A Look at the Past 75 Years of Snowpack in the Cascades, Using a Streamflow-Based Proxy for Snowpack

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"April 1 snowpack in the Cascades declined about 50 percent from 1950 to 2000."
- *Oregon Strategy for Greenhouse Gas Reductions*, December 2004

"Snowpack levels in Washington, Oregon and California … are a fraction of what they were in the 1940s, and some snowpacks have vanished entirely."
- *Time Magazine*, March 2006

"The effects of climate change are already being felt in the state of Washington in the form of … snow pack in the Cascades declining by 35%."
- *Governor Gregoire's Executive Order*, Feb 2007

"The average snowpack in the Cascades has declined 50 percent since 1950."
- *Mayor Nickels' letter to Seattle Times*, Feb 2007

Two Purposes:

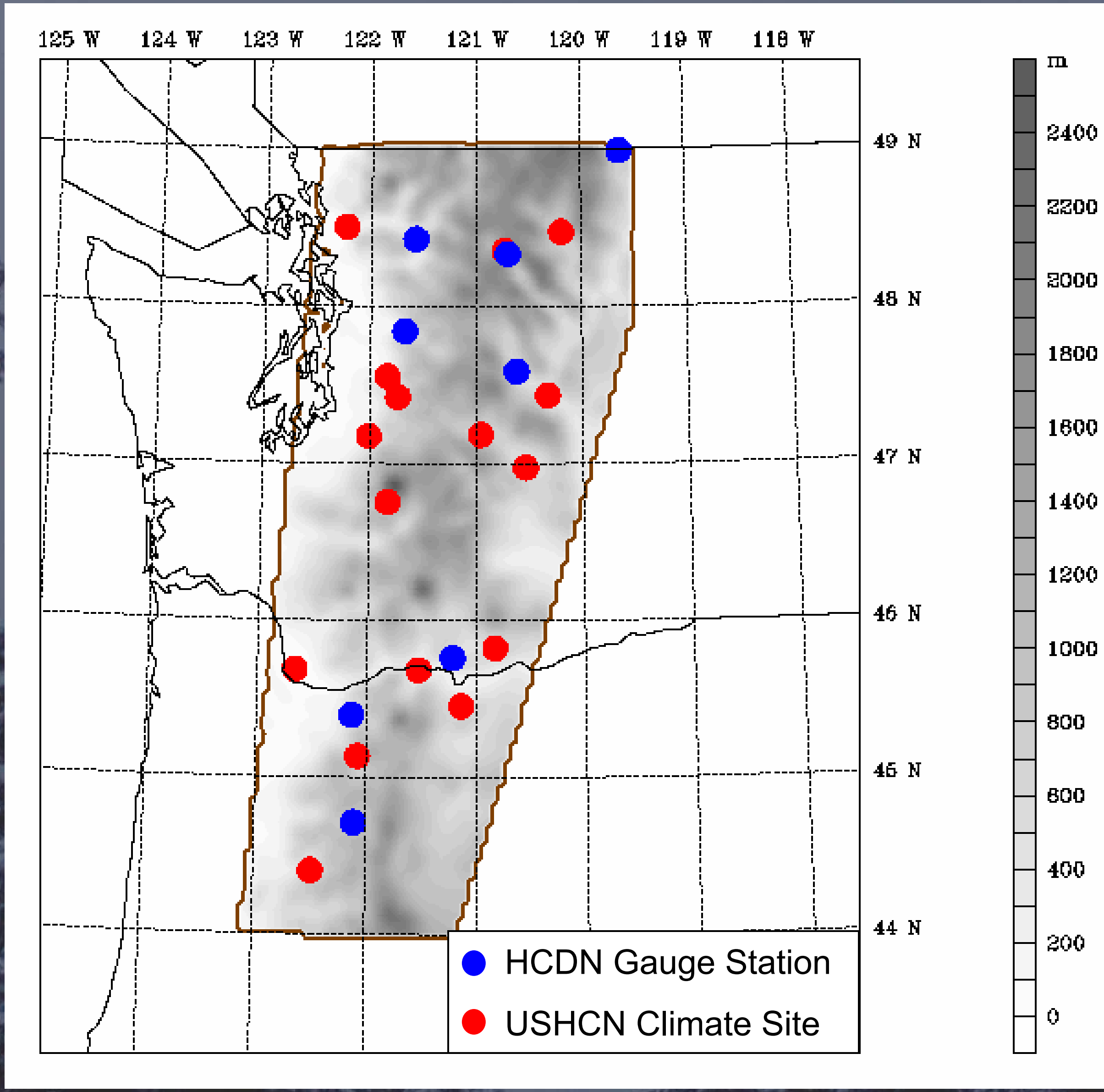
1. Develop and test a streamflow-based proxy for snowpack within mountain watersheds.

2. Revisit the question of what the true trends are in 1-April snowpack in the Cascade Mountains of Washington and Oregon, with emphasis on confidence limits and "detectability"

Why a streamflow-based proxy for snowpack?

- Direct observations of 1 April snow water equivalent (SWE) exist with sufficient density only back to ~1950, whereas several high-quality river gauge records (HCDN) are complete back to 1930 (extending into pre-1947 low-snow PDO/NPI epoch).
- Streamflow is a dominant term in the water balance equation, and it integrates processes over an entire watershed.
- A proxy based on monthly streamflow can produce monthly SWE.
- Also required: good precipitation data back to 1930 → USHCN

Data


125 W
124 W
123 W
122 W
121 W
120 W
119 W
118 W
49 N
48 N
47 N
46 N
45 N
44 N
m
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
HCDN Gauge Station
USHCN Climate Site

Water Balance in Watersheds

$$P = E + R + \Delta M + \Delta S$$

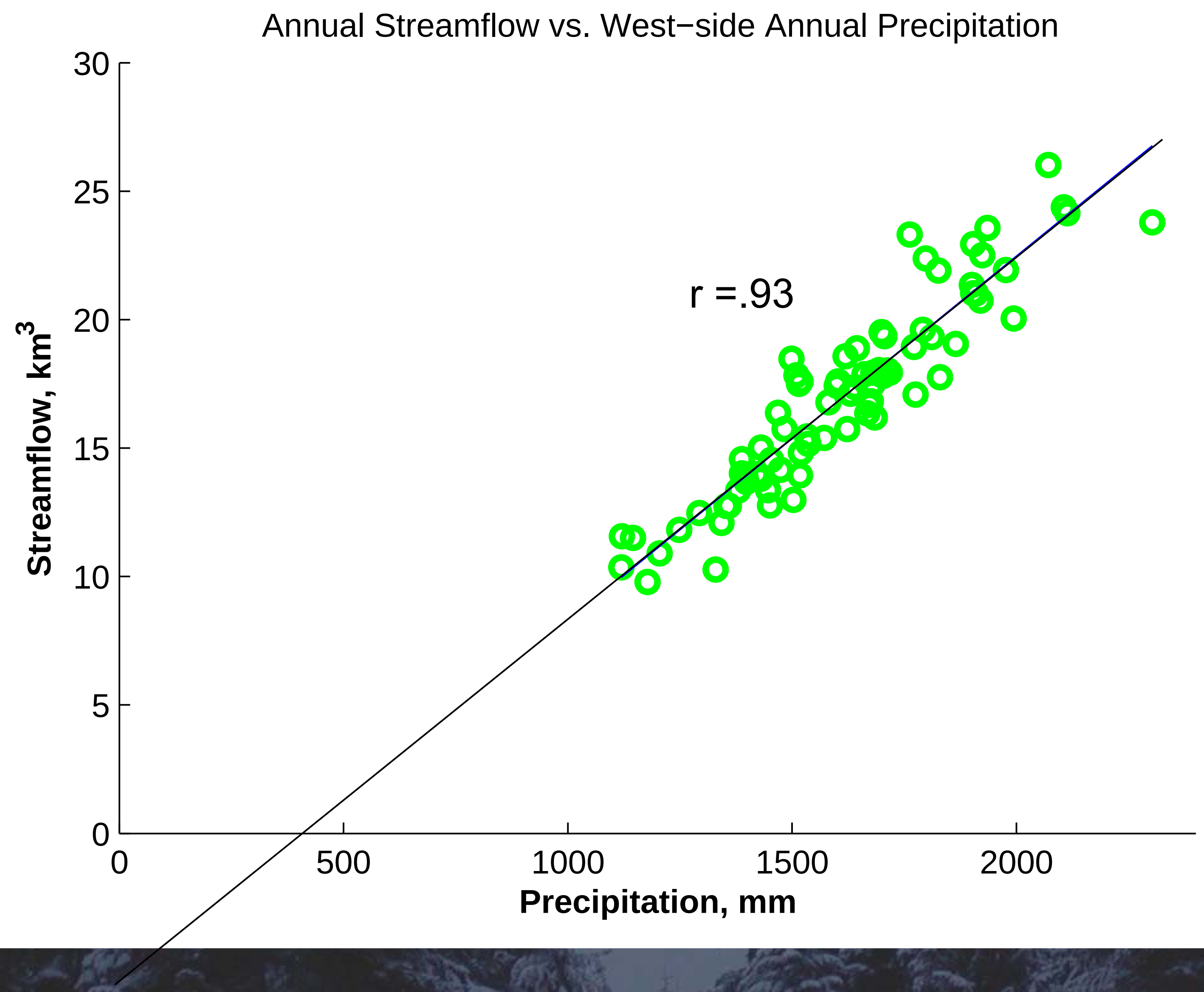
P: Precipitation
E: Evapotranspiration
R: Runoff
ΔM: Change in soil moisture
ΔS: Change in snowpack

Water Balance in Watersheds

$$P = E + R + \cancelto{0}{\Delta M} + \cancelto{0}{\Delta S}$$

Annual balance

P: Precipitation
E: Evapotranspiration
R: Runoff
ΔM: Change in soil moisture
ΔS: Change in snowpack



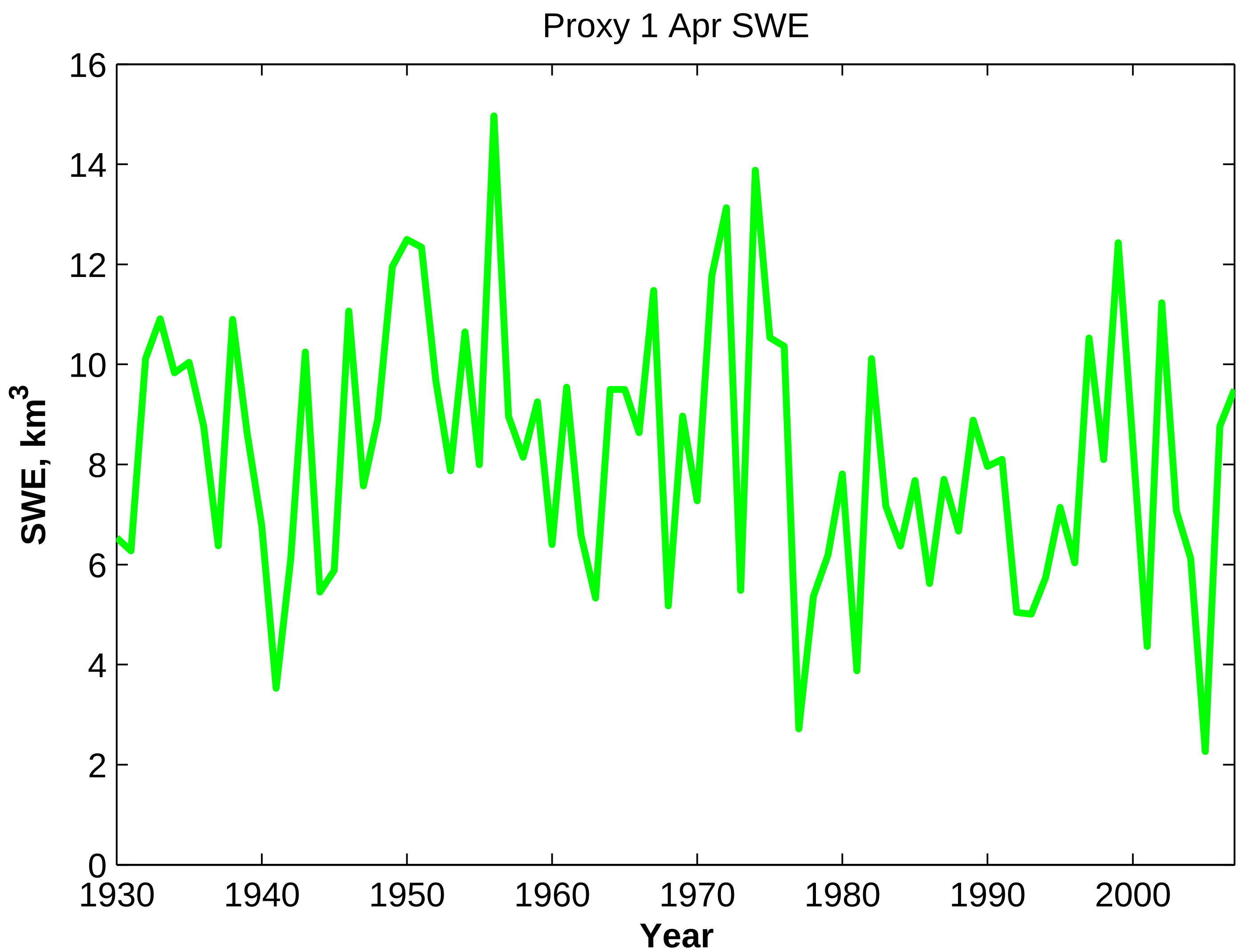
Annual Streamflow vs. West−side Annual Precipitation
r =.93
Streamflow, km^3
Precipitation, mm
0
5
10
15
20
25
30
0
500
1000
1500
2000

Monthly Water Balance in Watersheds

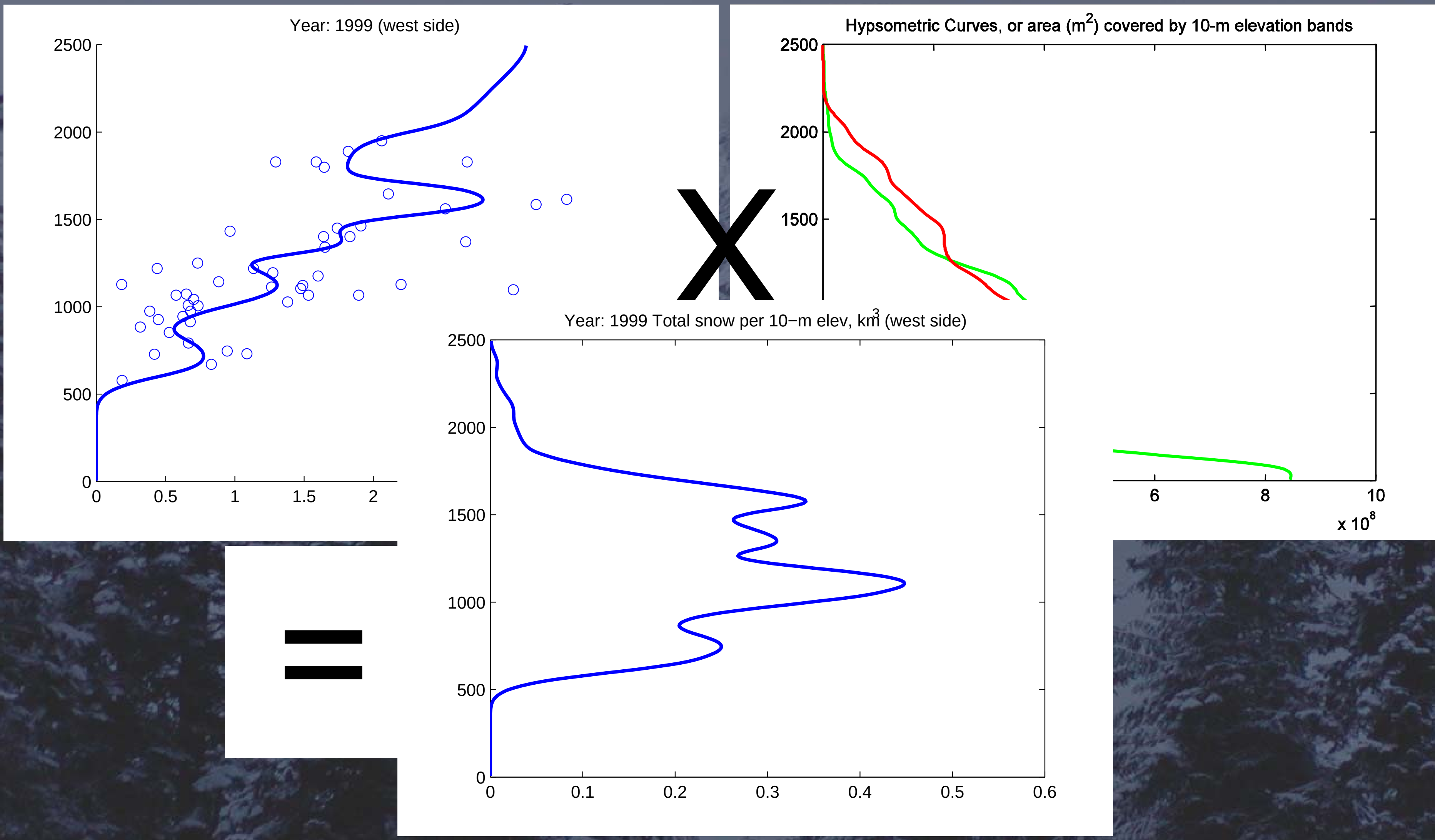
$$P_m = E_m(P) + R_m + \Delta M_m(P) + \Delta S_m$$

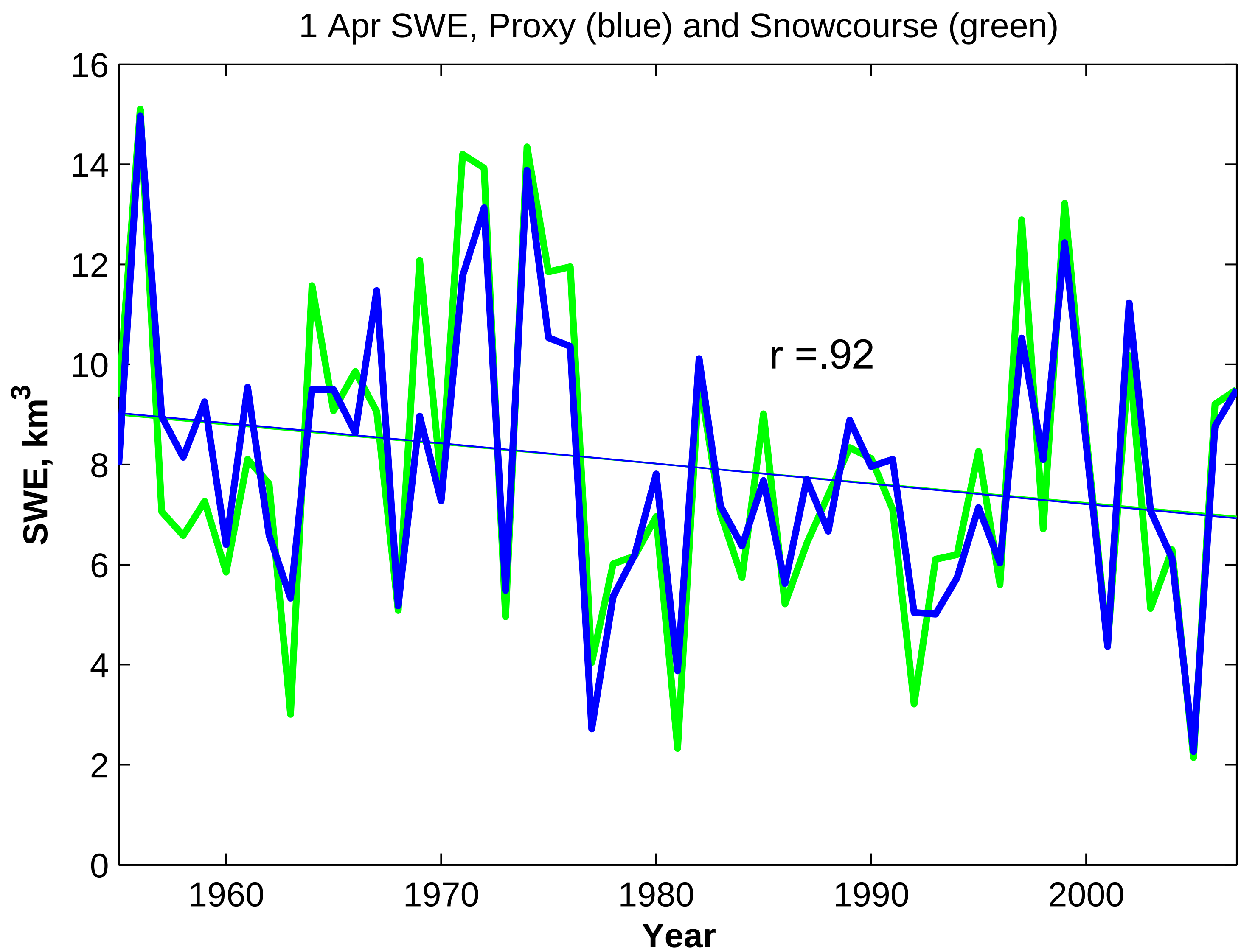
Monthly values not negligible

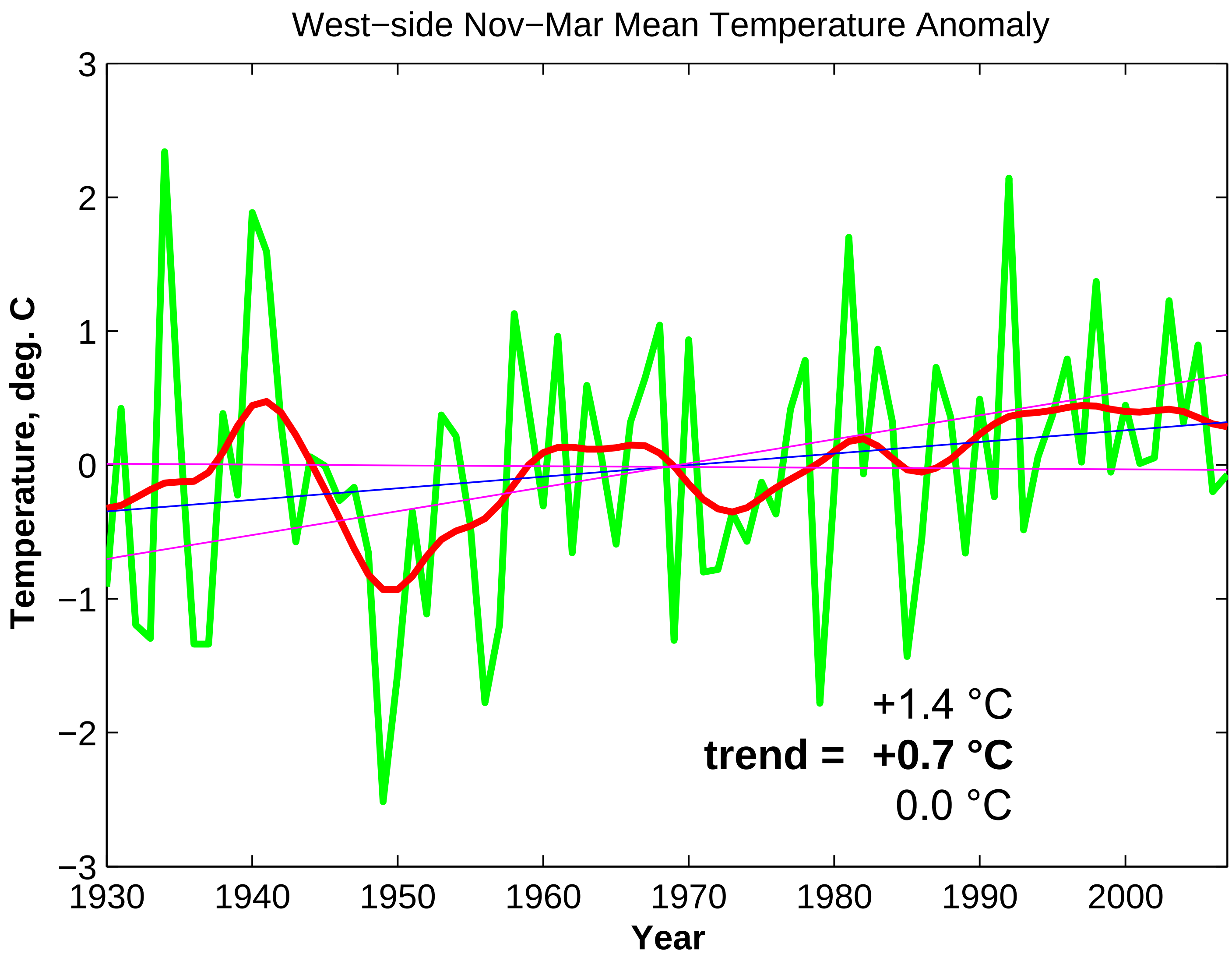
$$\Delta S_m = P_m - E_m - R_m - \Delta M_m$$

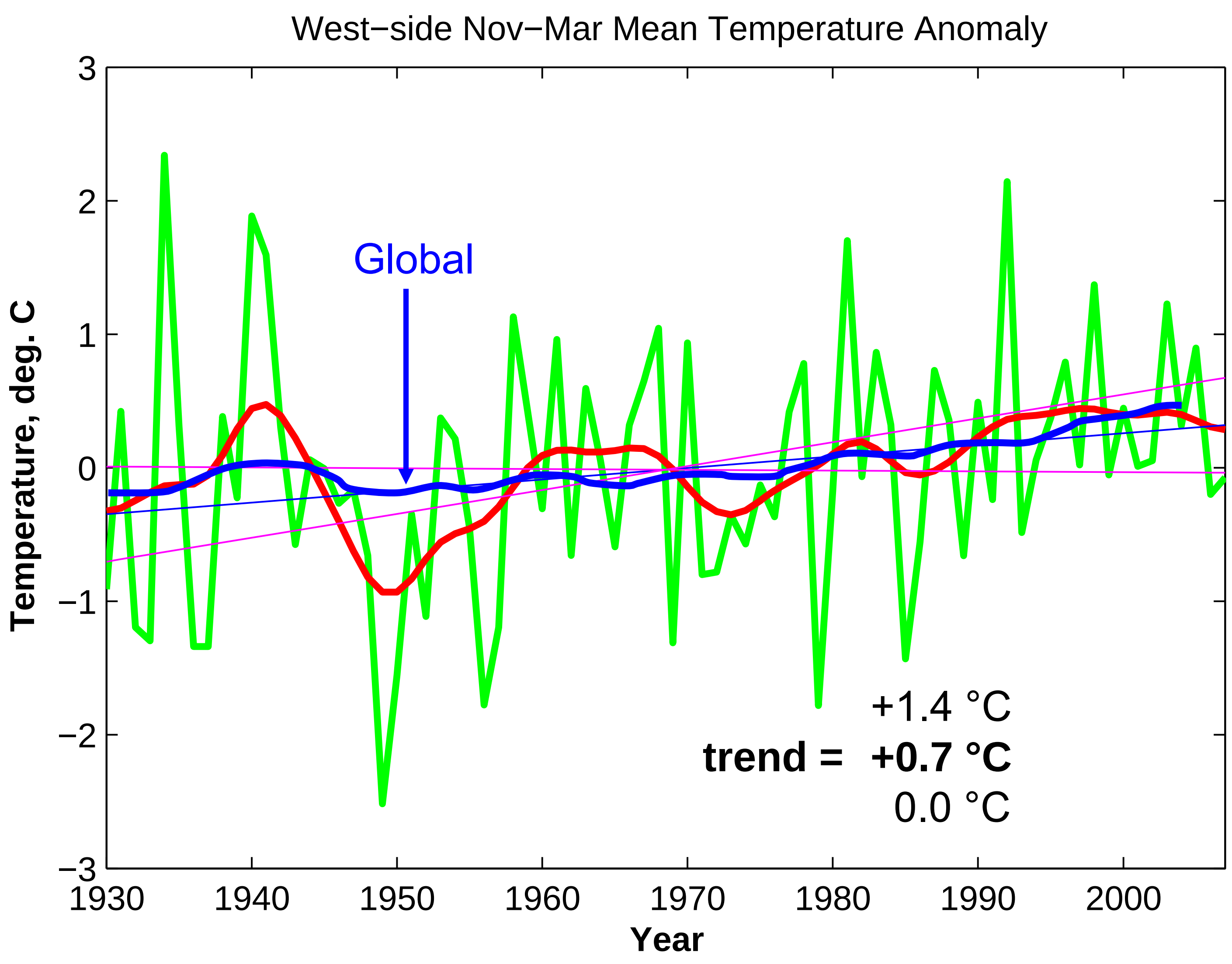

Proxy 1 Apr SWE
16
14
12
10
8
6
4
2
0
SWE, km^3
1930
1940
1950
1960
1970
1980
1990
2000
Year

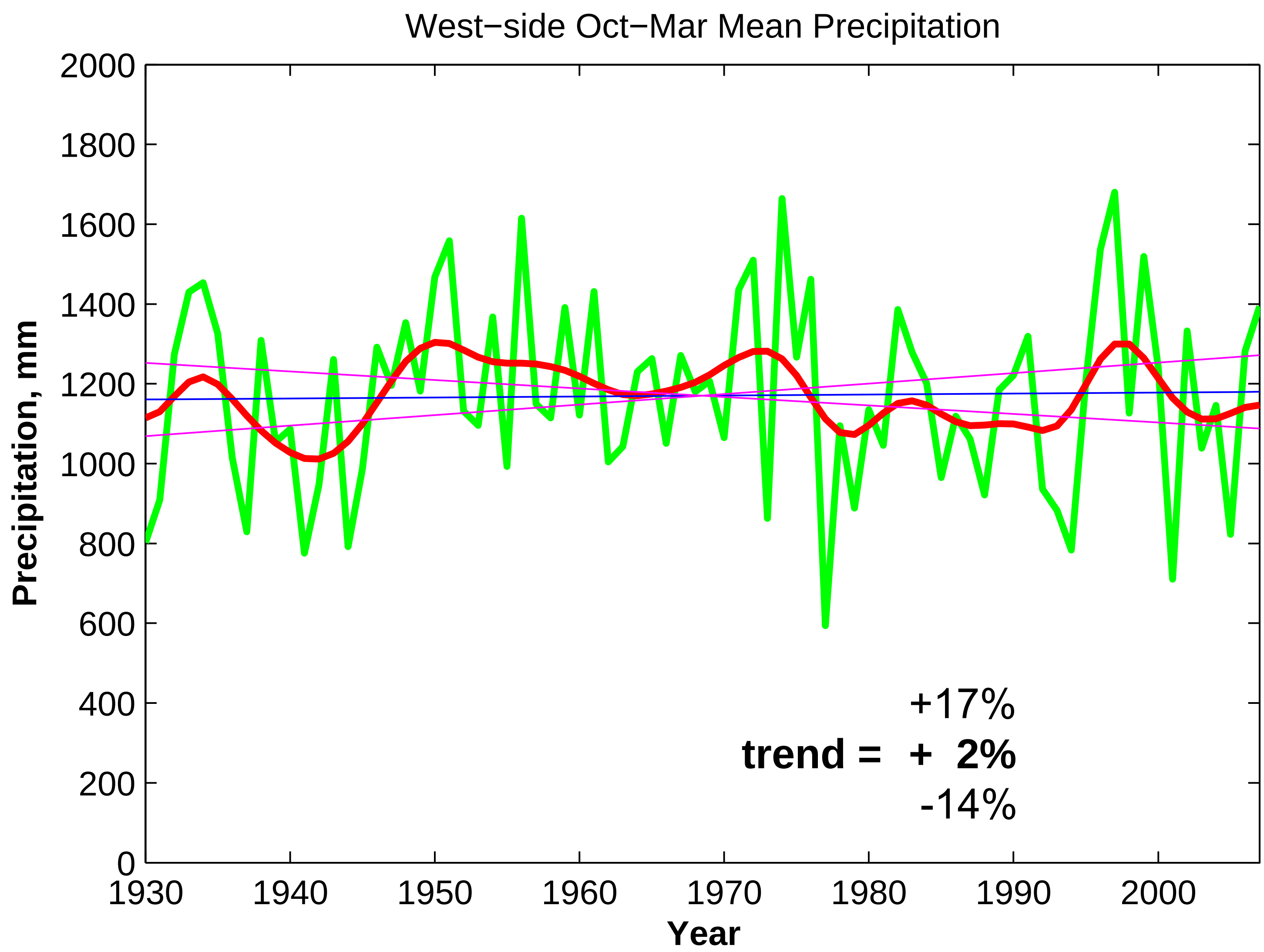
How do we know it works?
Compare with snow course-derived SWE

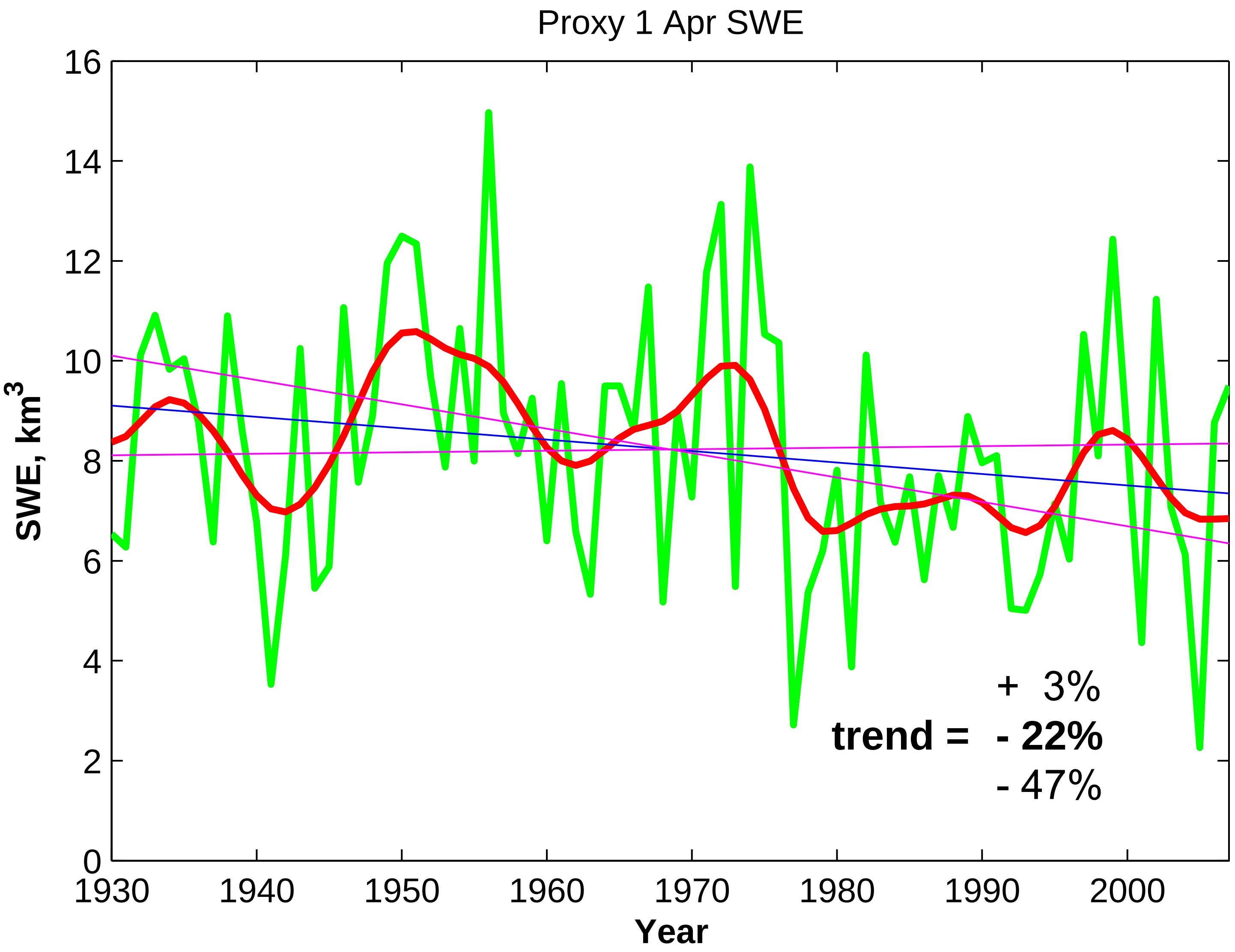



1 Apr SWE, Proxy (blue) and Snowcourse (green)
SWE, km3
Year
r =.92
0
2
4
6
8
10
12
14
16
1960
1970
1980
1990
2000


West−side Nov−Mar Mean Temperature Anomaly
Temperature, deg. C
3
2
1
0
−1
−2
−3
1930
1940
1950
1960
1970
1980
1990
2000
Year
+1.4 °C
trend = +0.7 °C
0.0 °C

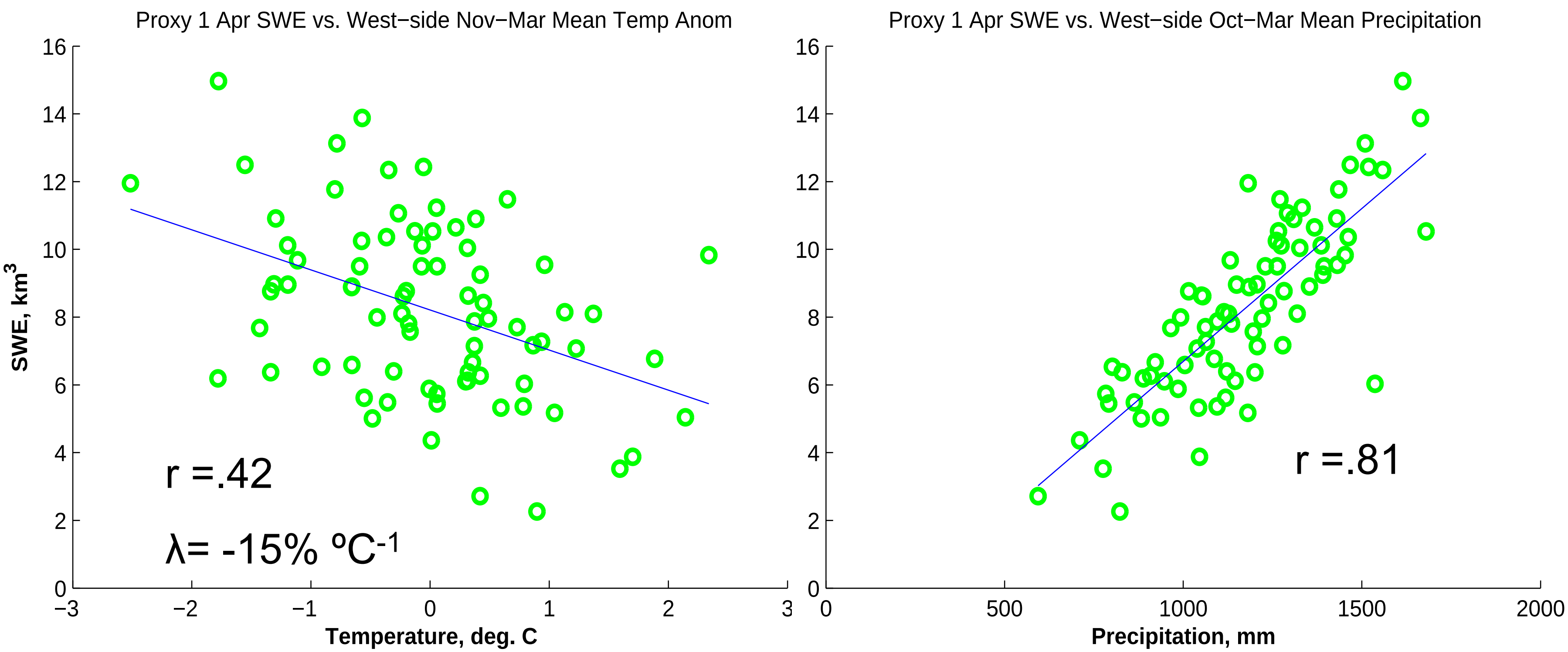

West−side Nov−Mar Mean Temperature Anomaly
Temperature, deg. C
Year
3
2
1
0
−1
−2
−3
1930
1940
1950
1960
1970
1980
1990
2000
Global
+1.4 °C
trend = +0.7 °C
0.0 °C


West−side Oct−Mar Mean Precipitation
Precipitation, mm
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1930
1940
1950
1960
1970
1980
1990
2000
Year
+17%
trend = + 2%
-14%

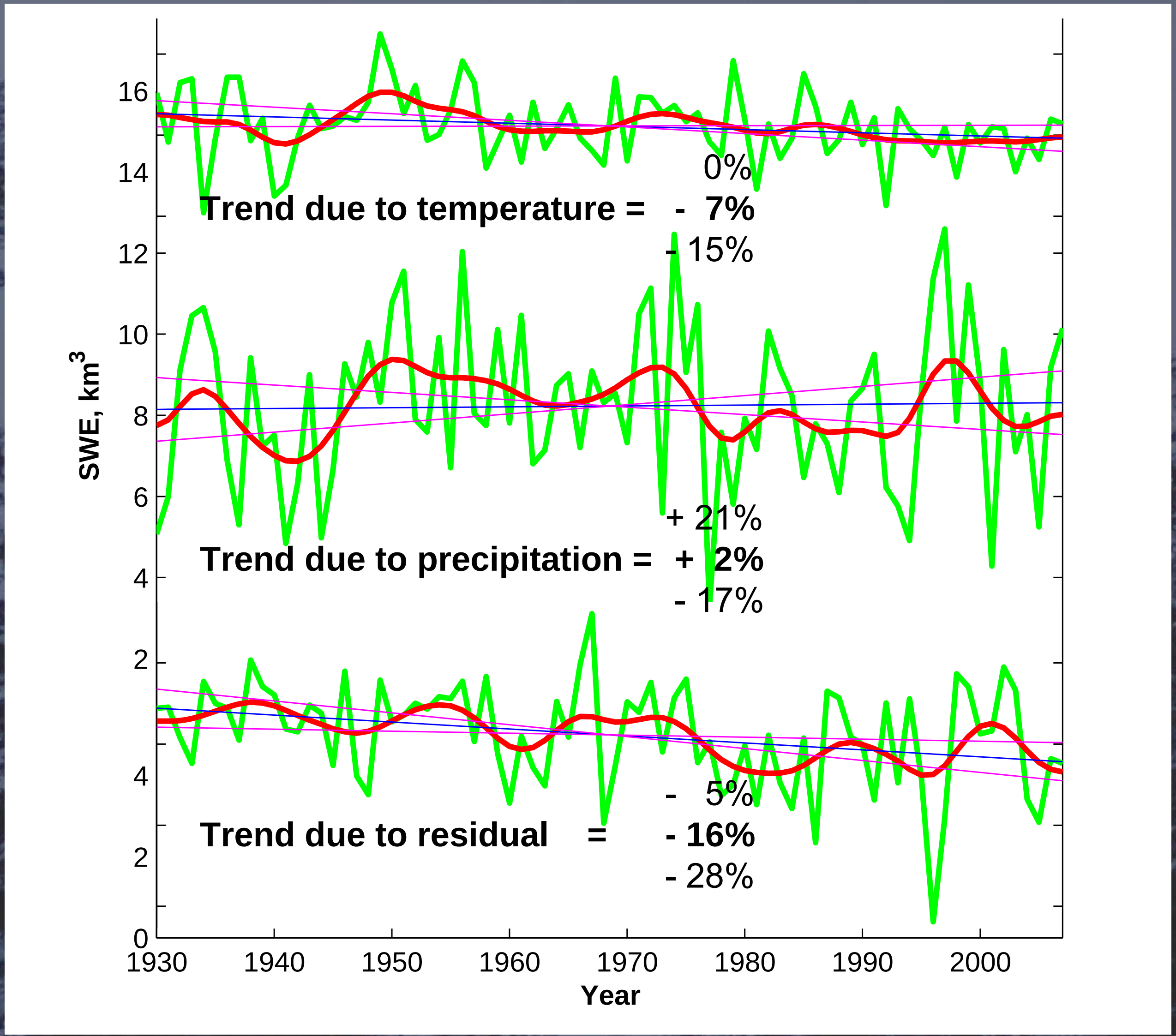


Proxy 1 Apr SWE
SWE, km3
Year
0
2
4
6
8
10
12
14
16
1930
1940
1950
1960
1970
1980
1990
2000
+ 3%
trend = - 22%
- 47%

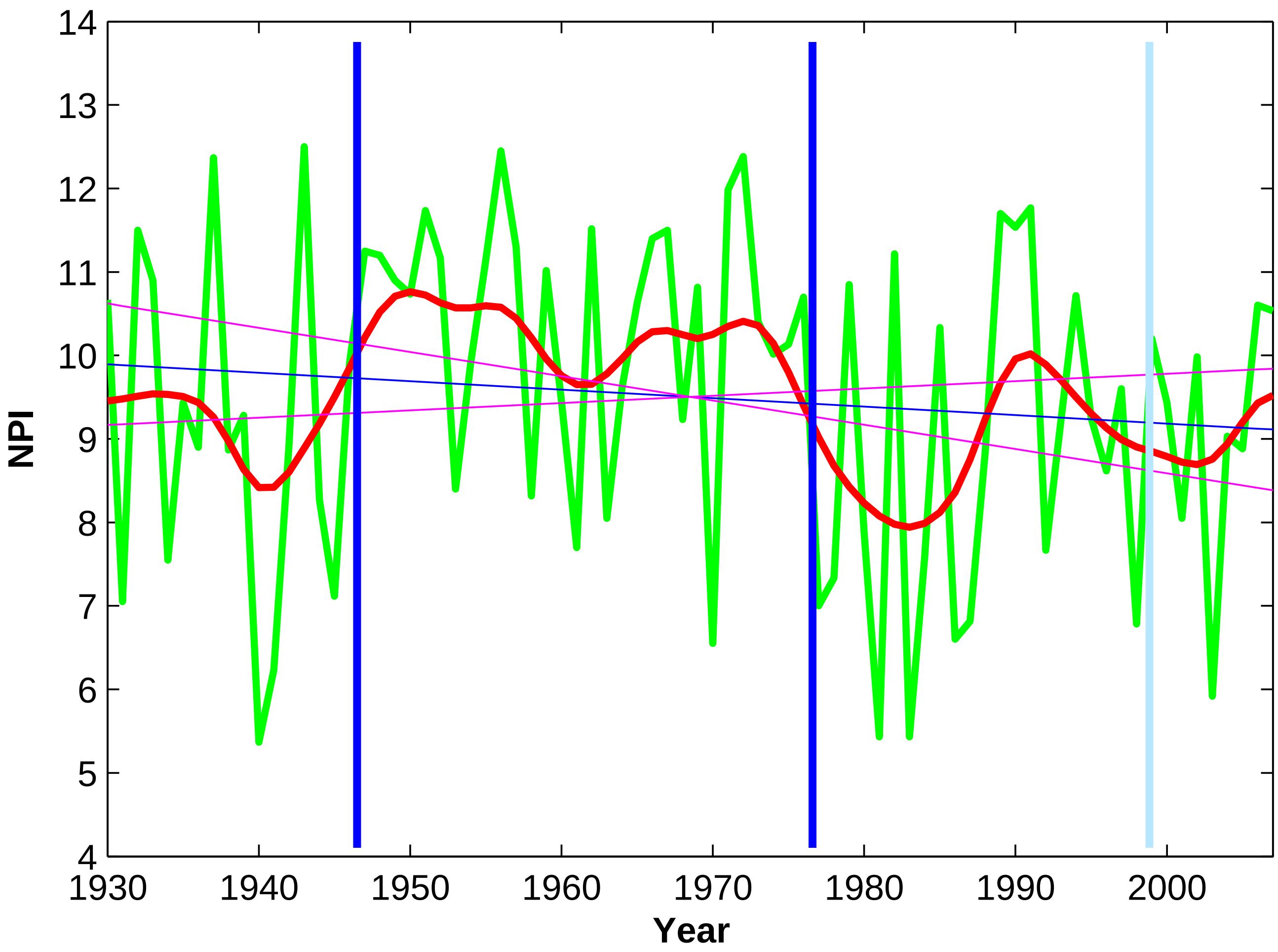
Multiple Linear Regression of SWE vs. Cold Season Temperature and Precipitation



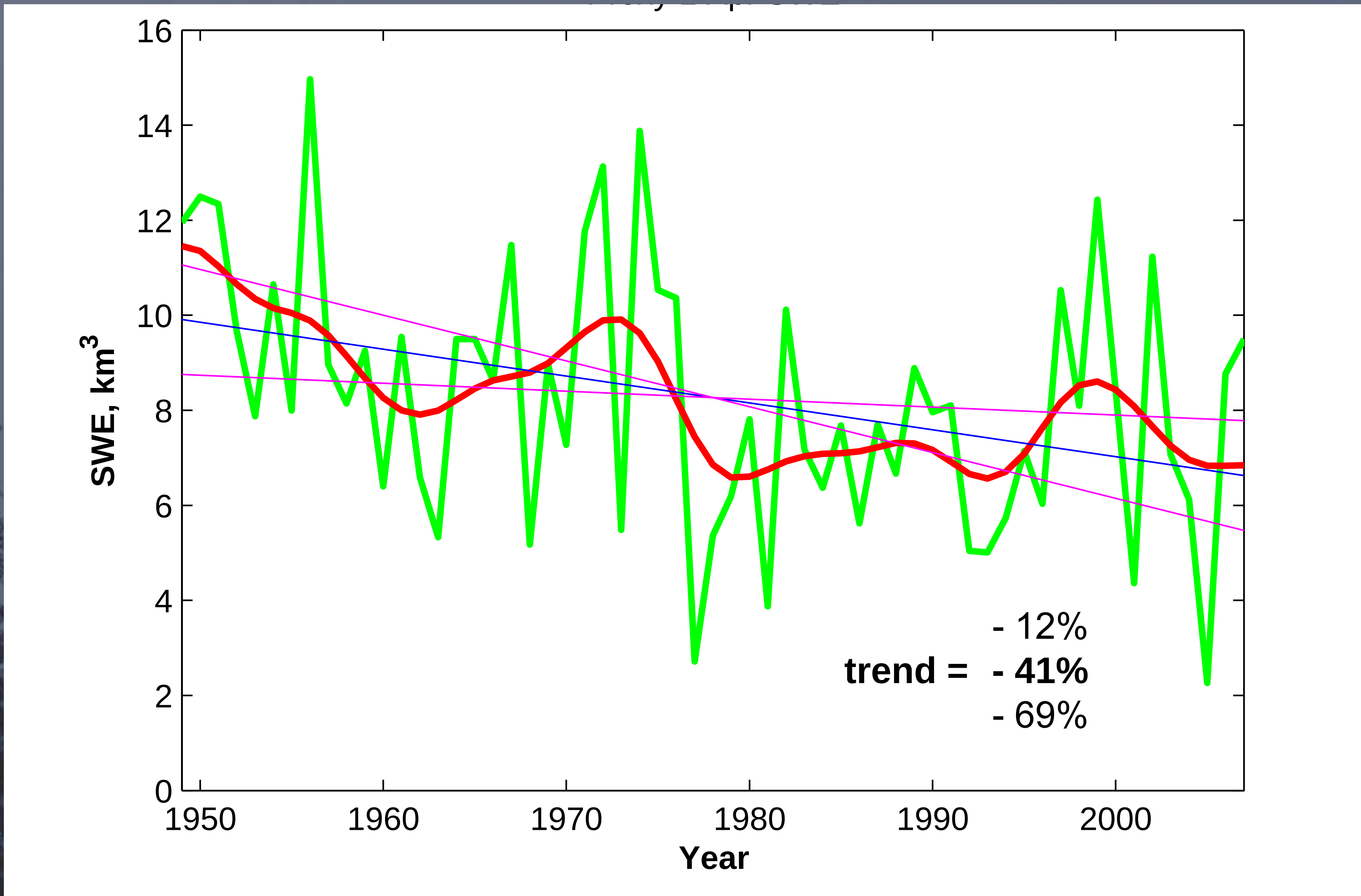
Multiple Linear Regression of SWE vs. Cold Season Temperature and Precipitation



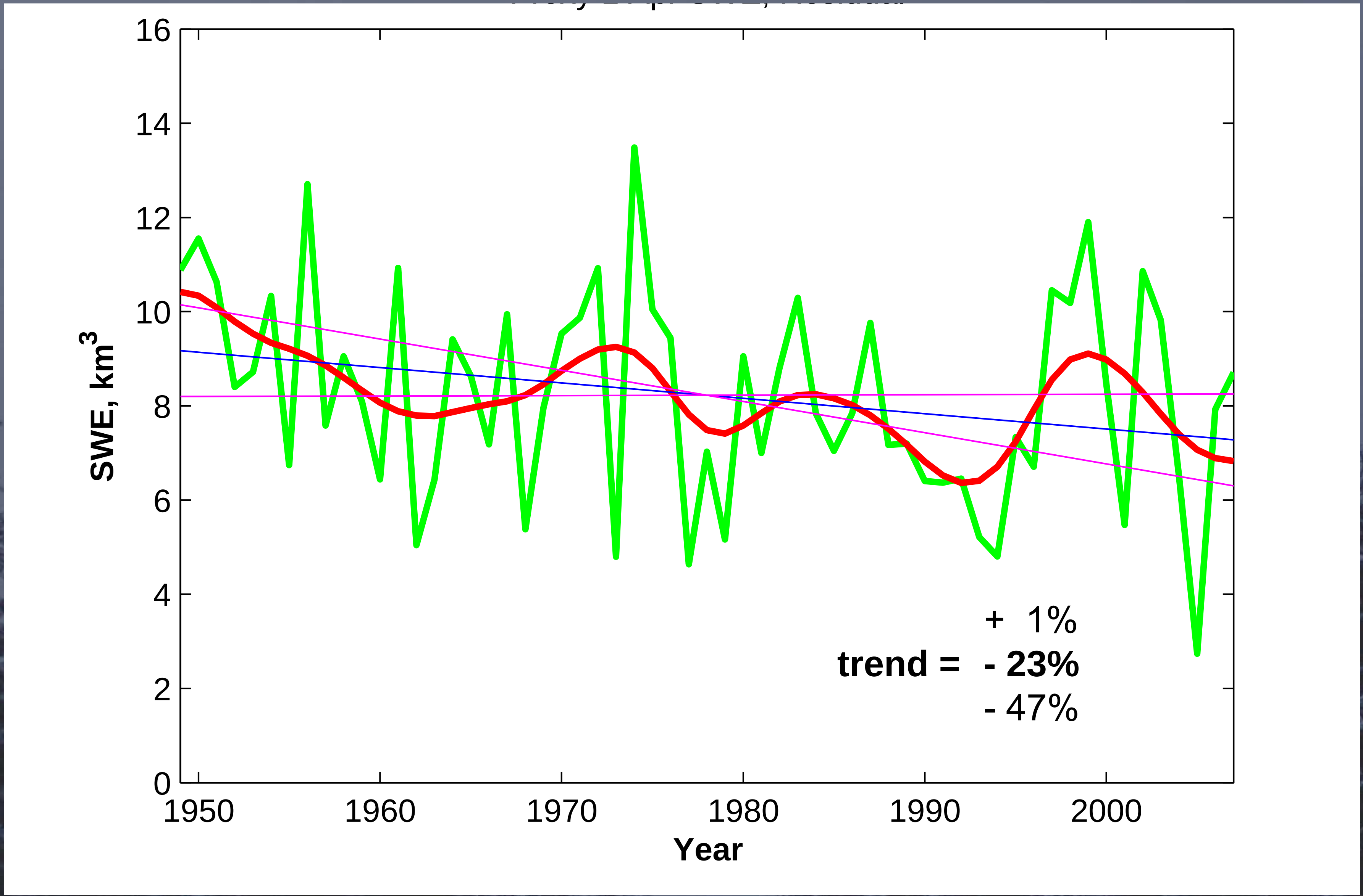
Linear Regression of SWE vs. Oct-Mar Mean North Pacific Index (NPI)



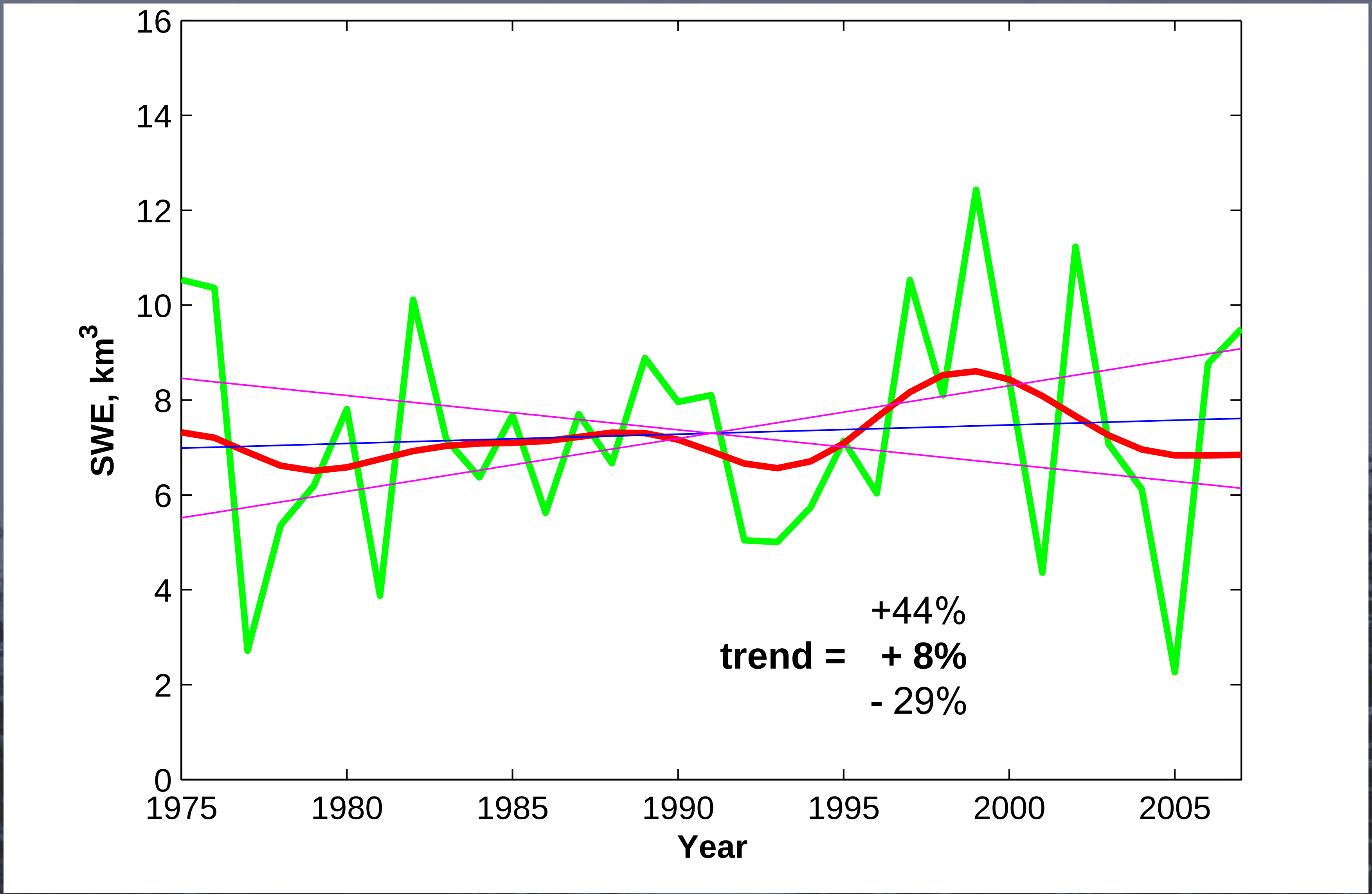
SWE Since 1949



SWE Since 1949, NPI-explained variability removed



SWE Since 1975



Conclusions

- High-quality climatological streamflow and precipitation data can be used to construct a useful proxy for monthly SWE back to 1930.
- Since 1930, the trend in Cascade snowpack is –22%, but is not of large enough magnitude to constitute a confidently detected negative trend.
- Snowpack trend since 1930 due to precipitation alone is close to zero, and snowpack trend due to temperature alone is negative but barely significantly so. The most significant negative trend remains in the unexplained residual.
- For the starting year that produces the most negative trend (to present day), removal of the NPI-correlated part yields a smaller negative trend that is nearly, but not quite, statistically significant.
- Snowpack trend since the ramp-up in global temperature in the 1970s is slightly positive, although the range of possible true trend is huge.