Isotopic Records of Past Hydroclimatic Change in the Red River Basin, Southern Manitoba, Canada

William M. Buhay[1], Danny Blair[1], Erik Nielsen[2], Scott St. George[3] and Greg Brooks[4]

[1]Department of Geography, University of Winnipeg, Winnipeg MB, Canada, R3B 2E9; b.buhay@uwinnipeg.ca; d.blair@uwinnipeg.ca
[2]Manitoba Geological Survey, 360-1395 Ellice Avenue, Winnipeg MB, Canada, R3G 3P2; Enielsen@gov.mb.ca
[3]Geological Survey of Canada, 360-1395 Ellice Avenue, Winnipeg MB, Canada, R3G 3P2; sstgeorg@NRCan.gc.ca
[4]Geological Survey of Canada, 601 Booth St., Ottawa ON, Canada, K1A 0E8; gbrooks@NRCan.gc.ca

Experience during the 20th century has shown that southern Manitoba is prone to intense hydrological changes, including multi-year droughts and extreme flooding. Models project some portions of the Canadian prairies to experience a 40 percent decrease in average soil moisture by the second half of the 21st century, with an attendant increase in the frequency and magnitude of future prairie droughts. A shift to more arid conditions would have considerable socio-economic impacts and lead to lower crop yields, increased demand for groundwater and reduced hydroelectric power production. However, these predictions are limited by the length and spatial distribution of modern instrumental records. As instrumental records in Manitoba are relatively short and sparse, conditions observed during the 20th century may not represent true "worst-case" scenarios. Projections regarding the magnitude of future climatic change and the frequency of extreme climate events can be enhanced by the extension of regional climate history prior to instrumental and written historical records.

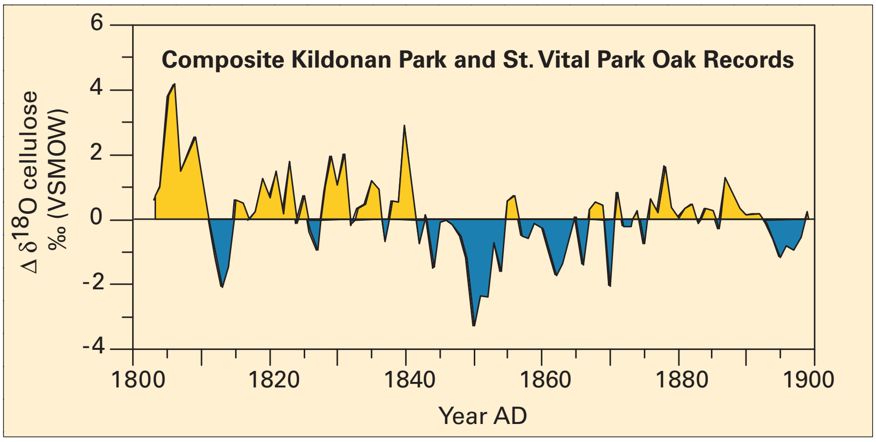

Fig. 1: Amalgamated δ^{18}O values for three oak trees from the Red River basin (Kildonan 1, Kildonan 2, St. Vital 1) for the 19th century. Negative departures from the mean (blue) correspond to flood and high water stages of the Red River (historically: 1811, 1826, 1849-52, 1861 and 1896). Positive departures from the mean (yellow) correspond to drought and dry periods (historically: 1803-1805; 1816-1820, and 1840).

Isotope variations in tree-ring cellulose offer great potential for yielding good proxy flood records because of the wide geographical distribution of suitable sites, fine temporal resolution, and length of available records, as well as their identified environmental sensitivity. Isotope dendroclimatology has proven to provide accurate estimates of atmospheric climate parameters that cannot be provided by conventional analysis. This approach to paleoclimatic reconstruction is based on deconvolution of the independent isotopic signatures of oxygen and carbon preserved in the cellulose fraction of plant tissues. The isotopic ratios depend on the initial composition of water taken up by the tree (which often correlates with local air temperature) and the degree of subsequent isotopic enrichment of the plant water due to evapotranspirative vapour loss (which is dependent on the atmospheric moisture regime). Isoto-

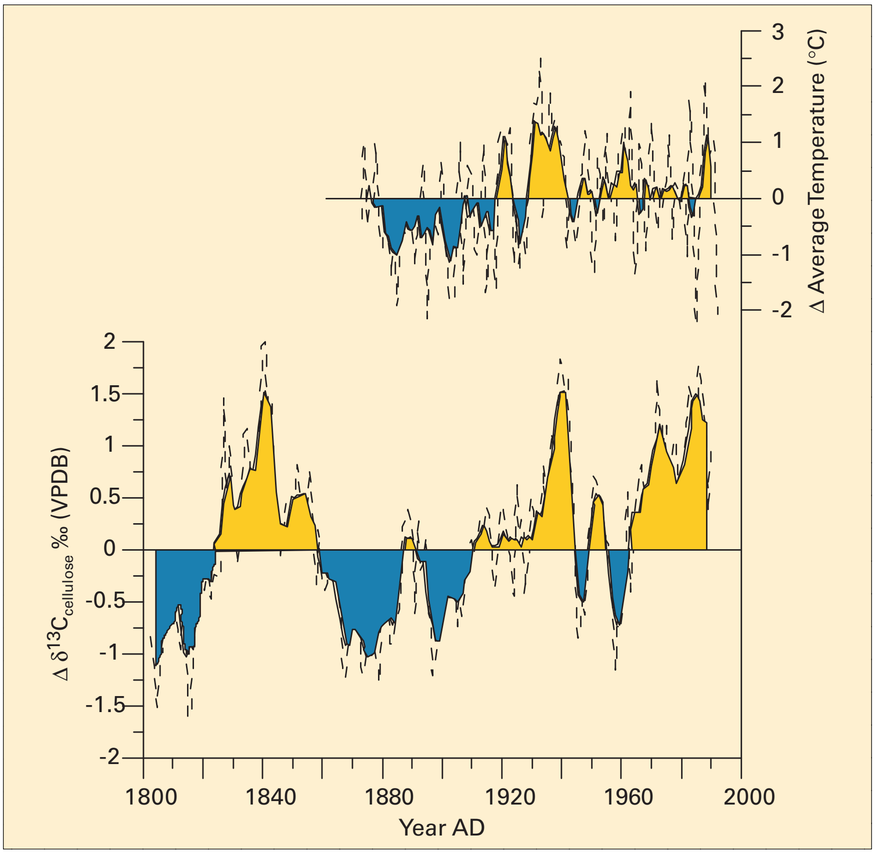

Fig. 2: Top: Average growing season temperature (departures from average) (June to September) for the Red River basin from 1874 to 1992). Bottom: δ^{13}C values for three oak trees from the Red River basin (Kildonan 1, Kildonan 2, St. Vital 1) for the 19th and 20th centuries.

pic fractionations occurring during evapotranspiration and cellulose synthesis can be modelled semi-empirically to permit quantitative derivation of paleo-isotope values for local meteoric water (and hence paleotemperature) and paleohumidity.

This preliminary study utilizes stable isotope techniques to examine recent climate change in the Red River basin of southern Manitoba, Canada. At present, the regional tree-ring record extends from AD 1999 to AD 1286. Isotopic data has been extracted from three trees from Winnipeg parks to generate an annual record of fluctuations in oxygen and carbon isotopes from 1802 to 1990 (see Figs. 1 and 2 below). These preliminary results suggest that the isotopic variations in the trees are closely linked to past variations in regional hydroclimate and growing season temperature.

Amalgamated oxygen and carbon isotopic values for the three tress (2 oak trees from Kildonan Park and one from St. Vital Park) are presented to illustrate departures from mean oxygen (Fig. 1) and carbon (Fig. 2) values.

In Figure1, negative oxygen-18 anomalies (indicating significantly depleted oxygen isotope values) are centred on the historical 1811, 1826, 1852 and 1861, 1896. Positive oxygen-18 anomalies correspond nicely with historical droughts (1803-1805; 1816-1820) and excessively dry periods (1840).

When compared with Winnipeg instrumental records, preliminary delta $\delta^{13}C$ cellulose values portrayed as departures from a mean show a fairly positive relationship with recorded growing season temperature variations (average monthly daytime temperatures from June to September). Particularly noteworthy in Figure 2 is a period between 1874 and 1935 characterized by increasing growing season temperatures, which is positively mimicked by delta $\delta^{13}C$ cellulose that change from below to above average values. Additionally, Figure 2 hints towards a particularly warm period during the middle of the 19th century proceeded by a cold period that mimics the historical late 19th century cold period. The initial results of this research indicate that oak cellulose oxygen isotope departures from a mean do provide historically reasonable chronological signatures of floods and droughts in the Red River basin. Additionally, carbon isotope results provide qualitative estimates of growing season temperature variations and therefore a climate framework in which to place these flood and drought anomalies.

A New Conceptual Model for Predicting Isotopic Enrichment of Lakes in Seasonal Climates

John J. Gibson

Department of Earth Sciences, University of Waterloo, Waterloo ON, Canada, N2L 3G1 (Present address: International Atomic Energy Agency, Wagramerstrasse 5, P.O. Box. 100, Vienna, AUSTRIA) J.J.Gibson@iaea.org

Steady-state isotope balance models have often been applied to estimate long-term average water balance conditions for lakes (Dinçer, 1968; Gat, 1995). Such studies have commonly employed values for the kinetic isotope fractionations for oxygen and hydrogen determined from wind tunnel experiments (e.g. Vogt, 1976; see also Gonfiantini 1986) and have assumed isotopic equilibrium between atmospheric moisture and local mean annual precipitation (Rozanski et al., 2001; Gibson et al., 1993). In climates with a pronounced seasonality in evaporation rates, especially in environments where ice cover is present, such models have frequently predicted evaporative enrichment slopes that differ from observations (commonly lower than observed), and have therefore resulted in poor agreement between oxygen-18 and deuterium estimates, or have required use (or fitting) of kinetic fractionation factors that are not in agreement with experimental results (Zuber, 1983; Gibson et al., 1993).

A program of field investigations conducted at a variety of sites in northern Canada over the past decade has focused on development and application of quantitative isotope mass balance methods for water resources assessment in seasonal climates (see Gibson et al., 1994). These studies have included detailed comparisons of weekly to monthly evaporation in small, well-instrumented lakes using non-steady isotope balance methods (Gibson et al., 1996a,b, 1998; Gibson 2002), regional comparisons of long-term water balance in boreal and arctic lakes (Gibson 2001; Gibson et al., 2002; Gibson and Edwards 2002), and application of evaporation pans and cryogenic vapour sampling to characterize isotopic composition of atmospheric moisture near the ground (Gibson et al., 1999). Overall, these studies have shown that application of isotope mass balance using pan-derived atmospheric moisture and laboratory values for kinetic exchange parameters yields consistent results for short time periods as compared to conventional water balance where evaporation is determined using Bowen ratio and aerodynamic profiling methods. Local and regional sampling surveys have also revealed a pronounced latitudinal steepening of the slope of local evaporation lines from about 5 to 7 in δ^2H - $\delta^{18}O$ space over the latitude range of 50 to 71°N.

A recent sensitivity analysis was conducted to investigate possible seasonality effects on the slope of the local evaporation lines that would explain the steeper slopes at higher latitudes, and the general lack of agreement between predicted evaporation slopes using