The 2009 New Zealand Snow and Ice Research Group (SIRG)

Annual Workshop

Albert Town, Otago, New Zealand
February 16 to 18 2009

Programme

Sponsored by:

Antarctica New Zealand

NIWA
Taihoro Nukurangi

Time	Presenter	Topic
Monday 16 February		
1200	Lunch	
1300	Jordy Hendrikx & Trevor Chinn	Welcome and introduction etc.
Session chaired by: Associate Professor Ian Owens		
1320	Jordy Hendrikx NIWA	Modelling the impact of climate change on seasonal snow in New Zealand.
1340	Heather Purdie School of Earth Sciences, VUW & Department of Geography University of Canterbury	Simultaneous measurement of snow accumulation east and west of the Southern Alps, New Zealand
1400	Ruzica Dadic ETH Zurich, Switzerland	Monitoring and modelling snow accumulation processes in glacierized alpine basins.
1420	Blair Fitzharris Department of Geography Otago University (Emeritus)	Maximum snow melt revisited
1440	Tim Kerr Department of Geography University of Canterbury & NIWA	Dual peak cross mountain precipitation peak
1500	Einar Orn Hreinsson NIWA	Assimilating snow covered area into a snow model.
1520	Afternoon tea	
Session chaired by: Professor Blair Fitzharris		
1600	Trevor Chinn Alpine & Polar Processes	The NIWA Snowline Survey Programme and the 2008 results
1620	Natalya Reznichenko Department of Geological Sciences University of Canterbury	Effects of debris-cover on glaciers ablation: Some laboratory experiments.
1640	Paul Sirota Department of Geography University of Otago	Effects of impurities and temperature on the shear strength of basal ice in polar glaciers.
1700	Simon Allen Department of Geography University of Canterbury	Probing Aoraki's Icy Cracks – Mountain permafrost distribution in the Aoraki/Mt Cook region based on rock temperature measurements
1720	Joel Thomas Department of Geography University of Canterbury	Measuring volume change of the Tasman Glacier with remote sensing (Abstract withdrawn).
1740	Discussion time	
1900	**Conference Dinner at Albert Town Tavern**	

Time	Presenter	Topic
Tuesday 17 February		
Session chaired by: Dr Nicholas Cullen		
0800	Trevor Chinn Alpine & Polar Processes	Interpretations of Glacier Fluctuations – A story of the Godley Glaciers
0820	Delia Strong Department of Geography University of Otago	Patterns and processes of ice loss at Tasman Glacier: an evaluation using historic data sources and remotely sensed imagery (Abstract withdrawn)
0820	Dorothea Strumm Department of Geography University of Otago	Brewster Glacier's mass balance modelled over three decades
0900	Andrea Barrueto Department of Geography University of Otago & U.Zurich	Accumulation on Brewster Glacier, New Zealand
0920	Sarah Gillett Department of Geography University of Otago	Modelling summer ablation on the Brewster Glacier, New Zealand.
0940	Andrew Mackintosh School of Earth Sciences, VUW	Mt Ruapehu End of Summer Snowline and mass balance trends, 1988-2007
1000	Morning Tea	
Session chaired by: Dr Trevor Chinn		
1040	Andrew Mackintosh School of Earth Sciences, Victoria University of Wellington	Last major retreat of Antarctic ice sheets forced by sea level rise and warming.
1100	Jeremy Fyke School of Earth Sciences, VUW	Simulating ice shelf stability with a climate model.
1120	Kurt Joy Department of Geological Sciences University of Canterbury	Reconstructing the East Antarctica Ice sheet margin along the Transantartic Mountains
1140	Mette Riger-Kusk Gateway Antarctica & Department of Geography University of Canterbury	Preliminary results from a study of ice dynamics of the Darwin-Hatherton glacial system, Antarctica.
1200	Christina Hulbe Portland State University & University of Otago	Discharge variability and grounding line migration in the Ross embayment of the West Antarctic Ice Sheet, observations & numerical models.
1220	Lunch	

Time	Presenter	Topic
Tuesday 17 February		
Session chaired by: Mette Riger-Kusk		
1340	Shulamit Gordon Antarctica New Zealand	Antarctic Research - How to Get New Zealand Logistics Support
1400	Shelley MacDonell Department of Geography University of Otago	The effect of sediment deposition timing on the seasonal meltwater generation variability of the Wright Lower Glacier, McMurdo Dry Valleys, Antarctica.
1420	Inga Smith Department of Physics, University of Otago	The use of oxygen isotopes to determine sea ice growth rates.
1440	Nikolai Kruetzmann Department of Physics University of Canterbury	Snow morphology and radar characteristics in the Ross Sea Region measured by ground penetrating radar
1500	Brian Anderson School of Earth Sciences, VUW	A methodology for ice core site selection
1520	Afternoon tea	
Session chaired by: Dr Andrew Mackintosh		
1600	Abha Sood NIWA	Modelling Greenland ice sheet (GIS) and atmosphere to estimate the GIS mass budget (1986-1995)
1620	Pascal Sirguey School of Surveying, University of Otago	Application of the SRM model in the Upper Waitaki
1640	Glenn Thackray Idaho State University & University of Canterbury	Influences of annual insolation, bedrock type, and avalanching on rock glacier occurrence in the Lemhi Range, Idaho, USA.
1700	Nicholas Cullen Department of Geography University of Otago	Detecting climate change of the recent past from glacier recession on Kilimanjaro.
1720	Alice Doughty School of Earth Sciences, VUW	^{10}Be Cosmogenic exposure ages of late Pleistocene moraines near the Maryburn Gap of the Pukaki Basin.
1740	Jordy Hendrikx & Trevor Chinn	Field trip outlines
1750	Discussion time	
1900	Dinner at conference lodge.	

MODELLING THE IMPACT OF CLIMATE CHANGE ON SEASONAL SNOW IN NEW ZEALAND

Hendrikx, J. [1], Clark M.[1], Hreinsson E.[1], Tait A[1],
Woods R[1], Slater A[2], and Mullan B[1]
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[2] Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO 80309, USA

Seasonal snow directly affects New Zealand's economy through the energy, agriculture and tourism sectors. In New Zealand very little is known about the long-term variability of the snow cover and the expected impacts of climate change on snow cover. 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. We present a preliminary analysis of simulations of the interannual variability of seasonal snow in New Zealand for the period 1998 - 2006 inclusive, and of snow in two future climate scenarios. The model uses an hourly time step to calculate the accumulation and ablation of the snowpack for more than 250,000 model elements in the South Island of New Zealand. 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 a down-scaled "middle of the road" (A1B) climate change scenario 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. This decrease in snow is more marked at elevations below 1000m. Relative to snow simulations for average maximum snow accumulation for the present, we observe that by the 2040s, there is a 30% reduction at 1000m, and a 10% reduction at 2000m. By the 2090s the reduction is greater, with a decrease of more than 50% at 1000m and 25% at 2000m. These results are preliminary and are based on a short, nine year simulation period and a single climate change scenario. Future work should consider additional scenarios to assess uncertainty in the climate change scenarios and consider the changes in extremes in future climates. Improved ways to estimate alpine precipitation should also be investigated.

SIMULTANEOUS MEASUREMENTS OF SNOW ACCUMULATION EAST AND WEST OF THE SOUTHERN ALPS, NEW ZEALAND

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Understanding how synoptic weather systems manifest in snow accumulation on glaciers is of increasing scientific interest, with indications that climate warming will result in changes to atmospheric circulation patterns (Mullan *et al.*, 2001; IPCC, 2007). The use of glaciers as indicators of climate change is well established, yet gaps in knowledge about processes affecting glacier mass balance, in particular, snow accumulation, still exist. Current glacier mass balance models calculate accumulation as a function of elevation, and other spatial information is not included (Oerlemans, 2001; Anderson *et al.*, 2006). Yet recent research indicates that this approach is too simplistic (Machguth *et al.*, 2006) ignoring potential effects of preferential deposition, wind re-distribution or avalanching. Different synoptic weather types could result in each of these effects having an altered prominence, and therefore have potential to create significant variability in snow accumulation on glaciers.

We measured snow accumulation simultaneously east (Tasman Glacier) and west (Franz Josef Glacier) of the Southern Alps during July/August 2008. Zonal atmospheric flow conditions marked the start and finish of the study period, while alternations between troughing and blocking regimes dominated the middle part. Comparison of daily snow accumulation (mm water equivalent) showed the Franz Josef Glacier generally received more snow. There was little difference in average snow density between the two sites, with 164 and 162 kg m^3 being recoded at Franz Josef and Tasman Glacier respectively. Both glaciers received over 75% of their total snow during troughing regimes, with Franz Josef recording 65 mm w.e. more than Tasman. Zonal regimes brought warmest temperatures, lowest humidity and lowest wind speed to both glaciers, and consequently the least snow. The largest difference in accumulation east and west of the Southern Alps occurred under blocking conditions, which saw significant snow loss (29 mm w.e.) from the Franz Josef during strong south-east winds. Total snow loss (depth) recorded at Franz Josef during the study was 54 mm w.e. compared to only 23 mm we at Tasman Glacier. Due to the exposed aspect of the Franz Josef Glacier névé, it is likely that snow is often completely removed from the accumulation area during such events. In contrast, Tasman Glacier is a confined topographic system with more turbulence-inducing surface roughness, and a greater proportion of wind drifted snow is probably retained within the névé, still contributing to the mass balance of the glacier

Selected References:

Anderson, B., Lawson, W., Owens, I. and Goodsell, B. 2006: Past and future mass balance of 'Ka Roimata o Hine Hukatere' Franz Josef Glacier, New Zealand. *Journal of Glaciology* 52, 597-607.

IPCC 2007: Summary for Policymakers. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change,* Cambridge.

Machguth, H., Eisen, O., Paul, F. and Hoelzle, M. 2006: Strong spatial variability of snow accumulation observed with helicopter-borne GPR on two adjacent Alpine glaciers. *Geophysical Research Letters* 33, 1-5.

Mullan, B., Wratt, D. and Renwick, J. 2001: Transient Model Scenarios of Climate Changes for New Zealand. *Weather and Climate* 21, 3-34.

Oerlemans, J. 2001: *Glaciers and Climate Change*. Lisse: A.A. Balkema Publishers.

MONITORING AND MODELING SNOW ACCUMULATION PROCESSES IN GLACIERIZED ALPINE BASINS

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Assessing the impact of future climate scenarios on water availability in mountain basins requires accurate estimation of water stored within the snow and ice cover and thus knowledge of the distributed snow and ice mass balance throughout the year. While many observations and models are available to describe the ablation season, the evolution of the winter snow distribution is relatively unknown, especially in complex terrain. The inhomogeneous snow distribution in Alpine terrain is the result of wind and precipitation interacting with the (snow) surface over steep topography. Physically-based, spatially distributed models of snow redistribution have been developed for flat to gently rolling terrain, but extensions of these findings to steep terrain as found in the Alps or the Himalayas have been limited by the complexity of wind fields in such areas.

In order to understand and quantify the redistribution of snow due to these mechanisms in Alpine terrain, we implemented a combination of models, which describe the wind and topography influence on snow accumulation. Existing models of energy balance, gravitational mass transport, wind fields and wind induced snow transport were linked together to describe and understand processes that govern the mass accumulation and ablation in glacierized mountain regions. The observed correlation between modeled local wind fields, measured snow depth and glacierization suggests that accurate description of wind fields over glacierized areas in steep terrain is a key factor for understanding the mass balance of glaciers. The correlation between snow accumulation and wind velocities was used for the parameterization of preferential deposition, which was based on wind speed only. It was further found that gravitational mass transport (avalanches) has a large effect on snow melt, because it can significantly reduce the snow extent area, and therefore reduce surface melt. Both processes lead to an increase in snow depth over flat glacierized areas, leading to a later exposure of ice and to reduced ice melt. The combination of models that we used lead to a better understanding of the processes that govern the snow accumulation in complex terrain, and showed that including snow accumulation processes can significantly improve glacier mass balance models.

"MAXIMUM SNOW MELT REVISITED"

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Just how big can snow melt get? This question is of importance for calculating design floods in mountain catchments, yet has received little attention in the New Zealand context. Conventional extreme-event analyses suppose that the sequence of extremes is homogeneous and all drawn from the same population. But this may not be so where extreme snowmelt is involved. Hydrometeorologic mechanisms of rain on snow events complicate analysis and estimation of large floods. A similar paper was given in November 2008 to the joint conference of the Meteorological Society of NZ and the NZ Hydrological Society. Useful feedback there has provided more information and helped to improve estimates of maximum snow melt.

Overseas researchers, particularly in Russia and North America, offer a range of methods for estimating snow melt, based on theoretical energy balance considerations and empirical parameterisations. These are applied to get approximations of extreme snow melt for typical Southern Alps situations and are compared with field measurements, mainly in Canterbury and Otago. Results indicate that snow melt can easily exceed 100 mm/d when there is input from the convective energy fluxes. This is usually associated with strong advection of warm, moist air from the subtropics. It is concluded that snowmelt can increase peak runoff by up to 30%.

DUAL PEAK CROSS MOUNTAIN PRECIPITATION PEAK

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Background
Observations in the Aoraki/Mt Cook region indicate the possibility of a dual peak cross-mountain precipitation transect. This is in contrast to the single peak transects considered more appropriate in regions to the north and south.

Aim
To identify precipitation processes that could lead to a dual peak transect in the Aoraki/Mt Cook region, and the stability of these processes under a changing climate.

Methods
A review of orographic precipitation modelling studies has been undertaken. A comparison of the conditions required for a double peak precipitation transect in the modelling studies was made against those found in the Southern Alps under current and different temperature regimes.

Results
Where the orographic barrier elevation is near to, but above the freezing level elevation, the enhanced accretion and advection of snowflakes can lead to a lee side precipitation peak in addition to the common windward peak. The Aoraki/Mt Cook region is unique in the Southern Alps in that it presents an orographic barrier above the estimated mean annual 0^{o} isotherm. Under cooler temperatures additional barrier/0^{o} isotherm combinations occur throughout the Southern Alps. Under warmer temperatures no such locations exist.

Conclusions
According to recent modelling studies, the Aoraki/Mt Cook region has the correct conditions for a dual peak cross-mountain precipitation transect. Other regions of the Southern Alps would have had appropriate conditions under a cooler climate. The loss of the second leeward peak under warming conditions leads to a step change in precipitation in those areas with implications for glacier-climate relationships and catchment hydrology.

ASSIMILATION OF SNOW COVERED AREA INTO A HYDROLOGIC MODEL

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[2]National Institute of Water and Atmospheric Research

In this study, a distributed temperature index snow model based on temperature and precipitation as forcing data, is used to estimate snow storage in the Jollie catchment approximately 20 km east of the main divide of the central Southern Alps, New Zealand. The main objective is to apply a frequently used assimilation method, the ensemble Kalman square root filter, to assimilate remotely sensed snow covered area information into the model and evaluate the impacts of this approach on simulations of snow water equivalent.

The snow cover images were given with a 250m resolution derived from Moderate Resolution Imaging Spectroradiometer (MODIS) and specifically tuned to the study site. This dataset is a product of the University of Otago, processed by Pascal Sirguey. Temperature and precipitation were given on a 0.05° latitude/longitude grid supplied by NIWA and derived from their measurement network. Precipitation was perturbed as input into the model, generating 100 ensemble members, which represent model error. Two model states were updated in the assimilation, the total snow accumulation state variable and the total snow melt state variable. As the model was not calibrated, two withholding experiments were conducted, in which observations withheld from the assimilation process were compared to the results. The assimilation method only affected simulated snow storage during the ablation period. That corresponds to higher correlation between modelled snow covered area and the updated state variables during the ablation season. The results of this study indicate that the model underestimates snow storage at the end of winter and/or does not detect snow fall events during the ablation period.

THE NIWA SNOWLINE SURVEY PROGRAMME AND THE 2008 RESULTS

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[2] NIWA, Auckland
[3] NIWA Dunedin

The "snowline" as used here is the altitude of the "end-of-summer glacier snowline" or EOSS as used in NIWA literature. This value very closely approximates the annual equilibrium line altitude (ELA). The present survey programme, which evolved from a series of annual flights made for the N.Z. glacier inventory, were initiated in 1977. The current 50 index glaciers were not chosen until the early 1980s, and with only two years of no record, the dataset now contains 13,650± photos up to 2006. From that year onward, most images have been digital. An even larger set of photos was taken for the glacier inventory (GLIN) work.

The snowlines record has four unique assets:-

[A] FROM THE INVENTORY WORK

1. A current snowline trend surface for the entire Southern Alps, resulting from the GLIN work, which serves as a datum for mass balance changes.

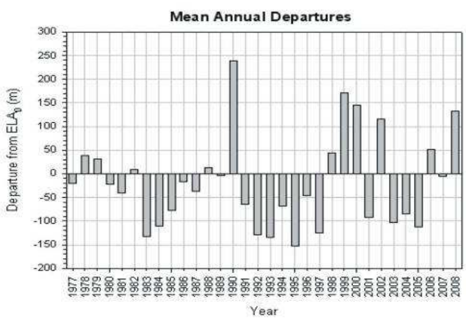
2. The mean aspect differences in snowline altitudes on 8-point compass directions, also derived from the GLIN work. This allows comparisons made between snowlines of glaciers of different aspects to be standardised, be they modern or paleoglaciers.

[B] FROM A FORTUNATE SWITCH IN CLIMATE

1. At the very start of the snowline surveys, there was a reversal in the Interdecadal Pacific Oscillation system (IPO) which halted the ubiquitous glacier wasting trend and changed to 30 years of both positive and negative mass balances with a net mass change of near zero.

2. This spread of both positive and negative mass balances has provided a means to interpolate (NOT average) the values for the long-term ELA for the index glaciers.

The processed data of the March 2008 flight has shown that the 2008 glacier year was the 4th most negative on record



Mean annual departures from the ELAo
for all glaciers for the entire period of these surveys

EFFECTS OF DEBRIS-COVER ON GLACIERS ABLATION: SOME LABORATORY EXPERIMENTS

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Glacial systems are responsive to climatic fluctuations but may also be sensitive to tectonic events. In tectonically active areas, earthquakes trigger rock avalanches onto glaciers, potentially modifying the mass balance of the glacier through reduced ablation and altered flow rates. There is a large body of literature on rates of ice ablation but taking ice ablation measurements under debris layers on glaciers is difficult and most studies infer rather than directly measure rates through estimates of conduction rates (e.g. Purdie and Fitzharris, 1999). Consequently, it was decided to hold a set of experiments in controlled laboratory conditions to examine the effect on ablation of debris thickness, debris sedimentology, day-night cycles and sensible heat flux from water percolation.

Here we present the results of some initial experiments comparing ice ablation rates on bare ice in comparison with ablation rates of buried ice under various thickness of debris-cover (1, 5, 9 and 13 cm). During these experiments controlled conditions were set up to replicate diurnal temperature and radiation cycles and rainfall conditions. Ice surface lowering on bare ice and under the cover was measured by system of strings that are ice-bound inside the ice block. Constant temperature profiles were recorded for calculation of thermal conductivity fluctuations within the debris layer. The latest results will be presented.

EFFECTS OF IMPURITIES AND TEMPERATURE ON THE SHEAR STRENGTH OF BASAL ICE IN POLAR GLACIERS

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Isotropic ice samples containing measured concentrations of solutes and debris similar to basal material in cold-based glaciers in Antarctica were manufactured and direct-shear tested for peak shear strength at constant strain rates. Tests on synthetic samples showed that differences in shear strength and rheology are related to impurity concentration. Debris-laden ice becomes weaker and more ductile with increased concentrations of solutes, whereas, high debris-concentration ice with low solute-concentrations has greater shear strength but increasingly brittle behaviour. Additionally, natural anisotropic samples containing high solute and debris concentrations were very sensitive to small temperature changes. Tests on samples between -25°C and -10°C showed approximately 10% loss in shear strength with 1°C increase in temperature during tests. Stress exponents from Glen's Flow law, $\acute{\varepsilon} = A\tau^{\eta}$, calculated for synthetic solute and debris-laden ice samples ranged between 4 and 5. Therefore, higher rates of deformation can be expected in dirty basal ice than predicted by glacial ice models using stress exponents where, $\eta = 3$. Contrasts in rheological behaviour and rates of deformation are also responsible for the development of debris-laden ice structures within cold-based glaciers flowing over unconsolidated substrates. Layered sedimentary bedding preserved in blocks within deforming basal ice suggests that each glacier has interacted with its bed and entrained portions of the substrate material. Rheological changes identified in impurity-laden ice along with measurements and structural observations acquired during fieldwork in Antarctica support the argument that cold-based glaciers flowing over beds of unconsolidated sediment are capable of erosion and causing geomorphic alteration.

PROBING AORAKI'S ICY CRACKS – MOUNTAIN PERMAFROST DISTRIBUTION IN THE AORAKI / MT COOK REGION BASED ON ROCK TEMPERTAURE MEASUREMENTS

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Background/Aims:

Permafrost (ground temperature <0ºC) is discontinuous in steep high mountain regions, and its distribution is primarily governed by air temperature and solar radiation. During recent years, scientists have become increasingly concerned with climate related degradation of mountain permafrost and related implications for bedrock stability. Despite widespread rockfalls and rock avalanches in the Southern Alps during the past 100 years, until now we have known nothing of the likely permafrost distribution, and therefore any possible links with slope instability.

Methods:

In summer 2007, a network of 15 temperature dataloggers were installed into steep bedrock faces at a range of elevations and on various slope expositions near the Main Divide, and on the Liebig Range. Mean annual ground surface temperature (MAGST) is calculated, and adjusted for temperature variations over the past 20 years to establish a local zero degree ground temperature elevation (*E*o) for each logger site. A simple linear regression relates *E*o with modelled global solar radiation for each logger site, establishing a robust relationship that can be used to model *E*o, and therefore rock temperature for any given location.

Results and Conclusions:

Initial results from the Liebig Range indicate that on shaded aspects, the permafrost limit extends down to ~2600 m, rising to ~3000 m on sunny aspects. This corresponds remarkably well with the initial estimate based on Haeberli's empirical 'rules of thumb' describing permafrost occurrence in the Swiss Alps. It is expected that increased cloud cover near the Main Divide will significantly dampen the effect of solar radiation, such that permafrost limits will be much lower on sunny aspects in this region. It is striking to note, that of the 17 rock avalanche events recorded over the past 100 years, 10 of these have occurred within 300 m of the estimated lower boundary of permafrost, where marginal, warm, degrading ice is expected within the highly fractured rock mass. Future work must consider how a changing climate and disappearance of steep hanging glaciers etc, will impact upon permafrost distribution and slope stability in this region.

MESURING VOLUME CHANGE OF THE TASMAN GLACIER WITH REMOTE SENSING

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Mountain glaciers are expected to be the greatest contributor to sea level rise over the next century. Glaciers provide a good indicator of global climate and how to monitor their change is an increasingly important issue for climate science and for sea level rise forecasts. This study explores the use of remotely sensed data for measuring volume change from 1965 to 2006. Digital photogrammetric methods were used to extract topographic data of the Tasman Glacier from aerial photography and ASTER imagery for the years 1965, 1986, 2002 and 2006. SRTM C band data from 2000 were also analysed.

Data were compared to the existing TOPODATA DEM to test for their reliability. Using regression analysis, the data were filtered and points representing rock were used to correct points on the glacier ice for vertical bias. The quality of the data extracted from the aerial photography was very good on rock and debris covered ice, but poor on snow. The data extracted from ASTER was much more reliable on snow in the upper glacier than the aerial photography, but was very poor in the lower debris covered region of the glacier. While the quality of the SRTM data is very high, there is a second order distortion present in the data that is evident over elevation differences. However, the overall mean difference of the SRTM rock from TOPODATA is close to zero.

An overall trend could be seen in the data between dates. However, the 2006 ASTER data provided unreliable results on the debris covered section of the glacier. Total volume change is therefore calculated for the period between 1965 and 2002. The data show a loss of 3.4 km3 or 0.092 km3 per year, an estimated 6% of the total ice in New Zealand.

ABSTRACT WITHDRAWN

INTERPRETATION OF GLACIER FLUCTUATIONS – A STORY OF THE GODLEY GLACIERS

Chinn T[1]
[1]Alpine & Polar Processes, Lake Hawea

The two large LIA glaciers, the Classen and Godley, of the upper Godley Valley have collapsed into 4 main glaciers, Classen, Grey, Maud and Godley, which front 3 lakes; Classen, Grey-Maud and Godley.

The substantial moraines of the **Classen Glacier** appear to be a composite of stacked neoglacial moraines finally overtopped by the late maximum LIA advance, which has spilled over older lateral ridges. All deposits lie stratified within approximately the same area, where the various ice fronts are all at similar elevations.

The **Godley Glacier** in contrast has no Neoglacial frontal moraines, the main features being high lateral trim lines which were ice filled when Haast made his visit in 1862. Recently the massive collapse of the Godley has revealed a large lateral moraine lying between the Maud and Godley Glaciers. Other overridden moraines also survive. The question is why did the Godley Glaciers reach their apparent maximum Neoglacial size as late as 1862 when other glaciers reached their LIA maxima centuries earlier?.

Hypothesis (1) is that the common sequence of decreasing size of Neoglacial events found elsewhere have been constrained into glaciers of similar sizes for each Neoglacial advance by the continual rising of the "fan head" of the Godley River outwash gravels. Aggradation associated with ongoing infilling of Lake Tekapo since the Pleistocene has elevated the base levels of the entire Godley Valley. By comparing elevations with other neoglacial elevation differences, the rate of rise of the alluvial fan head may be calculated at 11 to 14 m/century.

Hypothesis (2) is that when the first of the Neoglacial advances commenced 4915±45 radioocarbon yr BP, (a Grey Glacier date) throughout the early and mid Neoglacial time, the Godly did not join the Grey-Maud, and this latter constructed a large lateral moraine across the valley in front of the Godley. By LIA times, fan-head build up of the Godley river outwash gravels raised the Grey-Maud ice levels sufficient to overtop this moraine and flow into the Godley terminus. As the LIA expansion progressed, Godley ice was constrained by both the obstructing moraine and the invading Maud ice and ponded in its valley. Rising Godley ice levels would be slow because it would take centuries of small positive balance gains to fill the valley. Finally by the time of the last cool episode of the LIA, Godley ice levels had risen enough to lift a large area of the trunk into the accumulation zone. The three combined glaciers then advanced downvalley. But at the same time the snowlines rose with the end of the LIA and the Godley lost a large part of its accumulation area. Catastrophic accelerating collapse followed as the upper Godley ice levels fell below the accumulation zone.

PATTERNS AND PROCESSED OF ICELOSS AT TASMAN GLACIER: AN EVALUATION USING HISTORIC DATA SOURCES AND REMOTE SENSED IMAGERY

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Tasman Glacier, located in Aoraki/Mount Cook National Park, is New Zealand's longest glacier and an iconic landscape that has undergone dramatic change since the earliest glaciological observations were made in the 19th century. Historic maps and aerial photographs record sustained ice loss from the lower glacier during a prolonged period of down-wasting from the late 1800s, although the glacier terminus maintained its maximum 19th century position until the formation of Tasman Lake in *c.* 1990. Tasman Lake formed from a series of supraglacial ponds that coalesced to form a single large proglacial lake, and subsequent lake expansion has driven rapid terminus retreat by a combination of calving and episodic merging of supraglacial ponds into the lake margin. Terminus retreat rates and lake growth rates quantified from ASTER and Landsat images reveal accelerating retreat over the period 2000 - 2007. The glacier terminus retreated at an average rate of 0.2 km^2y^{-1} and a maximum rate of 0.6 km^2y^{-1} during the period December 1990 – April 2007. Episodic peaks in the rate of terminus retreat and lake growth reflect periods of supraglacial pond coalescence into Tasman Lake. In 2007 Tasman Lake measured 5.57 km^2 and the glacier terminus had retreated 5.2 km from its latero-terminal moraine complex. It is predicted that the terminus could retreat a further *c.* 10 km before it reaches a topographic pinning point that would halt lake expansion.

ABSTRACT WITHDRAWN

BREWSTER GLACIER'S MASS BALANCE MODELLED OVER THREE DECADES

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The aim of this study was to model the mass balance and snowlines on Brewster Glacier for the past three decades, by using a distributed mass balance model.
The mass balance model is based on the energy balance, and runs with meteorological input data. Input data are an interpolated climate dataset from NIWA, and the ERA-40 re-analysis dataset from the European Centre for Medium-Range Weather Forecasts (ECMWF). Direct mass balance measurements, which were initiated in 2004, provided data to calibrate the model. These measurements were collected with the glaciological method that includes stake and snowpit measurements. For model validation, we used the yearly end-of-summer snowline (EOSS) records from the Glacier Snowline Survey, which document the evolution of the Brewster Glacier excellently since 1978. After calibrating the mass balance model, the mass balance and snowlines were simulated for the past three decades. The modelling results were then compared to the yearly EOSS records.
The mass balance model performed well with the interpolated NIWA dataset for the calibration period. But for the previous 30 years, the model calculations did not correspond well to the EOSS records. Therefore, the model input dataset was exchanged with the ERA-40 re-analysis data. The results compared much better to the EOSS records, and fit better with mass balance estimates from a parameterisation scheme and a GPS mass balance survey. Furthermore, mass balance trends were modelled well. However, spatial resolution of the ERA-40 data set is very coarse, and we suggest testing in future studies whether the performance of mass balance modelling can be improved by applying finer resolution Regional Climate Model data driven from re-analysis.

ACCUMULATION ON BREWSTER GLACIER, NEW ZEALAND

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Mass balance is the sum of accumulation and ablation processes on a glacier. There are still many uncertainties related to accumulation and its spatial distribution, such as snow redistribution by avalanches or wind drift (Machguth et al, 2006; Dadic, 2008). Machguth et al, (2006) further emphasise that major improvements of mass balance modelling can be achieved by focusing on the accumulation process. It is therefore important to gain more knowledge of the snow distribution and its temporal evolution.
In this master's thesis, the focus is on following topics and questions:

1. Evolution and temporal condition of the accumulation during winter (July to November). How does density change? When is the peak of the winter season? How does it vary with altitude? How accurate are measurements with stakes, probes and pits?
2. Spatial accumulation patterns. Does the precipitation gradient change with altitude? Can a variation on different slopes be detected?
3. Comparison of accumulation data to climate data. Are the climate data measured at the weather station accurate for future mass balance measurements? Does the wind speed and direction help to understand spatial snow distribution?
4. Temporal and spatial comparison between modelled and measured accumulation by applying an existing mass balance model of intermediate complexity, which is provided by Horst Machguth from the University of Zurich. Can the collected data be used for the model? Are there more information required?

To answer these questions, monthly fieldtrips were necessary. On the first fieldtrip a permanent stake network of 15 sites was installed. Furthermore, 5 snow probe examples were taken in between the stakes in 100 meters distance. To finally calculate snow water equivalent, 2 to 4 pits in different altitudes were dug and snow weight was measured every 10 centimetres.

MODELLING SUMMER ABLATION ON THE BREWSTER GLACIER, NEW ZEALAND

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Micrometeorological data collected over a total of 85 days during summer on the Brewster Glacier, Mt Aspiring National Park, are used to determine the main processes controlling ablation. Understanding the processes controlling glacial ablation is necessary to develop robust models to predict ablation in future scenarios. Ablation is modelled using an energy balance model and a degree-day model to (1) determine the main controls of ablation and (2) assess the strength of the degree-day model.

Net radiation overall, provides the largest source of energy for ablation (54%), followed by the sensible heat flux (24%), the latent heat flux (19%) and the rain heat flux (3%). A comparison between daily total ablation estimated by the degree-day model to the energy balance model shows the degree-day model performs well but not under all situations. The largest differences in ablation estimated by the two models occur when the latent heat flux is the largest energy source. To account for some temporal variability in the degree-day factor, a 'super degree-day factor' of 11.8 mm d^{-1} $C^{\circ-1}$ is deris.

Measured ablation derived from stake measurements over the whole measurement period at 1770 m asl is 3441.6 mm w.e. The energy balance model overestimates ablation by 7.2%, while the degree-day model using published degree-day factors underestimates ablation by 8.8%. Despite its simplicity, these results suggest that the degree-day model is sufficiently reliable as a tool to estimate summer ablation on the Brewster Glacier.

MT RUAPEHU END OF SUMMER SNOWLINE AND MASS BALANCE TRENDS, 1988-2007

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We present an end-of-summer snowline (EOSS) study of Mt. Ruapehu glaciers from 1988 to 2007, direct measurements of mass balance on the Whangaehu Glacier for 2006 and 2007, and a climatic interpretation of glacier trends over this period. The EOSS survey reveals a ~5 year pattern, with high snowlines evident in the late 1980s and again in the mid 1990s to early 2000s. Lower snowlines were recorded during the early to mid 1990s and between 2003 and 2007. The similar number of high (9) and low (9) snowline years indicates that the Whangaehu glacier may have been close to balance during this period. Direct measurements showed (slightly) negative balance in 2006 and positive balance in 2007. Velocity measurements and aerial photos indicate that the Whangaehu Glacier no longer sources ice from Summit Plateau, and that the summit area is now an ablation zone. Although no longer dynamically connected, Summit Plateau remains an important source of wind-drifted snow for the Whangaehu Glacier in Winter and Spring.

Snowline variations and mass balance trends are strongly correlated with locally measured temperature, but show little relationship with precipitation. Inter-annual variation in the snowline record correlates with the Southern Oscillation Index, but not the Southern Annular Mode or New Zealand (southerly or westerly) atmospheric circulation indices. The demonstrated sensitivity of Mt. Ruapehu glaciers to temperature does not bode well for the future, although the Whangaehu Glacier may do better than north and west-facing glaciers.

LAST MAJOR RETREAT OF ANTARCTIC ICE SHEETS FORCED BY SEA LEVEL RISE AND WARMING

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The retreat of Antarctic ice sheets during the transition from the last glacial period to the Holocene provides the most recent example of ice sheet response to climate and sea level change, and thus allows an assessment of rates of ice sheet decay as well as attendant contributions to sea level rise. We present a highly-resolved temporal record of deglaciation of the East Antarctic Ice Sheet in Mac.Robertson Land which demonstrates that the deglaciation was taking place from 12 to 7 ka, with a cessation of ice loss at 7 ka. The marine record is based upon a sedimentologic and radiocarbon chronology of two 20 m-long jumbo piston cores whose relationship to glacial flow is fixed by multibeam seismic imagery. The paleo-ice flow is further constrained spatially by nunataks in the Framnes Mountains and temporally by a set of ^{10}Be and ^{26}Al ages from erratic clasts perched thereon. We link ice retreat to Meltwater Pulse 1a (MWP-1a) at ~14 ka and warming of the marginal oceans and atmosphere to near-modern levels ~2 ka later. In support of this interpretation is the comparison of our land-marine sequence to marine deglacial events from both West and East Antarctica. Hence, our results indicate that Antarctic ice masses are sensitive to retreat when threshold rates and amounts of sea level rise (> 5 m/century, >>10 m) and warming are exceeded, explaining the asymmetric nature of Antarctic ice volume changes during the last glacial period, where retreat lagged behind that of Northern Hemisphere ice sheets.

SIMULATING ICE SHELF STABILITY WITH A CLIMATE MODEL

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Recent collapse of long-lived ice shelves along the Antarctic Peninsula and Ellesmere Island have been triggered by warm surface air temperatures (SAT) which cause melt ponding, ice weakening and fracture. This observation suggests that SAT can be used as a proxy for ice shelf stability and that predictions of future ice shelf stability may be obtained using climate model output. To test this idea, climate model surface air temperature anomalies are applied to an NCEP base climatology to infer regions of ice shelf stability based on simulated annual positive degree days and summer melt period duration. Model results are first compared to observed ice shelf collapses, and then used to predict further evolution of the ice shelf stability zone based on a coupled-carbon climate model simulation. The model is able to capture the extent of preindustrial ice shelf stability zones in both hemispheres and the large-scale migration of this zone in response to recent warming. Forcing of the climate model with projected anthropogenic carbon emissions to year 2800 results in loss of ice shelf stability zones in the Northern Hemisphere and the Antarctic Peninsula, and significant summer melt periods on the Ross, Ronne-Filchner and Amery ice shelves and a large portion of the grounded West Antarctic Ice Sheet.

RECONSTRUCTING THE EAST ANTARCTICA ICE SHEET MARGIN ALONG THE TRANSANTARCTIC MOUNTAINS

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An understanding of how the Antarctic continent has reacted to past climates is necessary to accurately predict the response of its ice sheets to future climate change. The thickness and proximity of ice to the continental margin are key to this discussion and relate directly to the volume of ice within the East Antarctica Ice Sheet (EAIS) and its melt water contribution to sea level post LGM.

This work will contribute fundamental data to an important international debate on the scale of the glaciation in the last ice age. It will help validate ice thickness reconstructions for the EAIS and it may give insight into the timing and nature of Antarctic contributions to global sea-levels.

The Darwin / Hatherton is an outlet glacial system that drains the EAIS into the Ross Sea through the Transantarctic Mountains. In this region a suite of moraines exists at altitudes up to 1000m above the current ice surface. Recent cosmogenic dating has shown that the upper moraines previously thought to be of LGM age are approximately 600ka. Ice sheet modelling has shown that ice in the area during the LGM was approximately 1000m thicker than present; therefore a discrepancy exists between these models and the geological evidence.

The 2009 field season in the Darwin/Hatherton is mapping sites at either end of the glacier and aims to construct a timeline of post-LGM glacial retreat based on cosmogenic dating. Preliminary data and an introduction to the problem of the Antarctic contribution to post-LGM sea level rise will be presented.

PRELIMINARY RESULTS FROM A STUDY OF ICE DYNAMICS OF THE DARWIN-HATHERTON GLACIAL SYSTEM, ANTARCTICA

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The Darwin-Hatherton outlet glacial system flows from the East Antarctic Ice Sheet through the Transantarctic Mountains into the Ross Ice Shelf, which is predominantly fed by the West Antarctic Ice Sheet. Recent changes in ice thickness of this glacial system have previously been used to infer variations of the grounded Ross Ice Sheet during the last glaciation. However, differing conclusions have been reached about the maximum ice thickness of the ice sheet and the rate of subsequent retreat (Anderson, Hindmarsh and Lawson, 2004; Bockheim et al. 1989; Conway et al. 1999). The discrepancies are primarily a result of insufficient knowledge of key parameters of the Darwin-Hatherton glacial system such as ice thickness, mass balance, climate and the ages of glacial sediments in neighbouring ice-free valleys. This research aims to examine the ice dynamics of the Darwin-Hatherton glacial system using geophysical and numerical modelling techniques.

Presented here are the preliminary results from a recent ground penetrating radar survey, investigating ice thickness, internal structures, basal temperature conditions and grounding line position of the Darwin-Hatherton glacial system. When the processing of the data from this survey has been finalised, the results will be utilised with other relevant information from the study area in adapting a numerical ice flow model constructed by Pollard and Deconto (2007). The numerical model will then be employed to explain both recent changes within the glacial system and responses to possible future climatic forcing. By investigating the dynamics of the Darwin-Hatherton glacial system, the research will thus contribute to an improved understanding of the behaviour of the West and East Antarctic Ice Sheets.

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DISCHARGE VARIABILITY AND GROUNDING LINE MIGRATION IN THE ROSS EMBAYMENT OF THE WEST ANTARCTIC ICE SHEET, OBSERVATIONS & NUMERICAL MODELS

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Flow features on the surface of the Ross Ice Shelf, West Antarctica, record at least two episodes of ice stream stopping and reactivation within the last 1000 year. These events are documented using maps of streaklines emerging from individual ice streams, together with numerical models of ice shelf flow. Whillans Ice Stream must have stopped its rapid flow about 850 years ago and restarted about 400 years later and MacAyeal Ice Stream either stopped or slowed significantly between 800 and 700 years ago, restarting about 100 years later. A Kamb stagnation cycle prior to the current stagnation is possible, but the evidence is challenging to interpret.

Ice stream stagnation and reactivation cycles yield large variations in ice thickness, which in turn yield widespread migration of the ice sheet grounding line. The models used to interpret past discharge events are also used to investigate this migration. Unsurprisingly, grounding and ungrounding is intimately connected to bathymetry in the ice stream outlet region, emphasizing the three dimensional nature of the the problem. Comparison with internal layers imaged using ground-based ice penetrating radar is used to evaluate model grounding and ungrounding scenarios.

ANTARCTIC RESARCH - HOW TO GET NEW ZEALAND LOGISITICS SUPPORT

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Antarctica New Zealand was established to develop, manage and execute New Zealand's activities in Antarctica and the Southern Ocean, particularly in the Ross Sea region. Key activities include supporting scientific research, conserving the intrinsic values of Antarctica and the Southern Ocean and raising public awareness of the international significance of the continent. In the 2008/09 season we supported 26 science events, 6 of which would fall in the 'snow and ice' category. As a 'snow and ice' researcher wanting to undertake research in Antarctica - how do you 'get into the system' of Antarctic logistics support? *Applicability to the New Zealand Antarctic Science Strategy, science funding, approval through the bidding round process, logistics review, scholarship applications* are all terms you will need to become familiar with. I will give a basic introduction on Antarctica New Zealand and discuss the main ways of getting your science supported in Antarctica through the New Zealand Antarctic programme.

THE EFFECT OF SEDIMENT DEPOSITION TIMING ON THE SEASONAL MELTWATER GENERATION VARIABILITY OF THE WRIGHT LOWER GLACIER, MCMURDO DRY VALLEYS, ANTARCTICA

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Sediment has an important influence on meltwater generation patterns on the surface of glaciers and snowpacks. In the McMurdo Dry Valleys, the amount of research into the impact of sediment on hydrological processes on glaciers has dramatically increased recently, due to an increase in research into the role of cryoconite holes in drainage systems. In this study, the role of sediment in driving the temporal variability of melt on a cold-based glacier was investigated.

This study incorporated field, laboratory and numerical analyses to evaluate the role of sediment in meltwater generation on the Wright Lower Glacier, McMurdo Dry Valleys, Antarctica, during the 2005/06 ablation season. The findings showed that sediment on the glacier surface caused 16 times more melt to occur under sediment cover than for the clean ice surface over the 2005/06 measurement period. More importantly, the study found that sediment cover affected the timing of melt occurring through the season. Specifically, as westerly katabatic winds transported sediment onto the glacier during the winter, sediment was available for melt in the early ablation season. The presence of sediment on the glacier surface then caused melt to start several weeks before equivalent clean ice surfaces melted. The impact of this differential ablation has implications for the development of cryoconite holes, nutrient fluxes across the glacier surface and meltwater delivery timing to the glacier outlet.

THE USE OF OXYGEN ISOTOPES TO DETERMINE SEA ICE GROWTH RATES

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Background/Aims
Sea ice thicknesses and growth rates are important climate indicators. However, remote sensing of sea ice thicknesses is difficult due to the presence of brine inclusions in sea ice. Direct measurements of sea ice thickness growth rates are rare, due to the logistic constraints associated with Antarctic and Arctic field work. Sea ice growth rates in the vertical dimension have traditionally been indirectly determined by analysing salinity profiles of sea ice cores. Eicken (1998) proposed a method for determining sea ice growth rates that relied upon oxygen isotope measurements from sea ice core samples. This piece of research aims to test the role of oxygen isotope analysis in determining sea ice growth rates.

Methods
Direct measurements of sea ice growth rates were made in McMurdo Sound, Antarctica, in 1999 and 2000. The results of these direct measurements were then compared with the results of the Eicken (1998) sea ice growth rate model using oxygen isotope analysis carried out on sea ice and sea water samples taken at the sites in 1999 and 2000.

Results
The model of Eicken (1998) predicted the trend of bulk sea ice growth rates well, but there were differences in magnitude. Modifications to the model of Eicken (1998) are proposed, particularly where platelet ice formation is likely. There are some issues that arise with oxygen isotope analysis for sea ice.

Conclusions
Further work is needed on both the models and on the protocols for preparing and handling sea ice samples for oxygen isotope analysis.

SNOW MORPHOLOGY AND RADAR CHARACTERISTICS IN THE ROSS SEA REGION MEASURED BY GROUND PENETRATING RADAR

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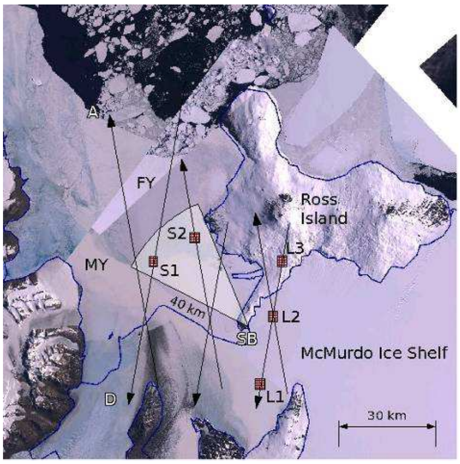
Radar data acquired from satellite, aircraft, or ground, provide spatially distributed information of snow properties. The vicinity of Scott Base, Antarctica, shows areas with significant differences in snow morphology and hence radar backscattering. This results in variations of the reflected wave forms of radar altimeters and complicates the determination of surface height of ice sheets and sea ice. This project is part of ESA's validation program for the Cryosat altimeter (launch date 2009).
In November 2008, three stake farms, similar in size to the altimeter foot print, were established as land ice test sites near Scott Base. Stakes are set in a regular 100m grid and are used for spatially distributed accumulation measurements. Two stake farms are aligned along a descending satellite track at the ice shelf in or near the percolation zone, another stake farm is located on a gentle slope at Mt. Erebus in the dry snow zone. Snow density, hardness (layers), and grain size were measured in several snow pits down to 3 m depth at each site. A ground penetrating radar (GPR) system was used to collect data simultaneously at 500 and 1000MHz in a regular grid connecting the snow stakes and pits in order to obtain a three dimensional model of snow layers down to 12m depth. Radar data are processed using two methods: commercial processing software and a newly developed retrieval method using complexity measures. We present results of the measurements showing how snow morphology is related to GPR features in different snow regimes.



Cryosat ground truthing sites in the western Ross Sea region showing land ice sites (L1, L2, L3) and sea ice sites (S1, S2) placed along descending (D) and ascending (A) satellite orbits.

A METHODOLOGY FOR ICE CORE SITE SLECTION

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Temperate glaciers are a potentially valuable target for ice core drilling, especially in the Southern Hemisphere where climate proxy records for the last 1000 years are less developed than their northern counterparts. Low-elevation temperate glaciers present a difficulty in that meltwater percolation tends to compromise the chemical and isotopic signals present in the core. For this reason, site selection is crucial.

Several attempts have been made to obtain ice cores in the southern mid-latitudes, primarily from Patagonia but also the Southern Alps. Low elevation sites have shown chemical and/or isotopic degradation, with the best record to date being a 40-year/15m firn core on Monte San Valentin, Patagonia. A ~50 m core taken by GNS Science, University of Maine and a Chinese team from Tasman Glacier is presently being analysed.

We propose a methodology for selecting sites in the Southern Alps to obtain an ice core that has the best integrity of climate proxies with the longest temporal coverage. To meet these goals, we are searching for sites which are potentially: cold-based, have a low melt and accumulation rate, and have favourable dynamic characteristics (preferably an ice-divide, with no crevasses/low ice velocity and deep ice). Any site selected must also be logistically practicable.

The site selection process will include two stages: first a desktop study to identify potential sites, and second, field measurement of ice thickness and accumulation at the most promising sites. Melt rates will be assessed with a mass balance model which calculates ablation throughout the Southern Alps. A simple accumulation model will be used to constrain accumulation rates. Topographic analysis will identify areas with low surface slope which is indicative of deep ice and low flow rates.

We present the results of some preliminary trials of the desktop study methodology and identify some sites that might be chosen for site survey work with the aim of initiating further discussion.

MODELLING GREENLAND ICE SHEET (GIS) AND ATMOSPHERE TO ESTIMATE THE GIS MASS BUDGET (1986-1995)

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The ice and melt water discharge from Greenland and Antarctica contributes to the fresh water flux into the neighbouring oceans which may strongly influence the ocean circulation patterns with climate feedbacks. Since the longterm discharge data is not normally available from measurements, the climate models can provide an estimate of the total accumulation rate while the ice and melt water discharge can be determined using appropriate physically based land/ice surface and dynamical ice flow models.

In this feasibility study, a simplified ice flow model based on shallow ice approximation and Glen flow law is presented. A regional climate model (REMO) is integrated for a decade (1986-1995) over Greenland which combined with the Multiple Path Distributed Flow (MPDF) routing scheme is used to estimate the total mass loss at the Greenland Icesheet (GIS) margins. Some important processes such as refreezing or basal sliding are not considered in this study. The simulation results are compared with remote sensing measurements results [1] and other modelling studies [2].

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APPLICATION OF THE SRM MODEL IN THE UPPER WAITAKI

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New Zealand relies largely on water as its main renewable energy source. In Alpine and temperate regions, a great part of the water resource is temporarily stored in the form of seasonal snow and ice.

MODIS/TERRA has been used to support the operational monitoring of the snow pack dynamics in the upper Waitaki catchment[1]. Daily meteorological data (i.e., temperature and precipitations) and the frequent observations of the snowpack enabled the use of the Snowmelt Runoff Model[2] (SRM) to simulate the discharge of the Tekapo, Pukaki, and Ohau catchments.

The results obtained for hydrological years 2000-2007 brought considerable improvement in terms of modelling performances compared to previous modelling efforts that relied on meteorological data only. The annual discharge was consistently modelled within close to 5% of its measured value and within less than 2% when considering the whole period. Over this time frame, the contribution of seasonal snowmelt and glacier melt has been substantially larger than the long term estimations. Snow and ice melt accounted for 30.6% (Ohau), 32.2% (Tekapo), and 36.8% (Pukaki) of the total annual runoff. In addition, the results suggest that, between April 2005 and March 2006, the severe drought was greatly mitigated by ice melt from glacier retreat in the Pukaki catchment. Only a contribution of glacier melt much larger than normal permitted to sustain the inflow into Lake Pukaki within 17% of the mean annual inflow over the period under investigation, although the precipitations were reduced by 34%.

Once calibrated, the SRM model has the potential to provide short-term forecasts about the discharge that can help the hydroelectric industry to improve its management of the resource.

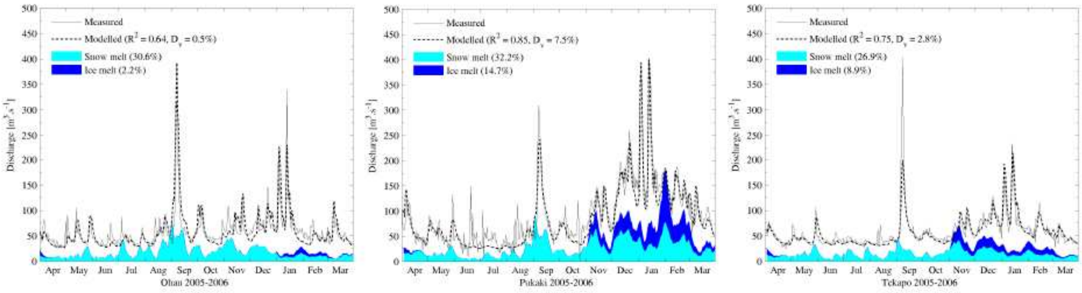

Figure 1 – Daily discharge, observed and modelled in Ohau, Tekapo, and Pukaki catchments for hydrological year 2005-2006.

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INFLUENCES OF ANNUAL INSOLATION, BEDROCK TYPE, AND AVALANCHING ON ROCK GLACIER OCCURRENCE IN THE LEMHI RANGE, IDAHO, USA

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Rock glaciers are important features of high alpine basins in many areas, but neither the factors controlling rock glacier occurrence nor their mechanisms of development are typically well understood. Rock glaciers occupy numerous high alpine basins in the Lemhi Range, an elongate, normal-faulted mountain range in semi-arid east-central Idaho. We identified and characterized 48 rock glaciers in 171 high alpine basins, utilizing GIS-based exploration techniques, aerial photographs, optical remote sensing data, and field investigation, and conducted detailed statistical analyses of possible controlling factors.

In the Lemhi Range, elevation >2600 m, north-facing aspect (300–60°), and <2300 h/yr of direct sunlight are necessary conditions for the existence of rock glaciers. The majority of alpine valleys in the Lemhi Range meet these requirements. Thus, other parameters must determine rock glacier occurrence.

Multivariate statistical analysis of controlling parameters demonstrates that annual insolation and latitude influence Lemhi Range rock glacier occurrence most strongly. Whereas duration of insolation is a logical controlling factor, latitude is more enigmatic. Additional statistical analysis indicates that the latitude factor is likely a reflection of lithologic changes with latitude along the range. Lithology may affect rock glacier distribution through its effects on hydrology or air ventilation. Statistical analysis also shows that rock glacier occurrence correlates with protalus lobe occurrence, suggesting that protalus lobes play a role in rock glacier genesis.

The specific locations of rock glaciers and the identified controlling parameters suggest that most of these rock glaciers have a non-glacial origin. As no satisfactory mechanism exists for in-situ ice segregation within rock glaciers, we have explored alternative non-glacial mechanisms for rock glacier origin. These alpine basins lie in a zone of heavy snow loading from strong westerly wind flow, and we thus propose that snow avalanching in areas of high talus production engenders segregated ice within the rock glaciers.

We conclude that rock glacier occurrence in the Lemhi Range is a function of low annual insolation and of lithology, through its effects on subsurface hydrology and talus ventilation. We further propose that segregated ice forms in the rock glaciers through burial of snow avalanche masses. These factors and processes may well influence rock glacier occurrence in other regions.

DETECTING CLIMATE CHANGE OF THE RECENT PAST FROM GLACIER RECESSION ON KILIMANJARO

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The persistent retreat of glaciers on Africa's highest mountain since the late 19th century has become an unavoidable symbol of climate change. In a unique approach to better understand past atmospheric processes in the mid-troposphere at the end of the 19th century in East Africa we use known past glacial extents on Kilimanjaro to reconstruct climate. Our approach is to perform inverse modeling using a physically-based glacier mass balance model, which is dependent on data collected on the mountain using automatic weather stations, to determine what conditions must have allowed the Kersten Glacier on the southern part of the mountain to reach its most recent maximum areal extent. This not only allows us to characterize quantitatively the climate of the recent past but helps us to understand the current recession and expected future behaviour of glaciers on Kilimanjaro. Results from multiple scenarios reveal that a more humid climate, with higher precipitation (+160 to +240 mm/year) and increased fractional cloud cover constitutes the only possibility to bring the glacier down to its 19th century maximum extent. An increase in energy transfer to the glacier due to more moisture in the atmosphere is almost entirely compensated for by a decrease in absorbed solar radiation (due to both a decrease in global radiation and increased albedo). Inverse modeling also shows that changes in wind speed, air pressure and air temperature on Kilimanjaro do not appear to be as important as changes in moisture. The most striking aspect of the inverse modeling is that it shows us that the energy-driven mass loss per unit area (sublimation plus meltwater runoff) at the end of the 19th century was actually very similar to what we see today. The difference is that slightly higher precipitation rates in the past dominated the mass budget resulting in the former larger glacier extents, which is telling evidence that glaciers on Kilimanjaro don't require major shifts in climate to initiate periods of recession or perhaps growth.

^{10}BE COSMOGENIC EXPOSURE AGES OF LATE PLEISTOCENE MORAINES NEAR THE MARYBURN GAP OF THE PUKAKI BASIN

Doughty, AM[1], Denton, GH[1]
[1]University of Maine, Earth Science Department

Milankovitch Theory explains the basic link between variations in earth's orbital parameters and the occurrence of ice ages. By this hypothesis, glaciers in the at different latitudes respond to different insolation signals, which are out of phase between the Northern and Southern Hemispheres because they are precession-dominated. However, existing moraine chronologies indicate that glaciers in the middle-latitude Southern Hemisphere may be in-sync with those in the Northern Hemisphere (Mercer, 1984). To provide a basis for understanding what drives glaciations in southern middle latitudes I developed a ^{10}Be exposure-age chronology for Last Glacial Maximum (LGM) moraines in the Pukaki Basin, New Zealand. Results show that the regional glacial maxima were achieved at ~35,000, 27,000, 25,000, 20,000, 19,000 and 18,200 years ago. Moraines distal to the LGM sequence yield an age range of 60,300 ± 1,400 to 69,300 ± 1,600 years ago. The precision of these exposure ages allows for detailed comparisons with climate records from Northern Hemisphere and Southern Hemisphere middle latitudes as well as with insolation curves. This chronology allows me to test several hypotheses about the predicted timing of ice maxima and whether the theories are supported, rejected, or in need of revision. The maxima occur during both local summer intensity insolation maxima and minima, suggesting that overhead insolation is not the only factor controling glacier mass balance.

Field Trips:

The 2009 New Zealand Snow and Ice Research Group (SIRG) Annual Meeting, Albert Town, Otago Lakes.
Field Trips, Wednesday 18 February, 2009

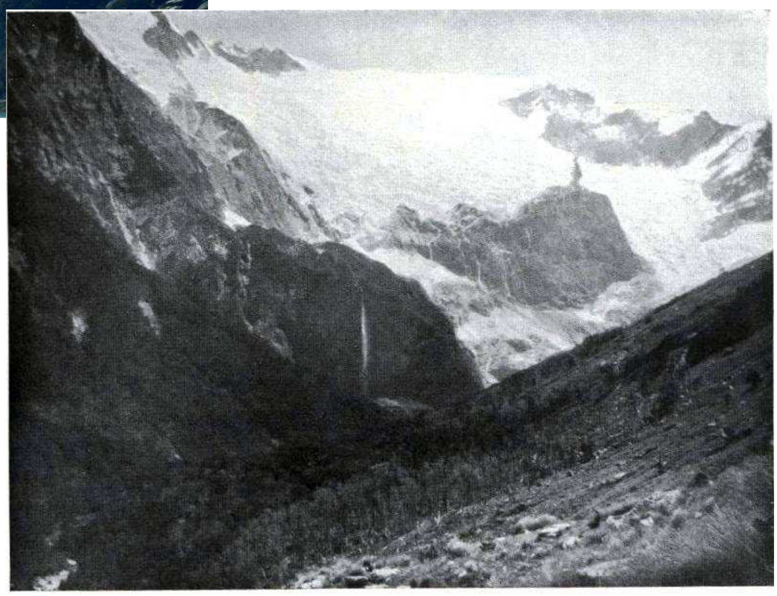
Participants have the choice of two proposed field trips which will be run concurrently. Transport for both will be by the various vehicles available from the meeting. Field trips will start at 0800 at Albert Town Lodge.

<u>Field Trip 1 to Rob Roy Glacier, Matukituki Valley</u>
Trip leader – Laurel Morrison

The excursion will travel for about 11/2 hrs up the Matukituki Valley to Raspberry Flat car park. From there it is a further 11/2 hr walk up a good bush track to the glacier which has the form of an ice avalanche cone.

(Below) Rob Roy Gl, 1906, Maud Moreland

(Above) Rob Roy Glacier, 2008, T. Chinn



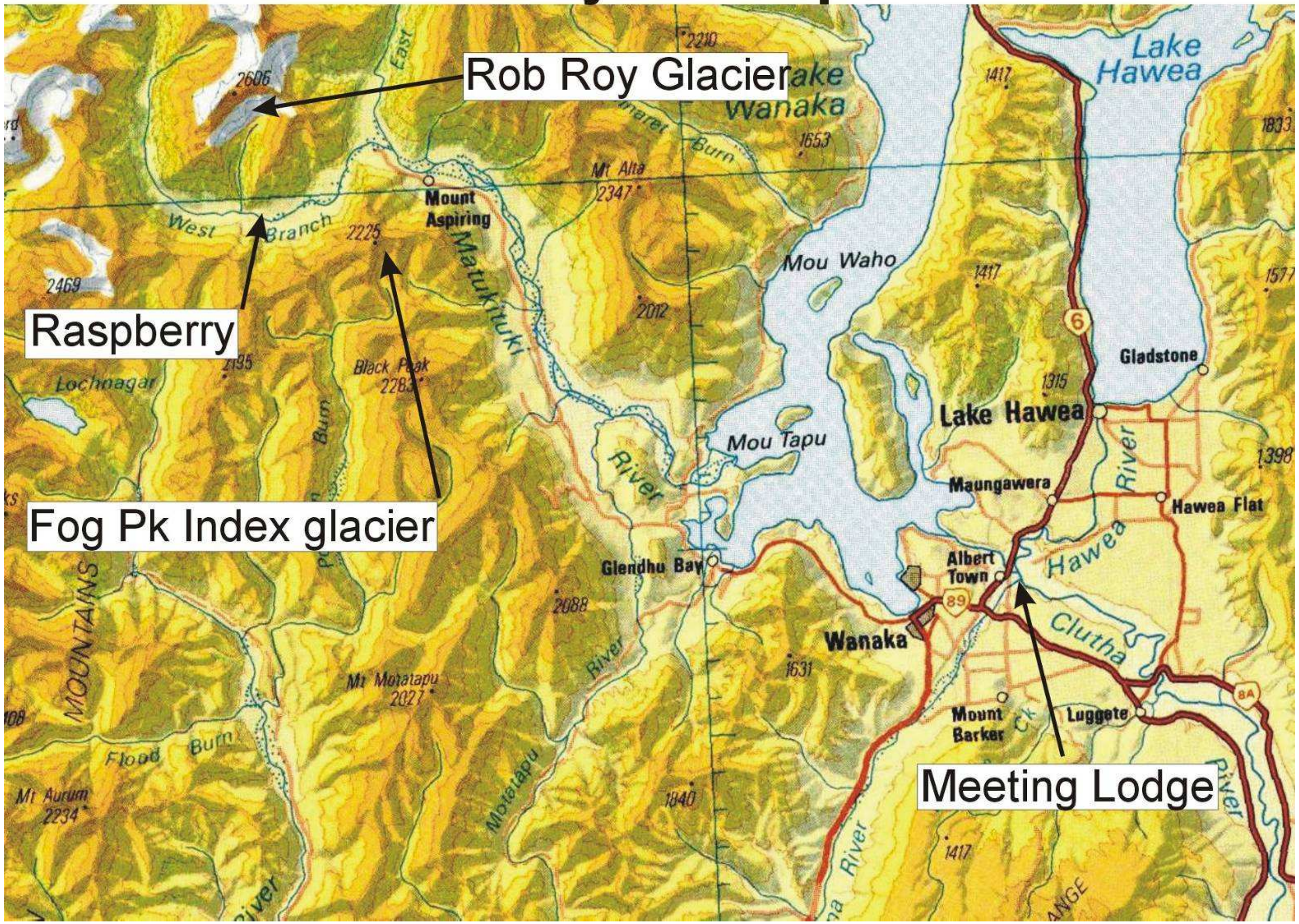
THE ROB ROY GLACIER. [178

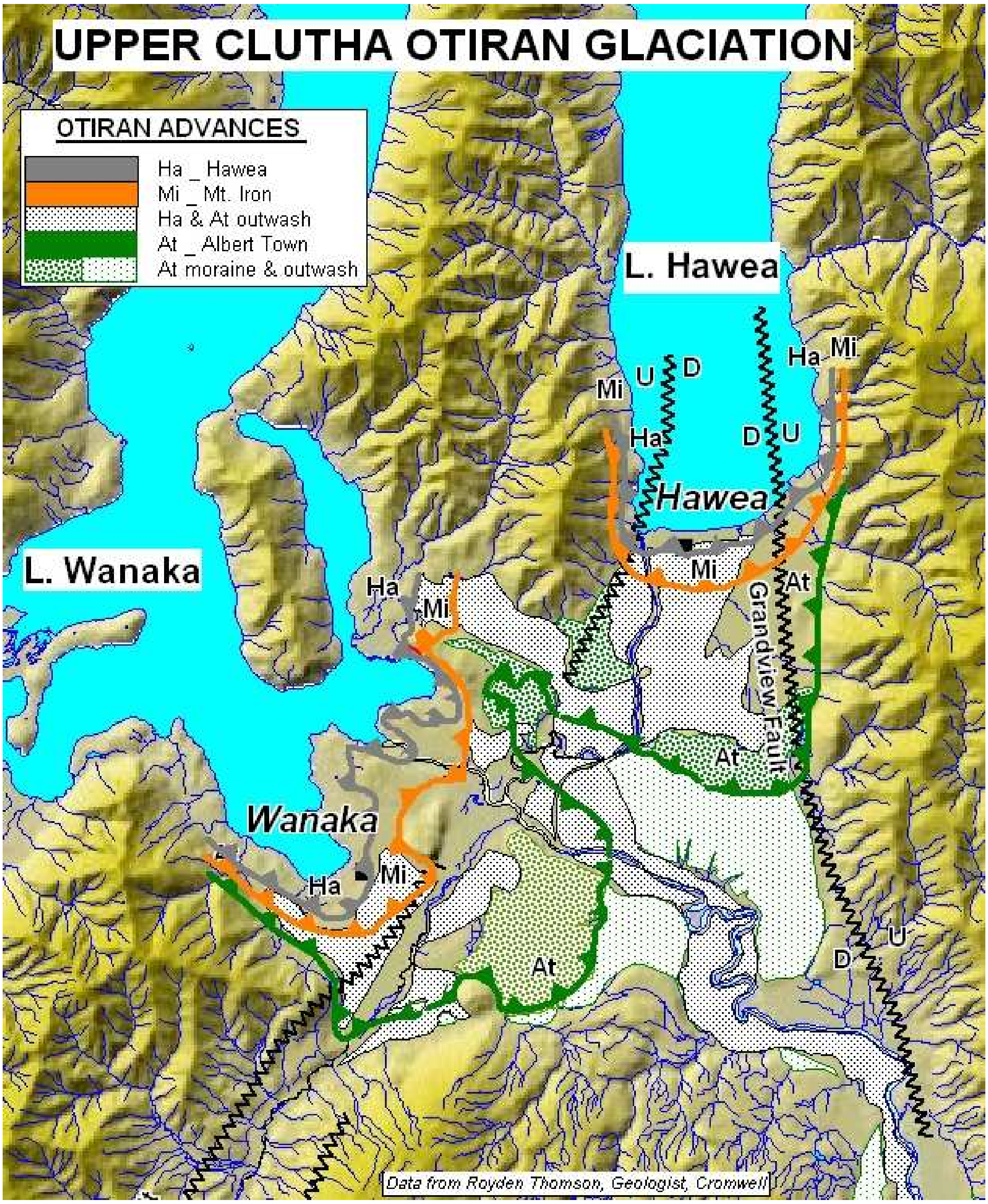
<u>Field Trip 2 to the glacial history of the Upper Clutha</u>
Trip Leader - Trevor Chinn with the glacial history given by Royden Thomson

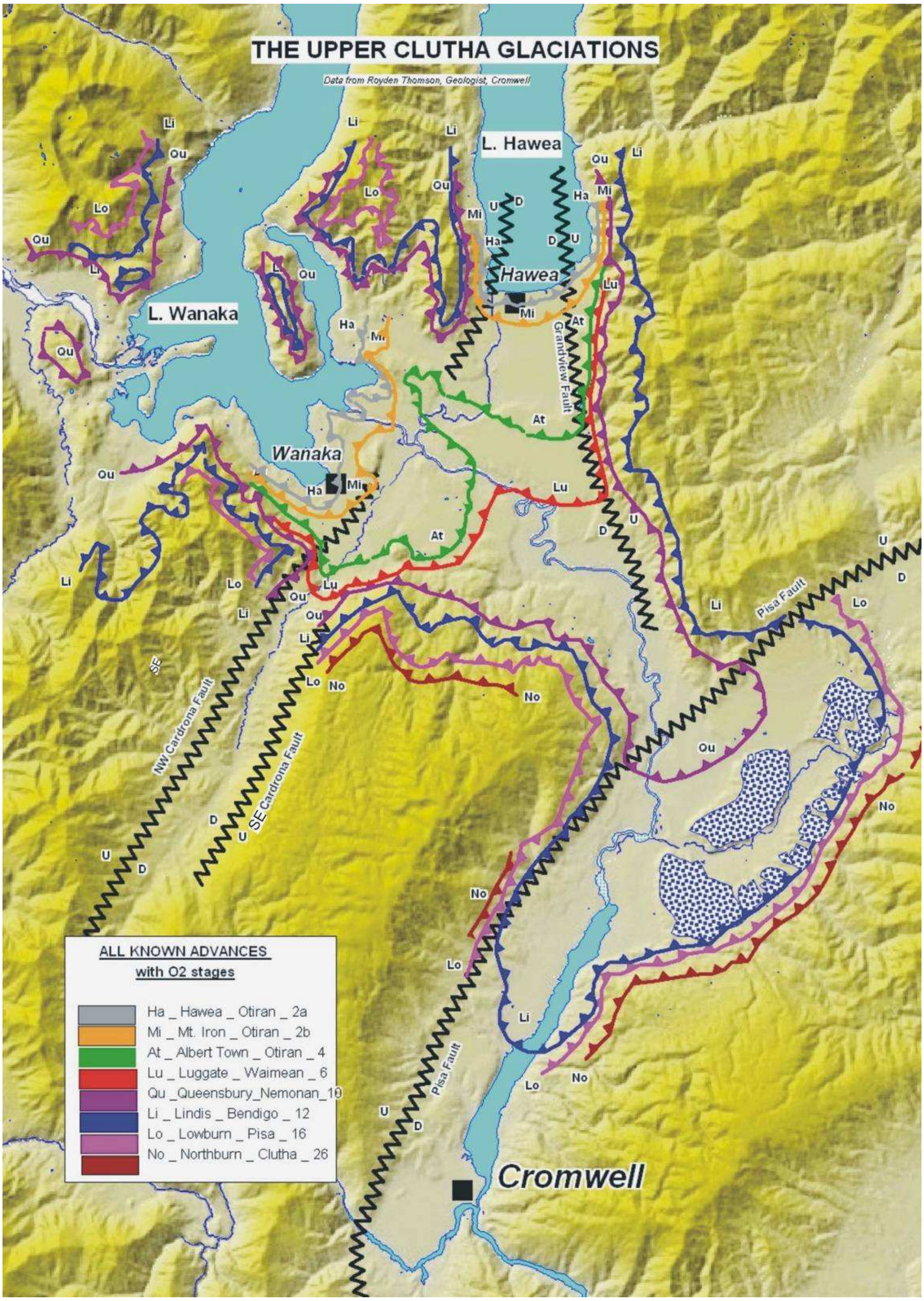
This excursion commences with a walk to the top of Mt Iron to view the youngest features, and then proceeds downvalley towards Cromwell, stopping at various points. Royden Thomson, guru of the Clutha glaciations, will be the commentator and guide.

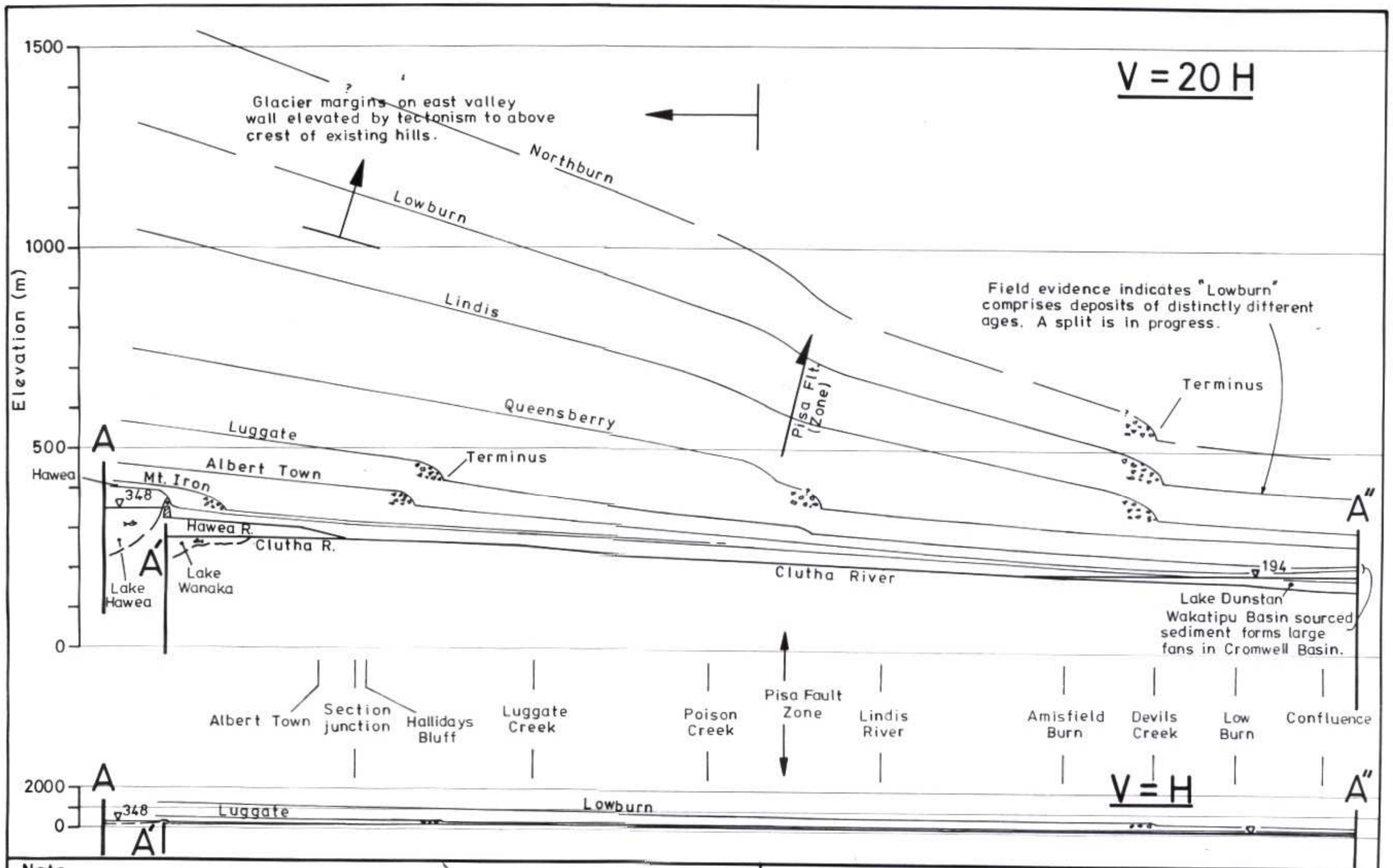
This field trip will start with a presentation from Royden Thompson at 0800, before departing on the field trip.

Rob Roy Field Trip




UPPER CLUTHA OTIRAN GLACIATION
OTIRAN ADVANCES
Ha _ Hawea
Mi _ Mt. Iron
Ha & At outwash
At _ Albert Town
At moraine & outwash
L. Hawea
L. Wanaka
Hawea
Wanaka
Grandview Fault
Data from Royden Thomson, Geologist, Cromwell

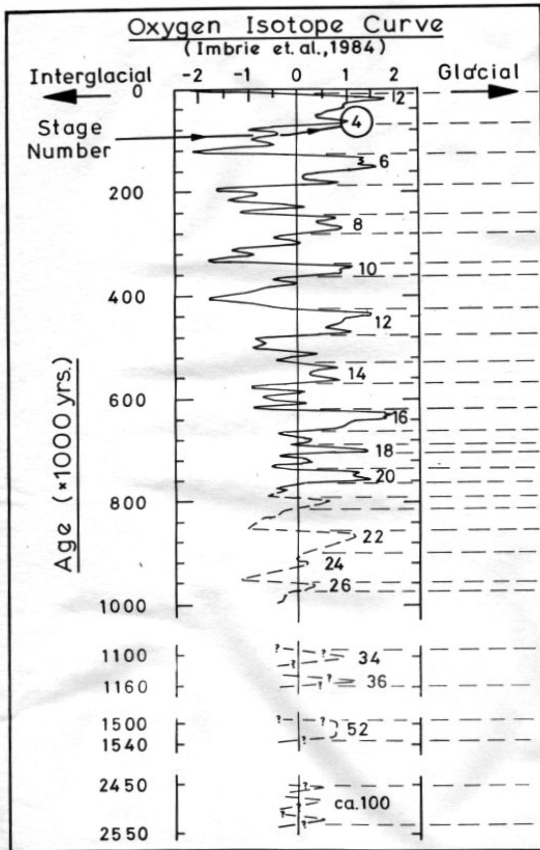

THE UPPER CLUTHA GLACIATIONS
Data from Royden Thomson, Geologist, Cromwell
L. Hawea
L. Wanaka
Hawea
Wanaka
Cromwell
Grandview Fault
NW Cardrona Fault
SE Cardrona Fault
Pisa Fault
ALL KNOWN ADVANCES
with O2 stages
Ha _ Hawea _ Otiran _ 2a
Mi _ Mt. Iron _ Otiran _ 2b
At _ Albert Town _ Otiran _ 4
Lu _ Luggate _ Waimean _ 6
Qu _Queensbury_Nemonan_10
Li _ Lindis _ Bendigo _ 12
Lo _ Lowburn _ Pisa _ 16
No _ Northburn _ Clutha _ 26



Note

a. Profiles of glaciers and fluvioglacial surfaces for the older (≥qu) advances vary on opposing valley flanks due to tectonism and valley morphological changes. Profiles shown approximate true right bank constructions.
b. Fault dislocations have not been established in post Albert Town deposits.
c. Assessed 'old' fluvioglacial deposits are not shown.

Source: Royden Thomson, Cromwell. Unpublished



Glaciation	Catchment Glacial Advance Terminologies: Upper Clutha	Catchment Glacial Advance Terminologies: Kawarau
	Wilkin Junction	Mt. Alfred
Otira	Hawea Albert Town Mt. Iron	Morven Hill Morven Ferry Doonholme
Waimea	Luggate	K1 Arrow Shotover K2
Waimaunga		K3
Nemona	Queensberry	Chard
Bendigo	Lindis	Crown Terrace
Crown Range		K4 Eastbourne
Pisa	Lowburn	Nevis Bluff
Clutha	Northburn	Kawarau
Cardrona	Hunter	
	Not resolved. Thick remnants of highly weathered and tectonically deformed greywacke alluvium at Lowburn, Clyde.	
Ross	Not resolved. 'Old', tilted alluvial remnant east of Albert Town.	

Note

Source: Royden Thomson, Cromwell

SIRG 2009 Attendance list

Name	Affiliation	E-mail address
Abha Sood	NIWA	a.sood@niwa.co.nz
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Trevor Chinn	Alpine & Polar Processes, Lake Hawea	t.chinn@xtra.co.nz

The 2009 New Zealand Snow and Ice Research Group (SIRG) Annual Workshop
Albert Town, Otago, New Zealand
February 16 to 18 2009
Organising Committee:

Jordy Hendrikx – NIWA
Trevor Chinn - Alpine & Polar Processes
Jim Salinger - NIWA