Northern Rocky Mountain streamflow records: global warming trends, human impacts or natural variability?

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PARC

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

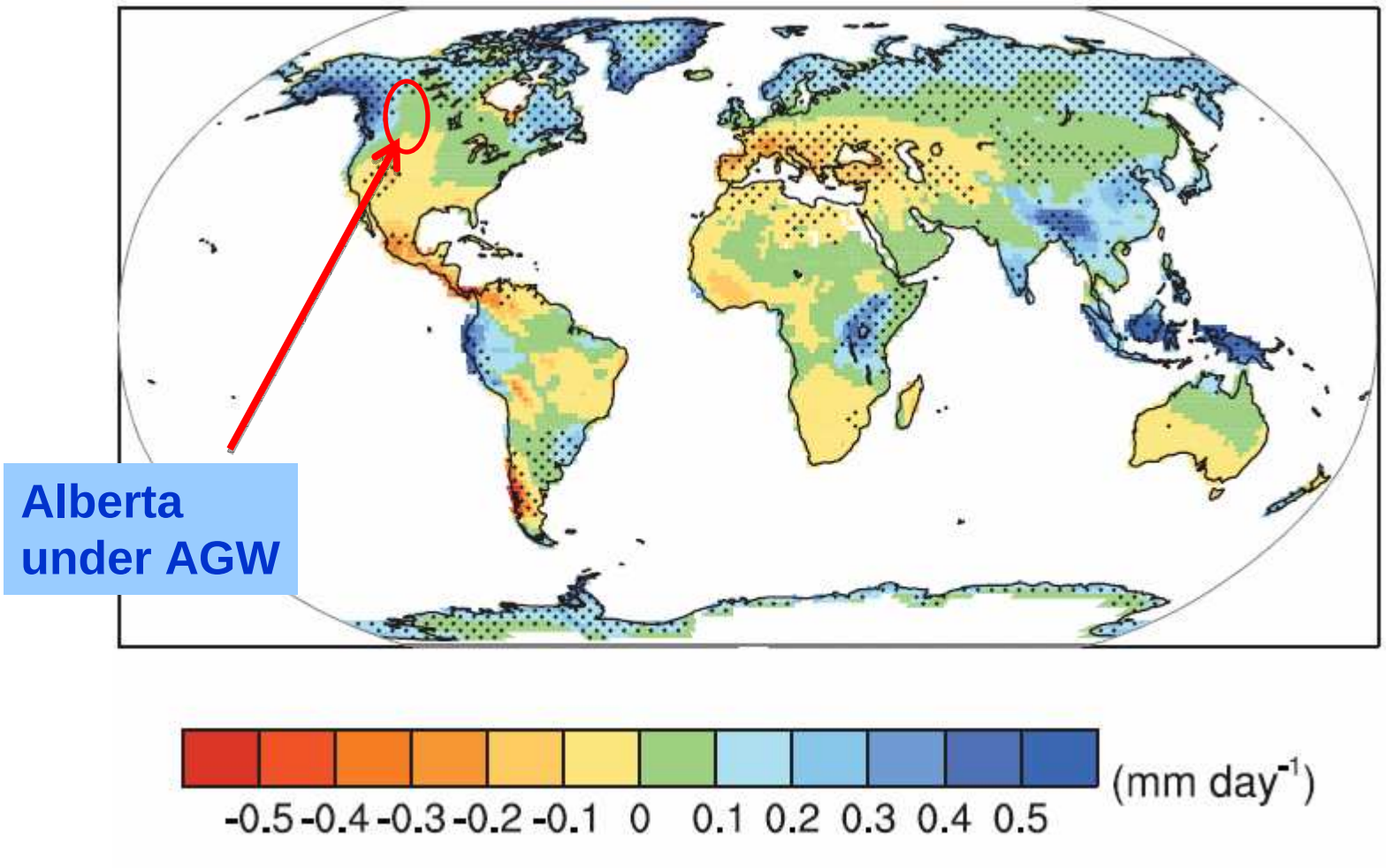


Fig. 10.12 IPCC 4. Multi-model mean changes in runoff (mm/day). Changes are annual means for the SRES A1B scenario for the period 2080 to 2099 relative to 1980 to 1999.

Introduction:

Southern Alberta is located in a **transitional** region of GCMs.

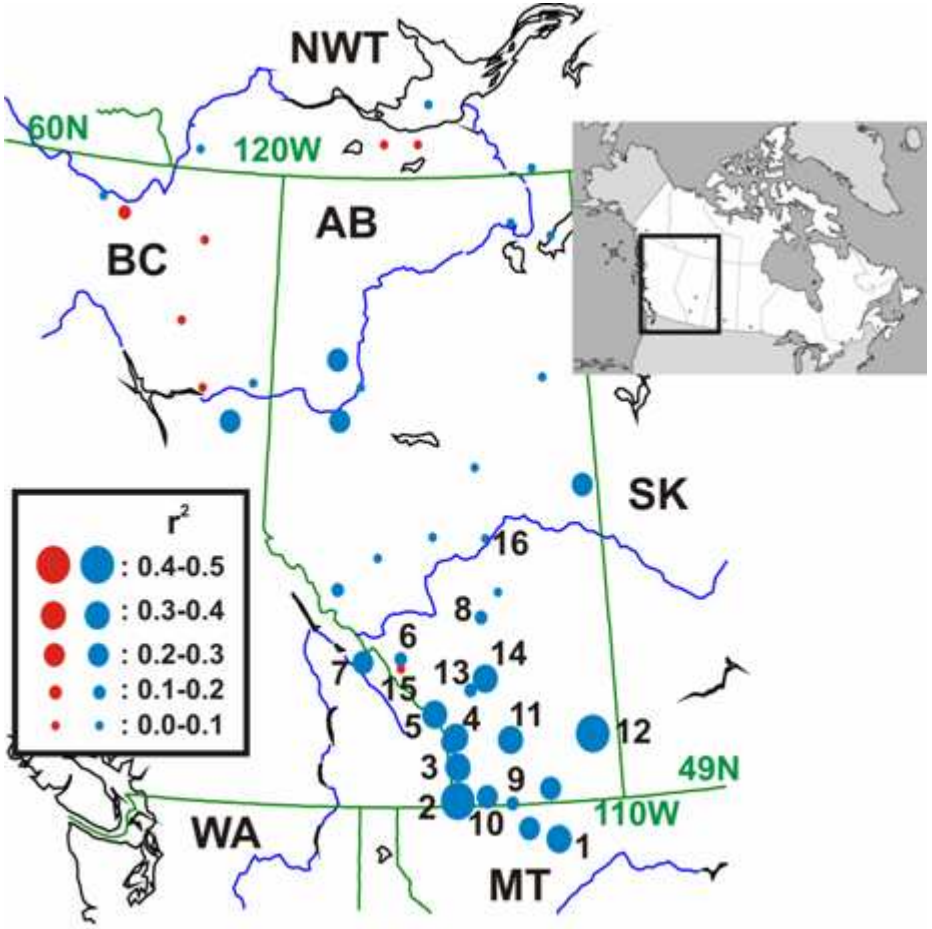
Are there any developing trends in the instrumental streamflow records?

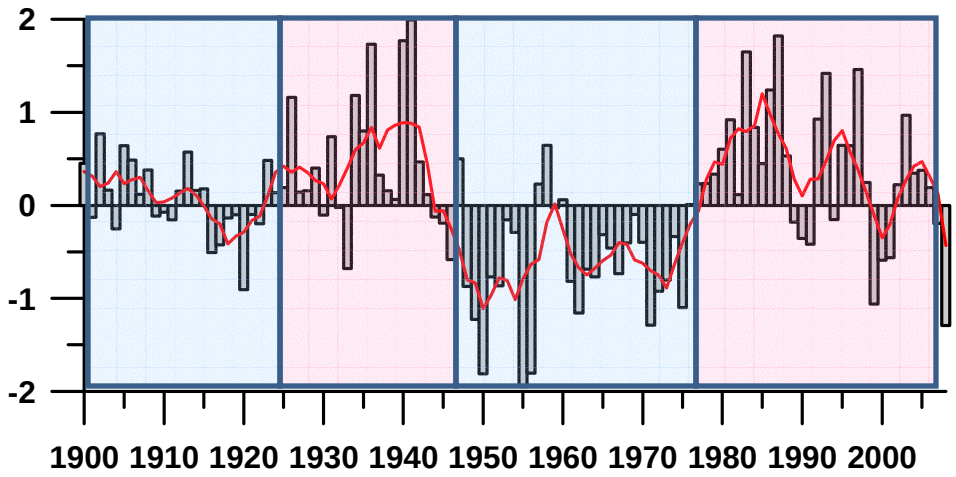
Recent research showed **declining trends** in Alberta instrumental records
(Zhang *et al*., 2001; Rood *et al*., 2005, 2008; Schindler and Donahue, 2006)

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.

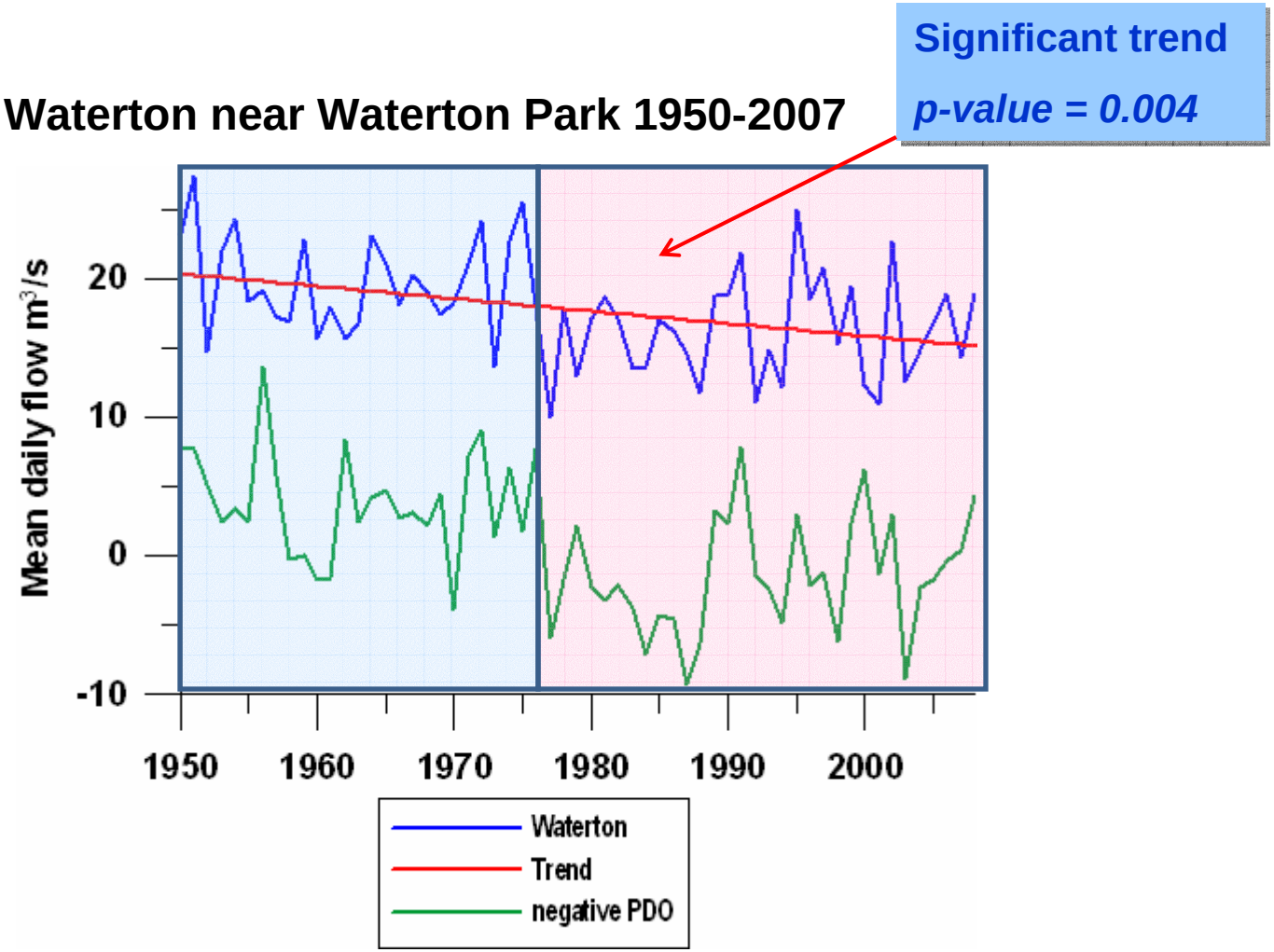
A strong negative relationship exists between the two

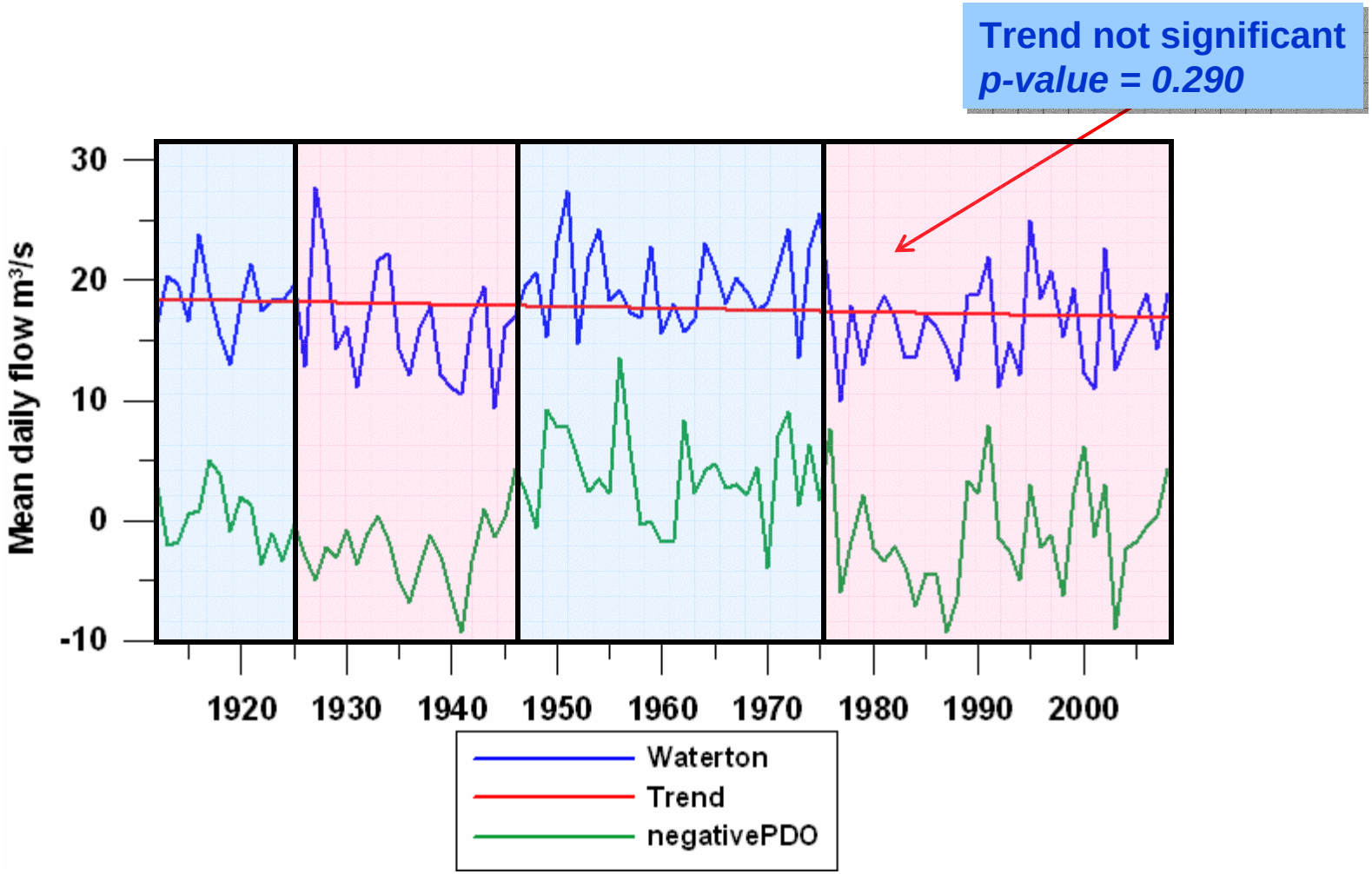




Correlations between same yr PDO and rivers
Both filtered by 5-yr binomial smoother

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





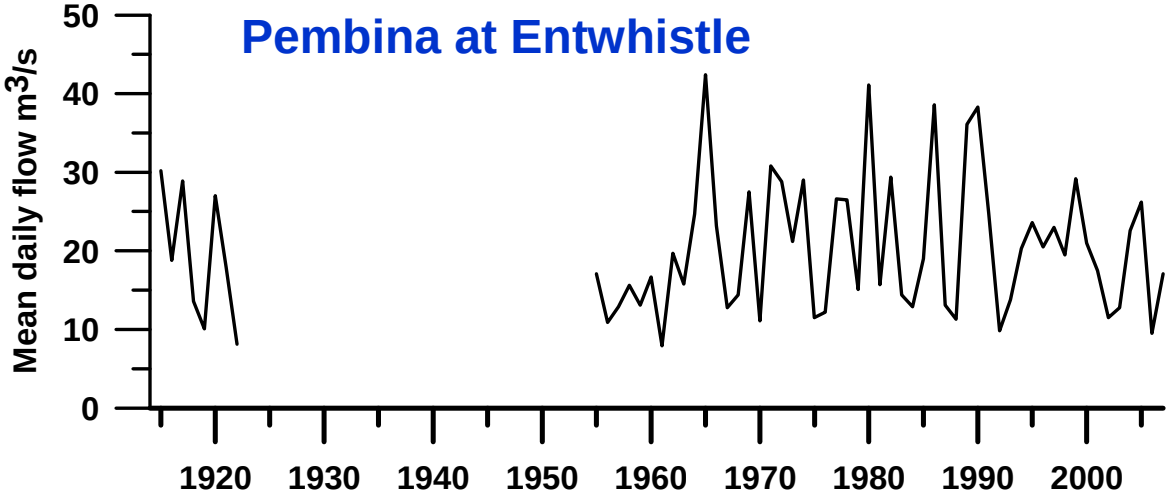
Many Alberta instrumental records begin in the 1950s, or omit the 1930s and 1940s (periods of high positive PDO, hence low AB streamflow).

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

Further problems with the instrumental streamflow records:

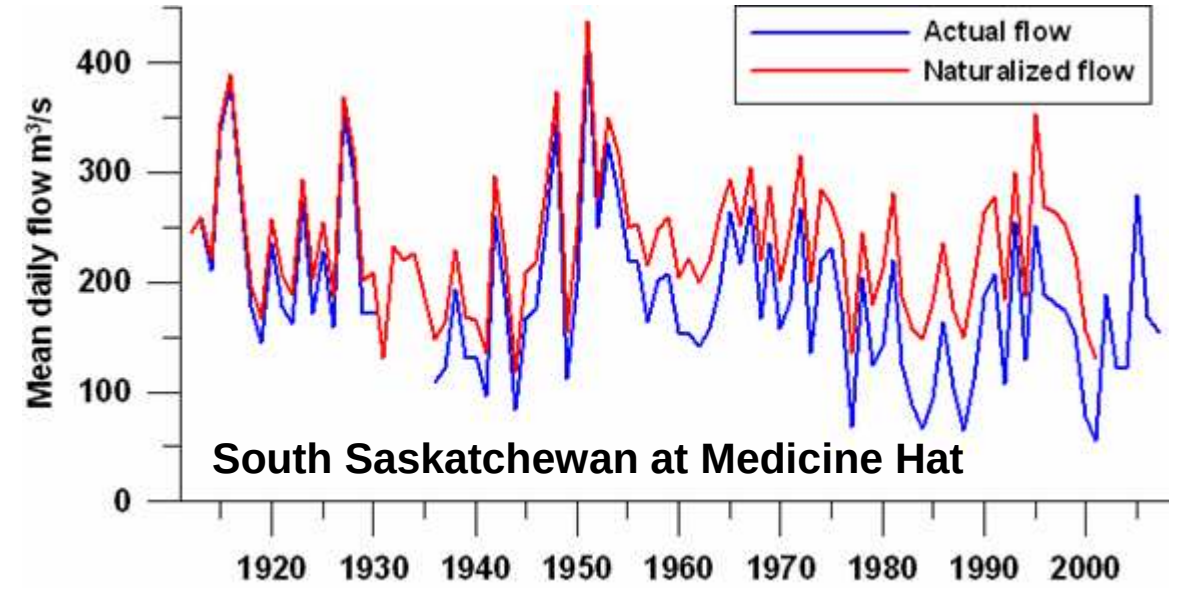
- ***Short*** **typically have periods of record of ~40-50 years in N. Alberta and at most ~95 years in S. Alberta.**

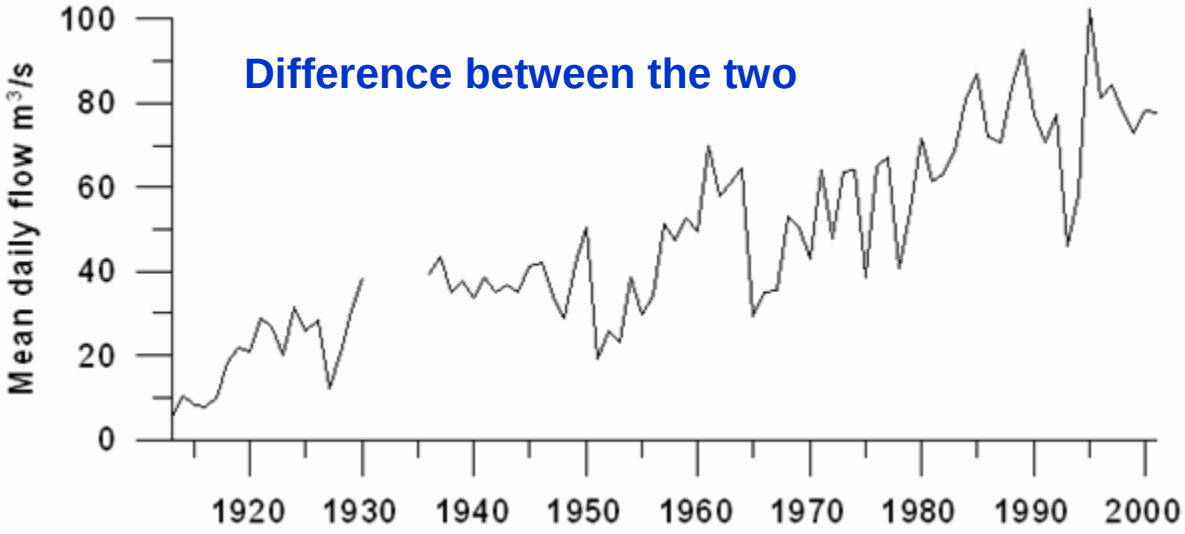
- ***Gappy*** **especially in 1930s (economic collapse) and the 1940s (war).**



- ***Frequent serial correlation in the residuals*** **therefore classical linear regression and Mann-Kendall non-parametric methods will disproportionately reject null hypothesis of no 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, overlaying and obscuring natural hydrology.**





Naturalized record courtesy of

Alberta Environment

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 Ocean Index), **NAO** (North Atlantic Oscillation). Climate variables also low-pass filtered and leading streamflow by **-1, 0, +1, +2** years.

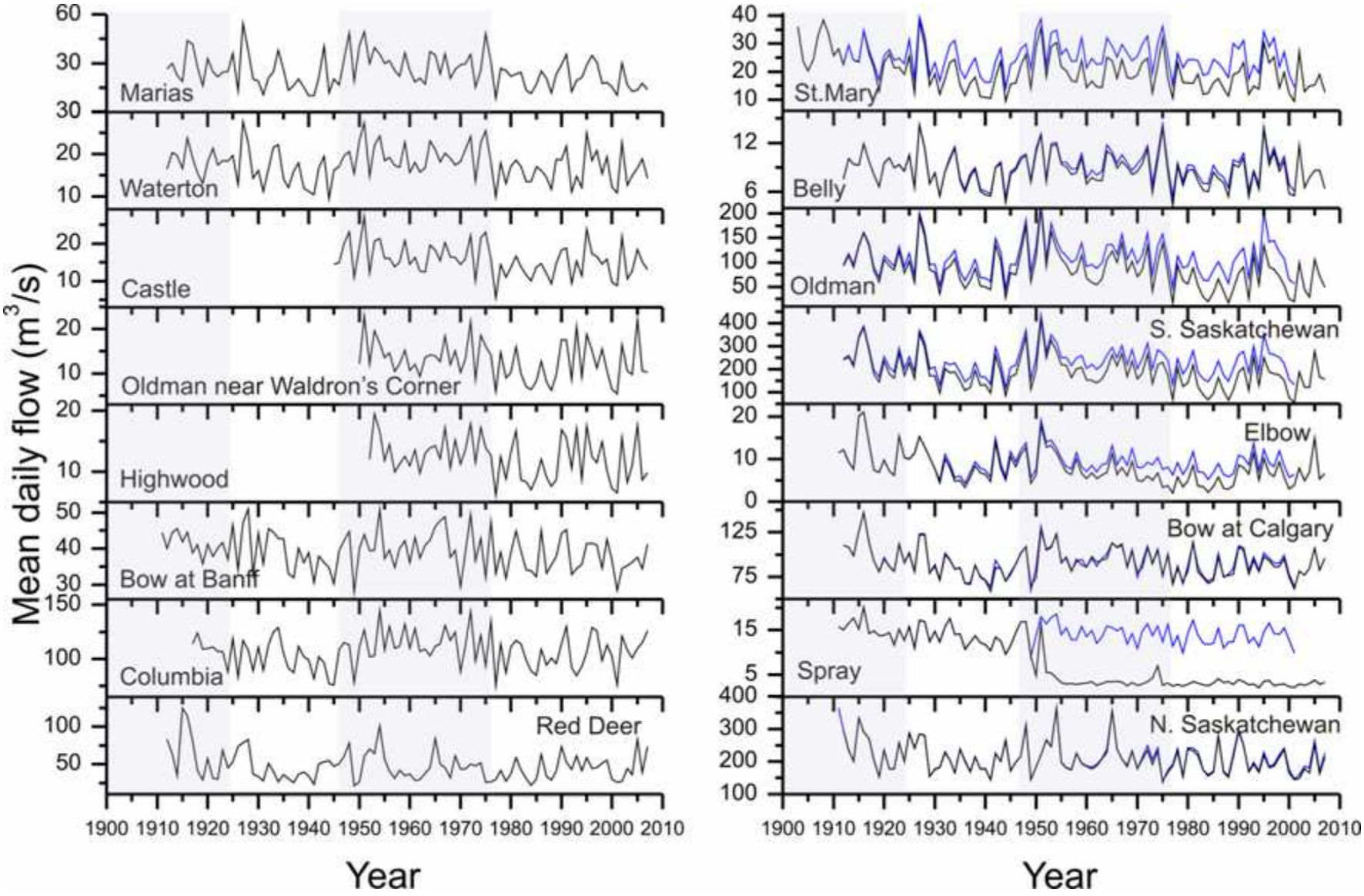
For each river
Loop { for all |{predictor subsets}| ≤ *6*, for all *p,q* such that *p* ≤ *8, q* ≤ *5*
fit GLS model predicting river flow, using subset of predictors and
ARMA(*p,q*) residuals
(arima(river,order=c(*p,*0,*q*), xreg=predsubset, method=c("ML"))
} end Loop

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



Grey shading of negative phase of PDO

Results

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

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AGW **Human impacts**

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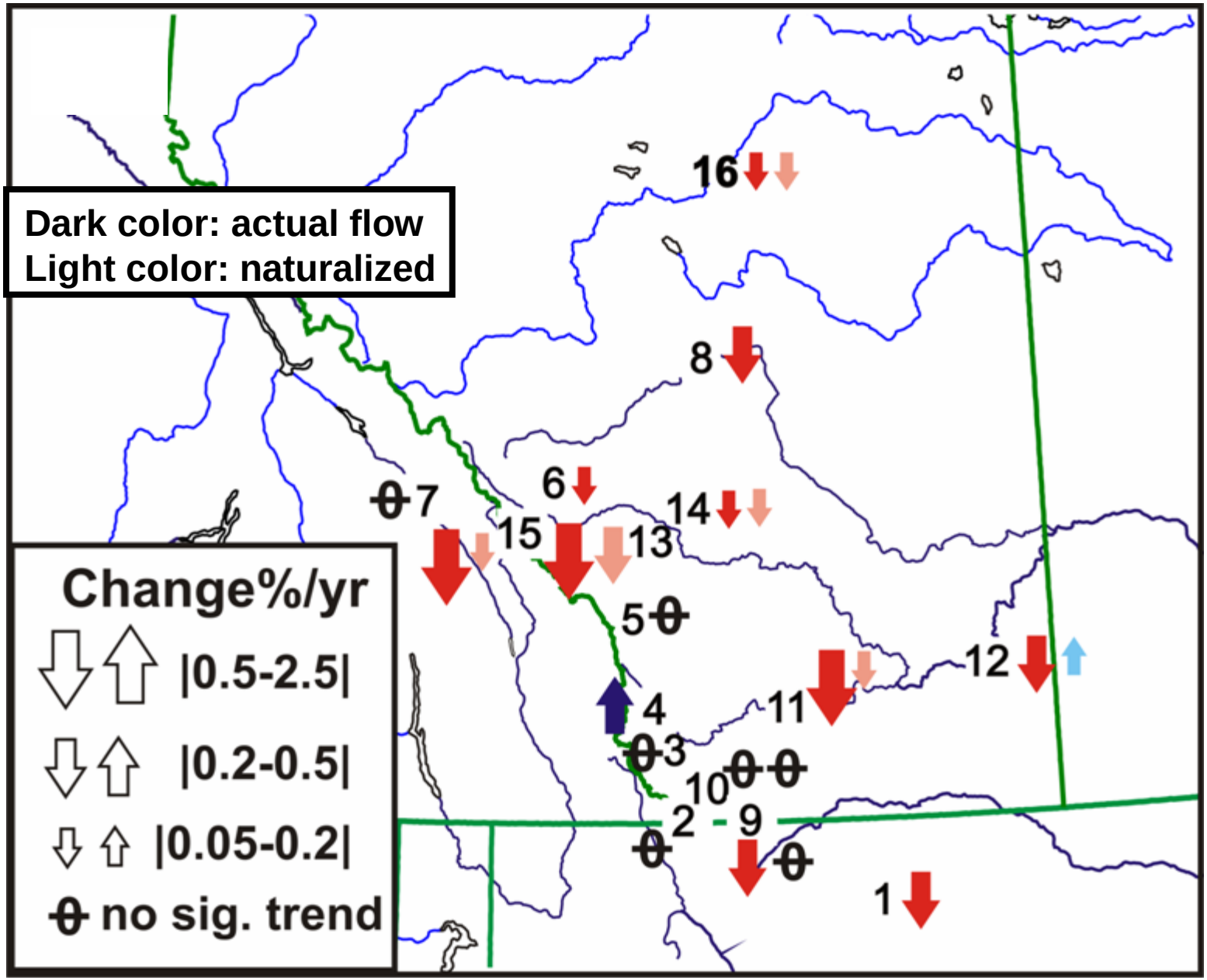
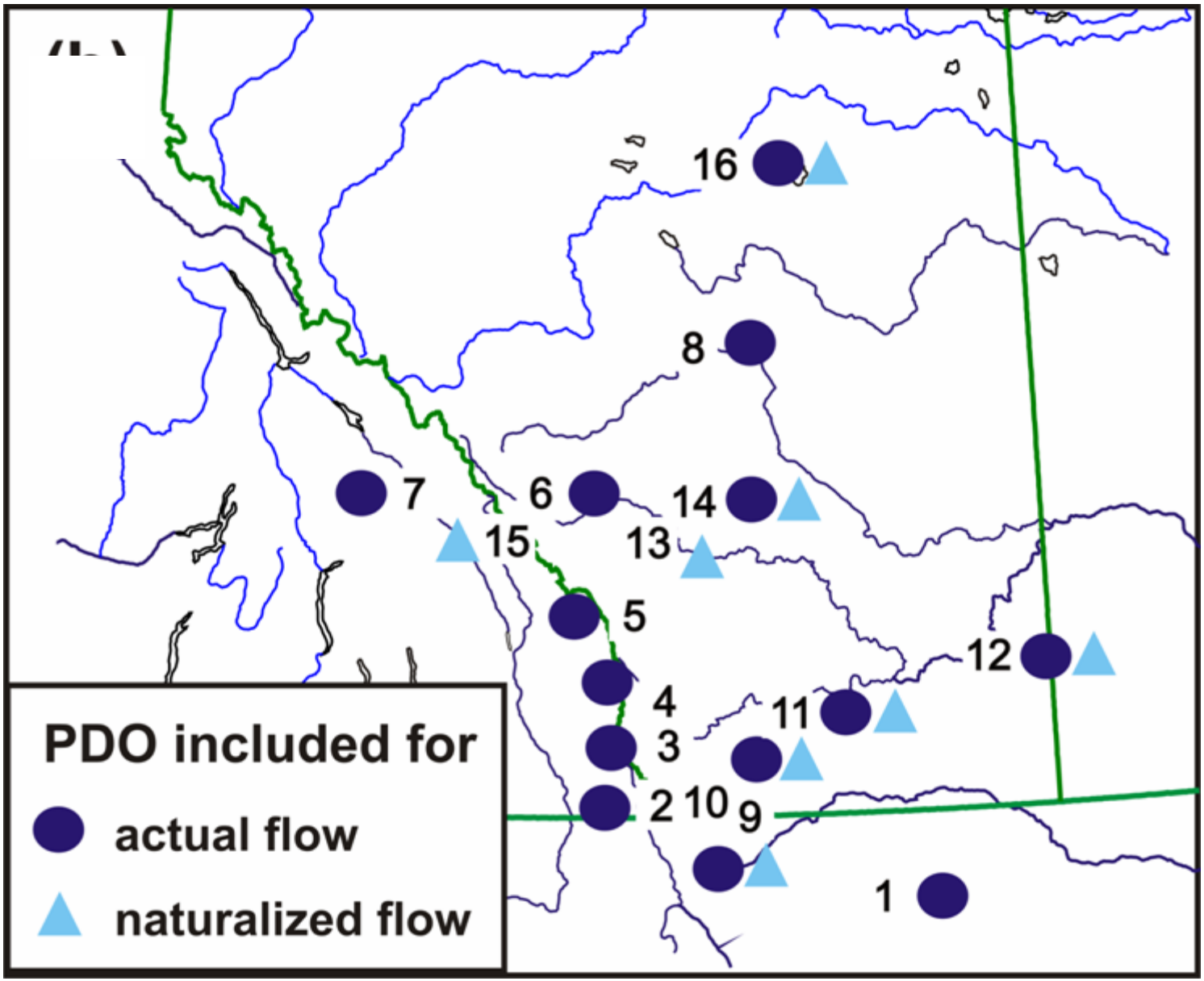
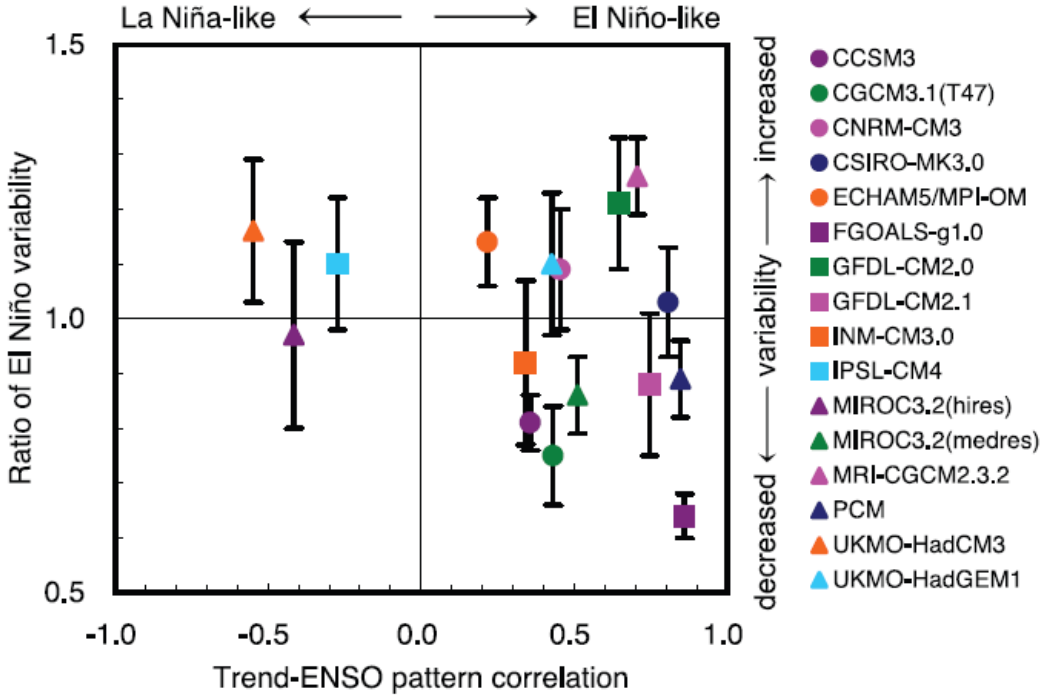
Geographical pattern: Bow River Valley worst?



PDO in optimum predictor subset in all but 2 records:



Future projections under AGW assumptions



An El Niño-dominated world (Fig. 10.16 IPCC4)

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

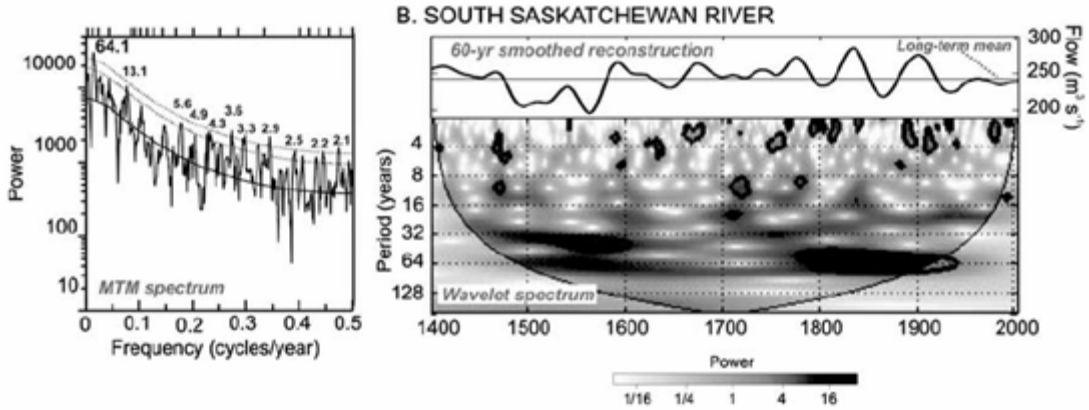
Newman *et al.* (2003) propose PDO is red-shifted ENSO.

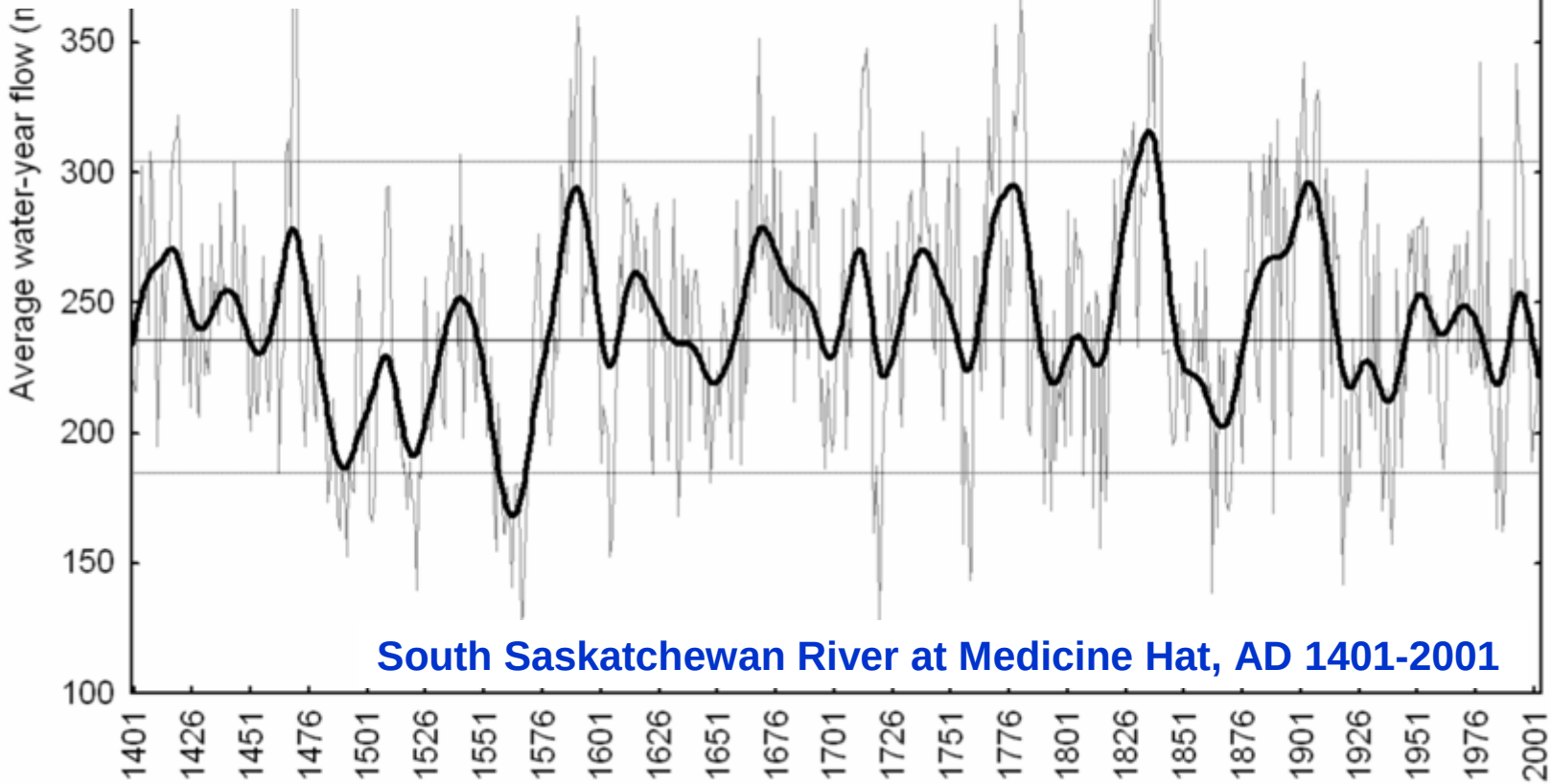
More frequent **El Niño** => more frequent **warm phase** PDO => more frequent **dry** conditions in S. Alberta.

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 frequent **El Niño** + **warm phase** PDO => more severe **dry** conditions in S. Alberta.

Past: S. Alberta hydrology dominated by low frequency ~64 yr variability





South Saskatchewan River at Medicine Hat, AD 1401-2001

Axelson, Sauchyn and Barichivich, (2009) *Water Resources Research*

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 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**.

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