New Zealand Snow and Ice Research Group (SIRG) annual meeting 2020

3-5 February 2020

Matiu/Somes Island, Wellington

Sponsors:

NIWA Taihoro Nukurangi

Antarctica New Zealand

Antarctic Science Platform

Good Buzz

Garage Project Aro St Wellington

icebreaker

SIRG 2020 Program and key information

(mostly correct, as of 5 pm 28/1/20)

KEY INFORMATION

What to bring:

- For those staying the house accommodation (details on next page), you need to bring a sleeping bag and pillowcase.

- Campers you obviously need a tent, sleeping bag, and maybe a torch, etc.

- IMPORTANT: MATIU/SOMES ISLAND HAS STRICT BIOSECURITY. YOUR BAGS AND OUTDOOR GEAR WILL BE INSPECTED ON ARRIVAL. **TENTS MUST BE PRISTINE CLEAN** OR THEY MAY NOT BE ALLOWED ON THE ISLAND. PLEASE ENSURE ALL OUTDOOR GEAR IS FREE FROM DIRT/VEGETATION BEFORE BOARDING THE FERRY.

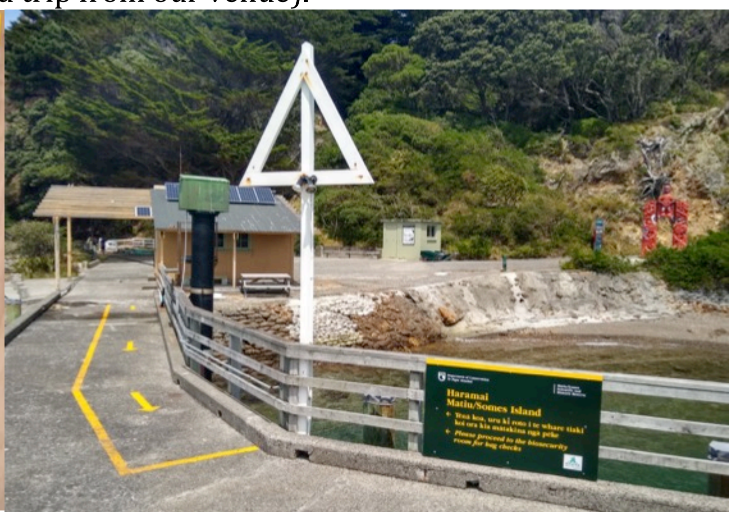
- Please bring your presentation on a portable USB storage device – we will use a single laptop for presentations.
    - Presentations are 15 min duration (12min pres. +3min Q+A)

- DOC asks that we take our shoes off in the houses and cottage, bringing slippers and/or s/jandals that are easy to slip on and off makes this easier

- Our friendly local brewers, Garage Project, have kindly supplied a couple of slabs of beer to support an IGS early-career glaciologist reception (open to all SIRG attendees). You might like to bring a bottle or a six-pack to supplement this supply (cans are easier to transport when empty – as we're responsible for bringing all trash and recycling back to Wellington).

What not to bring:

- Mice, rats, stoats, seeds, dirty boots/tents
- Power-hungry electrical appliances – power generation is by solar/wind
- Note also: there is total fire ban on the island. Smoking is only permitted on the ferry wharf (~20 min round trip from our venue).



Travel:

Wellington Airport-City options

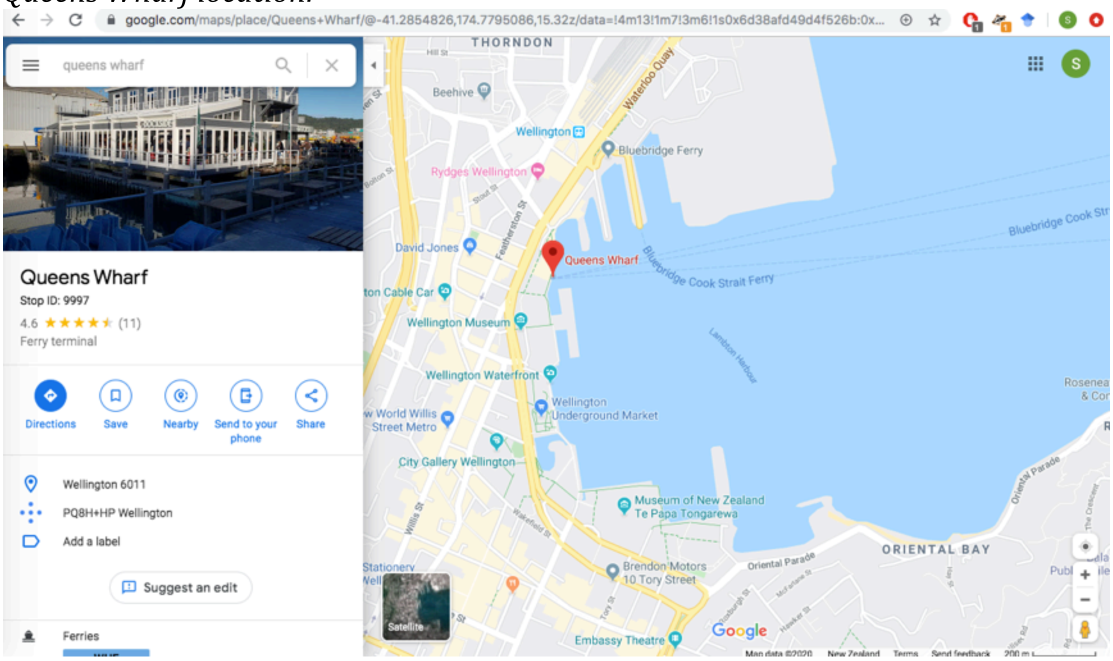
- There is an airport-city bus service (91 – Airport Flyer; $12pp one way) that has multiple stops in the city – exiting at Wellington Station leaves a 5-10 min walk to the Queens wharf ferry terminal.
- There is a cheaper bus option ($5 cash, $3 with a snapper card) if you're willing to walk: walk ~10 minutes from the airport to stop 7033 (corner of Hobart and Broadway, behind Burger King), take the #2 bus to the Willis St at Grand Arcade stop, walk 5-10 minutes to the ferry terminal
- Alternatively, taxis from airport to the city will cost $30-40 – maybe cost effective if there are more than 2 of you travelling in a group.

Return ferry travel from Queens Wharf to Matiu/Somes Island is included in your registration. Our intention is to meet at the Queens Wharf ferry terminal at ~1.50 pm to travel as a group on the 2.05 pm sailing. Alternatively, if you wish to travel earlier, there are 10.00 am and 12.00 pm sailings, please let us know in advance. There will be some of us going ahead to do some food prep – any help greatly appreciated!

For those joining on Tuesday, you should take the 10.00 am ferry. I will leave a list of names with the East-by-West ticket desk. You shouldn't need to pay anything.

For those staying overnight on Tuesday, we will return to the city on the 10.55 am sailing on Wednesday morning.

Queens Wharf location:



ACCOMMODATION

Forest and Bird House (<u>need sleeping bags and pillow case, torch</u>)
https://www.doc.govt.nz/parks-and-recreation/places-to-go/wellington-kapiti/places/matiu-somes-island/things-to-do/forest-and-bird-house/

Jim	Salinger	
Todd	Redpath	
Usama	Farooq	
Stefan	Vogel	
Martin	Forbes	
Hamish	Prince	
Stefan	Jendersie	Tuesday only
Levan	Tielidze	Tuesday only

Education House (<u>need sleeping bags and pillow case, torch</u>)
https://www.doc.govt.nz/parks-and-recreation/places-to-go/wellington-kapiti/places/matiu-somes-island/things-to-do/education-house/

Alex	Winter-Billington	
Maren Elisabeth	Richter	
Pat	Langhorne	
Florence	Isaacs	
Jessie	Lindsay	
Christine	Dow	Tuesday only
Becky	Macneil	
Holly	Winton	

Camping (tents must be clean clean!)
https://www.doc.govt.nz/parks-and-recreation/places-to-go/wellington-kapiti/places/matiu-somes-island/things-to-do/matiu-somes-island-campsite/

Jono	Conway
Lauren	Vargo
Tim	Kerr
Lynda	Petherick
Samuel	Walker
Shona	Mackie
Arran	Whiteford
Shaun	Eaves
Oliver	Wigmore
Lisa	Craw
David	Prior
Cliff	Atkins
Nitay	Ben-Shahar

Monday 3 February

Time	Presenter	Title
15.30-15.45	SIRG-2020 organising committee	Welcome
Session 1: Chair: Florence Isaacs		
15.45-16.00	Lisa Craw	Twenty Sheep and a Lasagne: using temperature changes to shorten ice deformation experiments
16.00-16.15	Hamish Prince	Glacial mass balance and Atmospheric Rivers; Categorizing the Occurrence of Extreme Alpine Weather Events
16.15-16.30	Pat Langhorne	Land-fast sea ice of the South West Ross Sea
16.30-16.45	Martin Forbes	Fractures modify stress state in ice shelf
16.45-17.00	Maren Elisabeth Richter	Not straight (forward). Where is the bottom of the sea ice?
17.00-17.15	Todd Redpath	Resolving and recreating the spatial structure of snow depth with high resolution surface models and regression trees
17.15-onwards: camp setup, group dinner prep., dinner		

Tuesday 4 February

Session 2. Chair: Alex Winter-Billington		
09.00-09.15	Oliver Wigmore	Assessing the impact of variable snow cover on alpine productivity with multispectral drones
09.15-09.30	Jessie Lindsay	Subaqueous Terminus Morphology, Tasman Glacier
09.30-09.45	Usama Farooq	Satellite based wind-driven sea ice drift analysis
09.45-10.00	Holly Winton	Novel ice core proxies for paleoclimate reconstruction
10.00-10.15	David Prior	Lateral shear of the Priestly Glacier, Antarctica
10.15-10.30	Florence Isaacs	Climate variability and sea ice in East Antarctica
10.30-11.00 **MORNING TEA** (AND FERRY ARRIVAL)		
Session 3. Chair: Rilee Thomas		
11.00-11.15	Lynda Petherick & Cliff Atkins	Determining the impact of Australian dust and charcoal on New Zealand's glaciers
11.15-11.30	Jono Conway	Modelling seasonal snow in the Southern Alps

11.30-11.45	Heather Purdie	Geomorphological contrast between advance and retreat phases at the terminus of a dynamic maritime glacier: Fox Glacier/Te Moeka o Tūwae, New Zealand
11.45-12.00	Arran Whiteford	Surveying the shape of a subglacial channel
12.00-12.15	Jim Salinger	Glacier volume change in the Southern Alps
12.15-12.30	Angela Landgraf	Deep glacial erosion and long-term safety of a deep nuclear waste repository
12.30-13.15 LUNCH		
Session 4. Chair: Maren Elisabeth Richter		
13.15-13.30	Lauren Vargo	Attribution of global glacier mass loss
13.30-13.45	Stefan Jendersie	The Nansen Ice Shelf, a Miniature Version of the Ross Ice Shelf
13.45-14.00	Tim Kerr	Ten Years of Rolleston Glacier Measurements
14.00-14.15	Alex Winter-Billington	Accuracy of models of debris-covered glacier melt
14.15-14.30	Stefan Vogel	Surface melting on the Amery Ice Shelf – a quick look on the past decade
14.30-15.00 AFTERNOON TEA		
***** DAY ATTENDEE DEPART FOR 15.15 FERRY TO WELLINGTON *****		
15.00-15.30	**ALL**	**SIRG group discussion**
Session 5. Chair: Lisa Craw		
15.30-15.45	Rilee Thomas	Water chemistry and ice mechanics
16.00-16.15	Samuel Walker	Frazil dynamics: Modelling small floating sea ice
16.15-16.30	Levan Tielidze	Late Quaternary glaciation of Ahuriri valley, Southern Alps
16.30-16.45	Christine Dow	Ice shelf fracture formation in Terra Nova Bay
16.45-17.00	Nitay Ben-Shahar	A Refined First Year Antarctic Sea Ice Growth Model
17.00-17.15	Shaun Eaves	Are New Zealand glaciers now smaller than ever before?
17.15-onwards: group dinner prep., dinner, IGS ECR social		

Wednesday 5th Feb – breakfast, camp pack-up and island exploration.
Ferry to Queens Wharf departs at 10.55 am

LIST OF PARTICIPANTS

Cliff	Atkins	Victoria University of Wellington
Nitay	Ben-Shahar	Victoria University of Wellington
Jono	Conway	NIWA
Lisa	Craw	University of Tasmania
Christine	Dow	University of Waterloo
Shaun	Eaves	Victoria University of Wellington
Usama	Farooq	University of Canterbury
Martin	Forbes	University of Otago
Florence	Isaacs	Victoria University of Wellington
Stefan	Jendersie	Victoria University of Wellington
Tim	Kerr	Rainfall.NZ
Angela	Landgraf	NAGRA, Switzerland
Pat	Langhorne	Department of Physics, University of Otago
Jessie	Lindsay	University of Canterbury
Shona	Mackie	University of Otago
Becky	Macneil	Antarctica NZ
Lynda	Petherick	Victoria University of Wellington
Hamish	Prince	University of Otago
David	Prior	University of Otago
Heather	Purdie	University of Canterbury
Todd	Redpath	University of Otago
Maren Elisabeth	Richter	University of Otago
Jim	Salinger	Visiting Scholar
Rilee	Thomas	University of Otago
Levan	Tielidze	Victoria University of Wellington
Lauren	Vargo	Victoria University of Wellington
Stefan	Vogel	Glaciology Tasmania
Samuel	Walker	University of Otago
Arran	Whiteford	Victoria University of Wellington
Oliver	Wigmore	Victoria University of Wellington
Alex	Winter-Billington	Victoria University of Wellington / University of British Columbia
Holly	Winton	Victoria University of Wellington

Abstracts (alphabetical by first author surname)

A Refined First Year Antarctic Sea Ice Growth Model

Nitay Ben-Shahar[1], Mark McGuinness[1], Joe Trodahl[2]
[1] *School of Mathematics and Statistics, Victoria University of Wellington*
[2] *School of Chemical and Physical Sciences, Victoria University of Wellington*
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A 1D model of the freezing of sea-ice with a snow cover is presented and coded in MATLAB. The model is based on historical models in the literature, and is primarily intended to provide a computational tool to be used when detailed temperature measurements are available in growing sea ice. The model is validated by comparing the modeled ice temperature profile and growth rate to measurements from 1997 in McMurdo Sound, Antarctica. This comparison shows evidence of platelet ice growth. Despite this, an accuracy on the order of 1% is achieved throughout the entire ice temperature profile. The model is also used to explain a previously speculated discrepancy between ice growth rates measured via banding structures in ice cores and simple steady state ice growth models with the inclusion of a thin 15mm snow layer.

Observations and modelling of seasonal snow in the Southern Alps / Kā Tiritiri o te Moana

Jono Conway[1], Christian Zammit[2], Ambre Bonnamour[2,3] Lucas Loumy[2,3]

[1] *NIWA Lauder*
[2] *NIWA Christchurch*
[3] *École Polytechnique Universitaire de Montpellier*

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Understanding and modelling snow cover dynamics in the Southern Alps of New Zealand is an important step towards quantifying the effects of the snowpack on stream hydrology and how these may change in a future climate. Along with potential effects on steam ecology, changes in the timing and magnitude of snow storage and melt may have economic and social implications in catchments with hydro-electric generation and abstraction for irrigation and other uses.

NIWA's Snow and Ice Network (SIN) was designed to fill gaps in the climate network at high-altitude areas and provide the information needed to improve our understanding of snowpack dynamics in the Southern Alps. The sites cover a diverse range of alpine environments from Fiordland to Nelson Lakes and from 1140 m to 2000 m above sea level. Along with standard meteorological variables, at each site, a snow pillow provides continuous measurements of the SWE stored in the snowpack and a sonic ranging instrument provides snow depth. This work presents collated timeseries of snow water equivalent and snow depth at six SIN sites over the period 2007-2018 and discusses the challenges associated with modelling snow at these sites.

Future efforts to model the seasonal snowpack at SIN sites will be aided by improvements in the precipitation and radiation data available at the sites along with efforts to simulate more of the physical processes that control snow accumulation and melt in these environments

Twenty Sheep and a Lasagne: using temperature changes to shorten ice deformation experiments

Lisa Craw[1], Adam Treverrow[1,2], Sheng Fan[3], Sue Cook[1,2], Felicity McCormack[1], Jason Roberts[4]

[1] *Institute for Marine and Antarctic Studies, University of Tasmania, Hobart, Australia*
[2] *Antarctic Climate and Ecosystems Co-operative Research Centre, University of Tasmania, Hobart, Australia*
[3] *Department of Geology, University of Otago, Dunedin, New Zealand*
[4] *Australian Antarctic Division, Hobart, Australia*
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It is vital to understand the mechanical behaviour of flowing ice in order to model the behaviour of ice sheets and ice shelves, and to predict their behaviour in the future. We can do this by performing deformation experiments on ice in the laboratory under varying conditions, and examining its mechanical and microstructural responses to stress. However, if we wish to emulate natural ice shelf and ice sheet conditions, we must deform ice to high strains (>15%) and at low temperatures (<-5°C), which can take an impractically long time. It is possible to accelerate an experiment by running it at a higher temperature in the early stages, and then lowering the temperature to emulate the target conditions once the tertiary strain stage is reached. We deformed polycrystalline ice samples in uniaxial compression at -2°C before lowering the temperature to -7°C, and compared the results to samples deformed at a single temperature. Tertiary strain rates adjusted to the change in temperature almost instantly with no lasting effects from the temperature history, and there is no detectable effect on the measured microstructure which could introduce a bias in experimental results. We propose this method as a viable technique for reducing the time taken to run low stress and low temperature experiments in the laboratory.

Ice shelf fracture formation in Terra Nova Bay

Christine Dow[1], Peter Wray[1] Christine Indrigo[1], Derek Mueller[2], Won Sang Lee[3], Duncan Young[4], Jamin Greenbaum[4], Don Blankenship[4], Mathieu Morlighem[5]

[1] *Department of Geography and Environmental Management, University of Waterloo, Canada*
[2] *Geography and Environmental Studies, Carleton University, Canada*
[3] *Korea Polar Research Institute, South Korea*
[4] *Institute for Geophysics, University of Texas at Austin, U.S.A.*
[5] *Earth System Science Department, University California – Irvine, U.S.A.*

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Terra Nova Bay in East Antarctica is home to the Drygalski Ice Tongue and Nansen Ice Shelf. Both of these ice bodies demonstrate relationships between basal channels, fracture formation, and buttressing effects that can be widely applied to other regions of the Antarctic. The Drygalski Ice Tongue is 140 km long, extending for 90 km into the Ross Sea, and has a series of fractures along its northern edge that eventually culminate in large-scale calving of icebergs once they reach the terminus region of the tongue. We use a combination of remote sensing, aerial radar data and subglacial hydrological modeling with the Glacier Drainage System (GlaDS) model to examine the relationship between these calving events, the formation of new fractures and the role of basal channels that initiate from subglacial water flux over the grounding line. At the nearby Nansen Ice Shelf, we use ground based and aerial radar data to examine the evolution of basal ice draft both spatially and temporally, and the role that a large basal channel plays in ice strain and related ice fracture. Combined analysis of these ice bodies illustrates important interconnections between ice shelf/tongue stability, ocean forcing and subglacial water fluxes over the grounding line.

Are New Zealand's glaciers now smaller than ever before?

Shaun Eaves[1,2], Lisa Dowling[1,2], Andrew Mackintosh[1,2], Kevin Norton[2], Brian Anderson[1], Alan Hidy[3], Andrew Lorrey[4], Matthew Ryan[2], Lauren Vargo[1], Stephen Tims[5]

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[2] *School of Geography, Environment, and Earth Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140*
[3]*Lawrence Livermore National Laboratory, Livermore, CA, USA*
[4]*National Institute Water and Atmospheric Research, New Zealand*
[5]*Department of Nuclear Physics, Research School of Physics and Engineering, Australian National University, Canberra, ACT 2601, Australia*

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Understanding pre-industrial or natural climate variability provides an important context for assessing the impact of anthropogenic climate change. However, detection and attribution of human impact on the climate system is limited by short instrumental climate records, especially in the Southern Hemisphere. Mountain glaciers are sensitive climate indicators, thus geological records of their past variability offer the potential to augment instrumental records.

Here we present a new cosmogenic ^{10}Be chronology of length changes at Dart Glacier in the Southern Alps. Prominent moraines deposited 321 ± 44 yr ago (n=11) show glacier advances during the Little Ice Age were smaller than during the early Holocene (7.8 ± 0.2 ka; n=5). This pattern of net Holocene glacier retreat is consistent with emerging data from other catchments in New Zealand and across the southern mid-latitudes. Measurements of ^{10}Be in bedrock surfaces uncovered by retreat of Dart Glacier over the last 3 centuries yielded no evidence for prior exposure, which is consistent with net glacier decline during the Holocene and may indicate a present-day glacial minimum for the interglacial.

Interpreting this climate proxy data in the context of existing global climate model simulations, we suggest that net decline of New Zealand glaciers through the Holocene was caused by rising summer air temperatures through the interglacial due to increasing summer insolation intensity – which is currently at its Holocene maximum. The current glacial minimum may have been pre-conditioned by orbital forcing of summer temperature and augmented in recent decades by radiative forcing effects of anthropogenic greenhouse gas emissions.

Satellite based wind-driven sea ice drift analysis

Usama Farooq[1], Wolfgang Rack[1], Adrian McDonald[1,2]
[1] *Gateway Antarctica, University of Canterbury, Christchurch, New Zealand*
[2] *School of Physical and Chemical Sciences, University of Canterbury, Christchurch, New Zealand*

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Sea ice drift is forced by winds and ocean currents and is an essential element in the dynamics of the polar oceans. Sea ice extent, concentration, and thickness are heavily influenced by ice dynamics. Satellite observations of sea ice drift provide valuable information about the governing dynamical processes of sea ice and its role within the Antarctic climate system. This study used the high-resolution satellite images to calculate the sea ice deformation fields of the Western Ross Sea. The Ross Sea region has experienced a significant increase in sea ice extent in recent decades. This region includes three main polynyas; McMurdo Sound (MSP), Terra Nova Bay (TNBP) and the Ross Ice Shelf Polynya (RISP). For this study, we used sequential Advanced Synthetic Aperture Radar (ASAR) images from the Envisat satellite. We downsampled the Wide Swath (WS) mode (swath width of 400km) images from 75 m pixel resolution to 150m. The drift velocity is calculated in centimeters per second using phase correlation techniques. Average motion vectors are correlated with wind velocity, which is one of the main forces responsible for driving sea ice motion. We used the Antarctic Mesoscale Prediction System (AMPS) wind velocity data set having a spatial resolution of 5km. Here we present the results showing the high correlation between sea ice drift velocity and wind velocity.

Simulated fractures modify stress state in ice shelf model(ers)

Martin Forbes[1], Christina Hulbe[1]
[1] *School of Surveying, University of Otago*

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Last year, we presented a method for modeling rift propagation in ice shelves. The method works as follows: internal loads in an elastic XFEM (eXtended Finite Element) domain are applied, recreating a stress field close to a rift tip determined from a viscous flow model and then the XFEM domain is solved using classic fracture mechanics modeling. Here, we evaluate the quality of our simulated stress fields in an area of interesting rift geometry near the front of the Ross Ice Shelf (RIS) in West Antarctica.

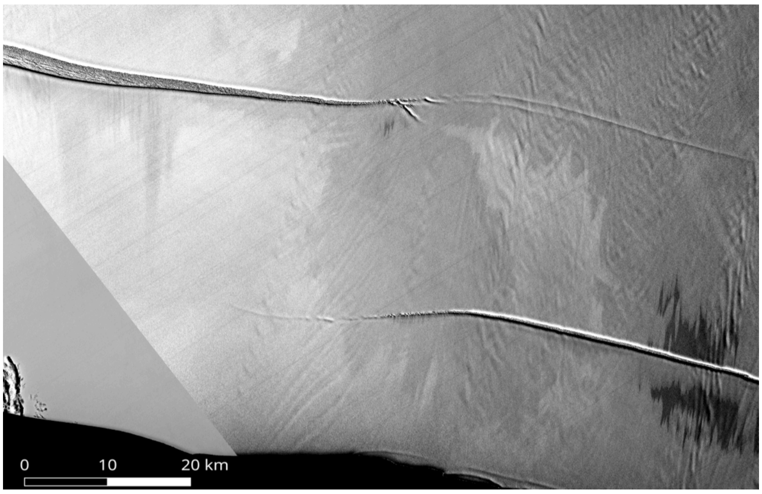

Figure 1: Two rifts near the RIS front interact (Landsat 8 Imagery)

The case study involves two long rifts near the RIS front. The observed geometries are a classic example of tip interaction (Figure 1). As two tips interact, their propagation directions deviate in response to near-field modifications to the far-field, glaciological, stress field. In sum, the tips initially propagate away from each other and then turn back toward the original propagation direction. Ability to reproduce this pattern demonstrates that our method correctly simulates how the rifts modify their stress field environment that they experience.

ENSO modulates summer and autumn sea ice variability in Dronning Maud Land, Antarctica

Florence Isaacs[1], James Renwick[1], Andrew Mackintosh[2], Ruzica Dadic[1]
[1] *Victoria University of Wellington, Wellington, NZ*
[2] *Monash University, Melbourne, AU*

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Antarctica's sea ice cover is an important component of the global climate system, yet the drivers of sea ice variability are not well understood. Here we investigate the effects of climate variability on sea ice concentration (SIC) around East Antarctica by correlating the 40-year (1979-2018) satellite sea ice record and ERA5 reanalysis data. We find that summer and autumn SIC around Dronning Maud Land (DML) between 10 - 70°E exhibited a statistically significant negative correlation with the Nino 3.4 ENSO index. Sea ice in DML was also correlated with sea surface temperature (SST) anomalies in the tropical Pacific, and to an atmospheric wave train pattern extending from the South Pacific to DML. We suggest that a southward-propagating atmospheric wave train triggered by ENSO SST anomalies in the tropics extends into DML and alters local heat fluxes and advection, affecting the formation, melt, and transport of sea ice.

The Nansen Ice Shelf, a Miniature Version of the Ross Ice Shelf

Stefan Jendersie[1]
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The Terra Nova Bay region in the western Ross Sea is host to various distinct Antarctic geophysical phenomena. Large outlet glaciers, such as the Priestley and the David Glacier, a (presumably) very cold ocean cavity beneath the Nansen Ice Shelf with a deep grounding line and, driven by strong katabatic winds, a highly productive latent heat polynya that produces a significant portion of the global AABW exist within a comparably small footprint of ~100km. Models and observation also hint the presence of CDW nearby over Crary Bank in the east, within impact reach of the Terra Nova Bay Polynya. The TNB region can be viewed as a natural lab where all the major components of the Antarctic ice-ocean-athmosphere system are fully represented.

In this talk we will highlight the great potential of observation and model based research in the TNB region to substantially improve our understanding about the evolution of Antarctica's sea ice, ice shelves and outlet glaciers from subseasonal to geological time scales. Some preliminary results will be presented, in particular recent developments of a resolution adaptable, coupled ocean-sea ice-iceshelf simulation framework that aims to bridge the gap between land based and ocean based ice.

Ten Years of Rolleston Glacier Measurements

Tim Kerr [1], Heather Purdie[2], Wolfgang Rack[2]
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[2] *University of Canterbury*

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The Rolleston Glacier loses enough water each year to fill an Olympic swimming pool 31 times. Put another way, an average of 0.7 m depth of water across the entire glacier has been lost each year for the last ten years. The last two years had the greatest loss with over 2.0 m. The greatest gains occurred in 2013 and 2015 when 0.7 m was added.
The Rolleston is a small glacier (0.1 km^2) located near Arthur's Pass. The glacier can be accessed within 3 hours walk from the road, and measurements can be achieved within a day from Christchurch. The glacier is low angled, nestled in a south facing corner of a ridge with winter avalanches contributing to the glacier's snow. The glacier receives about 5 m of snow each year predominantly from westerly events.
Measurements are made twice a year. Once at the end of winter to find out how much snow has fallen, and once at the end of summer to determine how much melt has occurred.
End-of-winter measurements consist of snow depth observations in as many places as possible across the glacier. These depths are converted to a water equivalent based on measured snow density and then spatially interpolated to provide an all-of-glacier average.
End-of-summer measurements consist of determining how much of four plastic stakes (inserted into drilled vertical holes at the end of winter) are exposed by the melting snow and ice. This is combined with further snow probing of any remaining snow fields. The stake exposure depths are interpolated across the glacier based on an elevation relationship, and combined with the interpolated snow probe measurements to find the all-of-glacier average melt. The winter gain less the summer loss provides the annual change.
The Rolleston is one of two glaciers in New Zealand, and one of 200 in the world with annual mass measurements. For context, there are 3000 glaciers in New Zealand, and 200000 in the world.
The measurements are submitted to the World Glacier Monitoring Service where they are freely available.
The Rolleston Glacier's average mass loss of 0.7 m per year is a little less than the global average loss from monitored glaciers of 0.8 m per year.
This year is the 10th consecutive year of measurements of the Rolleston Glacier. The intention is to continue monitoring for at least thirty years so that the glacier will become a global reference glacier.

Deep glacial erosion and long-term safety of a deep nuclear waste repository

Angela Landgraf[1], Urs H. Fischer[1], Gaudenz Deplazes[1], Michael Schnellmann[1], Jens K. Becker[1]

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Future erosion is an important aspect in evaluating the geological long-term evolution of deep nuclear waste repositories. The main processes that drive erosion are fluvial incision and deep glacial erosion. We therefore examine the potential evolution of the overburden in each siting area at different times over the next one million years.

Overdeepenings were carved by glacial erosion into the topography of northern Switzerland in Quaternary times, a process that is also expected to occur over the next one million years. Thus, to evaluate the potential for deep glacial erosion in the future, it is important to identify the past overdeepenings in northern Switzerland and to understand the glaciodynamic and climatic settings responsible for their formation. Nagra has initiated substantial Quaternary research within Switzerland, including Quaternary drilling into glacial overdeepenings and approaches to date their sedimentary filling. These field studies are complemented with ice flow modeling of past ice ages as well as global and regional climate modeling of the past and deep future. Besides the studies in Switzerland, however, we also aim for better process understanding and try to compare the Swiss case to analogue situations worldwide. A global comparison of glacially overdeepened basins, for instance, contributes to a better understanding of the factors that influence the genesis and variability in form and depth of such features. The synthesis is expected to corroborate our argumentation regarding future deep glacial erosion.

Here, we will present some of the key research efforts in this context and some initial results of the global comparison.

Land-fast sea ice of the South West Ross Sea

Pat Langhorne[1], Wolfgang Rack[2], Christian Haas[3], Greg Leonard[4], Gemma Brett[2], Natalie Robinson[5], Dan Price[2], Justin Beckers[6], Alex Gough[1]

[1] *Department of Physics, University of Otago, Dunedin, New Zealand;*
[2] *Gateway Antarctica, University of Canterbury, Christchurch, New Zealand;*
[3] *Alfred Wegener Institute, Bremerhaven, Germany;*
[4] *School of Surveying, University of Otago, Dunedin, New Zealand;*
[5] *NIWA, Wellington, New Zealand;*
[6] *University of Alberta, Edmonton, Canada.*

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The SW Ross Sea is a unique region with a highly variable sea ice cover including thin pack ice formed in polynyas, and extremely thick pack ice where it is deformed and exported into the Ross Sea proper. The Victoria Land coast is fringed by land-fast sea ice that interacts with ice shelves and floating ice streams, resulting in the presence of a sub-ice platelet layer as an indicator of supercooled ice shelf meltwater at the ocean surface. Airborne electromagnetic induction (AEM) sounding characterises the thickness of sea ice and its sub-ice platelet layer. AEM surveys, from helicopter and from fixed-wing DC3T aircraft, have been conducted over the spring fast ice of McMurdo Sound on five years between 2009 and 2017. The ice was mostly level and more than 2 m thick. It was underlain by a sub-ice platelet layer, with maximum thickness of more than 6 m near the ice shelf edge. The sub-ice platelet layer thickness distribution was in good agreement with in-situ measurements and was remarkably similar from year to year, suggesting a lack of annual variability in the ocean outflow from beneath the McMurdo Ice Shelf.

In November 2017 the AEM survey extended along the coast of Victoria Land. Fast ice between Terra Nova Bay and the Adare Peninsula was more than 2 m thick and heavily deformed by onshore pack ice drift. A sub-ice platelet layer, up to 2.5 m thick, was observed in front of the Hell's Gate Ice Shelf beneath 2 m of level sea ice. We use our knowledge of ice shelf outflow in McMurdo Sound to draw conclusions regarding fast ice adjacent to less accessible features of the Victoria Land coast. Our results have important implications for understanding and modelling ice shelf melt and interactions with sea ice, for sea ice remote sensing, and for studies of the biological productivity of the fast ice/platelet ice system and its role for the ecosystem and carbon fluxes in the region.

Processes and feedbacks associated with iceberg calving and subaqueous terminus morphology, Tasman/Haupapa Glacier, New Zealand

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Calving is an important process influencing the mass balance of a glacier.
The calving rate and magnitude of iceberg calving can be influenced by the presence of subaqueous ice ramps. Some calving glaciers form subaqueous ice ramps or 'ice feet' due in part to differences in the rates of subaerial and subaqueous calving. Spatial and temporal variation of these subaqueous features indicate that other processes also exert control. A relationship between velocity and calving was identified from this study. Velocity was found to influence calving whereby an increase in surface velocity would result in higher longitudinal strain rates and crevasse propagation that would lead to calving. The margins of the terminus with slower surface velocity and higher lateral drag, had less crevasse propagation and were considered more stable, these areas typically had the longest ice ramps. The central part of the ice cliff with higher surface velocity was more prone to crevassing. Ice ramps in these areas were typically steeper and shorter. The distribution of ramp lengths from 2013 – 2018 are commonly between 40 – 120 m in length (n=17) with the next largest group (n=12) between 120 – 200 m, only three ramps have been identified as greater than 200 m over the five-year survey time. From 2013-2018 a limited number of ice ramps exceeded 200 m in length, suggesting that ice ramps greater that 200 m are highly prone to buoyant calving. Findings to date indicate the primary driver of subaqueous ice ramp formation is the faster aerial calving rate over subaqueous calving. Spatial and temporal variation in velocity, lake limnology and subglacial hydrology also drive the formation and calving of subaqueous morphology but on a lesser scale than that of aerial calving.

Determining the impact of Australian dust and charcoal on New Zealand's glaciers

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Here we introduce our new project, which aims to explore the impacts of far-traveled Australian dust and charcoal on New Zealand's glacial environments. Using geochemistry and organic biomarkers to identify dust and charcoal respectively, we seek to quantify trans-Tasman aeolian sediment flux. Using pyranometers we aim to quantify the impact of far-traveled dust and charcoal on the albedo of the Tasman Glacier. These measurements will be used to input into the existing mass balance model for the glacier, to determine the role of far-traveled dust and ash on glacier ablation rates.

In addition to the far-traveled dust, the role of local sediment must also be quantified. Under a previously funded project, a robust vertical sediment trap was designed and created, to collect saltating and wind-blown sediments. A transect of these traps will be set up across the outwash plain of the Tasman Glacier to identify and quantify the movement of locally-sourced sediment across the landscape.

Glacial mass balance and Atmospheric Rivers; Categorizing the Occurrence of Extreme Alpine Weather Events

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Recent focus on the occurrence of extreme weather events in New Zealand has highlighted the role of atmospheric moisture fluxes on local hydrological systems. Atmospheric Rivers (ARs) are of particular focus as drivers for climatic extremes with 90% of extreme precipitation (98^{th} percentile) on the West Coast of New Zealand occurring within 12 hours of an AR (Cropp Waterfall rain gauge). With such significant statistics at lower elevations, it would be expected that the occurrence of ARs and subsequent delivery of extreme moisture fluxes at higher elevations would have substantial consequences for the local cryosphere. Exploratory research on the hydroclimatology of Brewster Glacier has been undertaken by Little et al. (2019) and Cullen et al. (2019), assessing the weather systems controlling mass balance at Brewster Glacier. The addition this current research makes is the application of an automated detection algorithm to allow for a systematic assessment of the role of AR's on the New Zealand cryosphere over a significantly longer time period.

An object orientated AR detection algorithm is run on atmospheric moisture flux data (ERA-Interim) from the last 40 hydrological years (1979-2019) to develop a long-term dataset of ARs in New Zealand. A newly proposed categorization scheme, which imitates similar scales used for hurricanes and tornadoes is applied to the detected AR features (Cat 1 – Cat 5). An AR climatology is developed and seasonal occurrences are calculated. The categorization scheme considers the intensity and duration of the atmospheric moisture flux; the longer and stronger an event is, the higher the category. Glaciological and meteorological data from Brewster Glacier are used to assess the relationship between ARs and extreme ablation and accumulation events. Five out of six of the largest melt events on Brewster Glacier occurred during ARs, with Categories ranging from Cat 1 to Cat 4. Four out of five of the largest snowfall events occurred during ARs of only Cat 1. Higher category events are less common in the winter and along with the presented results it becomes apparent that weak wintertime ARs are the weather events that bring some of the highest snowfall events.

Geomorphological contrast between advance and retreat phases at the terminus of a dynamic maritime glacier: Fox Glacier/Te Moeka o Tūwae, New Zealand

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Fox Glacier/Te Moeka o Tūwae is a fast-responding maritime glacier that has undergone multiple advance and retreat phases during recent decades. Here we use a combination of repeat photography, Structure from Motion (SfM), and ice discharge measurement, to identify key morphological differences associated with these repeated phases changes, and assess how much of the current terminus is still active. Increasing surface-debris cover at the margins and topographic shading result in asymmetry of the retreating terminus, with central portions receding faster than the margins. In 2019, the glacier is already shorter than in any time in recorded history, and ice flux is insufficient to sustain the current glacier length, meaning that a further 450 m of the glacier terminus region is potentially vulnerable to collapse.

Resolving and recreating the spatial structure of snow depth with high resolution surface models and regression trees

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In order to improve distributed snow models, there is a need to better understand the processes that control the spatial distribution of snow in alpine areas. Historically, there has been a lack of data sufficient to capture spatial variability in snow depth over short spatial scales in New Zealand. Advances in photogrammetry now permit the capture of high resolution maps of snow depth by remotely piloted aircraft systems (RPAS). RPAS photogrammetry has been demonstrated to be a reliable means of accurately mapping snow depth. In this study, six maps of snow depth, captured over winter and spring of 2016 and 2017 for a study basin in the Pisa Range, Central Otago, are considered to:

1) Resolve the spatial structure of observed snow depth, and
2) Assess the role of topographic and vegetative controls in controlling the observed spatial structure.

Semivariogram analysis of maps of observed snow depth reveals ranges of spatial autocorrelation of 10 – 30 m. The spatial observed spatial is persistent through time, with greatest coherence between spring observations. The majority of snow water equivalent stored within the study basin was found to reside within relatively small areas of maximal snow depth. The influence of topographic controls was assessed by constructing regression trees between topographic parameters (elevation, maximum upwind slope, topographic position index, shading and tussock density) and snow depth for each observation date. The performance of regression tree models was assessed by comparing maps and semivariograms of predicted and observed snow depth. While not able to resolve the full magnitude of spatial variability in snow depth, the regression tree models reproduced a reasonable component of the observed spatial structure. In doing so, the regression tree models highlight the relative importance of processes influencing snow depth, including variability in wind regime between winters, the increased importance of solar radiation through the ablation season and the role of vegetation in the development and maintenance of the snow pack. These results provide new and improved insights into the the processes controlling snow distribution over scales up to hundreds of metres in New Zealand, and can provide valuable guidance for snow modelling efforts.

Not straight (forward). Where is the bottom of the sea ice?

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A precise knowledge of sea ice thickness is important for many different reasons. It allows the volume and mechanical strength of sea ice to be estimated, influences the amount of light available under the ice and gives information on the growth and decay of the ice cover. However, defining the underside of the ice is not as trivial as it may appear, for example where there is a sub-ice platelet layer under the ice. Sea ice in McMurdo Sound, Antarctica is influenced by supercooled water exported from a nearby ice shelf which allows the formation of a sub-ice platelet layer. This friable layer consists of ice platelets of seemingly random orientation under the consolidated sea ice and influences the sea ice growth rate. The transition, when there is a sub-ice platelet layer present, from solid ice to water, via a matrix of loose or semi-consolidated ice crystals, complicates the definition of sea ice thickness.

Here, we present an analysis of sea ice thicknesses calculated from thermistor strings deployed in McMurdo Sound over two decades. We compare the robustness, precision and accuracy of different methods of processing thermistor string data to determine the ice-ocean interface. The resulting thickness time-series can be used to study interannual variability and existing or emerging trends in McMurdo sea ice and the sub-ice platelet layer. Although sub-ice platelet layers are rarely found outside the vicinity of deep drafted ice shelves, our results are of relevance to other situations in which the ice bottom is ill-defined.

Climate forcing of glacier volume change in the Alps of New Zealand

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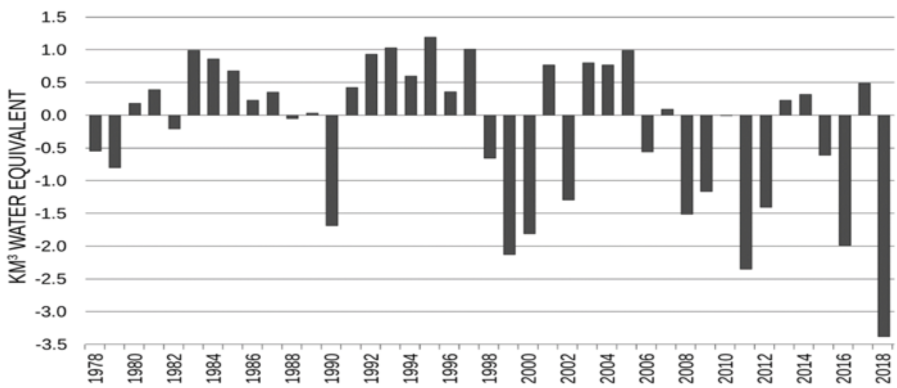
New Zealand has a long, continuous record of annual measurements of the altitude of end-of-summer-snowline for a set of 50 Southern Alps 'index glaciers'. The record begins for the 1976-1977 glacier year and continues to the present. These are equivalent to equilibrium line altitude (ELA) data. An earlier paper used these to estimate annual mass balance and ice volume for all glaciers up to 2008 and showed a steady decline in ice volume, but with considerable inter-annual fluctuations. These results are updated to 2018 for the more than 3000 small and medium-size glaciers of the Southern Alps. The inclusion of the latter year enabled assessment of the impacts on ice volume of these glaciers from an unprecedented coupled ocean-atmosphere heatwave in the New Zealand region during the austral summer (DJF) 2017/18. The main purpose of this paper is to examine how these changes in ice volume relate to variability and trends in atmospheric circulation and weather types over four decades. Years with ice volume gains are characterized by below average temperature anomalies, enhanced southwest flow and a tendency for trough weather types over New Zealand. Years with ice volume losses have above average temperature, reduced southwest flow, and increased blocking weather types, with more anticyclones east of New Zealand. Largest annual ice volume loss of 3.6±0.6 km^3 (-13.5%) occurred during the 2017/18 summer heatwave for which the main atmospheric anomalies are discussed. Total ice volume of the Southern Alps for the small and medium glaciers has decreased from 26.6 km^3 in 1977 to 17.9 km^3 in 2018 (a loss of 8.6 km^3 or 33 %) at a rate of 0.21 km^3a^{-1}. From 1977-1997 there was an annual ice gain of +0.30 km^3a^{-1} but was followed by an accelerating ice loss of -0.67 km^3a^{-1} for the period 1998-2018.



Time series of volume changes for small to medium glacier, Southern Alps, 1978–2018 Annual volume changes in water equivalents km^3. Series are for April to March years.

Water chemistry and ice mechanics

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Laboratory experiments have been used to quantify the creep behaviour of polycrystalline ice. These are the basis of flow laws, such as the Glen flow law, which describe the strength of ice for given applied stresses and temperatures. Flow laws are crucial in modelling the flow of bodies of ice, such as the West Antarctic Ice Sheet, and their response in a warming climate. All existing flow laws are based on experiments that use ice free of soluble (chemical) and insoluble (particulate) impurities. This is unrealistic in natural Antarctic ice. Past work has shown ice with impurities tends to be weaker than pure ice, as intracrystalline impurities should encourage the formation of dislocations and deformation of grains. As ice flows, the impurities are swept to grain boundaries and influence mechanical behaviour by inhibiting grain growth through grain boundary pinning. This is seen in natural ice cores, with higher concentrations of ionic species found in finer grained bands of ice. The effects of chemistry have proven difficult to quantify, as different chemical species appear to behave differently; Recent work has shown Ca^{2+} ions have a hardening effect, while H_2SO_4 enhances creep rates in ice. In this study, ice with major ion chemical compositions comparable to coastal and central Antarctic ice has been synthesised, and deformed in a series of uniaxial compression experiments at varying strain rates (10^{-4}, 10^{-5}, $5x10^{-6}$ s^{-1}) and temperatures (-10 and -30°C) at the University of Pennsylvania. Mechanical data suggest chemistry has no significant effect on the strength of ice. This suggests insoluble impurities or higher ionic concentrations than those studied contribute to the softening of natural ice. Microstructural and detailed chemical analysis in the coming months will be vital in determining this.

Comparison of Late Quaternary glacier extent from the Southern Alps and Greater Caucasus

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During the Late Quaternary, the Earth's surface was subject to multiple glaciations and there are several views about the limits of their extension. Sometimes these views complement each other, but sometimes they are mutually exclusive. Modern methods such as ^{10}Be dating provide an opportunity to test competing hypotheses about past glacial extent and climate conditions.

We have ultimately chosen the valleys from the Sothern Alps and Greater Caucasus mountain ranges because:

i) They contain well preserved moraine records that offer an opportunity to constrain changes in Late Quaternary glacier length and paleoclimatic conditions;

ii) These mountain ranges are situated in a similar but opposing latitudes, but in quite different climatic settings (Southern Alps – maritime, distal to Quaternary ice sheets; Greater Caucasus – continental, proximal to Quaternary ice sheets), which should help to test the relative importance of regional vs. global climate drivers;

iii) Modern glaciers in both regions show quite similar strong reactions to global warming over the last several decades (Tielidze and Wheate, 2018) and both mountain ranges have almost same percentage amount of supraglacial debris cover. It is particular interest to better understand how much different or similar reaction past glaciers had in both mountain regions during the Late Quaternary.

References

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Attribution of global glacier mass loss

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Glaciers are iconic sentinels of climate change. Retreating ice and extreme melt events are often used as examples of human impact on the climate. However, only one study has shown a formal link between decadal-scale glacier mass-loss and anthropogenic forcing. The study required long-term records of mass-balance measurements, which are rare, especially in the Southern Hemisphere. Using long-term records dampens the signal of extreme mass-loss years, which have become more prevalent in recent decades.

In this study, for the first time, a direct link is made between extreme glacier mass-loss years and anthropogenic forcing. We develop a framework to apply formal attribution methods to years of extreme glacier melt. We show that for the two New Zealand glaciers with direct mass-balance measurements, the highest mass-loss year, 2018, was at least 25 times more likely to occur with anthropogenic forcing. This framework can be applied to any glaciers with direct mass-balance measurements, without the need for long-term records. We aim to use this framework to calculate the anthropogenic influence on extreme mass loss years for glaciers globally.

Surface melting on the Amery Ice Shelf – a quick look on the past decade

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A general notion about Antarctica is that it is dry and cold. Yet along its coast line significant melting is observed each summer. In various places melt water has been responsible for changes in the dynamic of glaciers, ice sheet and ice shelves. One spectacular event was the collapse of the Larsen B Ice Shelf. Here melt water ponding had a destabilising effect on the ice shelf. Melt water draining through an ice sheet can enhance lubrication of the glacier bed leading to flow acceleration and enhanced ice discharge. Freshwater input to the sub ice shelf environment may enhance thermohaline circulation with the potential of enhancing the draw of warmer water masses into the sub ice shelf cavity.
Here we present initial results investigating surface melting and surface melt-distribution in the Lambert Graben- Amery Ice Shelf. Clearly visible from space, each year a network of lakes and rivers forms on the surface of the Amery Ice Shelf south of Jetty Peninsula (~ 70.5 °S). Surface melt features are absent in the front half of the Amery Ice Shelf likely due to high snow accumulation. Microwave imagery as well as snow temperature data indicate melting with melt water percolation into and refreezing inside the snow cover. Closer examination of satellite imagery shows an extensive surface hydrological network covering the back of the Amery Ice Shelf transporting melt water over large distances. During high melt years supra glacial lakes can reach tens of kilometres in length and >1 kilometre in width. The most southern surface lake is found adjacent to the Cumpston Massif on the Mellor Glacier (73.5 °S). This is a significant distance upstream from the ice shelf grounding zone and raises the possibility that surface melting under 21st climate warming scenarios could enhance lubrication of East Antarctic outlet glaciers.

Frazil dynamics: Modelling small floating sea ice crystals

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Underneath Antarctic Ice Shelves a layer of supercooled Ice Shelf Water (ISW) is sometimes present. The behaviour of ISW changes depending on the presence of frazil Ice Crystals. Concentration and size distributions of frazil Ice are necessary for work on the Marsden-funded HIPSMI project regarding making direct measurements of supercooling. Direct measurements of frazil are not available so recourse is made to frazil ice models. Higher resolution of frazil size significantly increases computational complexity. A one-dimensional model would be beneficial to reduce computational overheads. A pre-existing one-dimensional model was adapted to include the vertical distribution of frazil ice derived from the work of another group. Preliminary results showed physically reasonable behaviour. Both the original and adapted model show frazil ice behaviour has a dependence on the poorly constrained basal drag and Shields criterion parameters. We find that accurate description of frazil ice behaviour using a one-dimensional model is not possible with currently available physical observations of ISW. Direct observations of frazil Ice in situ could improve the predictive capabilities of one dimensional frazil Ice models.

Surveying the shape of a subglacial channel with radio-echo sounding

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Changes in the size of Antarctica's ice sheet are controlled by the discharge of ice into the sea. 90% of this discharge comes from fast flowing ice streams, which slide at hundreds of times the speed of most Antarctic ice. Such fast sliding relies on a base saturated with water. Ice stream models rely on poorly constrained estimates of subglacial water. To better estimate subglacial water flux, in December 2019, we used ground based radio echo-sounding to survey a subglacial channel. The channel is carved by a buoyant plume of fresh water, which melts into the base of the Ross Ice Shelf. The narrow channel incises as deep as one third of ice thickness. Results from the survey will be used to model a meltwater plume to find estimates of subglacial water flux.

Assessing the impact of variable snow cover on alpine productivity with multispectral drones

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Alpine environments are highly heterogeneous. Dramatic variations in climate, hydrology, snow depth, soil, and vegetation can occur over relatively short distances, and are dynamic through time. Wind redistribution drives the development of snow banks and scour zones which impacts water supply and growing season length. These localized and spatiotemporally variable water and energy limitations lead to the development of hot spots and hot moments in alpine vegetation productivity. Where certain locations and/or times are disproportionately responsible for regional observations. However, many of these processes operate at sub 10m to sub 1m spatial resolutions at daily to weekly time scales. Consequently, these processes are not resolved with widely used moderate resolution satellite remote sensing, and, are often poorly represented by point measurements. Fortunately, unmanned aerial systems (UAS) or drones can provide contiguous data at high spatial and temporal resolution that can help to bridge spatiotemporal gaps in our knowledge of alpine ecohydrology pattern and process. We deployed a custom built multispectral (visible, near infrared, thermal infrared) UAS at weekly interval over the Niwot Ridge Long Term Ecological Research sites saddle catchment in Boulder Colorado. We used the data to observe changes over the 2017 summer snowmelt season. Thermal imagery was used to map surface/subsurface hydrologic flowpaths, and improve our understanding of hydrologic connectivity. Weekly NDVI was used to assess spatiotemporal variability in vegetation productivity, and to quantitatively assess the impact of water, energy, and wind limitations on NDVI across the ~40ha study site. We observed a roughly 15% reduction in NDVI values as a consequence of water and wind limitation. Energy limitations due to late snow cover decreased observed NDVI by around 20%; and delayed the date of peak NDVI by over 10 days. Our results illustrate the novel insights that can be provided by high resolution UAS data collection.

Accuracy of models of debris-covered glacier melt

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Supraglacial Debris is significant in many regions and complicates modelling of glacier melt, which is required for predicting glacier change and its influences on hydrology and sea-level rise. Energy-balance models are preferred but their accuracy is dependent on extensive input data, which may not be available or reliable over large areas. Empirical temperature-index models are a popular alternative, but their transferability among glaciers and inherent uncertainty have not been well documented in application to debris-covered glaciers. The aim of this project is to quantify and contrast the accuracy of predictions of debris-covered glacier melt using empirical and energy-balance models, with climate reanalysis and on-site input data. Using observed melt data compiled directly from published literature for 27 debris-covered glaciers around the world, linear mixed-effects models were fitted to predict melt factors from debris thickness and variables including debris lithology and MERRA-2 climate reanalysis radiative change. The best model included debris thickness (fixed effect) and glacier and year (random effects). The models were tested by leave-one-site-out cross-validation based on predicted melt rates. Linear fixed-effects models were fitted using previously unpublished data from three Himalayan glaciers. Predictions made for glaciers around the world using the best mixed-effects model were more accurate than those made using the fixed-effects models fitted and transferred within the same geographic region. Pooling the data from multiple glaciers to fit the mixed-effects models improved cross-validation accuracy more than including additional predictions such as solar or longwave radiation. The accuracy of predictions made using MERRA-2 was equal to that of predictions made using on-site air temperature data. In the final stage of the project, the open-source Simultaneous Heat and Water (SHAW) mass- and energy-balance model is being tested in application to the same data sets. SHAW was developed to predict changes in permafrost and is maintained by the USDA. It has been validated in a range of environments but not yet applied to debris-covered glaciers.

Novel ice core proxies for paleoclimate reconstruction

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The past decade has seen vast innovation in methods of ice core extraction, analysis and interpretation. Many paleoclimate proxies have been identified from ice cores, with ongoing effort to extend their application and refine their interpretation. Traditional ice core proxies include temperature, snow accumulation rate and greenhouse gases, with recent advances in biomass burning, sea ice proxies, for example. The emergence of ice core biomarkers show great promise for reconstructing marine primary productivity and sea ice change in Antarctic waters. Challenges remain in the field of ice coring sciences, including the interpretation of chemical records from rapid advancements in analytical techniques, understanding of post-depositional processes, and spatial integration of multi-archive paleoclimate records.

Here, I show examples of novel proxy development and interpretation focusing on ice core biomarkers. Spectroscopy of fluorescent Organic Matter (fOM), when paired with Imaging Flow Cytometry (IFC), offers new information on changes in microscopic plankton and tryptophan-like and tyrosine-like substances deposited in Antarctic ice. We summarise the latest development in this proxy, and highlight exciting results from Antarctic ice cores. Future work will investigate fOM in Ross Sea ice cores to reconstruct past marine primary productivity, and provide new constraints on Antarctic sea ice change.