SIRG 2011

SNOW AND ICE RESEARCH GROUP (NZ) Annual Workshop

Fox Glacier Township, 9th – 11th February 2011

SCHEDULE & ABSTRACTS

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Alice Doughty
Brian Anderson
Katrin Sattler
Catherine Hines
Andrew Mackintosh
Kate Sinclair
Karen McKinnon

Cover Image: Fox Glacier; Courtesy of Trevor Chinn

PROGRAMME

WEDNESDAY, 9TH FEBRUARY

2:00	Welcome and housekeeping

2:15 – 3:30	SESSION 1 – Glacier behaviour and dynamics (Chair: Alice Doughty)
2:15	*Robert Dykes* Buoyancy induced calving at Tasman Glacier, New Zealand
2:30	*Huw Horgan* Dynamic thinning of the Thwaites Glacier, West Antarctica
2:45	*Clare Robertson* Subaqueous terminal morphology of a proglacial lake, Mount Cook National Park
3:00	*Todd Redpath* A comprehensive ten year flow velocity record for the Tasman Glacier from optical satellite Imagery
3:15	*Marijke Habermann* A principled stopping criterion for bed strength reconstructions

3:30 – 4:00	Afternoon tea

4:00 – 4: 30	Short talks and APECS (Chair: Katrin Sattler)
	Daniel Price *Ben Thomson* *Samantha Goodhue* *Philip Bennington* *Lisa Hahn-Woernle*

4:30 – 5:45	SESSION 2 – Fox and Franz Josef Glacier (Chair: Tim Kerr)
4:30	*David Alexander* High basal melting rates within high-precipitation, temperate mountain glaciers
4:45	*John Appleby* Structural Glaciology of a temperate maritime glacier: Lower Fox Glacier, New Zealand

5:00	*Brian Anderson* Diurnal to decadal ice velocity variations on Franz Josef Glacier (Ka Roimata o Hine Hukatere), South Westland, New Zealand

6:00	Dinner

7:30	Public Talk and interactive discussion

THURSDAY, 10TH FEBRUARY

7:00	Breakfast

8:15	Announcements

8:30 – 11:00	SESSION 3 – Antarctica (Chair: Pat Langhorne)
8:30	*Alexander Gough* Multiyear Sea Ice in McMurdo Sound – Insights into Snow Ice and Brine Migration
8:45	*Inka Koch* Processes of sediment entrainment at the base of the Southern McMurdo Ice Shelf, Antarctica
9:00	*Abigail Lovett* An investigation into the origin, formation and deformation of Mirabilite deposits, Hobbs Glacier Region, Antarctica
9:15	*Oliver Marsh* A new velocity map of the Ross Ice Shelf, derived from cross-correlation of ICESat altimetry
9:30	*Laurie Burn-Nunes* Investigation of lead and its isotopes in Antarctic ice
9:45	Short break
10:00	*Inga Smith* Sea ice thicknesses: Results from the 2010 Antarctic winter
10:15	*Andy Mahoney* The seasonal arrival of ice shelf water in McMurdo Sound and its effect on sea ice growth

10:30	*Greg Leonard* Measurement of coastal sea ice vertical and horizontal displacements using a differential GPS and Total Station measurement array
10:45	*Daniel Price* Three-dimensional assessment of sea ice in McMurdo Sound, Antarctica, using satellite data sets

11:00 – 11:30	Morning tea

11:30 – 12:45	SESSION 4 – Modelling (Numerical and Analytical) (Chair: Inga Smith)
11:30	*Alice Doughty* Modelling late-glacial ice extent in the Ben Ohau Range to estimate past temperatures
11:45	*Karen McKinnon* Climatic and non-climatic influences on Tasman Glacier extent
12:00	*Jono Conway* Surface climate of Brewster Glacier
12:15	*Natalya Reznichenko* Diagnostic criteria for the identification of the rock avalanche derived sediments in moraines
12:30	*Phil Weir* Applications of engineering-style approaches to the analysis of ocean wave - ice floe interactions
12:45	*Fabien Montiel* Experimental Approach to Water Wave Interactions with Sea-Ice Floes

1:00 – 2:00	Lunch

2:00 – 3:15	SESSION 5 - Climate , Glaciers and Permafrost (Chair: Andrew Mackintosh)
2:00	*Jim Salinger* Climate trends in the Southern Alps 1860s - 2010
2:15	*Tim Kerr* Design of a precipitation observation campaign to investigate the precipitation distribution in Westland Tai Poutini National Park, New Zealand
2:30	*Trevor Chinn* Response times and glacier behaviour interpretation from glacier fluctuation

	records
2:45	*Nikolai Kruetzmann* Measuring snow accumulation and compaction with ground-penetrating radar
3:00	*Heather Purdie* Interannual variability in net accumulation on Tasman Glacier and its relationship with climate
3:15 – 3:45	Afternoon tea
3:45	*Katrin Sattler* In search of the Frozen Ground ...
4:00	*Martina Barandun* Mass Balance Modeling of the Basodino Glacier with a simple Analytical Model
4:15	*Pascal Sirguey* Measurements of glacier albedo using terrestrial and spaceborne remote sensing, assimilation into a mass balance model
4:30	*Sebastian Vivero* Chilean glacier inventories: a review
4:45	*Martyn Tranter* Biogeochemistry of the global glacial sediment cycle

6:00	Dinner

FRIDAY, 11TH FEBRUARY

7:00	Breakfast

8:00 – 2:00	Fieldtrip to Fox Glacier

2:00	Vans depart to Christchurch/ Dunedin

PUBLIC LECTURE

GLACIERS IN OUR BACKYARD
– Hazards, monitoring, and adaptation

Graham Wilcox, Cornelia Vervoorn & Brian Anderson

Fox and Franz Josef glaciers are two of the most frequently visited glaciers in the world due to their spectacular setting, dramatic advance and retreat, and easy access. Facilitating as well as regulating people's access to the ice is a difficult task. Visitors range in experience from complete novice to mountaineer, and they are expected to make the right decisions about their personal level of expertise. Monitoring and modelling of these glaciers over the last decade has shown that they are vulnerable to climatic change. Adapting to these changes will be a key challenge in the coming decades.
The public lecture and subsequent discussion include a unique combination of speakers who will discuss day-to-day observations of glacier change, safety management, and glacier research.

Graham Wilcox
Graham Wilcox has been working as a glacier guide at Fox Glacier for the past 10 years. He is passionate about glaciers and likes to keep up-to-date with current scientific understanding. Consequently, Graham has assisted scientists on a number of glaciological field trips in the Southern Alps and has been co-ordinating on-going mass balance measurements on the lower Fox Glacier.

Cornelia Vervoorn
Cornelia Vervoorn is the community relations manager for the Doc Franz Josef Waiau area, and previously worked as a glacier guide at Fox Glacier. She continues to be an active part in the alpine, primary school, and tourist communities, offering opportunities, workshops, and functions through her position at Doc.

Brian Anderson
Brian Anderson is a glaciologist at Victoria University with primary interests in modelling the interactions between glaciers and climate. Brian lives on the West Coast and has been monitoring the mass balance and flow of Franz Josef Glacier for more than a decade. He has also made projections on the impact of climatic change on the glacier.

Wednesday, 9th February 2011,
7.30 pm, Community Hall

BUOYANCY INDUCED CALVING AT TASMAN GLACIER, NEW ZEALAND

Dykes, R.C.[1], Brook, M.S.[1], Lube, G.[2]

[1]Geography Programme, School of People Environment and Planning,
Massey University, Palmerston North, New Zealand.
[2]Volcanic Risk Solutions, Institute of Natural Resources, Massey University, New Zealand.

Throughout the months of July and August 2010 a large section of the terminus of Tasman Glacier was observed to lift out of the water, eventually calving on the 22nd of August. Calving of this large section of the glacier likely occurred as a result of torque-induced buoyancy, caused by large areas of the glacier reaching flotation. Buoyancy of the terminus at calving margins occurs as a result of thinning associated with longitudinal stretching and subaerial melt altering the stress regime of the terminus, decreasing ice overburden pressure. Evidence for buoyancy induced calving at Tasman Glacier is expressed by the tilting of thermo-erosional notches, the formation of transverse crevasses cutting across the hinge point, and the presence of large 'tabular' icebergs after calving. The flotation and calving of the terminus of Tasman Glacier has significantly altered the dynamics of the terminus region. This has resulted in a series of comparatively smaller calving events as the glacier readjusts to its new geometry.

DYNAMIC THINNING ON THWAITES GLACIER, WEST ANTARCTICA

Horgan H.J.[1], Christianson K.[2], Anandakrishnan S.[2]

[1]Antarctic Research Center, Victoria University of Wellington
[2]Pennsylvania State University

Thwaites Glacier drains the Amundsen Sea Sector of West Antarctica, and is presently undergoing substantial mass loss. Bedrock topography within the Thwaites catchment is well below sea level and slopes inland, making Thwaites inherently unstable. At the coast, a narrow (50 km) sill of shallow bed-topography presently stabilizes the system. During the austral summers of 2007-2008 and 2008-2009, a network of continuous GPS stations were installed on Thwaites Glacier. Combining the resulting observations with ICESat surface elevation data reveals the distribution of dynamic thinning and velocity variations on Thwaites between 2003 and 2009. These data indicate that the mass imbalance on Thwaites is leading to thinning at rates that greatly exceed those possible from changes in accumulation rate or firn compaction. As the floating tongue of Thwaites Glacier provides little to no resistive longitudinal stress, the causes of the recent thinning are likely not to be directly linked to recent proximal ocean changes.

SUBAQUEOUS TERMINAL MORPHOLOGY OF A PROGLACIAL LAKE, MOUNT COOK NATIONAL PARK

Robertson, C.M.[1], Brook, M.S. [1], Fuller, I.C. [1] and Holt, K.A. [1]

[1]Geography Programme, Massey University, Palmerston North

Many studies have alluded to the presence of ice ramps or ice feet extending from glaciers into proglacial lakes and tidewater glaciers, however little quantitative data exists. A better understanding of subaqueous terminus morphology and calving processes, and how they contribute to overall glacier mass loss may assist in refining calving models and predictions. This project aims to study the temporal evolution of a subaqueous ice ramp at Mueller Glacier lake in Mount Cook National Park and investigate the processes controlling its development. These data will then be compared with subaqueous terminal morphologies in Hooker and Tasman proglacial lakes. Sub-bottom profiling using Compressed High Intensity Radar Pulse (CHIRP) seismic reflection data has been completed in Mueller, Hooker and Tasman lakes. An ice ramp was identified in Mueller Lake in November 2009 and April 2010. Lake temperature has been measured continuously in Mueller and Hooker lakes since November 2009 and lake level data has been collected in Mueller Lake from April 2010. To better understand what controls the extent and evolution of the ice ramp in Mueller Lake, further surveys of lake, glacier and climatic parameters are being made (Jan/Feb 2011) including bathymetry, lake level and temperature, terminus strain-rates, horizontal and vertical velocities, and subaerial terminus changes. Preliminary results will be presented for Mueller lake including bathymetry, subaqueous terminus morphology, and lake temperature.

A COMPREHENSIVE TEN YEAR FLOW VELOCITY RECORD FOR THE TASMAN GLACIER FROM OPTICAL SATELLITE IMAGERY

Redpath, T.[1], Fitzsimons, S.[1], Sirguey, P.[2], Kääb, A.[3]

[1]Department of Geography, University of Otago, Dunedin, New Zealand
[2]School of Surveying, University of Otago, Dunedin, New Zealand
[3]Department of Geosciences, University of Oslo, Oslo, Norway

The Tasman Glacier is New Zealand's largest, with a long observational record. Velocity measurements are present throughout this record, but sparse through the first part of the 21st century. Previous studies have applied digital image matching techniques to the Tasman Glacier. These studies have, however, utilized temporally limited data sets. Additionally, precise quantification of uncertainties is not common; with an accuracy of ± 1 pixel (15 m where ASTER imagery is used) typically assigned to measured velocities. Large and ambiguous uncertainties make significance assessment of small inter-annual velocity changes difficult. Here, digital image matching techniques are applied to a series of images from the ASTER and Landsat 7 sensors, providing a set of flow fields for the period 2000 – 2010. The use of geostatistics makes these flow fields spatially comprehensive. Assessment of image co-registration accuracy, a major control on the accuracy of velocities measured by image matching, allows spatialised confidence intervals to be constructed for individual velocity measurements. Generally 90% confidence intervals are of sub-pixel size. Subsequently, the threshold at which significance can be attributed to observed changes in velocity from year to year is precisely quantified for individual measurements. Good agreement was found between remotely sensed and *in situ* data collected during GPS surveys in 2009 and 2010. Results show that the Tasman Glacier exhibits highly dynamic behaviour through the study period, with oscillations between acceleration and deceleration occurring. This data set provides new insights into the dynamic variability of large valley glaciers such as the Tasman Glacier.

A PRINCIPLED STOPPING CRITERION FOR BED STRENGTH RECONSTRUCTIONS

Habermann, M.[1], Maxwell, D.A.[2], and Truer, M.[1]

[1]Geophysical Institute, University of Alaska Fairbanks, USA
[2]Dept of Mathematics and Statistics, University of Alaska Fairbanks, USA

A crucial assumption in all ice sheet models concerns the nature and parameterization of the basal boundary condition. Direct observations on large spatial scales are not possible, but inverse methods can be used to determine the distribution of a basal friction parameter from surface measurements. Such reconstructions are not unique– a range of substantially different basal friction parameter distributions will lead to surface data that match observation to within measurement and model error levels. Additional information must be used to reconstruct a reasonable distribution.

We present iterative methods that aim to determine parameterizations that fit ob- served surface velocities to within a given tolerance. We compare steepest descent, nonlinear conjugate gradient and incomplete Gauss-Newton algorithms. These iterative techniques have the common property that they tend to correct large-scale features first, and thereby generate minimally featured distributions that are consistent with surface observations. The additional information needed by these methods is an initial estimate for the friction parameter and the desired tolerance for matching observation.

We test our methods by creating synthetic data sets and running them through a forward model, the Shallow Shelf Equations. The resulting surface velocity is then perturbed and the inverse methods applied to the perturbed fields. We show that the use of an appropriate and principled stopping criterion avoids fitting noise in the data and leads to a smooth parameterization of basal friction. We also demonstrate the effect of different initial guesses.

We plan to incorporate the faster converging incomplete Gauss-Newton method in PISM (Parallel Ice-Sheet Model) and to use the Pine Island and Thwaites glacier area in West Antarctica as a testbed. This glacier basin has been studied intensively and multiple groups have used inverse methods to find basal conditions in this region, which will give us the possibility to compare our results.

HIGH BASAL MELTING RATES WITHIN HIGH-PRECIPITATION, TEMPERATE MOUNTAIN GLACIERS

Alexander, D.J.[1], Shulmeister, J.[1], Davies, T.R.[2]

[1]School of Geography, Planning and Environmental Management, University of Queensland, Brisbane, Australia
[2]Department of Geological Sciences, University of Canterbury, Christchurch, New Zealand

The role of basal melting on high-turnover temperate glaciers represents a significant gap in our understanding of glacier melting processes. We use a basal melt equation to calculate a geothermal- and frictional heat-induced basal melt rate and develop a simple equation to calculate the rainfall-induced melt for Franz Josef Glacier in New Zealand, a high-precipitation, high-ablation temperate glacier. Data are collated from published information on glacier dynamics and climate station data. Results show that on average, geothermal -and frictional heat-induced melt, and rainfall-induced basal melt contribute ~0.20 m a^{-1} and ~1.70 m a^{-1} to total glacier melt rates respectively, which is equivalent to ~10% of the total ablation for the glacier, indicating that basal melting is an important component of mass-balance for high-precipitation, temperate glaciers.

STRUCTURAL GLACIOLOGY OF A TEMPERATE MARITIME GLACIER: LOWER FOX GLACIER, NEW ZEALAND

Appleby, J.R.[1], Brook, M.S.[1], Vale, S.S.[1], and MacDonald-Creevey, A.M.[2]

[1]Geography Programme, School of People, Environment and Planning,
Massey University, Palmerston North, New Zealand
[2]Department of Earth Sciences, Institute of Natural Resources, Massey University,
Palmerston North, New Zealand

This paper describes the structural glaciology of the lower Fox Glacier, a 12.7 km-long valley glacier draining the western side of the Southern Alps, New Zealand. Field data are combined with analysis of aerial photographs to present a structural interpretation of a 5 km- long segment covering the lower trunk of the glacier, from the upper icefall down-glacier to the terminus. The glacier typifies the structural patterns observed in many other alpine glaciers, including: primary stratification visible within crevasse walls in the lower icefall; foliation visible in crevasses below the lower icefall; a complex set of intersecting crevasse traces; splaying and chevron crevasses at the glacier margins; transverse crevasses forming due to longitudinal extension; longitudinal crevasses due to lateral extension near the snout; and, arcuate up-glacier dipping structures between the foot of the lower icefall and the terminus. The latter are interpreted as crevasse traces that have been reactivated as thrust faults, accommodating longitudinal compression at the glacier snout. Weak band-ogives are visible below the upper icefall, and these could be formed by multiple shearing zones uplifting basal ice to the glacier surface to produce the darker bands, rather than by discrete fault planes. Many structures such as crevasses traces do not show a clear relationship with measured surface strain-rates, in which case they may be ‘close to crevassing’, or are undergoing passive transport down-glacier.

DIURNAL TO DECADAL ICE VELOCITY VARIATIONS ON FRANZ JOSEF GLACIER (KA ROIMATA O HINE HUKATERE), SOUTH WESTLAND, NEW ZEALAND.

Anderson, B.M.[1], Goodsell, B.[1], Owens, I.F.[2], Willis, I.C.[3], Lawson, W.J.[2], Mackintosh, A.N.[1]

1. Antarctic Research Centre, Victoria University of Wellington
2. Department of Geography, University of Canterbury
3. Department of Geography, University of Cambridge

Franz Josef Glacier provides a rare opportunity to observe the dynamics of a fast-flowing, maritime glacier that differs significantly from many 'typical' alpine glaciers. In particular, Franz Josef Glacier tongue has limited diurnal and seasonal temperature ranges, has significant volumes of melt and rainwater that are generated throughout the year, and has been through a recent advance/retreat cycle. Previous studies indicate these factors have a significant influence on surface motion. We present the analysis of velocity measurements made between 2000 and 2010 at a variety of timescales, notably diurnal, daily, sub-seasonal, seasonal, and intra-annual. Diurnal and seasonal velocity variations are linked to temperature variations, a proxy for melt rates. Large rainfall events also have an influence on short to medium-term velocity variations. Longer-term velocity variations are linked to variations in glacier geometry and advance/retreat cycles. Short-term variation reflects rapid changes in basal motion, whereas longer-term variations reflect changes in ice deformation and longitudinal stress gradients.

MULTIYEAR SEA ICE IN MCMURDO SOUND – INSIGHTS INTO SNOW ICE AND BRINE MIGRATION

Gough, A. J.[1], Mahoney, A. M.[1,2], Langhorne, P. J. [1], Williams, M. J. M.[3], Frew, R. D. [1], Haskell, T. G. [4]

[1]University of Otago
[2]University of Alaska, Fairbanks
[3]National Institute for Water and Atmospheric Research Ltd.
[4]Industrial Research Ltd.

Multi-year sea ice has covered the southern portions of McMurdo sound since the late 1990s, a situation which is somewhat unusual in the short history of human occupation. A number of roads, routes and field camps utilise the multiyear ice, probably making it the most trafficked ice in Antarctica. While conducting oceanographic measurements at a site between Cape Armitage and the edge of the McMurdo ice shelf, we were able to profile the thickness, crystal structure, temperature and growth of an area of sea ice from the last days of summer in February 2009 through to the end of the following winter. Structural and stable isotope measurements indicate that the ice thickens early in the winter through the formation of snow ice, and later by accreting and consolidating a layer of platelet crystals at its base. Strong fluxes of heat during the summer melt away the previous winter's growth, so that after a number of years the entire ice thickness is composed of frozen flooded snow. We present a salinity time series from around the time of snow ice formation in February which provides evidence for upwelling of brines through the sea ice. We present a thickness map which extends our findings over the Sound and which may be of use to parties operating on the sea ice of the Sound.

PROCESSES OF SEDIMENT ENTRAINMENT AT THE BASE OF THE SOUTHERN MCMURDO ICE SHELF, ANTARCTICA

Koch, I.[1], Fitzsimons, S.[1], Cullen, N.[1] and Hambrey, M.[2]

[1]Department of Geography, University of Otago, Dunedin, New Zealand
[1] Department of Geography and Earth Sciences, University of Aberystwyth, Wales, U.K.

Moraines are actively forming at the Southern McMurdo Ice Shelf (SMIS) and this study is part of an effort to understand the moraine formation processes at SMIS - a small ice shelf adjacent to but separated from the Ross Ice Shelf by a strike-slip shear zone. On Minna Bluff, at the southern end of the ice shelf, several moraine ridges were formed during ice advances, possibly when the ice shelf was grounded. This study aims to improve the understanding of the moraine formation processes in order to interpret moraine dates and thus past ice advances correctly. In particular, this study focuses on properties of the ice-cored moraines and the ice shelf edge. The ice shelf is upwarping toward Minna Bluff and the surface is stripped bare by katabatic winds. Due to the erosion by the katabatic wind, an upward motion of ice from the bottom of the ice shelf is created. Hence, sediment layers that were originally accreted at the ice shelf base and will later form moraines can be easily investigated at the surface. Similarly, the ice between the sediment layers can be sampled and, through the means of oxygen isotope, major ion and crystallographic analyses, the formation processes of the sediment ice-mix (or sediment entrainment) can be determined. This will inform about the origin of the ice-cored moraine debris, which could be accreted during basal adfreezing at the ice shelf base in open water conditions or eroded as the ice shelf was grounded. Results from the oxygen isotopes analysis will inform about this since the ratios vary with open and closed system freezing. Crystallographic analysis (crystal size and orientation) of thin sections of the ice from the ice shelf edge further inform about the type of ice thermal processes at the base of the ice shelf. In this talk I will focus on results from the recent 2010 field season.

AN INVESTIGATION INTO THE ORIGIN, FORMATION AND DEFORMATION OF MIRABILITE DEPOSITS, HOBBS GLACIER REGION, ANTARCTICA.

Lovett, A.P.; Fitzsimons, S.J. and Mager, S.M.

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Extensive accumulations of almost pure sodium sulphate (mirabilite) are located in the ice cored moraine between the terminus of Hobbs Glacier and McMurdo Sound. Although several investigations have attempted to determine brine origin and subsequent salt formation, specific processes remain poorly understood. Understanding the origin and formation of salt deposits in this environment can reveal important information about past climate, hydrological and glaciological processes and environmental conditions. An initial theory for salt deposit formation suggested that brine concentrated from weathering of sulphur rich volcanic material in local valleys. Alternatively, several theories for a marine origin of the salt deposits were suggested including the injection of brines to the ice surface during the grounding of the Ross Ice Shelf. This research aims to determine a brine origin, and understand processes of salt formation and glaciological deformation in the McMurdo Sound Region. Ice and salt samples were extracted from an exposed mirabilite outcrop, which was embedded in the ice cored moraine near the terminus of the Hobbs Glacier. X-Ray Diffraction of the salt identified the primary mineralogical characteristics to be sodium sulphate deca-hydrate $Na_2SO_4.10H_2O$ (mirabilite). Ion Chromatography (IC) has provided a detailed chemical composition of ice samples including important transitions between sodium sulphate and sodium chloride dominated systems. Dry sieving and particle size analysis has provided debris characteristics for use in a facies analysis of the ice samples. A combination of the chemical, sedimentary and mineralogical data is currently being interpreted to determine potential origins and formation pathways for mirabilite deposition in this environment.

A NEW VELOCITY MAP OF THE ROSS ICE SHELF, DERIVED FROM CROSS-CORRELATION OF ICESAT ALTIMETRY

Marsh, O.J. and Rack, W.

Gateway Antarctica, University of Canterbury

Ice-shelf behaviour provides an important indication of the processes occurring at the boundary of marine-terminating ice sheets. It is particularly important to establish the rate of discharge across grounding-lines in order to calculate ice-sheet mass-balance and the potential contribution of grounded ice to sea-level rise. Here we present a method of using surface elevation data from the Ice, Cloud and Land Elevation Satellite (ICESat) to track horizontal movement of large-scale surface undulations on the Ross Ice Shelf, Antarctica. ICESat provides a high precision record of surface elevation, allowing undulations in the kilometre scale with amplitudes as small as 1m to be identified and tracked. Over 1000 separate tracks obtained by ICESat between October 2004 and October 2009 are compared using an automated cross-correlation algorithm. Distinct patterns in surface slope are observed in successive tracks and show the ice shelf moving steadily in a north-westerly direction. As the ICESat tracks do not always overlap exactly, a method to minimize the error caused by perpendicular track offsets is also discussed. These results highlight the potential of altimetry as a method of estimating surface velocity on ice shelves which are apparently feature-less or where more traditional optical and radar feature tracking methods are not feasible.

SEA ICE THICKNESSES: RESULTS FROM THE 2010 ANTARCTIC WINTER

Smith, I.J.[1], Langhorne, P.J.[1], Leonard, G.H.[2], Gough, A.J.[1], Frew, R.D.[3], Trodahl, H.J.[4], Mahoney, A.R.[1], and Haskell, T.G.[6]

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[4]School of Chemical and Physical Sciences, Victoria University of Wellington, P.O. Box 600, Wellington 6140, New Zealand
[5]Geophysical Institute, University of Alaska Fairbanks, P.O. Box 757500, Fairbanks, AK 99775, USA
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Sea ice is a significant component in the operation of the climate and ecosystems of the Southern Hemisphere. Sea ice thickness is a key parameter, yet remote sensing of Antarctic sea ice thicknesses using satellite sensors is difficult. Thus the change in sea ice thickness with respect to time is poorly documented. Direct measurements through coring, drilling, or the use of temperature (thermistor) probes are resource intensive to collect, and are therefore limited to a few sites. An ideal methodology would be one that allowed retrospective reconstruction of sea ice growth rates from any site. Such a methodology using oxygen isotopes has been formulated by previous authors, but our previous research in McMurdo Sound has suggested that modifications to the existing models are needed. This talk will present direct measurements of sea ice growth rates made in McMurdo Sound, Antarctica, in the winter of 2010. The results of the direct measurements of bulk sea ice growth rates are then compared with an existing sea ice growth rate model, using oxygen isotope analysis carried out on sea ice and sea water samples taken at the site. Modifications to the existing model are proposed for sea ice formation occurring near ice shelves, where platelet ice formation is likely.

THE SEASONAL ARRIVAL OF ICE SHELF WATER IN MCMURDO SOUND AND ITS EFFECT ON SEA ICE GROWTH

Mahoney, A. [1,6], Gough, A. [1], Langhorne, P. [1], Robinson, N. [2,3], Stevens, C. [3], Williams, M. J.M. [3], Haskell, T. [4] and Frew, R. [5]

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2 Department of Marine Science, University of Otago, Dunedin
3 National Institute of Water and Atmospheric Research, Greta Point, Wellington
4 Industrial Research Ltd, Lower Hutt
5 Department of Chemistry, University of Otago, Dunedin
6 Geophysical Institute, University of Alaska, Fairbanks, Alaska

Over the winter of 2009, we worked out of Scott Base, Antarctica conducting a combined field study of both the oceanography and sea ice of McMurdo Sound. As part of this, we deployed what we believe was the first year-round mooring underneath sea ice in this region, which provided temperature, salinity and current data from a complete annual cycle. Our measurements also included full-depth ocean profiles, sea ice growth and crystallography, under-ice photography and isotope sampling. In this paper, we identify the incremental arrival of ice shelf water (ISW) and link this to enhanced growth of the sea ice. Furthermore, we indentify the conditions necessary for persistent growth enhancement and the incorporation of platelet crystals into the sea ice. In doing so we demonstrate the possibility of inferring the presence of ISW beneath sea ice through analysis of crystallographic analysis of cores. In addition, we found that the local growth of first year landfast sea ice only accounted for half of the observed increase in salinity over the water column, which indicates that polynyas are responsible for approximately half of the salt flux into McMurdo Sound.

MEASUREMENT OF COASTAL SEA ICE VERTICAL AND HORIZONTAL DISPLACEMENTS USING A DIFFERENTIAL GPS AND TOTAL STATION MEASUREMENT ARRAY

Leonard, G.H[1], Wright, J.W.[1] and Haskell, T.G.[2]

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[2]Industrial Research Limited, Gracefield Road, P.O. Box 31310, LOWER HUTT

Here we present preliminary results from fieldwork conducted in November / December 2010 in McMurdo Sound, Antarctica. Observations of coastal sea ice displacements were made utilising a measurement array comprising two differential GPS receivers, a robotic Total Station (an instrument that precisely measures distances and horizontal and vertical angles), and thirteen optical prisms placed on fibreglass roads mounted into the sea ice. The GPS receivers were placed approximately 200 m apart in a north-south direction and logged observations generally at 1-second intervals for the duration of the experiment. The Total Station was positioned at the central GPS site and observed the thirteen prisms generally at 15-minute intervals. The two GPS receivers are utilised to create a reference baseline so that Total Station observations can be fixed absolutely in space. The prisms were positioned in three lines radiating out from the central site: a north-south line, an east-west line and a line that spanned the interface between first-year and multi-year ice. Prisms were placed generally at distances of 200 and 750 m from the central site. Preliminary results indicate that vertical oscillations due to tidal forcing are well resolved by the GPS receivers while the Total Station measurements indicate horizontal displacements at some of the prism sites of up to 30 mm day^{-1} relative to the centre of the array.

THREE-DIMENSIONAL ASSESSMENT OF SEA ICE IN MCMURDO SOUND, ANTARCTICA, USING SATELLITE DATA SETS

Price, D.D.F[1]., Rack, W[1]., Langhorne, P[2]., Haas, C[3]

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The modern unprecedented loss of Arctic summer sea ice during the 2007 and 2008 melt seasons has supported great advancements in the study of sea ice. The alarming rates at which ice was lost from the Arctic Basin initiated realisation of the potential impact of anthropogenic change to the polar regions, and in turn the global climate system. The Southern Ocean and Antarctic coastline remain unexplored in terms of the collation of large data sets on sea ice characteristics. A slight overall increase in areal extent of Antarctic sea ice has been documented, however with significant regional differences. A 5% loss in the Amundsen Sea is almost exactly balanced by an increase in the Ross Sea. A major unknown is the thickness of sea ice in the Southern Ocean, which is needed to understand the volume flux of ice and to better quantify its role in the global climate system. In this study we investigate the potential of satellite based observations for mapping the spatial characteristics and freeboard heights of sea ice in the McMurdo Sound area. The data presented stem from the ICESat laser altimeter, and the Envisat imaging radar. We also envisage showing first examples from the new CryoSat-2 radar altimeter. At this initial stage of the project we compared the satellite data with sea ice thickness and freeboard from helicopter measurements, which have been acquired in McMurdo Sound during the 2009/10 field season. These results will be used to plan helicopter measurements for the next field season.

INVESTIGATIONS OF LEAD AND ITS ISOTOPES IN ANTARCTIC ICE

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The ability to trace the sources of impurities deposited into Antarctica allows an understanding of the atmospheric transport paths that are involved. To this end, the analysis of Pb in Antarctic ice has provided a useful tool for such investigations because of its unaltered chemical presence in the atmosphere largely as a result of deflated mineral dust, volcanic emissions and anthropogenic industrial emissions. Additionally, based on regional Pb isotopic variations that exist in the Earth's crust, precise analysis of the isotopic composition of Pb in Antarctic ice further enables different sources of Pb to be distinguished. These characteristics of Pb have been utilised by Kevin Rosman and co-workers at Curtin University since the 1990s. Using sensitive techniques to analyse the ultra-trace amounts of Pb inherently present in East Antarctic ice, long-term, short-term and seasonal records of Pb concentrations and isotopes have been produced. Results show that prior to the onset of industrial activity in the Southern Hemisphere, Pb present in East Antarctic ice varied with changing climatic conditions and could be sourced to varying long-range contributions from mineral dust from southern South America and possibly Australia and, regional volcanic emissions from the Antarctic Ross Island volcanic region [1]. Short-term investigations of Pb have demonstrated the impact of large-scale anthropogenic activities in the Southern Hemisphere on the Antarctic environment, with isotopic systematics indicating Australian Pb ore smelting activities to be responsible for the onset of anthropogenic pollution [2]. More recently, based on Pb concentrations and isotopes in late 19th century Eastern Antarctic ice, seasonal cycles in impurity deposition have been demonstrated with implications for relatively direct air trajectory pathways from southern Australia to Eastern Antarctica [3].

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MODELLING LATE-GLACIAL ICE EXTENT IN THE BEN OHAU RANGE TO ESTIMATE PAST TEMPERATURES

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Late-glacial moraine construction in New Zealand culminated at the end of the Antarctic Cold Reversal (~14,500 to 12,800 years ago) (Kaplan *et al.*, 2010; Putnam *et al.*, 2010). Moraine chronologies in unison with detailed geomorphic maps, from the Ben Ohau Range, eastern side of the Southern Alps, New Zealand afford an opportunity to model the effects of climatic variables that could have forced late-glacial ice advances. Here we discuss experiments using a fully-coupled, two-dimensional, energy balance/flow model aimed at finding the best fit of modelled glacier extents with the mapped Ben Ohau moraine patterns. Ice flow is calculated on a 100 m horizontal grid, and the model accounts for topographic shading and present-day valley hypsometry. Input climate is based on an interpolation of nearby climate station data from 1990-2009. Late-glacial runs include insolation values from ~13,000 years ago, and an imposed temperature reduction. Preliminary model runs indicate that a 2.5-3°C cooling relative to the present-day produces an ice distribution compatible with late-glacial moraine limits in Irishman Stream (Kaplan *et al.*, 2010). This cooling is similar to chironimid-derived estimates of late-glacial temperature at Boundary Stream Tarn (eastern flank of the Ben Ohau Range; Vandergoes *et al.*, 2008), and a minimum temperature depression modelled for late-glacial advance of Franz Josef Glacier (western side of the Southern Alps; Anderson and Mackintosh, 2006). Further work will define limiting envelopes of late-glacial temperatures and precipitation changes. These estimates will be tested via sensitivity experiments using variable gradients in temperature and precipitation, and examined for fit against landform records. Ultimately, we will use models to test whether the late-glacial cooling was pervasive in New Zealand.

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CLIMATIC AND NON-CLIMATIC INFLUENCES ON TASMAN GLACIER EXTENT

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Mountain glaciers respond to climatic changes by advancing or retreating, leaving behind a potentially powerful record of climate through moraine deposition. Non-climatic factors, however, may also exert influence on glacial extent, complicating the characterization of glaciers as climate indicators. Using a coupled energy balance-flowline model and focusing on the Last Glacial Maximum and MIS 3 and 4, we examine the relative influences of changes in bed topography, temperature and precipitation on glacial extent. The behavior of the Tasman is found to depend heavily on bed elevation, indicating that quantifying the relative strength of erosive and depositional processes in forming valley topography may be critical for accurate modeling of past glacier extent. We utilize existing gravity and seismic data, as well as estimates of sediment transfer capacity of the Tasman, to produce a suite of potential reconstructions of the bed through the last glacial-interglacial cycles, and explore the range of glacier extent as a function of the topography. Some reconstructions include multiple bed overdeepenings, which cause hysteretic behavior, important for understanding the dynamic evolution of the glacier in response to climatic forcing. The consideration of these factors will allow for an envelope of uncertainty around the climates that influenced the Tasman during the LGM, MIS 3 and MIS 4.

SURFACE CLIMATE OF BREWSTER GLACIER

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High quality measurements of glacier surface climate are vital for validation of energy and mass balance models, and in understanding mountain meteorology and hydrology. Such measurements are relatively sparse in New Zealand. Initial results from an AWS deployed on the Brewster Glacier are presented in the context of energy and mass balance modeling. The AWS is situated at 1774m asl on the centerline of the glacier in the ablation zone. The four component net radiometer provides a useful means to understand changes in incoming short and long-wave radiation under different synoptic conditions, as well as changes in albedo through the season. An adaptable and robust platform will enable measurements to continue through a full year on this high melt and high accumulation glacier. Key uncertainties in energy and mass balance modeling that are being addressed include an assessment of the scaling coefficients for calculating the turbulent sensible and latent heat fluxes, as well as deriving parameterizations for short and long-wave radiation fluxes for distributed modeling. It is hoped that by reducing these uncertainties the use of globally gridded data sets for energy and mass balance modeling will be achievable in the future.

DIAGNOSTIC CRITERIA FOR THE IDENTIFICATION OF THE ROCK AVALANCHE DERIVED SEDIMENTS IN MORAINES

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It is widely argued that moraine formation can be interpreted as the direct signal of climatic forcing. In active orogens, however, sediment delivery to the glacier surface is strongly affected by mass movement processes and many authors have argued that rock avalanche debris can affect moraine formation. Rock avalanches can alter the glacier mass balance by inhibiting ablation and also provide additional sediments for the production of moraines. This may result in a moraine formation event that is triggered non-climatically and it is important that such moraines can be distinguished from climatically derived moraines. There are techniques for the identification of rock avalanche derived sediments based on geomorphology, lithology, clast morphology and fabric description (e.g. Hewitt, 2008), but these are all of limited applicability. Here we present a new diagnostic criterion based on the recognition of agglomerates composed of clay sized particles.

SEM (Scanning Electron Microscope) examination of rock-avalanche-sourced sediment reveals agglomerations of the fine (sub-micron sized) particles which adhere to larger grains, and these behave as larger grains. The agglomerates are ubiquitous in rock avalanche deposits. These agglomerations are produced under high stress conditions during the emplacement of the rock avalanche. They are specific to these conditions and are not replicated in lower-stress environments. The agglomerates are not present in sediment from modern glacial deposits that we know are not affected by rock avalanches including modern moraines in Westland, New Zealand and inner Nordfjord, Norway. In contrast, these agglomerations are present in some Holocene moraines in the Aoraki/Mt. Cook region, which indicates rock avalanche contributions to these moraines.

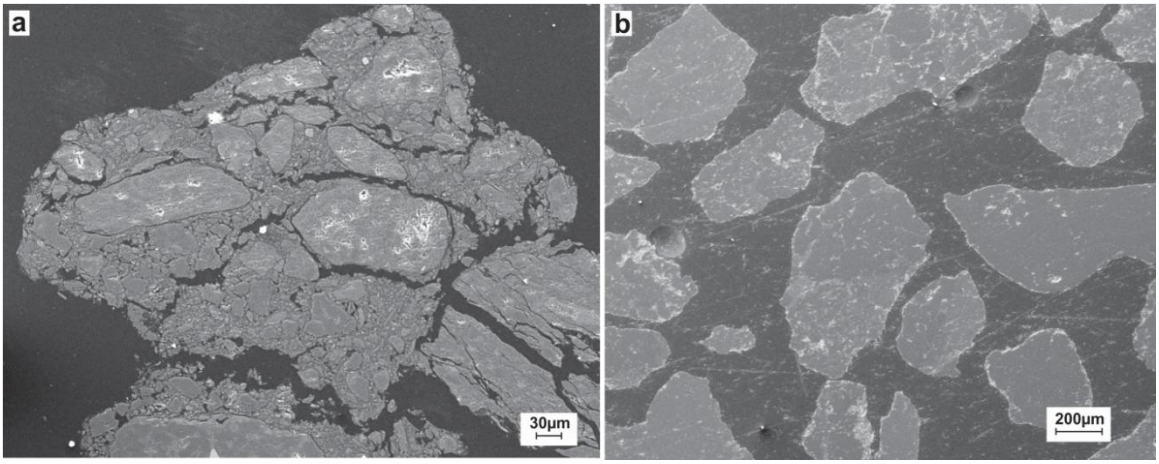

Fig. 1. Comparison of the polished mounted grains of the particles less than 1 mm from different environments, SEM: a) clay size particle agglomerations in Coleridge rock avalanche deposit (New Zealand) b) non-fragmented grains of the sediment from a terminal deposit of the Nigardsbreen Glacier for 2010 (Norway). Darker grey material between grains is resin.

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APPLICATIONS OF ENGINEERING-STYLE APPROACHES TO THE ANALYSIS OF OCEAN WAVE - ICE FLOE INTERACTIONS

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An examination is presented of the response of ice floes to sea waves, such as may occur in the region of loosely-spaced ice around the Antarctic known as the Marginal Ice Zone. By dispersing incident wave energy, this zone provides some protection for land-fast ice from erosion. As such, the understanding of these dispersive interactions forms a component in the consideration of Antarctic contributions to global climate dynamics.

The problem is represented by a floating elastic beam in a fluid basin. The computational domain is discretised and a time-stepping approach employed, applying a predictor-corrector method to find the combined motion of the beam and fluid at each iteration. This leads to an extensible formulation able to incorporate a wider variety of physical properties than is possible using the frequency domain techniques predominant in sea-ice research. Thus we provide for more robust, physically realistic models of polar ice floes.

The coupled system is formulated in a cleanly articulated manner, such that the beam and fluid models are independently interchangeable. This description enables straightforward comparison of the performance of standard elastic beam and fluid models and provides a framework for incorporating more complex models in the future.

The finite element (FEM) techniques underpinning this method have been the subject of a greater degree of investigation in the twin field of floating structures research. The incorporation of this approach into the current research has allowed, for instance, the capture of nonlinear effects in the fluid and time-dependent phenomena.

EXPERIMENTAL APPROACH TO WATER WAVE INTERACTIONS WITH SEA-ICE FLOES

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A series of wave tank experiments were recently conducted at Ecole Centrale de Nantes in France to validate the linear theory used to model the interactions between regular water waves and sea-ice floes. The experimental setup involved a single circular floating elastic plate responding to a controlled incident wave train, generated by a wavemaker. The vertical displacement of the plate was recorded by tracking a finite number of points of the plate's surface using Infra Red cameras. The wave height around the plate was measured with wave gauges, allowing us to extract the scattered wave field radiating away from the plate. The plate was only allowed to have the rigid body motions in heave, roll and pitch, in addition to the flexural response. The same restrictions are present in the mathematical. Aspects of the technical solutions and measurement devices used in the experiments will be described. I will also present preliminary comparative numerical vs. experimental results for validation.

CLIMATE TRENDS IN THE SOUTHERN ALPS 1860S – 2010

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Climate observations commenced in 1867 in the Southern Alps of New Zealand. After a break from 1881, precipitation monitoring commenced again in the 1900s, and full climate observations around 1930, giving the region 105 years of rainfall and 80 years of cxontinuous temperature observations respectively. Mean temperatures have increased in the area by about 0.6°C over the 80 year period, with precipitation showing variability because of circulation changes owing to the Interdecadal Pacific Oscillation (IPO) and El Nino/Southern Oscillation. Mid-range climate scenarios for the 2090s indicate a temperature increase of 2°C and precipitation increase in the order of 10 percent. The trends over the period of instrumental record are described for temperature and precipitation, and projections for the 21st century according to the range of climate scenarios are given. From these changes in the snow line are calculated with comments on implications for the Southern Alps snow resource.

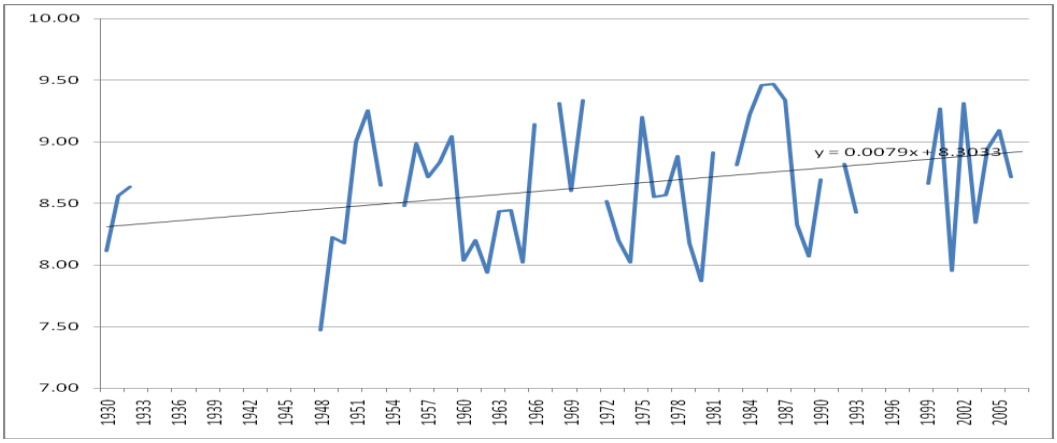

Figure 1. Trends in mean annual temperature, Mt Cook, 1930-2010.

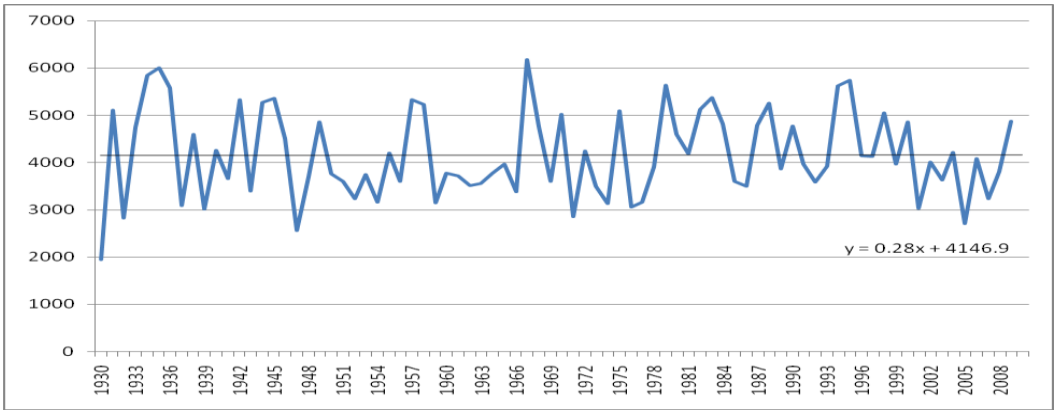

Figure 2. Trends in annual precipitation, Mt Cook, 1930-2010.

DESIGN OF A PRECIPITATION OBSERVATION CAMPAIGN TO INVESTIGATE THE PRECIPITATION DISTRIBUTION IN WESTLAND TAI POUTINI NATIONAL PARK, NEW ZEALAND.

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The precipitation distribution in the Southern Alps has been characterised by west-east precipitation transects showing a peak precipitation location west of the main divide. The observed precipitation transect for the central Southern Alps, east from Westland Tai Poutini National Park, is missing observations from this peak precipitation region. While glacier mass balance studies indicate the precipitation transect is similar in shape to those observed elsewhere in the Southern Alps, observations immediately to the east of the main-divide indicate it is not. An understanding of the precipitation regime in the area is critical for elucidating past, present and future glaciation and for current and future water resource management. A new precipitation observation campaign has been designed to fill the gap in this precipitation transect. Precipitation gauges have been designed capable of recording very high magnitudes of either rainfall or snowfall and to limit under-catch. Additional instrumentation is to be installed to enable under-catch correction. The locations of the gauges have been selected to optimise sampling of the un-gauged sector, to limit under-catch, not be buried by snowfall or avalanche, and not be washed away by flood. The observation campaign is to begin in late summer 2011 and continue for two years. It is anticipated that correlations to nearby long term rain gauge sites will enable mean annual precipitation values to be estimated, and the precipitation transect for the region to be refined.

RESPONSE TIMES AND GLACIER BEHAVIOUR INTERPRETATION FROM GLACIER FLUCTUATION RECORDS

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If one perceives a glacier as an instrument that provides a running mean series of annual climates, then the length changes should be an approximation of the climate averaged over a number of years. The period of time averaged should then be governed by the response time of the glacier, ie the time taken for the first indication of a mass balance change to affect the terminus.

A suitable set of glacier frontal variation data to test this idea is available from opportunistic photography taken during the annual end-of-summer glacier snowline surveys when fluctuations have been photographed for near 100 glaciers. The record, which commenced in 1977, is qualitative in degree of change as the data has been obtained by comparing oblique photographs.

The second set of data, the glacier response time, or the length of the glacier "running mean" may be obtained from the fortuitous climate change that occurred sometime close to 1975. This was essentially a swing in the IPO which introduced a couple of periods of positive mass balance into our glacial system. The positive mass pulses fed into every glacier appeared first as advances at those glaciers with the fastest response times. The advances of the slower response glaciers followed in later years until, in the long response time glaciers, the net mass inputs have yet to travel all of the way through to the termini. In fact proglacial lake expansion has become the dominant change on most of these glaciers.

The data is presented on a simple spreadsheet with glaciers listed by column and observations for each glacier are noted under the year observed. Next the rows are arranged in order of "response times" ie the earliest observed advance to those that have yet to advance (if at all) then many very significant patterns become apparent. It was found that there is a very uniform increase in response time with glacier type, from about 5 years for the fast glaciers to no response yet over the three decade period. Thus the method permits the normally elusive response time for any of the observed glaciers to be simply read from the spreadsheet, and this value is the length of the running mean of the climate that the glacier is measuring.

MEASURING SNOW ACCUMULATION AND COMPACTION WITH GROUND PENETRATIONG RADAR

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We present a method for using a 500 MHz ground penetrating radar (GPR) system for estimating snow accumulation and compaction rates over large areas in Antarctica. We process this data to produce radargrams with unambiguous layers which can be observed and tracked in repeat GPR measurements made one year apart. Our processing methodology is a deterministic deconvolution via the Fourier domain using an estimate of the emitted waveform from direct measurement. Using the processed radargrams from two measurement sites near Scott Base, Antarctica, we can extrapolate point measurements of average accumulation from a snow pit on the ice shelf in Windless Bight (251 kg m^{-2} a^{-1}) and a firn core from the lower slopes of Mt. Erebus (437 kg m^{-2} a^{-1}), to a larger area by identifying a dateable dust layer from the firn profiles with a reflection in the radargram. In Windless Bight we find an average accumulation of 280 ± 30 kg m^{-2} a^{-1} over an 800 m x 800 m area. The second site shows higher overall accumulation of 450 ± 80 kg m^{-2} a^{-1} and considerably greater local variability related to the undulating terrain. Tracking several internal reflection horizons along the profile lines and calculating the average change in separation of horizon pairs between the two field seasons allows us to estimate compaction rates for snow between 2 m and 13 m depth. The derived compaction rates range from 7 cm m^{-1} a^{-1} at a depth of two meters, down to no measurable compaction at 13 meters depth, and are similar to published values, while probably being conservative estimates.

INTERANNUAL VARIABILITY IN NET ACCUMULATION ON TASMAN GLACIER AND ITS RELATIONSHIP WITH CLIMATE

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Mid-latitude maritime glaciers are already responding quickly and directly to climate warming. This response is expected to continue, and result in maritime glaciers making a large contribution to sea level rise over the coming decades. Maritime glaciers in the New Zealand Southern Alps provide an opportunity to learn more about climate-mass balance relationships in a high precipitation setting, and how these relationships might change in the future. Ice core and direct glaciological measurements are used to construct a 24-year record of net accumulation, the longest of its type in New Zealand. We demonstrate that variations in net accumulation on Tasman Glacier are more strongly influenced by temperature than by precipitation. Further, it is temperature during the ablation season that exerts most control. Atmospheric circulation patterns, in particular the state of the El Niño Southern Oscillation (ENSO) and Southern Annular Mode (SAM), were found to influence net accumulation. When the SAM and the ENSO are in their positive phase, they enhance easterly and northerly wind anomalies increasing temperature in the Southern Alps region and resulting in more negative glacier mass balance. Conversely, when in negative phase, westerly and southerly winds prevail, temperatures decrease in the Southern Alps region resulting in increased net accumulation and more positive glacier mass balance. However relationships between glacier mass balance and these atmospheric circulation modes are not straight forward, with some of the lowest net accumulation years associated with inverse polarity between the SAM and the ENSO.

IN SEARCH OF THE FROZEN GROUND …

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With many South Island summits rising above 2000 m a.s.l. and extensive areas experiencing mean air temperatures at or below 0˚C for several months a year, occurrences of discontinuous alpine permafrost can be expected in New Zealand's Southern Alps. Numerous intact rockglaciers, protalus ramparts and perennial snow patches are indicators of the existence of this thermal subsurface phenomenon. However, research on the geographic extent of permafrost has been rudimentary to date, and existing estimates are restricted to a few locations.

In my PhD research project, I'm investigating the relation between permafrost occurrence and debris-flow activity in New Zealand's Southern Alps. By comparing recent trends in debris-flow activity in selected high-alpine areas to the contemporary permafrost distribution as well as to changes in general climatic (e.g. amount/ pattern of rainfall, snowfall level, freeze-thaw level) and non-climatic parameters (e.g. seismic activity), I will systematically evaluate the potential role of permafrost degradation in the climate-change response of high-alpine debris flows. A regional-scale estimate of the spatial permafrost extent is therefore needed. Two approaches are currently being trialed for determining the contemporary permafrost distribution in the Southern Alps: 1) Local permafrost occurrences are being assessed by DC resistivity surveys and associated annual ground surface temperature measurements from data logger records. This empirical data will be used to deduce thresholds of permafrost probability from modelled surface temperatures calculated by an energy balance model. 2) The RILA (rockglacier initiation line altitude) of more than 350 rockglaciers and protalus ramparts mapped in the Canterbury Southern Alps will be used to analyse climatic controls on rockglacier distribution and hence to identify potential lower distribution limits of permafrost.

In this talk I will outline my methodological approach, present preliminary results and talk about the challenges encountered so far.

Active rockglaciers, Irishman Stream Valley, Ben Ohau Range, March 2010 (B. Anderson)

MASS BALANCE MODELING OF THE BASODINO GLACIER WITH A SIMPLE ANALYTICAL MODEL

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A general retreat and predominant negative mass balance trend of Swiss glaciers in recent years make detailed mass balance observations increasingly important to reach more precise knowledge about glacier-climate interaction. Unfortunately, entire coverage of accurate direct measurements of the total glaciated area seems still difficult. To bridge this lack of observational data, a range of analytical and numerical models were developed to simulate glacier's mass balances.

In these studies I used a simple analytical model, developed by Oerlemans (2001) to display annual mass balance changes of a small mountain glacier in the Swiss Alps. The model should be approved for a glacier with limited size and strong retreat pattern. Model results were compared with a 10 years long mass balance series of in-situ measurements at the considered glacier. A high correspondence between model output and measured balance could be reached. The simple model allows descrying general trends of the glacier's behavior without complicating it by numerous factors influencing in the system; however many important details like local distributional patterns or feedback effects cannot be included in the modeling. The model seems to give a good overall estimation of mass balance behavior of the Basodino Glacier in the Swiss Alps.

J. Oerlemans (2001), Glacier and Climate change, Swets and Zeitlinger BV, Lisse, p.45

MEASUREMENT OF GLACIER ALBEDO USING TERRESTRIAL AND SPACEBORNE REMOTE SENSING, ASSIMILATION INTO A MASS BALANCE MODEL.

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[2]Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE), Grenoble, France
[3]IRD-LTHE, Grenoble, France
[4]Météo-France, Centre d'Etude de la Neige (CEN), Grenoble, France

Temperate glaciers are extremely sensitive to climate change as modification of their energy budget affects in turn their mass balance. Energy fluxes at the surface of glaciers are governed by parameters such as the albedo which controls the ratio of shortwave radiation effectively absorbed by the glacier. Remotely sensed data, either acquired by spaceborne or terrestrial sensors enable the surface albedo to be determined with a relatively high spatial and temporal resolution.

Two methods have been designed to measure and map the surface albedo of the Saint Sorlin glacier (Grandes Rousses, France). The first method takes advantage of terrestrial photography acquired in the visible and near infrared range of the electromagnetic spectrum. The second method uses reflectance data from the visible to shortwave infrared captured by the sensor MODIS aboard TERRA. Both algorithms have been developed in order to convert measurements of spectral reflectance into a value of albedo that is directly usable towards the computation of the energy budget of the glacier. This required accounting for the bidirectional reflectance behaviour of ice and snow, as well as a careful conversion from narrowband spectral albedo to broadband albedo.

Two time series of the surface albedo of the Saint Sorlin glacier have been computed covering the summers 2008 and 2009. The maps of albedo were validated based on ground measurements of the albedo at selected locations on the glacier. These maps of albedo were then assimilated into the model CROCUS (Météo-France) that simulates the snowpack. It was shown that such an assimilation of measured maps of albedo enables the mass balance simulation of the glacier to be improved. The accuracy of this method was assessed based on glaciological measures of the glacier conducted by the observatory service Glacioclim.

CHILEAN GLACIER INVENTORIES: A REVIEW

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In the Southern Hemisphere, the Andes in South America is the only mountain range that can support almost all types of glaciers, from small glacierets to vast ice fields. These glaciers are sensitive indicators of climate change as well as important sources of fresh water for population, agriculture and hydroelectric power generation. With a total glacier area of ca. 21,000 km^2 (Naruse, 2007), Chile is the largest country by glacier area in the Southern Hemisphere. Several glacier inventories have been recently compiled in central and southern Chile by means of satellite images. However, there is still a lack of detailed glacier inventories and a lack of information regarding recent glacier variations and glacier-volcano interactions. Additionally, different approaches in the earlier inventories obtained by old and uncorrected aerial photographs and different definitions of "glacier" generate some inconsistencies with the new ones. A review of the main advances in the Chilean glacier inventories is presented, based on the available data. Finally, this contribution will feature some regions which have been insufficiently studied and highlight the future challenges.

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BIOGEOCHEMISTRY OF THE GLOBAL GLACIAL SEDIMENT CYCLE

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Glacial erosion creates a fine rock flour that contains ready sources of energy and nutrient to microbes in subglacial environments. These microbes facilitate subglacial chemical weathering, and in so doing they produce another suite of chemicals, both in solution and as secondary reaction products, that are readily utilisable by microbes and higher organisms in down stream freshwater and marine environments. Both runoff and ice bergs transport these bioutilisable compounds. These relatively short term effects of glacial sediment on geochemical cycles contrast with the longer term release of inorganic P and N from recently deglaciated terrain. This talk summarises what we know of the fluxes of bioutilisable compounds from glacial sediments and the timescales of their effects on local, regional and global biogeochemical cycles, using examples of Fe fertilisation of the Southern Ocean by ice bergs and the release of P into oceans during the onset of glacial cycles.

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