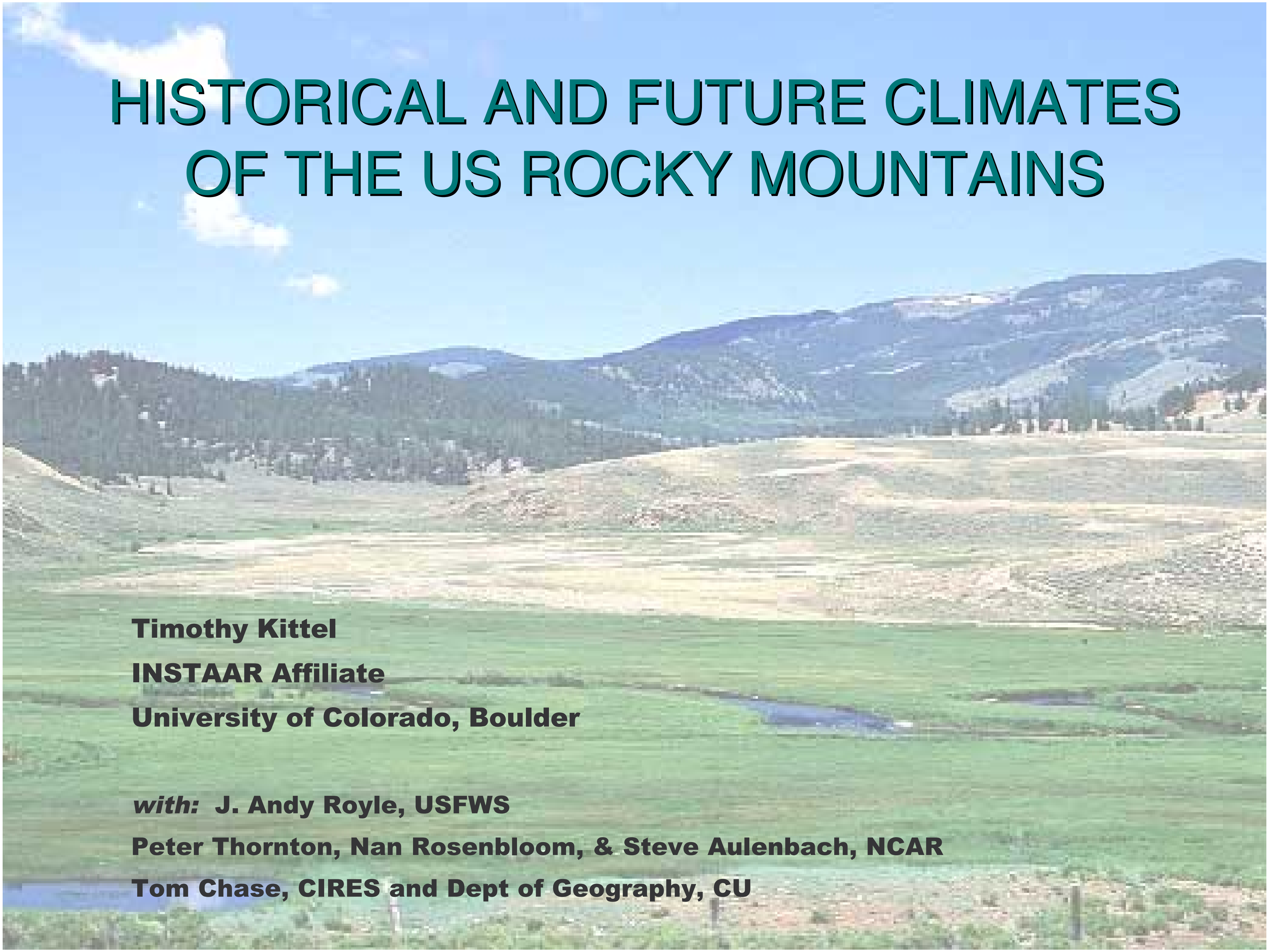
Selected Presentation from the INSTAAR Monday Noon Seminar Series.

07 Oct. 2002 **Tim Kittel** et al., National Center for Atmospheric Research, INSTAAR affiliate, Email: kittel@ucar.edu
"Historical and Future Climates of the Rocky Mountains".

Kittel presentation (0.5 Mb PDF).



HISTORICAL AND FUTURE CLIMATES OF THE US ROCKY MOUNTAINS

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Tom Chase, CIRES and Dept of Geography, CU

- Citations for presented research are:
  - Kittel, T.G.F., P.E. Thornton, J.A. Royle, and T.N. Chase. 2002. Climates of the Rocky Mountains: Historical and Future Patterns. Pages 59-82 (Chapter 4), in: J.S. Baron (ed.). *Rocky Mountain Futures: An Ecological Perspective.* Island Press, Covelo, CA. 325 p.
  - Kittel, T.G.F. and J.A. Royle. 100-year climate history of the U.S. Rocky Mountains. *J. Climate*, in preparation.
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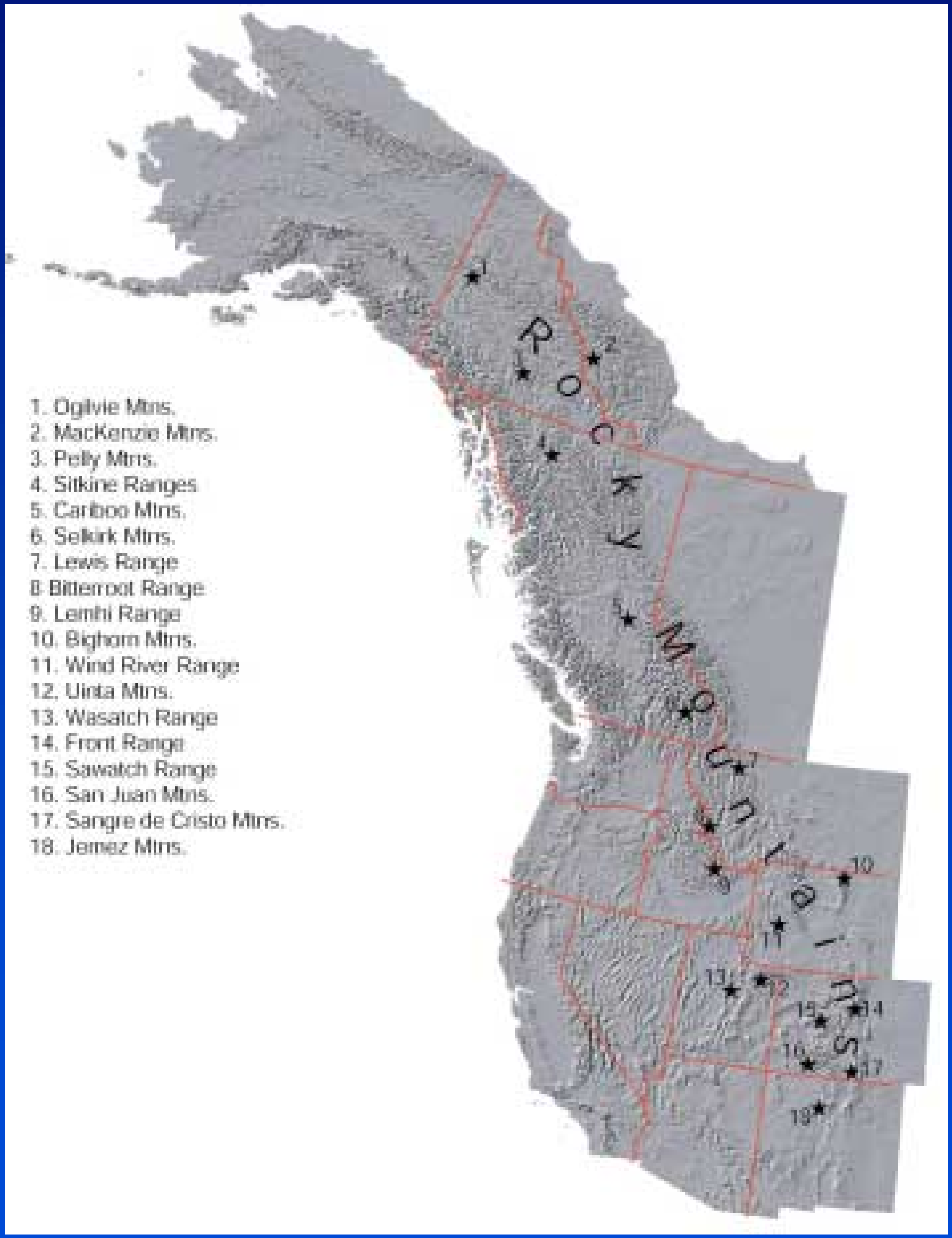
THE ROCKY MOUNTAINS

- Geographic context
  - Societal
  - Hydrological
  - Ecological
- Spatially extensive –
  - 35-65°N
  - warm temperate ‡ boreal
- Source for great river systems



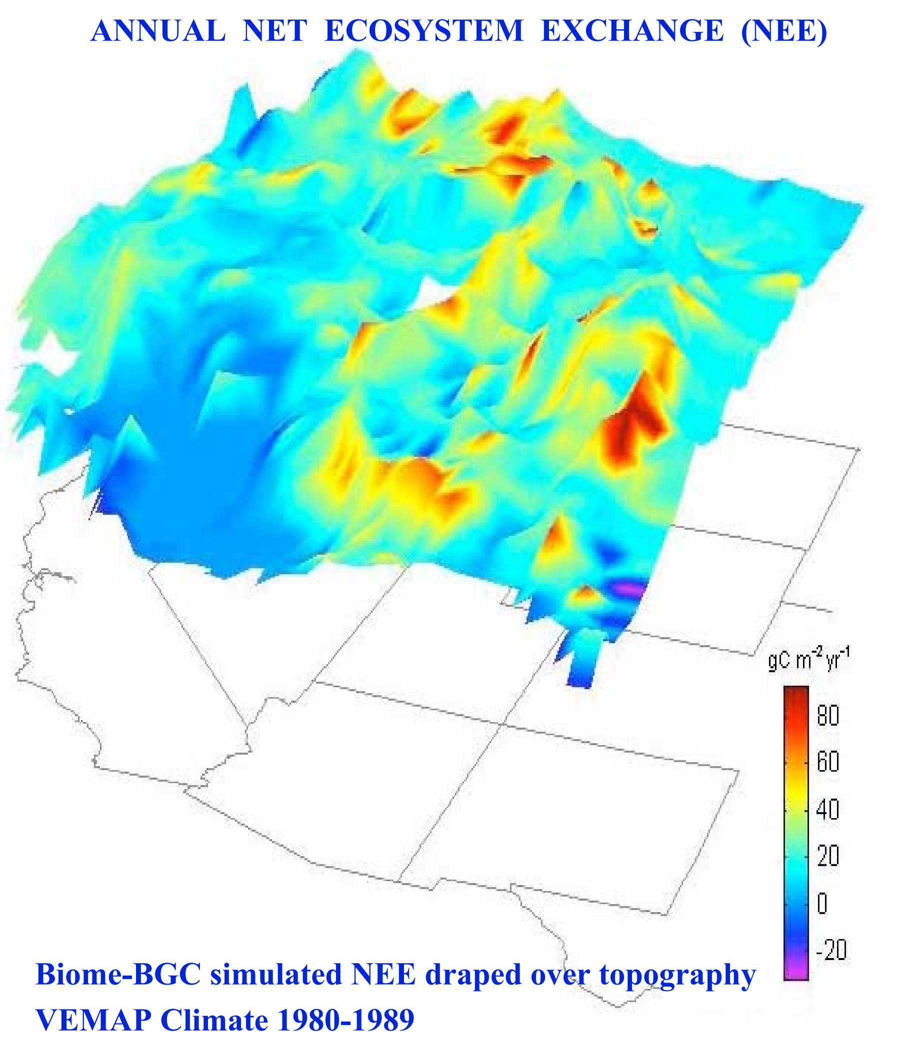
D. Cairns in Baron 2002

GEOGRAPHY OF BIOGEOCHEMICAL PROCESSES

The Mountain West:

+ Positive net ecosystem exchange (C sequestration)

+ Net exchange sensitive to climate variability and directional change



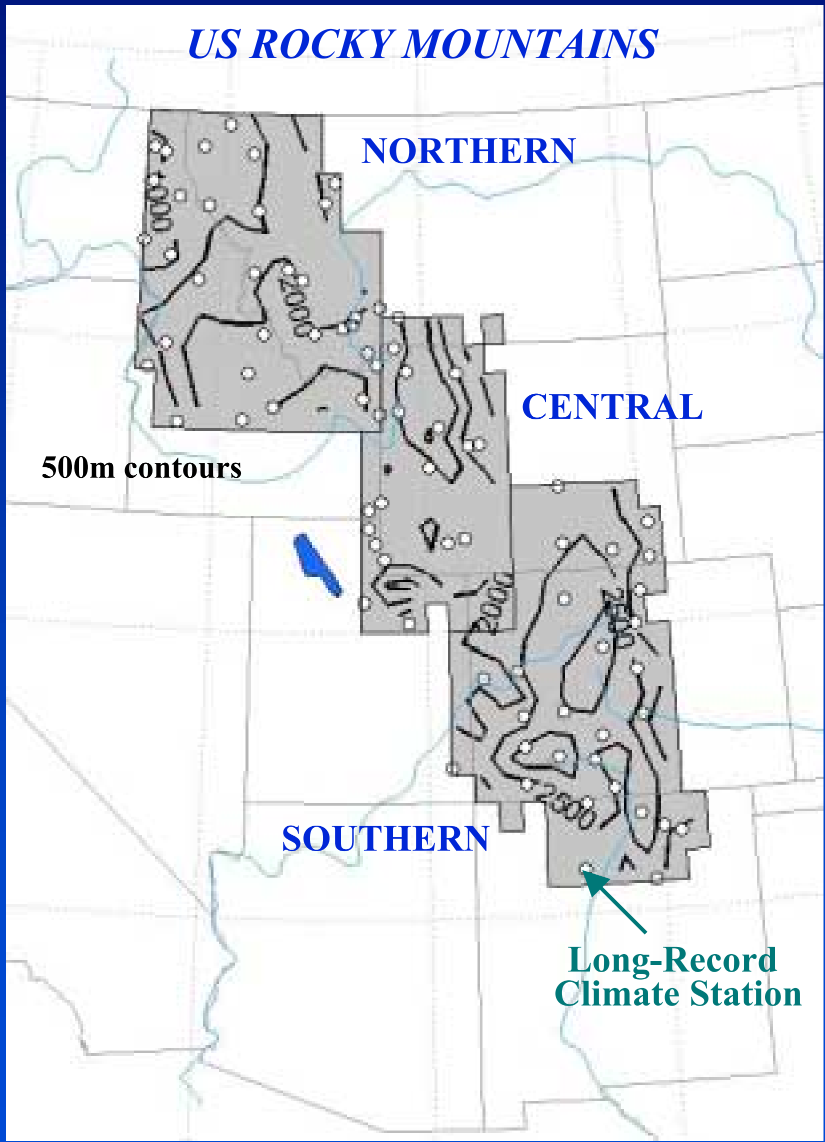
Schimel et al. 2002. *Eos*

OBJECTIVES

- Are there significant historical temporal patterns in climate – trends and interannual variability – across the US Rockies?
- Are there lessons from a retrospective – and from climate models – that can be applied to understanding effects of continued altered forcing on high elevation climates?

HISTORICAL ANALYSIS

- US Rockies
  - 3 regions
- 1895-1993
  - 79 long-record stations
    - US HCN and coop stns (NCDC)
  - Statistical in-filling
    - Moving-window kriging model
      (Kittel et al. in review)
- Variables
  - T_{min} T_{max}
  - Diurnal temperature range (DTR)
  - Precipitation

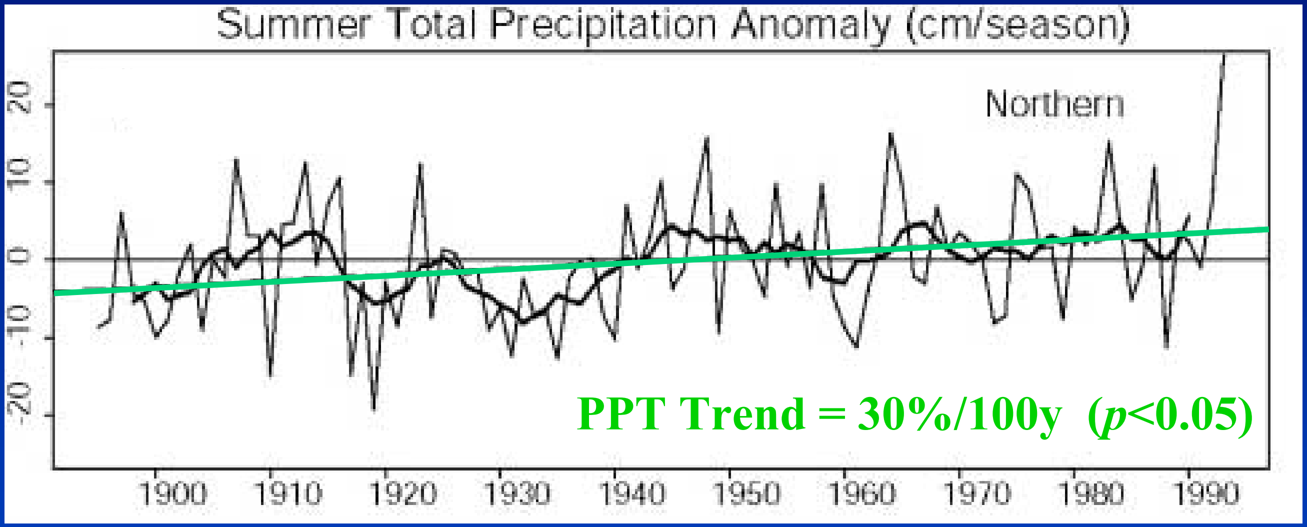


SPECIFIC QUESTIONS

- *Are there significant trends in temperature and precipitation in the historical record?*
  - *Do these trends depend on:*
    - Region
    - Elevation

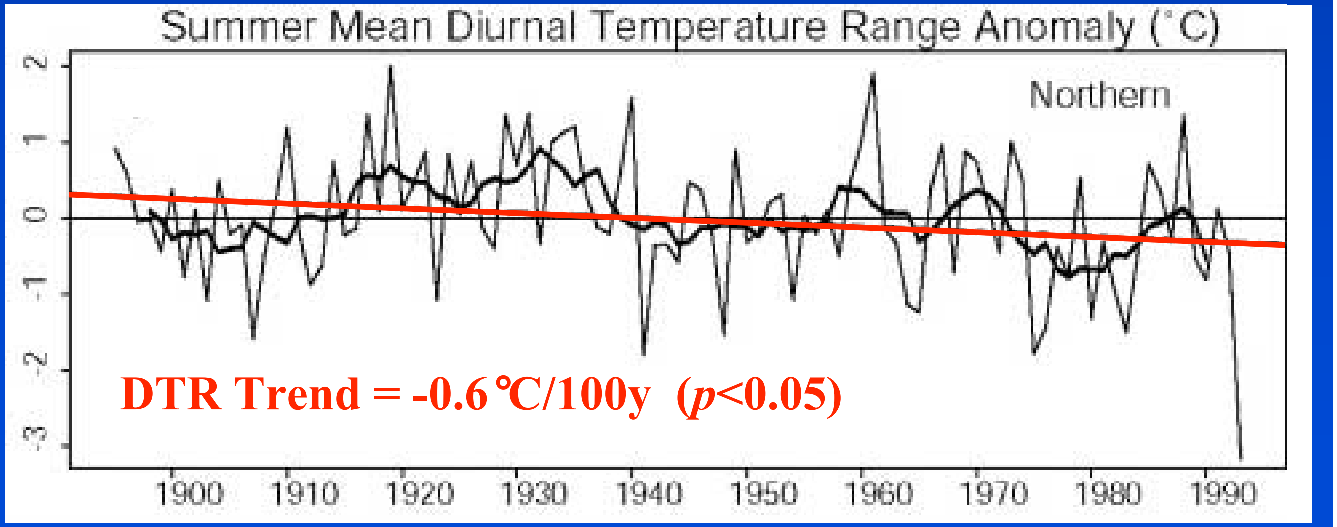
- *What is the character of climate variability in the Rockies?*
  - *Does this variability (and its teleconnections) depend on:*
    - Region
    - Elevation

ARE THERE 20th CENTURY TRENDS?

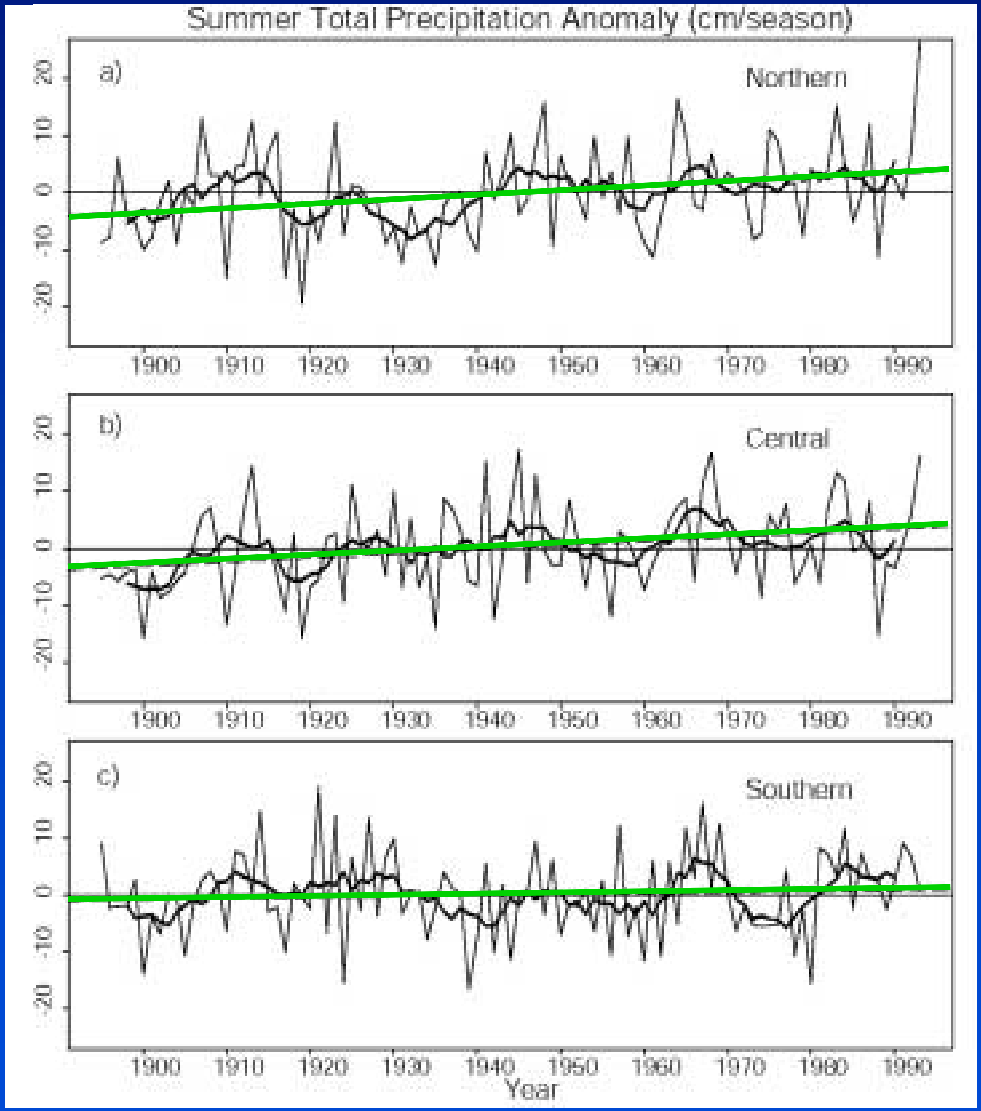


+ Precipitation
  - Significant trends tend to be >0

+ Temperature
  - Significant T trends tend to be >0
  - T_{min} (+0.5 - +1.0℃/100y) > T_{max}
  - Diurnal T Range trends <0



DO TRENDS DIFFER BY REGION? – PPT



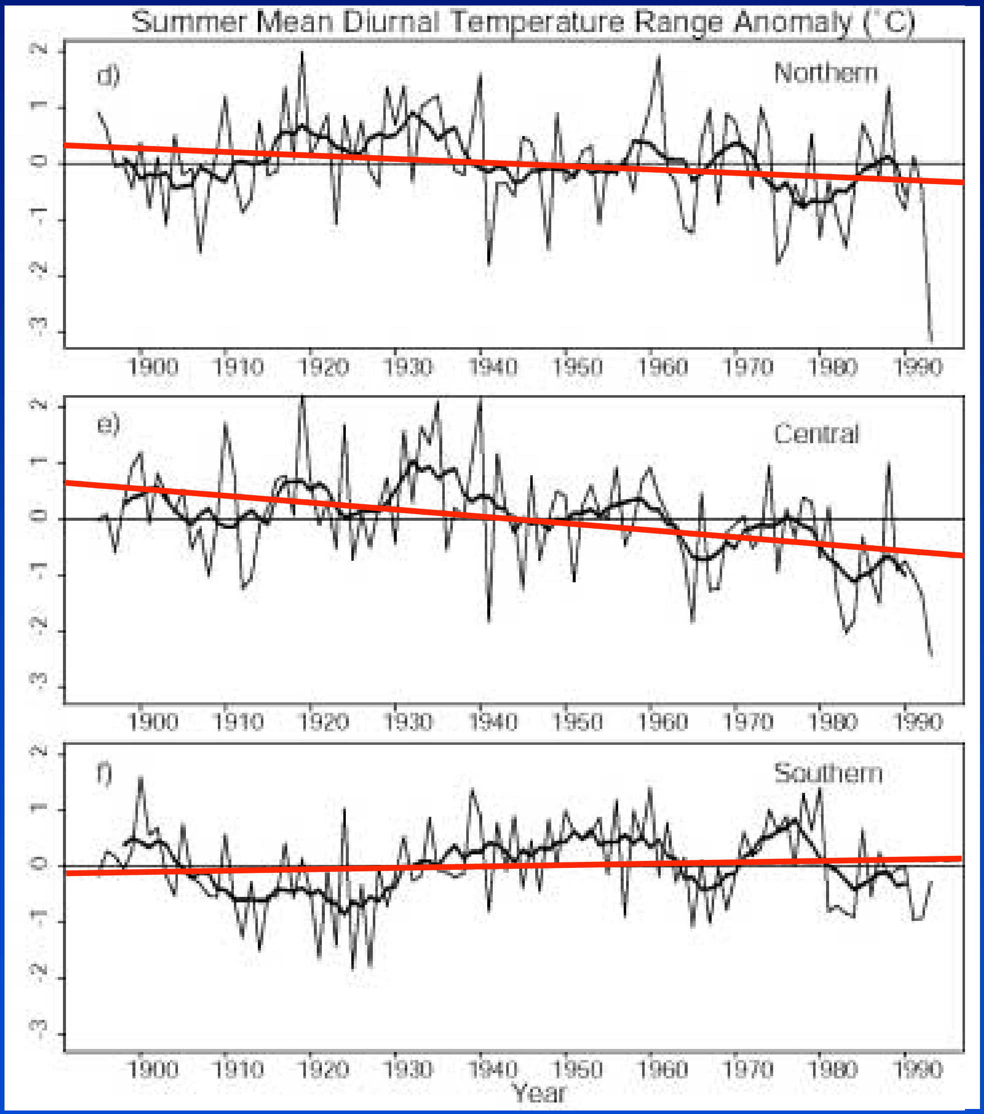
Precipitation Trend (%/100y)

	WINTER	SUMMER
NORTH	3%	30%*
CENTRAL	2%	33%*
SOUTH	-5%	5%

*$p<0.05$

+ Regional differences vary with season

DO TRENDS DIFFER BY REGION? – DTR



Diurnal T Range Trend (°C/100y)

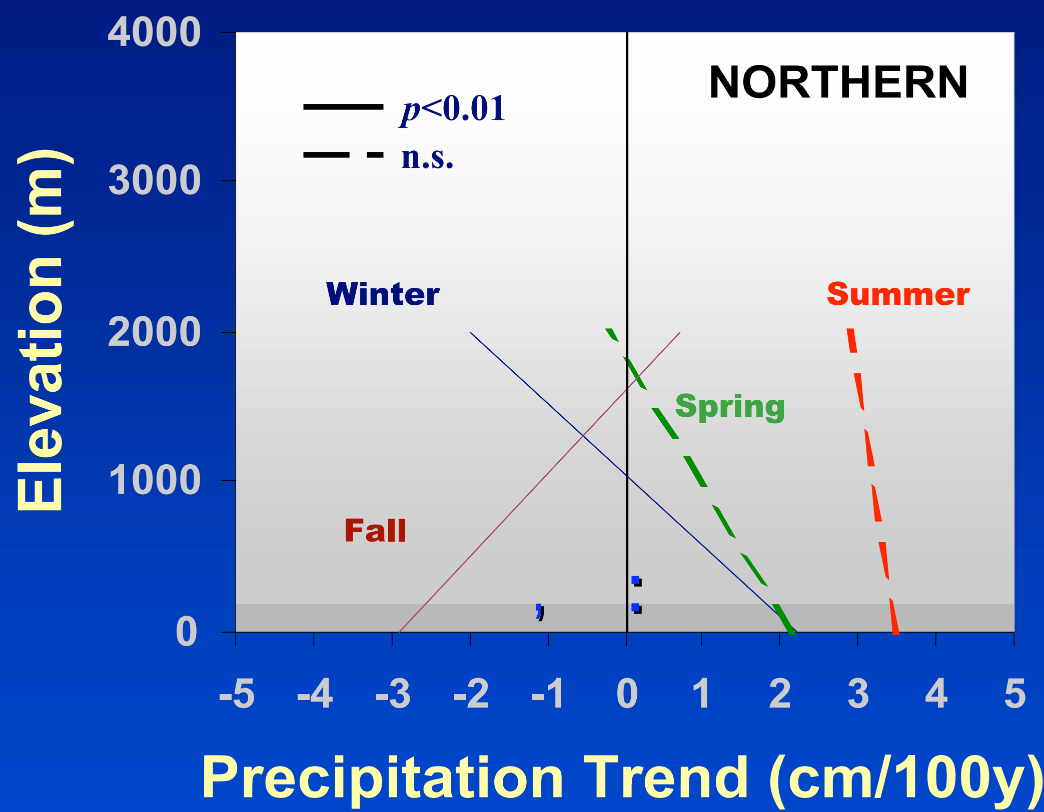
	WINTER	SUMMER
NORTH	-0.6*	-0.6*
CENTRAL	-0.5	-1.2**
SOUTH	-0.2	+0.2

*$p<0.05$ **$p<0.005$

- Regional differences follow continental pattern
  - Strongest DTR decreases in mid-latitude NAmer, weakening poleward (Easterling et al. 1997)
  - Due to increased cloud cover (Dai et al. 1999)
  - Consistent with increasing ppt

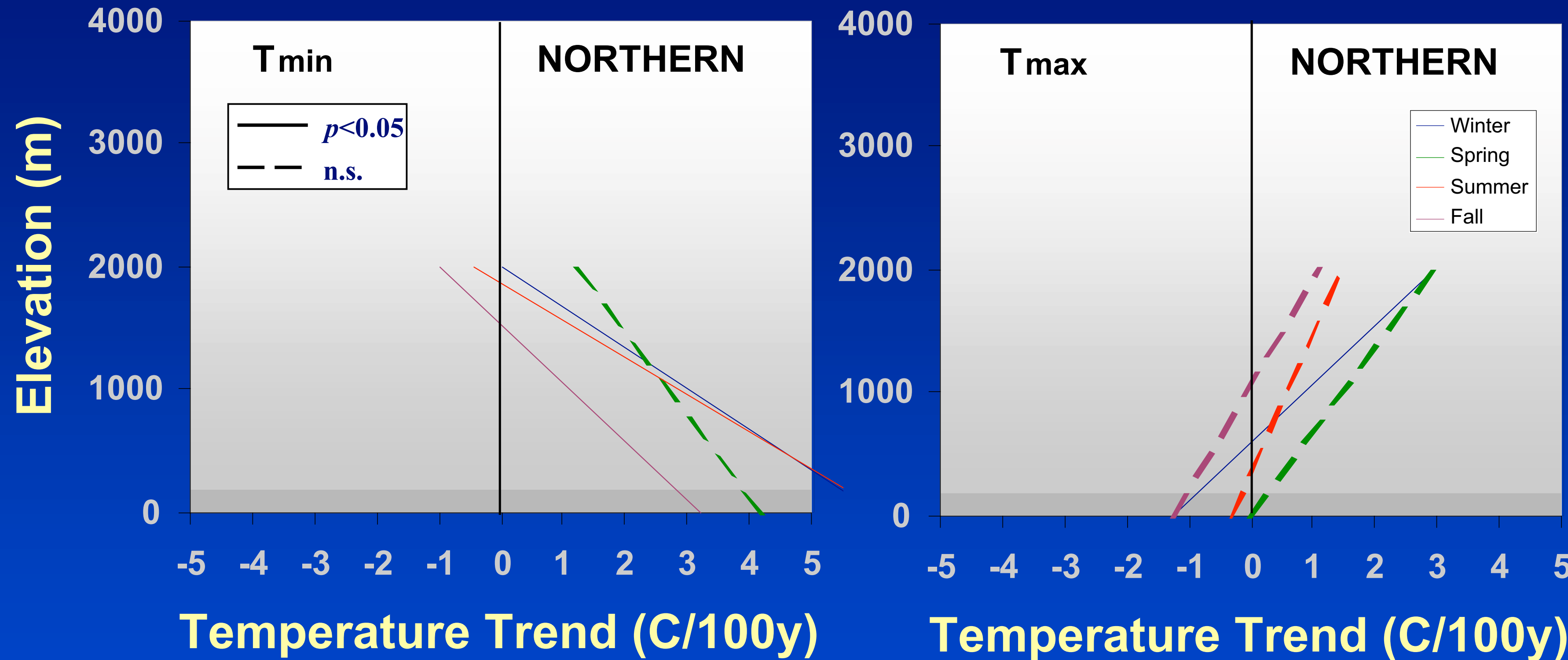
DO TRENDS VARY WITH ELEVATION? – PPT

- PPT trends *f* (elevation)
  - Reduction or amplification of lowland signal
    - > Strong trends at one elevation zone
  - Trend sign switching with elevation
    - > Decoupling
- Seasonal dependence
  - Elevation effect switching with season



TRENDS vs. ELEVATION

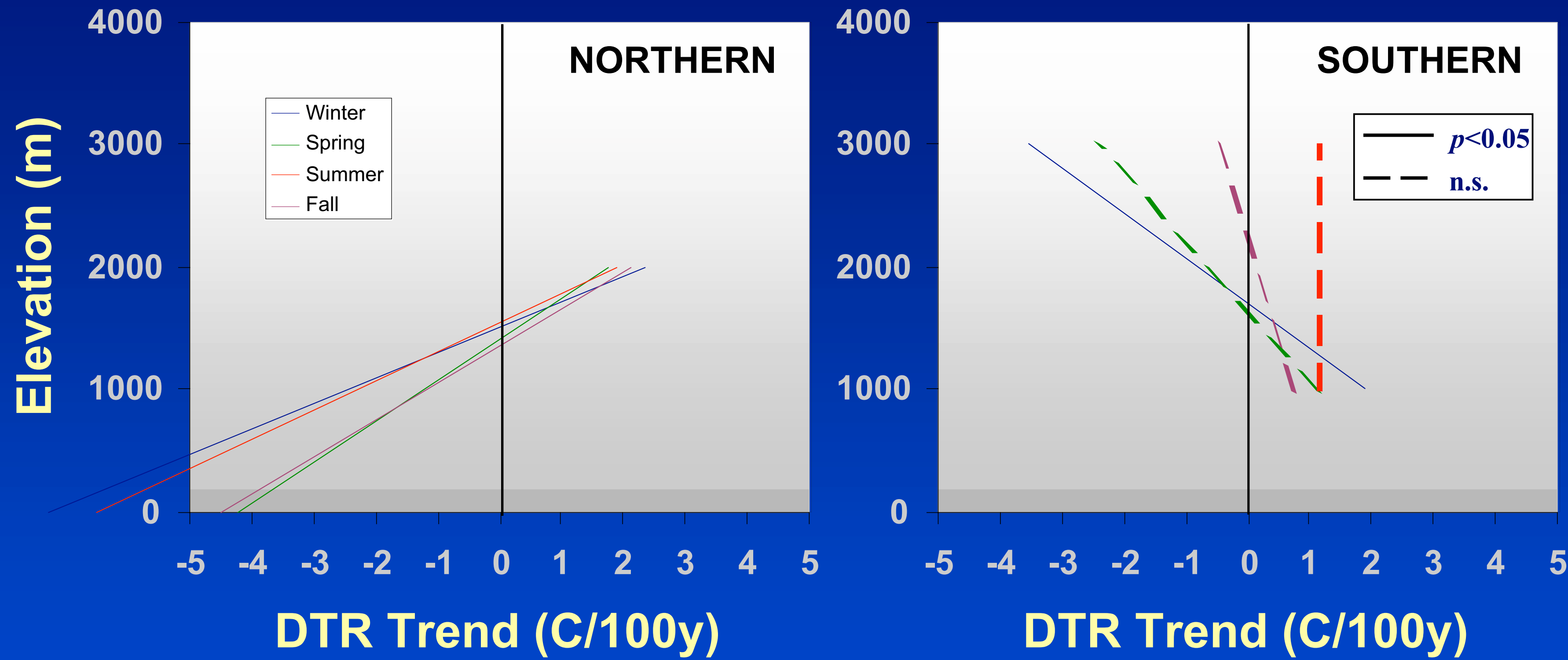
T_{min} and T_{max}



- Significant changes in trends with elevation
  > trends in lapse rate
- Sign switching with elevation
- Diurnal dependence

TRENDS vs. ELEVATION? –

Diurnal Temperature Range



- Diurnal T Range trend elevation dependent
- Region dependent

AN ELEVATION EFFECT?

+ Higher reaches of mountain systems in closer contact with free troposphere
  - Respond rapidly to upper-air changes (Greenland and Losleben 2001)
  - Less affected by ameliorating surface processes (Giorgi et al. 1997)

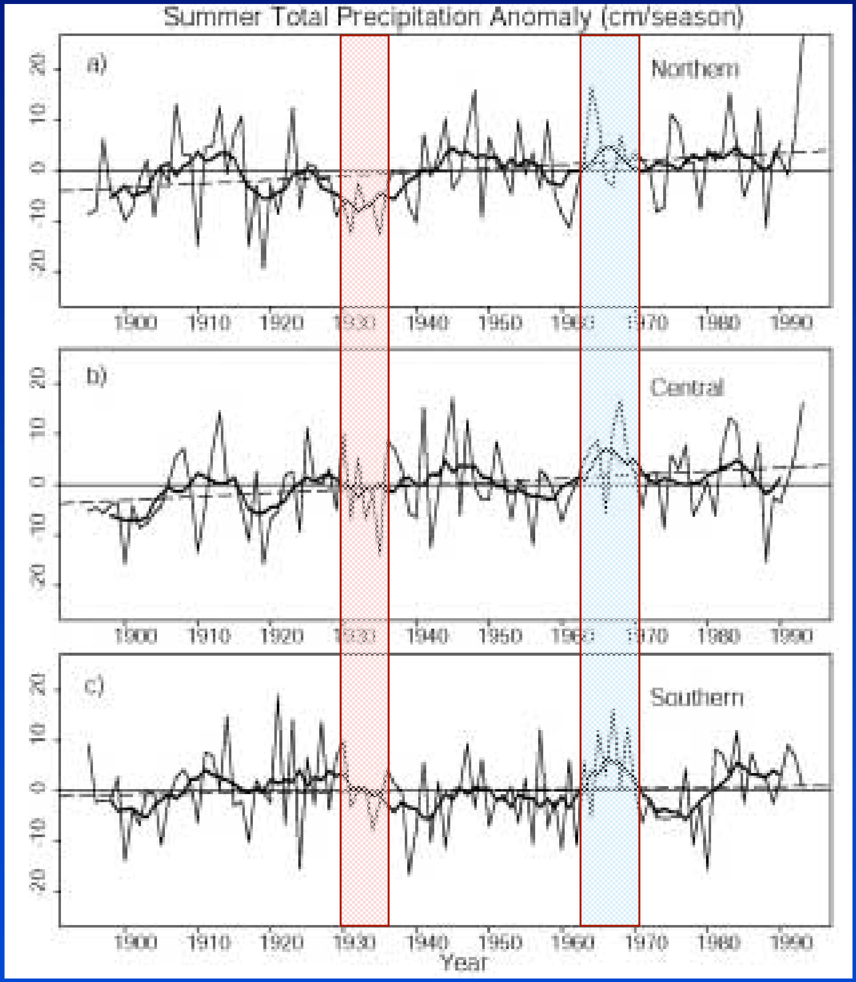
+ Upper air overrides lower air in presence of inversions
  - Widely differing air mass sources
  - Decoupled from lower-level convective mixing, valley fogs

    (Beniston and Rebetez 1996, Diaz and Bradley 1997)

+ Snow-albedo feedback
  - *Amplification of regional temperature signal –*
    - Years with regionally higher temperatures have less snowcover at elevation
      - > more absorption of solar radiation
      - > greater high elevation warming (Giorgi et al. 1997)

INTERANNUAL VARIABILITY

– SIMILAR ACROSS REGIONS? –



CROSS-CORRELATION

	Annual PPT	Annual Tmin	
	NORTH	CENTRAL	SOUTH
NORTH	-	0.9*	0.6*
CENTRAL	0.6*	-	0.8*
SOUTH	0.2	0.4*	-

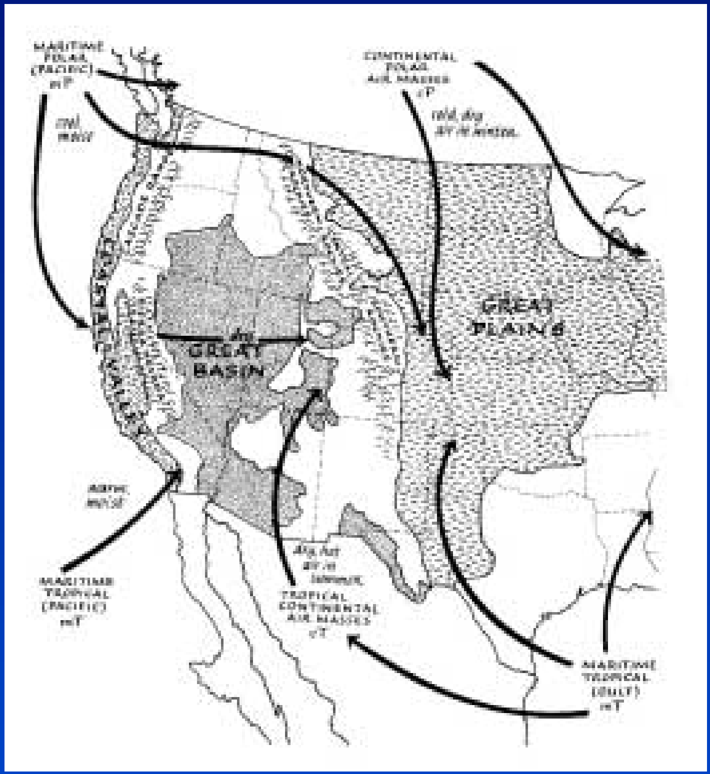
*$p<0.01$

- Adjacent regions more strongly correlated
- Cross-correlations similar by season

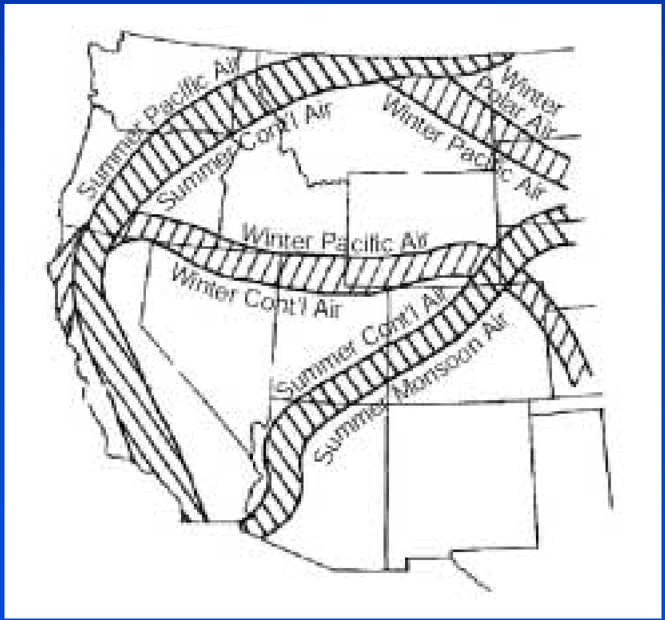
TELECONNECTIONS?

GENERAL ATMOSPHERIC CIRCULATION

- Drivers of regional patterns in mean climate
- Indicators of sources of interannual climate variability

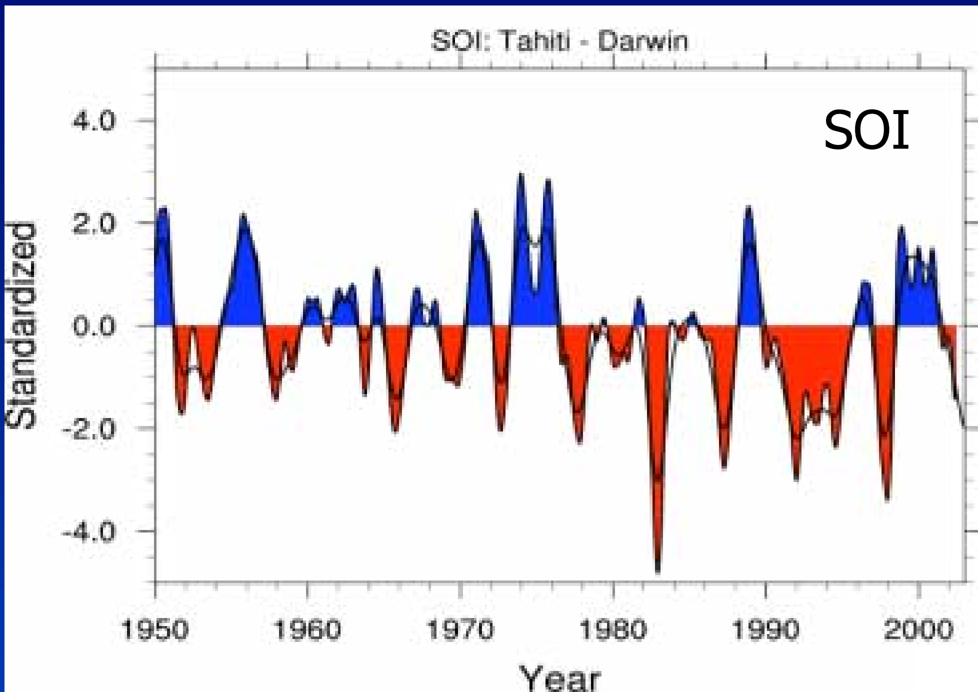


Bash, in Benedict 1991



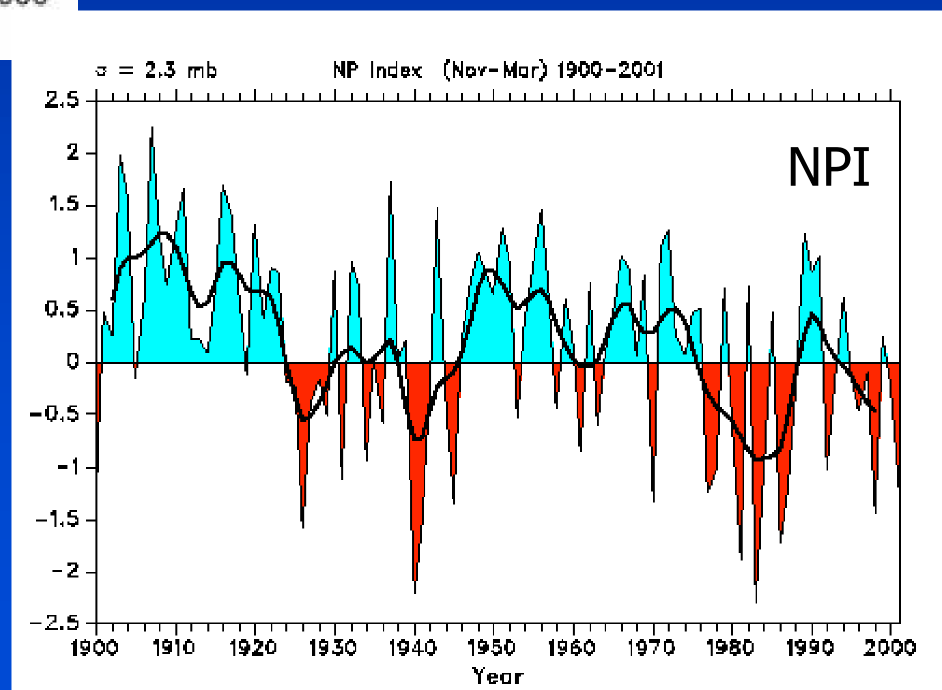
modified from Mitchell 1976

- Teleconnections with:
  - North Pacific SST and Lows (NPI)
  - El Niño/Southern Oscillation (SOI)



TELECONNECTIONS

- Southern Oscillation Index (SOI)
  - Associated with El Niño
  - Negative SOI = Warm SST phase (El Niño)
  - Positive SOI = Cold phase

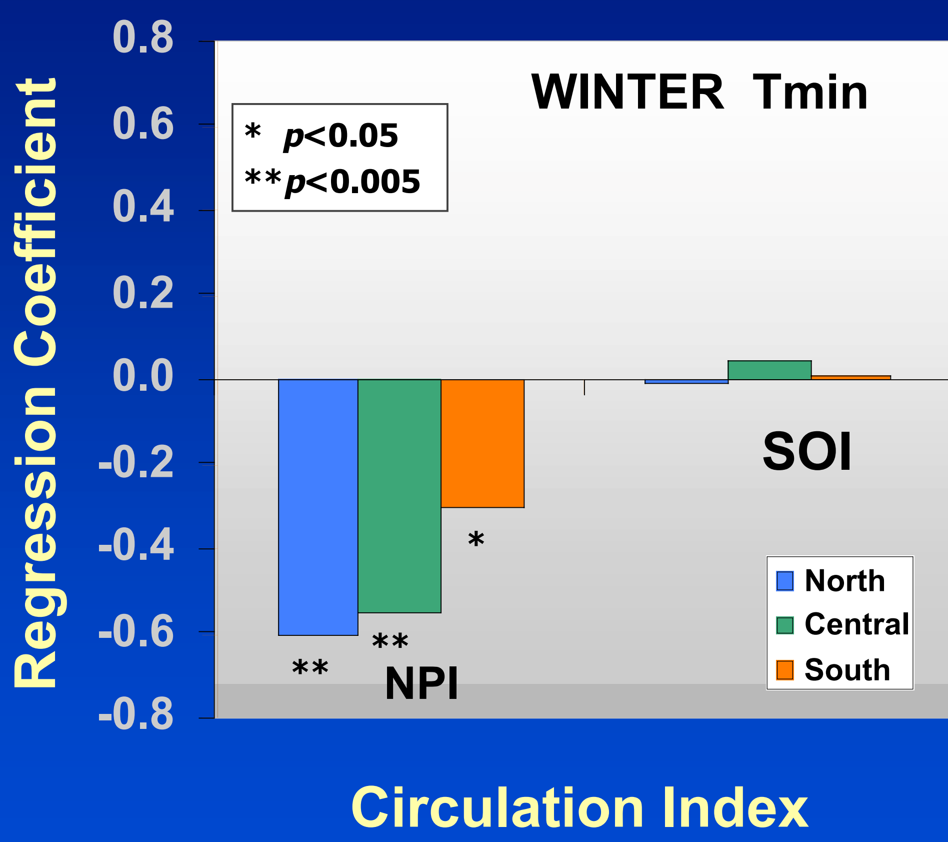


- Northern Pacific Index (NPI)
  - Aleutian Low Pressure System
  - Negative NPI = Deep Low ‡ Blocking, meridional flow
  - Positive NPI = Weak Low ‡ Zonal flow
  - Pacific Decadal Oscillation

Trenberth and Hurrell

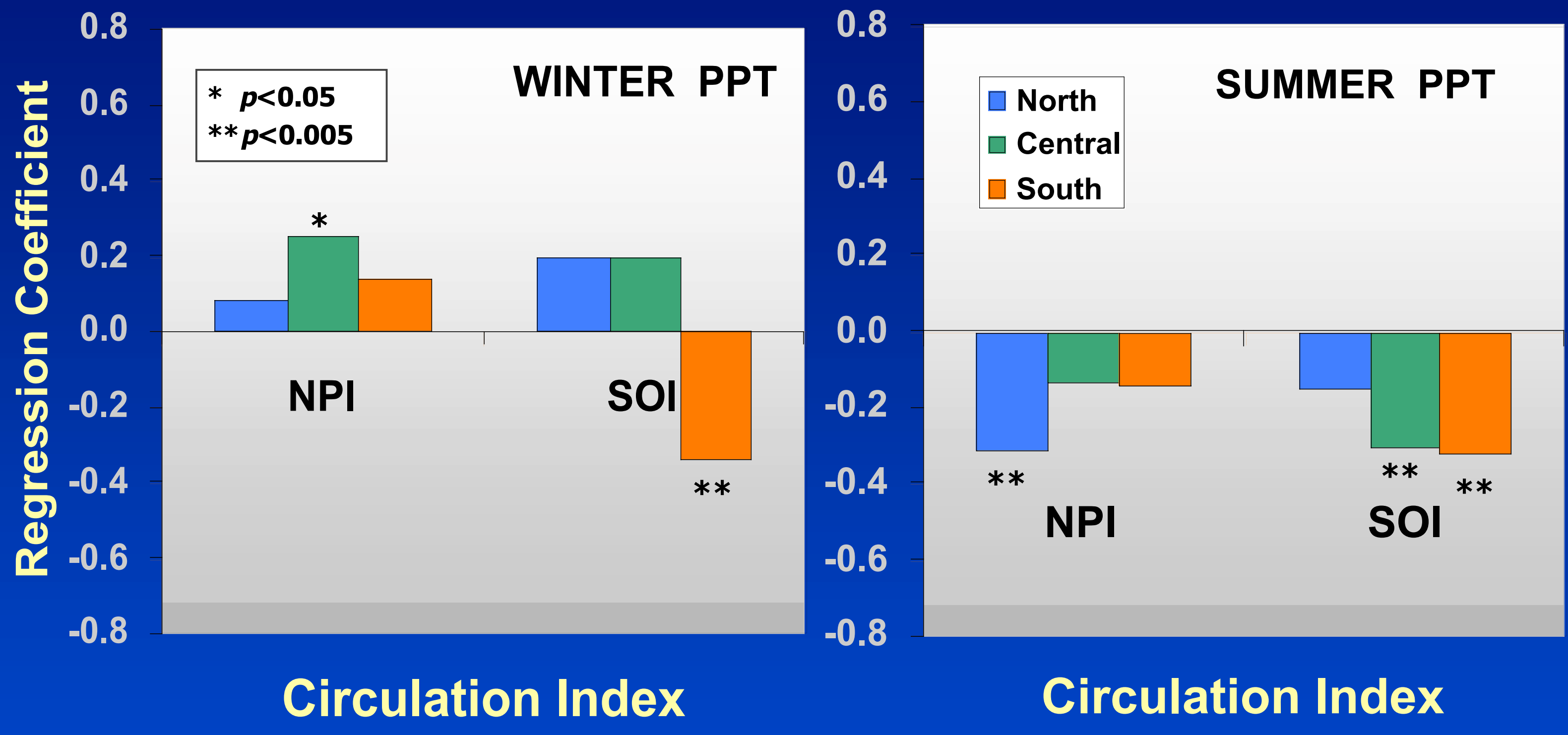
ARE THERE TELECONNECTIONS?

- Negative NPI corresponds to deeper Aleutian Low
  - Negative coefficient > warmer winter with deeper Low
  - Stronger circulation around Low > more southerly flow (warmer air) into the US Rockies in winter
- Gradient in teleconnection strength: S ‡ N



TELECONNECTIONS

– Vary along N-S Gradient and by Season –



WINTER

- Positive NPI > Zonal flow
  - More storm tracks into mid-lats
- Negative SOI > Warm phase
  - More ppt in the South

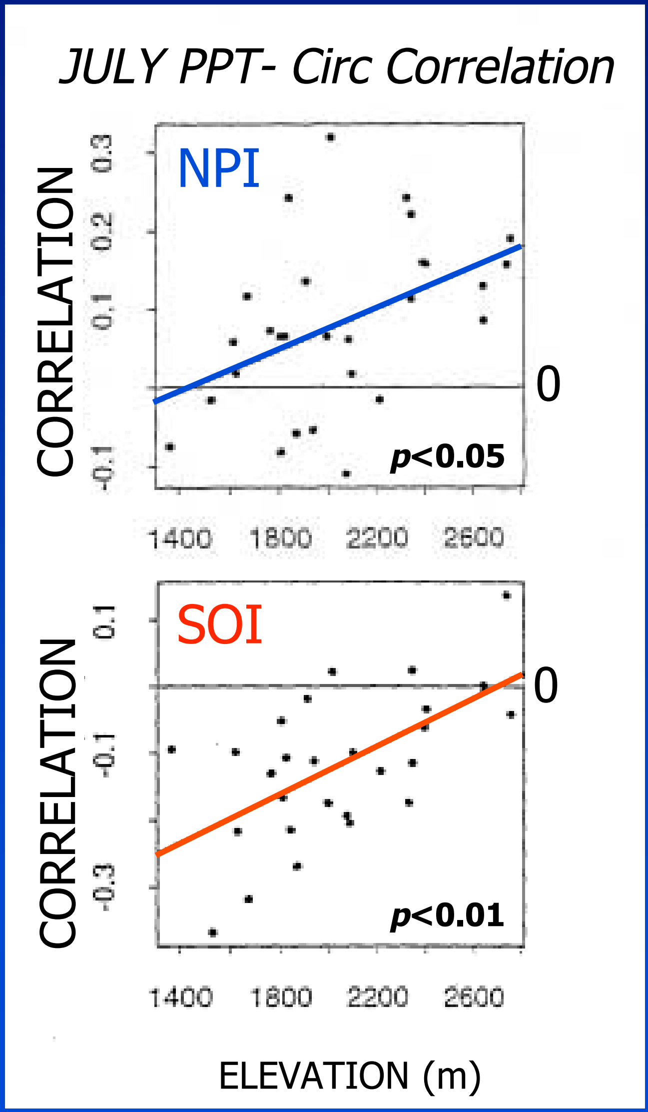
SUMMER

- Negative NPI > Stronger Low
  - More ppt in North
- Negative SOI > Warm phase
  - More ppt in the South & Central

DO TELECONNECTIONS VARY WITH ELEVATION?

- Relative importance of circulation index changes with elevation
- Behavior dependent on region and season

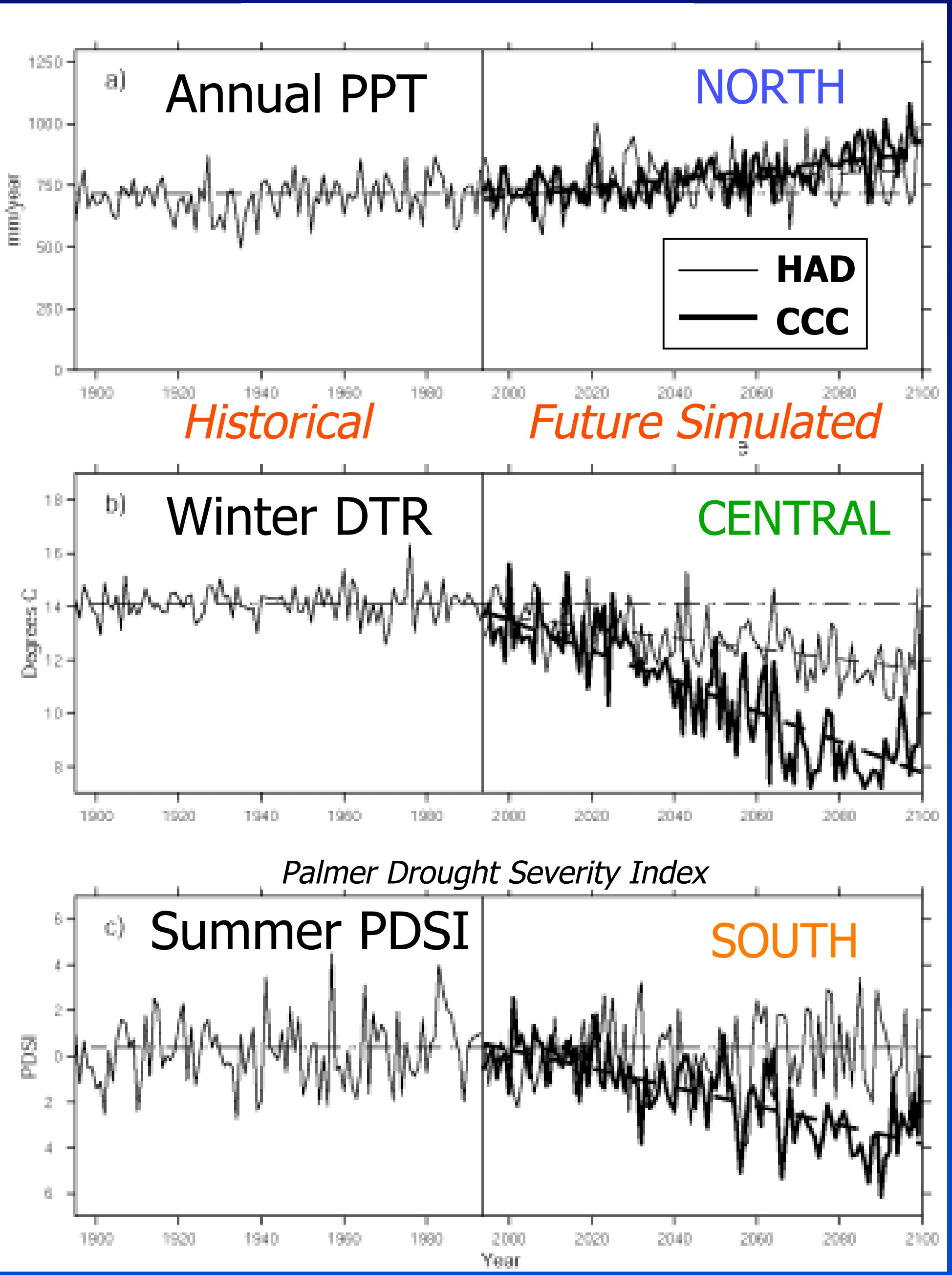
SOUTHERN ROCKIES



THE FUTURE?

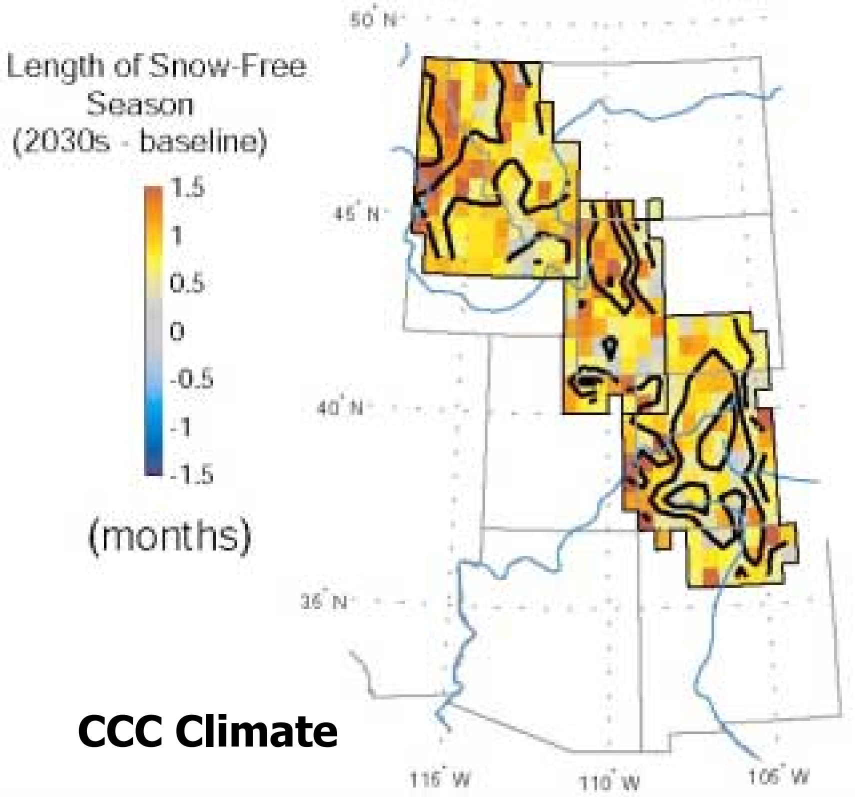
+ Multiple Forcings
  - Increasing greenhouse gases
  - Landuse change, regional and global

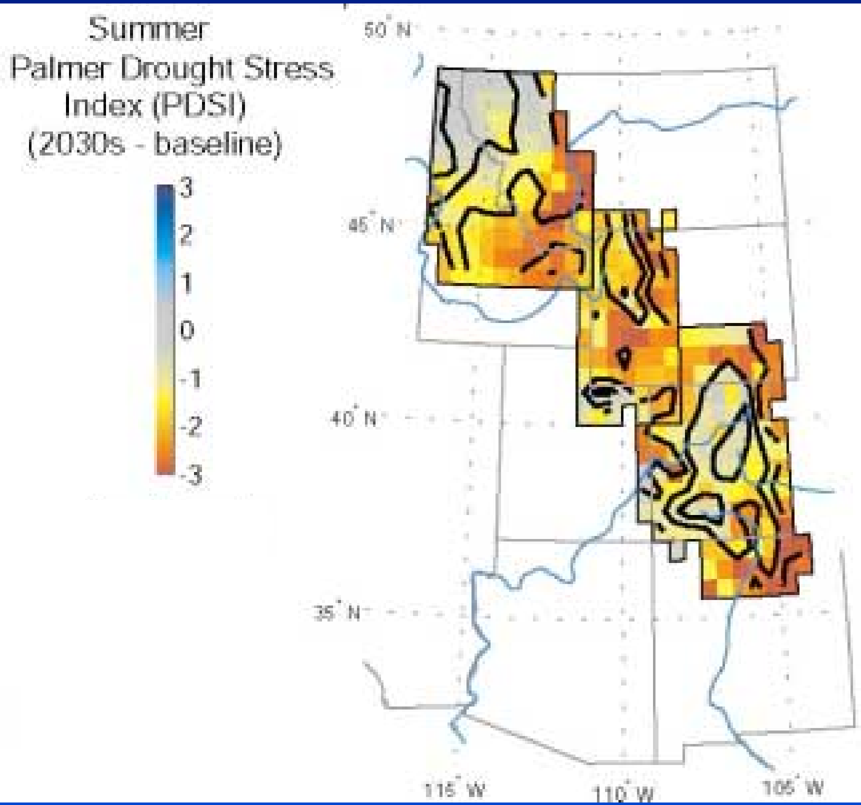
+ Regional sensitivity to altered GHGs and sulfate aerosols
  - Comparable for landuse change
    (Chase et al. 2001)



SURFACE RESPONSES TO REGIONAL FORCING

Coupled Climate Model Experiment – Increasing GHG+Sulfate Aerosols

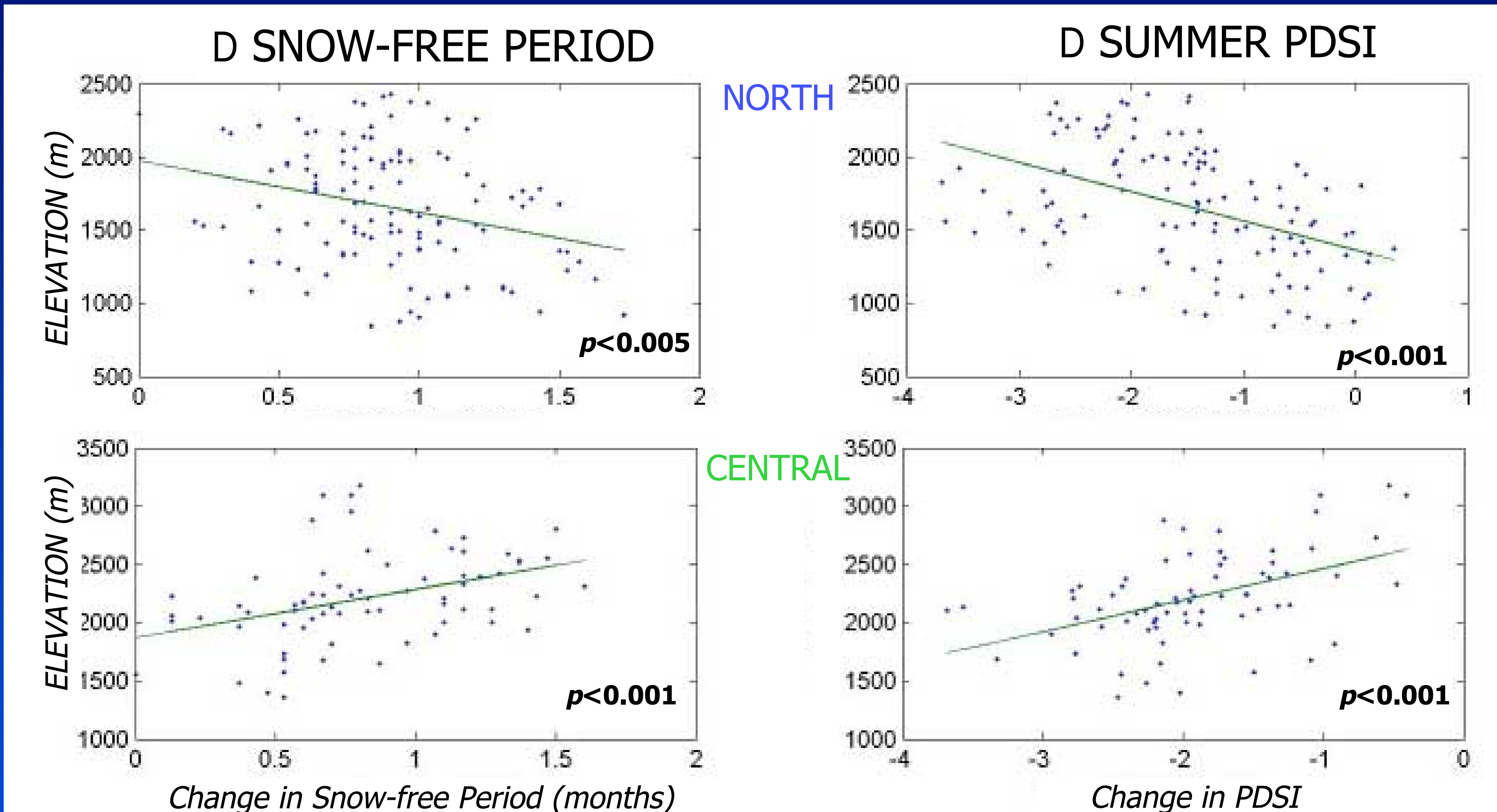




Snowfree period calculated with Biome-BGC (P. Thornton, in Kittel et al. 2002)

- Broad extraregionally forced changes result in finer scaled responses

SURFACE RESPONSES TO REGIONAL FORCING – ELEVATIONAL DEPENDENT?



- Elevation effect
- Region dependent
- Climate model experiment dependent

SUMMARY

HISTORICAL TRENDS

+ Significant, generally positive 20th century regional trends in PPT, T_{min}, and T_{max}
    - T_{min} trends > T_{max} trends – Diurnal T Range narrowed
    - Differed by region – larger in North and Central

+ Trends varied with elevation
    - High elevation trends were amplified, reduced, or opposite from lower elevation
    - No consistent pattern with season or region

SUMMARY

INTERANNUAL VARIABILITY

- Interannual variability in PPT, T_{min}, and T_{max} was regional in nature
  - Adjacent regions more strongly correlated
- Significant teleconnections with global atmospheric circulation patterns
  - Regional dependence: NPI influence stronger in north, SOI in South
  - Strength and/or sign of relationship can depend on season
  - Depend elevation

SUMMARY

FUTURE PATTERNS?

+ Extraregional forcing from altered atmospheric composition, land cover change

+ Strong, complex regional and elevation dependent reworking of this forcing by mountain climatic processes – atmospheric, hydrological, and ecological

    - Amplification or reduction of lowland signal, or decoupling

Further reading:

Kittel, T.G.F., P.E. Thornton, J.A. Royle, and T.N. Chase. 2002. Climates of the Rocky Mountains: Historical and Future Patterns. Pages 59-82 (Chapter 4), in: J.S. Baron (ed.). *Rocky Mountain Futures: An Ecological Perspective.* Island Press, Covelo, CA. http://www.islandpress.com