The Argentine Basin OOI array:
temperature and salinity profiles from Apex mooring, surface mooring, Subsurface flanking mooring A and B processing, calibration, validation

1. The Argentine Basin array:

The Argentine Basin array was part of the National Science Foundation's (NSF) Ocean Observatories Initiative (OOI; http://www.oceanobservatories.org). The Argentine Basin (AB) array was deployed and maintained at 42°S 42°W, in international waters (Figure 1a). Moorings were located in a frontal region with large Sea surface Height (SSH) gradients and large SSH standard deviations (Figure 1a-e). Moorings were deployed for the first time in March 2015. The mooring site was then visited in three other opportunities: October 2015, September 2016 and January 2018. Moorings were recovered and redeployed at the same position in 2015 and 2016 . January 2018 was the end of operations in the Argentine Basin (Figure 1f) with the final mooring recovery. In addition, in each expedition CTD casts with water sampling at the mooring sites were performed for instrument calibration and data verification.

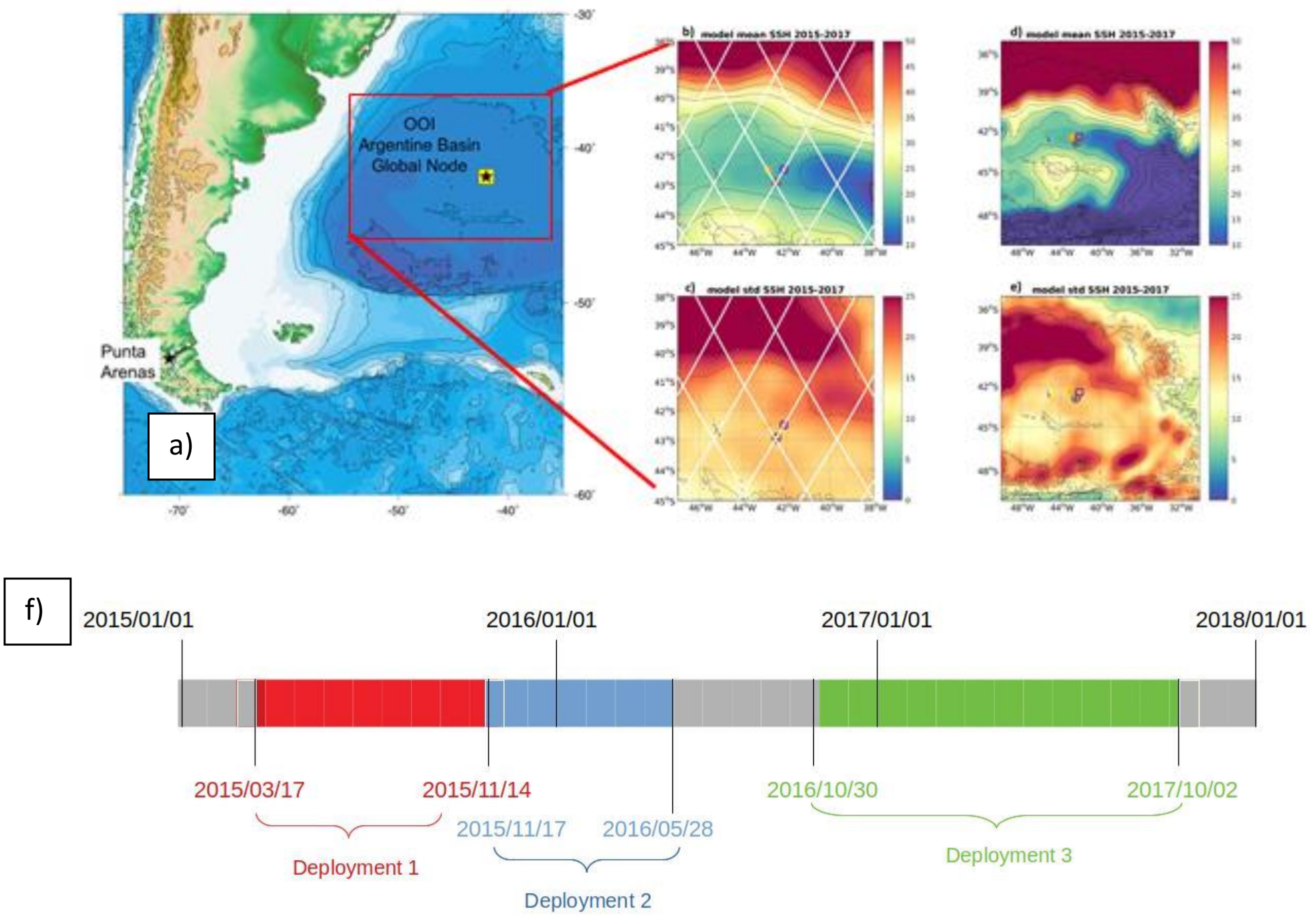


Figure 1: a) Location of the Global Argentine Basin Array, b-c) Mean and standard deviation of SSH over the mooring years (2015-2017) from GLORYS12 reanalysis. Mooring position is indicated with colored markers. d-e) Zoom out from b and d. f) Schematic time series indicating the mooring deployment period for the Apex mooring profiler. Note the early stop of mooring from the second deployment in May 2016. White lines indicate the position of Jason tracks.

1.1 The Apex profiler mooring:

The AB included four moorings (Figure 1b) and a number of ocean gliders. The Apex profiler mooring (Figure 2) was a subsurface mooring located at 5,200 meters depth and contained two Wire-Following Profilers that housed several sensors (T, S, DO, current-meters among others). Here we focused on T and S calibration and quality control. The Wire-Following Profilers moved through the water column along the cable, continuously sampling ocean characteristics at a high vertical and temporal resolution (5 db and one to two profiles per day) over a specified depth interval (310-2,445 meters for the upper profiler and 2,470-4605 meters deep for the lower profiler)

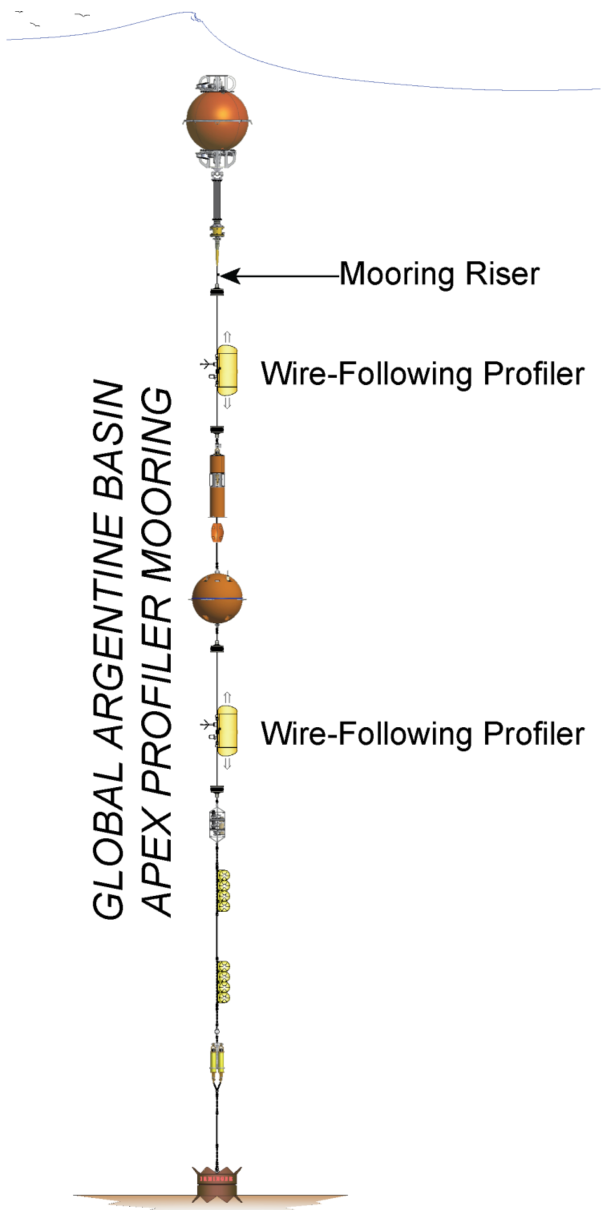


Figure 2: Global Apex Profiler Mooring.

1.2 The surface mooring:

The Argentine Basin Apex Mooring was 7km next to the Surface Profiler Mooring, allowing data intercomparison. The surface mooring contained instruments attached to a surface buoy floating on the sea surface, Near Surface Instrument Frame 12 meters below the surface, and instruments attached to a cable at fixed depths through the water column. The surface buoy provided a platform on which to secure surface instruments above the sea surface, below the sea surface, and across the interface (Figure 3).The majority of the surface mooring instruments measured with a sampling frequency of 15 min.

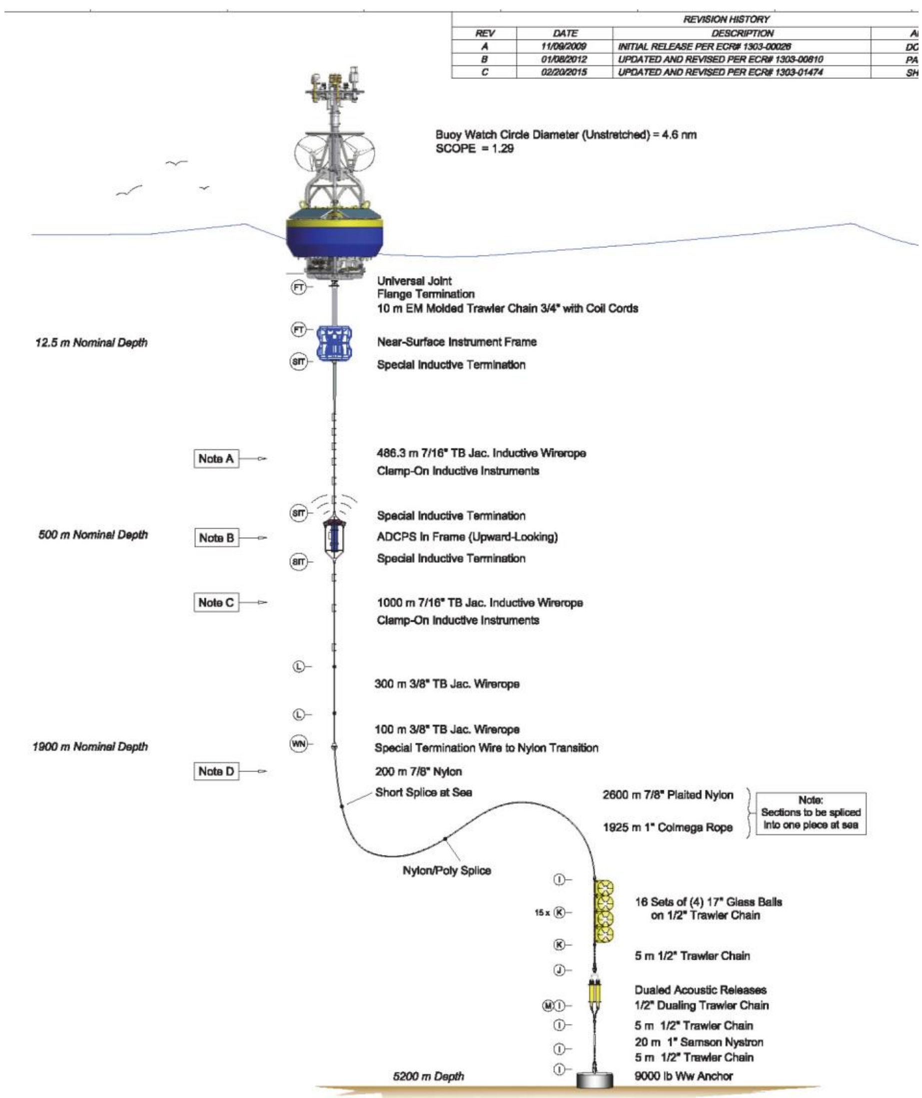


Figure 3: Surface Mooring.

1.3 Subsurface flanking mooring A and B:

The Argentine Basin array had two identical Flanking Moorings that make up the equidistant sides of a triangle of Moorings (62 km). Like the subsurface mooring, the Flanking Subsurface Moorings contained instruments fixed at specific depths along the mooring riser throughout the water column to a depth of 1500 meters (Figure 4).

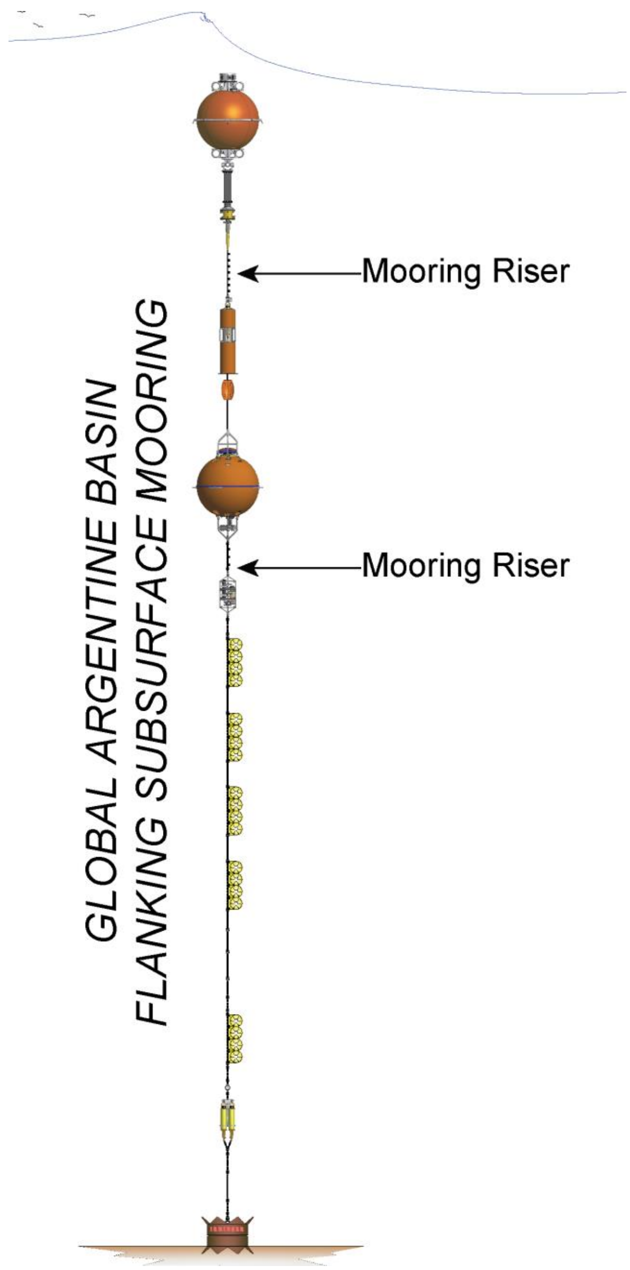


Figure 4: Global Argentine Basin Flanking subsurface mooring.

2.1 CTD data:

Figure 5 and Table 1 show the location of each mooring position for each deployment (blue markers) and the CTD stations performed at each cruise (red points with numbers).

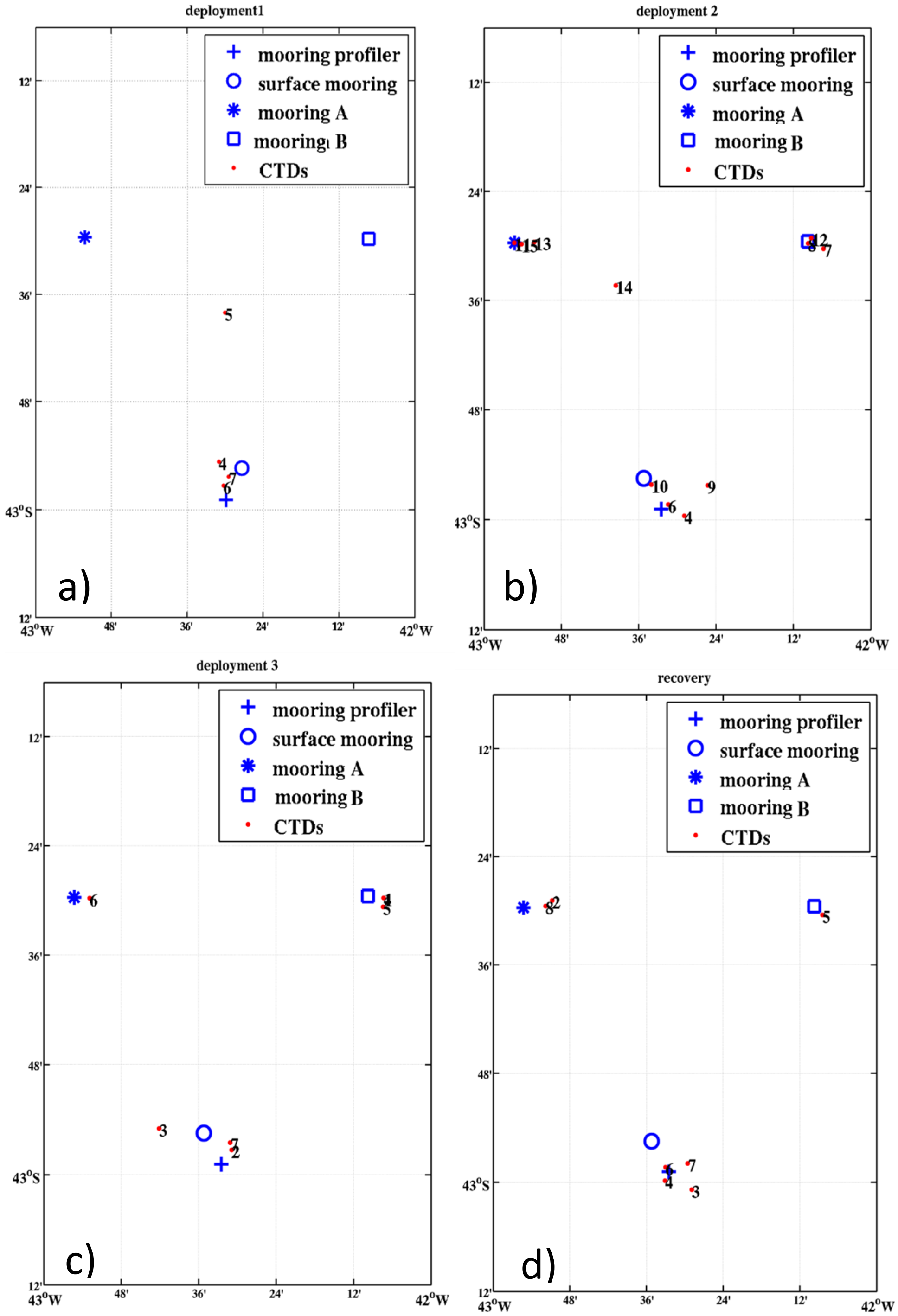


Figure 5: Position of mooring (blue markers) and CTD stations (red points) for deployment 1 (a), deployment 2 (b), deployment 3 (c) and recovery (d).

Deployment 1				
CTD cast #	date	location	Cast depth	Bottle sampled
4	16/03/2015	42°54.64S 42°30.969W	5190 m	
5	17/03/2015	42°38.03S 42°30.02W	1000 m	X
6	17/03/2015	42°57.34S 42°30.24W	5026 m	X
7	21/03/2015	42°56.27S 42°59.50W	1000 m	X
Deployment 2				
CTD cast #	Date	location	Cast depth	Bottle sampled
4	15/11/2015	42°59.57S 42°28.94W	5160 m	X
6	16/11/2015	42°58.36S 42°31.44W	5187 m	X
7	18/11/2015	42°30.34S 42°7.34W	5156 m	X
8	19/11/2015	42°29.75S 42°9.72W	5082 m	
9	20/11/2015	42°56.25S 42°25.29W	1800 m	X
10	20/11/2015	42°56.16S 42°34.03W	1800 m	X
11	21/11/2015	42°29.70S 42°55.32W	5137 m	
12	22/11/2015	42°29.14S 42°09.26W	5080 m	X
13	24/11/2015	42°29.59S 42°52.20W	5442 m	X
14	24/11/2015	42°34.36S 42°34.56W	1000 m	X
15	25/11/2015	42°29.84S 42°54.19W	5141 m	X
Deployment 3				
CTD cast #	Date	location	Cast depth	Bottle sampled
2	27/10/2016	42°57.310S 42°30.88W	5187 m	X
3	29/10/2016	42°54.98S 42°42.12W	5185 m	
4	31/10/2016	42°29.75S 42°07.35W	5175 m	
5	01/11/2016	42°30.73S 42°07.45W	5163 m	

6	06/11/2016	42°29.77S 42°52.88W	5166 m	
7	09/11/2016	42°56.50S 42°31.12W	5150 m	X

Recovery				
CTD cast #	Date	location	Cast depth	Bottle sampled
2	08/01/2018	42°28.88S 42°50.76W	2001 m	X
3	10/01/2018	43°0.82S 42°28.93W	5000 m	X
4	10/01/2018	42°59.81S 42°33.14W	2000 m	
5	12/01/2018	42°30.48S 42°8.46W	2002 m	X
6	13/01/2018	42°58.36S 42°33.03W	2000 m	
7	13/012018	42°57.94S 42°29.56W	3000 m	X
8	16/01/2018	42°29.50S 42°51.81W	5001 m	X

Table 1:Date, location and depth of CTD casts

CTD casts and water sampling were conducted in each station. Figure 6 shows as an example the salinity profile from the deep CTD casts (5187 m) done during deployment 2 and the bottle samples. In general, there is a good agreement between the salinity measured by the CTD and the bottle samples. Differences between the calibrated CTD and the bottle sample are smaller than 0.008 psu. Figure 7 shows the temperature and salinity profiles from the CTD stations that were done close to the Apex mooring profiler (Figure 5). The time interval between the stations is indicated in Table 1.

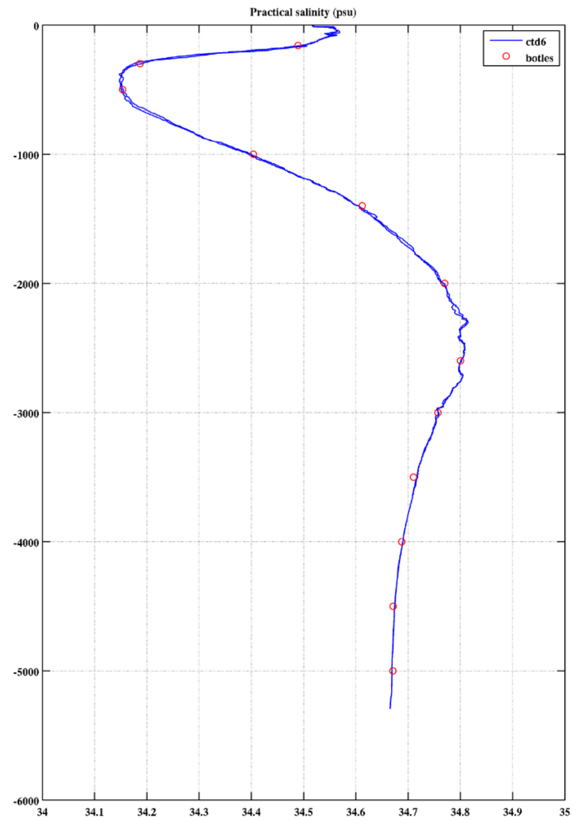


Figure 6: Upward and downward salinity profiles from CTD and bottle sample at station 6 from the second deployment. Location indicated in Figure 5b.

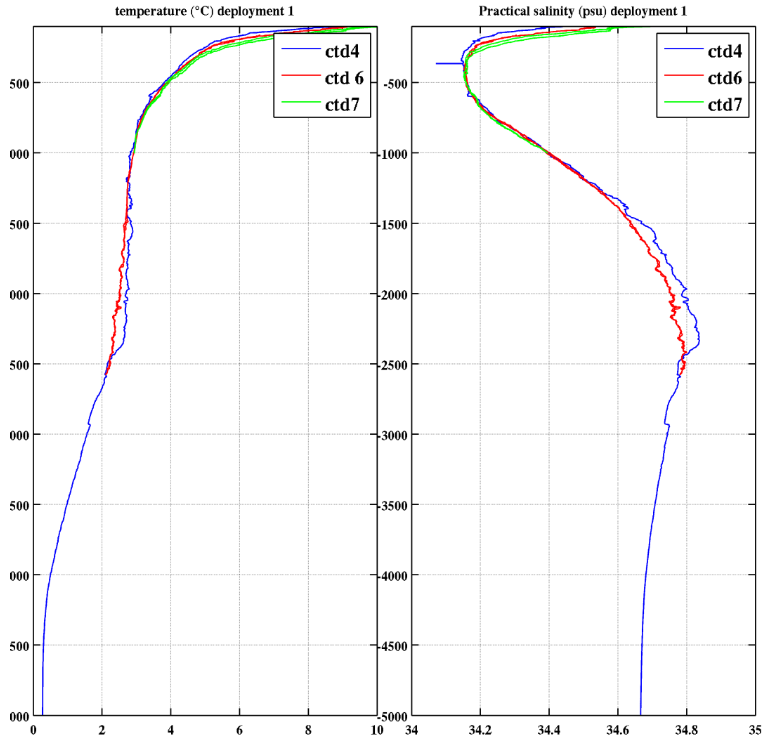


Figure 7 a – Temperature (left) and salinity (right) profiles from CTD stations 4, 5 and 7 from deployment 1 (cf Figure 5a for CTD location).

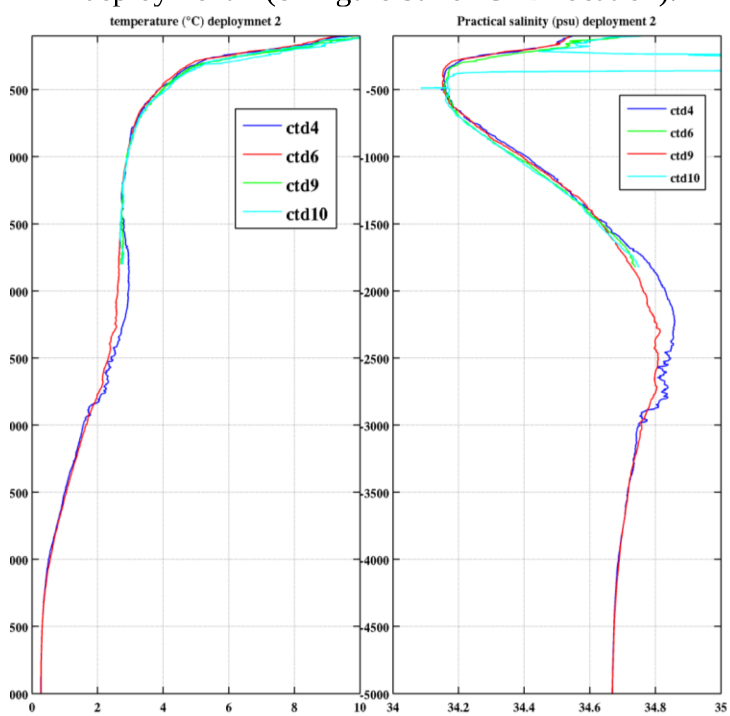


Figure 7 b – Temperature (left) and salinity (right) profiles from CTD stations 4, 6, 9 and 10 from deployment 2 (cf Figure 5b for the CTD location).

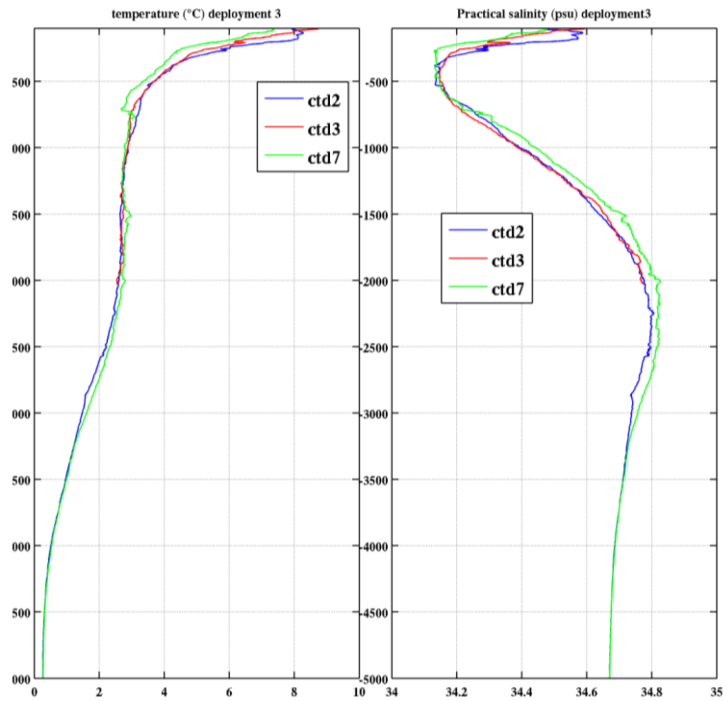


Figure 7 c – Temperature (left) and salinity (right) profiles from CTD stations 2, 3 and 7 from deployment 3 (cf Figure 5c for CTD location)

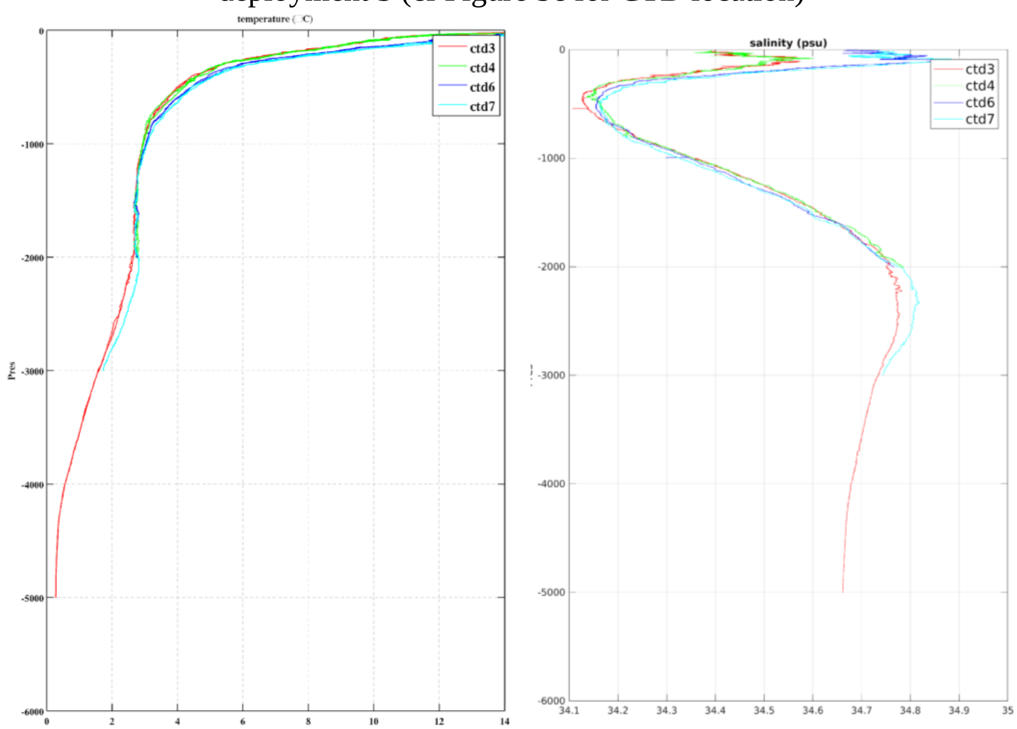


Figure7 d– Temperature (left) and salinity (right) profiles from CTD stations 3,4,6 and 7 from recovery (cf Figure 5d for CTD location)

The salinity profile from CTD 10 from deployment 2 (Figure 7b) was discarded due to spurious values recorded above 500 m depth. Salinity profile from CTD 7 from deployment 3 presents significant salinity differences compared to CTD 2 and 3 (Figure 7c). The agreement with the salinity profile and the bottle samples for this deployment was remarkable (not shown) and any salinity profile was removed.

The CTDs sampled a wide variety of water masses (Figure 8). The lighter densities (<27 kg/m^3) correspond to South Atlantic Central Waters (SACW) for salinities larger than 34.2 psu (4<T<5) and to Subantarctic Surface Water (SAMW) for lower salinities (T>5). The salinity minimum (S<34.2 psu) between 27 and 27.3 kg/m^3 corresponds to the Antarctic Intermediate Water (AAIW). The salinity maximum around 34.8 psu and 2°C corresponds to the North Atlantic Deep Water (NADW) and waters colder than 2°C and denser than 27.8 kg/m^3 correspond to Antarctic Bottom Water (AABW).

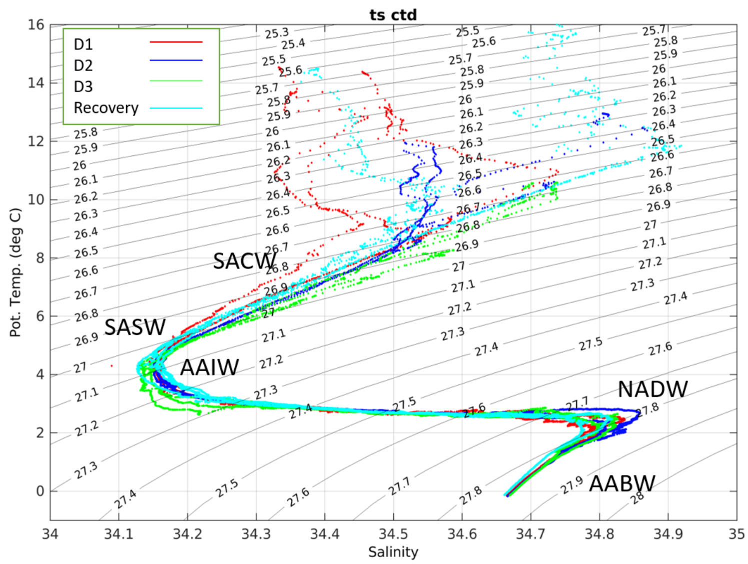


Figure 8. Potential temperature-salinity diagram from CTDs

A zoom of the TS diagram (below) shows that ctd 3 from the recovery was not well calibrated (cf Figure 7d). In fact, 6% of the data was missing and there were no bottle samples below 3000 m depth, therefore we removed this CTD cast.

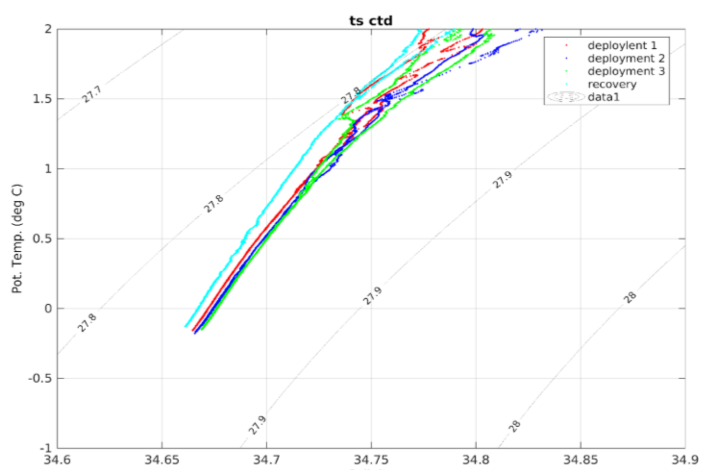


Figure 9: Zoom in of the potential temperature - salinity diagram shown in Figure 8.

The standard deviation (std) was computed considering a total of 12 CTDs (Figure 10). The CTD profiles vary over a large range of values in the upper 500 m (by about 2°C for temperature and 0.15 psu for salinity). The salinity and temperature std show a local minimum at 500m and 1300 m respectively and a local maximum between 2500 and 3000m. Below 4000 m depth the salinity std is smaller than 0.001 psu and the temperature std is smaller than 0.006°C.

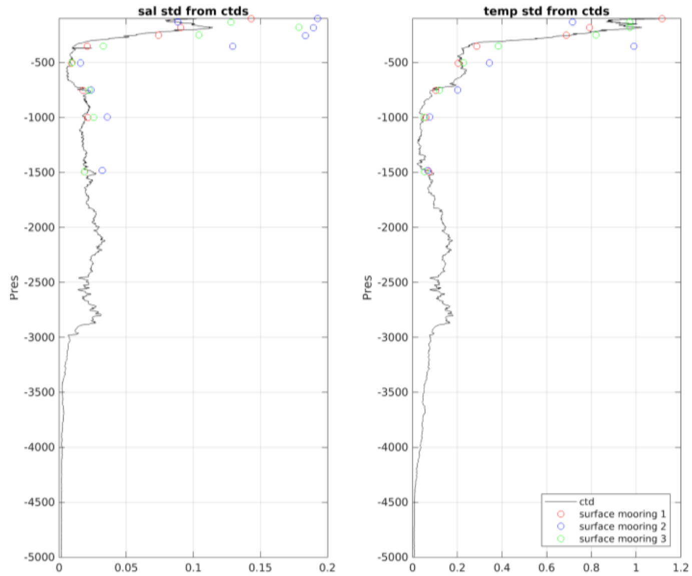
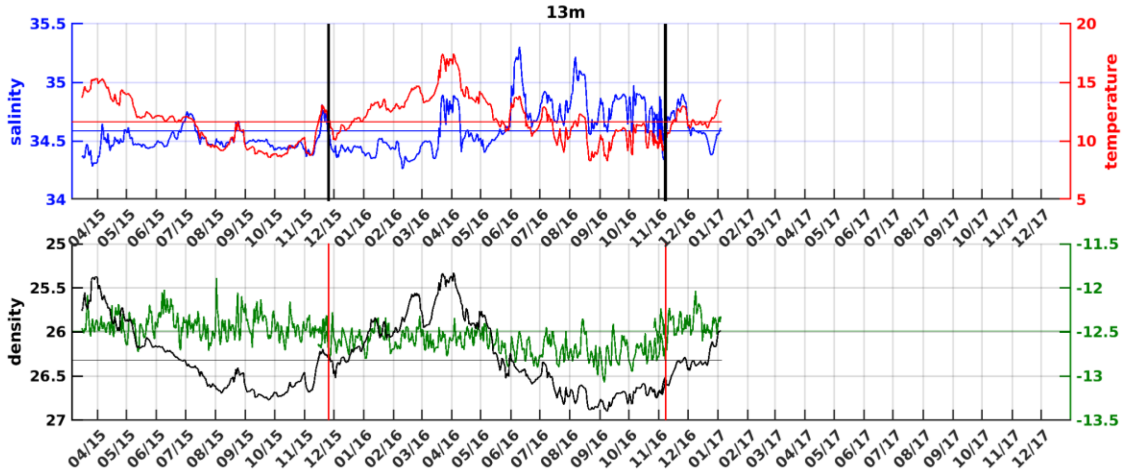


Figure 10: Salinity and temperature std from ctds and from seacats of the surface mooring

2.2 The surface mooring data:

Salinity, temperature, pressure and density time series of the surface mooring from the three deployments resampled at a daily resolution are shown in Figure 11. Spikes were removed from the time series. The salinity and temperature stds are shown in Figure 10 (circles). The potential temperature-salinity diagrams for each mooring deployment is shown in Figure 12. The density at 180 m shows a large increase at the end of deployment 3 starting in September 2017 (Figure 11 and 12). These values are spurious as density at 180m is larger than at 250m. They are probably associated to a problem in the salinity sensor. Therefore these values were removed.


13m
salinity
temperature
density
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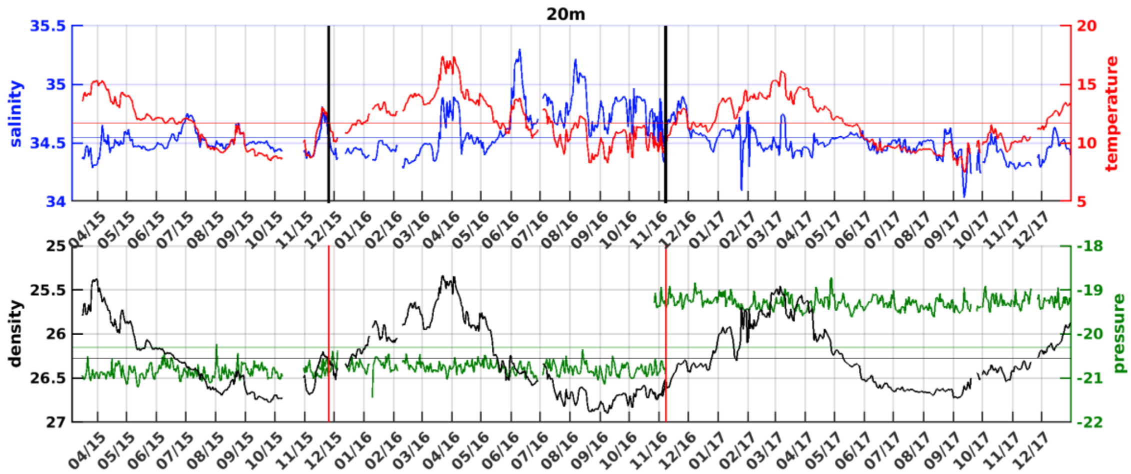
20m
salinity
temperature
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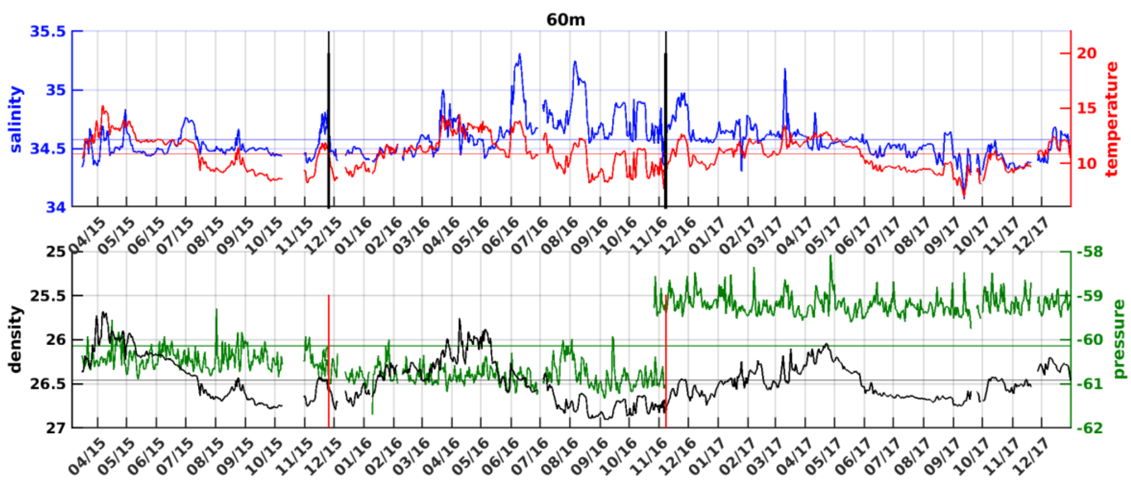
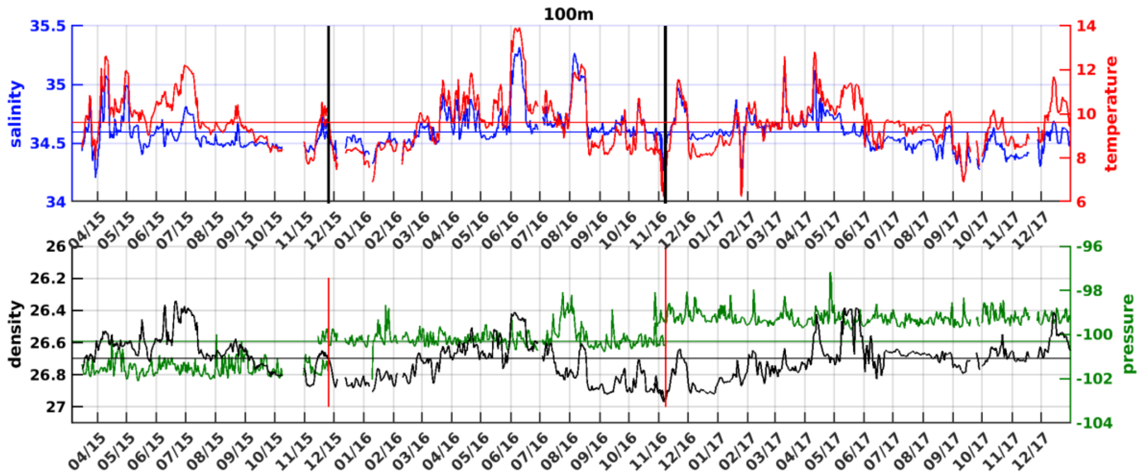

60m
salinity
temperature
density
pressure


100m
salinity
temperature
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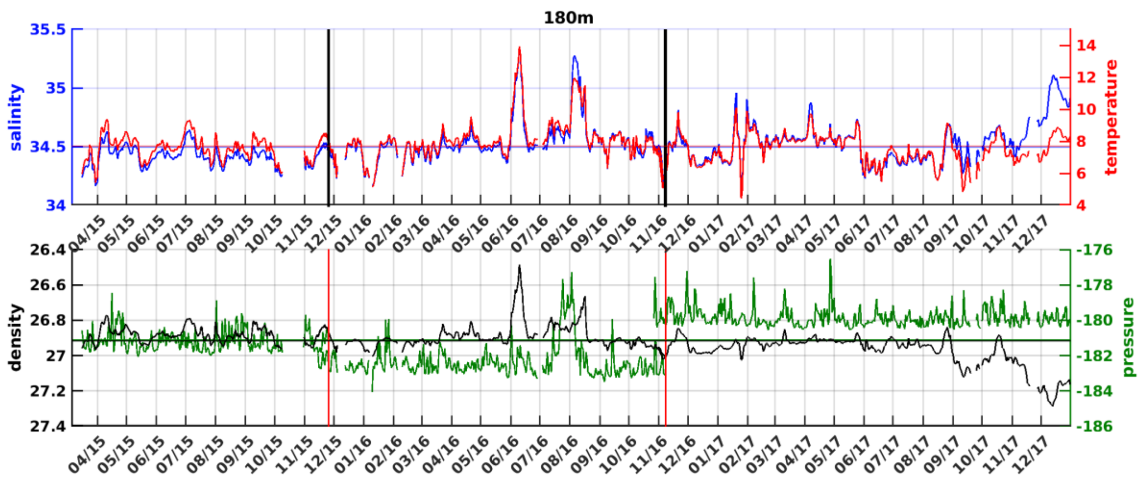
04/15 05/15 06/15 07/15 08/15 09/15 10/15 11/15 12/15 01/16 02/16 03/16 04/16 05/16 06/16 07/16 08/16 09/16 10/16 11/16 12/16 01/17 02/17 03/17 04/17 05/17 06/17 07/17 08/17 09/17 10/17 11/17 12/17


180m
salinity
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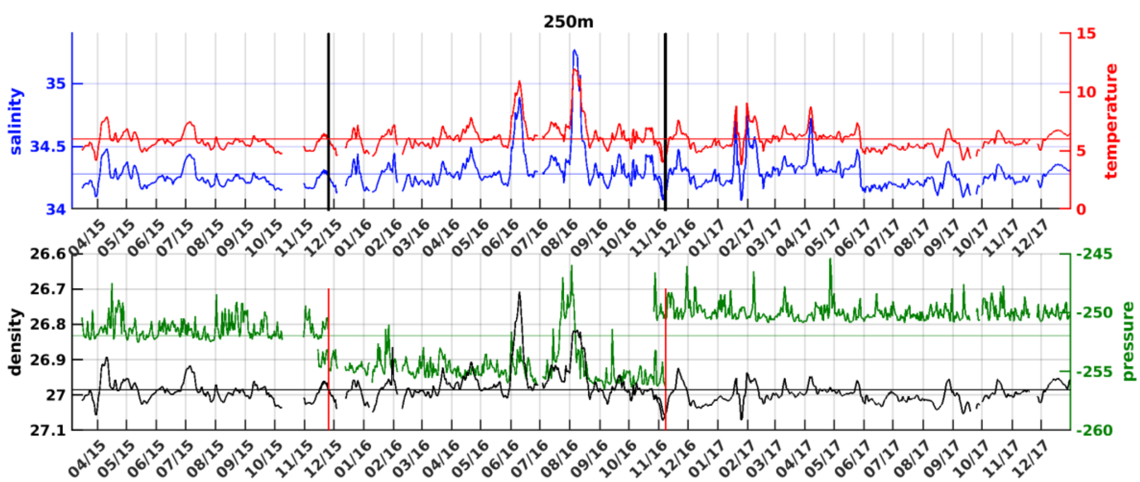
04/15 05/15 06/15 07/15 08/15 09/15 10/15 11/15 12/15 01/16 02/16 03/16 04/16 05/16 06/16 07/16 08/16 09/16 10/16 11/16 12/16 01/17 02/17 03/17 04/17 05/17 06/17 07/17 08/17 09/17 10/17 11/17 12/17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salinity
temperature
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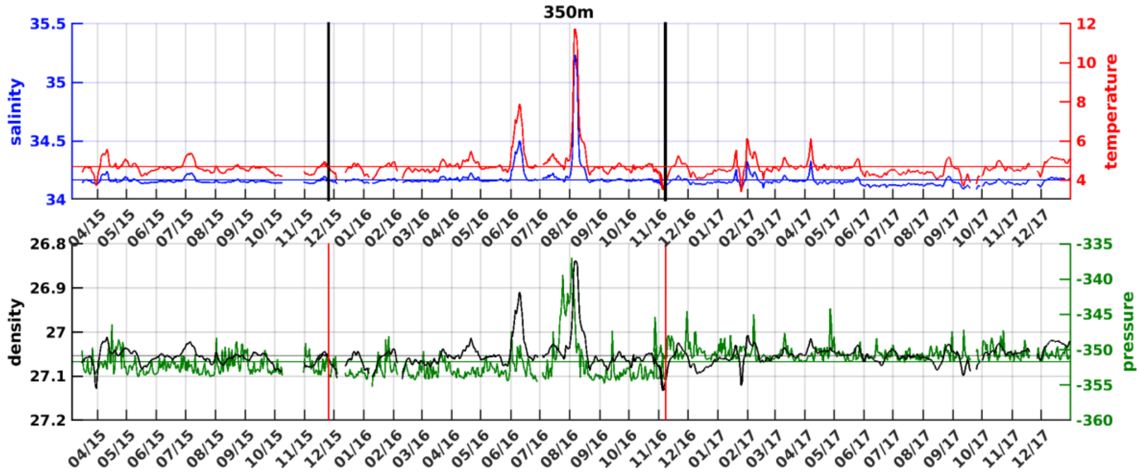
04/15 05/15 06/15 07/15 08/15 09/15 10/15 11/15 12/15 01/16 02/16 03/16 04/16 05/16 06/16 07/16 08/16 09/16 10/16 11/16 12/16 01/17 02/17 03/17 04/17 05/17 06/17 07/17 08/17 09/17 10/17 11/17 12/17


350m
salinity
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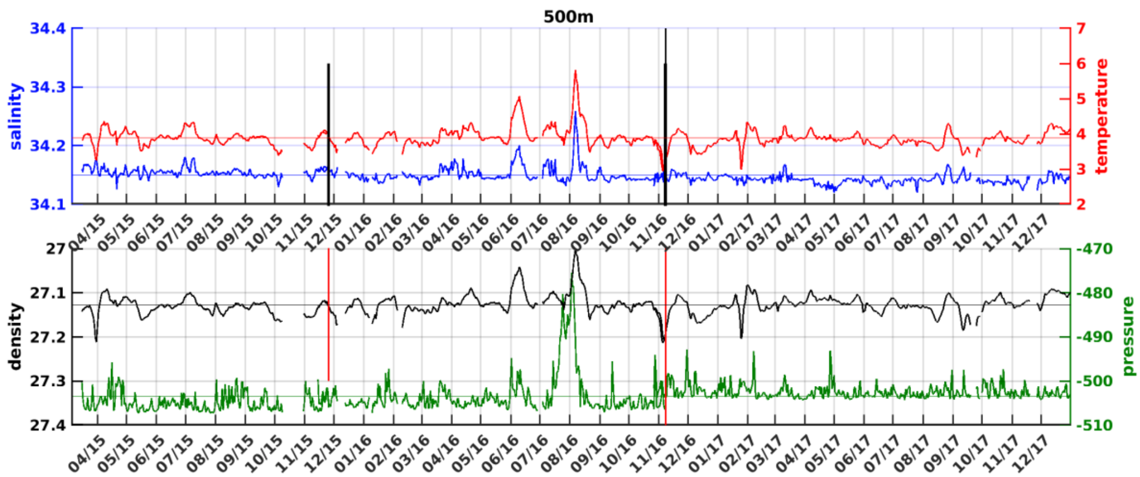
500m
salinity
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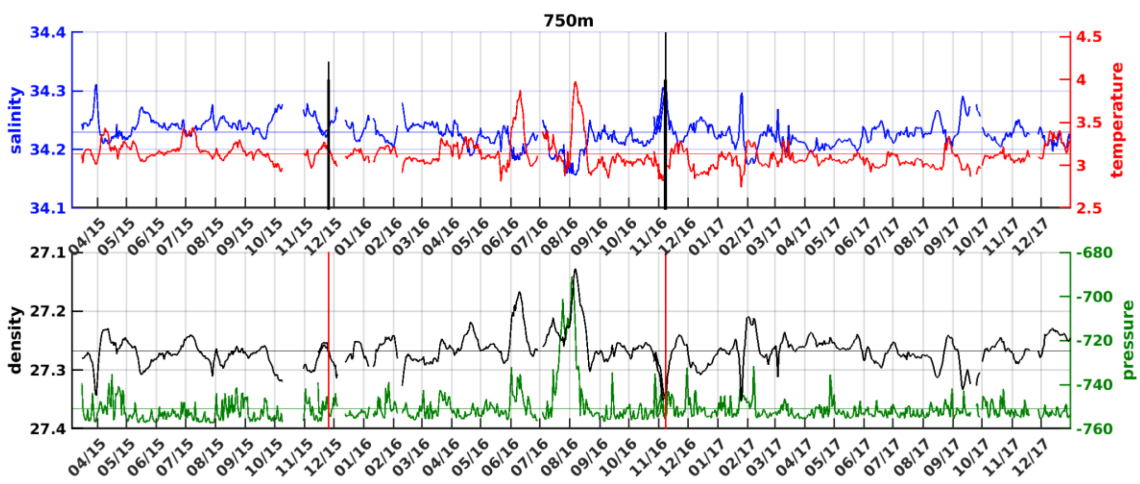
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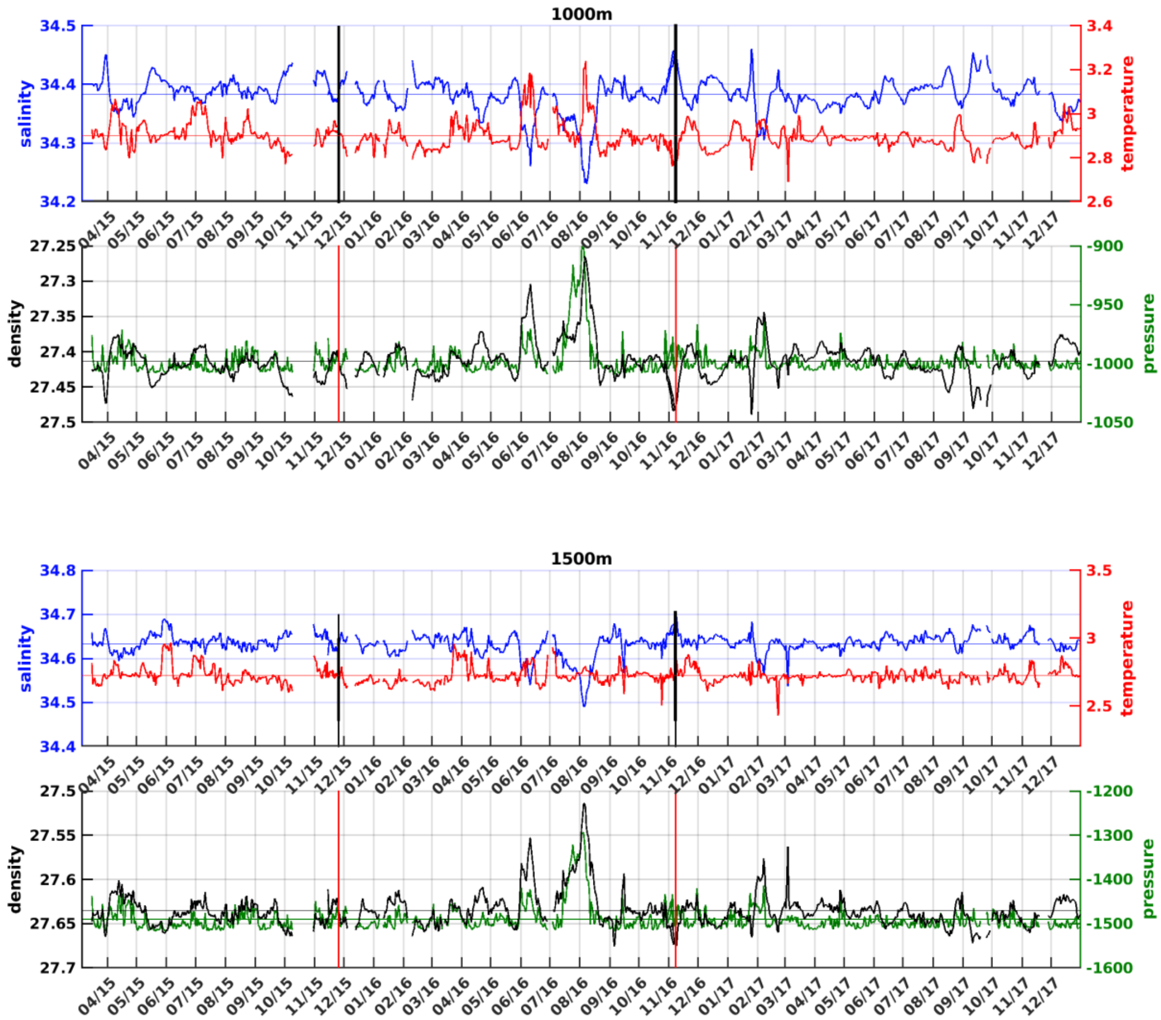


Figure 11: Pressure (from the surface mooring, black curve) and salinity times series from the Apex profiler mooring (blue), surface mooring (blue) and bottle samples (blue dots).

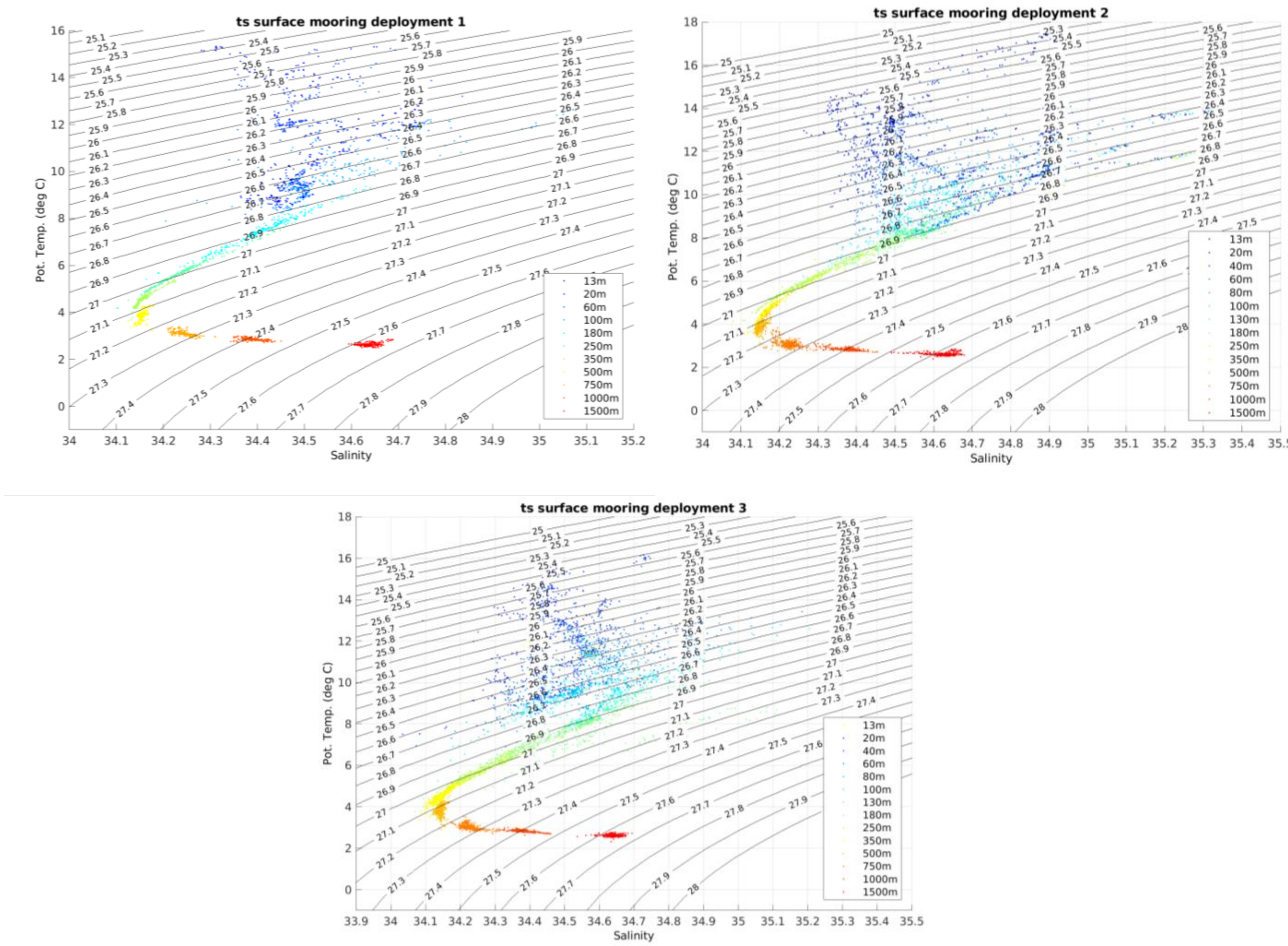


Figure 12: Potential temperature-salinity diagram from surface mooring for each deployment

3.1 Apex mooring:

The data recovered from the Apex profiler was resampled at 1 db of vertical resolution (from 2500 to 5000 db). Figure 13 shows the time series of temperature and salinity from each deployment recorded by the upper and lower profilers after deployment 1, 2 and 3.

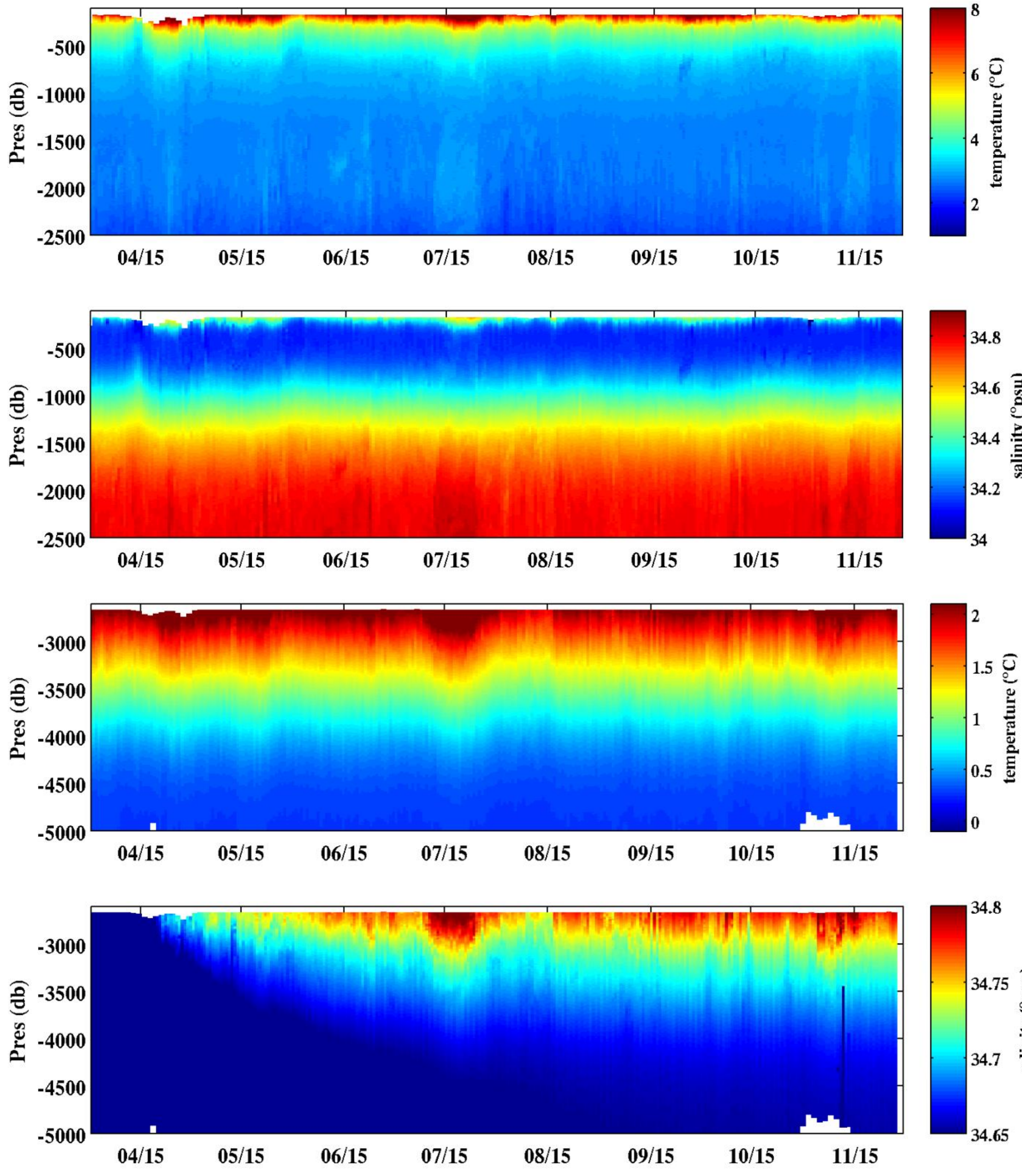


Figure 13 A: Temperature and salinity profiles from the wire-following upper and lower profilers after deployment 1.

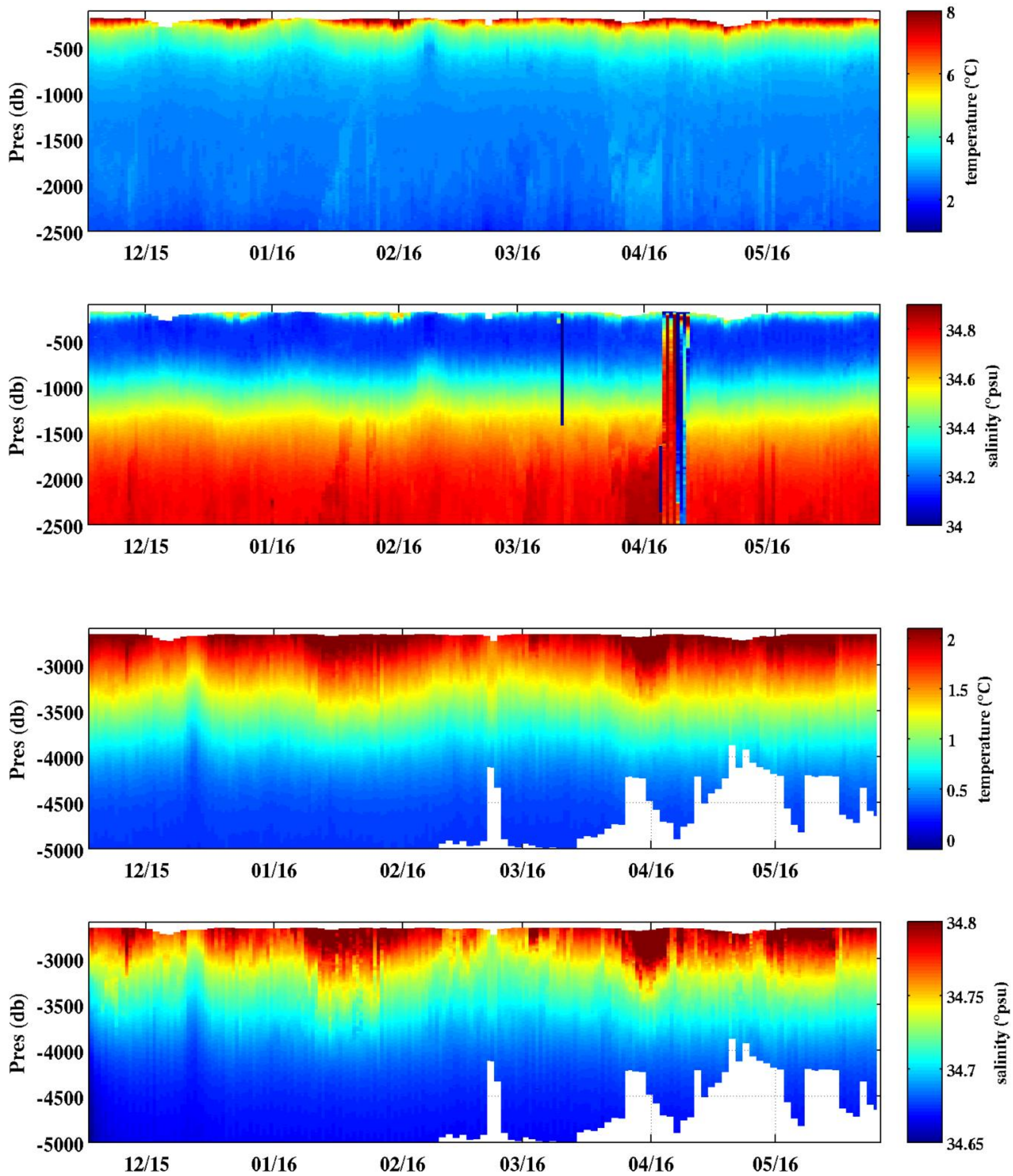


Figure 13 B: Temperature and salinity profiles from the wire-following upper and lower profilers after deployment 2.

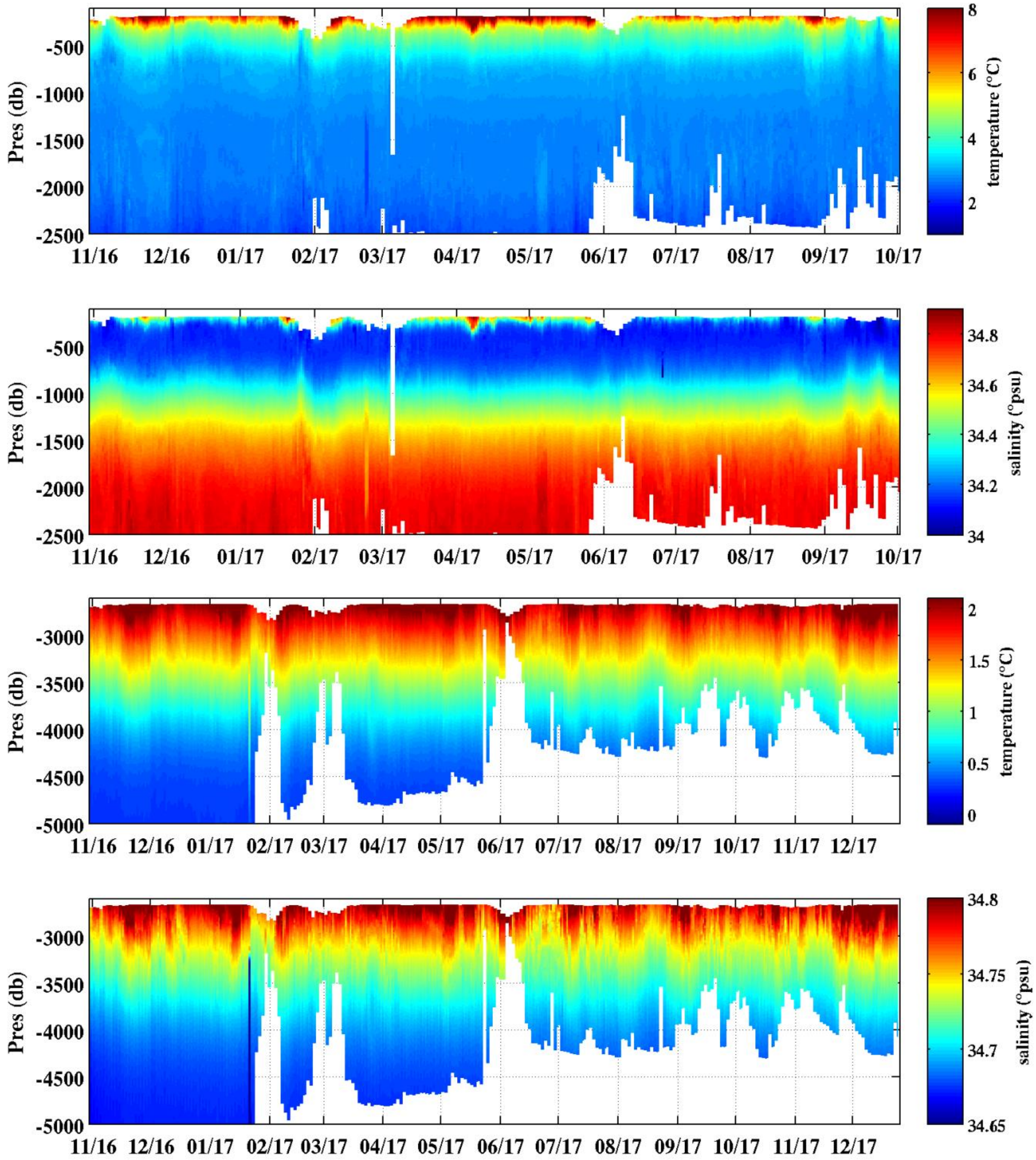
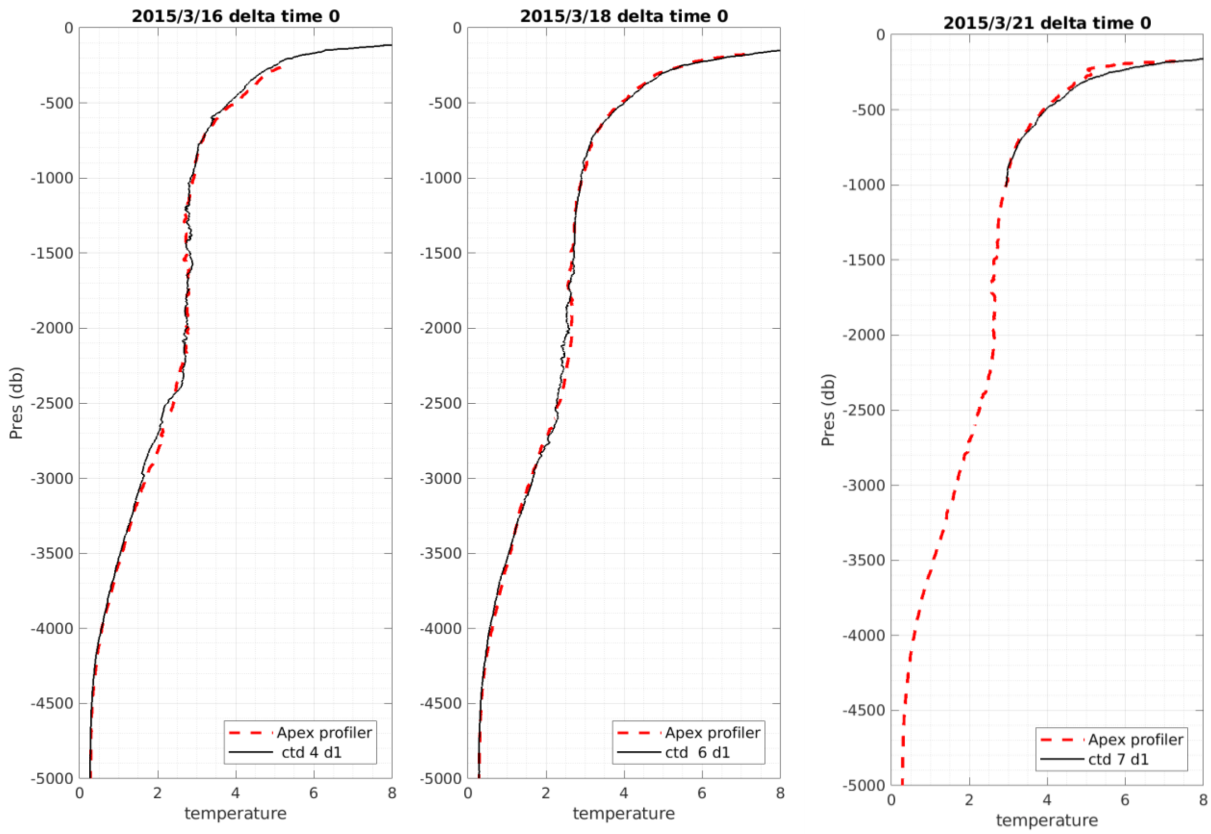


Figure 13 C: Temperature and salinity profiles from the wire-following upper and lower profilers after deployment 3.

3.2 Apex profiler Temperature corrections:

We removed spikes from temperature time series and compared the Apex temperatures to the CTDs measurements (Figure 14) and to the surface mooring temperature time series. Mean temperature differences between the Apex upper profiler and the CTDs measurements were lower than 0.02°C.Temperature differences were larger in the upper 500m and below 2500 m (where the CTDs temperature show large std values , Figure 10). Mean temperature differences between the Apex lower profiler and the CTD measurements were lower than 0.009 °C.



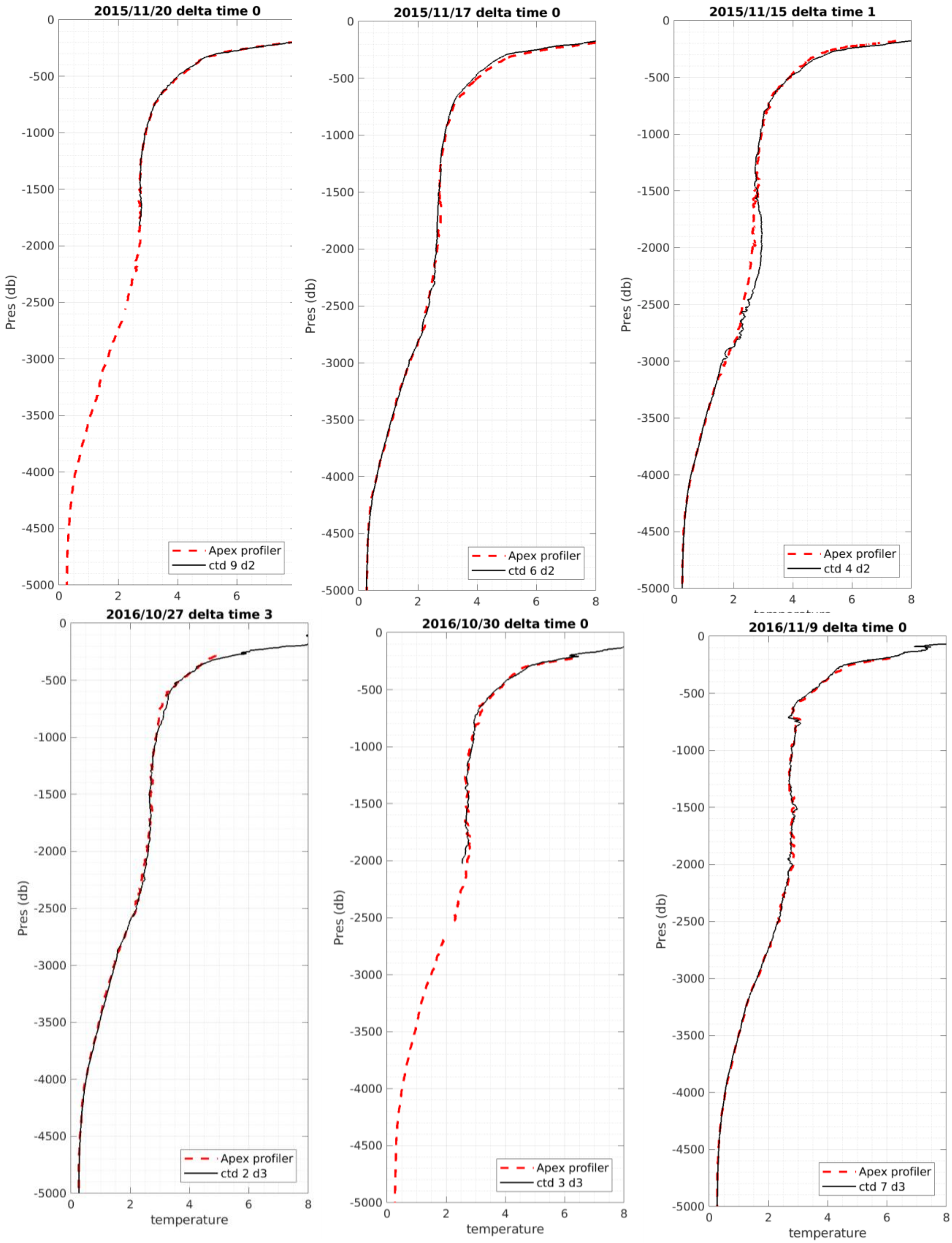


Figure 14: Apex profiler and CTDs temperature measurements

Comparisons with the surface mooring temperature measurements in terms of means and standard deviations were very satisfactory (Figure 15 and 16). Differences in the mean temperature were lower than 0.05°C in the upper 500 m (where std is larger, Figure 16) and lower than 0.002 below 1000 m. There was also a good agreement in terms of standard deviation (Figure 16). The Apex upper profiler temperature standard deviation is slightly larger since in some occasions two profiles are performed in one day while surface mooring measurements were resampled at an exactly daily rate.
The mean temperature at the deepest depth measured by the Apex upper profiler is consistent with the mean temperature measured by the lower upper profiler at the shallowest depth (around 2500m).

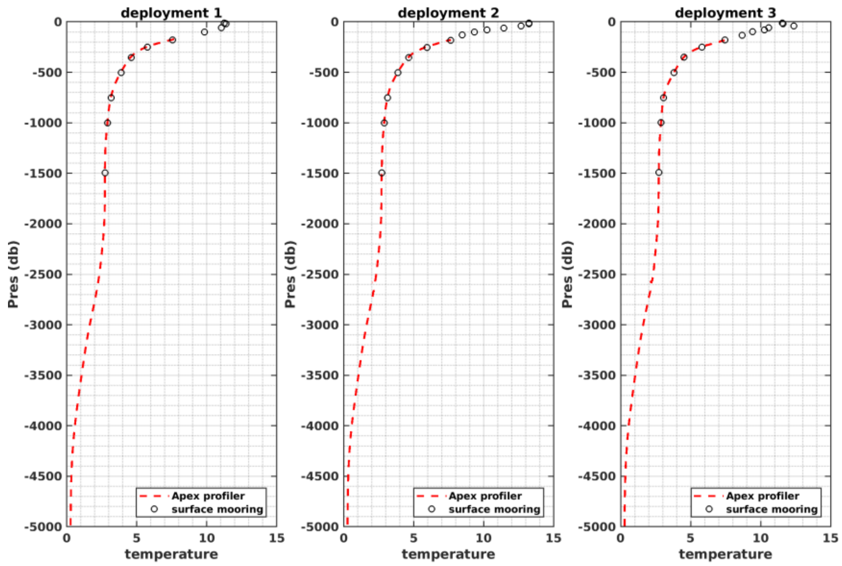


Figure 15: Mean temperature profile from the Apex mooring profiler and the surface mooring measurements for each deployment.

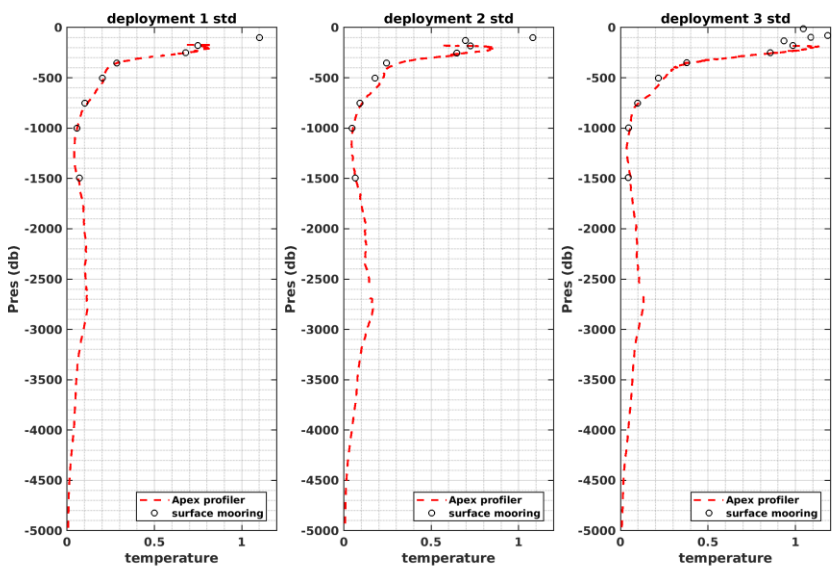
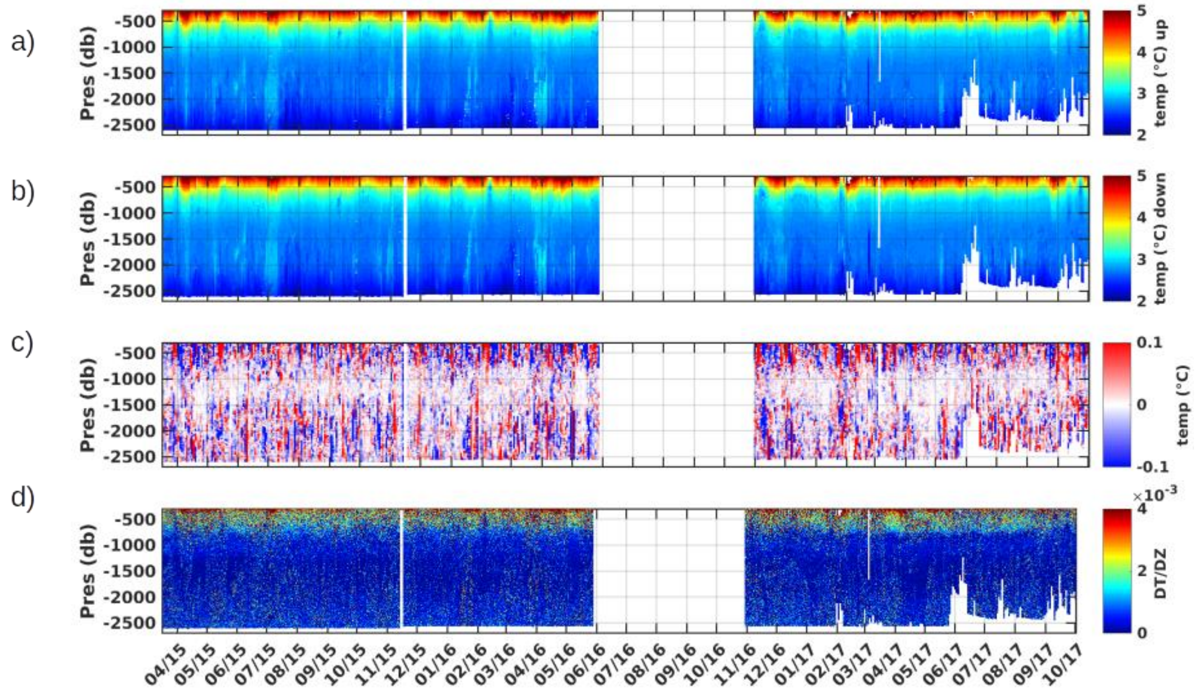


Figure 16: Standard deviation of temperature profiles from the Apex mooring upper profiler and the surface mooring measurements for each deployment.

Upward (Figure 17 a and e) and downward (Figure 17 b and f) temperature profiles from the Apex profilers show differences of the order of 0.1°C between 500 m and 1000 m and between 1500 m and 4000 m (Figure 17 c and g). Differences are smaller between 1000 and 1500 m where the temperature measurements show low std values (Figure 16). To check the consistency of these differences, temperature measurements from the surface mooring were resampled at the Apex mooring measurement rate and differences between consecutive measurements were computed (Figure 18). The temperature differences derived from the surface mooring are in good agreement with the Apex mooring temperature differences, confirming that temperature can fluctuate of the order of 0.1°C over one day.



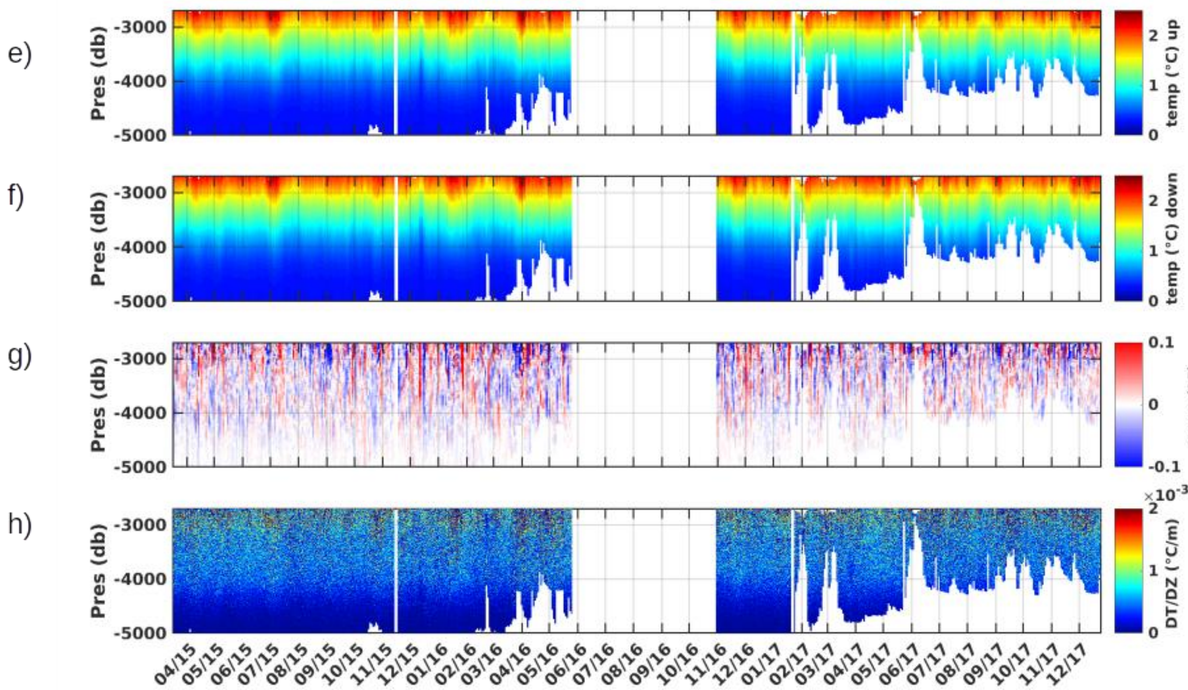


Figure 17 : Upward (a and e) and downward (b and f) temperature profiles from upper and lower Apex mooring profiler, differences between upward and downward profiles (c and g) and vertical temperature gradient (d and h).

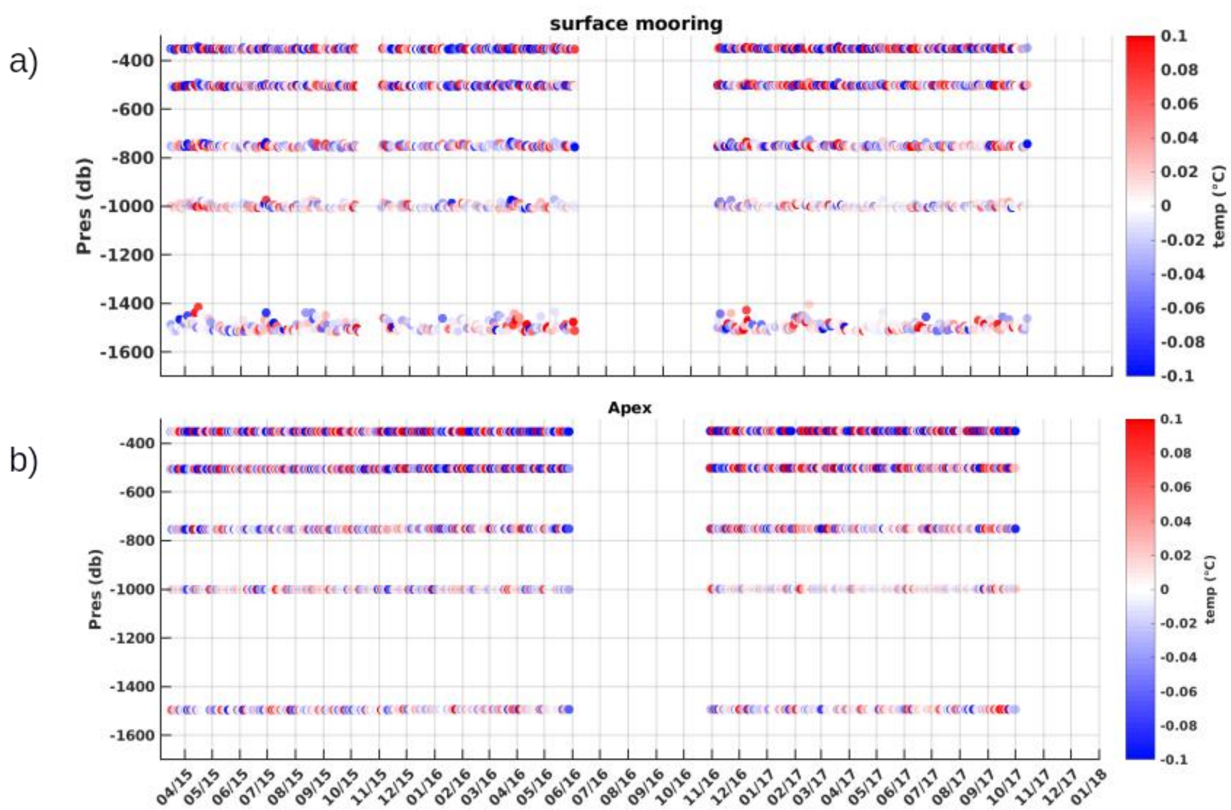


Figure 18. a) Differences between consecutive temperature measurements from surface mooring resampled at the Apex profiler rate. b) Differences between upward and downward temperature profiles at the depths of the surface mooring instruments.

3.3 Apex lower profiler salinity drift:

There is an evident drift in the salinity time series recorded by the lower Apex profiler from deployment 1 and 2 (Figure 13 A and B). Potential drifts are less obvious for deployment 3 and seem to occur at the beginning of the time series. To correct the time series from the drift we assume that the salinity at 4800 m is constant and use the CTD data to compute the offset to correct the data (Figure 19,20 and 21). Indeed, the standard deviation of the deep CTDs at 4800 m is lower than 0.001 psu providing an estimation of the error associated to the correction.

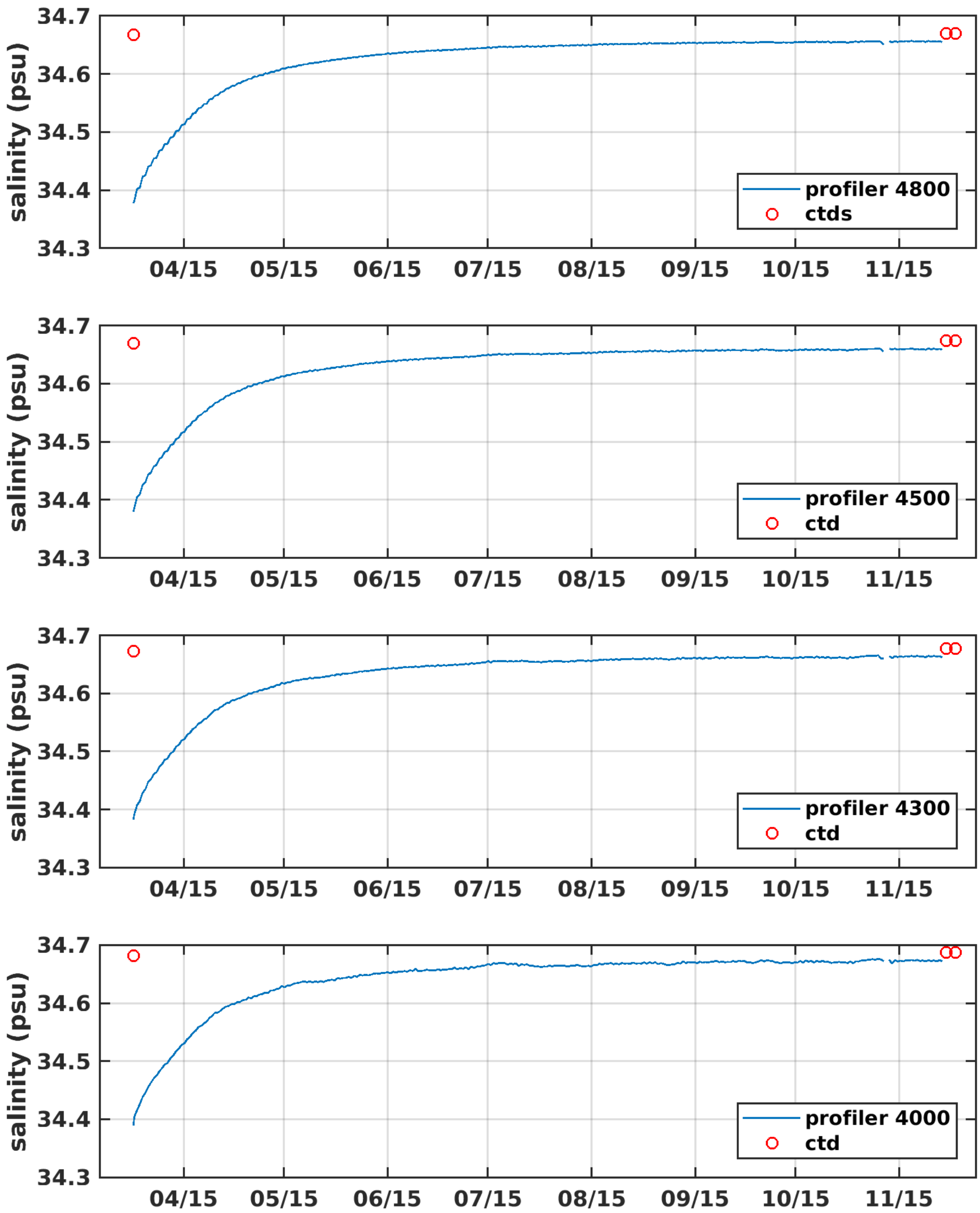


Figure 19: Salinity time series from the Apex lower profiler at different depths and corresponding ctd measurements (red dots) from deployment 1 .

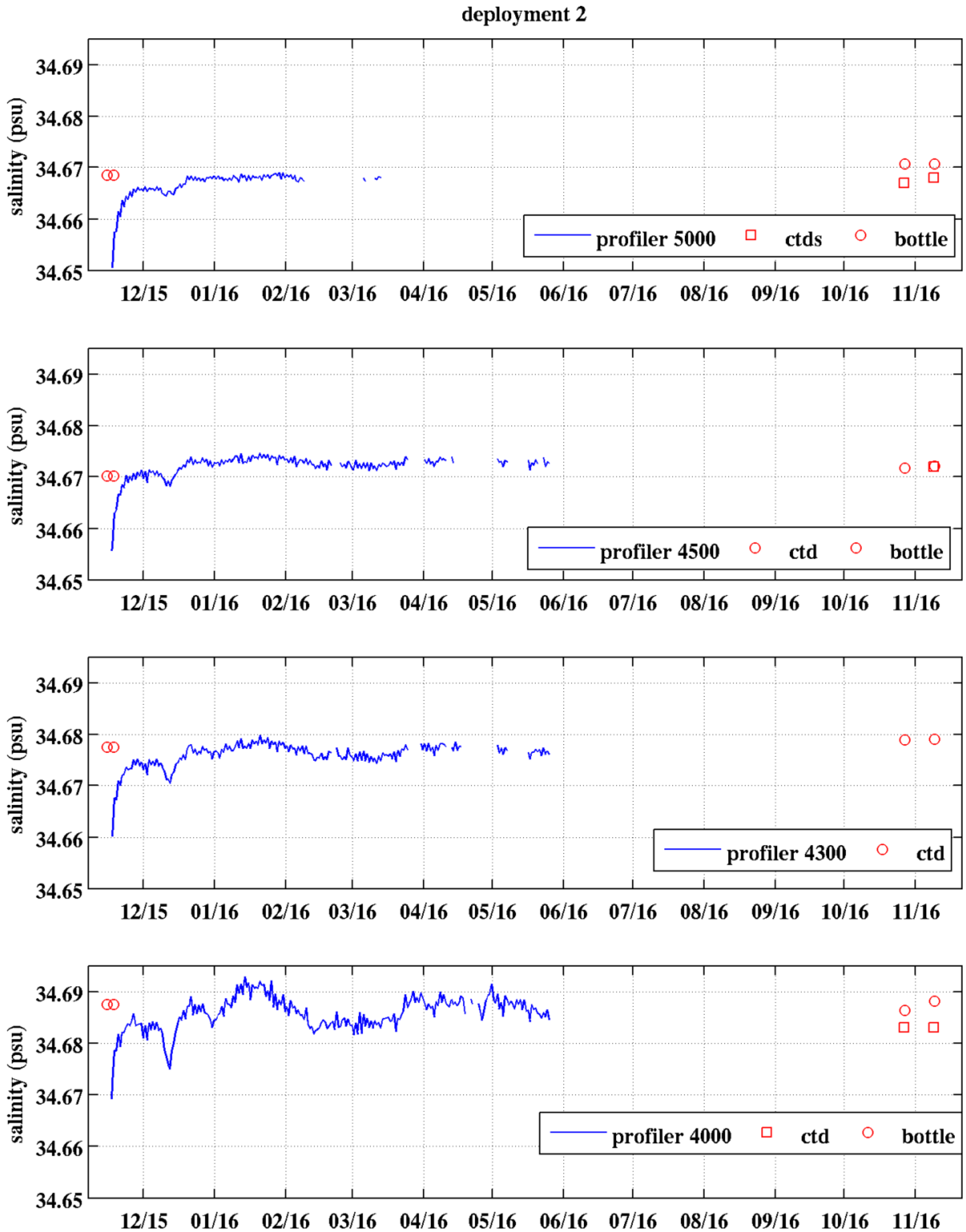


Figure 20: Salinity time series from the Apex lower profiler at different depths and ctds (red dots) and bottle samples (squares) measurements from deployment 2 . Note that the Apex lower profiler suffers an early stop in June 2016.

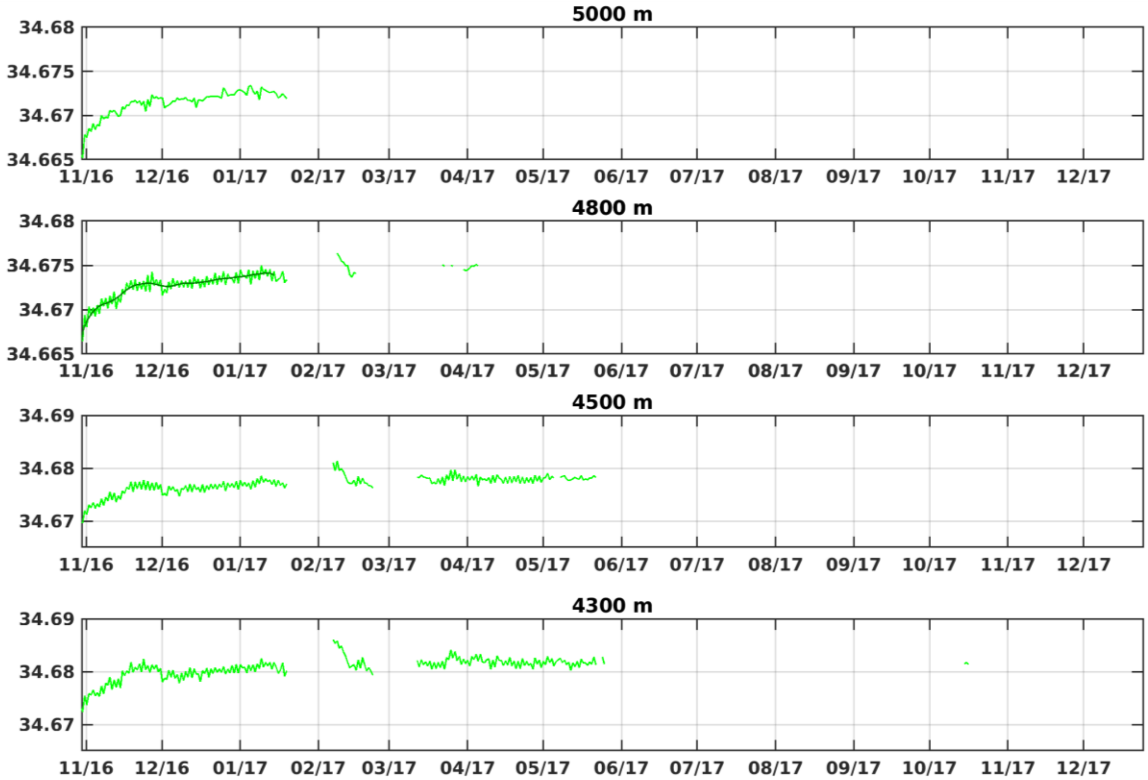


Figure 21: Salinity time series from the Apex lower profiler from deployment 3 at different depths. Correction was applied from November 2016 to January 2017.

Time series at selected depths after drift correction are shown in Figure 21. It seems to be a small increase of salinity below 3500 m between deployments. The increase in salinity is on the order of 0.002 psu which is the instrument precision. The salinity profiles from the CTD also show a salinity increase of 0.01 psu at depths between the first and last deployment (Figure 22).

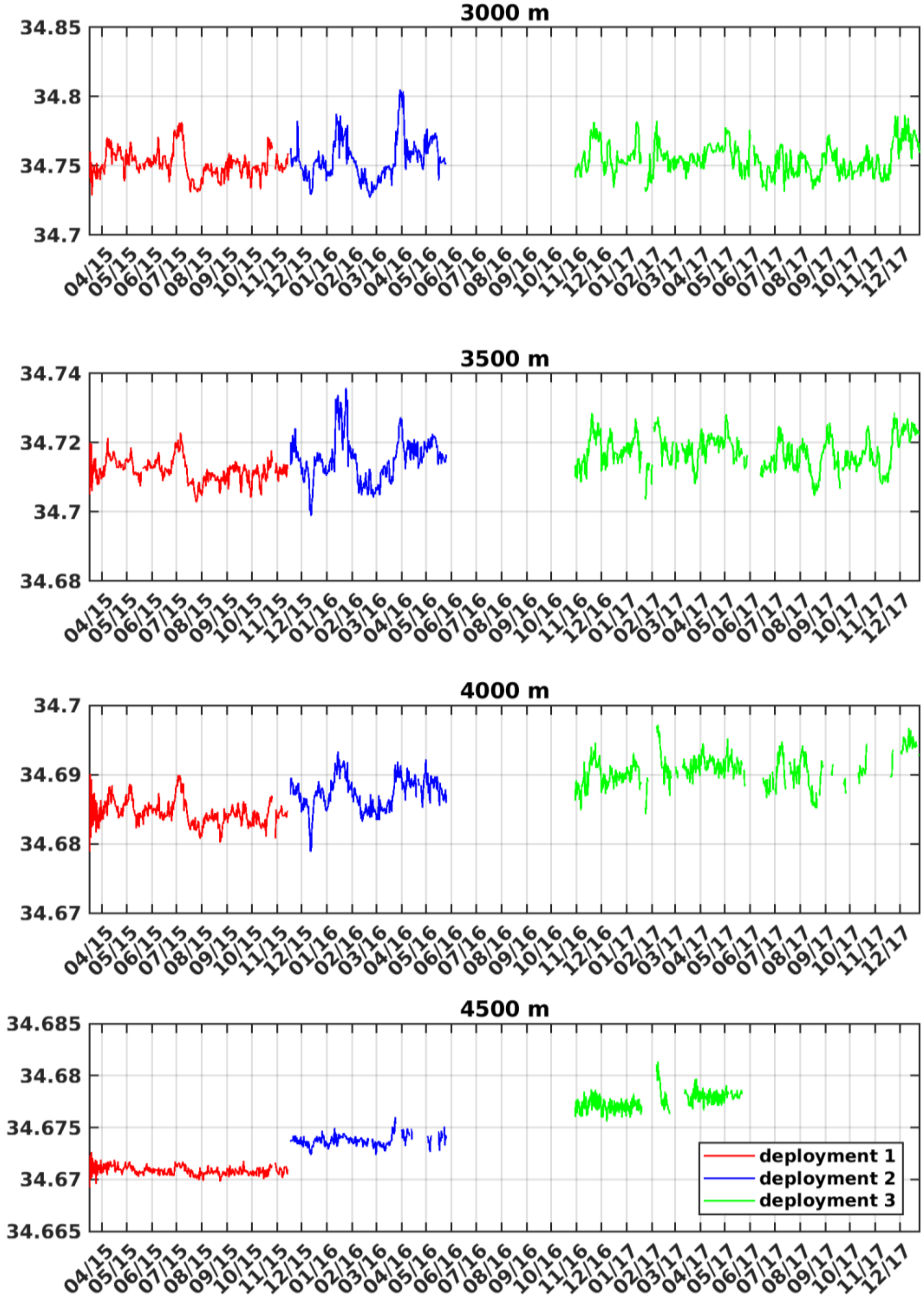


Figure 21: Salinity time series at selected depths from lower Apex profiler from deployment 1 (red), 2 (blue) and 3 (green) after drift correction was applied.

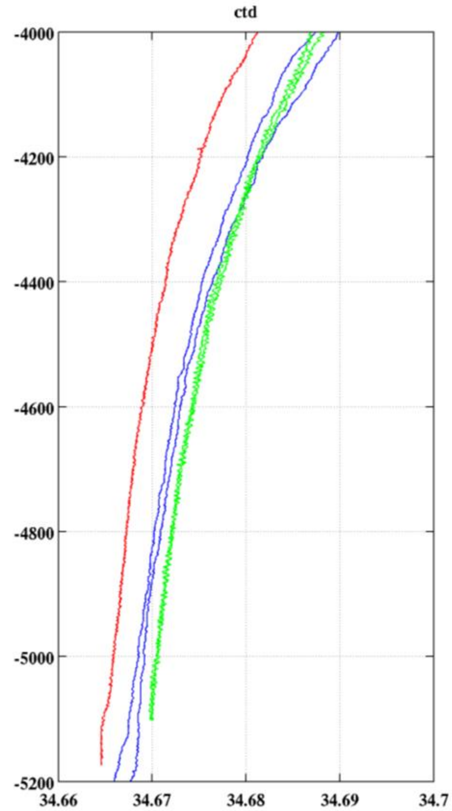
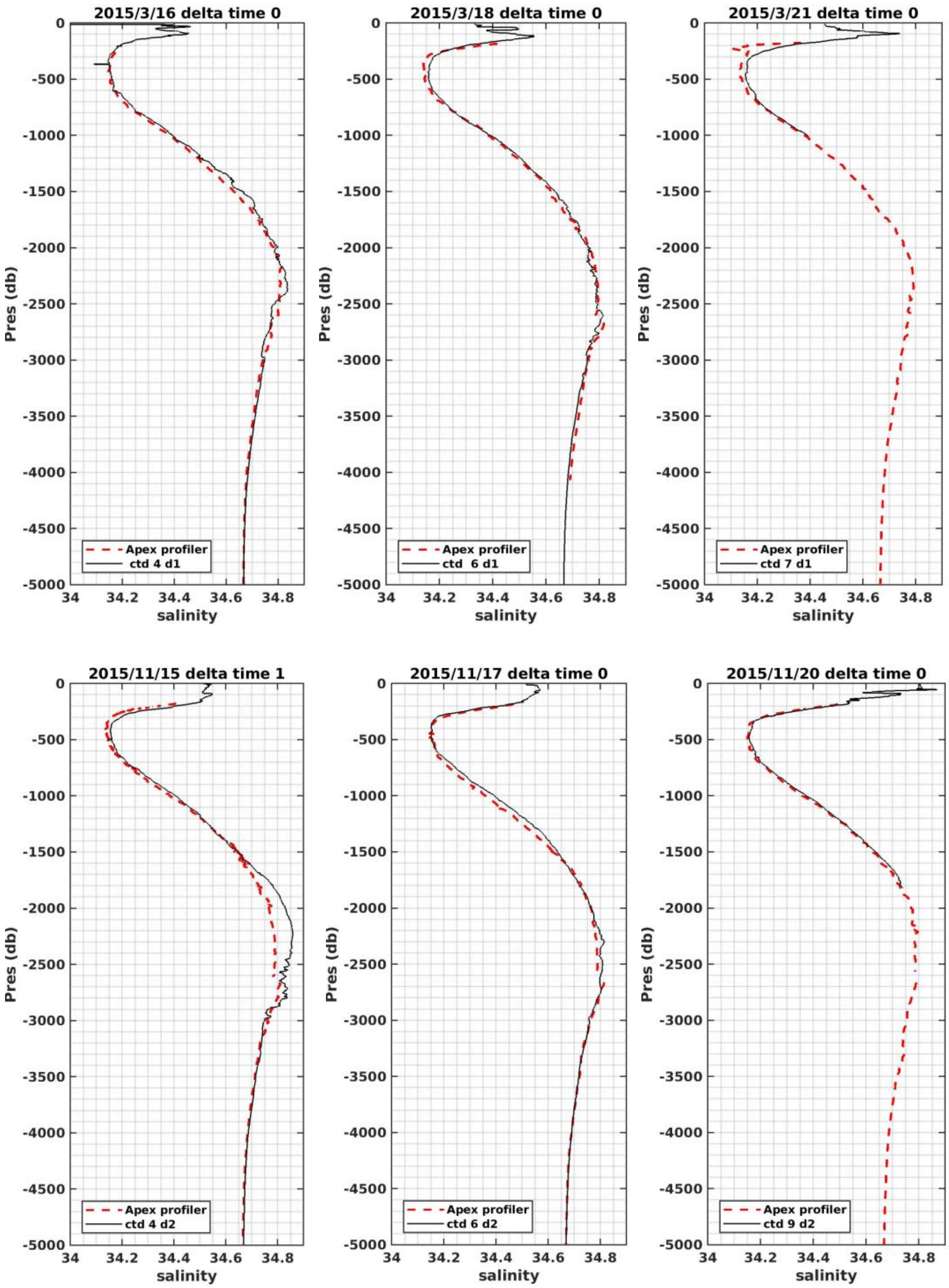


Figure 22: Salinity profiles in the last 1200 m from the CTD from the first deployment (red profile), second deployment (blue profile) and third deployment (green profile).

3.4 Apex upper and lower profiler salinity corrections:

We removed spikes from salinity time series and compared the Apex salinities to the CTDs measurements (Figure 23) and to the surface mooring temperature time series. Mean salinity differences between the Apex upper (lower) profiler and the CTD measurements were smaller than 0.003 psu (0.0005 psu).



2015/3/16 delta time 0
Apex profiler
ctd 4 d1
2015/3/18 delta time 0
Apex profiler
ctd 6 d1
2015/3/21 delta time 0
Apex profiler
ctd 7 d1
2015/11/15 delta time 1
Apex profiler
ctd 4 d2
2015/11/17 delta time 0
Apex profiler
ctd 6 d2
2015/11/20 delta time 0
Apex profiler
ctd 9 d2
Pres (db)
salinity

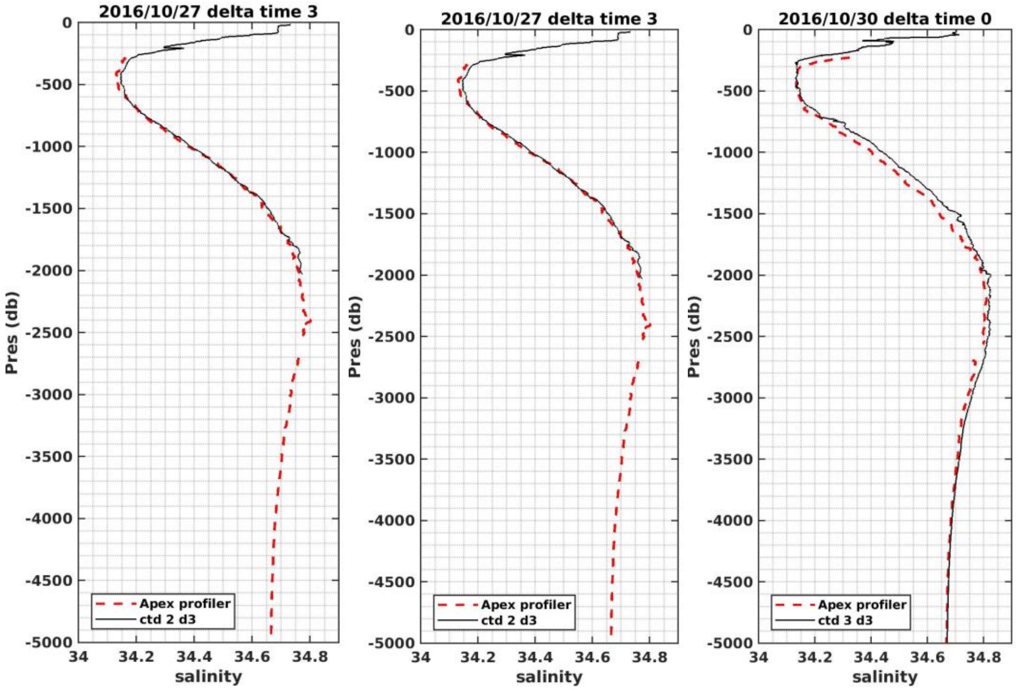


Figure 23: Apex profiler and CTDs salinity measurements

Comparisons with the surface mooring salinity measurements in terms of mean and std were very satisfactory (Figure 24 and 25). Differences in the mean and std salinity were of the order of 0.05 psu and 0.005 psu (slightly larger during the second and third deployment).
As observed in the mean Apex temperature profiles, the mean Apex salinity profiles (Figure 24) show a consistency between the upper profiler deepest measurements (around 2500 m) and the lower profiler shallower measurements.

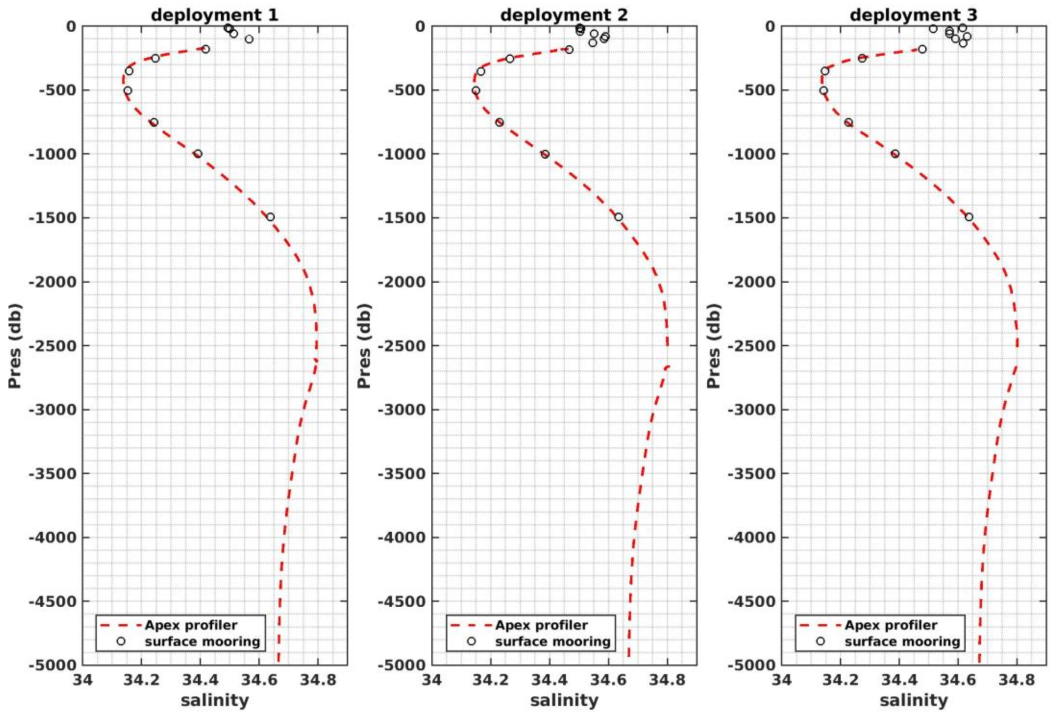


Figure 24: Mean salinity profile from the Apex mooring profiler and the surface mooring measurements for each deployment

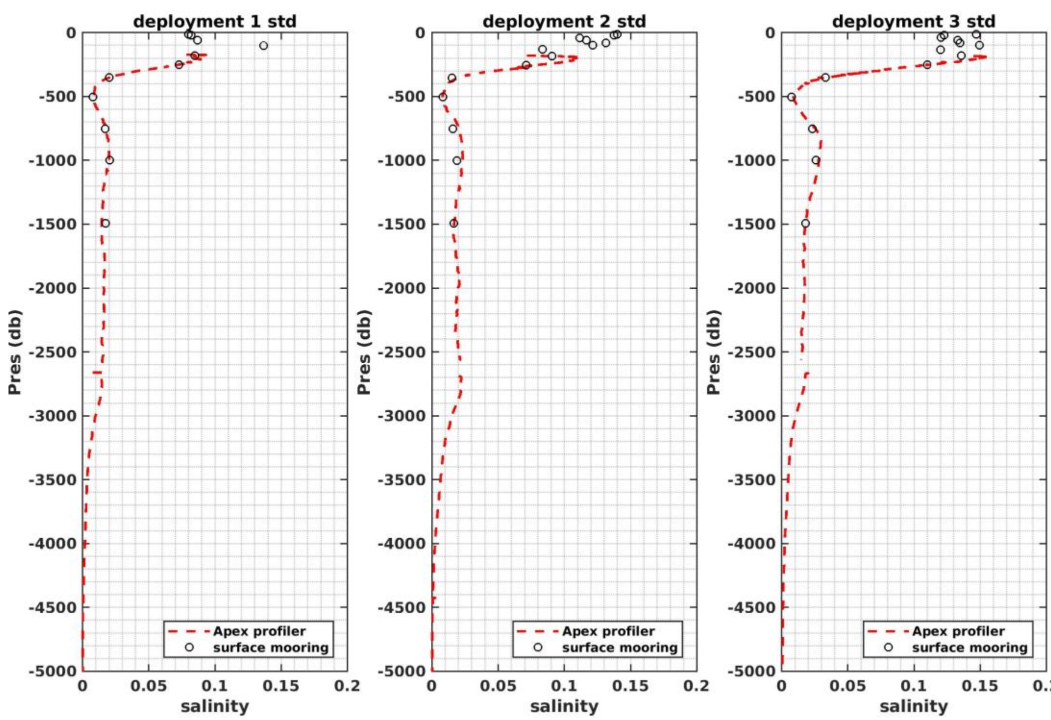


Figure 25: Mean salinity profile from the Apex mooring profiler and the surface mooring measurements for each deployment

We separated the ascendant (Figure 26. a and e) and the descendant salinity profiles (Figure 26.b and f) and computed their differences (Figure 26.c and g). The differences between the ascendant and descendant profiles are relatively small (<0.01 psu) except for the beginning of the salinity time series recorded by the lower Apex profiler from deployment 1 (Figure 26.g). Therefore salinity values from April to mid May 2015 need to be considered with caution.

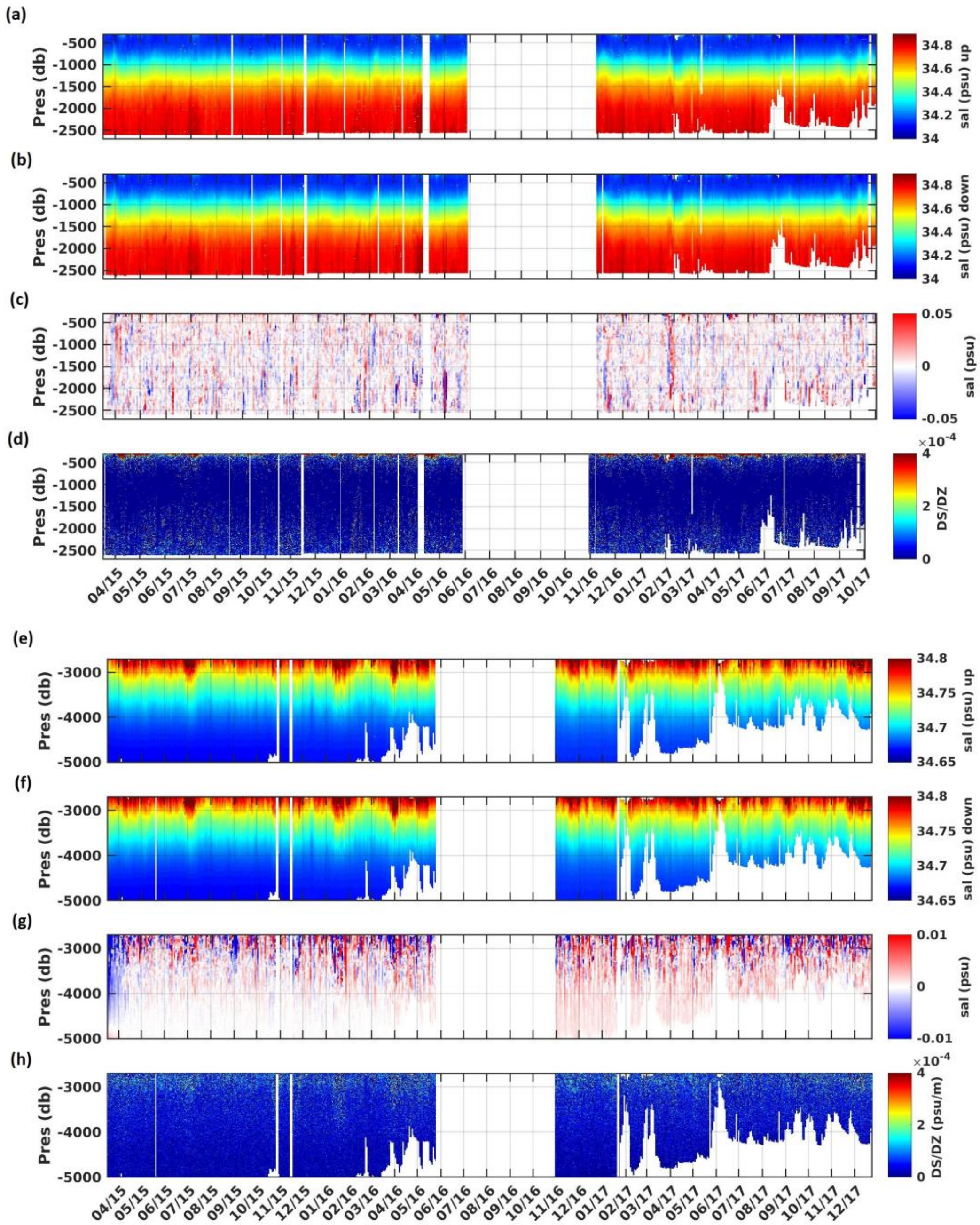


Figure 26 : Upward (a and e) and downward (b and f) salinity profiles from upper and lower Apex mooring profiler, differences between upward and downward profiles (c and g) and vertical salinity gradient (d and h).

To check the consistency of the salinity differences between the ascendant and descendant profiles, salinity measurements from the surface mooring were resampled at the Apex mooring measurement rate and differences between consecutive measurements were computed (Figure 27). The salinity differences derived from the resampled surface mooring are in good agreement with the Apex mooring salinity differences, confirming that salinity can fluctuate of the order of 0.05 psu over one day.

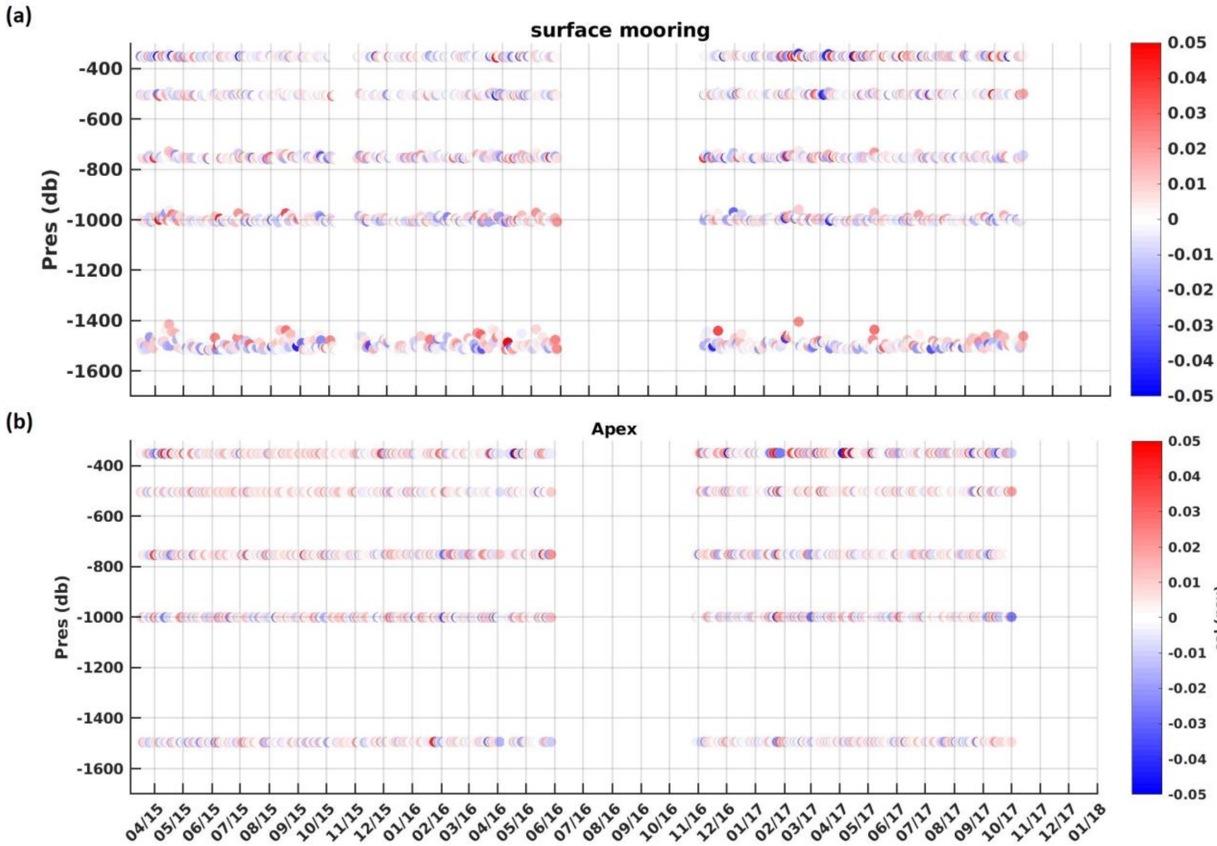


Figure 27. a) Differences between consecutive salinity measurements from surface mooring resampled at the Apex profiler rate. b) Salinity differences between upward and downward temperature profiles at the depths of the surface mooring instruments.

After removing spikes from temperature and salinity time series, we checked for density inversions. We computed the density vertical gradient for the upper and lower profiler measurements and removed those points that presented a vertical density gradient smaller than -0.001 (c.f Figure 28 as an example). Approximately 0.15% of the total points were removed for the upper and lower Apex mooring profiles.

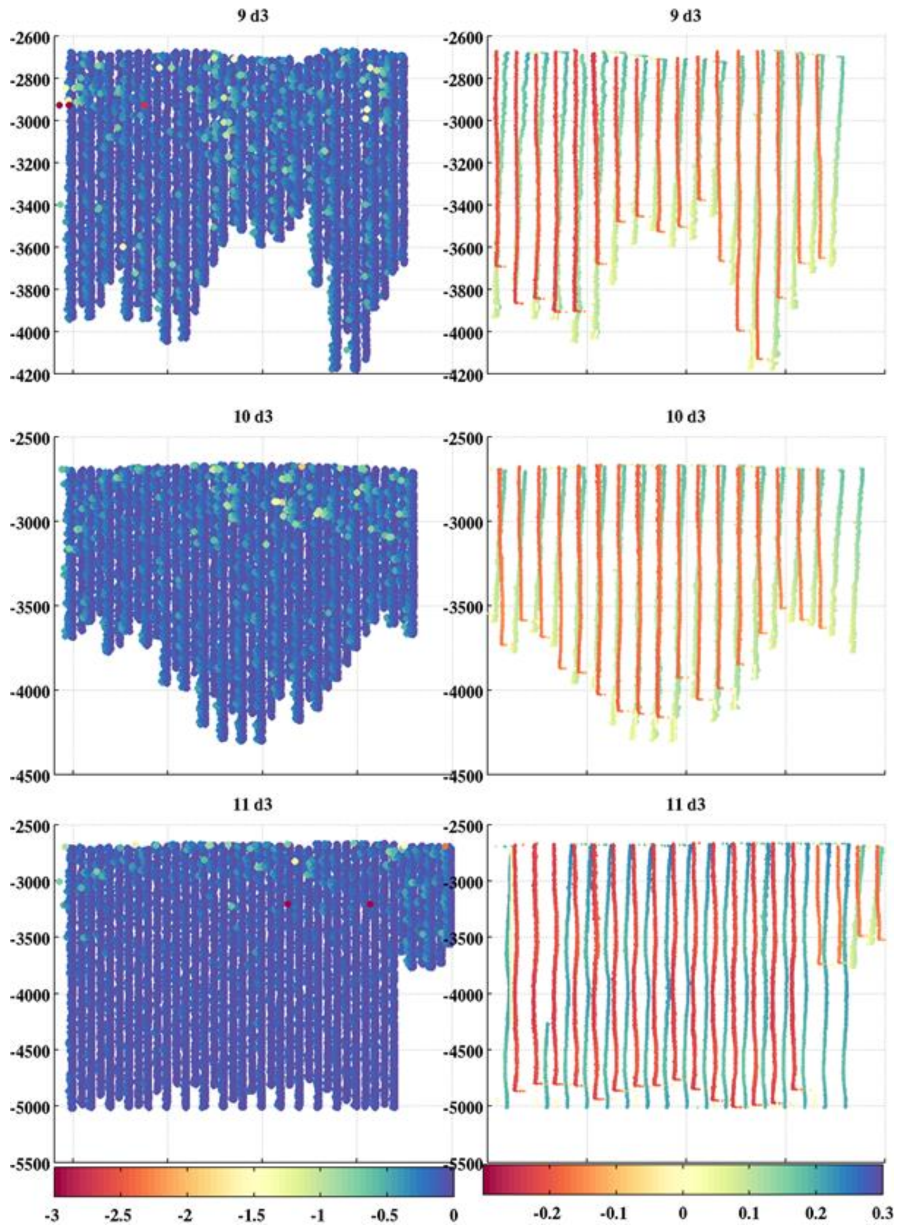


Figure 28: Left column vertical density gradient for September (upper), October (middle) and November 2017 for the Apex lower profiles. Values smaller than -0.001 kg/m^2 (corresponding to red colors) were removed. The left column indicates the ascendant and descendant velocity of the Apex for each profile in m/s.

4. Corrected time series:

The time series obtained after applying corrections and calibrations described in section 3 are shown in Figure 29.

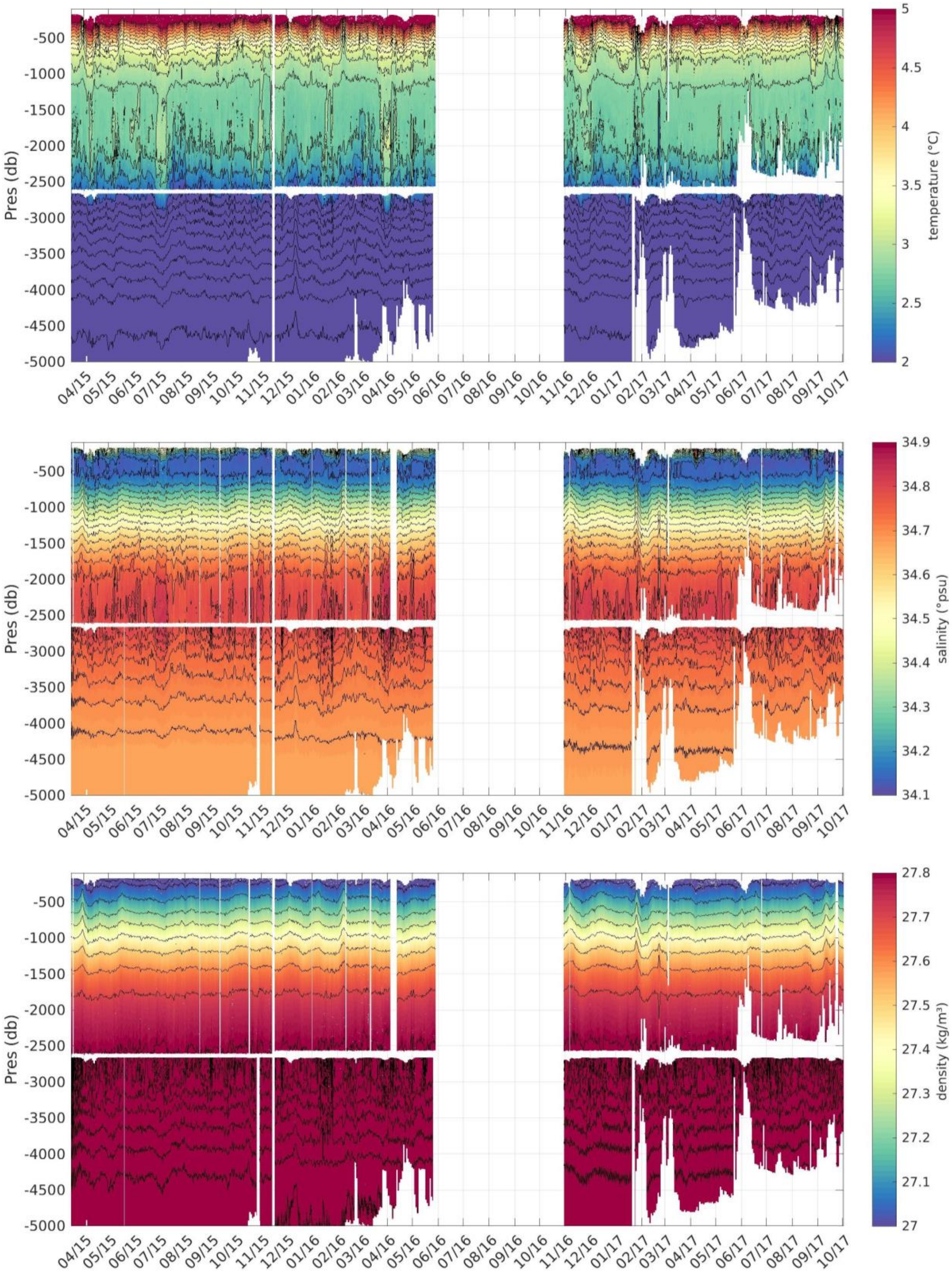


Figure 29: Corrected time series corrections described in section 3

5. Mooring A and B:

Salinity, temperature,pressure and density time series of the subsurface flanking mooring A and B from the three deployments resampled at a daily resolution are shown in Figure 30 and 31. Spikes were removed from the time series.

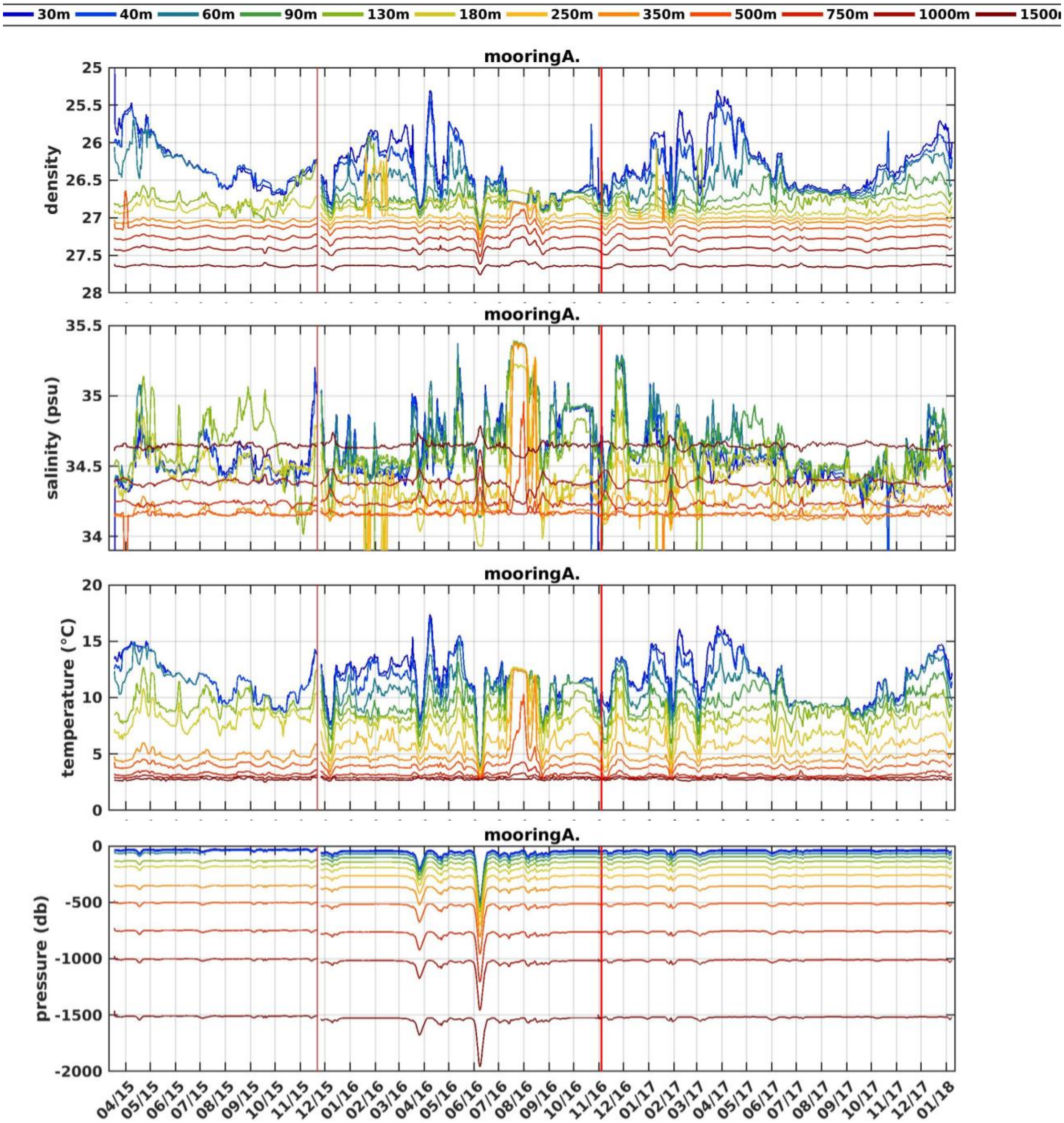


Figure 30: Potential density, salinity, temperature and pressure time series from Subsurface Flanking Mooring A.

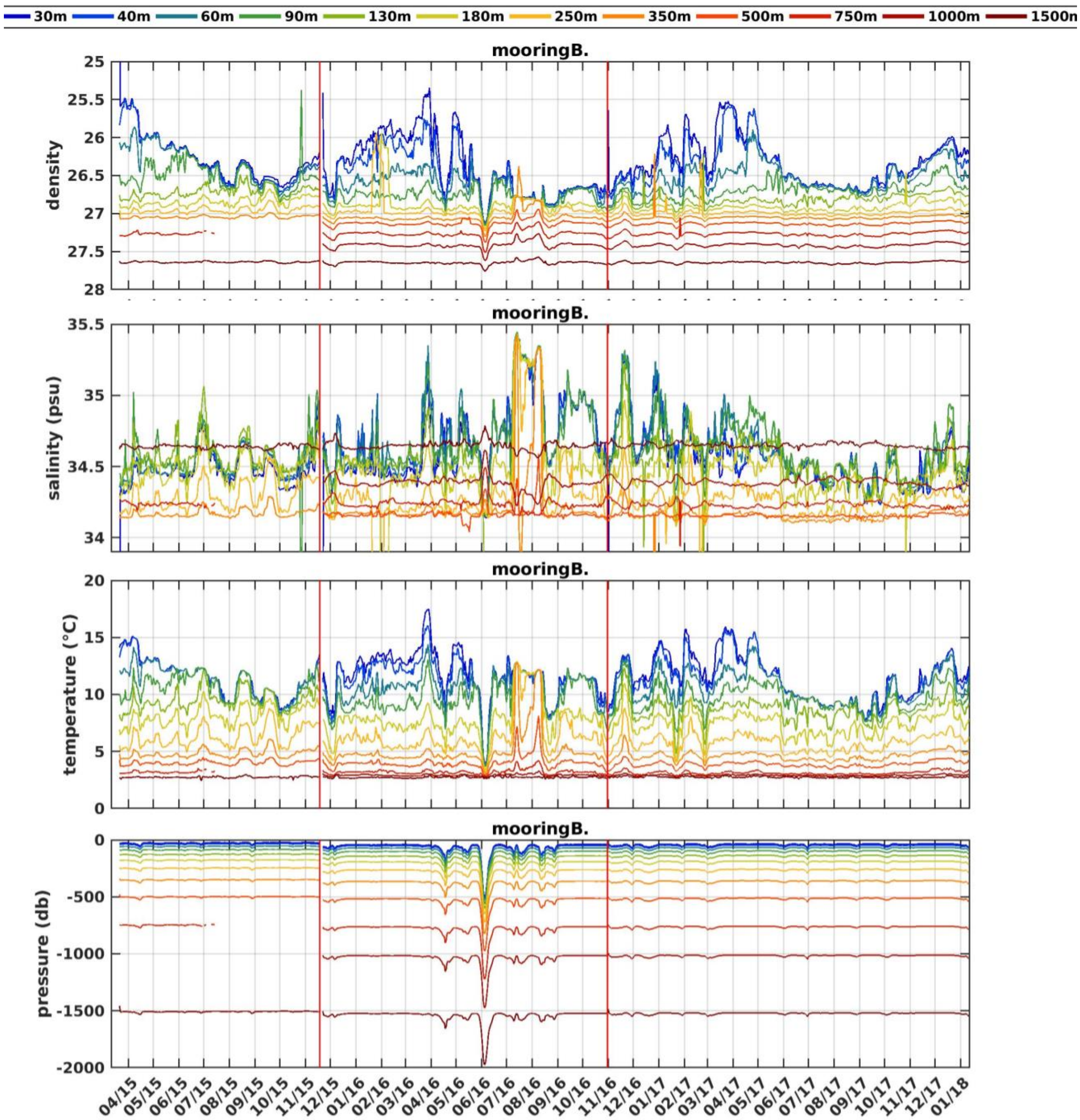


Figure 31: Potential density, salinity, temperature and pressure time series from Subsurface Flanking Mooring B.

Comparisons between temperature and salinity measurements from subsurface flanking moorings A and B with bottle samples and CTD cast were very satisfactory (Figure 32 and Figure 33).

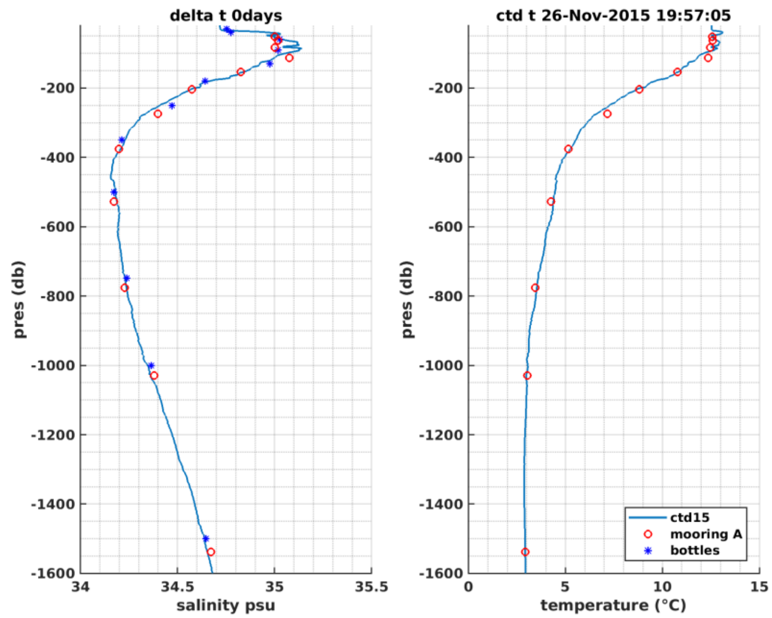


Figure 32: Salinity (left) and temperature (right) profiles from CTD cast from 26 November 2015 (see location in Figure 5), salinity from bottle samples is shown with blue stars and measurements from Subsurface flanking mooring with red circles.

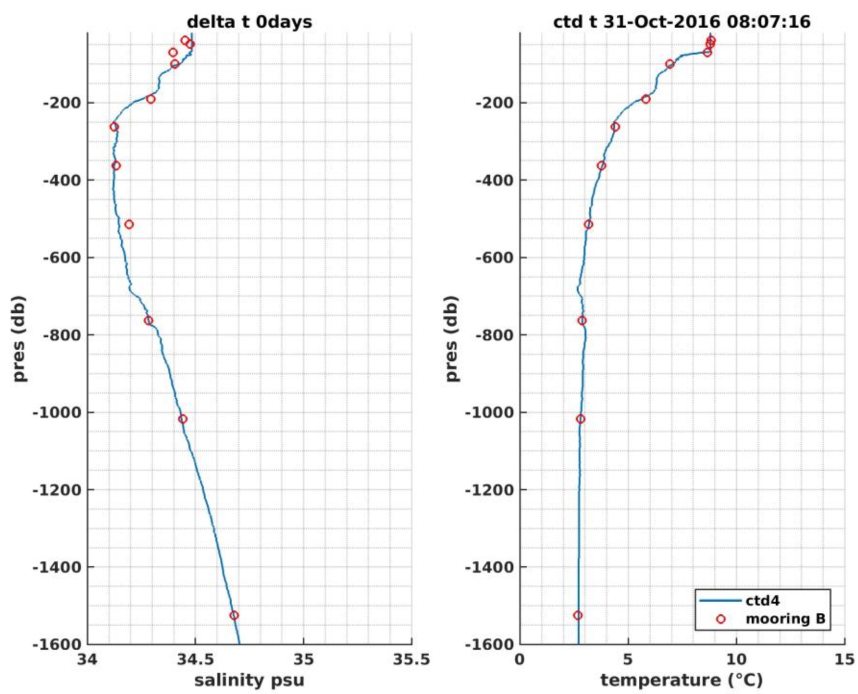


Figure 32: Salinity (left) and temperature (right) profiles from CTD cast from 31 October 2016 (see location in Figure 5), salinity from bottle samples is shown with blue stars and measurements from Subsurface flanking mooring with red circles.