A CLIMATE STUDY IN WESTERN NEWFOUNDLAND: PRECIPITATION $\delta^{18}O$ AND $\delta^{2}H$ EXAMINATION USING PICARRO L2130-I LIQUID WATER ISOTOPE ANALYZER

by

Brittany Marche

A Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science, Honours

Environmental Science, Grenfell Campus

Memorial University of Newfoundland

April 06, 2016

Corner Brook Newfoundland

Grenfell Campus

Environmental Science Unit

The undersigned hereby certify that they have read, and recommend to the Environmental Science Unit (Division of Science) for acceptance, a thesis entitled "A Climate Study in Western Newfoundland: Precipitation $\delta^{18}O$ and $\delta^{2}H$ Examination Using Picarro L2130-i Liquid Water Isotope Analyzer" submitted by Brittany Marche in partial fulfillment of the requirements for the degree of Bachelor of Science, Honours.

Dr. Don-Roger Parkinson, Supervisor

(In absentia)

Dr. Harunur Rashid, Supervisor

Dr. Julian Dust

Dr. Chen Liu

April 07, 2016

Acknowledgements

First and foremost, I am very thankful to Dr. Harunur Rashid for giving me the opportunity to complete this research, in a field I knew relatively little about when we started almost two years ago. He has been a wonderful professor, as well as a mentor, and always took the time to explain the answers to my endless questions. I can’t thank him enough in these few sentences. As well, I am thankful to Dr. Don-Roger Parkinson for stepping up to the plate when Dr. Rashid unfortunately could not continue my supervision.

I am also very grateful for my lab-mates Devon Parry, Emilie Fournier, Marli Vermooten, Keesha Langer, Michaela Webb, Brent Brockway, and Heather Spicer; they put up with my complaining when things were not going as planned and always lent a helping hand.

I would like to thank the laboratory staff in Chemistry including Wanda Ellsworth, Bobbie-Ann Parsons, and Wade Goulding; for allowing me to borrow their conductivity meter and copious amounts of glassware, and just for taking an interest in how my research was going. As well, I give thanks to Dr. Doug Forbes and his colleagues in Physics for providing me with the weather station data.

Finally, I am forever in debt to my friends, my boyfriend, and my family; this has probably been one of the most stressful periods of my life and without all your support I would not be sitting here writing the last of my thesis. Thank you all!

Table of Contents

Abstract

The measurement of stable water isotopes (i.e., $\delta^{18}O$ and $\delta^{2}H$) in precipitation is a powerful tool for detecting changes in climate patterns, as well as in assessing groundwater movement and studying hydrological budget. In this study, daily precipitation was collected and $\delta^{18}O$ and $\delta^{2}H$ were analyzed in Corner Brook, Newfoundland and Labrador, for 2015. More than 130 samples were analyzed using a state-of-the-art cavity ring-down spectrometer, the Picarro Liquid Water Isotope Analyzer L2130-i, with minimal instrumental error. The data suggest seasonal variations in which the $\delta^{18}O$ varies from -33.372 to -0.033 ‰ (±0.023 ‰) and $\delta^{2}H$ ranges from -253.375 to 15.103 ‰ (±0.148 ‰). Our data are compared with modern meteorological data as well as published $\delta^{18}O$ and $\delta^{2}H$ data from greater Atlantic Canada, which suggest that the atmospheric circulation patterns, spatial features, and other climate factors are distinct in Corner Brook. It is noteworthy that the $\delta^{18}O$ and $\delta^{2}H$ are the first data from western Newfoundland and if measurement of $\delta^{18}O$ and $\delta^{2}H$ in precipitation in this area could be continued, it could indicate the impact of regional climate change in the fractionation of liquid water isotopes. Furthermore, these data could be used to model hydrological processes.

1.0 Introduction and Literature Review

1.1 Past Work Using Stable Isotopes of Hydrogen and Oxygen in Climate Studies

The work of many scientists has taken advantage of the fact that varying climatological, geological, and hydrological conditions have direct and measureable effects on isotopic abundance.[1-3] The composition of stable isotopes of hydrogen and oxygen (seen in Table 1.1.1) in water reflect changes in hydrological processes because they undergo measurable and systematic fractionations as they transfer between phases in the water cycle.[4] This makes them a useful tool in examining the hydrological cycle with respect to changes in climatic and geographic conditions from which modern precipitation is formed, such as latitude, temperature, altitude, and humidity.[3,5-7] The variation of stable isotope abundances of hydrogen and oxygen in meteoric precipitation has been documented by the International Atomic Energy Agency's Global Network of Isotopes in Precipitation (IAEA GNIP) for over 45 years.[5] As will be demonstrated in Sections 1.2 and 1.3, the origin and dynamics of air masses which affect a certain area dictates the patterns seen in the isotopic composition of precipitation, especially when these patterns change with seasonality.

Table 1.1.1: The stable isotopes of oxygen and hydrogen.[8]

Element	Isotope	Molecular Weight (amu)	Natural Abundance (%)
Oxygen	^{18}O	17.999	0.200
	^{17}O	16.999	0.0379
	^{16}O	15.995	99.762
Hydrogen	^{2}H (deuterium)	2.014	0.015
	^{1}H (protium)	1.008	99.985

In isotope geochemistry, isotopic composition is conventionally expressed as a delta value (*δ*) as follows:

$$\delta = \left(\frac{R_{sample} - R_{standard}}{R_{standard}}\right) x10^{3}‰ \quad \textbf{(Equation 1.1.1)}$$

where *R* is the relative abundance of $^{18}O/^{16}O$ (for $\delta^{18}O$) or $^{2}H/^{1}H$ (for $\delta^{2}H$) of the measured sample and standard.[1,2,5] Isotopic δ-values are presented as per mille (parts per thousand; ‰) deviations from an appropriate standard. For liquid water, isotope ratios are compared to the internationally accepted standard Vienna Standard Mean Oceanic Water (VSMOW), or Standard Light Antarctic Precipitation (SLAP) seen in Table 1.1.2.[1] Positive δ-values indicate that the sample is enriched in the heavy isotope relative to the VSMOW standard, while negative δ-values indicate depletion of the heavy isotope.[1,9]

Table 1.1.2: Internationally accepted water isotope standards, United States Geological Survey Vienna Standard Mean Oceanic Water (USGS VSMOW) and International Atomic Energy Agency Standard Light Antarctic Precipitation2 (IAEA SLAP2).[10,11]

Standard	$\delta^{18}O$ (‰)	$\delta^{2}H$ (‰)
USGS VSMOW	0.0	0.0
IAEA SLAP2	-55.5	-427.5

The measurement of $\delta^{18}O$ and $\delta^{2}H$ was traditionally carried out using isotope ratio mass spectrometry (IRMS); however, in the last 20 years it has most often been carried out using cavity ring-down spectroscopy (CRDS), which is a very sensitive laser absorption technique.[12-14] CRDS has a number of advantages when compared to traditional absorption techniques; it is virtually immune to shot-to-shot fluctuations in laser intensity, and utilizes ultra-high reflectivity mirrors to create very long effective path-lengths (of up to tens of kilometres) which allows for trace detection of isotopemers.[14,15] Please refer to Section 1.5 for a full explanation of the CRDS technique.

As mentioned previously, measurements of $\delta^{18}O$ and $\delta^{2}H$ are useful tools in examining the hydrological cycle and have a wide range of applications, as can be seen in a summary of key literature in Table 1.1.3.

Table 1.1.3: Summaries of literature utilizing meteorological $\delta^{18}O$ and $\delta^{2}H$ data

Publication	**Location**	**Applications of Research**
Klein et al. (2015)[16]	Alaska, USA	Study of Arctic cyclone water vapor isotopes and Greenland ice core water isotopes to infer paleoclimate events leading to sea ice retreat
Martín-Gómez et al. (2015)[17]	Spain and USA	Use of stable isotopic composition of soil and xylem water as a tracer to study plant-water sources
Good et al. (2014)[18]	Eastern USA	Analysis of precipitation samples collected from Superstorm Sandy in order to study storm evolution, hydro climatological impacts, and paleo-storm proxies
Birks & Edwards (2009)[19]	Manitoba & Saskatchewan, Canada	Investigation of isotope relations to circulation-dependent climate variability in mid- to high-latitudes
Van der Veer et al. (2009)[20]	Global except Antarctica	Development of global prediction maps of isotopic composition of modern precipitation to be used in forensic and food authentication purposes

Burnett, Mullins, & Patterson (2004)[21]	Central New York State, USA	Improvement in techniques to construct atmospheric history using present-day relations between isotope signals and winter atmospheric circulation patterns
Peng et al. (2004)[22]	Calgary, Alberta, Canada	Reinforcement of utility of short-term sampling of individual precipitation events to study localized climate processes as opposed to monthly composite sampling
Edwards, Birks, & Gibson (2002)[23]	Global	Improvement of present and paleo atmospheric general circulation models using isotope tracers
Kendall & Coplen (2001)[24]	Continental USA	Spatial/temporal analysis of river water isotopes to aid in reconstruction of continental paleo-hydrology
Jamieson & Wadleigh (1999)[25]	Eastern Newfoundland, Canada	Tracing pollution sources of atmospheric sulphur compounds from precipitation collected near a small oil-fired power plant

Sklash, Farvolden, & Fritz (1976)[26]	Southern Ontario, Canada	Development of $\delta^{18}O$ as a tracer to study the role of hydraulic gradients in groundwater discharge after heavy rainfall

1.2 Isotopic Fractionation of $^{18}O/^{16}O$ and $^{2}H/^{1}H$

There are four main principles of isotopic fractionation: isotope exchange reactions (replacement of light isotopes by heavy isotopes decreases molecular energy thereby increasing stability), mass differences affecting rates of physical and chemical processes, velocity differences of isotopic molecules of the same compound undergoing diffusion or evaporation, and differences in bond strengths.[9] The fractionation of isotopes during diffusion and evaporation is caused by differences in the velocities of isotopic molecules of the same compound.[2,9] Since kinetic energy is $E = \frac{1}{2}mv^2$, the ratio of the velocities (v) of the two isotopic molecules of mass (m) of the same compound is:

$$\frac{\nu_L}{\nu_H} = \left(\frac{m_H}{m_L}\right)^{1/2} \qquad \textbf{(Equation 1.2.1)}$$

where *L* and *H* indicate the light and heavy isotopic species, respectively.[9] From this equation, it can be seen that velocity differences among isotopic molecules of the same compound contribute to isotope fractionation.[9] Molecules that contain a light isotope of an element may diffuse out of a system more rapidly than the molecules containing a heavier isotope, thereby enriching the system to favor the heavier isotope.[9] For example, during evaporation of water, $H_2{}^{16}O$ molecules escape into the vapor phase more rapidly than $H_2{}^{18}O$ and thus enrich the vapor in ^{16}O leaving the remaining water enriched in ^{18}O.[9] This process enhances the isotope fractionation that takes place when liquid water and water vapor are in equilibrium, as often takes place in the atmosphere.[9] The equilibrium constant of an isotope exchange reaction is referred to as the "fractionation factor".[6,9] The fractionation factor is defined as the ratio of the numbers of any two isotopes in one chemical compound A divided by the corresponding ratio for another chemical compound B, and is represented as α_B^A.[6] The fractionation factor concerning water vapor (v) versus liquid water (l) is of importance during the analysis of hydrological components and is dependent on temperature and kinetic factors.[9] In general the liquid-vapor fractionation factor is calculated by:

$$\alpha_{\mathrm{V}}^{\mathrm{L}} = \frac{\mathrm{R_L}}{\mathrm{R_V}} \qquad \textbf{(Equation 1.2.2)}$$

where R is the absolute ratio of the abundance of the heavy isotope over the light isotope, and the subscripts L and V indicate the liquid and vapor phases.[9]

1.3 Meteorological Drivers of Isotopic Fractionation in Water

The composition ratios of oxygen and hydrogen isotopes in water molecules vary widely because of isotopic fractionation due to phase changes throughout the hydrological cycle, shown in Figure 1.3.1. The Rayleigh distillation graph, i.e. Figure 1.3.1, shows how the preferential removal of ^{18}O (and ^{2}H) isotopes from water vapor by condensation of water or snow from moist air masses drifting from the equatorial region toward higher latitudes results in atmospheric water vapor that is initially depleted in ^{18}O and ^{2}H.[2,6,9,27] However, when compared to the isotope composition of water vapor remaining in the air mass, the condensate is enriched in ^{18}O and ^{2}H.[2] This is due to the difference in the masses of the isotopic molecules of water (as per Equation 1.2.1), which causes them to have a range of vapor pressures such that the lightest molecule evaporates preferentially.[2] Conversely, the heaviest molecule condenses preferentially. As a result, the vapor that remains in the air mass is progressively depleted in ^{18}O and ^{2}H after rain-out events, $\delta^{18}O$ and $\delta^{2}H$ values become more negative as condensate in the form of rain or snow continues to be removed from it, known as Rayleigh distillation.[2] The liquid is always enriched in ^{18}O and ^{2}H relative to the vapor at any selected fraction of vapor remaining, as seen in Figure 1.3.1; nevertheless, the liquid phase is also depleted in ^{18}O and ^{2}H relative to SMOW, as indicated by the fact that $\delta^{18}O$ and $\delta^{2}H$ become progressively negative with successive rainout.

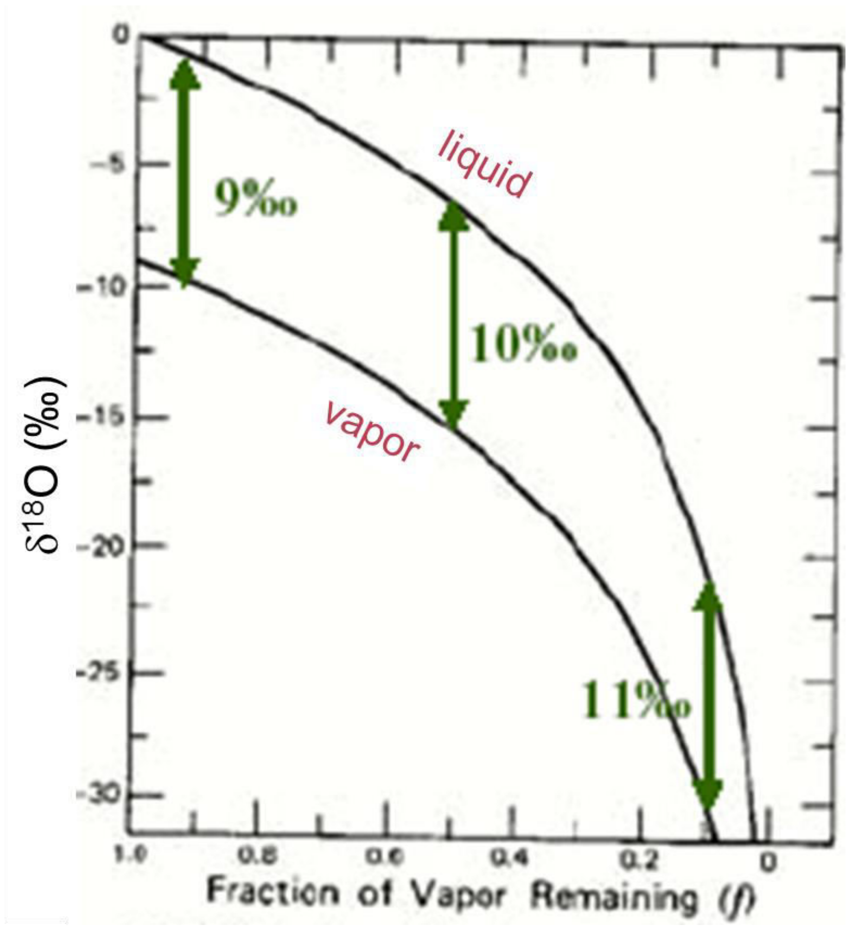

Figure 1.3.1: The Rayleigh distillation graph, which shows that as water condenses and falls out of an air mass, the vapor left behind becomes more depleted.[2]

The extent of isotope fractionation of meteoric water is generally related to a number of environmental parameters that characterize a given sampling site: surface air temperature, latitude, altitude, distance to the coast, and amount of precipitation.[2,6,7,20,28] The amount effect occurs due to enhanced cooling of the air in heavy rainfall with only slight enrichments possible in later evaporation.[6] Isotope studies of individual rain events have revealed that successive portions of single events may vary drastically.[6,18] The most depleted isotope values usually occur during the period of most intense rain.[18] It has also been observed that convective cloud types produce precipitation with higher δ-values than clouds formed in the stratosphere.[6] Thus, the isotope composition of precipitation from a given rain event depends heavily on the meteorological history of the air mass from where the precipitation is formed. Rain and snow (or hail) can differ in their isotope compositions because rain drops may undergo evaporation and isotope exchange with residual atmospheric vapor while falling to the Earth's surface.[6,29] Measurements of the water isotopes collected in single rainout events have revealed that in-storm variations can be relatively large, reaching in some cases >21‰ in $\delta^{18}O$ and >160‰ in $\delta^{2}H$.[18,27]

Raindrops leaving a cloud base continuously isotopically re-equilibrate with the surrounding moisture on their way to the surface. The degree of this re-equilibration is controlled by the size of the raindrops, the actual height of the cloud base and the relative humidity of the atmosphere beneath the cloud.[27] This causes the isotopic composition of rainfall collected at the ground surface to be close to isotopic equilibrium with near-ground water vapor.[27] Solid precipitation (snow or hail) is usually more depleted in heavy isotopes, reflecting equilibrium conditions at much lower in-cloud temperatures.[27,29] The isotopic composition of precipitation samples, representing a certain rainfall event in whole or part, therefore depends strongly on the meteorological history of the air mass and specific conditions in which the precipitation is produced, as well as the isotopic composition of humid air through which it falls.[5,27,29] Regular seasonal variations of isotopes in precipitation are observed at mid- and high latitudes where seasonal variations of temperature are well developed.[3,7,27]

To summarize, the seasonal differences in isotopic composition of precipitation result from the interplay of several factors, including: seasonal changes of the temperature at the precipitation site leading to substantial changes of the total precipitable water in the atmosphere with season, when compared to the source area(s); seasonal changes in the evaporation transportation flux on the continents, amplifying seasonal differences in total precipitable water; and seasonal changes of prevailing circulation patterns which changes the origin of moisture.[6,27]

Vapor leaving the surface of the ocean in the tropics cools as it rises and rain forms when the dew point is reached.[2,6] This air mass is displaced in a north-easterly direction within the northern hemisphere by atmospheric circulation, and therefore enters cooler climatic zones. Due to the decrease in temperature, the air becomes saturated with water vapor, which causes condensation and precipitation of water as rain, snow, or hail. During removal of rain from a moist air mass, the residual vapor is continuously depleted in the heavy isotopes, because the rain leaving the system is enriched in ^{18}O and ^{2}H.[2,5,6,9] If the air mass moves towards the Earth's poles and becomes cooler additional rain formed will contain less ^{18}O than the initial rain and thus, the condensate is preferentially enriched in the heavier isotopes of oxygen and hydrogen while the vapor left behind is enriched in the lighter isotopes (as was discussed in relation to Figure 1.3.1).[2,6,9] Consequently, the $\delta^{18}O$ and $\delta^{2}H$ values of meteoric precipitation become progressively more negative (more depleted of heavy isotopes) with increasing geographic latitude.

This latitude effect on the isotope composition of meteoric water is therefore caused by: progressive condensation of water vapor and the removal of water droplets from the air mass and resulting isotopic fractionation, the increase of isotopic fractionation factors caused by decreasing temperature, the re-evaporation of meteoric water from the surface of the Earth, and evapotranspiration of water by plants.[9] Since both hydrogen and oxygen experience the same sequence of events as water molecules during the migration of air masses, the $\delta^{18}O$ and δ^2H values of meteoric water are strongly linked.[2,3,5,6,27,30] This correlation is expressed as an empirical equation known as the Global Meteoric Water Line (GMWL, pictured in Figure 1.3.2)[5]:

$$\delta^2H = 8(\delta^{18}O) + 10$$ (**Equation 1.3.1**)

The slope is determined by the ratio of equilibrium isotope enrichments for ^2H and ^{18}O respectively[27], which is the result of relating the liquid-vapor fractionation factors for ^2H and ^{18}O at 25°C:

$$\text{slope} = \frac{\alpha_V^L(H)-1}{\alpha_V^L(O)-1} = \frac{1.074-1}{1.0092-1} = 8$$ (**Equation 1.3.2**)

The intercept of the GMWL is controlled mainly by parameters of the evaporation processes in major source areas for atmospheric moisture (the subtropical oceans).[5,27] The numerical coefficient 8 and the constant 10, are not actually constant in nature.[6]

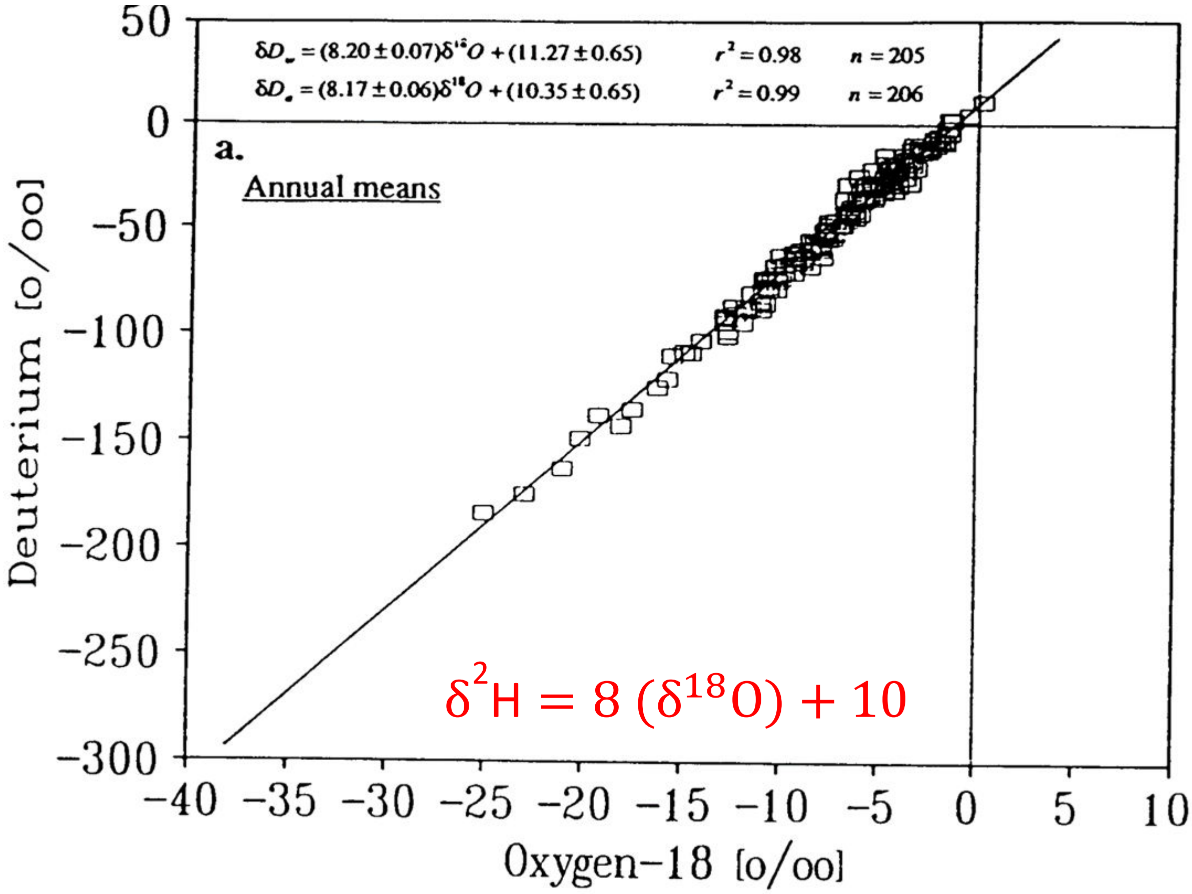

Figure 1.3.2: The Global Meteoric Water Line, a global empirical collection of precipitation $\delta^{18}O$ and $\delta^{2}H$ data, and its approximated linear equation.[5]

Local deviations from the GMWL are found on a seasonal basis in many regions. This is mainly because of enhanced partial evaporation of raindrops below the cloud base during summer months and varying seasonal conditions in the source area(s) for the vapor.[27] These effects are responsible for Local Meteoric Water Lines (LMWL) with slopes lower than 8.[5,27] Substantial differences from the GMWL occur in regions where the atmospheric circulation pattern of an area varies seasonally, bringing moisture to the precipitation site from two or more different sources that may differ in both absolute $\delta^{18}O$ and δ^2H values as well as the 'deuterium excess'.[5,27] The deuterium excess, (*d*) accounts for these deviations from the GMWL by changing y-intercept:

$$\delta^2H = 8(\delta^{18}O) + d \quad \textbf{(Equation 1.3.3)}$$

The deuterium excess can be calculated by rearranging the above Equation 1.3.3 very simply. The deuterium excess of a sample is considered to be a kind of tracer for re-evaporation of meteoric water.[3] It is more accurate to describe the relation between the $\delta^{18}O$ and δ^2H on a regional level. A LMWL is obtained by plotting the $\delta^{18}O$ along the x-axis and δ^2H on the y-axis for a group of samples from a certain geographic area. The slope and deuterium excess values obtained from the equation of the line serve as a useful way to compare the isotopic patterns of an area to the GMWL, and is a good way to evaluate the extent of seasonality and the latitude effect, among other factors.[2,3,5,6,27,30]

In mountainous regions, temperature decreases with increasing elevation. This leads to enhanced condensation and therefore to a progressive depletion in the heavy isotopes of precipitation with altitude, known as the 'altitude effect'.[27] In mid-latitudes, a progressive depletion of precipitation in heavy isotopes with increasing distance from the coast has been observed as well, pictured in Figure 1.3.3.[6,27,31] This is a consequence of the gradual rainout of the air masses entering the continents, and gradual decrease of contribution of water vapor from the ocean.[6,27]

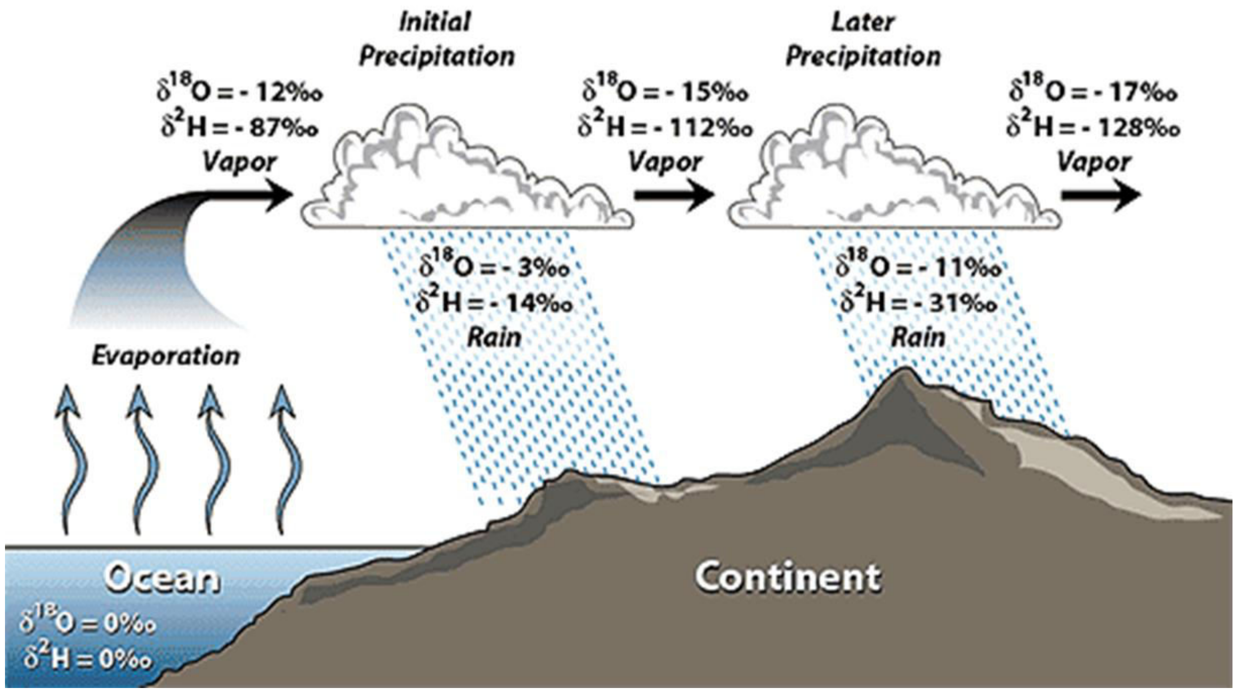

Figure 1.3.3: Conceptual diagram of successive depletion of precipitation $\delta^{18}O$ and $\delta^{2}H$ values during rainout events moving further inland from the coast (can also be interpreted as successive rainout from air masses moving towards the poles from equatorial regions)[31]

1.4 Water Isotope Studies in Atlantic Canada

Among the various initiatives to characterize the isotopic variability in precipitation at global and regional scales, the Global Network for Isotopes in Precipitation (GNIP), jointly operated by the International Atomic Energy Agency (IAEA) and the World Meteorological Organization (WMO), is by far the largest undertaking.[27] Within Canada, the Canadian Network for Isotopes in Precipitation (CNIP) and the Canadian Air and Precipitation Monitoring Network (CAPMoN) have been responsible for precipitation collection and analysis over various time periods since 1961.[4] Several sites of interest within Atlantic Canada have publicly available water isotope data, including: Truro in Nova Scotia, Goose Bay in Labrador, and Bay D'Espoir in Newfoundland (see Appendices 2-4).[32] These sites provide a useful mode of comparison of the data obtained in this study because these sites are geographically similar in latitude, and all experience the same seasonal fluctuations as Corner Brook; however each differs in topography and specific climates, as will be discussed in later sections.

1.5 Underlying Theory of Cavity Ring-down Spectroscopy

Small gas-phase molecules have unique near-infrared absorption spectra, and below 1 atmosphere of pressure this consists of a series of narrow, well-resolved, sharp lines, each at a characteristic wavelength. The concentration of any species can be determined by measuring the strength of this absorption using the Beer-Lambert Law:

$$A = \ln\left(\frac{I_o}{I}\right) = \sigma L_{abs} N \quad \textbf{(Equation 1.5.1)}$$

where A is the absorbance, I_o is the initial light intensity, I is the transmitted light intensity, σ is the absorption cross section, L_{abs} is the path length of light through the absorber, and N is the number density of absorber molecules (per unit volume).

From the above equation, it can be seen that for molecules that have small absorption cross sections (σ), absorbance (A) can become undetectable. In order to achieve a detectable absorbance, either the concentration of absorber molecules could be increased (N), or the path length could be increased (L_{abs}).[14] Cavity ring-down spectroscopy opts to increase the path length by using three highly reflective mirrors to create an optical cavity with effective path length of many kilometers, thereby increasing instrumental sensitivity.[12] A single-frequency laser diode beam is injected into the cavity and transmitted through the gas molecules to the detector, as shown in Figure 1.5.1.

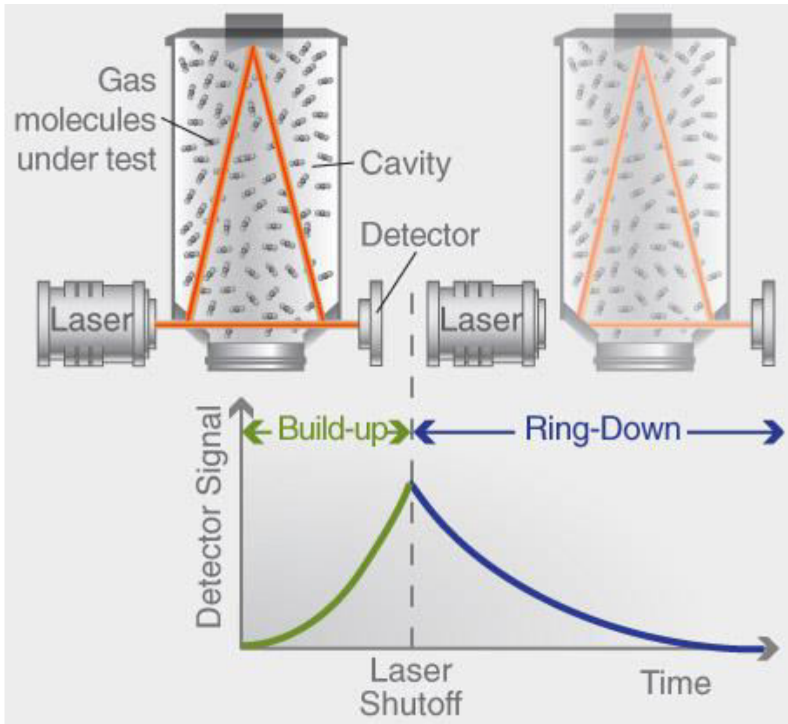

Figure 1.5.1: Depiction of optical cavity inside a cavity ring-down spectrometer and signal received by photodetector, before and after laser shutoff.[33]

The intensity of transmitted light is proportional to the intensity of light in the cavity, and once the laser is shut off, over time that amount reaching the photodetector decays exponentially, also shown in Figure 1.5.1.[13] This decay, called "ring down" is characterized by:

$$I = I_o \exp\left(\frac{-t}{\tau_o}\right) \quad \textbf{(Equation 1.5.2a)}$$

$$\tau_o = \frac{t_r}{2(1-R)} = \frac{L_{opt}}{c(1-R)} \quad \textbf{(Equation 1.5.3a)}$$

where t_r is the roundtrip time for light in the cavity, R is the mirror reflectivity, L_{opt} is the distance between the two mirrors, c is the speed of light, and τ_o is the 1/e decay time of the light (called the ring down lifetime).[14,33] When a sample is in the cavity, the laser light intensity within the cavity decreases causing ring down time to decrease, as shown in Figure 1.5.2.

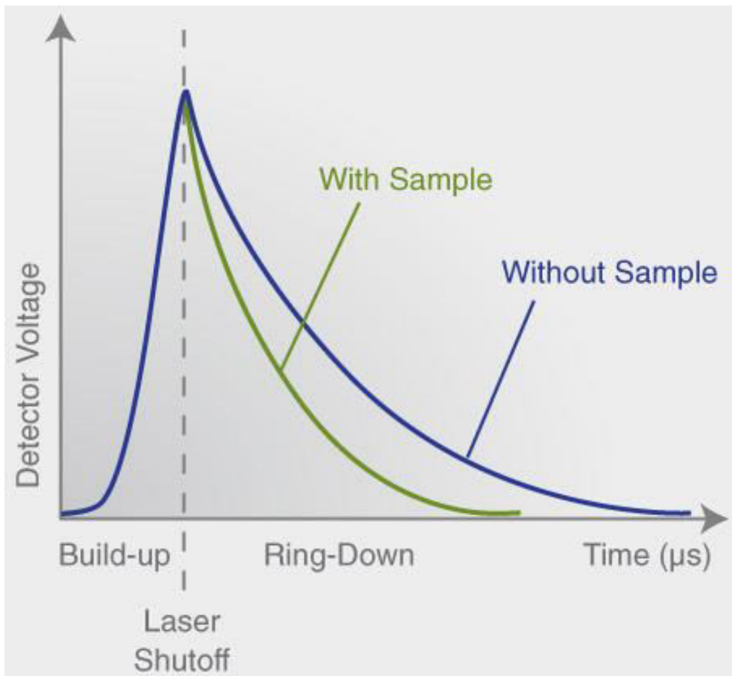

Figure 1.5.2: Discrepancy in ring-down time within the optical cavity, when a sample is present or absent.[33]

The above Equations 1.5.2a and 1.5.3a are modified:

$$I = I_o \exp\left(\frac{-t}{\tau}\right) \quad \textbf{(Equation 1.5.2b)}$$

$$\frac{1}{\tau} = \frac{1}{\tau_o} + (\sigma L_{abs} N)\left(\frac{c}{L_{opt}}\right) \quad \textbf{(Equation 1.5.3b)}$$

where L_{abs} is the path length of the absorber and τ is the 1/e decay time for light in the presence of the absorber. Final concentration data is derived from the difference between these ring-down times and is therefore independent of laser intensity fluctuations or absolute laser power.[12,14] For more information on the specific cavity ring-down instrument used in this study please see Section 2.1.

1.6 Aims of This Research

There are distinct differences in seasonal climatic conditions in the precipitation-laden area of Corner Brook, NL as can be seen from Figure 1.6.1, and the abundance of rain and snow throughout the year presents an opportunity to study the process of isotopic fractionation in precipitation over a range of differing weather patterns. Using the cavity ring-down Picarro L2130-i Liquid Water Isotope Analyzer, the $\delta^{18}O$ and $\delta^{2}H$ values of precipitation collected for 2015 in Grenfell Campus, MUN, Corner Brook, NL (48°56'24.15"N 57°56'11.59"W) can be determined. These data will be used to assess seasonal trends characteristic to the region of Western Newfoundland. In the winter months (in this study defined as January-March and November-December), it is expected that the precipitation will be more depleted in both of the heavy isotopes (i.e. ^{18}O and ^{2}H) as compared to those in the summer (in this study defined as April-October). We also expect to see some similarity to publicly available precipitation $\delta^{18}O$ and $\delta^{2}H$ data from Atlantic Canada due to similar geographic and climatic factors such as latitude, distance from the coast, and seasonal atmospheric fluctuations (see Sections 3.0 and 3.2 for details). The results of this analysis would provide the first background data of any kind related to liquid water isotopes in Western Newfoundland. Establishment of this baseline is fundamental to any further isotope hydrological/climatic studies that could be completed in the area.

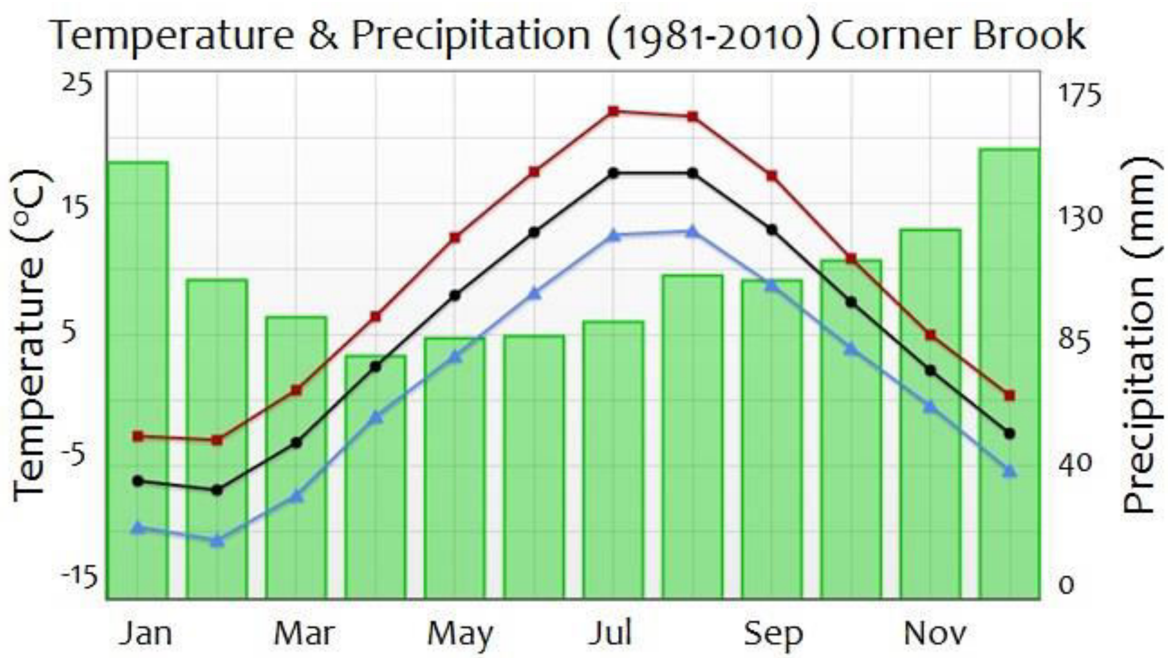

Figure 1.6.1: Climate norms for Corner Brook, NL from 1981-2010. Blue triangles = monthly temperature minimums, black circles = monthly temperature averages, red squares = monthly temperature maximums, green bars = monthly average precipitation.[34]

2.0 Experimental Methods

Precipitation samples were collected beginning on January 12th, 2015 until December 19th, 2015. A large plastic container was placed on the ground at Grenfell Campus, MUN, Corner Brook, NL (48°56'24.15"N 57°56'11.59"W) between the Arts and Science Extension and the Library buildings (as seen in Figure 2.0.1).

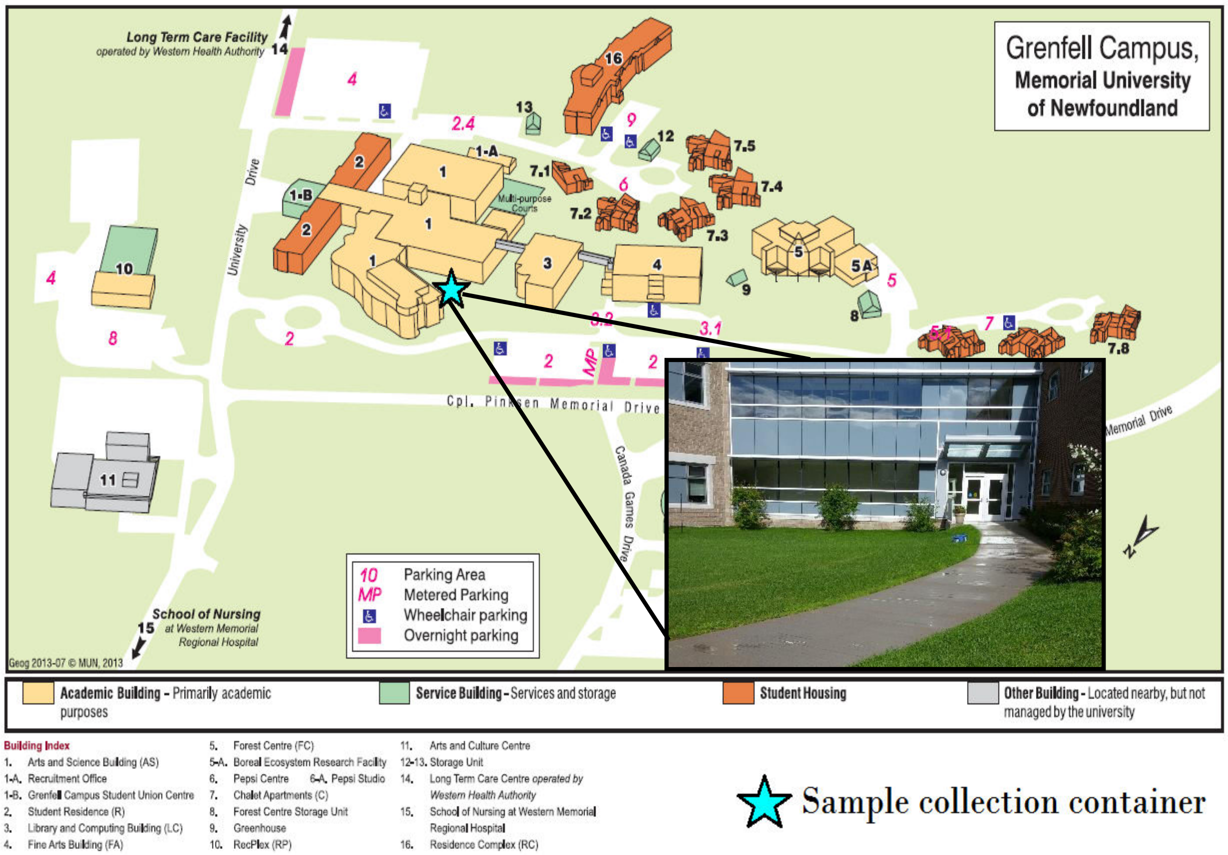

Figure 2.0.1: Placement of sample collection container outside Grenfell Campus, indicated by blue star symbol, and picture of container in sheltered area (inset). (Base map obtained from http://www.mun.ca/campus_map/Grenfell_Campus_2014.pdf)

This position was chosen as it seemed away from major walkways and it was partially sheltered from the wind, which was thought to give more representative data of the area as well as to prevent snow previously fallen on the ground from blowing into the container. On April 25, May 12, May 20-22, June 6, June 13, July 8-22, September 1-12, September 20, October 19, November 14-15, and December 17-19 the container was moved to Meadows, Bay of Islands, NL (48°59'38.99"N 58° 1'57.04"W), because the author was unable to monitor the container at Grenfell. The method of water collection was to leave out a container outside anywhere from 30 minutes to several hours, depending on the time required to collect an adequate amount of precipitation (no less than 200 mL). Once a sufficient amount of precipitation was collected, the container was brought inside the lab. Snow samples were allowed to melt at room temperature and then processed, whereas rain was processed right away. Processing consisted of the transfer of precipitation from the container using a large funnel into a 2000 mL plastic graduated cylinder. The liquid sample was then filtered (using Whatman #4 filter paper) to remove solid particle impurities in the sample. The 200 mL water sample was filtered directly into two clear plastic 75mL bottles and sealed to prevent air bubbles. The sample bottles were labelled with the date and times the container was set and retrieved, and stored in a refrigerator at approximately 2.0°C until instrumental analysis. One of the two 75mL portions of filtered water was used for salinity and conductivity estimates, when sample contamination seemed a possibility, using an Orion Model 105 conductivity meter with the factory supplied 1413µS/cm (692ppm as NaCl) standard solution. The other 75mL portion of the sample was used in isotopic analysis, which will be elaborated upon in the following section. In total, 134 precipitation samples were collected from January 12th – Dec 19th, 2015, as can be seen from Table 2.0.1.

Table 2.0.1: Precipitation collection data in Corner Brook, NL and Meadows, NL (indicated by "at home") 2015. (N/A = measurement not available)

Date and Time		Weather/ Comments	Sample #	Collection Duration (hh:mm)	Conductivity (µS)	Salinity (‰)
Collected	Retrieved					
1-12-15 10:17	1-12-15 15:13	container lid	1	4:56	N/A	N/A
1-12-15 16:25	1-12-15 20:59	container lid	2	4:34	N/A	N/A
1-16-15 12:30	1-16-15 16:56	lots of snow	3	4:26	N/A	N/A
1-17-15 13:22	1-17-15 15:31	snowing heavily	4	2:09	N/A	N/A
1-17-15 16:21	1-17-15 23:00	snowing heavily	5	6:39	N/A	N/A
1-20-15 16:52	1-20-15 19:13	moderate snow	6	2:21	N/A	N/A
1-21-15 4:00	1-21-15 10:30	moderate snow	7	6:30	N/A	N/A
1-21-15 17:00	1-21-15 23:30	moderate snow	8	6:30	N/A	N/A
1-23-15 22:00	1-24-15 11:30	light snow	9	13:30	N/A	N/A
1-24-15 13:15	1-25-15 0:10	light snow, lid was lost	10	10:55	N/A	N/A
1-25-15 15:25	1-25-15 23:30	mixed rain/snow, using tote	11	8:05	N/A	N/A
1-26-15 1:00	1-26-15 10:28	heavy snow flurries	12	9:28	N/A	N/A
1-26-15 12:30	1-26-15 16:45	flurries	13	4:15	N/A	N/A
1-27-15 0:00	1-27-15 16:50	no snow until afternoon	14	16:50	N/A	N/A
1-27-15 17:00	1-28-15 11:31	snow, broke the tote	15	18:31	N/A	N/A
1-28-15 21:00	1-29-15 9:30	freezing rain, new tote	16	12:30	N/A	N/A
1-30-15 6:00	1-30-15 17:00	light snow	17	11:00	N/A	N/A
1-31-15 16:00	2-1-15 16:30	heavy snow	18	24:30	N/A	N/A
2-1-15 17:30	2-2-15 0:30	light snow	19	7:00	N/A	N/A
2-2-15 17:00	2-3-15 12:00	stormy overnight	20	19:00	N/A	N/A
2-3-15 14:00	2-4-15 11:00	stormy daytime, clear overnight	21	21:00	N/A	N/A
2-5-15	2-5-15	snowing heavily, mixed	22	3:45	N/A	N/A

12:00	15:45	w/rain				
2-5-15 16:20	2-5-15 19:15	rain mostly, some snow mixed	23	2:55	N/A	N/A
2-5-15 19:30	2-5-15 21:00	rain	24	1:30	N/A	N/A
2-5-15 21:15	2-5-15 22:15	rain back to snow	25	1:00	N/A	N/A
2-5-15 22:45	2-6-15 12:30	55cm snow overnight	26	13:45	N/A	N/A
2-8-15 3:00	2-8-15 11:00	snow	27	8:00	N/A	N/A
2-13-15 9:30	2-13-15 16:15	moderate snow	28	6:45	N/A	N/A
2-19-15 17:00	2-20-15 9:00	freezing rain overnight	29	16:00	N/A	N/A
2-20-15 19:00	2-21-15 13:00	flurries	30	18:00	N/A	N/A
2-21-15 13:30	2-21-15 16:45	flurries, snow squall warning	31	3:15	N/A	N/A
2-21-15 17:50	2-22-15 13:00	light snow	32	19:10	N/A	N/A
2-24-15 12:00	2-25-15 9:00	snow overnight and evening	33	21:00	N/A	N/A
2-25-15 18:30	2-26-15 9:40	stormy	34	15:10	38.6	0.0
2-26-15 9:55	2-26-15 15:00	snowing heavily	35	5:05	34.3	0.0
2-26-15 16:25	2-27-15 17:00	snow overnight, some in am	36	24:35	846	0.4
2-27-15 18:15	2-28-15 12:50	flurries	37	18:35	83.9	0
2-28-15 15:00	3-1-15 15:00	snow overnight, ending in am	38	24:00	185.4	0.1
3-2-15 9:30	3-2-15 12:45	snow storm warning, steady snowfall	39	3:15	74.9	0.0
3-2-15 13:20	3-2-15 16:35	heavy snow, a bit wet	40	3:15	13.6	0.0
3-2-15 16:50	3-2-15 19:45	heavy, damp snow	41	2:55	338.0	0.2
3-2-15 20:30	3-2-15 22:00	heavy snow	42	1:30	18.0	0.0
3-3-15 15:35	3-3-15 19:45	university closed in am, blowing snow	43	4:10	479.0	0.2
3-3-15 20:00	3-4-15 10:15	not much snow overnight	44	14:15	104.5	0.0
3-4-15 11:30	3-4-15 14:00	heavier snow	45	2:30	10.5	0.0
3-4-15 14:35	3-4-15 17:45	big flakes of snow, drier	46	3:10	37.4	0.0
3-4-15 18:00	3-5-15 13:30	mostly snow in morning	47	19:30	50.1	0.0

3-5-15 15:20	3-5-15 21:10	windy, light snow	48	5:50	N/A	N/A
3-11-15 10:15	3-11-15 14:20	snow/rain mix	49	4:05	64.8	0.0
3-11-15 15:00	3-11-15 17:30	rain	50	2:30	84.9	0.0
3-11-15 17:55	3-11-15 19:10	rain	51	1:15	10.6	0.0
3-11-15 19:20	3-11-15 23:50	rain/snow	52	4:30	35.9	0.0
3-16-15 10:30	3-16-15 14:50	blowing snow	53	4:20	127.3	0.1
3-16-15 16:05	3-16-15 21:45	blowing snow, university closed at 5pm	54	5:40	837.0	0.4
3-16-15 22:50	3-17-15 11:40	blowing snow	55	12:50	233.0	0.1
3-17-15 16:00	3-18-15 10:00	not much snow	56	18:00	N/A	N/A
3-18-15 15:15	3-18-15 20:35	lots of snow, heavy	57	5:20	13.8	0.0
3-18-15 20:55	3-19-15 12:00	heavy snow	58	15:05	18.7	0.0
3-19-15 15:30	3-19-15 21:00	blowing snow	59	5:30	64.4	0.0
3-23-15 11:00	3-23-15 15:45	blowing snow, wind warning	60	4:45	274.0	0.1
3-23-15 17:00	3-24-15 8:30	blowing snow in evening, cleared off by morning	61	15:30	119.5	0.1
3-26-15 15:20	3-26-15 22:30	rain/snow, light	62	7:10	90.4	0.0
3-31-15 19:20	4-1-15 11:00	clear daytime, heavy snow then stopped ~ 11:30pm	63	15:40	16.7	0.0
4-25-15 17:20	4-25-15 19:26	at home, light rain and fog	64	2:06	N/A	N/A
4-28-15 9:00	4-28-15 11:30	wind and rain, tote slightly tipped when I went out	65	2:30	539	0.3
5-12-15 17:12	5-12-15 21:00	at home, mixed hail and rain	66	3:48	N/A	N/A
5-13-15 8:45	5-13-15 12:15	rain and snow	67	3:30	45.9	0.0
5-13-15 12:30	5-13-15 16:30	rain	68	4:00	N/A	N/A
5-20-15 18:50	5-20-15 20:35	at home, heavy showers	69	1:45	N/A	N/A
5-20-15 20:45	5-20-15 23:00	at home, heavy showers	70	2:15	N/A	N/A
5-22-15 21:25	5-22-15 22:10	at home, steady rain	71	0:45	N/A	N/A
5-22-15 22:20	5-22-15 23:00	at home, steady rain	72	0:40	N/A	N/A
5-27-15	5-27-15	showers	73	2:00	26.5	0.0

8:15	10:15					
6-6-15 17:45	6-6-15 19:15	at home, showers	74	1:30	N/A	N/A
6-9-15 8:20	6-9-15 12:00	steady rain	75	3:40	32.5	0.0
6-13-15 14:00	6-13-15 15:00	at home, heavy rain	76	1:00	N/A	N/A
6-13-15 15:15	6-13-15 16:35	at home, heavy rain	77	1:20	N/A	N/A
6-13-15 16:45	6-13-15 17:40	at home, heavy rain	78	0:55	N/A	N/A
6-25-15 8:40	6-25-15 11:00	rain and fog	79	2:20	22.5	0.0
6-25-15 11:15	6-25-15 13:00	rain and fog	80	1:45	12.4	0.0
6-25-15 13:10	6-25-15 16:40	rain	81	3:30	9.8	0.0
7-8-15 20:55	7-8-15 22:35	at home, rain showers	82	1:40	N/A	N/A
7-12-15 12:45	7-12-15 14:45	at home, heavy rain	83	2:00	N/A	N/A
7-12-15 14:50	7-12-15 16:40	at home, heavy rain	84	1:50	N/A	N/A
7-12-15 16:45	7-12-15 18:55	at home, heavy rain	85	2:10	N/A	N/A
7-12-15 19:00	7-12-15 22:40	at home, lighter rain	86	3:40	N/A	N/A
7-22-15 20:25	7-22-15 21:55	at home, heavy rain showers	87	1:30	N/A	N/A
7-22-15 22:00	7-22-15 23:20	at home, heavy rain showers	88	1:20	N/A	N/A
7-23-15 10:45	7-23-15 16:05	rain showers	89	5:20	61.4	0.0
7-29-15 8:35	7-29-15 10:30	rain and fog	90	1:55	48.1	0.0
8-6-15 10:35	8-6-15 11:15	heavy rain shower, thunder	91	0:40	9.0	0.0
8-6-15 11:30	8-6-15 12:05	lots of rain, thunder& lightning, **sample rejected**	92	0:35	4.0	0.0
8-6-15 12:20	8-6-25 13:15	rain slowed then stopped	93	0:55	8.1	0.0
8-10-15 8:25	8-10-15 9:50	rain and fog	94	1:25	29.9	0.0
8-10-15 10:05	8-10-15 10:55	heavy rain	95	0:50	22.2	0.0
8-10-15 11:10	8-10-15 11:50	heavy rain	96	0:40	2.8	0.0
8-10-15 12:00	8-10-15 12:40	heavy rain	97	0:40	3.3	0.0
8-10-15	8-10-15	heavy rain	98	0:40	17.0	0.0

13:25	14:05					
8-10-15 14:15	8-10-15 14:45	heavy rain!!	99	0:30	28.5	0.0
8-10-15 15:00	8-10-15 15:25	windy and rain, stopped suddenly	100	0:25	26.2	0.0
9-1-15 10:45	9-1-15 11:20	at home, rain	101	0:35	N/A	N/A
9-12-15 22:45	9-13-15 0:35	at home, light rain	102	1:50	N/A	N/A
9-14-15 15:50	9-14-15 17:35	heavy rain	103	1:45	23.2	0.0
9-14-15 17:50	9-14-15 19:20	heavy rain	104	1:30	22.4	0.0
9-14-15 19:30	9-14-15 23:10	heavy rain!	105	3:40	20.5	0.0
9-20-15 18:30	9-20-15 21:00	at home, heavy rain showers	106	2:30	N/A	N/A
9-26-15 13:40	9-26-15 17:45	rain and snow mix!	107	4:05	N/A	N/A
9-30-15 8:30	9-30-15 10:25	moderate rain	108	1:55	80.7	0.0
9-30-15 10:45	9-30-15 16:15	moderate rain	109	5:30	N/A	N/A
10-1-15 11:10	10-1-15 13:05	heavy rain	110	1:55	44.1	0.0
10-1-15 13:15	10-1-15 18:00	heavy rain, slacked off by evening	111	4:45	40.4	0.0
10-10-15 13:10	10-10-15 16:40	moderate rain showers	112	3:30	115.2	0.1
10-12-15 21:40	10-12-15 22:10	sudden rain showers	113	0:30	112.8	0.1
10-18-15 14:10	10-18-15 16:10	light rain	114	2:00	33.1	0.0
10-19-15 14:45	10-19-15 16:15	light rain mixed with snow!	115	1:30	49.8	0.0
10-19-15 17:00	10-19-15 20:15	at home, rain	116	3:15	N/A	N/A
10-27-15 21:05	10-28-15 0:15	light snow and hail, **sample rejected**	117	3:10	N/A	N/A
10-29-15 13:20	10-29-15 15:15	rain/snow mix	118	1:55	25.8	0.0
10-29-15 15:20	10-29-15 18:05	rain	119	2:45	16.6	0.0
10-29-15 18:25	10-29-15 21:30	rain	120	3:05	13.1	0.0
11-2-15 8:25	11-2-15 10:30	moderate rain and slight wind	121	2:05	44.7	0.0
11-2-15 10:45	11-2-15 15:45	light rain	122	5:00	24.8	0.0
11-4-15	11-4-15	mixed rain with snow (in two	123	2:20	N/A	N/A

20:40	23:00	small vials)				
11-6-15 10:20	11-6-15 15:30	light snow/rain	124	5:10	30.5	0.0
11-9-15 15:25	11-9-15 19:30	light snow	125	4:05	55.5	0.0
11-14-15 12:45	11-14-15 16:00	at home, rain	126	3:15	N/A	N/A
11-15-15 10:15	11-15-15 12:20	at home, wet snow	127	2:05	N/A	N/A
11-22-15 15:30	11-22-15 19:45	light rain (bit dirty)	128	4:15	70.9	0.0
11-22-15 20:00	11-22-15 23:30	moderate rain	129	3:30	42.1	0.0
11-24-15 14:55	11-24-15 16:45	light blowing snow	130	1:50	N/A	N/A
11-29-15 19:15	11-29-15 22:35	moderate snow	131	3:20	N/A	N/A
12-12-15 8:50	12-12-15 13:35	rain	132	4:45	N/A	N/A
12-17-15 23:00	12-18-15 13:30	at home, very light snow	133	14:30	N/A	N/A
12-19-15 14:30	12-19-15 18:30	at home, heavy snow	134	4:00	N/A	N/A

Several samples of surface waters within the region were collected as well. Samples include: Tipping's Pond 48°55'55.97"N 57°53'2.32"W (February 16, 2015), Big Bonne Bay Pond 49°21'1.35"N 57°33'12.25"W (September 4, 2015), Meadows Water Supply Pond 49° 0'8.44"N 58° 2'4.33"W (September 6, 2105), and an unknown named Pond 49° 3'42.13"N 58° 3'34.22"W (September 6, 2015). To collect the sample, a 500mL plastic bottle was completely submersed in the water vertically to allow the dispersal of air, and the bottle was sealed underwater to prevent trapping of air bubbles. The sample was then filtered and stored in the exact same manner as the precipitation samples, and subsequently analyzed for possible use in future research (and hence will not be discussed further).

2.1 Instrumentation & Method Development

A state-of-the-art cavity ring-down spectrometer, the Picarro L2130-I Liquid Water Isotope Analyzer with an auto-sampler, was utilised in this study as pictured in Figure 2.1.1. The instrument automatically and continuously calculates and compares the ring-down time of the cavity with and without absorption due to the target gas species.[33] This accounts for any losses of absorption present in the optical cavity that could be changing over time or due non-uniformity of reflection in the mirrors.[33] The laser is tuned to several locations across the target gas's spectral absorption line (and ring-down measurements are conducted at all these points), and the instrument gives a direct numerical output of $\delta^{18}O$ and $\delta^{2}H$ once it has been calibrated. Screenshots of the user interface and the laser monitoring utilities during operation of the analyzer are shown in Figures 2.1.2 and 2.1.3.

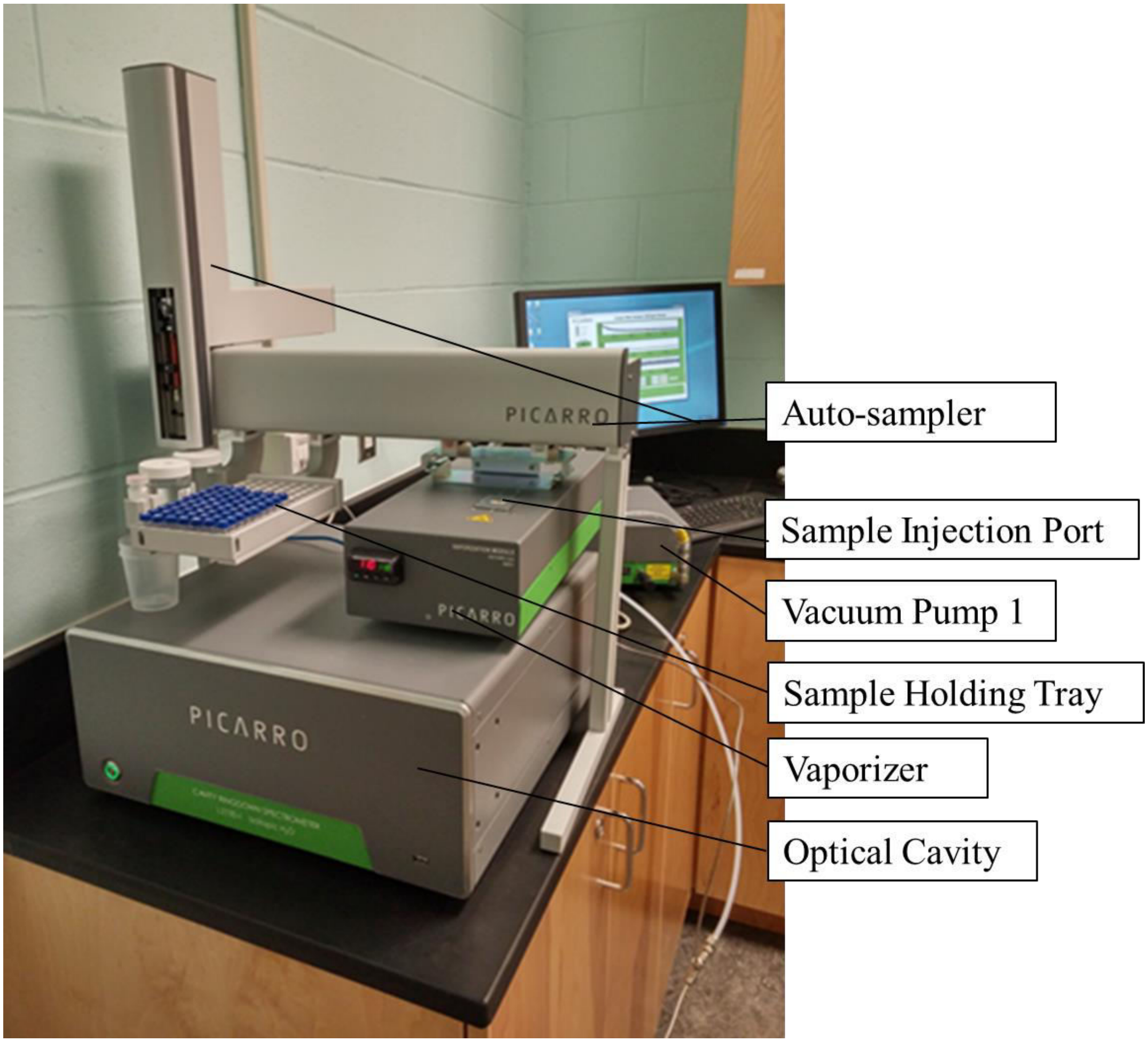

Figure 2.1.1: The Picarro L2130-i Liquid Water Isotope Analyzer with auto-sampler used in this study, with components indicated.

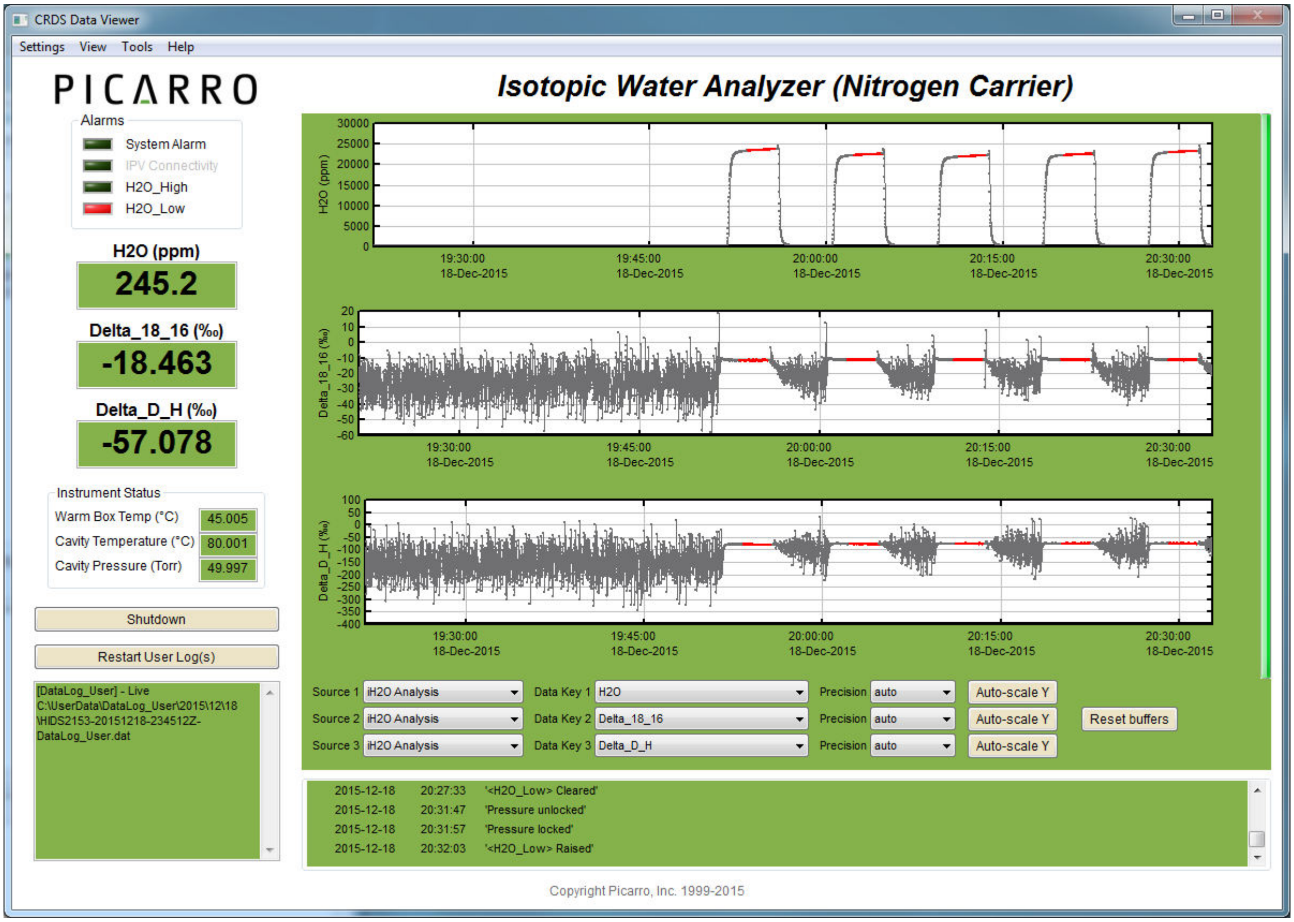

Figure 2.1.2: The active user display during isotope measurements. Peaks in the top graph show individual water injections, while the middle and bottom graphs show isotope measurements. Red highlighted parts are active measurement, whereas grey parts are flushing of the system before and after injections. It can also be seen that temperatures and pressures are kept constant during measurement. These data are exported to a file which is readily accessible to the user.

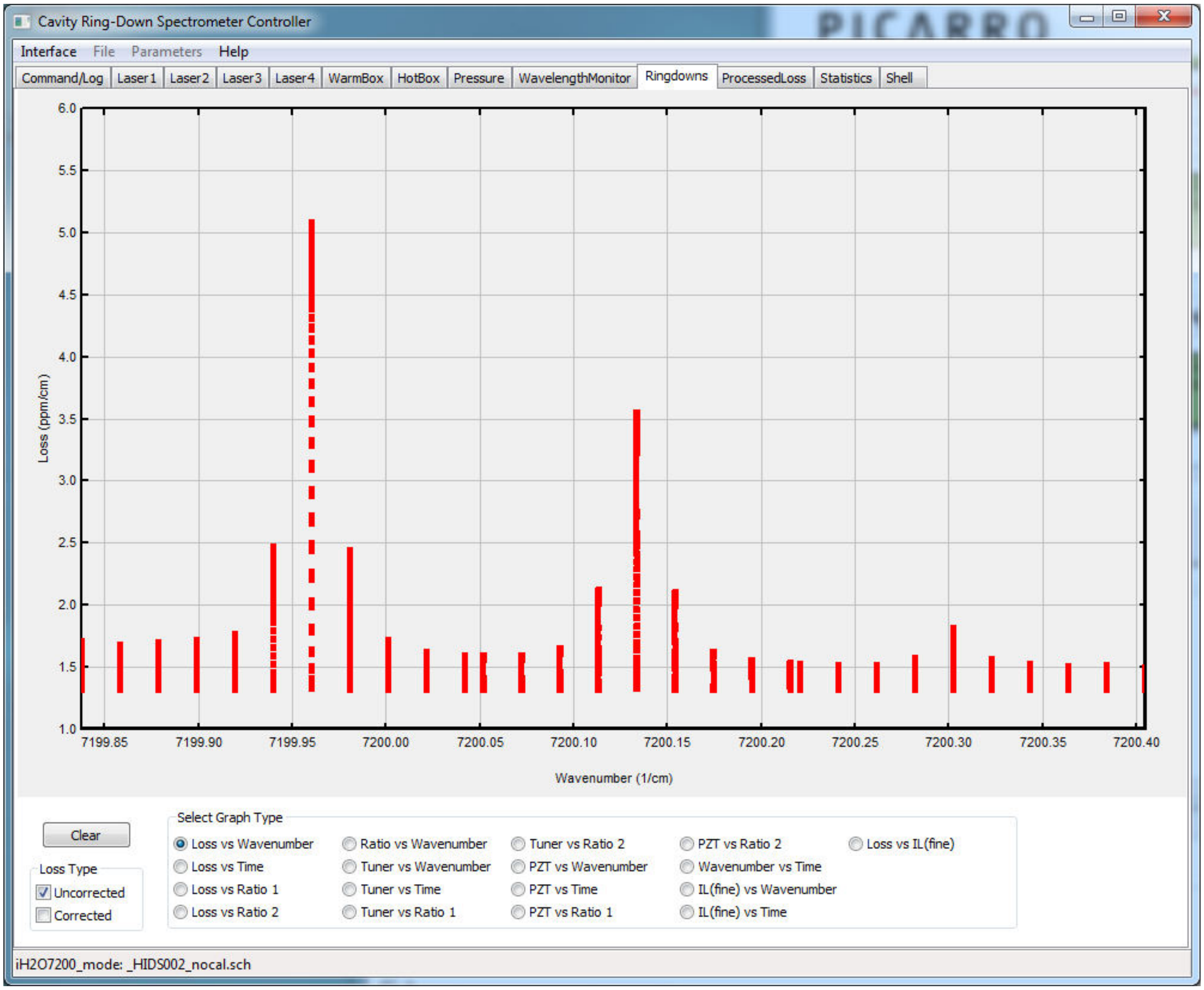

Figure 2.1.3: The spectrometer monitoring dashboard during measurement. In this particular window the user can view the range of wavenumbers actively being analyzed by the instrument, and here it is showing the loss peaks within the infrared range. This window can be used to detect problems with the laser.

Initial drift testing and the development of a consistency standard were carried out using United States Geological Survey (USGS) Vienna Standard Mean Oceanic Water (VSMOW) and International Atomic Energy Agency (IAEA) Standard Light Antarctic Precipitation 2 (SLAP-2), which are internationally accepted water isotope standards (see Table 1.1.2).[10,11] One of the two previously mentioned 75mL sample bottles provided the water for analysis. A clean and dry Pasteur pipette was used to transfer approximately 2mL of each of the water samples into vials which had caps with a septa appropriate for use with the auto-sampler syringe. The auto-sampler was set to rinse the syringe once in 2μL of n-methyl-2-pyrrolidone (NMP) wash solvent (as recommended in the user instruction manual), once in 2μL deionized water, and once in 2μLof the sample to be analyzed, before taking active measurements of each vial. After rinsing, 6 separate 2μL injections of the sample in the vial were analysed (as per recommendations in the instrument user manual). The first 3 injections data were discarded to reduce any possibility of contamination from prior samples, resulting in 3 isotope measurements for every vial. The sampling method used groups of 25 vials (one vial per sample) plus a consistency standard in the middle, bracketed by the international standards as well as the consistency standard, to produce three-point calibration lines. An example of such will be given in Section 3. Sample measurements were fitted to the corresponding line for each group of 25 samples, one for each of the oxygen isotope and hydrogen isotope measurements, producing the calibrated measurements. A number of samples were re-measured in order to increase analytical confidence and assess variance. All statistical analyses were conducted using Microsoft Excel 2013. Standard deviation (σ) for each triplicate analysis was calculated using the following:

$$\sigma = \sqrt{\sum \frac{(x-\bar{x})^2}{(n-1)}} \qquad \textbf{(Equation 2.1.1)}$$

where x is each measurement value of the set, $\bar{x}$ is the statistical mean of the set, and n is the number of values. Possible data outliers were evaluated using the standard Dixon's Q-test with 90% confidence level ($CL_{90\%}$), given by:

$$Q_{exp} = \frac{x_2 - x_1}{x_n - x_1} \qquad \textbf{(Equation 2.1.2)}$$

$$Q_{exp} > Q_{crit} \text{ (reject outlier)}$$

where x_1 is the suspect value, x_2 is the nearest value to the suspect, and $x_n - x_1$ is the range of the data.[35] If the experimental Q-value (Q_{exp}) was less than the critical Q-value (Q_{crit}), values of which are given in Table 2.1.1, the suspect value was rejected.

Table 2.1.1: Table of critical Q-values at confidence level of 90%.[35]

Number of Replicates	Q_{crit} ($CL_{90\%}$)
3	0.941
4	0.765
5	0.642
6	0.560

2.2 Modern meteorological data

The Physics department at Grenfell Campus runs a weather station located on the roof of the Arts and Science Extension building. Data is automatically recorded every 30 minutes, and includes outside temperature, wind speed and direction, wind chill, heat index, atmospheric pressure, solar radiation, and rain amounts among others. Data for January 1, 2015 (12:30 am) to December 31, 2015 (11:30 pm) was provided to the author by Dr. D. Forbes. Processing of meteorological data included the calculation of daily averages of temperature measurements as well as monthly averages (see Appendix 5).

3.0 Results and Discussion

As was previously mentioned in the above section, two calibration plots (one for $\delta^{18}O$ and one for $\delta^{2}H$) were constructed for every group of 25 samples. An example of which can be seen in Figure 3.0.1. Calibration curves obtained for the data gave good linearity, with R^2 values of greater than 0.999. The calibration curves were used to obtain calibrated δ-values, which were then used to construct a local meteoric water line (LMWL) for Corner Brook, from the raw data, as seen in Figure 3.0.2. Average instrumental error (1σ) across all samples was $\delta^{18}O$ (‰) = ±0.023, and $\delta^{2}H$ (‰) = ±0.148, indicating very good precision. In total, 134 samples were analyzed. Two samples were discarded after statistical analysis (using the standard Q-test for each triplicate measurement) and were suspected of contamination by salts during sample collection.

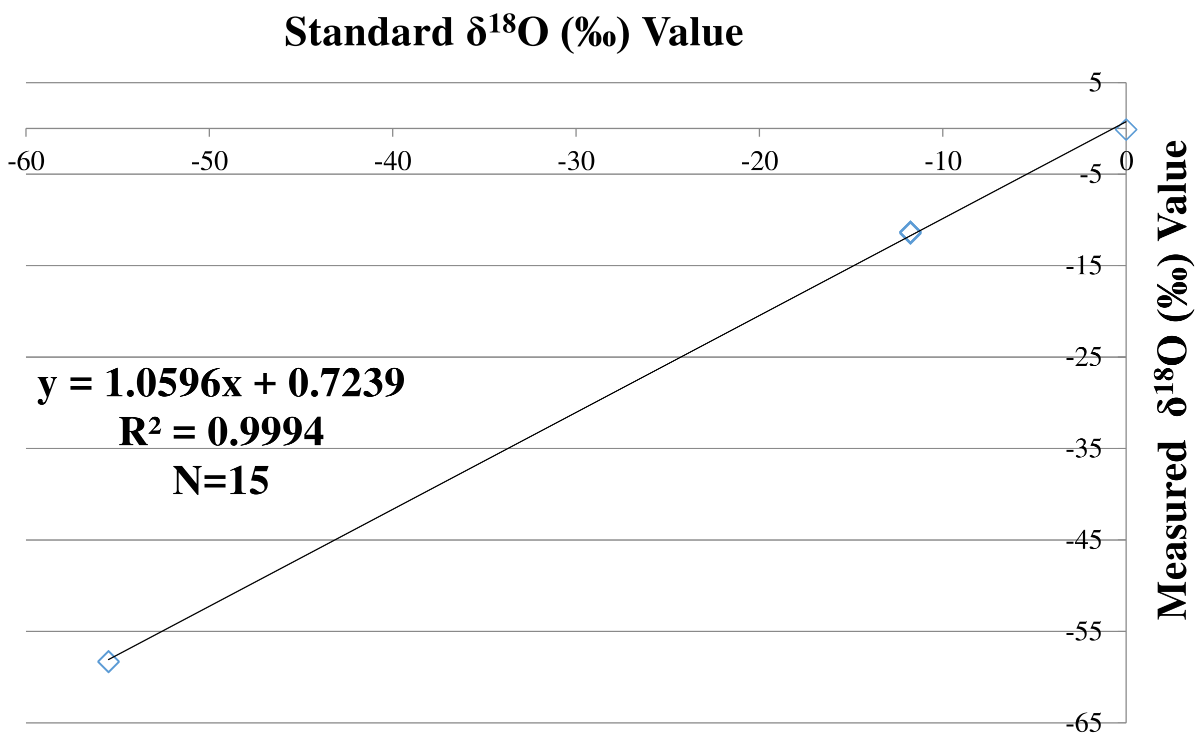

Figure 3.0.1: Calibration plot for oxygen isotopes, samples 1-25.

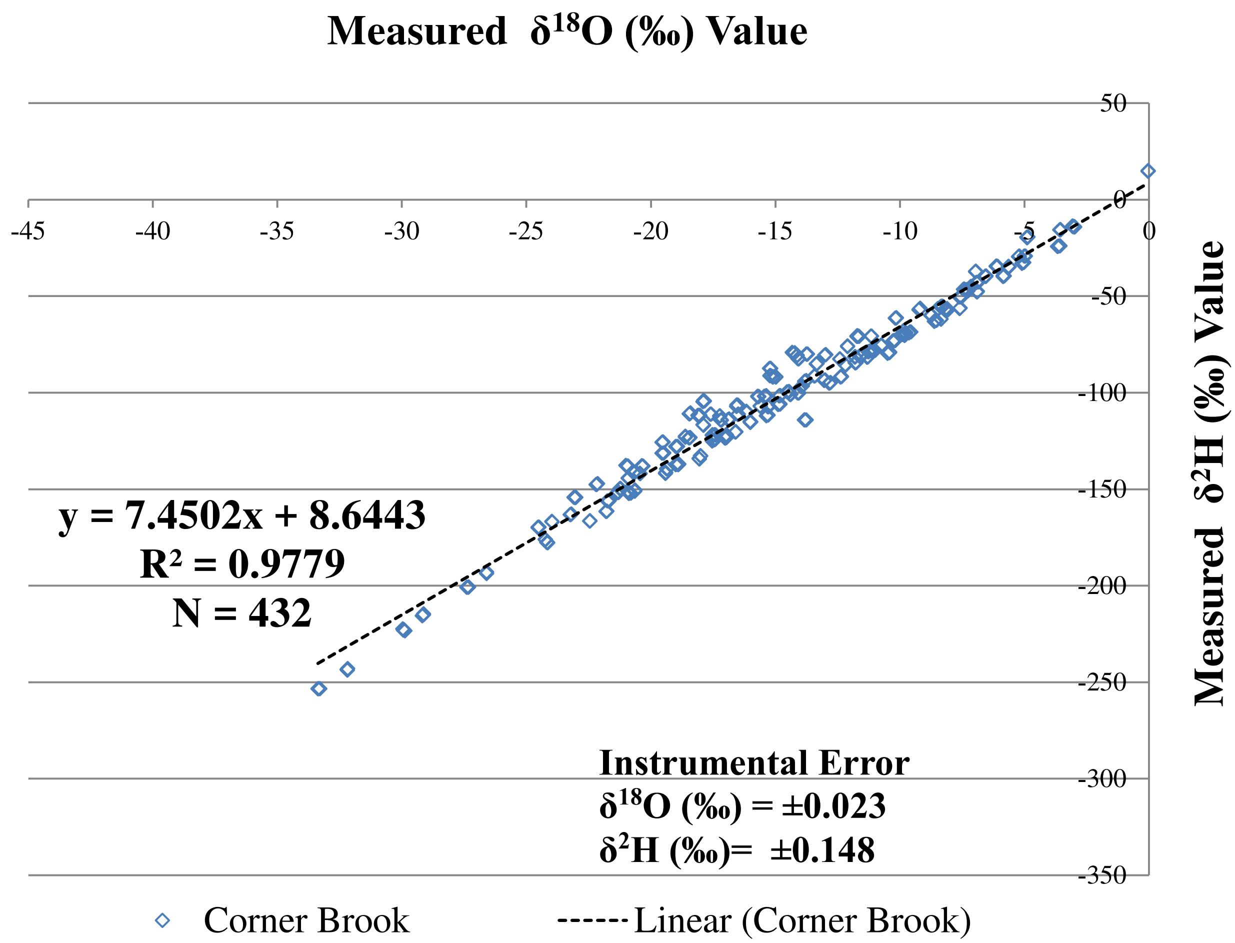

Figure 3.0.2: Data obtained in this study for the year of 2015 in Corner Brook, NL. The equation of the yearly LMWL obtained is $\delta^2H = 7.4502(\delta^{18}O) + 8.6443$, with an $R^2 = 0.9779$.

Unfiltered isotope data, when combined with daily summaries of temperatures obtained from the meteorological data, were used to produce Figure 3.0.3. Figure 3.0.4 shows data where the weighted monthly averages of both data sets were used. From both the daily and monthly averages a prominent pattern can be seen. In the cold winter months, from January-March, data shows very depleted $\delta^{18}O$ and $\delta^{2}H$, and this is followed by a sharp incline of less depletion to April, and a general trend of less depleted $\delta^{18}O$ and $\delta^{2}H$ from April-October. A sharp decline of more depletion occurs to November, where more depleted $\delta^{18}O$ and $\delta^{2}H$ are observed from November-December. Additionally, changes in the temperatures lines are clearly mirrored by the isotope lines. A clear distinction between highly depleted $\delta^{18}O$ and $\delta^{2}H$, and less depleted $\delta^{18}O$ and $\delta^{2}H$ can be made between winter and summer seasons. From this data, it is possible to create two different LMWLs for the area for each season, as shown in Figure 3.0.5. It is noteworthy that the deuterium excess obtained for the winter line (20.837) is much higher than 10, while that of the summer line (9.552) is slightly less than 10, the significance of which will be discussed in the following section.

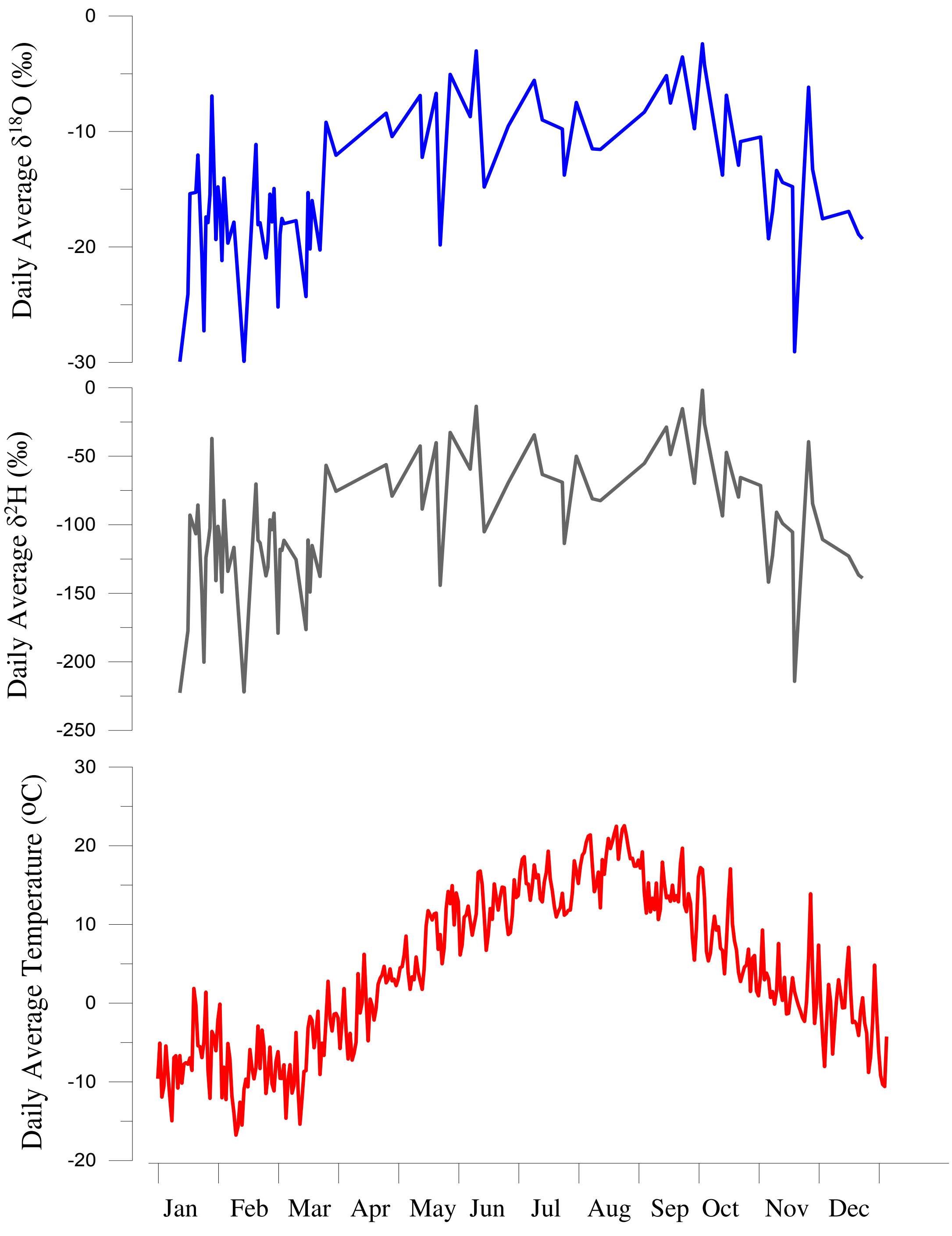

Figure 3.0.3: Daily average temperatures and precipitation isotope measurements for Corner Brook, NL (2015)

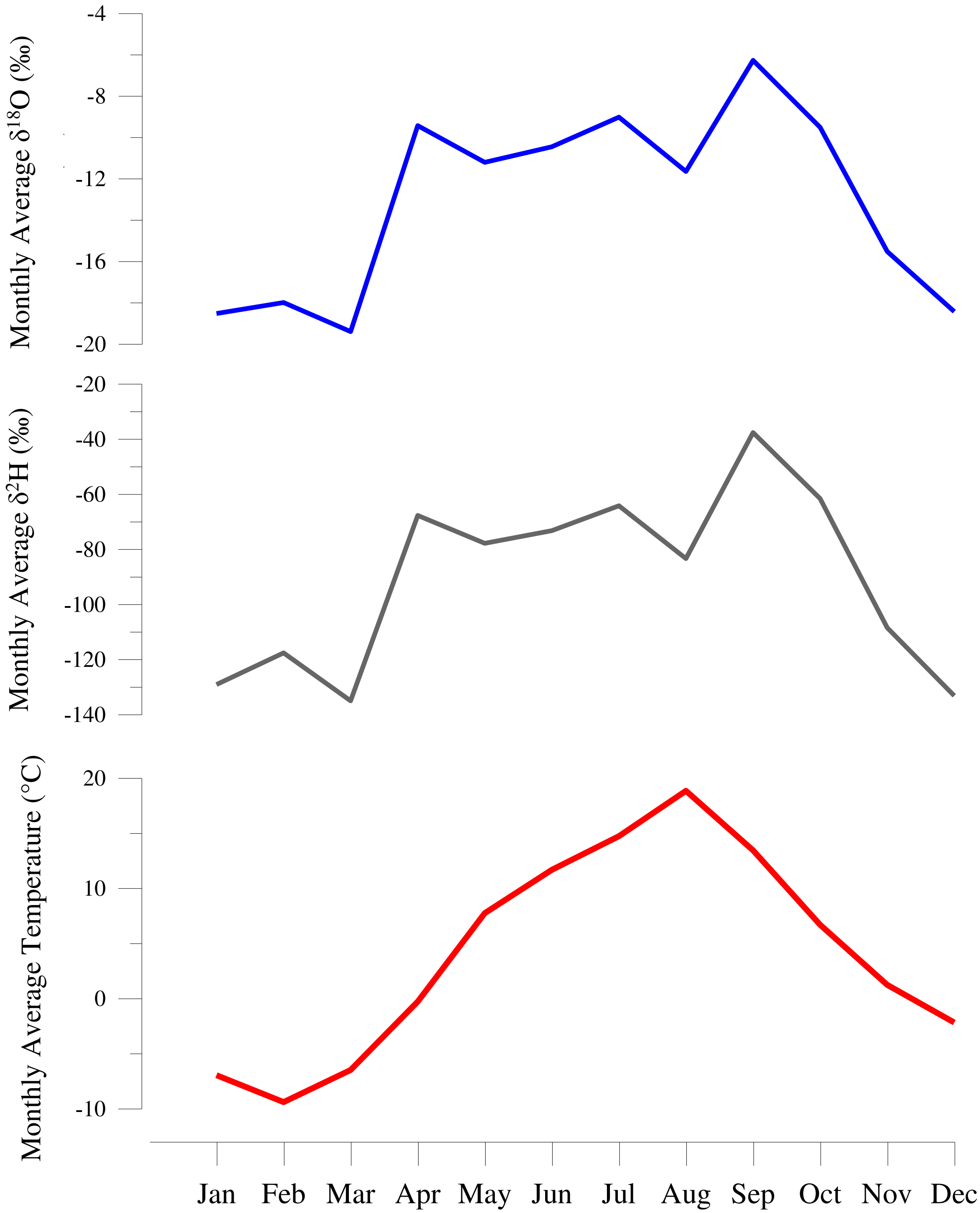

Figure 3.0.4: Monthly average temperatures and weighted monthly average precipitation isotope measurements for Corner Brook, NL (2015)

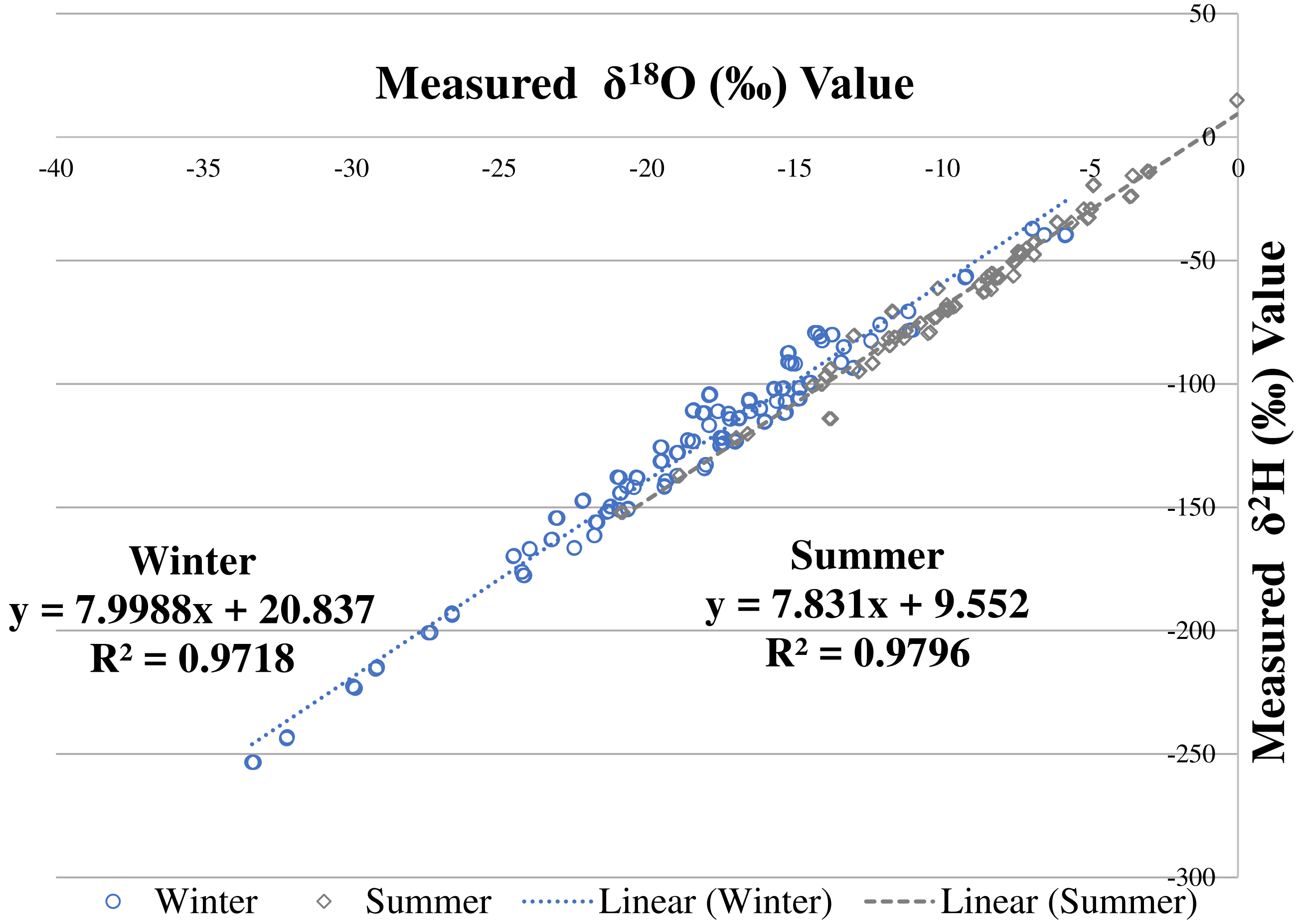

Figure 3.0.5: LMWLs for two seasons in Corner Brook NL, in this study defined as Winter (Jan-Mar, Nov-Dec) and Summer (Apr-Oct).

Other studies carried out in Atlantic Canada have been incorporated and serve as comparisons to our new data. Among the various initiatives to characterise the isotopic variability in precipitation within Canada, the Canadian Network for Isotopes in Precipitation (CNIP) and the Canadian Air and Precipitation Monitoring Network (CAPMoN) have been responsible for precipitation collection and analysis over various time periods since 1961.[4] Several sites of interest within Atlantic Canada have publicly available water isotope data, including: Truro in Nova Scotia (CNIP: January 1975-December 1983), Goose Bay in Labrador (GNIP: May 1961 - June 1969, CAPMoN: March 1997 - November 2010), and Bay D'Espoir in Newfoundland (CAPMoN: February 1997 - November 2010).[32] These sites provide a useful mode of comparison of the data obtained in this study. All of these sites are geographically similar in latitude, as seen in Figure 3.0.6, and all experience the same seasonal fluctuations as Corner Brook.[36] However each differs in specific climates as a result of differing atmospheric circulation patterns in each area (as will be discussed). Data from these three sites are plotted along with the GMWL for comparison in Figures 3.0.7-3.0.9, and data from all four studies are plotted in Figure 3.0.10 showing the extent of overlap between all data.

Water isotope data from this study, as well as those from the three other studies in Atlantic Canada, are given in Appendices 1-4. Daily and monthly temperature data are given in Appendix 5, and the Microsoft Excel file of complete raw meteorological data may be obtained upon request from the author.

Figure 3.0.6: Map of sites of interest in Atlantic Canada with publicly available precipitation water isotope data (Goose Bay, Bay D'Espoir, and Truro), as well as location of this study (Corner Brook). Blue star at Corner Brook indicates new data obtained by this research.

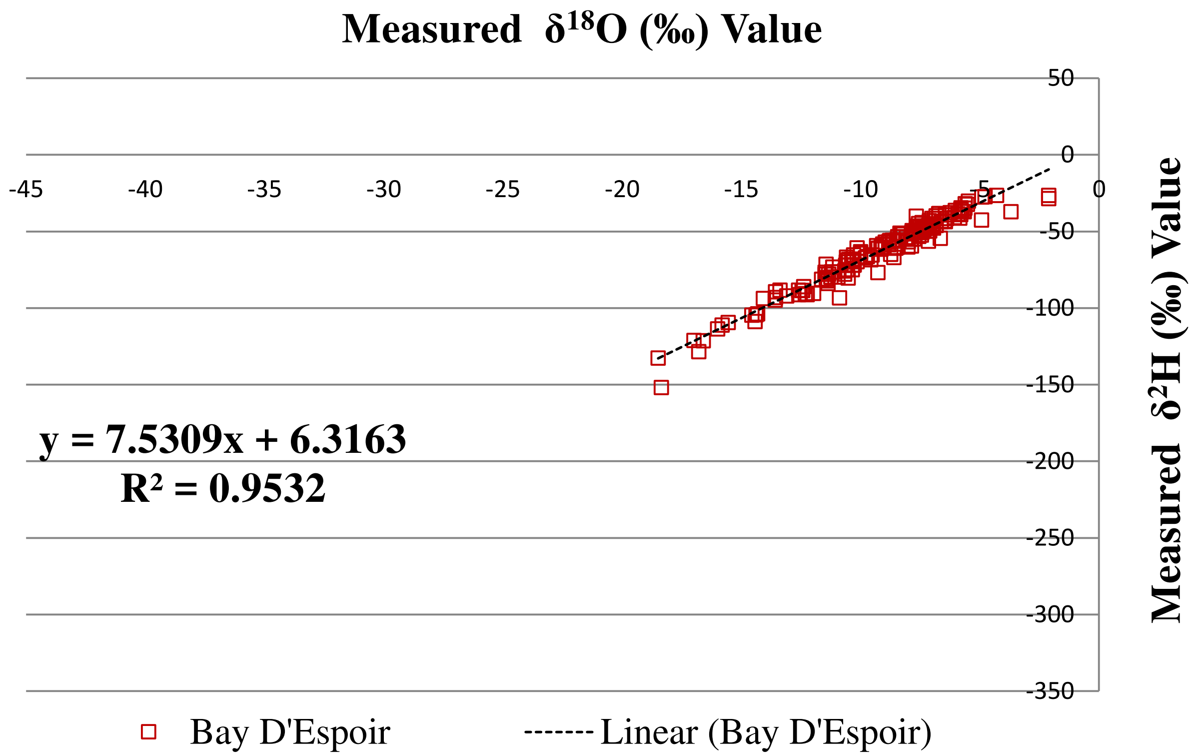

Figure 3.0.7: LMWL Bay D'Espoir (CAPMoN, Feb 1997-Nov 2010)

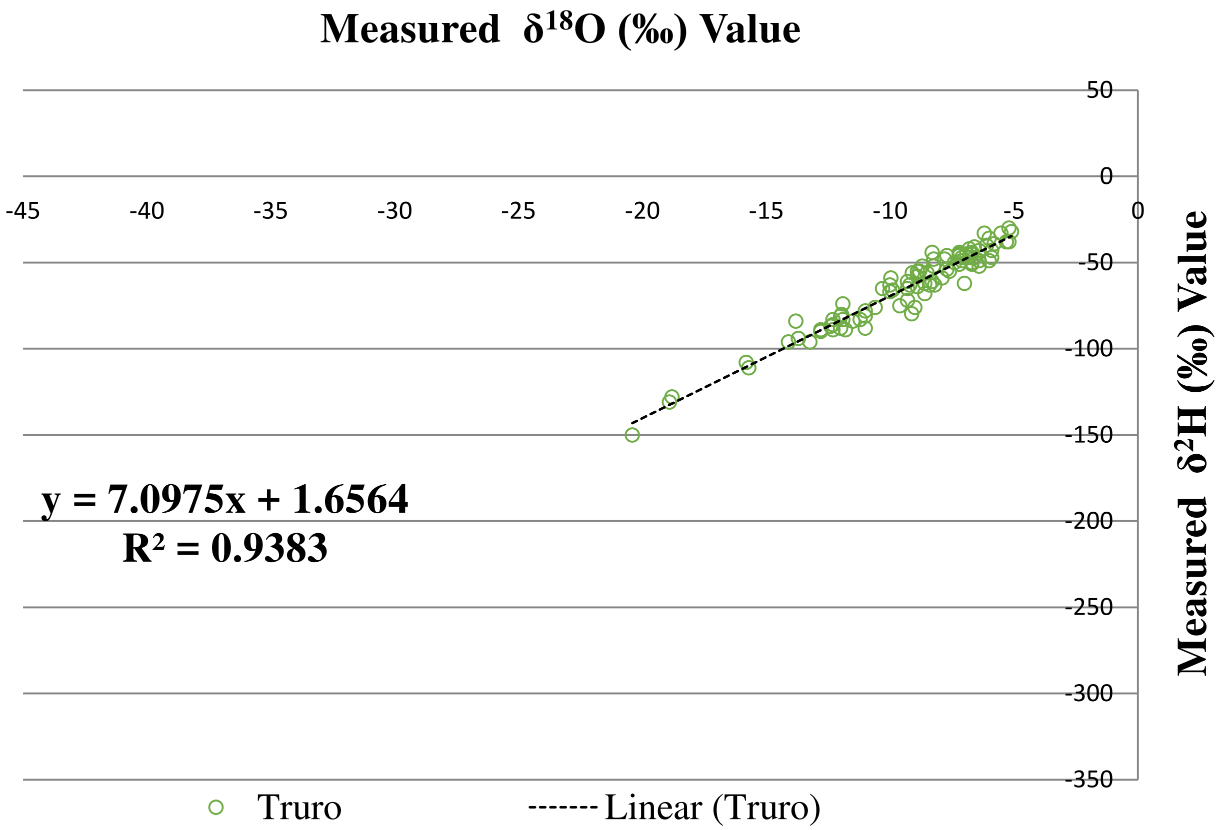

Figure 3.0.8: LMWL Truro, NS (CNIP, Jan 1975-Dec 1983)

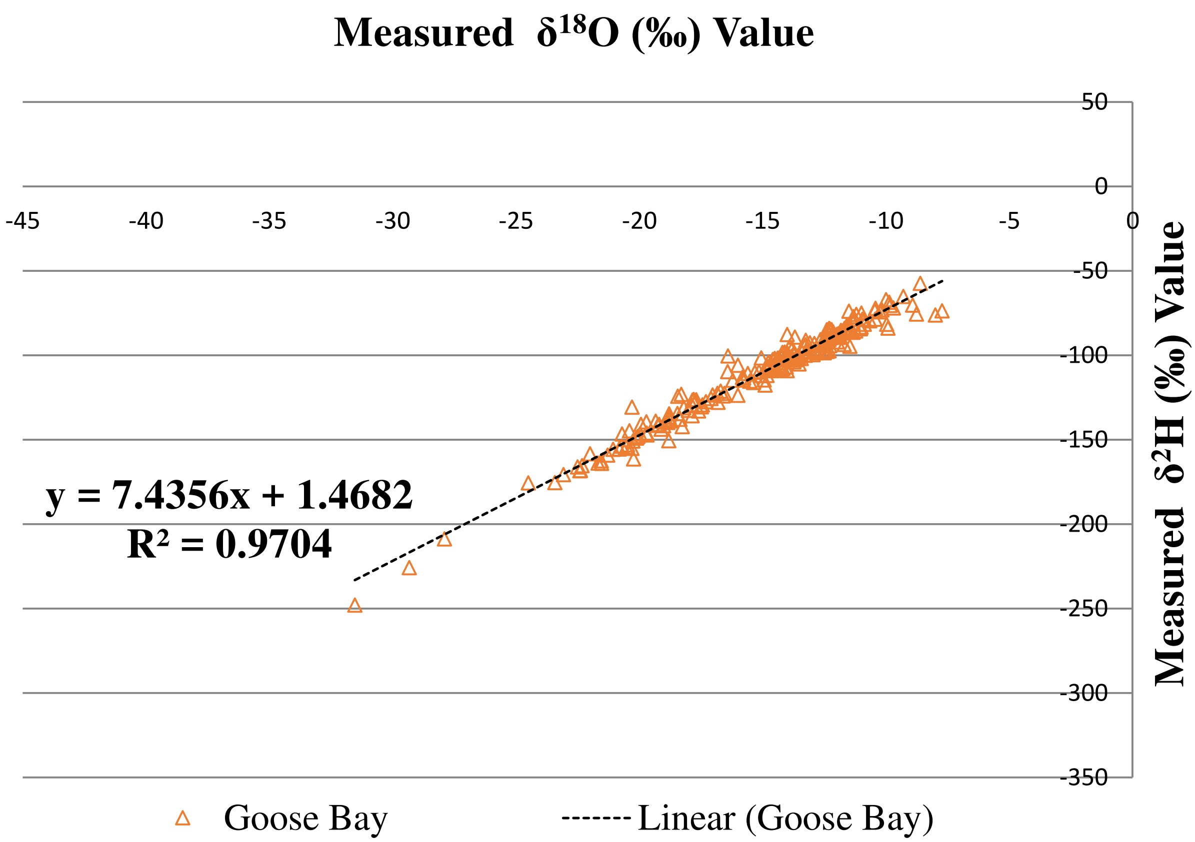

Figure 3.0.9: LMWL Goose Bay, NL (GNIP/ CAPMoN, May 1961-Jun 1969/ Mar 1997-Nov 2010)

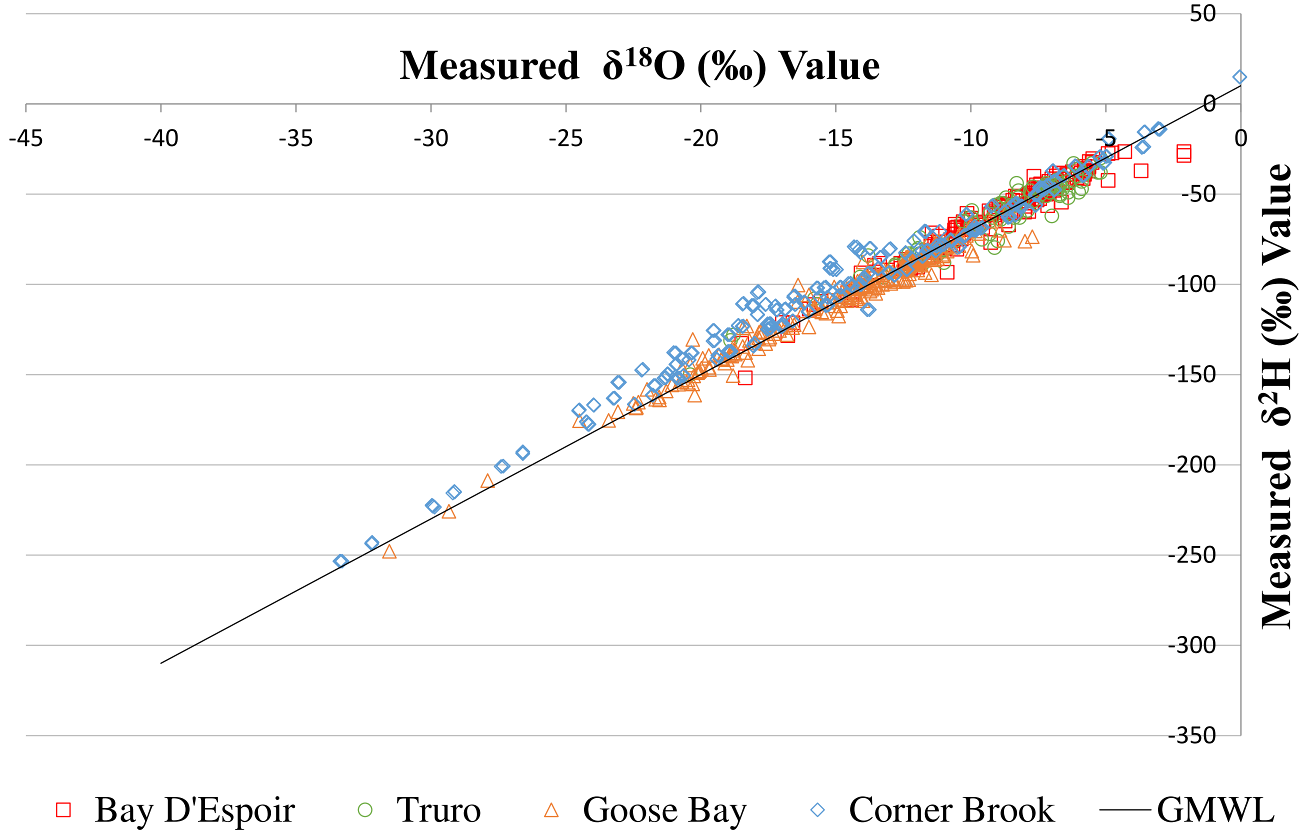

Figure 3.0.10: Plot of water isotope data from all studies in Atlantic Canada, with GMWL for comparison

3.1 Limitation of Data in This Study

The data obtained in this study may not necessarily be representative of long-term trends in the Western Newfoundland region. This record, being shorter than five to ten years, introduces biases including: not capturing both phases of the El Nino/La Nina Southern Oscillation, the Arctic Oscillation, and climate change.[7] This should be kept in mind during further discussion of these results, however if water isotope records could be continued in Corner Brook, NL, a clearer interpretation could be made.

3.2 Validation with Others' Data from Atlantic Canada

As was discussed, the composition of $\delta^{18}O$ and $\delta^{2}H$ is controlled by Rayleigh distillation of atmospheric vapor, which is mainly determined by changes in air-mass temperature because the moisture carrying capacity of air is temperature-dependent.[2,7] Many different geographic and climatic factors - such as latitude, elevation, distance inland from the coast, and humidity – are correlated with changes in temperature and therefore rain-out isotopic composition.[6,7] Further, changes in moisture sources, transport processes, rainout history, and seasonality also strongly influence the composition of stable water isotopes.[7] Moisture sources to the country of Canada include the Pacific, Arctic, Gulf of Mexico, Gulf of North Atlantic, Gulf of St. Lawrence, and potentially large lake systems such as the Great Lakes.[7,36] It is noteworthy that the Atlantic Provinces (New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland and Labrador) typically exhibit more enriched $\delta^{18}O$ and $\delta^{2}H$ patterns than throughout the rest of Canada, predominantly as a result of their close proximity to the ocean and lower latitude location.[7]

Due to geographic similarities (e.g. similar latitude, distance from the coast), it can be expected that $\delta^{18}O$ and $\delta^{2}H$ patterns in Corner Brook, NL would be similar to those in other localities of Atlantic Canada. It is clear from Figure 3.0.10 that both Truro and Bay D'Espoir appear higher on the GMWL than do Corner Brook and Goose Bay. This can be attributed to influences by the Labrador Current and the North Atlantic Oscillation (NAO), which is a cyclic variation of pressure systems that influences weather patterns in northern areas including Newfoundland and Labrador.[36] When a strongly positive NAO phase is in effect, much colder temperatures are experienced in Labrador and slightly below average temperatures are experienced along the northern parts and eastern coastlines of Newfoundland.[36] This can also produce strong northwesterly to northeasterly winds varying in latitude throughout NL.[36] In any case, the areas of Labrador and Western Newfoundland are under these direct influences, which do not reach Nova Scotia or Southern Newfoundland, giving more depleted isotope signals in the winter in these regions. As well, Nova Scotia and Southern Newfoundland are more heavily influenced by warm air masses coming from the Gulf Stream in the summer, which do not reach as far north as Labrador.[36] Western Newfoundland does experience some of this effect, however air masses lose most precipitation when moving over the Long Range Mountains (due to aforementioned elevation effect), which can result in slightly more depleted isotope signatures in the Humber Valley and Corner Brook.

On this basis it should be expected that Bay D'Espoir and Truro would have very similar $\delta^{18}O$ and $\delta^{2}H$ signatures, slightly higher on the GMWL. It is also unsurprising that there is much similarity between Corner Brook and Goose Bay $\delta^{18}O$ and $\delta^{2}H$. Principally both locations $\delta^{18}O$ and $\delta^{2}H$ are moderately lower on the GMWL, but it is notable that Corner Brook has a wider range of $\delta^{18}O$ and $\delta^{2}H$. This is possibly due to the routinely warmer temperatures and fluctuation of atmospheric circulation patterns that are observed in Corner Brook. In Goose Bay much colder weather is experienced, especially in the winter because it is essentially unaffected by the aforementioned warm systems that have some impact on the weather in Corner Brook during the summer.

In summary, it is reasonable that the location of the Corner Brook $\delta^{18}O$ and $\delta^{2}H$ signatures along the GMWL is higher than observed at Goose Bay, but lower than both Bay D'Espoir and Truro. As well, since Corner Brook is affected to some extent by warmer climatic systems in the summer such as the Gulf Stream, and colder climatic systems in the winter such as the Northern Arctic air flows, the $\delta^{18}O$ and $\delta^{2}H$ signatures have a wider range along the GMWL than those in Goose Bay, Bay D'Espoir, and Truro. The significant overlap of water isotope data from all four sites is a testament to the similar seasonality, latitude, elevation, distance inland from the coast, and humidity.

3.3 Seasonal Assessment and Distinctions

As previously mentioned, the isotopic composition of $\delta^{18}O$ and $\delta^{2}H$ are heavily dependent upon kinetic factors, and therefore temperature changes. It has been noted in previous work, that fluctuations in air temperature are closely reflected by $\delta^{18}O$ and $\delta^{2}H$ signals.[7] In fact, $\delta^{18}O$ and $\delta^{2}H$ have been used to develop surface air temperature proxies (see Table 1.1.3). It is therefore unsurprising that a clear distinction can be made between summer and winter seasons based on the $\delta^{18}O$ and $\delta^{2}H$ measurements in Corner Brook, NL. Figures 3.0.3 and 3.0.4 show that winter time $\delta^{18}O$ and $\delta^{2}H$ are much more depleted than those obtained in the summer (here we define winter to include the months from January-March and November-December, whereas summer includes April-October). This pattern is reinforced when examining Figure 3.0.5, which depicts two different LMWLs for winter and summer. The winter LMWL equation is $\delta^2H = 7.9988(\delta^{18}O) + 20.837$ with $R^2 = 0.9718$, whereas the summer LMWL equation is $\delta^2H = 7.831(\delta^{18}O) + 9.5517$ with $R^2 = 0.9796$. This is expected since the deuterium excess in winter is higher than 10, indicating less re-evaporation of water, whereas the summer deuterium excess is less than 10, indicating more re-evaporation of water.[3] Paired with daily temperature data, as in Figure 3.0.3, it can be seen that the lower winter-time temperatures experienced in Corner Brook produce more depleted $\delta^{18}O$ and δ^2H than in the warmer summer-time. This is a clear expression of several known isotopic fractionation mechanisms, including depletion due to lower in-cloud temperatures (and thereby formation of snow instead of rain), as well as the changing air pressure system which affect the area in different seasons (all discussed in previous sections). It should be noted however, that during the winter season there is increased complexity of driving forces of water isotope patterns, such as enhanced kinetic effects during phase changes at below-zero temperatures, which accounts for the imperfect reflection of temperature by $\delta^{18}O$ and δ^2H.[7]

4.0 Conclusions

Using the cavity ring-down Picarro L2130-i Liquid Water Isotope Analyzer, the $\delta^{18}O$ and $\delta^{2}H$ values of precipitation collected for 2015 in Grenfell Campus, MUN, Corner Brook, NL were determined. The $\delta^{18}O$ and $\delta^{2}H$ data in this study was validated with precipitation $\delta^{18}O$ and $\delta^{2}H$ data from: Truro in Nova Scotia, Bay D'Espoir in Newfoundland, and Goose Bay in Labrador. The similarity in geographic and climatic factors such as latitude, distance from the coast, and seasonal atmospheric fluctuations were evident in $\delta^{18}O$ and $\delta^{2}H$ data from all four locations.

In this study, the $\delta^{18}O$ varied from -33.372 to -0.033 ‰ (±0.023 ‰) and $\delta^{2}H$ ranged from -253.375 to 15.103 ‰ (±0.148 ‰), and these measurements reflected local air temperature fluctuations. In the cold winter months (i.e. January-March and November-December), the precipitation was more depleted in both of the heavy isotopes (i.e. ^{18}O and ^{2}H) as compared to those in the warmer summer (i.e. April-October). Therefore, it was confirmed that $\delta^{18}O$ and $\delta^{2}H$ data from this study can be used to assess seasonal trends characteristic to the region of Western Newfoundland.

The results of this analysis provide important background data related to liquid water isotopes in Western Newfoundland. Establishment of this baseline is fundamental to any further isotope hydrological/climatic studies that could be completed in the area, and continued measurement of $\delta^{18}O$ and $\delta^{2}H$ in atmospheric precipitation is necessary to give better representation of long-term trends in the Western Newfoundland region.

Literature Cited

1 Craig, H. Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. *Science* **1961**, *133*(3467), 1833-1834.

2 Dansgaard, W. Stable isotopes in precipitation. *Tellus* **1964**, *16*(4), 436-468. doi: 10.1111/j.2153-3490.1964.tb00181.x

3 Bowen, G. J. Isoscapes: Spatial pattern in isotopic biogeochemistry. *Annu. Rev. Earth Planet. Sci.* **2010***, 38*, 161–87. doi:10.1146/annurev-earth-040809-152429

4 Birks, S.J.; Gibson, J.J. Isotope hydrology research in Canada, 2003-2007. *Canadian Water Resources Journal* **2009**, *34*(2), 163-176.

5 Rozanski, K.; Araguás-Araguás, L.; Gonfiantini, R. Isotopic patterns in modern global precipitation. In *Climate Change in Continental Isotopic Records, Geophysical Monograph 78;* Swart, P.K., Lohmann, K.C., McKenzie, J., Savin, S., Eds.; American Geophysical Union: Washington, DC, 1993; pp 1-36.

6 Hoefs, J. *Stable isotope geochemistry,* 4th ed.; Springer; New York, 1997; pp 4-23, 28-32, 47-51, 103 -106.

7 Delavau, C.; Stadnyk, T.; Birks, J. Model based spatial distribution of oxygen-18 isotopes in precipitation across Canada. *Canadian Water Resources Journal* **2011***, 36*(4), 313-330. doi:10.4296/cwrj3604875

8 Gat, J.R. *Isotope hydrology: A study of the water cycle;* World Scientific: London, SG, 2010; pp9-10.

9 Faure, G. *Principles and applications of inorganic geochemistry: A comprehensive textbook for geology students*; Macmillan Pub. Co.: New York, 1991; p 341-349.

10 International Atomic Energy Agency (IAEA). Reference sheet for international measurement standards, 2009. http://nucleus.iaea.org/rpst/Documents/VSMOW2_SLAP2.pdf (Accessed August 2, 2015)

11 United States Geological Survey (USGS), Reston Stable Isotope Laboratory. Report of stable isotopic composition: Reference material VSMOW, 2012. http://isotopes.usgs.gov/lab/referencematerials/VSMOW.pdf (Accessed August 2, 2015)

12 Zalicki, P.; Zare, R.N. Cavity ring-down spectroscopy for quantitative absorption measurements. *Journal of Chemical Physics* **1995**, *102*(7), 2708-2717. doi: 10.1063/1.468647

13 Romanini, D.; Kachanov, A.A.; Stoeckel, F. Diode laser cavity ring down spectroscopy. *Chemical Physical Letters* **1997**, *270*, 538-545.

14 Wheeler, M.D.; Newman, S.M.; Orr-Ewing, A.J.; Ashfold, M.N.R. Cavity ring-down spectroscopy. *J. Chem. Soc., Faraday Trans.* **1998**, *94*(3), 337-351.

15 Bailey, A.; Noone, D.; Berkelhammer, M.; Steen-Larsen, H. C.; Sato, P. The stability and calibration of water vapor isotope ratio measurements during long-term deployments. *Atmospheric Measurement Techniques Discussions* **2015**, *8*(5), 5425-5466. doi:10.5194/amtd-8-5425-2015

16 Klein, E. S.; Cherry, J. E.; Young, J.; Noone, D.; Leffler, A. J.; Welker, J. M. Arctic cyclone water vapor isotopes support past sea ice retreat recorded in Greenland ice. *Scientific Reports* **2015**, *5* doi:10.1038/srep10295

17 Martín-Gómez, P.; Barbeta, A.; Voltas, J.; Peñuelas, J.; Dennis, K.; Palacio, S.; Dawson, T.E.; Ferrio, J.P. Isotope-ratio infrared spectroscopy: a reliable tool for the investigation of plant-water sources?. *New Phytologist* **2015**, *207*, 914-927. doi: 10.1111/nph.13376

18 Good, S. P.; Mallia, D. V.; Lin, J. C.; Bowen, G. J. Stable isotope analysis of precipitation samples obtained via crowdsourcing reveals the spatiotemporal evolution of superstorm sandy. *PloS One* **2014**, *9*(3), e91117. doi:10.1371/journal.pone.0091117

19 Birks, S. J.; Edwards, T. W. D. Atmospheric circulation controls on precipitation isotope–climate relations in western Canada. *Tellus B* **2009**, *61*(3), 566-576. doi:10.1111/j.1600-0889.2009.00423.x

20 Van der Veer, G.; Voerkelius, S.; Lorentz, G.; Heiss, G.; Hoogewerff, J.A. Spatial interpolation of the deuterium and oxygen-18 composition of global precipitation using temperature as ancillary variable. *Journal of Geochemical Exploration* **2009**, *101*, 175-184. doi:10.1016/j.gexplo.2008.06.008

21 Burnett, A. W.; Mullins, H. T.; Patterson, W. P. Relationship between atmospheric circulation and winter precipitation δ 18 O in central New York state. *Geophysical Research Letters* **2004**, *31*(22), L22209. doi:10.1029/2004GL021089

22 Peng, H.; Mayer, B.; Harris, S.; Krouse, H.R. A 10- yr record of stable isotope ratios of hydrogen and oxygen in precipitation at Calgary, Alberta, Canada. *Tellus B* **2004**, *56*(2), 147-159. doi:10.1111/j.1600-0889.2004.00094.x

23 Edwards, T.W.D.; Birks, S.J.; Gibson, J.J. Isotope tracers in global water and climate studies of the past and present. In *International Conference on the Study of Environmental Change Using Isotope Techniques;* International Atomic Energy Agency: Vienna, April 2001; IAEA-CN-80/66, 2002; pp 1-9.

24 Kendall, C.; Coplen, T. B. Distribution of oxygen- 18 and deuterium in river waters across the United States. *Hydrological Processes* **2001**, *15*(7), 1363-1393. doi:10.1002/hyp.217

25 Jamieson, R.; Wadleigh, M. A study of the oxygen isotopic composition of precipitation sulphate in eastern Newfoundland. *Water, Air, and Soil Pollution* **1999**, *110*(3), 405-420. doi:10.1023/A:1005002026009

26 Sklash, M. G.; Farvolden, R. N.; Fritz, P. A conceptual model of watershed response to rainfall, developed through the use of oxygen-18 as a natural tracer. *Canadian Journal of Earth Sciences* **1976**, *13*(2), 271-283. doi:10.1139/e76-029

27 Darling, W.G.; Bath, A.H.; Gibson, J.J.; Rozanski, K. Isotopes in water. In *Isotopes in palaeoenvironmental research;* Leng, M.J., Ed.; Springer: Dordrecht, The Netherlands, 2006; Vol 10, pp 1-51.

28 Jouzel, J.; Froehlich, K.; Schotterer, U. Deuterium and oxygen- 18 in present-day precipitation: Data and modelling. *Hydrological Sciences Journal* **1997**, *42*(5), 747-763. doi:10.1080/02626669709492070

29 Jouzel, J.; Merlivat, L. Deuterium and oxygen 18 in precipitation: Modeling of the isotopic effects during snow formation. *Journal of Geophysical Research* **1984**, *89*(D7), 11749-11757.

30 Sharp, Z. *Principles of stable isotope geochemistry,* 1st ed; Pearson Prentice Hall: Upper Saddle River New Jersey, 2007; pp 64-86.

31 Arizona Board of Regents: Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA). Isotopes and Hydrology: Oxygen, 2005. Web site http://web.sahra.arizona.edu/programs/isotopes/oxygen.html (Accessed November 30, 2015)

32 International Atomic Energy Agency (IAEA)/ World Meteorological Organization (WMO) (2015). Global Network of Isotopes in Precipitation. The GNIP Database, 2015. https://nucleus.iaea.org/wiser/index.php (Accessed August 27, 2015)

33 Picarro. Technology: Cavity ring-down spectroscopy (CRDS), 2015. Web sites http://www.picarro.com/technology/cavity_ring_down_spectroscopy,

http://www.picarro.com/technology/cavity_ring_down_spectroscopy/brief_technical_description_of_crds (Accessed October 28, 2015)

34 Government of Canada. Canadian climate normals 1981-2010 station data: Corner Brook, 2015. Web site http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?stnID=6610&lang=e&province=NL&provSubmit=go&dCode=0 (Accessed October 28, 2015)

35 Rorabacher, D.B. Statistical treatment for rejection of deviant values: critical values of Dixon's "Q" parameter and related subrange ratios at the 95% confidence level. *Analytical Chemistry* **1991**, *63*(2), 139-146.

36 Vasseur, L.; Catto, N. Atlantic Canada. In *From impacts to adaptation: Canada in a changing climate 2007*; Lemmen, D.S., Warren, F.J., Lacroix, J., Bush, E., Eds.; Government of Canada: Ottawa, ON, 2008; pp 119-170.

Table A1: All water isotope data obtained in this study

Corner Brook, NL			This Study		
January 2015-December 2015					
Lat	Long				
48.94 N	57.93 W				
Collected	Retrieved	Sample	$\delta^{18}O$	$\delta^{2}H$	d-excess
mm/dd/yy hh:mm	mm/dd/yy hh:mm	#	‰VSMOW	‰VSMOW	‰
1-12-15 10:17	1-12-15 15:13	1	-26.600	-192.829	-19.974
		1	-26.606	-193.492	-19.352
		1	-26.596	-193.746	-19.023
1-12-15 16:25	1-12-15 20:59	2	-33.372	-253.343	-13.632
		2	-33.353	-253.375	-13.447
		2	-33.292	-253.311	-13.029
1-16-15 12:30	1-16-15 16:56	3	-24.148	-177.756	-15.429
		3	-24.141	-177.577	-15.549
		3	-24.190	-177.537	-15.987
		3	-24.230	-176.266	-17.570
		3	-24.231	-176.188	-17.657
		3	-24.244	-176.008	-17.947
1-17-15 13:22	1-17-15 15:31	4	-16.568	-107.093	-25.448
		4	-16.506	-106.393	-25.657
		4	-16.555	-106.349	-26.091
1-17-15 16:21	1-17-15 23:00	5	-14.294	-79.599	-34.752
		5	-14.222	-79.208	-34.566
		5	-14.331	-79.163	-35.484
1-20-15 16:52	1-20-15 19:13	6	-15.323	-107.091	-15.490
		6	-15.303	-107.280	-15.140
		6	-15.281	-107.310	-14.941
1-21-15 4:00	1-21-15 10:30	7	-11.125	-78.435	-10.561
		7	-11.001	-78.116	-9.888
		7	-11.081	-78.240	-10.409
1-21-15 17:00	1-21-15 23:30	8	-13.028	-93.510	-10.711
		8	-13.048	-93.640	-10.742
		8	-13.001	-93.320	-10.689
1-23-15 22:00	1-24-15 11:30	9	-20.932	-150.945	-16.513
		9	-20.926	-151.158	-16.249
		9	-20.942	-150.978	-16.556
1-24-15 13:15	1-25-15 0:10	10	-27.319	-200.714	-17.842
		10	-27.327	-200.814	-17.801
		10	-27.399	-200.876	-18.316
1-25-15 15:25	1-25-15 23:30	11	-17.441	-124.348	-15.178
		11	-17.394	-123.958	-15.195
		11	-17.416	-124.023	-15.309
1-26-15 1:00	1-26-15 10:28	12	-20.685	-141.351	-24.131
		12	-20.688	-141.546	-23.962
		12	-20.686	-141.273	-24.218
1-26-15 12:30	1-26-15 16:45	13	-15.205	-87.411	-34.230

		13	-15.189	-87.387	-34.127
		13	-15.246	-87.476	-34.496
1-27-15 0:00	1-27-15 16:50	14	-18.620	-123.072	-25.888
		14	-18.606	-122.784	-26.067
		14	-18.622	-122.637	-26.340
1-27-15 17:00	1-28-15 11:31	15	-12.418	-82.624	-16.722
		15	-12.419	-82.343	-17.012
		15	-12.416	-82.585	-16.745
1-28-15 21:00	1-29-15 9:30	16	-6.965	-37.373	-18.350
		16	-6.974	-37.159	-18.632
		16	-6.958	-36.957	-18.707
1-30-15 6:00	1-30-15 17:00	17	-19.409	-141.268	-14.000
		17	-19.412	-141.717	-13.576
		17	-19.415	-141.781	-13.538
1-31-15 16:00	2-1-15 16:30	18	-14.835	-101.499	-17.183
		18	-14.806	-101.576	-16.869
		18	-14.861	-101.691	-17.194
2-1-15 17:30	2-2-15 0:30	19	-16.486	-111.068	-20.821
		19	-16.507	-111.169	-20.890
		19	-16.518	-111.196	-20.947
2-2-15 17:00	2-3-15 12:00	20	-21.232	-149.512	-20.344
		20	-21.214	-149.739	-19.973
		20	-21.249	-149.797	-20.195
2-3-15 14:00	2-4-15 11:00	21	-14.074	-82.496	-30.100
		21	-14.092	-82.498	-30.242
		21	-14.062	-82.383	-30.111
		21	-14.136	-80.680	-32.406
		21	-14.122	-80.660	-32.315
		21	-14.139	-80.899	-32.211
2-5-15 12:00	2-5-15 15:45	22	-23.199	-162.930	-22.659
		22	-23.221	-163.130	-22.638
		22	-23.251	-163.150	-22.855
2-5-15 16:20	2-5-15 19:15	23	-17.173	-114.189	-23.193
		23	-17.210	-114.169	-23.509
		23	-17.188	-114.171	-23.329
		23	-17.237	-111.959	-25.937
		23	-17.238	-112.040	-25.864
		23	-17.250	-112.187	-25.811
2-5-15 19:30	2-5-15 21:00	24	-18.934	-127.802	-23.669
		24	-19.006	-127.910	-24.137
		24	-18.987	-127.862	-24.032
2-5-15 21:15	2-5-15 22:15	25	-20.889	-144.267	-22.843
		25	-20.924	-144.287	-23.103
		25	-20.877	-144.213	-22.804
2-5-15 22:45	2-6-15 12:30	26	-18.429	-123.141	-24.288
		26	-18.453	-123.369	-24.255
		26	-18.476	-123.324	-24.486

2-8-15 3:00	2-8-15 11:00	27	-17.891	-116.880	-26.249
		27	-17.914	-116.646	-26.669
		27	-17.889	-116.760	-26.352
2-13-15 9:30	2-13-15 16:15	28	-29.962	-222.400	-17.294
		28	-29.936	-222.661	-16.830
		28	-29.938	-222.982	-16.526
2-19-15 17:00	2-20-15 9:00	29	-11.168	-70.601	-18.739
		29	-11.145	-70.645	-18.518
		29	-11.161	-70.580	-18.709
2-20-15 19:00	2-21-15 13:00	30	-18.124	-111.747	-33.247
		30	-18.110	-111.812	-33.064
		30	-18.095	-111.786	-32.971
2-21-15 13:30	2-21-15 16:45	31	-13.739	-80.085	-29.828
		31	-13.758	-79.983	-30.083
		31	-13.715	-79.934	-29.784
2-21-15 17:50	2-22-15 13:00	32	-22.146	-147.025	-30.142
		32	-22.201	-147.516	-30.093
		32	-22.186	-147.534	-29.956
2-24-15 12:00	2-25-15 9:00	33	-21.009	-137.707	-30.362
		33	-20.948	-137.938	-29.648
		33	-20.919	-138.004	-29.344
2-25-15 18:30	2-26-15 9:40	34	-19.492	-131.303	-24.631
		34	-19.485	-131.129	-24.754
		34	-19.553	-131.397	-25.028
2-26-15 9:55	2-26-15 15:00	35	-15.703	-102.237	-23.390
		35	-15.666	-101.972	-23.357
		35	-15.714	-101.894	-23.817
2-26-15 16:25	2-27-15 17:00	36	-15.231	-91.159	-30.690
		36	-15.180	-91.209	-30.234
		36	-15.216	-91.069	-30.662
2-27-15 18:15	2-28-15 12:50	37	-17.886	-104.002	-39.085
		37	-17.851	-104.306	-38.501
		37	-17.914	-104.661	-38.655
2-28-15 15:00	3-1-15 15:00	38	-14.983	-91.908	-27.952
		38	-14.990	-91.725	-28.195
		38	-14.984	-91.856	-28.012
		38	-15.100	-91.815	-28.985
		38	-15.110	-91.814	-29.062
		38	-15.101	-91.737	-29.072
3-2-15 9:30	3-2-15 12:45	39	-32.179	-242.963	-14.470
		39	-32.200	-243.509	-14.093
		39	-32.192	-243.762	-13.773
3-2-15 13:20	3-2-15 16:35	40	-24.533	-170.002	-26.263
		40	-24.493	-169.611	-26.331
		40	-24.525	-169.662	-26.534
3-2-15 16:50	3-2-15 19:45	41	-23.963	-167.024	-24.679
		41	-23.977	-166.719	-25.094

		41	-23.981	-166.810	-25.037
3-2-15 20:30	3-2-15 22:00	42	-20.357	-138.193	-24.660
		42	-20.363	-137.798	-25.107
		42	-20.312	-138.009	-24.489
3-3-15 15:35	3-3-15 19:45	43	-18.447	-111.020	-36.553
		43	-18.467	-110.889	-36.845
		43	-18.418	-110.465	-36.879
3-3-15 20:00	3-4-15 10:15	44	-19.503	-125.599	-30.428
		44	-19.554	-125.627	-30.808
		44	-19.528	-125.580	-30.643
3-4-15 11:30	3-4-15 14:00	45	-20.451	-141.856	-21.752
		45	-20.435	-141.948	-21.533
		45	-20.449	-141.851	-21.741
3-4-15 14:35	3-4-15 17:45	46	-16.879	-114.104	-20.924
		46	-16.916	-113.935	-21.390
		46	-16.858	-113.573	-21.294
3-4-15 18:00	3-5-15 13:30	47	-15.370	-101.530	-21.434
		47	-15.387	-101.880	-21.220
		47	-15.446	-101.867	-21.699
3-5-15 15:20	3-5-15 21:10	48	-18.031	-111.760	-32.489
		48	-18.048	-111.766	-32.618
		48	-18.062	-111.726	-32.768
3-11-15 10:15	3-11-15 14:20	49	-16.160	-110.298	-18.978
		49	-16.162	-109.671	-19.622
		49	-16.186	-109.964	-19.524
3-11-15 15:00	3-11-15 17:30	50	-15.612	-106.980	-17.915
		50	-15.610	-106.820	-18.058
		50	-15.605	-107.053	-17.791
3-11-15 17:55	3-11-15 19:10	51	-17.508	-124.466	-15.602
		51	-17.539	-124.968	-15.345
		51	-17.511	-124.760	-15.325
3-11-15 19:20	3-11-15 23:50	52	-21.802	-161.456	-12.958
		52	-21.781	-161.444	-12.801
		52	-21.769	-161.429	-12.723
3-16-15 10:30	3-16-15 14:50	53	-29.916	-222.835	-16.495
		53	-29.916	-222.835	-16.495
		53	-29.872	-223.345	-15.630
3-16-15 16:05	3-16-15 21:45	54	-21.366	-151.953	-18.979
		54	-21.311	-151.769	-18.722
		54	-21.299	-151.587	-18.803
3-16-15 22:50	3-17-15 11:40	55	-21.750	-156.027	-17.974
		55	-21.675	-155.992	-17.407
		55	-21.711	-156.066	-17.621
3-17-15 16:00	3-18-15 10:00	56	-15.333	-111.516	-11.145
		56	-15.287	-111.546	-10.752
		56	-15.370	-111.898	-11.059
3-18-15 15:15	3-18-15 20:35	57	-22.453	-166.445	-13.176

		57	-22.454	-166.349	-13.281
		57	-22.468	-166.537	-13.211
3-18-15 20:55	3-19-15 12:00	58	-18.003	-132.731	-11.295
		58	-17.999	-132.887	-11.106
		58	-18.020	-132.666	-11.496
3-19-15 15:30	3-19-15 21:00	59	-16.019	-115.485	-12.665
		59	-16.029	-114.997	-13.238
		59	-15.990	-115.091	-12.830
3-23-15 11:00	3-23-15 15:45	60	-23.089	-154.263	-30.452
		60	-23.019	-154.291	-29.865
		60	-23.036	-154.433	-29.859
3-23-15 17:00	3-24-15 8:30	61	-17.539	-122.031	-18.282
		61	-17.527	-121.973	-18.239
		61	-17.524	-121.761	-18.434
		61	-17.405	-121.909	-17.329
		61	-17.439	-121.744	-17.765
		61	-17.465	-121.967	-17.753
3-26-15 15:20	3-26-15 22:30	62	-9.242	-56.987	-16.951
		62	-9.230	-56.755	-17.082
		62	-9.186	-56.300	-17.190
3-31-15 19:20	4-1-15 11:00	63	-12.111	-76.067	-20.820
		63	-12.111	-75.808	-21.079
		63	-12.105	-75.842	-20.994
4-25-15 17:20	4-25-15 19:26	64	-8.457	-56.488	-11.168
		64	-8.467	-56.425	-11.307
		64	-8.488	-56.434	-11.467
4-28-15 9:00	4-28-15 11:30	65	-10.497	-79.566	-4.406
		65	-10.411	-79.010	-4.276
		65	-10.419	-79.230	-4.124
5-12-15 17:12	5-12-15 21:00	66	-6.925	-42.869	-12.533
		66	-6.946	-42.904	-12.667
		66	-6.855	-42.547	-12.295
5-13-15 8:45	5-13-15 12:15	67	-16.976	-121.748	-14.056
		67	-16.981	-121.799	-14.047
		67	-16.962	-122.218	-13.476
5-13-15 12:30	5-13-15 16:30	68	-7.609	-56.346	-4.523
		68	-7.598	-56.198	-4.586
		68	-7.580	-56.064	-4.577
5-20-15 18:50	5-20-15 20:35	69	-7.402	-46.483	-12.733
		69	-7.462	-46.433	-13.267
		69	-7.426	-46.253	-13.158
5-20-15 20:45	5-20-15 23:00	70	-6.086	-34.553	-14.135
		70	-6.147	-34.517	-14.663
		70	-6.135	-34.320	-14.758
5-22-15 21:25	5-22-15 22:10	71	-18.883	-137.056	-14.010
		71	-18.901	-137.173	-14.037
		71	-18.908	-137.361	-13.900

5-22-15 22:20	5-22-15 23:00	72	-20.876	-152.173	-14.834
		72	-20.894	-152.041	-15.110
		72	-20.802	-152.057	-14.357
5-27-15 8:15	5-27-15 10:15	73	-5.100	-33.075	-7.721
		73	-5.082	-32.586	-8.066
		73	-5.034	-32.565	-7.705
6-6-15 17:45	6-6-15 19:15	74	-8.770	-59.922	-10.238
		74	-8.725	-59.892	-9.912
		74	-8.769	-59.833	-10.318
6-9-15 8:20	6-9-15 12:00	75	-3.066	-13.980	-10.549
		75	-3.070	-13.655	-10.908
		75	-3.047	-13.764	-10.613
		75	-2.985	-14.073	-9.807
		75	-3.017	-14.166	-9.969
		75	-2.998	-13.966	-10.016
6-13-15 14:00	6-13-15 15:00	76	-13.920	-96.489	-14.875
		76	-13.947	-96.681	-14.895
		76	-13.971	-96.848	-14.923
6-13-15 15:15	6-13-15 16:35	77	-14.075	-100.033	-12.569
		77	-14.062	-100.128	-12.372
		77	-14.111	-100.204	-12.685
6-13-15 16:45	6-13-15 17:40	78	-16.586	-120.303	-12.382
		78	-16.604	-120.227	-12.602
		78	-16.612	-120.377	-12.520
		78	-16.587	-120.169	-12.523
		78	-16.595	-120.253	-12.507
		78	-16.605	-120.331	-12.505
6-25-15 8:40	6-25-15 11:00	79	-8.623	-62.971	-6.013
		79	-8.585	-62.722	-5.957
		79	-8.541	-62.575	-5.757
6-25-15 11:15	6-25-15 13:00	80	-8.350	-61.802	-4.995
		80	-8.356	-61.789	-5.059
		80	-8.354	-61.640	-5.191
6-25-15 13:10	6-25-15 16:40	81	-11.764	-84.427	-9.685
		81	-11.803	-84.397	-10.029
		81	-11.804	-84.569	-9.865
7-8-15 20:55	7-8-15 22:35	82	-5.618	-34.820	-10.122
		82	-5.638	-34.640	-10.463
		82	-5.646	-34.487	-10.683
7-12-15 12:45	7-12-15 14:45	83	-10.249	-72.929	-9.060
		83	-10.280	-73.178	-9.065
		83	-10.288	-73.446	-8.857
7-12-15 14:50	7-12-15 16:40	84	-8.206	-57.135	-8.509
		84	-8.157	-57.170	-8.084
		84	-8.070	-57.003	-7.556
7-12-15 16:45	7-12-15 18:55	85	-9.602	-68.445	-8.373
		85	-9.562	-68.450	-8.046

		85	-9.636	-68.924	-8.165
7-12-15 19:00	7-12-15 22:40	86	-8.163	-56.560	-8.745
		86	-8.114	-56.425	-8.490
		86	-8.185	-56.538	-8.945
7-22-15 20:25	7-22-15 21:55	87	-9.901	-69.899	-9.309
		87	-9.961	-69.907	-9.785
		87	-9.885	-69.814	-9.268
7-22-15 22:00	7-22-15 23:20	88	-9.769	-68.984	-9.164
		88	-9.770	-68.998	-9.159
		88	-9.793	-69.022	-9.322
7-23-15 10:45	7-23-15 16:05	89	-13.832	-114.094	3.441
		89	-13.762	-114.105	4.012
		89	-13.844	-114.047	3.293
7-29-15 8:35	7-29-15 10:30	90	-7.528	-50.350	-9.877
		90	-7.560	-50.478	-10.003
		90	-7.558	-50.144	-10.320
		90	-7.625	-50.448	-10.552
		90	-7.550	-50.328	-10.071
		90	-7.567	-50.250	-10.285
8-6-15 10:35	8-6-15 11:15	91	-11.798	-81.335	-13.048
		91	-11.831	-81.382	-13.264
		91	-11.818	-81.672	-12.872
8-6-15 11:30	8-6-15 12:05	sample rejected			
8-6-15 12:20	8-6-25 13:15	93	-11.318	-81.594	-8.949
		93	-11.319	-81.539	-9.012
		93	-11.285	-81.348	-8.932
8-10-15 8:25	8-10-15 9:50	94	-11.572	-81.282	-11.296
		94	-11.636	-81.070	-12.017
		94	-11.619	-81.177	-11.773
8-10-15 10:05	8-10-15 10:55	95	-10.240	-72.971	-8.950
		95	-10.205	-72.919	-8.723
		95	-10.198	-73.036	-8.546
8-10-15 11:10	8-10-15 11:50	96	-12.367	-91.470	-7.466
		96	-12.357	-91.626	-7.234
		96	-12.370	-91.616	-7.345
		96	-12.351	-91.658	-7.149
		96	-12.385	-91.764	-7.313
		96	-12.387	-91.796	-7.298
8-10-15 12:00	8-10-15 12:40	97	-12.794	-94.690	-7.662
		97	-12.826	-95.051	-7.555
		97	-12.847	-95.071	-7.705
8-10-15 13:25	8-10-15 14:05	98	-12.198	-85.601	-11.986
		98	-12.185	-85.727	-11.751
		98	-12.193	-85.367	-12.178
8-10-15 14:15	8-10-15 14:45	99	-11.281	-78.717	-11.529
		99	-11.261	-78.727	-11.358
		99	-11.225	-78.449	-11.348

8-10-15 15:00	8-10-15 15:25	100	-10.777	-75.477	-10.742
		100	-10.733	-75.383	-10.480
		100	-10.746	-75.296	-10.669
9-1-15 10:45	9-1-15 11:20	101	-8.368	-55.643	-11.302
		101	-8.360	-55.555	-11.322
		101	-8.367	-55.427	-11.509
9-12-15 22:45	9-13-15 0:35	102	-5.205	-29.159	-12.480
		102	-5.216	-29.118	-12.614
		102	-5.252	-29.483	-12.535
9-14-15 15:50	9-14-15 17:35	103	-8.340	-55.219	-11.499
		103	-8.304	-55.309	-11.122
		103	-8.332	-55.185	-11.473
		103	-8.282	-55.257	-10.997
		103	-8.311	-55.522	-10.968
		103	-8.313	-55.558	-10.949
9-14-15 17:50	9-14-15 19:20	104	-7.279	-47.310	-10.925
		104	-7.285	-47.136	-11.141
		104	-7.267	-47.172	-10.961
9-14-15 19:30	9-14-15 23:10	105	-7.153	-45.128	-12.096
		105	-7.131	-45.008	-12.039
		105	-7.163	-44.957	-12.351
9-20-15 18:30	9-20-15 21:00	106	-3.584	-15.650	-13.025
		106	-3.557	-15.419	-13.037
		106	-3.552	-15.616	-12.798
9-26-15 13:40	9-26-15 17:45	107	-9.814	-70.235	-8.276
		107	-9.783	-69.907	-8.360
		107	-9.827	-70.279	-8.333
9-30-15 8:30	9-30-15 10:25	108	-0.033	14.838	-15.098
		108	-0.046	14.815	-15.185
		108	-0.040	15.103	-15.423
9-30-15 10:45	9-30-15 16:15	109	-4.862	-19.277	-19.616
		109	-4.906	-19.759	-19.488
		109	-4.913	-19.339	-19.967
10-1-15 11:10	10-1-15 13:05	110	-4.958	-29.148	-10.520
		110	-4.991	-29.125	-10.804
		110	-5.011	-29.126	-10.963
10-1-15 13:15	10-1-15 18:00	111	-3.582	-23.821	-4.837
		111	-3.645	-24.013	-5.150
		111	-3.673	-24.177	-5.205
10-10-15 13:10	10-10-15 16:40	112	-13.828	-94.047	-16.576
		112	-13.768	-93.704	-16.439
		112	-13.826	-94.121	-16.486
10-12-15 21:40	10-12-15 22:10	113	-6.899	-47.565	-7.629
		113	-6.898	-47.785	-7.400
		113	-6.914	-47.818	-7.493
		113	-6.912	-47.584	-7.711
		113	-6.910	-47.372	-7.906

		113	-6.892	-47.404	-7.730
10-18-15 14:10	10-18-15 16:10	114	-12.980	-80.215	-23.627
		114	-12.984	-80.324	-23.552
		114	-13.036	-80.633	-23.655
10-19-15 14:45	10-19-15 16:15	115	-10.140	-61.238	-19.885
		115	-10.187	-61.395	-20.098
		115	-10.158	-61.144	-20.122
10-19-15 17:00	10-19-15 20:15	116	-11.705	-70.447	-23.194
		116	-11.720	-70.564	-23.194
		116	-11.710	-70.739	-22.943
		116	-11.649	-70.743	-22.451
		116	-11.730	-70.745	-23.097
		116	-11.673	-70.634	-22.754
10-27-15 21:05	10-28-15 0:15	sample rejected			
10-29-15 13:20	10-29-15 15:15	118	-14.380	-100.788	-14.249
		118	-14.411	-101.050	-14.240
		118	-14.421	-100.859	-14.507
10-29-15 15:20	10-29-15 18:05	119	-9.864	-67.888	-11.021
		119	-9.872	-68.203	-10.773
		119	-9.860	-67.921	-10.962
10-29-15 18:25	10-29-15 21:30	120	-7.319	-46.595	-11.958
		120	-7.342	-46.730	-12.009
		120	-7.330	-46.655	-11.983
11-2-15 8:25	11-2-15 10:30	121	-20.635	-150.388	-14.693
		121	-20.651	-150.599	-14.609
		121	-20.652	-150.995	-14.222
11-2-15 10:45	11-2-15 15:45	122	-18.050	-134.271	-10.125
		122	-18.071	-133.983	-10.582
		122	-18.053	-134.257	-10.165
11-4-15 20:40	11-4-15 23:00	123	-16.999	-122.987	-13.005
		123	-17.014	-122.865	-13.245
		123	-17.014	-122.869	-13.241
11-6-15 10:20	11-6-15 15:30	124	-13.409	-91.228	-16.044
		124	-13.444	-91.414	-16.137
		124	-13.434	-91.165	-16.311
11-9-15 15:25	11-9-15 19:30	125	-14.459	-99.391	-16.279
		125	-14.461	-99.476	-16.211
		125	-14.535	-99.539	-16.738
11-14-15 12:45	11-14-15 16:00	126	-14.822	-105.734	-12.839
		126	-14.899	-106.149	-13.040
		126	-14.824	-105.990	-12.600
11-15-15 10:15	11-15-15 12:20	127	-29.133	-214.665	-18.402
		127	-29.126	-215.061	-17.948
		127	-29.187	-215.570	-17.928
11-22-15 15:30	11-22-15 19:45	128	-5.858	-39.874	-6.991
		128	-5.805	-39.486	-6.957
		128	-5.857	-39.324	-7.532

11-22-15 20:00	11-22-15 23:30	129	-6.556	-39.782	-12.669
		129	-6.577	-39.708	-12.904
		129	-6.542	-39.550	-12.784
11-24-15 14:55	11-24-15 16:45	130	-13.324	-84.959	-21.631
		130	-13.348	-85.103	-21.681
		130	-13.362	-85.009	-21.884
11-29-15 19:15	11-29-15 22:35	131	-17.609	-111.172	-29.698
		131	-17.613	-111.181	-29.722
		131	-17.587	-111.045	-29.647
12-12-15 8:50	12-12-15 13:35	132	-16.968	-123.210	-12.536
		132	-17.042	-123.384	-12.954
		132	-17.021	-123.562	-12.607
12-17-15 23:00	12-18-15 13:30	133	-18.967	-137.075	-14.664
		133	-18.982	-137.220	-14.637
		133	-19.006	-137.306	-14.746
12-19-15 14:30	12-19-15 18:30	134	-19.356	-139.276	-15.569
		134	-19.379	-139.416	-15.615
		134	-19.340	-139.377	-15.341

Table A2: Water isotope data from Bay D'Espoir, NL 1997-2010

Bay d'Espoir, NL		CAPMoN	
February 1997 - November 2010			
Lat	Long		
47.98 N	55.82 W		
Date	$\delta^{18}O$	$\delta^{2}H$	d-excess
mmm-yy	‰VSMOW	‰VSMOW	‰
Feb-97	-10.5	-80.5	3.7
Mar-97	-8.6	-67.0	1.9
Apr-97	-10.9	-93.4	-6.3
May-97	-7.6	-53.3	7.1
Jun-97	-5.8	-41.4	5.3
Jul-97	-7.2	-56.4	0.8
Aug-97	-6.7	-54.4	-1.2
Sep-97	-5.8	-39.0	7.4
Oct-97	-7.9	-59.5	3.4
Nov-97	-7.4	-50.5	8.9
Dec-97	-12.2	-91.3	6.6
Jan-98	-3.7	-37.1	-7.6
Feb-98	-7.4	-44.4	15.0
Mar-98	-10.7	-78.0	7.3
May-98	-2.1	-26.4	-9.5
Jun-98	-4.9	-42.5	-3.1
Jul-98	-2.1	-28.7	-11.9
Aug-98	-5.5	-32.4	11.7
Sep-98	-8.7	-65.0	4.9
Oct-98	-8.5	-55.5	12.3
Nov-98	-10.4	-68.1	14.9
Jan-99	-10.6	-69.9	14.9
Feb-99	-7.5	-47.3	12.7
Mar-99	-7.8	-49.6	13.1
Apr-99	-10.4	-74.9	7.9
May-99	-7.5	-52.4	7.2
Jun-99	-8.4	-56.0	11.1
Jul-99	-10.1	-69.7	11.5
Aug-99	-6.7	-38.3	15.5
Sep-99	-8.3	-51.9	14.4
Oct-99	-10.0	-63.3	16.6
Nov-99	-6.9	-41.5	13.8
Dec-99	-10.6	-66.8	17.9
Jan-00	-11.3	-77.9	12.8
Feb-00	-10.6	-68.7	15.8
Mar-00	-9.5	-65.4	10.6
Apr-00	-11.4	-83.9	7.0
May-00	-9.1	-60.4	12.6
Jul-00	-5.7	-37.2	8.0
Aug-00	-6.4	-39.2	12.4

Sep-00	-7.3	-48.4	10.1
Oct-00	-7.8	-54.9	7.1
Nov-00	-11.4	-81.1	10.4
Dec-00	-9.1	-58.2	14.4
Jan-01	-18.4	-151.9	-5.0
Feb-01	-14.6	-104.7	11.8
Mar-01	-12.4	-86.1	13.0
Apr-01	-5.6	-32.0	12.9
May-01	-6.1	-40.9	7.6
Jun-01	-7.9	-55.0	8.1
Jul-01	-7.5	-50.4	9.8
Aug-01	-7.0	-45.2	10.9
Sep-01	-7.3	-46.8	11.7
Oct-01	-6.4	-41.6	9.4
Nov-01	-7.1	-42.9	14.0
Dec-01	-10.6	-72.1	12.9
Jan-02	-15.8	-111.1	15.4
Feb-02	-10.1	-60.7	20.4
Mar-02	-8.4	-53.3	14.2
Apr-02	-11.5	-77.9	13.9
May-02	-7.8	-50.4	12.1
Jun-02	-7.5	-50.7	9.2
Jul-02	-7.1	-48.0	8.9
Aug-02	-4.9	-27.5	11.8
Sep-02	-7.7	-50.5	10.9
Oct-02	-11.2	-76.5	13.2
Nov-02	-12.6	-91.2	9.5
Dec-02	-16.0	-113.7	14.2
Jan-03	-13.6	-93.1	15.5
Feb-03	-11.6	-81.2	11.8
Mar-03	-13.6	-89.4	19.1
Apr-03	-9.3	-59.3	15.3
May-03	-9.3	-76.8	-2.6
Jun-03	-7.2	-49.9	7.7
Jul-03	-6.8	-46.2	8.5
Aug-03	-5.8	-34.6	11.7
Sep-03	-9.3	-61.0	13.1
Oct-03	-7.6	-44.9	15.7
Nov-03	-9.3	-61.1	13.1
Dec-03	-13.6	-94.9	13.7
Jan-04	-16.6	-121.3	11.4
Feb-04	-14.3	-103.8	10.7
Mar-04	-12.3	-90.7	7.8
Apr-04	-8.0	-56.8	7.1
May-04	-12.0	-90.4	5.3
Jun-04	-9.0	-57.1	14.6
Jul-04	-5.7	-36.9	8.9

Aug-04	-6.0	-36.3	11.9
Sep-04	-8.2	-51.4	14.3
Oct-04	-5.9	-38.5	8.8
Nov-04	-8.6	-56.4	12.6
Dec-04	-11.1	-76.5	12.6
Jan-05	-12.6	-88.3	12.5
Feb-05	-10.7	-75.9	9.4
Mar-05	-14.4	-108.7	6.6
Apr-05	-9.6	-68.5	7.9
May-05	-8.0	-60.0	4.1
Jun-05	-7.1	-49.7	7.1
Jul-05	-6.6	-43.6	9.3
Aug-05	-6.4	-43.6	7.9
Sep-05	-6.7	-38.5	15.2
Oct-05	-11.4	-82.3	8.9
Nov-05	-6.8	-40.0	14.7
Dec-05	-11.2	-73.2	16.1
Jan-06	-7.9	-51.7	11.1
Feb-06	-13.1	-92.0	12.7
Mar-06	-14.4	-104.5	10.6
Apr-06	-7.9	-50.9	12.0
May-06	-10.3	-71.8	10.3
Jun-06	-7.3	-48.6	10.2
Jul-06	-6.5	-43.1	8.7
Aug-06	-8.4	-51.1	15.7
Sep-06	-7.5	-49.3	10.4
Oct-06	-8.7	-55.8	13.6
Nov-06	-8.8	-56.3	14.1
Dec-06	-15.6	-109.5	14.9
Jan-07	-12.5	-88.6	11.1
Feb-07	-12.4	-88.6	10.8
Mar-07	-17.0	-121.1	14.7
Apr-07	-7.7	-40.1	21.2
May-07	-8.8	-56.9	13.6
Jun-07	-7.0	-41.5	14.5
Jul-07	-7.2	-47.3	10.2
Aug-07	-6.9	-47.9	7.6
Sep-07	-7.4	-47.9	11.2
Oct-07	-4.8	-27.2	11.0
Nov-07	-8.8	-55.9	14.3
Dec-07	-10.0	-64.3	15.7
Jan-08	-13.4	-88.3	18.7
Feb-08	-11.4	-71.5	20.1
Mar-08	-10.6	-72.1	12.3
Apr-08	-10.5	-68.3	15.6
May-08	-8.5	-60.9	7.3
Jun-08	-8.8	-58.7	11.8

Jul-08	-7.0	-47.0	8.8
Aug-08	-5.6	-34.8	10.2
Sep-08	-8.1	-53.8	10.8
Oct-08	-7.4	-46.6	12.3
Nov-08	-7.6	-46.5	14.6
Dec-08	-6.2	-37.7	12.2
Jan-09	-8.3	-51.5	14.6
Feb-09	-11.5	-76.6	15.2
Mar-09	-11.0	-79.7	7.9
Apr-09	-8.5	-60.4	7.2
May-09	-5.5	-30.3	13.6
Jun-09	-9.1	-61.6	11.5
Jul-09	-6.8	-46.2	8.5
Aug-09	-7.3	-47.3	10.9
Sep-09	-9.8	-67.2	11.2
Oct-09	-10.3	-69.1	13.6
Nov-09	-7.2	-46.2	11.0
Dec-09	-14.1	-93.7	18.9
Jan-10	-18.5	-132.6	15.3
Feb-10	-16.8	-128.4	5.8
Mar-10	-10.6	-74.9	9.6
Apr-10	-10.3	-65.3	17.0
May-10	-11.2	-79.7	10.2
Jun-10	-9.7	-66.3	11.3
Jul-10	-7.7	-49.4	11.9
Aug-10	-4.3	-26.5	7.9
Sep-10	-10.3	-72.1	10.1
Oct-10	-7.4	-47.7	11.5
Nov-10	-5.8	-35.8	10.6

Table A3: Water isotope data from Truro, NS 1975-1983

Truro, NS		CNIP	
January 1975-December 1983			
Lat	Long		
45.37 N	63.27 W		
Date	$\delta^{18}O$	$\delta^{2}H$	d-excess
mmm-yy	‰VSMOW	‰VSMOW	‰
Aug-75	-6.7	-45.0	8.6
Sep-75	-5.2	-30.0	11.6
Oct-75	-8.9	-58.0	13.2
Nov-75	-6.0	-36.0	12.0
Dec-75	-10.3	-65.0	17.4
Jan-76	-10.0	-63.0	17.0
Feb-76	-10.0	-67.0	13.0
Apr-76	-7.2	-45.0	12.6
May-76	-6.8	-47.0	7.4
Jun-76	-9.2	-63.0	10.6
Jul-76	-5.2	-38.0	3.6
Aug-76	-5.3	-38.0	4.4
Sep-76	-7.1	-47.0	9.8
Oct-76	-11.0	-78.0	10.0
Nov-76	-12.0	-81.0	15.0
Dec-76	-11.9	-74.0	21.2
Jan-77	-12.8	-89.0	13.4
Feb-77	-12.3	-89.0	9.4
Mar-77	-12.0	-88.0	8.0
Apr-77	-6.9	-45.0	10.2
May-77	-8.7	-52.0	17.6
Jun-77	-7.6	-55.0	5.8
Jul-77	-5.9	-43.0	4.2
Aug-77	-6.1	-40.0	8.8
Sep-77	-8.4	-63.0	4.2
Oct-77	-6.4	-43.0	8.2
Nov-77	-9.1	-56.0	16.8
Dec-77	-11.9	-83.0	12.2
Jan-78	-8.8	-55.0	15.4
Feb-78	-20.4	-150.0	13.2
Mar-78	-12.8	-90.0	12.4
Apr-78	-9.9	-66.0	13.2
May-78	-6.8	-42.0	12.4
Jun-78	-5.1	-32.0	8.8
Jul-78	-8.9	-55.0	16.2
Aug-78	-6.2	-33.0	16.6
Sep-78	-8.2	-48.0	17.8
Oct-78	-8.3	-52.0	14.0
Nov-78	-12.0	-80.0	15.6
Dec-78	-13.2	-96.0	9.8

Jan-79	-11.5	-84.0	8.0
Feb-79	-11.0	-88.0	0.0
Mar-79	-10.0	-59.0	20.8
Apr-79	-9.1	-79.7	-6.7
May-79	-5.5	-33.0	11.2
Jun-79	-7.2	-51.0	6.6
Jul-79	-8.9	-64.0	7.2
Aug-79	-5.8	-39.0	7.4
Sep-79	-7.8	-48.0	14.4
Oct-79	-8.3	-44.0	22.4
Nov-79	-9.3	-65.0	9.4
Dec-79	-12.3	-83.0	15.4
Feb-80	-18.8	-128.0	22.4
Mar-80	-11.2	-83.0	6.6
Apr-80	-8.6	-62.0	6.8
May-80	-6.7	-50.0	3.6
Jun-80	-6.6	-47.0	5.8
Jul-80	-7.2	-44.0	13.6
Aug-80	-6.7	-51.0	2.6
Oct-80	-7.9	-59.0	4.2
Nov-80	-11.8	-89.0	5.4
Dec-80	-13.8	-84.0	26.4
Jan-81	-18.9	-131.0	20.2
Feb-81	-7.2	-46.0	11.6
Mar-81	-12.4	-87.0	12.2
Apr-81	-8.2	-63.0	2.6
May-81	-9.6	-75.0	1.8
Jun-81	-7.4	-50.0	9.2
Jul-81	-7.1	-49.0	7.8
Nov-81	-6.4	-52.0	-0.8
Dec-81	-11.0	-81.0	7.0
Jan-82	-13.7	-94.0	15.6
Feb-82	-12.3	-86.0	12.4
Mar-82	-14.1	-96.0	16.8
Apr-82	-8.5	-56.0	12.0
May-82	-6.7	-44.0	9.6
Jun-82	-9.3	-61.0	13.4
Jul-82	-6.6	-41.0	11.8
Dec-82	-15.8	-108.0	18.4
Jan-83	-10.6	-76.0	8.8
Feb-83	-15.7	-111.0	14.6
Mar-83	-9.3	-72.0	2.4
Apr-83	-5.9	-47.0	0.2
May-83	-6.0	-49.0	-1.0
Jun-83	-6.4	-49.0	2.2
Jul-83	-7.0	-62.0	-6.0
Aug-83	-9.0	-76.0	-4.0

Sep-83	-7.7	-54.0	7.6
Oct-83	-7.7	-46.0	15.6
Nov-83	-8.3	-61.0	5.4
Dec-83	-8.6	-68.0	0.8

Table A4: Water isotope data from Goose Bay, NL 1961-1969 and 1997-2010

Goose Bay, NL		**GNIP**	
May 1961 - June 1969			
		CAPMoN	
March 1997 - November 2010			
Lat	**Long**		
53.32 N	60.42 W		
Date	**δ^{18}O**	**δ^{2}H**	**d-excess**
mmm-yy	‰VSMOW	‰VSMOW	‰
May-61	-12.2	-84.9	12.7
Jun-61	-12.4	-84.9	14.3
Jul-61	-14.6	-109.0	7.8
Aug-61	-12.9	-92.9	10.3
Sep-61	-10.0	-67.0	13.0
Oct-61	-14.0	-100.3	11.7
Nov-61	-17.8	-126.1	16.3
Dec-61	-13.7	-89.2	20.4
Jan-62	-27.9	-208.7	14.5
Feb-62	-17.3	-127.4	11.0
Mar-62	-14.9	-117.5	1.7
Apr-62	-18.3	-123.0	23.4
May-62	-12.5	-90.4	9.6
Jun-62	-12.3	-90.4	8.0
Jul-62	-12.4	-89.8	9.4
Aug-62	-11.0	-75.0	13.0
Sep-62	-13.8	-95.9	14.5
Oct-62	-15.6	-110.8	14.0
Nov-62	-16.7	-121.2	12.4
Dec-62	-18.8	-136.6	13.8
Jan-63	-20.7	-146.5	19.1
Feb-63	-22.0	-158.2	17.8
Mar-63	-17.6	-132.9	7.9
Apr-63	-16.0	-123.6	4.4
May-63	-11.9	-88.5	6.7
Jun-63	-14.8	-108.3	10.1
Jul-63	-12.5	-98.4	1.6
Aug-63	-14.0	-98.4	13.6
Sep-63	-17.7	-126.7	14.9
Oct-63	-13.9	-94.7	16.5
Nov-63	-16.0	-105.8	22.2
Dec-63	-20.4	-144.7	18.5
Jan-64	-18.2	-131.1	14.5
Feb-64	-24.5	-175.5	20.5
Mar-64	-15.8	-114.5	11.9
apr674	-19.2	-140.9	12.7
May-64	-14.4	-101.6	13.6
Jun-64	-13.7	-99.0	10.6

Jul-64	-12.2	-87.9	9.7
Aug-64	-9.7	-71.9	5.7
Sep-64	-12.0	-87.9	8.1
Oct-64	-13.2	-97.8	7.8
Nov-64	-14.0	-101.6	10.4
Dec-64	-14.0	-109.0	3.0
Jan-65	-19.7	-145.9	11.7
Mar-65	-20.3	-155.1	7.3
Apr-65	-15.7		
May-65	-11.7	-93.5	0.1
Jun-65	-11.2	-75.8	13.8
Jul-65	-11.5	-81.8	10.2
Aug-65	-11.5	-73.8	18.2
Sep-65	-14.0	-87.7	24.3
Oct-65	-16.4	-100.3	30.9
Nov-65	-14.6	-106.9	9.9
Dec-65	-20.3	-130.6	31.8
Jan-66	-16.9		
Feb-66	-24.3		
Aug-66		-96.0	
Sep-66		-99.0	
Oct-66		-144.0	
Nov-66		-134.0	
Dec-66		-126.0	
Jan-67		-146.0	
Feb-67		-180.0	
Mar-67		-164.0	
Apr-67		-119.0	
May-67		-95.0	
Jul-67		-84.0	
Aug-67		-119.0	
Sep-67		-90.0	
Oct-67		-86.0	
Nov-67		-110.0	
Dec-67		-149.0	
Jan-68		-139.0	
Feb-68		-115.0	
Mar-68		-140.0	
Apr-68		-114.0	
May-68		-91.0	
Jun-68		-122.0	
Sep-68		-86.0	
Oct-68		-77.0	
Nov-68		-109.0	
Dec-68		-98.0	
Jan-69		-133.0	
Feb-69		-126.0	

Mar-69		-112.0	
May-69		-119.0	
Jun-69		-90.0	
Mar-97	-18.8	-150.5	0.0
Apr-97	-9.9	-83.9	-4.5
May-97	-11.0	-84.2	4.0
Jun-97	-10.0	-81.6	-1.8
Jul-97	-10.7	-79.5	5.8
Aug-97	-13.7	-103.7	6.1
Sep-97	-11.3	-86.3	4.3
Oct-97	-11.6	-82.0	10.7
Nov-97	-16.8	-127.8	6.7
Dec-97	-13.5	-105.0	3.2
Jan-98	-20.2	-161.4	0.5
Feb-98	-13.2	-98.2	7.3
Mar-98	-14.8	-112.0	6.6
Apr-98	-11.5	-94.8	-3.1
May-98	-8.0	-76.1	-12.1
Jun-98	-7.7	-73.7	-11.9
Jul-98	-10.2	-74.2	7.8
Aug-98	-12.4	-97.8	1.3
Sep-98	-13.3	-100.0	6.2
Oct-98	-13.0	-99.5	4.2
Nov-98	-16.6	-124.0	8.9
Dec-98	-21.3	-159.1	11.2
Jan-99	-17.0	-123.4	12.8
Feb-99	-15.8	-113.5	12.7
Mar-99	-15.0	-111.9	8.4
Apr-99	-11.6	-85.4	7.2
May-99	-8.9	-70.1	1.2
Jun-99	-8.6	-57.4	11.5
Jul-99	-13.3	-94.6	11.8
Aug-99	-14.5	-101.9	14.2
Sep-99	-13.1	-92.5	12.1
Oct-99	-19.7	-147.2	10.3
Nov-99	-14.3	-105.7	8.5
Dec-99	-21.1	-155.6	12.9
Jan-00	-18.7	-138.7	11.1
Feb-00	-20.8	-155.4	11.2
Mar-00	-13.3	-91.1	14.9
Apr-00	-17.5	-130.4	9.5
May-00	-13.7	-102.6	6.8
Jun-00	-12.5	-92.2	7.7
Jul-00	-10.4	-72.0	11.3
Aug-00	-11.9	-87.2	8.3
Sep-00	-12.4	-92.2	7.2
Oct-00	-14.8	-104.1	14.1

Nov-00	-9.3	-65.2	9.3
Dec-00	-14.9	-114.5	5.0
Jan-01	-31.5	-247.9	4.4
Feb-01	-20.5	-153.0	10.9
Apr-01	-14.1	-102.1	10.9
May-01	-11.0	-83.3	4.8
Jun-01	-12.0	-87.5	8.4
Jul-01	-10.4	-73.6	10.0
Aug-01	-11.5	-84.9	7.1
Sep-01	-12.1	-86.2	11.0
Oct-01	-11.7	-84.1	9.4
Nov-01	-18.8	-137.9	12.4
Dec-01	-18.4	-137.8	9.0
Jan-02	-29.3	-225.7	8.9
Feb-02	-19.7	-139.3	18.4
Mar-02	-19.9	-140.9	18.5
Apr-02	-17.7	-126.3	15.2
May-02	-14.3	-105.6	8.9
Jun-02	-14.2	-108.0	5.8
Jul-02	-12.1	-88.8	8.1
Aug-02	-12.7	-90.7	10.5
Sep-02	-11.3	-77.0	13.5
Oct-02	-17.9	-129.7	13.2
Nov-02	-17.1	-125.5	11.2
Dec-02	-23.4	-175.4	12.0
Jan-03	-19.3	-141.5	12.5
Feb-03	-22.5	-166.1	14.0
Mar-03	-20.1	-149.0	11.9
Apr-03	-16.5	-122.4	10.0
May-03	-12.5	-97.1	2.5
Jun-03	-11.7	-86.8	7.1
Jul-03	-13.6	-100.0	8.4
Aug-03	-11.8	-85.2	9.5
Sep-03	-9.8	-70.3	8.3
Oct-03	-14.2	-100.9	13.0
Nov-03	-14.2	-98.3	15.3
Dec-03	-18.5	-134.5	13.1
Jan-04	-15.5	-115.3	8.9
Feb-04	-19.0	-141.6	10.6
Mar-04	-18.9	-139.8	11.0
Apr-04	-15.4	-116.0	6.9
May-04	-11.9	-89.4	5.5
Jun-04	-12.3	-97.3	1.1
Jul-04	-10.4	-78.5	5.0
Aug-04	-13.4	-98.1	9.2
Sep-04	-12.0	-88.9	6.8
Oct-04	-12.3	-84.4	13.7

Nov-04	-18.0	-132.4	11.7
Dec-04	-21.7	-163.8	9.7
Jan-05	-22.4	-168.1	11.0
Feb-05	-21.5	-164.0	8.2
Mar-05	-18.3	-142.1	4.0
Apr-05	-12.3	-94.2	4.0
May-05	-13.8	-100.8	9.9
Jun-05	-10.2	-73.0	8.3
Jul-05	-13.9	-101.2	10.3
Aug-05	-12.4	-89.8	9.1
Sep-05	-14.1	-102.4	10.4
Oct-05	-11.9	-86.1	8.8
Nov-05	-13.3	-93.8	12.3
Dec-05	-19.1	-143.7	9.3
Jan-06	-17.4	-129.4	10.2
Feb-06	-20.3	-150.8	11.3
Mar-06	-14.5	-107.5	8.7
Apr-06	-14.6	-102.4	14.4
May-06	-13.1	-97.5	7.1
Jun-06	-10.9	-78.8	8.2
Jul-06	-12.0	-92.0	3.8
Aug-06	-14.0	-106.8	5.6
Sep-06	-12.4	-91.6	7.3
Oct-06	-11.3	-80.6	10.1
Nov-06	-13.6	-101.2	7.2
Dec-06	-22.4	-168.4	10.9
Jan-07	-23.1	-170.7	13.9
Feb-07	-20.5	-154.3	10.0
Mar-07	-19.3	-139.0	15.7
Apr-07	-14.6	-105.8	10.6
May-07	-14.3	-104.4	9.8
Jun-07	-8.8	-75.6	-5.5
Jul-07	-12.8	-98.4	4.1
Aug-07	-12.6	-97.3	3.9
Sep-07	-13.8	-99.1	11.0
Oct-07	-13.9	-101.5	9.7
Nov-07	-15.8	-113.1	13.5
Dec-07	-18.9	-139.4	12.2
Jan-08	-17.9	-126.6	16.2
Feb-08	-21.6	-162.5	10.0
Mar-08	-20.1	-148.5	12.3
Apr-08	-15.2	-109.5	11.7
May-08	-14.2	-107.8	5.6
Jun-08	-11.8	-85.6	8.6
Sep-08	-16.4	-109.5	21.8
Oct-08	-9.9	-68.6	10.4
Nov-08	-15.1	-101.4	19.1

Dec-08	-18.8	-134.6	15.7
Jan-09	-22.3	-165.3	13.3
Feb-09	-18.4	-124.2	23.3
Mar-09	-17.9	-135.7	7.2
Apr-09	-15.3	-110.0	12.5
May-09	-10.9	-81.5	5.5
Jun-09	-11.2	-85.7	4.2
Jul-09	-12.3	-89.6	8.5
Aug-09	-12.5	-88.3	11.3
Sep-09	-14.1	-98.2	14.7
Oct-09	-16.2	-114.8	14.9
Nov-09	-20.0	-146.5	13.3
Dec-09	-16.8	-122.5	12.3
Jan-10	-20.7	-153.8	11.9
Feb-10	-14.8	-106.8	11.5
Mar-10	-20.1	-147.9	12.5
Apr-10	-12.3	-84.0	14.4
May-10	-14.4	-101.6	13.4
Jun-10	-12.9	-97.2	6.1
Jul-10	-11.4	-84.8	6.7
Aug-10	-11.0	-78.6	9.1
Sep-10	-12.0	-88.7	7.3
Oct-10	-13.4	-101.8	5.7
Nov-10	-12.9	-96.6	6.4

Appendix 5: Daily and Monthly Average Temperature Measurements for Corner Brook, NL 2015

Table A5.1: 2015 Monthly temperature data from weather station at Grenfell Campus, NL

Month	Temperature (°C)		
	Average	Maximum	Minimum
January	-7.0	8.4	-19.2
February	-9.4	8.8	-23.0
March	-6.5	5.4	-17.3
April	-0.3	12.8	-12.9
May	7.7	22.2	-2.7
June	11.6	22.8	-0.3
July	14.7	27.7	5.6
August	18.8	28.1	7.8
September	13.4	25.2	2.3
October	6.7	20.2	-1.6
November	1.2	16.3	-11.0
December	-2.2	10.0	-16.2

Table A5.2: 2015 Daily temperature data from weather station at Grenfell Campus, NL

Date	Average Temperature (°C)
01-Jan	-9.7
02-Jan	-5.1
03-Jan	-12.0
04-Jan	-10.6
05-Jan	-5.5
06-Jan	-9.0
07-Jan	-12.2
08-Jan	-15.0
09-Jan	-7.0
10-Jan	-6.7
11-Jan	-10.9
12-Jan	-6.7
13-Jan	-10.2
14-Jan	-7.8
15-Jan	-7.6
16-Jan	-7.8
17-Jan	-7.0
18-Jan	-8.6
19-Jan	1.8
20-Jan	-0.3
21-Jan	-5.5
22-Jan	-5.6
23-Jan	-7.0
24-Jan	-5.0
25-Jan	1.3
26-Jan	-8.6
27-Jan	-12.2
28-Jan	-3.7
29-Jan	-4.3
30-Jan	-6.1
31-Jan	-2.2
01-Feb	-0.2
02-Feb	-12.1
03-Feb	-8.2
04-Feb	-12.3
05-Feb	-5.2
06-Feb	-7.1
07-Feb	-11.9
08-Feb	-14.0
09-Feb	-16.8
10-Feb	-15.8
11-Feb	-12.7
12-Feb	-15.6

13-Feb	-11.0
14-Feb	-9.7
15-Feb	-10.7
16-Feb	-6.0
17-Feb	-8.3
18-Feb	-9.7
19-Feb	-8.3
20-Feb	-3.0
21-Feb	-8.4
22-Feb	-3.5
23-Feb	-5.5
24-Feb	-11.6
25-Feb	-9.3
26-Feb	-5.7
27-Feb	-10.3
28-Feb	-11.2
01-Mar	-7.5
02-Mar	-6.2
03-Mar	-9.6
04-Mar	-9.6
05-Mar	-7.9
06-Mar	-14.7
07-Mar	-9.9
08-Mar	-7.9
09-Mar	-11.5
10-Mar	-10.5
11-Mar	-3.8
12-Mar	-11.1
13-Mar	-15.5
14-Mar	-12.2
15-Mar	-8.8
16-Mar	-8.7
17-Mar	-3.2
18-Mar	-1.8
19-Mar	-2.3
20-Mar	-5.7
21-Mar	-3.8
22-Mar	-1.1
23-Mar	-9.1
24-Mar	-5.2
25-Mar	-6.7
26-Mar	-2.1
27-Mar	2.7
28-Mar	-2.0
29-Mar	-3.6
30-Mar	-1.5
31-Mar	-1.4

01-Apr	-1.9
02-Apr	-5.8
03-Apr	-2.3
04-Apr	1.8
05-Apr	-3.6
06-Apr	-7.2
07-Apr	-3.9
08-Apr	-7.3
09-Apr	-6.5
10-Apr	-5.1
11-Apr	3.7
12-Apr	-1.3
13-Apr	0.0
14-Apr	6.1
15-Apr	0.4
16-Apr	-4.9
17-Apr	0.4
18-Apr	-0.3
19-Apr	-2.2
20-Apr	-0.7
21-Apr	2.3
22-Apr	3.1
23-Apr	3.5
24-Apr	4.6
25-Apr	2.5
26-Apr	2.9
27-Apr	4.3
28-Apr	2.7
29-Apr	3.0
30-Apr	2.1
01-May	2.9
02-May	4.4
03-May	4.5
04-May	6.1
05-May	8.4
06-May	3.9
07-May	1.7
08-May	3.3
09-May	2.9
10-May	5.8
11-May	3.9
12-May	2.8
13-May	1.7
14-May	4.2
15-May	9.7
16-May	11.7
17-May	11.1

18-May	10.5
19-May	11.3
20-May	11.4
21-May	6.8
22-May	8.7
23-May	4.9
24-May	6.9
25-May	11.9
26-May	14.1
27-May	12.6
28-May	14.9
29-May	9.9
30-May	13.9
31-May	12.8
01-Jun	6.0
02-Jun	7.3
03-Jun	10.9
04-Jun	11.1
05-Jun	12.3
06-Jun	10.4
07-Jun	8.6
08-Jun	9.9
09-Jun	11.3
10-Jun	16.5
11-Jun	16.7
12-Jun	15.0
13-Jun	11.1
14-Jun	6.6
15-Jun	8.6
16-Jun	12.0
17-Jun	10.6
18-Jun	15.1
19-Jun	13.5
20-Jun	11.7
21-Jun	13.5
22-Jun	14.7
23-Jun	14.6
24-Jun	10.8
25-Jun	8.6
26-Jun	8.9
27-Jun	11.1
28-Jun	15.6
29-Jun	13.3
30-Jun	13.6
01-Jul	16.7
02-Jul	18.2
03-Jul	18.5

04-Jul	15.1
05-Jul	15.1
06-Jul	13.0
07-Jul	14.8
08-Jul	17.5
09-Jul	15.8
10-Jul	16.2
11-Jul	13.2
12-Jul	12.8
13-Jul	15.3
14-Jul	16.6
15-Jul	19.2
16-Jul	15.8
17-Jul	14.3
18-Jul	12.3
19-Jul	10.9
20-Jul	11.6
21-Jul	12.1
22-Jul	13.9
23-Jul	11.1
24-Jul	11.3
25-Jul	11.7
26-Jul	11.7
27-Jul	13.9
28-Jul	18.0
29-Jul	16.7
30-Jul	15.1
31-Jul	17.3
01-Aug	18.7
02-Aug	19.1
03-Aug	20.4
04-Aug	21.2
05-Aug	21.3
06-Aug	17.5
07-Aug	14.1
08-Aug	15.0
09-Aug	16.6
10-Aug	12.0
11-Aug	18.2
12-Aug	16.3
13-Aug	18.8
14-Aug	20.9
15-Aug	19.6
16-Aug	20.4
17-Aug	21.5
18-Aug	22.4
19-Aug	18.2

20-Aug	20.2
21-Aug	22.0
22-Aug	22.5
23-Aug	21.3
24-Aug	19.6
25-Aug	18.3
26-Aug	18.3
27-Aug	17.3
28-Aug	17.3
29-Aug	18.1
30-Aug	17.1
31-Aug	19.2
01-Sep	13.9
02-Sep	11.4
03-Sep	15.2
04-Sep	11.5
05-Sep	13.3
06-Sep	11.8
07-Sep	15.2
08-Sep	10.5
09-Sep	11.9
10-Sep	17.9
11-Sep	15.2
12-Sep	13.3
13-Sep	13.5
14-Sep	12.9
15-Sep	14.9
16-Sep	13.0
17-Sep	13.6
18-Sep	12.8
19-Sep	17.6
20-Sep	19.6
21-Sep	12.4
22-Sep	11.5
23-Sep	13.8
24-Sep	12.6
25-Sep	8.2
26-Sep	5.4
27-Sep	9.5
28-Sep	16.0
29-Sep	17.2
30-Sep	16.9
01-Oct	13.4
02-Oct	6.5
03-Oct	5.3
04-Oct	6.3
05-Oct	9.0

06-Oct	11.0
07-Oct	9.2
08-Oct	9.6
09-Oct	6.9
10-Oct	6.6
11-Oct	3.6
12-Oct	7.7
13-Oct	13.1
14-Oct	17.0
15-Oct	10.0
16-Oct	7.8
17-Oct	6.7
18-Oct	3.8
19-Oct	2.7
20-Oct	3.6
21-Oct	4.5
22-Oct	4.7
23-Oct	6.8
24-Oct	1.4
25-Oct	5.7
26-Oct	6.0
27-Oct	1.4
28-Oct	0.9
29-Oct	3.4
30-Oct	9.2
31-Oct	2.9
01-Nov	3.8
02-Nov	3.0
03-Nov	0.6
04-Nov	1.4
05-Nov	-0.2
06-Nov	1.5
07-Nov	7.5
08-Nov	1.6
09-Nov	0.3
10-Nov	3.2
11-Nov	-1.5
12-Nov	-1.4
13-Nov	0.9
14-Nov	3.2
15-Nov	1.4
16-Nov	0.4
17-Nov	-0.4
18-Nov	-1.1
19-Nov	-1.9
20-Nov	-2.4
21-Nov	0.1

22-Nov	5.8
23-Nov	13.8
24-Nov	4.0
25-Nov	-2.7
26-Nov	-0.1
27-Nov	7.3
28-Nov	0.3
29-Nov	-4.3
30-Nov	-8.1
01-Dec	-2.6
02-Dec	2.3
03-Dec	0.1
04-Dec	-6.6
05-Dec	-3.0
06-Dec	0.4
07-Dec	2.9
08-Dec	1.2
09-Dec	-0.7
10-Dec	-0.7
11-Dec	3.9
12-Dec	7.0
13-Dec	1.4
14-Dec	-2.6
15-Dec	-2.4
16-Dec	-2.8
17-Dec	-4.2
18-Dec	-1.1
19-Dec	0.6
20-Dec	-2.6
21-Dec	-3.9
22-Dec	-8.9
23-Dec	-6.9
24-Dec	-2.4
25-Dec	4.8
26-Dec	-1.1
27-Dec	-6.1
28-Dec	-9.3
29-Dec	-10.4
30-Dec	-10.7
31-Dec	-4.3