SIRG2013

Snow and Ice Research Group (NZ) Annual Workshop

Otago Yacht Club, Dunedin, New Zealand, 11th-13th February 2013

SCHEDULE & ABSTRACTS

UNIVERSITY of OTAGO
Te Whare Wānanga o Otāgo
NEW ZEALAND

UNIVERSITY OF OTAGO
GEOGRAPHY
Te Ihowhenua

NIWA
Taihoro Nukurangi

POLAR ENVIRONMENTS
otago research theme

IGS

The SIRG 2013 Annual Workshop was kindly sponsored by

National Institute of Water and Atmospheric Research (NIWA)
The Polar Environments Research Theme, University of Otago
The Department of Geography, University of Otago

Organising Committee:

Nicolas Cullen
Pascal Sirguey
Inka Koch
Jono Conway
Sebastian Vivero

Cover image: Glenmary Glacier; Courtesy of Pascal Sirguey

PROGRAM

MONDAY 11th FEBRUARY 2013		Pg.
BY 12:00	**ARRIVE AT OTAGO YACHT CLUB – REGISTRATION PAYMENT**	
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	KEYNOTE SPEECH	
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17:00	*Heather Purdie* 'Glacier retreat and glacier tourism: potential for collaboration of science and industry'	16
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9:15	*Pascal Sirguey* 'Linking glacier annual mass balance and glacier albedo retrieved from MODIS data'	20
9:30	*Kimberly Hageman* 'Increased concentrations of organic contaminants in New Zealand alpine streams during annual snowmelt'	21
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13:00	**DEPARTURE**	

TEN YEARS ON FROM THE INAUGURAL SIRG WORKSHOP OF 2003 AND WHITHER THE NEXT DECADE?

Fitzharris, B.B.[1]

[1]Department of Geography, University of Otago

This meeting marks a decade of the NZ Snow and Ice Research Group (SIRG). It was first established at a Workshop held at the University of Otago, Dunedin on 13-14 February 2003 and consolidated at a second Workshop in Queenstown a year later. After ten years it is perhaps timely to look back to issues and ideas discussed then, to reflect on how far we have come, and look ahead another decade.

A first aim of our inaugural Workshop was to explore ways in which the research community in New Zealand might further our involvement with GLIMS and the remote sensing of seasonal snow. A second was to review the current status of research on snow and ice in NZ. A third was to develop a strategic view and action plan for research. SIRG was established to help pursue this plan and to provide a forum where people might meet, network and discuss research programmes.

Key issues for research were identified as follows:

- We need to know both relative and absolute changes in ice volume for NZ glaciers.
- We noted that although their contribution to global sea level change is likely to be small, NZ glaciers are key indicators as to what might be happening in the Southern Hemisphere.
- We need to better understand the links between global and regional climate change and the likely impacts on snow and ice in NZ.
- We recognized that snow/ice data is important for understanding and quantifying the contribution of seasonal snow and glacier melt to NZ water resources. Data is also required for development and testing of snow and ice models.
- We need to improve our understanding of glacier dynamics and of sedimentary and geomorphological changes.
- We considered that all of the above will help in our understanding of the geography of impacts likely to occur with projected climate change.
- We thought that more attention needs to be given to sources of funding for field experiments and their ongoing management.
- We called for the establishment of stronger partnerships among universities, CRIs, DOC, as well as with commercial guides, ski and helicopter companies.

Some big issues underlay this thinking, especially ways to better interact with GLIMS and its international community, the UNFCCC plus the Kyoto Protocol, and the need for improved resource management, planning decisions and hazard mitigation. Specific monitoring needs were also discussed: more glacier mass balance experiments; ice thickness measurements from ground penetrating radar; and information on vertical mass balance gradients across the Southern Alps.

The presentation will initiate discussion as to how well these issues have been addressed over the last decade. What more needs to be done? Have new issues arisen in importance? What are the issues that the snow and ice community of NZ think will be important over the next decade?

INTERPRETING GLACIER BEHAVIOURS

Chinn, T. J.[1], Willsman, A.[2]

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[2]National Institute of Water and Atmospheric Research, Dunedin

Much of the interest in glaciers is because they make spectacular meteorological instruments where interpretation can be driven by sensation rather than information. A rewarding method of interpreting glacial response to climate is to use two basic principles of glaciers;

1. A glacier has formed because the regional snowline (ELA) lies below the highest topography. This provides the net annual mass input that is subsequently shaped by the local topography.
2. A glacier's response to climate is fundamentally a change in ice volume brought on by shifts in the ELA. Thus a glacier should be picked up and weighed at regular intervals, but we are forced to use a surrogate that is related to this weight measurement.

Here we first consider the effects of ELA rises on small cirques and glacierettes; next, the larger and generally steeper mountain glaciers which are commonly assessed by length changes.

Lower the snowlines on an array of alpine glaciers and they will advance to coalesce into a big valley glacier. Such glaciers may be treated as a group of alpine glaciers feeding into a valley ice pond. These systems have multiple additional processes to consider that include parallel downwasting, debris cover, delayed equilibrium response and inundation by Lake Invasion. Debris mantled glaciers present some additional processes such as thermokast decay with stepped retreat, simultaneous advance and retreat, and finally "stagnant ice".

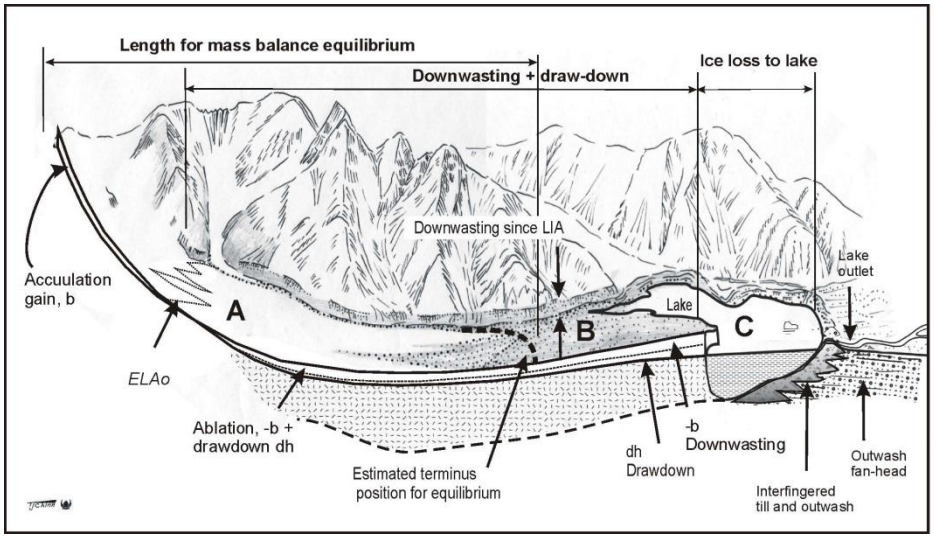

Figure 1 - Zones encountered on the large debris mantled glaciers with invading lakes. A = area about ELA0 which would be used for annual volume changes were it not for the additional relict debris covered ice tongue 'B' and the volume lost to invading lake 'C'.

Chinn,T., Salinger, J., Fitzharris, B.B., Willsman, A. 2012. Annual Ice Volume Changes 1976-2008 for the New Zealand Southern Alps. *Global and Planetary Change* **92-93**: 105-118.

WHAT CAN NEW ZEALAND'S NORTHERNMOST GLACIERS TELL US ABOUT PAST CLIMATE CHANGE?

Eaves, S. R.[1], Mackintosh, A.[1], Townsend, D.[2], Anderson, B.[1]

[1]Antarctic Research Centre, Victoria University of Wellington, NZ.
[2]GNS Science, Avalon, Lower Hutt. NZ.

Here we report findings from detailed field- and remote sensing-based geomorphological mapping of glacial deposits on the volcanic cones of Mt. Ruapehu and the Tongariro massif. This work has revealed a more complex moraine record than previously recognised, potentially documenting orbital and millennial-scale glacier fluctuations through the late Quaternary to present day. Surface exposure dating and numerical modelling of these former glacial extents will constrain the timing and magnitude of these changes. Understanding the driving forces behind large-scale climatic shifts in the recent geological past is vital in order to improve prediction of future change. Milankovitch's orbital theory of the ice ages predicts anti-phased glacial cycles between the hemispheres, in response to local insolation forcing. However, glaciers and ice sheets worldwide reached their late Quaternary maximum extents synchronously during the Last Glacial Maximum (26-19ka). Subsequent global deglaciation was punctuated by rapid, millennial-scale climate reversals that were directly anti-phased between the poles. The precise mechanisms of these orbital- and millennial-scale climatic shifts remain equivocal; however recent hypotheses invoke complex global-scale teleconnections through components of the global atmosphere-ocean system such as, local insolation, atmospheric CO2, zonal wind belts, polar sea-ice and oceanic meridional overturning circulation. The relative roles of such components in driving past climatic changes in New Zealand will be assessed through comparison of our results with well-dated climate proxy data from the Southern Alps and more distal locations, in order to identify regional and interhemispheric lead-lag times, or phasing, of climatic events.

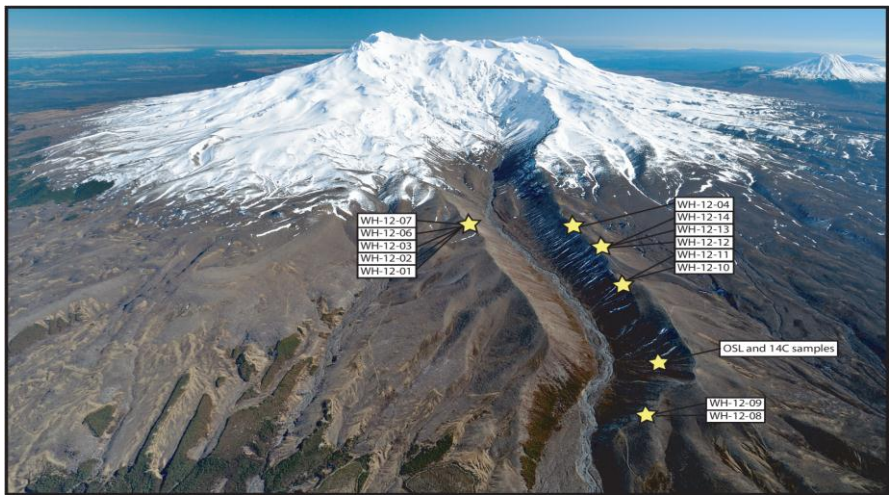

Figure 1 - Mt Ruapehu (2797m. asl) is the highest peak in the North Island and forms the northernmost limit of modern glaciation in New Zealand. Moraine-lined glacial valleys (e.g. image centre) radiate from the active volcanic cone, indicating more extensive ice cover in the recent geological past. Geochronological samples are shown in yellow (Photo: D. Townsend).

ARE TEMPERATE, AVALANCHE-FED GLACIERS SENSITIVE TO CLIMATIC CHANGE?

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[2]Alpine and Polar Processes Consultancy, Lake Hawea, New Zealand

Glaciers in complex mountain topography are typically avoided for mass balance studies because of fieldwork avalanche hazards and uncertainty in the sensitivity of avalanche-fed glaciers to climatic change. Gravitational mass transport and deposition (MTD) of snow occurs frequently in the steep and complex terrain of the Southern Alps of New Zealand and is a significant contributor of snow accumulation for many glaciers. We combine a gravitational snow MTD model with an energy-balance model at a daily time step to simulate 33 years of mass balance (1977 to 2010). This modelling approach allows us to assess the importance of gravitational snow redistribution on the overall mass balance of the Cameron, South Cameron, and Douglas glaciers, located in the Arrowsmith Range. We also compare the modelled annual mass balance to observed end of summer snowline (EOSS) for Douglas Glacier. The modelled mass balance and observed EOSS values fluctuate together, showing that the models are capturing the climatic signals that drive glacier mass balance. The amplitude of modelled annual mass balance from the mean for Cameron Glacier is much greater than that of Douglas Glacier, indicating that snow MTD processes have an amplifying effect on mass balance for glaciers that receive a large volume of mass from this process.

Figure 1 - Cameron Glacier in the Arrowsmith Range, New Zealand.

INTER-ANNUAL VARIABILITY OF ICEBERG CALVING EVENTS AT TASMAN GLACIER

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At Tasman Glacier, a retreating freshwater-terminating glacier, iceberg calving occurs across a wide range of temporal and spatial scales. During the past decade Tasman Glacier has retreated *c.* 6 km, corresponding to an average decrease in ice surface loss at the terminus of 0.37 $km^2\ a^{-1}$, through a combination of melting of the lower glacier and iceberg calving. However, an order of magnitude increase in retreat occurred since 2006 with peak retreat rates in excess of 1.5 $km^2\ a^{-1}$. To better understand calving at time-scales shorter than annually derived calving rates a time-lapse camera was installed overlooking Tasman Glacier between October 2011 and November 2012. Using this continuous image set we describe how iceberg calving varies temporally, spatially, and dynamically. A total of 365 individual calving events were identified at a rate of 0.94 events d^{-1}. Significant seasonal differences in the number of calving events were observed with up to 2 events d^{-1} recorded during January and February 2012 compared with 0.1 events d^{-1} between July and August 2012. The lateral length scales of ice blocks calved during individual events varied by almost 5 orders of magnitude, ranging from very small (metre) to very large events encompassing the entire width of the terminus (*c.* 1 km across). The image set time-series allowed for grouping all identified calving events into one of four dominant calving style classes: calving induced thermo-erosional notching, over-steepening of the ice-cliff, sub-aqueous calving and buoyancy-driven calving events. Calving events driven by thermo-erosional notching were the most frequent of all calving events, followed by over-steepening event, sub-aqueous calving and buoyancy-driven calving events. Despite being the least frequent of the four calving style classes, buoyancy-driven calving events were the largest magnitude calving events and had the greatest effect on glacier retreat during the observation period. The increase in calving frequency during spring and summer 2011/12 is directly related to the increase in thermo-erosional notch events. Correlation of calving frequency, lake level and lake temperature time-series data shows that these frequency changes are related to the stability in lake level and elevated lake temperatures. This indicates that although Tasman Glacier has increased in the rate of retreat, smaller calving events dominate the total number of events; with larger magnitude buoyancy-driven calving events having the greatest impact on net glacier retreat.

THICKNESS AND VOLUME CHANGES OF THE TASMAN GLACIER, NEW ZEALAND, FROM GEODETIC ELEVATION CHANGES

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[4]Instituto de Geología y del Medio Ambiente - IGEMA, La Paz, Bolivia

The Tasman Glacier is New Zealand's largest ice body, and since the early 1990s it has undergone rapid frontal retreat associated with proglacial lake development. In this study, aerial photographs and bathymetric data were used to derive two high-resolution digital elevation models (DEM) of the Tasman Glacier. Detailed multitemporal DEM differencing analyses facilitated quantification of geodetic surface elevation and mass balance changes. The main glacier and its tributaries have lost 1.972 ± 0.005 km^3 of ice between 1986 and 2008. Approximately 28% of this lost volume has been substituted by the Tasman proglacial lake. This volume loss corresponds to a geodetic balance of ¬0.87 ± 0.002 m w.e. yr^{-1}. Our analysis revealed diverse spatial patterns of thickness change, varying between the tributaries and within and between elevation bins. Reworked and transported material from rockfall deposits produced localised areas of positive elevation changes on the lower trunk. Previous ice volume change estimates may have underestimated mass loss from the Tasman Glacier, at least partly due to a lack of bathymetric data to account for glacier-wide volume variation. The methods developed in this study offer promise for glacier monitoring in New Zealand, where old aerial photographs are available but have not previously been processed using such advanced techniques.

APPLYING GEOPHYSICAL METHODS TO CONSTRAIN ICE THICKNESS: TASMAN GLACIER, NEW ZEALAND

Hart, R.J.[1], Mackintosh, A.M.[1], Horgan, H.J.[1], Anderson, B.M.[1]

[1]Antarctc Research Centre, Victoria University of Wellington

The Tasman Glacier in the Southern Alps is New Zealand's largest glacier and is an important indicator of climate. The climatic response of the Tasman Glacier is complicated by two factors: 1) several metres of debris blankets the lower glacier which retards surface melt, and 2) the glacier has recently entered a period of iceberg calving into a pro-glacial lake (Lake Tasman). Along with climatic controls, these complications have an important role in the mass-balance of the Tasman Glacier. In particular, basal topography, which may be linked to the rate of iceberg calving at Lake Tasman, is still largely unexplored beneath the Tasman Glacier.

The study is focussed on contributing a higher resolution dataset of basal topography for the Tasman Glacier. This will be achieved by exploring the distribution of ice-thickness across the glacier using geophysical techniques. Ice-thickness will be measured using Ground-Penetrating Radar (GPR), gravity and active-source seismic methods across the clean and debris covered portions of the glacier. By constraining basal topography to a higher degree, inferences into the future response of the terminus can be made for the Tasman Glacier.

TOWARDS A NETWORK OF GROUND-BASED CAMERAS FOR MONITORING GLACIER CHANGE

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[1]Victoria University of Wellington

Terrestrial photogrammetry offers several advantages over other forms of glacier monitoring, by providing data on snow cover, glacier dynamics and ice thickness change at high temporal and spatial resolution. The advantages are particularly pronounced in areas where glaciers are steep and fast flowing and cloud cover is frequent. Given the relatively low cost of digital cameras and emerging open-source software and electronics it is now possible to construct telemetred programmetry systems at low cost, using largely off-the-shelf parts. The system described here is controlled by an Arduino-based, GPS-disciplined timer which provides the accurate timing required for timelapse photography and low-power intermittent wireless networks. Camera settings, data capture, and network data transfer are controlled by a Raspberry Pi linux computer. Wireless communication is via consumer-grade wireless modules which are capable of up to 10 km range and 150 Mbps transfer rate. The system is easily extensible by, for example, adding information from high-precision GPS units installed on glaciers to the data stream, and repeaters where line-of-sight to a base station is not available. Examples are given at Franz Josef and Tasman Glaciers, where three cameras using this system have been recently installed, giving near real time images of glacier change. A collaborative project expanding this network would add greatly to the availability of glaciological data from New Zealand glaciers.

ENGLACIAL HYDROLOGY OF ANNETTE PLATEAU, A TEMPERATE ALPINE GLACIER

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[1]Victoria University Wellington, [2]Geological & Nuclear Sciences

Recent ice coring attempts in New Zealand's temperate alpine glaciers were not successful in coring to bedrock due to the interception of water at depth. The hydrology of temperate alpine glaciers is poorly understood due to the inaccessibility of englacial environments. Ground penetrating radar (GPR) is used to conduct high-resolution surveys on the upper 600 m of Annette Plateau, a temperate alpine glacier. The first survey was completed at the end of winter 2011 and second in early summer 2011. Across glacier profiles were acquired at 20 m spacing and 100 m down glacier to enable tracking of englacial reflectors between profiles. Models of temperate englacial features were made to produce synthetic radargrams, which aid feature identification within radar profiles. Radar data is also compared with ice core chemistry drilled at Annette Plateau in winter 2009. The early-summer survey indicates an increase in water content compared with the late-winter survey. Englacial reflectors show evidence of (a) spatially continuous englacial conduits, (b) the formation of a water table feature which shallows down glacier, and (c) detailed bedrock topography. Hydro-potential surfaces, calculated for the water table and bedrock horizons, show the preferred flow of water. Ice core chemistry shows a correlation between the depth of the water table and an age break in the tritium record. We infer that an extensive water table has formed on an old melt surface where ice from ~1930-1991 has been removed. This water table responds to the seasonal temperature changes and hydrological inputs.

HOW SIGNIFICANT IS BASAL AND ENGLACIAL MELTING TO TEMPERATE GLACIER MASS BALANCE?

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Omission of basal and englacial processes from temperate glacier mass balance models is an oversight that needs addressing. Mass balance models are one of the most widely used tools for exploring climatological-glaciological processes including the response of glaciers to climatic change. Since surface ablation is the dominant contributor to glacier melt and is relatively easy to measure, it is often the only source of ablation used in models. Basal and englacial melting is traditionally considered insignificant and it is more challenging to measure; consequently it is often ignored. However, recent quantification of melt water contributions from these sources, show that they may be significant components of glacier mass balance. The purpose of this presentation is to: (i) provide an overview of basal and englacial melting processes in relation to melting within temperate glacier settings; (ii) discuss methods that can be used to overcome issues associated with estimating the spatial distribution of basal and englacial melt; (iii) use a one-dimensional ice-flow model to investigate the significance of basal and englacial melt in temperate glacier settings; and (iv) assess the implications for glacier mass balance if basal and englacial melt processes are not included in models. Not including basal and englacial melt components when considering glacier mass balance may represent a systematic bias error in balance calculations, which may lead to misinterpretation of some positive balance years.

MODELLING SURFACE TEMPERATURE ON A COLD-BASED GLACIER

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Whilst the quantity of energy received at the glacier surface is clearly an important control on melt timing and quantity, often the major determinant of melt, especially over cold glaciers, is the surface temperature (TS). Admittedly, not only is TS important for dictating whether melt occurs or not, but it also controls several heat fluxes, such as outgoing longwave radiation, the turbulent heat fluxes and the subsurface heat flux. Modelling ice TS is never a trivial matter, especially over glaciers where the temperature may be near but not at the melting point. In this study we compare three different treatments of calculating TS over a cold glacier in the semi-arid Andes of Chile in order to assess the suitability of different methods over cold-based glaciers. Ice TS was calculated: using the residual flux scheme of Klok and Oerlemans (2002) (M1); using an iterative adjustment (M2); and assuming that the TS was constant at 0ºC (M3). These three methods were compared with measured TS results to assess the 'best' model. All models were subsequently used within an energy balance model to assess their impact on modelled melt results. For this environment, using M1 appeared to give the most reasonable surface change results from the energy balance modelling. However, when the TS results were compared with measurements, the phase and amplitude of the data did not correspond well. From this study we would promote caution in the use of TS models on cold-based glaciers, and would suggest a reanalysis of suitable approaches.

References

Klok E.J., Oerlemans J. 2002. Model study of the spatial distribution of the energy and mass balance of Morteratschgletscher, Switzerland. *Journal of Glaciology* **48**(163): 505–518.

GLACIER RETREAT AND GLACIER TOURISM: POTENTIAL FOR COLLABORATION OF SCIENCE AND INDUSTRY

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Glacier tourism is a multi-million dollar industry in New Zealand, but recent rapid glacial retreat is presenting challenges to the guiding companies who try to maintain safe access routes. As glaciers thin, surface morphology changes, for example crevassing, debris cover and slope angles, can complicate foot access. However, while access onto the Franz Josef Glacier has become limited, an enlarging pro-glacial lake has increased tourism opportunities at Tasman Glacier. Internationally, adaptation measures to maintain glacier-related tourism have in some cases, been extreme. Currently the Department of Conservation is undertaking a review of the Westland *Tai Poutini* National Park Management Plan, seeking to find balance between utilisation and conservation of the glacial resource. Opportunity exists for scientists to refocus glaciological research over shorter timescales, thereby providing knowledge that will assist policy development and decisions on future glacier utilisation and accessibility. Results of a preliminary geophysical survey of ice thickness on the lower Fox Glacier are a step in this direction; such surveys may help predict potential changes and challenges for guiding companies as the glaciers continue to retreat.

NEW ZEALAND GLACIOLOGY: WHERE NEXT?

MacAyeal, D.R.[1]

[1]Department of Geophysical Sciences, University of Chicago
and representing the
International Glaciological Society

New Zealand has an extremely accomplished and productive glaciological research community. What has inspired this excellence in the past has been the natural curiosity of the Kiwi and the fact that New Zealand's snow and ice systems exemplify global ice and climate problems writ small within the local confines of an island nation. It is time for New Zealand glaciology to take pause from its work and to reflect on what comes next. My suggestion is for a focus on how the ice and snow systems of NZ present opportunities to study supraglacial hydrology – the part of glaciology that will arguably take the greatest impact from climate change over the coming century. I shall review the field of supraglacial hydrology from the standpoint of my participation in large-scale ice sheet supraglacial lake research, as well as that gained from the fact that I have attended 11 glaciological research symposia, meetings and workshops since I took office as the IGS president in summer of 2011. With New Zealand's strong gradients of precipitation and elevation, and variable snow and ice regimes ranging from high-snowfall névés to debris covered ice, there may be many local analogues for supraglacial systems found elsewhere in the world. This may represent an opportunity for NZ researchers to both address important problems at home and abroad.

AN ASSESSMENT OF THE UNCERTAINTY IN DAILY SNOW ACCUMULATION MODELS THAT USE A TEMPERATURE THRESHOLD TO DISCERN BETWEEN SNOW AND RAIN

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Snow models that operate at a daily time step are common through their computational efficiency and compatibility with available data. Applying a simple temperature threshold to determine whether precipitation falls as snow or rain is often used as part of the snow accumulation component of these models. This approach has an inherent uncertainty in that when the threshold temperature falls between the daily maximum and minimum, there is an over or under estimation of the actual precipitation.

This uncertainty is difficult to assess in New Zealand because of a lack of precipitation gauges that can measure both snow and rain. To overcome this problem, an assessment has been made of thresholding rain at a warm temperature for a site where only rain falls. The observed rainfall is divided into warm and cold bins according to various different threshold levels at daily and ten-minute (the frequency of observations at the site) time steps. The difference in the amount of cold rain between the daily and the ten minute assessments provides an estimate of the uncertainty of the daily model. The uncertainty is found to be dependent on where the threshold level is with respect to the daily temperature range. Over a long term, for regions with an average temperature much higher than the threshold, a daily model will underestimate the amount of cold rain. For regions with an average temperature cooler than the threshold, the cold precipitation will be overestimated. This result indicates that daily temperature-thresholded snow accumulation models have spatially variable uncertainty that may be predetermined and corrected for enabling improved results.

CLOUD FORCING OF SURFACE ENERGY AND MASS BALANCE IN THE SOUTHERN ALPS OF NEW ZEALAND

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Glaciers in the Southern Alps of New Zealand are seen as sensitive indicators of changing regional climate because periods of anomalous mass balance are associated with changes in the regional ocean-atmosphere system, notably the arrangement of the westerly jet stream, sea surface temperatures and surface level pressure in the New Zealand region. However the mechanisms that transfer these anomalies to changes in glacier surface mass balance are still not well established. While the influence of air mass and precipitation changes has received much attention, the effect of clouds on glacier mass balance variability in the Southern Alps is not well developed. This is despite the marked effect clouds have on both short and long-wave radiative fluxes. A high quality two year record of surface climate and mass balance from the Brewster Glacier has been used to a) constrain the parameterisation of both turbulent and radiative fluxes, with respect to both air mass and cloudiness, b) investigate the sensitivity of mass balance to changes in air mass and cloudiness and c) investigate how changes in season or air mass characteristics modify this sensitivity. An improved understanding of the role clouds play in modifying surface energy and mass balance of glaciers in the Southern Alps of New Zealand will enable a more confident attribution of glacier change in the past to be established.

LINKING GLACIER ANNUAL MASS BALANCE AND GLACIER ALBEDO RETRIEVED FROM MODIS DATA

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The albedo is one of the variables controlling the mass balance of temperate glaciers. Multispectral imagers, such as MODerate Imaging Spectro-radiometer (MODIS) on board the TERRA and AQUA satellites, provide a means to monitor glacier surface albedo. In this study, different methods to retrieve broadband glacier surface albedo from MODIS are compared.

The effect of the multiple reflections due to the rugged topography and of the anisotropic reflection of snow and ice are particularly investigated. The methods are tested on the Saint Sorlin Glacier (Grandes Rousses area, French Alps). The accuracy of the retrieved albedo is estimated using both field measurements and albedo derived from terrestrial photographs.

The Root Mean Square Deviation between field measurements and the broadband albedo retrieved from MODIS pixels at 250m spatial resolution was found to be 0.052 or about 10% relative error for summers 2008 and 2009. The RMSD estimated for the MOD10 daily albedo product is about three times higher.

One decade (2000-2009) of MODIS data were then processed to create a time series of albedo maps of Saint Sorlin Glacier during the ablation season. The annual mass balance of Saint Sorlin Glacier was compared with the minimum albedo value (averaged over the whole glacier) observed with MODIS during the ablation season. A high linear correlation exists between the two variables. Furthermore, the time at which the albedo reaches a minimum over the glacier closely corresponds to the time at which the snowline is found to be at its highest elevation, thus close to the glacier's equilibrium line.

This indicates that the strong correlation can be explained by the fact that this minimal albedo contains a high degree of information regarding the relative share of areal surfaces between the ablation zone (i.e. ice with a generally lower albedo) and the accumulation zone (i.e. snow with a relatively high albedo). This implies that monitoring the albedo of glacier with MODIS data can provide a useful means to approach the inter-annual variability of the glacier's mass balance. Finally, it appears that the albedo in the ablation area of the glacier does not exhibit any marked decreasing trend during the decade under study. This contrasts with the situation observed on other glaciers in the Alps.

INCREASED CONCENTRATIONS OF ORGANIC CONTAMINANTS IN NEW ZEALAND ALPINE STREAMS DURING ANNUAL SNOWMELT

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Semi-volatile organic contaminants can travel through the atmosphere to locations distant from where they originated. In cold regions, the contaminants may then be scavenged by dry or wet deposition processes and transferred to the ground or water bodies. If the scavenging process happens by snowfall in the winter, the contaminants accumulate in the snowpack and may remain there as long as the ambient temperature allows them. When temperature increases and the snow begins to melt, the contaminants accumulated in the snowpack may be released to the environment and specifically to the surrounding streams. This process can create pulses in concentrations of contaminants in the water and adversely affect the biological communities living in the streams. The present study aimed to assess if the annual snowmelt phenomenon affects the concentrations of atmospherically transported organic contaminants at three stream sites located in Arthur's Pass National Park, New Zealand. We investigated the water concentrations of polycyclic aromatic hydrocarbons (PAHs) at the sites before, during, and after annual snowmelt period from July to December 2010. We used silicon passive samplers which enabled us to measure the time-averaged water concentrations for analytes in the kinetic uptake phase at the end of field exposure. Several specific PAH congeners (including fluorene, phenanthrene, fluoranthene, and pyrene) were detected in all samples. Overall, the results indicated that total concentrations of PAHs significantly increased during the period from 9 September to 21 October, especially at the lower elevation stream sites, and in connection with snowmelt.

SPATIAL AND TEMPORAL VARIABILITY OF SNOWPACK STABILITY IN THE CRAIGIEBURN VALLEY, NEW ZEALAND

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Spatial variability of snowpack stability has been a topic of considerable contemporary research in the Northern Hemisphere, yet relatively few studies have examined the issue in New Zealand. In order to address this gap in knowledge, the present study has two objectives: (1) to analyse the avalanche terrain of Craigieburn Valley using a geographic information system; and (2) to investigate the spatial and temporal variability of snowpack stability within Craigieburn Valley. To facilitate the achievement of these objectives, 35 consecutive days were spent 'on-mountain' at Craigieburn Valley, between 22 June and 26 July 2012. This enabled valuable observations of the weather, and associated implications for the seasonal snowpack of the area, to be obtained prior to snowpack stability testing. Compression tests (CTs) and extended column tests (ECTs) were performed within the Craigieburn Valley backcountry on an undisturbed, uniform slope of a southerly aspect at 1,650 m.a.s.l. Considerable spatial variability of snowpack stability was observed. As such, stability testing from a single snowpit could not reliably represent the snowpack stability of the entire slope. In addition, very unstable stability test results were obtained, despite an expectation that the slope had good stability. Temporal changes in snowpack stability were also observed. Given a lack of adverse weather conditions, overall slope stability increased. However, the spatial variability increased, and furthermore, very poor stability results were still obtained. Terrain analyses showed that 94% (93 ha) of primary avalanche terrain (slope angle between 30° and 45° in the Craigieburn Valley backcountry is of southerly, south-westerly and south-easterly aspect, compared to just 25% (38 ha) of the Craigieburn Valley ski area. These findings offer improvements to the understanding of avalanche terrain within Craigieburn Valley. In addition, given a relative paucity of previous research, the present study offers a valuable contribution to the knowledge of spatial and temporal variability of snowpack stability in the New Zealand setting.

RECENT CHANGES IN THE FLOW OF THE ROSS ICE SHELF, WEST ANTARCTICA

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Comparison of surface velocities measured during the Ross Ice Shelf Geophysical and Glaciological Survey (RIGGS, 1973 to 1978) and velocities measured via feature tracking between two Moderate-resolution Imaging Spectroradiometer (MODIS) mosaics (compiled from 2003-4 and 2008-9 images) reveals widespread slowing and minor areas of acceleration in the Ross Ice Shelf (RIS) over the ~30 year interval. The largest changes (-13 m/a/a) occur near the Whillans and Mercer Ice Streams grounding line in the southernmost part of the ice shelf. Speed has increased over the interval (up to 5 m/a/a) between the MacAyeal Ice Stream grounding line and the shelf front, and along the eastern part of the shelf front. Here, a well-tested model of the ice shelf is used to discern between longer and shorter time scale transients in ice shelf flow. Changes in ice thickness computed using ICESat laser altimetry are used to test various model outcomes. The observed transients represent a combination of ongoing response to ice stream discharge variations and resulting shelf thickness changes over the past millennium and while faint impressions of past events are evident, the modern signal is dominated by shorter time scale events, including the stagnation of Kamb Ice Stream about 160 years ago, recent changes in basal drag on the Whillans Ice Stream ice plain and, apparently, iceberg calving. Details in embayment geometry, for example the shallow sea floor below Crary Ice Rise, modulate the spatial pattern of ice shelf response to flow perturbations.

MARINE ICE FORMATION AT THE SOUTHERN MCMURDO ICE SHELF

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Marine ice forms from a mixture of sea and glacial water at the base of ice shelves and is thought to enhance ice shelf stability by adding layers of dense ice mass or filling bottom crevasses, rifts or inverted depressions at the ice-water interface. Although widespread in Antarctic ice shelves, the conditions for marine ice formation remain poorly understood. This study aims to improve the understanding of marine ice formation processes and rates at the Southern McMurdo ice Shelf (SMIS) focusing on the chemical composition and crystallography of the ice. Measured water isotope samples were compared with the output of a boundary layer freezing model, indicating that some of the marine ice at SMIS could have formed from sea water only (with very low freezing rates) but that the bulk of the marine ice is of mixed glacial and ocean water origin. Some of the relatively more enriched marine ice samples (between -5 and +2 $\delta^{18}O$), show presence of elongated (banded) ice crystals in vertical thin section - a clear indication that frazil ice formation is relevant for marine ice formation at SMIS. Frazil ice crystals are small discoid suspended ice crystals, that form fast (~ 2.7×10^{-6} m s^{-1}) from supercooled water. Results from this study provide new data on marine ice composition and insights about the mechanisms and rates for marine ice accretion, which can be used in numerical models to predict ice shelf behaviour in a changing climate considering local melting and refreezing of ice shelf material.

THICKNESS AND FREEBOARD OF MCMURDO ICE SHELF BASED ON HELICOPTER BORNE ELECTROMAGNETIC INDUCTION SOUNDING

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Ice shelves play an important role in both the mass balance of the Antarctic ice sheet, as well as in oceanic processes and sea ice processes by producing cold ice shelf Water. The thickness of freely floating ice shelves can be estimated from surface elevation measurements like satellite altimetry by applying the hydrostatic equilibrium assumption. This requires the knowledge of the bulk density, which is therefore a key variable to detect thickness changes in this climatically most sensitive part of the ice sheet. In this contribution we discuss airborne and satellite based measurements to investigate the thickness of the western McMurdo Ice Shelf. Because of basal freezing and surface ablation, as well as brine intrusions in the central part of the ice shelf, conventional radar systems are limited in detecting the ice thickness in this area. In November 2009 we used a helicopter borne electromagnetic induction sounder (HEM bird) to measure several thickness profiles across the ice shelf. Although the HEM bird is designed to detect the thickness of much thinner and conductive sea ice, the maximum ice thickness measured in this case study was about 60 m. The measurement is independent of the ice density. The simultaneous measurement of ice freeboard was used to derive its bulk density, which can now be used to convert satellite based surface elevation measurements to total thickness. Details of the measurement and the processing as well as a calibrated ice thickness map are presented.

SUBGLACIAL WATER AND SEDIMENT TRANSPORT ACROSS THE GROUNDING ZONE OF WHILLANS ICE STREAM, WEST ANTARCTICA

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Much of the threshold behaviour of marine ice sheets is thought to result from processes occurring at the grounding zone, where the ice sheet transitions into the ice shelf. At short time scales (decades to centuries) grounding zone behaviour is likely to be influenced by processes not included in the current generation of ice sheet models. Here we report on two such processes: the flow of subglacial water from beneath the ice sheet, and the associated transport, and deposition, of sediment. We present a ground-based geophysical study across the grounding zone of a major West Antarctic Ice Stream (Whillans Ice Stream). Using a combination of active source seismology and Radio Echo Sounding (RES) we image the outlet of a large subglacial drainage system. This drainage system deposits sediment, the lithology of which we determine with seismic amplitude analysis, into a thin (< 15 m) ocean water column. RES reflectivity indicates that this ocean water column is capped by a layer of fresh water at least 3 m thick. These findings have implications for the evolution of grounding zones and the basal melt of ice shelves; knowledge of both of which is required if well-informed models are to provide accurate estimates of future sea level rise.

GROUNDING ZONE ICE THICKNESS FROM SATELLITE: INVERSE MODELLING OF TIDAL ELASTIC BENDING

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Ice shelves and outlet glaciers around Antarctica are subjected to periodic forces associated with ocean tides. Vertical motion of the ice in response to these tides varies spatially across the grounding zone region where the ice shelves are supported by the land. This vertical displacement can be measured using Interferometric Synthetic Aperture Radar (InSAR) from satellite by comparing multiple interferograms with different tidal displacements. This differential method has been widely applied to mapping the location of the grounding line. Finite element modelling shows that this tidal response can be well simulated if ice thickness and internal ice properties are known. Here we discuss a new inverse modelling optimization approach, using spatial patterns of ice flexure derived from differential interferograms to calculate ice thickness in the grounding zone. Sensitivity analyses are conducted for synthetic ice profiles in 1D. The method is then applied to the Beardmore and Skelton Glaciers in Antarctica with results compared to new ice penetrating radar measurements of thickness from the 2010-11 and 2011-12 seasons. This method improves current estimates of grounding zone ice thickness based on hydrostatic equilibrium assumptions. Thickness estimates at tracks across the grounding zone agree to within 100m with observed values.

GLACIAL HISTORY OF THE EAST ANTARCTIC ICE SHEET FROM COSMOGENIC EXPOSURE AGES IN THE ROSS EMBAYMENT

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Current ice sheet-models that attempt to quantify past changes in the East Antarctic Ice Sheet (EAIS) volume are poorly constrained by field data. Yet, understanding past changes in the EAIS are critical for identifying the sources of sea-level rise since the Last Glacial Maximum (LGM) and for predicting future responses of the ice sheet to climate change. Cosmogenic exposure age dating of exposed rock surfaces provides an ideal tool for constraining past ice sheet elevations and rates of retreat. Geomorphological and glacial geological mapping, along with multiple cosmogenic 10Be and 26Al surface exposure ages from bedrock surfaces and glacially transported erratics from Escalade and Tate Peaks in the upper Skelton Glacier will be used to identify the past extent and timing of the EAIS, as well as glacial retreat history from the LGM and throughout the Quaternary. New data collected from a series 'bathtub ring' moraines on the ice surface, scattered glacial erratics found up to over 500 metres above the current ice surface, bedrock and perched erratic samples from an altitudinal transect and bedrock surfaces marked by glacial grooves and striae will provide independent ice elevation measurements from the Ross Embayment margin of the EAIS. Cosmogenic exposure ages from a complex of moraines and drift sheets in southern McMurdo Sound will provide ice elevation measurements and retreat history of a grounded ice sheet fed from the Ross Embayment. Resolving the age and timing of these glacial events is critical for understanding past behaviour of the ice sheet in McMurdo Sound. The purpose of this research is to provide an analogue of how the EAIS behaves as it warms and retreats and can be used to create boundary conditions for future climate and ice sheet models. Subsequently, comparing the glacial history of the high elevation interior terrestrial ice sheet sites in the Skelton Névé with the low elevation sites in McMurdo Sound should allow us to predict past extent and rates of retreat for the West Antarctic Ice Sheet.

THE GLACIOLOGY OF A TRANSANTARCTIC MOUNTAINS OUTLET GLACIER – IMPLICATIONS FOR COSMOGENIC NUCLIDE DATING

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Terrestrial cosmogenic nuclide (TCN) dating provides the most direct chronological evidence of terrestrial ice thickness and extent for Antarctica. It provides an alternative method to radiocarbon dating, which is hampered by the sparsity of dateable organic material on the Antarctic continent and carbon reservoir effects in the marine environment. Developing a valid chronology with a simple relationship between measured cosmogenic radionuclide concentrations and exposure ages requires the identification of samples that have been sufficiently 'reset' by glacial erosion. Therefore the largest limitation of using this technique in Antarctica is the presence of non-erosive ice which fails to remove cosmogenic inheritance from previous episodes of exposure, for bedrock at the surface and for transported material which has been previously exposed. TCN dating has been applied throughout Antarctica to obtain LGM-to-Holocene thinning histories. The purpose of such chronologies is to quantify ice thickness changes, from which the associated deglacial contribution to sea level rise can be estimated. In order to interpret the TCN signal of ice surface elevation change most accurately, it is important to understand the local and regional glaciology.

We present satellite imagery, bed topography, ice thickness, ice surface elevation and surface velocity data, as well as data of modelled subglacial conditions for Skelton Glacier, an outlet glacier of the East Antarctic Ice Sheet. These data describe the present-day glaciological conditions but also allow inferences to be made about the palaeo conditions. We discuss our interpretations of the glaciology of Skelton Glacier and the implications for TCN dating with reference to dated samples collected from nunataks in the glacier's névé. Our data show older ages in sections of the glacier which are less dynamic and/or cold-based. Further analyses will be able to test whether (1) the upper névé of Skelton Glacier has remained ice-free for most of the last 1 Ma, or (2) only the lower névé has experienced warm-based 'resetting' of cosmogenic inheritance.

MIGRATION DIRECTION AND DIFFERENTIAL ACCUMULATION OF ANTARCTIC MEGADUNES

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The main characteristics of Antarctic Megadunes, besides their long wavelengths (2-5 km) and low amplitudes (2-4 m), are their low accumulation and the high grade of metamorphism. The higher accumulation on the windward side and the near-zero accumulation on the lee side lead to large differences in physical properties of snow, differences in surface roughness and also to upwind migration of the Megadunes. While the windward side of the Megadunes is characterized by net accumulation and high surface roughness with up to 1.5 m high sastrugi, the leeward sides of the megadunes are characterized by near-zero accumulation and “wind glazed" smooth surfaces. Previous studies agree that the megadunes are a result of complex wind and topography/snow interactions, as they run perpendicular to persistent regional katabatic winds. It is, however, not clear how they form or why they accumulate on the windward side, leading to their upwind migration. In this study, we combine surface profiles from ICESat elevation data, theoretical constraints for possible anti-dune migration directions and high-resolution regional climate modelling of katabatic winds to explain the differential accumulation in the region and to understand the upwind migration of the Megadunes.

SIMULATION OF A UNIQUE SUMMERTIME SNOW EVENT IN MIERS VALLEY, ANTARCTICA

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Miers Valley is one of the four east-west oriented ice-free valleys in the Denton Hill area and one of the biodiversity 'hotspots'. While most of studies on precipitation climatology carried out in the larger valley systems, little work has been done on this part of the McMurdo Dry Valleys (MDVs). This research presents the first investigation of the physical mechanism of precipitation in Miers Valley. An exceptional amount of observational data documenting a case in January 2012 is available. This data is complemented with high-resolution numerical modeling using a polar optimized weather prediction model (PWRF) to elucidate the role of local and regional forcings and also spatial distribution of snow in Miers. A two-way interactive grid nesting with 4 nests (16-, 4-, 1-km and 250-m horizontal resolution) has been employed in the simulations. To account for the characteristics of dry valleys, initial data for land-use categories, soil temperature/moisture and some profiles were adapted to the study area. Moreover, a LIDAR derived elevation data (4-m resolution) has been adapted for the highest resolution PWRF grid, while terrain height for the coarser grids obtained from RAMP 200-m DEM dataset.

Numerical simulations confirm dominant role of topography and land-use in determining precipitation. While previous studies attributed precipitation-shadowing effects to the Transantarctic Mountains, our investigation underlines the importance of Ross Island in modifying northeasterly moist air masses reaching the region. Simulations suggest while the along-valley gradients is mainly related to the coastal origin of air masses, the cross-valley gradient can be related to local topographic and thermal circulation effects.

CLIMATE OF THE DARWIN HATHERTON GLACIAL SYSTEM AND THE INFLUENCE OF THE SYNOPTIC STATE

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Glaciers in the Transantarctic Mountains (TAM) bordering the Ross Ice Shelf (RIS), are not only important for the stability of the East Antarctic Ice Sheet from which they emanate, but also for the shelf into which they drain. One key ingredient of glacial studies is surface mass balance (SMB), however, as in many areas of Antarctica, this is not well constrained for the TAM. Available estimates are too coarse in spatial and temporal resolution to resolve many smaller scale SMB features like blue ice areas.

Knowledge of climate is important to understand the nuances of a regions SMB, as there are indelible links between them. While there is accumulating knowledge about important large scale wind regimes in the region, information about the finer scale is very limited. A series of past studies concerned with the dynamics of the glaciers and ecosystems of the Darwin Hatherton Glacial System, has resulted in relative wealth of climate data from automatic weather stations (AWS). Analysis of these AWS data has confirmed that the wintertime climate of the valley is dominated by strong dry winds, with frequent, but brief interruptions of warm moist air. Summer climate is markedly different, mean wind speeds are much lower, and thermally generated winds are a prominent feature. A comparison of recorded climate in the valley, and the synoptic circulation over the RIS using Self Organising Maps reveals strong links.

ANTARCTIC SURFACE CHARACTERISTICS DERIVED BY REMOTE SENSING AND GIS ANALYSIS AS INPUT TO HIGH RESOLUTION WEATHER MODELS

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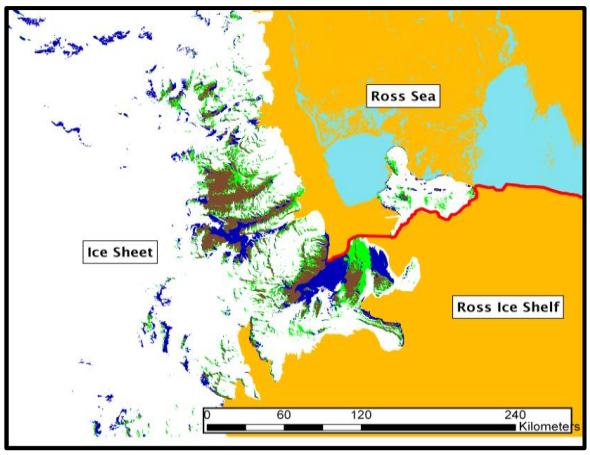
Spatial and temporal distribution of snow and ice as well as surface characteristics such as roughness and albedo are the main forcings on the atmospheric boundary layer of Antarctica. The resolution of climate and weather models and their ability to simulate the interaction of atmosphere, lithosphere and cryosphere are limited by the quality of datasets rendering these properties. The goal of this study is to establish high resolution landcover and topographic datasets by remote sensing methods as input for a polar-optimized weather prediction model. It includes a snow transport model to investigate the climate and snow accumulation over the western Ross Sea Region.

A new Digital Elevation Model (DEM) was created near the Transantarctic Mountains by merging the existing Radarsat Antarctic Mapping Project DEM at the ice sheet with the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM to cover the more topographically complex areas. By making use of MODIS (Moderate Resolution Imaging Spectroradiometer) and ASTER data a land cover classification scheme was created to identify significant land cover types through their optical properties based on normalized reflection indices in the visible and near infrared spectral range.

The preliminary results of this summer scholarship project are the successful classification of six surface types using MODIS. The next steps include the separation of snow and ice on land and sea at high temporal resolution, and potentially the correction of topographic effects on surface reflection.



Key	
	Water
	Ice Free Land
	Snow/Ice
	Blue Ice
	Sea Ice
	Debris Covered Ice
	Ross Ice Shelf Extent

Figure 1 - Land classification of the study area at 250m resolution for 17 Nov. 2012 based on MODIS Bands 1 and 2 and boundary between ice shelf and sea ice.

THE HYDOLOGICAL SIGNIFICANCE OF ICE CLIFFS IN THE DRY VALLEYS VERSUS KILIMANJARO

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Dry, land-based ice cliffs are found at the margins of ice masses all around the globe, existing on steep slopes (hanging glacier fronts) as well as over flat ground. Over steep terrain the interaction between ice flow and calving is the dominant control on cliff occurrence and shape, while sublimation and melting on cliffs located over flat and slightly inclined surfaces, such as those found in the McMurdo Dry Valleys (MDVs) and on the top of Kilimanjaro, play a more dominant role. Though the physical processes responsible for the formation and maintenance of ice cliffs in the MDVs and Kilimanjaro remain uncertain their existence depends on a delicate interaction between ice flow (deformation), accumulation on the cliff faces and ablation processes that include calving, melting and sublimation. Because the loss of mass through calving from cliff faces in the MDVs appears to represent a small fraction of total ablation (1-10%) melting is particularly important as it is the primary source of water to stream flow in summer. The terminal cliffs are critical for initiating and maintaining stream flow as they are often the first part of the glacier system to start melting and the last to stop. In contrast, melting of the terminus cliffs on the top of Kilimanjaro does not contribute to run-off and is therefore not important to the lower mountain's hydrological system. However, cliff ablation through melting and sublimation is critical in governing the on-going retreat of the glaciers on the top of Kilimanjaro. Further effort to determine the relative importance of different ablation processes in these unique environments is warranted, especially as cliffed margins are expected to respond differently to climatic changes than glaciers with moderately sloped termini.

ICE MICROSTRUCTURES IN A SCANNING ELECTRON MICROSCOPE

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Ice microstructure and fabric data help us interpret processes associated with deformation, grain-growth recrystallization and phase transformations. Fine-grained ice (<<1mm grain-size) is particularly important in experiments to determine grain-growth kinetics and grain-size sensitive creep mechanics. Quantitative measurements of grain-size and crystallographic preferred orientation (CPO) are essential to such experiments.

Electron backscatter diffraction (EBSD) is a scanning electron microscope (SEM) based technique that enables automated measurement of the full crystallographic orientation of each point on a grid with spacing down to 50nm. EBSD has been applied to water ice samples but the procedures for doing so have not yet been perfected.

Chief problems associated with ice EBSD include contamination from frost, specimen sublimation and specimen charging. Controlled sublimation is often used to remove surface frosting and to control charging. This approach is ineffective in studying fine-grained (<500·m) ice as even a small loss from the sample surface can make data collection impossible. We have developed a method where samples are prepared in a dry N_2 filled glove box built around the SEM. Samples with prepared surfaces can be put into the SEM without exposure to moist air and good quality EBSD data collected

The method has clear application to fine-grained (<500·m) synthetic ice as used in the experimental investigations underway in Otago. The limitation for natural water ice samples is that they need to be cut down to be smaller than ~ 20 by 10 by 5mm. Nevertheless the EBSD (or other electron beam signals- e.g. X-Ray compositional data for included particles) may be useful. Adapting existing technologies to deal with larger samples is a project for the next few years.

VORONOI DYNAMICS SIMULATION OF PLATELET SEA ICE

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Platelet ice is a sea ice type found near an ice shelf. Ice crystals, which originate in the water column, rise to the surface and accumulate under the sea ice cover in a loose layer. There they grow in the near-surface supercooled water to become frozen into the ice cover as incorporated platelet ice. Several Antarctic field campaigns have collected ice cores, measured crystallographic and physical properties and simultaneously recorded oceanographic conditions. However, some in situ measurements are difficult to acquire experimentally, for example porosity which is required in this regions to obtain sea-ice thickness from remote-sensing measurements.

Voronoi dynamics is a simple but efficient grain growth technique. By integrating this with mechanical stability and heat and mass transfer, virtual ice cores are simulated in three dimensions. This model shows topological similarity with incorporated platelet ice from the real ice cores. The calibrated spatial-temporal distributions of porosity, salinity, temperature and crystallographic c-axes are extracted and presented here.

SEA ICE MEASUREMENTS IN MCMURDO SOUND, ANTARCTICA FOR THE VALIDATION OF REMOTELY SENSED SEA ICE PROPERTIES

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This investigation employs the use of the Geoscience Laser Altimeter System (GLAS) onboard NASA's ICESat to derive Antarctic sea ice freeboard in McMurdo Sound for the time period 2003-2009. Two techniques relating sea ice surface elevation to the water reference level are compared. The primary method closely follows those previously presented in the literature using a near simultaneous measurement of relatively close open water surfaces detecting the actual sea level; because of the lack of open leads in the study area a second method was used which is based on utilising a tide model which show good agreement with nearby tide gauge measurements. The study is bolstered by measurements on sea ice characteristics in the study region as well as airborne and ground based measurements of sea ice freeboard and thickness in 2009. The seven year acquisition period is segmented into annual, spring (September-December) and autumn (February-June) periods, and the seasonal investigations were further segmented by ice type using Envisat ASAR and MODIS imagery. The multiyear sea ice area increased from 1213 km^2 in 2003 to 4293 km^2 in 2005. This maximum coverage then gradually diminished, by 2009 covering 1453 km^2. The mid study period increase is attributed to the passage of large tabular icebergs altering oceanic processes and preventing the annual sea ice breakout. Both applied methods reveal an increase in freeboard height over multiyear sea ice in both spring and autumn, which is statistically significant using the primary method. For the latter, the mean freeboard increased over the study period from 0.53 m to 1.00 m and from 0.56 m to 1.16 m in spring and autumn, respectively. No statistically significant trends were observed over firstyear ice in either season. A cross over analysis of GLAS derived freeboards underlines that a small negative linear trend for first year ice detected by the second method is attributed to inaccuracies in establishing the height reference level. Freeboard statistics from satellite measurements compare well with airborne measurements in spring 2009. We attempt to extend this time series of satellite derived freeboard in the region using CryoSat-2 data which is complemented by an extensive sea ice fieldwork campaign in November 2011.

MODELLING THE SPATIAL DISTRIBUTION AND EXTENT OF ANCHOR ICE IN ANTARCTICA

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The term anchor ice describes clusters of ice attached to the beds of rivers, lakes and the sea. This ice is an important factor in the mobilization of bed sediments and also takes on ecological roles as a food source, habitat and potentially fatal environment for biological communities. In Antarctica, ice shelves and their associated plumes of supercooled water are believed to be a main driver behind the formation of anchor ice. Relatively warm, salty water contacts the base of an ice shelf at depth, causing part of the ice shelf to melt. The resulting water is more buoyant than the ambient water, and rises along the base of the ice shelf, becoming potentially supercooled in the process due to the pressure dependency of its freezing point. If this water contacts the seafloor, it may initiate anchor ice growth. In this study we aim to identify potential sites suitable for anchor ice formation around the Antarctic continent through the use of a simple geospatial model. The inputs to this model are a database of Antarctic ice sheets and a digital elevation model of the surrounding bathymetry. We are using the Python interface in ESRI ArcGIS 10.1 to predict the spatial distribution of anchor ice around the Antarctic continent. We will also be assessing the sensitivity of the distribution on model input parameters such as the maximum depth at which anchor ice will form. As this paper is still in progress, preliminary results will be discussed in the presentation.

CAN ANTARCTIC LAND-FAST SEA ICE BE USED TO TRACK OCEAN ISOTOPIC CHANGES ASSOCIATED WITH ICE SHELF BASAL MELTING?

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Near the Antarctic coast, land-fast sea ice often forms from ocean waters with an ice shelf basal meltwater seasonal input. In McMurdo Sound, this meltwater causes a change in the sea ice structural fabric from columnar to incorporated platelet ice. Since year-round oceanographic measurements are challenging, a method to retrospectively determine the timing and quantity of the seasonal input of ice shelf meltwater would be ideal. Stable isotope measurement, particularly $\delta^{18}O$, are a promising method. Tracking $\delta^{18}O$ composition changes for Antarctic surface waters is examined in this presentation through application of a revised version of an existing isotope fractionation based model to sea ice and ocean data from McMurdo Sound, Antarctica. Reconstructed ocean $\delta^{18}O$ values are compared with measurements of $\delta^{18}O$ in Antarctic surface waters sampled at the time of sea ice growth. The data presented have been collected for land-fast sea ice from 2009 and 2010, with the 2009 data used to validate the reconstruction method. The late season sea ice data were influenced by the seasonal appearance of waters from beneath the nearby ice shelf, which resulted in platelet ice formation and a negative oceanic heat flux. From late May to late July 2009, with growth rates between approximately 0.7 and 1.5 cm d^{-1}, the reconstructed ocean $\delta^{18}O$ bounded the mean of the measured values by up to ±0.2 ‰. Outside of that period, differences between reconstructed $\delta^{18}O$ and measured values suggest further work is needed on: (i) for high sea ice growth rates, a validated parameterization of the relationship between fractionation and growth rates, and (ii) for sea ice growth near ice shelves, the inclusion of late season negative ocean heat flux in thermodynamic sea ice growth models.

POSTER

A GLOBAL EXPERIMENT TO IMPROVE OBSERVATIONS OF SNOW: THE WORLD METEOROLOGICAL ORGANIZATION SOLID PRECIPITATION INTERCOMPARISON EXPERIMENT (WMO-SPICE)

Hendrikx, J.[1], MacDonell, S.[2], Bilish, S.[3], Harper, A.[4], Nitu, R.[5], Rasmussen, R.[6], Baker, B.[7], Lanzinger, E.[8], Joe, P.[5], Yang, D.[5], Smith, C.[5], Roulet, Y.-A.[9], Goodison, B.[10], Liang, H.[11], Sabatini, F.[12], Kochendorfer, J.[7], Wolff, M.[13], Aulamo, O.[14], Vuglinsky, V.[15], Earle, M.[5], Mrozinski, L.[16], Koldaev, A.[17], Timofeev, A.[15]

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The measurement of solid precipitation has been the subject of extensive investigations, including international collaborative studies. These investigations have focused primarily on manual measurement methods and have revealed significant challenges in the measurement of snowfall and snow on the ground. Since these studies were conducted, an increasing percentage of precipitation and snow depth measurements around the world have been obtained using a broad range of automatic instruments, many operated unattended for extensive periods of time. At the same time, new non-catchment type instruments and systems have been introduced for the measurement of solid precipitation. In the context of the transition from manual methods to automatic instruments and with the introduction of new technologies in measurement networks worldwide, there is an acute need for an internationally coordinated study to understand and characterize the errors in precipitation measurement of in-situ automatic instruments, and their capabilities for measuring solid precipitation. WMO-SPICE has been initiated to focus on the performance of modern automatic instruments measuring solid precipitation and snow depth. In this regard, the key goals are to investigate and report on the measurement of precipitation amount as a function of precipitation type (liquid, solid, mixed), and of snow on the ground (i.e. snow depth). An important outcome will be to develop correction methods and adjustments for measurements from the various automatic gauge and wind shield combinations used in different countries, to enable the provision of better estimates of regional snowfall. WMO-SPICE began in November 2012 and will last for two to three winter seasons. The paper will present the organization of the experiment, an overview of the participating sites and the instruments selected for inclusion in the intercomparison. The presentation will highlight southern hemisphere sites.

NOTES

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SOCIAL TOUR

Otago Peninsula Wildlife Tour

The group will embark at 9:00am onboard the Monarch (and possibly an additional vessel) for a cruise along the Otago Harbour, passing by the historic fishing village of Careys Bay and the working port of Port Chalmers.

Arriving to the tip of the Otago Peninsula you will enjoy unrivalled wildlife viewing. See what cannot be seen from land: Albatross, New Zealand Fur Seals and up to 20 species of bird and marine life in their undisturbed and otherwise inaccessible environment. Learn the fascinating history and geology of the area.

Finally, a scenic drive along the Otago Peninsula will take us back home, enjoying spectacular harbour and ocean views.

WHEN

Wednesday 13 February, 8:30am (bus pick up from meeting point)

Return at 12:30pm

WHERE

Meeting point for bus pick up is the Executive Residence (see map on next page)

Alternatively, the boat departs from 20 Fryatt Street, people intending to walk there directly should be on the wharf at 8:40am.

VENUE & ACCOMODATION

Otago Yacht Club 25 Magnet St, Dunedin Tel 03-477 1255 otagoyachtclub.org.nz	**Executive Residence** 68 Forth Street, Dunedin Tel 03-479 9151	**Studholme College** 127 Clyde Street, Dunedin Tel 03-479 5504