H06: Advances in Cold Regions Hydrology

Conveners: John Pomeroy[1], Howard Wheater[2], Sean Carey[3], and Chris DeBeer[2]

Co-chairs: John Pomeroy[1], Howard Wheater[2], Sean Carey[3], and Chris DeBeer[2]

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Session Description

Roughly half the world's population and all of Canada are dependent on water from cold regions, which are at the forefront of global warming and undergoing rapid change. The major hydrological events in cold regions are related to storage and melt of snow and ice and the related energetics of phase change, along with other cryospheric processes, resulting in a unique assemblage of hydrological processes and parameters that produce a very distinctive hydrological response. Because these regions will be strongly affected by climatic warming in the near future, we must advance our understanding of cold regions hydrological systems and their representation in numerical models to better manage uncertain water futures in the face of dramatically increasing risk. This session invites papers that describe recent advances in observations, process understanding, model development or model application in cold region environments. We particularly welcome papers that deal with the diagnosis of past hydrological change, shedding insight on the complexities of interacting cold region processes, or that focus on the application of models toward predicting future change in response to climate warming.

Primary Affiliation: Hydrology

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 H06a

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Monday, May 29th

TIME	AUTHORS	TITLE
9:00	P. Lamontagne-Halle, J.M. McKenzie, B. Kurylyk & S.C. Zipper	Groundwater models for cold regions: How do surface-layer boundary conditions affect hydrology simulation outcomes?
9:15	M. Elshamy, A. Pietroniro & H. Wheater	Initializing deeper soil profiles in land surface models for better representation of permafrost in cold regions
9:30	R. Connon, W. Quinton, E. Devoie & M. Hayashi	The influence of shallow taliks on permafrost thaw and active layer thickness in subarctic Canada
9:45	L.E. Stone, X. Fang, J.W. Pomeroy, O. Sonnentag & W.L Quinton	Modelling the effects of permafrost loss on discharge from wetland dominated basins in the discontinuous permafrost zone
10:00	M. Hayashi, J. Harrington & A. Paznekas	Hydrogeological characteristics of coarse blocky sediments in alpine watersheds
10:15	S.C. Zipper, J.M. McKenzie & S. Gruber	Permafrost response to fire-induced changes in the energy and water balance

ORAL SESSION H06b

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Monday, May 29th

TIME	AUTHORS	TITLE
11:00	C. Marsh, J. Pomeroy, H. Wheater & R. Spiteri	The Canadian Hydrological Model: A multiscale, Multiphysics, variable-complexity hydrological model
11:15	N.E. Wayand, C. Marsh & J. Pomeroy	Evaluation blowing snow and avalanche models over the Canadian Rockies
11:30	X. Fang, J. Pomeroy & N. Wayand	Evaluating meteorological forcing sources for simulation of snowpack and streamflow in the Canadian Rockies
11:45	M. Queinnec & S.V. Weijs	Use of a mountain shading model for spatial snowmelt predictions
12:00	P. Harder, W. Helgason & J. Pomeroy	Modelling the snow surface energy balance during melt considering the effect of exposed crop stubble
12:15	K. Smith, M. Richardson & J. Shirley	A comparison of empirical vs physically-based approaches for modeling end of winter snow distribution on South Baffin Island near Iqaluit, Nunavut

ORAL SESSION H06c

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Monday, May 29th

TIME	AUTHORS	TITLE
16:00	D.R. Casson, M. Werner, A. Weerts, J Schellekens & D. Solomantine	Application of global datasets and data assimilation for hydrological modelling in the Canadian Sub-Arctic
16:15	J. Murfitt & L.C. Brown	Monitoring lake ice growth and decay in central Ontario using RADARSAT-2: 2008-2016
16:30	F. Larue, A. Royer, D. De Seve, A. Roy, G. Picard & V. Vionnet	Snow water equivalent monitoring using a coupled snowpack evolution and microwave emission models over North-Eastern Canada
16:45	J.M. Shea, P. Harder & J.W. Pomeroy	Improving quantification of mountain snowpack properties using observations from Unmanned Air Vehicles (UAVs)
17:00	D. Tokarski & M. Richardson	Temporal and spatial variability of snow water equivalent, snow depth, and snow density in a 15,000 km2 sub-arctic basin
17:15	N.J. Kinar, J.W. Pomeroy, J. Shea, M. Schirmer & P. Harder	2D Frequency Analysis of Irregularly Sampled Snowpack Properties

ORAL SESSION H06d

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Tuesday, May 30th

TIME	AUTHORS	TITLE
9:00	S. Gharari, S. Safaei, S. Razavi & H. Wheater	On the closure of the water balance in the catchments of the Canadian Rockies
9:15	M. Chernos, R.J. MacDonald & J. Craig	Current and future projections of glacier contribution to streamflow in the upper Athabasca River Basin
9:30	K. Stahl, I. Kohn, M. Bohm, D. Freudiger, K. Gerlinger, J. Seibert & M. Weiler	Quantifying centurial changes in the contribution of upstream snow and glacier melt to downstream river discharge
9:45	M.A. Schnorbus, B. Menounos, A. Schoeneberg, F. Anslow, G. Jost & R.D. Moore	Improvements to Regional Hydrologic Modeling by Incorporating Ice Dynamics
10:00	D. Pradhananga & J. Pomeroy	Hydrological response of Peyto Glacier to climate change and glacier recession

ORAL SESSION H06e

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Tuesday, May 30th

TIME	AUTHORS	TITLE
11:00	S.A. Krogh & J.W. Pomeroy	Trends in the hydrology of a small Arctic basin in the tundra-taiga treeline region
11:15	O. Sonnentag, M. Helbig, R. Connon, G.H. Gosselin, E. Haughton, K. Wischnewski, J. Hanisch, T. Moore & W. Quinton	The subcatchment- and catchment-scale hydrology of a boreal headwater peatland complex with sporadic permafrost
11:30	A. Nazemi, E. Melhe, J. Manashti & P. Jaramillo	Climate and Geographic Controls on Changing Landscape Freeze and Thaw Patterns in Quebec (1979 – 2010)
11:45	P. Marsh, P. Mann, B. Walker, A. Toure, E. Wilcox, M. Tusi, A. Jitnikovitch, O. Sonnentag & C. Derksen	The changing snow environment of the western Canadian Arctic
12:00	K. Rasouli, P.H. Whitfield, L.W. Martz, A.M. Ireson, J.R. Janowicz, D. Marks & J. Pomeroy	Are effects of transient vegetation and soil changes as important as climate change impacts on hydrological processes?
12:15	M.C. Elmes, D.K. Thompson, J.H. Sherwood, & J.S. Price	Exploring the hydrological and meteorological conditions leading to the 2016 Horse River Wildfire, and the subsequent burning of a fen watershed in Northern Alberta, Canada

ORAL SESSION H06f

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB 1012**

Tuesday, May 30th

TIME	AUTHORS	TITLE
16:00	D. Costa, J. Pomeroy & H. Wheater	An experimental tool for the simulation of snowmelt nutrient release and transport from cultivated areas – the WINTRA model
16:15	H.J. Annand, J.W. Pomeroy & H.S. Wheater	Simulations of the influence of wetland drainage on the Canadian Prairies: an example at Smith Creek Research Basin, Saskatchewan
16:30	K. Shook & J. Pomeroy	Causes of the shapes of hysteretic connected-fraction curves of Prairie drainage basins
16:45	S. Dery, T. Stadnyk, M.K. MacDonald & K. Koenig	Flow regulation controls on daily river discharge into Hudson Bay

17:00	J.R. Dierauer, D.M. Allen & P.H. Whitfield	Water-Energy Nexus and Future Water Security in Northeast British Columbia
17:15	F. Yassin, S. Razavi & H. Wheater	Improved representation of water management and reservoirs in a land surface-hydrology model

POSTER SESSION H06

Chairs: J. Pomeroy, H. Wheater, S. Carey & C. DeBeer **Room: ESB Atrium**

Monday, May 29th

Poster No.	AUTHORS	TITLE
P01-H06	S. Budhathoki, A. Ireson & J. Steeves	Quantifying snowmelt infiltration and runoff
P02-H06	M. Rabie, G. Ali, C. Spence, S. Bansah, V.T. Tang & S. Carey	Investigating streamflow generation and streamflow sources during a wetting-up period in an engineered prairie watershed
P03-H06	W. Tang, S.K. Carey, R. Rolick & B. Kurylyk	Using wavelet analysis to evaluate the spatio-temporal variability of stream temperature in two alpine watersheds
P04-H06	A. Szeitz & R.D. Moore	Modelling snow density from snow depth combined with air temperature time series interpolated from the North American Regional Re-analysis
P05-H06	R.L. Rolick, S.K. Carey & B.L. Kurylyk	Thermal regimes of streams within an alpine discontinuous permafrost catchment, southern Yukon Territory
P06-H06	S.S. Ariano & L.C. Brown	The influence of consecutive El Niño and La Niña events on lake ice in Central Ontario
P07-H06	A. Robinson & L.C. Brown	Lake ice modelling of two high arctic lakes
P08-H06	J. Peters & S.F. Lamoureux	Landscape controls over subsurface water flow pathways in the Canadian High Arctic
P09-H06	J.R. Adams & W.L. Quinton	On the similarity of land-cover among lowland peatland complexes in the southern Taiga Plains discontinuous permafrost region, NWT
P10-H06	H. Gleason, S. Déry, J. Rex, V. Foord, R. Kabzems & C. Mottishaw	Forecasting of Spring Runoff Events in the Kiskatinaw Watershed, Dawson Creek, British Columbia
P11-H06	E. Mathieu, W. Quinton & O. Sonnetag	The effects of wildfire on snowmelt and ground thaw on a permafrost peat plateau, Scotty Creek, Northwest Territories
P12-H06	H. Bonn, S. Carey & B.L. Kurylyk	Measuring and modeling infiltration and water movement in frozen ground, Wolf Creek, Yukon

P13-H06	L. Langs & R. Petrone	Methods investigating alpine forest water use under varying environmental conditions in the Canadian Rocky Mountains
P14-H06	Z. Lv & J.W. Pomeroy	Detecting intercepted snow on mountain needleleaf forest canopies using satellite remote sensing
P15-H06	M.C. Elmes, D.K. Thompson & J.S. Price	Monitoring the hydrological response of a burned moderate-rich fen watershed in the Athabasca Oil Sands Region, Alberta

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SUBMITTED ABSTRACTS

H06-01: Groundwater Models for Cold Regions: How do Surface-Layer Boundary Conditions Affect Hydrology Simulation Outcomes?

Pierrick Lamontagne-Hallé[1*], Jeffrey M. McKenzie[1], Barret L. Kurylyk[2] and Samuel C. Zipper[1]

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Abstract
The storage and movement of groundwater in cold regions is greatly affected by the presence or absence of permafrost, or perennially frozen ground. Under saturated conditions, permafrost acts as an impermeable barrier and confines groundwater flow to the active zone above permafrost, below permafrost or through perennially unfrozen areas known as taliks. Thawing of permafrost due to ongoing climate warming is already modifying hydrologic processes by increasing groundwater storage and base flow in arctic rivers. In order to understand and predict these impacts of permafrost thaw, effective groundwater models that include heat transfer with dynamic freezing and thawing processes are required. These types of models represents a new challenge for the design and the parameterization of the surface boundary conditions. We present a parametric study that compares the model outcomes of permafrost – groundwater simulations with different couplings of surface boundary conditions in a theoretical permafrost environment driven by global warming. In particular, we focus on permafrost thaw rates and variations of groundwater discharge to the land surface across different landscape positions. Based on the model sensitivity to boundary conditions, an easily applied model configuration for cold regions groundwater modelling is proposed for users wanting to simulate the interactions of groundwater flow and permafrost thaw. The simulation results also improve our understanding of the processes involved in permafrost thaw and our conceptualization of permafrost – groundwater models. [225 words]

Presentation type: Oral Presentation

H06-02: Initializing deeper soil profiles in land surface models for better representation of permafrost in Cold Regions

Mohamed Elshamy[1], Alain Pietroniro[2] and Howard S. Wheater[1]

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Abstract
Earth system models (ESMs) are widely used to project climate change and they show a current global warming trend that is expected to continue during the 21st century and beyond. High rates of warming have been observed in high latitudes, resulting in permafrost thaw with implications for soil moisture, hydraulic connectivity, streamflow seasonality, land subsidence, and vegetation. Feedbacks are generally complex and depend on a multitude of several inter-related factors including changes to precipitation intensity, timing, and phase as well as soil composition and hydraulic and thermal properties. Several studies indicated the need to have a deep soil column (20-25m at the least) in land surface models (embedded within ESMs) to be able to capture changes in freeze and thaw cycles and active layer depth. A deeper soil column implies larger soil hydraulic and thermal memory that requires proper initialization to be able to capture the evolution of current and future changes. This is either achieved by spinning up the model for many annual cycles to reach some steady state or to run it for a long transient simulation for 100s of years. Generally, spinning up will also be needed for the second option as records of soil moisture and temperature are sparse in time and space. In this study, an investigation of the number of cycles needed for such initialization is presented based on experiments at three sites in the Mackenzie River Basin with different permafrost characteristics (continuous, extensive discontinuous, and sporadic) using the Canadian Land Surface Scheme (CLASS). The sensitivity of the results to the selection of the climate of the spinning up period and the layering of soil is also presented. Results indicate that 50-100 cycles are sufficient in most cases for 20-25m soil depth. The thermal and hydraulic profiles at the end of the spinning up cycles from those experiments can guide the initialization of similar areas to further reduce the number of cycles required.

Presentation type: Oral Presentation

H06-03: The influence of shallow taliks on permafrost thaw and active layer thickness in subarctic Canada

Ryan Connon[1*], William Quinton[1], Élise Devoie[2] and Masaki Hayashi[3]

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Abstract
Increasing mean annual air temperatures in northern Canada have triggered rapid thawing of permafrost, especially near the southern edge of discontinuous permafrost. Permafrost thaw has the potential to fundamentally alter the processes giving rise to streamflow in this region by altering the physical structure, type and relative proportions of biophysical terrains. Field studies were conducted at the Scotty Creek Research Basin, a 152 km^2 watershed located near Fort Simpson, Northwest Territories, Canada. We have found that in recent years, summer thaw depth has exceeded the depth of the freezing front in winter, resulting in the development of shallow taliks in terrestrial environments (forested peat plateaus). In this study we measured the depth of seasonal freeze back at 150 points along nine transects to determine the presence and thickness of taliks on permafrost cored peat plateaus at Scotty Creek. The increase in the depth to the permafrost table between five years (2011 to 2016) was significantly greater at points with taliks (0.37 m) than those without (0.06 m). Furthermore, we found that the proportion of points with taliks increased from 20% to 48% over the five year period. We attribute this to a warm and wet summer in 2012, followed by a winter with higher than average snowfall. Together, this produced the highest net annual ground heat flux of the 15 year record at Scotty Creek. Exceptionally warm years have the potential to induce talik development, which may serve as a tipping point for thawing of the underlying permafrost. We suggest that permafrost thaw exhibits a non-linear response to warming air temperatures, and that thresholds such as those found here can trigger wide-spread rapid permafrost degradation. [276 words]

Presentation type: Oral Presentation

H06-04: Modelling the effects of permafrost loss on discharge from wetland dominated basins in the discontinuous permafrost zone

L.E. Stone[1*], X. Fang[2], J.W. Pomeroy[2], O. Sonnentag[3], W.L. Quinton[1]

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Abstract
Permafrost degradation in the peat-rich southern fringe of the discontinuous permafrost zone is resulting in substantial changes to land cover with expansion of permafrost-free wetlands resulting from thermokarst of upland forest-covered ice-rich peat plateaux. Predicting discharge from basins that originate in this region depends on understanding the interactions between storage and discharge in various land covers, and how they are changing. A peat plateau-bog-channel fen system representative of the headwaters in the Scotty Creek Research Basin was implemented as a model in the Cold Regions Hydrological Modelling Platform (CRHM) between 2008 and 2015. The model calculates snow interception and sublimation from forest canopies, energy balance snowmelt, peat soil water storage and transmission, frost table dynamics, and runoff by surface, subsurface and deep groundwater flows. Model parameters were estimated using the extensive body of research from Scotty Creek field studies. The model was validated using time series data of soil moisture, snow depth, snow density, and evapotranspiration, measured at multiple sites. After validation, a sensitivity analysis was done to assess the impact of permafrost loss on channel fen surface and subsurface flows by varying the ratio of wetland to upland forest permafrost plateaux in the modelled basin. Preliminary results suggest that a decrease in permafrost plateau area and an increase in wetland area results in decreased annual surface flows due to increased surface storage capacity and reduced runoff efficiency. A decrease in permafrost plateau area also results in decreased annual groundwater flows, though the impact is smaller, particularly in dry years. [250 Words]

Presentation type: Oral Presentation

H06-05: Hydrogeological characteristics of coarse blocky sediments in alpine watersheds

Masaki Hayashi[1], Jordan Harrington[1], and Andrius Paznekas[2]

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Abstract
River flow originating from the Canadian Rockies is characterized by a few months of freshet followed by a prolonged period of baseflow, which is critically important for freshwater ecosystems and water supply during dry months. While meltwater from glacier, buried ice, and late-lying snowpack can sustain some of the baseflow during summer months, groundwater discharge is the only year-around source of water. Due to the difficulty of field work, groundwater in alpine environments (i.e. above the tree line) has not been studied extensively. However, over the past decade or so, a number of studies have shown that groundwater in coarse blocky sediments is an important component of the alpine hydrologic cycle. Using a case study from two small (< 5 km^2) watersheds in the Canadian Rockies, we will highlight hydrogeological functions of typical alpine aquifers including proglacial moraine, rock glacier, and talus cone and slope. They share common behaviours characterized by a relatively fast recession of groundwater discharge followed by a much slower recession. We hypothesize that the fast recession represents fill-spill process of bedrock depressions and the slow recession represents drainage of disconnected depressions by seepage through fractures or some other mechanisms. Alpine aquifers consisting of coarse blocky sediments appear to have a sufficient capacity to store snowmelt and provide baseflow for the entire year. This suggests that late fall and winter flow in alpine streams may be insensitive to changes in the amount and timing of rain and snowmelt fluxes, which may have important implications in water resource management of the region.

Presentation type: Oral Presentation

H06-06: Permafrost response to fire-induced changes in the energy and water balance

Samuel C. Zipper[1], Jeffrey M. McKenzie[1], Stephan Gruber[2]

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[2] Department of Geography & Environmental Studies, Carleton University, Ottawa, ON, K1S 5B6

Abstract
While it is well known that fire can lead the degradation of permafrost, prior work has primarily focused on increases in the conduction of energy into the subsurface due to a decrease in the thickness of surface organic layers. Here, we shift the focus to changes in groundwater recharge caused by reduced plant water uptake and changes in the vertical distribution of soil hydraulic properties. We hypothesize that heat transport via advection (infiltration) is a significant contributor to post-fire permafrost degradation, particularly over short timescales, and that over longer timescales lateral heat transport via groundwater flow can lead to degradation of permafrost in areas not directly affected by fire. We test these hypotheses with a newly developed numerical modeling approach focusing on the 2007 Anaktuvuk River tundra fire. Our approach couples a one-dimensional land surface water/energy balance model to a three-dimensional groundwater flow model including freeze/thaw dynamics to represent key processes occurring across the critical zone. The simulations highlight spatiotemporal variability in post-fire permafrost degradation and the relative importance of changes in the water and energy balance. [177 words]

Presentation type: Oral Presentation preferred

H06-07: The Canadian Hydrological Model: A multiscale, multiphysics, variable-complexity hydrological model

Christopher B. Marsh[1,2]*, John W. Pomeroy[1,2], Howard S. Wheater[2,1], Raymond Spiteri[3,1]

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Abstract:
The Canadian Hydrological Model (CHM) is a modular, multi-physics, spatially distributed modelling framework designed for representing cold-regions hydrological processes. CHM uses existing high-quality open-source libraries and modern high-performance computing practices to provide a framework that allows for integration of a wide range of process representations, ranging from simple empirical relationships to physics-based, state-of-the-art algorithms. Modularity in structure and process representation allows for diagnosis of deficiencies in these aspects of the model. CHM also has sufficient flexibility in spatial representation and algorithm parameterisation to assess uncertainty in model structure, parameters, initial conditions, process representation, and spatial and temporal scales. By utilizing unstructured meshes, fewer than 1% of the computational elements of high-resolution structured (raster) grids are usually necessary. This preserves surface and sub-surface heterogeneity but results in fewer parameters and initial conditions. Snowpack, soil moisture, and streamflow observations at multiple spatial scales were used to evaluate CHM-modelled outputs in a sub-arctic and a mountain basin. The inclusion of a steady-state scalar-transport blowing-snow model in CHM improved simulations. Falsification of this process demonstrated the key role of mass transport on pre-melt snowcover heterogeneity and post-melt soil moisture and runoff generation.

Presentation type: Prefer Oral

H06-08: Evaluating blowing snow and avalanche models over the Canadian Rockies

Nicholas E. Wayand[1,2], Chris Marsh[1,2], and John Pomeroy[1,2]

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[2] Global Institute for Water Security, University of Saskatchewan, Canada

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Abstract
Horizontal and altitudinal redistribution of snow by avalanches and wind transport can dominate snowcover and snow depth patterns in alpine environments. This redistribution controls the amount of snow available for snowmelt and the timing of melt. It also influences areal albedo and spring snowmelt rates. However, the majority of large-extent land surface models do not consider redistribution by blowing snow and snow avalanching processes. This study evaluates several snow redistribution methods within the newly developed Canadian Hydrological Model (CHM) framework, using remotely sensed snowcover and albedo products. Initial results using the moderate-resolution imaging spectroradiometer (MODIS) at 500 m resolution found that CHM overestimates the snowcover fraction on mountain peaks without horizontal redistribution physics turned on. Landsat and Sentinel-2 products (spatial resolutions 30 m and 20 m, respectively) were used to identify winter and spring snow-free areas, indicative of wind scouring or avalanche sources and summer snowcover, indicative of snow deposition in drifts and avalanche deposits. An evaluation of the tradeoffs between model skill and the computational expense, depending on spatial resolution used, is discussed.

Presentation type: Oral Presentation

H06-09: Evaluating meteorological forcing sources for simulation of snowpack and streamflow in the Canadian Rockies

Xing Fang[1], John Pomeroy[1], and Nicholas Wayand[1]

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Abstract
This study evaluates two sources of meteorological forcing data for hydrological simulation of streamflow and snowpack in the Canadian Rocky Mountains. Hydrological models created using the Cold Regions Hydrological Modelling platform (CRHM), and parameterized using local research results include relevant streamflow generation processes for mountain forest basins: wind redistribution of alpine snow, gravitational snow transport on steep mountain slope, intercepted snow from forest canopies, infiltration to frozen and unfrozen soils, hillslope sub-surface water redistribution, and evapotranspiration from forests and alpine tundra. These models were driven by in-situ observations from 14 high altitude weather stations and near-surface output from the 2.5 km Global Environmental Multiscale (GEM) atmospheric model over two headwater basins: Marmot Creek Research Basin (~9.4 km^2) and Fortress Mountain Basin (~5.9 km^2). Air temperature, relative humidity, wind speed, incoming shortwave radiation, and precipitation were extracted from stations and GEM forecasts over each basin to drive the hydrological models during November 2014-September 2015. The simulations of snow accumulation and seasonal soil moisture using both sets of forcing showed differences in snow redistribution as GEM winds did not reflect the high wind speeds measured over ridges. Other difficulty for simulations with GEM 2.5-km included the timing of seasonal soil moisture fluctuation. The simulation of basin streamflow using station data was far better than that using GEM 2.5-km output, which missed timing and magnitude of seasonal streamflow compared to the observations and showed low predictive capability. [234 words]

Presentation type: Oral Presentation

H06-10: Use of a mountain shading model for spatial snowmelt predictions

Martin Queinnec[1,2*], Steven V. Weijs[2]

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Abstract
Snow is a major component of the water cycle and many regions depend on snowmelt as a water resource. Understanding the key principles driving snowmelt is therefore essential in order to make predictions on melt out dates and volumes of water stored in the snowpack. The morphological transformations of the snowpack are driven by meteorological variables, but other parameters, like the terrain topography, greatly influence the spatial distribution of snow and the snowpack radiation budget due to, for example, mountain shadowing. In this study the mountain shadows in Val Ferret catchment (Switzerland) are modeled from the digital elevation model and sun path. Thanks to the shading predictions, one can estimate the radiation budget at the snow surface without instruments on the ground and use these estimations as an input in snow models. These estimations can be further improved by taking into account clouds detected from time lapse images. SNOWPACK is a snow model that has been developed by the Swiss Institute for Snow and Avalanche Research (SLF) and used to simulate snow cover and snowpack microstructure. Simulations of the snowpack at chosen points and its evolution over time can be obtained from meteorological data and implemented physical models. The first objective of the project is to use the radiation budget estimated from the shadow model as an input in SNOWPACK and compare the results with other simulations using measured or estimated meteorological variables. Then the snow spatial distribution over the watershed is investigated using a set of variables obtained from the interpolation of SNOWPACK point simulations and snow shading predictions. Melt-out dates are used as ground truth to check the accuracy of the simulations.

Presentation type: Oral Presentation

H06-11: Modelling the snow surface energy balance during melt considering the effect of exposed crop stubble

Phillip Harder[1*], Warren Helgason[1,2], and John Pomeroy[1]

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Abstract
Spring snowmelt is the most important hydrological event on the Canadian prairies, recharging soil moisture and generating the majority of annual runoff. No-till agricultural practices results in most of the prairies have standing crop stubble throughout the winter and spring. The gradual emergence of this stubble during snowmelt may have important implications for the underlying snowpack energy balance over the large prairie region. However, stubble has not been accounted for in hydrological modelling or energy balance studies. Therefore, a physically based stubble-snow-atmosphere surface energy balance model has been developed that relates measurable stubble parameters (stubble height, stalk width, stalk density and stubble albedo) to the underlying snow surface energy balance. This model includes: the attenuation of shortwave radiation through stubble; the calculation of sky and stubble view factors to solve for the stubble and snow surface temperatures for longwave radiation; and a flux-gradient approach to estimate turbulent fluxes with a parallel resistance scheme for stubble and snow sources/sinks. The small-scale nature of stubble-snow-atmosphere interactions makes direct validation of the energy balance terms challenging. However, model performance can be assessed by comparing to measured snow surface temperature, stubble temperature, surface incoming shortwave radiation and areal average turbulent fluxes. Observations for model assessment came from two intensive field campaigns during snowmelt in 2015 and 2016 for wheat and canola stubble fields in north-central Saskatchewan, Canada. The model was not calibrated to melt rates, yet compared well with available observations, providing confidence in the model structure and parameterization. Sensitivity analysis using the model revealed compensatory relationships in energy balance terms resulting in a slow reduction of energy available for snowmelt as stubble height increases.

Presentation type: Oral Presentation

H06-12: A comparison of empirical vs physically-based approaches for modeling end of winter snow distribution on South Baffin Island near Iqaluit, Nunavut

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Abstract
Snowmelt is the largest annual hydrologic event in the Arctic, and prediction of freshet volume and timing requires an accurate estimate of watershed snow accumulation. North of the treeline, snow is redistributed by wind during and after snowfalls, causing a spatially variable end-of-winter snow distribution (EOWSD). Therefore, point measurements of snowfall or standing snow depth are poor estimates of watershed accumulation. To improve estimates of EOWSD, we have employed modeling techniques and extensive field sampling in a small watershed near Iqaluit, Nunavut. This research focuses on development and inter-comparison of two contrasting modelling approaches: an empirically-based, discrete landscape-unit approach, versus a well-established, spatially distributed and physically-based blowing snow model. The first method segments the landscape into "terrain units", each characterized by a distinct average snow depth. These are empirically determined from statistical examination of field data. Terrain variables (such as slope, curvature, or topographic openness) are calculated from a digital elevation model (DEM) and compared to snow water equivalent (SWE) depths measured over 3 seasons. Two approaches (K-means clustering of terrain variables and moving-window focal functions) can discriminate 3-4 terrain units with distinct accumulation patterns, with deeper "drift zones" accumulating a disproportionate share of the watershed's SWE on leeward slopes, locally-sheltered areas, and the base of hillslopes. The second method employs a fully-distributed, physically-based blowing snow model (SnowModel: Liston, 2006). Parameterized with topographic and meteorological data from the study watershed (including wind-bias corrected snowfall), the software distributes the meteorological conditions over the landscape, and resolves snow mass fluxes between grid elements per time step, culminating in the EOWSD. This model's ability to reproduce the EOWSD, including the "drift zones" observed in field data and empirical models, will be evaluated and reported. [281 words]

Presentation type: Oral presentation

H06-13: Application of global datasets and data assimilation for hydrological modelling in the Canadian Sub-Arctic

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Abstract
Hydrological modelling in the Canadian Sub-Arctic is hindered by limited local meteorological data. Local watershed modelling often relies on data from a sparse network of meteorological stations with a rough density of 3 active stations per 100,000 km². Global meteorological datasets which combine a variety of data sources hold great promise due to complete spatial and extended temporal coverage. This study demonstrates the application of global datasets and data assimilation techniques for hydrological modelling of a Sub-Arctic watershed. The Snare Watershed is a 13,300 km² snowmelt driven sub-basin of the Mackenzie River Basin in the Northwest Territories. The Snare Watershed is data sparse in terms of meteorological data, but well gauged for river discharge since the late 1970s. End of winter snowpack surveys have been conducted every year from 1978-present. Precipitation data are taken from Multi-Source Weighted-Ensemble Precipitation (MSWEP) and temperature data from Watch Forcing Data applied to European Reanalysis (ERA)-Interim data (WFDEI). These global re-analysis datasets prepared by the European Union FP7 eartH2Observe project extend from 1979 to 2014. GlobSnow-2 is a global product funded by the European Space Agency (ESA) that provides Snow Water Equivalent (SWE) measurement. Downscaled datasets are used as forcing data in a distributed version of the HBV model implemented in the wflow framework. Study results demonstrate the successful application of global datasets to the Snare Watershed, but that validation of actual frozen precipitation and snowpack conditions is difficult. The distributed hydrological model shows good stream flow simulation performance based on statistical model evaluation techniques. It is expected that data assimilation of stream flow using an Ensemble Kalman Filter will further improve model performance. This study shows that global re-analysis datasets hold great potential for understanding the hydrology and snowpack of the expansive Sub-Arctic.
[289 words]

Presentation type: Oral Presentation

H06-14: Monitoring Lake Ice Growth and Decay in Central Ontario using RADARSAT-2: 2008-2016

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Abstract
Lakes are an important component of the Canadian landscape and an important component in understanding regional climate. Additionally, understanding lake ice processes helps to better model changes in regional climate systems. In recent years, there has been a decrease in the monitoring of lake ice events across Canada. Remote sensing provides a method to improve the spatial and temporal coherence of lake ice databases. Radar can solve the traditional problems associated with optical remote sensing, which can experience limitations due to clouds or other factors. Radar has been applied extensively at northern latitudes for studying growth and decay, however, it has been used less extensively for temperate latitudes. This study investigates the application of radar in temperate latitudes through the use of RADARSAT-2. The focus of this research is ice cover in the Haliburton Forest and Wildlife Reserve in Central Ontario between October 2008 and April, 2016. Radar data was used to identify the occurrence of freeze onset, melt onset and ice-free / open water. Initial patterns observed in the backscatter values for sixteen lakes in Central Ontario reflect expected patterns in lake ice backscatter return; noticeable increases observed in the winter season and subsequent decreases in the spring as the ice melts. The identification of ice phenology events was conducted through the application of previous methods that were identified as being successful in the Arctic compared to optical satellite images and visual observations. This research works towards applying and modifying the existing algorithms for use in lower latitudes. The development of these algorithms for automated detection will aid in more effective identification of lake ice events and improve the spatial and temporal resolution of lake ice databases. [278 words]

Preferred Presentation Type: Oral Presentation

H06-15: Snow water equivalent monitoring using a coupled snowpack evolution and microwave emission models over North-Eastern Canada

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Abstract
Over northern snowmelt-dominated basins, the snow water equivalent (SWE) is of primary interest for hydrological forecasting. However, ground-based SWE measurements are very sparse and SWE retrieval from satellite data is still not well resolved, in particular from microwave (MW) measurements, the only type of data sensible to the snow mass. For improving the SWE prediction, the proposed approach is the coupling of a detailed multilayer snowpack model (Crocus) with a microwave snow emission model (DMRT-ML) in order to be able to assimilate microwave satellite observations. Crocus simulations were driven by meteorological prediction generated by the Canadian Global Environmental Multiscale (GEM) model at 10 km spatial resolution, and compared to continuous daily snow depth (SD) and SWE measurements over Québec, North-Eastern Canada (56° - 45°N) at 14 nivometric stations and during up to 4 years (2012-2016). The results presented show a mean bias of the maximum SD at the end of the winter overestimated by 37% and a mean bias of the annual maximum SWE of 37.3 ± 39.3 $kg.m^{-2}$ (15.7%) with variations up to +32%. This observed large variability could lead to significant and dramatic consequences on spring flood forecasts and hydropower production. We show how MW Tb could reduce the uncertainties in SWE and SD forecasts without any ground-based measurements.

Presentation type: Oral Presentation

H06-16: Improving quantification of mountain snowpack properties using observations from Unmanned Air Vehicles (UAVs)

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Abstract
Mountain snowpacks in western North America represent a critical seasonal reservoir of water, and snowmelt is a significant component of mountain hydrological budgets. Ground-based snow measurements are typically point-based and unable to describe the spatial variability of snow accumulation and melt rates. Unmanned Air Vehicle (UAV) technologies allow the creation of high resolution digital surface models which, on repeat flights, have demonstrated usefulness in measuring snow depth and ablation patterns in alpine environments. This study presents results from a UAV-based observation campaign that captured imagery at the Fortress Mountain Snow Laboratory, Canadian Rockies, in 2017. The UAV was flown multiple times from February to May with both an RGB camera and thermal infrared imager, and the ability of UAV remote sensing to measure the spatial variability of snow properties and their change is assessed. Simultaneous *in situ* measurements of snow density, snow temperature, snow liquid water content, and snow water equivalent, in conjunction with UAV observations, are used to evaluate the seasonal evolution of snow water equivalent, wetness and energy state and to examine individual storm events, wind redistribution, melt variability, and snow surface temperature contrasts. The spatial covariances of variables important to snow ablation are examined and their implications for scaling snow ablation calculations and selecting model resolution and discretization are quantified.

Presentation type: Oral

H06-17: Temporal and spatial variability of snow water equivalent, snow depth, and snow density in a 15,000 km^2 sub-arctic basin

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Abstract

End of year, basin-wide, snow water equivalent (SWE) is an important hydrologic variable for use in hydro-power management and spring water level prediction. For large basins, SWE is often estimated using a sparse network of snow survey sites. In remote northern basins increasing the number of sites to improve SWE estimates can be costly. In this study, historical snow surveys (1978-2016) conducted by the NWT Power Corporation across the ~15,000 km^2 Snare River basin near Yellowknife, NWT at a network of ten survey sites were analyzed to identify local and regional scales of variability in SWE, snow depth, and snow bulk density. Snow regimes were found to differ significantly between sites above vs below treeline. The coefficient of variation of SWE in sites above treeline was 0.74 compared with a much lower value of 0.28 below. The regression R^2 between snow depth and SWE above treeline was 0.91 compared to 0.55 below. By consideration of these differences and the time required to perform a snow depth measurement compared to a density measurement, optimal sampling ratios were computed. Above treeline, a depth to density ratio of 10:1 was found to be optimal while below treeline the optimal ratio was 5:1. Although the three snow parameters varied more above treeline than below, the much weaker correlation between depth and density resulted in the different sampling schemes. Finally, on a larger regional scale, above treeline sites were poorly correlated to each other while below treeline sites correlated well. Above treeline sites consistently contributed approximately three times the error to basin wide SWE estimates than sites below. Therefore, sampling strategies for this large sub-arctic basin should be refined for improved efficiency and accuracy by accounting for differences in both within and between-site variations in snow depth and density.
[294 words]

Presentation type: Oral Presentation

H06-18: 2D Frequency Analysis of Irregularly Sampled Snowpack Properties

N.J. Kinar[1], J.W. Pomeroy, J. Shea, M. Schirmer, P. Harder

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Spatial datasets in environmental science are often sampled in an irregular fashion, where the spacing between successive data points varies. This is a characteristic of the densified point cloud obtained using structure from motion (SfM) analysis of airborne photography from UAVs (Unmanned Air Vehicles). The densified point cloud is then interpolated to form a digital surface model (DSM). One example of a DSM with trends of interest to cold regions hydrology is of the snow surface elevation and if temporally sequenced imagery is used then the snow surface ablation rate and snow depth are two important derived measurements. Frequency analysis of the point cloud irregular datasets can show spatial trends, but interpolation or kriging is often necessary to extract a DSM and to use 2D Fourier analysis on a regular grid. A new periodogram was introduced that allows for spectral analysis of the point cloud irregular datasets without transformation to a regular grid. This periodogram suppresses interpolation artefacts that may cause errors in the gridded datasets. These artefacts include aliasing for interpolation and "bullseye" effects for kriging. Moreover, non-uniform discrete Fourier transform algorithms applied to an interpolated dataset can show spurious low-frequency noise. The periodogram was used to analyze UAV-derived datasets to obtain snow surface elevation, snow depth and snow depth ablation rate during accumulation and melt without the use of nominal interpolation algorithms prior to frequency analysis. Datasets were obtained from SfM analysis of digital photography from an Ebee UAV flown over a Saskatchewan prairie field and an Alberta mountain ridgetop. The point cloud can be analyzed by the periodogram to produce a better DSM, whereas peridogram analysis of an existing DSM can be used to show spatial trends.

Presentation type: Oral presentation

H06-19: On the closure of the water balance in the catchments of the Canadian Rockies

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Abstract:
In this study, we aim to improve our understanding of the main water balance components (i.e., precipitation, evaporation and stream flow) across a range of catchments in the Canadian Rockies. To this end, we conduct a combined analysis of multiple observations and model simulations.
Runoff ratio (the ratio of observed stream flow to precipitation) in these catchments is relatively high (>0.5) and in some cases exceeds one, which can be due to underestimation of precipitation or glacier melt. To gain insight into this problem, we make use of a simple conceptual model with reasonable process representation. The model is forced with precipitation estimates from different products (ANUSPLIN, WFDEI and CaPA). To investigate the accuracy of existing orographic correction in the precipitation products a parametric relation between elevation and precipitation is applied additionally. The parameters of this relation are calibrated together with the parameters of the model. The simulated evaporation fluxes are forced to be in the range of, and in harmony with, evapotranspiration from independent products (such as MODIS). The change in simulated glacier storage is required to be consistent with in situ estimates of glacier mass loss. The overall storage dynamics of the catchments can also be constrained using GRACE data.
Our results show that the precipitation products, to a large extent, underestimate the precipitation. However, the established relationship between elevation and precipitation can be implemented in precipitation models over the Canadian Rockies to account for this input error.
[240 words]

Presentation type: Oral Presentation

H06-20: Current and future projections of glacier contribution to streamflow in the upper Athabasca River Basin

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Abstract
The Athabasca River flows over 1,500 km from its source at the Columbia Icefield in Jasper National Park to its confluence with the Peace River near Lake Athabasca, making it one of longest free-flowing rivers in North America. The region has experienced a recent dramatic loss in glacier area, and while 240 km^2 (6%) of the area upstream of Jasper, AB was glaciated as of 2010, a further loss of 30-40% is projected by 2050. Here we present a modified HBV-EC hydrological model within the Raven Hydrological Modelling Framework for the upper Athabasca River Basin (ARB). The model dynamically incorporates decadal changes in glacier area under past and future climate scenarios, and applies a tracer routine to estimate the daily contribution of glacial melt to streamflow. From 1980 – 2010, we estimate that glacial melt contributed 7% of the total annual streamflow and up to 15% during late summer. Future climate scenarios generally project warmer air temperatures, higher precipitation, and large decreases in glacial area. Under these scenarios, we estimate an earlier, larger freshet due to a higher snowpack and earlier melt, and a decrease of 10-20% in late summer streamflow due to a reduction in glacial melt contributions. By 2050, no climate scenarios provided conditions to offset the decrease in fall streamflow due to large reductions in glacier area and melt. These results present a widely applicable means of simulating the effects of glacier change on streamflow, and suggest future decreases in fall streamflow in the upper ARB are likely, presenting significant implications for future watershed management.

Presentation Type: Oral Presentation

H06-21: Quantifying centurial changes in the contribution of upstream snow and glacier melt to downstream river discharge

Kerstin Stahl[1*], Irene Kohn[1], Mario Böhm[2], Daphné Freudiger[1], Kai Gerlinger[2], Jan Seibert[3], Markus Weiler[2]

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Abstract
Mountain headwaters provide water to many lowland regions. In particular during summer, river discharge is often sustained by the snow and icemelt contributions from mountain headwaters upstream. Concerns over the future loss of these contributions suggest that past changes should be analyzed and modeled to better understand the processes and quantitative changes. This study explored long-term changes in the rain, snowmelt and icemelt components of the discharge of the River Rhine. The Rhine's alpine headwaters have rapidly been deglaciating whereas downstream water uses have been increasing in recent decades. Quantification of the discharge components was based on a new method of runoff component tracking that was implemented into a hydrological model chain that consists of the HBV-Light model in the headwaters and the distributed hydrological model LARSIM for the remaining Rhine basin. To obtain a transient model run over the long period from 1901 to 2006 at daily resolution, the models were driven with a reconstructed climate input and were constrained by a multi-site multi-criteria calibration to glacier volume change, snow cover and snow water equivalent distribution and discharge variability. The analysis of the resulting daily discharge components revealed that over the course of the 20th century, the loss of glacier volume and glacier area in the headwaters appears to have compensated an increasingly negative glacier mass balance, resulting in a mostly non-significant long-term change to the ice melt component in summer streamflow. For extremely dry years, record daily ice melt fractions can still provide more than 20% of the daily discharge during fall low flow conditions along the mid and lower reaches of the Rhine. As the rain and snow components during summer have declined in recent decades, the simulated changes in discharge components allow to quantify the low flow hazard that may loom ahead. [296 words]

Presentation type: Oral Presentation

H06-22: Improvements to Regional Hydrologic Modeling by Incorporating Ice Dynamics

M.A. Schnorbus[1], B. Menounos[2], A. Schoeneberg[3], F. Anslow[3], G. Jost[4] and R.D. Moore[5]

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Abstract:
The cryosphere is particularly vulnerable to changes in climate. For many catchments, glaciers provide water to streams, especially during summer and early autumn when seasonal snow packs have been depleted. Increased emissions of greenhouse gasses will accelerate warming in the decades ahead leading to strong mass loss and subsequent retreat of alpine glaciers. Understanding how the contribution of glacier runoff may change in future has important implications for a variety of water resources issues ranging from the impacts of higher water temperatures and lower summer flows on aquatic habitat to the effects of seasonal changes in runoff on hydropower generation. Consequently, there is a need to increase understanding of the influence of glacier storage changes on runoff and streamflow in mountainous watersheds. We developed a modeling system that explicitly simulates ice dynamics, glacier mass balance and runoff. Our short-term objectives are to use this modelling system to assess potential future hydrologic changes in glaciated drainages throughout western Canada (watersheds draining the Rockies, Columbia and Coast Mountains). The modelling system employs an upgraded version of the Variable Infiltration Capacity (VIC) hydrology model (which now includes glacier mass balance) coupled to a glacier dynamics model (UBC Regional Glaciation Model). Our presentation will focus on the verification and application of this new model to simulate inflow to: i) the Bridge River catchment above La Joie Dam; and ii) the Columbia River above Mica Dam.

Presentation Type: Oral

H06-23: Hydrological response of Peyto Glacier to climate change and glacier recession

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Abstract
Mountain snow and ice play important roles in hydrological cycle of alpine regions by regulating water availability downstream. This study considers the combined impacts of climate change and glacier recession on the hydrology and water balance of a glacierized basin in the Canadian Rockies. A glacier hydrology model developed in the Cold Regions Hydrological Modelling platform was used to simulate runoff from Peyto Glacier in Banff National Park, Alberta. Peyto Glacier has undergone a continuous mass loss over the last five decades, leading to reductions in glacierized area, increase in proportional and areal ice exposure, and changes to elevation and slope of the glacier surface. The model considered redistribution of snow by wind and avalanche, full radiation and turbulent transfer energetics to snow and ice and firnification of perennial snow. It was set up using hydrological response units that considered elevation bands, surface slope and aspect, as well as the landcover and its change. Long-term observations of mass balance, snow and ice depths and discharge at the glacier outlet were used to evaluate the model performance, which was adequate for this purpose. Using meteorological forcing data from 1965–2014, basin glacier hydrology was simulated using the fixed glacier configurations of 1966 and 2006. The outputs show that both changes in climate and glacier configuration are causing changes in melt rate and streamflow discharge. There is increased discharge in recent decades compared to the 1960-70s. The results suggest that the increased exposure of glacier ice and lower surface elevation due to glacier thinning are less influential than climate warming in increasing streamflow over time; and that the streamflow from this glacier is still in the increasing phase.

Presentation type: Oral Presentation

H06-24: Trends in the hydrology of a small Arctic basin in the tundra-taiga treeline region

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Abstract

Arctic air temperatures and tundra shrub coverage and density have increased, with a poorly understood impact on hydrology. Long term analysis of well-studied small Arctic basins with reliable weather data is useful to describe and quantify the connections between a changing environment and hydrology. This study presents the implementation of a physically based hydrological model over a 56-yr period to a small basin underlined by permafrost in the tundra-taiga treeline transition region in northwestern Canada. The model includes all the key physical processes found in this region, such as permafrost freeze/thaw, flow through organic terrain, blowing snow sublimation and redistribution, snow interception from canopy, and snow accumulation and melt. The model was implemented to allow changing vegetation by increasing shrub cover and stem density following estimations from field ecological studies in the region. Model performance was validated against daily streamflow, snow water equivalent, ground surface temperature and ground freeze/thaw records, showing an adequate representation of all of them. A long term seasonal and annual trend analysis of weather forcing data and hydrological fluxes, such as evapotranspiration, snow redistribution, sublimation, snowmelt and streamflow is presented. Trends in active layer thickness, peak flows, peak flow timing and flow duration curves are quantified and discussed. Results from this study can help anticipate the impact of future changes in climate and vegetation on the hydrology of Arctic basins.

Presentation type: Oral Presentation

H06-25: The subcatchment- and catchment-scale hydrology of a boreal headwater peatland complex with sporadic permafrost.

Oliver Sonnentag[1], Manuel Helbig[1], Ryan Connon[2], Gabriel Hould Gosselin[1], Emily Haughton[2], Karoline Wischnewski[1], Jessica Hanisch[1], Tim Moore[3], and William Quinton[2]

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Abstract
The permafrost region of the Northern Hemisphere has been experiencing twice the rate of climate warming compared to the rest of the Earth, resulting in the degradation of the cryosphere. A large portion of the high-latitude boreal forests of northwestern Canada grows on low-lying organic-rich lands with relative warm and thin isolated, sporadic and discontinuous permafrost. Along this southern limit of permafrost, increasingly warmer temperatures have caused widespread permafrost thaw leading to land cover changes at unprecedented rates. A prominent change includes wetland expansion at the expense of *Picea mariana* (black spruce)-dominated forest due to ground surface subsidence caused by the thawing of ice-rich permafrost leading to collapsing peat plateaus. Recent conceptual advances have provided important new insights into high-latitude boreal forest hydrology. However, refined quantitative understanding of the mechanisms behind water storage and movement at subcatchment and catchment scales is needed from a water resources management perspective. Here we combine multi-year daily runoff measurements with modeled spatially explicit estimates of evapotranspiration to characterize the monthly growing season catchment scale (~150 km^2) hydrological response of a boreal headwater peatland complex with sporadic permafrost in the southern Northwest Territories. The corresponding water budget components at subcatchment scale (~0.5 km^2) were obtained from concurrent cutthroat flume runoff and eddy covariance evapotranspiration measurements. The highly significant linear relationships for runoff (r^2=0.64) and evapotranspiration (r^2=0.75) between subcatchment and catchment scales suggest that the mineral upland-dominated downstream portion of the catchment acts hydrologically similar to the headwater portion dominated by boreal peatland complexes. Breakpoint analysis in combination with moving window statistics on multi-year time-series of daily total and liquid precipitation, and snow water equivalent suggest a recent transition to a more rainfall-controlled runoff regime. [279 words]

Presentation type: Oral Presentation

H06-26: Climate and Geographic Controls on Changing Landscape Freeze and Thaw Patterns in Quebec (1979 – 2010)

Ali Nazemi, Elias Melhe, Javad Manashti, and Pablo Jaramillo

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Abstract
Landscape Freeze and thaw (F/T) cycles play an important role in determining surface energy and water balance in cold regions. Using satellite observations available at the 25 kilometer scale, we look at the annual trends in the dynamic of F/T in the province of Quebec from 1979 to 2010. Grid scale trends are inspected using the Mann-Kendall trend test within each of the eight ecozones of Quebec as well as the province as a whole. It is shown that there is a general decrease in the frozen conditions combined with a province-wide increase in the thawed states, particularly in the higher latitudes. The geographic controls on the annual trend in the frozen, thawed and transitional (i.e. AM frozen, PM thawed or vice versa) in each ecozone are demonstrated, which reveals stepper trends towards increasing number of thawed days and decreasing number of frozen days in northern latitudes. An attempt is also made to link the annual trends in landscape F/T to annual trend in average minimum and maximum daily temperatures as well as diurnal temperature differences over each of the ecozones as well as the whole province. Our study provides a comprehensive understanding on the changing temperature control on the F/T in Quebec and can provide another evidence for unfolding effects of climate change in the region. [218 words]

Presentation type: Oral Presentation

H06-27: The changing snow environment of the western Canadian Arctic

Philip Marsh[1], P. Mann[1], B. Walker[1], A. Toure[1], E. Wilcox[1], M. Tusi[1], A. Jitnikovitch[1], O. Sonnentag[2] and C. Derksen[3]

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3. Environment and Climate Change Canada, Downsview, ON

Abstract
The arctic climate is changing at an unprecedented rate, transforming all aspects of the arctic environment, including vegetation, snow and the active layer. Understanding the integrated impacts of these changes on lake levels and streamflow is essential to understanding past and future implications of a changing climate on the arctic hydrologic system. This paper will focus on studies of the snow environment at the Trail Valley Creek research watershed south of Tuktoyaktuk, NWT, in the western Canadian Arctic. We will present an analysis of snow data from the early 1960s to present in order to document changes in the snow regime to date. We will also describe novel observation methods to characterize current snowfall and snow accumulation, as well as the spatial variability of end of winter snow cover, and how the snow cover evolves over the spring melt period. This integrated field program includes the use of snow surveys, unmanned aerial systems, cosmic ray sensors, and eddy covariance systems for example. These data sets will be used to test the high resolution hydrologic models required to understand past, and future, changes in hydrology.

Presentation type: Oral Presentation

H06-28: Are effects of transient vegetation and soil changes as important as climate change impacts on hydrological processes?

Kabir Rasouli[1,3], Paul H. Whitfield[1,2], Lawrence W. Martz[1,3], Andrew M. Ireson[1,4,5], J. Richard Janowicz[1,6], Danny Marks[7] and John W. Pomeroy[1,3,4]

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Abstract:
Understanding the sensitivity of hydrological processes to transient vegetation, soils, and climate changes in snow-covered mountains is important for water and energy security. The objective of this study is to quantify the response of mountain hydrology to transient climate and vegetation/soil changes in light of uncertainty due to climate models. Three basins were selected for this research: Wolf Creek Research Basin (WCRB), Canada; Marmot Creek Research Basin (MCRB), Canada; and Reynolds Mountain East (RME) catchment, USA. A hydrological model for each basin was set up in the Cold Regions Hydrological Modelling platform (CRHM) and a climate perturbation sensitivity analysis was conducted based on a monthly perturbation of measured meteorological time series at multiple elevations in the mountain basins. Perturbations were developed from 11 NARCCAP regional climate models for 2040-2070. Model parameter changes due to transient changes of vegetation and soils were obtained from a review of mountain ecology. In response to climate change, modelled peak snow water equivalent (SWE) decreased whilst evapotranspiration and annual discharge volume increased in all basins. Warming increased the rainfall ratio so that all three snowfall-dominated basins became rainfall-dominated. Vegetation/soil changes moderated the impact of climate change on peak SWE at high elevations, timing of peak SWE, peak discharge, evapotranspiration, annual discharge volume, soil moisture, and permafrost degradation. However, these changes intensified the impact of climate change on decreasing peak SWE at medium elevations, spatial variability of peak SWE, and sublimation. The uncertainty due to climate models was greater than the differences in discharge due to climate change in the three basins and differences in snow regimes due to climate change at high elevations and high latitudes. The results of this research can be used to anticipate the detailed hydrological impacts of climate, vegetation, and soil changes on mountain environments.

Presentation type: Oral Presentation

H06-29: Exploring the hydrological and meteorological conditions leading to the 2016 Horse River Wildfire, and the subsequent burning of a fen watershed in Northern Alberta, Canada

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Abstract
In the sub-humid Athabasca region of the Western Boreal Plain (WBP), Alberta, peatlands comprise ~50% of the landscape, primarily as moderate-rich fens. During the spring of 2016, the 590,000 ha Horse River wildfire began near Fort McMurray and spread across the WBP, resulting in many burned fens, including an instrumented moderate-rich fen watershed (Poplar Fen), located ~30 km north of Fort McMurray. Efforts are underway to look into the hydrological and meteorological conditions leading up to the Horse River Wildfire. Currently, it is unknown whether the conditions prior to the fire were outside the range of natural variability for WBP climate cycles. The primary objective of this research is to characterize the fall (antecedent), winter, and early spring hydrological and meteorological conditions leading up to the Horse River wildfire. Results illustrate that from the fall of 2015 to the spring of 2016, Poplar fen underwent a drying period of decreasing water table and soil moisture. Due to dry fall conditions as well as over-winter drainage, the modest winter snowfall was not sufficient to raise soil moisture levels above those observed in the fall. Following melt, Poplar fen continued to dry in the presence of the warm and dry meteorological conditions that existed in the region prior to the fire in April 2016. For three of the previous 20 years, the region experienced meteorological conditions that were comparable to 2016. Thus, the wildfire was likely not a result of abnormal drought conditions, but rather the synchronicity of dry fall, winter, and spring conditions, which are not uncommon for the WBP. Spring wildfire predictive strategies could therefore be improved with enhanced hydrological monitoring of watersheds over this time period, including accounting for mid-winter drainage of unfrozen peatlands and high snow sublimation rates during warm winters.

Presentation Type: Oral Presentation

H06-30: An experimental tool for the simulation of snowmelt nutrient release and transport from cultivated areas – the WINTRA model

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Abstract

For many cold regions, nutrient transport during snowmelt represents the dominant runoff event of the year and accounts for most annual N (nitrogen) and P (phosphorous) export. However, modelling this process remains a major scientific challenge. The main challenges include adequate spatial representation of soil processes, harmonization of transport phenomena occurring at multiple timescales, process dependency on climate, and model over-parameterization. Process-based models that are suitable for nutrient simulations in cold climates are scarce and have been seldom tested in cold regions subject to cultivation, such as the Canadian Prairies. In such regions, snowfall is redistributed by the wind over the winter and snow accumulations melt in spring where their disposition to infiltration and runoff is strongly affected by ice-filled and water-filled pores in partially frozen soils. In this research, a newly developed, diagnostic tool, the WINTRA model of hydrochemical transport from melting snow over partially frozen soils, is used to investigate the release and transport of N and P from a series of experimental, intensely monitored agricultural sites located in the South Tobacco Creek basin, a tributary of the Red River basin in Manitoba, Canada. The results show promising model performance and demonstrate how a diagnostic model can be used to provide insights into key snowpack and soil nutrient release mechanisms. A parameter sensitivity test was also conducted to investigate the effect of spatial and temporal changes in soil and snow processes on snowmelt runoff concentrations. This model underpins basic research into process dynamics and assists in the development of more accurate and reliable process-based models for large-scale nutrient export predictions for agricultural cold regions.

Presentation type: Oral Presentation

H06-31: Simulations of the influence of wetland drainage on the Canadian Prairies: an example at Smith Creek Research Basin, Saskatchewan

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Abstract

Wetland drainage is influencing the hydrological behaviour of Canada's Prairie Pothole Region. Wetlands provide social and environmental benefits such as wildlife habitat and flood attenuation, but may also be a nuisance to agricultural producers. The continued unlicensed drainage of wetlands in Saskatchewan is expected to increase Disaster Financial Assistance payments in the next 5 years. The Smith Creek Research Basin, 60 km southeast of Yorkton, Saskatchewan, has recorded a 14-fold increase in annual streamflow volume and a tripling of peak daily discharge rates from 1975 to 2014. Between 1958 and 2015, the number of wetlands impacted by drainage rose from 8% to 74% and the length of installed ditches increased from 56 km to 1342 km. This study investigates the influence of wetland drainage on streamflow generation in the Smith Creek Research Basin. The Prairie Hydrological Model configuration of the Cold Regions Hydrological Modelling Platform (CRHM) was used to simulate changes over a historical period using the Pothole Cascade Model for runoff routing between wetlands. The model was forced with meteorological data from nearby Environment Canada weather stations and parameterised using the results of local field studies. Runoff routing between wetlands was calibrated using the dynamically dimensioned search (DDS) algorithm to optimize Nash *Sutcliffe* efficiency (NSE) between simulated and observed streamflow. A sensitivity analysis was performed to determine the influence of reduced wetland storage volumes and increased drainage channels on streamflow generation. Observed wetland configurations, from the late 1950s to the current state, were used and held constant for individual model runs. Results indicate that decreased wetland storage volumes and increased drainage channel networks increase annual streamflow volumes and peak discharge rates over a wide range of meteorological and antecedent conditions. These results demonstrate the impact of wetland drainage on streamflow generation in agriculturally dominated basins of the Canadian Prairies.

Presentation Type: Oral

H06-32: Causes of the shapes of hysteretic connected-fraction curves of Prairie drainage basins

Kevin Shook[1], and John Pomeroy[2]

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Abstract
The Prairie Pothole Region (PPR) of the Canadian Prairies and northern United States Great Plains is characterized by the presence of millions of topographic depressions left after deglaciation. Internally drained catchments and surface water storage in depressions result in variations in the fractions of the basins that are hydrologically connected, as when depressions are full they can spill and so conduct water overland to the basin outlet. Small-scale, high resolution models have demonstrated that the variability of the connected fraction is non-linear and hysteretic with respect to the water storage. This study examines the causes of the relationship between connected fraction and storage of water in depressions. The effects of "gatekeeping", where a large depression prevents land upstream from contributing flow until it is filled, are examined. The spatial arrangement of depressions is demonstrated to be important to the storage-connected fraction relationship at small scales, but becomes less important as the size of the basin, and consequently the number of depressions, increases. However, where the storage is concentrated in a single large depression at the basin outlet, the effects of gatekeeping can be extreme. It is demonstrated that the relationship between the connected fraction of a basin and its fractional storage of water is linear due to the a) the frequency distribution of water storage in the depressions and b) the magnitude of the area contributing flow to each depression. Given these findings, it may be possible to develop simplified large-scale models of how the connected fraction varies with depressional storage.

Presentation type: Oral Presentation

H06-33: Flow regulation controls on daily river discharge into Hudson Bay

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Abstract
Apart from net precipitation, sea ice production and melt, and oceanic transport, terrestrial river discharge largely controls the freshwater budget of Hudson Bay, with the largest contributions from the Churchill/Nelson and La Grande Rivière systems. These two river systems are managed for hydropower production leading to significantly altered hydrological regimes. This presentation will explore flow regulation controls on daily river discharge variations and trends in the Churchill/Nelson and La Grande Rivière over the period 1960-2016. Daily observed streamflow data from the Water Survey of Canada, Manitoba Hydro and Hydro-Québec are used in the analyses. Decadal climatological hydrographs of the mean and coefficient of variation of daily river discharge are first developed to assess the changing hydrological regimes in both systems. Then spectral analyses are used to infer the dominant controls on daily river discharge input to Hudson Bay from the Churchill/Nelson and La Grande Rivière systems. Apart from the expected peak in spectral power on an annual timescale arising from the nival regimes observed in both systems, a strong secondary peak emerges at the weekly timescale from flow regulation due to hydropower production. Further analyses reveal robust declines in daily river discharge during weekends and statutory holidays, demonstrating the importance of regulation on freshwater influx to Hudson Bay. The presentation will close with a brief discussion of the potential physical, biochemical and ecological impacts of observed changes in the hydrology of the Churchill/Nelson and La Grande Rivière systems and prospects for the future.

Presentation type: Oral Presentation

H06-34: Water-Energy Nexus and Future Water Security in Northeast British Columbia

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Abstract
In recent decades, the Peace River watershed in northeast British Columbia (NEBC) has experienced rapid growth in shale gas development activities; resulting in significant increases in surface water and groundwater use and a growing conflict over the use and protection of these water resources. Industrial water demand in the Peace River watershed is projected to increase by over 300% by 2030 under a high development scenario, and future water security in the context of the water-energy nexus is unknown, especially with the continued climate warming. In this study, the Cold Regions Hydrological Model (CRHM) is used to simulate the current and future water balance for two headwater catchments of the Peace River watershed, one in the mountains and one in the plains. These catchments have both been impacted by the recent shale gas development and contain one or more oil and gas industry water use permits. Statistically downscaled forcing datasets based on three Global Climate Models (GCMs) from phase 5 of the Coupled Model Intercomparison Project (CMIP5) were disaggregated to an hourly time step and used to drive the CRHM models, under representative concentration pathways (RCPs) 4.5 and 8.5. Water quantity projections for future decades (2020s, 2030s, 2040s, and 2050s) were then compared to the projected water use for low, medium, and high shale gas development scenarios and used to estimate the potential for water scarcity in the region. Results from this study provide insight into future water management challenges in NEBC. [242 words]

Presentation type: Oral Presentation or Poster – no preference.

H06-35: Improved representation of water management and reservoirs in a land surface-hydrology model

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Abstract
Reservoirs significantly affect the flow regime in river systems by changing the magnitude and timing of streamflows. Failure to represent these effects limits the performance of most land surface-hydrology models in highly regulated basins such as the Saskatchewan River Basin (SaskRB). Adequate representation of reservoirs and their operation in a model is therefore essential for realistic representation of the downstream flow regime. To this end, we implemented a reservoir routine algorithm in the MESH land surface-hydrology model and tested it over the Saskatchewan River Basin (SaskRB). The implemented reservoir algorithm uses an inflow-outflow relationship that accounts for the physical characteristics of reservoirs (e.g., reservoir capacity and storage-area-elevation relationships) and includes simplified operational characteristics based on local information (e.g., monthly target volume and release under limited, normal, and flood storage zone). To calibrate the model enabled with the new reservoir routine, we used a multi-objective optimization algorithm (Borg). Results showed that the reservoir routine significantly improved the MESH model performance in generating streamflows across the SaskRB, and that this relatively simple approach provides an improved basis for large scale hydrological modelling. [180 words]

Presentation type: Oral Presentation

P01-H06: Quantifying snowmelt infiltration and runoff

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Abstract:
Cold region processes significantly influence surface and sub-surface hydrological processes in seasonally frozen regions of Canada. In particular, freezing and thawing of the soil governs soil physical properties such as hydraulic conductivity and water holding capacity, that shape local surface and groundwater hydrology. The partitioning of snowmelt infiltration and runoff has important implications for integrated water resource management and flood risk. However, as we will show, there is inadequate representation of the snowmelt infiltration into frozen soils in most land-surface and hydrological models, creating the need for improved models and methods. In this study, we use extensive field observations from St Denis, Saskatchewan, to provide insights into cold regions hydrological processes, including the partitioning of snowmelt between infiltration and runoff. We demonstrate the limitations of conventional coupled flow and heat transport models, and we propose potential pathways forward to improve these models.

Presentation type: Poster

P02-H06: Investigating streamflow generation and streamflow sources during a wetting-up period in an engineered Prairie watershed

Maliheh Rabie[1,2,3*], Genevieve Ali[1,2,3], Christopher Spence[4], Samuel Bansah[1,2,3], Victor Weigang Tang[5], Sean Carey[5]

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Abstract
Determining streamflow sources in typical Prairie watersheds in the presence of numerous anthropogenic disturbances is not straightforward. In order to quantify the relative contribution of surface and subsurface flow pathways to streamflow generation, a combination of hydrometric methods and isotopic hydrograph separation was used in the Elm Creek Watershed (Manitoba, Canada). Surface water ponding depths and water table depths were measured at a high frequency at nine stations across the watershed, while streamflow was monitored at the outlet and soil moisture conditions at four different depths were monitored at two stations. Six hydrological events were delineated in spring and summer 2014 and characterized in terms of event hyetograph and hydrograph parameters, soil moisture conditions, water table fluctuations, and ponding water depths (i.e., overland flow response). Isotopic hydrograph separation based on $\delta^{18}O$ data was also used to compute the percentage of new water contributing to the hydrograph during each event. Total event rainfall ranged from 9 to 48 mm for the six monitored events, while runoff ratios ranged from 0.02 to 0.40. The average proportion of new water feeding streamflow was 0.69, 0.66, 0.23, 0.50, 0.49, and 0.55 for events 1 through 6, respectively. Those high fractions hint at major new water contributions whereas hydrometric data did not reveal significant overland flow response, suggesting that new water travels via shallow subsurface flow. Future analyses will focus on soil moisture data to infer the presence of shallow preferential flow that might explain the subsurface transport of new water.

Presentation type: Poster

P03-H06: Using wavelet analysis to evaluate the spatio-temporal variability of stream temperature in two alpine watersheds, Wolf Creek, Yukon

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Abstract
Wavelet analysis is a powerful statistical tool to evaluate the frequency and location of temporal variability in time series across a range of scales. Wavelet analysis has certain advantages over other statistical methods as the periodicity/frequency, power, and phase of signals can be identified within time series. In addition to investigating multi-scale temporal patterns in a time series, Wavelet Transform Coherence (WTC) determines the correlation between the wavelet transforms of two time series. This method has been applied in hydrology to analyse time series with climatic forcing inputs and other external factors, and also has wide applications in meteorology and oceanology. The objective of this research is to apply WTC to evaluate spatial and multiple-scale temporal variability in stream temperature for two headwater tributaries of the Wolf Creek Research Basin, Yukon. WTC is used to explore the thermal influence of air temperature, precipitation, and shortwave and longwave radiation over the course of the open water season. WTC is also applied to identify the positions of groundwater springs and other transverse water inputs (e.g. small tributaries) by comparing the thermal regimes upstream and downstream of certain points. Wavelet coherency reveals that air and water temperatures were coupled at time scales greater than 0.5 day. However, significant coherence with shortwave and longwave radiation only appeared between 0.5 and 2 days. The influence of rainfall on the air-water temperature relationship was ambiguous, but heavy storm events in late summer moderately disturbed air-water temperature coherence. In addition, groundwater and tributary inflow weakened the coherence between upstream and downstream locations. WTC proved useful for examining in-stream thermal influences of meteorological factors at multi-temporal scales, and also for locating transverse water inputs when spatially continuous observations of water temperature are available along the stream.

Presentation type: Poster

P04-H06: Modelling snow density from snow depth combined with air temperature time series interpolated from the North American Regional Re-analysis.

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Abstract
Airborne LiDAR surveys can provide detailed maps of snow depth over spatial scales useful for water supply forecasting. However, converting snow depth to water equivalent requires knowledge of the spatial variability of snow density. The metamorphism processes that control snow density are complex. As a first step, this study explores the potential for modelling snow density as a function of snow depth and positive degreedays during the accumulation season. Snow density data were compiled from 248 snow course sites in British Columbia, a hydroclimatically diverse domain. Air temperature time series were generated by downscaling from the North American Regional Reanalysis product. On a station-by-station basis, significant relations were found with reasonable predictive ability. However, model parameters exhibit substantial inter-site variability. Ongoing analysis is focused on modelling the variability of model parameters based on climatic indices derived from the ClimateWNA product. [145 words]

Presentation Type: Poster

P05-H06: Thermal regimes of streams within an alpine discontinuous permafrost catchment, southern Yukon Territory

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Abstract
Stream temperature, which influences many biogeochemical processes, is controlled by the interplay of factors including atmospheric conditions and groundwater inflow. Because upwelling groundwater influences the energy balance of a stream through streambed heat fluxes, stream thermal regimes can be analyzed to investigate stream-aquifer interactions. The overall goal of this study is to identify and quantify zones of surface water-groundwater fluxes in alpine streams and examine the role of these interactions on the stream thermal regimes. To facilitate intercomparison, the thermal signals of two neighboring streams within the Wolf Creek Research Basin, Yukon Territory were collected. Temperature was recorded every fifty meters along a two-kilometer reach in each stream at a fifteen-minute frequency from June to September, 2016. Linear regression between daily mean values of air and stream temperature produced low regression slopes with relatively high intercepts in both streams, indicating groundwater influence within the watersheds. This is consistent with locations along the longitudinal profile of each creek that consistently display decreases in water temperature, indicating possible groundwater upwelling. Although diel stream temperature signals are typically lagged and damped in comparison to diel air temperature signals, cross-correlation analyses revealed that air temperature often lags stream temperature throughout the season. Data collected from vertically spaced streambed temperature sensors indicate efficient downward propagation of the diel temperature signal into the bed sediment, which is indicative of downwelling. While each stream has a similar diel range, Buckbrush Creek is consistently ~2˚C colder than Granger Creek and displayed a lower regression slope and higher intercept, suggesting more groundwater influence. Differing influences of tributaries are also observed, with Granger Creek warming downstream of tributary inflow while Buckbrush Creek experiences cooling. Further analyses will be conducted using the stream temperature numerical model HFLUX to determine reach-scale aquifer-stream exchange from the temperature dynamics in the stream.

Presentation type: Poster

P06-H06: The influence of consecutive El Niño and La Niña events on lake ice in Central Ontario

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Abstract

Lake ice models provide the ability to assess and understand both ongoing and projected changes in ice covered environments by incorporating data from global/regional climate models or in situ meteorological data. Understanding changes in ice cover are particularly vital for areas likely to be impacted by changing climate conditions, as increases in air temperature have been shown to be associated with decreases in ice cover duration. The Canadian Lake Ice Model (CLIMo), is a well-tested one-dimensional thermodynamic freshwater ice cover model that has been used successfully in many studies to simulate Arctic lake ice covers. The back-to-back ENSO events through 2016-2017 provide the ideal variability in snow and ice cover for testing/evaluating the model for use in temperate ice conditions. Local climate, snow, and ice cover conditions were recorded for three lakes in Central Ontario for the 2016 and 2017 ice seasons. The 2016 study season experienced a strong El Niño event while the 2017 season experienced a La Niña. The 2016 El Niño resulted in delayed ice formation as seasonal temperatures were approximately 3.2°C above normal. Significant variations in temperature promoted early season snow ice development in 2016. When temperatures fell in February, black ice growth was predominant for the remainder of the study season. Delayed ice break up in 2016 was due to below average seasonal temperatures during April, as well as substantial snow ice development from earlier in the season. The 2017 La Niña resulted in earlier ice formation, and promoted greater black ice growth. Early 2017 snow depth and density measurements were greater than the 2016 season. Model results indicate that snow cover and snow density are the key parameters that require refinement in southern Ontario lakes to accurately predict ice on/ice off dates.

Presentation type: Poster

P07-H06: Lake Ice Modelling of two High Arctic lakes

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Abstract
Lakes are a dominant feature in Canada's landscape, where lake coverage is estimated to be between 15-40% depending on location; with a substantial proportion of lakes located in the Arctic. Research indicates that Arctic lake ice cover is sensitive to climate variability with strong relationships to air temperature and large scale atmospheric patterns. Through this relationship, ice phenology is a key indicator of climatic change occurring in the high-latitudes; such that warmer temperatures are resulting in lake ice regime shifts. These changes have major implications for physical, ecological (e.g. aquatic primary productivity, flora, and fauna) and biogeochemical processes (e.g. water quality). Previous studies observing changes in lake ice regimes have successfully used a combination of methods including in situ observations, modelling, and remote sensing. This study presents preliminary ice cover simulations of lake ice phenology (freeze-up and break-up dates, and ice cover duration) and ice thickness for Hunting Camp Lake in Polar Bear Pass National Wildlife Area and Small Lake at Resolute, NU. Climate and lake ice interactions are examined using observed meteorological data (provided by Environment Canada and Campbell Scientific; daily mean values of air temperature, precipitation, relative humidity, cloud amount, wind speed, snow depth) and reanalysis climate datasets (ERA-Interim) for both study sites. Meteorological data is used to force the Canadian Lake Ice Model (CLIMo) and simulations for both study sites are detailed and compared. Future research includes retrieving observation data from Hunting Camp Lake at Polar Bear Pass and Small Lake, Resolute, NU (meteorological data, as well as ice phenology and ice thickness). This research will highlight the current state of High Arctic lake ice cover and provide further understanding of the response to climate and hydrological process changes occurring within the water and energy budgets of these environments. [292 words]

Presentation type: Poster

P08-H06: Landscape controls over subsurface water flow pathways in the Canadian High Arctic

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Abstract

Permafrost in the High Arctic is often ice-rich and deeper active layer thaw caused by warming temperatures may alter the subsurface hydrological pathways. This research investigated the hydrological characteristics of subsurface preferential water flow pathways that develop in the active layer to predict how changing climate will alter hydrological processes. Research took place at the Cape Bounty Arctic Watershed Observatory (CBAWO) on Melville Island, Nunavut, in a small headwater catchment between June 13 and August 8, 2016. Two active layer cores were collected prior to thaw for cryostructure and ice content analysis, and seasonal active layer development was quantified. Established soil moisture and temperature, pore water pressure, and meteorological sensor stations were supplemented with a network of piezometers installed across four land cover types (high and low hummock, mesic slope, polar semi-desert, and an area with established soil pipe drainage) to evaluate hydrological function of preferential pathways. Results indicate that active layer thawed progressively towards depths that active layer cores indicated were ice-rich (60-80 cm depth). The hydrologic response of the subsurface water table showed patterns of either drainage or a sustained high water table, within and between land classes, suggesting strong spatial heterogeneity of subsurface drainage pathways. Electrical conductivity (EC) of water from piezometers indicated initially high solute availability, and well-drained areas showed increases in EC over the season most likely from solutes stored in the lower active layer. An area of former active layer disturbance (mesic slope) showed no indication of preferred subsurface drainage, indicating that drainage networks may take considerable time to become established. Future work will aim to distinguish the sources of subsurface waters using stable water isotopes. This research will advance knowledge of the factors and processes that affect subsurface flow pathways, an important predictor of water supply and quality in northern regions. [298 words]

Presentation type: Poster

P09-H06: On the similarity of land-cover among lowland peatland complexes in the southern Taiga Plains discontinuous permafrost region, NWT

Justin R. Adams and William L. Quinton

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Waterloo, Ontario

Abstract
Scientific evidence is growing that shows significant changes are occurring to the climate, hydrology, and land cover of the southern Taiga Plains discontinuous permafrost region of Northwest Territories. In terms of broad hydrological response unit delineation, the landscape of this region can predominantly be divided into (i) treed uplands or (ii) lowland peatland complexes. The latter include a composition of treed permafrost plateaus and wetland features (bogs and fens). Much of the field-based research conducted in this region has focussed on understanding physical processes exclusively within peatland complexes for modelling these systems. However, the transfer of knowledge gained from field-based process studies to operationalizing models at nonresearch sites in this region is hindered by a lack of high quality, and high resolution, land surface information. For instance, information on land cover of this region is typically limited to coarse (e.g. 30 m) land cover products derived from optical remote sensing. Although such products can be useful for delineating between treed uplands and lowland peatland complexes at a regional scale, this resolution is insufficiently coarse to capture information on land cover properties within peatland complexes. In addition, the land cover of this region is considerably dynamic due to permafrost-thaw related wetland expansion and wildfire. This poster discusses the importance and development of multi-scale (spatial and temporal) land cover information for modelling sub-basins in this region. In addition, results are presented from a remote sensing analysis comparing the spatial and temporal similarity of land cover properties among selected peatland complexes for this region.

Poster Presentation

P10-H06: Forecasting of Spring Runoff Events in the Kiskatinaw Watershed, Dawson Creek, British Columbia

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Abstract
The Kiskatinaw River Basin (KRB), a 2838 km^2 watershed southwest of the city of Dawson Creek (CDC), British Columbia, Canada, forms an important regional water supply as the primary municipal water resource for Dawson Creek since the 1940's. Over the last 15 years, hydro-meteorological changes have imposed stress on water reserves. Spring runoff volumes have been declining and occur earlier, resulting in low flows during peak demand from August into October. The current water storage infrastructure accommodates about three months' storage, but filling these reservoirs can take significant amounts of time. The ability to make predictions of the timing and volume of runoff associated with spring snowmelt runoff in the KRB would allow for the CDC to better time water withdrawals. Using in-situ climate observations from the BC Ministry of Forests, Lands and Natural Resource Operations, the CDC, University of Northern British Columbia and the BC Ministry of Transportation in combination with metrics of snow extent and water equivalent derived from satellite platforms relationships with runoff timing and volume will be explored in the KRB. Multiple regression will be used to determine if the timing and volume of daily flows in the Kiskatinaw River can be hindcast accurately using only in situ meteorological data, only satellite derived snow cover/water content, and/or a combination of these. In addition, the Snowmelt Runoff Model (SRM) will be tested for its ability to simulate weekly and seasonal flows in the KRB in comparison to the strictly empirical methods.

Presentation type: Poster

P11-H06: The effects of wildfire on snowmelt and ground thaw on a permafrost peat plateau, Scotty Creek, Northwest Territories

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Abstract

The global increase in air temperatures over the last century has been especially pronounced at high latitudes (Johannessen *et al*., 2004). In northwestern Canada, this warming has coincided with an increase in the frequency, size and severity of wildfires (Wotton *et al*., 2010). The influence of wildfires on the distribution of the snowpack, and on the rates and patterns of snowmelt and ground thaw are not well understood, and as a consequence, the impacts of fire on the flux and storage of water in northern ecosystems cannot be properly assessed. This study evaluates impacts of a 2.7 ha wildfire at Scotty Creek, Northwest Territories in July, 2014, by comparing the end-of-winter snowpack snow water equivalent (SWE), and the rates and spatial patterns of snowmelt and ground thaw of adjacent burned and unburned sites.

A field campaign from March to August, 2015 acquired measurements of depth and density of the snowpack, snowmelt rates and frost table depths. Burned and unburned sections of a permafrost peat plateau were instrumented to measure differences in air and soil temperature, snow depth and net radiation. A 1-D energy balance equation was used to quantify the rates of snowmelt and energy available for snowmelt (Qm) in the burned and unburned forests. A modified form of the Stefan's equation was used to calculate frost table depths and the energy required for thawing, known as the latent heat used to melt the ice in the active layer (Qi). This study demonstrates that the late winter snowpack of the burned plateau SWE was 22% greater than the unburned plateau, and the ground surface became snow free 4 days earlier. Average frost table depths in August on the burned plateau were 30% deeper than the unburned plateau, equivalent to a 20 cm difference in depth. Cumulative Qm and Qi were greater on the burned plateau, due to increased incoming shortwave radiation received at the ground surface resulting in increased ground surface temperatures. These results indicate that wildfires change the rate and timing of the snowmelt as well as increase seasonal ground thaw which can develop taliks, aiding in the degradation of permafrost.

Presentation Type: Poster

P12-H06: Measuring and modelling infiltration and water movement in frozen ground, Wolf Creek, Yukon

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Abstract
Frozen ground is an important consideration in cold regions hydrology because pore ice can impede the ability of water to infiltrate into and migrate within soils, thereby altering water flow paths and increasing surface runoff. High latitude regions are particularly susceptible to changes in climate, where increases in temperature and changing precipitation trends can alter soil freezing and thawing dynamics. However, there has been limited research on infiltration processes in subarctic alpine environments due to sparse historic data and difficulties with gathering direct measurements. In addition, few hydrological models consider the complexity of frozen soils in such environments. The objectives of this research are to assess the ability of the GeoStudio finite element modeling suite to simulate observed soil temperature and moisture data and to apply the models to evaluate the sensitivity of the parameters and driving meteorological data. GeoStudio integrates several models (e.g. TEMP/W, SEEP/W and VADOSE/W) that allow it to simulate concurrent water flow and temperature dynamics in variably saturated environments experiencing soil freezing and thawing. Field data for this study are obtained from Wolf Creek Research Basin (WCRB) in southern Yukon, Canada. Data for quantifying snowmelt, soil moisture, soil temperature, and soil composition were collected at six sites in WCRB from April 2015 to August 2016, adding to the available historical data. Recent data show warming temperatures and earlier snowmelt in WCRB than previous years. Results of the GeoStudio models illustrate the dominance of snowmelt in the basin and in governing infiltration dynamics. Furthermore, air temperature and SWE parameters are adjusted to predict how infiltration and soil water movement vary in future conditions with a changing climate. This research helps elucidate the complex heat transfer and water movement processes that control infiltration in northern environments and provides a quantitative assessment of their sensitivity to future climate warming.

Presentation type: Poster

P13-H06: Methods investigating alpine forest water use under varying environmental conditions in the Canadian Rocky Mountains

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Abstract
Fresh water supplies in mountainous regions are at risk as snow and ice stores continue to decline under rising global temperatures, earlier winter snowmelt and changing climate regimes. Alpine forests are of particular importance due to their hydrological connectivity within watersheds such as controlling groundwater base flow, influencing evapotranspiration and snow storage dynamics. A change in the water availability to alpine vegetation could have a drastic effect on the health of these forests, making it imperative to understand the hydrological systems of high alpine forests. The study sites are located at Fortress Mountain in Kananaskis, Alberta and are tree stands consisting of *Abies lasiocarpa* and *Picea engelmannii*. Little is known about water use dynamics of these species at high elevations, specifically where and when they intake their water during the shoulder and growing seasons. In addition, model projections show a rapidly declining tree population in mountain valley bottoms of the Kananaskis area within 50-100 years. With a potentially limited future tree population at lower alpine elevations, the hydrologic services of trees at higher elevations will become even more important to the watershed. Groundwater hydrology, tree water use and soil characteristics will be examined within this study to gain a better understanding of forest hydrology in the alpine. Methodologies will focus on determining the seasonal transpiration patterns using the stem-heat balance method to determine sap-flow and understanding tree response to precipitation and drying events using an eddy covariance tower installed at the site in 2015. Instrumentation to examine water sources will include monitoring wells, soil moisture probes and tensiometers with measurements of precipitation and snow at the beginning and end of the green season. By closely examining the patterns of alpine tree water use, we can begin to clarify how these important ecosystems services will be impacted under a changing climate. [300 words]

Presentation type: Poster

P14-H06: Detecting intercepted snow on mountain needleleaf forest canopies using satellite remote sensing

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Abstract

Snow interception in cold regions needleleaf forest canopies is a crucial process that controls local snow accumulation and redistribution. Various ground-based methods exist to measure intercepted snow, however no research has focused detecting large areal canopy snow using satellite observations. In this study, four remote sensing indices (NDSI, NDVI, albedo, and Land surface temperature (LST)) were retrieved from Landsat images to study their sensitivity to canopy snow and the possibility of using them to detect this snow. The results indicate that canopy snow increased NDSI and albedo but decreased NDVI. It also decreased the regional variation of NDSI and NDVI while increasing the heterogeneity of albedo. Differences for these three indices between snow-free and snow-covered canopies are correlated to topography and forest canopy cover. Of these indices, NDSI has the greatest absolute change. Canopy snow noticeably decreased the LST difference between forest and open areas in spring time while the influence in winter time was relatively smaller. A canopy snow detecting approach that uses both NDSI and NDVI to classify pixels into either snow-covered canopy or others (snow free canopy and non-forest areas) is proposed and in a case study the results of this approach were compared to simulations by the snow interception model implemented in the Cold Regions Hydrological Modelling platform (CRHM) and run using local meteorological data for Marmot Creek Research Basin in the Canadian Rockies. The remote sensing detection of snow in the canopy agrees well with CRHM simulations for non-forested areas (98% of the cells classified correctly based on CRHM simulation) and dense forests (83%) and less well for sparse forests (72%) and clearings with small trees (70%). Therefore, the approach is suitable for canopy snow load detection, which can contribute to large scale snow interception model validation and data assimilation to cold regions hydrological forecasting models.

Presentation type: Poster

P15-H06: Monitoring the hydrological response of a burned moderate-rich fen watershed in the Athabasca Oil Sands Region, Alberta

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Abstract
In the sub-humid Athabasca region of the Western Boreal Plain (WBP), Alberta, peatlands comprise ~50% of the landscape, primarily as moderate-rich fens. Little is known about the hydrogeology of these systems and how they are connected to various groundwater sources. During the spring of 2016, the 590,000 ha Horse River wildfire began in Fort McMurray and spread across the WBP, resulting in many burned fens, including an instrumented moderate-rich fen watershed (Poplar Fen), ~30 km north of Fort McMurray. Understanding how the hydrologic regime of these systems is altered by fire will be important for predicting their ecological response post-fire. The objectives of this research are to understand the hydrolgeologic setting of a moderate-rich fen watershed and its associated flow regime, and how this regime changes following wildfire. This research capitalizes on pre-existing hydrological data obtained at Poplar Fen prior to the Horse River wildfire from 2011-2016, as well as data collected following the fire. Pre-fire results illustrate that Poplar Fen is located in a headwater region sourced by localized groundwater flow that is recharged in adjacent uplands. As a result, Poplar Fen is highly vulnerable to extended dry periods, which reduces groundwater discharge and enhances water table decline. These conditions influenced the uneven burning of Poplar Fen, where topographically higher fen regions experienced a higher depth of burn and associated fuel consumption than lower-lying fen regions that were better connected to groundwater. With burning of fen/upland vegetation, evapotranspiration was greatly reduced and the region experienced above-average precipitation, resulting in high water tables at Poplar Fen. These conditions resulted in better upland fen-connectivity, observed by higher horizontal hydraulic gradients from upland to fen. This reduction in ET may help promote the moisture conditions necessary for moss recovery, as the internal water transport mechanisms of fen mosses were compromised by wildfire.

Presentation Type: Poster Presentation