Working group proposal submitted to SCOR

AEROS

Atmospheric aerosol deposition as forcing factor for microbial ecology and biogeochemistry in the ocean

1. Summary

Mineral dust, sea spray, combustion black carbon rich and volcano ash particles are among the major global primary aerosols. Their role in climate forcing, e.g. by reducing albedo, or as nuclei for cloud condensation, is well recognized. Aerosols are constantly deposited into the ocean, where they release nutrients and toxins that can significantly influence microbial physiology, diversity and ecology. Aerosols can also increase the density of particles (ballasting), enhancing aggregation and absorbing organic matter, thereby influencing the carbon export into the deep sea. The impact of atmospheric deposition on biogeochemical cycles, and the response of the marine microbial community depend on the trophic status of the system and on the aerosol sources and deposition rates. The AEROS working group initiative strives to: 1) Develop a database of the chemical composition of different aerosol types and their deposition rates to better identify knowledge gaps, and better constrain data for different ocean basins, 2) Establish a best practice booklet on sampling strategies and experiments with aerosols in order to improve the comparability of data, 3) Summarize data on the effects of aerosols on the microbial ecology and biogeochemistry of the ocean and 4) Use the expertise of participants of the WG to move beyond the current focus on specific types of aerosols, and attempt a more holistic approach to understand the effects of aerosols on the microbial ecology and biogeochemistry in the ocean.

2. Scientific Background and Rationale

2.1 Aerosols

The atmosphere contains aerosols (i.e. airborne solid particles and liquid droplets in suspension) of different sources and compositions. Aerosols are significant players in the global climate system, e.g. by affecting the heat budget, increasing albedo and acting as nuclei for cloud formation. Mineral dust aerosols (MDA), volcano ash aerosols (VAA), black carbon rich aerosols (BCA) and sea spray aerosols (SSA) are among the major aerosol components in the atmosphere.

Aerosols can be transported and spread over great distances (http://gmao.gsfc.nasa.gov/animations/aerosols_geos5.mov). The deposited aerosols release abiotic and biotic components into the water column, including material adsorbed during atmospheric transport, thereby affecting the chemistry and biology of the water column. This influences ocean productivity, microbial diversity, biogeochemistry (e.g. carbon and nitrogen uptake and regeneration), toxicity, aggregation and export of organic matter (ballasting). Current data suggest that atmospheric deposition may supply significant loads of bioactive elements and airborne microorganisms to oceanic surface waters (Mayol et al. 2017). The exposure to acidic conditions during gas-aerosol interactions and in clouds and to solar radiation during atmospheric transport increases the solubility of aerosols and exerts selection on airborne microbes (Archer et al. 2019, Caliz et al. 2018, Dien et al. 2017).

It is estimated that between 5 and 50 percent of the mineral aerosols are of anthropogenic origin (Hamilton et al. 2018). Organic and black carbon emissions occur in large amounts in developing regions where extensive biomass and fossil fuel burning occurs seasonally. In some regions, climate change tends to increase wildfires, but land-use and human activity tend to decrease fires, so that there are likely regional changes in BCA in the future

(Andela et al. 2017, Hamilton et al. 2010). Hence it is timely to assess the various roles by which aerosols affect ocean processes.

2.2 Aerosol–microbe interactions: known and potential roles

Microorganisms, i.e. viruses, bacteria, phytoplankton and other single-celled organisms, make up the largest fraction of total marine biomass (Whitman et al. 1998). They are the key biological factors involved in element cycling in the ocean (Moore et al. 2013), playing a crucial role in controlling biogeochemical cycles, ecosystem functions, and climate change (Kirchman 2000; Kirchman 2010; Gasol and Kirchman 2018). Aerosol deposition can impact the microbial food web and biogeochemical cycles in various ways, by releasing nutrients, toxins, airborne microbes, viruses, or through ballasting of organic particles.

There are large physical and chemical differences within and between each type of aerosol. Sea-borne organic material and microorganisms are horizontally transported with SSA, whereas with MDA, VAA and BCA, organic matter and microorganisms either from terrestrial origin or absorbed during horizontal transport in the atmosphere are deposited in the ocean. Aerosol deposition varies strongly with seasonal and geographical scales, which can potentially result in complex responses of planktonic microbial communities.

Since iron is associated with MDA, BCA and VAA (Myriokefalitakis et al. 2018, Ito et al. 2019), aerosol deposition is linked to the iron hypothesis, i.e. that phytoplankton growth and many microbial processes are limited by iron in large so-called high-nutrient low-chlorophyll (HNLC) areas (Boyd et al. 2007; Smetacek and Naqvi 2008). It is assumed that release and total deposition rates of bioavailable iron from VAA are possibly of similar importance compared to MDA (Olgun et al. 2011, Weinbauer et al. 2017). VAA deposition from volcanic eruptions can induce anomalously large blooms of diatoms and increase bacterial diversity and activity in HNLC regions (Hamme et al 2010, Zhang et al. 2017). Manganese, phosphorus and ammonia deposition by aerosols could also be important in some oceanic areas especially in low-nutrient low-chlorophyll (LNLC) regions for which such a nutrient addition could be of crucial importance. Such an area is the ultra-oligotrophic Mediterranean Sea which receives high quantities of MDA from the adjacent Sahara desert (Guerzoni et al. 1999). Large scale mesocosm experiments have shown the importance of atmospheric deposition for the vulnerable Mediterranean ecosystem (Guieu et al. 2014; Pitta et al. 2017). Basin scale correlation approaches also show an influence of aerosol deposition on chlorophyll in the Mediterranean (Gallisai et al. 2014; Gallisai et al. 2016).

Aerosols may also contain toxic metals and toxic organic compounds which can potentially influence phytoplankton. Furthermore, freshly produced sea-spray aerosol contains bacterial enzymes active in cleaving proteins, sugars, lipids and phosphorus rich compounds further coupling the oceanic and atmospheric biogeochemistry. Changes in organic matter quality and quantity due to phytoplankton blooms followed by bacterial enzymatic degradation influences chemical properties of SSA and therefore the process of cloud formation, which can be considered as a feedback process of aerosol deposition in the ocean.

MDA and BCA deposition are sources of bioavailable organic carbon (absorbed during atmospheric transport), and it has been shown both *in situ* and in the lab that this organic matter can stimulate bacterial abundance and respiration (Romero et al. 2011, Marín-Beltrán et al. 2017, 2019). Observation and experiments suggest that marine organic matter such as transparent exopolymeric particles (TEP) and microorganisms can become rapidly associated to MDA, VAA and BCA. This aggregation enhances bacterial production. In studies with MDA and VAA, the role of aerosols as particles is typically neglected, i.e. only release rates are considered, although particles and particle associated processes are crucial for the understanding of the ecology and biogeochemistry of the ocean. Previous studies suggest that aerosol deposition causes shifts in biodiversity (e.g. Hamme et al 2010, Zhan et al. 2017). The matrix and material of aerosols could, for example, provide niches for microorganisms, hence sustaining overall diversity. Larger particles sink faster than smaller ones, hence the role of particles will strongly depend on particle size distributions.

Owing to their high density, aerosols deposited into the ocean and aerosols attached to organic particles can sink out of the euphotic zone and transport organic matter and attached microorganisms into the deep sea (ballasting). This could affect the fate of organic matter. Export into the deep ocean represents an aerosol link to the biological pump (lithogenic pump, for MDA and VAA; black pump for BCA).

The stimulation of massive phytoplankton blooms by VAA deposition events causes the production (P) to respiration (R) ratio to be shifted towards autotrophy (P:R > 1). Current knowledge suggests that BCA deposition stimulates bacterial production, but not primary production (citation). Therefore, the findings suggest a shift toward autotrophy by VAA (P:R > 1), and shifts toward heterotrophy by BCA (P:R < 1). For MDA, the most thoroughly studied aerosol, the response depends on the degree of oligotrophy (Marañón et al. 2010), and for VAA a concentration effect was observed (Weinbauer et al. in preparation).

Anthropogenic material in the atmosphere such as metals, organic compounds, nano-particles and plastic particles (Kuznetsova et al. 2005; Thompson et al. 2009), and SSA, a significant, marine-borne aerosol, can interact with MDA, VAA and BCA. The effects of these aerosols on microbial plankton communities are poorly studied, and represent an additional future avenue for the study of aerosol–microbe interactions. Sea-borne organic material and microorganisms are horizontally transported with SSA, whereas with MDA, VAA and BCA, organic matter and microorganisms either from terrestrial origin or absorbed during horizontal transport in the atmosphere are deposited in the ocean.

2.3 Why a SCOR Working Group?

Although there are initiatives to address ocean-atmosphere studies such as SOLAS or GESAMP, here are not many (in space or in time) direct deposition measurements, and besides some cruise samples, none over the ocean, and especially time series are missing (e.g. Baker et al. 2007). Some time series exit from islands, which always also include local sources. Extensive data can be calculated from air quality measurements but variability in actual settling velocities (needed to get the deposition measurements) are a challenge (not only for wet vs. dry deposition) and again only coastal or island data are available. There is also the issue that the local sources are typically not resolved, although they can sometimes be filtered out using wind direction. Satellite data can give the concentration in the air column, but again obtaining actual deposition from it remains challenging.

Since atmosphere and ocean sciences are different disciplines, and there is very little interdisciplinary overlap, we lack a combined approach to this research and consensus in the methods used. This prevents us from reaching a holistic understanding of the impact of aerosols on marine microbial communities and marine primary production, which is responsible for about 50% of global primary production. The main goal of AEROS is to compile data to enable the comparison of the effects of different types of aerosols on marine microbial ecology and biogeochemistry, and prepare guidelines for future research, thus linking atmosphere with ocean sciences, and (bio)geochemistry with microbiology. Such an endeavor transgresses typical national projects, and calls for an international collaboration. As global change intensifies aerosol production (potentially even for VAA; (Brothers et al. 2013)), a comparative assessment of the effects of aerosol deposition is imperative for understanding the future ocean.

3. Terms of Reference

ToR1. To establish a database on deposition rates of different types of aerosols.

ToR2. To evaluate sampling strategies and experimental approaches for aerosols.

ToR3. To evaluate the role of different types of aerosols in the marine food web, and their potential impact on biogeochemical cycles.

ToR4. To assess the impact of aerosols along trophic gradients and along gradients of aerosol deposition rates.

ToR5. To come up with a global assessment of the combined role of aerosols on the ocean.

The ToR will be met by:

* **ToR1** will be realized establish a long-lasting data base e.g. to the BCO DMO in the USA.

* **ToR2** will be realized by writing a best practice paper (for example an L&O eBook or SCOR booklet) on sampling, experiments and specific analyses. This will include solids and soluble fractions analyses as well as microorganisms.

* **ToR3** and **ToR4** will be realized by writing a review paper comparing the role of different aerosols in the food web, and evaluating their potential impact on biogeochemical cycles along with guidelines for future needs.

* **ToR5**: The AEROS WG will also try to come up with a global assessment of the combined role of the effect of different aerosols. If this is not possible, e.g. due to the lack of comprehensive data, we will strive to define the knowledge gaps needed to be overcome in order to allow for such an assessment.

4. Working plan

We will convene annual meetings over the next three years (upon funding by SCOR), together with regular email exchange and online meetings to achieve the goals listed above.

The main activities for the work plan are

1. A data base will be developed on the variability of deposition rates of aerosols to better identify knowledge gaps and better constrain data for different ocean basins. This is a necessary step to evaluate the combined effects of aerosols on the microbial ecology and biogeochemistry of the ocean.
2. In addition, aerosols are also subject to strong temporal and spatial variations. We will try to constrain this variability or at least define knowledge gaps.
3. In order to improve the comparability of data, we will publish a best practice eBook.
4. The expertise of the participants of the WG AEROS is needed for a holistic approach. A first brief attempt has been made (Weinbauer et al. 2017) but needs to be extended and expanded.

Timeline

Year 1:
First WG meeting (e.g. during the Aquatic Sciences Meeting in 2021)

*Details on the data base will be discussed and the tasks will be distributed.
*The general structure of the paper on best practices will be discussed, and writing tasks will be assigned.
*The general structure of the review paper will be discussed and writing tasks will be assigned.

Year 2:
Second WG meeting (e.g. During the EGU meeting 2022)

*Progress reports on the database and the publications will be discussed within the WG.
*This year is mainly devoted to paper writing.

Year 3:
Third WG meeting (e.g. During the Aquatic Sciences Meeting 2023)

*In this meeting, we will submit a special open session on the effect of aerosols deposition on microbial ecology and biogeochemistry in the ocean. We envision a special issue that will include the presentations of this session.
* The discussions of WG meetings and compilation of different parts already written will be synthesized to obtain a first draft of the review paper.
* Future collaborative proposals will be discussed

5. Deliverables (Max 250 words)

A database with information on aerosol' impact on ocean processes will be established.
A best practices eBook with open access will be compiled.
A review paper will be published in an open access journal reviewing the effects of aerosols on marine microbial ecology and biogeochemistry and their combined impact for the future ocean.

Organize short meetings during large meetings such as AGU, EGU, ASLO. In addition, full meetings will be organized before or after these meetings to allow a stronger representation by associate members and other participants of these larger meetings. The meetings will in part be restricted to AEROS WG members and in part open to others.

To expose the AEROS WG and SCOR in general to a larger audience, social media will be used, and the review paper will be adapted to a more general audience.

6. Capacity Building

The SCOR WG is balanced with respect to gender (11 females, 9 males) and career stage, and diverse in terms of geographic representation (two full members and one associate member from Africa and South America). Its members are experts in atmospheric chemistry, biogeochemistry, viral and microbial oceanography, allowing for an interdisciplinary scientific dialogue.

The SCOR Working Group will actively help building capacity by funding participants from developing nations as well as early-career scientists to attend workshops and working with the community to leverage further funding from other sources.

7. Working Group Composition

Full members

Name	Gender	Place of work	Expertise
Markus G. Weinbauer (Co-chair)	M	Laboratoire d'Océanographie de Villefranche (LOV), **France**	Effect of black carbon on viral microbial diversity and food web dynamics; viral and microbial oceanography
Koji Hamasaki (Co-chair)	M	Atmosphere and Ocean Research Institute (AORI), Univ. Tokyo, **Japan**	Microbial oceanography; bacterial diversity and functions in relation to biogeochemical cycles
Renato Carreira	M	Pontifical Catholic University of Rio de Janeiro (PUC-Rio), **Brasil**	Lipid biomarkers and isotopic composition in marine organic biogeochemistry and paleoceanography
Linn Hoffmann	F	University of Otago, Dunedin, **New Zealand**	Marine phytoplankton eco-physiology, effect of trace metals on phytoplankton production and community composition

Maria Kanakidou	F	Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, Heraklion, **Greece**	Atmospheric deposition of aerosols, nutrients and trace gases and their variability driven by emissions, climate and atmospheric chemistry
Hongbin Liu	M	Department of Ocean Science, Hong Kong University of Science and Technology, **Hong Kong**	Effect of dust of different sources on the microbial food web dynamics, with particular focus on community and functional changes using molecular approaches
Francesca Malfatti	F	Department of Life Science, University of Trieste, **Italy**	Marine microbial ecology, marine aerosol microbiology, marine microscale biogeochemistry, marine organic matter cycling
Adina Paytan	F	University of California Santa Cruz, **USA**	Biogeochemistry, effect of atmospheric deposition on ocean biogeochemistry
Paraskevi Pitta	F	Institute of Oceanography, Hellenic Centre for Marine Research, Heraklion, Crete, **Greece**	Structure and function of pelagic microbial food webs in oligotrophic environments: from viruses to ciliates, effects of atmospheric deposition on the ultra-oligotrophic Mediterranean, ciliate mixotrophy, field work, mesocosm experiments
Miri Trainic	F	Weizmann Institute of Science, Department of Earth and Planetary Sciences, **Israel**	Sea spray aerosol and cloud properties as a function of phytoplankton ecology and anthropogenic pollution in the ocean

Associate Members

Name	**Gender**	**Place of work**	**Expertise**
Zanna Chase	F	Institute for Marine and Antarctic Studies, University of Tasmania, **Tasmania**	Marine biogeochemistry; quantification of dust deposition to the modern and paleo ocean
Benjamin Guinot	M	Laboratoire d'Aérologie, CNRS, Université Toulouse III, **France**	Aerosol collection, aerosol sources and aging, black carbon, bioaerosols
Cui Guo	F	Ocean University of China, Qingdao, **China**	Effect of east Asian aerosols on diversity and function of bacteria and phytoplankton; biological oceanography and microbial ecology
Yoko Iwamoto	F	Graduate School of Integrated Sciences for Life, Hiroshima University, **Japan**	Physical and chemical measurement of atmospheric aerosol, atmosphere-ocean link of biogeochemical cycles between the atmosphere and the oceans, interaction between atmospheric aerosols, clouds, and precipitation.

Sekou Keita	M	University Peleforo Gon Coulibaly, Korhogo, **Ivory Coast**	Measurements of atmospheric compounds, emission factor and emission inventory development, modelling of atmospheric pollution and its impacts
Natalie Mahowald	F	Department of Earth and Atmospheric Sciences. Reducing Climate Risk Working Group co-leader for the Cornell Atkinson Center for Sustainability, Cornell University, Ithaca, NY, **USA**	Atmospheric inputs of nutrients into the ocean
Jutta Niggemann	F	Research Group for Marine Geochemistry (ICBM-MPI Bridging Group) of the Institute for Chemistry and Biology of the Marine Environment (ICBM) at the University of Oldenburg, Germany	Sources and fate of dissolved black carbon in aquatic environments; chemical analytics and biogeochemistry of dissolved organic matter, interactions of microorganisms and organic matter
Francesc Peters	M	Institute of Marine Sciences (ICM, CSIC), Barcelona, Catalunya, **Spain**	Atmospheric deposition measurements, effects of natural and anthropogenic aerosols on algal and bacterial production and community composition, marine microbial ecology
Véronique Yoboué	F	Félix Houphouët Boigny University of Abidjan (UFHB), **Ivory Coast**	Atmospheric physics and chemistry: measurements of deposits (dry and wet) and emissions of atmospheric compounds - Study of urban pollution and its impact on health and climate change.
Rui Zhang	M	Key State Laboratory of Environmental Marine Science, University of Xiamen, **China**	Marine viral ecology, volcano ash aerosols

8. Working Group contributions

Renato Careira works on lipid biomarkers and isotopic composition in marine organic biogeochemistry and paleoceanography.

Koji Hamasaki is an expert in marine microbial ecology, especially focusing on bacterial diversity and functions in the process of ocean biogeochemical cycles.

Linn Hoffmann is an expert in marine phytoplankton eco-physiology with a focus on the effect of trace metal additions on phytoplankton growth and community composition.

Maria Kanakidou is an atmospheric chemist with expertise on atmospheric aerosols and deposition of nutrients to the ecosystems and subsequently on climate with emphasis on understanding the impact of human activities.

Francesca Malfatti is a marine microbial ecologist, focusing on small scale biogeochemical processes mediated by bacteria in the ocean and in sea-spray aerosol.

Adina Paytan is a marine biogeochemist with ample experience on the effects of atmospheric deposition on marine phytoplankton with emphasis on in-situ experimental data collection and observations.

Francesc Peters is interested in marine microbes and plankton, especially from dynamic and biogeochemical perspectives. He has worked on temperature effects, turbulence, protistan grazing, nutrients in coastal areas and atmospheric deposition in marine systems. Now getting also interested in polllution, climate change, marine production and planetary and human health.

Paraskevi Pitta is a marine microbial ecologist with an extended experience on the effect of Saharan dust deposition on oligotrophic microbial plankton communities as studied by means of large-scale mesocosm experiments.

Miri Trainic is an expert in aerosol chemistry and optical properties, specializing in sea spray aerosol properties and link to the oceans' microbiological as well as anthropogenic components.

Markus G. Weinbauer is expert in viral ecology and in the effect of black carbon rich aerosols on viral and microbial ecology and diversity.

9. Relationship to other international programs and SCOR working groups

Related work is done in GESAMP WG38, Atmospheric Input of Chemicals to the Ocean http://www.gesamp.org/work/groups/38 and Surface Ocean Lower Atmosphere Studies (SOLAS), especially Theme 3: Atmospheric deposition and ocean biogeochemistry. However, the proposed work will be complementary to GESAMP WG38 or SOLAS theme 3, since it will provide a review the aerosol types impact on the microbial ecology and biogeochemistry of the ocean while GESAMP WG38 until recently was more focused on the impact of atmospheric deposition (gases and aerosols) on the GHG sink/ emissions to/ from the ocean and did not get into much details on microbial ecology. The same holds for SOLAS where microorganisms are rather restricted to their role in biogeochemistry and not in microbial, ecology and diversity.

AEROS is also related to the TARA Oceans expeditions studying marine biodiversity and the Malaspina circumnavigation expedition, an interdisciplinary research project to assess the impact of global change on the oceans and explore their biodiversity. These expeditions did not assess aerosols input as suggested by AEROS.

AEROS will also benefit from previous working groups such as WG 141: Sea-Surface Microlayers, WG 134: The Microbial Carbon Pump in the Ocean, WG 126: Role of Viruses in Marine Ecosystems and WG 120: Marine Phytoplankton and Global Climate Regulation: The *Phaeocystis* spp. Cluster as a Model.

10. Key references

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