Research trajectory

In 2007 I obtained my degree in Environmental Sciences at the University of Barcelona (UB), with a major in Water Quality and Management (receiving an Extraordinary Degree award). My early interest in marine biogeochemistry is demonstrated by the undergraduate research traineeships I conducted at the University of Helsinki, the Marine Sciences Institute in Barcelona (ICM-CSIC) and the Department of Ecology (UB), working on diverse areas such as aquatic photochemistry, zooplankton dynamics and marine sediment biogeochemistry.

I obtained my MSc in 2008 (MSc thesis award) and my PhD in 2012 (with honors, "Cum Laude"), both under the supervision of Dr. Rafel Simó at ICM-CSIC. Since the PhD period my research has revolved around the biogeochemistry of dimethylsulfide (DMS), a sulfur gas produced by marine plankton through a complex network of biological and chemical processes. Marine DMS emission regulates the formation of aerosols and their effects on cloud properties, whose poor knowledge severely hampers climate projections.

During my PhD thesis I studied the effects of solar radiation on DMS production by marine plankton (the microorganisms that drift with ocean currents). The amount and spectral quality of solar radiation received by marine plankton depends strongly on the depth of the surface mixed layer (the layer stirred by wind at the sea surface). By manipulating light exposure, I showed that solar radiation enhances planktonic DMS production, with the strongest effect caused by ultraviolet radiation. By studying DMS budgets in oceanographic cruises across polar, temperate and tropical oceans, I demonstrated that vertical mixing controls marine DMS emission through light-driven processes.

My PhD research was published in five papers in first quartile journals and presented at international conferences. In addition, my PhD findings were the basis of two comprehensive literature meta-analyses, completed and published during my postdoc. The first meta-analysis resolved the so-called "DMS summer paradox", the counterintuitive seasonal pattern of DMS concentration at low latitudes, which had puzzled scientists for over a decade. The second meta-analysis addressed the variable efficiency of photochemical DMS removal at the global scale. Both studies provide key observational constraints for biogeochemical models.

Since late 2013 I have been a postdoc at Laval University (Quebec, Canada) under the mentoring of Pr. Marcel Babin (a world leader in marine optics and remote sensing) and Pr. Maurice Levasseur (a renowned expert in Arctic DMS biogeochemistry). Between 2014 and 2016 I benefited from a highly competitive Beatriu de Pinós outgoing postdoctoral fellowship. During my postdoc I focused on the development of a new empirical algorithm to predict marine DMS emission from satellite data (DMS-SAT). This project has largely benefited from my solid knowledge of planktonic ecosystems and the marine sulfur cycle, while enhancing my skills in statistical analysis and empirical modeling, scientific programming and processing of large (petabyte-sized) datasets.

The first part of the DMS-SAT algorithm developed during my postdoc was published in 2015 (journal Remote Sensing of Environment). Yet, the scientific articles conveying the main achievements of my postdoc are presently in writing phase. These include (1) the description of the full DMS-SAT algorithm for estimating DMS emission at global scale, and (2) an analysis of Arctic Ocean DMS emission over 19 years of satellite data (1998-2016). The latter article, aimed at a high impact journal (Nature Climate Change), highlights the impact of Arctic ice retreat and ecosystem changes on DMS emission. The DMS-SAT product developed during my postdoc has raised the interest of, and is being used by, different atmospheric research groups (Stockholm U. - Sweden, Dalhousie U. - Canada). These interdisciplinary collaborations are yielding valuable insights into the changing Arctic climate (paper in Atmos. Chem. Phys., 2017).

Beyond my dedication to a specific research field, my research achievements have been possible thanks to a number of overarching skills. I master scientific communication in its different formats: scientific writing (as attested by my 8 first-author publications in first-quartile journals, mean impact factor 4.5; h-factor 8); formal oral presentations (with over 25 conference presentations); and outreach for non-scientist audiences. I enjoy interdisciplinary collaboration, as demonstrated by my 12 coauthored publications in the fields of microbial ecology, carbon biogeochemistry, underwater optics and atmospheric sciences. I have played a leading role in numerous occasions, for example chairing conference discussions, promoting synthesis studies involving various research groups and contributing to community papers.

Moving beyond my comfort area has been a constant driving force in my career. With this proposal I want to gain expertise in numerical modeling and biogeochemical forecasting, complementing my previous expertise in the analysis of large observational datasets. This will enable me to tackle new questions, ultimately helping society make informed decisions to prevent, adapt to and mitigate the impacts of global climate change.

Scientific proposal: ORganic CArbon Sequestration in the ocean: constraining model predictions with novel high-resolution observations (ORCAS)

The ORCAS project aims to bring new light to the *biological carbon pump*, the process by which atmospheric carbon dioxide is sequestered in the deep ocean in the form of sinking particles produced by plankton. In the sunlit surface layer of the ocean, phytoplankton cells take up inorganic carbon and nutrients to produce particulate organic matter, capturing 50 x 10^{15} g C/year (50% of the planetary *net primary production* —NPP). Although the majority of this organic matter is decomposed at shallow depths, releasing carbon dioxide back to the atmosphere, a significant fraction escapes short-term degradation and sinks to deeper layers. This vertical flux is known as *export production* (EP) and plays a pivotal role in marine ecosystems and global climate. However, its magnitude is highly uncertain, with current estimates ranging between 4–13 x 10^{15} g C/year[1].

The fate of the EP flux that enters the mesopelagic layer, which extends between 100 and 1000 m depth, is also poorly understood. A fraction of EP undergoes bacterial degradation, releasing nutrients and consuming oxygen as it sinks. The remainder can either be transferred up the detrital food web, ultimately sustaining fisheries[2], or reach the ocean bottom layers and the sediment, sequestering carbon over centennial to millennial time scales. Climate-driven shifts between these competing pathways can have important impacts on mesopelagic fisheries[2] and feed back into the accumulation of atmospheric greenhouse gases[1,3]. Unfortunately, uncertainty in EP is large enough to confound the estimation of anthropogenic carbon uptake by the oceans (about 2 x 10^{15} g C/year)[4] in climate change projections.

EP is strongly controlled by the structure and productivity of the upper ocean ecosystem[1,5]. At high latitudes, intense wintertime stirring replenishes each year the upper ocean with nutrients from deeper layers. As soon as light levels are sufficient, strong phytoplankton blooms dominated by large cells (diatoms) start to form in late winter and spring. At the peak of the bloom, intense herbivorous predation and aggregation of phytoplankton cells pack organic material into large and fast-sinking particles. This produces a short and intense export event[1,5], further enhanced by the ballasting effect of the mineral shells that cover diatoms. Nutrient exhaustion, cell mortality and sinking eventually decrease phytoplankton biomass to background levels dominated by small cells.

The classical view of the biological carbon pump, described above, emerged during the late sixties and the seventies, when sediment traps were the only measurement technique at hand to quantify vertical fluxes of *particulate organic matter* (POC) (complemented afterwards with radiochemical methods). Nowadays, it is widely recognized that these estimates are plagued by uncertainties[6] and biased towards a short period of the seasonal cycle[7]. Therefore, the classical paradigm is being challenged from different perspectives: budget calculations suggest that additional POC sources are needed in order to sustain mesopelagic bacterial respiration rates[6] and fish biomass[2]; new observation technologies like satellites[8] and autonomous floats[7–9] (ARGO) are being used to study EP with high spatial-temporal resolution, showing that significant POC export can take place at different times of the year; and genomic analyses are revealing the potential contribution to EP of unexpected organisms[10].

Recent observations suggest that POC export can occur through a wider variety of mechanisms, like the *seasonal mixed layer pump*[8,11] and *intermittent mixing and blooming dynamics*[7,12] (as opposed to single large export events). These additional mechanisms emphasize the role of small slow-sinking particles[8,11] and the global importance of low-biomass high-export regimes[7,9,12]. Since current biogeochemical models were validated using a small set of observations[1,3,5], their ability to capture EP dynamics over the full seasonal cycle[1], and the mesopelagic processing of slow-sinking particles, remains largely unexplored.

Current models predict that global EP will decrease by 7–18% during the 21st century[3], and attribute this trend to a reduction in NPP caused by a decrease in nutrient supply. Yet, the predicted global trend is convolved with a complex spatial response, whereby EP decreases strongly in the North Atlantic and increases in the Southern Ocean[1,3] (these regions together contribute about one third of the global EP). This hemispheric asymmetry can alter global productivity patterns by changing nutrient delivery through mesopelagic waters. While the physics driving these changes are being intensively investigated, the spatial-temporal response of the biological carbon pump remains highly uncertain[1,3]. The **objectives** of the ORCAS project are to **(1) validate a state-of-the-art biogeochemical model against novel high-resolution EP data sets, (2) understand the operating mechanisms and formulate improved parameterizations for EP and POC processing,** and **(3) implement the new formulation to constrain the predictions of oceanic EP under climate change scenarios for the 21st century**. The project is divided in three work packages (WP):

WP1. Producing annual time series of EP and related processes from biogeochemical (bio-) ARGO floats. Bio-ARGO floats profile the upper ocean between the surface and 1000 m depth every few days and over the entire seasonal cycle. Besides temperature and salinity, which define water masses, they measure several variables that can be used to understand the biological carbon pump[7,9], including nitrate, oxygen, light, chlorophyll fluorescence and particle backscatter (a proxy for POC); backscatter and chlorophyll can be combined to deduce the relative abundance of large and small phytoplankton. In WP1 I will lead the processing of bio-ARGO data, obtained through collaboration with the team of Hervé Claustre (http://www.oao.obs-vlfr.fr/web/), to produce more than 100 vertically resolved annual time series of EP, NPP and related parameters over representative areas of the Global Ocean.

WP2. Modeling annual time series of EP in 1 dimension. I will run the NEMO-PISCES[13] model in 1D (depth), forcing it with observed physical data, and analyze its ability to reproduce the seasonal cycles of EP derived from bio-ARGO float observations (WP1), as well as the underlying mechanisms. Since the floats drift with the currents, they sample a coherent water mass over time. This simplifies the study of ecosystem processes by reducing them to the dominant vertical dimension, minimizing the interference from horizontal transport. The PISCES[13] biogeochemical model has a state-of-the-art representation of planktonic food webs and size-resolved POC sedimentation schemes. I will test a range of available model configurations[13] and develop new ones to achieve the best fit to observations. This will lead to significant improvements of the particle export and degradation schemes used in the current generation of biogeochemical models (*output of WP1+WP2: article #1*).

WP3. Modeling historical and future Global Ocean EP in 3 dimensions. I will run ocean-only 3D model simulations relaxed towards observed physical data while letting PISCES free to compute the solution of biogeochemical processes. I will perform four alternative model runs, resulting from the combination of two spatial resolution levels and two PISCES configurations (standard and improved —WP2). This will allow testing whether enhanced model skill results from higher spatial resolution (known to improve the representation of ocean physics), from an improved PISCES model, or both. I will validate the simulations against 3D fields of oxygen, nutrients and carbonate system parameters observed by ARGO floats between 2003 and 2017[14], assuming that an improved representation of the biological carbon pump should also improve the prediction of closely related chemical variables. Finally, I will run model projections until 2100 under a climate change scenario[15] using the two PISCES configurations, to evaluate their impact on oceanic EP and its biogeochemical and climatic consequences (*output of WP3: article #2*). WP2 and WP3 will benefit from short stays with the PISCES development team (Olivier Aumont–LOCEAN and Laurent Bopp–IPSL).

Thanks to the outcomes of these complementary work packages, the ORCAS project will lead to a better understanding and prediction of the biological carbon pump, improving a key component of climate models. The capacity to predict climate change brings important socio-economic benefits and is the very aim of the Climate Prediction group led by Virginie Guemas at the Barcelona Supercomputing Center. This group is at the forefront of seasonal-to-decadal climate prediction and includes among its members Dr. Raffaele Bernardello who has extensive expertise in ocean biogeochemical modeling. This guarantees the success of this project, which will leverage my career to become a leader in ocean biogeochemical modeling.

1. Laufkötter, C. *et al*. *Biogeosciences* **13,** 4023–4047 (2016).

2. Irigoien, X. *et al. Nat. Commun.* **5,** (2014).

3. Fu, W., Randerson, J. T. & Keith Moore, J. *Biogeosciences* **13,** 5151–5170 (2016).

4. Le Quéré, C. *et al. Earth Syst. Sci. Data* **7,** 349–396 (2015)

5. Dunne, J. P. *et al*. *Global Biogeochem. Cycles* **19,** 1–16 (2005).

6. Burd, A. B. *et al. Deep. Res. Part II Top. Stud. Oceanogr.* **57,** 1557–1571 (2010).

7. Bishop, J. K. B. & Wood, T. J. *Global Biogeochem. Cycles* **23,** 1–12 (2009).

8. Dall'Olmo, G. *et al*. *Nat. Geosci.* **9,** 820–823 (2016).

9. Johnson, K. S. *et al*. *J. Geophys. Res. Ocean.* **122,** 6668–6683 (2017).

10. Guidi, L. *et al.Nature* 1–16 (2016).

11. Giering, S. L. C. *et al*. *J. Geophys. Res. Ocean.* **121,** 6929–6945 (2016).

12. Bernardello, R. *et al*. *Biogeosciences* **9,** 4233–4245 (2012).

13. Aumont, O. *et al*. *Geosci. Model Dev.* **8,** 2465–2513 (2015).

14. Sauzède, R. *et al. Front. Mar. Sci.* **4,** 1–17 (2017).

15. Stocker, T. F. *et al.* in *Climate Change 2013: The Physical Science Basis.* (eds. Stocker, T. F. et al.) 33–115 (Cambridge University Press, 2013).