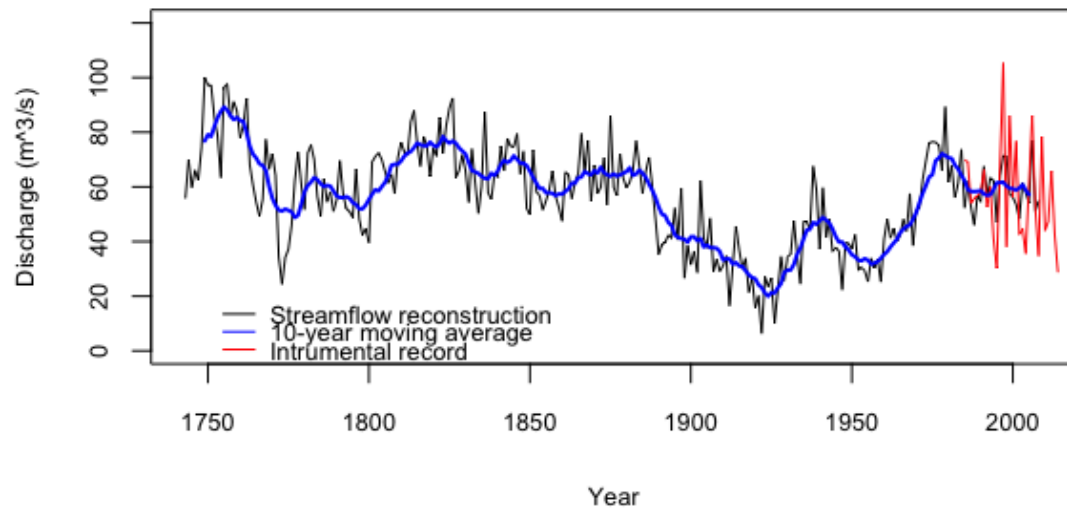


TREE-RING BASED STREAMFLOW RECONSTRUCTION OF THE SNARE RIVER BASIN



PRELIMINARY REPORT

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Executive summary

Following the droughts of 2014 and 2015, there is an uncertainty about the sustainability of hydroelectricity as a primary source of energy for the Yellowknife area. Given the short instrumental record of hydrological data, there is a need to better understand the long-term variability in the water level of the Snare River. This ongoing study aims at using tree-rings of jack pines to reconstruct the streamflow of the Snare River basin from today to prior to 1850.

The first objective is **to assess the relationship between streamflow of the Snare River and climate at different spatial scale**. The growth of tree-rings is partially controlled by climatic parameters (temperature and precipitation), which are responsible for the variability in hydrological conditions. A better understanding of these relationships will allow to corroborate the linkages between tree-ring, climate and streamflow. The second and most important objective is **to reconstruct the hydrological conditions of the Snare River basin using tree-rings**. This will allow to evaluate the frequency and the magnitude of the higher and lower flow periods.

During a field campaign, last July, we sampled approximately 950 radii from 478 trees at 12 different sites. These sites are located either on a transect between Rae-Edzo and the Snare River facility, along the Highway 3 or along the Ingraham trail. Most of the work during Fall was devoted to preparing the samples for measurement in the lab. One jack pine chronology is completed for a site located near Slemon Lake, albeit the last 20 years of this chronology must be reevaluated. This chronology was used for the analysis of this interim report.

The preliminary results show that we can predict with a high level of accuracy the mean summer streamflow from May precipitation (current year) and April rain (previous year). Moreover, an analysis of the dominant atmospheric circulation systems during dryer and wetter years show that drought conditions are caused by a blocking above the Western Cordillera that impedes the moisture from the Pacific Ocean to be carried to the interior. This atmospheric pattern seems to be well correlated with a global index called the North Atlantic Oscillation, which could be referred to as the El Nino of the northern Atlantic.

The jack pine chronology from Slemon Lake, as well as Michael Pisaric's jack pine chronologies from the Ingraham Trail, correlate well with June precipitation. However, since the discharge of the Snare River is correlated with earlier spring precipitation, it was impossible to reconstruct the streamflow from this tree-ring series. Hopefully, increasing the quantity of jack pine chronologies from the Snare River basin will settle this problem. In any cases, this reconstruction allows to appreciate the periodic fluctuations in precipitation, occurring on a scale of 10-30 years, approximately.

Using an existing white spruce chronology from three sites south of Gordon Lake, I could reconstruct the previous streamflow of the Snare River with a low level of confidence. The variation in streamflow would account for 15% of the variance in the tree-ring growth, which is low, albeit statistically significant. This reconstruction seems to have a limited capacity to model the most extreme flows, either high or low. However, it gives nonetheless a primary sketch of the evolution of the discharge of the Snare River since 1750. The first half of the 20th century was the driest period and the streamflow regime of the last decades is similar to the regime prior to 1900 (see figure on the cover page).

The assessment of the relationships between this long-term reconstruction and large-scale oceanic and atmospheric indices is still underway. At this stage, the analysis that were performed cannot allow to make any conclusive statement in that regard.

Finally, it is the opinion of the author that this preliminary work is encouraging. Indeed, it was possible to make a primary reconstruction, even if it was with an unexpected species. As we complete the jack pine chronologies, it will be possible to state with a higher level of certainty whether it was an appropriate choice of species. In any way, conducting an analysis on two species could promote an even more robust reconstruction.

By the end of this postdoctoral fellowship, in September, I aim to provide de GNWT with the following results:

- 1) An analysis of the periodicity and the return period of drought or drought-like conditions.
- 2) A first estimate of the frequency of years with an insufficient level of water to produce hydroelectricity.
- 3) An analysis of the large-scale atmospheric patterns responsible for the variability in the Snare River discharge. As these patterns are predictable, or given the presence of a lag in the local response to these patterns, this understanding will allow a better planning of water use.

However, given the scarcity of white spruce chronologies near the Snare River basin (only three sites), and considering other tree-ring indicators that we have yet to test, I am confident that with an additional year of funding, it would be possible to further refine these results and have a clearer picture of the past hydrological conditions of the Snare River.

Context

Drought is an important component of many ecosystems in North America, resulting in many environmental (e.g. fires) or socioeconomic impacts (Cook et al., 2007). As climate continues to change and temperatures warm, issues of drought are becoming problematic in locations that have not traditionally been associated with drought or drought-like conditions. Since 2014, the southern Northwest Territories (NT) is one such region that has experienced significant drought conditions. Across the southern NT water levels and stream flows were significantly lower in 2014/2015. Low winter precipitation and limited spring/summer rain caused flows of the Snare River (which is the main hydroelectric power generation system for the City of Yellowknife) to reach their lowest annual maximum water discharge and annual water level of the instrumental record. The Government of the NT had to spend nearly \$50 million to purchase diesel fuel to generate enough electricity to supplement the reduced hydroelectric power generation.

The Snare River basin is part of the North Slave Region. Located in the Taiga Shield, it is characterized by its subarctic nival hydrological regime (Church, 1974), meaning that the major annual peak occurs in late June following the snowmelt (Kokelj, 2003).

Yellowknife receives an average of 267 mm of annual precipitation. This low precipitation amount makes the streams of the region vulnerable to water shortage in drought-like conditions. However, aside from this recent episode, little is known about previous occurrence of drought conditions in the NT and associated water levels, since the hydrological records of the region provide only continuous records back to the 1980s.

Dendroclimatology, or the study of past climates using tree-ring growth records, has been widely used as a paleoclimatic proxy to reconstruct past hydroclimatic conditions. An example of this type of research was the development of a millennial reconstruction

of the Palmer Drought Severity Index for most of North America (Cook et al., 2004) and the projection of increasing drought hazards for the Central Plains and southwest of western North America (Cook et al., 2015). However, significant portions of northern Canada were underrepresented in this analysis and therefore little is known about the projected evolution of drought hazards at higher latitudes (Cook et al., 2007). In the NT, Pisaric et al. (2009) reconstructed June precipitation for the past 3 centuries using tree-ring records from jack pine (*Pinus banksiana* Lamb.) growing on moisture-limited sites. The results from Pisaric et al. (2009) show a multi-decadal fluctuation in the precipitation regime for the Yellowknife region that is in agreement with reconstructed lake levels from Lake Athabasca (Stockton and Fritts, 1973) and reconstructed stream flow for the North Saskatchewan River (Case and MacDonald, 2003). Lower reconstructed precipitation in Yellowknife was typically associated with lower Lake Athabasca water levels and lower flows on the North Saskatchewan River. This broad-scale hydrologic agreement over such a large geographic area suggests some large-scale atmospheric and/or oceanic pattern(s) may be driving the broad-scale hydrology of the southern NT and southwards into Alberta.

Linkages with the north Pacific, such as the Pacific Decadal Oscillation (PDO), is one possibility and will be explored in the proposed research. The synoptic meteorology of the study region also indicates that cyclonic activity transporting moisture from the north Pacific is an important source of precipitation for the Great Slave Region (Spence and Rausch, 2005). Moreover, the climate of circumpolar regions is also influenced by other teleconnections, such as the North Atlantic Oscillation (Polyakov et al., 2003). Indeed, at similar latitudes, in Northern Quebec, a tree-ring based hydrological reconstruction of the Caniapiscau Reservoir shows that the summer water supplies are significantly correlated with the Arctic Oscillation (AO) (Nicault et al., 2014).

In the North Slave region of the NT, no study has reconstructed stream flows or lake levels at annual scales using tree rings. In the context of ongoing and anticipated

changes in climate, a better understanding of previous variability in river discharge is key in projecting future trends. Global-scale climate models project an increase in river discharge for northern Canada (IPCC, 2013). However, stream flows are also expected to respond to other external forcings imposed by large-scale atmosphere-ocean interactions (Milly et al., 2005), and should therefore continue to oscillate around this general increasing trend related to climate change at the decadal to multi-decadal scale. A better knowledge of past hydroclimatic conditions is therefore needed for a good stewardship of water resources and better climate change adaptation planning in terms of power generation.

Research objectives

Even if the growth of the jack pines is sensitive to the moisture conditions, there is a possibility that we could not find a direct relationship between tree-ring growth records and river discharge. In that regard, we feel that it is necessary to get a better understanding the relationship between streamflow and climate on the Snare River using instrumental record. **Therefore, on the short-term, we would like to assess the relationship between climate and streamflow at different spatial scale.** This objective could be declined in several questions:

- What are the best meteorological predictors of streamflow?
- Which synoptic patterns are characteristic of high flow and low flow years?
- Are there teleconnections between large scale atmospheric patterns and streamflow?

However, the instrumental record is too short to capture adequately the lower-frequency (decadal scale) variability of hydrologic and climatic systems. **In that regard, on the longer-term, we aim to reconstruct the hydrological conditions of the Snare**

River basin using tree-rings. To achieve this objective, we aim to answer these questions.

- Can we reconstruct the streamflow or climate of the past ~ 150 years in the Snare River basin using tree-rings?
- How does the streamflow oscillate over the longer term?
- What are the large-scale atmospheric mechanisms explaining this interdecadal variability in the hydrology of the Snare River?

Structure of the report

This interim report presents the work achieved during the field campaign (July) and since the beginning of my research contract in September. It will be divided in four parts:

- 1) Study sites and data acquisition
- 2) Methods and lab work achieved
- 3) Preliminary results and discussion
- 4) Next steps and schedule
- 5) Research perspective

Study sites and data acquisition

Study sites and sample collection

Our sample effort focused on jack pine. The species selection was based on previous research that shows that its growth was conditioned by June precipitation (Pisaric et al., 2009). If the growth of a species is so well correlated to precipitation, we assumed that they would provide the best chance at reconstructing streamflow. Jack pine samples

were collected from different rock outcrops in three different regions (Figure 1; Table 1). First, eight sites in the southern part of the Snare River basin between the Snare River Dam and Russel Lake were visited by helicopter. Given the fire situation in July 2016, it was impossible to stay at the Snare facility and to sample sites further north. Moreover, satellite imagery suggests that above Big Spruce Lake, jack pine is less abundant than spruce. Second, four sites were visited along Highway 3 between Yellowknife and Rae-Edzo, to connect the Snare River sites to the jack pine chronologies located east of Yellowknife, collected in 2005. Finally, two of these 2005 chronologies were updated (50 km and Dettah Road), and another site was added east of Yellowknife (Ponton Lake). The later site, even if far from the Snare River facility, shows a great potential for a long reconstruction, since many samples were at least 250 years old.

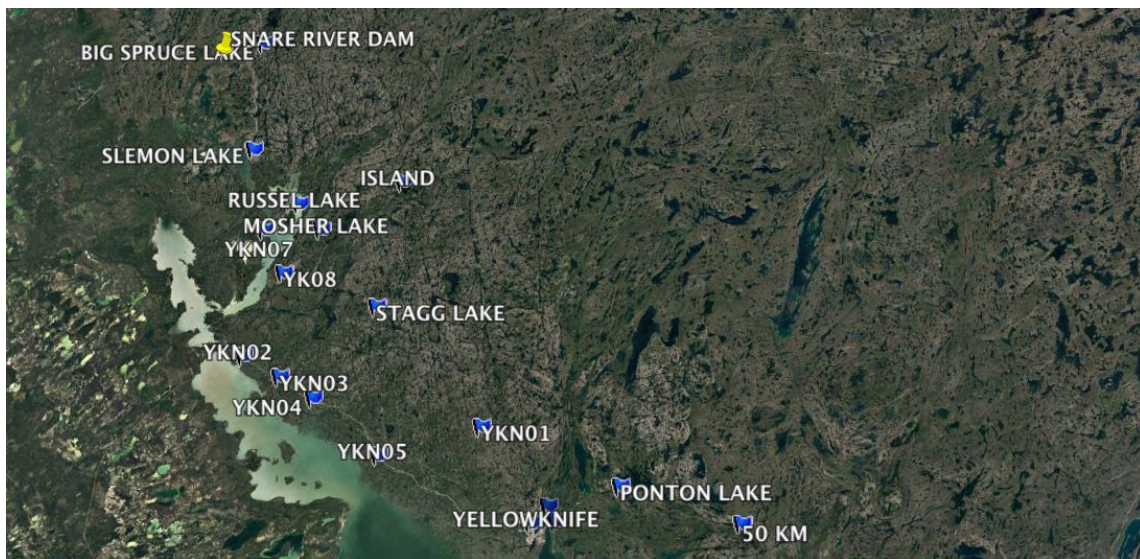


Figure 1. Sampling sites.

Region	Site name	Trees (samples)	M/S	M	CD
Snare Basin	Big Spruce Lake (BSL)	32 (64)	X	X	
	Slemon Lake (SLE)	32 (64)	X	X	X
	Russel Lake (RUS)	32 (64)	X		
	Mosher Lake (MOS)	16 (32)	X		
	Stagg Lake (STA)	31(61)	X		
	YKN01	48 (95)	X		
	YKN07	43 (85)	X		
	YKN08	35 (69)	X		
Highway 3	YKN02	29 (58)	X	X	
	YKN03	30 (60)	X		
	YKN04	30 (60)	X	X	
	YKN05	35 (68)	X		
East of Yellowknife	Ponton Lake	48 (92)	X	X	
	50 km	20 (40)	X	X	
	Dettah Road	17 (34)	X		

Table 1. Summary of sampling sites and the progress in lab work. M/S: Mounting and sanding; M: Measuring; CD: cross-dating.

White spruce chronologies from a former master student of Michael Pisaric have been added to this analysis. His sites were located near Gordon Lake. Two chronologies were built: one using five sites close to the treeline. COMP1 comprises five sites located at the treeline and are more temperature sensitive. COMP2 is a chronology built from three sites located more to the south and is more sensitive to moisture condition. We will only refer to that later chronology hereafter.

Instrumental data

Streamflow data comes from Environment Canada stream gauge located on the Snare River below Ghost River. This station records daily discharge since 1984 and provides the longest record in the Snare River drainage basin. We were told that data from the Big Spruce Lake stream gauge (1949-1976) are considered unreliable and therefore were discarded. Meteorological data comes from the Yellowknife meteorological station, which records temperature and precipitation since 1943.

Methods

Chronology development and progress

Trees were sampled this summer using an increment borer that extracts a core from the stem. Two radii were collected per tree if possible. The samples are then mounted on wooden rods and sanded to increase the contrast between each ring and facilitate their measurement. Every radius is then scanned with a high-resolution scanner. Tree-rings are measured with a 0.01 mm resolution using OSM software. At each site, to make sure that there are no missing rings, ghost rings or pale rings, we cross-date every tree by superimposing their growth patterns. To do that, we use significant years (either with a particularly high or low growth) as markers. We then make a chronology for each site by creating a mean growth for every year. Right now, all samples have been sanded and mounted. Six sites have been completely or partially measured, and the chronology from one site has been completed. Further results are based on this chronology.

Analysis

Most of the results presented here are based on correlations and linear regression models between different climatic variables, streamflow and tree-ring growth. As these variables are time series, correlations can be misleading, as their strength (r value) can be biased by the time variable. However, to conduct a preliminary analysis, they provide quick estimate of a presence or absence or relationship between climate, streamflow and tree growth. It is intended to get into more thorough time-series analysis as soon as the building of chronologies is completed.

Preliminary results

Meteorological predictors of streamflow

We investigated how seasonal and annual streamflow of the Snare River were correlated to temperature, rain, snow, total precipitation and snowdepth. It is important to notice that due to the small temporal overlap between meteorological and hydrological data (1984-2014), a high correlation is necessary to be considered statistically significant.

Temperature is not a good predictor of streamflow. However, there is a positive correlation between spring streamflow and the average temperature of the water year ($r=0.52$). Obviously, rain is more highly correlated with streamflow. The highest correlation was achieved between spring liquid precipitation and summer flow ($r=0.58$). Spring snow also exhibits a strong relationship with summer streamflow ($r=0.5$). There were few significant relationships between snowdepth and the Snare River discharge.

Summer streamflow is best correlated with spring precipitation. On a monthly scale, only May precipitation shows a significant correlation with summer streamflow, albeit weaker than the relationship at the seasonal scale ($r=0.52$ vs $r=0.68$; Figure 2). Although summer and fall precipitation are generally higher, a wetter spring probably results in less evaporation of lake water as well as less snow sublimation. This situation would lead to an increased amount of water in the Snare River system. Spring precipitation also exhibits a good correlation with the average discharge of the water year ($r=0.55$) and the calendar year ($r=0.51$). Indeed, the peak of the annual hydrograph generally occurs in July.

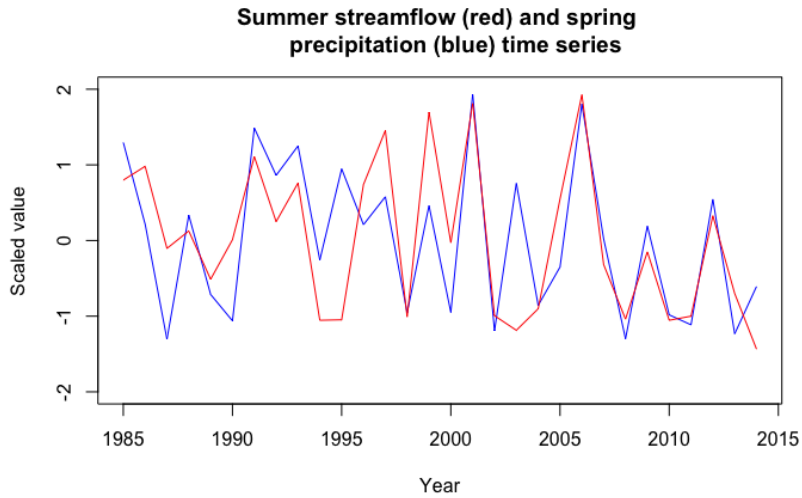


Figure 2.

Linear regression model of streamflow

The high correlation between precipitation and discharge allowed to build different linear regression models. Comparatively to correlation, regression models can use multiple independent variables (meteorological variables) to predict streamflow. Below are presented the best models to predict the mean discharge of summer, calendar year and water year (Table 2 to 5). The best regression model was obtained using two predictors for summer discharge: spring precipitation and april precipitation of previous year. This model accounts for 62% of the variance in the average summer streamflow and reproduces every year accurately (Figure 3).

Variable	Estimate	Std. Error	t value	p-value
Intercept	-9.88	16.83	-0.587	0.562
Spring precipitation	1.81	0.37	4.916	<0.001
April precipitation (last year)	3.10	0.82	3.759	<0.001

Table 2. Regression model for the average summer streamflow.

Variable	Estimate	Std. Error	t value	p-value
Intercept	-1.23	10.32	-0.120	0.906
April precipitation (last year)	1.03	0.32	3.20	0.003
Water year total rain	0.16	0.05	3.35	0.003
Spring precipitation	0.43	0.15	2.93	0.007

Table 3. Regression model for the average calendar year streamflow.

Variable	Estimate	Std. Error	t value	p-value
Intercept	19.81	7.70	2.57	0.016
April precipitation (last year)	1.33	0.38	3.54	0.002
Spring precipitation	0.53	0.17	3.16	0.004

Table 4. Regression model for the average water year streamflow.

Independent variable	Number of predictors	R ²	Normality test ¹	Durbin-Watson test ²
Summer flow	2	0.62	PASS	PASS
Annual flow	3	0.55	FAIL ³	PASS
Water year flow	2	0.48	PASS	PASS

Table 5. Summary of the regression models.

¹ Shows that the residuals are normally distributed, hence the use of a linear regression is appropriate

² Shows that the residuals are not serially autocorrelated

³ $0.5 < p < 0.1$ and failure threshold at 0.05

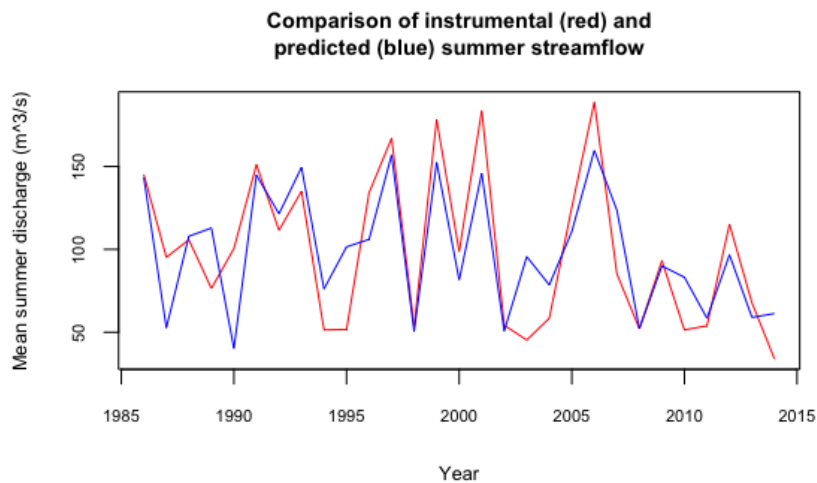
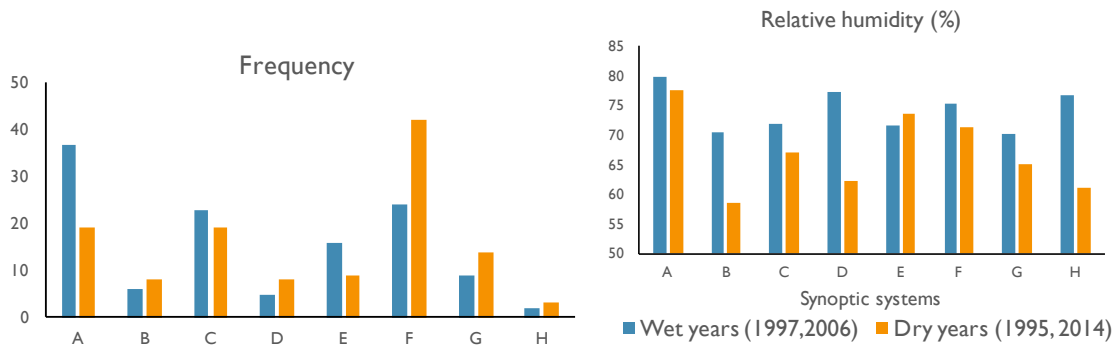


Figure 3.

While these models do not allow to predict the daily streamflow, they provide a good argument that precipitation is the main parameter to consider in understanding the fluctuations in the amount of water in the Snare River basin. However, the lack of instrumental data on the date of disappearance of the ice cover on the lakes is an issue in refining the model.

Characteristic synoptic patterns

As presented at the Geoscience workshop, there seems to be a difference in characteristic atmospheric patterns at the synoptic scale during wet years and dry years (Figure 4). The five years with the highest average annual streamflow are characterized by a high frequency of a low-pressure system above the North Slave Region (Figure 4; synoptic system A), whereas the five driest years of the instrumental record presented more frequent Aleutian Lows – a low pressure system located in the Gulf of Alaska (Figure 4; synoptic system F). Moreover, the composite maps of the winds show that during wet years, there is no blocking above the Western Cordillera. This means that during these years, the dominant winds transport the Pacific moisture inland (Figure 4). During dryer years, the blocking above the Western Cordillera favors the presence of dry, arctic air masses in the study region (Figure 4). This synoptic scale analysis proposes a mechanism to explain how the global atmospheric patterns have local impacts in the Northwest Territories, by controlling the quantity of precipitation and, ultimately, the amount of water in the Snare River basin. This strong argument for such a global control means that we might be able to identify relationships between large-scale atmospheric and oceanic patterns and streamflows.



WET YEARS

DRY YEARS

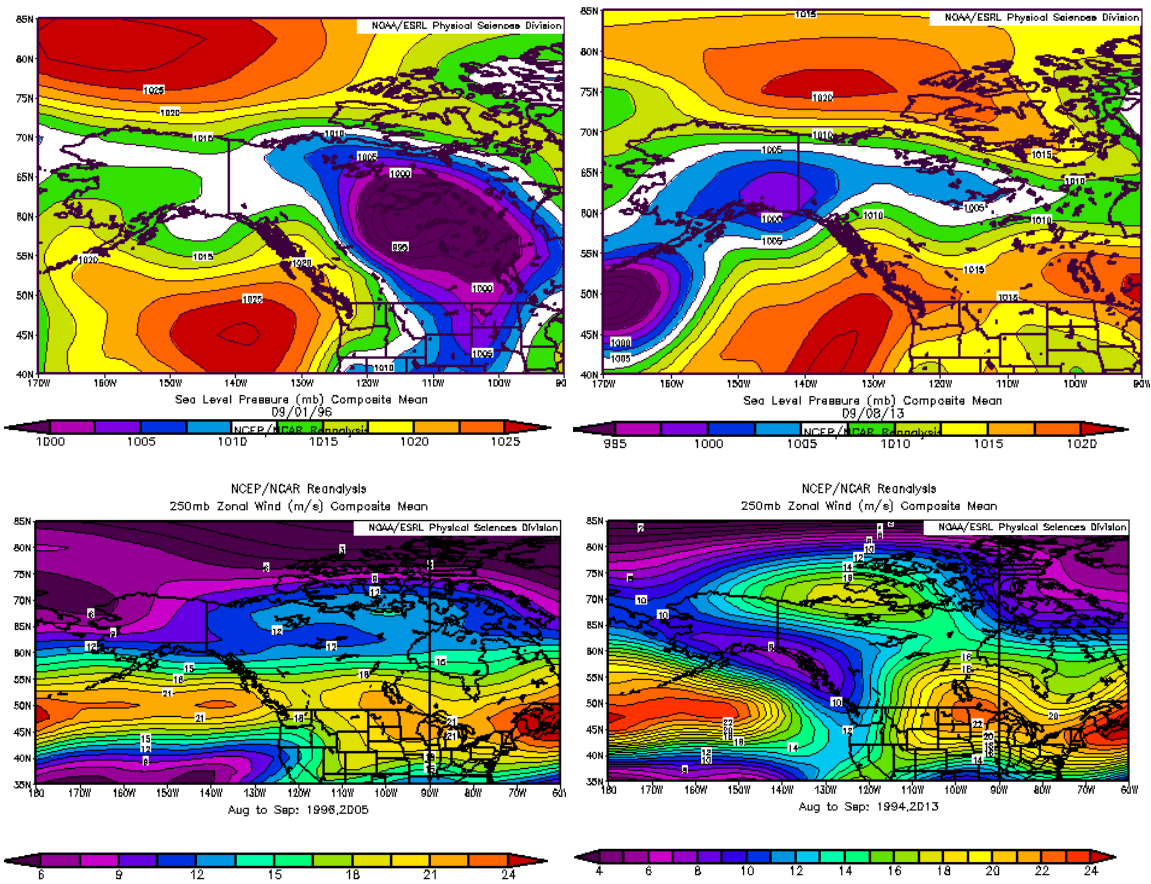


Figure 4. Contrast in the synoptic conditions between wet years and dry years. First row: frequency of different synoptic systems. Second row: illustrations of the 500mbar geopotential height of system A (a low-pressure system centered above the study region) and system F (a low-pressure system located above the Gulf of Alaska). Third row: composite mean of the zonal wind for the two wettest and the two driest year.

Teleconnections between atmospheric patterns and streamflow

Many large-scale atmospheric and oceanic patterns are defined in the scientific literature. These global systems are generally teleconnected (i.e. remotely connected) to local or regional climate variability. The most well-known is El Niño Southern Oscillation, which is an index of the sea level pressure difference between Western and Eastern Pacific.

These patterns all vary in frequency (i.e. the average time between a positive and negative phase) as well as in the strength and the lag of their connection with different regions. Whereas El Niño Southern Oscillation has a strong, direct impact on South American climate, the Pacific Decadal Oscillation is considered an important driver of climate, especially moisture conditions, in western Canada. This index, which is sometimes referred to as a long-lived El Niño Southern Oscillation, is based on the sea surface temperature of the Northern Pacific. However, as its name implies, it fluctuates on the decadal scale, and therefore it is hard to correlate it with a short instrumental record. The Arctic Oscillation is another index that could be correlated with moisture conditions in the North Slave basin.

Using the short instrumental period, the only relationship that we could find was with the North Atlantic Oscillation (Figure 5), which is based on a latitudinal pressure difference between Iceland and Portugal. The NAO of the previous year is highly correlated with the average discharge of the water year ($R^2=0.33$). This is coherent with the fact that a positive NAO favors zonal flows in the jet stream (i.e. no blocking above the Western Cordillera).

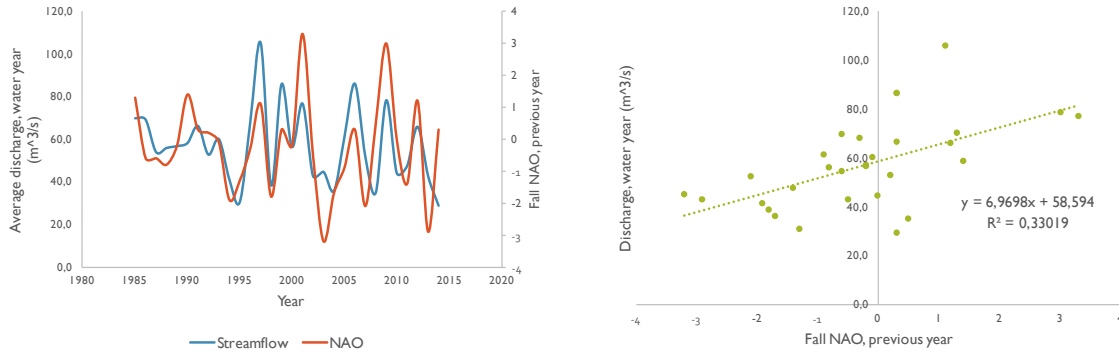


Figure 5. Time-series and correlation between NAO of the previous Fall and the average discharge of the water year, using instrumental data.

This preliminary result is interesting in terms of water management, since these large-scale indices are usually predictable. It is therefore possible to plan, with a high margin of error, whether the average streamflow should be high or low in the near future. However, the fact that streamflow correlates with an index located in the North Atlantic is strange, since most of the weather systems come from the prevailing winds from the West. In that regard, given that these large-scale patterns are to some extent connected, we believe that this strong relationship is an artefact of teleconnexions between moisture conditions in the North Slave region and the other large-scale patterns in the Pacific or the Arctic Ocean. It is our hope to find a relationship between these indices and a tree-ring based reconstructed streamflows.

Jack pine chronology of Slemmon Lake

The chronology is robust (Table 6) and the pointer years (i.e. years with a ring that is especially large or narrow) match well with other jack pine chronologies from East of Yellowknife (Pisaric et al. 2009). The Slemmon Lake chronology extends back to 1626, but could only be considered robust for the period 1854-2016 (Figure 6). It is important to note that the trees at Slemmon Lake were hard to read on the last 20 years and this part should not be trusted for the moment.

Site	Chronology	n	Mean ring width (mm)	Mean sensitivity	Autocorrelation
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interval

SLE	1626-2016	29	0.366	0.386	0.615
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Table 6. Summary of the Slemon Lake chronology

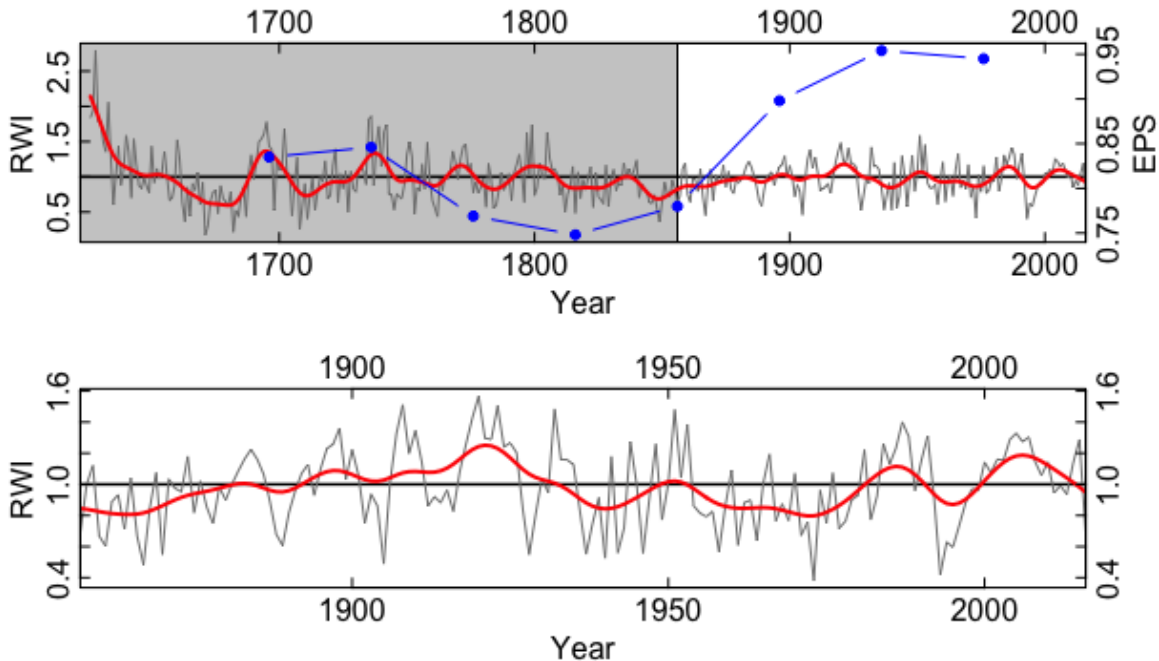


Figure 6. Tree-ring chronology of jack pines sampled at Slemon Lake. The grey-line is the annual ring-width index and the red line presents the 20 years average. First row: complete chronology. RWI: ring width index. EPS is a value to determine if the chronology is robust. The shaded area is not considered robust. Second row: close-up of the robust section of the chronology.

[Relationships between jack pine, climate and streamflows](#)

There are no strong correlations between the growth of jack pine and snow, snow depth or temperature during the growing season. There is a strong correlation with June ($r=0,51$; Figure 7) or summer ($r=0.34$) precipitation. There were no correlations between tree-ring growth and any meteorological predictors from the previous year. The correlation is even better if we remove the last 20 years ($r=0.61$), given the problems in measurement.

The strength in the correlation allows to build a transfer function to predict previous June precipitation from jack pine growth (Figure 8-9). Pisaric et al. (2009) already

provided a reconstruction of June precipitation extending back to 1819. The fact that we sampled in sites with old trees such as Slemon Lake leads us to believe that we will be able to extend this chronology further back in time.

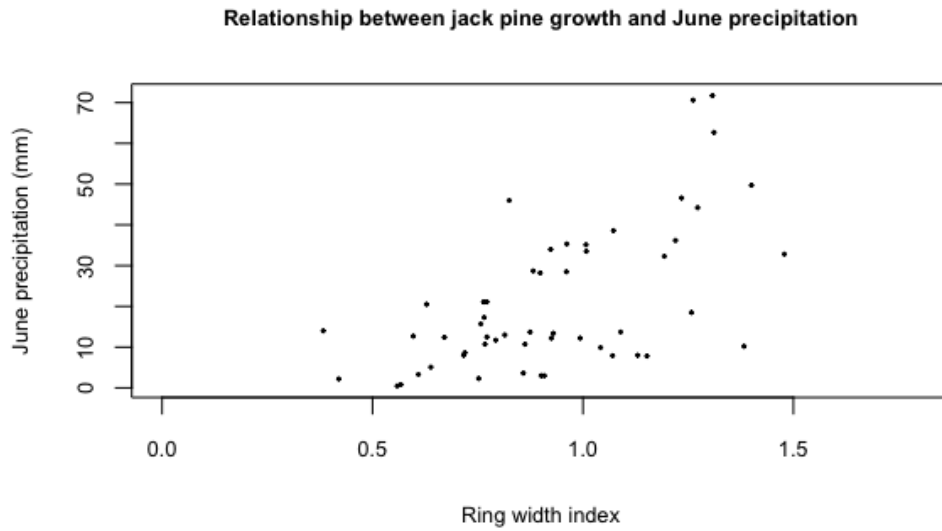


Figure 7.

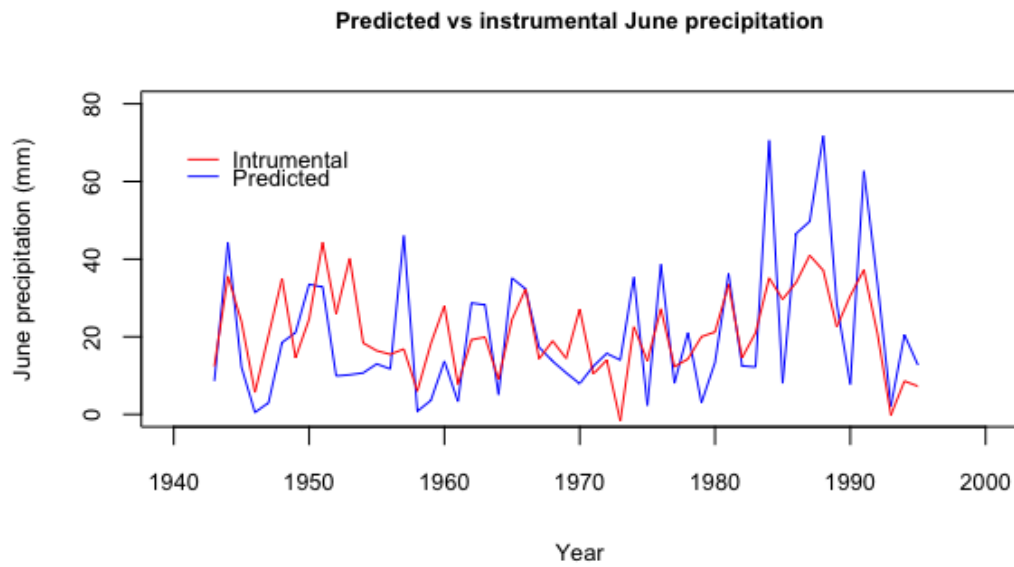


Figure 8.

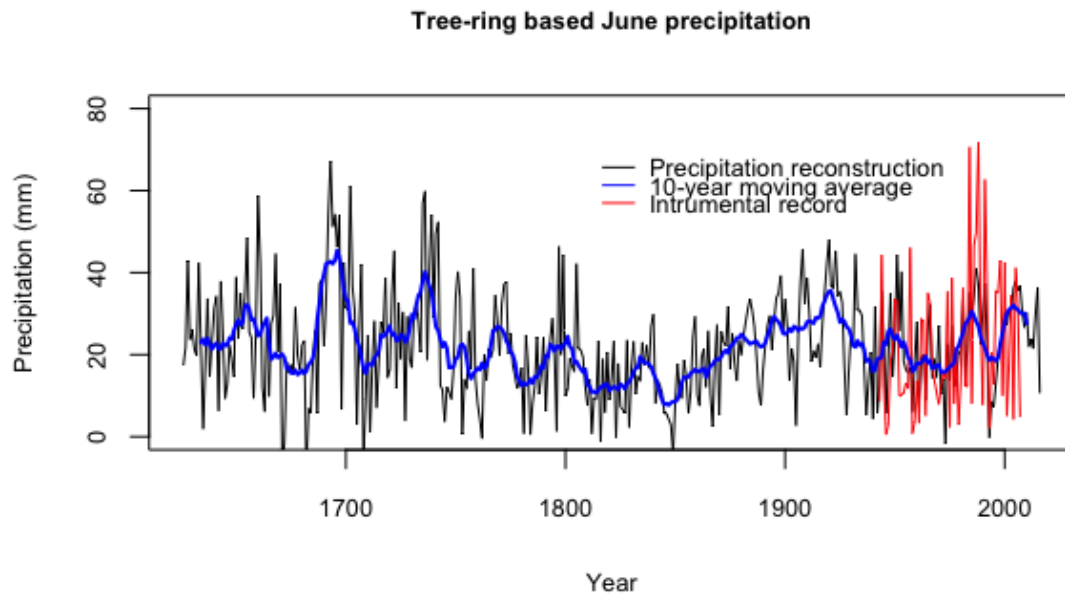


Figure 9.

While a June precipitation reconstruction is not ideal given the lack of correlation between this variable and streamflow, it will nonetheless allow to understand the low frequency fluctuations in moisture conditions as well as eventual connections between precipitation and large-scale atmospheric or oceanic patterns.

Relationships between white spruce, climate and streamflow

Whereas jack pine correlates better with summer precipitation, the southernmost white spruce chronologies from Gordon Lake correlates well with the previous water year streamflow. Indeed, the water discharge could explain 15% of the variance in the tree-ring growth which is statistically significant. We could therefore build a transfer function and reconstruct the water year average discharge for the period 1854-2009 (Figure 10-11; Table 7-8). The level of confidence in this reconstruction is low, since it is based on only three sites. The variance of the model is lower than the interannual variance of the instrumental record, which could mean that it is not sufficiently precise to predict the most extreme flows, either high or low.

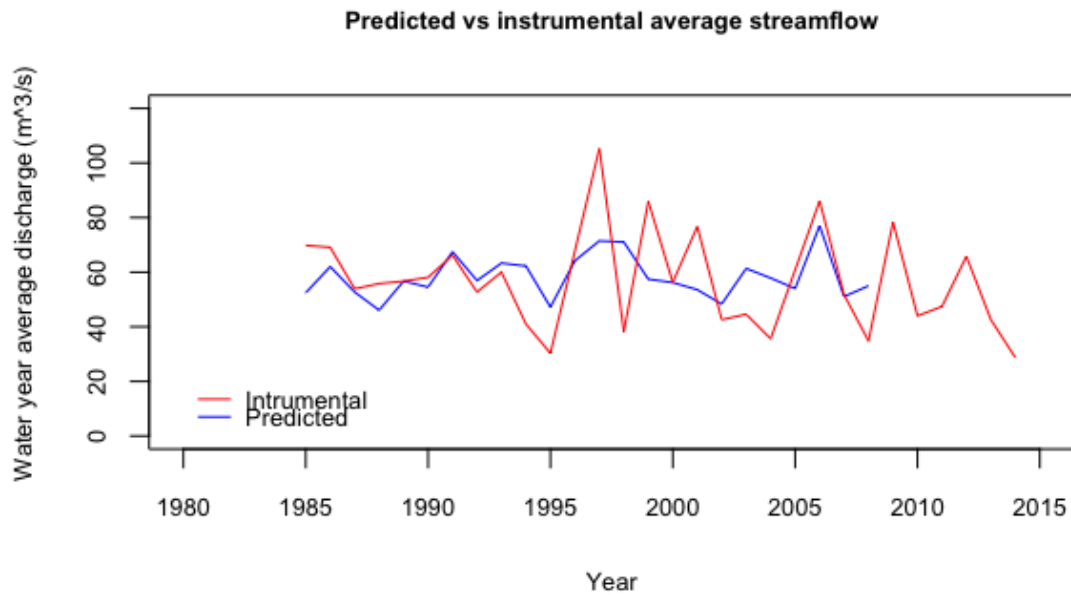


Figure 10.

Variable	Estimate	Std. Error	t value	p-value
Intercept	51.68	4.5	11.47	<0.001
COMP2 (t-1)	-51.47	22.7	-2.26	<0.03

Table 7. Regression model for the average water year streamflow based on tree-ring.

Independent variable	Predictor	R ²	p-value	Normality test ¹	Durbin-Watson test ²
Water year flow	COMP2 (t+1)	0.15	0.033	PASS	PASS

Table 7. Statistics of the model.

Tree-ring based streamflow reconstruction

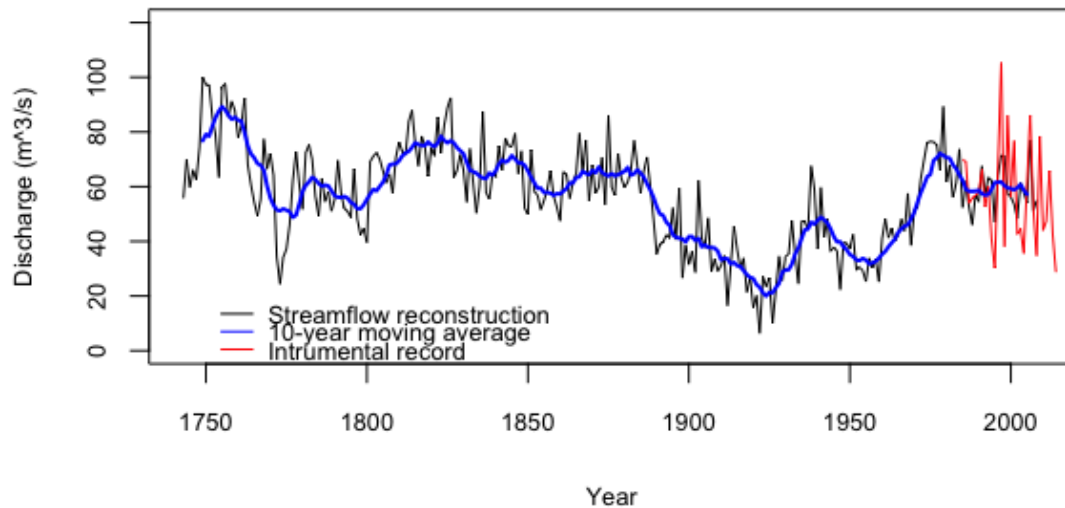


Figure 11.

Relationship between streamflow reconstruction and climatic indices

There seems to be non-stationary relationships with some large scale climatic indices. While the reconstructed streamflow appears to correlate moderately with the Pacific Decadal Oscillation and well with the North Atlantic Oscillation ($r=0.46$), a qualitative appreciation of the figure below shows that this relationship does not hold for the whole time-series. In that regard, there is still a lot of work to be done to better understand these patterns (Figure 12).

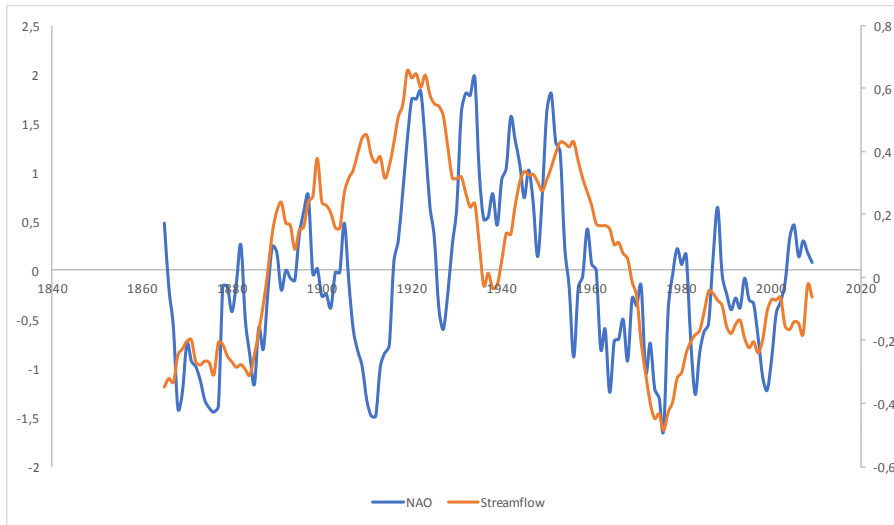


Figure 12. Comparison of the reconstructed streamflow with the summer North Atlantic Oscillation. Data presented are 5-year (streamflow) and 10-year (NAO) moving averages.

Discussion

Despite the lack of correlation between streamflow and jack pine growth, the preliminary results are somewhat encouraging. Our analysis of the instrumental record shows that we will be able to understand the climatic mechanisms responsible for the interannual variability in drought condition and ultimately in the streamflow of the Snare River system. Indeed, the creation of systems above the Western Cordillera blocking the zonal winds and the moisture from the Pacific from entering the interior of the continent seems to explain the drought conditions. While we do not understand the underlying mechanisms yet, it seems that these systems are connected to larger-scale indices, such as the North Atlantic Oscillation.

We finished building the tree-ring chronology for one site, Slemon Lake. The results show a good correlation with June precipitation, but an absence of relation with the discharge of the Snare River. The first reason for this absence of relationship could be the low quality of the 1995-2016 period of our reconstruction. This means that the only

reliable overlap with the Snare River data is for the period 1984-1995, which is too short to find any tendencies. We tested with Michael Pisaric's jack pine chronologies, and no relationship with streamflow were identified either.

Considering the strong relationship between the growth of jack pine and June precipitation, there is no doubt that this species is moisture sensitive. However, there is a question whether the growth season of this species starts too late. Considering the strong relationship between May precipitation and the discharge of the Snare river, a species that would start to grow only in June would not be able to record it. In that regard, Dana Harris, a master student of Michael Pisaric, is conducting her research project on getting a better understanding of the ecological parameters controlling the growth of jack pine. By next Fall, we will know better about this question, especially the timing of the onset of the growing season.

Curiously, the growth of the white spruce, a species that is usually considered as temperature sensitive, is a better indicator of the average water year discharge of the Snare River. My confidence in this reconstruction is low for a couple of reasons.

- 1) The sampling sites were located south of Gordon Lake, which is a bit far from the drainage basin of the Snare River.
- 2) There were only three sites in this chronology.
- 3) There is an evident problem about the stationarity of the chronology. This means that the variance is not constant in time, and hinders our ability to draw solid conclusions from this time-series.

Nonetheless, these preliminary results are promising. First, they show that there is clear possibility to reconstruct past streamflow of the Snare River using tree-rings. Moreover, while I did not quantify it yet, it is possible to qualitatively appreciate the longer-term fluctuations between periods of higher flows and periods of lower flows. Based on this reconstruction, the mean annual discharge was especially low during the period 1890-

1960, but was almost as high or higher than today prior to that. It is our hope to continue the analysis in the upcoming months to better understand this periodicity and to link it to larger-scale atmospheric and oceanic patterns.

Next steps and expected results

Given their sensitivity to moisture condition, I still feel that the jack pine tree-rings could give us useful information about past drought conditions. In that regard, I first aim to finish to build a robust, multi-site jack pine chronology. Having two species instead of one is always a good thing, since we can couple them to extract a common signal, which is usually linked with specific environmental conditions. Simultaneously, I will continue to work on the understanding of the climatic drivers of streamflow.

The academic objective of my postdoc would be to publish two papers:

- 1) A tree-ring reconstruction of the streamflow of the Snare Basin, if possible; otherwise I aim to do a reconstruction of the drought conditions in the NT, which will inform us about the periodicity of the water levels in the fluvial system.
- 2) An analysis of the climatic controls of the river levels.

From an operational standpoint, this will hopefully translate to this information to the GNWT:

- 1) An analysis of the periodicity and the return period of drought or drought-like conditions.
- 2) A first estimate of the frequency of years with an insufficient level of water to produce hydroelectricity.
- 3) An analysis of the large-scale atmospheric patterns responsible for the variability in the Snare River discharge. As these patterns are predictable, or given the presence of a lag in the local response to these patterns, this understanding will allow a better planning of water use.

Schedule

February – March: chronology building

This step consists in measuring and cross-dating the remaining sites.

April – June: analysis

The plan is to further refine the correlations and regression models by taking into account the temporal dimension, to conduct a principal component analysis using the jack pine and white spruce chronologies together, and conduct cross-spectral analysis to test whether the periodicity of the streamflow is caused by large-scale atmospheric or oceanic teleconnections. This will allow to evaluate the return period of low flow years.

June – August: field work and writing

If the GNWT agrees to continue the project, a 10-15 day field campaign will be organized during summer. The final part of the fellowship will be devoted to producing an extensive final report with answers that will facilitate decision makings regarding the energetic strategy of the GNWT.

Research perspective

I firmly believe that having a supplementary year to work on this project could yield more robust results. The quality of these results could come from one of these three solutions that I envision to better refine our streamflow reconstruction.

First, since two species is always better than one, I propose to a conduct second field campaign next summer to get ~10-15 sites of white spruce inside the Snare River basin. This species seems to better respond to streamflow variations and is abundant in the drainage basin of the Snare River. If the forest fire situation allows it next summer, a

field campaign around Rae, Russell Lake and the NTPC facility should yield interesting results. As mentioned earlier, multi-species reconstruction can allow the extraction of common environmental signals that are stronger than with a single species.

Second, ring width is only one of the growth parameters that can correlate to climate or hydrological conditions. We can measure other parameters such as blue light intensity and wood density. While I hope to have time before September to experiment the feasibility and the potential of these techniques to solve the question of streamflow reconstruction, time will be missing to conduct a complete analysis.

Finally, Étienne Boucher is inverting an ecophysiological model to evaluate past conditions from tree-ring using a deterministic approach, i.e. an approach based on mathematical equations representing the ecological processes controlling the growth of a tree. This approach contrasts with the linear regression approach by making sure that past conditions, such as the difference in atmospheric CO₂ before the industrial era, are considered as factors controlling the width of the tree-rings. The results are more stable in time with this approach. Étienne Boucher and I discussed the possibility of applying his inverted model to the bioclimatic context of NWT. In the regard of these perspectives, I am confident that an additional year of funding would yield interesting results to better understand past hydrological conditions of the Snare River.

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