Atmospheric Drivers of Spring Snowmelt Trends on the Headwaters of the Mackenzie River

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Introduction

- River runoff provides the largest influx of freshwater to the Arctic Ocean *(Aagaard and Carmack 1989)*
- The majority of the annual flow of the Mackenzie River originates as winter snowpack in mid-latitude headwaters, released from frozen storage during the spring freshet *(Lammers et al. 2001)*
- Spring freshet induces river ice break-up and often results in flooding in high-latitude basins *(Prowse and Beltaos 2002; de Rham et al. 2008)*
- Evidence indicates a trend toward an earlier spring freshet on north-flowing rivers *(Burn 2008; Bawden et al. 2013)*
- Surface hydroclimatic variables are strongly influenced by large-scale mid-tropospheric circulation *(Newton et al. 2014)*.

Goal and Objectives

Evaluate the dominant synoptic-scale circulation patterns as they relate to the spatial and temporal distribution of spring snowmelt in the alpine headwaters of the Mackenzie River.

- Classify daily winter geopotential heights (gph) at 500 hPa from 1950-2010.
- Identify patterns of surface temperature associated with each synoptic type.
- Analyze trends in spring snowmelt and synoptic type frequencies.

Study Area

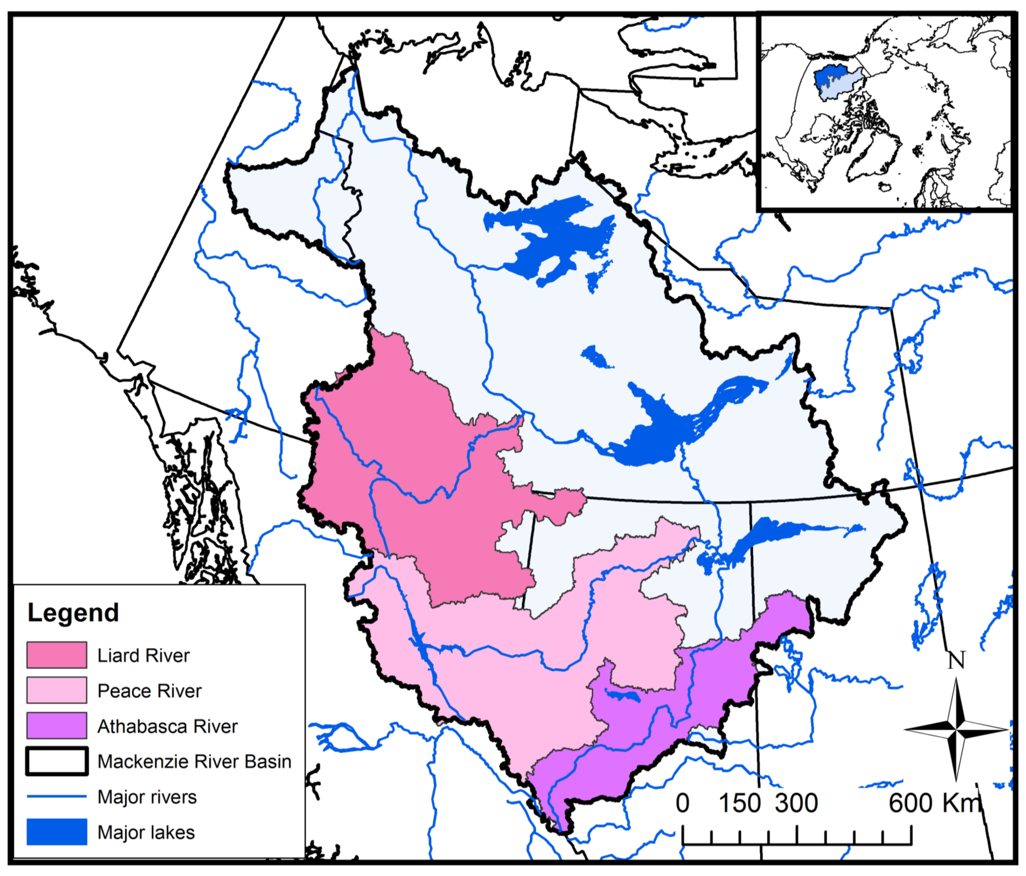

Figure 1: The Liard, Peace, and Athabasca Rivers are alpine tributaries to the north-flowing Mackenzie River

Data and Methodology

- Daily winter (Nov-Apr) 500 hPa gph for 1950-2010, obtained from NCEP/NCAR *(Kalnay et al. 1996)*, are classified using the batch algorithm Self-Organizing Maps (SOM), which clusters and projects dominant synoptic circulation patterns onto an organized array *(Kohonen 2001)*.
- Daily ANUSPLIN gridded temperature and precipitation data in 10 km resolution *(McKenney et al. 2011)* are used to identify spatial patterns of temperature anomalies and calculate the temperature-index snowmelt model.
- Temporal trends of spring snowmelt and synoptic type frequencies are analyzed using the non-parametric Mann-Kendall (M-K) test for trend *(Mann 1945; Kendall 1975)*.

Winter Synoptic Climatology

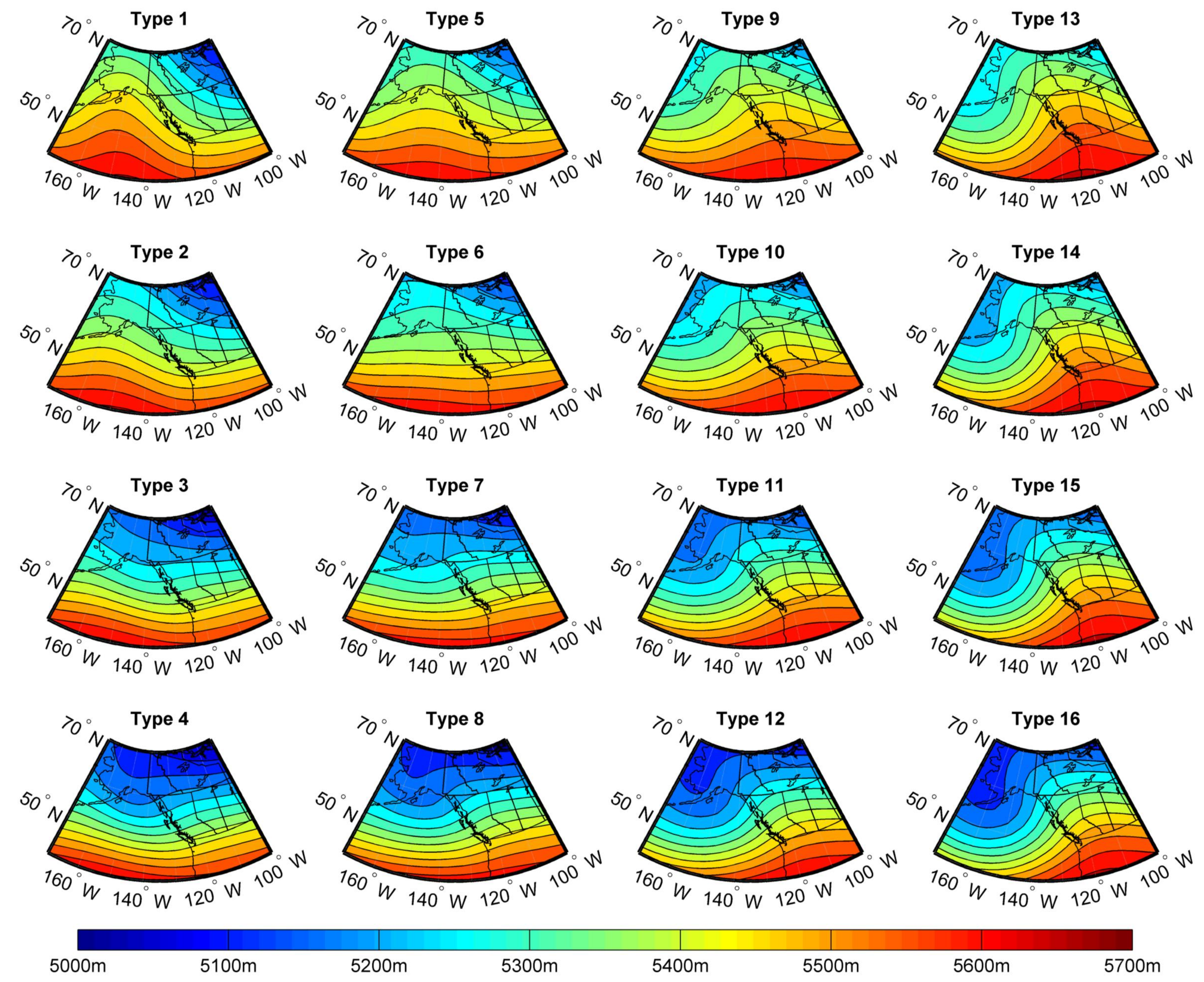

Figure 2: Winter (Nov-Apr) geopotential heights at 500 hPa classified using Self-Organizing Maps. Neighbouring synoptic types are most similar while opposite corners represent maximum variance.

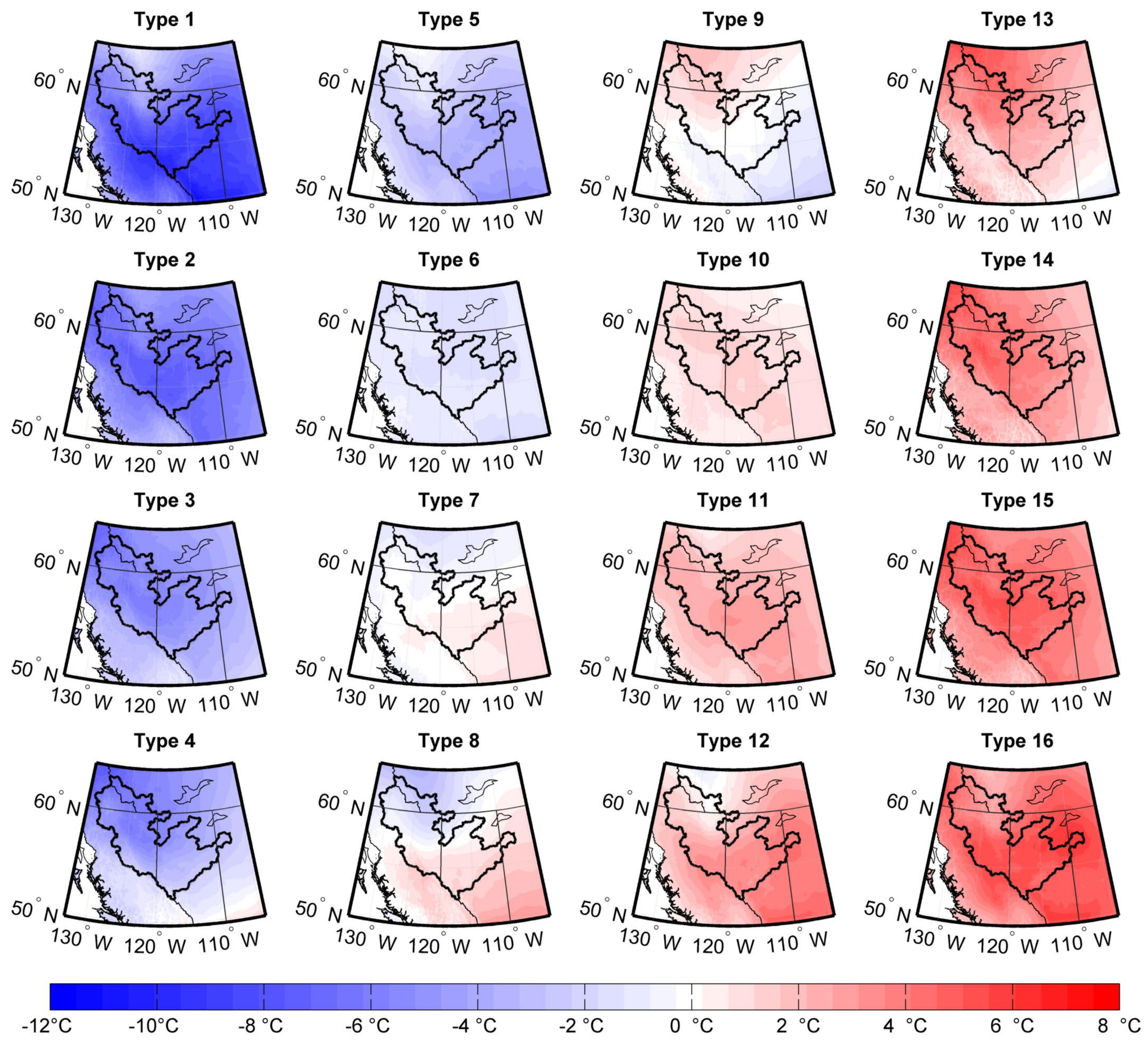

Figure 3: Surface temperature anomalies associated with each synoptic type (in the same order as Fig. 2) calculated as the average departure from the mean 1950-2010 values.

Spring Snowmelt Trends

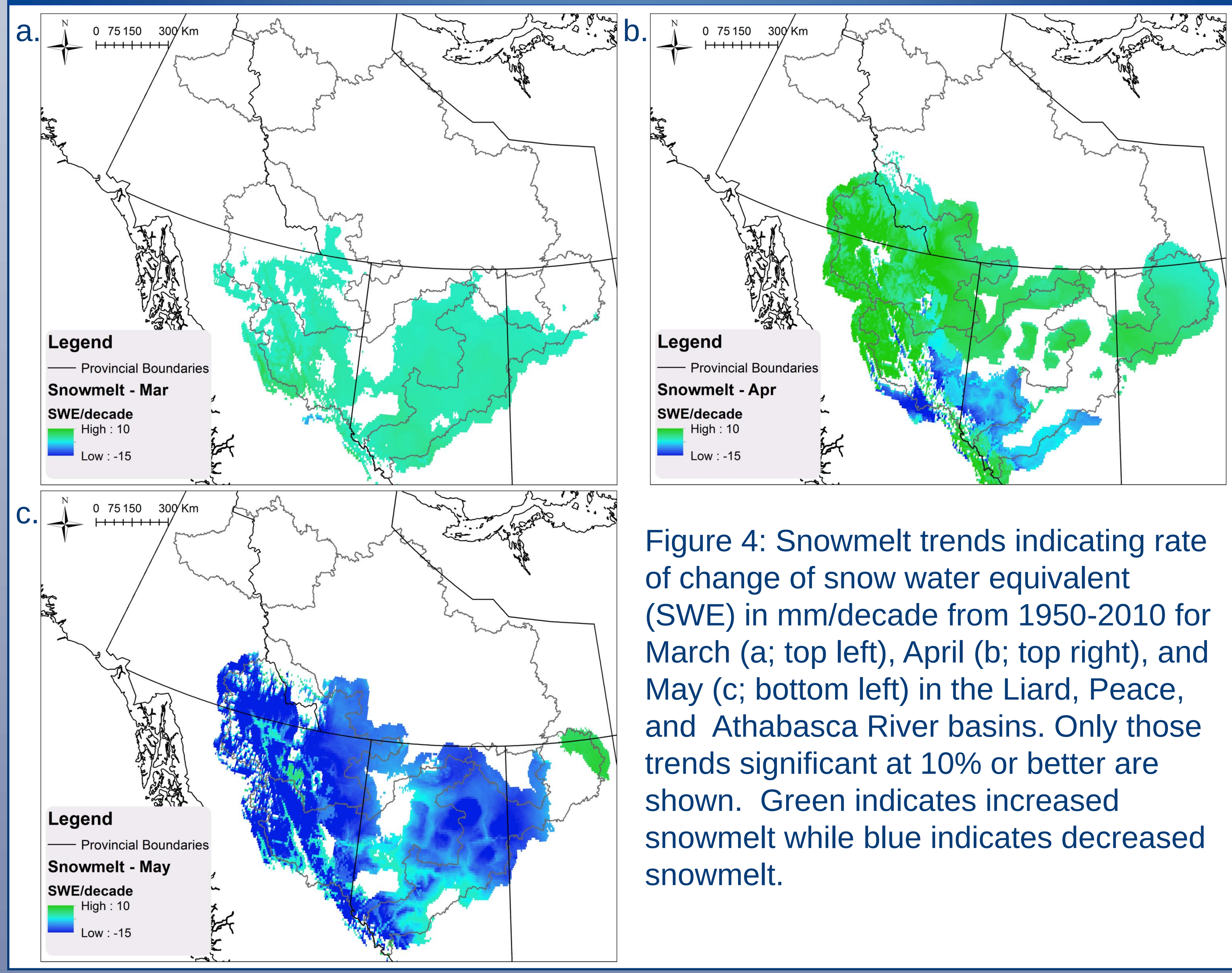

Figure 4: Snowmelt trends indicating rate of change of snow water equivalent (SWE) in mm/decade from 1950-2010 for March (a; top left), April (b; top right), and May (c; bottom left) in the Liard, Peace, and Athabasca River basins. Only those trends significant at 10% or better are shown. Green indicates increased snowmelt while blue indicates decreased snowmelt.

Synoptic Type Trends

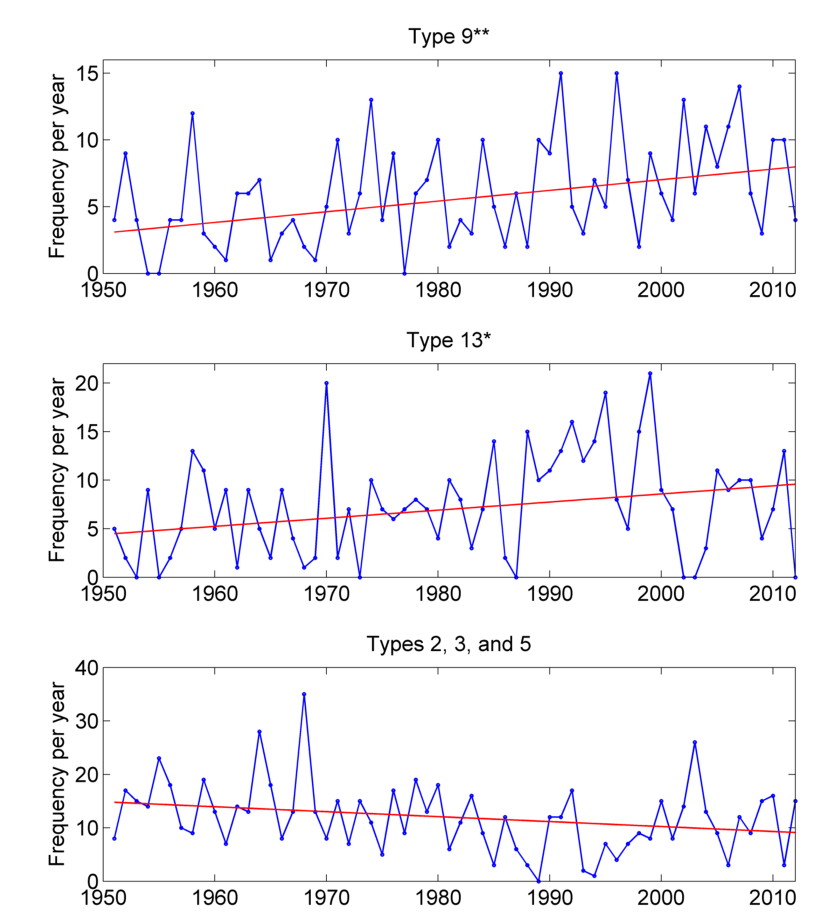

Figure 5: Spring (Mar-Apr) synoptic type frequency trends from 1950-2010. Type 9 (sig. 1%) has increased by 157% and Type 13 (sig. 5%) has increased by 113%. Types 2, 3, and 5 are shown as a combined frequency (-38%); however, these trends are not statistically significant.

Discussion and Conclusions

- Above-average surface temperatures in the study basins are associated with a ridge of high-pressure over western North America (Figs. 2-3 right columns) while below-average temperatures are associated with a ridge over the Pacific Ocean and northerly meridional flow over the study region (Figs. 2-3 left columns).
- Snowmelt has increased earlier at lower elevations and latitudes (Fig. 4a) and shifts to higher latitudes as spring progresses (Fig. 4b). Snowmelt decreases are apparent at lower elevations and latitudes during Apr (Fig. 4b), and are particularly pronounced during May (Fig. 4c). This indicates a shift toward an earlier freshet on the Liard, Peace, and Athabasca Rivers, consistent with Burn (2008) and Bawden et al. (2013).
- Synoptic Types 9 and 13, characterized by a ridge of high-pressure over western North America have significantly increased in frequency and Types 2, 3, and 5 have decreased (Fig. 5) during spring (Mar-Apr), indicating an atmospheric driver of snowmelt and freshet in the Mackenzie headwater basins.
- Combining this research with winter snowpack trends (Linton et al. 2014) and drivers (Newton et al. 2014) will provide a comprehensive analysis of spring freshet magnitude and timing.

References

Aagaard, K, Carmack, EC. 1989. The role of fresh water in ocean circulation and climate. J Geophys Res 94, 14,485–14,498.
Bawden AJ, Burn DH, Prowse TD. 2013. Recent changes in patterns of western Canadian river flow and association with climatic drivers: A CROCWR component. MASc. Thesis. University of Waterloo, Ontario, Canada
Burn DH. 2008. Climatic influences on streamflow timing in the headwaters of the Mackenzie River Basin. J Hydrol 352:225–238.
de Rham, LP, Prowse, TD, Beltaos, S and Lacroix, MP. 2008. Assessment of annual high-water events for the Mackenzie River basin, Canada. Hydrol Process., 22: 3864–3880.
Kalnay E and co-authors 1996. The NCEP/NCAR 40-year reanalysis project. B Am Meteorol Soc 77: 437–471.
Kendall MG. 1975. Rank Correlation Measures. Charles Griffin: London.
Kohonen T. 2001. Self-Organizing Maps. Springer: New York.
Linton, HC, Prowse, TD, Dibike, YB, and Bonsal, BR. 2014. Spatial and temporal variations in hydroclimatic variables affecting streamflow across western Canada. MSc. Thesis. University of Victoria, BC, Canada
Lammers RB, Shiklomanov AI, Vörösmarty CJ, Fekete BM, Peterson BJ. 2001. Assessment of contemporary Arctic river runoff based on observational discharge records. J Geophys Res 106(D4): 3321–3334.
Mann HB. 1945. Non-parametric tests against trend. Econometrica13: 245–259
McKenney DW and co-authors 2011. Customized spatial climate models for North America. B Am Meteorol Soc 92: 1611–1622.
Newton BW, Prowse TD, Bonsal BR. 2014. Evaluating the distribution of water resources in western Canada using synoptic climatology and selected teleconnections. Part 1: winter season. Hydrol Process.
Prowse, TD and Beltaos, S. 2002, Climatic control of river-ice hydrology: a review. Hydrol. Process., 16: 805–822.

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