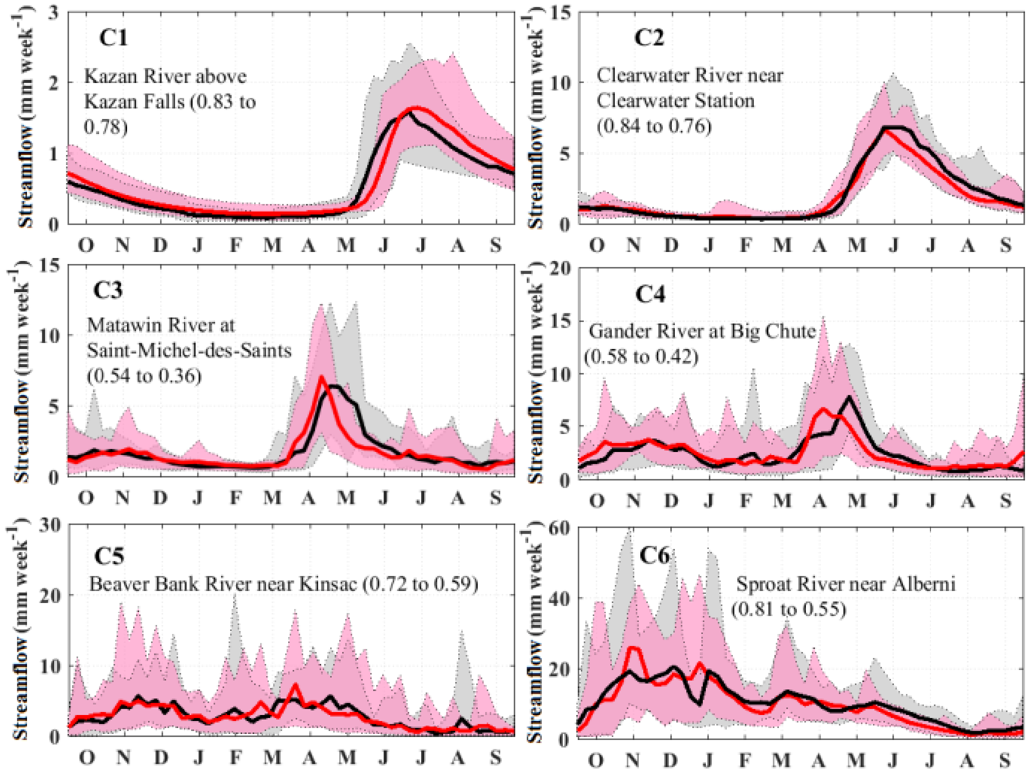
Changing Canadian Natural Streamflow Regime (1966-2010)



Ali Nazemi, PhD, PEng (ali.nazemi@concordia.ca)

2023-03-30

Zoom

First things first

- The driving force behind this work has been a former PhD student
- A chapter in Masoud's thesis, which is also published in HESS as:

Zaerpour, M., Hatami, S., Sadri, J., & Nazemi, A. (2021). A global algorithm for identifying changing streamflow regimes: application to Canadian natural streams (1966–2010). *Hydrology and Earth System Sciences*, 25(9), 5193-5217.

Masoud Zaerpour | University of Calgary Contacts (ucalgary.ca)

Motivation and context

- Streamflow regime is changing during the *"Anthropocene"*

Stressors

- Climate change
- Human intervention in land and streams

Climate change impacts in cold regions

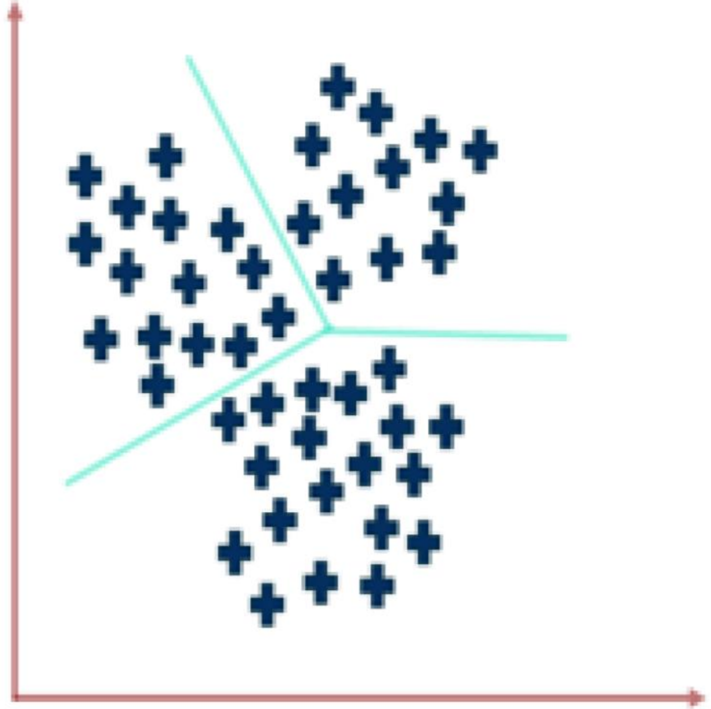
- Changes in the form of precipitation
- Changes in the amount of precipitation
- Changes in the hydrological processes

"A river is the report card for its watershed"

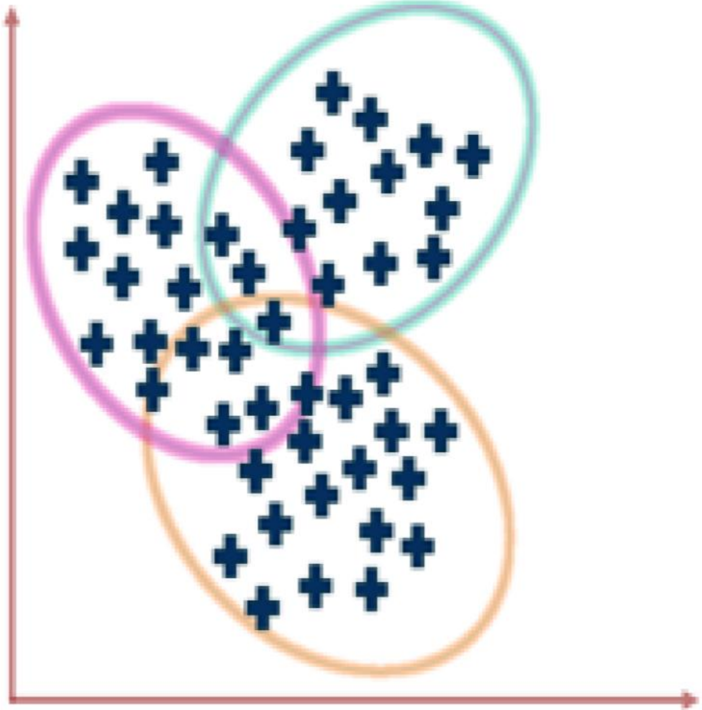
Alan Levere

Problem definition

- Streamflow regime is constituted by multiple streamflow characteristics → multiple dimensions
- Shift in natural streamflow regimes over landscape in rather gradual than sharp → Level of association.
- Climate change induced alterations in streamflow regime are caused by multiple physical processes that may not be easily distinguished from one another → multiple attributes
- Climate change induced transition from one streamflow regime to another is rather gradual than sharp → existence of trend



vs.

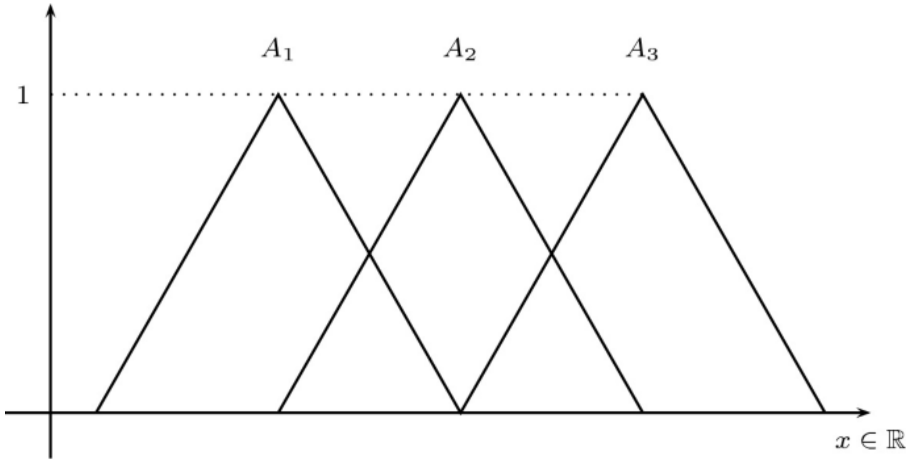


Breakthrough

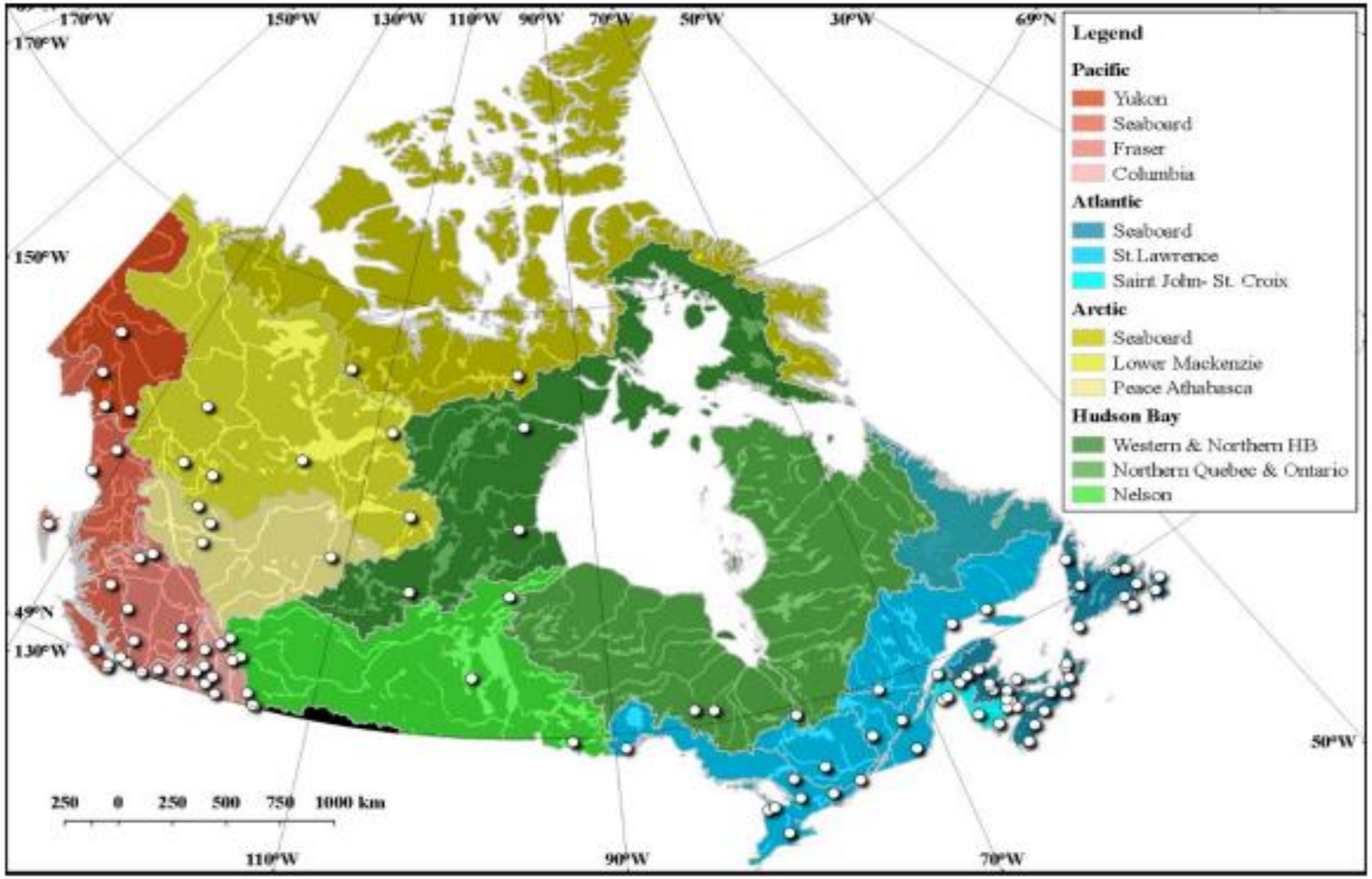
- Regime is identified by the changes in long-term annual streamflow hydrograph and the variability

Feature	Notation	Feature	Notation	Feature	Notation	Feature	Notation	Feature	Notation
October mean flow	Mean: x_1 Variance: y_1	November mean flow	Mean: x_2 Variance: y_2	December mean flow	Mean: x_3 Variance: y_3	January mean flow	Mean: x_4 Variance: y_4	February mean flow	Mean: x_5 Variance: y_5
March mean flow	Mean: x_6 Variance: y_6	April mean flow	Mean: x_7 Variance: y_7	May mean flow	Mean: x_8 Variance: y_8	June mean flow	Mean: x_9 Variance: y_9	July mean flow	Mean: x_{10} Variance: y_{10}
August mean flow	Mean: x_{11} Variance: y_{11}	September mean flow	Mean: x_{12} Variance: y_{12}	Annual flow	Mean: x_{13} Variance: y_{13}	Timing of the annual low flow	Mean: x_{14} Variance: y_{14}	Timing of the annual high flow	Mean: x_{15} Variance: y_{15}

- Distinction between streamflow are fuzzy rather than sharp.
- Temporal transition in streamflow regime in a given stream can be identified by the trend in belongingness of streamflow regime to a set of known reference regime.

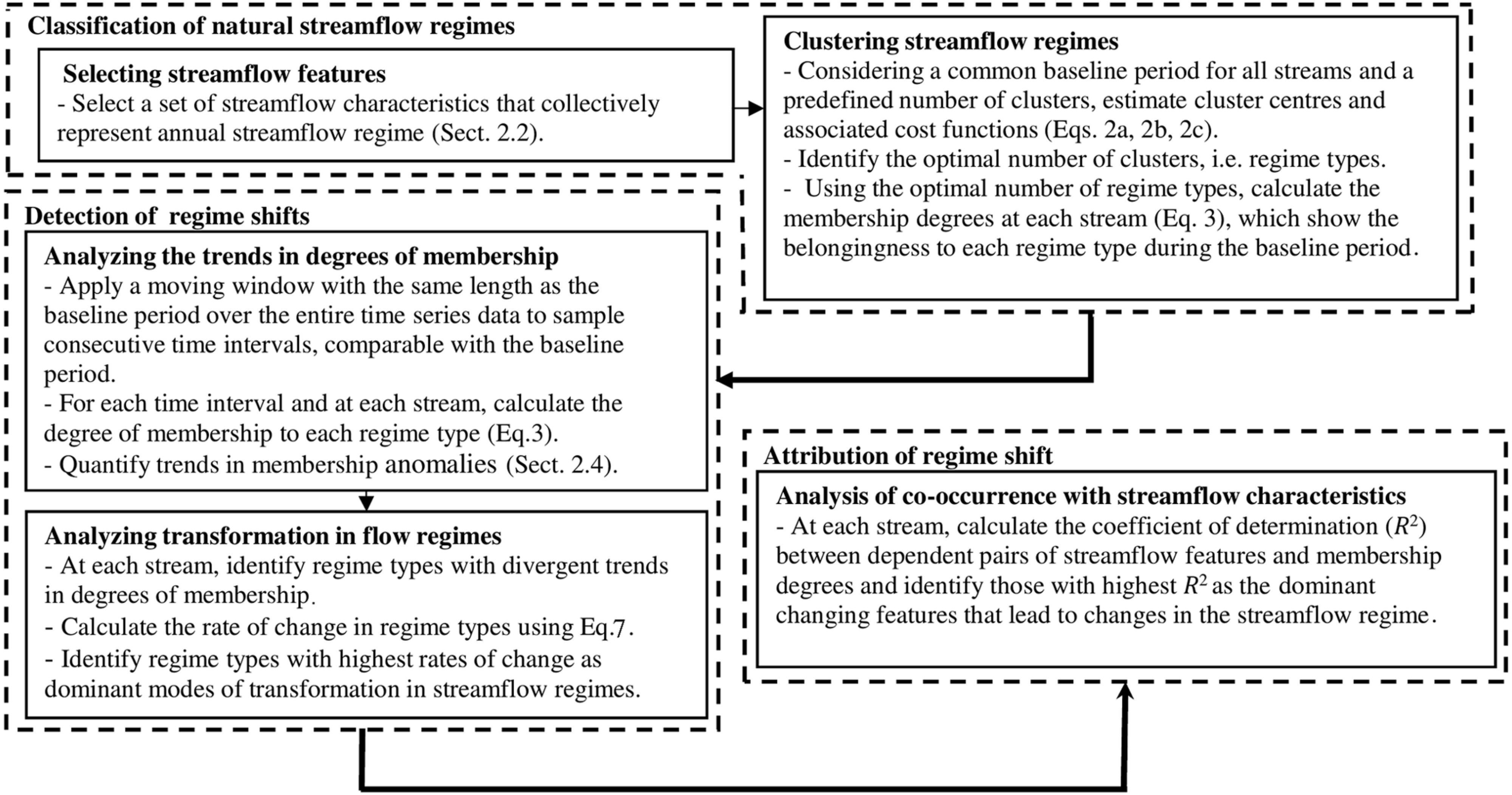


Case study



Major Basin	Sub-basin	Area (1000 km^2)	# of stations	Abbreviation
Pacific	Yukon	330.4	4	P1
	Seaboard	334.2	8	P2
	Fraser	232.5	8	P3
	Columbia	102.8	10	P4
Atlantic	Seaboard	499.7	28	At1
	St. Lawrence	860.1	16	At2
	Saint John- St. Croix	41.9	5	At3
Arctic	Seaboard	1,739.3	2	Ar1
	Lower Mackenzie	1,321.1	7	Ar2
	Peace Athabasca	482.7	3	Ar3
Hudson Bay	Western & Northern HB	1,243.9	3	H1
	Northern Quebec & Ontario	1,889.2	3	H2
	Nelson	1,138.5	8	H3

Methodology



Concordia University

Fuzzy clustering

1

$$\bar{x}_{i,j} = \frac{x_{i,j} - \min\{x_{i=1:N,j}\}}{\max\{x_{i=1:N,j}\} - \min\{x_{i=1:N,j}\}} \forall j \in \{1,\ldots,n\},$$

$$\bar{y}_{i,j} = \frac{y_{i,j} - \min\{y_{i=1:N,j}\}}{\max\{y_{i=1:N,j}\} - \min\{y_{i=1:N,j}\}} \forall j \in \{1,\ldots,n\},$$

2

$$\mathbf{J}\left(\mathbf{U},\mathbf{V}|\bar{\mathbf{X}},\bar{\mathbf{Y}}\right) = \sum_{c=1}^{C} \cdot \sum_{i=1}^{N} (u_{i,c})^2 \cdot \mathbf{d}^2\left([\bar{x}_{i,j=1:n}\bar{y}_{i,j=1:n}], v_{c,m=1:2n}\right)$$

This objective function is subject to the following two constraints:

$$\sum_{c=1}^{C} u_{i,c} = 1 \forall i \in \{1,\ldots,N\},$$

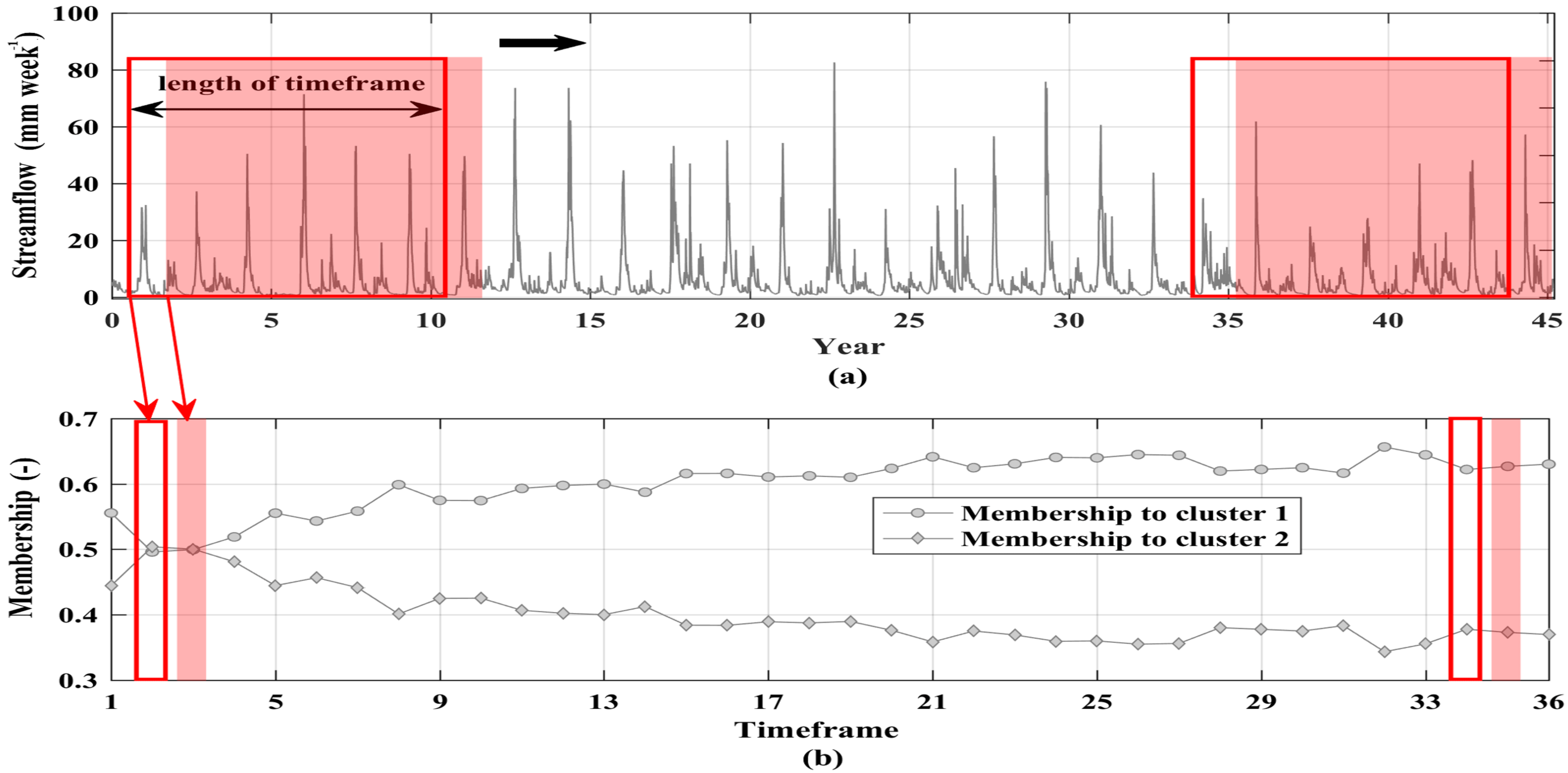
$$0 < \sum_{i=1}^{N} u_{i,c} < N \forall c \in \{1,\ldots,C\},$$

3

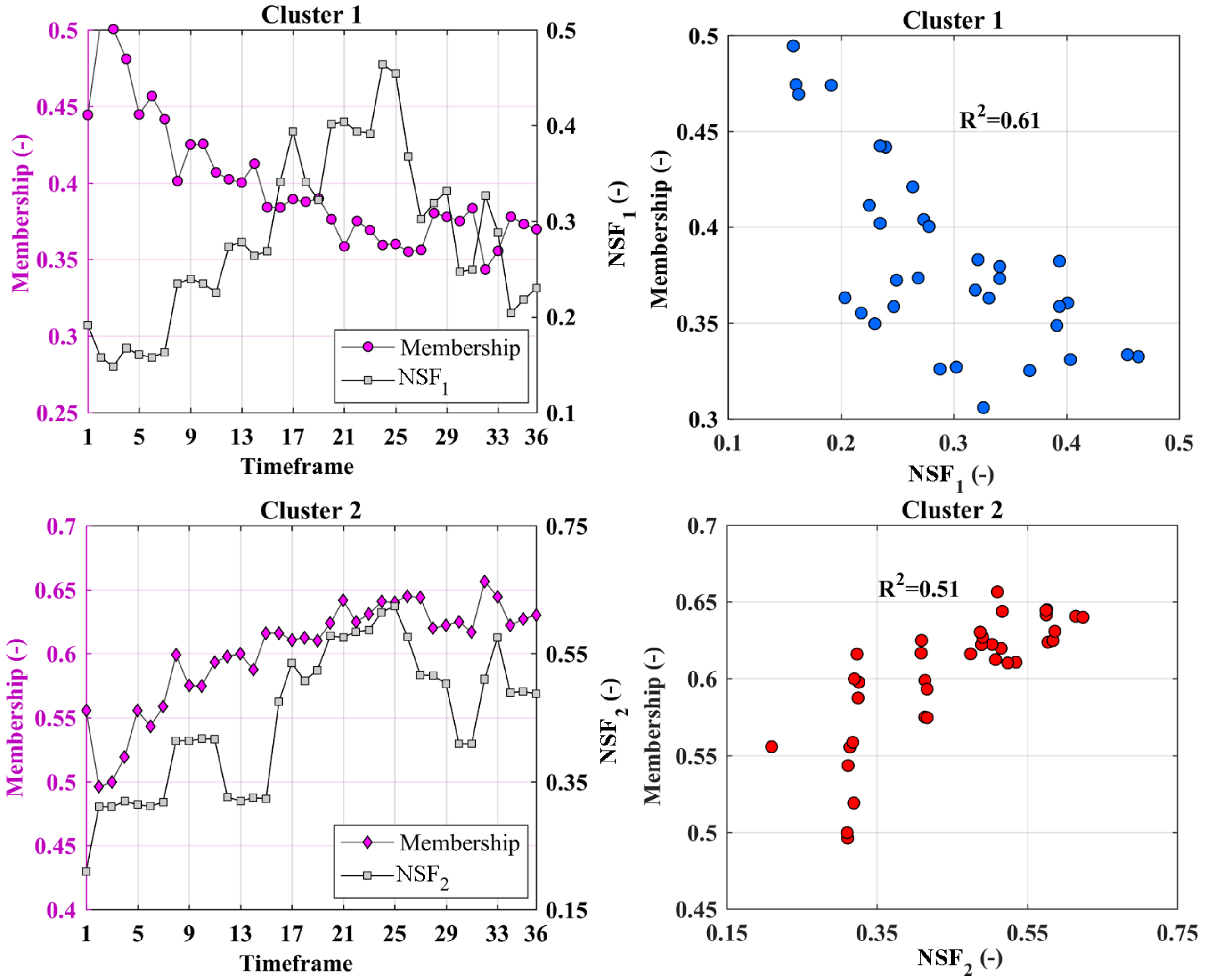
$$u_{i,c} = \frac{\left(\frac{1}{\mathbf{d}^2([\bar{x}_{i,j=1:n}\bar{y}_{i,j=1:n}], v_{c,\, m=1:2n})}\right)}{\sum_{c=1}^{C}\left(\frac{1}{\mathbf{d}^2([\bar{x}_{i,j=1:n}\bar{y}_{i,j=1:n}], v_{c,\, m=1:2n})}\right)};$$

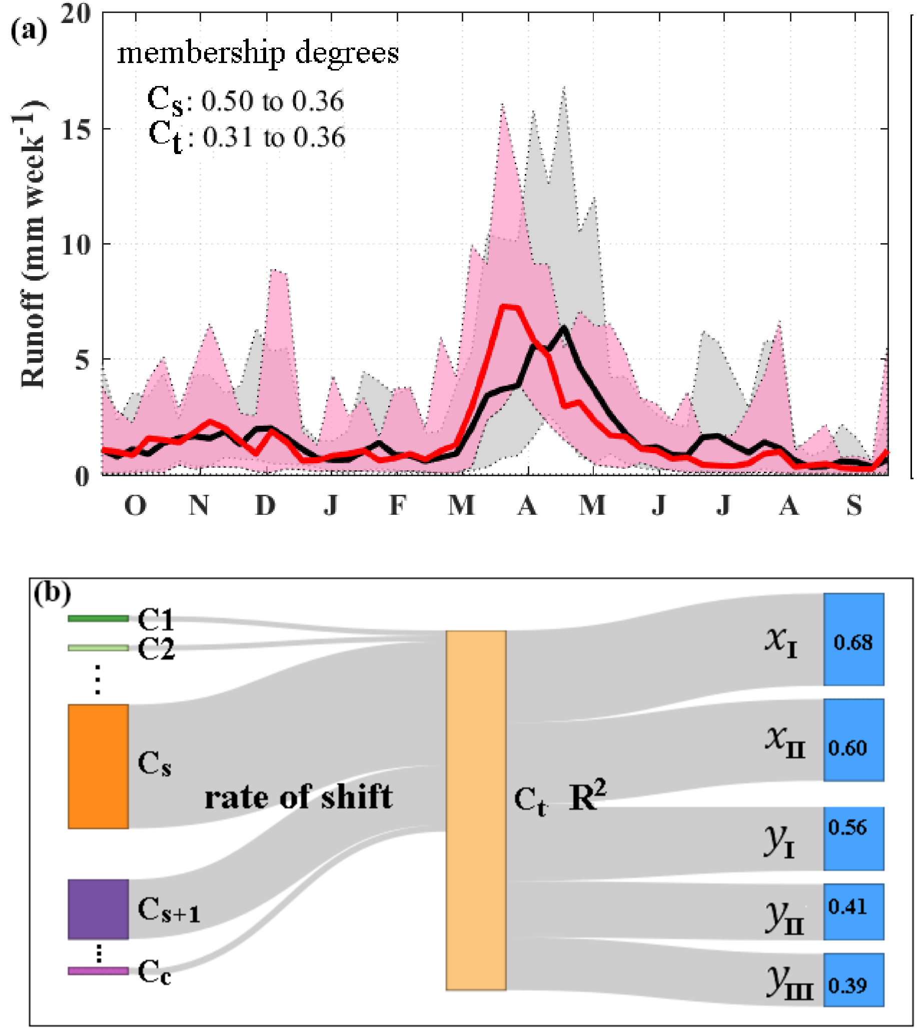
$$i \in \{1,\ldots,N\},\ c \in \{1,\ldots,C\}.$$

Detection of change in streamflow regime

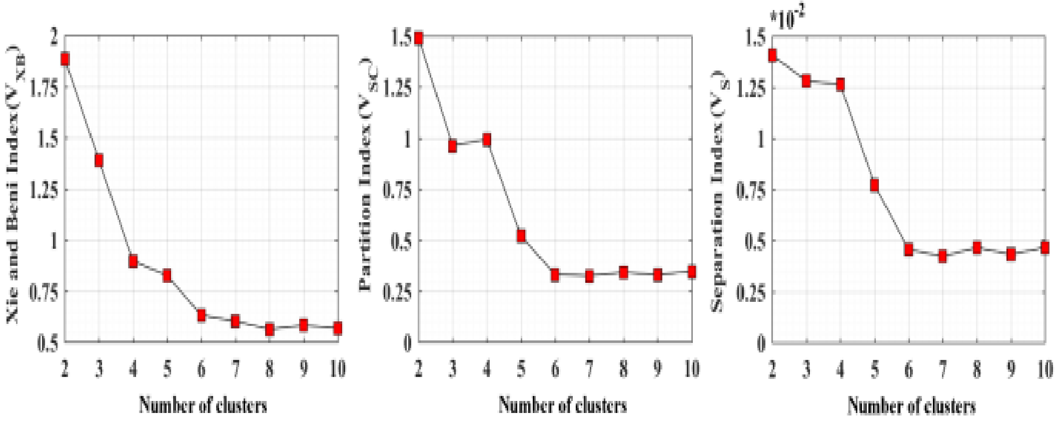


Attribution and shift detection

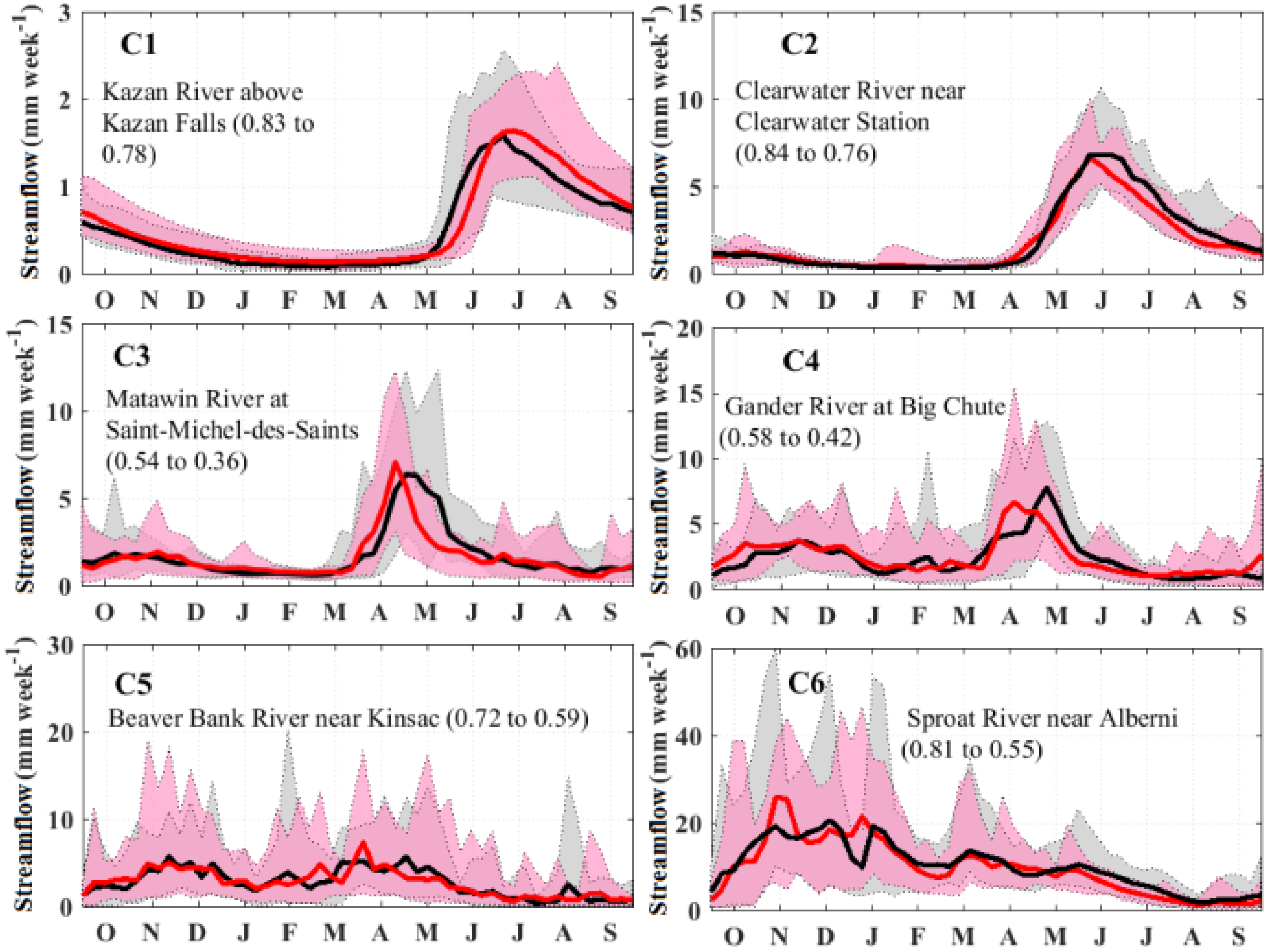




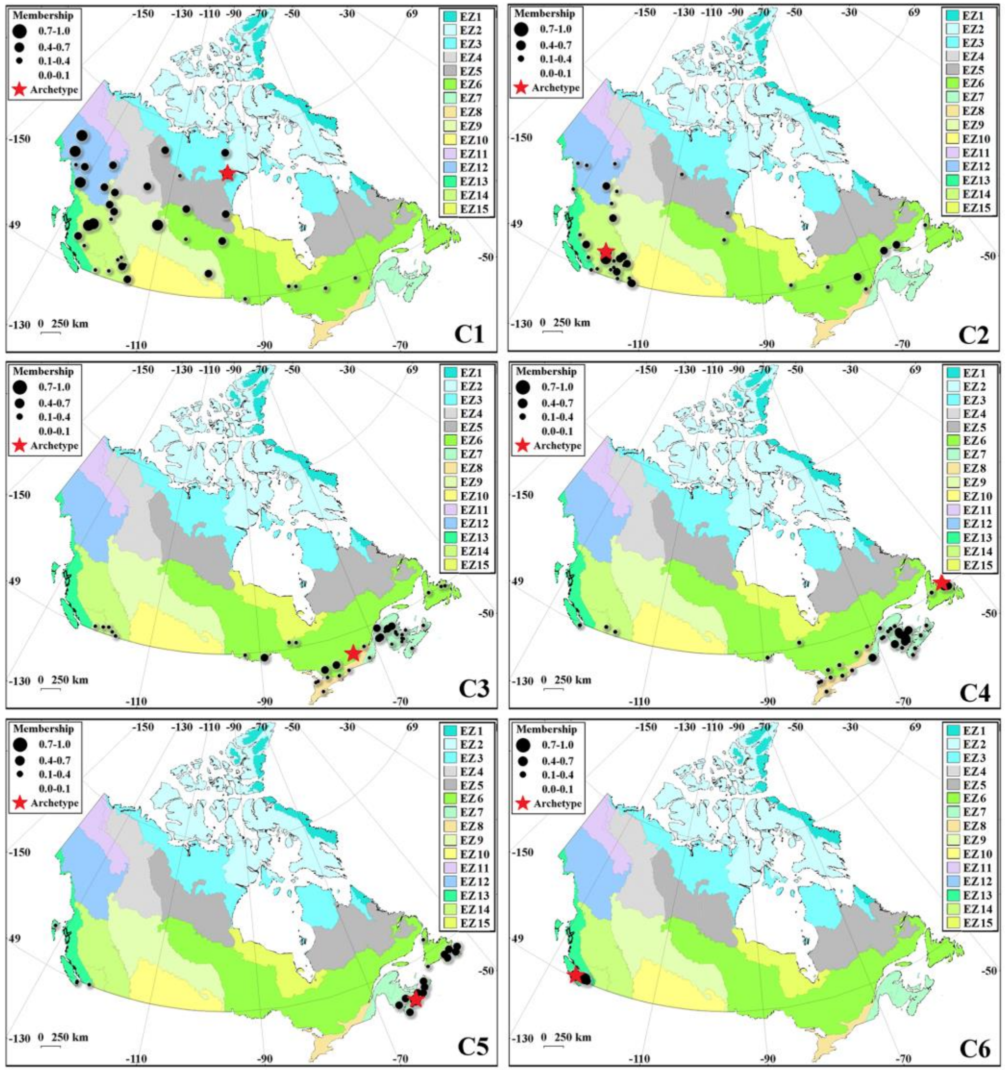
Streamflow types in Canada

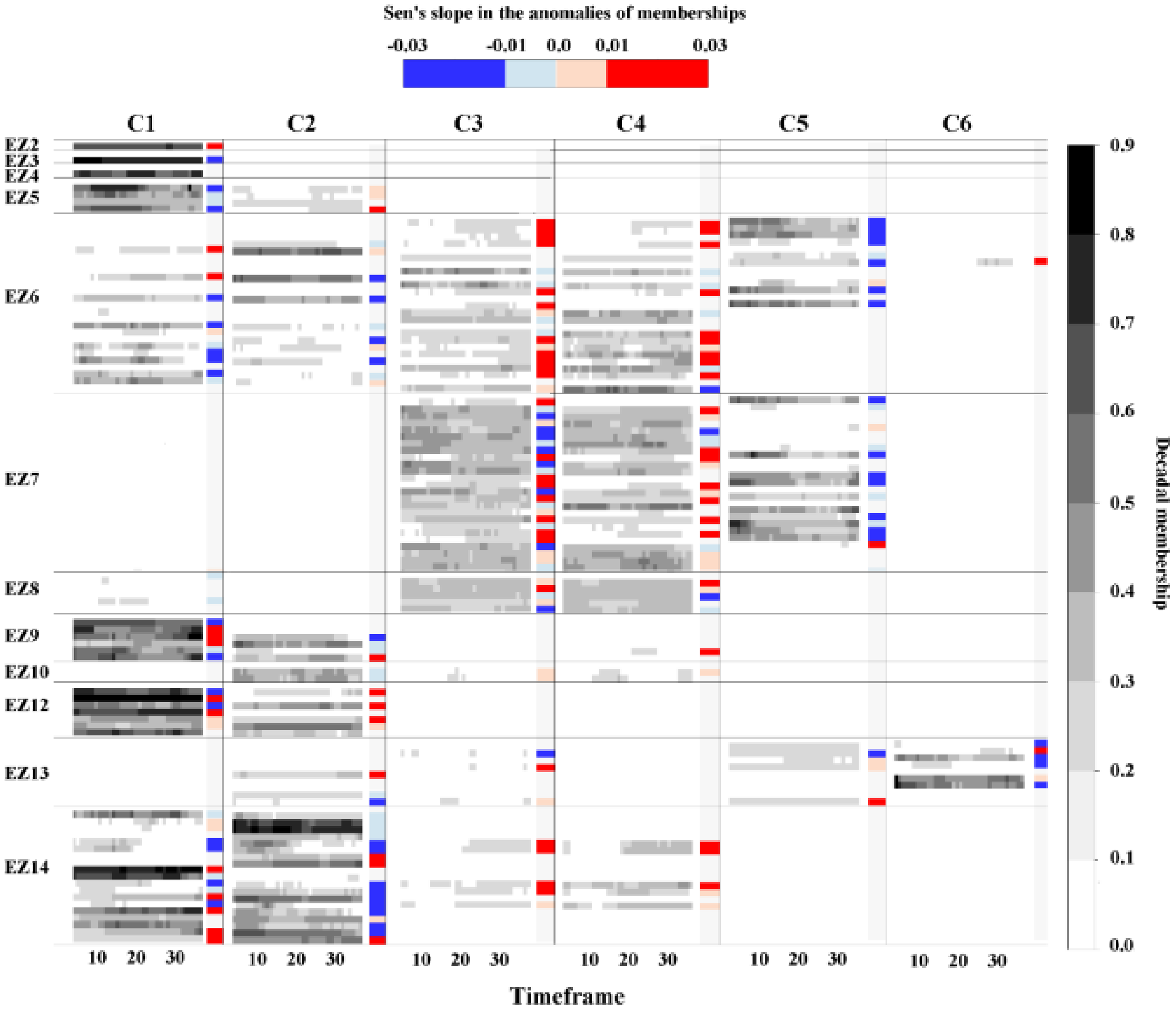


Cluster	Regime type	Archetype (representative) stream
C1	Slow-response/warm-season peak	Kazan River above Kazan Falls (HYDAT ID: 06LC001)
C2	Fast-response/warm-season peak	Clearwater River near Clearwater Station (HYDAT ID: 08LA001)
C3	Slow-response/freshet peak	Matawin River at Saint-Michel-des-Saints (HYDAT ID: 02NF003)
C4	Fast-response/freshet peak	Gander River at Big Chute (HYDAT ID: 02YQ001)
C5	Slow-response/cold-season peak	Beaver Bank River near Kinsac (HYDAT ID: 01DG003)
C6	Fast-response/cold-season peak	Sproat River near Alberni (HYDAT ID: 08HB008)

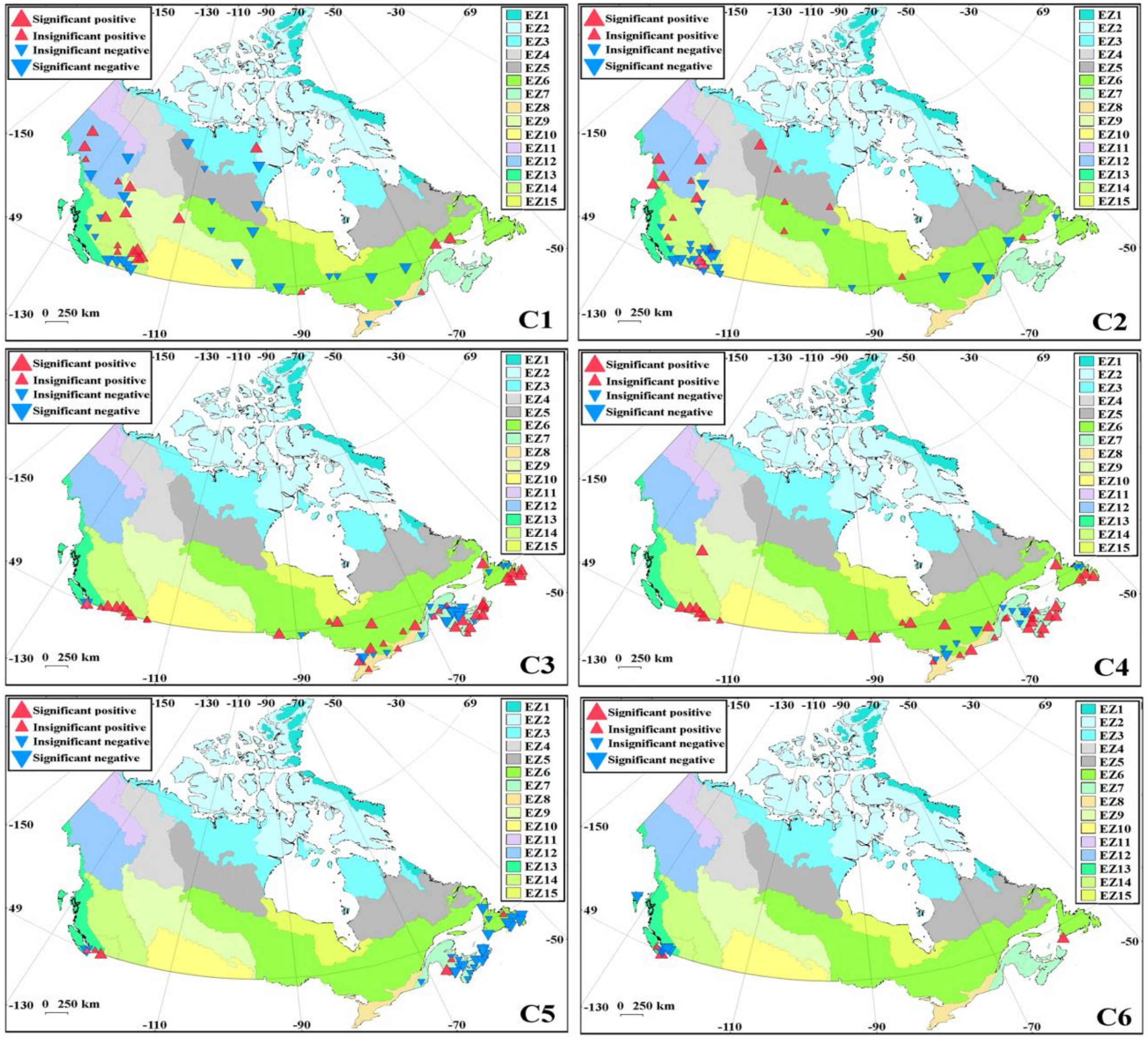


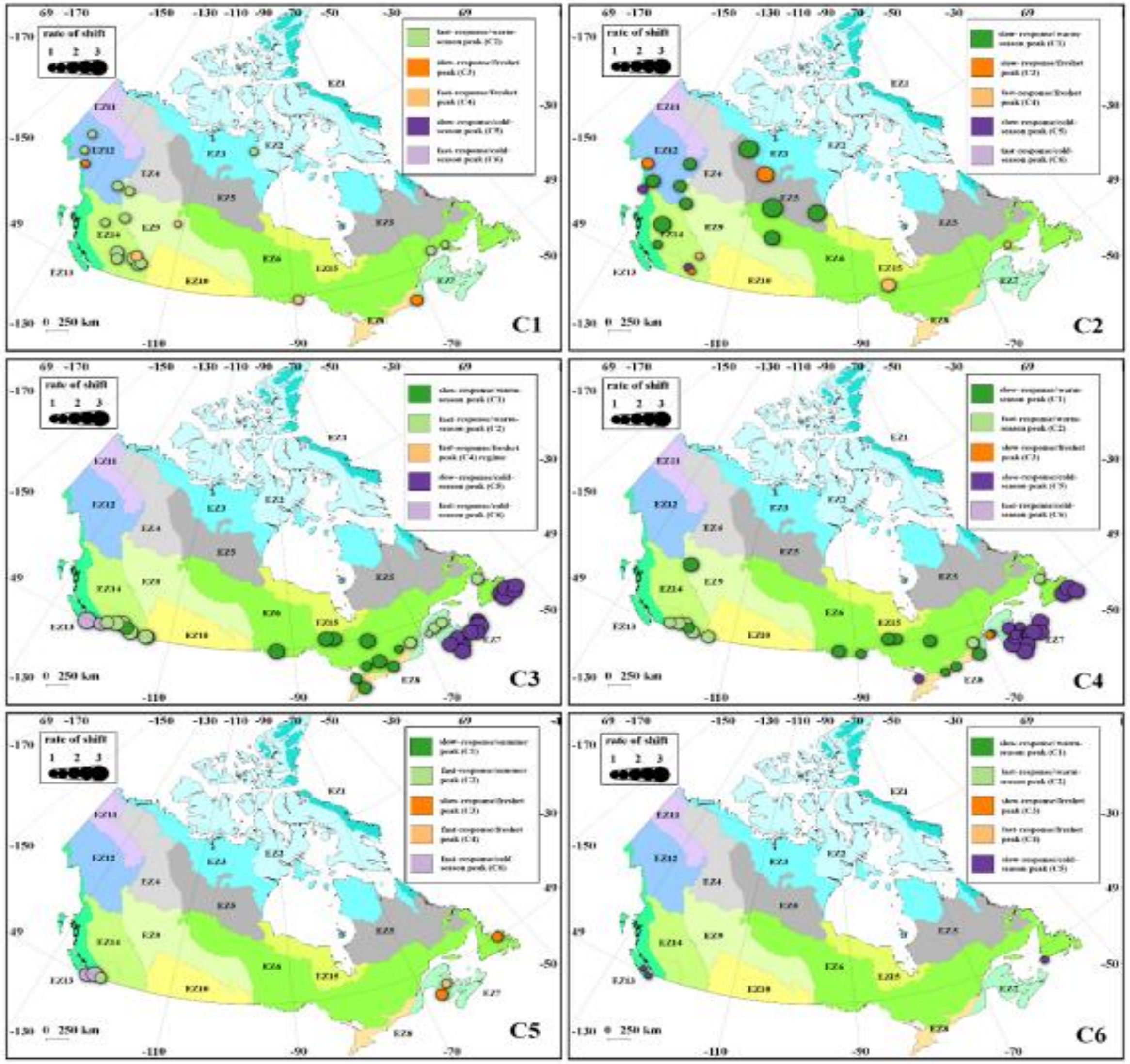
Streamflow types in Canada and their changes



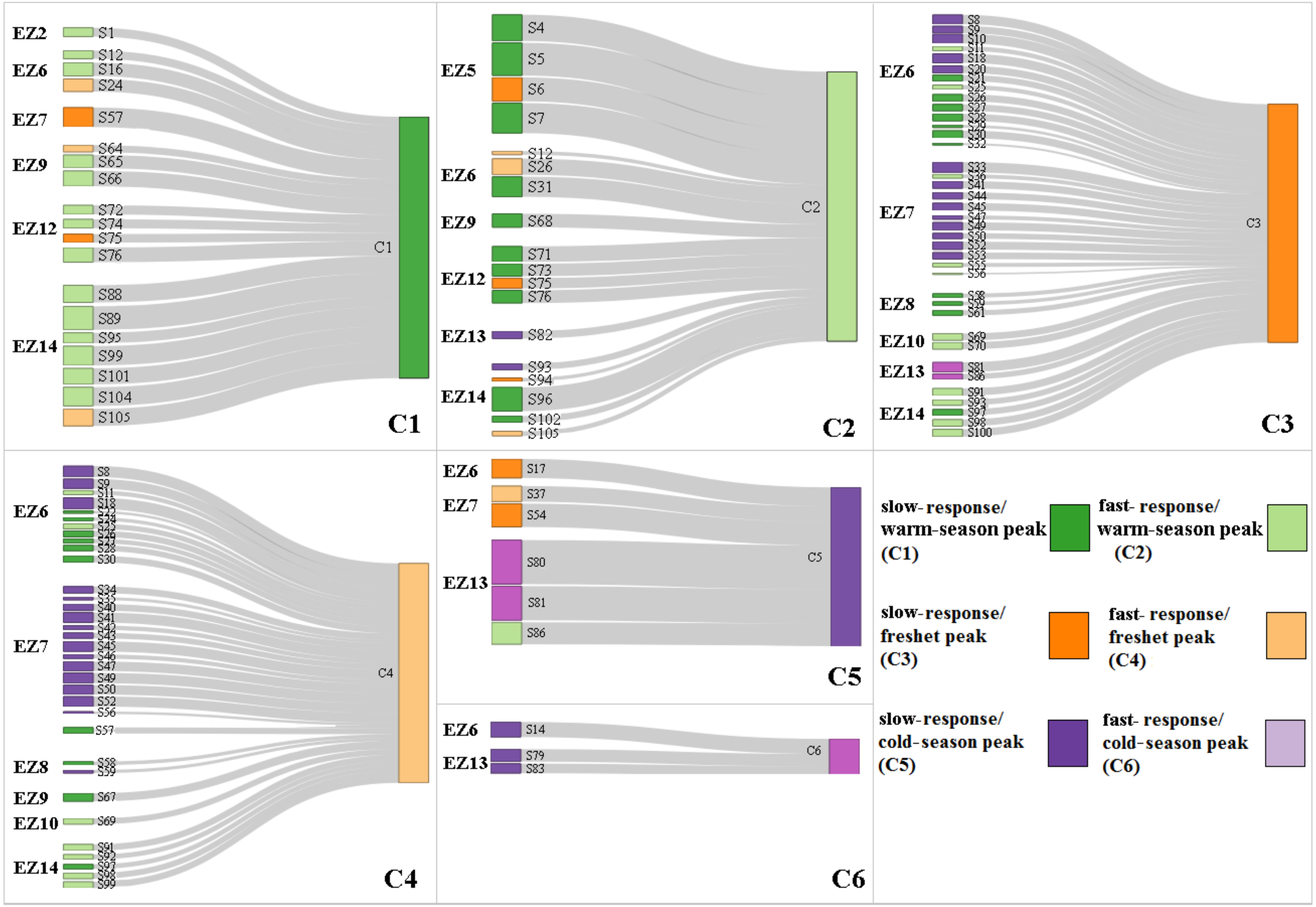


Streamflow types in Canada and their changes

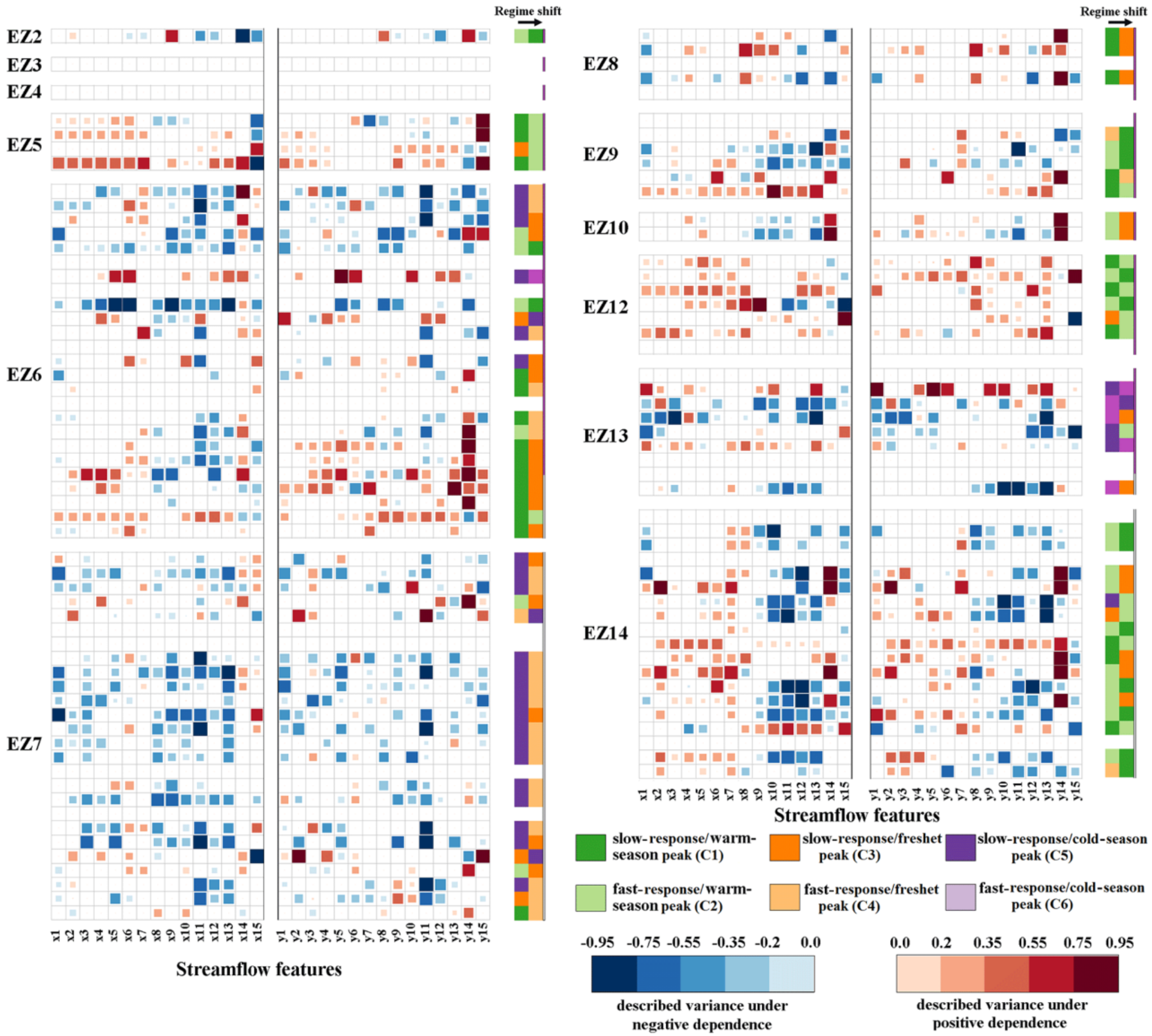




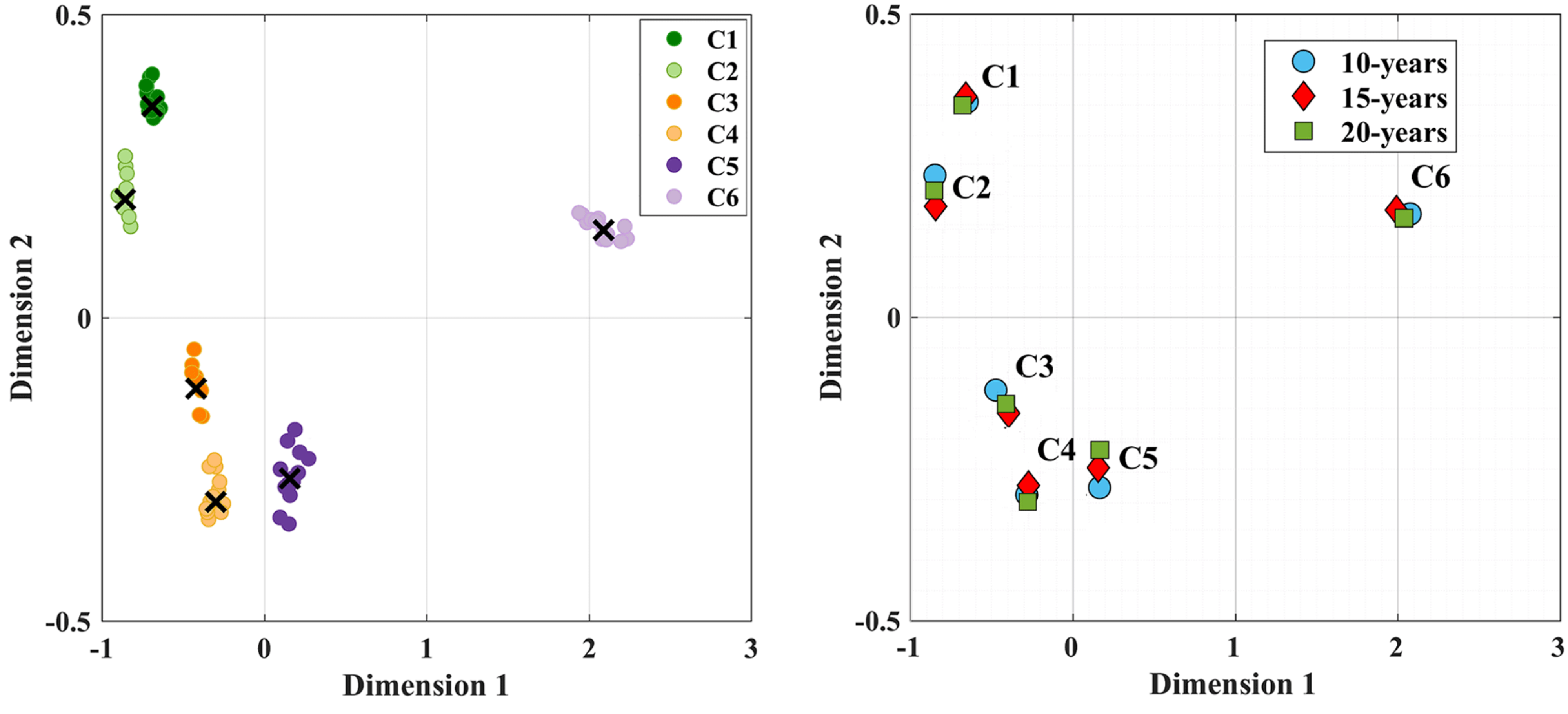
Regime shifts



Attribution to changes in streamflow characteristics

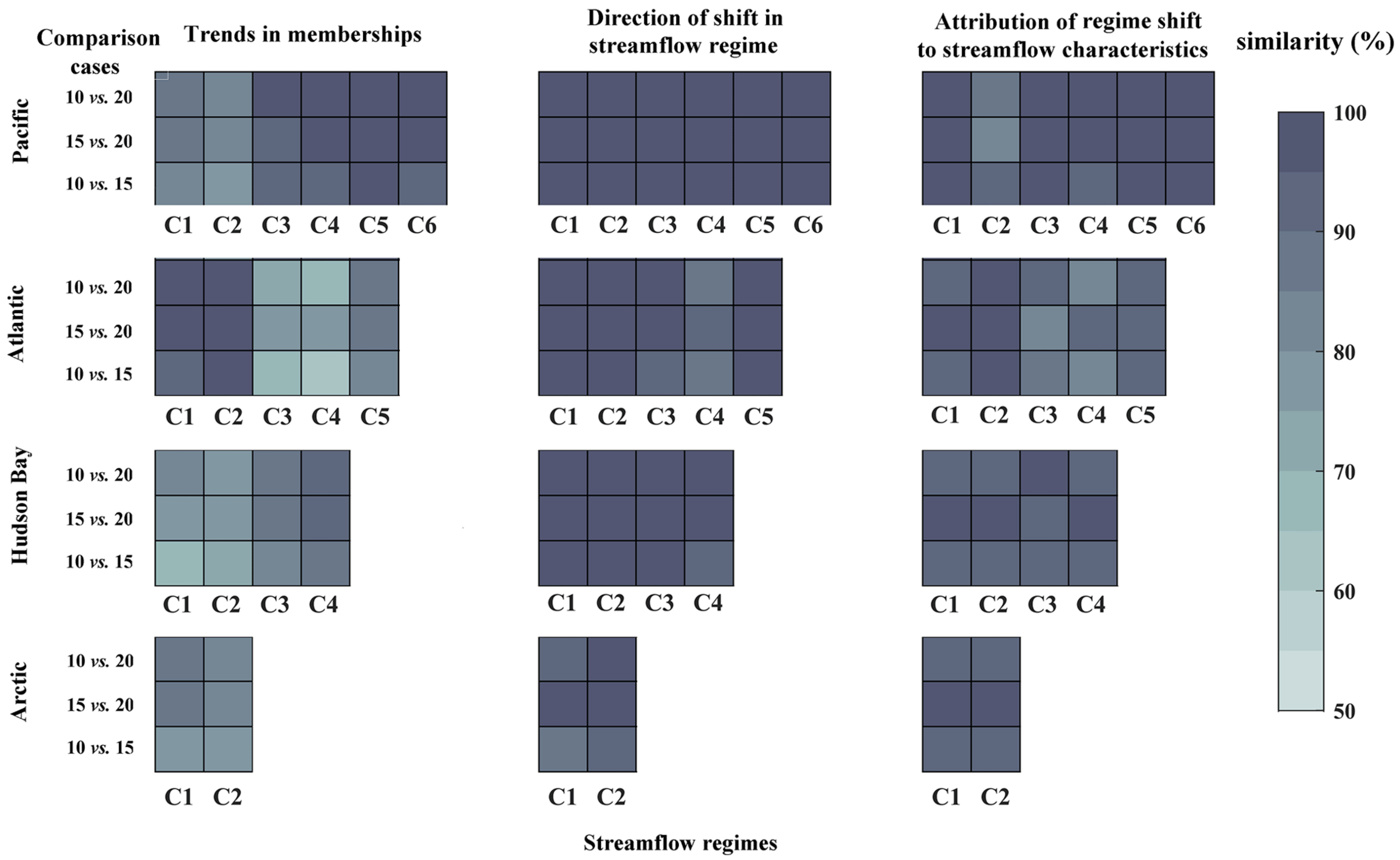


Validation



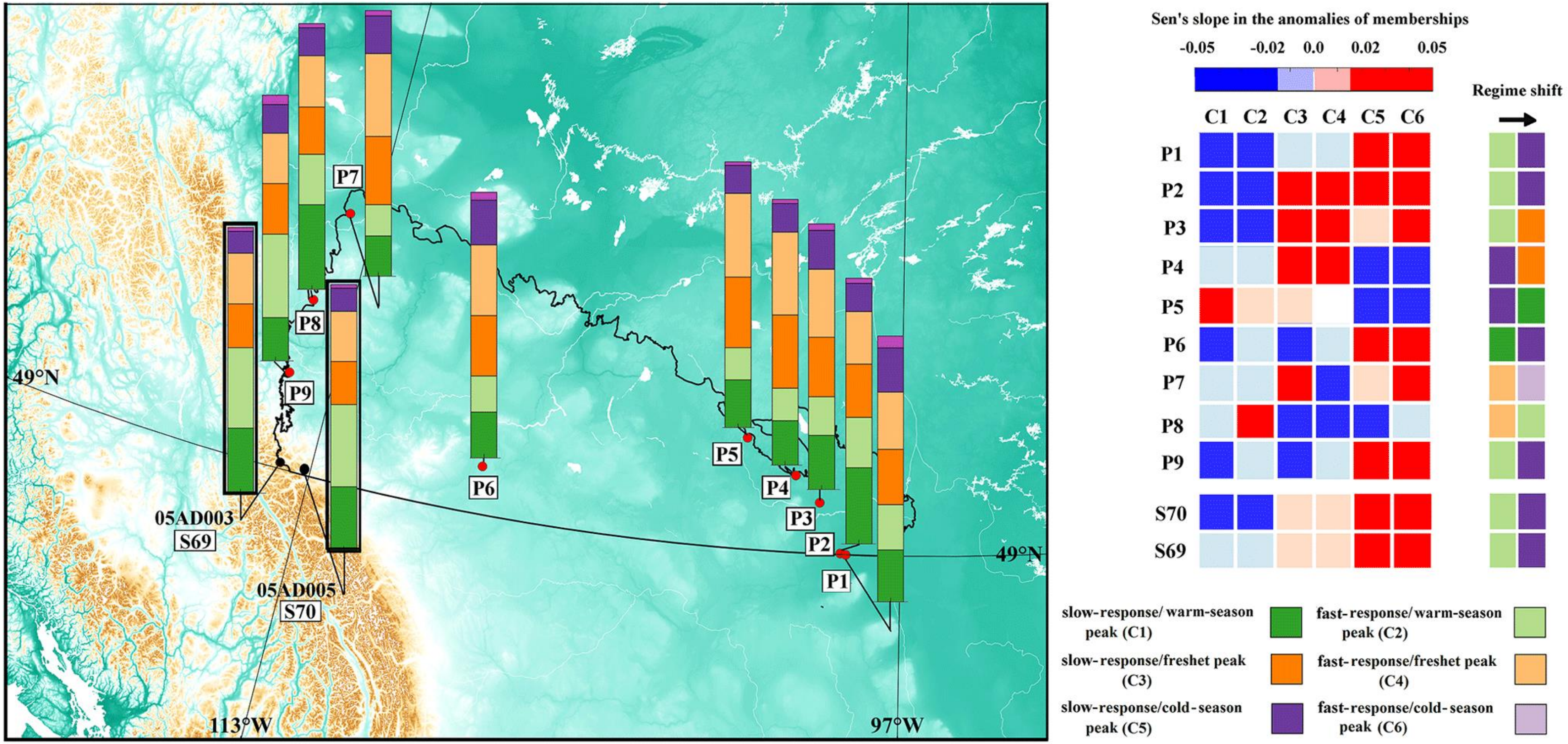
(a) (b)

Validation



Comparison cases
Trends in memberships
Direction of shift in streamflow regime
Attribution of regime shift to streamflow characteristics
similarity (%)
Pacific
Atlantic
Hudson Bay
Arctic
10 vs. 20
15 vs. 20
10 vs. 15
C1 C2 C3 C4 C5 C6
100
90
80
70
60
50
Streamflow regimes

Validation



Sen's slope in the anomalies of memberships
-0.05
-0.02
0.0
0.02
0.05
Regime shift
C1
C2
C3
C4
C5
C6
P1
P2
P3
P4
P5
P6
P7
P8
P9
S70
S69
P7
P8
P9
P6
P5
P4
P3
P2
P1
49°N
49°N
05AD003
S69
05AD005
S70
113°W
97°W
slow-response/ warm-season peak (C1)
fast-response/warm-season peak (C2)
slow-response/freshet peak (C3)
fast-response/freshet peak (C4)
slow-response/cold-season peak (C5)
fast-response/cold-season peak (C6)

Concordia University

Verification

Basin	Sub-basin (stream location)	Dominant regime shifts	Earlier findings on changes in streamflow characteristics (reconfirmed in this study)	New findings on changes in streamflow characteristics (discovered exclusively in this study)
Pacific	Yukon	C3 to C1	Earlier timing of low and high flows; greater variability in timing of high flows (Burn, 2008; Brabets and Walvoord, 2009; St. Jacques and Sauchyn, 2009)	Increasing flow in September; increasing flow variability in April and May
	Seaboard (north)	C1 to C2	Increasing winter flows (Déry et al., 2009)	Increasing monthly flow in May; earlier timing of low flow; increasing variability in March, May, and annual flows
	Seaboard (south)	C1 to C3	Decreasing annual and monthly flows from April to June; decreasing flow in fall (Déry et al., 2009; Pike et al., 2010)	Delayed and more variable timing of annual low flow; increasing variability in February's monthly flow
	Fraser (north)	Case 1: C1 to C2 Case 2: C2 to C1	No earlier study in this region found	Case 1: increasing mean of and variance in annual and summer flows; increasing monthly flows in May and June; increasing variation in timing of low flow and the quantity of spring flows. Case 2: decreasing mean of and variance in annual flow; decreasing monthly flows in July and October; earlier timing of high flow; decreasing variability in monthly flows in May, August, and September
	Fraser (south)	C2 to C5	Decreasing summer flows (Stahl and Moore, 2006); Increasing variability in monthly flows in November and April (Déry et al., 2012; Thorne and Woo, 2011)	Earlier timing of high flows; increasing mean monthly flows in November and April
	Columbia (north)	C2 to C1	Decreasing annual and summer flows (Stahl and Moore, 2006; Fleming and Weber, 2012; Forbes et al., 2019)	Decreasing variability in annual flow and monthly flows of August and September
	Columbia (south)	C1 to C3	Increasing flow in April and decreasing flow in September (Whitfield and Cannon, 2000; Whitfield, 2001); earlier timing of high flow (Burn and Whitfield, 2016; Burn et al., 2016)	Delayed timing and greater variability in the annual low flow; increasing mean of and variance in November's flow

Conclusion and further remark

- The first consistence (temporally and spatially) pan-Canadian study on understanding climate-change induced changes in streamflow regime.
- A globally-relevant algorithm was provided to (1) cluster streamflow regime based on the characteristics of the annual streamflow hydrograph, (2) detect regime shift and understanding where the regime is approaching, (3) attribute regime shifts to changes in the streamflow characteristics.
- While changes in regime was attributed to changes in streamflow characteristics, we know that changes in streamflow characteristics are caused by changes in hydrological processes.
- What are the hydrological causes of the shifts?

Show must go on…

Dedication

- This study is dedicated to the memory of Richard Janowicz, the iconic Yukon-based hydrologist who made fundamental discoveries on recent changes in natural streamflow regimes in the Great White North.

Northern hydrology owes you, *Ric*...

Richard Janowicz

1953-2018