

Southern Alberta streamflow records: global warming trends, human impacts or natural variability?

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Projected changes in runoff by the end of the 21st century

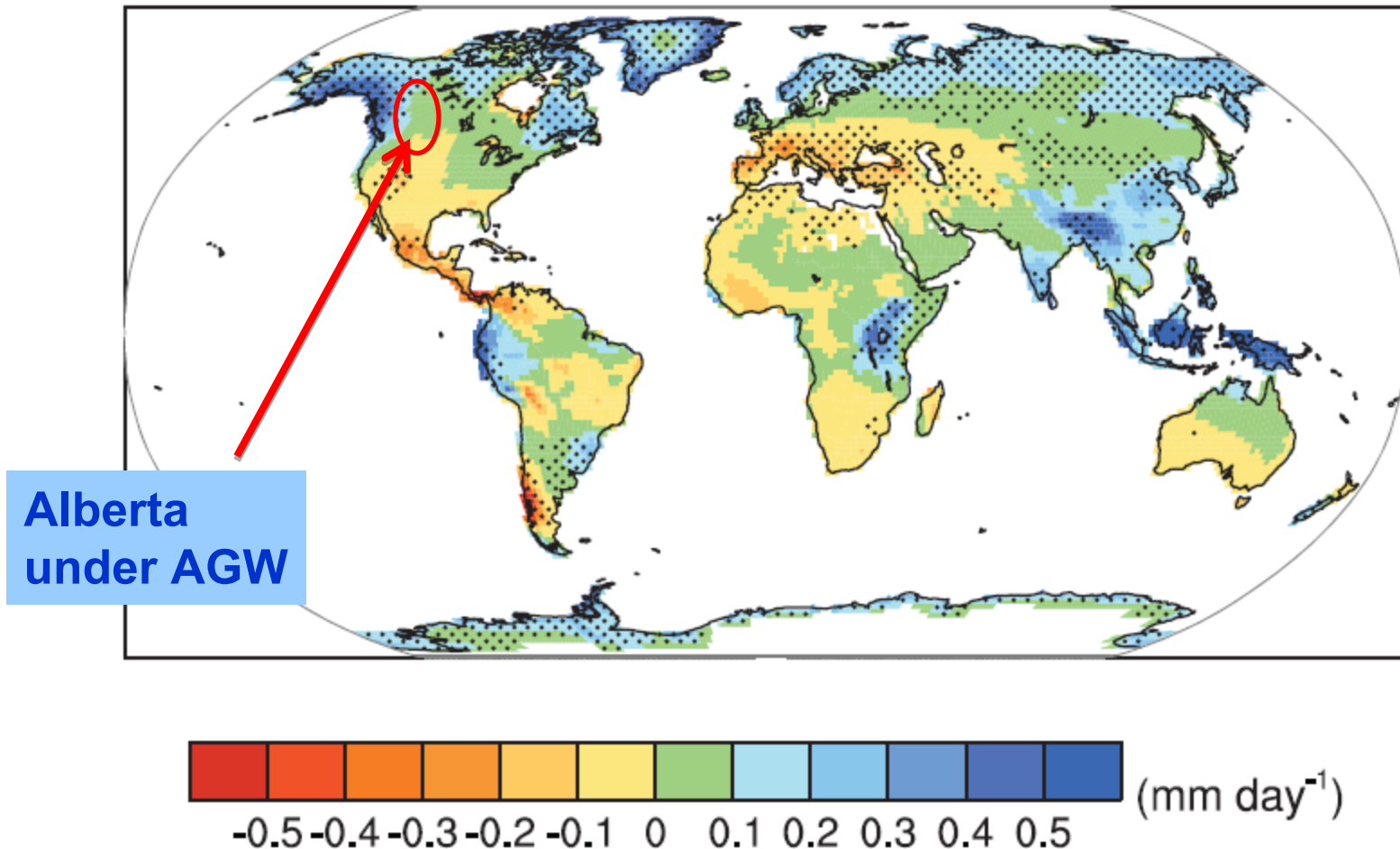


Fig. 10.12 IPCC 4. Multi-model mean changes in runoff (mm/day). Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999.

Introduction:

South and North Saskatchewan River basins are located in a **transitional** region of GCMs.

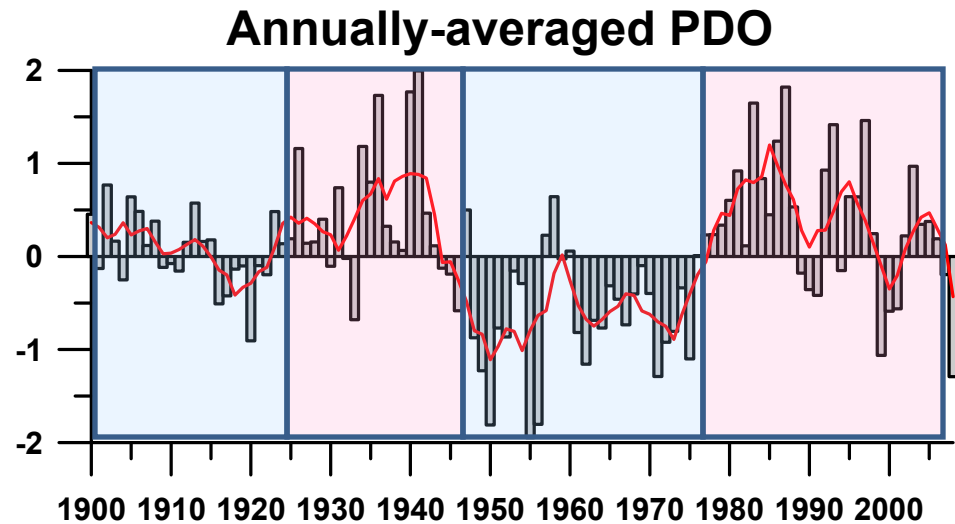
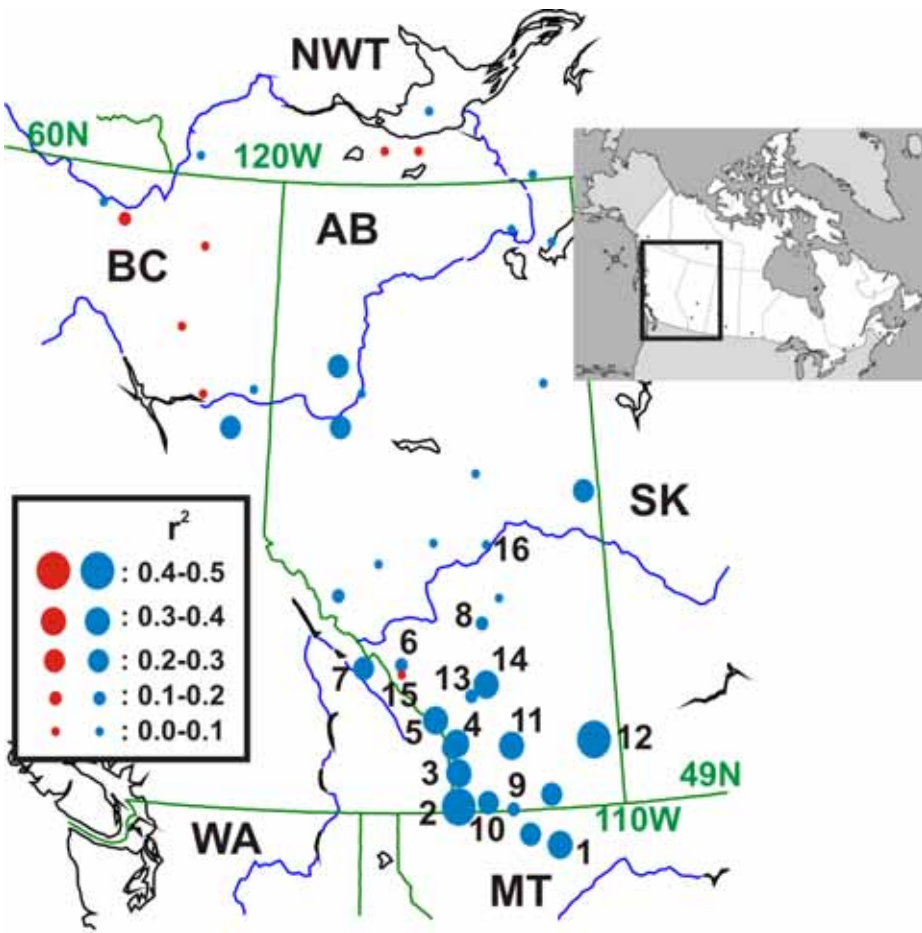
Are there any developing trends in the instrumental streamflow records?

Recent research showed **declining trends** in Alberta instrumental records (Zhang *et al.*, 2001; Rood *et al.*, 2005, 2008; Schindler and Donahue, 2006)

However, there are challenging **data analysis issues** in S. Alberta streamflow records that must be **explicitly addressed** in any trend study:

The *Pacific Decadal Oscillation (PDO)* is a major factor controlling streamflow in Alberta.

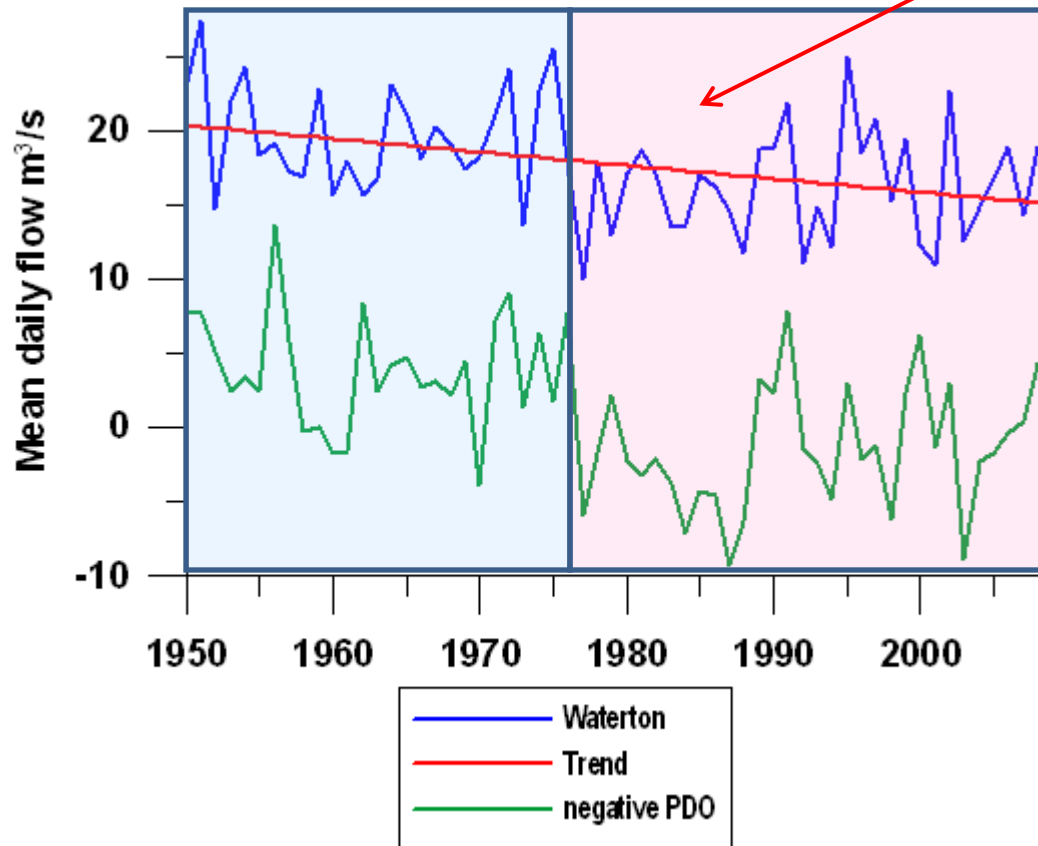
A strong **negative** relationship exists between the two



Correlations between same yr PDO and rivers
Both filtered by 5-yr binomial smoother

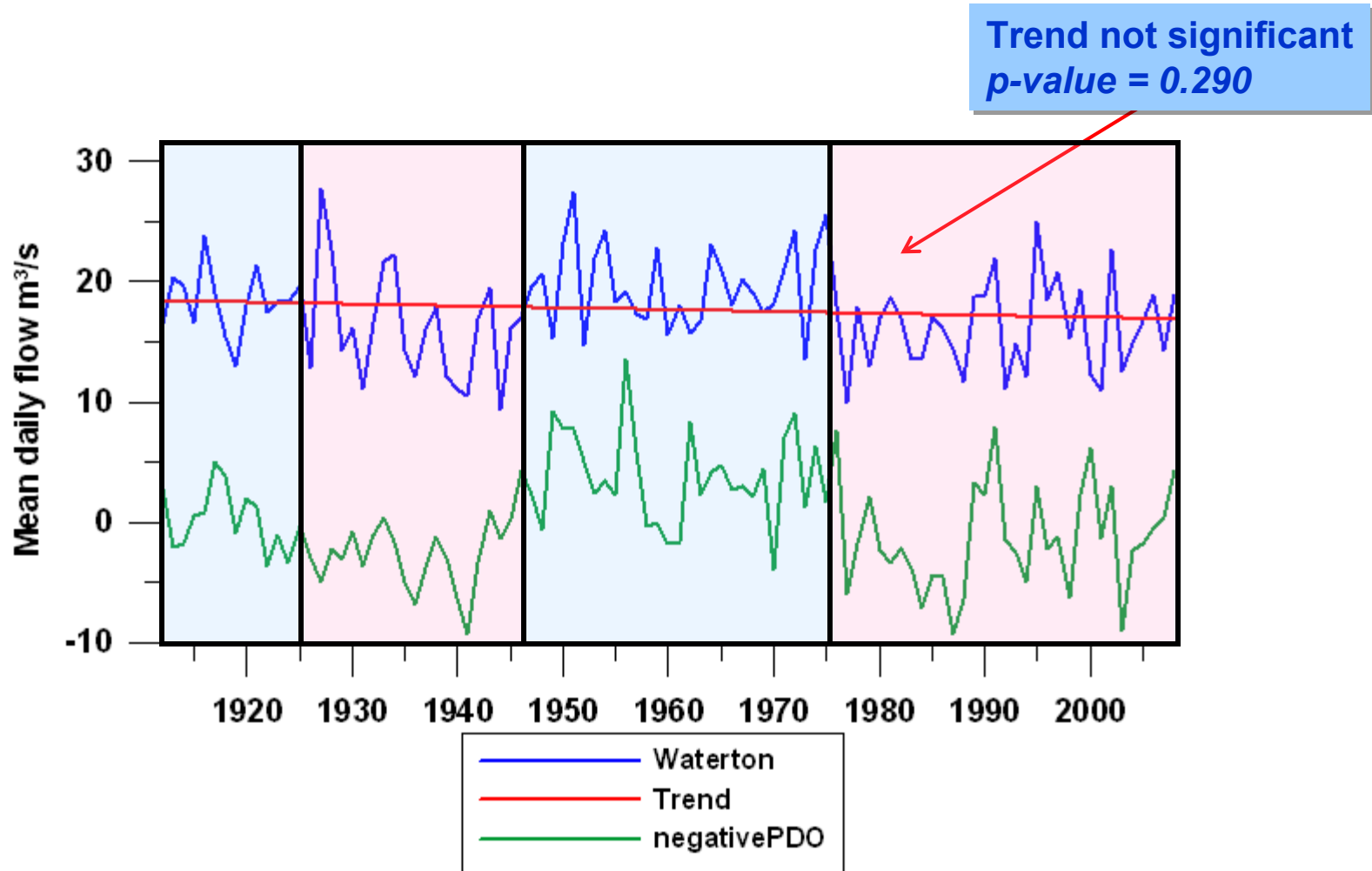
Problem: PDO phase and sampling period can induce false AGW trends

Waterton near Waterton Park 1950-2007



Significant trend

$p\text{-value} = 0.004$

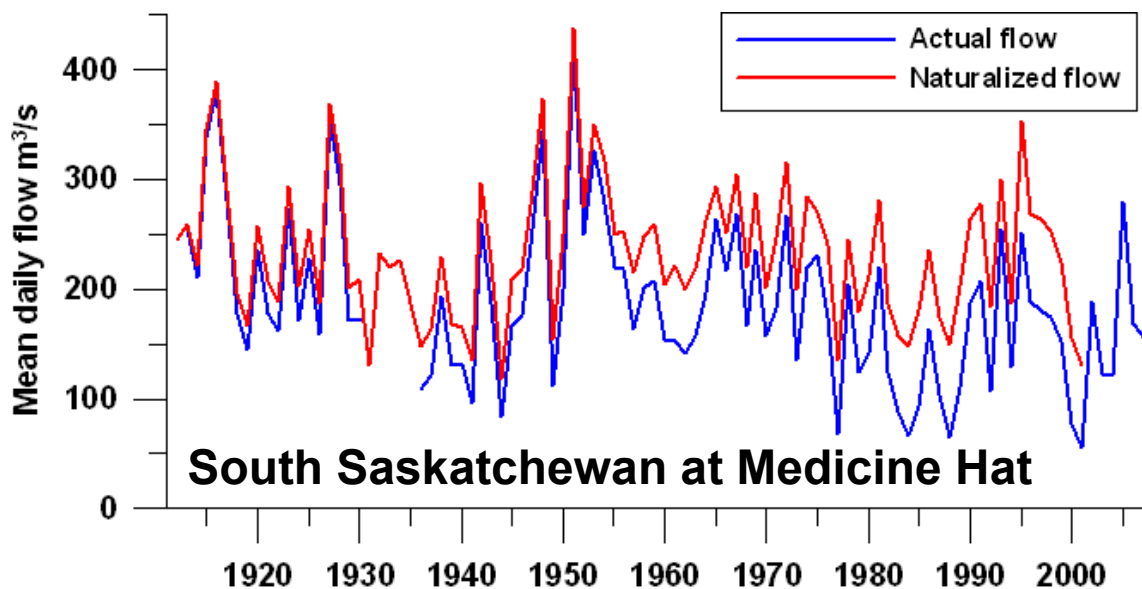


Many Alberta instrumental records begin in the 1950s, or omit the 1930s and 1940s (periods of high positive PDO, hence low AB streamflow).

If **PDO** not taken into account, this could produce **false AGW declines**.

Further problems with the instrumental streamflow data:

- **Short** typically ~40-50 years in N. Alberta and at most ~95 years in S. Alberta.
- **Gappy** especially in 1930s (economic collapse) and the 1940s (war).
- **Frequent serial correlation in the residuals** therefore classical linear regression and Mann-Kendall non-parametric methods will disproportionately detect trend.
(Kulkarni and von Storch, 1995; Zheng *et al.*, 1997; Zheng and Basher, 1999; Zhang *et al.*, 2000, 2001; Burn and Hag Elnur, 2002; Yue *et al.*, 2002)
- **Heavy human impact** from irrigation, dams, cities, tar sands, especially in S. Alberta, obscuring natural hydrology.



Naturalized record
courtesy of



Solutions

PDO: explicitly include its effect in **model**.

Short, gappy data: use **longest** (80-90 years), **most complete** records with modest infilling.

Serial correlation in residuals: use **Generalized Least Squares regression (GLS)** which fits ARMA models to the residuals. Use **R** programming language.

Heavy human impact:

- (1) examine **unregulated rivers**, and
- (2) compare actual flows to their corresponding **naturalized** flows from Alberta Environment.

Statistical Methodology

Use **low-pass filtered mean daily streamflow** (5-year binomial smoother).

Use as predictors: **trend, PDO, SOI** (Southern Oscillation Index), **NAO** (North Atlantic Oscillation). Climate variables also low-pass filtered and leading streamflow by **-1, 0, +1, +2** years.

For each river

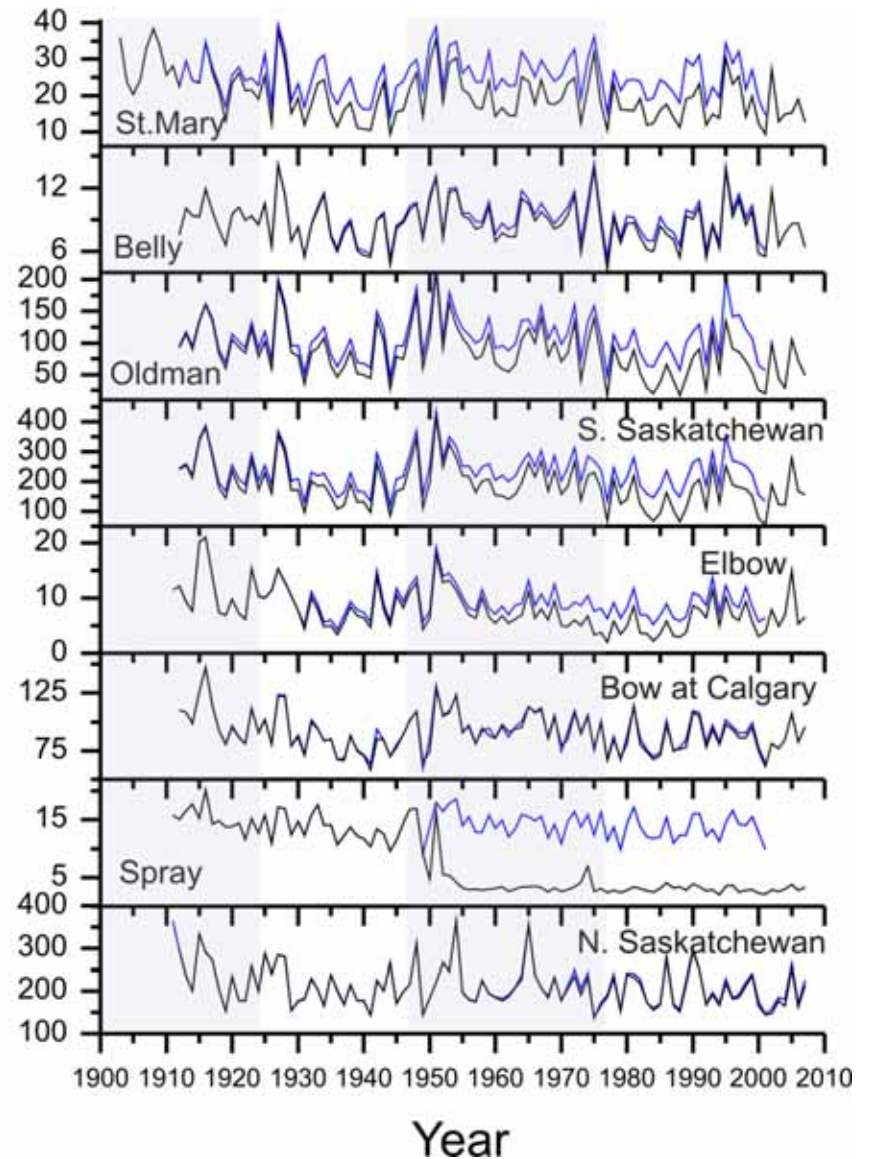
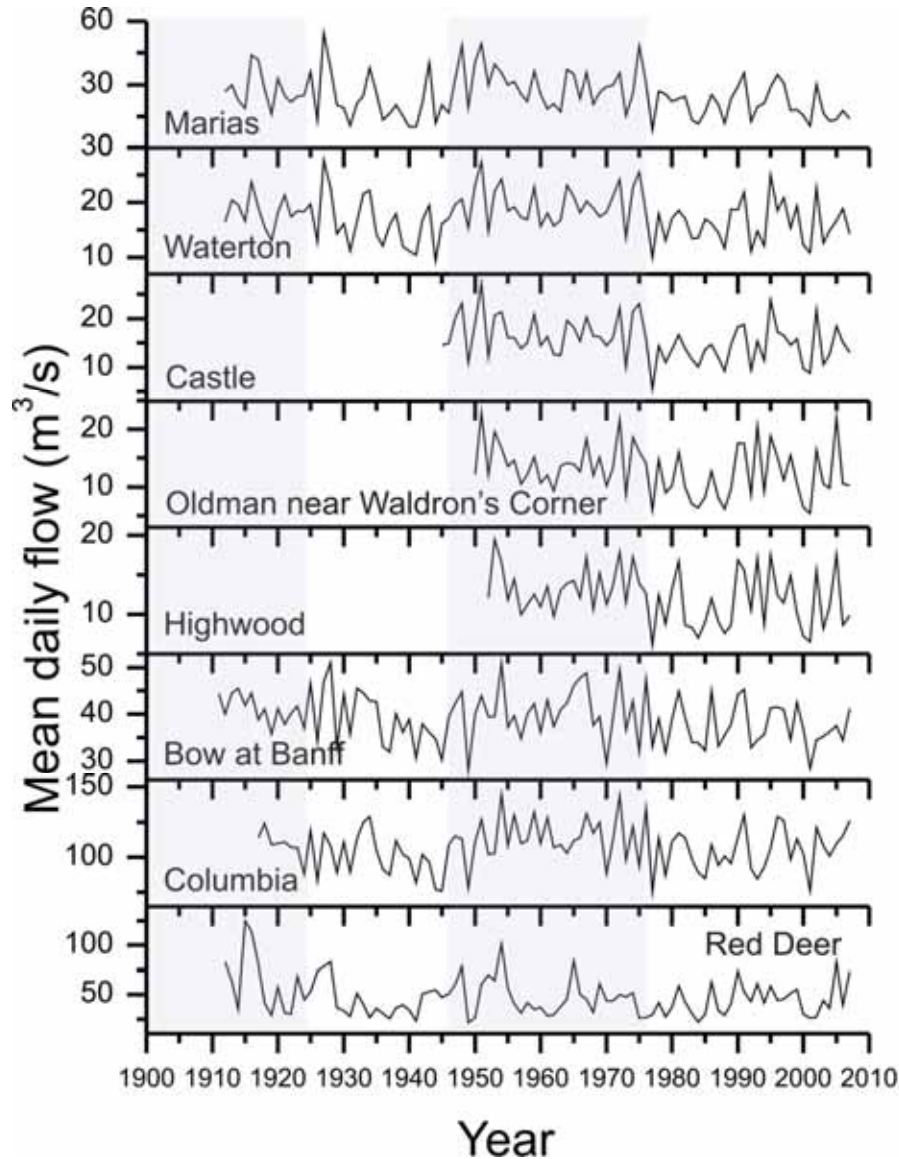
```
Loop { for all |{predictor subsets}| ≤ 6, for all  $p, q$  such that  $p ≤ 8, q ≤ 5$   
      fit GLS model predicting river flow, using subset of predictors and  
      ARMA( $p, q$ ) residuals  
      (arima(river, order=c( $p, 0, q$ ), xreg=predsubset, method=c("ML"))  
    } end Loop
```

Choose model with least **corrected Akaike Information Criterion (AIC_c)** goodness-of-fit statistic.

Assess significance of trend with **Neyman-Pearson** statistic (RP).

following Zheng *et al.* (1997) *Journal of Climate*

24 Southern Alberta streamflow records analyzed so far...



Grey shading of negative phase of PDO

Results

Flow Record	Actual flow record			Naturalized flow record			Human impact /yr
	Record period	Significant linear Trend?	Change %/yr	Record period	Significant linear trend?	Change %/yr	
<i>Marias R. near Shelby, MT</i>	1912-2007	decreasing	-0.26	n.a.			
<i>Waterton R. near Waterton Park</i>	1912-2007	none	-0.05	n.a.			
<i>Castle R. near Beaver Mines</i>	1945-2007	none	-0.04	n.a.			
<i>Oldman R. near Waldron's Corner</i>	1950-2007	increasing	0.43	n.a.			
<i>Highwood R. at Diebel's Ranch</i>	1952-2007	none	0.11	n.a.			
<i>Bow R. at Banff</i>	1911-2007	decreasing	-0.12	n.a.			
<i>Columbia R. at Nicholson, BC</i>	1917-2007	none	-0.001	n.a.			
<i>Red Deer R. at Red Deer</i>	1912-2007	decreasing	-0.22	n.a.			
<i>St. Mary R. at International Boundary</i>	1903-2007	decreasing	-0.46	1912-2001	none	0.006	-0.47
<i>Belly R. near Mountain View</i>	1912-2007	none	0.02	1912-2001	none	0.02	-0.002
<i>Oldman R. near Lethbridge</i>	1912-2007	decreasing	-0.76	1912-2001	decreasing	-0.18	-0.58
<i>S. Saskatchewan R. at Medicine Hat</i>	1912-2007	decreasing	-0.36	1912-2001	increasing	0.05	-0.41
<i>Elbow R. below Glenmore Dam</i>	1911-2007	decreasing	-0.70	1912-2001	decreasing	-0.35	-0.35
<i>Bow R. at Calgary</i>	1912-2007	decreasing	-0.16	1912-2001	decreasing	-0.16	-0.01
<i>Spray R. at Banff</i>	1911-2007	decreasing	-2.20	1912-2001	decreasing	-0.11	-2.09
<i>N. Saskatchewan R. at Edmonton</i>	1912-2007	decreasing	-0.14	1911-2007	decreasing	-0.10	-0.04

15 declines, 7 no trends and only **2 increases**

From analyzing both actual and corresponding naturalized flows, infer direct human impacts:

Human impacts \geq AGW effects

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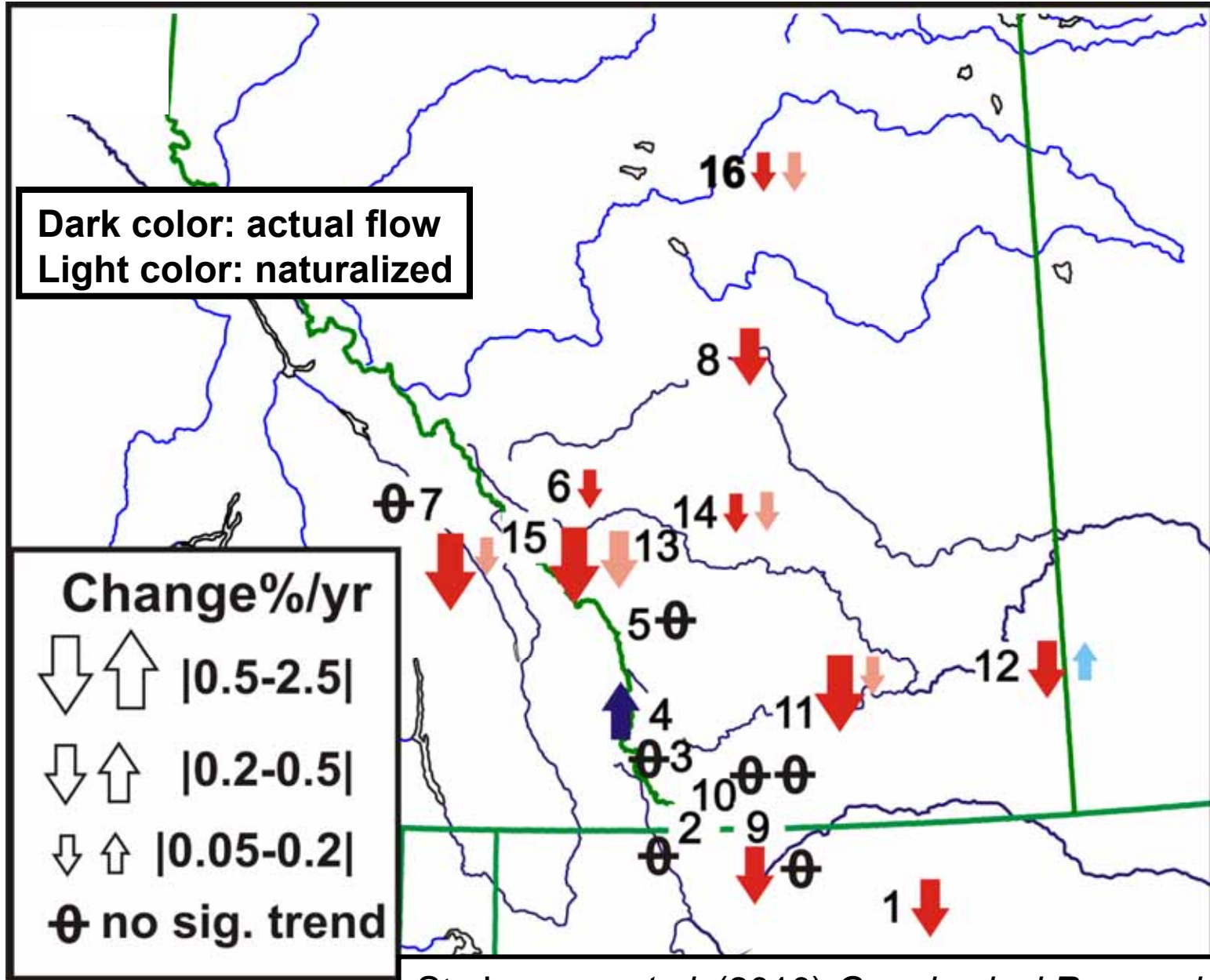
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AGW Human impacts

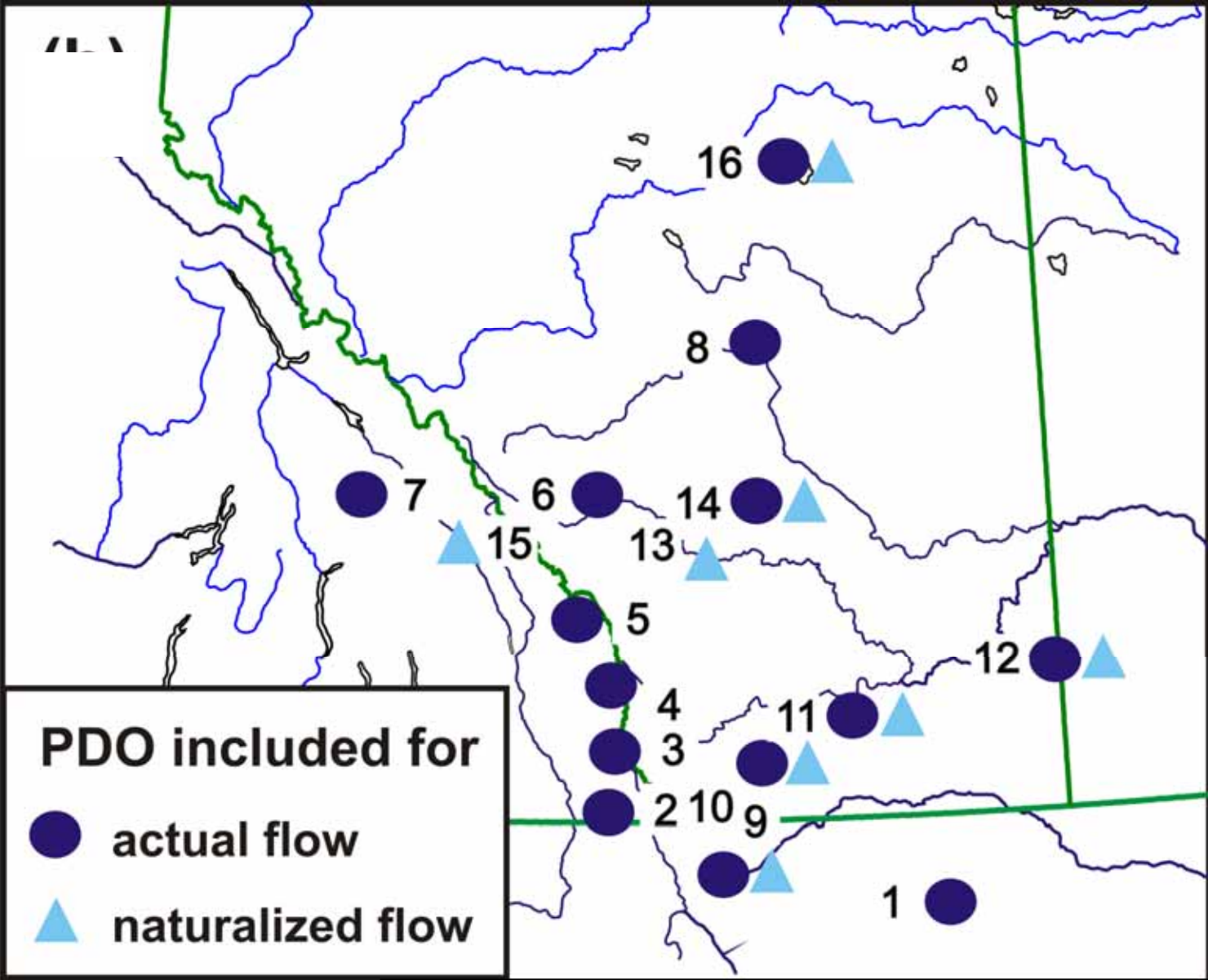
From analyzing both actual and corresponding naturalized flows, infer direct human impacts:

Human impacts \geq AGW effects

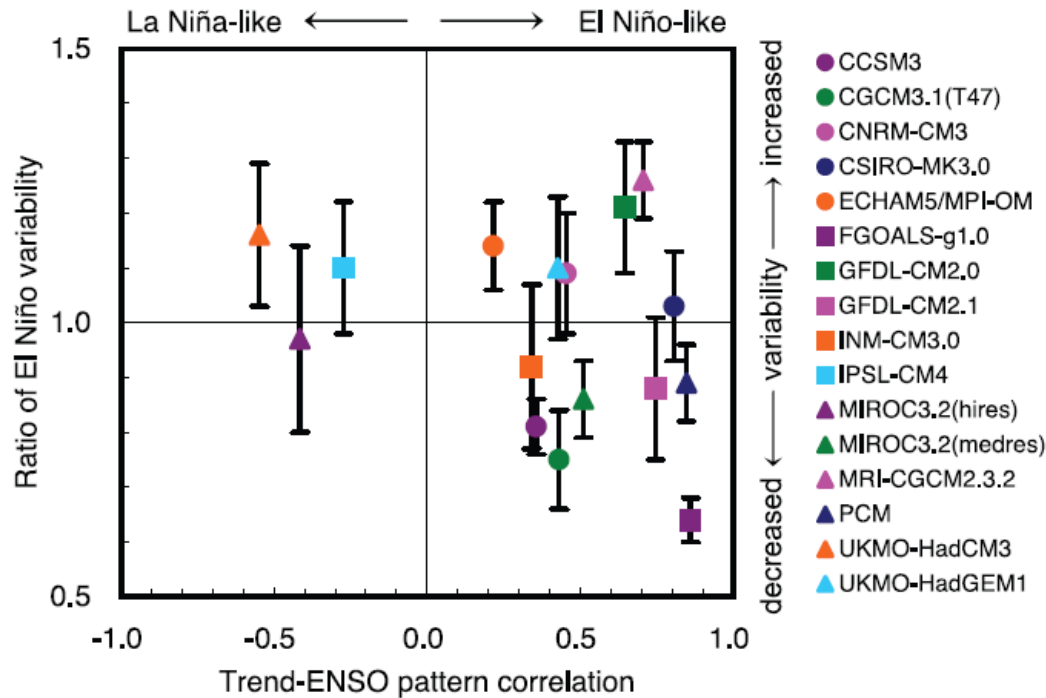
Geographical pattern: Bow River Valley worst?



PDO in optimum predictor subset in all but 2 records:



Future projections under AGW assumptions



An **El Niño**-mean state world (Fig. 10.16 IPCC4)

1. The **PDO** is a function of **ENSO** (Newman *et al.*, 2003; 2007, Schneider and Cornuelle, 2005).

Newman *et al.* (2003) propose PDO is red-shifted ENSO.

More **El Niño**-like conditions => more **warm phase** PDO-like conditions => more frequent **dry** conditions in S. Alberta.

2. The **PDO** and **ENSO** are independent (Zhang *et al.*, 1996, Yu *et al.*, 2007a,b) but they can interact and re-enforce downstream effects (Yu *et al.*, 2007a,b).

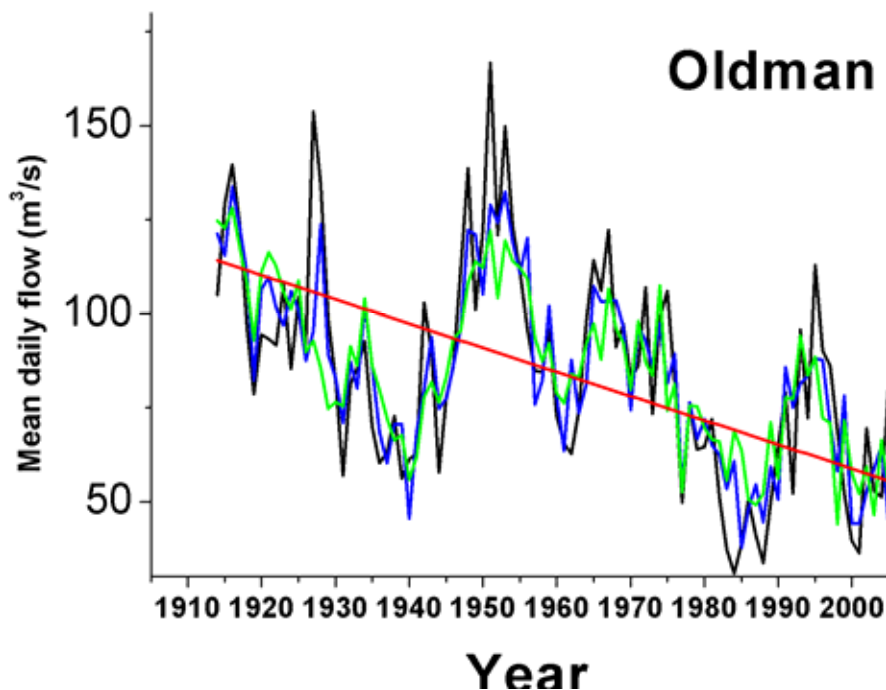
More **El Niño**-like conditions + **warm phase** PDO => more severe **dry** conditions.

GLS regression equation projection

$$\text{Oldman}(Q_t) = 0.11 - 17.17 \cdot \text{trend} - 9.25 \cdot \text{PDO} - 9.52 \cdot \text{PDO}_{P2} - 9.75 \cdot \text{SOI}_{P2} \\ + \text{ARMA}(2,3) \text{ error term } \varepsilon_t$$

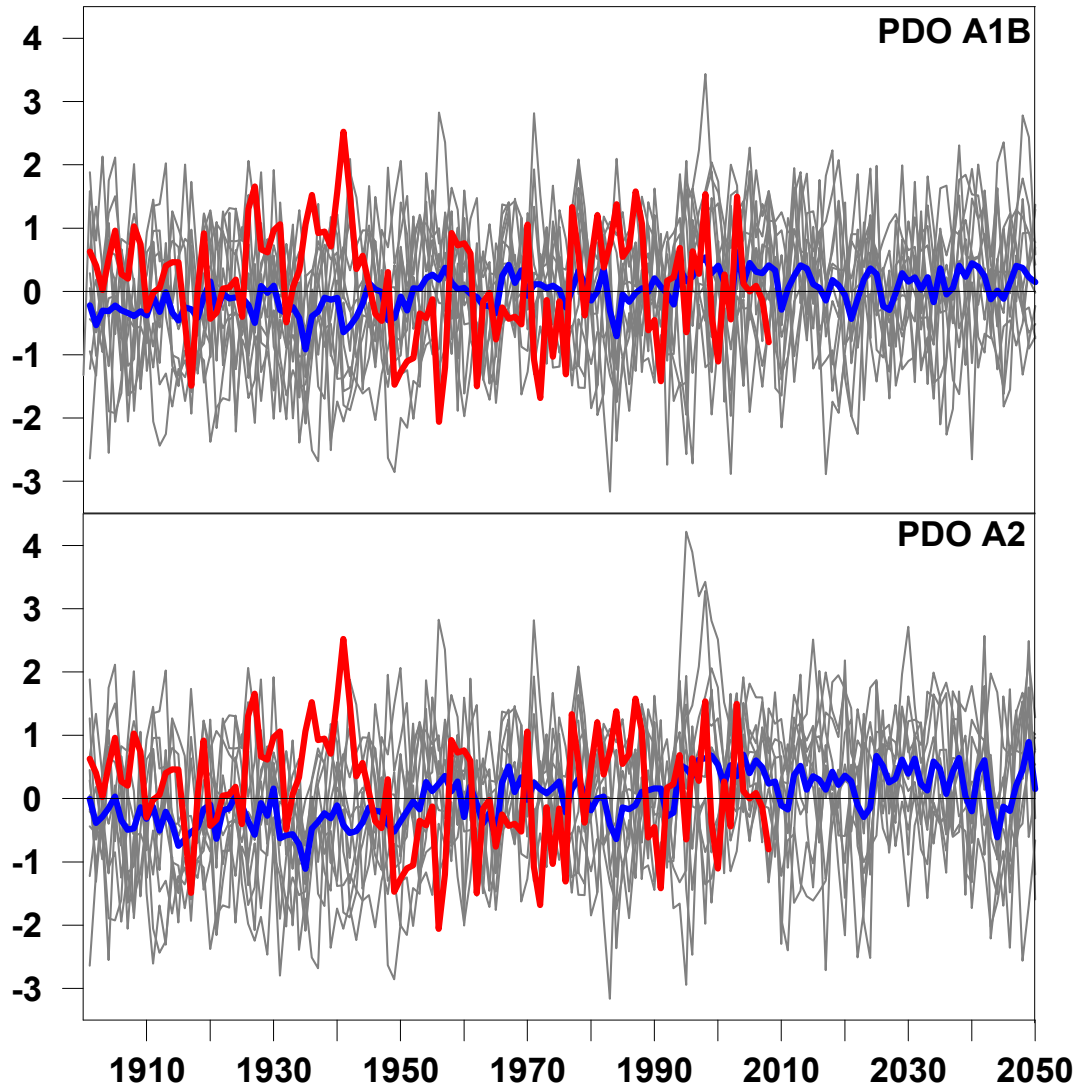
$$R^2_{(\text{regular})} = 0.62 \\ R^2_{(\text{innovations})} = 0.73$$

If have projected **PDO**, **SOI**
(and **NAO**), can project out
streamflow regression equation
~45 yrs



Black line : observed streamflow
Red line: trend
Blue line: fitted GLS model with error term
Green line: fitted GLS model without error

PDO projections: 2010-2050



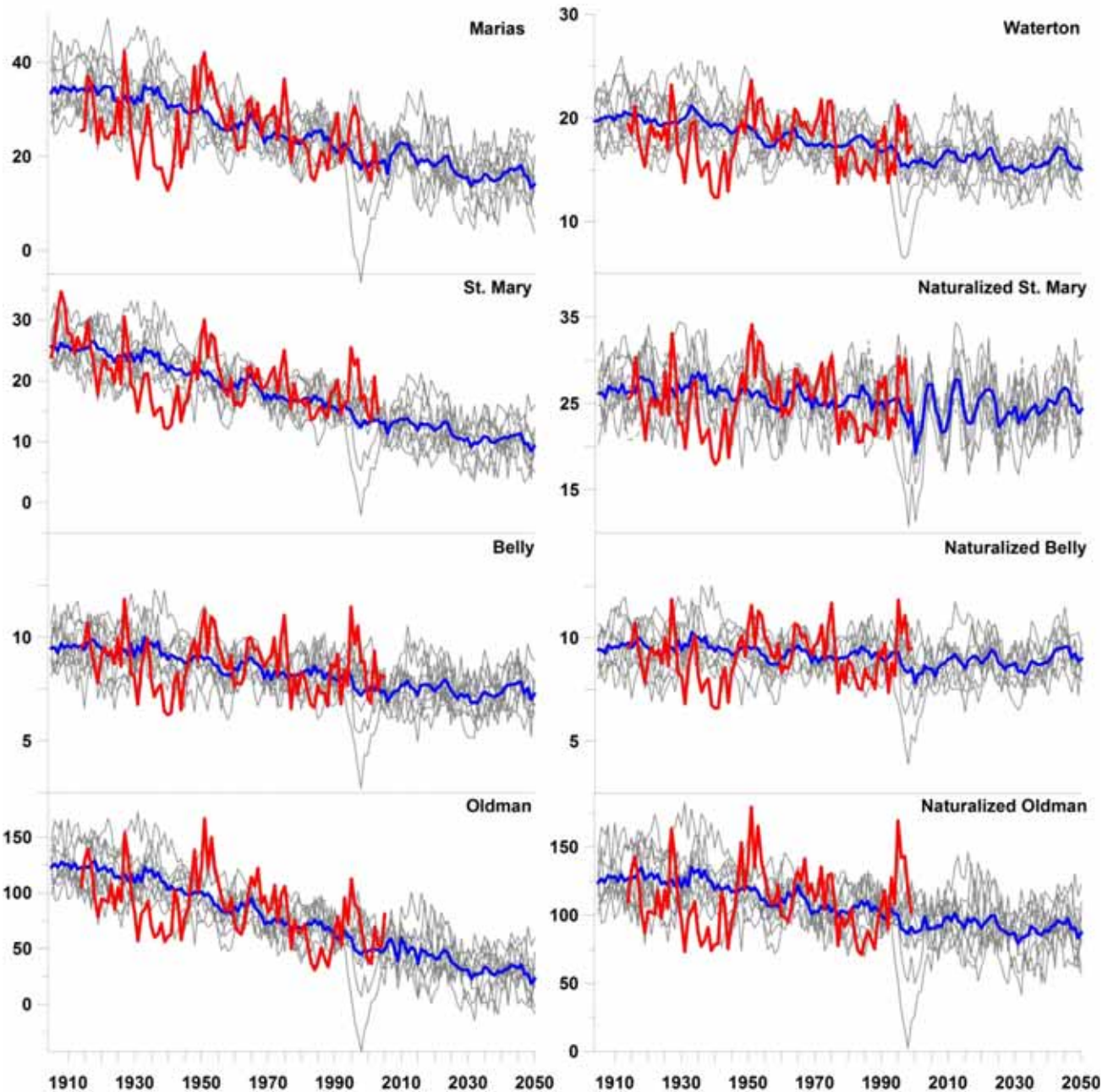
All-model means show shift towards **more positive** PDO-like conditions.

Also have **SOI** and **NAO** projections.

Lapp *et al.* (*in prep. a*)
Geophysical Research Letters

Red line: observed PDO
Grey lines: individual GCM runs PDO
Blue line: all-model mean PDO

South Saskatchewan streamflow projections



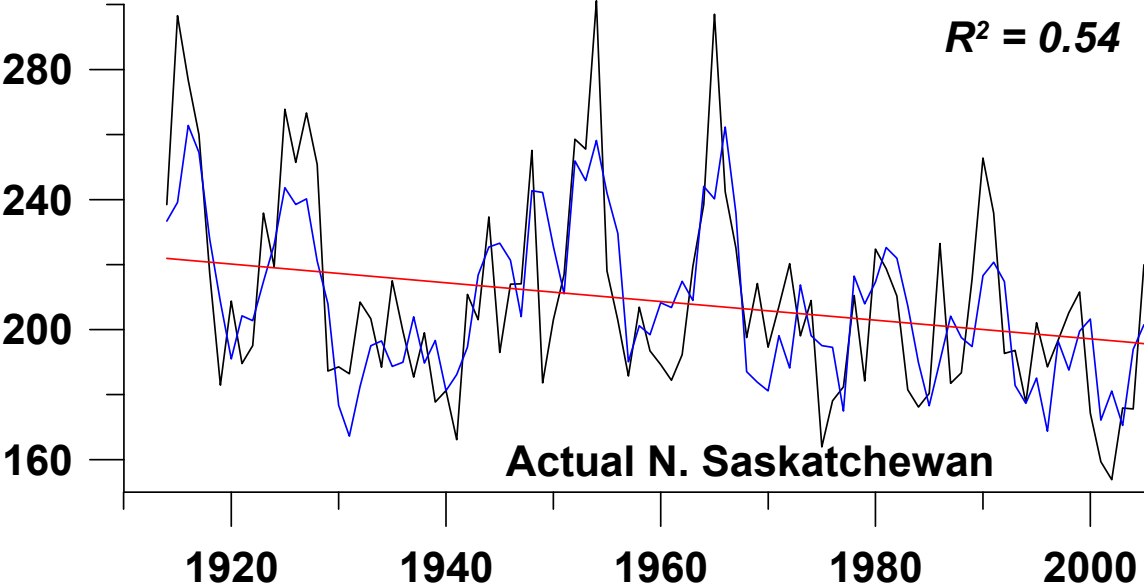
Idea: using the best 8 streamflow GLS equations ($R^2 > 0.64$) project for 2010-2050

A2 emissions scenario:
6 of 8 all-model means show **declines**, no increases.
A1B same.

Lapp *et al.* (in prep. b)

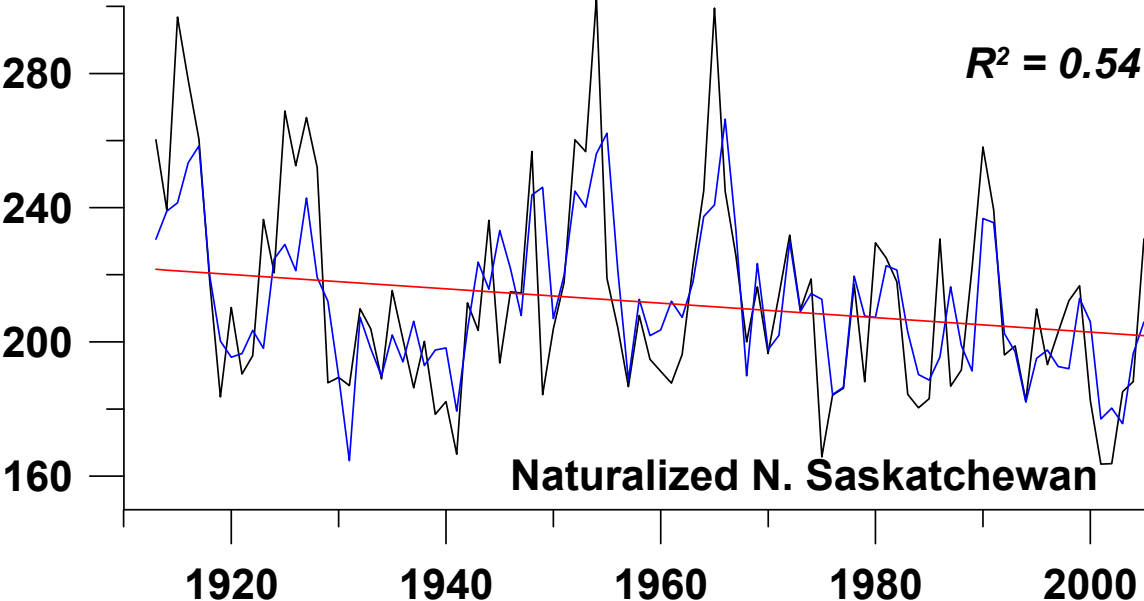
Red line: observed streamflow
Grey lines: individual GCM runs
Blue line: all-model mean streamflow

North Saskatchewan River Trends



more GLS analysis
in progress

significant
declining trends
in observed data.



Black line : observed streamflow
Red line: trend
Blue line: fitted model with error term

Conclusions

- **PDO** has a large effect on Southern Alberta streamflow.
- There are **15 decreasing trends**, **7 no trends**, and **2 increasing trends** detected in the 24 S. Alberta instrumental streamflow records.
- Most streamflows are **declining** due to hydroclimatic changes (from AGW) and severe human impacts, which are of the same order of magnitude as the AGW changes, if not greater.
- Regardless of the exact relationship between the **PDO** and **ENSO**, the change to a more **El Niño**-dominated AGW world is expected to have major impacts (probably **decreases**) on southern Alberta riverflow, given its strong connection to the **PDO**.
- Our GCM projections show a shift towards **more positive-phase PDO mean state**. GLS streamflow projections show mainly **declines (6 out of 8)** and no increases.



Thanks to Mike Seneka,
Xiaogu Zheng, Chris Ray,
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and our sponsors:

