Oceanography of the Ross Ice Shelf – M2 Moored Observations

Antarctic Data Series Report (Victoria University)
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Introduction

A Woods Hole Oceanographic Institution (WHOI) current meter mooring was deployed December 2, 2010 to January 23, 2011 through the Ross Ice Shelf (RIS) at the M2 site in support of the ANtarctic geologic DRILLing (ANDRILL) project. This report characterizes the science and engineering objectives, deployment/recovery activities, and some initial results from the deployment. More complete details about the mooring deployment, access to the edited data, and the mooring design can be found online at http://www.whoi.edu/science/PO/coastal/ANDRILL_2010_Mooring/.

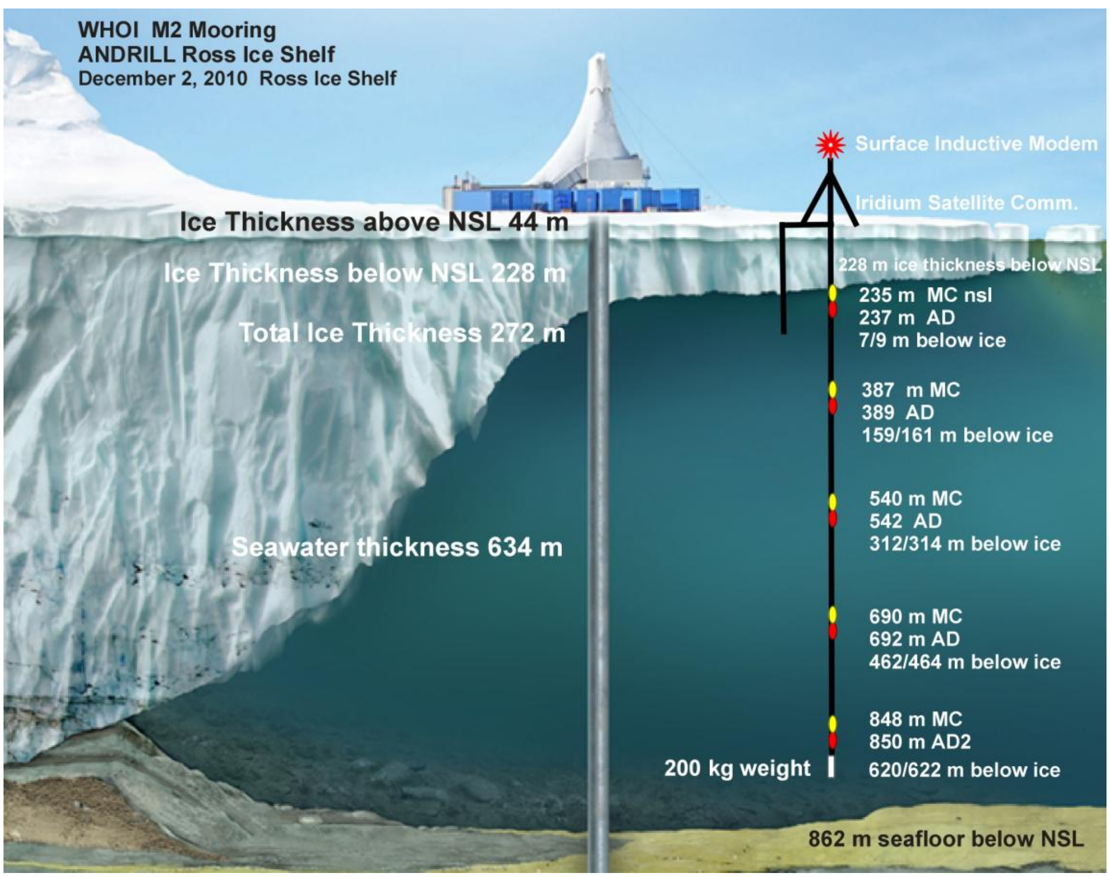


Figure 1 Design of the 2010-2011 M2 mooring relative to nominal sea level (NSL). Not drawn to scale.

Background

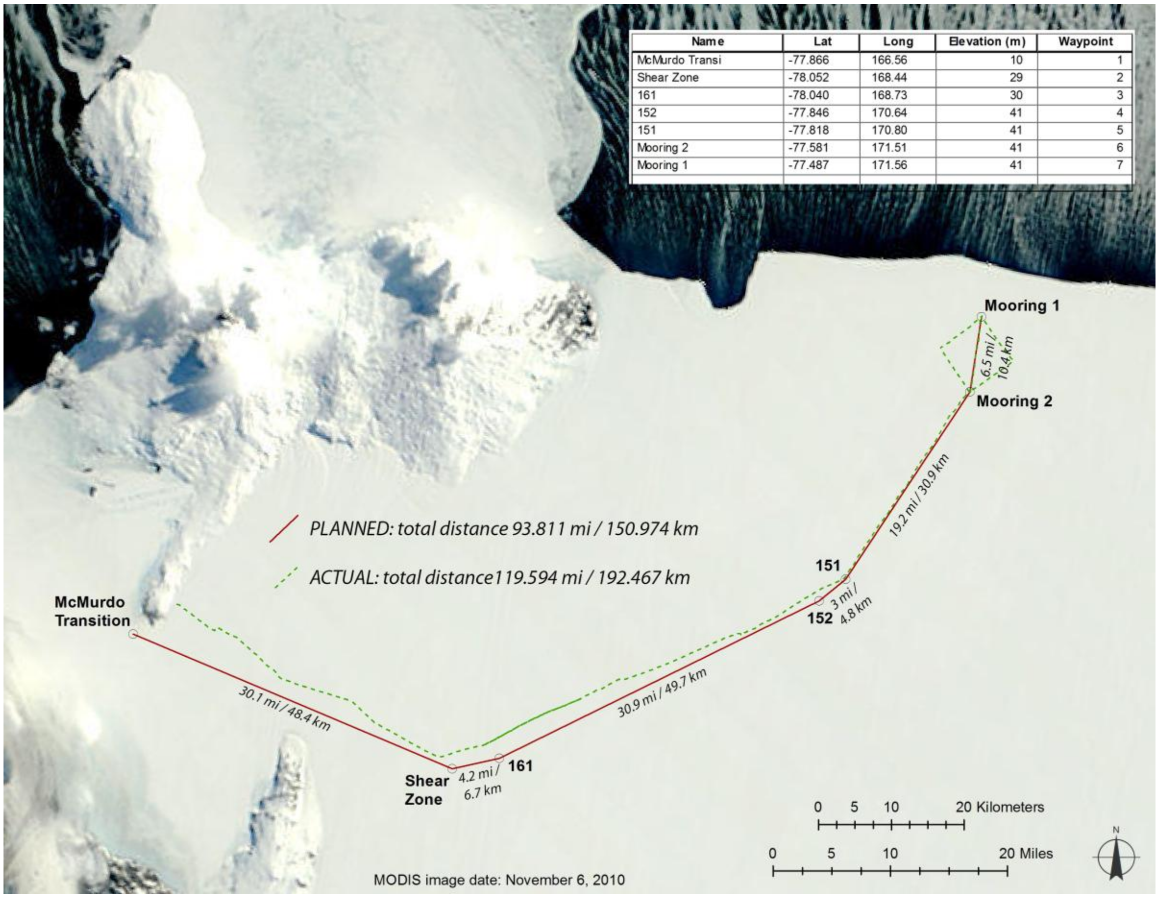
This report documents the first real-time observations of velocity and water properties from the WHOI M2 mooring deployed through the Ross Ice Shelf (RIS) at the ANDRILL Coulman High (CH) drill site. Moored velocity and pressure, temperature, conductivity (PTC) observations were made at the M2 site in support of the ANtarctic geologic DRILLing (ANDRILL) program, an international NSF supported program designed to investigate Antarctica's role in global environmental change (Rack, 2010). Drilling of sediment cores is planned by ANDRILL at Coulman High on the RIS in 2014-15 to obtain records of historical climate change on the Antarctic continental shelf. The New Zealand National Institute of Water and Atmosphere (NIWA) deployed a similar mooring at the M1 site located approximately 10 km north of the WHOI M2 mooring. The NIWA M1 and WHOI M2 current meter moored observations will provide direct input to the engineering design of the future ANDRILL drill structure that will be used to obtain bottom sediment cores.

The Woods Hole Oceanographic Institution (WHOI) research program is primarily intended to support the operational needs of the ANDRILL program by measuring currents and water properties under the RIS near the future Coulman High core site. This RIS field program presented a valuable opportunity for us to investigate processes under the ice shelf. In particular we will focus on the following objectives:

- Assess the tidal and summer seasonal variability of the water column structure and transport across the ice front, including influences on and response to ice shelf basal melt, sea ice formation and variability of the Ross Sea Polynya;
- Characterize the under-ice-shelf boundary layer, the heat transport across this layer, and scales of vertical mixing throughout the water column.

Pre M2 Deployment

The WHOI M2 mooring was located at the Coulman High site approximately 140 km east northeast of McMurdo Station, Antarctica and 16 km south of the northern edge of the ice shelf. The NIWA M1 mooring was located 6 km south of the northern edge of the ice shelf and 10 km north of the WHOI M2 mooring shown in Figure 2.



Name	Lat	Long	Elevation (m)	Waypoint
McMurdo Transi	-77.866	166.56	10	1
Shear Zone	-78.052	168.44	29	2
161	-78.040	168.73	30	3
152	-77.846	170.64	41	4
151	-77.818	170.80	41	5
Mooring 2	-77.581	171.51	41	6
Mooring 1	-77.487	171.56	41	7

Figure 2 Location of the Coulman High (CH) moorings M1 & M2 near the northern edge of the Ross Ice Shelf, approximately 130 km northeast of McMurdo Station, Ross Island, Antarctic. The traverse made during October 2010 to build the access road and supply the remote field camp on the Ross Ice Shelf is shown. This satellite (MODIS) image dated November 6, 2010 shows the northern edge of the ice shelf (black/white upper right) and open water polyna near the two mooring sites with surface foam streak–like patterns visible on the sea surface due to a strong northward wind. Solid sea ice less than 2 m thick extends north from Ross Island in the upper left.

The two RIS mooring sites were normally covered with ~275 m of freshwater ice (Figure 1). Before deployment we first needed to melt two ice holes approximately 20 m apart through the RIS at each mooring site. A 272 m x 0.1 m diameter ice hole was first made at the M2 site for the inductive modem ground wire. After the ground wire was deployed, a 272 m x 0.3 m ice hole was made for the instrumented mooring wire.

Melting these ice holes were of primary importance to successfully recovering the M2 mooring. The ice holes were melted with the elaborate ANDRILL hot water drilling (HWD) system operated successfully by NIWA researchers J. R. Rigden and H. Berge with help from many other individuals.

CTD Cast at M2

After the M2 ice hole was opened up with the HWD, a CTD cast was made to the sea floor to determine the total pressure and the keel pressure of the ice shelf (Figure 3). A maximum CTD (6 m above a bottom weight) pressure at M2 of 866.6 dbar was converted to the depth 862 m at latitude 77.5° S. The keel depth of the RIS relative to nominal sea level (NSL) was determined from the CTD profile density gradient to be 230 dbar or 228 m below NSL.

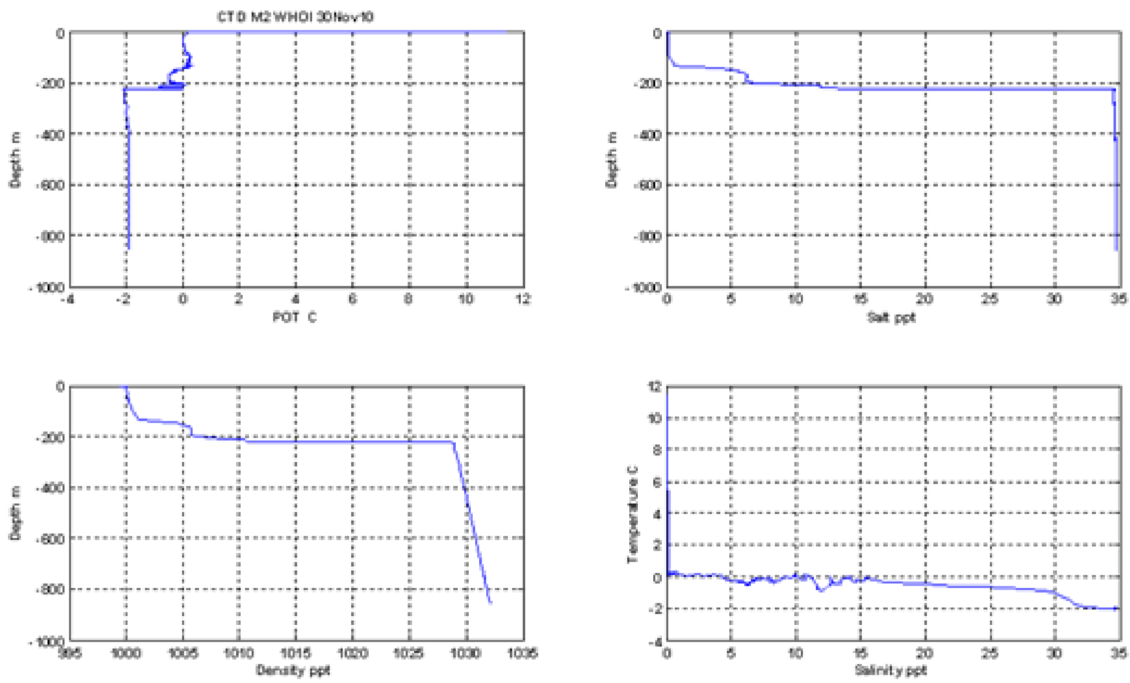


Figure 3 NIWA CTD cast at the M2 mooring site after the ice hole was melted through the RIS.

The distance from the upper ice surface (in the air) to the water level in the ice hole was measured by C. Stewart (NIWA) using a float and tape measure lowered in the ice hole to be 38.5 m (Figure 4).

Once the ice hole was open to the atmosphere and the sea level adjusted to the horizontal pressure gradients there was a freshwater level in the ice hole approximately 5.6 m above MSL. To understand this freshwater level first assume there were no horizontal pressure gradients at the level of the keel of the ice shelf between the open ocean 16 km to the north and the M2 ice hole was open to the atmosphere.

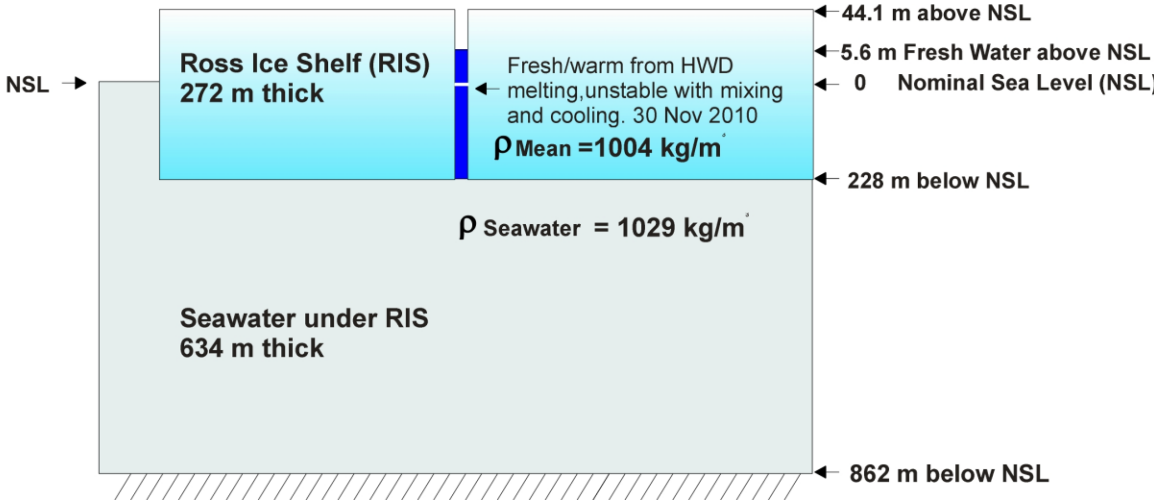


Figure 4 Water level and nominal sea level in the open M2 ice hole.

The height of the fresh, warm melt water in the M2 ice hole of 233.6 m was calculated from integrating the specific volume from the pressure at the bottom of the RIS (228 m) to nominal sea level. This artificial, transient height can also be estimated from bulk properties.

If no horizontal pressure (p) gradients and $\frac{dp}{dy} = 0$ and $dp = \rho\, g\, dz$,

$$\rho_{seawater}\, g\, h_{seawater} = \rho_{freshwater}\, g\, h_{freshwater}$$

$$h_{freshwater} = h_{seawater}\ \rho_{seawater} / \rho_{freshwater},$$

where h relative to MSL is 228 m from the CTD profile in the ice hole, average freshwater density was ~1004.5 kg/m^3 and sea water density was 1029 kg/m^3

$$= 228 \text{ x } (1029/1004.5) = 233.6 \text{ m}$$

Thus the freshwater in the ice was approximately 5.6 m above sea level. This height decreased to mean sea level as saltwater mixed into the hole and the water cooled to the in situ density of the seawater just below the ice hole.

The M2 mooring was deployed during a blizzard inside the ANDRILL Hot Water Drill (HWD) protective structure (MECC). The M2 mooring was designed and built with lithium batteries and 14 battery heater pads and an advanced electronic heater control system for a 14 month deployment by R. Limeburner, W. Ostrom and J. Obrien (WHOI) and B. Magnell, A. T. Morrison, and M. H. Vu (Woods Hole Group, Falmouth, MA).

Video Inspection of the Ice Hole through the Ross Ice Shelf

A Sony high definition movie camera was lowered into the primary ice hole by R. Levy and H. Berge to assess the physical dimensions of the hole at depth and to inspect the bottom sediments. Figure 5 shows a single frame of the movie as the camera descended into the seawater cavity from the ice hole. Note the groves worn into the side of the ice hole, presumably by the spectra rope used to repeatedly lower and raise the gravity core tool and camera as the 20 cm/s current in the seawater cavity below the ice shelf dragged the cable to one side of the opening. Videos of the ice hole inspection are available on the WHOI M2 mooring website.

Figure 5 Snapshot looking up of the bottom of the Ross Ice Shelf where the ice hole interfaces with seawater. A light facing away from the camera is approximately 1 m above the camera and mounted on two rigid metal bars. Photo courtesy of R. Levy and H. Berge.

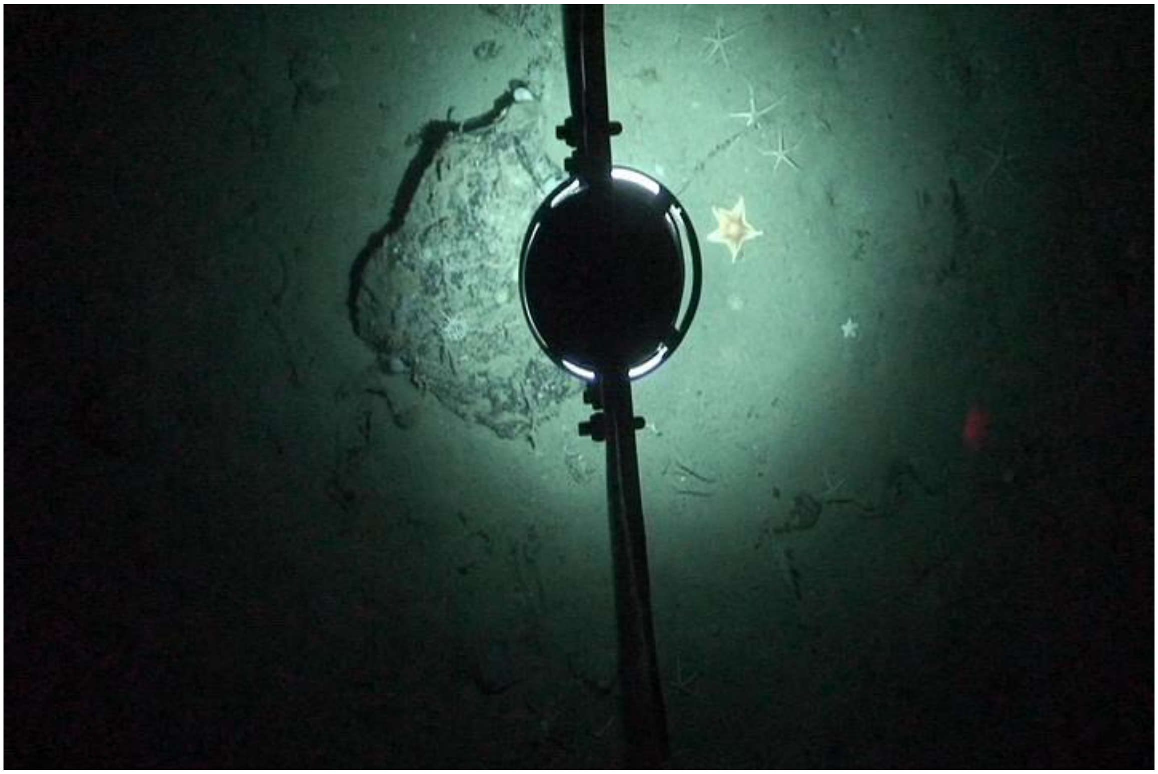


Figure 6 The seafloor beneath the Ross Ice Shelf at the Coulman High site. A boulder with approximate diameter of 200 mm is directly below the camera. Starfish on the seafloor are observed to be fleeing the descending camera in the movie. Photo courtesy of R. Levy and H. Berge.

M2 Deployment

The ANDRILL current meter moorings M1 and M2 were deployed through the RIS near 77° 26.211'S, 171° 32.391'E on November 24 and December 2, 2010 by R, Limeburner and W. Ostrom (WHOI), C. Stewart and M. Williams (NIWA), and S. Maas (Victoria University, Wellington, NZ).

Five Nortek Aquadopps and five SeaBird Microcats, all equipped with inductive modems, were deployed on a wire rope at five levels below the ice shelf at the M2 site (Figure 1). Plastic cones were attached to the mooring wire above each instrument pair to center the cable in the ice hole during recovery. A surface inductive modem logger and Iridium satellite communication package were installed on the ice shelf upper surface at the M2 mooring site. The mooring was planned for recovery in January 2012, but a Rapid proposal to extend the measurements for 14 months of this functioning real-time observatory under the RIS was not funded by NSF.

The M2 mooring transmitted real-time data to WHOI every 2 hours during December 2010 to January 2011. This data was then served on the WHOI ANDRILL website http://www.whoi.edu/science/PO/coastal/ANDRILL_2010_Mooring/

in real-time during the deployment. Successful recovery of the M2 mooring was completed during January 2011. The M2 moored data have been edited and a descriptive paper will be written during August 2011 on the mean and temporal variability of the observations. A full analysis of the combined M1 and M2 observations will be made in late 2011.

Preliminary Observations

The raw 30 minute magnetic velocity data were first rotated into an earth coordinate reference system by applying a magnetic variation correction of 134° E. The data were then checked for bad points and the data before deployment and after recovery were removed. Figure 6 presents a preliminary summary stick plot of the five velocity measurements separated by approximately 150 m from ~7 m below the keel of the RIS to ~10 m above the seafloor

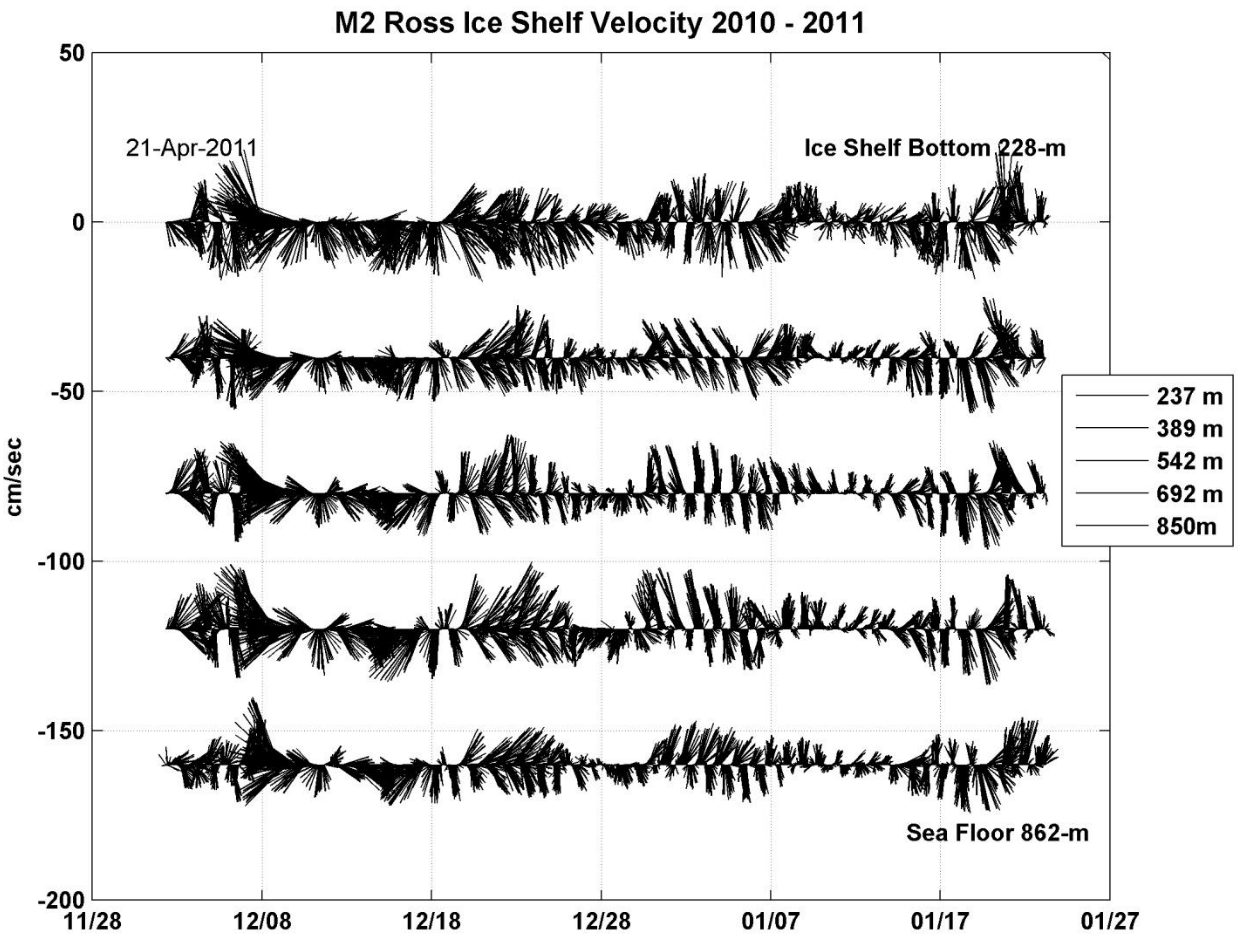


Figure 7 Stick plots of edited 30 minute velocity data at the M2 mooring.

The M2 currents shown in Figure 7 indicate:

1. Diurnal variability in the meridional velocity component was observed at all depths.
2. Semidiurnal fortnightly modulation in the velocity was observed at all depths. Note that the semidiurnal frequency is near resonant with the inertial frequency at this latitude.
3. Strong events in the observed velocity occurred during December 8-10, 2010 and January 21, 2011. There were strong wind events during these periods that may or may not be relevant.
4. Mean velocity at all levels was much less than the velocity variability indicating the mean current estimates were not significant.
5. The classical model of outflow under the ice shelf and inflow near the bottom was not observed.

Maximum M2 Speed

The speed (top) and direction (bottom) with respect to true north at the five current meter depths are shown for the entire deployment in Figure 8. Speeds above 20 cm/s were observed at a depth of 237 m (red) just under the ice and at 692 m (cyan) just below mid depth. The maximum speed of 24.9 cm/s was observed at a depth of 692 m occurred for about 2 hours on December 8, 2010 starting at about 2200 z.

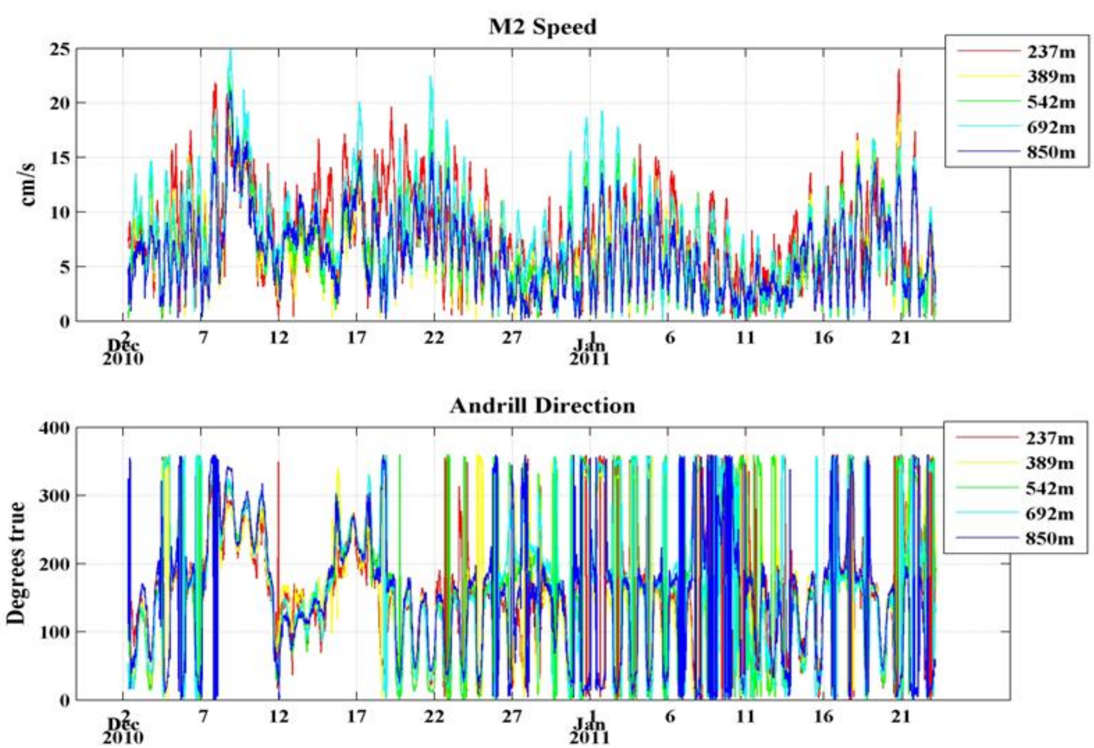


Figure 8 Speed (top) and the direction the current flows toward with respect to true north (bottom) at the five current meter depths for the entire deployment period.

The diurnal variability in the Figure 8 speed is primarily due to the meridional tidal current, but there were times when the tidal current was less dominant (e.g., during December 8-17, 2010 when the currents were toward the southwest backing to southeast at all levels and during December 18-22, 2010 when the currents were generally toward the northeast to southeast at all levels).

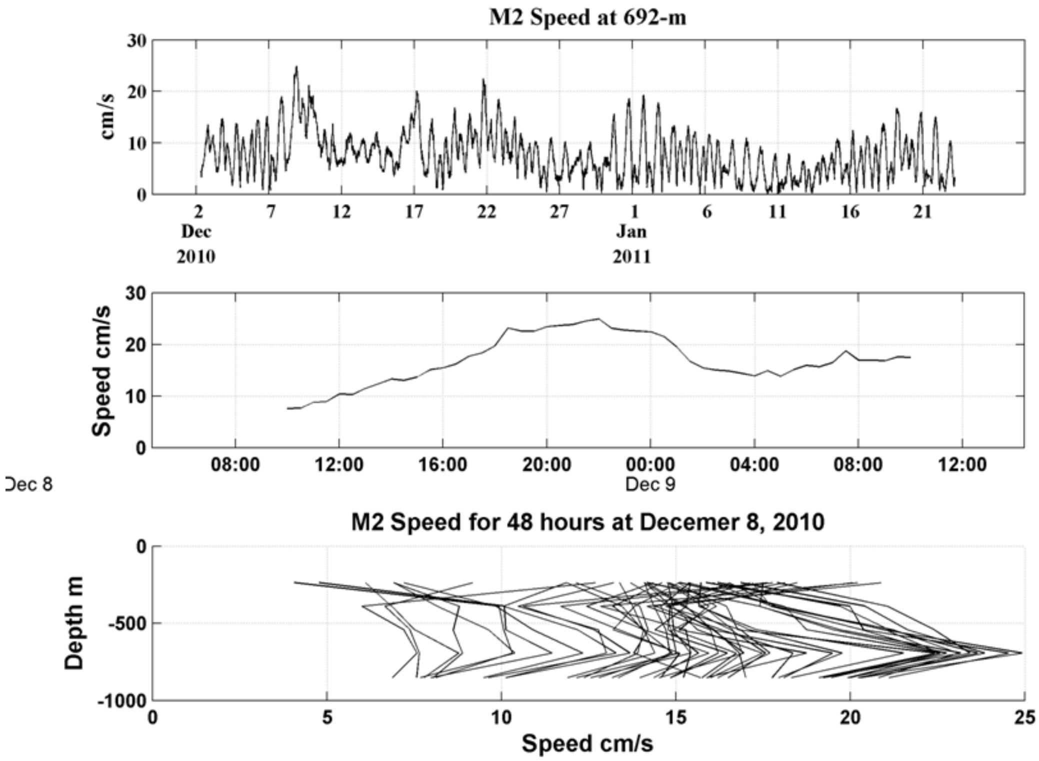


Figure 9 Speed at a depth of 692 m for the entire record (top), speed for 24 hours at 692 m at the time of maximum speed (middle), and speed from all five depth levels for 48 hours centered at the time of maximum speed (bottom).

The speed at a depth of 692 m is shown in Figure 9 for the entire deployment period (top), the speed at 692 m for 24 hours centered on the time of the maximum speed measured for the deployment (middle), and the speeds at the five current meter depths for 48 hours centered on the time of maximum speed. The December 8, 2010 2200 Z maximum speed of over 24 cm/s at 692 m lasted for about four hours. Table 1 gives the east velocity, north velocity, speed and direction (with respect to true north) of the currents at the five depth levels at the time of maximum measured speed at a depth of 692 m. The currents were generally west northwestward in the upper water column and veered to northwestward in the lower water column with an increase in speed that was near-bottom intensified. The classical concept of a shear flow under the ice shelf that is northward under the RIS and southward near the bottom was not observed during the time of maximum current at mooring M2.

Depth m	East cm/s	North cm/s	Speed cm/s	Dir wrt N
237	-14.43	4.49	15.1	287
389	-17.8	2.87	18	279
542	-17.11	12.08	20.95	305
692	-18.6	16.58	24.92	312
850	-7.26	18.98	20.31	339

Table 1 East velocity, north velocity, speed and direction (with respect to true north) for the currents at the five measurement depth levels during the time of maximum measured speed December 8, 2010 starting at about 2200 Z.

The preliminary data from the five M2 Microcats are shown in Figure 8.

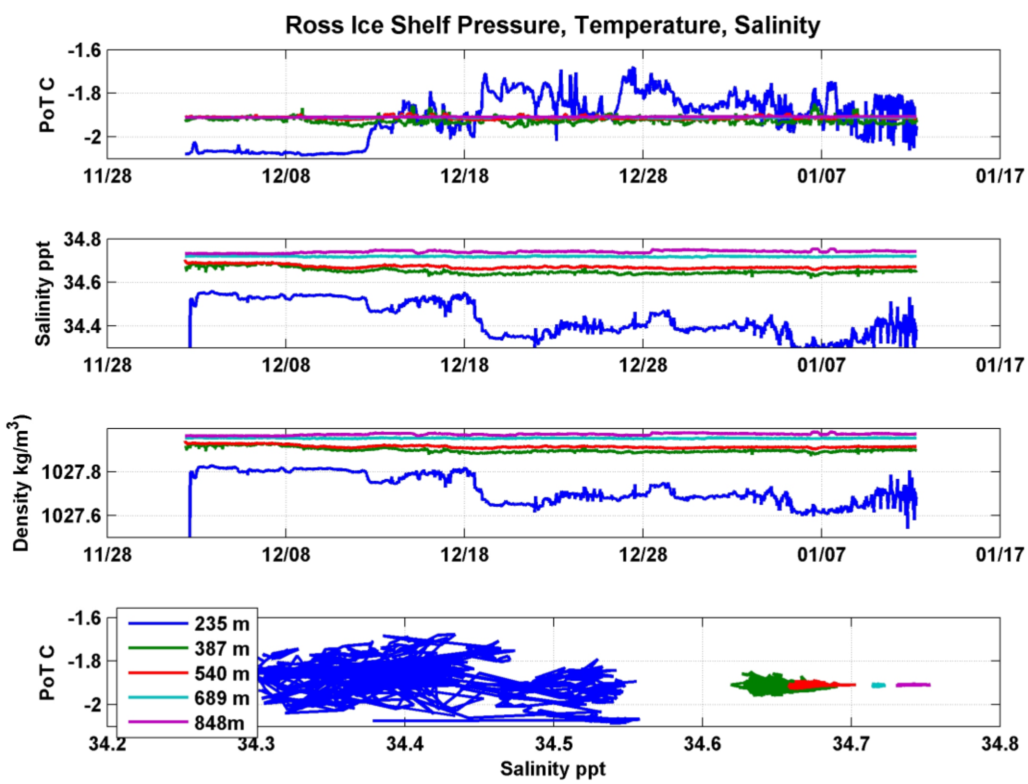


Figure 10 Water properties below the RIS at M2.The anomalous data are from the upper Microcat instrument at a depth of 235m, ~ 7 m below the lower ice shelf seawater boundary.

The future analysis of the combined M1 and M2 data sets will provide important first-time characteristics of the spatial and temporal variability under the RIS near the CH site.

References

Carter, Lionel, Gavin Dunbar, Rob McKay and Tim Naish, 2007. Sedimentation and Oceanography Beneath the McMurdo Ice Shelf at Windless Bight, 2006. Antarctic Research Center ISSN 0375 8192, Antarctic Data Series No 32, Victoria University of Wellington, Te Whare Wananga o te Upoko o te Ika Maui. http://www.vuw.ac.nz/Antarctica/publications/ADS/ads.aspx

Rack, Frank, 2009. ANDRILL Record of Environmental Review Order. RPSC, Document MCFC1100.R01