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The effects of turbulence on vertical distributions and concentrations of phytoplankton in (Case II) coastal waters

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Appendices

Appendix A: Instrumentation Information

Instruments were deployed on all survey days, except for the MSS not being available for the first survey. Table A.1 shows a summary of these instruments.

Table A.1: Instrumentation used on each survey summaries with sampling frequency, the main sensors of the instrument and any additional sensors that were available.

Instrumentation and Company	Sampling Frequency (Hz)	Sensors	Additional Sensors
Seabird SBE 19plus V2 CTD	4	• Conductivity • Temperature • Pressure	• Fluorometer
Biospherical Instruments Inc. Profiling Reflectance Radiometer	1	• Irradiance • Pressure • Surface Irradiance	
ISW Wassermesstechnik MSS-90 freefall microstructure profiler	1024	• Microstructure Temperature • Precision Conductivity • Precision Temperature • PNS Shear Probes x2 • Pressure	• Fluorometer • Turbidity

A. Thorpe Scales

Density profiles obtained from both the raw 4 Hz CTD and 1024 Hz MSS data can be used to estimate changes in ε throughout each profile, using Thorpe displacements, d_t, (Thorpe, 1977). ε changes with different tidal states and is modulated by the bathymetry, where higher ε generally are seen on the flood tide, and lower on the ebb tide. Stratification determines the vertical extent this increase in ε, due to tidal energy inputs, propagates through the water column (Peters, 1997).

The observed density profile was modified to remove any sections where pressure is decreasing to remove false overturns. A statically stable profile was then formed using a bubble sort algorithm, again to remove false overturns. The vertical distance that a parcel of water in the observed profile has to move to from the statically stable profile is the d_t (Figure B.1).

The Thorpe scale, L_t, is defined as the root mean square Thorpe displacement; $L_t = \langle {d_t}^2 \rangle^{0.5}$; assuming that the horizontal density gradients are much smaller than vertical density gradients.

The Thorpe scale follows the relationship with the Ozmidov scale; $L_o \approx 0.8L_t$; (Dillon, 1982) which represents the largest overturn that can occur in a

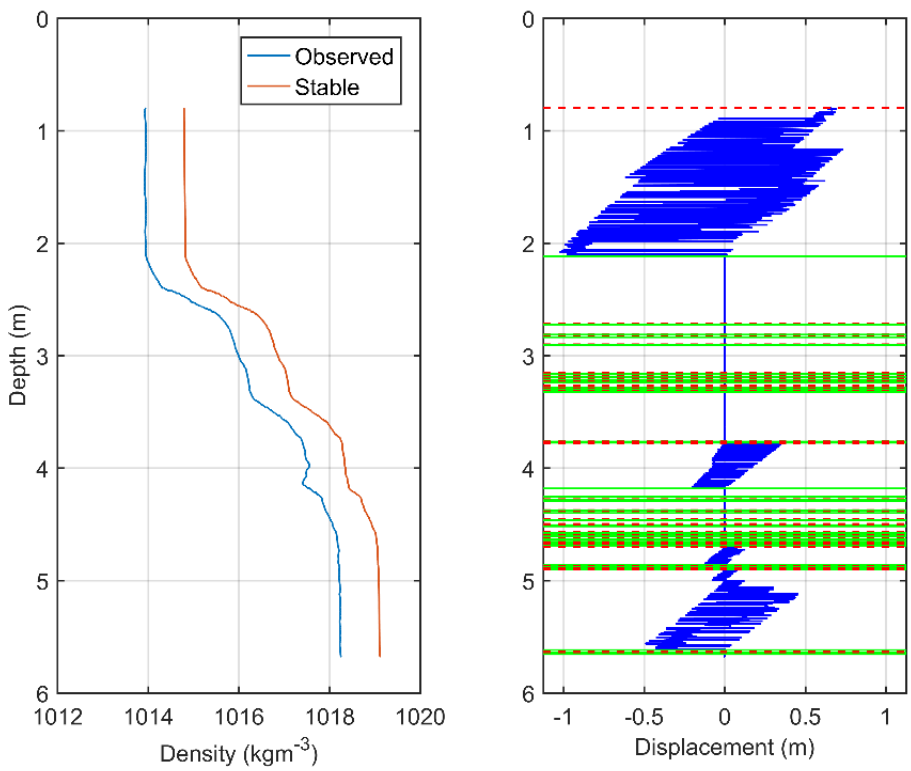


Figure B.1: (left) An observed profile (blue) sorted using a bubble sort algorithm to create a statically stable profile (orange) that is offset from the observed profile by 1 kgm^{-3}. (Right) indicates the Thorpe Displacement (d_t) moving down the profile, where displacements indicate an overturn occurring. An overturn detection script (Appendix F, Thorpe Displacement and Dissipation) was created to determine the vertical extent of each overturn resolvable by the instrument. Red dashed lines indicate the start of an overturn, and green dashed lines the end. Larger overturns are seen at the surface and seabed, with much smaller overturns also present throughout the water column.

stratified flow. This was found to be closer to; $L_o \approx 1.5L_t$ by Peters (1997), and this will be the approximation used. The Ozmidov scale can be related to ε through the following expression; $L_o = (\varepsilon/N^3)^{0.5}$; such that the Thorpe scale can be used to indirectly determine the value of ε as; $\varepsilon = N^3(1.5L_t)^2$.

B. MSS Shear

The MSS profiler contains two PNS air foil shear probes, that both measure turbulent velocity as the profiler free falls to within 1 m of the seabed. The turbulent shear, $\delta u/\delta z$, is dependent on the fall speed of the profiler, V, the shear sensor gain, G, the calibrated shear probe sensitivity, S and the sensor voltage output, U, by;

$$\frac{\delta u}{\delta z} = \frac{1}{2\sqrt{2}\rho G S V^2}\frac{\delta U}{\delta t} \qquad \text{C.1}$$

where ρ is the density of water.

Before conversion of sensor output to turbulent shear, outliers were detected as values 2.7 standard deviations away from the mean which were replaced with

interpolated values. A low pass filter was then applied across approximately every 1 m depth block, to remove spiking of the shear sensors. The linear shift on the shear sensors (32768 arb. units) was removed and the turbulent shear calculated using Equation C.1.

The turbulent shear was then used to determine the rate of dissipation of turbulent kinetic energy, ε, under the assumption of isotropic turbulence as (Osborn, 1980);

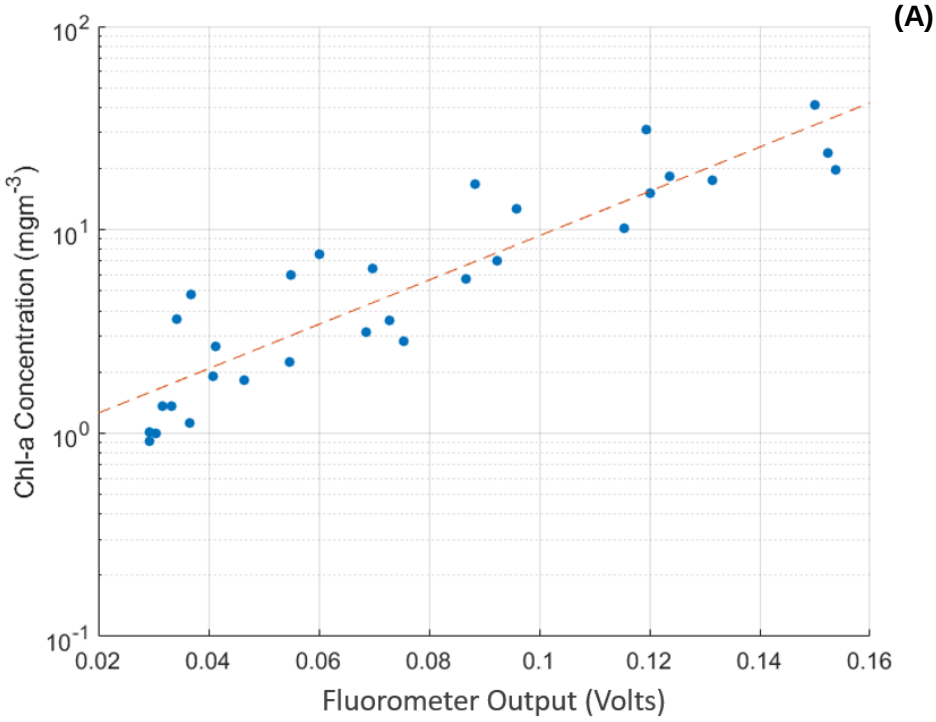
$$\varepsilon = 7.5v\,\langle({}^{\delta u}/_{\delta z})^2\rangle \qquad \text{C.2}$$

where ν is the kinematic viscosity of water (calculated from the temperature using the polynomial approximation), and $\delta u/\delta z$ represents turbulent shear fluctuations with the angled brackets indicating a vertical spatial averaging taken as 0.5 m. This was conducted for both shear probes and the average taken unless the difference between the probes was above a threshold (5 times the minimum value), where in this case the minimum is taken.

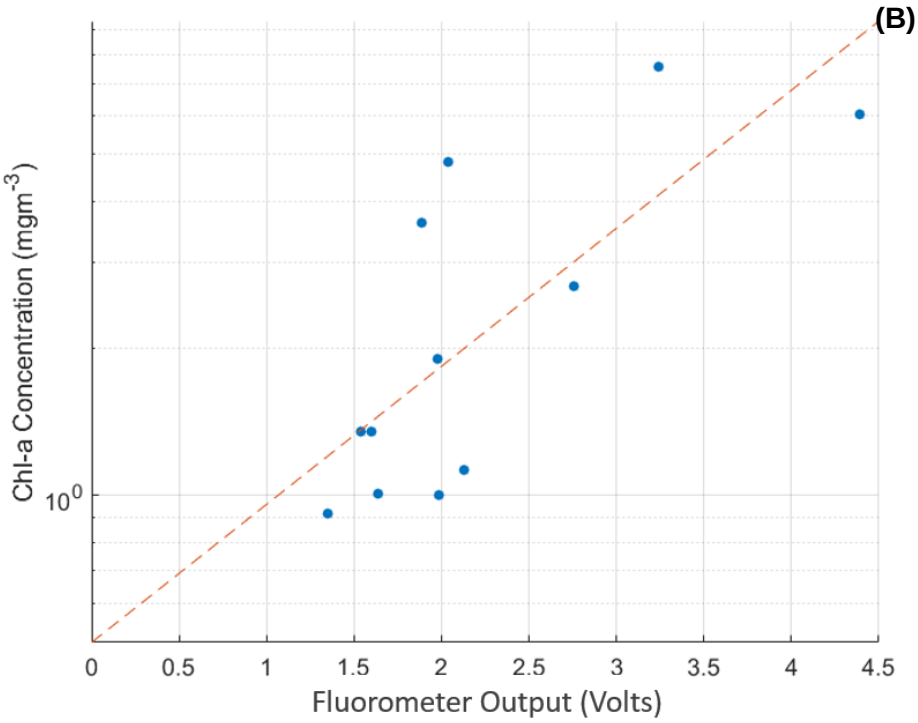
Isotropic turbulence can be defined by the non-dimensional isotropy parameter; $I_k = \varepsilon/\nu N^2$. For isotropy to be assumed $I_k > 200$, and for non-zero buoyancy flux $I_k > 16$ (Gargett, et al., 1984). In cases where $200 > I_k > 16$, isotropic turbulence cannot be assumed due to stratification suppressing vertical turbulent motions, and thus ε can be overestimated.

C. Fluorometer Calibration

Fluorometer values for each discrete sample depth were taken as the average value across the width of the van Dorn water sampler (0.15 m) in each profile. Regression lines were then taken, with a log transform (Campbell, 1995) on the chl-a concentrations (Figure D.1). The MSS fluorometer became saturated after Station B (Figure 1) and this explains the small number of usable data compared to the CTD fluorometer.



$Chla = 0.7597e^{25.1(Voltage)}$; $R^2 = 0.8225$; n = 30; $p < 0.01$



$Chla = 0.4991e^{0.6521(Voltage)}$; $R^2 = 0.5514$; n = 12; $p = 0.063$

Figure D.1: (A) Regression line (orange dashed) for CTD fluorometer output against discrete chl-a concentrations, obtained from spectrophotometric determination. A log transform was applied to the chl-a concentrations. **(B)** Similar to A, but for the MSS fluorometer.