Cryosphere (SIP)

C51A MCC: Hall C Friday 0830h

Recent Changes in the Antarctic Ice Sheet, Natural Variability, and Global Warming I Posters *(joint with A, H, OS, GC, PP)*

Presiding: **C Hulbe,** Portland State University**; A J Payne,** Centre for Polar Observation and Modelling

C51A-0917 0830h POSTER

Observation and Modelling of the Evolution of a Field of Rifts Near Hemmen Ice Rise, Ronne Iceshelf, Antarctica, Before the Rupture of Iceberg A38 on October 13th 1998.

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Hemmen Icerise, on Ronne Iceshelf, Antarctica, is at the origin of a large field of rifts, which were involved in the calving of iceberg A38 on October 13 th 1998. We use radar interferometric images collected by ERS 1 and RSAT 1 between 1992 and 2000 to observe the behavior of this field. From the interferograms generated, we retrieve important kinematic data, which we use to validate a model of ice deformation. This model is based on a viscous behavior of the iceshelf in which the rifts propagate according to a Linear Elastic Fracture Mechanics criterion.

We then reconstruct the entire sequence of events before the final calving. We are able to reach a good agreement with the observations on several points: 1) The propagation rates and the activity of the rifts are correctly evaluated throughout time. 2) The evolution of the iceflow around Hemmen Icerise is mapped adequately and plays a key role in the activation of rifts. 3) The acceleration of the active rifts and the onset of instability are determined with enough precision as to validate the LEFM theory behind our model. These results are an important step towards the setting up of a calving law for iceshelves.

C51A-0918 0830h POSTER

Progressive thinning of the Larsen Ice Shelf

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During the 20th century, the Antarctic Peninsula (AP) has experienced a considerable warming of climate, and several ice shelves have recently disintegrated. We used 9 years of European Remote Sensing (ERS) satellite radar altimeter measurements to determine the elevation change of the Larsen Ice Shelf (LIS), the most northerly ice shelf at the AP. We removed the periodic signal of ocean tide using a model derived from the same ERS dataset. Since 1992, the surface of the LIS has lowered by up to 0.27 +/- 0.17 m each year. This elevation change corresponds to 21 +/- 13 m of ice thinning, or 6 % of the ice shelf thickness. The thinning preceded the 2002 collapse of the Larsen B and has progressively weakened the remaining Larsen C, so that within 40 years it too may undergo a similar collapse.

C51A-0919 0830h POSTER

Short-Term Sensitivity of Sub-Antarctic and Global Thermohaline Ocean Circulation to Disintegration of West Antarctic Ice Shelves

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We began using a numerical ocean-circulation model to investigate the degree to which sub-Antarctic and global thermohaline circulation can be perturbed by disintegration of large West Antarctica ice shelves (RIS = Ross Ice Shelf and RFIS = Ronne-Filchner Ice Shelf). Ice shelves represent the most vulnerable element of the Antarctic ice sheet. They may undergo near-future disintegration due to the recent decrease in ice influx from the surrounding ice sheet combined with an enhanced basal and surface melting triggered by warming of ocean and atmosphere. For instance, ice inflow into RIS decreased by about one third in the last 200 years and it is still shrinking. If a general retreat of RIS and FRIS would occur, one mln km^2 of additional shallow sea area would become exposed to sea-ice production. Since brine rejection during sea-ice freezing is believed to be an important mechanism driving thermohaline circulation, thermodynamic consequences of the conjectured ice-shelf disintegration could be felt regionally and globally. Several numerical experiments spanning <50 years of model time were performed using the coupled sea-ice and ocean circulation model (CICE-POP) developed at LANL. Each run requires about a week of computational time on a LANL high-performance computer. We evaluate how ocean circulation may respond to disintegration of RIS and FRIS by analyzing difference maps of fundamental oceanographic variables. The difference maps are constructed using output from a baseline run, in which the two ice shelves were retained, and from test cases, in which the ice shelves are removed. We examine several test cases to check the sensitivity of our results to different boundary conditions. Preliminary results from our numerical experiments indicate that sub-Antarctic ocean circulation is significantly altered by removal of the two ice shelves, particularly in the sector along the axis RIS-Antarctic Peninsula-FRIS. There, sea-surface temperatures decreases by about 1° C and ocean salinity increases by up to 0.5 psu within just a few decades. Further afield, meridional water flux increases by more than 50% in the bottom parts of the Southern Ocean. These circum-Antarctic changes are accompanied by smaller global effects. Their magnitude may be muted by the fact that we are examining a relatively short time period (<50 years). We conclude that disintegration of the two large West Antarctic ice sheet would have immediate and significant consequences for ocean circulation (and presumably for climate patterns) at least in the Southern Hemisphere.

C51A-0920 0830h POSTER

Climatically-Driven Migration of Ice-Stream Margins as the Main Cause for Holocene (and Future?) Decay of the West Antarctic Ice Sheet

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Large and fast-moving ice streams carry almost all of the ice mass draining out of the West Antarctic Ice Sheet (WAIS). It is expected that changes in the ice-stream drainage system are responsible for the high sensitivity of WAIS to climate variations. For instance, this ice sheet shrank drastically in volume in response to the global warming that marked the end of the Last Glacial Maximum (LGM, ∼20,000 years ago) while its East Antarctic counterpart changed much less within the same time period. It is also expected that the response of WAIS to future climate changes will be dominated by the behavior of fast-moving ice streams. Yet, the mechanism through which ice streams change their discharge and geometry after a large global warming is unclear. Here, I conjecture that the main mechanism connecting ice stream dynamics to climate variations is the thermally-driven migration of ice-stream margins. In my model, the margins are assumed to represent a lateral boundary in basal thermal regimen, with basal melting occurring on the ice-stream side and basal freezing beneath adjacent, slow-moving interstream ridges. After a climatic warming event, the thermal signal is propagated gradually to the bed of interstream ridges, pushing their basal thermal regimen toward basal melting. In response, lateral ice-stream margins can migrate outward to incorporate parts of interstream ridges and increase ice-stream width. Since ice-stream velocity is highly sensitive to ice-stream width, even relatively small (∼1-10%) increases in width may lead to large (∼10-10000%) increases in velocity. Increased ice stream discharge may trigger general ice-sheet thinning and grounding line retreat. The proposed mechanism provides a highly sensitive connection between climatic warming and WAIS behavior. It also suggests that modern ice streams may increase their width and discharge in the future since the post-LGM climatic warming is still being propagated to the bed of interstream ridges.

C51A-0921 0830h POSTER

Temporal Changes in Spatial Distribution of Basal Melting and Freezing in the Catchment Areas of Whillans Ice Stream and Ice Stream C, West Antarctica: Interplay of Climatic Changes and Ice Dynamics

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Basal thermal regimen of West Antarctic Ice Sheet (WAIS) plays the key role in determining the dynamics and stability of this ice sheet. Basal melt water lubricates the ice base allowing fast ice streaming while basal freeze-on increases basal resistance to ice flow. Within WAIS, basal melting is dominant in the interior, where geothermal heat is trapped underneath ∼2-to-4-km-thick layer of ice. Basal freeze-on is dominant beneath the slow moving, ∼1-km-thick interstream ridges separating fast-moving ice streams. There, conductive heat escape through exceeds the geothermal flux and basal frictional heating is low. Using a time-dependent basal energy balance model (Vogel et al., in press) we examined spatial and temporal distribution of basal melting and freezing in the catchment areas of Whillans Ice Stream and Ice Stream C since the Last Glacial Maximum (LGM, ∼20,000 years ago). Model results indicate that basal melting peaked despite lower surface temperatures during late LGM (∼15,000), due to a thickened ice sheet (Steig et al., 2001). This widespread and abundant basal lubrication may have initiated the retreat and thinning of the ice sheet that continued through the Holocene. However, the ice-sheet thinning itself caused gradually a general decrease in basal melting rates in spite of higher Holocene surface temperatures. This reduction in basal water production may be responsible for the recent stoppage of Ice Stream C and slow down of the Whillans Ice Stream. Our modeling results indicate that WAIS is still adjusting to the significant climate warming that marked the end of the LGM and the beginning of Holocene. Only the thinnest portions of the Whillans Ice Stream and Ice Stream C (<1 km) might have adjusted enough to cause locally significant basal freeze-on and to, at least temporarily, slow the ice sheet decay (Joughin and Tulaczyk, 2002). Basal thermal regimen of the rest of WAIS is changing in such a way as to favor increased basal melting, and presumably further ice-sheet decay, in the near future (e.g., Engelhardt, pers. communication). Evaluation of near-future contribution of WAIS to sea-level changes has to take into account the delayed response of the ice sheet to the large global warming that took place at the LGM-Holocene boundary.

C51A-0922 0830h POSTER

Modeling the Transition from Inland to Ice-stream Flow in West Antarctica

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Fast-flowing ice streams evacuate slow-moving inland ice from the interior of West Antarctica and have a controlling influence on the mass balance of the ice sheet. Discharge through the ice streams may be controlled by the rate at which inland ice passes through

the onset regions. Recent studies suggest that the transition from inland- to ice-stream flow may migrate inland over time, although the causes for such behavior are unclear. One result of such migration would be ice stream lengthening and increased mass discharge over time. An improved understanding of the physics that control onset regions seems a necessity for assessing the future balance state of the West Antarctic Ice Sheet. We address the following questions: (1) Are the ice stream onsets "fixed" spatially, or can they migrate over time? (2) What physical controls and processes are important in determining the fixed or migratory nature of the onsets? (3) What range of behaviors might the onsets exhibit over time? (4) What are the relative importances of external conditions (e.g. bed morphology, geothermal flux) versus those related to ice flow (e.g. basal temperature gradient, frictional melting, basal hydraulic potential gradient) in establishing and controlling the inland- to ice-stream-flow transition. We formulate a 2-D "flowband" (vertical and along-flow coordinate) model using Control-Volumes. We account for motion within the ice and at the ice-bed interface; diffusion and advection of heat; frictional-heat generation and basal melting; partitioning of resistive stresses between basal drag, longitudinal-stress gradients, and drag from the lateral margins; and feedbacks between stresses in the ice and conditions at the ice-bed interface. Future advances in modeling will allow ice streams to evolve naturally, from the physics specified in the model, rather than requiring them to be specified a priori.

C51A-0923 0830h POSTER

Three-dimensional Ice Velocities Derived from Multiple Look Direction InSAR: An Example from Ice Stream A, West Antarctica

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Two mapping campaigns of the Antarctic Ice Sheet have been completed using the Radarsat-1 SAR. The first Radarsat Antarctic Mapping Project (RAMP) acquired data over a 30-day period in the fall of 1997 providing a static "snapshot" of the entire ice sheet. Since Radarsat-1 has a 24-day orbit cycle, repeat-pass interferometric SAR (InSAR) data were also acquired for large portions if the ice sheet, permitting ice surface velocities to be derived. Crossing InSAR swaths close to the South Pole have provided the first opportunity to study surface velocity using multiple look directions, rather than the conventional two (ascending and descending) look directions. This has permitted us to derive ice velocities for all three dimensions without the need for a surface parallel flow assumption. We present our technique and compare our three dimensional results to conventional ascending/descending surface parallel flow assumption results, particularly in regard to vertical ice motion. Our study is centered on Ice Stream A, West Antarctica, giving us an insight into the implications for ice sheet and ice stream velocity mapping.

C51A-0924 0830h POSTER

Analysis of 2001 US-ITASE Traverse Deep-Penetrating Radar Studies in West Antarctica

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The 2001 US-ITASE traverse route covered 835 km from Byrd Surface Camp to Pine Island Glacier (PIG), crossing the Ross Sea/Amundsen Sea (RS/AS) divide and the PIG/ Rutford Ice Stream divide at two separate locations and recording bed topography and internal layers along most of the route. In regions where previous radar data have been available our bed topography corresponds well with the BedMap dataset. Elsewhere, disagreements as high as 50 percent, but generally less than 20 percent of the ice thickness, appear to be the result of interpolation necessary in creating BedMap where no data previously existed. These results have implications for those developing regional or continental-scale ice flow models based on BedMap.

The location where the traverse crossed the RS/AS divide is just south of the proposed inland West Antarctic Ice Sheet (WAIS) deep core location. One of our goals is to assist in characterizing the ice sheet flow in the vicinity of the proposed deep core site and at other divide locations. Using the deep-penetrating radar data taken along the traverse, we have analyzed the internal ice stratigraphy to make a preliminary investigation of ice flow and ice divide stability at the RS/AS and PIG/Rutford Ice Stream divides. Ice divide stability is a key factor in determining where an ice core should be drilled. Cores should be drilled where the ice flow and accumulation history are well known in order to interpret the ice core record. A qualitative inspection of ice internal stratigraphy near the RS/AS divide indicates possible changes in local or regional ice velocity and/or ice accumulation rates. These factors should be taken into account when determining the location for the Inland WAIS Deep Core drill site.

C51A-0925 0830h POSTER

A Challenge to the Detection of Regional to Local Scale Ice Sheet Movements in JARE Research Area by the Combination of GPS and Precise Gravity Measurements

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The successful launch of CHAMP (CHAllenging Mini-satellite Payload) in 2001 and GRACE (Gravity Recovery And Climate Experiment) in 2002 has opened a new era of satellite gravimetry. Especially, GRACE and its follow-on missions will provide not only data for precise gravity mapping but also time series of global gravity fields coefficients. These data are precise enough to reveal the temporal variations of the gravity fields due to mass redistribution in and on the Earth, and will contribute to the understanding of various problems in the Earth sciences, i.e., meteorology, hydrology, oceanography, glaciology as well as the solid Earth sciences (NRC, 1997; Wahr et al., 1998).

Of particular importance in the Antarctic region is the studies of ice sheet mass balance and/or postglacial rebound related to sea level changes and global water circulation. The data sets will impose a strong constraint on these issues in terms of total mass conservation (Wahr et al., 2000).

The Antarctic region is also expected to become a promising CAL/VAL (Calibration/ Validation) field (Shum et al, 2001). In general, CAL/VAL of gravity satellite data by means of ground base observations is not an easy problem, because of extreme high precision of the satellite data and strong locality of in-situ gravity data. In Antarctica, expected gravity signals mainly due to the ice sheet movements are relatively large in amplitude and comparatively simple for modeling. Besides these, the detection of mass changes due to regional to local scale ice sheet movements is a challenging study for both satellite gravimetry and in-situ precise gravity measurements.

The ice sheet thinning rate of the Shirase Glacier drainage basin in the JARE (Japanese Antarctic Research Expedition) research area is estimated about 10-20 cm/year. Although the corresponding gravity signal is relatively large, the detection of the signal still requires very careful gravity measurements. Moreover, there are several problems to be solved in precise gravity measurements on the ice sheet.

In this paper, we first introduce the JARE research area and several observations conducted by JARE. Then, estimating the expected gravity signal due to the ice sheet movements in the area, we proposed an effective configuration of in-situ precise gravity measurements, which consists of 20-30 gravity survey sites with several tens kilometer interval. In each site, at least one absolute gravity measurements and precise GPS measurements are conducted as well as several surrounding relative gravity measurements with a kinematic GPS positioning system. These measurements will contribute not only for glaciological studies, but also for CAL/VAL purpose of the gravity mission data.

C51A-0926 0830h POSTER

An Application of Kriging Method to Study Ice Volume Changes Using ERS Radar Altimetry Data

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In preparation for laser altimetry data produced by the Geoscience Laser Altimeter System (GLAS) on board of the Ice, Cloud, and Land Elevation Satellite (ICESat), we will apply kriging method to existing radar altimetry data from the two European Remote Sensing Satellites missions ERS-1 and ERS-2 to study elevation change in Antarctica. Our primary goals are to investigate the extent to which radar altimetry can resolve ice-volume change due to annual and long term effects, and to test softwares which will be used for GLAS. Previously known problems associated with ice-sheet roughness anisotropy, slope distribution anisotropy will be addressed in modeling anisotropic covariance functions. We will use previously calculated topography models based on ERS-1/ERS-2 as our a-priori information and compare and cross-check our elevation change results with those done in parallel by Zwally et al [*2001*] based on other techniques. A comparison summary of different techniques used to study ice-volume balance will be presented to demonstrate the effectiveness and/or advantages/disadvantages of using kriging.

C51A-0927 0830h POSTER

Three Stage Ice Sheet Recession as Recorded by Swath Bathymetry in the Mertz Trough: East Antarctica

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A multibeam swath bathymetric survey of 5000 km^2 was conducted off the George V (eastern Wilkes Land) Coast, East Antarctica in January-February 2001. We focused our efforts within a prominent cross-shelf trough (The Mertz Trough) that served as the axis of ice drainage during past glacial advances. The bathymetric data illustrate, in unprecedented detail, three stages of glacial recession in this area of East Antarctica. Evidence of an ice stream formed during glacial maximum is shown by the presence of mega-scale glacial lineations, which trend due north within the main axis of the Mertz Trough. Two pauses in glacial recession are shown by two prominent grounding-line wedges (submarine moraines). The grounding-line wedges contain superimposed lineations that are clearly associated with, but aligned obliquely to, the older set of mega-scale glacial lineations. The younger lineations are aligned towards the northeast as opposed to towards the north, indicating a change in the ice-flow direction as ice receded landward. The grounding-line wedges range from at least 10 km to over 30 km in length and are 30-80 m in height, their crests trend in a northwest-southeast direction. These wedges are clearly dissected by a channel system, which originates on the landward side and terminates in a seaward direction as marked by a circular depression and sediment fan, respectively. We suggest that meltwater eroded into one of the grounding-line wedges, which formed a breach point, and deposited sediment into a fan in the seaward direction. This event is clearly associated with, but postdates, most of the grounding-line wedge accretion; therefore suggesting that meltwater outburst was associated with the final stages of ice recession from the moraines. The ice has since retreated southward into its present drainage pattern defined by the Mertz and Ninnis Glacier Tongues. In addition we collected seismic surveys and seafloor sediment cores in the region. These data are used to illustrate the stratigraphy of the Mertz Trough, which is divided into two units. The lower unit, a diamicton, was deposited directly by the ice and the upper unit, a diatom mud and ooze, was deposited after the ice retreated. Evidence of a period of expansion of the Mertz and Ninnis Ice Tongues is shown in the upper unit by three periods of iceberg rafting events and an increase in terrigenous sediment. Nine radiocarbon dates were used to show that this occurred about 2000 years ago. The most recent deposition in the Mertz Trough consists of diatom mud without the presence of ice rafted debris.

We acknowledge the use of some swath data provided by Stan Jacobs (Lamont Doherty Geological Observatory).

C51A-0928 0830h POSTER

Reconstructing the Maximum Extent of Glacial Systems and the Nature of their Retreat in Marguerite Bay, Antarctic Peninsula, Since the Last Glacial Maximum (LGM). Preliminary Results from Nathaniel B. Palmer Cruise 2002 (NBP0201)

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Models suggest that up to 2 km of ice may have been lost from the Antarctic Peninsula since the LGM. Marguerite Bay trough potentially represents the largest paleo-ice drainage outlet in the Peninsula region. Current work indicates that ice system behavior may be largely controlled by subglacial geology. Marguerite Bay ice stream has completely retreated from the trough, providing a unique opportunity to investigate the maximum extent of the glacial systems within the bay, the nature of their retreat and the interaction of the paleo-ice systems and substrate. The nature of the retreat of both the palaeo-ice stream and the subsequent ice shelf is investigated from the onset of streaming on the inner shelf to the shelf break.

Geological and geophysical data were acquired during the NBP0201 Peninsula cruise to complement our existing dataset. Data includes multibeam swath bathymetry, high-resolution 3.5 kHz and intermediate-resolution seismic and deep tow side-scan sonar data and 23 sediment cores. Preliminary results include geomorphic evidence of grounded ice at the shelf break in the form of mega-scale glacial lineations and line-sourced shelf break gullies. A link between subglacial geology and paleo-ice behavior has been identified. A succession of geomorphic features grades from erosional bedrock forms on the crystalline inner shelf, to drumlin fields in the transition zone, to depositional mega-scale glacial lineations on the sediment covered outer shelf. Previous work suggests that this succession is indicative of slow ice sliding in the erosional zone, accelerating ice flow in the transition zone where sediment begins to accumulate, and relatively fast moving ice on a deformable bed in the depositional zone respectively. Evidence of subglacial meltwater exists on the inner shelf in the form of interconnected anastomosing channels. Conclusions reached include evidence of grounded ice on the outer shelf, evidence of a strong subglacial geological control on paleo-ice behavior and evidence of an organized sub-ice sheet meltwater system.

C51A-0929 0830h POSTER

Geomorphic and Sedimentary Imprint of an Antarctic Peninsula Palaeo-Ice Stream

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The Marguerite Trough ice stream was a marine-based ice stream that flowed west from the Antarctic Peninsula to the continental shelf edge at the last glacial maximum. The ice stream drained an area of about 60,000 km2, was 75-80 km wide, 370 km long, and was responsible for an ice flux of about 22 km3 per year. Swath bathymetry, TOPAS sub-bottom profiler data and vibrocores have allowed a detailed picture of the former ice-stream bed to be obtained. Subglacial bedforms record the passage of the ice stream through the trough. The longest bedforms are mega-scale glacial lineations up to 17 km long, which occur over a "soft-bed" on the outer shelf. The lineations are formed in an acoustically transparent, sediment layer that is composed of a soft (shear strengths of 0-0.4 kg per cm2) massive, matrix-supported diamict facies containing striated clasts. This overlies a much stiffer (shear strengths commonly greater than 1 kg per cm2), massive matrix-supported diamict facies. Mega-scale glacial lineations formed in the soft diamict indicate that it is of subglacial origin and it is interpreted as a deformation till, formed, at least partially, by subglacial cannibalization of the underlying stiff diamict. Using TOPAS and core data, the extent and thickness of the deformation till layer has been mapped throughout Marguerite Trough. The till layer is up to 19 m thick and is confined to the outer-shelf trough. Based on the thickness of the layer and its association with mega-scale glacial lineations, it appears that the zone of fastest flow within the ice stream occurred over the area of the trough floored by deformation till. Massive silty-clayey muds overlie the till and record a transition from subglacial to glacimarine, probably ice shelf, conditions. Rapid deglaciation is indicated by an absence of coarse-grained ice-proximal glacimarine lithofacies, the well-preserved nature of the subglacial bedforms, and absence of recessional moraines or zones of cross-cutting bedforms. Diatomaceous muds cap the cores and record a transition to an open-marine environment.

C51A-0930 0830h POSTER

Composite Ice Sheet Temperature Record From In Situ and Satellite Data Sets, Siple Dome, West Antarctica

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During December 1996, ice core drilling activities were begun at Siple Dome, West Antarctica. In January 1997, the University of Wisconsin installed an automatic weather station (AWS) at Siple Dome as part of its Antarctic Meteorological Research Center?s (http://uwamrc.ssec.wisc.edu/aws/) network of instruments. A multi-year to decadal-length temperature record is needed to accurately calibrate ice core proxy temperature data (stable isotopes of hydrogen and oxygen) among other things. As part of an ongoing research activity, a composite temperature record has been developed using infrared temperatures (TIR) and passive microwave brightness temperatures (TB) in conjunction with near-surface measurements (TA) from the AWS.

The intent of this research was to define a new technique that can be applied at other Antarctic and Greenland sites. This effort builds on a published emissivity modeling technique that uses TA and TB data (e.g. Shuman et al., 1995) and recently developed TIR data (e.g. Comiso 2000). All three data types have various limitations: 1) the TA record is relatively short and may have data gaps; 2) the TIR record requires calibration and has data gaps due to clouds; and 3) the TB record requires calibration especially due to periods of emissivity variability related to melt events. Emphasis was also placed on understanding the uncertainty of the resulting temperature record so that confidence in these data could be maximized.

The resulting data set provides a daily-average temperature time series for the Siple Dome site with constrained uncertainties. It effectively minimizes the limitations of all three types of input data. The time series covers more than 20 years as it begins in 1981 and extends through 2001. Daily, monthly, seasonal, and annual average values have been calculated and trend analysis has been conducted.

URL: http://uwamrc.ssec.wisc.edu/aws/

C51A-0931 0830h POSTER

Influences of the Southern Annular Mode and the El Nino-Southern Oscillation on Antarctic climate and Their Expression in Remotely-sensed Climate Data

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We show that much of the interannual variability in Antarctic surface temperatures of the last two decades can be explained by the influences of two well-known features of large-scale climate variability, the Southern Annular Mode and the El Nino-Southern Oscillation. Several recent studies have found strong evidence connecting these modes to Antarctic surface climate [e.g. Thompson and Solomon, 2002; Kwok and Comiso, 2002; Schneider and Steig, 2002 in press] and have suggested that changes in these modes have contributed to the warming and cooling trends observed in different regions of Antarctica. Thus an understanding of the major factors affecting Antarctic climate is important in evaluation of the dynamic response of the Antarctic ice sheet to climate change. The first goal of this study is to show the relative contributions of these modes to the overall temperature variability of Antarctica and to highlight the spatial patterns of temperature anomalies that they produce. Secondly, as a means of assessing the reproducibility of the spatial patterns and the quality of remotely-sensed data over Antarctica, we present statistical comparisons between two data sets covering the Antarctic continent, the infrared-based AVHRR surface temperatures and passive microwave brightness temperatures at 37 GHz vertical polarization from the SMMR and SSM/I satellites. Principal component analysis (PCA), singular value decomposition analysis, and other statistical methods demonstrate that the two data sets share much of the same variance and reflect the same climatic influences. However, some attention must be paid to spatial-temporal contrasts in microwave emissivity when interpreting the later data set. An interesting consequence is that strong emissivity changes due to surface melting can efficiently identified with PCA, forming a rough index of the strength of annual melt seasons. After accounting for melting signals, the two data sets have similar first and second EOFs which in turn are each closely related to the modes in the NCEP-NCAR reanalysis pressure and temperature fields that describe the Southern Annular Mode and ENSO connections with Antarctica. Longer records such as ice cores are needed to confirm the importance of these modes in forcing Antarctic temperatures (and thus the ice sheet itself) and to understand their variability through time.

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C51A-0932 0830h POSTER

Interannual (AAO, ENSO, etc) Antarctic Tropospheric Circulation and Precipitation Variability

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Main modes of variability of the Antarctic tropospheric circulation (500 hPa geopotential height) and precipitation are identified through their Empirical Orthogonal Functions (EOF). This is done by combining various sources of information, including meteorological analyses and forecasts (NCEP and ECMWF), atmospheric general circulation model (LMDZ) simulations, and satellite data (GPCP). Unlike previous similar work on circulation variability, the mode analyses are restricted to the Antarctic region. The main modes that relate the Antarctic region to the mid and tropical latitudes, e.g. in association with ENSO, are nonetheless clearly identified and thus robust. The contribution of the sea-surface or of the circumpolar Antarctic atmospheric dynamics to the occurrence and to the chronology of these modes is evaluated through various atmospheric model simulations. EOF analyses results are somewhat less stable, across the various datasets, and more noisy for precipitation than for circulation. Yet, through moisture advection considerations, the 2 most significant precipitation modes can be well related to the 3 main modes of circulation variability. The signatures of both the Southern Oscillation Index (SOI) and the Antarctic Oscillation Index (AOI) are found in one same precipitation mode, suggesting that they have a substantially common spatial structure. In addition, the relative strength of the signature of the AOI and SOI appears to change in time. In particular, the signature of the SOI was weak in the 1980s precipitations, but turned very strong in the 1990s. Common spatial patterns and variable strength in time may explain why hints of an ENSO signature in Antarctic precipitation have been reported but not unequivocally demonstrated so far.

C51A-0933 0830h POSTER

Data holdings of the Antarctic Glaciological Data Center

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The National Science Foundation's Office of Polar Programs funds the Antarctic Glaciological Data Center (AGDC) at the National Snow and Ice Data Center (NSIDC) to archive and distribute Antarctic glaciological and cryospheric system data collected by the U.S. Antarctic Program.

In an effort to better understand past, present, and future temperatures and mass balance of the ice sheet, the AGDC, working from data contributed by numerous Principle Investigators, has developed the Antarctic Ten Meter Temperature Data set (THERMAP): Firn temperature at a depth of around ten meters gives a close estimate of the mean annual surface temperature at that location. However, recent field and remote sensing work suggest that the temperature field over the ice sheet may be modified by local topography. The Antarctic Ten Meter Temperature Data set is a compilation of measurements dating back prior to IGY. The data are represented with a map showing the traverse route, station location and temperature measurement. Data can also be viewed in tabular form, which includes data sources, information on data acquisition techniques, and additional measurements made at each site, such as density and accumulation.

In addition, the AGDC's data holdings include data sets collected by individual investigators on specific grants, and compiled products assembled from many different P.I. data sets, published literature, and other sources. Data sets are available electronically on our Web site, http://nsidc.org/agdc/, from which users can access the data, plus find useful documentation, citation information about the P.I.(s), locator maps, derived images and references.

Examples of "P.I." data sets at the AGDC:

Tephra in Siple and Taylor Dome Ice Cores, Dr. Nelia Dunbar

Central West Antarctic Glaciochemistry from Ice Cores, Dr. David Reusch

Snow and Firn Temperature and Permeability Measurements from Siple Dome, Antarctica, Dr. Mary Albert

Examples of compiled products at the AGDC include:

Antarctic Ten Meter Temperature Data (THERMAP archive)

Antarctic Ice Velocity Data (VELMAP archive)

BEDMAP archive (An ice thickness and subglacial topographic model of the Antarctic)

WAISCORES Data (ice cores from the West Antarctic Ice Sheet)

URL: http://nsidc.org/agdc

C51A-0934 0830h POSTER

The Ice Core Data Gateway: The one stop gateway to ice core data held at the Antarctic Glaciological Data Center (AGDC), the World Data Center for Paleoclimatology, and the Arctic System Science's Data Coordination Center (ADCC).

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The Ice Core Data Gateway archives and distributes physical and geochemical data from ice cores collected in both the northern and southern hemispheres.

Typical data sets include age-depth relationships, oxygen and hydrogen isotope concentrations, major element chemistry, accumulation rates and pollen. The data are in general presented as ASCII files with a short text metadata description.

The archive is designed to provide access to ice core data sets over the long term, thereby making them available for comparison with future data: a critical component of change detection studies. By facilitating broad data access, the center promotes interdisciplinary scientific research.

Investigators are encouraged to contribute data sets derived from ice cores to the Ice Core Data Gateway. Data center staff will work with you to compile data set documentation prior to making the data available to users. Contributing scientists are given prominent recognition in the documentation, and while the data center answers technical questions about format, citations for usage, etc., it can refer scientific questions to contributors if requested. Contributing your data to the Ice Core Data Gateway and associated data centers directly supports to NSF Office of Polar Programs Guidelines and Award Conditions for Scientific Data (http://www.nsf.gov/pubsys/ods/getpub.cfm?opp991).

This effort is being coordinated with the West Antarctic Ice Sheet (WAIS) Initiative and U.S. component of the International Trans Antarctic Science Expedition (ITASE), and includes data from the Arctic System Science Program's Greenland Ice Sheet Project 2 (GISP2) ice core.

URL: http://www.ngdc.noaa.gov/paleo/icgate.html

C51A-0935 0830h POSTER

The Antarctic Master Directory – a resource for Antarctic Scientists

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Under the auspices of the Antarctic Treaty, a group of nations conducting Antarctic scientific research have created the Antarctic Master Directory (AMD), a resource for Antarctic scientists. The AMD is a Web-based, searchable directory containing data descriptions (metadata in the form of DIF entries) of Antarctic scientific data, and is a node of the International Directory Network/Global Change Master Directory (IDN/GCMD). The data descriptions in the AMD, essentially a data catalog of Antarctic scientific data, include information about what data were collected, where they were collected, when they were collected, who the scientists are, who the point of contact is, and information about the format of the data and what documentation and bibliographic information exists.

As part of the AMD effort, the National Science Foundation Office of Polar Programs (OPP) funds the National Snow and Ice Data Center to operate the U.S. Antarctic Data Coordination Center (USADCC), the US focal point for the AMD. The USADCC assists PIs as they meet the requirements of the OPP "Guidelines and Award Conditions for Scientific Data", which identify the conditions for awards and responsibilities of PIs regarding the archival of data, and submission of metadata, resulting from their NSF OPP grants. The USADCC offers access to free, easy-to-use online tools that PIs can use to create the data descriptions that the NSF policy data requires. We provide advice to PIs on how to meet the data policy requirements, and can answer specific questions on related issues. Scientists can access data set descriptions submitted to the AMD, by thousands of scientists around the world, from the USADCC web pages.

URL: http://nsidc.org/usadcc

C51A-0936 0830h POSTER

Ice Shelf Elevation Changes due to Atmospheric Pressure Variations

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Floating ice shelves undergo vertical motion as a result of the response of the underlying ocean to changes in atmospheric pressure (P_{air}). This response is known as the inverse barometer effect (IBE). Open-ocean measurements of P_{air} and sea level agree with the theoretical response of 1 cm per millibar for low frequency variability of P_{air}. Here we demonstrate, using simultaneous records of P_{air} and GPS measurements of surface elevation (h_{IS}) from several ice shelves, that shelves experience a response of similar magnitude. A simple correction for the IBE is justified for ice shelf response to low-frequency (ω <0.5 cycles per day) of P_{air}. At higher frequencies the IBE becomes weaker. The IBE contribution to h_{IS} can exceed 50 cm, with typical magnitudes of 10-20 cm. Although the IBE is usually smaller than the tidal contribution to h_{IS}, the tide can be removed with current Antarctic tide models with an accuracy similar to the IBE. Global atmospheric models, however, do not presently predict P_{air} with sufficient accuracy to be used to correct measured variability of h_{IS}. Thus, in the absence of concurrent *in situ* P_{air} data, the IBE is a major source of error in correcting ice shelf heights for tasks such as deriving mean ice flow rates from SAR imagery, and measuring long-term trends in ice shelf height from satellite altimeters.

URL: http://www.esr.org/antarctic/IBE.html

C51A-0937 0830h POSTER

InSAR-derived grounding features of the Amery Ice Shelf, East Antarctica

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Differential SAR interferometry has the potential to delineate the location of the grounding lines of the Antarctic ice shelves, at unprecedented resolution. Using the available ERS SAR data, we have mapped 50-60% of the Amery Ice Shelf grounding zone. Usually the location of the grounding zone determined from SAR with this technique is identified based on the fringes which correspond to the limit of flexing of ice due to ocean tidal effects. However in one interferogram we show that the tidal contribution to the signal is small and instead, changes in sea level caused by changing atmospheric pressure (the "inverse barometer effect") make up most of the signal. In this interferogram we identify an ephemeral grounding point close to the eastern margin, and calculate the water column thickness there. In addition we discuss field measurements to be made on the ice shelf to help further interpret further the features we observe in the interferograms. In the southern limit of the grounding zone, we compare the location given by SAR with that from a hydrostatic assessment using ERS radar altimetry and airborne radio-echo sounding data.

C51A-0938 0830h POSTER

Interferometric Mapping of the Velocity of the Antarctic Ice Sheet Using ERS Tandem Phase Data

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Over 2500 minutes of synthetic aperture radar (SAR) data suitable for interferometric analysis were collected over Antarctica during the ERS tandem mission in late 1995 and early 1996. We have processed a large subset of this ERS tandem dataset recorded at the US McMurdo Reception Facility (and archived at the Alaska SAR Facility) to produce estimates of ice motion. Spatial coverage includes a large part of West Antarctica between the Antarctic Peninsula and the eastern Ross Ice Shelf, and the part of East Antarctica between the western Ross Ice Shelf and the Amery Ice Shelf north of 80S. Velocity maps are created by blending interferometric observations with available temporal baselines of 1-, 35-, 36-, 70-, and 71-days. The longer baselines provide estimates of velocity with accuracy of better than 1 m/yr and thus give a first glimpse of the velocity field at higher elevations. The blending methodology, the control of the velocity field, the assessment of the data quality, and the spatially dependent error field are discussed. Preliminary large scale comparisons of our results with lower resolution balance velocity fields show interesting differences between the patterns and the magnitude of motion fields. Anomalies in the observed velocity field are highlighted.

C51A-0939 0830h POSTER

Widespread thinning of the Amudsen Sea sector of West Antarctica

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We present a synergistic analysis of interferometric synthetic-aperture radar (InSAR) observations of ice flow at the grounding line and satellite radar altimetry (SRA) observations of elevation change to determine the present evolution of the Amundsen Sea sector of West Antarctica. InSAR reveals that the grounding line of large glaciers is retreating rapidly, which indicates thinning; and that several major glaciers are accelerating, hence increasing their contribution to sea level rise with time. The calculated mass budget of the two largest ice streams, Pine Island and Thwaites glaciers, is certainly negative, but even larger imbalances are

calculated for smaller glaciers such as Smith, Kohler, DeVicq and Land. SRA observations confirm that the elevation of this sector of the ice sheets is decreasing with time, with thinning larger nearer to the coast and propagating hundreds of km inland. The combination of mass budget and elevation change suggest that this sector of Antarctica is losing enough mass to raise global sea level by 0.2 mm/yr. In addition, SRA reveals that large sectors of ice shelves are thinning rapidly, up to 4 m/yr on Dotson ice shelf. Melting of the ice shelves does not raise sea level, but the ice shelves may exert some control on the ice discharge from the glaciers. If the ice shelves buttress the glaciers, the contribution to sea level rise of this sector of Antarctica may be larger in the future.

C52A MCC: 123 Friday 1330h

Recent Changes in the Antarctic Ice Sheet, Natural Variability, and Global Warming II *(joint with A, H, OS, GC, PP)*

Presiding: **S Tulaczyk,** University of California, Santa Cruz**; A Shepherd,** Scott Polar Research Institute

C52A-01 1335h INVITED

On the sensitivity of the Antarctic Ice Shelves to a Warming Ocean

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The underside of ice streams flowing from the Antarctic continent typically melt into the ocean where they cross the grounding line and begin to float as ice shelves and ice tongues. Melting is governed by the transport of ocean heat and by the seawater freezing point dependence on pressure. The resulting melt water participates in the ventilation of the deepest parts of the ocean. Here, we calculated bottom melt rates of > 25 of the largest glaciers in Antarctica, combining satellite radar interferometry with other data, and compared the results with thermal forcing from the ocean. Melt rates are calculated close to grounding lines of deep-draft glaciers because discharge of contineral ice is principally controlled by these glaciers, and because these regions are the locus of high bottom melting. The bottom melt rates ranges from < 4m/yr to > 40 m/yr. The wide range of values is consistent with limited prior studies, and stems from different groudning line drafts and sea water temperatures. The melting rate is postively correlated with thermal forcing, increasing by 1 meter per year for each 0.1°rise in ocean temperature. Those results have important consequences for modelling studies of the evolution of Antarctica in a warming climate and for the analysis of observations of cryospheric changes from satellites: 1) the inferred rates are much higher than used in modelling studies, which often assume melting to be uniform over the entire ice shelf area, and henceforth underestimate the impact of thermal forcing of the ocean on the ice sheet evolution; 2) The potential impact of bottom melting on short-term ice sheet stability is greatest in regions where deep water has access to glacier grounding lines, e.g. the south-east Pacific-west Antarctic Sector, but also sectors of East Antarctica; 3) Ocean temperature seaward of Antarctica's continental shelf break have risen 0.2°over recent decades, enough to account for the rapid thinning of ice shelves in the western Amundsen sea, which may play an essential role in the observed flow acceleration and mass loss of their nourishing glaciers.

This work was performed at the California Institute of Technology's Jet Propulsion Laboratory and at the University of Columbia, under a contract with the Cryospheric Science Program of the National Aeronautics and Space Administration.

C52A-02 1355h INVITED

Rift formation and growth on the Ross Ice Shelf

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The Antarctic ice sheet sheds much of its mass via the calving of large icebergs. The fronts of the Ross and Filchner-Ronne ice shelves, which produce large tabular icebergs, calved three large icebergs in the year 2000 that, collectively, contained roughly twice the annual accumulation for all of Antarctica. Several other large calving events occurred in 2001-2002, including the dramatic breakup of the Larsen B ice shelf. Located much further south than the Larsen, the Ross and Filchner-Ronne ice shelves are believed to be more stable in that it would take a rise in summer temperatures of several degrees to produce surface meltwater in the quantities that are believed to have contributed to the demise of the Larsen.

Calving events along a given section of the ice front occur decades apart, making it difficult to obtain sufficient observations to statistically separate the natural variability typical of a stable ice shelf from any longer term trend. It thus becomes necessary to better understand the process of tabular iceberg calving to develop the ability to determine whether individual events are normal or signify a response of the ice sheet/shelf system to climate change.

The process of calving from the large ice shelves appears to be driven by the formation and propagation of large-scale ice-shelf rifts that become iceberg detachment boundaries. We have collected interferometric synthetic aperture radar observations (InSAR) of the actively growing rift system on the western side of the Ross Ice Shelf that gave rise to iceberg C19 in May 2002. Our analysis of these data suggests that the rifts open at a steady rate, largely in response to the stresses present in the ice shelf.

C52A-03 1415h INVITED

Explosive break-up of Larsen Ice Shelf, Antarctica, by a meltwater-triggered iceberg capsize mechanism

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Two disintegration events leading to the loss of Larsen A and B ice shelves in 1995 and 2002, respectively, proceeded with extreme rapidity (order several days) and reduced integrated ice shelf to a jumble of small iceberg fragments. These events strongly correlate with warming regional climate and accumulation of surface melt water, supporting the hypothesis that meltwater induced propagation of pre-existing surface crevasses may have started ice-shelf fragmentation. What we address in this study is not the crevasse propagation process that triggers disintegration, but rather a mechanism that may sustain the ice-shelf break-up once it begins. The proposed mechanism involves the coherent capsize of narrow (less than thickness) ice-shelf fragments by rolling 90° in a direction toward the ice front. We envision such fragments as being pieces of ice shelf liberated when two surface or basal crevasses oriented across the pre break-up flow direction suddenly cleave the entire ice thickness, *e.g.,* as a result of meltwater crevasse wedging. Fragment capsize liberates gravitational potential energy and creates forces that wedge open ice-shelf rifts (void space containing the fragment). We speculate that the wedging forces so created may stimulate further fragmentation of the ice shelf and thereby contribute to its sudden disintegration. The process we propose is analagous to the overflow of a champagne bottle that has been opened after having been vigorously shaken. In the analogy, bubbles play the role of ice-shelf voids (rifts) that contain floating ice fragments that can capsize, and CO_2 gas within the bubbles plays the role of capsizing ice fragments that create wedging forces tending to widen the rifts that contain them. Observational support for our proposed mechanism is provided by post-break-up MODIS (visible) satellite imagery that reveals formerly englacial debris exposed at the surface and small, blue-colored sub-pixel-sized icebergs that have rolled onto their sides.

C52A-04 1430h INVITED

Sediment Lithofacies From Beneath the Larsen B Ice Shelf: can we Detect ice Shelf Fluctuation ?

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Cruise 01-07 of the USAP research vessel N. B. Palmer was part of a multi-year investigation of the sediment processes and paleohistory of the Larsen Ice Shelf. Data includes: real-time satellite derived (SEA-WIFS) surface productivity estimates, surface pC02, salinity and temperature measurements, surface to bottom CTD measurements, bottom photos, swath bathymetry, and surface grabs, kasten cores and multi-cores. Observations document the characteristics of the oceanographic and seafloor setting prior to the most recent collapse of the Larsen B system (late February-March of 2002) but following the penultimate retreat (1999). Swath (multibeam) mapping revealed a streamlined seafloor that clearly delineates the former flow path of glacial ice that at one time filled the embayment. A broad trough extends to depths in excess of 700 m in the center of the embayment. This deep extends beneath the edge of the Larsen-B ice shelf as it stood in December-January 2001-2002. A pavement of angular pebbles and cobbles covers the seafloor within the embayment and is underlain by 20 to 60 cm of silty clay, followed by poorly sorted granulated sediment and, finally, a gray diamicton (interpreted as a till). It appears from our preliminary stratigraphy and chronology that the Larsen-B ice shelf has not experienced a history of recession and reformation since the LGM. Instead the ice shelf appears to have been in-place for some time while embayment to the north were experiencing open marine conditions (Domack et al., 2001 & Pudsey et al., 2001). This working hypothesis remains to be tested against a growing geochemical and micropalentological database.

URL: http://www.hamilton.edu/news/exp/Antarctica2001/

C52A-05 1450h

Retreating ice shelves on the Antarctic Peninsula

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In recent decades, several ice shelves on the Antarctic Peninsula have retreated, some reduced to fragments of their original size. These retreats have been linked to the rapid recent region atmospheric warming, however, the mechanisms by which small rises in temperature cause retreat are still unclear. Earlier this year, there was a dramatic collapse of Larsen Ice Shelf B, 3250 sq. km of ice shelf were lost in a few weeks. This collapse, was predicted by modelling, as a final-stage dynamic failure following many years of progressive retreat. Less dramatically but no less important, Jones Ice Shelf has also retreated. Although it was stable between 1947 and 1969, retreat began in the early 1970s and continued until 2001, when only a fragment remained. Unusually, Jones Ice Shelf has two ice fronts only a few kilometres apart which provides a unique opportunity to compare how different icefronts retreat when subjected to similar climate forcing. We show that, while particular episodes of retreat may be related to warm summers the overall progress of retreat of the two ice fronts has been controlled by the geometry of their embayments and is substantially different. These observations and a new determination of climate variability on the Antarctic Peninsula allows us to redefine the distribution of retreating and stable ice shelves, and to map a ?limit of viability for ice shelves?. The magnitude of recent rapid regional warming is sufficient to explain the distribution of retreating ice shelves as a result of migration of this limit, and to allow prediction of ice shelves under threat in near future.