The Impact of Climate Change and Forest Management on the Hydrometeorology of a Canadian Rockies subalpine basin

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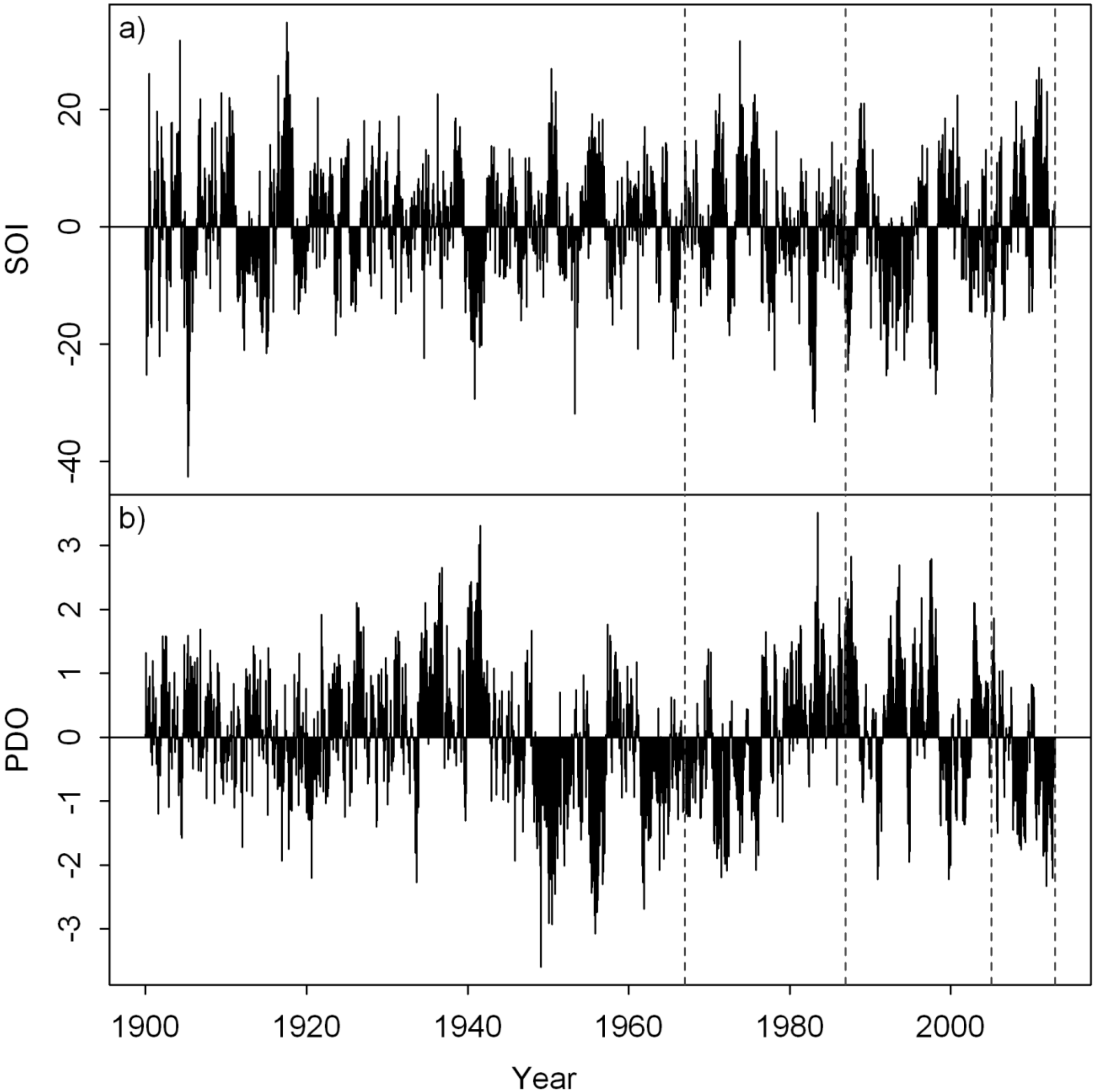
Hydrometeorological Change in the Canadian Rockies

- The hydrometeorology of the Canadian Rockies is changing:
  - Rising air temperature, +0.5°C to +1.5°C (Zhang et al. 2000)
  - Increasing rain/snow ratio (Zhang et al. 2000)
  - Declining streamflow, ~20% over last 100 yrs (Rood et al 2005)
- Hydrometoerological changes are predicted to have significant impacts on hydrology
  - Cold region hydrological processes are very temperature-sensitive
- Changes in regional climate attributed to
  - Anthropogenic climate change
  - Teleconnections (PDO and ENSO)

ENSO and PDO Teleconnections



El Niño-Southern Oscillation

- Perturbation of air pressure and ocean temperature over the South Pacific
- Quantified by the Southern Oscillation Index (SOI)
- Positive values associated with cooler and wetter conditions and vice versa
- ~5 year cycle

Pacific Decadal Oscillation

- Variable pattern of Northern Pacific surface water temperature
- Warm phase linked to declining snowpack and streamflow and increased air temperature
- Cool phase leads to more streamflow
- Decadal scale cycle

Hydrologic Implications of Forestry

- Forestry affects Canadian Rockies hydrology primarily through how changes in canopy affect snow processes

- Canopy removal leads to less snow interception
  - 10%-45% of snowfall is intercepted and sublimated in Canadian forests (Pomeroy and Gray, 1995)

- Reduced sublimation translates directly into increased snow accumulation
  - Increased volume of snowmelt (Pomeroy and Gray, 1995)
  - Higher water tables (Adams et al. 1991)
  - Increased runoff at or near the surface (Hetherington, 1987)
  - Increased streamflow (Winkler et al. 2010)

Research Gap/Opportunity

- Studies to date have not described how temperature, precipitation, snow, groundwater, and streamflow trends vary with one another, elevation and land cover change.

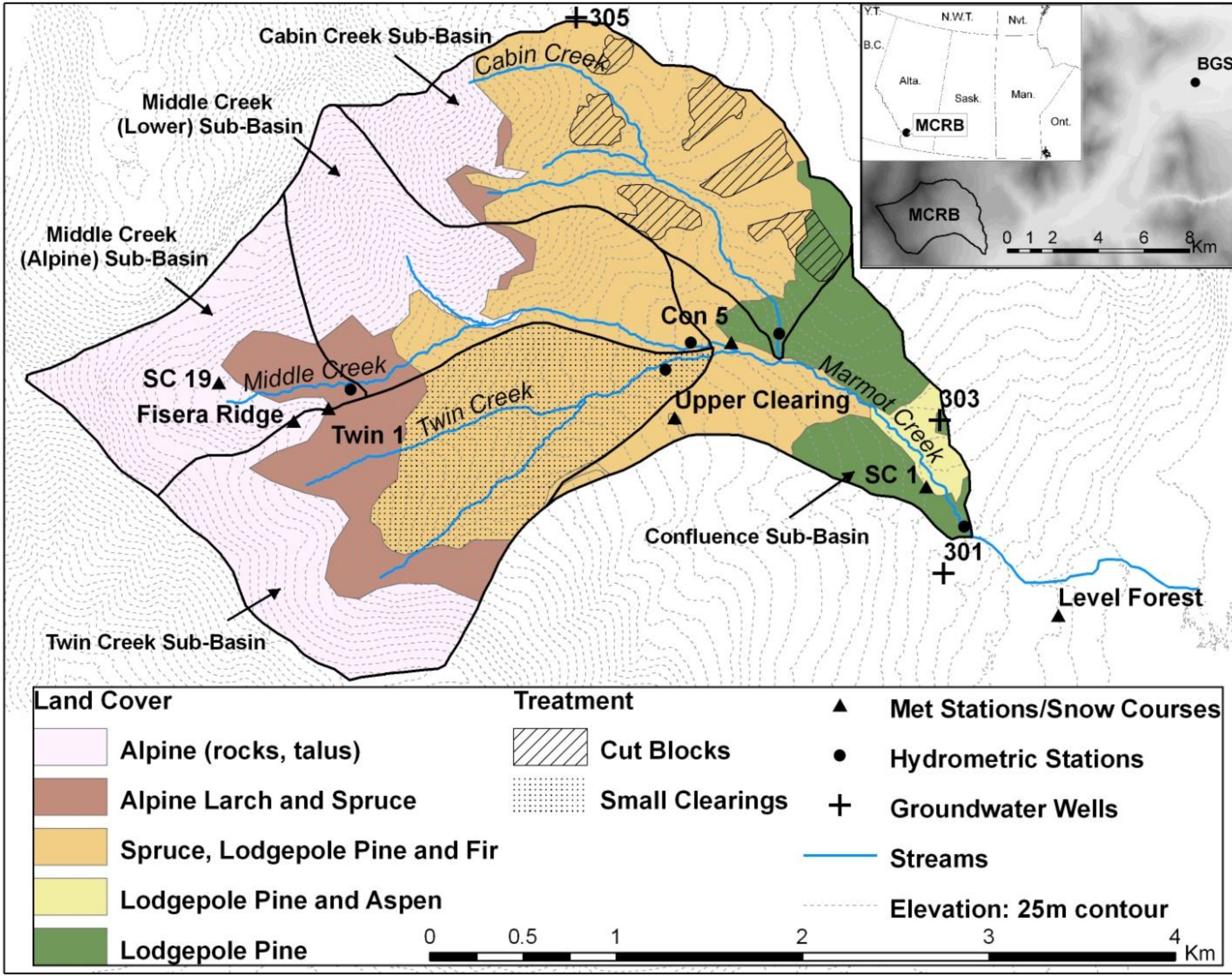
- Marmot Creek Research Basin (MCRB) provides a comprehensive dataset of hydrometeorological observations.
  - Observations spanning 50 years
  - Observations can be separated by elevation
  - Basin has experienced significant forest cover removal

Objectives

- The overall objective is to examine the hydrometeorological records of MCRB for climate and land cover related changes

- Specifically:
  - to quantify hydrometeorological changes with respect to time and elevation
  - to examine the role that the Marmot Basin Project forest harvesting in 1970s has had on observed hydrometeorological trends

Marmot Creek Research Basin



Hydrometeorological Change Methodology

- Variables considered:
  - Air Temperature (Min, Mean and Max)
  - Precipitation
    - Temperature and precipitation were considered annually and seasonally
  - Annual Peak Snow Water Equivalent
  - Streamflow (seasonal average, peak and timing)
  - Groundwater (Min, Mean, Max, Max-Min, SD and timing)

- Large data gap (1987-2004) in most observations was problematic
  - not gap filled to ensure statistical rigor
  - BGSI climate data provided temporal context

Hydrometeorological Change Methodology

- Meteorological stations paired between observation periods based on location and elevation
  - Confluence 5 and Upper Clearing
  - Twin 1 and Fisera Ridge
- Slight elevation differences were addressed through calculation of lapse rates on the current 15 minute data
  - corrected current stations to historic station elevations

- Snow courses paired between observation periods based on location, elevation and landcover
  - SC#1 and Lower Forest: confluence area lodgepole pine
  - SC#19 and Fisera Ridgetop: exposed terrain above treeline

Hydrometeorological Change Methodology

- Mann-Kendall test used to identify and assess significance of monotonic trends
  - Power of test directly related to observation length and inversely with data gaps
  - Not used across whole period when methodologies from different periods were deemed to be inconsistent

- Statistical significance of differences in median and distribution between observation periods was assessed with the non-parametric Mann-Whitney U (MW) and Kolmogorov-Smirnov (KS) tests

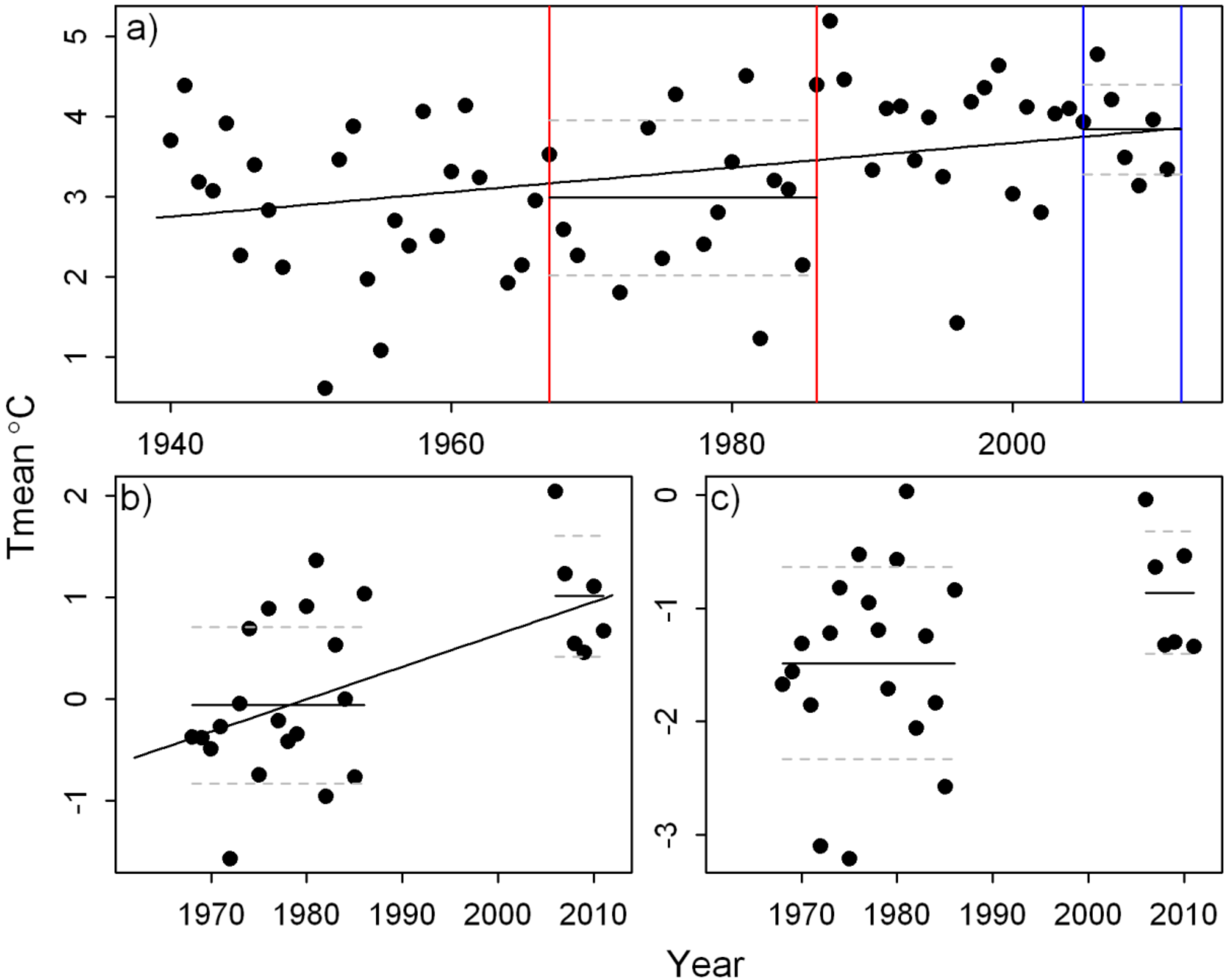
- Relationships between variables and teleconnections were explored through generalized least squares analysis

Forestry Impact Methodology

- Forestry impact was assessed through:
  - Calculation of experimental/control basin runoff ratio
  - Statistical comparison of pre and post harvesting ratio values
    - MW and KS Test

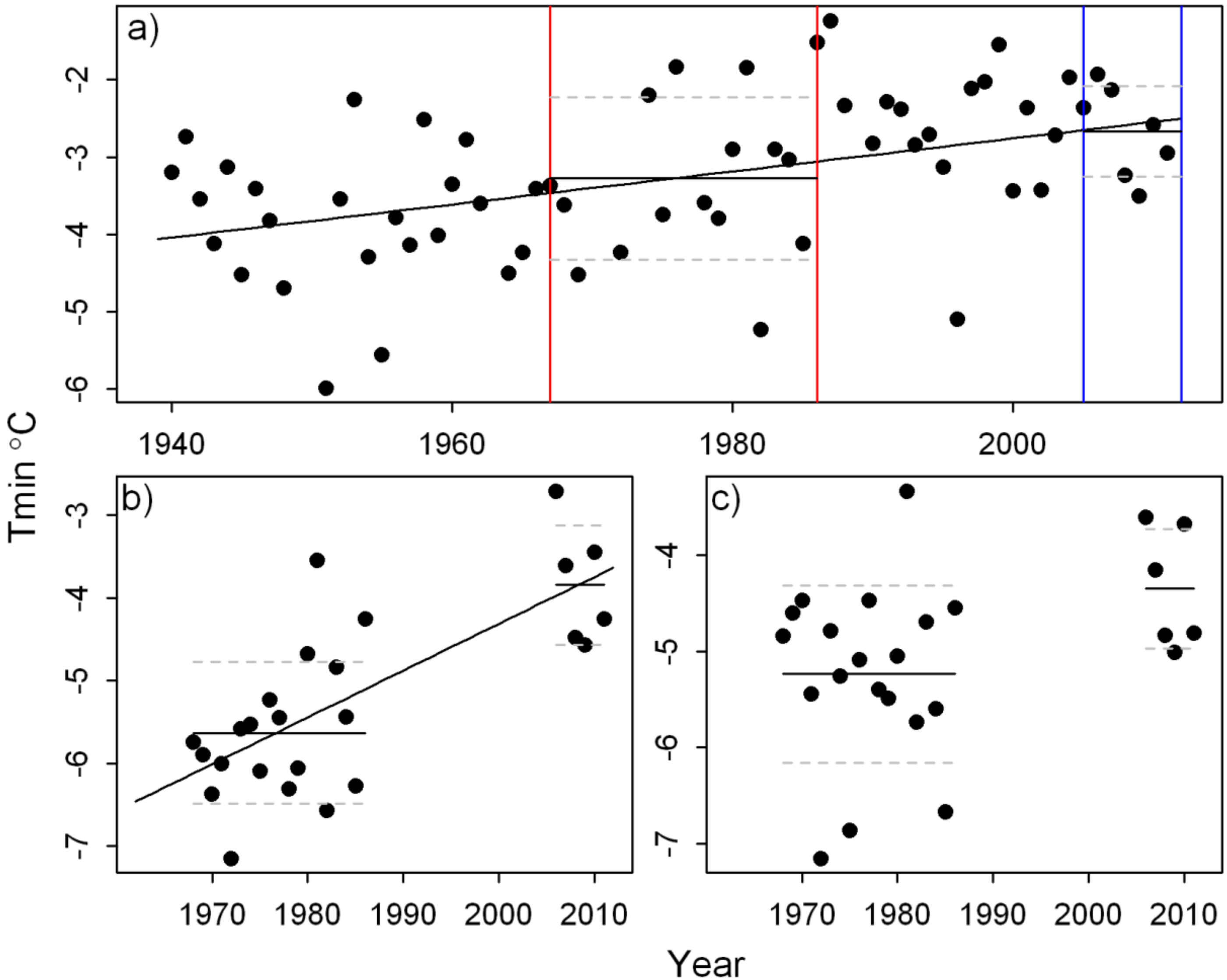
Results

Annual Mean Air Temperature



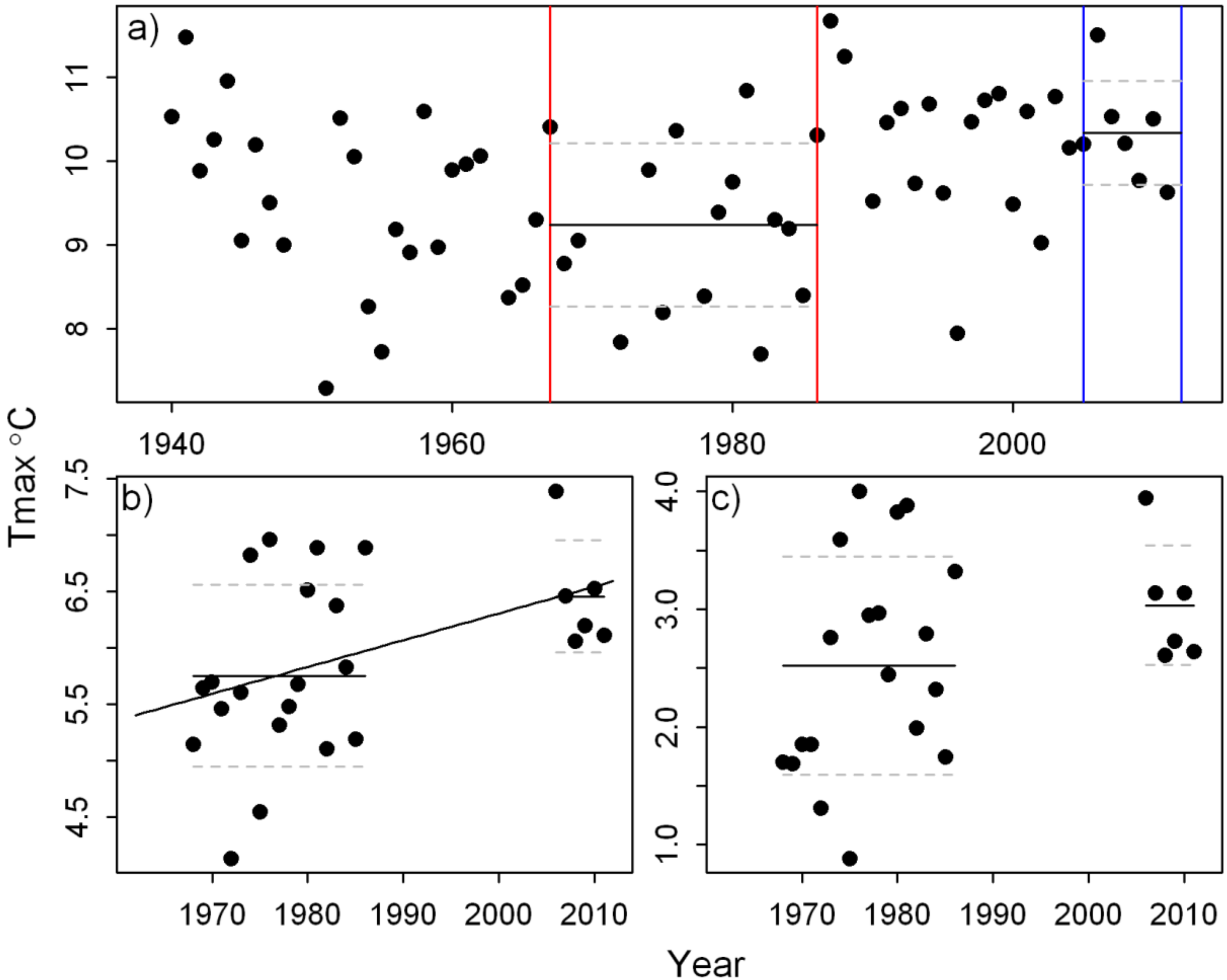
Annual mean air temperature for BGSI (a) from 1939-2011 and CN5 UC (b) and TN1 FR (c) from 1967-2012

Annual Minimum Air Temperature



Annual minimum air temperature for BGSI (a) from 1939-2011 and CN5 UC (b) and TN1 FR (c) from 1967-2012

Annual Maximum Air Temperature

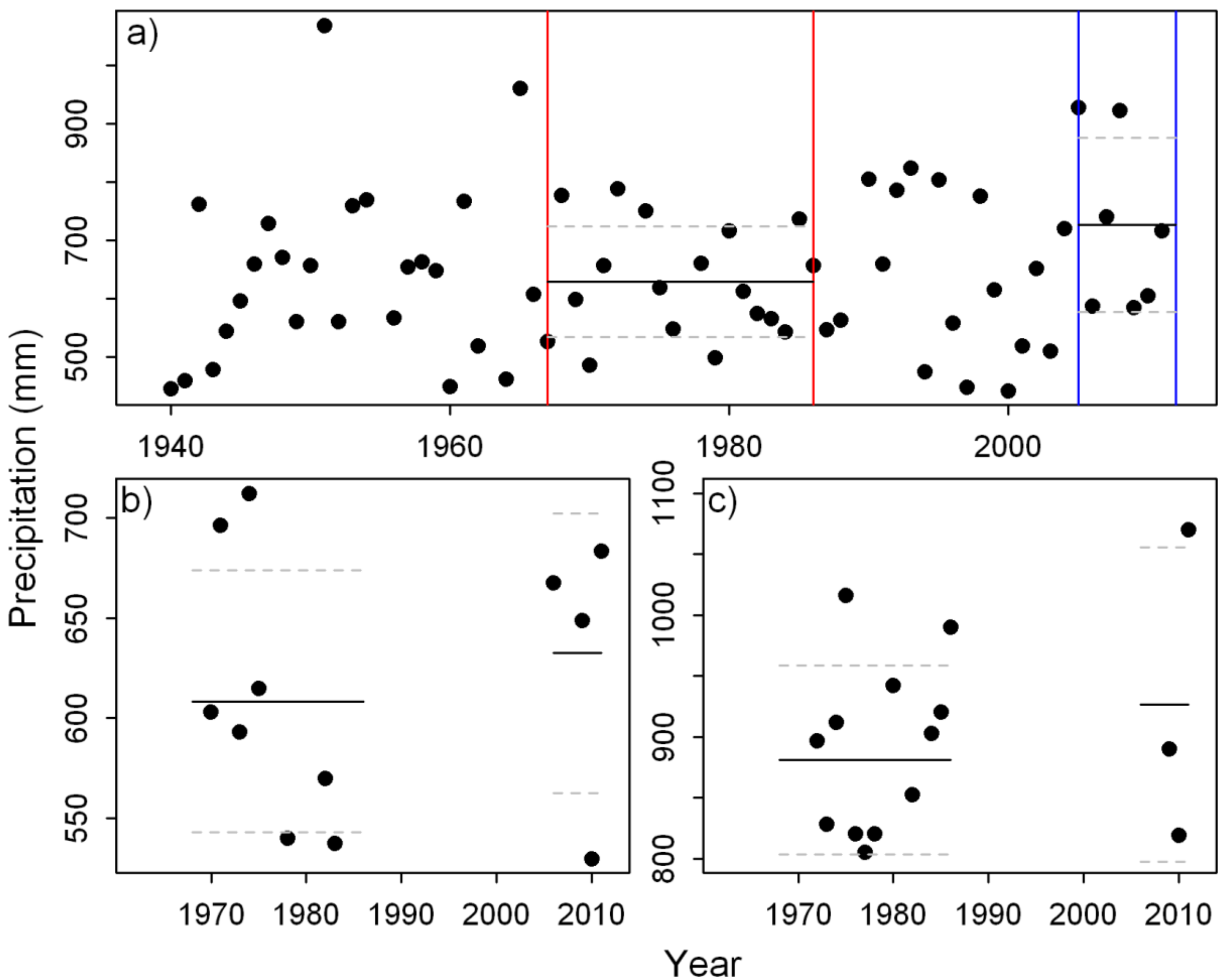


Annual maximum air temperature for BGSI (a) from 1939-2011 and CN5 UC (b) and TN1 FR (c) from 1967-2012

Temperature Trend Summary

- Tmin increasing more than Tmean and Tmax
  - Annual CN5_UC over 1967-2012
  - Tmin 2.6°C > Tmean 1.4°C > Tmax 1.1°C
- More increasing trends in Tmin than Tmean and Tmax
  - Percentage of time series showing trends
  - Tmin 60% > Tmean 33% > Tmax 20%
- Greatest increases in winter
  - CN5_UC Tmin over 1967-2012
  - DJF 5°C > MAM 2.4°C > JJA 2.2°C > SON 1.9°C
- Greatest increases at lower elevation
  - Annual Tmin median difference between periods
  - CN5_UC 1.8°C > TN1_FR 0.6°C

Annual Precipitation



Seasonally:

BGSI

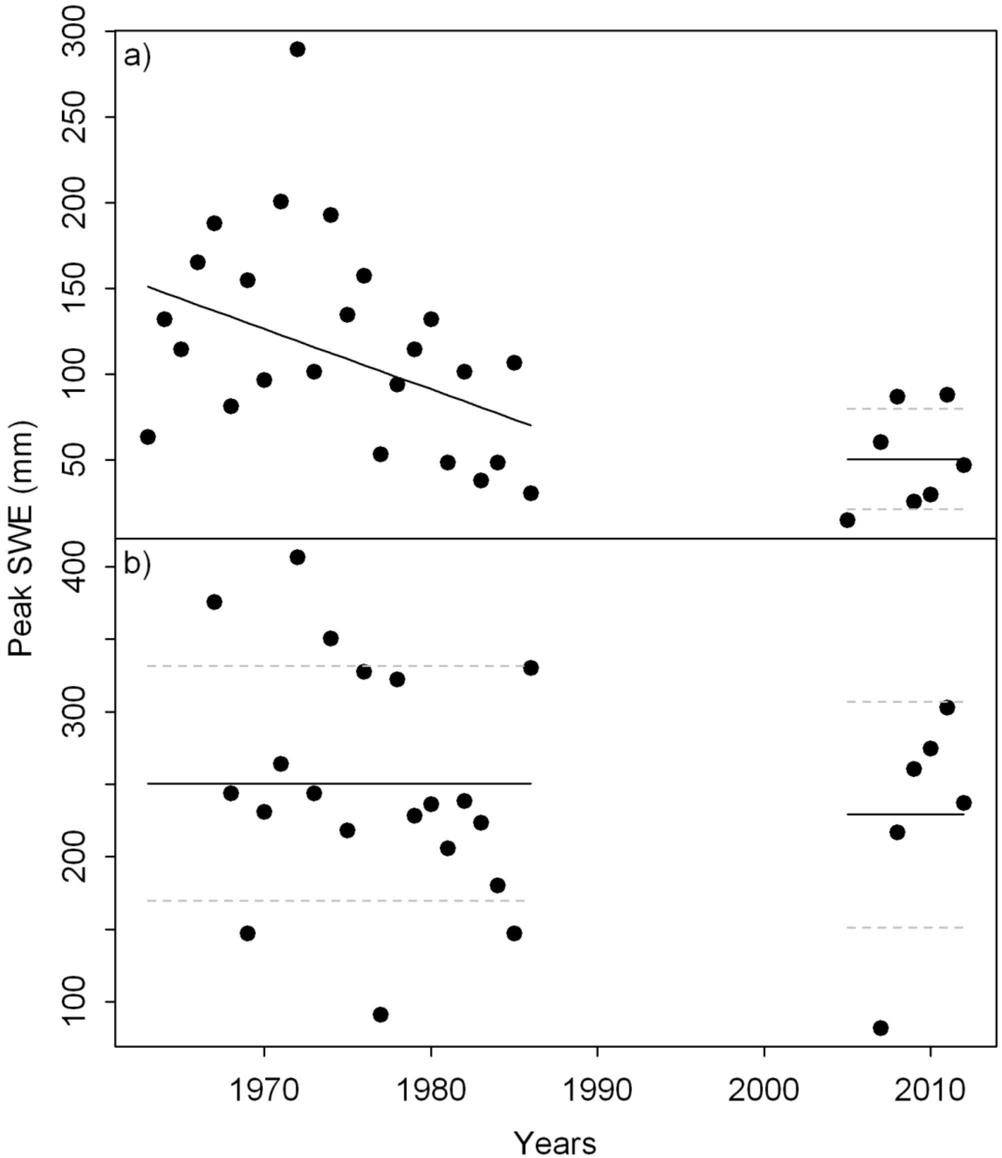
- MAM increase in snow
- DJF increase in precipitation

FR_TN1

- MAM increase in precipitation

Annual precipitation (mm) for BGSI (a) from 1939-2011 and CN5_UC (b) and TN1_FR (c) from 1967-2012

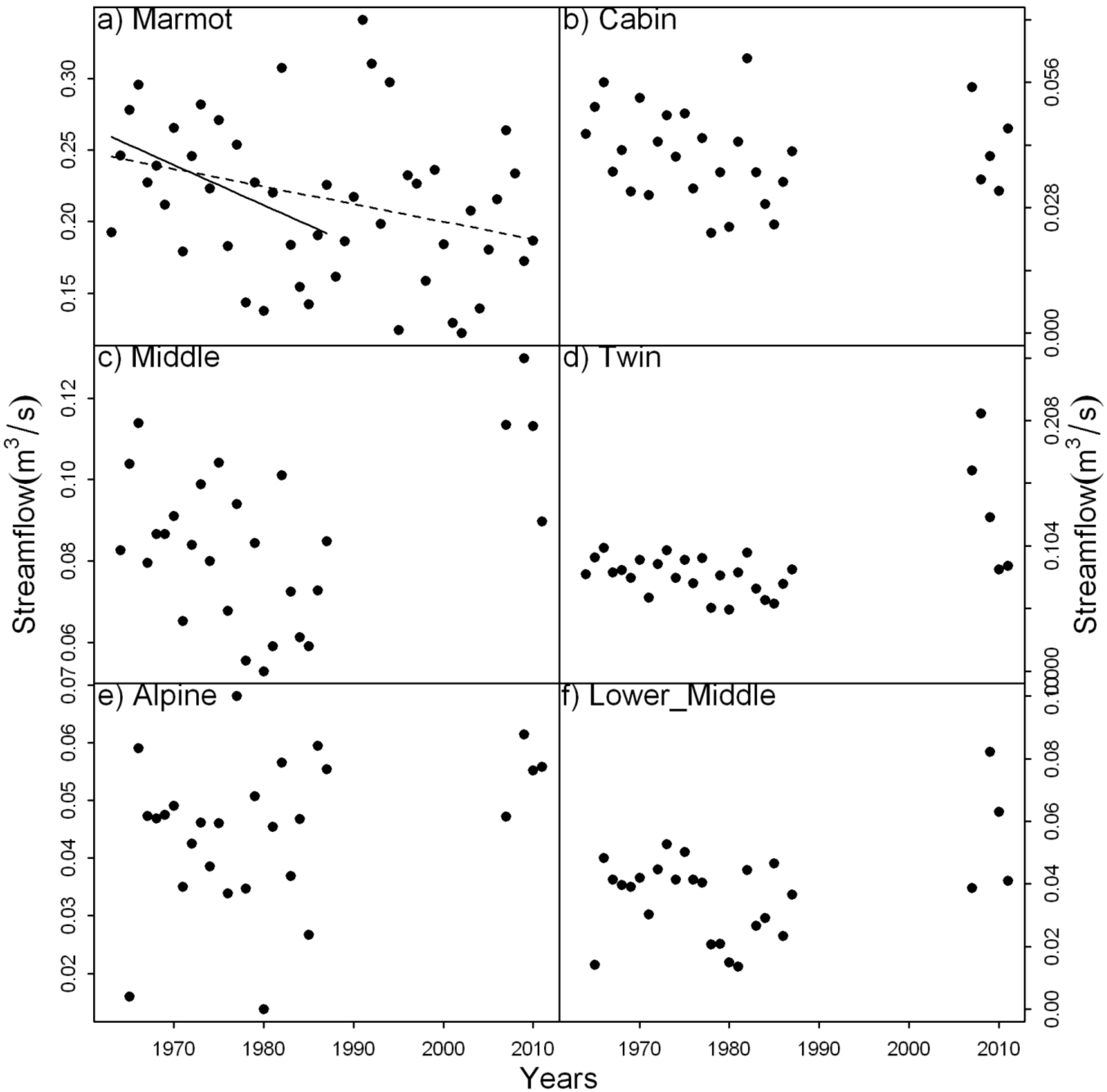
Peak Snow Water Equivalent



Peak snow water equivalent (mm) for lower forest (a) and alpine (b)snow courses

- No change in alpine snow course
- 54% decline in lower forest over 1963-1986
- Consistent with observation of greater warming at lower elevations

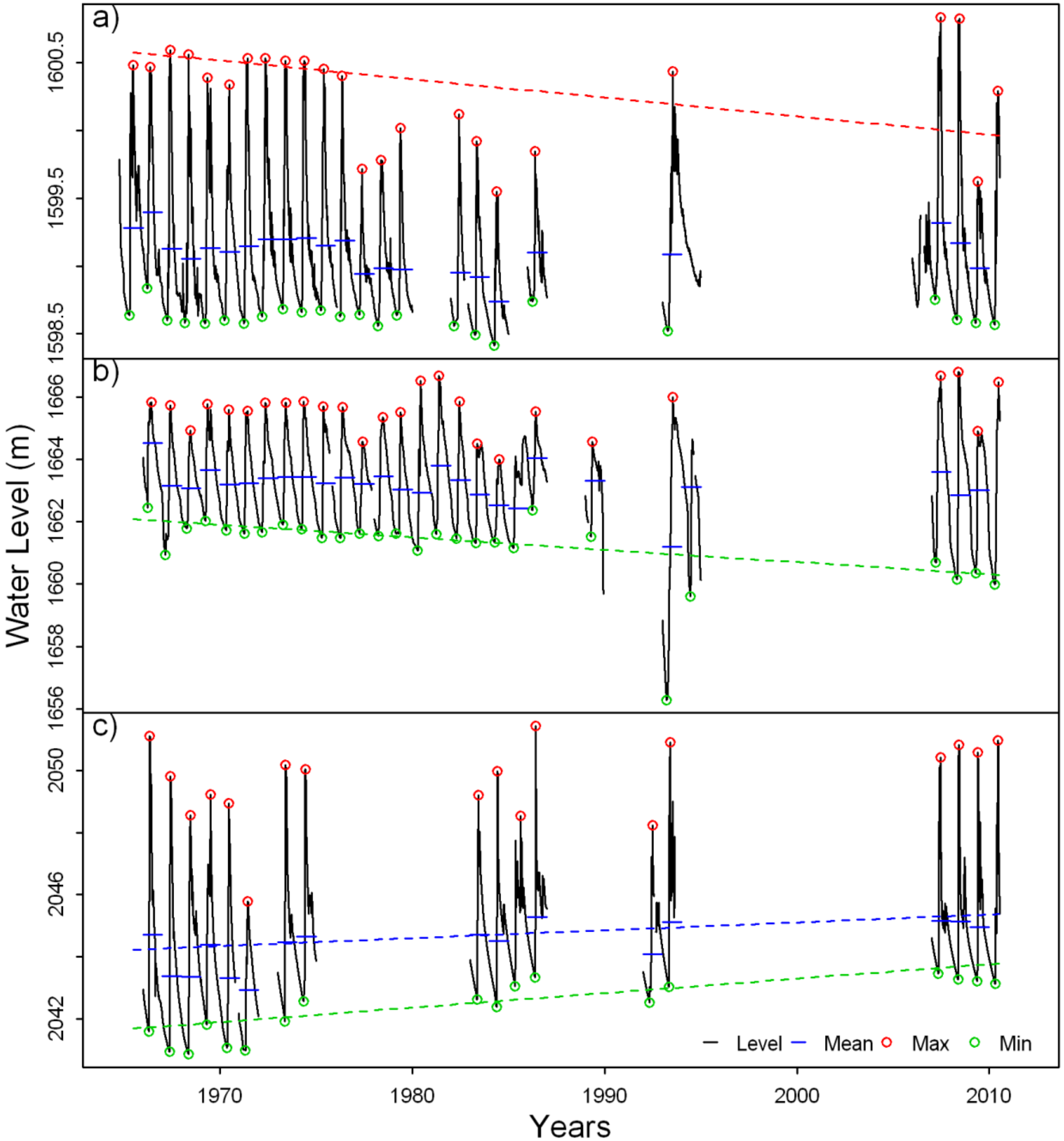
Seasonal Discharge



- Marmot Creek seasonal discharge -24% over 1962-2011
- Sub-basin flows show no significant trends for 1963-1986
- Continuity trumps stats, thus:
  - Nearly significant trends at Cabin, Twin and Middle, but not Alpine, imply low elevations are changing
  - Consistent with low elevation declining snow cover and increasing air temperature

May-October average discharge (m^3/s).

Water Table



Water table levels at a) Well 301: 1601m , b) Well 303: 1669m, c) Well 305: 2052m

- Low elevation wells show declines
  - Located in areas without forestry impact
- Upper elevation well shows increase
  - Nearby clear-cut a contributing factor

Trends in Terms of MCRB Water Balance

- Simple water balance:

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

  - Where P is precipitation, R is runoff , E is evapotranspiration and ΔS is change in storage
  - E and ΔS are quantified by the residual
    - ΔS is small, relative to E, as MCRB is small, highly responsive, has no surface detention and has extensive (transpiring) forest cover.

- Mean Annual MCRB Water Balance over 1963-2011

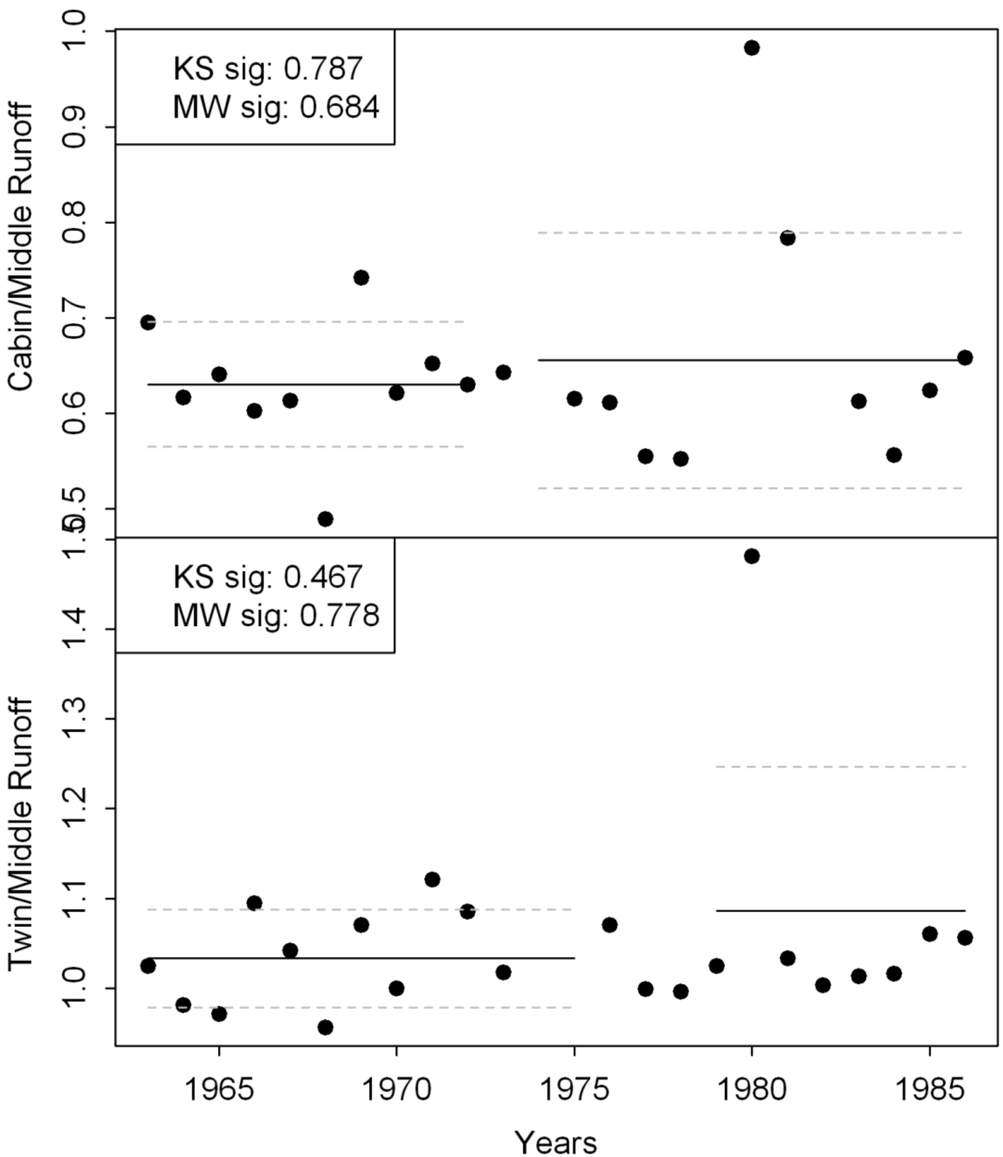
$$752\text{mm } P = 363\text{mm } R + 389 \text{ mm } (E + \Delta S)$$

- MCRB Annual Water Balance in terms of change over 1963-2011

$$0 \text{ mm } P = -102\text{mm } R + 102 \text{ mm } (E + \Delta S)$$

  - Low elevation water balance changes would be greater
  - Corresponds to increased energy for E from warmer air temperature

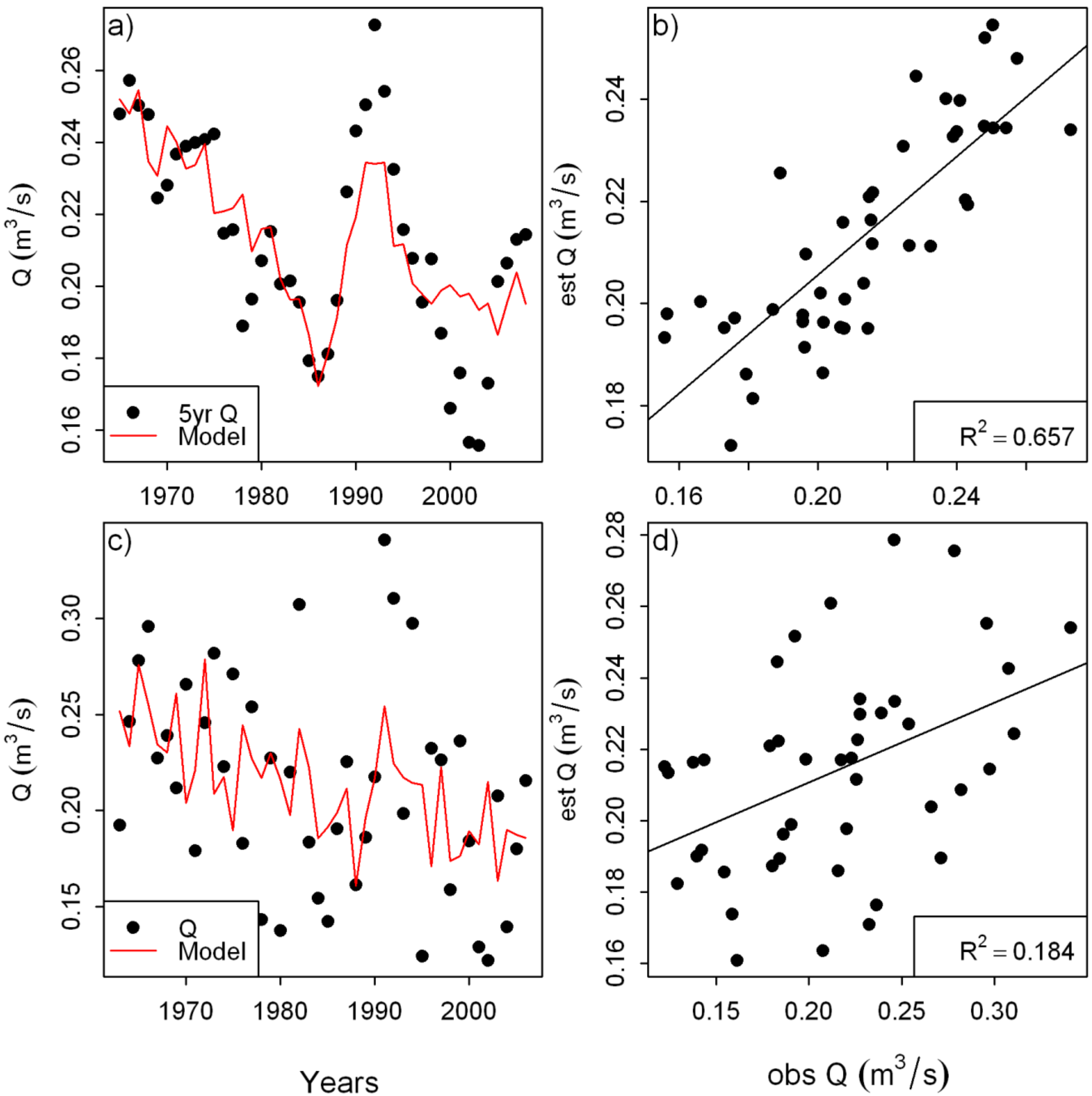
Forestry Impact on Discharge



Cabin Creek (a) and Twin Creek (b) as ratio of Middle Creek runoff .

- Experimental/control basin runoff ratio would be expected to increase and then gradually decline after logging
  - Not observed in MCRB
- Differences between pre and post treatment periods non significant

PDO and ENSO relationship to MCRB Discharge



GLS Model of Q, PDO, ENSO and trend for smoothed (5 yr moving average) (a and b) and annual (c and d)

Generalized Least Squares analysis of Q , PDO and ENSO shows:

- No relationship on annual scale
- Skill improved with 5 year moving average

5 year moving average has no physical meaning in Marmot Creek

- Small highly responsive basin with no storage

Relationship between Q, PDO and ENSO was strongest of all variables considered

Summary: Hydrometeorological Trends

- Air temperature is increasing
  - Greatest increases in Tmin, winter and low elevations
- Snow cover declining at low elevations
- Streamflow declining
  - Changes occurring at low elevations
- Groundwater trends variable
  - Likely due to forestry impact
- Warmer temperatures, from water balance perspective, have led to increased evapotranspiration

Summary: Forestry and Teleconnections

- Forestry has not had statistically significant impact on seasonal discharge
  - changes are not large enough to be clearly identifiable
- Role of teleconnections not significant on annual scale
  - May contribute to variability but are not responsible for observed trends
- Climate change is the dominant forcing of the observed hydrometeorological trends

Acknowledgements

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