surface ocean solas lower atmosphere study

solas event report

Report 30 I July 2023

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 38 - SOLAS Workshop:

Potential role of atmospheric deposition in driving ocean productivity in the Southwest Indian Ocean

04 – 07 October 2022
Gqeberha, South Africa

The western Indian Ocean is one area of the world ocean that is warming particularly fast. This warming is predicted to decrease the ocean's primary productivity in this region, and there is evidence of this occurring already (e.g., Roxy *et al.,* 2016). Such a decrease in primary productivity likely leads to a decrease in fisheries upon which millions of people along the Indian Ocean coast of southern Africa depend (Wilson *et al*., 2021). However, south of Madagascar is one region of the southern Indian Ocean which appears to be behaving rather differently, with large-scale summer algal blooms occurring in some years (see satellite image below). These summer blooms are different in many aspects from the spring blooms, which do also occur in the southern Indian Ocean (Dilmahamod *et al*., 2021).

The drivers of these summer blooms are yet to be understood despite several investigations, and therefore it is not possible to predict what may happen to them in a future warmer world or to develop an appropriate policy response in terms of regional food security. This region lies

In this report

Attendees research profiles

Figure 1: In-person participants of the workshop "Potential role of atmospheric deposition in driving ocean productivity in the Southwest Indian Ocean", 2022, Gqeberha, South Africa. Photo credit: Tara Bonesse.

downwind of an important atmospheric flow transport path from southern Africa and so it has been suggested that atmospheric nutrient inputs may play a role in triggering and/or sustaining these blooms. This suggested role for atmospheric inputs led the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) to endorse and support its working group 38 (WG38) to set up an expert group to consider this atmospheric input issue using a workshop approach they have successfully developed over recent years. (WG 38: Atmospheric inputs to the ocean | GESAMP).

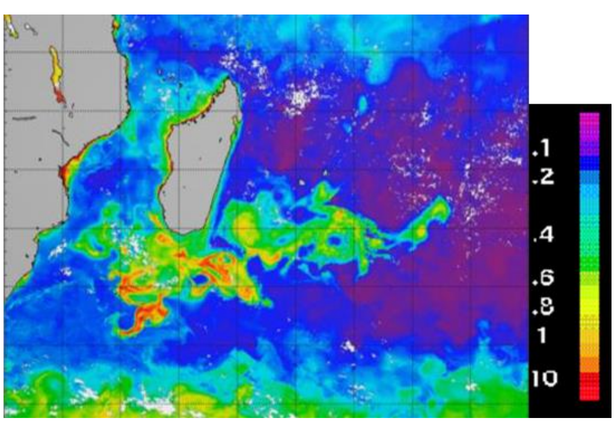

Figure 2: Satellite image of chlorophyll in Madagascar bloom.

From the outset, it was planned that this workshop would also embrace two additional tasks. The first of these was to include an element of capacity building in the form of talks to regionally based students on day one. These students would then, after this introduction, fully participate in the main workshop discussions, learning about the science itself and also the processes by which teams of scientists evaluate complex problems such as the drivers of these blooms. The second additional task involved including within the workshop a final day of interactions with policymakers. In this part of the workshop, the outcome of the previous days scientific discussions would be considered as a case study of adaptive management, and specifically how policymakers and scientists can work together to develop policy responses in the face of inevitable scientific uncertainty.

This workshop was scheduled to take place in Gqeberha (formerly Port Elizabeth), South Africa in 2020, but the restrictions arising from the Covid pandemic led to a series of postponements. It was felt that the capacity building and adaptive management components of the workshop were very important and difficult to deliver in a virtual meeting, and so postponement was preferred to moving the meeting online. The meeting finally took place in October 2022, with most attendees participating in person, although we were able to include a group of virtual participants who could not attend the workshop in person for various reasons. In total, there were 48 participants from 18 countries (see group photo).

Gqeberha in spring proved to be an excellent location for the meeting. The timing of the meeting was deliberately set a few days after the SOLAS Open Science Conference in Cape Town, allowing some participants to participate in both meetings and reduce their carbon footprint. Nelson Mandela University was a generous host on their new ocean sciences campus, with the local arrangements being expertly coordinated by Tara Bonnesse and Ammaarah Abrahams alongside Mike Roberts and his team.

The workshop format worked well. The day one capacity building component comprised contributions on atmospheric and ocean processes at both global and relevant regional scales, and of course, the interactions between them. The following two days involved talks and discussions amongst all the workshop participants to understand both the nature and significance of the summer blooms in this region and also the magnitude and potential impact of atmospheric inputs of nutrients to the blooms. The blooms in this region have only rarely been directly sampled, reflecting the difficulty of mounting major oceanographic cruises in this region and the highly episodic nature of the blooms; some years they occur, and some years do not. Similarly, while there has been quite extensive work on atmospheric transport within the continental South African region in the context of pollution control studies, there has been limited amount of work in terms of sampling downwind over the ocean. Oceanic and atmospheric models and satellite observations, therefore, formed a crucial component of this part of the workshop providing information in regions that have not been extensively sampled. The atmospheric inputs considered both; biomass burning and industrial activity, with the workshop conclusion that the latter were more likely to be important, given the known atmospheric transport paths and the timing of biomass burning emissions.

The workshop concluded that the triggering and sustaining of the blooms could not be easily explained by any single factor but rather the result of several factors periodically aligning to allow the blooms to be triggered and sustained. Atmospheric inputs are likely to contribute to the supply of nutrients to sustain the blooms. The final day of the workshop involved the participants working with a group of regional policymakers discussing the outcomes of the workshop. These were then used as a case study of how policymakers and scientists can work together to develop effective policy interventions when an environmental issue is identified as both potentially very important (when as in this case, for example the food security of millions of people is at stake), but also the scientific understanding of the issue is limited. This kind of interaction of policymakers and scientists was novel for many of the participants and helped them develop a better understanding of both the specific regional issue of the blooms in this region and how to make best environmental policy decisions in the face of uncertainty.

The results of the deliberations from the workshop are now being written up for publications in the scientific literature, with at least two publications anticipated, one focused on environmental sciences and one focused on the discussions of improving interactions between the scientific community and policymakers.

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References

Dilmahamod, F., Penven, P., Aguiar‐González, B., *et al.* (2020). A Model Investigation of the Influences of the South-East Madagascar Current on the South-East Madagascar Bloom *Geophysical Research*: Oceans, *125* (6), e2019JC015761.
https://doi.org/10.1029/2019JC015761

Roxy, M., Modi, Z., Murtugudde, R., *et al*. (2016). A reduction in marine primary productivity driven by rapid warming over the tropical Indian Ocean. *Geophysical Research Letters, 43*, 826-833.
https://doi.org/10.1002/2015GL066979

Wilson, R., Sailley, S., Jacon, Z. I., *et al.,* (2021). Large projected reductions in marine fish biomass for Kenya and Tanzania in the absence of climate mitigation. *Ocean & Coastal Management, 215,* 105921.
https://doi.org/10.1016/j.ocecoaman.2021.105921

Workshop Sponsors

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The South-East Madagascar Bloom – An observational and modeling perspective

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A unique and intriguing aspect of the biologically oligotrophic South-West Indian Ocean is the occurrences of a local sporadic enhancement of primary productivity, known as the South-East Madagascar Bloom (SEMB). This summer bloom is highly variable in space and time, covering ~2 million km^2 at its peak (Figure 3a). Various hypotheses explaining the bloom have been proposed, but none have as yet been clearly substantiated. Given its potential implications and roles in the fishing industry and carbon uptake (Metzl *et al*., 2022), it is essential to understand the drivers of the bloom.

To address these knowledge gaps, we employed an observational approach consisting of in-situ and satellite data, as well as a high-resolution coupled physical-biogeochemical model. The observational analysis of the study resulted in a new hypothesis to explain the onset of the bloom (Dilmahamod *et al*., 2019), which was then tested successfully within a modeling context (Dilmahamod *et al*., 2020).

With an extended ocean colour time-series, a hypothesis-testing model was devised to assess previous theories. Three important findings were unveiled (Dilmahamod *et al*., 2019). (1) Originally proposed to be a contributor to the bloom, a current-driven upwelling south of Madagascar was surprisingly found to be dampened when the SEMB occurs. (2) Moreover, the SEMB seems to coincide with the mature phase of La Niña events. (3) The vertical water mass characteristic hosting high chlorophyll-a (Chl-a) concentration was also investigated and compared to areas of low Chl-a concentration. High Chl-a values occurred within a shallow stratified water mass, with a low-salinity signature in the upper water column (Figure 3b-c). This low-salinity water was hypothesized to originate from the eastern Madagascan coast. Aligning these three findings, a new hypothesis was proposed. The South-East Madagascar Current (SEMC), being stronger and less stable during La Niña events, would favour a detachment from the coast, weakening the current-driven

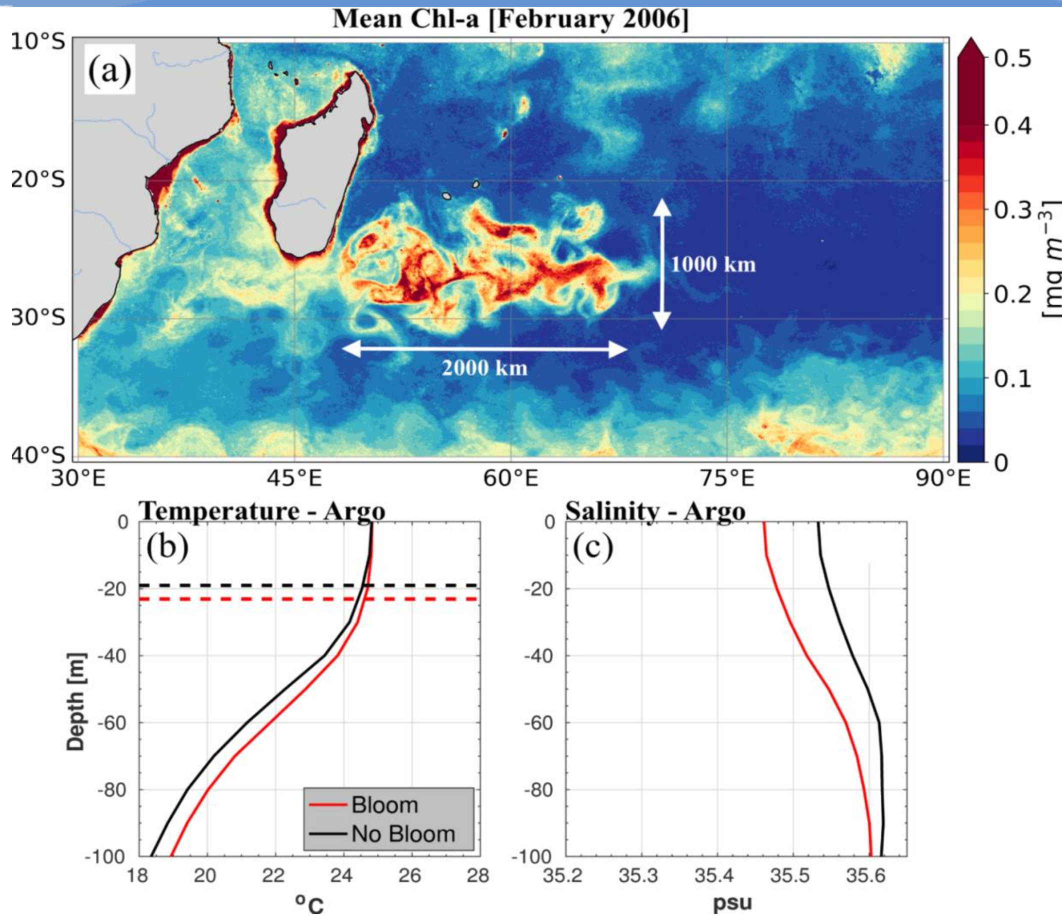

Figure 3: (a) Mean chlorophyll-a concentration in February 2006, from European Space Agency- Ocean Colour -Climate Change Initiative (ESA OCI-CCI) satellite data, (b and c) mean vertical thermohaline structure of the water column associated with bloom (red line) and non-bloom (black line) years; red and black dotted lines indicating the mixed layer depth.

upwelling south of Madagascar. This detachment would bring low-salinity coastal waters into the bloom region, inducing an increase in stratification and, together with excess light availability, providing the right conditions for a cyanobacterial phytoplankton bloom.

To test this hypothesis, a biophysical model based on CROCO-PISCES with a high level of regional specificity (1/12°) was employed. The model was able to reproduce the sporadic nature of the phytoplankton bloom but in the subsurface levels. Additionally, the simulated blooms exhibit similar observational vertical water mass structure, occurring in shallow-stratified spots with low-salinity surface signature. A nutrient flux analysis revealed an input of high-nutrient low-salinity waters being advected from the eastern Madagascan coast, in agreement with the hypothesis proposed. Hence, this new hypothesis, corroborated by the model, suggests that the fertilization of the simulated SEMB occurs concurrently with an early detachment/ retroflection of the SEMC (Figure 4a) (Dilmahamod *et al.,* 2020).

This newly proposed variability of the southern extension of the SEMC was later investigated, revealing three extensions, namely an early retroflection, a canonical retroflection and no retroflection (Ramanantsoa *et al.*, 2021). The early retroflection cases occurring in austral summer confirmed this fate of the SEMC as a contributor to the sporadic SEMB (Figure 4b).

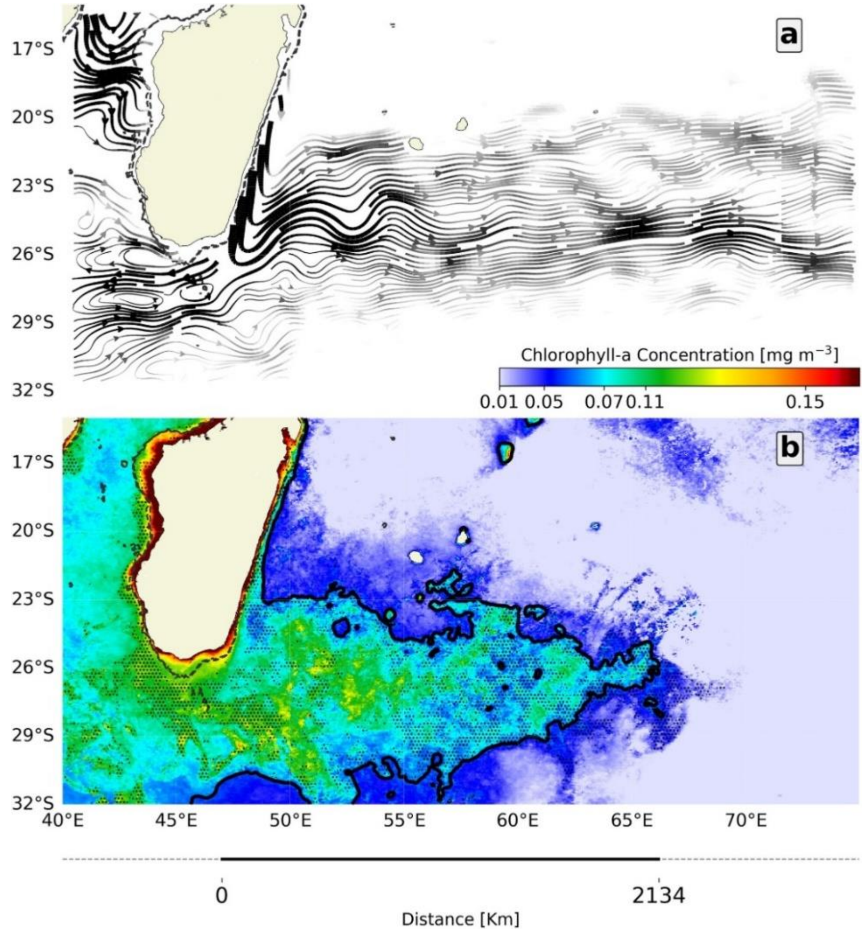

Figure 4: Connection between the South-East Madagascar Current (SEMC) retroflection and the SEMB, with (a) composite of surface current directions during SEMC retroflection periods, and (b) composite period of chlorophyll-a concentration during periods of SEMC early retroflection occurrences in austral summer (from Ramanantsoa *et al*., 2021).

References

Dilmahamod, A. F., Penven, P., Aguiar - González, B., *et al.* (2019). A new definition of the South-East Madagascar bloom and analysis of its variability. *Journal of Geophysical Research: Oceans, 124*(3), 1717-1735. https://doi.org/10.1029/2018JC014582

Dilmahamod, A. F., Penven, P., Aguiar-González, B., *et al.* (2020). A Model Investigation of the Influences of the South-East Madagascar Current on the South-East Madagascar Bloom. *Journal of Geophysical Research: Oceans, 125*(6), e2019JC015761. https://doi.org/10.1029/2019JC015761

Metzl, N., Lo Monaco, C., Leseurre, C., *et al.* (2022). The impact of the South-East Madagascar Bloom on the oceanic CO_2 sink. *Biogeosciences, 19*(5), 1451-1468. https://doi.org/10.5194/bg-19-1451-2022

Ramanantsoa, J. D., Penven, P., Raj, R. P., *et al.* (2021). Where and how the East Madagascar Current retroflection originates? *Journal of Geophysical Research: Oceans, 126*(11), e2020JC016203. https://doi.org/10.1029/2020JC016203

Tanya Marshall is conducting her doctoral research at the University of Cape Town, South Africa. She is studying ocean biogeochemistry, using nitrate isotope ratios, nutrient stoichiometry and ocean physics. Tanya's research explores nutrient fluxes, particularly nitrogen, in the South Atlantic and Indian Oceans.

Mechanisms of Nutrient Supply to the Surface Waters of the Southwest Indian Ocean

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The Indian Ocean is the least well studied ocean basin. Publications on its biogeochemical functioning are almost threefold less than those of the Atlantic and Pacific Oceans. The southwest Indian Ocean is a highly dynamic region with multiple pathways of circulation converging along the western boundary (Figure 5). Lateral and vertical mechanisms of nutrient supply to the nitrogen-limited surface waters are thus likely important, yet their investigation and impact on regional productivity, remain limited.

The southeast Madagascar bloom (SEMB) is an irregular late summer bloom that can occupy a surface area of ~2,500 km^2 and extends westward into the Mozambique Channel (Dilmahamod *et al*., 2019). The episodic increase in ocean productivity is recorded in the significant elevation in chlorophyll a recorded by satellites. The nutrient sources and mechanisms of delivery to the surface ocean that drive this dramatic open-ocean bloom remain a mystery to the scientific community. Here, we outline the potential lateral and vertical nutrient fluxes that could promote the SEMB.

The Agulhas Current has recently been shown to laterally advect large quantities of nutrients in its subsurface (Marshall *et al*., 2023). While the East Madagascar Current (EMC) is yet to be investigated, elevated nutrient concentrations in its subsurface waters (World Ocean Circulation Experiment, WOCE IO4 data) suggest it too could laterally advect high nutrient loads into the area southeast of Madagascar. Additionally, the ubiquity of eddies in the region, particularly eddy-dipoles that spawn off the EMC, could also facilitate the lateral advection of nutrients from the relatively nutrient-rich current into the open ocean. Lastly, westward propagating tropical cyclones, which peak in frequency in the late summer, could stimulate the SEMB following increased rainfall over Madagascar that enhances runoff with high loads of terrestrially-derived nutrients (Dilmahamod *et al*., 2019) (and references therein).

Mechanisms of vertical nutrient supply could also stimulate the SEMB. In this region, winter- and springtime mixing reaches to 100 m depth (Zhang *et al.,* 2018), thus late-spring mixing could entrain

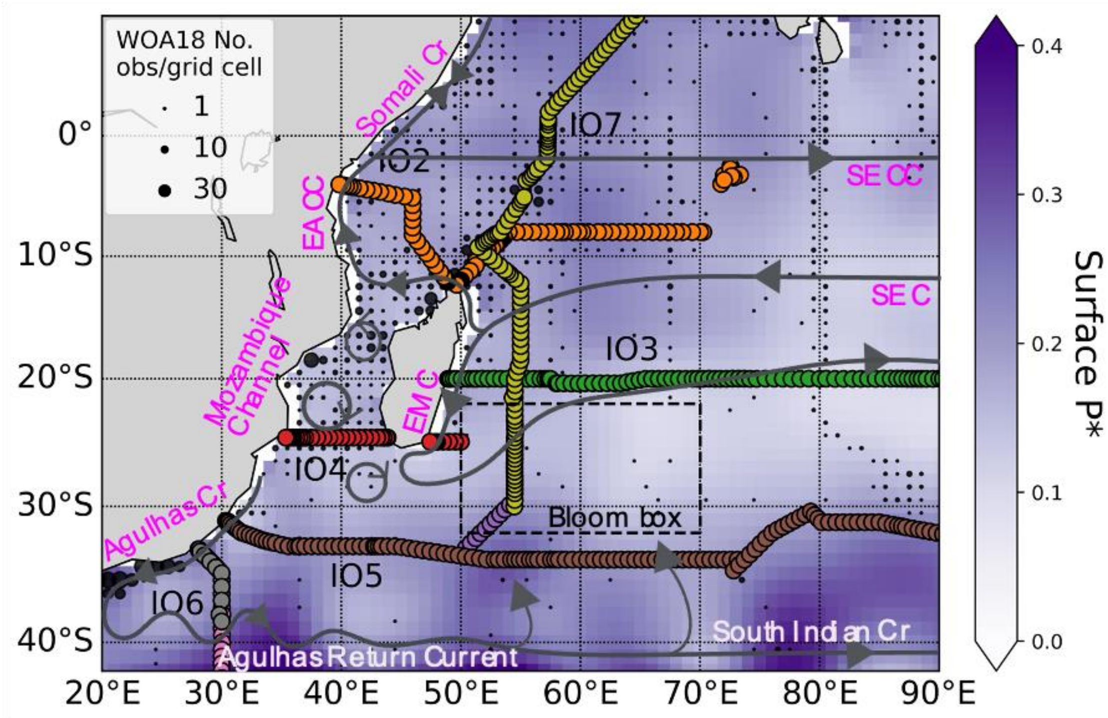

Figure 5: Map of the southwest Indian Ocean with surface P* = [PO_4^{3-}] – 16 x [NO_3^-] as the background colour. The location of multiple World Ocean Circulation Experiment (WOCE) repeat transects are shown as coloured circles on the map. The black points show the World Ocean Atlas 2018 gridded data used to calculate P*.

subsurface nutrients required to fuel the SEMB. Other more episodic events could similarly vertically entrain nutrients into the surface water, such as eddies and cyclones. Nutrients can also be vertically supplied from the atmosphere. Deposition of natural and anthropogenic nutrients, particularly nitrogen and iron, has been observed over this region (Jickells *et al*., 2017; Grand *et al*., 2015), however, their fluxes are likely too small to account for all nutrients required to fuel the bloom. Lastly, N_2 fixation could provide the nitrogen required to alleviate plankton in these oligotrophic surface waters. Observations of diazotrophs (Poulton *et al*., 2007) and surface N_2 fixation rate measurements (Metzl *et al*., 2022) during SEMB events, as well as a recent geochemical estimate of 7-25 TgN.a^{-1} for the greater Agulhas region (Marshall *et al*., 2023) all support the idea that N_2 fixation plays a role in fuelling the SEMB.

While there are numerous potential nutrient sources that fuel the SEMB, quantifying their fluxes and mechanisms of delivery to the surface ocean will require high temporal resolution sampling like that provided by autonomous floats.

References

Dilmahamod, A. F., Penven, P., Aguiar - González, B., *et al.* (2019). A new definition of the South-East Madagascar Bloom and analysis of its variability. *Journal of Geophysical Research: Oceans, 124*, 1717-1735. https://doi.org/10.1029/2018JC014582

Grand, M., Measures, C., Hatta, *et al.* (2015). The impact of circulation and dust deposition in controlling the distributions of dissolved Fe and Al in the south Indian subtropical gyre. *Marine Chemistry,176*, 110-125. https://doi.org/10.1016/j.marchem.2015.08.002

Jickells, T. D., Buitenhuis, E., Baker, AR., *et al*. (2017). A reevaluation of the magnitude and impacts of anthropogenic atmospheric nitrogen inputs on the ocean. *Global Biogeochemical Cycles, 3*, 6868. https://doi.org/10.1002/2016GB005586

Marshall, T. A., Sigman, D. M., Foreman, A., *et al.* (2023). The Agulhas Current transports signals of local and remote Indian Ocean nitrogen cycling. *Journal of Geophysical Research: Oceans, 128*. https://doi.org/10.1029/2022JC019413

Metzl, N., Lo-Monaco, C., Leseurre, C., *et al.* (2022). The impact of the South-East Madagascar Bloom on the oceanic CO_2 sink. *Biogeosciences, 19*(5), 1451–1468. https://doi.org/10.5194/bg-19-1451-2022

Poulton, A., Stinchcombe, M., & Quartly, G. (2009). High numbers of Trichodesmium and diazotrophic diatoms in the southwest Indian Ocean. *Geophysical Research Letters, 36*. https://doi.org/10.1029/2009GL039719

Zhang, Y., Xu, H., Qiao, F., Dong, C. (2018). Seasonal variation of the global mixed layer depth: comparison between Argo data and FIO-ESM. *Frontiers of Earth Science, 12* (1), 1-13. https://doi.org /10.1007/s11707-017-0631-6

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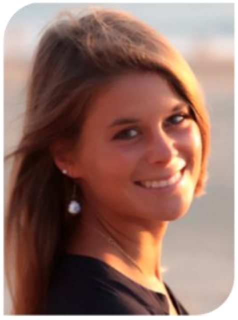

Morgane M.G. Perron completed a PhD (2020) and a 2-year post-doctoral position at the Institute for Marine and Antarctic Studies, University of Tasmania, Australia. She then moved to Brest, France, to continue her work on the solubility of atmospheric trace metals over the Southern Hemisphere oceans.

Constraining the ORganic Speciation of Atmospheric IRon (CORSAIR)

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Photosynthesis by marine primary producers is responsible for the fixation of atmospheric carbon dioxide (CO_2) and its sequestration to the ocean interior in regions of deep-water formation like the Southern Ocean (Boyd *et al*., 2000). Paradoxically, the growth of phytoplankton in the Southern Ocean is drastically limited by the availability of the trace metal (Fe) (Martin *et al*., 1990). Iron is mostly available to phytoplankton in its dissolved form (dFe < 0.2 <m), yet the metal is poorly soluble in seawater. Complexation of Fe with organic ligands (Fe_{org}) in surface water is a key mechanism which maintains oceanic dFe concentrations well above its inorganic limit of solubility. It is estimated that 99% of dFe in seawater is associated with organic ligands (Whitby *et al*., 2020).

In the geological past, increased atmospheric deposition of Fe-rich dust to the Southern Ocean could have stimulated phytoplankton photosynthesis, resulting in a significant drawdown of atmospheric CO_2 (Watson *et al*., 2000). Our work on the 2019-2020 unprecedented Australian fires also demonstrated that fire emissions can also relieve Southern Ocean productivity limitation in the present time (Tang *et al*., 2021; Perron *et al*., 2022). The soluble fraction of Fe (SFe) delivered to seawater by aerosols (dry deposition) and rainwater (wet deposition) determines the ability of marine biota to assimilate the metal for growth. However, the variety of leaching protocols used to date to assess aerosol Fe solubility results in a poor understanding of the biogeochemical form in which aeolian SFe is supplied to marine phytoplankton. This also creates significant uncertainty in aeolian SFe databases (Perron *et al*., 2020).

The atmosphere and the ocean contain organic ligands, which may assist the formation of soluble Fe_{org} complexes in the atmosphere as well as following atmospheric deposition. To date, direct measurement of Fe_{org} was achieved both in rainwater (Cheize *et al*., 2012) and in cloud water (González *et al*., 2022) using Competitive Ligand Exchange adsorptive Cathodic Stripping Voltammetry (CLE-CSV) analysis. Both studies shed light on the importance of organic complexation for controlling the bioavailability

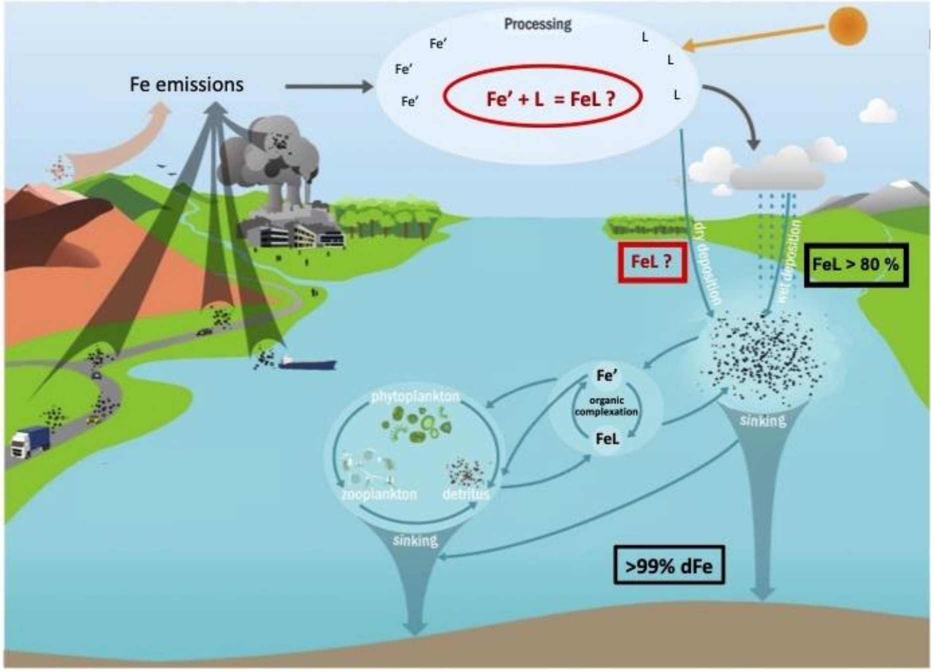

Figure 6: The Constraining the ORganic Speciation of Atmospheric IRon (CORSAIR, Drs. Perron, Bucciarelli and Sarthou) project, addressing the organic speciation of Fe in dry deposition (figure adapted from Ito *et al*. 2021).

aeolian Fe to marine ecosystems as they found that over 80% of Fe contained in wet deposition was present as Fe_{org}. To date, no study has reported direct measurements of Fe_{org} in dry atmospheric samples.

The Constraining the ORganic Speciation of Atmospheric IRon (CORSAIR, Drs. Perron, Bucciarelli and Sarthou) project aims at developing a new CLE-CSV method for performing direct quantification of the organic speciation of Fe in aerosol samples (Figure 6). Measurements of Fe_{org} in atmospheric samples (wet and dry deposition) will be compared to operationally defined SFe measurements (leaching schemes) in order to refine the global understanding of the bioavailable fraction of Fe in aerosols. Once established on coastal samples, this approach will be applied to atmospheric samples collected over the Southern Ocean in the south of South Africa, where the data coverage is currently very poor (collaboration with Stellenbosch University).

References

Boyd, P. W., Law, C. S., Abraham, E., *et al.* (2000). A mesoscale phytoplankton bloom in the polar Southern Ocean stimulated by iron fertilization. *Nature, 407,* 695-702. https://doi.org/ 10.1038/35037500

Cheize, M., Sarthou, G., Croot, P. L., *et al.* (2012). Iron organic speciation determination in rainwater using cathodic stripping voltammetry. *Analytica Chimica Acta, 736,* 45-54. https://doi.org/10.1016/j.aca.2012.05.011

González, A. G., Bianco, A., Boutorh, J., *et al.* (2022). Influence of strong iron-binding ligands on cloud water oxidant capacity. *Science of the Total Environment, 829*, 154642. https://doi.org/10.1016/j.scitotenv.2022.154642

Ito, A., Ye, Y., Baldo, C., & Shi, Z. (2021). Ocean fertilization by pyrogenic aerosol iron. *npj Climate and Atmospheric Science, 4,* 30. https://doi.org/10.1038/s41612-021-00185-8

Martin, J., Gordon, R., & Fitzwater, S. (1990). Iron in Antarctic waters. *Nature, 345,* 156-158. https://doi.org/10.1038/345156a0

Perron, M. M. G., Meyerink, S. W., Corkill, *et al.* (2022). Trace elements and nutrients in wildfire plumes to the southeast of Australia. *Atmospheric research, 270,* 106084. https://doi.org/10.1016/j.atmosres.2022.106084

Perron, M. M. G., Strzelec, M., Gault-Ringold, M., Proemse, B. C., Boyd, P. W., & Bowie, A. R. (2020). Assessment of leaching protocols to determine the solubility of trace metals in aerosols. *Talanta, 208,* 120377. https://doi.org/10.1016/j.talanta.2019.120377

Tang, W., Llort, J., Weis, J., *et al.* (2021). Widespread phytoplankton blooms triggered by 2019-2020. *Nature, 597,* 370-375. https://doi.org/10.1038/s41586-021-03805-8

Whitby, H., Planquette, H., Cassar, N., *et al.* (2020). A call for refining the role of humic-like substances in the oceanic iron cycle. *Scientific Reports, 10*(1), 6144 (2020). https://doi.org/10.1038/s41598-020-62266-7

Watson, A., Bakker, D. C., Ridgwell, A. J., Boyd, P. W., & Law, C. S. (2000). Effect of iron supply on Southern Ocean CO_2 uptake and implications for glacial atmospheric CO_2. *Nature 407,* 730-733. https://doi.org/10.1038/35037561

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