

## **CLASH OF THE ICEBERGS**

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Iceberg harmonic tremor (IHT) associated with Southern Ocean icebergs and around the coast of Antarctica has been observed as seismoacoustic signals on islands in the equatorial Pacific, as hydroacoustic signals in the Indian Ocean, and as seismic phases at local and regional Antarctic seismic stations. To identify the IHT source, four IRIS PASSCAL seismographs with 30 s seismometers were sited on the 25 km by 50 km tabular iceberg C16 in the Ross Sea, Antarctica while it was lodged against the northern shore of Ross Island and in sporadic contact with an even more massive giant tabular iceberg, B15A. This study (MacAyeal et al., 2008, in press) revealed that IHT is a superposition highly similar repeating and reversing stick-slip icequake subevents. These subevents occur at typical rates of thousands per hour and persist for up to several hours. IHT subevents are generated when the ice-cliff edges of two tabular icebergs rub together during glancing, strike/slip type collisions, which were monitored with GPS data collected from B15A. With the source mechanism revealed, IHT may provide a promising signal useful for the study of iceberg behavior and iceberg-related processes such as climate-induced ice-shelf disintegration. We further note that iceberg-sited seismographs provide spectacular records of ocean swell arising from distant (e.g., trans-Pacific) and regional (e.g., Ross Sea) events arising from storms and glacial events, and that the modes of iceberg deformation at swell periods are spectacularly revealed by iceberg seismometer arrays.

## **POSTER 6**

## **BROADBAND ARRAY DEPLOYMENTS AND CRUST—MANTLE STRUCTURE AROUND THE LÜTZOW-HOLM BAY, EAST ANTARCTICA**

*Masaki Kanao (National Institute of Polar Research), Yuusuke Usui (Ehime University), Tomofumi Inoue (Ehime University), Akira Yamada (Ehime University)*

Broadband seismic array deployments have been carried out from 1996 on the coastal outcrops in the Lützow-Holm Bay Region (LHB), East Antarctica. The recorded teleseismic and local seismic signals have sufficient quality for the various analyses to clarify the dynamics and heterogeneous structure of the crust and upper mantle. Conventional passive source studies such as receiver functions and shear wave splitting were carried out; indicating heterogeneous structure from the north to the south along the coast in LHB. Data obtained may be applied not only to lithospheric studies, but to study of the Earth's deep interior by integration with large span arrays from Eastern Dronning Maud Land. The broadband array deployments in LHB could make effective contributions to the 'Global Alliance of Regional Networks; GARNET', principle international Antarctic Array programs, together with 'POLER observation NETWORK; POLENET' during IPY 2007-2008.

### **POSTER 1**

## **BROADBAND SEISMIC DEPLOYMENTS IN EAST ANTARCTICA: IPY CONTRIBUTION TO UNDERSTANDING THE EARTH'S DEEP INTERIOR**

*Masaki Kanao (National Institute of Polar Research), Satoru Tanaka (Japan Agency for Marine–Earth Science and Technology), Seiji Tsuboi (Japan Agency for Marine–Earth Science and Technology), Douglas Wiens (Washington University)*

“Deployment of Broadband Seismic Stations on the Antarctica Continent” is an ambitious project to improve the spatial resolution of seismic data across the Antarctic Plate. The project has several components, including 1) process-oriented experiments such as 3D-arrays; 2) evolving regional arrays; and 3) a permanent backbone network. Temporary broadband stations deployed on outcrops and continental ice sheet around Eastern Dronning Maud Land – Enderby Land areas will contribute strongly to IPY related major programs such as the ‘POLER observation NETWORK (POLENET) (IPY project #185)’. The observed data during IPY will be available from Japanese library servers (ex., POLARIS of NIPR), and sent to world data centres (IRIS/DMS, PACIFIC21), and to AMD/JCADM of the SCAR/ANTEC. In addition to lithospheric studies, data from the large span arrays of broadband stations will allow more detailed investigations of the Earth’s deep interior under high southern latitudes.

### **POSTER 2**

## **SEISMIC RADIATION FROM ICEBERGS**

*Douglas MacAyeal (University of Chicago), Emile Okal (Northwestern University), Richard Aster (New Mexico Institute of Mining and Technology), Jeremy Bassis (Scripps Institution of Oceanography)*

Iceberg harmonic tremor (IHT) emanating from tabular icebergs in the Southern Ocean and around the coast of Antarctica is observed as seismoacoustic signals on islands in the equatorial Pacific, as hydro-acoustic signals in the Indian Ocean, and in local and regional Antarctic seismograms. To identify the IHT source mechanism and to understand the relevance of IHT to iceberg calving, drift and break-up, we deployed seismometers on a 25 km by 50 km iceberg called C16 in the Ross Sea, Antarctica. The seismograms reveal that the IHT signal consists of extended episodes of stick-slip icequakes (typically thousands per hour) generated when the ice-cliff edges of two tabular icebergs rub together during glancing, strike/slip type iceberg collisions (e.g., between icebergs C16 and B15A). With the source mechanism revealed, IHT may provide a promising signal useful for the study of iceberg behavior and for teleseismically monitoring iceberg activity.

Success in identifying one source of iceberg-generated seismicity motivates asking whether there are additional seismic signals generated by icebergs that can inform glaciological science at a time when iceberg-related phenomena are of concern in future climate change. The recent disintegration of ice shelves along the Antarctic Peninsula (e.g., the February, 2008, break-up of Wilkins Ice Shelf) remains largely unexplained because break-up mechanisms are poorly constrained by observations. It is possible that seismology, through the study of signals associated with ice-shelf fragmentation and subsequent iceberg motions, may provide the key to unlocking our understanding of the Antarctic Ice Sheet's most worrisome behavior.

## **GLACIER FLOW AND GLACIAL EARTHQUAKES IN GREENLAND**

*Meredith Nettles (Lamont-Doherty Earth Observatory, Columbia University)*

We have obtained a suite of detailed geophysical observations, spanning two summer seasons, at Helheim Glacier, East Greenland. This interdisciplinary dataset includes geodetic, seismic, radar, and lidar observations, in addition to tidal, weather, and satellite remote-sensing data. Continuous high-rate GPS observations from a period of 50 days in July--August, 2007, extend a 60-day summer-season time series obtained in 2006. This dataset also includes continuous observations for periods as long as four weeks on the lowermost part of the glacier, within a few km of the calving front.

We observe significant changes in glacier behavior between 2006 and 2007. The 2006 summer season saw a substantial readvance of the calving front compared with the minimum position recorded in 2005; a retreat of the front was observed in 2007 with respect to 2006. The 2006 summer season was seismically quiescent, with 2007 marking a return to glacial-earthquake activity. We also observe significant variations in glacier flow speed during the 2007 summer season, including accelerations along the length of the glacier trunk occurring on timescales of less than one day. We will present a joint analysis of seismic and geodetic data focused on elucidating the nature of short-time-scale variations in glacier flow, including glacial earthquakes.

## **DESIGN AND IMPLEMENTATION OF COLD-HARDENED SEISMIC STATIONS**

*Tim Parker (IRIS PASSCAL), Bruce Beaudoin (IRIS PASSCAL), Brian Bonnett (IRIS PASSCAL), Jim Fowler (IRIS), Kent Anderson (IRIS)*

PASSCAL supports roughly 60 experiments per year worldwide, with 5-10% funded by the National Science Foundation (NSF) Office of Polar Programs (OPP). Polar projects commonly require a level of support that is several times that of seismic experiments in less demanding environments inclusive of very remote deployments (e.g. Tibet). In order to ensure OPP funded Antarctic projects the highest level of success, we have established a PASSCAL Polar Program and have secured funds from OPP to better support new and ongoing experiments in the extremely cold Polar Regions.

In 2006, the NSF awarded a Major Research Initiative (MRI) grant to UNAVCO and the Incorporated Research Institutions for Seismology (IRIS) to develop a power and communications system that will improve remote autonomous geophysical observations in the polar environments. Our strategy for designing cold-hardened seismic systems is driven by the need to maximize heat efficiency and minimize payload while maintaining continuous recording throughout the Polar winter. Our design is for a basic 2W autonomous system. Power is provided by a primary Lithium Thionyl Chloride battery pack and is backed by a secondary, solar charged AGM battery pack. Station enclosures are heavily insulated utilizing vacuum-sealed R-50 component panels and rely on instrument-generated heat to keep the dataloggers within operating specification. Although insulated, broadband sensors are operated close to ambient temperature.

In 2007, the NSF awarded a second MRI to IRIS as a result of intermediate results and successes with the autonomous station design MRI 2006. The purpose of this grant to IRIS is to begin establishing a pool of seismic instrumentation and station infrastructure packages designed to operate PASSCAL experiments in Polar Regions. Procurement has begun on this new pool and support of field operations have already begun on projects in Greenland and Antarctica. Along with the equipment, PASSCAL has now established a dedicated staff to polar projects to further enhance the support and quality of the data return from these challenging projects.

In conjunction with the MRI efforts, PASSCAL (in collaboration with the IRIS GSN and Quantarra) is developing an Iridium modem capability for the Quanterra Q330 datalogger. The system will be used for transmitting both state-of-health and daily file transfers and is being tested for integration into a standard full time telemetry link.

### **POSTER 4**

## AMBIENT NOISE RAYLEIGH WAVE GROUP VELOCITIES IN ANTARCTICA FROM A LARGE SCALE BROADBAND ARRAY

*Moira Pyle (Washington University in St. Louis), Douglas Wiens (Washington University in St. Louis), Andy Nyblade (Penn State University), Sridhar Anandakrishnan (Penn State University)*

We image the crust and uppermost mantle structure of the Transantarctic Mountains using Rayleigh wave group velocities obtained from the cross-correlation of ambient seismic noise. The data was recorded by the Transantarctic Mountain Seismic Experiment (TAMSEIS) which was the first large scale broadband seismic deployment in Antarctica. The stations ran from December 2000 until December 2003, but due to the difficulty of running seismic stations in such extreme conditions we often obtain only 40-100 useful days of data for any station pair. To obtain travel times between station pairs we first normalize the recorded data with a running absolute mean to remove the effect of any earthquakes and then cross-correlate day long segments of the vertical component. Correlelograms from each station pair are then stacked, and then the positive and negative time lags are averaged and filtered at a range of periods between 6 and 25 seconds. Errors for travel times measured from the filtered correlelograms are estimated using a bootstrap technique. We obtain good quality waveforms with high signal to noise ratios for station pairs located on both rock and ice.

Preliminary results include two cross-sections using station pairs from the array which fall along an East-West striking line and a North-South striking line. The North-South line includes 17 stations with roughly 80 km interstation spacing and the East-West line includes 16 stations with 20 km interstation spacing. We invert travel times from all available station pairs to obtain group velocities along each line. Each period is inverted separately. Along the North-South line the fastest velocities lie over the Belagica Subglacial Highlands while the slowest velocities correspond to the area over the Wilkes Subglacial Basin and may indicate a small amount of sediment infill. Along the East-West line, the thinner crust near the coast shows somewhat faster velocities than those further inland over thicker crust. We continue to work on the construction of group velocity maps and inversion for shear wave velocities.

### POSTER 8

## OVER-SEA-ICE SEISMIC REFLECTION SURVEYS IN ANTARCTICA USING A GI AIR GUN AND A SNOWSTREAMER

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During the austral spring-summer, 2005, approximately 28 km of over-sea-ice seismic reflection data were recorded over McMurdo Sound, Antarctica, in support of the ANtarctic geological DRILLing program (ANDRILL). The 2005 ANDRILL Southern McMurdo Sound (SMS) seismic survey used techniques that improved the quality of over-sea-ice seismic data. Previous over-sea-ice seismic experiments had limited success because of poor source coupling caused by thin sea ice, source bubble-pulse effects caused by explosive seismic sources placed in the water column, and ice flexural-mode noise caused by surface sources. To mitigate these problems, a Generator-Injector (GI) air gun was used as the seismic source. The GI air gun was lowered into the water column through holes drilled through the sea ice. The GI air gun provided good source coupling and minimized the source bubble effects and flexural mode problems that had plagued previous over-sea-ice experiments in polar regions. Moreover, a 60-channel seismic snowstreamer was employed to aid rapid data collection. During the austral summer, 2007, a Vertical Seismic Profile (VSP) seismic survey was conducted at the newly-drilled SMS Project borehole. The VSP survey used an air-gun source and demonstrated that high-quality borehole seismic data could be collected in a sea-ice environment. During the austral spring-summer, 2007, ANDRILL collected approximately 20.5 km of high-quality seismic reflection data in Granite Harbor. This survey incorporated and refined techniques of over-sea-ice seismic data collection that had been used previously during the ANDRILL SMS seismic site survey. This survey successfully located a thin succession of low-amplitude reflections atop the higher-amplitude granite basement reflections in the deepest parts of the valley that underlies Granite Harbor. The low-amplitude reflections are likely caused by layers of pelagic sediment. Future coring of these recent sediments could provide a high-resolution Quaternary climate record. In the austral spring-summer, 2008, an over-sea-ice multi-channel seismic reflection survey will be conducted in Offshore New Harbor to investigate the stratigraphic and tectonic history of westernmost Southern McMurdo Sound during the Greenhouse World (Eocene) into the start of the Icehouse World (Oligocene). This survey will use over-sea-ice seismic methods employed by ANDRILL's 2005 and 2007 surveys.

### POSTER 5

## SHEAR WAVE SPLITTING BENEATH LÜTZOW-HOLM BAY REGION, EAST ANTARCTICA AND SRI LANKA

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We investigate the upper mantle anisotropy using broad-band seismic data from 1996 to 2007 recorded at ten seismic stations in Lützow-Holm Bay (LHB), East Antarctica and Sri Lanka, and discuss the origin of the anisotropy, the history of the Antarctic plate motion and the effects of continental collision and/or break-up.

We calculate the splitting parameter ( $\delta$ ,  $\tau$ ) for teleseismic SKS, SKKS, and pSKS waves.  $\delta$  is fast direction of split shear wave and  $\tau$  is the delay time of two split waves. The splitting parameters are determined by minimizing the energy of the transverse component by net grid search technique with intervals of  $1^\circ$  and 0.1s, respectively. Additionally, we assume more complex models as a two-layer model with four independent parameters. The apparent splitting parameters are fitted by the four parameters ( $\delta_1$ ,  $\tau_1$ ,  $\delta_2$ ,  $\tau_2$ ), with index 1 corresponding to the lower layer and index 2 to the upper layer. For 7 stations except PAD, S16, and STR, azimuthal variations of the splitting parameters do exist. In this case, we modeled two-layer model of azimuthal anisotropy.

Investigations of seismic anisotropy may contribute to ideas about influence of recent or fossil mantle flows and/or the tectonic evolution of the study regions. Fast polarization directions of the lower layer are generally parallel to the directions of Absolute Plate Motion (APM) based on the HS3-NUVEL1 both LHB and Sri Lanka. We consider that it is reasonable that the structures of lower layers anisotropy might have been produced asthenospheric mantle flow.

The upper layers don't coincide with the APM direction (the difference is about  $70^\circ$ - $90^\circ$ ). The directions correspond well to polarization of NE-SW convergence direction between East and West Gondwana in Pan-African age. Furthermore, the spreading direction of the Gondwana break-up was NW-SE and the strike of the rift is generally parallel to continental margin. The fast polarization directions of upper layer are roughly parallel to the continental margin in LHB. Therefore, it is plausible that break-up processes affected the formation of anisotropy in the upper layer. The preexisting lithospheric structure may also influence the formation of the anisotropy during Gondwana break-up. We conclude that the upper layer anisotropy is caused by plate convergence during Pan-African time involving Gondwana assembly, subsequently modified by rifting and continental break-up.

### POSTER 3

## TELESEISMIC LONG-PERIOD RADIATION FROM MW 7.0 STICK-SLIP MOTION OF THE WHILLANS ICE STREAM, WEST ANTARCTICA

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Long period seismic waves radiated by ice motion, observed primarily from sources in Greenland but also from Alaska and Antarctica, have recently generated considerable interest. However, little is known about the specific mechanism by which glacial motion generates long period seismic waves. We combine surface wave observations with simultaneous Global Positioning System (GPS) measurements of ice displacement to study the tidally modulated stick-slip motion of the Whillans Ice Stream (WIS) in West Antarctica. Long period surface waves are observed at GSN seismic stations QSPA and VNDA, at distances of 600-1000 km, and geodetic observations result from the TIDES temporary deployment of 19 GPS receivers on the WIS in 2004. The geodetic observations confirm previous reports that a  $\sim 100$  km x 200 km region of the ice stream slips by up to 70 cm approximately twice per day, synchronized with the ocean tides in the Ross Sea. The seismic origin time corresponds to slip nucleation at a region of the bed of WIS that is likely stronger than surrounding regions, and thus acts like an “asperity” in traditional fault models. In addition to the initial pulse, two seismic arrivals occurring 10-25 minutes later represent stopping phases as the slip terminates at the ice stream edge and the grounding line. Seismic amplitude and average rupture velocity are correlated with tidal amplitude for the different slip events during the spring-to-neap tidal cycle. Although the total seismic moment calculated from ice rigidity, slip displacement, and rupture area is equivalent to an Mw 7 earthquake, seismic amplitudes are modest (Ms 3.6-4.2) due to the source duration of 20 to 30 minutes. Seismic radiation from ice movement is proportional to the derivative of the moment rate function within the band 25-100 s; very long period radiation is not detected due to the source geometry. Long period seismic waves from ice stream slip thus useful for detecting and studying sudden ice movement but are relatively insensitive to the total amount of slip.

### POSTER 9

## **MICROSEISMIC AND GEODETIC OBSERVATIONS OF ICE SHEET DYNAMICS**

*Paul Winberry (Penn State University), Sridhar Anandakrishnan (Penn State University)*

Fast-moving ice streams dominate discharge from the interior of large ice sheets. These narrow rivers of ice obtain their high velocity by rapid basal motion. However, this motion is unsteady in both time and space. We present observations of variable flow at a range of spatial scales from several Antarctic ice streams. We demonstrate the use of passive seismic data to study small-scale variations (meters) in basal friction by monitoring the seismic activity originating from the flow of the ice stream over its bed. In addition, we use GPS observations of surface motion to study large scale (hundreds of kilometers) stick-slip motion that is present in one Antarctic ice stream. These observations present unique opportunities to understand the dynamic flow of large ice streams.

### **POSTER 7**