Sujet de stage de M2 2019-20	Fine scale variability of nitrogen fixation in the western tropical South Pacific Ocean
Mots clés	N_2 fixation, diazotrophs, high spatio-temporal resolution, (sub)mesoscale variability, *nifH* gene
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Contexte scientifique

Marine microbial activity has an important impact on ecosystem productivity and climate, and varies according to environmental properties including temperature, light and nutrient resources. These properties are dispersed by ocean circulation, which shapes their geographical distribution creating microbial niches (Barton et al. 2013). Within the large-scale ocean circulation, smaller and faster flow instabilities such as mesoscale (10-100 Km, weeks/months) and submesoscale (0.1-10 Km hours/days) structures alter resource gradients by moving and mixing different water parcels. Studies combining remote sensing observations and modelling have illustrated that sub- and mesoscale structures (collectively termed "fine scale") significantly impact productivity (chlorophyll) and consequently the oceanic carbon pump (Lévy et al. 2014, 2015, Mahadevan 2016, McGillicuddy 2016). However, remote sensing and modelling studies do not provide information on the ecological structure and metabolic processes that occur within these structures. *In situ* sampling may not provide enough resolution either, as oceanographic cruise transects typically sample at stations hundreds of Km apart.

Dinitrogen (N_2) fixation is carried out by specialized prokaryotic microbes so-called **"diazotrophs".** N_2 fixation is thought to sustain ~50% of marine new primary production (Karl et al. 2002) and has been estimated to contribute >70% to carbon sequestration in the vast oligotrophic regions of the ocean (Karl et al. 2012, Caffin et al. 2018). These fluxes are computed from *in situ* data gathered during short and geographically constrained oceanographic cruises. Such sampling efforts provide only a partial picture of diazotrophic activity dynamics and no information on smaller spatiotemporal scales or seasonal variability. **To accurately constrain the global nitrogen budget, the dynamics of diazotrophs need to be assessed at higher spatiotemporal scales.**

Less than ten studies have looked at the effect of hydrodynamics on diazotrophs (some cited in the following text). *A priori,* isopycnal deepening in mesoscale anticyclonic eddies inhibits the upwelling of deep nutrients, which should promote the development of diazotrophs that preferably thrive in nutrient-poor waters. Indeed, high cyanobacterial diazotroph abundances (Davis & McGillicuddy 2006) and N_2 fixation rates (Fong et al. 2008) have been reported within anticyclonic eddies in the North Atlantic and North Pacific Oceans. Conversely, high N_2 fixation rates and non-cyanobacterial diazotrophs (proteobacteria) were detected within cyclonic eddies in the South China Sea, presumably due to the alleviation of limitation by other nutrients such as phosphorus and iron (Zhang et al. 2011).

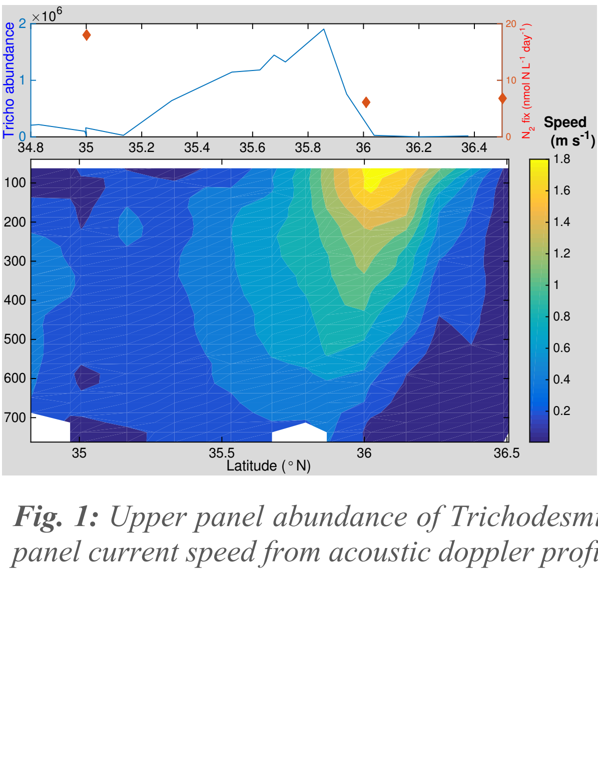

Fig. 1: Upper panel abundance of Trichodesmium and N_2 fixation rates across the Gulf Stream. Lower panel current speed from acoustic doppler profiler data. Preliminary unpublished data by M. Benavides.

It is conceivable that (sub)mesoscale structures exert **different effects on diazotroph phylotypes depending on their autoecology**. For example, on a time-series study positive sea surface height anomalies were correlated to N_2 fixation rates associated with large (>10 µm) cells, but not with smaller ones (<10 µm) (Church et al. 2009). In a recent study, *Trichodesmium* colonies aggregated in a frontal area over the Gulf Stream (Fig.1), whereas gammaproteobacteria were more sparsely distributed (Benavides et al. unpublished data, presented at 2018 Ocean Sciences Meeting).

(Sub)mesoscale features are dynamic and change from their formation to their dispersal. Hence, their effect on altering environmental properties evolves over space and time. (McGillicuddy 2016). It is thus legitimate to **hypothesize** that (sub)mesoscale structures affect diazotroph phylotypes:

- ▷ **Actively:** when (sub)mesoscale structures alter environmental properties in a way that favors diazotroph development. This effect is likely selective, favoring phylotypes with growth rates that take place at timescales comparable to those of the physical nutrient supply mechanism.
- ▷ **Passively:** when water parcel trapping structures isolate diazotroph phylotypes, causing a merely physical accumulation of cells.

Objectif du stage

The main goal of this M2 project is to study the (sub)mesoscale variability of diazotrophs in the western tropical South Pacific Ocean. Samples will be collected during the TONGA cruise, which will take place onboard *the R/V L'Atalante* in November 2019 (the sampling will be done by the co-supervisors during this cruise). The cruise will cover an area between 20-30ºS in the Southwest Pacific well known for its intense mesoscale activity, and where previous studies have highlighted the importance of fronts in the horizontal distribution of phytoplankton (Rousselet et al. 2018).

OBJECTIVE 1: To geolocalize and characterize (sub)mesoscale structures

Satellite sea surface temperature (SST), surface Chlorophyll concentration and altimetry-derived current will be characterized using the SPASSO software in delayed-time mode. In particular, the use of Lagrangian diagnostics (e.g. finite size Lyapunov exponents -FSLE-, retention and advection indices, Okubo-Weiss parameter, etc) will allow for the identification of water mass pathways, mesoscale structures such eddies, and submesoscale features such as fronts (e.g. de Verneil et al., 2017; Hu et al., 2011; Kersalé et al., 2013; Marrec et al., 2018; Nencioli et al., 2011; Rousselet et al., 2016, 2018).

OBJECTIVE 2: To depict the effect of (sub)mesoscale structures on diazotroph community diversity

- ▷ *DNA sampling and extraction:* Plankton biomass will be sampled at high resolution using the OCE-5, an automated device that obtains samples as the ship navigates at resolutions ≤0.5 nautical miles. Biomass concentrated will be later extracted to obtain DNA samples as described in (Benavides et al. 2015).
- ▷ *Diazotroph quantification:* The abundance of the main diazotrophic groups will be determined by quantitative polymerase chain reaction assays (qPCR) of the nifH gene as described in (Benavides et al. 2016)

Profil

We are looking for a curious and highly motivated candidate, interested in biological-physical coupling in the ocean. The allocated tasks include satellite image treatment as well as molecular biology tools, hence the project is highly multidisciplinary.

Skills :

- Programming skills in Matlab and/or Python and shell, familiarity with Linux.
- Experience with DNA extractions and PCR are highly desirable but not indispensable.
- Good English speaking/reading/writing skills

Réferences

Barton AD, Pershing AJ, Litchman E, Record NR, Edwards KF, Finkel Z V., Kiørboe T, Ward BA (2013) The biogeography of marine plankton traits. Ecol Lett 16:522–534

Benavides M, H. Moisander P, Berthelot H, Dittmar T, Grosso O, Bonnet S (2015) Mesopelagic N2 fixation related to organic matter composition in the Solomon and Bismarck Seas (Southwest Pacific). PLoS One 10:1–19

Benavides M, Moisander PH, Daley MC, Bode A, Arístegui J (2016) Longitudinal variability of diazotroph abundances in the subtropical North Atlantic Ocean. J Plankton Res 38

Caffin M, Moutin T, Ann Foster R, Bouruet-Aubertot P, Michelangelo Doglioli A, Berthelot H, Guieu C, Grosso O, Helias-Nunige S, Leblond N, Gimenez A, Alexandra Petrenko A, Verneil A De, Bonnet S (2018) N2 fixation as a dominant new N source in the western tropical South Pacific Ocean (OUTPACE cruise). Biogeosciences

Church MJ, Mahaffey C, Letelier RM, Lukas R, Zehr JP, Karl DM (2009) Physical forcing of nitrogen fixation and diazotroph community structure in the North Pacific subtropical gyre. Global Biogeochem Cycles 23

Davis CS, McGillicuddy DJ (2006) Transatlantic abundance of the N2-fixing colonial cyanobacterium Trichodesmium. Science (80-) 312:1517–1520

Fong AA, Karl DM, Lukas R, Letelier RM, Zehr JP, Church MJ (2008) Nitrogen fixation in an anticyclonic eddy in the oligotrophic North Pacific Ocean. ISME J 2:663–676

Karl DM, Church MJ, Dore JE, Letelier RM, Mahaffey C (2012) Predictable and efficient carbon sequestration in the North Pacific Ocean supported by symbiotic nitrogen fixation. Proc Natl Acad Sci 109:1842–1849

Karl D, Michaels A, Bergman B, Capone D, Carpenter E, Letelier R, Lipschultz F, Paerl H, Sigman D, Stal L (2002) Dinitrogen fixation in the world’s oceans. Biogeochemistry 57/58:47–98

Lévy M, Jahn O, Dutkiewicz S, Follows MJ (2014) Phytoplankton diversity and community structure affected by oceanic dispersal and mesoscale turbulence. Limnol Oceanogr Fluids Environ

Lévy M, Jahn O, Dutkiewicz S, Follows MJ, D’Ovidio F (2015) The dynamical landscape of marine phytoplankton diversity. J R Soc Interface

Mahadevan A (2016) The Impact of Submesoscale Physics on Primary Productivity of Plankton. Ann Rev Mar Sci

McGillicuddy DJ (2016) Mechanisms of Physical-Biological-Biogeochemical Interaction at the Oceanic Mesoscale. Ann Rev Mar Sci 8:125–159

Rousselet L, Verneil A De, Doglioli AM, Petrenko AA, Duhamel S, Maes C, Blanke B (2018) Large- to submesoscale surface circulation and its implications on biogeochemical/biological horizontal distributions during the OUTPACE cruise (southwest Pacific). Biogeosciences 15:2411–2431

Zhang Y, Zhao Z, Sun J, Jiao N (2011) Diversity and distribution of diazotrophic communities in the South China Sea deep basin with mesoscale cyclonic eddy perturbations. FEMS Microbiol Ecol 78:417–427