

Supplementary information

Part 1. The GYR station as a representative end member of ultra-oligotrophy

One of the objectives of the BIOSOPE cruise was to perform a detailed investigation (~5 days) of a station corresponding to the most oligotrophic conditions of the global ocean. The choice of this station was first guided by the historical analysis of SeaWiFS ocean color data from which it was concluded that the lowest chlorophyll concentration of the global ocean were encountered at 26°S 115°W, west of Easter Island (see http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=16409).

The cruise took place in austral summer, when the conditions are expected to be most oligotrophic. To evaluate how this season is representative of the oligotrophic conditions in the SPG, an historical record of SeaWiFS data for the SPG has been analysed (Figure 1). During the austral summer, the surface chlorophyll concentration in the vicinity of the GYR station is the lowest, returning each year to around 0.02 mg Chla m⁻³. If the surface of the region with surface chlorophyll concentration lower than 0.03 mg Chla m⁻³ is chosen as a measure of the oligotrophy of the SPG (Fig. 1), the austral summer shows its maximal spatial extension with an area around 7 10⁶ km² (roughly 3 times the area of the Mediterranean Sea).

In summary, the GYR station is located at the centre and most oligotrophic zone of the SPG and is surrounded by a large mass of water with similar biogeochemical characteristics. It was investigated during its most oligotrophic period. Thus, the data acquired at the GYR station are representative of an end-member of oceanic hyperoligotrophy. Any extrapolation of production and flux data acquired at this station to other oligotrophic zones of the global ocean thus represents a minimal estimate.

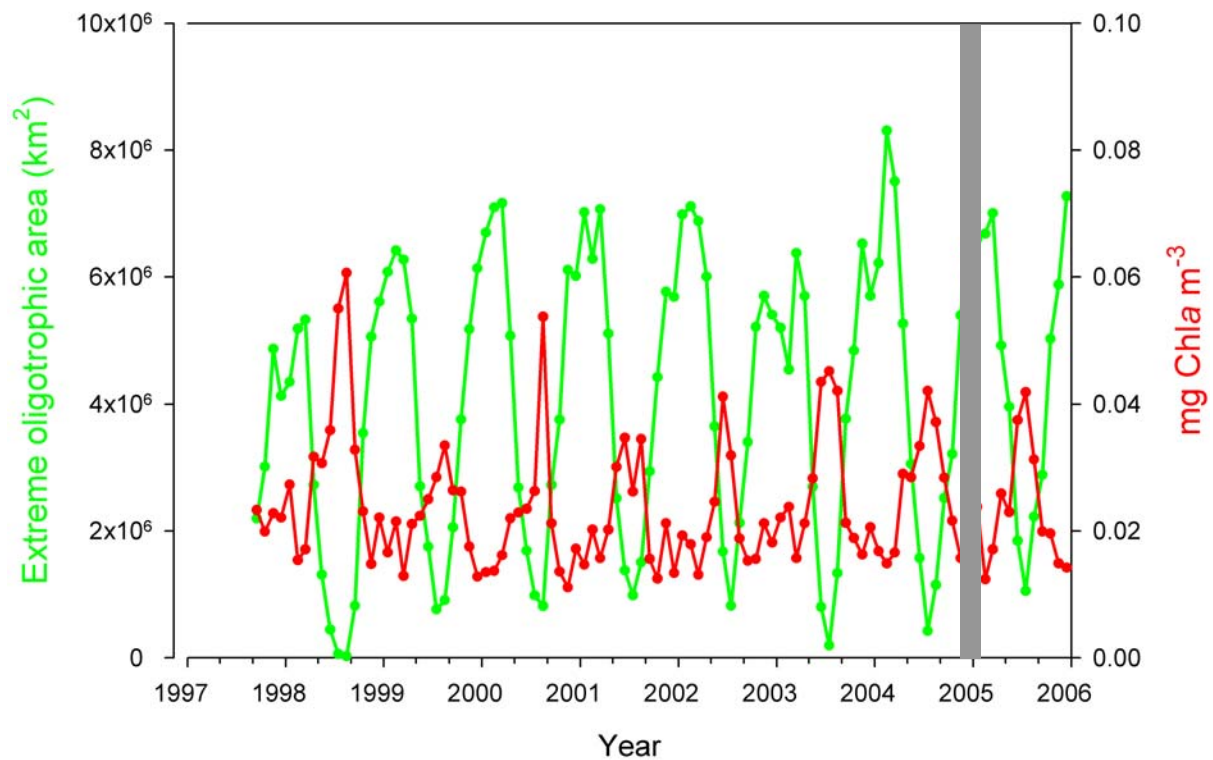


Fig. 1: Temporal evolution of oligotrophic conditions in the South Pacific Gyre. The green dots identify the variation in the area of waters with surface Chla concentration lower than 0.03 mg m^{-3} . The red dots represents the mean Chla concentration within a square of $50 \text{ km} \times 50 \text{ km}$ centered on the GYR station. The greyed band area identifies the time period of the BIOSOPE cruise.

Part 2 Significance of c_p variations at the diel scale in terms of POC variations

Beside the overall general relationship linking POC to c_p , it is important that this relationship is stable (or at least weakly variable) at the daily scale when deriving carbon flux from the analysis of daily cycle of c_p (Cullen et al., 1995; Stramski and Reynolds, 1993). This prerequisite is practically impossible to establish *in situ*: while the optical method is precise enough in such oligotrophic conditions to detect daily change, the precision of POC determination is not sufficient. Based on culture of a few selected phytoplankton submitted to diel change, the variation in the POC to c_p relationship over the daily scale has been examined (Stramski and Reynolds, 1993; Stramski et al., 1995; Durand et al., 1998; Claustre et al., 2002). No clear and systematic trend has been reported so that the use of a constant c_p vs POC can be considered as an acceptable approximation (e.g. Stramski and Reynolds, 1993) for deriving production and loss carbon terms from diel c_p variations recorded *in situ*.

The two sources of variation in c_p are the cell number (N , cell) per unit volume (V , m^3) and the cell attenuation cross section σ_c ($m^2 \text{ cell}^{-1}$) such that:

$$c_p = N/V \sigma_c$$

$$\text{with } \sigma_c = \sigma_g Qc(d, n)$$

where σ_g ($m^2 \text{ cell}^{-1}$) is the geometrical cross section and $Qc(d, n)$ (dimensionless) is the attenuation efficiency, which is a function of cell size (d , m) and refractive index (n , dimensionless).

Diel changes in c_p are thus recording processes that affect cell abundance (grazing, sinking, lysis and cell division) as well as σ_c (growth, respiration and cell division). Cell concentration is linearly related to c_p , and hence similarly recorded as a change in POC. The effect of growth, respiration and cell division on the attenuation cross section, and thus on POC, is more complicated and can be addressed as follows.

When a cell is assimilating CO₂ by photosynthesis, respiring or assimilating DOC, it changes its internal carbon concentration. This can be achieved by means of two extreme processes, with reality likely being some combination of the two: 1) by keeping a constant cell size and changing its refractive index due to variations in the internal carbon concentration; or 2) by changing the cell size while keeping a constant refractive index by the exchange of water with the environment. In both cases, only Q_c is affected. In the first case due to its effect on n, and in the second due to its effect on d. In both cases, processes of growth, respiration and DOC assimilation are measured by c_p.

The effect of cell division on the attenuation cross section can be quantified using the Van de Hulst approximation, and assuming a refractive index of 1.05. In the size range (0.5-2 μm) for cells dominating phototrophic (*Prochlorococcus*, *Synechococcus*, picoeukaryotes) and heterotrophic (heterotrophic bacteria) growth and respiration in these oligotrophic systems, if the whole community is experiencing synchronous cell division, c_p will decrease by at most 20%. That is, even without any changes in POC (all carbon remains in the daughter cells, repackaged in twice the number of cells with each half the volume), the c_p measurement would estimate a decrease associated only with changes in cell size during division. This estimate is extremely biased as it is based on the following unrealistic assumptions: (1) all particles contribute to c_p changes at the diel scale, and (2) these particles all divide once per day. We will now consider more realistic conditions to obtain an improved estimate of this bias.

Cytometric measurements performed every 3 hours over the course of the study show at most a 35% variation for *Prochlorococcus* cell densities between sunset minima and sunrise maxima. At the same time, picoeukaryotes do not show any trend in cellular abundance.

Using the method proposed by Claustre et al., 1999 relying on cytometric determination, the contribution of picoeukaryotes, *Prochlorococcus* and *Synechococcus* to c_p is estimated to be ~ 5%, ~ 12% and 0%, respectively. Using cytometric counts, heterotrophic bacteria are estimated to contribute 13% of c_p . Other (larger) heterotrophs are assumed to also contribute an additional 13% of c_p (see ref Claustre et al., 1999 for this assumption). A reasonable estimate of 43% can thus be made for the contribution of living particles (phototrophs and heterotrophs) to c_p (the remainder being attributed to bio-detritus or other particles, and corresponding to a background level of c_p at the diel scale). Given this information, we provide a “worst case scenario” for the bias in the c_p signal due to cell division. To do this, since we do not have diel cell counts for the heterotrophic particles (26% of c_p), we assume that they undergo 100% cell division between sunrise minima and sunset maxima. It then follows that cell division by living particles would be responsible for at most a 6% decrease in c_p (0.8% for *Prochlorococcus* and 5.2% for heterotrophic particles). This value must be compared to an average daily change of ~18% for c_p in the photic zone. In any case, this 6% bias is still an uppermost limit because: (1) it is assumed that the number of heterotrophic particles doubles between sunrise minima and sunset maxima, and (2) heterotrophic particles also contain larger predators (nano-heterotrophs, 5-10 μm , representing ~50% of the heterotrophic pool) whose division has a weak impact, if any, on the decrease in c_p (e.g. 8-9 μm cells have no impact).

References

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