The 2008 New Zealand Snow and Ice Research Group (SIRG)

Annual Meeting

February 4th to 6th 2008

Cass Field Station, Castle Hill Basin, Canterbury, New Zealand

Programme

The Cass Field Station 1936
Rita Angus (University of Canterbury Arts Collection)

Sponsored by:

UC UNIVERSITY OF CANTERBURY Te Whare Wānanga o Waitaha CHRISTCHURCH NEW ZEALAND

NIWA Taihoro Nukurangi

Antarctica New Zealand

Time	Presenter	Topic
Monday 4th		
12:30	Lunch	
13:20	Mette Riger-Kusk and Tim Kerr	Welcome and introduction
Chaired by Blair Fitzharris		
13:30	Alex Winter-Billington	The hydrological system and climate of Brewster Glacier, Tititea Mt Aspiring National Park, Aotearoa New Zealand in the context of regional and global climate change.
13:50	Delia Strong	Landscape change at the terminus of Tasman Glacier, Aoraki/Mt Cook National Park
14:10	Heather Purdie	Controls on spatial and temporal variation in glacier accumulation, Southern Alps, New Zealand.
14:30	Ross Woods	Modelling of spatial variability of snow water equivalent - guidance from field data
14:50	Simon Allen	Investigating permafrost distribution in the Mt Cook region for improved modelling of glacial hazards
15:10	Brian Anderson	Gradients of mass balance sensitivity and volume changes in the Southern Alps
15:30	Afternoon Tea	
Chaired by Ian Owens		
16:00	Bryan Storey	Glacial history of the Darwin-Hatherton glacial system in the central Transantarctic Mountains; Field mapping and sampling for cosmogenic dating
16:20	Andrew Mackintosh	Response of Mueller and Tasman Glacier to climate change
16:40	Pascal Sirguey	Analysis of relationships between time series of snow-cover parameters and tributary inflow in the lakes of the upper Waitaki Catchment
17:00	Trevor Chinn	Recent ice volume changes (1976-2005) for the big glaciers of the Southern Alps
17:20	Jim Salinger	Overall ice volume trends and variation in ice volume in the Southern Alps 1976 - 2005
17:40	Blair Fitzharris	Changes in ice volume of glaciers of the Southern Alps since 1977
18:00	Dinner	
20:00	Colin Burrows	The glaciological sketches of Julius von Haast

Tuesday 5th	
8:00	Fieldtrip
17:00	Return from Field trip
19:00	Dinner at Bealey Hotel

Time	**Presenter**	**Topic**
Wednesday 4th		
Chaired by Andrew Mackintosh		
8:30	Alun Hubbard	The dynamic response of the Warszawa Icecap, Antarctica to past and future climate change
8:50	Nita Smith	An ASTER Digital Elevation Model (DEM) for the Darwin-Hatherton Glacial System, Antarctica.
9:10	Wolfgang Rack	Precise surface elevation mapping of polar ice sheets using differential SAR interferometry
9:30	Jeremy Fyke	Implementation of the GLIMMER ice sheet model in the UVic ESCM
9:50	Giovanni Dalu	Influence of the snow cover in the Northern Hemisphere on the climate in Western Europe during the cold season
10:10	Eleri Evans	Mapping and modelling seasonal snowcover over Storglaciären, Northern Sweden
10:30	Morning Tea	
Chaired by Wendy Lawson		
11:00	Paul White	Snow and groundwater recharge in Canterbury
11:20	Tim Kerr	Presenting snow and ice research information to the world through Google Earth
11:40	Mark Crompton	A ten year photographic record of perennial snow in the Southern Alps
11:50	Stephen Thompson	Evidence of climate states in the records of flow into the southern lakes
12:10	Andrew Mackintosh	The International Glaciological Society
12:30	Finishing discussion	Suggested topics: - Timing/patterns/climate-drivers of late-glacial maximum limits and subsequent deglaciation of New Zealand – *Alun Hubbard* *Other suggestions are welcomed*
13:00	Lunch, cleanup, group photo, departure	

The hydrological system and climate of Brewster Glacier, Tititea Mt Aspiring National Park, Aotearoa New Zealand in the context of regional and global climate change.

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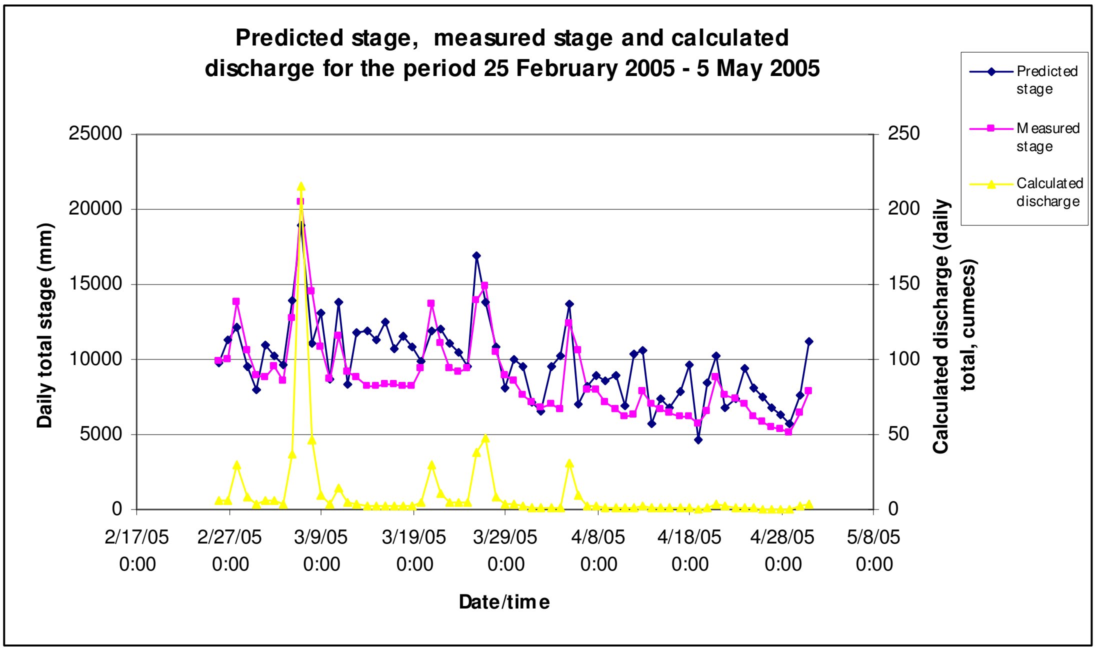
Temporal and spatial variability in stream discharge is controlled by variations in local climate, and this in turn is intimately related to both regional and global atmospheric circulation and climate change. In non-glacierised catchments, the relationship between atmospheric variables and streamflow can be readily ascertained and the stream hydrograph predicted fairly certainly with weather forecasts. The relationship is more complicated in glacierised catchments. This study attempts to quantify the relationship between Brewster Glacier proglacial discharge and both local (measured) atmospheric variables and broader atmospheric circulation patterns with sufficient accuracy and specificity that prediction of discharge can be made using local weather forecasts and atmospheric circulation indices. It is found that temperature and rainfall are consistently the most influential variables in predicting discharge production, that wind speed contributes significantly during autumn while humidity does so in summer, and atmospheric pressure contributes very little. A multiple regression equation can predict 64% of variation in the proglacial stream hydrograph, but only 46% of discharge calculated with a ratings curve, and around 90% of the total discharge volume. A qualitative relationship is established between discharge at Brewster Glacier proglacial stream and Aotearoa New Zealand atmospheric circulation indices. An estimation of future discharge from Brewster proglacial stream is made in accordance with regional climate change scenarios.



Landscape change at the terminus of Tasman Glacier, Aoraki/Mt Cook National Park

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Landscape change in the Aoraki/Mount Cook National Park is occurring rapidly, as valley glaciers appear to have entered a phase of accelerating retreat. Using remotely sensed images and historical maps, spatial and temporal changes in the behaviour and position of the terminus of the Tasman Glacier are examined. A chronology of change since early European settlement will be developed from historical maps, vertical aerial photographs and Advanced Spaceborne Thermal Emission and reflection Radiometer (ASTER) images. While historical maps and vertical aerial photographs only allow a qualitative assessment of landscape change, the seven year dataset of ASTER images provides an opportunity to quantify changes in geomorphology and the rate of terminus retreat. For example preliminary results show a 37% increase in the area of Tasman Lake from 2000 to 2006. Based on the ASTER images, feature tracking will be assessed as a tool for determining short term fluctuations in glacier velocity. The application of satellite imagery to mapping debris covered glaciers is known to be problematic and this study will attempt to assess the value of ASTER images in the context of mapping and quantifying landscape change at a low gradient, debris covered valley glacier in New Zealand.

Controls on spatial and temporal variation in glacier accumulation, Southern Alps, New Zealand.

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Glacier mass balance, the difference between snow and ice accumulation and ablation on a glacier, is an important signal of climate change. Variations in glacier mass balance are derived, in part by field measurements, and also through the application of computer modelling. On temperate maritime glaciers where high rates of precipitation make accumulation measurement difficult, accumulation processes are poorly understood. In such areas, accumulation calculations may be sensitive to the assumptions made in models, in particular, relationships between elevation, temperature and precipitation. In New Zealand, few direct measurements of snow accumulation have been made, modelling of glacier mass balance and ice core studies are just beginning, and both require empirical data and an improved understanding of snow accumulation processes for their development and interpretation.

In this study, I will attempt to quantify glacier accumulation rates at high temporal and spatial resolution on the Tasman, Brewster, and Franz Josef glaciers. The influence of elevation, topography, and ice flow on derived accumulation rates will be investigated. Variations in glacier accumulation rates are commonly interpreted as climate signals therefore it is important to identify and extract spatial signals prior to temporal analysis. Furthermore, temporal changes in snow accumulation will be related to local and synoptic-scale climate variability. It is hoped that our improved understanding of the fundamental processes affecting accumulation variability will improve our understanding of past climate (through ice cores) and strengthen model predications of longer-term glacier behaviour in relation to changing climate. Specifically this study will attempt to:

1. Identify how elevation, topography and ice flow influence measurements of glacier accumulation rates.
2. Consider spatial and temporal variability in accumulation in relation to regional climate patterns, in particular, varying synoptic storm types.
3. Analyse an ice core previously collected at Tasman Glacier and ascertain whether, given the spatial and temporal variability in accumulation, it provides a regional signal of glacier-climate variations.

Modelling the spatial variability of snow water equivalent - guidance from field data

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This talk reports on the use of field data on the spatial variability of snow water equivalent to guide the design of distributed snow models. Diagnosis of field data from the Jollie catchment in the New Zealand Southern Alps shows that there are numerous factors that control snow distribution and many of these display variability at different scales. At the hillslope scale (less than ~100 meters), spatial variability in snow depth is caused by drifting and avalanching, whereas at the watershed scale (100-10000 meters) spatial variability in snow depth is caused by variability in freezing levels and melt energy. Similar conclusions can be gleaned from previous studies. The spatial variability in hillslope-scale processes can be represented in models as a continuous function (e.g., as a probability distribution), but several problems are encountered when using continuous functions to describe the spatial variability in watershed-scale processes. Fortunately, the variability at the hillslope scale is separable from variability at the watershed scale, and it is possible to identify an "ideal" modelling scale that distinguishes hillslope-scale and watershed-scale processes. Based on these results, we suggest a general strategy for configuring snowmelt-runoff models in mountainous river basins. Watershed-scale variability in freezing levels and melt energy should be explicitly resolved by disaggregating the river basin into multiple model elements (grid cells or sub-basins) that are ~3-4 km across, and using multiple elevation bands of ~100-200 m in height within each model element. At the sub-grid scale (i.e., within each elevation band) the aggregate impact of hillslope-scale variability should be implicitly modeled using probability distributions. In this approach the within-element variability is clearly separated from the variability between model elements.

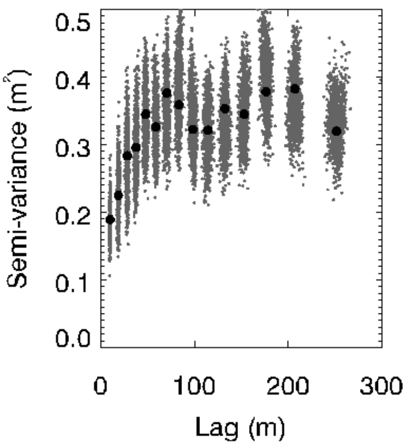

Figure 1: Spatial variogram of snow water equivalent within each transect (data from all transects are pooled). The large black circles show semi-variance computed using all data, and the small grey circles show alternative estimates of semi-variance that is due to sampling variability.

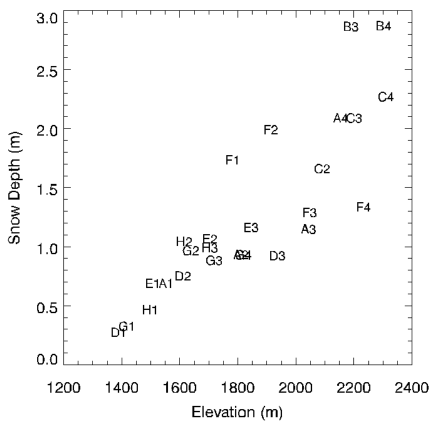

Figure 2: Relationship between elevation and transect-average snow depth in the Jollie River basin. The codes (A1, A2 etc) refer to different sampling transects, and will be explained in the presentation.

Investigating permafrost distribution in the Mount Cook region for improved modelling of glacial related slope instability hazards

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During the extremely hot and dry summer of 2003 in the European Alps, the occurrence of numerous rockfall events from high elevation steep bedrock exposed visible ice within the associated detachment zones (Gruber et al. 2004), confirming qualitatively what had earlier been demonstrated in both theory and laboratory based experiments regarding permafrost degradation, climate warming, and related slope instabilities. Numerous large rock avalanche events have been documented in high mountain regions of the earth, often with catastrophic consequences owing to process interactions and chain events involving mass movements of ice, debris or glacial lake water. Although geological and geometric conditions of bedrock are the most significant factors for the stability of steep slopes, permafrost and its degradation represent a highly sensitive, rapidly changing factor of crucial relevance to alpine slope stability. The thawing of ice-filled rock joints and associated destabilisation in response to climate warming can primarily be attributed to direct loss of ice/rock adhesion and elevated internal water pressure due to the phase change from ice to water (Gruber & Haeberli 2007).

Although permafrost processes have been discussed in relation to rock glacier distribution in New Zealand, there has been no scientific consideration in New Zealand given to the likely wider distribution of permafrost within bedrock slopes, and in particular, on steep slopes which dominate at higher elevations throughout the Mount Cook region. Recent large rock avalanches, including the spectacular summit failure of Mount Cook (McSaveney 2002) have awoken interest in the understanding of permafrost and slope stability interactions in the region. Here we present the first results from permafrost distribution modelling for the MCR, based upon local application and calibration of topo-climatic relationships established in the European Alps. Initial validation of the estimated permafrost distribution is discussed on the basis of a rock glacier inventory and remote sensing based vegetation mapping. An extensive field campaign to record rock wall temperature data throughout the region is outline, and these data are expected to significantly improve the validation of systematic permafrost distribution modelling in the region. Ultimately, this improved knowledge of permafrost distribution will be coupled with analyses of recent glacial terrain changes, topographic and geological analyses, to assess current and future slope instability hazards in the region.

Gruber S., Haeberli W. (2007). Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. *Journal of Geophysical Research 112* (F02S18, doi:10.1029/2006JF000547).
Gruber S., Hoelzle M., Haeberli W. (2004). Permafrost thaw and destabilization of Alpine rock walls in the hot summer of 2003. *Geophysical Research Letters 31* (L13504).
McSaveney M.J. (2002). Recent rockfalls and rock avalanches in Mount Cook National Park, New Zealand. *Geology Society of America, Reviews in Engineering Geology XV*, 35-69.

Glacial history of the Darwin-Hatherton glacial system in the central Transantarctic Mountains; Field mapping and sampling for cosmogenic dating

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In order to accurately predict the response of the Antarctic Ice Sheet to future climate change, we need a well-constrained understanding of its current behaviour, and of the way it has responded to past climate change. Although we now have a relatively detailed understanding of behaviour and recent change of some of the fast-flowing components of the Antarctic cryosphere, we know relatively little about the way in which the outlet glaciers that drain the East Antarctic Ice Sheet through the Transantarctic Mountains have behaved in the recent past, or the processes that control their behaviour and response.

The key aims of this research project is to accurately evaluate the amount and rate of recent change of the outlet Darwin-Hatherton glacial system that drains the East Antarctic Ice Sheet (EAIS) through the Transantarctic Mountains into the Ross Ice Shelf at 79°55′ S. This glacier system is a significant site for understanding change, because it is one of the few locations in the central Transantarctic Mountains where well-preserved glacial moraines provide geomorphological evidence for the recent (Holocene) behaviour of the ice sheet. Bockheim et al. (1989) mapped five separate glacial drift sequences (Hatherton, Britannia I, Britannia II, Danum and Isca).

This presentation will report on recent field work undertaken in December 2007 in the Lake Wellman area on the margin of the Hatherton Glacier. The aerial extent of the glacial drift deposits indicate that in the past, ice was over 800 metres thicker than it is today. Although numerous recessional moraines are present, the boundaries between the different drift sequences are not always obvious. There has been extensive reworking of older drift sequences. Extensive sampling of glacial erratics was undertaken for cosmogenic dating.

Bockheim, J.G., Wilson, S.C., Denton, G.H., Andersen, B.G. & Stuiver, M. (1989). Late Quaternary Ice-Surface Fluctuations of the Hatherton Glacier, Transantarctic Mountains, *Quaternary Research*, *31*, 229-254

Response of Mueller and Tasman glaciers to climate change

Andrew Mackintosh[1], Jörg Schaefer[2] , Bjørn Andersen[3], David Barrell[4], George Denton[5], Robert Finkel[6], Mike Kaplan[2], Aaron Putnam[5] and Rosanne Schwartz[2]
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We explore the forcing mechanisms that drive advance and retreat of Mueller and Tasman Glaciers in the Mt. Cook region of New Zealand during the Holocene and in particular, the last few centuries. The motivation for our work is a new moraine chronology based on high-precision terrestrial cosmogenic nucleide (^{10}Be) measurements. The ages show that Mueller Glacier probably reached its Holocene maximum ~6000 years ago. Less extensive advances occurred ~ 3100-2800, ~1800-1700, ~600-450, ~300-200 and ~170-150 years ago. The Tasman moraine sequence comprises fewer preserved moraine loops, but advances have been dated to ~6100-5800 and ~1700-1500 years ago.

The responses of debris-covered, lake-terminating glaciers to climate change may be complicated. On temperate glaciers, most ablation occurs directly by melt, but changing surface debris cover and/or iceberg calving in lakes can significantly alter a glacier's balance. Using the case study of Tasman and Mueller Glacier retreat since the 19th Century, we argue that these processes are important, but do not mask the overarching climate signal. Surface debris acts to increase glacier response time during retreat, thus delaying the 'climatic' reaction, whilst lake formation enhances retreat once a critical point of surface lowering is exceeded.

Modelling of Brewster and Franz Josef Glaciers by Brian Anderson indicates that the mass balance of high-precipitation glaciers is sensitive to small atmospheric temperature changes. We hypothesise that the Tasman and Mueller moraines, which clearly document changing terminus length, are also dominantly indicators of past temperature. Simple response-time calculations show that these glaciers may 'view' climate a little differently. We speculate that the Mueller and Tasman Glaciers respond in decades during cold intervals when they have a cleaner ice surface and centuries during warmer times, when significant debris mantles develop. Differences in timing of moraine formation of these two glaciers may be a function of their response times.

Acknowledgement
I have benefited from recent discussions with Tim Kerr, Heather Purdie and Brian Anderson and earlier teaching by Andrew Ruddell and Martin Kirkbride. The Comer Science and Education Foundation is gratefully acknowledged.

Analysis of relationships between time series of snow-cover parameters and tributary inflow in the lakes of the upper Waitaki Catchment

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Time series of snow cover distribution and surface temperature have been retrieved from MODIS images over the period 2000-2007 in the Ohau, Pukaki and Tekapo catchments. The analysis of these time series along with the daily tributary inflows observed in the corresponding lakes offers promising perspectives towards a better understanding of the relationships between these parameters. We investigated the use of signal processing tools such as wavelet analysis to explore the dynamic of these signals and identify possible relationships.

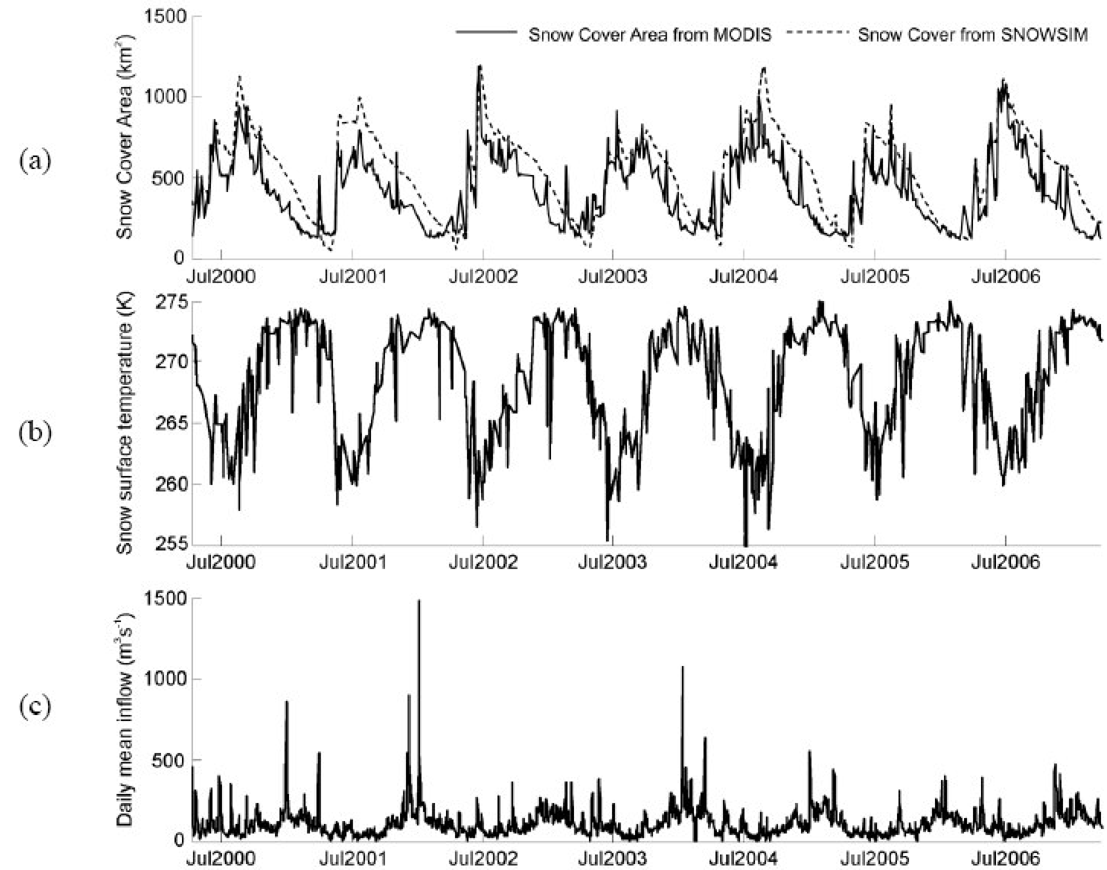

Figure 1 – Examples of times series used for the analysis: (a) comparison between the snow cover area retrieved from MODIS in the Pukaki catchment and the Snow cover area estimated in the SNOWSIM-Pukaki model; (b) Mean surface temperature of 23 selected sites of perennial snow in the Mount Cook region; (c) Daily mean tributary inflow of lake Pukaki (data courtesy of Meridian Energy).

Recent ice volume changes (1976-2005) for the big glaciers of the Southern Alps

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This paper presents the findings of ice lost to both surface lowering (downwasting) and proglacial lake growth, using topographic maps and longitudinal profile surveys, made in April 2007, on the 12 largest glaciers of Mt Cook National Park. The profile work, arranged by A. Willsman of NIWA, was carried out by helicopter and GPS.

The NIWA EOSS programme has found that, despite global warming, mass balance for most glaciers of the Southern Alps is near zero, but with substantial ice loss from down-wasting and calving into lakes at terminal areas of the largest valley glaciers. This follows a period of warming and persistent and accelerating glacier wastage from the termination of the "Little Ice Age" (1850 to 1890) to the mid 1970's. The largest debris-covered valley glaciers are still responding to this warming and have maintained their "Little Ice Age" areas for all but the last three decades. The relatively thick ice of the lower reaches of these glaciers was largely relict and insulated beneath thick protective mantles of debris. Ice loss was by slow surface lowering alone, with little or no terminus retreat.

The loss of ice volume from larger glaciers due to calving into the growing glacial lakes was 0.63 km^3 and tongue down-wasting, 5.37 km^3. This is large compared with those from the mass balance changes. The mass balance and overall ice losses are described in companion papers by Fitzharris et al and Salinger et al.

Overall ice volume trends and variation in ice volume in the Southern Alps 1976 - 2005

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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, described in a companion paper by Fitzharris et al., and the other using topographic changes, described in the companion paper by Chinn et al.

Years and seasons of considerable negative mass balance are marked by either, above average temperature anomalies, and/or reduced precipitation in the Southern Alps and increased east or north easterly circulation. Temperature and circulation appear to be the most important factors. Years and seasons with positive mass balances have below average temperature anomalies and above average or average precipitation. Generally these are associated with periods of stronger westerly or southwesterly circulation over New Zealand. The Southern Oscillation Index encapsulates all these features and is a useful climate index associated with variability. The large glaciers are still reacting to regional warming of about 1°C since the Little Ice Age, are extensively covered by a debris mantle in their lower reaches and are calving into pro-glacial lakes.

The overall results show a significant decrease in ice volume of the Southern Alps from 1976-2005, despite only a slightly negative mass balance averaged over this period. Ice volume over the monitoring period, as derived from $EOSS_{Alps}$ and estimates of mass balance, shows little cumulative change, with a loss from this source of only 0.49 km^3 from an estimated starting total volume of 54.60 km^3. This is but 8% of the total ice volume loss of for this period. The bulk of the ice volume loss (5.37 km^3) 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. For example, Ruddell (1995) estimates the total ice volume of the Southern Alps to be about 100 km^3 at about 1880, and at about 170 km^3 at 1850 (Heolzle and others, 2007). 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.

Changes in ice volume of glaciers of the Southern Alps since 1977

B.B. Fitzharris[1]*, J. Salinger*[2]*, T. Chinn*[3]*, A. Willsman*[4]
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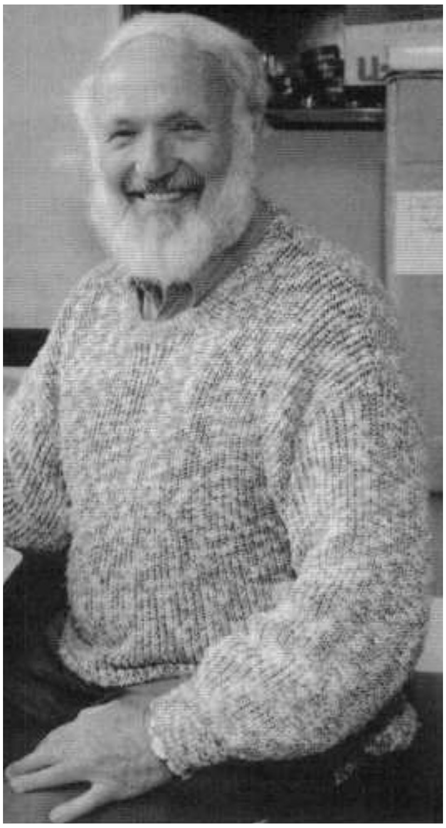
Methods for estimating changes in ice volume of the Southern Alps with global warming are briefly reviewed. New Zealand has a long and continuing record of annual end-of-summer-snowline (EOSS) measurements for a set of 46 index glaciers of the Southern Alps from 1977 to present. The EOSS values give an immediate, annual signal of mass change. There are also area-elevation curves available for each of the index glaciers. Estimates of the mean mass balance gradient can be used to convert changes in EOSS to changes in ice volume. Two gradient values, one for the accumulation area, and one for the ablation area are used. Ice volume changes since 1977 are calculated for each index glacier and extended to all small to medium sized glaciers of the Southern Alps using the New Zealand glacier inventory. Results show that over the last 30 years there has been a small loss of ice volume for these of 0.49 km^3. However, the method is not appropriate for calculating loss of ice volume from our largest glaciers. They have complications that arise from calving into growing glacial lakes and down-wasting beneath a debris cover at their tongues. Estimates of ice losses for these require a different method. Ice losses are much larger, as described in a companion papers by Chinn et al. and Salinger et al.

Guest speaker Colin Burrows



Colin Burrows. Photo: Duncan Shaw-Brown.

Author of "Julius Haast in the Southern Alps" published in 2005 in Christchurch by the Canterbury University Press.

Colin will be sharing his insight into glaciological changes in New Zealand's Southern Alps as revealed by the sketches by Julius Haast during Haast's explorations of the 1860's.

The following is taken from the back cover of the book:

"Colin Burrows is Canterbury-born and taught plant science at the University of Canterbury from 1960 to 1993. He has a PhD in plant ecology and a DSc in Quaternary science. His research has included study of recent as well as ancient glacial phenomena. His keen interest in mountaineering took him to most of the places that Haast visited."

To follow is a selection from some of snow and ice relevant publications of Colin Burrows:

Burrows, C.J. and Lucas, J., 1967. Variations in two New Zealand glaciers during the past 800 years. Nature, 216: 467-468.

Burrows, C.J., 1975. Late Pleistocene and Holocene moraines of the Cameron Valley, Arrowsmith Range, Canterbury, New Zealand. Arctic and Alpine Research, 7(2): 125-140.

Burrows, C.J., 1976. Icebergs in the Southern Ocean. New Zealand Geographer, 32: 127-138.

Burrows, C.J. and Burrows, V.L., 1976. Procedures for the study of snow avalanche chronology using growth layers of woody plants., United States Program on Man and the Biosphere UNESCO MAB project 6.

Burrows, C.J., 1977. Late-pleistocene & Holocene glacial episodes in the South Island New Zealand & some climatic implications. New Zealand Geographer, 33: 34-47.

Burrows, C.J., 1979. A chronology for cool-climate episodes in the Southern Hemisphere 12000-1000 Yr B.P. Palaeogeography, palaeoclimatology, palaeoecology, 27: 287-347.

Burrows, C.J. and Gellatly, A.F., 1982. Holocene glacier activity in New Zealand. Striae, 18: 41-47.

Salinger, M., Heine, M.J. and Burrows, C.J., 1983. Variations of the Stocking (Te Wae Wae) Glacier, Mount Cook and climatic relationships. New Zealand Journal of Science, 26: 321-338.

Burrows, C.J., 1989. Aranuian radiocarbon dates from moraines in the Mount Cook region, New Zealand. New Zealand Journal of Geology and Geophysics, 32: 205-216.

The dynamic response of the Warszawa Icecap, Antarctica to past & future climate change

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In 2002 a glaciological field-campaign was initiated on King George Island, South Shetlands with the aim of providing detailed geophysical, geodetic and meteorological measurements to constrain a modeling investigation of the response and sensitivity of its local ice-mass to recent past and forecast future climate scenarios. Ongoing measurements of surface velocity, mass-balance, englacial and basal radar reflectors along with remotely-sensed imagery provide boundary conditions for a 3D higher-order, thermomechanical flow model of the Warszawa icecap at 100 m resolution. The model is coupled to climate through a temperature-index melt and accumulation algorithm incorporating direct net radiation and snow-drifting effects which yield the time-dependent surface mass-balance boundary condition. Feedbacks between surface-melt and basal decoupling are also incorporated through the transfer of longitudinal stresses and a basal dynamics parameterization. An ensemble of spin-up experiments were run to validate the model against contemporary observables and to determine the primary influences on the present ice geometry. These experiments reveal the icecap to be ultra-sensitive to climate, rapidly responding to perturbations in temperature, precipitation, basal dynamics and ice calving. Prevailing wind-direction and aspect also exert control through their primary effect on mass accumulation and ablation. A further set of time-dependent experiments forced by palaeo-climate records/proxies to replicate post-Little Ice Age history through to the end of this century under the best and worst-case IPCC temperature trajectories reveals that the icefield was relatively stable until the mid-1950s, after which it's retreat has steadily accelerated. Given continuation of the recent rapid warming observed across the region, the Warszawa icefield will dwindle to <5% of its present volume by the end of this century though more conservative estimates of climate forcing, offset by enhanced precipitation, are arguably more likely and result in significantly less depreciation in ice cover. Hypsometric up-scaling of these results across the sub-Antarctic yields a net volume loss of between 143 GTonnes under a stabilization of the 2000 – 2005 climate to 986 GTonnes with an assumed 4ºC warming by the end of this century.

An ASTER Digital Elevation Model (DEM) for the Darwin-Hatherton Glacial System, Antarctica

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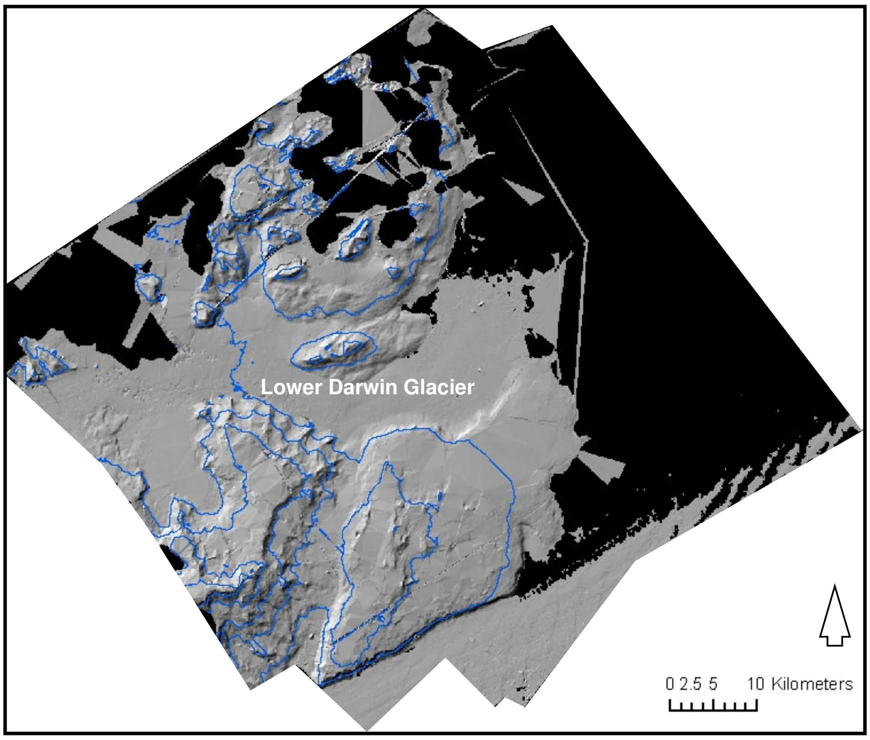
The Darwin-Hatherton glacial system is an outlet glacial system in the Transantarctic Mountains, Antarctica, which drains ice from the East Antarctic Ice Sheet into the Ross Ice Shelf. This research provides remotely sensed data that can be used in modelling research for the Darwin-Hatherton glacial system, which in turn can be used in mass balance research for the West Antarctic Ice Sheet.

Two improved digital elevation models (DEM) are produced to cover the lower Darwin Glacier and to cover the upper Darwin and Hatherton Glaciers. The new improved DEMs are generated from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data, with a resolution of 45 m. To produce the two final DEMs, multiple DEMs are firstly adjusted to remove systematic errors and are then stacked and averaged to increase the accuracy and produce the final two DEMs. For the lower Darwin Glacier, 5 DEMs were averaged and in the upper Darwin and Hatherton Glaciers, 6 DEMs were averaged. The accuracy is quantified by a remaining error of ± 9 m for the lower Darwin Glacier DEM and ± 37 m for the upper Darwin and Hatherton Glaciers DEM. This is a significant improvement from the existing 200 m resolution Radarsat Antarctic mapping project (RAMPv2) DEM which has a remaining error of ± 138 m over the lower Darwin Glacier and ± 152 m over the upper Darwin and Hatherton Glaciers. The accuracy is assessed by comparing the ASTER and RAMPv2 DEMs to highly accurate ice, cloud and land elevation satellite (ICESat) laser altimetry data.



DEM of the lower Darwin Glacier at 45 m resolution. Averaged from five individual ASTER DEMs. Hill-shade version with 500 m interval topographic contours.

Precise surface elevation mapping of polar ice sheets using differential SAR interferometry

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The surface elevation at the margins of the Antarctic ice sheet is largely unknown at the required accuracy to detect short term changes. This is partly because the resolution of conventional radar altimeters especially on the sloping coastal areas is too coarse. The Geoscience Laser Altimeter System (GLAS) onboard IceSat performs well with respect to vertical accuracy, but the satellite orbit allows only incomplete coverage. The derivation of accurate digital elevation models (DEM) using interferometric Synthetic Aperture Radar (INSAR) requires at least one pair of coherent interferograms, a precondition often not met. Other limitations for INSAR are, besides lack of ground control points, inaccuracies in the data processing and atmospheric conditions. In general, INSAR is especially useful to measure horizontal and vertical displacement due to the high sensitivity to ice motion.

In our study we try to fill the gaps between IceSat elevation profiles. We investigated the potential and accuracy of mid 1990s ERS-1/2 SAR data to derive DEMs by including large amounts of IceSat data, acquired after 2002, as ground control. Our main study area was Dronning Maud Land in East Antarctica, where we had a large amount of SAR data available.

The result of our study is a high resolution DEM with varying vertical and horizontal accuracy, which mostly outperforms currently available DEMs of that region. Taking all the uncertainties into account, we investigated the possibility that remaining errors and differences in quality are related to snow surface and volume properties, or are more likely a consequence of a real elevation change between the acquisition of SAR and IceSat data. Applying the proposed method to data in the western Ross Sea region, we also show an example of a preliminary DEM near Scott Base.

Implementation of the GLIMMER ice sheet model in the UVic ESCM

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The successful coupling of an updated, modular, standardized ice sheet model to an earth system model of intermediate complexity (EMIC) will allow for past and future behaviour of large-scale ice sheets to be studied over a wide range of timescales.
The coupling of the GLIMMER ice sheet model to the UVic ESCM is ongoing. The UVic ESCM is an established modular EMIC. It has been extensively used to study aspects of past, present and future climate over timescales of decades to millennia. GLIMMER is (at the core) a 3-D finite difference thermomechanical ice sheet model, with significant add-ons developed to enable efficient coupling to global climate models. It is also used for standalone studies of ice sheet dynamics, using prescribed boundary conditions.
Coupling and debugging of the UVic ESCM/GLIMMER model will be followed by initialization and validation tests and simulations of the coupled system to present and future climate change forcing. Future development of the model system will likely include the addition of ice sheet/shelf/ocean interactions and simulation of ice stream processes in large ice sheets.

Influence of the snow cover in the Northern Hemisphere on the climate in Western Europe during the cold season

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Latitudinal gradients of temperature and geopotential are large in winter and weak in summer, therefore in the mid latitude regions the prevailing westerly atmospheric flow is strong in the cold season and weak in the warm season. In a planet with continents, stationary Rossby waves are forced by the topographic features. The long waves, forced by the Rockies and by the Himalayas, have their trough at about one quarter of wavelength on the lee side of the mountains. As a result the planetary flow has a positive meridional component over the oceans off the east coast of the continents, and the streamfunction has a north-easterly tilt over the oceans. During winter, when the continents in the NH are colder than oceans, continents act as a diabatic source on the long planetary waves, and therefore they are a negative diabatic source, while the oceans are a positive diabatic source for the air mass in transit. This diabatic perturbation enhances the amplitude of the planetary waves on the lee of the continents, and the north-easterly tilt of the streamfunction over the ocean.

A westerly jetstream separates the cold high latitude air from the temperate mid latitude air. In a planet with continents the jetstream is broken into different branches by the alternate presence of the oceans and of the land masses. In wintertime, because of the thermal gradient between the continents and the oceans, the jetstream off the east coast of the continents is further south than the jetstream off the west coast of the continents. Since the jetstream acts as a waveguide for the winter storms over the oceans, and these storms carry most of the rain to west side of the continents during the cold season, it is important to evaluate the intensity and the north-easterly tilt of these stormtracks.

The intensity of AO (Arctic Oscillation) is strongly related to the extension of the ice coverage over the polar region, i.e., when the AO is positive the westerly jetstream is generally stronger and at lower latitude. The regional indices NAO (North Atlantic oscillation) and PNA (Pacific North America oscillation) are related to the environmental conditions over the continents and over the oceans. For instance, when it is cold and the snow is abundant over the North American continent, we expect that the NAO is positive, and that the Atlantic storms are, in the average, diverted towards North Europe.
We present preliminary results of a study on the slow variability of the long planetary waves in relation to the environmental conditions over continents in wintertime, mainly in relation to the snow cover over the North American continent and over the Asian continent and results on the teleconnection of the environmental conditions in North America with climate variability in West Europe.

Mapping and modelling seasonal snowcover over Storglaciären, Northern Sweden

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To investigate the relationship between changing seasonal snow cover and the net mass balance of Storglaciären in the Kebnekaise Massif, Northern Sweden, the seasonal snow cover over the glacier was both mapped and modelled. Classified remotely sensed imagery was used to test the accuracy of the snowline elevations produced by the climate model. The model simulated net specific and total seasonal snow, with the results being evaluated against field measurements of the winter and net mass balance of the glacier.

The snow cover was identified and mapped in two aerial photographs (2/9/1990, 9/9/1999), one Landsat 7 ETM+ image (31/7/2002) and two ASTER images (15/4/2004, 8/5/2004). The imagery was preprocessed to remove atmospheric interference before being georeferenced to the UTM WGS-84 Zone 34N projection. This was done in the programme ENVI version 4.2. Image classifications were then carried out within eCognition Professional version 5.0. This programme segmented the images into objects, which were then assigned a class based on user-defined rules. These rules were based on the spectral signatures of the object and the defining land cover type. From these images the snowline over the glacier surface was delineated. The elevation of the snowline was identified by overlaying the classified images onto a DEM. These results were then compared to the modelled snowline elevations.

A snow-wedge model was used to simulate the snow accumulation and ablation over Storglaciären for the period 01/01/1990 to 23/07/2006. Average daily air temperatures from the Tarfala Valley and total daily precipitation values from Kråkmo (Norway) were required as inputs. An initial run of the model using a degree-day factor (DDF) of 3.2 mm $^{o}C^{-1}$ d^{-1} and a threshold temperature of 1.5 ^{o}C over-simulated total seasonal snow volume, but accurately simulated snowline elevations. Increasing the DDF to 8.0 mm $^{o}C^{-1}$ d^{-1} and changing the threshold temperature to 1.0 ^{o}C produced results which best fitted the observed Storglaciären net mass balances. Though this model simulated more realistic total seasonal snow volumes it produced snowline elevations that were too high compared to the remotely sensed imagery results. Therefore, the correct degree-day factor lies somewhere between the two.

The model run with the DDF of 8.0 mm $^{o}C^{-1}$ d^{-1} indicated a decrease during the study period in the volume of total seasonal snow at the highest elevations. After 2002 no snow remained on the glacier surface following the summer melt seasons. These results are correlated to the rising ELA over the study period and the observed negative mass balances from 2001 onwards. Though the model used was found to be sensitive to errors in the input parameters, a strong link between seasonal snow distribution and the net mass balance of Storglaciären is evident. These findings also highlight the important implications for the combined use of remotely sensed imagery analysis with climate model simulations in order to obtain accurate representation of the snow cover distribution within a glacierised catchment.

Snow and groundwater recharge in Canterbury

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Recharge to groundwater associated with two snowfalls on the Canterbury Plains is assessed at five groundwater recharge monitoring sites.

Snow and rainfall from a snow storm on and around 19 September 2005, following dry antecedent conditions on the Canterbury Plains, produced up to 77.5 mm of ground-level precipitation at groundwater recharge sites. Recharge to groundwater at three of the five groundwater recharge sites is associated with the snow storm. The largest measured groundwater recharge was 24 mm at Winchmore; no recharge was measured at Lincoln and Hororata.

Snowfall was widespread in Canterbury on 11 and 12 June 2006 after a period of relatively wet conditions in Canterbury. Up to 65 cm of snow was recorded on the Canterbury Plains with the largest snowfall at Winchmore. Precipitation (including rainfall, presumably, and snow melt) during the storm event at five groundwater recharge sites was at most 59.1 mm.

Groundwater recharge began soon after (3 to 4 hours) the onset of precipitation in the storm. Groundwater recharge and precipitation for the period 11 June to 30 June 2006 (including snow and rainfall) is large:

- Christchurch Airport 65.5 mm groundwater recharge from 100.5 mm precipitation;
- Lincoln 39.7 mm groundwater recharge from 119 mm precipitation;
- Dunsandel 148 mm groundwater recharge from 172 mm precipitation;
- Hororata 136.2 mm groundwater recharge from 136 mm precipitation;
- Winchmore 58 mm groundwater recharge from 102.5 mm precipitation.

Snowfall, and rainfall in large storm events, is significant to total groundwater recharge in Canterbury and is therefore important for Canterbury water resources. For example groundwater recharge for the period 11 June to 30 June 2006 is:

- greater than total groundwater recharge for the 2005 calendar year at Lincoln and Hororata;
- equivalent to approximately 200 million cubic metres of water on the Canterbury Plains in the catchment of Te Waihoa/Lake Ellesmere which is 53% to 99% of the range in estimated annual groundwater use in the catchment of Te Waihoa/Lake Ellesmere.

White, P.A. (2007) Snow storms in Canterbury and recharge to groundwater. *GNS Client report 2007/87 to Environment Canterbury*, 46p.

Gradients of mass balance sensitivity and volume changes in the Southern Alps

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Maritime glaciers have the greatest sensitivity to climatic changes, because they occur in high-precipitation environments. This high sensitivity, combined with short response times compared to ice sheets, means that maritime glaciers will make a significant contribution to sea-level rise in the coming decades, as the climate warms. Calculations of glacier sensitivity and volume change are common for individual glaciers, but have rarely been undertaken on a regional basis. Here, we use an energy balance model on a regional scale to calculate the mass balance sensitivity of the ice mass in the central portion of the Southern Alps of New Zealand. Using a thirty-year dataset of gridded climatology, the changes in mass balance and glacier volume in this area are calculated. The model is tuned against mass balance measurements on a few glaciers, and evaluated against annual snowline measurements on many glaciers over the thirty-year period.

Snow and ice research information to the world through Google Earth

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The recent explosion of open source virtual globe systems such as Google Earth, Microsoft Virtual Earth and NASA World Wind provide an ideal platform for sharing geographic research information with the world. Three examples of using the Google Earth platform to share snow and ice geographic information with the world are presented.

The first example presents maps of the estimated daily snow cover in the Lake Pukaki region from output of the SnowSim-Pukaki snow storage model. This example uses time stamps, allowing for viewing of a specific day's snow cover, or animating a sequence to see how the snow cover changes.

The second example provides avalanche hazard area information for the Aoraki/Mt Cook region. The hazard areas were derived from an operational hazard report. Geographic information system processing based on the hazard report was used to prepare the hazard maps prior to publishing to a Google Earth format.

The third example compares snow and ice photographs with the Google Earth view as seen from the location that the photo was taken from. This provides a simple but powerful method of placing an image in its correct spatial and/or temporal context.
The three examples demonstrate the potential for public access to research in a user-friendly format enabling improved community outreach.

Evidence of climate states in the records of flow into the southern lakes

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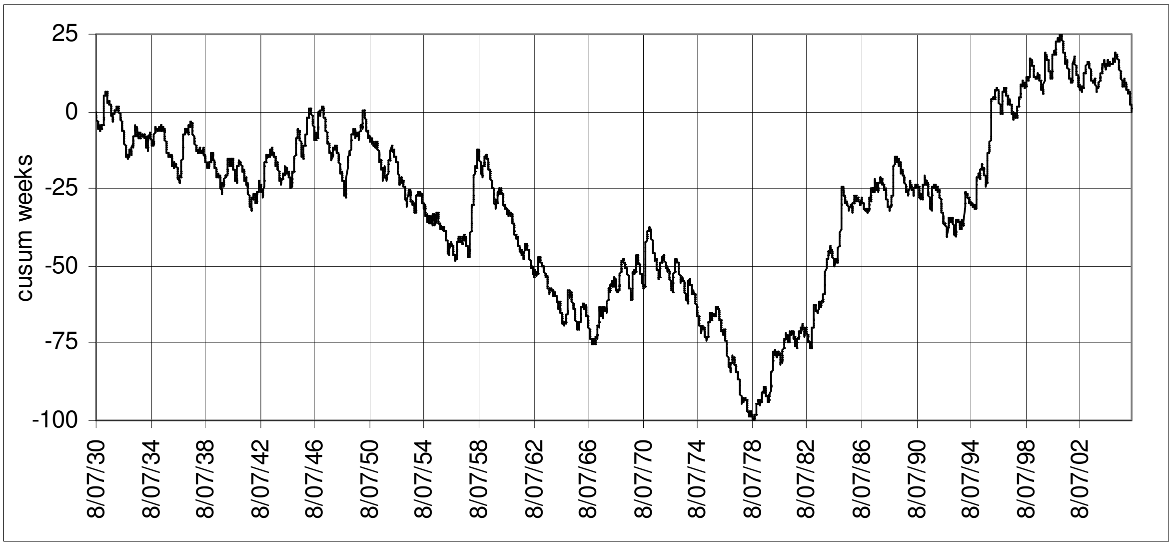
Flows from the eight largest lakes in the Southern Alps: Tekapo, Pukaki, Ohau, Hawea, Wanaka, Wakatipu, TeAnau and Manapouri have all been measured since 1926, or soon after.

Using these out-flow records and the lake level records measured at the same time we can calculate eight in-flow records, and these are highly cross-correlated.

The in-flow records all look like the following graph when each is plotted as a "cusum", that is as the accumulated sum of (one minus the flow divided by its mean).



The climate states were:

normal before 1946, drought to 1978, wet to 2001 then drought.

The change in 1978 was 18%. The periods of drought before and wet after 1978 correspond to opposite phases of the Pacific Decadal Oscillation, and aspect of global atmospheric circulation.

It seems likely that some snow fields that were melting away up to 1978 will have been accumulating snow since then, at least until 2001, and more recently will be melting again.

Are there snow records that show this? Do the shorter period fluctuations in this graph show up in snow records?

Field trip option 1 – Glaciation of the Waimakariri Valley

Led by Dr Trevor Chinn

Dr Trevor Chinn mapped the late quaternary moraine deposits of this area as part of his Masters research. This makes him admirably qualified to lead this field trip and share his knowledge of past and present glaciations in the valley. The exact itinerary of the field trip will be decided on the day (depending on weather and whim) but will include transportation by both motor vehicle and foot.

The map below, taken from Maxwell Gage's 1958 paper on the glaciations in the area, provides an impression of the variety of glacial deposits within close vicinity of the Cass field centre.

There is no limit to the number of participants on this trip. Personal gear for walking and protection from the sun is required.

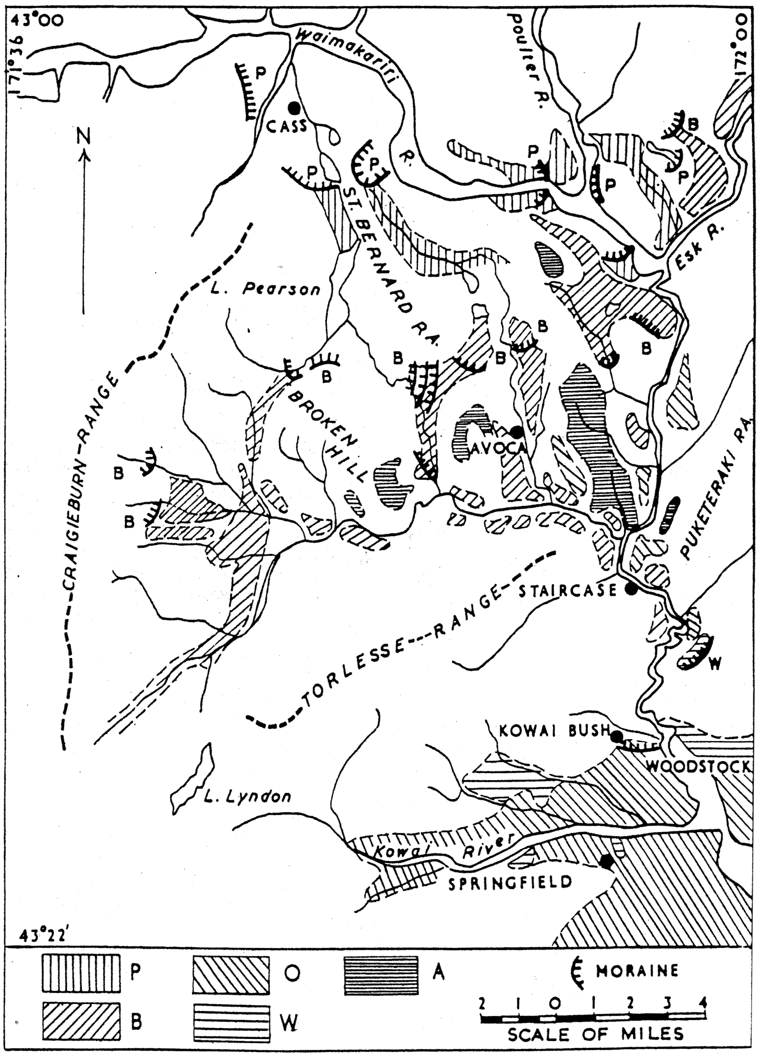


Figure 1. Late Pleistocene deposits in the middle reaches of the Waimakariri Valley. A = Avoca Glaciation; W = Woodstock Advance; O = Otarama Advance; B = Blackwater Advance; P = Poulter Advance. From Gage1958. Note the position of Cass in the upper middle part of the map.

Field trip option 2 – Rolleston Glacier

Led by Tim Kerr

Dorothea Stumm advocated during the 2007 NZ SIRG meeting that the Rolleston Glacier should be monitored as part of New Zealand's glacier research commitments. This field trip will visit the glacier to enable meeting participants to see first hand what Dorothea has been describing. The plan is for an early start, drive to Arthurs Pass (30-40 min), walk up to the glacier (a steep trail taking about three hours), install a climate station, re-drill ablation stakes, scope out the area in anticipation of future glaciological work, walk back down and be back at Cass in time for tea. This will take all day. See the map below for an idea of the journey.

For safety numbers will be limited on this trip (two groups of five). Participants will need to be fit and healthy and be fully equipped for a day in the mountains:

Sunglasses	Complete warm layer (e.g. long johns and top)
Sun hat	A second warm top (e.g. fleece jacket)
Boots, socks	Complete waterproof layer, both coat and leggings
Water bottle	Gloves
Sun screen	Warm hat

A helmet and an ice axe will be provided. Crampons will not be required. In the unlikely event that the glacier surface is too firm for safe travel with boots alone, then it will be viewed but not touched.

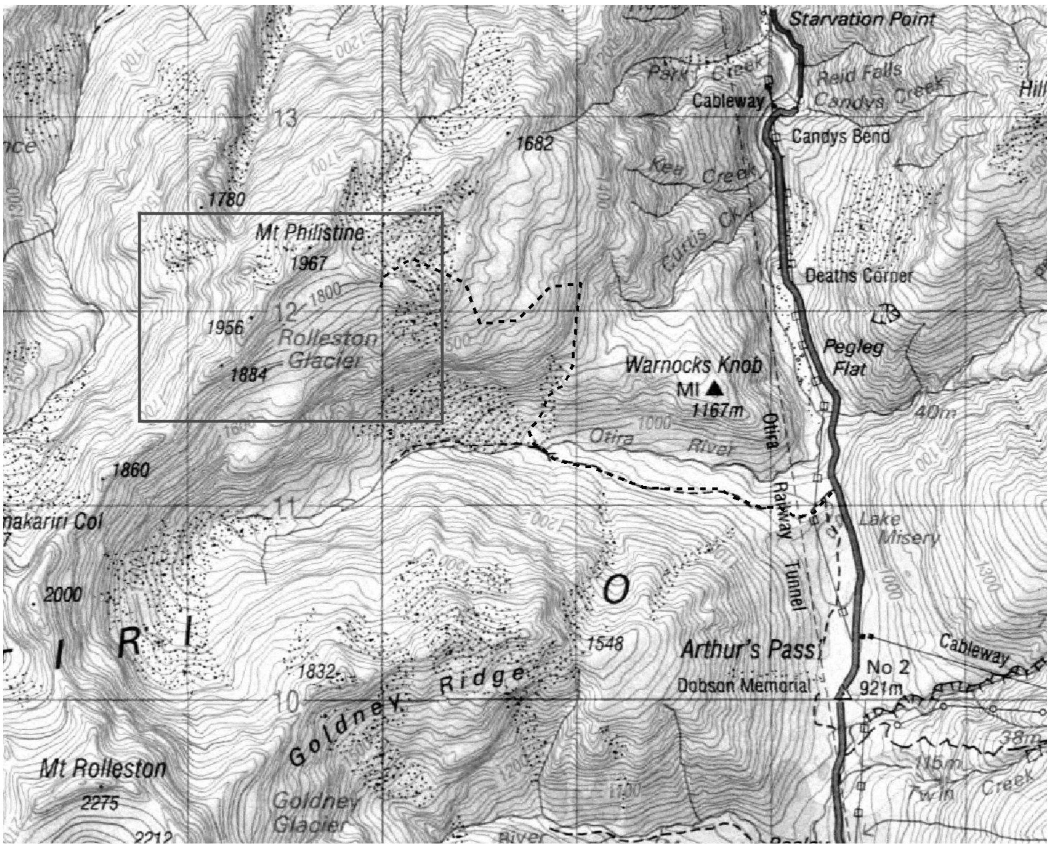


Figure 2. Trail to the Rolleston Glacier from the road near Arthurs Pass. Contour interval is 20 m, grid squares are at 1 km spacing. North is up.

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