0.19338	0.000198 ***
pdo\$DJF	0.05432	0.057575 .

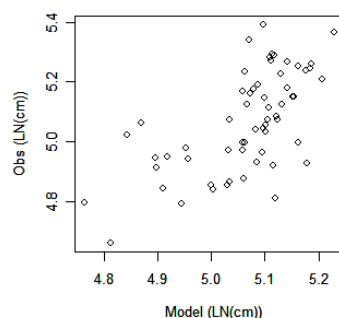
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.1348 on 55 degrees of freedom

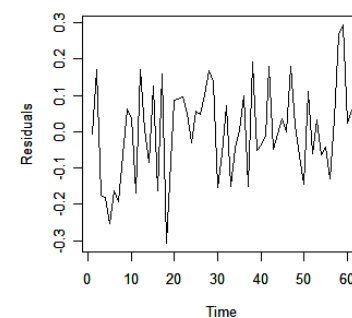
Multiple R-Squared: 0.3827, Adjusted R-squared: 0.3265

F-statistic: 6.819 on 5 and 55 DF, p-value: 5.178e-05

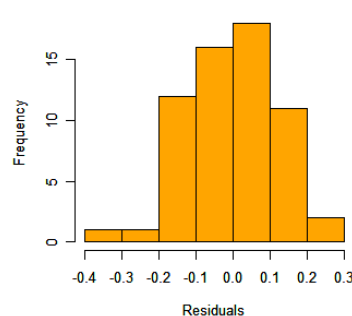
Model Predictions and Observations



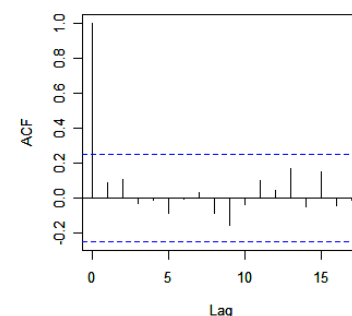
Model Residuals



Model Residuals

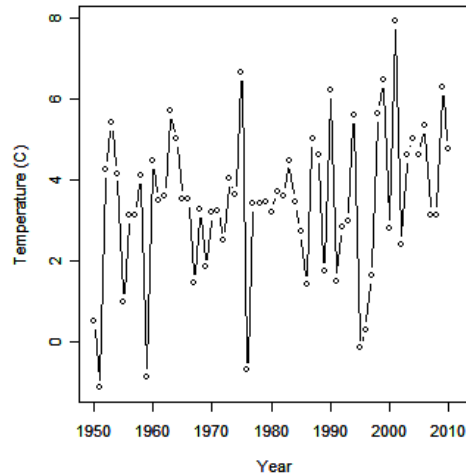


ACF of Model Residuals

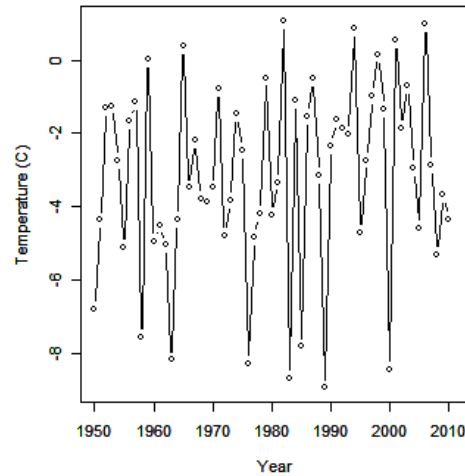


Temperature for Individual Months

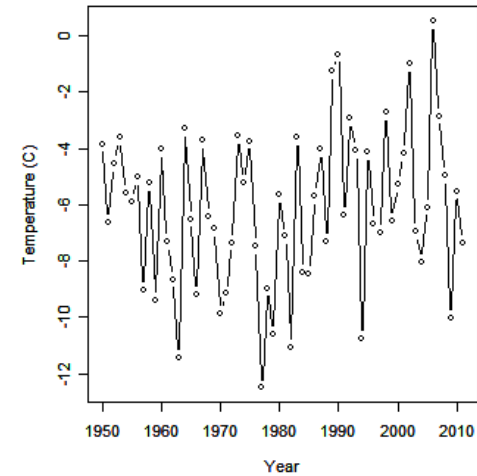
NOV Temperature



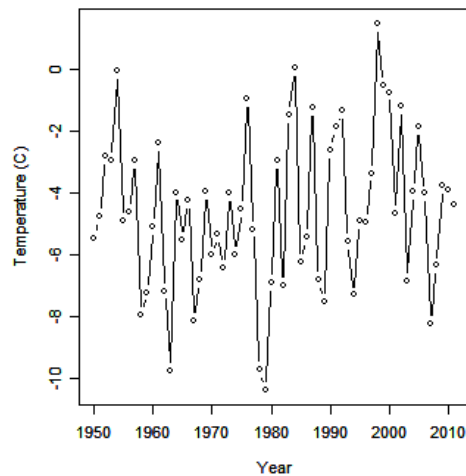
DEC Temperature



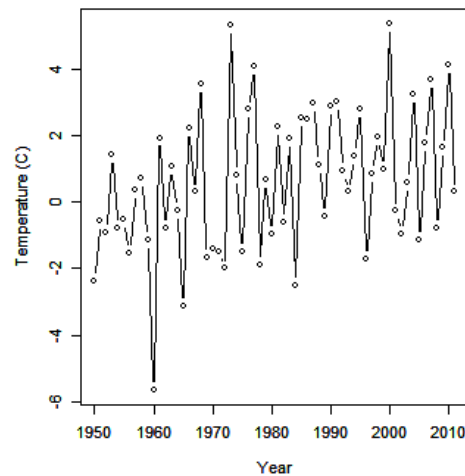
JAN Temperature



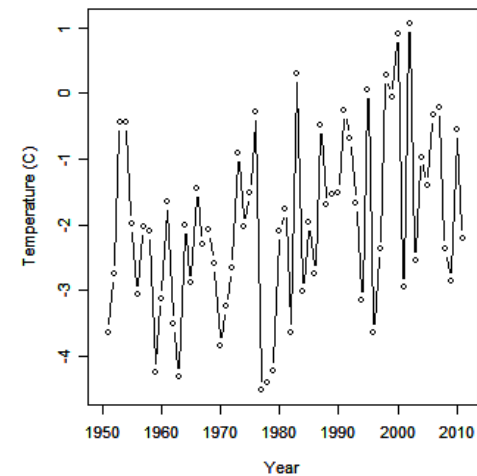
FEB Temperature



MAR Temperature

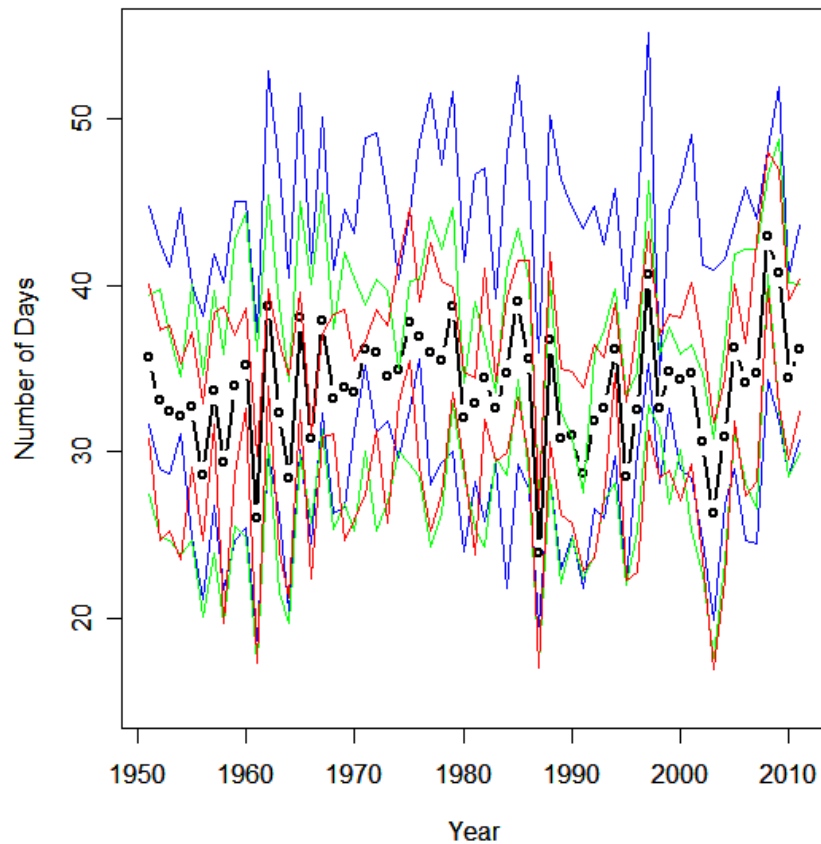


NOV to MAR Temperature

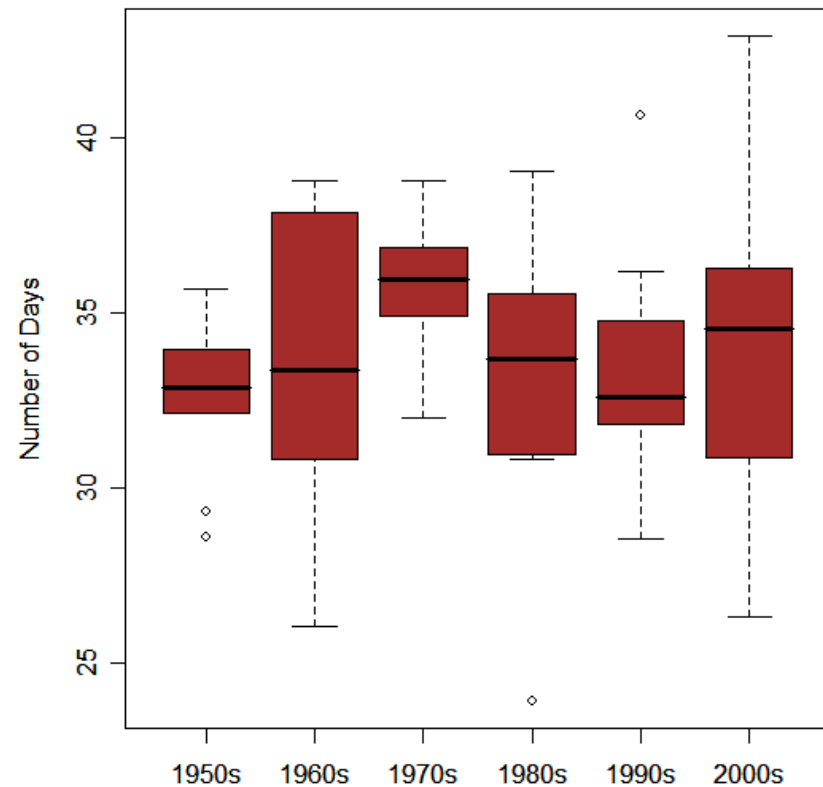


Precipitation Days

Composite DJF Precipitation Days

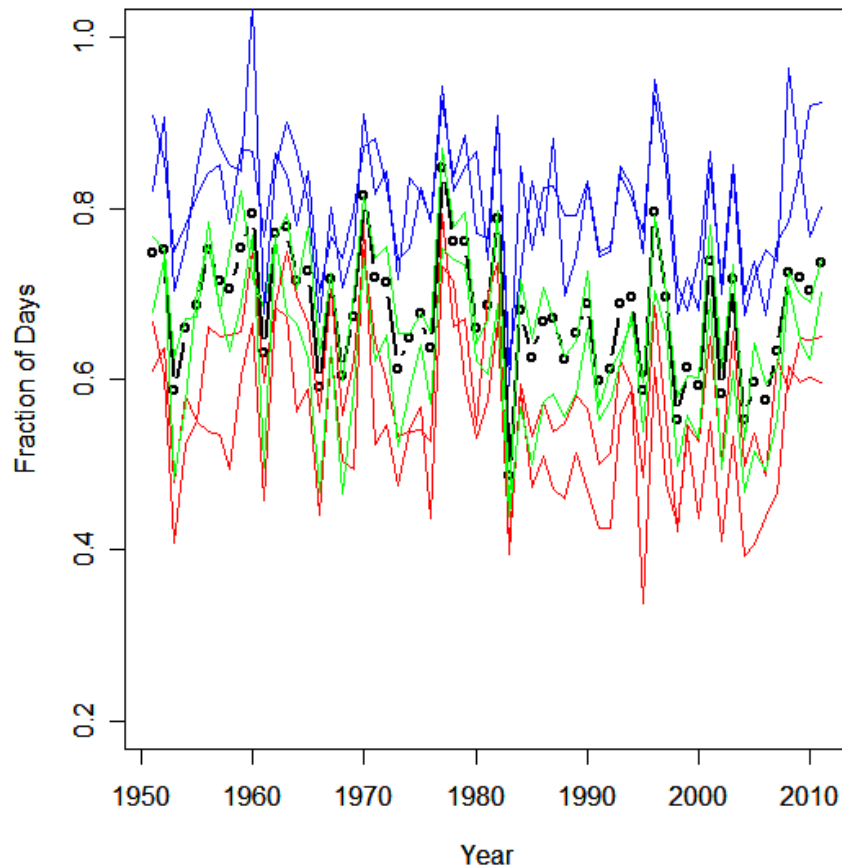


Composite DJF Precipitation Days

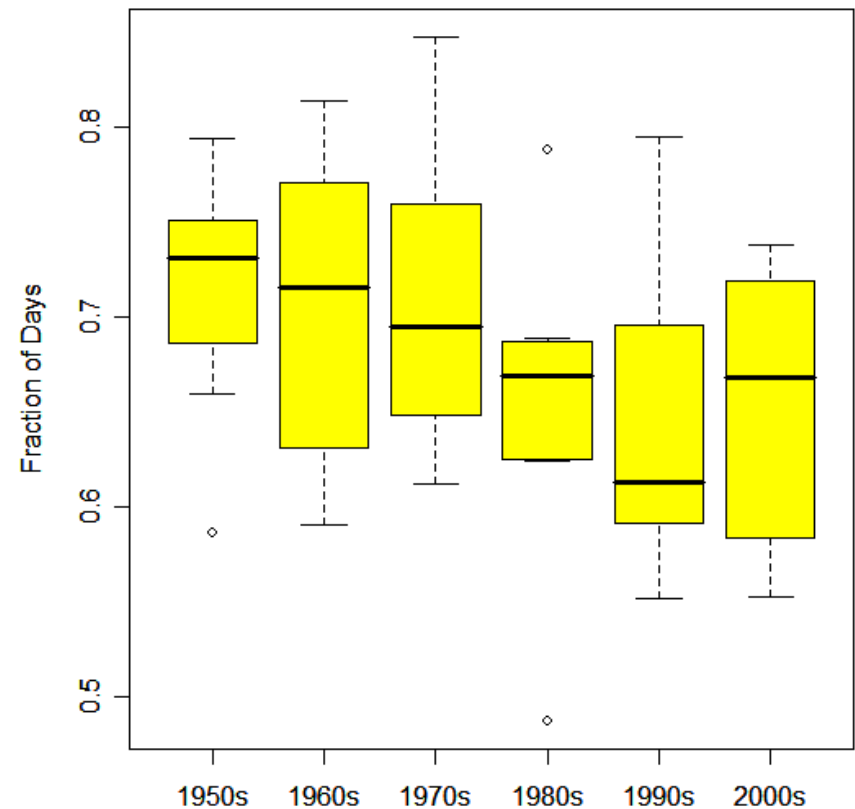


Fraction of Snow/Precipitation Days

Seasonal Snow Days/NDJFM Precipitation Days

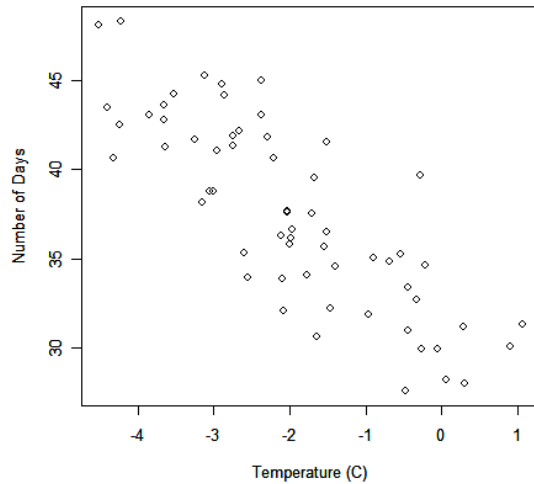


Seasonal Snow Days/NDJFM Precipitation Days

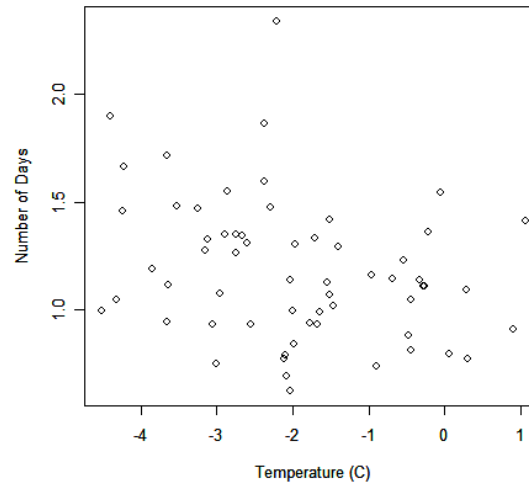


Relationship to Temperature

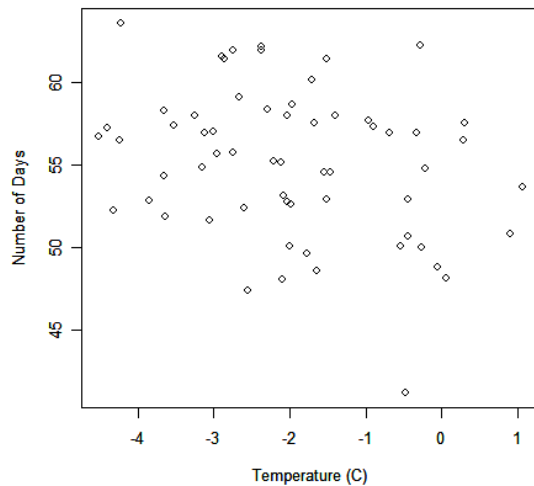
NOV to MAR Temperature and Seasonal Snow Days



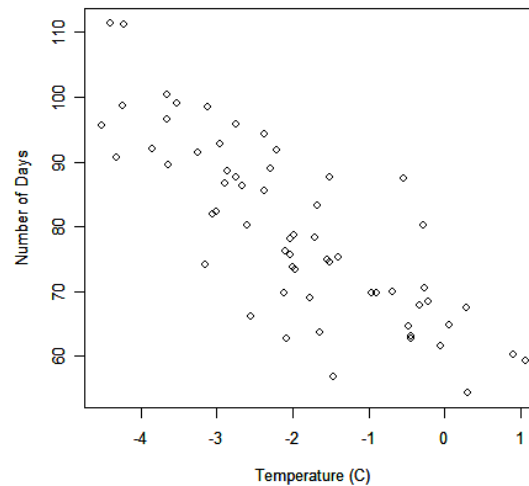
NOV to MAR Temperature and 15 cm Seasonal Snow Days



NOV to MAR Temperature and Precip Days

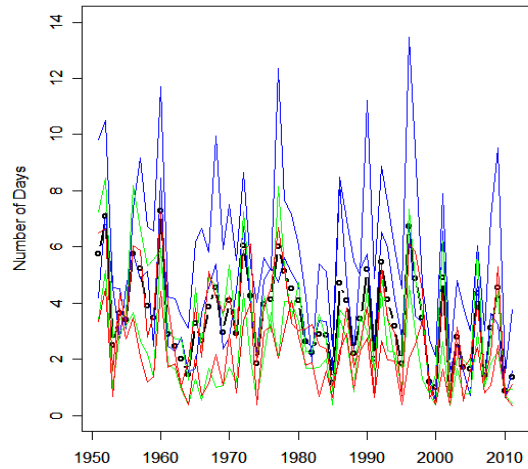


NOV to MAR Temperature and Seasonal Snow Cover Days

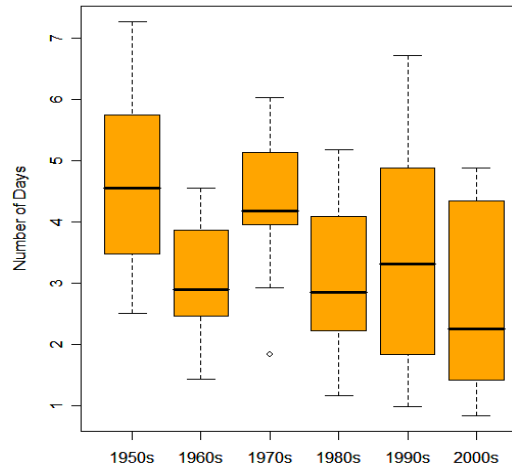


November

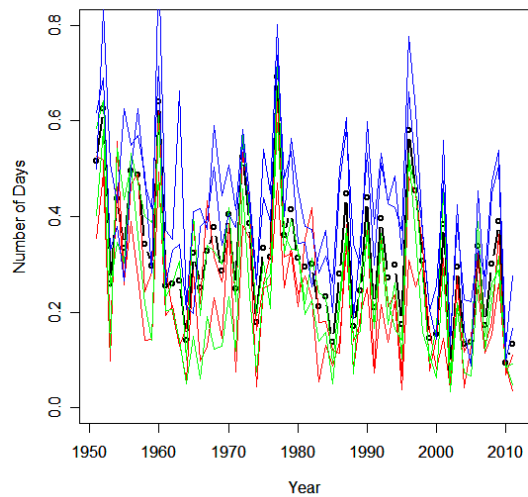
Composite NOV Snow Days



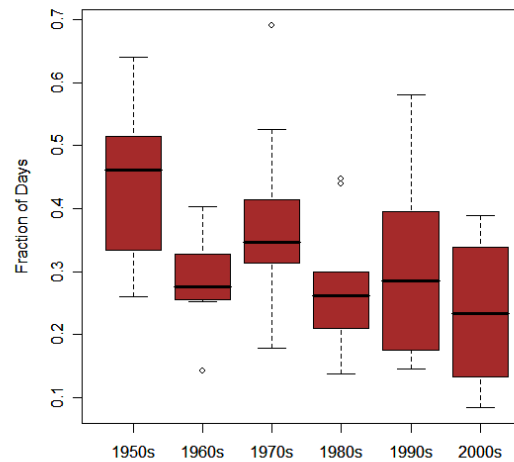
Composite NOV Snow Days



NOV Snow/Precip Days

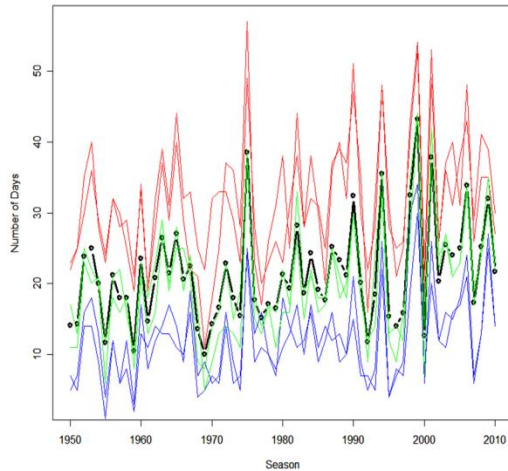


NOV Snow/Precip Days

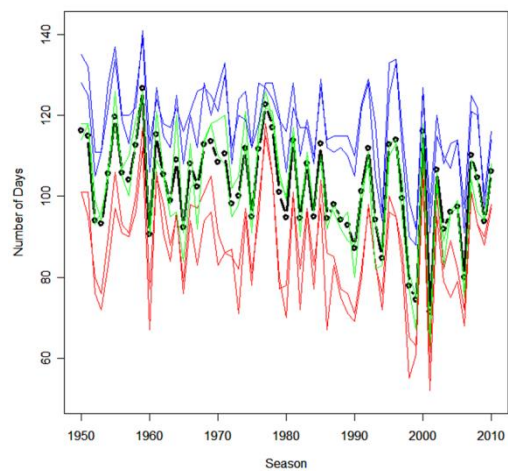


Daily T Thresholds

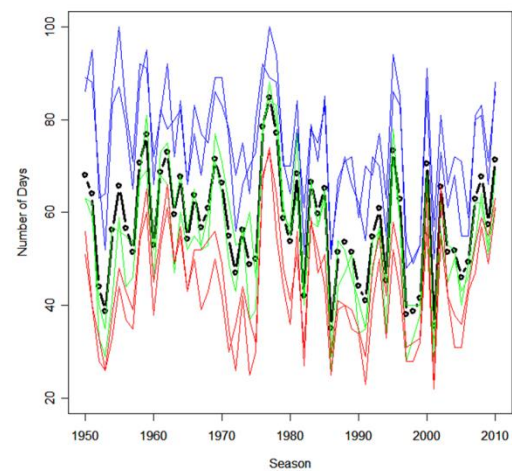
Composite Days 10 C or Warmer



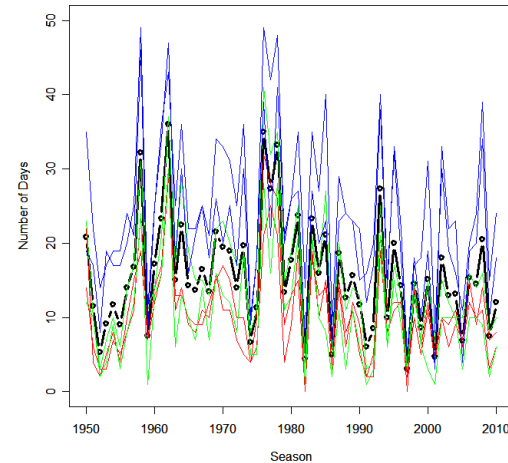
Composite Days Below 4.5 C



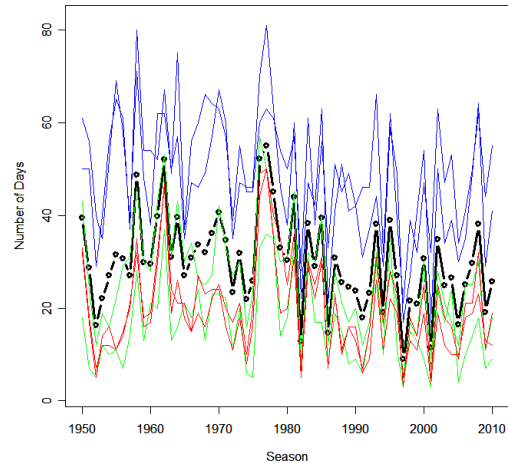
Composite Days 0 C or Below



Composite Days Below -6.5 C



Days with a Low Below -12 C



Days with a Low Below -17.5 C

