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Hot water drilling on the Amery Ice Shelf, East Antarctica

Mike Craven, Alan Elcheikh, Russell Brand, Ian Allison

Australian Antarctic Division and Antarctic CRC (University of Tasmania)

ABSTRACT

In 1999 the Glaciology Program of the Australian Antarctic Division initiated a 5-year study of glaciological investigations into the interaction between the Amery Ice Shelf and the underlying ocean. The principle objectives of this project are: to quantify the characteristics and circulation of ocean water in the cavity beneath the Amery Ice Shelf; to determine the distribution and rates of basal melting and re-freezing processes beneath the shelf; and to establish how important ice melt beneath the shelf is to both the modification of circulating water masses and the total loss of ice draining from the Lambert basin.

The AMISOR (Amery Ice Shelf Ocean Research) Project consists of integrated ground-based, ship-based, remote sensing and modelling components. This paper describes the construction and use of a hot water drill (HWD) for the production of access boreholes through the ice shelf at several locations.

The drill was tested for the first time in Antarctica during the 1999-2000 summer field season, and successfully deployed in two subsequent seasons to produce ice shelf access boreholes to depths of 373 m (2000-01), and 479 m (2001-02) respectively, allowing direct measurements to be made in the ocean cavity beneath the shelf. Future holes are planned to provide further data suites at several sites around the northern section of the ice shelf to yield meridional and zonal variation of ice shelf-ocean processes and interactions.

1. INTRODUCTION

A modular hot water drill (HWD) system was designed and built in-house, with the ulimate capability of drilling a 250 mm diameter borehole to depths around 1000 m in cold ice. The drill design and development drew heavily on the expertise and experience of a number of international research groups (see acknowledgement).

The AMISOR HWD system is powered by a Hatz 12 kVA 3-phase diesel generator, with an identical Hatz bare shaft motor driving a CAT 1051 high pressure surface pump for delivering water at rates up to 45 litres/minute. Five 80 kW K'Archer Volcano portable car wash heaters are plumbed in parallel via inlet and outlet manifolds to heat this water flow to temperatures up to around 80°C. The system uses 1" (50 mm) internal diameter 580N-16-SL thermoplastic hose in 600 feet lengths (183 m), to deliver hot water to a 90 kg stainless steel drill stem via a motor driven hose drum winch, and an electronically controlled capstan drive. A set of Spraying Systems nozzles, covering a range of outlet diameters, deliver either a solid stream or full cone spray to the borehole depending on whether drilling is underway in a water filled ice cavity, or in

the upper air filled porous firn section of the hole. A subsurface water recovery system is employed using a Grundfos SP5A-38 4 kW submersible pump, in an adjacent shallow hole with hydraulic connection around sea level with the main borehole. This method has been described and successfully employed elsewhere, such as on the Ronne Ice Shelf (Nicholls et al., 1991; Makinson, 1993), and the Ross Ice Shelf (J9) and associated Ice Streams.

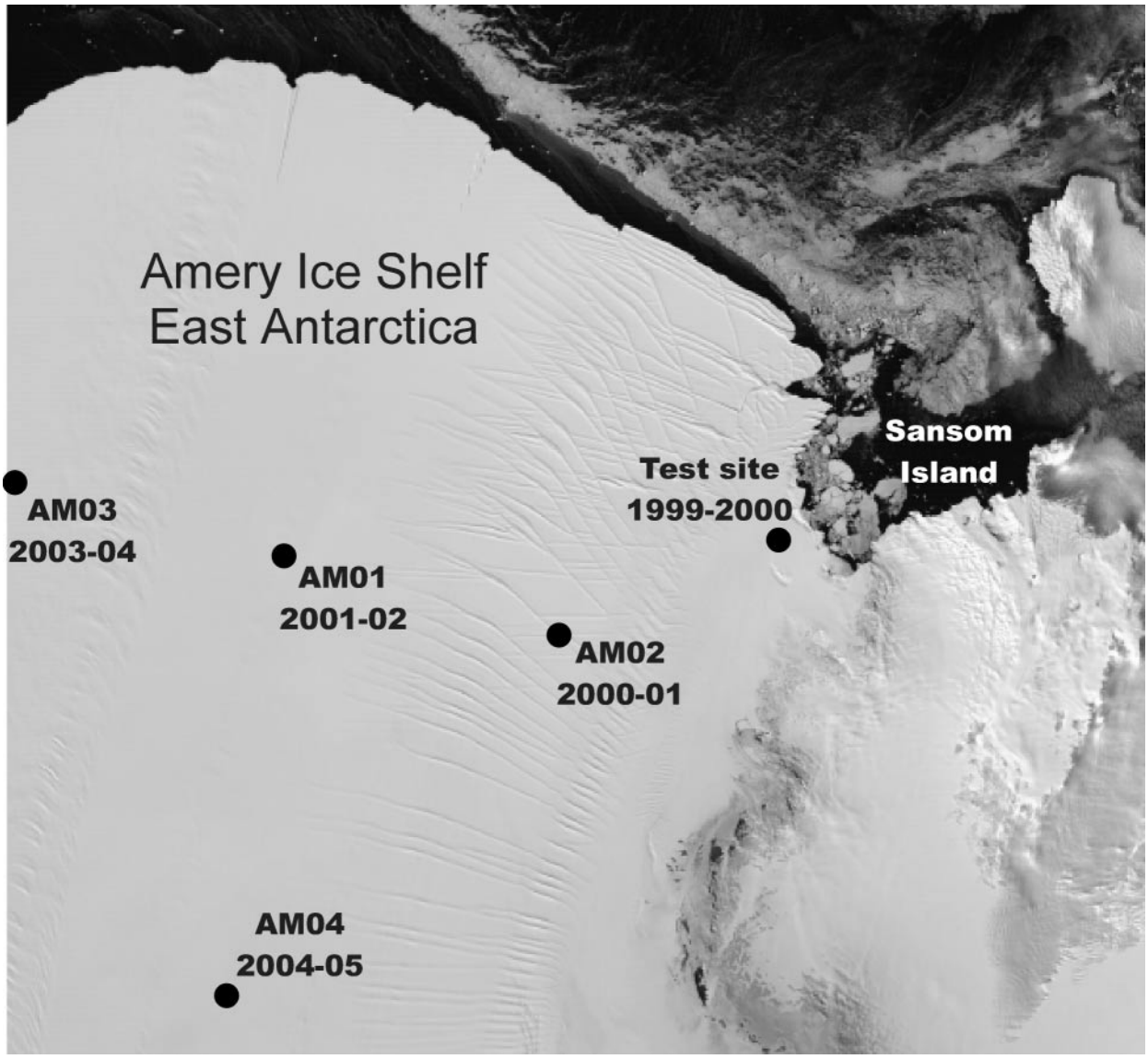

Figure 1. Approximate locations of present and proposed future AMISOR HWD field sites (background image, Landsat TM 127-109, acquired 21-02-1988).

2. FIELD OPERATIONS

The AMISOR HWD was field tested at a site 5 km west of Sansom Island, Sandefjord Bay (Figure 1) in the 1999-2000 austral summer. A combination of heavy katabatic ground drift and snow bearing winds from incursion of synoptic systems across the nearby coast resulted in repeated burial of the plant and equipment (generator, pumps) required to operate the drill. This forced a redesign of system layout involving the use of Weatherhaven protective tents to house

all major components of the system (apart from an 8000 litre surface reservoir tank, or flubber), effectively weatherproofing the drill (Figure 2). These initial tests proved the basic integrity of the HWD with a shallow borehole drilled to a depth of 47 m, beyond the porous firn cut-off limit where meltwater began to pool in the base of the hole.

Figure 2. Plant and equipment digout during drill trial season (left), exhaust ducting from 80 kW heaters inside new plant shelter in current set-up (right).

In the following season, during the last week of December 2000, a 300-350 mm diameter 373 m deep borehole was drilled through the Amery Ice Shelf at site AM02 (69° 42.8' S, 72° 38.4' E), some 50 km west of Sansom Island. The area was believed to be a basal melt zone, evidence for this related to the clarity of the return pulse (specular reflection) from radio echo sounding in the vicinity, and agreement between local surface elevations and ice thicknesses from hydrostatic equilibrium considerations indicating the lack of a marine ice (basal accretion) layer (Fricker et al., 2001). A total of 14 hours was required from commencement of drilling the main borehole past well depth (at 45 m) to shelf breakthrough, including reaming to a depth of 250 m. With repeated reaming the borehole was maintained open for one week for sampling and measurement that included: caliper and inclinometer profiles within the boehole; CTD profiling of the 468 m wide water column beneath the shelf; attempts at water sampling with Niskin bottles; and the collection of a 1.5 m long sediment core from the sea bed below the site. A mooring array was then deployed and allowed to freeze in situ comprising: 3 x MicroCAT CTD recorders at selected depths in the water column; an 8 x thermsitor string with sensors straddling the ice-water interface; and a pair of thermistors within the body of the ice shelf. An automatic weather station (AWS) for recording local meteorological conditions was deployed at the site. Some cargo was then stored in a depot on nearby Sansom Island, the remainder returned to Australia for maintenance and minor modification over winter.

During the austral summer of 2001-02 a 479 m deep borehole was melted at site AM01 (69° 26.5' S, 71° 25.0' E), a further 50 km WNW of AM02. A 4-man wintering party previously occupied the same geographic location in 1968 obtaining ice cores from a hole drilled to a depth of 315 m (Morgan, 1972). They collected accreted marine ice from depths below 270 m, but it is yet to be determined if active re-freezing is occurring at the site, or all the marine ice is a result of downstream transport from zones to the SSW. During hot water drilling an hydraulic connection was achieved with the ocean cavity beneath the shelf at a depth of 376 m, still some 100 m or so above the true base of the shelf. Subsequent ice samples obtained using a HWD ice coring head (Englehardt et al., 2000) revealed: meteoric ice at a depth of 240 m; marine ice with

debris bands at 290 m; marine ice with bubble structure, possibly pockets of brine, from 360 m; and highly porous "honeycomb" ice at a depth of 390 m. Detailed analysis of these irregular core samples is in progress. The main borehole was again maintained open for one week, this time with more success collecting water samples, but failure to obtain a sediment core believed to be due either to a very firm and/or steeply sloping sea bed. The long term mooring instruments this season also included: an upward looking sonar (ULS) deployed 20 m below the base of the shelf to monitor basal changes; and a more elaborate thermistor string within the body of the ice, to record the temperature profile with a view again to determining the nature of basal processes at the site. A 10 km long GPS transect was conducted to look for possible surface anomalies contributing to the local thickness of the marine ice layer, and ground penetrating radar was used to try and map the depth of the top of the marine ice layer in the area, but returned ambiguous results (possibly due to the "honeycomb" nature of the ice at depth).

3. OBSERVATIONS

The CTD profiling of the 468 m deep water column beneath the Amery Ice Shelf at site AM02 showed a characteristic cool fresh layer indicative of a melt water plume in the upper 40 m immediately beneath the shelf (Figure 3). There followed a gradual increase in both temperature and salinity toward the base of the shelf. A number of persistent plumes of warmer water were evident in the lower portion of the water column, on both down and upcasts of the CTD unit (a Falmouth Scientific Instruments FSI-3" Micro CTD). No uncontaminated water samples were obtained at this site due to a faulty housing distorting the Niskin bottles and producing leakage around the o-ring seals. The FSI results have been intercalibrated however with the ship-board CTD unit on the research vessel *Aurora Australis*, for which numerous water samples were available at a range of depths in the open ocean.

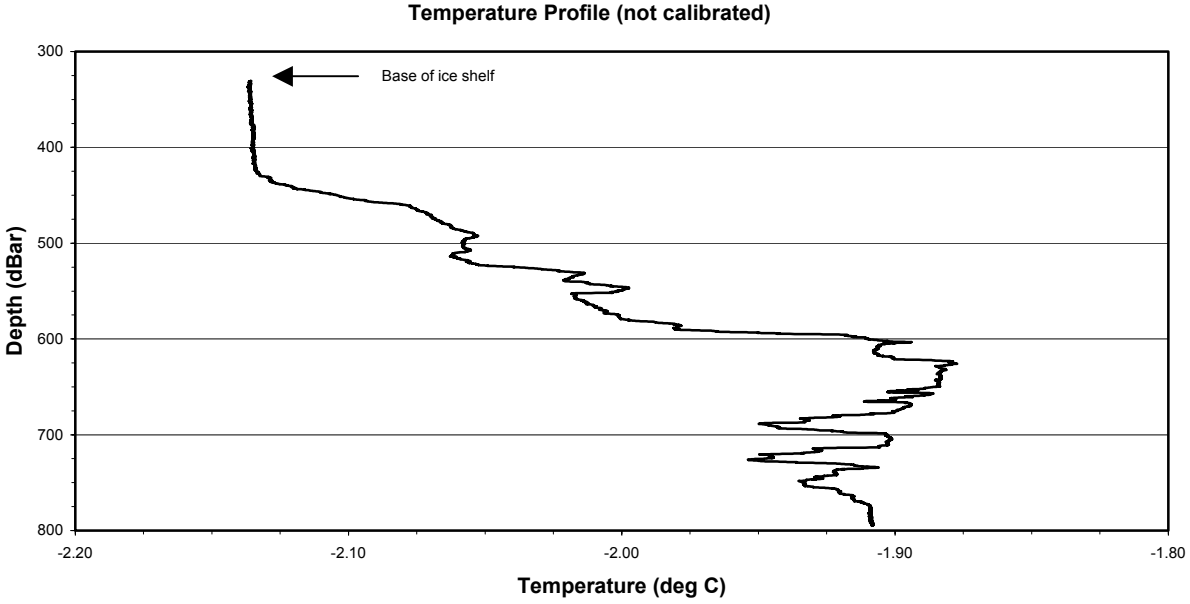

Figure 3. Temperature-depth (uncalibrated) plot for CTD cast at AM02 showing cool melt layer immediately below the base of the shelf.

A single 1.5 m long sediment core was obtained from the sea floor at a depth of 841 m below the ice shelf surface (57 m,asl), with the site located some 80 km SW of the shelf calving front. The core contained a Holocene age siliceous mud and diatom ooze surface layer of marine origin (Hemer & Harris, in press). There is evidence for an increase in sea ice associated diatom deposition (*Fragilariopsis curta*) around 3500-5000 yr BP, suggestive of a major retreat of the Amery Ice Shelf front during the mid-Holocene climatic optimum.

One complete annual cycle of CTD (MicroCAT SBE 37-IM) recordings at three depths in the water column has been uploaded from the site (Figure 4). These data are in the stages of being calibrated. Data from the uppermost instrument suspended 20 m below the ice shelf base indicate a change in water mass to a warmer and fresher regime at the onset of autumn and into winter, possibly due to incursion of high salinity shelf water (HSSW) from the front of the shelf.

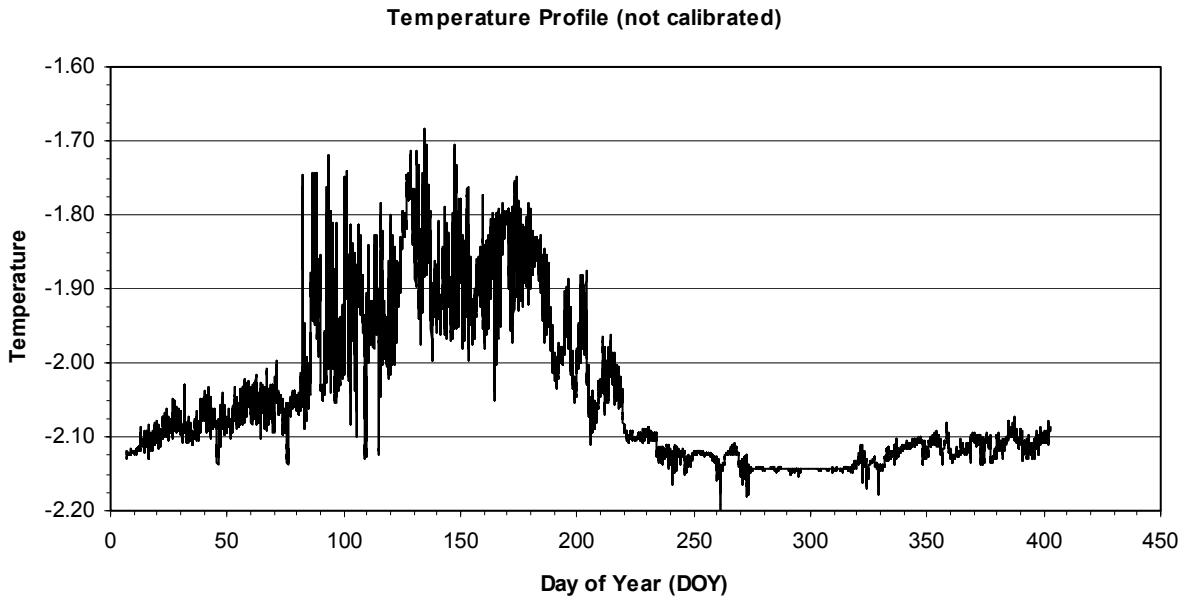

Figure 4. Temperature-depth (uncalibrated) plot for uppermost MicroCAT over a complete annual cycle showing presence of warmer water mass from onset of autumn.

CTD profiles in the 360 m deep water column at AM01 captured a 60-80 m thick layer of water at or near the local freezing point immediately beneath the shelf. These data are yet to be calibrated and analysed. Only a handful of data points is available from the long term monitoring instruments here due to inclement weather conditions early in the season forcing very late installation of the mooring immediately prior to retrieval of personnel and equipment.

4. FUTURE OPERATIONS

No drilling is scheduled for the 2002-03 austral summer. Data sets are planned to be uploaded from both existing drill sites, hopefully yielding 24 months continuous records at AM02, and 12 months at AM01. The AMISOR project will by then have run the course of its initial 5-year mandate, but the promising results thus far attained bode well for continued funding for a further 5-year study. Should project continuation be approved and funded, it is intended to drill a third in the transverse series of holes across the northern front of the shelf, thus yielding a full meridional

variation array for study. This hole, AM03 (69° 11.1' S, 70° 17.8' E), is expected to be through an ice thickness of some 360 m in what may well be a zone of active basal accretion. It is therefore possible that frazil ice may form a plug at the base of the borehole providing a new obstacle to be overcome during the sampling and mooring phases of the fieldwork. Future boreholes would then likely be drilled further south down the centre of the shelf to form a network of sites for zonal variation studies of ice shelf ocean interaction and processes. With a shift in emphasis by the Australian Antarctic Division from helicopter based to fixed wing aircraft deployment, the AMISOR project can look to extend its activities further afield with this expanded capability in future seasons.

There exists also the possibility of international collaboration with the Polar Research Institute of China who intend to commence ice core drilling on the Amery Ice Shelf in the 2002-03 field season (initial intentions indicate coring near the AM01 site). Negotiations are also underway with the California Institute of Technology and the Jet Propulsion Laboratory (USA) for deployment of their Antarctic ice borehole probe used so successfully on Ice Stream C in 2000-01 (see http://telerobotics.jpl.nasa.gov/~behar/JPLAntIceProbe.html). The instrument already has downward and sideward looking real time video capability, and is being redesigned to incorporate a spectrophotometer for borehole wall measurements and the possible detection of organic matter trapped in accreted marine ice layers.

Acknowledgements

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