H03: Recent Advances in Isotopes as Tracers of Hydrology and Earth-System-Science

Conveners: Tricia Stadnyk[1] and John Gibson[2]

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Session Description

At a World Summit on Sustainable Development, a partnership between the International Atomic Energy Agency (IAEA) and United Nations Educational, Scientific and Cultural Organization (UNESCO) was formed to focus on enhancing technology applications for water resources management. The IAEA announced a need to "*develop a methodology and monitoring network for isotopes"* with the fundamental goal of improving our understanding of hydrology in river basins. Since then, many studies have incorporated isotope tracers to elicit understanding of the connectivity between meteorology, hydrology and geology, or earth system science. Canadian researchers are leaders in using isotope tracers in global and catchment-scale studies to examine change related to climate and land-use factors. Establishment of national and regional-scale tracer networks have progressively advanced research initiatives, and have enabled the coupling of isotope measurements to hydrometric observation. The goal of this session is to provide a forum for multi-disciplinary discussion on the recent applications of isotope tracers in hydrology and earth-system-science, with the specific goal of fostering new and unique collaborations. We encourage contributions relating to the use of isotopes as tracers of earth-system-science including hydrometeorological, hydrogeological, and hydrological applications. Submissions focusing on all spatial and temporal scales, field or laboratory studies, coupled modelling approaches, and various temporal scales are invited.

Primary Affiliation: Hydrology (CGU)

NOTE: THIS DOCUMENT CONTAINS INFORMATION FOR ALL SESSION SUB-SECTIONS. PRESENTER ABSTRACTS ARE FOUND AT THE END OF THE DOCUMENT.

SCHEDULE MAY BE SUBJECT TO CHANGE.

ORAL SESSION H03a

Chairs: T. Stadnyk & J. Gibson **Room: EOSC 135**

Wednesday May 31st

TIME	AUTHORS	TITLE
16:00	M. Weiler, M. Sprenger, T. Volkmann, S. Seeger & H. Leistert	Coupled field sampling and modelling of soil and plant water stable isotopes to quantify site specific hydrological fluxes
16:15	A. Smith, C. Welch & T. Stadnyk	On establishing watershed scale temporal partitioning of evapotranspiration in high-latitude watersheds
16:30	J. Gibson, Y. Yi, J. Birks, E. Taylor & M. Moncur	Isotope-based hydrograph separation in large rivers: assessing flow sources and water quality controls in the Athabasca oil sands region

POSTER SESSION H03

Chairs: B. Amiro & S. Nolan **Room: ESB Atrium**

Wednesday, May 31st

Poster No.	AUTHORS	TITLE
P01-H03	J. Taulu, T. Prowse & T. Edwards	Quantifying seasonal contributions of snow and glacial melt to streamflow in the Upper Athabasca River, Alberta, Canada
P02-H03	A. Coles, S. Chad, A. Al Masum, M.F. Nehemy, A. Niazi, C.A. Ross, T. Vogel, K. Janzen & J.J. McDonnell	Improving prairie snowmelt process understanding with high-resolution stable isotope tracing
P03-H03	J. Exler, A. Christen, M. Merkens & R.D. Moore	Water and energy fluxes at a disturbed and rewetted white beakrush-sphagnum site in a raised bog near Vancouver, British Columbia.
P04-H03	S. Bansah, A. Haque, J. Laing & G. Ali	Spatio-temporal assessment of mean transit times in a Canadian prairie watershed
P05-H03	Y. Yi, J. Gibson, J. Birks & P. Shaw	Regional Survey of Lake Water for Isotopic Characterization and Water Yield Estimations in BC
P06-H03	Q. Chang, M. Hayashi, Z. Sun, S. Want & R. Ma	Using multiple tracers to identify source water and flow paths in an alpine catchment in the Qilian Mountain, Qinghai-Tibet Plateau, China
P07-H03	T. Holmes, T. Stadnyk & C. Welch	Improving Hydrological Model Calibration using Stable Water Isotope Tracers

SUBMITTED ABSTRACTS

H03-01: Coupled field sampling and modelling of soil and plant water stable isotopes to quantify site specific hydrological fluxes

Markus Weiler[1], Matthias Sprenger[2], Till Volkmann[3], Stefan Seeger[1], Hannes Leistert[1]

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Abstract
Stable water isotopes have been used for many decades to study water transit times, water balances and separation of water fluxes, water sources, etc. at a variety of spatial and temporal scales. Due to the slow movement of water, long-term observations are general required for these tasks. We have developed a novel coupled field and modelling approach to quantify and predict hydrological fluxes such as evaporation, transpiration and recharge for different land-use and vegetation cover types that requires less and shorter-term observations. The field component consists of the sampling of soil water isotope profiles (SWIP) to a depth of 1.5-3 m at 10 cm intervals twice a year, in spring and fall. The modelling component requires climatic variables and stable water isotope composition of precipitation and optimizes a soil isotope hydrological model (Richards equation, liquid and water vapor compartments, root water uptake and relevant water isotope fractionation processes) to the observed SWIPs. Samples of plant water isotopes at the same location are beneficial. As the information content of the SWIP regarding transport processes, separation between evaporation and transpiration and root water uptake patterns is very high, this combined approach generally outperforms long-term soil water observations for predicting the relevant fluxes at the plot scale, needing only two measurements within 6 months to define the system. In addition, occurrence of lateral subsurface flow can be detected in the profiles. Using this approach at a variety of locations shows its potential for predicting the influence of land-use and vegetation changes on the water balance components and transit time distributions of recharge and transpiration, but also for tree ring analysis and the identification of long-term effects on water quality. [276 words]

Presentation type: Oral Presentation

H03-02 On establishing watershed scale temporal partitioning of evapotranspiration in high-latitude watersheds

A.Smith[1], C. Welch[2], T. Stadnyk[2]

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Abstract: In high latitude watersheds, climate change is of concern due to increasing temperatures, permafrost degradation, and decreasing seasonal frozen soils. Seasonal changes in sub-surface conditions are likely to change evaporation (E) and transpiration (T) rates, influencing water availability. Tracers have emerged as tools to apportion component contributions to streamflow, and as a method to partition ET into its components. Stable isotopes of water have been used to identify temporal changes in E/ET in small-scale studies (<50km^2), and annual average E/ET in large-scale studies; but not temporal changes in E/ET at the watershed scale. A lumped tracer-aided model was developed and used to identify the fractionation effects of land covers evident in streamflow at the catchment outlet. Behavioural parameter sets were identified by limiting evaporative fractionation in subsurface storage. The relative depletion of the simulated stream composition was used to define a temperature-dependent ET partition equation within four meso-scale (400-6000 km^2) high-latitude watersheds. The seasonal trend of E/ET is generally sinusoidal: highest in spring and fall and lowest during the summer. Annual average E/ET ranged between 0.2 and 0.4 for the four watersheds. Differentiation of E/ET between unsaturated soils and wetlands reveals higher E/ET in wetlands than unsaturated soils. ET partition parameters were sensitive to the volume of storage, with increased storage volume leading to increased parameter uncertainty. Riverine isotopic composition was proportionally more dependent on evaporation fractionation within wetlands than within unsaturated soil water. The temperature-dependent ET partition method identifies a means to partition ET in meso-scale high-latitude watersheds where data are sparse with limited parameterization. The method has applicability to different land covers and soil conditions (saturated vs unsaturated).

Presentation Type: Oral

H03-03: Isotope-based hydrograph separation in large rivers: assessing flow sources and water quality controls in the Athabasca oil sands region

John J. Gibson[1,2*], Y.Yi[1,2], Jean Birks[2,3], Emily Taylor[3], Michael Moncur[3]

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Abstract
Hydrograph separation using stable isotopes of water is used to partition streamflow sources in the Athabasca River and its tributaries in the oil sands region of northern Alberta, Canada. Snow, rain, groundwater and surface water contributions to total streamflow are estimated for multi-year records and provide considerable insight into runoff generation mechanisms operating in six tributaries and at four stations along the Athabasca River. Groundwater, found to be an important flow source at all stations, is the dominant component of the hydrograph in three tributaries (Steepbank R., Muskeg R., Firebag R.), accounting for 39 to 50% of annual streamflow. Surface water, mainly drainage from peatlands, is also found to be widely important, and dominant in three tributaries (Clearwater R., Mackay R., Ells R.), accounting for 45 to 81% of annual streamflow. Direct runoff of precipitation sources including rain (7-19%) and snowmelt (3-7%) account for the remainder of sources. Fairly limited contributions from direct precipitation illustrate that most snow and rain events result in indirect displacement of pre-event water (surface water and groundwater), due in part to the prevalence of fill and spill mechanisms and limited overland flow. Systematic shifts in the groundwater: gsurface-water ratios, noted for the main stem of the Athabasca River and in its tributaries, is ostensibly an important control on the spatial and temporal distribution of major and minor ions, trace elements, dissolved organics and contaminants, as well as for evaluating the susceptibility of the rivers to climate and development-related impacts. Runoff partitioning is likely to be a useful monitoring tool for better understanding of flow drivers and water quality controls, and for determining the underlying causes of climate or industrial impacts.

Presentation type: Oral Presentation

H03-04: Quantifying seasonal contributions of snow and glacial melt to streamflow in the Upper Athabasca River, Alberta, Canada

Jasmine Taulu[1*], Terry Prowse[2] and Tom Edwards[3]

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Abstract

As climate warms it is expected that, in addition to the quantity of water provided by snow and glacial melt lessening, the timing will also shift to earlier in the season, both of which affect downstream users. Though this problem has been identified, the percent of snowmelt and glacial melt has not been largely quantified outside of small basins and headwater regions. This information is essential for resource management in large catchments, as it is fundamental for determining the magnitude of the decline in water resources and the effect that will have on the users downstream. Due to the conservative nature of stable water isotopes as tracers, they have been identified as an ideal tool in quantifying water sources. This study aims to quantify seasonal sources to streamflow in the Upper Athabasca, a large catchment in Alberta Canada, with both snow and glacial inputs from the headwaters. This catchment is heavily relied upon for water resources by industries in the region, including coal mines, pulp mills and oil sands. Sampling is ongoing, utilizing synoptic sampling when snow and glacial melt contributions to streamflow are expected to be at their highest, and ice core sampling, a proxy to winter streamflow, during ice on periods. Ice core samples are validated by weekly streamflow samples to substantiate the accuracy of this method, which has yet to be tested. The preliminary results from one exploratory synoptic campaign in August of 2016 and the 2016 - 2017 winter season will be discussed.

Presentation type: Poster

H03- 05: Improving prairie snowmelt process understanding with high-resolution stable isotope tracing

Anna E. Coles[1], Spencer Chad[2], Abdullah Al Masum[2], Magali F. Nehemy[3], Amir Niazi[4], Cody A. Ross[5], Tim Vogel[2], Kim Janzen[1], and Jeffrey J. McDonnell[1]

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Abstract
On the Canadian Prairies, a third of the annual *c.*350 mm precipitation falls as snow. Rapid springtime snowmelt over seasonally-frozen ground of reduced infiltrability means that snowmelt is the main streamflow driver and accounts for approximately 80% of the region's runoff. Stable isotope tracers have been an invaluable tool for tracing water movement during snowmelt. However, there are several outstanding questions related to the effect of snowpack melt/re-freeze/sublimation dynamics on the snowpack isotope composition. We also lack understanding of the spatial variability of snowmelt isotope composition and its impact on the meltwater hydrograph separation, as well as quantification of meltwater infiltration into frozen ground. Here we explore these processes using a high spatial- and temporal-resolution hydrometric and stable isotope (^{18}O and ^{2}H) dataset of snowpack, snowmelt, soil water, ponded water, and runoff. Samples were collected through the 2014 snowmelt season on one of the long-term 5 ha experimental monitoring hillslopes of Agriculture and Agri-food Canada at Swift Current, Saskatchewan. We observed high spatial variability of snowmelt stable isotope composition over the hillslope. This negatively correlated with snowpack water equivalent. Isotopic hydrograph separation, in which the 'new' end-member was defined as the hillslope-averaged snowmelt composition, showed a 22% 'old' soil water contribution to hillslope runoff over the whole 12 day snowmelt period. The daily contribution of 'old' soil water positively correlated with the active layer depth, with both increasing through the snowmelt season. While existing empirical approaches to calculating infiltration into frozen ground performed poorly at this site, the soil water isotopes provided a useful estimate of this flux. Our work has implications for methods of directly measuring infiltration into frozen ground – a notoriously difficult flux to measure in situ. Overall, our isotope-based analyses provide deeper process understanding of multiple stages of the prairie snowmelt season.

Presentation type: Poster

H03-06: Water and energy fluxes at a disturbed and rewetted white beakrush-sphagnum site in a raised bog near Vancouver, British Columbia.

Johannes Exler[1]*, Andreas Christen[1], Markus Merkens[2], R.D. (Dan) Moore[1]

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Abstract

Energy and water fluxes were studied in the center of the Burns Bog Ecological Conservancy Area (BBECA), a 20 km^2 raised maritime bog about 15 km south-east of Vancouver. A flux tower was installed at a disturbed white beakrush-sphagnum dominated site, with a negligible topographic gradient. Since summer 2014, an eddy-covariance system measures sensible and latent heat fluxes and climate sensors record precipitation, radiation, temperature, relative humidity and wind. Five nests, each comprising three piezometers and one well, were arranged in a cross, centred on the flux tower. Vertical water flux was computed from piezometer measurements, while water table elevation was used to compute horizontal gradients. Soil heat flux was calculated from plate measurements and satisfactory closure of the energy balance was achieved. The energy balance was quantified for the years 2014 to 2016, while the water balance was calculated for the second half of 2016. Lack of energy balance closure was mostly directed towards the latent heat flux and a high degree of closure was reached with corrected latent heat flux values. Latent heat was the dominant energy flux, and monthly averages were always directed away from the surface, while sensible heat and ground heat flux showed seasonal change in orientation, directed towards the surface in winter. Water storage change was computed as the sum of change in specific yield and specific storage. During summer, when the water table was below the surface and weak hydraulic gradients limited subsurface flow divergence, precipitation minus corrected evapotranspiration agreed reasonably with computed storage change. During winter, when the water table rose above the surface, precipitation minus evapotranspiration significantly exceeded storage change computed from water level measurements, with the surplus assumed to leave the site as overland flow.

Presentation type: Poster

H03-07: Spatio-temporal assessment of mean transit times in a Canadian prairie watershed

Samuel Bansah[1,2,3*], Aminul Haque[1,2,3], Janelle Laing[2], Genevieve Ali[1,2,3]

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The mean transit time (MTT), defined as the average elapsed time from when a water molecule first enters a catchment until it exits said catchment at an outlet, is an important descriptor that reflects the storage, flowpath and sources of water in a catchment. And while MTT estimates have been published for a wide range of catchments around the world, such estimates are rare to non-existent for prairie catchments. A network of eight nested sites located within a 74.6 km^2 prairie catchment in southcentral Manitoba was therefore the focus of the current study. Rain water and stream water samples collected in 2014 and 2015 were analyzed for □^{18}O and □^{2}H and their isotopic time series used to estimate MTTs by way of two methods: the sine wave method and the gamma distribution (GM) convolution integral lumped-parameter method. In particular, the GM transfer function enabled the transit time distributions of the catchments to be established in addition to acquiring the best model parameters for MTT estimation and behavioral solutions via the generalized likelihood uncertainty estimation (GLUE) method. The ability of both methods to simulate the streamwater isotopic timeseries was fairly good, as evidenced by coefficients of determination ranging from 0.2 to 0.9, and Nash-Sutcliffe efficiencies ranging from 0.3 to 0.9. However, considerable uncertainties in GM-derived estimates were shown by GLUE. Water age, irrespective of the method used, was usually estimated to be less than 5 months. Regardless of the method used, MTT estimates obtained using 2014 versus 2015 data were markedly different, hinting at how sensitive both methods are to the assumption of non-stationary catchment dynamics. Future work will focus on quantifying the uncertainty surrounding MTT estimates that might be attributable to data structure (e.g., number of data points) and annual water balance (e.g., normal versus wet year).

Presentation type: Poster presentation

H03-08: Regional Survey of Lake Water for Isotopic Characterization and Water Yield Estimations in BC

Y.Yi[1,2], John Gibson[1,2], Jean Birks[2,3], P. Shaw[4]

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Abstract

An extensive campaign of sampling and archiving lake water isotopic compositions in the coastal region of BC were conduct in recent years. As a practical alternative to classical hydrological monitoring for understanding water balance in often remote locations, the isotopic approach was employed to determine basic lake hydrological characteristics such as the evaporative over inflow ratio (E/I) and water yield. Evaporation /inflow was found to range from 0.1 to 90.4% and water yields are estimated from near zero to more than 5000 mm/yr. According to the regional survey, water yields weekly correlate with elevations, highlights the physical location of the watershed on the runoff generation. The correlation between water yields and pH in a narrow range also appears to maybe interesting to the acid sensitivity analysis. Other important geochemical and landuse characteristics of watersheds are also measured for most of the surveyed lakes. The potential role of landuse on hydrological and geochemical characteristics of watersheds will be explored and discussed.

Presentation type: Poster

H03-09: Using multiple tracers to identify source water and flow paths in an alpine catchment in the Qilian Mountain, Qinghai-Tibet Plateau, China

Qixin Chang[1*], Masaki Hayashi[2], Ziyong Sun[1], Shuo Wang[1], Rui Ma[1]

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Abstract
Hydrogeology of alpine catchments containing mountain permafrost and taliks is complex, as the active-layer and permafrost depths have a strong influence on flow paths and streamflow generating mechanisms. There are uncertainties regarding the influences of glaciers, permafrost and seasonally frozen ground on the sources and pathways of runoff. We used multiple chemical and isotopic tracers to investigate hydrologic features and connectivity of different water pools in the Hulugou catchment (23 km^2), a glaciated alpine catchment in the northeastern Qinghai-Tibet Plateau, China. Based on the multi-tracer analysis, the connections between glacier-snow meltwater, stream water, soil water, thermokarst and overland flow were assessed within the catchment. Results indicate that there are three main water sources and flowpaths contributing to stream flow: 1) glacier-snow meltwater from the periglacial zone, which either flows directly or through moraines into secondary tributaries, 2) overland flow via rainfall runoff from bare bedrock areas, which converges directly into secondary tributaries or infiltrates through the soil and the unsaturated zone, and 3) 'old' supra-permafrost water and sub-permafrost water recharged and displaced by local precipitation and glacier meltwater, which partly discharge into secondary tributaries while some are lost as recharge to alluvial aquifers. Additionally, dissolved organic carbon (DOC) concentrations in streamflow showed significant seasonal variations, suggesting seasonal changes of water sources and flow paths. Over 80% of annual DOC export occurred during the peak flow season, whereas DOC concentrations were the lowest (0.63±0.21 mg/L) in the season as glacier meltwater and rainfall dominated the hydrograph, which probably diluted stream DOC. DOC concentrations were highest during winter (1.01±0.31 mg/L). In mid to late spring, DOC concentrations were stable (0.88±0.39 mg/L), whereas dissolved inorganic carbon (DIC) declined considerably, as groundwater from the alluvial aquifers and snowmelt from alpine meadows contributed to streamflow.

Presentation type: Poster

H03-10: Improving Hydrological Model Calibration using Stable Water Isotope Tracers

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Abstract
Precise and accurate prediction of streamflow under changing climatic conditions, or in ungauged or recently gauged locations, requires hydrologic models capable of accurately representing the processes generating streamflow. Often, however, data for individual processes and storages are even less common than meteorologic or hydrometric data in mid-to-high latitude regions, and is more costly and less feasible to obtain. Data scarcity can result in large amounts of uncertainty in model calibration and simulation output. Isotope tracer-aided hydrologic modeling increases the calibration data available to modelers, potentially reducing the uncertainty in model output. In this study, we explore the potential of stable water isotopes to reduce uncertainty in hydrologic simulation for a remote, minimally gauged, meso-scale watershed (>6000 km^2) in northern Canada. Both deuterium and oxygen-18 simulations are embedded within the continuous, semi-distributed, tracer aided hydrologic model isoWATFLOOD. Multiple methods for incorporating isotope simulation error into model calibration are evaluated. Inclusion of both tracers as additional requirements in model calibration produced the largest reductions in flow simulation uncertainty; however, improvements from adding deuterium are marginal. The primary benefit of the second isotope is realized through enhanced internal storage verification because of the feedback it provides on evaporative flux from the model. Results indicate that stable water isotope-aided calibration reduces flow simulation uncertainty and model equifinality. [213 words]

Presentation type: Poster [oral requested]