**Website Implementation Plan - Version 2**
Version from: 12 January 2018

Theme 1: Greenhouse gases and the oceans

Introduction

Carbon dioxide ($CO_2$), nitrous oxide ($N_2O$), and methane ($CH_4$) are the most significant long lived greenhouse gases (GHGs) after water vapour. Physical and biogeochemical processes in the surface ocean play an important role in controlling the ocean-atmosphere GHG fluxes. Understanding the sensitivities of these processes to climate and environmental change is of critical importance for the mitigation of climate change.

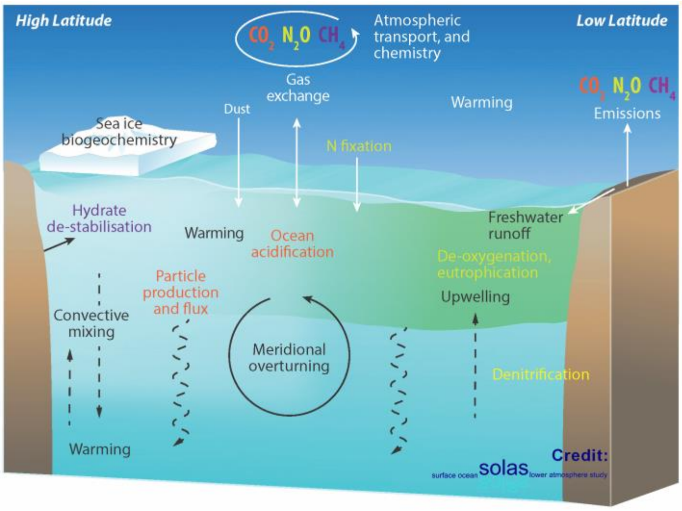


Figure 1: Processes and impacts/stressors associated with long-lived greenhouse gases.

Theme 1 Team

Team leaders:
Parvadha Suntharalingam (United Kingdom, p.suntharalingam@uea.ac.uk)
Guiling Zhang (China, guilingzhang@ouc.edu.cn)

Team members:
Hermann Bange (Germany, hbange@geomar.de)
Dorothee Bakker (United Kingdom, d.bakker@uea.ac.uk)
Tom Bell (United Kingdom, tbe@pml.ac.uk)
Minhan Dai (China, mdai@xmu.edu.cn)
Sam Wilson (United States, stwilson@hawaii.edu)

Research questions

Key questions to be addressed within this theme are:

- Which surface ocean processes control GHG cycling at regional to global scales?
- What are the main feedback mechanisms between climate change and oceanic GHG emissions?
- How can we assess future oceanic fluxes of GHGs in a changing ocean and

atmosphere?

Priorities

Detailed regional analyses

To better quantify and predict the evolution of oceanic GHG budgets and air-sea fluxes, detailed analyses of key regions for GHG fluxes are required. These include the Southern Ocean, coastal zones, and oceanic Oxygen Minimum Zones. Recommended approaches include higher resolution numerical models which represent the coupling of key processes for circulation, ecosystems and relevant biogeochemistry, and detailed biogeographical sampling of marine ecosystems across gradients to characterise the variations in environmental drivers and GHG flux responses.

Increased density of observations

In order to reliably assess variations in GHG fluxes within the ocean and across the air-sea interface, a denser observing system is required; e.g. from ships, autonomous platforms (e.g., Argo floats, gliders), and moorings. Satellite observations of relevant marine ecosystem and oceanic properties should also be exploited and linked systematically to in-situ oceanic measurements.

Development of new analysis tools and extension of existing methodologies

Improved quantification of ocean-atmosphere carbon dioxide fluxes has been achieved by combining existing particulate carbon dioxide surface data with a range of mapping methods including spatial interpolation, multi-variate regressions, and neural network analyses. These tools can be extended to the other GHGs to improve flux quantification and to further investigate the key underlying processes.

Planned activities

Workshop on Dissolved $N_2O$ and $CH_4$ measurements

This workshop will be organized by SCOR WG#143 as a final meeting. The purpose is to establish framework for an $N_2O$ and $CH_4$ ocean time series network and write a global oceanic $N_2O/CH_4$ summary paper for publication, make comparison of standard gases, intercompare underway equilibrator systems and $N_2O$ and $CH_4$ measurements of discrete seawater samples.
Location: Portland, USA
Dates: February 10, 2018
Chairs: Hermann Bange and Sam Wilson

Nationally funded research programs on regional ocean-atmosphere GHG fluxes

Current nationally-funded programs investigating ocean $CO_2$ uptake in the Southern Ocean include the US National Science Foundation's "Southern Ocean Carbon and Climate Observations and Modeling" (SOCCOM) project, and the UK National Environmental Research Council funded "Role of the Southern Ocean in the Earth System" (RoSES). Information on planned observational programs and workshops can be found via the respective program websites:
SOCCOM: https://soccom.princeton.edu/
RoSES: http://www.nerc.ac.uk/research/funded/programmes/roses/

Carbon Group
Following the successes of the joint SOLAS/IMBER Carbon groups (SIC) a new Carbon Group is being formed jointly sponsored by IMBER, SOLAS, IOCCP, GCP, CLIVAR, and WCRP.

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## Theme 2: Air-sea interface and fluxes of mass and energy

### Introduction

Ocean-atmosphere fluxes play a critical role in the regulation of climate. We therefore need to come to a mechanistic understanding of physical, chemical, and biological processes affecting exchange of gases, mass, and energy across the air-sea interface from nanometer to global scales.

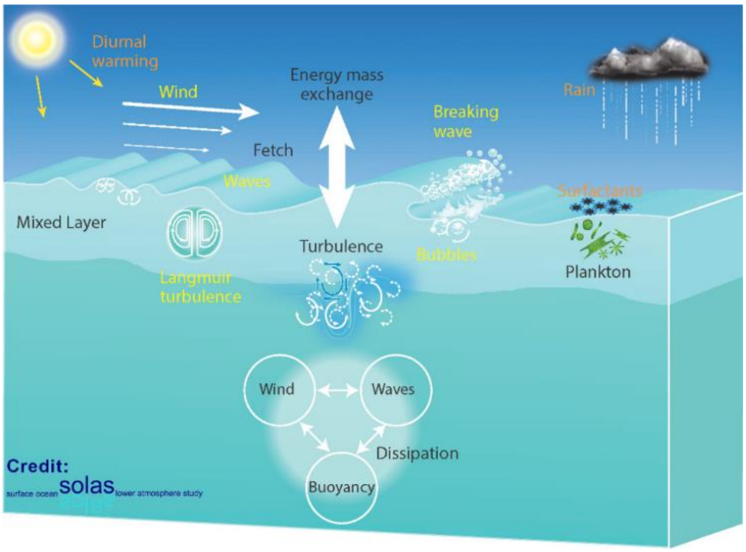


Figure 2: Dominant processes controlling air-sea fluxes of mass and energy in the open ocean.

### Theme 2 Team

Team leaders:
Anja Engel (Germany, aengel@geomar.de)
Peter Minnett (United States, pminnett@miami.edu)
Anna Rutgersson (Sweden, anna.rutgersson@met.uu.se)
Hiroshi Tanimoto (Japan, tanimoto@nies.go.jp)

Team members:
Susannah Burrows (United States)
Haibing Ding (China, dinghb@ouc.edu.cn)
Robert Upstill-Goddard (United Kingdom, rob.goddard@ncl.ac.uk)

Research questions

Key questions to be addressed within this theme are:

- What are the biogeochemical mechanisms that influence fluxes of gas, mass, and energy at the surface ocean boundary layer?
- How can the turbulence-controlling processes be incorporated into parameterisation schemes describing the air-sea fluxes of mass and energy?
- What are the feedbacks between processes governing air-sea fluxes and climate?

Priorities

Coordinated measurements

We should support joint coordinated measurement efforts of fluxes as a basis to compare methods, instruments, and processes. This can be either achieved with existing stationary stations, where instruments are attached to buoys, or with ongoing and planned cruises. Remote sensing is an important tool to determine features of sampling sites prior to studies.

Station and cruise lists

We should provide a list of air-sea flux time series stations and cruises on the webpage.

Time Series Station

In addition, we should establish a SOLAS Time Series Station (SLIC – Surface ocean Lower atmosphere International/Integrated Campaign/Center) with long-term observing systems to combining methods and conduct intercomparisons. We propose to establish this station at the Cape Verde observatory. An initial working group to pursue this initiative includes Prof. Anja Engel (aengel@geomar.de) and Prof. Christa Marandino (cmarandino@geomar.de) .

Planned activities

Projects

There are several ongoing national/international projects of relevance, information concerning these projects and their outcomes should be distributed to the community (Milan, Peacetime, Integral). The list of ongoing and new projects is being regularly updated on this SOLAS webpage, with links to individual projects.

In addition, joint international projects focusing the Theme 2 science questions (EU, NSF, SCOR, COST) should be initiated.

We are working on setting up joint international collaborations focusing the Theme 2 science questions, for example:

- SOLAS Time Series Station (SLIC) at the Cape Verde Observatory. An initial working group, including Prof. Anja Engel (aengel@geomar.de) and Prof. Christa Marandino (cmarandino@geomar.de), has been set up for this.
- Setting up benchmark measurements for model validations (a SCOR project to combine modelers and observationalists for defining relevant parameters and identify existing and new data sets).
- Structured and broad method evaluation of flux measurements or surfactant analysis (anna.rutgersson@met.uu.se)
- Remote sensing. Contact person is Peter Minnett (pminnett@miami.edu)

Joint meetings and workshops

For an active development of the science and the community it is needed to organise joint activities including:

- Sessions at major international meetings (AGU, EGU, Gordon Research Conference)
- Contribution to the SOLAS Summer School 2018
- Coordinate publication efforts (e.g. Research TOPIC in Frontiers)
- Update SOLAS website on activities, publications, cruises etc.

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## Theme 3: Atmospheric deposition and ocean biogeochemistry

### Introduction

Atmospheric deposition is an important nutrient source for marine ecosystems, with consequences on local, regional, and global biogeochemical cycles, as well as on the climate system. Theme 3 focuses on the relationships between natural and anthropogenic atmospheric inputs, the marine carbon cycle, and feedbacks to climate. The fundamental processes driving aerosol emissions, transportation, chemical reaction, and deposition may change atmospheric fluxes and surface mixed layer turnover times. In turn, microbial communities respond to changing atmospheric inputs which may result in opposite effects on the marine carbon and nitrogen budget, as well as on atmospheric carbon dioxide uptake.

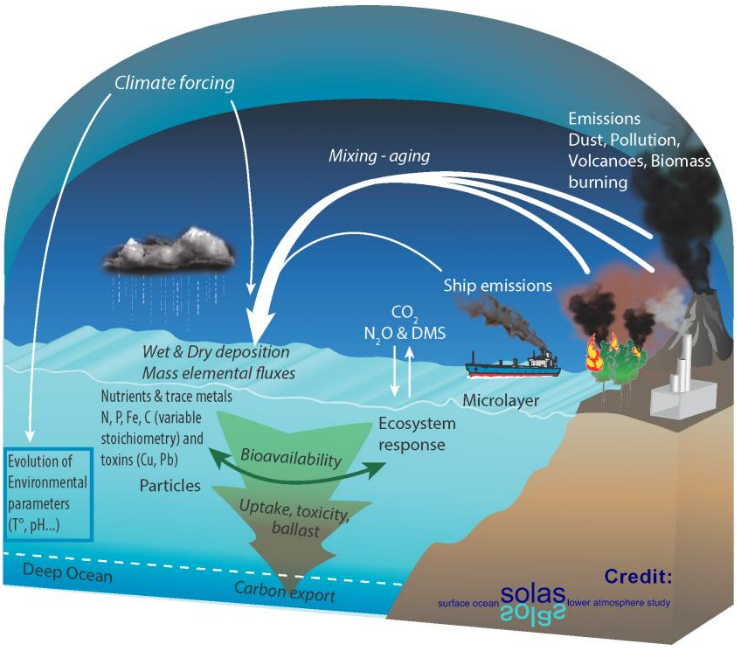


Figure 3: Main issues, processes, and species relating to Core Theme 3 (processes are indicated in italics).

### Theme 3 Team

Team leaders:
Phil Boyd (Australia, philip.boyd@utas.edu.au)
Huiwang Gao (China, hwgao@ouc.edu.cn)
Maurice Levasseur (Canada, maurice.levasseur@bio.ulaval.ca)

Team members:
Alex Baker (United Kingdom, alexander.baker@reading.ac.uk)
Ying Chen (United Kingdom, y.chen65@lancaster.ac.uk)
Peter Croot (Ireland, peter.croot@nuigalway.ie)
Cecile Guieu (France, guieu@obs-vlfr.fr)
Akinori Ito (Japan, akinorii@jamestec.go.jp)
Natalie Mahowald (United States, mahowald@cornell.edu)
Mitsu Uematsu (Japan, uematsu@aori.u-tokyo.ac.jp)

## Research questions

Key questions to be addressed within this theme are:

- How do biogeochemical and ecological processes interact in response to natural and anthropogenic material input from the atmosphere across different regions?
- How do global warming and other anthropogenic stressors synergistically alter the uptake of atmospheric nutrients and metals by marine biota in different oceanic regions?
- What are the large-scale impacts of atmospheric deposition to the ocean on global elemental cycles (e.g., C and N) and climate change feedbacks in major marine biomes?

## Priorities

<u>Global key areas</u>
Identify the key areas globally where atmospheric deposition and its impacts are important to marine primary production and biogeochemistry, especially in the Mediterranean Sea, Southern Ocean, Tropical Atlantic, and Western Pacific.

<u>Coupled atmosphere-marine time series Stations</u>
Encourage the setup of time series sampling stations to monitor continuously and estimate precisely the atmospheric deposition fluxes of bio-available nutrients in the open ocean and coastal areas.

<u>Comparative studies and modelling</u>
Carry out comparative studies on the budgets of bio-available nutrients in the surface waters of the Atlantic, Indian Ocean, Pacific, and Southern Ocean in order to address the role of atmospheric deposition, particularly in nitrate- and iron-limited regions. With these comparative studies, regional coupled modelling can address both, the atmosphere and the ocean.

<u>New tools</u>
Use new and improved tools to effectively study the impacts of atmospheric deposition on ocean biogeochemistry, such as isotope tracers and molecular biology protocols.

## Planned activities

Theme 4: Interconnections between aerosols, clouds, and marine ecosystems

Introduction

At any given moment, clouds cover more than half of the sky and are responsible for about 2/3 of the Earth's albedo. Clouds are also a key component of the water cycle. Any change in cloud properties can affect the Earth's energy budget, as well as amounts of fresh water over the continents. Oceans represent an important source of aerosols, especially in remote regions. Theme 4 focuses on the interconnections between aerosols, clouds, and marine ecosystems, with the overall goal of reducing the related climate uncertainties.

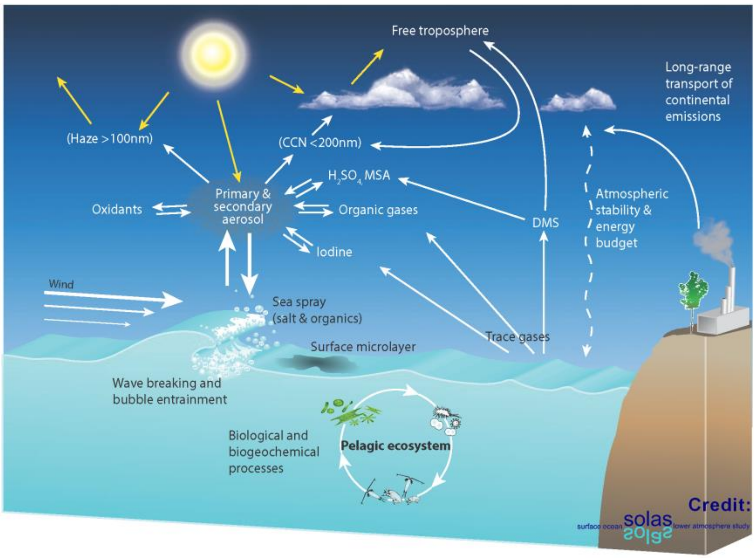


Figure 4: Ocean sources of atmospheric primary and secondary aerosol and subsequent atmospheric processing. Also shown are aerosol direct and indirect radiative impacts.

Theme 4 Team

Team leader:
Maurice Levasseur (Canada, maurice.levasseur@bio.ulaval.ca)

Team members:
Maria Cristina Facchini (Italy, mc.facchini@isac.cnr.it)
Ilan Koren (Israel, ilan.koren@weizmann.ac.il)

Research questions

Key questions to be addressed within this theme are:

- How are aerosol load and properties linked to the marine ecosystem?
- How do aerosols affect marine clouds?
- What are the feedbacks between clouds and the marine ecosystem?

Priorities

Biological and environmental drivers
Conduct combined measurements of surface ocean plankton taxonomy/eco-physiology/bloom dynamics, surface concentrations of aerosol precursors and aerosol characteristics to constrain and model the biological and environmental drivers of biogenic aerosol emission.

Surface microlayer
Assess the chemical and biological properties of the ocean surface microlayer; determine how they compare with the properties of the ocean upper mixed layer, and how they relate to aerosol properties, thermodynamic profiles and cloud properties.

Time Series Stations
Initiate (or join) a SOLAS Time Series Station in order to better assess short-term (through phytoplankton bloom phases) and long-term (through seasons and years) variations in primary and secondary aerosols ocean production/emission and their impacts on atmospheric chemistry and cloud properties. Provide access to the collected data via links on the SOLAS website.

Ocean-derived aerosol effects
Acquire high-quality and high-resolution measurements of the physical, chemical and biological properties of the surface ocean mixed layer and of the atmospheric marine boundary layer to decouple ocean-derived aerosol effects on marine clouds from physical effects. This involves the development of techniques for the identification of the most important players among marine secondary aerosols precursors (beyond dimethyl sulfide, isoprene and iodine) and the determination of their sources, volatility, and aerosol yields (amines and semi-volatile hydrocarbons could be target candidates). It also involves techniques that allow for counting and characterising nascent ultra-small aerosols to better assess the frequency and mechanisms of particle nucleation in the marine boundary layer.

Remote sensing
Connect with the marine aerosol community to develop new remote sensing platforms, drones, and sensors, as well as inform the community of remote sensing potentials.

Cloud microphysics
Acquire high-resolution numerical models to integrate cloud microphysics into small-scale process dynamics.

Planned activities

Workshop on The Interconnections between aerosols, clouds, and marine ecosystems in contrasting environments
Several large national and international research programs have been initiated during the last five years in order to improve our understanding of the complex and highly dynamical interconnections between aerosols, clouds, and marine ecosystems (e.g. NAAMES, NETCARE SOAP, ACE, MarParCloud, R2R, PEACETIME, and Tara Pacific). These interconnections were investigated in the North Atlantic, the Arctic, the Southern ocean, the Pacific Ocean, the Mediterranean Sea, and coral reefs regions. The number and size of these programs

illustrate the dynamical nature of this field of research. Participants to these different programs as well as all interested researchers working on this topic are invited to attend this workshop in order to share and compare their findings with the purpose to cross-fertilize between these programs and contribute to a community paper.
Location: Roma, Italy
Dates: 28 - 29 November, 2018
Chairs: Emmanuel Boss, Ilan Koren, Maurice Levasseur

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## Theme 5: Ocean biogeochemical control on atmospheric chemistry

### Introduction

Atmospheric chemistry is crucial to understand the sources of gases and particles, their chemical transformations in the atmosphere, and to assess how atmospheric composition is influenced by changes in human and natural inputs. Ocean emissions of reactive gases and aerosols influence atmospheric photochemistry and oxidising capacity, air quality, and stratospheric ozone. Theme 5 focuses on the role of marine biogeochemical controls on the release and atmospheric chemistry of reactive and climate active gases, and how that will evolve in the changing ocean and atmosphere. Reliable characterisation is still missing of the chemical composition of sea surface emissions of reactive volatile gases (e.g., organohalogens, VOCs, OVOCs), how these are formed at the sea surface, and how a changing ocean is affecting the biogeochemistry of these emissions.

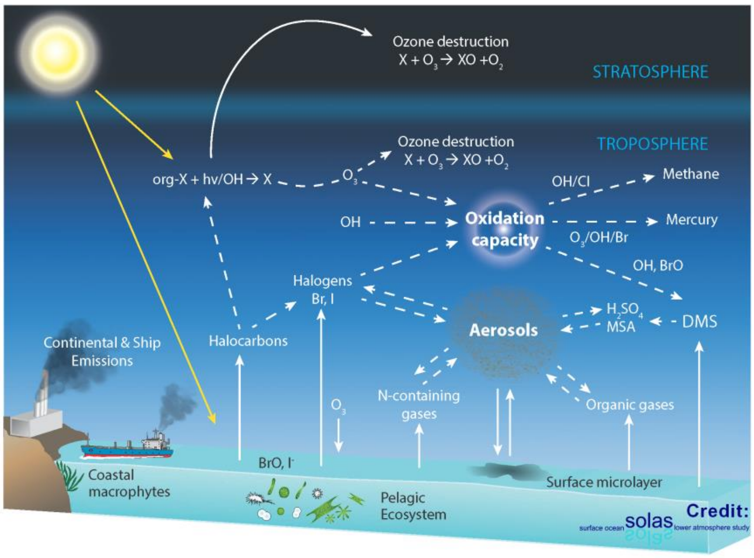


Figure 5: Simplified schematic depiction of the most important couplings between ocean biogeochemical cycles and atmospheric chemistry.

### Theme 5 Team

Team leaders:
Maria Cristina Facchini (Italy, mc.facchini@isac.cnr.it)
Alfonso Saiz-Lopez (Spain, a.saiz-lopez@ciac.jccm-csic.es)

Team members:
Tom Bell (United Kingdom, tbe@pml.ac.uk)
Anoop Mahajan (India, anoop@tropmet.res.in)
Jurgita Ovadnevaite (Ireland, jurgita.ovadnevaite@nuigalway.ie)

## Research questions

Key questions to be addressed within this theme are:

- What are the marine biogeochemical controls on the release of photochemically reactive gases into the atmosphere?
- How will future changes in ocean biogeochemistry and anthropogenic emissions ($NO_X$, VOCs) interact to influence tropospheric photochemistry and stratospheric ozone?

## Priorities

Process-oriented campaigns

Conduct process-oriented campaigns to simultaneously study surface ocean cycling, sea-air gas exchange and atmospheric photochemistry. These will include marine biogeochemical studies to determine the link between gas emissions and the biological factors controlling their production (e.g. bloom dynamics, microbial ecology). The atmospheric component will provide the rates and mechanisms of atmospheric cycling of reactive emissions including their potential feedback processes with the ocean and anthropogenic pollution.

Reactive volatiles

Laboratory investigations of the reaction mechanisms and rates of formation of reactive volatiles at the sea surface should be conducted.

Combined modelling studies

We need combined modelling studies to improve mechanisms at the process level and to upscale from the local and regional scale to the global scale to study climate and biogeochemical impacts.

## Planned activities

Workshop on Influence of coastal pollution on marine atmospheric chemistry: effects on climate and human health

Coastal pollution (air and water) is currently increasing and will most likely continue in the future as anthropogenic environmental pressure upon coastal marine areas increases. Coastal pollution has the potential to contribute to changes in marine atmospheric chemistry including air quality in coastal areas, in addition to contributing to global air pollution and climate. Furthermore, the influence of the coastal pollution on the atmospheric chemistry of gas and particles can have adverse effects on human health in populated coastal environments. Within this context, this 2-day workshop invites contributions on laboratory, field and modelling work in the following topics: (1) How coastal pollution *(air and water*) affects gas and particles emitted over the coasts and human health? (2) Effects on air quality-climate system (regional scale) and human health
Location: Roma, Italy
Dates: 27 - 28 November, 2018
Chairs: Cristina Maria Facchini, Alfonso Lopez, Hiroshi Tanimoto

## Integrated Studies of High Sensitivity Systems

### Introduction

In the complex, non-linear system of the surface ocean and lower atmosphere, the five SOLAS core themes interact and influence each other. Understanding the processes involved and making predictions will not be possible by studying these themes independently. Integrated SOLAS studies are currently underway and being developed in a number of regional, high-sensitivity, and high priority systems. These are broad topics that overlap, and this list is not exclusive; SOLAS scientists continually identify new topics for integrated studies. In particular, SOLAS would like to encourage more international collaboration on the implications of coral reef ecosystems for air-sea exchange of climatically active substances.

### Upwelling Systems

#### Representatives

Véronique Garçon (France, veronique.garcon@legos.obs-mip.fr)
Michelle Graco (Peru, mgraco@imarpe.gob.pe)
Arne Körtzinger (Germany, akoertzinger@geomar.de)

#### Present understanding

Upwelling systems, both coastal and equatorial, are natural laboratories for studying the impacts of multiple stressors on air sea-exchange processes and marine ecosystem services. These systems are characterised by high productivity closely related to the presence of an extensive oxygen minimum zone (OMZ) and low pH-high carbon dioxide values. An active research during recent decades has determined the role of upwelling systems in the exchange of climatic active gases such as $CO_2$, $N_2O$ and $CH_4$, the OMZ variability, and the biogeochemical cycles of nitrogen, carbon and sulphur.

#### Priorities

In order to better understand the ocean-atmosphere connection, several temporal (diurnal, intraseasonal, seasonal, interannual, decadal, and multidecadal) and spatial (mesoscale, local, regional, and global) scales of variability and physical forcing in the system need to be considered. There is still a critical knowledge gap in understanding the driving mechanisms, the extent, and the spatial and temporal variability of ocean deoxygenation in upwelling systems, as well as impacts on marine food webs and biogeochemistry. Understanding how land-air-sea interactions control the dynamics behind the OMZs in the eastern boundary upwelling systems and may potentially exacerbate deoxygenation is not just a matter of scientific interest, but also a major societal concern.

### Polar Oceans and Sea Ice

Representatives

Lisa Miller (Canada, lisa.miller@dfo-mpo.gc.ca)
Maurice Levasseur (Canada, maurice.levasseur@bio.ulaval.ca)
Jun Nishioka (Japan, nishioka@lowtem.hokudai.ac.jp)
Alfonso Saiz-Lopez (Spain, a.saiz-lopez@ciac.jccm-csic.es)

Present understanding

Changing sea ice coverage in the polar oceans is impacting air-sea exchanges of both energy and climatically active substances. The dynamics and consequences of changes in sea-ice characteristics and distribution in the polar oceans are critical to understanding and modelling feedback effects and future scenarios of climate change. Sea ice was long assumed to inhibit air-sea gas and material exchange, but extensive research over the last ten years has shown that sea ice is a very rich and complex system that actively exchanges with both the atmosphere and the underlying water, and impacts exchanges in surrounding waters.

Priorities

BEPSII

Within sea ice, biotic and abiotic processes interact in changing ways throughout the freeze-melt cycle, and thus, sea ice is an active participant in the biogeochemical cycles of many elements, producing climatically active atmospheric aerosols, modulating the surface ocean ecosystem, contributing to substantial seasonal gas fluxes, and possibly facilitating long-term export and carbon dioxide sequestration in deep waters. The 5-year science plan for the SOLAS- and CliC sponsored Biogeochemical Exchange Processes at Sea-Ice Interfaces (BEPSII) research community emphasizes goals 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;
- 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;
- synthesize and integrate observational and modeling efforts;
- continually revise and renew scientific foci, teams, and objectives; and
- develop conceptual models describing sea-ice interactions in or with the Earth system.

CATCH

The CATCH mission is to facilitate atmospheric chemistry research within the international community, with a focus on natural processes specific to cold regions of the Earth. Cold regions include areas which are seasonally or permanently covered by snow and ice, from the high mountains to the polar ice sheets and sea ice zones, as well as regions where ice clouds are found. CATCH scientists will aim to understand and predict:

- How aerosols are formed and processed in cold regions?
- How cold region aerosols act as cloud precursors and impact cloud properties?
- What are the feedbacks between climate change and atmospheric chemistry that are determined by changes in the cryosphere?
- How the ice core record can be used to understanding global environmental change?
- How physical, chemical, biological, and environmental change ecological changes in sea ice and snow impact atmospheric chemistry?
- Establish the background composition (trace gases and aerosols) in cold regions that are undergoing industrialisation, as well as being impacted by climate change.

ECV-Ice

SCOR working group 152 on Measuring Essential Climate Variables in Sea Ice (ECV-Ice) is planning two intercalibration experiments in 2018 (primary production and gases, Saroma-Ko, Japan; gases, University of East Anglia, UK). In 2019, ECV-Ice plans to hold another intercalibration experiment (primary production) and a sea-ice school in Cambridge Bay, Canada during early spring. Both BEPSII and ECV-Ice will be holding their 2018 annual meetings during June in association with the POLAR2018 meeting in Davos, Switzerland.

MOSAiC

The upcoming Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) will be the first year-round expedition into the central Arctic exploring the Arctic climate system and will improve observations of underrepresented seasons in polar systems.

## Coastal Waters

### Representatives

Jun Nishioka (Japan, nishioka@lowtem.hokudai.ac.jp)
Anna Rutgersson (Sweden, anna.rutgersson@met.uu.se)
Guiling Zhang (China, guilingzhang@ouc.edu.cn)

### Present understanding

To understand Earth systems, it is important to understand how land–ocean–atmosphere biogeochemical cycles are linked, and coastal waters, including marginal seas, are key environments for such linkage. Coastal waters and marginal seas are all strongly influenced by land via river discharges, which also reflect human influences. Land also influences circulation patterns in both the atmosphere and ocean. Compared with other oceanic regions, coastal waters and marginal seas have high productivity and biogeochemical cycling activity, which are controlled by variable local processes, such as freshwater discharge, interior current systems, tidal mixing, local upwelling, interactions with the continental shelf, and human activities. Both physical and biogeochemical processes in coastal waters and marginal seas are highly variable in time, as well as space. Thus, coastal waters and marginal seas are the places where the biogeochemical interaction of the atmosphere and the ocean is occurring dynamically.

### Priorities

The changes in nutrient dynamics (including atmospheric supply) generally affect the abundance, composition and metabolic activity of marine organisms such as phytoplankton and bacteria. Marine phytoplankton can produce volatile organic compounds (VOCs) and marine atmospheric aerosols, which strongly influence on atmospheric chemistry. Therefore, biogeochemical cycles in coastal waters and marginal sea have a tight and sensitive linkage between the ocean and the atmosphere. The enhanced supply of nutrients to coastal regions has also led to widespread bottom hypoxia and subsurface acidification that would affect the production and air-sea fluxes of climatic related trace gases.

## Indian Ocean

### Representatives

Hermann Bange (Germany, hbange@geomar.de)
V.V.S.S. Sarma (India, mailto:sarmav@nio.org)

### Present understanding

There have been significant advances in recent years in our ability to describe and model the Earth system, but our understanding of oceanic and atmospheric processes in the Indian Ocean region is still rudimentary in many respects. This is largely because the Indian Ocean remains under-sampled in both space and time, especially compared to the Atlantic and Pacific Oceans. The situation is compounded by the Indian Ocean being a dynamically complex and highly variable system under monsoonal influence. Many uncertainties remain in terms of how oceanic and atmospheric processes affect climate, extreme events, marine biogeochemical cycles, atmospheric chemistry, meteorology, ecosystems, and human populations in and around the Indian Ocean. There are also growing concerns about food security in the context of global warming and of anthropogenic impacts on coastal environments and fisheries sustainability. One impact of global warming is sea level rise, which leads to coastal erosion, loss of mangroves, and loss of biodiversity. Anthropogenic impacts include pollution, with water quality deterioration as a result of nutrient and contaminant inputs and detrimental ecosystem effects, such as eutrophication and deoxygenation. There is a pressing need for ecosystem preservation in the Indian Ocean for both tourism and fisheries.

SCOR, IOC, and IOGOOS have initiatd a new phase of international research focused on the Indian Ocean (i.e. the 2nd International Indian Ocean Expedition, IIOE-2) that began in late 2015 (see: www.iioe-2.incois.gov.in).

### Priorities

The Indian Ocean represents one of the last great frontiers and challenges of oceanographic/atmospheric research. The biogeochemical cycles and ecosystems of the Indian Ocean appear to be particularly vulnerable to anthropogenic impacts (including climate change, eutrophication, atmospheric pollution and aerosol load).

Major research questions to be addressed with high priority are:

- Which processes determine the natural variability of the biogeochemical cycles, ecosystems and atmospheric chemistry over the Indian Ocean?
- What is the effect of the (long-range) transport of air pollution on ocean biogeochemistry, ecosystems, atmospheric chemistry and climate?
- How are human-induced stressors impacting the biogeochemistry and ecosystems of the Indian Ocean?
- How, in turn, are these impacts affecting human populations?

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## Geoengineering

### Introduction

The first implementation strategy of SOLAS (2003) had a major focus on the science that underlies ocean iron fertilisation, and the oceanic and atmospheric feedbacks (such as the release of dimethyl sulfide, and the drawdown of carbon dioxide) to this perturbation. This research informed policy, via the Intergovernmental Oceanographic Commission guide to policymakers, and international legislation (International Maritime Organisation 2013 amendment to the London Convention (LC) and London Protocol (LP)).


Figure 6: The five core themes of phase two of SOLAS. Each overlaid with specific physico-chemical and biogeochemical observations, process studies, and modelling that will together provide detailed insights into the challenges and benefits of using negative emission techniques (NETs) to intervene in global climate. Their combined impact will be to enhance the ability of international researchers to conduct independent assessment of the efficacy of a range of atmospheric and oceanic geoengineering approaches, which is a key requirement for governance.

Team members

Phil Boyd (Australia, philip.boyd@utas.edu.au)
Cliff Law (New Zealand, cliff.law@niwa.co.nz)

Priorities

Provide knowledge
A multi-disciplinary focus on the interface between the ocean and atmosphere places SOLAS in an ideal position to provide Future Earth, and organisations such as SCOR, with fundamental knowledge (Figure 6) that will inform assessment of the two primary forms of geoengineering (Carbon Dioxide Removal (CDR); and Solar Radiation Management (SRM)).

Extend previous research
The second SOLAS science plan comprises five distinct themes each of which have multiple strands with the potential to provide insights into physical, chemical, biological, and ecological facets of geoengineering. Hence in the second phase of SOLAS each of the five themes will broaden previous research to assess oceanic and atmospheric responses to perturbation of the boundary layer (such as foams to modify albedo); lower atmosphere (such as marine cloud brightening) and upper ocean (such as ocean alkalisation).

Policy

This joint focus will involve lab experiments, observations, natural analogues, and modelling, for assessment of feedbacks between the Surface Ocean and Lower Atmosphere (Figure 6). Importantly, these approaches will not contravene existing codes of conduct or regulation (such as the United Nations Convention on Biological Diversity moratorium, or the LC/LP convention), but will provide detailed information on a suite of unaddressed questions. As was the case in the first phase of SOLAS, the implementation of this science will go hand in hand with the translation of the science into policy and environmental legislation.

Planned activities

- Prepare a 4-5 page working document that will be used to structure the subsequent cross theme workshop.
- Co-ordinate and run a cross-theme SOLAS workshop to bring together observationalists and modellers to assess where and how SOLAS Science can best inform negative emission techniques (NETs).
- Assess broader (Earth System) NETs approaches & requirements with scientists from other programmes within Future Earth, including socio-economists.
- Foster an "umbrella" organisation (perhaps a Knowledge Action Network) for governance and/or guidelines for scientists to independently carry out NETs-related activities.

Each of the above steps are essential to develop and co-ordinate the proposed research areas identified in Figure 6, and their uptake by Future Earth.

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## Science and Society

### Introduction

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 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 in the light of anthropogenic influence on the ocean-atmosphere system. Three main topics are currently being pursued.

### Theme members

Team leaders:
Erik van Doorn (Germany, edoorn@wsi.uni-kiel.de)
Christa Marandino (Germany, cmarandino@geomar.de)

Team members:
Emilio Cocco (Italy, ecocco@unite.it)
Sonja Endres (Germany, sendres@geomar.de)

Martin Johnson (United Kingdom, m.johnson@uea.ac.uk)

Valuing carbon in the ocean

Priorities

At the Monaco workshop in March 2017, a series of key questions and knowledge gaps around marine carbon have been identified. These include the lack of consensus on its definition and purpose to identification of the need to apply Earth-systems scale understanding of the ocean carbon cycle and if the concept of Blue Carbon is to be used to incentivise positive action, particularly in marine systems beyond those at or very close to the coast.

Planned activities

At least one paper is currently being drafted to address these issues and a second workshop is planned to take place in Norwich, United Kingdom in 2018 to discuss how to continue the work from then on

Air-sea interaction, policy, and stewardship

Priorities

The open ocean and the atmosphere are either perceived as "common good", one with no owner, or a combination of the two. Moreover, the actual forms of stewardship beyond national jurisdiction leave some blurred spaces where political and economic interests often clash. Thus, although ocean governance requires a global approach, it was found that there is no general answer to the question of how policy-making deals with an uncertain future beyond national borders. Many examples were identified where international law strives to require states to act collectively through international or regional organizations, or to adopt measures at a regional or national level as agreed in binding agreements or voluntary instruments. Nevertheless, the challenges that arise from the lack of implementation, compliance, and enforcement were acknowledged as an impediment to achieving the desired outcomes.

Another pressing issue is if there are cultural differences at the local, national or regional level in how to effectively promote long-lasting stewardship of the open ocean. The perception of the nature of the sea is socially constructed in different ways and deeply affected by colonial and post-colonial history, post-cold war scenarios and new transnational identities. Also, different stakeholders use the ocean in different ways for different purposes via marine spatial planning. As a result, it is difficult to communicate the ocean to a global audience and accordingly to promote a shared approach to its stewardship.

Planned activities

The first draft of a manuscript is in preparation. It is then to be decided if it is worthwhile going further down this avenue by, for instance, submitting proposal to funding agencies.

This theme could likely lead to a project studying global attitudes towards the open ocean in general and the development of methods to promote long lasting stewardship (including the identification of what methods work for whom). We mainly depend on the expertise of social scientists here and expect first progress in autumn 2017. A potential paper, the second from this group, could form the basis for further pursuing research on stewardship of the open ocean in 2018 and beyond.

## Ship emissions

### Priorities

There is an increasing awareness of the impacts increasing shipping traffic may have on environmental processes in the surface ocean and the lower atmosphere in the future. The ability to accurately forecast ship emissions based on ship traffic data and data from shipping companies is a potentially powerful tool to evaluate the environmental impact of ship traffic and ensure compliance with legal regulations. However, due to its complex nature, this area requires traditional experimental research as well as modelling efforts combining economic and natural science. Legal regulations of air pollution and liquid discharge from ships need to be considered as well including the legal obligation to refrain from transforming one type of pollution into another.

The usage of new technologies in the shipping industry, such as scrubbers, is supposed to benefit the environment by significantly reducing certain ship emissions to the atmosphere. However, using scrubbers may lead to other, yet unascertained and unquantified impacts on the marine environment. Several interdisciplinary research priorities were identified which helped to improve our understanding of these potential impacts and the development of a sustainable shipping industry.

### Planned activities

A follow-up workshop on this topic took place in Gothenburg in October 2017. This topic received the most encouragement to be pursued further. We aim at a proposal for a large international grant related to a Future Earth call, which has not been released yet. There has been suggestions that this could form the basis of an own institute with more permanent means of funding.

In future work, we hope to include topics like the evolving policy frameworks for floats, involvement in the development of an international regime for the protection of the atmosphere, and co-operation with the group working on geoengineering.