

# Antarctic Peninsula Climate Variability:

Observations, Models, and Plans for IPY Research



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# Antarctic Peninsula Climate Variability: Observations, Models, and Plans for IPY Research

Hosted by the National Snow and Ice Data Center at the University of Colorado

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## Introduction

Recent events in the Antarctic Peninsula (AP) demonstrate that ice and climate systems can change rapidly in a warming world. Air temperatures in the AP have risen six times faster than the global average in recent decades, which has triggered glaciological and ecological events in the last 1,000 years that are unique in the history of the region. Studies based on remote sensing and the available in situ data show that a complex interaction is underway, one that involves climate warming, air and ocean circulation changes, sea ice retreat, and surface and basal melting of land and shelf ice. Such changes have contributed to melt percolation and fracturing, seasonal fluctuations in ice flow, and rapid glacial acceleration in the aftermath of shelf breakup. As shelves disintegrate, they uncover a glacial history preserved on the seafloor beneath them, indicating that the current retreats are rare to unprecedented in the Holocene. Biological and oceanographic studies are active along both coasts, as scientists strive to understand how ocean currents and ecosystems migrate during climate change. During a period of rapid change, the recent discovery of a new chemotrophic ecosystem native to the sub-iceshelf environment confirms that there are still unknowns in the Earth and life systems of the AP.

The goals of the Antarctic Peninsula Climate Variability (APCV) workshop are:

- Present the most recent research results and identify the current frontiers of knowledge in the AP ice and climate systems.
- Discuss evolving research plans for the IPY period, and promote the formation of collaborative interdisciplinary research groups.
- Provide a forum for graduate-student presentations.
- Discuss outreach ideas and plans for IPY-AP activities.
- Discuss national and international logistical assets and possible logistical linkages for conducting IPY-period field work.

The workshop reviews recent high-profile research results. Warming has continued in the AP area through at least 2003 (Skvarca and DeAngelis, 2003; Morris and Vaughan, 2003), and an exceptional weather pattern in 2002 led to both unprecedented summer warming and intense, prolonged surface melting, which culminated in the disintegration of the Larsen B ice shelf (van den Broeke, 2005; Rack and Rott, 2005, in press; Scambos et al., 2003). Subsequent to this disintegration, significant glacier acceleration and thinning occurred (Rignot et al., 2004; Scambos et al., 2004), confirming the link between ice shelf stability and glacier force balance. This had been previously suggested by observations of the Larsen A feeder glaciers and the valley walls of the Larsen B glaciers (Rack and Rott, 2002; DeAngelis and Skvarca, 2003). More broadly, a survey of aerial and satellite photos spanning 50+ years has shown that glaciers throughout the region north of 70° S are presently in retreat, and that this retreat progressed southward as climate warmed in the region in previous decades (Cook et al., 2005). There is substantial evidence emerging that many AP glaciers undergo seasonal accelerations due to meltwater percolation, which hastens the mass balance changes in the ice sheet as the melt season lengthens.

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Sea ice and ocean circulation changes in the region are also profound and are likely a part of the amplified warming this region has seen. Comiso (2000) and Parkinson (2002) have described a trend of 20% sea ice decline in the past few decades in the Bellingshausen Sea. Ocean circulation may be changing on the western AP continental shelf (Martinson, 2005) and there is a possibility of changes propagating *from* the AP in the form of increasing or decreasing rates of bottom water formation as new sites of dense water production are created by ice shelf and glacier changes (Gordon et al., 2001).

Causes of the warming are uncertain, but several model-based theories are emerging with robust support from observation. Thompson and Solomon (2002) show that a large fraction of the warming is likely due to stratospheric cooling, a result of autumn ozone depletion. Liu et al. (2003) and many others suggest that changes in the frequency and intensity of the Antarctic Oscillation and the Southern Oscillation explain part of the warming signal. Raphael (2003) shows that the third-order wave in the circumpolar tropospheric circulation changed significantly around 1975, and the pattern now tends to force warmer, northwesterly flow across the peninsula.

Results from marine geological work are also stunning. Earlier work on the exposed Larsen A seabed, and in the Prince Gustav Channel to the north, revealed that these areas had seen previous retreats of their ice shelf covering, coinciding with warmer global climate episodes in the recent past (such as the Medieval Warm Period, and the period between 2500 and 3500 BCE; Pudsey et al., 2001; Brachfield et al., 2003). But, the retreat of the Larsen B in 2002 is apparently unprecedented in this interglacial epoch (Domack et al., 2005).

The Antarctic Peninsula may well be a model for a future, warmer Antarctica. What we see there are changes of greater scale, speed, and magnitude than were considered possible before. This meeting will be a step towards understanding this system and its responses, knowing what the future may hold, and planning future field observations and research.

This is the third in a series of workshops focused on the topic of Antarctic Peninsula Climate Variability (APCV), following workshops at Hamilton College, New York, USA (April 2002) and University of Cambridge, Cambridge, England (September 2004).

Funding support for the “Antarctic Peninsula Climate Variability: Observations, Models, and Plans for IPY Research” workshop is provided by the National Science Foundation grant OPP-0550099, CIRES, and the National Snow and Ice Data Center.

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# Agenda

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## Sunday May 14

### NSIDC meeting rooms at 1540 30th Street, Boulder, Room 151

5:00 pm – 7:00 pm Pre-Meeting Registration, Poster Show for NSIDC Posters, and Reception

## Monday May 15

### APCV-III Meeting at Folsom Stadium Conference Center (5th floor, East Side Folsom Stadium)

**Morning** Continental breakfast at Millennium Harvest House Hotel

8:00 am Registration begins  
Poster set up

8:30 am Introductions, agenda, and workshop information – Ted Scambos

8:50 am Welcome from NSIDC Director – Roger Barry  
Welcome from CIRES Associate Director – Bill Lewis

9:10 am IPY Outlook – Mark Parsons, NSIDC

9:30 am **Keynote Speaker:** "A century of climate change in the Antarctic Peninsula" by Dr. Susan Solomon

10:10 am Break

10:25 am **1st Session:** Climate and Oceans, Past and Present, in the AP  
Invited Speakers (20-minute presentations, 5 minutes for questions)  
Contributed talks (15-minute presentations, 5 minutes for questions)

- Dr. Marilyn Raphael (Invited)
- Dr. Douglas Martinson (Invited)
- Dr. Michael Meredith (Contributed)
- Dr. Gareth Marshall (Contributed)
- Dr. Alberto Setzer (Contributed)

12:15 pm Lunch: Colorado Deli sandwich buffet

1:05 pm **2nd Session:** Climate and Oceans, Past and Present, in the AP  
Invited Speakers (20-minute presentations, 5 minutes for questions)

- Dr. Jefferson Simões
- Dr. David Vaughan
- Dr. Robert Massom

2:20 pm Break

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- 2:35 pm**    **3rd Session:** Ice Shelves/Glaciers in a Warming Climate  
Invited Speakers (20-minute presentations, 5 minutes for questions):
- Dr. Wolfgang Rack
  - Dr. Ian Joughin
  - Dr. Andrew Shepherd
- 3:50 pm**    Break
- 4:05 pm**    **4th Session:** Ice Shelves/Glaciers in a Warming Climate (continued)  
Contributed talks (15-minute presentations, 5 minutes for questions):
- Ms. Daniella Jansen
  - Dr. Christopher Shuman
  - Dr. Olga Sergienko
  - Dr. Ted Scambos
- 5:25 pm**    **Poster Session:** One minute introduction to posters
- 5:40 pm**    Browse posters (posters will be displayed for entire meeting)  
Cash bar available
- 7:30 pm**    Meeting Dinner at Millennium Harvest House

## Tuesday May 16

### APCV-III Meeting at Folsom Stadium Conference Center (5th floor, East Side Folsom Stadium)

- Morning**    Continental breakfast at Millennium Harvest House Hotel
- 8:30 am**    Registration
- 8:40 am**    **Keynote Speaker:** “Glaciological Evidence for Abrupt Climate Change: Past and Present” by Dr. Lonnie Thompson
- 9:20 am**    **5th Session:** Climate and Oceans, Past and Present, in the AP (continued)  
Contributed talks (15-minute presentations, 5 minutes for questions):
- Dr. David Schneider
  - Mr. Carlos Moffat
  - Dr. Sharon Stammerjohn
- 10:20 am**    Break
- 10:40 am**    **6th Session:** Marine Geology/Biology  
Invited Speakers (20-minute presentations, 5 minutes for questions)  
Contributed talks (15-minute presentations, 5 minutes for questions)
- Dr. Bill Fraser (Invited)
  - Dr. Amy Leventer (Invited)
  - Dr. Eugene Domack (Invited)
  - Ms. Michèle Koppes (Contributed)
  - Ms. Kristy Milliken (Contributed)

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- 12:35 pm** Lunch: Arriba! Mexican buffet
- 1:35 pm** IPY-AP Overview (format TBD)  
Science Plan, Logistics, Outreach:
- Dr. Jefferson Simões
  - Dr. Ted Scambos
  - Mr. Mark Parsons
  - Dr. David Vaughan
  - Dr. Eugene Domack
  - Mr. Mark McCaffrey
- 3:00 pm** Break
- 3:15 pm** Discussion Groups on IPY-AP plans
- 5:00 pm** Adjourn workshop

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## Abstracts

### Oral Presentations

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#### Environmental change across the Northern Antarctic Peninsula, evaluating the reach of global processes

##### Eugene Domack (Invited Speaker)

The fundamental changes taking place across the Northern Antarctic Peninsula present the scientific community with the rare opportunity to evaluate regional-scale processes as they may be impacted by, and/or impact, global scale perturbations in our environment. Only by collecting a set of interlinked and complimentary data sets from the marine, cryospheric, atmospheric, and biotic systems will we be able to move forward in understanding earth systems in this rapidly changing polar region. The collapse of the Larsen A and B shelves in recent years has not only demonstrated strong feedback relationships to oceanographic circulation and terrestrial glaciers but has also revealed an unprecedented view of the seascape beneath a long-lived ice shelf setting from the near coastal grounding lines to the distal calving fronts, which have been historically documented for over 150 years.

The new seafloor contains the first documented existence of a chemotrophic ecosystem beneath an ice shelf setting, and the first such ecosystem for the entire Antarctic plate. The new influx of seasonal phytoplankton detritus upon the seafloor represents a modern case example of permissive ecology, a concept widely used (but rarely observed) to describe environmental perturbations and evolutionary jumps following the aftermath of large scale mass extinctions and/or extreme habitat change. The role of glaciation and bedrock geology in the development of the chemotrophic habitat is as yet unclear, but this example provides us with the possibility that life in extreme environments may indeed be stimulated by glaciation, rather than simply exist in spite of it. The morphology of the seafloor also provides a vital link in understanding how and why terrestrial glaciers have surged, following the ice shelf collapse. Deep troughs (well over 1200 m) exist within and near the former grounding lines of the ice shelf and these are now converting to fjords, as valley glaciers retreat, in-step with increased flow velocity, during and after the surge. Hence, the dynamic link between ice shelf and tributary glaciers is more complex than a simple buffer effect, of the former upon the later. The time scale of change and climate induced nature of ice shelf collapse also needs to be placed into a paleoclimate perspective. While excellent marine sediment cores exist for parts of the area, we urgently need confirmation of our marine proxy data from independent time series, archives that only ice cores can provide; at present none exist for the region. These important records could be obtained from across a linear plateau (2 km in elevation) and would be ideally located to intercept changing records of meridional and zonal circulation across the northern AP. The dominance of the later (during strong southern annular modes in circulation) are thought to be tied to decreases in stratospheric ozone, and hence may not be a particularly strong feature of paleoclimate during the Holocene when anthropogenic influence upon ozone loss were not occurring. Deep ventilation of the Weddell Sea is also tied to circulation beneath the ice shelves and there are signs that this process as well as mid-depth water masses are in a state of flux.

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The unique and catastrophic decay of the regions ice shelves under regional warming demands serious investigation into all of these questions and provides, by the vacancy of ice cover, a unique opportunity to examine earth system linkages at an epic level during the IPY.

## **Western Antarctic Peninsula glacial history and its importance to understanding contemporary marine ecosystem structure and function**

### **William R. Fraser, Hugh W. Ducklow (Invited Speaker)**

As fields of study, ecology and glaciology have historically remained intellectually isolated from one another. A major barrier limiting the exchange of information between these two disciplines is due to the inherent differences that exist in the temporal scales that define discipline-specific processes of interest. As a result, both ecologists and glaciologists tend to operate with little appreciation of how decadal to millennial-scale processes interact to shape the structure and function of contemporary ecosystems. The Western Antarctic Peninsula marine ecosystem exhibits extreme heterogeneity in the distribution of a number of biological populations and properties. Research during the last 15 years in particular by the Palmer Long Term Ecological Research Program has shown that this heterogeneity can be attributed directly to the effects of past glacial events on regional bathymetry. One of the most conspicuous examples of this heterogeneity is the distribution of Adélie penguins, whose breeding populations occupy only five locations along the entire length of the WAP. These locations are associated with deep, glacially-incised canyons that reach from the land margin to the shelf break. These canyons function as conduits for Circumpolar Deep Water that upwells near the land margins, altering heat and nutrient budgets, and ultimately encouraging the growth of phytoplankton communities favorable to the krill and fish on which Adélie penguins depend. These conditions satisfy a most critical component of the life history of Adélie penguins, which as flightless predators require access to nearby, ecologically predictable sources of prey to breed successfully and survive winter. These dynamics establish an intellectual and empirical bridge between disciplines that may lead to more robust models of WAP ecosystem processes and their response to continued climate warming.

## **Basal melting of tabular icebergs: a mixed layer approach**

### **D. Jansen, M. P. Schodlok, W. Rack, H. Sandhaeger**

Drifting tabular icebergs represent large natural ice bodies under influence of rapidly changing boundary conditions. To study the change of iceberg geometry during its drift an iceberg evolution model was applied to several icebergs from the Weddell Sea region. Basal erosion dominates these changes, releasing a considerably large amount of cool melt water into the Southern Ocean. Comparison with ICESat GLAS data, however, showed that melt rates in lower latitudes are only half of melt rates predicted with a simple thermohaline ice-shelf-ocean-interaction model. Model experiments with a new melting approach, i.e. the melt rate was fitted by varying the turbulent exchange parameter for temperature ( $\gamma_T$ ) and salt ( $\gamma_S$ ), identified two melting regimes: (1) In the Weddell Sea  $\gamma_T$  is set to 0.001 m/s due to the slow drift velocity of about 5 km/day and several grounding phases. (2) In the Scotia Sea  $\gamma_T$  is set to  $5 \cdot 10^{-5}$  m/s, as the iceberg drifts unhindered with the ocean current (about 15 km/day) and is surrounded by more melt water, having a larger cooling effect.  $\gamma_S$  is set to 0.00505  $\gamma_T$  in both cases.

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In order to improve the solution with respect to the melt water plume we followed a mixed layer approach for the ice-ocean boundary. We will present first results from this mixed layer iceberg melting approach.

### **A recently funded analysis of rapidly changing Antarctic ice shelves using ERS and GLAS altimetry, RADARSAT SAR interferometry and 3-D ocean modeling**

#### **I. Joughin, L. Padman, and H. Fricker (Invited Speaker)**

We are beginning a detailed analysis of Antarctic ice shelves that have undergone recent rapid change, focusing on the role of ocean-ice interactions in thinning the Larsen B, Larsen C, and Pine Island Bay (PIB) ice shelves. Our long-term goal is to contribute towards an answer to the question: In a changing climate, what role do Antarctica's ice shelves play in controlling the mass balance of the Antarctic ice sheet, and thus Antarctica's contribution to global mean sea level? Because this project has begun, we will focus on similar results from other ice shelves.

### **Sediment yields and associated glacier dynamics from Patagonia to the Antarctic Peninsula**

#### **Michèle Koppes, Bernard Hallet, John Anderson**

We will present results from a multi-year study of ice dynamics and sediment fluxes along a transect of tidewater glaciers from Patagonia to Antarctica. Using seismic profiling and piston coring near the terminus, we measured the decadal and centennial sediment yields from three glaciers in Patagonia. These yields are compared to modeled ice fluxes from NCEP reanalysis data, to understand the relationship between ice dynamics and glacial erosion rates. We will be continuing the transect with a cruise on the Palmer to the Antarctic Peninsula during IPY to collect seismic data and cores in the fjords, and to measure ice thickness and velocities on the adjacent glaciers. We also seek collaboration in setting up longer-term climate stations around the Peninsula as part of our field effort.

### **Diatom assemblages from the ex-Larsen A and B ice shelf regions: a comparison of the modern and Holocene record**

#### **Amy Leventer, Nicky West, Maureen Lynch, Eugene Domack (Invited Speaker)**

The breakup of the Larsen A and B ice shelves, in 1995 and 2002 respectively, has provided a unique opportunity to track the role of pelagic processes in influencing biogenic sedimentation. Consequently, diatom assemblages in surface water samples and surface sediments from the ex-Larsen A and B Ice Shelf regions were analyzed to assess differences between these two regions given the longer time period that the Larsen A region has been ice shelf free. Downcore analyses were aimed at investigating the use of diatoms as paleoenvironmental indicators of changes in glacial and sea ice extent during the Holocene. Water and surface sediment samples from the ex-Larsen A Ice Shelf region were dominated by diatoms of the genus *Chaetoceros*, indicating more productive waters. In contrast, the genus *Fragilariopsis*, here comprised mainly of sea ice associated species, was most abundant in water samples and surface sediments from the ex-Larsen B region. The strong similarities between the water column diatom assemblages and those found at the sea floor, and the distinct differences between the two geographic regions demonstrates that the composition of overlying phytoplankton blooms is faithfully recorded at the sea floor.

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Limited lateral transport and rapid downward flux of diatoms is indicated further by the presence of green chloroplasts in the patchy diatomaceous fluff observed at the sea floor. The dramatic increase in diatom abundance in the upper 5 cm of each core from the ex-Larsen B region marks the initiation of primary productivity following the in the 2002 collapse of the ice shelf. A single sub-surface diatom abundance peak in a core just south of the Seal Nunataks, which separates the Larsen A and Larsen B regions, is thought to reflect material transported south during a previous breakout of the Larsen A ice shelf.

### **The role of a changing summer Southern Annular Mode (SAM) in warming the Larsen Ice Shelf region**

**Gareth J. Marshall, Andrew Orr, Nicole van Lipzig, John C. King**

Rapid regional summer warming on the east coast of the northern Peninsula has contributed significantly to the northern Larsen Ice Shelf collapse. A contemporaneous trend in the summer SAM has resulted in stronger westerlies across the northern Peninsula, reducing its blocking effect and allowing greater eastward advection of air masses over it. Subsequent formation of a warm foehn wind on the lee side and a negative climatological temperature gradient across the barrier results in a summer surface temperature sensitivity to the SAM three times greater on the eastern Peninsula than on the west.

### **12-Years of PAL-LTER: physical oceanography, spatio-temporal variability and ventilation of ocean heat along the Western Antarctic Peninsula**

**Douglas G. Martinson, S. E. Stammerjohn, R. A. Iannuzzi, R. C. Smith (Invited Speaker)**

This presentation focuses on 12 years of physical oceanography data, collected during the Palmer, Antarctica, Long-Term Ecological Research program (PAL-LTER) over the continental margin of the western Antarctic Peninsula (WAP). The physical characteristics, water column structure and spatio-temporal variability of the various properties, are examined for physically consistent and ecologically-important patterns and modes of variability. Specific findings of note include: (1) the water masses in the grid are well separated according to bathymetrically controlled features, dividing the sample domain into 3 sub-regions: slope, shelf and coastal waters; (2) the Antarctic Circumpolar Current (ACC) is always present along the shelf-break where Upper Circumpolar Deep Water (UCDW) shows its farthest southern extent and forms the Southern ACC Front (SACCF); (3) flooding of UCDW onto the continental shelf provides the heat responsible for providing approximately  $28 \text{ Wm}^{-2}$  on annual average to the WAP, which is presently undergoing the most recent rapid winter regional warming on Earth. The spatiotemporal variability of the delivery and distribution of ocean heat is dictated by the dynamics which are consistent with changes in the state of ENSO (La Niña drives enhanced upwelling in this region) and in the strength of the Southern Annular Mode (SAM). The large 1997-1998 El Niño, followed by the transition to the strong La Niña of 1998-1999 (amplified by a large +SAM) introduced a regime shift on the shelf, resulting in a jump in ocean heat flux of approximately  $3 \text{ Wm}^{-2}$  followed by a linear trend of an equal increase in heat flux each year thereafter. 2002 was an anomalous year coinciding with an extraordinary storm forcing driving a  $10\sigma$  increase in the heat content on the shelf (which is shown to be proportional to the heat flux). These jumps coincide with considerable changes in sea ice distribution as well.

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Pure UCDW is primarily restricted to the deep canyons on the shelf, with occasional appearances on the regular shelf floor near the middle of the grid (presumably an area with enhanced nutrients closer to the surface). Anomalies in summer sea surface temperatures reflect wind strength (stronger winds mixing more cold winter water to the surface, with cooler SST; light winds, the opposite).

### **Extreme sea ice conditions in the Antarctic Peninsula region, their impact and possible links with the disintegration of the Larsen B Ice Shelf**

**Robert Massom, Sharon Stammerjohn, Ted Scambos, John Turner, Ian Simmonds, et al. (Invited Speaker)**

Recent studies have revealed that complex interactions are occurring in the Antarctic Peninsula (AP). Here, we present case studies of extreme sea ice conditions resulting from large-scale and persistent anomalies in atmospheric circulation. The impacts are profound, and indeed paradoxical, with seemingly counteractive processes occurring simultaneously. Such anomalies deliver above-average snowfall, and cause both extensive ice melt and dynamic thickening – the latter by compaction against the West Antarctic Peninsula. In 2001/2, this resulted in the Bellingshausen Sea in an unusually early and rapid (short) retreat season (negative ice-extent anomaly) driven by ice dynamics. Major ice convergence, deformation and thickening in turn lead to the atypical persistence of highly-compact coastal ice through summer. Ecological effects were both positive and negative, the latter including an impact on the growth rate of larval Antarctic krill and the largest recorded between-season breeding population decrease and lowest reproductive success in a 30-year Adélie penguin demographic time series. Evidence is also presented of possible causal links between the 2002 disintegration of the Larsen B Ice Shelf and anomalous patterns of atmospheric circulation and associated sea ice distribution in the AP region.

### **Rapid climate change in the ocean adjacent to the WAP during the second half of the 20th**

**Michael P. Meredith, John C. King**

The climate of the Western Antarctic Peninsula (WAP) is the most rapidly changing in the southern hemisphere, with a rise in atmospheric temperature of nearly 3 °C since 1951 and associated cryospheric impacts. We demonstrate here, for the first time, that the adjacent ocean showed profound coincident changes, with surface summer temperatures rising more than 1 °C and a strong upper-layer salinification. Initially driven by atmospheric warming and reduced rates of sea ice production, these changes constitute positive feedbacks that will contribute significantly to the continued climate change. Marine species in this region have extreme sensitivities to their environment, with population and species removal predicted in response to very small increases in ocean temperature. The WAP region is an important breeding and nursery ground for Antarctic krill, a key species in the Southern Ocean food web with a known dependence on the physical environment. The changes observed thus have significant ecological implications.

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## Deriving a high-resolution-continuous record of climate change for the past 15,000 cal BP, Maxwell Bay sediment core, South Shetland Islands

**K. T. Milliken, J. B. Anderson, J. S. Wellner, P. Manley, S. Bohaty, B. Michalchuk**

In the Antarctic Peninsula area, a climatic gradient, created by orographic and oceanographic effects, is manifested in extreme temperature and precipitation patterns. Thus, the area provides a natural laboratory to study the nature and timing of climate change at high southern latitudes during the past several thousand years. Two benchmark long term continuous records can now be compared; Maxwell Bay, situated in a warm wet subpolar climate setting and Palmer Deep, located in a cold wet subpolar climatic regime. Both of these records span the past 14000 years, document the timing of ice pullback from the last glacial maximum, and provide the means to contrast climate fluctuations in two different area.

This paper presents the preliminary results from a 108 m sediment core (93% recovery) recovered from Maxwell Bay (South Shetland Islands). The pre-existing Palmer Deep cores sampled 50 m of structureless diatom ooze/mud, rhythmically interbedded diatom ooze and pebbly mud and muddy diatomicton (Domack et. al., 2001). The alternation of diatom ooze and diatomaceous mud is interpreted to represent climate driven oscillations of biogenic productivity. Magnetic susceptibility and other paleoenvironmental proxies track biogenic productivity and provide a means to quantify decadal, century, and millennia scales of climate change. Additionally, five global climate intervals are noted including, deglaciation, climatic reversal, Hypsithermal (Holocene Climatic Optimum), Neoglacial, and Little Ice Age.

Several radiocarbon dates are used to establish an age model and show significant variations in sedimentation rates through time. The sedimentation rate variations correspond to sediment facies changes within the core. High sedimentation rates (10 to 30 mm/yr) correspond to silty diatomaceous mud with abundant sand laminae interpreted as proximal glaciomarine facies. Lower sedimentation rates (4 mm/yr) are associated with diatomaceous mud with few sand laminae and abundant bioturbation, interpreted to represent distal glaciomarine sedimentation. Preliminary analysis of magnetic susceptibility data shows decadal, century, and millennial scale cyclicity. Additionally, the character of the magnetic susceptibility signal changes within the core. The changes correspond to climate intervals noted in the Palmer Deep cores. Whereas the Palmer Deep record is derived from a biogenic productivity signal as a proxy for climate; the Maxwell Bay system potentially records a terrestrial sediment derived signal and is more directly linked to climatically driven glacial advance and retreat.

## A first description of the Antarctic Peninsula Coastal Current (APCC)

**Carlos Moffat, Robert Beardsley, Breck Owens**

The Southern Ocean Global Ecosystem Dynamics (SO GLOBEC) program aims to understand the circulation patterns and dynamics of the shelf waters west of the Antarctic Peninsula (wAP). This region is characterized by a strong seasonal cycle of surface forcing, with a fully ice-covered shelf during the winter which melts almost completely during the spring. The mountainous land mass of the Peninsula also provides a source of fresh water during the warmer ice-free season.

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The SO GLOBEC data set, including drifter trajectories, a year long mooring record as well as density and underway velocity profiles from large scale hydrographic cruises, reveals the presence of a large (approximately 30 km wide, 150 m deep) coastal buoyant current attached to the coast of the Peninsula. The Antarctic Peninsula Coastal Current (APCC) flows south along the coast during the ice-free season and disappears during the winter, shortly after the onset of ice on the shelf. Although coastal buoyant plumes are typically associated with river discharge in mid-latitudes, fresh water from melting glaciers provides a line buoyancy source for the formation of the APCC. This work provides a first description of the APCC, a discussion of the mechanisms involved in its formation and evolution (including fresh water fluxes and down welling - favorable wind forcing) and its role in the advection of biologically relevant tracers.

### **Satellite observations of ice acceleration and numerical studies of the flow regime at Larsen Ice Shelf**

#### **W. Rack, H. Rott, D. Jansen, H. Sandhaeger, C. Riedl (Invited Speaker)**

We studied the dynamic behavior of Larsen A and B Ice Shelves and inflow glaciers from the peninsula, based on time series of radar satellite images and numerical modeling. Particular emphasis of the presentation is on temporal changes of ice flow of Larsen B and of the related glaciers. The pattern of retreat and disintegration of Larsen B, with acceleration of ice flow previous to the collapse, as well as the behavior of the glaciers after the collapse, is very similar to that of Larsen A. After acceleration and rapid frontal retreat during the first few years after the collapse, the glacier fronts retreat at slower rate, and the terminal velocities started to slow down. This suggests that the glaciers will eventually approach a new equilibrium as observed for retreating tidewater glaciers in other regions. The analysis of the satellite image time series shows also further retreat of the remnant section of Larsen B, as for example the calving of a major tabular iceberg in February 2006. This calving event and the drift of the iceberg during the first few days show major impact of ocean currents, as also observed in time series of radar images for the disintegration events of Larsen A and B.

For interpretation of the dynamic response of the ice shelf a numerical model solving the continuum-mechanical equations by means of finite differences was applied. The model also considers influences of tensional and shear fractures on the flow regime. Input data are obtained from flow fields of satellite data and field measurements. In addition, the patterns of rifting and calving events as well as the oceanographic boundary conditions seem to play a crucial role for the retreat and disintegration of the ice shelf.

### **The influence of extra-tropical, atmospheric zonal wave three on the regional variation of Antarctic sea ice**

#### **Marilyn Raphael (Invited Speaker)**

This research deals specifically with the response of Antarctic sea ice concentration to zonal wave three, the asymmetric component of the large scale atmospheric circulation associated with meridional flow in the Southern Hemisphere. A zonal wave 3 index (ZW3) is created from the NCAR-NCEP Reanalyses, 1979-2004 and used to explore the influence of the large-scale atmospheric circulation on Antarctic sea ice concentration (SIC).

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Results indicate that this index is strongly associated with the empirical orthogonal functions of SIC, which isolates the simultaneous variation in the three regions of sea ice production around Antarctica - the Weddell and Ross Seas and the Amery ice shelf. The index is also strongly associated with sea ice variability in the region ranging from the west Antarctic Peninsula to the Bellingshausen-Amundsen Seas. The relationship is most strongly expressed in the southern late fall to early winter and is discussed in terms of the surface temperature and sensible heat flux anomalies associated with ZW3. The amplitude of ZW3 increased over the decades of the 1980s and 1990s. The influence of this change in amplitude on Antarctic sea ice concentration trends is also discussed.

### Using drifting icebergs as proxies for studying climate change effects on ice shelves: the ICETrek Project

**T. Scambos, D. MacAyeal, R. Ross, R. Bauer, Y. Yermolin, J. C. Quinteros, D. Long, P. Skvarca, J. Thom**

Tabular icebergs in the vicinity of the northern Antarctic Peninsula show in most cases a rapid drift to the northeast, across the Scotia Sea to South Georgia Island. During this drift, their climatic and oceanographic environment changes significantly. In two recent cases, of seven studied, large icebergs experienced break-up events similar to those of the Larsen A, Wilkins, and Larsen B ice shelves (events of 1995, 1998, and 2002, respectively) as they endure successively warmer ocean and air conditions. The icebergs respond to these conditions in several ways, and in particular significant differences are seen among icebergs in colder water (within sea ice) versus bergs that are north of the sea ice edge. Laser altimetry from ICESat shows that the bergs thin at rates up to 50 m/yr when north of the sea ice, and less than approximately 10 m/yr south of it. Edge-wasting rates increase as well. Moreover, bending forces at the ice edge change from dominantly convex-up to concave-up, associated with the formation of an ice bench below the water line as warmer surface waters are encountered. Significant changes are seen in backscatter as the iceberg firn rapidly evolves via warming and melt percolation, culminating in the formation of ponds or water-soaked firn on the surface, and rapid disintegrating break-up. It is noted, however, that no shelf or iceberg thicker than approximately 200 m has disintegrated in this fashion, so a combination of precursor characteristics may be required.

In February and March of this year, research teams visited three icebergs in the northwest Weddell Sea, and installed automated observing systems on two of them. Small icebergs north of the ice edge in February in the vicinity of Marambio Station show extensive surface fracturing suggesting whole-berg flexure by long-wavelength ocean swell, and subsurface ice benches. Surface snow was extremely coarse 'corn snow', actively melting at the time of observation, with audible flowing water in the subsurface. Further south, a 12x13-kilometer iceberg, visited later in the season, had recent warm but fine-grained snow accumulating over coarse 'summer' firn and re-frozen melt layers. At the ice edge, a convex-up profile was confirmed, and no ice bench or cavernous edge-wasting was seen. A third, very large, iceberg (A22A, derived from the western Filchner Ice Shelf in 1986) was visited in mid-March, just north of the ice edge. Here, firn conditions suggestive of modification by rainfall and/or melt ponding were observed. Snow pit density measurements indicated a range of 0.5 to 0.6 with many ice layers.

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An 11-meter ice core revealed an intense near-surface thermal gradient, indicating surface winter-onset cooling (0 - 0.5 m), a very warm summer thermal wave (1.0 - 5.0 m) and a steep gradient to very cold temperatures (-15.1°C at 11 m). A partial ice bench and extensive cavernous erosion were observed at the edge.

The in-situ automated systems (AMIGOS: Automated Met-Ice-Geophysical Observation System) use steerable digital cameras, GPS, and simplified radio-echo-sounders to provide on-going data collection during drift and evolution of the icebergs. The systems were placed approximately 2.5 km from the iceberg edges so that edge observations could be made after anticipated edge-wasting occurs during northward drift. Flag lines were set (200 m spacing, 1 to 2.2 km) towards the berg edge to observe ice edge flexure. Additionally, accumulation and ablation stakes were set for camera observation. The systems are intended to survive until close to berg break-up, which is expected to occur in the next austral summer or shortly thereafter. Initial results show the flag line experiment is promising, GPS-derived ice motion is very closely associated with tidal forcing, and radar echo traces may require extensive post-processing because of interference by the metal structure of the AMIGOS station.

### Long-term temperature trends in Antarctica: the view from ice cores

#### David Schneider

There have been several investigations of surface temperature changes across the Antarctic, but these are limited by the instrumental records which generally extend back only to the IGY. Obvious contrasts in trends between the Peninsula region, where major warming has been observed, and the rest of the continent, where some cooling has been observed, have been noted by several studies. Here, I present results from an ice core based reconstruction of temperatures over the continent. From the comparison with the long instrumental record from Orcadas, it is evident both the Peninsula and the continent warmed over the 20th century, although the Peninsula at a much greater rate. Interannual to decadal-scale variability in the records is clearly tied to the Southern Hemisphere Annual Mode. Another point of comparison is with the mean global temperature record – while the reconstruction of continental temperatures shows a predominantly in-phase relationship with the global record, the Orcadas record shows no clear relationship, suggesting the importance of regional processes in driving the observed changes.

I also seek collaboration on a synthesis of high-resolution ice core data from across the Antarctic and elsewhere to be used in conjunction with water stable isotope modeling.

### Reconstruction of the firn thermal processes from the firn temperature measurements

#### Olga Sergienko, Douglas R. MacAyeal, Kelly M. Brunt, Laurence Mac Cathles

Disintegrations of Larsen Ice Shelf A and B in 1995 and 2002, respectively, were preceded by two decades of extended summer melt seasons. The presence of melt ponds on the both Larsen A and B immediately before their collapses suggests a strong connection between surface melting and break-up events. Thus, monitoring of ice-shelf surface melting is required for the ice shelf stability estimations.

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Large tabular icebergs, which recently calved from the various Antarctic ice shelves and drifted north, can be considered natural experiments depicting the ice shelf behavior under warming conditions. Therefore, the observation of surface melting on icebergs is essential. During the Austral summer 2004-2005 a field study of surface melting was undertaken on iceberg C16 (Ross Sea). Twelve thermistors were installed in 2.5 m subsurface layer for continuous firn temperature measurements. Two 4.5 m firn core were extracted during two successive field seasons (2004-2005 and 2005-2006). Analysis of the core densities shows increasing surface melting during 2005. Thermistor temperature data is used to reconstruct thermal processes in the firn subsurface layer.

### **Meridional circulation between the Antarctic Peninsula and southeastern South America: cold surges one way and biomass burning emissions the other way.**

**Alberto Setzer, Francisco E. Aquino, Marcelo Romao O.**

In this paper we present two meridional circulation patterns in the lower troposphere between the north of the Antarctic Peninsula (AP) and South America (SA) that occur in all seasons of the year, so far not yet presented in the literature. Low pressure systems in the Weddell Sea produce outbursts of cold air at surface level that protrude 60° of latitude northwards, causing temperature declines of 10°C and precipitation in tropical areas in southeast and east SA. In the opposite direction, southward flow from central SA reaches the north AP under high pressure ridges, causing temperature increases of also 10°C or more. These meridional flows are corroborated with plenty of evidence of observational data from weather stations in the north of the AP and southeast SA, satellite imagery, synoptic charts, and with aerosol sampling in the South Shetlands.

### **Melting and freezing beneath the Larsen Ice Shelf**

**Andrew Shepherd, Zhijun Du, Andreas Vieli (Invited Speaker)**

We use interferometric synthetic aperture radar (InSAR) data recorded by the European Remote Sensing (ERS) satellites to determine velocity changes of the Larsen B ice shelf and its tributary glaciers. Because the precision of velocity mapping is affected by the action of tide, we correct the velocity data for tidal effects using an adaptive prediction from the AntPen tide model. By differencing a series of InSAR pairs, we derive ice shelf and glacier velocities and grounding line locations in 1995 and 1999. Assuming the ice shelf is floating in hydrostatic equilibrium, we model ice thickness and density at each mapped velocity grid point using point measurements of ice thickness within the BEDMAP database and a spatially continuous model of surface elevation derived from satellite altimetry. We combine the InSAR velocity data, ice thickness model, and a time series of ice thickness change to determine the rates of ice melting and freezing at the ice shelf base at each epoch, assuming mass continuity.

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## Satellite-Derived Changes of the Larsen C System from ICESat and MODIS Data

**Christopher A. Shuman, Ted A. Scambos, Mark A. Fahnestock, Christina L. Hulbe**

The remaining ice shelves of the Antarctic Peninsula are a challenging but essential target for remote sensing studies. Recent observations of outlet glacier response to loss of the Larsen B ice shelf indicate that ice shelves play an important role in regulating glacier flow, at least in the terminal region. Once collapse occurs, acceleration and associated thinning at the glacier terminus can propagate upstream, sending formerly grounded ice into coastal waters and contributing to sea-level rise. It is thus important to evaluate the collapse potential of the Peninsula's remaining ice shelves. These "at risk" ice shelves, are now being monitored using ICESat laser altimetry data overlaid on temporally-similar imagery from MODIS. Thinning, thickening, crevassing, extension, and calving can all be monitored by these repeated satellite observations.

The Larsen C ice shelf, the largest in the Antarctic Peninsula is specifically targeted in this project. The Larsen C ice shelf is located in an area that is experiencing a regional temperature increase, has a mean January temperature of about  $-1.5^{\circ}\text{C}$ , has very high radar backscatter, and experiences a melt season of about 50 days duration. Extensive meltwater ponding, a key characteristic of the Larsen A and B, and other shelves before disintegration, is not currently observed on this ice shelf. The ICESat data currently available is well positioned for monitoring the Larsen C ice shelf. Approximately 20 ground tracks (ascending and descending) of the current operations plan have been repeatedly profiled in 2003-2005 across this feature and these elevation profiles are located nearly perpendicular to flow across the area. Although cloud cover, potentially causing significant gaps and/or anomalously low elevations, is a concern, the available ICESat data provides critical measurements of the surface elevations and their change with time across the Larsen C ice shelf. The MODIS data ensures the best interpretation of the available elevation data across specific changing features, and also helps identify cloud impacts.

## Signals of climatic variations in the northern most part of the Antarctic Peninsula and the South Shetlands Islands

**Jefferson C. Simões, Francisco E. Aquino, Alberto W. Setzer, Jorge Arigony-Neto, Siclério Ahlert, Ulisses F. Bremer, Cláudia D. Beck, Norberto Dani (Invited Speaker)**

This paper explores climatic and cryospheric data sets to examine signals of climate variations in the extreme north of the Antarctic Peninsula (north of  $64^{\circ}\text{S}$ ) and its offshore islands. Glaciers and ice caps of four islands (Brabant, Joinville, King George, and Nelson) show a non-uniform reduction for the period 1956-2001. For example, King George Island (KGI) has lost 7.1% (89 km<sup>2</sup>) of its ice cover since 1956. On the other hand, on Nelson Island, separated from the former island by a narrow strait, the amount of ice lost is almost imperceptible. Further south and nearer to the Antarctic Peninsula, Joinville Island's loss is also restricted (0.6% of a total area of 1477 km<sup>2</sup>, from 1990 to 2000). Glacier retreat on these three islands shows a clear general pattern: ice loss occurred mainly in outlet tidewater glaciers flowing to the southeastern coasts and mainly in bays and other well protected areas. On the other hand, in mountainous and irregular Brabant Island, no glacier retreat has been detected from 1989 to 2001.

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Having this in mind, we considered the influence of sea occurrence in bays and in other sheltered coasts. At least at Admiralty Bay (KGI), sea ice cover area decreased from 1977 to 1999. This trend was concomitant to an air temperature and wind speed increase and a greater frequency of northerly and north-westerly winds, advecting relatively warmer air masses from lower latitudes. On the other hand, the greatest amount of ice loss in Admiralty Bay (22 km<sup>2</sup> since 1956) occurred before 1980. Rather than a common response to an observed general atmospheric warming trend (0.022°C a<sup>-1</sup> from 1948 to 1995 in Admiralty Bay), glacier retreat in the region results from an interplay of ice front and coast morphologies, sea ice extent and variations in other climatic parameters such as precipitation. Further, from 1998 to 2005, the mean annual air temperature declined about 1°C.

## A century of climate change on the Antarctic Peninsula

### **Susan Solomon, David W. J. Thompson (Invited Speaker)**

The Peninsula has special places in Antarctica's past and in its present, and both will be described in this talk. The first expedition to winter-over in the Antarctic spent 1898-1899 locked in the grip of sea ice near its coastline. That remarkably international team made pioneering measurements of the climate through that first 'Antarctic night'. The crew, their experiences, and their data will be briefly reviewed. Just over a century later, evidence of systematic climate change in this region is now available. The Antarctic continent holds a unique place in the world as the sole large region not experiencing warming over much of the interior, while parts of the Peninsula display enhanced warming in certain seasons. Much of this behavior has been explained through improved understanding of changes in the atmospheric circulation and related parameters linked to the Southern Annular Mode (SAM), which in turn are driven in part by ozone depletion and Antarctica's unique ozone hole. Changes in ozone, greenhouse gases and other factors that are currently making Antarctica's climate distinct from the land first explored a century ago will be reviewed.

## Trends in sea ice retreat and subsequent advance in response to ENSO and SAM variability

### **S. E. Stammerjohn, D. G. Martinson, R. C. Smith, X. Yuan**

The Antarctic Peninsula (AP) region is rapidly warming, ice shelves and marine glaciers are retreating, and winter sea ice duration is decreasing. Elsewhere in Antarctica and the Southern Ocean, climate trends are weak or indicate cooling. In an attempt to understand the mechanisms of climate change in the AP region, we first identify when and where the most profound sea ice changes in the Southern Ocean are occurring, then we explore how the physical system is sensitive to these changes. Towards this objective, newly analyzed data reveal strongly opposing trends in the timing of annual sea ice retreat (November - February) and the subsequent advance (February - May) in two regions of the Southern Ocean. Sea ice is retreating earlier and advancing later in the southern Bellingshausen Sea, resulting in a decrease of  $80 \pm 13$  annual sea ice days over 1979-2002. In the western Ross Sea, opposite trends have resulted in an increase of  $55 \pm 12$  annual sea ice days. An intensification of the high latitude response to La Niña (more so than to El Niño) during the spring-to-autumn period in conjunction with increased polarity of the Southern Annular Mode (SAM) help to explain both the intensification and localized nature of these opposing sea ice trends.

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Additionally, inter-seasonal feedbacks help to explain the amplified winter warming in the Antarctic Peninsula region: changes occurring in the atmospheric circulation during austral spring, summer and autumn are negatively affecting the advance and retreat such that winter sea ice duration, concentration and thickness are decreasing, and ocean winter heat flux is increasing; these changes in turn amplify the increase of air temperature in autumn and winter.

### Glaciological evidence for abrupt climate change: past and present

#### **Lonnie G. Thompson, Ellen Mosley-Thompson (Invited Speaker)**

It is essential to determine whether the abrupt climate changes underway in the Antarctic Peninsula (AP) over the past few decades reflect, in part, a response to anthropogenically driven, globally averaged warming or whether they lie within the natural range of past climate variability. Records providing the necessary time perspective may be reconstructed from chemical and physical properties preserved in the regional ice cover and ocean sediments. Comparisons are made among the geographically dispersed, annually dated ice cores records from the Antarctic Peninsula, the tropical Quelccaya ice cap (Peru) and Bona-Churchill (southeast Alaska) over the past 500 years. Decadally averaged  $\delta^{18}\text{O}$  histories demonstrate that the current warming at high elevations in mid- to low-latitudes is unprecedented for at least the last two millennia. Is this the case for the Antarctic Peninsula? Data to address this question are lacking.

A longer, multi-millennial time perspective from a variety of recording systems suggests that an abrupt climate event, roughly 5000 years ago, was widespread and spatially coherent throughout much of the tropics. A possibly contemporaneous abrupt event is evident in the Ocean Drilling Project (ODP) 108 Palmer Deep core magnetic susceptibility record (highest terrigenous sediment input and reduced marine productivity) and is coincident with enhanced input of ice rafted detritus. These observations suggest a very large scale mid-Holocene event in the Antarctic Peninsula region. Moreover, the current melting of the ice fields on Kilimanjaro's summit is unprecedented in its 11,700 year ice core history just as the recent collapse of the Larsen B Ice Shelf is unprecedented within the Holocene. These data argue that recent and rapid climate changes in both the Antarctic Peninsula and much of the tropics may be linked by common forcing mechanisms. Long, high temporal resolution ice core histories from the Antarctic Peninsula are essential to complement other proxy records in the region and to better isolate and quantify the dominant processes forcing these climate and environmental changes.

### Recent decades of climate and cryospheric change on the Antarctic Peninsula

#### **David Vaughan, Hamish Pritchard, Alison Cook, Adrian Fox, Jane Ferrigno**

This talk will cover four examples of recent changes in the cryosphere of the Antarctic Peninsula; each of which has been significantly advanced since the meeting, "Antarctic Peninsula Climate Variability: History, Causes and Impacts" (Cambridge, 2004). We use a new analysis of meteorological data to show clear and significant trends in surface melting conditions over the last 50 years. We use satellite imagery, aerial photography, and survey data to chart the course change in length of approximately 244 glaciers over the last 61 years, and demonstrate a strong trend toward glacier retreat over this period.

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We use Satellite SAR images to monitor the velocity of these glaciers over the last ten years, and find a clear pattern of increase in glacier velocity of around 10%. Finally, we record the demise of Jones Ice Shelf over the last 30 years. The examples demonstrate that the recent changes in climate on the Antarctic Peninsula are having a dramatic impact on the extent or dynamics of the ice sheet – arguably the only demonstrable impacts of contemporary climate change on the ice sheet of Antarctica – but also that the changes could continue, given only modest rates of summer warming. We will discuss the likelihood that such changes will continue, or accelerate, in coming decades, and their potential to make a substantial contribution to sea-level rise.

## Poster Presentations

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### The sub-Antarctic atmospheric circulation between 15° W and 90° W and its effects on the climates of the Antarctic Peninsula and Southern South America

**Francisco Eliseu Aquino, Alberto Setzer, Jefferson Cardia Simões**

Surface air temperature increases of up to about 3°C in the last 50 years have been recorded in the western coast of the Antarctic Peninsula (AP). Following world-wide tendencies, temperatures in continental South America have also increased in the same period, but to a much smaller extent; southern Brazil shows for the same half century an increase of 0.4°C, which for the last 20 years amounts to less than 0.2°C. Most studies have focused on global and hemispherical atmospheric circulation patterns and indices averaged over seasons and years during long-term periods to explain the temperature variations in the AP.

This paper considers specifically the longitude sector of 15° W to 90° W and shows that an important regional context in the scale of days can have marked effects in the temperatures of AP and in south South America as a result of meridional flows at surface level that result from synoptic systems in the region. Analyzing observational data for the period of 2004-2005 we show that cool and rainy spells in southeast South America result from the outflow of Weddell Sea surface air, and that increases of 10°C are common in the South Shetland Islands under northern flow from South America. The latitudinal position of the subpolar jet stream is one of the key factors in such synoptic configurations, and the further north it is located, the warmest temperatures are found in the north AP. An extended investigation for a period of 40 years to detail this meridional flow is under way to evaluate its effects in the warming records of AP temperatures.

### A spatial database in support to glaciological research during the International Polar Year 2007-2008

**Jorge Arigony-Neto, Steffen Vogt, Ricardo Jana, Frank Rau, Helmut Saurer, Jefferson C. Simões, Hermann Gossmann**

In the framework of the international project Global Land Ice Measurements from Space (GLIMS), a glacier inventory of the Antarctic Peninsula was established. The GLIMS objectives are to monitor glaciers on the Earth using primarily satellite data. The Department of Physical Geography of the University of Freiburg is integrated in GLIMS as the Regional Center (RC) for the Antarctic Peninsula.

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As the Antarctic Peninsula covers a large region extending from approximately 60° S/55° W to 75° S/80° W, the RC Antarctic Peninsula cooperates with several international scientific and administrative institutions. These partners are responsible for the analysis of glaciers in specific sub-regions of the research area.

To record and manage results from satellite image analyses on glaciers on the Antarctic Peninsula and to administer metadata describing such analyses, we implemented a glacier database containing data on more than 950 glaciers. The relational database design is compatible with the GLIMS data transfer standards and was developed using free and open source software. The semantics are compliant with the GLIMS data dictionary and the Scientific Committee on Antarctic Research (SCAR) Feature Catalogue. It enables full compatibility with the GLIMS central database and the emerging Antarctic Spatial Data Infrastructure (AntSDI). Furthermore, the relational structure of the database facilitates the record of additional cryospheric data resulting from further projects.

Web access interfaces have been developed both for human interaction and for machine to machine communication. A browser-based interface allows users to query the glacier data base using text search or through interactive maps. The machine-to-machine accessibility is based on open web services implementing Open GIS Consortium (OGC) specifications and relevant ISO TC211 standards. Querying and retrieving spatial features and their attributes through an OGC Web Feature Service (WFS) interface for example enables interoperability with other OGC compliant applications such as GIS packages or spatially enabled data mining tools at the feature level.

In this paper, we describe the structure and functionality of the Antarctic Peninsula Glacier Database and its web based interfaces. In addition, we give examples of using the database to support glaciological research during the International Polar Year 2007-2008.

### Improving glacier surface models for mass balance assessment using laser scanning and aerial imagery – implications for reconstruction of recent Antarctic Peninsula mass change

**Nicholas E. Barrand, Tavi Murray, Timothy D. James, Stuart L. Barr, Adrian J. Fox**

This research is presented as an analogue case study for future analyses of Antarctic Peninsula ice masses. Airborne laser scanning and digital aerial photogrammetric techniques may be combined to provide high-quality, high-resolution surface models for measuring changes in glacier mass balance. A data set of airborne laser data acquired over Midre Lovénbreen, Svalbard, is shown to provide elevation information accurate to 0.17 m root mean square over the glacier surface. Although the repeatability of laser data degrades over very steep mountain-sides and peaks it is possible to extract large numbers of ground control points from surrounding bedrock features. In the case of Midre Lovénbreen, a small (approximately 4 km long) polythermal-type valley glacier, more than 70 ground control points can be identified using laser return intensity information and 3-D data visualization techniques. Elevation models are produced using digital photogrammetry from a block of 19 overlapping vertical stereo photographs imaged concurrently with the laser data. Comparisons of photogrammetrically-derived models with a laser data derived 'base' model show that marked increases in DEM quality are achieved with the addition of extra ground control data.

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Models are generated using a set of historical vertical aerial photographs of the glacier and surrounding areas from 1966. Changes in frontal position and the volume, and hence mass balance of the glacier between 1966 and 2003 are given. The availability of historical aerial photographs of parts of the Peninsula along with high-quality elevation information from NASA's Ice, Cloud and land Elevation Satellite (ICESat) offers the possibility of combining laser data and aerial imagery in a similar way (e.g. Schenk et al., 2005). This approach has the potential to extend the temporal record of surface topographic change significantly further back in time than is possible using current altimetry measurements.

### **The ADELIE project: Antarctic Drifter Experiment; Links to Isobaths and Ecosystems**

**Karen J. Heywood, Sally E. Thorpe**

In January-February 2007 we will undertake a hydrographic section, float and drifter deployment at the tip of the Antarctic Peninsula as part of the ADELIE project. Recent data suggest that, contrary to prevailing views, there are pathways for near surface currents around the Antarctic Peninsula to the west. If proved, these would be important for the retention and/or dispersal of krill larvae and other passive drifting particles. The Antarctic Slope Front appears to lose its properties as it enters the Weddell Scotia Confluence. These pathways will be mapped by deploying surface drifters and Argo floats to the southeast of the tip of the Antarctic Peninsula, spanning the Antarctic Coastal Current and Antarctic Slope Front into the Weddell Sea. A CTD/LADCP section across these flows will indicate their locations and transports. Output from eddy resolving ocean models will be analysed and virtual drifters deployed in their flow fields. The influence of bathymetry controlling the splitting and steering of these frontal jets will be studied. The poster will describe the background to the project and the fieldwork planned for 2007.

### **Investigation of King George Island climatology**

**Victor Lagun, Nikolay Ivanov, Svetlana Jagovkina**

Recent numerical estimations of climate variability parameters for the Southern Hemisphere indicate that the Antarctic Peninsula region is a main hemispheric "hot spot." This phenomena is traced in surface and troposphere warming trends, in prevailing large-scale circulation form, surface pressure decreasing, in sea ice retreat tendency, ozone decreasing, Antarctic Circumpolar warm water propagation over the Peninsula's shelf, in appearance of natural emissions of greenhouse gases from oritogenic soils at sub-Antarctic Islands, in lichen and penguin area systematic change, and so on. However, the Climate and General Circulation Models based on modern atmospheric trace-gas content scenarios are not able to reproduce evident warming conditions near the Antarctic Peninsula. Therefore, the study of current and historic regional climatic variations based on observed data is very important for numerical model development using different relationships between the Antarctic Climate System parameters. Some ideas for physical-processes parameterization can be obtained from diagnostic estimates of the Antarctic Climate System parameters distribution and from their variability. The King George Island (KGI) climate variability pictures based on manned stations data completed with SCAR READER (REference Antarctic Data for Environmental Research) Projects and SCAR King George Island Working Group information resources are presented.

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The results of the probabilistic analysis of a comprehensive time series of surface air temperature and air pressure at sea level in this region undertaken for determining the interannual variability characteristics showing the annual cycle modulation by synoptic scale variability are demonstrated. Current meteorological, upper air sounding, solar radiation, ozone, hydrological, sea ice, biological and greenhouse gas concentration data for total measurements period are used for unique local climate regime formation description. Interannual tendencies of seasonal surface and tropospheric temperatures over King George Island are more prominent than those observed in continental Antarctica. Three IPY Project (CLICOPEN, ANTPAS and COMPASS) plans related to KGI natural complexes investigation are discussed.

### **Glacier behavior after ice shelf collapse in Crane Glacier, Antarctic Peninsula**

**Amie Lamb, Christina Hulbe, Ted Scambos, Jennifer Bohlander**

Since the early 1990s, many changes have been observed in the Antarctic Peninsula's glacier systems, presumably in response to warming of about 2.5 C over the last 60 years. One such change, the speed-up of Crane Glacier, is of interest here. Crane is a large glacier on the eastern side of the Antarctic Peninsula that began to speed up in 2002, after the disintegration of the Larsen B ice shelf into which it had flowed. We use a combination of satellite remote sensing data sets to study this change. Glacier velocity is measured using standard image-correlation techniques and Landsat 7 and ASTER images. Speeds in the downstream trunk of the glacier were significantly slower between 18 December 2002 and 20 February 2003 (summer) than speeds computed over the entire 392-day period between 18 December 2002 and 13 January 2004. No significant differences were observed in the upstream region of the glacier. Calculated speeds due to internal deformation of the ice are significantly smaller than the observed speeds. Together, these lines of evidence suggest that the glacier is sliding over its bed during at least part of the year. The relatively slow summertime speeds (compared to the annual speed) may indicate that by this time in the melt season, the basal water system has become efficient, and basal water pressures a lower than at other times of the year. If this interpretation is correct, it suggests that in the absence of the Larsen B, Crane Glacier is behaving as a tidewater glacier.

### **Holocene paleoceanography recorded in a sediment core from South Orkney Plateau**

**Jae Il Lee, Ho Il Toon, Kyu Cheul Yoo**

A 533 cm-long gravity core sediment retrieved from the northwestern end of the South Orkney Plateau, West Antarctica, records high-resolution information on changes in oceanographic process and paleoclimate that occurred during the last 8,700 years. Age of the sediment was determined by accelerator mass spectrometry radiocarbon dating for organic matter in six sediment samples including one sea-floor sediment sample from box-core top, which shows very old reservoir age of approximately 2900 radiocarbon years. Sedimentation rate varies between 46 and 84 cm/kyr with an average of 61 cm/kyr. Content of biogenic opal ranges from 18 to 31%. Detailed geochemical analyses (content of total organic carbon (TOC), C/N ratio, and content of biogenic opal (BSi)) and grain size analysis indicate that major shift in the content and nature of organic matter had occurred between 5750 and 4480 yr BP.

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Highly variable TOC, high C/N ratio, and high BSi/TOC ratio of the lower part of the core implies that this area was under the influence of Scotia Sea water until 5750 yr BP. High TOC, low C/N ratio, and low BSi/TOC ratio of the upper part suggests increased influence of Weddell Sea water in the area since 4480 yr BP. We suggest that northward shift of Weddell-Scotia frontal system occurred between 5750 and 4480 yr BP, and it marks the onset of Neoglacial condition in the South Orkney Plateau.

### Characteristics of tephra in Holocene lake sediments on King George Island, West Antarctica: implications for deglaciation and paleoenvironment

**Hyoun Soo Lim, Yong Il Lee, Ho Il Yoon, Andrzej Tatur**

Several reworked tephra layers in gravity-flow deposits are present in lacustrine core sediments collected from Hotel and Rudy lakes on King George Island, South Shetland Islands, West Antarctica. The tephra record is more abundant in a long Hotel Lake core (515 cm long). In this study, the morphology, grain size characteristics and composition of volcanic glass samples from five tephra layers (A, B, C, D and E) of Hotel Lake and from one (R) of Rudy Lake were examined to characterize the eruptive mechanisms that produced them and to test the suggestions that they were derived from Deception Island.

Two distinct types of tephra were identified on the basis of color, vesicularity and morphology: the dominant, pale to dark brown basaltic shards and the minor, light-colored pumice shards. The relative proportions of basaltic and pumice pyroclasts are different from sample to sample, and both types have various degrees of vesicularity. Concentrations of major elements were analyzed with electron microprobe. The analyzed tephra samples show the wide range in composition from basalts to rhyolite magmas with medium-K tholeiites, though there is a predominance of basalts and basaltic andesites. Therefore, the tephra samples were divided into basic and silicic glass populations. The basic tephra occur in all studied horizons, but the silicic tephra present in only three layers in the Hotel Lake (A, D and E). The silicic tephra can be divided into two groups: rhyolitic tephra with high- and low-K content. The geochemical similarity between glasses in individual tephra layers was compared using the similarity coefficient as a discriminator. Similarity coefficients (SC) were calculated for basic and silicic tephra separately. Based on the very high SC (0.95-0.99), A, B, C and R tephra are geochemically indistinguishable from one another, and thus are considered equivalent. The same is true for D and E tephra. SC values for silicic tephra in A, D and E are relatively low from 0.84 to 0.92. However, all the rhyolitic tephra with high-K content in A, D and E tephra samples have SC values larger than 0.96, suggestive of geochemical equivalence. The presence of such geochemically equivalent tephra suggests that they were the product of single volcanic eruption event and reworked in different times.

Most of the basic tephra probably represent products of explosive eruptions of Deception Island, the most active subaerial volcano in the Antarctic Peninsula region. Less than 20% of tephra belongs to silicic glass and occurs in three tephra horizons of Hotel Lake. However, source volcano(es) for about 10% of basic tephra and silicic tephra are not readily identified from nearby volcanic centers.

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Except for the studied tephra in Rudy Lake, all tephra samples in Hotel Lake are not ashfall deposits but reworked and redeposited pyroclasts derived from retreating ice sheet, resulting in the occurrence of geochemically equivalent tephra samples in different tephra horizons. The dating of the studied tephra horizons represents the timing of deglaciation rather than that of volcanic eruptions. The result of this study implies that combined with sedimentological information more chemical criterion is necessary to study tephrochronology and regional correlation and to understand paleoenvironmental changes using tephra.

### **Sea-swell induced vibration of ice shelves: an iceberg calving mechanism capable of trans-oceanic connections?**

**Douglas MacAyeal, Kelly Brunt, L. Mac Cathles**

Over the past 3 years, we have deployed broad band seismometers on the Ross Ice Shelf, Antarctica, and various icebergs recently calved from this ice shelf (B15A and C16), to investigate the effect of sea swell on bobbing, rocking and pitching motions that contribute to the calving process. Our observation reveal a curious, unexpected relationship between storm activity in the distant North Pacific and swell induced vibration along a wide swath of Antarctica's calving margin. The implication of our observation is that intensity variations of storms within the usual storm tracks of the global circulation system can influence far-separated ice sheets in a nearly synchronous manner. This influence offers a possible clue toward understanding how iceberg calving in the glacial North Atlantic may respond to atmospheric triggers, and further highlights the role of sea swell as an environmental process capable of influencing climate. A future observation that we recommend for study of ice-shelf disintegration along the Antarctic peninsula will be the deployment of broadband seismometers on various parts of the Larsen and Ronne ice shelves to determine the extent to which sea-swell generated in the far North Atlantic, as well as in the close field environment of the Weddell Sea, has an impact on ice-shelf fragmentation and breakup.

### **The dynamics of palaeo-ice streams draining the Antarctic Peninsula Ice Sheet during the Late Quaternary**

**Benedict Reinardy**

Multibeam bathymetric data, sub-bottom profiler (TOPAS) data and sediment cores had been collected from the NE Antarctic Peninsula continental shelf on cruise JR71 of the RRS James Clark Ross. The data sets had been used to reconstruct the flow-dynamics of the Antarctic Peninsula Ice Sheet (APIS) since the Last Glacial Maximum (LGM). Highly attenuated bedforms in an acoustically transparent sedimentary unit were observed in several cross-shelf troughs documenting that the APIS was drained by ice streams flowing towards the shelf break. Some areas are characterized by cross-cutting bedforms suggesting a change in ice flow direction since the LGM, possibly during the deglaciation. Cores recovered from the bathymetric troughs indicate a stiff till overlain by a soft till. The availability of sediments at the seabed may have facilitated the development of a deforming till layer. The aim of this research is to interpret the varying bed conditions below ice grounded on the shelf NE of the Antarctic Peninsula since the LGM, particularly during APIS retreat. 3D mapping of Robertson Trough from TOPAS and multibeam bathymetric data along with sediment cores will be carried out. The micromorphology of sediment samples taken from the cores will be analyzed to reconstruct the different bed conditions responsible for the deposition of the soft and the underlying stiff till.

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The change in ice source documented by the cross-cutting bedforms in some areas and its relationship to ice streaming will be further investigated. Geomagnetic palaeointensity measurements will be used to date both the timing of ice retreat and to discover whether ice streaming occurred during deglaciation. Particular attention will be paid to distinct sedimentary wedges on the shelf, which are interpreted as grounding line still stands during overall APIS retreat.

### Quaternary deglaciation of the South Shetland Islands, Antarctica

**Yeong Bae Seong, Hyoun Soo Lim, Ho-Il Yoon, Yong Il Lee, Lewis Owen**

Knowledge of the past configurations and behavior of the West Antarctic Ice Sheet (WAIS) is necessary to calibrate glaciological models that attempt to predict future responses of the ice sheet and to quantify the contribution of the Antarctic ice sheets to eustatic sea-level rise during the last deglaciation. The WAIS (West Antarctic Ice Sheet) of Saalian-Illinoian age collapsed catastrophically during the Eemian-Sangamon interglacial, to be followed by renewed ice-sheet growth during the last glacial stage. This collapse caused a eustatic sea-level rise to about 6m some 120,000 years ago. Extended through Cenozoic era, the debate on Ice Sheet stability cannot be far reached on a consensus. Antarctic ice sheet has remained stable since middle Miocene time, whereas massive deglaciations occurred during Pliocene and Pleistocene period. However, It is likely that traces of interglacial landforms and sediments within the sphere of the WAIS have been destroyed or obscured during the most recent stage of expansion. This is why there is as yet no unequivocal geomorphological evidence for large-scale melting of the WAIS during the last interglacial, excepting marine-geophysical and sedimentological works. Possibly it is more noteworthy to search for such remnants either on the coasts of Antarctic Peninsula or on the sub-Antarctic islands of the Scotia Sea beyond the present northern limits of shelf Ice. We propose here to investigate the raised beach sediments in the South Shetland Islands in order to test the hypothesis. We will undertake geomorphic mapping and collect samples for cosmogenic radionuclide and optically stimulated luminescence dating. This work will lead to define the timing and configuration of former deglaciation of the WAIS and help us model the future behavior of the WAIS in light of global eustatic sea-level change.

### Climate tendencies in the South Shetlands: was 1998 a climate divider?

**Alberto Setzer, Francisco E. Aquino, Marcelo Romao O.**

Temporal series of meteorological data for the South Shetland Islands in widely distributed data basis show air temperature increase and pressure drop at surface level during the last decades. These patterns are particularly clear in reanalysis data that start in 1948, and a large number of papers is found describing and interpreting these tendencies, and using them to support future scenarios and to correlate them with assorted environmental variables. However, a closer look at more recent station records in the region present a puzzling contradiction to the long term series and reanalysis tendencies. Surface pressure raised some 8 hPa in the last 20 years and appears to be currently at a maximum; since 1998-99, therefore for seven years, air temperature declined about 1oC. Surface winds in the last years are also decreasing, as a possible indication of a change of weather pattern in the region.

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This paper presents the evidence to the contradictions in the data sets and points to relevant effects in generating wrong analyses of Antarctic climate. For instance, an incorrect reference of surface pressure results in wrong temperatures at standard pressure levels in the atmosphere leading to non existing temporal variations.

### **Plausible oceanographic interpretation on the recent rapid warming trends of the South Shetland Islands**

#### **Kyu-Cheul Yoo, Ho Il Yoon**

Marian Cove (3.5 km long and 1.5 km wide) is one of tributary embayments in Maxwell Bay, King George Island, West Antarctica. King George Island, the largest of the South Shetland Islands off the northern tip of the Antarctic Peninsula (AP). The retreat rate of tidewater glacier of the cove is rapid up to about 81 m/yr in more recent years (1988 to 2001) than the past (1957 to 1988) (about 12.5 m/yr). The recent rapid trend has significant oceanographic implications along with atmospheric change. We will present results of hydrographic data (2000 and 2004) on a fixed station near the head glacier of Marian Cove, and mooring results of temperature and salinity for two years (2004 to 2005).

### **Late Holocene cyclic glaciomarine sedimentation in subpolar fjord of the South Shetland Islands, Antarctica and its paleoceanographic significance: sedimentological, geochemical and paleontological evidence**

#### **Ho Il Yoon, Kyu-Cheul Yoo, Young-Suk Park, Hyoun Soo Lim, Boo-Keun Khim, Sung Joong Kim**

The glaciomarine sediment record of Maxwell Bay, South Shetland Islands (West Antarctica), a large marine calving embayment, contains distinctive cyclic deposits. Each glaciomarine couplet forms alternating clast-rich massive diamicton deposited in cold climate by iceberg rafting detached from coastal fast ice in which algal plants as well as sand and/or gravel were entrained and, in warmer climate, meltwater deposits of weakly laminated mud with clast-poor stratified diamicton deposited by iceberg rafting coming from the tidewater glaciers depleted in sand and algal components. Although iceberg rafting occurs throughout the deposition of the whole cores, organic matters are deposited in high concentration and forms organic-rich massive diamicton only during cold condition because of minimal dilution of siliclastic particle by meltwater influx in Maxwell Bay. When the meltwater discharge decreases in colder condition, and resultant biological productivity was reduced on the surface water, ice rafting from the shorefast sea ice along the coastal region might play an important role for transporting benthic plants and/or coastal macroalgal components as well as loads of sediments and dropstones, resulting in increased C/N ratio in clast-rich massive diamicton. AMS radiocarbon analyses conducted on calcite shells in sediments revealed an excellent chronology for the past 3000 years. Fluctuations in total organic carbon preserved during cold period record approximately 4 cycles over the same time period, with the average duration of cooling cycle being about 500 years. In spite of rarity in southern hemisphere, this can be correlative with the high frequency (550 years) variability in reduced NADW (North Atlantic Deep Water) production during cold climatic conditions, as demonstrated for glacial periods throughout the Pleistocene.

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## Late Quaternary sedimentary processes in the northern continental margin of the South Shetland Islands, West Antarctica

**S. H. Yoon, H. I. Yoon, K. C. Yoo**

Sedimentary facies and high-resolution (3.5 kHz) echo facies were analyzed to elucidate sedimentation pattern of the late Quaternary glaciomarine deposits in the northern continental margin of the South Shetland Islands, West Antarctica. Six sedimentary facies are classified based on grain texture and sedimentary structures in gravity cores. The high-resolution echo characters are classified into 6 echo facies on the basis of clarity, continuity, and shape of bottom and subbottom echoes together with sea floor topography. Distribution of the echo and sedimentary facies suggest that a large part of the continental margin deposits formed during the Last Glacial Maximum (LGM) and subsequent glacier-retreating period. When the grounded glaciers extended to the present shelf break during LGM, coarse-grained subglacial tills were widespread in the shelf area, and deep troughs in the shelf were carved beneath the fast-flowing ice stream. As the glacial margin retreated landward after LGM, dense meltwater plumes released from the retreating ice-front were funneled along the glacier-carved troughs, and accumulated channel- or canyon-fill deposits in the shelf and the upper to mid slope. At this time, some upper slope sediments seem to have been rarely reworked by slope failures and contour currents. After the glacial retreat, sediments in the shelf and slope areas have been mainly introduced by persistent (hemi) pelagic settling, and fine-grained turbidity currents frequently occur along the axis of the South Shetland Trench.

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