AMPS SUPPORT FOR ANTARCTIC SCIENCE AND LOGISTICS— A DECENNIAL RETROSPECTIVE

Jordan G. Powers[1*], Kevin W. Manning[1], David H. Bromwich[2], and John J. Cassano[3]
[1]Mesoscale and Microscale Meteorology Division
NCAR Earth System Laboratory, National Center for Atmospheric Research
Boulder, CO
[2]The Ohio State University, Columbus, OH
[3]University of Colorado, Boulder, CO

* *Corresponding author address*: Jordan G. Powers, MMM Division, NCAR Earth System Laboratory, NCAR, P.O. Box 3000, Boulder, CO 80307 (powers@ucar.edu).

1. INTRODUCTION

AMPS achieved its 10-year anniversary (decennial) in September 2000. It was in late 2000 that the National Science Foundation's (NSF) Office of Polar Programs (OPP) began backing an experiment to improve the weather forecasting support for the United States Antarctic Program (USAP)— the Antarctic Mesoscale Prediction System (AMPS) (Powers et al. 2003). As conceived, AMPS was to be a real-time, mesoscale modeling system targeted to, and tuned for, the USAP forecaster needs at the main American base, McMurdo Station (see Fig. 1).

It became apparent early on that AMPS could benefit a broad spectrum of activities in Antarctica, i.e., beyond those of the USAP just at McMurdo. In particular it was found that AMPS could be useful to the international Antarctic community, with its unique backdrop of cooperation.[1] As will be shown, over the past decade AMPS's contributions have surpassed the original objectives. With 2011 marking the centennial of Amundsen's attainment of the South Pole, it is patent that Antarctic exploration and science have come a long way. Support for these has as well, and AMPS has significantly advanced this.

AMPS is currently a collaboration of the National Center for Atmospheric Research and The Ohio State University (OSU). The system employs the Weather Research and Forecasting (WRF) model (Skamarock et al. 2008) generates numerical forecasts, and its products are posted freely. Apart from its USAP support mission, AMPS serves a range of science over the southern high latitudes. Thus, investigators proposing field activities or needing atmospheric datasets should consider availing themselves of AMPS. In return, AMPS may benefit from their forecast reviews or their advancement of polar meteorology. Summarized here are the system and service that is AMPS and the returns on NSF's investment over its first decade.

2. HISTORY

a. Motivations

Prior to AMPS, real-time NWP over Antarctica was generally the province of global models run by operational centers (e.g., NCEP, U.S. Navy, ECMWF).[2] In May 2000 the Antarctic Weather Forecasting Workshop (AWFW), held at the Byrd Polar Research Center of The Ohio State University, reviewed the state of weather forecasting over the Ice. The workshop found that the guidance from the existing global models was lacking due to: (i) horizontal resolution inadequate to resolve mesoscale features affecting forecasting and flight operations; (ii) inadequate representation of physical properties affecting the Antarctic atmosphere; and (iii) poor representation of Antarctic topography and surface features (Bromwich and Cassano 2000). A key conclusion was thus the need for a focused effort to improve NWP for the Antarctic through a mesoscale modeling initiative (Bromwich and Cassano 2000).

The AWFW report recommended to NSF the improvement of NWP capabilities for the USAP through: implementing higher-resolution Antarctic forecast domains (i.e., grid sizes ≤15 km) for the 2000–2001 field season; dedicated Antarctic NWP centers to provide robust capabilities and products tailored for the forecasters; and a research program for improving model parameterizations for the Antarctic and for performing verification. AMPS was conceived from these identified needs. The original principals were NCAR, OSU, and the University of

[1] The Antarctic Treaty is an agreement regulating the relations of the countries operating in the Antarctic. Currently signed by 48 nations, it directs that Antarctica shall be used for peaceful purposes only, that freedom of scientific investigation in Antarctica and cooperation toward that end shall continue, and that scientific observations and results from Antarctica shall be exchanged and made freely available. See Secretariat of the Antarctic Treaty—http://www.ats.aq/index_e.htm.

[2] One (restricted-access) mesoscale model application that included Antarctica was that of the U.S. Air Force Weather Agency, which ran the MM5 (Fifth-Generation Penn State/NCAR Mesoscale Model.

Colorado. NCAR was the logical home for the actual system, as it was an NSF-funded institution, a leader in mesoscale model development, and experienced in real-time applications. The project goals for AMPS were as follows:

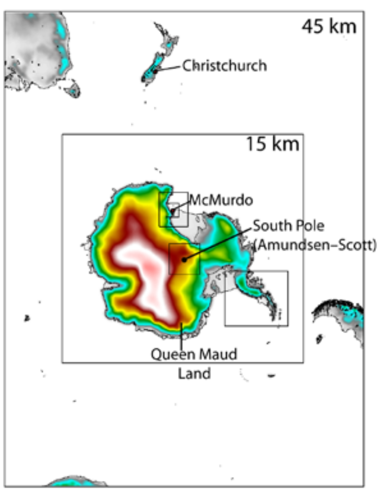
(1) to provide real-time mesoscale and synoptic model products for Antarctica, tailored to the needs of the field forecasters at McMurdo Station;

(2) to improve and incorporate model physical parameterizations suitable for the Antarctic;

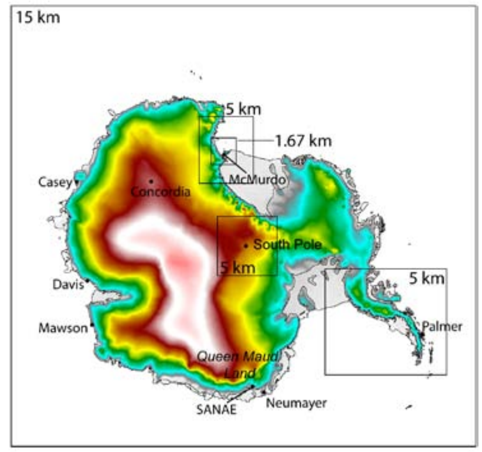
(3) to perform qualitative and quantitative system verification; and

(4) to stimulate close collaboration between forecasters, modelers, and researchers by making the model output available to the community through a web interface, an archive, and workshop interactions.

Since October 2000, AMPS has furnished twice-daily model guidance for Antarctica. It has supported forecasting for the seasonal missions between Christchurch, New Zealand and McMurdo and across the Ice. As presented here, it has also assisted researchers, field experiments, and emergency operations.



1(a)



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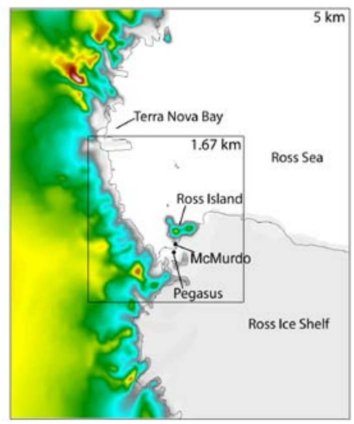

1(c)

Fig. 1: AMPS domains. (a) 45-km and 15-km grids. (b) 15-km Antarctic grid with 5-km western Ross Sea, South Pole, and Antarctic Peninsula grids. (c) 5-km western Ross Sea and 1.67-km Ross Island grids.

b. AMPS Evolution

AMPS began in 2000 with an implementation of the Fifth-Generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model (MM5) (Grell et al. 1995). The MM5 code that was used contained polar modifications to capture better the high-latitude conditions. These were originally developed by the Polar Meteorology Group of the Byrd Polar Research Center (Bromwich et al. 2001; Cassano et al. 2001) at Ohio State. Later, the modifications were ported to WRF (Powers 2009). The polar versions of the models have been reviewed in both the Arctic and Antarctic (Bromwich et al. 2001; Cassano et al. 2001; Hines and Bromwich 2008; Powers 2009; Bromwich et al. 2009; Hines et al. 2011).

AMPS's beginning setup ran the MM5 with nested grids of 90-, 30-, and 10-km (western Ross Sea) horizontal spacings. As compute power increased, the configuration added a 3.3-km grid over the Ross Island area and 10-km grids over the South Pole and

Antarctic Peninsula. 2005 saw the MM5 grid spacings reduced to 60/20/6.67/3.3-km. WRF was implemented in 2006, with the 60/20/6.67/3.3-km setup and the polar modifications. WRF is now the sole model in AMPS, and the grid spacings stand at 45/15/5/1.67-km.

3. THE SYSTEM

Figures 1(a)–(c) show the WRF configuration in AMPS. The polar modifications include a fractional sea ice representation, adjustments to thermal and radiative properties of ice and snow surfaces, and use of the latent heat of sublimation for processes over ice sheets.[3] In 2009 the polar modifications were implemented into the official WRF release. This is an example of development in AMPS benefitting the mesoscale modeling community.

WRF in AMPS uses high-resolution topographic data from the RAMP2 (Radarsat Antarctic Mapping Project Digital Elevation Model Version 2) dataset (http://nsidc.org/data/nsidc-0082.html). This provides 200m digital elevation model information for the continent.

Apart from the basic six-domain configuration, AMPS implements one-way WRF grids to provide higher resolution (e.g., 15-km, 5-km) over areas of special activity. These have covered Palmer Station, the Central TransAntarctic Mountains, West Antarctica, and the South Atlantic/Indian Oceans.

In addition to the computational domains, AMPS offers numerous plotting windows. These display output over requested areas, often for foreign countries. The areas have included: the Australian sector (e.g., the Casey and Davis regions), the South Atlantic (support of South African missions), the Ross Sea–Beardmore Glacier region (for USAP field site support), and Queen Maud Land.

AMPS produces two forecasts per day, initialized at 0000 and 1200 UTC. The 45- and 15-km domains run out to five days and the 1.67- and 5-km domains to 36 hours. WRF uses the National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) model output for the first-guess field and boundary conditions. The initial conditions are generated by the WRF data assimilation system (WRFDA) through a 3DVAR reanalysis.

AMPS forecast products are disseminated primarily through its web page: http://www.mmm.ucar.edu/rt/amps. Users can also download tar files of plots from the web server, and those with limited bandwidth (e.g., on ships) receive products via e-mail.

AMPS injects model output into the Antarctic Internet Data Distribution (IDD) system. The Antarctic IDD (Lazzara et al. 2006) is a dissemination of Antarctic observations and model output using Unidata's Local Data Manager (LDM) data sharing software.

Another facet of the AMPS effort that has served research and logistics over the years has been the AMPS archive. This is a repository of model output, and it has been applied to a very wide range of studies. These have included forecast verification, site/region climatologies (e.g., Monaghan et al. 2005), and precipitation in Queen Maud Land (Schlosser et al. 2008; Schlosser et al. 2010).

Performance assessment of AMPS occurs on an ongoing basis. First, verification is done before introduction of new model versions or configurations, typically over warm- and cold-season periods. In addition, for polar modification development OSU has reviewed longer-period simulations. Second, review attends the daily and seasonal scrutiny of the forecasts by SPAWAR. Third, international users contribute verifications (e.g., Adams 2010). Their analyses of AMPS outside the USAP's turf (e.g., the Australian sector, Queen Maud Land) exemplify the community returns to the AMPS effort.

4. APPLICATIONS

a. USAP

For the weather forecasting role, the USAP engages the Space and Naval Warfare Systems Center (SPAWAR). Air operations dominate the forecasting needs. The primary heavy lift transport for the USAP is provided for by the U.S. Air Force's 62nd Airlift Wing and the New York Air National Guard's (NYANG) 109th Airlift Wing. SPAWAR also forecasts for the small aircraft of Kenn Borek Air, Ltd. and the helicopters of Petroleum Helicopters, Inc., which both shoulder some of the USAP transportation burden. SPAWAR's forecasting responsibilities also encompass high-latitude marine operations.

The AMPS group interacts on a regular basis with SPAWAR. The communication drives the design of the products and capabilities. This has helped to fulfill one of the original motivations to create an NWP system tailored for the USAP forecasters.

b. Scientific Field Programs

One prominent area in which AMPS has supported Antarctic science is that of scientific field campaigns. The system has provided them with special grids, windows, and products for forecasting and planning. Recently, for the 2011 cruise of the R/V *Nathaniel B.*

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[3] Details on the polar modifications to WRF can be found in Hines and Bromwich (2008), Bromwich et al. (2009), and Hines et al. (2011).

Palmer through the Ross Sea, AMPS developed a ship-following plotting window to keep the forecast charts focused on the ship.

Table 1 lists the field campaigns that AMPS has assisted. These include: GLOBEC (Global Ocean Ecosystem Dynamics), MaudNESS (Dronning Maud Land Nonlinear Equation of State System), WAIS (West Antarctic Ice Sheet initiative), AGAP (Antarctica's Gamburtsev Province), LARISSA (Larsen Ice Shelf System, Antarctica), and ICEBRIDGE (NASA's Operation Icebridge). On a multi-season basis AMPS forecasts have also supported the NASA's Columbia Scientific Balloon Facility for launches of its high-altitude balloons from McMurdo.

Figure 2 presents an example of a campaign product from AMPS. In September 2009, a study headed by the University of Colorado explored the Terra Nova Bay polynya using unmanned aerial vehicles (UAVs) flying out of McMurdo. For this, AMPS developed new real-time products to guide UAV flight planning. Figure 2 shows a 48-hr AMPS forecast of sea level pressure, surface winds, and surface sensible heat fluxes.

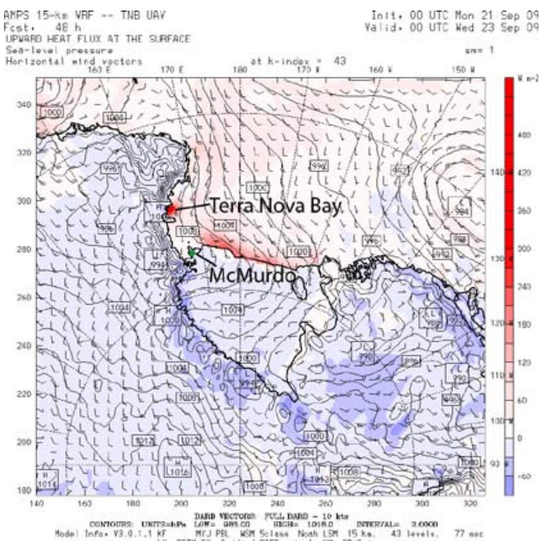

Fig. 2: AMPS product for the Terra Nova Bay polynya field campaign, September 2009. 48-hr forecast SLP and surface wind barbs (full barb=10 kt; half-barb= 5 kt) shown. Surface sensible heat fluxes (Wm^{-2}) shaded (red= positive; blue= negative). Initialization: 0000 UTC 21 Sept 2009.

While not an original aim of the project, AMPS's NWP guidance for field campaigns has emerged as a significant avenue for its supporting science over the decade. It also exemplifies the leveraging of OPP funding to assist Antarctic studies consonant with NSF's goals.

c. International Use

The Antarctic Treaty establishes a unique relationship among the nations in Antarctica. In scientific exploration they share, and in crises they cooperate. While not charged with doing so, AMPS has made an effort to assist foreign interests across the continent. Typically, this has been through site/station products such as soundings, tables, and meteograms and plotting windows. For example, AMPS generates windows for Queen Maud Land for Germany, the Davis and Mawson station areas for Australia, and the South Atlantic for South Africa.

Nations that have been aided by AMPS include: Italy, Australia, UK, Germany, South Africa, China, Chile, Norway, Russia, and Japan. A group that AMPS supports is the DROMLAN (Dronning Maud Land Air Network) consortium: Belgium, Finland, Germany, India, Japan, Netherlands, Norway, Russia, South Africa, Sweden, and UK. These nations pool resources for logistical needs, such as weather forecasting, in their common sector, Queen (Dronning) Maud Land (Fig. 1(b)). AMPS specifically provides NWP guidance to the German forecasters for DROMLAN based at Neumayer Station.

AMPS has also provided support for research and resupply cruises. Examples are the missions of the South African vessel *Agulhas* to the South Africa's sub-Antarctic islands (e.g., South Thule Is., Marion Is.) and to its SANAE base on continent (Fig. 1(b)). Likewise, each year AMPS supports forecasters on the German vessel *Polarstern* on its Antarctic voyages.

d. Antarctic Rescues— Emergency Situations

The isolation and harshness of Antarctica can amplify any problems that arise. Given that weather typically becomes a factor in these, AMPS's service has often extended to on-Ice emergencies.

AMPS's first involvement was in the high-profile medical evacuation (medevac) of a physician at Amundsen-Scott Station in April 2001. With the problem erupting post-season, darkness and falling temperatures made the dispatch of a Twin Otter aircraft to extract the ailing doctor a borderline proposition. As described in Powers et al. (2003) and Monaghan et al. (2003), AMPS was one of the NWP sources consulted by rescue flight forecasters. It accurately predicted a period in which blowing snow at the pole would cease, contributing to the success of the rescue.

Emergency situations are not always medical. In June–July 2002, the German supply ship *Magdalena Oldendorff* became trapped in sea ice while servicing stations along the Queen Maud Land coast (Powers et al. 2003). To extract crew and scientists on board, the *Agulhas* and the Argentinian icebreaker *Almirante Irizar* sailed to the *Magdalena Oldendorff*. The South

African Weather Service used AMPS to forecast for the *Agulhas* transit and for the helicopter offload of those on the *Magdalena Oldendorff*.

On average, AMPS has assisted in an emergency every 17 months. The latest was in January 2011, when a member of the French program at Concordia Station (see Fig. 1(b)) was medevac'd, via NYANG aircraft, from Concordia to McMurdo to Christchurch.

e. Miscellaneous Applications

AMPS has fulfilled various requests outside of USAP operations or scientific field campaigns. One application is the site climatology. In this, model output substitutes for an observational record (lacking) at a location. Using the AMPS archive, MM5- and WRF-based climatologies have been built for many sites across the Ice.

A recent example (2011) is the USAP inquiry into potential alternate McMurdo-area airfield locations. Pegasus Runway (see Fig. 1(c)) is situated about 12 km south of McMurdo Station on permanent ice. To explore the idea of a location closer to McMurdo, AMPS has been used to analyze alternate sites. From this study, Fig. 3 shows the average of model precipitation over the season of October–March for the years 2008–2010. AMPS suggests that, compared to Pegasus, the precipitation is 25% higher at Alternate 1 (80 v. 64 mm) and 56% higher at Alternate 2 (100 v. 64 mm). This kind of information has proved valuable in preliminary planning.

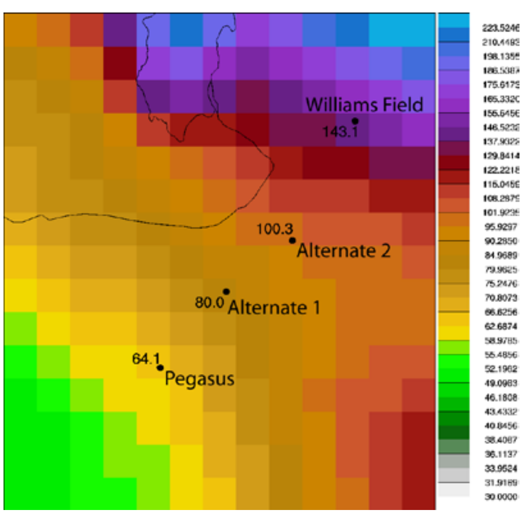

Fig. 3: Accumulated precipitation (mm) from AMPS for the October–March period for the 2008–2009, 2009–2010, and 2010–2011 seasons.

f. The AMPS Archive

The AMPS archive[4] is a repository of the forecast model output (MM5 and WRF) since 2001. It holds full model output in native format for all domains, as well as subsets of data (selected fields and levels) in GRIB format. The latter, smaller dataset has proven handier for some researchers. Also stored, since 2008, are the forecast graphics. The NCAR High-Performance Storage System (HPSS) holds the data.

OSU has created and maintains a related dataset, the online AMPS database. It offers a subset of the full model output, containing selected fields, levels, and times. Its key advantage is its accessibility, through the database page: http://polarmet.osu.edu/PolarMet/ampsdd.html.

The AMPS archive has been used for climatologies, process studies, and verification. Specific investigations have targeted: mass/energy balances; the synoptic conditions in different regions (e.g., western Ross Sea, the Dry Valleys, Adelie Land); the climates of West Antarctica and the Dry Valleys; and the Ross Ice Shelf air stream. The archive has also served analyses to improve logistical capabilities for science (such as the Pegasus site study described above) and to evaluate weather forecasts.

g. Workshops and Education

Because it cuts across Antarctic groups, AMPS has been an important facet of annual workshops from early on. Annual meetings for AMPS began in 2001. From 2003–2005, the AMPS workshop was held jointly with the annual meetings of the Antarctic Meteorological Research Center and the Automatic Weather Station (AWS) Program, both housed at the University of Wisconsin–Madison. In 2006 the three were combined to create the Antarctic Meteorological Observation, Modeling, and Forecasting (AMOMF) Workshop. The AMOMF Workshop has been held annually since and has prominently included the international Antarctic community.[5]

Over the years the AMPS effort has hosted SPAWAR forecasters, graduate students, and foreign scientists to work on forecast reviews, polar model development, and archive-based research. In addition, both the University of Colorado and OSU have supported graduate students with thesis and other study involving AMPS. Thanks to OPP funding, graduate students in these programs have also gotten the opportunity to visit McMurdo and work with the forecasters on meteorological and forecast studies. AMPS has thus served as a platform for research, education, and training in Antarctic science.

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[4] For information see: http://www.mmm.ucar.edu/rt/wrf/amps/information/archive_info.html.

[5] Meeting sites have included Rome, Italy (2007) and Hobart, Australia (2011).

5. SUMMARY AND FUTURE DIRECTIONS

The Antarctic Mesoscale Prediction System (AMPS) has now been serving National Science Foundation (NSF) and international Antarctic science for over a decade. The system was initiated in late 2000 to fulfill the needs for higher-resolution, tailored mesoscale model guidance for the USAP. The goals of the effort were: to provide real-time model forecasts for Antarctica, tuned to the needs of the McMurdo forecasters; to improve model physics for the Antarctic; to perform verification; and to stimulate collaboration between forecasters, modelers, and researchers. These aims have been accomplished.

While AMPS was developed to support the USAP with priority, it has reached out to a range of groups and needs. AMPS has supported diverse research and logistics and has assisted in Antarctic emergencies. Its aid to field campaigns has contributed to Antarctic science and represented a leveraging of NSF funding. Its role in the annual Antarctic Meteorological Observation, Modeling, and Forecasting Workshop has lead to greater communication and connectedness among Antarctic players. The support of international science and emergency activities has been a valuable unanticipated contribution.

For the future AMPS will target improvements in the modeling capabilities. One goal is increased horizontal resolution, with a target of a continent-wide grid spacing of 10–12 km. This would translate to a Ross Island grid of 1.1–1.3 km.

The development of WRF polar physics will continue. Polar modifications will be implemented into the WRF repository, and thus into future releases, advancing the modeling system for the entire research community. The WRFDA data assimilation system in AMPS will be seeing regular upgrades, and new satellite-derived measurements will be impact-tested. The AMPS archive will be maintained and will continue to support verification and research. Lastly, AMPS stands ready to respond to the inevitable emergencies. The effort looks forward to continued service to the USAP, to science across the Ice, and to the diverse disciplines of the Antarctic community.

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Table 1: Scientific Field Campaigns/Activities Supported by AMPS

Campaign	Period	Activity
GLOBEC Ecology	2002+	Global Ocean Ecosystem Dynamics Operations in Marguerite Bay, Antarctica
MaudNESS Oceanography	2005	Dronning Maud Land Nonlinear Equation of State system Weddell Sea oceanography
WAIS Divide Ice Core Glaciology	2005+	West Antarctic Ice Sheet
Pine Island Bay survey	2007	Investigation of Pine Is. Bay glacier region
CSBF Atmospheric science	2007+	Columbia Scientific balloon facility Launches of high-altitude, long-duration balloons from McMurdo
AGAP Geology	2008–2010	Antarctica's Gamburtsev Province Surveys of Gamburtsev subglacial mountains
Terra Nova Bay polynya study Atmospheric science	2009	Study of PBL and surface fluxes over Terra Nova Bay region
ICEBRIDGE Glaciology	2009–2010	NASA study of Antarctic ice sheets, glaciers, sea ice
R/V *Nathaniel B. Palmer* cruise	2011	Ross Sea mission of NSF vessel *N.B. Palmer*
Pine Island Glacier study Glaciology, climatology	2011–2012	Field camps at Pine Is. Bay glacier for survey/studies