Reducing Uncertainty in Soluble aerosol Trace Element Deposition (RUSTED)

SCOR WORKING GROUP PROPOSAL (MAY 2022)

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1. Summary

The availability of iron, and other trace elements (TEs), is central in controlling biological activity and CO_2 sequestration in many ocean regions. Atmospheric deposition provides an external source of TEs to the ocean, but most fluxes are currently poorly understood. To predict how ocean ecosystems respond to changes in soluble TE fluxes, it is vital that models represent and reproduce current TE distributions. This Working Group proposes to bring together a diverse group of experts from the ocean biogeochemistry and modelling communities to focus on assuring the quality of TE solubility data from aerosol leaches and improving the handling of soluble iron in Earth System models. This will be facilitated through the creation of a new, comprehensive database of atmospheric TE measurements taken across the world's oceans, allowing easier evaluation and calibration of global models than is currently possible. This WG is important and timely as the transfer of micronutrients and pollution across the air-sea interface is a current research priority of large international programmes such as SOLAS and GEOTRACES. Furthermore, this WG addresses many challenges laid out in the UN Decade of Ocean Science for Sustainable Development. Capacity building is at the heart of this proposal; the database will be open-access and a proposed workshop–seminar series will be held in India with the aim of widening participation and creating a strong, global network of scientists working at the air-sea interface. A SCOR Working Group is the only practical way to achieve the aims detailed in this proposal.

2. Scientific Background and Rationale

Approximately 50% of primary production occurs in the oceans (Falkowski and Raven, 1997). Iron (Fe) is an essential micronutrient as it is required for carbon (C), nitrogen (N) and phosphorus (P) acquisition by primary producers. However, production is limited over large regions of the ocean due to insufficient Fe availability or due to the scarcity of a combination of two or more micronutrient trace elements (TEs) (e.g., Moore et al, 2013). Thus, the availability of TEs exerts a fundamental control on marine biological activity, from bacterial and primary productivity through to fisheries, thereby supporting marine ecosystem services over various timescales (Martin, 1990; Mahowald et al., 2014; Hamilton et al., 2022).

Large aerosol deposition events can relieve micronutrient (co-)limitation. Following aerosol deposition, new resource competition among primary producers can alter the balance between smaller and larger phytoplankton sizes (Paytan et al. 2009) and between autotrophic and heterotrophic communities (Gazeau et al. 2021), thus influencing the capacity of the ocean to sequester CO_2 (Guieu et al. 2014a). Furthermore, marine microbes exert a climate feedback by altering cloud properties, temperature, and precipitation rates through the production of biological gases. The degree to which autotrophs or heterotrophs are stimulated depends on the physicochemical form in which aerosol-bearing nutrients are delivered to seawater and on the initial biogeochemical conditions of the water column, such as *in situ* nutrient limitation (Guieu et al. 2014b).

Micronutrients, both bio-essential and potentially toxic, are delivered to the surface ocean via wet or dry aerosol deposition (Duce et al., 1991). Aerosols are composed of a dynamic mixture of natural (mineral dust, volcanoes, sea salt, wildfires, secondary organic aerosols) and anthropogenic (industrial and vehicular emissions, fossil fuel burning) particles. The very different chemical compositions and degrees of atmospheric processing of these various aerosol mixtures directly impacts their solubility in seawater and, thus, the ability of biota to assimilate the associated TEs for growth. Mineral dust is proportionally the largest source of aerosols to the global ocean. However, anthropogenic and wildfire aerosols have a greater ability to dissolve in seawater, resulting in the liberation of a larger fraction of bioaccessible TEs, due to several factors including their smaller size (Hamilton et al. 2020; Ito et al., 2020).

The Challenge

A challenge for models is that different ocean regions receive different aeolian inputs, and different phytoplankton respond differently to these inputs. For example, all numerical models over-estimate total Fe concentrations near dust source regions and under-estimate the low concentrations and high solubilities observed over remote ocean regions (Myriokefalitakis et al., 2018). Future changes in climate, land use and industrialisation are expected to alter the composition and magnitude of aerosols deposited to the surface ocean (Tegen et al., 2004; Klingmüller et al., 2016). Improving model predictions of the biogeochemical response to such changes requires a deeper understanding of the key processes controlling aerosol TE fluxes and dissolution rates. For example, recent collaborations between modellers and experimental scientists led to improved understanding of how different aerosol types impact Fe solubility and the biological response (Ito et al., 2020; Tang et al., 2021).

At present, most aerosol solubility data is for Fe. Therefore, this WG will initially focus on improving model parameterisation of soluble Fe, before broadening the focus to other TEs which can help answer questions about, or rule out, the factors influencing Fe solubility (Meskhidze et al. 2019). To achieve this aim, we will bring together experts in experimental procedures to estimate aerosol Fe (and other TE) solubility as well as members from the atmosphere and ocean modelling communities to review the current understanding and identify the most pressing research questions.

A further challenge is that aerosol TE solubility in the ocean cannot be measured directly. Instead, solubility must be estimated from laboratory experiments. As numerous leaching schemes are used, uncertainties are introduced when attempting to relate the solubility back to the environment in which the observation was collected (Shelley et al., 2018; Perron et al., 2020). To compound the problem, there has been very little comparison of the various leaching protocols in use. Leaches following different protocols access slightly different soluble fractions and represent processes on different and undefined timescales, yet models treat all solubility data as equal. It is not known the extent to which the results of different leaches bias model predictions. This lack of standardisation is thought to have hindered accurate representation of soluble aeolian TE fluxes to surface waters (Anderson et al., 2016; Baker et al., 2016; Meskihidze et al., 2019). The urgent need to standardise techniques will be addressed by producing a set of Standard Operating Procedures following the first community intercomparison exercise for aerosol TE solubility.

Why a SCOR proposal?

Much of our current understanding on the relationship between aerosol TE solubility and its availability to marine microbes is operationally defined, but few of these methods have been properly compared. Under the coordination of Mingjin Tang (Associate Member), members of this WG, representing six laboratories across four continents, will undertake a study comparing data from common leaching methods for assessing aeolian TE solubility. This intercomparison study aims to quantify uncertainties resulting from the use of different protocols and will lead to an international consensus on Standard Operating Procedures. The collection of natural aerosols for this intercomparison is underway and does not require funding.

A lack of consent between modelling groups results in large differences in the type and number of observational data included in different models. This hinders comparisons between models which have been calibrated to represent different observationally-defined climatologies. Furthermore, all TE solubility data is treated equally, despite the different leaching schemes representing different environmental processes. This SCOR WG will engage discussion between experts from the observational and modelling communities to best address research questions and understand the data requirements of the two communities. RUSTED will build on the work of FeMIP (WG151), which is coming to the end of its term, via inviting FeMIP Members to participate in RUSTED's meetings. The modelling component of RUSTED will focus on evaluating atmospheric models' representation of soluble aerosol Fe (and other TEs), thereby providing a key link with FeMIP which focused on ocean biogeochemistry.

We propose the creation of a comprehensive database of atmospheric TEs which will allow easier evaluation and calibration of global models than is currently possible from the GEOTRACES and SOLAS data repositories. This database is further motivated by the fact that only a fraction of the community's enormous investment in TE measurements is currently being used by models. The knowledge acquired from the intercomparison will allow the identification of existing biases, thus enabling future model constraints to reduce uncertainty in the prediction of rapidly changing aerosol fluxes on biogeochemical cycles. Guidance will be provided to the modelling community on how to best compile and use spatially and temporally sparse data, especially in regions with minimal data coverage.

Although of interest to the GEOTRACES community, the objectives proposed here address fundamental questions which need resolving but would be challenging to address in the type of process study which national bodies fund. In contrast, SCOR WGs provide the ideal platform for groups of international experts to produce guidance for future research directions and standardisation for methods currently in use. Additionally, GEOTRACES will be drawing to a close around 2025, although spin off programmes (e.g., BioGeoScapes) will continue to focus on fluxes of nutrients and contaminants across the air-sea interface. As many of the membership of this WG have participated in SOLAS and GEOTRACES studies, served on their committees, and contributed data to their data repositories, they are familiar with both programmes and believe that a SCOR WG is necessary to provide the expert guidance needed for future studies of deposition fluxes across this important interface.

The outputs of this SCOR working group will provide both the foundation and a framework for future proposals to address questions of methodology and biogeochemical cycles (experimental and modelling). Furthermore, because of the far-reaching consequences that changes in the soluble TE deposition fluxes are predicted to have on marine ecosystems, the RUSTED outputs will have broad applicability to different research communities, e.g., climate change, human health, fisheries, and paleoclimate.

3. Terms of Reference (ToR)

ToR1. With a primary focus on Fe, review the past three decades of literature to identify knowledge gaps in relating the physicochemical properties of aerosol micronutrients with their solubility and bioavailability in the ocean. Synthesise data collected into: (1) an open access peer-reviewed research directions manuscript, providing guidance for future research; and (2) a database of soluble aerosol Fe measurements, providing a consistent constraint for models and a spatiotemporal focus for where new observations are most needed.

ToR2. Incorporate the results of the ongoing aerosol TE intercomparison to: (1) recommend a set of Standard Operating Procedures for common leach schemes; (2) publish a manuscript of comparative results for the leach schemes investigated; and (3) assess aerosol TE solubility data produced in the last 20-30 years to inform modellers on how to choose the optimal data for model validation and constraint.

ToR3. Utilise the available data for other aerosol trace elements and aerosol chemical composition to advance our understanding of the solubility of Fe and other biogeochemically-important elements. A synthesis paper of the relationship between aerosol TE concentrations and fractional solubility will be published.

ToR4. Bring together the observational and modelling communities to capitalise on the progress made from ToRs 1-3 to identify ways in which current numerical models can improve their handling of Fe, including impacts beyond ocean biogeochemistry. Address differences between laboratory and model solubilisation schemes, linking to their environmental relevance. Initiate transdisciplinary discussion to identify which micronutrients most require study next and publish the related guidance.

4. Working plan

To deliver **ToR1**, we will focus primarily on Fe. The interdisciplinary experts of the WG will **review the current understanding of aerosol TE solubility**, through the synthesis of recent workshops, three decades of publications, and recent research in under-studied, yet biologically important regions (e.g., Southern Hemisphere and North Indian Ocean). In addition, we will review the language and terminology used by different research communities, resulting in the production of a **glossary of terms**. These actions will culminate in our first publication (to *Biogeosciences*). We aim to reach a wide audience with this review as changes to the magnitude and timing of atmospheric deposition is relevant to several disciplines including marine biogeochemistry, human health and climate. The Fe data will be curated into a database and made immediately available to the community via GitHub. This database will provide a single, concise picture of aerosol Fe distribution and fractional solubility, allowing different numerical models to be constrained in a harmonised way.

Two tasks will be undertaken to deliver **ToR2**: (1) **an intercomparison study using aerosols** (collected in China) to quantify the errors associated with common leach schemes used to estimate aerosol TE solubility. Following on from the Morton et al. (2013) intercalibration for aerosol total digestion methods, this study will be the first to directly compare the results of several leaching schemes performed on the same samples. This work will culminate in a publication in *Limnology and Oceanography: Methods* (open access) and the production of Standard Operating Procedures for common aerosol leaches which will be added as an appendix to the GEOTRACES cookbook (https://www.geotraces.org/methods-cookbook/). (2) **a review and collation of aerosol dissolution studies, undertaken over the past 20-30 years**. In the first year of the WG term, the focus will be on aerosol Fe (thus, contributing towards **ToR1**), but in subsequent years other TE dissolution studies will be reviewed. The solubility data for other species beyond Fe and auxiliary information will be added to the Fe database.

To deliver **ToR3** we will drive discussion on: (1) **how other elements can be used to further our understanding of aeolian Fe solubility** by addressing the (sometimes incorrect) assumption that there is an inverse relationship between aerosol fractional solubility and total atmospheric loading (Baker et al., 2020). This will be achieved by revisiting and expanding Sholkovitz et al. (2012) to include other elements commonly measured simultaneously to Fe. This action will result in a publication in *Atmospheric Chemistry and Physics*. (2) **the use of tracers for aerosol source apportionment**. As aerosol type exerts a strong control on solubility, it is of particular interest to the modelling community to understand ways in which aerosol source can be incorporated into models. Information about caveats and limitations, lack of analytical capabilities, use/misuse of multi-variate statistics and use of isotopic ratios for source apportionment will be provided. A session on this topic will be chaired by WG members at the Aquatic Sciences Meeting 2025. Recommendations will be published on the SOLAS website

A unifying theme of **ToRs 1-3** will be the collection and collation of aeolian TE data for the **aerosol database**.

The delivery of **ToR4** will require the full scope of expertise gathered in this WG. As few numerical models include essential micronutrient elements other than Fe, how to **extend Fe theory to other essential elements** is the focus. Implementation will be guided by the discussions and research priorities identified under ToRs1-3. We propose to use numerical models to highlight areas of the ocean where a better understanding of atmospheric TE solubility could facilitate a better understanding of how the C and N cycles in key/sensitive ocean regions will likely respond to climate change. The Bay of Bengal – Arabian Sea is suggested as the test bed for this sensitivity study as these two regions have similar climates but different atmospheric inputs and hydrographic regimes. The region is the focus of the International Indian Ocean Experiment 2 (IIOE-2). Collaboration with the IIOE-2 will be actively pursued. The outcomes will be used to inform future grant proposals and result in two peer-reviewed papers: 1) Recommendations for efficient inclusion of TEs other than Fe in Earth System models; and 2) description of the relationship between measurements of aerosol solubility in field samples, laboratory simulations and numerical simulation of solubilisation processes.

We plan to hold five WG meetings. In order to stretch the available funding, the first and final meetings will be fully online, and the subsequent ones will coincide with major international meetings and be in hybrid format to maximise participation. We also propose holding a workshop and seminar series in India during year 3.

Months 1-12:

Call for aerosol Fe data contributions.

Nov 2022: Initial online WG meeting to plan ToRs1&2, with reference to ToRs3&4. Database creation will be discussed, resulting in the compilation of a data provider list and agreement on a data use protocol. Other issues to be addressed will include: the allocation of tasks; compilation of a list of external contacts for consultation; and plans for securing additional funding.

Feb 2023: Full WG meeting at ASLO Aquatic Sciences Meeting (hybrid). Members will chair a session on atmospheric deposition of soluble trace elements and isotopes and hold a Townhall to introduce the WG, report early progress towards ToR1&2 targets, and refocus and reassign tasks, if necessary.

Seek co-sponsorship and additional funding from SOLAS, GEOTRACES and other bodies yet to be identified for an early-career workshop and seminar series to be hosted at the National Institute of Oceanography (NIO), India during year 3.

Review and intercomparison papers submitted at the end of year 1.

Standard Operating Procedures for common leaches added to GEOTRACES methods ‘cookbook’.

Month 13-24:

Feb 2024: Full WG meeting at ASLO Ocean Sciences Meeting (hybrid). Members will chair a session on aerosol source apportionment. Townhall for aerosol Fe database soft release.

Continued development of database (e.g., review of aerosol TE dissolution papers, feedback request, call for other TE data for inclusion in the database).

Publish an assessment of aerosol TE solubility data produced in the last 20-30 years, with the aim of allowing modellers to better choose which data to use to validate their models.

Work on ToR2 finalised. Work begins on ToR3. ToR4 task leaders are identified, alongside how to incorporate observations from ToRs1-3 in ToR4.

Month 25-36:

Feb 2025: Full WG meeting at ASLO Aquatic Sciences Meeting (hybrid). Members will chair a session on the impacts of changing soluble TE fluxes to the ocean.

Apr 2025: Early career workshop/seminar series hosted at the NIO, India.

Revisited and expanded Sholkovitz et al (2012) manuscript submitted.

Sensitivity studies on impacts of changes to soluble Fe (TE) inputs.

Month 37-48:

Final online meeting. Will reflect on previous 3-years work and allocate tasks for the final synthesis paper (*Biogeosciences*) and White Paper. Launch of database with a concurrent publication in *Earth System Data Science* to guide external users.

Database online release via co-sponsors, SOLAS/GEOTRACES and other yet to be identified organisations.

5. Deliverables

1. *Eos* article announcing WG.
2. Session and Townhall to introduce the WG at the Aquatic Sciences Meeting, 2023.
3. Review paper on aerosol TE solubility including recommendations and research priorities – and glossary of terms. Delivers ToR1.
4. Aerosol Fe database (soft release at the Ocean Sciences Meeting, 2024). Contributes to ToRs 1-3.
5. Paper on aerosol TE leaching schemes and intercomparison results. Contributes to ToR2.
6. Standard Operating Procedures for aerosol leaches published as Appendix to GEOTRACES cookbook. Contributes to ToR2.
7. Paper assessing aerosol TE solubility data produced in the last 20-30 years. Contributes to ToR2.

8. Session on aerosol source apportionment at the Aquatic Sciences Meeting, 2025. Contributes to ToR3.
9. Paper on the relationship between aerosol TE concentrations and fractional solubility. Contributes to ToR3.
10. Recommendations for aerosol source apportionment. Contributes to ToR3.
11. Paper describing the relationship between measurements of aerosol solubility in field samples, laboratory simulations and numerical simulation of solubilisation processes. Contributes to ToR4.
12. Final synthesis paper including SWOT analysis of what was learned and what the remaining outstanding gaps and challenges are, recommendations for improving the handling of soluble Fe data from observations, handling non-dust aerosols, and TEs other than Fe. Contributes to ToR4.
13. Final release of database of aerosol TEs for external users. Contributes to ToRs 1-3.
14. A White Paper for policy makers which will present the impacts of changing soluble TE fluxes on ocean ecosystems. Contributes to ToR4.

6. Capacity Building

Our vision is that this WG will identify and bridge significant gaps in the current knowledge of nutrient bearing aerosols and their role in marine biogeochemical cycles. The proposed work is designed to build a common research framework that facilitates knowledge transfer between ocean biogeochemistry and atmospheric science communities and stimulate new research proposals and collaborations between established and early-career scientists around the world. This goal is reflected by the proposed multi-disciplinary membership, which is diverse in terms of gender, career stage and geographical representation. We have Full and Associate Members from countries which are developing their scientific capacities, such as India, Argentina and South Africa, who also conduct research in regions which are traditionally understudied. During the term of the WG, we are committed to create at least one opportunity for these Members, or Early Career Researchers (ECRs) from their labs, to pursue a POGO-SCOR Fellowship at an institution with the appropriate analytical and/or computing capabilities. The sensitivity study of ToR4 is an ideal candidate for a POGO-SCOR Fellowship. It is anticipated that future POGO-SCOR Fellowship opportunities resulting from this WG will promote training and capacity building and result in new collaborations well past the conclusion of the WG.

In some respects, the pandemic has provided opportunities and facilitated wider participation in scientific meetings through online and hybrid meeting formats. We therefore propose online meetings at the initiation of the WG and towards the end of the term, and the hybrid format for membership meetings (to coincide with Aquatic/Ocean Sciences Meetings), with members from emerging countries and ECRs encouraged to attend in person. However, we must be cognisant that it is often daunting for ECRs to make their voices heard during online discussions, especially with established researchers. We will take a number of steps to ensure that ECR's voices are heard. For example, discussions will be moderated with students/postdocs asked to comment first, equitable allocation of presentation time at conferences will be scheduled, and we will offer plenty of opportunities for networking in smaller groups (such as break out rooms – physical and virtual) where people at all career stages can get to know each other, and thus promote chances of ECRs feeling comfortable speaking up.

During the first year, we will take advantage of the change in travel funding for SCOR WG meetings to allow Associate Members from developing/emerging countries and ECRs to benefit from travel funding as in-person networking remains vital for generating new ideas and forging new connections. The working group will actively encourage early-career members to chair and host sessions and Townhalls at international conferences related to the group's topic, as well as providing mentoring for them, which will aid their career development (Urban and Boscolo, 2013). An online meeting early in year 4 will be hosted with the purpose of allocating tasks for the final synthesis paper and ensuring that the outputs are disseminated effectively. An ECR will be encouraged to be the lead author.

During the third year, we propose to deliver a 4-day workshop-lecture series on trace elements at the air-sea interface at the National Institute of Oceanography, India. On Day 1, lectures will be delivered in hybrid format. This will allow as many people to contribute and participate as possible. The speakers will be invited to give talks on their area of expertise. The keynote lecture will be broadcast live via YouTube or a similar open-access platform. This will be publicised in advance (via social media and newsletters of SOLAS, SIBER and other organisations) and members of the public may attend online. At the end of the day, there will be an ice-breaker networking opportunity for delegates and speakers. On the second day, an early-career workshop is proposed. Depending on the logistics, the workshop could provide hands-on training in clean room techniques (e.g., aerosol leaches of natural aerosols and reference materials) and sample analysis (using ICP-MS), followed by data handling and deposition flux calculations. As the risk of sample contamination is high and clean room standards will be compromised by high footfall, the WG will investigate novel ways for the delegates to get clean room experience if physical presence is not possible. Ideas under consideration will include, but not be limited to, virtual or augmented reality and digital twinning, as well as in-person practical work. This day will conclude with a poster session and networking. The second networking opportunity is important as it gives delegates more time to formulate their questions and approach the speakers while also showcasing their own research. Thereby providing a greater chance of interactions leading to future work possibilities. On the third day, delegates will get hands-on experience of global climate modelling. On the final day, we propose a career skills development workshop followed by an organised recreational activity to help establish a strong peer network.

Co-sponsorship and additional funding for this workshop-lecture series will be sought from SOLAS, SIBER (Sustained Indian Ocean Biogeochemistry and Ocean Research) and other bodies yet to be identified early in the term of the WG. Collaboration with IIOE-2 and SIBER scientists will be sought as the outputs of this WG (improved parameterisation and data handling of soluble TEs) have broad applicability; particularly under Science Theme 3 of the IIOE-2 (Monsoon variability and ecosystem response) and Science Themes 3 (Controls and fate of phytoplankton and benthic production in the Indian Ocean), 4 (Contrasting physical, biogeochemical and ecological processes in the Arabian Sea and the Bay of Bengal) and 5 (Climate and anthropogenic impacts on the Indian Ocean and its marginal seas) of SIBER. We propose to submit this WG for endorsement by the UN Decade of Ocean Science for Sustainable Development as an Ocean Decade Action as this workshop will be a key component of the submission which addresses Priority Challenges 5 (Unlock ocean-based solutions to climate change), and 9 (Skills, knowledge and technology for all; https://www.oceandecade.org/ challenges/). Event attendance will be prioritised for ECRs and those from emerging and developing countries.

Hosting the workshop-lecture series in India is timely. The Indian Ocean has long been identified as under-studied and a priority for further research. From an atmospheric inputs perspective, the Indian Ocean is of great interest; it receives large inputs from the atmosphere year-round from the various dust source regions proximal to the northern basin, which include the Arabian Peninsula, African continent and Asia. Anthropogenically-derived aerosols from industrial pollution and biomass burning on the surrounding continents are also prevalent, and evident in the brown haze that lingers over the Arabian Sea, Bay of Bengal and southern tropical Indian Ocean. There are specific questions about how the supply of trace elements from the atmosphere impacts carbon and nitrogen cycles. The dominant controls on primary production in the Arabian Sea (i.e., zooplankton grazing versus Fe limitation) remains an active research topic. Furthermore, the Indian Ocean is a globally important denitrification zone, and it also appears to be a region where nitrogen fixation rates are significant (Hood et al., 2009), although patchy and very much under discussion (e.g., Löscher et al., 2020; Saxena et al., 2020).

Running a workshop in this region at this time will have great benefit to the host institution as it will turn the international spotlight onto this under-studied region. It will give the institution the opportunity to showcase its research facilities and provide students and ECRs with networking and mentorship opportunities from international experts working at the air-sea interface. We would also introduce delegates to the near-final version of the database at this event. The benefits will be twofold: delegates will be a valuable source of feedback as well as gaining access to a useful resource before its general release.

Our over-arching goal is that this WG will result in a strong peer network that will facilitate global knowledge transfer and collaborations that will long outlast the term of this WG.

7. Working Group composition

This WG has 10 Full and 10 Associate members that bring together state-of-the-art expertise in experimental methods for the assessment of aerosol TE solubility, Earth System modelling, biogeochemical modelling and aerosol composition which will guide key requirements and shape future directions. The Full Members are responsible for the successful delivery of the objectives of the ToRs. The Associate Members will provide valuable inputs from complimentary fields, e.g., organics in aerosols, uptake and bioaccessibility of micronutrients and dissolution kinetics). Our Full membership represents 9 countries, including two emerging/developing countries (India and Argentina), and has 4 early career members.

7.1 Full Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Rachel Shelley (co-chair)	F	University of East Anglia, UK	Aerosol TE solubility, novel tracers of atmospheric deposition, biogeochemical cycles. Contributed to GEOTRACES Intermediate Data Product (IDP).
2 Douglas Hamilton (co-chair)	Non-binary	Cornell University, USA (moving to North Carolina State University, USA, July 2022)	**Early Career.** Earth System models, wildfire and dust aerosols
3 Morgane Perron (co-chair)	F	GESAMP WG38, France	**Early Career.** Aerosol TE solubility, Southern Hemisphere aerosols, biogeochemical cycles.

			Contributed to GEOTRACES IDP.
4 Hind Al-Abadleh	F	Wilfred Laurier University, Canada	Physical chemistry of aerosols
5 Peter Croot	M	Irish National University, Galway, Ireland	Biogeochemical cycles, metal binding ligands, aerosol TE solubility. Contributed to GEOTRACES IDP. GEOTRACES representative to SOLAS theme 4. FeMIP Associate Member.
6 Diego Gaiero	M	Universidad Nacional de Córdoba, Argentina	High latitude dust, Fe biogeochemistry in Southern Ocean
7 Cassandra Gaston	F	RSMAS/University of Miami, USA	**Early Career.** Atmospheric chemistry, composition and aging of aerosols
8 Akinori Ito	M	JAMSTEC, Japan	Atmospheric Fe modelling
9 Ashwini Kumar	M	CSIR-National Institute of Oceanography, India	Biogeochemical cycles, aerosol TE solubility, Sr and Nd isotopes
10 Ying Ye	F	Alfred Wegener Institute, Germany	**Early Career.** Biogeochemical models, role of Fe and Si in marine biological carbon pump

7.2 Associate Members

Name	Gender	Place of work	Expertise relevant to proposal
1 Holly Winton	F	Victoria University of Wellington, New Zealand	**Early career.** Aerosol chemical composition, biomarkers, dust provenance, TEs in ice cores
2 Andrew Wozniak	M	University of Delaware, USA	Organic composition of aerosols
3 Mingjin Tang	M	Guangzhou Institute of Geochemistry-CAS, China	Aerosol TE solubility
4 Yeala Shaked	F	Hebrew University of Jerusalem, Israel	Uptake of micronutrients, bioavailability, biogeochemical cycling. FeMIP Full Member.
5 Nicholas	M	North Carolina State	Aerosol dissolution, reaction

Meskhidze		University, USA	kinetics
6 Tung-Yuan Ho	M	Academia Sinica, Taiwan	Biogeochemical cycling, biological response to atmospheric deposition
7 Cecile Guieu	F	Laboratoire d'Océanographie de Villefranche, France	Biological response to atmospheric deposition, biogeochemical cycling. Co-Chair of the SOLAS SSC. Contributed to GEOTRACES IDP.
8 Suzanne Fietz	F	Stellenbosch University, South Africa	Biogeochemical cycling, biological response to atmospheric deposition
9 Andrew Bowie	M	University of Tasmania, Australia	Biogeochemical cycling, aerosol TE solubility, Southern Hemisphere aerosols. Contributed to GEOTRACES IDP, GEOTRACES SSC co-chair (2018-2020), member of GEOTRACES exec.
10 Alex Baker	M	University of East Anglia, UK	Aerosol TE solubility, biogeochemical cycling. GESAMP WG38 co-chair, contributed to GEOTRACES IDP, FeMIP Associate Member.

8. Working Group contributions

Rachel Shelley (co-chair)

Total and soluble trace element composition of atmospheric deposition and marine biogeochemical cycles. Uses novel tracers (e.g., beryllium-7 and thorium) for quantification of the atmospheric deposition flux of TEs.

Douglas Hamilton (co-chair)

Atmospheric scientist and Earth System modeller with expertise in natural aerosols and their changing influence on climate and biogeochemical cycles through the Anthropocene. Led the development of an intermediate complexity iron aerosol module for the latest version of the Community Earth System Model.

Morgane Perron (co-chair)

Total and soluble trace element (and chemical tracer) composition of atmospheric deposition and marine biogeochemical cycles. Research has primarily focused on the Southern Hemisphere oceans through ship-board expeditions and a new aerosol time-series station installed in Hobart, Australia.

Hind Al-Abadleh

Physical chemistry of aerosols. Dark and photochemical reactions of iron in multicomponent aerosol systems that lead to complexation, degradation, or oligomerization/polymerization of the organic components.

Peter Croot

Marine biogeochemist focused on understanding the role of biogeochemical processes on the concentration and distribution of trace elements and chemical species in the ocean.

Cassandra Gaston

Measurements of the physical and chemical properties of aerosols using both bulk and single-particle methods. Quantification of the solubility of aerosol nutrients, distinguishing source, mixing-state and surficial properties, and prediction of how aerosol size and shape alters deposition and dissolution rates.

Diego Gaiero

Expertise in understanding dust activity in Southern Hemisphere low latitudes. Research focuses on determining dust fluxes from southern South America, improving understanding of present-day and past dust provenance, and evaluating the relevance of iron-rich dust on the biogeochemistry of the Southern Ocean.

Akinori Ito

Earth System model development and application with a focus on Fe in the atmosphere.

Ashwini Kumar

Aerosol chemistry. Aeolian dust characterization using geochemical tools including radiogenic isotopes, Sr and Nd. Total and soluble trace element composition and fluxes over the Indian Ocean.

Ying Ye

Biogeochemical modelling with a focus on the marine cycle of iron, silicon and carbon. Estimation of contribution of different iron sources to marine iron concentration and bioavailability.

9. Relationship to other international programmes and SCOR Working groups

SCOR Working Groups: By focusing on improving aerosol Fe solubility representation in atmospheric models, we will build on the work done by **WG151 (FeMIP)**. To facilitate this, several Members are either Full or Associate Members of WG151. In addition, all Members will be added to the FeMIP mailing list by Alessandro Tagliabue (FeMIP co-chair) which will provide a direct mechanism for engaging the FeMIP community in RUSTED projects, workshops, and meetings. There is potentially some common interest with **SCOR WG163 (CIce2Cloud)**. The composition of chemical species in the Polar atmosphere could provide valuable insights into the nature of TE solubility. We will contact the Chairs to discuss possible collaboration.

GESAMP WG38 (Atmospheric Inputs to the Ocean): This group was formed in response to concern about the impact of atmospheric deposition on ocean chemistry, biology, biogeochemistry and climate. This group has recently advanced knowledge of how changes in atmospheric acidity are likely to impact the dissolution of aerosol TEs. Close communication with this group will be facilitated through Morgane Perron (co-chair of this WG) and Alex Baker (Associate Member and co-chair of GESAMP WG38).

GEOTRACES, SOLAS and SIBER (Sustained Indian Ocean Biochemical Biogeochemical and Ecological Research)**:** The deliverables from all four ToRs will benefit these communities, e.g., the Standard Operating Procedures (a ToR2 deliverable) and recommendations for handling aerosol Fe and TE solubility data. The database will be of particular interest to these communities as it will provide quality-assured TE solubility data from these programmes, alongside auxiliary information, to numerical modellers. The sensitivity study (ToR4 deliverable) will be of interest to the SIBER programme, especially. We anticipate inviting SOLAS and SIBER to co-sponsor our workshop-lecture series. These organisations recognise the importance of improving the representation of soluble Fe in models. Full and Associate Members are currently serving, or have served, on GEOTRACES and SOLAS committees. A SCOR WG will promote greater collaboration between these programmes.

IIOE-2: We anticipate close communication and collaboration with IIOE-2 participants to leverage their data and guide future research directions in the region (ToR4 deliverable). This programme will be approached for co-sponsorship of the workshop-lecture series.

International Global Atmospheric Chemistry and Global Atmosphere Watch programmes of the World Meteorological Organization (WMO) and NASA's Plankton, Aerosol, Cloud and ocean Ecosystem (PACE) programme: The database will be of use to these programmes who are interested in the impact of aerosol metals (especially Fe) on air quality, weather and climate. These programmes will be invited to co-sponsor the database.

UN Decade of Ocean Science for Sustainable Development: The WG will be submitted for endorsement as an Ocean Decade Action as the open-access database and workshop-seminar series address Priority Challenges 5 (Unlock ocean-based solutions to climate change) and 9 (Skills, knowledge and technology for all) directly, and Priority Challenges 1 (Understand and beat marine pollution) and 7 (Expand the Global Ocean observation system) indirectly. In addition, the discussions of this WG will provide recommendations for future research questions on the flux of essential and potentially toxic TEs across the air-sea interface, thus addressing Priority Challenges 1 and 5. Publication in open access journals addresses Priority Challenge 9.

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Appendix

Key Publications of Full Members of relevance to this Working Group (5 each)

Rachel Shelley

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Glossary

ASLO – Association for the Sciences of Limnology and Oceanography
ECR – Early Career Researcher
Eos – The science news magazine published by the American Geophysical Union (AGU)
GEOTRACES - An international study of the marine biogeochemical cycles of trace elements and isotopes
GESAMP - Group of Experts on the Scientific Aspects of Marine Environmental Protection. Advises the United Nations on scientific aspects of marine environmental protection.
Fe – Iron
ICP-MS – Inductively-coupled plasma – mass spectrometry
IIOE-2 – Second International Indian Ocean Expedition (2015-2025)
NIO, India – National Institute of Oceanography, India
POGO – SCOR Fellowship - This programme is designed to promote training and capacity building leading towards a global observation scheme for the oceans, jointly funded by POGO and SCOR
RUSTED – Reducing Uncertainty in Soluble aerosol Trace Element Deposition (the proposed SCOR WG)
SIBER – Sustained Indian ocean Biogeochemistry and Ecosystem Research. The long-term goal is to improve understanding of the role of the Indian Ocean in global biogeochemical cycles and the interaction between these cycles and marine ecosystem dynamics. IIOE-2 is a major component of SIBER.
SOLAS – Surface Ocean Lower Atmosphere Study. Aims to understand the key biogeochemical-physical interactions and feedbacks between the ocean and atmosphere in order to understand and quantify the role that ocean-atmosphere interactions play in the regulation of climate and global change.
SWOT analysis - Strengths, Weaknesses, Opportunities, and Threats. A strategic planning and management technique.
TE – Trace elements
WG – Working Group