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solas event report

Report 01 I May 2017

Two workshops in parallel on:

"Changing Atmospheric Acidity and its Impacts on the Oceanic Solubility of Nutrients"

and

"The Impact of Ocean Acidification on Fluxes of Non-CO_2 Climate Active Species"

27 February - 2 March, 2017 Norwich, United Kingdom

From February 27 to March 2, 2017, two workshops took place at the University of East Anglia (UEA), Norwich, United Kingdom under the auspices of Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 38 and sponsored by World Meteorological Organization (WMO), National Science Foundation (NSF), Scientific Committee on Oceanic Research (SCOR), Surface Ocean - Lower Atmosphere Study (SOLAS), and UEA. These workshops focused on the changes in the acid/base balance of the atmosphere and ocean, and their impacts on air-sea exchange.

While workshop 1 was on "Changing Atmospheric Acidity and its Impacts on the Oceanic Solubility of Nutrients", workshop 2 dealt with "The Impact of Ocean Acidification on Fluxes of Non-CO_2 Climate Active Species". These two themes recognise the importance of both (1) atmospheric nutrient deposition to the biogeochemistry of the oceans and (2) the emissions of trace gases from the ocean for atmospheric chemistry and climate regulation.

Continued …

In this report

Figure 1: Participants of the workshops at the University of East Anglia, Norwich, United Kingdom.

Left to right - Back row: Athanasios Nenes, Eric Buitenhuis, David Turner, Andrew Rees, Martin Johnson, Laurent Bopp, Oliver Andrews, Isabelle Dadou, Nadine Goris, Natalie Mahowald (hiding!), Steve Archer
Next row: Peter Croot, Rob Middag, Alex Baker, Robert Duce, Marion Gehlen, Frances Hopkins, Gill Malin, Parvadha Suntharalingam, Fiona Keng Seh Lin, Yuan Gao
Next row: Cécile Guieu, Martine Lizotte, Rachel Shelley, Morgane Perron, Maria Kanakidou, Peter Liss,
Front row: Hema Uskaikar, Akinori Ito, Manmohan Sarin, Stelios Myriokefalitakis, Cliff Law, Kitack Lee
Missing: Tim Jickells. © Tim Jickells, UEA.

The focus of workshop 1 considered the changing atmospheric acidity and its effects on ocean biogeochemistry, utilising a wide range of approaches from fundamental chemistry, through modelling, to field work. The atmosphere has already been through a major phase of anthropogenic acidification due to the emissions of extra sulphur dioxide and nitrogen oxides to the atmosphere from combustion sources. This acidification has been offset to some extent by neutralisation associated with ammonia emissions which originate mainly from agriculture. Vigorous regulatory efforts over the last few decades have greatly decreased sulphur dioxide emissions, and the impact of nitrogen oxides control measures on cars indicate that those emissions have been stabilising. However, continuing intensification of agriculture has increased ammonia emissions. The combined effect of these changes in emissions is a steady reduction in atmospheric acidification. This process has reduced acidity in many areas of the world and may even lead to alkaline rain. The solubility of several aerosol derived key ocean nutrients (particularly iron and phosphate) is very pH-sensitive and hence sensitive to changing atmospheric acidity. In consequence these changes have the potential to alter the inputs of bioavailable soluble nutrients in the future.

The other key context for the meeting was the changing nature of ocean acidity. Given that there has been a great emphasis on the air-sea exchange of CO_2 in many symposia, the focus in workshop 2 was on a range of other climatically important gases including halogen, nitrogen and sulphur species. These gases play a key role in controlling radiative forcing, atmospheric oxidising capacity and atmospheric chemistry.

As a result of increasing CO_2 concentrations in the atmosphere, the oceans are now demonstra-

As a result of increasing CO_2 concentrations in the atmosphere, the oceans are now demonstrably being acidified by CO_2 uptake.

bly being acidified by CO_2 uptake. This process will continue for decades, before hopefully the Paris Climate Agreement (United Nations Framework Convention on Climate Change, 2015) tackles the problem. While there were great advances in our understanding of the direct biogeochemical impacts of ocean acidification, the question addressed by workshop 2 was how ocean acidification may affect the production and air-sea exchange of trace gases, and whether this effect will mitigate or enhance global change pressures. Thus, the impacts of ocean acidification on ocean biogeochemistry and ecosystems, and how this in turn can affect air-sea exchange at both the global and regional scale were discussed. The workshop considered a wide range of approaches, from fundamental cellular processes through ecosystem considerations to global models, and from laboratory to mesocosm and field studies. Also linkages to other global change stressors, particularly global warming and its ramifications for ocean circulation, were taken into account.

Given the intriguing symmetry of potentially important impacts of changing acidity (albeit in opposite directions) on both sides of the air-sea interface we wanted to host these two meetings in parallel to allow crossovers between the various experts. Hence, 25 scientists from around the world gathered in Norwich along with 8 locally based experts and discussed a wide range of issues around these respective themes. These discussions were done often as two separate groups, but with structured joint sessions, and also regular social interactions over shared refreshments.

The meetings featured rather informal presentations from experts, followed by intense discussion sessions, exploring the multiple topics and feedbacks evident in the complex air-sea interaction issues. The invited scientists were selected according to their expertise and interest in these areas, as well as to provide a wide spectrum of knowledge, and ranged from modelers to experimentalists. We drew scientists from sixteen different countries and from a wide range of career stages, from senior scientists through to graduate students. The participants all seemed to leave Norwich full of enthusiasm for the process and the new scientific insights the groups had developed. The aim now is to write a series of papers synthesising these conclusions. By an interesting coincidence two papers (Jickells *et al*., 2017; Sharples *et al*., 2017) from

Figure 2: Prof. Dr. Tim Jickells, who is missing from figure 1. © Tim Jickells; UEA

a similarly sponsored and structured workshop (Duce *et al*., 2008) were published at about the time of the workshop, which in turn revised work from an earlier workshop.

To conclude, we thank workshops sponsors and all the participants for travelling from near and far to participate, for leaving their families, day-to-day cares and duties (well the email still finds you!) and for embracing the excitement of this scientific dialogue, and we look forward to the speedy preparation of all of the promising manuscripts.

Robert Duce & Tim Jickells
(co-chairs of GESAMP WG 38)

Alex Baker, Cécile Guieu and Manmohan Sarin
(for workshop 1)

Parvadha Suntharalingam, Marion Gehlen,
Frances Hopkins and Martine Lizotte
(for workshop 2)

The outcomes of the workshops contribute to advance our knowledge of the Core Theme 3 “Atmospheric Deposition and Ocean Biogeochemistry” of the SOLAS 2015-2025 Science Plan and Organisation.

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Event sponsors

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Morgane Perron completed a Master degree in marine chemistry in France at the Institut Universitaire Europeen de la Mer, Brest, France, in 2015. She started her PhD in 2016 at the Institute for Marine and Antarctic Studies, Hobart, Tasmania, to investigate the role of atmospheric dust as a vector of trace nutrient, e.g. iron, to Australian marine ecosystems.

Natural iron fertilization of the oceans around Australia, linking terrestrial aerosols to marine biogeochemistry

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Atmospheric aerosols modulate global climate in numerous significant ways, impacting the Earth's radiative forcing or acting as cloud condensation nuclei or ice nuclei (Jickells *et al*., 2005). Thereby, atmospheric aerosols have an indirect influence on global weather and being, for example, able to facilitate the occurrence of rainfall. Moreover, the atmospheric pathway has been highlighted as an important if not the main source of iron (Fe) and other key biogeochemical nutrients to the open ocean, where riverine input or sediment resuspension are rare (Duce and Tindale, 1991). Among these areas and in regard to our understanding of climate change, the Southern Ocean is of major interest because of its potential role in the carbon dioxide (CO_2) sequestration in deep ocean layers. However, iron scarcity in these so-called High Nutrient Low Chlorophyll regions limits greatly primary producers' growth.
The southern hemisphere comprises only of a few potential dust sources, when compared to the northern hemisphere (Mahowald *et al*., 2005). Recently, studies have pointed out Australia's desert as a substantial and previously underestimated nutrient carrier to the southern hemisphere and particularly the Southern Ocean, either during the present time and/or during the Last Glacial Maximum (Luo *et al*. 2003). In Australia, mineral aerosols are produced by aeolian erosion of surface soils in the Lake Eyre and the Murray-Darling Basins arid regions. The country is characterised by highly episodic dust storms (Mackie *et al*., 2008) that lift up and transport desert dust within specific air masses toward the surrounding coastal or open oceans (Fig. 3). After mixing with air masses, aerosols are finally deposited back to the earth (or ocean), either by dry settling or by wet deposition (rain) (Knippertz and Stuut, 2014). Figure 4 shows a schematic of the dust cycling (Bowie, pers. comm.). However, regarding this, Australia is still largely underexplored and the knowledge on the biogeochemical

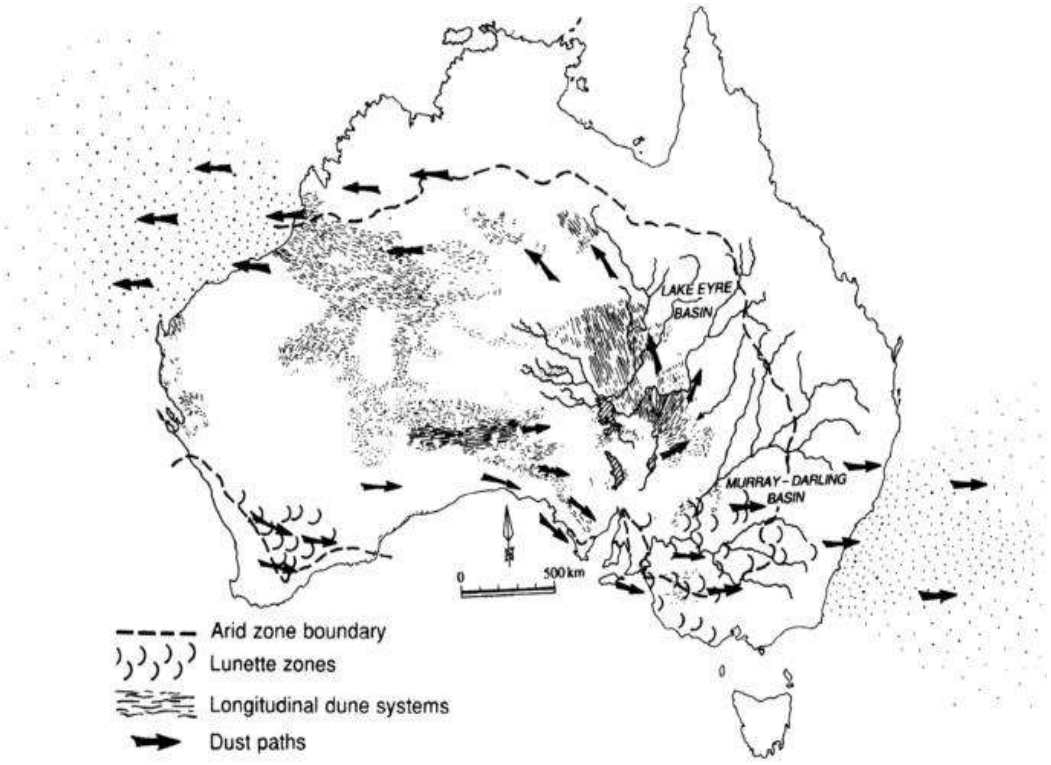

Figure 3: Australian arid zones and major dust pathways (Hesse and McTainsh, 2003)

processing of dust in the atmosphere on its way from the source area to the ocean remains limited. Current global model predictions on dust deposition and its impact on the marine ecosystems are computed against northern hemisphere parameters and do not represent the southern hemisphere processes well (Luo *et al*. 2003; Mahowald *et al*., 2005). To answer the issues given above, my PhD project involves an intense sampling activity all around the Australian coasts and the ambient waters. The aim of my study is to qualify and quantify the content of dust loading brought from the central Australian 'outback' to the ocean. By a series of leaching experiments (Baker *et al*. 2006; Bowie *et al.* 2010), we will determine the proportion of water soluble, potentially bioavailable (labile), and refractory iron along with other trace nutrients in collected aerosol samples. This dataset will support or contradict the hypothesis of dust as an essential source of nutrients to the ocean in the study area. Finally, by this extensive dataset, we will be able to constrain dust cycle model parameters relative to the southern hemisphere, as well as model predictions

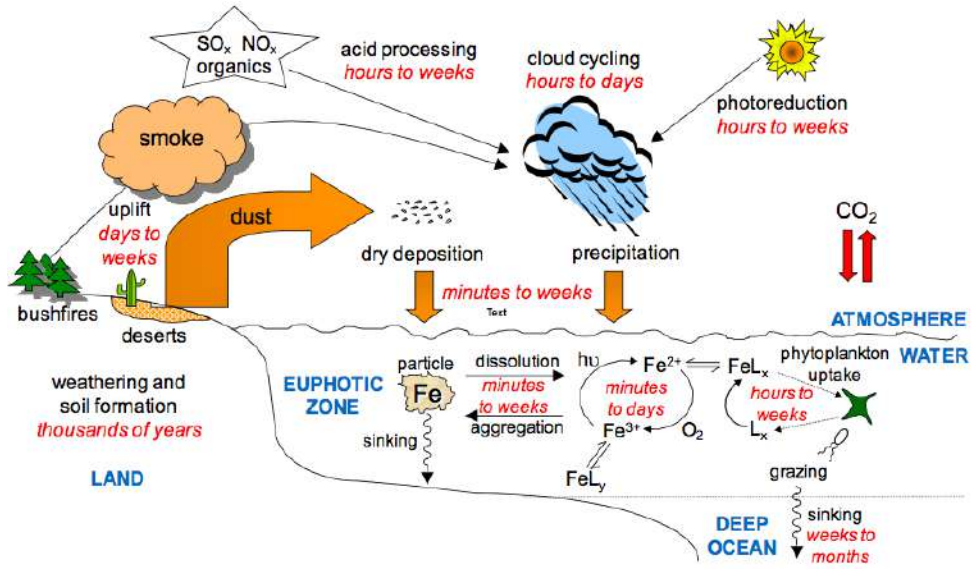

Figure 4: Schematic of air-sea exchanges of trace metals, with iron as an example (Bowie, pers. comm.)

of dust impact on southern hemisphere marine ecosystems, particularly in the Southern Ocean.

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Fiona Seh Lin Keng studied biotechnology at the University of Malaya, Malaysia, where she also conducted her master studies in the field of environmental science. In 2016, Fiona started her PhD at the Institute of Ocean and Earth Sciences, University of Malaya, focusing on the changing environmental effects on the emission of halocarbons by tropical seaweeds.

Will ocean acidification affect the biogenic emission of volatile short-lived halocarbons by marine algae?

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Marine algae emit volatile halocarbons under stressed conditions during grazing, microbial attack, and exposure to varying environmental parameters, which include high light intensity, desiccation, and nutrient limitation, as well as variations in temperature, salinity, and carbon dioxide (CO_2). Phytoplankton in the open ocean has been reported to emit around 19 – 304 Gg Br yr^{-1} (Lim *et al.,* 2017), while marine macroalgae (seaweeds) from the South East Asian region (Fig. 5) were shown to emit between 6 – 224 mmol Br yr^{-1} (Leedham *et al.*, 2013). These halocarbons can affect atmospheric oxidation capacity and radiation balance, change the local climate and even contribute to the halogen pool in the upper troposphere/lower stratosphere.

The emission of biogenic halocarbons by marine algae can be affected by ocean acidification. The rise in both, atmospheric CO_2 and eutrophication, affect the photosynthesis activity of the algae, decreases calcification in coralline algae and change the physiology of the marine plants. An increase in the partial pressure of carbon dioxide (pCO_2) increases photosynthetic activities in non-calcified marine algae (Roleda *et al*., 2015). The effect of halocarbons on photosynthesis has

Figure 5: *Kappaphycus spp.* red algae farms dominate the South East Asian region.

been linked, as halocarbons are produced from photosynthetic and photorespiratory products i.e. hydrogen peroxide, but these effects vary between different marine algae species (Fig. 6). The presence of halogens, hydrogen and dissolved organic matter in the seawater will produce polyhalogenated compounds, for example bromoform ($CHBr_3$) and dibromomethane (CH_2Br_2) through the reaction of haloperoxidases (Wever & ven der Horst, 2013). Despite the observed correlation between photosynthesis and halocarbon emissions, mesocosm studies on phytoplankton in the arctic and brackish water

Figure 6: Halocarbon research and sampling for laboratory incubations at the University of Malaya, Kuala Lumpur, Malaysia.

temperate communities, found no or little significant effect of increased pCO_2 levels on the halocarbon emissions by phytoplankton at levels up to those projected under the various Intergovernmental Panel on Climate Change (IPCC) scenarios for year 2100 (Hopkins *et al.*, 2013; Webb *et al.*, 2016). Taken into account the IPCC scenarios of the Representative Concentration Pathways 8.5 (global annual greenhouse gases emissions continue to rise throughout the 21st century) and 2.6 (global annual greenhouse gas emissions peak between 2010-2020 and decline substantially thereafter), projections for the future global oceanic emissions indicate increased emissions of $CHBr_3$, CH_2Br_2 and methyl iodide. These increases could be attributed to a potential increase of the sea surface temperature in the tropics and subtropics, intensified vertical transport, and sea-to-air fluxes by the end of the century (Ziska *et al.*, 2016). However, human influences, including seaweed cultivation which could be a significant contributor of $CHBr_3$ and $CHBr_2$, were not included in the model. Challenges encountered for predicting the contribution and significance of marine algal emission of halocarbons in the regional and global scale include: the species-specific responses of the algae towards changing environmental condition, the complex interactions between marine algae species at the community and ecosystem levels, the spatial and temporal variations of emissions, as well as the restricted availability to regional primary production, biomass, and species distribution data. Efforts are on-going to understand the response and adaptation of the marine algae

to the changing climate; the information obtained will facilitate better predictions of future marine biogenic halocarbon emissions.

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Report 02 I June 2017

“Ocean Acidification - Training and Community Networking: Pathways to Success”

13 - 16 February, 2017
Dakar, Senegal

The Ocean Acidification - Senegal practical training and networking meeting (OA-Senegal) took place for the first time in West Africa at the University of Cheikh Anta Diop, Dakar, Senegal. The OA-Senegal events were organised by Future Earth Coasts with the support of the following organisations, represented by attendees: the oil & gas company Kosmos Energy, SOLAS, the Center for Marine and Renewable Energy, the Ocean Acidification International Coordination Center, and the Institut de Recherche pour le Développment; to name a few. The OA-Senegal events were attended by fifteen participants originating from Benin, Cameroon, Côte d’Ivoire, Nigeria, Senegal, and Togo. Overall, six lecturers coming from France, Sweden, Spain, South Africa, and

Figure 1: Networking session during the OA-Senegal events. © Cheikh Anta Diop University, Dakar, Senegal.

In this report

Attendee testimonies

Figure 2: Participants of the OA-Senegal events. © Cheikh Anta Diop University, Dakar, Senegal.

the United States, guided the participants through the events. Lectures and discussions covered a general introduction to oceanic conditions off the West African coast, the goal and urgency to study ocean acidification, as well as the chemistry involved in the acidification and its impacts on marine biodiversity. In addition, presentations were given regarding measurement techniques of ocean acidification, design of relevant acidification manipulation experiments, and research in the field and in the laboratory.

Figure 3: Practical training on ocean acidification during the OA-Senegal events. © Lisa Robbins.

Following the practical training, a networking meeting took place, where the training participants discussed ocean acidification in plenary sessions. In total, seventeen participants attended the sessions, coming from: Algeria, Benin, Cameroon, Côte d'Ivoire, Egypt, Ghana, Kenya, Madagascar, Morocco, Nigeria, Senegal, South Africa, Tanzania, Togo, and Tunisia. Presentations and discussions involved the development and improvement of the Ocean Acidification - Africa network (OA-Africa), the general knowledge exchange on operational outcomes and identification of current needs (resources and capacity) of the project. Potential scientific collaborations including research funding were discussed, as well as opportunities to extend the OA-Africa network in Africa. A steering committee involving researchers from Africa was identified, which will provide guidance and support to the network. The final part of the OA-Senegal events was a one-day field trip, which should give insights into building up ocean acidification experiments. These experiments were set up in aquaria and environmental parameters were manipulated. Finally, the trainees received their certificates of

completion.
To conclude the OA-Senegal events, a dinner with all participants, local non-governmental organisations, and government officials from Senegal was organised. This event confirmed the importance of involving resident organisations and stakeholders, who can provide significant local expertise and experience. This dinner provided an invaluable opportunity to connect researchers, non-governmental organisations, and government officials and develop the OA-Africa network across the continent.

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Marie Boye is a researcher at the National Center for Scientific Research working at the Laboratory of Oceanography and Climate: Experiments and Numerical Approaches at the University of Pierre and Marie Curie, Paris, France. Her research focus is on the interactions between climate change and the biogeochemical cycles in the ocean, including trace elements, isotopes and ocean acidification. Marie Boye assesses the biogeochemical drivers influencing the phytoplankton ecosystem and the carbon cycle at different scales of time and space, combining observations, calibration of emerging proxies of acidification and warming in phytoplankton, experimentations, and simulations. Her research provides key functions to develop biogeochemical models from the pre-industrial area, at present and for future projections on the carbon cycle. She was a trainer at the OA-Senegal events and works on the development of the OA-Africa network.

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Sam Dupont is a researcher and an associate professor in marine eco-physiology at the University of Gothenburg, Sweden. His main research topic is on the effect of global changes, including ocean acidification, on marine species and ecosystems. Sam works actively on the development of the OA-Africa network and was a trainer at the OA-Senegal events.

The Ocean Acidification - Africa network: Putting Africa on the ocean acidification map

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Ocean acidification is identified as a major threat to marine species and ecosystems and is one of the United Nations Sustainable Development Goals: Goal 14.3: Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels (United Nations, 2015). When it comes to understanding, projecting and anticipating the impacts of ocean acidification, some countries or even continents are left relatively unexplored, despite their biological and socio-economical vulnerability to future marine global changes. This problem was the rationale behind the development of a new network focusing on ocean acidification in Africa. The OA-Africa network has been built over four training courses (www.oa-africa.net/). A first general training course was organised in Cape Town, South Africa (November 2-6, 2015) by the Ocean Acidification International Coordination Centre. It was quickly followed by more specific courses: (i) a practical course on biological experiments in Inhaca, Mozambique (March 7-11, 2016) organised by the Global Ocean Acidification Observing Network; (ii) a course focusing on chemical monitoring in Flic en Flac, Mauritius (July 25-30, 2016) organised by The Ocean Foundation through the ApHRICA project; and (iii) a practical training combined with a networking meeting in Dakar, Senegal (February 13-16, 2017) organised by Future Earth Coasts. All together, these courses gathered participants from more than 24 different African countries

Figure 4: Left: Participants of an OA-Africa network event in South Africa. Right: Participant Mohamed Elsafy at the OA-Africa network event in South Africa. © Sam Dupont.

(Algeria, Angola, Benin, Cameroon, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Djibouti, Egypt, Ghana, Kenya, Liberia, Madagascar, Mauritius, Morocco, Mozambique, Namibia, Nigeria, Senegal, Seychelles, South Africa, Tanzania, Togo, Tunisia). The OA-Africa network, led by Dr. Chibo Chikwililwa (Namibia) and Dr. Warren Joubert (South Africa), was launched officially on October 20, 2016 and the first face-to-face meeting was organised recently in parallel of the OA-Senegal events. Prominent researchers from several African coastal countries discussed the coordination and regional priorities for ocean acidification activities on the continent. Generally, the OA-Africa network aims to coordinate ocean acidification related research and its monitoring, provide information and guidance to stakeholders and policy makers, and promote and advance ocean research through outreach and capacity building initiatives. With a strong support from the international community, including the International Atomic Energy Agency project "Supporting a global ocean acidification network - toward increased involvement of developing states" the challenges and opportunities for ocean acidification research and governance across Africa are currently evaluated. The first three African institutions will be equipped with a new ocean acidification research beginner kit (funding ApHRICA project). These kits contain affordable technologies for ocean acidification experiments. Practical guidance is provided by the Scripps Institution of Oceanography, San Diego, United States (Dr. Andrew Dickson, carbonate chemistry measurement) and the University of Gothenburg (Dr. Sam Dupont, biological experimentation). These efforts will combine both, the basic equipment and knowledge to start chemical and biological monitoring, as well as perform general biological experiments. The OA-Africa network already encouraged some of the participants and trainers to cooperate on a range of different projects. For example, two new PhD projects funded by the Swedish International Development Cooperation Agency will focus on the impact of ocean acidification in Mozambique. The OA-Africa network is already working toward addressing the indicator of the Sustainable Development Goal 14.3: Average marine acidity (pH) measured at agreed suite of representative sampling stations (United Nations, 2015). Additionally, the OA-Africa network will initiate and lead the Ocean Acidification Day. On the World Ocean Day (June 8, 2017), researchers from all over Africa and in partner countries will join and measure pH (www.oa-africa.net/events/world-oceans-day/). This initiative led by African scientists (Folasade Adeboyejo, Excel Research Academy, Nigeria and Dr. Andry Herizo Rasolomaharavo, University of Antananarivo, Madagascar) and facilitated by Dr. Sam Dupont (University of Gothenburg, Sweden) and Dr. Martin Le Tissier (University College Cork, Ireland) will be broadly communicated through a national and international press and social media campaign, as well as during the United Nations 'The Ocean Conference' held during June 5-9, 2017 in New York. The OA-Africa network is a success story demonstrating how capacity building combined with a real local passion for the ocean can transfer into self-organisation and actions toward addressing one of the Sustainable Development Goals of the United Nations.

Figure 5: Practical training on ocean acidification during an OA-Africa network event in South Africa. © Sam Dupont.

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Felix Besack is a member of the OA-Africa network and a junior lecturer at the University of Douala, Douala, Republic of Cameroon, working in the laboratory of oceanography and limnology. He participated in the OA-Senegal events.

The OA-Senegal events were inspiring and an enrichment of knowledge. The events had a new and interdisciplinary approach, where every participant was able to find his or her research interest, which is a key factor to implement this new field of research in the participating countries. One of the most interesting parts of the events was to discover the different reasons why ocean acidification occurs and how to investigate it. Regarding factors that favour ocean acidification, the human demography and the industrialisation are good examples what happens in Central Africa and particularly in Cameroon. Some indicators of ocean acidification in Cameroon are salinity changes and rise in sea level, which are both causing serious damages to the marine and coastal environment along the coast of Cameroon. Numerous investigations are being carried out by many scientists. However, in Cameroon the understanding of ocean acidification is still limited due to little financial support, lack of political interest, and little or no network among scientists.

What I gained from the events

The events familiarised me with a wide range of topics, from the general lectures to practical sessions. These sessions involved how to evaluate the impact of pH changes on some biological relevant species (calciferous organisms) by using the simple pH specification method (requiring a pH meter, small aquariums and a Conductivity, Temperature, Depth sensor). Additionally, lectures dealt with how to measure and calculate the marine carbonate chemistry, experimental designs and large scale projections of biological impacts.

Future plans

The University of Douala, Republic of Cameroon, is looking forward to a strong cooperation with the newly-build OA-Africa network. We plan to conduct broad investigations along the coast of West Africa and the Republic of Cameroon, where we want to investigate the following:

- The spatial and temporal variation/distribution of carbon dioxide in marine ecosystems;
- The impact of pH changes on the species distribution;
- The conditions of ecologically important species regarding ocean acidification and climate change (Coccolithophores and Diatoms);
- The role of mangrove forests on carbon dioxide sequestration; and
- The potential reasons for the pH decrease along the African coast, which will be investigated by monitoring these areas and modelling.

Importance to my research

Currently, I am working on high resolution modelling of the hydrodynamics along the coast of Cameroon using 3D SYMPHONIE model developed at the Laboratoire d'études en géophysique et océanographie spatiales, Toulouse, France. This model has to be validated against *in situ* data by parameters such as temperature, salinity, pH, and carbon dioxide. The knowledge I acquired during the events has given me plenty of state-of-the-art information on marine pH concentrations, carbon dioxide and alkalinity, as well as how to sample, measure and calculate these variables in the field.

Ibrahima Diack is a PhD candidate in the laboratory of atmospheric and ocean physics at the Cheikh Anta Diop University, Dakar, Senegal. He was a participant of the OA-Senegal events.

The OA-Senegal events, organised in Dakar, were a wonderful opportunity.

What I gained from the events

One of the major benefits from the events was the interaction between trainers and participants. This course helped me to better understand the relationship between the ocean and the atmosphere, particularly with the carbon pathway and its association with other research fields, including physics, chemistry, and biology. My awareness and curiosity regarding ocean acidification have considerably increased. Ocean acidification broadly impacts the marine ecosystems and because a lot of people have the ocean as their source of life, also the local communities and policymakers should be aware of this issue and its impacts.

Hands-on experiences during the course were done via collecting data with a partial pressure of carbon dioxide sensor which gave some theoretical ideas of the values. To investigate ocean acidification, a special software (CO_2Calc) was introduced, which allowed to compute parameters such as pH, total alkalinity, and the partial pressure of carbon dioxide.

Future plans

In the context of global warming, Africa is one the most exposed continents. Only a few studies on ocean acidification have been conducted in Africa and thus, it is extremely important to support African students that are interested in this research. The OA-Africa network is a step forward and it should be further strengthened by capacity building and data sharing between the institutions.

Folasade Adeboyejo is a PhD candidate, focusing on marine ecology at the Excel Research Academy, Lagos, Nigeria. Folasade is a member of the OA-Africa network and participated in the OA-Senegal events.

It was a privilege to attend the OA-Senegal events. Overall, the events were very interesting and educative. I participated in an event that brought together researchers and stakeholders across several coastal African states, for the first time. The OA-Africa network is a great platform to develop collaborative science and individual research efforts, as well as connect different African states.

What I gained from the events

Prior to the OA-Senegal events, ocean acidification and its impacts were not really clear to me. The most important points that I gained from the events were the ability to communicate the concept of ocean acidification and changing ocean chemistry to the society, as well as the fact that we have to change our behaviour. If we do not change anything, ocean acidification will have terrific effects on the ecosystem with large effects on the society. The practical training, including ocean acidification experiments, helped me to better understand the relationship between human activities, marine biological systems and ocean chemistry. The presentation of instruments and equipment to explore ocean acidification highlighted that we could start with this kind of research.

Future Plans

Attending the OA-Senegal events raised my interest in ocean acidification research using ecosystem based approaches. Thanks to the OA-Africa network, this research may provide more scientific opportunities for African scientists. Personally, I am taking the bull by the horns as I am promoting the upcoming World Ocean Day as a platform to make the African society aware of the goals and visions of the OA-Africa network. On the World Ocean Day we will join the global initiative and measure the pH of the coast along Africa.

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solas event report

Report 03 I June 2017

Annual meeting of:

"Biogeochemical Exchange Processes at Sea Ice Interfaces (BEPSII)"

3 – 5 April, 2017
La Jolla, United States

The Biogeochemical Exchange Processes at Sea Ice Interfaces (BEPSII) research community is a global community of sea-ice researchers including biogeochemists, atmospheric scientists, oceanographers and sea-ice physicists, which was initiated as Scientific Committee on Oceanic Research (SCOR) working group 140 to address fundamental communication and methodological issues in sea-ice biogeochemistry. BEPSII was then approved by SOLAS and the Climate and Cryosphere project (CliC) as a longer-lived activity with additional endorsement from the Scientific Committee on Antarctic Research. The second phase of BEPSII is focused on developing the tools to tackle big-picture questions about the global relevance of biogeochemical processes within and around sea ice, including climate-change feedbacks. The current BEPSII objectives are to:

- Develop dedicated consistent methodologies for sea ice biogeochemical research;
- Establish effective sea-ice biogeochemical data archiving approaches and databases;
- Foster process studies to determine impacts on ecology and biogeochemical cycles;

In this report

Figure 1: Participants of the Biogeochemical Exchange Processes at Sea Ice Interfaces annual meeting.
Front row left to right: Jeff Bowman, Jacqueline Stefels, Letizia Tedesco, Maria Vernet, Daiki Nomura, Melissa Chierici, Agneta Fransson, Ana Aguila-Islas, Nadja Steiner, Marie Kotovitch, Lisa Miller, Daniella Koenig, Marion Lebrun, Bonnie Raffel, James France.
Back row left to right: Klaus Meiners, Max Thomas, Martin Vancoppenolle, Eric Mortenson, Ollie Legge, Florian Deman, CJ Mundy, Brent Else, Jens Ehn, Francois Fripiat, Lynn Russel, Janne Rintala

- Foster technological developments and international knowledge transfer towards large-scale, autonomous and high-frequency sampling of sea-ice biogeochemical parameters;
- Improve the representation and evaluation of sea-ice biogeochemistry in regional and Earth system numerical models;
- Synthesise and integrate observational and modeling efforts; and
- Develop conceptual models describing sea-ice interactions in or with the Earth system.

With additional support from the International Arctic Science Committee, BEPSII held a 3-day workshop in April 2017, joined by the new SCOR working group 152 on Measuring Essential Climate Variables in Sea Ice, financially supported by SCOR. Twenty-six scientists from Australia, Belgium, Canada, Finland, France, Germany, Japan, the Netherlands, Norway, Switzerland, the United Kingdom, and the United States gathered in La Jolla, California to discuss the results of the past year's activities, plan upcoming activities, and to present scientific talks and posters.

Some of the biggest activities planned for the coming three years include:

- Method intercalibration experiments for the measurement of gas exchange, primary production and trace metals;
- Advising the Multidisciplinary drifting Observatory for the Study of Arctic Climate field program;
- 1-D and 3-D model intercomparisons of sea ice algae production; and
- Afield school (tentatively scheduled for summer 2019);

In addition, new experimental and modelling approaches will be fostered to enhance our understanding of biogeochemical exchange processes

at sea-ice interfaces. A set of five task groups have been formed to forward the BEPSII objectives, which comprise the basis of a 5-year science plan currently being drafted. The task groups and their leaders are:

- Essential Climate Variables in Sea Ice: Francois Fripiat (Germany), Daiki Nomura (Japan), Brent Else (Canada)
- Data Collation: Klaus Meiners (Australia), Lisa Miller (Canada)
- Modelling and Observational Process Studies: Nadja Steiner (Canada), Hauke Flores (Germany)
- Syntheses: Delphine Lannuzel (Australia), Martin Vancoppenolle (France)
- Outreach: Letizia Tedesco (Finnland), Bruno Delille (Belgium)

We encourage anyone interested in getting involved with BEPSII or Essential Climate Variables in Sea Ice to send a message to the chairs Jacqueline Stefels and Nadja Steiner or to the leaders of the relevant task groups. In the meantime, for additional entertaining reading, see the BEPSII special feature in *Elementa: Science of the Anthropocene* (http://bit.ly/2qHK7QZ).

Nadja Steiner
(Co-chair, Institute of Ocean Sciences, Canada)

Link to the event page
http://bit.ly/2qHo2lp

The outcomes of the meeting contribute to the Cross-Cutting Theme 'Integrated Topics' (polar oceans and sea ice) of the SOLAS 2015-2025: Science Plan and Organisation.

Event sponsors

Ollie Legge studied oceanography at the National Oceanography Centre, Southampton, United Kingdom. Currently, he is doing his PhD at the University of East Anglia, Norwich, United Kingdom, focussing on carbonate system processes in the Southern Ocean.

Seasonal sea-ice impacts carbon dioxide uptake in the coastal Southern Ocean

Legge, O.J.[a,*], Bakker, D.C.E.[a], Johnson, M.T.[b], Meredith, M.P.[c], Venables, H.J.[c], Brown, P.J.[d], Jones, E.M.[e], and Lee, G.A.[a]

[a]Centre for Ocean and Atmospheric Sciences, University of East Anglia, Norwich, United Kingdom
[b]British Antarctic Survey, Cambridge, United Kingdom
[c]Centre for Environment Fisheries and Aquaculture Science, Lowestoft, United Kingdom
[d]National Oceanography Centre, Waterfront Campus, Southampton, United Kingdom
[e]Centre for Energy and Environmental Sciences, Energy and Sustainability Research Institute Groningen, University of Groningen, Groningen, Netherlands

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Approximately 15 million km^2 of the Southern Ocean is seasonally covered by sea-ice, yet the processes affecting carbon cycling and gas exchange in this climatically important region remain inadequately understood. The uptake of atmospheric carbon dioxide (CO_2) by the seasonally ice-covered Southern Ocean is poorly constrained due to a scarcity of observations (Bakker *et al*., 2016) and is not well represented in models (Lenton *et al*., 2013). Most estimates are largely based on the open ocean and do not account for the variability and importance of the coastal ocean. A unique coastal time series provides insights into the mechanisms controlling ocean-atmosphere CO_2 flux in this complex and under-sampled environment (Legge *et al*., 2017). Dissolved Inorganic Carbon (DIC) and Total Alkalinity (TA) measurements from the surface water of Ryder Bay on the West Antarctic Peninsula (Fig. 2) show strong, asymmetric seasonal cycles, driven by physical processes and primary production. In summer, the dominant process affecting the carbonate system is net photosynthesis which reduces DIC. Melting glacial ice and sea ice, and a reduction in mixing with deeper water further reduce DIC. This rapid decrease in DIC indicates that the ocean is a sink of atmospheric CO_2 in summer (Fig. 3). In winter, net heterotrophy and mixing with deeper water increase surface water DIC concentrations, making the ocean a source of CO_2 to the atmosphere. The direction of CO_2 exchange between the ocean and the atmosphere depends on the difference in the fugacity of CO_2 between the water and the

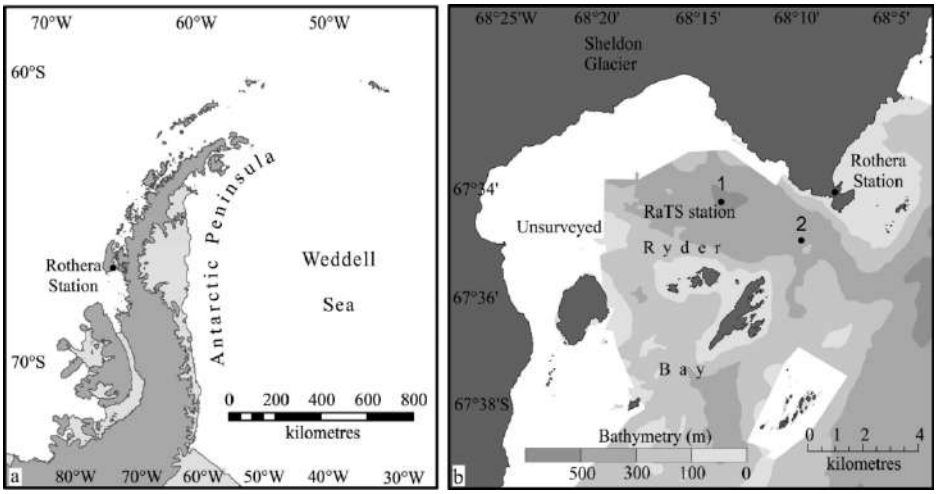

Figure 2: (a) Location of the Rothera Station on Adelaide Island at the West Antarctic Peninsula. (b) Location of the Oceanographic and Biological Time Series (RaTS) sites 1 and 2 in Ryder Bay.

air, but the rate of this exchange is strongly dependent on physical conditions such as wind speed and, importantly in this region, ice cover. Sea ice is present during winter in Ryder Bay (Fig. 2) which reduces the rate of winter outgassing. However, much uncertainty remains around how sea ice affects ocean-atmosphere gas exchange (Loose *et al*., 2014). Overall, Ryder Bay is found to be a net sink of atmospheric CO_2 of 0.90–1.39 mol C m^{-2} yr^{-1} (Legge *et al*., 2015) and the observed inter-annual variability in the time series demonstrates the influence of various processes on the strength of this sink. For example, during the winter of 2013, surface water CO_2 was higher than during the two preceding winters due to greater upwelling of DIC rich Circumpolar Deep Water. Also, sea ice cover was lower during this winter, allowing more CO_2 to be released to the atmosphere. As a result, winter outgassing was greater in 2013 than in the two preceding years, causing a weaker net annual sink of atmospheric CO_2. The DIC and TA time series in Ryder Bay was initiated in December 2010 and is ongoing, with a sampling interval

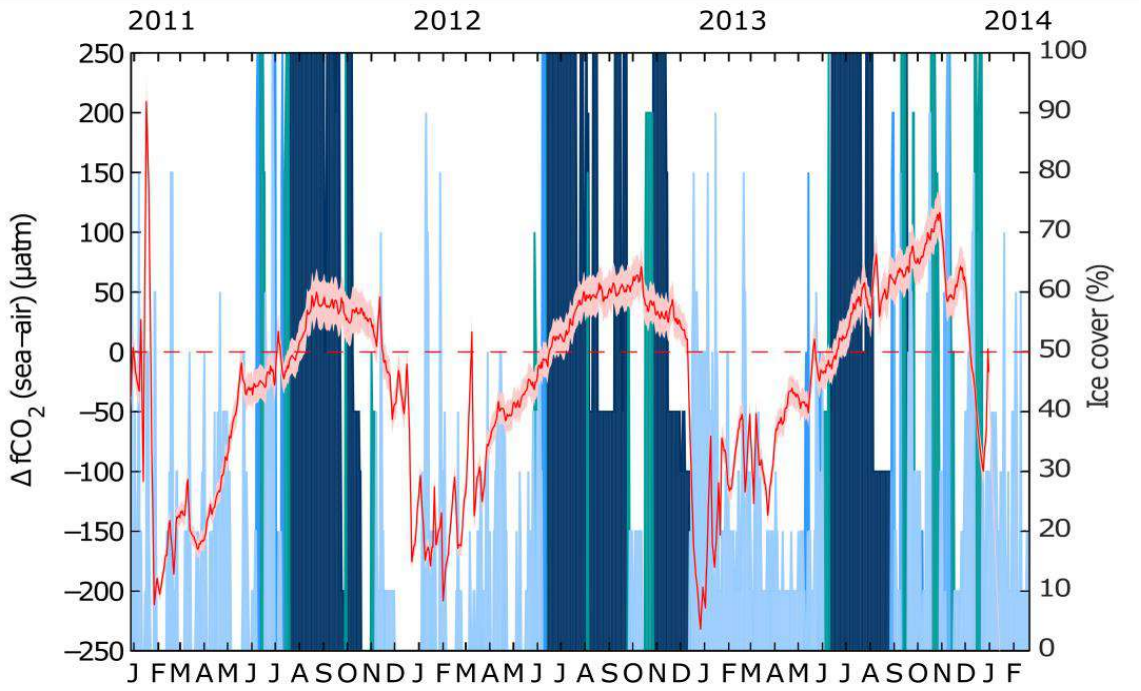

Figure 3: The difference in CO_2 fugacity between the air and the sea surface (red line), with negative values representing an ocean sink of atmospheric CO_2. Blue bars show percentage of ice cover in the bay with dark blue representing fast ice, turquoise representing pack ice and light blue representing brash ice.

of a few days to a few weeks. This growing dataset will continue to help us develop a better mechanistic understanding of the carbonate system in seasonally sea-ice covered waters.

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Marie Kotovitch is a PhD student at the University of Liège, Belgium and at the Université Libre de Bruxelles, Brussels, Belgium. During her master thesis, Marie was working on the exchanges of fluxes of carbon dioxide at the air-sea ice interface. Now as a PhD student, she expanded her focus by also taking other greenhouses gases, such as nitrous oxide and methane,

Greenhouse gases exchange at the air-sea ice interface

Kotovitch, M.[a,b,*], Delille, B.[a], Tison, J.L.[b], Moreau, S.[c], and Van der Linden, F.[a,b]

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[b]Université Libre de Bruxelles, Brussels, Belgium
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While greenhouse gases play an elemental role in climate change and global warming, sea ice is involved in gas exchanges between the ocean and the atmosphere. To investigate the relationship between these two processes, a tank experiment was conducted (Kotovitch *et al*., 2016). This tank allowed the controlled freezing of seawater and has been used to reproduce ice growth and decay over the course of 19 days. The temperature of the atmosphere above the tank water was set to -15 °C for 14 days. After 14 days, the temperature was set to -1 °C until the end of the experiment (day 19). During the time of the experiment, the *in situ* ice temperature, the temperature above the ice, the underwater salinity, and the air-ice carbon dioxide (CO_2) flux were measured continuously (Fig. 4). Additionally, ice cores were collected on a regular basis to measure biogeochemical variables. Results indicate that sea ice shifts from: (i) being a sink for CO_2 during the first crystals formation, (ii) to being a source for CO_2 during ice growth and, finally (iii) return to a CO_2 sink during ice melt. To mimic the observed air-ice CO_2 fluxes, we used a 1D model (Fig. 5, Moreau *et al*., 2015). The inversion between outward CO_2 fluxes during ice growth and

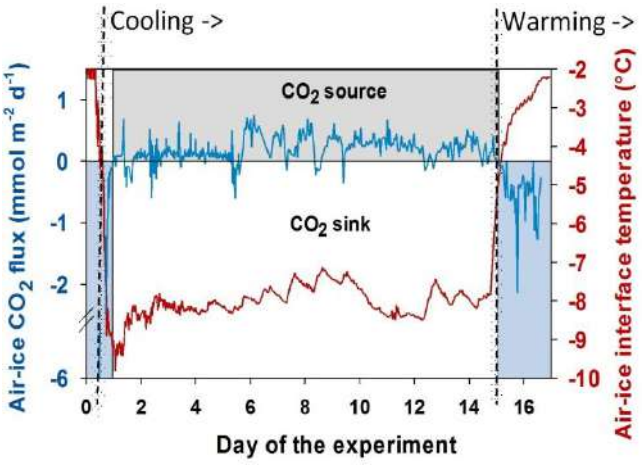

Figure 4: Air-ice CO_2 fluxes and air-ice interface temperature during the cooling and the warming stages. Air-ice CO_2 above 0 mmol m^{-2} d^{-1} represent a CO_2 source and values below represent a CO_2 sink.

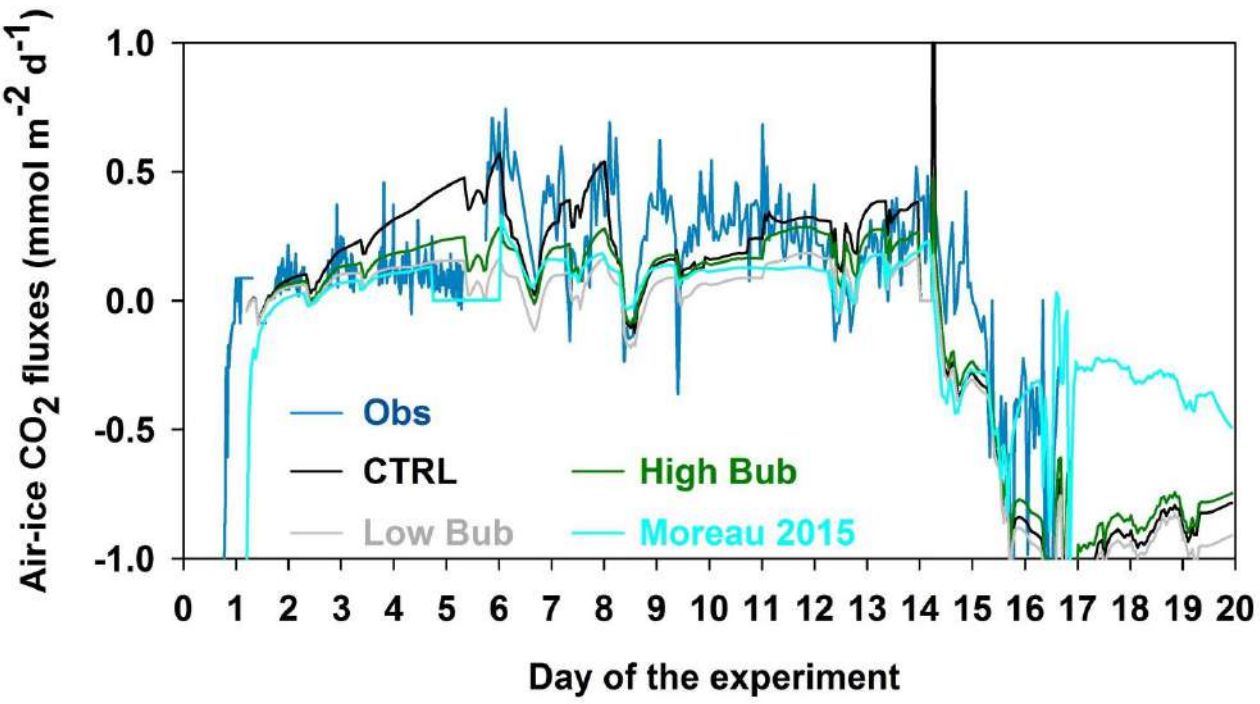

Figure 5: Observed (Obs, dark blue) air-ice CO_2 fluxes and simulated air-ice CO_2 fluxes including: low and high gas bubble formation rate (Low Bub, grey; High Bub, green), the control simulation (CTRL, black) and with the bubble formation rate by Moreau *et al.* (2015) (light blue).

inward CO_2 fluxes during ice melt depicts well the observations. However, the model (Moreau *et al*., 2015) strongly underestimates the fluxes during the cold phase if the formation rate of gas bubbles is low. Since ice is permeable throughout the cold phase, higher gas bubble formation rates lead to higher CO_2 fluxes (i.e. gas bubbles escape the ice surface and add to the outward CO_2 flux).

Our final aims are to develop air-sea ice fluxes measurements for other greenhouse gases and to compute global budget for each of these gases.

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James Lawrence France studied geosciences at Royal Holloway, University of London in 2000-2004 and continued for a PhD in snow chemistry and subsequent post-docs in photochemistry and then Arctic methane. He moved to the University of East Anglia, Norwich, United Kingdom in 2014 to help build a new experimental sea-ice facility which he now runs.

Methane fluxes from sea-ice in the Roland von Glasow Air-Sea-Ice Chamber

France, J. M.*, and Thomas, M.

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The Roland von Glasow Air-Sea-Ice Chamber (RvG ASIC) is a purpose-built sea-ice facility designed to allow investigations into young sea-ice within the relative safety and comfort of a controlled laboratory environment. The facility was the brainchild of Professor von Glasow, who sadly passed away very suddenly in late 2015. The facility couples the ocean, sea-ice and atmosphere making it ideal for investigating processes that occur across the sea-ice interface, which is technically and logistically very challenging in the field. Other sea-ice facilities exist around the world (such as the Sea-ice Environmental Research Facility at Manitoba, Canada), but we have aimed to create something new by building a coupled ocean-sea-ice-atmosphere system illuminated by optional ultraviolet and visible lighting to create a microcosm of the Polar oceans. The sea-ice tank is 2.4 m length by 1.4 m wide by 1 m deep with optional additional up to 1 m high polytetrafluoroethylene-fluorinated ethylene propylene atmosphere and housed in an environmental chamber capable of temperatures -55 to +35°C with stability of ~ ±0.3°C (Fig. 6).
The key features of the facility are:

- Coupled ocean and atmosphere;
- Capable of growing sea-ice to ~30 cm;
- Programmable, temperature controlled environmental chamber;
- Each section (ocean, ice or atmosphere) can be sampled separately;
- Focus on continuous/non-destructive sampling where possible; and
- Real-time data collection.

We have been performing a range of proof of concept experiments for the last 12 months in order to demonstrate the viability of the facility for a range of research uses. Various experimental set ups have been tested in order to validate the methodologies used at the facility. However, for this experiment we focused on investigating the uptake in sea-ice and flux to the atmosphere of dissolved greenhouse gases as sea-ice grows and melts (other work undertaken has included investigating sea-ice physics, sea-ice radiative-transfer and chemical pollutant uptake into sea-ice). Previous work on gas transfer through sea-ice has shown that methane can be released from the sea to the air during sea-ice break up

Figure 6: The sea-ice chamber under visible light illumination. In this instance, a polytetrafluoroethylene-fluorinated ethylene propylene atmosphere is partly enclosing the tank which measures 2.4 m x 1.4 m x 1.1 m and contains ~3,500 litres of sea-water saturated with methane.
© James Lawrence France.

(Kort *et al.*, 2012; Damm *et al*., 2015), so to test this hypothesis the tank was filled with North Sea water. The water was sand filtered and treated with ultraviolet C radiation to remove biology and then supersaturated with methane to reproduce Arctic Ocean conditions (Damm *et al.*, 2015). Sea-ice was then allowed to form to a thickness of ~14 cm with an atmospheric temperature of -18°C above the tank. The tank is fully insulated at the sides and base to prevent supercooling and platelet ice forming within the water column, and to ensure that ice can only form due to cooling at the top of the water column, as occurs in the real-world system. Continuous measurements of methane were made above the ice, and spot samples from the ocean taken from beneath the ice using a heated line through the side of the tank. Post experiment, ocean samples and sea-ice samples were then sent for analysis at University of Liège (Liège, Belgium) and Alfred Wegener Institute (Bremerhaven, Germany). In collaboration with these two institutions, we have seen a methane efflux above the ice upon the initial warming stage of the experiment, post-ice formation (Figure 7). The increased methane mixing ratios were ~10% increase over atmospheric background, but it is uncertain as to whether it is methane from the water column travelling through the ice or from release of methane in brine or air pockets trapped within the ice. Experiments to further investigate this are required and planned for later in the year as well as detailed analysis of the spot samples taken during the experiments. As part of BEPSII and the new SCOR working group 152 on Essential Climate Variables in Sea-Ice, we are now in the planning stages for a large intercalibration experiment at the RvG ASIC to measure concentrations of climatically important gases in the sea-ice using a variety of methods to test their robustness and intercomparability. The RvG ASIC is open for collaborative science and can also be accessed through the transnational access scheme run through EUROCHAMP 2020

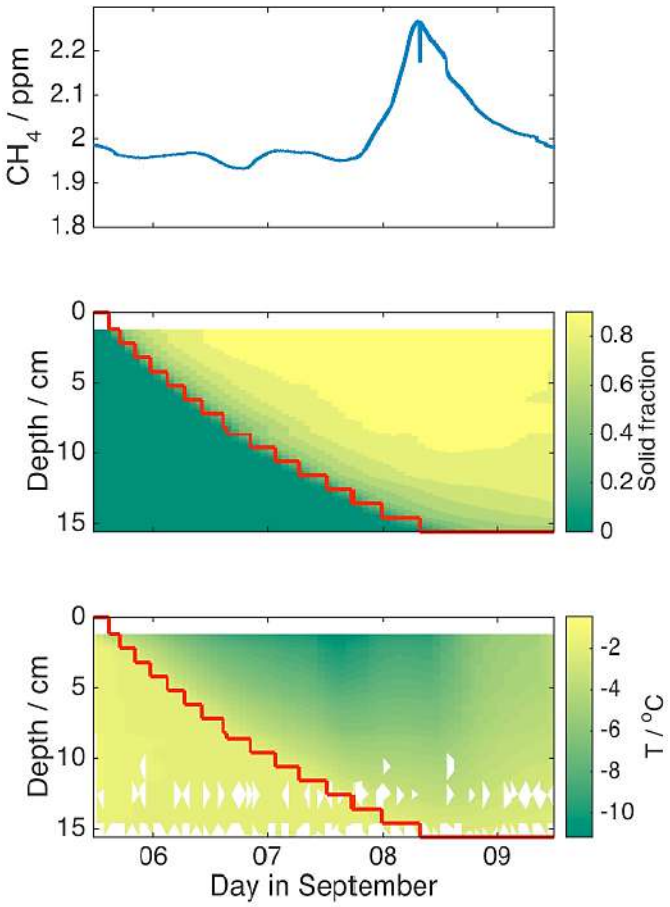

Figure 7: Timeline of the experiment by various parameters. Top: Methane mixing ratio in the atmosphere above the tank. Middle: The solid fraction of ice versus depth into the ice. Bottom: In-ice temperature versus depth and ice thickness (red line). Note that the methane efflux coincides with the ice beginning to warm.

(http://www.eurochamp.org/). Please contact James France for further details about potential collaborative work using the facility.

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Acknowledgements

This work and the existence of the facility would not have been possible without the hard work of the late Prof. Roland von Glasow, to whom the facility is devoted. His European Research Council Consolidator Grant (ERC 616938) allowed the construction of the chamber and we hope that it will contribute to sea-ice interface research. We would also like to thank Bruno DeLille, Ellen Damm, Jean Louis Tison and Marie Kotovitch for their extensive time and input into this ongoing work.

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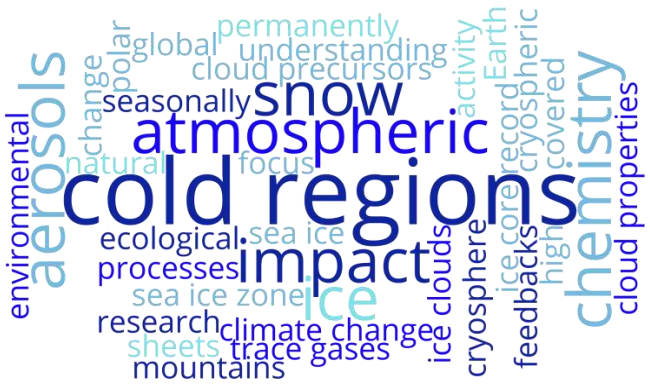
Report 04 I July 2017

Community workshop on:

“Cryosphere and Atmospheric Chemistry (CATCH)”

19 - 21 April, 2017
Guyancourt, France



The first workshop of the “Cryosphere and Atmospheric Chemistry” (CATCH), a new IGAC activity, took place at the Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS) in Guyancourt, France from 19 to 21 April 2017. CATCH aims to build a network of scientists to facilitate atmospheric chemistry research within the international community with a focus on the chemistry, biology and physics of the natural environment in cold regions. The two main workshop objectives were 1) to foster future collaborative work by highlighting cross-disciplinary research questions and 2) to identify future research needs and opportunities.

In total, 48 scientists from 14 countries from a wide range of disciplines and all career stages, including many graduate students and postdocs, came together to present over two days their science related to CATCH in short talks or posters and to discuss ways of how to develop this new initiative. The themes of the eight sessions were each introduced with a general overview talk accessible to non-specialists, followed by shorter science talks on a specific topic and then a general discussion. Poster sessions during lunchtime

In this report

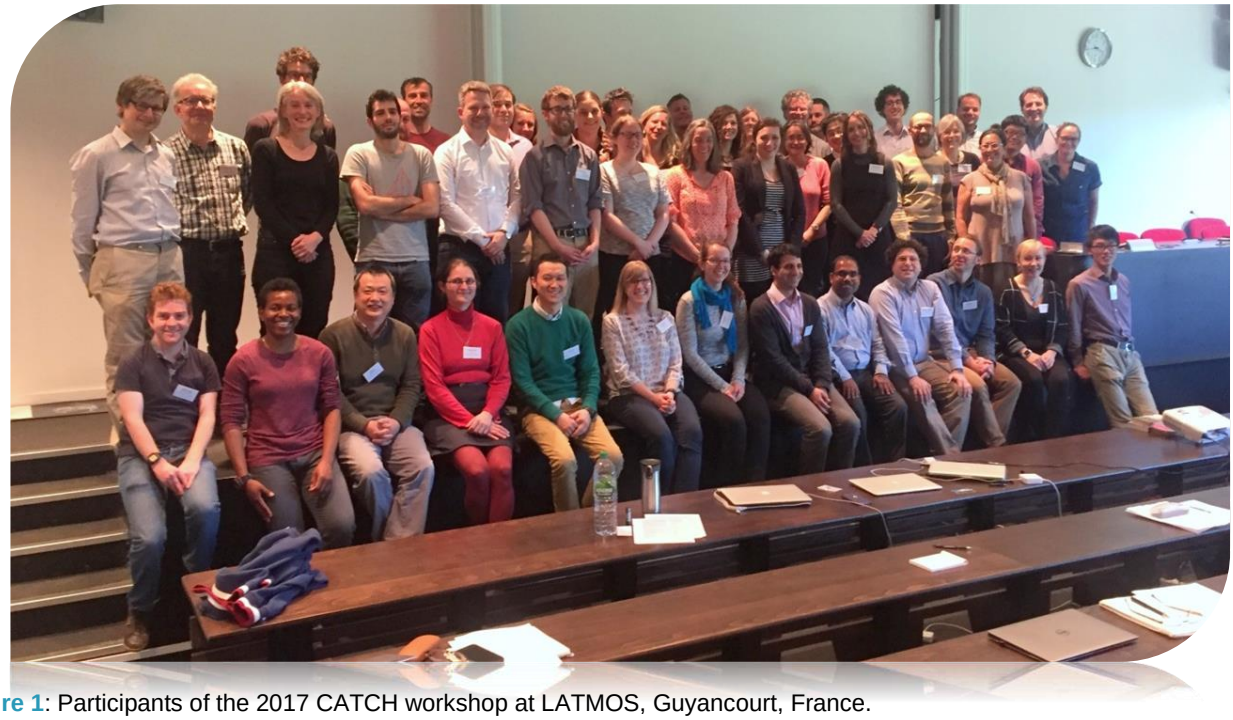


Figure 1: Participants of the 2017 CATCH workshop at LATMOS, Guyancourt, France.

Left to right - Back row: Thorsten Bartels-Rausch, Pablo Corrochano, Manuel Dall'Osto, Jochen Stutz, Gesa Eirund, Audra McClure, Aurelien Dommergue, Catherine Larose, Markus Frey, Martine Lizotte, Jennifer Murphy, Didier Voisin, Paul Griffiths, Kenjiro Toyota, Louis Marelle, John Burkhart, Alfonso Saiz-Lopez.
Middle row: Dominik Heger, Niels Bohse Hendriksen, Anna Jones, Niccolò Maffezzoli, Björn-Martin Sinnhuber, Wes Halfacre, Jo Browse, Megan Melamed, Samantha Tremblay, Valérie Gros, Becky Alexander, Roberto Grilli, Kathy Law, Taneil Uttal, Lei Geng, Jennie Thomas.
Front row: James France, Jacinta Edebeli, Xin Yang, Stefanie Falk, Kitae Kim, Kerri Pratt, Megan Willis, Michael Giordano, Kirpa Ram, Marcelo Guzman, Ben Murray, Tuija Jokinen, Xucheng He.
Missing: Claudia Di Biagio and Solène Turquety. © Jennie Thomas

provided opportunities for informal discussions and networking. After the workshop, members of the CATCH implementation team (for information on team members, see box below the summary) and some participants met for an extra day to plan the future of CATCH.

Background - The cold and polar regions are currently undergoing significant changes with implications for regional and global climate, ecosystems and society. The underlying natural chemical, biological and physical processes and feedbacks, which control the Earth system in the cold regions, are still poorly understood. However, reliable predictions of environmental change require a quantitative understanding of processes and feedback mechanisms, which can only be achieved through trans-disciplinary and international collaboration. Thus, workshop session themes included: aerosol and clouds; biogeochemistry and biology; halogens, ozone, and mercury; surface processes and ice, fundamentals of chemistry in cold regions; as well as project overviews and facilities. The discussions were used to brainstorm and identify issues and open questions, a selection of which is briefly summarised below.

Aerosol and clouds - Atmospheric aerosol and associated climate impacts, particularly in cold regions have one of the largest model uncertainties (Flato *et al*., 2013), which need to be resolved. In particular, origin, fate and cloud forming capability of particles formed at or near the surface in the Arctic and Antarctic are not well understood. However, a quantitative understanding of natural processes is needed, e.g. to reduce the model bias above the Southern Ocean linked to errors in representation of clouds and precursors (Flato *et al*., 2013) or to assess and

mitigate the anthropogenic impacts from increased ship emissions in the high Arctic. Furthermore, fundamental aspects of the ability of aerosol to form clouds such as the difference in importance as cloud condensation nuclei or ice nuclei are still unresolved. It became clear that better links to the aerosol and cloud microphysics community, facilitated by CATCH, would likely enable a step change for answering some of the open questions.

Biogeochemistry and biology - Changes in the cryosphere, such as those observed in seasonality, extent and thickness of sea ice have profound impacts on biogeochemistry and biology. These changes include impacts on ecosystems, feedbacks on greenhouse gas emissions, and changes in the cycling of elements. Therefore, the engagement of scientists investigating the biology of the surface ocean and sea ice is crucial to CATCH. Workshop participants who are also involved in the projects "Biogeochemical exchange processes at Sea Ice Interfaces" (BEPSII) and SOLAS highlighted that many areas of research at the air-sea ice-ocean interface would benefit tremendously from collaboration and joint activities with CATCH.

Halogens, ozone, and mercury - Even though the atmospheric chemistry of halogens, ozone, and mercury above snow and ice covered regions has been the subject of research for the last 30 years, the relevant processes are not yet systematically integrated into regional and global models. A recent report evaluated air pollution in the Arctic, focusing on short-lived climate forcers such as ozone and black carbon (AMAP Assessment, 2015). But associated wider impacts of natural air-snow processes on climate and air quality have not been evaluated systematically. It was also pointed out that in some areas the fundamental process understanding is not yet mature enough to be included in general circulation models. Another issue raised, was that the interpretation of atmospheric observations needs to integrate better available information and expertise from the fields of atmospheric boundary layer physics, as well as snow physics and chemistry. Better integration of the science community can be achieved by network initiatives such as CATCH. And finally, it was recognised that results from laboratory experiments, e.g. reaction rates, need to be evaluated critically before they are transferred to the real world.

Surface processes and ice, fundamentals of chemistry in cold regions - An on-going debate related to surface processes and ice, and fundamentals in chemistry, revolves around the nature of the air-ice interface and how it affects uptake, release and chemical reaction rates (Bartels-Rausch *et al*., 2016). A challenge researchers are facing is to identify the origin of model errors. Knowing the source of uncertainties would allow to better target relevant and important processes in field and laboratory experiments. In order to realise these experiments, field and modelling communities need to work together to develop hypotheses, which are then tested in the laboratory. It is recognised that scale matters, i.e. global models may not be sensitive to some parameters (e.g. reaction rate constants) and therefore reducing their uncertainty would not result in much improved model performance.

Project overviews and facilities - The study of natural processes in the cold and polar regions is highly inter-disciplinary, logistically challenging and expensive. It therefore relies heavily on international collaboration, which enables shared access to research facilities and collaborative research projects. Workshop presentations highlighted existing opportunities for field work at research stations in the Arctic (e.g. Villum Station North or Summit Station, Greenland), in the Antarctic (e.g. Halley Station), at terrestrial snow sites (e.g. Finse Research Station, Norway, and Joseph Fourier Alpine Station, France), on research ice breakers, but also in mesocosms (e.g. the Roland von Glasow Air-Sea-Ice Chamber, University of East Anglia, United Kingdom). Existing network activities and projects such as "Air

Pollution in the Arctic: Climate, Environment and Societies" (PACES), BEPSII or "Network on Climate and Aerosols: Addressing Key Uncertainties in Remote Canadian Environments" (NETCARE) have overlaps with CATCH and a liaison with some of them would clearly enhance CATCH research and impact.

Next steps of CATCH - There was consensus that the focus in the next two years will need to be on identifying key research questions, which CATCH will then address through a number of activities. Such activities can include developing a white paper, scientific reviews, research proposals, a summer school, and coordinated field campaigns (Fig. 2).

Workshop feedback - Overall, 23 responses were received from a post-workshop survey, which rated the workshop as excellent regarding overall quality (60%) and organisation (74%), range of scientific topics covered (52%), and the quality of scientific discussions (39%). The latter may be due to the lack of time for in-depth discussions (48%), which is probably characteristic for inter-disciplinary workshops covering such a large range of topics. The workshop objectives were met (87%), in particular enough time was given for networking and informal discussions (91%). Thus, a majority of participants recognised either many opportunities (30%) or at least some chance for collaborations and future work (52%). An important challenge CATCH is facing based on various comments is that on the one hand CATCH needs to find the right balance of being focused and define research questions, which allow distinction from other initiatives and on the other hand remain inclusive and not too narrow in scope.

Overall, everyone left the workshop after two full days of intense discussions invigorated and with the positive feeling of having learned about neighbouring science disciplines and having met new collaborators and colleagues. We thank the workshop sponsors and all the participants to have come from near and far to join CATCH, to engage in truly cross-disciplinary and international dialogue and scientific discussions which often require a lot more patience than talking to your specialist colleague. We are also thankful to

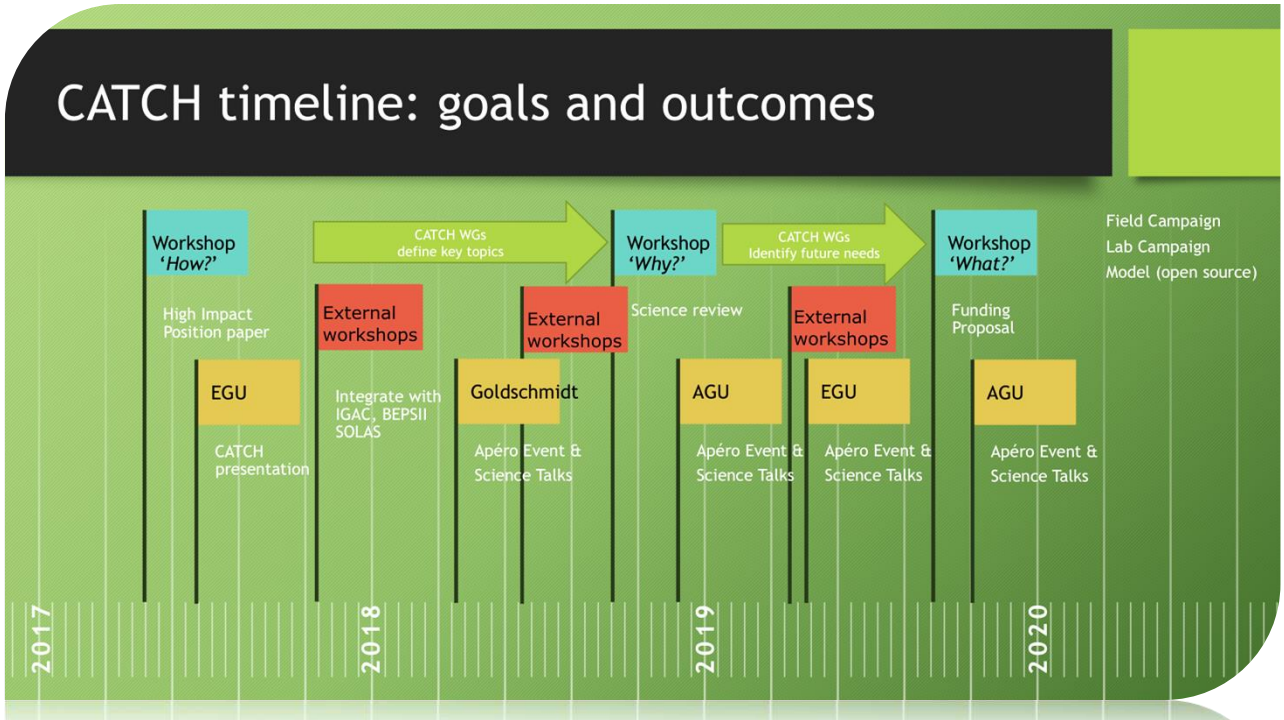


Figure 2: A potential timeline for the development of goals and anticipated outcomes of CATCH. © Thorsten Bartels-Rausch

IGAC executive officer Megan Melamed who moderated the science strategy discussions. We are looking forward to taking the next steps in the development of CATCH.

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Link to the event website: http://bit.ly/2rpJXlI

The outcomes of this workshop contribute to advance our knowledge of the Core Theme 4 “Interconnections between aerosols, clouds, and marine ecosystems” and Cross-Cutting Theme “Integrated Topics” of the SOLAS 2015-2025 Science Plan and Organisation.

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Martine Lizotte obtained her PhD at Laval University, Canada, investigating the oceanic cycling of dimethylsulfide (DMS). Since 2010, she has been working on the impact of various environmental stressors (ocean acidification, iron depletion, light) on the biogeochemistry of DMS, with a more recent focus on Arctic regions.

High-frequency profiling of oceanic dimethylsulfide in a fast changing Arctic

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There is mounting evidence that marine dimethylsulfide (DMS)-derived aerosols may significantly contribute to cloud albedo forcing in the pristine atmosphere of the Arctic during summer (Leaitch *et al*., 2013). At a time when the top of the Earth is unremittingly turning from white to blue, due to reductions in sea-ice extent, understanding what drives the cycling of DMS within the hydrosphere-cryosphere complex, has become a pressing matter. Localised hotspots of DMS have been observed in association with sea-ice habitats such as brine channels in bottom-ice and melt ponds at the ice's surface (Levasseur, 2013). With expanses of sea-ice being extremely dynamic, i.e. subject to pronounced freeze-melt cycles and advective processes giving rise to fractures, leads and drifting floes, DMS-producing communities are often exposed to large fluctuations in temperature, salinity, and light. Autotrophic organisms, both pelagic and sympagic, may cope with these strong environmental gradients by synthesising the compatible solute and precursor of DMS, dimethylsulfoniopropionate (DMSP), known for its roles in osmoregulation, cryoprotection, and scavenging of free radicals (Stefels *et al*., 2007). Beyond the potential direct enzymatic conversion of DMSP into DMS by autotrophic organisms themselves, heterotrophic bacteria's use of DMSP as a source of carbon also leads to the production of DMS. Zooplankton grazing and viral attacks on phytoplankton may further contribute to the community DMSP-to-DMS yield; undoubtedly making the cycling of DMS a "food web affair". As the Arctic continues to change, thinning and retreating of sea-ice allows for the earlier onset of phytoplankton blooms potentially rich in DMS, even under the ice itself, as many autotrophic organisms possess low light adapted photosystems. Increasing amounts of protons (H^+) and decreasing reservoirs of carbonates ensuing from ocean acidification, may impact DMS-producing communities (Hussherr *et al.,* 2017). And what of increasing temperatures, changes in nutrient availability, potential shifts in community dominance and successions, as well as other fast-pace changes that lie in wait? As of yet, establishing large-scale empirical relationships among oceanic DMS pools, changes in sea-ice extent, and phytoplankton productivity has prov-

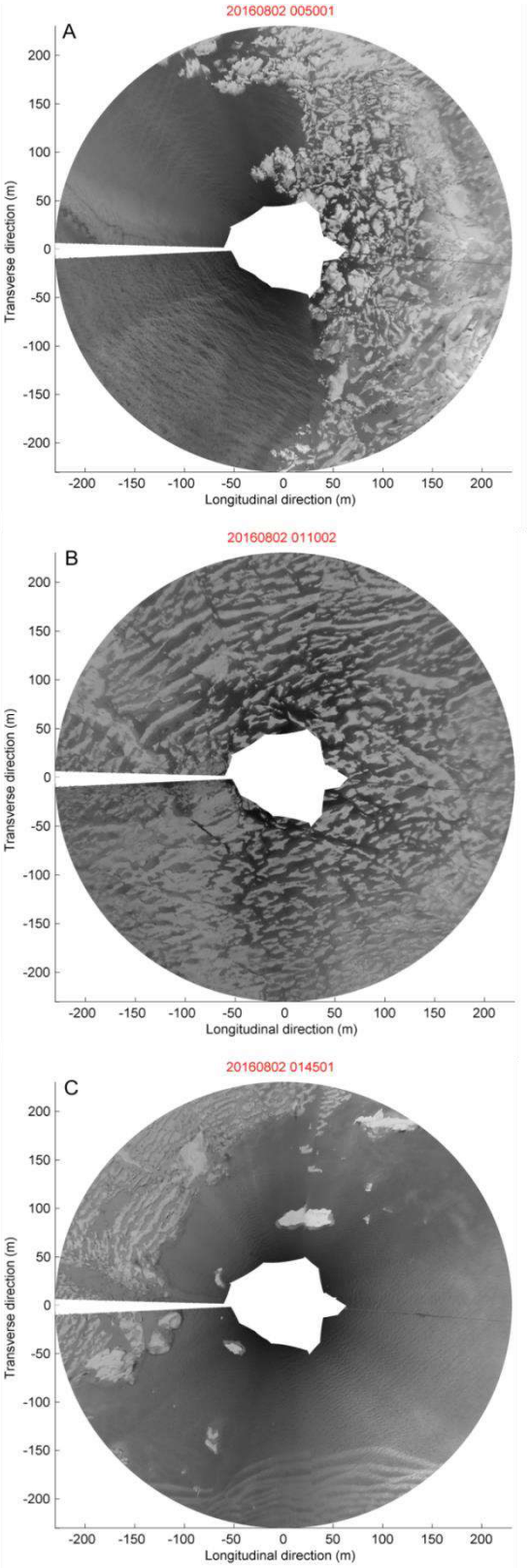

Figure 3: A 360° landscape imagery collected by the Canadian Coast Guard Ship 'CCGS Amundsen' in the Canadian Arctic in 2016. Processed data, composite image of a 12-lenses array of cameras located above the bridge. Version 1. Accessed in mid-August 2016. (A) Icebreaker entering a giant ice floe in Northern Baffin Bay; (B) Icebreaker passing through the ice floe exhibiting significant melt pond cover; (C) Icebreaker exiting the ice floe.

en to be challenging. This is partly because concurrent measurements of those parameters at relevant time and spatial scales are scarce. However, the advent of high-frequency underway measuring systems, coupled with satellite and 360° landscape imagery (Fig. 3) now provide remarkable frame of reference to tackle these issues. During the joint Arctic Network of Centres of Excellence of Canada/Network on Climate and Aerosols (ArcticNet/Netcare) campaign in 2016, our team explored SOLAS-relevant DMS topics through the deployment of automated underway systems, acquiring unique datasets, which would be otherwise industrious to collect. Transiting through a giant drifting ice floe (Fig. 3) revealed elevated DMS concentrations associated with an abrupt freshening of sub-ice waters suggesting a potential up-regulation of DMS production under salinity downshock or under increased doses of solar radiation. Further work is needed to explore large-scale relationships within the extensive dataset collected, but already this information has started to feed into Netcare modelling products that will further our predictive capabilities of the potential impact of DMS on climate.

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Kitae Kim completed his doctorate in environmental science, focussing on enhanced inorganic redox reactions in ice and their environmental implications, at the Pohang University of Science and Technology, Korea. In 2012, he started his career at the Korea Polar Research Institute, where he is investigating intrinsic chemical reactions in ice and its impacts on polar regions.

Abiotic production of reactive iodine species in ice and its implication

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Reactive halogens (including chlorine, bromine, and iodine) play a significant role in ozone depletion events, oxidizing capacity in the atmosphere, mercury depletion events, the perturbation of the hydroxide/nitrogen oxide cycles, and in dimethylsulfid oxidation to form cloud condensation nuclei. Compared to chlorine and bromine compounds, the fate of iodine species in polar region has been less investigated; although, iodine has a key role in forming ultrafine aerosols which may influence solar radiative force and finally also the climate (Abbatt *et al*., 2012; Saiz-Lopez *et al*., 2012; Simpson *et al*., 2015). While the high concentration of atmospheric active iodine monoxides during the Antarctic spring season have been observed by ground and satellite based techniques, sources and mechanisms of this large iodine burden are not yet fully understood (Saiz-Lopez *et al*., 2007). Especially abiotic sources of atmospheric iodine from the Antarctic are less understood when compared to biological iodine sources from micro- or macro algae. In general, chemical reactions are slow when temperature drops according to Arrhenius equation (IUPAC, 1997); however, some processes are accelerated by freezing (Takenaka *et al*., 1992; Kim *et al*., 2010). The oxidation of nitrite to nitrate, which is a very slow reaction, was significantly accelerated by freezing. When a solution solidifies, the organic/inorganic compounds are being concentrated in unfrozen parts of the ice. This so called freeze concentration effect affects chemical variables such as protons, dissolved gases and the concentration of reactants. Thereby, this effect is regarded as the main driving force for the enhanced processes in sea ice (Fig. 4). Our experimental results show that the production of tri-iodide via iodide oxidation, which occurs negligibly in aqueous solution, was signif-

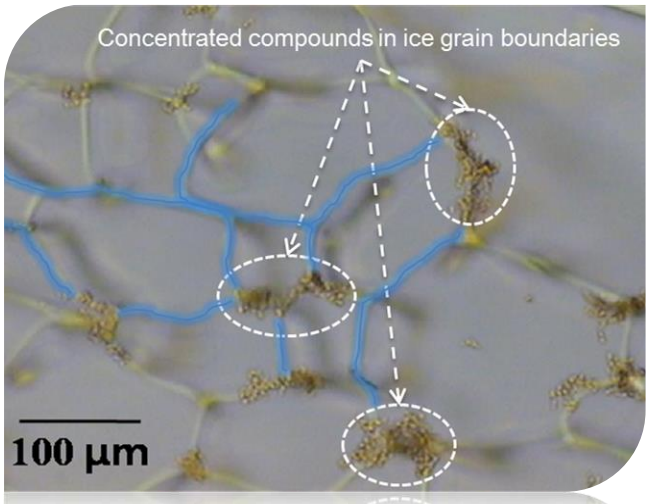

Figure 4: Microscopic image showing the freeze concentration phenomena of the concentrated compounds (circled) by freezing in ice grain boundaries (blue).

icantly accelerated in the ice phase, in the presence and absence of irradiation (Kim *et al*., 2016). The produced tri-iodide is converted into iodine molecules and iodide ions (Fig. 5). Once the iodine molecule is released into the atmosphere, it forms iodine oxides via photolysis and then affects the formation of ultrafine aerosol particles. Field experiments carried out under ambient conditions for the Antarctic region (King George Island, 62°13′S 58°47′W, sea level), confirmed that the formation of tri-iodide via photo-oxidation is enhanced when iodide is trapped in the ice media. An enhanced release of gaseous iodine molecules and iodine monoxide radical was observed by Cavity Ring Down Spectroscopy. The enhanced oxidation of iodide and iodine molecules formation in ice is largely owing to the freeze concentration of iodide, protons, and dissolved oxygen in the ice crystal grain boundaries. This result shows that the intrinsic chemical reaction of iodide and the following release of gaseous iodine molecules can be accelerated in ice media and consequently may contribute to ozone depletion events and new particle formation in cold environments.

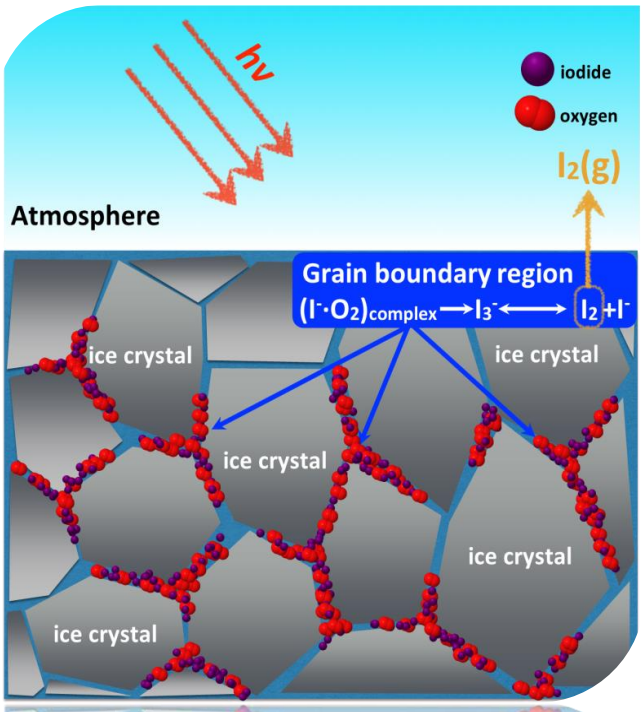

Figure 5: Schematic diagram for the enhanced production of reactive iodine compounds in ice (iodide I^-, iodine molecules I_2, tri-iodide I_3^-).

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Acknowledgements

I thank CATCH and the Korea Polar Research Institute for allowing me to participate in the first CATCH workshop.

Jo Browse studied Physics at the University of Edinburgh, United Kingdom, before moving to Leeds in 2008 to start her PhD. In 2016, Jo started as a lecturer in physical geography at the University of Exeter, United Kingdom. She develops complex models to forecast the evolving Arctic environment.

The problem with Arctic clouds

Browse, J.*[,a], Pringle, K.[b], Yoshioka, M.[b], Johnson, J.[b], and Carslaw, K.[b]

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Modelling studies have suggested that the Arctic cloud response to sea-ice retreat may mitigate the ice-albedo feedback (Struthers *et al.,* 2011). However, the response of Arctic clouds to increasing temperatures (in particular with respect to aerosol interactions) is uncertain (Browse *et al.,* 2014). This uncertainty derives from multiple factors, most significantly, from our lack of understanding of the source of high-latitude cloud condensation nuclei, to which Arctic clouds are peculiarly sensitive (Birch *et al.,* 2012). Observations suggest a combination of primary and secondary sources ranging from ammonia induced nucleation of dimethylsulfide derived sulphur dioxide (Croft *et al.,* 2016) to organic (microgel) emissions from sea-ice leads and polynyas (Orellana *et al.,* 2011). However, models struggle to reproduce observed Arctic cloud condensation nuclei (Fig. 6) and cloud droplet concentration using existing nucleation parameters or scavenging processes. Indeed, the introduction of sophisticated aerosol nucleation schemes has in many cases reduced the skill of our models in the Arctic (Fig. 6). Furthermore, while it is possible to 'fill the gap' in modelled cloud condensation nuclei with numerous tuned emission fluxes or processes, the response of Arctic cloud albedo to sea-ice retreat is likely predicated on the assumed dominant aerosol source (Browse *et al.,* 2014).

Thus, we will investigate the urgent 'problem with Arctic clouds' in global climate models. We will introduce novel modelling methods which could inform observation. These include the use of perturbed parameter ensembles (Fig. 7) and emula-

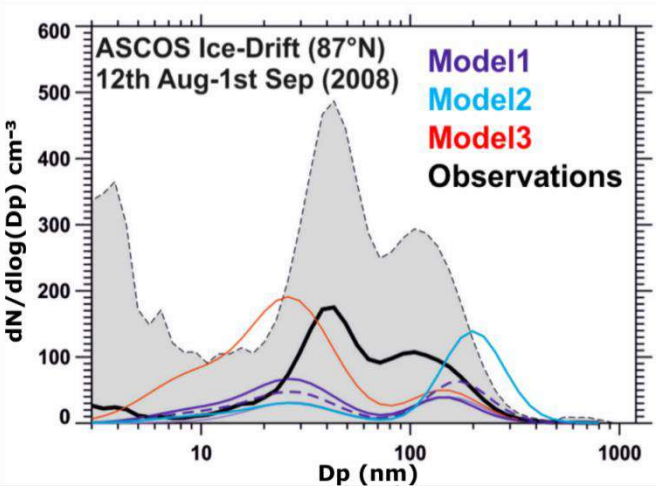

Figure 6: Arctic aerosol size distribution observed during the Arctic Summer Cloud Ocean Study (ASCOS) at 87°N (grey shading) and median of observations (black), compared to a model with a high wet scavenging rate (Model 1), a low wet scavenging rate (Model 2) and a model where boundary layer nucleation is linearly dependent on sulphur dioxide concentration only (Model 3).

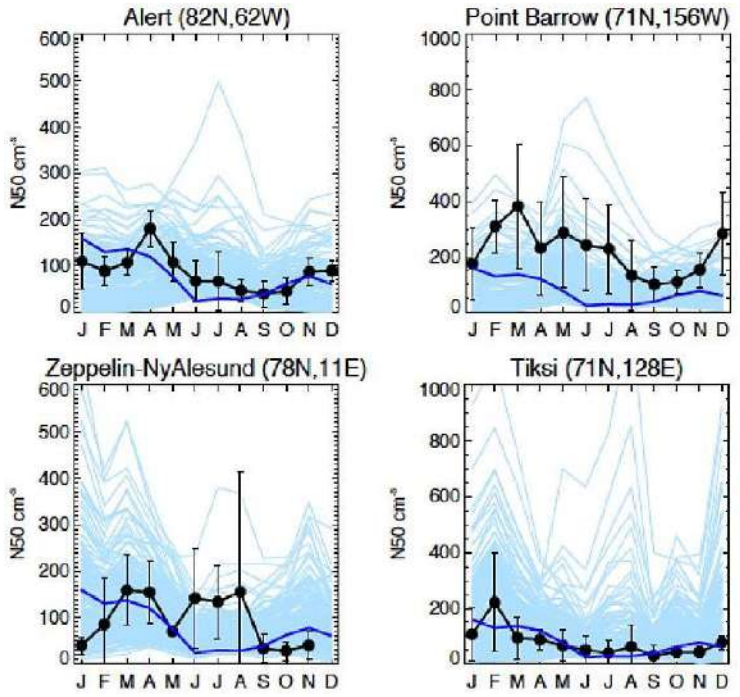

Figure 7: Example of a 'particles with diameter >50 nm' (PPE N50) output compared to observations at four Arctic ground stations. Model runs are shown in light blue and observations in black. Error bars indicate temporal error in monthly mean observation. The median (baseline) run is shown in dark blue. Acknowledgements: Original model runs completed by Pringle, K. and Yoshioka, M.

tion methods to quantify parametric model uncertainty and identify crucial yet poorly constrained parameters contributing to model error. Finally, we call for a combined use of modelling and observational techniques across diverse fields to address the following knowledge gaps:

- Understand the nucleation process in the Arctic boundary layer, including the likely significant but unconstrained role of biological sources.
- Determine the importance of primary biogenic emission in the Arctic to Arctic cloud condensation nuclei and cloud forcing.

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Report 05 I September 2017

Workshop on:

“Frontiers in ocean-atmosphere exchange: Air-sea interface and fluxes of mass and energy”

15 - 18 May, 2017
Cargèse, Corsica, France

On 15 - 18 May 2017 a workshop on “Frontiers in ocean-atmosphere exchange: Air-sea interface and fluxes of mass and energy” took place at the Institut d'Etudes Scientifiques de Cargèse, Corsica, France, which is a unique facility for hosting scientific workshops and summer schools.

The motivation behind the workshop derived from the recently-produced SOLAS 2015-2025: Science plan and organisation, which focus is on linking ocean-atmosphere interactions with climate and people. This new science plan is based on five Core Themes, with the workshop focussing on Core Theme 2: “Air-sea interface and fluxes of mass and energy”. Ocean-atmosphere fluxes of momentum, heat, freshwater, gases, and aerosols play a critical role in the regulation of climate and uncertainties in these fluxes constrain our ability to understand and model our changing climate. All exchanges between the ocean and the atmosphere cross the air-sea interface and it is through these fluxes that the ocean and atmosphere are connected. The problem of adequately describing air-sea fluxes is complex and simplistic parameterisations to represent the fluxes in models are not sufficient.

A full understanding of the processes at the air-

In this report

Figure 1: Participants of the Workshop.
Back row from-left-to-right: Lucia Robles-Diaz, Valentina Giunta, Lucia Gutiérrez-Loza, Graig Sutherland, Magdalena Anguelova, Kyeong Ok Kim, Francesc Peters, Henry Potter, Anoop Mahajan, Nicolas Meskhidze, Sebastian Zeppenfeld, Wade McGillis, Rik Wanninkhof, Evangelos Voyiatzis, Eun Jin Kim, Anna Rutgersson, Anja Engel.
Front row from-left-to-right: Leonie Esters, Stéphane Laussac, Joel Sudre, Liselotte Tinel, Christa Marandino, Nathalie Hayeck, Adrian Callaghan, Matt Salter, Tom Bell, Oyvind Breivik, Kai Christensen, Ilan Koren, Peter Liss, Royston Uning, Johnson Zachariah, Luisa Galgani, Anneke ten Doeschate, Brian Ward, Penny Vlahos.

sea interface will only evolve by interdisciplinary efforts. Thus, twelve speakers from different research disciplines were invited to present their work. The programme should promote strong interaction between the participants and invited speakers, with the presentations in the morning and interdisciplinary breakout sessions in the afternoon, each led by two invited speakers. These sessions were followed by poster presentations, particularly from doctoral candidates and early career scientists.

The initial session was an overview of basic SOLAS themes and presented scientific highlights of the past decade. Additionally, fundamental science topics such as air-sea gas exchange, the microlayer, the role of surfactants and bubbles were discussed, as well as policy-relevant activities like the carbon cycle, the ocean as carbon dioxide sink, ocean acidification, ship emissions, and marine particles were covered. A session on clouds and rainfall as part of the ocean-atmosphere system demonstrated that global warming, which is attributed to anthropogenic climate change, has been linked to changes in the global hydrological cycle. Ocean salinity is a much more reliable indicator of the water cycle than any land-based measurement. Salinity is an important constraint in ocean models and an indicator of freshwater capping. Sea surface salinity is correlated with differences between precipitation and evaporation, and improved knowledge on these differences would provide a better estimation of latent heat flux, and improve the characterisation of stratification of the near-surface ocean layer. Gas exchange is driven by turbulence at the air-sea interface and rain has the effect of modifying the ocean surface turbulence. In addition, has also been shown to enhance near-surface stratification (through buoyancy forcing), which affects sea surface temperature, surface mixing, near-surface currents, as well as communication between the surface and the mixed layer. Most essential for the SOLAS community, rain dampens surface gravity waves (with the potential to enhance capillary waves) and also affects the air-sea gas exchange (enhances the gas transfer coefficient and affects chemistry). Thus, the role and the composition of the sea

surface microlayer in the air-sea gas exchange were discussed, as well as sampling methods evaluated. Another major point for discussion during the workshop was the impact of surfactants on surface waves, which has several outstanding issues to be resolved, including rheology (which impacts the remote sensing of slicks); nonlinear wave-wave interactions (which impacts the wave spectrum); and parameterisations of small scale, anisotropic processes (which cause the redistribution of slick material by the wave-induced drift).

To conclude the workshop, a dinner with all participants was organised. We thank the workshop sponsors: SOLAS, the Office of Naval Research Global (ONRG); the World Climate Research Programme (WCRP); and the European Space Agency (ESA), whose support allowed us to provide the facilities for a very fruitful workshop. We also thank the invited speakers, the breakout session leaders, and indeed the participants, all of whom provided a full week of their time to contribute toward the advancement of the SOLAS Theme 2 “Air-sea interface and fluxes of mass and energy”'.

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Link to the event website:
https://airsea.nuigalway.ie/cargese/workshop

The outcomes of this workshop contribute to advance our knowledge of the Core Theme 2 of the SOLAS 2015-2025: Science Plan and Organisation.

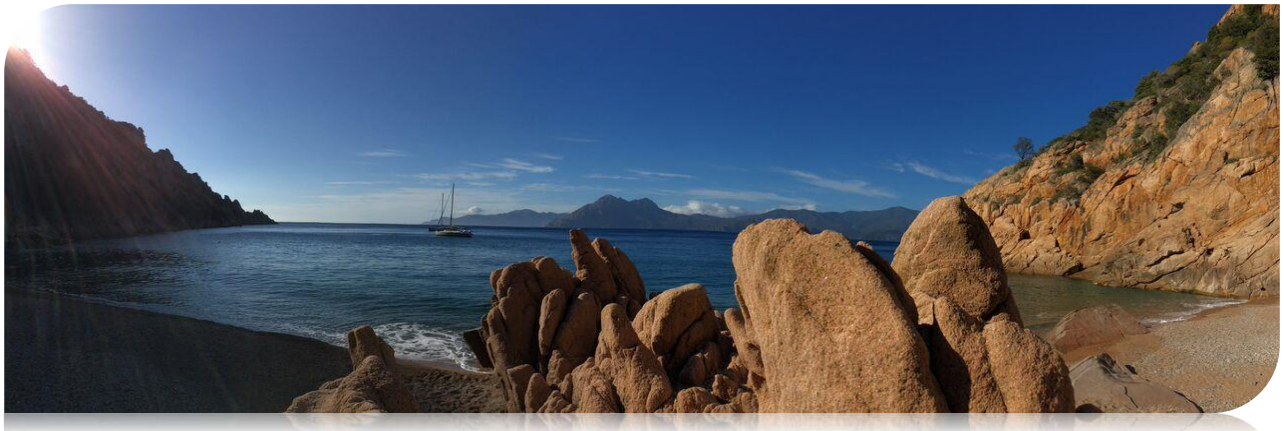

Figure 2: Ocean, atmosphere and beach near Cargese during the workshop © Anneke ten Doeschate

Event sponsors

Christa Marandino has been a professor of marine and atmospheric chemistry at GEOMAR Helmholtz Centre for Ocean Research Kiel and Kiel University, Germany since 2012. She investigates air-sea interactions, specifically dealing with how trace gases produced and consumed in the ocean influence atmospheric chemistry and climate. Her expertise is in direct air-sea trace gas flux measurements using the eddy covariance technique, as well as mass spectrometric method development and process studies in the ocean's euphotic zone.

What can we learn from eddy covariance direct flux measurements of multiple gases simultaneously?

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Air-sea exchange is vital for the planet and a crucial component of biogeochemical cycling in the Earth system, as it affects climate through the transfer of heat, momentum, and water, as well as radiatively active trace gas species. Historically, without air-sea gas transfer we would not have terrestrial life on Earth. However, what the future holds, with respect to the ocean and global environmental change, is a serious question. What happens if the carbon dioxide (CO_2) ocean sink strongly weakens? What impact would a less alkaline ocean have on biogeochemical cycling and climate? What would be the resulting influence on the atmosphere if an increasing fraction of the world's ocean was made up of oxygen minimum zones? At the centre of all of these questions is gas exchange across the ocean-atmosphere boundary, one of the Earth's largest boundaries. Research in the last decade has shown that there are already serious changes occurring at the air-sea interface, such as the slowing of the ocean carbon sink (e.g. Watson *et al*., 2009), possibly due to ocean acidification increasing bacterial remineralisation (e.g. Segschneider and Bendtsen, 2013). As the ocean is the largest sink for anthropogenic CO_2 in the atmosphere, its slowing has major implications for climate change. Such major changes and their impacts can only be fully quantified and predicted with a complete understanding of air-sea gas exchange. Unfortunately, our mechanistic understanding of the processes impacting air-sea gas transfer is still lacking in many aspects, especially in the open ocean setting. Two main problems have been identified with traditional, indirect methods to compute gas exchange: oversimplified/uncon-strained parameterisations of gas exchange physics and heterogeneity in actual gradients across the interface not represented by gas concentration measurements. Solving these problems requires moving beyond traditional methods to more direct techniques. Eddy covariance is the most direct flux measurement technique and can open doors in gas exchange research. No other technique can directly measure flux on the scales of the forcing parameters, nor reveal the disconnect between calculated fluxes and concentration gradients. However, its wide-

spread use has been hampered by its challenging technical requirements. Direct eddy covariance flux measurements of heat, momentum, carbon dioxide, and dimethylsulphide (DMS) were performed in the Indian Ocean on board the research vessel 'Sonne'. The cruise took place in July and August, 2014 (Fig. 3a and 4) with the science partnerships for the 'Assessment of Complex Earth System Processes' and 'Organic very short lived substances and their Air sea Exchange from the Indian Ocean to the Stratosphere'. Air-sea distributions of CO_2 and DMS were also measured and the gas transfer coefficient (k) was directly derived. The cruise took place during the summer monsoon season and air masses were mostly of marine origin. The prevailing winds were northeasterly south of the Equator and southwesterly north of the Equator (up to 16 ms^{-1}). The cruise traversed regions with different surface water partial pressure CO_2 levels, including areas of strong undersaturation and those at approximately atmospheric equilibrium. The distribution of seawater DMS concentrations was also variable, leading to different flux patterns for the two gases. The directly derived k values can be compared to each other and commonly used parameterisations/models (Fig. 3b). The k values for CO_2 are higher than those for DMS, especially at higher wind speeds (U). The functional form of k versus U appears to be linear with U for DMS, whereas the CO_2 functional form more closely resembles the Nightingale *et al.* (2000) parameterisation and is much lower than cubic relationships. A "rollover" in the DMS k values can be seen at wind speeds higher than 11 ms^{-1}, which is in agreement with Bell *et al*. (2013). We hypothesise that the rollover is connected with how waves alter the physics of gas transfer and are currently investigating how to predict this rollover for future calculations. The influence of bubbles on gas exchange at wind speeds above 11 ms^{-1} can also be detected with this dataset. We will calculate the magnitude of this bubble effect and will compare with recently published estimates to assess if the magnitude of bubble mediated gas transfer is universal over different environmental conditions. Interestingly, the rollover seen in DMS k values should be generally applicable to sparingly soluble gases and it occurs at similar wind speeds as bubble mediated exchange. The implications of these findings will be explored in our upcoming publications and Alex Zavarsky's doctoral dissertation.

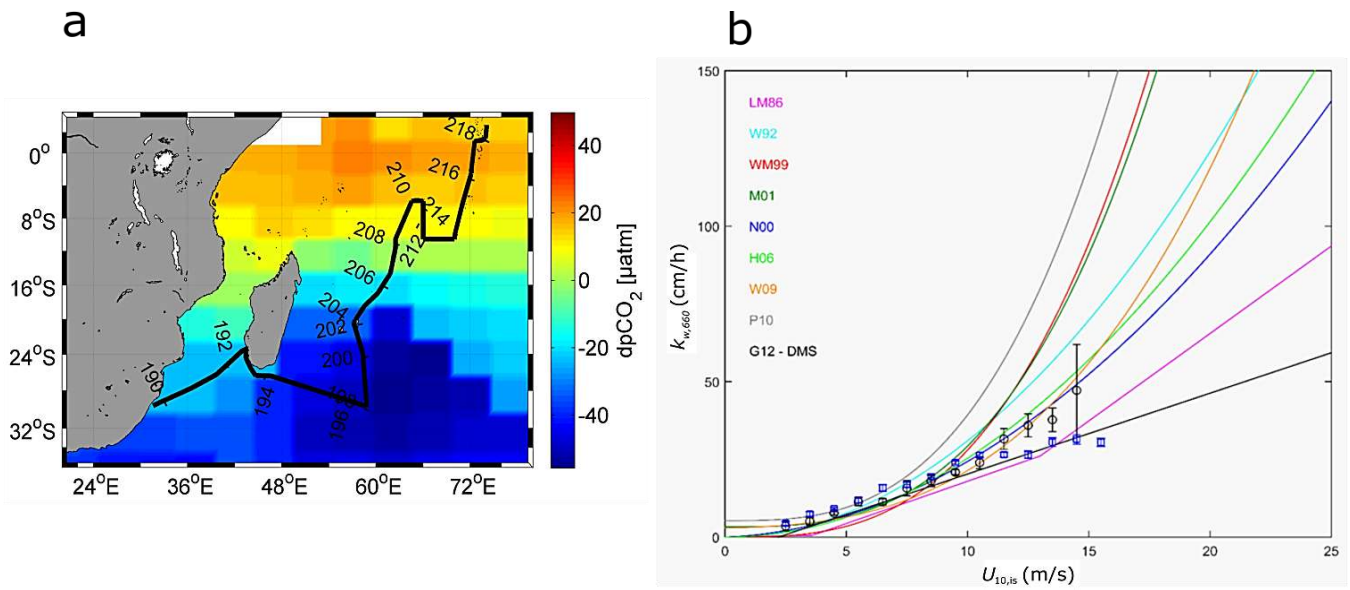

Figure 3: a) 'Sonne' cruise track plotted on top of the CO_2 concentration gradient. Numbers are day of year during cruise. b) The directly derived gas transfer coefficient for CO_2 and DMS plotted against wind speed (GM12-DMS). Also pictured are commonly used k parameterisations (LM 86, Liss and Merlivat, 1986; W92, Wanninkhof, 1992; WM99, Wanninkhof and McGillis, 1999; M01, McGillis *et al*., 2001; N00, Nightingale *et al*., 2000; H06, Ho *et al*., 2006; W09, Wanninkhof *et al*., 2009; P10, Pyrtech *et al*., 2010; G12-DMS, this study).

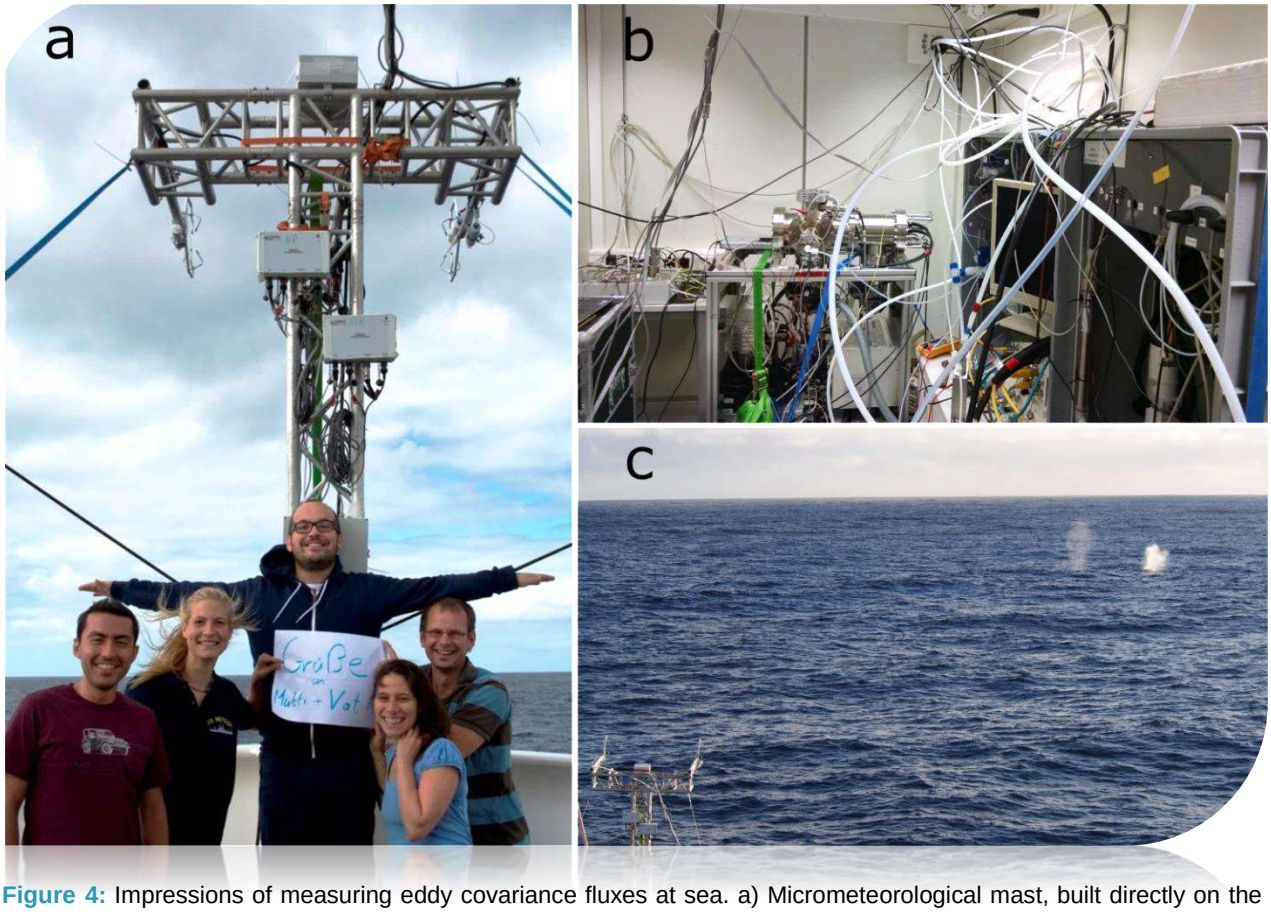

Figure 4: Impressions of measuring eddy covariance fluxes at sea. a) Micrometeorological mast, built directly on the bow, houses two sonic anemometers to measure wind speed and direction, an inertial motion unit to measure the movement of the ship, and two gas inlets for CO_2 and DMS air measurements. © Bendix Vogel. b) Instruments housed in the lab container on the bow of the ship, including all data acquisition equipment, the atmospheric pressure chemical ionisation mass spectrometer to measure DMS, and an analyser (LiCor 7200) to measure CO_2. © Christa Marandino. c) The eddy covariance tower measuring acetone fluxes from a whale's breath. © Folkard Wittrock.

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Acknowledgements

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Royston Uning completed his bachelor and master degree in physics at the University of Technology Malaysia, Johor Bahru. In 2015, Royston started his PhD at the National University of Malaysia, Bangi, studying the biogenic volatile organic compound sea-to-air flux at the ocean-atmosphere interface.

Isoprene sea-to-air flux from the sea surface microlayer

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Biogenic volatile organic compounds are climatically-active trace gases in the atmosphere, which can affect the global atmospheric radiation budget. Isoprene (2-methyl-1,3-butadiene, C_5H_8) is very short lived in the atmosphere and has been shown to be an important precursor to tropospheric ozone (Chameides *et al*., 1988) and secondary organic aerosol formation (Claeys *et al*., 2004). C_5H_8 is released into the atmosphere from the marine environment (Bonsang *et al*., 1992). The sea surface microlayer (SML) is the boundary layer between the ocean and the atmosphere and covers more than 70 % of the Earth's surface (Cunliffe *et al*., 2013). The SML is enriched with organic matter (i.e. dissolved organic matter including ultraviolet-absorbing humic substances, amino acids, proteins, lipids, and phenolic compounds) and surfactants (i.e. fatty acids) (Liss and Duce, 1997). Additionally, photosensitised reactions involving the SML lead to production of significant amounts of C_5H_8 based on field samples and laboratory experiments (Ciuraru *et al*., 2015) (Fig. 5). Estimating the C_5H_8 flux is of major importance when determining the impact of marine C_5H_8 on atmospheric oxidation and organic aerosol particle size distribution in box-, regional-, and global chemistry models. Meas-

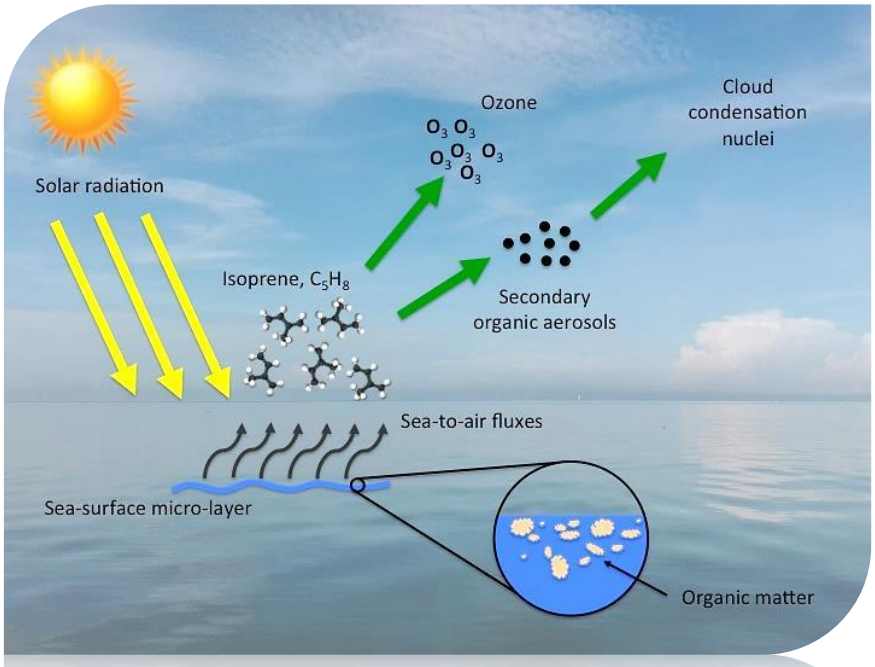

Figure 5: Production and fate of C_5H_8 in the marine boundary layer © Royston Uning

ured field datasets are one of the key inputs when using models to estimate the annual global emissions of marine C_5H_8. Existing calculated C_5H_8 emissions, using the current model, achieved comparable results. However, as suggested by Booge *et al*. (2016), the existing model does not simulate a production of estimated C_5H_8 emissions in the SML. Therefore, the role of the SML on C_5H_8 sea-to-air fluxes remains an open question. Moving forward, future field measurements should incorporate SML C_5H_8 sea-to-air flux measurements to determine marine C_5H_8 emissions to the atmosphere. To fill the knowledge gap, the current study is focusing on method development for *in situ* sample collection (Fig. 6) and field sampling off the east coast of the Peninsular Malaysia (representing a tropical region). The main objective of this study is to determine

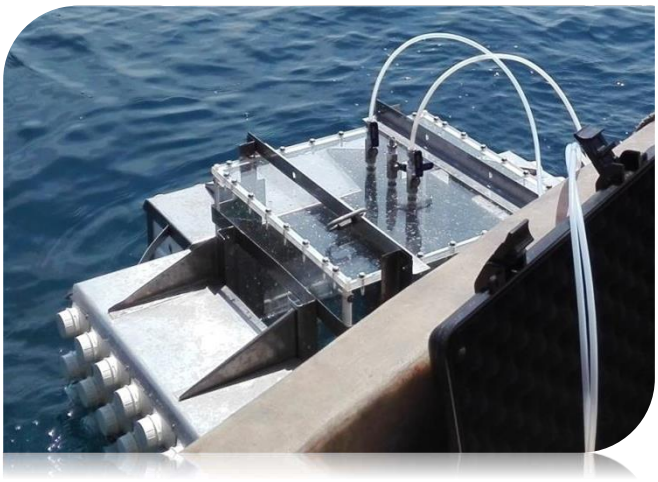

Figure 6: Freshly emitted C_5H_8 from the SML, measured using a floating flux chamber. © Royston Uning

the SML C_5H_8 sea-to-air flux. In addition, factors that might influence the sea-to-air flux will be studied (e.g. incoming solar radiation and inorganic nutrients). By using bottom-up measurements, results of this study will provide essential SML C_5H_8 sea-to-air flux data. Consequently, the measured SML C_5H_8 flux is expected to improve the estimation and/or correct the underestimation of total annual marine C_5H_8 emissions from regional to global scales.

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Nathalie Hayeck studied analytical chemistry at the Lebanese University, Beirut, Lebanon. She moved to France in 2012 to start her PhD in environmental chemistry. Since 2015, she is a post-doctoral fellow in the group of Christian George at the Centre national de la recherche scientifique - Institut de Recherches sur la Catalyse et l'Environnement de Lyon, Lyon, France, working on photosensitized reactions of surfactants at the air/water interface.

Interfacial photochemistry of biogenic surfactants: a major source of abiotic volatile organic compounds

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Air-sea interfaces are ubiquitous in the ambient atmosphere, starting from a single aerosol particle to the surface of the ocean, and cover more than 70% of the Earth's surface. It was shown that unique photochemical reactions with significant implications for atmospheric processes can occur at such interfaces, leading to the formation of volatile organic compounds (VOC) and secondary organic aerosols (Bernard *et al.*, 2016; Rossignol *et al.*, 2016). This interfacial photochemistry is exclusively due to the presence of surfactants enriched in surface layers with respect to the bulk water. Additionally, the presence of such surfactants increases the propensity of less surface-active compounds to concentrate there as well, creating a unique chemical environment, affecting not only chemistry but also trace-gas exchange (Carpenter *et al.*, 2015). A major source of biogenic surfactants in the ambient environment are so-called biofilms, loosely defined as a population of microorganisms (i.e., fungi, algae, archaea) that accumulate at an interface (Hall-Stoodley *et al.*, 2004) (Fig. 7). Nowadays the global presence of surfactants at air-sea interfaces of aquatic systems is attributed to microbiological activity.

We studied photochemical processes at the air/water interface of biofilm-containing solutions, showing abiotic VOC production from biogenic surfactants under ambient conditions (Brügge-

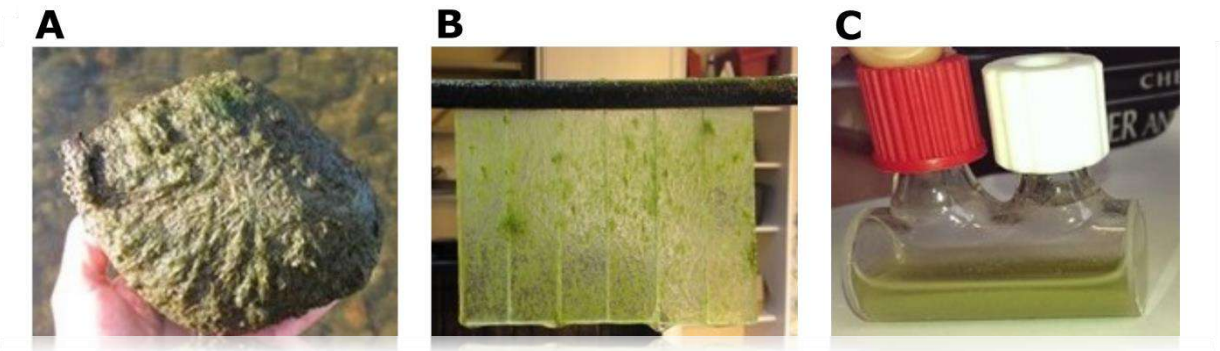

Figure 7: A) Biofilm accumulating on a river stone. B) Biofilm grown on glass substrate in an aquarium. C) Biofilm suspension used in this study.

mann *et al.*, 2017). Online atmospheric pressure chemical ionisation-ion trap-mass spectrometry and proton-transfer-reaction time-of-flight mass spectrometry were used to monitor VOC production. Unsaturated and functionalised VOCs were identified and quantified, giving emission fluxes comparable to previous field and laboratory observations. Interestingly, VOC fluxes increased with the decrease of living cells in the samples, indicating that the cell lysis was the main source for surfactants and VOC production.

Up to now, such VOC emissions were directly attributed to high biological activity in surface waters. However, our results suggest that abiotic photochemistry can lead to similar atmospheric emissions, especially in oligotrophic regions. Furthermore, chamber experiments suggested that oxidation of the produced VOCs by ozone and hydroxyl radicals leads to aerosol formation and growth, possibly affecting atmospheric chemistry and climate-related processes, such as cloud formation and the Earth's radiation budget. These findings are summarised in Fig. 8, illustrating the impact of photo-induced VOC production on atmospheric chemistry. Due to the large surface area of the oceans, even a small production of VOCs can have important effects on a global scale. However, up to now, abiotic photochemical production of VOCs and their resulting impacts are not included in atmospheric chemistry models.

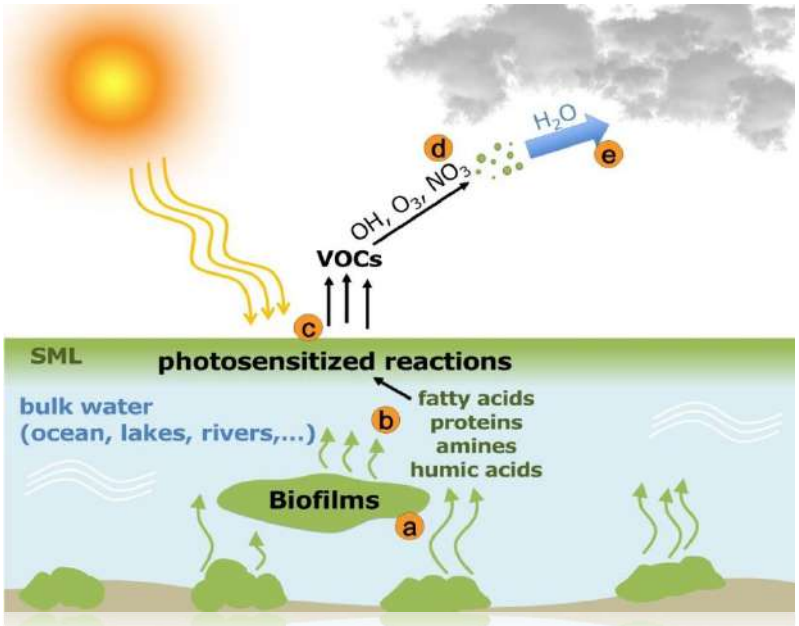

Figure 8: The impact of photo-induced VOC production on atmospheric chemistry. (a) Cell lysis of dying biofilm organisms releasing organic components into the bulk water. (b) Hydrophobic compounds such as fatty acids tend to concentrate on the air-water interface. (c) Photosensitized reactions can take place at the sea surface microlayer (SML) interface producing VOCs. (d) Oxidation of VOCs by hydroxyl (OH) radicals or ozone (O_3) produces organic aerosols, which could (e) influence cloud formation (H_2O, water) and their lifetime.

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Kyla Drushka has been a senior oceanographer at the University of Washington Applied Physics Laboratory, Seattle, United States, since 2014. She specialises in understanding processes in the upper ocean and at the air-sea interface from *in situ* and satellite observations.

The impact of rain on near-surface ocean turbulence

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Over the tropical oceans, rainfall is characterised by spatial scales of O(1-10) km and timescales of O(10) minutes. Rain falling on the ocean forms buoyant surface layers O(0.1-1) m thick of relatively fresh, cold water, which are mixed and advected away on time scales of hours to days. The near-surface stratification from rain-formed fresh layers modulates the impacts of heat and momentum fluxes on the upper ocean, affecting surface temperature and currents, air-sea gas exchange, and turbulent kinetic energy dissipation. At the same time, fresh layers can act as a barrier between the atmosphere and the deeper mixed layer. These processes have not been well measured as a result of the transient nature of rain events and the difficulty of making surface measurements in the open ocean. We have recently carried out two experiments designed to characterise the temperature, salinity, and turbulence anomalies associated with rainfall.

The Friday Harbor Rain Experiment, which took place on a dock in Friday Harbor, Washington, United States, was designed to understand the near-surface turbulence generated by rain falling on the ocean. Acoustic Doppler velocimeters, conductivity-temperature-depth sensors (CTD), and a suite of meteorological instruments were deployed on the dock in the northeast Pacific from December 2015 to March 2016, providing a continuous time series of rain rate and raindrop size, wind speed, and vertical profiles of turbulence dissipation rate (ε) from 3 to 65 cm depth during different rain and ocean conditions. Figure 9 shows averaged profiles of ε under different wind and rain conditions. In non-rain conditions, dissipation rate is dominated by wind forcing at all depths, showing an ~8-fold increase between low (<4 m/s) and moderate (4-10 m/s) winds. The impact of rain is prominent, but depends on wind speed: at low wind speeds, moderate rain rates enhance turbulence (compared to no-rain conditions) by a factor of five and strong rain rates enhance turbulence by a factor of twenty (Fig. 9a). When winds are stronger; however, only the strong rain rates enhance turbulence above non-rain conditions (Fig. 9b). We hypothesise that this occurs because only when winds are relatively weak the kinetic energy input from

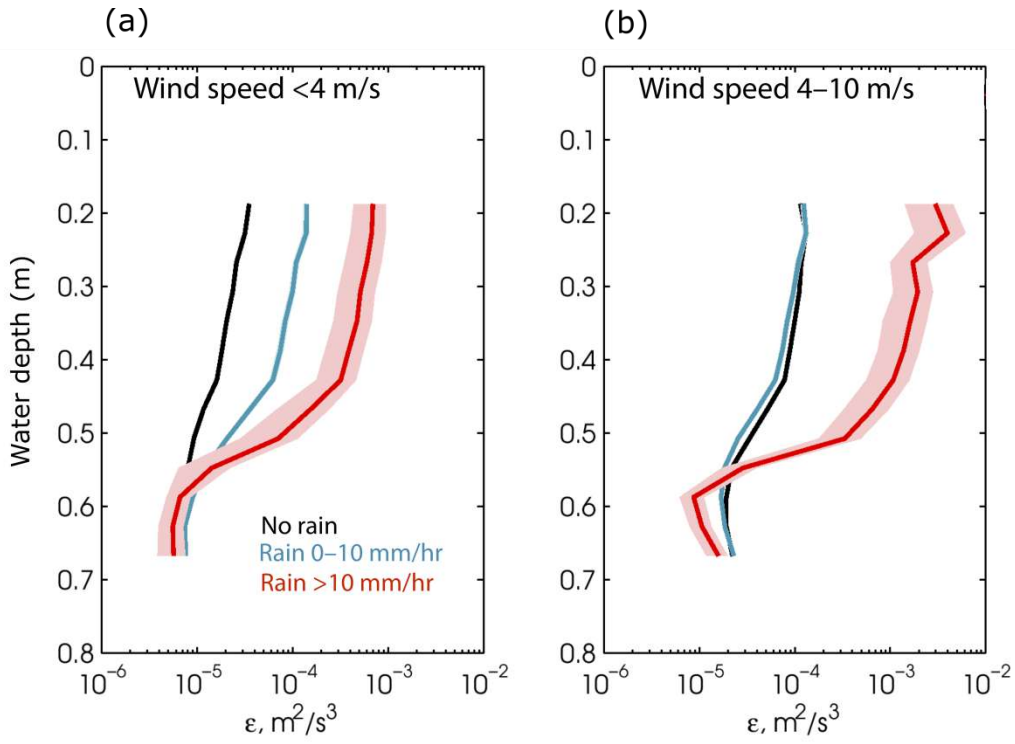

Figure 9: Turbulence dissipation rate under (a) low-wind and (b) moderate wind conditions, for different rain rates.

rain can exceed that from wind. This has implications for parameterising the impacts of rainfall on air-sea exchange under different wind regimes.

The impact of rainfall on near-surface salinity is currently being studied as part of the second Salinity Processes in the Upper Ocean Regional Study (SPURS-2), taking place in the eastern tropical Pacific Ocean from 2016 - 2017. As part of SPURS-2, we deployed the Surface Salinity Profiler (SSP), a towed, surface-following platform to which five CTD sensors in 5 cm to 1 m are mounted (Asher *et al.,* 2014). As the SSP is towed, this gives a continuous time series of temperature and salinity profiles in the upper meter of the ocean. During the SPURS-2 cruise in August 2016, 37 rain events were sampled with the SSP, allowing characterising the impacts of rainfall on the upper ocean. Figure 10 shows an example of a rain event observed during SPURS-2. Strong, steady rainfall up to 40 mm/hr (Fig. 10a) resulted in the formation of an extremely strong salinity anomaly of 9 practical salinity units (PSU) at the ocean surface (Fig. 10c). As a result of very low wind speeds (1 m/s), the fresh signal was trapped above 50 cm: the salinity anomaly is only seen at the 5-20 cm depth instruments until the wind signal picked up at around 13:15 (local time). Statistics from the set of 37 rain events measured with the SSP during SPURS-2 demonstrate that, for a given wind speed, the magnitude of salinity anomalies produced by rainfall is linearly related to the rain rate, meaning stronger rain produces a larger salinity anomaly. For a given rain rate, the salinity anomaly is inversely proportional to the wind speed; thus, under stronger winds, mixing is enhanced and the salinity anomaly is reduced, whereas with weak winds a strong salinity anomaly can form (Fig. 10). These results are consistent with results from a recent modeling study (Drushka *et al*., 2016). The SSP also carries microstructure temperature and conductivity sensors in order to estimate the turbulence dissipation rate; current efforts are underway to link

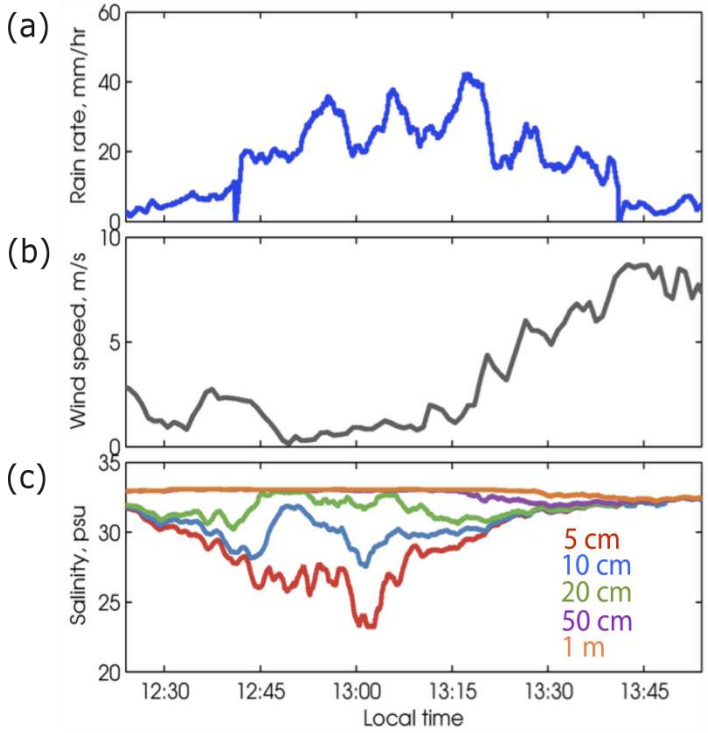

Figure 10: Rain event observed during the Salinity Processes in the Upper Ocean Regional Study. (a) Rain rate, (b) wind speed, and (c) salinity at five depths measured with the Surface Salinity Profiler.

wind and rain rate to ε with the SPURS-2 dataset, as it was done with the Friday Harbor data (Fig. 10), in order to understand rain-generated turbulence in the ocean.

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Report 06 I September 2017

Workshop series on:

“SOLAS Science and Society”

26 - 27 October 2016, Brussels, Belgium
30 - 31 March 2017, Monaco
14 - 15 June 2017, Rome, Italy

Understanding the physical and biogeochemical interactions and feedbacks between the ocean and atmosphere is a vital component of environmental research. Indeed, our ability to predict and respond to future environmental change (e.g. climate) relies on a detailed understanding of these processes. SOLAS has grown in recent years to accommodate this need for better process understanding to include more disciplines, from the natural sciences to computing and socioeconomics, as well as a diversity of stakeholders. However, the SOLAS research community has recognised that greater efforts are needed to increase interaction between natural scientists and social scientists – especially because many of the changes in the Earth system are anthropogenic (Brévière *et al.,* 2016).

Overview of integrated research topics

SOLAS science and society, kickoff meeting, 26 - 27 October 2016, Brussels, Belgium

To this end, in October 2016, 25 social and natural scientists participated in a community workshop in Brussels (Fig. 1). The meeting focused on bridging the gap between SOLAS science and the societal realm by identifying research topics

In this report

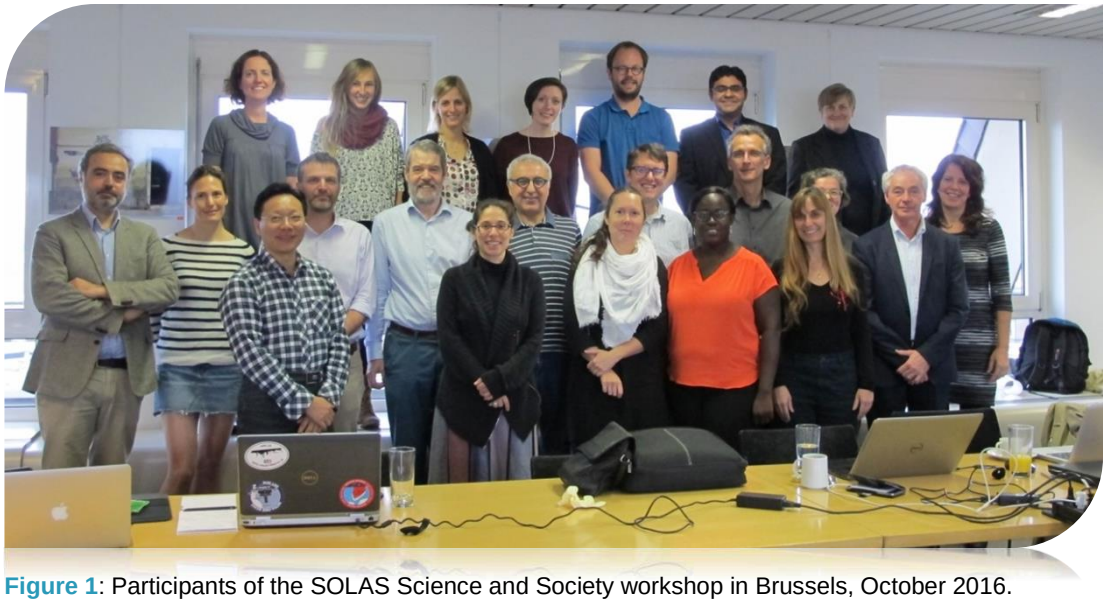

Figure 1: Participants of the SOLAS Science and Society workshop in Brussels, October 2016.
Back row from left: Silvina Carou, Hanna Campen, Sonja Endres, Frances Hopkins, Erik van Doorn, Pradeep Singh, Monica Martensson.
Middle row from left: Emilio Cocco, Helen Czerski, Andrew Peters, David Turner, Bülent Acma, Martin Johnson, Helmuth Thomas, Kate Houghton.
Front row from left: Shang Chen, Christa Marandino, Natasha McDonald, Mary Oloyede, Nathalie Hilmi, Frank Maes, Birgit Quack; Not pictured: Johannes Oeffner.
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within the following three themes: the economics of ocean carbon storage, policy across the air-sea interface, and the impact of shipping on biogeochemical cycling. The workshop consisted of both plenary and breakout sessions. The plenaries focused on the broader context of SOLAS, Future Earth, and the challenges facing interdisciplinary research. The breakout sessions were designed to brainstorm around the three identified topics. Each session was moderated by one social scientist and one natural scientist (one moderator of each topic is highlighted in the following research profiles). Approximately eight people attended each of the three topical breakout discussion sessions. The number of participants was chosen to be large enough to have a diversity of viewpoints, but small enough to allow for full participation in discussion. The ratio of social and natural scientists among participants was 30% to 70%. The group was mixed geographically, with representation from North America, Europe, Africa, and Asia, as well as by stage of career, ranging from postgraduate students to full professors. The specific goal of the workshop was to have at least three concrete outcomes that are to be finalised in the following year through continuing work among the group members (e.g. paper in peer-reviewed journal or research proposals). Two follow up meetings have already taken place: 1) The carbon group met in Monaco in March, 2017 (Fig. 2); 2) The policy group met in Rome in June, 2017 (Fig. 3). There is an upcoming meeting on shipping in Gothenburg in October, 2017, that will expand on the group included in the Brussels meeting.

Valuing carbon in the ocean, follow up meeting, 30-31 March 2017, Monaco

The ocean system takes up carbon from the atmosphere by a series of physical and biological mechanisms. The physical uptake of carbon dioxide (CO_2) by the oceans has increased in response to anthropogenic carbon input to the atmosphere, but this has potentially negative consequences through ocean acidification. While there have been extensive, ongoing discussions in the scientific community about roles and vulnerabilities of the physical, biological and microbial carbon pumps in regulating CO_2 uptake from the atmosphere, we rather consider manageable options to enhance the shallow ocean's carbon uptake. The related trade-offs between seques-

Figure 2: At Monaco harbour during the March 2017 meeting.
Back row from left: Alain Safa, Martin Johnson, Erik van Doorn, Helmuth Thomas.
Front row from left: Laura Recuero Virto, Christa Marandino, Mary Oloyede, Nathalie Hilmi, Denis Allemand, Yasser Kadmiri.
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tration benefits and negative consequences were discussed.

For the purpose of this workshop, we considered any carbon stored in the marine realm by processes whose absence would lead eventually to an equivalent quantity of carbon being released to the atmosphere. We also account for the balance of the associated uptake or emission of other climate-active agents. Explicitly, this definition excludes natural carbon storage mechanisms, rather it focused on manageable options, which either enhance, i.e., go beyond the natural carbon storage, or which intentionally prevent loss of natural carbon stocks. As compared to the terrestrial realm, the oceans are subjected to water movement and, accordingly, points of discussion of the working group has been on the geopolitical attribution and valuation of measures to enhanced carbon storage in coastal waters. Positive or detrimental effects might be seen in territorial waters; however, depending on the ocean current systems along the coast, such effects might materialise in waters of neighboring countries. Active measures to enhance carbon storage are crucial for any international agreements or assessments of carbon storage initiatives, while approaches that attribute and value effects of circulation patterns simply describe natural background conditions (e.g. Canu *et al*., 2015), which should not be counted as an asset or mismanagement of individual countries. A further point of discussion was devoted to the timescale of carbon storage. The baseline is the (former) long-term geological storage of fossil fuels in the Earth system, while at the opposing end are the annual or multi annual time-scales of economic budgeting and valuation or election frequency. The underlying key question is: what carbon storage time scale is applied to carbon stocks? Given the variability in coastal oceans and the natural decay of plant material alternatively, or possibly even more importantly, enhanced carbon storage might also considered as a (local?) measure to mitigate effects of ocean acidification.

Air-sea interaction and policy, follow up meeting, 14 - 15 June 2017, Rome, Italy

Figure 3: At the top of the American University of Rome during the June 2017 meeting.
Back row from left: Emilio Cocco, Silvina Carou, Erik van Doorn.
Front row from left: Christa Marandino, Hanna Campen, Andrew Peters.
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This topic was the broadest of the three, and as a consequence, most of the discussion was spent on framing possible questions on which to focus. The first question the participants discussed was if the interaction between the lower atmosphere and the upper layer of the ocean is sufficiently considered in regulation. They came to the conclusion that regulations do not need to target the air-sea interface directly, because regulating the source of pollution (e.g. atmospheric sources at the national level) or designated protected areas would be more effective. The rationale behind this conclusion is the recognition that, although there is a general obligation under international law for states to prevent, reduce and control pollution of the marine environment from or through the atmosphere, the regulation of activities on land or ships (i.e. the cause of atmospheric pollution) is mostly a sovereign act of states, which is exercised pursuant to their national policies. The second question discussed was if the air-sea interface should be considered for its process implications (e.g. Steinacher *et al*., 2013). If the answer is yes, then how do we prove that air-sea interaction is important without overstating the effect? Air-sea exchange is an important process in biogeochemical cycling and environmental issues, but rarely the defining feature that requires regulation. The ocean uptake of mercury, a highly toxic substance, serves as an example. For carbon dioxide, regulation was an evolutionary process and started only with a focus on its warming influence. Policy consideration of CO_2 crossing the air-sea interface came only after its confirmed role as a pathway to that leads to lower pH (i.e. ocean acidification.).

The group found that there is no general answer to the question of how law deals with an uncertain future, but were able to identify the existence of many examples where international law increasingly strives to require states to act collectively through international or regional organisations, or to adopt measures at a regional or national level as agreed in binding agreements (hard law) or voluntary instruments (soft law). This include measures to address airborne pollutants, dumping at sea, trace metals, nitrogen, sewage, emissions from ships and land-based sources e.g. sulfur/nitrogen oxides, red tides, as well as general requirements to conduct envi-

ronmental impact assessment prior to conducting harmful activities and the prerogative to establish marine protected areas.
Nevertheless, the challenges that arise from the lack of implementation, compliance and enforcement were acknowledged as impediments to achieve the desired outcomes.

Upcoming: SOLAS science and the shipping industry, follow up meeting, 25-26 October 2017, Gothenburg, Sweden

As shipping traffic continues to increase, there is growing concern about the marine environmental impacts, ranging from species-level to ecosystem services. Today, commercial shipping mainly uses low-cost heavy fuel oil, emitting significant amounts of sulphur, nitrogen, metals, organic compounds and aerosols to the atmosphere during combustion (Eyring *et al.* 2005). As most of these compounds have a limited residence time in the atmosphere, they are deposited relatively close to the source and dissolve or are suspended in the surface ocean. During the meeting, the expert group started with an assessment of known effects of sulphur emissions on marine biogeochemistry and identified scientific knowledge gaps. Several abatement techniques exist for achieving the required emission limits, such as novel engine technologies, exhaust gas recirculation or fuel emulsifiers etc. Open-loop exhaust gas cleaning systems ('scrubbers') belong to the commonly used technologies as an alternative to low-sulphur fuel oil (LSFO) for shipping companies. The increased costs associated with the high-quality LSFO is shaping scrubber technology to be an attractive and viable alternative for shipping companies. However, it is not clear what the consequences of scrubber implementation will be on the marine systems.
The ability to accurately forecast scrubber effluents using models in combination with the ship traffic data and data from shipping companies requires further modelling efforts combining economic and natural science. Besides scrubbers, there are several alternative technologies for complying with requirements for fuel sulphur content, such as fuel conversion or fuel switching (Johansson *et al.* 2013), which should be considered in further research efforts. Legal regulations of air pollution from ships and wash water discharge from scrubbers need to be considered as well.
The usage of new technologies in the shipping industry, such as scrubbers, can benefit the environment by significantly reducing ship emissions to the atmosphere and surface ocean. However, the use of scrubbers may lead to other, yet unascertained and unquantified negative impacts on the marine environment. During the workshop, several interdisciplinary research priorities were identified which help to improve our understanding of these potential impacts and the development of a sustainable shipping industry.

Outlook

Despite prominent examples of successful interdisciplinary, integrated research over recent years, the participants in Brussels noted that some challenges remain. As a result of sharing experiences, the workshop attendees found that one major challenge is communication, in particular the lack of a common language and the frequent use of jargon. It was highlighted that it is important to forge relationships across disciplines in order to obtain insights into the various research styles. Some hurdles that need to be overcome were identified during the workshop. Perhaps the most problematic of these is to find an appropriate balance between curiosity-driven fundamental research and the perceived need to co-design science jointly as a product of scientists and stakeholders. In addition, it was clear that more social scientists, covering a broader array of fields within the social sciences, need better representation in future workshops and projects. All groups identified the need for a review paper on their chosen questions, for which further workshops have been conducted and are planned. The outcome of these reviews will highlight the gaps in knowledge that could be addressed through joint research. Appropriate fund-

ing sources to support these types of interdisciplinary initiatives will be explored.

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The outcomes of this workshop contribute to advance our knowledge of the Cross-Cutting Theme “Science and Society” of the SOLAS 2015-2025: Science Plan and Organisation.

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Coral reefs management and decision making tools

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The importance of coral reefs in terms of shore line protection, as hosts for marine habitat and biodiversity, as well as a tourism attraction has been well documented. Coral reefs are known to support to create jobs and are as such, the livelihood of millions of people around the world by the supplying nutrition and healthy food (Cinner *et al*., 2012). The protection and conservation of coral reefs and their biodiversity is of primary importance at the local, regional and national levels.

Policymakers in coral reef regions around the world have to make management decisions that take the positive effects or benefits, such as tourism revenues into account. However, also the negative effects or exploitation costs, such as natural resource destruction, have to be taken into account in order to avoid a tragedy of the commons. The biologist Garret Hardin put forth his "tragedy of the commons" idea in 1968. He described a situation in which multiple individuals, acting independently and rationally based on their own self-interest, will ultimately deplete a shared limited resource (Hardin, 1968). Elinor Ostrom believed that if users decide to cooperate with one another, monitoring each other's use of the resource and enforcing rules for managing it, they can avoid such tragedy (1990). For Ostrom, social control mechanisms and collective actions regulated the use of the commons and she demonstrated that informal approaches for managing common property resources are superior to government-enforced ones. Hardin revised his theory and called it ultimately "tragedy of the unmanaged commons" (Hardin 1968, 1994, and 1998). Cooperative behaviour is the key to success when commons are used as a framework for solving environmental problems (e.g. Bailey *et al.,* 2010). For worldwide problems such as global warming, decisions have to be taken at many different levels, including global, regional, national, and local ones. In particular for coral reefs and related resources, stakeholders are manifold (Burke *et al*., 2002). Policymakers could be unable to act when it comes to management and benefit/cost analysis of common resources,

as they have to elaborate strategies within the boundaries of a solitary game. These strategies, including their uncertainty in the exploitation of a common-property resource, are being discussed (e.g. Antoniadou *et al*., 2013). Our paper focuses on one particular common property resource: coral reefs (Hilmi *et al.,* 2017). Our examples, using previous estimations on net benefits, give guidelines on how to form public policy and management strategies.

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"Common Oceans?" Fluid ontologies, conflicting representations and the social construction of the high-sea

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The anthropologist Stefan Helmreich claims that "The sea has disappeared into our heads", although the greatest share of international trade depends on thousands of giant cargo ships crossing the ocean every day and tons of minerals being extracted from the depth of the high sea bed for energy supply (Baldacchino, 2015). Over 10% of the world's population lives on islands, and 60% of the world's population live along or near the coast (Sielen, 2008). The oceans are vast, and most of them fall outside state control, these are Marine Areas beyond National Jurisdiction for which no nation has sole responsibility for management (Fig. 4). The common oceans make up 40% of the surface of our planet, comprising 64% of the surface of the oceans and nearly 95% of its volume. In contrast, about 80% of all marine pollution originates on

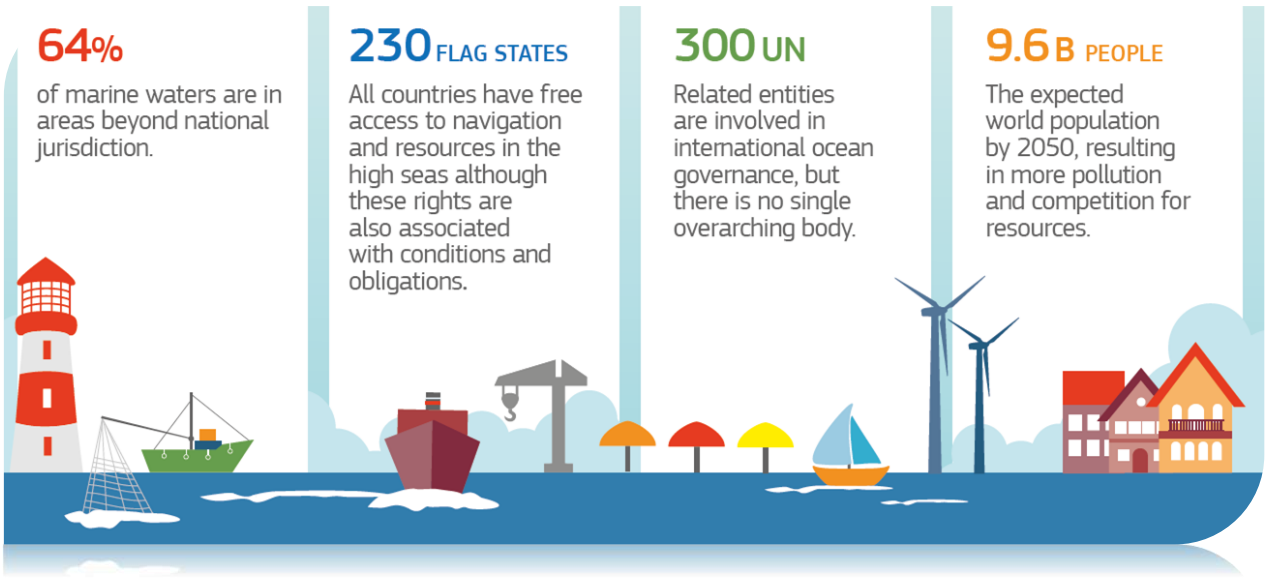

Figure 4: Seas and oceans cover 71% of our planet, and are fundamental for food, trade, energy and global environmental services. International Ocean Governance by the European Commission, Maritime Affairs and Fisheries, International ocean governance: an agenda for the future of our oceans.

land and not necessarily only from coastal states.
As a result of these facts, a growing number of people are directly affected by the use and abuse of the ocean's resources, but only a small percentage of the world's population has a direct experience of the ocean's materiality (Helmreich, 2009).
The property of the ocean is a controversial issue with serious political and ecological implications. This is mostly true when we think of the high seas, which is the water lying more than 200 nautical miles offshore. As a matter of fact, the problem is that the preservation of the ocean has a tremendous impact on everybody's life everywhere on our planet, from climate change, trade, medical research, and food consumption. However, only a few people have direct contact with the high seas and the access to its common resources are difficult.
Accordingly, the portion of the seabed lying beyond the continental shelf, named according to the United Nation convention on the Law of the Sea, The Area, is considered a common heritage of mankind (Fig. 5). However, the question of who is in charge of taking care of The Area and what one can or cannot do there, remains unsettled. This issue is not just a matter of property and commodification which involves frictions and clashes between states, corporate actors, scientists, and non-governmental organisations. It is also a question of the nature of the sea, i.e. of cultural representations and ontological assump-

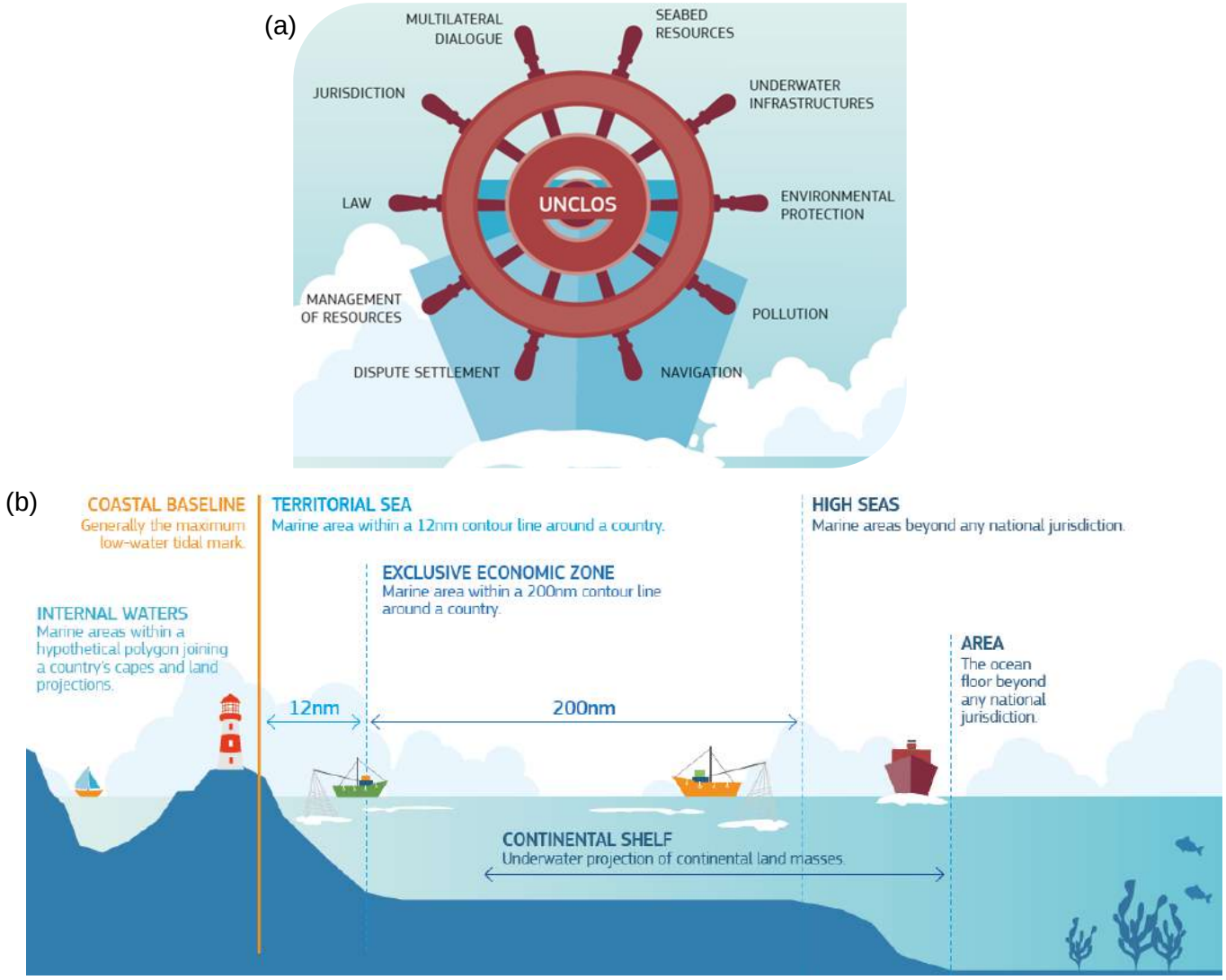

Figure 5: United Nations Convention on the Law of the Sea (UNCLOS) framework.
a) Overview of UNCLOS. b) The framework created by UNCLOS is based on delimiting different maritime areas. European Commission, Maritime Affairs and Fisheries, International ocean governance: an agenda for the future of our oceans.

tions about the ocean. Thus, as scholars are eager to rethink nature through the lens of biogenetic and bioengineering in the age of biotechnology, one should follow this lead to reassess the nature of seawater.

In my current research activities I am exploring: 1) the way current scientific, legal and political accounts contribute to the social construction of the common oceans, 2) conflicts between competing sectors, and 3) the role played by cultural differences on a global scale. As a matter of fact, Western reconstructions of the sea's nature as a fluid and a protean, or as another world (...) without human culture, in contrast to the grounded culture of land, are not universal. However, these constructions remain powerful, perhaps nowhere as much as in views of ocean resources as common by nature (Raban 1993, Davis 1997).

On the contrary, the experimentation with new forms of sovereignty and legal stewardship such as the Exclusive Economic Zones and the Large Maritime Protected Areas in the ocean marks ownerships and responsibilities a complicated issue, as fish, ship, pollution, and bacteria tend to not stop at a border but bridge those.

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How ship effluents from exhaust gas cleaning systems may affect marine microbial ecosystems

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Commercial shipping uses cheap, low-quality fuels that contribute significant emissions of sulphur (SOx), nitrogen (NOx), metals, organic compounds and aerosols to the atmosphere during combustion (Eyring *et al.,*2005). These compounds are deposited relatively close to the source and dissolve or are suspended in the surface ocean as most of them have a limited residence time in the atmosphere. In order to reduce marine pollution from ship emissions, regulations on the sulphur-content of ship fuel have been implemented through MARPOL Annex VI and EU Sulphur Directive EU 2012/35. Since shifting to high-quality fuel with the required low sulphur levels is amplifying transport costs, it has become attractive to use exhaust gas cleaning systems, so-called scrubbers, instead. However, little is known about the chemical composition of the scrubber effluent and its consequences for marine microorganism and biogeochemical processes.

The wash water obtained from the scrubbing process has a very low pH value (>pH 3) and elevated temperatures (Buhaug *et a*l., 2006). Following the 2015 Guidelines for Exhaust Gas Cleaning Systems (MEPC.259(68)), wash water is diluted with fresh seawater or amended with sodium hydroxide before discharge to ensure a pH of no less than 6.5 in a distance of four metres from the discharge point. The pH of an uninfluenced marine environment ranges between 7.8 and 8.4. Depending on depth and the season, extreme pH fluctuations occur already locally. On a global scale, climate change has already caused a pH decrease of 0.1 compared to the pre-industrial era. A further decrease of 0.3 is expected until the end of this century (Feely *et al*. 2009). Ocean acidification is supposed to have a variety of consequences for marine carbon and nutrient cycles. Several studies in the recent years argue that primary production, bacterial activities and community composition will be affected by ocean acidification in the future (e.g. Hutchins *et al.,* 2009, Piontek *et al*., 2010). In this context, direct effects of pH on cell physiology, enzyme activities, and organic matter accessibility have to be considered. Decreasing pH stimulated hydrolytic enzyme activities in ocean acidification studies thus enhancing the microbial turnover and the recycling of nutrients from organic matter (e.g. Cunha *et al*., 2010, Unger *et al*., 2013, Endres *et al.*, 2014).

Model calculations of global ship traffic revealed that ship emissions of SOx and NOx in heavily trafficked waters may lead to regional pH reductions of the same order of magnitude as the CO_2-

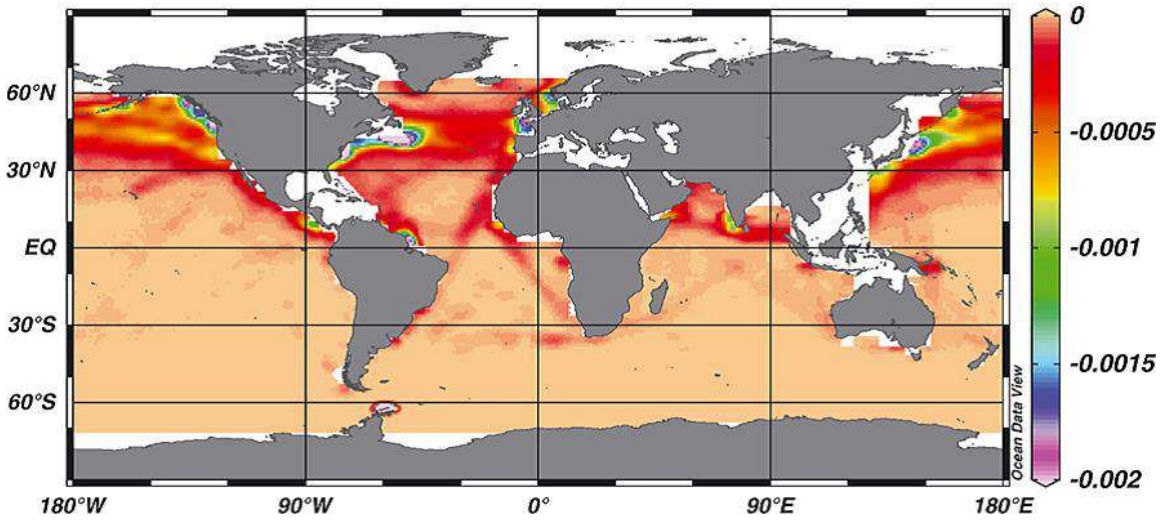

Figure 6: Calculated surface water pH changes for August arising from shipping-derived inputs of sulphur (SOx) and nitrogen (NOx) (from Hassellöv *et al*., 2013)

driven acidification (Hassellöv *et al.,* 2013) - not considering acidification related to scrubber wash water (Fig. 6). A lowering of the pH in seawater by scrubber effluents occurs in the upper water column, may contribute to ship-derived acidification and accelerate the expected consequences of climate change. Furthermore, local and temporal restricted addition ('pulse') of low pH wash water may affect both, metabolism and density of the microbial communities, while long term, gradual decrease in pH (related to ocean acidification) allows the community to adapt. Besides the decrease in pH, scrubber wash water may lead to temperature and nutrient increase, turbidity and introduction of pollutants from combustion residues and additives (Fig. 7). Contaminants include PAHs and heavy metals but also increased nitrate concentrations (Buhaug et *al*., 2006, Hansen 2012) as scrubber technology does not remove any NOx, or only to a very small degree, from the exhaust. In areas of low seawater alkalinity and temperature, e.g. North-Eastern Baltic Sea, the buffering capacity and therefore cleaning performance of seawater is reduced leading to increasing requirements of wash water or addition of buffering substances. The expected significant increase of use of scrubbers will likely have a substantial environmental impact on

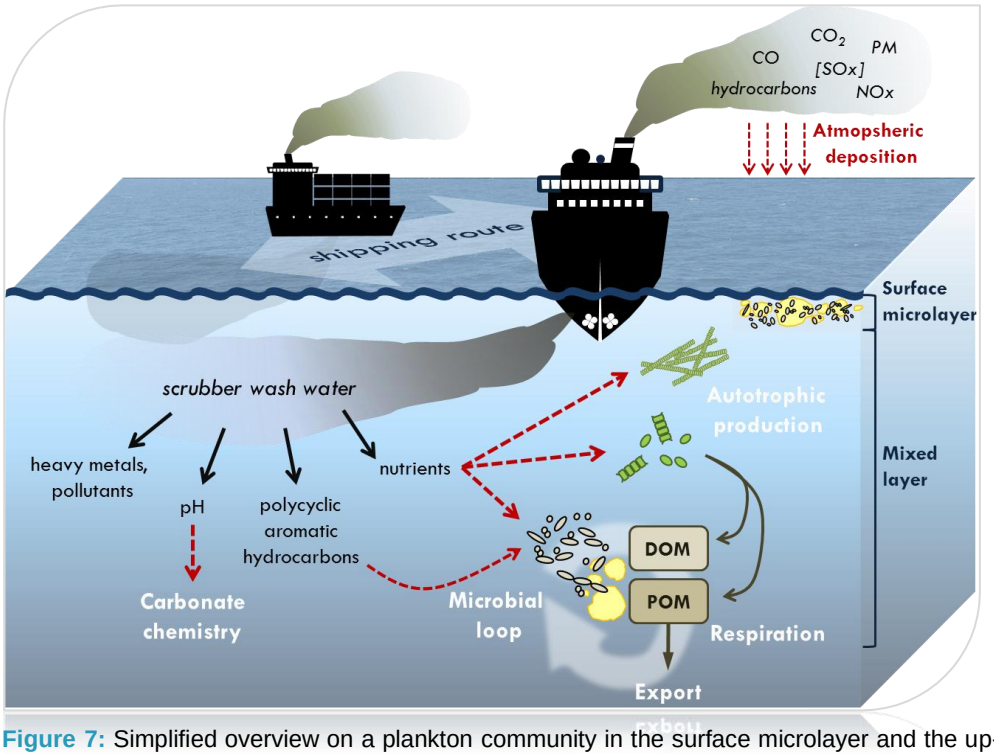

Figure 7: Simplified overview on a plankton community in the surface microlayer and the upper mixed layer and potential impact (red arrows) of ships' effluent (CO, carbon monoxide; CO_2, carbon dioxide; PM, particulate matter; SOx, sulphur; NOx, nitrogen) on microbial processes biogeochemistry due to release of nutrients, organic matter (DOM, dissolved organic matter; POM, Particulate organic matter), heavy metals, pollutants and inorganic acids.

the ecologically sensitive areas in the Baltic Sea and other marine environments.
Due the small number of previously conducted studies, there is a great need for further research on this topic. To date, there are only very few quantitative and qualitative measurements on the amount and composition of ship effluents and their biological impact in the marine environments. The consequences of ship emissions for marine chemistry, organic matter cycling and biodiversity are highly relevant to the development of shipping as sustainable transport medium. Profound scientific data will be valuable for subsequent policy recommendations and remove operational and investment uncertainty for shipping industry.

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solas event report

Report 07 I November 2017

Session on:

“Good Hope for Earth Science: Atmospheric Chemistry and Physics for the 21st Century

SOLAS sub-session: A tribute to Prof. Roland von Glasow”

28 August - 1 September, 2017 Cape Town, South Africa

From 28 August until 1 September 2017, the session M01 “Atmospheric Chemistry and Physics for the 21st Century” has been organised under the auspices of the International Commission on Atmospheric Chemistry and Global Pollution (iCACGP) at the International Convention Center in Cape Town, South Africa.

The sessions on August 28 and 29 were dedicated to SOLAS as a tribute to Prof. Roland von Glasow, who served on the Scientific Steering Committee of SOLAS (2008-2013), and was an active Commission Member of iCACGP when he suddenly passed away in 2015. Roland’s leadership and increasingly important contributions to the SOLAS community were honoured during the presentation of the two invited speakers Prof. Rainer Volkamer and Prof. Maria Kanakidou, who outlined the scientific path of Roland and presented recent results as a continuation of research topics initiated by him.

Roland studied Physics at the University of Mainz (Diplom in 1997), followed by a PhD in Atmospheric Physics at the Max Planck Institute for Chemistry (2001) working on tropospheric

In this report

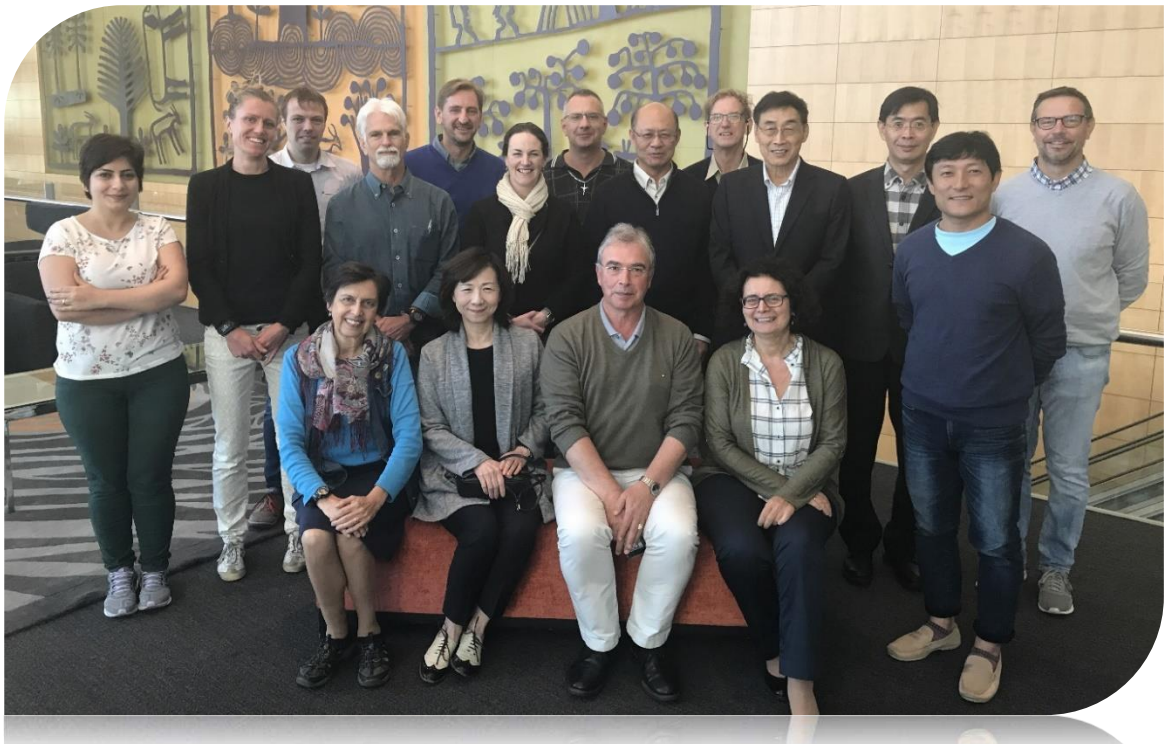

Figure 1: The iCACGP members and delegates, who organised the SOLAS sub-session. © Maria Kanakidou
Front row (sitting) from left to right: Anne Thompson, Sachiko Hayashida, John P. Burrows, Maria Kanakidou
Back row (standing) from left to right: Soheila Jafariserajehlou, Fiona Tummon, Sven Krautwurst, Russell R. Dickerson, Rainer Volkamer, Robyn Schofield, Stuart Piketh, Tong Zhu, James R. Drummond, Shaw Chen Liu, Charles C.-K. Chou, Hiroshi Tanimoto, Christian George.

halogens, a topic that he has developed and extended throughout his scientific career as is exemplified by his role as co-chair of the SOLAS/ International Global Atmospheric Chemistry (IGAC) task "Halogens in the Troposphere" (since 2005). After a Postdoc at Scripps Institution of Oceanography, San Diego, USA (2001-2003), he returned to Germany to head a Junior Research Group (Emmy Noether) at the Institute for Environmental Physics, University of Heidelberg, Germany (2004-2007). Roland joined the University of East Anglia (UEA), Norwich, UK, in 2007, where he was promoted to Professor in Atmospheric Sciences in 2012. At UEA he conceived and directed the Centre for Ocean and Atmospheric Sciences in 2013, unifying physical and biogeochemical sciences under one umbrella. Today Roland's work continues at UEA within "The Roland von Glasow Air-Sea-Ice Chamber" built following his ideas. He was a member of numerous scientific committees (including SOLAS and iCACGP), generously giving his time and sharing his enthusiasm for research. From 2009-2012 he co-chaired the International Geosphere-Biosphere Program (IGBP) Fast Track Initiative on "Air-sea interactions in megacities and the coastal zone" to provide an integrated view of the human impacts on the Atmosphere-Land-Marine Ecosystem. Inspired by Roland, SOLAS researchers are organising a workshop on 26 October 2017 in Gothenburg, Sweden, to develop a research theme that assesses the effects of commercial shipping on the ocean-atmosphere system.

The SOLAS part of session M01 highlighted two aspects of Roland's work on "Halogens in the Troposphere" and "Coastal Megacities", and was attended by ~50 participants from five continents. On 28 August, the "Roland von Glasow Memorial Lecture: Tropospheric Halogen Sources from Sea Spray Aerosol" by Prof. Volkamer presented new field measurements that inform the bromine conundrum, i.e. the fact that atmospheric models often predict more bromine oxide (BrO) radicals compared to surface measurements over remote oceans. This phenomenon had been puzzling

Roland since the early days of his career. Roland had highlighted the important role of aerosol acidity, and its changes with altitude that accelerate the heterogeneous recycling of bromine in the free troposphere. New measurements of gas- and aerosol bromide probed for the first time the bromine hot-spots over the tropical Pacific Ocean as part of the Tropical Ocean tRoposphere Exchange of Reactive Halogens and Oxygenated Volatile Organic Compounds (OVOC) project cruise, and identify a missing gas-phase process that converts BrOx (= Br + BrO) into inorganic bromine. The field measurements also identify unaccounted sources of marine OVOC, incl. glyoxal, aliphatic aldehydes and ketones, providing evidence that a more vigorous chemical coupling between the marine organic carbon cycle and tropospheric halogens might be responsible for the bromine conundrum. Sea salt aerosols are a source of bromine in the free troposphere, and possibly the upper troposphere and lower stratosphere (UTLS). The chemical detail identified by Roland's early work appears to be relevant to understanding the global distribution of halogens, yet it is missing from most atmospheric models today.

Following the first presentation, Prof. Monica Rhein spoke about "Ocean ventilation changes and impact on oxygen and anthropogenic carbon distributions in the North Atlantic". She discussed the changes in global decline in oxygen in the ocean of the recent past, and in particular in the tropics and North Pacific and Atlantic Ocean. These changes have been attributed to reduced ventilation. Prof. Rhein also presented results from the Labrador Sea on temperature and salinity changes that appear to be linked to global warming, and results on the use of Helium and Neon isotopes to calculate melt water fractions from the Greenland Ice Sheet into the Labrador Sea.

Dr. Chistian George presented about "Photosensitized chemistry at the air-sea interface: Biology vs Chemistry", challenging the audience to rethink air-sea exchange processes. He stressed that the interface between the atmosphere and the ocean is a good place for chemistry to take place, due to the enrichment of surfactants and photosensitizes that can harvest solar photons within the actinic flux region of the sun, and convert them into chemical energy that is available to trigger photochemical reactions. He presented results from laboratory experiments about the products of photosensitised chemistry of alcohols and fatty acids at the interface, which upon irradiation appear to dehydrate and form unsaturated products such as isoprene, and unsaturated OVOC. This chemistry presents an abiotic pathway to isoprene formation from organic matter that originates from cell lysis in the surface ocean, and accumulates at the air-sea interface.

On 29 August, the "Human driven changes in the marine atmosphere and in the nutrient deposition to the global ocean. A tribute to Roland von Glasow" by Prof. Kanakidou first presented the wide range of chemical, physical and biological interactions between land-ocean and atmosphere at the coastal interface that is vulnerable to climate change as reviewed in the conceptual paper issued from the fast track initiative workshop on "Air-sea interactions in megacities and the coastal zone" led by Roland. Then focus was put on the impact of anthropogenic emissions that are intensively occurring over urban areas but having regional and global impacts due to atmospheric transport, and how these emissions impact atmospheric deposition of nutrients to the ocean. New global model results from the Pollution Alters Natural aerosol composition: Implications for Ocean Productivity, Climate and air quality (PANOPLY) project and the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 38 (on atmospheric input of chemicals to the ocean) have been presented for nitrogen, phosphorus and iron deposition. In particular, the impact of cloud and aerosol water acidity and multiphase chemistry on the production of organic ligands (represented in the model by oxalic acid) from soluble carbonyls, and on solubilising nutrients (namely iron and phosphorus) present in atmospheric aerosol, has been shown to be

significant. The global modelling studies evaluated the large contribution of the organics to the global atmospheric deposition of these nutrients, producing the first global deposition maps of organic nitrogen and organic phosphorus, in agreement with existing observations. They have revealed the potentially large contribution of bioaerosols as a source of bioavailable nitrogen and phosphorous to the ocean, which under certain circumstance is of comparable importance with soluble dust inputs of phosphorous. This fraction has been neglected in most global modelling studies until now.

Following the presentation of Prof. Kanikadou, Dr. Joseph Adesina discussed the "Contribution of marine aerosols to the total columnar aerosol loading over Ascension Island". A cluster method was used to interpret sunphotometer measurements of wavelength dependent aerosol optical depth, single scattering albedo, and their seasonal variations to identify the types of aerosols (marine, dust, urban and biomass burning, and continental average) that influence the air column above five stations in Southern Africa and Ascension Island, on a seasonal basis. Significant differences of the aerosol sources were corroborated by back trajectory analysis that point to different source regions from the West African continent, that influence the air column above Ascension in different seasons.

Finally, Dr. Hans Schlager, presented on "Aircraft observations of sulfur dioxide (SO_2) transport to the UTLS from major source regions". The High Altitude and Long Range Research Aircraft (HALO) and Falcon aircrafts operated by Deutsches Zentrum für Luft- und Raumfahrt (DLR), Oberpfaffenhofen, Germany, were used to measure SO_2 and aerosol size distributions with special attention to separating the nucleation mode sized particles (2-4 nm diameter) from Aitken mode and larger diameters. SO_2 concentrations above 10 km typically ranged from 10-100 pptv, though concentrations up to 1 ppbv were observed. The back-trajectory analysis suggests an important role of the warm conveyer belt for lofting air masses containing SO_2; the subsequent oxidation to form sulfuric acid provides a possible mechanism for the initial cluster formation from air pollution. Dr. Schlager also discussed tracer release studies from urban areas as a technical approach to use aircraft observations to normalize dilution of air during transport downwind.

We thank the workshop sponsors: the International Association for the Physical Sciences of the Oceans (IAPSO), the International Association of Meteorology and Atmospheric Sciences (IAMAS), the International Association of Geomagnetism and Aeronomy, the International Union of Geodesy and Geophysics (IUGG), iCACGP and SOLAS, whose support allowed us to have such a fruitful and warm session to recall Roland.

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Link to the event website:
http://www.iapso-iamas-iaga2017.com/

The outcomes of the session contribute to the Cross-Cutting Theme ‘Integrated Topics’ (polar oceans and sea ice), and Core Theme 5 ‘Ocean biogeochemical control on atmospheric chemistry’ of the SOLAS 2015-2025: Science Plan and Organisation.

Stelios Myriokefalitakis holds a Ph.D in atmospheric chemistry from University of Crete, Greece. In 2014, he moved to Columbia University, New York, United States of America, to conduct research in coupled climate modelling as a Fulbright Visiting Scholar. From 2016, Stelios is a Marie-Curie Fellow at Utrecht University, Netherlands, investigating the effect of air-pollution on ocean biogeochemistry.

Modelling the impact of air pollution on iron deposition fluxes over the marine environment

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Oceans modulate the carbon cycle by contributing to the removal of atmospheric carbon dioxide (CO_2) via physical, chemical, and biological processes. Atmospheric deposition has been suggested as an important source of nutrients for the marine environment in the open ocean. The overall impact of aerosol deposition on the carbon cycle is likely causing an increased CO_2 uptake in the current climate (Krishnamurthy *et al.,* 2009). Atmospheric composition, however, has been heavily perturbed by human activities and considerable uncertainty remains in our understanding of the impact of atmospheric deposition on the marine limitations. My current work is focused on the iron (Fe) deposition fluxes calculations in an Earth System Model (ESM).

Fe is considered as a key micronutrient that significantly modulates the gross primary production in High-Nutrient-Low-Chlorophyll oceans, where macronutrients like nitrate are abundant but primary production is limited by Fe scarcity. Aeolian dust is the principal source of Fe to the surface open ocean, followed by Fe-containing aerosols from biomass burning and fossil-fuel combustion emissions. However, Fe can only be utilised by phytoplankton in a dissolved form (aqueous, colloidal, or nanoparticulate). Atmospheric processes related to air-quality can convert Fe to become more soluble in the atmosphere. Indeed, strong acids (e.g., sulfuric acid, nitric acid) and organic ligands (e.g., oxalic acid) that coat deliquesced minerals, eventually transform part of the contained insoluble forms of Fe (e.g., ferric oxide) into soluble forms (e.g., Fe(II), inorganic soluble species of Fe(III), and organic Fe-complexes) during atmospheric processing. State-of-the-art chemistry-transport modelling studies (e.g. Luo *et al.*, 2008; Johnson and Meskhidze, 2013; Myriokefalitakis *et al.,* 2015; Wang *et al.*, 2015; Ito and Shi, 2016) currently calculate an oceanic dissolved Fe deposition flux of ~0.1-0.3 Tg Fe yr^{-1}, clearly supporting the view that air-quality affects its deposition pattern over oceans. Furthermore, it is demonstrated that the future air-quality may decrease soluble Fe deposition by roughly 25% (Myriokefalitakis *et al.*, 2015), owing to the projected reduction in mineral-Fe dissolution (~55%).

Although current offline studies successfully reproduce the main aspects of present-day dissolved Fe concentrations compared to in-situ observations, giving thus high-confidence to our

understanding on Fe-release processes, ESM simulations are required to estimate the holistic impact on the global marine primary productivity (Figure 2).

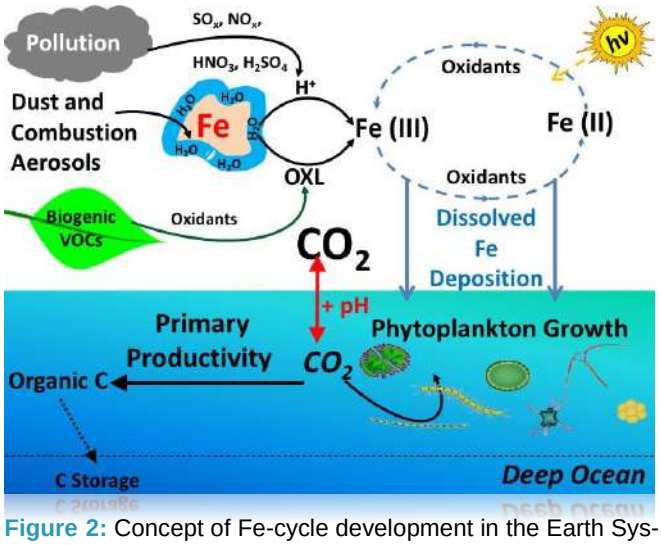

Figure 2: Concept of Fe-cycle development in the Earth System Model-EC-Earth.

For this, the state-of-the-art ESM EC-Earth has been extended with an on-line atmospheric Fe dissolution scheme, taking into account dust minerals and combustion aerosols, and it is extensively evaluated against Fe-containing aerosol observations. Currently, we develop the coupling of the new Fe deposition fields to the ocean biogeochemistry component of EC-Earth. Overall, this will allow us to investigate in more detail the potential ocean biogeochemistry perturbations due to changes in Fe deposition for the past and future atmosphere.

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Acknowledgements

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Joseph Ayodele Adesina received his master's degree in Physics in Nigeria in 2010 and moved to South Africa in 2012 for his Ph.D. He investigated aerosol characteristics over different regions of southern Africa - using sunphotometer and satellite measurements.

Intercomparison and assessment of long-term (2004–2013) multiple satellite aerosol products over two contrasting sites in South Africa

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To establish a long-term database for climatological studies, an intercomparison of aerosol optical depth (AOD) values derived from different satellite sensors is needed. The advantage of this is an improvement in accuracy, while such a coverage cannot be achieved by single sensors (Prasad and Singh, 2007; Zhang and Reid, 2010). The study compares the variation of monthly AOD values retrieved from the two sampling stations at Skukuza and Richards Bay (SKZ and RBAY) respectively in South Africa, during the study period 2004–2013 from MODerate resolution Imaging Spectroradiometer (MODIS, on satellites Aqua and Terra) and Multi-angle Imaging Spectro-Radiometer (MISR). The common feature observed at both locations is that the three satellites noticed high AOD from August to October, which is considered as a seasonal phenomenon of the region (Queface *et al.,* 2011; Adesina *et al*., 2014). In SKZ, all the sensors noticed high aerosol loading (> 0.25) during late winter and springtime for the years 2005, 2008, and 2010 (Figure 3). Similar variations of high AOD have been clearly depicted at RBAY for the same years, with more pronounced AOD observed from MODIS-Aqua (Figure 3). This suggests the better performance of MODIS-Aqua over coastal sites compared to MODIS-Terra, which is in agreement with Chu *et al.* (2002).

The seasonal mean AOD is highest in spring (0.16 ± 0.05) followed by summer (0.11 ± 0.04) and autumn (0.10 ± 0.04), while the lowest was observed during the winter (0.09 ± 0.04). In springtime, the highest AOD is attributed to increased absorbing aerosols emitted from biomass burning, agricultural residues burning to clear harvest and forest fires over the study region and its surroundings. High AOD was also observed in summer months because high temperature and humidity are beneficial for the formation and hygroscopic growth of aerosols. In addition, strong atmospheric convection enhances the vertical transportation of near surface particles in summer. In addition, high temperatures in summer favour the photochemical reactions, leading to the production of secondary aerosols.

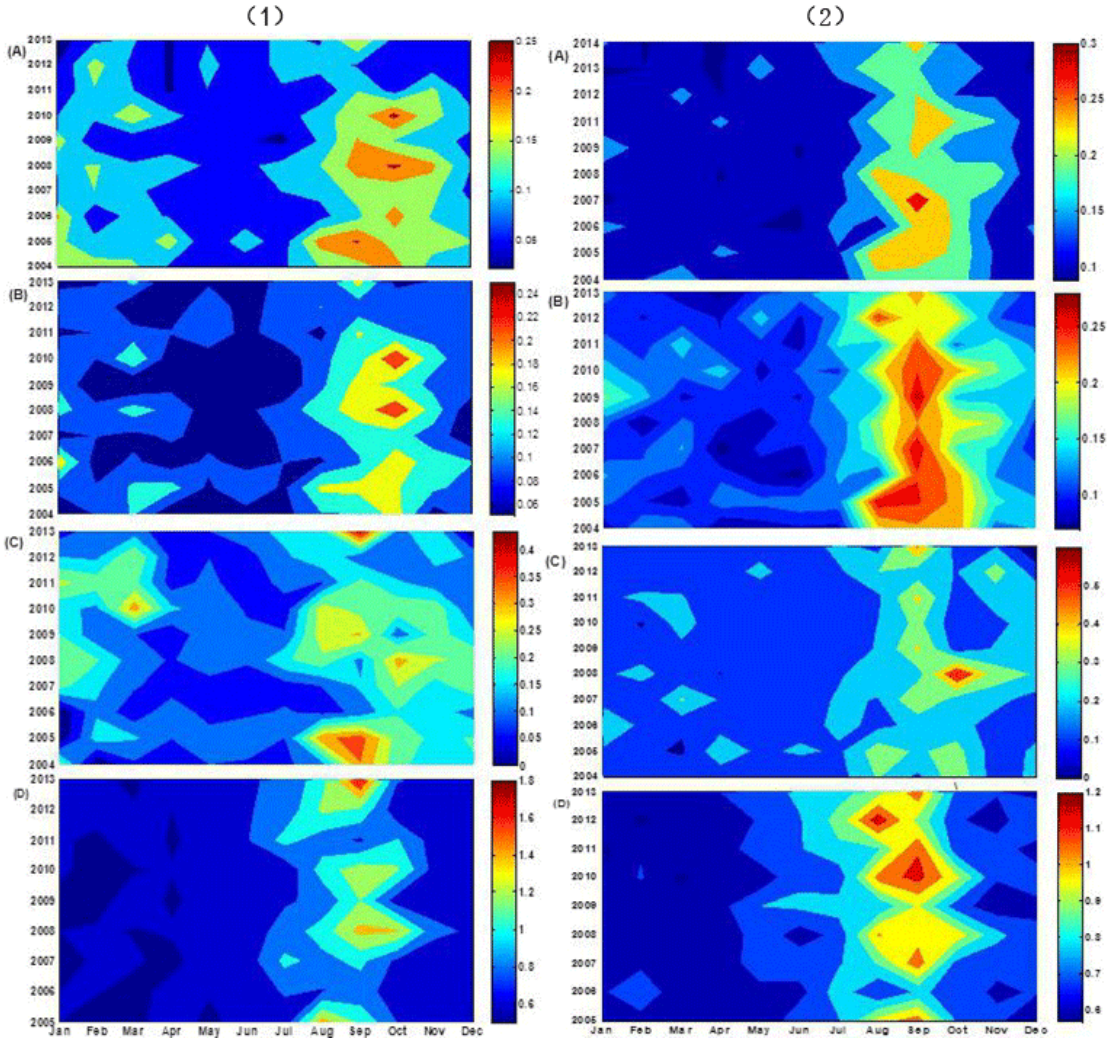

Figure 3: Averaged inter-annual variations of AOD retrieved from (A) MODIS-Terra, (B) MODIS-Aqua, (C) MISR, and ultra violet aerosol index variations from (D) Level-2 OMI at study sites (1) SKZ and (2) RBAY.

Further, the frequent occurrence of long-range transport of dust from north-western South Africa lead to an increase in AOD during spring and summer seasons (Kumar *et al.*, 2013). The annual and seasonal variability of ultra violet aerosol index retrieved from the Level-2 Ozone Monitoring Instrument data for the two study regions during 2005–2013, showed a significant increase at SKZ, having an increment of +0.009 yr^{-1} and RBAY with +0.006 yr^{-1}. Overall, the performance of MISR and MODIS sensors based on the validation showed that MISR is better correlated with the AErosol RObotic NETwork (AERONET) sunphotometer than the MODIS products at SKZ and RBAY.

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Theodore Konstantinos Koenig completed his Bachelors of Science at California Institute of Technology, Pasadena, United States of America, in 2012, majoring in Chemistry with minors in Geological and Planetary Science and History. Since 2012, he has pursued a Ph.D in Chemistry at the University of Colorado, Boulder, United States of America, focusing on passive remote sensing of trace gasses, particularly halogen oxides, from aircraft and mountaintops.

Inorganic bromine and iodine in the remote marine troposphere

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Oceans and coastal marine ecosystems are the primary sources of halogens to the atmosphere. The halogens bromine and iodine have a number of important impacts in the troposphere. Both catalytically destroy ozone, and modify oxidative balance and capacity, e.g. hydrogen oxide radicals and nitrogen oxides. In addition, bromine is the primary reactant which oxidizes atmospheric mercury and reacts with some oxygenated organic compounds, and iodine contributes to particle nucleation and growth (Sherwen *et al*., 2016). These effects in turn have important impacts on climate and human health. Halogens are emitted as organic and inorganic chemical species from biotic and abiotic sources which were particularly important in preindustrial times (Parella *et al*., 2011). One of the sources of halogens that is of particular interest is from sea salt aerosol (SSA). Heterogeneous reactions can activate and liberate halogens to the gas phase from SSA in the free troposphere just as what they do at the sea surface. Biogeochemical control of atmospheric chemistry extends from the surface ocean through the marine boundary layer and free troposphere into the lower stratosphere.

Historically, inorganic bromine and iodine in the free troposphere and stratosphere have been believed to be derived from the processing of organic species. However, recent modelling studies (Long *et al*., 2014) suggest that much of the bromine in the mid and upper troposphere can instead be explained by this sea salt source. Aircraft measurements over the Western and Eastern Pacific during the Troposphere Exchange of Reactive Halogen Species and Oxygenated VOC (TORERO) and Convective Transport of Active Species in the Tropics (CONTRAST) campaigns (Volkamer *et al*., 2015; Wang *et al*., 2015; Dix *et al*., 2016; Koenig *et al*., 2017) confirm that inorganic bromine concentrations peak near the altitudes of outflow from deep marine convection (around 12 km), and suggest that SSA sources influence the composition of the free troposphere.

There are very few measurements that constrain the vertical distribution of inorganic bromine and iodine in the atmosphere. Aircraft studies such as those cited above are ideal for investigating vertical distributions, but they are expensive, offer only snapshots in time, and do not constrain the seasonal and interannual variation. Surface stations on remote tropical mountaintops on oceanic islands provide a platform to observe the tropical free troposphere and lower stratosphere, while

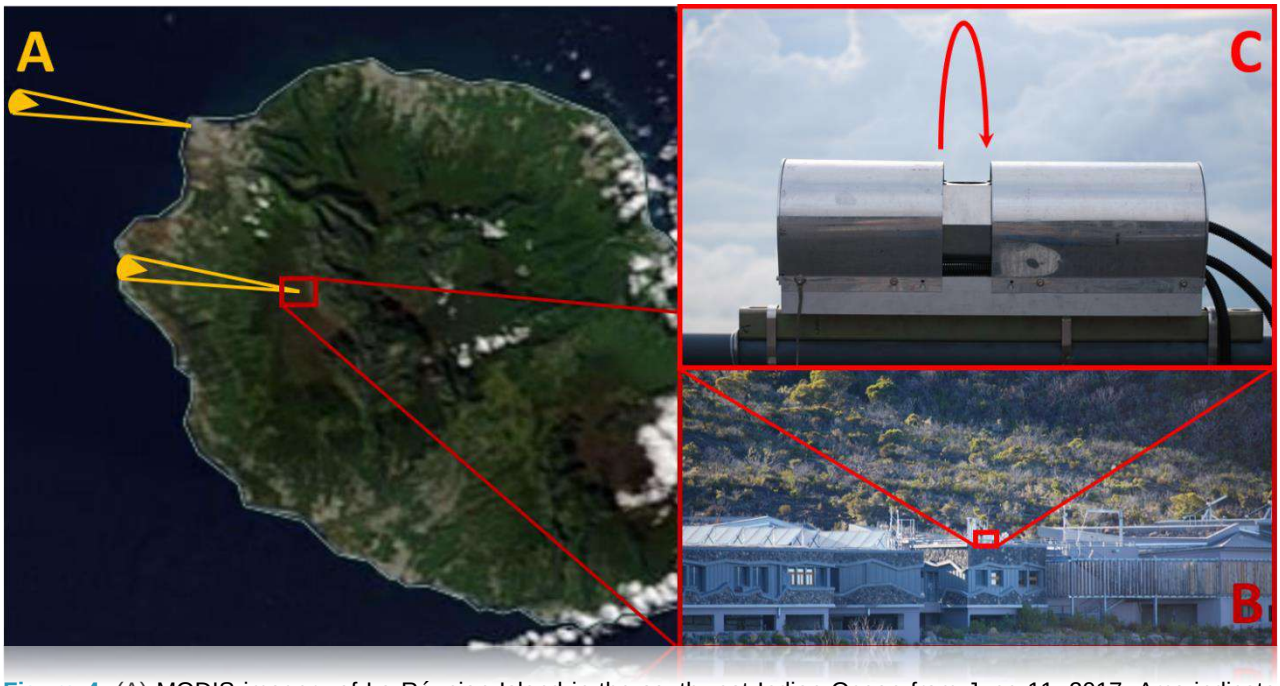

Figure 4: (A) MODIS imagery of La Réunion Island in the southwest Indian Ocean from June 11, 2017. Arcs indicate the viewing direction of the BIRA operated Multi Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) in Le Port on the coast and the University of Colorado Boulder MAX-DOAS at Maïdo Observatory at 2.16 km. B) The Maïdo Observatory. The MAX-DOAS telescope is mounted on the roof with the rest of the instrument below it. During the intensive phase other instruments will be on the roof, or use inlets extending above the roof, or horizontally from the observatory. C) The University of Colorado Boulder MAX-DOAS telescope. The telescope can move in the vertical plane, which is perpendicular to photo, to gather profile information by probing different altitudes.

maintaining access to the boundary layer.

The Volkamer group at University of Colorado Boulder has been operating an instrument at Mauna Loa Observatory (19.5°N, 155.6°W, 3.40 km altitude) on Hawai'i for a period in January to June 2014, and again since February 2017 to present. Another one is operating at Maïdo Observatory (21.1°S, 55.4°E, 2.16 km altitude) on La Réunion since February 2017. We are further collaborating with the Royal Belgian Institute for Space Aeronomy (BIRA/IASB) who operates an instrument at sea level on La Réunion (Figure 4). Utilizing recent advances in profile retrieval methods (Coburn *et al*., 2016), state-of-the-art retrievals are being developed for both sites to retrieve profiles with five degrees of freedom distributed among the boundary layer, free troposphere and lower stratosphere.

From March to May 2018 I will be participating in an intensive operating phase at Maïdo Observatory. In addition to our passive remote sensing instrument we will have an in situ sensor to better characterize halogens and small OVOC at the site. Other instruments will also sample aerosol when the observatory is in the free troposphere to characterize the potential SSA contribution and processing. Other instruments present will further characterize organic species, the interplay of the marine boundary layer and free troposphere, and aerosol nucleation events which have been observed.

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solas event report

Report 08 I December 2017

Conference on:

"Shipping and the Environment - From Regional to Global Perspectives"

24 - 25 October, 2017
Gothenburg, Sweden

Workshop on:

"Shipping"

26 October, 2017
Gothenburg, Sweden

Given its importance for the transport of goods on a global scale, there is a growing interest on the sustainability of the shipping industry. It has long been recognised that shipping is a very carbon-efficient transport medium, but there is an increasing focus on its broader environmental consequences. The Science for a better future of the Baltic Sea region (BONUS) and the Sustainable Shipping and Environment of the Baltic Sea region (SHEBA) project addresses a wide range of environmental impacts of shipping in the Baltic Sea including air pollution, marine pollution, underwater noise and climate change as well as the socio-economic consequences of these impacts.
SOLAS and SHEBA joined forces to organise a two-day conference "Shipping and the Environment - From Regional to Global Perspectives", which was held at the University of Gothenburg's conference centre on 24-25 October 2017, and attracted 117 participants from 15 countries. The conference was followed by a SOLAS workshop on "Shipping" on 26 October 2017. These two closely linked events provided a unique opportunity to review the latest research across a

In this report

Figure 1: Participants of the Shipping Workshop. Left to right - Standing: Birgit Quack, Christa Marandino, Kate Mackey, Tom Bell, David Turner, Sov Atkinson, Volker Mattias, Peter Louie, Frank Maes, Huan Liu, Fan Zhang, Monica Mårtensson, Jana Moldanová, Josefine Maas, Markus Quante, Ida-Maja Hassellöv, Jim Corbett, Sonja Endres, Payam Amir-Heidari, Johannes Oeffner, Zongbo Shi. Kneeling: Laura Recuero Virto. Photo credit: Marcelo Valderrama/Markus Quante.

broad interdisciplinary perspective, and to discuss priorities for future work. The conference programme was divided into five sessions with wide interdisciplinary coverage: Atmospheric processes; Assessments of integrated effects on environment and climate; Marine processes; Noise; and Socioeconomic aspects and policies. Each session included both oral and poster presentations. The oral presentations were followed by a panel discussion between researchers and stakeholders. A joint special issue in the journals Atmospheric Chemistry and Physics, and Ocean Science will provide a platform for disseminating the new research presented at the conference. Several participants noted with pleasure that this was the first international conference addressing the environmental consequences of shipping from a wide range of perspectives. Some interest was expressed in developing a regular series of conferences from this initiative.

Twenty-two participants then took part in the SOLAS workshop (Figure 1) that was held immediately after the conference. This workshop was the third event in an initiative to develop shipping emissions and their consequences as a component of the SOLAS research programme. This initiative started with a discussion session at the 2015 SOLAS Open Science Conference in Kiel, Germany, which was followed by a breakout group on shipping at the 2016 SOLAS Science and Society workshop held in Brussels, Belgium. The aim of the third SOLAS workshop was to develop an outline for SOLAS research on shipping, and to identify a core group that will lead the coming work. Tom Bell, Christa Marandino and Anna Rutgersson have formed this core group and will lead this initiative in moving forward. The “Shipping” workshop resulted in a common framework for considering the various types of ship emissions (i.e. atmospheric, ballast water, grey/black water, scrubber water, noise, and emissions from ship hulls as part of antifouling strategies) and how current and future regulations could potentially impact these emissions. The framework reflected how different

regulations could influence ship emissions and have both intended and unintended consequences. These consequences are important at an environmental and a societal level and directly link the science of ocean-atmosphere interaction with stakeholders, economists and policy makers.
It was recognised that the common framework could provide a contribution to the Knowledge Action Network “Oceans” within Future Earth, and would be eligible to apply for funding that may become available through the Belmont Forum.

Link to the event website:
http://shipping-and-the-environment-2017.ivl.se/

The outcomes of the session contribute to the Cross-Cutting Theme ‘Science and Society’ of the SOLAS 2015-2025: Science Plan and Organisation.

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Josefine Maas studied Climate Physics in Kiel, Germany, and started her PhD at GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany, in 2016. Her research focuses on the increase of anthropogenic volatile halocarbons from oxidative water treatment in shipping and industry. Her work contributes to the Emmy-Noether project: A new threat to the stratospheric ozone layer from Anthropogenic Very Short-lived Halocarbons (AVeSH).

Anthropogenic halocarbons from ballast water treatment

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In the course of the new International Maritime Organization (IMO) Ballast Water Convention (IMO, 2004), entry into force since September 2017, ships have to treat ballast water (BW) in order to prevent invasion of harmful aquatic species and organisms. The volume of BW discharged each year is highly uncertain and estimates assume a global BW discharge of 3-5 x 10^9 m³/yr (David, 2015, Globallast IMO, 2015). It is expected that about 50% of the BW treatment systems (BWTS) use chemical disinfection, e.g. chlorination. Chlorination is a widely used disinfection method in industry and is known to produce a variety of halogenated compounds as disinfection by-products (Werschkun *et al*., 2012). The most abundant compound measured in BW after chemical treatment is bromoform with an average concentration of ~900 nmol/L (Figure 2). Once the bromoform is discharged and emitted into the atmosphere it has a strong ozone depletion potential and can alter the radiative balance and oxidising capacity of the atmosphere (Tegtmeier *et al*., 2012). Especially in the tropics, a region with dense ship traffic and biggest harbours, bromoform can reach the ozone layer in the stratosphere through deep convection.

To assess the bromoform concentration from BW discharge in the ocean, pathways of treated BW are simulated with Lagrangian trajectories. Particles are continuously released at a source region and passively advected with the high-resolution velocity field from Nucleus for European Modelling of the Ocean alias (NEMO)-ORCA12. Source region for the BW spread experiments are major ports and surroundings in Southeast Asia because of the high density of large har-

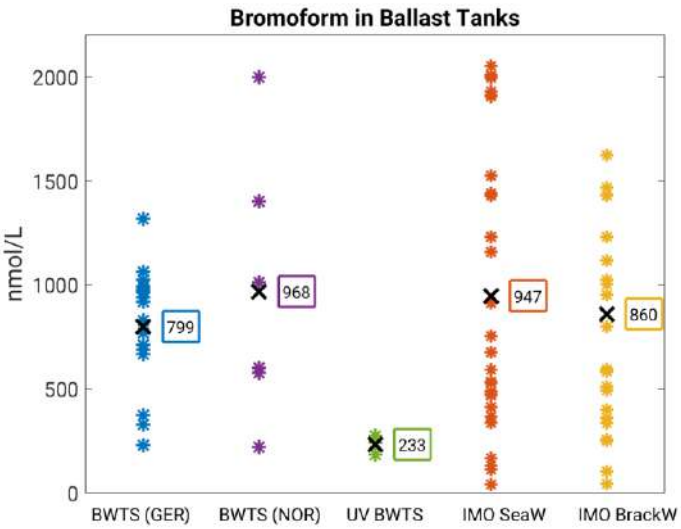

Figure 2: Bromoform concentration measured after BW treatment [nmol/L]. Blue, purple and green: samples measured at GEOMAR, Germany, from two chlorination BWTS (blue and purple) and one UV system (green). Red and yellow: concentrations in seawater (red) and brackish water (yellow) from the IMO Marine Environment Protection Committee (MEPC) Reports for BWTS approval.

bours and the low latitudes.

The simulations at Singapore harbour reveal major pathways of the anthropogenic halocarbons and the resulting ocean surface concentration with an average of ~10 pmol/L after a runtime of one year (Figure 3). Maximum bromoform concentrations of ~30 pmol/L are found in the Strait of Malacca. These values are locally of similar amplitude as shelf water concentrations from databases which lie around 40 pmol/L (Ziska *et al*., 2013). Oceanic degradation processes (Hense and Quack, 2009), as well as an interactive sea-to-air flux with a steady atmospheric surface concentration of bromoform (Ziska *et al*., (2013) are taken into account. Concentrations and emissions decrease when the plume is stronger diluted further in the open ocean. Therefore, regional and coastal processes play an important role in the modelling of BW spread. Regional areas with high oceanic surface concentrations provide a strong gradient at the air-sea interface, which can result in very high flux rates into the atmosphere. Further trajectory modelling studies will be done for different harbours and industrial sites in the tropics and shall be compared to bromoform measurements in these areas.

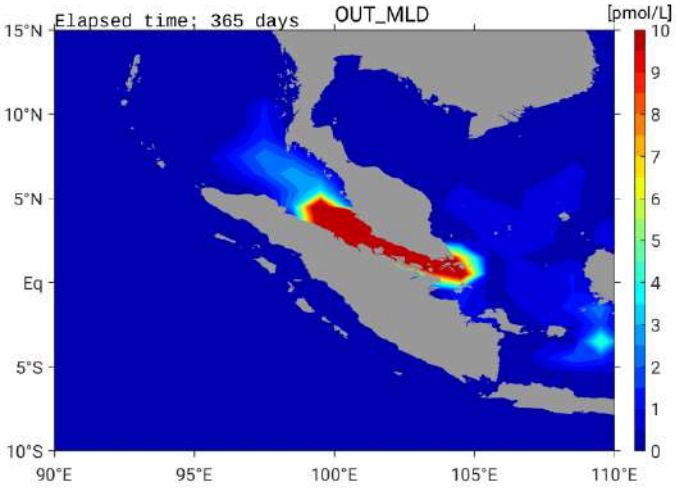

Figure 3: Bromoform concentration [pmol/L] in the surface ocean (<20m) after one year of release of BW at Singapore harbour.

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I would like to thank the working group of the DFG project AVeSH and especially my supervisor Susann Tegtmeier for her support and giving me the possibility to conduct this research.

Sov Atkinson finished her Bachelor of Science (Chemistry and Biochemistry) with Honours at Griffith University, Brisbane, Australia. She started her PhD in 2014 at Plymouth University and Plymouth Marine Laboratory, United Kingdom, investigating the deposition of trace elements from atmospheric aerosol into the surface coastal marine environment.

Observation of atmospheric derived trace metals into the marine coastal environment, Cornwall, United Kingdom.

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The delivery of trace elements to the ocean can regulate the uptake of carbon in some marine ecosystems and, in turn, the atmospheric concentration of carbon dioxide (Maher *et al*., 2010). Trace elements, such as iron (Fe), are essential micronutrients which are involved in the biological functions of many enzymes in phytoplankton (Morel *et al*., 2003), whereas some trace metals, such copper (Cu) and lead (Pb) can be toxic to some ecosystems (Payton *et al*., 2009).

Figure 4 outlines the mode of transport of trace metals to the ocean. The project focuses on the wet and dry deposition of trace metals via aerosol particles at Penlee Point Atmospheric Observatory (PPAO). PPAO is situated in an inlet to Plymouth Sound, United Kingdom, which is a busy shipping route, and is of particular interest as it has a high amount of anthropogenically derived trace element emissions from ships, ferries, and city traffic. Typical southwesterly winds tend to bring relatively clean background Atlantic air towards the site. In contrast, winds from the southeast are often more contaminated by exhaust plumes from passing ships and shipping lanes (Yang *et al*. 2016) (see top right-hand corner of Figure 5 for the different wind directions at PPAO). The impact of such ac-

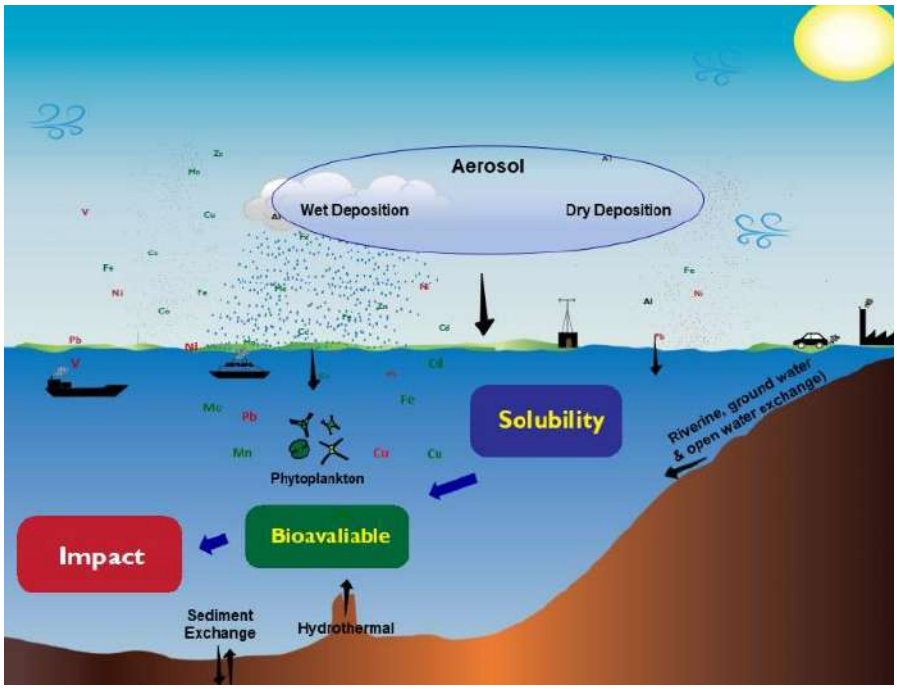

Figure 4: Mode of transport of trace metals to the ocean. The project focuses on the wet and dry deposition of trace metals via aerosol particles.

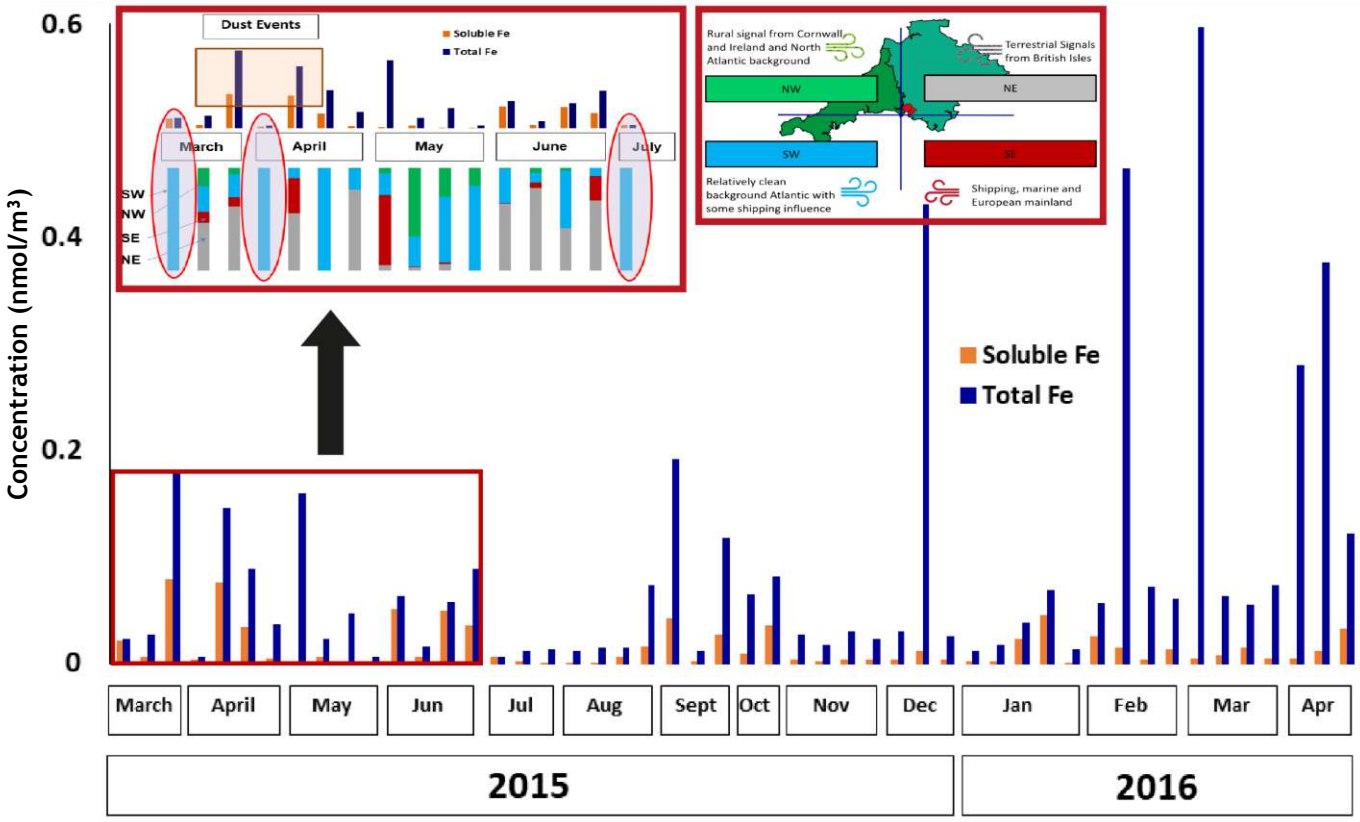

Figure 5: One-year observation of soluble and total Fe concentration in aerosol samples at PPAO.

tivities would subsequently be detectable in the trace element concentrations (e.g. vanadium (V) and nickel (Ni)) of the aerosol samples collected. The PPAO is in close proximity to the Western Channel Observatory, enabling better understanding of the ocean-atmosphere coupling.

My project involved collecting weekly aerosol samples (February 2015 to August 2016) and rain sampling (October 2015 to November 2016) at PPAO. One batch of filter samples was leached with ultra high pressure water (18.2 mΩcm), resulting in the formation of soluble or potentially bioavailable fractions. Another batch of duplicate samples was completely digested by using hydrofluoric/nitric acid (based on Morton *et al*., 2010). Both aerosol fractions and rain samples were analysed using Inductively coupled plasma mass spectrometry to determine the concentrations of trace elements, such as aluminium (Al), V, chromium (Cr), manganese (Mn), Fe, cobalt (Co), Ni, Cu and zinc (Zn) etc.; whilst inductively coupled plasma optical emission spectrometry was used to determine sodium (Na), magnesium (Mg), etc., in order to remove the influence of sea spray on the trace metal concentrations. The main aim of this study was to observe the impact of both local activities, such as shipping traffic, and long-range dust transport on trace element concentrations in the aerosol samples collected and their solubility in the surface ocean in the coastal environment.

Figure 5 shows an example of a typical one-year observation of soluble and total Fe concentrations. The solubility was between 0.78% - 85%; the high loading in the winter months was not always correlated to high solubility. Local wind direction may not influence the solubility of Fe, therefore the dataset will be combined with local wind data, rainfall, Hybrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) air mass back trajectories, Numerical Atmospheric-dispersion Modelling Environment (NAME) dispersion model back trajectories, other gases measurements, and aerosol numbers. This combined investigation will help get a better understanding of the variability in atmospheric deposition of trace metals and their solubility in the surface ocean.

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State Key Laboratory of Marine Environmental Science (Xiamen University)

WCRP World Climate Research Programme

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