FALCON SPIRIT 13.8.2021

BACKGROUND

50° 18.914’ N, 4° 9.268’ W (roughly halfway between Renney Point and eastern tip of Rame Peninsula).

MSS

Two time series of 15 and 16 casts respectively.

Time series 1 (TS1) 10:56 – 11:43.

Time series 2 (TS2) 12:02 – 12:43.

Processing chain:

- Raw .mrd files for each cast converted to .tob files (SSDA software)
- Utility “cutgraf” (MSSpro software) used to cut off top and bottom of profiles (when instrument is not free falling).
- Batch processing modules “shear_c”, “eps+all”, and “eddy” (MSSpro) used in sequence to calculate parameters of interest from raw sensor data, as well as binning the data to integer dbar pressure values.
- Utility “export” (MSSpro) used to export data as .dat files, which can then be imported into MATLAB for data analysis.

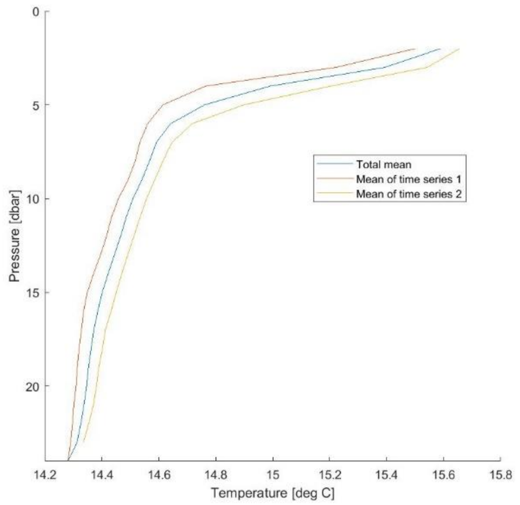
Sensitivity testing:

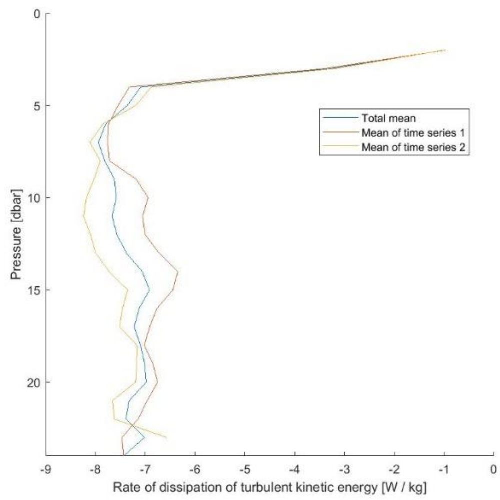
- The following average percentage changes in ε and temperature are seen when changing the value of the shear-temperature sensor offset by certain factors:

Change in offset →	**Halved**	**Doubled**	**Reduced by factor of 10**	**Increased by factor of 10**
Average change in values of temperature (%)	1.43×10^{-4}	-2.92×10^{-4}	2.57×10^{-4}	– 0.0026
Average change in values of ε (%)	6.51×10^{-7}	-3.94×10^{-6}	-3.63×10^{-7}	-2.96×10^{-5}

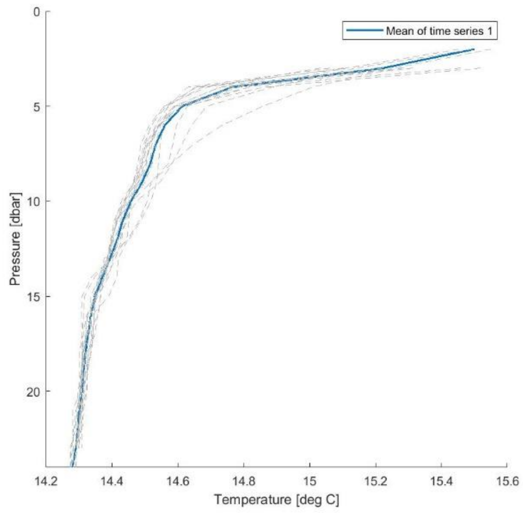
- The changes in temperature are larger than those seen in epsilon, but are still well below 1%, and so neither parameter is particularly sensitive to changes in the sensor offset.
- The final step in the “shear_c” batch is three passes of a Butterworth filter to the data from both shear probes, and to the calculated pseudoshear data. Removing these filters and continuing with processing as normal (the batch “eps+all”, which calculates ε from the shear data, and finally the batch “eddy”) produces very little change in the final values of ε – average percentage change is -1.80×10^{-6}.

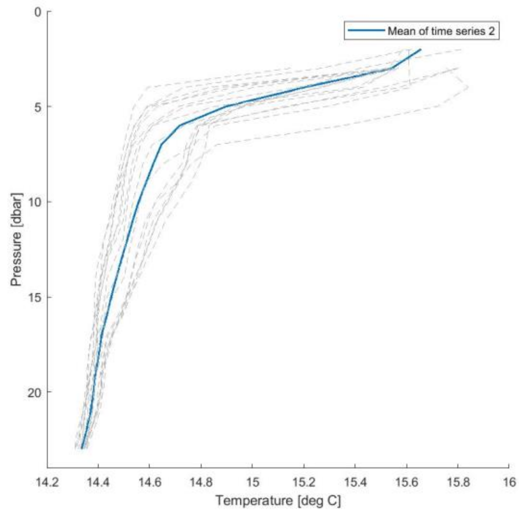
Preliminary plots of mean temperature and epsilon (rate of dissipation of turbulent kinetic energy):





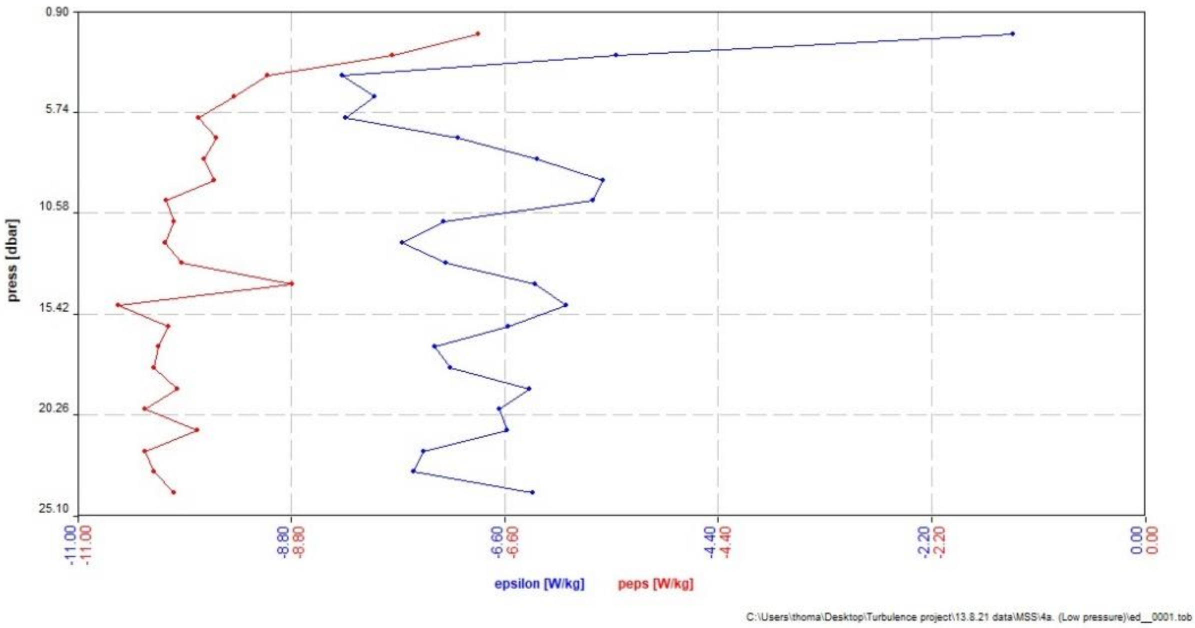
Plots of mean temperature against background of temperature for individual casts:

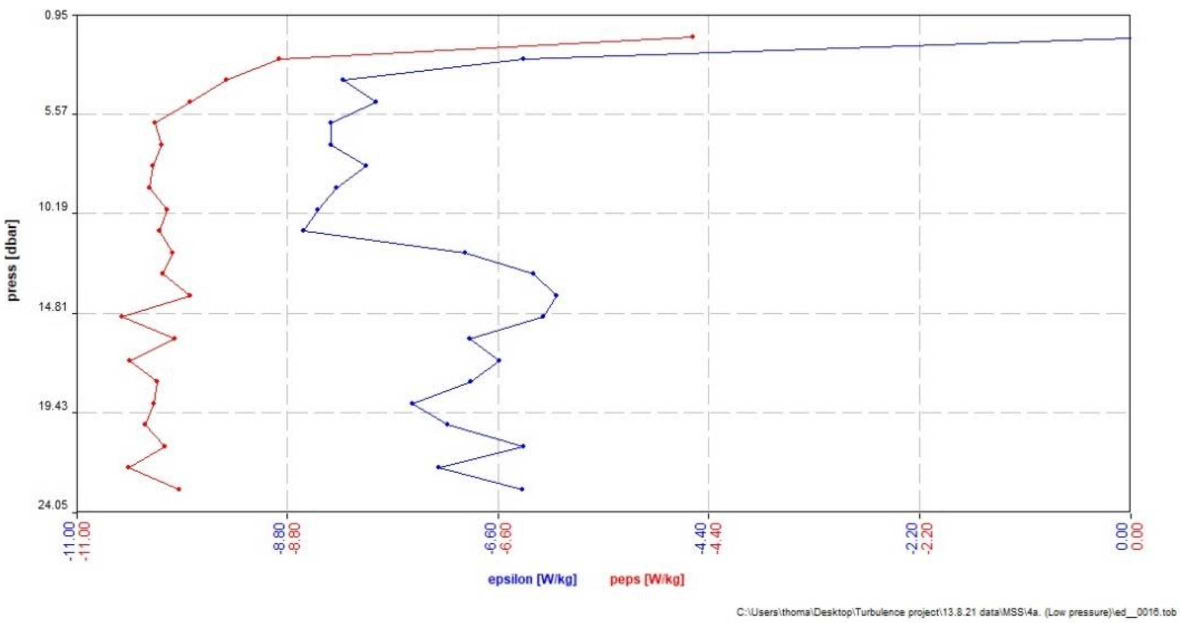




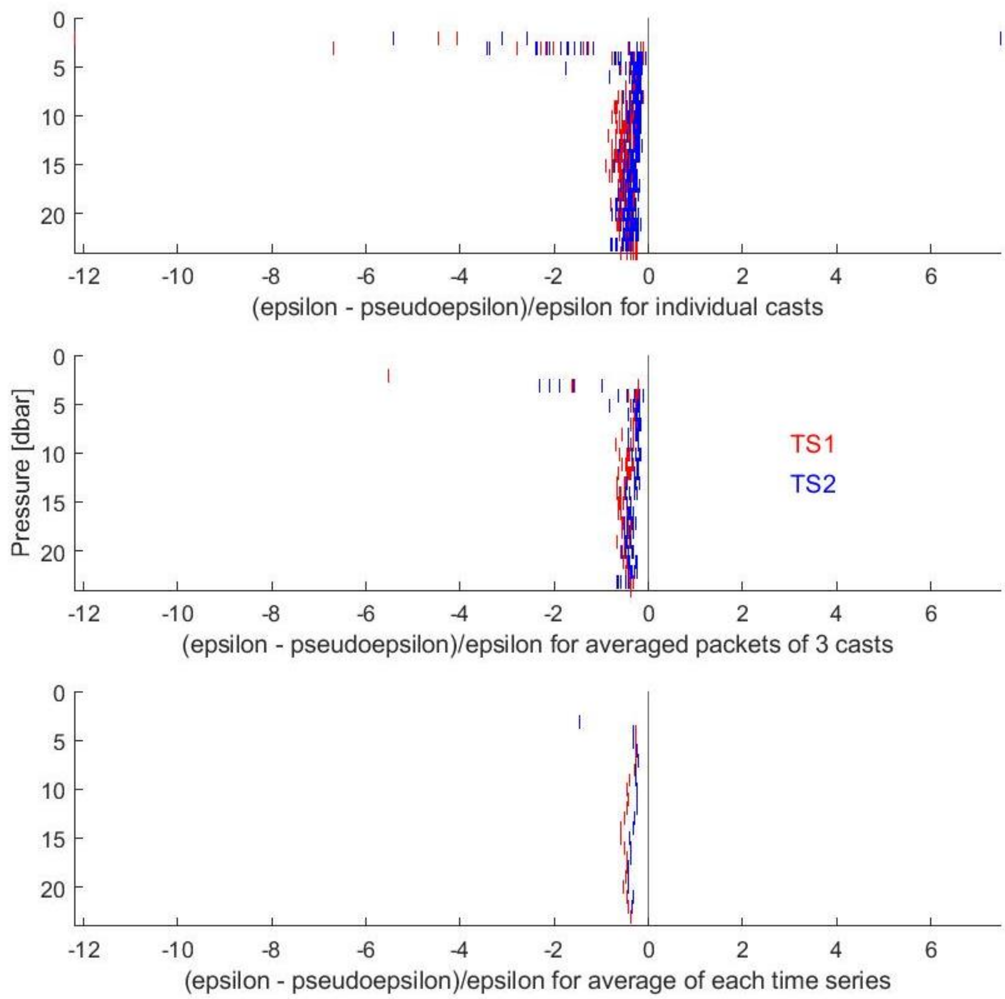
Checking that data is above noise floor:

- The values for epsilon should be above pseudoepsilon as the instrument reaches greater depths (i.e., as the vibration of the instrument decreases, the epsilon signal is well above the noise floor)
- This is evidenced in all casts
- Example plots from first cast of each time series shown below (the blue line, epsilon, should be to the right of the red line, pseudoepsilon, towards the bottom of the graph):



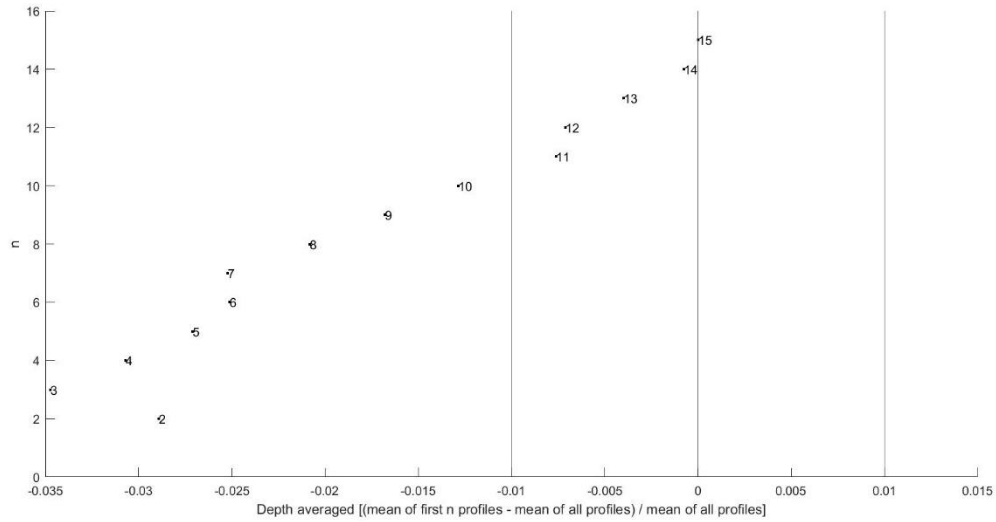


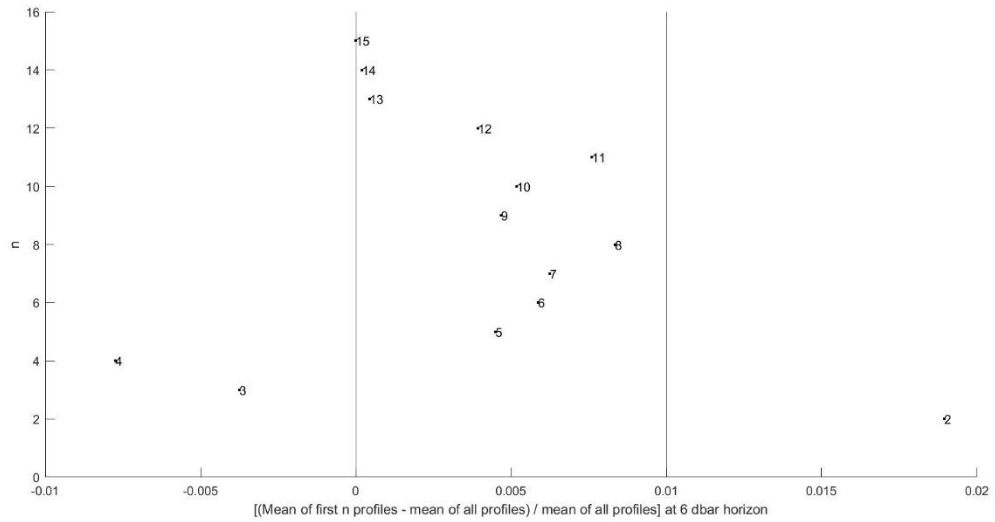
- Further to this, the following plots show how the extent to which the data is above the noise floor changes between individual casts, averaged packets of 3 casts, and the two time series averages (epsilon is above noise floor when the value on this plot is < 0 (i.e., epsilon is less negative than pseudoepsilon):

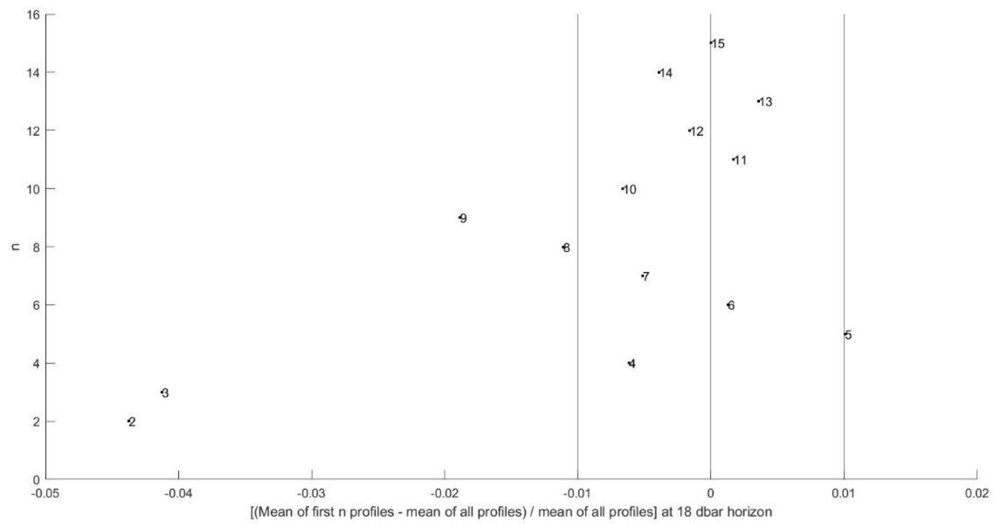


Two linked questions: how many MSS casts are needed until the average value of epsilon (with depth) is reliable; is the epsilon structure of our sample location changing with time? To begin to answer these questions:

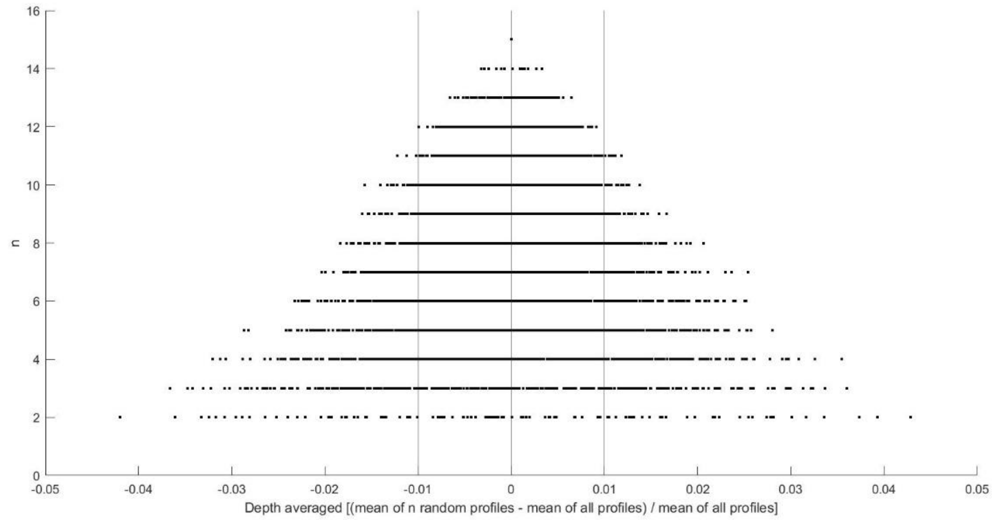
- Taking profiles of epsilon for each time series, compare the difference between the total time series mean to the first profile, then to the average of the first 2 profiles, and then to the average of the first 3, and so on.
- How many do you need to average until the difference between this average and the total time series average is negligible?
- But the profiles may also be changing in time; so, repeat the exercise for different permutations (1000) of the order of casts.
- Plots made for the total depth-averaged difference, as well as the difference at 6 dbar and 18 dbar horizons.
- Plots are shown with vertical lines at 1% either side of zero difference:

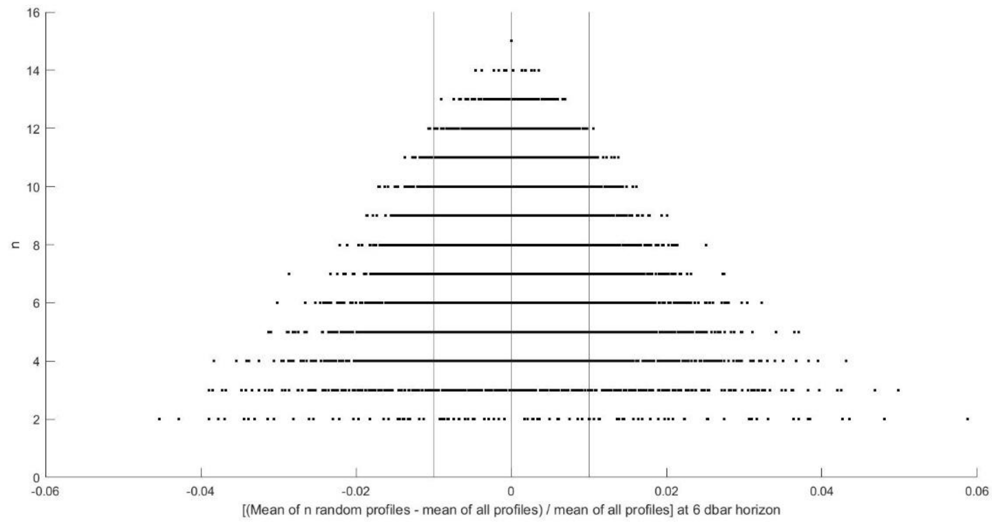

n
Depth averaged [(mean of first n profiles - mean of all profiles) / mean of all profiles]

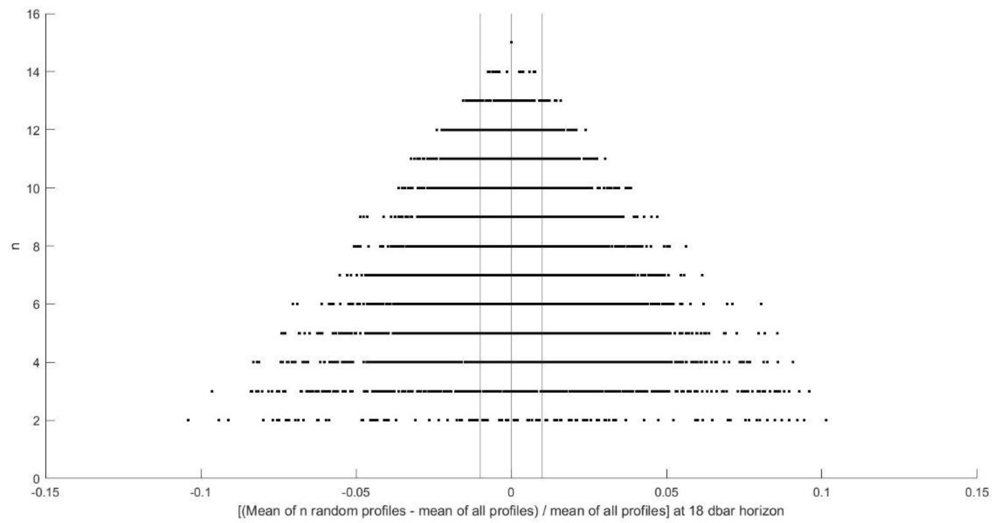

n
[(Mean of first n profiles - mean of all profiles) / mean of all profiles] at 6 dbar horizon


n
[(Mean of first n profiles - mean of all profiles) / mean of all profiles] at 18 dbar horizon

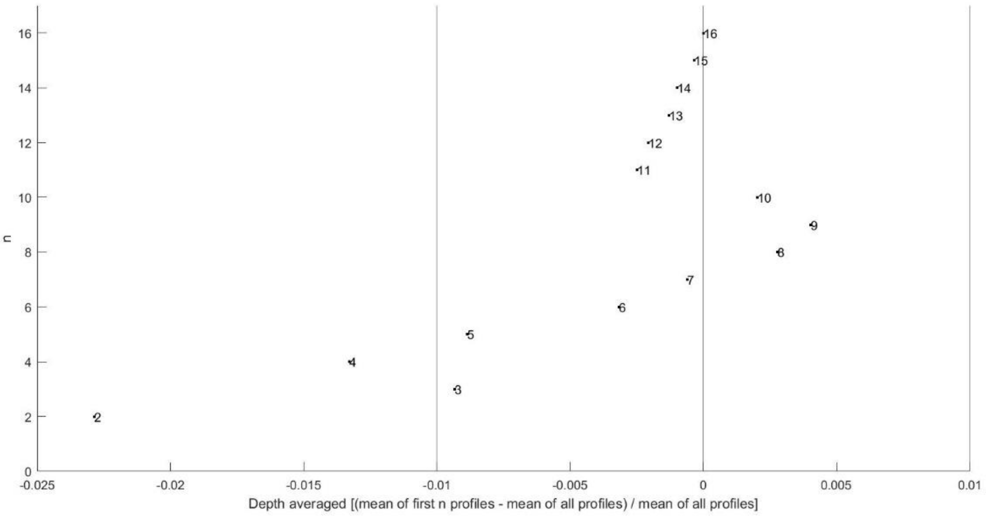
TS1

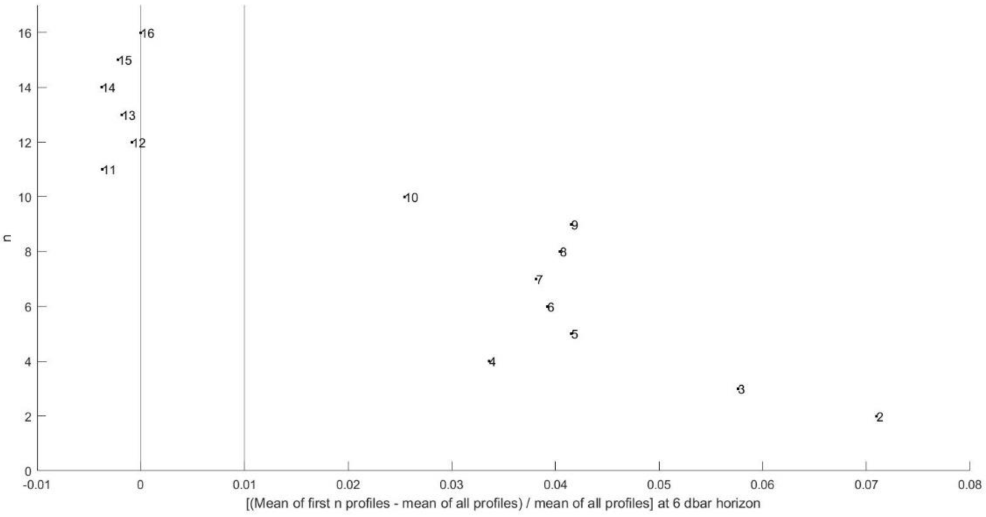

n
Depth averaged [(mean of n random profiles - mean of all profiles) / mean of all profiles]

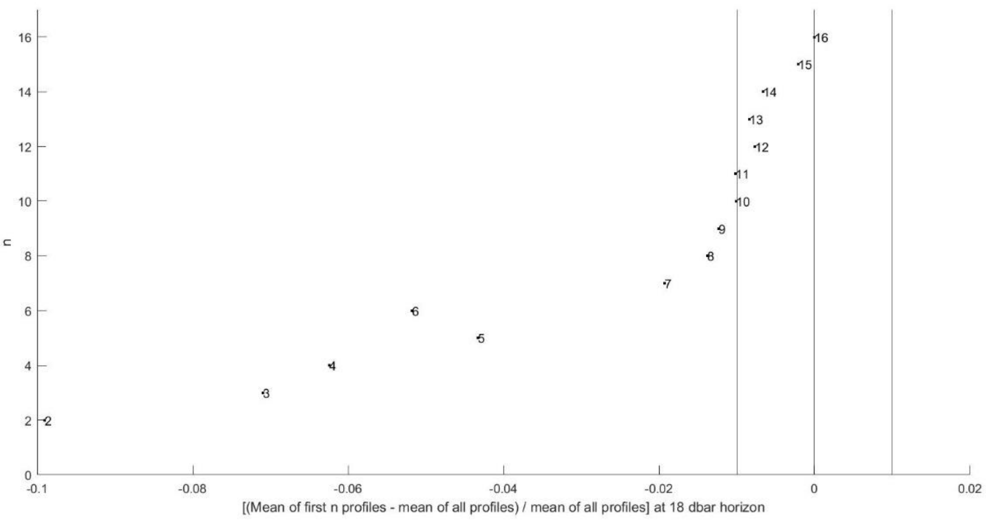

n
[(Mean of n random profiles - mean of all profiles) / mean of all profiles] at 6 dbar horizon


n
[(Mean of n random profiles - mean of all profiles) / mean of all profiles] at 18 dbar horizon

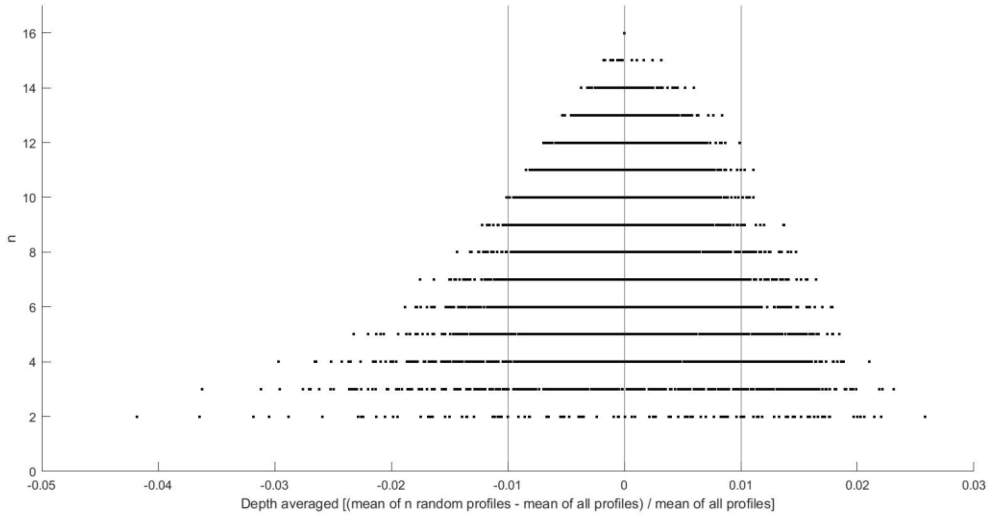
TS1

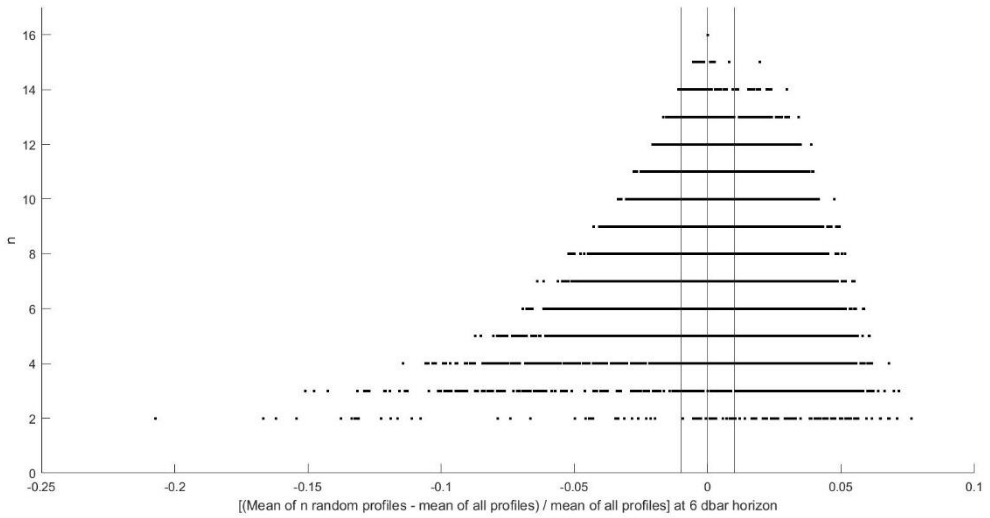

n
Depth averaged [(mean of first n profiles - mean of all profiles) / mean of all profiles]

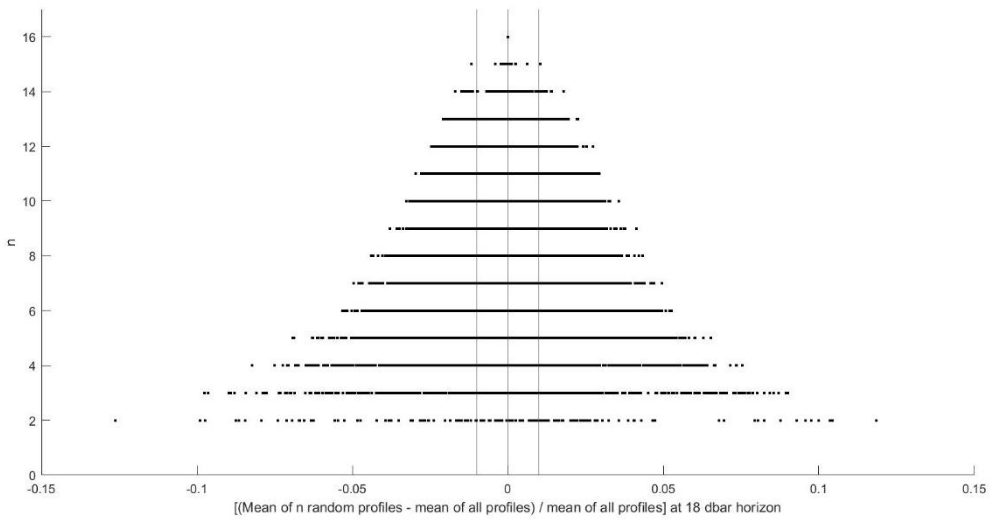

n
[(Mean of first n profiles - mean of all profiles) / mean of all profiles] at 6 dbar horizon


n
[(Mean of first n profiles - mean of all profiles) / mean of all profiles] at 18 dbar horizon

TS2


n
Depth averaged [(mean of n random profiles - mean of all profiles) / mean of all profiles]

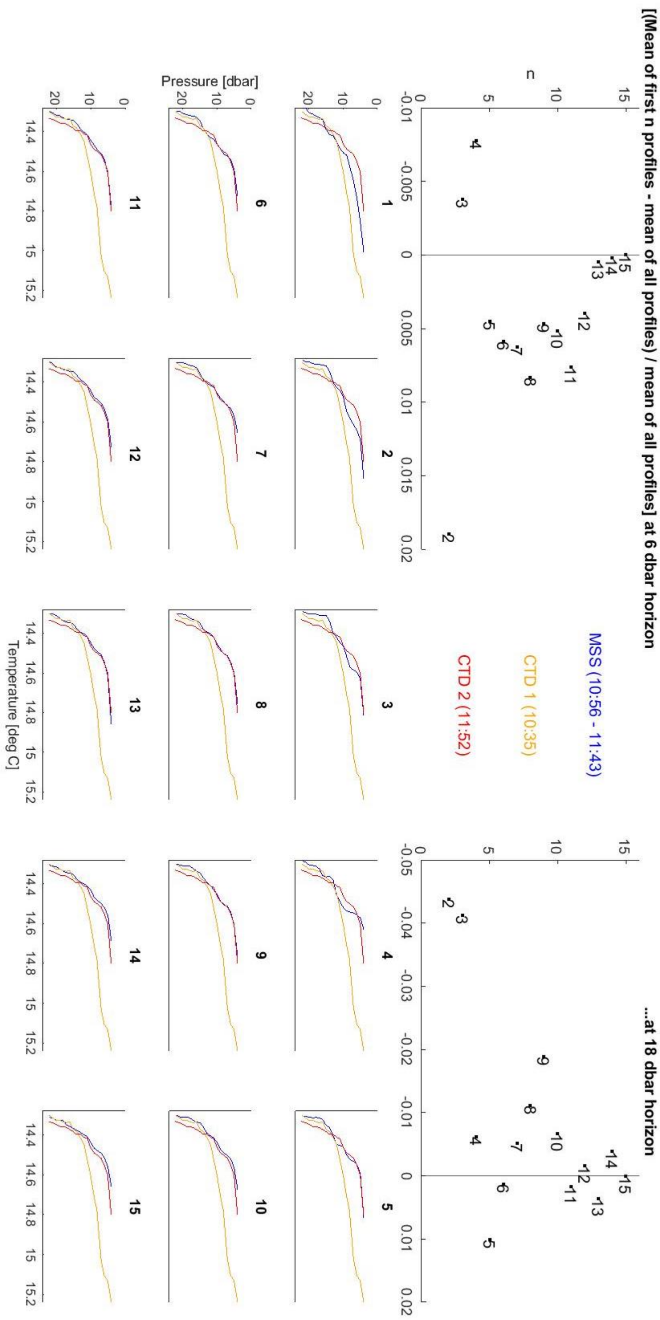

n
[(Mean of n random profiles - mean of all profiles) / mean of all profiles] at 6 dbar horizon


n
[(Mean of n random profiles - mean of all profiles) / mean of all profiles] at 18 dbar horizon

TS2

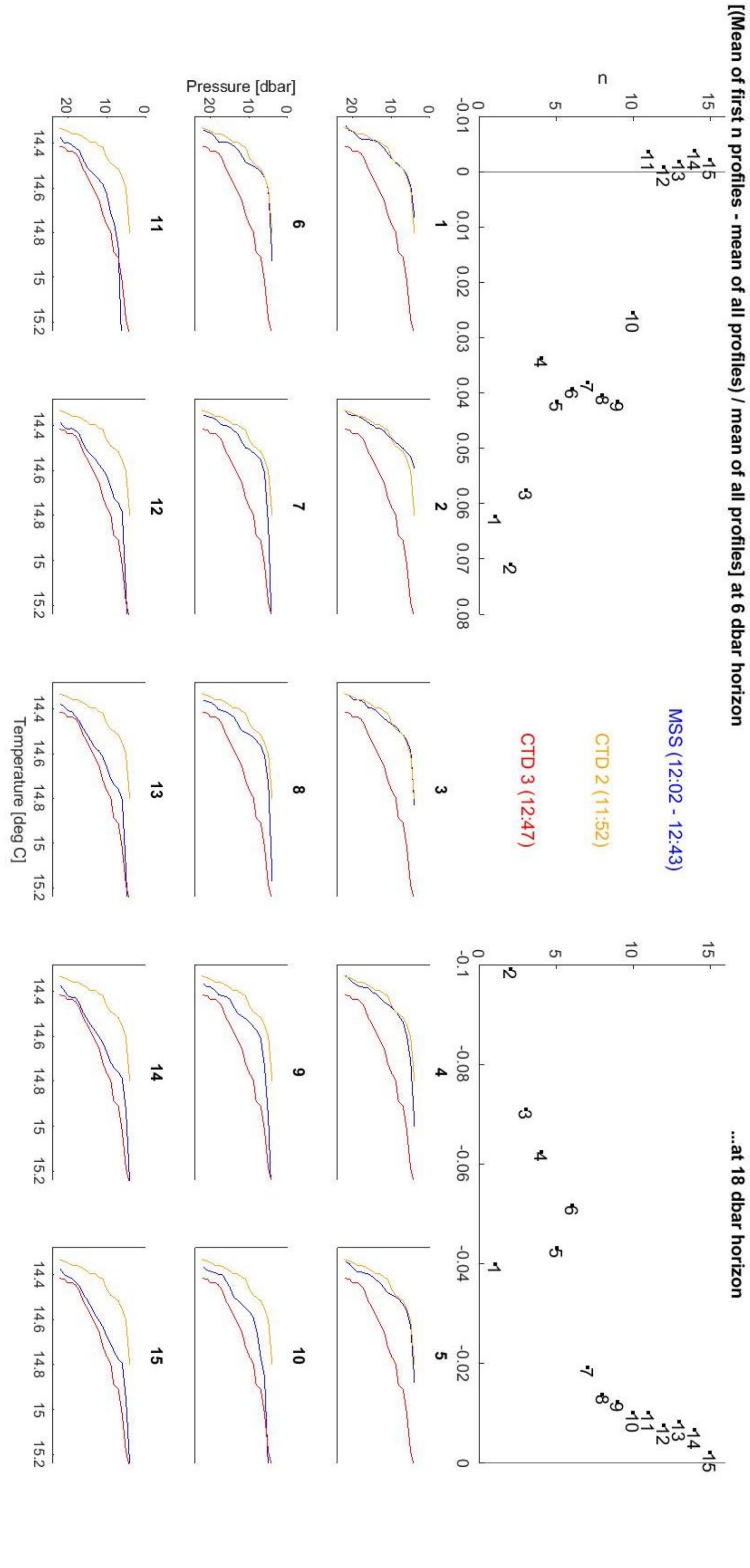
When the casts are kept in time order, the difference converges much more unidirectionally in TS2 compared to TS1, indicating that it is likely that change of the epsilon structure over time was more significant in TS2 compared to during TS1. Were changes in epsilon in each cast due to noise only, it would be expected that as n increases, the difference on the plot crosses back and forth over the zero point. This occurs at the 6 and 18 dbar horizons in TS1 (although the depth averaged difference does appear more unidirectional, indicating that there is change over the course of the time series). Can we detect a change in the physics of the water column over the course of either time series by looking at another parameter?

Temperature profiles for each MSS cast are plotted against the temperature profiles for the two CTD casts which bookend the MSS deployment for TS1 (times are shown on plot):



The instability in the difference between the average of the first n profiles and the average of all profiles is most prevalent from MSS casts 3 – 11. Looking at the MSS temperature profiles for these casts, some features that indicate multiple layering do begin to show from MSS cast 2. These do settle, to what appears to be two layers by the end of TS1 and in CTD cast 2. There is potential to form some hypothesis based on interaction and mixing of multiple water layers changing the epsilon structure and meaning that it takes more MSS casts for the average value to settle.

A similar plot can be made for TS2:

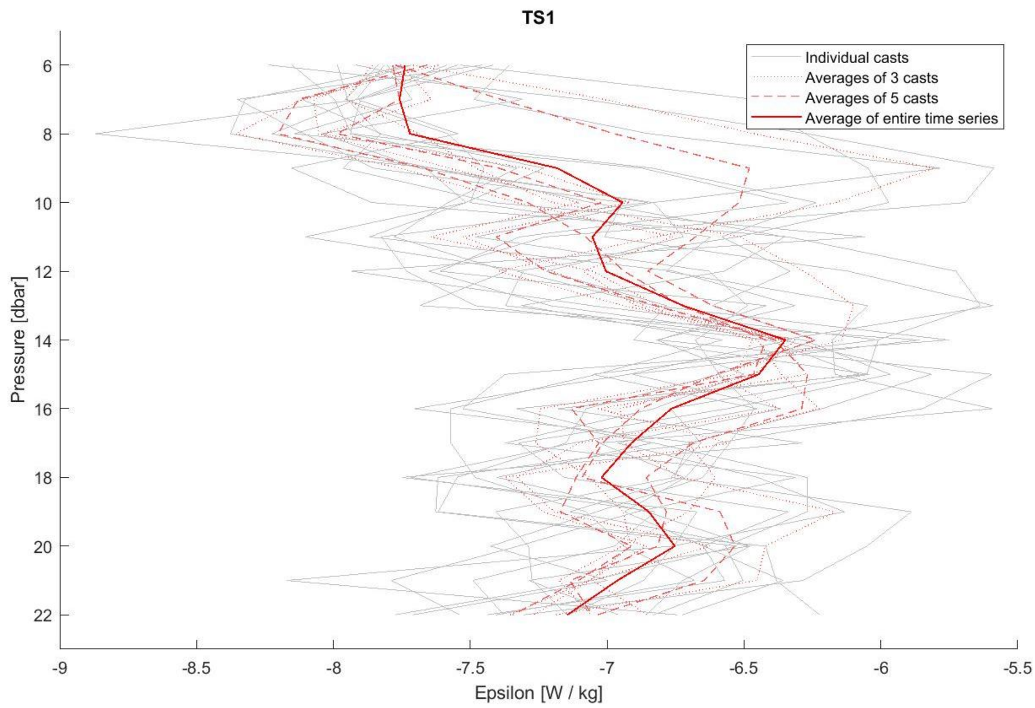


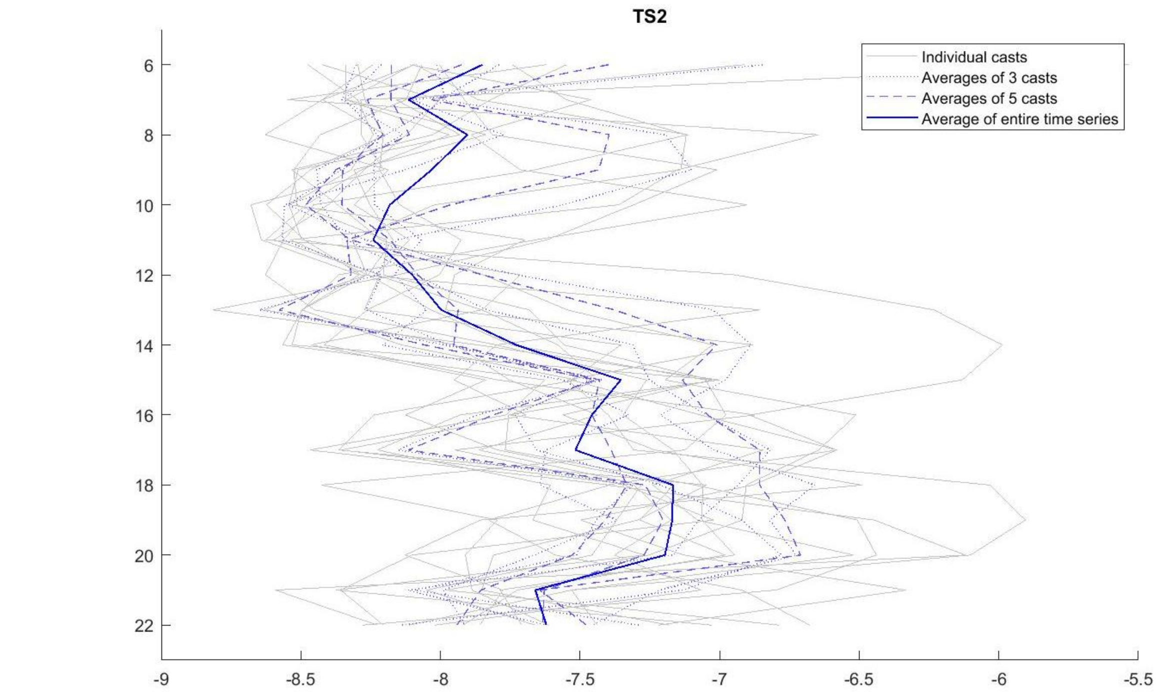
The plots for when cast order is permuted look symmetrical for TS1, but appear to be skewed positively for TS2. Tests for the skewness of the data (i.e., MATLAB "skewness" function applied to vectors of the normalised difference variable for each n for both time series, at every depth level and for the depth-averaged values) and are saved in the file skew.mat (the script skew.m has the steps for calculation).

The MATLAB function "jbtest" was also used on these vectors to test for normality, which the test did not find at the $\alpha = 0.05$ significance level. Neither was the log of the absolute values of the vectors found to be normally distributed (so the data is not lognormal either).

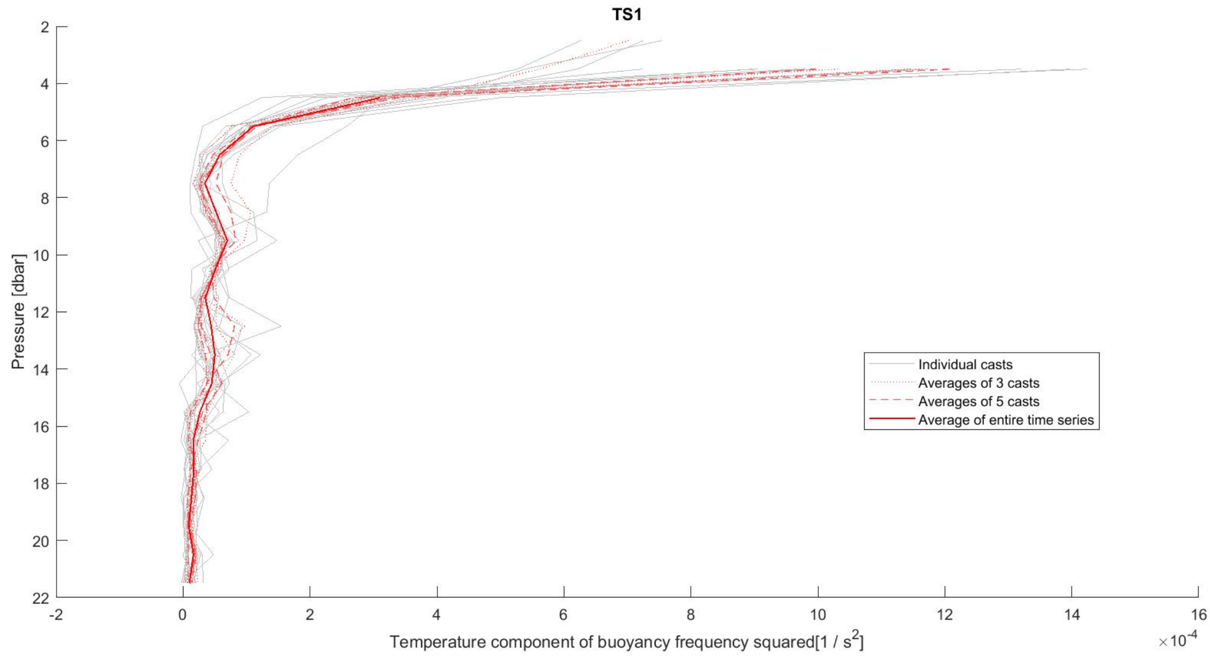
The other question is in regards to how many profiles needed to get a reliable average; looking at the size of n required for the difference to fall within 1% of the total time series average on each plot, an appropriate number of casts appears to be somewhere in the region of 5 to 10. However, is this question now meaningless, given that significant change over time has been identified?

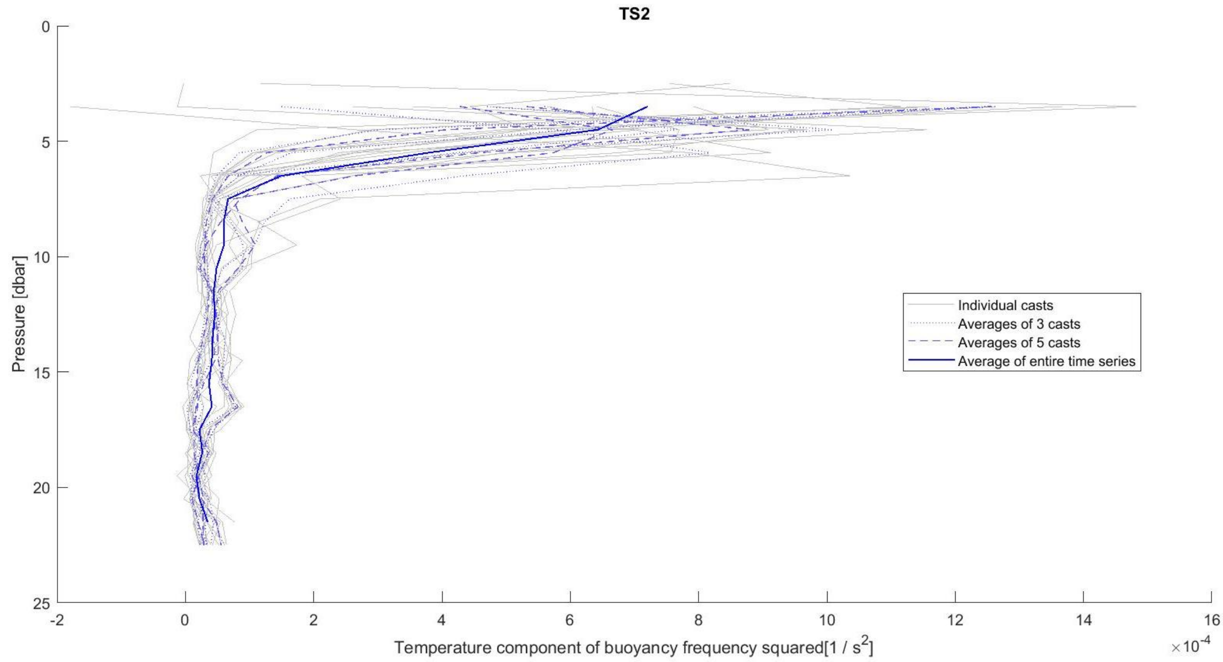
Plots below highlight the actual spread in the epsilon data, and how this changes with different degrees of averaging:



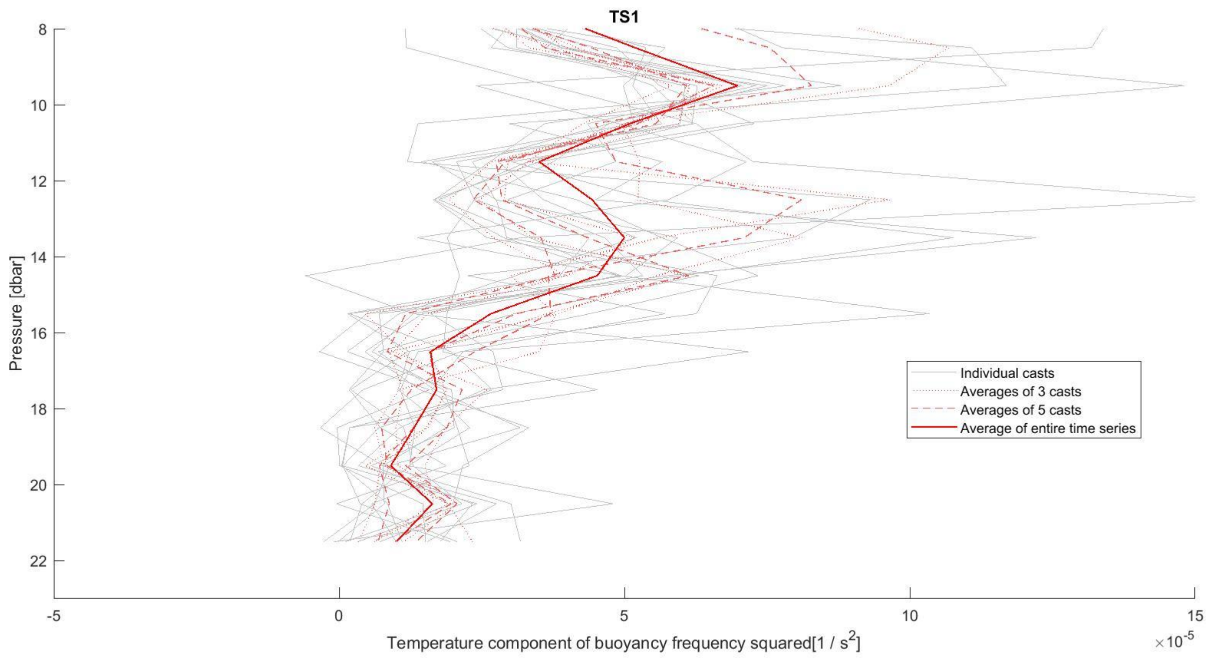


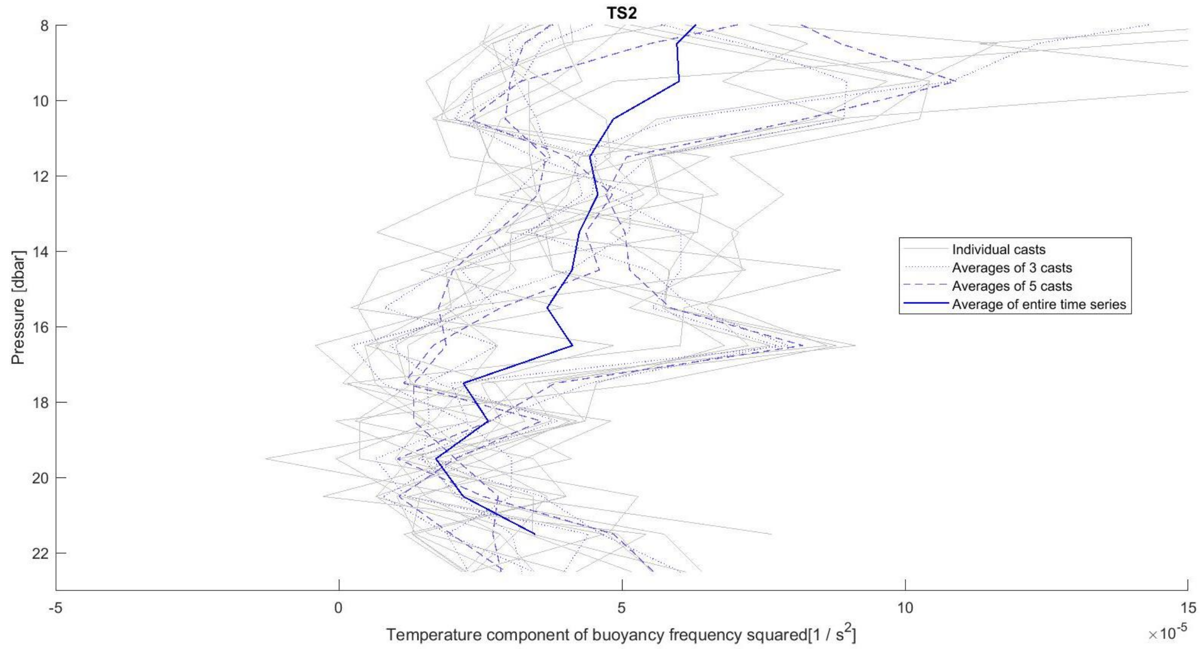
Similar plots can be made for the temperature component of the squared buoyancy frequency. Note that this relies on some CTD data. The GSW toolbox requires absolute salinity, from measured practical salinity, in its calculation of conservative temperature from temperature, which is the variable then used to calculate the temperature component of the squared buoyancy frequency. The conductivity probe on the MSS is faulty, and so CTD-derived salinity is used. The temperature profiles used for the calculation are still from the MSS:





Zooming into 8 dbar and deeper:

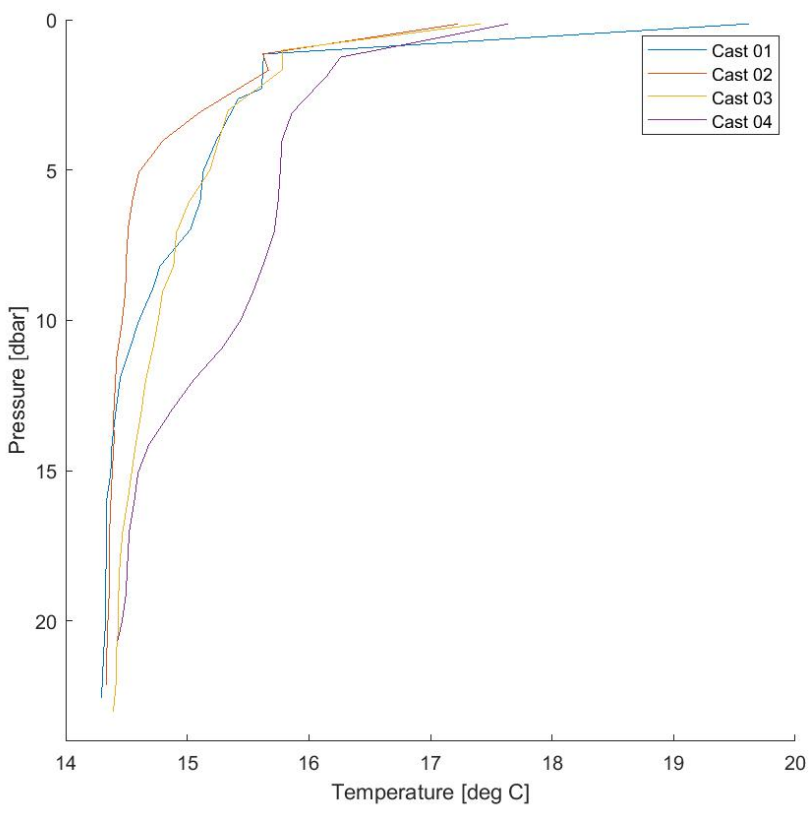


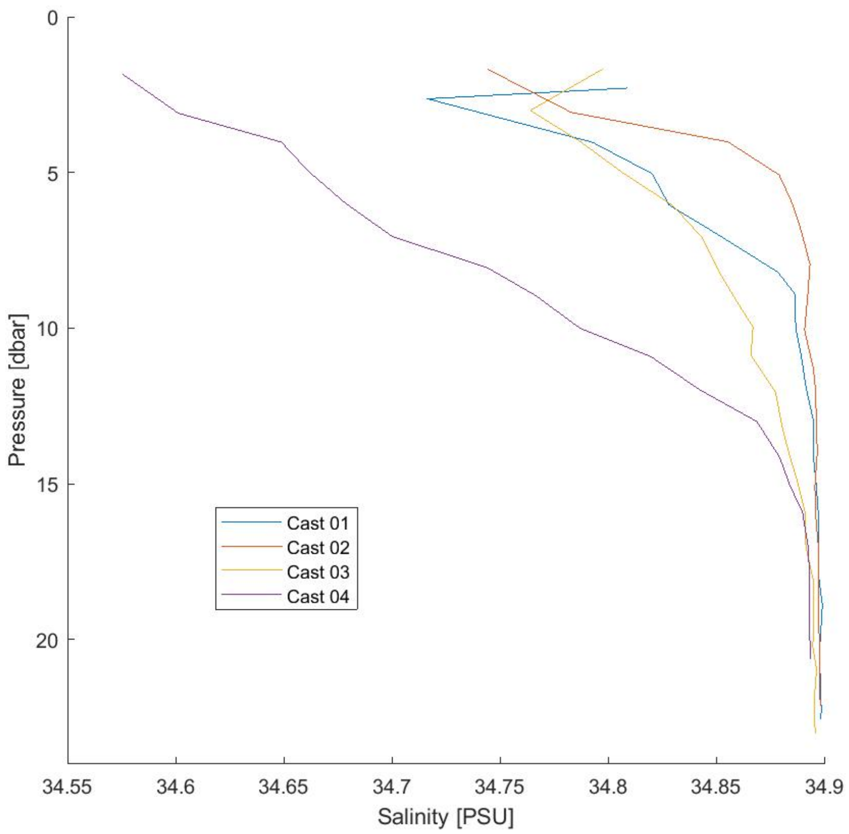


CTD

4 casts: 10:35, 11:52, 12:47, 14:20.

Plots of temperature and salinity against pressure:

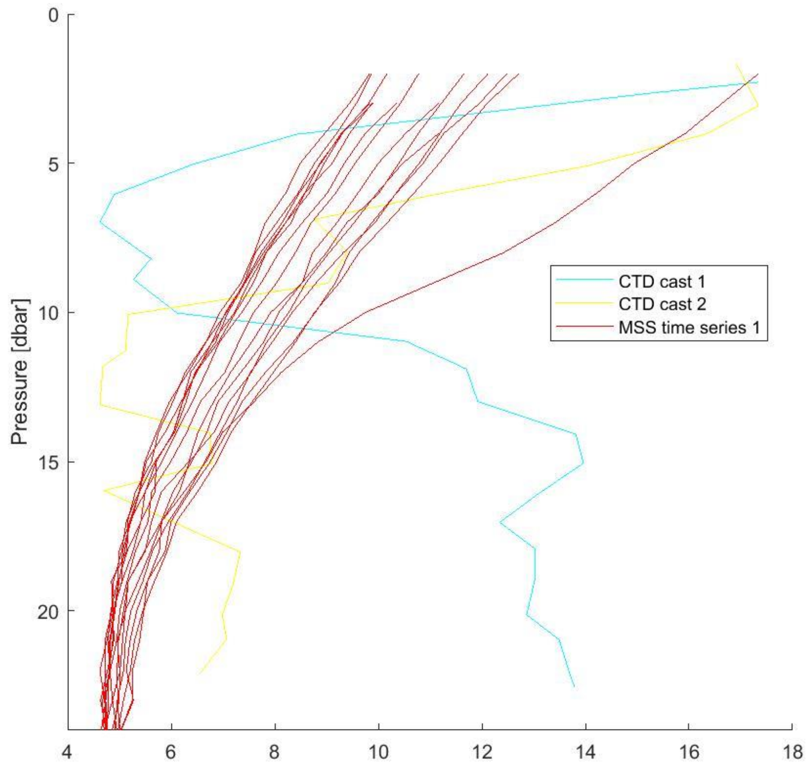




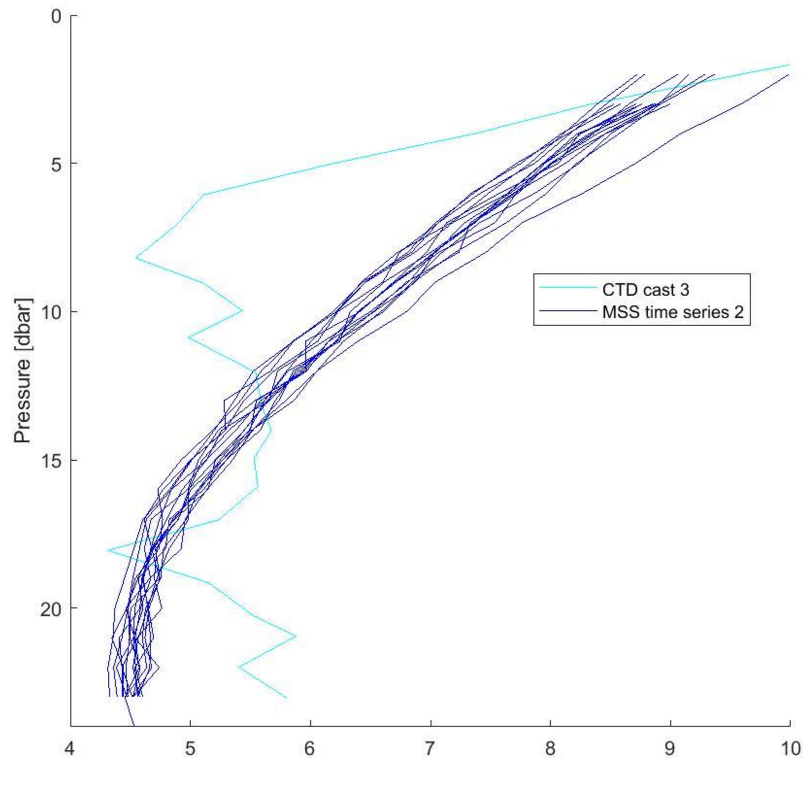
The most notable feature is the increase in temperature and decrease in salinity seen in the top ~15 m (15 dbar) of the water column between casts 3 and 4. Is this a tidal change, or due to a riverine input?

Comparison of fluorescence profiles with those from the MSS sensor:

- CTD sensor records a raw voltage; consider this as arbitrary units.
- MSS software outputs “[Chl_a]”, but it is best to consider this as arbitrary units also (as the calibration is unlikely to be correct).
- Comparison plots for the two instruments shown below (after rescaling, and mirroring the CTD voltage along a line in the y-direction, so that there is a general decrease with depth as seen in the MSS data):



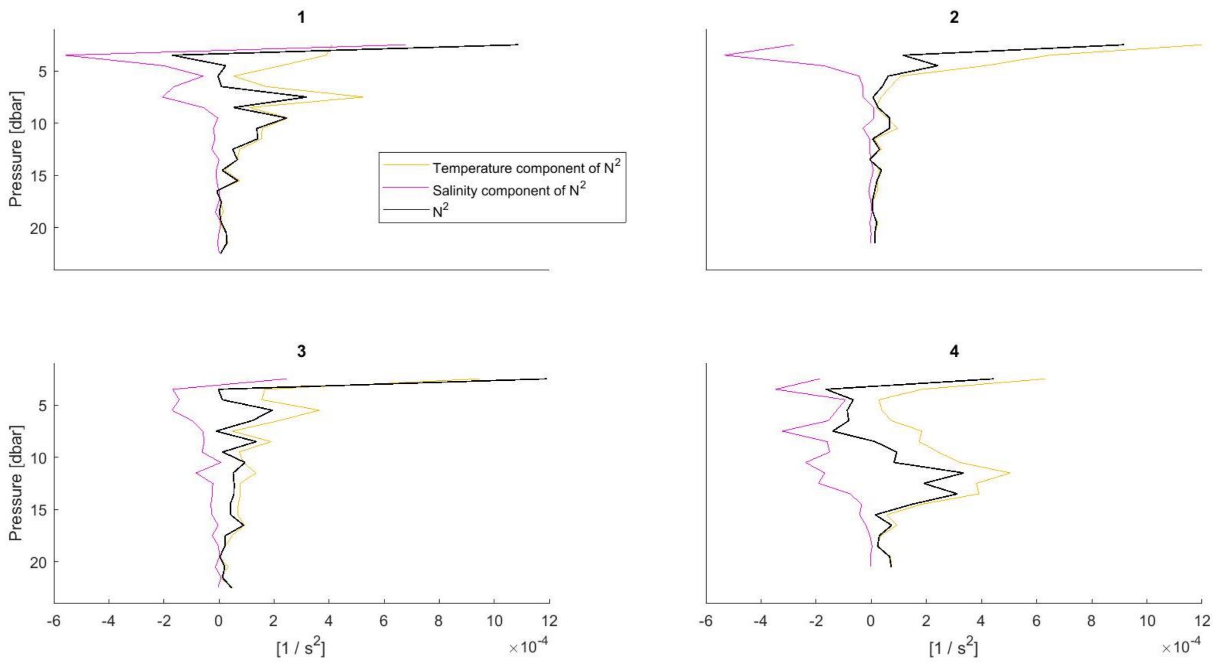
0
5
10
15
20
Pressure [dbar]
4
6
8
10
12
14
16
18
CTD cast 1
CTD cast 2
MSS time series 1



0
5
10
15
20
Pressure [dbar]
4
5
6
7
8
9
10
CTD cast 3
MSS time series 2

- CTD casts 1 and 2 are compared with MSS TS1 as they bookend it, and CTD cast 3 is compared with MSS TS2 as it is the closest in time.
- Based on these plots, it is probably best not to use the MSS fluorescence data – it appears to capture none of the detail that the CTD does, and has a simple decreasing pattern.
- However, it is worth noting that the plots for CTD casts 1 and 2 are also very different.

Buoyancy frequency from CTD casts:



Clearly, stratification is dominantly controlled by temperature, as expected. Salinity does play a greater role at the surface, and until about 15 dbar in cast 4 (another water mass passing over the study area? Corresponds to increase in temperature and decrease in salinity.)

Summary of current hypotheses:

- There is change in time of the epsilon structure in both TS1 and TS2; potentially more in TS2.
- Looking at the temperature profiles from CTD casts 1 – 3, both show significant change over the course of TS1 and TS2; cooling and potential multiple stratification in TS1, and warming in TS2.
- Can this be related to epsilon? Is there movement of water masses through the study area, which increase or change the spatial pattern of mixing? The CTD data also show potential for this.

- It probably takes on the order of 10 MSS casts to get a reliable average for epsilon with depth – but this question may be meaningless in our case due to the change over time.
- If the time series averages of epsilon with depth are taken as representative of the study area at that time, a pattern does appear: there is a decrease (becomes less negative) with depth to a midwater minimum, and a following increase; the minimum is centred around 14 dbar in TS1, and 18 dbar in TS2.
- I believe this minimum is quite reliable in TS1, as the spread of the data decreases at this horizon (does this generally make sense anyway, as there is less dissipation of turbulent kinetic energy and therefore less potential for the instrument to be moved around and noise generated?)

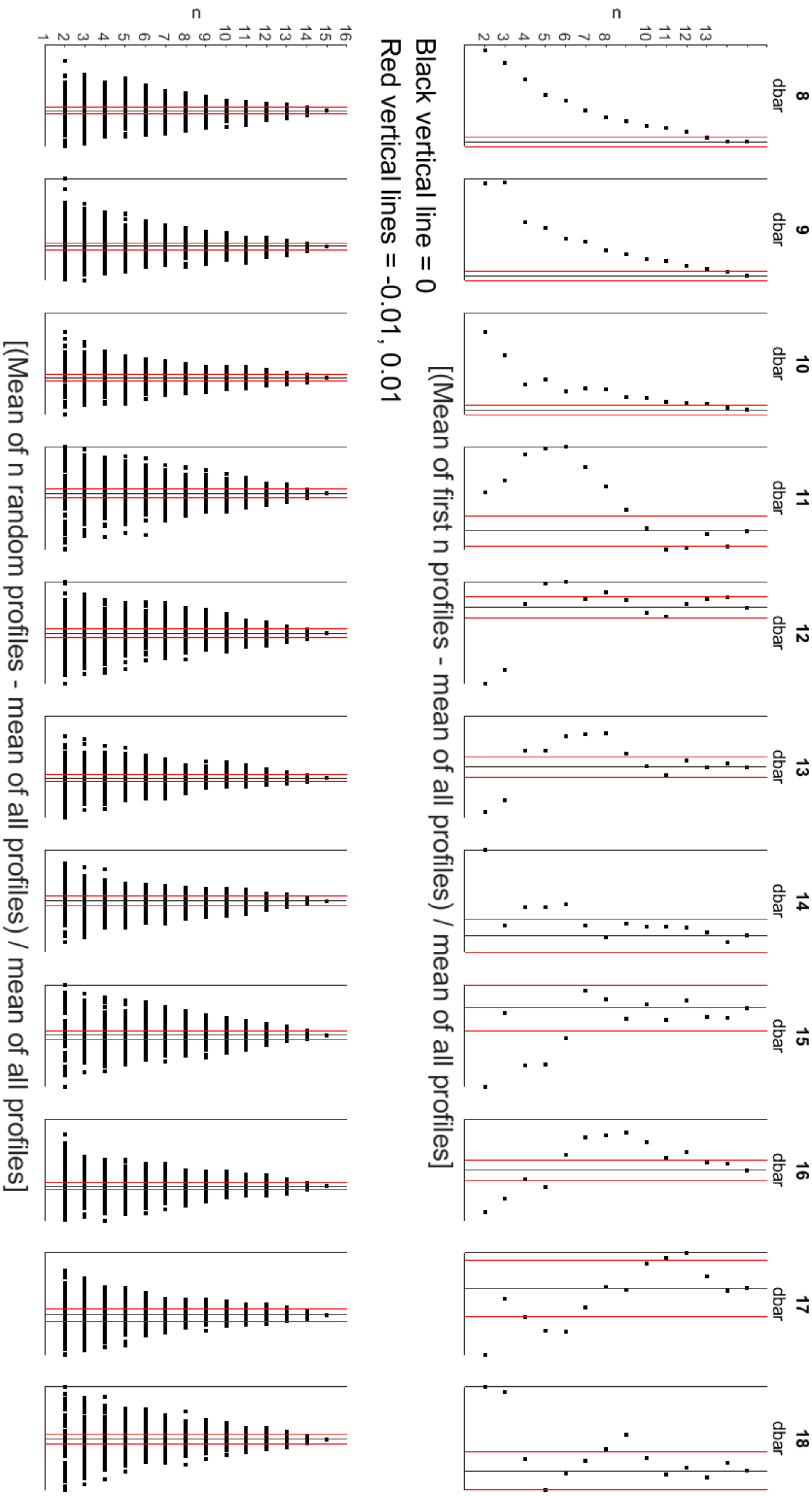
Next steps – look at more depth-resolved plots for averaging of epsilon values/sensitivity test

Certain depths can be chosen based on where interesting observations have been made so far:

- All integer pressure values from 8 – 15 dbar, especially for TS1 where potential for multiple layering during casts 3 – 11.
- Make particular note of epsilon maxima – 14 dbar in TS1, and 18 dbar in TS2.
- To cover everything – plots at all pressures from 8 – 18 dbar for both time series.

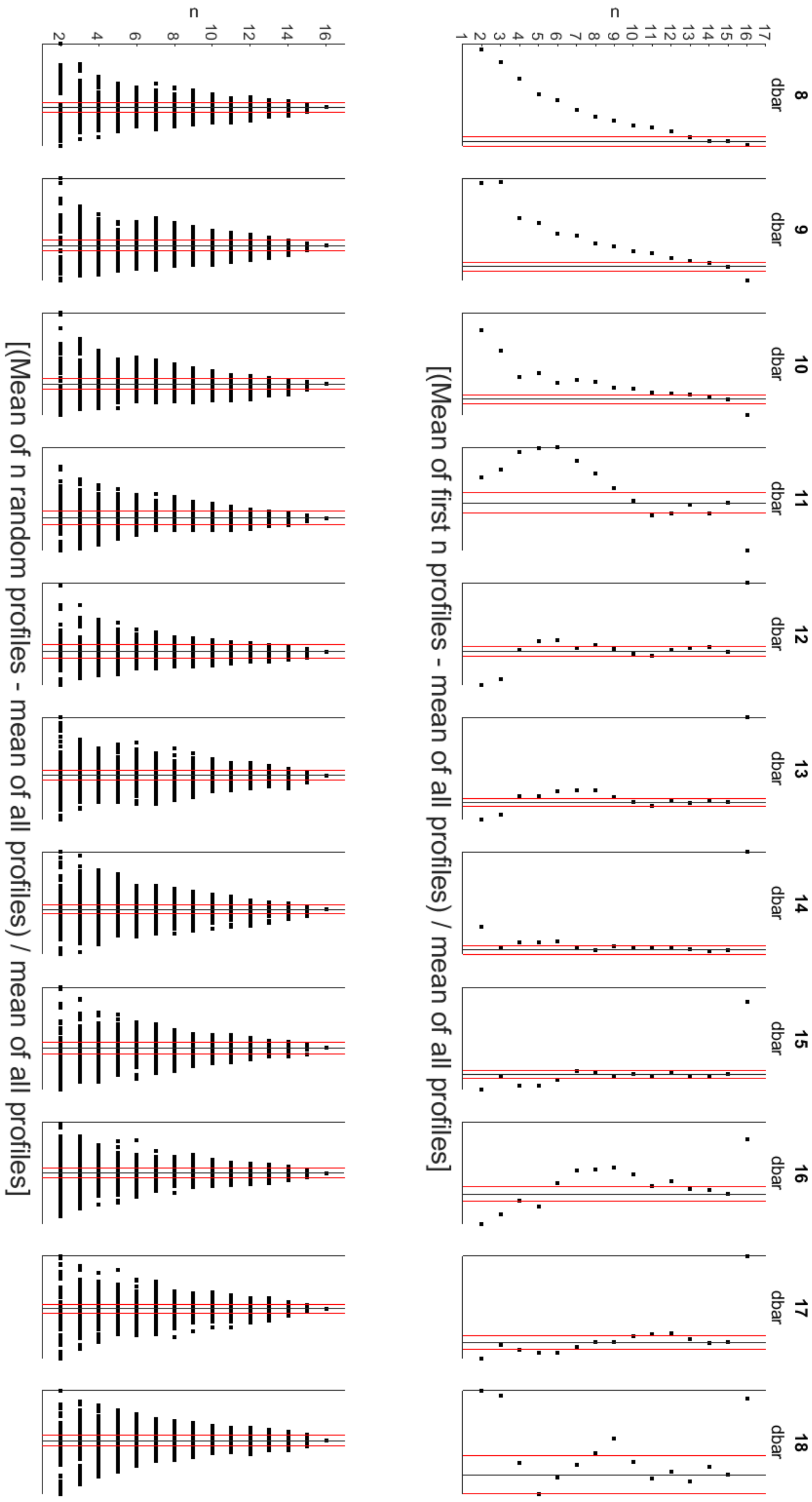
The plots are shown on the following two pages.

The top row of plots for TS1 how unidirectionality for 8 – 10 dbar, where there is also minimal skew in the bottom row. Skew in the bottom row looks largest at 11 dbar. Looking at where the epsilon minimum is (14 dbar), and also 12 and 13 dbar, the top row of plots show minimal spread – again reiterating that where epsilon is small, it might be easier to measure accurately. The pattern is very similar for TS2 – there may not have been as much change between the two time series as thought.



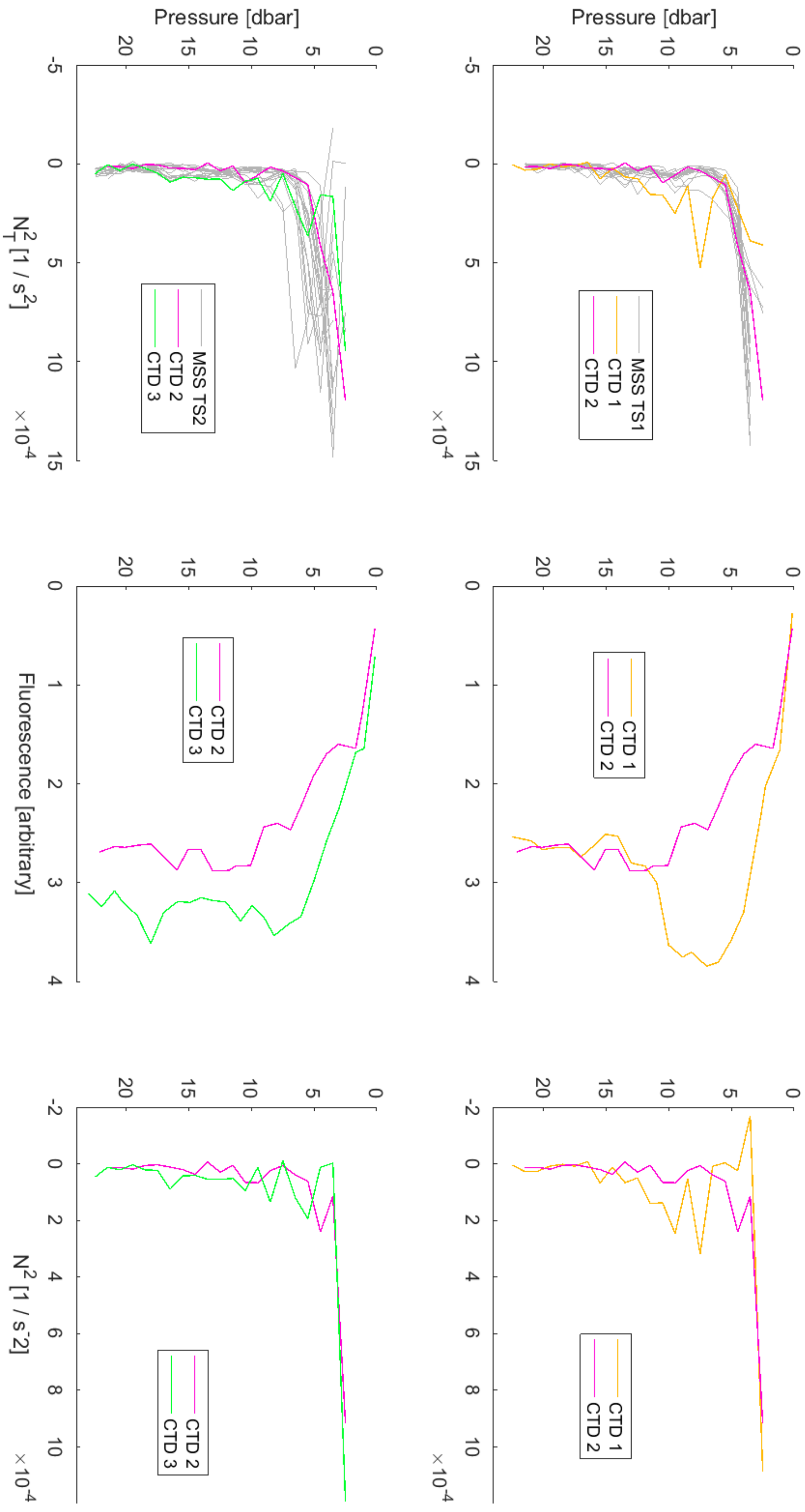
8 dbar
9 dbar
10 dbar
11 dbar
12 dbar
13 dbar
14 dbar
15 dbar
16 dbar
17 dbar
18 dbar
n
Black vertical line = 0
Red vertical lines = -0.01, 0.01
[(Mean of first n profiles - mean of all profiles) / mean of all profiles]
[(Mean of n random profiles - mean of all profiles) / mean of all profiles]

TS1


8 dbar
9 dbar
10 dbar
11 dbar
12 dbar
13 dbar
14 dbar
15 dbar
16 dbar
17 dbar
18 dbar
n
[(Mean of first n profiles - mean of all profiles) / mean of all profiles]
[(Mean of n random profiles - mean of all profiles) / mean of all profiles]

TS2

Where are the high chlorophyll concentrations relative to the mixing/stratification structure?



CTD cast 1:

Peak in N^2_T and N^2 coincide roughly with peak in fluorescence; i.e., where stratification is greatest, chlorophyll is also high (why? Because cells are restricted to the stratified layer they find themselves in?)

CTD cast 2:

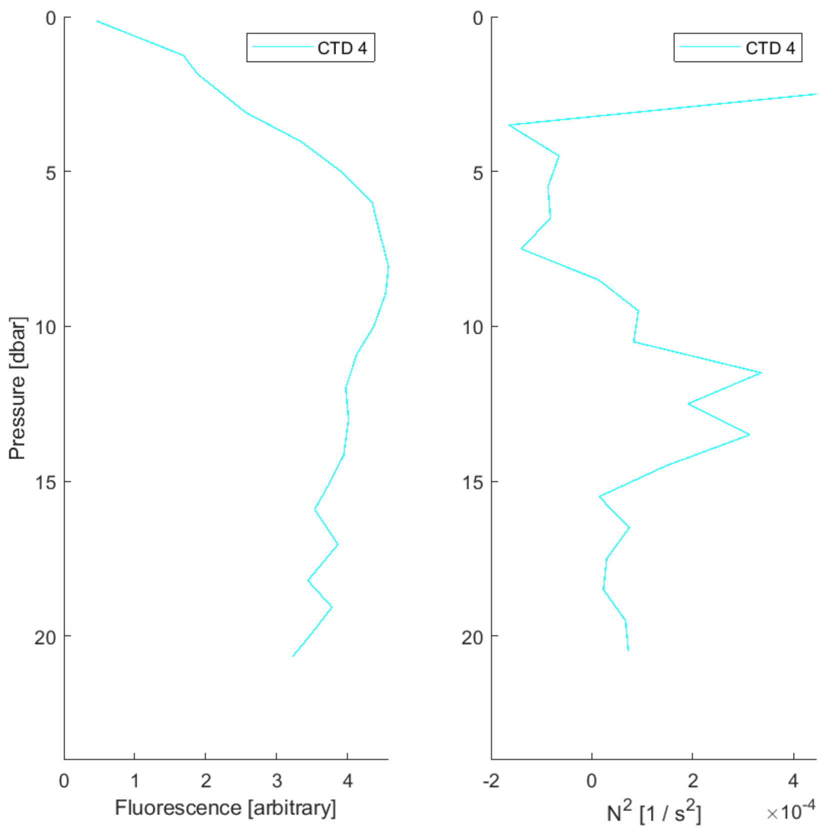
Buoyancy frequency lacks large peak seen in cast 1, as does the fluorescence – does this reinforce that they are related? The MSS data from TS1 appears to match this cast the best.

CTD cast 3:

Very similar fluorescence profile to cast 2, albeit shifted to higher values. The buoyancy frequency profile is also very similar to cast 2. Is there another factor causing the increase in fluorescence/in chlorophyll?

The MSS profiles for N^2_T have a much larger spread for TS2 than for TS1 – is there more noise? Does that make the CTD profiles less trustworthy?

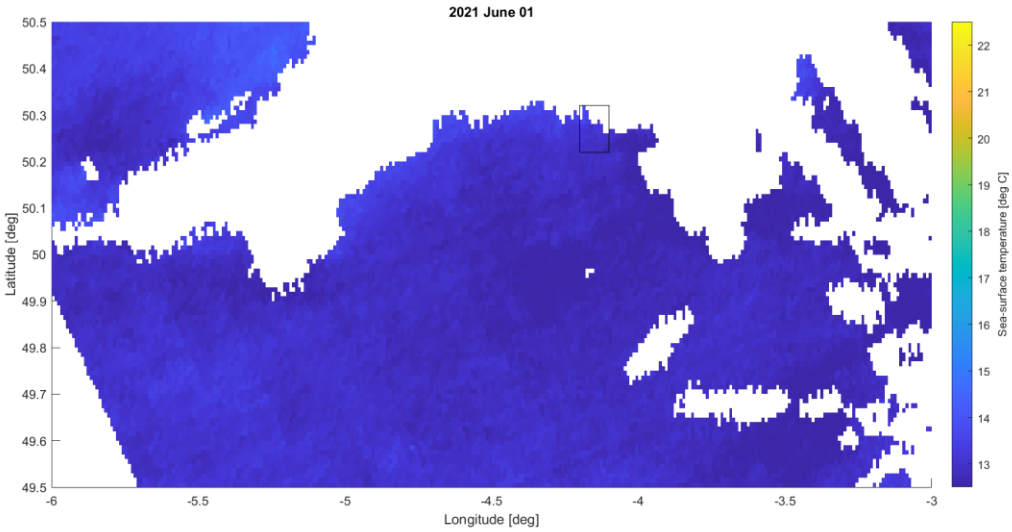
A final plot comparing buoyancy frequency and fluorescence for cast 4 (no MSS data):

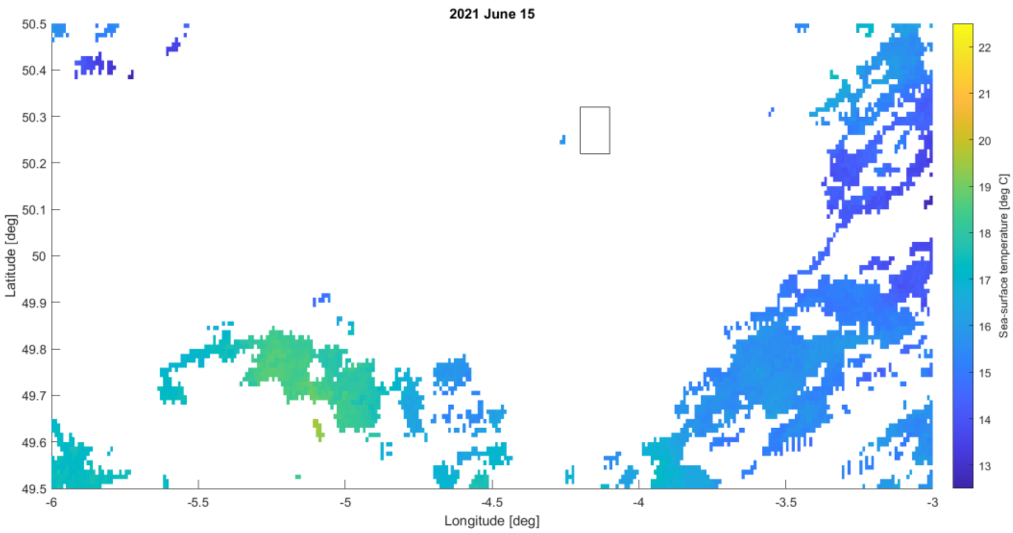


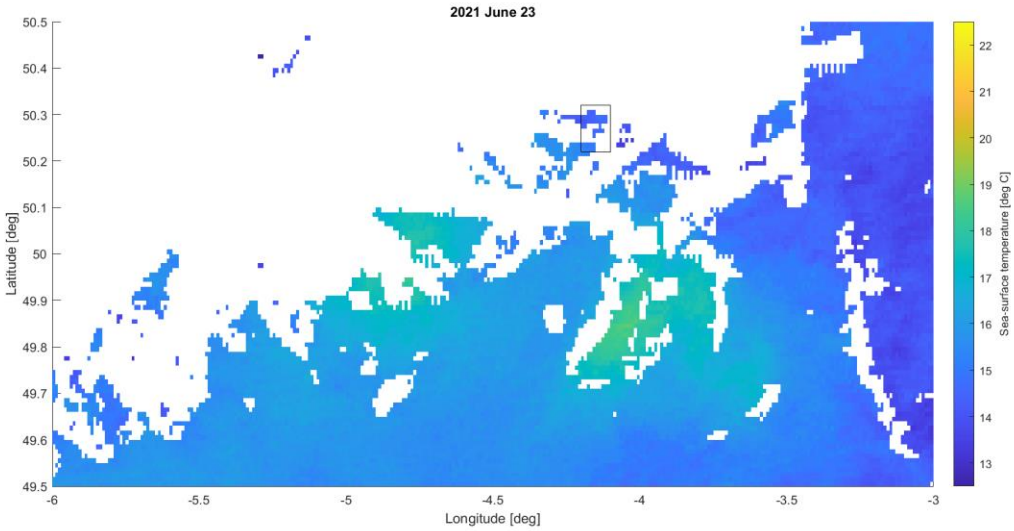
In cast 4, the peak in fluorescence appears to coincide with a negative peak in the buoyancy frequency.

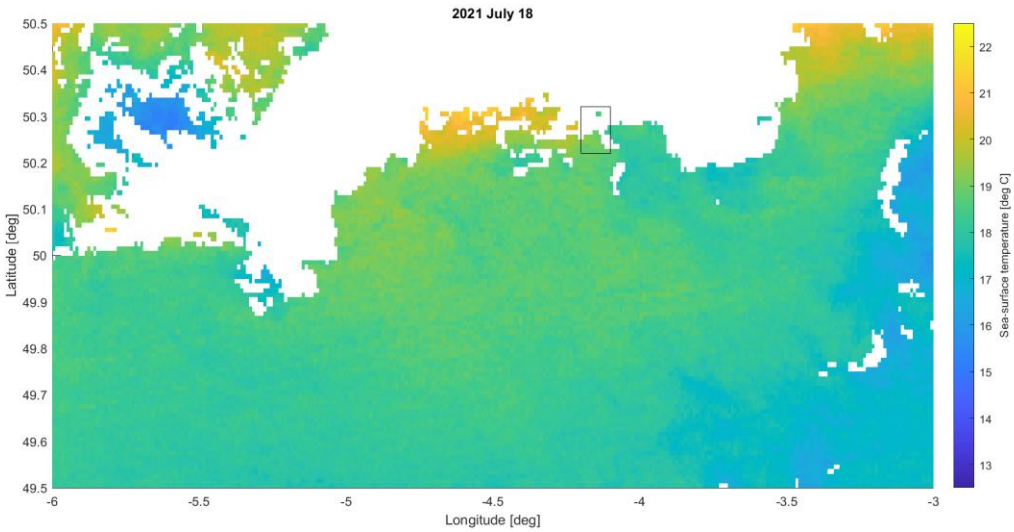
Context – sea-surface temperature at study location in months leading up to sampling

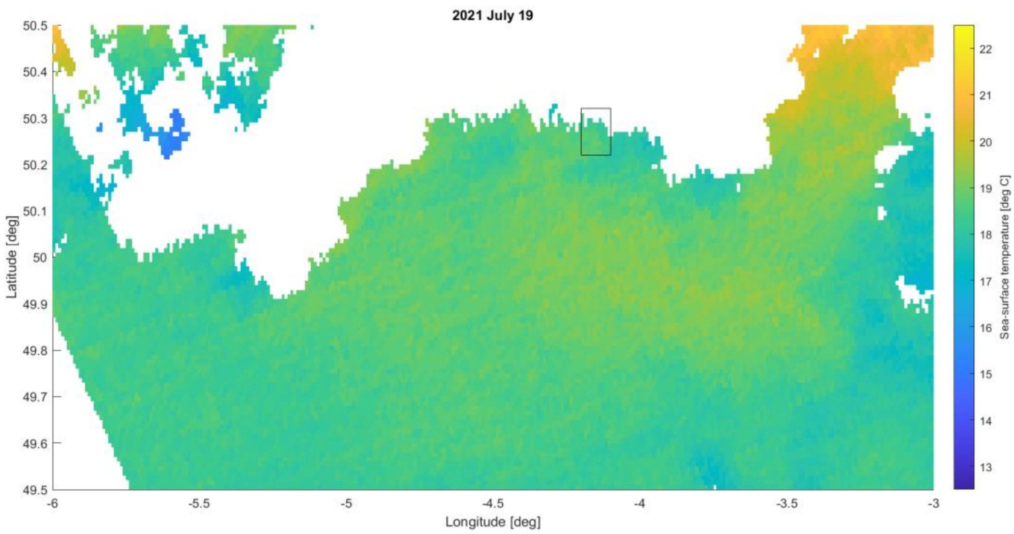
Below are sea-surface temperature (SST) data products from NASA's MODIS-Aqua satellite instrument (NASA Goddard Space Flight Center, Ocean Ecology Laboratory, Ocean Biology Processing Group. Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua Sea-Surface Temperature Data; NASA OB.DAAC, Greenbelt, MD, USA. Accessed on 08/26/2021), for the available cloud-free days:

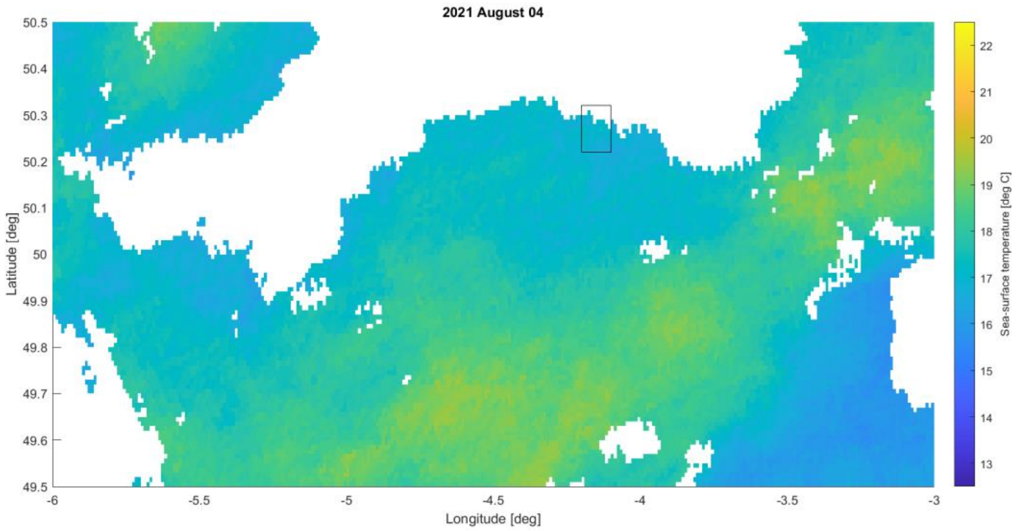


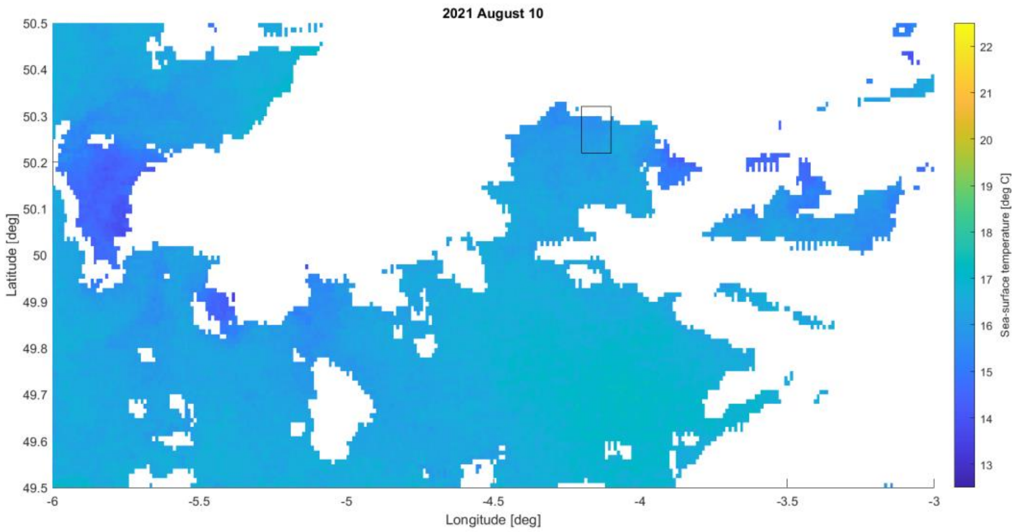


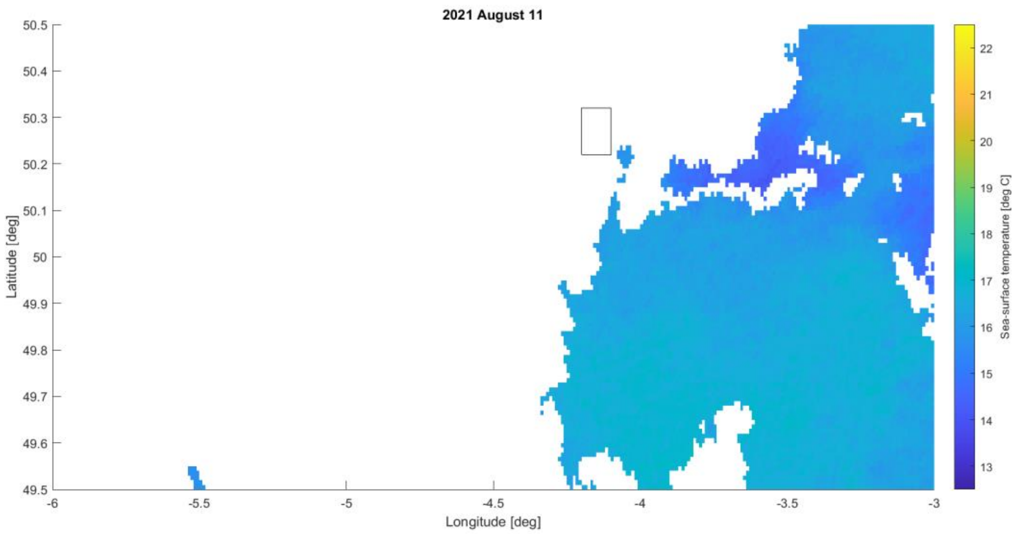

2021 June 23
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]
50.5
50.4
50.3
50.2
50.1
50
49.9
49.8
49.7
49.6
49.5
-6
-5.5
-5
-4.5
-4
-3.5
-3
22
21
20
19
18
17
16
15
14
13

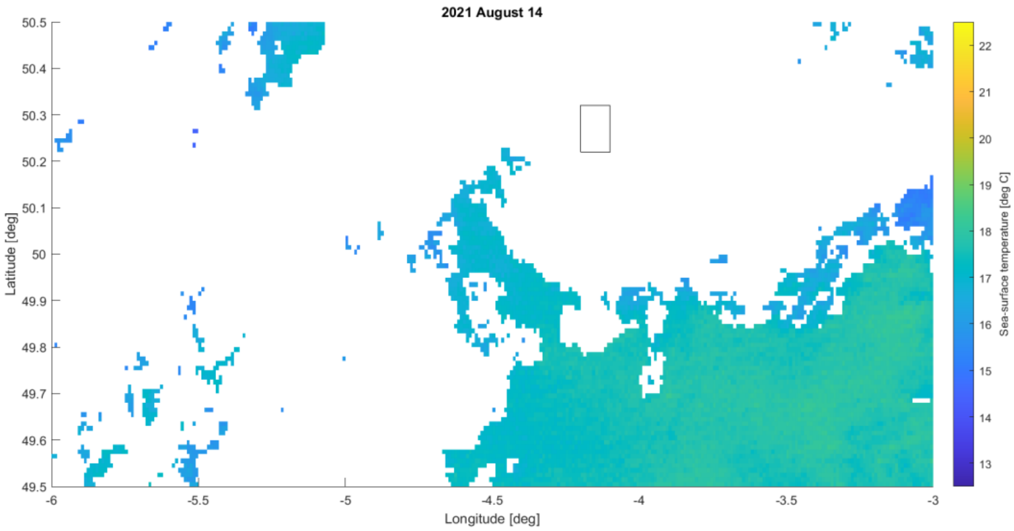

2021 July 18
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]
50.5
50.4
50.3
50.2
50.1
50
49.9
49.8
49.7
49.6
49.5
-6
-5.5
-5
-4.5
-4
-3.5
-3
22
21
20
19
18
17
16
15
14
13


2021 July 19
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]
50.5
50.4
50.3
50.2
50.1
50
49.9
49.8
49.7
49.6
49.5
-6
-5.5
-5
-4.5
-4
-3.5
-3
22
21
20
19
18
17
16
15
14
13


2021 August 04
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]


2021 August 10
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]


2021 August 11
Latitude [deg]
Longitude [deg]
Sea-surface temperature [deg C]



White cells are either cloud-covered or flagged for low-quality. The study location is at the centre of the top line of the black rectangle. The rectangle shows the area within which an SST mean and standard deviation for each day has been calculated:

Date	**Mean SST (°C)**	**Standard deviation in SST (°C)**
2021 June 01	13.07	0.24
2021 June 15	no data	no data
2021 June 23	14.67	0.34
2021 July 18	18.84	0.32
2021 July 19	18.48	0.26
2021 August 04	16.90	0.18
2021 August 10	15.96	0.22
2021 August 11	no data	no data
2021 August 14	no data	no data

There is warming to a peak in July followed by a slight cooling, with the standard deviation varying little.