UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

SIRG 2010

Snow and Ice Group (NZ) Annual Workshop

Queenstown, New Zealand 15 - 17 February 2010

Programme and Abstract Book

Sponsored by:

NIWA
Taihoro Nukurangi

Antarctica New Zealand

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The Polar Environments Research Theme, University of Otago

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National Institute of Water and Atmospheric Research (NIWA)

Organising Committee:

Pat Langhorne
Inga Smith
Greg Leonard
Sarah Mager
Nicolas Cullen

Cover Image: Lake Wakatipu, courtesy of Jordy Hendrikx.

Programme

MONDAY 15 FEBRUARY 2010

2:00	Opening of SIRG Workshop and Housekeeping (Inga Smith)

2:15 - 2:45	WORKSHOP 1: Summary of Research Agendas at each Institute (Chair: Tim Kerr)

2:45 - 3:45	SESSION 1: Chair Tim Kerr
2:45	Sean Fitzsimons Debris entrainment processes in Svalbard valley glaciers
3:00	Alice Doughty Using glacier models to reconstruct Climate Change over the last 13,000 years
3:15	Kat Lilly The Antarctic contribution to Holocene sea level rise: evidence from cosmogenic exposure dating
3:30	Rebecca O'Donnell Modelling Quaternary glacier extent and climate in Tasmania, Australia
3:45 - 4:15	Afternoon Tea

4:15 - 5:45	SESSION 2: Chair Blair Fitzharris
4:15	Sam McColl The Hillocks: kame field or rock avalanche?
4:30	Natalia Reznichenko GPR surveys on the Mt Cook and Beatrice rock avalanches and their effect on glacier behaviour in the Southern Alps
4:45	Wendy Clavano Correcting for uneven illumination in near-infrared images of snow layers in a dry zone, Ross Island, Antarctica
5:00	Lawrence Kees Assessment of a snow storage gradient across a maritime mountain environment: a GPR investigation
5:15	Nikolai Kruetzmann Processing of GPR data of Antarctic Snow

8:00 (ish)	FIELD TRIP BRIEFING (Royden Thomson & Trevor Chinn)

TUESDAY 16 FEBRUARY 2010 (Morning)

8:00 - 10:15	SESSION 3: Chair Martin Brook / Brian Anderson
8:00	Trevor Chinn Topographical effects on the glacier AAR for deriving paleosnowlines
8:15	Kate Sinclair Tracing precipitation pathways to Antarctic ice core sites by integrating weather station and reanalysis datasets
8:30	Delia Strong Proglacial lake growth in the Southern Alps, monitored using remotely sensed imagery
8:45	Todd Redpath Utilizing optical satellite imagery to derive multi-temporal flow fields for the Tasman Glacier
9:00 - 9:15	Mini Break
9:15	Wendy Lawson Mass balance-climate relationships for New Zealand's index glaciers: a statistical modelling approach
9:30	Mette Riger-Kusk Hydrology and hydrochemistry of a high arctic glacier: Longyearbreen, Svalbard
9:45	Bob Noonan Imaging Antarctic snow - analysis of snow radar data from Ross Island
10:00 - 10:30	Morning Tea

10:30 - 12:00	SESSION 4: Chair: Mette Riger-Kusk
10:30	Pat Langhorne Antarctic Landfast sea ice: the role of ice shelf-ocean interactions
10:45	Inga Smith Sea ice thicknesses: measurement techniques used in the field
11:00	Oliver Marsh The influence of ice roughness on melting and freezing at the ice-ocean interface: a laboratory study
11:15	Wolfgang Rack Measurements of ice shelf thickness and morphology using helicopter-borne electro-magnetic induction measurements

11:30 - 12:00	WORKSHOP 2: Careers Workshop (Chair: Inga Smith) Shulamit Gordon (Antartica New Zealand) Daniel Pringle (NZX)
12:00 - 2:00	Lunch

TUESDAY 16 FEBRUARY 2010 (Afternoon)

2:00 - 3:30	SESSION 4: Chair Sarah Mager
2:00	Jordy Hendrikx Current and future seasonal snow in New Zealand
2:15	Andrew Willsman The results of the NIWA 2009 index glacier snowline survey
2:30	Jim Salinger Overall trends and variations in ice volume in the Southern Alps
2:45	Tim Kerr Spatial variability of snow in a mountain catchment derived from oblique digital imagery
3:00 - 3:30	WORKSHOP 3: Brief Student Introductions (Chair: Inga Smith) John Appleby, Martina Armstrong, Robert Dykes, Jessie Herbert, Abigail Lovett, Zara McWilliams, Clare Robertson, Phil Weir
3:30 - 4:00	Afternoon Tea

4:00 - 5:00	SESSION 5: Chair Pat Langhorne
4:00	Nicolle Britland Surface climatology and ablation on the floating section of Petermann Gletscher, Greenland
4:15	Fabien Montiel Numerical and experimental study of ocean wave scattering by a set of circular ice floes
4:30	Stephen Stuart Modelling of precipitation in the Southern Alps of New Zealand
4:45	Brian Anderson Mountain glacier velocity variation during a retreat-advance cycle quantified using high-precision analysis of ASTER images

6:00 - 7:00	PUBLIC LECTURE (Copthorne Hotel) Climate Change, Snow, Ice and Tourism by Emeritus Prof. Blair Fitzharris and Dr Jordy Hendrikx
7:30	Workshop Dinner in Queenstown

WEDNESDAY 17 FEBRUARY 2010

8:00 - 2:00	FIELD TRIP Royden Thomson and Trevor Chinn lead a field trip examining the glacial geomorphology of the Glenorchy and Paradise area at the head of Lake Wakatipu

Public Lecture

Climate Change, Snow, Ice and Tourism

Emeritus Prof. Blair Fitzharris and Dr Jordy Hendrikx

What climate changes can be expected for southern New Zealand over the rest of this century? What are the potential impacts on snow and ice in our mountains? What are the implications for our tourist industry? These questions will be addressed using the latest findings from the Intergovernmental Panel on Climate Change, the World Meteorological Organisation and NIWA. Reference will be made to case studies, including important tourist glaciers such as Franz and Tasman, snow on ski fields and alpine scenery. There are also wider implications of climate change for tourism related to issues that might control changes in supply and demand. While many of these are more indirect, they could be very important for New Zealand.

Professor Blair Fitzharris

Blair Fitzharris is Emeritus Professor of Geography at the University of Otago and has undertaken research on climate change in NZ, Canada, Norway, UK, Switzerland and Australia. He has written over 130 research papers on the subjects of climate, snow and glaciers and acted as a consultant on climate matters for resource development for many of New Zealand's largest corporations. Professor Fitzharris has been a Convening Lead Author for the Intergovernmental Panel on Climate Change (IPCC) since 1993. IPCC and Al Gore were jointly awarded the Nobel Peace Prize for 2007. Blair is a past member of the Royal Society of NZ Standing Committee on Climate Change, a former President of the Meteorological Society of NZ and former Chair of the NZ Mountain Safety Council.

Dr Jordy Hendrikx

Jordy Hendrikx is a NIWA Snow and Ice Scientist based in Christchurch and has undertaken research on snow, glaciers, avalanches and climate change in New Zealand, USA, Switzerland and Antarctica. Before working for NIWA he spent time working as a researcher at the Swiss Federal Institute for Snow and Avalanche Research, and on the Milford Road as an avalanche scientist. Jordy is now leading a number of key cryosphere projects at NIWA including; the design and development of a National Snow and Ice Monitoring Network; is an objective leader in a large multi-year project aimed at modelling future New Zealand climate and its downstream impacts; and leads a government / industry partnership funded project to assess the impacts of, and adaptation opportunities for, climate change on seasonal snow. He has recently also started contributing to a project examining climate change impacts on tourism.

Tuesday 16 February 2010 6pm, Copthorne Hotel conference room

Workshops

WORKSHOP 1: Summary of Research Agendas at each Institute

Representatives briefly describe the scope and focus of the research in snow and/or ice research at CRIs and the Universities. Presenters are: National Institute of Water and Atmospheric Research (Tim Kerr); University of Otago (Sean Fitzsimons); University of Canterbury (Wolfgang Rack); GNS Science (Delia Strong); Victoria University of Wellington (Brian Anderson); and Massey University (Martin Brook).

WORKSHOP 2: Careers Workshop

This workshop is designed for students to explore their vocational opportunities after completing their degrees in snow and ice, outside of academic or crown research institutes. Two presentations will be given by Daniel Pringle (NZX) and Shulamit Gordon (Antarctica New Zealand). Non-students are also very welcome to participate.

SHULAMIT GORDON

Shulamit grew up in England, lived in Canada for four years, and has called New Zealand home for the past 9 years. She graduated in Geography at Bristol University, UK then went on to do a Masters in Earth and Atmospheric Sciences, specialising in Glaciology at the University of Alberta in Canada under Martin Sharp. For these degrees she spent four seasons working on the Haut Glacier d'Arolla in the Swiss Alps studying its hydrology using boreholes drilled to its bed. Subsequent to her finishing her Masters degree, Shulamit spent a season in the Canadian High Arctic on Ellesmere Island assisting a doctoral student with his fieldwork and avoiding the polar bears. This was followed by 2 years as a project coordinator in an environmental consulting company in Canada. She then spent two summer seasons in Antarctica as a research technician with a US glaciology event led by Barclay Kamb and Hermann Engelhardt studying the movement of the ice streams that feed the Ross Ice Shelf. Between these seasons Shulamit fell for New Zealand when she got a chance to travel and work there.

Shulamit has worked with the New Zealand Antarctic programme (Antarctica New Zealand) for 8 years as Science Advisor. Her role includes coordinating the annual application round for NZ science support, administering postgraduate scholarships, and organsing Antarctica NZ's annual Antarctic conference. She is also the Project Manager for the Latitudinal Gradient Project (a long term ecological project studying sites along the Victoria Land coast), the Secretary for Evolution and Biodiversity in the Antarctic (one of SCAR's five science programmes), and the co-deputy chair of SCAR's Standing Committee on Antarctic Data Management.

Out of work, Shulamit's interests include playing ice hockey, bike riding, swimming, tramping in the New Zealand bush and singing.

3 key transferable skills:
- Synthesising information
- Organising your time
- Flexibility

DANIEL PRINGLE

Daniel has made the shift from research to the corporate world. Following a PhD in physics at Victoria University and a postdoctoral fellowship at the University of Alaska Fairbanks (UAF), Daniel now works at NZX whose business includes operating the New Zealand stock market. After studying math and physics, Daniel took an MSc in physics doing experimental work on high-temperature superconductors at Victoria University (VUW) and Industrial Research Limited under Joe Trodahl and Jeff Tallon. After a stint at Cornell University, and some time away from academia, Daniel combined his love of the outdoors with his physics training to pursue a PhD at VUW on the thermal properties of sea ice and Antarctic permafrost. Highlights were interdisciplinary and international fieldwork in Antarctica and an exchange to UAF. Daniel later completed a three year postdoc under Hajo Eicken at the Geophysical Institute and Arctic Region Supercomputing Center at UAF. Researching the microstructural properties of sea ice, Daniel combined fieldwork, laboratory experiments and computational work. He cherishes frequently having worked with local Inupiaq in Barrow, Alaska. Daniel was involved in outreach activities in the International Polar Year, establishing the Alaska Young Researchers' Network and was an executive committee member of the Association of Polar Early Career Scientists (APECS).

Whilst enjoying this variety or work and opportunities, the environment and community in Alaska (not to mention groomed ski trails out the office door!) Daniel decided to pursue new challenges on returning to New Zealand. He worked at The Marketplace Company, market operators in the New Zealand electricity market, who were acquired by NZX. He now works in the strategy team at NZX. His current role draws on none of the content of his research work but plenty of the skills and experience acquired. Daniel is an avid rock climber and loves getting outdoors; he's enjoyed his first year of Toastmasters and recommends it.

Key transferrable skills, and advice:

- Your skills are more transferable than you think: if you can think, count and write clearly, and are personable, you are ahead of the bunch!
- Moving sideways can be easier than you think!
- If shifting career paths, businesses will probably not care that much about the details of your research; they do want to know that you cared, and that the skills you gained in the process will be useful to them.
- Spend some time really thinking about why you like (or don't like) your work: the underlying attractions and attributes will be found in other roles work places and roles.
- I got a lot out of career services providers (who I had ignored while studying), especially talking through the results of "personality tests" e.g. Myers Briggs and Strong Interest Inventory.

WORKSHOP 3: Brief Student Introductions

This workshop is designed to introduce students who are not giving a full talk during the workshop to briefly describe the scope and focus of their research. Each student will have a few minutes to outline their projects and progress so far.

Presenters:

- John Appleby *Structural glaciology, dynamics and evolution of Fox Glacier*
- Martina Armstrong *Examination of the Hawea moraines for glaciotectonic deformation*
- Robert Dykes *The effect of iceberg calving on glacier dynamics: Tasman Glacier*
- Jessie Herbert *Ice dynamics of glaciers in the Ross Sea region derived by satellite imagery*
- Abigail Lovett *Origin of mirabilite deposits in moraines from Hobbs Glacier, Antarctica*
- Zara McWilliams *A structural map of the Darwin-Hatherton glacial system, Antarctica*
- Clare Robertson *Ice-ramp evolution in proglacial lakes, Mt Cook National Park*
- Phil Weir *Analysis of interaction of ocean waves with sea ice and very large floating structures*

Abstracts

SURFACE CLIMATOLOGY AND ABLATION ON THE FLOATING SECTION OF PETERMANN GLETSCHER, GREENLAND, 2002-2006

Britland, N.L.[1], Cullen, N.J.[1], Steffen, K.[2]

1 Department of Geography, University of Otago, Dunedin
2 CIRES, University of Colorado, Boulder, Colorado

The Greenland Ice Sheet is currently experiencing warming, which has led to significant changes in its mass balance. While the interior of the ice sheet is thought to be in balance, or even thickening, the margins are thinning at a rate exceeding the accumulation occurring at higher elevations. This thinning is most pronounced on outlet glaciers, the northernmost of which form floating ice tongues. These ice masses are not only subjected to warming from the atmosphere, but also from the ocean below. The Petermann Glacier is a large floating ice tongue, with an area of 1300 km^2 afloat. Previous studies have established that basal melt into the ocean is the predominant form of mass loss; however there is no existing data describing the surface melt regime, nor the climatology. This study aims to fill these knowledge gaps, primarily using Greenland Climate Network (GCNet) data from an AWS located on the floating surface. The data record spans from June 5th, 2002 through to May 1st, 2006. Measurements of incoming and outgoing shortwave radiation, net radiation, relative humidity, air temperature and wind speed at two levels, as well as surface height measurements are used to construct a comprehensive climatology for this location. Surface ablation has been calculated as 1.31 m w.e in 2002, and 1.07, 0.88 and 1.01 m w.e for 2003, 2004 and 2005, respectively. Positive degree-day modelling has been employed, using the surface height and temperature record to characterise the relationship between ablation and air temperature. There is some discrepancy between the melt observed using surface height measurements and that modelled using positive degree days. To resolve this, a surface energy balance has been calculated to identify which energy balance components are controlling the melt regime throughout the ablation season. This study is of contemporary importance, as recent satellite images show a series of large cracks traversing the glacier, and are expected to cause extensive ice loss when they propagate the entire width. With such large changes imminent, an understanding of the surface processes operating prior to (potential) collapse will be of importance in understanding the extent to which surface melt affects the stability of this ice tongue.

TOPOGRAPHICAL EFFECTS ON THE GLACIER ACCUMULATION AREA RATIO (AAR) FOR DERIVING PALEOSNOWLINES

Chinn, T.J.

Alpine Holidays Inc, Lake Hawea.

This study is founded on the availability of a unique dataset, some 30 years of data from the 50 'index' glaciers distributed throughout the New Zealand Southern Alps, that permits empirical assessments to be made on the relationship between glacier shape and its accumulation area ratio (AAR) value. This ratio of the accumulation area to the area of the entire glacier has a universally accepted average of 2:1. This dataset has also provided a precise value for the long term ELA for each of the glaciers, which is essential for determining the equilibrium AAR. Here, the inverse of the question "what controls the ELA" was taken. Rather than ask what is it that controls the (climatically set) ELA? the problem was perceived in relation to ice delivery through the ELA followed by the rate of ice removal from below the ELA. The problem then becomes "how does a glacier fit its shape to the given long-term average 'snowline' to maintain its equilibrium size with this given ELA. This approach provides a useful philosophy for identifying features that determine the equilibrium AAR. A contour map, a longitudinal gradient profile plus a table of essential characteristics was constructed for each of the studied glaciers, and the information perused for likely common features. The following topographic categories associated with the AAR values soon emerged:

<u>Catergory</u> [1] HIGH AAR values (> 0.70) were associated with;
- Diverging flow
- Steepening (convex) front
- Steep & planar gradient

<u>Catergory</u> [2] NORMAL AAR (0.63 – 0.69)
- Normal gradient & flow
- Parallel flow

<u>Catergory</u> [3] LOW AAR, (AAR > 0.60)
- Flattening tongue
- Steep & concave profile.

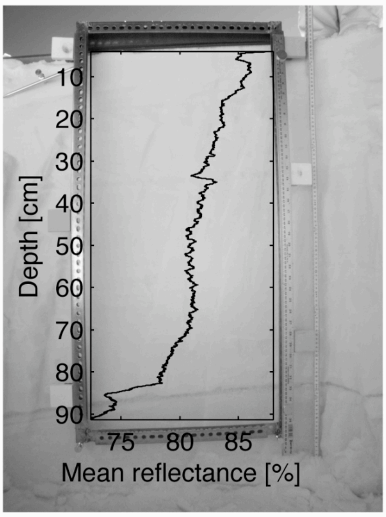
Of the few simple configurations drove the AAR values, the most significant are the surface gradients below the ELA, and any divergence of ice flow. Intuitively it was expected that a steep avalanching headwalls, or wide compared to narrow glaciers would have the greatest effect. In fact it was found that downward redistribution of mass on steep glaciers by avalanches did drag the ELA downward, and that diverging flow had a similar dramatic effect on shrinking the ablation zone. The most surprising and common effect was that a flattening tongue drives a high ELA. Surprisingly parallel flow as is common in ice aprons, did not change the AAR. This apparent anomaly must arise from some mutually compensating effects.

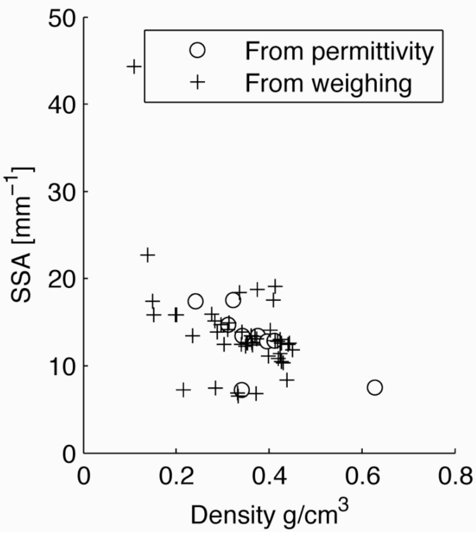
CORRECTING FOR UNEVEN ILLUMINATION IN NEAR-INFRARED IMAGES OF SNOW LAYERS IN A DRY SNOW ZONE, ROSS ISLAND, ANTARCTICA

Clavano, W. R.[1,2], Sharp, M.[1], and Rack, W.[2]

[1] Arctic and Alpine Research Group, University of Alberta, Edmonton, Canada
[2] Gateway Antarctica, University of Canterbury, Christchurch, New Zealand

Ground-based radar measurements can be used to relate spaceborne altimeter signals to sub-surface snow properties, especially in areas that are not flat relative to a satellite footprint. Validating these requires stratigraphic analysis or permittivity profiles by coring and/or digging snowpits. Collecting images of snowpit walls using an off-the-shelf digital SLR camera leaves samples undisturbed--allowing the sampling of even very loose snow, uses simple, inexpensive and unrestricted equipment, while recording spatial variability at the centimeter scale that is appropriate for snow radar frequencies. Near-infrared wavelengths (850-1000nm) are sensitive to the specific surface area of snow that others investigators have related to snow density and thus permittivity, of which contrast forms radar signals. However, relying on only natural light, uneven illumination of a scene is unavoidable and a correction is necessary to convert reflectances to density. Capturing the illumination variation for it to be removed from the scene can be done more accurately by using a rigid and flat diffuse gray board. Shown is an image taken in the dry snow zone on Mt. Erebus in Antarctica (77°40.56'S,167°11.22'E) with mean reflectances along each (horizontal) row down the profile. Comparisons with weighed samples for density and permittivity using a snowfork have been made.





Acknowledgments. Antarctica New Zealand, SCAR Fellowship, the Alfred Wegener Institute, and Christian Haas.

THE HILLOCKS: "KAME FIELDS" OR ROCK AVALANCHE?

Davies, T. and McColl, S.T.

Geological Sciences, University of Canterbury

The Hillocks is a well-known feature of the Dart Valley near Glenorhy; it is noted as a glacial deposit of scientific interest. A number of its characteristics, however, suggest that it may not be glacial in origin:

- In plan, the Hillocks are predominately arranged in lines radiating from a point on the western foot of the valley slope;
- They decrease n size with distance from the proposed origin;
- They comprise of angular clats of Caples terrane lithology, rather than being of mixed lithogies;
- High on the valley wall above the radial centre of the Hillocks is a large, deep-seated slope failure scar with a fault trace defining its headwall.

We suggest that these indicate the possibility of a coseismic rock avalance origin for this feature. We are investigating this further, including dating the deposit.

Fig. 35. 'The Hillocks' near the Dart bridge are a kame field that formed when the glacier extended down to this point. Wind blown dust (loess) has been deposited on them, softening their outlines. The milky colour of the Dart River is due to the rock flour in the water.
Photo: D. L. Homer, N.Z. Geological Survey.

USING GLACIER MODELS TO RECONSTRUCT CLIMATE CHANGE OVER THE LAST 13,000 YEARS

Doughty, A.[1], Mackintosh, A.[1], Anderson, B.[1], Putnam, A.[2], Kaplan, M.[3], Denton, G.[2], Schaefer, J.[3], Barrell, D.[4], Andersen, B.[5], and Kees, L.[1]

[1]Victoria University of Wellington
[2]University of Maine, U.S.A.
[3]Lamont-Doherty Earth Observatory, New York, U.S.A.
[4]GNS-Dunedin
[5]University of Oslo, Norway

New Zealand paleoclimate records of the past 13,000 years span a wide range of proxy records, each of which responds to a specific season and climatic component. Moraines afford the opportunity to date the age of their deposition and map past extents of a glacier front. Paleoclimate reconstructions of moraine chronologies are typically represented in Equilibrium Line Altitude (ELA) fluctuations, which are then converted to temperature changes. Rother and Schulmeister (2006) report not only the importance of precipitation in glacier mass balance, but that increased accumulation can be the sole cause of glacier advances in high precipitation regions. I will evaluate the effects the two variables, precipitation and temperature, have on glacier fluctuations using a combination of empirical field evidence and numerical modelling from several sites in the Southern Alps of New Zealand. With a combination of (a) the results of these sensitivity tests, (b) the available high-resolution moraine chronologies, (c) moraine sequence positions, and (d) further numerical modelling, I will attempt to interpret Holocene and Late Glacial climate in the Arrowsmith and Ben Ohau ranges. This unique combination of data and interpretation will allow us to constrain an envelope of possible climatic conditions necessary for the glacier to advance and stabilise at specified lengths. Because the moraines are dated, these climatic conditions can then be linked to specific times, allowing for comparisons with other regional climate proxy records, such as tree ring, pollen, choronomid, and sea surface temperature records.

Oblique aerial photograph (by T. Chinn) of the Cameron Glacier and associated Holocene moraines, Arrowsmith Range, New Zealand.

DEBRIS ENTRAINMENT PROCESSES IN PROCESSES IN SVALBARD VALLEY GLACIERS

Fitzsimons, S.[1] and Hambrey, M.[2]

1. Department of Geography, University of Otago, New Zealand
2. Centre for Glaciology, Aberystwyth University, United Kingdom

The principal objectives of this paper are to understand the processes of debris entrainment and transfer in polythermal glaciers. Ground-penetrating radar was used to map the internal structure of the terminal regions of Austre Brøggerbreen and Austre Lovénbreen by means of a series of closely spaced radar profiles. GPR data were collected using a PulseEKKO pro system, using 100 MHz antennae used in a parallel broadside configuration. Some 20 lines were surveyed ranging in length from 30 m to over 300 m, both longitudinally to define surface transverse features, and transversely across medial moraines to determine whether folding was evident. Some lines were taken also to investigate the location of englacial and subglacial conduits, which have bearing on the thermal interpretation of each glacier. Based on field data acquired, and limited laboratory analyses, we conclude that in the upper area of the glaciers debris-entrainment is controlled by folding of ice to form medial moraines, and that in the terminus area by the formation and propagation of thrusts which transport fine basal sediment to the glacier surface. We conclude that the relationship between debris and ice structures (stratification, foliation and fracturing) is the key to understanding the manner in which debris is transferred through glaciers and that these structures are directly related to the formation of proglacial landforms. In addition comparison of the predominant structures mapped in these polythermal glaciers with structures in cold-based glaciers suggests that debris entrainment processes are strongly controlled by thermal conditions at the glacier bed.

CURRENT & FUTURE SEASONAL SNOW IN NEW ZEALAND: AN UPDATE ON THE MONITORING AND MODELLING

Hendrikx, J. [1], Clark M. [1], Hreinsson E.[1], Kerr, T.[1], Poyck, S. [1], Harper, A[1], Tait A[2], Woods R[1] and Mullan B[2].

[1] National Institute of Water and Atmospheric Research (NIWA), Christchurch, New Zealand
[2] National Institute of Water and Atmospheric Research (NIWA), Wellington, New Zealand

Seasonal snow directly affects New Zealand's economy through the energy, agriculture and tourism sectors. The lack of systematic historical snow observations in New Zealand means that information on interannual variability, trends and projections of seasonal snow must be generated using simulation models. This paper will present the progress to date on the three key tiers of our work; monitoring, process understanding and modelling.

In 2006 NIWA started the development of National Snow and Ice Monitoring Network to address the deficiency in the national climate network elevation coverage and add snow monitoring capabilities. We present the status of the current network, discuss site selection, show example data, and discuss the final development phase. Process understanding has focused on the assessment of spatial variability at multiple scales and using innovative automated camera technology to examine accumulation and melt processes. A synthesis of results from these works will be presented. Modelling work has focused on the development and validation of a robust snow model. Historical snow data and water balance approach has been used to calibrate and validate the model. Using this model, which captures the gross features of snow under the current climate, we assess the likely affects of climate change on seasonal snow in New Zealand using down-scaled climate change scenarios for the 2040s and 2090s. The results of this work are consistent with our understanding of snow processes, indicating that at nearly all elevations, the 2040s and 2090s scenarios result in a decrease in snow as described by all of our summary statistics; snow duration, percentage of precipitation that is snow, and mean maximum snow accumulation in each year.

ICE DYNAMICS OF GLACIERS IN THE WESTERN ROSS SEA REGION DERIVED BY SATELLITE IMAGERY

Herbert, J. and Rack, W.

Gateway Antarctica, University of Canterbury, Private Bag 4800, Christchurch
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A fascinating glaciological feature of Antarctica are fast flowing glaciers which transport the accumulated snow and ice from the interior of the continent like conveyor belts to the sea. Measuring the ice discharge of these glaciers and understanding their flow variability is equally important in order to quantify and predict sea level change as a consequence of a changing climate. My summer project focuses on glaciers in the Transantarctic mountains and Ross Island which flow with significantly different velocity into the western Ross Sea developing characteristic glacier tongues. Examples are the Erebus glacier tongue and the Drygalski glacier tongue. I use an interferometric method for repeat pass SAR (Synthetic Aperture Radar) images, and a feature tracking method for radar and high resolution optical image data. This allows to measure the ice dynamics of the glacier – ice tongue system and to detect a possible temporal variability in the ice flow. Radar interferometry uses repeat pass satellite data and measures not only horizontal displacement, but also vertical displacement and topography. Topography needs to be subtracted from the interferogram in order to obtain ice displacement using a Digital Elevation Model (DEM). The DEM can be derived either by differential SAR interferometry or, more easy, could come from an already existing DEM. The vertical displacement seen in the interferogram can be used to estimate the location of the grounding line, where the glacier starts to float on the sea. I will present results on glacier flow from SAR interferometry and feature tracking and estimations on ice discharge across the grounding line.

MOUNTAIN GLACIER VELOCITY VARIATION DURING A RETREAT-ADVANCE CYCLE QUANTIFIED USING HIGH-PRECISION ANALYSIS OF ASTER IMAGES

Herman, F.[1], Anderson, B.[2] , Leprince, S.[3]

[1]Geological Institute, Earth Sciences Department, ETH Zurich
[2]Antarctic Research Center, Victoria University of Wellington
[3]Geological and Planetary Science division, California Institute of Technology

Analysis of optical satellite imagery (ASTER) has revealed the contrasting response of mountain glaciers to similar climatic forcing. High-resolution and near-complete coverage of ice velocities in the central part of the Southern Alps, New Zealand, has been obtained from feature tracking using repeat imagery in 2002 and 2006. Precise orthorectification, co-registration and correlation is carried out using the freely available software COSI-Corr. This analysis, combined with short time windows, has enabled velocities to be captured even in the accumulation areas, where velocities are lowest and surface features ephemeral. The results indicate large dynamic changes in some glaciers have occurred between 2002 and 2006. The steep and more responsive Fox and Franz Josef Glaciers increased speed by factors of as much as three during the period, while the low-angled and debris covered Tasman Glacier showed no measurable velocity change. Velocity increases on the steeper glaciers are the result of an observed thickening and steepening of the glacier tongues as the glaciers moved from a retreat phase in 2002 to an advance phase in 2006. This contrasting behavior is consistent with observed terminus position changes. The steeper glaciers have undergone several advance/retreat cycles during the period of observation (1894 - present) while the low-angled glaciers showed little terminus response until retreat resulting from the accelerating growth of a pro-glacial lake in 1983.

ASSESSMENT OF A SNOW STORAGE GRADIENT ACROSS A MARITIME MOUNTAIN ENVIRONMENT; A GPR INVESTIGATION

Kees, L[1]., Anderson, B[1]., Mackintosh, A[1].

[1]Antarctic Research Centre; Victoria University of Wellington

Seasonal snow is a sensitive indicator of the current climatic state, and of high economic value. Despite its importance, there is a limited knowledge of snow distribution in mountainous environments, especially in New Zealand where accumulation rates are very high and access is difficult. This study sets out to assess seasonal and perennial snow volumes and distribution at high elevation within the Southern Alps in the neve of the Franz Josef Glacier, Annette Plateau and Jollie Valley. Standard Ground Penetrating Radar (GPR) methodology was tested in deep maritime snow packs, and modified to increase the efficiency of radar wave speed calculation and data collection using 500 mHz frequency antennae. Snow accumulation was measured in a north-west to south-east orientation in keeping with the prevailing atmospheric flow and orographic gradient experienced in this region. Presented are the results of the accumulation season of April to October 2009. These results allow a trans-alpine snow storage gradient and effective precipitation index to be derived from climate station data. Applications of this new scheme for estimating snow pack data will be discussed within the context of water resource usage.

SPATIAL VARIABILITY OF SNOW IN A MOUNTAIN CATCHMENT DERIVED FROM OBLIQUE DIGITAL IMAGERY

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Daily snow cover observations, in combination with a snow melt energy model has enabled the estimation of the spatial distribution of snow mass in a steep alpine catchment at a 30 m grid scale. The resulting distribution shows a relationship to slope in that above a critical angle, slopes have less or no snow. This observation is linked to the physical process of sloughing and avalanching, and the angle of repose of snow. Ignoring steep slopes at the sub-grid level in a snow-melt model leads to an overestimation of melt at the beginning of the melt season, and a premature end to the snow melt season. The significance of this effect is related to the proportion of a region that is greater than the critical slope, and the relative hydrological importance of the complex terrain to the required model output.

PROCESSING OF GROUND PENETRATING RADAR DATA OF ANTARCTIC SNOW

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In snow and ice, internal layers are created by changes in the ambient conditions at the time of deposition, and represent contrasts in density, electrical conductivity, and ice crystal orientation. By identifying and tracing internal layers in ground penetrating radar (GPR) measurements of the Antarctic snow cover, these layers can be used to measure snow accumulation over time. This is particularly relevant for determining the Antarctic mass balance, as the areal coverage can be greatly expanded from the common, but potentially unrepresentative, point measurements from firn-cores, snow pits, or stake farms. However, the processing and interpretation of the GPR information on internal layers is far from trivial and different approaches have been used, giving varying results (e.g., Sinisalo *et al*., 2003; Arcone *et al*., 2004; Dunse *et al*., 2008). This presentation compares several methodologies for radar processing, including frequency filters, deconvolution in the Fourier domain, and frequency analysis using the S-transform (Stockwell *et al*., 1996). The utility of the different approaches for identification and tracking of internal layers in snow is discussed and illustrated with high-resolution GPR data acquired at three research sites in the vicinity of Scott Base (Antarctica), each site being characterised by different snow and surface properties.

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ANTARCTIC LANDFAST SEA ICE: THE ROLE OF ICE SHELF-OCEAN INTERACTION

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Much of the coastline of Antarctica is bounded by ice shelves, which influence the coastal sea ice by processes occurring in the ocean cavity at their base. Theoretical studies estimate that basal meltwater may contribute as much as 0.2 m to the sea ice thickness over significant portions of the sea ice cover. In particular supercooled water, formed as a result of interaction with the ice shelf, acts as a heat sink in which ice crystals can nucleate and grow. These crystals, called frazil or platelet ice, accumulate in loose, porous layers beneath the ice cover, and become incorporated into the fabric of the sea ice cover. They are most abundant when the ocean is at its coldest, from May onwards. We have therefore investigated these processes in McMurdo Sound in the austral winters of 2003 and 2009. During each 8-month experiment, simultaneous observations were made of the growth of the land-fast sea ice and the conditions in the ocean beneath. This talk will examine some of the similarities and differences between these experiments, following the progress of the cooling of the ocean, its evident interaction with the ice shelf and the effect that this has on the growing sea ice cover.

MASS BALANCE-CLIMATE RELATIONSHIPS FOR NEW ZEALAND'S INDEX GLACIERS: A STATISTICAL MODELLING APPROACH

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The relationship between glacier mass balance and climate at various scales is one of the key linkages in the earth-atmosphere system. Understanding statistical relationships between glacier mass balance and climate parameters at individual glacier scale can assist with evaluation of the likely regional impact of climate change.

The overall aim of this paper is to determine which climate parameters, and at which time scales, control the mass balance of New Zealand's glaciers. In order to explore this issue, we use the proxy record of mass balance derived from end-of-summer-snowline monitoring for a representative and geographically spread sub-sample of 18 of the 47 index glaciers, and climate data from 5 low-elevation climate stations in and around the Southern Alps. We construct a local glacier climate for each glacier by lapsing the low elevation temperature and precipitation measurements from an appropriate station to the glacier elevation.

Results of bivariate regression modeling indicate that variation in mean annual temperature alone can explain up to 39% of the variation in annual mass balance as inferred from the proxy mass balance data. This single variable has a statistically significant explanatory role for 15 glaciers. Total annual precipitation is only weakly related to annual mass balance at most glaciers, with significant explanatory power for only 2 glaciers. Backwards elimination multiple linear regression modeling indicates that at a seasonal scale, the variable with the greatest explanatory power for annual mass balance at 14 glaciers is summer temperature. Winter temperature is the most important variable at 2 glaciers, and winter precipitation at 1 glacier.

This analysis indicates that sub-annual climate data are the most useful predictors of the annual mass balance of the sub-sample of New Zealand's glaciers, and that summer temperature in particular has the greatest explanatory power.

THE ANTARCTIC CONTRIBUTION TO HOLOCENE SEA LEVEL RISE: EVIDENCE FROM COSMOGENIC EXPOSURE DATING

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The eustatic sea level curve since the Last Glacial Maximum is characterised by a rapid rise until 7 ka, with a much slower rise since that time. Most of the Pleistocene ice sheets of the Northern Hemisphere had completely melted by 7 ka, including major alpine glacier systems. Continued melting of alpine glaciers and the Antarctic and Greenland ice sheets is assumed to be the source of the sea level rise that occurred over the past 7 ka. Eustatic sea level appears to have increased by 3-5 m since 7 ka (Fleming *et al*., 1998), but there are few constraints on the sources of this meltwater. We present cosmogenic exposure ages for a transect of glacial erratics at Vestfold Hills, on the coastal margin of the East Antarctic ice sheet. These results show that the ice sheet margin continued to retreat at a very slow rate after 7 ka, in the absence of temperature or sea level forcing. If we were to assume a similar retreat history for the entire coastal margin of the East Antarctic ice sheet, this retreat will have contributed less than 1 % of the 3-5 m of post-7 ka sea level rise. This leaves Greenland and West Antarctica as possible sources of the missing meltwater.

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THE INFLUENCE OF ICE ROUGHNESS ON MELTING AND FREEZING AT THE ICE-OCEAN INTERFACE: A LABORATORY STUDY

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Rapid thinning observed on a number of Antarctic ice-shelves can be explained primarily by variation in the transfer of mass at the ice-ocean interface. Calculating the controls on this mass transfer is the key to predicting the future behaviour of these ice-shelves. The remote boundary where the cryosphere interacts with the ocean is poorly understood, but recent ice-shelf cavity investigations suggest that sub-ice shelf surfaces may be much rougher than previously assumed. The importance of roughness at scales of around 50mm is measured by combining laboratory experiments and numerical modelling to calculate melting and freezing rates at temperatures and salinities typical of ice-shelf cavities. The results indicate that roughness strongly influences both water circulation at small-scales and melting and freezing, with rough ice in certain configurations producing over twice as much melting as that observed for smooth ice. The effect of roughness is particularly great at low temperatures. Melting is shown to peak at a threshold roughness with very jagged ice inducing more freezing. These results highlight the need for further research into ice shelf topography and refinement of ice roughness parameters in ice shelf cavity models.

NUMERICAL AND EXPERIMENTAL STUDY OF OCEAN WAVE SCATTERING BY A SET OF CIRCULAR ICE FLOES

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A three-dimensional model of water-wave scattering by a collection of compliant floating bodies has been devised, which will provide the basis of the numerical component of a project looking at the propagation of waves through a field of ice floes. The work will supplement wave-tank experiments scheduled to take place later this year. The model considers regular waves of small-amplitude, incident on a set of floating circular elastic plates resting on water of finite depth. The problem is solved by combining the scattering response of a single circular floe and an interaction theory that relates the diffraction processes occurring around each floe. This work is intended to be validated by a laboratory experimental study. A short presentation of the facilities and of the experimental process will be given, as well as preliminary results of the numerical model.

IMAGING ANTARCTIC SNOW – ANALYSIS OF SNOW RADAR DATA FROM ROSS ISLAND

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The knowledge on Antarctica's ice sheet mass balance is critical in climate change research to evaluate the amount of projected sea level rise. The mass balance is the sum of snow accumulation onto the ice sheets in the interior of the Antarctic continent and the export through ice discharge at the continental margins. CryoSat 2, a new satellite to be launched in February 2010, will help determine changes in the Antarctic mass balance more accurately, by continuous measurement of surface elevation over the whole continent. This is achieved by radar surface altimetry. In order to validate the satellite instrument, fieldwork was conducted in the Ross Island region, Antarctica, to determine how surface accumulation is related to the internal structure of snow. A ground penetrating radar (GPR) system was dragged along grid lines in order to obtain an accurate representation of the subsurface, since this will potentially also effect the satellite radar signal. The GPR data, commonly used for geological purposes, can also be used to determine subsurface snow properties by identifying and tracking individual layers in the radargrams. The results can then be used with coincident layer information from snow pits and ice cores, to characterise the identified layers more accurately. We will present initial results from one of the three test sites, with particular focus on snow properties and annual accumulation as determined from snow pits, firn cores and the radargrams.

MODELLING QUATERNARY GLACIER EXTENT AND CLIMATE IN TASMANIA, AUSTRALIA

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The aim of this study is to improve our understanding Quaternary glaciations in Tasmania and in particular to assess the climatic significance of glacier advances. Tasmania is known to have experienced Quaternary ice cap development in the West Coast Ranges and Central Plateau, with smaller cirque and valley glaciers on surrounding mountains. Geomorphic evidence suggests at least 4 discrete glacial advances occurred. With the purpose of investigating glacio-climatic linkages, a 500 m resolution, three-dimensional thermomechanical ice-sheet model is used to reconstruct and simulate these glacier fluctuations. The model, while a simplification of reality provides a powerful framework in which ice dynamics are allowed to freely interact and evolve over time. Input specifications of basal topography, temperature and precipitation are required, with the latter two interpolated from present-day datasets. Numerous experiments involving a number of model configurations were carried out, involving systematic alterations to both temperature and precipitation values, as well as basal sliding and lapse-rate values. Modelled output was then quantitatively compared to empirical evidence with the aim of identifying the optimised parameter space in which model mismatch was minimized. Initial results suggest a minimum annual temperature depression of 7°C is required in order to generate ice growth in Tasmania. More specifically, Last Glacial Maximum (LGM) reconstructions require a temperature depression of 8°C as well as steep westward and southward gradients imposed on the present-day precipitation regime. Earlier glacial advances necessitate temperature depressions of at least 8.5-9.5°C. Mismatch between geomorphic and modelled reconstructions is interpreted as a result of local climatic factors, such as slope aspect and wind-blown snow redistribution not accommodated by the model. However, despite the limitations, preliminary modelled output compares well to multi-proxy palaeo-temperature reconstructions from Tasmania, although the amount of cooling identified is greater than that identified from nearby ocean cores.

MEASUREMENTS OF ICE SHELF THICKNESS AND MORPHOLOGY USING HELICOPTER-BORNE ELECTROMAGNETIC INDUCTION MEASUREMENTS

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Ice Shelves, interacting with both the ocean and the atmosphere, are a sensitive indicator for a changing environment. The repeated observation of ice shelf thickness as a result of surface and bottom mass balance and ice shelf dynamics yields insight in this sensitive balance. Ice thickness is normally measured by ice penetrating radar, or derived from freeboard height using knowledge about ice density and sea level height. The use of seismics is limited to small scale studies. In general, melting at the underside of the ice shelf is expected to be highest near the grounding line, and rising and outflow of diluted undercooled water may result in bottom freezing. However, in the presence of saline ice at the ice shelf bottom the use of radar for ice thickness measurements is limited, as the radar energy is effectively absorbed. In November 2009 we conducted helicopter-borne electromagnetic induction measurements in the McMurdo Sound to measure sea ice and ice shelf. The instrument used was a "EM bird", which is more frequently used in the Arctic to map sea ice thickness. Ice thickness could be detected to about 50 m, with a strong longitudinal gradient and significant undulations parallel to the ice shelf front. The laser profiler on the EM bird yielded information on freeboard height, which is used together with total ice thickness to derive information on ice shelf density. In this contribution we discuss our initial findings of the first EM bird measurement over an Antarctic ice shelf, which indicate promising results to detect total ice shelf thickness and ice shelf morphology.

Preparing the EM bird at Scott Base for a measurement flight over the McMurdo Sound

UTILISING OPTICAL SATELLITE IMAGERY TO DERIVE MULTI-TEMPORAL FLOW FIELDS FOR THE TASMAN GLACIER

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Recent advances in remote sensing technologies, and the techniques used to process and analyse remotely sensed imagery have made data obtained from space-borne sensors increasingly useful for glaciological studies. This has been widely demonstrated through the instigation of the Global Land Ice Measurements from Space (GLIMS) program. The primary focus of GLIMS has been to map and monitor the change in the areal extent of glaciers worldwide, in order to assess their response to climate change. Additional work has seen the development of computer software, which is capable of tracking the movement of features on the surface of glaciers between successive remotely sensed images. Digital and manual versions of this method have been widely applied to glaciers, and have proven to be an effective and efficient means of determining the distribution of velocity vectors across the surface of a glacier. This distribution is known as the glaciers flow field, and provides a powerful dataset for investigating glacier dynamics. Some of this work has been carried out for the Tasman Glacier. These studies have, however, utilized small data sets, covering only a few years at a time. This study applies digital image matching techniques to a series of remotely sensed images obtained by the ASTER and Landsat sensors, allowing derivation of a set of multi-temporal flow fields covering the period 2000 – 2010. Flowfield derivation will provide a comprehensive data set, previously unavailable for the Tasman Glacier. The dynamic response of the Tasman Glacier to a changing climate can subsequently be assessed, further strengthening predictions of the future behaviour of this glacier. Additionally, this study will feature a coincident field campaign of GPS measurements made on the glacier surface during 2009/2010 allowing for a rigorous accuracy assessment of the ASTER derived flow fields.

GPR SURVEYS ON THE MT. COOK (1991) AND BEATRICE (2004) ROCK AVALANCHES AND THE EFFECT OF ROCK AVALANCHES ON GLACIER BEHAVIOUR IN THE SOUTHERN ALPS OF NEW ZEALAND

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Rock avalanches, or catastrophic rock slope failures, are high-magnitude (>1 x 10^6 m^3) and extremely rapid (>25 ms^{-1}) mass movements. Emplacement of rock avalanche deposits onto a glacier can modify glacier mass balance (e.g. McSaveney, 1975; Post, 1986; Hewitt, 2009) and can contribute to moraine formation (Shulmeister et al., 2009). In order to investigate (1) the current thickness of the rock avalanche deposit, (2) changes in ablation under the avalanche debris cover and (3) the interaction of the rock avalanche deposit on ice with clear ice, Ground Penetrating Radar (GPR) surveys were carried out on rock avalanche deposits on the Tasman and Hooker Glaciers, Southern Alps of New Zealand. The Mt. Cook rock avalanche deposit cover is up to 10 m in thickness and has caused a 25 m high ridge to form at the upstream edge of the deposit. The recent and smaller Mt. Beatrice rock avalanche on Hooker Glacier has formed an elevated plateau with raised edges because of reduced ice melting, while its platform has been modified by underlying ice flow. Similar patterns are observed on other glaciers, where the rock avalanche deposit typically forms a platform up to 30 m above surrounding ice surfaces due to significantly reduced ablation over time (e.g. Netland and Sherman Glaciers, Alaska). The latest findings will be presented.

HYDROLOGY AND HYDROCHEMISTRY OF A HIGH ARCTIC GLACIER: LONGYEARBREEN , SVALBARD

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Presented are the results of a detailed study of the hydrology and hydrochemistry of Longyearbreen, a small High Arctic glacier on Svalbard. The glacier is thought to be entirely cold-based and drainage of meltwater is predominantly by stable, deeply incised supraglacial channels, which become englacial and eventually subglacial towards the debris-covered front. Fieldwork was carried out in the summer of 2004 and comprised a detailed provenance study as well as sampling of glacial meltwater for oxygen isotope, solute and suspended sediment analyses. Discharge was measured continuously throughout the ablation season (May to September) and conductivity measurements and water samples were collected manually at daily maximum and minimum discharge during most of the period. The ablation season was divided into three periods based on drainage dynamics and solute provenances: 1) the early melt season, where water originates predominantly from snowmelt; 2) the peak flow period, characterised by large discharge fluctuations caused by a collapse of the remaining snow cover, increasing ice ablation and wet precipitation events; and finally 3) the late melt season, where snow melt was limited and a fully developed drainage system resulted in clear diurnal variations in discharge and solute concentrations. Runoff in the three periods comprised 1.7%, 89.7% and 8.6% respectively, while solute flux distribution was 1.9%, 82.1% and 16.0% respectively, signifying the importance of the late melt season in glacial solute flux studies.

OVERALL TRENDS AND VARIATION IN ICE VOLUME IN THE SOUTHERN ALPS 1976-2008

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New Zealand has a long and continuing record of annual end-of-summer-snowline (EOSS) measurements for a set of 46 index glaciers of the Southern Alps from 1977 to present. Two methods are used to determine changes in glacier mass since 1977 one using mass balance gradient, and the other using topographic changes. The present sizes and distribution of the NZ glaciers is the product of a century of accelerating recession, recently halted by a three-decade period of near zero average mass balance.. Since 1977 there has been little size change. The effect of this switch from recession to a stable equilibrium has been fortuitous as (1) those glaciers with long response times have continued to retreat while (2) those that respond quickly to climate have remained near the same size. Circulation, temperature and precipitation control the mass balance of this group. The overall results show a significant decrease in ice volume of the Southern Alps from 1976-2008, despite only a small negative mass balance averaged over this period. Ice volume over the monitoring period, as derived from $EOSS_{Alps}$ and estimates of mass balance, shows a modest cumulative change, with a loss from this source of around 10% from an estimated starting total volume of 54.60 km^3. The bulk of the ice volume loss comes from calving into pro-glacial lakes and tongue down wasting of 12 large glaciers. The overall rate equates to rate of loss of -0.2 km^3/a, which is probably slower than earlier in the 20th century. The rate of ice loss between the 19th century and 1977 is estimated at between -0.5 km^3/a and -0.8 km^3/a.

TRACING PRECIPITATION PATHWAYS TO ANTARCTIC ICE CORE SITES BY INTEGRATING WEATHER STATION AND REANALYSIS DATASETS

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Snow depth and meteorological data from November 2007–October 2008 from two ice core sites (Skinner Saddle and Evans Piedmont Glacier) in the Ross Sea region, Antarctica, are analysed to elucidate the controls on moisture delivery to both locations. The storm tracks associated with each major accumulation event at both sites are produced from daily back-trajectories generated from reanalysis data. Cluster analysis of these trajectories reveals that the highest frequency of accumulation days at both sites are associated with south-easterly air flow, but that high-accumulation days tend to result from fast-moving air masses with strong upper-level cyclonic vorticity. Over the study period, Evans Piedmont Glacier received most precipitation from these events, which are associated with the incursion of synoptic-scale cyclonic systems and marine moisture across the margin of the Ross Ice Shelf. Skinner Saddle also received snow from these synoptic-scale systems, but a large proportion of annual snowfall at this site was also derived from short-duration events that appear to be the result of mesocyclone development over the southern Ross Ice Shelf. The frequency and seasonal distribution of both of these mechanisms of precipitation delivery will have a marked impact on annual accumulation totals over time and consequently the interpretation of ice core records from these sites.

SEA ICE THICKNESSES: MEASUREMENT TECHNIQUES USED IN THE FIELD

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The thickness of a sea ice cover is an important parameter in determining the response of sea ice to climate change. Despite this importance, efforts to measure sea ice thicknesses remotely have met with ongoing challenges. Manually drilling or coring are traditional sea ice thickness measurement techniques that are used, particularly on land-fast ice. In the pack ice, techniques that rely on ship-based observers have also been used. On land-fast sea ice, longer-term monitoring is sometimes possible, such as the deployment of vertical strings of thermistors, frozen through the sea ice, to estimate the evolution of the position of the ice-water interface. A key limitation of the use of thermistor strings is that they can only be deployed at a limited number of sites, restricting the geographical range of the resulting data. Methods for inferring the time-development of sea ice thicknesses retrospectively are still being developed and refined. Predicting sea ice thickness evolution with time, can be attempted with the use of existing models, but such models are empirical, location specific, and require access to local weather data, which is often difficult or impossible to obtain. Previous researchers have suggested methods for calculating sea ice thickness evolution based on the segregation of oxygen isotopes. This talk will compare techniques for determining sea ice thickness in Antarctica by drilling, coring, thermistor arrays, and video camera recordings, along with oxygen isotope analysis of sea ice and sea water samples. Modifications to existing methods will be suggested.

PROGLACIAL LAKE GROWTH IN AORAKI/MT COOK NATIONAL PARK, EXAMINED USING REMOTELY SENSED IMAGERY

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Aoraki/Mt Cook National Park is home to some of New Zealand's most iconic glaciated landscapes. The large, debris-covered valley glaciers of the area have undergone dramatic change since the earliest glaciological observations were made in the 19th century, and historic maps and photographs record sustained ice loss from many of the glaciers throughout the 19th and 20th centuries. In recent decades proglacial lakes have formed at the termini of the Tasman, Murchison, Hooker and Mueller glaciers. Terminus retreat rates and proglacial lake growth rates quantified from ASTER and Landsat imagery reveal accelerating retreat at Tasman Glacier over the period 1990-2009, while the rate of retreat at the Murchison, Hooker and Mueller glaciers has been relatively steady.

Sequences of ASTER and Landsat imagery can be used to map and quantify change at the margins of debris-covered, proglacial lake-terminating glaciers in high mountainous settings. Such an approach represents a significant advance over point measurements made in the field. The use of satellite imagery to quantify rates of terminus retreat and proglacial lake growth at Tasman, Hooker, Mueller and Murchison glaciers has challenged the validity of reporting linear rates of change at proglacial lake margins in this setting, as are widely reported in the literature. Satellite images capture the totality of margin change over time, whereas field studies are restricted to reporting linear rates of change at point locations. The value of satellite imagery in this setting lies in its provision of holistic growth rates that quantify the sum of all lake growth processes. Furthermore, satellite imagery has the advantage of capturing both the spatial and temporal domains of change.

MODELLING OF PRECIPITATION IN THE SOUTHERN ALPS OF NEW ZEALAND

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The Southern Alps of New Zealand experience more precipitation than any other part of the country. The distribution of this precipitation influences important hydrological processes such as river flows and glaciation. However, there is still some uncertainty about the actual amount of precipitation, and its spatial distribution, over these mountains. The HadRM3P regional climate model (RCM) can be used to estimate long-term and future patterns of precipitation in New Zealand. This RCM is based on the Unified Model, which is developed by the Met Office Hadley Centre in the United Kingdom. However, the steep and rugged topography of the Southern Alps is smoothed at the RCM's horizontal resolution of ~30 km. This hinders the accurate simulation of orographic precipitation. Previous studies suggest that orographic forcing of moist air over and across the main axis of the Alps and synoptic wind direction are dominant processes governing the distribution of precipitation in the central Southern Alps. In this research, in order to quantify empirical relationships, observations of surface rainfall have been gathered from several hundred rain gauges, covering a broad region of the Southern Alps during the period from 1971 to 2000. These observations have been compared to regional atmospheric properties from NCEP global reanalyses. The mean annual profile of precipitation across several transects of the Southern Alps is categorised by different synoptic wind directions. The categorised profiles are then used to guide the interpolation and downscaling of precipitation that has been simulated by the RCM in the central Southern Alps.

THE RESULTS OF THE NIWA 2009 INDEX GLACIER SNOWLINE SURVEY

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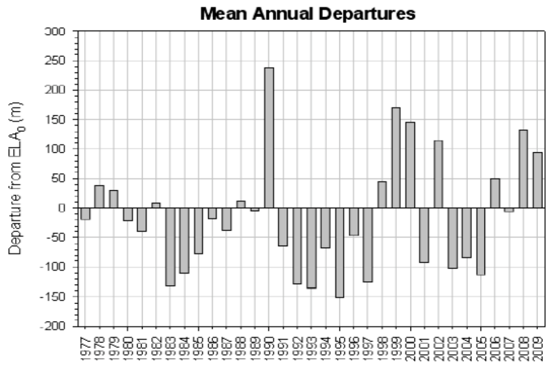
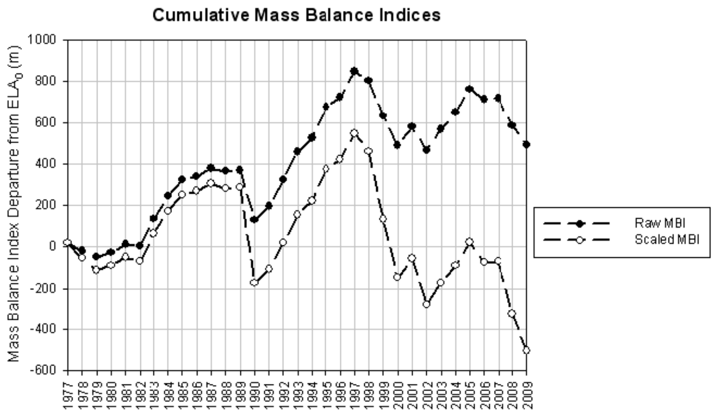
The 33rd NIWA End of Summer snow survey was completed during March 2009 with all 50 index glaciers photographed along with a selection of other glaciers that were on the flight path. Nearly all the glaciers exhibited clear snowlines at high elevations. The results indicated strong negative mass balance for the index glaciers for the 2008/09 glacier year. This is a continuation of the



negative mass balance in the 2007/2008 glacier year.

The glaciers have shown a varying trend of positive (21 years) and negative (12 years) mass balance over the monitoring period. Some of the index glaciers with well-defined permanent ice areas have lost ice during the course of the 33 year monitoring period. This mass loss has occurred during large negative mass balance years and has not been replaced after a cycle of positive mass balance years. The results of the mean annual departures have been scaled this year using published



mass balance gradient rates to derive a time series mass balance index for the Alps.

The negative ELAs in the 2008/09 season were a result of Northerly and easterly quadrant flow anomalies related to La Nina, with associated normal to above normal temperatures, except during Spring.