Cruise Report: Maud Rise Nonlinear Equation of State Study

(NBP0506 — MaudNESS)

assembled by:
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1. Background

The region surrounding the Maud Rise seamount in the eastern Weddell Sea is characterized by marginal water column stability and persistent low ice concentrations well inside the limits of the seasonal ice pack. The Weddell Polynya of the 1970s and another notable polynya in 1994 originated nearby. Data from winter cruises in 1986 and 1994 indicate that toward the end of winter, thermobaricity, cabbeling, and possibly other nonlinearities in the equation of state for seawater are important preconditioners for deep convection powerful enough to overcome the large stabilizing buoyancy from ice melt. Satellite data of ice coverage often show low ice concentrations over the flanks of the Rise, and CTD data from various years indicate a Taylor column circulation trapping a cap of dense water over the Rise itself. The Maud Rise Nonlinear Equation of State Study (MaudNESS) was developed to investigate upper ocean mixing in the low-stability regime found in the Maud Rise region. Our objectives were:

1) To measure by a combination of techniques how mixing in winter is enhanced by turbulent kinetic energy derived from the potential energy of the water column in this unique environment; and

2) By a combination of CTD, satellite and modeling studies to assess the role of regional circulation in the localization of these mixing processes.

To realize these objectives we formulated a plan consisting of three (and possibly, four) phases: Phase 1, a rapid, relatively shallow CTD survey covering different locations along the slopes of the seamount and across its summit; Phase 2, a ship-supported sea ice station (or stations) in the Taylor cap ocean regime; and Phase 3, a series of relatively short drift stations for which all of the instrumentation was deployed from the ship to allow us to work safely in regions covered by thin ice. Phase 3 included a float tracking component designed to acoustically track a Lagrangian float parked in the pycnocline, so that we could return to a “marked” water parcel between Phase 3 drifts. A fourth phase would have been executed had we encountered a large, open polynya calling for more conventional, open ocean measurement techniques. This situation did not arise.

2. Instrumentation Systems

Several measurement systems were deployed for MaudNESS, providing a wide range of techniques for understanding what controls turbulent mixing in the weakly stratified upper ocean of the Weddell.

2.1 Maudness Cycling CTD/Microstructure Profiler

A computer controlled winch system cycled two coupled instruments vertically through the water column to measure high resolution temperature, salinity, density and turbulence microstructure profile timeseries. The upper instrument was a dual sensor seabird 911+ CTD in a small cross-section cage providing 24Hz high accuracy, redundant sensor, C/T measurements. This cage supported a spring-decoupled 1.2m long microstructure package equipped with a dual needle microconductivity sensor, an fp07 fast response thermistor, a microscale shear probe, and internal three axis accelerometer sensors. Shear sensor, thermistor and microconductivity data were digitized to 22 bit resolution at 100, 100 and 200 Hz respectively. The simple mechanical mass/spring decoupling system was effective in greatly attenuating cable strumming noise, while postprocessing of the shear and accelerometer data resulted in a noise floor of 10^{-9} for the turbulent energy dissipation rates. Data and control information for the microstructure package was communicated through the RS232 link in the Sea Bird 911+ underwater package and deck unit link, then through an Ethernet terminal server to the remote Linux computer.

Figure 1. A photograph of the CTD profiler (upper instrument) and microstructure instrument (lower) hanging over the moon pool just prior to deployment. The microstructure sensors were at the bottom of the suspended package 1.5m lower than the CTD package. These instruments were continuously raised and lowered through the water column at 0.6 m/s between 18m and 350m depth by a computer-controlled winch.
[deSteur photo]

C and matlab coded software running on a Linux computer in the dry lab plotted real-time T/S and microstructure data vs. depth in real time for each profile, while using the current depth data to cycle the winch between depth limits specified in a control file. Data flow between the C control and data acquisition software for the two sensor systems and the remote winch controller used the ship's Ethernet connectivity, with simple hardware timeouts implemented to stop the winch if the controlling software was not communicating with the winch system every second. This system performed without problems throughout the Phase II and III operations, gathering 2610 profiles between 18m and 350m depth (see table 1). An Ethernet web camera provided important remote observation of the winch system on the main Linux console in the dry lab.

Drift	Start Time	End Time	Start Profile	End Profile
P2D1	222.60832	223.30994	8	131
P2D2	224.61316	228.91914	132	966
P3D1	231.64999	232.23743	981	1076
P3D2	232.61101	233.46388	1077	1210
P3D3	234.91685	235.32296	1211	1282
P3D4	235.67252	236.78917	1283	1476
P3D5	237.13966	238.53100	1477	1718
P3D6	239.00663	239.57299	1719	1804
P3D7	239.70144	240.57366	1805	1920
P3D8	240.89135	242.40797	1921	2149
BERG1	242.53174	242.55564	2150	2153
BERG2	242.60902	242.71818	2154	2170
BERG3	242.81471	242.84928	2172	2176
P3D9	243.15537	243.81611	2177	2269
P3D10	244.67869	246.29343	2270	2479
P3D11	246.94317	247.80966	2480	2610

Table 1: Moonpool cycling CTD/microstructure profiler

2.2 The Vertical Microstructure Profiler

The Vertical Microstructure Profiler (VMP, a.k.a. "Vampire") is a tethered, free-fall profiler measuring microscale (order 1 cm) temperature and conductivity (*T* and *C*), and velocity shears. Vampire also carries pumped CTD-quality *T* and *C* sensors (SeaBird SBE-3 and SBE-4), for providing simultaneous high-accuracy (but lower vertical resolution) scalar data. Instrument depth and motion (speed and tilt) are monitored by a pressure sensor and 3-axis accelerometer. The latter data provide a means for removing instrument-induced "noise" from the shear sensors. The instrument fall speed *w* is ~0.6 m/s, the rate determined by a balance between buoyancy and drag. Syntactic foam buoyancy elements reduce the instrument's effective weight in water, and significant drag is provided by a 1-m diameter "chimney sweep" drag brush at the tail. The chosen fall speed is a compromise between sensitivity of the shear probes and the vertical resolution of the microscale scalar sensors. Vampire is ~2.2 m long when fully assembled.

Vampire was deployed from the "helo hut" (Fig. 2), which was first deployed on sea ice

Figure 2. Helo hut housing the VMP profiler during Phase 2, Drift 2, with the Palmer in the background, approx. 300 m away. The helo hut also housed electronics for the met tower and nearby shallow turbulence mast deployment. [ESR photo]

during MaudNESS "Phase II", then from the fantail of the ship during "Phase III". A total of ~450 casts were obtained, typically to ~300 m but with a maximum depth of ~660 m.

Drift	#profiles
Phase II, Drift 01	31
Phase II, Drift 02	34
Phase III, Drift 01	25
Phase III, Drift 02	06
Phase III, Drift 03	19
Phase III, Drift 04	31
Phase III, Drift 05	46
Phase III, Drift 06	34
Phase III, Drift 07	35
Phase III, Drift 08	80
Phase III, Drift 09	34
Phase III, Drift 10	51
Phase III, Drift 11	23

Table 2: VMP profiles

2.3 Shallow Turbulence Mast

The shallow turbulence mast, designed to measure fluctuations in velocity, temperature and salinity close to the ice/ocean interface, comprises a SonTek acoustic doppler current meter in addition to SeaBird temperature, conductivity and microconductivity sensors. Sensors are mounted on a rigid metal rod, all aligned to measure at the same vertical level below the ice and deployed through a hydrohole in the ice. The mast has a fixed orientation, normally with the ADV pointing towards the mean flow. Power to run the system is provided from generators and data logging is maintained in a nearby heated shelter using a SeaBird Deck Unit and a laptop. Included in the shallow mast system was also an acoustic doppler profiler (ADP) from SonTek which was deployed separately from the ice and measured the 3-dimentional, bin averaged velocity in a specified depth interval, normally the upper 40m close to the ice. During MaudNESS, the shallow mast system was only deployed during phase 2. In Drift 1, the ice conditions only allowed a close to ship deployment and the mast was deployed ~50m off the starboard side of the ship. The system was powered from the ship and a generator and data logging was maintained inside the ship, running cables out to the deployment site. Due to ice break up, only a short period of data exists from this drift. During the first part of Drift 2, from day 225 to 226, the mast and the ADP were deployed ~300m from the ship, set up close to the helo hut, running on generator power from the helo hut. After the ice broke up on Drift 2, the shallow mast was relocated to a site ~50m from the ship together with the ADP, with a setup similar to the one of Drift 1.

2.4 Mid-level Turbulence Mast

The midlevel mast was deployed to measure turbulent fluxes of momentum, heat, and salt in the middepth range of the mixed layer. The mast included two Turbulence Instrument Clusters (TICs), comprising a combination of a Sontek 3-axis ADVOcean with Sea-Bird sensors mounted in the same horizontal plane as the current measurement volume. Data from each cluster feeds to a custom SBE 911+ CTD, with 5 frequency channels, 8 voltage channels (pressure, compass, plus 4 analog data channels from the lower ADV). The upper TIC on the midlevel mast was similar to the shallow mast cluster, except that the standard SBE conductivity/temperature combination was pumped to more closely match the temperature and conductivity signals. The lower cluster, mounted 4 m below the upper TIC, did not include a mC sensor. The whole mast could be lowered to 100 m, but spent most of the time at around 50 m depth, except near the surface during Phase 2, Drift 1, before the shallow mast was deployed.

Two different deployment methods were used (Fig 3). For Phase 2, the mast was deployed from a derrick situated about 60 m of the starboard beam, with the sea-cable running from the ship providing power and data transfer. The mast was suspended with a separate Kevlar strength member on a battery powered winch attached to the off-ship derrick. For Phase 3 the mid-level mast was deployed from the Baltic room.

2.5 Deep Mast

A 9-m long deep turbulence frame supported three types of instruments tomeasure current velocity profiles and shear, finescale vertical thermal structure, and turbulent fluxes of heat, salt and momentum (Fig. 4). The assembly included a wide aperture (9 m) thermistor array, two TICs similar to the mid-level mast, but separated by 3 m, plus upward looking (1.2 Mhz) and downward looking (0.6 Mhz) acoustic doppler profilers mounted near the bottom of the mast. Sensors

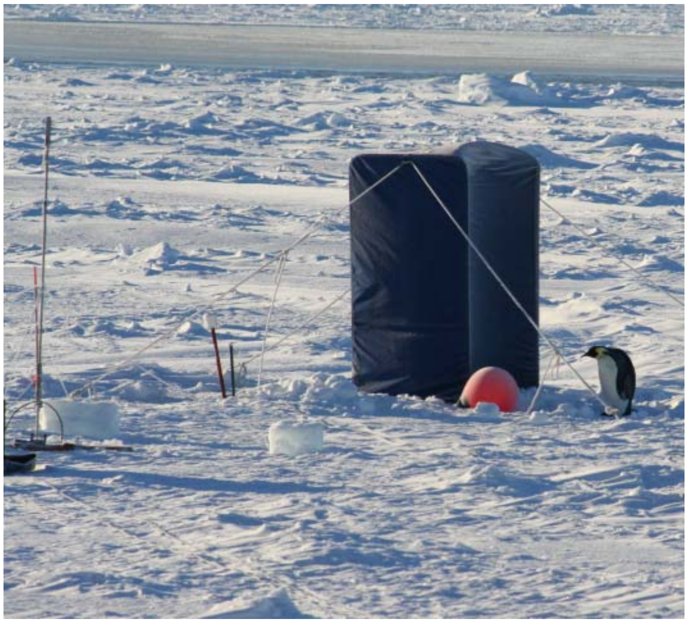
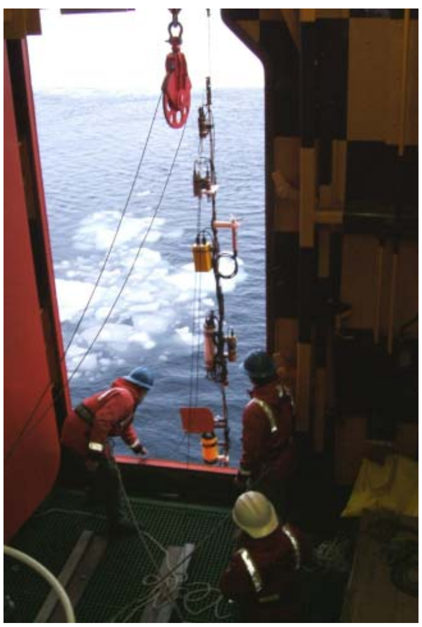


Figure 3. Penguin contemplating the deployment strategy for the midlevel mast (under the blue derrick cover) and near surface mast (far left) during Phase 2, Drift 2 (upper). Phase 3 deployment of the midlevel mast through the Baltic Room door (lower left). To accomodate the 6 m mast, the bottom section was articulated, and swung into position via 30 kg ballast (lower right). [deSteur photos]



were assembled onto 2 m long stainless rods that bolted together to form the complete frame. A computer controlled winch mounted on the fore-deck of the ship allowed the frame to be remotely raised and lowered through the water column to track selected parts of the water column. About half the time the frame was positioned above the pycnocline such that it measured finescale shear across the base of the mixed layer while concurrently measuring the vertical fluxes near the bottom of the ocean mixed layer. The rest of the time the frame was lowered (typically to 100-200m depth) within the pycnocline into internal mixing features that were frequently observed. In this

Figure 4. The deep mast assembly being hoisted into position with the forward crane (left). Between deployments it was stowed in two sections suspended beneath the forward cargo hatch. For Phase 2 operation, it was deployed through a hydrohole near the bow, shown here during the recovery of P2D2, after cracks had appeared off the bow (below). [Stanton, deSteur]

mode, the continuous sampling, high speed sensors allowed the evolution of these mixing patches to be captured with far greater temporal resolution than was possible with the 20 minute cycle of the CTD/microstructure package. Power for the instrument systems and high speed data streams from the sensors were communicated through a 7 conductor armored cable on the winch. Between deployments, the frame was disconnected into two sections and stored through the ship's forward hatches into foreward storage areas spanning two decks. This greatly simplified the deployment of this delicate system.

2.6 Maudness Ocean and Ice Flux Buoys

Four buoys were deployed (Fig. 5) during the phase I CTD survey to provide ocean and ice flux observations at remote sites across Maud Rise during the subsequent drift stations in order to help identify areas likely to be approaching thermobaric instability. The ocean flux buoys are similar to systems deployed near the North Pole as part of the North Pole Environmental Observatory during the last four years. Each buoy had a 16 element thermistor string frozen into the ice 1.5m distant from the buoy providing a timeseries measurement of ice thickness, near-ice air

Figure 5. Flux buoy deployment during the Phase 1 survey. The radome shelters the GPS and iridium modem antennas, and the top of the thermistor string can be seen in the lower left of the photograph. The temperature/conductivity sensor is suspended 8m below the buoy within the ocean mixed layer.

temperature, ocean temperature, and estimates of the ice/snow heat flux from the ice temperature profile. Three buoys had high resolution temperature and salinity sensors sampled at 1.5 Hz deployed at 8m below the ice, allowing ocean heat fluxes to be estimated from the ocean water temperature elevation above freezing point, and modeled estimates of the turbulent friction velocity inferred from the buoy motion. On the fourth buoy, T/S sensors were collocated with a low noise three component velocity acoustic travel-time sensor providing direct eddy-correlation based fluxes of momentum, heat and salt to be measured 6m below the ice. A GPS receiver in each buoy measured high resolution buoy position and platform speed every 15 minutes (Fig. 6). These data streams were sampled for 40 minutes every hour, processed, stored and then forwarded to a server at the Naval Postgraduate School every 4 hours using Iridium satellite telephone modems.

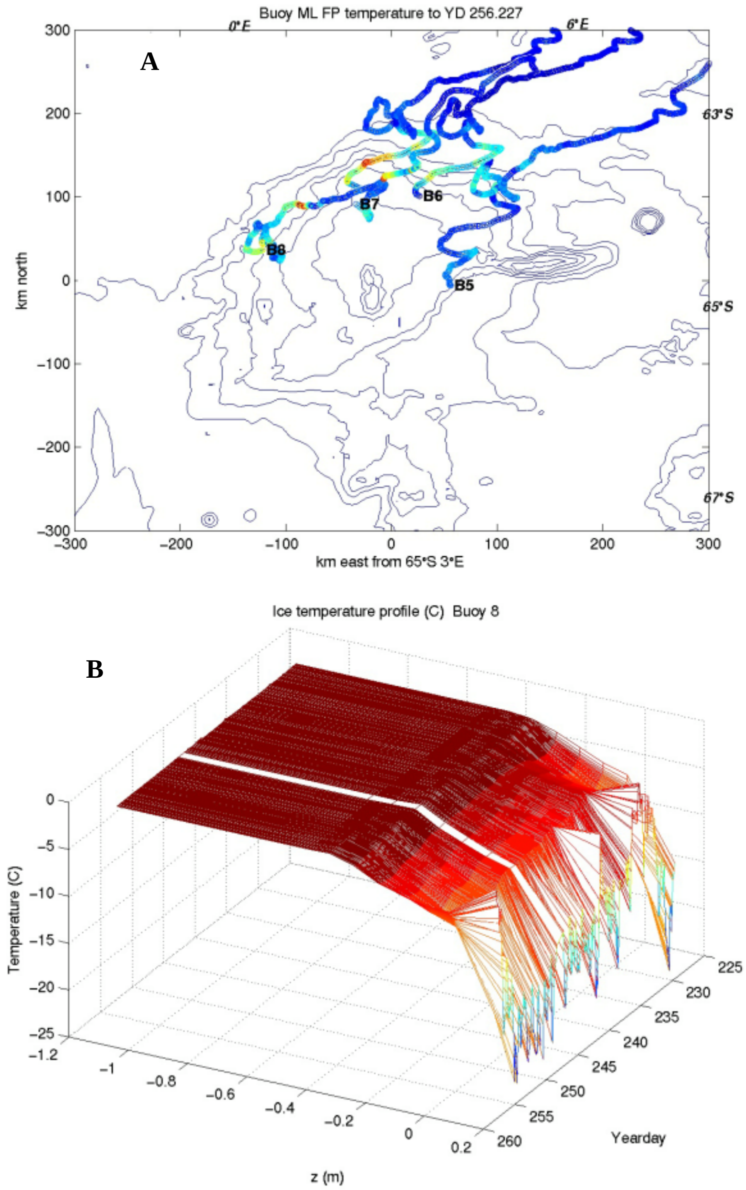


Figure 6. (A) The trajectory of the 4 buoys during the Maudness observation period. Deployment positions are labeled for each buoy ID (see table 2). The color scale of the buoy position symbol represents the evelation above the freezing point of water on a 0 to 0.3C scale, showing the influence of the warm and diffusive maud Rise halo water on ocean mixed layer temperatures.

(B) A mesh plot of the thermistor string temperature profile timeseries for buoy ID8. The top thermistor (right side of the mesh surface) is responding to air temperature fluctuations, then there is a large temperature gradient to the first thermistor within the ice. During this drift interval, the ice has grown in excess of 8 cm as the buoy drited north out of the influence of the Maud Rise water modification processes.

Yearday	Latitude	Longitude	Buoy ID	Buoy Type
215.62995 -	64.18644	2.17582	7	MicroCat
216.62938	65.03052	4.17767	5	MicroCat
220.56708	64.11610	3.51732	6	MicroCat
227.72775	64.70430	0.49325	8	Eddy-Correlation Flux

Table 3: Flux buoy deployment schedule

2.7 Subsurface Floats

Two types of floats were deployed during MaudNESS. A cooperative effort between

RAFOS FLOAT LOG

Float	Date	Station	Time	Lat-s	Long-e
267	8/3/05	Station 15	2009	64 22.3	002 32.6
694	8/3/05	Station 14	1332	64 10.3	002 05.9
695	8/3/05	Station 16	2236	64 28.7	002 49.6
696	8/4/05	Station 17	0117	64 36.1	003 07.0
697	8/4/05	Station 18	0345	64 42.8	003 24.2
698	8/5/05	Station 21	1135	65 00.8	004 09.9
699	8/6/05	Station 41	1800	64 26.07	004 46.87
700	8/7/05	Station 45	0610	64 10.66	004 28.085
701	8/8/05	Station 59	1052	64 06.0	003 36.8
702	8/8/05	Station 62	1955	64 18.9	003 22.4
703	8/8/05	Station 63	2301	64 28.54	003 13.884
704	8/9/05	Station 65	0551	64 47.90	002 52.957
705	8/9/05	Station 66	0905	64 54.20	002 41.958

LAGRANGIAN FLOAT LOG

Float	Date	Station	Time	Lat-s	Long-e
29trans	8/19/05	Station 91	1519	65 32.90	001 03.673
30	8/5/05	Station 33	2026	64 37.1	005 49.2
31	8/3/05	Station 14	1657	64 14.8	002 13.6
32	8/7/05	Station 47	1054	64 00.70	004 36.845
33trans	8/23/05	102 revisited	1101	65 45.44	001 00.832
34	8/8/05	Station 59	1200	64 05.700	003 36.090

UWAPL and Alfred Wegener Institute (AWI) resulted in launching 13 RAFOS floats at the station locations listed in Table 3. In addition, six Lagrangian floats (UWAPL) were deployed. The latter are designed to cycle between density determined limits beneath the mixed layer. Two of the

Lagrangian floats were equipped with acoustic transponders, with the intent of tracking them from the ship. In one instance we were able to detect the float as we drifted across it during the second Phase 3 drift; however, subsequent attempts to locate either of the transponder equipped instruments were unsuccessful.

After launch further communication with both the UWAPL and AWI floats will await summer conditions when they can surface and relay their data via satellite connection.

2.8 Meteorology

The overall goal of the MaudNESS meteorology program was to characterize the atmospheric forcing of the ocean and ice. and to support weather forecast products. The program was performed by Peter Guest, with assistance from Brian Powell and other members of the science and support group. The measurement program had four components:

2.8.1 Upper Air Characteristics

The measurements used Vaisala RS-80GH rawinsondes attached to 100 gm weather balloons. These measured profiles of pressure, temperature, humidity, wind speed and wind direction. We produced a total of 77 separate profiles giving the value of these variables as a function of height every 2 seconds or approximately every 10 meters. The typical elevation range was from 10 m to 1350 m above sea level, covering the entire troposphere and the lower stratosphere. When possible, we determined lowest cloud base height by observing when the balloon was no longer visible. These measurements occurred from June 30 to September 9, 2005 nominally at 1115 and 2315 (all times Universal Time Convention). For the first 14 profiles there were several gaps in the wind speed and direction data which wereevnetually determined to be due to interference from the ship data. Later profiles were performed with the radar secured and data collection of all variables was close to 100%. We sent data in coded format using email to the international upper-air network so that it could be included in numerical weather prediction models.

2.8.2 Lead Heat Fluxes

We performed 6 low level measurement series using rawinsondes attached to kites (Fig. 7). Each series consisted of 10 to 12 up and down profiles of pressure, temperature and humidity from the surface to approximately 120 m elevation. The measurements occurred on August 14, 15, 16, 20, 29 and September 2, 2005. We performed the first three profiles from the ice about 200 meters away from the ship, the next two were from the bow of the ship and the final one was from the ship fantail. All but the first series occurred downwind of leads or open areas in the ice. In

Figure 7. Preparing to launch rawinsonde instrument package beneath a kite for studies of downwind effects of a lead (20 m to the left of the scene), during Phase 2, Drift 2. [deSteur photo]

conjunction with measurements of wind speed, these profiles allowed us to measure the sensible and latent heat fluxes generated by the lead and open water areas.

2.8.3 Radiation Downwelling

Longwave and Shortwave Radiation were measured using Eppley PIR and PSP sensors from the aft center of the helicopter deck. The sensors were mounted on gimbels to so that the were level to approximately 2 degrees at all times. Data were collected every second and averaged into 1 minute records for storage from the time period from June 20 to mid-September (still operational at time of writing). Sensors were cleaned of frost and water drops every day if needed. The data appear free of any spikes or biases.

2.8.4 Surface Layer Times Series

We deployed a meteorological tower on the ice and obtained data in 1 minute records from 1147 August 13 to 2037 August 14. Unstable ice conditions prevented deployment at other times. Air temperature and humidity were measured using aspiratored sensors at heights of 0.14 m and 1.56 m above the snow surface. An R. M. Young Wind Bird measured wind speed and direction 3.7 m above the surface. An Eppley PIR sensor provided upwelling longwave radiation and surface temperature information. A thermistor on the surface provided an in situ surface temperature measurement.

2.8.5 Ship Meteorological Measurements

In addition to these measurements, we also incorporated standard ship meteorological measurements of temperature, humidity and winds with our radiation measurements to create a combined meteorological data set. The ship also had radiation measurements, but these were found to be inaccurate for unknown reasons. The combined meteorological data set was compared to weather predictions provided to the ship once a day. The comparison showed that in general the model predictions were excellent in the 0 to 24 hour forecast period that was examined. In addition the combined data were used as input into surface models that provided real time forecasts of surface energy and momentum into the ocean. Future work will include analysis of how the atmopsheric forcing was related to the non-linear equation of state ocean processes that were the focus of the MaudNESS project.

2.9 Ice and Snow Measurements

At all drift stations, as well as at the ice-buoy sites, ice surveys were carried out that included measurements of

- ice and snow thickness distribution along various profile lines
- salinity and temperature profiles in ice cores
- snow density profiles
- ice-snow and snow-air interface temperatures
- the temporal evolution of all of the above.

All together, 8 ice cores were taken and more than 120 ice thickness measurements were carried out. For the former, a standard Kovacs-ice core drill was used, which was manually driven into the ice. Directly after sampling, the temperature distribution was measured along the core, using a standard thermistor probes. The cores were then cut into 5 cm thick slices, which were allowed to melt for salinity and Delta O18 analysis. The salinities were measured on board, whereas the Delta O18 analysis will be taken care of by D. Holland after the end of the cruise. Ice and snow thickness distribution as well as interfacial temperatures were measured along sampling lines up to 300 m long. The measurements were repeated once a day as long as the drift stations lasted and allowed the calculation of, for example, ice thickness changes and heat fluxes.

3. Operations

3.1 Phase 1

The Phase 1 CTD survey was accomplished nearly as scheduled, except that additional legs were added after the 2nd Phase 2 ice station, and again after Phase 3, Drift 3 (P3D3). A map (Fig. 8) showing all stations (except a deep station at 63°S 0°E) indicates the extent of coverage

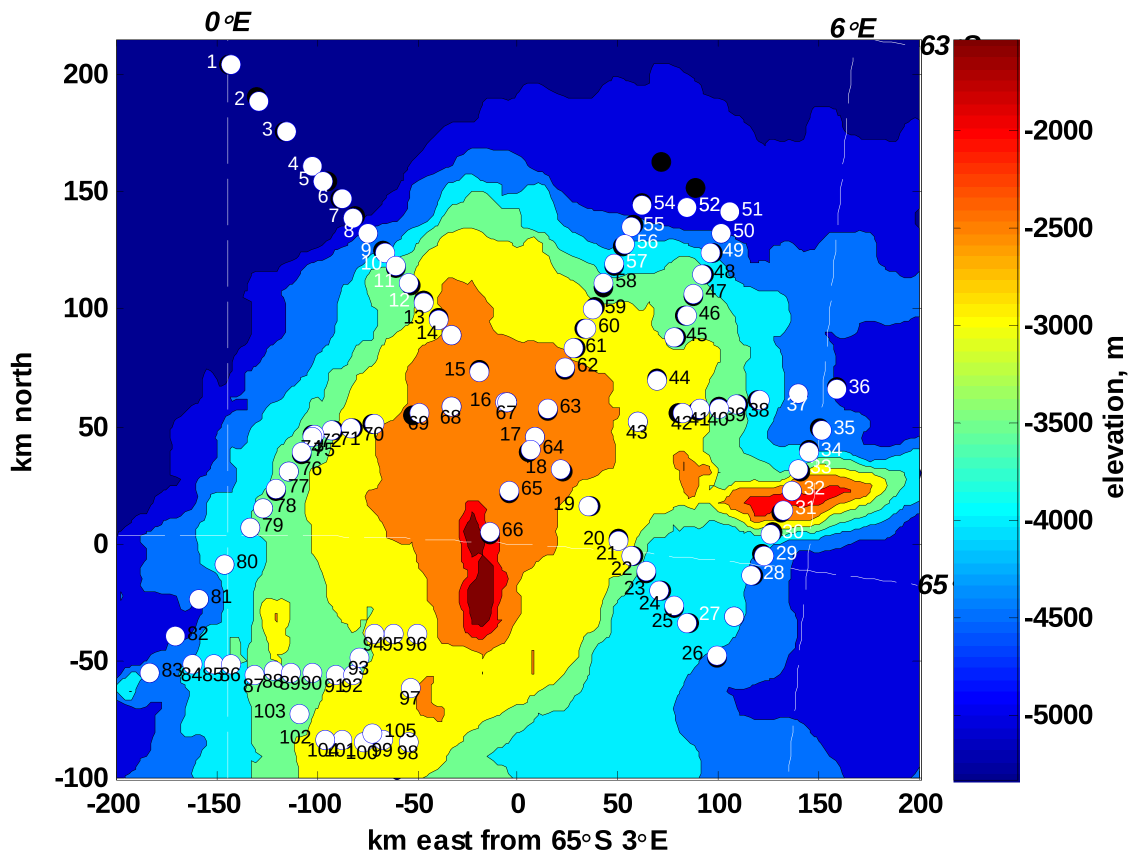


Figure 8. Map of Phase 1 CTD stations during MaudNESS. Position listings corresponding to the number sites are given in Appendix 1.

accomplished. All told, 106 stations were occupied with the ship CTD/Rosette sampler. Appendix 1 lists the NBP designation, times, and positions of all stations made with the ship SBE 911+ system. Variability of ocean conditions encountered during the Phase 1 survey (with extensions) is illustrated by considering the maximum temperature in the water column (Fig. 9), clearly showing the "halo" of warm water around the periphery of Maud Rise.

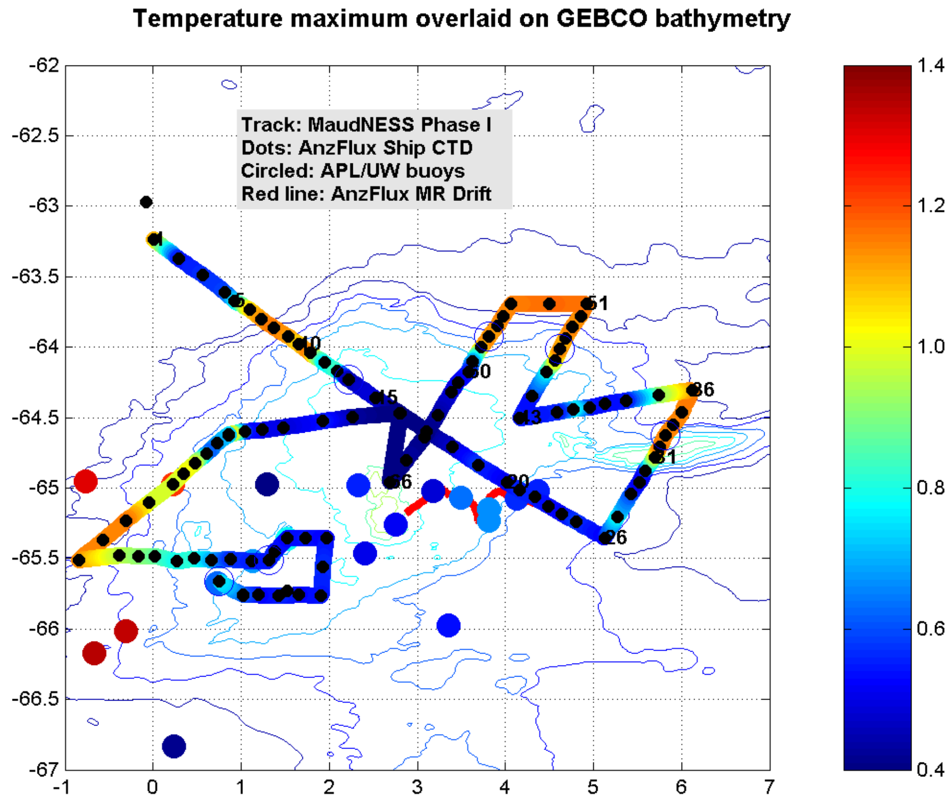


Figure 9. Example of upper ocean property, in this case, the maximum temperature in the water column, mapped on the Gebco batymetry.

3.2 Phase 2

In Phase 2, the ship was moored on the starboard side to an icefloe providing access for off-ship deployment of the met tower, VMP, shallow turbulence mast, mid-depth turbulence mast, as well as ice/snow studies. We found it difficult to locate stable ice (see Weekly Science Summary #4 below), and in the end settled for two relatively short-duration stations. The first, P2D1, was established during windy conditions, and with relatively unstable ice, with offs-ship deployment of the midlevel mast from about 2100 on 9 Aug. Other off-ship programs were not deployed until the next day. Measurements continued until about 1800 when cracks appeared off the starboard, with rapid recovery of the off-ship systems. Pertinent parameters for Phase 2, Drift 1 are shown in Fig. 10. After again having difficulty locating stable ice, we decided to resume a leg of the Phase 1 survey toward the west, to station 73. We then encountered a large, relatively intact floe about noon on 12 Aug, at which we deployed Phase 2, Drift 2 (Fig. 11).

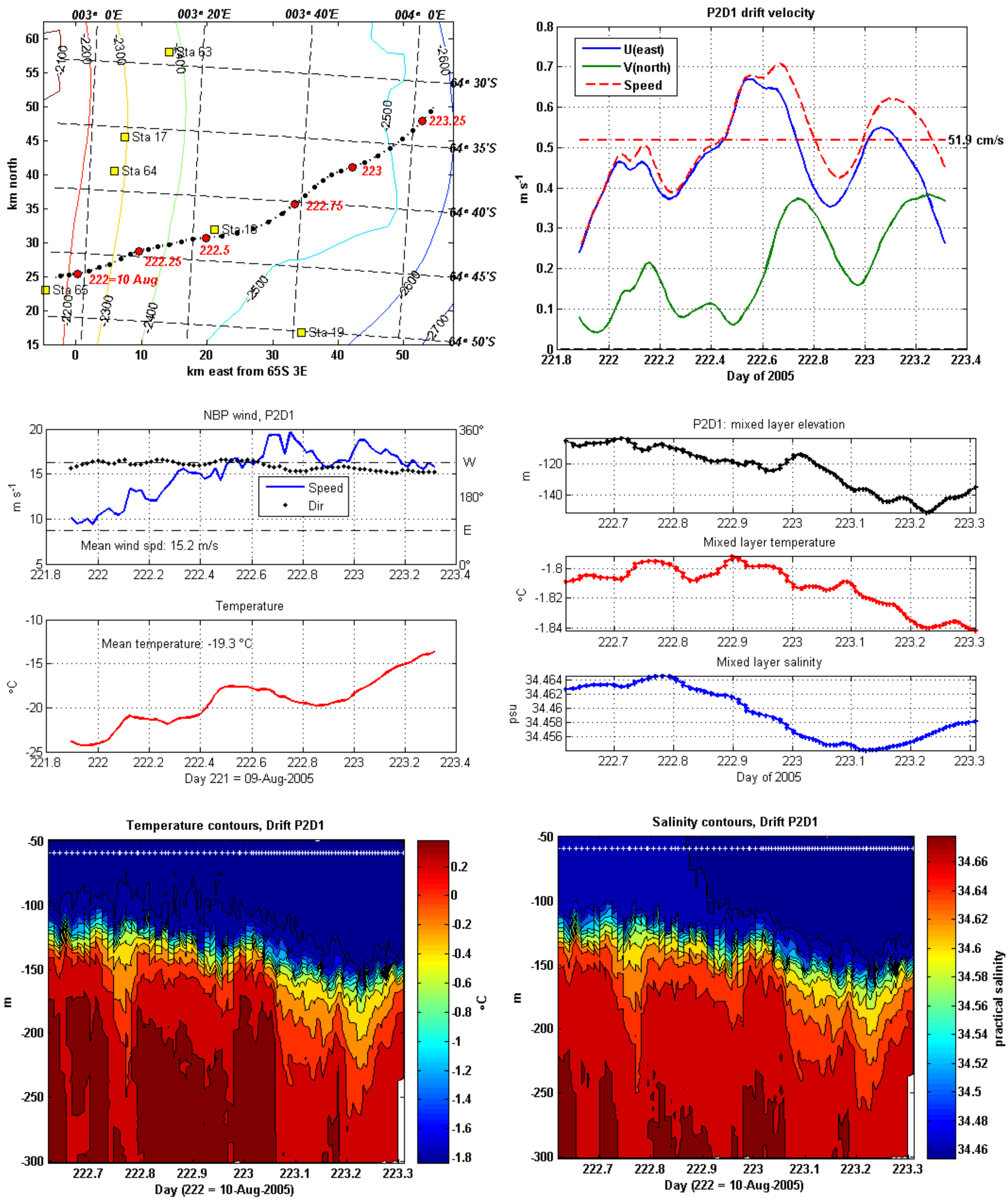


Figure 10. Phase 2, Drift 1 characteristics

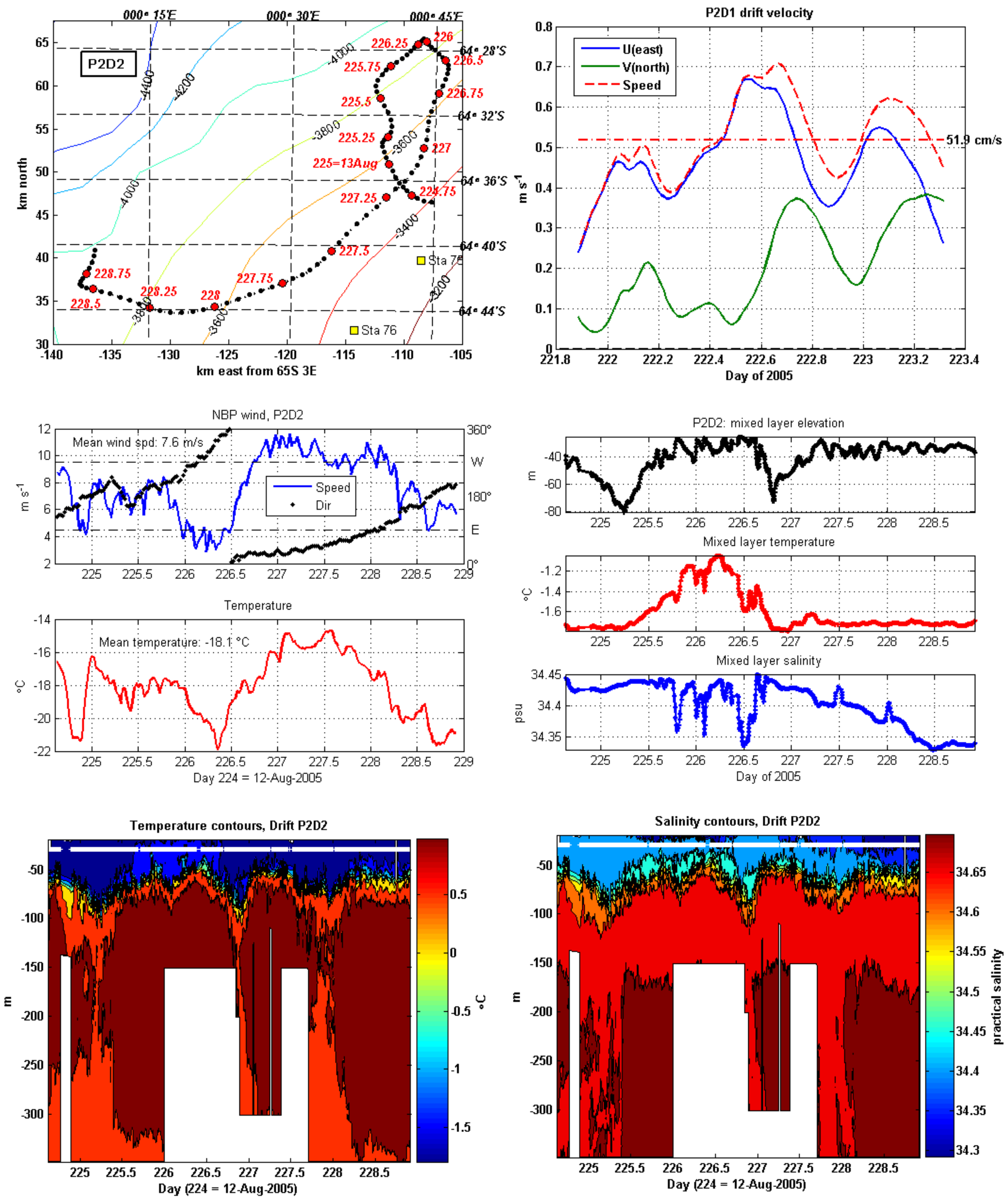


Figure 11. Phase 2, Drift 2 characteristics

3.3 Phase 3

After the premature breakup of the P2D2 floe, we resumed the ship-based Phase 1 survey on a pattern covering the southwest flank of Maud Rise, then east to a location correponding to an ANZFLUX station that had exhibited low stability in 1994 (Phase 1 stations 74-91). By several measures, the last station in that series had the least stable upper ocean yet encountered, and we decided to deploy a transponder equipped Lagrangian float there, and to commence with Phase 3 of the experiment, in which the major instrument systems were deployed from the ship by keeping the starboard and stern areas ice free as much as possible. Phase 3 elements included: a CTD/microstructure profiler in the moonpool, a loose tethered microstructure profiler deployed from the helo hut mounted off the fantail, a midlevel turbulence frame operated from the Baltic room, the deep turbulence/ADP/thermistor frame off the starboard bow, and the combination of Lagrangian float and shipboard acoustic tracking used to tag and follow a particular parcel of pycnocline water.

The Phase 3 drifts were planned to traverse the least stable upper ocean conditions that we could find. In some cases, this meant that in situ density of mixed layer water at the base of the mixed layer was between 0.01 and 0.02 kg m^{-3} less dense than water 10 m deeper in the pycnocline. This small difference could be eliminated by salt rejection from ice growth of only a few centimeters, and we were sampling in a regime where the density contrast was so small near the base of the mixed layer that despite significant gradients in salinity and temperature in the thermo/halocline, the regime was close to being neutrally stable. Despite evidence of freezing in the thin ice where we located our P3 drifts, mixed layer salinity remained amazingly stable, indicating a delicate balance between buoyancy loss at the surface and that furnished from below. Our hope was for a significant wind event that would provide vigorous mixing at the pycnocline level. Unfortunately, this did not materialize during the time alloted for Phase 3, and as weather forecasts reaching to the end of the experiment indicated little change, we decided to move north in order to deploy the last two drifts in the transition zone between the halo and Taylor cap water (P3D10) and in the cold, more stable regime to the north (P3D11).

Characteristics of each of the 11 Phase 3 drift stations are shown in Figs. 12-22.

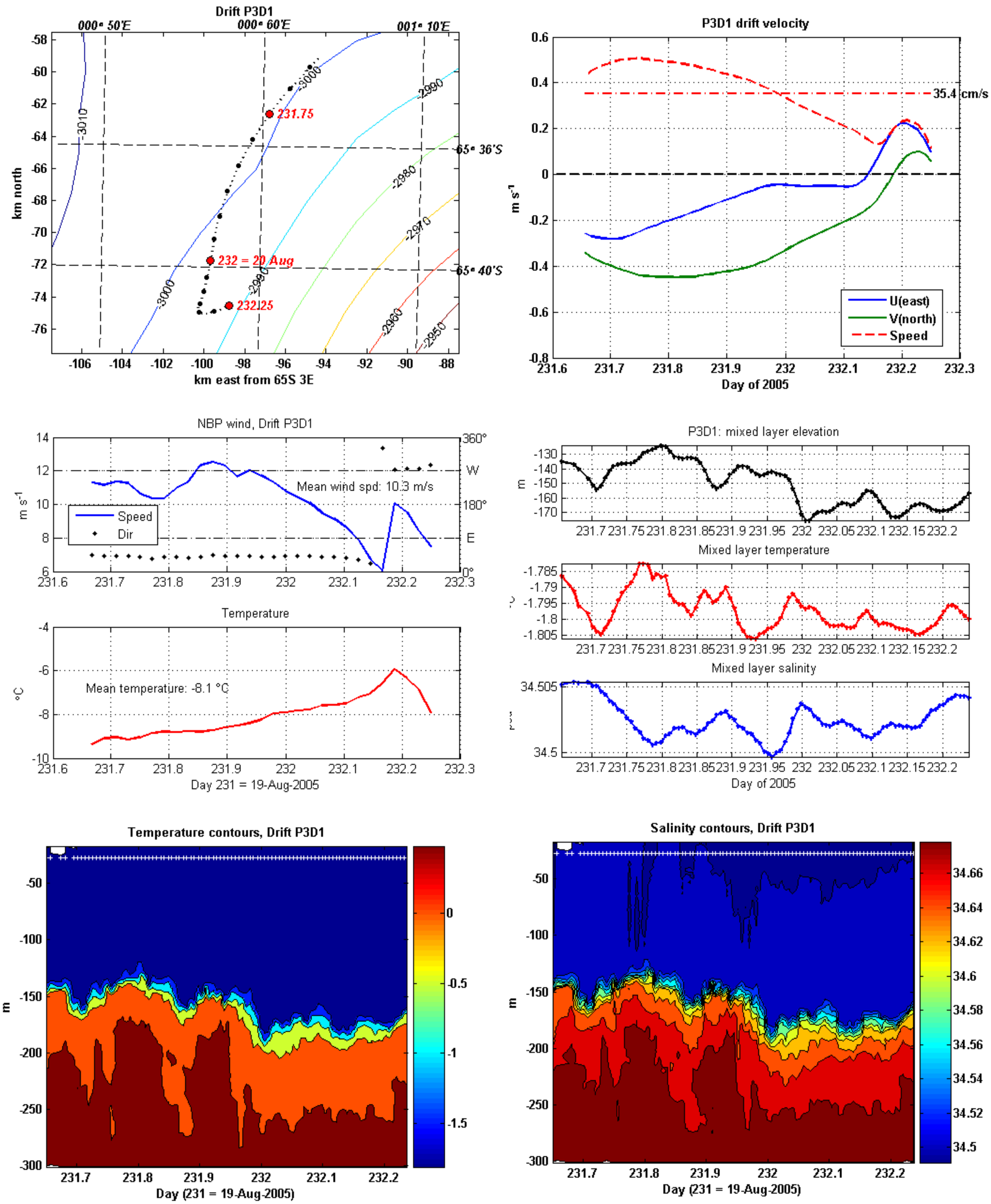


Figure 12. Phase 3, Drift 1 characteristics

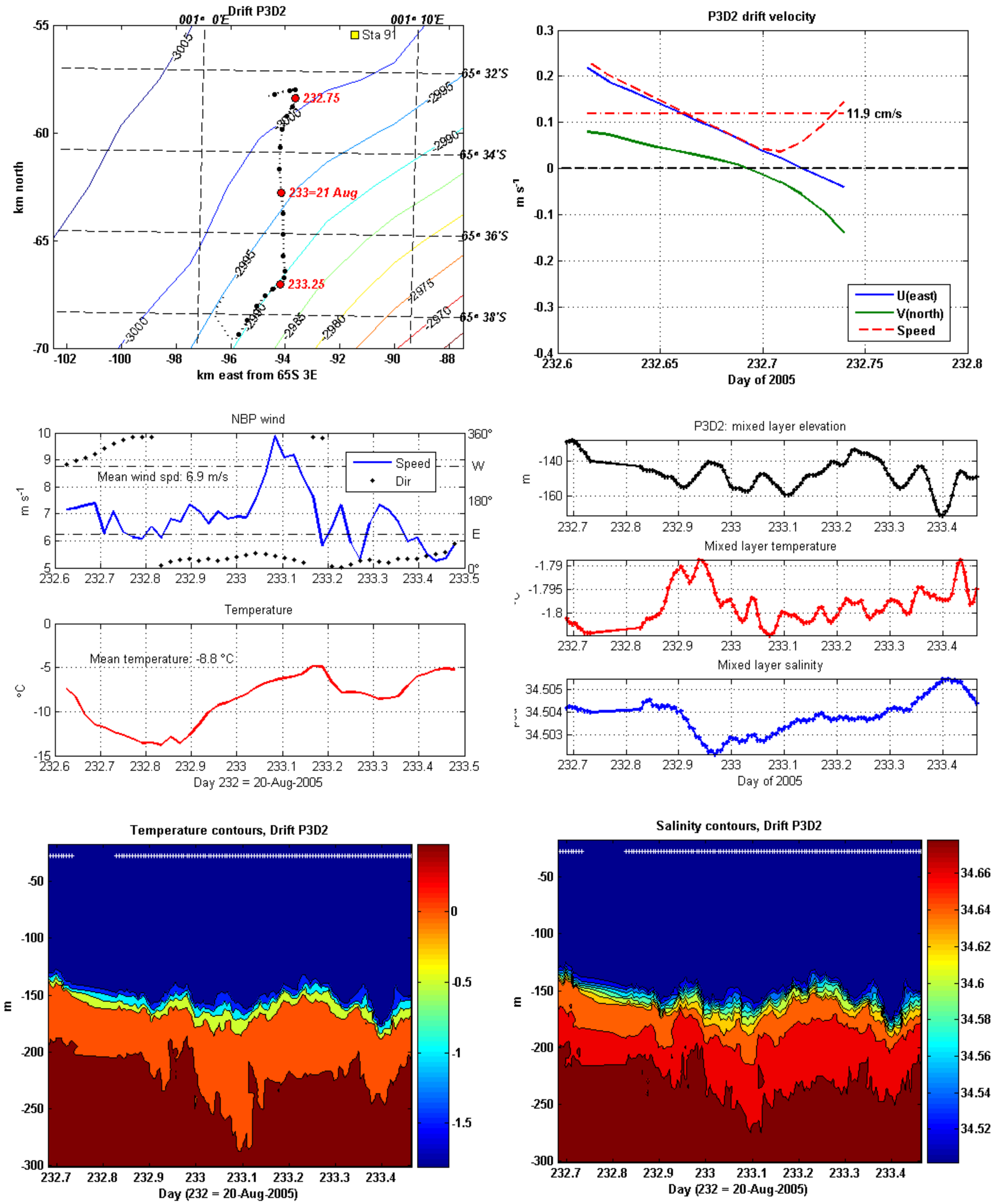


Figure 13. Phase 3, Drift 2 characteristics

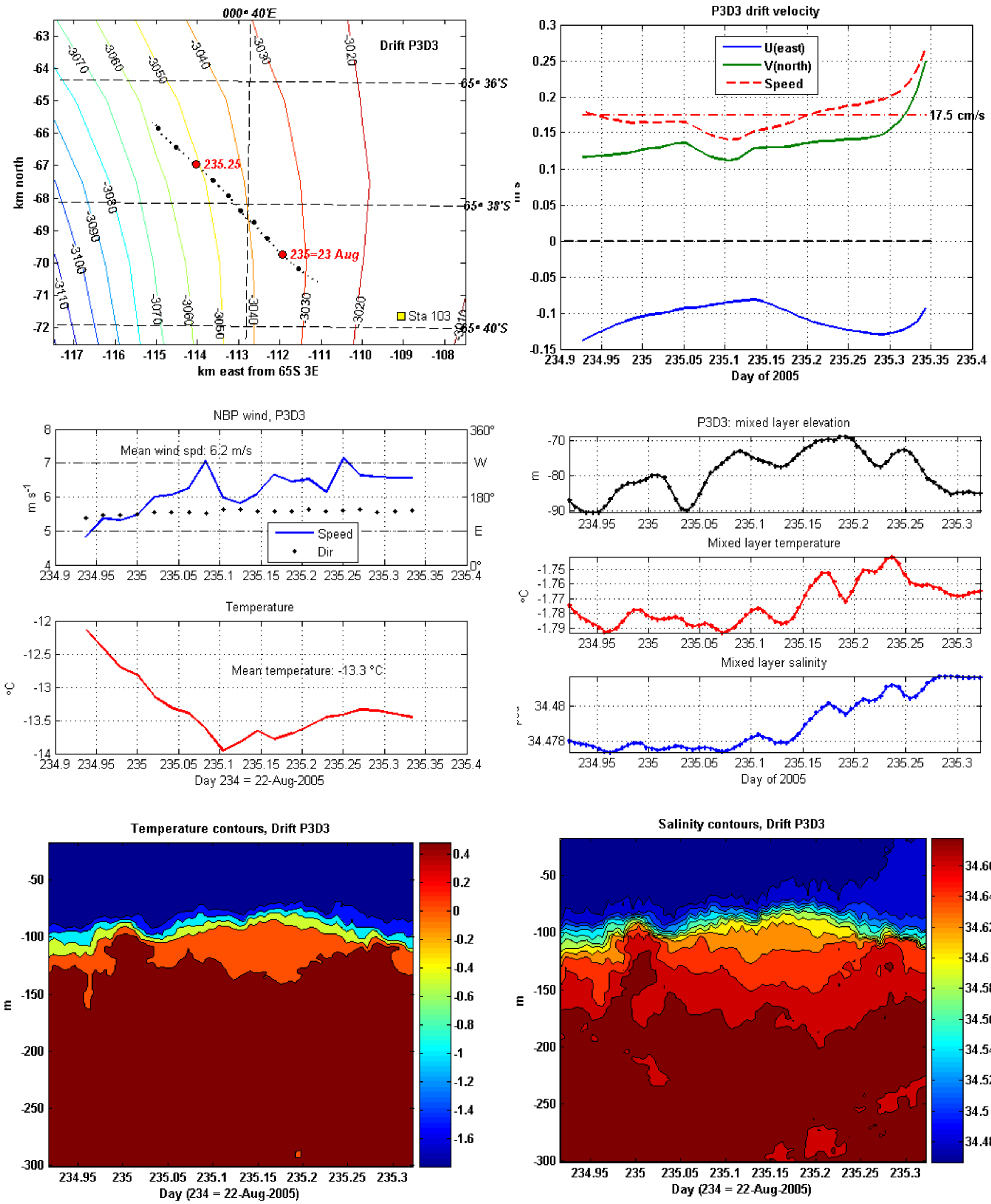


Figure 14. Phase 3, Drift 3 characteristics

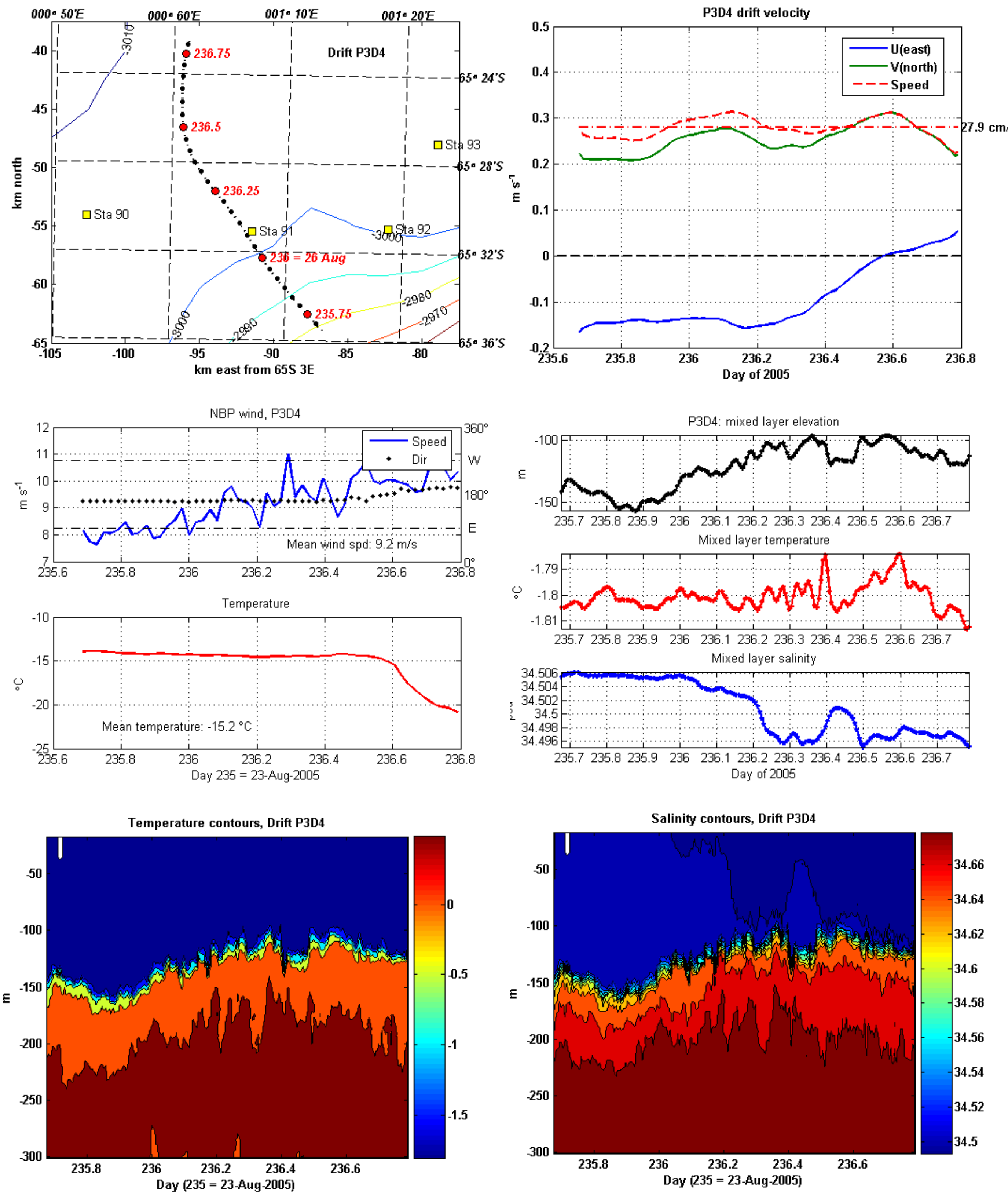


Figure 15. Phase 3, Drift 4 characteristics

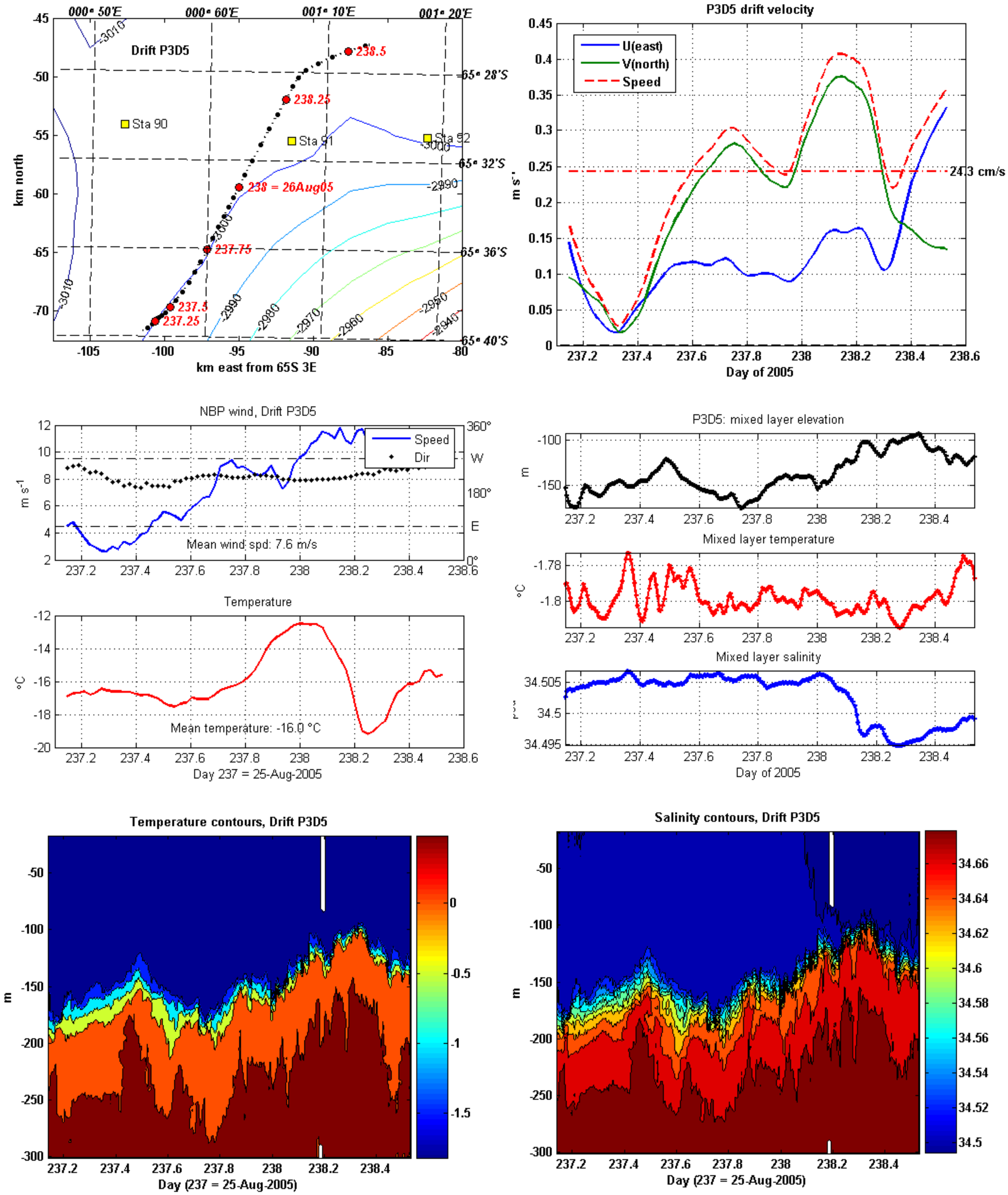


Figure 16. Phase3, Drift 5 characteristics

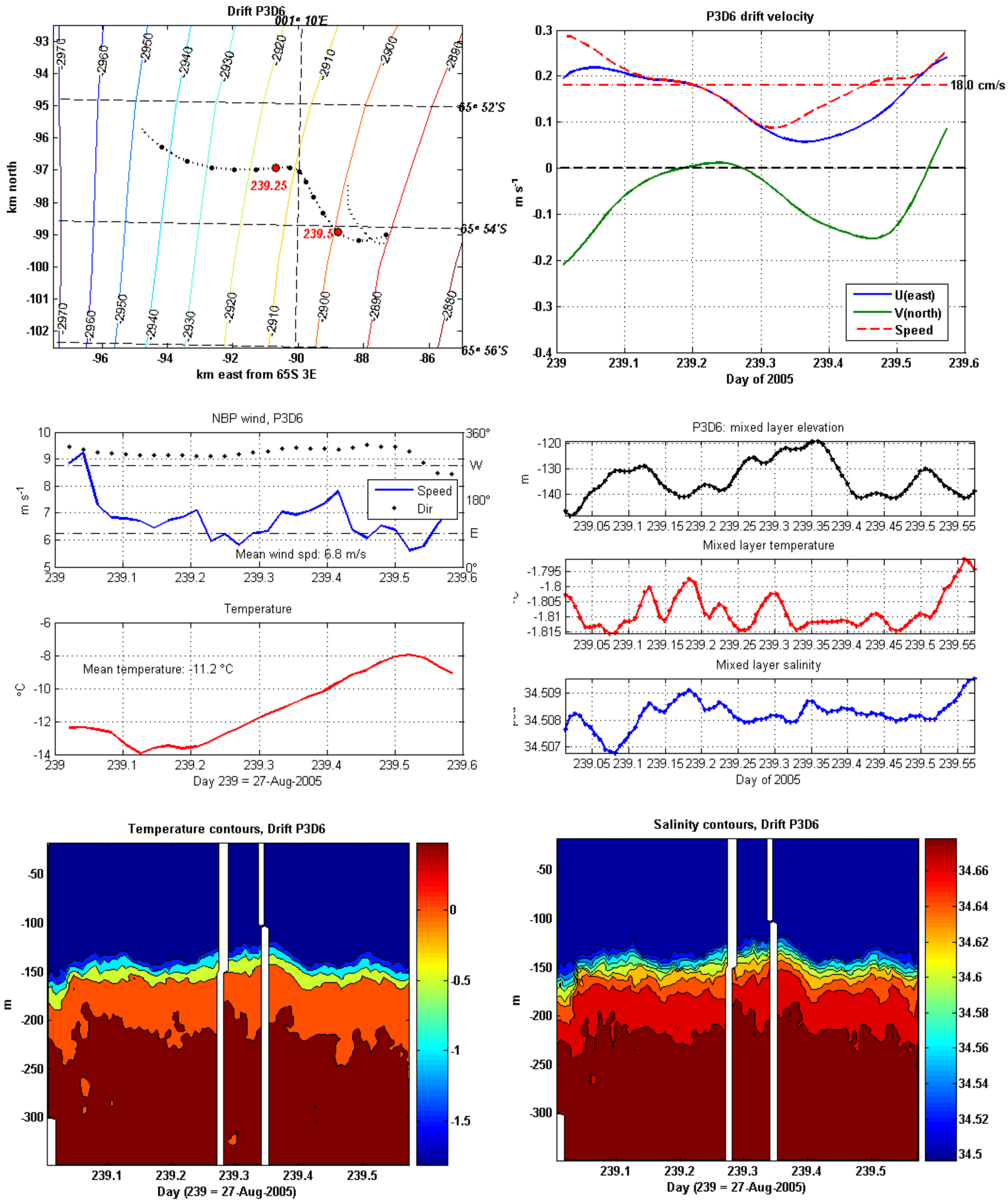


Figure 17. Phase 3, Drift 6 characteristics

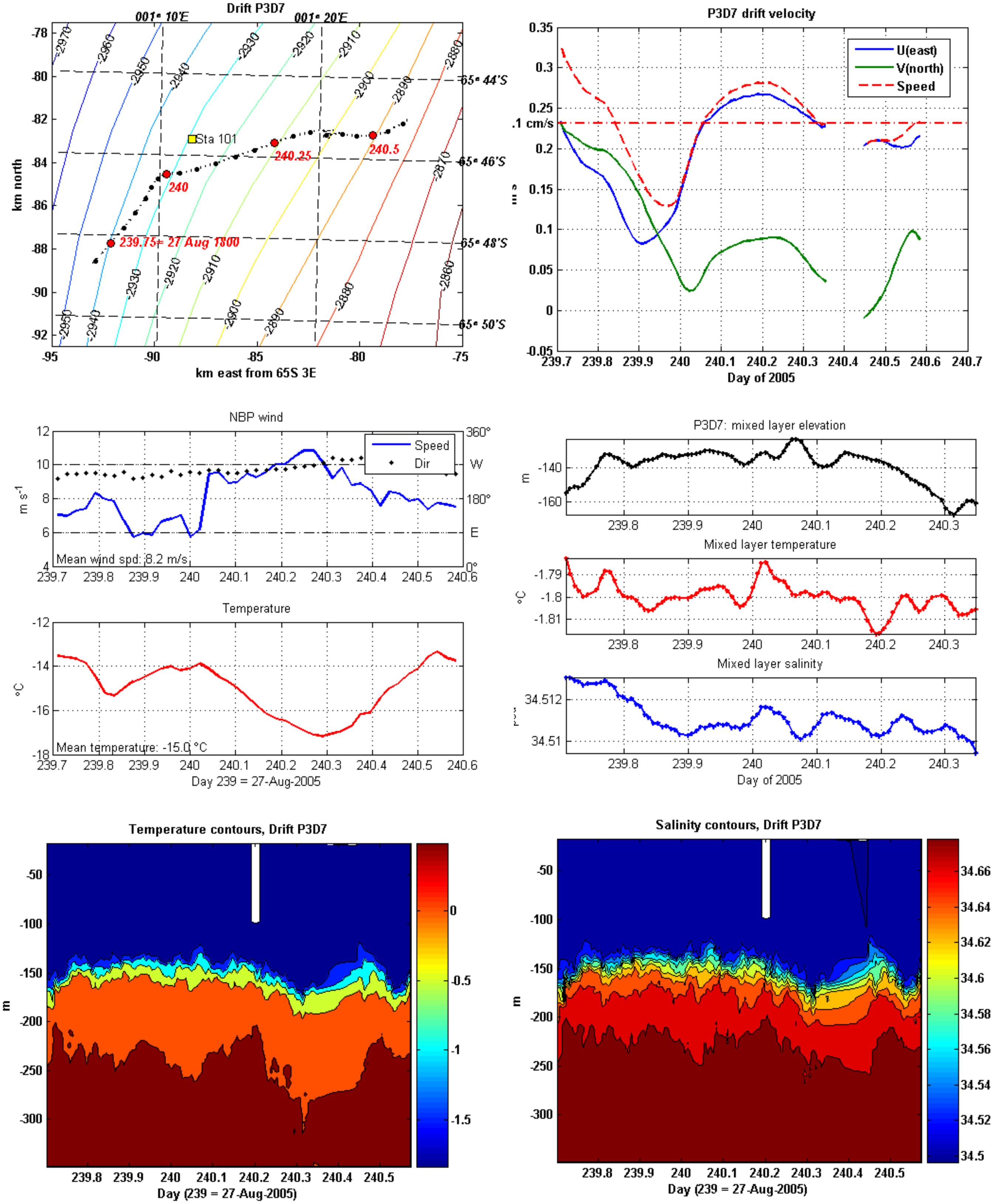


Figure 18. Phase 3, Drift 7 characteristics

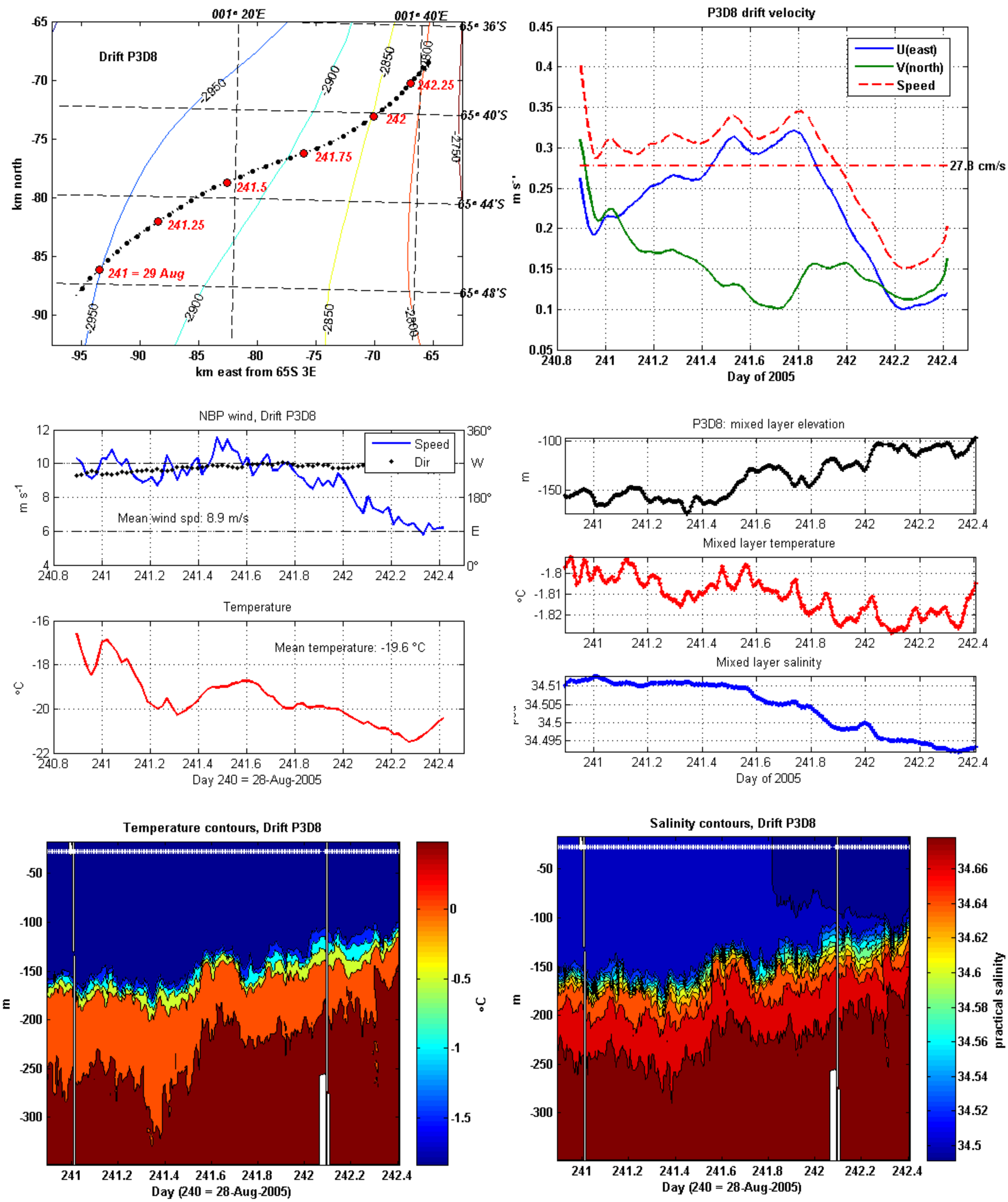


Figure 19. Phase 3, Drift 8 characteristics

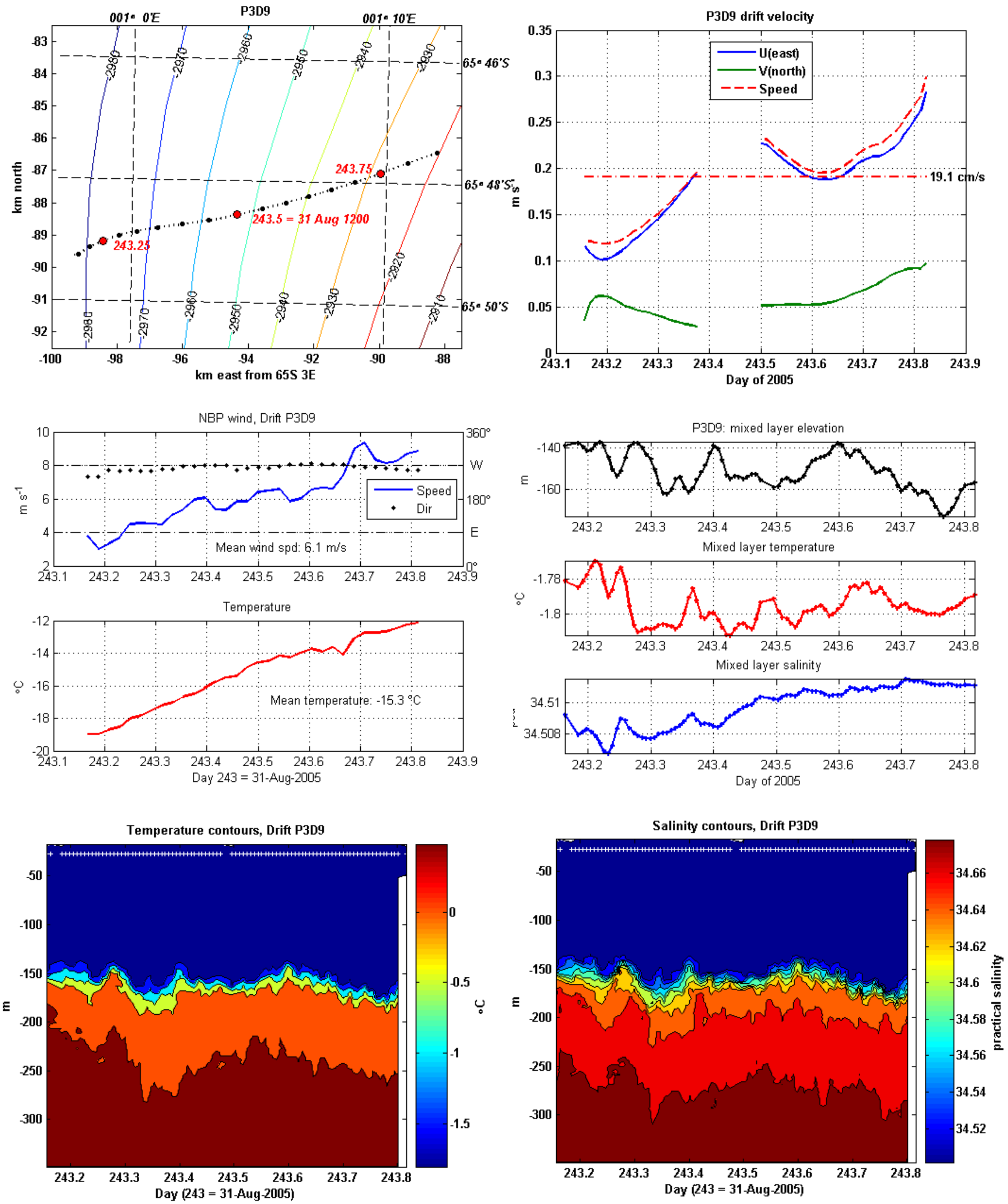


Figure 20. Phase 3, Drift 9 characteristics

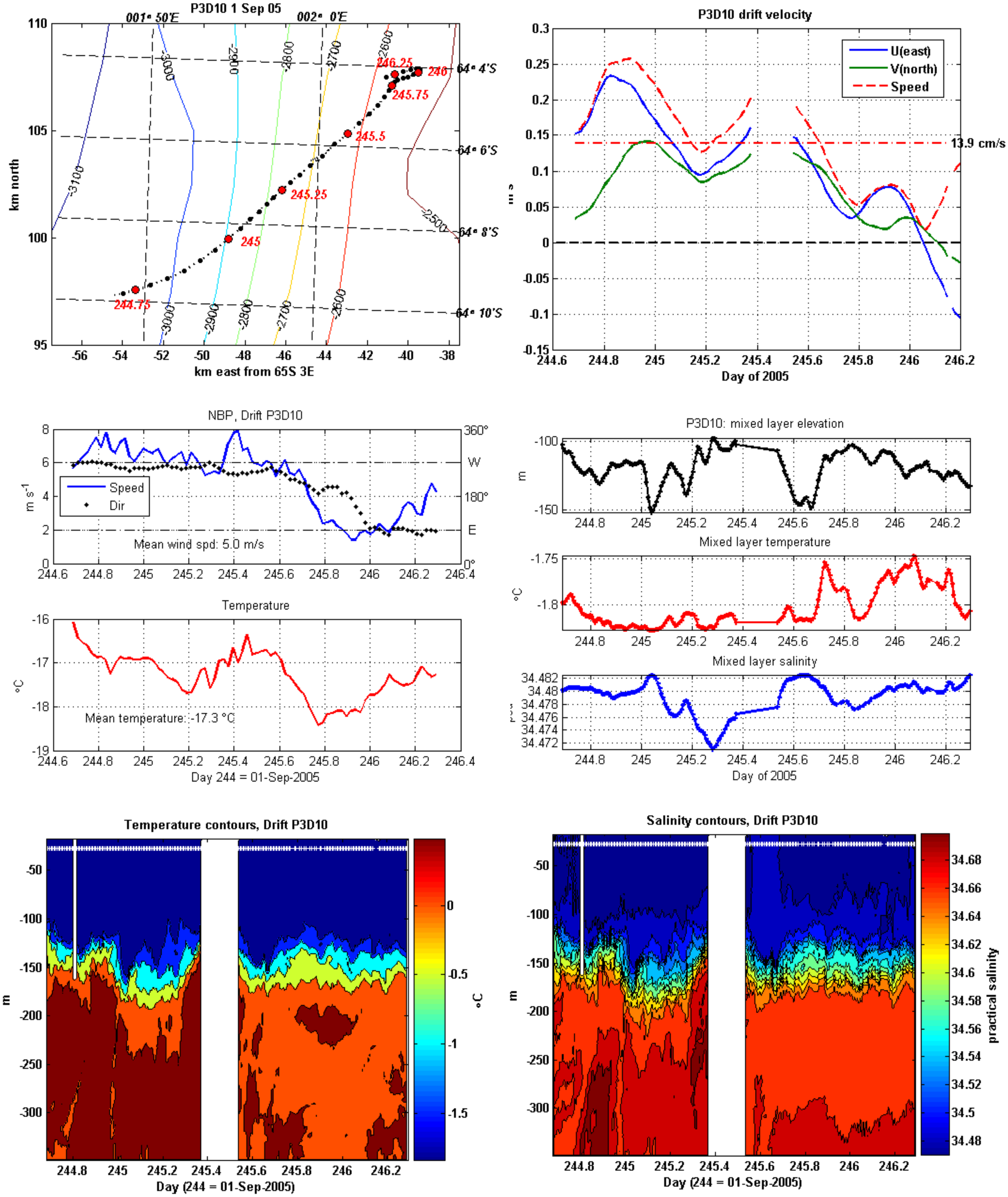


Figure 21. Phase 3, Drift 10 characteristics

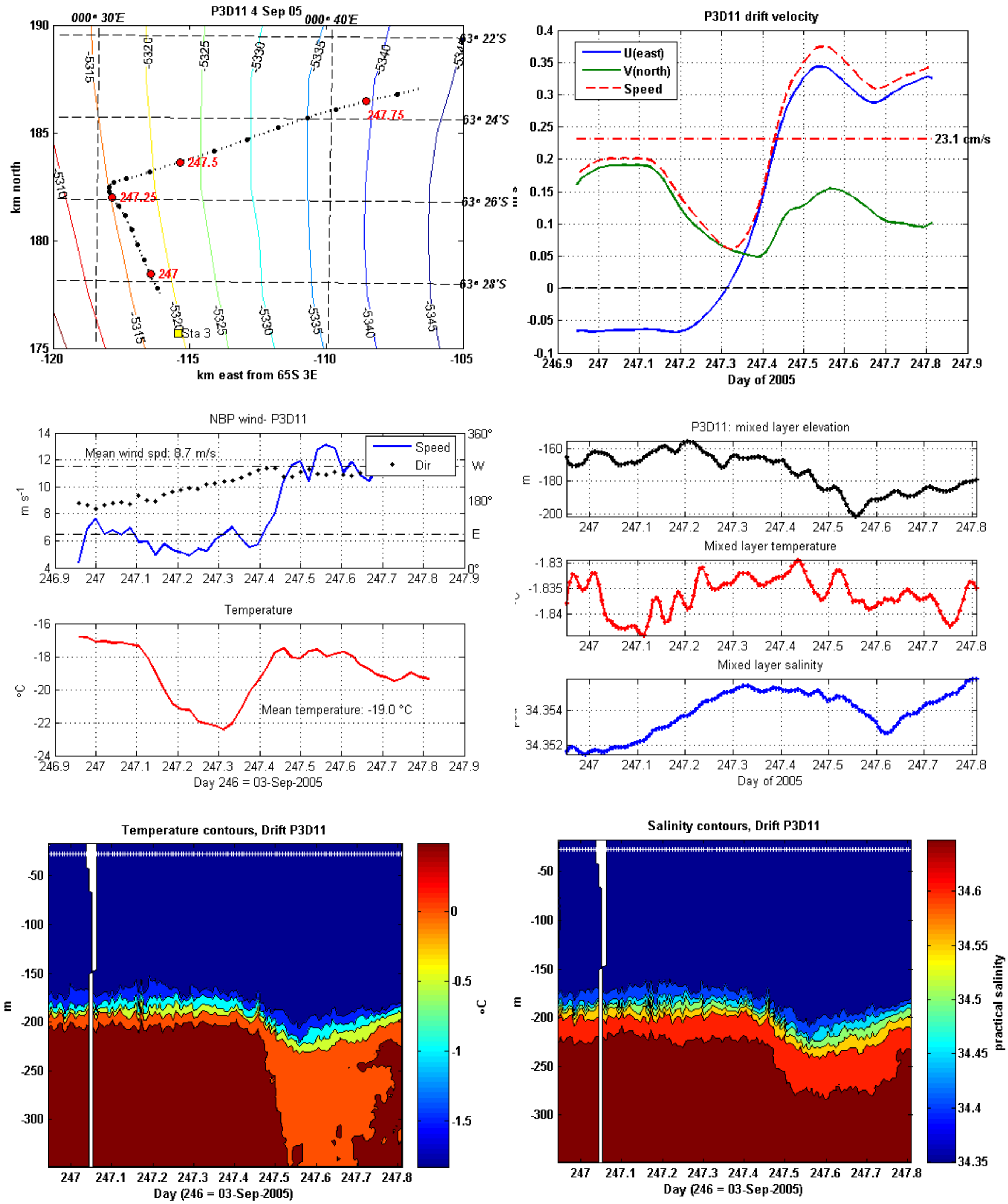


Figure 22. Phase 3, Drift 11 characteristics

3.4 The Maudness Iceberg Study (MaudBerg)

On Tuesday, August 30, we took advantage of an opportunity to briefly study mixing in the vicinity of an iceberg (Fig. 23) encountered during transit from Phase 3 Drift 8 to Phase 3

Figure 23. The MaudBerg iceberg. The downstream (upwind) aspect of the iceberg is shown. Profiles taken on each side of the iceberg showed substantial upwelling of pycnocline water in the wake of the iceberg, which was drifting with the pack ice.

Drift 9. Icebergs are a potentially important source of fresh water and mechanical mixing in the Weddell Sea. Though our study was far from exhaustive, as far as we know this was the first time such specialized instrumentation has been used to examine ocean mixing near an iceberg. The MaudBerg iceberg was 200-300 m across and about 30m high. We first set the ship about 400 m upstream of the iceberg and made two yoyo CTD casts with the moonpool system. We then made longer sequences of yoyo measurements downstream to one side and directly downstream of the iceberg. Additionally we made mid-depth turbulence mast measurements and used the ship's CTD rosette to obtain a deep profile and water samples for Del O18 detection of meltwater at the downstream position. The iceberg geometry was mapped with radar observations and photographs. The pycnocline showed increased variability at the downstream sites and the site directly behind the berg showed a marked shoaling of the mixed layer. The estimated draft of the iceberg is 270 m, substantially deeper than the mixed layer. We have estimated the reduced gravity or interfacial internal wave speed near the iceberg to be about 0.27m/s. The speed of the ice relative to the upper ocean as measured by the ship's ADCP was 0.17m/s near the end of the experiment. Therefore, the iceberg was traveling at less than the speed of interfacial gravity waves, but it was probably moving close enough to the interfacial wave speed to generate a substantial internal wake. This may explain the observed large variations in mixed layer depth, because the depth of the pycnocline would vary with position in the wake. The observations raise an interesting idea. An iceberg moving at near the interfacial wave speed would experience substantial internal wave drag, the "dead water" effect. The greatly increased drag at the interfacial wave speed may explain why icebergs were seen to move with the pack ice when wind speeds were low, such as during our study, but have been observed to move much slower than the surrounding sea ice when the wind blows hard. The sea ice rubble heaps we observed on the "shore" of the MaudBerg iceberg may have been made when the ice drift was 0.5 m/s and the iceberg's drift was greatly retarded by internal wave drag.

4. Outreach

The Maudness web site (www.oc.nps.navy.mil/~stanton/thermo) has been updated and maintained by two Monterey High School students enrolled in the Monterey Academy of Ocean Sciences (MAOS) during the last six months. The web site has two main sections, the first containing background information of thermobaricity including the results of earlier modeling studies and workshops, while the second describes the components of the MAUDNESS field experiment. Daily position maps, activities and weekly sitreps and photographs transmitted from the Palmer have been posted by the students on the web site throughout the cruise. In addition, Gerhard Behrens from Adams Elementary School, Corvallis School District, who has accompanied us on the MaudNESS cruise, has provided almost daily material, both text and photographs, to a web site (http://www.esr.org/mcw_index.html) that describes the cruise from the perspective of a non-scientist.

5. Personnel

Science Staff		
Gerhard Behrens	VMP/ASPECT	Corvallis School District
Laura De Steur	Modeling/VMP	Courant Institute, NYU
Daniel Goldberg	Ice sampling	Courant Institute, NYU
Peter Guest	Meteorology	Naval Postgraduate School
Ramsey Harcourt	Modeling	Univ. Washington APL
Miles McPhee	Chief Scientist	McPhee Research Co
David Morison	Modeling	Univ. Washington APL
James Morison	Moonpool cycling CTD	Univ. Washington APL
Robin Muench	VMP/ship CTD	Earth & Space Research
Dirk Notz	Ice sampling/floats	MPI Hamburg
Michael Ohmart	Floats	Univ. Washington APL
Laurence Padman	VMP/ship CTD	Earth & Space Research
Brian Powell	Modeling/meteorology	Courant Institute, NYU
Kristin Richter	VMP/Ship CTD	U. Bergen
William Shaw	Turb frm/MP cycler/buoys	Naval Postgraduate School
Anders Sirevaag	Turbulence frame	U. Bergen
Timothy Stanton	Turb frm/MP cycler/buoys	Naval Postgraduate School
James Stockel	Turb frm/MP cycler/buoys	Naval Postgraduate School

RPSC Support Staff	
Sheldon Blackman	Electronics Technician
John Evans	Marine Technician/safety coordinator
Brent Evers	Electronics Technician
Peter Fitzgibbons	Marine Technician
Kathleen Gavahan	Information Technician
Eric Hutt	Marine Science Technician
Richard Lichtenhan	Marine Technician
Craige Mazur	Information Technician
Karl Newyear	Marine Project Coordinator
Isaiah Norton	Information Technician
Joshua Spillane	Marine Technician
Jennifer White	Marine Technician

6. Weekly summaries

6.1 MaudNESS Weekly Science Summary #1

July 24, 2005

The Maud Rise Nonlinear Equation of State Study commenced with our departure aboard the RVIB Nathaniel B. Palmer from Punta Arenas at 1400 LT on 21 Jul 2005, following days of intense activity checking and sorting equipment aboard, and observing and advising during completion of ship modifications that include adapting the moonpool for use in the ice pack and arranging the CTD van that will cover the moonpool on station. In addition, the fantail support for the turbulence microstructure shelter during phase 3 of the experiment was installed. The degree of cooperation among the science party, the RPSC party, and ship personnel during this period was exceptional, setting the tone for what we anticipate will be a very productive cruise.

Our departure was delayed one day due to temporary illness of one of the RPSC personnel.

Ship orientation and general science meetings were held on Jul 21. After consultation with Captain Mike Watson, the tentative schedule is as follows:

Transit to first Phase 1 survey CTD station: 21 Jul to 1 Aug

Phase 1 rapid CTD survey: 1 Aug to 9 Aug

Phase 2 Maud Rise drift station: 9 Aug to 19 Aug

Phase 3 & 4 Parcel following/open polynya operations: 19 Aug to 4 Sep

Ice egress including full CTD stations: 4 Sep to 10 Sep

Transit ice edge to Punta Arenas: 10 Sep to 18 Sep

We began underway measurements (swath bathymetry, acoustic doppler currents) after leaving the Falkland EEZ about 0230 UT this morning. Other activities include preparation of instrument systems, setting up on board modeling activities, and testing digital data streams being passed to the ship including 5-day AMPS MM5 forecasts for the Maud Rise region, and AMSR microwave ice concentration and motion fields.

My impression is that there is a high degree of excitement among the science party and that morale is high--perhaps influenced by the fact that the Scotia Sea has treated us kindly, at least for the first three days of our passage eastward.

Miles McPhee, Chief Scientist, MaudNESS

6.2 MaudNESS Weekly Science Summary #2

31 Jul 05

At last we have turned south into the Weddell ice pack after our long trek east through the Scotia Sea and South Atlantic. Today (Saturday) skies are relatively clear with good visibility, we have a 20kt wind from the SW, and the temperature is -17C: starting to feel like a polar region. We have had remarkably good sailing for nearly the whole crossing, and the lack of expected tossing and heaving has helped our preparations greatly as detailed in the individual PI reports below. The degree of cooperation between the scientists and RPSC personnel remains very high. Several ad hoc planning meetings for CTD operations, buoy and float deployment, and the Phase 2 ice station staging, have added to our sense of adequate preparation.

We are making full use of the incoming digital weather forecast, ice concentration, and ice motion data, with daily maps, and 5-day forecast animations of pressure, temperature, and winds in the study area. According to the weather model data, the past week has seen predominantly south winds and relatively cold temperatures in the Maud Rise region, with the microwave imagery suggesting high ice concentrations. We are anxious to get there and see what it is really like. The Phase I CTD survey is scheduled to start sometime on Tuesday, Aug. 2.

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): Completed cycling CTD and winch control software with end to end tests. Full testing through the moonpool will take place during Phase 1. Four autonomous ocean/ice flux buoys (OIFB) have been assembled with operational checks through the Iridium system prior to deployment during Phase 1. Tests and calibrations of a 40 element fast thermistor string have been completed, along with control software for the digital servo winch controlling the deep frame position.

Harcourt, Modeling (Powell, D. Morison, deSteur): Morison has implemented the cable watch circle model; Powell has made adjustments to Lindsay's lagrangian ice model for MaudNESS conditions, and will make model fluxes and ice concentration available for 1-D ocean models. DeSteur is adapting a regional subset of global model results provided by Robin Tokmakian to estimate drift of water at the temperature maximum from Phase I CTD stations. Harcourt has implemented two 1-D models, one being a bulk-mixed layer type, modified to generate a second internal mixed layer beyond the point of cabbeling instability. His second model is a plume-based nonlocal mixing formulation that produces similar results. These will be driven with input from Powell's ice model. McPhee's LTC 1-D model has been tested with fields generated from the digital AMPS and AMSR nowcast weather and ice concentration fields being received at the ship. J. Morison, Cycling CTD: Mechanical preparations for the yo-yo CTD have been finished as much as possible until the van is brought down to 00 deck. Full testing of the moonpool/cycling CTD system will be accomplished in stages during the Phase 1 survey.

Guest, Meteorology: Downwelling longwave and shortwave radiation and atmospheric pressure data have been collected since we left port. A test rawinsonde (weather balloon) atmospheric profile was performed in port,and will be done twice daily when we enter the ice pack. Occasional low-level kite-borne measurements will also be made in the pack ice. There have been no problems detected in any of these systems.

Ohmart, Lagrangian and Rafos floats: Several issues regarding the Alfred Wegener rafos floats have been resolved in exchanges with AWI and SeaScan. The floats will be deployed during Phase 1.

Goldberg, Ice Observations: AsPECT ice observations started 7/30, afternoon. Notz is developing a photographic image processing routine for analyzing ice concentration objectively.

Padman, Microstructure & Ship Systems: Phase 1 responsibilities, watches assigned, previous VMP turbulence data analyzed for noise floor, etc.

Miles McPhee, Chief Scientist

6.3 MaudNESS Weekly Science Summary No. 3

Sunday, 7 Aug 2005

After our blessedly calm crossing in open water, now that we are well within the pack, the Weddell has reverted to her old winter self (the one we know and love) by throwing a 943 mbar low at us midweek, with winds approaching 70 kt on Tuesday (2 Aug) and temperatures dropping from +2C (above freezing) in the morning to -16C by mid afternoon. Even to us jaded oldtimers, these storms are awesome. At times low visibility from blowing snow brought the NBP to a halt. Still, despite the storm, superb ship handling kept our Phase 1`CTD program right on schedule. We were also able to get the first drift buoy deployed (along with on-site ice and snow sampling) on Wednesday, and are getting data returned from it showing that ocean heat fluxes reached 70 watts per square meter during the storm. Our weather predictions are proving accurate enough to instill confidence, and are now showing a similar system hitting us early next week.

During the survey, which is about 2/3s done by late Saturday, we have also deployed 6 AWI rafos floats, and two Lagrangian mixed layer floats. Real time data flow over the ship network is working well, with, for example, CTD data showing up for all scientists on the network within about 5 min of the end of each station.

On Friday, we gave the moonpool plunger its first test, and although a little technique tweaking is needed, the hole was successfully cleared and we are confident that it will work as advertised. Big relief! We also smoothly accomplished an on-ice transfer of the deep-mast winch to the 02 foredeck.

It looks now as if we will be in position for the Phase 2 ice camp early on Tuesday, 9 Aug. Much preparation has gone on this week and we are all anxious to get turbulence instrumentation into the water.

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): Two ocean flux buoys instrumented with an ice/snow temperature profile thermistor string and a 6m depth temperature / salinity sensor were successfully deployed during the week. Both buoys have been reporting hourly observations through the Iridium phone system to NPS and email link to the Palmer with all instruments functioning well, allowing ice and ocean heatfluxes to be calculated at each buoy drift site. The deep turbulence frame computer controlled winch has been moved to the bow and cabling for power and data to the drylab completed.

Harcourt, Modeling. Ice model refinements completed & for/nowcast modeling operations (Powell). Using POCM model output to simulate T_max Lagrangian trajectories (deSteur). Using mixed layer models to diagnose instability prospects for CTD casts. Stn 32 identified as likely to become unstable; Lagrangian float deployed into similar profile at subsequent Stn 33 (Harcourt). More refinements in real-time cable model and exported display (D. Morison).

J. Morison, Cycling CTD: On Friday August 5 we successfully tested the moon-pool plunger method for clearing the moon-pool of ice. The 2-m diameter moon-pool has been sleeved down to 1-m diameter with a temporary insert. The plunger is a 1-ton weight (2 railroad wheels) with a circular plate on the bottom that fits the inside diameter of the moon-pool sleeve. We lower the plunger through the moon-pool with a hoist suspended from the steel container van structure and the plunger forces accumulated ice out the bottom of the moon-pool. In the test the method worked pretty much as planned, though it took repeated short lowering strokes to force ice out of the sleeve. Two periods of reverse thrust from the ship' starboard propellor washed most of the ejected ice away from the the moon-pool opening. Science centered on capturing the ship's ADCP records during CTD stations when the ship is stationary. Currents appear to be dominated bysemi-diurnal tides and near inertial motion.

Guest, Meteorology: Radiation and upper air rawinsonde measurements continued this week. A problem with the rawinsonde winds has been solved. The ship radars were interfering with the GPS signal, turning the radars off during and just after rawinsonde launch has resulted in 100% wind data collection. Meteorological ice tower has been test deployed inside and all measurements working. Comparison of ship meteorological data with ship nowcasts show good agreement with the exception of the storm on 2 Aug when wind speeds were underpredicted and air temperature was over predicted.

Ohmart, Harcourt: Six AWI RAFOS floats deployed Aug. 3-5 at Stations 14-18, 21. Two Lagrangian floats deployed at stations 14 and 33, on Aug. 3 and 5, respectively.

Goldberg, Notz: Carried out measurements of snow and ice properties and thickness distributions at the two buoy sites (temperature, salinity, and dO18 profiles). The continuing ASPECT manual ice-observation data have been analysed to estimate the ice - ocean heatflux along the ship's track.

Padman, Muench: We are over half-way through Phase I CTD survey. First two legs are complete, starting leg 3. No significant instrument failures. Most casts are to 700 m, with 3 bottles for checking calibrations of CTD salinity and oxygen sensors. Survey has identified major hydrographic features, including distribution of warm and cold regimes relative to bathymetric features including a poorly mapped pronounced ridge east of Maud Rise. Working with Harcourt, we are updating maps of ocean stability with respect to the nonlinear equation of state processes that are the focus of this study.

Miles McPhee, Chief Scientist

6.4 MaudNESS Weekly Science Summary #4

14 Aug 05

The past week for MaudNESS has been, to put it mildly, interesting. It started calmly enough with more or less routine completion of the Phase 1 shallow CTD survey with the northeast legs and the final leg from NE to SW across the center of Maud Rise. We completed all but one of the 66 planned station, eliminating one at the very NE corner of the survey in deep water, in order to begin the search for the Phase 2 drift station floe with maximum daylight on Aug. 9. Thatís when it got interesting. We were in a field of relatively small floes embedded in new ice and open leads. A small party (McPhee, Morison, Evans) landed and evaluated a larger floe spotted midday. But by the time the moonpool had been cleared (which requires aid from the main screws and starboard thruster) and the ship moved forward to a mooring spot, the floe had developed serious cracks, and we decided to move on. The next floe evaluated seemed more promising and we began preparations for the ice camp deployment. Due to darkness and rising wind, only the mid-level turbulence mast was deployed offship on Aug 9, leaving the helo hut microstructure turbulence, near surface turbulence mast, and on-ice met station for the following morning. But about 2215 that evening, a large crack emanating at about 45 deg from the starboard bow developed. It did not appear to pose an immediate threat to the mid-level turbulence installation. Since by this time the moonpool profiling system was on line providing valuable data, we decided to ride out the storm (winds were 35-40 kt on Wednesday), gathering data from the moonpool profiler and mid-level mast through the next day (Aug 10). But early in the evening, a complex of cracks appeared just past the turbulence mast installation, prompting its rapid recovery. The moonpool profiling continued through the night. In the short time we occupied it, the floe drifted 64 km to the ENE in response to 30-40 kt winds.We resumed the search for a suitable floe at first light on Thursday (Aug 11). It was a study in frustration. No matter whose theory (and there were many) we followed in approaching what we thought were suitable floes, they would crack after a few minutes, often before we could even get the recon party off the ship. We were apparently in a thin-ice stress field unlike what any of us had seen before. After our fourth try and with darkness settling, we held an ad hoc science meeting at which it was decided to resume the Phase 1 survey with a previously unplanned leg toward the west flank of Maud Rise, where our imagery showed large floes in an otherwise low concentration ice field. We would look for more suitable Phase 2 ice as we went. Toward the end of that CTD transect, as we crossed out of the cold Maud Rise deep water around noon on Friday (12 Aug), we came across an expansive and relatively thicker floe. All agreed that it looked superior to anything we had seen earlier, so we carefully drove the ship into it and set up station, with the moonpool cleared and cycling profiler running within about two hours. All the hydroholes and off-ship shelters were in place by supper. As of this writing on Sunday, the floe retains its integrity and all of the planned instrument systems for Phase 2 are deployed and operating. Whew!

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): The third of four ocean/ice flux buoys was deployed on yearday 220.7 at 64 7' N, 3 31' E, and is reporting hourly ice temperature profiles and ocean mixed layer temperature and salinity along with earlier two buoys to the Palmer, allowing ice and ocean heat fluxes to be calculated at each buoy drift site. The moonpool deployed automated cycling CTD and microstructure system has now been operated in collaboration with Jamie Morison at two ice drift stations. The moon pool cleared with the plunger system in between 10 minutes and an hour depending randomly on the packing of ice. Upper ocean T/S structure and turbulence profiles are being made from 15m to 350m with 20 minute repeat cycles, and 580 profiles have been made to date. At the second ice camp, the 9m long ocean turbulence frame was deployed off the bow of the ship from a computer controlled winch designed to track the pycnocline. In collaboration with Miles McPhee the frame is instrumented with 2 ocean flux sensor packages, two ADCP's and a 30 element thermistor array spanning the 8m vertical aperture of the frame. All instruments on the frame and the winch system have been operating well since deployment on 8/13/05 1600 measuring fluxes, shear, and temperature fine-structure through weak shallow pycnocline under light wind forcing conditions.

McPhee, Ocean Turbulence (w/Sirevaag): The midlevel mast was deployed during the short drift after Sta. 66, about 50 m off the starboard working deck in the evening of Aug. 9. It was kept shallow (3, 7 m). A second near surface mast was deployed nearby (the drift was optimum relative to ship interference) in the afternoon of Aug 10. Ice cracks forced evacuation about 1900 on Aug 10. About 22 h of high energy, near surface turbulence data were gathered. At the 2^nd drift, both shallow and midlevel masts were in by evening of 12 Aug, and have been recording since. The deep mast (w/Stanton) was assembled and deployed off the bow crane on 13 Aug, and began recording by late afternoon.

Harcourt, Modeling. Ice model adjusted to account for elevated temperatures over warm halo. Current mean ice formation rate over rise on yearday interval [218, 228] is approx. 1 cm/day (Powell). Comparison of ANZFLUX ADCP and POCM fields finds model velocity fields high by factor of ~2. Working on approximating Lagrangian parcel trajectories (deSteur). Stations 46, 47, 48 and station 73 were identified as being within 5-10 cm of ice-formation proximity to cabbeling instability. Ship drifts following stn. 66 and 73 appear more stable, but unable to analyze data yet. Two more Lagrangian floats without transponders were put out near stations 47 and 59 (Harcourt). Cable model parameters determined before beginning of drift from stn. 66. Cable model display exported to ship video monitors (D. Morison).

J. Morison, Cycling CTD: The yoyo CTD has been running well. The moon pool was cleared and the yoyo CTD was running within less than 2 hours of arriving at the second phase 2 site. The first 12-15 hours at the present station showed interleaving with regions of slight instability down to 350 m. Starting about 0700 on August 13 we abruptly entered a region with mixed layer depth of about 30m and without intrusions except for a warm layer between about 30m to 60m. Presently winds are relatively light, but if they strengthen we should see significant heat flux from the ocean to the ice.

Guest, Meteorology: We continue to collect upper-air basic meteorological data twice daily and continuous downwelling shortwave and longwave radiation. The ice tower is now operational and relaying data to ship via radio link. The latter is instrumented to measure temperature and humidity at two levels, surface temperature, wind vector and upwelling longwave radiation. No problems are apparent in any of these systems.

Ohmart, Harcourt: All of the RAFOS floats and four of the Lagrangian floats have been deployed. The fourth Lagrangian float had trouble sinking. It is not exactly clear why but as the ship maneuvered to recover the float, it sank out of site. The floats are programed to report any mission failures, like not being able to reach it's target depth, via Iridium phone. An error message was never received. The float is assumed to be operation normally. Temporary weight will be added to the remaining two Lagrangian floats to avoid this problem.

Goldberg, Notz: Continued with ice studies. Ice cores were taken at the third buoy site and at the first ice floe, and the ice-thickness distribution was measured at the first ice floe. Further work has gone into the modelling of heat fluxes through layers of snow and ice for > given atmospheric conditions.

Padman, Muench: We completed the Phase I CTD survey as planned, with 65 stations ending at the proposed Phase II drift camp site. After adding on an extra CTD transect from central Maud Rise to the west, we have mapped the extent of the warm halo over the northern half of the Rise, at cross-slope resolution of 10-20 km. Analyses of these data in terms of the large-scale oceanographic conditions required to trigger nonlinear equation-of-state instabilities is ongoing. > On August 12 we began set-up of the Phase II drift station. The helo hut used for off-ship Vampire microstructure profiling was rapidly deployed. After solving some wiring and grounding problems with the aid of RPSC staff, the profiler is operating properly. We have been analyzing backscatter data from the ship ADCP systems, and believe now that this could be a valuable tool for high-frequency ìimagingî of the large convective events we hope to see in the next few weeks.

Miles McPhee, Chief Scientist

6.5 MaudNESS Weekly Science Summary No. 5

21 Aug 05

A pivotal meeting was held Thursday morning (18 Aug) for the science party to reassess where we had been and where we were going. There was general agreement that by comparison with the two previous winter experiments in this region (1986, 1994), our upper ocean survey showed lower surface salinity, hence less likelihood of deep convection capable of forming a sizable polynya. The section to the SW that we initiated after the breakup of the 2^nd Phase 2 drift on Tuesday evening held no particular promise of NES instabilities. But there was also recognition that the 2^nd drift station provided very interesting data as we drifted in and out of the transition between the Maud Rise ìTaylor capî and warmer deep water to the west. And there was still the southwest approach to Maud Rise that we had not yet sampled, with one example from the 1994 ANZFLUX data suggesting that this could be an area where NES issues were important.

At the Thursday meeting we decided to shift immediately to Phase 3 of the experiment, scheduling a ìwalk-throughî practice run of the ship positioning and deployment for operations conducted entirely from the ship. This involves five major measurements systems: a CTD/microstructure profiler in the moonpool, a loose tethered microstructure profiler deployed from the helo hut mounted off the fantail, a midlevel turbulence frame operated from the Baltic room, the deep turbulence/ADP/thermistor frame off the starboard bow, and the combination of Lagrangian float and shipboard acoustic tracking used to tag and follow a particular parcel of pycnocline water (naturally the last was not deployed during the practice run). After the practice exercise, we began another CTD transect across the Maud Rise slope, this one along approximately S65 30'. As we worked east Thursday night and Friday morning, mixed-layer salinity increased and overall stability decreased, and much to our delight, the last station, which coincided in position with one of the least stable of the ANZFLUX stations, was also almost identical in its temperature and salinity structure. In other words, we were back in the ballgame! We deployed the transponder equipped Lagrangian float nearby at about 3 pm on Friday, and followed quickly with the entire ship-deployed instrument suite. By supper time all the systems were going, and the ice was moving south at just under 1 kt under a moderate north breeze. The mixed layer was relatively deep, with a very active underlying thermocline/halocline. Although it is premature to say with any certainty, the consensus was that between about 1700 on Friday and 0400 on Saturday, we collected a truly exceptional upper ocean physics data set. At about 0415, the wind shifted suddenly, and we recovered the instrumentation without difficulty. We had drifted about 20 km overnight, but were able to return to near our starting point and easily find the subsurface float, and to start another drift Saturday afternoon.

As we anticipated, the Phase 3 operations are difficult. Each instrument system must be watched continuously for entanglement with sea ice drifting by the starboard and stern, as well as with other instruments. Positioning the ship to hold station while optimizing the wire angles and watch circles is a huge challenge. The digital AMPS weather forecasts that we receive daily have proven critical in this effort by consistently providing good wind direction prognostics. The effort requires close teamwork from all on the ship, and that has materialized in a really gratifying way.

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): Upper ocean measurements of temperature, salinity and microstructure profile timeseries continued at the second ice camp of phase two as the wind-driven drift took the ice camp three times across a front between warm regime and Maud Rise Taylor column water (with Jamie Morison). Nearly continuous timeseries of the water column properties were made to 350m depth resolving the complex interleaving structures near this front. Concurrent measurement of small scale shear and temperature structure and eddy-correlation based fluxes were made from a 9m long instrumented frame that tracked the top of the pycnocline (with Miles McPhee). Entrainment processes were well resolved during both moderate and initially energetic surface stress conditions. The fourth ocean flux buoy was successfully deployed at the end of the drift ice camp and continues to report upper ocean heat and salt fluxes and ocean-ice-atmosphere temperature profiles. This buoy is equipped with an eddy correlation T/C/u,v,w instrument deployed at 6m depth. The deep frame and profiling microstructure/CTD system were deployed yesterday at the first ship-based drift of phase 3 of the Maudness science program with all instruments working well.

McPhee, Ocean Turbulence (w/Sirevaag): The midlevel and shallow turbulence masts operated continuously through the 2nd Phase 2 drift, except for the hiatus on Sunday evening, when a crack developed between the ship and helo hut. Both were operational again on Monday, with the shallow mast moved to a location close to the midlevel mast. With the start of Phase 3, we have adapted the midlevel mast operation to the Baltic room, and have deployed it rapidly in both Phase 3 drifts to date.

Harcourt, Modeling (w/deSteur, Powell, D. Morison). Stations 84-91 identified as being within 5-8 cm of ice-formation proximity to cabbeling instability. Trackpoint operational after initial difficulties with (earstwhile correct) default frequency settings, and with multipath effects due to propeller motion. Float 29 currently being tracked while screws are de-clutched. Initial motion was approx. 1 km/day to the SW. One of two redundant tracking programs with display operational (Harcourt). Cable model and video display operational. One of two float tracking models operational with video display. Lack of any more NBP Matlab licenses limits some potential further modeling activity (D. Morison). Ice model received further major adjustments to (1) alter hardwired northern hemisphere seasonal triggers not previously noted, and (2) offset-rescaling of AMPS air temperatures to reconcile with Guest's measurements during ice formation periods (Powell). Acquired tidal model with instruction from Padman, and used this in combination with ADCP and POCM fields to model Lagrangian parcel trajectories (deSteur).

J. Morison, Cycling CTD: The yoyo CTD and moonpool have worked great so far especially in the phase 3 rapid set up mode. Operationally it is just what we wanted. The float tracking method is looking promising too. The data from the CTD during the first set up showed remarkable variations in the pycnocline structure, with step structures rapidly building and breaking down. During the second set up this Sat afternoon and this morning things have been interesting but quieter. It appears that stronger wind stress during the first period was important for initiating overturning that then cascaded through the pycnocline due to marginal stability. Processing of ship's ADCP data gathered so far during the 91 ship's CTD stations has been done. As of 0400 this morning we have made 1157 yoyo CTS profiles from the moon pool. At approximately 300 m per profile, that's 347 km of vertical motion. The next ice breaker should have four moon pools.

Guest, Meteorology: This week we performed 4 sessions of atmospheric profiling using a rawinsonde attached to a kite. Each of these sessions consisted of 12 profiles of temperature, humidity and pressure from the surface to 100 meters. These provided estimates of heat flux from leads, which complimented the ice surface heat flux measurements from the ice tower. Normal balloon rawinsondes measurements continue twice a day, along with continuous radiation measurements . The ice tower is no longer deployed, but all other systems are working well.

Ohmart, Harcourt: One more (5th of 6) Lagrangian float with transponders put out near station 91. Lagrangian Float #29: 19 August 2005, 15:19 hr; -65, 32.900; +001, 03.673

Goldberg, Notz: Goldberg and Notz have carried out extensive ice and snow surveys on the ice floe of the drift station. They have measured the temporal evolution of the snow and ice thickness and temperature along a 300 m long transect and have calculated the heatflux through the ice. They found ice thickness changes between -3 and +1.5 cm per day on average, indicating large variations in the oceanic heat flux. The ASPECT ice observations were taken up again after the ship had left the drift station.

Padman, Muench: We added two CTD lines to the original Phase I survey. The final line (east across the southern neck of Maud Rise) led to selection of the first Phase III ship-based drift station in a region of low ocean stability. We operated our microstructure profiler ìVampireî from the helo hut on the fantail, obtaining 25 profiles over a typical depth range of 10-300 m during a 12-hour period. We found energetic mixing in the surface layer associated with the moderate wind stress (typical winds of ~20 kt) and in the pycnocline at the base of a deep surface mixed layer (~150 m deep, but highly variable).

Miles McPhee, Chief Scientist

6.6 MaudNESS Weekly Science Summary # 6

28 Aug 05

This has been an intense week with a series of Phase 3, ship-based short term drifts. We are now in Phase 3, Drift 7, (P3D7 for short) started in a location just south of the last line of CTD stations done on 22 Aug, which in addition to station 91, were judged least stable both to deep boundary layer mixing, and slower cabbeling type mixing in the pycnocline. By various measures P3D7 is the least stable of the drifts to date.

The procedure that has evolved for establishing the P3 drifts begins by using the AMPS weather forecast to model ice drift, choosing the initial site so that the ship will drift over our designated patch of interesting water about midway through the drift, often roughly 15-20 km downrange. The wind forecast also provides critical information on how to orient the ship for optimum wire angles - wind off the starboard stern quarter works best, since the counterclockwise Coriolis deflection of drift with respect to wind direction holds consistently here. We drive to the target area and look for a combination of thin ice/open water and a floe edge that will give us the proper orientation. Then begins an intricate dance in which the Palmer pirouettes with its mains and thrusters to clear the ice from a “lake” that will end up on the starboard beam, giving us ice free access, bow and stern, for the duration of the drift. To an uninitiated observer on the bridge (me) it seems like magic. Once the “lawn is mowed” (as J. Morison more prosaically puts it), we plunge the moonpool, clear the ice away underneath with the main screws, declutch the mains, and ease the ship against the floe edge with the bow thruster. At that point, we are ready to deploy the instrument systems, which after a bit of practice, now goes quickly. Most impressive is the deep frame off the forward bow. It is stored vertically in two sections under a forward supply hatch, lifted by the forward crane to join as a single unit 9 m (30’) long and hoisted over the side. Thus begins the actual drift station, which requires constant watch for encroaching ice and veering watch circles. Generally a drift ends when the wind shifts, the lake freezes, or we have gone too far from the interesting water patch. So far we have made two nighttime deployments, both successful.

The Phase 3 drifts, ranging in duration from 10 to 32 hours, and net displacement from 8 to 39 km, are providing a wealth of upper ocean data, but the sought after condition of neutral stability between the mixed layer and underlying pycnocline still eludes us. It is a matter of increasing the most dense mixed layers by as little as 0.01 kg per cubic meter, but that last 0.01 change in salinity is proving hard to come by. Clearly there is a very intricate balance at work here; understanding how that balance is maintained presents a real challenge. It is quite a sight: a gaggle of scientists grouped around the profiler display, intently watching the third decimal place of mixed layer salinity as the instrument cycles through the mixed layer. What we need now is a good blow, which has also eluded us since we started Phase 3. But we still have another week, and this is the Weddell.

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): Phase III operation of the deep turbulence frame and temperature, salinity and microstructure profile timeseries systems from the ship have been successful for 6 short drift stations. With good choices of ship orientation there have been no problems of cable tangling with the mid-water mast or Padman microstructure profiler. At these drift sites there have been small increases in mixed layer salinity and a corresponinding decrease in water column stability, with frequent internal mixing layers just below the pycnocline. The deep frame has been used in two distinct modes. In the first, fine scale shear is measured across the pycnocline with the downward 5 beam BADCP, while concurrently measuring turbulent fluxes and finescale temperature structure at the base of the mixed layer. In the second mode, the frame is lowered into developing internal mixing layers (typically 5 to 40 m deep) to resolve the temporal evolution of these features in the context of concurrent CTD/microstructure profiles every 10/20 minutes. Preliminary analysis of both data sets has shown that the shear acting across the pycnoline is well resolved and several methods are being developed to estimate vertical fluxes through the mixed layer and pycnocline. All four drifting buoys are functioning well and reporting every 4 hours. During the last week there were warmer mixed layer temperatures at the southern two buoys, with cooler temperatures and ice formation at the northern two.

McPhee, Ocean Turbulence (w/Sirevaag): Our procedure for deploying the midlevel frame from the Baltic room is working well, with deployment and recovery a matter of minutes. We typically position the frame at about 50 m depth, at which level turbulent stress and heat flux values have been moderate under the relatively light winds encountered so far: typically u* between 2 and 8 mm/s and heat flux from 0 to 10 W m2. By poling the occasional ice floe away from the Baltic room door, we have managed to keep the frame operational through most of the P3 drifts.

Harcourt, Modeling (w/deSteur, Powell, D. Morison). Float tracking no longer successful at this point, probably due to lower than expected tracking range limits in local environment. Trackpoint now being left in water at nearly all times during drift stations. Multibeam and Knudsen sonar are being turned off during drifts in order for tracking to be possible. Noise from bow thruster necessary to maintain open water around cabled instruments under drift is tolerable as it is sporadic and distinguishable from trackpoint fixes on floats. Assisting in Vampire and Yoyo CTD watches (Harcourt). Cable model operational with continuing modification for enhanced utility. Assisting in Yoyo CTD watches and operations (Morison, D.). Ice model is run operationally now and updated daily with each AMPS forecast, and the comparison of motion with both ship drifts and flux buoys has been consistent. Assisting in weather observations with Guest (Powell). Using modeled tides and ADCP data to project Lagrangian parcel trajectories. Assisting in Vampire operations (deSteur).

J. Morison, Cycling CTD: The last week has been devoted mainly to keeping the moon pool CTD/LMP system cycling, and operationally it has gone well. As of now we have collected 1906 profiles, mostly to 300m. We have recently changed the bottom depth to 350 m in hopes of getting farther below the intrusive features, both for a more complete picture of the general hydrographic condition and allow us to compute some representative internal wave displacement or strain spectra. I have been processing the 2-m average quick look profiles, particularly looking at Brunt-Vaisala frequency. Drift 3 comes out looking the most interesting with two patches of relatively low stratification at the pycnocline (N=1-2 cycles per hour) overlying complicated intrusive features and small regions of instability.

Guest, Meteorology (w/Powell): We continue to perform 2/day rawinsonde upper-air soundings and radiation measurements. All systems working well. Coded messages have been sent in special packet to insure timely delivery while email problems are addressed.

Goldberg, Notz: On-ship ice observations were taken up again after we left phase II and briefly continued in between drifts. However, it was decided after the 22^nd , that it was not worth it to continue ASPECT during Phase III, unless we move large distances; most potential volunteers have their phase III shift schedules, and periods of movements are relatively short. When we head Northeast ASPECT will continue.

Padman, Muench: We have been operating the Vampire microstructure profiler from the fantail helo hut during all on-ship Phase III mini-drift stations. Microstructure show weak mixing on the pycnocline in most of the profiles. We hypothesize that this mixing is associated with vertical shear across the pycnocline as seen in the ship's 150 kHz ADCP record. In turn, the primary source of this shear appears to be mixed layer near-inertial response to wind stress, although baroclinic tides might also be a contributing factor. The weak stratification of the pycnocline, combined with nonlinear equation-of-state effects (mostly cabbeling), leads to instabilities which are seen as high thermal gradient variance and formation of steps. These latter features are either transient or have small lateral scales since they frequently appear and disappear between successive casts 20-30 minutes apart.

Miles McPhee, Chief Scientist

6.7 MaudNESS Weekly Science Summary # 7

4 Sep 05

At the time of writing, we are midway through Phase 3, Drift 11, which will be the final one. We pull the instruments aboard for the last time by 2000 this evening, and will curtail science activities except for a couple of deep CTD stations and several XBT (expendable bathythermograph) launches during egress from the ice, along with continued meteorological observations on the journey back to Punta Arenas. In the past week we continued three Phase 3 drifts (P3D7-9) in the low stability region on the SW flank of the Rise, and conducted an ad hoc iceberg experiment (see below). After weather forecasts reaching toward the end of the science program indicated no significant changes, we decided to return to the north, first to the transition region where warm core "halo"water interacts with the Maud Rise "Taylor cap" (P3D10) near Phase 1 station 12. Following that we again moved north to the site of Phase 1, station 3, for a drift in the relatively cold, stable water found north of the halo, where we are now. Winds have been quite light - the mean hourly wind speed for the week was around 7 m/s. This is disappointing in that we lacked a really significant wind storm to stir things up after we started Phase 3. On the other hand, we measured several moderately swift events during the ten previous drifts that should provide a wealth of data on what maintains the amazingly delicate balance between the thin ice cover and upper ocean stability.

From a technical standpoint, we demonstrated a number of firsts in how the Palmer can be used successfully as a drifting platform in ice too thin for safe off-ship deployment. If pressed to choose the most significant, I would say that the capability of rapidly clearing the moonpool, along with the van arrangement for housing an automated cycling system, contributed greatly to the success of the experiment. Definitely worth the pre-cruise effort! At times when the other systems required fending off errant ice floes or breaking newly formed ice (with a heavy shackle attached to the sea cable in the case of the forward frame), the moonpool operation has clicked along with very little interruption. No less significant has been the ship-handling technique (described last week) that has evolved rapidly to provide us with long lasting ice free (or at least manageable) ìbreathing holes.

During P3D8 (Mon-Tues), we were in view of several smallish icebergs, drifting as we were, with the ice pack (since their location relative to us did not change). These typically rise about 30 m above the surface, so must extend downward to well below the mixed layer. At J. Morisonís suggestion, we decided to spend a few hours investigating, at least qualitatively, what impact a small berg might have on the pycnocline. The strategy was simple: measure the upper ocean with the moonpool profiler on the downwind (ìupstreamî) side of the berg, then move to the opposite side (downstream) to see what if any changes occurred. We also rigged the ship CTD to collect water samples in the wake, to look for O18 depletion indicating water of meteoric origin (glacial ice melting). The results were pretty impressive, with the pycnocline rising from about 150 m depth on the upstream side to around 70 m in the immediate wake. Toward the edge of the wake, the pycnocline was very active. During the study, the berg drifted about 3 km NNE with drift velocity ranging from about 15 cm/s at the start to ~10 cm/s near the end. In addition to its intrinsic interest, the exercise (which as far as we know is unprecedented) again demonstrated the utility of the Palmer as a highly mobile drift station.

Tonight we end the intensive data collecting and begin packing for the long haul back to PA. We are thankful for a rich, scientific harvest.

Following are brief reports from each PI subgroup:

Stanton, Ocean Turbulence (w/Shaw, Stockel): Phase III operation of the deep turbulence frame and temperature, salinity and microstructure profile timeseries systems from the ship have been successful for 11 short drift stations. The deep frame deployments have gone well thanks to the use of the tall forward storage lockers on the Palmer, and we have only had to halt observations twice due to ship or ice movement. After leaving the southwest drift sites, and starting the last two drifts over the outer edge of the halo and north of it, the ice has formed more rapidly and has required frequent clearing of a hole around the frame cable from high up on the forward deck. Processing and analysis of the frame data has shown well resolved shear structures across the pycnocline from the dual ADCP systems on the deep mast. The 40 element thermistor string failed during phase three drift 5 due to a sea-water leak in one of the potted assemblies, but the previous data resolves vertical thermal structure and turbulence within or above the pycnocline depending on the frame position. Preliminary analysis of the 2500 CTD / microstructure profile timeseries from the moon pool-deployed cycling instruments reveal high resolution T/S and turbulence level profiles to 350m throughout the drift operations. These measurements quantify vertical fluxes through the weak pycnocline that are being compared with the concurrent eddy-correlation flux measurements within the lower and upper mixed layer. These observations are being used to understand the processes that maintain a very delicate balance between ice production (and destabilization) from the cold, moderately forced ice cover, and continual vertical transport of heat and salt from the pycocline, due in part to tidal / inertial shear across the pycnocline. The local ship observations of upper mixed layer fluxes are being extended regionally through the 4 ocean flux buoys deployed earlier in the cruise

McPhee, Ocean Turbulence (w/Sirevaag): We continued measuring turbulence with the midlevel mast during all the drifts, usually with it situated about 50 m deep in the mixed layer. Preliminary results have shown brief episodes of large upward heat flux, one example reaching as high as 90 watts per square meter (1-h average) during P3D8. Analysis of deep frame turbulence cluster data has also begun.

Harcourt, Modeling (w/deSteur, Powell, D. Morison). Float tracking operations concluded without further contact with either float 29 or 33 (that was distinguishable from noise) during subsequent drifts, beyond the initial tracking fixes on float 29 over the two days following its deployment near Station 91. Assisting in Vampire and Yoyo CTD watches (Harcourt). Cable model operational, with critical input during ice drifts with orientations made difficult due to loss of NBP bow thruster. Assisting in Yoyo CTD watches and operations (D.Morison). Ice model is run operationally now and updated daily with each AMPS forecast, and the comparison of motion with both ship drifts and flux buoys has been consistent. The Lagrangian ice model will be updated with fore/nowcasts through the end of September for purposes of ocean modeling and float data interpretation. Assisting in weather observations with Guest. (Powell). Examining Maud Rise flow characteristics in light of new bathymetric data. Assisting in Vampire operations (deSteur).

J. Morison, Cycling CTD: The YoYo CTD/LMP continued operating normally this week through the various Phase III drifts. As of Sept. 3 at 1200 we have made a total of 2478 profiles (through about 743 km of water column). On Tuesday, August 30, we took advantage of an opportunity to briefly study mixing in the vicinity of an iceberg we encountered during transit from drift 8 to drift 9. Icebergs are a potentially important source of fresh water and mechanical mixing in the Weddell Sea. Though our study was not exhaustive, as far as we know this was the first time such specialized instrumentation has been used to examine ocean mixing near an iceberg. The "Maudberg" was 200-300 m across and about 30m high. We first set the ship about 400 m upstream of the iceberg and profiled briefly with the YoYo system. We then made longer sequences of YoYo measurements downstream to one side and directly downstream of the iceberg. Additionally we made mid-depth turbulence measurements and used the ship's CTD rossette to obtain a deep profile and water samples for del O18 detection of meltwater at the downstream position. The iceberg geometry was mapped with radar observations and photographs. The pycnocline showed increased variability on the downstream sites and the site directly behind the berg showed a marked shoaling of the mixed layer. We have estimated the reduced gravity or interfacial internal wave speed near the Maudberg to be about 0.27m/s. The speed of the ice relative to the upper ocean as measured by the ship's ADCP was 0.17m/s near the end of the experiment. So the Maudberg was not traveling at the speed of interfacial gravity waves but probably was moving close enough to the critical speed to explain the observed large variations in mixed layer depth in terms of an internal wake. An iceberg moving at near the interfacial wave speed would experience substantial internal wave drag, the "dead water" effect. This may explain the observations that when the wind blows hard sea ice moves around icebergs, but with reduced wind speed, such as during our study, icebergs are towed along by the surrounding sea ice. The sea ice rubble heaps we observed on the "shore" of Maudberg were likely made when the ice drift was 0.5 m/s and Maudberg's drift was retarded by internal wave drag.

Guest, Meteorology (w/Powell): We continue rawinsonde and radiation measurements. We performed another low-level series of profile measurements using a kite. Analysis of previous kite flights shows this method can be successfully used to quantify sensible and latent heat fluxes from leads.

Goldberg, Notz: ASPECT observations will resume as we depart the ice in the next few days.

Padman, Muench: During the last week, Vampire operations from the fantail helo hut during Phase III Drifts 6-10 yielded ~280 microstructure profiles to a maximum depth of ~560 m. Drifts 6-9 provided many examples of the steppy pycnocline that appears to be correlated with low stability of the surface layer relative to the underlying deep water. Our previously expressed hypothesis, that the steps are a response to shear and nonlinear equation-of-state processes (primarily cabbeling), remains viable in light of the current weekís data. The just-completed Drift 10 yielded 51 profiles during a period of cold, calm conditions with a slightly more stable stratification due to a fresher surface layer. Active mixing was found throughout the surface layer, with several examples of upward diffusion of heat from the upper pycnocline into the lower mixed layer. We hypothesize that this mixing was associated with convection driven by local ice formation and associated brine rejection in the lead created by the ship. In previous drift stations the drift rate relative to the upper ocean was sufficiently rapid that measured mixed layer conditions were most likely a response more to under-ice processes upstream of the ship drift. During Drift 10 the negligible drift of the ship relative to the upper ocean suggests that local lead processes created the mixing and hydrographic states that we measured.

Acoustic backscatter from the hull-mounted ADCPs has helped with interpretation of the high-frequency variability in the pycnocline. It is clear that the signal includes a significant biological component - diel migrations centered around local midday are the dominant signal in backscatter records from all drift stations. Nevertheless, it appears that high frequency variability can be interpreted as pycnocline displacements, resolving time scales faster than either profiling system (yo-yo CTD and Vampire).

Miles McPhee, Chief Scientist

6.8 MaudNESS Weekly Science Summary # 8

11 Sep 05

We finished the final drift station Sunday evening a week ago, pulled the helo hut support bracket back aboard, moved the cycling CTD van to the helo deck, and were underway without much delay. On Monday, we did a deep CTD station near 63*S, 0 E, close to two previous stations. We transferred the forward deep frame winch back to the helo deck by moving it on to the ice with the forward crane, then easing the ship forward enough to pick it with the midship crane. All went smoothly. After it had become apparent from the Terrascan imagery that the SW and W winds of the previous week had moved the ice edge northward thus making our transit in the ice longer, we decided to forego a planned second deep CTD station. We did maintain a schedule of XBT drops at quarter degree (~15 nm) spacing on our NNW track out of the ice pack. We put good use of the time in the ice to pack, label, and secure the scientific gear, which was just as well since when we did exit the ice it was in the face of a 40 kt west wind with enough swell to ensure that the ship was a pretty quiet place on Friday. Yesterday and early today we have been fairly close to the northern ice edge, hence less fetch. We are making up time lost earlier, and will still be able to call at Grytviken, probably in the morning of 13 Sep. Today the wind has shifted to north at 35-40 kt, so we are getting a good roll, as opposed to the pitch that comes with the west wind.

A highlight of the ice egress was a gracious offer from Capt. Mike and 2nd mate Rachelle Pagtalunan to let scientists take the helm for short periods during the afternoon watch (under close supervision). So almost all of us now can tell our kids and grandkids that we steered the ship through the treacherous ice pack of the Weddell, with Titanic size icebergs on all sidesÖ(well, I suppose with time it will undergo some exaggeration). Regardless, we all appreciated the unique opportunity.

The long transit back to Punta Arenas is providing time for preliminary analysis and collation of the data gathered during MaudNESS. Below is a summary of the measurement activities since the end of Phase 3, Drift 11 a week ago.

Meteorology, (Guest w/Powell) The rawinsonde program was completed with a cross-ice edge survey. One more kite flight was performed this week and radiation measurements continue.

Goldberg, Notz: ASPECT observations halted on Thurs night as we left the pack ice.

Padman/Muench: After Phase III we headed north towards the ice edge, obtaining a transect of temperature with T-5 XBTs (max depth of 1830 m) at 1/4 degree spacing in latitude from 62.75 to 56 degrees S. The transect identified the approximate edge of the "cold regime" (cool T-max water at the northern edge of the Weddell Gyre) near 58.5 degrees S. Occasional anomalies in T_max suggest the presence of eddies or filaments associated with this front.

Miles McPhee, Chief Scientist

Appendix 1. Ship CTD list

Sta	NBP no.	Date	Time	Lat/Lon (dec)		Lat/Lon (deg/min)
1	p506001	02-Aug-2005	12:43:14	-63.236	0.010	S63 14.140’ E000 0.580’
2	p506002	02-Aug-2005	15:42:01	-63.373	0.292	S63 22.380’ E000 17.520’
3	p506003	02-Aug-2005	18:17:07	-63.488	0.559	S63 29.270’ E000 33.550’
4	p506004	02-Aug-2005	21:09:33	-63.611	0.816	S63 36.630’ E000 48.970’
5	p506005	02-Aug-2005	22:32:47	-63.670	0.919	S63 40.190’ E000 55.140’
6	p506006	03-Aug-2005	00:31:10	-63.736	1.103	S63 44.180’ E001 6.180’
7	p506007	03-Aug-2005	02:11:27	-63.801	1.229	S63 48.060’ E001 13.730’
8	p506008	03-Aug-2005	03:53:05	-63.862	1.369	S63 51.720’ E001 22.120’
9	p506009	03-Aug-2005	05:37:02	-63.927	1.539	S63 55.630’ E001 32.350’
10	p506010	03-Aug-2005	07:11:43	-63.981	1.659	S63 58.880’ E001 39.540’
11	p506011	03-Aug-2005	08:39:11	-64.043	1.780	S64 2.610’ E001 46.790’
12	p506012	03-Aug-2005	10:44:11	-64.112	1.945	S64 6.690’ E001 56.690’
13	p506013	03-Aug-2005	12:43:24	-64.171	2.088	S64 10.230’ E002 5.290’
14	p506014	03-Aug-2005	15:42:52	-64.229	2.222	S64 13.750’ E002 13.340’
15	p506015	03-Aug-2005	19:26:32	-64.362	2.521	S64 21.700’ E002 31.250’
16	p506016	03-Aug-2005	21:47:54	-64.470	2.802	S64 28.190’ E002 48.140’
17	p506017	04-Aug-2005	00:35:05	-64.596	3.104	S64 35.760’ E003 6.260’
18	p506018	04-Aug-2005	03:04:50	-64.709	3.401	S64 42.540’ E003 24.050’
19	p506019	04-Aug-2005	05:59:45	-64.835	3.693	S64 50.120’ E003 41.570’
20	p506020	04-Aug-2005	09:10:20	-64.959	4.016	S64 57.530’ E004 0.950’
21	p506021	04-Aug-2005	11:00:49	-65.014	4.162	S65 0.830’ E004 9.690’
22	p506022	04-Aug-2005	16:08:58	-65.064	4.332	S65 3.840’ E004 19.930’
23	p506023	04-Aug-2005	18:05:36	-65.130	4.486	S65 7.780’ E004 29.180’
24	p506024	04-Aug-2005	20:08:54	-65.184	4.643	S65 11.020’ E004 38.600’
25	p506025	04-Aug-2005	22:19:02	-65.240	4.802	S65 14.400’ E004 48.100’
26	p506026	05-Aug-2005	01:38:58	-65.352	5.127	S65 21.100’ E005 7.630’
27	p506027	05-Aug-2005	04:32:37	-65.202	5.274	S65 12.120’ E005 16.450’
28	p506028	05-Aug-2005	07:04:24	-65.041	5.429	S65 2.460’ E005 25.740’
29	p506029	05-Aug-2005	09:05:08	-64.959	5.525	S64 57.520’ E005 31.520’
30	p506030	05-Aug-2005	12:29:38	-64.876	5.586	S64 52.570’ E005 35.150’
31	p506031	05-Aug-2005	15:43:52	-64.782	5.693	S64 46.930’ E005 41.560’
32	p506032	05-Aug-2005	17:39:41	-64.705	5.755	S64 42.300’ E005 45.270’
33	p506033	05-Aug-2005	19:36:58	-64.625	5.814	S64 37.500’ E005 48.830’
34	p506034	05-Aug-2005	22:34:22	-64.551	5.908	S64 33.080’ E005 54.500’
35	p506035	06-Aug-2005	00:36:16	-64.466	6.005	S64 27.940’ E006 0.280’
36	p506036	06-Aug-2005	03:28:51	-64.305	6.118	S64 18.270’ E006 7.100’

37	p506037	06-Aug-2005 07:28:53	-64.339	5.746	S64 20.350’	E005 44.750’
38	p506038	06-Aug-2005 10:25:23	-64.380	5.366	S64 22.820’	E005 21.970’
39	p506039	06-Aug-2005 12:36:25	-64.404	5.131	S64 24.230’	E005 7.850’
40	p506040	06-Aug-2005 15:06:45	-64.427	4.962	S64 25.630’	E004 57.690’
41	p506041	06-Aug-2005 17:18:59	-64.440	4.770	S64 26.400’	E004 46.220’
42	p506042	06-Aug-2005 19:51:24	-64.461	4.587	S64 27.640’	E004 35.240’
43	p506043	06-Aug-2005 23:36:51	-64.506	4.158	S64 30.380’	E004 9.460’
44	p506044	07-Aug-2005 02:18:26	-64.345	4.305	S64 20.720’	E004 18.320’
45	p506045	07-Aug-2005 05:26:52	-64.180	4.462	S64 10.790’	E004 27.740’
46	p506046	07-Aug-2005 07:30:52	-64.098	4.564	S64 5.880’	E004 33.870’
47	p506047	07-Aug-2005 10:03:32	-64.012	4.619	S64 0.720’	E004 37.110’
48	p506048	07-Aug-2005 12:41:00	-63.936	4.683	S63 56.180’	E004 40.960’
49	p506049	07-Aug-2005 14:21:10	-63.857	4.758	S63 51.400’	E004 45.470’
50	p506050	07-Aug-2005 16:23:01	-63.778	4.853	S63 46.680’	E004 51.190’
51	p506051	07-Aug-2005 18:25:42	-63.694	4.920	S63 41.630’	E004 55.190’
52	p506052	07-Aug-2005 20:58:58	-63.695	4.497	S63 41.700’	E004 29.830’
53	eliminated					
54	p506054	07-Aug-2005 23:35:02	-63.696	4.067	S63 41.740’	E004 4.020’
55	p506055	08-Aug-2005 02:07:37	-63.780	3.976	S63 46.800’	E003 58.550’
56	p506056	08-Aug-2005 03:58:36	-63.850	3.908	S63 51.030’	E003 54.450’
57	p506057	08-Aug-2005 06:17:12	-63.924	3.816	S63 55.440’	E003 48.950’
58	p506058	08-Aug-2005 08:15:00	-63.998	3.730	S63 59.890’	E003 43.810’
59	p506059	08-Aug-2005 10:14:46	-64.102	3.625	S64 6.110’	E003 37.500’
60	p506060	08-Aug-2005 15:09:29	-64.177	3.584	S64 10.610’	E003 35.030’
61	p506061	08-Aug-2005 17:21:48	-64.248	3.460	S64 14.890’	E003 27.570’
62	p506062	08-Aug-2005 19:18:29	-64.322	3.382	S64 19.290’	E003 22.950’
63	p506063	08-Aug-2005 22:21:46	-64.483	3.229	S64 28.970’	E003 13.740’
64	p506064	09-Aug-2005 01:48:55	-64.641	3.077	S64 38.470’	E003 4.630’
65	p506065	09-Aug-2005 05:09:28	-64.800	2.880	S64 48.010’	E002 52.790’
66	p506066	09-Aug-2005 08:19:54	-64.957	2.688	S64 57.390’	E002 41.290’
67	p506067	11-Aug-2005 20:34:48	-64.469	2.808	S64 28.170’	E002 48.470’
68	p506068	11-Aug-2005 23:57:40	-64.495	2.263	S64 29.690’	E002 15.760’
69	p506069	12-Aug-2005 02:24:14	-64.526	1.927	S64 31.590’	E001 55.610’
70	p506070	12-Aug-2005 05:42:29	-64.569	1.474	S64 34.160’	E001 28.460’
71	p506071	12-Aug-2005 07:51:37	-64.588	1.244	S64 35.310’	E001 14.650’
72	p506072	12-Aug-2005 09:43:16	-64.597	1.044	S64 35.820’	E001 2.640’
73	p506073	12-Aug-2005 11:24:08	-64.618	0.862	S64 37.100’	E000 51.740’
74	p506074	17-Aug-2005 02:23:19	-64.623	0.856	S64 37.370’	E000 51.350’

75	p506075	17-Aug-2005 04:38:06	-64.681	0.729	S64 40.880’	E000 43.750’
76	p506076	17-Aug-2005 06:52:59	-64.754	0.612	S64 45.230’	E000 36.740’
77	p506077	17-Aug-2005 08:55:07	-64.822	0.475	S64 49.290’	E000 28.500’
78	p506078	17-Aug-2005 11:17:56	-64.897	0.344	S64 53.820’	E000 20.630’
79	p506079	17-Aug-2005 13:27:14	-64.972	0.224	S64 58.350’	E000 13.450’
80	p506080	17-Aug-2005 16:29:36	-65.104	-0.048	S65 6.240’	W000 2.860’
81	p506081	17-Aug-2005 19:38:31	-65.233	-0.311	S65 13.990’	W000 18.640’
82	p506082	17-Aug-2005 22:36:36	-65.371	-0.568	S65 22.280’	W000 34.090’
83	p506083	18-Aug-2005 01:29:19	-65.510	-0.847	S65 30.580’	W000 50.790’
84	p506084	18-Aug-2005 21:06:29	-65.479	-0.381	S65 28.720’	W000 22.840’
85	p506085	18-Aug-2005 23:16:36	-65.482	-0.166	S65 28.940’	W000 9.970’
86	p506086	19-Aug-2005 01:03:21	-65.483	0.022	S65 28.990’	E000 1.340’
87	p506087	19-Aug-2005 03:01:36	-65.522	0.269	S65 31.290’	E000 16.150’
88	p506088	19-Aug-2005 05:06:57	-65.501	0.462	S65 30.060’	E000 27.740’
89	p506089	19-Aug-2005 07:13:55	-65.510	0.662	S65 30.570’	E000 39.710’
90	p506090	19-Aug-2005 09:24:48	-65.507	0.879	S65 30.430’	E000 52.750’
91	p506091	19-Aug-2005 11:37:26	-65.518	1.117	S65 31.090’	E001 7.040’
92	p506092	21-Aug-2005 16:07:37	-65.515	1.312	S65 30.890’	E001 18.730’
93	p506093	21-Aug-2005 18:37:53	-65.450	1.381	S65 27.010’	E001 22.840’
94	p506094	21-Aug-2005 21:21:34	-65.355	1.523	S65 21.310’	E001 31.410’
95	p506095	21-Aug-2005 23:02:26	-65.356	1.734	S65 21.370’	E001 44.030’
96	p506096	22-Aug-2005 01:08:26	-65.352	1.966	S65 21.130’	E001 57.960’
97	p506097	22-Aug-2005 04:41:27	-65.557	1.928	S65 33.430’	E001 55.660’
98	p506098	22-Aug-2005 07:55:45	-65.763	1.910	S65 45.810’	E001 54.590’
99	p506099	22-Aug-2005 10:12:43	-65.758	1.653	S65 45.490’	E001 39.190’
100	p506100	22-Aug-2005 11:59:26	-65.765	1.428	S65 45.880’	E001 25.690’
101	p506101	22-Aug-2005 14:25:04	-65.760	1.199	S65 45.600’	E001 11.960’
102	p506102	22-Aug-2005 16:07:10	-65.760	1.018	S65 45.580’	E001 1.090’
103	p506103	22-Aug-2005 18:29:50	-65.663	0.747	S65 39.810’	E000 44.830’
104	p506104	26-Aug-2005 19:31:08	-65.761	1.022	S65 45.690’	E001 1.310’
105	p506105	30-Aug-2005 18:12:15	-65.730	1.524	S65 43.780’	E001 31.440’
106	p506106	05-Sep-2005 09:20:54	-62.974	-0.083	S62 58.430’	W000 4.950’

Appendix 2. Moonpool Discussion and Recommendations

Two important operational concerns we had with regard to sampling with multiple instruments during the Phase 3 drifts were how to deploy the instruments rapidly for sustained operation and how to keep 4 instrument lines, all deployed within tens of meters of each other, from tangling. A major part of our solution for the first problem was the utilization of the ships moonpool for an automated yoyo CTD/microstructure instrument. The existing 2-m moonpool on the main deck was equipped with a 1-m diameter sleeve that Raytheon built for us. They also provided a special 20’ cargo container turned science van equipped with a 1-ton traveling hoist, hatch in the floor, entrance door, and electrical power. They also constructed a moonpool “plunger” from steel stock and two railroad wheels. In operation, this “moonpool van” also contained our yoyo CTD winch and instruments. It was positioned during ice operations over the moonpool. On arrival at a drift station, the Raytheon technicians removed the moonpool cover and stowed it against the wall of the van. They then lowered the plunger through the moonpool with the hoist to remove the ice that collected there during transit. Depending on the degree to which ice jammed in the moonpool, vigorous flushing of the outside of the ship with the main engines was used to help clear ice debris from the moonpool mouth. Once final ship positioning was complete, the remaining ice chuks were removed with nets, then heated seawater was piped into the moonpool to melt small pieces of ice and slush. This operation was generally completed in less than one hour, the time depending on the amount of jamming encountered and time for ship positioning. Once moonpool clearing was complete, the science party would rig a separate block from the gantry frame and deploy the CTD with attached microstructure unit through the moonpool and begin automatic operation of the winch. Cable chafing at the bottom of the moonpool was prevented with a Delrin collar placed over the winch wire and held firmly against the lip at the bottom of the moonpool by means of a grapnel and tension line arrangement. Data from the CTD/microstructure package, winch control information, and a web camera view of the winch was transmitted to the forward dry lab space via the ship’s Ethernet as described below.

The second operational concern, instrument tangling, was addressed with a near real time simulation of the motion of each of 4 instruments operated from the ship. These were, from fore to aft on the starboard side, the deep turbulence frame operated from the foredeck, mid-depth turbulence frame deployed from the Baltic room, yoyo CTD operated from the moonpool, and VMP loose-tethered microstructure instrument deployed from a special hut hanging over the back of the fantail. The cable simulation program consisted of dynamic cable models for the three-dimensional path of each instrument for several depth cycles, e.g. typically 20-40 minutes of yoyo CTD operation time. The models for the frames and yoyo CTD assume tension at the cable end is always applied by the instrument. The VMP model allows the instrument to move with the ocean velocity on downcast without tension on the top of the cable and be retrieved under cable tension on upcast. (This difference in operation was probably the primary cause for worry about tangling.) The simulations ran at faster than real time with input data updated every 5 minutes so that characteristic instrument behavior under present conditions could be assessed by watch-standers. Input data included ship's drift and orientation data and ADCP derived water velocity taken in real time off the ships servers. During periods when the Trackpoint acoustic tracking system was being used to track Lagrangian floats, float range and bearing was also assimilated by the cable program. The cable information was presented with ship orientation in a 3-view illustration along with a fourth panel for ship's drift and Lagrangian float position in a simple moving map depiction. The display was carried on one channel of the ship's video system so that watch-standers could remain aware of potential cable conflicts. Our experience was that cable tangling was not a problem if the ship was oriented with wind from 20 degrees forward to 30 degrees aft of abeam on the starboard side, particularly if winds and ice motion were reasonably high. Thus the ultimate key to success in this area was proper (and sometimes repeated) ship positioning.

Appendix 3: Timeline

2005 21 Jul	Leave Punta Arenas
30 Jul	Ice edge, begin ASPECT observations
2 Aug	Begin Phase 1 Survey Sta 1-5
3 Aug	P1 Stations 6-16; Ice/Ocean Buoy ID 7; RAFOS 267, 694, 695, Lagr 31
4 Aug	P1 Stations 17-25; I/O Buoy ID 5; RAFOS 696, 697
5 Aug	P1 Sta 26-34; RAFOS 698; Lagr 30
6 Aug	P1 Sta 35-43; RAFOS 699;
7 Aug	P1 Sta 44-54; RAFOS 700; Lagr 32
8 Aug	P1 Sta 55-63; I/O Buoy ID 6; RAFOS 701-703; Lagr 34
9 Aug	P1 Sta 64-66; RAFOS 704-705; Start Phase 2, Drift 1
11 Aug	End P2D1, resume P1 Sta 67-68
12 Aug	P1 Sta 69-73; Start Phase 2 Drift 2
16 Aug	End P2D2
17 Aug	Resume P1 Sta 74-82
18 Aug	P1 Sta 83-85, “dry run, Phase 3”
19 Aug	P1 Sta 86-91, Lagr. 29w/trans; Start Phase 3, Drift 1
20 Aug	End P3D1, start P3D2; contact Lagr 29
21 Aug	End P3D2, resume P1 Sta 92-95
22 Aug	P1 Sta 96-103, Start P3D3
23 Aug	End P3D3, Lagr. 33 w/trans; start P3D4
24 Aug	End P3D4
25 Aug	Start P3D5
26 Aug	End P3D5, resume P1 Sta 104
27 Aug	Start P3D6, end P3D6, Start P3D7
28 Aug	End P3D7, start P3D8
30 Aug	End P3D8, MaudBerg, P1 (ship) Sta 105 (iceberg)
31 Aug	Start P3D9, end P3D9, begin transit north
1 Sep	Start P3D10
3 Sep	End P3D10, transit north, start P3D11
4 Sep	End P3D11, end Phase 3, Begin ice egress
5 Sep	Deep station Sta 106
7Sep	End ASPECT observations
8 Sep	exit ice

MAUDNESS SAFETY AND OPERATIONS
By John Evans
17 Sep 2005

INTRODUCTION

A strong emphasis on safety was maintained throughout the MaudNESS project. As discussed below, a number of factors contributed to this safety emphasis, and although there is no reliable way to assess the impact of any specific factor, the fact remains that this complex project was completed with no accidents or injuries. Reassuring as this may be, it would be naïve to deny the important role of good luck in this, without which the safety record could easily have been less favorable.

This document will attempt to describe the overall approach to safety as well as the particular safety considerations for various MaudNESS operations. No attempt is made to describe non-safety-related operational details or the many vital aspects of the MaudNESS project that have little direct safety implications, such as bathymetry and data logging, network support, shipboard ASPECT ice observations, and modeling. The purpose of this report is not only to document the safety aspects of the 2005 MaudNESS project but also to provide information that may be of use for future projects.

Since the 1994 ANZFLUX project served as a model for MaudNESS in essentially all significant respects, it also was used as the basis for the approach to MaudNESS safety management and operations--particularly with regard to the extensive off-ship work during the MaudNESS Phase II Drift Station.

BACKGROUND: THE ANZFLUX CONNECTION

The similarities between the MaudNESS and ANZFLUX projects are obvious: both took place at essentially the same season and location (July-September in the Eastern Weddell Sea), and both involved preliminary CTD transects en route to establishing "Drift Stations" from which floes of sea ice were used as platforms through which various experiments were conducted. The suites of experiments were similar, as was the team of scientists, including Chief Scientist Miles McPhee and six other returning ANZFLUX scientists, Peter Guest, Jamie Morison, Robin Muench, Laurie Padman, Jim Stockel, and Tim Stanton. Edison Chouest officer continuity was vested in Captain Mike Watson and Mate Jay Bouzigard, who had sailed on ANZFLUX as Second Officer and AB respectively. Contractor continuity was vested solely in John Evans, who assumed a similar role in the development and organization of safety procedures for both projects.

For all Drift Stations the Nathaniel B. Palmer was moored to a floe of sea ice some 50 cm in thickness. By way of contrast, ANZFLUX entailed two 4-5-day Drift Stations with several manned "remote" temporary structures while MaudNESS involved a single Drift Station of the same duration and with only a single continuously-occupied "remote" structure-- the "helo hut" which housed the Vertical Microstructure Profiler (aka "vampire"); this was situated 300yards from the ship and was monitored round the clock. Other obvious differences from ANZFLUX included the extensive on-ship “Phase III mini drift” work and the more comprehensive program of buoy deployments, kite-borne meteorology data gathering, and modeling of MaudNESS. (As the modeling had no direct safety implications it is not discussed here.)

In further contrast to ANZFLUX was the complete lack of instances of either hampered visibility or strong wind events during the MaudNESS drift (although it should be noted that a single extreme wind event with wind speeds of 70 knots occurred during MaudNESS Phase I). Other unanticipated differences that appeared in MaudNESS included far lower temperatures--very often below -20°C-- and several instances of leads opening in the near vicinity of the drift camp. In hindsight, safety planning would have benefited from a better appreciation of the likelihood of these very low temperatures and the frequent openings of leads.

SAFETY PLANNING AND MANAGEMENT

As with ANZFLUX, a substantial part of the safety approach involved issues of how best to communicate current procedures and conditions to all parties--especially when people were standing 12-hour watches. A somewhat lesser issue was the balance of trying to keep safety at an appropriately state of awareness without seeming to micro-manage a constituency of highly trained professionals. These issues ultimately were addressed more or less successfully through the efforts of Miles McPhee, John Evans, and MPC Karl Newyear by a combination of e-mail, word of mouth, the white notice boards, and “ScienceWatch”.

Specific safety-related planning began in May with pre-cruise telephone conversations involving various combinations of Miles McPhee, Karl Newyear, Mike Watson, and John Evans. Per these conversations Evans drafted a document “Off-Ship Safety Considerations for the Maudness Project”, modeled after a similar document which had been sanctioned by NSF as a guiding document for ANZFLUX. This document was weighted toward safety management and procedures for decision making rather than toward operational details, on the assumption that the latter could best be designed in consultation with the highly experienced personnel during the cruise. NSF input was not solicited for the MaudNESS document.

In particular this document called for the establishment of a 4-person “Executive Committee”, which would have the authority and oversight responsibility for all safety-related aspects of sea ice operations. This committee consisted of Chief Scientist Miles McPhee, Captain Mike Watson, MPC Karl Newyear, and John Evans.

Among other provisions of this initial document were a “Staged Readiness Schedule”, which stipulated guidelines for off-ship travel under specified weather and visibility conditions, and the establishment of “ScienceWatch”-- a system of round-the-clock monitoring of off-ship personnel movements. This document further identified the following as anticipated potential hazards:

- Industrial Hazard such as hot or cold burns from equipment or chemicals, crush injury, cuts and abrasions.
- Exposure (hypothermia/frostbite)
- Accidental immersion (hypothermia/cold water near drowning)
- Drift-camp Breakup
- Wildlife hazard

The last of these related solely to the presumed possible presence of leopard seals and was assumed to be a very low risk. As there were no sightings of leopard seals this is not discussed further. The other risk categories were present fairly routinely, and were managed routinely by appropriate combinations of good practices and judgment and protective clothing and equipment. As described below, to this list might well have been added as a separate category the risk of personnel being separated from the ship by a rapidly-opening lead.

This document was distributed in advance to all PI's prior to the cruise, and followed up by further documentation as listed below. All procedures were discussed at various meetings, and Evans also had a brief meeting with the two EMTs to discuss and make preparations for fast response to cold injury and cold-immersion incidents.

GENERAL SEQUENCE AND PHASE II DRIFT STATION LAYOUT

Phase I included a transect of CTD casts and several buoy deployments. These are discussed briefly in a subsequent section.

Phase II began with the selection of a suitable floe for the Drift Station, starting with a visual observation and assessment from the bridge, followed by a walking reconnaissance / evaluation by McPhee, Morison, and Evans. This evaluation included probing the floe surface, drilling to ascertain thickness, and sometimes cutting a hydro hole.

Following floe selection, the moonpool was flushed, the gangway lowered, and the ship secured by toggles of 4-foot pipe off the port and starboard bow. The ECO crew and RPSC Marine Technicians placed the toggles and secured the ship's lines, using the skidoo to haul the mooring lines into place. As this was being done, the other hydro holes were started and the offload and setup begun. Each installation was secured to four toggles made out of 2-foot pieces of two-by-four with a tie loop of rope. The met tower was based on a 3-foot piece of plywood secured by ice screws.

The shallow turbulence mast, the met tower, and the helo hut constituted the "remote" installations at around 300 meters from the ship; the latter two of these shared power from a common generator. The deep turbulence mast was deployed from the bow of the ship, and the midlevel mast through a hydro hole some 60 meters from the ship. Ice studies were conducted on a nearby grid as well as along lines through the camp, and kite-borne rawinsonde instruments were flown just outside the main camp area.

The final ice buoy was deployed off the port side of the ship, and very soon after the return of the ice buoy team a lead opened very rapidly between the buoy installation and the ship. Had this lead opened before the team had returned, a complex and difficult rescue operation would likely have been required. (See below.)

Phase II was interrupted by the opening of a lead system just outside the remote sites just after dark on August 16. All remote installations were recovered within two hours and without incident. The shallow mast was left in place as it was considered to still be safe, and in fact the helo hut with the vampire was redeployed the following evening through a new hydro hole nearby.

Early on August 18 a decision was made to shift into Phase III mode. All off-ship installations were recovered and a "dry run" of Phase III operations begun.

Phase III operations ultimately entailed eleven separate "mini-drifts", for which instruments were deployed from the ship while it was held against drifting ice by a combination of wind, sea currents, and the ship's thrusters. These drifts were of several hours to a day and a half in duration, limited sometimes by science requirements and sometimes by the inability of the ship to hold position--the latter made more severe by the loss of one of the ship's two thrusters.

For most of the eleven Phase III "mini-drifts" there were five different instruments in the water simultaneously, introducing issues of monitoring watch circles. Fortunately, watch circles could be monitored remotely from the forward dry lab by grantees, who also made frequent physical inspections of the various systems. These operations were further overseen by the RPSC marine staff, augmented by a variation of the Phase II ScienceWatch system in which hourly physical inspections were made of all operating systems. This ScienceWatch also provided an early warning of encroaching ice and the watchstanders frequently were able to clear ice with a boathook.

Phase III came to a close late on September 4 as scheduled, except for some CTD casts and XBT launches planned for the transit to the ice edge. By midnight on September 4 all instruments had been recovered and secured, and the moon pool van and helo hut moved to the 02 deck and secured. The winch for the deep mast was moved the following day, first to the ice by the bow crane and then--after repositioning the ship--to the back deck with the midship crane.

SAFETY COMMENTS RE SPECIFIC MAUDNESS OPERATIONS

- <u>Routine shipboard CTD casts and XBT launches.</u> These were carried out in Phases I and III by RPSC marine staff using established procedures. No safety concerns or incidents.

- <u>Shipboard weather balloon launches.</u> These were carried out from the helo deck twice daily during all Phases by P.I. Peter Guest in close communication with the bridge. No safety concerns or incidents.

- <u>RAFOS buoy deployments.</u> Thirteen of these were done during Phase I by Mike Ohmart with the assistance of the RPSC Marine Technicians. No safety concerns or incidents.

- <u>Ocean flux buoy (aka "ice buoy") deployments.</u> Per plan, three ice buoys were deployed during Phase I and the fourth on the final day of Phase II. All were done by P.I. Tim Stanton and one or more of his team, with John Evans providing assistance for all except the Phase II deployment. Each 200-pound buoy required a 10" hole plus a separate smaller hole for a thermistor string. All ice buoy deployments were accompanied by a small ice survey done by Dirk Notz and Dan Goldberg, in which ice cores were taken and thicknesses and freeboard measured over a small grid.

Personnel and coring gear were moved to the ice in the personnel basket by the midship crane, to be followed by the buoy on a Nansen sled. All these Phase I operations were done within about 30 meters of the ship off the starboard quarter. There were no safety incidents or concerns, despite the fact that they were carried out under extreme weather conditions--the initial operation during windchill conditions below -50°C.

The Phase II deployment was done about a hundred yards off the bow on the port side, using the skidoo and Nansen to pull the buoy and equipment into position. Although there were no incidents or safety concerns, the fact remains that there was no provision for access back to the ship from the port side. Therefore any operation--or even any travel--on the port side of the ship had the added risk of increased difficulty of rescue.

- Back deck operations. Standard back deck operations without exception were well managed by the RPSC Marine Technicians with ECO crew operating cranes. There were no safety concerns or incidents, although it should be noted that the elaborate breakdown for transit at the conclusion of Phase operations was done under windchill conditions of below -50°C.

  Many non-standard back deck operations were required while the ship was moored to the ice during Phase III, including several buoy deployments, multiple deployments and recoveries of the midlevel mast, track point transducer and vampire, frequent checking of the moon pool van with its continuously cycling CTD, and frequent manual clearing of ice by boat hook from the midlevel mast and the vampire. Most of these operations required some combination of hard hats, personal harnesses and safety lines. There were no safety incidents or concerns other the fact that some instances were noted of the lines being not adjusted to the proper length.

  Despite the efforts of the Marine Technicians, float coat requirements were not consistently followed by grantees making a quick trip to check the moon pool van. Because this was done only when the ship was moored this was at most of procedural rather than safety concern.

- Routine on-ice travel. Once a network of paths had been established within a clear view of the ship, the risks of cold or cold immersion during routine travel to and from the ship seemed very small and quite manageable, entailing little more than proper clothing (including flotation) and communication with ScienceWatch. Because of the small distances involved (a maximum of 300 yards from the ship to the helo hut) and the assumed very low risk, the initial prohibition against solo travel was dropped for travel within the camp area and during periods of good visibility and low wind. With these stipulations, no differentiation was made between mission-related and recreational travel such as for photography.

  There was a small amount of ski travel, which seems to have neither more nor less inherent risk, although this might lead to a temptation to travel informally beyond the camp perimeter.

Although there were no specific incidents, the fact remains that on-ice travel, whether solo or accompanied, entails a degree of risk of personnel becoming separated from the ship by a rapidly-opening lead. Until the final day of the Phase II Drift, each of the several leads that opened nearby widened quite gradually, a fact that led to a general lack of concern about rapidly-opening leads. (More on this below.)

- Non-routine on-ice travel. Any travel either outside of the camp area or under conditions of high wind or poor visibility was considered non-routine, and required both a minimum of two people and explicit clearing of plans with Science Watch. Although the 2-person rule was not consistently followed, no real incidents resulted.

- Hydro holes. Five separate hydro holes were cut for Phase II and a couple others during the search for a suitable floe. With due care the cutting and clearing involved little risk and each completed hole was partially blocked or marked to guard against accidentally falling in. Although the risks associated with cutting and working around hydro holes can be readily managed by a combination of hole covers, safety lines, and very basic attentiveness, it must be remembered that because of the rapid differential movement between the ice and the underlying water, a person falling into a hydro hole would require near-instant extrication not to be swept under the ice.

- Met Kite flights. These were done by P.I. Peter Guest with the assistance of Brian Powell and sometimes others. Basic diligence was required--especially when a flight over the ice / open water boundary placed people very close to the edge of the lead. But there were no safety concerns or incidents, and in fact there were no indications that lead edges are particularly unstable.

- Lagrangian buoys, aka “MLFs” (Mixed Layer Floats). Six of these were deployed by Mike Ohmart with the assistance of the RPSC Marine Technicians. These were done at each phase, at locations based on water column criteria. No safety concerns or incidents.

- Positioning of the winch for the deep turbulence mast. Because the winch for the deep mast was too cumbersome to move manually to its required location on the foredeck, it was necessary to move it forward off the ship. Two options were considered, one using a Zodiac in open water, and the other using a floe of ice. After achieving a high degree of confidence that the ship could be repositioned along an ice floe gently enough not to cause cracking, the latter option was selected. This entailed first easing the ship into a floe and holding position while RPSC Marine Technicians and the winch were offloaded by the midship crane. Then the ship was eased back until the winch could be lifted by the bow crane, and finally the ship eased forward again so that the personnel could be picked up by the midship crane. This operation was done as planned and without incident, and was subsequently reversed in the same manner at the end of Phase III.

- Phase II Turbulence masts (deep, midlevel, and shallow). All three of these were deployed during Phase II, for which the midlevel and shallow masts were connected by power and data cords to the ship and deployed through hydro holes using a winch system--all of which covered by a small “outhouse” shelter. The deep mast--some 30 feet in length--was deployed through a hydro hole from the ship, using the bow crane.

None of these led to safety incidents or concerns, although it should be noted that a quick-connect system for power and data cords near the ship's rail would be useful if a rapid recovery were necessary.

- Phase III Turbulence masts (deep and mid-level). For all eleven of the Phase III "mini-drifts" the shallow mast was not deployed, and the deep and midlevel masts were deployed through holes made by the ship as part of its positioning operation The deep mast wire was kept ice-free by means of a large shackle belayed by a hand line and dropped around the wire. A specially-made rack allowed the mast to be suspended vertically and intact in the ship's foreward deck and galley stores between Phase III drifts.

  For this phase, the midlevel mast was deployed from the Baltic room, using the ship's CTD boom and a grantee-provided winch. Deployment entailed manually using the CTD winch wire to pull the block aside in order for the Baltic room door to open and close. In one instance this manual pulling dislodged the wire from position in the block, resulting in damage to the wire and requiring it to be reterminated.

  Both the deep and the mid-level masts were so long that the lowest portion of each needed to be manually lifted during each deployment and re-deployment--the deep mast to clear the railing at the bow and the mid-level mast to clear the Baltic room door. None of this involved safety concerns except indirectly in manually keeping ice clear from the Baltic room wire.

- The moon pool / continuously cycling CTD. At each new location, moon pool operations required initially plunging the moon pool to clear it from ice. This entailed moving a 1 ton weight by hoist and chain in very close quarters between the hole and the deck, and with a hoist that appeared marginal for the load. Once the continuous cycling began, it still was necessary to check the pool frequently for ice. For both initial and continuous operations, people often were working in close confinement and very close to a heavy weight, a revolving drum, and an open hole. Although there were no incidents, this combination of course demanded care and diligence.

- The Vertical Microstructure Profiler, aka "vampire". Deployment and redeployment of the vampire required a minimum of four people and entailed the combination of a substantial electric winch and a 60-lb torpedo-shaped instrument with very delicate instruments on one end and a 2-foot diameter fan of brushes on the other--all deployed through a hydro hole within the very restricted confines of the helo hut. These operations entailed two people working directly over the hole, requiring safety belts and leashes. Routine cycling could be done by a single person, but two became the norm for operational considerations as well as safety.

  A similar configuration was used for Phase III as Phase II, but for Phase III the helo hut was cantilevered over the fantail on a specially-designed steel rack. After the fact the obvious observation was made that the ad hoc fence separating the ingress to the hut door from the open water below was very flimsy. No incidents occurred, but this should have been noted and beefed up at the start.

The PI also reported a slight electric shock from an unidentified source while checking out the vampire system on the helo deck.

- Toggling / releasing the ship. The ship was toggled only a single time--this at the Phase II location. As mentioned above, ECO crew and RPSC marine staff placed pipe toggles off the port and starboard bow, using the skidoo to pull the ship's lines into place. At the conclusion of Phase II the toggles were released by cutting the chains with bolt cutters. Although eminently workable and with little risk, this system would benefit from a quick-release capability of some kind.

SUMMARY AND CONCLUSIONS

As described above, concerted efforts were made to address safety at an appropriate level throughout the MaudNESS project. The various safety and operational stipulations and procedures were presented to all RPSC and grantee personnel, discussed, and sometimes revised. Despite a few rather minor instances of non-compliance there was never any indication of resistance, and the project was completed with no significant accidents, illnesses, or near-miss incidents.

A specific few items warrant particular mention:

Despite concerted efforts to do so, we never were able to predict floe longevity or the opening of leads. (The same could be said for ridging events, of course--but these were never a factor.) As mentioned above, our initial experience with slowly-opening leads lulled us into ignoring the fact that leads may open quite abruptly. This was brought home late in Phase II when a lead opened very quickly off the port side of the ship shortly after the return from that side of the ice buoy deployment team. Had it opened while they (and our only ski-doo) were on the other side, their rescue would have been quite difficult-- probably entailing manually putting a Zodiac on the one remaining Nansen and manhauling it around the also-breaking-up floe at the bow of the ship.

Two take-home messages from this appear:

1. Unless portside access to the ship has been put in place, activities and travel to port should be considered "Non-standard" and treated as such--meaning preceded by detailed and safety considerations.

2. We were not well-prepared for recovery across water. The Zodiac staged at the Phase II helo hut was arguably sufficient, but at best marginal and quite cumbersome. Further thought needs to be given to how to effect a recovery across an open lead.

Among the many things done right, the following warrant additional comment:

The “Executive Committee”. Although this didn’t meet as a body after the initial days of the cruise, it was essential to have a fail-safe system to interface between the operational and safety perspectives of the ship, the grantee community, and the support contractor. For projects having only routine operations this interface can generally be done without the need for a formal committee, but this is not the case when there are requirements such as for MaudNESS in which there is so great a need to deal with extensive non-routine operations.

ScienceWatch/Walkabout. Although not called upon for any emergency communication during MaudNESS, ScienceWatch provides an essential centralized communications system. Similarly the Walkabout routine seems a useful early warning system for activity at the perimeter of the floe. The Phase II ScienceWatch also was able to perform a useful degree of clearing ice from wires and the vampire hole. In contrast to ANZFLUX, all these duties were done by RPSC during MaudNESS, but this was solely a matter of manpower availability.

The ECO connection. It would be hard to overstate the contribution of the ECO staff--not only in their individual and collective contribution to MaudNESS safety, but also in supporting the cruise in every way and the research in particular. Not least of these contributions was the business of maintaining and finely-adjusting the position of the ship against ice floes of varying stability, under varying conditions of wind and sea currents, and often with five separate instruments in the water. This project threw many challenges their way, and had they not risen to meet each one the MaudNESS story would certainly have had a far less satisfactory ending.

************** END *********************

Relevant (?) Documentation

Off-Ship Safety Considerations for the MaudNESS Project (01 July)
MaudNESS Phase II—Drift Station Sequence of Events (24 July)
Idiot’s Guide to MaudNESS Buoys (30 July)
MaudNESS Safety Procedures for Phase II Drift Station (Revised August 08)
MaudNESS PHase II Drift Station Setup (August 08)
MaudNESS ScienceWatch Watchstander Cheatsheet (Undated)