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CTD Data Quality on Discovery Cruise D242

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ABSTRACT
Two separate problems were encountered with the CTD data collected on Discovery Cruise D242 in autumn 1999; the data were unusually noisy in salinity, and the data from SOC CTD DEEP04 showed salinity hysteresis (upcast values differing from the downcast values). The salinity spikes were the result of the temperature and conductivity sensors measuring slightly different water in small vortices shed by a horizontal flat bar on the CTD rosette frame. The well-mixed, less noisy, up-cast data offer the best data set for CTD stations during D242 and other cruises exhibiting the same spike problem. Removing a section of the horizontal flat bar close to the CTD sensors eliminated the problem on D245. Future frame design and modification should be carried out with more attention to the impact of water flowing through and around the instruments, so that the CTD sensors sample the least disturbed water. Data from CTD DEEP04 were examined to try to determine the cause of the salinity hysteresis. Examples from other datasets are shown to assess the extent of the problem. The source of the problem is not yet identified, but is not thought to be the conductivity cells, or the pressure sensor. It is recommended that DEEP04 should not be used for high quality sections (WOCE one-time survey quality).

KEYWORDS
CTD; DATA QUALITY; CRUISE D242 1999, DEEP04, DISCOVERY

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1. Introduction

High quality data from CTD (Conductivity-Temperature-Depth) instruments are critical to the work of physical oceanographers at SOC. Much time and effort has been spent in understanding the instruments and assessing their accuracy and precision to attain the highest standards possible. Occasionally some unexpected behaviour is found in the data collected at sea which requires some additional investigation. This report describes two separate problems on hydrographic cruises in 1999; the CTD profiles showed unusual and unacceptable levels of high frequency noise in salinity, and some showed hysteresis in salinity. Some deep oceanographic instruments are known to exhibit hysteresis, that is a difference in values between the down-cast and the up-cast caused by pressure or temperature effects on the sensors as they travel down and up through the water column. Such hysteresis can sometimes corrected for (e.g. in pressure sensors) or else the down-cast data is used in preference to the up-cast data (e.g. oxygen sensors). Conductivity cell construction is such that they are not affected by cumulative pressure or temperature effects and so the salinity profiles should not suffer from hysteresis. When a difference was observed between the down-cast and the up-cast on cruise D242 in September/October 2000 (Cunningham, 2000) it was clear there was an unidentified problem with the instrument. On D242 2 deep CTDs were deployed, the WOCE-standard CTDs DEEP03 and DEEP04 and only DEEP04 displayed the salinity hysteresis. This report describes the problems encountered on Discovery Cruise D242 compares the data with profiles from other cruises, discusses the causes and suggests solutions.

2. Spiking in Salinity Profiles

2.1 Description of the problem

On cruise D242 initial inspection of early CTD profiles led to the impression that the salinity profiles were quite noisy. In deeper stations, particularly those in the Faroe Bank Channel, the problem became more obvious. Both CTD instruments on the cruise (DEEP03 and DEEP04) were deployed at different times and both exhibited noisy salinity. The down-casts were noisier than the up-casts, and the spikes towards higher salinity were larger in regions of stronger vertical temperature gradients. Visual comparison of the 1hz data from a CTD station near 61° 20'N, 20°W (D242 station 13669) with nearby stations occupied on D230 (FOUREX station 118, Bacon 1998) and D233 (CHAOS station 13507, Smythe-Wright, 1999) showed that the D242 stations exhibited substantially more and larger spikes in salinity than the previous cruises (Figure 1). The spikes were generally of order 0.005-0.01 but reached up to 0.05 in high salinity and temperature gradients. Figure 2 contains Temperature-Salinity plots which illustrate the problem well; Figure 2a shows an example from the high gradient water in the Faroe Bank Channel, with decreased amount of spiking on up-casts compared to the down-casts at the same station. It is clear that averaging that down-cast profile would cause the data to be anomalously salty compared to the up-cast. Figure 2b shows the relatively few spikes and similar down- and up-casts from D230.

During D242 some difficulties were experienced with the operation of the Lowered ADCP (see Cunningham 2000) and 3 different instrument/frame set-ups were used. Most stations were completed with the borrowed WHOI 30° LADCP which has a relatively short pressure case (e.g. 13707), one was completed with no LADCP in the frame (13732), and one with the usual SOC 20° LADCP used on D230 and D233 (13738). The difference between these 3 profiles in similar locations is very striking; the worst spiking is in ctd13707, it is reduced at ctd13738, and ctd13732 shows very peculiar oscillating spikes (Figure 3). These remarkable changes associated with the LADCP case changes suggested that the instrument set-up in the frame may have been contributing to the noise problem.

2.2 Possible Causes

There were two possible reasons for the spiking which occurred with 2 separate CTD instruments; an error in the processing path or a problem with the instrument set-up. The temperature sensor on the Deep CTDs responds marginally slower than the conductivity sensor, and during the typical CTD processing path the temperature is corrected to match the response speed of the conductivity cell. Early in the course of D242 it was suspected that adjustment of the time correction ("delta-t") could reduce the salinity noise. However varying the delta-t times from its standard value of 0.2 seconds over a range of -0.25 to 0.5 seconds had very little effect on the salinity spikes. The CTDs carry an additional temperature sensor, "Fast-T", which has a response speed similar to the conductivity sensor, but generally has an inaccurate absolute temperature value. When the Fast-T temperature data were used to calculate salinity, the profiles still showed the spiking, further proof that the time adjustment was not causing the problem.

The 1 Hz CTD data are downloaded from the Data Acquisition and Processing Software (DAPS) which averages the 25 Hz data generated by the CTDs. Correspondence with Nick Crisp confirmed that the averaging method used by DAPS on D242 was identical to that performed by the RVS Level A utilised on D230, and the DAPS used in D233, so it was unlikely that DAPS was generating the spikes. He also noted that salinity had been noisy during the UEA Albatross cruise in April 1999 (Chief Scientist, Karen Heywood), and that his solution had been to average the data over 3.5 seconds. During D242 other CTD data experts were contacted for alternative suggestions. From the D242 cruise report (Cunningham, 2000):

"Robert Millard (WHOI) reported noisiness in one of McCartney's data sets which he had traced to small eddies caused by the interference from the wake of a nearby LADCP; small vortices caused the conductivity and temperature sensors to sample different waters. He urged us to examine the relative position of instruments on the rosette frame. John Smithers (SOC) noted that the only substantial change since the D233 CHAOS cruise was the used of a shorter LADCP.

"To accommodate the installation of an LADCP on the rosette frame during recent cruises, the frame has been lengthened so that the CTD conductivity and temperature sensors sit about 38 cm above the bottom of the frame. In addition, the temperature and conductivity sensors are just above (15 cm) and outboard (6 cm) of a metal plate to which the pinger is attached. For most of this cruise [D242] the WHOI LADCP was installed on the frame. This LADCP is shorter than the two SOC instruments which we usually use so that its transducer heads were appreciably closer to the CTD sensors than on previous cruises. The top of the nearest transducer was just below the metal plate. It seems possible that as the package descends through the water, the nearest transducer head channels water up onto the flat metal plate producing wake vortices which could interact with the CTD sensors."

The conclusions onboard cruise D242 were:
"a) the metal plate may be the origin of small-scale vortices which differentially affect the CTD temperature and conductivity sensors;
b) the shorter LADCP effects a small amount of mixing before the approaching water interacts with the plate;
c) the longer LADCP protruding to the bottom of the CTD frame mixes up the approaching water so that the CTD sensors measure well-mixed water passing through the frame."

Subsequent analysis and comparison with data from other cruises provides no evidence to contradict these conclusions. Thus we also conclude that the salinity spikes were the result of the temperature and conductivity sensors measuring slightly different water in small vortices shed by a horizontal flat bar on the CTD rosette frame

2.3. Solutions

2.3.1 Existing Data Sets

The down-cast data are generally taken as the standard profiles from each cast principally because they offer a continuous profile without interruptions caused by bottle firings, and because some sensors (e.g. dissolved oxygen) suffer from hysteresis on the up-cast. However the down-cast data from D242 are not only noisy, they are biased to higher salinity which means that even smoothed and de-spiked data would not be accurate because the salinities are calibrated by comparing the bottle salinity values with the up-cast salinity. During the up-casts the approaching waters are heavily mixed by the bottles, instruments and frame before it reached the CTD sensors, and the D242 up-cast data show no anomalous spikes. We conclude that the well-mixed and less noisy up-cast data offer the best data set for CTD stations during D242 and other cruises exhibiting the same spike problem.

2.3.2 Future Cruises

Ideally the CTD should be positioned below any flat horizontal metal plates so that the temperature and conductivity sensors sample nearly undisturbed waters at a level commensurate with the LADCP transducers. Because of the design of the current CTD frame and the increasing number of instruments attached to it, this is not a practical solution for the present rosette frame. However, after D242 it was possible to remove part of the flat bar nearest the CTD to reduce the generation of wake vortices.

Cruise D245 in January/February 2000 (Holliday and Griffiths 2000) deployed the modified rosette frame in conjunction with the longer SOC LADCP. Figure 4 shows the absence of salinity spikes in the D245 data, suggesting that the frame modification had improved the quality of the data.

The problems caused by the addition of the horizontal flat bar on the frame were hidden for several cruises by the fortuitous usage of the long-pressure case of the SOC LADCP, and only became obvious when the short case WHOI LADCP was used. However once it was clear there was a noise problem caused by the frame arrangements and not by the processing procedures, it appeared obvious that the bar was to blame. The addition of the bar and rearrangement of various instruments on the rosette had gone unnoticed by scientists collecting the data. It is recommended that future frame design and modification should be carried out with more attention to the impact of water flowing through and around the instruments particularly on the down-cast, and that the CTD sensors should sample the least disturbed water.

3. Hysteresis in Salinity Profiles

3.1 Description of the problem

Differences between salinity down-cast and up-cast profiles (plotted against pressure) are common because of vertical motions such as internal waves, and some movement of the ship through the water during the period of the cast. However data plotted in Temperature-Salinity (T-S) space should not show major differences because vertical motions do not alter the properties in density co-ordinates. This is the case in well-mixed deep or intermediate waters where the horizontal variations that may show through ship-drift or lateral movement of the water are minimal, and is less true in the upper ocean. If T-S plots show differences between the up-cast and down-cast data in deep or intermediate waters, this is a clear indication there is a problem. The D242 test station gave cause for concern when at the bottom of the cast the salinity jumped to higher values, and a further jump occurred during a period of no vertical motion at depth as the winch was being repaired (Figure 5). The CTD technician's advice was to leave the conductivity cell in place since it may well be simply adjusting after an extended period of not being used. However the first few deep casts on D242 showed clear differences between the down- and up-cast (Figure 6); the conductivity cell was thought to be faulty and a replacement cell fitted to the CTD. Data from the second cell soon proved to have the same problem (Figure 7), and the CTD was replaced by DEEP03 for the rest of the cruise (see Cunningham 2000 for details of station numbers for each instrument). DEEP03 did not display any hysteresis in salinity (Figure 8). The excess noise in the salinity data of these profiles is discussed in section 2 of this report. Typically the offset between the down- and up-casts was around 0.003 at a constant temperature. Because of the noise in the profiles it is often difficult to assess whether the offset changed with depth, but it is thought that the offset occurred at the bottom of the profiles and did not change with decreasing pressure.

After cruise D242, the 1Hz profiles from previous cruise were inspected to assess how bad the problem was. It was obvious that the data from DEEP03 were markedly more consistent between down- and up-casts, but how did they compare to historical data? Figure 9 shows data from cruise D230 (FOUREX, Bacon 1998) for which another SOC CTD, DEEP01, was used and no hysteresis was present. Figure 10 shows data from cruise D233 in May 1998(CHAOS, Smythe-Wright 1999) when DEEP04 was used, and some hysteresis was clearly present in those data. The hysteresis problem with DEEP04 had therefore existed at least since 1998 and it is unfortunate that it had gone unnoticed during that cruise.

3.2 Possible Causes

There are 3 possible causes for the observed hysteresis in the salinity profiles; both conductivity cells used in DEEP04 were faulty, or there was some component of the CTD electronics suffering from temperature and/or pressure, or the pressure sensor was suffering from hysteresis. Laboratory tests for pressure hysteresis have suggested negligible hysteresis in DEEP03 and DEEP04 (Mark IIIc CTDs). We can investigate this to some degrees by doing a direct comparison with the altimeter data in the deep section of the cast, and we can compare the on-deck pressures before and after a cast. From Fofonoff and Millard (1983) the sensitivity of derived salinity on pressure is approximately 0.001 per 2.5 dbar, so to create an offset of 0.003 as observed, the pressure discrepancy needs to be 7.5 dbar. On-deck pressure values for cruises D230 (DEEP01, pressure corrected for hysteresis), D233 (DEEP04) and D242 (DEEP03 and DEEP04) are shown in Figure 11. While it can be seen that DEEP04 has a tendency to have a greater difference between the start and end of a cast, that difference is still less than 2.0 dbar which is considerably less than the 7.5 dbar required to achieve the offset of 0.003.

To utilise the altimeter data to look for hysteresis in the pressure sensor, the down-cast pressure can be compared to the up-cast pressure at the same height off bottom where there was a insignificant gradient in the seafloor during the cast. If there is a substantial pressure difference (around 7.5 dbar) then that may be causing the apparent salinity offset. Station 13504 in the centre of the Iceland Basin has corrected seafloor depth drifting by around 1m during the deep section of the down- and up-casts. Table 1 lists some examples of the altimeter and pressure data and shows that the difference is small even accounting for changes in depth (1-2 dbar). So the possibility of hysteresis of the pressure sensor can be discounted.

Down-cast Altimeter Height off bottom	Down-cast Pressure	Up-cast Altimeter Height off Bottom	Up-cast Pressure
60	2701	60	2699
80	2680	80	2679
180	2577	180	2575

Table 1. D242 Station 13504 in the Iceland Basin; pressure readings for the down-cast and up-cast and equivalent height off bottom according to the altimeter.

The problems on D242 persisted despite twice changing the conductivity cell, suggesting that the sensor was not the source of the problem. However it is generally thought that production tests for new conductivity cells were not as stringent as they had been in the past, and it was always possible that the two new cells were both faulty. To test whether the fault lies with the conductivity cell, the working cell originally used in DEEP03 for D242 (and D245) was transferred to DEEP04 and deployed on an RVS trials cruise in April 2000 (Charles Clayson). The resulting profile is shown in Figure 12 and clearly shows the hysteresis persisting. The conclusion from this experiment is that the conductivity cells are not the cause of the hysteresis.

The final possible cause for the hysteresis problem is some temperature or pressure effect on electronic components of the CTD. At the time of compiling this report this had not been investigated.

3.3 Solutions

Salinity data are calibrated by comparing bottle samples with the CTD data at the time of firing. Thus the calibrated data are the up-cast profiles. Because of this it is recommended that the upcast data be used from data sets affected by the DEEP04 salinity hysteresis for greatest accuracy. The disadvantages of this solution are that the upcast suffers from smoothing caused by mixing by the CTD package, and that the downcast must be used for oxygen sensor data which is known to suffer from marked hysteresis in the upcast. The error in calibrated salinity caused by this problem is of the order 0.003 and may not be a great problem to repeat hydrography style cruises.

In conclusion the source of the salinity hysteresis still needs to be identified. In the meantime it is suggested that DEEP04 be used as a backup instrument on hydrographic cruises, and not used as the main CTD.

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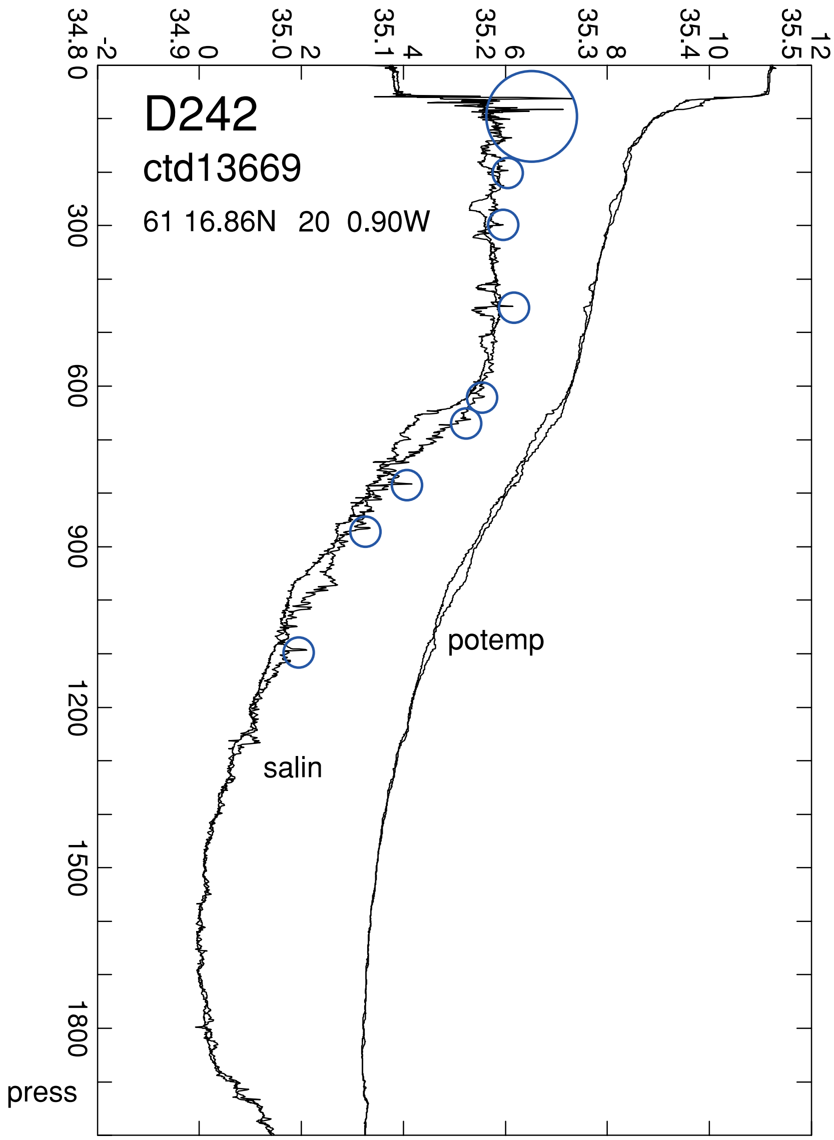


Figure 1 -Temperature and Salinity profiles from 3 cruises in approximately the same location. Data shown are 1hz data from up and down-casts;
a) D242 Station 13669 with examples of spikes highlighted by circles.

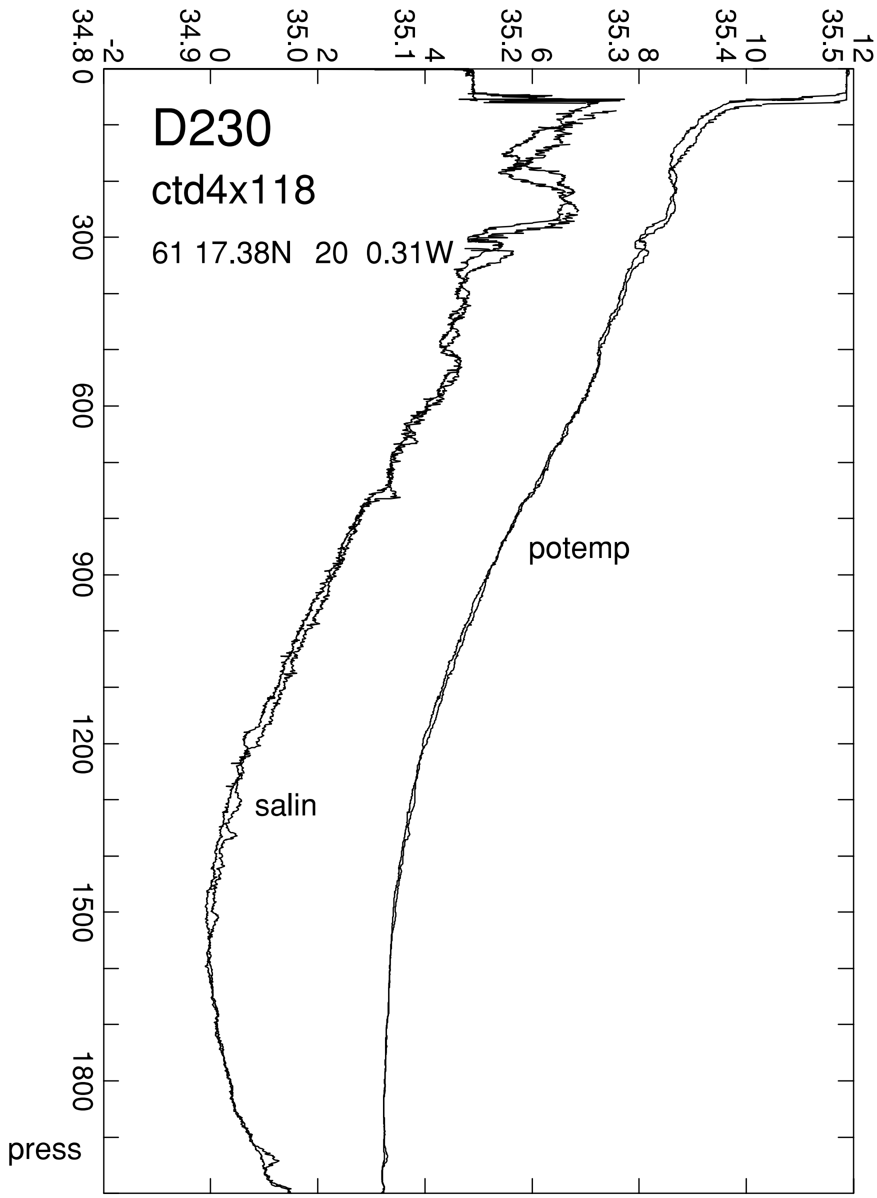


Figure 1 Continued
b) FOUREX Station 118

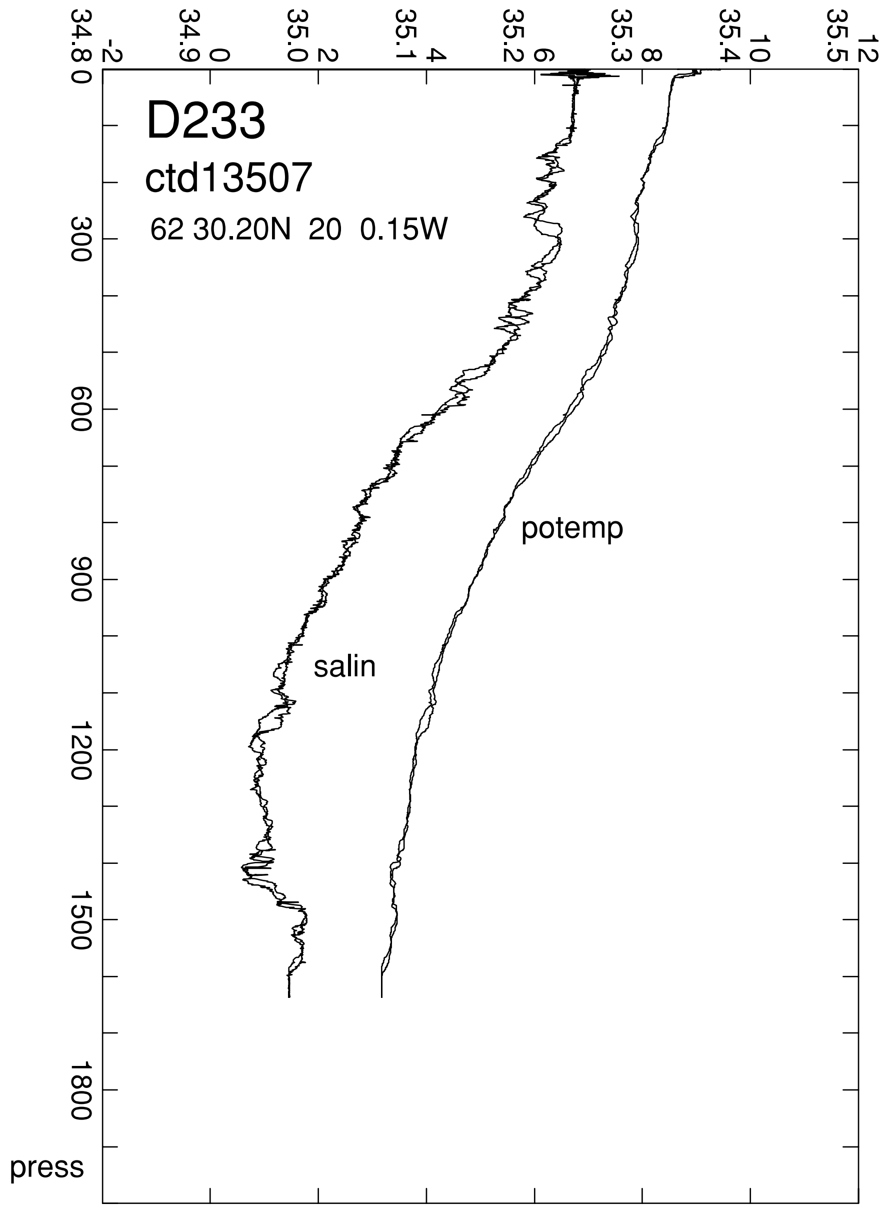


Figure 1 Continued
c) CHAOS Station 13507

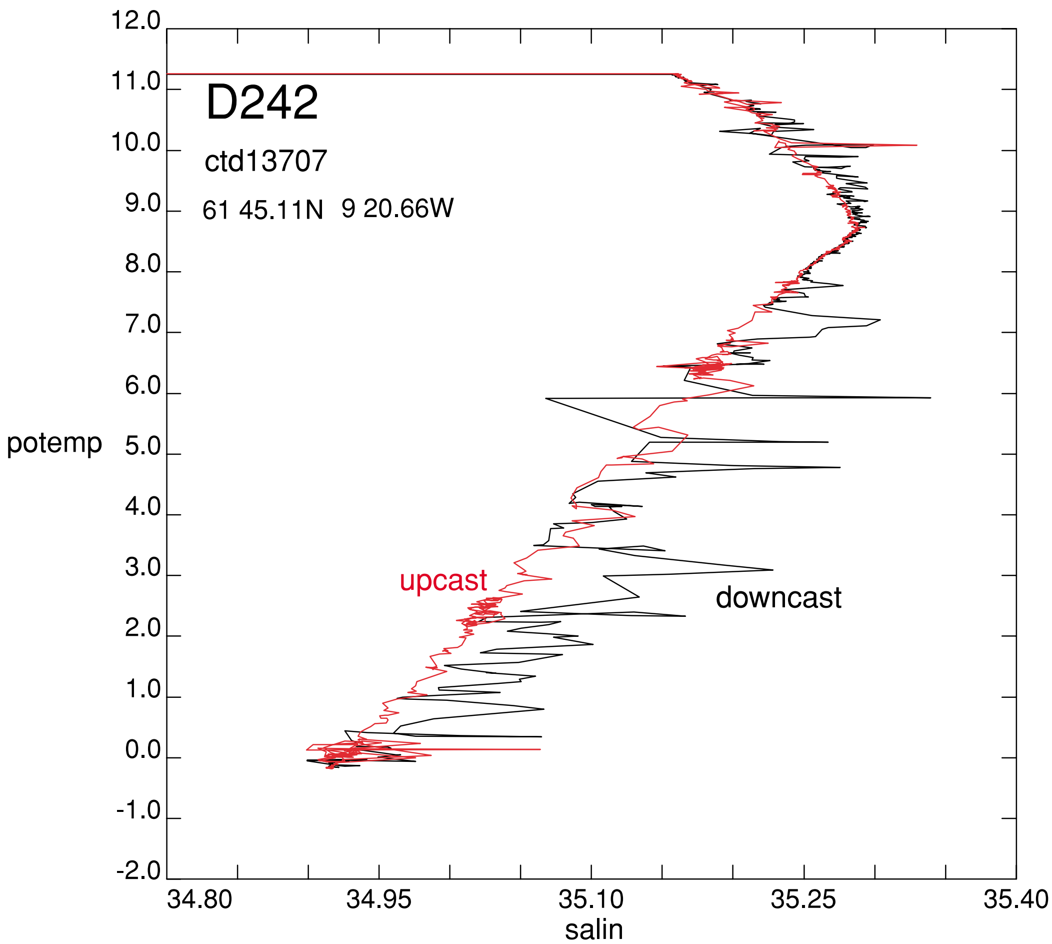


Figure 2a - Temperature-salinity plot for D242 station 13707 in the Faroe Bank Channel with very strong salinity and temperature gradient producing very bad spiking in the deep water. Data shown are 1hz; down-cast is in black, up-cast in red.

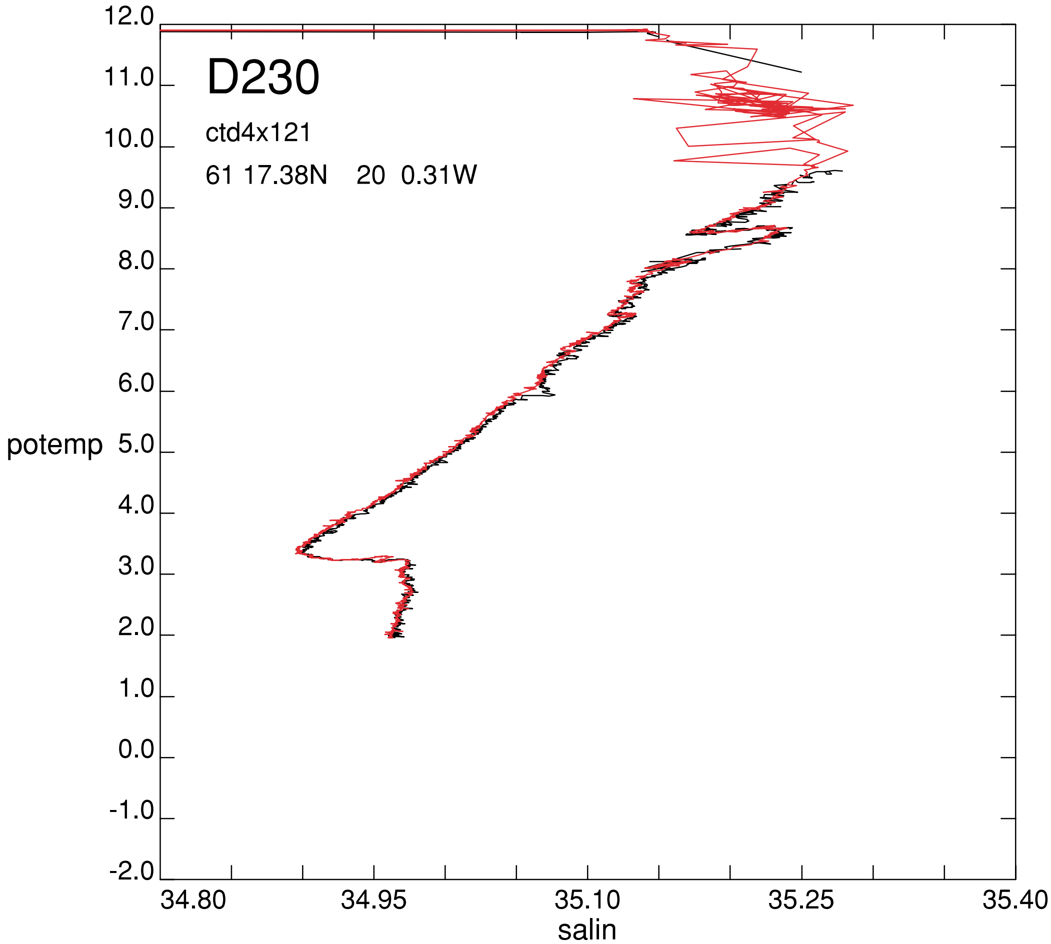


Figure 2 - Continued
b) FOUREX Station 118. Data shown are 1hz; down-cast is in black, up-cast in red.

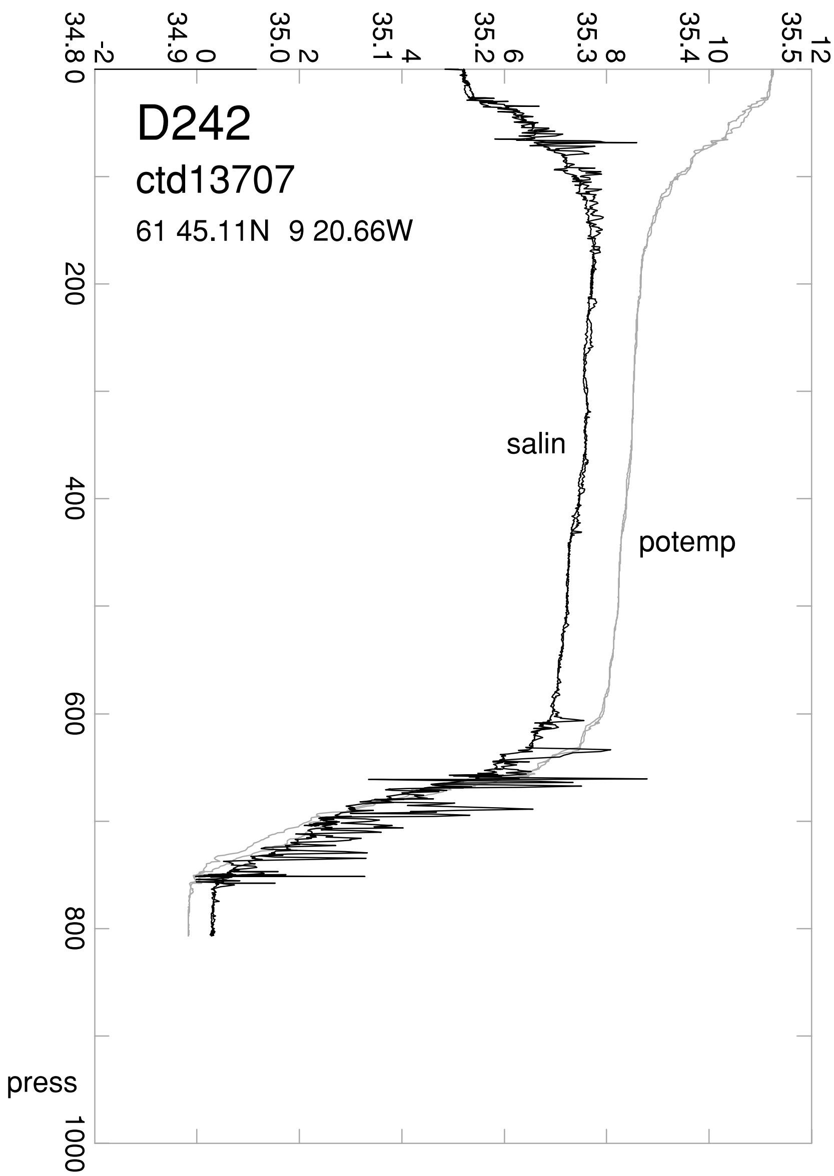


Figure 3 - Temperature and Salinity profiles from 3 stations with different LADCP arrangements;
a) 13707 with the WHOI 30° LADCP (used on most D242 stations).

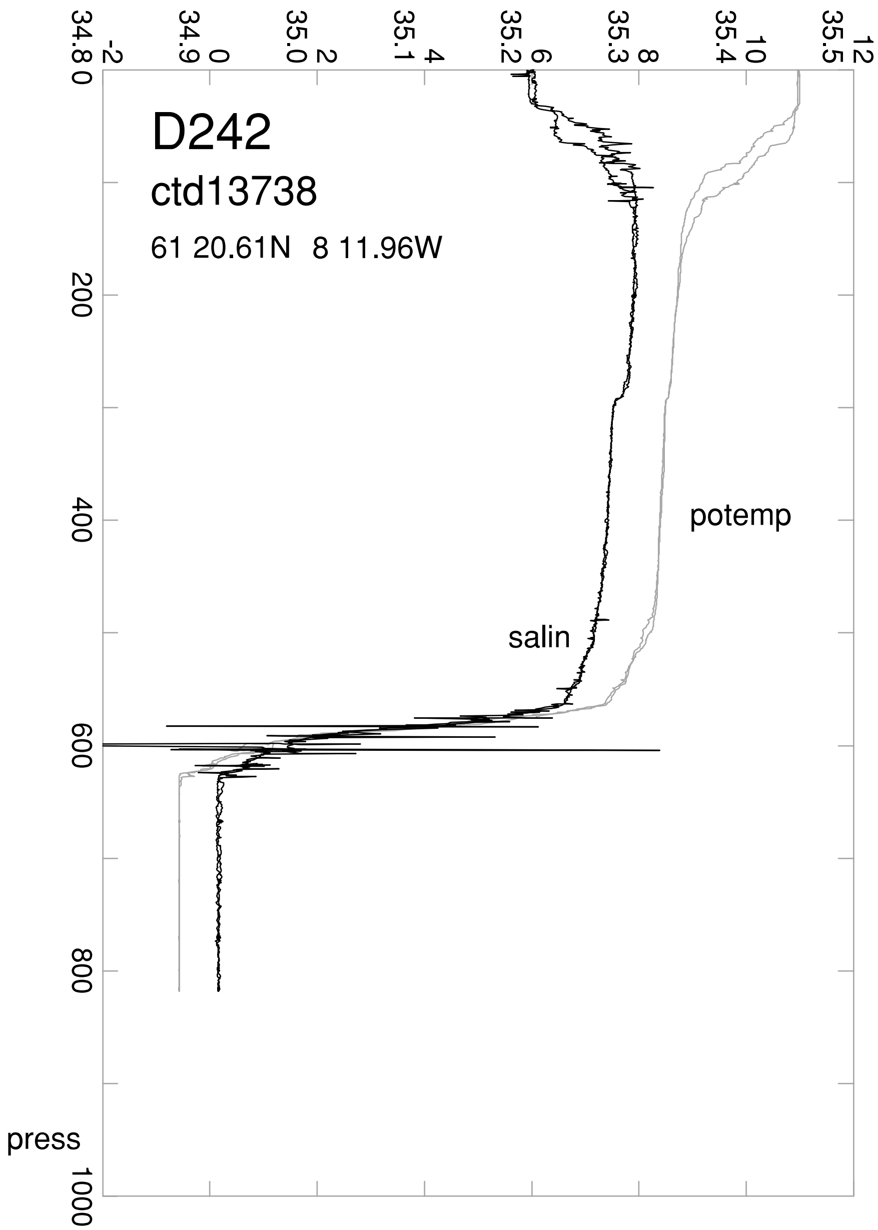


Figure 3 Continued
b) 13738 with the SOC 20° LADCP

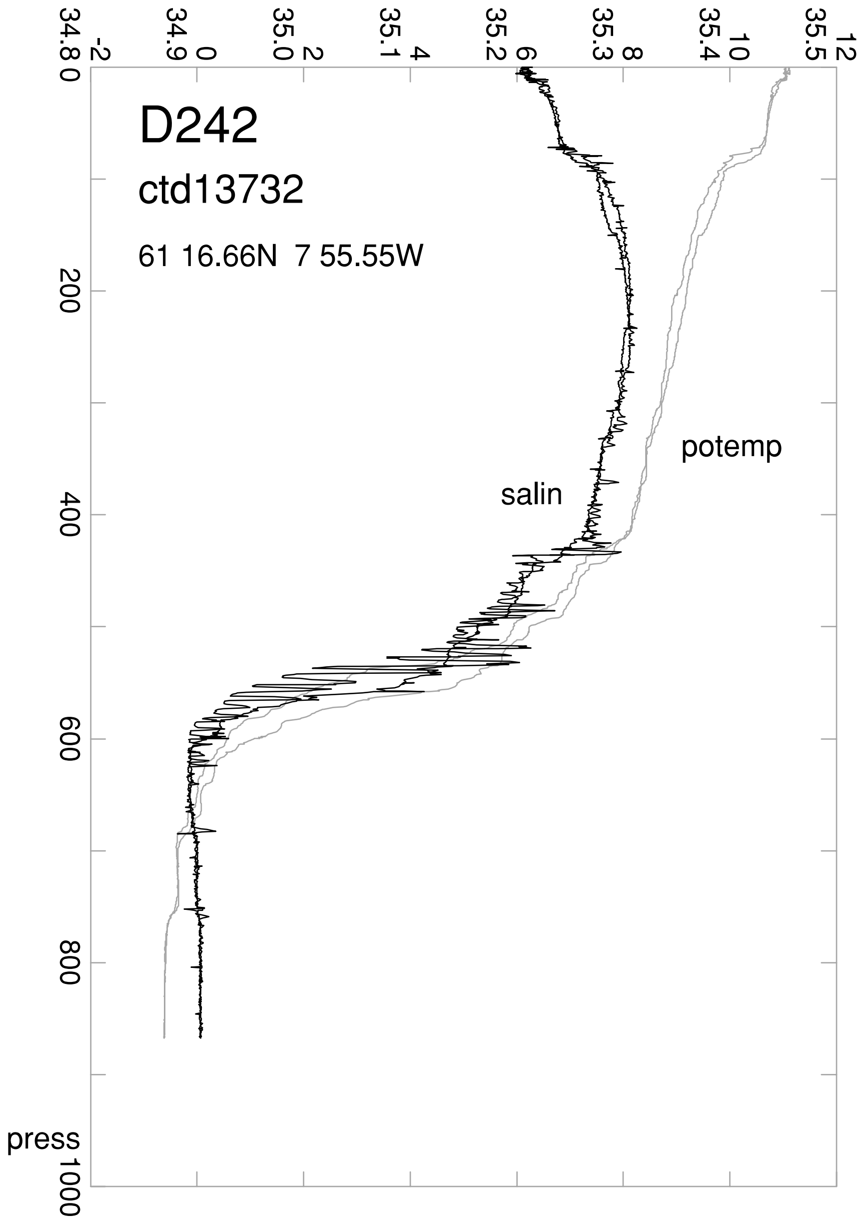


Figure 3 Continued
c) 13732 with no LADCP in the frame

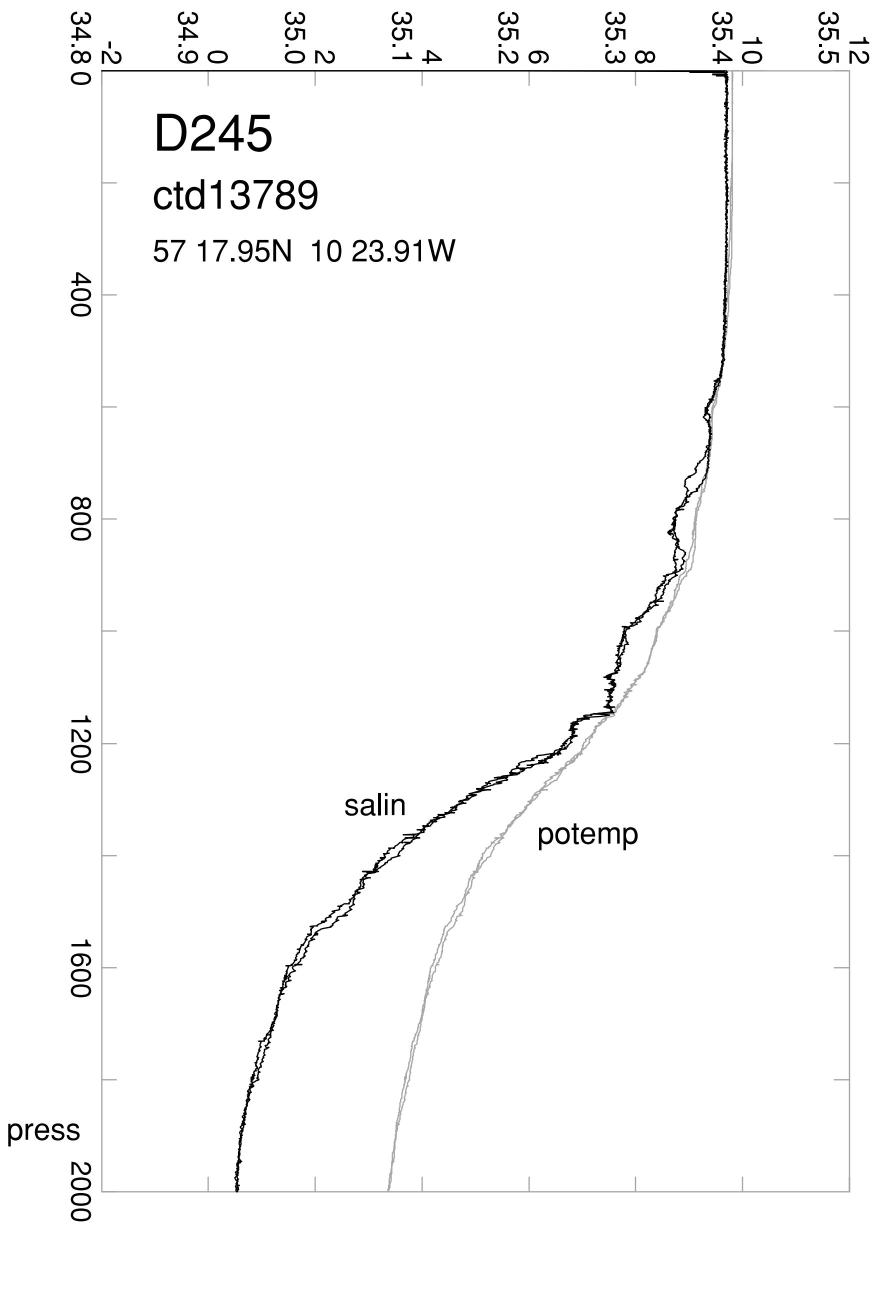


Figure 4 - Temperature and Salinity for D245 station 13789 showing the clean up and down profiles collected with the modified CTD frame and long LADCP.

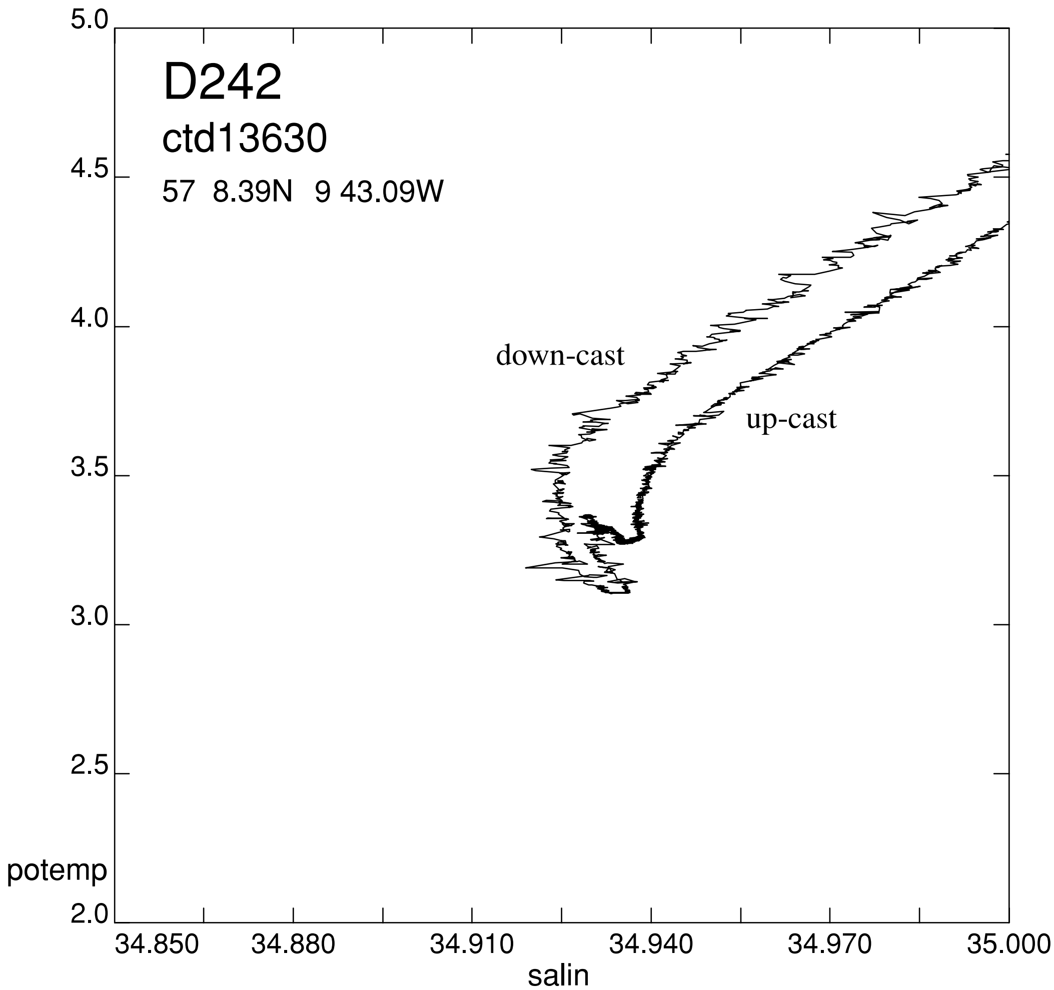


Figure 5 - D242 Station 13630, the test station, showing two jumps to higher salinity; at the bottom of the cast, and during an extended winch-stopped period.

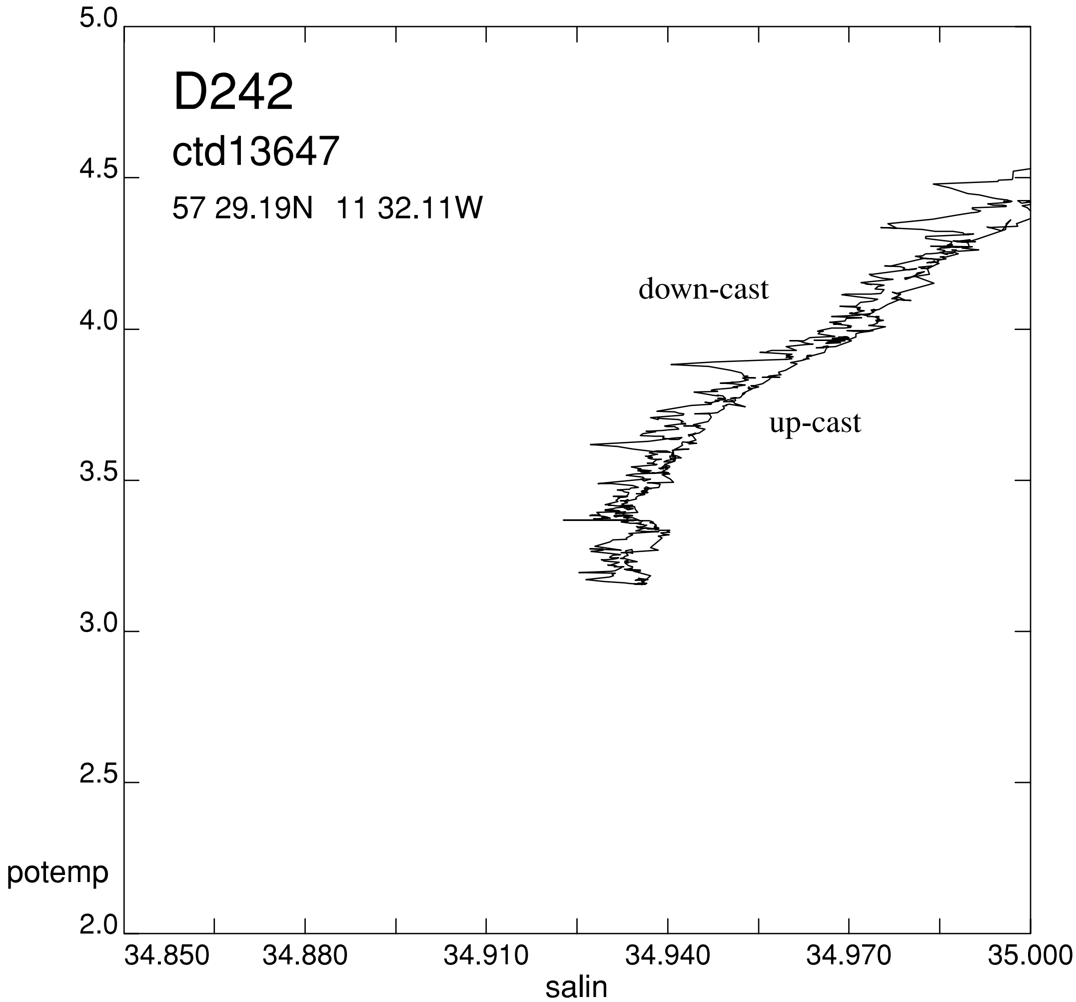


Figure 6 - D242 Station 13647, the first deep station of the Ellett hydrographic section.

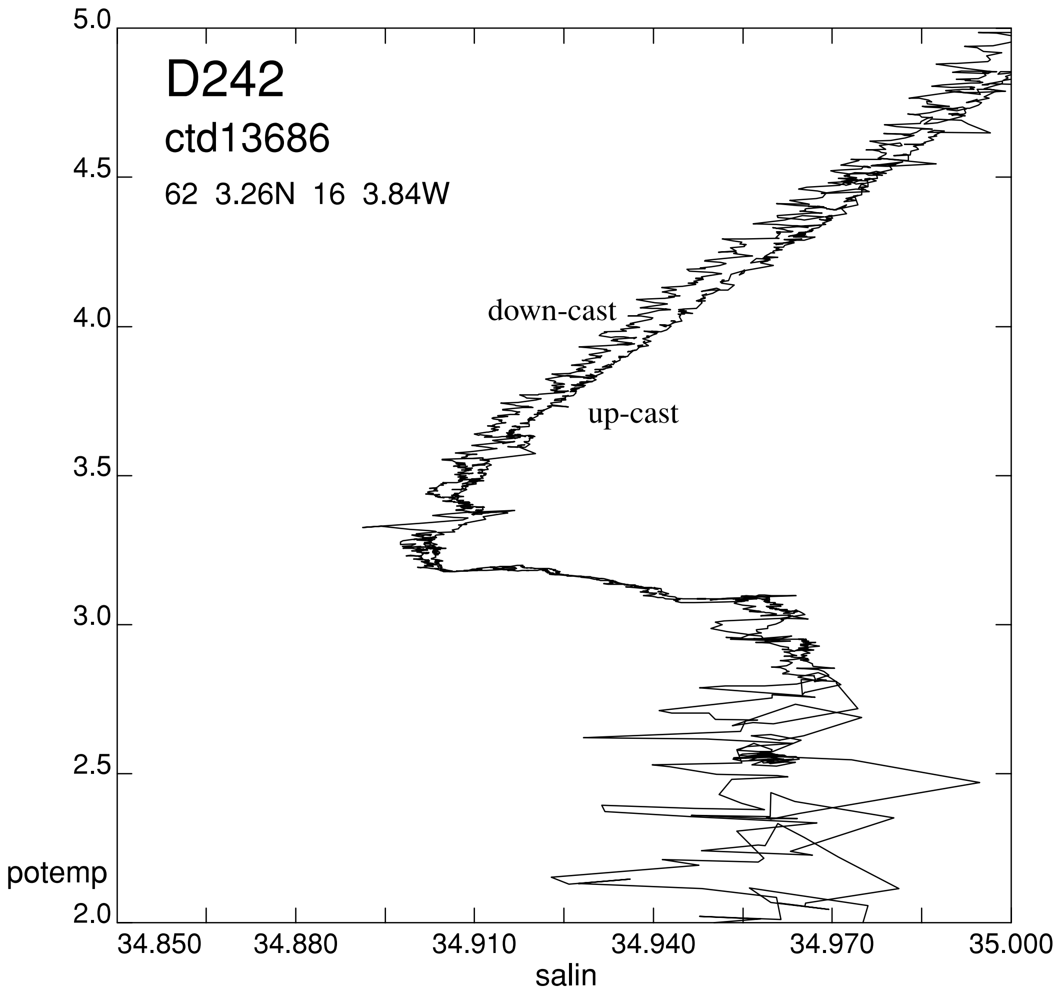
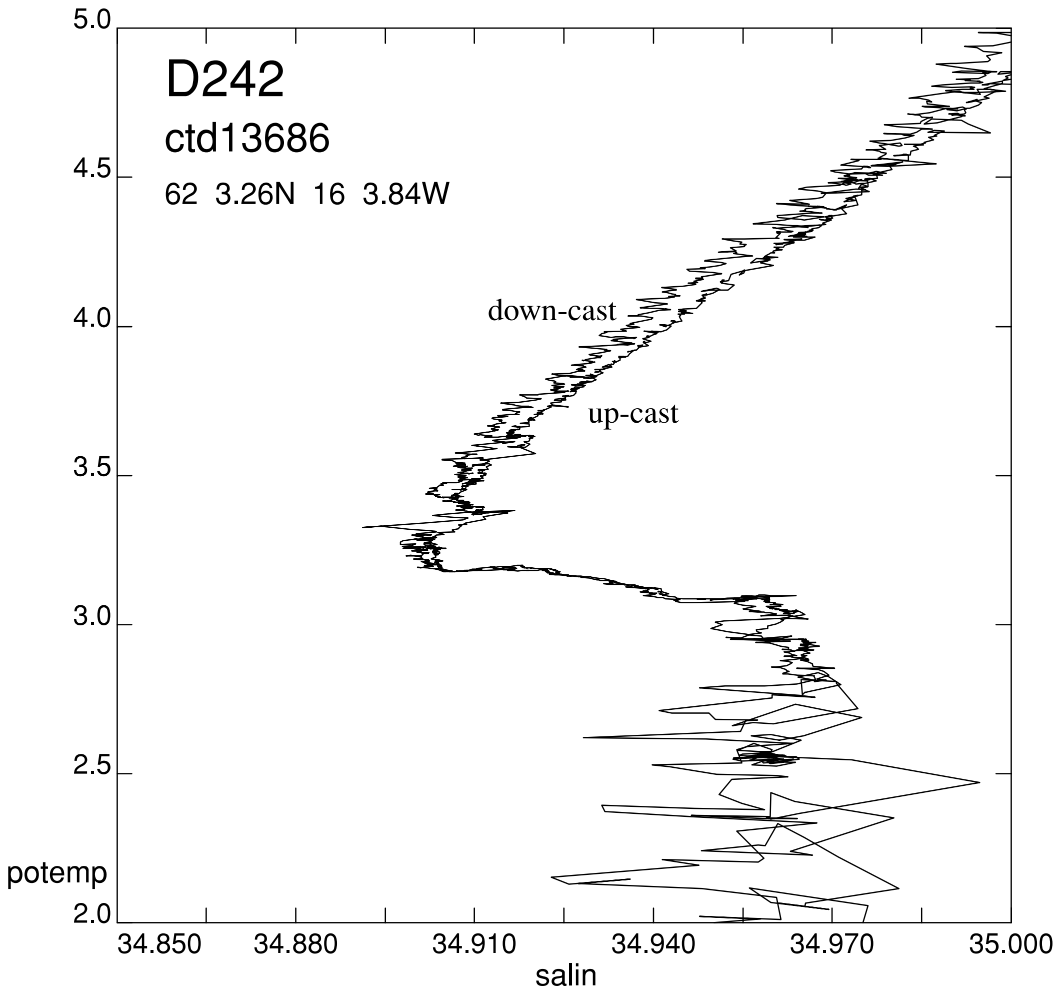


Figure 7 - D242 Station 13686, the first deep station with the replacement conductivity cell in DEEP04.



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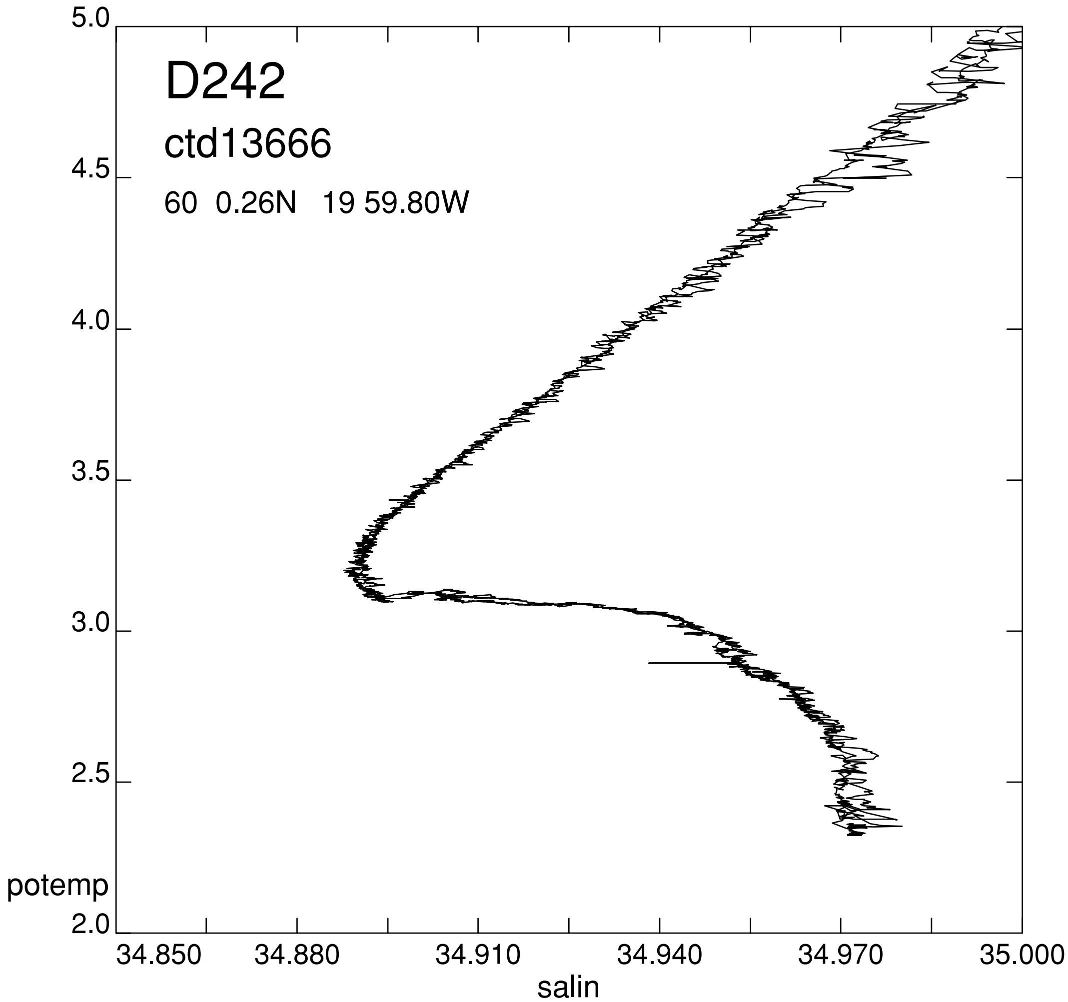

Figure 8 - D242 Station 13666, using DEEP03 and showing no hysteresis.

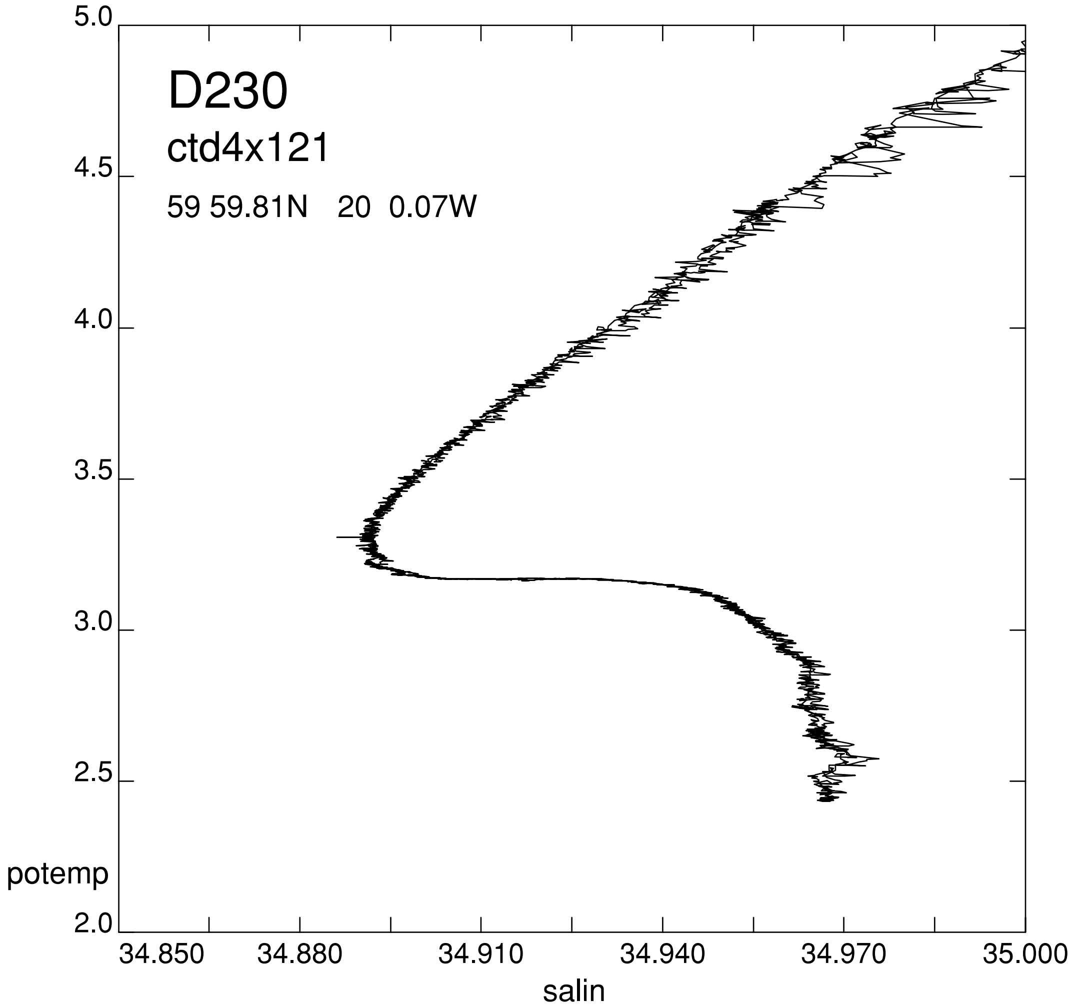

Figure 9 - D230 Station 121 using DEEP01 and showing no hysteresis.

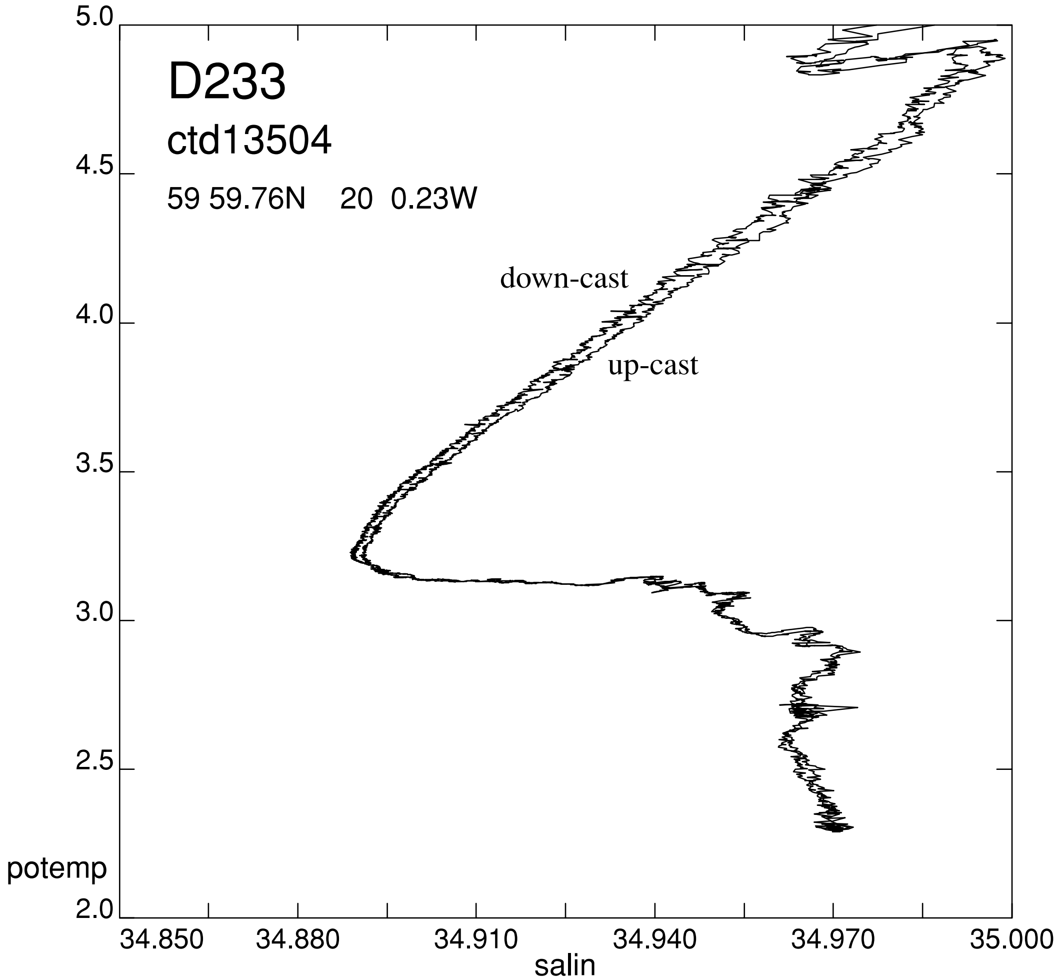

Figure 10 - D233 Station 13504 using DEEP04 in May 1998, showing some hysteresis.

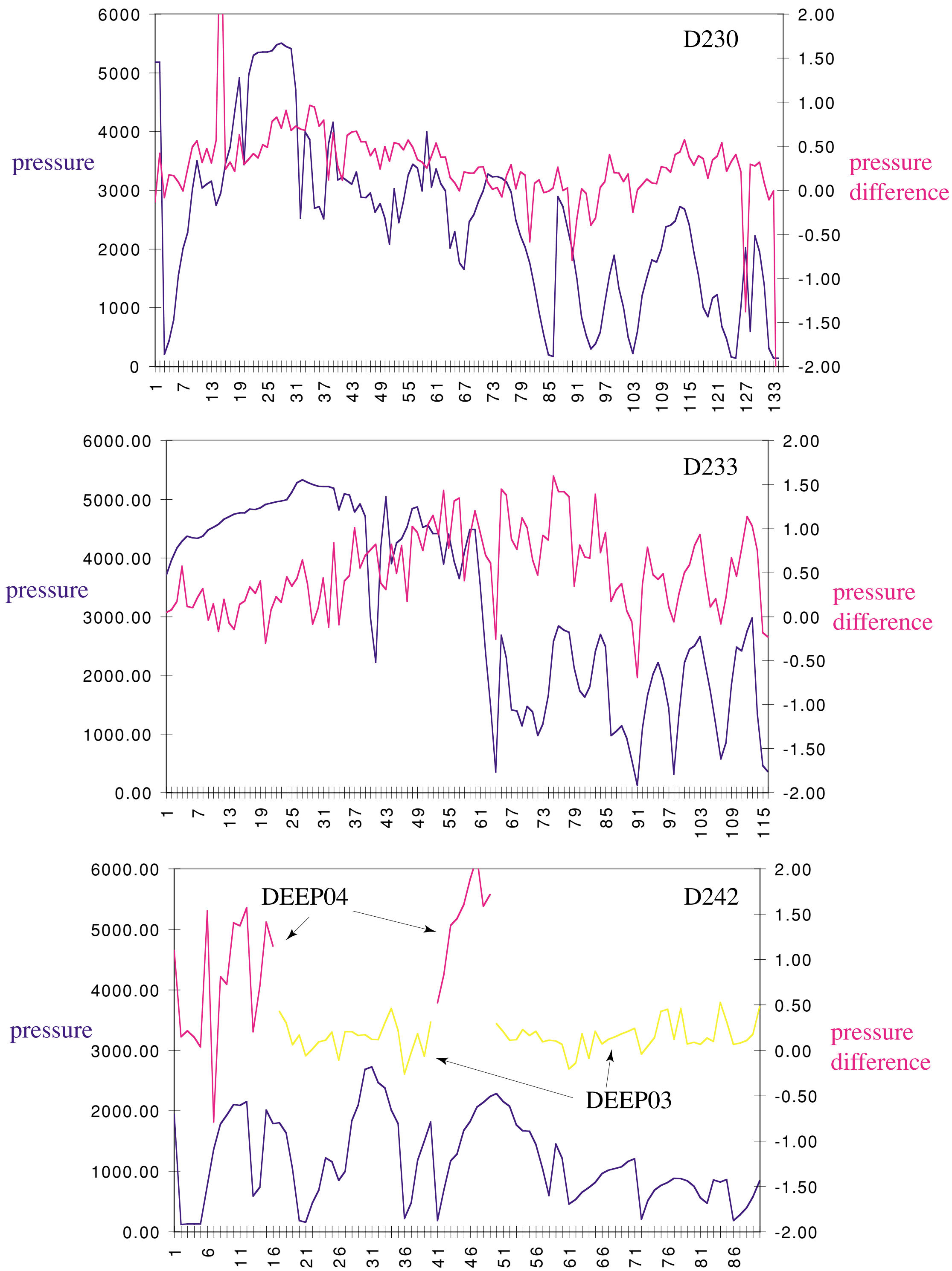

Figure 11 - Pressure differences between the on-deck readings before and after each cast on D230 (DEEP01, pressure corrected for hysteresis), D233 (DEEP04) and D242 (DEEP03 and DEEP04). Maximum pressure of each cast is also shown in blue.

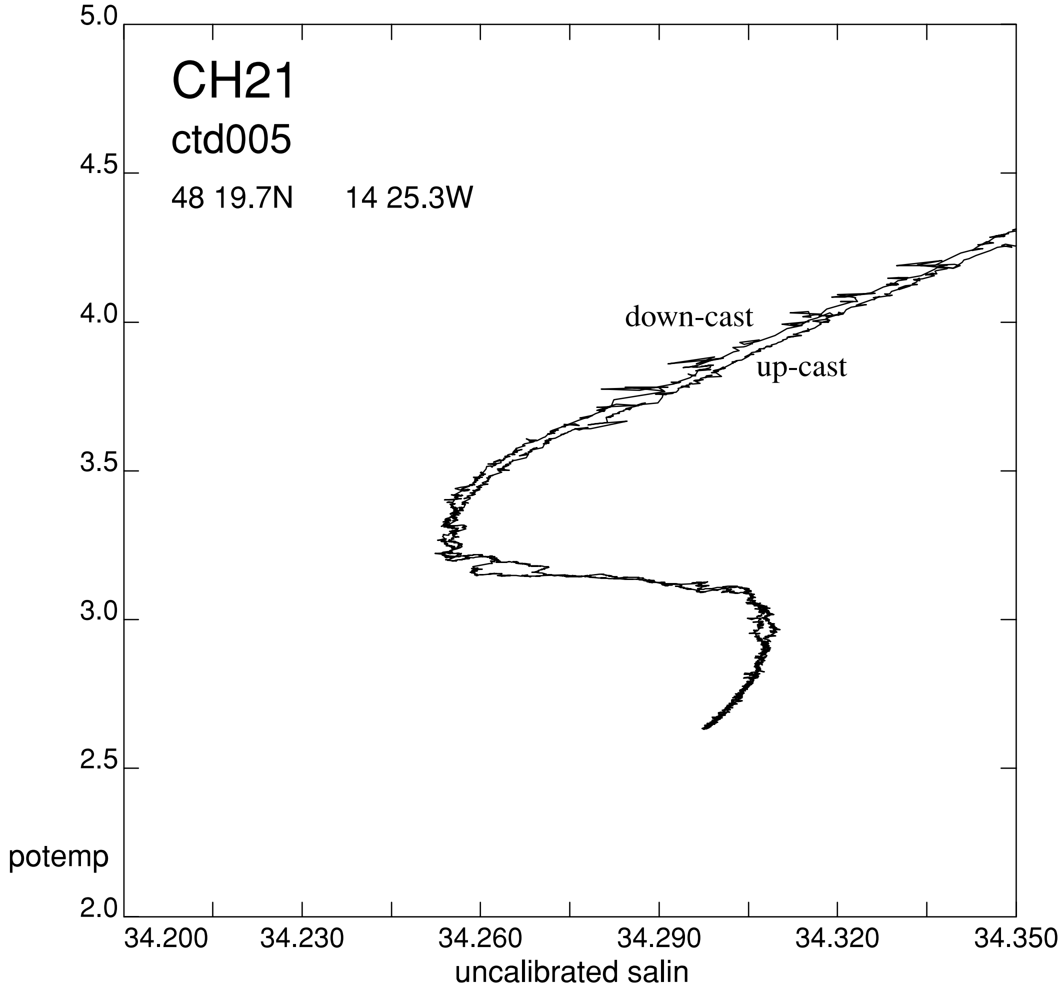

Figure 12 - CH21 Station 005 using DEEP04 with the conductivity cell used in DEEP03 on Station 13666 (Fig. 8) and throughout D242.