Supplement of Biogeosciences, 15, 7315–7332, 2018
https://doi.org/10.5194/bg-15-7315-2018-supplement

Biogeosciences
Open Access

Supplement of

Turbulence measurements suggest high rates of new production over the shelf edge in the northeastern North Sea during summer

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Analysis of turbulence variation and uncertainty

Temporal variation and uncertainty associated with the shear probe measurements were assessed at a time series station, T1, located on Tr2 (57.287 °N, 7.758 °E; 62 m deep) starting 20 July 23:25 and ending 21 July 21:44 (Fig. S1). In total, 107 profiles were made to ~50 m depth in three sequences during the period with typically ~3 minutes between each cast. The temporal variation showed a modest change in temperature between 10-20 m (Fig. S1a) and a relatively small dissipation of turbulent kinetic energy (TKE) at mid-depth during the first 6 hours of the measurements (Fig. S1b). The instrument was equipped with two shear probes and the dissipation of TKE (ε) was calculated from each of the probes. The difference between these two estimates, made across the same water volume, are analysed below to assess the uncertainty of the ε-values.

Samples above 15 m were disregarded in the error-analysis to avoid any influence from the movement of the ship. The relative difference between the calculated dissipation of TKE (ε) obtained from each of the two shear probes (i.e., ε_1 and ε_2) was calculated as: $\Delta Log_{10}\varepsilon = Log_{10}(\varepsilon_1) - Log_{10}(\varepsilon_2)$. In total, there were 1145 pairs over the 22h period with a relatively small $\Delta Log_{10}\varepsilon$ average value of -0.063 and a standard and absolute deviation of 0.23 and 0.14, respectively. We applied the absolute deviation, i.e. the more conservative estimate, as being representative of the uncertainty of the ε-values. The relative probability distribution of $\Delta Log_{10}\varepsilon$ showed a qualitative accordance with a normal distribution characterised by the average value and absolute deviation (Fig. S1b), although the error-distribution showed a tendency to a broader variance for $\Delta Log_{10}\varepsilon$ larger than ~0.4. This was also clear from the cumulative probability distribution (Fig. S1d) where the error-distribution deviated from a normal distribution (confirmed by a Kolmogorov-Smirnov test). We considered the largest values of $\Delta Log_{10}\varepsilon$ to indicate sources of errors which could not be directly related to the instrument but potentially associated with the measurement procedure, for example influence from the rope on the free-falling instrument (all casts were made with free and undisturbed line to the free falling instrument during the whole cast). Therefore, we applied the criterion that only measurements where $\Delta Log_{10}\varepsilon$ was less than 3 times the absolute deviation (i.e. 0.42) were considered to be acceptable and these were included in the analysis. This criterion eliminated only a small number of the ε-values from the data set.

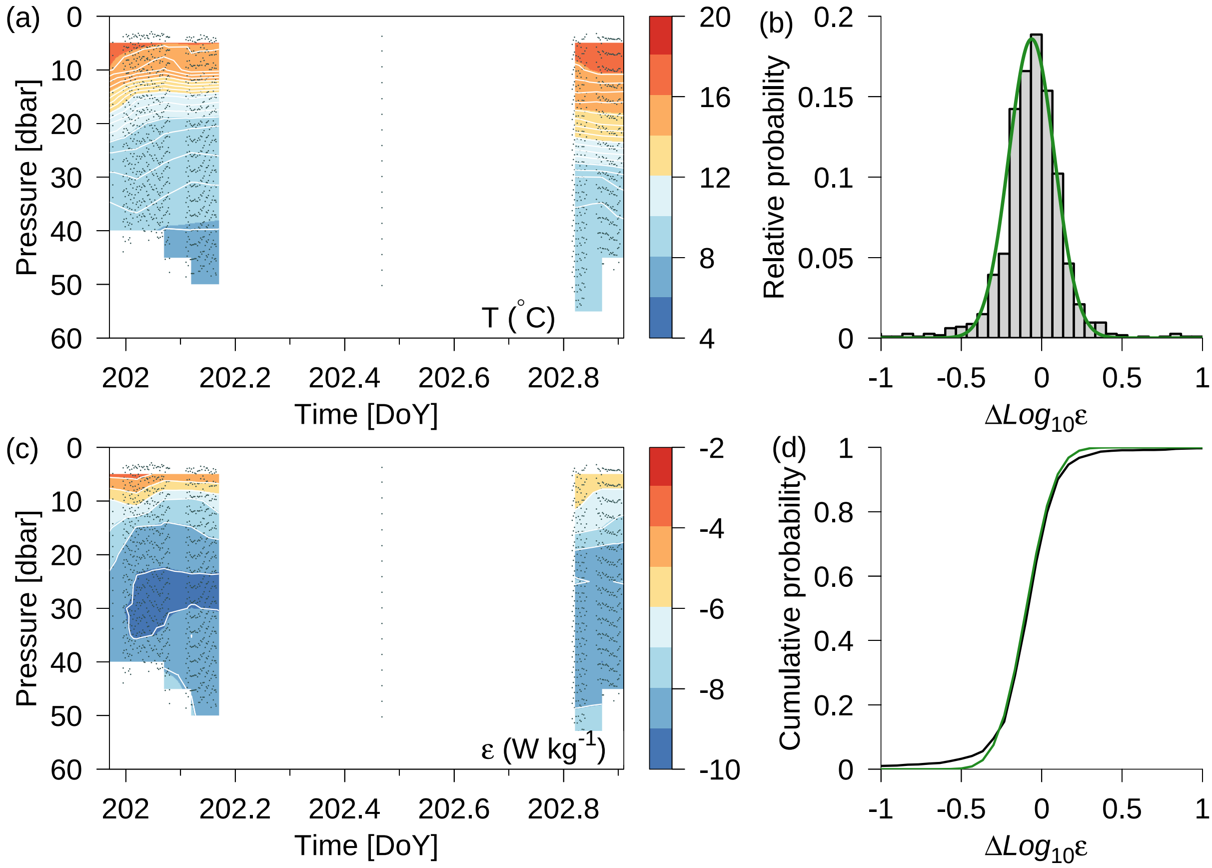
Temporal variation was also considered from the time series measurements at T1. Variation of ε is expected to vary due to tides, wind, breaking internal waves etc. Therefore, variations at a single time series station cannot be expected to be representative for the data set as a whole. However, the short-term temporal variation was analysed from samples of ε binned in 5 m intervals and analysed over a period of 30 minutes (i.e. 11 casts) resulting in average values and absolute standard deviations of 1.6±0.6, 1.4±0.6 and 2.1±1,.0 in depth intervals between 25-30m, 30-35m and 35-40m, respectively (in units of 10^{-9} W kg^{-1}). Thus, short term variation was relatively small and temporal changes between subsequent casts were considered to have a small influence on the calculated ε-values. Therefore, ε-values were, in general, derived from a single cast between the relatively closely spaced stations, where the ε-value obtained by averaging the calculated value from the two probes was reported. In addition to the time series station, T1, a similar time series station (T2) located at Tr4 is discussed in the text.

Supplementary figure legends

Figure S1 Turbulence measurements from time series station, T1, located on Tr2 (57.287 °N, 7.758 °E) starting 20 July 23:25 and ending 21 July 21:44. (a) Temperature (°C) and (c) turbulent kinetic energy dissipation (ε, W kg^{-1}) were measured in 107 profiles (small bullets) in three sequences during the 22h period and are shown as a function of pressure and time (Day of the Year). (b) The error-distribution ($\Delta Log_{10}\varepsilon$ in units of Log_{10}(W kg^{-1}), see text) between calculated ε from the two shear probes (gray bars) and the normal distribution (green) associated with the average and absolute deviation of the error-distribution. (d) The cumulative probability of the error-distribution (black) compared with the associated normal distribution (green).

Figure S2 Example of incubation results. Incorporation of carbon (photosynthesis) is shown versus PAR for the surface (5 m, bullets) and the SCM (diamonds) and non-linear best fit solutions (lines) from stations located at a) Tr1, 57.832 °N, b) Tr2, 57.480 °N and c) Tr2, 56.261 °N (cf. Fig. 1a). The following results are obtained from the (surface, SCM) at a): P_{max}^{*} = (2.5, 3.2) [µg C h^{-1}], α = (0.027, 0.074) [µg C·(h µE m^{-2} s^{-1})$^{-1}$], β = (0.0013, 0.0088) [µg C (µE m^{-2} s^{-1} h)$^{-1}$] and E_{max}^{*} = (338,141) [µE m^{-2} s^{-1}]; b): P_{max}^{*} = (4.2, 2.3), α = (0.050, 0.057), β = (0.0019, 0.0056) and E_{max}^{*}=(282,130) (units as in a); and c): P_{max}^{*} = (1.0, 1.2), α = (0.012, 0.019), β = (0.0013, 0.0012) and E_{max}^{*} = (284,219) (units as in a). Chlorophyll normalized values (i.e. $P^{B}_{max}{}^{*}$, α^{B} and β^{B}) are obtained by dividing with the chlorophyll a concentration at the three stations: a) (0.52, 0.95), b) (0.38, 0.82) and c) (0.26, 0.38) mg chl a L^{-1}.

Figure S3 Distributions along the five transects of (a) vertically integrated chlorophyll a (mg chl a m^{-2}), (b) primary production (mg C m^{-2} d^{-1}), (c) nutricline depth (m), (d) maximum nitrate flux into the euphotic zone (mmol N m^{-2} d^{-1}) and (e) f-ratio in euphotic zone. Repeated stations on Tr2 and Tr4, separated in time by about a week, are shown with bullets and open circles.



(a)
Pressure [dbar]
0
10
20
30
40
50
60
202
202.2
202.4
202.6
202.8
Time [DoY]
T (°C)
20
16
12
8
4
(b)
Relative probability
0.2
0.15
0.1
0.05
0
-1
-0.5
0
0.5
1
ΔLog10ε
(c)
Pressure [dbar]
ε (W kg-1)
-2
-4
-6
-8
-10
(d)
Cumulative probability
1
0.8
0.6
0.4
0.2
0

Figure S1

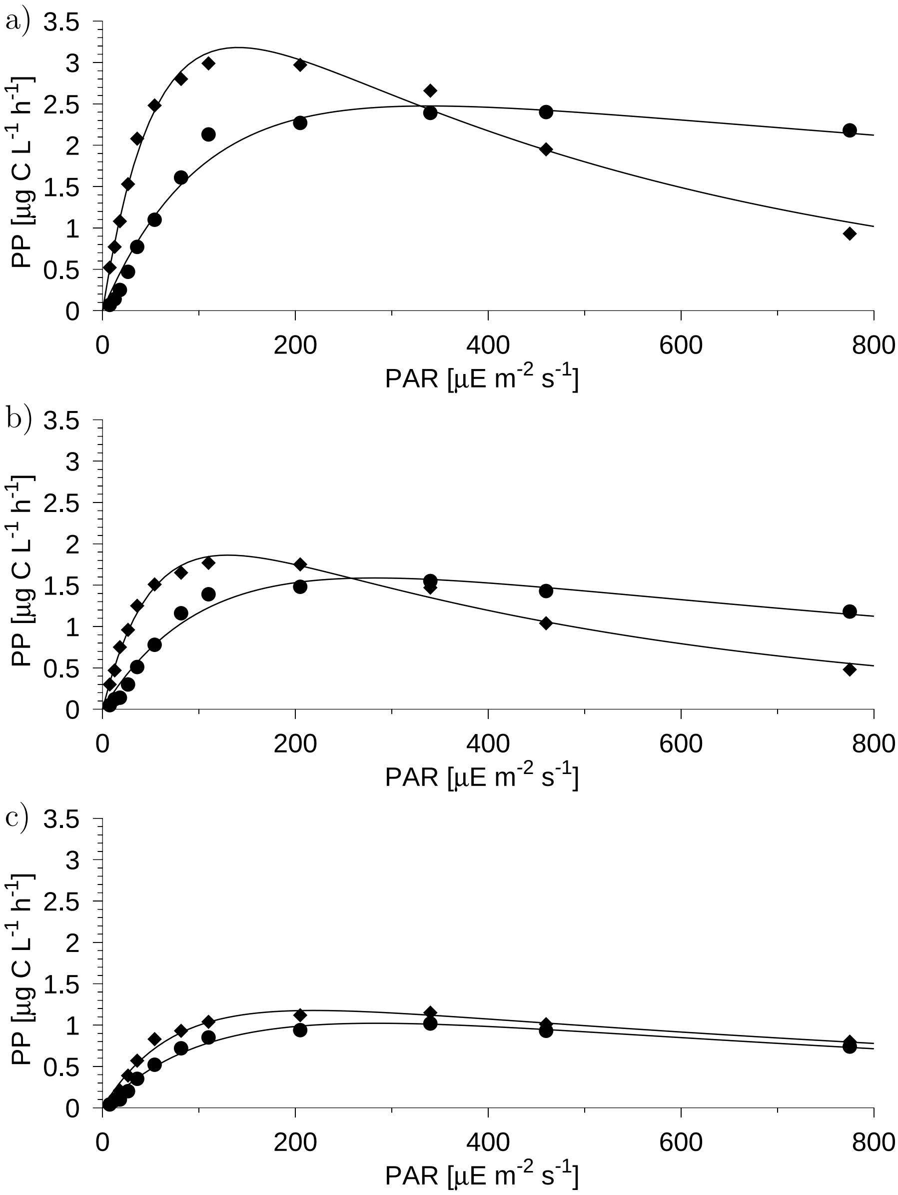


Figure S2

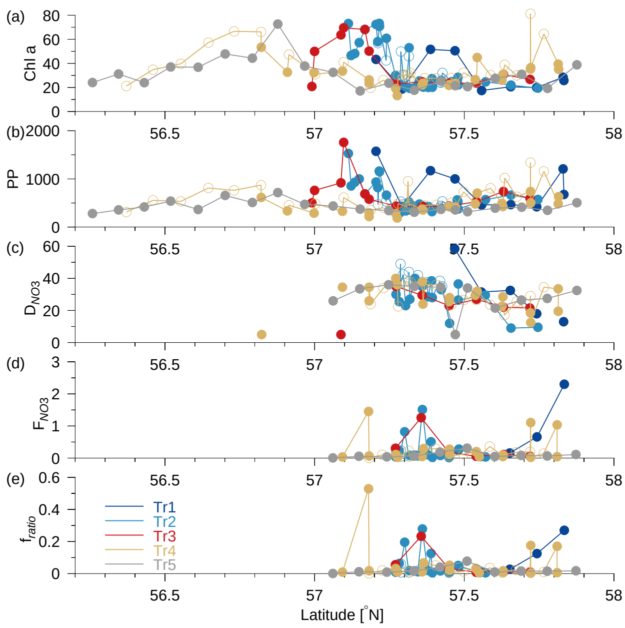

(a)
80
60
40
20
0
Chl a
(b)2000
1000
0
PP
(c)
60
40
20
0
D_{NO3}
(d)
3
2
1
0
F_{NO3}
(e)
0.6
0.4
0.2
0
f_{ratio}
56.5
57
57.5
58
Latitude [°N]
Tr1
Tr2
Tr3
Tr4
Tr5

Figure S3