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Technical note: determination of the height of deep-sea mooring lines above seafloor using turbulence measurements

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29 **Abstract.** Height variations $O(1)$ m of closely spaced moored oceanographic instrumentation are
30 difficult to measure in the deep sea, requiring high-accuracy pressure sensors preferably on all
31 instruments in a mooring-array. In this paper, an alternative method for relative height determination is
32 presented using 2-m spaced high-resolution temperature sensors moored on multiple 9.5-m-spaced lines
33 in the deep Western Mediterranean Sea. While it was anticipated that height variations between lines
34 could be detected under near-homogeneous conditions via adiabatic lapse rate $O(10^{-4} \text{ } ^\circ\text{C m}^{-1})$ by the
35 $3 \times 10^{-5} \text{ } ^\circ\text{C}$ -noise-level sensors, such was prevented by the impossibility of properly correcting for short-
36 term bias due to electronic drift. Instead, a satisfactory height determination was achieved during a
37 period of relatively strong stratification and large turbulence activity. By band-pass filtering data of the
38 highest-resolved turbulent motions across the strongest temperature gradient, significant height
39 variations were detectable to within ± 0.2 m.

40

41 **1 Introduction**

42 Height variations in moored oceanographic instrumentation can occur above unknown topographic
43 features such as small rocks and gullies and due to line stretching by buoyancy force. For example,
44 0.005-m diameter steel cables (breaking strength ~ 20 kN, where kN is Kilo Newton) stretch about 0.1%
45 of cable length under 1.25-kN tension, and 0.3% under 4-kN tension for common oceanographic (e.g.,
46 <https://www.spaceagecontrol.com/calcre.htm>). If closely-spaced mooring lines and attached
47 instrumentation are used, one may need to correct for the unknown height variations, for example to be
48 able to distinguish thin $O(1)$ m stratified layers. Such a correction is possible using high-resolution
49 temperature sensors.

50 In this technical-performance paper, deep-sea instrumental-height determinations will be
51 demonstrated using 45 mooring lines of 125-m tall and 9.5-m apart horizontally each holding 65 self-
52 contained high-resolution temperature ‘T-’sensors in a 70-m diameter steel-pipe ring (van Haren et al.,
53 2021). Each line, nylon-coated 0.005-m diameter steel cable, was pulled up by a net buoyancy of 1.25
54 kN, imposed by a single buoy on top, and was attached to the anchoring ring via a suspended steel-cable
55 grid. The problem of this set-up was not so much the vertical-line stretch, but the unknown suspension
56 of the steel-cable grid. In contrast with a fixed-anchor on a single-line mooring, the steel-cable grid has
57 different heights between the anchoring steel pipes.

58 The ring was moored on a flat seafloor in nearly 2500-m deep weakly density-stratified waters of the
59 Western Mediterranean Sea. The ‘large-ring mooring’ was constructed for three-dimensional studies of
60 deep-sea internal waves, their breaking and turbulence generation, to learn more about their dynamical
61 development via short movies (van Haren et al., 2026) and detailed statistics.

62

63 **2 Materials and Methods**

64 A nearly half-cubic-hectometer of seawater was sampled using 2925 self-contained updated high-
65 resolution, stand-alone T-sensors, new version ‘NIOZ4n’. The ensemble large-ring mooring (Fig. 1a)
66 was deployed in drag-parachute controlled free-fall at the $<1^\circ$ flat and 2458-m deep seafloor of 42°
67 $49.50'N$, $006^\circ 11.78'E$ of the Western Mediterranean Sea in October 2020 (Fig. 1b). The mooring was
68 near the site of neutrino telescope KM3NeT/ORCA (Adrián-Martinez et al., 2016) off the coast of

69 Toulon, France, just 10 km south of the steep continental slope (and 5 km from its foot in the abyssal
70 plain).

71 Fig. 1c shows the numbering of 45 vertical mooring lines, which were ordered in six groups for
72 synchronisation purposes. As with all NIOZ4 T-sensors (van Haren, 2018), the individual clocks were
73 synchronised via induction to a single standard clock on the mooring-array every 4 hours, so that all T-
74 sensors were sampled within 0.01 s. Three buoys also held a Nortek AquaDopp single-point acoustic
75 current meter. Details of design, construction and deployment are given in van Haren et al. (2021).

76 With the help from Irish Marine Institute Remotely Operated underwater Vehicle (ROV) ‘Holland
77 I’ on board Dutch R/V Pelagia, all lines with T-sensors were successfully cut and recovered in March
78 2024. Of the 45 lines, 43 were in good mechanical order, line 1.8 (line 8 of synchronization group 1;
79 henceforth indicated without decimal point) was hit by the drag parachute whereby 10 sensors were lost,
80 and line 65 was about 0.5 m lower than nominal because of a loop in the vertical line near the cable grid.
81 Only line 36 did not register synchronisation, possibly due to an electric wire failure. Three T-sensors
82 leaked and <10 were shifted in position due to tape malfunctioning. In total 2902 out of 2925 T-sensors
83 functioned as expected mechanically.

84 Due to unknown causes all T-sensors switched off unintentionally when their file-size on the 8-GB
85 Kingston memory card reached 30 MB. It implied that a maximum of 20 months of data was obtained,
86 which were recorded at an interval of once per 2 s. After post-processing, 50-150, depending on moment
87 in the record and type of analysis, extra T-sensors are not further considered due to electronics, noise
88 problems. With respect to previous NIOZ4 version, here named ‘NIOZ4o’, the slightly modified
89 electronics resulted in about twice lower noise levels of 0.00003°C and twice longer battery life.

90 Laboratory-bath calibration yielded a relative precision of <0.001°C (van Haren, 2018). Instrumental
91 electronic drift of typically 0.001°C per month after aging was primarily corrected by referencing daily-
92 averaged vertical profiles, which must be stable from turbulent-overturning perspective in a stratified
93 environment, to a smooth, commonly third-order, polynomial without instabilities (van Haren and
94 Gostiaux, 2012). Because vertical gradients of temperature, and thus density, are so small in the deep
95 Mediterranean so that buoyancy frequency $N = O(f)$, where f denotes the inertial frequency, a secondary

96 drift correction was applied. For this correction, reference was made to periods of typically one-hour
97 duration that were quasi-homogeneous with temperature variations smaller than instrumental noise level
98 (van Haren, 2022). Such >125-m tall quasi-homogeneous periods existed on days 350, in 2020, 453 and
99 657, both -366 in 2021, in the records. These two drift corrections allowed for proper calculations of
100 turbulence values using the method of Thorpe (1977), as extensively described for moored T-sensors in
101 van Haren and Gostiaux (2012) and van Haren (2018), under weakly stratified conditions. As will be
102 demonstrated in Appendix A, under very weakly stratified conditions with $N < 0.5f$ a tertiary drift
103 correction involved low-pass filtering of data. This additional correction addresses short-term drift that
104 was about 2-3 times larger in NIOZn than in NIOZo T-sensors.

105

106 **3 Results**

107 While a single-line mooring attached to an anchor at the seafloor may modify the nominal positions of
108 instrumentation due to buoyancy-stretch of typically 0.1-1% of the total line length, depending on
109 amount of buoyancy and line fabric and make, the large-ring mooring will experience an additional
110 differential positioning due to the variable anchor height of the cable grid. Given the anchor being the
111 steel ring, the distributed buoys on top of each of the 45 lines are expected to pull the steel-cable grid
112 (Fig. 1) up in the form of a dome. Hence, different heights are expected for different lines above the,
113 presumed flat, seafloor. Simple geometrical models mimicking a dome will be compared with
114 observations of height variations between the different mooring lines.

115 Prior to deployment, stretch-tests were performed with the grid's steel cable on a harbour quay.
116 Under nominal tension of the planned buoyancy it was found that the exerted tension delivered a
117 measured cable stretch to a value that the typical angle of grid inflection was expected to amount 5° .
118 This angle to the horizontal could not be verified from visual inspection using ROV, although at various
119 images a non-zero angle is discernible, which also seems to vary between different cable sections in the
120 grid (Fig. 2a), as, e.g., in a dome.

121 Eight 'corner-lines' (Fig. 1c, 2b) were also displaced to an amount not precisely verifiable from
122 ROV-inspection. These lines were attached differently to the steel-cable grid as they could not be
123 attached directly to their intersection points at the steel ring. Estimating the height of corner-line can be

124 attempted from Fig. 2b. Visually, the right side of the small ring holding a vertical line in its center does
125 not touch seafloor and the small ring rotates around the smallest of three short assist cables of which the
126 centre is elevated to approximately $h = 0.6$ m above seafloor. If angles are measured on the basis of
127 vertical/horizontal ratio 4/4.5, then the small-ring makes an angle of about 40° to the horizontal, so that
128 its center is 0.8 m above the edge of the small-ring. In that case, the corner-line will start at $h = 1.0$ m.

129

130 **3.1 Parabola model**

131 Taking the 5° -angle due to distributed tension stretch as starting point, some simple models of half cable-
132 grid cross-section can be made (Fig. 3). Quasi-parabola and straight-cable models are considered.
133 Considering that grid attachments are made in the center of the large-ring pipes at 0.3 m, the models
134 start from that height above seafloor. All grid attachments were made to extra enforced steel rings that
135 were bolted around the pipes, to guarantee the pipes remain circular. The steel rings and pipes were
136 protected against corrosion with zinc anodes (Fig. 2).

137 The simplest, albeit unrealistic, straight-cable model makes a fixed angle of 5° (green model in Fig,
138 3). A slightly better model is a paraboloid, a 3D form of the mathematical parabola, as would be
139 approximately found in a weighed cable grid held upside down under gravity. A 5-m discretized
140 parabola model intersecting the straight-cable model halfway will have its top at $h = 2.07$ m above (blue
141 model). The steepest part, exceeding 5° , of the cable in this model has a horizontal distance of 5 m to
142 the large ring, which corresponds with the position of, e.g., line 57 (cf. Fig. 1c). In the model, line 57
143 has its lowest T-sensor at $h = 1.2$ m. If an overall maximum angle of 5° is maintained, the top of that
144 parabola model will be at $h = 1.12$ m, and the first line inside the large ring will have its lowest T-sensor
145 at $h = 0.72$ m (red model). In an attempt to verify these cable-grid models, data from the altimeter and,
146 in a relative sense, the pressure gauge of the ROV were used. They gave a value of $h = 0.7 \pm 0.1$ m after
147 the ROV had landed on the small-ring of the first line of the grid's centre cable.

148 If the maximum- 5° parabola model is correct, all vertical lines are a maximum of 0.4 m, or ± 0.2 m,
149 apart vertically. This is difficult to correct for in practice. Unfortunately no pressure sensors were
150 available on the vertical lines, the three mounted on current meters being too inaccurate, to quantify

151 height variations between lines. As a result, quantification is sought using the T-sensor data to verify,
152 and possibly improve when necessary, above geometrical model values.

153

154 **3.2 Adiabatic lapse rate height-determination method**

155 Considering that the T-sensors have a noise level of 0.00003°C , potential temperature differences of
156 $>5\times 10^{-5}^{\circ}\text{C}$ are statistically significantly detectable, in theory. Thus, given local deep Western
157 Mediterranean adiabatic lapse rate of $\Gamma = -1.7\times 10^{-4}^{\circ}\text{C m}^{-1}$ (here for simplicity a pressure of 10^4 Pa is
158 transferred to a vertical distance of 1 m), vertical height differences of >0.3 m are potentially detectable
159 using T-sensor data under near-homogeneous conditions in which temperature variations are
160 predominantly due to compressibility effects. Such conditions do occur in the deep Western
161 Mediterranean regularly, see the lower 250 m above seafloor in a shipborne-CTD profile (Fig. 4). Γ
162 dominates the temperature lapse with the vertical in Fig. 4a. In time series from moored T-sensor data,
163 near-homogeneous conditions over 125-m vertical range occur about 60% of the time (Fig. 5a). These
164 conditions lead to very low temperature variance across all frequencies outside instrumental white noise
165 (Appendix A).

166 However, a complicating factor in ‘adiabatic lapse rate height-determination’ method is the
167 electronic drift of T-sensors, which varies in intensity per sensor but typically amounts about 10^{-3}°C per
168 month. While the value is one order of magnitude larger than the adiabatic lapse rate per unit length, in
169 principle T-sensors attached to a particular vertical line can be corrected to within a precision, i.e.
170 relative accuracy, of 10^{-4}°C (van Haren, 2018). All depends on a calibration with a precision of $<5\times 10^{-4}$
171 $^{\circ}\text{C}$, which is achievable using a thermostatic bath with constant temperature levels to within $\pm 10^{-4}^{\circ}\text{C}$
172 of their preset values. The standard post-processing correction is by fitting a smooth curve over
173 sufficiently time-averaged vertical temperature profile that must be stable over an inertial period. When
174 the temperature range is not too large, above precision is obtainable with some effort and careful search
175 in the data. In the weakly stratified deep Mediterranean however, this correction is not achievable
176 between different lines, because the low precision is not transferrable to a low absolute accuracy.

177 As a result, the height determinations from translated temperature differences between lines attached
178 to the steel-cable grid are too large and erratically distributed (Fig. 6). Obviously, there is no consistency
179 between lines in the image of Fig. 6, which shows no signs of expected lower relative values at the edges
180 close to the ring and higher values near the center, following parabola models as in Fig. 3. Moreover,
181 the variation in values is nearly an order of magnitude greater than expected from the parabola models
182 in Fig. 3. Clustering per calibration -- approximately 190 T-sensors are used in the thermostatic bath per
183 cycle (van Haren, 2018) -- does not give improvement of consistency in the image (not shown).

184

185 **3.3 Turbulence variance height-determination method**

186 As the adiabatic pressure effect on temperature is not a suitable measuring method for the expected
187 doming of the steel-cable grid inside the large ring, another method is sought. In contrast with the
188 adiabatic lapse rate method, this other method is not working under near-homogeneous conditions.
189 Instead, it works when vertical temperature stratification is rather large, with peaks resulting in $N = 6f$,
190 and turbulent temperature variations are large (Figs 5a, 7, 8). The combination of these two conditions,
191 relatively large stratification and large turbulence, seems counter-intuitive, as stratification is generally
192 considered to suppress turbulence. Whilst stratification indeed suppresses the vertical length-scale of
193 turbulence, it may have variable effects on temperature variance.

194 In case of the deep Western Mediterranean, relatively large vertical temperature gradients of a few
195 10^{-3} °C over O(10-100) m occur with the advection of warmer waters (Figs 5a, 7a). The advection is
196 regularly slanted towards the vertical, either induced by internal-wave action and/or by sub-mesoscale
197 and mesoscale eddies, as inferred from quasi-3D movies (van Haren et al., 2026). When mainly
198 governed by planetary vorticity deflection, it represents in part convection-turbulence that appears in a
199 vertically stratified environment at mid-latitudes (Marshall and Schott, 1999). All warming events
200 observed thus far associate with considerable turbulence. In the entire time series (Fig. 5a) no significant
201 cooling events occur. Current speeds (Fig. 5b) seldom exceed 0.1 m s^{-1} and thus there is no evidence
202 strong flow events such as associated with deep dense-water formation that might occur in late winter.

203 Due to the relatively low-noise T-sensors, deep Western-Mediterranean waters can be characterized
204 by frequency (ω) spectra in which turbulence manifests itself over a range of at least two orders of

205 magnitude (Fig. 8), approximately across $10 < \omega < 3000$ cpd (cycles per day), under the relatively large
206 turbulence conditions. Outside this band, spectra are dominated by internal waves, for $\omega < 10$ cpd, and
207 roll-off to instrumental white noise, for $\omega > 3000$ cpd. A strong temperature gradient produces high-
208 frequency internal waves, but is also accompanied by turbulent eddies, probably as a result of breaking
209 internal waves. Under near-homogeneous conditions similar temperature spectra are found, except that
210 the variance is two orders of magnitude lower and turbulence drops into instrumental noise at about 500
211 cpd (*cf.* Fig. A2).

212 Here, we take the high-frequency portion $\Theta'(t, z)$ of the well-resolved turbulence band and, somewhat
213 arbitrarily, band-pass filter between $600 < \omega < 1800$ cpd (frequency range indicated by the black bar in
214 Fig. 8) that is certainly outside internal wave and white noise bands. Although temperature variations in
215 this range are part of inertial subrange of isotropic turbulence (Kolmogorov, 1941) reflecting a continual
216 transfer between large energy-containing turbulence scales and small dissipative scales via shear-
217 induced motions, such are mainly found well away from the seafloor. Within $h = O(10)$ m from the
218 seafloor, motions are partly of isotropic nature and partly of anisotropic convection-turbulence nature
219 in a buoyancy subrange (Bolgiano, 1959; Obukhov, 1959), which manifests at all heights in the range
220 $10 < \omega < 100$ cpd, albeit the spectral smoothing is coarse. Irrespective of a variation in slope and
221 turbulence behaviour, the main goal here is the practical use of temperature (turbulence) variance
222 outlined below. Future investigations will be directed to improve statistics in part by averaging data
223 from the 45 lines and data from different periods of stratified turbulence.

224 During such a period of slanted warm waters from above, temperature variance may be relatively
225 low within a few meters from the seafloor, but it increases to high levels well above common interior-
226 values in $O(10)$ m above seafloor (Figs 8, 9). The 1.3-day root-mean-square value of the 600-1800 cpd
227 band-pass filtered signals is calculated for every T-sensor. In this example, the peak in turbulence-
228 temperature variance is found around $h = 11$ m. Above and below the peak one can take advantage of
229 two depth-levels of high gradients in turbulence temperature-variance. Common interior-values are
230 reached at about $h > 40$ m = h_{sst} , which could reflect the upper limit of layer of strong stratified turbulence
231 (Figs 7-9).

232 After referencing local turbulence temperature variance $\Theta^2(\text{line}, z)$ to the value of an arbitrary
233 line(x), by subtracting $\Theta^2(\text{line}(x), z)$, taking the mean of two levels z_1 and z_2 and scaling with the 45-
234 line average $\langle \cdot \rangle$ value of their vertical gradient $\langle d(\Theta^2)/dz \rangle$ over $dz = z_2 - z_1$, commonly the, here
235 constant, 2-m distance between T-sensors, a transfer from temperature to height value is established.
236 Hereby it is assumed that over the 1.3-day period the statistics are homogeneous over the mooring array.
237 Heterogeneity is not expected to affect the average value over a period longer than the inertial period.
238 Subsequently, below or above the peak value in Fig. 9, a height pattern can be computed relative to
239 values of an arbitrary vertical line, 44 in this case (Fig. 10). Here, the pattern is given for height
240 determination by computing across the largest gradient of temperature-variance, between T-sensors at
241 $h = 3.5$ and 5.5 m. An example of an eight times shorter period is given in Appendix B.

242 The difference between this pattern and that in Fig. 6 is obvious. First, all values are between 0 and
243 2 m in Fig. 10, and a consistent statistical significance is found to within ± 0.2 m. Cross-sections of the
244 cable grid also confirm the doming of the pattern (Fig. 11). While the observed doming is close to the
245 parabola models of Fig. 3, larger height-determination values than in the models are observed in the
246 center, with slightly steeper overall grid cables that still roughly obey the maximum 5° slopes (Fig. 11).
247 The ± 0.2 -m error range is easily verifiable after comparison with the provided bar. Corrections to
248 vertical positioning of T-sensors are therefore feasible and necessary, because the difference between
249 the center and edges of the cable grid is approximately 1.5 m.

250

251 **3.4 Stratified turbulence quantification**

252 The temperature variations of the well-stratified day 485 demonstrating the necessary height
253 determination for the doming of the steel-cable grid show a background value of turbulence dissipation
254 rate $O(10^{-10}) \text{ m}^2 \text{ s}^{-3}$. Reduced values $O(10^{-11}) \text{ m}^2 \text{ s}^{-3}$ are basically only found within a few meters from
255 the seafloor, underneath the largest 2-m small-scale stratification with maximum buoyancy-frequency
256 values of $N_{\max} \approx 1.6 \times 10^{-3} \text{ s}^{-1}$ (Fig. 7). This is observable in time-depth plots of temperature, small-scale
257 stratification and non-averaged turbulence dissipation rate ‘values’. The largest overturns, which
258 dominate the vertically averaged values of turbulence dissipation rate, have a scale $O(100)$ m (Fig. 7a,c).

259 Turbulent overturns reach close to the seafloor, but only sporadically touch it, mostly at begin and end
260 of the warm-water depression. Coarsely every two hours, 124-m vertically averaged turbulence
261 dissipation rate peaks in value (Fig. 2d). The $h = 40$ m of elevated high-frequency temperature variance
262 (Fig. 9) and stratification (Fig. 7b) show non-negligible turbulence dissipation rate values with further
263 elevated values reaching the seafloor before and after the warm-water passage (Fig. 7c).

264 Time-depth mean values from the 1.3-day period are for turbulence dissipation rate $[\langle \varepsilon \rangle] = 6 \pm 3 \times 10^{-10}$
265 $\text{m}^2 \text{s}^{-3}$ and for turbulent diffusivity $[\langle K_z \rangle] = 1.4 \pm 0.7 \times 10^{-3} \text{m}^2 \text{s}^{-1}$ under $[\langle N \rangle] = 2.8 \pm 0.3 \times 10^{-4} \text{s}^{-1} \approx 3f$.
266 These 1.3-day, 124-m mean turbulence values are about one order of magnitude larger than open-ocean
267 values observed in stratified waters well away from boundaries (Gregg 1989; de Lavergne et al. 2020;
268 Yasuda et al. 2021). The reader is reminded that the experiment was located close to the foot of the
269 continental slope, where the strong Liguro-Provençal current flows, (internal) tides are weak, and total,
270 (sub-)mesoscale plus near-inertial, water-flow speeds never exceed 0.1m s^{-1} .

271 Although the warm-water event of Fig. 7 is of relatively strong turbulence, it is not exceptional and
272 elevated temperature-stratification and -variance alternate in time with near-homogeneous episodes
273 throughout the 20-month records (Fig. 5a). This will be reported elsewhere in more detail, notably using
274 three-dimensional investigations.

275

276 **4 Conclusions**

277 The expected height variation due to vertical buoyancy pull across a steel-cable grid, which was
278 suspended within a large anchoring steel-pipe ring, was modelled as an inverted parabolic with
279 maximum 5° angle to the horizontal. To verify the height variation of the instrumented vertical mooring
280 lines across the grid, we expected to use an observational period with negligibly small vertical density,
281 and thus temperature, stratification so that the adiabatic lapse rate $\Gamma = dT/dz$ would dominate vertical
282 temperature variations $T(z)$. The T-sensors have a noise level of about $3 \times 10^{-5} \text{ }^\circ\text{C}$, while $|\Gamma| \approx 1.7 \times 10^{-4}$
283 $\text{ }^\circ\text{C m}^{-1}$ in the deep Western Mediterranean and thus is potentially measurable by sensors nominally 2-m
284 apart vertically. However, the sensor's electronic drift at all scales turned out insufficiently correctable
285 under near-homogeneous conditions.

286 Instead, a mooring-height determination was achieved during a period of relatively large
287 stratification, during a slump down of warm water presumably slanted from above and induced by
288 internal waves. By band-pass filtering the highest resolved turbulence variance, mainly from inertial
289 subrange, across the strongest temperature gradient, the dome of pulled-up grid was significantly
290 detectable, and fine-tuned a parabola model with height variations between the moorings of correctable
291 $(0.5-2.0)\pm 0.2$ m.

292 The impact of investigating turbulence signals from high-resolution moored T-sensors in the deep
293 Mediterranean is several-fold. First, it demonstrates the dynamics of internal-wave breaking governed
294 by either near-inertial or sub-mesoscale motions slumping relatively warm waters to within a few meters
295 above the seafloor. Thereby, an episodic-average turbulence dissipation rate is provided, which is about
296 ten times larger than ambient values above a flat seafloor. The enhanced turbulence affects deep-sea
297 life. Deep-sea turbulence is studied more elaborately in van Haren (2026 submitted).

298 Second, the strong vertical variation in turbulence temperature-variance profiles, across relatively
299 large local vertical temperature gradients, may be useful for height determinations in nearby moorings
300 over flat seafloors also in shallow seas, and, more difficult, above sloping seafloors, whereby a
301 correction may be applied for unknown mooring-line stretch under tensioning by buoyancy. Such height
302 determinations may also be necessary when moorings are accidentally placed on small rocks or in small
303 gullies. The resulting determination demonstrated that the parabola model based on in-house line-
304 tensioning was adequate and required only secondary adjustment in the slightly steeper cables of the
305 underwater large-ring mooring, albeit all showed $<5^\circ$ sloping to the horizontal as anticipated from the
306 in-house tests.

307

308 *Data availability.*

309 Processed temperature data used in this study are available from van Haren (2026) “Processed
310 temperature data to: Determination of the height of deep-sea mooring lines above seafloor using
311 turbulence measurements”. Mendeley Data, V1, <https://doi.org/10.17632/24n7dwjhp.1>. Current meter
312 and CTD data are available from van Haren (2025): “Large-ring mooring current meter and CTD data”,
313 Mendeley Data, V1, <https://doi.org/10.17632/f8kfwcvtdn.1>.

314

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316

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325

326 **Appendix A Extra drift correction for T-sensors in near-homogeneous waters**

327 When waters are very weakly stratified or near-homogeneous with $N < 0.5f$ over the range of moored
328 T-sensors, a short-term drift error may emerge. This drift partially causes the impossibility to determine
329 instrumental height variations under such conditions. Albeit electronic drift is well known to occur on
330 long timescales of weeks-months, short-term hourly drift may appear because of nonlinear temperature
331 dependency and/or inadequate contact between the Negative Temperature Coefficient NTC thermistors
332 and the environment through the glass tube and its contact paste. NTC thermistors are the measuring
333 component of NIOZ T-sensors. This short-term drift was previously observed in NIOZ4o deep-trench
334 data and, especially clear, in air (van Haren and Bosveld, 2022). It turned out difficult to correct for.
335 During a 2017/2018 test experiment in the deep Western Mediterranean it did not pose a great problem
336 in NIOZ4o data. Unfortunately, NIOZ4n appear to have about twice larger short-term drift than previous
337 NIOZ4o, despite their smaller long-term drift and smaller instrumental noise, both by a factor of two-
338 three approximately. A correction for short-term drift of NIOZ4n is proposed below, with reference to
339 NIOZ4o.

340 Half-day NIOZ4n data (Fig. A1a-c) from arbitrary line 25 are compared with a 104-m tall set of
341 NIOZ4o data (Fig. A1d-f). The investigated samples are from almost homogeneous waters, with a total
342 colour-range over a Conservative-Temperature difference of only 1.7×10^{-4} °C, for both data sets.
343 Although NIOZ4o are more noisy (Fig. A1a,d), the NIOZ4n show a more horizontal-stripy pattern that
344 has different values through time, compared to T-sensors above and below. This is evidence of
345 remaining bias due to short-term drift. Low-pass time filtering, with a cut-off frequency of 500 cpd,
346 does not reduce these (Fig. A1b,e), but additional vertical filtering, with a cut-off wavenumber at 10
347 cpm, adequately removes the bias (Fig. A1c,f).

348 As a consequence of near-homogeneity, energetic overturning scales are expected to be large due to
349 the reduced restoring force. In both data sets in the center of images, albeit clearer in the NIOZ4o, one
350 notices a slanting jet of warmer waters over a vertical range of about 60 m in short bursts of 10-20 m.
351 Such jets of convection turbulence were found abundant in the Mariana Trench (van Haren, 2023), but
352 relatively rarely in the deep Mediterranean.

353 Depending on the rate of stratification, the vertical filter cut-off at 0.05-0.2 cpm (cycles per meter)
354 is obtained after fine-tuning in an attempt to retain the relevant overturning scales as much as possible.
355 Under weakly but stable stratified conditions 0.1-0.2 cpm is used, while under near-homogeneous and
356 unstable conditions 0.05-0.1 cpm is used. The fine-tuning of the vertical filter concerns relatively
357 adequate spectral improvement and turbulence calculations. Naturally, all data-corrections yield a
358 certain loss of information, but it is informative to estimate how much the loss may be.

359 In 4-d-average spectra (Fig. A2) that include the 0.5-d period of Fig. A1, the impact of small-scale
360 drift is seen to be larger for NIOZ4n (Fig. A2a) than for NIOZ4o (Fig. A2b). In these plots spectra are
361 scaled with the slope of buoyancy subrange, for clarity. As a reference for the correction, the temperature
362 difference $\Delta\Theta$ (magenta spectrum) is taken between the two neighbouring T-sensors at $h = 29$ and 31
363 m. That difference spectrum is compared with the spectrum of temperature data from the upper T-sensor
364 (green). The magenta spectrum has a higher noise level by about a factor of two for $\omega > 100$ cpd than
365 that of the green spectrum. This is commensurate with random white noise.

366 At lower frequencies, the magenta spectrum crosses the green spectrum around 50 and 150 cpd for
367 Fig. A2a and A2b, respectively. This means that data are no longer dominated by white noise, but by
368 other parametrizations, which are governed either by natural processes or by instrumental flaws other
369 than noise. Around the crossing frequency, temperature spectra become horizontal following buoyancy-
370 subrange scaling. This scaling, which represents convection turbulence of an active scalar (Bolgiano,
371 1959; Obukhov, 1959), was no longer dominant at frequencies higher than that of the crossing, more so
372 in Fig. A2b than in Fig. A2a.

373 After correction by applying vertical low-pass-filtering (red), the weak slope towards lower
374 frequencies, especially that of Fig. A2a, is correctly removed and white noise levels are lower. The
375 spectral slope change to white noise is now at the same frequency, 400 cpd, for both data sets. The quasi-
376 transfer function of correction depicted in the blue spectra is less steeply sloping for $\omega < 1000$ cpd in
377 Fig. A2a than in Fig. A2b, which demonstrates the larger effects of short-term drift correction for the
378 NIOZ4n compared to the NIOZ4o. However, in both data sets of very weakly stratified deep-sea waters

379 it prevents resolution of the transition from buoyancy and/or inertial subranges to the viscous turbulence
380 dissipation range.

381 Resuming, after vertical-filtering correction, temperature data at $\omega < 400$ cpd seem useful for
382 turbulence calculations under weakly stratified conditions. Note that this correction is not needed during
383 periods with relatively large temperature variance and stratified, generally more shear-induced,
384 turbulence. For turbulence dissipation rate calculations, 10-30% reduction is obtained from short-term
385 drift correction. This reduction is well within the error range of a factor of two normally achieved for
386 ocean turbulence data.

387

388 **Appendix B Height determination from a short warm-water period**

389 Naturally the method sketched in Section 3.3 does not work under all circumstances. One requires a
390 rather vigorous appearance of stratified warm-water turbulence to preferably reach close to the seafloor.
391 Such periods are sought manually. Even a short 3.6-h period returns a reasonable estimate of the cable
392 grid height (Fig. A3). It mimics Fig. 10, and has some larger noise level with values that remain within
393 the error bar.

394

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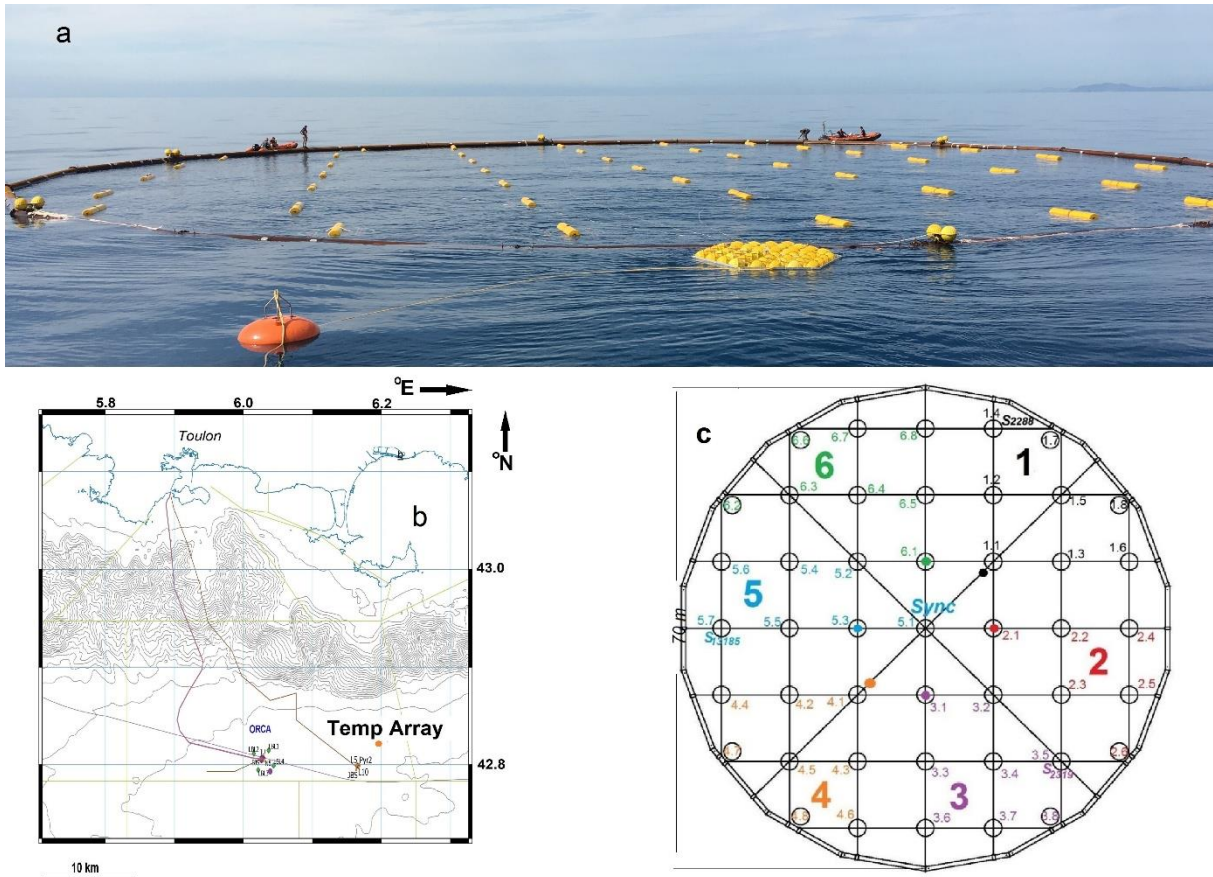
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438



439

440 **Figure 1.** Large ring in fold-up form at sea, during deployment just prior to finish the opening of air-

441 valves. The front part of the large steel-pipe ring is already underwater. Almost all top-buoys of the 45

442 small-ring-compacted mooring lines are visible. In the front still outside the ring, the yellow drag

443 parachute and orange pick-up buoy are floating. (b) Location named "Temp Array" (orange dot) off

444 southern France. The mooring is well east of main neutrino telescope 'NT' site "ORCA" of KM3NeT

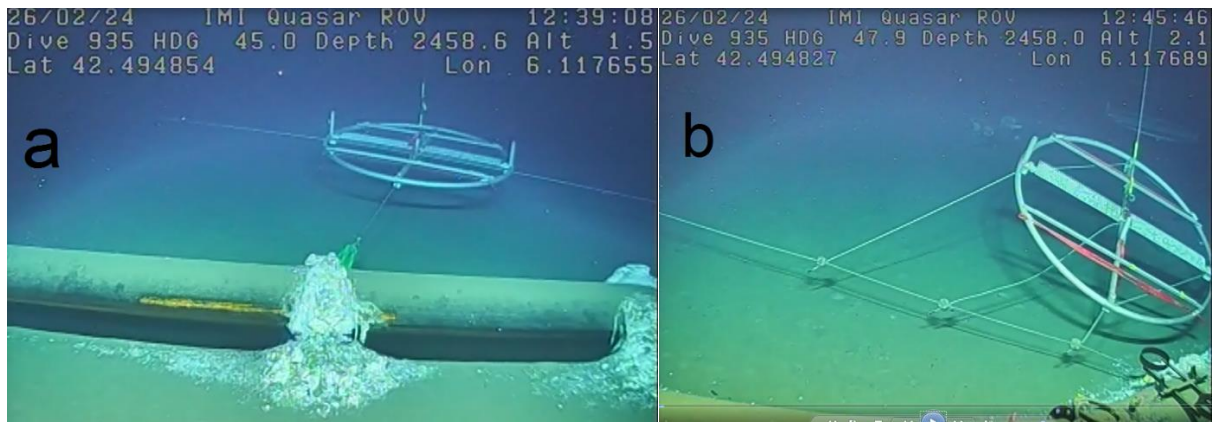
445 (Adrián-Martinez et al., 2016) and just northeast of the former ANTARES NT-site. Isobaths are given

446 every 100 m. (c) Layout of the large-ring mooring viewed from above, with steel-cable grid and small-

447 rings numbered in six synchronisation groups. Lines 14, 35 and 57 (omitting the decimal point) held a

448 current meter at the top-buoy. Corner-lies are, in clockwise direction: 17, 18, 26, 38, 48, 47, 62 and 66.

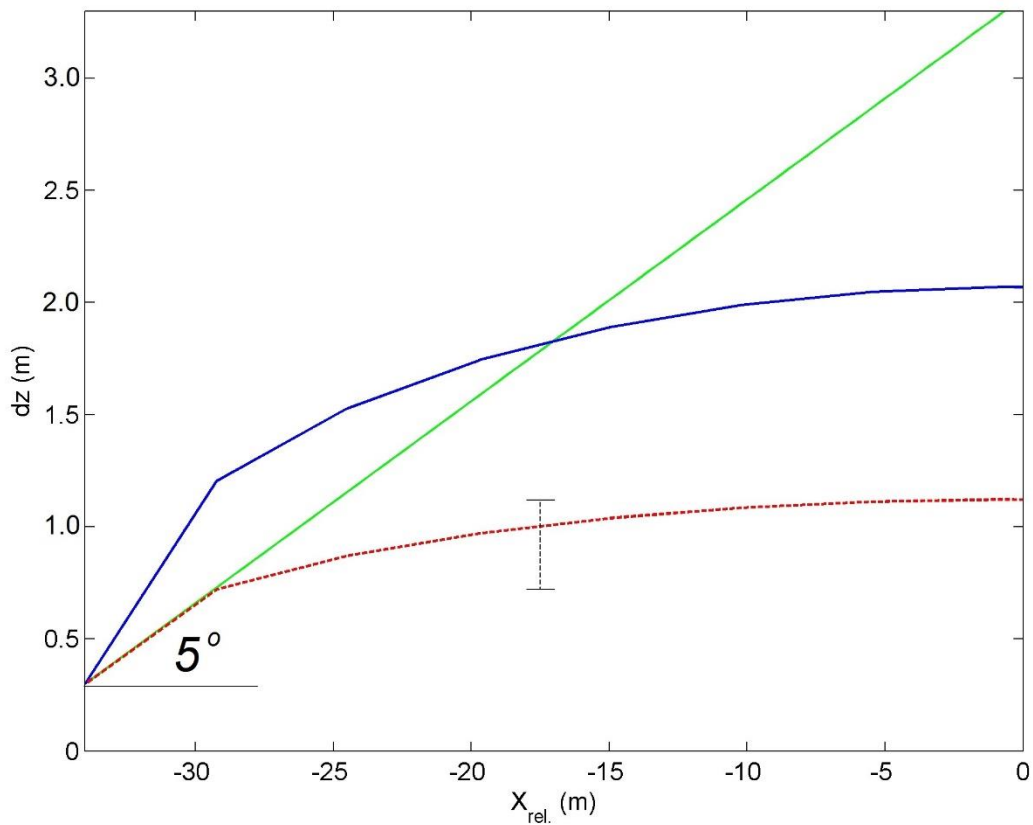
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451 **Figure 2.** Underwater video stills of small-rings demonstrating steel-cable grid elevation and cable-
 452 inclinations. The 0.61-m diameter steel pipe in the foreground is part of the large anchoring ring, which
 453 sank 0.07 ± 0.02 m in the sediment of the $< 1^\circ$ flat seafloor. All steel cables are attached to the middle of
 454 the steel pipes, and thus at height $h = 0.24$ m above sediment. (a) Line 44 (cf. Fig. 1c). To the right of
 455 the small-ring the wire visibly makes a larger angle to the horizontal than to the left. (b) Estimating
 456 height of ‘corner-line’ 47, see text. (Images from video by ROV Holland I).

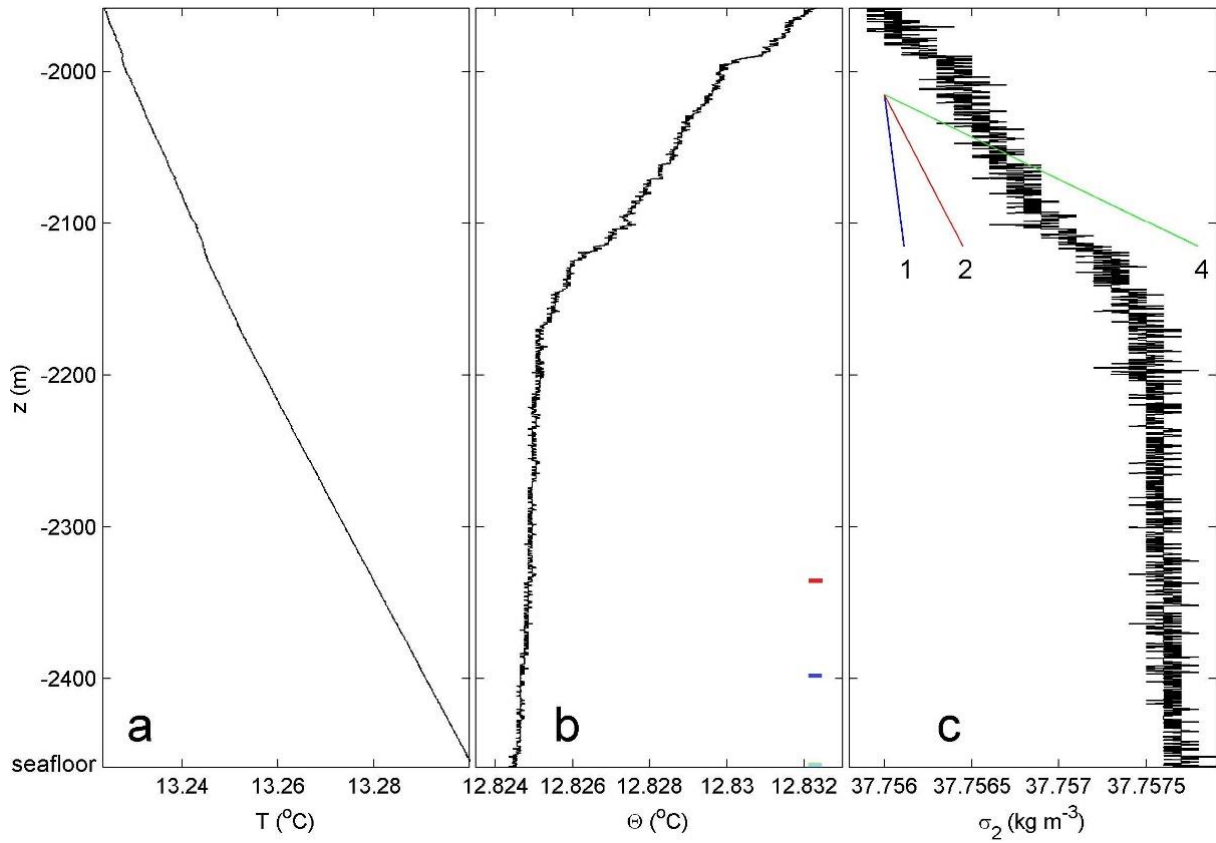
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459 **Figure 3.** Some expected quasi-parabola and straight-line models, for half centre steel cable of large-
 460 ring mooring grid. The seafloor is at the horizontal axis, the cable-grid attachment to the large-ring is
 461 for a steel pipe at a solid floor. The green straight line has a fixed angle of 5° with the horizontal, which
 462 angle was established after in-port tension tests. The blue (solid line, 5-m discretized) parabola model
 463 intersects the green line halfway, so that its top is at $h = 2.07$ m. If an overall maximum angle of 5° is
 464 maintained (red dashed model), the parabola top is at $h = 1.12$ m, and the first vertical line attached to
 465 relative horizontal position $x_{rel} = -29$ m will be at $h = 0.72$ m.

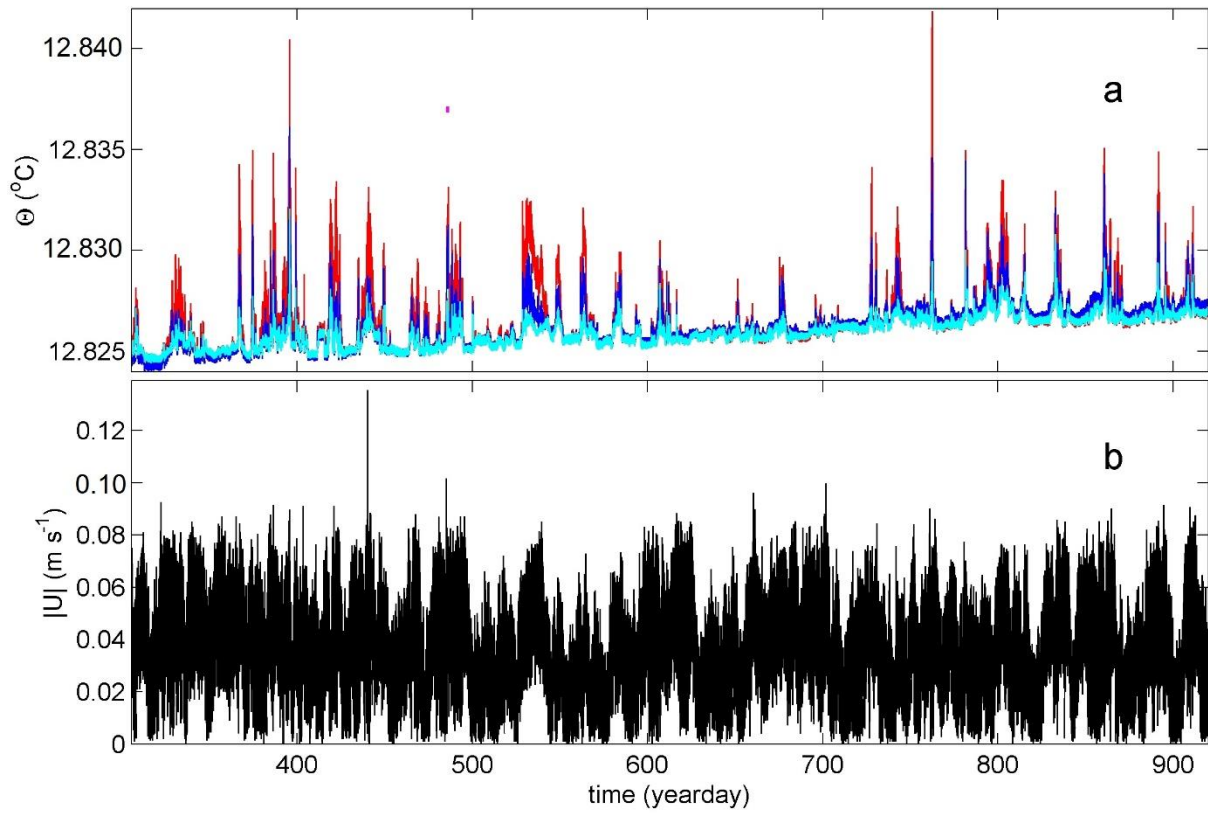
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468 **Figure 4.** Lower 500 m of shipborne CTD-profile data obtained near the large ring during mooring
 469 deployment. (a) In situ temperature. (b) Conservative Temperature (IOC et al., 2010), data in a. corrected
 470 for compression. Small colour bars indicate nominal heights of moored T-sensors at lowest (cyan),
 471 middle (blue) and upper (red) positions. (c) Density anomaly referenced to 2×10^7 Pa. The sloping lines
 472 indicate several stratification rates in terms of buoyancy frequency $N = xf$, $x = 1, 2, 4$ times the local
 473 inertial frequency f .

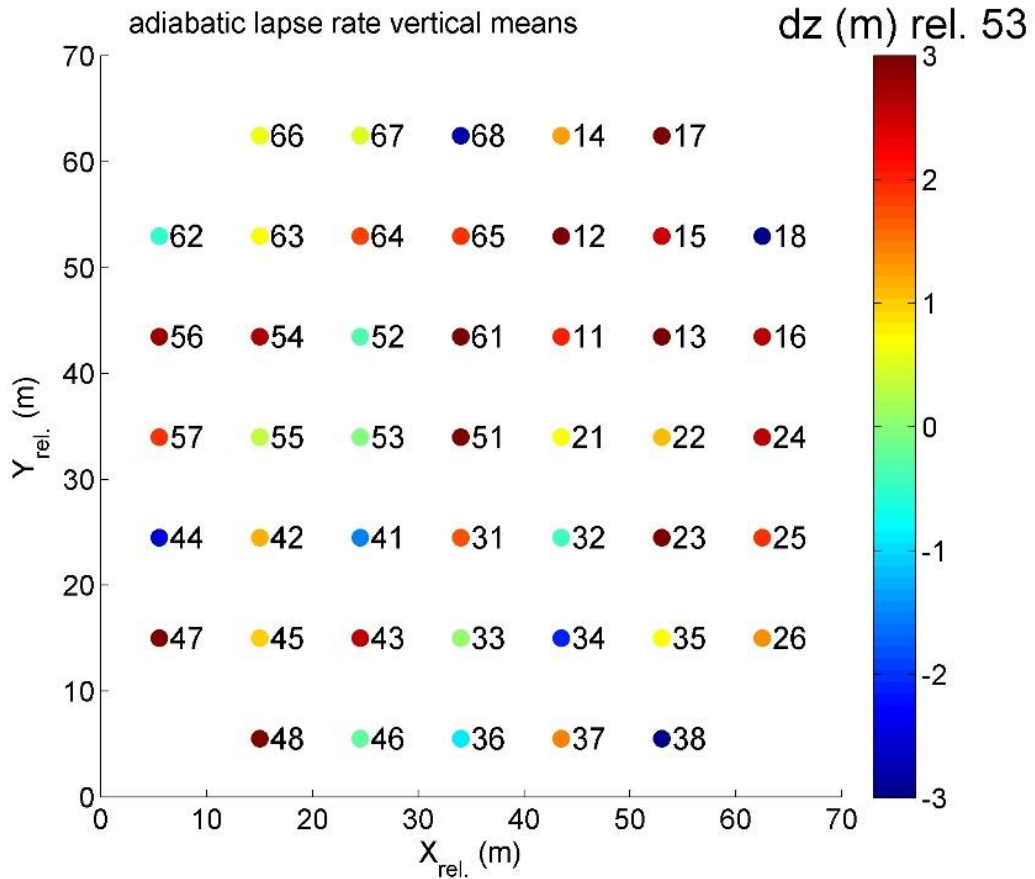
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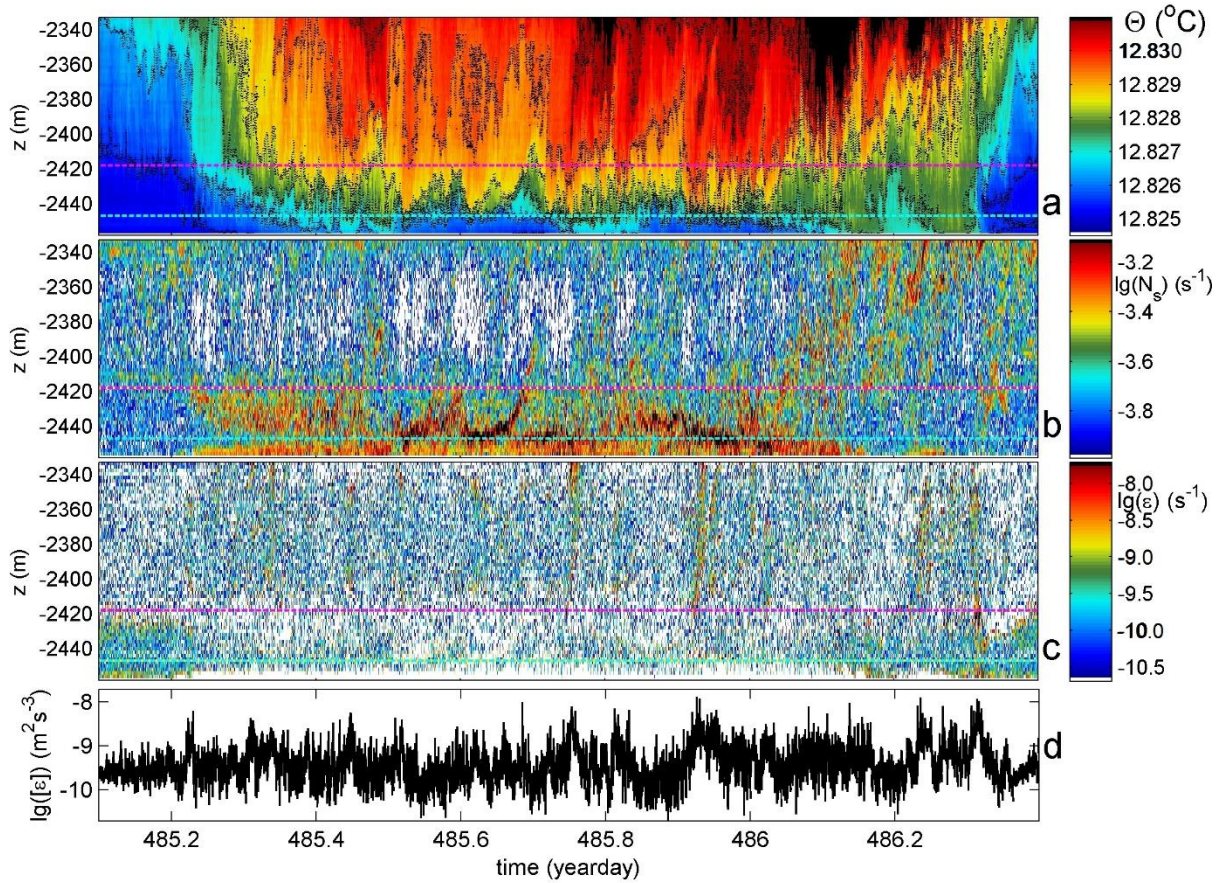
476 **Figure 5.** Overall 20-month time series of moored temperature and current meter data. (a) Conservative
 477 Temperature at $h = 1$ (cyan), 63 (blue) and 125 m (red) cf. Fig. 4b of arbitrary line 53. Data are
 478 subsampled at once per 6 s and not corrected for electronic-drift bias. The magenta dot indicates day
 479 485. (b) Unfiltered current speed at $h = 126$ m of line 14.

480



481

482 **Figure 6.** Vertical displacement calculation for vertical lines of the large-ring mooring using the local
 483 adiabatic lapse rate Γ . This height-determination method is based on temperature shift per line after
 484 calibration and drift correction for near-homogeneous period 350.04-350.08, with arbitrary line 53 as
 485 reference. The conversion of meters into degrees Celsius is via $\Gamma = 0.00017^{\circ}\text{C m}^{-1}$, so that a vertical
 486 difference of $dz = 3 \text{ m}$ reflects approximately 0.0005°C . Corner-lines are 17, 18, 26, 38, 47, 48, 62 and
 487 66.



488

489 **Figure 7.** Thirty-one hours of data from line 53 during a turbulent passage of relatively warm water.

490 Horizontal dashed magenta and cyan reference lines are at $h = 40$ and 11 m above seafloor, respectively.

491 (a) Time-depth plot of Conservative Temperature with black-dotted contours every 0.001°C , low-pass

492 filtered ‘lpf’ with cut-off at 3000 cpd (cycles per day). (b) Logarithm of 2-m small-scale buoyancy

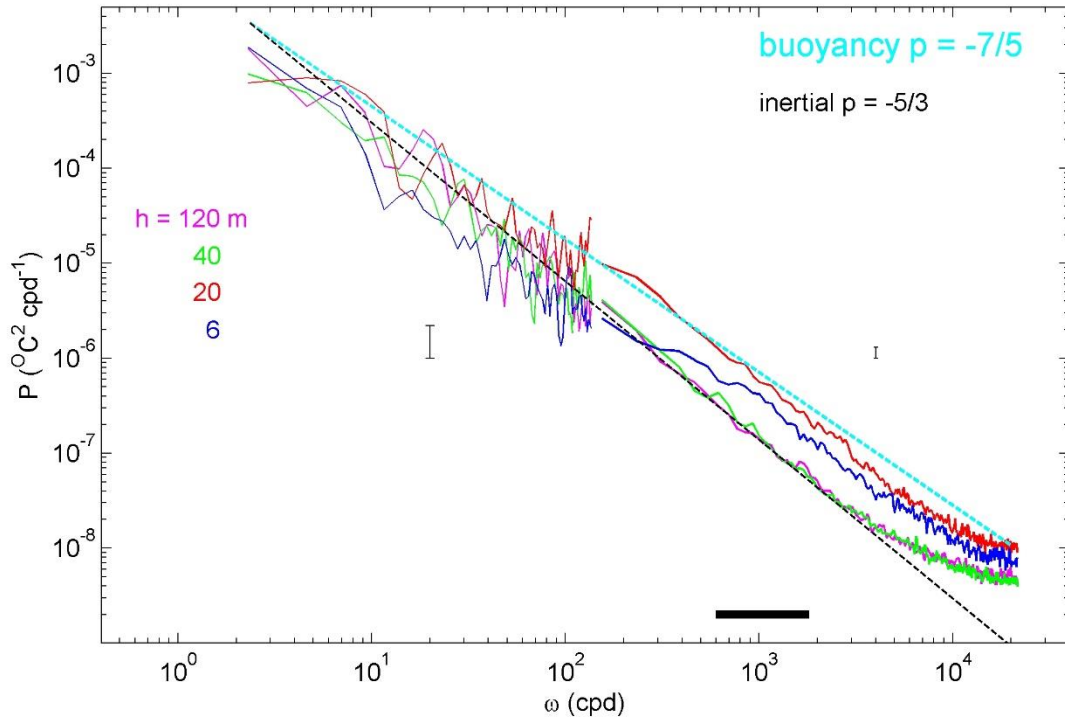
493 frequency from reordered profiles of data in a. (c) Logarithm of non-averaged displacement values from

494 data in a. following the reordering method by Thorpe (1977) and cast in units of turbulence dissipation

495 rate. (d) Time series of logarithm of turbulence dissipation rate averaged over the 124-m vertical extent

496 of T-sensors.

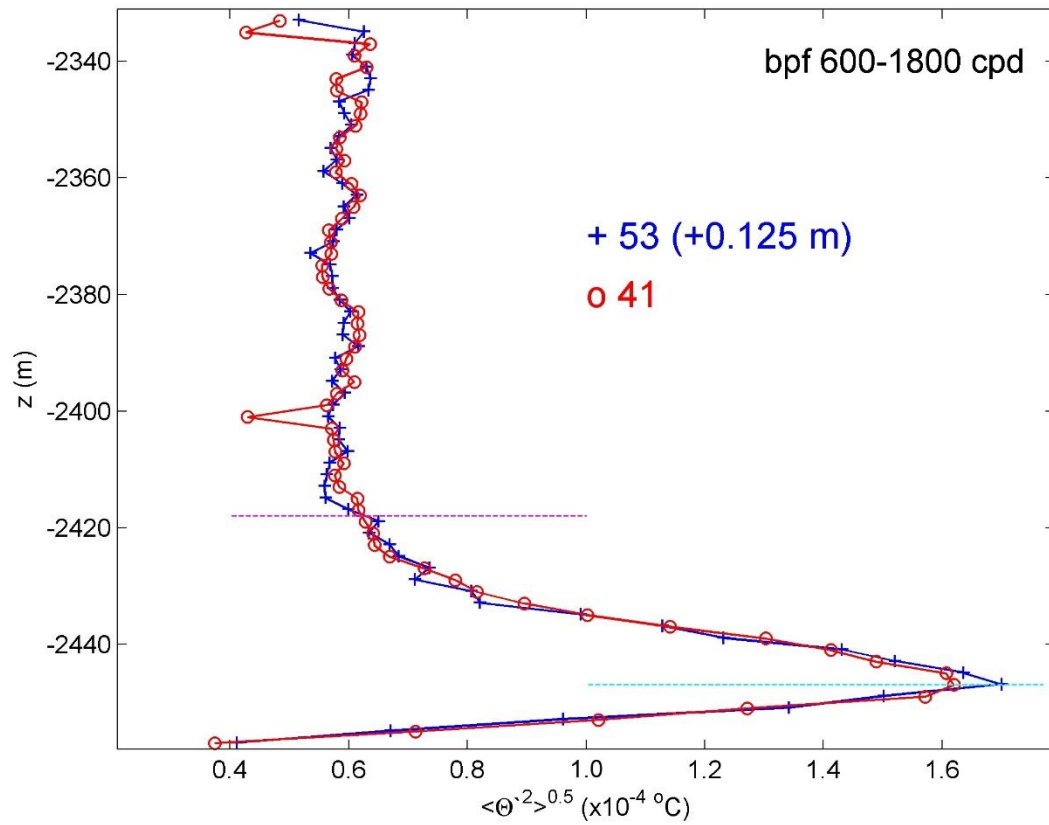
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499 **Figure 8.** Unscaled frequency spectra, patched from weakly and heavily smoothed parts, for four T-
 500 sensors of line 53 at indicated heights h above seafloor, averaged over the 1.3-day period of Fig. 7 for
 501 unfiltered data. Spectral slopes ω^p for inertial and buoyancy subranges of turbulence are indicated with
 502 straight dashed lines and exponents p . The horizontal black bar indicates frequency range of the pass-
 503 filter band that is applied for the turbulence-variance method of height determination.

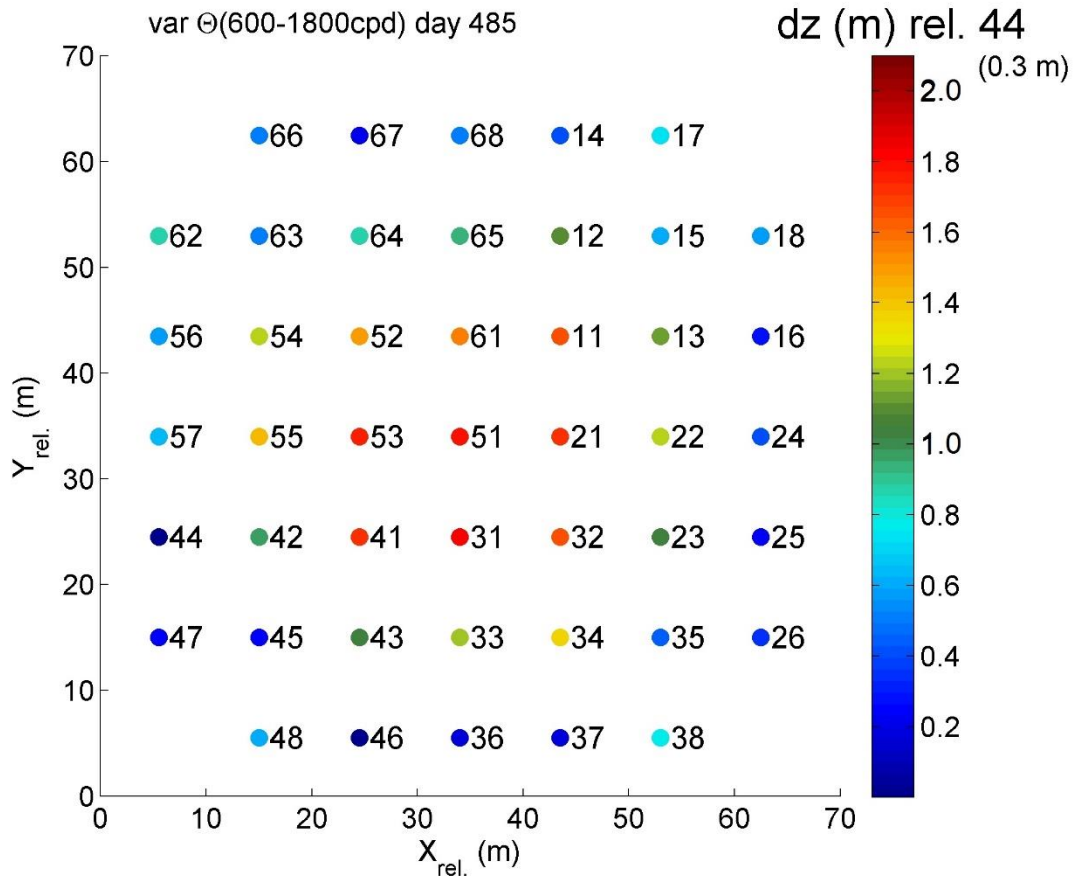
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506 **Figure 9.** Vertical profiles of standard deviation of band-pass filtered ‘bpf’ high-frequency turbulence
 507 signals for temperature data in Figs 7a, 8 for two neighbouring lines, with off-set relative height
 508 determination. The variance-peak height (cyan-dashed line) corresponds also to the height of strongest
 509 layering in stratification in Fig. 7b. The magenta-dashed line delineates the vertical extent of enhanced
 510 temperature variance above interior values.

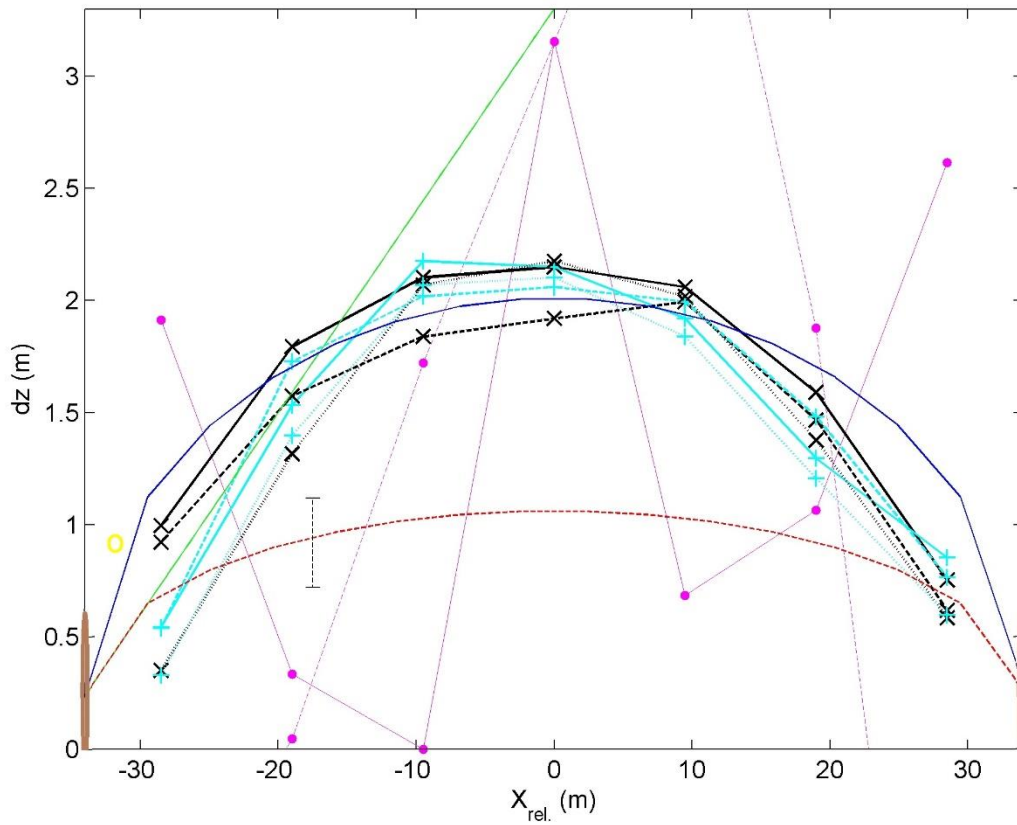
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513 **Figure 10.** As Fig. 6, but for turbulence-variance height-determination method determined from profiles
 514 like in Fig. 9 using T-sensor data between positions 2 and 3 above seafloor, where the gradient in
 515 temperature variance is maximum, divided by the average gradient over 2 m. Values are given relative
 516 to those of line 44 (0.3 m), arbitrary line near the edge of the cable-grid.

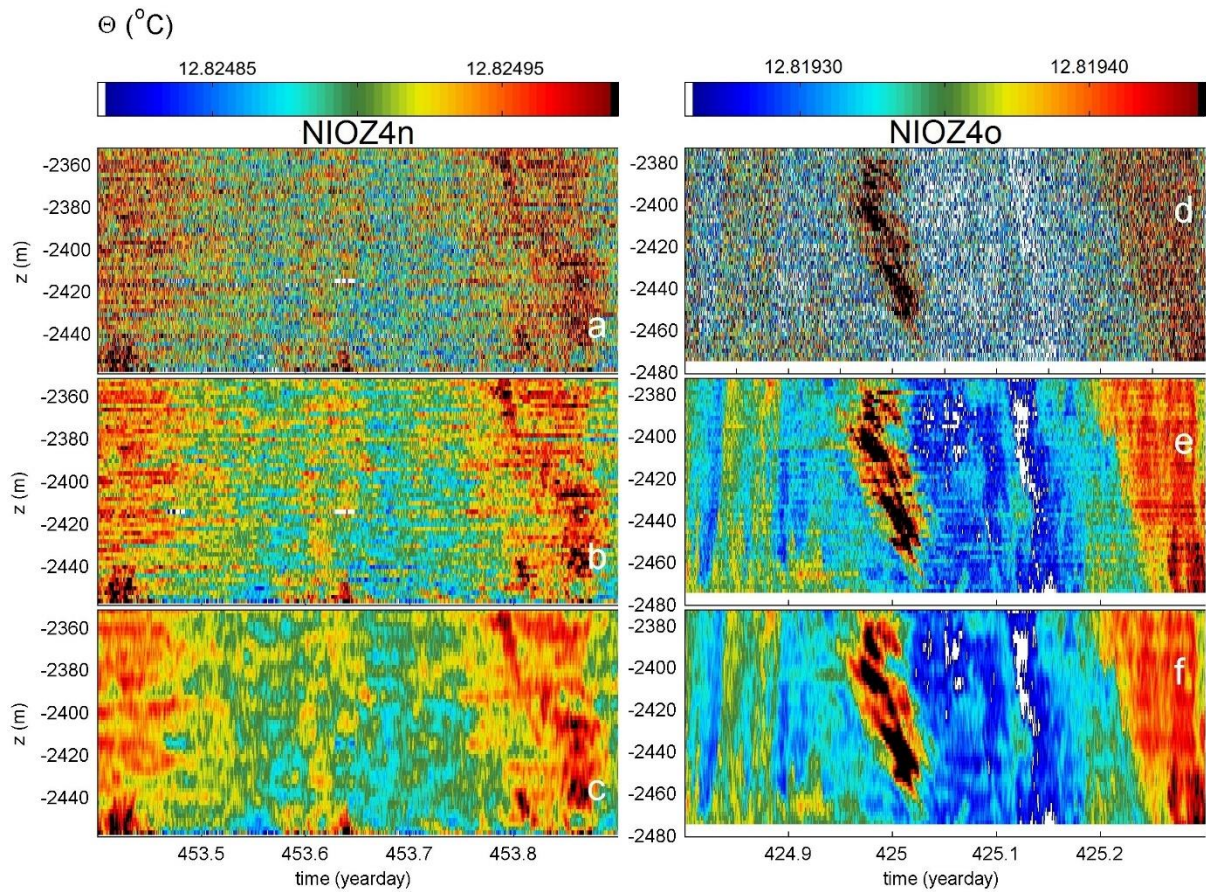
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519 **Figure 11.** Constant-Y (black x graphs) and constant-X (cyan +) cross-sections without corner-lines of
 520 height determinations from Fig. 10 vertically shifted +0.3 m. Solid lines indicate center lines in both
 521 directions. Corner-line height determination is indicated by yellow o. For comparison, data in Fig. 6 are
 522 given for central lines with magenta dots (thin solid x-direction; dashed y-direction). In the background,
 523 models are given in green, blue and red of double distance than in Fig. 3.

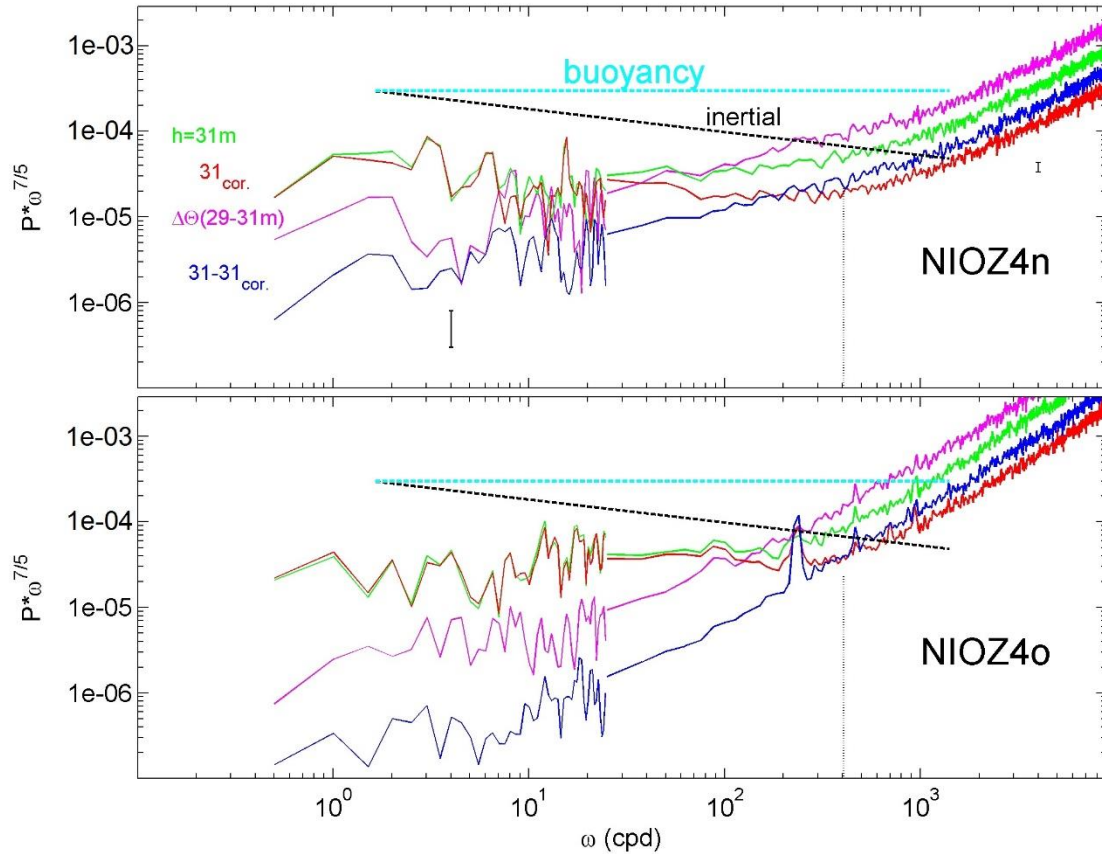
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525

526 **Figure A1.** Half-day Conservative-Temperature data from $h = 1-104$ m demonstrating the correction of
 527 short-term drift. The conditions are near homogeneous, as full the temperature range is only $1.7 \times 10^{-4} \text{ } ^\circ\text{C}$
 528 during both the present experiment in 2020/2021 (left column) and during a test-experiment in 22-m
 529 deeper water in 2017/2018 (right column). (a, d). Unfiltered data, after post-processing involving
 530 calibration, referencing to CTD-, homogeneous-period-, and smooth-polynomial data. (b, e) Lpf with
 531 cut-off at 500 cpd. (c, f) Corrected for short-term drift: 500-cpd and 10-m vertical-scale lpf data.

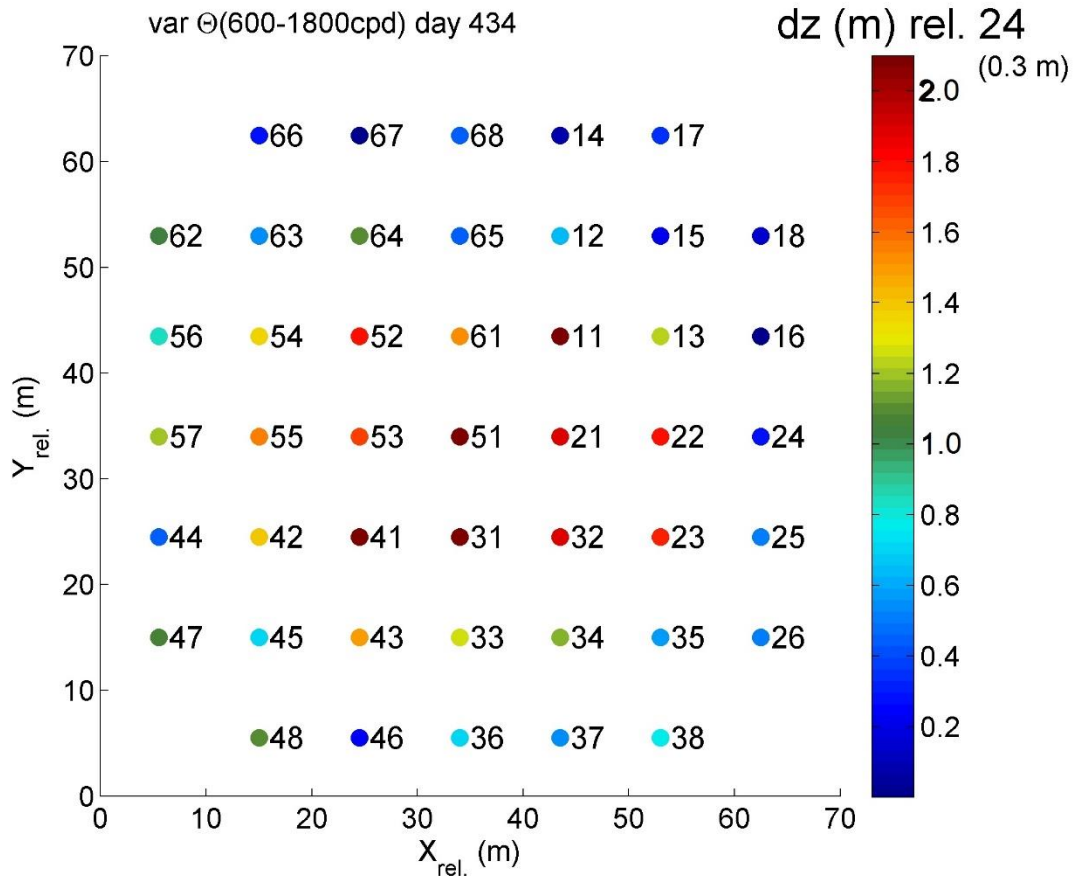
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534 **Figure A2.** Four-day average spectra that are patched together from two, a weakly- and a heavily
 535 smoothed part, and scaled with the buoyancy-subrange slope (horizontal cyan). From 2-s sampled T-
 536 sensor data. The spectra demonstrate effects of and correction for short-term drift in T-sensor data
 537 around $h = 30$ m during near-homogeneous periods between days 453-457, including those of Fig. A1.
 538 Plotted are spectra for unfiltered data (green), vertical temperature difference with data from T-sensor
 539 2-m lower (magenta), 500-cpd and 10-m vertical scale corrected data (red), and the difference between
 540 green and red spectra (blue). For reference, the relative log-log plot slope is given for inertial subrange
 541 (black). The vertical dotted line at 400 cpd is explained in the text. a) NIOZ4n data. b) NIOZ4o data.

542



543

544 **Figure A3.** As Fig. 10, but for a 3.6 h short warm-water period between days 434.95 and 435.1 and
 545 relative to line 24. The temperature variance gradient is determined between positions 2 and 4 (dz = 4
 546 m) above seafloor for some smoothing.

547