H09: Measuring and modelling glacier change

Conveners: Alexandra Pulwicki[1], Laura Thomson[2], Valentina Radic[3], Brian Menounos[4]

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Session Description

Measuring and modelling glacier change is central to understanding the current health of glaciers and for predicting future glacier change. Ice conditions and surface processes affect both the mass balance and flow characteristics of glaciers. While measurements of ice velocity and deformation, mass balance, and glacier hydrology have a long history, there are a number of opportunities and challenges that persist. Field and remote sensing techniques continue to provide new data about environmental and ice conditions, such as energy balance and ice velocity. This allows for finer resolution of variables that affect glaciers, including ice formation and melt as well as hydrological conditions. Replicating these observations with physically-based and statistical models and interpreting the results often provides a new understanding of factors that control glacier change but the spatial and temporal variability can make it difficult to generalize interpretations. This session will focus on research that aims to increase our knowledge about glacier change through novel field observations, physically-based and statistical models, as well as remote sensing. We welcome submissions that address questions of how to better understand and represent spatial and temporal changes of mass balance and ice change.

Primary Affiliation: Hydrology and Glaciology

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 H09a

Chairs: A. Pulwicki & L. Thomson **Room: GEOG 200**

Tuesday, May 30th

TIME	AUTHORS	TITLE
9:00	D. Schroeder	Advances in ice penetrating radar time series observations
9:15		
9:30	A. Bevington & B. Menounos	Large area glacier change for western Canada over 31 years of satellite imagery
9:45	J.M. Shea, W.W. Immerzeel, P. Wagnon & P. Kraaijenbrink	Variability in debris-covered glacier change in the Nepal Himalayas
10:00	A. Winter-Billington, M. Koppes, S. Singh, A. Banerjee, R. Shakar & H.C. Nainwal	Seasonal variation of controls on ablation of debris-covered glaciers
10:15	N. Fitzpatrick, V. Radic & B. Menounos	The surface energy balance and turbulence characteristics of a mid-latitude glacier

ORAL SESSION H09b

Chairs: J. Crompton & G. Flowers **Room: GEOG 200**

Tuesday, May 30th

TIME	AUTHORS	TITLE
14:00	A. Rempel	Ice-rock-water interactions on a soft, wet bed
14:15		
14:30	A. Hubbard & J. Ryan	Tidewater Dynamics at Store Glacier, West Greenland from Daily Repeat UAV Survey
14:45	G.K.C. Clarke & M. Hambrey	Structural evolution of Trapridge Glacier in response to cyclic surging: models and observations
15:00	A. Whiteford & C. Schoof	Pattern forming instabilities in the coupling of ice sheet and basal hydrology
15:15	R. Nath & S.J. Marshall	Applying Flow Line Modelling, and GIS to Reconstruct the Glacier Volume Loss for Athabasca Glacier, Canadian Rockies.

POSTER SESSION H09

Chairs: A. Pulwicki & L. Thomson **Room: ESB Atrium**

Monday, May 29th

Poster No.	AUTHORS	TITLE
P01-H09	J. Crompton*, G. Flowers	The influence of bedrock fracture intensity on

		glacier dynamics
P02- H09	B. Pelto, B. Menounos, V. Radic & S. Marshall	Evaluation of Methods Used to Estimate Ice Thickness, Columbia and Rocky Mountains, Canada
P03- H09	H. Williams, M. Koppes & V. Radic	Determining the influence of glacier hypsometry on sensitivity to climate change
P04- H09	A. Pulwicki & G. Flowers	Multi-scale investigation of snow accumulation on alpine glaciers
P05- H09	L. Thomson	The stability of White Glacier changes since 1960
P06- H09	G.C. Racz, C. Schoof & E. Haber	Estimating permeability of the subglacial drainage system using inverse modelling
P07- H09	M. Tessema, V. Radic & B. Menounos	Modeling surface glacier melt with the use of dynamically downscaled climate fields over Castle Creek Glacier, British Columbia, Canada

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SUBMITTED ABSTRACTS

H09-01: Advances in Ice Penetrating Radar Time Series Observations

Dustin M. Schroeder[1]

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Abstract
Recent and planned airborne radar sounding of Antarctica and Greenland are providing repeat coverage of previous survey lines, enabling direct observation of temporal variation in ice sheet basal boundary conditions. Additionally, the earliest radar sounding data – recorded on optical film in the 1960s and 70s – are being digitized, extending the baseline for such comparisons by decades. In parallel, stationary active radar sounders are providing an exciting new tool to geophysical glaciology. The availability and proliferation of relatively low-cost, low-power stationary sounders are producing time series observations of ice-shelf melt rates and advection rates. The development of systems with array-based and quasi-continuous-wave architectures also promises to extend these time series into 2D and 3D records. Finally, passive radio sounding approaches under development for planetary exploration are being adapted to the observation of terrestrial ice sheets and glaciers. We present these advances, the technical and interpretative challenges they face, and the glaciological processes and conditions they make it possible to observe.

Presentation type: Oral Presentation

H09-02: Large area glacier change for western Canada over 31 years of satellite imagery

Alexandre Bevington[1,2*], Brian Menounos[1]

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Abstract
Analysis of glacier extent though time provides one method to assess the magnitude and spatial pattern of recent climate change. Previous work in western Canada used semi-automatic methods to delineated glacier extents from Landsat imagery for the years 1985, 2000 and 2005. Over that time period rates of glacier area change averaged -0.55 % yr^{-1}. We build upon that work by providing post 2005 area change assessment and also increase the number of years over which glacier change is evaluated. Our workflow runs in Google Earth Engine that analyzes publically available satellite imagery [Landsat Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+) and Operational Land Imager (OLI) sensors] for all available late-summer scenes between 1985-2016. Our algorithm employs a semi-automated method based on band ratios, a normalized difference snow index (NDSI) and a green band threshold. Areas of recent deglaciation are delineated and trends in glacier extents are compared to change in energy and mass flux present in climate stations and reanalysis products. We also discuss preliminary results of a 2016 western Canada glacier extent produced from Sentinel-2A Multispectral Instrument (MSI) imagery. Sentinel-2A offers a higher spatial resolution (10 m) than Landsat satellites (15-30 m). Validation and uncertainty estimates are conducted using air photos, LiDAR and high resolution satellite imagery for different environmental settings. Debris-covered glacier ice still presents a challenge to this mapping and is only manually corrected for the 2016 Sentinel-2 glacier inventory.

Presentation type: Oral Presentation

H09-03: Variability in debris-covered glacier change in the Nepal Himalayas

J.M. Shea[1,2], W.W. Immerzeel[3], P. Wagnon[4], P. Kraaijenbrink[3]

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Abstract
Debris-covered glaciers occupy between 10 and 25% of the total glacierized area in the Hindu Kush, Karakoram, and Himalayan mountains, and may contain an even higher proportion of the total volume of ice. While ice melt is insulated by a thick layer of debris, actively evolving ice cliffs and ponds can generate substantial amounts of mass loss on seasonal time scales. This study looks at ongoing research in the Nepal Himalayas using unmanned aerial vehicles (UAV) to monitor changes in the debris-covered Changri Nup Glacier. Total glacier surface elevation change is a combination of (1) ice melt due to heat conduction through the debris, (2) backwasting and undercutting of exposed ice cliffs, and (3) emergence velocities. In this study, we estimate the mean and range of surface lowering rates observed on stagnant debris-covered ice to isolate the downwasting component. Given an estimate of mean emergence velocities from the flux gate method, we then quantify the surface lowering due to ice cliff backwasting and undercutting from a range of pond and ice cliff concentrations in the active part of the glacier. Combined with object-based image analysis, our results suggest that a simple remotely sensed based parametrization that incorporates pond and ice cliff dynamics can be used to evaluate relative surface lowering rates for debris-covered glaciers in the region.

Presentation type: Oral

H09-04: Seasonal variation of controls on ablation of debris-covered glaciers

Winter-Billington, A.[1]*, Koppes, M.[1], Singh Shah, S.[2], Banerjee, A.[3], Shankar, R.[4], and Nainwal, H.C.[2]

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Abstract
Glacier melt data is required for hydrological forecasts and sea-level rise projections but direct measurements are difficult to obtain. Temperature index models are important because they are simple with low data requirements. They can reliably reproduce melt of clean glaciers but do not exhibit the same accuracy for regions where supraglacial debris is widespread, such as High Mountain Asia (HMA). Thorough understanding of sub-debris melt processes is required for the development of models for regions like HMA where hydrological projections retain much uncertainty. We present initial observations from debris-covered Satopanth Glacier in the monsoon-dominated Garwhal Himalaya. We have six and twelve month records of hourly subsurface debris temperature from six pits across the 8.5km2 ablation area, ablation stake measurements, continuous meteorological data on- and off-glacier and ground penetrating radar data of debris depths (which vary from 2 to 180 cm) from our 2015-2016 program. We find hysteresis in the relationship between the meteorological energy fluxes and heat flux through the debris and use finite differencing to characterise a variety of heat transfer responses to changes in the surface energy flux that we synthesise into a conceptual model of five energy-balance "seasons". Key amongst our findings is that 1. Onset of the melt season is supressed by enhanced insulation of the snow meltwater-saturated debris layer, 2. Melt rates do not vary through the ablation season despite highly variable meteorological energy fluxes because reduced solar radiation during monsoon is offset by increased thermal conductivity of the debris layer saturated with warm rain, and 3. Melt rates have little spatial variability at scales on the order of kilometers, because decreasing debris thickness with elevation offsets the temperature lapse rate. These results suggest that debris-covered glaciers can be accurately reproduced with highly simplified models of debris depth and spatially and temporally averaged melt factors. [300 words]

Presentation type: Oral Presentation

H09-05: The surface energy balance and turbulence characteristics of a mid-latitude glacier

Noel Fitzpatrick[1*], Valentina Radić[1], and Brian Menounos[2]
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Abstract

In the majority of glacier surface energy balance (SEB) studies, parameterisation rather than direct measurement is used to estimate one or more of the individual heat fluxes. Turbulent fluxes of sensible and latent heat (QH and QL) are commonly parameterised using the bulk aerodynamic technique. This method was developed for horizontal, uniform landscapes rather than sloped, inhomogeneous glacier terrain, and significant uncertainty remains regarding the selection of appropriate roughness length (z0) values, and the validity of the atmospheric stability schemes employed. Customised weather stations were installed on Nordic and Conrad glaciers in the Purcell Mountains of British Columbia, over the 2014 – 2016 melt seasons, to directly measure all relevant heat fluxes, including the use of eddy covariance sensors to observe QH and QL, and to calculate z0 values. Ablation rates and surface conditions at each station were also simultaneously recorded. The obtained dataset was used to design a SEB model, and to evaluate the most common forms of the bulk method. Modelled ablation showed good agreement with observed rates at seasonal, daily, and sub-daily timescales, effectively closing the SEB, and giving a high level of confidence in the flux observation method. Significant differences were noted between observed z0 values and those commonly used in the literature, particularly for water vapour roughness lengths. The three stability schemes tested with the bulk method (Log Profile, Bulk Richardson, and MoninObukhov) resulted in either over or under-suppression of the calculated turbulent fluxes during stable atmospheric conditions. The Monin-Obukhov method returned mean daily flux values closest to those observed, but displayed poor performance on sub-daily timescales, and insufficient suppression of the fluxes during katabatic conditions.

Presentation type: Oral Presentation

H09-06: Ice–rock–water interactions on a soft, wet bed

Alan Rempel[1]

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Abstract

Glacier beds constitute some of the most extensive and weakest faults on Earth. Approximately 90% of the areal extent of both the Greenland and Antarctic ice sheets is subject to a driving stress and hence resisted by an average basal shear stress of less than 1.5 bars (median values are approximately 0.7 and 0.6 bars, respectively). Where cold-based conditions prevail, the driving stress is typically assumed to be lower than the bed strength, but recent estimates suggest that warm-based conditions prevail beneath more than 50% of each of these ice masses. Of particular contemporary relevance, sliding dominates the discharge rates of the ice streams and outlet glaciers that promote concerns over accelerating sea level rise. Water pressures close to flotation reduce the frictional resistance between entrained debris and underlying rock and sediment, and bring the effective stress supported by mineral contacts to within the range typical of the upper few meters of soil in subaerial environments. Long-established, experimentally supported thermo-mechanical treatments of ice–rock–water interactions under such conditions (leading to phenomena that include needle ice and frost heave) have only recently been applied to the subglacial environment. Further work is needed to fully integrate this understanding and its implications for glacier sliding, basal facies, and subglacial drainage, as well as the deposits and landforms that record past glacial history. This contribution builds from an elementary description of the phase behavior in ice–rock–water systems to explore their effects on bed strength and other aspects of subglacial behavior. [249 words]

Presentation type: Oral Presentation

H09-07: Tidewater Dynamics at Store Glacier, West Greenland from Daily Repeat UAV Survey

Alun Hubbard and Johnny Ryan

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Abstract

A significant component of Greenland ice sheet wastage to sea level rise is attributed directly to increased calving and dynamic thinning across its marine terminating margins. To improve understanding of these mass loss processes, a series of 70 daily repeat aerial surveys were conducted across the terminus of Store Glacier, a large tidewater outlet draining the western sector of the Greenland Ice Sheet. The UAVs were equipped with digital cameras, which, in combination with onboard GPS, enabled construction of high spatial resolution orthophotos and digital elevation models (DEMs) using standard structure-from-motion techniques. These daily data provide insight into the calving dynamics of Store Glacier during an extended period spanning May to August 2014 which includes the break-up of the sea-ice mélange in early June. Our results reveal a mean terminus velocity of 16 – 18 md^{-1} which increases along with calving rates, after melange break-up and buttressing. Differencing bulk freeboard volume of icebergs within the fjord over our survey period enables constraints to be placed on the magnitude and variation of submarine melt. We calculate a mean submarine melt rate of 0.18 md^{-1} throughout April and May, a period with little supraglacial runoff and active plumes to stimulate fjord circulation and upwelling of deeper, warmer water masses. We relate calving rates to changes in the principal strain regimen, and the zonation and depth of water-filled crevasses, which were apparent from June onwards.

Presentation type: Oral Presentation

H09-08: Structural evolution of Trapridge Glacier in response to cyclic surging: models and observations

Garry K. C. Clarke[1] and Michael J. Hambrey[2]

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Abstract
Interpreting the relationships among the internal processes of glaciers and their micro- to mesoscale structural products has been a longstanding challenge for glaciologists. Examples include supraglacial moraine patterns, surface crevassing, the orientation and number density of the healed traces of former crevasses, and folded structures preserved in exposed ice. Efforts to represent these structures using glacier flow dynamics models remain at an early stage but provide informative tests of model skill and of current understanding of the processes that control structure generation. We tackle this problem by comparing observed structures on surge-type Trapridge Glacier, Yukon, with computer simulated structures for the same glacier. The vertically-integrated thermomechanical ice dynamics model makes use of the observed surface and subglacial topography, surface mass balance, ice flow, and englacial temperature to predict temporally-evolving surficial moraine patterns, density and orientation of crevasse traces, and the occurrence of folding. Surges occur every 50 years in response to a prescribed cyclic change in the bed friction and the model evolves from an initial ice-free state to a cyclically-repeating state after roughly 1000 model years. Moraine patterns are simulated by tracking the englacial and supraglacial trajectory of debris injected at a fixed point in the accumulation region. Crevasses form when and where the intensity of tensile resistive stress exceeds a prescribed threshold and the crack planes, initially vertical and oriented perpendicular to the maximum tensile resistive stress, rotate passively with the flow as they are transported from their point of formation to down-flow sampling sites. Crack damage is cumulative so that crevasse traces observed at sampling sites are a superposition of the damage accumulated en route. Folding is treated as a sub-grid process so folds are parameterized but not resolved. Model predictions for 2006 are compared with observations for that same year. [294 words]

Presentation type: Oral Presentation

H09-09: Pattern forming instabilities in the coupling of ice sheet and basal hydrology.

Arran Whiteford* , Christian Schoof

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Abstract
In recent years, there has been speculation as to whether dynamical instabilities are causing patterns in both the thickness of the Antarctic ice sheet and in its basal shear stress. We attempt to elaborate this idea by providing a theoretical model on the mechanism of pattern formation. Due to the diffusive nature of subglacial hydrology we can derive pattern forming instabilities in the model ice sheet. Such instabilities require a less-deformable bed and a friction law more dependent on effective pressure than ice velocity. Instabilities are driven by the hydrostatic pressure in the basal hydrology and friction on the ice sheet. Under these forcings we see pattern development due to the growth of small wavelength perturbations while larger wavelengths are capped by stronger diffusion. These results are found through a linear analysis and checked using a finite difference simulation.

Presentation Type: Oral Presentation

H09-10: Applying Flow Line Modelling, and GIS to Reconstruct the Glacier Volume Loss for Athabasca Glacier, Canadian Rockies.

Rituparna Nath[1] and Prof. Dr. Shawn J. Marshall[1]

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Abstract
Glaciers respond strongly to small climatic shifts, so records of historical glacier change can be used to reconstruct past climate. In turn, understanding glacier sensitivity to climate variability is important for regional water resources and for projecting glacier response to ongoing climate change. We develop an enhanced flow-line model of glacier dynamics to simulate the past and future extent of glaciers in the Canadian Rocky Mountains, with the aim of coupling this model within larger scale regional climate models of glacier response to climate change. Longitudinal stress and shape factors are introduced to provide a more complete treatment of glacier dynamics. This presentation focuses on glacier volume reconstructions from the Little Ice Age (LIA) to present for Athabasca Glacier, Alberta, Canada. Athabasca Glacier, located on the continental divide of the Canadian Rocky Mountains, is the second largest outlet of the Columbia Icefield. With the availability of SPOT 5 imagery, Digital Elevation Model and GIS Arc Hydro tool, ice catchment properties- glacier width and LIA moraines have been extracted using automated procedures. Simulating backwards in time from present day to 1850, we model glacier thickness, volume and mass change and examine different climate and glaciological parametrizations that are able to give good reconstructions of LIA ice extent. Mass balance modelling is based on modelled and observed temperature records from the region, along with the winter Pacific Decadal Oscillation index as a precipitation proxy. Dated lateral and terminal moraines provide geological control on the LIA maximum glacier geometry. Reconstructions of glacier mass change will inform estimates of meltwater run off over the historical period and model calibration from the LIA reconstruction will aid in future projections of the effects of climate change on glacier recession. Furthermore, the model developed will be effective for further future studies with ensembles of glaciers.

Presentation Type: Oral

H09-11: The influence of bedrock fracture intensity on glacier dynamics

Jeff Crompton[1*], Gwenn Flowers[1]

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Abstract

Glacier surges are characterised by dramatic oscillations in flow velocity between short surge phases truncated by relatively longer periods of slow flow during quiescence. Explaining the geographical distribution and underlying cause of glacier surges remains elusive. A glacier's mass balance partially controls its ability to surge, but surges are not caused by changes in climate. Rather, the flow instability is internal to the system. Anecdotal evidence suggests that surge-type glaciers in Alaska are proximal to "fault-shattered valleys", and in Svalbard correlated with bedrock lithology. To test the hypothesis that bedrock geology or the degree of bedrock damage influences the ability of a glacier to surge, we sampled geotechnical and geological properties of the bedrock in the basins of 16 surge-type and non-surge-type glaciers in the Donjek Range of the St. Elias Mountains, Yukon. We find no direct correlation between the presence of surge-type glaciers and the lithology of the bedrock, but a statistically significant tendency for surge-type glaciers in our study area to be situated in basins with relatively less damaged bedrock. This result is counter-intuitive. On a global scale, there is little evidence for surges occurring where glaciers overly intact bedrock; we suggest that the bedrock fracture intensity is too low for subglacial till development in these locations. One hypothesis to reconcile this global-scale observation with our seemingly contradictory result is that surges occur within an intermediate range of bedrock fracture intensity. We suggest that, through bedrock quarrying at higher elevations, the fracture intensity controls the location at which a matrix supported till can develop. We further propose that a matrix supported till cannot provide sufficient resistance to flow during quiescence. Instead, the growth and release of an ice reservoir during the surge cycle occurs within a zone where a matrix supported till has not yet fully developed. [299 words]

Presentation type: Poster

H09-12: Evaluation of Methods Used to Estimate Ice Thickness, Columbia and Rocky Mountains, Canada

Ben M. Pelto[1]*, Brian Menounos[1], Valentina Radic[2], Shawn J. Marshall[3]

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Abstract
Estimates of glacier ice thickness are an important prerequisite for many glaciological and hydrological studies. To date, few direct observations of ice thickness have been published from the Columbia and Rocky Mountains. Here we present observations of ice thickness from five glaciers in the Columbia Mountains and one in the Rocky Mountains. Our ground penetrating radar (GPR) surveys are conducted with the IceRadar system designed by Blue System Integration, using 10 MHz antennas, and collecting a sample every 5 m on average. Our survey lines are designed to approximate flux gates, perpendicular to flow, with a flowline profile to tie the lines together. We compare these measurements with modelled estimates of ice thickness. For Conrad Glacier, the range of our data (20–260 m) agrees with that of two independent methods to model ice thickness, ranging from 20–195 m and 20–260 m. However, our point measurements are, on average, 26 ± 37 and 53 ± 37 m thicker respectively. Similarly, data from the Zillmer Glacier are 18 ± 28 and 34 ± 28 m thicker than the model estimates of Huss and Clarke respectively, with neither capturing the maximum of 160 m. At Nordic Glacier, measured ice thickness exceeds that from the two models by 12 ± 19 and 18 ± 17 m. Our analysis will also evaluate existing methods to infer ice thickness based upon these point measurements and test model performance with high resolution DEMs obtained from aerial LiDAR surveys. Our observations are the first ice thickness data collected in the Columbia Mountains; we plan to contribute these data to worldwide datasets used to develop more accurate models of global ice volume.

Presentation type: Poster

H09-13: Determining the influence of glacier hypsometry on sensitivity to climate change

Haley Williams[1*], Michele Koppes[1], and Valentina Radic[2]

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[2] Earth, Ocean and Atmospheric Sciences Dept., University of British Columbia, Vancouver, BC, V6T 1Z4

Abstract
Glaciers in Alaska span climatic regimes ranging from mountainous coastal to continental that dictate both glacier type (tidewater or terrestrial, temperate or polar) and glacier dynamics. Recent warming trends have driven glacier thinning and retreat across the region, with temperate tidewater glaciers experiencing the most rapid change due to shifting conditions at the terminus. The shape, or hypsometry, of these glaciers have the potential to be used in combination with observed changes in glacier area and thinning rates to draw general conclusions about their sensitivity to regional warming. Glacier hypsometry represents the distribution of ice mass (area) by elevation. Hypsometric curves that are symmetrical about the equilibrium line altitude (ELA) are indicative of relative stability, while asymmetrical curves may indicate advance/retreat. In addition, if the hypsometric peak coincides with the ELA, any shifts in ELA would have a large effect on glacier mass balance. Here we present hypsometric curves for over 27,000 glaciers in the Alaska region that we derived from the Randolph Glacier Inventory (RGI 5.0). From this dataset, six prominent types of glacier hypsometry were identified using a self-organizing map; the six types are spatially distributed across the state. Using Climate WNA reanalysis data, we also gathered the monthly and mean annual temperature and precipitation at the mean elevation of each glacier in the Alaskan dataset. The spatial distribution of each of the six hypsometric clusters was statistically compared to the climate regime of the individual glaciers within each cluster to investigate the role of climate in controlling glacier shape, and to produce a probability distribution of glacier sensitivity to climate change. The analysis was performed using split-sample testing within the Alaskan dataset, and then applied to glaciers in British Columbia to assess these relationships in other regions. [290 words]

Presentation type: Poster

H09-14: Multi-scale investigation of snow accumulation on alpine glaciers

Alexandra Pulwicki[1*] and Gwenn Flowers[2]

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Abstract
Variability in the spatial and temporal distribution of accumulation is the leading uncertainty in glacier mass balance. Processes such as orographic lifting, preferential deposition, and wind redistribution affect the spatial and temporal variability of snow. To better understand the effects of these processes, statistical models have been developed to relate meteorological and topographic variables to snow accumulation. However, accurate measurements of snow accumulation that are needed to inform models are scarce, particularly on remote glaciers in the St. Elias Mountains. In this study, field observations of snow depth and density are used to estimate accumulation and its variability at the point, hillslope, watershed, and regional scale on three glaciers in the Donjek Range, St. Elias Mountains. Sub-basin accumulation variability differs between glaciers and a negative accumulation gradient is observed at greater distances from the large-scale topographic divide. Regressions of DEM-derived topographic parameters (e.g. elevation, slope, curvature, aspect) and accumulation, found using a cross-validated multiple linear regression as well as Bayesian model averaging, have varying predictive abilities for the three glaciers (R^2 = 0.13, 0.68, 0.42). Elevation is a strong predictor of snow water equivalent (SWE) on two glaciers while no predictors are able to explain SWE variance on the glacier with highest mean accumulation. Regression coefficients differ considerably between glaciers and are not strongly affected by the snow density measurement tool, snow density interpolation method or the choice of regression technique. Choice of winter balance measurement location and spacing as well as the transferability of statistical relationships between glaciers is also investigated. This study highlights the spatial variability of snow accumulation on glaciers.
[266 words]

Presentation type: Poster

H09-15: The stability of White Glacier changes since 1960

Laura Thomson

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Abstract

As the only mountain glacier monitored in the Canadian Arctic, White Glacier on Axel Heiberg Island, Nunavut, supports study of the long-term response of polar ice masses in alpine basins. Glacier sensitivity is directly related to the distribution of ice area with elevation (glacier hypsometry) and this study reports on changes to glacier hypsometry associated with 1) ice thinning, 2) glacier retreat, 3) mass balance, and 4) the changing rate of ice delivery to low elevation by ice flow. Ice thinning and glacier retreat, determined through comparison of historic surveys in 1960 and a new 1:10,000 map created in 2014 using Structure from Motion methods, indicate an average thinning of the glacier by 11.9 m and a reduction in area by 2.53 km^2. This change in ice area and volume indicate a glacier wide mass loss of ~450 Mt that is primarily attributable to glacier retreat, rather than ice thinning, which is interpreted as a stable hypsometric response. However, comparing the observed ice fluxes through cross-sections along the glacier terminus and the theoretical mass flux derived from the glacier mass balance record indicate that the rate of ice delivery to low elevations is unsustainable in contemporary climate conditions and that ice velocities need to decline significanly at low elevations to sustain accumulation area elevations into the future.

Presentation type: Poster

H09-16: Estimating Permeability of the Subglacial Drainage System Using Inverse Modelling

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Abstract
Surface water that reaches a glacier bed through openings in the ice can act as a lubricant, reducing friction between ice and bed and facilitating basal sliding. This has been documented for both valley glaciers and the Greenland ice sheet. There is a functional relationship between meltwater supply, basal water pressure and basal sliding that depends on the configuration of subglacial drainage system. However, the drainage system configuration is not fixed but evolves over the melt season from a less efficient, distributed system to a more highly developed, channelized system. In order to investigate the evolution of the subglacial drainage system, we use a subglacial water pressure data set from a small, surge-type alpine, polythermal glacier in the St. Elias Mountains, Yukon. Similar pressure signals between boreholes can be interpreted as evidence of the existence of either a fairly efficient hydraulic between them. Here we use inverse modelling techniques to estimate a permeability structure at the glacier bed, focusing on a dense grid of 51 sensors installed over summer 2015 as well as from synthetic data.

Presentation type: Poster

H09-27: Modeling surface glacier melt with the use of dynamically downscaled climate fields over Castle Creek Glacier, British Columbia, Canada

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Abstract
Climate change studies often need to downscale low-resolution Global Climate Model (GCM) fields in order to represent local scale climate forcing. Recent studies of projected changes in glacier mass balance use regional climate models to dynamically downscale these GCM fields. We test this approach by using the Weather Research Forecasting (WRF) model to dynamically downscale meteorological fields needed to force a surface energy balance (SEB) model for an alpine glacier. An automatic weather station (AWS) measured the SEB in the ablation area of the glacier during summers of 2010 and 2012; this station provide reference energy fluxes to evaluate the performance of WRF. The model simulation is set with three nested domains with spatial resolution of 33 km, 11 km and 3.6 km, each domain being centered at the AWS glacier site. Default WRF model topography and land category datasets are used, while the boundary conditions are provided by the ERA-Interim climate reanalysis. The results show that WRF overestimates near-surface air temperature and incoming short wave radiation and sensible and latent heat fluxes. Six-hourly incoming long wave radiation shows a weak but statistically significant correlation with observations. No agreement exists between measured and modeled wind speed and wind direction values. We conclude that increasing the spatial resolution of the inner WRF domain, from 11 km to 3.6 km, does not improve the match with the observations. We plan to test WRF further by using a higher resolution topography data (1 km), better land category data that includes more recent glacier inventory, and model physics and dynamics schemes that are more applicable to complex mountainous terrain and ice covered surfaces.

Presentation type: Poster