Proceedings of the 2015

New Zealand
Snow and Ice Research Group

2-4 July 2015

Cass

Cass Basin. By Alistair Austin Deans 1915-2011. University of Canterbury Art Collection

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha

bivouac/outdoor
COMMITTED TO ADVENTURE

NIWA
Taihoro Nukurangi

Antarctica New Zealand

Foreword

The 2015 New Zealand Snow and Ice Research Group workshop was held at the University of Canterbury Cass field center on July 2–4, 2015.

Organising Committee

Heather Purdie (Chief organiser)

Sandrine Roy
Michelle Ryan
Christian Wild
Oliver Marsh
Wolfgang Rack
Tim Kerr

The New Zealand Snow and Ice Research Group (SIRG)

The New Zealand Snow and Ice Research Group 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/

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Program

Thursday, July 2, 2015

13:30	*Welcome*	Heather Purdie (UC)

New Zealand - Session sponsor: Bivouac Outdoor, Chair: Heather Purdie (UC)

13:40	A new method to consolidate a decade of mass balance measurements on Brewster Glacier, Southern Alps, New Zealand	Nicolas Cullen (Otago)
14:00	Reconstructing the mass balance record of Brewster Glacier using satellite-derived albedo data	Holly Still (Otago)
14:20	Statistical analysis of sub-annual iceberg calving at Tasman Glacier, 2011-2012	Rob Dykes (Massey)
14:40	Ice age over Wanaka, Lake excavation	Trevor Chinn (Hawea)
15:00	*Interglacial*	

Snow and Posters plus - Session sponsor: NIWA , Chair: Brian Anderson (VUW)

15:30	Seasonal streamflow forecasting in Chile	Tim Kerr (Aqualinc)
15:50	Update on NIWA snow and ice network and SPICE experiment	Cristian Zammit (NIWA)
16:10	(Poster talk) Rockfall at Fox Glacier: a hazard analysis using structure from motion and spatial modelling	Sandrine Roy (UC)
16:20	(Poster talk) Anisotropic Fabrics in Deformed Polycrystalline Ice; In-situ Ultrasonic Velocity Measurements	Matthew Vaughan (Otago)
16:30	(Poster talk) Spatial and temporal dynamics of the Tasman Glacier through pixel correlation of an image time-lapse	Ed Liu (VUW)
16:40	(Poster talk) Microstructural analysis of natural and synthetic ice samples in a	Kat Lilly (Otago)

scanning electron microscope using EBSD

16:50 (Poster talk) Ice thickness of the Southern McMurdo Ice shelf — Michelle Ryan (UC)

17:00 Accumulation preparation - help required
17:00 !!!!Ice Breaker!!! - BYO

18:30 Accumulation consumption - all in

Friday, July 3, 2015
07:00 Accumulation preparation and consumption - all in

Glaciology - Session sponsor: University of Canterbury, Chair: Trevor Chinn (Hawea Institue of Glaciology)

08:30 Direct reconstruction of glacier bedrock from known free surface data using the one-dimensional shallow ice approximation — Mathieu Sellier (UC)

08:50 Sensitivty studies of an ice flow model — Christian Wild (UC)

09:10 Reconstructing glacier geometry using terrestrial and airborne photogrammetry — Brian Anderson (VUW)

09:30 Bathymetric and terminus evolution as determined by remote-sensing techniques: Tasman Glacier, NZ — Heather Purdie (UC)

9:50 Interglacial

Sea Ice and Antarctica Part I - Session sponsor Antarctica New Zealand, Chair: Kat Lilly (Otago)

10:30 The sea ice and ice shelf of McMurdo Sound — Pat Langhorne (Otago)

10:50 Sea ice thickness growth in McMurdo Sound, Antarctica, derived by satellite — Wolfgang Rack (UC)

11:10 Scanning electron microscopy of sea ice samples — David Prior (Otago)

11:30 Ice creep phenomena bridges research to education through practical sessions, with laboratory experiments from crystal lattice to the bulk ofi ce — Mathilde Banjan (Otago)

11:50 Accumulation preparation and consumption-all in

Sea Ice and Antarctica Part II, Chair: Rob Dykes (Massey)

13:30 How does changing meteorology affect sea ice production in the Ross Sea? — Ethan Dale (UC)

13:50 Impacts on Antarctic sea ice and the Southern — Andrew Pauling (Otago)

	Ocean from freshwater forcings in an earth system model	
14:10	Ross Ice Shelf firn core analysis	Marcus Arnold (UC)
14:30	Temperature Fluctuations in Antarctic Land-fast Sea Ice	Pat Wongpan (Otago)
14:50	*Interglacial breather*	

Sea Ice and Antarctica Part III Chair: Wolfgang Rack (UC)

15:30	Strand cracks and tidal bending at the Kamb Ice Stream grounding line, West Antarctica	Christina Hulbe (Otago)
15:50	Satellite observations of ice thickness and deformational properties in Antarctic grounding zones	Oliver Marsh (UC)
16:10	Field trip briefing	Christian Wild (UC)
16:30	SIRG future planning	Wolfgang Rack (UC)
16:50	*Accumulation preparation-help required*	
18:30	*Accumulation consumption-all in*	
20:00	*Simon Morris - Guest Speaker* High resolution snow mapping for snow safety	

Saturday, July 4, 2015

07:00	*Accumulation preparation and consumption-all in*	
08:30	*Depart Cass Field Station*	
09:00	*Meet at Porter Heights Skifield access road*	
09:00	*Porters Skifield development and snow safety field trip*	Simon Morris (Porters Ski Area)
09:00	*Snow measurement intercomparison field exercise*	Christian Wild (UC)
12:00	*Post-glacial, until next year*	

A NEW METHOD T0 CONSOLIDATE A DECADE OF MASS BALANCE MEASUREMENTS ON BREWSTER GLACIER, SOUTHERN ALPS, NEW ZEALAND

Cullen, N.J.[1], Anderson, B.[2], Sirguey, P.[3], Stumm, D.[4], Mackintosh, A.[2,5], Conway, J.P.[6], Horgan, H.J.[2], Dadic, R.[2], Fitzsimons, S.J.[1], Lorrey, A.[7]

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[5]*School of Geography, Environment and Earth Sciences, Victoria University of Wellington, Wellington, New Zealand*
[6]*Centre for Hydrology, University of Saskatchewan, Saskatoon, Canada*
[7]*NIWA, Auckland, New Zealand*

We report on the recent consolidation of the glaciological measurements used to reconstruct mass balance on Brewster Glacier. The efforts to gather direct measurements of accumulation and ablation on Brewster Glacier over the period 2004-2015 have been considerable, with a large number of people contributing in different ways over the last decade. Despite the logistical challenges, it is the longest in situ record of a glaciers mass ever obtained in the Southern Alps and as a result, has become an important benchmark for a range of glaciological and climatological studies. To help reconcile differences in historical data acquisition, which has influenced the spatial density of data obtained, we have recently re-analysed all the observational data and propose a new method to calculate mass balance. The method evolved from our hypothesis that the spatial structure of accumulation and ablation over Brewster Glacier for any individual mass balance year should contain sufficient similarity to other years to allow universal accumulation and ablation indices to be developed. This hypothesis was tested using a regression and geo-statistical analysis of the entire mass balance record using elevation gradient as a primary co-factor. The co-variance of both accumulation and ablation with elevation enabled co-kriging to be used to develop indices for the entire surface of Brewster Glacier. Regression analysis revealed the newly derived indices are more powerful in revealing the spatial structure of accumulation and ablation than elevation. Changes in winter and summer mass balance were obtained directly by calibrating the indices with data points available for any given year, which as an approach helped distribute errors associated with potential artefacts introduced from outliers from any particular measurement campaign. The method also enabled a mass balance index to be resolved, which provided the basis to produce glacier-wide estimates of winter, summer and annual mass balance. The uncertainty of these estimates, as well as additional information about snow line altitude (SLA) and accumulation area ratio (AAR) were resolved. Of interest, modelled SLA from our consolidated dataset compares favourably to photos obtained from the end of summer snow line (EOSS) programme.

RECONSTRUCTING THE MASS BALANCE RECORD OF BREWSTER GLACIER USING SATELLITE-DERIVED ALBEDO DATA

Still, H.[1,2], Sirguey, P.[2], Cullen, N.J.[1], Dumont, M.[3]

[1]*Department of Geography, University of Otago, Dunedin, New Zealand*
[2]*School of Surveying, University of Otago, Dunedin, New Zealand*
[3]*Meteo-France/CNRS, CNRM-GAME UMR 3589, CEN, Grenoble, France*

Annual mass balance represents the direct response of a glacier to local climatic conditions (e.g., air temperature and precipitation), while long-term records of mass balance provide information on regional and global-scale climate change. In New Zealand, direct measurements of mass balance are sparse due to the inaccessibility of glaciers in the Southern Alps and the logistical difficulties associated with maintaining a mass balance record. Remote sensing techniques are thus a more practical approach to mass balance monitoring. This research presents a novel remote sensing method where albedo measurements derived from Moderate Resolution Imaging Spectroradiometer (MODIS) data form the basis of a model used to reconstruct and extend the mass balance record of Brewster Glacier. The minimum albedo (averaged over the glacier surface) is the quantity of interest because it represents the relative proportions of highly reflective snow (the accumulation zone) and less reflective exposed ice (the ablation zone). Firstly, 14 years of MODIS data (2000-2013) were processed to create a record of the spatial and temporal albedo variability of Brewster Glacier. The annual albedo minima extracted from the MODIS albedo record were strongly related (R^2 = 0.93) to Brewster Glaciers observed mass balance record (2005-2013). Using this linear relationship, annual mass balances were modelled over the imaging period of the MODIS sensor (2000-present). MODIS-derived mass balances were also strongly related to the corresponding end-of-summer snowline (EOSS) elevations for Brewster Glacier. Therefore in a second model, EOSS elevations obtained between 1978 and 2013 were used to reconstruct the Brewster Glacier mass balance record over a 36-year time period.

STATISTICAL ANALYSIS OF SUB-ANNUAL ICEBERG CALVING AT TASMAN GLACIER, 2011-2012

Dykes, R.C., Bebbington, M. and Lube, G.

Institute of Agriculture and Environment, Massey University, Palmerston North, New Zealand

To better understand calving and its effect on glacier terminus dynamics at time-scales shorter than annually derived calving rates, a time-lapse camera was installed overlooking the water-terminating Tasman Glacier between October 2011 and November 2012. From this image dataset a catalog of calving events was developed so that the temporal patterns and controls of calving could be understood. In total, 365 individual calving events were identified over the study period at a rate of 0.94 events d^{-1}, with significant seasonal differences in the number of calving events observed. From statistical analysis and modelling of calving event distributions and volumes, it was found that the volume of calving events over the study period did not play a part in controlling the annual distribution of calving events. The observed distribution of calving volumes was then modelled to quantitatively relate the calving event distribution to external parameters (such as lake temperature, fluctuations in lake level, and previous calving event volume), by applying a proportional hazards Weibull renewal model. From this modelling, the observed distribution of calving events was shown to be controlled primarily by lake temperature at an annual time-scale. At shorter time-scales (e.g., days) fluctuations in lake level suppressed calving rates, even in the presence of high lake temperatures. This work therefore reinforces the importance of lake temperature and fluctuations in lake level by regulating calving rates over annual time-scales at freshwater-terminating glaciers. It also highlights that at Tasman Glacier there is no time-dependency in calving event volumes, with events of any size able to occur at any time during the year; a result also found at similar calving glaciers globally.

ICE AGE OVER WANAKA, LAKE EXCAVATION

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

[1]*Alpine and Polar Processes Consultancy, LGM, Lake Hawea, New Zealand*
[2]*Engineering Geology, Lietrum St. Cromwell, New Zealand*

The Upper Clutha Pleistocene has been mapped in considerable detail by engineering geologist Royden Thomson, and has preserved some of the oldest terrestrial Pleistocene deposits recorded in New Zealand, with some deposits surviving from over 500,000 years ago. These mapped ice extents show a striking shrinkage in area of each subsequent glaciation, quite out of character with the relative consistent MIS (Marine Isotope Stages) record which shows no similar reverse trend in climate severity.

Most descriptions and interpretations of the Pleistocene glacial processes are dominated by descriptions of those landforms left by the last major Pleistocene event, the retreat features formed from the termination of the LGM. Such studies tend to minimize the massive duration of the Pleistocene era and infer that all observed features were constructed by this last single LGM and its termination.

Thus many important glaciation questions have not been satisfactorily explained; such as?

Why are the main valley lakes and fiords of Westland and Canterbury in-filled?

Why are the fiords and lakes of Fiordland virtually sediment free?

Why are the main valley lakes of Upper Clutha and Waitaki only partially in-filled?

SEASONAL STREAMFLOW FORECASTING IN CHILE

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[2] *Centro de Estudios Avanzados en Zonas Aridas, La Serena, Chile*

Seasonal forecasting of stream flow enables improved water management for irrigation and drinking water supplies. In the Coquimbo region of Chile the summer stream flows are highly correlated to the previous winter's precipitation which falls as snow in the high mountains. Statistical relationships were identified between summer month stream flows and previous month stream flows, as well as between summer stream flows and the previous winter's precipitation. Applying these relationships to the most recent winter precipitation enabled forecasting of summer flows.
This system was implemented operationally for the 2014-2015 summer. This year was forecast to continue a multi-year drought. The forecast was distributed to the community via a public monthly climate bulletin as a simple graph showing the upcoming summer's forecast relative to long term values. The forecast supported local expert subjective forecasts. The forecast proved to be accurate within uncertainty limits giving the community confidence in its skill and ensuring its continued use in future years.

UPDATE ON NIWA SNOW AND ICE NETWORK AND SPICE EXPERIMENT

Zammit, C., Harper, A., Rutherford, J., Willsman, A., McDermott, H., Newland, R., Hay, R.

NIWA-National Institute of Water and Atmospheric Research, Christchurch, New Zealand

Monitoring plays a pivotal role in determining sustainable strategy for efficient overall management of the water resource. Though periodic monitoring provides some information, only long-term monitoring can provide data sufficient in quantity and quality to determine trends and develop predictive models. These can support informed decisions about sustainable and efficient use of water resources in New Zealand. However the development of such strategies is underpinned by our understanding and our ability to measure all inputs in headwaters catchments, where most of the precipitation is falling.

Historically New Zealand has had little to no formal high elevation monitoring stations for all climate and snow related parameters. This leads to sparse and incomplete archived datasets. Due to the importance of these catchments to the New Zealand economy (eg irrigation, hydro-electricity generation, tourism) NIWA has developed a climate-snow and ice monitoring network (SIN) since 2006. This network extends existing monitoring by Meridian Energy. In 2013 the network comprises 13 stations located at elevation above 700 masl.

As part of the WMO Solid Precipitation Intercomparison Experiment (SPICE), NIWA is carrying out an intercomparison of precipitation data over the period 2013-2015 at Mueller Hut. The site was commissioned on 11 July 2013 and comprises two Geonor weighing bucket raingauges, one shielded and the other un-shielded, in association with a conventional tipping bucket raingauge and conventional climate measurements (temperature, wind, solar radiation, and relative humidity). The experiment was designed mainly to quantify the potential underestimation of the total precipitation at high elevation using conventional measurement procedure, to quantity the effect of the wind induced undercatch on precipitation measurement, and to provide a better understanding of local snow related processes.

The presentation aims to outline the strengthening work completed on the SIN over the past two years, and present results obtained part of SPICE experiment over the period September 2013-April 2015.

ROCKFALL AT FOX GLACIER: A HAZARD ANALYSIS USING STRUCTURE FROM MOTION AND SPATIAL MODELLING.

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[3]*Institut de Physique du Globe de Strasbourg, CNRS, Universit de Strasbourg, Strasbourg, France*

As glaciers retreat, downwasting of the ice increases the instability of surrounding rock slopes. In addition, ice thinning can lead to surface morphology changes that can result in a progressively concave transverse profile. This short-term paraglacial process may lengthen the run-out distance of potential rockfalls. The Fox glacier is a temperate maritime glacier located on the western side of New Zealands Southern Alps. Large annual precipitation and a relatively warm climate results in a high mass turnover, which makes Fox glacier extremely sensitive to climate. Current rapid retreat appears to be associated with an escalation of rockfall activity, particularly in the terminus region where walking-tracks are located. Glacier-related tourism is important to the local economy, so maintaining safe-access to the glacier is crucial from both an economic and hazard management perspectives. The area was therefore relevant to develop a rockfalls assessment using a physics-3D model (RockFall Analyst, Lan et al 2007) with a high resolution digital elevation model (DEM) acquired by Structure from Motion (SfM). Our analysis improves 2D-hazard profiles by spatial modelling rockfall trajectories and taking into account the local geology and mechanical properties of rock falling on the ice surface. Our simulations show that as the glacier thins, blocks travel further out onto the glacier. We identify potential rockfall run-out on hazard maps thus providing a first assessment tool for local guides for working in this dynamic environment. We suggest that future research should focus on the interaction between paraglacial processes, climate and rockfall occurrence to further understand the dynamics at seasonal scale. Worldwide, numerous alpine glaciers are retreating and exposed slopes become prone to natural hazards, thus resulting in the increase of the issues outlined here of management between risk and glacier tourism.

SPATIAL AND TEMPORAL DYNAMICS OF THE TASMAN GLACIER THROUGH PIXEL CORRELATION OF AN IMAGE TIME-LAPSE

Liu E.A.

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Tasman Glacier is the largest lake-calving glacier in the Southern Alps of New Zealand. Following the formation of the pro-glacial lake around the 1990s, an acceleration of glacial retreat has been observed and has spurred renewed interest in this unique geomorphic feature of NZ. My personal interests lie in understanding the response of glaciers to increasing atmospheric warming, particularly in the spatial/temporal hydrological dynamics of valley glaciers.

Our work on the Tasman Glacier entails analysis of real-time hourly photos captured from a nearby valley wall overlooking the terminus and pro-glacial lake interface. Using this high-frequency photographic technique, a reliable time-series of glacial dynamics has been developed over the last 2 years. The images require correction for uncertainties presented by camera distortions and movement as well as errors generated from cloud cover, shadowing and varying coloration that may affect our results. Image-correlation of supra-glacial features has provided an accurate matrix of pixel displacements which represent glacial-surface flow velocities and provides insights into the dynamics during, before and after observed calving events.

Little is currently known about the mechanics of sub-glacial hydrology regime and its influence on surface velocity and it is the hope of this work to illuminate on this complex but fascinating topic. Moreover, the technique used in the study is relatively novel and may be a feasible approach for monitoring and studying other geomorphic features in New Zealand and abroad.

ANISOTROPIC FABRICS IN DEFORMED POLYCRYSTALLINE ICE; IN-SITU ULTRASONIC VELOCITY

Vaughan, M.[1], Prior, D.[1], Seidemann, M.[1], Mitchell, T.[2], Brantut, N.[2], Jefferd, M.[2]

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[2] *Geology Department, University College London, U.K.*

Understanding the flow of ice in glaciers and large grounded ice sheets is of increasing importance as climate change moves to the forefront of modern scientific investigation. The highly anisotropic visco-plasticity of ice leads to development of strong C-axis orientation fabrics (COF's). In ice undergoing uni-axial shortening at high homologous temperatures, mechanisms operate to reduce stored strain energy and lead to the concentration of crystallographic c-axes into an orientation cone symmetric about the principle compression direction. This imparts an acoustic anisotropy that manifests as en-glacial reflectivity under seismic investigation on large ice sheets. This presentation provides an overview of preliminary results from a unique set of experiments which monitor the development of acoustic anisotropy in deforming ice in real-time. These results are compared to modeled anisotropy values derived from Cryo-EBSD data sets collected from the deformed samples at various increments of strain. Here we show how velocity anisotropy evolves as a function of strain and fabric evolution and explore the implications of these results for large scale seismic investigations of ice sheets.

MICROSTRUCTURAL ANALYSIS OF NATURAL AND SYNTHETIC ICE SAMPLES IN A SCANNING ELECTRON MICROSCOPE USING EBSD

Lilly, K., Prior, D., Seidemann, M., Vaughan, M.

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In the Zeiss Sigma FEGSEM at the Otago Centre for Electron Microscopy we have the capability to image ice samples and to map their microstructure using electron backscatter diffraction (EBSD). We are able to analyse very large samples, up to 70 mm by 30 mm, as well as very fine-grained samples, smaller than 10 micron grain size. The greatest obstacle is in preparing a surface on the sample that is sufficiently flat and is frost free, without altering the grain size or damaging the microstructure of the sample. We have developed a methology to reliably prepare a sample surface with an unaltered microstructure, through pressure cycle sublimation. We have measured the thermal effects of our sample preparation, storage and transfer procedures and modelled the likelihood of these resulting in modification of the microstructures in our samples. Study of ice microstructures is of relevance to understanding the flow of ice sheet and glaciers, including through experimental studies of grain-growth kinetics. To date most of our work has been looking at synthetic ice samples, but as we can now work with very large samples we can now also work with natural (usually large grain size) samples.

ICE THICKNESS OF THE SOUTHERN MCMURDO ICE SHELF

Ryan, M., Wild, C.T., Rack, W., Purdie, H.,

Gateway Antarctica, University of Canterbury, Christchurch, New Zealand

Preliminary results of a Ground Penetrating Radar (GPR) survey of the Southern McMurdo Ice Shelf during the 2014/2015 season are presented. A 25 MHz Pulse-EKKO GPR system was dragged along a grid over the White Island grounding line. Standard processing techniques were applied and ice thickness measurements extracted with a theoretical vertical resolution of 3.5 m. Ice and surface snow depths are thickest near the grounding line. An inverse distance weight algorithm is used to interpolate ice thickness across the entire area. Thickness is in the range of 180-270 m, with uncertainty of approximately 20 m. These results will be used as validation for a tidal ice flexure model developed by Christian Wild.

DIRECT RECONSTRUCTION OF GLACIER BEDROCK FROM KNOWN FREE SURFACE DATA USING THE ONE-DIMENSIONAL SHALLOW ICE APPROXIMATION

Gessese, A.[1], Heining, C.[2], Sellier, M.[1], McNish, M.[1], Rack, W.[3]

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Glaciers are an important component of the climate system that respond sensitively to climate change. Small glaciers respond more quickly to changing weather patterns compared to large polar ice sheets and ice caps that make them ideal to study climate variability. This study relates to the numerical reconstruction of the glacier bed in order to generate basal boundary data for ice flow models. Bedrock elevation is a paramount input parameter in glacier flow modelling to accurately capture its flow dynamics but is difficult to measure. We present an easy to implement direct numerical and analytical methodology to infer the bedrock geometry under glacial ice from the knowledge of the free surface elevation or the free surface velocity in one space dimension. The numerical and analytical methods are both based on the shallow ice approximation and require the time series of the surface mass balance distribution. Moreover, the analytical method requires the knowledge of the glacier thickness at one arbitrary location. Numerical benchmark test cases are used to verify the suitability and applicability of the algorithms, and a sensitivity analysis demonstrates the robustness of the method.

SENSITIVITY STUDIES OF AN ICE FLOW MODEL

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[3] *Institute of Earth Sciences, University of Iceland, Reykjavik, Iceland*

Successfully linking the cryosphere to the global ocean circulation requires a better understanding of the physical properties of ice as well as the mechanical processes of ice discharge. Hence, computational simulation of ice dynamics is a useful tool to investigate the glaciers response to an ongoing climate change.Nevertheless, parameter uncertainties persist in Glens flow law for ice since its formulation in the early 1950s, thus directly affecting the reliability of current sea-level forecasts. An existing state-of-the-art regional glacier model has been analyzed to quantify the impact introduced by inaccuracies of Glens law within plausible bounds. The model at hand is based on the zeroth-order shallow ice approximation and the finite difference method as well as a flux-limiting numerical spatial scheme. The conducted sensitivity tests demonstrate how rate factor and creep exponent variations cause a strong decay of the model outputs (meltable ice volume, glacierized area, ice thickness) from highly-viscous towards low-viscous ice rheologies, under the same climatic forcing. Using numerical ice flow models to simulate the past, present and future behaviour of actual glacier systems should be accompanied by comprehensive sensitivity analysis to be aware of the consequences induced by uncertainties in the ice flow module.

RECONSTRUCTING GLACIER GEOMETRY USING TERRESTRIAL AND AIRBORNE PHOTOGRAMMETRY

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[2] *Agribotix, Boulder, Colorado, U.S.A.*

Generation of orthophoto mosaics and digital elevation models (DEMs) from image sets captured from airborne and ground-based platforms allows the measurement of glacier geometry changes at high spatial and temporal resolution and low cost. Autonomous aerial vehicles provide a platform for low-cost acquisition of aerial imagery. Glaciological applications include geodetic mass balance studies and glacier dynamics. To test how well these techniques can be applied to glaciers, results from ground-based and aerial image capture campaigns at Tasman and Brewster Glaciers are presented. Ground-based photography was used to generate DEMs at Tasman Glacier with sub-metre accuracy, but the oblique photography angles result in topographic shadowing and distorted orthophotos. Depending on the application these factors may not be an issue, e.g quantifying displacements in time-lapse images taken from a similarly oblique viewpoints. Aerial capture of images on the lower Tasman Glacier allows production of a highly-detailed orthophoto and DEM, but the number of images (c. 3000) means that there is a significant processing overhead. Lack of suitable vantage points made DEM generation from ground-based photographs at Brewster Glacier impractical, but aerial photographs taken from an autonomous micro-aerial vehicle, and a light aircraft, both resulted in high-quality DEM and orthophoto generation. Ultimately, repeat missions will allow the spatial pattern of speed-up events at Tasman Glacier, and geodetic mass balance at Brewster Glacier, to be calculated.

BATHYMETRIC AND TERMINUS EVOLUTION AS DETERMINED BY REMOTE-SENSING TECHNIQUES: TASMAN GLACIER, NEW ZEALAND

Purdie, H.[1], Bealing, P.[1], Tidey, E.[2], Gomez, C.[1]

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

Global glacier recession is increasing the number of glaciers that terminate in proglacial lakes, yet knowledge about the processes that drive ice-berg calving are still poorly understood. This knowledge-gap is in part due to the challenge of obtaining good data sets in a highly dynamic and dangerous environment. We are using emerging remote technologies, in the form of a remote controlled jet boat to survey bathymetry, and Structure from Motion (SfM) to characterise terminus morphology, to better understand relationships between lake growth and terminus evolution. Comparison of results between the jet boat mounted dual-frequency Garmin fish-finder with an Odom Echotrac DF3200 MKII with 200/38 kHz dual-frequency transducer, showed that after a sound velocity adjustment, the remote survey obtained depth data within 1 m of the higher grade survey equipment. A maximum water depth of 240 m was recorded 250 m away from the terminus, and the sub-aerial cliff height ranged from 5-44 m. However in some regions, water depth was 180 m only 20 m away from the calving face. Here the sub-aerial cliff height was around 20-25 m, meaning portions of the terminus were, or very close to, buoyancy. A sub-aqueous ice-ramp, 30 m below the water, extended out into the lake from the terminus for approximately 80 m in the central-eastern region. Despite a lake expansion of nearly 1 km since the Rob Dykes survey in 2011. The spatial similarity of the sub-aqueous ramp may indicate that other processes, for example, subglacial hydrology, have influence on the evolving terminus morphology.

THE SEA ICE AND ICE SHELF OF MCMURDO SOUND

Langhorne, P.J.[1], Stevens, C.L.[2], Rack, W.[3], Williams, M.J.M.[2], Smith, I.J.[1], Robinson, N.J.[2], Leonard, G.H.[1], Haas, C.[4], Bitz, C.M.[5], Jendersie, S.[1,2], Pauling, A.G.[1], Wongpan, P.[1], Gough A.J.[1], Hughes, K.G.[1], Price, D.[3], Haskell, T.G.[6]

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Antarctic coastal waters are conditioned by interaction with ice shelves. In turn, the formation and decay of sea ice must be also influenced by proximity to an ice shelf, although the areal extent of this influence is not well documented. Close to an ice shelf, sea ice often grows in water that has been supercooled by interacting with the ice shelf at depth. An important consequence is that the sea ice loses heat to the ocean as well as to the atmosphere. This negative ocean heat flux causes the sea ice to grow thicker than it would without the ice shelf. The thermal deficit also means there are tiny frazil crystals in the water column. While they sometimes accumulate and grow on any object suspended in the near-surface ocean, they also accumulate under the sea ice where they form a porous layer of crystals in an evolving state of consolidation. The crystallographic structure is modified, leaving a detectable signature frozen into the sea ice cover. Using in situ sea ice measurements, we have derived an oceanic heat flux index that indicates the influence of ice shelf-conditioned surface water on sea ice. This includes the longest ice-ocean record for Antarctica, which dates back to 1902 near the McMurdo Ice Shelf. These historical data indicate that, during the twentieth century, any change in the volume of very cold surface outflow is less than the uncertainties in the measurements.

SEA ICE THICKNESS GROWTH IN MCMURDO SOUND, ANTARCTICA, DERIVED BY SATELLITE

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Antarctic sea ice cover has been routinely monitored since 1979 but sea ice thickness remains one of the least understood physical components of the global cryosphere. Quantification of thickness is of crucial importance, since when combined with area it allows the computation of sea ice volume providing insight into the heat budget of the Antarctic sea ice system and quantification of freshwater and saltwater fluxes in the Southern Ocean.
The use of satellite altimetry for sea ice thickness estimation relies on the measurement of freeboard. Thickness can then be estimated based on the assumptions of hydrostatic equilibrium given densities of snow, ice, water, and snow thickness are known.
Using in situ data for 2011 and 2013 we evaluate the ability of CryoSat-2 (CS-2) to retrieve sea ice freeboard over fast-ice in McMurdo Sound. Three different satellite data products are compared: (i) ESA (ii) NASA, and (iii) AWI. We use a supervised freeboard retrieval procedure to reduce errors associated with sea surface height identification and radar velocity in snow.
We find ESA freeboards located between the ice and snow freeboard rather than the frequently assumed snow-ice interface. NASA is within 0.04 m of the ice freeboard but is influenced by variable snow conditions causing increased radar backscatter from the air/snow interface; in such conditions a positive bias of 0.14 m away from the ice freeboard is observed. AWI freeboards are within 0.03 m of the snow freeboard. The difference in freeboard estimates is primarily driven by different retracker assumptions, although waveform alteration by variations in snow properties and surface roughness is evident. Techniques are amended where necessary and automatic freeboard retrieval procedures are presented.
CS-2 detects annual fast-ice freeboard trends in McMurdo Sound using all three automatic procedures that are in line with known sea ice growth rates in the region. The validation of CS-2 data provides insight into the assumptions currently used to process CS-2 data.

SCANNING ELECTRON MICROSCOPY OF SEA ICE SAMPLES

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We will present some hot-off-of the instrument, scanning electron microscope (SEM) data from sea ice samples from McMurdo sound. We have adapted a SEM to allow us to work on ice samples with surface areas of 40mm by 60mm. Backscattered electron (BSE) images resolve materials of different composition and can be used to map the distribution of water ice, porosity and various salt crystals. Energy dispersive X-Ray microanalysis allows us to characterise the composition of the salts. Electron Backscatter diffraction (EBSD) enables us to map the ice crystal structure with a new level of detail. We aim to present some preliminary data and images to illustrate the potential of these techniques for improving our understanding of the processes important in sea ice development and in characterizing the physical properties of sea ice.

ICE CREEP PHENOMENA BRIDGES RESEARCH TO EDUCATION THROUGH PRACTICAL SESSIONS, WITH LABORATORY EXPERIMENTS FROM CRYSTAL LATTICE TO THE BULK OF ICE

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Geological, environmental and climate change mechanisms are directly linked to Glacier Science. The Geological team of research within Otago University has a specialized and major glaciological focus reflecting the increased engagement of glacier studies with broad themes in environmental geophysics as an interdisciplinary scientific subject. Ice creep phenomenon is part of Glaciology: the study of ice in all its forms. In his *Letter to Professor Jameson*, Forbes wrote: All these facts, attested by long and invariable experience, prove that the ice of the glaciers is insensibly and continually moulding itself under the influence of external circumstances.
This leads to our study focused on the physical principle of Ice Creeping as rock analog for deformation. The work aimed to be presented is a compilation introducing the essential notions of glaciers flows, ice structure and mechanics for students through laboratory experiments as the finality is to bridge research into education by proposing targeted experimental tests during practical sessions involving experiment creation and procedure, flow law calculation, microstructure observation, EBSD (Electron Backscatter Diffraction) data analysis and much more.
From ice sheets to crystal lattice, ice creeping phenomenon brings multi parameters and scientific fields together. Technical method of EBSD and compression tests are proposed as providing an insight into grain-scale processes and a flow law understanding through fracture, recrystallization and grain growth that are important in terrestrial ice systems and consequently environmental interactions.

HOW DOES CHANGING METEOROLOGY AFFECT SEA ICE PRODUCTION IN THE ROSS SEA?

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Wind driven sea ice export from coastal polynyas is an important driver in sea ice production. Areas of major polynyas in the Ross Sea have been suggested to produce the vast amount of the sea ice in the region. We investigate the impacts of strong wind events on polynyas and the subsequent variability in sea ice production.

A time series of sea ice area in the region of the Ross Sea Polynya (RSP) was derived from Bootstrap sea ice concentration (SIC) data based on SSMI satellite measurements and are compared with wind data measured by automatic weather stations of the University of Wisconsin-Madison Antarctic Meteorology Program. Wind data was used to classify each day into characteristic regimes based on the change of wind speed. For each regime, a composite of SIC anomaly was formed for the Ross Sea region. We found that persistent weak winds near the edge of the Ross Ice Shelf are generally associated with positive SIC anomalies in the Ross Sea polynya. Conversely we found negative SIC anomalies in this area during persistent strong winds.

Furthermore, the time derivative of SIC was correlated with wind data close to the RSP with varying time delays. We found a significant negative correlation for change in sea ice preceding strong wind events, representing the break-up and advection of the sea ice in the vicinity. However, after the strong wind events we observe a significant positive correlation linked to an increase in SIC which highlights the production of new sea ice.

IMPACTS ON ANTARCTIC SEA ICE AND THE SOUTHERN OCEAN FROM FRESHWATER FORCINGS IN AN EARTH SYSTEM MODEL

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Antarctic sea ice extent has slightly increased(but with regional variations) in recent decades. In contrast, the majority of global climate models predict a decrease. The reason for this discrepancy is as yet unidentified. Proposed mechanisms include natural variability of the climate system, the influence of strengthening winds, and freshwater fluxes produced as a result of basal melting and calving of ice shelves.
The interaction between ice shelves, sea ice and the ocean is a poorly represented process in global climate models at present. In particular the models omit the process of basal melting of ice shelves by the intrusion of relatively warm water into ice shelf cavities that results in the outflow of relatively fresh, cold, buoyant meltwater. This surface meltwater stratifies the ocean and reduces mixing of water at the surface with that at depth. Consequently heat upwelled in the Southern Ocean could be inhibited if there was an increase in the meltwater flux from the ice shelves. We perform a series of integrations to test the response of sea ice to a substantial increase in freshwater fluxes. We add an additional 167 to 2670 Gt yr^{-1}, and introduce this source either at the ocean surface or at depth and either distributed or at the ice shelf front. This source is designed to mimic the injection of meltwater from the basal melt of ice shelves. We present the preliminary results of this novel experiment on Antarctic sea ice and the Southern Ocean in the CESM1CAM5 global climate model.

ROSS ICE SHELF FIRN CORE ANALYSIS

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Ground measurements of the surface mass balance of the Ross Ice Shelf are required for validating and calibrating satellite measurements which further enhance numerical model simulations of its future behaviour. Comprehensive field studies on the surface mass balance of the Ross Ice Shelf are scarce. In this project the annual snow accumulation on the Ross Ice Shelf will be analysed from firn cores based on annual cycles of isotope ratios (δ^{18}O). This will be used to date annual accumulation layers in radar profiles, filling the gaps over large areas as basis for satellite data analysis. Drill site of firn core locations will be connected with ground penetrating radar to ascertain an improved picture of surface mass balance over the Ross Ice Shelf.

TEMPERATURE FLUCTUATIONS IN ANTARCTIC LAND-FAST SEA ICE

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Vertical temperature strings are often used in sea ice research to obtain details of heat flow, ice growth rate, and ocean-ice-atmosphere interaction. The aim of this research is to inform integrated physical and biological studies. We show the feasibility of using temperature fluctuations, extracted from temperature field data, as a proxy for the movement of fluid within the sea ice structure. We focus on the region close to the growing ice-ocean interface. Fluid transport is assumed to be a key process to resupply nutrients to Antarctic land-fast sea ice algal communities. Six temperature strings (including four winter-long records) were deployed in the land-fast sea ice of McMurdo Sound, Antarctica. By smoothing temperature data with the robust LOESS regression method, we explore temperature fluctuations that cannot be explained by insolation or heat loss to the atmosphere. The statistical distributions of these temperature fluctuations are investigated with sensitivities to the distance from the ice-ocean interface, mean ice temperature, sea ice growth rate, and sea ice type. We show that the statistical distributions of temperature fluctuations are greatest close to the ice-ocean interface at warmer temperatures.

STRAND CRACKS AND TIDAL BENDING AT THE KAMB ICE STREAM GROUNDING LINE, WEST ANTARCTICA

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An extensive set of shore-parallel fractures, strand cracks, are observed at the grounding line of Kamb Ice Stream (KIS) in West Antarctica. As elsewhere around Antarcitca, seismicity measured at the grounding line is tidally modulated and moreover, low-frequency signals associated with shallow fracture propagation are recorded nearly exclusively on the falling tide. Inspired by this observation, we use measured tidal deflection and horizontal strain rates to examine the relationship between bending and fracture propagation in the grounding zone. We conclude that bending on the falling tide favors propagation while bending on the rising tide suppresses propagation. Without the perturbation due to tidal flexure, strand cracks would be rare and appear farther downstream than observed. We speculate that the very large number of cracks observed at KIS is due to the stagnant-to-floating transition at that grounding line, which promotes repeated working of the same ice and relatively large stretching rates.

SATELLITE OBSERVATIONS OF ICE THICKNESS AND DEFORMATIONAL PROPERTIES IN ANTARCTIC GROUNDING ZONES

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Remote measurement of ice thickness in the Antarctic grounding zone is the key to understanding catchment-scale ice discharge and local mass-balance, and for quantifying ice-shelf basal-melt rates in the vicinity of the grounding line. Here we use satellite altimetry and InSAR to map the surface profile of the ice and changes in this profile due to interaction with the ocean. Both the static buoyancy bending length scale and the time-dependent vertical movement of the surface due to tides provide us with information about ice stiffness, rheology and basal properties. We show how regularization can be used to control the inverse form of the Euler-Bernoulli equation for an elastic plate. By combining satellite-derived diurnal flexure patterns and a regional tide model we can infer ice stiffness and estimate grounding zone ice thickness. At the Beardmore Glacier, a 2-D thickness map produced using detailed differential flexure information from TerraSAR-X imagery agrees with radio-echo sounding measurements to within 50 m. A more extensive comparison of surface elevations with ice-penetrating radar data highlights the spatial extent of error in the commonly used hydrostatic equilibrium assumption in this region, reaching over 100 m in some areas, and the consequent potential for miscalculation of ice shelf basal melt rates close to grounding zones. This new satellite-based approach provides potential for improvement to remote grounding line ice thickness measurements where airborne surveys are not available.

HIGH RESOLUTION SNOW MAPPING FOR SNOW SAFETY

Morris, S.

Porters Ski Area

Simon Morris is the snow safety research officer at Porters Ski Area.

Porters Ski Area is the second largest ski area in the Canterbury region, the largest in the Cass Basin, and is currently undertaking planning for extensive development. This development includes opening up Crystal Valley , a basin adjacent to the current ski area.

Simon has been tasked with researching the distribution of snow in the valley to optimise location of infrastructure and to plan for how to best manage skier safety.

Simon's work represents the intersection of snow and ice research with business development.

Simon has embraced new technologies in surveying cornice depth and development in the valley providing high resolution three dimensional models to be generated. His impressive visualisations simplify communication of the snow issues to engineers, managers, safety staff and to fellow snow and ice researchers.

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