Website Implementation Plan

version 2020 (team leadership and membership updated in Apr 2022)

Legend

Not highlighted	Shown on the website as plain text.
Grey	You can click on and a drop down accordion opens.
Blue	Hyperlink to website or email address. Opens in new window.

Introduction

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

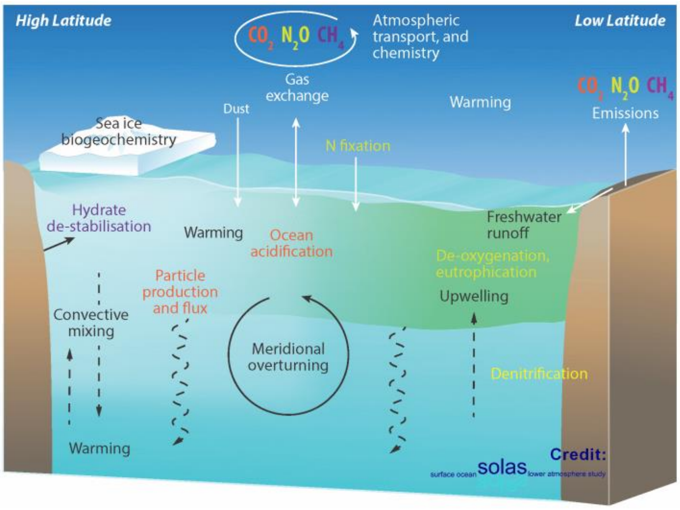

Figure 1: Processes and impacts/stressors associated with long-lived greenhouse gases.

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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 GHG in a changing ocean and atmosphere?
- What is the role of natural vs. anthropogenically forced variability in ocean greenhouse

gas fluxes?

Priorities

Detailed regional analyses

To better quantify and predict the evolution of oceanic GHG budgets and air-sea fluxes, we highly recommend detailed analyses of GHG fluxes in key regions. These include the Southern Ocean, coastal and marginal seas, and oceanic Oxygen Minimum Zones (OMZs). Recommended approaches include (i) higher resolution numerical models, which represent the coupling of key processes for circulation, ecosystems and relevant biogeochemistry, and (ii) detailed biogeographical sampling of marine ecosystems across gradients to characterise the variations in environmental drivers and GHG fluxes responses. A coordinated synthesis of these approaches is also required to enable accurate quantification and prediction of GHG fluxes from these regions.

Increased density of observations

In order to reliably assess the spatial and temporal variation of air-sea GHG fluxes, significant increases in the coverage of current observations are required; these include measurements from ships, autonomous platforms (e.g., Argo floats, gliders), and moorings. Sustained time-series observations at fixed sites are also necessary to characterize the seasonal and interannual variability and long-term trends in regional GHG fluxes. 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 to quantify GHG fluxes

Improved quantification of ocean-atmosphere CO_2 fluxes has been achieved by combining surface-ocean carbon measurements with a range of mapping methods including spatial interpolation, multi-variate regression, and neural network analyses. These methods are valuable tools and should be applied to ocean measurements of N_2O and CH_4 to provide improved quantification of other GHG fluxes.

Future changes in ocean GHG fluxes

Significant questions remain in predicting how future oceanic GHG fluxes will evolve in response to the combined impacts of multiple environmental stressors (e.g., ocean warming, deoxygenation, and acidification). Successful prediction of future GHG evolution requires the development of ocean biogeochemical models able to represent the key physical, chemical, and ecosystem processes and their interactions, in order to reliably estimate the impacts of anthropogenic pressures and environmental changes on the ocean GHG fluxes. Relevant biogeochemical and ecosystem component models should also be incorporated into Earth System Models (ESMs) employed for climate prediction to enable accurate quantification of the important GHG-climate feedbacks.

Links to Ocean Obs'19

https://www.frontiersin.org/articles/10.3389/fmars.2019.00091/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00157/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00544/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00337/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00400/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00356/full

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf)

Research programmes on regional ocean-atmosphere GHG fluxes

Current national and international 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, the European Union's Integrated Carbon Observation System (ICOS), the UK National Environmental Research Council funded projects "Role of the Southern Ocean in the Earth System" (RoSES), and "Ocean Regulation of Climate by Heat and Carbon Sequestration and Transports" (ORCHESTRA), and the European H2020 project "Southern Ocean Carbon and Heat Impact on Climate" (SO-CHIC). Further programs investigating the ocean fluxes include the "Atlantic Meridional Transect Ocean Flux from Satellite Campaign" (AMT4oceanSatFlux), "Role of Eddies in the Carbon Pump of Eastern Boundary Upwelling Systems" (REEBUS), and the Boknis Eck time series station. Information on planned observational programs and workshops can be found via the respective program websites:

AMT4oceanSatFlux: https://amt4oceansatflux.org/
Boknis Eck: http://www.bokniseck.de
ICOS: https://www.icos-cp.eu/
ORCHESTRA: https://www.bas.ac.uk/project/orchestra/
REEBUS: https://www.ebus-climate-change.de/reebus
SOCCOM: https://soccom.princeton.edu/
SO-CHIC: http://www.sochic-h2020.eu/
RoSES: http://www.nerc.ac.uk/research/funded/programmes/roses/

Integrated Ocean Carbon Research (IOC-R) Group
Following on the successes of the previous SOLAS/IMBER Carbon group (SIC), a new Integrated Ocean Carbon Research Group has been formed. This initiative is jointly sponsored by IOC, IMBER, SOLAS, IOCCP, GCP, CLIVAR, and WCRP. The group will identify the key research needs for ocean carbon science for the next decade, develop strategies to address these needs, and address the links to societal and policy applications. An initial expert group workshop was held at the International Oceanographic Commission, Paris, in October 2019; the development of the Integrated Ocean Carbon Research Plan is now in progress and will most likely be presented in 2020.

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

Introduction

Ocean-atmosphere fluxes play a critical role in the evolution 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 nanoscale to global scale.

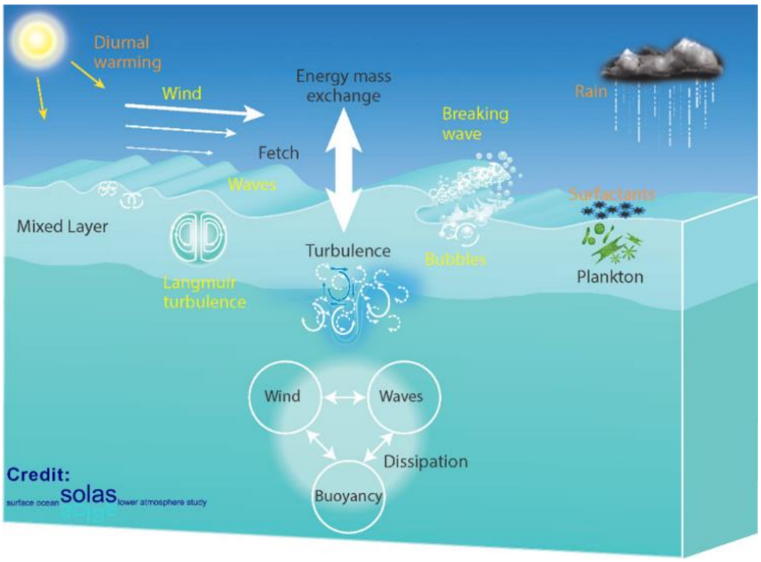

Figure 2: Dominant processes controlling air-sea fluxes of mass and energy in the open ocean.

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Research questions

Key questions to be addressed within this theme are:

- What are the biogeochemical properties and 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?
- How can remote sensing instruments and techniques for estimating global air-sea fluxes be improved?
- How can methods of estimating air-sea fluxes be improved?

Priorities

Coordinated measurements

Support joint, coordinated flux measurements to compare methods, instruments, and processes. This should be achieved both with stationary stations, where instruments are attached to buoys or platforms, and with ongoing and planned cruises, as well as method evaluation of flux measurements and surfactant analysis.

Remote sensing

Develop and apply remote sensing tools to determine features of sampling sites prior to studies as well as interpreting the results.

Time Series Stations

Establish a network of SOLAS Time Series Stations with long-term observing systems to combine methods and conduct intercomparisons.

Links to Ocean Obs'19
https://www.frontiersin.org/articles/10.3389/fmars.2019.00419/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00430/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00251/full

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf)

Research programs on fluxes of mass and energy across the air-sea interface

Programs investigating the air-sea interface and ocean fluxes include the "Atlantic Meridional Transect Ocean Flux from Satellite Campaign" (AMT4oceanSatFlux), the project on "Role of Eddies in the Carbon Pump of Eastern Boundary Upwelling Systems" (REEBUS). The "Global Ocean Ship-based Hydrographic Investigations" (GO-SHIP) program investigates surface meteorology and near surface oceanographic measurements. The observational program Integrated Carbon Observational System (ICOS) includes flux monitoring over some European waters. Information on planned observational programs and workshops can be found via the respective program websites:

AMT4oceanSatFlux: https://amt4oceansatflux.org/
GO-SHIP: https://www.go-ship.org/index.html
ICOS: https://www.icos-cp.eu/
REEBUS: https://www.ebus-climate-change.de/reebus

Current national and international programs investigating processes at the air-sea interface include amongst many: the Sea Surface Microlayer at Night (MILAN), ProcEss studies at the Air-sEa Interface after dust deposition in the MEditerranean sea (PEACETIME), and Integrated carboN and TracE Gas monitoRing for the bALtic sea (INTEGRAL). More details on their websites:

MILAN: https://www.ncl.ac.uk/nes/news/item/sea-surface-microlayer-functioning-during-the-night.html
PEACETIME: http://peacetime-project.org/index.html
INTEGRAL: https://www.io-warnemuende.de/integral-home.html

New joint international projects focusing on the Theme 2 science questions to be initiated and encouraged include:
- A SOLAS Time Series Station at the Cape Verde Observatory.
- A proposed SCOR working group to set up benchmark measurements for model validations, gathering modellers and observationalists to define relevant parameters and identify existing and new data sets.

Joint meetings and workshops
- The 8th International Symposium on Gas Transfer at Water Surfaces, May 2021, Plymouth, UK
- Sessions at major international meetings (i.e., AGU, EGU)
- Activities at the SOLAS Summer Schools introducing surface flux methods
- Coordinated publication efforts (e.g., Research TOPIC in Frontiers)
- Workshop focusing on marine-specific issues of Eddy-covariance measurements

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 and nitrogen cycles, 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 significant effects on the marine carbon and nitrogen budgets, as well as on atmospheric carbon dioxide uptake.

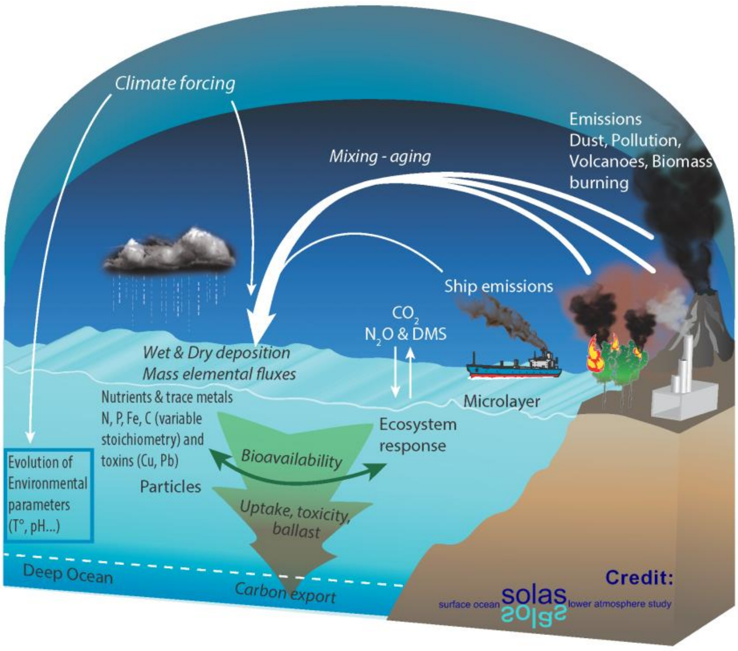

Figure 3: Main sources, cycling, processes, and species relating to Core Theme 3 (processes are indicated in italics).

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Research questions

Key questions to be addressed within this theme:

- 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, ocean acidification, and other anthropogenic (such as ocean acidification) 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, P, and N) and climate change feedbacks in major marine biomes?

Priorities

Global key areas

Focus on key regions where atmospheric depositions and their impacts are important to marine primary production and biogeochemistry. These regions include the Mediterranean Sea, the Southern Ocean, the Tropical Atlantic, and the North Pacific.

Coupled atmosphere-marine time series stations

Encourage the setup and maintenance of time series sampling stations (over the ocean, on islands, and/or in coastal areas) to monitor and accurately estimate atmospheric depositions and fluxes (vertical and horizontal) of bio-available nutrients to the marine environment.

Comparative studies and modelling

Support comparative studies on the budgets of bio-available nutrients in the surface waters of the key regions mentioned above in order to address the role of atmospheric deposition, particularly in nitrate-, phosphate- and iron-limited regions. With these comparative studies, regional coupled modelling can address both the atmosphere and the ocean.

New tools

Use new and improved tools to effectively study the impacts of atmospheric deposition on ocean biogeochemistry, such as isotope tracers and molecular biology techniques (genomics, transcriptomics, and proteomics). Also, new remote sensing platforms have become available in the recent years and may provide significant advances. Specifically, the new network of Geostationary satellites (GOES 16/17, Himawari 8/9, GOCI, and others) make observations of the ocean basins every 10 minutes (day and night). A much better understanding of aerosol transport evolution and deposition will be gained through these new tools. While only one of them has dedicated channels for ocean observations (GOCI), its observing region is the North Pacific, a key of interest for aerosol-ocean interactions. An improved understanding of wet deposition over the ocean by precipitation is expected with the new merged data base of senior and newest measurements from the constellation of satellites in the Global Precipitation Mission (GPM) into the Integrated Multi-satellitE Retrievals for GPM (IMERG; https://gpm.nasa.gov/gpm/imerg-global-image) with a half hour frequency and 6 hr latency.

Links to Ocean Obs’19

https://www.frontiersin.org/articles/10.3389/fmars.2019.00035/full

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf)

Iron model intercomparison

With the increase of trace metal surveys in all ocean basins, we now have a better understanding of the nutrient flows and it is clear the importance of not only oceanic Fe sources but also those of atmospheric origin. Therefore, a coherent explanation for the biological response to input nutrients needs knowledge of both atmospheric and oceanic inputs of Fe. This subject is the core theme of SCOR Working Group 151 FeMIP.
SCOR WG 151: https://scor-int.org/group/151/

Research programs on atmospheric deposition and ocean biogeochemistry
Current national and international programs investigating atmospheric deposition and ocean biogeochemistry include the "Impact of atmospheric multi-stressors to coastal marine systems in a changing climate scenario" (AMBIEnCE) and the Tudor Hill Marine-Atmospheric Observatory. Information on planned observational programs and workshops can be found via the respective program websites:

AMBIEnCE: https://projectambience.wordpress.com/
Tudor Hill: http://www.bios.edu/research/projects/tudor-hill-marine-atmospheric-observatory/

Trace metal deposition
Because of the overlapping nature of many SOLAS and GEOTRACES activities, closer interactions between the two organizations are being pursued, particularly in the area of atmospheric and water column sampling, where each program has different strategies and different overall goals. A first attempt to bring the two communities together towards coordinating common goals and protocols resulted in a recent publication (Meshkidze *et al.*, 2020, Perspective on identifying and characterizing the processes controlling iron speciation and residence time at the atmosphere-ocean interface, https://doi.org/10.1016/j.marchem.2019.103704).

Aerosol transport and deposition in the North Pacific
Given the recent discovery of dust deposition in the NE Pacific from North American sources and the large volume of research output from the East Asian community on the subject of aerosol deposition, the team leaders recommend investigating whether there is US and Asian interest for a joint study focusing on aerosol transport and deposition in the North Pacific. The team leaders will contact individual key scientists on both sides of the Pacific and evaluate if there is interest for a coordinated initiative. The topic session "Atmospheric nutrient deposition and microbial community responses, and predictions for the future in the North Pacific Ocean" was accepted for the PICES-2020 and -2021 annual meetings.

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

Introduction

At any given moment, over half of the sky is covered by clouds and they 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 affects the Earth's energy budget, as well as amounts of fresh water over the continents. Cloud formation depends on both meteorological parameters and availability of cloud condensation nuclei, thus, aerosols. The oceans, as an important source of primary and secondary aerosols, have a huge impact on clouds, especially in regions away from anthropogenic sources. Moreover, the strength and impact of the ocean sources of aerosols will vary with climate change. Theme 4 focuses on the interconnections between aerosols, derived from marine ecosystems, and clouds, with the overall goal to reduce the related climate uncertainties.

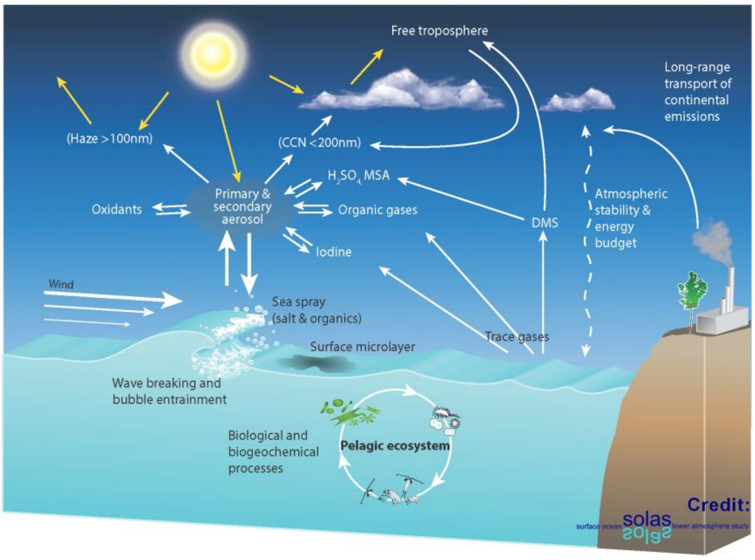

Figure 4: Ocean sources of atmospheric primary and secondary aerosol and subsequent atmospheric processing. Also shown are aerosols direct and indirect radiative impacts.

Theme 4 Team

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Research questions

Key questions to be addressed within this theme are:

- How are aerosol load and properties linked to the marine ecosystem?
- How and if anthropogenic emissions affect the natural abundance and properties of marine aerosol.
- How do primary marine emissions and secondary aerosol formation processes influence aerosol activation of cloud droplets and ice crystals?
- What are aerosol effects on marine clouds?
- What are the feedbacks between clouds, the marine ecosystem, and climate?

Priorities

Biological and environmental drivers
Conduct coordinated oceanic (physical, chemical and biological) and atmospheric (aerosols, CCNs, INPs, their physicochemical properties) measurements in order to constrain and model the biological and environmental drivers of biogenic aerosols.

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-relevant properties.

Time Series Stations
Develop and maintain a dedicated network of SOLAS Time Series Stations. The network will facilitate an assessment of short-term (through phytoplankton bloom phases) and long-term (through seasons and years) variations in primary and secondary ocean aerosol 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 the atmospheric marine boundary layer to decouple ocean-biogeochemical aerosol effects on marine clouds from physical effects, such as meteorology. This involves the development of techniques for identifying the most important players among marine secondary aerosol precursors (beyond dimethyl sulphide, 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 remote sensing community to develop new platforms, drones, and sensors, and work to inform the SOLAS community on remote sensing potentials. In addition, new space remote sensing platforms have become available in the recent years and may provide significant advances. Specifically, the new network of geostationary satellites (GOES 16/17, Himawari, GOCI, and others) make observations of clouds and aerosols over the ocean basins of interest every 10 minutes (day and night). For example, it will be possible to separate the effects of the meteorology with those due to aerosol-microphysics thanks to the time evolution information, also, a better understanding of the microphysical evolution of cloud properties will be gained with the better temporal information. In addition, better satellite detection of atmospheric composition (especially trace gases) has become available through the deployment of the TropOMI and GEMS satellites.

Cloud microphysics
Develop high-resolution numerical models to integrate cloud microphysics into small-scale process dynamics. Measurements of cloud microphysics above oceans needs to be addressed by developing small microphysical cloud probes that can be integrated on platforms such as drones or balloons

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf).

Research programs on marine ecosystems, aerosols, and clouds
Current national and international programs investigating marine ecosystems, aerosols, and clouds include the “Atmospheric Composition and Radiative forcing changes due to UN International Ship Emissions regulations” (ACRUISE), the program on “The Great Barrier Reef as a significant source of climatically relevant aerosol particles”, “Sea2Cloud: Are marine microorganisms influencing clouds?”, “Shipping Emissions in the Arctic and North Atlantic Atmosphere” (SEANA), and the North Atlantic Aerosols and Marine Ecosystems Study (NAAMES). Information on planned observational programs and workshops can be found via the respective program websites:

ACRUISE: https://www.pml.ac.uk/Research/Projects/ACRUISE
Great Barrier Reef: https://bit.ly/2zps2k2
NAAMES: http://naames.larc.nasa.gov/
Sea2Cloud: https://www.europeandissemination.eu/sea2cloud-by-karine-sellegri-2/2704
SEANA: www.birmingham.ac.uk/seana

A workshop on Interconnections between aerosols, clouds, and marine ecosystems in contrasting environments, held in Rome, November 2018 brought together representatives of 10+ large European and International projects aiming to improving our understanding of the connection between ocean and aerosols and ultimately clouds. To maintain the momentum from that workshop, share their findings and improve communications as the different programs evolve, we will explore different options to strengthen the links between these programs (online exchanges, special session during conferences (AGU, EGU), workshops, etc.).

Interact with IGAC representatives at the 16th IGAC Science Conference, Manchester, UK, September 12-16, 2021, to investigate the opportunities in developing more collaborations between SOLAS and IGAC.
Engage with the aerosol community during the 21st ICNAA Conference, Brisbane, Australia, 2021.
Planning to submit a working group proposal on clouds to IUGG Grants Program 2020-2023 as joint IGAC-SOLAS initiative.

Theme 5: Ocean biogeochemical control on atmospheric chemistry

Introduction

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.

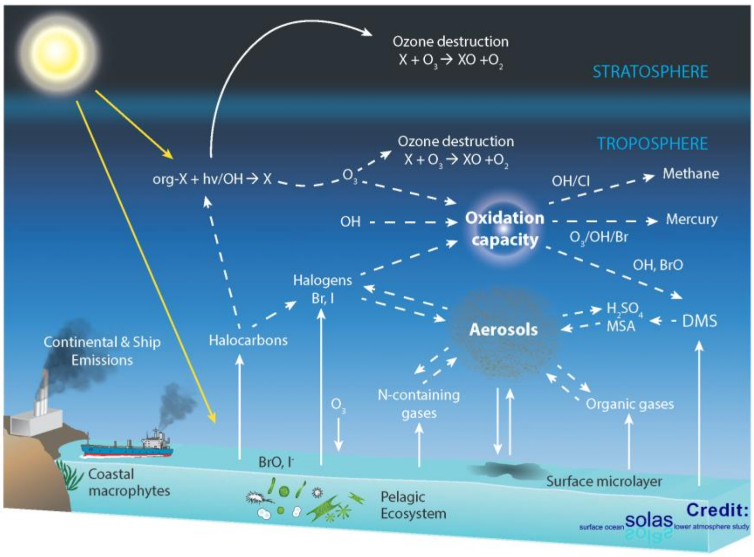

Figure 5: Simplified schematic depiction of the most important couplings between ocean biogeochemical cycles and atmospheric chemistry.

Theme 5 Team

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Research questions

Key questions to be addressed within this theme are:

- What are the marine biogeochemical controls on the release of reactive gases into the atmosphere?
- What are the characteristics and chemical interactions of biotic and abiotic volatile organic compounds from ocean in the atmosphere?
- How do photochemistry and oxidation influence the fate of atmospheric gases and aerosols in 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 chemistry. 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 in coastal areas. The provision of information of reactive gases from satellite instruments will be an important component of such studies.

Reactive volatiles

Conduct laboratory investigations of the reaction mechanisms and rates of formation of reactive volatiles at the sea surface.

Combined modelling studies

Combine 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. These modelling studies must involve information from the remote sensing of reactive gases.

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf).

Research programs on biogeochemical control on atmospheric chemistry
Current national and international programs investigating biogeochemical control on atmospheric chemistry include “Sea2Cloud: Are marine microorganisms influencing clouds?”, and “Shipping Emissions in the Arctic and North Atlantic Atmosphere” (SEANA). Information on planned observational programs and workshops can be found via the respective program websites:

Sea2Cloud: https://www.europeandissemination.eu/sea2cloud-by-karine-sellegri-2/2704
SEANA: www.birmingham.ac.uk/seana

Satellite remote sensing of atmospheric trace gases is done by Sentinel 5P, which was launched in 2017, and conducts the following ozone measurements: nitrogen dioxide, sulfur dioxide, formaldehyde, aerosol, carbon monoxide, methane, and clouds.
Sentinel 5P: https://earth.esa.int/web/guest/missions/esa-eo-missions/sentinel-5p

Events
2020 16th IGAC Science Conference, September 12-16, 2021, Manchester, UK.
Session: Sea-atmosphere interaction
Website: http://www.igacproject.org/events/2020-16th-igac-science-conference

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

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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 very high biological productivity closely related to the presence of an extensive oxygen minimum zone (OMZ) and a low pH-high carbon dioxide regime. Active research during recent decades has determined the role of upwelling systems in the exchange of climatically active gases (such as CO_2, N_2O, and CH_4), OMZ variability, and the biogeochemical cycles of nitrogen, carbon, sulphur, halogens and trace metals.

Priorities

In order to better understand ocean-atmosphere connections in upwelling regions, several temporal (diurnal, intra-seasonal, 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 and the connectivity to climate change, the extent and spatiotemporal 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. Given the high socioeconomic importance of coastal upwelling systems, a complete understanding of the complex atmosphere-ocean interaction and physical-chemical-biological coupling in eastern boundary upwelling systems is needed. For SOLAS, this is an ideal research area and requires involvement and interaction of all 5 core themes.

Planned activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf).

Research programs on Upwelling

Current national and international programs investigating upwelling include “Role of Eddies in the Carbon Pump of Eastern Boundary Upwelling Systems” (REEBUS) and SCOR WG 155 on Eastern boundary upwelling systems (EBUS): diversity, coupled dynamics and sensitivity to climate change.

REEBUS: https://www.ebus-climate-change.de/reebus
SCOR WG 155: https://scor-int.org/group/155/

Events

Eastern boundary upwelling systems (EBUS) Conference, Lima, Peru, postponed
Liège Colloquium May 2022: GO2NE International Conference
SCOR WG 155 Summer School in Dakar, Senegal, postponed to 2021

Polar Oceans and Sea Ice

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Present understanding

Changing sea-ice coverage in the polar oceans is impacting air-sea exchanges of chemically, biologically, 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 mechanisms 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 couple of decades 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. Sea-ice harbors a highly productive ecosystem, which interacts with both the ocean and the atmosphere and supports multiple ecosystem services. Understanding changes to the system is crucial in understanding potential impacts on these ecosystem services. The snowpack on sea ice is a highly reactive environment controlling uptake and release of many photochemically active trace gases, particles and their precursors, interacting with the lower atmosphere and the sea ice underneath. Understanding emission and deposition fluxes above snow on sea ice is critical to assess the impact of a changing sea-ice environment on atmospheric composition (oxidizing capacity, budgets of mercury, halogens and organics), aerosol direct and indirect effects, and climate.

Priorities

Continue efforts to understand how the structure of sea ice impacts the uptake and release of climatically-active substances to/from the atmosphere and the underlying water. This involves exploring the changing nature of ice, which is generally becoming thinner and warmer, and in the Arctic, increasing pack ice mobility and rafting is potentially redistributing sympagic biological communities throughout the ice. Melt ponds, which are becoming increasingly prevalent in spring in the Arctic, may also represent a significant albeit poorly quantified source of gases and particles to the atmosphere. Thinner ice and enhanced snowfall might cause flooding and snow-ice formation, impacting both ice biology and chemistry. Both processes are more commonly observed in the Southern Ocean. With a more brittle ice pack, more open water is present in the winter, with more potential for direct air-sea gas exchange and changes in pelagic versus sympagic primary production, as well as more seasonal ice formation. Deeper snowpacks may dampen ice-air trace gas fluxes, whereas increased flooding and saltier first year ice may increase salt loading of the snow column with unknown impact on photochemical processes and air-snow fluxes of trace gases, particles, and their precursors. The question of whether air-sea gas exchange rates are enhanced in the presence of a broken, mobile ice cover (including leads and polynyas) is still open, and contradictory results from laboratory and field measurements need to be resolved. The extent to which sea-ice brines directly contribute to deep-ocean carbon sequestration is also still unresolved. Answering these questions requires both detailed process studies (lab, field, and numerical) and integrated, large-scale observation systems.

An effort will be made to coordinate results from the large number of Southern Ocean field campaigns being conducted in 2019 – 2021 by holding a workshop in the Southern Hemisphere in 2021/22.

Links to Ocean Obs’19
https://www.frontiersin.org/articles/10.3389/fmars.2019.00421/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00429/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00433/full
https://www.frontiersin.org/articles/10.3389/fmars.2019.00451/full

Planned Activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf).

BEPSII (Biogeochemical Exchange Processes at Sea-Ice Interfaces)
A research community co-sponsored by SOLAS and CliC, BEPSII focuses on how the biogeochemistry of sea ice influences both the ocean and the atmosphere. 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. Near-future priorities for BEPSII include:

- A position analysis (PA) on Antarctic sea ice biogeochemical responses to climate change (An Arctic PA has been submitted to Nature Climate Change)
- A community paper on sea-ice ecosystem services
- A commentary on geoengineering proposals for Arctic sea-ice restoration
- 1-D model intercomparison.
- A sea-ice field school for early-career scientists
- Expert contribution to the sea-ice biogeochemistry, ecosystem, and modelling components of the MOSAiC project
- A coordinated 2nd Ice Algae Model intercomparison Project (IAMIP2)

BEPSII will hold their 2020 meeting virtually and their 2021 meeting in Ventura, USA, alongside the Gordon Conference on Polar Marine Science.
Website: https://sites.google.com/site/bepsiiwg140/home

CATCH (the Cryosphere and ATmospheric CHemistry)
Cosponsored by SOLAS and IGAC, 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 that 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. Upcoming activities and priorities for CATCH include:

- Planning of a CATCH focused Gordon Conference
- Develop a joint SCOR working group and research expedition with BEPSII to investigate feedbacks between atmospheric chemistry and sea-ice biogeochemistry

Website: https://www.catchscience.org/

Research programs on Polar Oceans
Current national and international programs investigating air-sea exchange in the polar oceans include “Processes Influencing Carbon Cycling: Observations of the Lower limb of the Antarctic Overturning” (PICCOLO), “Shipping Emissions in the Arctic and North Atlantic Atmosphere” (SEANA), and SCOR WG 152 on Measuring Essential Climate Variables in Sea Ice (ECV-Ice).

ECV-Ice: https://sites.google.com/view/ecv-ice/
PICCOLO: https://gtr.ukri.org/projects?ref=NE%2FP021409%2F1
SEANA: www.birmingham.ac.uk/seana

Indian Ocean

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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 because 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.

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?

Links to Ocean Obs’19
https://www.frontiersin.org/articles/10.3389/fmars.2019.00355/full

Planned Activities

See SOLAS Activities 2020-2021 table here (hyperlink to pdf).

IIOE-2
SCOR, IOC, and IOGOOS have initiated a new phase of international research focused on the Indian Ocean (i.e. the 2nd International Indian Ocean Expedition, IIOE-2) over the period 2015-2020 (see: https://iioe-2.incois.gov.in/IIOE-2/index.jsp).
IIOE-2 will have its International Indian Ocean Science Conference (IIOSC) in 2021. Website: https://iiosc2020.incois.gov.in/
SOLAS Indian Ocean meeting

SOLAS Indian Ocean online meeting
Date of the meeting: 30th September 2020
Objectives: Present and discuss current, ongoing, and planned SOLAS research and initiatives taking place in the Indian Ocean and help forge collaborations.
Website: available soon

Climate intervention

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, an example of a geoengineering approach. 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).

Since 2013, there has been a reassessment of the role that geoengineering approaches, in the atmosphere and the ocean, may play in reducing anthropogenic carbon dioxide and/or global warming. Since COP 21 in Paris in December 2015, it has become evident that climate mitigation alone cannot help us restrict warming 2 degrees or less. The Paris Agreement, which entered into force in 2016, employed the term ‘negative emissions’ in the context of the need to both decrease emissions but also purposely remove greenhouse gases and store them in reservoirs within the earth system. The terminology ‘climate intervention’ has superseded that of geoengineering. In line with these recent developments, SOLAS has developed a position statement on climate intervention.

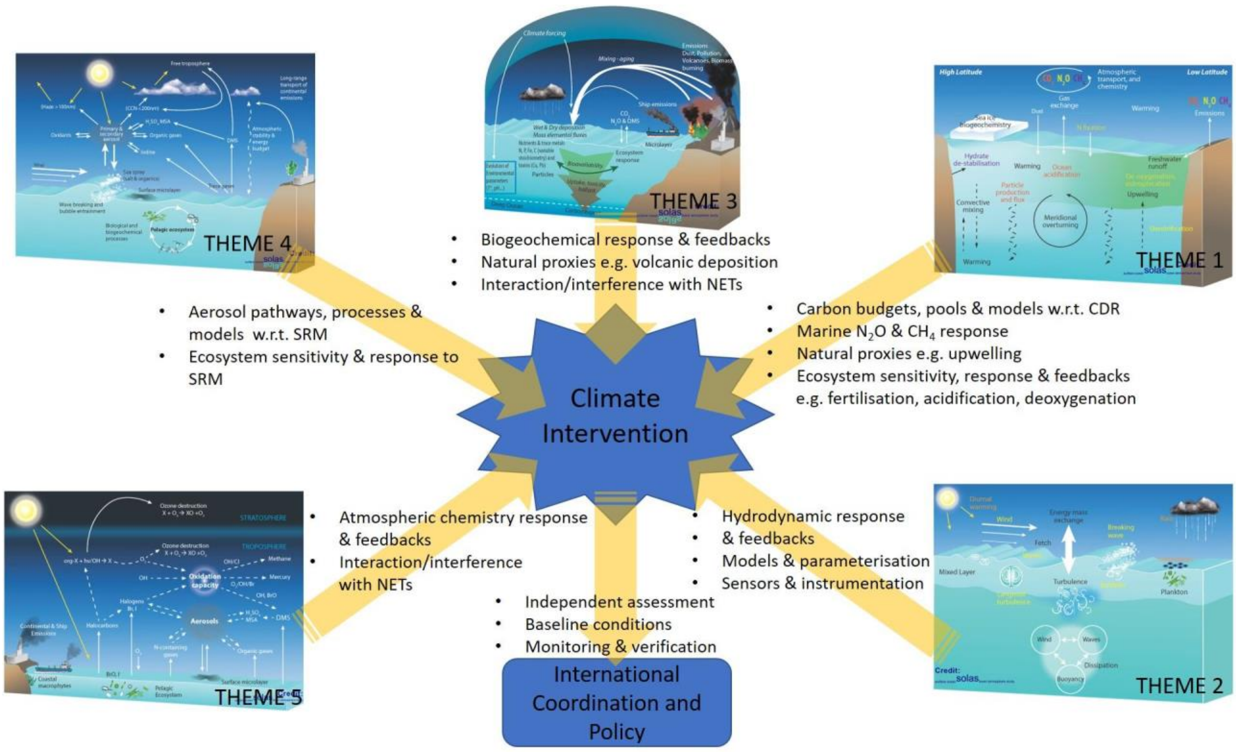

Figure 6: The five core themes of phase two of SOLAS. Each overlaid with specific physico-chemical and biogeochemical observations, process studies, and modelling that will together provide detailed insights into the challenges and benefits of using climate intervention on a range of scales from global to regional. 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 climate intervention approaches, which is a key requirement for governance.

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SOLAS Position Statement on Climate Intervention Research

Given the importance and sensitivity of this topic, SOLAS defined a position statement in July 2018:

The many dimensions and consequences of human perturbation of the climate system pose enormous and unprecedented challenges to human society. In light of widespread international agreement to limit increasing global temperatures, policy decisions will be made in the near future about climate intervention. It is essential that this decision making process be informed by sound and robust science. The SOLAS community has specific expertise and can provide critical insights into interactions between the atmosphere and the ocean, and therefore, SOLAS has a responsibility to make a multi-faceted contribution to discussions on climate intervention.

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 climate intervention (Negative Emissions Technologies (NET); and Solar Radiation Management (SRM).

Extend previous research

The second SOLAS science plan comprises five distinct themes, each of which has multiple strands with the potential to provide insights into physical, chemical, biological, and ecological facets of climate intervention. Hence, each of the five themes broadens 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

The integrated SOLAS 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), 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 results into policy and environmental legislation.

Planned activities

- 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 climate intervention.

- Assess broader (Earth System) climate intervention approaches & requirements with scientists from other programmes within WCRP and Future Earth, including socio-economists.
- Foster an "umbrella" organisation for governance and/or guidelines for scientists to independently carry out activities related to climate intervention.
- Form clear links with SOLAS Science & Society by providing robust scientific knowledge that can be subsequently explored through the lenses of societal needs.

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

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 necessary to increase interaction between natural scientists and social scientists, especially in light of anthropogenic influence on the ocean-atmosphere system. Next to the societal questions related to climate intervention, three main topics are currently being pursued.

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Valuing carbon in the ocean

Priorities

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

Planned activities

Review paper summarizing these issues.

Air-sea interaction, policy, and stewardship

Priorities

The actual forms of stewardship beyond national jurisdiction leave some blurred spaces where political and economic interests often clash. Thus, there is no general answer to the question of how policy-making deals with an uncertain future beyond national borders, although frameworks for both ocean and atmosphere governance require a global approach. There are many examples in which international law 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 or voluntary instruments. Nevertheless, the challenges that arise from the lack of implementation, compliance, and enforcement are an impediment to achieving the desired outcomes.

Another pressing issue is cultural differences at the local, national, or regional level that impact effective promotion of long-lasting stewardship of the open ocean. The perception of the nature of the ocean is socially constructed in different ways, and colonial and post-colonial history, post-Cold War scenarios, and new transnational identities deeply affects any of these perceptions. In addition, different stakeholders use the ocean in different ways for different purposes, governed through tools like 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

Following on a review paper summarising air-sea governance challenges, it would be useful to evaluate global attitudes towards the open ocean, in general, and to develop ways to promote long lasting stewardship (including the identification of what approaches work for whom and why). We will need to draw heavily on the expertise of social scientists in this effort.

Ship emissions

Priorities

There is an increasing awareness of the impacts that shipping traffic may have on environmental processes in the surface ocean and the lower atmosphere in the future. For example, the use 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 have been identified to help improve our understanding of these potential impacts and the development of a sustainable shipping industry.

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 subject also 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.

Planned activities

Current national and international programs investigating ship-plumes within the context of interactions between the surface ocean and lower atmosphere include “Shipping Emissions in the Arctic and North Atlantic Atmosphere” (SEANA) and “Atmospheric Composition and Radiative forcing changes due to UN International Ship Emissions regulations” (ACRUISE). There have also been suggestions that the ShipTRASE project funded by the Belmont Forum could form the basis of an institutional entity with more permanent means of funding.

In future work, we hope to include topics like the evolving legal framework for ocean observations, involvement in the development of an international regime for the protection of the atmosphere, and co-operation with the group working on climate intervention.