

Dossier scientifique

Nom du porteur du projet : Thierry Moutin & Sophie Bonnet

Titre du projet : OUTPACE (Oligotrophy to ULtra-oligotrophy PACific Experiment)

Cette soumission constitue un **nouveau projet** visant à soutenir la réalisation d'une **campagne océanographique de 45 jours dans le Pacifique sud ouest** en 2015 pour profiter de la présence rare de l'Atalante dans le Pacifique SO le 1^{er} semestre 2015 (Cf AO CNFH juin 2014).

Le porteur principal n'a pas obtenu de financement LEFE au cours des 3 dernières années. Le co-porteur a obtenu le financement du projet VAHINE pour une durée de 2 ans (**fin en 2014**). Le projet **OUTPACE** est un projet océanographique multi-disciplinaire d'envergure. Certains résultats obtenus lors de l'expérience en milieu contrôlé VAHINE (suivi de mésocosmes), en particulier de modélisation, seront utiles à la réalisation de OUTPACE.

Intérêt scientifique et état de l'art

The additional CO₂ in the atmosphere, mainly resulting from fossil fuel emissions linked with human activities (anthropogenic CO₂), is the main cause of global warming. The ocean has acted as a major sink of anthropogenic CO₂ (Sabine et al., 2004) preventing a greater accumulation in the atmosphere and therefore a greater increase in the earth's temperature. The biological pump (Fig. 1) provides the main explanation for the vertical gradient of carbon (C) in the ocean. Its strength and efficiency depends upon the complex balance between organic matter production in the euphotic zone and its remineralisation in both the epipelagic and mesopelagic zones. The biological pump was thought to be in an equilibrium state with an associated near-zero net exchange of CO₂ with the atmosphere (Broecker 1991, Murnane et al., 1999). Climate alterations are beginning to disrupt this equilibrium and the expected modification of the biological pump will probably considerably influence oceanic C sequestration (and therefore global warming) over a decadal time scale (Sarmiento and Gruber, 2006). The long term decrease of phosphate availability and the shift from previously nitrogen (N) to phosphorus (P) limited production associated with increasing inputs of N by N₂ fixation was one of the first evidence of the biological pump alteration observed at the HOT time series station in the north Pacific gyre (Karl et al., 1997; 2008).

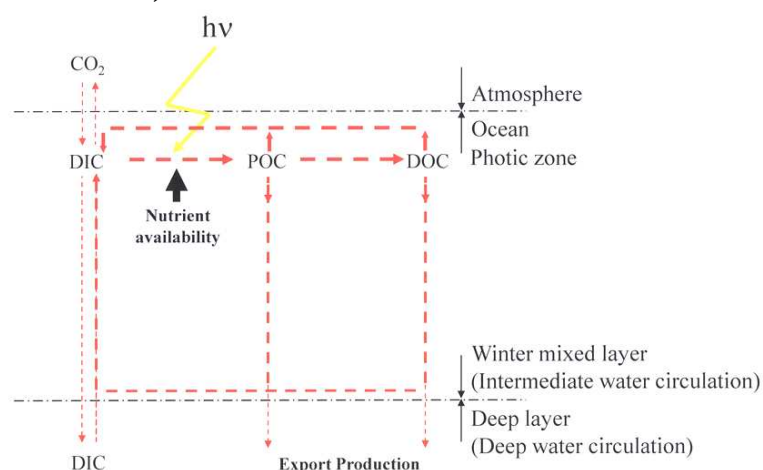


Fig. 1. Major C fluxes for a biological pump budget. Biological pump: C transfer by biological processes into the ocean interior. DIC: Dissolved Inorganic C, POC: Particulate Organic C, DOC: Dissolved Inorganic C. See Moutin *et al.*, (2012) for a detailed description.

The input of new N to the surface ocean through biological N₂ fixation represents a major link between the C and N biogeochemical cycles, i.e between the upper ocean nutrient availability and the biological pump, i.e between ocean and climate. This link was recently shown to play a central role in previous natural climate changes over long time scales (Galbraith et al., 2013, Dernières nouvelles de l'INSU

n°200: Le cycle océanique de l'azote face aux changements climatiques, Jeudi, 25 Juillet 2013). It is nevertheless clear that expected climate changes followed by anthropogenic atmospheric CO₂ changes may concern shorter time scales: the increase in atmospheric CO₂ over the past 200-y is equal to the increase in atmospheric CO₂ between glacial to interglacial conditions, which took place over several thousand y (Sarmiento and Gruber, 2006). It is therefore necessary to obtain a precise representation of the N₂ fixation process in global biogeochemical models. Even if considerable scientific progresses have been made over the last decades (see reviews from Sohm et al., 2011; Zehr, 2011), many questions remain regarding the impact of this process on biogeochemical cycles and C export.

The role of N₂ fixation in the oligotrophic ocean and overview of previous cruises in the SW Pacific:

The efficiency of oceanic C sequestration depends upon many factors, among which is the availability of nutrients to support phytoplankton growth in the photic zone of the surface ocean (Fig. 1). Large amounts of N are required for phytoplankton growth, as it is an essential component of proteins, nucleic acids and other cellular constituents. Fixed N in the form of nitrate (NO₃⁻) or ammonium (NH₄⁺) is directly usable for growth, but concentrations of fixed N are low (<0.1 μmol L⁻¹) in the oligotrophic ocean and often growth-limiting in most of the open ocean euphotic zone (Falkowski et al., 1998). Dissolved dinitrogen (N₂) gas in seawater, on the other hand, is very abundant in the euphotic zone (ca. 450 μmol L⁻¹) and could constitute a nearly inexhaustible N source for the marine biota. Some prokaryotic organisms (Bacteria, Cyanobacteria, Archaea) called 'N₂-fixers' (or diazotrophs) are able to use this gaseous N source since they can break the triple bond between the two N atoms of the N₂ molecule, and convert it into a usable form (i.e. NH₃) for assimilation thanks to the nitrogenase enzyme system (Zehr et al., 1998; 2001). By doing this conversion, they release dissolved N in surface waters. At the global scale, they provide 100-200.10¹² g of N to the surface ocean every year (Mahaffey et al., 2005). It is the major external source of N for the ocean, significantly larger than atmospheric and riverine sources (Codispoti et al., 2001; Gruber and Sarmiento, 2002; Gruber, 2004). N₂-fixing organisms act thus as 'natural fertilizers', and contribute to sustain life and potentially C export in coastal and oceanic environments.

Most of the ocean (60%, Longhurst et al., 1995) is comprised by low-nutrient, low-biomass oligotrophic ecosystems, which constitute the largest coherent biomes on our planet. They support a large part (40%) of the photosynthetic C fixation in the ocean (Antoine et al., 1996). This C fixation is mainly performed by pico-plankton (smaller than 2-3 μm in diameter) that are generally thought to represent a negligible fraction of the total particulate organic C (POC) export flux due to their small size, slow individual sinking rates, and tight grazer control that leads to high rates of recycling in the euphotic zone. Consequently, the efficiency of the biological C pump in these oligotrophic systems has long been considered to be low as the greatest proportion of fixed C is thought to be recycled in the surface layer and rapidly re-exchanged with the atmosphere.

Recent studies have challenged this view and indicate that all primary producers, including picoplanktonic cells, contribute to export from the surface layer of the ocean at rates proportional to their production rates (Richardson & Jackson, 2007). Export mechanisms differ compared to larger cells as picoplanktonic export is mainly due to packaging into larger particles and via grazing and/or aggregation processes (Jackson et al., 1990; 2001; Lomas et al., 2010). More recently, Close et al. (2013) pointed out that 40-70% of picoplanktonic cells are small enough to escape detection under the most common definition of suspended particulate organic matter (POM). Thanks to a coupling between lipid profiles, radiocarbon and stable isotopic signatures of lipids from the North Pacific Subtropical gyre (Hawaii Ocean Times-series station), they showed that the transfer of submicron POM from the surface to mesopelagic waters is an important contributor to the global biological pump. Besides submicron POM export, Karl et al. (2012) have reported an efficient summer export flux of C (3 times greater than the mean wintertime particle flux) at the same HOT station thanks to a 13-year sediment trap experiment. This summer export flux has been attributed to an increase in biomass and productivity of symbiotic N₂-fixing cyanobacteria associated with diatoms, which have high sinking and low remineralization rates during downward transit. This efficient POM export was thus not related to submicron particles but rather to large-size phytoplankton that could grow in the oligotrophic waters of the NPG thanks to new N provided by N₂ fixation (Karl et al., 2012). **Consequently, the conventional**

view of low POM export in oligotrophic areas should be revised to include alternative pathways for picoplankton export and the role of N₂ fixation in potentially promoting C export.

The SW Pacific is an ideal location to study this question, as it is considered to be one of the highest areas of global N₂ fixation (Capone et al., 1997; Sohm et al., 2011). It exhibits among the highest abundances, diversity of N₂-fixing organisms (Moisander et al., 2010) and activity (Montoya et al., 2004; Bonnet et al., 2009) in the world ocean. While average N₂ fixation rates range from 50-200 $\mu\text{mol N.m}^{-2}.\text{d}^{-1}$ in the tropical North Atlantic (Capone et al., 2005) and Pacific (Dore et al., 2002 ; Karl et al., 2011), they reach 126-4000 $\mu\text{mol N.m}^{-2}.\text{d}^{-1}$ (Montoya et al., 2004) and 50-360 $\mu\text{mol N.m}^{-2}.\text{d}^{-1}$ (Bonnet et al., 2009) in the SW Pacific, in the Arafura Sea (off Australia, TRICHONESIA cruise) and the western warm pool (EUC-Fe cruise), respectively. The seasonal DIAPALIS cruises (INSU-PROOF DIAPAZON programme) in the Loyalty channel off New Caledonia also reported high rates ranging from 151 to 703 $\mu\text{mol N.m}^{-2}.\text{d}^{-1}$ (Garcia et al., 2007), the highest being measured in austral summer which has been directly linked to phosphate availability (Van den Broeck et al., 2004; Moutin et al., 2005). The seasonal distribution of N₂ fixation is corroborated by *in situ* and satellite observations (TRICHOSAT algorithm, Dupouy et al., 2011) of recurrent large *Trichodesmium* blooms during the austral summer (October-March) during the 1998-2010 period in the Melanesian archipelagos around New Caledonia (Vanuatu, Fiji Islands). In addition to *Trichodesmium*, high abundances of unicellular diazotrophic cyanobacteria have been reported in the SW Pacific (Campbell et al., 2005; Bonnet et al., 2009; Hewson et al., 2009; Moisander et al., 2010). Campbell et al., (2005, TRICHONESIA cruise) reported $1.6 \cdot 10^3$ cells.ml⁻¹ of Crocosphaera-like cells (UCYN-B) between New Caledonia and Fiji, which is on the same order of magnitude as *Synechococcus* abundance, the most widespread non-diazotrophic cyanobacterium in the ocean (Partensky et al., 1999). The newly discovered and uncultured UCYN-A (Zehr et al., 2001; 2008) also displays extremely high abundances (10^5 - 10^6 nifH copy.l⁻¹, Moisander et al., 2010, KM0703 cruise; Bonnet et al., Unpublished, BIFURCATION cruise) in the SW Pacific (between New Caledonia and Australia), but they seem to have different ecological niches compared to *Trichodesmium* and UCYN-B (Moisander et al., 2010).

When going eastward towards the South Pacific gyre, Halm et al., (2011) have reported rates of 12–190 $\mu\text{mol N m}^{-2} \text{ d}^{-1}$ on the western border of the gyre and Raimbault and Garcia, (2008) and Moutin et al., (2008) reported rates of $60 \pm 30 \mu\text{mol N m}^{-2} \text{ d}^{-1}$ in the central gyre during the BIOSOPE cruise (INSU-LEFE BIOSOPE programme), indicating a decreasing gradient of N₂ fixation from W to E and low N₂ fixation rates relative to other ocean gyre ecosystems. The organisms responsible for these fluxes are different from common autotrophic diazotrophs such as *Trichodesmium* or *Crocosphaera*, and are mainly affiliated with heterotrophic proteobacteria and low abundances of UCYN-A (Bonnet et al., 2008, BIOSOPE cruise; Halm et al., 2011).

The W to E zonal gradient of N₂ fixation and the distinct diversity of N₂-fixing organisms along this gradient provide a unique opportunity to study how production, mineralisation and export of organic matter depends upon N₂ fixation in contrasting nutrient conditions. Comparisons between different systems along a zonal gradient of trophic status and N₂ fixation will provide new insights for identifying and understanding fundamental interactions between marine biogeochemical C, N, P, Si, Fe-cycles and oligotrophic ecosystems.

General objectives and associated strategy (detailed strategy in Annexe 1 – Document CNFH)

OBJECTIVE 1: CHARACTERIZATION OF THE BIOGEOCHEMICAL AND BIOLOGICAL DIVERSITY IN THE SW PACIFIC DURING THE STRONGEST STRATIFIED PERIOD

One of the main objectives of the **OUTPACE** (Oligotrophy to ULTra-oligotrophy **PAC**ific Experiment) cruise is to characterize the biogeochemical parameters and biological diversity/function along a W-E gradient from the North of New Caledonia, an area exhibiting high N₂ fixation rates, to the central South Pacific gyre, which has been characterized as the most oligotrophic oceanic area of the world ocean (Claustre et al., 2008), and exhibiting low N₂ fixation rates (e.g. Moutin et al., 2008) (Fig. 2).

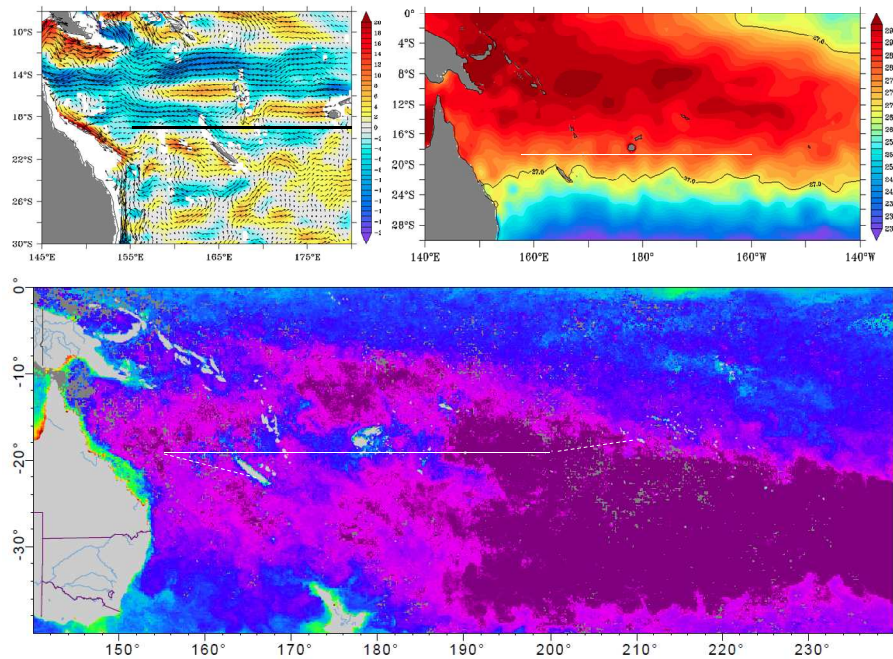


Fig. 2. Transect of the OUTPACE cruise superimposed on several maps (A) Absolute geostrophic currents (from CARS climatology ref to 1000 m, plus currents 0-200 m deduced from Argo floats drift, Kessler and Cravatte, 2013, JGR, accepted. Colorbar: zonal currents; Arrows: horizontal currents), (B) CARS2009 SST climatology (Ridgway and Dunn, 2003) (Dec-March), and (C) Surface chlorophyll concentrations (MODIS, composite Dec-March 2011-2012).

Objective 1.1: Biogeochemical description

The classic variables temperature, salinity, dissolved oxygen concentration, along with alkalinity, pigments, organic and mineral C and other biogenic elements (N, P, Si) pools, and trace metals of biogeochemical importance (Fe, Zn, Cu, Co, Ni), will be measured, as well as other specific variables at selected depths (N_2 fixation, diazotroph diversity, recycling times for dissolved phosphate...) in 18 short duration (SD, 8h) stations across the 3000 nm transect. The aim is to describe the variations in the biogeochemical characteristics (nutrient and trace metals availability in the photic layer, depth of the nutricline, ratios of dissolved/particulate and organic/mineral in the biogenic elements pools, drawdown of CO_2 of anthropogenic origin, phytoplankton biomass and diversity, N_2 fixation rates...). This biogeochemical description will extend to the gyre in the central South Pacific where oligotrophic conditions are the most extreme (Claustre and Maritorena, 2003). **Our recently acquired techniques for biogeochemical measurements in ultra-oligotrophic waters should enable us to significantly improve our understanding of the biogeochemistry of the SW Pacific.** We do not have a good insight into the spatial distribution of certain biogeochemical variables, such as N_2 fixation, or absolute nutrients concentrations in surface waters, which have a predominant role in controlling planktonic production. Recent studies infer the importance of oligotrophic areas in the drawdown of anthropogenic C (e.g. Close et al., 2013). **It is necessary to quantify the C fluxes in the upper water of the SW Pacific** and their potential links with dinitrogen fixation.

Specific question: *What is the actual zonal distribution of main C, nutrients stocks/fluxes and trace metals in the SW Pacific?*

Objective 1.2. Biological diversity

A major objective will be to produce an overall description of the planktonic community composition in the SW Pacific pelagic ecosystems, providing a “functional” structure for specific analysis. A detailed description of the biological diversity is essential as it is hypothesised that biodiversity increases the functional redundancy of marine ecosystems. Such redundancy may play an important role in an ecosystems ability to withstand natural and anthropogenic disturbances (Fonseca and Ganade, 2001). The need to describe a more “operational” functional structure should not replace having a “complete” description of the species composition. Variation in species composition probably remains the most effective tool in identifying natural and / or anthropogenic perturbations. A coupling of complementary techniques will be used along the transect, including surface continuous flow cytometry (CYTOSUB)

and discrete flow cytometry for bacteria, pico-, nano- and micro-phytoplankton (Marie et al., 1999), microscope determination of taxonomy for microphyto-, microzooplankton (Hasle et al., 1978) and heterotrophic nanoflagellates, and imagery (zooscan, flowcam) for metazooplankton taxonomy (Grosjean et al., 2006), associated with particle counters (UVP, LISST, LOPC) for spatial distribution and size-structure of particules and plankton.. The UVP will also assess the *Trichodesmium* spp. colony abundance in the water column (Guidi et al., 2012).

A special attention will be given to studying the diversity of diazotrophs. The scientific community made intense progress over the last decade thanks to the emergence of molecular methods, which allowed the discovery of an increasing diversity of N₂-fixing organisms (Zehr et al., 2001; 2008), active in previously unsuspected ecological niches such as N-rich areas (e.g. Short and Zehr, 2007; Needoba et al., 2007; Moutin et al., 2008; Bonnet et al., 2011; Fernandez et al., 2011; Dekaezemacker et al., 2013). The filamentous photosynthetic cyanobacterium *Trichodesmium* spp. has long been considered the dominant marine diazotroph. Recent molecular studies have challenged this view as new evidence suggests that photosynthetic unicellular nano-planktonic diazotrophic cyanobacteria (UCYN; belonging to Group B or C, Zehr et al., 2001), photo-heterotrophic unicellular picoplanktonic cyanobacteria from Group A (Zehr et al., 2008) or heterotrophic bacteria are widespread in the oceans and capable of fixing N₂ (Halm et al., 2012; Riemann et al., 2010; Zehr et al., 2008; Zehr et al., 1998; Zehr et al., 2001). The discovery of heterotrophic and photo-heterotrophic (UCYN-A) diazotrophs implies that N₂ fixation is not necessarily linked with C fixation in the euphotic zone, and N₂ fixation has recently been reported in aphotic waters down to 800 m (Hamersley et al., 2011; Rahav et al., 2013) and 2000 m (Bonnet et al., Accepted). However, despite the increasing recognition of their abundance in the global ocean (Luo et al., 2012), very few studies have examined in details the precise role and regulation of N₂ fixation in photo-heterotrophic and heterotrophic (cyano)bacteria in marine waters. Their ubiquity has significantly widened the geographical limits where N₂ fixation was supposed to occur and, therefore, the potential amount of fixed N entering the oceans. The physiology of these (photo)-heterotrophic diazotrophs as well as the environmental factors controlling their distribution, their activity and their relation with other organisms in the ocean are still very poorly known. However, the little knowledge we have on these diazotrophs suggests that they are very different from *Trichodesmium* spp and are regulated in the SE Pacific by organic C and N availability (Bonnet et al., Accepted.). In the North Pacific Subtropical Gyre (NPSG) at station ALOHA, Dore et al. (2008) estimated that the highest integrated N₂ fixation rates occurred during summer while either *Trichodesmium* sp. or diatom blooms (mainly constituted by *Rhizosolenia* sp. or *Hemiaulus* sp. with *R. intracellularis*) were observed. However, the Southern Pacific exhibits a negative Si* (SiOH₄-NO₃) whereas it is strongly positive in the Northern Pacific (Sarmiento and Gruber, 2006) and the relative importance of diatoms in N₂ fixation remains unknown in the proposed study area. We should not dismiss the role of diazotrophs living in association with diatoms as possible key players in N₂ fixation and C export (Karl et al., 2012), and offering a link between the N and silicon biogeochemical cycles. **There is a clear need to study all diazotrophs if we want to know how N₂ fixation and therefore the oceanic N budget will respond to global change in the ocean.**

The cruise transect will cross a gradient of phytoplanktonic biomass identified from satellite data, providing *in situ* observations to compare with such satellite-based analysis. It will be used to calibrate PHYSAT, which allows determining large organism's classes from space (Alvain et al. 2005; 2008), toward a better representation of N₂ fixing organisms. A comparison with vertical distribution of phytoplankton communities based on surface chlorophyll determination (Uitz et al., 2006) will also be undertaken. Ocean color remote sensing will also give a synoptic overview of the chlorophyll concentration in the South Pacific during the cruise. In parallel, synoptic observations of satellite SST and Sea Level anomaly will provide insights about the physical context of the upper water column at basin scale: i.e. variability of ocean stratification and thermocline depth (which can be used as a proxy of the nutricline depth) as well as horizontal and vertical advection from the surrounding waters of the transect (Wilson and Coles, 2005; Martinez et al., 2009). These physical observations will also be compared to *in situ* measurements to validate the use of this proxy.

Specific questions: What species currently characterize the SW Pacific's pelagic ecosystems during austral summer conditions? Which species or group is responsible for specific functions (N₂ fixation, dissolved organic phosphate utilization, bacterial production, silification rates)?

OBJECTIVE 2. PRODUCTION AND FATE OF ORGANIC MATTER IN CONTRASTING OLIGOTROPHIC ENVIRONMENTS WITH PARTICULAR EMPHASIS ON THE PRODUCTION SUSTAINED BY N₂ FIXATION

The major objective is to study how production, mineralisation and export of organic matter depends on the N₂ fixation process in contrasting oligotrophic areas: 3 long duration (LD: 7 days) stations. We will quantify the flow of material (biogenic elements) through each ecosystem and particularly focus on the role of N₂ fixation in the production and fate of organic C. **The fate of newly fixed N by diazotrophs in the ocean has been poorly studied so far, despite the fact that N₂ fixation provides the major external source of N for the global ocean.** In most studies, the input of N brought to surface waters by N₂ fixation is converted using Redfield ratios in order to ‘theoretically’ evaluate the C production potentially sustained by this source of N. It is not clear whether this N fuels photoautotrophic phytoplankton and can be transferred along the trophic chain and rapidly exported out from the euphotic zone, and/or if it fuels heterotrophic growth and thereby contributes to remineralisation in surface waters. In addition, the plankton diversity and its evolution after the development of a diazotroph bloom (classical food web versus microbial loop) have been very poorly studied, mainly due to the difficulty of observing and monitoring a bloom in the natural environment.

Objective 2.1. Physical and biogeochemical characterization of contrasting oligotrophic environments

A real added value for the project will be to sample 3 water masses along the trophic gradient characterized by different populations of N₂-fixing organisms. We expect to locate the first LD station (A) in an area dominated by autotrophic diazotrophs *Trichodesmium* spp. and/or UCYN-B, which appear often spatially associated in the SW Pacific (Moisander et al., 2010). The previously developed algorithms **TRICHOSAT** (Dupouy et al., 2011) and **PHYSAT** (Alvain et al. 2005; 2008; the *Trichodesmium* algorithm is currently being developed in the framework of the SAVALEFER project, PI: C. Menkès) will help to locate a *Trichodesmium* spp. bloom from space. We expect to locate the second LD station (B) in an area associated with high abundances of UCYN-A, probably in the transition zone between the SW Pacific and the gyre (Halm et al. 2011). Because it will not be possible to identify it from space, we will use **diazotroph abundance, diversity and gene expression assessed onboard in near real time** using qPCR at each 18 SD stations to decide which one will be used for a process study (LD station). The Third LD station (C) will be located in the low N₂ fixation region (gyre), where heterotrophic diazotrophs dominate (Bonnet et al., 2008; Halm et al., 2011).

The physical dynamics of the regions around the 3 LD stations will be first characterized in terms of large scale general circulation through the analysis of satellite (SST, Ocean color, Altimetry) and operational model data. These will be automatically retrieved and processed (to derive Eulerian and Lagrangian diagnostics such as the Okubo-Weiss parameter and Lagrangian Coherent Structures), and then transmitted onboard by a dedicated server on land. These data will be analysed in near realtime both on board and on land in order to optimize the sampling strategy according to the local physical and ecological characteristics. This approach has already been successfully implemented by the proposed team and employed during several previous cruises: LATEX (Nencioli et al. 2011), KEOPS2 (d'Ovidio et al., 2012) and STRASSE. Local meso and submesoscale dynamics within each region (eddy, filaments and frontal processes and their impact on regulating vertical fluxes and structuring the ecological community) will be first characterized through multisensor MVP 200 mapping at the beginning and at the end of each survey. This will allow to accurately identify the homogeneous and coherent water masses which will be the focus of each LD station. For this purpose the MVP 200 will represent an extremely useful instrument to sample a large zone in a short time to preserve synopticity. If not available, a classical strategy with numerous CTD casts will be undertaken as during the BOUM cruise (Moutin et al., 2012). A glider mapping within a smaller region around the station will integrate the initial and final LD mappings. This will allow to investigate the impact of high-frequency small-scale physical phenomena on biomasses and biogeochemical fluxes. A recently improved version of the Lagrangian navigation software developed during the LATEX project (Doglioli et al., in press) will be used in order to take into account the translation, rotation and deformation of the studied water masses.

3 Bio-Argo floats, specifically equipped with low level phycoerythrin sensors will be deployed at each LD station. In addition to conventional sensors for monitoring physical and biogeochemical parameters,

they will allow to characterize *Trichodesmium* spp. blooms in the SW Pacific ocean during our cruise and on a longer time scale.

Specific questions: *How do physical processes structure the planktonic community? How accurately are phytoplanktonic communities, and specially N_2 -fixing organisms, represented by remote sensing data?*

Objective 2.2. Measurements of nutrient concentrations and/or availabilities in the photic zone, and identification and quantification of the major external fluxes.

Nutrient availability (N, P, Si, Fe) in the photic zone controls primary production of organic matter, and thus exerts a strong influence on the species composition of the food web. It is dependent on several input, recycling and export fluxes. Nutrient concentrations in the upper layer represent the equilibrium state between all those fluxes and is the first indicator of nutrient availability. **Nevertheless, as nutrient concentrations are very low in marine oligotrophic habitats, these measurements represent a major observational challenge.** Nanomolar methods developed by the proposed team will be used for nutrient concentrations measurements when necessary (Rimmelin & Moutin, 2005, Rimmelin et al., 2007, Pascoa et al., 2012).

New nutrient inputs in the upper mixed layer include fluxes induced by ocean dynamics (meso- and submesoscale pumping; vertical turbulent mixing), interior sources (N_2 fixation) and surface fluxes (atmospheric deposition). The dynamics of meso- and submesoscale structures is often associated with strong vertical motion that can induce intense upwelling of deeper, nutrient-rich waters into the euphotic zone (Levy et al., 2012). The impact of those structures in regulating local nutrient availability and primary production will be investigated through the observations described in section 2.1.

Vertical turbulent mixing is a key process driving physical and biogeochemical fluxes between the mixed layer and the stratified ocean (Cuypers et al 2012) and can strongly impact primary production (Parad et al., in rev. 2013). While mixing in the mixed layer is mostly driven by direct atmospheric forcing, mixing in the stratified water column is mainly driven by internal wave breaking. Internal waves can be generated from inertial currents at the surface or tidal forcing at the bottom. The study area encompasses a large variety of environments regarding the internal waves (Internal tides notably vary from strong to negligible over the cruise area). As well we expect significant mixing resulting from instabilities of the strong currents of the western part. Therefore the measurements would provide a unique data set characterizing turbulent mixing in a poorly sampled area and under a variety of internal wave dynamical regimes and different current structures. Microstructure measurements that resolve the dissipative scales will be performed using a full ocean depth un-tethered profiling system, "VMP6000" (or a SCAMP that samples the first 100m). This profiler, that can profile down to 6000 m is equipped with microsensors for temperature and shear that enable two independent accurate estimates of the eddy diffusion coefficient K_z . These two estimates will be used to test the relevance of the different indirect methods based on classical CTD and ADCP measurements. This validation will allow to estimate K_z also when microstructure measurements are not performed. The same strategy has been used by the proposed team during the BOUM cruise (Cuypers et al., 2012).

In addition to the input of nutrients by turbulent mixing, we will quantify the N input through biological N_2 fixation, as it may be a major source in the SW Pacific. Gross and net N_2 fixation rates will be measured at every station (SD and LD) between 0 and 2000 m depth using both the acetylene reduction method (Capone, 1993) and the $^{15}N_2$ labelling procedure, incubation (24 h) and mass spectrometry analyses (MIO Marseille) as described in Montoya et al., (1996) and Bonnet et al., (2011). The $^{15}N_2$ enriched seawater method (Mohr et al., 2010; Wilson et al., 2012; Grosskopf et al., 2012) will be used during the cruise and several method inter-comparisons will be performed between the $^{15}N_2$ bubble method and the $^{15}N_2$ seawater enriched method, both performed under trace metal and DOM-clean (Bonnet et al., 2009) and non-trace metal clean and DOM-clean procedures.

In order to better understand the relationship between (photo)-heterotrophic diazotrophs and DOM, we will perform DOM characterization through FT-ICR MS (allows the detection of individual DOM compounds) simultaneously to N_2 fixation measurement and diazotrophs diversity.

Aeolian dust transport represents, on a global scale, the dominant source of iron, an essential micronutrient for phytoplankton growth, to the ocean (Jickells et al., 2005). Some of the melanesian archipelagos crossed during the transect (Vanuatu, Fiji) exhibit active volcanoes, which have been seen

(in the North Pacific) to provide sources of very soluble and bioavailable trace metals such as iron (Olgun et al., 2011) and potentially N and P. Consequently, dust inputs could stimulate *in situ* biological productivity in oligotrophic ecosystems and alter community composition, distribution of nutrients and finally the net sequestration of atmospheric CO₂. **We will quantify the input of nutrients by the atmosphere and study the influence of dust deposits on the food web and their potential impact on N₂ fixation, using microcosm experiments.**

Specific questions: *Is N₂ fixation a major source of new N for primary production in the photic layer? Do direct measurements of eddy diffusion coefficients reasonably agree with previous estimations? What could be the role of dust?*

Objective 2.3. Organic matter production and food web structure

Because of light/energy requirements, marine organic matter is almost entirely produced in the upper photic zone of the ocean. Variable primary production fuelled by physical processes acting over a wide range of scales interacts with predation to define the species composition of planktonic populations (Gargett & Marra, 2002). The basic principle of the conceptual food web structure, which has not been critically challenged since its original description (Johannes, 1965; Thingstad et al. 1999), is to consider two trophic strategies. Osmotrophy referring to organisms that feed by taking up dissolved nutrients and phagotrophy referring to organisms that feed by eating particulate matter. Osmotrophs include both heterotrophic bacteria and autotrophic phytoplankton, while the predatory food chain includes protozoa, mesozooplankton and higher predators (all heterotrophs).

Biogeochemical fluxes in relation to osmotrophic production

We will measure fluxes of biogenic elements (including C) and determine parameters that will help to represent these fluxes (P vs I parameters, K_s, V_{max}, affinity constants...). Classical approaches using stable (¹⁵N, ¹³C) and unstable (¹⁴C, ³³P, ³²Si) isotopes for measuring biogeochemical fluxes will be used for bulk measurements, along with new techniques at the single-cell level, which address by which species (or group of species) a specific element has been taken up. **New methods concerning both dominant species separation as cell sorting by flow cytometry developed by the proposed team (Duhamel et al., 2009, Gregori et al., 2011; Talarmin et al., 2011) and low detection limits of chemical analyses will allow us to define species-specific uptake parameters.** The contribution of mixotrophy and photoheterotrophy to the biogeochemical fluxes of C and N will be studied together with the environmental factors that control mixotrophy and symbiosis by microbial eukaryotes. **The methods proposed will allow us to significantly improve our understanding of the factors controlling the distribution and activity of different groups of plankton functional types and to link their phylogenetic and functional diversity.**

Regarding N₂-fixing organisms, recent major development in SIMS (Secondary Ion Mass Spectrometry) instrumentation (NanoSIMS 50TM) now allows for the measurement of isotopic ratios with a spatial resolution better than 100 nm (Guerquin-Kern et al., 2005; Slodzian et al., 1992). The capability of such instrument to measure isotopic composition makes it suitable to study environmental microbiology at the single-cell level (Lechene et al., 2006). Most of these recently discovered N₂-fixing micro-organisms are uncultured and many unresolved questions remain about their physiology and their importance in term of input of new N in the ocean. The nanoSIMS technology associated with cell sorting (Bonnet et al., In Rev.) or FISH (HISM-SIMS, Thompson et al., 2012, Krupke et al., 2013) will be applied to assess the contribution of every diazotrophic group to overall fluxes, and determine organic/inorganic nutrients controlling their activity. We will focus on the recently described UCYN (Moisander et al. 2010, Thompson et al. 2012) group whose role in C and N cycling is not well understood thanks to recent methods developments realized by the proposed team (see references above).

The silicification process in marine diatoms will be investigated at the single-cell level using the PDMPO labelling technique (Leblanc & Hutchins, 2005).

Phagotroph production (secondary production)

The planktonic food web structure influences the fate of primary production in the ocean and has consequences for the CO₂ transfer process. It is generally understood that when small eukaryotes or prokaryotes dominate the microbial community, the grazers of picoplankton are small protozoa which do not produce rapidly sinking faecal pellets. **Despite their omnipresence and their pivotal role in the**

energy flow in marine waters on a global scale, the physiological ecology of these organisms is poorly understood. Several grazing steps are necessary to enable primary production to be incorporated into the upper trophic levels. Therefore, most of the C fixed by phytoplankton is respired and remineralised by the microbial community in the surface mixed layer and there is little or no net uptake of CO₂ from the atmosphere to the sea. In contrast, when large phytoplankton cells dominate, they can either sink to depth or be grazed by copepods and other mesozooplankton which produce rapidly sinking faecal pellets. However, Mesozooplankton, i.e. copepods, have recently been coupled to lower trophic levels in the eastern Mediterranean Sea (Thingstad et al. 2005) and their contribution to the C cycle of oligotrophic areas needs to be reconsidered. **The upper meso- and macrozooplankton, largely under-sampled by classical techniques, may also significantly contribute to the vertical transport of organic matter.**

An apparently high contribution of diazotroph N to zooplankton directly east of New Caledonia was recently evidenced (Hunt et al., in press), supporting similar findings in diazotroph rich areas of the Atlantic (Hauss et al. 2013). It is possible to trace the diazotroph signature through the macrozooplankton to the micronekton component of the food web. These are the first detailed stable isotope measurements of the pelagic community presented for the region. We will now increase the geographic coverage of zooplankton and stable isotope sampling across the SW Pacific diazotroph gradient, **specifically to investigate the relative contributions of diazotrophs to food web N and the their role in structuring community composition. We will apply bulk stable isotope analysis in combination with amino acid specific N isotope analysis (CSIA).** The latter method provides the added resolving power of direct estimate of source N isotope signature for any organism measured (McClelland et al. 2003). **A key question remains what are the pathways that fixed N takes to reach primary consumers (microzooplankton and zooplankton grazers) and upwards.** In part we can contribute to answering this question by detailed species level stable isotope analysis of all lower trophic level community components. Additional insights will be gained by experimental studies using labelled N tracers (Loick-Wilde et al. 2012).

Biogeochemical process from optical measurements

Integrated measurements of bio-optical properties and pigments will be made with instruments measuring hyperspectral radiometry in the UV-Visible domain, with UV-VIS Trios spectroradiometers (Murakami and Dupouy, 2013). Two consecutive profiles of downward irradiance [$E_d(Z, \lambda)$] will be conducted at solar noon with a MicroPro free-fall profiler (Satlantic) that is equipped with pressure, temperature and tilt sensors and OCR-504 downward irradiance sensors for the UVR-B (305 nm), UVR-A (325, 340 and 380 nm) and PAR (412, 443, 490 and 565 nm) spectral domains, according to the protocol given in Tedetti et al. (2007) and Para et al. (2013). Surface (atmospheric) irradiance [$E_s(\lambda)$], which is equivalent to the downward irradiance just above the sea surface [$E_d(0^+, \lambda)$], will be continuously measured in the same channels from the ship deck with other OCR-504 downward irradiance sensors (surface reference). These measurements will be made to account for the variations in cloud conditions that occurred during measurement. Backscattering at the satellite channels will be obtained with the Hydroscat-6 (Dupouy et al., 2008; 2010; Loisel et al., 2011). Hyperspectral light absorption of particles and CDOM and FDOM characterization (with the identification of markers of bloom degradation in the surface, above and below the euphotic depth, etc...) in relation with pigment concentrations (Coble, 1996; Tedetti et al., 2011; 2012). Additionally, the characterization of optical properties of dominant species (Dupouy et al., 2008) encountered along the transect will be realized. In addition, inorganic aerosol quantification and atmospheric radiance measurements will be continuously done along the transect, especially around the Vanuatu archipelago. Simulations reveal that in Northern Atlantic atmosphere, dusts are able to induce a significant decrease of PP due to the attenuation of light by about 15-25% for dust optical depth (DOD) larger than 0.6-0.7 (at 550 nm).

Specific questions: *What are the characteristics of the dominant species concerning photosynthesis, N₂ fixation, nutrient uptake, osmotrophy and phagotrophy?*

Objective 2.4. Organic matter mineralization and food web structure

The study of organic matter degradation will focus on the relationship between mineralization and bacterial diversity. **Hence, examining the relationship between diversity and functionality within**

the bacterial community (ectoenzymatic activity, uptake of specific organic compounds representative of a chemical family) is a major challenge for understanding the impact of prokaryotic heterotrophic processes on mineralization of organic matter along the water column. We will also study the factors controlling bacterial production and the consequences of such controls on heterotrophic activity, and the hydrolysis rate of Dissolved Organic N and P.

The wide geographical and vertical (in the oceanic water column) distribution of heterotrophic diazotrophs suggests they are **bound to have a key role in global N₂ fixation**. However, failure to isolate and maintain these organisms in culture limits our knowledge on their activity and nutritional needs (Zehr, 2011). While the genetic information of these organisms reveals their dependence on organic matter (Riemann et al., 2010; Tripp et al., 2010), this relationship has not been studied so far. We will perform microcosm experiments at LD stations to test whether different sources of DOM (C-enriched, N-enriched or P-enriched commercially available sources, and natural *in situ* DOM) trigger N₂ fixation and/or the expression of *nifH* by different groups of heterotrophic diazotrophs. Additional nutrient amendment experiments will be performed using ¹³C- and ¹⁵N-labelled organic molecule and the **HISH-SIMS** (Thompson et al., 2012) method in order to identify which diazotrophs assimilate which organic molecule and in which quantity.

Specific questions: What are the changes in prokaryotic heterotrophic activity and community composition in relation with horizontal (west-east) and vertical (surface to depth) nutrient gradients and the composition/labability of the dissolved organic matter?

Objective 2.5. Organic matter export (particulate and dissolved matter)

The structure of pelagic ecosystems influences the size and type of downward flux of biogenic C in the sea (Legendre and Rassoulzadegan, 1996). This vertical flux is composed mainly of large particles such as fecal pellets, hard parts of zooplankton, amorphous aggregates, marine snow (Fowler and Knauer, 1986; Silver and Gowing, 1991), and senescent diatoms, particularly in the aftermath of blooms (Billet et al., 1983). Fecal pellets can sink quickly: 20-900 m d⁻¹ for copepods (Lorenzen, 1983; Welschmeyer and Lorenzen, 1985), and up to 2700 m d⁻¹ for large gelatinous zooplankton (Bruland and Silver, 1981; Madin and Purcell, 1992). High sinking velocities can lead to the efficient export of biogenic C. The downward flux of biogenic C can therefore be largely dominated by C of zooplankton origin (Thibault et al., 1999). We will use the Underwater Vision Profiler (UVP; Picheral et al. 2010) to assess vertical POC flux from particle size distribution (PSD) (Guidi et al. 2008) and vertical distribution of zooplankton (Stemmann et al., 2008) that are directly linked to the vertical flux. We will also complement the zooplankton distribution by an indirect estimate of zooplankton vertical profiles through acoustics from the ship borne S-ADCP and Lowered ADCP on stations as well as from ER 60 (200kHz) echosounder. In addition, using images from the UVP, we will describe vertical, horizontal, and temporal evolution of the *Trichodesmium* spp. colonies similar to what has been done recently in the North Pacific (Guidi et al. 2012). ***Trichodesmium* spp. colonies will be spatially and temporally correlated to vertical particle flux and their potential contribution will be estimated.**

We will study the C/N/P/Si stoichiometry of settling particulate matter because despite its biogeochemical relevance, there are few direct measurements available (Geider & La Roche, 2002). We will also examine the role of larger particulate matter responsible for the marine snow rarely observed in oligotrophic areas and quantify instantaneous DOC export.

It has been recently reported that bacteria living within colonies of the N₂-fixing cyanobacterium *Trichodesmium* spp. use cell-cell signaling to regulate the degradation of organic phosphorus compounds (Van Mooy et al., 2012). In a separate study, it has been found that bacteria living on sinking particles may also use cell-cell signaling to regulate organic matter degradation (Hmelo et al., 2011). Finally, rates of N₂-fixation were also found to be affected by cell-cell signaling (Van Mooy and Dyhrman, unpublished). We will combine these three findings and ask the next question: **How does cell-cell signaling** via acylated homoserine lactone (AHL) and autoinducer-2 (AI-2) molecules in senescent *Trichodesmium* spp. colonies **affect the export of new organic N in sinking particles?**

Specific questions: What is the ratio of particulate vs dissolved organic matter export? What is the role of *Trichodesmium* spp., and of cell-cell signalling in the export?

Objective 2.6. Fate of N₂ fixation

Although direct evidence of trophic transfer from diazotrophs through planktonic food webs is lacking, studies based on natural abundance of ¹⁵N in suspended particles and zooplankton suggest that N from diazotrophy would support a part of primary and secondary production in the subtropical Atlantic Ocean (Montoya et al., 2002; Landrum et al., 2011). In addition, a low delta ¹⁵N signature of exported material at the time series station HOT (Karl et al., 1997; 2002; Casciotti et al., 2008), and of nitrate accumulating in the upper thermocline of the Sargasso Sea (Knapp et al., 2008) would indicate that recently fixed N is transferred out of the euphotic zone. As fragments of *Trichodesmium* spp. are rarely recovered in sediment traps (Walsby, 1992) and are mostly ungrazed (O'Neil, 1999), transfer of fixed N is probably done through the dissolved pool (Mulholland, 2007). Indeed, *Trichodesmium* spp. has been seen in the natural environment and in cultures to release up to 50-80% of recently fixed N₂ as dissolved organic N (DON) and ammonium (NH₄⁺) (Capone et al., 1994; Mulholland & Bernhardt, 2005) potentially available for surrounding planktonic communities. Alternatively, Brandes et al., (1998) suggested that some material derived from N₂ fixation can be remineralized in surface waters, lightening the isotopic nitrate signal, which may be propagated along the trophic chain.

This lack of knowledge is essentially due to the lack of techniques which allow us to trace the N transfer through the different compartments of the food web. We propose here to overcome these difficulties by using a combination of powerful techniques previously used by the proposed team in the framework of the VAHINE project (INSU-LEFE – ANR JCJC PI: S. Bonnet), including: 1/ high-resolution nanometer scale secondary ion mass spectrometry (NanoSIMS) coupled to 2/ flow cytometry cell sorting and 3/ ¹⁵N₂ isotopic labelling (Bonnet et al., In Rev.).

Previous studies have shown that increased TEP production by *Trichodesmium* was coupled with caspase activation and programmed Cell Death (PCD, Berman-Frank et al., 2004, 2007). The concentration of TEP will be correlated to PCD of diazotrophs using diagnostic genetic markers currently developed by I. Berman-Frank (Univ. Bar Ilan, Israel).

In order to quantify the part of export production that has been sustained by N₂ fixation, a δ¹⁵N budget will be performed at LD stations, based on ¹⁵N natural abundance (collaboration with A. Knapp, Florida State University). δ¹⁵NO₃, δ¹⁵DON will be measured along the vertical at LD stations. Using the PN sinking flux and PN sinking δ¹⁵N, we will construct a 1-D (vertical) isotope budget, where the water mass at LD stations is treated as a single box. We will assume that there are two sources of new N to the surface waters, the first of which being total dissolved N (TDN) (TDN = NO₃⁻+NO₂⁻+DON) mixed up from subsurface waters, using the δ¹⁵N of TDN from the base of the seasonal mixed layer as the δ¹⁵N for this source term. The other source of new N will be assumed to be N from N₂ fixation, with a δ¹⁵N of -1‰ (Hoering and Ford, 1960; Minagawa and Wada, 1986; Carpenter et al., 1997). First we will construct a δ¹⁵N budget assuming that the TDN supplied from the subsurface is the only important source of new N, and assume that the two dominant export terms are represented by 1) the gradient in [TDN] and TDN δ¹⁵N from the surface to subsurface and 2) the PN sinking flux and its δ¹⁵N. We will then ask whether the δ¹⁵N budget can be balanced without N₂ fixation, or whether the δ¹⁵N of sediment trap material is too low to be explained by the TDN source alone, and the δ¹⁵N budget thus requires an additional, low δ¹⁵N source of new N, such as from N₂ fixation (see similar calculations in Altabet, 1988; Karl et al., 1997; Knapp et al., 2005). Using this δ¹⁵N budget, we will determine what fraction of export production is supported by N₂ fixation. By multiplying this fraction of export production supported by N₂ fixation by the PN sinking flux, we can calculate an absolute N₂ fixation rate for the duration of the sediment trap deployment and compare them with direct measurements.

Specific questions: What is the fate of N₂ fixation? Does programmed cell death ((PCD), induced in some of the dominant diazotrophs – *Trichodesmium*) induce enhanced vertical export as we see from lab experiments? Can we identify changes in physiological status of the populations using PCD markers (Bar-Zeev et al. 2013)?

OBJECTIVE 3. REPRESENTATION OF MAJOR BIOGEOCHEMICAL FLUXES AND OF THE DYNAMICS OF THE PLANKTONIC TROPHIC NETWORK

The multidisciplinary field data gathered during the OUTPACE cruise will be available to the international community as soon as possible (CYBER data base) in order to help represent the interactions between climate, biogeochemical cycles and marine ecosystems. **A multi-scale modelling**

approach is proposed from the beginning of the OUTPACE project. Its objective is to complement the observations with the analyzed data in order to understand the interactions between the biogeochemical cycles of the biogenic elements and the dynamics of the planktonic trophic network. Modelling will also be used in interaction with observation and measurements at several scales and at several moments of the project in order to optimize the potential of each of these tools.

Objective 3.1. Process scale studies

We first plan to focus on some physical and biogeochemical processes through (i) the zero-dimensional (0D) modelling of microcosm and through (ii) the simplified 1D vertical modelling of the physical and biogeochemical processes at the long duration stations. These stations will be positioned in regions where the horizontal variability of the hydrological and biogeochemical properties is supposed to be low over the duration of sampling making it possible to consider a 1DV modelling approach. Moreover, the majority of the model's needs, in terms of state variables and parameters, will be acquired through in situ measurements or by controlled activities i.e. sampling and microcosms during the cruises.

Microcosm experiments and modelling (0D) are important for several reasons, the main one being that they provide a vision of the biogeochemical and trophic web functioning deconvoluted from hydrodynamic aspects. This is a crucial step towards the understanding of the ecosystem. Microcosms are also useful to acquire certain model parameters (characteristics of nutrient assimilation, photosynthetic parameters, respiration rates, mineralisation...) and to test or develop new mathematical formulations for processes where current formula are not validated or represented. It is also important that these microcosm experiments are undertaken during the cruises (or field studies) with in situ water samples in order to obtain parameters which are representative of the studied ecosystem.

In practice, a biogeochemical model relevant for SW Pacific waters and developed during the VAHINE project will be used to model the 0D experiments. It is based on a previous version of a biogeochemical model developed for the Mediterranean sea which included 6 functional types, namely bacteria, two phytoplankton size-classes, HNF, ciliates and mesozooplankton and which was already implemented in the Eco3M modelling tool. In this model, organisms have flexible stoichiometry and are represented in terms of C, N, P biomasses as well as in abundances. During the VAHINE project, the diazotroph *Trichodesmium* spp. has been added and the introduction of other unicellular diazotrophs will be done in near future (Post Doc ANR JCJC VAHINE). This model will be validated in the frame of the VAHINE project but it can already be used as an a priori model to help in designing the microcosm experiments that will be held on board. The measurements will in turn be useful to refine the a priori model.

In terms of processes, this model gives a mechanistic or semi-mechanistic representation of the key processes of plankton dynamics (photosynthesis, photoacclimation, nutrient absorption, DOM release, respiration, grazing, mineralization, excretion,...). The majority of these processes have been validated using microcosm and mesocosm experiments (Baklouti et al., 2006b, Baklouti et al., 2011, Alekseenko et al., subm.). Among the processes that specifically need to be worked on, the diazotrophy process is certainly the main one. For *Trichodesmium* spp., the mechanistic model of Stephens et al. (2003) adapted to *Trichodesmium* spp. by Rabouille et al. (2006) has been used and adapted to our model. However, for unicellular diazotrophs, existing models for diazotrophy are scarce and rely on empirical laws deduced from macroscopic observations. In order to improve such models, the underlying mechanisms of diazotrophy need to be understood, especially the interaction between N_2 fixation and nutrient uptake of other N sources, phosphate, and iron.

Objective 3.2. In situ experiments at long duration station (1DV)

The major objective of 1DV modelling is to represent fluxes of biogenic elements in the surface layer and provide an accurate budget on the fate of the organic C produced (Re-mineralisation, export). The use of a flexible stoichiometry model (non Redfieldian) will potentially make it possible to illustrate the decoupling of the biogenic element cycles in the oligotrophic ocean. The objective is to understand the production and fate of organic matter in the oligotrophic food web, and their role in the global C cycle. To achieve this, we will proceed to the extraction of those criteria which appear essential in providing a satisfactory representation of the marine pelagic ecosystem and biogenic element fluxes. The complexity of the trophic relationships will be simplified by focusing on the groups of species

having similar biogeochemical functions (i.e. functional groups). The relevance of the 1DV modelling will depend on in situ measurements carried out at the long duration stations. Indeed, a certain number of parameters which will be measured are essential in achieving a realistic representation of the dynamics of the pelagic ecosystem and thus a precise estimate of the C budget. These parameters include all the parameters related to phytoplankton photosynthesis and to nutrient uptake by the plankton. In coupled physical-biogeochemical models, the parameterization of turbulence is frequently a source of error, because it is based on empirical laws, and because these laws are not then re-calibrated for each studied site (typical values found in the literature are used to parameterize these laws). Here, it will be possible to use realistic vertical profiles in the hydrodynamic 1DV model to accurately estimate the coefficients of turbulent vertical diffusion - K_z - (cf obj 2.1). The use of such realistic profiles is an essential step in representing the mixing processes in the surface layer and the nutrient fluxes at the base of the euphotic layer. However, a simplified 1D version could be achieved instead if the 1DV model is too difficult to parametrize. This simplified model would consider that the water column is divided in a number of boxes that would receive different light intensities according to the vertical profile of PAR, and which would exchange matter only through the sinking of detrital matter. The biogeochemical model that will be used for the 1DV configuration is the same as the 0D one except that it will benefit from the refining that will have been done thanks to the microcosm experiments. This type of model enables us to obtain a representation of the biogeochemical cycles of the principal biogenic elements (C, N, P) as well as representing organisms ("functional" groups) that play a key role in the dynamics of organic C production and transfer. The whole data set collected from the long duration stations, and in particular the data obtained in a quasi continuous manner such as nitrate fluxes and stocks, will offer the possibility of validating the coupled model which up to this point has never been carried out due to the strong mismatch between experiments and modelling.

Specific questions: *Is it possible to reproduce, with only one uniquely structured model, the principal physical and biogeochemical characteristics of the different oligotrophic areas studied?*

Liens avec les programmes nationaux et internationaux : [Annexe A](#) (dossier CNFH, p. 4).

Résultats attendus plus détaillés : [Annexe A](#) (dossier CNFH, p. 5).

Calendrier :

Février 2014: Réunion pré-campagne avec tous les participants (Marseille, France)

Septembre 2014: Réunion pré-campagne du comité organisateur (Marseille, France)

Octobre 2014-Février 2015: Préparation de la campagne, envoi du matériel sur l'Atalante à Nouméa

Février-Mars 2015: Mission dans le Pacifique SO (description détaillée dans l'annexe 1)

Décembre 2015: Réunion post-campagne avec tous les participants (Marseille, France)

Février-Mars 2016: Atelier de travail focalisé sur la physique (~10 personnes)

Mai-Juin 2016: Atelier de travail focalisé sur la biogéochimie (~10 personnes)

2016: Demande pour une session spéciale à l'OSM 2016, Nouvelle Orléans, Louisiane (USA)

2016-2017: Publication des résultats scientifiques (Issue spéciale, Journal à déterminer)

Valorisation des travaux antérieurs : [Annexe A](#) (dossier CNFH, p. 30-31).

Références : [Annexe A](#) (CNFH) p. 25-30 pour la communauté OUTPACE et p. 51-53 pour les autres

Lettres de soutien : IMBER ([Annexe A](#), dossier CNFH, p. 54) et B. Van Mooy (dossier CNFH, p. 55).

[Annexe A](#) (p. 1-55): dossier CNFH simplifié, [Annexe B](#) (p. 56): Tableau budget (postes de dépenses),

[Annexe C](#) (p. 57-58): Coûts analytiques, [Annexe D](#) (p. 59): devis transport personnel, [Annexe E](#) (p. 60-

61): devis transport matériel, [Annexe F](#) (p. 62): demande cellule piège.

Remarque : une contribution aux réseaux ARGO et Bio-ARGO est souhaité dans cette campagne. La demande sera réalisée en temps voulu. Le largage de 3 flotteurs Bio-ARGO à chaque station de longue durée a déjà été discuté avec Hervé Claustre du LOV. Il est envisagé notamment si ces flotteurs peuvent être équipés de capteurs de fluorescence capables de détecter certains diazotrophes : l'étude est en cours.

Ressources nécessaires à la réalisation du projet (Cf Annexe 4 pour Tableau correspondances N° de postes). NB : ce tableau inclue une 4^{ème} année (2017) qui ne figure pas sur le site INSU et explique le différentiel des postes 'fonctionnement' et 'salaires' par rapport au tableau INSU.

N° POSTE DE DEPENSE (Cf Tab. Annexe 2)	2014	2015	2016	2017	TOTAUX	TOTAL ACQUIS (Or salaires perm.)	TOTAL DEMANDE LEFE	TOTAL DEMANDE ANR
FONCTIONNEMENT Total -->	16000	10240	22740	12500	61480	FONCTIONNEMENT		
1	16000	0	0	0				
2	0	0	7500	7500				
3	0	0	5000	5000				
4	0	2500	2500	0				
5	0	7740	7740	0		0	16000	45480
PETIT EQUIPEMENT (<15K€) Total -->	6000	0	0	0	6000	PETIT EQUIPEMENT		
6	6000	0	0	0		non évalué ici mais > 1M€	6000	0
ANALYSES (incluant consommables) Total -->	113760	113760	45880	0	273400	ANALYSES		
7	43760	43760	21880	0				
8	70000	70000	24000	0		164000	43760	43760
MISSIONS + TRANSPORT DE MATERIEL Total -->	121760	53840	35200	0	210800	MISSIONS		
9	8800	0	0	0				
10	2780	0	0	0				
11	12660	14320	0	0				
12	5520	8320	0	0				
13	8000	0	0	0				
14	25000	0	0	0				
15	42000	0	0	0				
16	0	1800	0	0				
17	0	8000	0	0				
18	17000	0	0	0				
19	0	4000	0	0				
20	0	6000	0	0				
21	0	11400	0	0				
22	0	0	4100	0				
23	0	0	4100	0				
24	0	0	27000	0		72000	85600	35200
SALAIRES NON PERMANENTS Total -->	49949	152497	88598	32568	323612	SALAIRES		
25	18677	0	0	0				
26	7004	7004	4669	0				
27	4669	4669	0	0				
28	9338	28015	0	0				
29	0	9770	0	0				
30	3257	9770	0	0				
31	7004	14009	4669	0				
32	0	46692	46692	0				
33	0	32568	32568	32568		132524	0	191088
TOTAUX	598938	650434	362096	77636	TOTAUX	368524	151360	315528
TOTAL ACQUIS	185949	149237	33338	0				
TOTAL DEMANDE A LEFE	81640	69720	0	0	151360			
TOTAL DEMANDE A L'ANR	0	111380	159080	45068	315528			
TOTAL DEMANDE ACI IRD	18000	0	0	0	18000			
COUT GLOBAL (4 ans)	285589	330337	192418	45068	853412			
COUT GLOBAL France (4 ans)	135581	228655	159080	90136	613452			

Co-financements acquis ou soumis (hors INSU). Le tableau ci-dessus dresse la liste des besoins financiers pour le projet OUPACE. En vert figurent les co-financements acquis, en bleu, le co-financement demandé à LEFE. **Afin de réduire au minimum le budget demandé à LEFE**, des co-financements (en rouge) ont été acquis ou vont être demandés par ailleurs (cf section 4. Liens avec les programmes nationaux et internationaux doc CNFH en Annexe). **Co-financements acquis.** L'ensemble des coûts humains/missions/équipements/analyses afférents à la participation des 9 universités étrangères est pris en charge par nos partenaires étrangers. Pour la partie française, 2 doctorants et 6 postdoctorants impliqués dans ce projet sont déjà financés (bourses MRT, Postdoc Marie Curie, LABEX CORAIL). Une demande 'Banque Sud' MIO à hauteur de 24 K€ est acquise sur le principe (co-financement missions). **Co-financements demandés.** Une ACI IRD est demandée en septembre à hauteur de 18 K€ dans la mesure où ce projet implique plus de 10 scientifiques de l'IRD de 5 unités IRD (MIO, LEGOS, LOCEAN, EIO). Une demande ANR sera déposée le 23/10/2013 (Cf Annexe CNFE).

	coût total	Cofinancements (préciser la source pour chaque case concernée)						Total demande INSU (préciser l'action concernée en cas de projet multi-actions)		
		Acquis année 1	Acquis année 2	Acquis année 3	Demandés Année 1	Demandés année 2	Demandés année 3	demande INSU année 1	demande INSU année 2	demande INSU année 3
Moyens nationaux (<i>rempli automatiquement sur le formulaire informatisé</i>)	1170000 (Atalante)	0	0	0	0	1170000 (Cf dossier CNFH)	0	0	0	0
Personnel permanent (<i>rempli automatiquement sur le formulaire informatisé</i>)	1107743	205466	507358	394919	0	0	0	0	0	0
Personnel temporaire (<i>rempli automatiquement sur le formulaire informatisé</i>)	291044	49949	73237	9338	0	79260	79260	0	0	0
Fonctionnement - Consommables - Petit équipement - Missions Analyses Publications - Gratifications de stage	517300	136000 (MIO+étrangers)	76000 (étrangers)	24000	99640 (LEFE + IRD)	101840 (LEFE + ANR)	79820 (ANR)	81640	69720	0
Equipement > 15 k€ (<i>joindre devis</i>)	0	0	0	0	0	0	0	0	0	0

Récapitulatif (doivent correspondre aux cases du tableau du formulaire informatisé)

Total cofinancements acquis : 368 524 euro (hors salaires permanents)

Total cofinancements demandés : 310 340 euro (1 480 340 euro avec demande Atalante)

Total demande INSU : 151 360 euro