Petermann Ocean-Weather Station Deployment and Results

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1. Introduction

Ice shelf drilling by a group from the British Antarctic Survey (BAS) gave access to ocean waters below the floating segment of Petermann Gletscher. In close collaboration with Dr. Nicholls of BAS the University of Delaware (UDel) provided 16 SBE37sm ocean sensors as well as 3-conductor serial cables and Kevlar rope to develop a real-time mooring system. One of these ocean observing system was augmented by an automated weather station for initial investigation of boundary layer meteorology on a rough and undulating glacier surface.

Scientific goals of this moored ocean-atmosphere observing system include exploration of ocean temperature and salinity variability under a Greenland ice shelf strongly forced by the ocean. More specifically, I hypothesize that the waters below Petermann Gletscher increase in temperature and decrease in salinity over time in the core of the warm Atlantic layer that resides at depths of about 300 m.

A closely related research question investigates the spatial and temporal distribution of the glacial meltwater that, I hypothesize, will rise upward along the inclined cavity of the ice shelf. This cavity, however, contains a large number of cracks, crevasses, and undulating topography where buoyant meltwater can collect. Our array of ocean sensors is spatially distributed to answer questions on the potential pathways of both incoming warm and salty Atlantic waters and outgoing cold and fresher glacial melt waters.

While BAS data loggers support up to two SBE37sm, the design criteria for the UDel system was to support five such sensors in addition to a rudimentary automated weather station. Both BAS and UDel systems provide real time data access, but the two systems differ substantially in design and execution. I here only describe the UDel system, but emphasize that all design decisions were made in close consultation with Dr. Nicholls. These efforts were funded by NASA's Cryosphere program and are co-ordinated with the NASA-funded "Ocean Melts Greenland" initiative at the Jet Propulsion Laboratory in Pasadena, California.

2. System Design

The UDel system builts on a design developed for the networked weather observing systems in Delaware. These systems use Campbell Scientific CR-1000 data loggers and a diverse suite of meteorological sensors. New elements include the addition of ocean sensors via RS-232 serial ports and Iridium satellite communication.

Furthermore, in order to accommodate the 5 serial ports to connect the 5 ocean sensors, UDel technician David Huntley came up with the idea to daisy chain 2 CR-1000 data loggers emerged as a simple, yet elegant solution. None of these elements have been built into one system before and the successful deployment and operation constitutes a major technology break-through using cheap and simple off-the-shelf components to link ocean and atmosphere observing systems that both report hourly data in near real time. Initial design ideas and execution were developed collaboratively with David Huntley who built the system from scratch. Software was developed by the PI who used a template that supports UDel meteorological sensors and stations.

The system was built and assembled in April, tested for about 24 hours, and shipped to Sweden in May where it was set it up in a small meteorological container above the bridge on I/B Oden during mobilization in June for testing during Oden's transit from Landskrona to Thule, Greenland in July.

3. System Components and Integration

The station was tested as a completely autonomous system at sea on Aug.-03 for the first time. It contains sensors and components listed in Table-1:

Table-1*: Components of the UDel Petermann Ocean Weather Station*

Number	Model	Function
2	Vaisala HMP155	Temperature, humidity
1	Vaisala CS106	Pressure
1	RM Young 05103	Wind speed and direction
2	Campbell Scientific CR1000	Data logger
1	Garmin GPS 16xHVS	Latitude and longitude
1	Campbell Scientific 9522B	Iridium Communication
1	Campbell Scientific COM9522B	Iridium Communication interface
1	Genasun GV-5-Pb-12V	Power Regulator
2	Campbell Scientific SP20	20 W solar panels
2	AMG 8A22NF	Batteries
2	Campbell Scientific CFM100	Memory cards
5	SeaBird SBE37sm	Ocean temperature, salinity, pressure sensors

Initial tests failed miserably as several software and hardware conflicts obscured a major design flaw related to the way the CR-1000 regulated power to the Iridium communication unit. It took five days to diagnose and fix the system that was deployed on Petermann Gletscher Aug.-10 near the future ice shelf drill Site-3 at 80.66575 N latitude and 60.4920 W longitude after a successful 24-hour fully autonomous system test on Oden Aug.-09.

[Note to Self: The problem was temporarily solved on Aug.-04 by placing a jumper cable on the Iridium connectors between red power and yellow control port terminals which turned the communication port on permanently. The final solution to control the power supply to the Iridium modem in software was not completed until Aug.-08 after some major re-wiring of data loggers and communication devices and re-writing software to accommodate these hardware changes. The solution to switch control from C1 port to the SW12 port was suggested by Campbell field engineers communicating with staff at UDel.]

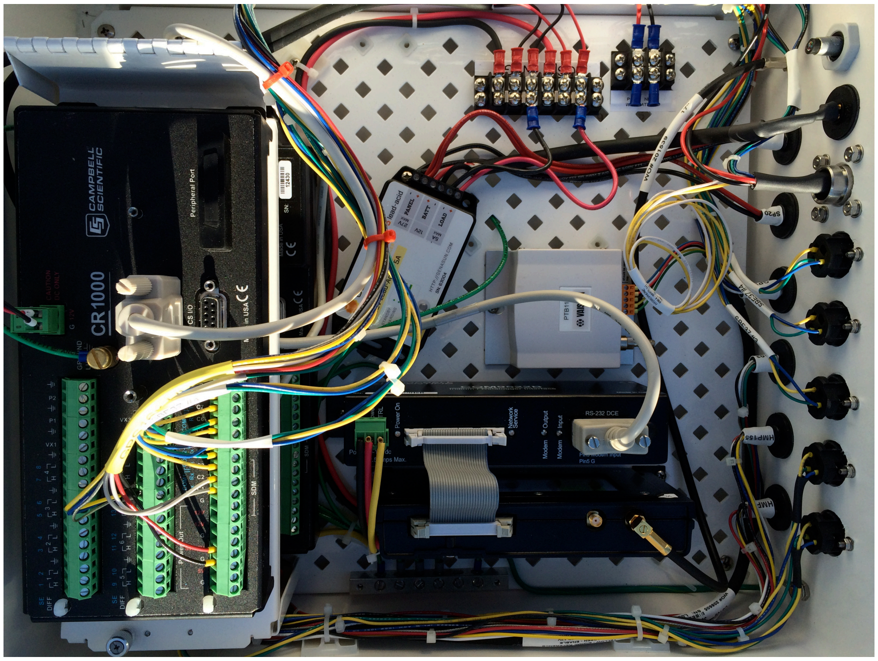

Figure-1: *Final version of the data loggers with Iridium control bottom right, two data loggers stacked vertically on the left, power regulator oriented diagonally in the center, and connectors for 14 serial and analog sensors on the right.*

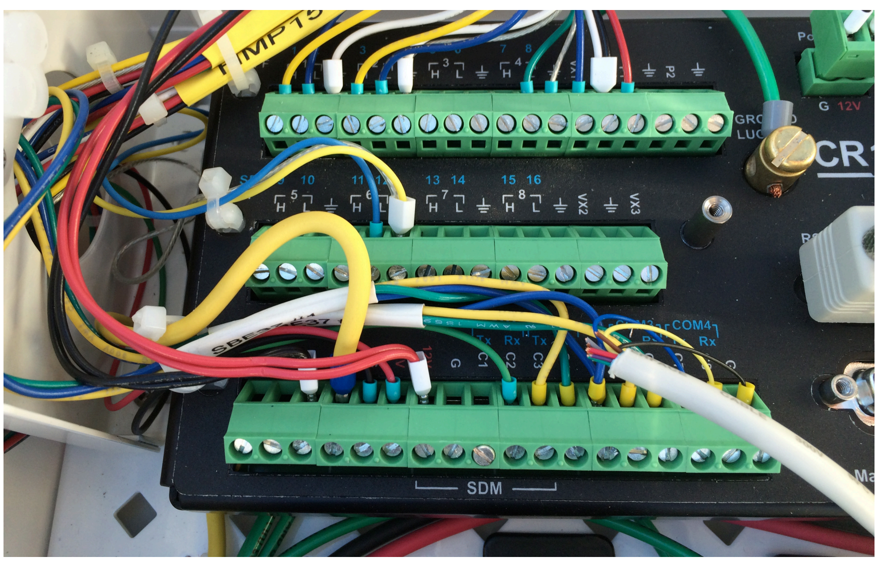

Figure-2: *Wiring detail of the lower, that is, primary data logger that was modified Aug.-08 switching air temperature for Iridium control ports.*

4. Initial Deployment without Ocean Sensors: Aug.-10 through Aug.-18

The UDel Ocean-Weather station was placed what was later to become Site-3 for the ice shelf drilling team. Without ocean sensors the station reported hourly wind speed and direction as well as GPS position, air temperature, and atmospheric pressure. Figure-3 shows the initial set-up on a tripod that as loaded down by the 55 kg heavy rechargeable lead-acid battery pack delivering up to 11 0 Amp-h to power data loggers, sensors, and Iridium communication through the winter.

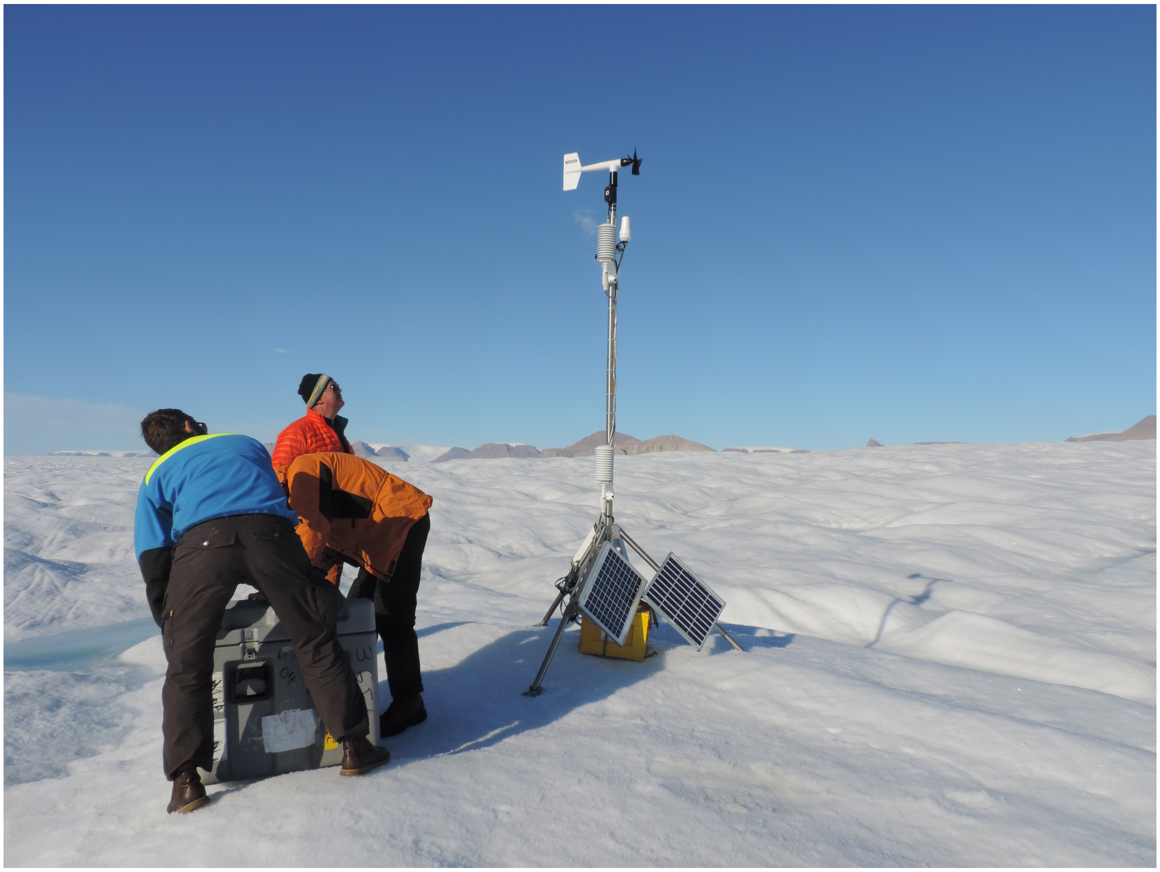

Figure-3: *Temporary weather station on Petermann Gletscher at 80.66575 N and 60.4920 W as installed Aug.-10, 2015. View is to the north-west. The tripod mounting design was abandoned for the final deployment shown in Figure-5.*

The 10-day time series from this installation is shown in Figure-4. The short data gap on Aug.-14 was caused by a software update that reduced the Iridium "ON" time interval from 1 hour to 3 hours. Despite the gap-free 10-day record, communication via Iridium has been irregular until Aug.-23:

Table-2: *Periods without Iridium connectivity*

Aug.-11, 03:15 to Aug.-12, 20:24	41 hours OFF, then 28 hours ON
Aug.-14, 00:24 to Aug. 15, 00:15	24 hours OFF, then 27 hours ON
Aug.-16, 03:15 to Aug.-18, 21:23	66 hours OFF, then 48 hours on
Aug.-20, 21:15 to Aug.-23, 00:15	51 hours OFF, then reporting every cycle

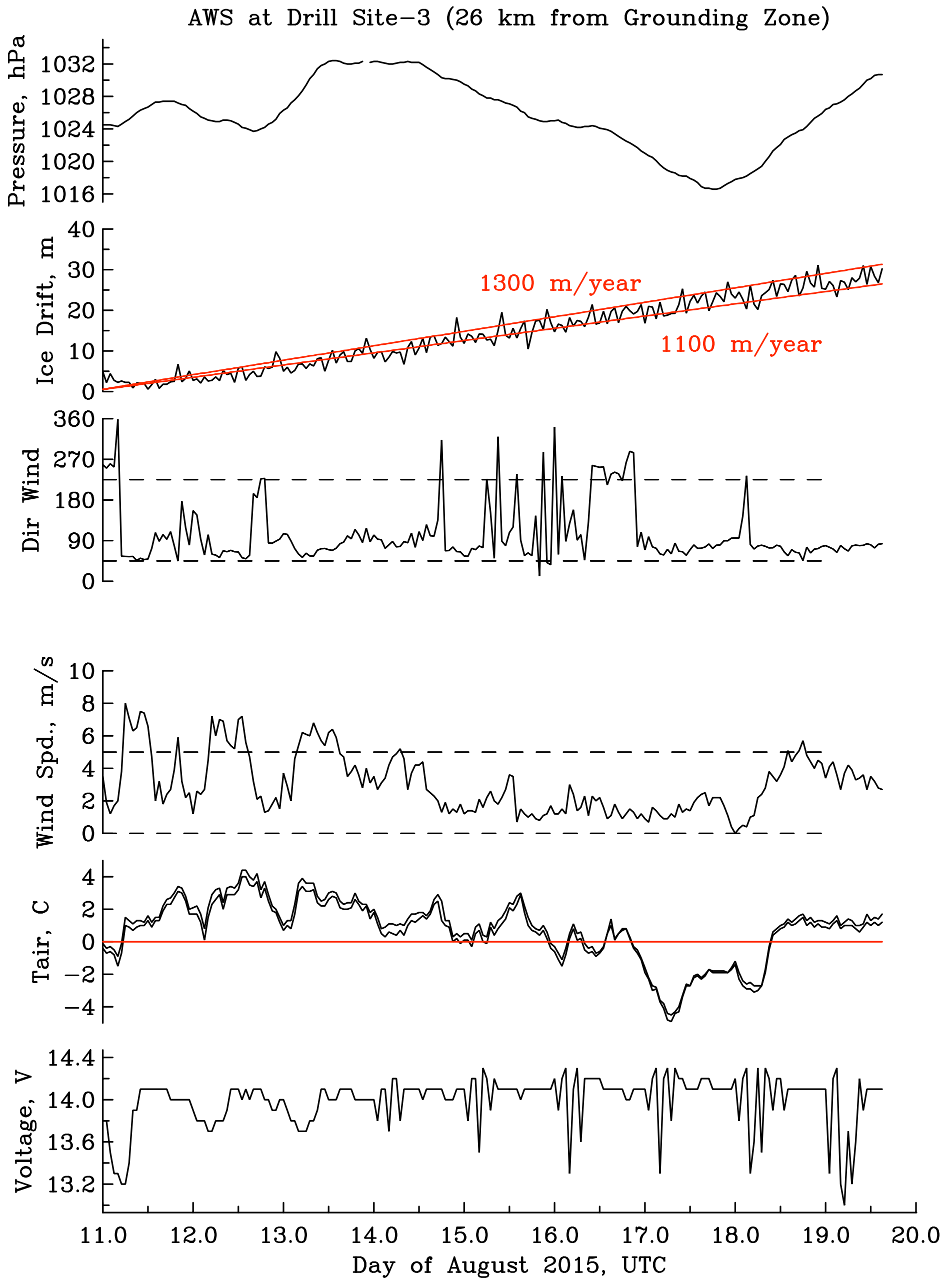

***Figure-4**: Time series of measured properties at the UDel ocean weather station. Note vertical temperature gradients shown in Tair which shows temperature at two levels Voltage drops are associated with 3-hourly Iridium data downloads (bottom).*

5. Final Deployment with Ocean Sensors Aug.-18, 2015

On Aug.-18 the ice shelf team drilled through the 100-m thick ice shelf, moved the working weather station, deployed 5 ocean sensors, and plugged terminations of RS-232 cables up to 810-m long into the data loggers. The five sensors and their nominal depths are listed in Table-3 while the mechanical set-up is shown in Figure-5. All instruments are reporting instantaneous temperature and conductivity measurements hourly via polled sampling initiated by the data logger at 4800 baud. The ice shelf at the deployment location and time was 845 m deep. Profiles of ocean properties and sediments at this site are reported elsewhere.

Table-3*: Sensors deployed at Petermann Ocean Weather Station at 80 39.9697 N and 60 29.7135 W on Aug.-20, 2015 17:00 UTC.*

Sensor	Vertical, m	Variable(s) measured
SBE37sm, s/n 2926	-810	Ocean T/S and pressure
SBE37sm, s/n 2899	-450	Ocean T/S
SBE37sm, s/n 2900	-296	Ocean T/S
SBE37sm, s/n 2904	-117	Ocean T/S
SBE37sm, s/n 2905	-97	Ocean T/S
Vaisala CS106	+0.54	Atmospheric pressure
Vaisala HMP155	+1.09	Air temperature and humidity
Garmin GPS 16xHVS	+3.00	Horizontal glacier motion
Vaisala HMP155	+3.08	Air temperature and humidity
RM Young	+3.69	Wind speed and direction

Utilizing a truly 2-way serial connection, I successfully uploaded new codes on Aug.-23 to activate a memory card on the second data logger and on Aug.-26 to change the open communication ports from 3 to 8 hours. Data downloads are enabled every day for 15 minutes starting 08:15, 16:15, and 00:15.

Figure-6 shows initial results from the ocean sensors until Sept.-02 02:46 UTC while corresponding atmospheric and location data from GPS are shown in Figure-7.

On Aug.-27 Dr. Maureen Walczak-Davies of Oregon State University and Hendrik Braathen of I/B Oden visited the station to calibrate wind directions. For 90 minutes they took readings of wind speed and direction every 3 minutes (Table-4). Directions from true north were determined with a handheld Garmin eTrex-10 GPS unit. Directions are given as those that the tail of the vane points. A value of 0 or 360 degrees corresponds to the direction when the wind blows from south to north. Directions are counted clockwise from true north. A direction of 270 degrees thus corresponds to a flow from south-east to north-west.

Table-4*: Wind measurements at Petermann Ocean Weather Station Aug.-27, 2015.*

Time, UTC	Direction	Speed, m/s	Time, UTC	Direction	Speed, m/s
14:31	350	2.1	15:01	320	2.2
14:34	340	2.1	15:04	320	2.0

14:37	340	3.1	15:07	320	2.0
14:40	330	3.4	15:10	330	1.8
14:43	330	2.4	15:13	320	1.5
14:46	330	2.0	15:16	325	1.8
14:49	325	2.8	15:19	320	1.7
14:52	320	2.3	15:22	330	1.4
14:55	320	2.0	15:25	330	1.3
14:58	310	2.0	15:28	330	1.6
15:31	330	2.0	15:48	350	3.1
15:33	330	2.1	15:51	360	2.5
15:36	330	1.8	15:54	330	2.7
15:39	340	2.6	15:57	330	1.7
15:42	345	2.9	16:00	330	1.9
15:45	350	2.4			

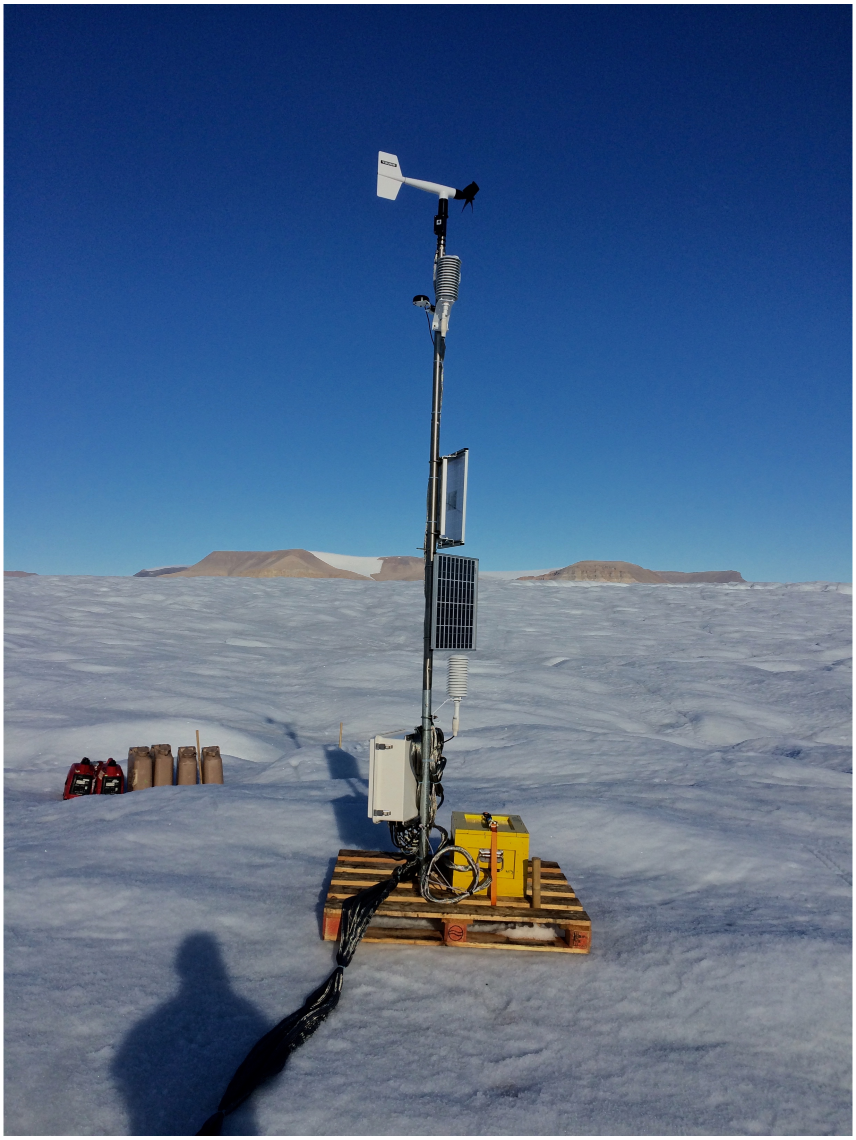

***Figure-5**: Final set-up of the UDel Petermann Ocean Weather station. The single metal pole extends about 1.5 m into the ice while the palette is designed to slide down bamboo poles on the ablating glacier surface.*

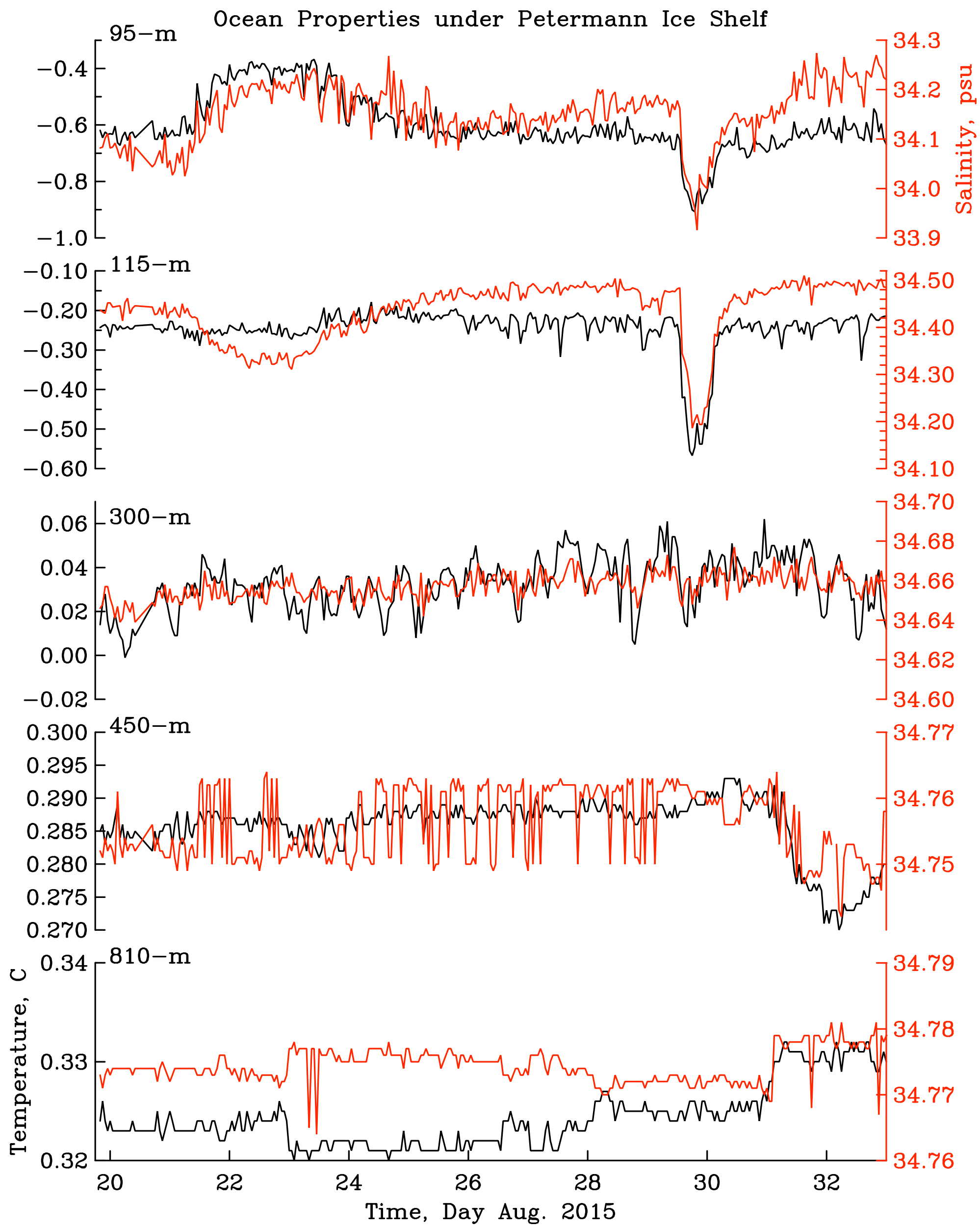

Figure-6*: Observations of temperature and salinity below Petermann Gletscher from 5 ocean sensors reporting in near real time. Black lines are temperatures with scales on the left while red lines are salinities with scales on the right. Note large variations under the ice shelf on Aug.-22 and Aug.-30 within about 20-m of the base of the ice shelf which is about 90 below the sea surface.*

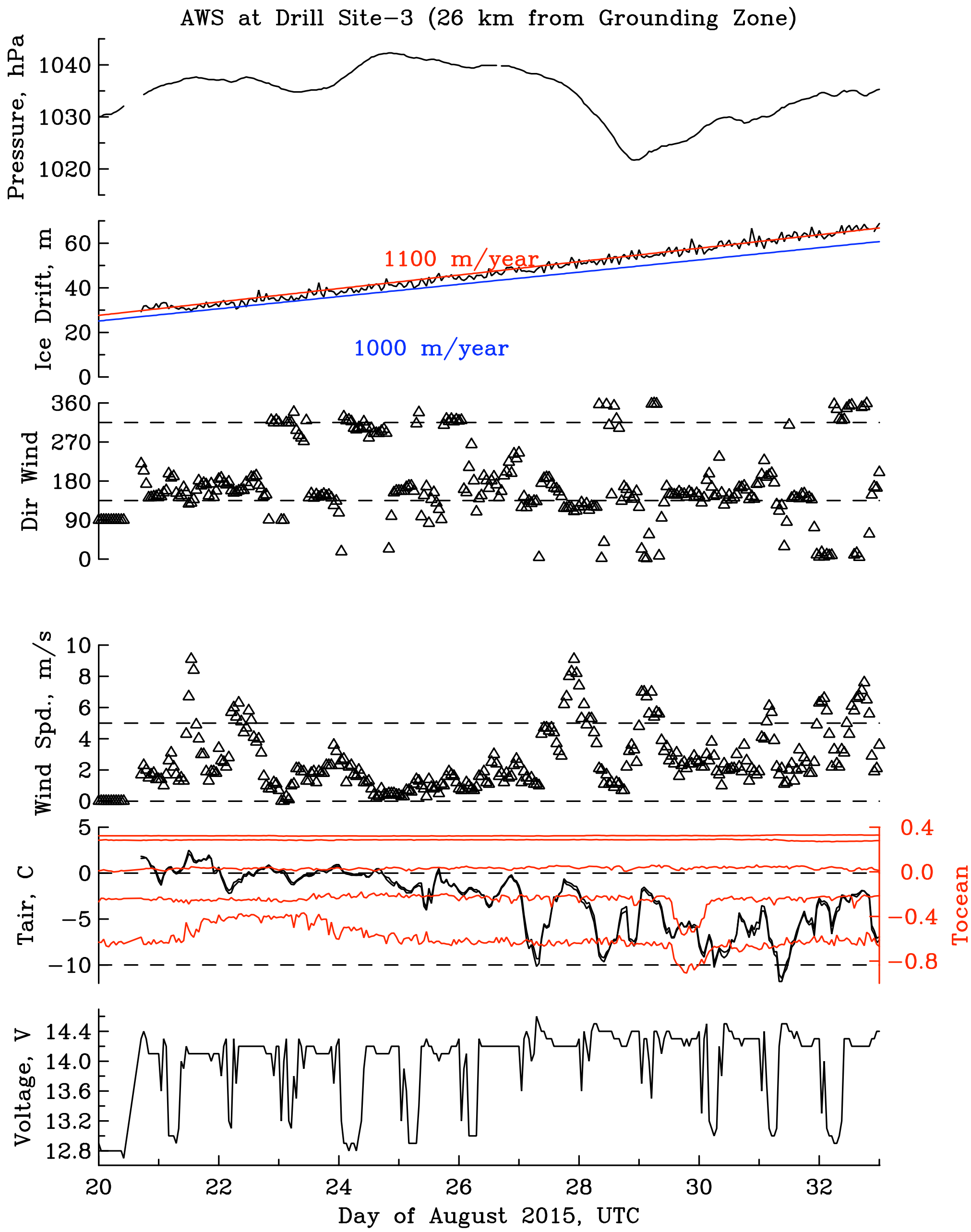

Figure-7: *Time series of atmospheric properties above Petermann Gletscher. Wind direction have the calibrations applied with dashed lines indicting seaward (135 degrees) and landward (315 degrees) atmospheric flow. Note off-axis flows that, I speculate, relate to large glaciers that enter Petermann from the north-east.*