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A coupled isotope tracer method to characterize input water to lakes

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Summary We develop a new coupled isotope tracer method for characterizing the isotopic composition of input water to lakes, and apply it in the context of ongoing hydrological process studies in the Peace-Athabasca Delta, a large, remote, riparian ecosystem in the boreal region of western Canada. The region has a highly seasonal climate, with floodplain lakes typically receiving input only during the 4–6 month open-water season from varying proportions of spring snowmelt, summer rains and river flooding. These possible input sources have distinct ranges of isotopic compositions that are strongly constrained to a well-defined local meteoric water line, thus affording the opportunity to derive lake-specific estimates of the integrated isotopic composition of input waters after accounting for the effects of secondary evaporative isotopic enrichment. As shown by comparison of the results of isotopic surveys of delta lakes prior to freeze-up in 2000 and 2005, this isotopic characterization of input waters can be combined with other data and field observations to provide new insight into spatial and temporal variability in delta lake recharge processes. This includes evidence that summer rainfall in 2000 played an important role in replenishing shallow basins delta-wide, especially in the central low-lying region, compensating for below-average snow accumulation during the previous winter. In contrast, 2005 was marked by greater relative contributions from both snowmelt and river flooding because of high winter snow accumulation and a spring ice-jam that caused river floodwaters to enter some basins in the southern part of the delta. The method is readily transferable to investigations in other remote regions that are sparsely monitored by conventional hydrometric networks.

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Introduction

Understanding the relative roles of hydrological processes on lake water balances in large and remote freshwater ecosystems is important for their management but is challenging because approaches that depend upon conventional instrumentation may be impractical. Installation of hydrometric devices in ecosystems with numerous aquatic basins requires substantial investment and assumptions are frequently required to, for instance, close lake water balances. For basins located in deltas and river floodplains that receive multiple sources of water, lake level recorders may provide useful knowledge of water level increases but other independent hydroclimatic information is needed to identify the cause of the observed change. Furthermore, results derived from only a few instrumented sites may be difficult or inappropriate to extrapolate over complex landscapes where the relative importance of hydrological processes is expected to vary spatially.

In recent years, water isotope tracers have become increasingly utilized as an alternative approach for providing assessments of lake water balances in remote regions. For example, Gibson and Edwards (2002) conducted a systematic survey of lake water isotope compositions to understand regional variations in evaporation losses and water budgets associated with the climate gradient across the northern boreal treeline in Canada. More recently, Mayr et al. (2007) used water isotope tracers in the southern Patagonia of Argentina to characterize contemporary lake water balances with the purpose of informing paleolimnological investigations. In these and other studies, quantitative estimates of lake water balances are derived using variations of the Craig and Gordon (1965) linear resistance model that describes isotopic evaporative enrichment. Applications commonly utilize lake water oxygen and hydrogen isotope compositions separately, which frequently generates small differences in water balance estimates using the individual tracers. Although these differences are often attributed to analytical or model uncertainties, mass conservation dictates that lake water balances calculated from lake water oxygen and hydrogen isotope compositions must agree.

Here we develop a new approach to the application of water isotope tracers that preserves the fundamental assumption of mass conservation allowing additional hydrological information to be derived regarding the nature of source waters to lakes in the Peace-Athabasca Delta (PAD), Canada. This large freshwater ecosystem contains hundreds of shallow (most are <2 m) basins where rainfall, snowmelt and river water are important to sustain aquatic habitat but their relative roles over space and time are not well characterized. These investigations build upon quantitative assessment of lake water balances across the PAD, which identified distinct landscape sectors of hydrolimnological conditions based on integration of isotope and chemistry analyses of lake water samples collected in October 2000 (Wolfe et al., 2007). In this previous study, as elsewhere, comparison of oxygen- and hydrogen-isotope estimated evaporation-to-inflow ratios revealed a small but systematic departure from the 1:1 line that was thought to emanate from uncertainties in model input values. We re-visit this dataset and utilize another from September 2005 to evaluate input water isotope compositions during two years characterized by very different hydrological and meteorological conditions. Results show marked spatial and temporal variability in input waters to lakes using our new coupled isotope tracer method, one that is readily transferable to other large, freshwater ecosystems.

Study area

The Peace-Athabasca Delta (PAD) is a large ($\sim$3900 km^2) wetland complex located at the convergence of the Peace, Athabasca and Birch rivers at the western end of Lake Athabasca, northern Alberta, Canada (Fig. 1). The PAD can be subdivided into three deltaic sectors: the Athabasca sector to the south ($\sim$1970 km^2), the Peace sector to the north ($\sim$1680 km^2) and the much smaller Birch sector to the west ($\sim$170 km^2) (PADPG, 1973). Several large shallow lakes (Claire, Baril and Mamawi lakes) are located in the center of the PAD, where the three sectors coalesce (Fig. 1). The Peace sector lies to the north of these lakes and is a relict fluviodeltaic landscape that is covered by mature forests with bedrock inliers in the northeast. This sector is flooded only during major ice-jams that periodically develop on the Peace River. The southern Athabasca sector is an active delta of extremely low relief that frequently receives river floodwaters during both the spring thaw and open-water seasons. Ice-jam flooding of portions of the Athabasca sector occurred in the spring of 2005, preceding one of our lake water sample collections (September 2005).

There are numerous shallow lakes in the PAD, which span a broad hydrological spectrum. Based on previous studies incorporating water isotope tracers and limnological characteristics, basins have been categorized into four drainage types (Wolfe et al., 2007). Open-drainage basins are located mainly in the low-lying central portion of the delta where they frequently receive discharge from many of the rivers and creeks that constitute the complex channel network of the PAD. Closed-drainage basins are generally found in the Peace sector and receive widespread river water only during periodic ice-jam flood events on the Peace River, and thus, input from precipitation is an important source of water to these lakes. Restricted-drainage basins are located mainly in the Athabasca sector, where the input of river water is the primary hydrological process that controls lake water balances. Rainfall-influenced basins are found mainly in the central portion of the delta adjacent to the large open-drainage basins and occupy shallow depressions in the landscape (depth <50 cm). Their water balances are similar to those of restricted-drainage basins but their source waters are dominated by summer precipitation.

Climate in the PAD is strongly seasonal. According to 1971–2000 climate normals at Fort Chipewyan, Alberta, (Weather Station ID 3072658; Environment Canada, 2004), mean annual air temperature is -1.9 °C, mean January air temperature is -23.3 °C and mean July air temperature is 16.7 °C. Precipitation averages 391.7 mm annually, with about 59% falling as rain during the May–September period. Meteorological conditions preceding the two sample collections (October 2000 and September 2005) were different (Fig. 2). The winter of 1999/2000 was warm and dry