Ross Ice Shelf 2010 M2 Moored Velocity Profiles

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Introduction

A Woods Hole Oceanographic Institution (WHOI) current meter mooring was deployed from December 2, 2010 to January 23, 2011 through the Ross Ice Shelf (RIS) in support of the ANtarctic geologic DRILLing (ANDRILL) project. This report characterizes the horizontal currents over the 52-day deployment at the 2010-2011 ANDRILL Coulman High M2 mooring site located on the Ross Ice Shelf 16 km south of the northern ice edge and about 200 km ENE of McMurdo Station. Details about the mooring deployment, the edited data, and the mooring design can be found at http://www.whoi.edu/science/PO/coastal/ANDRILL_2010_Mooring/. A schematic of the 2010-11 Coulman High mooring with instrument depths is shown below in Figure 1.

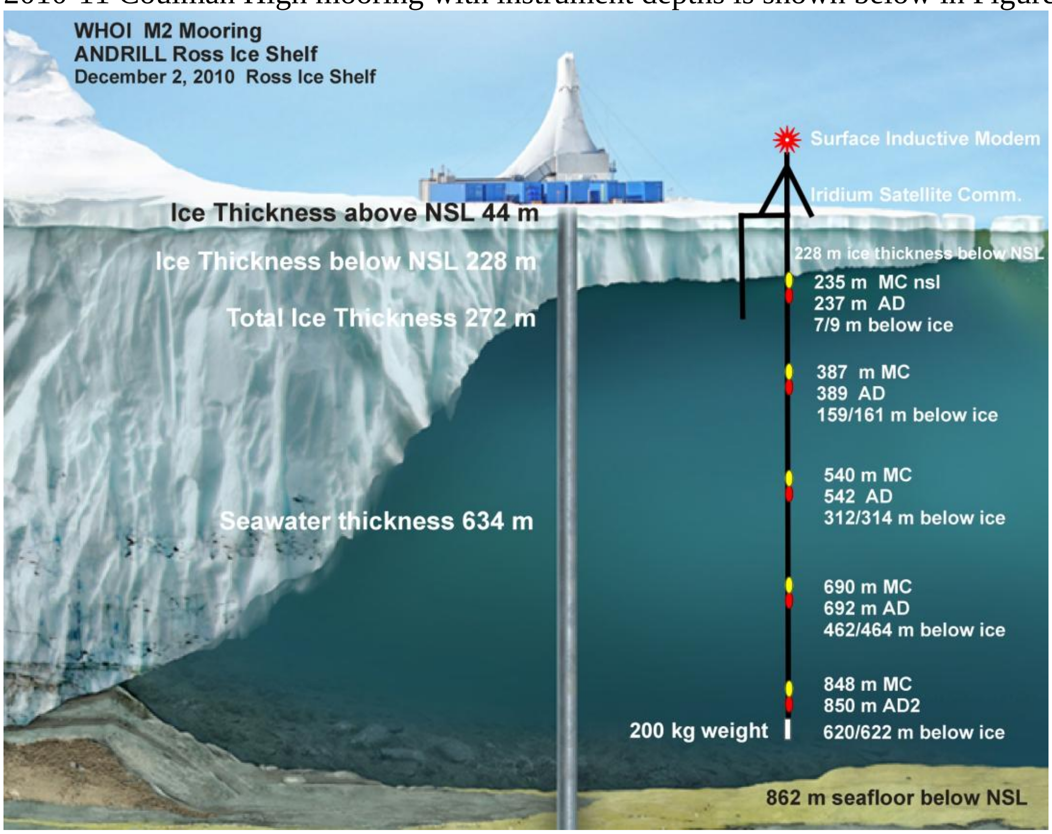

Figure 1 Design of the 2010-2011 M2 mooring relative to nominal sea level (NSL) not drawn to scale. A SeaBird MicroCat (MC) temperature and conductivity recorder and a Nortek Aquadopp acoustic current meter (AD) were deployed at each of the five measurement depths.

This report focuses on characterizing the strongest currents at the M2 Coulman High site with the objective of ultimately using this data to design a drilling platform for coring the bottom sediments. We will provide two characteristic profiles of the M2 ocean current at the Coulman High site: one profile from the data when the observed speed was a maximum, and a second profile from the data when the observed vertical shear in the horizontal velocity was at a maximum. These two characteristic current profiles should provide adequate forcing to model the response of a drilling riser to the local forcing by the currents.

Summary of the M2 Velocity Observations

The raw 30-minute velocity data were first rotated from magnetic into an earth coordinate reference system by applying a magnetic variation correction of 134° E. The data were then checked for clock drift and bad data points. Data before deployment and after recovery were removed. Figure 2 presents a preliminary summary stick plot of the velocity time series recorded at the five measurement depths each separated by approximately 150 m from 9 m below the keel of the RIS to 12 m above the seafloor.

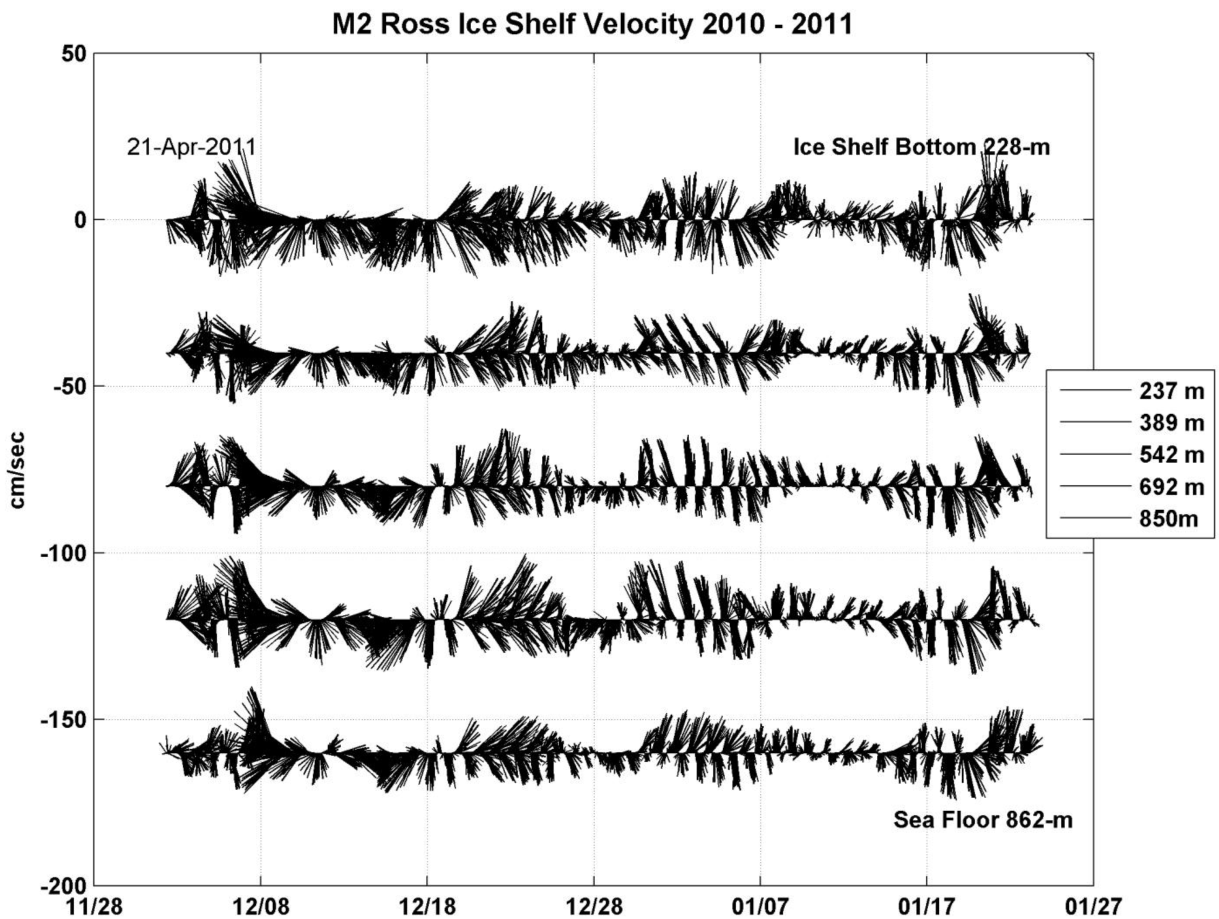

Figure 2 Stick plots of 30 minute velocity data at the M2 mooring. Current meter measurement depths are listed to the right.

The depths, mean currents, standard deviations and standard errors of the mean currents are listed in Table 1. The standard error with 95% confidence limits was calculated from

$$StdErr = 1.96 * STD / \mathrm{sqrt}(NDF)$$

STD = standard deviation
NDF = number of degrees of freedom = T/(2*ITS)
ITS = integral time scale, the integral of the autocorrelation function

Depth	U mean	V mean	U std deviation	V std deviation	U std error	V std error
m	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec
237	1.2	-1.6	4.8	6.9	2.3	1.1
389	0.6	-0.9	4.5	5.9	2.0	0.9
542	-0.1	0.0	4.3	6.5	1.9	1.0
692	0.4	-0.1	5.1	7.0	2.4	1.1
850	1.1	-0.7	4.0	5.6	1.8	0.9

Table 1. M2 mean currents, std deviations and standard errors of the means.

In general the M2 currents shown in Figure 2 indicate:

1. Diurnal tidal variability in the meridional velocity component was observed at all depths with near-bottom clockwise veering of direction.

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 also strong wind/low pressure events during these periods, but it is unclear if the wind/low pressure variability force the strong currents events at M2.

4. The mean velocity was smaller than the standard error indicating the mean current estimates were not statistically different from zero with 95% confidence.

5. The classic paradigm of northward outflow under the RIS and southward 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 3. The maximum speed of 24.9 cm/s was observed at a depth of 692 m for about 4 hours on December 8, 2010 starting at about 2200 Z. Speeds above 20 cm/s were observed at depths of 237 m (red, December 7 and January 21) just under the ice and at 692 m (cyan, December 8-10 and January 17 and 22) just below mid-depth.

The diurnal variability shown in the Figure 3 speed was 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).

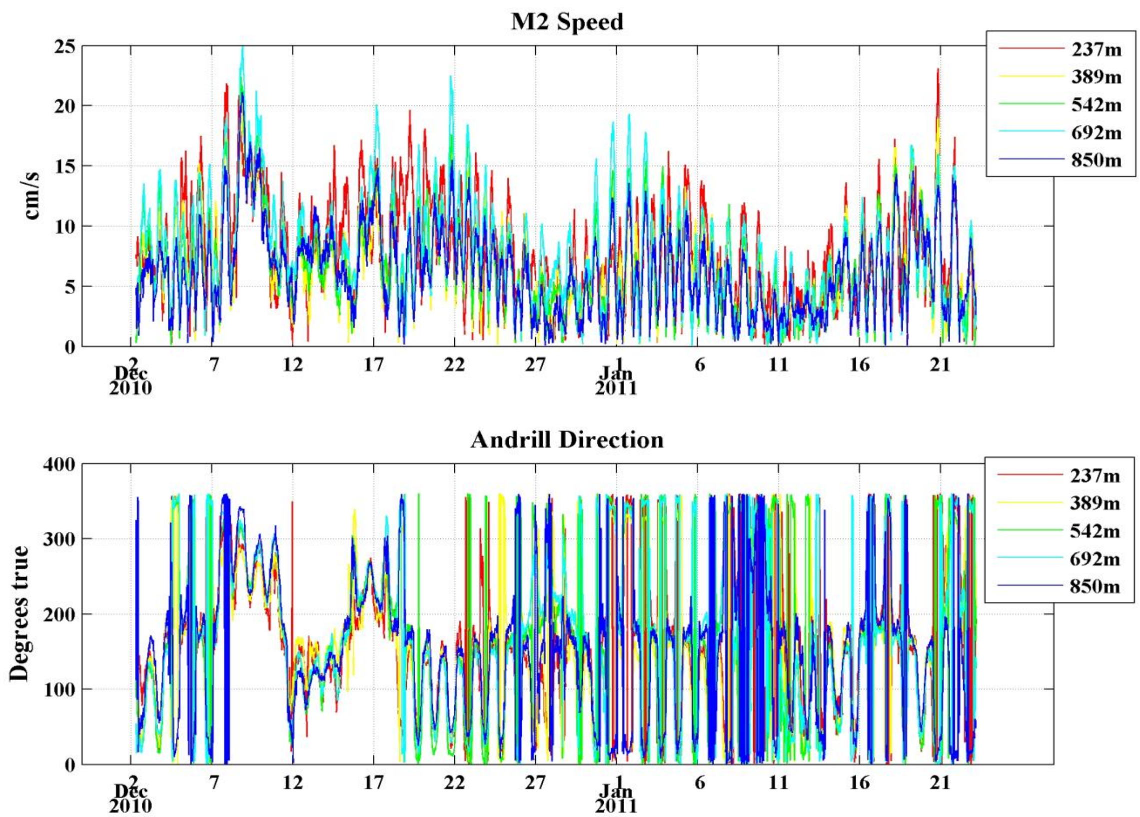

Figure 3 Speed (top) and the direction the current flows toward with respect to true north (bottom) at the five current meter depths for the entire deployment period.

The speed at 692 m (Figure 4) is shown for the entire deployment period (top), the speed at 692 m for 24 hours centered at the time of the maximum speed (middle), and the speeds at all five depths for 48 hours centered at the time of maximum speed. The December 8, 2010 maximum speed of over 24 cm/s at 692 m lasted for about four hours.

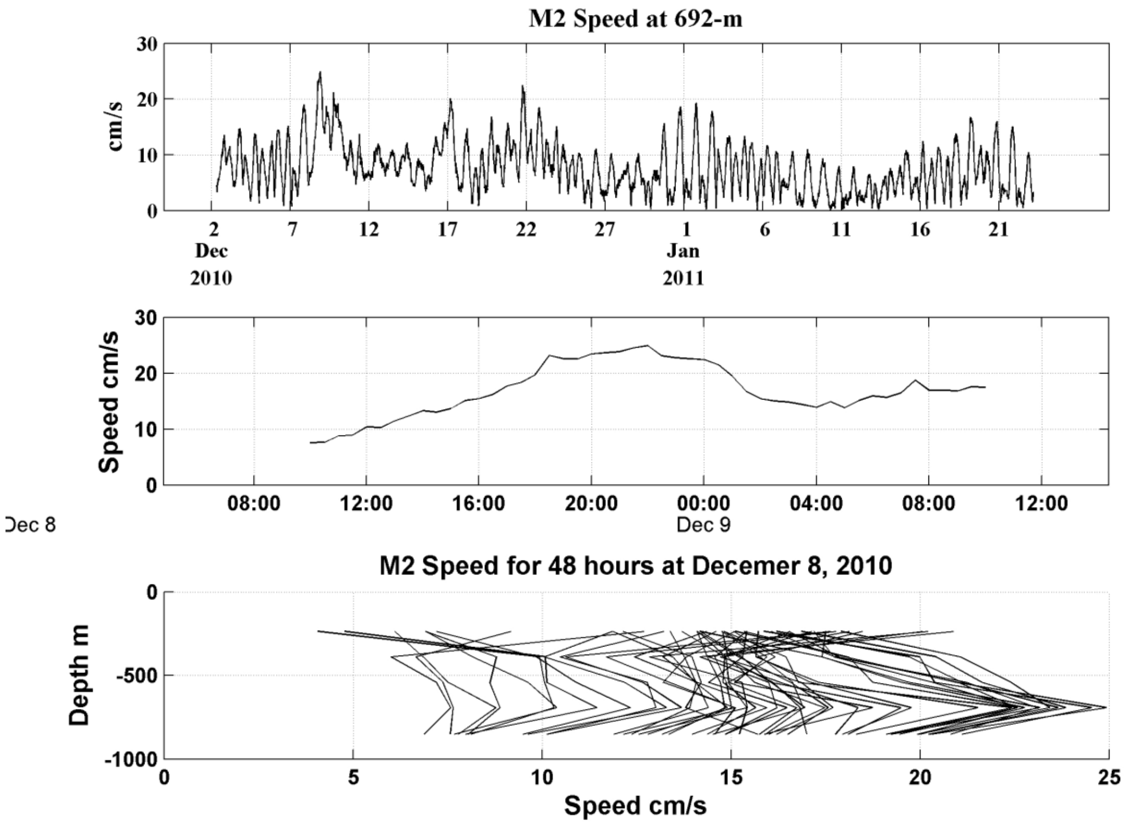

Figure 4 Speed at a depth of 692 m for the entire record (top), speed for 24 hours at 692 m at the time of maximum speed (middle), and speed from all five depth levels for 48 hours centered at the time of maximum speed (bottom).

Table 2 lists 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. **Note the strong bottom intensification of the meridional (northward) velocity and the barotropic structure of the zonal (eastward) velocity except for the bottom boundary layer**. This clearly shows the three dimensional veering character of the vertical shear in the horizontal current. Appropriate modeling of a drill rig riser should include this three dimensional spatial character of the M2 velocity profile.

Depth m	East cm/s	North cm/s	Speed cm/s	Dir wrt N
237	-14.4	4.5	15.1	287
389	-17.8	2.9	18.0	279
542	-17.1	12.1	21.0	305
692	-18.6	16.6	24.9	312
850	-7.3	19.0	20.3	339

Table 2 East velocity, north velocity, speed and direction (with respect to true north) at the five measurement depths during the time of maximum measured speed December 8, 2010 starting at 2200 GMT.

Maximum Shear

Next we will characterize the currents by focusing on the times when the current shear is a maximum. The complex velocity w is defined as

$$w=u+i*v$$

where u is the east velocity, v is the north velocity and i = sqrt(-1). The complex shear is defined as $\Delta w/\Delta z$ where Δw is the difference in w between two current meters, and Δz is the vertical instrument separation in meters. The magnitude of the complex shear is given by its absolute value, and the shear angle is the difference between the directions of the current vectors at the two depths.

Figure 5 (top) shows the shear from all instruments for the entire record. Note that there was one time when the shear was greater than 0.001 sec^{-1} between the upper two instruments.. This occurred on December 18, 2011 at 1730 GMT and the shear is shown in Figure 5 (middle) at a depth of 313 m (between 237 m and 389 m). The shear angle shown in Figure 5 (bottom) indicates most of the shear was between a depth of 237 m and 389 m and the current direction changes about 100°.

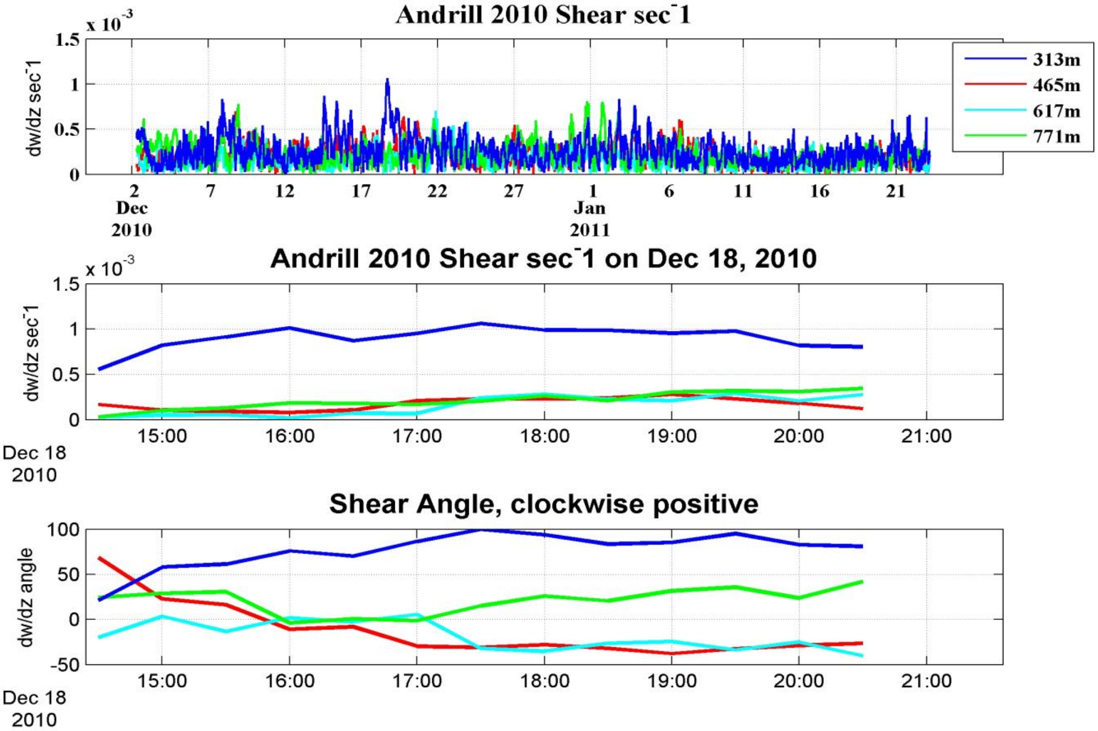

Figure 5 Shear for the entire record (top), for 6 hours on December 18, 2010 (middle), and shear angle (bottom).

The observed currents at the time of maximum shear are listed in Table 3. The currents in Table 2 were generally surface intensified for the meridional component of velocity, but the zonal current was strongest at uppermost instrument (237 m), but had a more complex structure at other depths.

Depth m	East cm/s	North cm/s	Speed cm/s	Direction wrt N
237	10.9	-8.9	14.1	129
389	-4.4	-3.8	5.8	229
542	-2.1	-6.5	6.8	198
692	1.5	-5.8	6.0	166
850	-0.1	-3.0	3.0	181

Table 3. 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 observed shear on December 18, 2030 at 1730 Z between 237 m and 389 m.

In general, the M2 velocity and shear were weaker than the observations at the 2006 SMS site in McMurdo Sound. This was partially due to 70% greater depth at the M2 Ross Ice Shelf site than the SMS depth. The M2 velocity variability was much greater than the mean velocity at all levels and so the M2 means were not statistically significant. The strongest observed M2 current and shear occurred during events that are not well understood. These strong velocity events are probably forced by variability in the open ocean to the north. The M2 Ross Ice Shelf record length was too short to properly characterize these strong currents.

The M2 velocity profiles during maximum speed and maximum shear were interpolated every 10 m using a cubic spline and are listed in Appendixes 1 and 2.

Appendix 1 – Interpolated speed profile at time of maximum speed

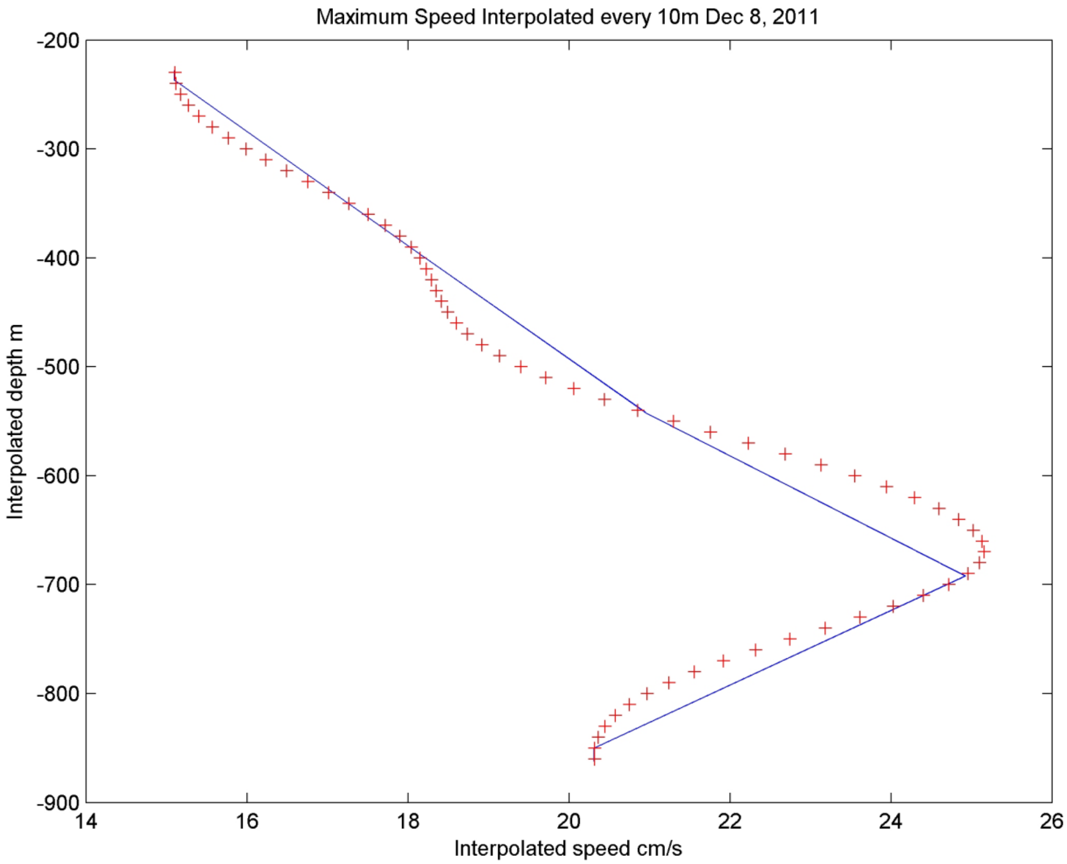

Figure 6 Maximum speed profile interpolated every 10 m with a cubic spline.

Max speed interpolated data

Depth m	**East cm/s**	**North cm/s**	**Speed cm/s**	**Direction wrt north**
-230	**-14.42**	**4.49**	**15.11**	**-73**
-240	**-14.44**	**4.48**	**15.12**	**-73**
-250	**-14.52**	**4.40**	**15.18**	**-73**
-260	**-14.66**	**4.27**	**15.27**	**-74**
-270	**-14.85**	**4.10**	**15.40**	**-75**
-280	**-15.08**	**3.90**	**15.57**	**-75**
-290	**-15.33**	**3.68**	**15.77**	**-76**
-300	**-15.61**	**3.46**	**15.99**	**-78**
-310	**-15.91**	**3.24**	**16.24**	**-78**
-320	**-16.21**	**3.03**	**16.49**	**-79**
-330	**-16.51**	**2.85**	**16.76**	**-80**
-340	**-16.80**	**2.70**	**17.02**	**-81**
-350	**-17.07**	**2.60**	**17.27**	**-81**

-360	**-17.32**	**2.56**	**17.51**	**-82**
-370	**-17.53**	**2.59**	**17.72**	**-82**
-380	**-17.69**	**2.70**	**17.90**	**-81**
-390	**-17.81**	**2.89**	**18.04**	**-81**
-400	**-17.87**	**3.19**	**18.15**	**-80**
-410	**-17.88**	**3.57**	**18.23**	**-79**
-420	**-17.84**	**4.03**	**18.29**	**-77**
-430	**-17.77**	**4.56**	**18.35**	**-76**
-440	**-17.68**	**5.15**	**18.41**	**-74**
-450	**-17.57**	**5.79**	**18.49**	**-72**
-460	**-17.44**	**6.46**	**18.60**	**-70**
-470	**-17.32**	**7.16**	**18.74**	**-68**
-480	**-17.20**	**7.88**	**18.92**	**-65**
-490	**-17.10**	**8.60**	**19.14**	**-63**
-500	**-17.02**	**9.32**	**19.41**	**-61**
-510	**-16.97**	**10.03**	**19.71**	**-59**
-520	**-16.96**	**10.71**	**20.06**	**-58**
-530	**-16.99**	**11.36**	**20.44**	**-56**
-540	**-17.08**	**11.97**	**20.86**	**-55**
-550	**-17.24**	**12.52**	**21.30**	**-54**
-560	**-17.44**	**13.01**	**21.76**	**-53**
-570	**-17.69**	**13.46**	**22.23**	**-53**
-580	**-17.96**	**13.86**	**22.69**	**-52**
-590	**-18.24**	**14.23**	**23.13**	**-52**
-600	**-18.52**	**14.55**	**23.55**	**-52**
-610	**-18.79**	**14.85**	**23.94**	**-52**
-620	**-19.02**	**15.11**	**24.29**	**-52**
-630	**-19.22**	**15.35**	**24.60**	**-51**
-640	**-19.35**	**15.57**	**24.84**	**-51**
-650	**-19.42**	**15.78**	**25.02**	**-51**
-660	**-19.40**	**15.98**	**25.13**	**-51**
-670	**-19.28**	**16.17**	**25.16**	**-50**
-680	**-19.05**	**16.35**	**25.10**	**-49**
-690	**-18.69**	**16.54**	**24.96**	**-48**
-700	**-18.19**	**16.74**	**24.72**	**-47**
-710	**-17.57**	**16.93**	**24.40**	**-46**
-720	**-16.85**	**17.14**	**24.03**	**-45**
-730	**-16.03**	**17.34**	**23.62**	**-43**
-740	**-15.16**	**17.54**	**23.18**	**-41**
-750	**-14.24**	**17.73**	**22.74**	**-39**
-760	**-13.30**	**17.92**	**22.32**	**-37**
-770	**-12.36**	**18.11**	**21.92**	**-34**
-780	**-11.43**	**18.28**	**21.56**	**-32**
-790	**-10.55**	**18.43**	**21.24**	**-30**
-800	**-9.73**	**18.58**	**20.97**	**-28**
-810	**-8.99**	**18.70**	**20.75**	**-26**

-820	**-8.35**	**18.81**	**20.58**	**-24**
-830	**-7.84**	**18.89**	**20.45**	**-23**
-840	**-7.47**	**18.95**	**20.37**	**-22**
-850	**-7.26**	**18.98**	**20.32**	**-21**
-860	**-7.24**	**18.98**	**20.32**	**-21**

Appendix 2 - Maximum shear October 27, 2006 - current profile interpolated every 10 m with cubic spline.

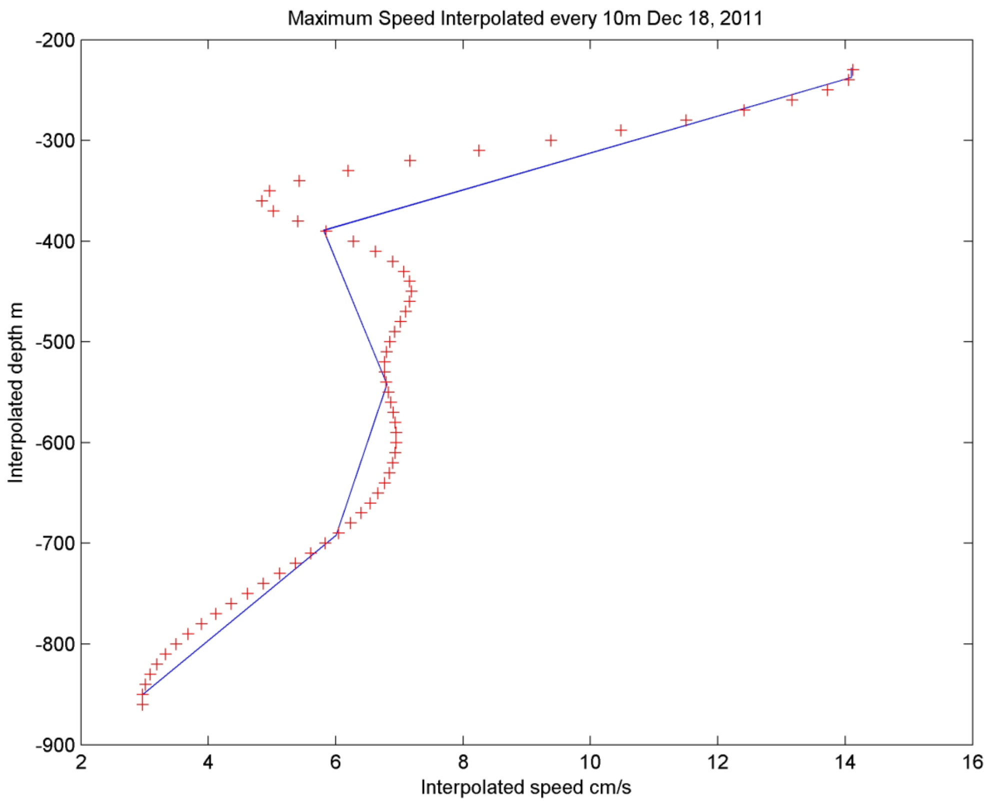

Figure 7 Maximum shear December 18, 2010 - current profile interpolated every 10 m with cubic spline.

Depth m	**East cm/s**	**North cm/s**	**Speed cm/s**	**Direction wrt north**
-230	**10.97**	**-8.90**	**14.12**	**129**
-240	**10.90**	**-8.87**	**14.05**	**129**
-250	**10.57**	**-8.75**	**13.72**	**130**
-260	**10.01**	**-8.55**	**13.16**	**130**
-270	**9.25**	**-8.27**	**12.41**	**132**
-280	**8.33**	**-7.94**	**11.50**	**134**

-290	**7.26**	**-7.55**	**10.48**	**136**
-300	**6.08**	**-7.14**	**9.38**	**140**
-310	**4.83**	**-6.70**	**8.25**	**144**
-320	**3.52**	**-6.25**	**7.17**	**151**
-330	**2.20**	**-5.80**	**6.20**	**159**
-340	**0.89**	**-5.36**	**5.43**	**171**
-350	**-0.38**	**-4.95**	**4.96**	**184**
-360	**-1.58**	**-4.57**	**4.84**	**199**
-370	**-2.68**	**- 4.25**	**5.02**	**212**
-380	**-3.65**	**-3.99**	**5.40**	**222**
-390	**-4.45**	**-3.80**	**5.85**	**230**
-400	**-5.08**	**-3.69**	**6.28**	**234**
-410	**-5.53**	**-3.66**	**6.63**	**237**
-420	**-5.82**	**-3.69**	**6.89**	**238**
-430	**-5.97**	**-3.79**	**7.07**	**238**
-440	**-5.99**	**-3.93**	**7.16**	**237**
-450	**-5.89**	**-4.12**	**7.19**	**235**
-460	**-5.69**	**-4.35**	**7.16**	**233**
-470	**-5.41**	**-4.60**	**7.10**	**230**
-480	**-5.05**	**-4.87**	**7.01**	**226**
-490	**-4.63**	**-5.15**	**6.93**	**222**
-500	**-4.17**	**-5.43**	**6.85**	**218**
-510	**-3.69**	**-5.71**	**6.80**	**213**
-520	**-3.18**	**-5.98**	**6.77**	**208**
-530	**-2.68**	**-6.22**	**6.77**	**203**
-540	**-2.19**	**-6.43**	**6.79**	**199**
-550	**-1.72**	**-6.61**	**6.83**	**195**
-560	**-1.29**	**-6.75**	**6.87**	**191**
-570	**-0.89**	**-6.85**	**6.90**	**187**
-580	**-0.52**	**-6.91**	**6.93**	**184**
-590	**-0.18**	**-6.95**	**6.95**	**182**
-600	**0.13**	**-6.95**	**6.95**	**179**
-610	**0.40**	**-6.92**	**6.93**	**177**
-620	**0.64**	**-6.87**	**6.90**	**175**
-630	**0.86**	**-6.79**	**6.84**	**173**
-640	**1.04**	**-6.69**	**6.77**	**171**
-650	**1.19**	**-6.56**	**6.67**	**170**
-660	**1.30**	**-6.41**	**6.54**	**169**
-670	**1.38**	**-6.25**	**6.40**	**168**
-680	**1.44**	**-6.06**	**6.23**	**167**
-690	**1.45**	**-5.87**	**6.04**	**166**
-700	**1.44**	**-5.65**	**5.84**	**166**
-710	**1.40**	**-5.43**	**5.61**	**166**
-720	**1.33**	**-5.20**	**5.37**	**166**
-730	**1.24**	**-4.97**	**5.12**	**166**
-740	**1.13**	**-4.73**	**4.87**	**167**

-750	**1.01**	**-4.50**	**4.61**	**167**
-760	**0.88**	**-4.27**	**4.36**	**168**
-770	**0.74**	**-4.05**	**4.12**	**170**
-780	**0.61**	**-3.84**	**3.89**	**171**
-790	**0.47**	**-3.65**	**3.68**	**173**
-800	**0.35**	**-3.47**	**3.49**	**174**
-810	**0.23**	**-3.32**	**3.33**	**176**
-820	**0.13**	**-3.19**	**3.19**	**178**
-830	**0.04**	**-3.08**	**3.08**	**179**
-840	**-0.02**	**-3.01**	**3.01**	**180**
-850	**-0.05**	**-2.97**	**2.97**	**181**
-860	**-0.06**	**-2.97**	**2.97**	**181**