Proceedings of the

New Zealand Snow and Ice Research Group

2018 Workshop

Mount Hutt Retreat, Canterbury

February 7-9

Rakaia Valley and Lake Coleridge

Chief Organiser

HeatherPurdie

Foreword

The 2018 New Zealand Snow and Ice Research Group workshop was held at:

Mount Hutt Retreat, Methven

On: February 7–9, 2018

Organising committee:

Heather Purdie (Chief organiser)

Wolfgang Rack

Oliver Marsh

Tim Kerr

The annual meeting of the New Zealand Snow and Ice Research Group provides an opportunity to meet and discuss our common interest in snow and ice research.

The New Zealand Snow and Ice Research Group (SIRG) are those people who have registered on the "SIRG" email group at: http://lists.vuw.ac.nz/mailman/listinfo/sirg SIRG maintains a website at: http://sirg.org.nz/

SIRG is the New Zealand chapter of the International Glaciological Society: http://www.igsoc.org/

SIRG maintains an on-line bibliography of New Zealand snow and ice research publications: https://www.zotero.org/groups/sirg/items/

Programme

Wednesday February 7th, 2018

13:00	*Welcome*	Heather Purdie (UC)	

New Zealand Research, Chair: Todd Redpath, Co-Chair: Oliver Marsh

13:15	Dynamics Of Advance At Franz Josef Glacier/Kā Roimata O Hine Hukatere	Brian Anderson (VUW)	Page 1
13:30	Measuring New Zealand Glacier Fluctuations From Historic Photographs	Lauren Vargo (VUW)	Page 2
13:30	Mass Balance And Climate Of Brewster Glacier	Nicolas Cullen (Otago)	Page 3
13:45	The Multi-Millennial Context Of Present-Day Glacier Retreat In New Zealand	Shaun Eaves (VUW)	Page 4
14:00	A New Snow Model To Assess The Impact Of Climate Change On New Zealand's Frozen Water Resources	Jono Conway (Bodeker Scientific)	Page 5
14:15	Predicting Precipitation Phase In The Maritime Southern Alps, New Zealand	Rasool Porhemmat (UC)	Page 6
15:00	Break		

New Zealand Research (continued), Chair – Lauren Vargo, Co-Chair – Nicolas Cullen

15:30	A Remotely Sensed Seasonal Snow Cover Climatology For The Clutha Catchment	Todd Redpath (Otago)	Page 7
15:45	Glacier Surface Albedo From Modis Data And Links To Annual Mass Balance For The Gardens Of Eden And Allah, Southern Alps, New Zealand	Angus Dowson (Otago)	Page 8
16:00	Finite-Element Modelling Of Glacier Sliding (Tasman Glacier)	Clarrie Macklin (VUW)	Page 9
16:15	Towards Determining The Impacts Of Freshwater In The New Zealand Earth System Model	Shona Mackie (Otago)	Page 10
16:30	Observed Changes To A Glacier Near The Top Of Aoraki/Mt Cook	Tim Kerr (Aqualinc)	Page 11
16:45	A Topographic Rather Than Climatic Origin Of Declining Lengths Of Upper Clutha Glaciations	Trevor Chinn (A&PPC)	Page 12
17:00	*Dinner preparation –please help*		

18:30 *Dinner and clean up – please help*

20:00 ***Guest Speaker: Julian Dowdeswell, Scott Polar Research institute*** ***Page 13***
"The Marine Geophysical Signature Of Past Ice Sheets"

Thursday February 8th, 2018

07:00 *Breakfast – please help with preparation and clean up*

Sea Ice, Chair - Martin Forbes, Co-Chair – Greg Leonard

08:30	Variability In The Thickness Of Sea Ice And The Sub-ice Platelet Layer In McMurdo Sound From Electromagnetic Induction Soundings.	Gemma Brett (UC)	Page 14
08:45	Regional Scale Variability In Antarctic Sea Ice Thickness, A Comparison Of ASPeCt Observations And CCSM4 Model Data	Kage Nebit (Otago)	Page 15
09:00	Centennial Timescale Impacts Of Increasing Ice Shelf Meltwater On Antarctic Sea Ice Area	Inga Smith (Otago)	Page 16
09:15	EBSD On Sea Ice	Pat Langhorne (Otago)	Page 17
09:30	Characterising Frazil Distributions In McMurdo Sound Using Acoustic Techniques	Eamon Frazer (Otago)	Page 18
09:45	Convectively-Driven Migration Of Brine Enclosures In Sea Ice: Effect Of Tilt Angle	Mira Schmitt (Otago)	Page 19
10:00	*Break*		

New Zealand Bonus, Chair – Brian Anderson

10:30	The Remote Sensing Of Seasonal Snow With Ultra-Long-Distance Ground-Based Lidar Sensing Along The Milford Highway	Simon Morris (Milford Rd Alliance)	Page 20

Sea ice (continued), Chair – Gemma Brett, Co-Chair – Inga Smith

10:45	Wind-Driven Sea Ice Drift Estimation From High Resolution Satellite Images In The Ross Sea – Antarctica	Usama Farooq (UC)	Page 21
11:00	A Drone Mounted Radar To Measure Snow Depth On Sea Ice	Wolfgang Rack (UC)	Page 22
11:15	Taking The Measure Of Winter Sea Ice From Beneath, Within And Above	Greg Leonard (Otago)	Page 23

11:30	The Influence Of Particulate Second Phase On The Creep Behaviour And Microstructural Evolution Of Experimentally Deformed Ice	Sheng Fan (Otago)	Page 24
11:45	Using High Resolution Airborne Imagery Over The McMurdo Ice Shelf, Western Ross Sea, To Improve Interpretation Of Historical Satellite Data	Jeff Turner (UC)	Page 25
12:00	*Lunch – please help with preparation and clean up*		

Ice shelf processes – Chair – Eamon Frazer, Co-Chair – Trevor Chinn

13:00	Spare spot		
13:15	Small-Scale Pinning Points Within The Ross Ice Shelf	Holly Still (Otago)	Page 26
13:30	Glaciological Context Of The Hwd2 Borehole On The Ross Ice Shelf	Kelly Gragg (Otago)	Page 27
13:45	The Shape Of Change: A New Method To Identify Sources Of Dynamic Thickness Change	Adam Campbell (Otago)	Page 28
14:00	Nature Or Nurture? Rift Generation(s) At The Northeast Front Of The Ross Ice Shelf	Martin Forbes (Otago)	Page 29
14:15	Tidal Grounding Line Migration At The Darwin Glacier	Oliver Marsh (UC)	Page 30
14:30	*Short Break*		

NZ Snow and Ice Research Group Business – Chair – Oliver Marsh

15:00	Where will SIRG 2019 be?
15:15	Collaborative research futures
15:30	*Briefing for Friday morning's field trip*
16:00	*Depart to Methven for Dinner*

Friday February 9th, 2018

07:00	*Breakfast – please help with preparation and clean up* *Make lunch for the field trip*
08:00	*Pack up, clean up*
09:00	*Depart on field trip to Mt Hutt Range and view of Rakaia Terminal Moraines*
14:00	*Field trip complete – head home*

Guest Speaker:

Professor Julian A. Dowdeswell, B.A., M.A., Ph.D., Sc.D.

Director of the Scott Polar Research Institute, Department of Geography, University of Cambridge, U.K.

Julian Dowdeswell graduated from the University of Cambridge in 1980, and studied for a Masters Degree at INSTAAR in the University of Colorado and for a Ph.D. in the Scott Polar Research Institute, University of Cambridge.

His research interests include: (a) the dynamics of large ice masses and their response to climate change; (b) the application of airborne and satellite geophysical techniques in glaciology, and (c) processes and patterns of sedimentation in glacier-influenced marine environments. He has worked, on the ice and from airborne platforms, in a number of areas of the Arctic, including Svalbard, Russian Franz Josef Land and Severnaya Zemlya, Iceland, East Greenland and Baffin, Devon and Ellesmere Islands in Arctic Canada. He has also undertaken many periods of work on icebreaking research vessels in the Norwegian-Greenland Sea, in the fjords and on the continental shelves of Svalbard and Greenland, and in Antarctica.

Julian has been awarded the Polar Medal by Her Majesty the Queen for 'outstanding contributions to glacier geophysics' and has also received the Founder's Medal (2008) and the Gill Memorial Award (1998) from the Royal Geographical Society. In 2011 he was awarded the Louis Agassiz Medal by the European Geosciences Union for 'outstanding contributions to the study of polar ice masses and to the understanding of the processes and patterns of sedimentation in glacier-influenced marine environments.' In 2014 he was awarded the IASC Medal by the International Arctic Science Committee.

DYNAMICS OF ADVANCE AT FRANZ JOSEF GLACIER/K Ā ROIMATA O HINE HUKATERE

Anderson, B.[1]

[1]Antarctic Research Centre, Victoria University of Wellington

Glaciers respond to climatic forcing on a variety of time scales. While many glaciers in the Southern Alps/Kā Tiritiri o te Moana have retreated more-or-less continuously in recent decades, some glaciers with fast response times have advanced at times due to positive mass balances over just a few years. Kinematic wave theory has been used to describe the ice velocity, ice thickness and terminus position changes associated with glacier advance, but there are very few observations of kinematic waves on real glaciers. Glacier recession at Franz Josef Glacier has made traditional monitoring difficult, but structure from motion photogrammetry from light aircraft has opened new possibilities for glacier monitoring. Between 2008 and 2016 Franz Josef Glacier retreated 1.42 km, but between December 2016 and October 2017 the glacier advanced 50 m, and the advance is continuing. While mass balance is not measured at Franz Josef Glacier, mass balance and snowline records on other glaciers suggest that the glacier experienced positive balances in glacier years ending 2013-2015 and 2017. The advance was preceded by thickening of the glacier tongue (10-20 m), but the thickening is not steady, but instead seasonally modulated with maxima of ice elevations at the end of winter. Ice velocities also show seasonal variation, making it difficult to discern inter-annual velocity variations. However, further analysis of these observations may provide details of the dynamics of glacier advance.

MEASURING NEW ZEALAND GLACIER FLUCTUATIONS FROM HISTORIC PHOTOGRAPHS

Vargo, L.J.[1], Anderson, B.M.[1], Horgan, H.J.[1], Mackintosh, A.N.[1], Lorrey, A.M.[2], Thornton, M.[1]

[1]Anarctic Research Centre, Victoria University of Wellington

[2]National Institute of Water and Atmospheric Research

Quantifying glacier fluctuations is important for understanding how the cryosphere responds to climate variability and change. Airborne photogrammetry enables glacier extent and equilibrium line altitudes (ELAs) to be monitored for more glaciers at lower cost than traditional mass-balance programs and other remote sensing techniques. Since 1977, end-of-summer-snowlines, which are a proxy for annual ELAs, have been recorded for 50 glaciers in the Southern Alps of New Zealand using oblique aerial photographs. We present a new method to quantitatively measure past glacier fluctuations from these historic images. The method uses a large set of modern geolocated photographs and Structure from Motion (SfM) to calculate the camera parameters for the historic images, including the location from which they were taken. We apply this method to a small maritime New Zealand glacier (Brewster Glacier) to derive annual ELA and length records between 1981 and 2017, and quantify the uncertainties associated with the method. Results show that Brewster Glacier has retreated 365 ± 12 m since 1981 and, using independent field measurements of terminus positions (2005 – 2014), we show that this SfM-derived length record accurately captures glacier change. The ELA record, which compares well with glaciological mass-balance data measured between 2005 and 2015, shows pronounced interannual variability. Mean ELAs range from 1707 ± 6 m a.s.l. to 2303 ± 5 m a.s.l., with the highest ELAs occurring in the last decade. Future work includes the application of this method to all 50 end-of-summer-snowline glaciers, further expanding the database of New Zealand glacier fluctuations.

MASS BALANCE AND CLIMATE OF BREWSTER GLACIER

Cullen, N.J.[1], Anderson, B.[2], Sirguey, P.[1], Conway, J.P.[1,3], Little, K.[1], Kingston, D.[1], Mackintosh, A.[2], and Lorrey, A.[4]

[1]University of Otago, Dunedin, New Zealand,

[2]Victoria University of Wellington, Wellington, New Zealand,

[3]Bodeker Scientific, Alexandra, New Zealand,

[4]NIWA, Christchurch, New Zealand

The mass balance and climate of Brewster Glacier continues to be monitored and new glaciological data have been processed since the publication of an eleven-year record last year, which served as a platform to develop a new geostatistical method to calculate mass balance. The latest glaciological data will be presented and discussed in the context of our strategies to obtain it. The meteorological data obtained from the terminus of Brewster Glacier will also be presented, and some insights provided about the influence of north-westerly airflow on controlling snowfall and melt extremes. In particular, the role atmospheric rivers play in controlling the advection of moisture over Brewster Glacier will be discussed, and how the timing of these precipitation events influences mass balance.

THE MULTI-MILLENNIAL CONTEXT OF PRESENT-DAY GLACIER RETREAT IN NEW ZEALAND

Shaun Eaves[1]

[1]Antarctic Research Centre, Victoria University of Wellington

Mountain glaciers represent a simple but robust barometer of present and past climate change. However, geological records of pre-historic glacier length changes are fragmentary and skewed towards past ice advance events. Evidence to constrain the extent, timing, and duration of pre-historic glacial minima is rare globally, and (to my knowledge) non-existent in New Zealand. Here I will outline a new research program that aims to answer the question: *Is present day glacier retreat in New Zealand unprecedented in the present interglacial?*

Central to answering this question are new cosmogenic nuclide inventories from proglacial bedrock sites where the most recent bedrock exposure period is well constrained by observations. Nuclide concentrations exceeding what is expected based on the observational record (termed *inheritance)* would indicate pre-historic exposure and provide a minimum integrated duration of times when ice extent was similar to, or smaller than, today (Fig. 1). The new cosmogenic data will inform the design of numerical model experiments, with the aim of better constraining the climatic significance of naturally-forced glacial minima in New Zealand during the present interglacial epoch. In this presentation I will review the present and proposed field sites and the research design of this project.

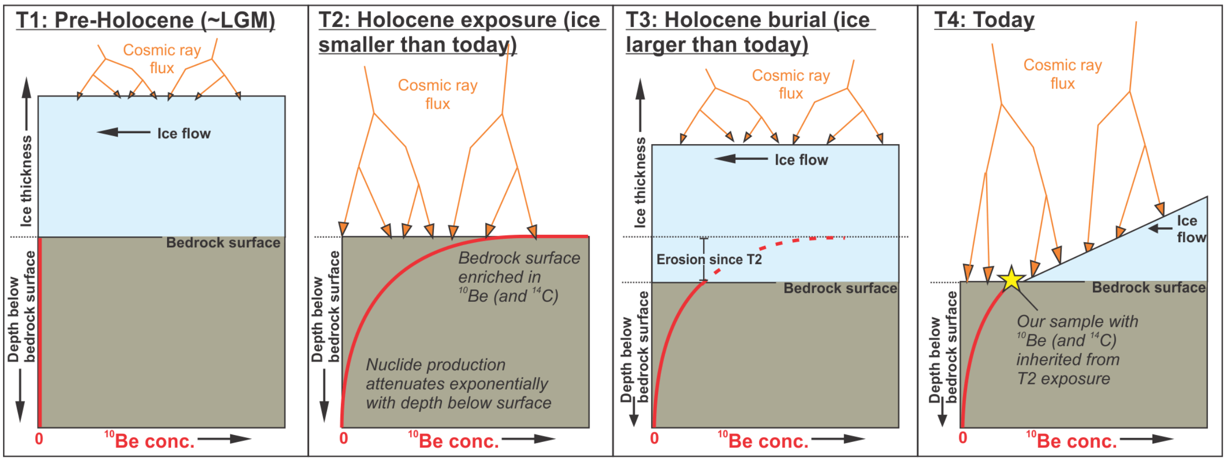

Fig 1: Schematic overview of in situ cosmogenic ^{10}Be evolution in bedrock under a simple Holocene exposure-burial-exposure scenario.

A NEW SNOW MODEL TO ASSESS THE IMPACT OF CLIMATE CHANGE ON NEW ZEALAND'S FROZEN WATER RESOURCES

Dadic, R.[1], Anderson, B.[1], Conway, J.P.[2,3], Mackintosh, A.[1], Cullen, N.J.[2], Horgan, H.[1], Kerr, T.[4], Purdie, H.[5], Sirguey, P.[2], Zammit, C.[6] and Redpath, T.[2].

[1]Victoria University of Wellington, Wellington, New Zealand,

[2]University of Otago, Dunedin, New Zealand,

[3]Bodeker Scientific, Alexandra, New Zealand,

[4]Aqualinc Research Ltd, Christchurch, New Zealand,

[5]University of Canterbury, Christchurch, New Zealand,

[6]NIWA, Christchurch, New Zealand

Glaciers and seasonal snow are major reservoirs in the hydrological cycle, and make a significant contribution to river flows in the North and South Islands of New Zealand. Mountain rivers feed our largest hydro-electric power schemes, and provide critical water for irrigation, especially during drought. Melting snow and ice may also cause increased flooding risk. The aim of this project is to make improved future projections of glacier and snow melt from New Zealand's alpine regions. New Zealand is projected to warm by 1-4°C during the 21st Century. While warming will lead to loss of frozen water resources, the magnitude, timing, and distribution of changes in meltwater is unclear. By developing and applying computer modelling tools to simulate snow and ice responses to climate change scenarios, we will make projections of future snow and ice cover, and resultant runoff from alpine catchments. Our findings will allow New Zealanders to be better placed to adapt, manage and thrive in our changing environment. Here, we report on progress towards developing and testing an enhanced temperature index snow model that will be used to model future snow melt. The model has been testing at a point scale using the detailed meteorogical and glaciological measurments available at Brewster Glacier. A regional-scale evaluation on a 250m square grid has been made against remotely-sensed fractional snow covered area retrieved from MODIS measurents. Methods to distinguish between uncertainties in input data, model structure and model parameters will be discussed, and future development outlined.

PREDICTING PRECIPITATION PHASE IN THE MARITIME SOUTHERN ALPS, NEW ZEALAND

Porhemmat, R.[1], Purdie, H.[1] , Zawar-Reza P.[1] , Zammit, C.[2] , Kerr, T.[3]

[1]University of Canterbury, Christchurch, New Zealand

[2]National Institute of Water and Atmospheric Research, Christchurch, New Zealand

[3]Aqualinc Research Ltd., Christchurch, New Zealand

Identifying the form of precipitation entering hydrologic system as rainfall or snow is crucial in mountain hydrology and water balance calculations. The transfer of precipitation to surface runoff, infiltration, and generation of streamflow can be delayed by change in snow storage and timing of peak flows and hydrograph recession. Therefore, the magnitude of baseflow components can be affected by phase partitioning methods. Since most temperature index models use a simple threshold temperature to distinguish the solid or liquid form of the precipitation, an accurate estimation of the rain/snow temperature threshold is highly required in snow accumulation/ablation and snowmelt-runoff modelling.

Research on the rain snow temperature threshold in New Zealand's Southern Alps has been limited. In this study, an analysis of air temperature measurements during snow and rain events at hourly and daily time scales has been carried out in the Southern Alps using the climate and snow measurement data from Snow and Ice Monitoring Network. The aim was to investigate the dynamic behaviour of the temperature threshold instead of using a static approach.

The results indicate that the phase transition takes place over a wide range of hourly air temperature between -6.6 to 5.9 °C. At hourly scale snow occurs over a range of 20.4 °C, from -14.5 to 5.9 °C while rain has been observed within a range between -6.6 to 17.3 °C. Daily snow events show a wider range of temperature compared to hourly measurements from -13 to 8.02 °C. The frequency-temperature relationship for snow show a similar behaviour at hourly and daily intervals both following a logistic distribution. The new findings are believed to help better simulate snow and hydrology processes in the Southern Alps catchments and increase our understanding of rain snow temperature threshold in maritime conditions.

A REMOTELY SENSED SEASONAL SNOW COVER CLIMATOLOGY FOR THE CLUTHA CATCHMENT

Redpath, T.[1,2], Sirguey, P.[2], Cullen, N. J.[1], Fitzsimons, S.[1]

[1]Department of Geography, University of Otago
[2]School of Surveying, University of Otago

Seasonal snow plays important hydrologic, environmental, and economic roles within the Clutha Catchment. Snowmelt contribution to annual streamflow reaches 30% in alpine headwaters on the main divide, and exceeds 20% in some headwaters of inter-montane basins. A scarcity of data concerning the spatio-temporal distribution and variability of seasonal snow within the catchment is addressed through the development of a snow cover climatology from remotely sensed MODIS snow-cover products. Analysis centred on a 16-year (2000 – 2016) time series of daily snow covered area (SCA) and derived snowline elevation (SLE). Mean snow cover duration (SCD) reveals an area of ~3000 km^2 (14% of catchment area) maintains snow cover for at least 120 days per year. SCD exhibits marked spatio-temporal variability, lowest on the high peaks of the Main Divide (coefficient of variation, C.V., <5%), increasing eastward and for mid-elevations. Principal component analysis reveals distinct modes in spatial variability between the west and east of the catchment. Considering SLE, the winters of 2005, 2012 and 2015 exhibited significant departures above the winter median (1178 m), while winter SLE was lower in elevation in 2004 and 2015. Analysis of anomalous winters, such as 2005 and 2011, and HYSPLIT back-trajectories provide insight into synoptic influences on inter-annual variability, and linkages to specific phase combinations of ENSO and SAM are also apparent. These observations provide a baseline for projected future changes to seasonal snow within the catchment, and climatological context for snowmelt runoff modelling for the Clutha River.

GLACIER SURFACE ALBEDO FROM MODIS DATA AND LINKS TO ANNUAL MASS BALANCE FOR THE GARDENS OF EDEN AND ALLAH, SOUTHERN ALPS, NEW ZEALAND

Dowson, A.J.[1,2], **Cullen, N.J.**[1], **Sirguey, P.**[2], **Kingston, D.**[1]

[1] Department of Geography, University of Otago, Dunedin, New Zealand

[2] School of Surveying, University of Otago, Dunedin, New Zealand

Continuous, long-term records of mass balance show the direct response of glaciers to a changing climate. However, direct measurements of mass balance in New Zealand are sparse, and only exist on a selection of easily accessible glaciers. Recent studies have demonstrated a significant relationship between direct glacier mass balance and the remotely sensed, annual minimum glacier-wide albedo ($\bar{a}_{min}^{yr}$). Near-daily satellite imagery captured since February 2000 by the Moderate-Resolution Imaging Spectroradiometer (MODIS), and processed with the MODImLab software, provides a continuous record of surface albedo for glaciers across New Zealand. The Gardens of Eden and Allah (GoEA) are two of the largest and least studied icefields in New Zealand's Southern Alps. Seventeen-year records (2000–2017) of glacier-wide albedo and $\bar{a}_{min}^{yr}$ were produced for twelve outlet glaciers identified within the GoEA. The results show the aspect and topography of glaciers in the GoEA exhibit a control on the small-scale variability of the $\bar{a}_{min}^{yr}$. Unshaded, north-facing glaciers tend to exhibit a lower $\bar{a}_{min}^{yr}$ occuring later in the year, compared to heavily shaded, south-facing glaciers. Importantly, these results suggest that even over small spatial scales, glaciers often display large variability in their annual mass balance. In the absence of direct mass balance data from the GoEA, a significant relationship was found between the annual end-of-summer snowline (EOSS; a proxy for mass balance) and the $\bar{a}_{min}^{yr}$ recorded on the Vertebrae Col 25 outlet glacier (R^2 = 0.49). This relationship has been used to validate the MODIS results elsewhere in New Zealand, such as Brewster Glacier (R^2 = 0.87) and Park Pass Glacier (R^2 = 0.87). The near-daily resolution of the MODIS images increases the likelihood of isolating the point of maximum summer ablation, compared to the EOSS study, which occurs annually in early March. For example, on the day of the EOSS flights in 2013 and 2014, glacier-wide albedo over Vertebrae Col 25 is shown to be more than 6% higher than the $\bar{a}_{min}^{yr}$. This method is therefore particularly useful for monitoring glaciers where the $\bar{a}_{min}^{yr}$ may not be consistently reached during early March (e.g. Vertebrae Col 25). This study has resolved independent temporal trends in the previously unknown behaviour of the GoEA, at a temporal resolution that exceeds many other currently available techniques. As a result, the albedo method has been shown to provide a tool that opens the gateway for widespread monitoring of all large glaciers in New Zealand.

FINITE-ELEMENT MODELLING OF TASMAN GLACIER'S BASAL SLIDING EVENTS

Macklin, C. A.[1], Horgan, H. J.[1], Anderson, B.[1]

[1]Victoria University of Wellington, Wellington, New Zealand

Glaciers and ice caps will be the largest contributors to sea-level rise over the next century, though a major uncertainty in sea-level rise prediction is the poorly constrained behaviour of glacial acceleration. A key process controlling short-term increases in glacier velocity is the fluctuation of basal water pressure. High rainfall-rates elevate basal water pressure by introducing additional water content beneath the glacier, resulting in a lower basal friction and enhanced sliding. Global Positioning System (GPS) data from instruments installed on Tasman Glacier, South Island, New Zealand, have recorded the fastest speed-up events known for any alpine glacier, and demonstrate a strong correlation between high-rainfall and glacial acceleration. We propose to employ a finite-element model that recreates the internal deformation and basal sliding of Tasman Glacier before, during, and after high-rainfall events. By varying the model's basal velocity component to match surface velocity observations, we seek to better constrain the sliding law linking basal velocity to basal water pressure. A range of sliding laws will be tested to determine the type of relationship that best represents observed glacier speed-up behaviour. Because of the process-based nature of this study, Tasman Glacier will provide a useful analogue for investigating the controls on sliding mechanisms common to all large glaciers and ice-streams.

TOWARDS DETERMINING THE IMPACTS OF FRESHWATER IN THE NEW ZEALAND EARTH SYSTEM MODEL

Mackie, Shona[1], Smith, Inga J.1, Ridley, Jeffrey K. [2], Stevens, David P. [3], Bitz, Cecilia M.[4], Langhorne, Patricia J.1.

[1] Department of Physics, University of Otago, P.O. Box 56, Dunedin, New Zealand

[2] MetOffice, FitzRoy Road, Exeter, EX1 3PB, United Kingdom

[3] School of Mathematics, University of East Anglia, Norwich, NR4 7TJ, United Kingdom

[4] Department of Atmospheric Sciences, University of Washington, Seattle, Washington, USA

The New Zealand Earth System Model (NZESM) is being developed and used through the Deep South National Science Challenge. NZESM is based on the UKESM1 physical model HadGEM3-GC3.1, which is a fully coupled atmosphere, land, ocean and sea ice model. In our research, we will use the NZESM to investigate the coupled response of the sea ice module (CICE) and the ocean module (NEMO) to freshwater forcings, including accounting for the meltwater latent heat. Freshwater flux runs have not been run for the NZESM and its predecessors in coupled (atmosphere-ice-ocean) mode. Runs with the NZESM will therefore fill a critical knowledge gap in terms of coupled model behaviour. We will initially run icebergs only (surface freshwater) runs, using state-of-the-art parameterisations for 1 degree models with and without their associated latent heat fluxes, to allow direct comparison with standardised control runs and the results from other models. Next, we will perform simulations with freshwater injection at depth to see if this makes any difference to the results.

ANALYSIS OF CHANGE OF THE UPPER LINDA GLACIER NEAR THE SUMMIT OF AORAKI/MT COOK

Kerr T.[1], Purdie H.[2]

[1]Aqualinc Research Ltd.

[2]Department of Geography, University of Canterbury,

A collection of photographs of the north-east aspect of Aoraki/Mt Cook have been analysed in an effort to document the impact of environmental change on climbing the mountain.

The earliest photo is from 1895, and the latest from 2015. Twenty photos were suitable for analysis with at least one from each decade. The photos show the state of the upper Linda Glacier, the most common climbing route on Aoraki/Mt Cook. Subjective visual interpretation of the photos did not detect unequivocal change to the upper Linda Glacier. A pragmatic objective method of measuring change was developed which calculates the ratio of the vertical distance (in pixels) between two rocks, with the vertical length of one of the rocks. The smaller the ratio, the greater the rock exposure. The time series of this ratio indicates there is an increasing trend (with large uncertainty that encompasses zero) in rock exposure, which may be interpreted as an indication of a reduction in glacier mass over the years. This interpretation is supported by interviews with climbers who perceive an increase in steepness and rock exposure in the Upper Linda Glacier. The barely-detectable change in the Upper Linda Glacier is in contrast to the well-measured large changes in glacier mass of the lower Tasman Glacier. In terms of the climate-change narrative, this research indicates that generalising climate change impacts observed on low elevation glaciers should be undertaken with care.

Figure 1. Photos of the upper Linda Glacier by (left) Edward Fitzgerald, February 1895, (Fitzgerald 1896) and (right) by Richard Measures, November 2015.

Fitzgerald, E.A., 1896. Climbs in the New Zealand Alps, being an account of travel and discovery. Fisher Unwin, London.

A TOPOGRAPHIC RATHER THAN CLIMATIC ORIGIN OF DECLINING LENGTHS OF UPPER CLUTHA GLACIATIONS

Chinn T. J.[1], Thomson, R.[2]

[1]Alpine & Polar Processes Consultancy, LGM, Lake Hawea

[2]Royden Thomson, Glacial Geologist, Cromwell

The Upper Clutha glacial sequence, provides one of the oldest terrestrial glacial history sequences in New Zealand and it shows a progressive contraction of individual glaciation extents. However the Pleistocene paleoclimate records present a consistent similarity of the 100,000-year glacial - interglacial cycles.

Our hypothesis suggests that record of declining glacier lengths towards the termination of the Pleistocene are the topographic restraints to ice flow persisting through the glaciation sculpturing cycles being rejuvenated by interglacial cycles of topographic fluvial erosion. As glacial erosion is the overall dominant process, any topographic constraints are successively lowered and valleys widened, so that "ponded ice" levels are lowered each glaciation causing the accumulation areas to shrink and ice discharge to decline.

To locate the intercepts between the glacier surface and the depressed snowline trend surface, the profiles of the ice levels of the Hawea and Lindis advances were plotted along the longitudinal flowline. From the numerous relatively recent models of the LGM extents of the Pleistocene glaciers, maximum depression values chosen were for a mean temperature depression of 5 - 6 ^{o}C or of 800m for the ELA altitude. From these works, a trunk surface ice gradient of 8 m/km was selected for the Lindis and 10 m/km for the shallower Hawea ice.

Results table;

HEIGHT of GLACIER ELA LEVEL ABOVE the HAWEA LGM for the OLDER GLACIAL ADVANCES

ADVANCE	AGE(approx ka)	LENGTH (km)	AREA (km2)	ELA RISE (m)
Hawea	18	69.7	2613	0
Mt.Iron	30	69.9	2664	12
Albert town	70	75.7	2825	50
Luggate	110	80.9	2930	71
Queensberry	320	94.0	3167	116
Lindis	440	111.7	3775	250
Loburn	640	118	4137	325

THE MARINE GEOPHYSICAL SIGNATURE OF PAST ICE SHEETS

Dowdeswell, J.A.[1]

[1]Scott Polar Research Institute, University of Cambridge, UK

The deglaciation of high-latitude continental shelves since the Last Glacial Maximum has revealed suites of subglacial and ice-contact landforms that have remained well-preserved beneath tens to hundreds of metres of water. Once ice has retreated, sedimentation is generally low on polar shelves during interglacials and the submarine landforms have not, therefore, been buried by subsequent sedimentation. By contrast, the beds of modern ice sheets are hidden by several thousand metres of ice, which is much more difficult than water to penetrate using geophysical methods. These submarine glacial landforms provide insights into past ice-sheet form and flow, and about the processes that have taken place beneath these ice sheets. Examples will be given of streamlined subglacial landforms that indicate the distribution and dimensions of former ice streams on high-latitude continental margins. Distinctive landform assemblages characterise ice stream and inter-ice stream areas. Landforms, including subglacially formed channel systems in inner- and mid-shelf areas, and the lack of them on sedimentary outer shelves, allow inferences to be made about subglacial hydrology. The distribution of grounding-zone wedges and other transverse moraine ridges also provides evidence on the nature of ice-sheet retreat – whether by rapid collapse, episodic retreat or by the slow retreat of grounded ice. Such information can be used to test the predictive capability of ice-sheet numerical models. These marine geophysical and geological observations of submarine glacial landforms enhance our understanding of the form and flow of past ice masses at scales ranging from ice sheets (1000s of km in flow-line and margin length), through ice streams (100s of km long), to surge-type glaciers (10s of km long).

VARIABILITY IN THE THICKNESS OF SEA ICE AND THE SUB-ICE PLATELET LAYER IN MCMURDO SOUND FROM ELECTROMAGNETIC INDUCTION SOUNDINGS.

Brett G. M. [1], Irvin A.[2], Rack W.[1], Haas C.[2,3], and Langhorne P. J.[4]

[1]Gateway Antarctica, University of Canterbury, Christchurch, New Zealand

[2]Department of Earth & Space Science & Engineering, York University, Toronto, Ontario, Canada.

[3] Sea Ice Physics, Alfred Wegener Institute, Bremerhaven, Germany.

[4]Department of Physics, University of Otago, Dunedin, New Zealand.

Interannual variability in the thickness of land-fast sea ice and the sub-ice platelet layer in McMurdo Sound was investigated using frequency-domain electromagnetic induction (EM) soundings carried out in 2011, 2013, 2016 and 2017. Sea ice formation in McMurdo Sound is influenced by the outflow of Ice Shelf Water (ISW) originating from oceanographic circulation between the Ross and McMurdo ice shelf cavities and adjacent coastal polynyas. High Salinity Shelf Water formed by polynya processes can sink down into the cavity and melt or dissolve the ice shelf base at depth. The resultant meltwater can become supercooled as it rises to shallower depths along the ice shelf base, promoting the formation of frazil ice crystals which can form a characteristic porous sub-ice platelet layer with continued growth. The extent of ISW outflow can be inferred from anomalously thick sea ice with an incorporated platelet ice fabric and by the presence of an unconsolidated sub-ice platelet layer. We obtain coincident sea ice and sub-ice platelet layer thicknesses from look-up tables of theoretical EM responses derived through forward modelling of horizontal conductive layers representing sea ice, a sub-ice platelet layer and seawater. EM transects detected a pattern of thicker fast ice and substantial accumulations of sub-ice platelets in the centre of the sound in proximity to the ice shelf margin with decreasing thickness to the east and north. This correlates with prior observations of sea ice and sub-ice platelet layer thicknesses, supercooling and the Ice Shelf Water plume in McMurdo Sound.

REGIONAL SCALE VARIABILITY IN ANTARCTIC SEA ICE THICKNESS, A COMPARISON OF ASPECT OBSERVATIONS AND CCSM4 MODEL DATA

Nesbit, K.O.F.[1], Pauling, A.G.[2], Langhorne, P.J.[1], Smith, I.J.[1], Bitz, C.M.[2]

[1]Department of Physics, University of Otago, Dunedin, New Zealand

[2]Department of Atmospheric Sciences, University of Washington, Seattle, USA

The accuracy of Antarctic sea ice in global climate models, such as the Community Climate System Model, Version 4 (CCSM4), is partially unknown. Model output for sea ice extent has been thoroughly compared with satellite observations, and found to accurately describe the seasonal variability in sea ice extent, while the linear trend in modelled sea ice extent is found to be different to observations. The accuracy of sea ice thickness model output is currently undetermined, largely due to a lack of observational data with which to make comparisons. Unlike sea ice extent, sea ice thickness cannot currently be reliably measured from satellites, thus observational data is hard to obtain. One of the few available observational datasets for Antarctic sea ice thickness is the Antarctic Sea Ice Processes & Climate (ASPeCt) dataset, containing data from 83 ship voyages and two helicopter flights in the Southern Ocean. We compare the seasonal variability of CCSM4's sea ice thickness model output with ASPeCt data in five different regions of the Southern Ocean. From these comparisons, we estimate the accuracy of CCSM4 sea ice thickness data.

CENTENNIAL TIMESCALE IMPACTS OF INCREASING ICE SHELF MELTWATER ON ANTARCTIC SEA ICE AREA

Smith, Inga J.[1], Bitz, Cecilia M.[2], Pauling, Andrew G.[1], Lilly, Katherine[1], Langhorne, Patricia J.[1], Hulbe, Christina L.[3].

[1] Department of Physics, University of Otago, Dunedin, New Zealand,

[2] Department of Atmospheric Sciences, University of Washington, Seattle, Washington, USA

[3] National School of Surveying, University of Otago, Dunedin, New Zealand

The West Antarctic Ice Sheet may already be undergoing an irreversible mass loss that would result in near complete melt within the next millennium. The sea ice and climate response to increased Antarctic meltwater over centennial timescales is investigated with simulations in the Community Earth System Model version 1, with the Community Atmosphere Model version 4 (CESM1-CAM4). To investigate the response to meltwater released at the base of ice shelves in a higher CO_2 warming world, meltwater was injected at the depth of the front of the ice shelves, while simultaneously cooling the ocean by an amount required to melt the ice. The amount of freshwater added increased linearly over time, to represent gradually increased basal melting of ice shelves. The response to increasing meltwater along with 20th and 21st century anthropogenic greenhouse gas forcing is presented.

EBSD ON SEA ICE

Wongpan P.[1], Prior D.J.[2], Langhorne P.J.[2], Lilly K.[2], Smith I.J.[1]

[1]Department of Physics, University of Otago, 730 Cumberland Street, Dunedin 9016, New Zealand

[2]Department of Geology, University of Otago, 360 Leith Street, Dunedin 9016, New Zealand

We have mapped the full crystallographic orientation of sea ice using electron backscatter diffraction (EBSD). This is the first time EBSD has been used to study sea ice. Platelet ice is a feature of sea ice near ice shelves. Pelagic ice crystals accumulate as an unconsolidated sub-ice platelet layer beneath the columnar ice (CI), where they are subsumed by the advancing sea ice interface to form incorporated platelet ice (PI). As is well known, in CI the crystal preferred orientation comprises dominantly horizontal *c*-axes, while PI has *c*-axes varying between horizontal and vertical. For the first time this study shows the *a*-axes of CI and PI are not random. Misorientation analysis has been used to illuminate the possible drivers of these alignments. In CI the misorientation angle distribution from random pairs and neighbour pairs of grains are indistinguishable, indicating the distributions are a consequence of crystal preferred orientation. Geometric selection during growth will develop the *a*-axis alignment in CI if ice growth in water is fastest parallel to the *a*-axis, as has previously been hypothesised. In contrast in PI random-pair and neighbour-pair misorientation distributions are significantly different, suggesting mechanical rotation of crystals at grain boundaries as the most likely explanation.

CHARACTERISING FRAZIL DISTRIBUTIONS IN MCMURDO SOUND USING ACOUSTIC TECHNIQUES

Frazer, E.K.[1], Langhorne, P.J.[1], Leonard, G.H.[1], Robinson, N.J.[2]

[1]University of Otago, [2]National Institute of Weather and Atmosphere

Frazil ice describes small disc-like ice crystals produced in supercooled waters, such as can be found in ice shelf meltwater plumes. In this context, frazil ice is a vital part of the “ice pump” mechanism that drives the transfer of ice from the base of ice shelves to the underside of sea ice. Despite their significant contribution to sea ice growth (12% by [1]), in situ quantitative measurements of quantity and concentration of frazil ice in the ocean are rare, largely due to the difficulty in making these measurements quantitatively. One increasingly popular method is to employ the use of a sonar and characterize the frazil in the ocean by the backscattered acoustics from the crystals. This method has been used previously (e.g. [2]) on frazil ice present in rivers to make inferences of particle size distributions. Here, we use similar multi-frequency techniques to analyse suspended particulate backscatter measurements in McMurdo Sound during the 2016/17 and 2017/18 seasons using alternative frazil backscatter models. From this, we characterise the particle size distribution of frazil ice in an Antarctic marine environment. In combination with other frazil observations in McMurdo Sound, this allows an improved understanding of “ice pump” processes.

[1] Gough, Alexander J.; Mahoney, Andrew R.; Langhorne, Pat J.; Williams, Michael J.M.; Robinson, Natalie J.; Haskell, Tim G.. Signatures of supercooling: McMurdo Sound platelet ice. Journal of Glaciology, Volume 58, Number 207, February 2012, pp. 38-50(13).

[2] Marko, J. & Jasek, M.. Sonar detection and measurements of ice in a freezing river I: Methods and data characteristics. Cold Regions Science and Technology, Elsevier, 2010, 63, 121-134.

CONVECTIVELY-DRIVEN MIGRATION OF BRINE ENCLOSURES IN SEA ICE

:EFFECT OF TILT ANGLE

Schmitt, M. [1,2], Langhorne, P. J.[1], Tuckey, B. J.[1,3] and Petrich, C.[1,4]

[1] Department of Physics, University of Otago, P.O. Box 56, Dunedin, New Zealand

[2] Department of Astro- and Geophysics, Georg-August-Universitaet, Goettingen, Germany

[3] DHI NZ, PO Box 300705, Auckland, New Zealand

[4] Northern Research Institute (Norut) Narvik, Narvik, Norway

Brine pocket migration in sea ice is the process by which an isolated, brine-filled enclosure migrates in the direction of an imposed temperature gradient due to melting at the warmer end of the pocket, and freezing at the cooler. In sea ice this is considered a very slow mechanism of brine movement, limited by the molecular diffusion of salt in the brine. In this study brine pocket migration is re-examined in circumstances in which the fluid enclosed in the pocket is likely to convect; that is, in the case where the long axis of a slender, cylindrical brine enclosure is tilted at an angle to gravity and to the temperature gradient. For tilted enclosures of nominal diameter in the range 1 to 5 mm, we measured vertical migration velocities that are an order of magnitude larger than would be expected if the phenomenon was controlled solely by the molecular diffusion of salt. High migration rates due to convection could noticeably affect the evolution of the pore space, potentially altering sea ice permeability, radar signature, and optical and mechanical properties. At constant tilt angle the migration velocity depends primarily on brine pocket diameter and on the temperature gradient imposed on the ice. The dependence on tilt angle remains to be explored and we will describe experiments to be carried out in the coming months.

THE REMOTE SENSING OF SEASONAL SNOW WITH ULTRA-LONG-DISTANCE GROUND-BASED LIDAR SENSING ALONG THE MILFORD HIGHWAY

Morris, S.J.[1]

[1]Milford Road Alliance, Downer NZ/ New Zealand Transport Agency, Te Anau

The Milford Road (State Highway 94) is in the southwest of the South Island and is New Zealand only public highway with a significant avalanche problem, that can seriously affect the road during avalanche season. Over the last 40 years traffic volumes and thence the level of hazard has diverged from relatively low in the 1970's to much higher numbers at the present.

When the glaciers retreated from Fiordiand, the terrain was left with near-vertical walls and large, steep snow basins that provide almost perfect environment for avalanches. The seasonal snowpack, in particular its stratigraphy and temporal evolution is important for avalanche forecasting along the highway. The monitoring of the snowpack in avalanche terrain requires techniques that work independently of the weather and avalanche conditions, that cannot be destroyed by avalanches and provides near real-time information on snow stratigraphy, accretion and ablation.

The Milford Road Alliance intented to operate a permanent fully autonomous ultra-long-distance ground-based laser scanner in the alpine environment along State Highway 94 to monitor seasonal snowpack. The laser scanner employs a Class 3B laser scanning system allowing for fast surveys, up to 222,000 measurements per second and targets up to 6,000 m with accuracy of 15 mm. The scanner operates at 1064 nm therefore the system is particularly well suited for measuring snow- and ice-covered terrain. The remote sensing will allow for safe, weather independence, coverage of inaccessible terrain, unbiased, high spatial and temporal resolution and for non-destructive continuous monitoring of the seasonal snowpack characteristics along the highway.

WIND-DRIVEN SEA ICE DRIFT ESTIMATION FROM HIGH RESOLUTION SATELLITE IMAGES IN THE ROSS SEA – ANTARCTICA

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

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 high resolution 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. The calculated displacement vector field was compared with the available low resolution sea ice motion vector standard product. Average motion vectors will be correlated with wind velocity, which is one of the main forces responsible for driving sea ice motion. We used Antarctic Mesoscale Prediction System (AMPS) wind velocity data set having spatial resolution of 5km. Here we present preliminary results of sea ice drift fields and wind velocity correlation

A DRONE MOUNTED RADAR TO MEASURE SNOW DEPTH ON SEA ICE

Rack, W.[1], Tan, A.[2], McCulloch, J.[3], Platt, I.[2], Eccleston, K.[2], Woodhead, I.[2], Brett, G.[1]

[1]University of Canterbury, Gateway Antarctica, Christchurch, NZ

[2]Lincoln Agritech Ltd, Lincoln University, NZ

[3]University of Canterbury, Spatial Engineering Research Centre, Christchurch, NZ

Sea ice in the Southern Ocean is a key climate ingredient for controlling global ocean circulation and ocean-atmosphere heat flux. Although sea ice area is reliably measured by satellites since the late 1970s, determination of thickness and therefore trends in sea ice mass are still unknown. One limiting factor in the remote measurement of sea ice thickness is the snow cover, which significantly changes the sea ice freeboard and influences the freeboard to thickness conversion.

In 2016 we conducted radar experiments and snow measurements on Antarctic sea ice with the aim to specify the requirements for a snow depth radar which can be flown on airborne platforms. These measurements were basis for the design of a purpose built stepped frequency radar to obtain snow depth from a minimum flight level of 5 meters at 5 cm accuracy. The beam focused radar operates at a centre frequency of 3 GHz and 4GHz bandwidth.

Mounted on a multirotor remotely piloted aircraft the snow radar was tested in November 2017 over sea ice in McMurdo Sound. A multitude of tests were conducted flying the radar with varying speeds and flight levels. The snow measurements were validated with in-situ data along transects of up to 2 kilometres length. In this presentation the radar development is explained and first results are presented.

TAKING THE MEASURE OF WINTER SEA ICE FROM BENEATH, WITHIN AND ABOVE

Leonard, G. H.[1], Langhorne, P. J.[2], Smith, I. J. [2], Robinson, N. J. [3], Rack, W. [4], Geiger, C. A.[5]

[1]*National School of Surveying, University of Otago, Dunedin*

[2]*Department of Physics, University of Otago, Dunedin*

[3]*NIWA, Wellington*

[4]*Gateway Antarctica, University of Canterbury, Christchurch*

[5]*University of Delaware, Newark, DE, USA*

The response of Antarctic sea ice in a warming ocean has been puzzling climate scientists for decades. Solving this problem is complex as sea ice forms in winter when it is very difficult to measure it. This NZARI funded project represents a unique step towards developing an autonomous system to monitor how ocean circulation, melting ice sheets, snow fall and air temperatures combine to influence the sea ice near the Antarctic coast. By sending data back to New Zealand in real-time, we seek to develop the capability to do this work remotely in a variety of critical locations throughout the harsh Antarctic winter. We will develop and deploy an autonomous sea ice mass balance station in the winter landfast sea ice of McMurdo Sound, Antarctica in 2018. Oceanographic instruments will measure temperature, salinity, currents and particle size distributions of ice crystals carried by Ice Shelf Water. A temperature probe will record the evolution of the vertical temperature gradient in the sea ice. An electromagnetic sensor will observe changes in the sea ice cover and sub-ice platelet layer, acoustic sensors will measure snow depth and the site will be overflown by a snow radar to capture the local snow cover. Data will be live-streamed to the public using an existing radio telemetry and data link to the University of Otago's sea ice website.

THE CORRELATION BETWEEN THE MECHANICAL BEHAVIOUR AND MICROSTRUCTURAL EVOLUTION IN ICE CREEP DEVELOPMENT: INSIGHT FROM EXPERIMENTALLY DEFORMED ICE WITH MICRON-SCALE PARTICULATE SECOND PHASE

Fan, S.[1], Prior, D.J.[1]

[1] Geology Department, University of Otago, Dunedin 9016, New Zealand

The typical mechanical behaviour of isotropic polycrystalline ice during high-temperature creep at constant load involves initial decreasing strain rate to a minimum (at ~1% strain) followed by accelerating strain rate. The creep behaviour is related to the ice microstructural evolution including the development of crystallographic preferred orientation (CPO). A key control on microstructure and CPO development is the relative contribution of different deformation and recrystallisation mechanisms, including dislocation creep, grain boundary migration (GBM) and grain boundary sliding (GBS). To better understand the correlation between the ice mechanical behaviour and the microstructural evolution, we have conducted creep tests with uniaxial compression on two-phase and pure water ice samples. The two-phase ice is fabricated from pure water ice with 1 vol.% of 1 micrometre graphite particles. The undeformed two-phase ice exhibits widely developed zig-zagged grain boundaries while the pure water ice has a conventional foam-like texture and straight grain boundaries. The creep rate of two-phase ice is lower than that of the pure water ice before 8% strain, after that it surpasses pure water ice and reaches the same tertiary creep rate at 12% strain. The CPO of two-phase ice is weaker compared to pure water ice before 8% strain. At 12% strain, there is a significant strengthening of two-phase ice CPO, surpassing that of pure water ice. There is a switch of dislocation system that contributes to the intragranular distortion in two-phase ice between low (<8%) and high (>12% strain). In contrast, the dislocation system in pure water ice exhibits no change across the whole range of strains. The graphite particles that accumulate in the grain boundaries contribute to the differences of mechanical and microstructural characteristics in the early strain history (<8%). It is likely the pinning of graphite particles favours the GBS, which accommodate part of the strain and leads to the CPO weakening and mechanical hardening. The driving force needed to instigate the GBM is not reached for the grain boundaries with particles till the later strain history (>8%). The GBM is strengthened as the distribution of grain boundary graphite become sparser due to the grain boundary expansion and the following pinning break through. The domination of GBM at high strain for both of the two-phase and pure water ice will lead to a similar CPO and mechanical behaviour.

USING HIGH RESOLUTION AIRBORNE IMAGERY OVER THE MCMURDO ICE SHELF, WESTERN ROSS SEA, TO IMPROVE INTERPRETATION OF HISTORICAL SATELLITE DATA

Turner, J.M. [1], Rack, W. [1], Purdie, H.L. [1]

[1]University of Canterbury, Department for Geography – Gateway Antarctica, Christchurch

Ice shelves constrain grounded Antarctic ice sheet progression to the melting ocean environment, and ice shelf stability is an important focus of climate change research. As environmental and logistical factors make direct observation of ice shelf phenomena difficult, satellite imagery is probably the most important source for assessing recent ice shelf change on a decadal time scale. Increase in surface melt has been identified as an indicator and precursor of ice shelf decay. However, the imagery can often lack the detail required to determine ice shelf characteristics such as the extent and trend of surface melt water.

In the Deep South National Science Challenge 2017 field work, ice shelf and sea ice thickness in the McMurdo vicinity was measured from a DC-3 aircraft at low altitude. During these flights, georeferenced high resolution aerial images were acquired as an auxiliary data set using a downward looking SLR camera at 3 Hz and at sub-centimetre resolution. These pictures were analysed with unsupervised classification using the ENVI software package identifying up to four major surface types. The classification is the basis for a linear spectral unmixing process for medium resolution (10-30 m) satellite data (Landsat and Sentinel). The aim is to reliably identify surface melt water extent in satellite images.

Preliminary results explaining the variation in the brightness values of pixels in near-synchronous satellite data are presented. If proven a robust method, this approach could enhance our ability to extract additional information from previously gathered satellite data to determine trends in surface melt.

SMALL-SCALE PINNING POINTS WITHIN THE ROSS ICE SHELF

Still, H.[1], Hulbe, C.[1], Campbell, A.[1]

[1]School of Surveying, University of Otago, Dunedin, New Zealand

The flow of the Ross Ice Shelf (RIS) is limited by regions of localised grounding termed pinning points. While pinning points are common features within the RIS and are generally assumed to have a stabilising effect, the mechanics of these features have not been studied in detail. This study focuses on a collection of small pinning points (and overlying ice rumples) located downstream from the outlets of the MacAyeal and Bindschadler Ice Streams within the eastern sector of the RIS.

Here we use high spatial resolution ice velocity derived from Landsat 8 imagery and thickness inferred from satellite laser altimetry to investigate the momentum balance and mass flux in the region. Drag forces exerted by the pinning points on the surrounding ice shelf are computed using a force budget approach and are compared to the forces expected for a similar ice shelf without pinning points. The pinning points have contrasting effects on the surrounding flow field. Upstream, compressive stresses act to resist ice flow from the MacAyeal Ice Stream, supporting thicker ice than would otherwise exist. As the ice flows over and around the pinning points, flow speed decreases and mass flux declines, creating a wake of thinner ice downstream. At the ice rumple boundaries, lateral shearing creates bands of heavily crevassed ice that advect downstream, further modifying the flow field. This analysis improves understanding of how small-scale pinning points regulate the flow of the RIS.

GLACIOLOGICAL CONTEXT OF THE HWD2 BOREHOLE ON THE ROSS ICE SHELF

Forbes, M.[1], Gragg, K.[1] , Hulbe, C.[1] , Rack, W.[2] Ryan, M.[2]

[1]University of Otago, School of Surveying

[1]University of Canterbury, Gateway Antarctica

Two boreholes were drilled through the Ross Ice Shelf in December of 2017 at approximately 80.658S, 174.463E. The boreholes lie along the margin of a slight along-flow oriented surface depression that is the downstream trace of a suture zone between ice from different outlet glaciers of the Transantarctic Mountains. The ice through which we drilled appears to have originated near the left (west) margin of Liv Glacier and a sequence from firn, to bubbly glacier ice, to bubble free glacier ice was observed in the borehole. The basal ~10 metres of ice contains glacial debris and a thin layer of marine ice was observed at the base of the borehole. Using modern flow speed along a streakline from the grounding line to HWD2, we estimate that the ice crossed the grounding line about 400 years ago. Contrary to expectation prior to drilling, the ice shelf base is not melting at the site and does not appear to have experienced significant melting along the flow path. In this presentation, we use radar imaging of ice together with features observed at the surface to characterise the glaciological context of the borehole site.

THE SHAPE OF CHANGE: A NEW METHOD TO IDENTIFY SOURCES OF DYNAMIC THICKNESS CHANGE

Campbell, A.J[1]., Hulbe, C.L.[1], Lee, C.-K.[2]

[1]University of Otago, School of Surveying

[2] Korea Polar Research Institute

The past few decades have brought an abundance of observations covering much of our changing ice shelves. However, it remains a challenge to interpret these observations without reliable frameworks. For example, the Ross Ice Shelf's (RIS) thickness has been observed to change at varying rates in different locations. Imprinting on that signal is thickness change from past flow changes of ice shelf tributaries, a type of internally driven variability. Another part of thickness change signal represents responses to external forcings, such as changes to surface accumulation and basal melting. Further complicating this process, is the satellite record is discontinuous in space and time, we therefore require a method to distinguish these sources under that constraint. We present a new method, called response surface analysis, that correctly attributes observations to past variations to ice shelf tributary flow. We apply empirical orthogonal function analysis to model data to generate response surfaces, which are fundamental spatial patterns for ice shelf response to tributary flux changes. Using response surfaces, we are able to determine the extent to which past flow variations are imprinting the present-day thickness change signal measure by ICESat satellite altimetry. Our response surface approach correctly identifies the magnitude and timing know past flow variations such as the Kamb Ice Stream shutdown, Whillans Ice Stream slowdown and Byrd Glacier acceleration. Other methods have separated thickness change observations into mass-balance changes and dynamic changes. Our method is distinguished from those methods in that we separate by source, acknowledging that both mass-balance driven and dynamic changes produce dynamic responses that evolve over time. Our new method makes specific predictions how dynamic signals will evolve over time, suiting discontinuous time series of observations.

NATURE OR NURTURE? RIFT GENERATION(S) AT THE NORTHEAST FRONT OF THE ROSS ICE SHELF

Forbes, M.[1], Hulbe, C.[1]

[1] University of Otago, School of Surveying

Understanding the conditions that govern ice shelf rift geometry and propagation is critical to understanding contemporary change in Antarctic systems. Rifts become the planes along which tabular icebergs calve and thus play an important role in ice shelf mass balance and response to climate change.

Using Landsat satellite imagery spanning from 1986 to 2017, we track the progression of a family of rifts at the front of the Ross Ice Shelf, between Roosevelt Island and the Shiraze Coast. The most recent addition to this family originates from very different circumstances than its immediate predecessor and yet develops into a similar near-front geometry. We use an ice shelf model to determine homogenized far field stress conditions and couple these to a Linear Elastic Fracture Mechanics (LEFM) model in order to determine Stress Intensity Factors (SIFs) at rift tips and consequently propagation paths. We show that despite different initial natures, the rifts are nurtured toward similar morphologies, in turn demonstrating the importance of far field stresses and the ice shelf geometry that constrain them. Excellent news.

TIDAL GROUNDING LINE MIGRATION AT THE DARWIN GLACIER

Marsh, O.J.[1], Wild, C.T.[1]

[1]Gateway Antarctica, University of Canterbury, Private Bag 4800, Christchurch, NZ

The Darwin Glacier is a small outlet glacier draining the East Antarctic Ice Sheet through the Transantarctic Mountains. Its motion is affected by ocean tides yet largely shielded from climate-driven variability, allowing observations of short-term grounding line (GL) behaviour without the added complexity of contemporary mass-imbalance. We conducted a detailed study of the glacier grounding zone in the 16/17 field season, mapping surface and internal flexure, GL migration, sub-daily velocity fluctuation and ice thickness. This high-resolution data is used to interpret a sequence of twelve TerraSAR-X interferograms. Double-difference tidal flexure fringes are heavily modified by migration of the GL across a two-kilometre ´ice-plain´ at the glacier´s upstream margin, despite relatively steep basal topography.

The asymmetric vertical displacement is identified by separating the four-image interferograms using flexural modelling with a migrating GL and homogeneous rheology. In the flexure zone, a neutral bending layer is found in the upper third of the ice column suggesting stiffer or cooler ice near the surface. We show that GL migration is proportional to the bed slope in the migration zone, but that it does not equal the rate expected from a simple flotation criterion. This simultaneous analysis of multiple interferograms reveals new information on GL and ice properties that can help predict future GL retreat associated with glacier thinning or sea level rise.

Presenter index

Name (Last,First)	***Organisation***	***Presentation title***	***Day***	***Time***	***Page***
Fan,Sheng	University of Otago	The Influence Of Particulate Second Phase On The Creep Behaviour And Microstructural Evolution Of Experimentally Deformed Ice	Friday 8th	11:30	24
Farooq,Usama	University of Otago	Wind-Driven Sea Ice Drift Estimation From High Resolution Satellite Images In The Ross Sea – Antarctica	Friday 8th	10:45	21
Forbes,Martin	University of Otago	Nature Or Nurture? Rift Generation(s) At The Northeast Front Of The Ross Ice Shelf	Friday 8th	14:00	29
Frazer,Eamon	University of Otago	Characterising Frazil Distributions In McMurdo Sound Using Acoustic Techniques	Friday 8th	9:30	18
Gragg,Kelly	University of Otago	Glaciological Context Of The Hwd2 Borehole On The Ross Ice Shelf	Friday 8th	13:30	27
Kerr,Tim	Aqualinc Research Ltd.	Observed Changes To A Glacier Near The Top Of Aoraki/Mt Cook	Thursday 7th	16:30	11
Langhorne,Pat	University of Otago	EBSD On Sea Ice	Friday 8th	9:15	17
Leonard,Greg	University of Otago	Taking The Measure Of Winter Sea Ice From Beneath, Within And Above	Friday 8th	11:15	23
Mackie,Shona	University of Otago	Towards Determining The Impacts Of Freshwater In The New Zealand Earth System Model	Thursday 7th	16:15	10
Macklin,Clarrie	Victoria University of Wellington	Finite-Element Modelling Of Glacier Sliding (Tasman Glacier)	Thursday 7th	16:00	9
Marsh,Oliver	University of Canterbury	Tidal Grounding Line Migration At The Darwin Glacier	Friday 8th	14:15	30
Morris,Simon	Milford Rd Alliance	The Remote Sensing Of Seasonal Snow With Ultra-Long-Distance Ground-Based Lidar Sensing Along The Milford Highway	Friday 8th	10:30	20

Name (Last,First)	***Organisation***	***Presentation title***	***Day***	***Time***	***Page***
Nebit,Kage	University of Otago	Regional Scale Variability In Antarctic Sea Ice Thickness, A Comparison Of ASPeCt Observations And CCSM4 Model Data	Friday 8th	8:45	15
Porhemmat,Rasool	University of Canterbury	Predicting Precipitation Phase In The Maritime Southern Alps, New Zealand	Thursday 7th	14:15	6
Rack,Wolfgang	University of Canterbury	A Drone Mounted Radar To Measure Snow Depth On Sea Ice	Friday 8th	11:00	22
Redpath,Todd	University of Otago	A Remotely Sensed Seasonal Snow Cover Climatology For The Clutha Catchment	Thursday 7th	15:30	7
Schmitt,Mira	University of Otago	Convectively-Driven Migration Of Brine Enclosures In Sea Ice: Effect Of Tilt Angle	Friday 8th	9:45	19
Smith,Inga	University of Otago	Centennial Timescale Impacts Of Increasing Ice Shelf Meltwater On Antarctic Sea Ice Area	Friday 8th	9:00	16
Still,Holly	University of Otago	Small-Scale Pinning Points Within The Ross Ice Shelf	Friday 8th	13:15	26
Turner,Jeff	University of Canterbury	Using High Resolution Airborne Imagery Over The McMurdo Ice Shelf, Western Ross Sea, To Improve Interpretation Of Historical Satellite Data	Friday 8th	11:45	25
Vargo,Lauren	Victoria University of Wellington	Measuring New Zealand Glacier Fluctuations From Historic Photographs	Thursday 7th	13:30	2

Participant List – Sorted by Last Name

First Name	Last Name	Affiliation
Brian	Anderson	Victoria University of Wellington
Gemma	Brett	University of Canterbury
Adam	Campbell	University of Otago
Trevor	Chinn	Alpine & Polar Processes Consultancy
Jono	Conway	Bodeker Scientific
Nicolas	Cullen	University of Otago
Julian	Dowdeswell	Scott Polar Research Institute
Angus	Dowson	University of Otago
Shaun	Eaves	Victoria University of Wellington
Sheng	Fan	University of Otago
Usama	Farooq	University of Canterbury
Martin	Forbes	University of Otago
Eamon	Frazer	University of Otago
Kelly	Gragg	University of Otago
Peter	Green	University of Otago
Florence	Isaacs	Victoria University of Wellington
Lucy	Just	University of Otago
Tim	Kerr	Aqualinc Research Ltd.
Pat	Langhorne	University of Otago
Greg	Leonard	University of Otago
Jessie	Lindsay	University of Canterbury
Franz	Lutz	AUK/Otago
Shona	Mackie	University of Otago
Clarrie	Macklin	Victoria University of Wellington
Oliver	Marsh	University of Canterbury
Simon	Morris	Milford Rd Alliance
Kage	Nesbit	University of Otago
Rasool	Porhemmat	University of Canterbury
Noel	Potter	University of Maine
Dan	Price	University of Canterbury
Hamish	Prince	University of Otago
Heather	Purdie	University of Canterbury
Wolfgang	Rack	University of Canterbury
Todd	Redpath	University of Otago
Maren	Richter	University of Otago
Josh	Scarrow	Antarctica New Zealand
Mira	Schmitt	University of Otago
Inga	Smith	University of Otago
Holly	Still	University of Otago
Peter	Strand	University of Maine
Jeff	Turner	University of Canterbury
Lauren	Vargo	Victoria University of Wellington