Some comments on the accuracy of the high frequency Temperature, Salinity and Pressure data from the FRS Seabird 911plus

Sherwin, Toby; Lichtman, D

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by

TJ Sherwin (SAMS) and D Lichtman (Fisheries Research Services, Aberdeen)

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Dunstaffnage Marine Laboratory
Dunbeg
Oban
Argyll
PA37 1QA

Tel: 01631 559000
Fax: 01631 559001
http://www.sams.ac.uk

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Summary

Raw laboratory and *in situ* data from the FRS CTD have been used to examine the performance of the system at a high sampling frequency (i.e. 24 Hz). The temperature signal is the best behaved and seems to perform according to the manufacturers' specification. There is a small oscillation in pressure that can be eliminated by averaging the data over 1 second. The salinity data have a 4.3 Hz oscillation with an amplitude of up to 0.01 units, and it is recommended that they are block averaged over at least 1 second to reduce the oscillation to an acceptable level

1. Introduction

The raw high frequency (24 Hz) data collected by the FRS Seabird 911plus during the Scotia cruise SC0703 have been used to compute Thorpe length scales and diffusion coefficients (see Sherwin and Turrell, 2004). Using 911plus data in this way tests the accuracy and stability of the instrument to its limit, since normal practice is to save and use data that have been averaged over 1 dbar, typically 1 second or 24 readings. It has been considered desirable to investigate its high frequency performance.

For this investigation two datasets have been studied. The first was part of an exercise to calibrate the transmissometer that was conducted in a laboratory tank, and the second comes from a CTD cast taken on a cruise. All the observations exhibited noise to a greater or lesser extent. The approach adopted here focusses on a detailed examination of the time series in order to determine the nature of the noise and, in particular, to differentiate between quantisation effects, environmental noise and other oscillations that may be in the circuitry of the instrument or, in the case of the laboratory measurements, within the test room itself.

2. Laboratory investigations

2.1 Procedure

The procedure for testing the transmissometer is given in Lichtman (2003). The observations were made with 'clean' seawater from the FRS Aquarium to which North Sea mud was progressively added whilst stirring the water in an 83.5×108×61 cm tank. The CTD rested on the bottom of the tank (in 40 cm of water with only 10 cm covering the CTD frame) so that the pressure was effectively constant, but the tank itself was not lagged or protected from evaporative effects. The system was not designed to calibrate temperature or salinity, and it should not be assumed that either temperature or salinity values were constant. These limitations are considered irrelevant to the present investigation. The instrument performed satisfactorily during the calibration and the transmissometer gave acceptable calibration values. The data used here come from the early part of the investigation before any mud had been added to the tank.

Before they could be plotted the raw data were converted into scientific units using the standard Seabird software. The options used were DATCNV, to convert the data from binary to ASCII format and derive salinity, and WILDEDIT, to check and identify wild data points which were then removed from the analysis. FRS conductivity calibration coefficients have not been not applied. Since we are only interested in the high frequency part of the signal at times of very little change, it is unnecessary to align the CTD or to compute accurate absolute values. (A test confirmed that using ALIGNCTD made no difference to the results).

For each record, time series of pressure, temperature, salinity and beam attenuation are plotted, and salinity is compared with beam attenuation and temperature. For the tank work temperature and conductivity sensors 2 were used since pump 1 was not functioning all the time. For the *in situ* data sensors 1 were used. The beam attenuation record is included for completeness and is not discussed in detail here.

2.2 Observations

The pressure record is likely to be less affected by the laboratory environment than any of the other sensors, and thus it should give the best indication of the performance of the circuitry. Although the recorded pressure was essentially constant at high frequency (Figs 1 and 2), it nevertheless exhibited two different sets of oscillations. The first is ubiquitous and has a range of about 0.065 dbar that is very close to the resolution of the sensor. This set is the main contribution to the standard deviation of the signal (0.046 dbar, Table 1), and looks as though it is due to quantisation. The second set of oscillations appears about every 6 seconds and has a much bigger range (about 0.5 dbar). It is unlikely to be due to real changes in the water level, and must have been caused by some other source, possibly oscillations in the circuitry of the 911plus or electrical signals in the lab. However, it is not possible to investigate its cause in any more detail from this data set.

The temperature record was about 5 times noisier than its stated resolution (see Table 1) but had some anomalous peaks with an amplitude of about 0.01 ºC (see Fig. 1b) that are probably due to small gradients in the water. Large scale changes in salinity are generally correlated with temperature (see also the Temperature / Salinity, or TS, plot), but the whole salinity record is affected by small amplitude high frequency noise. This noise can be clearly seen in Fig 2c where it has amplitude of about 0.01 units (range 0.02) and a frequency of about 4 Hz. This oscillation may explain some of the scatter in the TS plot (Figs 1e and 2e).

The spectral energy of the pressure signal (Fig. 3) rises to a peak at about 8 Hz, and there is a distinct peak in the salinity spectrum at about 4.3 Hz. There is an almost monotonic decrease in energy with frequency in the other data sets.

3. In situ CTD profile

It is possible that the ambient electrical fields, or other aspects of the laboratory conditions, may have affected the performance of the CTD in ways that would not be experienced in the field. For this reason, a further test has been conducted using data collected at cast 305 during the Scotia cruise SC0703 to the Faroe-Shetland Channel in May 2003. The data were derived from the bottom of the cast, between 620 and 670 m, when the CTD was moving slowly (through the vertical) and there was very little variation in temperature and salinity. The total record investigated was about 5 minutes long (see Fig. 4) and taken for the period from 17.5 to 22.5 minutes into the cast. In general both the pressure and temperature records were fairly smooth (at least in relation to the range of values shown in the plots). The salinity data on the other hand are noisy (Fig 4c).

A closer inspection of part of the record is provided in Fig. 5. A small amount of noise can be seen in the pressure signal, with a frequency of about 0.75 Hz and an amplitude of about 0.01 dbar (range 0.02 dbar). There are several small peaks in temperature of about 0.05 °C at intervals of about 3.5 s, but since this period coincides with a similar low frequency oscillation in pressure, and the signal shows a slight warming as the pressure falls (albeit with a short lag of about 6 seconds), it seems likely that these peaks were real and due to both swell and movement of the ship. There is noise again in the salinity signal with an amplitude of about 0.05 units and a frequency of about 4.3 Hz. This noise would account for the salinity scatter seen in the TS plot (particularly in Fig 5e, where salinity is otherwise almost constant).

The spectra, which are based on the data shown in Fig. 4, reveal an almost monotonic decrease in energy with frequency, with the exception of the salinity signal which again shows an anomalous peak at about 4.3 Hz, identical to that observed in the laboratory data. Unlike the laboratory data, however, the pressure signal did not have a significant peak in energy at very high frequencies.

4. Conclusions

A brief analysis has been conducted of laboratory and *in situ* high frequency CTD observations, with the intention of determining the temporal limit at which a Seabird 911plus can be used for Thorpe scale calculations.

Once allowance is made for environmental factors, the temperature signal appears to have behaved according to the manufacturers' specification. There is a small amount of noise in the pressure record just above the quantisation level. Since pressure observations should not vary significantly at frequencies > 1 Hz, pressure data should be smoothed over a period of 1 second, say, before being used.

The salinity signal has a significant oscillation with a frequency of about 4.3 Hz and amplitude of about 0.01 units using sensor 2 in the laboratory, but only 0.001 units using sensor 1 in the Faroe-Shetland Channel. The cause of this noise is unknown (it may be that it is only large in the laboratory environment, or it may vary from sensor to sensor) but if individual records are used then it might be significant at the level of accuracy needed to identify the decadal change in salinity of Norwegian Sea Deep Water (0.01 per decade). The noise accounts for the scatter seen in some of the TS plots shown here.

Fortunately the salinity oscillation can be largely eliminated by averaging the observations over 1 second (i.e. 1 dbar), which is normal practice for CTD data. For example, if data are smoothed over a period *T* using Box-car filter then the amplification, *a*, of a frequency, ω, is given by

$$a = \frac{\sin(\omega T/2)}{\omega T/2}$$

For ω = 4.3 Hz (i.e. 27 radians sec^{-1}) and T = 1 second, a = 0.06; thus a one second block average will reduce the observed salinity oscillation to order 0.001 to 0.0001 units. In places where the salinity gradients are very small it may be desirable to average the data over longer periods, or use a filter that is targeted at 4.3 Hz.

This investigation has shown that salinity data should not be used in Thorpe scale calculations at frequencies much higher than 1 Hz. If they are required at a higher frequency than this then the original data should be smoothed over at least 1 second and reconstituted at high resolution by mapping the smoothed values onto the high frequency temperature data.

References

Dougal, L (2003). A procedure for the post-calibration of a Sea-Tech 25 cm path transmissometer. FRS internal report *[in preparation]*.

Sherwin, T.J. and W.R. Turrell (2004). Mixing and advection of a cold water cascade across the Wyville Thomson Ridge. Deep-Sea Research [submitted]

Table 1
Stated resolutions and observed standard deviations from the Seabird 911plus laboratory data for different sensors from the data shown in Fig. 1

	pressure	**temperature**	**salinity**	**beam attenuation**
Stated resolution (from manufacturer's specification)	0.015% - 0.02% full scale (c6900 dbar) i.e. 1.02 - 1.36 dbar	0.0002 ºC	0.004	0.1% difference (or 0.004 m^{-1}) noise is 0.01%
Laboratory data	0.046 dbar	0.010 ºC	0.006	0.004 m^{-1}

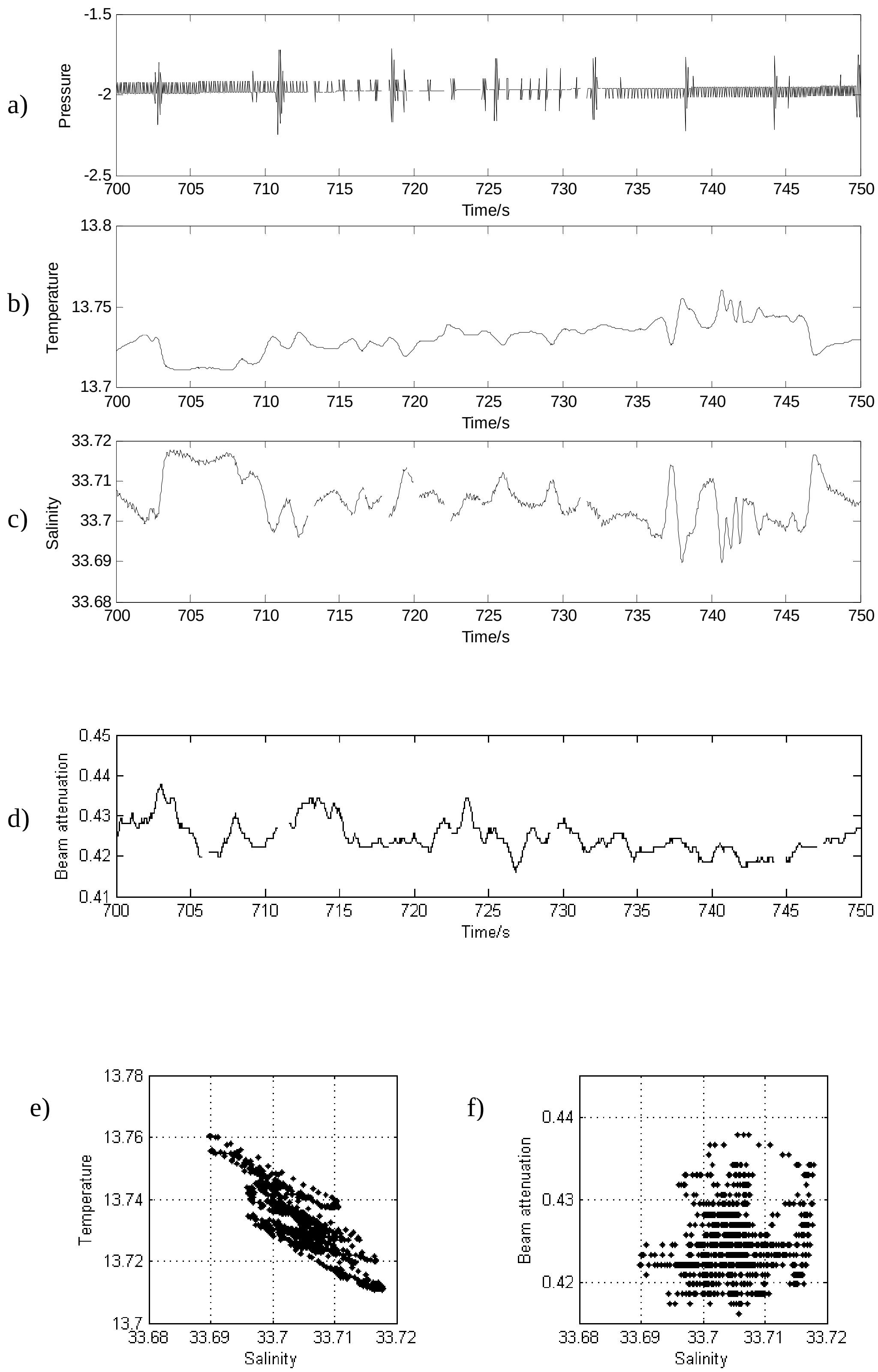

Figure 1. Laboratory observations. Individual panels, which are not labelled, are a) Pressure time series, b) Temperature time series, c) Salinity time series, d) Beam attenuation time series, e) Temperature / Salinity plot, f) Beam attenuation / Salinity plot

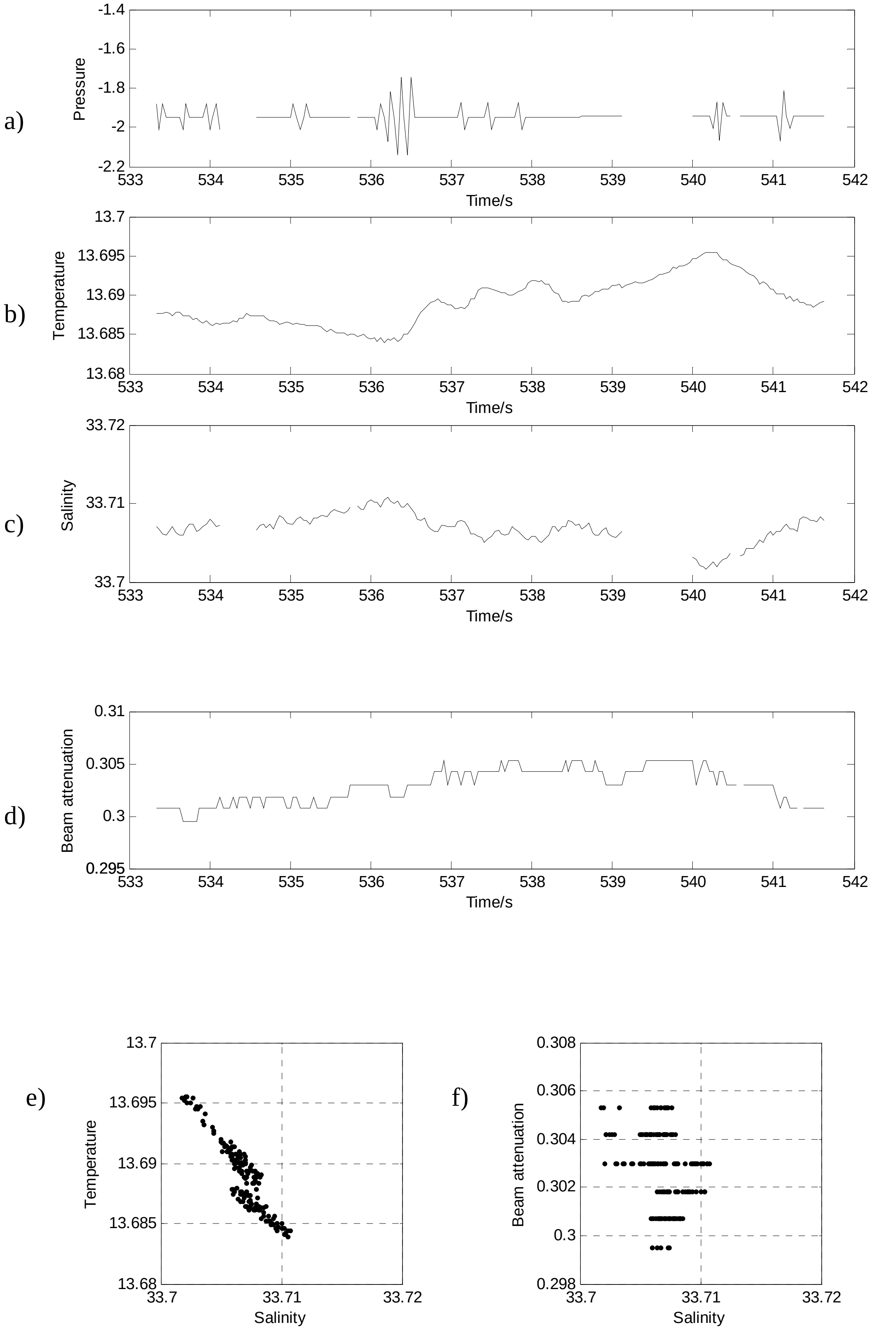

Figure 2. Expanded record of the laboratory observations. The salinity data show an oscillation at about 4.3 Hz.

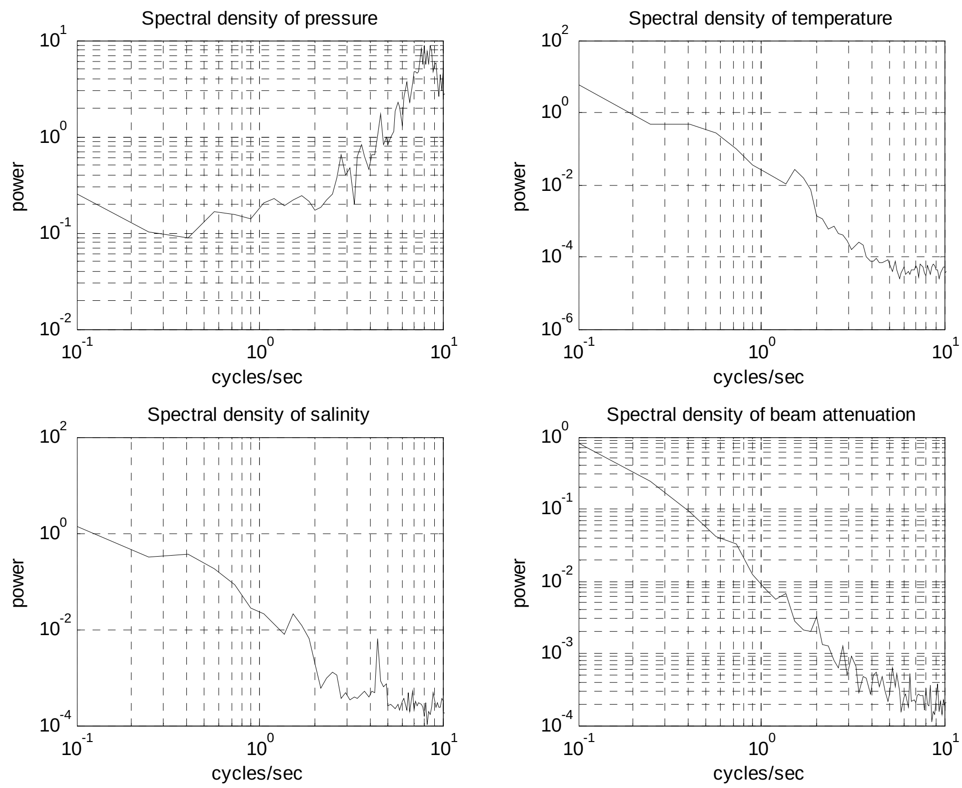

Figure 3. Spectral analysis of the data shown in Fig. 1. Notice, in particular the spike in salinity between 4 and 5 Hz.

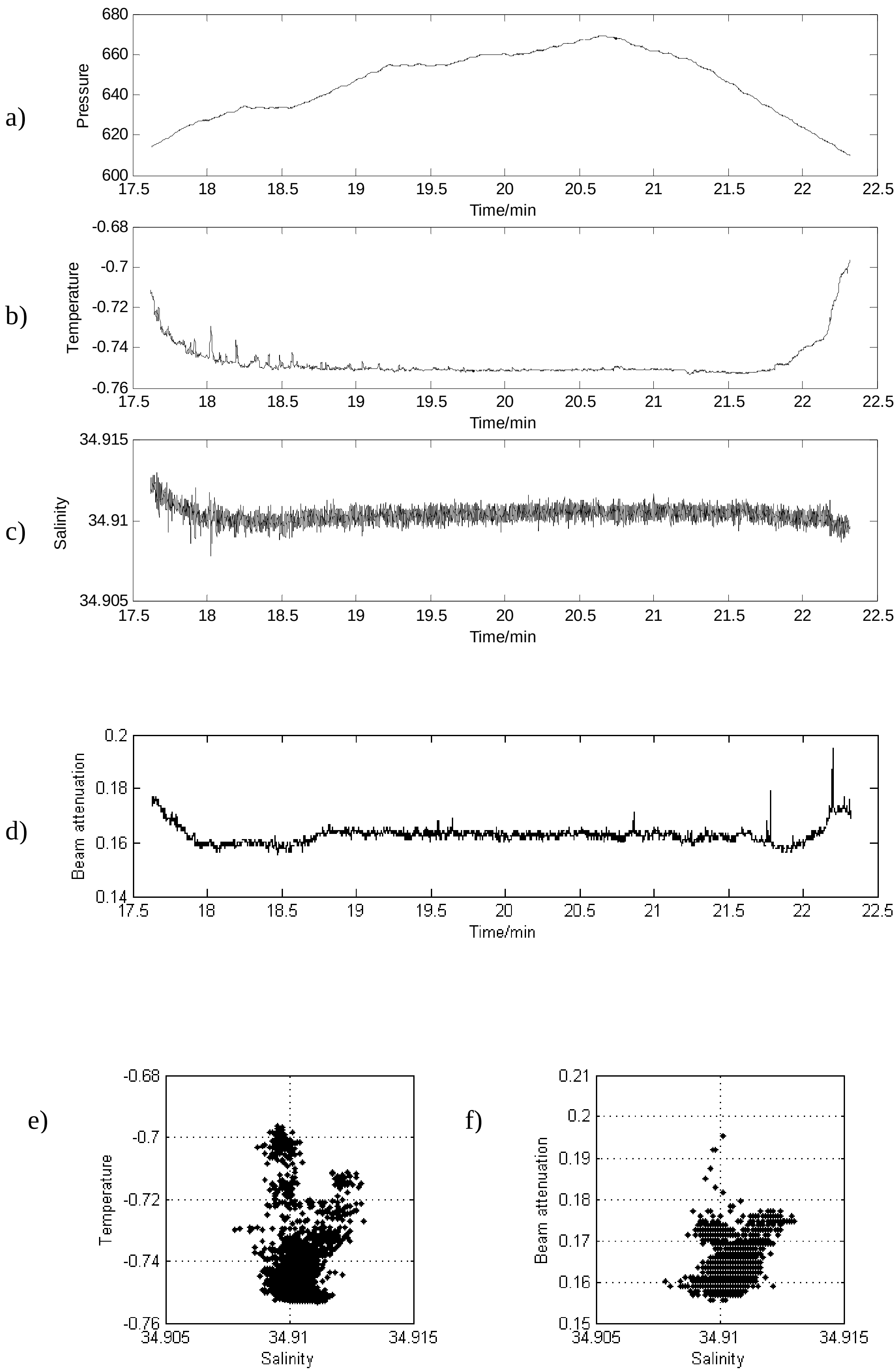

Figure 4. CTD data from the bottom of cast 350 in the Faroe-Shetland Channel

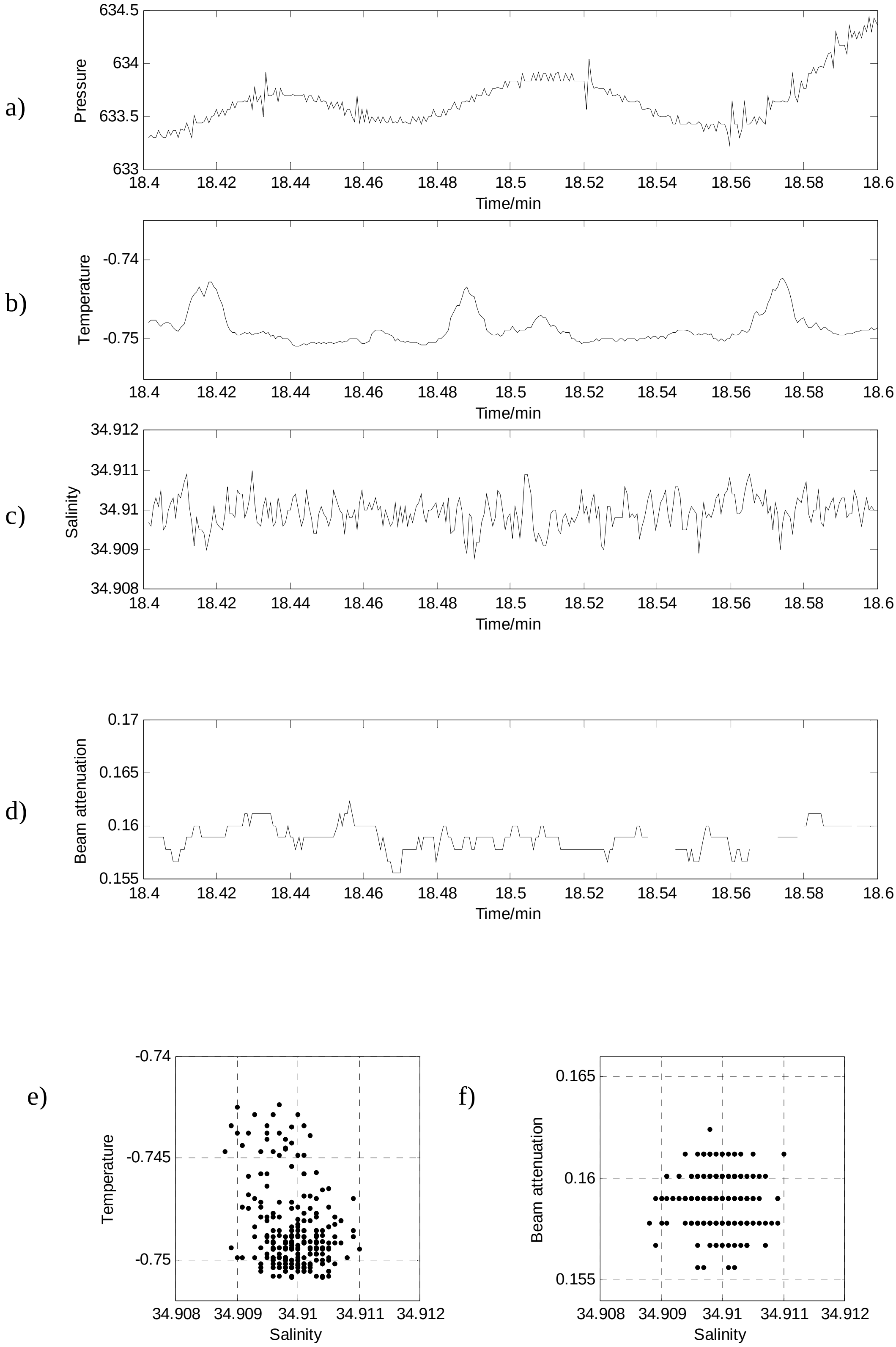

Figure 5. Subset of the data shown in Fig. 4.

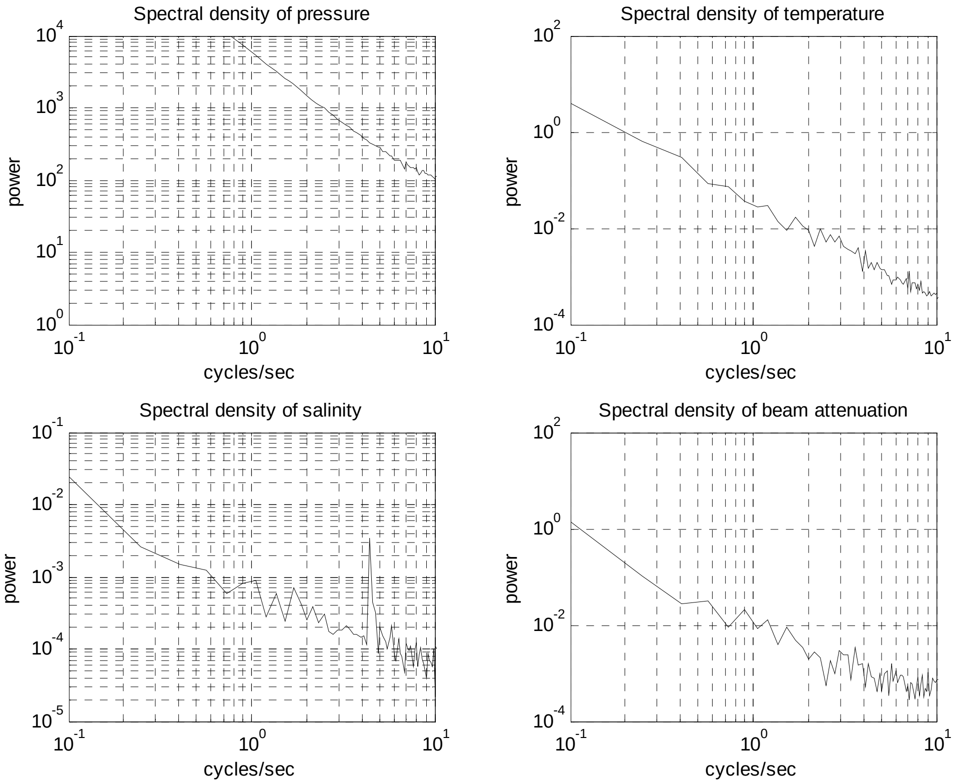

Figure 6. Spectral analysis of the data shown in Fig. 4.