Precipitation of Southwestern Canada - Wavelet, Scaling, Multifractal Analysis, and Teleconnection to Climate Anomalies

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INTRODUCTION

- Low frequency fluctuations at decadal and higher time scales could give rise to extreme floods & droughts that bring severe damages & economic losses. Western North America experiences low-frequency climate variability partly because Pacific Ocean has sufficient storage for long-term memory.

RESEARCH OBJECTIVES

- (1) To identify the dominant oscillations of precipitation data from southwestern (SW) Canada and their temporal variations using wavelet;
- (2) To relate detected precipitation signals to some large-scale teleconnection patterns found over the Pacific by frequency and time domain analyses;
- (3) To identify the scaling and multifractal properties of precipitation data; and (4) From the above, attempt to address issues such as whether different precipitation time scales correspond to different teleconnection patterns, whether decadal or higher-level precipitation variations arise from climate dynamics that are separate from interannual or lower-level variations, & feasibility of precipitation predictions by teleconnection with climate indices.

PRECIPITATION DATA

❖To avoid low elevation bias, we selected stations with elevations ranging from 8 m at Quatsino, British Columbia (BC) to 1073 m at Calgary, Alberta. The wavelet analysis (WT) was carried out on **21** stations of standardized seasonal precipitation anomalies for 1914–2001. Weekly totals from seven daily precipitation stations of SW Canada were analyzed for scaling and multifractal properties.

CLIMATE ANOMALIES

- Consider ENSO effects by Nino3 index, equatorial Pacific SST anomalies and the Southern Oscillation Index (SOI), normalized monthly differences in sea level pressure (SLP) at Tahiti and Darwin.
- Consider effects of extratropical Northern Hemisphere ocean/atmosphere circulation by Pacific/North America pattern (PNA), West Pacific pattern (WP), East Pacific pattern (EP), Central North Pacific index (CNP) & Pacific Decadal Oscillation (PDO).

RESEARCH METHODOLOGY

- Use **Morlet wavelet** to extract dominant oscillations for SW Canadian precipitation; principal components, wavelet coherence, composite & multi-scale correlation analyses to find relationships between detected oscillations & large-scale climate anomalies that influence the climate of western North America.
- Use Fourier power spectrum [$S(f)$ where f is the frequency] of the form $S(f) \sim f^{\beta}$ to study scaling behavior, & a power law probability distribution function (called hyperbolic), i.e. $Pr(R>r) = r^{-\alpha}$ [$\alpha>0$, r is precipitation intensity] that shows a characteristic of multifractal processes. Statistical moment, $M(n,q)$ is computed for weekly precipitation data as $M(n,q) = \frac{1}{N}\sum_{j=1}^{N} r(n,j)^q$
- where N = number of non-overlapping windows each of width n, & q = 0.5 to 4.0. $M(n,q)$ is related to the window width n by a momentum function $\tau(q)$ so that,

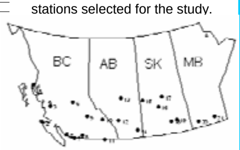
$$M(n,q) = n^{\tau(q)}$$

- If $\tau(q)$ is a **convex** (**linear**) function of q, precipitation is multifractal(monofractal)

RESULTS

Region, scale	PC	Variance (%)	Nino3	SOI	CNP	PNA	WP	PDO
Western								
a) 2-3 year	1	46.9	**-0.39**†	**0.47**†	**0.26**†	**-0.30**	**-0.42**†	**-0.26**
	2	18.0	0.00	**-0.19**	0.00	**0.25**	**-0.33**	0.04
	3	11.8	-0.12	0.07	**0.23**	**-0.42**	-0.18	**-0.23**
b) 3-8 year	1	46.3	-0.14	0.07	0.14	-0.15	**-0.36**	-0.12
	2	15.7	**-0.37**	**0.33**	**0.51**	**-0.61**	**-0.56**	**-0.34**
	3	9.9	-0.09	0.05	0.15	**-0.28**	**-0.26**	-0.17
c) 8-30 year	1	46.7	**-0.32**	**0.21**	**0.85**‡	0.14	-0.17	-0.16
	2	11.7	-0.03	**0.18**	0.07	0.18	**0.29**	0.04
	3	10.8	0.07	**0.18**	**-0.42**	**0.34**	**-0.37**	**0.37**
Central								
a) 2-3 year	1	50.8	-0.17	**0.21**	**0.34**†	-0.15	**-0.53**†	**-0.29**
	2	22.0	**0.41**†	**-0.42**†	-0.09	**0.46**	**0.33**	**0.30**
	3	9.8	0.04	-0.13	0.09	-0.01	**0.24**	**0.23**
b) 3-8 year	1	49.0	0.01	-0.16	-0.01	-0.14	0.21	0.08
	2	19.6	-0.04	0.02	-0.04	0.02	-0.19	-0.05
	3	10.7	**-0.32**	**0.37**	0.13	-0.03	-0.11	**-0.27**
c) 8-30 year	1	33.4	-0.16	-0.14	**-0.41**	**-0.24**	**0.50**	-0.14
	2	25.6	**-0.20**	0.16	-0.01	**-0.44**	-0.13	**-0.32**
	3	20.2	0.15	-0.02	0.19	-0.11	**0.32**	0.12
Eastern								
a) 2-3 year	1	59.9	**-0.46**†	**0.23**†	0.12	**-0.43**	-0.21	**-0.32**
	2	13.3	**-0.26**	-0.05	0.13	0.00	-0.20	**-0.20**
	3	11.0	-0.03	0.04	**-0.43**	-0.02	0.09	**0.21**
b) 3-8 year	1	59.4	**-0.41**	**0.23**	0.16	**-0.36**	**-0.24**	**-0.24**
	2	13.9	0.03	0.02	-0.03	-0.11	-0.12	-0.09
	3	11.6	-0.02	0.16	-0.06	-0.06	0.07	-0.12
c) 8-30 year	1	61.6	**-0.49**	0.05	0.05	**-0.43**‡	0.21	**-0.31**
	2	17.7	-0.14	0.05	**0.46**	0.22	-0.15	-0.10
	3	8.4	-0.12	0.04	0.12	**-0.36**	-0.04	**-0.39**

Location of the 21 precipitation stations selected for the study.



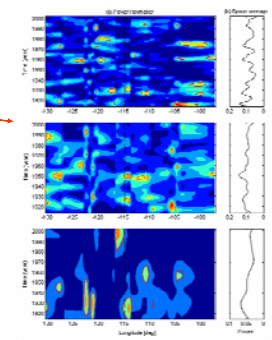
- **Pearson's correlations** between the PC scores of band-passed precipitation and band-passed climate indices for selected scale bands. Correlations significant at the 5% level based on 10,000 bootstrap samples are indicated in bold text.

Region	ENSO		PNA		WP		EP		CNP		PDO	
	La Nina	El Nino	Low	High	Low	High	Low	High	High	Low	Warm	Cool
Western	1.20	0.89	1.09	0.89	1.06	0.92	0.96	1.14	0.98	0.86	0.94	1.07
Central	1.25	0.86	1.13	0.87	1.12	0.84	0.99	1.12	1.05	0.92	0.90	1.12
Eastern	1.16	0.84	1.05	0.89	1.09	0.99	1.03	1.09	1.09	0.88	0.92	1.09
All	1.20	0.86	1.09	0.88	1.09	0.92	0.99	1.12	1.04	0.89	0.92	1.09

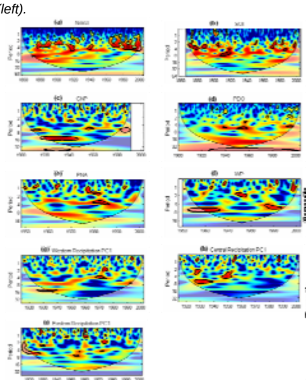
Aggregate **composites** of winter precipitation for the western, central and eastern regions

PC	Nino3	SOI	CNP	PDO	PNA	WP	EP
Western							
Lag-0	**-0.41**	**0.37**	**0.27**	**-0.44**	**-0.50**	-0.24	**0.31**
Lag-1	**-0.38**	**0.43**	**0.26**	**-0.25**	-0.18	-0.10	0.10
Lag-2	**-0.29**	**0.41**	0.11	**-0.27**	0.22	-0.07	0.12
Lag-3	**-0.33**	**0.22**	0.09	**-0.27**	-0.01	0.14	0.19
Central							
Lag-0	**-0.39**	**0.34**	**0.25**	**-0.54**	**-0.52**	**-0.46**	0.09
Lag-1	**-0.42**	**0.39**	**0.24**	**-0.37**	-0.18	-0.21	-0.01
Lag-2	**-0.32**	**0.42**	0.08	**-0.33**	0.12	0.18	0.01
Lag-3	**-0.39**	0.20	0.00	**-0.37**	-0.23	-0.13	0.10
Eastern							
Lag-0	**-0.40**	**0.26**	**0.28**	**-0.51**	**-0.44**	**-0.35**	0.09
Lag-1	**-0.42**	**0.26**	**0.25**	**-0.33**	**-0.28**	**-0.34**	-0.07
Lag-2	**-0.34**	**0.35**	0.10	**-0.25**	0.13	0.03	0.00
Lag-3	-0.21	0.03	-0.02	**-0.26**	-0.31	-0.16	0.19

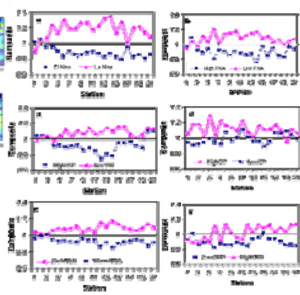
Pearson's correlations at zero to 3-season lags between selected climate indices and winter precipitation PC1 time series of western, central and eastern regions. Statistically significant correlations at the 5% level are indicated in bold text



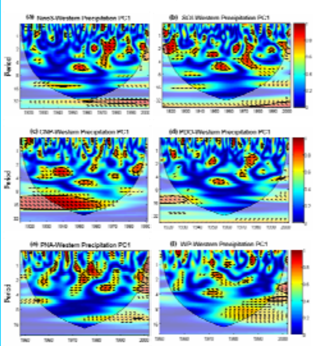
Scale Averaged Wavelet Power SAWP (left) and space-averaged SAWP (right) of seasonal precipitation anomalies at the 21 stations across SW Canada: 2–3-year scale band (top), 3–8-year scale band (middle), and 8–30-year scale band (bottom). The solid contours enclose periods of statistically significant SAWP against white noise at the 5% significance level. The vertical line in the Power Hovmöller corresponds to the boundary between precipitation stations from the Prairies (right) and BC (left).



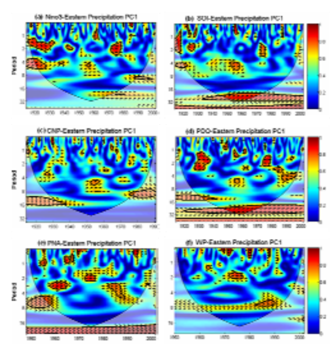
Wavelet power spectra of seasonal Nino3, SOI, CNP, PDO, PNA and WP indices (Figures a-f). Wavelet power spectra of the leading principal components (PC1) of seasonal precipitation anomalies for the western, central and eastern regions (Figures g-i). The contours enclose statistically significant wavelet power at the 5% level of a red noise process.



Composite winter precipitation associated with (a) El Nino & La Nina years. (b) High & low PNA years. (c) High & low WP years. (d) High & low EP years. (e) Warm & cool PDO years. (f) High & low CNP years. Each station composite is the ratio of the mean winter precipitation during anomalous years to the long-term mean winter precipitation.

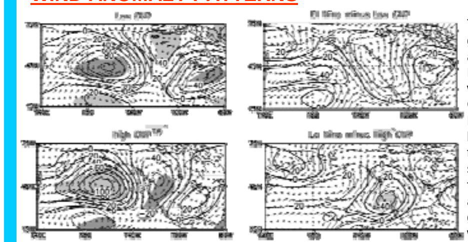


Wavelet coherence and phase difference between the **Western Region** PC1 and (a) Nino3, (b) SOI, (c) CNP, (d) PDO, (e) PNA, (f) WP. The solid contours enclose periods of statistically significant coherence at the 5% level of a red noise process. The phase difference is plotted only for time periods and scales with coherence over 0.5. Right-pointing arrows indicate that the two signals are in-phase while left-pointing arrows are for anti-phase signals.



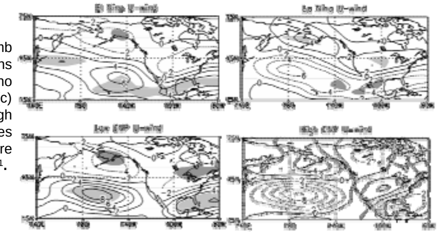
Wavelet coherence and phase difference between the **Eastern Region** PC1 and (a) Nino3, (b) SOI, (c) CNP, (d) PDO, (e) PNA, (f) WP. All features are the same as that of the Western Region.

WIND ANOMALY PATTERNS



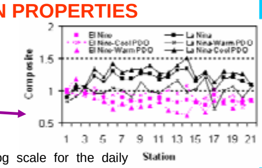
The composite DJF 300-mb geopotential and vector wind anomalies associated with (a) Low CNP winters, (b) High CNP winters. (c) El Nino minus Low CNP winters, (d) La Nina minus High CNP winters. In (a) and (b) height anomalies significant at the 1% significance level are shaded. In (c) and (d) difference fields significant at the 1% level are shaded. The units are m for geopotential height and ms^{-1} for wind speed.

The composite DJF 300-mb zonal wind anomaly patterns associated with (a) El Nino winters, (b) La Nina winters, (c) Low CNP winters, (d) High CNP winters. Anomalies significant at the 1% level are shaded. Wind speed is in ms^{-1}.

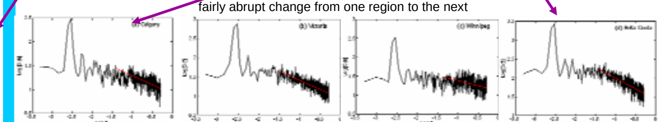


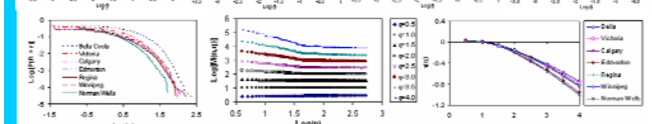
PRECIPITATION PROPERTIES

SW Canadian winter precipitation responses to ENSO stratified by PDO phases.



Power spectrum plots on a log-log scale for the daily precipitation data of (a) Calgary, (b) Victoria, (c) Winnipeg, and (d) Bella Coola, each showing scale invariant behavior within some linear decay regions, and with a fairly abrupt change from one region to the next





(a) Empirical probability distributions for 7 stations of daily precipitation data, which all show a power law behavior, Pr (R>r) = $r^{-\alpha}$, with some hyperbolic intermittency at the tail ends; (b) Log-log plots of M(n,q) vs. n for q = 0.5, 1.0, … 4.0 for weekly precipitation of Calgary, and (c) Momentum function, $\tau(q)$ vs. q, for weekly precipitation at 7 stations in (a).

CONCLUSIONS

At SW Canada, El Nino (La Nina) leads to a decrease (an increase) of about 14% (20%) in mean winter precipitation. The detected teleconnections could occur at interannual or inter-decadal levels, and their strength changes in time and space. Power spectrum plots above show 2 linear decay regions separated by a break point at 20 to 30 days, which distinguishes the time scales of synoptic and climatic dynamics that influence precipitation, & the latter likely represents teleconnection with climate anomalies. Empirical probability distribution plots reveal power-law behavior, hyperbolic intermittency, a general feature of atmosphere, & multifractal properties. The estimated correlation dimension $D2$ ranges from 8 to 9, showing precipitation as a high dimensional chaotic process. Compounded by their haphazard low frequency oscillations, it will be difficult to get consistent seasonal predictions of the highly nonlinear precipitation processes in SW Canada by only teleconnecting with climate indices.

REFERENCES: Gan, T. Y., Gobena, A. K., & Wang, Q., *J. Geophy. Resear.-Atmos.*, in press, 2007

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