Exploring the roles of turbulence and transparent exopolymer particles on particle transformation in the Southern Ocean

Antarctic Science Bursary report (awarded 2021 + 1 year extension)

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Rationale and Aims

The Southern Ocean is a key region for carbon sequestration driven by atmospheric (natural and anthropogenic) carbon uptake, carbon export via the biological carbon pump (BCP) and complex water mass structures in the Antarctic Circumpolar Current (ACC; Ito & Follows, 2013; Khatiwala et al., 2013; Le Quéré et al., 2016). The ultimate fate of sinking organic carbon transported by the BCP will depend on the remineralisation depth, with carbon remineralised in the upper limb of the ACC likely to upwell within decades, whereas carbon remineralised in the lower limb will be sequestered in the deep ocean for climate-relevant timescales (100s years). The fraction of organic carbon that penetrates into the interior ocean is a balance between sinking speed and remineralisation rate, with the former influenced by particle characteristics, such as size, shape and density (Iversen & Ploug, 2013).
The size, shape and structure of particles influence the rates at which they sink and are remineralised, with fast sinking particles increasing the potential for long-term carbon storage (Baker et al., 2017; Briggs et al., 2019). The role of turbulence on transparent exopolymer particle (sticky polysaccharides known as TEP) production and particle transformation in the upper ocean (0-150m) has not previously been explored using *in situ* observations. Unravelling the roles of turbulence and TEP on particle transformation is important as climate change is predicted to suppress turbulence and alter phytoplankton community structure, which may impact TEP production and have implications for the future efficiency of the biological carbon pump (Beauvais et al., 2006; Bopp et al., 2001; Takeuchi et al., 2019).

Particle aggregation is driven by the number and success rate of particle collisions (Takeuchi et al., 2019). Turbulence can increase the number of collisions, whilst TEP can increase the success rate of collisions, due to its stickiness (Beauvais et al., 2006; Takeuchi et al., 2019). Turbulence can also stimulate phytoplankton TEP production, which may further increase particle aggregation (Beauvais et al., 2006). Turbulence promotes aggregation up to a threshold particle size, beyond which turbulent shear leads to particle break up and disaggregation dominates. The greater the turbulence the larger the particles become before this threshold is reached (Takeuchi et al., 2019).

This study aimed to examine what controls particle aggregation in the Southern Ocean using the *in situ* cruise dataset alongside laboratory aggregation experiments to quantify aggregation processes under different TEP and turbulence conditions. We tested the hypotheses that 1) stations with greater turbulence and TEP will have a larger mean particle size and 2) the presence of TEP will increase the success of particle collisions and will shift the particle size (dis)aggregation threshold towards larger particles. A greater prevalence and persistence of large particles may increase the remineralisation depth and magnitude of carbon storage in the ocean interior.

Progress

The Antarctic science bursary funding has allowed for the >240 TEP samples, replicates and calibration standards collected on the CUSTARD cruise to be analysed and the data interrogated alongside other cruise data such as chlorophyll-a, nutrient and particulate organic carbon concentrations to assess the variability with depth, station and station visits. The results indicated that the least productive pre-bloom station (OOI) had the lowest TEP concentrations, whilst the most productive station (TS) had the greatest TEP concentrations which increased at the bloom progressed (Figure 1 and 2).

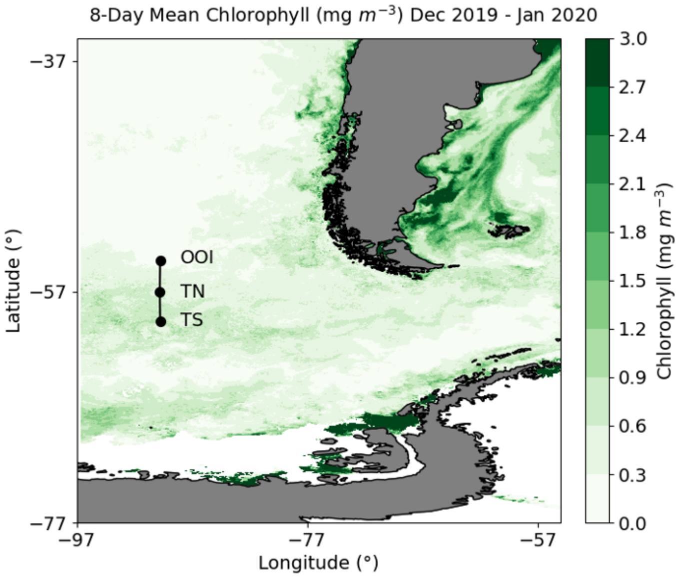

Figure 1 – Mean satellite-derived chlorophyll-a concentration in the southeast Pacific sector of the Southern Ocean during the cruise period (December 2019-January 2020). Our three stations along the transect are marked: Ocean Observatories Initiative mooring, OOI; Transect North, TN; Transect South, TS). Daily 4km spatial resolution merged chlorophyll-a data were extracted from the European Space Agency Ocean Colour Climate Change Initiative v5.0 release (Sathyendranath et al., 2019).

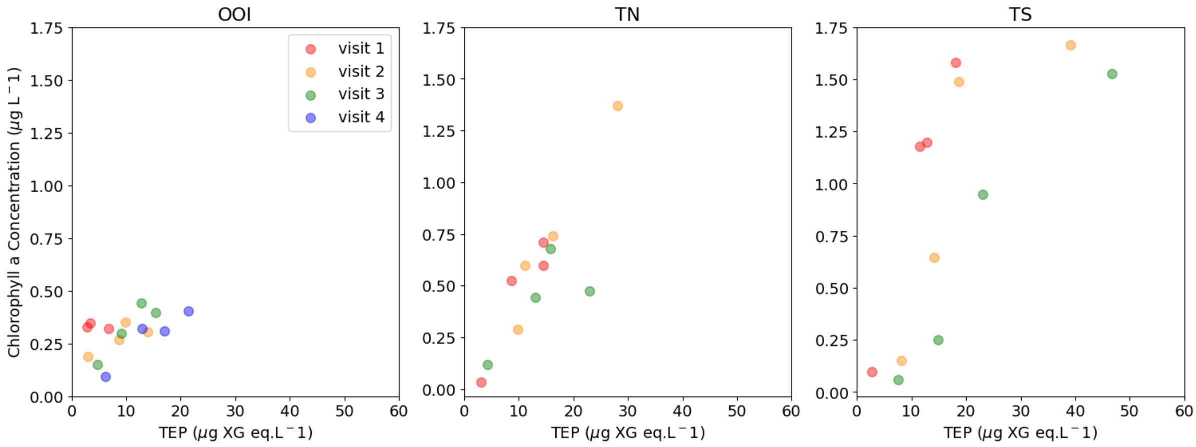

Figure 2 – TEP concentration (micrograms of Xanthan Gum equivalents per Litre) and chlorophyll-a concentration at the three stations (OOI, TN and TS) for 1-4 visits.

TEP is known to be produced by nutrient-stressed diatoms and this aligns with our findings. The TEP concentration was highest at station TS, which was dominated by diatoms (assessed using HPLC data). TEP concentration also exhibited a strong negative relationship with nitrate and silicate concentrations (both with depth and drawdown during the bloom) and a corresponding strong positive relationship with biogenic silica and particulate organic carbon. Interestingly, the slope of the relationships with TEP concentration and other variables were different for each station, which we suspect is due to differences in community dynamics and composition, but further work is needed to determine this.

We are still in the preliminary stages of quantitively analysing the TEP concentration, turbulence profiles and particle size datasets in tandem, due to the complex nature of the datasets. Mixed layer turbulence, particle concentration and TEP concentration were all greatest at TS. Mixed layer turbulence was very similar at OOI and TN whilst TN had greater particle concentrations than OOI. Interestingly, TS had more small (<250 µm) particles in the mixed layer than at OOI and TN but then comparatively more larger particles below the mixed layer, which may indicate that aggregation has occurred. This lends itself to suggest that our first hypothesis ‘stations with greater turbulence and TEP will have a larger mean particle size’ may be correct, but it warrants further investigation to understand whether turbulence, TEP or merely elevated particle concentration is the dominant controlling driver.

This is where our two-pronged approach is to be applied in the form of aggregation experiments in laboratory generated turbulence in collaboration with the University of Southampton engineering department. This allows us to quantify (dis)aggregation and collision processes with time-resolved optical particle sizing and tracking under controlled conditions. A new turbulence tank has been designed and built for the experiments by a Masters student at the University of Southampton and test experiments have been undertaken. There has been lots of fine-tuning required to get the experimental system to replicate the conditions and aggregation characteristics that we are hoping to study. Experiments are ongoing and we hope to have some exciting results soon.

Outputs and Future Work

The Antarctic science bursary funding allowed for us to leverage a SENSE DTP summer internship for an undergraduate student in which they attended and presented preliminary results at the AMBIO Conference in Plymouth in 2023. We also leveraged an MSc student at the University of Southampton who built a bespoke turbulence tank and undertook experiments.

This funding and research directly informed ideas for part of a work package focusing on the role of TEP, turbulence and aggregation in a recently funded project called PARTITRICS, which was funded under the BIO-Carbon NERC programme. It also inspired an application to a University of Southampton pump priming fund which was unsuccessful.

I am preparing a manuscript that will explore the drivers of aggregation along our cruise transect and depending on the results of the turbulence tank experiments a second manuscript may arise.

We would like to sincerely thank the Antarctic Science Bursary for the support of this work, which has acted as springboard to launch this area of research as part of my research portfolio.

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