# VICC 2010

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VICC 2010


International Glaciological Conference

## International Glaciological Conference

### Ice and Climate Change: A View from the South

**Valdivia, CHILE, 1-3 February 2010**

# ABSTRACT BOOK

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# WELCOME OF THE DIRECTOR

When one studies a very complicated system, a very precious tool to have at hand is an extreme regime, where key features of the complex problem are exhibited blatantly in a simplified context, without cumbersome details. In cosmology, that is, the study of the Universe as a whole, the black hole provides such a tool, and recent advancements have shown it to be, not only a key witness of, but also a key actor in, determining the present state of the Universe. The motivation for starting the research activity in glaciology at CECS about ten years ago followed that approach, with climate playing the role of the Universe and ice playing the role of the black hole. Since then, the field has become somewhat of a band wagon, and the phenomenon of climate change nowadays fascinates mankind. The sociological reasons for this are probably connected with atavistic feelings about eternal persistence of the human species, our planet, and the like. To the theoretical physicist who writes these words, and who has been forced by fact, to become used to the possibility that the Universe as a whole will come to an end, this fascination with climate change is quite remarkable and somewhat worrisome. Indeed nothing can be more dangerous for science and for the impact of science on society, than converting a line of research into a “cause”. The only useful cause is the rigorous search for more and more data, and more and more rigorous theories that account for them. This is why to us at CECS, this conference, with the promise implicit in the impressive set of abstracts contained in this volume, is such a happy event. We are enormously grateful for your presence here, which we take as a token of friendship and as a vote of confidence on the quality of the work that we have been doing. All of you give us renewed conviction to persist, persist and persist.

Claudio Bunster

# JENS WENDT

# This conference is dedicated to the memory of

## Jens Wendt

Born July 31st, 1965 in Leipzig, Germany

Deceased April 6th, 2009 in Morro Bonifacio, Chile

Unforgettable friend and colleague, the first CECS member fallen in the line of duty.

Jens Wendt was interested in the exploration of nature in his German homeland from an early age. Following in the footsteps of his father, he completed a Diploma degree in Geodesy (1994) and later a Ph.D. in Geodesy (1999) at the Dresden University of Technology (TUD), under the supervision of Prof. Reinhard Dietrich. Early in his career he focussed on GPS measurement of recent crustal deformation in the Vogtland area in Saxony. He soon developed a keen interest in polar geodesy, visiting Lake Vostok in the deep interior of Antarctica twice, where he measured ice flow, and performed pioneering observations of the tidal response in the lake region. While teaching at TUD he met Anja, who was then a student at TUD, and not long afterwards they were married. In 2004 Jens moved to the Centro de Estudios Científicos (CECS) in Valdivia, far from his homeland, where he started an ambitious geodesy programme, with Anja joining him one year later as a collaborator. It took Jens 3 arduous years to develop the CECS Airborne Mapping System (CAMS), a laser scanning system which could be deployed on fixed-wing aircraft and helicopters. Through CAMS, Jens was able to perform unique measurements of surface topography and glacier mass balance in Patagonia and Antarctica. In 2007, baby Lea was born, a truly Valdivian German, bringing increased happiness to Anja and Jens. It was a time for them to enjoy the beautiful natural environment of southern Chile, sharing their passion for horseback riding and forging new friendships. From the start of his stay at CECS Jens actively participated in glaciological expeditions, travelling from the volcanoes of southern of Chile to the Patagonian Icefields and on to Antarctica by foot, horseback, 4x4 vehicles, snow tractor, ship and aircraft. His never-ending capacity for hard work, his strong determination and his commitment to scientific excellence made him an asset in both the laboratory and the field. On the 6th of April 2009, after successful completion of an airborne laser scanning survey of Nevados de Chillán in the central-south Andes of Chile (37°S), and only 18 kilometres from his final destination of Las Marías airfield in Valdivia, the Piper Seneca II aircraft in which he was flying crashed into an ocean cliff along the Valdivian coast. In spite of his great endurance and the efforts of the rescue teams, Jens did not survive the accident. His death has been a tremendous loss, leaving a void within all of us that cannot be filled.

**Claudio Bunster (CECS), Gino Casassa (CECS), Reinhard Dietrich (TUD),Andrés Rivera (CECS) and Anja Wendt (CECS)**

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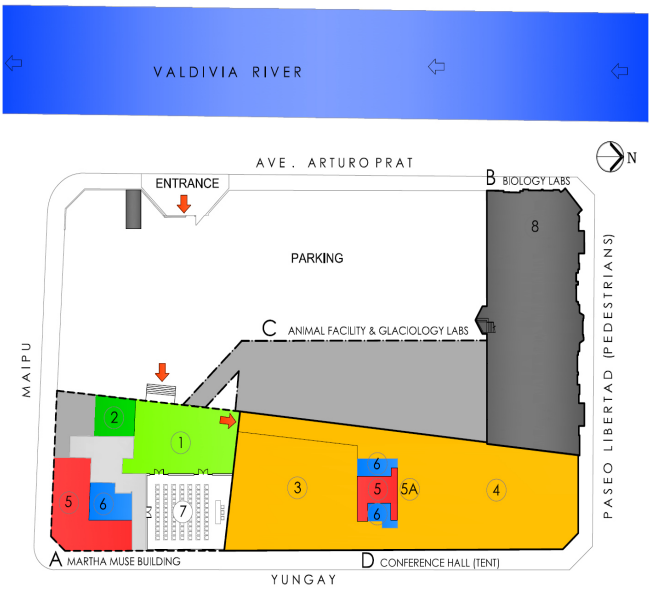


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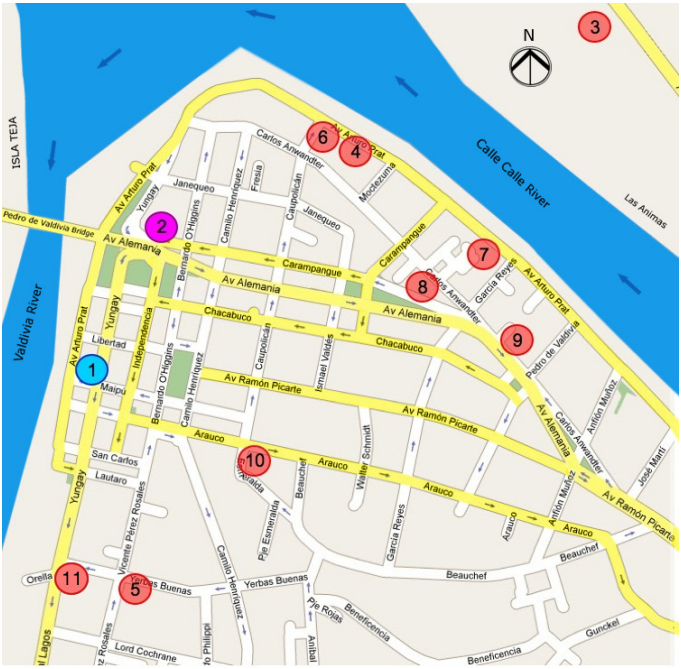


1. **CECS - Conference Venue**
2. Official Conference Hotel **Hotel Dreams Valdivia**
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10. **Hostal Esmeralda**
11. **Torreón de Los Canelos**

# Schedule

| | SUNDAY | MONDAY | TUESDAY | WEDNESDAY |
|---|---|---|---|---|
| **08:00-10:00** | | Registration | 1st morning session | 1st morning session |
| **10:00-11:00** | | Registration, Poster set up | Coffee & 2nd poster session | Coffee & 3rd poster session |
| **11:00-13:00** | | Official opening[1] | 2nd morning session | 2nd morning session |
| **13:00-14:30** | | Lunch | Lunch & APECS Meeting[3] | Lunch |
| **14:30-16:30** | | 1st afternoon session[2] | 1st afternoon session[3] | 1st afternoon session |
| **16:30-17:30** | | Coffee & 1st poster session | Coffee & 2nd poster session[3] | Coffee & 3rd poster session |
| **17:30-19:30** | | 2nd afternoon session | 2nd afternoon session[3] | 2nd afternoon session and Closing Session[4] |
| | **ICEBREAKER** | **WINE TASTING** | **BOAT TRIP + BANQUET** | **END 20:00 h** |
| | **20:00-22:00** | **19:30-20:30** | **19:30-22:30** | **FREE** |

[1] The official opening will last 45 minutes, followed by a coffee break, 30 min for brief presentation by poster authors and 1st poster session until lunchtime.

[2] The 1st afternoon session will have only 6 talks lasting 1.5 hours, allowing 1.5 hours for poster presentation in the afternoon in order to make up for the limited poster presentation time available during the morning.

[3] The APECS (Association of Polar Early Career Scientists) Meeting will finish at 15:00. Afternoon events will start 1/2 h later (15:00 for the 1st session, 17:00 for the coffee, 18:00 for the 2nd session. The 2nd session on Tuesday will only last 1.5 hours to allow enough time for the boat trip & banquet.

[4] The 2nd afternoon session on Wednesday will last 1.5 hours, with 1 extra hour for the closing session.

# Pre-Conference Tour

Saturday 30 January 2010. Glaciological and volcanological guided tour to Volcán Villarrica. Volcán Villarrica is located 120 km northeast of Valdivia. Guides Jorge Clavero (volcanologist) and Andrés Rivera (glaciologist).

**Day 1**

9 am: Start from CECS Valdivia by charter bus. Drive through Panguipulli, Coñaripe, Licanray, Villarrica, and Pucón. Observe volcanic formations from recent and prehistoric eruptions along the route. Lodging in Pucón not included. If you require assistance in securing lodging please contact Viajes Campanil, www.viajescampanil.cl/vicc.

A packed lunch will be given to each participant.

The tour will return at 19:00 h on a bus chartered by the Local Organising Committee.
The cost of the Saturday Pre-Conference Tour is US$ 50.

**Day 2**

Those attendees who wish to stay in Pucón on Saturday, January 30th should arrange their accommodation with Viajes Campanil (www.viajescampanil.cl/vicc).

Each attendee is responsible for arranging their own activities on Day 2.

Some possible activities that can be arranged through Viajes Campanil are:
1) Glaciological tour to Glaciar Pichillancahue, Volcán Villarrica
2) Whitewater rafting
3) Canopy tours
4) Climb to the summit of Volcán Villarrica
5) Hot springs.

For the tour to Glaciar Pichillancahue, CECS will provide two guides to assist with the tour. For those attendees returning to Valdivia on Sunday, the Organising Committee will provide the required transportation.

## Post-Conference Tour

Thursday and Friday February 4-5. Glaciological and volcanological guided tour to Volcán Mocho-Choshuenco, located 100 km east of Valdivia. Guides Jorge Clavero (volcanologist) and Gino Casassa (glaciologist).

Day 1

Start from CECS Valdivia by charter bus at 9 am. Drive via Panguipulli and Neltume to Huilo-Huilo Reserve. Each person will receive a packed lunch for the day. The afternoon will be spent observing volcanic formations at the base of the Mocho volcano, followed by a visit to the Huilo-Huilo waterfalls. Check-in at Baobab Hotel, Montaña Mágica Hotel, the cabins at Huilo Huilo Canopy Village (rooms for 2-4 people with camp beds), the Huilo Huilo campground, or a hostel in Neltume.

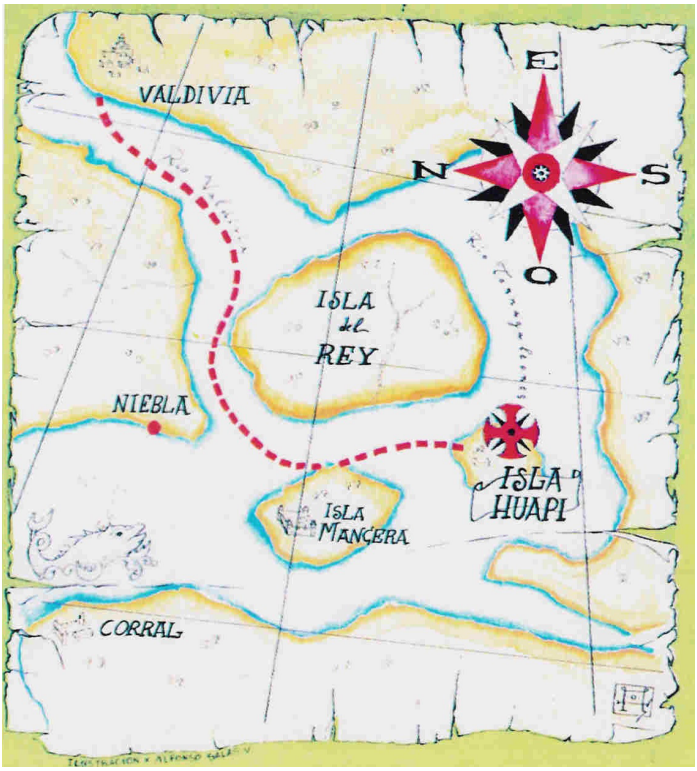
Day 2

8:30 am tour to Mocho volcano in 4x4 vehicles. Stop along the way at sites of volcanological/glaciological interest. Arrive at the glacier front, and then start walking on gentle slopes up the glacier to reach the base of the volcanic cone. Visit CECS's meteorological station and GPS reference station along the way. Optional climb to the summit for those equipped with mountain boots. Although it is an easy climb, the approximately 40° snow slope can be quite hard at that time of the year and open crevasses are found (ice axes and ropes will be provided). Each person will receive a packed lunch for the day.

The climb will be followed by a barbecue at Portal Huilo Huilo, the entrance to the Reserve. After the barbecue we will return to Valdivia.The Post-Conference Tour costs US$ 100, including round-trip travel from Valdivia to Huilo Huilo Reserve, guided exploration of Volcan Mocho, packed lunches on both days and the final barbecue. The costs of accommodation and the cost of dinner on the first night are not included. Accommodation should be coordinated by each participant through CECS (vicc2010@cecs.cl).

# Conference Banquet

The Conference Banquet will be held on Tuesday, February 2nd at the Isla Huapi Natural Reserve (www.islahuapi.cl), near Valdivia. The banquet includes boat travel from CECS to Isla Huapi (departing at 6:30 pm) down the Valdivia and Tornagaleones Rivers (1 h 15 min of navigation).



CECS

# ABSTRACTS

ABSTRACT #1(1). Poster presentation.

# Niño 3.4 region warming trend and extreme rainfall events with flood and drought years over India

**Umesh Singh[1*], P.P. Sarthi[2] and P.S. Salvekar[3]**
[1]APEC Climate Center (APCC), Busan, South Korea
[2]The Energy and Resources Institute (TERI), New Delhi, India
[3]Indian Institute of Tropical Meteorology (IITM), Pune, India
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*Presenter

An analysis of historical sea surface temperatures provides evidence for global warming since 1900, in line with land-based analyses of global temperature trends, and also shows that over the same period, the eastern equatorial Pacific cooled and the zonal sea surface temperature gradient strengthened. Recent theoretical studies have predicted such a pattern as a response of the coupled ocean-atmosphere system to an exogenous heating of the tropical atmosphere. The authors examine the relationships between Central Pacific Ocean (Niño 3.4) sea surface temperature (SST) and the interannual rainfall variability of Indian summer monsoon during 1975 to 2004 (30 years). The Niño 3.4 warming trend has a strong relation with extreme rainfall events with flood and drought years over India. It has been found that for normal/excess years a strong negative anomaly occurs and for bad/below normal years a strong positive SST anomaly takes place over the Niño 3.4 region.

ABSTRACT #2(3). Poster presentation.

# Monitoring and assessment of snow in the Hindu Kush-Himalayan region using improved MODIS satellite data and a Geographical Information System

**Amarnath Giriraj[1*], Deo R. Gurung[1]**
[1]International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal
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*Presenter

It is well understood that remote sensing allows detection of spatiotemporal patterns of snow cover across large areas having inaccessible terrain and heterogeneous land cover, providing useful information on a critical component for the hydrological cycle and climate change. Cloud coverage significantly affects the snow cover extent, which might produce misleading errors in snowmelt runoff modelling and upstream - downstream linkages. In this study, we have used MODIS 8-day snow products (MOD10A2 & MYD10A2) from 2002 to 2009 in the Himalayan region. Cloud removal methodology and spatial filters (SF) is adopted to reduce the cloud coverage from the MODIS products. This approach successfully reduced the cloud coverage from an average 16% for MODIS snow products and 6% for SF products. Further the MODIS data having MOD10C2 & MYD10C2 (Fractional Snow Cover) along with MODIS Land Surface Temperature (MOD11C2 & MYD11C2) was investigated to analyse if there is any relationship between them. The temperature pattern shows a gradual decrease in December, January and February of up to – 13°C and an increase of up to + 8°C by the end of May and early June. The overall temperature shows similar patterns during nine hydrological years with a maximum in winter and a minimum in summer, but with high annual variability in January based on MOD11C2. Variations in snow cover distribution were analysed at different topographical conditions, to understand onset season, snowmelt season and entire year, respectively. Results show large variations in snow cover between years while an increasing trend from west to east is observed. Inter-annual variation in the snow cover distribution may be associated with the global changes in air temperature and aerosol load resulting from the anthropogenic forcings. The improved methodology and the findings can provide better spatiotemporal variation of snow cover glacier and for snow-melting modelling.

ABSTRACT #3(4). Oral presentation.

# Repeated Glacial Lake Outburst Floods in Patagonia: an increasing hazard?

**Alejandro R. Dussaillant[1,2*], Gerardo Benito[3], Wouter Buytaert[4], Paul Carling[5], Claudio Meier[1,2] and Fabián Espinoza[6]**
[1]Universidad de Concepción, Concepción, Chile
[2] Centro de Investigación en Ecosistemas de la Patagonia (CIEP), Coyhaique, Chile
[3] Centro de Ciencias Medioambientales (CSIC), Madrid, Spain
[4] Imperial College London, London, England, UK
[5] University of Southampton, Southampton, England, UK
[6] Dirección General de Aguas (DGA) Aysén, Chile
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*Presenter

Five similar glacial-lake outburst floods (GLOFs) occurred in April, October and December 2008, March and September 2009 in the Northern Patagonia Icefield. On each occasion Cachet 2 Lake, dammed by the Colonia Glacier, released circa 200-million $m^3$ water into the Colonia River. Refilling has occurred rapidly, such that further outbreak floods can be expected. Pipe flow calculations of the subglacial tunnel drainage and 1D hydraulic models of the river flood give consistent results, with an estimated peak discharge surpassing 3,000 $m^3$ $s^{-1}$. These floods were larger in magnitude than any flood on record, according to gauged data since 1963. However, geomorphological analysis of the Colonia valley shows physical evidence of former catastrophic outburst floods from a larger glacial lake, with flood discharges possibly as high as 16,000 $m^3$ $s^{-1}$. Due to potential impacts of climate change on glacier dynamics in the area, jökulhlaups may increase future flood risks for infrastructure and population. This is particularly relevant in view of the current development of hydropower projects in Chilean Patagonia.

ABSTRACT #4(5). Poster presentation.

# Glacier Changes on Sierra Velluda massif, Chile (37°30'S): an approach to study forcing factors in a transitional climate setting

**Alfonso Fernández[1*], Edilia Jaque[1], Carolina Martinez[1] and Andrés Santana[1]**
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*Presenter

Central Chile has been defined as a Latin American hot spot in the last IPCC report (Impacts, Adaptation and Vulnerability), due to the impact of mountain glaciers' shrinkage on water resources. During several decades, this zone has been the primal engine of hydroelectric power for most of the national energy system. In addition, due to its transitional climatic setting, this zone is crucial in the studies of climate change impacts over human activities. However, apart from some inventory data, there is a lack of knowledge about the behavior of the ice bodies in recent decades, which is a serious shortcoming for the development of any planning policy. For helping in overcoming these issues, a research has been conducted on the Sierra Velluda massif, the main ice source to the Bio-Bio basin. At this stage, digital elevation models (DEMs) derived from cartography, satellite images and SRTM30 (approximately 1 kilometer resolution), aerial photographs, historical records, and gridded climate data, have been used to calculate and to explain the volumetric and morphometric changes of the glaciers. At present, the results suggest a frontal change of at least 2 m $a^{-1}$ since 1829 in the NE glacier. Furthermore, although the DEM comparison has yielded an overall change of high spatial and temporal variability, a net loss of -0.34 m $a^{-1}$ for 1961-2003 has been detected, although it is not statistically significant.

ABSTRACT #5(6). Poster presentation.

# Signature of increasing climatic parameters at Schimacher region of East Antarctica

**Alok S. Gautam[1*] and Sachin Ghude[1]**
[1]Indian Institute of Tropical Meteorology, Pune, Maharashtra, India
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*Presenter

A 43-year record of monthly averaged surface temperature observations (measured 4 times daily) over the 1963–2005 period for the Russian station Novolazarevskaya (70°46'04"S, 11°49'54"E) have been examined to reveal surface temperature trends in the Schimacher region of the East Antarctica. Similarly, monthly averaged surface temperatures derived from the NCEP reanalysis have been examined over the same time period for the Schimacher region (70°45.58'S 11°43.56'E). Considerable variation of temperatures from year to year has been observed in both data sets. Trends in annual mean temperature anomalies showed increase in surface temperature in the area during the past four decades. Based on mean monthly and annual surface air temperature records at the Novolazarevskaya base, gradual warming of the order of 0.22°C (±0.066°C) per decade has been observed. The annual surface temperature at Novolazarevskaya station is -10.80° C averaged during 1963-1967 and -9.94° C averaged during 2001-2005, showing an increase of 0.86° C during the observational period. NCEP reanalysis derived data showed a warming trend of 0.49°C (±0.060°C) per decade, which was found to be inconsistent with the observational records. We have also analyzed surface temperature records at Maitri station from various published technical reports, which show a warming signal. Finally, a global warming simulation has been made with the NASA EdGCM model to study the temperature change in the Schimacher region. We have used observed changes in greenhouse gases concentration to run the simulation, which begins in 1963 and ends in 2005. Model simulations also show a warming trend in the study region.

ABSTRACT #6(7). Oral presentation.

# Water resources vulnerability to glacier recession in Tierra del Fuego, Argentina

**Rodolfo Iturraspe[1,2*], Adriana Urciuolo[1,2], Rodrigo Iturraspe[1] and Sergio Camargo[1]**
[1]Dirección General de Recursos Hídricos de Tierra del Fuego, Ushuaia, Argentina
[2]Universidad Nacional de la Patagonia San Juan Bosco, Ushuaia, Argentina
iturraspe@tdfuego.com
*Presenter

As a consequence of global warming, most of the glaciers of Tierra del Fuego have been affected by a marked recessive behaviour. Glaciers show progressive shrinkage as well as significant mass reduction and several small ice bodies have disappeared during the last century with an accelerated glacier recession during the last 40 years. This global behaviour is affecting particularly the different cordilleras of North and South America. According to the IPCC report, the temperature increase during this century will be several times the one observed in the last 100 years. This work is focused on the Argentinean side of Tierra del Fuego island and presents results related to: a) glacier recession of two local pilot glaciers based on mass balance monitoring; b) advances on the regional glacier inventory; c) estimation of the importance of glacial contribution to the local basin runoff; and d) estimation of vulnerabilities of the hydrological regimes as a consequence of the feasible scenario of glacier extinction. On the basis of mass balance results, the glacier inventory and the analysis of hydrological data of the local rivers, it was possible to estimate the glacier contribution rates at basin level and its intra-annual distribution. The preliminary glacier inventory for 2002, which includes the calculation of the glacier surface by water basin, indicates a total glacier extension of 105.64 km$^2$ within the basins of the Argentinean side of Tierra del Fuego island, including the total area of the bi-national basins, of which a glacier area of only 19.6 km$^2$ is located in Argentina. The remaining ice area corresponds to the Chilean portion of the Fagnano and Lapataia basins. The information obtained through this work allowed evaluating the vulnerability of the hydrological regimes to the glacier extinction and to design vulnerability categories applicable to this kind of basins. The results are useful for designing climate change adaptation strategies related to water management in Tierra del Fuego.

ABSTRACT #7(8). Poster presentation.

# Temperate Ice Depth-Sounding Radar (TIDSoR) results from Jakobshavn, Greenland

**Víctor Jara[1*], Fernando Rodríguez[1] and Sivaprasad Gogineni[1]**
[1]Center for Remote Sensing of Ice Sheets, The University of Kansas, Lawrence, Kansas, USA
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[*]Presenter

Glaciers in several parts of the world are reported to be retreating and thinning rapidly over the last decade. Radar instruments can be used to provide a wealth of information regarding the internal and basal conditions of large and small ice masses. For temperate-ice sounding, the presence of water pockets (inclusions) produces volume scattering whose magnitude can bury weak backscattered bedrock returns. Therefore, radars operating in the HF band are better suited, given their relative long wavelength, for systematic surveys of the thickness and sub-glacial topography of temperate-ice regions. In 2008 at CReSIS, we developed a portable dual-frequency Temperate-Ice-Depth Sounding Radar (TIDSoR) for surface-based observations in which weight and volume are a constraint. In the northern hemisphere summer of 2009, TIDSoR was deployed at Jakobshavn Glacier in Greenland, where high water content was known to be present. In this survey, the radar was operated at the central frequencies: 7.5 MHz and 14 MHz, with an output peak power of 10 W over a bandwidth of 1 MHz. In this paper, we will discuss our design considerations and the results obtained in Jakobshavn glacier, Greenland.

ABSTRACT #8(9). Oral presentation.

# Basal reflectivity and bed conditions along the US-ITASE traverse, Taylor Dome to South Pole

**Robert Jacobel[1]*, Bern Youngblood[1], Jeff Stamp[1], Karl Lapo[1], Jacki Werner[1], Jessica Olson[1], Brian Welch[1] and Jonathan Bamber[2]**
[1]St. Olaf College Department of Physics Northfield, Northfield, Minnesota, USA
[2]School of Geographical Sciences, University of Bristol, Bristol, England, UK
jacobel@stolaf.edu
*Presenter

In 2006-2008 we recorded low-frequency ground-based radar data along the 1700 km US-ITASE traverse from Taylor Dome to South Pole, crossing major basins draining from the East Antarctic Ice Sheet to the Ross Sea. Acquiring one (stacked) trace every 3.5 m produced over 464,000 samples of the power returned from the bed, enabling us to make a detailed study of basal reflectivity along the traverse. Internal stratigraphy was also well depicted by the radar throughout the traverse, often to within meters of the bed at over 2.5 kilometers depth. Bed echo power values were corrected for geometric spreading losses and dielectric attenuation in order to derive values of basal reflectivity. Several approaches used to model the attenuation showed general agreement and the bed reflectivity results were not strongly dependent on which model was used. Correcting the values of received bed power for dielectric attenuation, we mapped basal reflectivity along the length of the traverse. Our results show several areas of high reflectivity which are likely zones of localized basal melt, as well as other larger-scale regions where the bed is more highly reflective, indicating thawed conditions. Based on bed topography, some of the kilometer-scale bright features are likely to be subglacial lakes, including one within 25 km of South Pole Station. In contrast, the traverse passed over at least three areas where subglacial lakes have been indicated by changes in surface elevation seen in satellite imagery that do not today show high reflectivity. Larger-scale areas of thawed bed, including one in the north portion of the Byrd Glacier catchment, appear to have dynamic significance and are associated with areas of higher ice flow speed as shown by correspondence with InSAR and balance velocities. While the correspondence between ice speed and basal reflectivity is not surprising, this observation, derived from two independent remotely-sensed geophysical data sets, extends the range of field observations to the interior of East Antarctica and confirms the importance of basal lubrication on modulating the ice dynamics of the largest ice sheet on the planet.

ABSTRACT #9(10). Oral presentation.

# Modelling point surface ablation and associated energy balance at Glaciar Tapado, Norte Chico, Chile

**Lindsey Nicholson[1], Thomas Mölg[1] and Shelley MacDonell[2,3,*]**
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*Presenter

Surface energy balance, and resultant ablation, of cold, high-altitude, arid glaciers of the Norte Chico region in Chile remains poorly understood at present. Widespread development of penitentes during the summer indicates that sublimation processes are active and should be contributing to total ablation, while ice temperatures below 0°C mean that conduction of energy into the ice body will be an important sink of energy delivered to the surface. We use meteorological data collected from the glacier surface during summer 2008 to drive a point surface energy balance model in order to determine the mass loss by surface ablation and the energy balance conditions driving the ablation rate. The modelled results pertain to a glacier surface without penitentes, and we discuss how such model output can be applied in the context of a glacier like Tapado which has widespread surface penitentes in summer. Ablation processes are apportioned into melt and sublimation components and we discuss the meteorological conditions resulting in surface meltwater production. Winter meteorological data from a nearby off glacier site is used to investigate the rate of winter sublimation of snow and ice, and corresponding loss of potential winter precipitation inputs to the hydrological cycle using the same model.

ABSTRACT #10(12). Oral presentation.

# Southern Hemisphere millennial glaciations during the past 30 ka driven by Antarctic ice sheet variability

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Exposure dating of last-glacial cycle deposits in Tasmania, New Zealand and Patagonia reveal a temporal and spatial variability of glacial advances different to that apparent in the Northern Hemisphere. Exposure ages from six alpine valley systems in Tasmania and three in New Zealand reveal similar trends: (1) MIS-3 (~30-40 ka) advances are of limited extent in Tasmania and less extensive than New Zealand MIS-2 advances; (2) peak glacial cold conditions ('LGM') occur between ~24-29 ka; (3) amelioration of LGM conditions and glacial retreat commenced ~19-22 ka; (4) deglaciation inferred from recessional moraine sequences continued to 14-15 ka; (5) there is little evidence for a major late glacial readvance younger than 14-15 ka with lower valley regions devoid of ice. This moraine chronology suggests that following a 'weak' MIS 3 cool phase, the Southern Hemisphere, or 'local' LGM, peaked and was followed by warming a few thousand years prior to that apparent in the Northern Hemisphere. These moraine ages from New Zealand and Tasmania for the LGM–LGIT (ca. 30 to 11 ka) show a remarkable similarity to the glacial chronology emerging from Lagos Buenos Aires in Patagonia. A near-complete record of glacial expansion phases over the last glacial cycle is preserved in the series of 10 glacial moraine benches (8 of which have been exposure dated) that flank the slopes of Mt Murchison above Lake Te Anau, Fiordland, New Zealand. Five other glacial advance phases are recorded as distinct benches with ages decreasing with altitude from LGM peak (27.2 ka, 830 m a.s.l.), recessional phases (24.4, 19.9, 20.7 and 17.2 ka) with the youngest terrace just above the lake (15.8 ka, 220 m a.s.l.). This deglaciation chronology correlates well with $\delta^{18}O$ variability apparent in the ice core records from Byrd and Law Dome in Antarctica, each of which display most depleted $\delta^{18}O$ values from 30 to 20 ka, followed by general warming to 10 ka. Hence, the general character of Antarctic climate variability as observed in $\delta^{18}O$ trends from the ice cores appear to be reflected in the Southern Hemisphere mid-latitude terrestrial deglaciation chronologies determined by cosmogenic exposure dating.

ABSTRACT #11(13). Poster presentation.

# The glacial history of Tasmania from mid-Pleistocene to the Last Glacial Maximum – new challenges and new ideas for hemispheric glacial climate correlations

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The study of the Quaternary glacial history of Tasmania using various relative dating methods (weathering, geomagnetic stratigraphy, U-Th series and radiocarbon) has resulted in the identification of a complex system of multiple glaciations and isolated ice caps active over the past one million years. The application of cosmogenic nuclides $^{10}$Be and $^{26}$Al for the exposure age dating of glacial landforms, such as terminal and lateral moraines, recessional moraine sequences, erratics and exposed polished bedrock throughout the Western and Central regions of Tasmania during the mid-late Pleistocene up to the LGM has forced a re-examination of the existing glacial chronology. This new chronology indicates a very different mode of glacial climate change in the high Southern Hemisphere latitudes – in both timing and extent- compared to that in the Northern Hemisphere. Moraines in the Pieman River valley and Tyndall Ranges of the west coast region, previously attributed to marine isotope-$^{18}$O Stage (MIS) 6 and 8 are now considered more likely to have been deposited during MIS 10-12. Glacial advances from MIS 2 to 6 appear to have been restricted and are much less extensive than suggested previously. $^{10}$Be and $^{26}$Al exposure age dating of LGM moraines from a range of sites in western Tasmania indicates that the sequence is more complex than hitherto considered. Significantly, there is no evidence for a Younger Dryas glacier re-advance in western Tasmania which supports palynological evidence for no significant regional cooling at this time. Our general conclusions based on over 150 exposure ages from multiple valley sites containing cirque and retreat phase moraines are: (1) MIS-8 (~240 ka) to MIS-16 (~660) glacial cycles are extensive in the low-lying plains of the west coast ranges and northern outlet valleys for the Central Plateau. 2) Stadials within the Last Glacial Cycle, i.e. <120 ka (MIS-2 to 6), are weakly represented throughout all regions studied. 3) The onset of the local LGM period is variable and appears to range from 24-28 ka and deglaciation appears to commence at ~19-22 ka. 4) Valley glacial systems were ice-free by at most 14-16 ka and no YD-chron readvance is apparent.

ABSTRACT #12(15). Oral presentation.

# Present-day fluctuations of glaciers in the Southern Alps, New Zealand, and their climatic drivers

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As in many glacierised parts of the world, glaciers in the Southern Alps of New Zealand have lost significant mass in recent decades. Much of this loss is due to ongoing dynamic changes to glaciers, including the formation of pro-glacial lakes, generally attributed to warming since the 1860s and particularly since the 1930s. However the cause of recent changes in mass, and in particular the advance of some of the more responsive glaciers such as Franz Josef Glacier/Ka Roimata o Hine Hukatere, has been variously attributed to temperature, precipitation, and/or atmospheric circulation changes. In order to better quantify these mass changes and understand the factors that drive them, an energy balance model, tuned to mass balance measurements on one glacier and verified against mass balance and snowline measurements on other glaciers, is used to link climatic changes to mass balance, and hence to ice volume changes over the mountain range. The results indicate that, removing the dynamic response to earlier warming, the volume of the Southern Alps ice mass has changed significantly in the period 1972 to 2008, with a substantial volume loss (0.7 $km^3$ or ~3%) between 1972 and 1983, followed by an equal mass gain between 1983 and the present. The terminus position of the Franz Josef Glacier tracks with the total ice volume very closely, with a lag of 2-3 years. Sensitivity analyses indicate that ice volume is rather sensitive to temperature changes, with a 40% increase in precipitation required to offset a 1°C warming. However modelling experiments where the temperature and precipitation are in turn held at their mean values indicate that the changes evident in recent decades cannot be attributed to either temperature or precipitation in isolation. The recent mass gain of some New Zealand glaciers has occurred during an overall period of Earth warming, widely agreed to be due to anthropogenic influence, whereas the majority of 20th century ice loss resulted from warming that predated this influence. Thus, New Zealand glaciers highlight the under-appreciated role of Southern Hemisphere decadal-scale climate variability.

ABSTRACT #13(17). Poster presentation.

# Data interpretation of Bolivian, Andean and worldwide glacier study network

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Since 1991, IRD associated with local partners was able to install and maintain permanent networks of glaciological mass balance, hydrological balance and local energy balance measurements over a dozen glaciers in Bolivia, Peru and Ecuador. This paper presents the characteristics of one of these pilot glaciers in Bolivia (Zongo glacier) and the monitoring network, as well as some relevant results focusing on the nature, intensity and coherence of the glacier shrinkage signal observed in the Andes and its linkage with climate evolution at regional scale. This Andean glaciological observation network is partly included in a broad program of mass balance monitoring (ORE GlacioClim, INSU/IRD, France) covering several glaciers in the French Alps and Antarctica, and provides its available data to the scientific community (http://www-lgge.obs.ujf-grenoble.fr/ServiceObs/index.htm) and to WGMS (ICSU[FAGS], IUGG[IACS], UNEP, UNESCO, WMO). This network has also expanded in recent years incorporating 2 glaciers in India and Nepal.

ABSTRACT #14(18). Oral presentation.

# The Andean ice core climatic archives: from Ecuador to Patagonia

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Since the 1980's, a series of ice cores have been extracted from the highest Andean glaciers. Initiated in the cordillera of Peru, this research topic was rapidly extended to the northern part of the Andes, and more recently to the southern range to Patagonia. These records have now been recovered along a continuous profile of 5000 km over different atmospheric circulation systems, and have been interpreted in terms of climatic and environmental archives covering a time range of up to 25 ka with variable time resolution. It appears there is a certain coherence of regional records from Peru and Bolivia linked to the extensive convective system flowing over the Amazon basin, while the Chilean archives seem rather discontinuous and related to specific conditions. The englacial temperature profile measured on Illimani (Bolivia) reveals a warming of +1.1°C over the 20th century. If the warming continues following the IPCC predictions, some ice archives will disappear in a few decades.

ABSTRACT #15(19). Poster presentation.

# Synoptic influences on snow accumulation on glaciers in the Southern Alps of New Zealand

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Understanding relationships between snow accumulation and synoptic climatology is important for assessing the way in which future climate variability will impact on glacier mass balance. However few studies have as yet examined these relationships, especially on glaciers in the Southern Hemisphere. The aim of this study was to describe how different synoptic weather systems influence snow accumulation on glaciers, and to identify the major moisture sources. We conducted daily measurement of winter snow accumulation at two glacierised sites east and west of the Southern Alps, including snow accumulation, density and redistribution, and snow isotope and trace element geochemistry. The Franz Josef Glacier site, west of the Alps, received ~30% more snow than Tasman Glacier site on the eastern side, but wind deflation meant that after 21 days, net snowfall was similar at both sites. We found that troughing synoptic regimes brought over 70% of total snow to both glaciers, with zonal or blocking flow contributing less. Blocking resulted in a reversal of prevailing westerly flow, generating strong down-slope winds at the western glacier site and snow loss from the accumulation area. Deuterium excess and trace element data showed that the Tasman Sea contributed ~70% of moisture received at both sites, with lesser contributions from the Pacific and Southern Oceans.

ABSTRACT #16(20). Oral presentation.

# Internationally coordinated glacier monitoring: a view to the south

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Changes in glaciers provide some of the clearest evidence of climate change and as such they constitute an Essential Climate Variable in the Global Climate Observing System. Internationally coordinated collection and distribution of standardized information about glaciers was initiated in 1894 and is today coordinated within the Global Terrestrial Network for Glaciers (GTN-G). The GTN-G is jointly run by three operational bodies in glacier monitoring which are the World Glacier Monitoring Service, the US National Snow and Ice Data Center, and the Global Land Ice Measurements from Space initiative. With a new online service, GTN-G provides fast access to regularly updated information on glacier inventory data. Currently, this includes global (Southern Hemisphere percentage) information from 100,000 (10%) glaciers mainly based on aerial photographs and outlines from 80,000 (3%) glaciers mainly based on satellite images, length change series from 1,800 (15%) glaciers, mass balance series from 240 (7%) glaciers, information on special events (e.g., hazards, surges, calving instabilities) from 130 (14%) glaciers, as well as 12,700 (<1%) photographs from some 500 (<1%) glaciers. In this presentation, we provide an overview of the operational structure, the monitoring strategy of, and the available datasets within GTN-G. Thereby, we will have a special focus to the data situation on the South American continent which hosts just under 4% of the global glacier cover. Although the observation density is not as high as for Europe, the available data series are widespread along the Andes from the tropical ice bodies in the north to the Patagonian Icefields and Tierra del Fuego in the south. Thereby, the available data series cover mainly the time period since the 1960s. Through its local contacts and regional networks GTN-G aims at continuing to foster the glaciological capacity in and at further improving the data contribution to the international community from the south.

ABSTRACT #17(21). Oral presentation.

# Evolution of Wordie Bay glaciers after disintegration of Wordie Ice Shelf

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The retreat of Wordie Ice Shelf in the 1980s was the first recent episode in a series of ongoing ice-shelf collapse events which culminated in the break-up of Wilkins Ice Shelf in April 2009. The reason for the widespread retreat of ice shelves in the Antarctic Peninsula has been attributed to atmospheric and oceanic warming. While atmospheric warming leads to a prolonged melt season and increased melt ponding, oceanic warming increases bottom melting, eroding ice shelves from below. Glaciers feeding into these ice shelves are known to accelerate after the loss of the buttressing force the ice shelf exerted. This increased outflow results in a surface lowering of the grounded glaciers and a positive contribution to sea level. Based on remote sensing, airborne and in-situ data collected during 3 recent field campaigns, we study the glaciers flowing into Wordie Bay. The analysis includes meteorological data, ice flow velocities and elevation changes to determine the interaction between local climate, ice shelf evolution and ice discharge. Ice flow even in the upper reaches of Fleming Glacier continues to be larger than in the 1970s prior to the major retreat. These large velocities together with a marked surface elevation decrease of up to 4 m $a^{-1}$ at the grounding line indicate that the glaciers are still losing mass and have not attained a new equilibrium stage after ice shelf removal.

ABSTRACT #18(22). Oral presentation.

# Trends in Antarctic sea ice extent over the last 30 years: mechanisms and links to regional climate change

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While sea ice extent has decreased markedly over the last 30 years in the Arctic with greatest loss in the autumn, around the Antarctic sea ice extent has increased throughout the year, with the greatest increase during the autumn. The largest changes have been in the sector between the Antarctic Peninsula and the Ross Ice Shelf with a large decrease in ice extent in the Bellingshausen Sea and an increase of greater magnitude in the Ross Sea. Model experiments have shown that the changes in this sector are a result of a deepening of the Amundsen Sea Low, primarily because of the ozone hole. The role of such changes in the large warming across the Antarctic Peninsula will be discussed and the possible mechanisms behind the large peninsula warming in the pre-ozone hole period will be considered.

ABSTRACT #19(23). Poster presentation.

# In situ observations of snow accumulation on the Larsen C ice shelf, Antarctica

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Dramatic warming of the Antarctic Peninsula over the past two decades has led to the break up of numerous ice shelves, including Larsen A and B. Larsen C, a 55,000 km$^2$ ice shelf, is the largest remaining ice shelf on the Antarctic Peninsula and is an ideal study site to understand ice shelf mass balance and stability. Three automatic weather stations (AWS) were installed in 2008 on the ice shelf along a latitudinal gradient (Larsen 1- 68°08'28"S, 63°57'09"S; Larsen 2- 67°33'55"S, 63°14'59" W; Larsen 3- 67° 01'55"S, 62°38'59"W). Seasonal and yearly climatological mean values from the AWS are presented, with a particular focus on winter snow accumulation. Preliminary results for 2008-2009 find 1.4 m (0.53 m w.eq.) of accumulation at Larsen 1, 1.2 m (0.46 m w.eq.) at Larsen 2 and 1.5 m (0.57 m w.eq.) at Larsen 3. Spatial variability in winter accumulation is ascertained from 15 snow pits across the ice shelf. Stratigraphic and conductivity analysis of shallow firn cores further elucidate the inter-annual variability in snow accumulation.

ABSTRACT #20(24). Poster presentation.

# Distributed albedo measurements on glaciers in the upper Huasco catchment, Chile

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Albedo is a main control on distributing melt over a glacier surface, and is often the most difficult parameter to constrain in energy balance models. Traditionally, albedo is calculated from the ratio of outgoing to incoming shortwave radiation, and distributed spatially using empirical relationships involving elevation and temperature. This approach is often inadequate, especially for glaciers whose surface facies only shows a weak dependance on altitude. This is the case for glaciers in the semi-arid Norte Chico region (27°S to 33°S). In this study, spatially and temporally distributed albedo is calculated for four glaciers and glacierets in the upper Huasco catchment, using repeat terrestrial photography and surface meteorological data from the glaciers. Glaciation in upper Huasco is limited to small (<130 ha), and high (> 4000 m) mountain glaciers, glacierets and rock glaciers. Snow drifting exerts a strong influence on winter snow accumulation, while net solar radiation is the dominant energy source for summer ablation. These factors result in non-uniform mass-balance and albedo conditions across the glacier surface. Albedo has been monitored at two year-round automatic weather stations (AWS) since summer 2007, in conjunction with an automatic camera overlooking the Guanaco and Estrecho glaciers and Toro 1 and Toro 2 glacierets. Photo processing involved georeferencing daily images to a DEM and calibrating reflectance values with albedo measurements from the AWS. These results are used to investigate spatio-temporal variations of albedo on these glaciers for 2007-2009, and to assess the albedo measurement process for use in spatial energy balance models.

ABSTRACT #21(25). Poster presentation.

# Surface height changes on Tapado Glacier, upper Elqui valley, Norte Chico (Chile) using DEM data

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Tapado glacier is an isolated ice mass located in the Chilean Norte Chico region (30°S), in the southernmost part of the South American Arid Diagonal. The glacier has an average elevation of 5000 m a.s.l. and is exposed to climatic conditions marked by pronounced seasonality–short accumulation and long, dry ablation seasons. This bare ice mass and its debris-covered front, together with surrounding rock glaciers, constitute a complex high mountain system which plays a fundamental role within the upper Elqui catchment, with ice melt contributing significantly to stream flow during the dry summer. Changes in the glacier surface height were measured using three different topography datasets: (1) Chilean topographical maps (Instituto Geográfico Militar, IGM) created from 1950's aerial photographs (1:50,000); (2) a Digital Elevation Model (DEM) from the 2000 Shuttle Radar Topography Mission (SRTM, 90 m resolution); and (3) a DEM derived from ASTER satellite imagery, released in 2009 (30 m). These three datasets were processed with GIS and image processing software to achieve a preliminary determination of glacier height change over the last 50 years. Preliminary results show an area where positive values (thickening) predominate (reaching values of 20 m), which would indicate enhanced accumulation processes or decreased ablation. Another area of enhanced negative values (thinning) can be seen as a probable negative mass balance area (reaching values of -30 m). A more detailed survey is expected to be accomplished with aerial photographs and DEM extraction from high resolution imagery, GPS survey, and other techniques.

ABSTRACT #22(26). Poster presentation.

# High-altitude, semi-arid catchments in North-Central Chile: key hydrological processes and relative glacier contribution to stream flow

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Mountains are often described as water towers for humanity. This is particularly true in the semi-arid Norte Chico region of Chile, where the populated lowlands rely on runoff and groundwater recharge generated in the high altitude areas of the Andes mountain range. In spite of its importance in terms of water resources, the water cycle in these areas is generally poorly understood. This is partly due to the lack of data, which restricts quantitative hydrological studies, as well as to the singularity of the key hydrological processes at play, such as snow sublimation and seasonal frost. This context makes it difficult to resolve the annual water balance equation and limits any modelling attempt. We address these issues for two high-altitude mountain catchments located in the upper Huasco Basin (70.1°W, 29.3°S). We use a combination of hydrological, glaciological, meteorological and remote sensing data to investigate the main water pathways, and estimate the relative contribution of glacier melt water to the hydrological regime of the area.

ABSTRACT #23(27). Oral presentation.

# Glacier and hydroclimate interactions in the high-altitude, semi-arid Chilean Norte Chico region: progresses and challenges

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The high mountain ranges of the semi-arid Norte Chico region of Chile (27°S to 33°S) support numerous small glaciers and glacierets. Knowledge of these glaciers, including their interaction with climate and the hydrological cycle of the region, is poorly known. Here we present an overview of recent results from the CEAZA glaciology program addressing these issues. In the Pascua-Lama area (29°S), a diverse array of glaciological, meteorological and hydrological measurements were collected as part of an extensive glacier monitoring program. Glaciers and glacierets in this area are of the cold type, and their present distribution is primarily dictated by topographic conditions, with glaciers developing on south-facing, shaded slopes and leeward of topographic ridges where snow redistribution by wind occurs. Mass-balance measurements made on six glaciers over the past 5 years show consistent negative values, except for the 2002-2003 El Niño year, when large snow accumulation occurred and a small but positive mass balance was measured. Both snow accumulation and ablation show little relationship with altitude, and hence glaciers do not exhibit clear accumulation and ablation zones. The surface energy balance is dominated by net shortwave radiation and latent heat fluxes. Consequently, spatio-temporal variations in albedo, sublimation rates, and ablation morphology such as penitentes exert important controls on ablation processes, which poses challenges for future distributed melt modeling. A glacier monitoring program initiated on Cerro Tapado, a valley glacier in the upper Elqui Valley (30°S, 4200-5500 m a.s.l.), will provide further insights into the functioning of glaciers in semi-arid areas.

ABSTRACT #24(28). Oral presentation.

# Implementation of ice shelf dynamics and marine ice dynamics in the ice sheet model SICOPOLIS

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Since the late 1970s, numerical modelling has become established as an important technique for the understanding of ice sheet dynamics. Ice sheet models are particularly relevant for predicting the possible response of ice sheets to climate change, and thus a number of such models have been developed over the years. SICOPOLIS (SImulation COde for POLythermal Ice Sheets; http://sicopolis.greveweb.net/) is an established model based on the widely-used shallow ice approximation, so that longitudinal stress gradients are neglected. Its particularity is the physically adequate implementation of basal layers of temperate ice (regions with a temperature at the pressure melting point). However, the current version 2.9 lacks a detailed treatment of marine ice, and ice shelves are not considered at all. Both phenomena are most likely crucial for the dynamics of the West Antarctic Ice Sheet, and also play a role for the dynamics of some smaller land ice bodies like the Austfonna Ice Cap in Svalbard. Therefore, the new version 3.0 of SICOPOLIS will feature treatments of both ice shelf dynamics and marine ice dynamics. The performance of the new model version will be tested for the case of an ice shelf ramp for which an analytical solution exists. The model will then be applied to realistic geometries of the Antarctic Ice Sheet and the Austfonna Ice Cap.

ABSTRACT #25(29). Poster presentation.

# The Antarctic Fast-Ice Network (AFIN): beyond IPY

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The Antarctic Fast-Ice Network (AFIN) is an international collaboration, endorsed as an International Polar Year (IPY) project, with the aim to establish and maintain a number of long-term measurement sites for Antarctic fast ice and where possible related meteorological and oceanographic parameters. Sea ice is an important component within the polar climate system, and at maximum ice extent, fast ice contributes about 14% to the overall extent. Recent studies have highlighted an increased interannual variability in several fast-ice parameters. To understand how sea ice responds to current and future climate change, detailed knowledge of the processes within the ocean-ice-atmosphere system is required. However, prior to AFIN, routine observations of ice formation, breakout, and ice/snow thicknesses have been carried out at very few Antarctic locations. Few of those fast-ice records (albeit intermittent) extend back in time, providing limited information on temporal variability and change. Furthermore, concurrent observations of fast ice and local atmospheric and oceanic conditions are rarely available. To alleviate this a number of sensors have integrated into AFIN stations, including mass-balance stations, digital cameras and automatic weather stations. Currently active AFIN sites are at Scott Base (New Zealand), Davis (Australia), Zhong Shana (China), and Mawson (Australia). In the very near future, we expect to implement AFIN observatories at Fimbul Ice Shelf (Norway), Dumont d'Urville (France), Soywa (Japan), and G.v.Neumeyer (Germany). Those AFIN observatories provide information on the vertical evolution of the fast ice and its snow cover during each season, auxiliary meteorological and oceanographic data, as well as local-scale information on the fast-ice extent. In addition to in situ observations, we also obtain remotely-sensed data, such as from MODIS, SSMR, SAR and AVHRR, to study the temporal variability of the fast-ice extent, lead opening and their relation to the pack-ice concentration and extent. The combined data (together with numerical models) allow us to investigate different regimes and identify how these circum-Antarctic locations relate to each other.

ABSTRACT #26(30). Poster presentation.

# High resolution ice velocity fields and glacier changes in the Patagonia Icefields derived from TerraSAR-X satellite data

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We retrieved ice motion fields of glaciers in Patagonia using 11-day repeat-pass data of the high resolution space borne X-band (9.65 GHz) SAR (Synthetic Aperture Radar) on board the TerraSAR-X satellite which was launched June 2007. Because the interferometric phase decorrelates within 11 days on these glaciers, an incoherent amplitude correlation approach is applied which delivers the velocity components in slant range and along-track (azimuth). The correlation measurements using image templates are unambiguous in range and azimuth, and highly accurate with respect to the orbital geometry of the satellite. The algorithm is applied on geocoded TerraSAR-X repeat pass images which were acquired over several large outlet glaciers of the Patagonia Icefields starting in January 2008. For most of these glaciers accelerated retreat has been reported over the last decades. The ice velocity data are relevant for assessing the dynamic state of the glaciers and their sensitivity to climatic forcing. The analysed data set of the Northern Patagonia Icefield includes the main outlet glaciers, San Rafael and San Quintín, which show distinct differences in ice flow behaviour. On the Southern Patagonia Icefield, glaciers of different type and size were investigated. Recently, large calving events and ice flow acceleration were observed with TerraSAR-X on Upsala Glacier. For many of the glaciers the analysis provides the first data set on ice velocities.

ABSTRACT #27(31). Oral presentation.

# The behaviour of turbulent heat fluxes on Guanaco Glacier, upper Huasco valley, Chile, using eddy covariance data and energy balance modeling

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On the cold, arid glaciers of the Norte Chico region, Chile, sublimation plays an important role in mass loss from the glacier surface. The ratio of sublimation to melt on these glaciers dictates not only the amount of meltwater delivered to the watershed, but it also drives the development of morphological features on the glacier surface, such as penitentes. As the rate of sublimation is driven by the latent heat flux, understanding the behaviour of the turbulent heat flux across the glacier surface is key to quantifying the spatial and temporal patterns of ablation. This paper presents our first set of experiments undertaken to quantify the turbulent heat fluxes on a Norte Chico Glacier. We measured the turbulent heat fluxes at a point on the surface of the Guanaco Glacier during 23-31 January, 2008 using an open-path eddy covariance system. The eddy covariance system was installed adjacent to an existing automatic weather station on the glacier surface, in a region devoid of penitentes and other surface deformities. The results from the eddy covariance measurements were subsequently used to validate a point energy balance model. Results showed that 0.5-3 mm w.eq. of sublimation occurred per day during the study period, which corresponded well to the energy balance results. The rate of sublimation accounted for over half of the daily ablation at this site. However to assess the total sublimation rate on this glacier, sublimation rates from penitentes, ablation cusps and debris-covered regions must be calculated.

ABSTRACT #28(32). Poster presentation.

# Mapping glaciomarine sediments at remote sites

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A number of geophysical methods including high frequency sub-bottom profiling and high-power seismic reflection systems are traditional tools for mapping the vertical and lateral extent of glaciomarine sediment. However, the high-frequency systems are only effective in fine-grained sediment and generally have limited subsurface penetration and the high power systems, and their requisite generator, are often quite large and not easily mobilized to remote sites. We have been using a low-frequency (350 to 800 Hz), low power (24 joules) seismic reflection system to map the seismic stratigraphy of marine glacial sediment at remote sites and have also achieved considerable success in deep-water lakes formed by glaciers. This system requires less than 1 kW of electrical power, can be deployed from small vessels, and can achieve over 200 m of subsurface penetration in most glacial sediment with 1.5 m vertical resolution. The data, acquired and viewed in real time, provide continuous profiles and images of bottom sediments and substrates that can be interpreted in terms of seismic stratigraphy or seismic facies analysis to determine depositional processes and unravel the history of glacial advance and retreat. The case studies to understand erosion rates during rapid deglaciation in Icy Bay, Alaska and to evaluate sediment yields of an advance-retreat cycle of a calving tidewater glacier in Laguna San Rafael, Chile, show the effectiveness of this system at remote sites.

ABSTRACT #29(33). Oral presentation.

# The last ten years in South American geocryology

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Argentina, Bolivia, Chile and Peru have been described (Trombotto, 2000) as the most important countries in South America regarding the presence of mountain permafrost (Andean permafrost). Cryogenic surfaces however still lack precise calculation. It is true that geocryological studies and research have begun very early with pioneer publications such as that of Luciano Catalano (1926) concerning rock glaciers of the Argentine Puna region, the identification of geoforms and periglacial processes in the Andes carried out by the German scientists Karsten Garleff (1977) and Helmut Stingl (Stingl & Garleff, 1983), or comparative studies made by Arturo Corte between Greenland and Mendoza since the 1950s explaining laws of horizontal and vertical sorting in ground with freezing and ice formation, laws which are applied worldwide today. Corte (1976) emphasized the hydrological importance of the rock glaciers in the Central Andes. But it is only in recent years of this millennium that geocryology advances at a faster pace, particularly because of the discussions about ecological changes in cryogenic environments in the Andes and thanks to private enterprise and human constructions expressing a cultural and socio-economic change on the subcontinent. In this presentation a short review of geocryological scenarios is given through their respective monitoring sites, their cryogenic or periglacial indicators, and recent research and results which contribute to the advances of geocryology in South American countries with permafrost occurrence during the last ten years.

ABSTRACT #30(34). Poster presentation.

# First thermal analysis of the caldera and the summit of the Peteroa volcano complex, Mendoza, Argentina

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With the support of the International Center for Earth Sciences (Malargüe) it was possible to overfly the Peteroa volcanic complex (highest peak 4100 m a.s.l. approximately) with a Cessna aircraft equipped with a thermosensible camera AGEMA TVH 550 on March 25, 2009. The volcano is located in the Cordillera Principal at 35°15' S and 70°35' W. The purpose of this inspection flight was to analyse the temperature of its caldera and of the summit which displays simultaneously volcanic activity, glaciation and neoformation of permafrost. The intention was to register the surface temperature of the summit and to distinguish different thermal areas, including uncovered or covered ice, shaded zones or zones exposed to solar radiation, as well as to calculate the temperatures which indicate permafrost and areas linked to present volcanic activity. Volcanism is expressed mainly by five large craters with fumaroles and emanations of sulphur and steam. The glaciated area was calculated as 19 km$^2$ based on aerial photographs from 1997. The glaciated surface is characterized by 10 glaciers of different sizes which occupy part of the summit and its surroundings, which are strongly conditioned by the volcanic activity. The largest glacier is located on the southern wall of the volcanic complex with an approximate size of 8 km$^2$. Geothermal heat at the monitoring site has a gradient of 1°C each 2.9 cm increasing with depth in the period 2007-2008, with sensors deployed at depths ranging from 20-80 cm. Mean annual air temperature is -2.5°C (2007-2008) at 3489 m a.s.l. The possible permafrost area was calculated to be 74 km$^2$.

ABSTRACT #31(35). Oral presentation.

# Relative importance of the turbulent fluxes in the energy balance of tropical Andean glaciers

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The turbulent fluxes remain poorly known on tropical glaciers. Different studies based on the bulk method have shown that sublimation can be important during the dry season, reducing the energy available for melting. However, uncertainties in the bulk method are large, especially when the katabatic wind causes a wind speed maximum at low height. Eddy correlation measurements have been conducted at 5050 m elevation on the Zongo Glacier, Bolivia (16°S) in July-August 2007. Concomitant measurements of all radiation components, snow surface temperature and of vertical gradients of air temperature and wind speed were made. The site was approximately level within several hundred meters, with drainage winds prevailing at night and most of the day. The surface roughness heights for temperature and momentum were derived from the profile measurements at the hourly time scale. Results indicate values from 0.1 to 1 cm in rough agreement with terrain observations. The results show that in this dry and thin atmosphere, surface temperatures below freezing are maintained with significant cooling of the surface due to sublimation and low long-wave radiation input. The agreement between the bulk and the eddy correlation methods is rather good, except during periods of calm wind when errors are large in both methods. The roughness height for momentum derived from the eddy correlation is also in good agreement with the heights derived from the profile measurements. However, the measurement period of the eddy correlation is short and more work must be done to quantify the errors on the method.

ABSTRACT #32(36). Poster presentation.

# Late-glacial re-advance during the Last Glacial-Interglacial transition; revisiting the Misery moraines in the Southern Alps of New Zealand

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Locating evidence for or against a glacial readvance commensurate with Northern Hemisphere YD-time (~11-13 ka) in Southern Hemisphere glacial systems is a key aspect in addressing millennial-scale hemispheric climate linkages during the late Quaternary. Paleoenvironmental evidence from New Zealand pollen records suggest a minor cooling or hiatus in warming during the period from ~14.5 – 12.0 ka that pre-dates the onset but overlaps with the YD chron, and is more commonly associated with the Antarctic Cold Reversal (ACR). Evidence for a glacial re-advance during the YD chron has been proposed previously (Waiho Loop moraine, Denton and Hendy, 1994) and more recently based on a limited exposure age sample set (n=4, 11.7 ± 0.3 ka) from the Misery moraine sequence at Arthur's Pass (~950 m a.s.l.), Southern Alps, NZ (Ivy-Ochs et al 1999). To further investigate this issue, we have determined paired $^{10}$Be and $^{26}$Al exposure ages from 38 greywacke samples taken from all major moraines throughout the Arthur's Pass area and including repeat sampling from the Otira Gorge (Misery) moraine complex. The new exposure ages show that the Arthur's Pass moraine system represents a glacial chronology for the last deglaciation spanning a period of 18.8 ka (at distal sites) to 10.4 ka (at proximal sites) (maximum to minimum sample age) with mean moraine ages following in chrono-stratigraphic sequence with ice flow direction. Although our new age for the proximal Misery moraine complex does not revise the conclusion reached by Ivy Ochs et al (1999) (though it does challenge the validity of the measurement) our more comprehensive sampling regime and extensive data set provide a different interpretation. The timing of deglaciation at Arthur's Pass is similar to that observed at more distal down-valley terminal positions of the Rakaia and Rangitata Valleys and suggests that the scale of any late glacial readvance, as evidenced at the Misery moraine site, was insignificant in comparison to the magnitude of ice volume at the end of the LGM in New Zealand. Details regarding age interpretation and the importance of production-rate corrections necessary to provide a robust and reliable glacial chronology at the required sub-millennial resolution will be presented.

ABSTRACT #33(37). Poster presentation.

# An updated glacier inventory for Ecuador

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The last inventory for the glaciers of Ecuador dates from 1997 (Jordan and Hastenrath, 1998), having been compiled by means of aerial photographs and satellite imagery, with a total glacier area of 97.21 km$^2$. An updated glacier inventory carried out in 2006-2008 is presented here. The present study involved field measurements performed in 2002, 2003, 2005 and 2006, and digital aerophotogrammetry. Since 1997 until 2006-2008 a glacier reduction of 40.74% has been detected, which corresponds to an area loss of 39.61 km$^2$.

ABSTRACT #34(38). Oral presentation.

# Glacier fluctuations as a temperature proxy

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As glaciers respond to changes in climate, historical glacier fluctuations give information on the past climate. For the period before meteorological measurements started, as well as for remote regions from which meteorological series are short or absent, documented glacier fluctuations can provide very useful information on climate change. We discuss a method to reconstruct temperature from glacier length records. We have collected a dataset of 281 glacier length records starting before 1945. Most of the records are in the Northern Hemisphere and there is a wealth of information on European glaciers. Despite recent efforts, the number of glacier length records in the Southern Hemisphere that go back to the 19th century or further limited. Our method is based on a linear response equation which has two parameters: the response time and the climate sensitivity of a glacier. The values of these parameters are estimated for each glacier by means of a simple model, requiring only limited information about the glacier. We show that glacier length records provide a reliable proxy for past temperature fluctuations on a global and hemispherical scale. The results are in agreement with measured temperature changes of for the last century, and with other proxies for the last 400 years. Provided a fair amount of records is available, temperatures can even be reconstructed on a continental scale.

ABSTRACT #35(39). Oral presentation.

# The glaciers of the Ojos del Salado-Tres Cruces Massifs, Atacama Andes

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*Presenter

Currently glaciers are undergoing considerable fluctuations in response to greenhouse gas-induced changes of the global temperature. Even at very short time-scales, regional climate changes are detectable at small tropical and subtropical glaciers acting as sensitive indicators of climate signals. Remote sensing studies and glaciological field investigations were carried out in the Nevado Ojos del Salado region in Chile – Argentina, situated in the southern Atacama high-Andes at a latitude of 27°S. The aim was to identify and address mountain glaciers in the south edge of the Arid Diagonal and to distinguish them from perennial snow cover. In situ field measurements indicate a glacial distribution of slope, cirque and niche glaciers, as well as glacierets between about 5300 and 6750 m. Optical remote sensing data of the Landsat TM (1986) and ASTER (2000) sensors with 30 m and 15 m resolution respectively were used to discriminate accumulation and ablation zones in the Nevado Ojos del Salado region. A supervised maximum likelihood classification was applied on a single band combination of the atmospheric reflectance band ratio TM4/5 (ASTER3/4), the Normalised Difference Vegetation Index, and the principal components PC2 to PC4. The total glacierised area in the study area is characterised by a considerable decrease of 40 % from 56.80 km² (1986) to 34.04 km² (2000). The shrinkage is related to a significant reduction of the ablation area from about 40.13 km² (1986) to 17.06 km² (2000), whereas the accumulation area remains nearly constant.

ABSTRACT #36(40). Poster presentation.

# A preliminary remote sensing glacier inventory for the Wet Andes, Argentina and Chile, between 42°S and 42°10'S

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The study presented here describes two major tasks. First, a preliminary glacier inventory of the Wet Andes between 42°S, 72°10' W and 42°10' S, 72° W, was made. The study area is characterised by a small ice field, from which valley glaciers or hanging glaciers flow out. Similar ice fields exist further west. The inventory was compiled using one ASTER scene of 2007, following Global Land Ice Measurements from Space (GLIMS) methodology. Because of the presence of cloud cover, cast shadow parts and proglacial lakes, a manual correction of glacier boundaries was necessary. The total area covered by glaciers and/or snow patches is ~100 km$^2$, with 103 glaciers larger than 0.1 km$^2$ of which 50% have an area smaller than 0.5 km$^2$. The largest glacier is the Esperanza Norte glacier which lies in Argentina with an area of 10.7 km$^2$. Secondly, 3-dimensional glacier parameters obtained from a digital elevation model (ASTER_GDEM) in a GIS environment were compared to the horizontal area change between 1987 and 2007 in order to characterise the influence of topography in the response of glaciers to climate. The glacier extent in 1987 was obtained from Landsat TM imagery. As a preliminary result, glaciers that lost more area between 1987 and 2007 are characterised by an ablation zone of low gradient and low elevation, with most of them having developed proglacial lakes in the 20 year period. Another significant change is related to valley glaciers that now are reconstituted. This dynamic behavior has to be considered when evaluating the response of glaciers to climate.

ABSTRACT #37(42). Poster presentation.

# A new surge event of Grande del Nevado glacier, Mendoza, Argentina

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*Presenter

Surging glaciers are characteristic of the Central Andes of Argentina. During their active phases, glacier tongues advance several kilometers in a sudden, brief and quick way. Glacier Grande del Nevado is a surging glacier located in the Argentinean side of the Andes, east of the international boundary with Chile (33°06'S, 70°03'W).The advances of this glacier have been documented from the beginning of the 20th century on the basis of historical documents, aerial photographs, satellite images and fieldwork. In 1934 a catastrophic flood was caused by a sudden discharge of a proglacial lake. That lake was formed by the rapid advance of the Grande del Nevado glacier, which flows transversal to the valley and produces river damming. In 1984 the glacier advanced again, but in this case the ice-dammed lake drained through a subglacial tunnel. A new surge took place between the end of 2006 and the beginning of 2007, but the main advance occurred during the winter of 2007. The glacier moved forward a total of 3.5 km, with a maximum measured velocity of 34 m $d^{-1}$. This new surge was studied with Landsat 5 TM and Aster images. Recent field observations made on September 2009 showed that the glacier tongue remains in the same position and the presence of a subglacial tunnel which continuously drains the river prevents the formation of a lake. Climate and weather could affect surge initiation, termination and magnitude. Due to this fact, a temperature series of a nearby meteorological station is being analysed to study the probable evolution of this new glacier surge.

ABSTRACT #38(43). Poster presentation.

# Glacial shrinkage and its relation with radiative factors and local climatic changes: case of study of Citlaltépetl Volcano, Mexico

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Small ice bodies capping the highest volcanoes of Mexico have been affected by both climatic factors and recent volcanic activity. Furthermore, the glaciers of Popocatépetl and Iztaccíhuatl volcanoes are further affected by the pollution of large cities located nearby which results in glacial retreat and extinction due to the albedo effect. Recent studies on the Glaciar Norte surface of Citlaltépetl volcano, where volcanic activity is very low and is far away from large cities, show how the variations in glacial retreat reflect the close relationship between climatic factors and the evolution of glaciers in Mexico. It has been possible to find the most vulnerable zones for glacial shrinkage as a relationship between the spatial distribution of the albedo and net radiation. During 2002-2007 the western part of Glaciar Norte lost 70% of its glacial area whereas the eastern part of the glacier lost only 13%. This is related to the values of net radiation over the surface since the western side of the glacier has stronger net radiation values than the eastern side. This paper emphasizes the importance of remote sensing to study the evolution of the glaciarised surfaces in Mexico which allows us, based on analysis of scanned aerial photographs and satellite images, to calculate the rates of glacial retreat, its variations over time and the spatial distribution of the albedo and net radiation over the entire glacial surface. Moreover, while these surfaces are determined by different volcanic and climatic conditions, it is possible to highlight the local impact of extreme climatic events over the glaciers as in the case of Glaciar Norte. Retreat rates change considerably from 204,115 $m^2$ $a^{-1}$ to 16,785 $m^2$ $a^{-1}$ in the period 2002-2007, a strong change considering that the glaciated area was only 843,372 $m^2$ in 2002. The glaciers of Citlaltépetl volcano show not only the local effects of climatic changes, but also the effects related to El Niño and La Niña at 19°N.

ABSTRACT #39(46). Poster presentation

# The cryosphere at the Mérida Andes: a small ice-cap, a big challenge for science

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The Mérida Andes is a range located in Venezuela at a latitude between 8° and 10°N, rising to a maximum elevation of 4981 m at the Bolívar peak. Geomorphologic evidences show that during the Pleistocene the glaciers covered at least 600 $km^2$ down to an elevation of 2600 m, coexisting at the same time with important regional tectonic pulses. Today only a small ice-cap covers the Humboldt-Bompland peaks and very small glaciers still exist on the Bolívar Peak, whereas seven glaciers have disappeared during the last seventy years. Two main ice-cover maps made in 1910 and 1952 (Jahn, 1921; Schubert, 1975) show a strong area reduction from 10 $km^2$ to 2.91 $km^2$ in the first half of the 20th century. At present we are studying the glacier evolution in the Mérida Andes in two ways: 1) A quantitative analysis of Pleistocene-Holocene evolution and their relationship with the paleoclimate and tectonics using cosmogenic $^{10}Be$ as a chronological control (results still in progress); 2) The annual-decennial evolution of the ice-cap by the temporal and multispectral analysis of Spot-5 images. Our preliminary results show that the total ice-cover in 2008 was 0.48 $km^2$ with a surface loss of 30.3 $m^2\ a^{-1}$ since 1952. However, mass and energy balances on the glaciers and ice cap and their behavior under climatic variability are still unknown. Thus, the future imposes on us the challenge of glaciological and Quaternary geology studies in the Mérida Andes, in order to improve the understanding of the evolution of one of the few glaciers with Caribbean influence, from the Pleistocene to their near extinction.

ABSTRACT #40(47). Poster presentation.

# The rock glaciers of the Cordillera del Tigre, Mendoza, Argentina

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An inventory of rock glaciers is presented for the Cordillera del Tigre, located between 32°11'S and 32°45'S in the NW of the province of Mendoza, Argentina. The surface of possible permafrost in this region is estimated to be 1284 km$^2$ approximately. The lower limit for permafrost is 3600 m a.s.l. Mesoforms have been mapped interpreting satellite images (Aster) and aerial photographs, which revealed a remarkable concordance with this limit. 95 active rock glaciers with an average surface of 0.5 km$^2$ and a minimum length of 200 m have been counted. The biggest rock glacier has a surface of 2.37 km$^2$. Rock glaciers are generated either as landforms derived from uncovered glaciers, glacieretes or nearby perennial snow patches, or they may also be created exclusively by cryogenic processes. A classification of the latter allows to affirm that a cryogenic origin (73 cases) is more frequent than an origin based on uncovered glaciers or perennial snow patches (22 cases). Comparing the surfaces, rock glaciers, which have a total area of 47.77 km$^2$, turn out to be more extensive than glaciated surfaces or perennial snow patches which have an area of 39.79 km$^2$. This is a common phenomenon in the dry Andes which explains the enormous importance of these landforms as water supplies.

ABSTRACT #41(49). Oral presentation.

# The retreat of glaciers in the tropical Andes: new evidences and regional context

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*Presenter

Glaciers have become essential tools for surveying evolution of the global environment. Here, we succinctly analyse glacier evolution during the last decades in the tropical Andes (Bolivia, Peru, Ecuador), where IRD (France) and South-American partners conduct a permanent monitoring program since the beginning of the 1990s. It is clearly visible that the magnitude of the glacier retreat increased dramatically after the 1980s, with losses close to 5-10 m of water equivalent per decade (specific net balance) since 1991 and shrinkage rates as high as 30-50% in glacier areas and volumes over the three last decades. In such condition, the most vulnerable are the small-sized glaciers situated at low elevation (<5500 m a.s.l.), which are currently disappearing. This evolution denotes drastic changes occurred in climatic conditions at the regional scale, which appear closely linked to the evolution of the sea surface temperature in the equatorial Pacific. Warm/cold events in the Central Pacific impose distinct ablation and accumulation conditions at the glacier surface, which are particularly critical in summer in Bolivia and during the equinox in Ecuador. Finally, timing and magnitude of the glacier retreat in the tropical Andes are compared with other mountain glaciers in the world.

ABSTRACT #42(51). Oral presentation.

# Glacier acceleration and increased ice export after the disintegration of Northern Larsen Ice Shelf, Antarctic Peninsula

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Surface motion and ice export of the glaciers above the previous northern sections of Larsen Ice Shelf (LIS) (the Larsen A, Larsen B and Prince Gustav Channel ice shelves) on the Antarctic Peninsula were studied using satellite radar images, acquired during the years 1995 to 2009. One-day repeat-pass interferometric data of the ERS-1/ERS-2 tandem mission from 1995 to 1999 were used to estimate the mass export through gates near the grounding line for pre-collapse conditions. Radar interferometry could not be applied later on because of the longer repeat pass intervals of the available radar missions resulting in decorrelation of the signal. Cross-correlation of templates in SAR amplitude images is an option for mapping ice velocities in case of incoherent data. TerraSAR-X, launched in June 2007, offers excellent opportunities for detailed mapping and monitoring glacier flow due to its high spatial resolution and frequent repeat coverage. Between July 2007 and August 2009 several stacks of TerraSAR-X 11-day repeat pass images with spatial resolution of about 3 metres were acquired over all outlet glaciers above the previous northern LIS sections. The current (2008-2009) export across the calving glacier fronts is estimated using velocity maps derived from TerraSAR-X images and information on ice thickness from various sources. All major glaciers accelerated significantly compared to the pre-collapse period, with an up to six-fold velocity increase observed for Hectoria-Green glaciers. The lower sections of the glaciers remain in accelerated state for several years and show little seasonal fluctuations of velocity. Taking into account the retreat of grounded ice and the increased calving flux, the total mass imbalance of the glaciers above the disintegrated Larsen Ice Shelf sections is estimated at about 5% of the current total contribution to global sea level rise from glaciers, ice caps and ice sheets.

ABSTRACT #43(52). Poster presentation.

# Monthly analysis of glaciological and hydrological mass balance from Zongo Glacier (Bolivia)

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Since 1991, a glaciological study program on Zongo glacier located on Huayna Potosi massif in Bolivia (4850-6000 m a.s.l., 2.4 km$^2$, 16°S) has involved monthly mass balance, hydrological and meteorological measurements. In the present work a monthly resolved mass balance reconstruction was done in both ablation and accumulation zones over 15 years. The monthly mass balance is compiled and validated in the ablation zone and the net mass balance was calculated. Additionally, the monthly mass balance was also calculated using the hydrological method. For all the results a detailed error analysis was done. Finally, we obtained a monthly mass-balance temporal series of 14 years (1993-2008). A remarkable monthly seasonality is detected and a good correlation is obtained between both methods used, especially during the wet season. In order to understand the variability, the mass balance was compared with local meteorological conditions. The strong monthly variability in the mass balance is mainly dependent on variations in ablation rates during wet season months. Net all-wave radiation is the main factor that governs ablation during this season and is well correlated with the mass balance. ENSO index analysis was performed over the period studied focussing on specific years characterised by "El Niño", "La Niña" and "Normal" patterns related to high mass balance variability.

ABSTRACT #44(53). Poster presentation.

# Evolution of a small glacier at the west Ecuadorean Andes

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The Carihuayrazo volcano in Ecuador has a small glacier cover. It has generated interest due to its rapid glacier recession, which is mainly related to the position of its mean equilibrium line altitude (ELA0) which in Ecuador corresponds to 5045 m a.s.l., located practically at the same altitude as the summit of Carihuayrazo (5050 m a.s.l.). That is, the accumulation area virtually does not exist and therefore there has been a rapid decline of its glacier cover, with a loss of 92% of its area in 1956-2008 and a decline of about 23% in 2003-2008. The latter result was obtained using direct field measurements. It is believed that if the present conditions will continue in the future, the glacier will disappear in the next 20 years.

ABSTRACT #45(54). Poster presentation.

# Norwegian-US Antarctic IPY Traverse

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Ground-based measurements in East Antarctica are limited, so that fundamental glaciological parameters such as mass balance and ice thickness are still unknown for large areas. Yet knowledge of these is crucial for determining ongoing changes and estimation of possible future sea-level change. The Norwegian-US International Polar Year (IPY) traverse through East Antarctica aims to close some of the data gaps. The traverse occurred over two austral summers, Troll to South Pole in 2007-2008, and the return trip via a more westerly route in 2008-2009. In both seasons the 1960s South Pole Queen Maud Land Traverse lines were crossed. A suite of geophysical data was collected as well as more than 1200 m of short and long firn cores distributed along the routes. Eight short firn cores were analysed at the Norwegian Polar Institute using dielectric profiling. The conductivity record was used to establish a volcanic chronology for dating the cores, allowing accumulation rates to be calculated. Results from the first season cores indicate a decrease in accumulation rates over the last 200 years. A low frequency impulse radar system was used to map ice thickness and internal layering. The deepest ice in the second season was found over the Recovery Lakes region. The edges of the lakes (identified in previous studies through surface features) are clearly seen in the bedrock profile.

ABSTRACT #46(56). Poster presentation.

# Developing an Argentinean glacier inventory: first results from the Southern Patagonia Icefield submitted to GLIMS

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Most glacier inventories for the Argentinean portion of the Andes (22°-55°S) are out-of-date and limited to few areas in the Cordillera. Here, we report on the first results from the ongoing research project "Perspectives for the development of a National Glacier Inventory: A Methodological Approach", which have been submitted to the GLIMS database (Global Land Ice Measurements from Space) as a first contribution of IANIGLA to this international programme. The inventory is based on ASTER satellite imagery and ASTER-based DEMs, and includes all glaciers between Lago San Martín (49°S) and Lago Viedma (49°30'S) on the northeastern margin of the Southern Patagonia Icefield. This area contains a variety of glaciers with different sizes and characteristics that allow testing different methodological approaches in a relatively reduced area. In addition, glacial deposits related to the Little Ice Age fluctuations have also been identified for selected glaciers in the region. The main limitation for the glacier inventory is the lack of good quality, cloud-free images for the area. Thirty five glaciers, representing a total glacier area of 160 km$^2$, were identified in an ASTER late summer image (20 Feb 2005). Presently, we are extending the inventory to other regions in Argentina, including those with larger proportion of debris-cover and rock glaciers. Based on these preliminary inventories we will develop a methodological protocol that includes standard procedures, management and submission of information to the Argentinean glacier database and international databases including GLIMS.

ABSTRACT #47(58). Poster presentation.

# Combined (ice, water, heat) balance on the Rinconada West Glacier, Aconcagua River basin, Chile, during February 2009

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In February 2009 21% of the Rinconada West Glacier (Aconcagua River basin, Chile, 33°10'S) surface was penitent snow, the rest was debris covered. Water equivalent ablation on the field of penitentes was measured with "snow frames" and snow density observations, and in the debris-covered area the ablation was measured based on the surfacing of casings within drill holes. Basal melting was estimated as produced by geothermal and frictional heat. All meteorological parameters to calculate the heat balance, including those needed to assess the vertical gradients of wind and air temperature, were measured hourly at an automatic weather station near the equilibrium line. Water discharge was recorded continuously in the stream draining from the glacier, at a station about 150 m from its terminus. The evaporation was repeatedly measured within the field of penitentes, and the infiltration within the glacier basin was estimated with an existing local hydro-geologic model. As an average monthly discharge, melting from penitentes amounts to 27.47 l $s^{-1}$, melting under the debris-covered area of the glacier was 8.99 l $s^{-1}$, melting at the glacier base 0.14 l $s^{-1}$, and precipitation minus evaporation 5.31 l $s^{-1}$; the sum of the above is 41.92 l $s^{-1}$. Discharge in the stream is 35.64 l $s^{-1}$, and the infiltration according to the model 6.35 l $s^{-1}$. The error in the water balance is thus 0.08 l $s^{-1}$. The main heat source is the short wave radiation balance with 12.829 Ly $cm^{-2}$ per month, while the long wave balance produces a heat loss of 4,502 Ly $cm^{-2}$ per month. The net heat contributed to the penitentes is therefore 8,452 Ly $cm^{-2}$ per month, causing a potential average daily ablation of 3.4 Ly $cm^{-2}$ of firn, similar to the 3.3 Ly $cm^{-2}$ measured with frames. Average daily melt rate under the debris cover is 0.2 Ly $cm^{-2}$.

ABSTRACT #48(60). Poster presentation.

# Physical characteristics of rock glaciers in the mountains of central Chile

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Twelve rock glaciers have been explored since 1998 in the upper Blanco River basin, an affluent of the Aconcagua river. Over 100 ODEX (Overburden Drilling with Excentric Drilling) drill holes to the basal rock provide information on thickness and composition, in addition to gravity cross sections and trenching which exposed the base of some glaciers. Glacier internal temperature was measured with sensors in drill holes and pits: all are temperate glaciers. Accumulation forms were observed. Average ablation rate on the top part of the debris-covered ice is 0.16 m $a^{-1}$ on average during the last decade, and was compared with continuous records of temperature gradient variations in the debris cover and measurements of thermal conductivity. Ice melting at the base of the glaciers was estimated from the thermal gradient on local rocks measured in existing exploration drill holes. Melting by frictional heat was calculated based on several inclinometer-controlled holes drilled to the base of the glaciers and the resulting basal velocities. Basal velocities are compared to annual and inter-annual velocities measured on the surface of the glaciers at over 80 points. In addition, surface deformations are controlled on 12 ice networks, and the corresponding stresses and their variations are calculated. Most of these glaciers have been affected by mining, and the results of these interventions have been monitored and controlled. Before the mining operations started one glacier had advanced slightly, while the rest were stable.

ABSTRACT #49(61). Oral presentation.

# Management of glaciers: experiences and results in Chile

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Glaciers are valued, among other characteristics, as water reserves and resources. Nevertheless, most of them are losing mass since the end of the last glaciation because of natural processes, and in recent decades because of additional anthropic causes, resulting in an extinguishable resource. In order to regard glaciers as a sustainable resource, the technology to use them when needed must be developed, as well as the know-how to replenish them at other times. In 1969 an economically efficient method to increase surface ablation rate during the summer season was developed and tested semi-industrially in Coton glacier, in the mountains of central Chile. During the summer seasons between 2006 and 2009 experiments consisting of dusting test areas of a glacier with various concentrations produced results of ablation rates. Again, during the last three years, the preservation of a relocated ice mass of about 30,000 tons and 16 m of thickness was successfully achieved, reducing the 2008-2009 ablation rate to 0.160 $ma^{-1}$, identical to the average rate on nearby rock glaciers, and avoiding the formation of “hot spots” within it, thus assuring the persistence of this ice mass for over a century. Together with the above, studies and works are being conducted to generate a new and self-sustaining glacier where none presently exists.

ABSTRACT #50(63). Poster presentation.

# Vertical wind and temperature gradients over a field of penitentes

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In order to evaluate the heat balance on a field of penitentes, vertical gradients of wind velocity and air temperature are important parameters. To obtain such data and other needed information, an automatic weather station was installed during the summer seasons of 2006, 2007 and 2009 in Rinconada West Glacier, Aconcagua River basin. Wind and temperature sensors were placed at three levels and up to 6 m above the furrows of the penitentes. The height of the set of sensors was periodically adjusted to account for the surface elevation reduction caused by the firn ablation. The hourly data were analysed by linear regressions, and the best fit resulted when comparing the slope of both parameters with the logarithm of the height. During one season the differences between hourly averages of the wind slope varies between 0.3 and 0.7, with the minimum occurring between 14:00 and 16:00 h and the maximum between 19:00 and 23:00 h local time. The slope of the temperature gradient is usually between 0.4 and 0.7 during sunless hours or hours of low sun, inverting to between –0.5 and –1.3 between approximately 12:00 and 18:00 h.

ABSTRACT #51(64). Oral presentation.

# Dust deposition in East Antarctica during the past 2000 years: linkages to South American climate

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Continental dust and other aerosols emitted from biomass burning, volcanoes, and industrial activities alter chemistry and radiative processes in air and snow, yet little is known about past sources, transport pathways, or fluxes prior to recent decades. Dust mobility and biomass burring emissions are linked to climate and glaciers and ice sheets contain detailed records of these aerosols. We use continuous, high-depth-resolution, trace and ultra-trace measurements of a broad range of elements and chemical species from four new ice cores from a Norwegian. U.S. scientific traverse to develop a detailed history of aerosol concentrations and fluxes in East Antarctica, a region thought to be dominated by aerosols from South America. We present these new records and discuss their implications for South American climate during the past ~2000 years.

ABSTRACT #52(65). Oral presentation.

# Glacial sediment yields in an era of warming climate

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To evaluate properly how glacial erosion influences orogenic processes and reflects climate variability, we seek to understand how ice dynamics control erosion rates. Contemporary glacial erosion rates based on sediment yields in Patagonia are among the highest worldwide, and significantly exceed long-term exhumation rates in the region. One issue likely to contribute to these high contemporary sediment yields is rapid retreat of most of the calving glaciers in Patagonia over the past 50-100 years, a period when they were anomalously dynamic and erosive. To investigate the influence of warming regional climate and rapid glacial retreat on glacial erosion, we compare annual to decadal sediment yields to reconstructed fluxes of ice for two glaciers in Chilean Patagonia: Glaciar Marinelli in Tierra del Fuego and Glaciar San Rafael in Campo de Hielo Patagónico Norte. NCEP-NCAR Reanalysis climate data, adjusted to local conditions by correlation with automatic weather stations installed at each glacier terminus, were used to reconstruct the annual accumulation into and ablation out of these glaciers since 1950, and estimate the annual ice budget. The sediment fluxes out of the glaciers are calculated from acoustic reflection profiles of the sediment volumes and subaqueous landforms collected in the proglacial fjords, and used to estimate annual erosion rates. A strong correlation emerges between glacial retreat rates and glacial sediment yields, implying that most contemporary sediment yield data from retreating tidewater glaciers that may correspond to contemporary erosion rates that are a factor of 3.5 ± 1.5 higher than during glacial advance, and/or when averaged over a complete glacial cycle. The marked retreat and thinning of these glaciers in the past century suggests that much more ice is being conveyed through the glaciers to the fjords than can be sustained by the input of snow, resulting in associated acceleration of sliding at the bed and more rapid erosion. Interestingly, current erosion rates from these glaciers are over an order of magnitude higher than long-term exhumation rates derived from detrital apatite thermochronometry in the basins, suggesting that current rates of erosion are highly anomalous and reflect only periods of warming climate and enhanced glacial dynamics.

ABSTRACT #53(66). Oral presentation.

# Evidence for minimal Pleistocene ice sheet elevation changes from the Shackleton Range, Weddell Sea embayment, Antarctica

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Studies using cosmogenic nuclide analysis in Antarctica have the potential to provide unique insights into Pleistocene ice sheet fluctuations. Here we report combined new geomorphological evidence and integrated cosmogenic isotope analysis ($^{21}$Ne, $^{10}$Be and $^{26}$Al) from the Shackleton Range, part of the Transantarctic Mountains overlooking the Weddell Sea. The Shackleton Range, bounded to the north by the Slessor Glacier and to the south by the Recovery Ice Stream, provides the ideal locality to record the trajectory of long term ice sheet changes in this sector of Antarctica. These major outlet glaciers drain large areas of East Antarctica and occupy deep troughs extending well below current sea level, which combine to contribute approximately one third of the total inflow to the Ronne-Filchner Ice Shelf. There is also evidence of subglacial lakes under the Slessor Glacier which potentially could destabilise the ice stream system. Past estimates of ice elevation at the Last Glacial Maximum in the Shackleton Range vary from <340 m to over 1000 m. The results of recent geomorphological mapping combined with the concentrations of cosmogenic isotopes from bedrock summits suggests minimal ice sheet thickening at the Last Glacial Maximum in this sector of Antarctica. These results are important as they have direct implications for two important related debates: Firstly these data suggest the Slessor Glacier has been stable throughout the Pleistocene with little or no expansion during glacial phases; secondly these data suggest that the Slessor Glacier has not grounded in the Weddell Sea for millions of years.

ABSTRACT #54(68). Oral presentation.

# A review of glacier fluctuations in southern South America (17°-55°S) during the past millennium

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An updated review of the evidence for glacier fluctuations during the past 1000 years across the extratropical Andes of South America is presented. Information on glacier fluctuations in the Desert Andes (~17°–31°S) is limited to the 20th century. In the Central Chilean-Argentinean Andes (31°–36°S), several glaciers reached their Little Ice Age (LIA) maximum expansion between the 16th and 19th centuries. Further south, in the Patagonian Andes and the Magallanes-Tierra del Fuego regions (36°–55°S), numerous glacier advances have been identified during the past millennium, but precisely dated maximum Little Ice Age (LIA) or post-LIA advances have only been identified at very few sites. The evidence available indicates that the maximum LIA expansion in these regions also occurred between the 16th and 19th centuries, but the data shows considerable variability in the extent and timing of events. A growing body of information is also being collected for glacier advances during the first half of the past millennium. Over the past century many glaciers throughout the extratropical Andes have experienced readvances but these events have not been sufficient to counteract the recent, generalised pattern of thinning and recession. The differences in the glacier histories observed at local and regional scales probably reflect the inherent limitations associated with the glacier records and/or the dating techniques used in each case together with the varying dominance of precipitation, temperature and other climatic and non-climatic factors on glacier mass balance and glacier dynamics. This suggests that the late Holocene glacier history of southern South America is more complex than commonly assumed.

ABSTRACT #55(69). Poster presentation.

# Glacier inventory in the Desert Andes of San Juan, Argentina (29°20'S)

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A glacier inventory was compiled of four small watersheds (100 km$^2$) in the Desert Andes of San Juan, Argentina. The inventory was based on high resolution satellite images of 2005 to 2007, aerial photos of 1959 to 2000, and was complemented with field observations. The information obtained was digitised on orthorectified Ikonos images of 3rd January and 1st March 2005, which were used as base map. The remote sensing and GIS methods are described. In the area, 6 glaciers, 15 perennial snow patches (larger than 0.1 ha) and 36 rock glaciers were identified and classified following the WGMS instructions. The glaciers studied show several features expected in the Desert Andes: glaciers are small, behave as "reservoir glaciers", show little evidence of ice motion, experienced small front fluctuations, and are largely covered by penitentes. In normal years only patches of firn are found on the glaciers. Also topographic control is very strong: glaciers develop on cold slopes, mainly southeasterly exposed. During the 1959-2007 period, the total debris-free glacier area shrank 19%, largely influenced by Canito Glacier which lost about 40% of its surface. In addition, local meteorological stations data were used to calculate the isotherms. The active rock glaciers are located above 4150 m a.s.l. and define the lower limit of the discontinuous permafrost, which is associated with the mean annual isotherm of -1°C. The equilibrium line altitude (ELA) lies at 5000-5250 m a.s.l., and was estimated from the median altitude of the studied glaciers.

ABSTRACT #56(70). Poster presentation.

# Active layer in Greenland permafrost and snow stratigraphy in the Antarctic ice sheet: an assessment of contrasting polar conditions through GPR

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Polar regions are expected to experience the largest changes and amplified variability in climate parameters during the coming decades. Large amounts of carbon currently stored in the Arctic permafrost will be available for turnover if it is thawed during summer. This amount of thawed permafrost in the active layer is important not only as an indicator of climate change but because its changes will alter the conditions for the vegetation and the ecosystem. Firstly, and as a main focus, we present preliminary results of a project that focusses on the interactions between the snow, soil and vegetation in Zackenberg valley, northeast Greenland, using Ground Penetrating Radar (GPR). In 2009, the unusual early melt and extremely low precipitation during the winter of 2008/2009 were a severe limitation for the study of seasonal snow by means of GPR. GPR measurements were performed along a permafrost transect using a frequency of 500 MHz, with a penetration depth of about 1 m in the saturated areas. Moisture conditions are assessed along a gradient of five different soil and vegetation types. The results suggest that significant variations in radar velocity are related to changes in moisture content in the active layer and hence to vegetation type. Secondly, shallow stratigraphy and snow accumulation by means of a 400 MHz GPR were undertaken as part of a terrestrial traverse in 2007, from Patriot Hills, latitude 80°S, to the South Pole, Antarctica. The penetration depth was more than 20 m with a vertical resolution of 15 cm. Results show that over the East Antarctic ice sheet, within the inner plateau, snow accumulation is significantly smaller than the accumulation estimated by GPR at lower latitudes in West Antarctica. Radar results also show the relevance of surface topography and wind redistribution of snow in the study of snow layer interpretation.

ABSTRACT #57(71). Oral presentation.

# Modelling bare ice cliff ablation on debris and tephra-covered glaciers

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*Presenter

The mountains of South America and New Zealand have a high proportion of debris-covered glaciers due to both high rates of debris supply from rapidly denuding mountain faces and deposition of tephra by active volcanoes. The large reduction of surface melt rates below 'clean' (uncovered) ice rates by debris-covers more than a few centimetres thick is well established. On glaciers with extensive and thick debris-cover it is therefore likely that small areas of bare ice or patchy debris-cover account for a disproportionately large amount of total surface ablation. Within zones of continuous debris-cover, bare ice tends to be restricted to steep ice cliffs which are difficult to detect in satellite imagery, making mapping and monitoring of their development over time problematic. In this paper a numerical energy-flux model is used to estimate ice-cliff back-wasting rates based on meteorological input data. Melt rates and the rate of slope angle change are found to be complex functions of initial slope and aspect angles and the proportion of debris, bare ice and sky within the field of view of the ice cliff. Model results match well with field measurements and the observation that poleward-facing ice cliffs tend to persist over several ablation seasons, maintaining a near-vertical slope angle, while ice cliffs with other orientations become less steep and buried by debris over time. The model allows an estimate of the contribution of bare ice cliffs to total surface melt in debris-covered ablation zones.

ABSTRACT #58(72). Poster presentation.

# A high magnitude midwinter melt event at Glaciar Pichillancahue, Volcán Villarrica, Chile

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A remarkable midwinter melt event occurred at Glaciar Pichillancahue, Volcán Villarrica (39°25'12''S, 71°56'27''W) between 8th-11th August 2004. Mean 2 m air temperature recorded at an automatic weather station at 1890 m a.s.l. over this 4-day period was 9.7°C (compared with a winter mean of -1.6°C) leading to an estimated 160 mm of water equivalent snow melt. The event was characterised by high night-time temperatures, with a minimum of 10.1°C on 9th -10th August, and extremely low relative humidity, with a mean of 6% on 10th August. Data recorded simultaneously at permanent lower-elevation weather stations in the region demonstrate that strong temperature inversions occurred, particularly during the night-time. NCEP/NCAR reanalysis data indicate the event was associated with incursion of a tropical air mass into southern Chile and Argentina and that the highest temperature anomalies occurred close to the elevation of the volcano station. Assessment of the overall significance of such winter melt events to glacier mass balance in the region is difficult since few high elevation meteorological or radiosonde data exist and low level station measurements are poor indicators of the presence of strong temperature inversions in the low to mid troposphere. Short periods of positive air temperatures were regular features of both the 2004 and 2005 winter seasons, when the volcano station was operational. The likelihood is that winter melt events will increase in frequency in the future, as GCM outputs predict the lower and mid-troposphere to warm faster than the surface.

ABSTRACT #59(73). Oral presentation.

# Radar profiles of stratigraphic structures in the Antarctic ice sheets

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When viewed on a scale of tens of km, radar profiles within the Antarctic ice sheets reveal a variety of structures, including unconformities, folds, sigmoidal beds, cavities and synforms. These structures are rarely caused by deformation, but by differential snow accumulation. We use radar systems along the ground surface for measuring firn profiles, which generally employ 200– 400 MHz center frequency pulses, while englacial profiles we have recorded used pulses generally centered from 3–4 MHz. Long distance horizons in firn are caused by hoar layers, which generate during widespread warming events on sunny days and offer a detectable density contrast to the radar signals. The basic cause of their distortion, or apparent deformation, is differential deposition, which results from wind interacting with surface topography. Ice speed further distorts firn layers by causing successive years to progressively move down ice. Regardless of surface slope magnitude, more snow accumulates on windward than on leeward slopes. The resulting apparent deformation carries into the englacial ice, where horizons are caused by contrasts in acidity between adjacent layers. In West Antarctica firn and englacial strata can be followed for hundreds of km and there is rarely loss of accumulation below the leeward slopes. This continuity makes many ideal sites to obtain ice cores. In major sections of the higher, drier and colder East Antarctic plateau however, deposition on leeward slopes is virtually absent, which results in surface glaze, deposition hiatuses, and eventual unconformities. In the extensive megadunes radar reveals that the windward slopes are the prograding faces of multi-km long regular cosets of bedding sequences identical to the climbing ripples of sedimentary geology. In non-megadune areas we have profiled similar coset phenomena but irregular and at much larger scales where bed thickness can reach over 100 m and 46 km length. These may be the longest sedimentary structures in the world. Englacially, we see similar structures, but much remains hidden between the low frequency unconformable horizons. These windward depositional faces appear to be the catchments for snow, which then spread by ice flow as they metamorphose and maintain the elevation of East Antarctica.

ABSTRACT #60(74). Oral presentation.

# Antarctic ice sheet mass balance from ICESat (2003-2008)

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The mass balance of the Antarctic ice sheet is derived from surface elevation changes (dH/dt) measured by ICESat laser altimetry for the period from autumn 2003 to autumn 2008. The rates of mass loss and gain by drainage system are compared to those derived from ERS radar altimetry for the period 1992 to 2002. Our firn-compaction model is used to account for elevation changes driven by temporal variations in accumulation rate, as well as temperature, and to determine the appropriate density for converting volume changes to mass changes. Rates of mass loss from parts of the Antarctic Peninsula and West Antarctica appear to have increased since the 1990's, but other parts appear to be losing mass at smaller rates or gaining at larger rates. East Antarctica is gaining more mass than in the 1990's. Overall, increases in mass in some regions, perhaps from increases in precipitation, are counterbalancing greater decreases in other regions, perhaps from dynamic changes. Therefore, the overall rate of mass loss from Antarctic grounded ice has not changed much since the 1990's.

ABSTRACT #61(75). Oral presentation.

# Stable Holocene ice flow in interior West Antarctica: evidence from the ice divide of Pine Island Glacier

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Glacial geology and ice core data has demonstrated that large-scale changes in the volume and configuration of the Ross Sea sector of the West Antarctic Ice Sheet (WAIS) occurred 8-4 ka BP. Information on WAIS history remains limited, however, despite its relevance to comprehend modern ice sheet changes. Here we analyse palaeo ice flow above and around Subglacial Lake Ellsworth (SLE), near the ice divide of Pine Island Glacier. Radio-echo sounding (RES) data have been used to map buckled englacial layers generated by ice flow over and around rugged subglacial topography in the upper part of the SLE catchment. The record of the palaeo-ice flow field, established by tracking buckled layers at various depths, has been compared with GPS surface measurements of present-day ice flow to indicate the absence of any deviation of the flow field between the past and present. Assuming a constant ice flow rate of ~5 m $a^{-1}$ (equal to the present-day value over the centre of SLE) indicates that flow has been stable for at least the last 6800 years, implying that: (i) SLE is a long-lived, resilient feature; (ii) the surface morphology of this sector of the ice sheet has experienced little change during the Holocene; (iii) the ice divide between the Amundsen Sea and Weddell Sea embayments has not undergone significant migration towards the Institute Ice Stream during the Holocene. Geomorphological mapping and cosmogenic dates from the Ellsworth Mountains suggest that the WAIS in this area has thinned by only a few hundred metres since the LGM and that the position of this ice divide has undergone little lateral migration. Owing to its apparent inherent stability the ice divide of Pine Island Glacier may not respond easily to perturbations elsewhere in the ice sheet. This may modulate the contrasting responses of the Ross Sea and Amundsen Sea sectors of WAIS during the Holocene and has important implications for our understanding of modern ice sheet change.

ABSTRACT #62(76). Poster presentation.

# State and dynamics of a tropical rock glacier on the Altiplano (Bolivia, 21.5°S) during the last two decades

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On the Southern Bolivian Altiplano (Sur Lipez), glaciers are almost absent today whereas ice-rich permafrost affects numerous debris accumulation sectors and constitutes an unknown contributor to the hydrology of the region as well as a precious climatic indicator. In this tropical, but rather arid mountainous environment, the Caquella rock glacier, which develops between 5600 and 5400 m a.s.l., has been surveyed for more than 15 years by IRD. This paper intends to synthesise the main results regarding the state of the rock glacier and its dynamics, especially with respect to the warm decades of the 1980's and 1990's. First, geomorphological analysis allows us to understand the genesis and history of the rock glacier during the Quaternary. A model of internal structure of the landform obtained from geoelectrical soundings is also coupled with repeated geodetic measurement of boulders on the surface to assess the rock glacier dynamics. Topo- and micro-climatic records associated with climatic data analysis provide new insights of the short- and mid-term relations between permafrost and climate at tropical latitudes. The potential degrading state of the permafrost at this site and its hydrological significance for the Altiplano is finally discussed.

ABSTRACT #63(78). Oral presentation.

# Rapid crustal uplift in Patagonia as a consequence of increased ice loss

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GPS observations were carried out between 2003 and 2006 at the northeastern edge of the Southern Patagonian Icefield. The data analysis was performed with the Bernese Software and revealed uplift rates of up to 39 mm $a^{-1}$. For the region an accelerated glacier wasting has been observed since the termination of the Little Ice Age. This increasing ice loss continues up to present time. Advanced modelling shows that the rapid ice melting in combination with relatively low viscosity of the Earth's mantle caused by the unique regional slab-window tectonics is central for the interpretation of the results. The profile of GPS observations link ice loss to the soft viscoelastic isostatic flow response over the time-scale of the Little Ice Age (LIA), including ice loss in the period of observation.

ABSTRACT #64(79). Oral presentation.

# Analysing trends, variability and climatic dependence of the hydrological regime of Chilean rivers using the annual hydrograph centroid during the 1961-2005 period

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This paper presents an analysis of the hydrological regimes from several rivers flowing from the western slope of the Andes Cordillera. A database of 37 unimpaired average monthly stream flow records located in central and south Chile was compiled, spanning the region between latitudes 30°S and 40°S and the period between 1961 and 2005. The hydrograph centroid (CT) corresponding to each water year was used as an indicator of flow regime. The CT for each river was calculated and correlated to climatic variables such as temperature and precipitation. Trends in the CT were analysed using parametric and non-parametric tests. General results for the 1961-2005 period show a significant (0.1>p-value) negative trend (centroid timing shifting earlier in the year) for nearly a third of the rivers measured, and negative but non-significant trends for most of the remaining stations. However, most of the trends disappear when analysing the 1977-2005 period. This last result, along with the strong correlations to precipitation rather than temperature suggests that the observed trend in the CT is related to trends in precipitation rather than in temperature.

ABSTRACT #65(80). Poster presentation.

# Reaction of a small glacier to recent climate change observed in the Arctic

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In the frame of the International Polar Year (IPY) programme "Hydro-Sensor-FLOWS", the response of the East Loven Glacier (10 km$^2$, Spitsbergen) to climate conditions has been studied, analysing the longest meteorological data time-series available for this area (1969-2008) recorded at Ny Alesund (79°N). The mean annual temperature increased by 2°C during the last 40 years and the annual amount of precipitation increased by 74 mm (+2 mm a$^{-1}$). But do these regional climate data reflect the most important processes? The annual air temperature of the last 10 years (1998-2008) is consistently above the long-term mean (1969-1999). The increase of the air temperature is in fact linked to an increase of the cold season's temperatures whereas summer temperatures seem less impacted. Moreover, daily data show an increase in the number of warm events during the cold periods, which is the most specific change in present-day climate compared to the 1970s. These warm events are particularly fatal to glaciers when associated with liquid precipitation. We analysed the reaction of the glacier to recent climate change using successive frontal positions and volume variations derived from aerial photos, maps, DEM and GPR measurements. The annual glacier area loss is 3 times greater for 1964-1995 than for 1995-2007, while the annual loss in volume is 2.3 times more important for 1995-2007 than for 1964-1995. In 2007, the East Loven Glacier volume represented 66% of its 1964 volume and 80% of its 1995 volume, showing an acceleration in thinning rate, still lower but consistent with Southern Hemisphere glacier observations.

ABSTRACT #66(81). Poster presentation.

# Modern ELA Variations in the Cordilleras Huayhuash and Raura, Peru

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The Cordilleras Huayhuash and Raura are remote glacierised ranges in the Andes Mountains of Peru. A robust assessment of modern glacier change is important for understanding how regional change affects Andean communities, and for placing the paleo glaciers in a context relative to modern glaciation and climate. Equilibrium Line Altitudes (ELAs) derived from satellite imagery are used as a proxy for modern (1986-2009) local climate change in a key transition zone in the Andes. Clear sky, dry season Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite images from 1986-2009 were used to identify equilibrium line positions, and their altitude ranges were extracted from an ASTER DEM. Based on satellite records from 31 glaciers, average ELAs for the Cordillera Huayhuash (13 glaciers) and Cordillera Raura (18 glaciers) over the period 1986-2005 were 5046 m a.s.l. and 5013 m a.s.l., respectively. The rate of ELA rise was 25 m/decade in the Cordillera Huayhuash and 62 m/decade in the Cordillera Raura. The time series is being updated to reflect ongoing changes in both ranges. We address why the rate of change may vary in these adjacent mountain ranges and the implications for climate change assessments.

ABSTRACT #67(82). Poster presentation.

# Meteorological analysis at Fleming Glacier, Antarctic Peninsula, derived from one-year in situ AWS data

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The Antarctic Peninsula is one of the regions most affected by the worldwide increase of air surface temperature, warming at a much higher rate than the global average. As a consequence of this regional warming, ice shelves adjacent to the Peninsula have collapsed during the last decades: Wordie in 1989, Larsen A in 1995, Larsen B in 2002 and recently (mid 2008s) Wilkins has also collapsed, among others. The ice shelves do not contribute to the sea level rise; however, their disintegration can change the dynamics of interior glaciers that prior to the collapse drained onto solid ice shelves, whereas after the collapse they flow directly to the sea. A study of these changes is being performed in Fleming Glacier through a three-year International Polar Year (IPY) project that began in mid-2007. One component of this study is to analyse the current meteorological environment and compare it with the surrounding available weather data. For that purpose, an automatic weather station (AWS) was installed upstream of Fleming Glacier during the first campaign in November 2007 in order to carry out permanent measurements of air temperature, radiation, relative humidity, wind direction and speed, at one-hour interval. In December 2008, the second campaign took place and data from the AWS was downloaded allowing analysing almost one year of meteorological parameters from this remote location. The top of the AWS in 2008 was found at about 25 cm above the surface, which indicates an annual snow accumulation around 4 m. The monthly mean air temperature ranged between -6 to -23°C (January and August, respectively), with a minimum (maximum) reaching -41.3 (0.7)°C. A good correlation of the air temperature behaviour was found among the Fleming Glacier AWS, the Fossil Bluff AWS (located toward the south-south west) and Larsen Ice Shelf AWS (located toward the north-north east), as well as with Rothera Station. The prevailing near-surface wind was from the NE indicating the katabatic origin of the boundary layer wind. Further analysis and glaciological implications are in progress.

ABSTRACT #68(83). Poster presentation.

# Modelling distributed ablation on Juncal Norte Glacier, Dry Andes of central Chile

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In the Aconcagua River Basin, Dry Andes of central Chile, summer water resources originate mostly from snow and glacier melt, and support important economic activities. We simulate distributed ablation on Juncal Norte Glacier, in the upper Aconcagua Basin, for two ablation seasons, using an energy-balance model (SnowDEM) and an enhanced temperature-index model (ETI). Meteorological variables measured at Automatic Weather Stations located on- and off-glacier are extrapolated in order to run both type of approaches at the distributed glacier-wide scale. Shortwave radiation is modelled with a parametric model taking into account shading, reflection from slopes and atmospheric transmittance. In the energy-balance model, the long wave radiation flux is computed from Stefan-Boltzmann relationships and turbulent fluxes are calculated using the bulk aerodynamic method. SnowDEM includes subsurface heat conduction and gravitational redistribution of snow. Glacier runoff is modelled using a linear reservoir approach accounting for the temporal evolution of the system. Hourly simulations are validated against ablation observations and runoff measured at the glacier snout by means of radar water level measurements and tracer injections. The predicted snowline is compared with that derived from georeferenced photos from an automatic camera. We show that extrapolation of meteorological input data, and of temperature in particular, is the largest source of model uncertainty, together with snow water equivalent initial conditions. We explore several schemes for redistribution of temperature from point measurements and demonstrate that extrapolation of temperature has a larger impact than recalibration of model parameters. Albedo modelling is also crucial for correct prediction of glacier runoff.

ABSTRACT # 69(84). Poster presentation.

# Modelling the runoff regime of the Aconcagua River basin using a distributed hydrological model: simulations of glacier and snow melt contributions to streamflow

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In the Central Andes of Chile, the interactions between snow, glaciers and water resources are governed by a distinct climatological forcing. Summers are dry and stable, with little precipitation, low relative humidity and intense solar radiation. During summer, water originates mostly from snow and ice melt. Evidence of glacier retreat and changes in seasonal snow suggests that climate change might affect water resources in the area. We use the physically-based, spatially-distributed hydrological model TOPKAPI to study the processes governing the exchange between climate, snow and ice in the Aconcagua River basin, and to evaluate future changes in the basin hydrology. The model incorporates snow and ice melt with a simplified energy-balance approach and the routing of melt water through the glacial system. We investigate differences in model parameters and performance resulting from applying the model at different spatial scales. The model's ability to simulate the relevant processes is tested against meteorological data, surface ablation and glacier runoff at the snout of Juncal Norte during two ablation seasons. Modelled snow height is compared to snow maps derived from terrestrial photos and MODIS images. Results show that the magnitude of snow and ice melt rates on the glacier tongue is correctly reproduced, but simulations at higher elevation have larger uncertainty. Crucial factors are the model's ability to simulate the redistribution of winter snow due to wind and gravity, correct modelling of temperature fields and evolution of albedo over the glacier. In particular, we suggest that albedo variations with elevations have to be incorporated.

ABSTRACT #70(85). Poster presentation.

# Changes with elevation in the energy balance of an Andean Glacier, Juncal Norte Glacier, Dry Andes of central Chile

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The energy balance of snow and ice surfaces in the Dry Andes of Chile is dominated by solar radiation. Sublimation is important at high elevations and radiative cooling at night is favoured by the absence of clouds. Because of the scarcity of data in the region, these processes have been studied only partially, and we intend to explore the variations in the interaction between climate and surface snow and ice associated with elevation. Two Automatic Weather Stations were set up on Juncal Norte Glacier, central Chile, for a 3-month period from December 2008 to February 2009. The two locations have an elevation difference of 300 m, and differ also in terms of fetch available for the development of the katabatic wind. The surface energy balance is studied with an energy balance model including subsurface heat flux. Computations are driven by measurements of incoming and reflected shortwave radiation, wind speed, atmospheric temperature and humidity. The glacier surface temperature is simulated and used for computation of the long wave radiation and turbulent fluxes. We analyse meteorological forcing, the components of the energy balance and resulting ablation at the two stations. We show that differential melt at the two sites is caused by the differences in albedo, resulting in a lower shortwave radiation flux at the uppermost station, and by differences in the sensible heat flux. Katabatic wind is evident at both stations, which together with air temperature governs the turbulent heat exchange. The heat flux into the snowpack is important at both sites.

ABSTRACT # 71(86). Poster presentation.

# The ecosystem associated with glaciers in the high basin of Rio Blanco, central Chile

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An ecosystem study associated with a glacier system was performed in the high basin of Rio Blanco, tributary of Rio Aconcagua, central Chile. The objectives were: i) to compile biological information of the study area, ii) to establish a baseline study of flora and fauna associated with glaciers, englacial and proglacial water bodies, iii) study physical and chemical characteristics of the water bodies, iv) baseline study of the macrofauna, fauna and aquatic flora associated with the water bodies, v) to identify species with conservation problems, and (vi) to evaluate the studied elements from an ecological perspective in terms of support and distribution. Nine representative sites of the basin were selected, located between 3397 and 4315 m a.s.l. Two field campaigns were performed: one in spring-summer 2006-2007 and the other in autumn-winter 2007. The results indicate that: i) the extreme environmental conditions determine that the relationships of the flora and fauna with their environment is always fragile and dependent on the “behaviour” of the ecosystem factors, ii) glacier-associated water bodies are essential, because they concentrate most of the biological diversity, and iii) a connection exists between the glacier system and the biological systems.

ABSTRACT #72(88). Oral presentation.

# Photogrammetric determination of spatio-temporal velocity fields at Glaciar San Rafael

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Glaciar San Rafael in the Northern Patagonia Icefield, with a length of 51 km and an ice area of 722 km$^2$, is the lowest latitude tidewater outlet glacier in the world and one of the fastest and most productive glaciers in southern South America in terms of ice flux. In a joint project of TU Dresden and CECS, spatio-temporal velocity fields in the region of the glacier front were determined in a campaign in austral spring of 2009. Monoscopic terrestrial image sequences were recorded with an intervallometer mode high resolution digital camera over several days. In these image sequences, a large number of glacier surface points were tracked by subpixel accuracy feature tracking techniques. Scaling and georeferencing of the trajectories obtained from image space tracking was performed via a multi-station GPS-supported photogrammetric network. The technique allows for tracking hundreds of glacier surface points at a measurement accuracy in the order of one decimeter and an almost arbitrarily high time resolution. The results show velocities of up to 13 m d$^{-1}$, which is in accordance with former measurements. A significant tidal signal could not be observed.

ABSTRACT #73(89). Poster presentation.

# Antarctic precipitation observations: challenges and new opportunities

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There is no operational precipitation gauge network over the vast Antarctic, despite the important role of snowfall in modulating ice sheet mass balance and subsequently global sea level. Precipitation data have been collected at selected monitoring sites and research stations over the Antarctic ice sheets. Cold temperatures and high winds create major problems for interpreting gauge observations of precipitation (particularly snowfall). The quality of gauge precipitation data has not been clearly defined, causing uncertainties in our understanding of precipitation patterns and their changes over time. Recently, new stations with automatic gauges or snow depth sensors have been added to the networks, and more surface meteorological data are becoming available. There is a need to compile the existing data and examine the impacts of wind and blowing snow on gauge observations. Mass balance measurements, particularly accumulation data from snow stake networks, ice cores, and snow pits, are also useful to determine snowfall over the Antarctic ice sheets. It is necessary to synthesise accumulation measurements with the limited snowfall data. Additionally, these relatively sparse ground-based snowfall and accumulation observations must be supplemented with atmospheric and blowing snow models and remote sensing products to determine the broader Antarctic snowfall distribution. We will discuss these issues and provide recommendations for integrated approaches to better determine precipitation variability and change over the Antarctic.

ABSTRACT #74(90). Oral presentation.

# Mass loss of Antarctica from GRACE

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With more than 6 years of GRACE satellite data now available, the ice mass loss trend of Antarctica and Greenland are clearly demonstrating ice mass loss in marginal zones of the ice sheets, and increasing trends in some regions. We estimate the overall mass balance of Antarctica at around -148 Gt $a^{-1}$, with largest uncertainties due to glacial isostatic adjustment (GIA) models, which contribute more than 1/3 of the measured signal. For Antarctica, mass loss is largest in the Thwaites-Pine Island Glacier regions of West Antarctica, and in the northern Antarctic Peninsula; changes in Greenland are largest in SE Greenland with mass loss trends increasing along the NW margin, in good agreement with height change results from ICESat. Although the mass changes are clearly detected by GRACE, overall mass loss estimates are still varying substantially between different processing methods and satellite data processing centres. In the paper we use a direct mass inversion method to estimate overall and regional mass balance of Antarctica in 2003-2009, and compare results for different GIA models and processing centres.

ABSTRACT #75(91). Oral presentation.

# Climate change and recent variations in small Andean glaciers

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Small glaciers in the Andes of Mendoza and San Juan provinces show the impacts of global change. In spite of their small size, their contribution to the water discharge of the rivers and streams of the region is very important during drought periods, when the annual snowfall in the central Andes is scarce. Previous studies in the central Andes of Argentina and Chile have shown that during drought periods the glacier contribution can reach up to 60 to 70 % of the total runoff. In this work we show the recent evolution of a number of small glaciers situated in the Andes between 29°S and 33°S. Field observations of seven small glaciers are included: Los Amarillos Glacier and its neighbour Amarillo Glacier, the Brown Glaciers, called Superior, Inferior and Norte, the Agua Negra Glacier and the Piloto Este Glacier. Studies at the larger Las Vacas Glacier are also included. The glaciological work conducted on each of these glaciers focussed on different aspects and spans different time intervals between 1965 and 2009. At Las Vacas Glacier (approximately 18.4 km$^2$), digital terrain models (DEM) from Aster stereoscopic images, level 1 A, are used for assessing volume changes in the period 2001-2007. The applied methodology gives results where the error propagations can hardly be assessed.

ABSTRACT #76(92). Poster presentation.

# Remote sensing of velocities and elevation changes at outlet glaciers of the Northern Patagonian Icefield, Chile

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Few velocity measurements have been made on the outlet glaciers of the ~4200 km$^2$ Northern Patagonian Ice Field (NPIF), mostly as a result of difficult access, bad weather and pervasive cloudiness over the region. The dynamic response of the outlet glaciers of the NPIF to changing climate is largely governed by the environment of the glacier front, whether it is tidewater or lacustrine calving, or land terminating. Sub-pixel offset tracking of optical and radar satellite imagery, supplemented with sparse SAR interferometry pairs, are used to derive the velocities of the outlet glaciers around the icefield through time. Differential Digital Elevation Models (DEMs) are used to examine elevation changes. Co-registered imagery is used to highlight terminus positions and retreat patterns. The terminus of Glacier San Rafael, one of the most studied glaciers on the western side of the NPIF, sustained an average speed of ~17 m d$^{-1}$ in the austral autumn of 2007, a speed similar to that observed at the front over the last two decades or so. Speeds of ~8 m d$^{-1}$ are observed 3.5 km upstream from the calving front, while new measurements of speeds of ~2.5 m d$^{-1}$ are observed about 20 km upstream, near the ELA. Similar speeds are measured for the Benito Glacier (~14 m d$^{-1}$), but slower speeds are observed for the terminus of the San Quintín glacier (~3.5 m d$^{-1}$). On the eastern side of the icefield speeds between 2 and 3 m d$^{-1}$ on the Cachet, Nef and Soler glaciers are detected upstream near their accumulation areas. 40 ASTER stereo images are used to generate individual 1 arc second relative DEMs (~30 m/pixel) to assess ice surface elevation changes. We horizontally co-register the DEMs and correct for vertical offsets automatically by examining bedrock outcrops near to the glaciers and applying a least squares adjustment so that bedrock elevation difference between images averages to zero. Once spurious elevations and clouds have been removed, the DEMs are differenced to provide a history of ice elevation change. Initial observations support the studies that show thinning of the NPIF occurs in the accumulation area as well as at the margins.

ABSTRACT #77(93). Oral presentation.

# Regional temperature reconstruction from Andean ice cores

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Assessing future climate change depends on the understanding of natural climate variability. High resolution ice core records may provide good proxies for past climate and atmospheric parameters, a kind of information especially valuable for the Southern Hemisphere, where instrumental data are sparse. Stable isotope data from high-elevation ice cores have been interpreted with respect to past temperature variability. However, calibration attempts and modelling studies for South America point to a dominant sensitivity to precipitation at least on annual and decadal timescales. We propose instead the ammonium concentration as a new proxy for tropical South American temperatures. This proxy was developed using a highly resolved and carefully dated ammonium record from an ice core that was drilled in 1999 on Nevado Illimani in the eastern Bolivian Andes. The reconstruction reveals that Medieval Warm Period and Little Ice Age type episodes are distinguishable in tropical South America, adding evidence that these climate phenomena were not confined to the Northern Hemisphere. The last decades of the past millennium are characterized by warm temperatures that seem to be unprecedented in the last ~1600 years.

ABSTRACT #78(94). Oral presentation.

# Monitoring of coastal sea ice thickness in the Arctic and the Antarctic

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Coastal sea ice (fast ice) and snow cover thickness are currently monitored at different coastal sites both in the Arctic and the Antarctic. Fast ice thickness is usually monitored by borehole measurements of the thickness of the fast ice, the depth of the snow cover, and the height of the upper ice edge versus the seawater level in a borehole (freeboard). Measurements are often carried out at several subsites for a main site. The evolution of fast ice throughout a season is directly linked to atmospheric and hydrographic conditions in a region. Therefore monitoring of fast ice thickness is important in the context of climate change related research. Sea ice in the Arctic and the Antarctic is different in several aspects. Examples from monitoring activities in both polar regions will be shown, and we will outline features that are typical for different sites and regions. Among the sites presented will be Kongsfjorden and Hopen on Svalbard in the Arctic, and sites off the Antarctic bases Davis (Australia), Mawson (Australia) and Troll (Norway) - the latter being part of the Antarctic fast ice network (AFIN) development. Beyond the measured data itself we will also present the individual monitoring setups, and we will discuss future plans and possibilities, including improved monitoring setups that include more autonomous and automatised observations within modern observation networks.

ABSTRACT #79(95). Oral presentation.

# Climate change and glaciers in the (semi-)arid zone of South America

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Glaciers in the subtropical Andes of South America are unique in terms of their sensitivity to climate change due to the arid conditions, leading to energy and mass balance characteristics that render them different from glaciers in the humid tropics or the mid- to high latitudes. Glaciers across the globe are showing signs of retreat and this decline in glacier size is commonly attributed to a rise in near surface temperature due to increasing anthropogenic greenhouse gas concentrations. Glaciers in the arid and semiarid areas of the Andes (north-central Chile), however, may be equally or even more sensitive to changes in the hydrologic regime due to their location at high altitude with their Equilibrium Line Altitude (ELA) located considerable above the 0°C isotherm freezing line. Indeed the region of north-central Chile (~28 to 32°S) has seen a decline in precipitation over the past ~130 years, with paleoclimatic evidence pointing to current drought conditions being unique in the context of several hundred years. Little is known, however, whether this decrease in precipitation, documented only at low elevation stations, extends up to the high Andes where glaciers are located. At lower elevation the drying trend has been linked to high-latitude forcing and changes in the location of westerly storm tracks due to the increasing positive polarity of the Southern Annular Mode (SAM). In conjunction with this southward displacement of the planetary west wind zone, observational evidence and modelling studies further suggest that the Hadley circulation is expanding, leading to further aridification along the cell's poleward, subsiding branch, which includes the area of north-central Chile. Here we will review the peculiarities of glacier mass and energy balance in arid environments with a special emphasis on the South American Andes and discuss their sensitivities to changes in climate and the atmospheric circulation. We will include a discussion of the current state of knowledge regarding presently observed and future projected climate change in the (semi-) arid Andes and what the consequences for future glaciation in the region might be.

ABSTRACT #80(96). Oral presentation.

# Managing glacial hazards in a changing climate

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Changes in glacial environments can have significant potential impacts on human activities and communities, sometimes with considerable physical and economic consequences. Worldwide, catastrophes associated with glaciers tend to occur relatively infrequently but can have high impact when they do. Many thousands of people have been killed and hundreds of millions of dollars worth of economic cost have been incurred as a direct consequence of sudden changes in glacial environments over the last century. Incidents include sturzstroms and rock/ice avalanches, catastrophic failure of moraine dams and subsequent glacial outburst floods, lahars, major slope instability in open-pit mines, and destruction of hydropower installations and communities and related infrastructure. As glacial systems respond to changing climate, so the potential hazards alter in style, magnitude and potential impact downstream. Simultaneously, populations are growing, there is more construction of infrastructure and more developments at higher altitudes, all effectively increasing vulnerability and, consequently, the risks associated with glacial environments. Significant advances have been made in the methods by which glacial hazards are assessed, ranging from sophisticated use of remote sensing imagery to detailed geophysical ground investigations. Having identified a particularly significant glacial hazard, it might be possible to mitigate the effects, either by engineering a solution at the source glacier or by introducing other measures, such as diversions or containment, downstream. It is essential, however, that the scientific assessment of hazards is shared with those with the responsibility for managing the consequences so that an integrated range of mitigation solutions can be found.

ABSTRACT #81(97). Poster presentation.

# Ongoing cryospheric changes and present climatic trends on the northeastern Antarctic Peninsula

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Unequivocal climatic warming is affecting drastically the cryosphere of the northeastern Antarctic Peninsula (NEAP) between 64 and 66°S. Satellite imagery and field surveys reveal a continuation of the ice-loss over all the region. The retreat rate of thirty-nine glaciers on James Ross Island has increased significantly from -1.8 $km^2$ $a^{-1}$ in 1975-1988 to -2.8 $km^2$ $a^{-1}$ in 1988-2009, yielding an ice loss of 81 $km^2$ since 1975. From 2001 to 2009 an additional 101 $km^2$ of ice shelf disintegrated in Röhss Bay and the annual mass-balance of a glacier on Vega Island has shown unabated negative values over the past decade. As the largest changes have occurred at glaciers which fed former ice shelves in Prince Gustav Channel, Larsen A and Larsen B ice shelves, particular attention is focussed to monitor their behaviour. Boydell and Sjögren glaciers lost 73 $km^2$ by retreating behind their grounding lines (GL) 9 and 11 km, respectively. GPS aero-surveys along Dinsmoor-Bombardier-Edgeworth glaciers reveal a strong retreat from 2006 to 2007, followed by a drastic advance of 1.9 km until early 2009 in a surge mode, as in 2000-2001. Major glaciers calving into Larsen B embayment have retreated by 216 $km^2$ behind their GL, and shelf-ice remnant in SCAR inlet has decreased between 2007 and 2009, an additional 180 $km^2$. During the last four decades air temperature has increased in NEAP by 0.58°C/decade, i.e. more than four times the average global warming. Despite an unusually cold year in 2007 all temperature records show increasing warming trends towards the south, with a consequent impact on tidewater calving glaciers which have lost 412 $km^2$ behind their GL, contributing thus to sea-level rise.

ABSTRACT #82(98). Oral presentation.

# Documenting 23 years of areal loss of Hielo Patagónico Sur, recent climate data and potential impact on Río Santa Cruz water discharge

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A combination of satellite images was used to measure the extent in 2009 of Hielo Patagónico Sur (HPS), the largest temperate ice body in the Southern Hemisphere. Analysis yields an area of 12,500 km$^2$ in 2009, i.e. about 500 km$^2$ less than in 1986, revealing more than double area-loss when compared to the period 1945-1986. High resolution ALOS images with the SRTM-2000 DEM allowed improving the location of ice-divides providing more accurate ice-covered areas of major outlet glaciers. Analyses of several largest glaciers show a consistent retreat with few exceptions during the period 1986-2009. Glaciar Pío XI gained 7.8 km$^2$ with both the northern and southern fronts in advanced positions, while Glaciar Jorge Montt lost 42.5 km$^2$ and retreated 10 km. Freshwater calving O'Higgins and Viedma glaciers decreased by 2.0 and 3.6 km$^2$, respectively. Glaciar Upsala retreated 6 km losing 45 km$^2$, while Glaciar Moreno remains in equilibrium. Steady-state conditions prevailed at Glaciar Moreno during the recent past five years, allowing the occurrence of three ice-damming events followed by ruptures, the last of which occurred in winter 2008. Meteorological data available since 1995 from an Automatic Weather Station (AWS) located near Glaciar Moreno and other temperature records are presented and compared with long-term climate data from the station Lago Argentino. Strong correlation during the overlapping periods shows no change in the mean annual temperature, colder winters since 1945, and strong increase in the mean summer temperature. The latter may be partly responsible for increased ice-loss and negative mass-balance of HPS due to enhanced summer melt-ablation. The HPS areal ice loss and Moreno outbursts will be analysed and discussed in relation to the Río Santa Cruz water discharge.

ABSTRACT #83(99). Poster presentation.

# Mass balance of Brewster Glacier, New Zealand revealed by geodetic methods

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To predict the effects of future climate change on the mass balance of ice masses and therefore sea level, the climatological processes controlling mass balance must be understood, and must be incorporated into numerical climate/mass balance models. Such models must be parameterised/tested against past mass balance measurements. There are several regions of the world where glacier mass balance measurements have been made which can be used for calibrating and checking predictive models. One region of the world where mass balance measurements are lacking is the Southern Alps of New Zealand where 3144 glaciers cover ~1,158 $km^2$ and contain ~53.3 $km^3$ of ice. In this paper we calculate the mass balance of one of these glaciers, Brewster Glacier, using geodetic methods. Three DEMs of the glacier surface are developed from a combination of digitised map contours (1986) and GPS survey (1997 and 2005). A bed DEM is derived from a GPR survey undertaken in 1997. The DEMS are used to calculate the glacier average surface mass balance and volume changes. The glacier average surface mass balance was +7.13 m between 1986 and 1997 (0.65 m $y^{-1}$) and -10.54 m between 1997 and 2005 (-1.32 m $y^{-1}$), giving a surface mass balance of just -2.98 m (-0.16 m $y^{-1}$) between 1986 and 2005. The glacier volume was 0.125 $km^3$ in 1986, 0.140 $km^3$ in 1997 and 0.123 $km^3$ in 2005. The volume-area relationship falls exactly on a regression line of volume-area relationships derived from 145 glaciers worldwide. The positive balance between 1986 and 1997 and the negative balance between 1997 and 2005 support measurements of ELA movement determined from air photographs of the glacier's late summer snow line made over the same time period. They also support a growing body of evidence that recent glaciological changes in New Zealand are driven by changes in atmospheric circulation patterns associated with a shift in the Interdecadal Pacific Oscillation (IPO), which occurred around 1998.

ABSTRACT #84(100). Poster presentation.

# Recent scientific expeditions to Fleming Glacier, Antarctic Peninsula

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This poster presents a synthesis of the logistics and the data collected during recent expeditions conducted by CECS to Fleming Glacier (69.5°S), Antarctic Peninsula, in November 2007, December 2008 and November 2009. The main aim of these expeditions was measuring ice dynamics in response to the removal of Wordie Ice Shelf and the relationship between the glacier and the local meteorological conditions prevailing in the area. Many scientific instruments and methodologies have been used, including the installation of an Automatic Weather Station (AWS) and a Continuous GPS Station (CGPS) at 1057 m a.s.l. In the second expedition, 250 days of AWS data and 75 days of CGPS data were collected. A new CGPS was installed to determine ice flow velocities. Also, during the 14-day campaign ice velocities were obtained with GPS at two other locations already measured in 1974. When the resulting data were compared (1974 versus 2008), a significant signal of ice acceleration was detected. The third expedition was conducted to the area in 2009, aiming to retrieve data, sensors and structures. Other logistic and technical details are described, including some of the CGPS and AWS data collected during the campaigns.

ABSTRACT #85(101). Poster presentation.

# Features of water and sediment discharges from the Glaciar Exploradores drainage basin, Chilean Patagonia

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Water and sediment discharges from a large outlet glacier were determined thanks to hydrological and meteorological observations carried out at the terminus of a drainage basin (196 $km^2$) including Glaciar Exploradores (92 $km^2$) located at the northeast corner of the Northern Patagonia Icefield, southern Chile. The results of the water balance analysis indicate that about 3200 mm of rainwater entered the drainage basin during the 2005/2006 hydrological year, while the specific volume of meltwater produced within the basin was about 3100 mm. The variations in suspended sediment concentration (SSC) during two periods (December 19, 2005 –April 1, 2006, and August 12, 2006 –December 22, 2006) showed the following features: In spring, when the water discharge was small, the amplitude of the variation in SSC was large. As the spring season progressed, the amplitude of the SSC variation became gradually smaller, remaining very small through the summer season while the water discharge was large. This feature implies the development of a shallow reservoir underneath the glacier in summertime. The annual mean water discharge and the annual sum of suspended sediment load (SSL) of this basin during the last 50 years yielded 31-45 $m^3 s^{-1}$ and 0.16-0.22 $\times 10^6$ t $a^{-1}$, respectively, as calculated by a discharge-SSL rating curve and a hydrological model, using the downscaled NCEP-NCAR reanalysis data as input.

ABSTRACT #86(103). Poster presentation.

# Variations of glacier surface albedo due to volcanic ash deposition derived from ASTER satellite data

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Satellite spectral reflectance data can be used to study the effect of volcanic ash deposition upon glacier surfaces. The albedo of a glacier is a key input to compute the energy balance, and satellite data offers a good opportunity to study these changes in detail. The ongoing eruption of Volcán Chaitén, southern Chile, since May 2008 has generated a large plume mainly distributed toward the east where active ice-capped Volcán Michinmahuida is located only 15 km away. Simultaneously to the Volcán Chaitén eruption, the glaciers of Michinmahuida began to advance, after several decades of continuous retreat. This recent advancing process was considered a non-climatic response, possibly caused by enhanced geothermal activity underneath the glaciers, and/or higher ablation at the glacier surfaces due to albedo reduction thanks to Volcán Chaitén's ash depositions. We use atmospherically corrected ASTER images in the visible and near infrared spectrum (0.52-0.6 μm) to measure albedo changes at Volcán Michinmahuida, before and after the eruption of Volcán Chaitén. The spatial variations in the surface albedo were accounted for by different snow and ice facies at different elevations. Results confirm the strong reduction in surface albedo of the glacier caused by volcanic ash deposition. By using only the remotely sensed imagery data, it is impossible to quantify the different thickness of ash deposition; therefore the enhanced ice melt due to ash deposition is still unknown. The albedo changes are analysed together with frontal variations of the glaciers.

ABSTRACT #87(104). Poster presentation.

# Ice mechanics and outlet morphology on Kamb Ice Stream, West Antarctica

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Outlet streams of the Ross Sea sector of the West Antarctic Ice Sheet (WAIS) are known to have experienced large changes in ice flux over the last 1000 years. Flux changes on individual streams can affect ice flow across the coastal region via perturbations to ice thickness. Stagnation events on ice rises can yield similar effects. Here, numerical models of ice flow are used together with a detailed elevation model of the downstream end of Kamb ice stream constructed using MODIS images and satellite laser altimetry to investigate changes in the stream's outlet region prior to its stagnation about 150 years ago. In particular, we examine the imprint of ice mechanics on short wavelength variations (~ km) in surface elevation and then consider what such features, preserved in the observed surface elevation, reveal about processes in the outlet region.

ABSTRACT #88(105). Poster presentation.

# Seasonal cycles in stable water isotopes of snow and firn in a region with high melt: a case study from the northern Antarctic Peninsula

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During the austral summer of 2008 and 2009, a study of the hydrological system of the northern Antarctic Peninsula and South Shetland Islands has been carried out. This region is characterized by relatively high temperatures (Mean annual air temperature - MAAT) of -4°C and strong oceanic input, complicating the understanding of climatic signals within precipitation and deposited snow and firn. At the Chilean station O´Higgins, precipitation samples have been collected since 2008 and meteorological observations are available since 1963. During summer expeditions, several firn cores (16 m depth) and snow pits were drilled and excavated. Snow stratigraphy, geochemical analyses (stable water isotopes $\delta^{18}O$ and $\delta D$) and dielectric profiling (DEP) reveal post-depositional processes (melting and percolation). From the co-isotope relation a first local meteoric water line has been generated for O'Higgins: $\delta D=7.8*\delta^{18}O+0.7$, likely associated with diffusion processes, whereas re-evaporation events can be neglected. An latitudinal isotope gradient is observed in a southward direction, as well as an altitude effect above 400 m a.s.l. (0.3‰/100 m). The secondary parameter deuterium excess (d) seems to better preserve the seasonal variability as compared to $\delta^{18}O$, allowing the dating and estimation of accumulation rates of the region (about 1,400 kg $m^2$ /year). The provenance of moisture was investigated using an air parcel trajectory model (Hysplit-NOAA), revealing year-round stable conditions and explaining d maxima present in all data sets. The main moisture source is located in the Pacific Ocean between 50° and 60°S. Despite snow melting at low elevation, higher areas are promising for future research and for the study of the present climate variability and linkage with South America.

ABSTRACT #89(106). Oral presentation.

# Climate change and tropical Andean glacier recession: evaluating hydrologic changes and livelihood vulnerability in the Cordillera Blanca, Peru

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Climate changes have forced dramatic glacier mass loss in the Cordillera Blanca region of Peru (8-10°S) that is transforming the hydrologic regime of the downstream Río Santa watershed and significantly increasing human vulnerability. We report on a collaborative geographic investigation (2007-2009) focussed on evaluating the complex nature of and relationships between environmental and social change in the region. First, our hydrochemical findings suggest there has been an average increase of 1.6 (± 1.1)% in the specific discharge of the glacierised catchments as a function of changes in stable isotopes of water ($\delta^{18}O$ and $\delta^{2}H$) from 2004 to 2006. Enhanced total stream discharge in more glacierised catchments (>20% glacier area) is demonstrated by a significant positive trend in a 43-year discharge anomaly record. Second, hydrological end members from our newly developed hydrochemical basin characterization method (HBCM) are strongly calibrated with historical stream discharge for monthly cumulative values. HBCM enables quantified predictions of stream end-member contributions that suggest a predominance (mean 60%) of groundwater in dry season discharge. Third, we present the findings from more than seventy-two randomly sampled households within communities located in two case-study watersheds that demonstrate local populations uniformly and overwhelmingly (90+% with very small confidence intervals) perceive that glacier recession is proceeding rapidly and climate-change related impacts are significantly increasing household vulnerability. We present our findings across multiple vectors of household vulnerability that include access to water resources, agro-pastoral production and weather variability.

ABSTRACT #90(107). Poster presentation.

# The Hydrography and Ocean Circulation of the West Antarctic Peninsula Continental Shelf

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*Presenter

Observations of current velocity, temperature, salinity and pressure from a 2-year moored array deployment and four hydrographic cruises conducted by the United States Southern Ocean GLOBEC program on the western Antarctic Peninsula continental shelf are used to characterise the ocean circulation and its connection to freshwater and heat fluxes on the shelf. Dominant features of the circulation are a seasonal coastal current driven by freshwater fluxes from the coast and a deep circulation strongly steered by bathymetric features connecting the shelf break with the near-shore regions. The heat budget on the shelf is still poorly understood, but observations and models suggest the net heat loss suffered by the ocean on the shelf could be partially compensated by intrusions of warm, oceanic water onto the shelf. Possible interactions between the ocean and the ice shelves on the Antarctic Peninsula are discussed.

ABSTRACT #91(108). Oral presentation.

# Rock glaciers as landforms and water resources in the Andes: present knowledge and research directions

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The Andes are a unique laboratory for studying the latitudinal and altitudinal distribution and significance of cryospheric features such as rock glaciers, the geomorphological expression of ice-rich creeping mountain permafrost. Rock glaciers exist in a wide variety of mountain environments from the humid Patagonia to the Atacama desert. They are best developed and most widespread – but also threatened by mining activities – in the semiarid Andes, where the presumably largest known rock glacier on earth is situated (2 $km^2$), and where active rock glaciers are observed at elevations with positive mean annual air temperatures. The ice volume stored in rock glaciers is ten times greater than the amount of glacier ice in some of the semiarid Andean watersheds of north-central Chile. Apart from punctual earlier measurements, monitoring of (natural) rock glacier dynamics started only in 2004 at Laguna Negra in the Andes of Santiago and more recently in the semiarid Elqui valley (Chile) and at Caquella (Bolivia). At Laguna Negra, two rock glaciers present average horizontal surface displacement rates of 25-35 cm $a^{-1}$. One of the rock glaciers is connected to a large debris-covered glacier, which is strikingly distinct in terms of its thermokarst surface morphology and observed vertical downwasting (-17 cm $a^{-1}$ in 2004-09). Long-term monitoring of rock glaciers is required especially in regions where these increasingly dominate over retreating glaciers, and near the lower limits of rock glacier distribution where the effects of rising air temperatures on rock glacier dynamics and water storage are expected to be most significant.

ABSTRACT #92(109). Poster presentation.

# Chemical characterisation of samples of snow and ice from the Andes, Metropolitan Region, Chile

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This paper reports the chemical characterisation of snow samples and ice cores located in areas of the Andes, 38 km northeast of Santiago, capital of Chile, to study the possible impact of air pollution in the Metropolitan Area, located 36 km away. At this first study stage the profile of major elements and trace elements in snow samples obtained in late winter 2003 in undisturbed environments near the ski resort El Colorado, Chile Metropolitan Region, was evaluated. Samples (in duplicate) were collected up to 5 cm in depth using Teflon materials and stored at -20°C. Subsequently, they were melted and treated with $HNO_3$ (5%). The analysis was performed on a Perkin Elmer ICP-MS ELAN 9000, using internal standard. The QA/QC was performed by multi-elements standards calibration and certified reference materials. Levels significantly different of certain markers of traffic and biomass burning in the samples analysed relative to values obtained in other geographical areas, with varying degrees of anthropogenic influence such as Illimani Glacier (Bolivia), Lambert Glacier (Antarctica), Asuka (Antarctica), Dolomites (Italy), Everest (Himalayas) and Atqasuk (Arctic), were found. The study will be completed in a future step with the evaluation of other chemical parameters (semi-volatile organic compounds and anions) in snow samples and it will be extended soon to the analysis of ice core samples retrieved from a glacier of Cerro El Plomo (5424 m a.s.l.), including in this case the additional determination of radioisotopes.

ABSTRACT #93(112). Oral presentation.

# Recent Climatic Change in the Tropics: the Quelccaya Ice Cap, Peru

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*Presenter

Although glaciers and ice caps in the tropics are relatively small compared to those at higher latitudes, they play an important role in regional hydrology, supplying water for cities and towns, agriculture, industry and hydroelectric power production in some regions. Tropical glaciers have been receding since their late neoglacial maxima in the Little Ice Age, but in recent years the rate of recession appears to have accelerated, with the complete loss of glacial ice in some places. These changes are related to a combination of changes in atmospheric conditions, including a steady rise in atmospheric freezing levels related to rising sea surface temperatures across the tropics, and a reduction in precipitation in some areas. We examine these issues with particular attention to the largest ice cap in the tropics -the Quelccaya Ice Cap in Peru- where comprehensive meteorological measurements have been maintained since 2004.

ABSTRACT #94(113). Poster presentation.

# Ice and climate change over the Tibetan Plateau (TP): potential socio-economic impacts

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There has been an obvious warming of the Tibetan Plateau (TP) in the last decades, with a warming rate of 0.2°C-0.3°C/decade during 1966-1999. Precipitation shows an increasing trend in the north TP while a decreasing trend is observed in the south TP. The glacier area on the TP and the adjacent area is 59,425 km$^2$ distributed in 46,377 glaciers. Around 81% of the glaciers experienced recession between the 1970's and 2000, and the vanished glacier area accounts for ~5% of the total area (ranging between 0.7%~17%) in the selected 14 sub-regions. However, advancing glaciers do exist, being mostly distributed over the west Kunlun Mountains and the southeast part of TP, where moisture supply is sufficient and is believed to be increasing or has experienced a cooling in the past decades. The area of permafrost on the TP is decreasing and its active layer is becoming thicker. Regional warming causes a decreasing of the permafrost area, and rising of its vertical limits. For instance, the lower limits of permafrost rose 25-80 metres on the TP in the past decades. Snow cover area shows an overall increasing trend between 1950-2000 and decreasing thereafter, probably because of a weakening monsoon. It is unknown how much melt water has been released from the frozen ground and snow cover. Melt water on the TP and surrounding areas can supply as much as 40% to the total fresh water discharge. Under the projected scenarios of future warming, the TP and surroundings will confront the challenges of water shortage, with predicted water stresses becoming more enhanced after 2030.

ABSTRACT #95(114). Poster presentation.

# First Ground Penetrating Radar studies of Martial Glacier, Ushuaia, Argentina

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In January 2009 the first radar soundings were performed at Martial Glacier, near Ushuaia, Argentina. Most of the glaciers in the eastern margin of Tierra del Fuego have shown significant changes in the last decades, indicating a general recessive process in the region. Like most of the glaciers in Patagonia, these ice bodies are characterised to be at the melting pressure point, where ice and water normally co-exist at the surface, within the glacier and at the glacier bed. A GSSI SIR-3000 Ground Penetrating Radar (GPR) unit combined with a 400 MHz monostatic antenna was used to collect the data. The aim of the survey was determining the ice thickness and the internal structure of the glacier. Preliminary results show that the glacier thickness ranges between 10 and 50 metres. In spite of some clear bottom reflections, in several profiles it was difficult to interpret the bed due to the steep and rough bedrock, as well as due to the presence of water bodies within the glacier.

ABSTRACT #96(115). Poster presentation.

# ASTER-derived glacier inventory of the Copiapó basin, northern Chile

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The glacier inventory of the Copiapó Basin in northern Chile is presented. This inventory is based upon satellite images (ASTER) and a Digital Elevation Model (DEM) produced by Instituto Geográfico Militar (IGM) of Chile. This basin is located at the southern limit of the South American Arid Diagonal (25-27°S), where the great majority of the perennial-ice bodies are very limited in extension. The band ratio method was applied to ASTER satellite images of different years in order to delineate glaciers. A total area for the year 2002 of 24.34 km$^2$ of glaciers and perennial snow fields larger than 0.01 km$^2$ was detected. The DEM also enabled the automatic extraction of the three-dimensional parameters for each glacier, including among others, aspect, minimum and maximum altitude. Glaciar Del Potro was confirmed as the largest glacier of this part of the Andes with an area of 5.02 km$^2$. Very few glaciers have been evaluated in terms of recent frontal or volumetric variations; however, the few studied glaciers are showing strong retreats, Glaciar Tronquitos (28°30'S, 2.7 km$^2$ in 2002) being the one with largest frontal retreat in this region with a total retreat of 916 m between 1955 and 2005.

ABSTRACT #97(116). Oral presentation.

# Acceleration in Antarctica ice mass loss from GRACE

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We use monthly measurements of time-variable gravity from the GRACE (Gravity Recovery and Climate Experiment) satellite gravity mission to determine the ice mass-loss for the Antarctic Ice Sheet during the period between April 2002 and August 2009. We find that during this time period the mass loss of the ice sheets is not a constant, but accelerates with time, i.e. the GRACE observations are better represented by a quadratic trend than by a linear one. This implies that the contribution of the Antarctic ice sheet to sea level is increasing with time. Acceleration rates in mass loss from GRACE are compared with estimations using InSAR-based mass budget approach.

ABSTRACT #98(117). Poster presentation.

# Monitoring of mountain glaciers: a synergistic task force involving students, mountaineers and scientists

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The Chilean Andes present from north to south a large number of relatively accessible glaciers of widely different conditions. These glaciers are critically important for water resources, as well as being an iconic attraction for the local communities, for summer and winter sports, and for tourism. In the present climate change scenario the environmental role of the glaciers is increasingly relevant. Glacier studies have been performed traditionally in Chile by scientists from academia, specialised consultants, by the Government, and by private companies (for e.g. mining, hydrology). In recent years glacier research in Chile has incremented greatly, but there are still large data gaps. Here we present a simple procedure for monitoring the basic mass balance characteristics of frequently visited mountain glaciers. The programme is designed to be implemented to a large extent by the community on a volunteer basis, being supervised by specialised field personnel and scientists. One ongoing example is presented for Nef Glacier (~47°S), Northern Patagonia Icefield, where a network of 5 ablation stakes has been set up during the past two summers at an elevation of 600 m, about 4 km from the glacier front. Maximum ablation can be larger than 10 cm $d^{-1}$, with a total summer loss of more than 15 m of ice. In the near future a stake network will be deployed in the high central Andes (~33°S). Replication of this programme is proposed for other pre-selected glaciers along the country on a long-term basis.

ABSTRACT #99(119). Oral presentation.

# A personal view of the Patagonian Icefields

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Much has been told about the Patagonian Icefields, for example in terms of its their exploration, the glaciological characteristics, the relationships to climate change, but much more is yet to be discovered. Being there and exploring the icefields is still a major challenge. This paper aims to give, in a more organic and human way, a glimpse of these unique icefieds, showing a piece of their history regarding the first traverse performed from the Chilean fjords (western side) to the Argentinean lakes (eastern side), which was carried out in the summer of 1955-1956 together with the legendary British explorer and mountaineer Harold W. Tilman.

ABSTRACT #100(121). Oral presentation.

# Kilimanjaro: 10 years of climate and glacier measurements

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Kilimanjaro's glaciers are among the mountain's most distinctive and best-known features, yet their notoriety is far out of proportion to their size (miniscule), importance as a water resource (negligible), or potential contribution to sea-level rise (zero). Currently there are ~8 distinct ice entities on the mountain, covering a total area of less than 2 $km^2$; all are remnants of a once larger ice cap. Glaciers on Kilimanjaro are a product of climatic conditions at the summit which no longer exist, as no area of accumulation has existed for many decades and perhaps since the current recession began in the mid- to late-19th century. An automated weather station (AWS) operating on the Northern Ice Field since February 2000 is providing a modern perspective on summit climate, revealing considerable interannual variability in the magnitude and timing of snowfall events. Accompanying mass balance measurements and modelling demonstrate that horizontal ice surfaces are very sensitive to this variability, and are becoming increasingly so as dirt concentration increases on exposed, aging ice surfaces.

Abstract #101(122) Oral presentation

# Interannual behaviour of the northwestward propagation of katabatic airflow across the Ross Ice Shelf

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Numerical model simulations of the katabatic wind regime in the Antarctic continent along with satellite images show that the airflow descends from the high plateau of East and West Antarctica, converging toward several locations in the coastal zones. Particularly in the Ross Ice Shelf (RIS) region, a large convergence zone takes place for example at the Siple Coast at the major glaciers that dissect the Transantarctic Mountains. Vertical mixing caused by the katabatic winds produces a rise in the near surface temperature while the boundary layer as a whole remains cooler than the surroundings. The air temperature was used as proxy data for examining the interannual behaviour of the katabatic winds during the winter months (April to August) for the period 1986-2008. Preliminary results indicate that, the winter average of total Katabatic Wind Events (KWE) was 12.6 ± 1.9 episodes for 1986-2008. Despite the interannual variability, an overall decrease of the katabatic events (and katabatic days) is revealed by the negative linear trend during the 1986-2008 period, while at the same time an increase in the non-katabatic wind events, or number of colder days, is shown by the analysis. In fact, a cooling of -0.11°C per year is found by the linear trend applied to the winter average for the period (statistically significant at 5% level). Analysis of the annual number of KWE along with the average ice concentration in August reveals that years with maximum (minimum) ice concentration coincide with years of lower (higher) KWE. The correlation between both is -0.52 for the whole period. Also, a correlation between the katabatic days (K_days) and the SAM/AAO index (averaged over April to August) obtained by Marshall (2003) is -0.281 for zero lag, but it increases to -0.52 (statistically significant at 1% level) for one year lag with the K_days year preceding the SAM.

ABSTRACT #102(123). Poster presentation.

# Remote sensing-derived glacier inventories and fluctuations in active volcanoes at the southernmost Southern Andean Volcanic Zone

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A large number of glaciers in southern Chile are located on active volcanoes. These glaciers respond primarily to climate, however they may also be impacted –negatively or positively- by prevailing volcanic activity. So far, two volcanoes (Villarrica, 39°S; Mocho, 40°S) in the Southern Andean Volcanic Zone (SVZ) have been widely investigated in terms of ice-volcano interactions, whilst many others have remained much less studied because of logistical constraints. We present recent results from poorly documented ice-capped volcanoes in the southernmost SVZ, where we have inventoried glaciers and determined glacier fluctuations using satellite imagery during recent decades, including Volcán Macá (45°S), an ice-capped volcano studied using Aster and Landsat scenes revealing important ice losses in recent decades, and Volcán Hudson (45°30'S), where plinian eruptions in historical times spread large volume of pyroclastic material, provoking lahars descending the Huemules valley. This volcano was studied with Aster and Landsat ETM+ images acquired since 1979, revealing a general trend of glacier retreat that was enhanced after the 1991 eruption. Most of the regional glaciers have been retreating in response to atmospheric warming and reduction in precipitations; however, the contrasting volcanic behaviors have resulted in a full range of responses, from small glacier advances, to the almost total disappearance of ice in some cases.

ABSTRACT #103(125). Oral presentation.

# Spatial and temporal accuracy of MODIS snow cover products in northern Chile

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Seasonal snow cover plays a key role in the hydrological cycle of many semi-arid regions of the world. In central and northern Chile, for example, runoff from mountainous snowpacks represents the major source of water streamflow and groundwater recharge. Consequently, understanding the spatial and temporal variability of snow cover over these large inaccessible mountainous areas is critical for managing water resources. Several snow covered area (SCA) products derived from MODIS data (e.g., MOD10A1, MOD10A2, MODSCAG) currently offer the opportunity of frequent monitoring terrestrial snow cover over large areas. Regional validation of these MODIS SCA products and understanding of their accuracy is essential if SCA wants to be used later in operational algorithms. Therefore, the objective of the present work is to assess the accuracy of the existing SCA products. In this framework, the accuracy assessment consists of comparing the MODIS SCA with high-resolution Landsat TM/ETM+ imagery and with snow cover data obtained in the field. This allows the creation of error matrices, and permits sensitivity analysis of accuracy in the determination of seasonal parameters, snow distribution, snow fraction, terrain characteristics, viewing angle, compositing and cloud cover. Results indicate that in winter, the MODIS SCA products and the snow-fraction products consistently overestimate snow cover by up to one-third compared to Landsat, whereas the opposite occurs in summer. Surprisingly, the spatial distribution of snow within the pixel does not appear to affect whether or not a partially snow-covered pixel will be classified as snow. Sensitivity analysis of the accuracy reveals moreover effects of snow fraction, viewing angle, and compositing on the accuracy of the SCA products.

ABSTRACT #104(126). Poster presentation.

# Mechanisms for moisture delivery to two ice core sites in the Ross Sea region, Antarctica

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

ABSTRACT #105(127). Poster presentation.

# Meltwater flux and runoff modeling in the ablation area of Jakobshavn Isbræ, West Greenland

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The temporal variability in surface snow and glacier melt flux and runoff were investigated for the ablation area of Jakobshavn Isbræ, West Greenland. High-resolution meteorological observations both on and outside the Greenland Ice Sheet (GrIS) were used as model input. Realistic descriptions of snow accumulation, snow and glacier-ice melt, and runoff are essential to understand trends in ice sheet surface properties and processes. SnowModel, a physically based, spatially distributed meteorological and snow-evolution modelling system was used to simulate the temporal variability of Jakobshavn Isbræ accumulation and ablation processes for 2000/01–2006/07. Winter snow-depth observations and MODIS satellite-derived summer melt observations were used for model validation of accumulation and ablation. Simulations agreed well with observed values. Simulated annual surface melt varied from as low as $3.83\times10^9$ m$^3$ (2001/02) to as high as $8.64\times10^9$ m$^3$ (2004/05). Modelled surface melt occurred at elevations reaching 1870 m a.s.l. for 2004/05, while the equilibrium line altitude (ELA) fluctuated from 990 to 1210 m a.s.l. during the simulation period. The SnowModel meltwater retention and refreezing routines considerably reduce the amount of meltwater available as ice sheet runoff; without these routines the Jakobshavn surface runoff would be overestimated by an average of 80%. From September/October through May/June no runoff events were simulated. The modelled interannual runoff variability varied from $1.81\times10^9$ m$^3$ (2001/02) to $5.21\times10^9$ m$^3$ (2004/05), yielding a cumulative runoff at the Jakobshavn glacier terminus of ~2.25 m w.eq. to ~4.5 m w.eq., respectively. The average modelled Jakobshavn runoff of ~3.4 km$^3$ a$^{-1}$ was merged with previous estimates of Jakobshavn ice discharge to quantify the freshwater flux to Illulissat Icefjord. For both runoff and ice discharge the average trends are similar, indicating increasing (insignificant) influx of freshwater to the Illulissat Icefjord for the period 2000/01–2006/07. This study suggests that surface runoff forms a minor part of the overall Jakobshavn freshwater flux to the fjord: around 7% (~3.4 km$^3$ a$^{-1}$) of the average annual freshwater flux of ~51.0 km$^3$ a$^{-1}$ originates from the surface runoff.

ABSTRACT #106(128). Poster presentation.

# Extracting small scale ice sheet topography using wavelet analysis

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The RADARSAT Antarctic Mapping Project (RAMP) data provide a detailed look at Antarctica's ice sheet morphology, rock outcrops, coastline, snow grain size and other features. Preprocessing of the RAMP data is essential before interpreting the data and includes terrain distortion removal using Digital Elevation Models (DEM). The RAMP DEM, a topographic compilation of a variety of data sources, represents the best currently available compilation of Antarctic surface topography and performs well at describing the first order topography of the ice sheets, particularly north of 81.4°S. In the interior of Antarctica, however, RAMP DEM captures the general trend of the terrain but many of the meter-scale relief features are absent. This precludes accurate correction for relief features and results in the presence of many small scale topography features in the preprocessed RAMP imagery. The aim of this work is to present a wavelet analysis-based methodology to extract these small scale ice sheet topography features from the RAMP data set. In this context, GSP surface elevation data, collected as part of tractor traverses by Chilean expeditions, were compared to RAMP backscatter data along the same transects. A Morlet wavelet transform was applied to both data sets and cross-wavelets were calculated to analyse the correlation between RAMP backscatter and GPS anomalies from general trend surface elevation. Results of the cross-wavelets confirm the usefulness of space-frequency representation of the wavelet transform to extract spatially variable topographic features on different scales (especially at 300-2000 m scale high amplitude and narrow wavelength) from the RAMP backscatter.

ABSTRACT #107(131). Poster presentation.

# Mass balance of Nef glacier (Patagonia) by means of laser altimetry

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Glaciers of the Southern Patagonia Icefield (SPI) and Northern Patagonia Icefield (NPI) have shown an enhanced wasting and an increased melting in recent decades, mainly in reaction to regional warming. In consequence, water resources originating from those glaciers are also affected by their negative mass balance. Mass balance measurements provide information about the mass changes of both the accumulation and the ablation zones. A main limitation in attempting estimations of glacier mass balance of the NPI and the SPI is the difficulty in performing field observations, particularly within the accumulation areas, largely because of unfavourable meteorological conditions as well as the limitations due to the large size of the icefields. There is thus a need for carrying out detailed analyses of individual representative glaciers in Patagonia, covering both the ablation and accumulation areas. The Nef Glacier (138 km$^2$ in February 2005), is one of the largest and most representative glaciers of the eastern side of the NPI. During the last century it has been retreating and losing mass, and its evolution has been similar to other large glaciers of the NPI. Moreover, the Nef River is one of the most important tributaries of the Baker River, the largest drainage basin in the region and the river with the highest discharge in Chile. In this paper we present results of seasonal and annual mass balance (2008-2009) of Nef glacier estimated using the geodetic method, where Digital Elevation Models (DEMs) of the glacier constructed at different dates are compared. The DEMs have been constructed using data from airborne laser altimetry with CECS Airborne Mapping System (CAMS), which has the advantage over airborne photogrammetry that it involves less data processing and practically no ground control, yielding excellent sub-meter precision.

ABSTRACT #108(132). Oral presentation.

# Lake and river ice responses to changing climate

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Freshwater ice, on both lakes and rivers, is an integral part of the hydrologic regimes of cold environments. Moreover, it acts as a primary control of the ecology of related aquatic systems, affecting a suite of physical, geochemical and biological processes. It is also important economically, through facilitation of relevant winter transport to remote locations and via generation of extreme hydrologic events, such as spring floods. Given projected changes in future climate, significant concern has been raised about related changes in freshwater ice. This presentation reviews the status and trends in records of lake and river ice around the circumpolar North from traditional observations, remote sensing, and paleo-sources. The temporal and spatial variability in trends are evaluated along with some of the approaches used to link them with climatic conditions. Of particular note are some of the rapid changes experienced in the timing of freeze-up and break-up for high-latitude lakes as compared to those at more southerly locations. Also considered are the nature and implications of changes in future freshwater-ice regimes that will have cascading effects on cold-regions hydrology, and a suite of hydro-ecological conditions such as UV-radiation receipts, thermal conditions, lake stratification, habitat quality and availability, fisheries productivity, and contaminant pathways. Overall, the duration and event timing of river and lake ice are proving to be useful indicators of climate change. Considering the scope and significance of ice-cover changes, a recommendation is made to place more emphasis on long-term and spatially diverse monitoring of freshwater ice both in northern and southern hemisphere cold-regions environments.

ABSTRACT #109(133). Poster presentation.

# Lake Greve (SPI): feasibility of occurrence of Ice Dammed Lake Outburst Flood (IDLOF)

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Given the current and predicted scenarios of climatic change, it is expected that the frequency, and in some cases the magnitude, of glacial risks will increase. The hydrology of a glacial system is characterised by the periodic or occasional release of large quantities of stored water, caused by the sudden drainage of a glacier-impounded lake, located in, on or under a glacier or its margins or its front, which is the product of breaching a moraine or ice dam. This type of floods occurs often in mountainous countries with important glacial bodies. These conditions are fully satisfied on the Patagonian Icefields. Lake Greve, located in the Southern Patagonia Icefield (SPI), is presented as an important case for study, where the homonymous river was dammed by the advance of the Pio XI glacier in 1962. The available historical record of fluctuations of the glacier has shown important environmental consequences from retreating and advancing periods. Based on the above, if the terminal tongue is weakened by the thinning and/or retreat of the glacier, we hypothesise a southward evacuation of the lake. In order to study the feasibility and mechanisms by which this phenomenon might be triggered, outburst flood models are tested based on different climate change scenarios. Some preliminary results and conclusions are presented.

ABSTRACT #110(134). Oral presentation.

# The NEEM deep ice coring in Greenland: do we get an ice core record of the previous interglacial, and why do we want it?

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Since the discovery of past abrupt climate changes (Dansgaard-Oeschger events) in the Dye-3 ice core (Greenland), they have been studied in detail in ice cores, marine records, corals, speleothems, etc., in both the Northern and Southern Hemispheres. Very robust time synchronization of Antarctic and Greenland ice core records through the greenhouse gas methane in the ice has revealed how temperatures in the north and the south have varied to the beat of the bi-polar see-saw. The abrupt changes indicate an unstable climate system during the last glacial, and the question is whether man-made global warming may push the climate system into another period of instability. Our present Holocene climate stands out in palaeoclimatic history as one of longest periods of climatic stability in the past 400,000 years; mainly due to the absence of abrupt changes. While the exact mechanism of abrupt changes remains unknown, it has been speculated that the absence of abrupt changes in our interglacial period is due to the lack of continental ice in North America and Northern Europe, i.e. the abrupt changes are partly due to an ice sheet feedback in the Northern Hemisphere and they are therefore only possible during glacial periods. It is one of the goals of the international North Greenland Eemian Ice Drilling (NEEM) project, to test this hypothesis by obtaining for the first time a high resolution Greenland ice core record through the entire previous interglacial period, the Eemian. The Eemian interglacial was 2-3°C warmer than today, and sea-levels were 3-5 m higher than today, thus the Eemian may serve as nature's own example of climate conditions in a future with global warming. Finally, I will discuss field work at NEEM in the field seasons 2008 and 2009.

ABSTRACT #111(135). Poster presentation.

# Do crustal deformations observed by GPS in Tierra del Fuego (Argentina) reflect glacial-isostatic adjustment?

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Tierra del Fuego, the southernmost part of South America, has repeatedly been glaciated during the Pleistocene/Late Pliocene. According to geological and geomorphological evidence, important ice lobes extended then from Cordillera Darwin far into the eastern parts of the main island. Such changing ice masses act as a surface load producing a long-lasting visco-elastic deformation of the earth's crust. In formerly glaciated regions the ongoing isostatic crustal response to the ice load changes since the Last Glacial Maximum has been detected by geodetic GPS (Global Positioning System) measurements. A regional geodetic GPS network has been established in the Argentine part of Tierra del Fuego and repeatedly observed since 1993. Based on these observations 3D site velocities have been determined for 30 sites. In this work we address the question if the observed vertical velocity components can be attributed to ice-load induced effects. In this particular region, the possible superimposition of crustal deformations due to tectonic processes associated with the active transform boundary between the South American and Scotia tectonic plates poses a special challenge for the separation of glacial-isostatic signals. However, geodetic observations of glacial-isostatic effects could potentially provide valuable constraints for the regional ice-load history.

ABSTRACT #112(136). Oral presentation.

# Monitoring and modelling glaciers and seasonal snow in New Zealand: past, present and future

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Since 1977 the glaciers of New Zealand have been surveyed using an annual aerial photographic survey timed to record the equilibrium line altitude (ELA) at the end of the summer melt season. This annual measure has been used to infer mass balance for each surveyed glacier, and for the Southern Alps of New Zealand as a whole. There are now more than 30 years of data for approximately 50 index glaciers in New Zealand. The data provide for a long and continuous time series of surrogate annual mass balance. Periods of mainly positive mass balance are observed from 1983-1987, 1991-1997 and 2003-2005, while periods of mainly negative mass balance are observed from 1998-2000 and 2006 to the present. Seasonal snow by contrast has been poorly monitored in New Zealand. Until recently there had not been any long term systematic network to record seasonal snow. However, since 2006 the National Institute for Water and Atmospheric Research (NIWA) has embarked on the establishment of a National Snow and Ice Monitoring network for New Zealand. There are now ten high elevation stations recording alpine meteorology (air temperature, relative humidity, wind speed and direction, solar radiation and precipitation) as well as snow depth, snow temperatures and snow water equivalence (SWE). Given the lack of data on seasonal snow in New Zealand a modelling approach has been adopted to examine both the historical and potential changes to future seasonal snow. This presentation will show the latest results for the 2009 glacier survey and place these results within the context of the longer record. We will also review the modelled historical seasonal snow and discuss the inter-annual variability. Finally, using a range of emissions scenarios we present an analysis of the potential impacts of climate change on seasonal snow in New Zealand. We illustrate these findings using results from our national scale snow model and through detailed analysis for a case study from a ski field to highlight the range and scale of potential impacts.

ABSTRACT #113(137). Oral presentation.

# Climatology of Larsen C Ice Shelf, Antarctic Peninsula

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The ice shelves, in particular in the Antarctic Peninsula, follow a cyclic process of rapid disintegration followed by gradual expansion. The collapse of Larsen B ice shelf is unprecedented during the Holocene. Most recent literature indicates that the recent ice-shelf collapse events are a direct result of atmospheric or oceanic warming. The limit for ice-shelf viability coincides with the -1.5˚C January isotherm and the -5˚C mean annual isotherm and they have both migrated south during the last 50 years. There has been a strengthening of the circumpolar westerly flow around Antarctica by approximately 15-20% in the mean annual velocity at lower levels, consistent with the trend towards the positive polarity of the Southern Hemisphere Annular Mode (SAM), beginning in the mid-1960s. There was also a decrease in surface level pressure (SLP) within the circumpolar trough, corresponding to an increase in strength of westerly winds. This local block-flow structure interacts with the increased and more frequent circumpolar westerly flow around Antarctica and contributes to the enhanced near-surface warming over the western Peninsula. Air temperature climatology from NCEP reanalysis for Larsen C ice shelf shows a mean 0.5°C warming for November 2000-2008 compared to the 30 year mean (1970-1999). This temperature increase reaches Larsen C ice shelf just before surface melt occurs in early summer. The largest temperature increase was observed in June (austral winter) with 2.5° to 3°C for 2000-2008 compared to the climatological mean value (1970-99). New results from three automatic weather stations on Larsen C ice shelf (November 2008 through January 2010) compared with other stations in the Peninsula will be presented, as well as in-situ GPS ice velocities, and seismic measurements from a pilot experiment in November-January 2008/2009.

ABSTRACT #114(138). Oral presentation.

# Late Holocene glacial fluctuations at Mount San Lorenzo, Aysén, Chile

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We collected wood samples of the oldest trees growing on moraines at Mount San Lorenzo area (47°30'S, 72°30'W), in the Calluqueo, Rio Tranquilo and Arroyo San Lorenzo valleys. We also examined the stratigraphic evidences associated with these moraines, identifying layers of volcanic ash (tephras), buried soils, and lacustrine phases. A detailed analysis of the glacial geomorphology of the valleys permitted us to compare similarities and differences of their Holocenic histories. Preliminary radiocarbon dating of organic samples associated with moraine deposits in Rio Tranquilo valley gave us the following results: sample RTQO-09/01-13 basal organic layer, upper part, 6,610±60 $^{14}$C years BP; sample RTQO-09/01-12 basal organic layer, lower part, 6,530±50 $^{14}$C years BP; sample RTQO-09/02-003 basal organic layer, 4,350±40 $^{14}$C years BP. These results confirm the Neoglacial character of the studied glacial processes. Additionally, we selected a small lake distally located to the more external moraine at the Rio Tranquilo valley (Lago Corazón, 47°27'13"S, 72°23'23"W). Preliminary bathymetric analysis gave a maximum water depth of 15 m. The study of the lake sediments will provide a chronological reference for the glacial fluctuations of the Mount San Lorenzo glaciers.

ABSTRACT #115(139). Poster presentation.

# Snowmelt detection with satellite passive microwave data: Patagonian ice fields and the Antarctic Peninsula

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A critically important aspect for climate change studies is the characterisation of the snow and ice melt over glaciers and ice sheets, and its secular changes. Snow and ice melt are not easily detectable in the visible spectrum but are well characterised with passive microwave satellite data due to the increase in emissivity resulting from the presence of water. In addition, microwaves have the ability to penetrate most clouds, which is advantageous in regions with frequent cloud cover, such as Patagonia and over the Antarctic Peninsula. This work aims at detecting trends in snow and ice melt patterns on the Patagonian icefields and in the Antarctic Peninsula. Brightness temperatures were analysed using the Scanning Multichannel Microwave Radiometer (SMMR) between 1979 and 1986, and the Special Sensor Microwave Imager (SSM/I) between 1986 and 2008 with 25 and 50 km resolution respectively. Cross-polarised gradient ratios (XPGR) were calculated based on 19 GHz (horizontal polarisation) and 37 GHz (vertical polarisation). The brightness temperature data for both the Patagonian icefields and the Antarctic Peninsula have distinct seasonal trends, frequently showing XPGR values above the typical melt onset, particularly during the summer. Shallow (<6 m) snow and firn cores were collected from the Larsen C ice shelf, Antarctic Peninsula, in November 2009, performing density and conductivity measurements. Emissivity values are calculated from the in situ measurements to calibrate passive microwave data.

ABSTRACT #116(140). Oral presentation.

# Climate variability in the Antarctic Peninsula

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Data series between 1970 and 2008 obtained at the Antarctic stations Eduardo Frei, Arturo Prat and Bernardo O'Higgins of extreme temperature, precipitation, atmospheric pressure and other events (i.e. fog) are presented. A lineal tendency analysis applied to the extreme temperatures showed that the largest warming was observed for the minimum temperatures with an increment of 0.1 and 0.5°C per decade. A decrease in the frequency of cold nights was also observed. During the same period of time, the maximum temperatures showed a negative trend (cooling) mainly associated with the decrease of extreme warm events during spring and summer. The analysis of the minimum temperatures resulted in a decrease in the number of extreme cold days. Decadal changes in the distribution of minimum and maximum temperatures are also significant. The precipitation between 1971 and 2008 showed a positive trend. The frequency of precipitation days presented a high correlation (0.90) with daily accumulated precipitation, exhibiting similar interannual variability and tendency. Changes in the type of precipitation were also observed, mainly in the summer season. Atmospheric mechanisms like the Antarctic Oscillation and the extra-tropical tropospheric circulation were studied in order to explain the observed changes in temperature and precipitation in the Antarctic Peninsula.

ABSTRACT #117(142). Poster presentation.

# A community of snow algae on a glacier in southern Chile

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Snow algae are cold-tolerant algae that grow on ice and snow during the melt season (in late spring-summer), which have been reported on glaciers in many parts of the world. As they become buried by snow in the accumulation areas, these algae are preserved in glacial strata every year, potentially providing new information about the past climate and environment which is of interest for ice-core analysis. In spite of the importance of the study of snow algae for glacier biology, few ecological studies have been carried out so far. A study of a community of snow algae on the glacier of Mocho-Choshuenco Volcano (39°55'S, 72°02'W) is presented here. Quantitative sampling of snow and ice was carried out during January 2006 at five locations (2000, 2100, 2200, 2300 and 2400 m a.s.l.) and in March 2007 at six locations (1900, 2000, 2100, 2200, 2300 and 2400 m a.s.l.). In addition, during 2006 the following surface snow samples were collected during the winter-spring period to establish temporal changes in the presence of algae: July (2000 m a.s.l.), September (2000 m a.s.l.), October (2000 and 2400 m a.s.l.) and December (2000 and 2400 m a.s.l.). The objective of this study is to determine quantitatively and qualitatively, by means of biological analyses, the altitudinal and temporal changes of algal biomass and community structure, in addition to their relation with abiotic factors on the glacier. Consequently, we discuss the ecological implications and the potential use of snow algae as bioindicators.

ABSTRACT #118(143). Oral presentation.

# World Climate Research Programme and its Climate and Cryosphere Project

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The objectives of the World Climate Research Programme (WCRP) are to study the predictability of climate and the impact of human activities on climate. In 2005-2015, guided by its Strategic Framework "Coordinated Observation and Prediction of the Earth System", WCRP will continue fundamental research on "physical climate" and expanding the scope of observations, process studies and modelling, in partnership with other programs, to the entire Earth system. Numerous scientific achievements of WCRP will be converted into practical applications of direct benefit for society. The Climate and Cryosphere (CliC) is one of the four core projects of WCRP. Its principal goal is to assess and quantify the impacts of climatic variability and change on components of the cryosphere and their consequences for the climate system and determine the stability of the global cryosphere. CliC is the only project in the Earth System Science Partnership that focusses on the global cryosphere and polar regions. WCRP calls on CliC to address the following major scientific challenges:

- explain and improve predictions of the rapidly changing Arctic sea ice
- assess uncertainties in climate projections associated with the possibility of increased release of carbon from thawing permafrost in a warming climate
- organise international research on all aspects of sea-level variability and change and substantiate sea-level assessments and predictions
- contribute cryospheric knowledge to seasonal, decadal and centennial climate predictions
- initiate prediction of the cryosphere at a variety of scales to enable projections of the future state of cryospheric sources of fresh water.

Contributions of scientists from all continents of the world, including South America, are key for the success of these research initiatives.

ABSTRACT #119(144). Oral presentation

# Using glacier surface characteristics and fjord sediments to examine controls on glacial erosion rates from Patagonia to the Antarctic Peninsula

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Glacial erosion is a principal component in contemporary research on landscape evolution at both high latitudes and high altitudes, which highlights increasingly the diverse linkages between mountain building, surface processes and climate. Understanding the relationship between climate and glacial erosion is also vital for deciphering past climate change from the rich glacial sedimentary record, which can help us anticipate future changes. In collaboration with J. Anderson, R. Fernández, M. Koppes, and J. Wellner, we are currently studying sediment accumulation rates in a number of fjords over a large latitudinal transect extending from the northern Patagonian icefields to the Antarctic Peninsula. Fjords are efficient sediment traps that can be conveniently studied to yield estimates of basin-wide erosion rates and to relate them to the overall characteristic of the glaciers producing the sediment. Herein, we use high-resolution satellite-derived measurements of surface velocity (courtesy of E. Rignot) and topography (DEM) to constrain the ice thickness and infer the spatial distribution of basal sliding speed, which controls rates of glacial erosion. We focus on San Rafael glacier that drains from the Northern Patagonian icefield, and explore the dependence of erosion rate on sliding speed, which is not well understood for any glacier. We examine the spatially varying erosion rates that correspond to specific inferred relations between rates of sliding and erosion. We seek relations yielding erosion rates that satisfy a global constraint; once integrated over the basin, the contemporary basin-wide erosion rates must be consistent with our measurements of sediment yields.

ABSTRACT #120(145). Poster presentation

# Microorganisms living on glaciers and their use for obtaining climatological and glaciological information

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Cold environments including temperate glaciers are habitats of microorganisms such as bacteria, cyanobacteria, microalgae, yeast, fungi and insects. More recently testate amoebae have also been reported. These microorganisms represent the most abundant cold-adapted life form in the biosphere, including psycrophilic and psychrotrophic organisms. They are often exposed to osmotic stress due to freezing and thawing processes, high UV (UV-B and UV-A) radiation which can cause lethal DNA damage, PAR (Photosynthetically Active Radiation), oligotrophic conditions, and in some cases low pH levels (3-6). These extremophiles have adaptive and acclimative strategies which allow them to survive and reproduce in these harsh environments, but the detailed mechanisms have so far been poorly studied. Ancient DNA has also been amplified from ice cores of polar regions, revealing a rich but reduced diversity of microorganisms as compared to temperate glaciers. The presence of active microbial assemblages has been documented in deep glacier ice, subglacial waters, basal ice, subglacial sediments and subglacial accreted ice. This has resulted in a new paradigm in the study of life and evolution on Earth. Besides, geochemical anomalies attributed to microbial activity in Greenlandic ice can make possible the interpretation of paleoclimate records obtained by chemical and isotopic species from ice cores. We present here recent results of biological components of firn/ice cores from southern Chile and Patagonia (Osorno and Mocho-Choshuenco Volcanoes, Pío XI Glacier and Mount San Valentín), which show relevant information as useful bioindicators of the southern Andes for dating and estimating glacier mass balance.

ABSTRACT #121(146). Oral presentation.

# An updated glacier inventory for South America and ice volume estimation by means of scaling algorithms

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Precise information of glacier areas and volumes are needed for estimations of sea level rise from glacier melt, and also for assessment of water resources in mountain basins. Glaciers in South America contain the largest ice mass of the Southern Hemisphere outside of Antarctica, and are known to be losing mass at an accelerated rate. Until recently only approximate assessments of glacier inventories have been compiled for South America, which show a total area of about 25,000 km$^2$, representing about 3% of the global area of mountain glaciers and ice caps (785,000 km$^2$). Recent studies of glacier inventories have been performed in practically all Andean countries of South America as a result of an increased governmental and public awareness of the relevance of glaciers for water resources and for the environment. Here the latest glacier inventories for each South American country are reviewed, calculating a total glacier area for the continent. The review also includes available ice thickness information. Local algorithms of volume-area scaling are derived for the Andes, which are compared with algorithms derived by different authors for other parts of the world. The total glacier volume is calculated for South America based on these algorithms.

ABSTRACT #122(147). Oral presentation.

# A nationwide strategic plan for improving current knowledge of Chilean glaciers and modelling glacier impacts of climate change

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Chile has more than 21,000 km$^2$ of ice distributed among thousands of individual glaciers located in a variety of environments from the summits of the Atacama desert of northern Chile to the Patagonian icefields in the south. In recent decades, the great majority of these glaciers have experienced volumetric reductions in response to ongoing climate changes. This deglaciation process is of increasing concern to national authorities, due to the likely multiple impacts of glacier recession on the environment, the water availability, and society at large. The Chilean water cadastre authority (DGA) funded a project at CECS, aiming to prepare a route map for the Chilean government for improving present understanding of glacier behaviour, including a diagnosis of recent changes, an evaluation of the current capability for scientific and technological glacier research in Chile, and proposing a systematic monitoring/observation system for future data collection, enabling modelling and forecasting of glacier responses to future climatic scenarios. This route map will provide data to decision makers for preparing adaptation/mitigation policies, urgently needed to confront the foreseen impacts of climate change. As part of this strategic plan, a hierarchical, multilevel and combined approach was proposed, aiming to study all glaciers of the country, with different tiers of details and methods. A prototype of this approach has been implemented at Universidad Glacier in central Chile, where multiple sensors were installed in 2009. The main characteristics of this project are presented, including a description of the strategic plan, the main findings of the diagnosis and some preliminary results from the new monitoring program.

ABSTRACT #123(148). Poster presentation.

# Mass balance of Mocho-Choshuenco Glacier: a new monitoring site in southern Chile

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In May of 2003 a mass balance monitoring programme was started by CECS on the south-eastern glacier of Mocho-Choshuenco volcano, southern Chile. The objective was to establish a systematic monitoring of a new glacier site without significant volcanic activity, and use it as a pilot glacier site for glaciological research. The summit area of the Mocho-Choshuenco volcanic complex (39°56'S, 72°02'W) has a glacier cover of 16.9 km$^2$. As is occurring generally in the Andes, this glacier is presently retreating at a rate of 0.4 km$^2$ a$^{-1}$ (1976-2003), in response to climate warming and also to precipitation decrease. The southeastern glacier basin of 5.1 km$^2$ (Glacier Mocho) was chosen for the mass balance measurements. Data are collected on a monthly or bi-monthly basis using 15 stakes, distributed between the front of the northern tongue at an elevation of 1723 m a.s.l. and the summit cone (2416 m a.s.l.). Mass balance results for 2003/2004 and 2004/2005 are -0.88 ± 0.18 m and +0.37 ± 0.07 m water equivalent (w.eq.). The net mass balance is to a large extent controlled by the variability in winter precipitation, which results in a winter snow cover from 5 m to 15 m over the glacier. Here we update the mass balance series of Glacier Mocho for the period 2003-2009. Glacier velocities obtained by GPS will also be presented, as well as shallow stratigraphy obtained with a 400 MHz ground penetrating radar and ice thicknesses derived with a 2 MHz radar.

ABSTRACT #124(149). Poster presentation.

# The diminution of glaciers in key regions of water stress in Chile and Canada – historical change and the evolution of debris-covered ice reservoirs

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As glacier extents in the eastern slopes of the Canadian Rocky Mountains and the Norte Chico region of Chile diminish, the influence of groundwater and other baseflow inputs to headwater river systems will increasingly define the nature of the available water resource. For several regions of the Canadian Cordillera, studies point to an already decreasing flow phase in late summer manifested by the long-term reduction of glacier cover during the past century. Commensurate with decreasing exposed ice extents there may be a volumetric increase in the reservoir of debris-covered and therefore insulated ice-cored moraines adjacent to and surrounding glacier margins in some regions. After first reviewing the glacier-climate history of two well-studied glaciers, the Peyto Glacier (western Canada) and the Glaciar Tapado (northern Chile), we look to geomorphic evidence at each site which suggests that storages of buried ice have been increasing during the current period of glacier recession. We illustrate and discuss several in-situ and remote sensing approaches that may assist in characterising the significance of the melt water produced from this buried ice, and its impact on the trajectory of the regions' water resources.

ABSTRACT #125(150). Poster presentation.

# GPS measurements at the terminus of Glaciar Horcones Inferior, Aconcagua, Argentina

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The present study analyses the ice velocities of the debris-covered Horcones Inferior Glacier (GHI) located in Mendoza, Argentina. GHI is located at 32°41'S, 69°57'W, in the Provincial Park Aconcagua, at the base of the south face of Cerro Aconcagua, with an approximate length of 11 km. The glacier constitutes a very unstable glacial environment with the presence of supraglacial lakes and thermokarst morphology. In the past GHI has experienced very relevant surging episodes. During the last surge of 2003 it advanced and its terminus reached an elevation of only 3400 m. GHI is part of a group of glaciers which provide water resources to the basin of Río Mendoza. Río Mendoza represents the most relevant water source for the development of the northern oasis of the province. For this study a semi-permanent GPS network was implemented, located on the surface of the glacier terminus, only a few metres away from a thermokarst area devoid of water. The GPS data are the first of its kind for GHI. GPS data were obtained during a period of 44 days, between February and March of 2009. The resulting ice velocities and ice elevation changes are discussed.

ABSTRACT #126(151). Poster presentation.

# Recent dynamics of the glaciers in Colombia

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There are currently 6 glaciers in Colombia with a total area of 48 km$^2$. These glaciers are of special scientific interest due to their regional geographic location since their current dynamics are influenced by surface conditions of the Pacific Ocean, possibly as well by the Caribbean Sea, in addition to influences from the local environment (climate, topography), and El Niño Southern Oscillation Events (ENSO). These influences have been compared to mass balance data collected between March 2006 and the present, at two distinctive glaciers located at Volcán Nevado Santa Isabel and at Sierra Nevada El Cocuy.

ABSTRACT #127(152). Poster presentation.

# The Snow and Ice Working Group of the International Hydrological Programme of UNESCO and its contribution to the knowledge of Andean glaciers

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The Working Group of Snow and Ice (GTNH) of the Andes was born as an initiative from a group of researchers who met in Valdivia in March 2003 during the First Seminar on Mass Balance of Andean Glaciers. Thereafter, and with the support of UNESCO through its International Hydrological Programme for Latin America and the Caribbean (PHI-LAC), annual meetings have been organised by means of which the group has strengthened to the point that at present it is a main consultative body of PHI-LAC in topics related to the study of Andean glaciers. The GTNH has supported regional initiatives through the collaboration of its members, and is contributing efficiently in recruiting glaciologists in Andean countries and in the Caribbean (Mexico) in topics related to glaciers such as mass balance, geophysical prospection (radar), hydrology, energy balance, GIS, etc. To date the GTNH is composed of researchers from Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Peru and Venezuela. There is also research collaboration from other countries such as Germany, Austria, USA, France, and Switzerland, among others.

ABSTRACT #128(153). Oral presentation.

# On a pronounced isostatic anomaly in central Queen Maud Land, East Antarctica: a result of ice retreat or sediment deposition?

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*Presenter

Gravity was surveyed in a 270x270 km area between 8°E and 15°E in Queen Maud Land (QML), East Antarctica, during the 1995/96 German GEOMAUD expedition. Offshore, the data were supplemented with satellite data (SEASAT). Using topographic, helicopter borne ice thickness and bathymetric data (ETOPO5), isostatic models of the crust/mantle boundary are calculated. Two possible models are examined: floating equilibrium with local compensation (Airy-Heiskanen model), and regional compensation by flexural bending (elastic plate on viscous medium). The results are very similar in each case, yielding a strong negative residual isostatic anomaly (as the difference of measured and model gravity) between the coast and the polar plateau with a trend parallel to the coast and a width of about 150 km. A thicker crust than today's isostatic equilibrium suggests might be one explanation. It could be due to relatively recent removal of ice masses not yet equilibrated, which is in agreement with glaciological observations. Current ice retreat in this sector of QML will be reviewed to illustrate this. An ice mass up to approximately 2 km thicker than at present would be necessary to explain the anomaly. Ice thickness changes of this magnitude, however, have not been previously considered. Alternatively, the negative anomaly could be explained by a mass deficit in the upper crust, for example, by sediments about 3 km thick. Owing to the nearly continuous ice cover, however, there are no geological observations so far that support or refute this explanation. Nevertheless, there is not much variation in the magnetic field surveyed simultaneously in this area, which might indeed suggest the existence of thick sediments.

ABSTRACT # 129(154). Poster presentation.

# Radar for cold ice measurements

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A pulse compression radar depth sounder was designed at CECS for thickness measurements of cold ice. The radar operates at a central frequency of 150 MHz, a bandwidth of 20 MHz and 400 W of peak power. Yagi antennae were used for both the transmitter and receiver. First test were done in West Antarctica in 2008 and 2009, where several profiles were surveyed, including a traverse of up to 150 km between Patriot Hills and Union Glacier, where maximum ice thicknesses of 2250 m were detected. The aim of these measurements was validating the radar before its installation onboard airborne platforms.

ABSTRACT #130(155). Poster presentation.

# Land gravity surveys in the Antarctic interior: crustal contrast between East and West Antarctica

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Gravity measurements have been performed along tractor traverses from Patriot Hills (West Antarctica) to the South Pole (East Antarctica) and back to Patriot Hills in December/January 2004/2005, covering a distance of 2200 km, and from 88°S/48°E to 88°30'S/82°30'W in East Antarctica in January of 2008, covering a distance of ~400 km. Surface topography was measured with a dual frequency GPS receiver, while bed topography was sounded with a 150 MHz chirp radar. Special considerations were necessary to control the drift of the LaCoste & Romberg gravimeter G-142. The calculated complete Bouguer anomaly starts to decrease 200 to 300 km before entering the East-Antarctic craton where it stabilises at about -130 mGal. Isostatic modelling yields residual anomalies oscillating around zero in the West Antarctic section and rising to a positive anomaly of about 50 mGal over East Antarctica. This positive anomaly can be explained by additional crustal masses in East Antarctica, by lighter sediments in West Antarctica, or alternatively by isostatic unbalance in the region. The potential effects of ice thickness changes since the Last Glacial Maximum to the present will also be discussed.

ABSTRACT #131 (156). Poster presentation

# A simulation algorithm for modelling lateral returns from airborne radio echo sounding signals: application to data collected with the SIRAHT HF radar in Patagonia

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Ice thickness is one of the main parameters needed for glacier studies. However, penetrating temperate glacier ice with ground penetrating radars is a challenging task due to the large electromagnetic losses compared to cold ice. The SIRAHT instrument (Sistema de Radar Aerotransportado para Hielo Temperado) was developed jointly by Centro de Estudios Científicos (CECS) and the Chilean Navy for probing deep temperate ice from an aircraft. SIRAHT operates at a central frequency of 1 MHz and has been tested successfully in 2006-2008 over the glaciers of the Patagonian Icefields with a CASA 212 aircraft measuring ice to a depth of 670 m at Tyndall Glacier. The SIRAHT system has the caveat that it is not focussed in the nadir direction and targets from both the rock and glacier surface below the aircraft are normally received with comparable intensity as the glacier bed returns. This results in a complex signal which is generally composed of a combination of surface topography returns and glacier bed returns. An algorithm is presented for generating simulated radargrams based on a digital elevation model (DEM) of the surface and the aircraft track. We describe the algorithm and compare the simulation results with SIRAHT radar data from Patagonia. The algorithm proves to be a useful tool for discriminating bedrock signals from surface topography returns.

ABSTRACT # 132(157). Poster presentation.

# Satellite-based monitoring of snow cover in the Southern Hemisphere at NOAA/NESDIS

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For over three decades satellites have been actively used for mapping and monitoring seasonal and perennial snow cover over the globe. High spatial resolution and frequent repeat cycle makes satellite observations of snow an important addition to conventional snow depth measurements at ground-based meteorological stations. The role of remote sensing data is especially important in remote areas where surface observations are rare or not conducted at all. At NOAA NESDIS information on the snow extent and the snow cover distribution in the Southern Hemisphere is derived from data of several geostationary and polar-orbiting satellites. Automated algorithms have been developed to identify and map snow cover using satellite observations in the visible/infrared and in the microwave. Maps are generated on a daily basis at the maximum spatial resolution of 4 km. In this presentation we discuss advantages and limitation of observations from different satellite platforms and of different snow remote sensing techniques for mapping snow cover in the Southern Hemisphere. It is shown that multiple observations from geostationary satellites can help making the detection of snow cover changes more accurate and timely. The latter is particularly important in warm-climate areas with occasional winter-time snowfalls and very short duration of seasonal snow cover (e.g., in South Africa). It is also demonstrated that due to frequent misses of melting snow and confusion of snow-free cold rocky surface with snow, application of microwave-based techniques for snow cover monitoring in the Southern Hemisphere and in particular in South America is problematic. We will present snow cover products generated at NESDIS from observations of NOAA AVHRR, GOES Imager and MSG SEVIRI. These maps will be compared with maps derived from data of MODIS and AMSR-E instruments onboard EOS platforms. Multiyear time series of derived snow maps and of estimated snow area extent over South America, South Africa, Australia and New Zealand will be analysed.

ABSTRACT #133(158). Oral presentation.

# Climate Change along the extratropical Andes: evidences and projections

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In this work we document the changes in the temperature and rainfall along the extratropical Andes (25-50°S) during the past few decades, using both surface observations and radiosonde data. Unfortunately, the observational network is relatively poor, with only a few long-term records above 2000 m a.s.l. and mostly concentrated in central Chile. In north and central Chile there is surface warming that increases with altitude, in good agreement with the trends in the free troposphere. In spite of a warming of about 0.25°C/decade at subtropical latitudes, detection of changes in river flow has been elusive, presumably due to a small contribution of glacier melting to the stream flow in relatively large basins in central Chile. Farther south the temperature signal is less clear, although warming also prevails to the east of the Andes. Detection of trends in precipitation is more difficult, in part because of the large ENSO-related year-to-year variability in the subtropics. Several records in southern Chile (37°-45°S), indicate a drying trend of about 100 mm/decade. We also discuss the projections of climate change for the next few decades on the basis of global and regional climate models. In general, there is continuity in the trends: further warming in high elevations and drying in southern Chile. The surface warming is 2-3 times larger than the free-tropospheric warming, likely because of enhanced diabatic heating over dry terrain.

ABSTRACT #134(159). Poster presentation.

# Radio echo sounding near the Chilean base station Bernardo O'Higgins, Antarctic Peninsula

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This work presents radar data collected in 2009 next to the Chilean base station Bernardo O'Higgins, near Jakenau Mountain, specifically the area called "Meseta de la Infantería". The measurements were made with a surface radar system that consists of three main components: transmitter, receiver with their respective antennas, and the data acquisition systems. The transmitter generates a radio frequency signal that is transmitted through the transmitting antenna toward the target, with the receiving antenna capturing the return signals from each target. After processing and storage in the data acquisition system the distance between the antenna and each target is computed. This system was implemented on a snowmobile and two sledges allowing movement along the glacier surface. The measured grid-points are located in a snow area normally used by Twin Otter aircrafts for landing, where crevasses were also detected using the same radar. The radar system allowed obtaining ice thicknesses of about 300 metres. The measurements were georeferenced using topographic-quality GPS receivers. These data will allow mapping surface and subglacial topography.

ABSTRACT # 135(160). Oral presentation.

# Climate change impacts on the hydrology of a snow-melt driven basin in semiarid Chile

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In this paper we present an analysis of the impacts of climate change on the hydrology of the upper watersheds of the snowmelt-driven Limarí river basin, located in north-central Chile (30°S, 70°W), which range in elevation from 1000 to 5500 m a.s.l. A climate-driven hydrology and water resources model was calibrated using meteorological and stream flow observations, and later forced by a baseline and two future climate change projection scenarios (A2, B2) that showed an increase in temperature of about 3-4°C and a reduction in precipitation of 10-30% with respect to the baseline. The results showed that annual mean stream flow decreases more than the projected rainfall decrease because a warmer climate also enhances water losses to evapotranspiration. Also in future climate projections, the seasonal maximum stream flow will tend to occur earlier than in current conditions, because of the increase in temperature during spring/summer and the lower snow accumulation in winter.

ABSTRACT #136(161). Oral presentation.

# Chilean programme for scientific research in Antarctica

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The Chilean Antarctic Scientific Research Programme, PROCIEN, brings together the projects that are funded, organised and coordinated by the Chilean Antarctic Institute, INACH. The Institute performs these tasks via open calls for proposals to be funded on its own or via other Chilean Funding Agencies, and also by delivering coordinated logistical support in Antarctica. Under the PROCIEN, 42 projects are being conducted in Antarctica in the 2009-2010 season. Eight of them are related to global warming and climate evolution, one of the four areas of research promoted by the Programme. Three of them correspond to Earth Sciences projects: "Southern Antarctic Peninsula Fleming Glacier stability. Interactions with Ice Shelves"; "Detroit Plateau deep ice coring"; and "Chemical fingerprint of Tephra from Holocene-Quaternary volcanoes". In Life Sciences there are other four projects: "Antarctic flora ecophysiological responses to global warming"; "Identification of ice cover fluctuations bio-markers"; "*Colobanthus quitensis* phenotypic plasticity under a global warming scenario"; and "Effects of climate change on the feeding habits of Ardley Island marine species populations". Finally, the last one is an Atmospheric Sciences Project: "Characterisation of northern Antarctic Peninsula fine tropospheric aerosols". A description of each one of these projects is given.

ABSTRACT #137(162). Oral presentation.

# Late Pleistocene-Holocene glacier fluctuations in the Las Leñas and Salado valleys (35°S), Argentina

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The late Pleistocene and Holocene record in the central Argentinean Andes is mostly unknown, so this research is an important step towards obtaining paleoclimatic information of climate changes in South America. In the Central Andes of Argentina between 33° and 35°S, paleoclimatic records with reliable chronologies are scarce. Some radiocarbon-dated glacial deposits (minimum ages), morphological and stratigraphical studies, permit the reconstruction of glacier fluctuations during the middle Holocene and late Pleistocene in the Las Leñas and Salado valleys located at 35°S. A well defined lateral-terminal moraine indicates glacial activity that probably occurred during the Last Glacial Maximum. This moraine defines an independent glacier that flowed about 7.7 km down Las Leñas valley to 2193 m a.s.l. reaching the junction of the Rio Salado. Rhytmically laminated lacustrine sediments are exposed immediately up-valley from Las Leñas terminal moraine in the Salado valley. These sediments have been sampled in two profiles and dated by radiocarbon and OSL methods as 12.3 ka BP and 8.4 ka BP, respectively. A lateral moraine not well defined could be related with a re-advance or a standstill that occurred at ca. 14.0 or between 11.0-10.0 ka BP. The oldest recognised Holocene glacial advance deposited the outermost Eros moraine in Las Leñas valley probably at ca. 4.0-5.0 ka BP. The second glacial advance is indicated by the Neptuno moraine which reached its maxima at *ca.* 2.2 ka BP. The late-Pleistocene and Holocene moraine sequence is compared with those studied previously in the neighbouring Río Grande basin.

ABSTRACT #138(163). Oral presentation.

# Tidal motion and the rheology of till

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On Rutford Ice Stream, West Antarctica, tidal modulation causes horizontal velocity to change by up to about 20% from its mean value. One of the peculiarities of the tides on Rutford is that the strongest modulation is at the Msf tidal frequency, or 14.76 days. This is despite the fact that the Msf tidal amplitude is almost absent in the vertical oceanic tides, and much smaller than the semi-diurnal and the diurnal tidal amplitudes. Previously, a simple conceptual model has been proposed suggesting that the fortnightly tidal motion on Rutford Ice Stream arises through a strongly non-linear interaction between the main semi diurnal tidal components. Non-linear viscous till rheology is a potential source of the non-linearity in the system. This idea is tested using a visco-elastic flow model. Both the ice and the till are modelled as a non-linear visco-elastic medium. All terms of the momentum equations are kept in the momentum balance. In full agreement with the much simpler conceptual model it is found that the fortnightly tidal motion can be generated through strong non-linear interaction between two main semi-diurnal oceanic tidal components for non-linear till rheology. The implication is that the rheology of till underneath Rutford Ice Stream (as experienced by the overlying ice), must be non-linear and viscous.

ABSTRACT #139(164). Poster presentation.

# Glacial isostatic uplift near SPI – an approach to estimate seasonal effects

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Repeated geodetic GPS measurements (2003 to 2006) at and around the Southern Patagonia Icefield (SPI) confirm high vertical uplift rates (39 mm $a^{-1}$) and short-term response to glacier wastage. Precise permanent stations to monitor seasonal uplift variations have been set up recently. Meanwhile the first continuous data are collected, based on global models for atmospheric pressure loading (Petrov, 2004) and hydrological loading (Doell, 2003), and time series for the vertical component at some selected sites near SPI have been computed and analysed. The contribution to vertical deformation from the seasonal lake level variations of up to 3 m of O´Higgins Lake was estimated to be less than 4 mm, using loading theory algorithms implemented at IPG. The expected vertical effect of seasonal variations of atmospheric and hydrological loading shows amplitudes up to the order of 10-15 mm for the sites OHIG (48.485°S,72.594°W) and GREY (50.995°S,73.247°W).

ABSTRACT #140(165). Oral presentation.

# The economics of climate change: a regional perspective

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The main objective of this study is to present, in aggregate terms, some of the main economic consequences of climate change in Latin America. These results indicate that there are significant transmission channels from the climate change phenomena to the economic activities. These impacts have certain important features such as: heterogeneity, asymmetry, and non-linear characteristics of the impacts; they will increase with time and they have specific limits. In this sense, it is expected that climate change impacts on the economic activities will increase during this century and that the countries with the lower per capita incomes will suffer larger impacts and at the same time they have less adaptation capacities. Although Latin American countries have lower per capita emissions than the world average, there is a convergence pattern in the region to higher values.

ABSTRACT #141(166). Oral presentation.

# Aridity changes in the temperate-mediterranean transition of the Andes since A.D. 1346 reconstructed from tree-rings

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The Andes Cordillera acts as regional “water tower” for several countries and encompasses a wide range of ecosystems and climates. Several hydroclimatic changes have been described for portions of the Andes during recent years, including glacier retreat, negative precipitation trends, an elevation rise in the 0° isotherm, and changes in regional stream flow regimes. The Temperate-Mediterranean Transition (TMT) zone of the Andes (35.5° - 39.5°S) is particularly vulnerable to climate change because it is a biodiversity hotspot with heavy human population pressure on water resources. In this research we utilize a new tree-ring network of *Austrocedrus chilensis* to reconstruct past variations in regional moisture in the TMT of the Andes by means of the Palmer Drought Severity Index (PDSI). The reconstruction covers the past 657 years and captures interannual to decadal scales of variability in late spring-early summer PDSI. These changes are related to the north-south oscillations in moisture conditions between the Mediterranean and Temperate climates of the Andes as a consequence of the latitudinal position of the storm tracks forced by large-scale circulation modes. Kernel estimation of occurrence rates reveals an unprecedented increment of severe and extreme drought events during the last century in the context of the previous six centuries. Moisture conditions in our study region are linked to tropical and high-latitude ocean-atmospheric forcing, with PDSI positively related to Niño 3.4 sea surface temperatures during spring and strongly negatively correlated with the Antarctic Oscillation (AAO) during summer. The 20th century increase in extreme drought events in the TMT may not be related to El Niño Southern Oscillation (ENSO) events, but to the positive AAO trend during late-spring and summer resulting from a gradual poleward shift of the mid-latitude storm tracks.

ABSTRACT # 142(168). Oral presentation.

# Field tests and first results of a 30 MHz helicopter-borne pulse radar (BGR-P30) in deep temperate ice of Patagonia

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Radio echo sounding of deep temperate ice is a challenge because of its high absorption due to the melting-point temperature of ice and scattering due to the presence of water inclusions within the glacier. Here we report recent experiments performed over the glaciers of Torres del Paine, Patagonia, with the novel 30 MHz airborne radar system BGR-P30 (originally developed as University of Münster Airborne Ice Radar). The antenna system comprises two cavity-backed broadband dipole antennas. The source pulse is a wavelet with a centre frequency of about 30 MHz stimulated by a 5 kV pulse unit. The digital receiver is equipped with an onboard Field Programmable Gate Array (FPGA). Up to 10 measurements per second are made with 256-fold stacking. The positions of the antenna are recorded at a rate of 10 Hz by a dual frequency GPS receiver. The antenna altitude above ground is ideally 35 m, and is recorded and displayed with a laser altimeter. In August of 2007 20 km of radar profiles were flown over Tyndall Glacier, and in March 2008 250 km were flown over Tyndall Glacier and 140 km over Grey Glacier with the support of a Chilean Navy Eurocopter HH-65 Dauphin helicopter. Profiles cover the ablation area at Tyndall and Grey glaciers, and also the lower accumulation area at Tyndall Glacier. The data show clear bed returns over more than 80% of the profiles, with a maximum recorded depth of 850 m. In the accumulation area a strong near-surface reflector was observed at a depth of 30 m, which is interpreted to correspond to a shallow water table which is typical of temperate ice. BGR-P30 has also been tested in 8 glaciers in the Swiss Alps, allowing probing up to 400 m of ice. Thus, it has proved to be a reliable instrument for the study of deep temperate ice. Here we present the technical characteristics of BGR-P30, as well as preliminary results from Patagonia.

ABSTRACT #143(169). Poster presentation.

# Seasonal and interannual melt characteristics of the Patagonian Icefields from AMSR-E, 2002-2008

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The Patagonian Icefields straddling the Andes in Chile and Argentina are harsh and largely inaccessible and span a range of climatic and topographic environments. The Advanced Microwave Scanning Radiometer for Earth Observing Systems (AMSR-E) makes it possible to detect the timing and extent of snow melt and refreeze across both icefields on a daily timescale. AMSR-E detects the frozen or unfrozen state of the snow surface. This is the first study on the icefields with complete coverage and both day and night observations showing the spatial and temporal variability of melt. Elevation, longitude (distance from the coast), and latitude affect the extent and timing of melt-refreeze cycles as detected by brightness temperature measurements (Tb) in the 37 GHz vertically polarised (V) channel. Using established thresholds for 37 V Tb (252 K) and the difference between day and night observations ("diurnal amplitude variation"), DAV (±18 K), melt onset is defined as the first occurrence where these conditions are both met. The spring melt-refreeze ends when the minimum Tb value exceeds 252 K six out of seven consecutive days. Melt is seasonal directly east of the Andean topographic divide, while the western side of the icefield is dominated by synoptic variability. Tb histograms display distinct melt regimes on the windward and leeward side of the Andes. Pixel melt characteristics seem to be driven by moisture on the west and temperature on the east side. Over the 2002-2008 interval, the spring melt-refreeze period has shortened. Melt characterisation is in development as a component for observing and modelling icefield-wide ablation.

ABSTRACT #144(170). Poster presentation.

# Remote sensing of Tres Cruces mountain glaciers using Landsat and CBERS 2b data

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A method for extracting snow and ice features from satellite imagery is presented for Cordillera Tres Cruces, Bolivia (67°22'S-67°32'W and 16°47'S-16°09'S). The data were acquired by the High Resolution Camera (HRC) and the Charge Coupled Device (CCD) sensors onboard the CBERS-2B (Satélite Sino-Brasileiro de Recursos Terrestres) satellite. For the CCD images, a linear stretch with saturation in band 2 (0.52-0.59 μm, green) was applied to separate the glaciers from other morphological features. Other methods such as red-infrared band ratios and Normalised Difference Snow Index (NDSI) were applied to Landsat images in order to compare the results with the techniques applied to the HRC scenes.

ABSTRACT #145(171). Oral presentation.

# Physical conditions for Equilibrium Line Altitudes and their long-term variation during the last 50 years

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Equilibrium line altitude (ELA) is one of the most important quantities connecting the climate with glaciers, representing the lowest boundary of climatological glacierisation. Understanding the physical conditions prevailing on the ELA in a particular region or in the global domain is essential also for predicting the influence of climate changes on the glacier variations. ELA presently ranges from about 6000 m a.s.l. in the regions of Llullaillaco and Ojos del Salado in the Andes, down to the sea-level on the northern coasts of Ellesmere Island and around the ice shelves of Antarctica. Based on the long-term energy balance measurements at ELA covering the entire melt season on eight glaciers, it was found that almost exactly 75% of the energy for the melt comes from atmospheric long-wave radiation (70%) and sensible heat (5%) both of which are strongly determined by air temperature. The remaining 25% is provided through absorbed solar radiation which is relatively independent of temperature. Therefore, the long-term variations of ELAs can be affected both by temperature and solar radiation. The time series of ELA was analysed for 50 glaciers in the 13 glacierised regions of the world with long-term observations, of which 37 have more than 30 years continuous records. Based on these mean regional ELAs, the area-weighted global mean ELA was computed after normalising the regional means based on the standard period (1992-1997) for which all regions had good observations. The global trend of the ELA since the International Hydrological Decade (IHD, 1965-1974) shows a systematic decrease from the 1960s, which hits bottom in the late 1970s to early 1980s. Since then ELA has been globally on the ascending trend during the last two decades and has reached an altitude which has never been experienced during the observational period. The long-term trend of the ELA is possible to interpret based on air temperature and the observed solar and long-wave radiation in the global radiation network. This analysis shows the importance, of the same order of magnitude, possessed not only by greenhouse gases but also by the aerosols in the atmosphere.

ABSTRACT #146(172). Oral presentation.

# Reconciling the glacial and dendrochronological records in the Cordillera de los Andes during the past centuries: a contribution from the LOTRED-SA initiative

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The South American continent contains a diverse array of documentary and natural climate archives that can be used to better understand climate changes and atmosphere dynamics during the past centuries as discussed in the LOTRED-SA initiative of IGBP-PAGES Special Issue (Palaeo 3, 2009). Recognizing the inherent differences in the nature of glacial and tree-ring records, we provide a comparative assessment between dendrochronological reconstructions for temperature and precipitation and glacier fluctuations for the southern tropical (20°S), subtropical (30°S), northern Patagonian (40°S) and southern Patagonian Andes (50°S) during the past four centuries. Humid conditions were reconstructed in the Bolivian Altiplano and the subtropical Andes during the 17$^{th}$ and 19$^{th}$ centuries which are consistent with more extended glaciers in both regions during the LIA (AD 1650-1850). However, different rates of glacier retreat observed after the LIA suggest differences in the patterns of precipitation and temperature variability in these regions during the last centuries. Peak LIA advances in Patagonia occurred between the 17$^{th}$ and 19$^{th}$ centuries. Subsequently glaciers have shown a generalized pattern of retreat that has accelerated during the past few decades. This rapid retreat has been particularly pronounced in northern Patagonia after the mid-1970s, where tree-ring based temperature estimates have been the warmest of the past 400 years. This warming has been concurrent with a marked negative trend in regional precipitation. Comparisons using the long-term climate variations in the selected regions along the Andes suggest the existence of coupled interactions between tropical and extratropical modes of climate variability. This may help understand the relationships between the glacier histories available for each region.

ABSTRACT #147(173). Oral presentation.

# Retreat of tidewater glaciers recorded in sediments of proglacial fjords

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As they retreat, tidewater glaciers deliver sediment to newly formed fjord environments. A number of sedimentological and radiochemical tools can be used in innovative ways to examine the record of glacial retreat. The following observations have been made from studies in proglacial fjords of southern Alaska, the Antarctic Peninsula, and southern Patagonia. Because most fjords have shallow sills at their distal ends, there is nearly complete entrapment of sediment discharged. Measurements of sediment accumulation rates using vertical profiles in the seabed of the short-lived radioisotope $^{210}$Pb (half life 22.3 y) allow calculations of accumulation rates and sediment budgets for fjords on decadal time scales. These estimates of sediment mass release can be related to glacier dynamics and land-surface erosion. Shorter-term release and deposition of sediment (3-month time scale) can be calculated from seabed profiles of $^{234}$Th (half life 24 days). This latter information is valuable for understanding seasonal variability of glacial discharge. Additional information can be gained from the shapes of these radioisotope profiles, which indicate whether sediment reaches the seabed in a steady-state manner or as episodic pulses. Typically deposition and accumulation rates decrease with distance from the ice front, and the nature of sedimentation changes from episodic to steady. This information is complemented by observations of grain size and sedimentary structure (by x-radiography). Near the ice front, much coarse material is observed in a matrix of physically laminated sediment. In distal areas, sediment becomes finer and bioturbated. The distribution of these sedimentary signatures likely differs with rates of retreat by tidewater glaciers.

ABSTRACT #148(174). Poster presentation.

# The effect of snow line rise on skiing in central Chile

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Our planet is currently experiencing a strong reduction of snow and ice which is largely due to global warming. One clear effect of this cryosphere shrinkage is snow line rise, which results in hydrological impacts in alpine basins, and is also affecting winter sports in many mountain areas on Earth. In order to understand these impacts, here we analyse air temperature records (surface and radiosonde data), precipitation data from surface stations and snow data from central Chile. Radiosonde data obtained from the stations Quintero/Santo Domingo in central Chile (33°S) showed a significant rise of the 0°C isotherm of 0.22°C/decade during the last 50 years. Air temperature records of surface stations also showed warming. Liquid precipitation and snowfall in central Chile have shown a non-significant increase in the last 4 decades. Based on snowfall data and skiing statistics at 4 ski centres in central Chile (Portillo, 2880 m a.s.l.; El Colorado, 2750 m a.s.l.; Valle Nevado, 3025 m a.s.l.; and Lagunillas, 2200 m a.s.l.) we show that only the lowermost centre has been affected by snowfall reduction. Under future scenarios of atmospheric warming, the snow line should continue to rise, which is projected to affect snow availability at higher altitude locations. Such future warming scenarios should be taken into account when planning future skiing infrastructure.

ABSTRACT #149(175). Poster presentation.

# Recent variations of glacier fronts on the Southern Patagonia Icefield

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In this study we used multi-temporal satellite imagery from the Landsat GeoCover series to quantify changes in glaciers draining the Southern Patagonia Icefield (SPI). Based on an analysis of 26 major glacier outlets, average retreat rates were 48.9 m $a^{-1}$ between the 1970s and 2000s, which increased to 59.4 m $a^{-1}$ between the 1980s and 2000s. Glaciers in the northeast of SPI experienced the greatest average retreat rate of 58.6 m $a^{-1}$, while those in the southwest experienced the lowest average retreat rate of 38.1 m $a^{-1}$. These patterns appear to be primarily related to increasing air temperatures in the north and east of SPI, but decreasing precipitation in the south and west. Further investigation is required to determine if additional local factors are also contributing to the observed retreat patterns.

ABSTRACT #150(176). Poster presentation.

# Climate change: contradictions and verification in Chile

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Climate change, when associated with inappropriate land management practices, is a major issue since it can frequently result in irreversible damages. In Chile, several climatic extreme events have increased during the last few decades, many of them associated to global warming. Although the events have been reported in most of the country, they are concentrated in central-southern Chile, where they have many times resulted in natural disasters. We refer specifically to gravity flows that include transported materials such as stones, soil, mud, sediment, and water. Water has a crucial role in generating damage and modifying the landscape, by means of glacial meltdown, flash flows (floods), concentrated and aggressive rain storms, etc., which can generate flood events, river overflows, landslides, and soil mass movements, among others. These phenomena generally affect society and can be responsible for great physical and economic damage. Appropriate interpretation of the data regarding extreme climatic events is needed for designing mitigation structures and policies. Here we present studies of hydro-meteorological data performed by Universidad de Talca, such as analysis of peak flows, extreme precipitations, glacial melting, and climatic aggressiveness, within the context of present and future climate change.

ABSTRACT #152(179). Poster presentation.

# Satellite System for Earth Observation (SSOT): a new high resolution satellite for Chile

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Among the policies of the Government of Chile is the establishment of a robust and modern programme in space science and technology, contributing effectively to the country's development. The Government of Chile has thus designed a programme to facilitate the functionality and operability of the Chilean Space Agency, in order to:

- Promote the formation and maintenance of new features and distinctive scientific and technological infrastructure in space,
- Generate results, new knowledge and technological advances, with applicability and relevance to the country's productive development, and
- Establish and strengthen local capacity building through partnerships with research centers in science and technology, business technology consortia, institutions and technological institutes and local universities.

During 2010, Chile will launch a new space vehicle, the Satellite System for Earth Observation (SSOT), manufactured by the French company EADS-Astrium and to be launched by Arianspace onboard a Soyuz spacecraft. SSOT will capture high resolution images from anywhere on the planet with a resolution better than the Latin American satellite systems that are operating to date, namely 1.45 m for panchromatic images and 5.8 m for multispectral images. The spectral resolution for colour images are 450-520 nm for blue; 530-590 nm for green; 625-695 nm for red and 760-890 nm for near-infrared. SSOT will have a polar orbit and will deliver images of 10.15 x 10.15 km, a revisit period of 5 days with ± 27° roll (side-looking capability) with stereo availability, orbiting at a height of 620 km with a speed of 7.54 km $s^{-1}$. SSOT satellite data will be especially suited for obtaining valuable information over snow and ice at a high spatial and temporal resolution.

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