Wintertime Climate Variability in the Lake Michigan Region:

Sensitivity of Snowfall to Temperature and Northern Hemisphere Teleconnection Patterns

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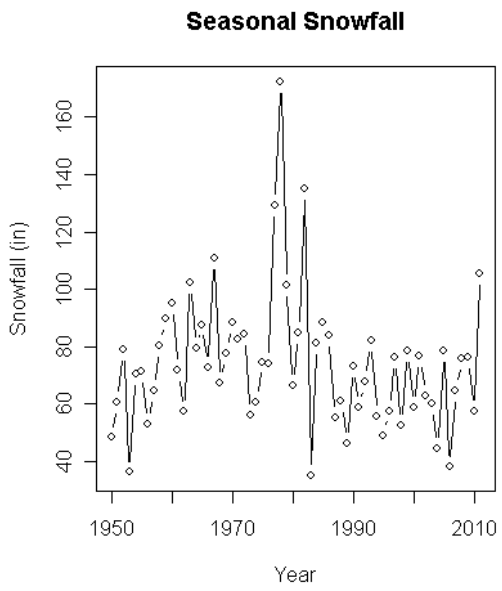
Outline

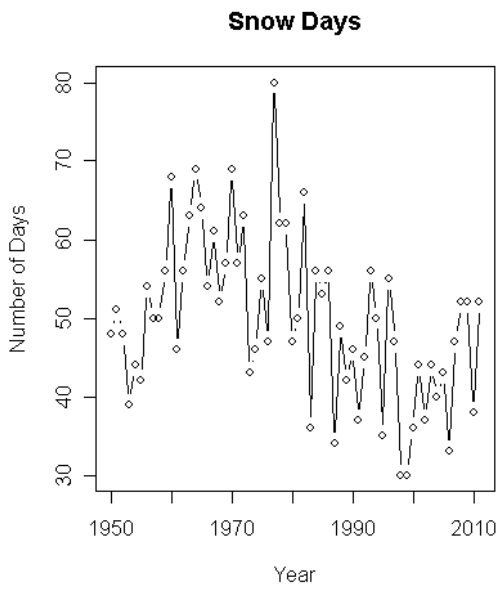
- Introduction
- Adventures with Data
  - Regions and station selection
  - Temperature and snowfall
    - Comparison of sub-regions
    - Sensitivity of snowfall to temperature
    - Sensitivity to tele-connection patterns
- Daily Data Winter Stew: PC1 and PC2
- Conclusions

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 ->



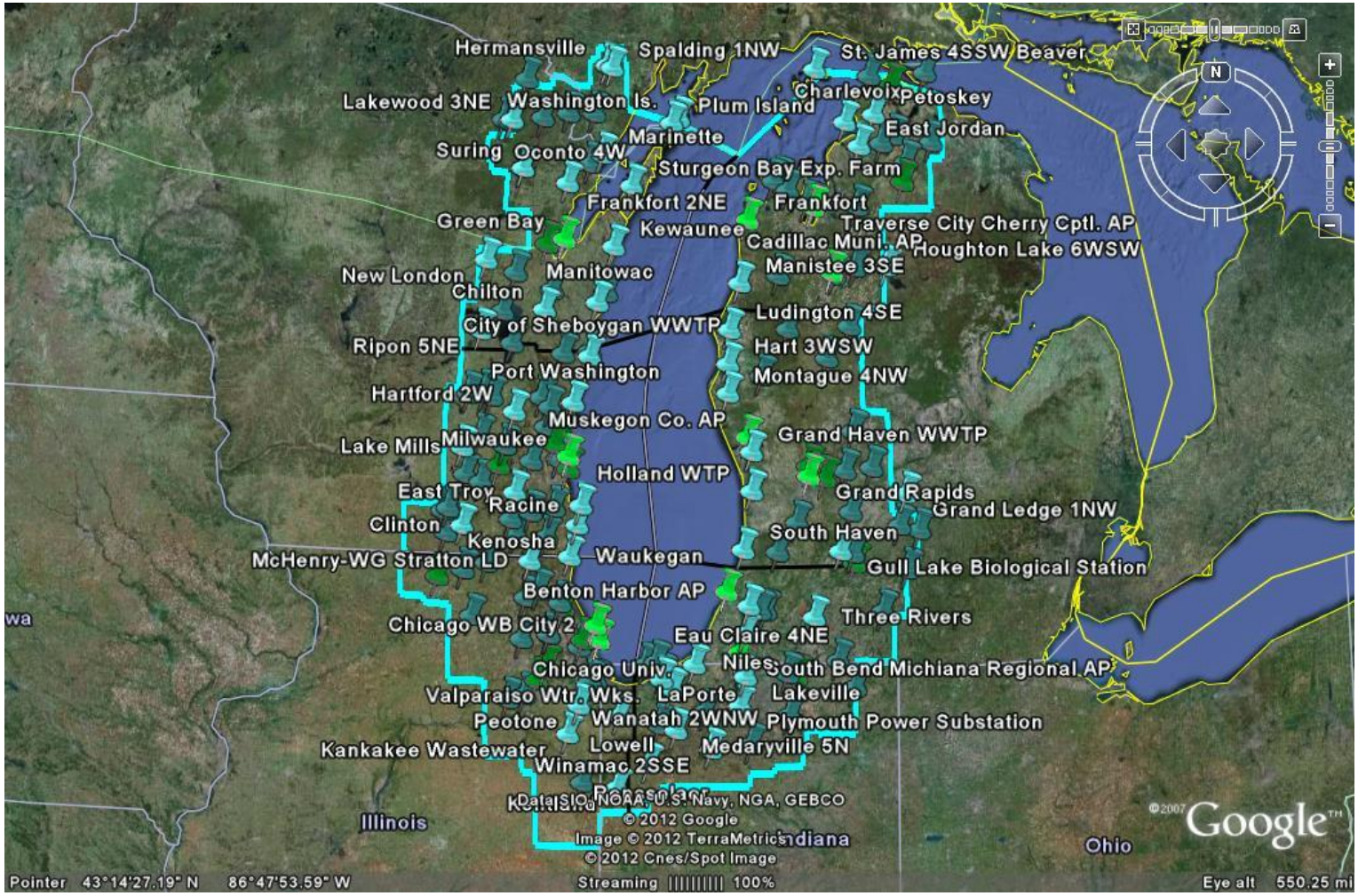


Questions and Charge to the Students

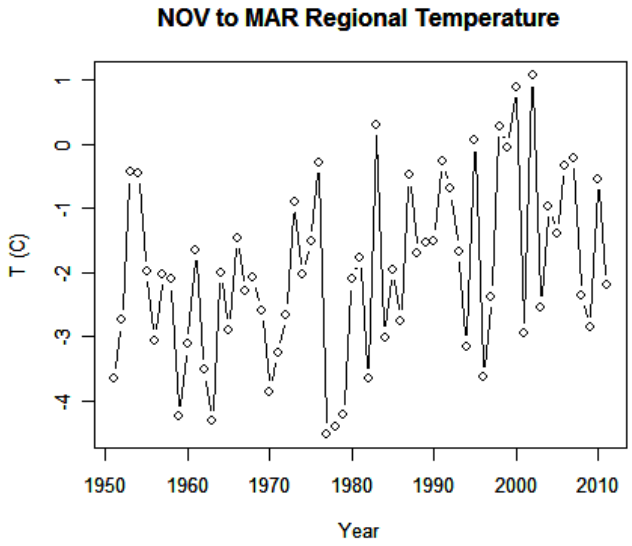
- How should we characterize the snowfall and temperature variability?
- How does the sensitivity of snowfall to temperature vary spatially?
- How do the temperature and snowfall vary with large-scale patterns?

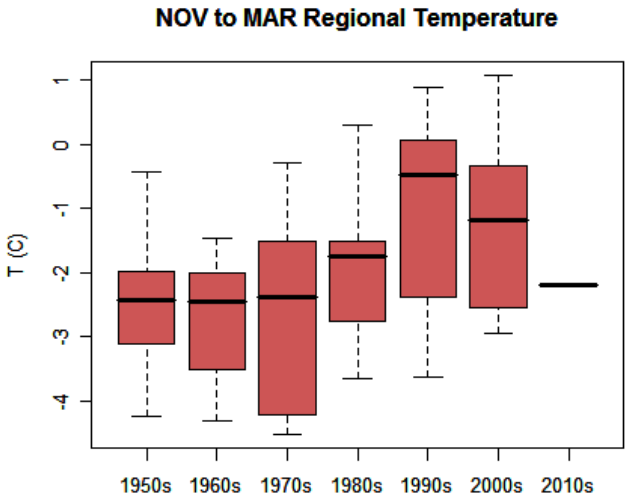
- Charge to the students
  - Design regions, pick stations, download from NCDC, and explore, plot, etc.
  - Compare results with another student group, which is examining November data
  - Experience the joys of working with snowfall data
    - Changes in observer, observation type, distribution shape, and NAs

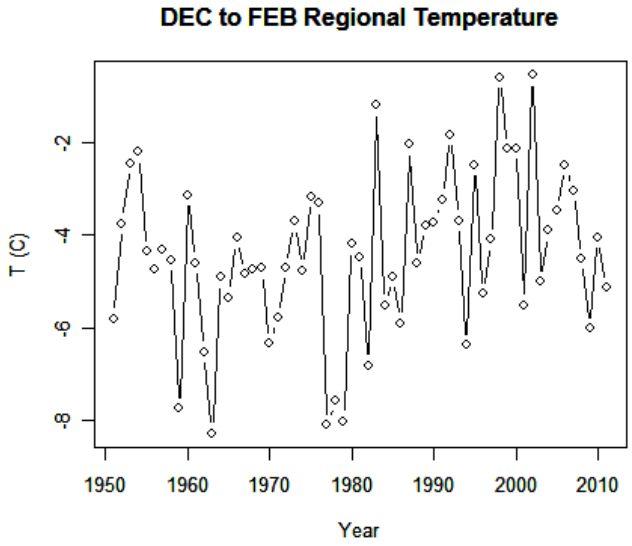
Map of Regions and Stations

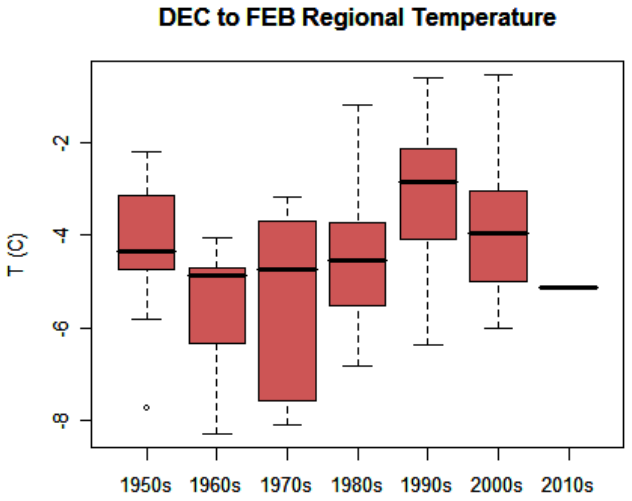


Regional Temperature Composite

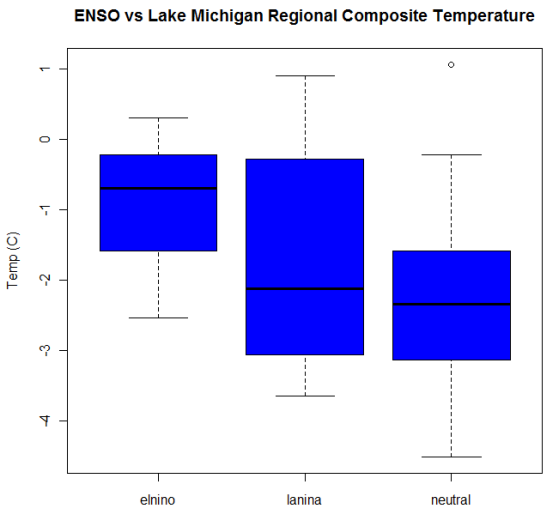


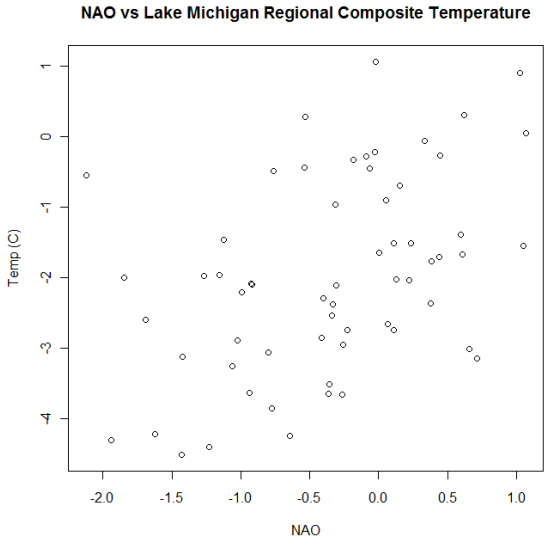


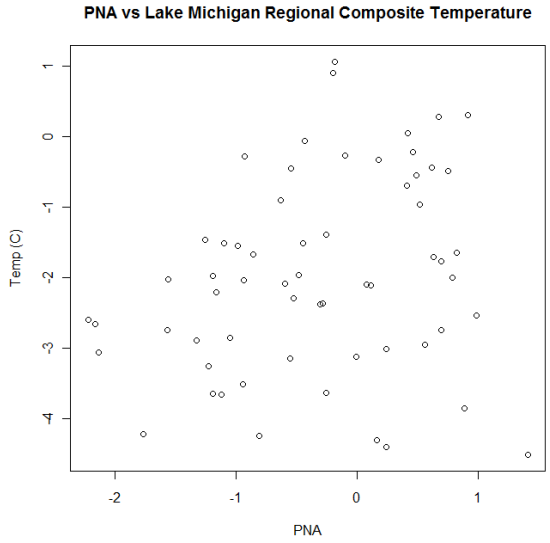


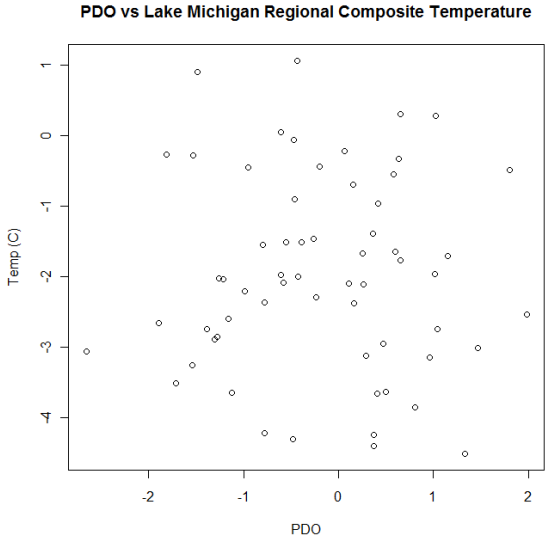


Sensitivity of Temperature to Teleconnection Patterns

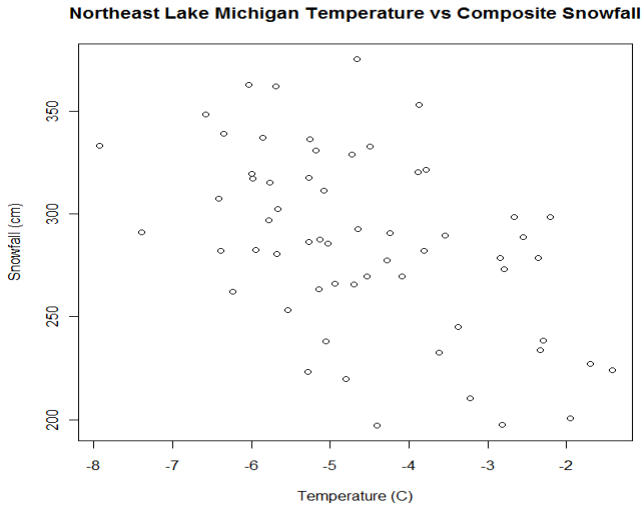


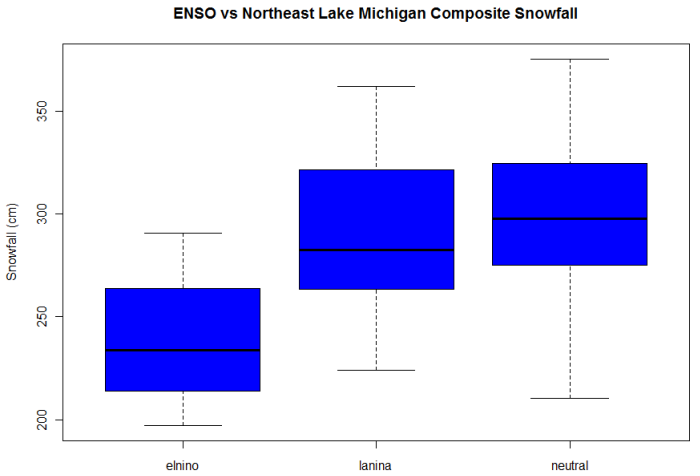


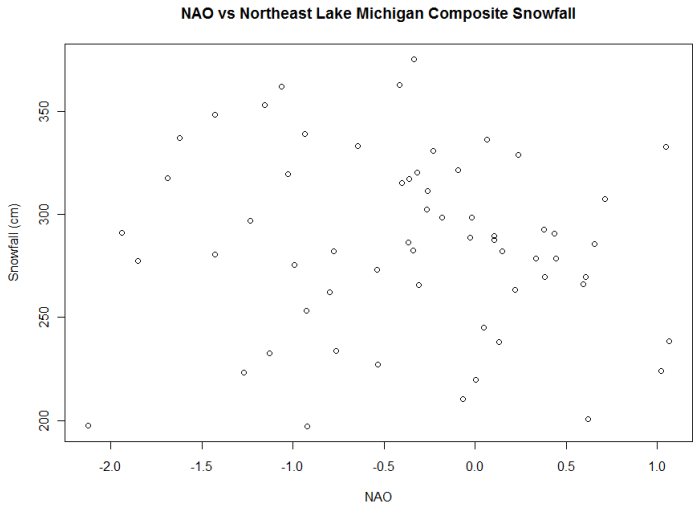


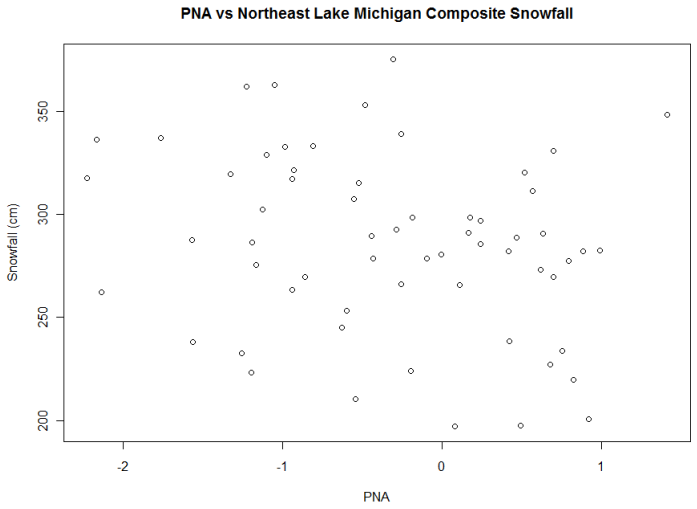


Northeast Region









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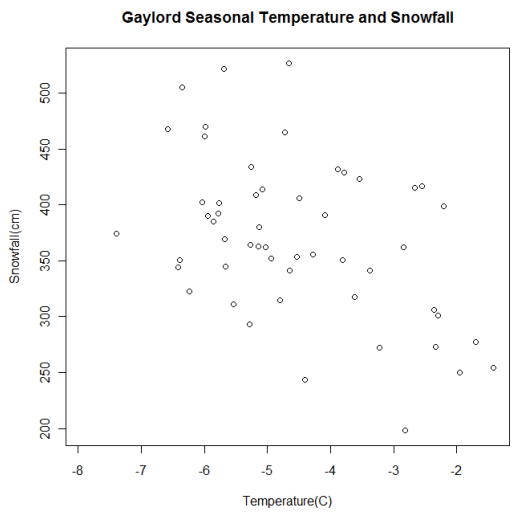
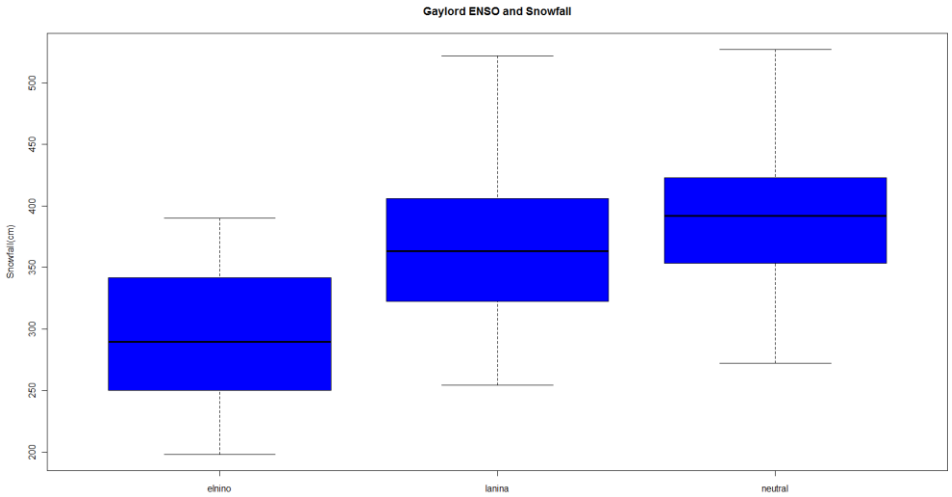
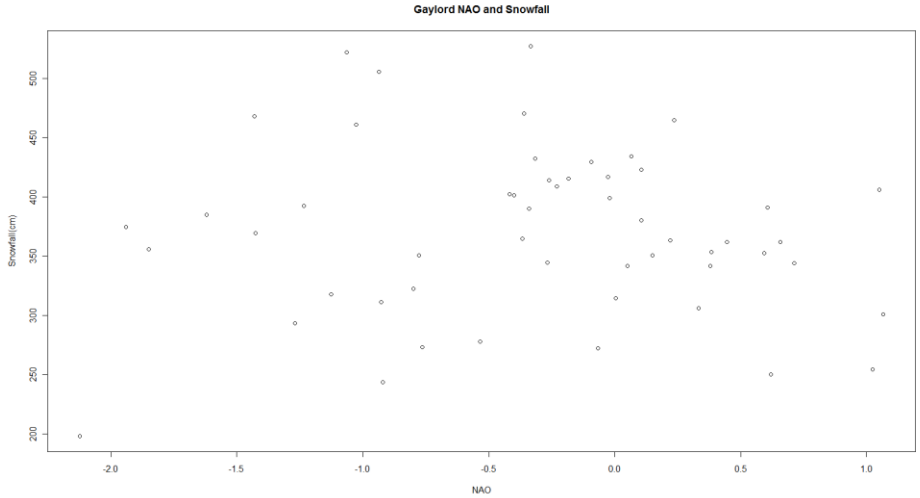
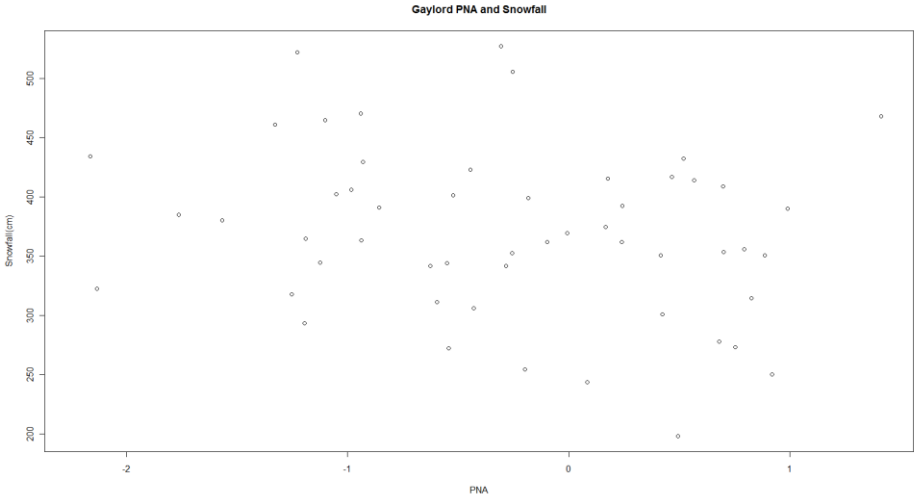
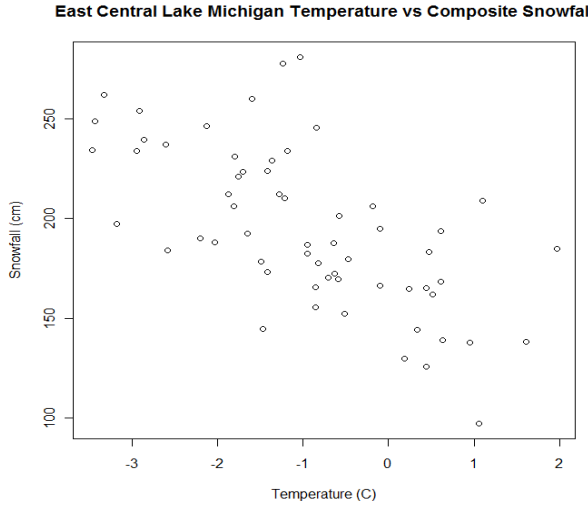


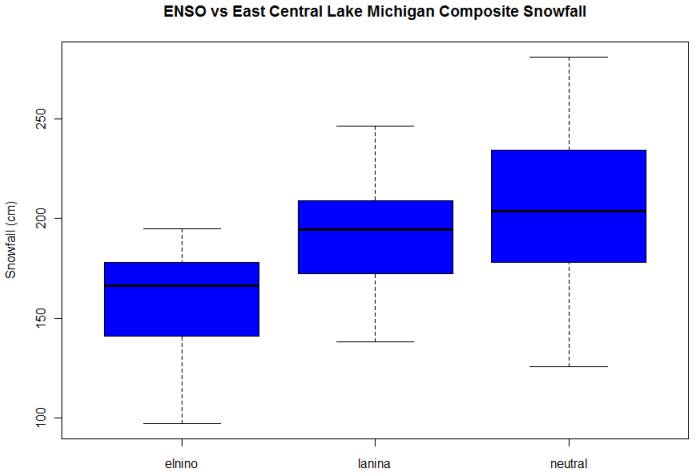


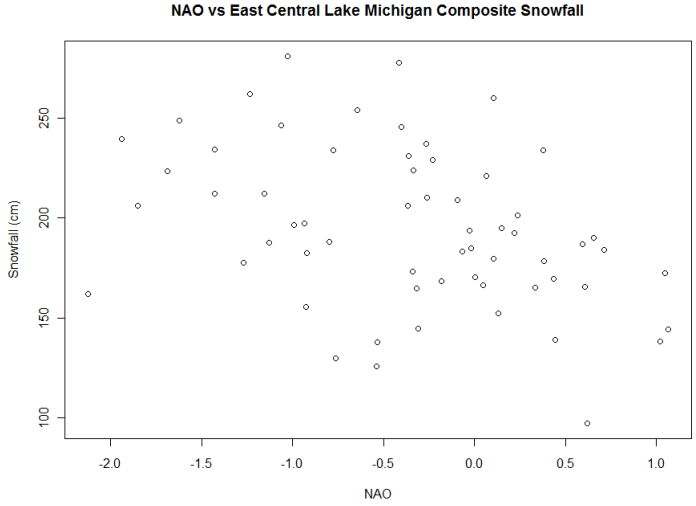


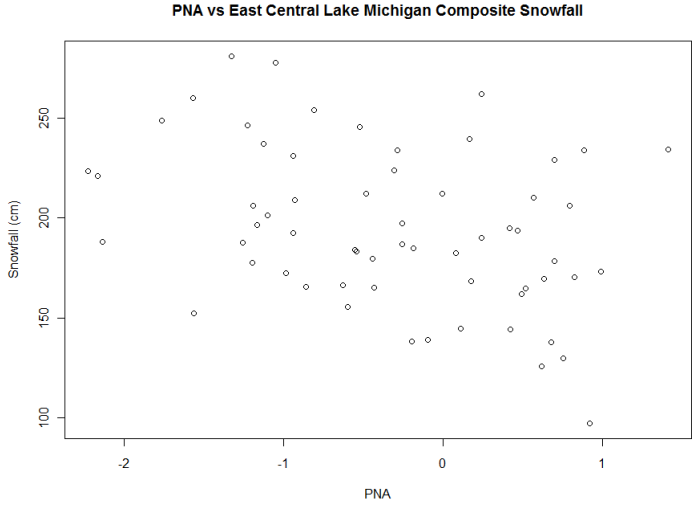


Eastern Region









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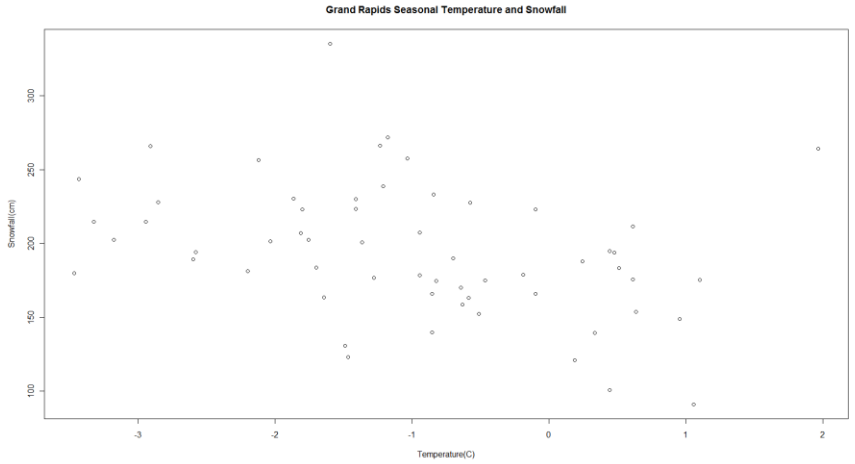
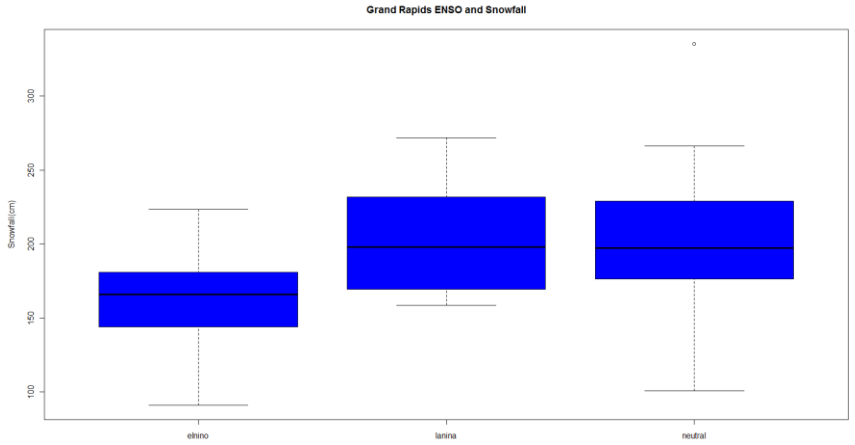
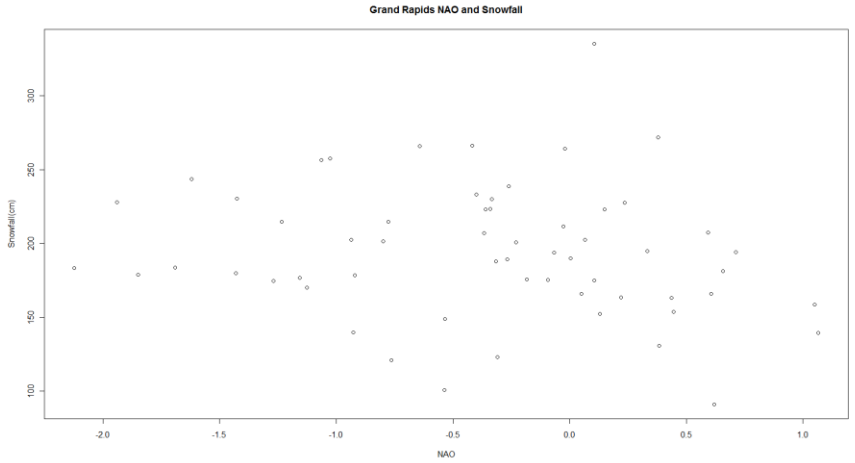
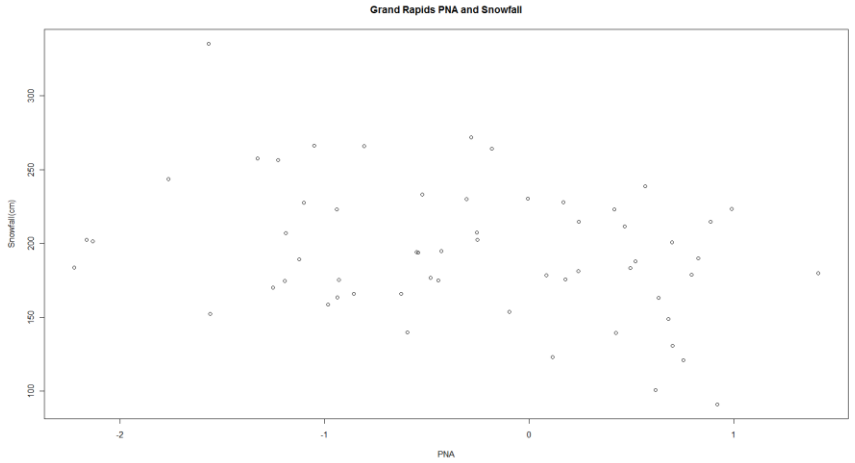
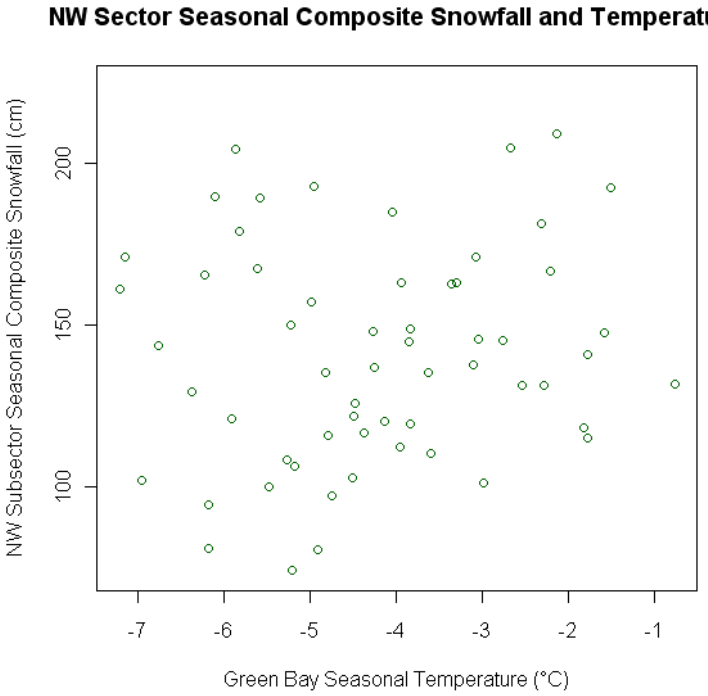


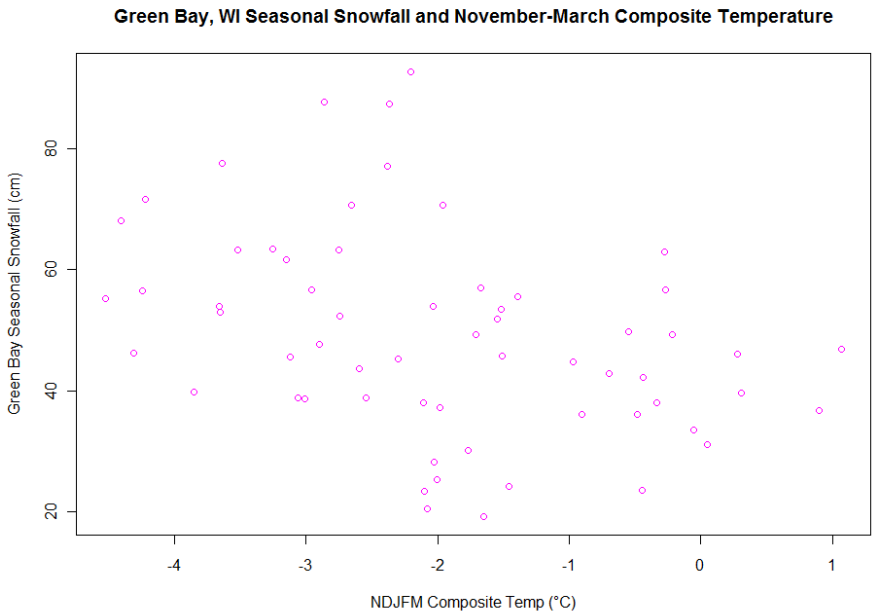






Northwest Region





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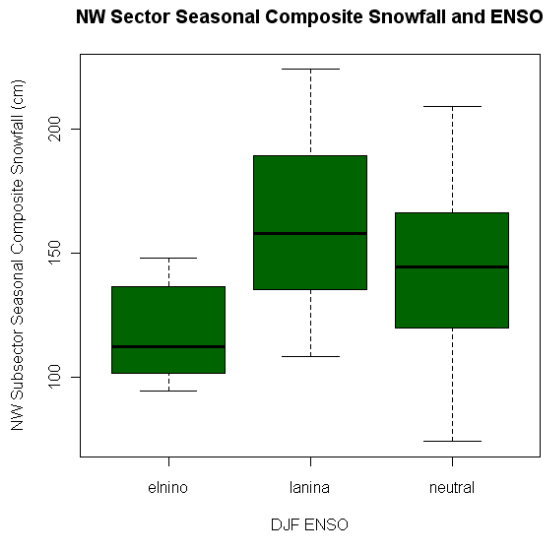

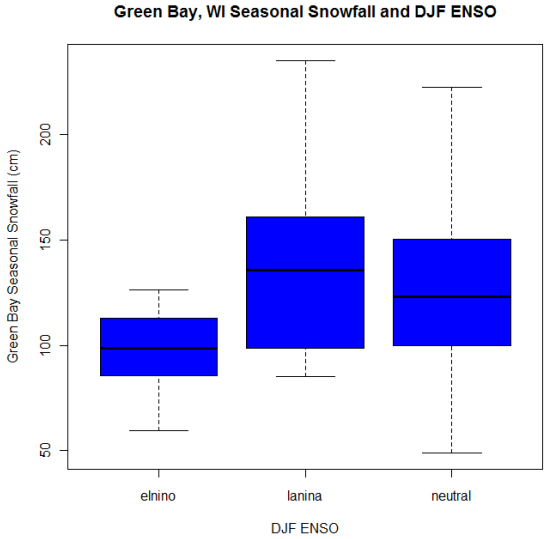

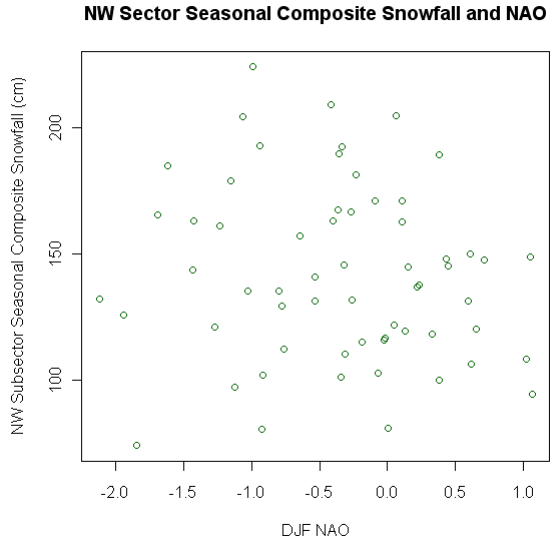

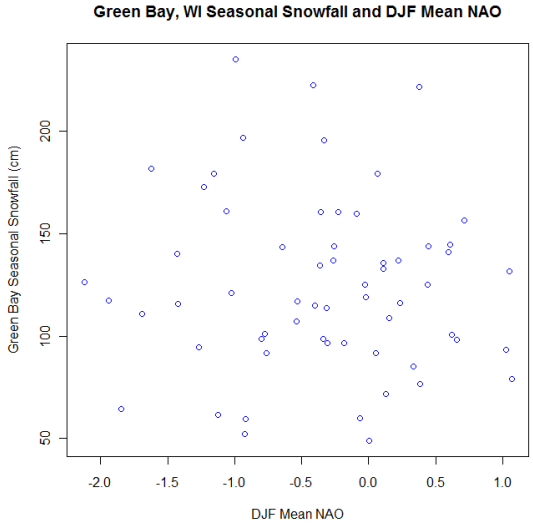

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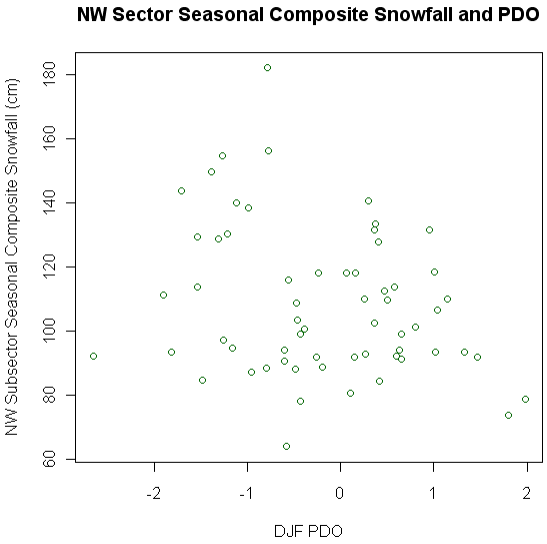
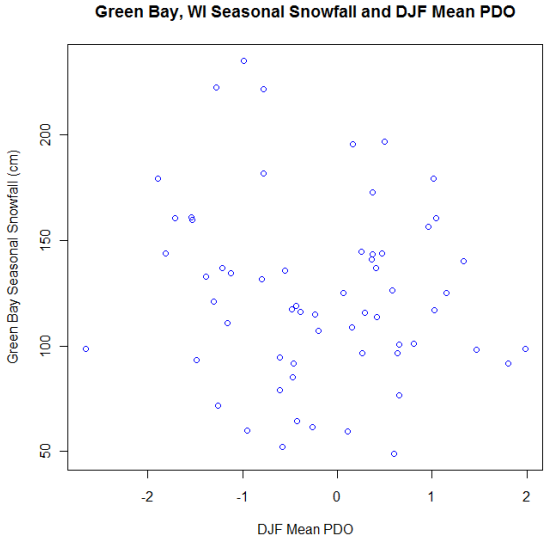
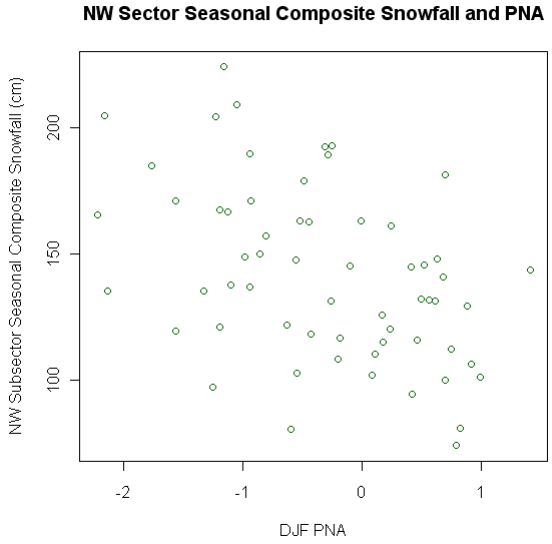
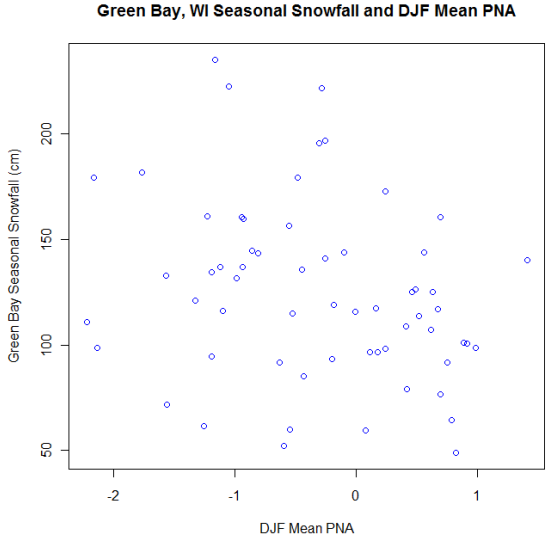
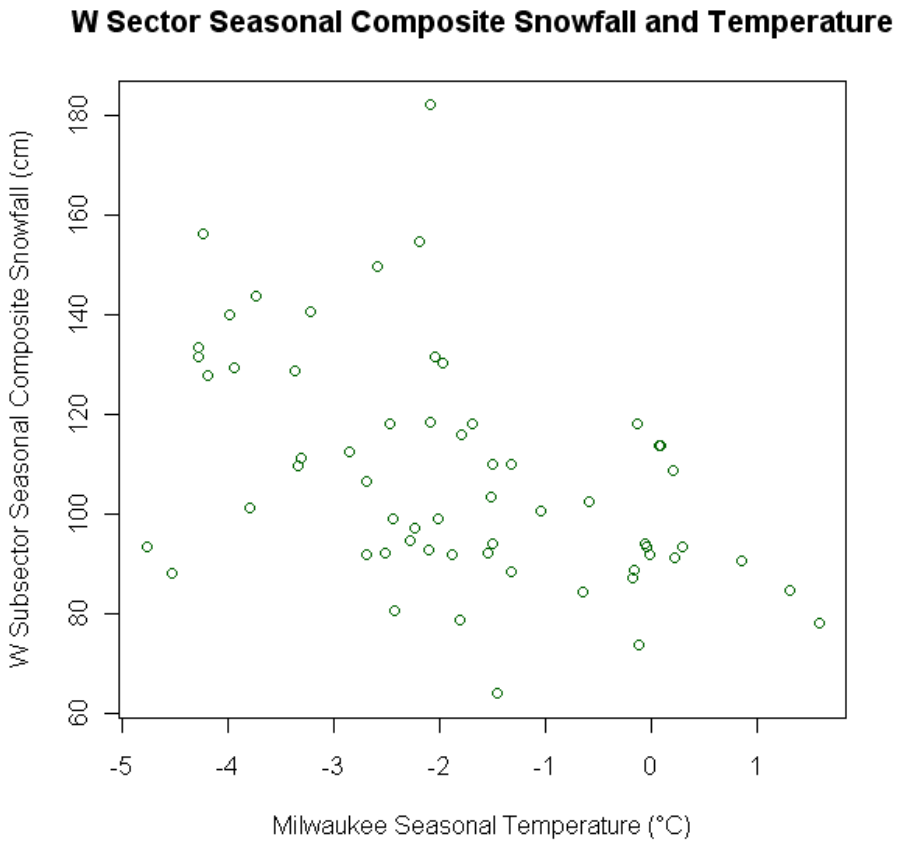


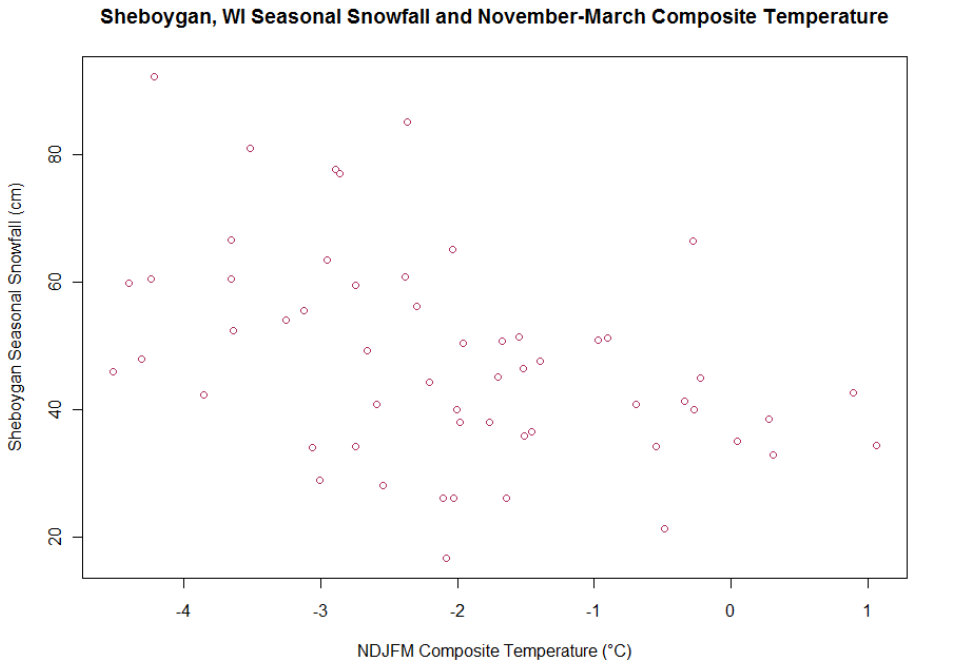






Western Region





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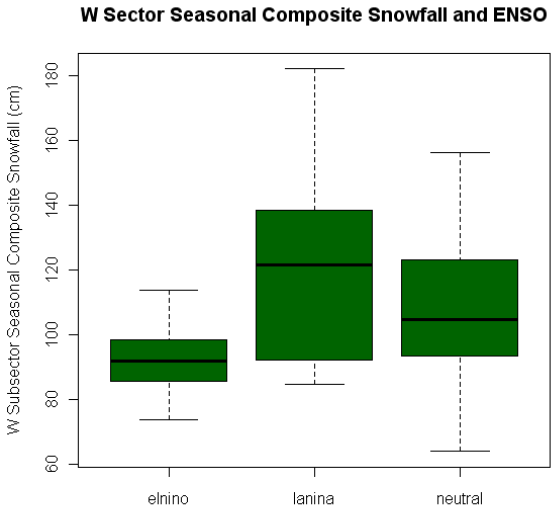

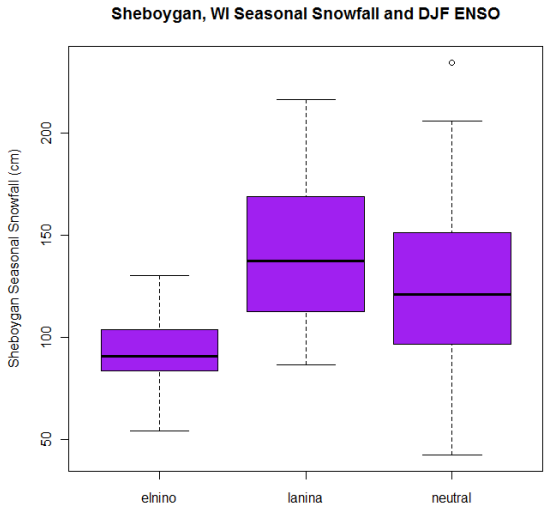

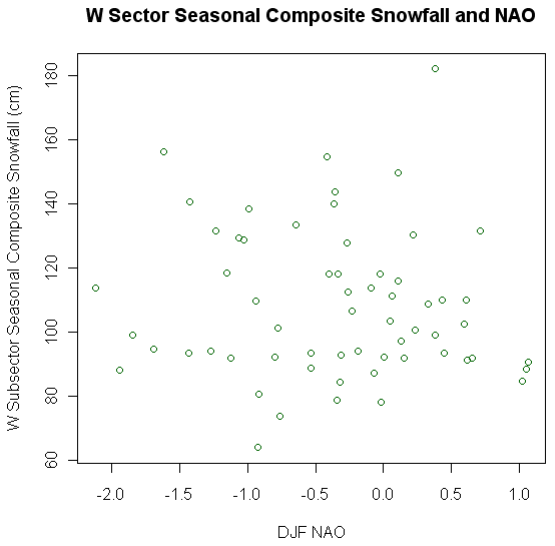

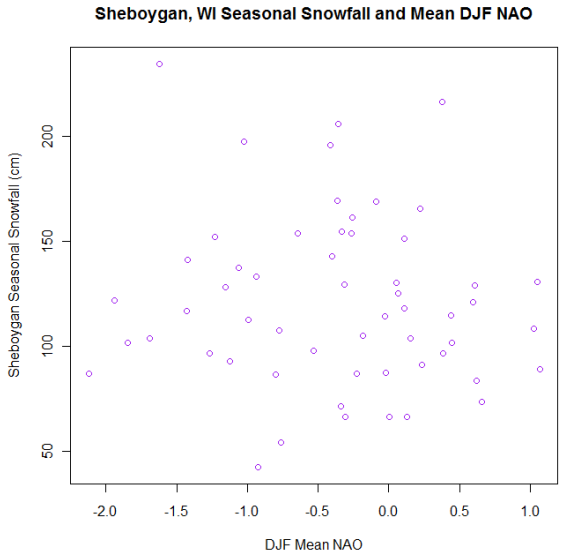

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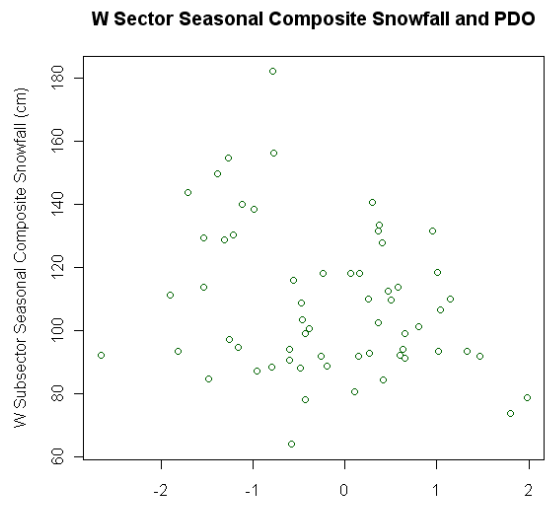
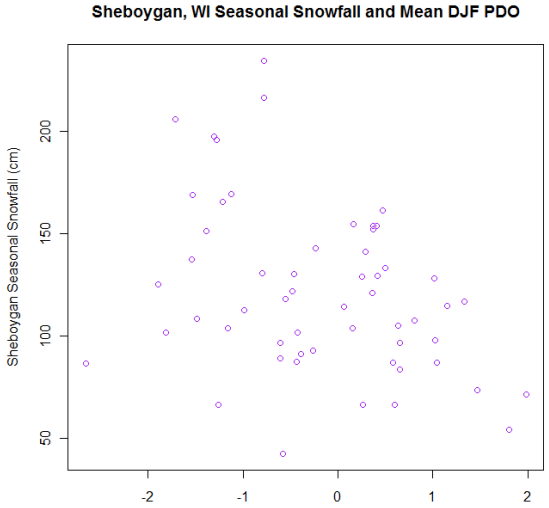
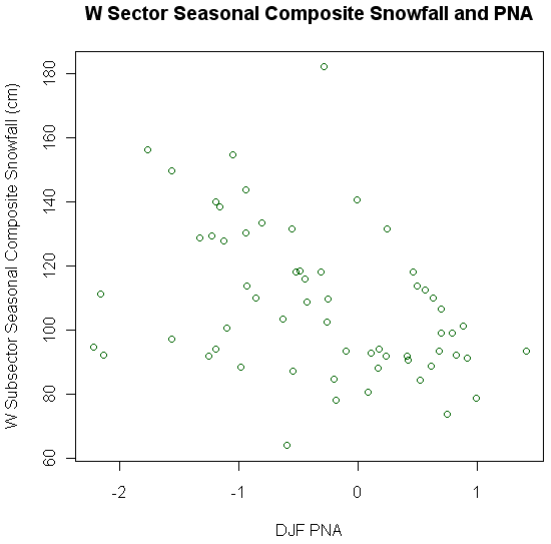
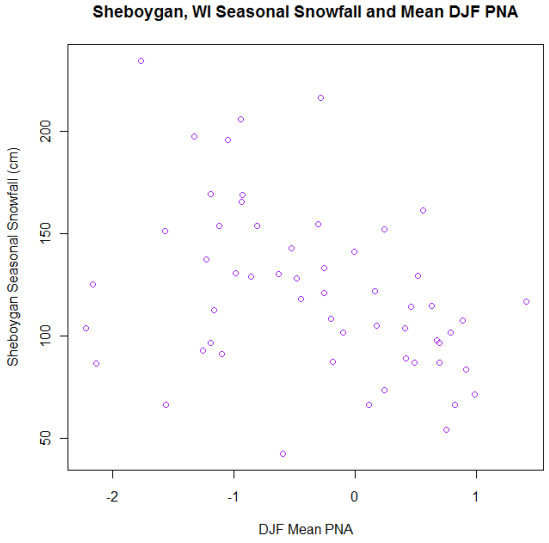
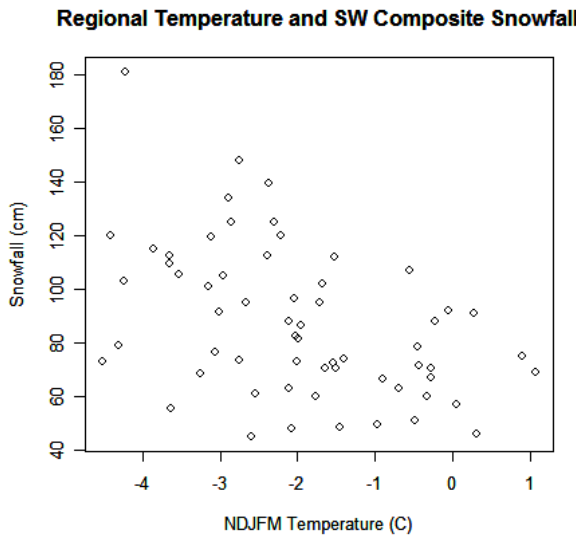


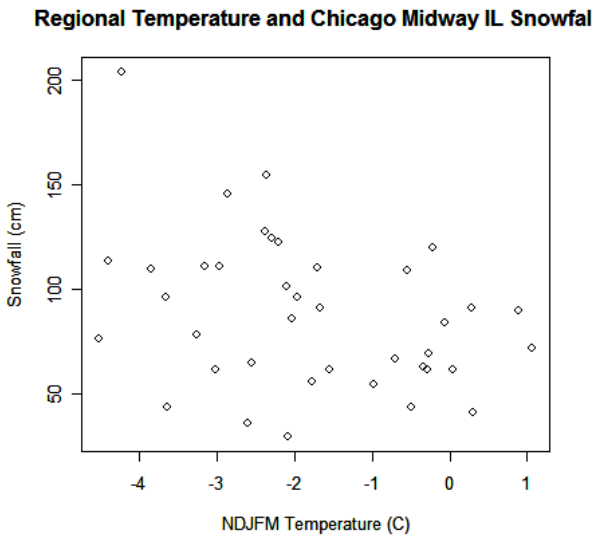


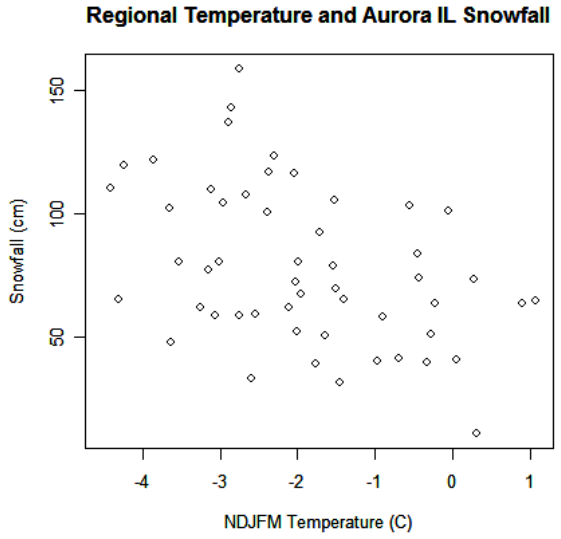


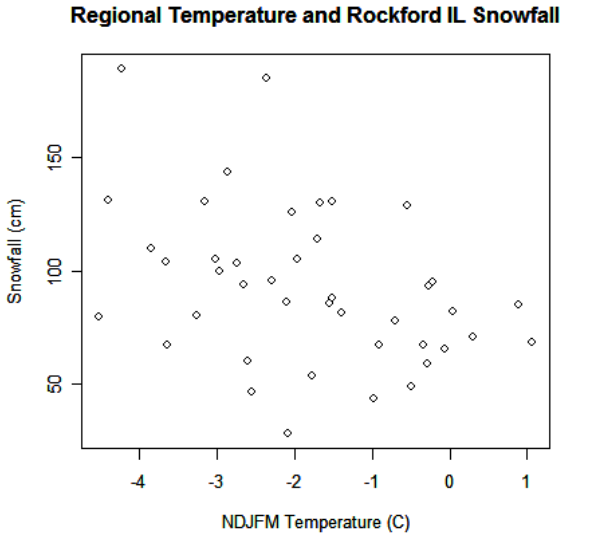


Southwest Region









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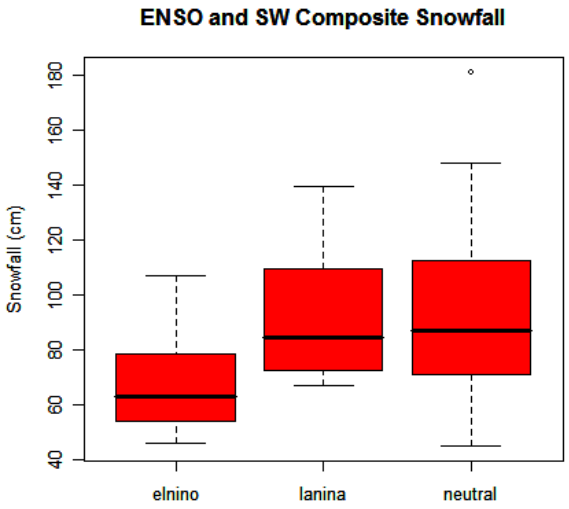
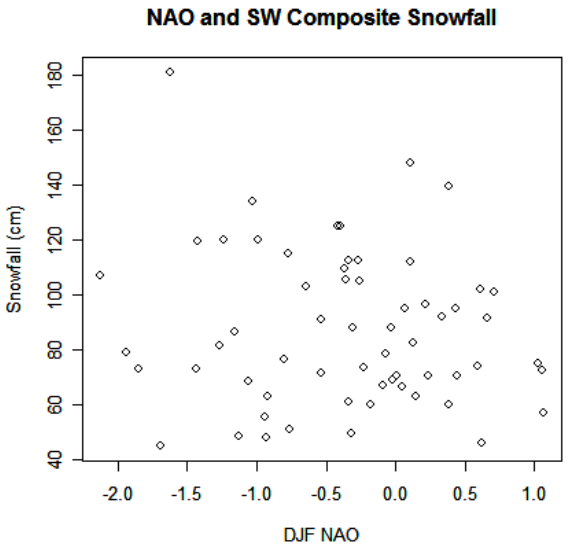
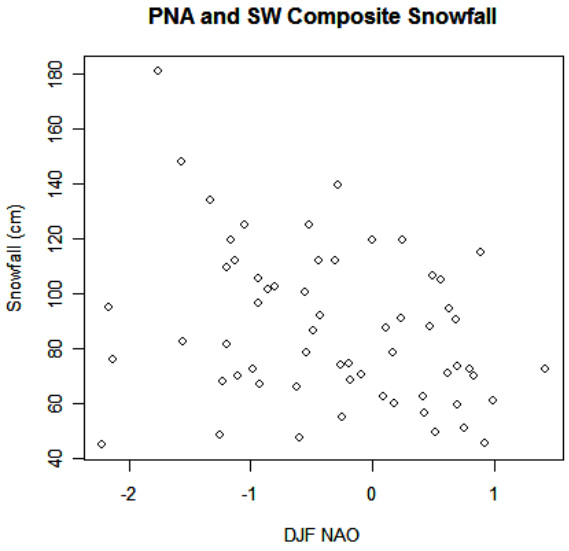
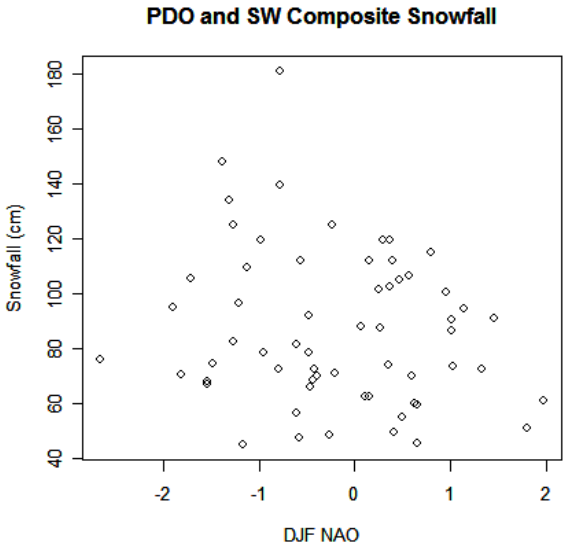
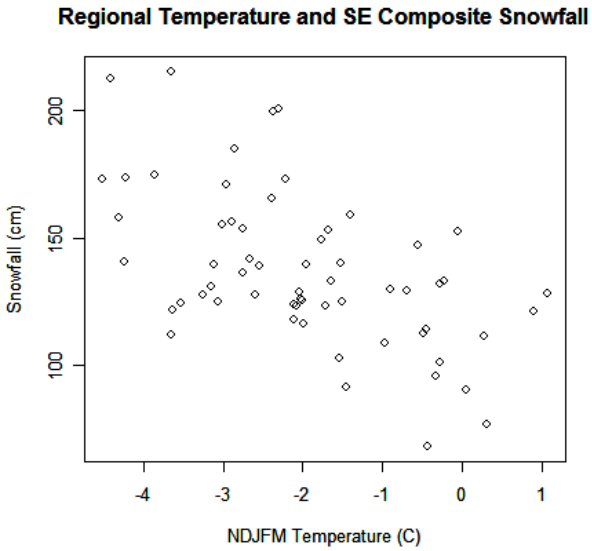


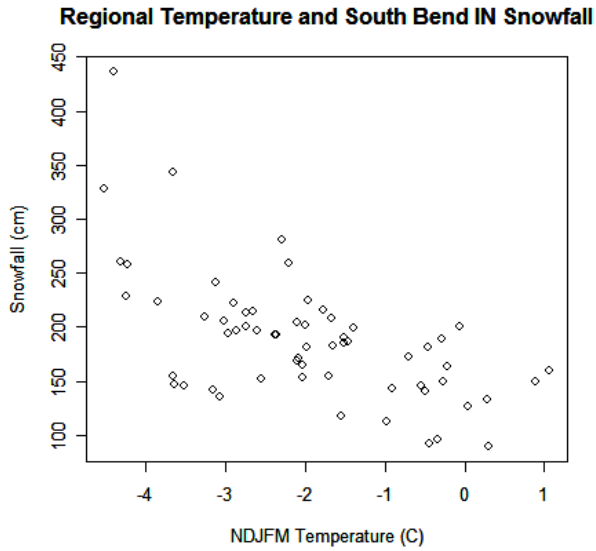


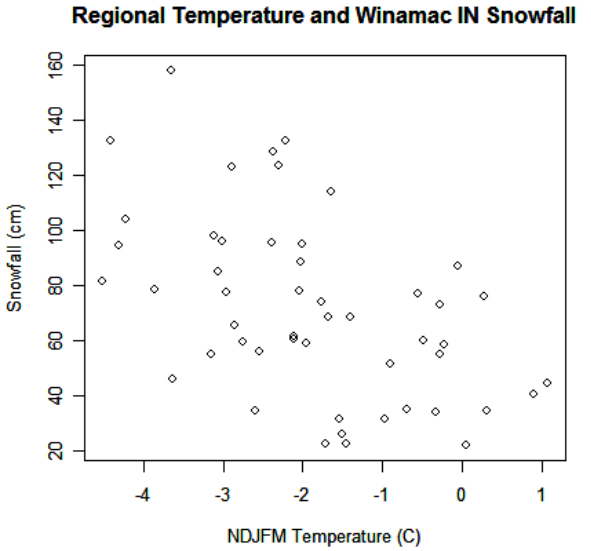


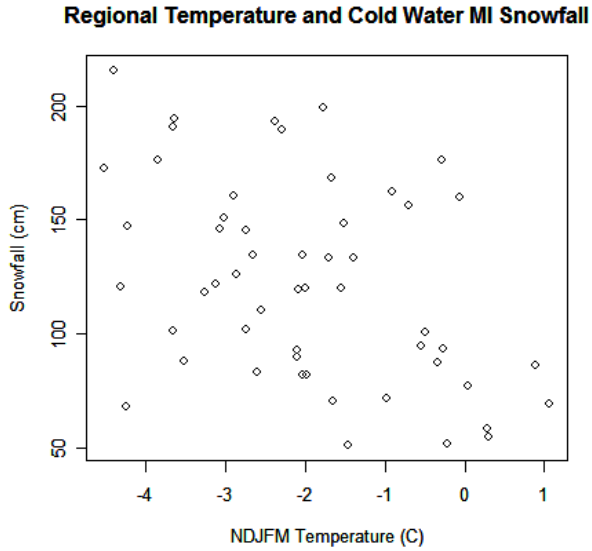


Southeast Region

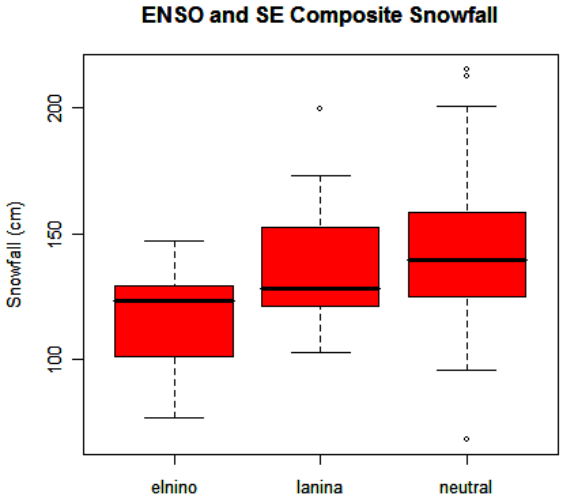


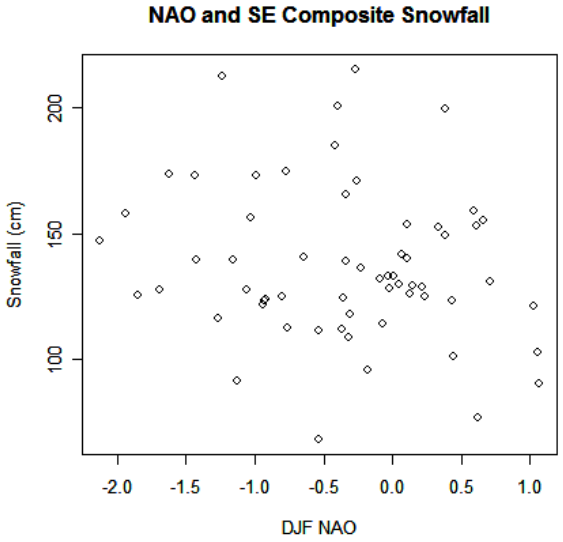


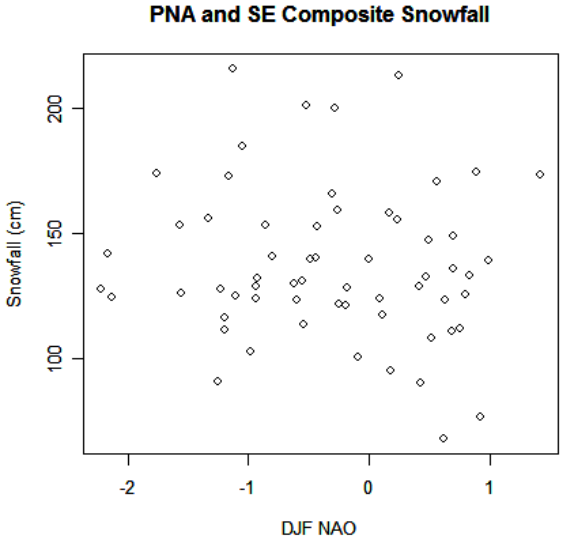


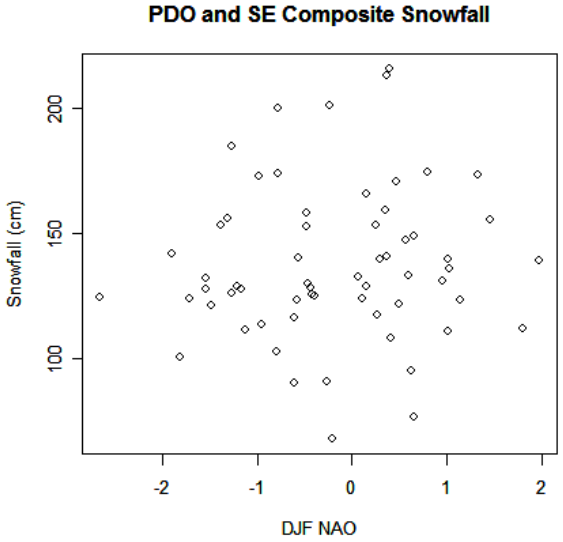


Southeast Region

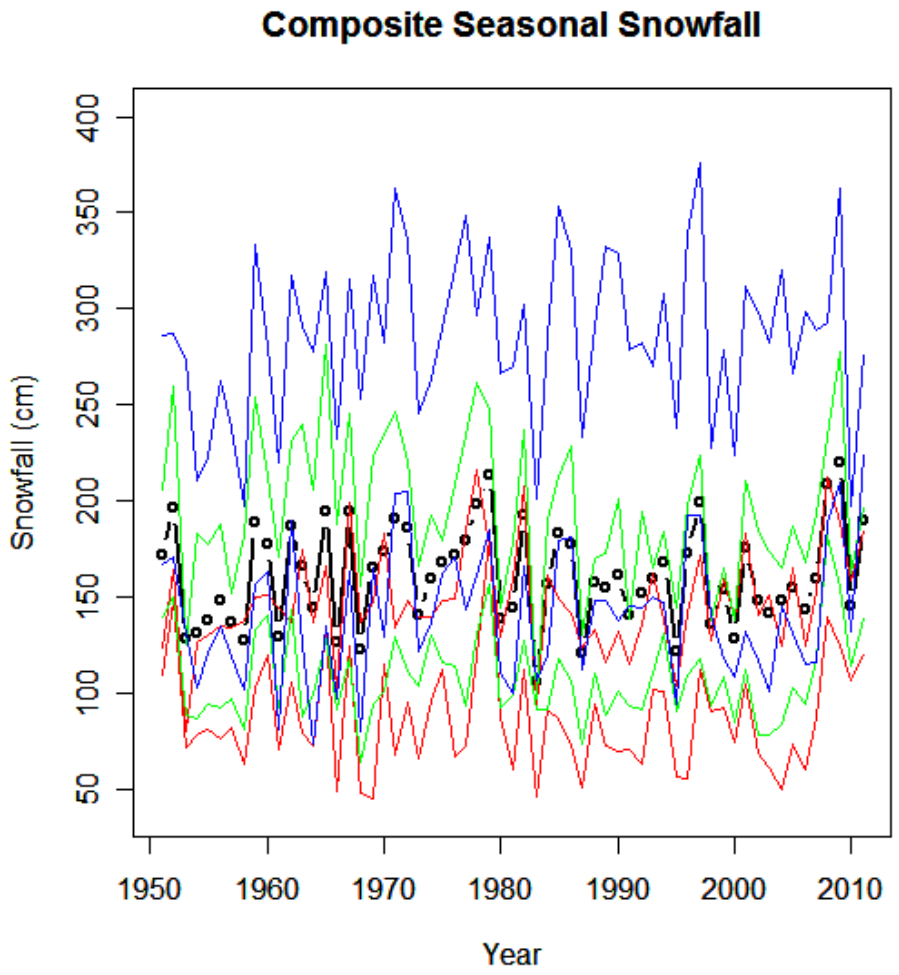


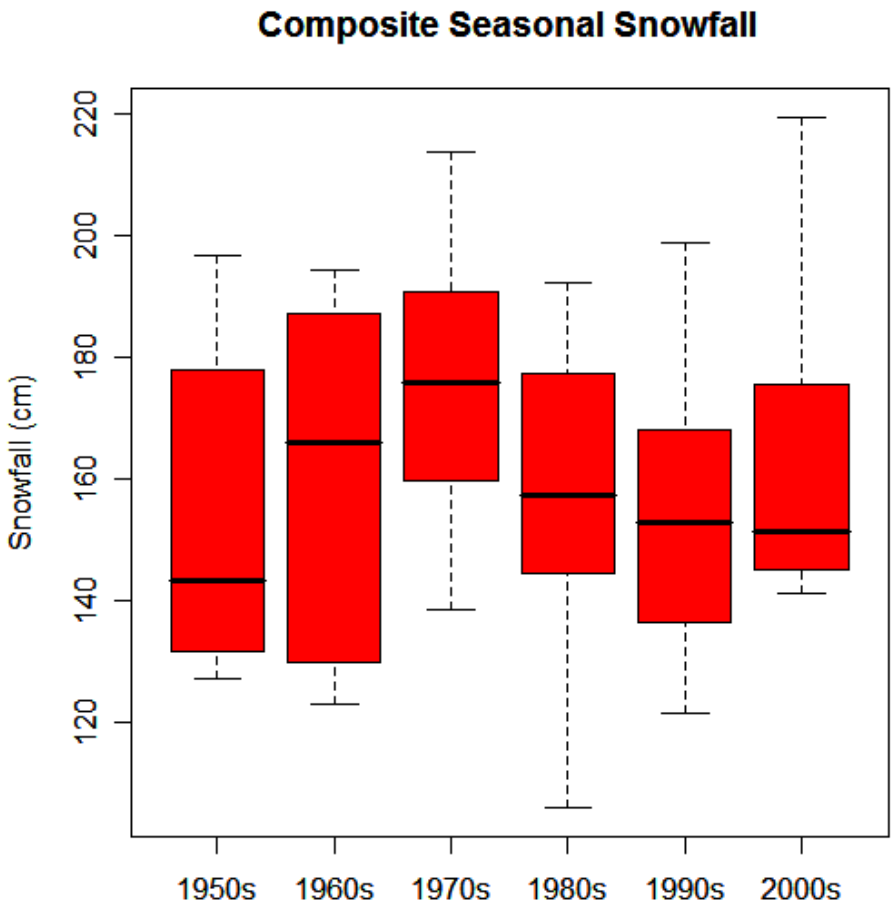






Regional Snowfall Composite



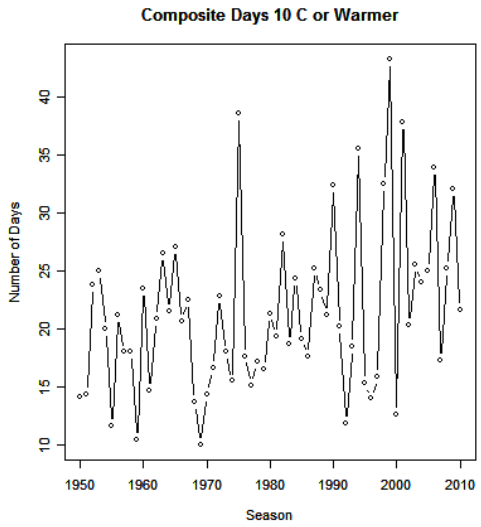


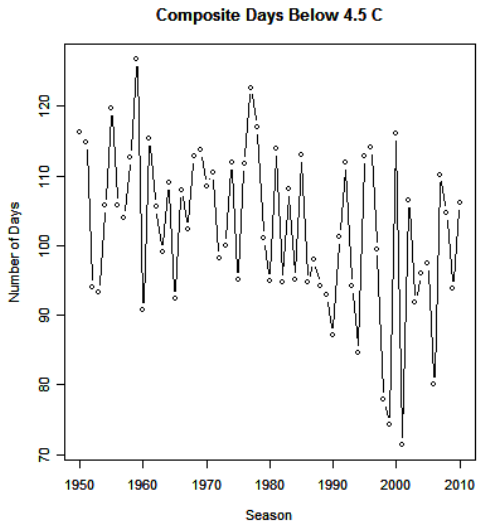
Daily Threshold Data

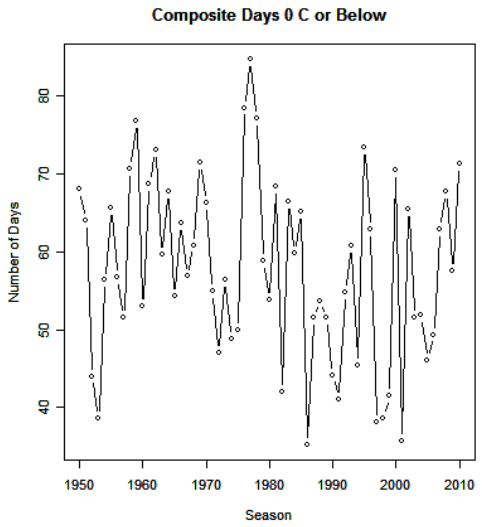
- Using their stations, regional composites were calculated for the seasonal number of days with:
  - High temperature
    - Thresholds of 10, 4.5, 0, -6.5 °C
  - Low temperature
    - Thresholds of -12, -17.5 °C
  - Snowfall
    - Thresholds of >T, 2.5 cm, 5 cm, 15 cm
  - Snow cover
    - Thresholds of 2.5 cm, 5 cm, 15 cm
  - Precipitation Days

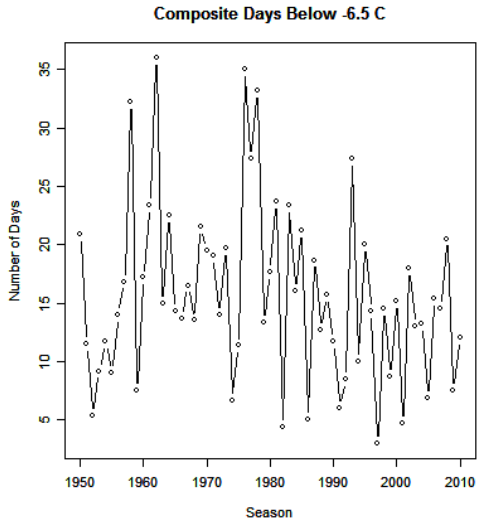
- NAs are fairly common with daily data:
  - Used standardized anomalies per station for each month to compute the regional composite – this reduces the NA bias relative to a simple average

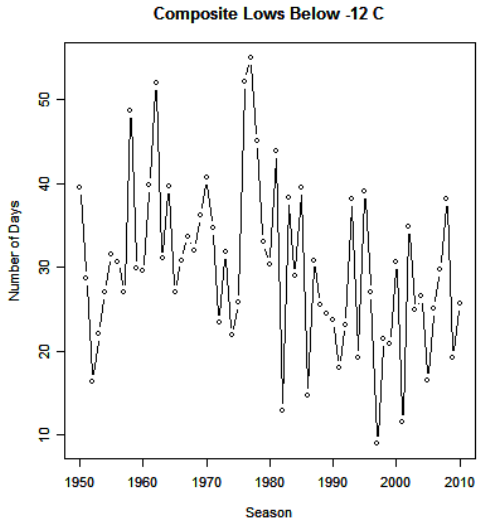
Composite Temperature Thresholds

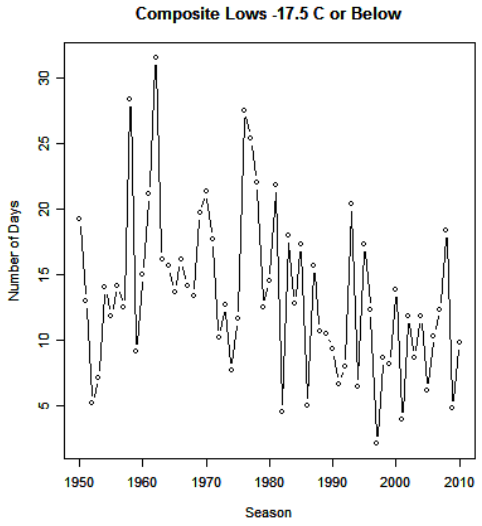




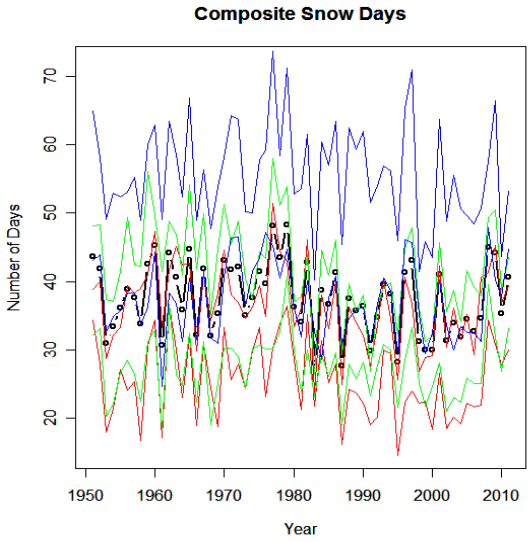


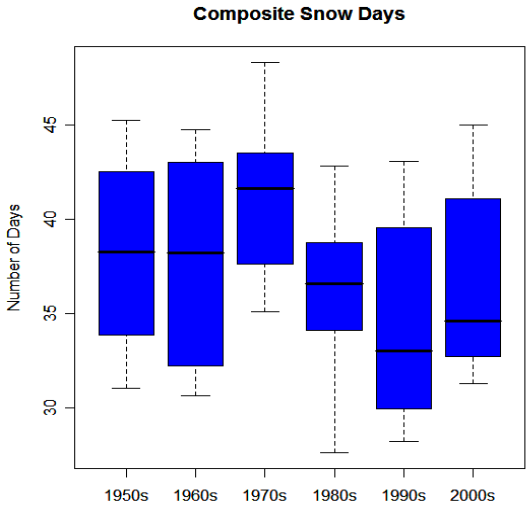


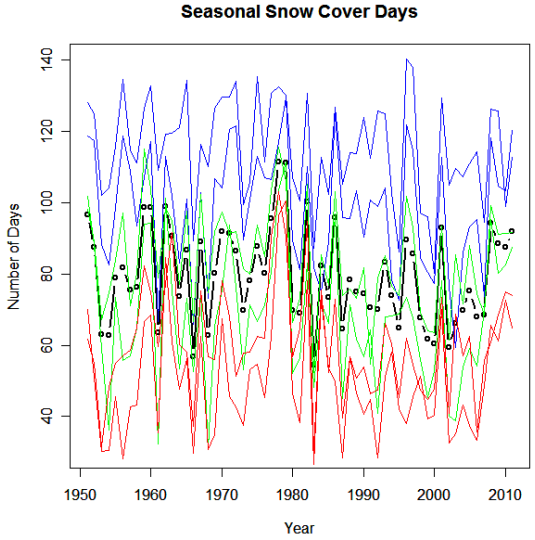


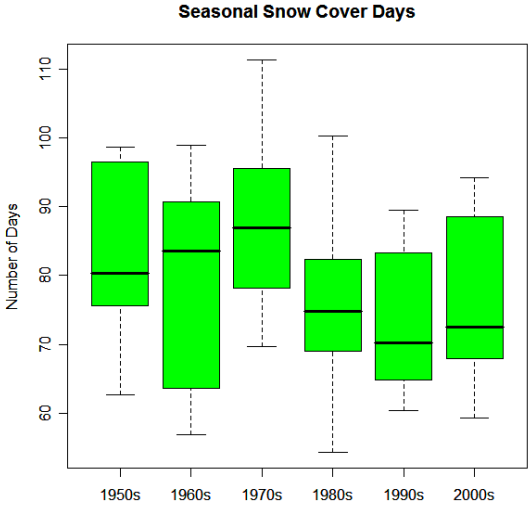


Composite Snow Days and Days with Snow Cover







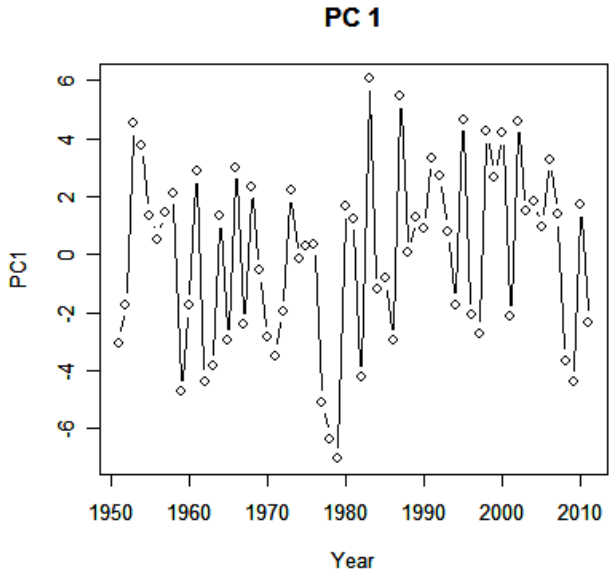


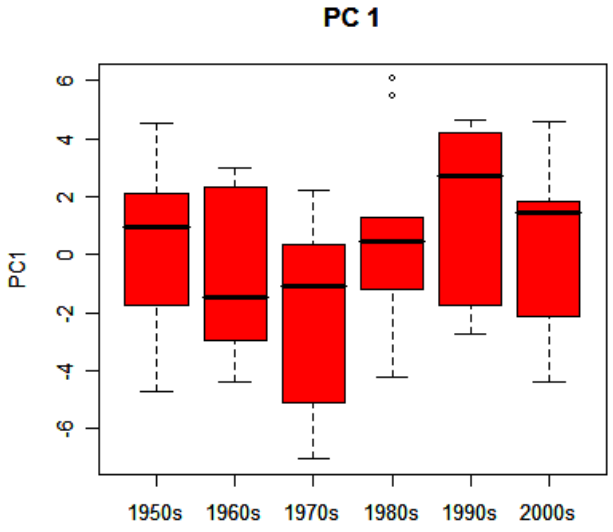
Numerical Approaches

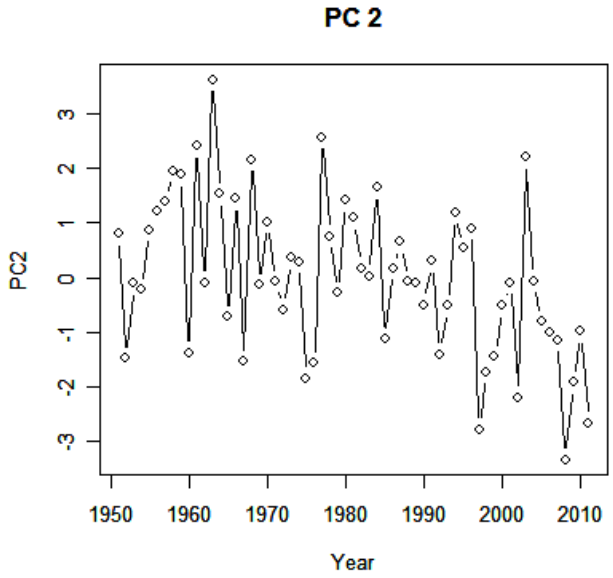
- Regression
  - Regression for most of the variables suggests that the tele-connection patterns together explain ~35% or more of the variance
- Classification
  - Supervised, unsupervised
- Trend Assessment
  - Trends are significant in most of the regional temperature variables, and some of the snow-related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

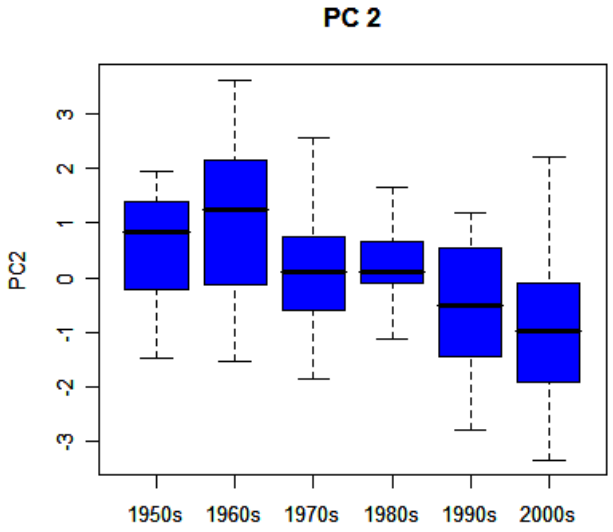
PCA Fever

Loadings	PC1	PC2
DJF T	0.28	-0.32
Snowfall	-0.29	-0.27
Days ≥ 50	0.17	-0.10
Days ≤ 32	-0.29	0.16
Days < 20	-0.25	0.35
Lows < 10	-0.28	0.33
Lows ≤ 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

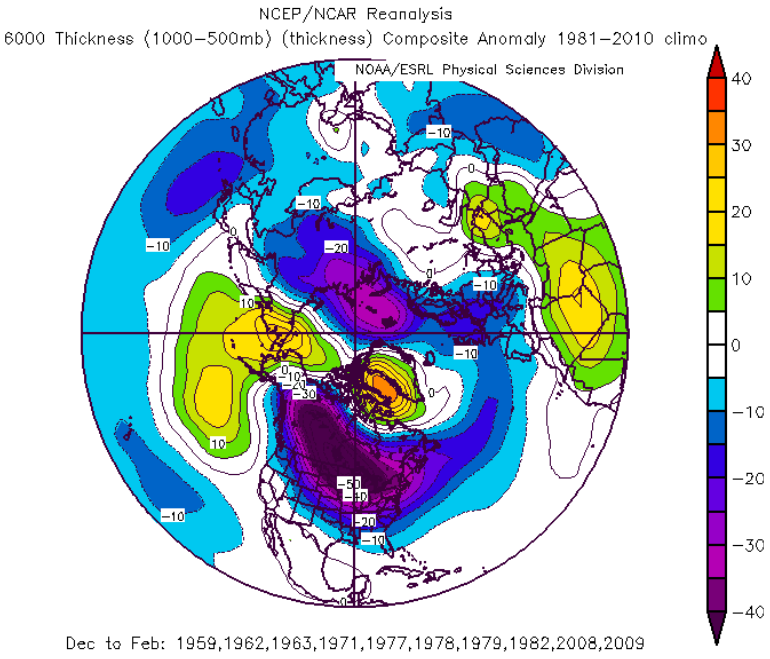




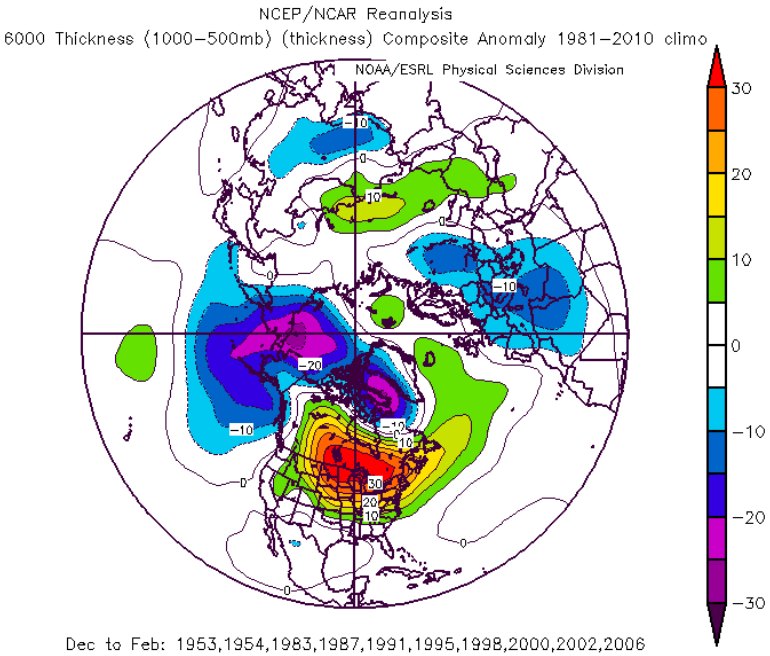




1000-500 hPa Thickness Top and Bottom 10 PC1



Dec to Feb: 1959,1962,1963,1971,1977,1978,1979,1982,2008,2009



Dec to Feb: 1953,1954,1983,1987,1991,1995,1998,2000,2002,2006

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

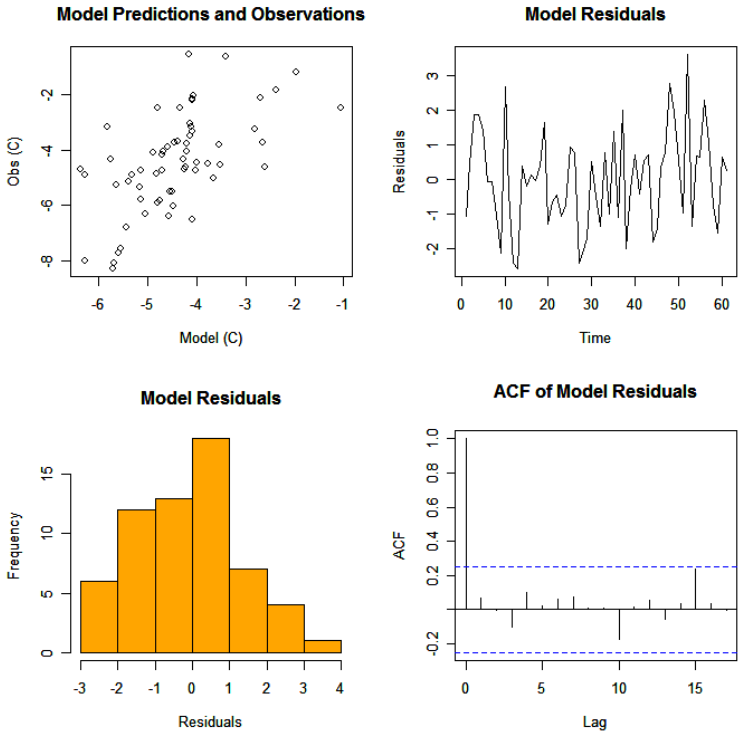
(if someone asks – not using interaction terms, for simplicity)

Coefficients:

	Estimate	Pr(>|t|)
(Intercept)	-2.6433	6.06e-07 ***
nao$DJF	0.9201	0.000597 ***
pna$DJF	0.5515	0.091981 .
mei$DJFlanina	-1.8166	0.021844 *
mei$DJFneutral	-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



Basic Regression with LN (Winter Snowfall)

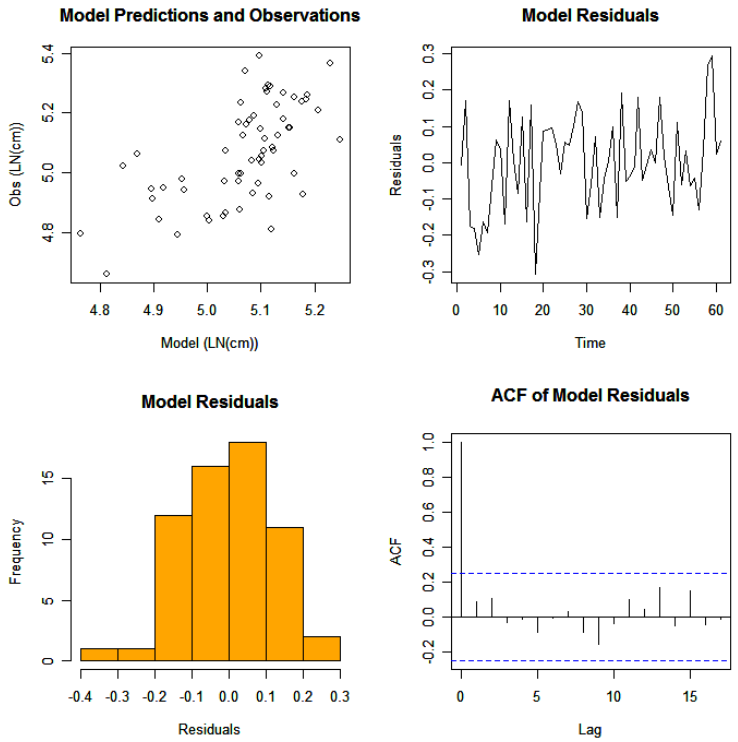
(if someone asks – not using interaction terms, for simplicity)

Coefficients:

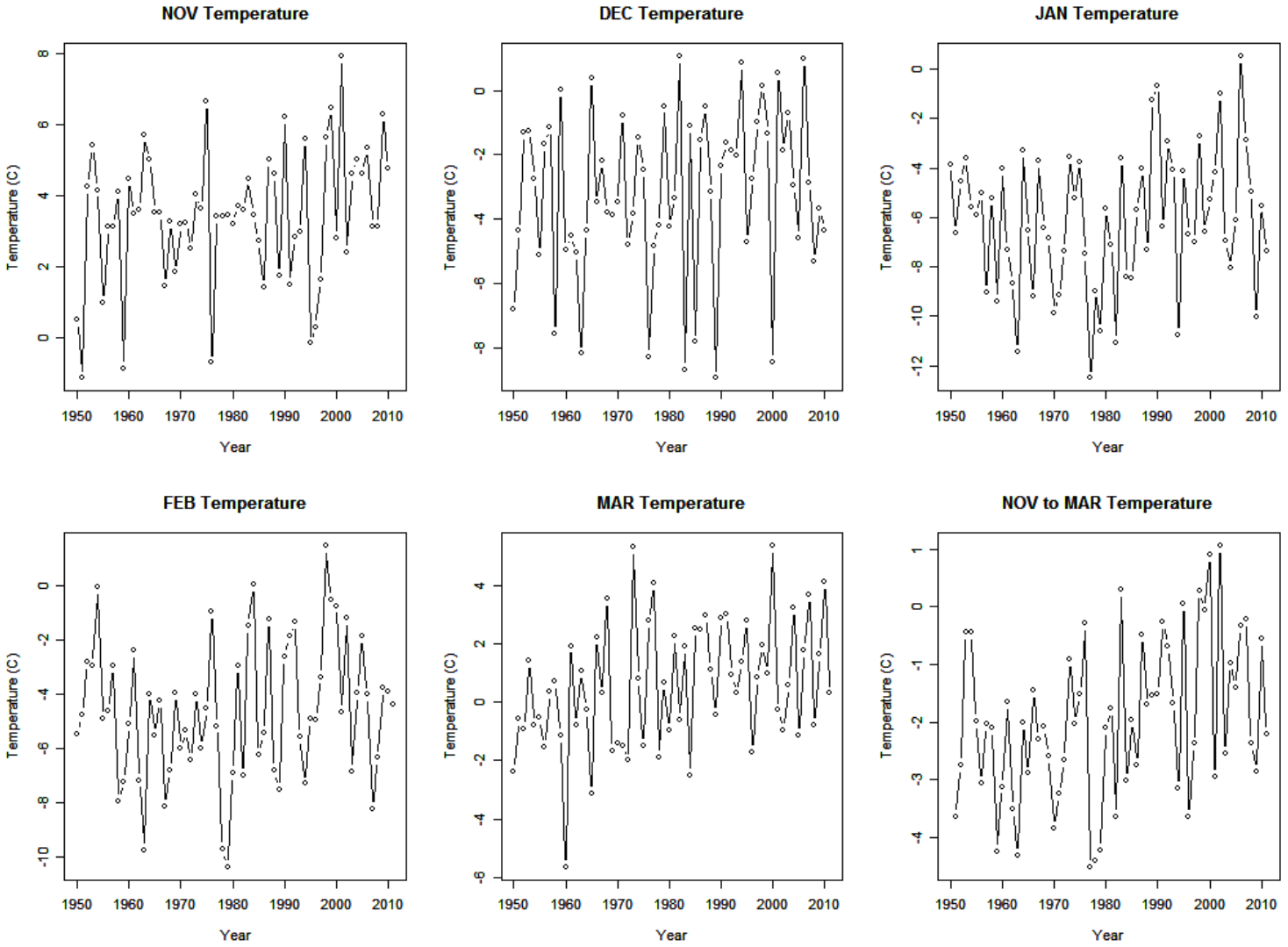
	Estimate	Pr(>|t|)
(Intercept)	4.87357	< 2e-16 ***
nao$DJF	0.04106	0.081807 .
pna$DJF	-0.07816	0.010499 *
mei$ensolanina	0.23292	0.001704 **
mei$neutral	0.19338	0.000198 ***
pdo$DJF	0.05432	0.057575 .

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

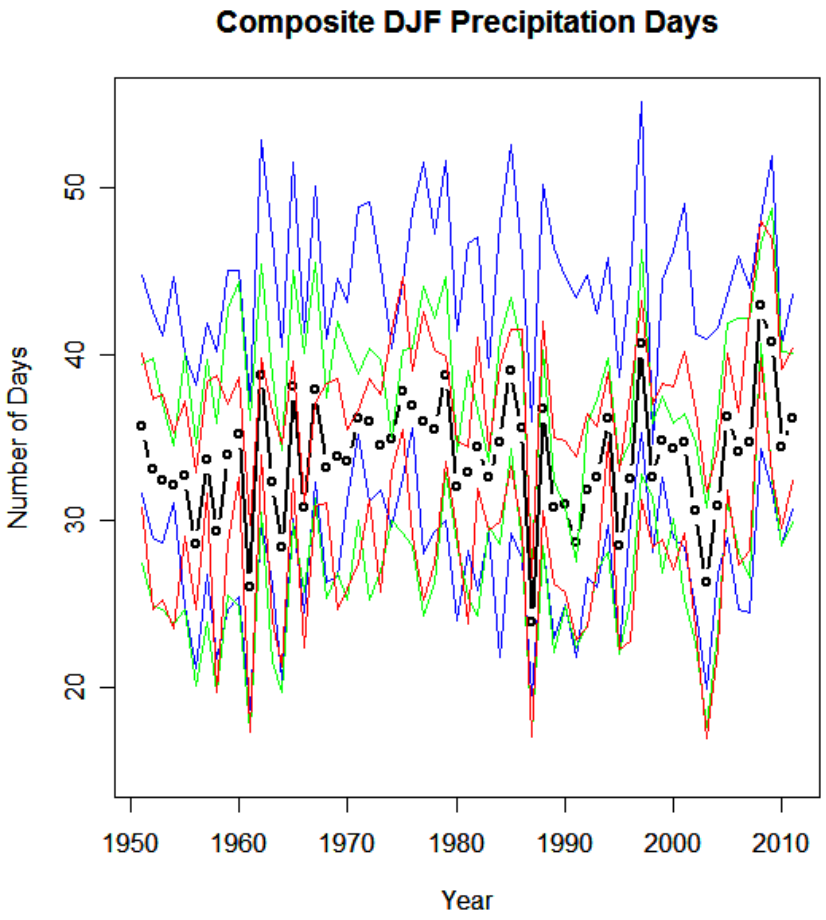
Residual standard error: 0.1348 on 55 degrees of freedom
Multiple R-Squared: 0.3827, Adjusted R-squared: 0.3265
F-statistic: 6.819 on 5 and 55 DF, p-value: 5.178e-05

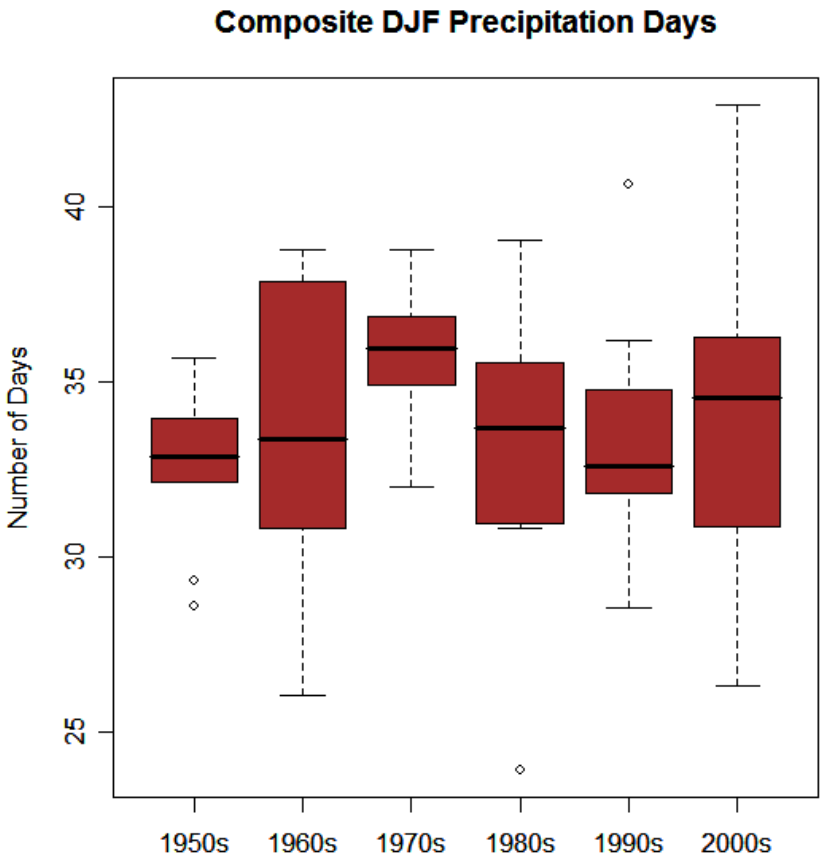


Temperature for Individual Months

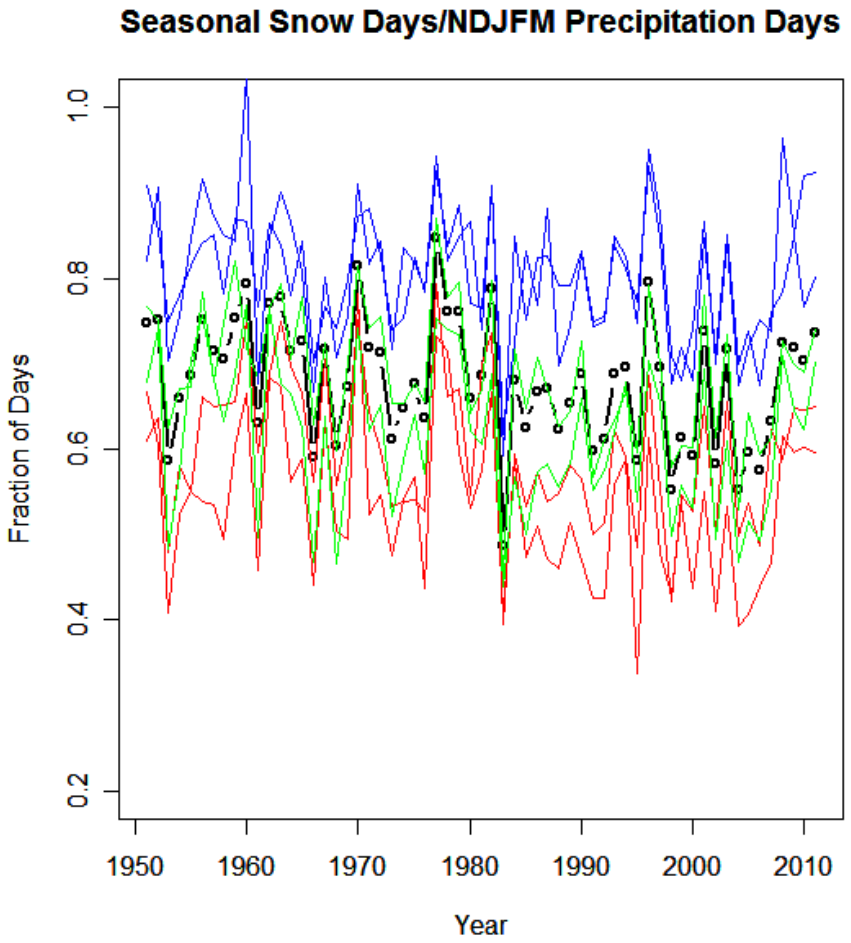


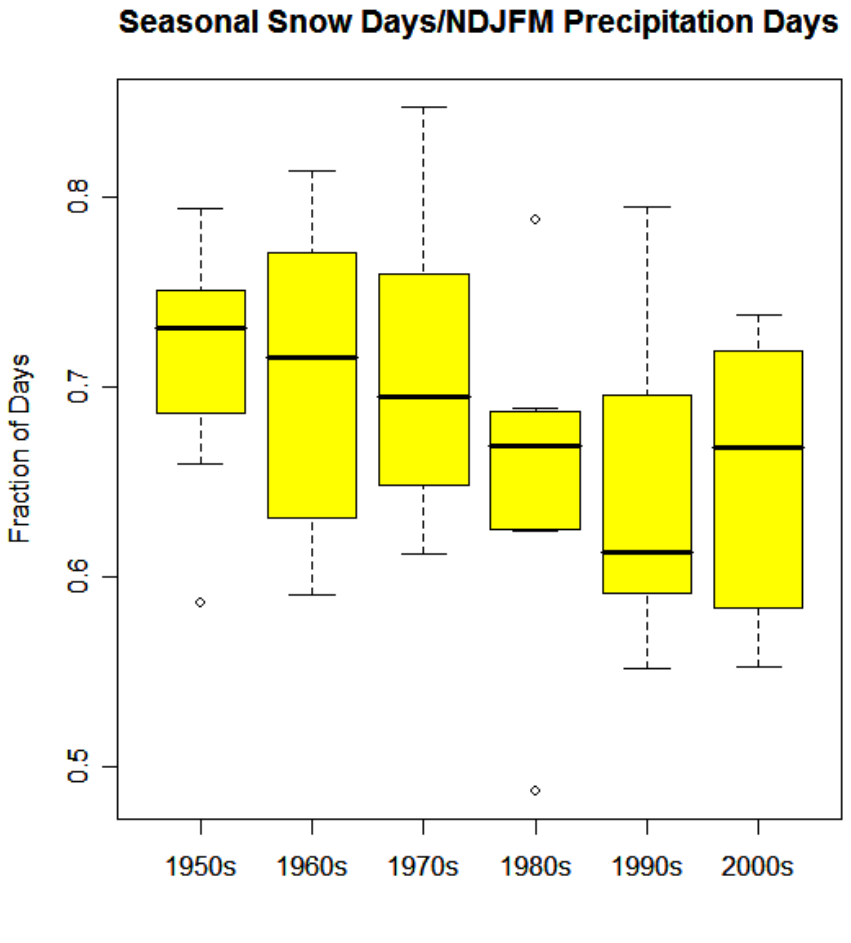
Precipitation Days



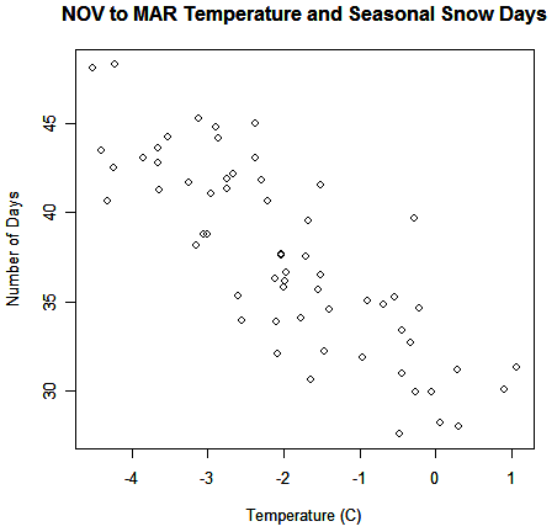


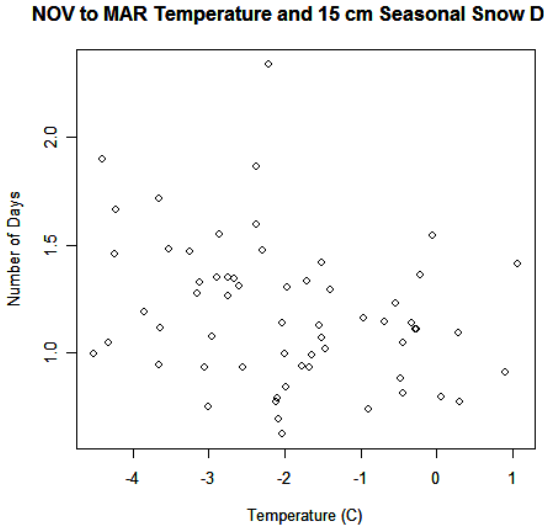
Fraction of Snow/Precipitation Days

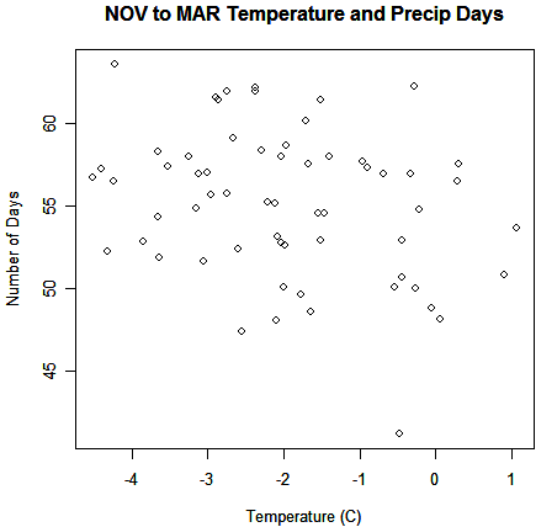


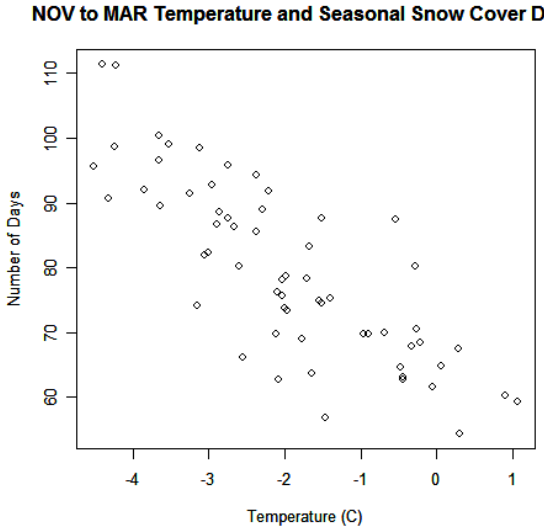


Relationship to Temperature

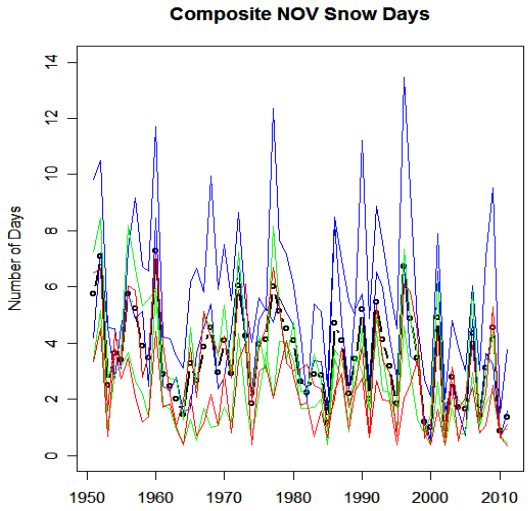


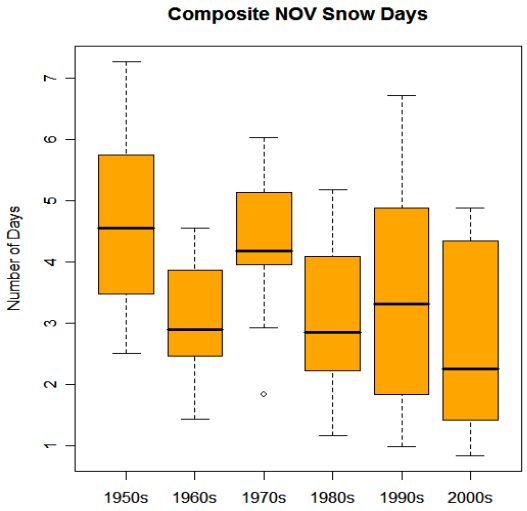


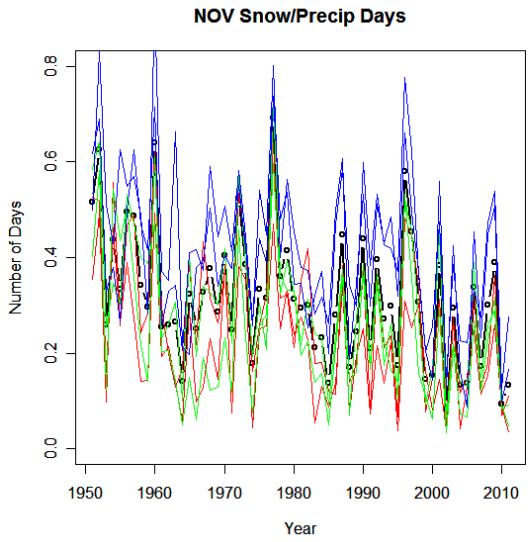


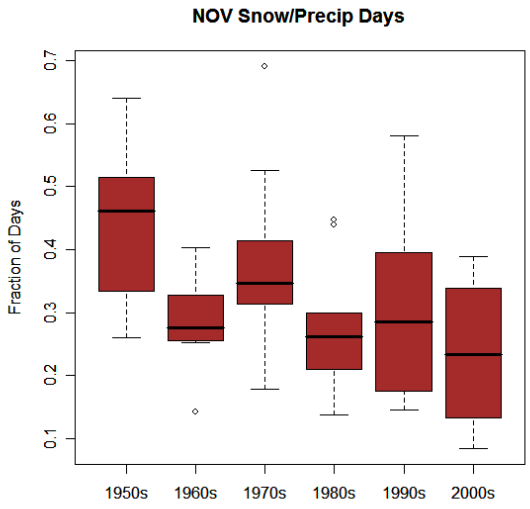


November


Composite NOV Snow Days
Number of Days
0
2
4
6
8
10
12
14
1950
1960
1970
1980
1990
2000
2010


Composite NOV Snow Days
Number of Days
1
2
3
4
5
6
7
1950s
1960s
1970s
1980s
1990s
2000s


NOV Snow/Precip Days
Number of Days
0.0
0.2
0.4
0.6
0.8
1950
1960
1970
1980
1990
2000
2010
Year


NOV Snow/Precip Days
Fraction of Days
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1950s
1960s
1970s
1980s
1990s
2000s

Daily T Thresholds