Early 21st Century Southern Alberta Streamflow Projections from GLS Modeling of Inter-annual to Decadal Variability

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

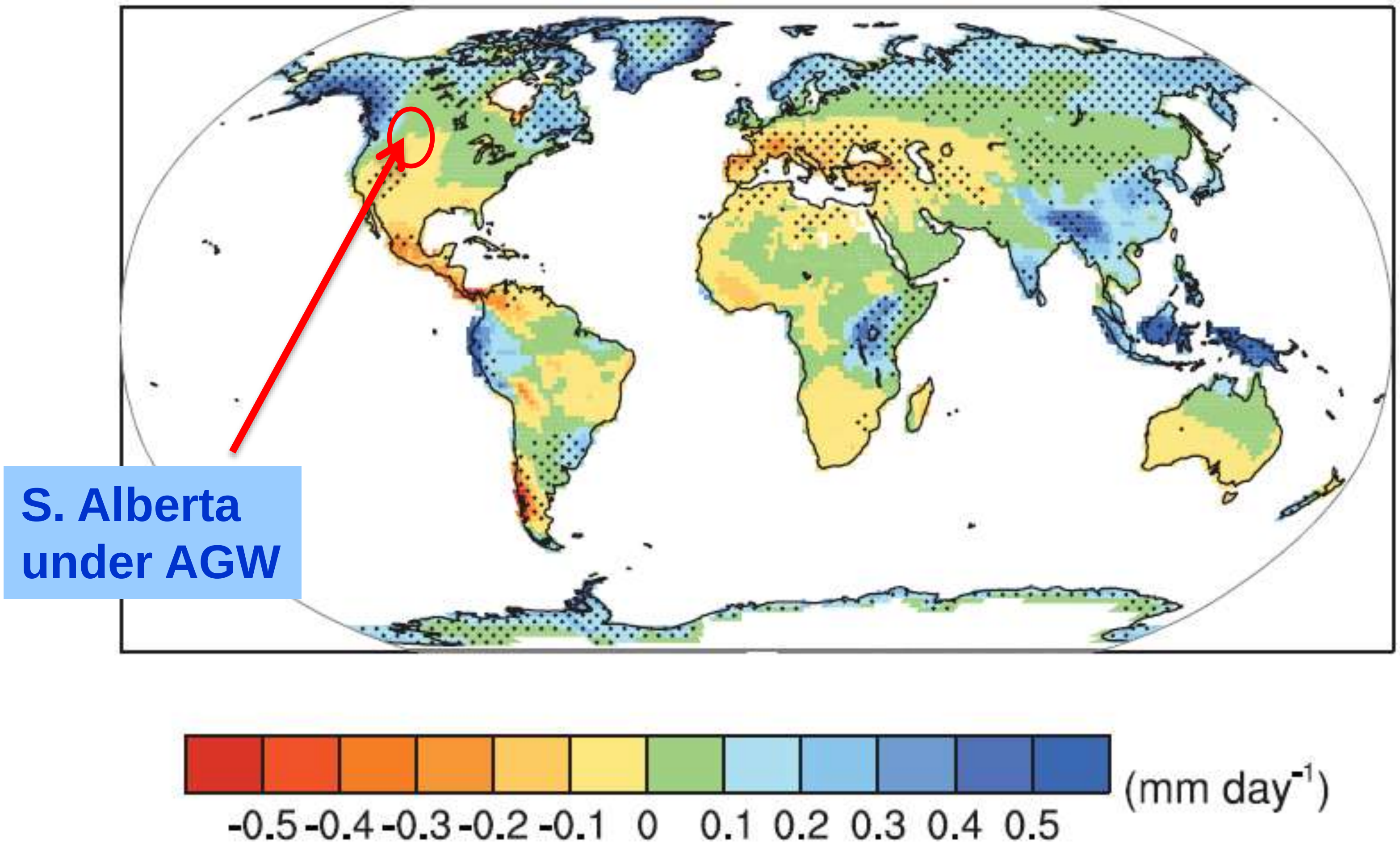
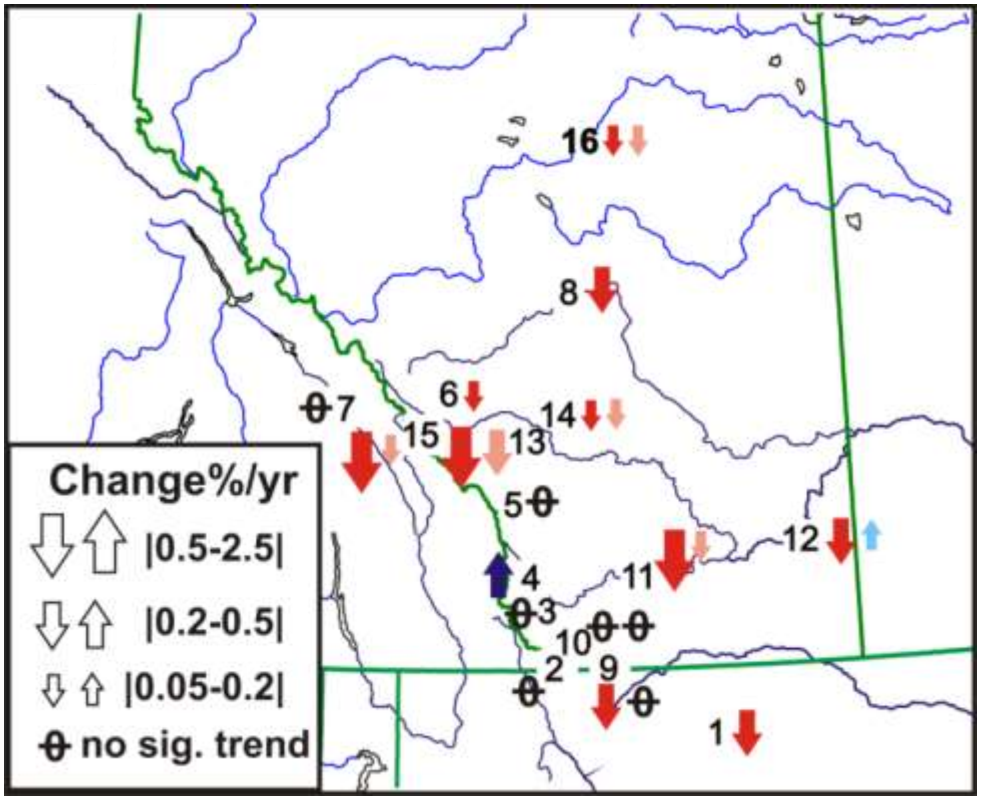


Fig. 10.12 IPCC 4. Multi-model mean changes in runoff (mm/day). Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999.

Introduction:

Southern Alberta river basins are located in a **transitional** region of GCMs.

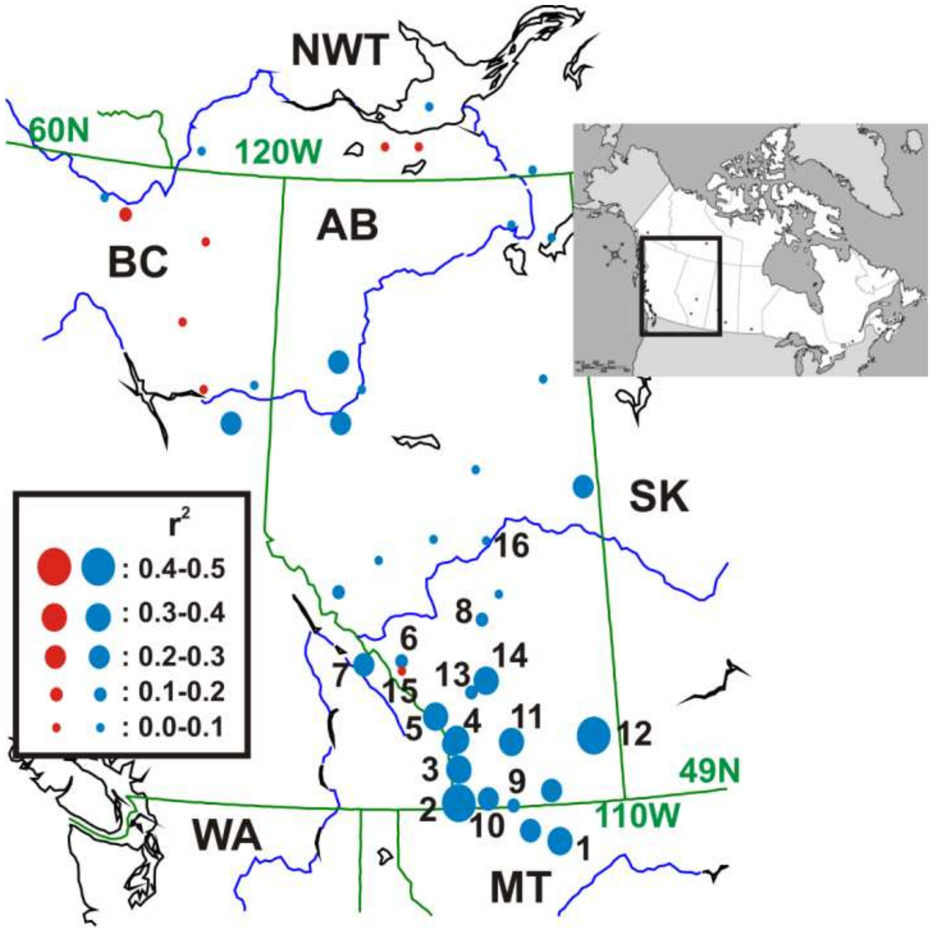
Recent research showed **declining trends** in S. Alberta instrumental records (Zhang *et al*., 2001; Rood *et al*., 2005, 2008; Schindler and Donahue, 2006; St. Jacques *et al*., 2010)



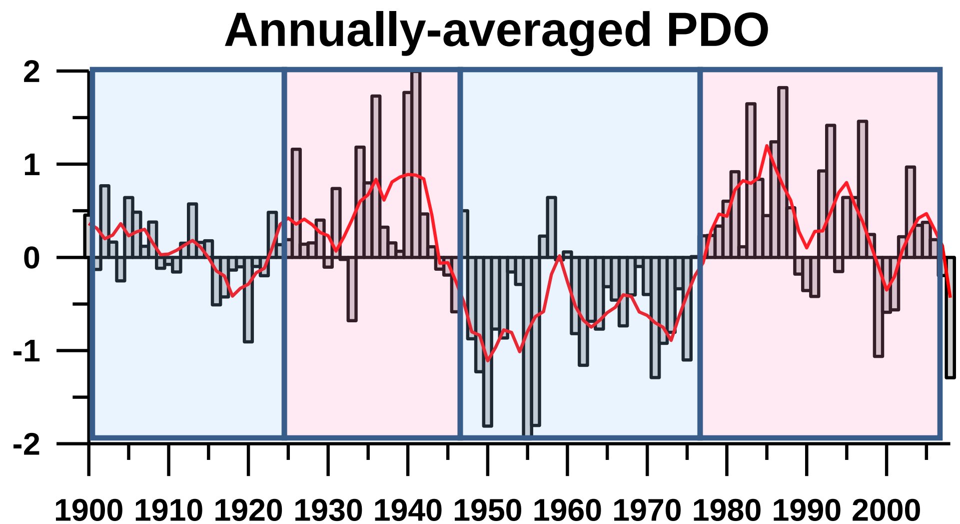
St. Jacques *et al*. (2010) *Geophysical Research Letters*

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

A strong negative relationship exists between the two

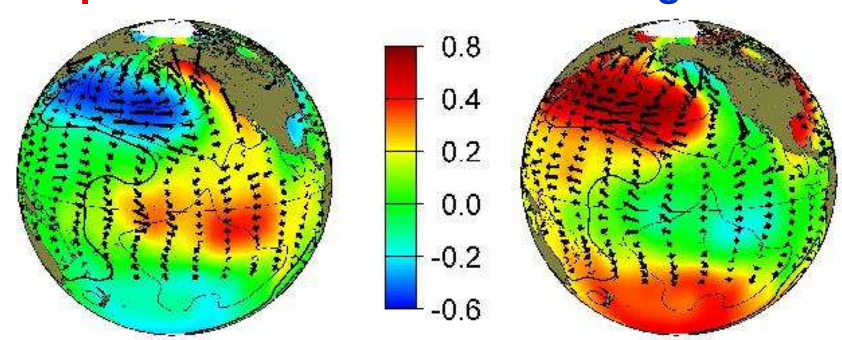


Correlations between same yr PDO and rivers
Both filtered by 5-yr binomial smoother



Warm positive PDO

Cold negative PDO



http://jisao.washington.edu/pdo/

The *El Nino-Southern Oscillation (ENSO)* also impacts streamflow in Southern Alberta.

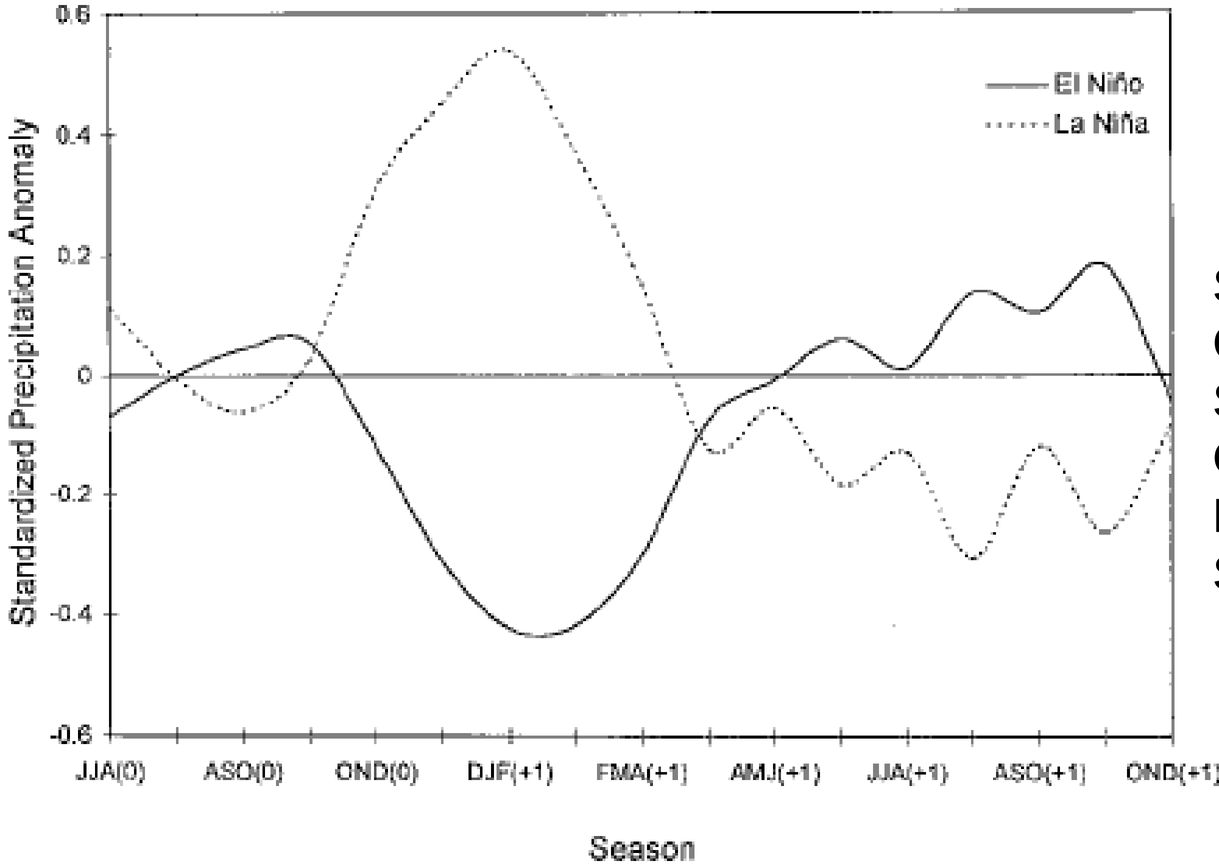
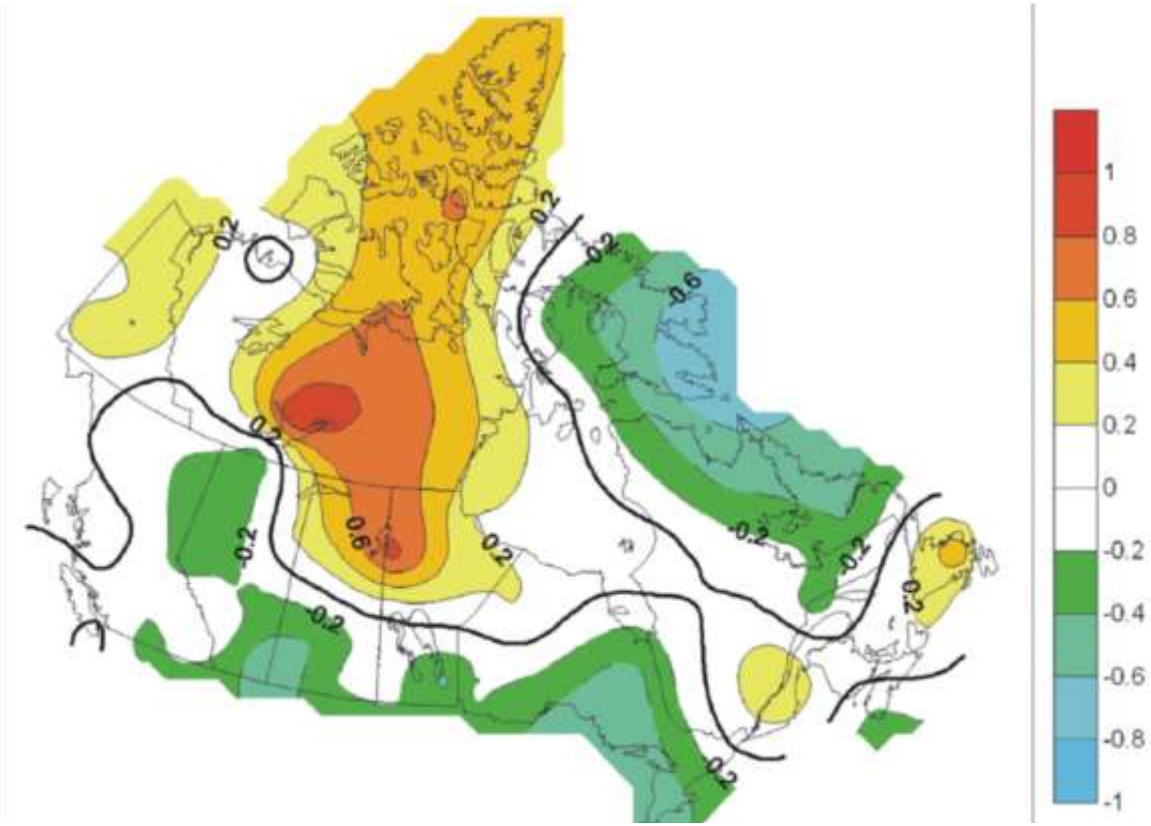


Fig. 4. Seasonal march of the areally averaged composite standardized precipitation anomalies over southern Canada from JJA of the El Niño/La Niña onset year [JJA(0)] to OND of year +1 with respect to the onset [OND(+1)]. El Niño (solid) and La Niña (dashed). See text for definition of southern Canada.

Shabbar *et al*., 1997
Cayan *et al*., 1999
Shabbar and Skinner, 2004
Gobena and Gan, 2006
Bonsal and Shabbar, 2008
St. Jacques *et al*., 2010

Shabbar *et al*., 1997

The *Arctic Oscillation/North Atlantic Oscillation (AO/NAO)* is yet another climatic impact on streamflow in Alberta.



Déry and Wood, 2004
Macias Fauria and Johnson, 2007
Bonsal and Shabbar, 2008
St. Jacques and Sauchyn, 2009

Figure 3. Correlation coefficients between winter (January to March) NAO (as determined by the first rotated EOF of Northern Hemisphere mean sea level pressure) and concurrent precipitation over Canada for the period 1950 to 1999. Correlations greater than 0.36 in magnitude are significant at the 5% level.

Bonsal and Shabbar, 2008

Idea

Model Southern Alberta river discharge using regression equations with the **PDO**, **ENSO** and **AO/NAO**, and a **trend** as the predictors.

If model explains a lot of the variance (*i.e.*, **high R^2_{inv} > 0.64**), it's a worthwhile model.

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

Examined **29 Northern Rocky Mountain rivers**

Heavy human impact in the region, so**:**

(1) examine **unregulated rivers,** and

(2) examine **actual regulated** flows,
only if corresponding **naturalized** flows exist (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

arima(*stats*) package in R

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

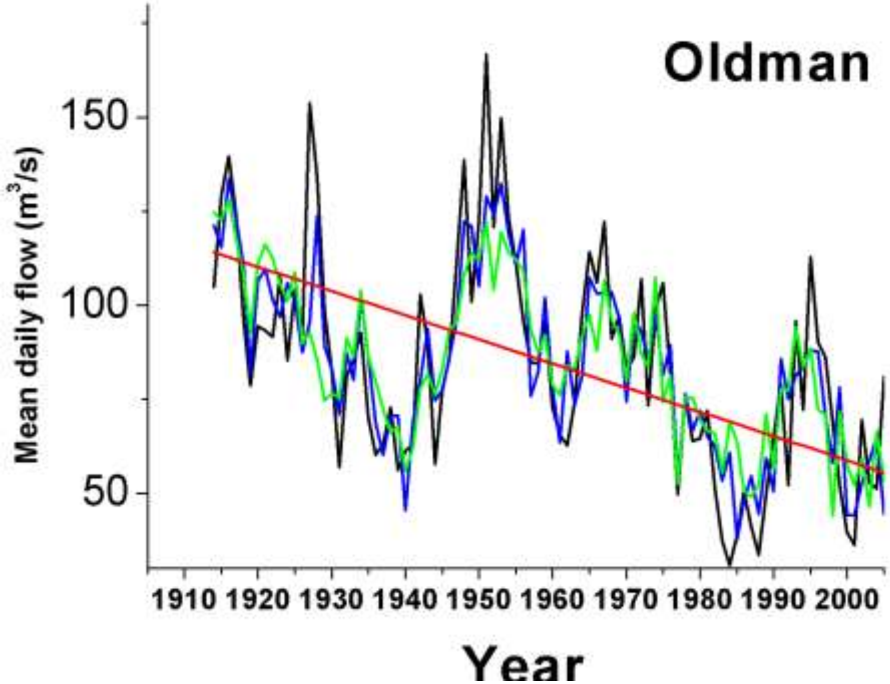
following Zheng *et al.* (1997) *Journal of Climate,* also St. Jacques *et al*. (2010).

GLS regression equation projection

$$\textbf{Oldman}(Q_t) = 0.11 - 17.17^{*}\textbf{trend} - 9.25^{*}\textbf{PDO} - 9.52^{*}\textbf{PDO}_{P2} - 9.75^{*}\textbf{SOI}_{P2}$$

$$+ \textbf{ARMA(2,3) error term } \varepsilon_t$$

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

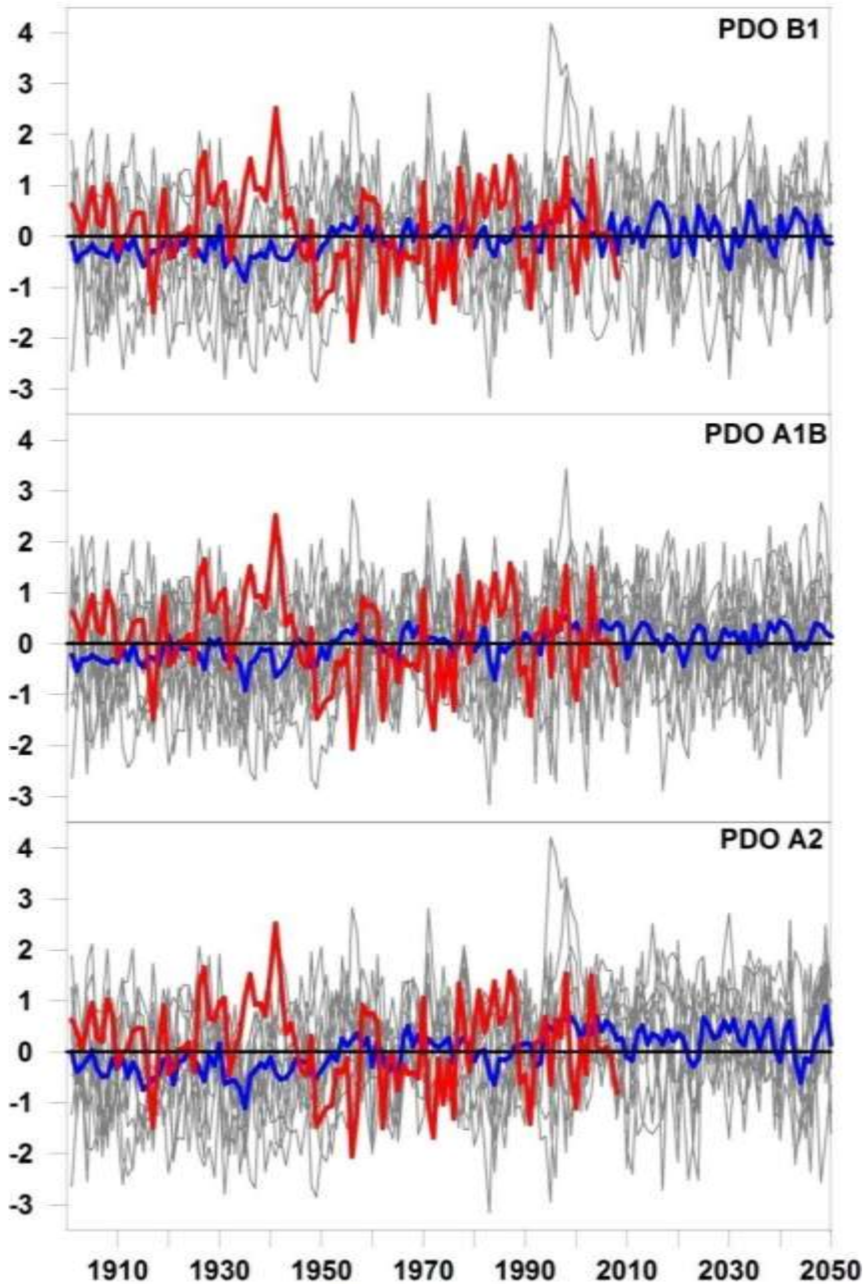


Idea: use archived CMIP3 GCM data to project **PDO**, **SOI**, and **NAO**.

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 term

PDO projections: 2010-2050



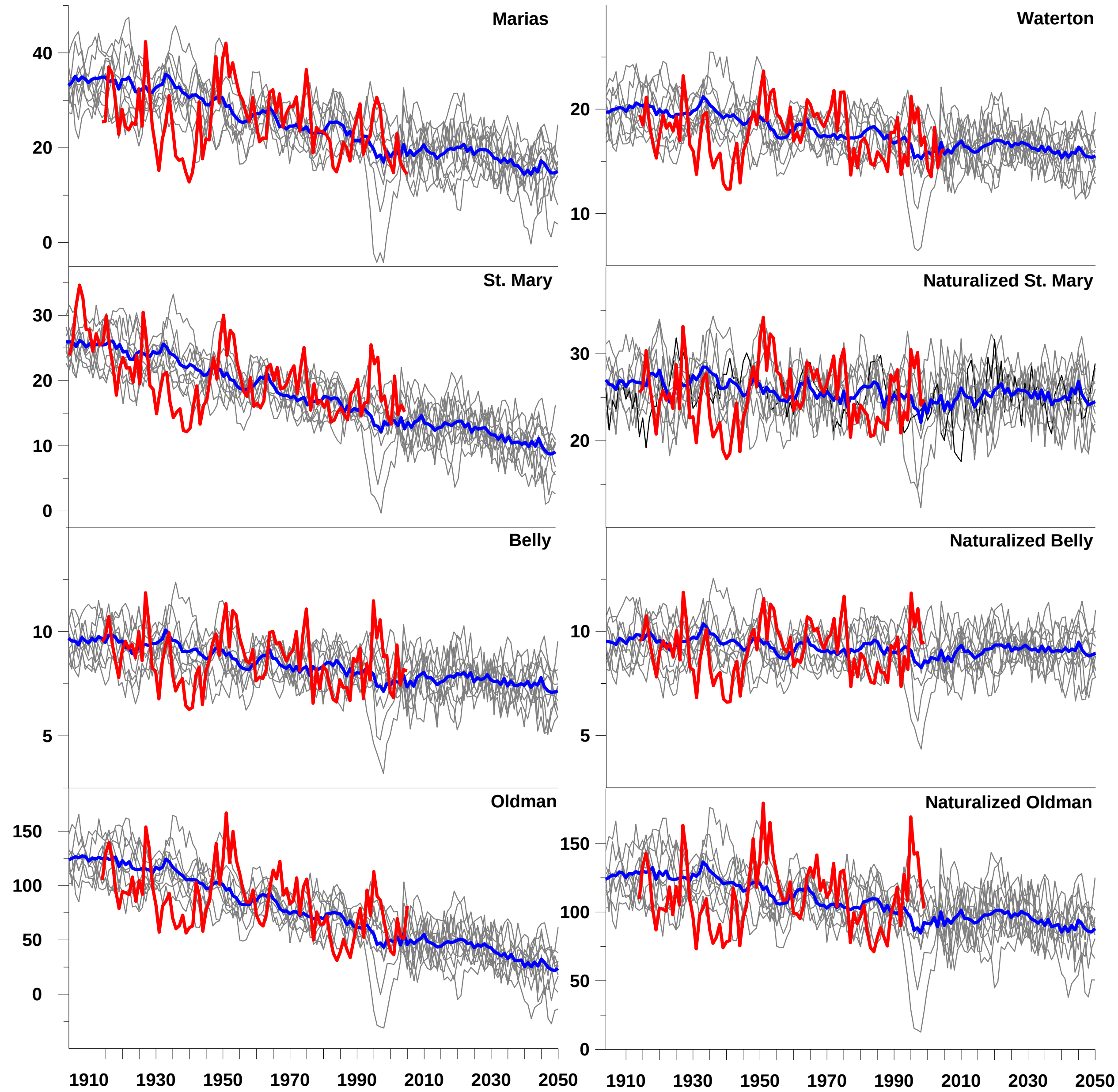
All-model means show shift towards **more positive PDO-like conditions**.

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

Lapp *et al*. (*in review*) *International Journal of Climatology*

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

Southern Alberta streamflow projections



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

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

A1B, **B1** same results**.**

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

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

Take-away message

- **PDO** has a large effect on Southern Alberta streamflow.

- Our GCM projections show a shift towards **more positive-phase PDO mean state** in the full range of emissions scenarios: B1, A1B, A2.

- GLS streamflow projections show mainly **declines** (**6 out of 8**) and no increases.

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