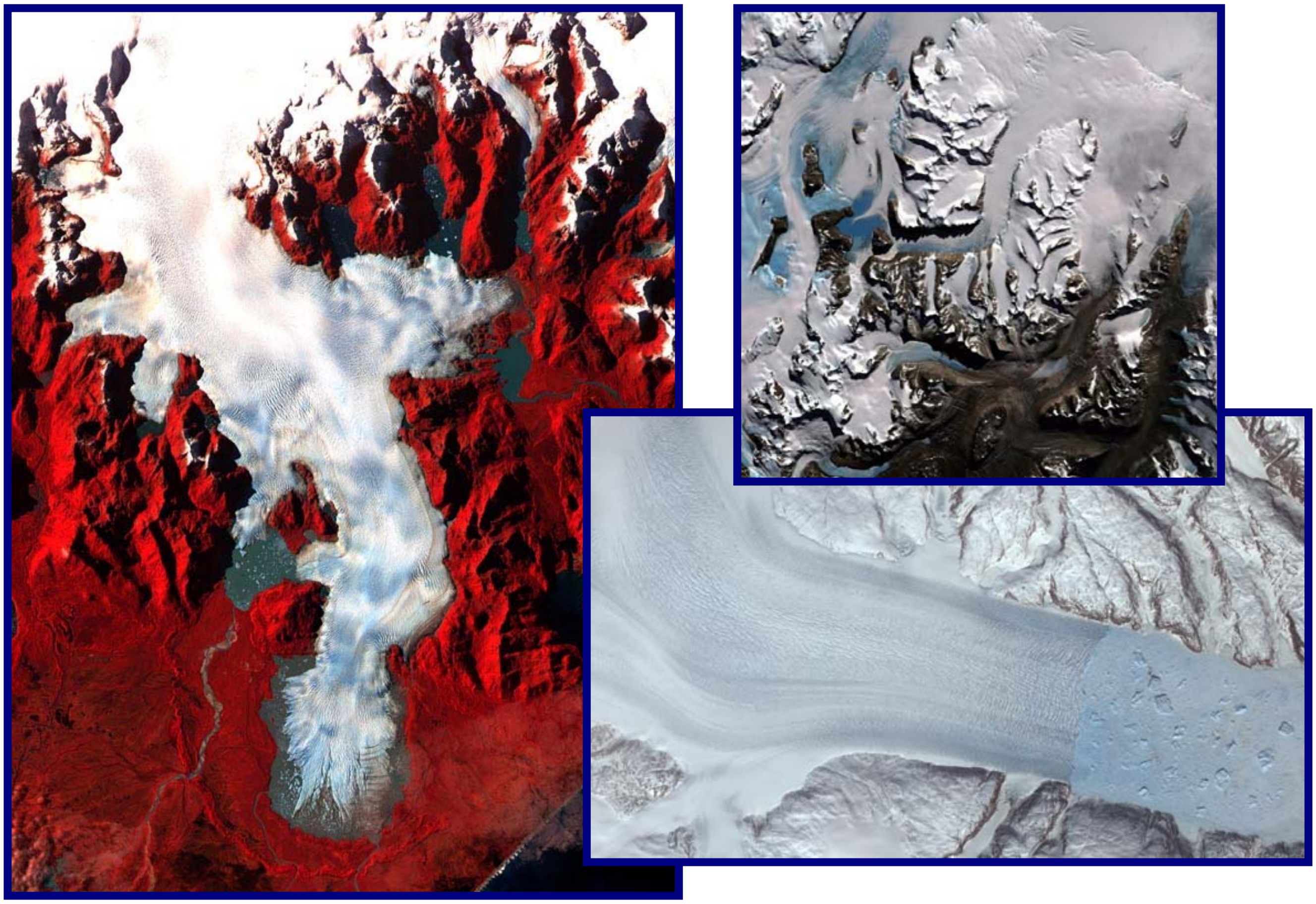
Global Land Ice Measurements from Space (GLIMS)

AND

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

WORKSHOP



Program and Abstracts

Twizel, New Zealand

6 – 10 February 2006

We would like to welcome you to the GLIMS/SIRG Workshop 2006, New Zealand

I would like to extend a warm welcome to all workshop participants on behalf of the Snow and Ice Research Group (SIRG) of New Zealand. SIRG is a community of New Zealand researchers interested in all aspects of snow and ice-related science, including glaciology, alpine climates, avalanche hazard, and glacial geology. Its primary objective is to increase collaboration and idea-sharing amongst a small scientific community, as combining resources and data allows us to gain a better overall representation of New Zealand's glacial systems.

This year we are fortunate to be able to combine our annual meeting with the GLIMS Workshop. Remote sensing is an important technique in assessing changes to glacial landscapes, and we are acutely aware of its potential to enhance existing research on snow and ice in New Zealand, and also to open up exciting new avenues in a country where there are many more glaciers than glaciologists.

We look forward to a productive and stimulating workshop.

- Wendy Lawson (SIRG)

Global Land Ice Measurements from Space (GLIMS) is dedicated to global glacier assessment using remote sensing methods and supporting field studies. Now involving researchers from 28 nations, GLIMS seeks a coherent basis for making objective measurements of the world's glaciers.

This meeting in New Zealand is our first workshop to be held in the southern hemisphere. GLIMS, represented here by researchers from at least five countries (with several more nations represented on the authors' lists), is pleased to have this opportunity to meet with SIRG members on this lovely archipelago. Thank you for your participation.

- Jeff Kargel (Director of GLIMS)

Front Cover - ASTER Images are: left - Patagonian Glacier, 2 May 2000[1]; top right - Dry Valleys, Antarctica, 5 November, 2001[2]; and bottom right - Helheim Glacier, Greenland, 19 June 2005[1]

Images are courtesy of:
1. Earth Observatory, NASA, http://earthobservatory.nasa.gov/
2. Luke Copland, University of Ottawa

Venue: Mackenzie Country Inn, Twizel, New Zealand

This Workshop would not have been possible without the following sponsors:

GLIMS-University of Arizona/Tucson

NASA: ASTER Science Team project support for Jeff Kargel

Global Land Ice Measurements from Space (GLIMS)
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We also extend thanks to all the individuals that put their time and energy into making this workshop successful.

Program

Program

Underline indicates speaker/presenter/discussion leader

Monday February 6, 2006

9:00 - 9:45 *Registration*
Narelle Baker

9:45 - 9:50 *Open sessions and general matters*
Narelle Baker

9:50 - 10:10 *Welcome: Meeting introduction, personal introductions, and agenda review*
Wendy Lawson

Topic 1 **Alpine glaciers and Antarctica**
(Narelle Baker, session chair person)

10:10 - 10:30 *Remote sensing and field studies of glacier lakes*.
Jeff Kargel, Ella Lee.

10:30 - 11:10 *Monitoring the behaviour of Alaska's glaciers - an opportunity for GLIMS*.
Bruce Molnia

11:10 - 11:40 *Break with refreshments.*

11:40 - 12:00 *Thermal detection of debris-covered-ice using ASTER imagery*
Tim Kerr, Burn Hockey.

12:00 - 12:15 Poster advertisements (brief oral introduction to posters).

POSTER: *Valley-glacier system modelling of the European Alps: A statistical approach to estimating glacier contribution to future sea-level rise.*
Tiernan Williams, Tony Payne, Jemma Wadham, Ros De'Ath and Jonathan Gregory

POSTER: *Change analysis of glacier ice extent in Southwest Alaska*,
Dorothy Hall, Bruce Giffen, Janet Chien and Kimberly Casey

POSTER: *Monitoring of Imja Glacier lake in the East Nepal using the satellite image*.
Hironori Yabuki

POSTER: *The Application of inventory data for estimating characteristics of and regional past climate-change effects on mountain glaciers: a comparison between the European Alps and the New Zealand Alps*.
M. Hoelzle, T. Chinn, D. Stumm, F. Paul, M. Zemp and W. Haeberli

POSTER: *Recent changes in the glacial meltwater due to glacial shrinkage in the Terskey-Alatoo Range, Kyrgyz Republic*.
C. Narama, K. Fujita, T. Kajiura, C. Ormukov and K. Abdrakhmatov

12:15 - 1:30 *Lunch*

1:30 - 2:00 *Glacier hazards and water resources issues*: *Alaska, Himalaya, Peru.*
Jeff Kargel

2:00 - 2:40 *Monitoring mountain glaciers: A view from the World Glacier Monitoring Service*.
M. Hoelzle, M. Zemp, F. Paul, R. Frauenfelder and W. Haeberli

2:40 - 3:00 *A statistical approach to estimating the contribution of glaciers to future sea-level rise.*
Ros De'Ath, A. Payne, J. Gregory, J. Hall and J. Oerlemans

3:00 - 3:30 *Break with refreshments.*

Topic 2 Presentations by GLIMS Young Researcher Awardees
(Bruce Raup, session chair person)

3:30 - 3:50 *The 2003 SPOT5-derived glacier inventory for Cordillera Blanca, Peru: a contribution to the GLIMS Geospatial Glacier Database.*
Adina Racoviteanu, Yves Arnaud and Mark Williams.

3:50 - 4:10 *Estimate on melt rates of debris-covered glaciers in the Himalayas using ASTER data.*
Ryohei Suzuki, Yutaka Ageta, Koji Fujita, Akiko Sakai and Nozomu Naito

4:10 - 4:25 Poster advertisements (brief oral introduction to posters).

POSTER: *Holocene deglaciation of Mac. Robertson Land, East Antarctica*.
Andrew Mackintosh, Duanne White, David Fink, Damian Gore, John Pickard and Trish Fanning

POSTER: Controls on surface energetics and ablation of the McMurdo Ice Shelf, Antarctica.
Penelope Clendon and Wendy Lawson.

POSTER:	*The hydrological regime of a cold-based glacier: Wright Lower Glacier*. Shelley MacDonell and Sean Fitzsimon.
POSTER:	*Is Byrd Glacier slowing down? Analysing the evolution of the Antarctic Ice Sheet*. Narelle Baker
POSTER:	*Access Antarctica: Maps, aerial photos and publications* Paul Barr
4:25	*Poster viewing and adjourn session.*

Tuesday February 7, 2006

Topic 3	**Global glacier change monitoring and GLIMS Programmatic Issues** (Hugh Kieffer, session chair person)
9:00 - 9:25	*GLIMSView description and update and plans*. Bruce Raup.
9:25 - 10:00	*Results of the GLIMS Analysis Comparison Experiments (GLACE)*. Bruce Raup and Siri Jodha Singh Khalsa.
10:00 - 10:25	*ASTER imaging re-prioritization for GLIMS acquisitions in 2006-2007*. Jeff Kargel, John Dwyer and David Gaseau.

See also informal posters on this topic of ASTER image acquisitions.

10:25 - 10:45	*Break with light refreshments and informal poster viewing.*
10:45 - 12:00	*Open discussion. Topics may include GLACE, GLIMSView, and GLIMS technology issues, problems of clouds and snow cover in satellite imaging, standardized analysis and protocol and how to achieve it*. Jeff Kargel and Bruce Raup, discussion leaders.
12:00 - 1:30	*Lunch*.
1:30 - 2:00	*GLIMS community journal publications, GLIMS book (Praxis-Springer), discussion of outline and writing assignments*. Jeff Kargel, discussion leader.
2:00 - 2:20	*Historical development of the GLIMS project.* Hugh Kieffer

2.20 - 2.45 *Break with refreshments*

2:45 - 3:30 *Open discussion, no agenda*.
Jeff Kargel, Bruce Raup and Hugh Kieffer

3:30 *Adjourn session*.

TUESDAY EVENING: *Group dinner – Mackenzie Country Inn*
Guest Speaker: George Denton on *New Zealand glacial history in a global context.*

Wednesday February 8, 2006

Topic 4 **New Zealand climate, snow and glaciers**
(Trevor Chinn, session chair person)

9:00 - 9:20 *Rainfall and snowfall measurement in Aoraki/ Mt Cook National Park, New Zealand.*
Tim Kerr, Ian Owens, and Roddy Henderson.

9:20 - 9:40 *The influences of atmospheric indices on the snow and avalanche regime, Fiordland, New Zealand.*
Jordy Hendrikx and Ian Owens

9:40 - 10:00 *Topnet Hydrological Model of the Pukaki Catchment, New Zealand*.
Ross Woods, Alistair McKerchar and Roddy Henderson

10:00 - 10:20 *Understanding the cause of contemporary glacier retreat on Mt Ruapehu, New Zealand.*
Tom Paulin, Andrew Mackintosh, Brian Anderson, and Harry Keys

10:20 - 10:40 *Intra-annual variation in ablation and surface velocity on the lower Fox Glacier, South Westland, New Zealand.*
Heather Purdie

10:40 - 11:00 *Break with refreshments*

11:00 - 11:20 *The spatial and altitudinal distribution of mass balance at Brewster Glacier 2004/5.*
Laurel George

11:20 - 11:40 *Annual-scale mass and energy transfers at Brewster Glacier, New Zealand*
Brian Anderson, Andrew Mackintosh, Tim Kerr, Laurel George, Dorothea Stumm, Sean Fitzsimons and Wendy Lawson

11:40 - 12:00 *The subglacial drainage of Brewster Glacier, Southern Alps, New Zealand/Aotearoa in relation to ice surface velocity*
Alex Winter-Billington, Andrew Mackintosh, Brian Anderson and Wendy Lawson

12:00 - 1:00 *Lunch*

1:00 - 1:40 *Mountain safety in New Zealand, an overview and latest developments.*
Guest Speaker: Don Bogie

1:40 - 2:00 *Mass balances and end-of-summer snowlines on glaciers of the Southern Alps, New Zealand.*
Dorothea Stumm

2:00 - 2:40 *Glacier volume changes in the Southern Alps: Computation from annual snowline surveys*.
T. Chinn, M. J. Salinger and B. Fitzharris

2:40 - 3:20 *The influence of atmospheric circulation on glacier snowlines and ice mass of the Southern Alps of New Zealand*.
B. Fitzharris, M. J. Salinger, C. Heydenrych and T. Chinn

3:20 - 4:00 *Glacier monitoring in the Southern Alps: Trends and variations from snowline monitoring*.
M.J. Salinger, T. Chinn, A. Willsman and B. Fitzharris

4:00 - 4:20 *Break with refreshments.*

4:20 - 4:40 *New Zealand glacier inventory by the use of ASTER imagery and aerial photographs.*
Endre Gjermundsen

4:40 - 5:00 *The sensitivity of New Zealand glaciers to climatic change*.
Andrew Mackintosh and Brian Anderson

5:00 - 5:40 Outstanding issues (open discussion). Possible discussion topics:
Future of New Zealand's glaciers.
Future of monitoring of glaciers in New Zealand and around the world.
Timetable for submission of glacier analysis data into GLIMS glacier database.
(Narelle Baker and Bruce Raup, discussion leaders)

5:40 - 6:00 *Overview of field excursions.* Heather Purdie.

6:00 Adjourn sessions.

Thursday February 9, 2006

Group walk up the Hooker Valley, Aoraki/Mount Cook National Park (4-5 hours).

Hooker Valley Track (DOC)
Walking track. Time to Hooker Lake: 4 hours return

Begin at the Visitor Centre or White Horse Hill camping areas. One of the most popular walks in the park, it leads up the Hooker Valley towards Aoraki/Mount Cook. The track passes close to the Alpine Memorial, which is a great viewpoint. Continue on to Hooker River and cross twice on swingbridges before reaching Stocking Stream Shelter. Continue beside the river to its source to reach the Hooker Glacier terminal lake.

This walk includes interpretation of past glacial history and an overview of previous research in the area.

Tramping boots or sturdy shoes and a good rain jacket and warm clothes are essential.

Photo: Narelle Baker (2005)

Friday February 10, 2006

Full information will be available at the workshop and you can book for activities of your choice after you have arrived. Heather Purdie will be at the conference to look after all your field trip needs and will be available to talk to you about what you want to do. Some possibilities are:

Glacier Explorers, explore one of the local glaciers.

Boat trip on the terminal lake of the Tasman Glacier.
Special GLIMS/SIRG member price of $85 pp (usually $105). Highly recommended.

Mount Cook Ski Planes
Scenic flights from $210 - $410 pp. and Tasman Glacier landings from $310.

Heliline Helicopter Flights
From Twizel $195 - $495 and from Glentanner (Mount Cook) $185 - $390.

Walks/Tramping: there are a number of other great walks in the Aoraki/Mount Cook National Park that provide fantastic views of the glaciated landscape.

Other Activities: 4WD tours, fishing and guided walks.

Abstracts

Abstracts

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Abstract 1:

A brief history of GLIMS and a perspective

Hugh H. Kieffer [1]

[1]Celestial Reasonings, Carson City, NV, USA

The suitability of an ASTER-like instrument for observations of glaciers was recognized in the proposal process in 1989. Initial exposure of the GLIMS concept was described at a IGS meeting in 1994, where the structure of core institutions, a common database, Regional Centers and Stewards was described; although the role of GLIMS in hazard monitoring and response was not then foreseen. The recognition of climate change as a global problem has grown throughout this period and provides much of the underlying scientific support for GLIMS and other glacier measurement activities. There is a growing recognition that the vigor of glaciers, these recumbent and largely silent giants, is inexorably connected to climate and habitability. The debate between the use of dense observations of a modest number of "benchmark" glaciers and of a comprehensive global survey is likely to continue although two ongoing developments tend to support the latter: the demonstration of reliable remote measure of mass balance; and the recognition of how variable glaciers can be in time and space. At least two types of integration challenges remain: Technical: Integration of visible imaging, synthetic aperture radar and Laser altimetry remains a substantial challenge, due as much to personal expertise and preference as to technical challenges. Political: Overlapping objectives of several organizations (WGMS, NSIDC, GLIMS, GTOS, OMEGA,...) and the need of each to emphasize its role in order to maintain financial support. The process of collaboration and cooperation is well underway.

Abstract 2:

Access Antarctica: Maps, aerial photos and publications

Paul Barr

GIS Technician, Gateway Antarctica: Centre for Antarctic Studies & Research, University of Canterbury
Website: www.anta.canterbury.ac.nz
Contact: paul.barr@canterbury.ac.nz or 643 364-2136

Gateway Antarctica at the University of Canterbury maintains Antarctica New Zealand's collection of maps, aerial photos and books. In addition, the University of Canterbury Library holds many other Antarctic-related materials. All of these collections are open to the public and catalogues can be perused online.

Aerial Photos

Begin with our online catalogue in Access Antarctica, the NZ Antarctic GIS, accessible from www.anta.canterbury.ac.nz. See something you need? Choose one of two options: free, low resolution copies of the photos online, or place a paid order for high-resolution digital images. Some photos and flight lines have not yet been added to the digital database, but the archives are available at Gateway Antarctica. For further information contact Paul Barr at paul.barr@canterbury.ac.nz or by phone on 643 364 2987 x4980.

Maps

Antarctica New Zealand's comprehensive map collection, now in the care of the University of Canterbury and comprising 1200 sheets, is one of the largest Antarctic map collections in the world. Records are included on the University of Canterbury Library's online catalogue at http://library.canterbury.ac.nz or contact the Map Librarian at maplibrary@geog.canterbury.ac.nz or by phone on 643 364 2904. Gateway Antarctica also produces digital maps upon request.

Publications

There are many Antarctic-related books and journals at the University of Canterbury Library and an online search is a snap. Go to http://library.canterbury.ac.nz/ or contact Alison Johnston, Physical Science Librarian at Alison.johnston@canterbury.ac.nz or 643 366 7001 x8721.

Abstract 3:
A Statistical Approach to Estimating the Contribution of Glaciers to Future Sea-level Rise.

Ros Death[1]*, A.J. Payne[1], J.M. Gregory[2], J.W. Hall[3] and J. Oerlemans[4]

[1] Bristol Glaciology Centre, School of Geographical Sciences, University of Bristol, Bristol BS8 1SS, U.K.
[2] Department of Meteorology University of Reading, Whiteknights, PO Box 217, Reading, RG6 6AH U.K.
[3] School of Civil Engineering and Geosciences,, University of Newcastle upon Tyne, NE1 7RU UK
[4] Institute for Marine and Atmospheric Research, Princetonplein 5, Utrecht, 3584 CC Netherlands

Valley glaciers and small ice caps are expected to provide the bulk of the cryosphere's contribution to sea-level rise over the next century (~ 0.23 m, IPCC, 2001). A lack of quantitative data for the vast majority of glaciers worldwide (only 100 glaciers out of a total population of 160,000 have mass balance records for longer than 5 years) makes this estimation difficult. Therefore, a different approach to modelling individual glaciers and applying to a region is proposed. A generic valley-glacier system model that predicts variations in width, depth, accumulation and ablation along the glacier has been developed. The model will be calibrated on a small number of glaciers for which data is available and the phase space of free parameters within the model will be constrained. Using the calibrated model and synthetic input, a response surface of sea-level contribution as a function of glacier climatology and topography will be constructed with an assessment of the associated uncertainty. The final stage of the project will be to sample the response function in accordance with estimates of the global distribution of glaciers in the climate-topography phase space to estimate overall sea-level rise. The work presented here details the first two stages of this project.

The 1-d flow model uses an energy balance scheme drives a melt model that includes refreezing within the snowpack and the development of a superimposed ice layer to buffer the loss of mass. The model uses ERA 40 data that is interpolated to the glacier as climatic input for the long wave radiation, turbulent fluxes and precipitation calculations. Glacier geometry is either given explicitly or derived from characteristics that can be remotely sensed (glacier length, width, area).

The model has been applied to two glaciers, South Cascade glacier, USA, and Midre Lovenbreen, Svalbard. These were chosen to represent two different regimes; one where superimposed ice is an important component of mass balance and one where it is not. South Cascade is a small (~ 2.5 km), north facing maritime valley glacier, with an altitudinal range of 1630 – 2150 m a.s.l. (Rasmussen and Krimmel, 1999). The summer temperatures are usually 5 – 20 °C, with small (< 0.05 m averaged over the glacier) or no superimposed ice forming in a season (Krimmel, 1999) and winter temperatures are usually warm (above -10 °C). Midre Lovenbreen is a north- facing polythermal Arctic glacier (~ 4.5 km), with an altitudinal range of 50 -550 m a.s.l. (Wright, 2005). Summer temperatures reach a maximum in July, with an average of ~ 5 °C, while winter temperatures are cold with the mean temperature between December to March below -10 °C (Wright, 2005). Superimposed ice on this glacier can account for up to 37 % of the average annual total accumulation (Wright, 2005).

Abstract 4:
Annual-scale mass and energy transfers at Brewster Glacier, New Zealand

Brian Anderson[1*], Andrew Mackintosh[1], Tim Kerr[2], Laurel George[3], Dorothea Stumm[3], Sean Fitzsimons[3], Wendy Lawson[2]

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2. Department of Geography, University of Canterbury, Private Bag 4800, Christchurch
3. Department of Geography, University of Otago, Dunedin

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Energy balance and run-off models are applied to a small, easily accessible glacier in the Southern Alps of New Zealand, with the goal of quantifying the energy and mass transfers that occur during an annual cycle. Locally collected climate data is used to drive the model, and the output compared with measurements of mass balance and the stage of the outlet stream.

The model simulates measured surface ablation very well, but is not able to calculate accumulation accurately, probably due to the difficulties of estimating precipitation in mountain environments. The combination of accurately modelled ablation and continuous snow surface height measurements allows the snow deposition to be recorded and compared to the snowfall recorded by the rain gauge, indicating that precipitation measured at the rain gauge underestimates snow deposition on the glacier.

A simple triple-linear reservoir lumped model is used to calculate discharge. The patterns of measured and modelled discharge correspond well, with both showing peaks corresponding to rainfall and ablation events, and a diurnal cycle during fine weather. However, the model does not simulate some high-discharge events that are recorded by the stream gauge. These events are the result of high rainfall, which the rain gauge does not fully capture.

Preliminary analysis of the results indicates that during summer conditions the dominant energy source during fine periods is net solar radiation, but turbulent heat fluxes dominate as cloud cover increases. During humid and windy periods the turbulent heat fluxes provide energy for snow and ice melt at rates that exceed that of fine periods. Rainfall is the dominant source of water for run-off, but snow and ice melt can provide as much water during humid and windy periods.

Abstract 5:
ASTER Imaging Re-prioritization for GLIMS Acquisitions in 2006-2007

Jeffrey S. Kargel

University of Arizona, Tucson, AZ 85721 USA, jkargel1054@earthlink.net

ASTER is in its "old age," having exceeded its nominal design life. It remains in excellent health and has been given at least three additional years of full-scale funded operations. Over 50,000 L1B glacier scenes (of all qualities) have been acquired, which is a sharp increase from two years ago. Only Greenland has been imaged with a repeat rate close to what was originally envisioned. Most other areas have at least one image, but a minority of the world's glaciers have high-quality repeat coverage using GLIMS gain states that minimize saturation over snow and ice. Clouds are a chief obstacle.

A realistic plan for completion of glacier coverage must include completion of imaging of the world's glaciers and at least one repeat image. To achieve this realistic goal without exceeding the ASTER imaging allocation of resources for GLIMS, regions of increased imaging priority have to be balanced with regions of decreased priority. The priority ranking below is one scheme, which will be discussed within GLIMS and with Mission Operations, modified as needed, and then implemented prior to the New Zealand workshop. This scheme is based on the percentage of acquired images in each region having ≤ 10% cloud cover (assessed manually at Eros Data Center in a large subset of images; Figure 1). No area is so cloudy that it is hopeless (even Bhutan has many partly clear scenes). The regional rankings based on this cloudiness parameter were then modified to account for the importance of the region's glaciers to people (water resources, hazards, tourism), the population affected by the glaciers, their importance for climate change tracking, and gaps in current coverage. The wide-pointing high-latitude Antarctic "ring" is given a high priority due to the unique ability of ASTER to image it.

The most notable features of these proposed rankings (Table 1) are the increased emphasis given to Himalayan and Alaskan glaciers and a halved priority for Greenland imaging (due to great imaging success there to date).

A working group to evaluate ASTER imaging successes and failures and to generate an optimum revised imaging strategy has been established by GLIMS. The group, called ASTER HAGGLING (ASTER Himalaya, Alaska, and Greenland GLacier Imaging Negotiations Group), will re-evaluate image acquisition parameters and will adopt an optimum and balanced imaging approach.

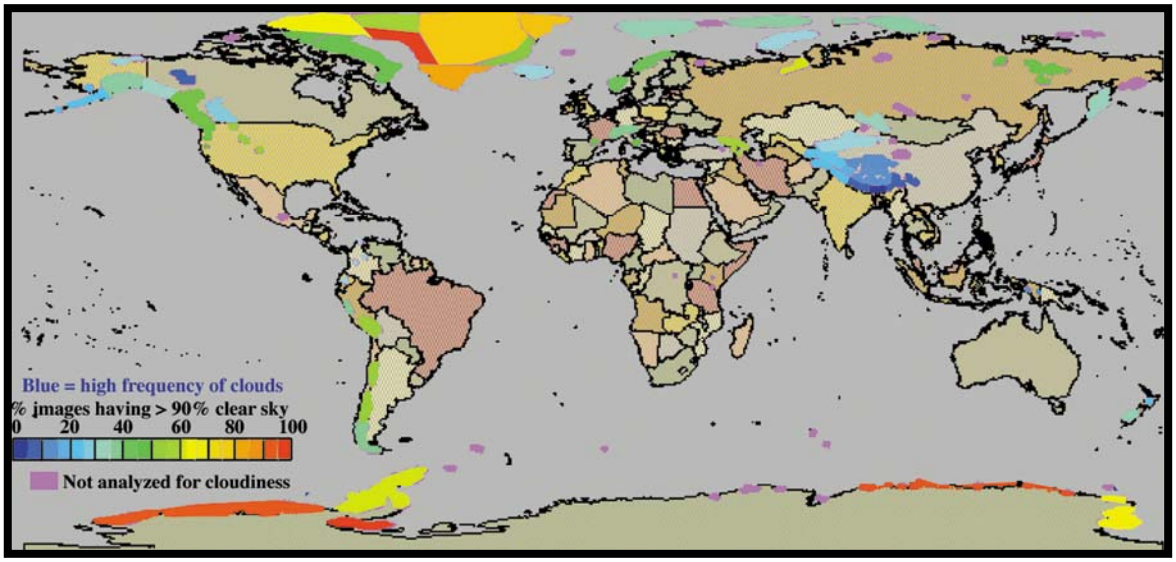

Figure 1. Regional average cloudiness parameter (tabulated values in Table I).

TABLE I. MODIFIED CLOUDINESS-BASED REPRIORIZATION OF REGIONS FOR CONTINUED ASTER IMAGING.

PROPOSED TRIPLED PRIORITY:
(Percent images with ≤ 10% clouds)

Bhutan	0%
Canada-Mackenzie Mountains	5%
China-far east Tibet/Sichuan	5%
Nepal	6%
Irian Jaya	11%
China-Kunlun Shan, Altun Shan	11%
China-mid-eastern Tibet	12%
China-western Tibet	17%
India- between Nepal & Pakistan	24%
Pakistan/Afghanistan	24%
Tajikistan/Kyrgyzstan	26%
China/Kyrgzstan-Tian Shan	28%
Ecuador and Colombia	30%
Alaska- St. Elias/ panhandle	31%
Alaska-Chugach/Wrangells/Alsk Rg	35%
Europe-Alps	36%
Peru-Cordillera Blanca	37%
Chile/Argentina-S.Patagonia Icefd	39%
High-latitude Antarctic "pointing" ring	--

TABLE I. MODIFIED CLOUDINESS-BASED REPRIORIZATION OF REGIONS FOR CONTINUED ASTER IMAGING (Cont.).

PROPOSED DOUBLED PRIORITY:

Alaska-Kuskokwim Mountains	20%
Alaska-Aleutian Is. & Peninsula	24%
New Zealand-North Island	25%
Canada-Rockies	27%
Russian Arctic-Novaya Zemlya	28%
Iceland	28%
Alaska-Brooks Range	29%
Mongolia and Russia-S Siberia	32%
Russia-Kamchatka	33%
New Zealand-South Island	34%
Norway-Svalbard	34%
Russia-Arctic-FranzJosef/Northland	35%
U.S. -Cascades	47%

PROPOSED NO CHANGE OF PRIORITY:

Norway-mainland	44%
Canadian Arctic-Devon Island	46%
Canadian Arctic-Baffin Island	46%
Europe-Pyrenees and Appennines	47%
Russia-Eastern Siberia	47%
Canada-British Columbia	49%
Chile-N Patagonia Icefield&N Chile	52%
U.S.-Rockies	52%
Southern Peru/Bolivia	53%
Russia and fmr Soviet-Caucasus	55%
Antarctic Peninsula	60%
Russia-Ural Mountains	61%
East Antarctica-Scott/Borch/Oates	64%
West Antarc.-Ellsworth Land	93%
East Antarctica-Wilkes Land coast	94%
West Antarc.-Ronne/Zumberge Cst	97%

REGIONS REQUIRING DECREASE OF PRIORITY:

Greenland-East Central	50%
Greenland-Northwest	57%
Canada Arctic-Axel Heib +Ellesm	65%
Greenland- Central	77%
Greenland-Northeast	79%
Greenland-South	82%
Greenland-West Central	96%

Abstract 6:

Change Analysis of Glacier Ice Extent in Southwest Alaska

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Glacier changes have been analyzed in the Harding Icefield and the Grewingk-Yalik Glacier Complex of Kenai Fjords National Park (KEFJ) for the National Park Service. These icefields are located in the mountains of the Kenai Peninsula, Alaska. The Harding Icefield spawns more than 38 glaciers of which some are tidewater and others are land-based, or wholly or partially terminate in lakes. We used Landsat Multispectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) scenes to outline glacier areas and terminus positions on four scenes. Glacier outlines were done using vector segments to produce shape files for the Geographic Information System (GIS) analysis. Results show that most of the glaciers in KEFJ have receded since 1973, some dramatically. These results are generally consistent with results from extensive work done in the 1990s on the Harding Icefield by previous researchers.

For this project, we derived GIS shape files, and from those we can calculate glacier area and terminus changes from 1973 to 2002, and estimate the 1986 equilibrium-line altitude (ELA) for the large glaciers. Some issues that complicate the analysis include: moraine covered ice, clouds, shadows, fresh snow cover and spatial resolution differences between images. This is the first part of a project for which the objective is to map glacier ice extent on a decadal scale beginning in the early 1970s and continuing to the early 2000s. Shape files are created for an analysis of change in glacier extent using a GIS for three national parks in Alaska. Work has begun in Katmai National Park (KATM), to create the shape files. By the summer of 2006, shape files for KATM and Lake Clark National Park and Preserve (LACL) will be completed. Following the creation of the shape files, we hope to obtain funding to analyze glacier changes in the context of meteorological and other satellite and aircraft data.

Abstract 7:
Controls on surface energetics and ablation of the McMurdo Ice Shelf, Antarctica.

Penelope Clendon* and Wendy Lawson

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The McMurdo Ice Shelf, in the Ross Sea Region, has extensive surface melting during the austral summer. Adding complexity to this system is the presence of subsurface melting which can occur when temperatures are not high enough for normal melting processes. Using an energy balance approach, the amount of energy available to cause surface ablation is calculated and the controls on this investigated.

Ablation stake and micrometeorological observations were made across the McMurdo Ice Shelf during the 2003/4 and 2004/5 summer periods. Turbulent fluxes were calculated using the aerodynamic approach while the radiation budget was measured directly. An eddy covariance system was used for correlating the turbulent flux estimates.

The primary source of energy into this system is shown to be net radiation. Although sensible heat flux can also be significant, it is not as important here as on the Antarctic Peninsula. The dominant controls of temporal variability of these energy balance components are albedo and atmospheric circulation. Albedo has a relatively large diurnal cycles as well as significant changes due to snowfall.

The regional climate is characterized by east moving low-pressure systems and katabatic winds that are subject to local topographic effects. During periods of stable atmospheric conditions the winds follow the surrounding topography. It is during these stable events that the residual energy was found to be the highest. High wind speed occurrences are typically from the south and are not as affected by topography, during these conditions the energy available was considerably reduced.

Abstract 8:
Decay of Gigantic Antarctic Icebergs

Wolfgang Rack and Daniela Jansen

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Unfortunately Wolfgang Rack was unable to join us at the Workshop, but we have included his abstract for your interest.

Break off events of gigantic tabular icebergs at the ice shelf fronts impressively reveal the dynamics of the Antarctic Ice Sheet. Calving of such icebergs, being several hundred meters thick and covering thousands of square kilometres, represent an essential mass budget quantity of the ice sheet. When moving very far north into warmer climate, the understanding of the pattern of decay may yield important links to the poorly understood mechanisms of rapid ice shelf collapse as a consequence of climate warming. In this study we use remote sensing data to validate a numerical model simulating the decay of the A38 iceberg, which calved off from Ronne Ice Shelf in October 1998.

Shortly after calving, A38 broke up into two halves of about equal size, A and B. Here we concentrate on the A38-B iceberg. ERS SAR interferograms of the ice shelf edge were analyzed in order to reveal dynamical conditions which triggered the break off or which could be of significance later on for the disintegration of the ice berg. The track of the iceberg from Ronne Filchner Ice shelf to South Georgia was obtained from low resolution active and passive microwave data. A-38B drifted slowly within the Wedell Gyre and followed the coastline northwards, but accelerated considerably in the Scotia Sea and got grounded north of South Georgia in January 2004.

On its path north, MODIS data, and high resolution Envisat ASAR and ASTER images are available. Icebergs from geocoded high resolution images were co-registered in order to analyze changes in size, calving events at the margins and changes in the surface structure. Several model runs were performed to investigate the impact of interactions with ocean and atmosphere on iceberg evolution. The boundary conditions of the numerical iceberg model along its track was forced by ECMWF air temperatures and water temperatures from an oceanographic model.

Iceberg observations and simulations clearly reveal that the thickness decrease during drift is mainly governed by basal melting. The only available melt rate estimates usually result from ocean modeling. A preliminary evaluation of satellite altimeter data suggests that the model forcing parameters may be quantified by satellite observations.

Abstract 9:
Estimate on melt rates of debris-covered glaciers in the Himalayas using ASTER data

Ryohei Suzuki [1], Yutaka Ageta [1], Koji Fujita [1], Akiko Sakai [1], Nozomu Naito [2]

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The shrinkage of debris-covered glaciers in the Himalayas generates many glacier lakes that may cause disastrous floods. To examine the processes of the lake formation and expansion, estimating melt rates of the debris-covered glaciers is essential. Direct measurement of the melt rates is difficult, however, since they depend on thickness and thermal properties of the debris that vary widely even on one glacier. We propose a methodology to estimate distribution of the melt rates on multiple debris-covered glaciers through thermal resistance of debris layer (thickness / thermal conductivity) by using remote sensing techniques. The present targets are ablation areas of three debris-covered glaciers in the Lunana region, Bhutan. Utilized remote sensing data are elevation, albedo and surface temperature of the glacier surfaces, which were acquired by ASTER on 21 July 2003. The ground meteorological data are also utilized, which were obtained annually, including the ASTER data acquisition date, by an automatic weather station at 4524 m a.s.l. We calculated spatial distribution of the thermal resistance on the ASTER data acquisition date. Assuming no temporal change in the thermal resistances, we calculated distribution of melt rates on the debris-covered areas for the melting season of 2003 (Fig. 1). The melt rates range widely on each glacier in spite of a small elevation range, because the thermal resistances range

depending on various thickness of debris. This result indicates that the methodology can be applied to wider areas in the Himalayas to evaluate the processes of glacier lake formation and expansion.

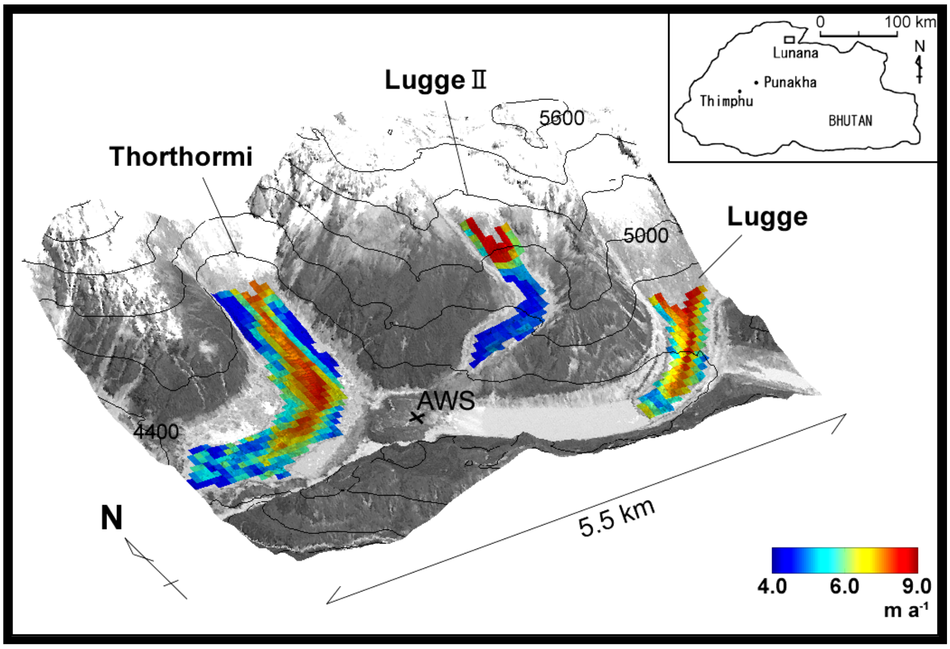

Fig. 1 - Melt rates of debris-covered glaciers in Lunana, Bhutan. A cross denotes the position of an automatic weather station (AWS).

Abstract 10:
Glacier Hazards and Water Resources Issues: Alaska, Himalaya, Peru.

Jeff Kargel

See separate sheet

Abstract 11:
Glacier monitoring in the Southern Alps: Trends and variations from snowline monitoring

M. J. Salinger[1], T. Chinn[2], A. Willsman[1] and B .Fitzharris[3]

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Glaciers of New Zealand provide an indisputable and enhanced response to the changing climate. Their response is recorded by annual aerial surveys. These surveys measure the altitudes of end-of-summer-glacier snowlines of 50 selected index glaciers. These data are used as a surrogate for annual glacier mass-balance. They have been made in most years since 1977, but rarely do weather conditions permit all of the index glaciers to be surveyed each year. The surveys are carried out by hand-held oblique photography taken from a light aircraft, where the position of the glacier snowline is recorded from a similar viewpoint each year.

Analysis of the data shows that end of summer snowlines (EOSS) are a useful measurement of glacier response to annual climate fluctuations, although there is much variability in the degree of response between glaciers in any given year. Comparisons of individual glacier annual EOSS with the mean for all annual EOSS of the Southern Alps show a large variation of individual glacier response with coefficients of variation (r2) ranging from 0.53 to 0.95. When combined the data indicate a change in EOSS since 1977 for the whole Southern Alps.

The EOSS data show detailed, but qualitative, annual mass balance variations on both regional and individual glacier scales. For the fast response glaciers, the EOSS record foreshadows glacier termini responses after appropriate response time delays, some of which are as short as 5-7 years. On the other hand, the long reaction time glaciers, such as the Tasman, are responding. The recorded variability in climate response for the whole of the ice mass of the New Zealand Southern Alps suggests that a large number of EOSS measurements may be as good an indicator of climate as direct mass-balance measurements restricted to just a few glaciers. There is a steep eastward rise in elevation of EOSS across the Alps, while the north-south fall in EOSS elevation along the Alps is a uniform 1m km^{-1}.

The glaciers have shown a cyclic trend over the 29-year monitoring period, with a tendency for periods of positive balances at near 11 year intervals. Given the appropriate gradient of changing mass balance with elevation, mass balance values may be calculated for any of the monitored glaciers and for the whole Alps when combined with the New Zealand glacier inventory.

ASTER satellite imagery offers good potential for providing a more comprehensive view of glacier EOSS variations throughout the Alps. The 15 m spatial resolution of the ASTER instrument is well suited to the New Zealand context (i.e. small and steep glaciers) when compared to the moderate spatial resolution of earlier satellites.

Abstract 12:
Glacier volume changes in the Southern Alps: Computation from annual snowline surveys

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Ice volume changes of the Southern Alps provide a valuable index value for the climate and energy balance at the earths surface, water resources and an indisputable measure of climate change. Without direct measurements, glacier ice volume calculations rely on many approximations, depending on the method used. In New Zealand we have the advantage of two additional sources of data; the long and continuing record of annual equilibrium line altitude (ELA) also known as the end-of-summer-snowline (EOSS), values from a set of 50 index glaciers. The ELA values give an immediate annual signal of mass change, unlike the

highly delayed and deformed signal of glacier length changes. Secondly, each of the index glaciers has an area-altitude curve constructed as part of the ELA studies.

Work has commenced on deriving EOSS values from images of the GLIMS project. In addition to providing EOSS data for the index glaciers, GLIMS images have the potential as a backup for missing data, to provide data from throughout the Southern Alps, and to record glacier lengths and outlines.

To calculate annual volume changes from ELA measurements, a mass balance gradient (MBG) is required for each glacier. The MBG is the rate of change of annual mass along the longitudinal profile of the glacier. In New Zealand, MBGs are available for only two glaciers, the Ivory and the Tasman. A single mean value is normally employed from the complex MBG curves, but the estimates of MBGs are imprecise and this procedure is likely to introduce errors in the estimation of change of glacial mass. A alternative approach is required. A basic rule of glaciology is the 2:1 ratio, where on average, the accumulation area (above the ELA) is twice that of the ablation area. This means that, on average, the mean annual accumulation is half that of the mean annual ablation. Thus it is important that the two separate values for MBGs be used, one for accumulation above the ELA and a higher rate for ablation below the ELA.

A preliminary estimate of New Zealand annual ice volume changes for a trial period from 1993 to 2001 was calculated in 2002 by using the EOSS data with a crude geometric model for each glacier.

The results of this study indicated that there has been a net volume gain of $6.7 Mm^3$ or 12.6% from 1993 to 2001. To estimate the error of this preliminary work, the results are compared with annual mass balance changes on three intensively measured glaciers.

% of glacier volume change each year

	Duration, yrs	Max vol. change, %	Min vol. Change, %
NZ Study	8	5.5	1.8
Storglacier (SWEDEN)	50	1.2	.1%
Blue (USA)	41	6.0	– 4.5
Peyto (CANADA)	33	1.1	3.8

Abstract 13:

GLIMS community journal publications, GLIMS book (Praxis-Springer), discussion of outline and writing assignments.

Jeff Kargel

See separate sheet

Abstract 14:
GLIMSView description and update and plans

Bruce Raup

Bruce will summarize the current and planned capabilities of GLIMSView. GLIMSView is a multi-platform graphical application for digitizing glacier boundaries from satellite imagery and for packaging the resulting data set for ingest into the GLIMS Glacier Database. The program can also be used to process previously existing glacier outline data into GLIMS-compatible form.

Abstract 15:
Holocene Deglaciation of Mac.Robertson Land, East Antarctica

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Changes in East Antarctic Ice Sheet volume exert a fundamental control on eustatic sea level, but ice sheet fluctuations are poorly documented since the Last Glacial Maximum. ^{10}Be and ^{26}Al exposure dating of 21 glacial erratic boulders from the Framnes Mountains, Mac.Robertson Land enables us to test whether the East Antarctic Ice Sheet was the source of Meltwater Pulse 1A, a rise in eustatic sea level of 20 m that occurred in less than 500 years at c. 14,600 years BP. Exposure ages show that the ice sheet remained at its maximum extent until c. 12,000 years BP, when geomorphic evidence indicates that 350 m of ice sheet thickening occurred near the present-day coastline, declining to less than 100 m at a distance of 70 km inland. The ice sheet reached its present elevation by c. 5000 years BP, at a time when eustatic sea level stabilised. The rate and volume of ice loss and timing of deglaciation in the Framnes Mountains does not support the hypothesis that the East Antarctic Ice Sheet was the source of Meltwater Pulse 1A. Conversely, our data indicate that deglaciation of Mac.Robertson Land occurred during the Holocene, and took thousands of years to complete.

Abstract 16:
Intra-annual Variation in Ablation & Surface Velocity on the lower Fox Glacier, South Westland, New Zealand

Heather Purdie

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Intra-annual variations in ablation and surface velocity were investigated on the lower Fox Glacier, South Westland, New Zealand. Large variation between summer and winter ablation rates were recorded, with daily averages of 129 mm d^{-1} and 22 mm d^{-1} respectively. During summer, debris-cover significantly reduced ablation (50%), and ablation suppression increased as debris thickness increased. In winter ablation suppression was not so apparent,

but during heavy precipitation events, ablation under debris cover was half of that occurring on the clean ice surface. Variations in climate variables were found to account for over 90% of ablative variability during both summer and winter monitoring. Significant increases in ablation were found to occur with heavy precipitation events. Surface velocity averaged 0.87 m d-1 during summer and 0.64 m d^{-1} in winter, a reduction of 26%, and if recent increases in ice thickness are taken into account, deceleration increases to 32%. Reductions in velocity during winter are attributed to a decrease in water supply. During winter, precipitation events were found to increase velocity by up to 44%. The velocity response to precipitation events could be instantaneous, but on some occasions a time lag was present. This temporal variability is interpreted as either variation in the morphology of the glacial drainage system, affecting the efficiency of water transport to the base of the glacier, and/or to water storage. Both processes influence water pressures in the sub-glacial drainage system, which when increased, can enhance basal sliding.

Abstract 17:
Is Byrd Glacier slowing down? Analysing the evolution of the Antarctic Ice Sheet

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The flow dynamics of the Byrd Glacier (Figure 1) were first examined by ice motion field surveys conducted in 1978. Recently Stearns and Hamilton (in press) compared the 1978 velocity data to velocities over the same area derived from feature tracking between two 2001 ASTER images. They found that the central trunk of the Byrd Glacier decelerated from ~820 ma^{-1} in 1978 to ~650 ma^{-1} in 2001, suggesting that outlet glaciers draining East Antarctica may not be as stable as previously thought. So is the East Antarctic Ice Sheet stable?

Figure 1 – Byrd Glacier, Landsat 1 MSS image of the Byrd Glacier where it joins the Ross Ice Shelf, Antarctica. 16 Jan. 1974.

Antarctica has been glaciated for approximately 34 million years, but its ice sheets have fluctuated considerably and are one of the major driving forces in global sea level and climate change. My research considers the evolution of the Antarctic ice sheet as a whole, but also downscales to look at more glacial-scale changes at the ice sheet margins, regions such as Byrd Glacier. I will use a combination of ice sheet modelling (GLIMMER, a three-dimensional thermo-mechanically coupled ice sheet model), remote sensing and secondary data (field observations etc.) to interpret how the Antarctic Ice Sheet has evolved over time.

This research is supported by the Scientific Committee on Antarctic Research (SCAR) and Bristol Glaciology Centre, University of Bristol (SCAR Fellowship, October 2005 - April 2006), and will be supported by Cambridge Commonwealth Trust, Trinity College (Cambridge) and Scott Polar Research Institute, University of Cambridge (PhD, April 2006 - April 2009). I would also like to thank Global Land Ice Measurement from Space (GLIMS) for the financial support to attend this workshop.

Abstract 18:
Mass balances and end-of-summer snowlines on glaciers of the Southern Alps, New Zealand

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Glacier mass balance changes are an excellent indicator of climate change. However, some glaciers reflect climate change better than others do. The equilibrium line altitude (ELA) represents the altitude where the mass balance on the glacier is zero. The end-of-summer snowline (EOSS) on a glacier gives an indication where the ELA is. Obviously, there is a relationship between the mass balance, EOSS and ELA.

Until recently there was no long-term mass balance measurement program in New Zealand. However, since 1977 an annual EOSS survey is carried out. This survey includes 50 glaciers, covering maritime and continental glaciers but as well glaciers from different latitudes in the Southern Alps.

In this research project, the mass balances of glaciers in the Southern Alps are investigated to find out if the selected glaciers are suitable climate indicators. The glaciers chosen for this study are Brewster, Park Pass and Rolleston Glacier which represent maritime glaciers, and Glenmary Glacier, standing for a continental glacier type. These four glaciers with EOSS records are selected to measure the mass balance, and hence the mass balance gradient, by the glaciological method. By using direct measurements on the glaciers, the relationship between the mass balance and the EOSS will be established. Then the mass balance of these four glaciers will be reconstructed using the EOSS records of the last 30 years and the measured mass balance gradient.

A simple mass balance model will be tested with the direct measurements for the chosen glaciers. The model is fed with climate information from a nearby climate station and a digital elevation model (DEM). With this mass balance model, the current mass balance and ELA will be calculated and compared to the measured mass balance and ELA and the EOSS. With climate data from the past 30 years, the mass balance and ELA will be calculated and compared to the EOSS records.

Abstract 19:
Monitoring Mountain Glaciers: A view from the World Glacier Monitoring Service

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Glaciers are key indicators in the global climate observations (IPCC, 2001). Therefore, a world-wide glacier monitoring programme called GTN-G was recently launched. This monitoring programme is led by the World Glacier Monitoring Service in Zurich, Switzerland. During recent years strategies were developed by the WGMS, which mainly focus of enforced coupling and use of in-situ measurements combined with remote sensing and numerical modelling approaches (Haeberli et al., 2000; Haeberli and Dedieu, 2004; Haeberli et al., 2002). This approach aims to link detailed process studies on one side to global overviews on the other hand by combining new methods of satellite imagery and digital terrain information The following levels of investigations were according to these strategies determined: a) extensive glacier mass balance and flow studies within major climatic zones for improved process understanding and calibration of numerical models; b) determination of regional glacier volume change within major mountain systems using cost-saving methodologies; c) long-term observations of glacier length change data within major mountain ranges for assessing the representativeness of mass balance and volume change measurement and d) glacier inventories repeated at time intervals of a few decades by using satellite remote sensing.

Application of numerical models at various scales and levels of sophistication increasingly enhances the value of the observations and improves the process understanding, which is the fundamental basis for adequate monitoring. 2-dimensional or spatial distributed energy/mass balance models are used to assess the sensitivity of glacier mass. Such local model runs can be coupled with Global Climate Models (GCMs) or Regional Climate Models (RCMs) in order to explore and explain large-scale and long-term variabilitie. Such studies also provide essential information with respect to regional and global impacts (water resources, sea level). Continuity considerations for assumed step changes between steady-state conditions reached after the dynamic response time enable the reconstruction of decadal to centennial mass balances from cumulative length changes worldwide or back into historical and even holocene times. In well-studied cases, dynamic fitting of time-dependent and coupled mass-balance/flow models to present-day geometries and observed long-term length change forms the basis for more detailed mass balance reconstructions and for extrapolations into a probably warmer world of the coming decades. Numerical modelling has, indeed, become a key element in modern glacier monitoring.

Abstract 20:

Monitoring of Imja Glacier Lake in the East Nepal using the satellite image

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The research of the glacial lake in the Nepal Himalaya region is carried out since 1990's (Ex. Yamada, 1998). The glacial lake has been stopped in the unstable moraine. The size of the lake expanded by the melting of the glacier ice in mountain region by the global warming. GLOF (Glacier Lake Over Flood) occurred by the moraine can not sustaining and collapsing quantity of water of glacial lake. However, unclear points such as glacial lake forming condition and process of the glacial lake extension have been left. In this study, the quantitative evaluation was carried out using satellite image in respect of the extension of glacial lake of Imja glacial lake in East Nepal of which a risk of a glacial lake collapse is high. The analysis was carried out on climate change and glacial lake formation using global temperature data. The analysis period was from 1962 to 2000, 10 scenes (1962, 1964, 1968, 1975, 1977, 1987,1991, 1993, 1995, 2000) in this period were analyzed. Used satellite image was used in 4 types. One is high-resoluble military affairs reconnaissance satellite CORONA image that the U.S.A. of which the resolution is 7.6m photographed was used in 60's. And LandsatMss of which the resolution was 83m was used in 70's. And SPOT of which the resolution was 10m was used in 80's and 90's. And Landsat ETM+ of which the resolution was 15m was used in 2000. Each image carried out the geometric correction using the map.

Climetological data used Global Historical Climate network Ver.2 of National Climate Data Center (NCDC). The glacial lake was formed around 1960, and that the area expanded after it at the almost fixed speed clarified. Glacial lakes were four small ponds at the initial stage in 60's. Next, glacial lakes spread during around 70's to the downstream direction by the expansion of those ponds. Those ponds expanded, and it became one lake. The end in the glacial lake did the extension by 1991, and it was stabilized after it. The glacial lake expanded to the upstream direction from the middle of 70's. ICIMOD (2000) is said that many glacier lakes of Himalayas would rapidly develop in here 1960's. The Imja glacial lake is also similar. The global warming is being caused from before formation of glacial lake with the mean deviation of annual mean temperature of the Northern Hemisphere. The shrinkage of the glacier by the global warming occurred before formation of glacial lake. The glacial lake might be formed by the glacier shrinkage process.

Abstract 21:
Monitoring the Behavior of Alaska's Glaciers - An Opportunity for GLIMS

Bruce F. Molnia

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Glaciers cover about 75,000 km^2 of Alaska, about five percent of Alaska's land area. They exist on 11 mountain ranges (Coast Mountains, Saint Elias Mountains, Chugach Mountains, Kenai Mountains, Aleutian Range, Wrangell Mountains, Talkeetna Mountains, Alaska Range, Ahklun and Wood River Mountains, Kigluaik Mountains, and Brooks Range), one large island (Kodiak Island), one island archipelago (Alexander Archipelago), and one island chain (Aleutian Islands). Glaciers in Alaska extend from as far southeast as N55º19' and W130º05', about 100 km east of Ketchikan; to as far southwest as Kiska Island at N52º05' and E177º35' in the Aleutian Islands; to as far north as N69º20' and W143º45' in the Brooks Range. The number of glaciers is unknown, having never been systematically counted, but probably exceeds 100,000. Alaskan glaciers range in elevation from above 6,000 m to below sea level. Most are unnamed. Less than 700 glaciers have been officially named by the U.S. Board on Geographic Names. Nearly all of these named glaciers and about 1,000 additional unnamed glaciers descend below an elevation of ~ 1,500 m.

During the Little Ice Age, the total glacier-covered area and the number of mountain ranges and islands with glacier cover was significantly larger than presently. Since then, as has been the case in all of Earth's temperate glacier-covered areas, there has been a significant decrease in glacier length, area, and thickness. However, the timing, magnitude, and complexity of this "Post-Little-Ice-Age" glacier change in each of Alaska's 14 glacier-bearing areas has been different. To understand these complexities, an assessment of each of Alaska's glacier-bearing regions was prepared. Key findings are synthesized and succinctly presented here to define the late-19th to early- 21st century behavior of Alaskan glaciers in response to changing regional climate. Although there is a significant thinning of lower-elevation glaciers and retreat of glacier termini, the current behavior of Alaska's glaciers varies significantly from area to area, varies significantly with elevation, and is extremely dynamic.

Today, not all Alaskan glaciers are retreating. Many glaciers at higher elevations are thickening or show no change. Several volcanoes, including Redoubt Volcano and Mt Katmai, had 20th century eruptions that melted summit glaciers. Since then, new glaciers have formed in their craters. At elevations below ~ 1,500 m, more than a dozen glaciers, including Hubbard, Harvard, Meares, and Lituya Glaciers, are currently thickening and/or advancing.

The information base developed in this ongoing project could be incorporated into the Global Land Ice Measurements from Space (GLIMS) international project, and would be a significant contribution towards achieving GLIMS' goal of surveying a majority of the world's estimated 160,000 glaciers. Conversely, data collected primarily by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument aboard the Terra satellite would be very useful for expanding our knowledge of the current behavior of many Alaskan glaciers.

Abstract 22:
Mountain safety in New Zealand, an overview and latest developments

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A brief look at the range of hazards faced by people on glaciers with a more in depth look at; the use of ropes for glacier travel and moving together on snow, snow anchor failure mechanisms and how to build the strongest anchor for the prevailing conditions. Don Bogie Technical Support Manager, DOC, Canterbury.

Abstract 23:
New Zealand glacier inventory by the use of ASTER imagery and aerial photographs

Endre Gjermundsen

The project is part of Endre Gjermundsens' master study at the Department of Geosciences at the University of Oslo. The master thesis is in cooperation with University of Otago, Dunedin. Endre Gjermundsen is working in collaboration with Andreas Kääb and Jon Ove Hagen in Norway, and Renaud Mathieu, Trevor Chinn and Blair Fitzharris in New Zealand.

Change in glacier extent is a good indication of climate change. Inventories for glaciated areas should therefore be made with certain intervals. For New Zealand a digitized glacial inventory including both the two main islands' glaciers was made from aerial photographs recorded in 1978. This inventory needs updating.

One Aster scene (60*60km) recorded 14. February 2002 covering the main glaciated areas of Mt Cook and Westland National Parks is used for the updating. This image will be classified into glaciated and non-glaciated areas using different classification methods including object oriented technique. For validation of the Aster image field work was conducted during late summer of 2005 (Feb-April). Glacier outlines were mapped for 6 individual glaciers using a differential GPS. These data were later corrected to a base antenna giving sub-meter accuracy. Aerial photographs of the field work glaciers from years of particularly positive or negative mass balance are also used for comparison between the satellite image and the 1978 inventory. Field work shows that glaciers which have generated lakes at their terminus after the 1978 inventory was made, have retreated dramatically during the 24 year period (due to lake calving). Smaller glaciers at high altitude, however, show only slight changes. The terminuses of Fox and Franz Josef glaciers have been pulsing back and forward during these 24 years.

Abstract 24:
Rainfall and snowfall measurement in Aoraki/ Mt Cook National Park, New Zealand

Tim Kerr[1], Ian Owens[1], Roddy Henderson[2]

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The hydrology of Aoraki/Mt Cook National Park is of national significance fro hydro-electricity generation, agriculture, tourism, recreation and conservation. A major component of this hydrology is the precipitation regime. Many assessments of the precipitation regime have been made based on stream flows, glacier mass balance, topography, analogy to similar catchments, and personal experience. These assessments vary considerably one from the other. Few precipitation measurements have been taken in the region to assess the validity of these estimated distributions.

A network of precipitation gauges is to be installed in Aoraki/ Mt Cook National Park to help characterise the precipitation regime. The gauges consist of simple 2 m high standpipes combined with a water level sensing data logger. The gauges have been designed to manage extreme precipitation events, sub 0ºC temperatures, Kea (alpine parrots), evaporation, high winds and dynamic glacial-surfaces.

Gauge sites were selected based on the following criteria:

- Safe location (distant from potential avalanches, rockfalls, crevasses)
- Accessible by foot throughout the year
- Not on a slope
- Unlikely to be buried by Snow
- Low visual impact
- Low environmental impact
- Sampling different precipitation magnitudes

The measurements are to be made for a complete year from April 1st 2006 until April 1st 2007. The 5 min data logging will enable single rain events to be captured. Measurements taken at the new gauges will be compared to those taken at nearby long term gauge sites to enable extrapolation beyond the single year. It is envisaged that the new information will provide valuable input to snow storage and rainfall-runoff models, probable maximum precipitation estimates, and climate change scenario investigations.

The research is supported by The Tertiary Education Commission, Meridian Energy, NIWA, Humes Pipes and the Department of Conservation.

Abstract 25:
Recent changes in the glacial meltwater due to glacial shrinkage in the Terskey-Alatoo Range, Kyrgyz Republic

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By comparing the images from Corona 1971 and Landsat 2002 satellites, it is revealed that the total glacier coverage in the western Terskey-Alatoo Range, Kyrgyz Republic decreased by 8% (17.8 km^2) over the 30-year interval. The shrinkage of small-scale glaciers was even higher, a finding suggests a future decline in water supply because this area has many small-scale alpine glaciers. To determine the effect of the recent glacial shrinkage on the river discharge in this area, meltwater amount from glaciers was estimated in the Chon-Kyzyr-Su watershed of the Terskey-Alatoo Range. The electric conductivity (EC) of the river water, glacial meltwater, and non-glacial water was measured in the Chon-Kyzyr-Su watershed in 2004 and 2005. The glacial meltwater amount was separated from river water using the EC and discharge data at a hydrometeorological station. Fluctuations in the glacial meltwater amount calculated by EC and discharge data coincided with those of glacial meltwater amount calculated from the heat-balance model based on data from an automatic weather station at the glacier front. The data show that the percentage of total river water that is from glacial meltwater achieve up to 40% in July-August in 2004. The glacier areas occupy only 15% in the watershed area of the Chon-Kyzyr-Su River, and the contribution of glacial meltwater to the river water is large in this area. We report here on the change in contribution of the glacial meltwater amount in the past by using a heat-balance model that was found to be consistent with EC data.

Abstract 26:
Remote sensing and field studies of glacier lakes

Jeff Kargel

See separate sheet

Abstract 27:
Results of the GLIMS Analysis Comparison Experiments (GLACE)

Bruce Raup

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I will present a summary of the results of the GLIMS Analysis Comparison Experiment II (GLACE II). In an ongoing effort to quantify the uncertainties in GLIMS results due to analyses being performed at different institutions and by different people, a second Comparison Experiment is being undertaken. Each Regional Center (RC) will analyze the same images to produce glacier outlines and various scalar attribute data. The first comparative image analysis experiment (dubbed the Round Robin) revealed several potential pitfalls in processing, data reporting, and image interpretation. In GLACE II we aim to help participants avoid these pitfalls while focusing on one of the main goals of GLIMS: Change Detection. Participants have analyzed glaciers in a region seen in two images separated by 9 years. The results have been sent to the GLIMS team at the U.S. National Snow and Ice Data Center (NSIDC) for compilation and analysis.

At the GLIMS workshop held on October 24 and 25, 2005 in Tucson, Arizona, a smaller scale and fully manual glacier digitization was carried out by the workshop participants. The results emphasized the importance of using topographic information (digital elevation model data) for the proper interpretation of glacial and periglacial features. This presentation summarizes the results from all three experiments and presents lessons learned and implications for future GLIMS work.

Abstract 28:
The 2003 SPOT5-derived glacier inventory for Cordillera Blanca, Peru: a contribution to the GLIMS Geospatial Glacier Database

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Changes in glacial area and extent over time are often conducted by comparing historical aerial photography with recent remote sensing imagery. However, several problems are often encountered: old inventories from aerial photography often lack metadata and quality control; processing methods used to derive glacier outlines from satellite images are not standardized, leading to inconsistencies in the various datasets; previous glacier datasets are not in public domain. This makes the comparison of glacier areas at different times a difficult process, posing a need for standardized processing methods and perhaps a reprocessing of old data.

Here we present a case study for Cordillera Blanca in Peru (8°30 S, 77°W). Rapid melting of glaciers in this area in the last two decades poses a threat for local water resources. An extensive glacier inventory for this region was conducted using 1962 and 1970 aerial photography. For the present study, a new set of glacier outlines was produced from 2003 SPOT5 satellite imagery. The dataset was stored in the GLIMS Glacier Database, maintained at the National Snow and Ice Data Center (NSIDC), Boulder. We compared glaciers from 2003 with the ones from 1962-1970 on a one-by-one basis to derive detailed glacier statistics and changes in glacier elevation and area. Glaciers that had separated into several ice bodies or that had disappeared were treated separately, with additional processing steps. The classification of SPOT5 satellite images yielded 532 glaciers with a total area of 557.82 km2. This represents a loss of 16 % when compared to the 1962/1970 inventory.

Abstract 29:

The Application of inventory data for estimating characteristics of and regional past climate-change effects on mountain glaciers: a comparison between the European Alps and the New Zealand Alps

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An extensive data basis on topographic glacier parameters has been built up in past regional glacier inventories. This helps analyzing changes at a regional scale and to assess the representativity of continuous measurements, which is only possible to do on a few selected glaciers. In addition, glacier inventory data also serves as a statistical basis for extrapolating the results of observations or model calculations from individual glaciers and for simulating regional aspects of past and potential future climate change effects. In the present study, the database from national glacier inventories in the European and the New Zealand Alps contain a total of 5154 and 3132 perennial surface ice bodies, covering 2909 km^2 and 1139 km^2, respectively and refers to the time of the mid-1970s. Only 1763 (35%) for the European Alps and 708 (23%) for the New Zealand Alps of these total numbers are ice bodies larger than 0.2 km^2 (covering 2533 km^2 (88%) and 983 km^2 (86%) of the total surface area) with complete information available about surface area, total length, maximum and minimum altitude.

A parameterisation scheme to estimate specific mean mass balance and glacier volumes in the mid-1970s and during the Little Ice Age (LIA) period is being applied to the samples with surface areas greater than 0.2 km^2, these samples yielding a total volume of 126 km^3 for the European Alps and 67 km^3 for the New Zealand Alps. The corresponding sea-level rise equivalent is 0.35 mm and 0.18 mm, respectively. These small values point to the limited significance for sea-level rise but also to the vulnerability of comparable small glaciers to climate change. The calculated volume loss since the LIA period is 61% for the New Zealand Alps and 48% for the European Alps. However, there is some uncertainty related to several unknown factors, such as values used in the parameterisation of mass balance gradients, which, in New Zealand vary between 0.5 and 2.5 m per 100 m altitude. Nevertheless both mountain regions experienced strong mass loss since the LIA, whereas the maritime climate dominated sample of New Zealand glaciers seem to react much more sensitively than the European glaciers.

Abstract 30:
The hydrological regime of a cold-based glacier: Wright Lower Glacier

Shelley MacDonell and Sean Fitzsimons

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Glaciers are important indicators of climate change. In an Antarctic context, most studies relating to climate change have focused on processes at an ice sheet level, and have largely ignored contributions of valley glaciers. One way to rectify this situation is to study the hydrological regimes of valley glaciers, to determine their interaction with the environment, and potential contribution to sea level rise. This study will characterise the hydrology of a cold based glacier in the McMurdo Dry Valleys at a watershed level, linking glacial and proglacial processes. The study aims to understand melt processes and drainage configurations, by determining the relative contributions from regions on the glacier surface. To aid this understanding, the chemistry of areas on the glacier surface will be characterised, and their connection with the supraglacial stream established. Through these studies, links between glacier melt and proglacial stream water will be assessed, with a focus on water contribution and chemistry. These aims will culminate in the development of an integrated hydrological model, based on a DEM of the valley. The research will be addressed through a combination of fieldwork, laboratory and analytical work, with the first field season already completed.

Abstract 31:
The influence of atmospheric circulation on glacier snowlines and ice mass of the Southern Alps of New Zealand

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The presentation will summarise findings of research studies of the last two decades which seek to understand the main atmospheric and sea surface temperature controls on glacier behaviour, and ultimately the changing ice mass of the Southern Alps.

An annual Snowline Survey Programme has monitored the end of summer snowline of 50 index glaciers in the New Zealand Southern Alps since 1977. The elevation of the end of summer snowline level (EOSS) is a surrogate for determining annual mass balance of a glacier. Research is underway to extend coverage of annual EOSS across the whole Southern Alps using GLIMS satellite images. There is a high correlation between EOSS for individual index glaciers and mean EOSS for the Southern Alps (EOSSAlps). Over 27 years, the EOSSAlps extended from 2100m down to1700m. High (low) EOSSAlps are associated with anomalous northerly (southerly) airflows and weaker (stronger) westerly flow over the Southern Alps. These patterns are associated with positive (negative) 700 hPa geopotential anomalies to the south-east of New Zealand, a weaker (stronger) subtropical jet, and negative (positive) anomalies over the south-east Pacific Ocean. High (low) EOSSAlps are also associated with warm (cool) sea surface temperature anomalies near New Zealand and cool (warm) sea surface temperature anomalies in the eastern equatorial region of the Pacific Ocean.

There is also a good historical record of changing terminus position of many of the significant glaciers which stretches back to the Little Ice Age. The behaviour of glacier termini vary depending on glacier reaction time and morphology. The large moraine-enclosed glaciers have changed volume by surface lowering, while the fronts of the less constrained glaciers have fluctuated markedly. . While there has been an overall retreat and thinning of glaciers, short response-time glaciers have shown periodic advances. Advances from 1980-2000 were the most dramatic, in some cases by over one kilometre and current research attempts to explain the climate forcing of these at a time of global warming.

Glacier response on inter-decadal timescales is linked with distinctive shifts in atmospheric circulation patterns around the Southern Hemisphere. Retreat (advance) of glaciers in the Southern Alps and southern Andean glacier and advance (retreat) of glaciers in the tropical Andes are all associated with weaker (stronger) westerlies, blocking events in the southeast Pacific, negative (positive) geopotential height anomalies over Southern Africa and higher latitudes of the Southern Hemisphere. Seasonal and decadal climatic features such as the El Nino/La Nina and Interdecadal Pacific Oscillation (IPO) are shown to have significant impacts on New Zealand glacier mass balances.

Abstract 32:
The influences of atmospheric indices on the snow and avalanche regime, Fiordland, New Zealand.

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While there is an extensive body of literature regarding the glaciers of the Southern Alps, their inter-annual variability, and their response to climate variability, there is comparatively very limited research undertaken on seasonal snow. This is despite the extensive seasonal snow cover in the Southern Alps, often covering a total of 55,000 km^2 or 35% of the South Island of New Zealand.

This presentation examines the annual snow depth variability and avalanche regime in the Milford Road region. Following the brief description of this variability, the snow depth and avalanche regime are related to indices that represent various forms and scales of atmospheric circulation, including the Trenberth circulation indices (Trenberth, 1975; 1976), Kidson (2000) synoptic typing and the SOI.

Initial results show significant correlations exist between particular atmospheric circulation indices, synoptic types and snow depth with even stronger correlations shown with avalanche occurrences and atmospheric circulations.

Abstract 33:
The sensitivity of New Zealand glaciers to climate change

Andrew Mackintosh and Brian Anderson

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New Zealand glaciers are sensitive to climatic change but the magnitude and timing of response is dependent on several geographic factors. We use glacier-climate theory, empirical evidence and numerical modelling to assess the importance of these factors. The most sensitive glaciers in New Zealand occur in Westland, where a combination of high relief and high precipitation result in two glaciers that descend 11 km from the Main Divide to terminate a few hundred metres above sea level. Ice ablation at this altitude and latitude is probably the highest in the world, exceeding 20 m/yr, and ice velocity exceeds 1 km/yr. Numerical modelling of the Franz Josef Glacier demonstrates that temperature change is the major driver of glacier fluctuations. Recent glacial advances reflect a short-term, dynamic response to several positive mass balance years. However, the glacier has retreated by several kilometers since the Little Ice Age maximum. In contrast to the Franz Josef Glacier, ablation and ice velocity on small alpine glaciers can be an order of magnitude lower. The Brewster Glacier near Haast Pass is 2 km long and teminates at ~1650 m above sea level. Annual ablation on the Brewster Glacier is approximately 2-4 m/yr and ice velocity is less than 30 m/yr. Although the Brewster Glacier has experienced several years of positive mass balance, it continues to retreat in response to 20th Century warming as a result of its longer response time and lower sensitivity. Our findings support the hypothesis that New Zealand glaciers may not have responded similarly to past climatic changes. For example, evidence for a glacial advance 13,000 years ago is geographically restricted to a few glaciers, including the Franz Josef, which we have identified as the most sensitive to climatic change.

Abstract 34:
The spatial and altitudinal distribution of mass balance at Brewster Glacier 2004/5

Laurel George[1], Sean Fitzsimons[1], Brian Anderson[2] and Andrew Mackintosh[2]

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The recognition of glaciers as important indicators of climate and the lack of direct measurements in New Zealand highlights the need for a glacier mass balance program in the Southern Alps. This paper addresses the need for glacier monitoring by investigating the spatial and altitudinal distribution of direct mass balance measurements at the Brewster Glacier. Through direct measurements using snow pits and ablation stakes, volume and surface change across the entire glacier was calculated, spatial distribution was investigated and the mass balance gradient and equilibrium line altitude (ELA) was determined. The calculated positive mass balance was 0.64 m w.e. or 1.63 x 10^6 m^3 volume gain. Accumulation was 2.57 m w.e. or 6.54 x 10^6 m^3 volume gain and ablation was -1.98 m w.e or –4.91 x 10^6 m^3 volume loss. The mass balance did not vary evenly with altitude and there was a distinct pattern of ablation measured on the true left of the glacier. A linear mass balance gradient was calculated as 9 mm w.e./m, though it was better represented by two slopes with a shift in slope at approximately the ELA. Localized factors such as surface

drainage and shading may have driven the pattern of ablation across the glacier surface. It is recommended that a re-evaluation of the stake network be considered for future studies.

Abstract 35:
The subglacial drainage of Brewster Glacier, Southern Alps, New Zealand / Aotearoa in relation to ice surface velocity

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Glaciers in the Southern Alps, New Zealand/Aotearoa are sensitive to climatic change because they are located in a mid-latitude maritime setting with extremely high winter accumulation and summer melt rates. Southern Alps glaciers are therefore ideal indicators of South Pacific climatic changes. In this context, glacier-flow modelling is a fast expanding and important area of research and development. Glacier flow has been found to be influenced by seasonal variation in the configuration of subglacial drainage systems and subglacial discharge of a number of Northern Hemisphere glaciers, where temporary velocity increase is correlated with strong melt events and/or rainfall events, and high discharge. No such study of these variables has been completed in New Zealand/Aotearoa and it is unclear to what extent 'fast flow' contributes to the overall dynamics of glaciers in the Southern Alps.

This M.Sc. study will attempt to establish a relationship between high rainfall events and/or strong melt events and corresponding increases in subglacial discharge with temporary increases in ice surface velocity on the Brewster Glacier. Brewster Glacier located near Haast Pass is around 3km^3 and has been continually monitored over the last three years by academics from Victoria, Otago and Canterbury Universities. Records of ice surface velocity and stage of the main drainage channel are available for at least part of the year 2005. Further to this, ice surface velocity will be measured every three to four days over a period of four weeks over February-March 2006 using a theodolite and the existing ice surface stake grid, and discharge of the main channel will be measured daily using a standard hydrological current meter. Rainfall and climate data are and will be available for the same periods from a weather station located at the ELA on the glacier. Together these data should allow any correspondence in melt or rainfall events, high discharge and temporary ice surface velocity variation to be distinguished and a relationship thereby established.

Abstract 36:
Thermal detection of debris-covered-ice using ASTER imagery

Tim Kerr* and Burn Hockey

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Debris covered ice may constitute a significant proportion of a glacier's mass yet the detection of the extent of debris covered ice is problematic when observing a glacier in the visible spectrum. Standard ice detection algorithms as used on satellite imagery (for example NDSI) poorly identify debris covered ice regions. Potential exists to utilise the thermal

properties of debris covered ice to identify the same using the ASTER thermal bands. Such an application is trialled on a daytime and night time image of a glaciated region of New Zealand's Southern Alps. Through subjective expert analysis of daytime images, areas of debris covered ice are identified. Comparison of the thermal emissions from these regions, as identified by the ASTER thermal bands, to nearby plain debris is carried out. The differences in thermal emissions detected by ASTER on sunlit debris regions are more strongly influenced by aspect than by sub surface ice. In shadowed regions the influence of sub-surface ice on debris thermal emissions is inconclusive. Investigation of the night time image indicates differentiation between debris covered ice and plain debris may be possible. The difference in pixel size between thermal and SWIR bands prevents region delineation to the same scale as obtained when identifying snow and ice using NDSI. This technique may enable objective preliminary automatic detection of debris-covered-ice from satellite imagery without recourse to expert analysis.

Abstract 37:
Topnet Hydrological Model of the Pukaki Catchment, New Zealand

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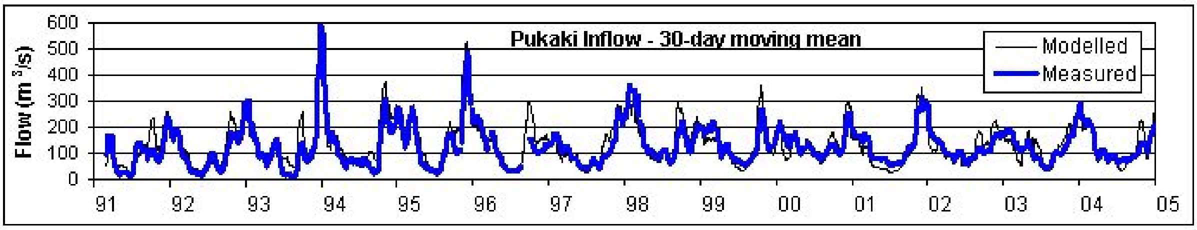
We report encouraging results from a multi-year physically-based simulation of Lake Pukaki inflows, using the Topnet model (Bandaragoda et al. 2004). The purpose of the simulation is to test whether the model adequately reproduces the recorded fluctuations in inflow since the early 20th century, with a time resolution of a few days. We also report tests of the model's ability to reproduce streamflow from two Pukaki sub-catchments, and at a snow-monitoring site.

The Topnet model (Bandaragoda et al. 2004) simulates water fluxes and storages at hourly or daily timesteps on a landscape discretised into sub-catchments, linked by a river network. Each sub-catchment and river reach has unique properties, which are automatically estimated using data from geographical information systems. Within each sub-catchment, water storage can be simulated for snowpack, plant canopy, root zone and shallow groundwater zone. Topnet has been used for flood forecasting and water resources planning, for catchment sizes ranging from a few square kilometres to the whole of New Zealand. It has had very little testing in alpine environments.

The model is driven using four time series of measured daily precipitation (Tekapo, Ohau, Mt Cook at Hermitage, and Franz Josef), and one time series of measured temperature (Mt Cook at Hermitage). The Lake Pukaki catchment is divided into 632 sub-catchments, and temperature for each catchment is estimated using a constant lapse rate of 0.0065 ^{o}C m^{-1}. Precipitation for each sub-catchment is estimated by taking a weighted average of 3 gauges (chosen using Delaunay triangles), but with the weights adjusted to account for known long-term variation of precipitation (Tait et al. 2005) between gauges. Precipitation is assumed to fall as snow if temperature is below 0^{o}C, and otherwise as rain. Melt occurs at a rate 10 mm/day/^{o}C, with this value being obtained by calibration to measured inflows. Little change in simulated inflow resulted if this value was reduced to 5 mm/day/^{o}C, a result that is not expected. This may be due to significant sources of lake inflow other than snowmelt; further testing with measured snow data is expected to resolve this.

Results for 1991-2004 show that the long-term mean modelled inflow is within 7% of the measured value, and that modelled monthly variations track the measured variations in most years. Simulations of snowpack at one monitoring site show that the timing and dynamics of the snow season are correct, but questions remain over the magnitude of simulated values. Further issues to be investigated include: the excessively rapid day-scale response of the model to precipitation input, and the underestimation of flow from the Jollie sub-catchment.

Bandaragoda, C.; Tarboton, D.G.; Woods, R.A. (2004). Application of TOPNET in the Distributed Model Intercomparison Project. *Journal of Hydrology 298(1-4)*: 178–201.
Tait, A.; Henderson, R.D.; Turner, R.; Zheng, X. (2005). Spatial interpolation of daily rainfall for New Zealand. *submitted to International Journal of Climatology*.



Abstract 38:
Understanding the cause of contemporary glacier retreat on Mt Ruapehu, New Zealand

Tom Paulin[1], Andrew Mackintosh[2], Brian Anderson[2], and Harry Keys[3]

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Located on the Central Plateau of North Island, glaciers on Mt. Ruapehu (2797 m) are the northernmost in New Zealand, and provide us with a valuable indication of North Island climatic trends. Glaciers on Ruapehu may behave differently to the Southern Alps, because of their different latitudinal, topographic, and climatic setting. For example, synoptic weather patterns that occasionally produce high winter snowfall in this region may result in low snowfall in the Southern Alps, as illustrated in winter 2005.

While glaciers in the Southern Alps of New Zealand have been studied in detail, glaciers on Mt. Ruapehu have received less attention with no major studies since the 1960s. Extending glacier studies to Ruapehu will greatly enhance the latitudinal (and altitudinal) scope of current glacial research in New Zealand. Volcanism on the active Mt. Ruapehu adds an interesting element to glacial dynamics. Tephra cover on the snow surface may act to enhance or decrease ablation, and large volumes of water stored within the glaciers and ice-dammed Crater Lake have major implications for lahar hazard.

This M.Sc. study will provide information on mass balance and glacier dynamics for the Whangaehu Glacier on Mt Ruapehu to address the following research questions:

1. What is the current mass balance state of Ruapehu's Glaciers?
2. How have the glaciers changed since the last survey in 1988?
3. Which climatic variables (e.g. increased temperature, reduced precipitation, increased windiness) are controlling the present-day retreat of Ruapehu's glaciers?
4. To what extent does tephra cover effect spatial variability in mass balance?
5. What is the likely affect of future climate warming on glacier mass balance and ice extent?

The focus will be to establish links between climate and mass balance, and ascertain how the glaciers will respond to future climate warming. Total winter accumulation on the glacier will be measured by snow pits, with ablation and surface velocity monitored with stakes from Spring 2005 until accumulation resumes in 2006. Linking mass balance gradients to the local climate will be achieved by installing a weather station at Dome Shelter (2670m) to measure climate variables, and these data will be compared to regional trends recorded in Whakapapa and Turoa ski areas and more widely. The baseline mass balance, velocity dynamics, and climatic data will be used to construct a computer model of the glacier, which will be used to predict future glacier behaviour.

Abstract 39:
Valley-glacier system modelling of the European Alps: A statistical approach to estimating glacier contribution to future sea-level rise

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This research utilised a generic valley-glacier system model and adapted it to a number of glaciers in the Swiss Alps, with the intention of understanding their spatial and temporal variations. By adapting the model to run accurately with 5 different glaciers it is hoped that similar characteristics can be identified within the climatological and topographic parameters. This information can then be added to a body of work which intends to provide a response function of predicted global sea-level contribution due to glacier response to climatology and topography.

To establish any trends in the data that could be used to develop a homogenous alpine glacier model the analysis was conducted in three parts. Firstly the analysis of raw data, secondly an attribute sensitivity analysis was conducted to calibrate the model around known data sets. Finally the model was optimised for the lapse rate and Positive Degree Day Factors (PDDF's) using the Nelder Mead method (1965). By tracking sets of points the method forms a simplex, then as the method evolves the simplex is shrunk as better points are formed until the desired bound is obtained.

The relationship between temperature and elevation provided a lapse rate of -4.8^{0}C/km, although during calibration this was found to be too general and a unique value between -7.5^{o}C/km and -4.8^{o}C/km was needed for each glacier. For each glacier the PDDF's showed a

similar trend and maintained a very limited variation (all glaciers had PDDF's within 0.0005 for snow and 0.001 for ice). Glacier thickness was found to be closely related to glacier width; and a simple method of finding a glacier's thickness was identified, quantified and successfully tested in the glacier model. One glacier needed to be removed from the project due to its complexity, although it should still be possible to apply a generalised glacier model to a region assuming complex glaciers are considered as outliers.

Work is currently underway to apply the glacier model to a recently completed HadCM3 simulation. When completed it should be possible to model the mass balance fluctuations of key ice masses over the last 500 years (Tett *et al*, 2005).

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NOTE: Participants with names written in italics were unable to attend the workshop.