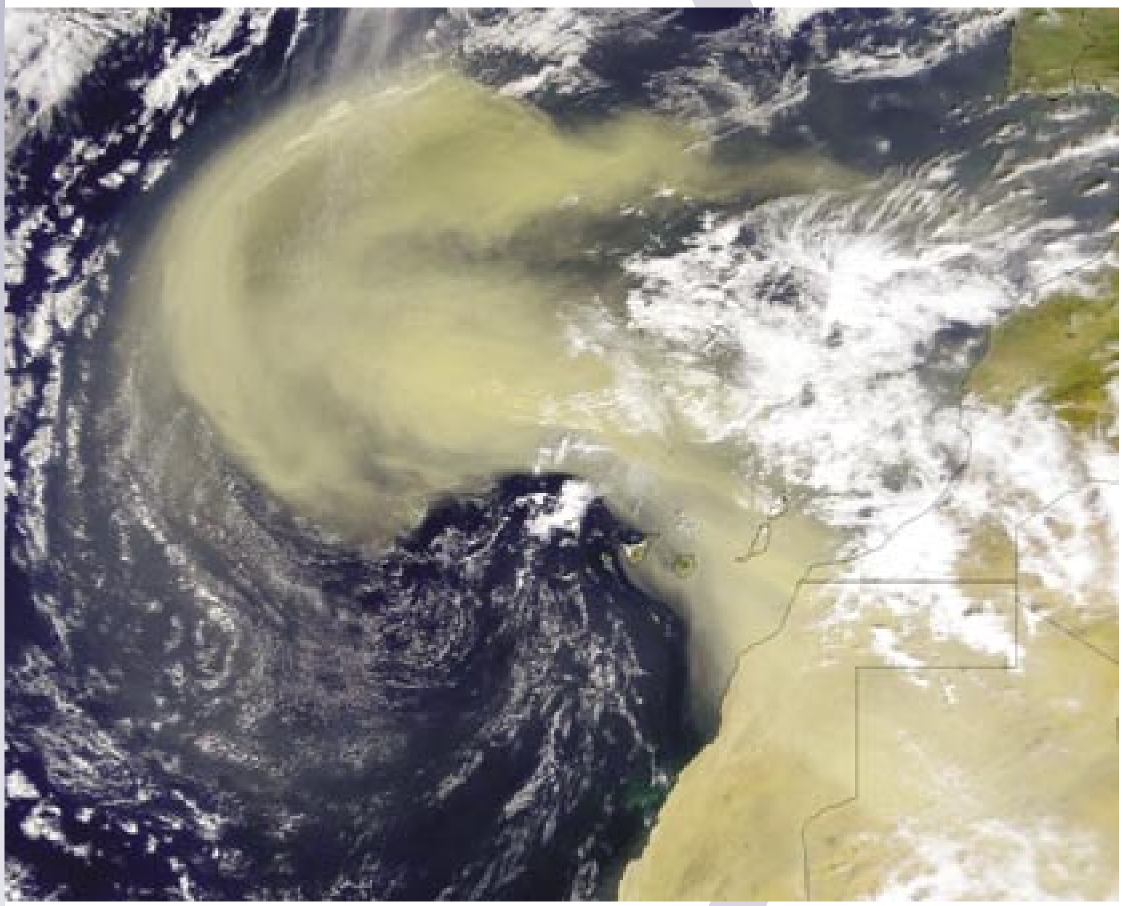
solas
surface.ocean lower.atmosphere.study

IGBP Report 50

The Surface Ocean – Lower Atmosphere Study



Science Plan and Implementation Strategy

GLOBAL IGBP CHANGE

CACGP

International Council for Science
Scientific Committee on Oceanic Research

WCRP Climate

Front Cover Image

A massive sandstorm blowing off the northwest African desert has blanketed hundreds of thousands of square miles of the eastern Atlantic Ocean with a dense cloud of Saharan dust. The massive nature of this particular storm was first seen in this SeaWiFS image acquired on Saturday, 26 February 2000 when it reached over 1600 km into the Atlantic. These storms and the rising warm air can lift dust 5000 m or so above the African deserts and then out across the Atlantic, many times reaching as far as the Caribbean where they often require the local weather services to issue air pollution alerts.

Provided by the SeaWiFS project, NASA/GSFC and ORBIMAGE

Financial Support

This work was financially supported by the UK Natural Environment Research Council, the International Council for Science (ICSU), the US National Academy of Sciences, the International Geosphere-Biosphere Programme (IGBP), the World Climate Research Programme (WCRP), and by US National Science Foundation (NSF) Grant No. 0003700 to the Scientific Committee on Oceanic Research (SCOR). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the US National Science Foundation.

Publication Details

Published by:
IGBP Secretariat
Box 50005
SE-104 05, Stockholm
SWEDEN
Ph: +46 8 166448, Fax: +46 8 166405
Email: sec@igbp.kva.se, Web: www.igbp.kva.se

Editor: Wendy Broadgate
Technical Editor: John Bellamy
Series Editor: Bill Young

ISSN 0284-8105

Copies of this report can be downloaded from the SOLAS website. Hard copies and CD-ROM copies can be ordered from the SOLAS International Project Office.

SOLAS International Project Office
School of Environmental Sciences
University of East Anglia
Norwich NR4 7TJ
United Kingdom

Web: www.solas-int.org

Science Plan and Implementation Strategy

Prepared by the SOLAS Scientific Steering Committee:

Peter Liss, UK, Chair
Philip Boyd, New Zealand
Elsa Cortijo, France
Ken Denman, Canada
Barry Huebert, USA
Tim Jickells, UK
Truls Johannessen, Norway
Gerbrand Komen, The Netherlands
Dileep Kumar, India
Paty Matrai, USA
William Miller, Canada
Ulrich Platt, Germany
Katherine Richardson, Denmark
Peter Schlosser, USA
Mitsuo Uematsu, Japan
Ilana Wainer, Brazil
Douglas Wallace, Germany

Casey Ryan, SOLAS International Project Officer

Preface

The SOLAS Science Plan and Implementation Strategy sets out the scientific scope of SOLAS and outlines a strategy for addressing the major issues that are identified. Thus the Science Plan and Implementation Strategy forms the basis on which the project is being built. However, it cannot remain current for the 10 years envisaged for SOLAS in view of the fast moving nature of this area of research.

To ensure that SOLAS moves with the times, detailed Implementation Plans will be produced for each Focus. These will be regularly updated by the Focus Implementation Groups and are intended to complement this document. As they are produced, the Plans will be made available for download from the SOLAS website: www.solas-int.org.

Acknowledgements

The SOLAS Scientific Steering Committee thanks the following people for contributing to the writing of this and earlier versions of the Science Plan and Implementation Strategy:

James Aiken, UK

Gregory Ayers, Australia

Hermann Bange, Germany

Richard Barber, USA

Gerrit de Leeuw, The Netherlands

Robert Duce, USA

Anton Eisenhauer, Germany

David Farmer, Canada

Martin Heimann, Germany

William Jenkins, UK

David Karl, USA

Wade McGillis, USA

Anthony Michaels, USA

Graeme Pearman, Australia

Alex Pszenny, USA

Peter Taylor, UK

Neil Tindale, Australia

Andrew Watson, UK

For help in preparing the Science Plan and Implementation Strategy, we are indebted to:

John Bellamy (IGBP Secretariat)

Wendy Broadgate (IGBP Secretariat)

Bill Young (IGBP Secretariat)

Adele Chuck (University of East Anglia)

Rosie Cullington (University of East Anglia)

Vladimir Ryabinin (WCRP Joint Planning Staff)

Ed Urban (SCOR Secretariat)

Phil Williamson (NERC)

PSL on behalf of the SOLAS Scientific Steering Committee

Norwich, UK

September 2003

Contents

Executive Summary

SOLAS (Surface Ocean - Lower Atmosphere Study) is a new international research initiative that has as its goal:

To achieve quantitative understanding of the key biogeochemical-physical interactions and feedbacks between the ocean and the atmosphere, and of how this coupled system affects and is affected by climate and environmental change.

Achievement of this goal is important in order to understand and quantify the role that ocean-atmosphere interactions play in the regulation of climate and global change.

The domain of SOLAS is focussed on processes at the air-sea interface and includes a natural emphasis on the atmospheric and upper-ocean boundary layers, while recognising that some of the processes to be studied will, of necessity, be linked to significantly greater height and depth scales. SOLAS research will cover all ocean areas including coastal seas and ice covered areas.

A fundamental characteristic of SOLAS is that the research is not only interdisciplinary (involving biogeochemistry, physics, mathematical modelling, etc.), but also involves closely coupled studies requiring marine and atmospheric scientists to work together. Such research will require a shift in attitude within the academic and funding communities, both of which are generally organised on a medium-by-medium basis in most countries.

SOLAS deals with the following issues or Foci. Each Focus is divided into several Activities.

Focus 1: Biogeochemical Interactions and Feedbacks Between Ocean and Atmosphere

The objective of Focus 1 is to quantify feedback mechanisms involving biogeochemical coupling across the air-sea interface, which can only be achieved by studying the ocean and atmosphere in concert. These couplings include emissions of trace gases and particles and their reactions of importance in atmospheric chemistry and climate, and deposition of nutrients that control marine biological activity and carbon uptake.

Activity 1.1	Sea-salt Particle Formation and Transformations
Activity 1.2	Trace Gas Emissions and Photochemical Feedbacks
Activity 1.3	Dimethylsulphide and Climate
Activity 1.4	Iron and Marine Productivity
Activity 1.5	Ocean-Atmosphere Cycling of Nitrogen

Focus 2: Exchange Processes at the Air-Sea Interface and the Role of Transport and Transformation in the Atmospheric and Oceanic Boundary Layers

The objective in Focus 2 is to develop a quantitative understanding of processes responsible for air-sea exchange of mass, momentum and energy to permit accurate calculation of regional and global fluxes. This requires establishing the dependence of these interfacial transfer mechanisms on physical, biological and chemical factors within the boundary layers, and the horizontal and vertical transport and transformation processes that regulate these exchanges.

Activity 2.1	Exchange Across the Air-Sea Interface
Activity 2.2	Processes in the Oceanic Boundary Layer
Activity 2.3	Processes in the Atmospheric Boundary Layer

Focus 3: Air-Sea Flux of CO_2 and Other Long-Lived Radiatively Active Gases

The air-sea CO_2 flux is a key inter-reservoir exchange within the global carbon cycle. The oceans also play an important role in the global budgets of other long-lived radiatively active gases, including N_2O and to some extent CH_4. The objective of Focus 3 is to characterise the air-sea flux of these gases and the boundary layer mechanisms that drive them, in order to assess their sensitivity to variations in environmental forcing.

Activity 3.1	Geographic and Sub-Decadal Variability of Air-Sea CO_2 Fluxes
Activity 3.2	Surface Layer Carbon Transformations in the Oceans: Sensitivity to Global Change
Activity 3.3	Air-Sea Flux of N_2O and CH_4

The Plan includes a description of the organisation and management of SOLAS and an outline of how it will be implemented.

Introduction

The Goal of SOLAS

SOLAS (Surface Ocean - Lower Atmosphere Study) is a new international research initiative that has as its goal:

To achieve quantitative understanding of the key biogeo-chemical-physical interactions and feedbacks between the ocean and atmosphere, and of how this coupled system affects and is affected by climate and environmental change.

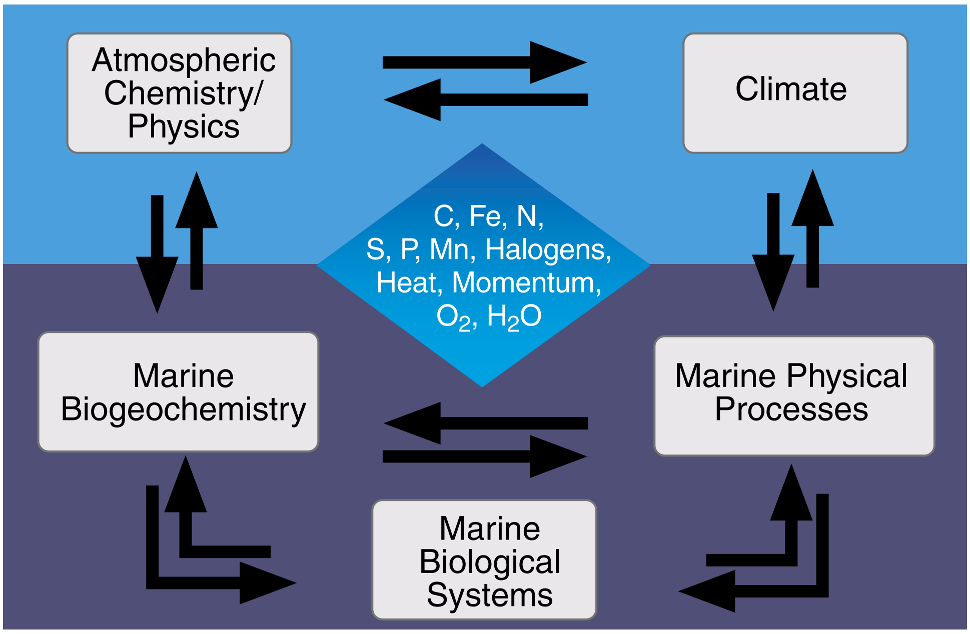
The scope of the study is illustrated in Figure 1 and described in detail in this Science Plan and Implementation Strategy. The Science Plan parts of this document are largely based on the results of the International SOLAS Open Science Meeting held in Damp, near Kiel, Germany in February 2000 which involved more than 250 scientists from 22 different countries. The International Geosphere-Biosphere Programme (IGBP), Scientific Committee on Oceanic Research (SCOR), Commission on Atmospheric Chemistry and Global Pollution (CACGP) and the World Climate Research Programme (WCRP) have approved SOLAS and are sponsors of it.

The SOLAS Approach

In this Plan we identify critical questions and hypotheses, as well as goals to quantify the rates and variability of various important processes. SOLAS will focus on important research issues that are not being emphasised by other projects and which require collaboration of atmospheric and marine scientists. It will concentrate on research that can be expected to produce results within a 10 year period, although some aspects will need to be continued beyond this timeframe.

The general approach to implementation is to assess the ambient situation as thoroughly as possible, identify the weak links in understanding, undertake laboratory work and focused field studies to resolve those issues, put the new understandings into process models, and test those models with carefully designed observations that bridge scales from the micro scale to the global. In many cases observations with high temporal and spatial resolution will be of great value for both process understanding and process model testing. It is clear that in some cases simultaneous observations with multiple platforms (ships, aircraft, buoys, satellites) will be required. The

Figure 1. The scope of SOLAS.



final step is to integrate this process understanding into diagnostic models which scale up to regional and global scales and can form the basis for modules in climate models.

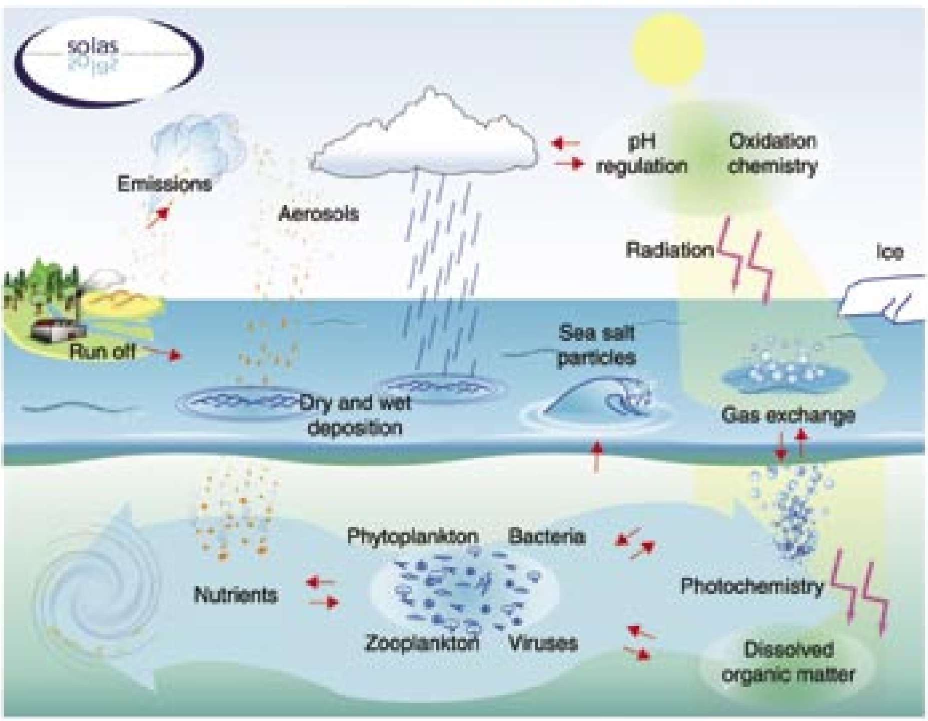
The key hypotheses under test in SOLAS will require numerical modelling studies for their systematic evaluation and quantitative assessment. Generally, SOLAS modelling activities will fall into three broad classes: (1) modelling as a key contribution to process studies, (2) modelling as a monitoring tool to integrate spatial and temporal scales, and (3) development of models and model components of SOLAS subsystems as parts of Earth System models.

Remote sensing data, mainly from satellite sensors, are expected to make a vital contribution to SOLAS. Satellites allow global observation of marine biogeochemical signatures (e.g. ocean colour, trace gases and aerosols), have good temporal coverage, and with 4-5 year missions, provide observations over an extended time period. In particular, satellite observations can put field experiments into a larger temporal and spatial perspective. A need will be to achieve coupling between field data, satellite observation, and models.

Many of the key questions in SOLAS can be addressed by time series studies that ideally should be conducted at strategic sites that are representative of large biomes or in regions that are likely to exhibit substantial interannual variability over large areas. Furthermore, these field investigations should be continued for at least several decades, in order to distinguish natural variability from that induced by human activities. Such observations, in combination with proxy records preserved in peat bogs, soil/dust deposits, firn, ice and lake and marine sediments, have clearly established the trends that are occurring in many individual components as well as in their gross budgets. They have also implicated human activities in many cases as the cause of change. In spite of their well recognised value, systematic, long-term, direct biogeochemical observations of the atmosphere are rather limited; for oceanic habitats they are indeed rare.

Considering the very considerable resources required to set up and maintain time series measurement sites, wherever possible they should address the goals of several SOLAS Foci/Activities and be shared with other projects (e.g. IGAC, IMBER, GEWEX). They should also build on the results of the current time series stations. Since SOLAS has a strong emphasis on process-

Figure 2. Diagram to illustrate the domain of SOLAS, its interdisciplinarity and the main operative processes.



driven research, it may well be that it is not the obvious main sponsor for time series studies. In this situation it will be the responsibility of the SOLAS Implementation Groups to specify their long-term measurement needs for both satellite and ground-based routine observations and for them and the SOLAS SSC to support the efforts of those mandated to make the measurements.

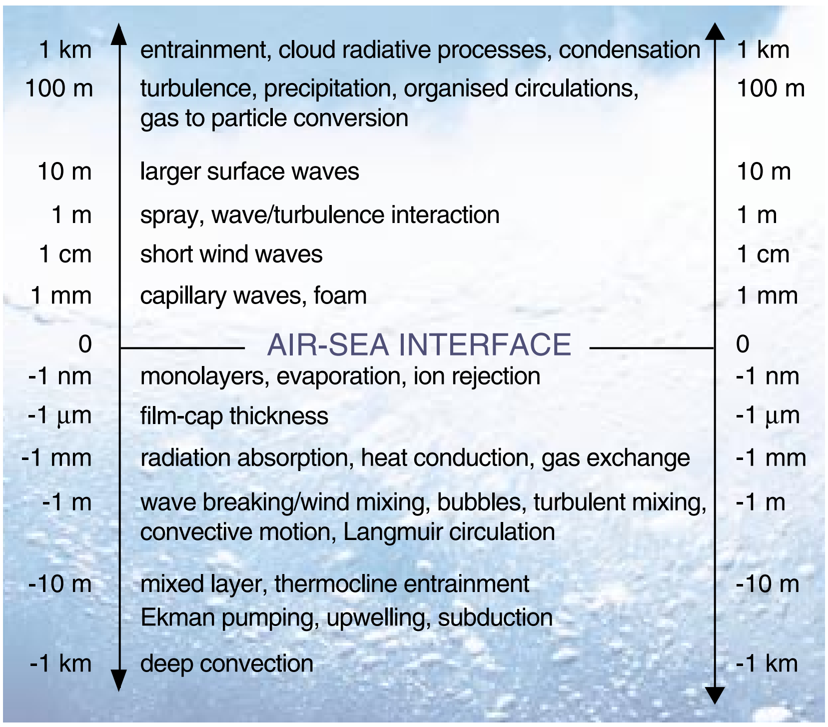
The ethos of SOLAS is to use the disciplines of biology, chemistry, physics, etc. to study biogeochemical interactions in the ocean-atmosphere system. In achieving this goal, these disciplines are not principally to be advanced in their own right, but should be seen as tools to pursue the larger aim. So, for example, SOLAS will not carry out research to study for its own sake the physics of air-sea exchanges of heat and momentum, but will and must use the best physical knowledge available, together with that from other disciplines, to quantitatively address the issue of how matter is exchanged across the air-sea interface.

The Domain of SOLAS

SOLAS will focus on research topics of linked ocean-atmosphere interactions at a multitude of space and time scales in each medium. This focus results in an unavoidable mismatch in time and space scales of processes (and hence measurement needs) because atmospheric transport is more rapid than oceanic circulation. A distinctive feature of the ocean surface and surrounding air and water boundary layers is the progressive change in scale and progressively greater interdependence of different processes as the interface is approached. Processes that might be usefully explored in isolation at depth/height, must be considered with a host of competing and interacting effects close to the interface. The scales of the interacting phenomena become smaller and start to overlap, and the nonlinear interactions increase in strength as the interface is approached.

The interdisciplinary nature and broad domain of SOLAS are illustrated in Figure 2. The vertical domain of SOLAS is focussed on processes at the air-sea interface and includes a natural emphasis on the atmospheric and upper-ocean boundary layers, while recognising that some of the processes to be studied will, of necessity, be linked to significantly greater depth/height scales (illustrated in Figure 3). The atmospheric boundary layer can be functionally defined as extending to the top of the boundary-layer clouds (typically to about 1 km). The

Figure 3. Vertical scales of processes important for air-sea exchange.



upper-ocean boundary layer functionally includes the actively mixed or euphotic zone (typically 100-200 m).

In the horizontal dimension, SOLAS research can be focussed anywhere over the ocean, extending into coastal areas and estuaries, as well as ice covered areas. Coastal ecosystems are characterised by higher primary production than open ocean systems, with associated high rates of carbon burial that are significant to the global carbon budget. In addition, coastal seas are dominant marine sources of some trace gases globally (e.g. nitrous oxide (N_2O), carbonylsulphide (COS), methane (CH_4)) and are important production sites for almost all trace gases. Coastal research is spread across the whole of the SOLAS research agenda and will be linked to the LOICZ programme. Likewise, processes that occur at ice edges and in ice covered seas are important for emission of trace gases such as DMS and organo-halogens, and each focus in SOLAS includes important research in these regions.

In the temporal domain SOLAS will need to be concerned with a continuum, from the past through the present to the future. Measurements of oceanographic and climatic indicators of past ocean and atmospheric chemistry and climate will be needed to determine how a variety of factors related to air-sea interactions varied in relation to one another in the past. Long term, regular observations at important sites are needed to provide understanding of interannual to interdecadal variability of important global processes. Models need information from both palaeo indicators and from studies of present-day processes, in order to develop an ability to predict environmental variability and the responses of global systems to the effects of human perturbations. Models also provide capabilities to extrapolate measurements up and down across scales and to integrate data from different sources. Model studies conducted in parallel with experimental and observational studies will allow a systematic evaluation and qualitative assessment of the different hypotheses emerging from the data. The necessity of involving both palaeo and modelling expertise in SOLAS illustrates the need for strong cooperation between SOLAS and the Past Global Changes Project (PAGES) especially its International Marine Global Changes Study (IMAGES), and the Global Analysis, Integration, and Modelling (GAIM) Task Force. Data assimilation techniques, similar to those being used at numerical weather prediction centres and developed by GODAE for oceanographic applications, will be required to handle the complex and disparate data sets generated by SOLAS field campaigns with many different platforms (e.g. ships, aircraft, satellites).

The chemical domain of SOLAS will include all natural elements (and their compounds) that play an important role in biogeochemical cycling (e.g. C, N, O, P, S, Group 1 and 2 elements, halogens, Fe, Mn and other trace metals and metalloids). Some inert gases and low chemical reactivity substances (lanthanides, natural and anthropogenic radionuclides), as well as a variety of persistent organic pollutants (POPs), will also be included in SOLAS, but only where their study can yield information useful in elucidating the ocean-atmosphere behaviour of biogeochemically and/or climatically active elements.

Societal Relevance

SOLAS can contribute to our understanding of the important role that the ocean-atmosphere interface plays in relation to issues relevant to society, including climate change, air quality, and the health of the ocean. For each of these topics, SOLAS will seek to develop collaborative research with related international projects. Likewise, the International Human Dimensions Programme on Global Environmental Change (IHDP) and SOLAS can work together to identify societal issues and important human drivers of changing biogeochemical fluxes, for example with respect to ethical, legal and financial implications of the research.

The Montreal and Kyoto Protocols marked a change in attitude within the international policy community to the issues of global change related to ozone and atmospheric carbon dioxide, respectively. Ozone depletion and greenhouse gas emissions are increasingly recognised as threats to the quality of human life, the global economy and natural ecosystems. Such threats require close observations and forecasts. As a practical matter, nations must plan to meet the commitments made in these agreements. Transparent and accountable verification of greenhouse and ozone-depleting gas sources and sinks is required. Within its area of research, SOLAS will help to better quantify the global emissions of these compounds and thereby address major societal needs.

However, at present, the political imperative is running well ahead of scientific knowledge. For example, from models that interpret atmospheric and marine measurements of CO_2, we know that the Northern Hemisphere land biota is taking up 1-2 PgC (petagrammes of carbon, 1 PgC = 1 GtC) of atmospheric CO_2 per year, and the global ocean a similar amount. But beyond this understanding, little scientific consensus exists as to where (which continent or ocean) or why (what processes are responsible) these sinks exist, or their variability on seasonal to decadal time scales. A second example of knowledge gaps is related to aerosols, which are now recognised as having a significant, but very poorly quantified, effect on global climate change. However, their generation, chemistry and fate have received relatively little attention. Without a substantial maturing and deepening of our knowledge about this complex aerosol system, scientists will be unable to provide the verification techniques and forecasts of future trends that will be required. Similar arguments apply to ozone depletion where, in spite of the success of the Montreal Protocol, ozone recovery is being delayed by the continued increases in brominated gases and CFC (chlorofluorocarbon) replacements and, potentially, by global warming. This perturbation must be evaluated within the context of the large scale and uncertain air-sea exchange of biogenic halogen gases (Br, Cl, I). A further example is the case of proposals to fertilise large parts of the open oceans with iron in order to enhance the oceanic sink for CO_2; an issue for which proposed industrial application is running substantially ahead of scientific understanding. All these topics, together with many others, are major basic scientific issues in the SOLAS programme, the results of which will form the sound foundations for policy making in the coming years.

Simulations of future climate are only now beginning to incorporate the biological and chemical feedbacks that may arise as the atmosphere-ocean system changes in response to climate and other environmental forcing. These simulations give divergent predictions, depending on which feedbacks are included and how they are modelled. Substantial changes in “natural” sources and sinks of climatically active gases are possible, indeed probable, once climate change effects become obvious. CO_2 is the most closely studied example, but dimethylsulphide (DMS) and other chemically active trace species such as organo-halogens may also have important effects, little addressed to date. These deficiencies lead to uncertainties in the timing and magnitude of global change effects by many decades, the social and economic implications of which are clearly profound. Adaptation strategies are highly dependent on the time scales of change. SOLAS is designed to address these issues, with the purpose of substantially reducing the uncertainties in our predictions of the timing and effects of future global and climate change.

SOLAS and the Global Carbon Cycle

SOLAS cannot address all issues related to the ocean’s present and future role in the global carbon cycle. Rather, it will address an important subset of carbon cycle issues that are compatible with its overall goals, domain and technical approaches. These topics can be summarised as:

- Quantification of the present-day exchange of CO_2 and carbon-related properties between the atmosphere and the surface ocean.

- Understanding of surface-layer ocean processes that can change the future air-sea flux of CO_2, with potential implications for altered sequestration of carbon within the ocean.

SOLAS will focus on providing a description of the contemporary geographical and temporal structure and variation of air-sea CO_2 fluxes, as well as mechanistic understanding of surface-layer processes that determine these fluxes, both now and in the future. This should include a strong emphasis on continental margins where forcing and fluxes can be particularly large. SOLAS is not the appropriate home for a global-scale pCO_2 measurement system, but its work will help guide the development and progress of such a programme, which the SOLAS SSC will strongly support. The limited SOLAS objectives above will provide a foundation for broader global carbon cycle science activities in the Global Carbon Project (GCP), particularly for the evaluation and parametreisation of processes in the models required to predict future ocean carbon sequestration.

Interdisciplinarity and Integration

More than is usually the case, meaningful developments in SOLAS will depend on research that is not only interdisciplinary, but also involves closely coordinated field studies in which the different research components are combined so as to produce comprehensive data sets.

Achieving understanding of processes that occur at the ocean-atmosphere interface will require an enhanced level of cooperation in planning and execution of research among many different disciplines in the environmental sciences. The success of SOLAS will depend on the effectiveness of such cooperation and ability to integrate measurements and analyses of many different types.

These challenges require some educational efforts, such as summer schools, to bring together young and established researchers for the mutual exchange of ideas and experience, and from countries with developed and developing science bases. (The first SOLAS Summer School was held in 2003 in Corsica). In addition and most importantly, research involving the coherent study of linkages between environmental compartments (in the case of SOLAS, atmosphere and oceans) will require a shift in attitude within the academic community and research funding agencies, both of which are generally organised on a medium-by-medium basis in most countries. Bridging such barriers is vital because knowledge of atmosphere-ocean interactions is key to understanding climate and other global changes.

Added Value and Legacy

As is the goal of many international projects, SOLAS will add value to the research in its area of interest by activities such as: answering broad questions that individual nations cannot address alone; coordinating large-scale international activities, encouraging multi-investigator studies and avoiding unnecessary duplication of effort; establishing a common data policy to allow sharing of results between investigators; synthesising and publicising the results obtained in the project; carrying out data and model intercomparisons; standardisation of methodologies; testing models against new and existing data sets.

Specifically, SOLAS will add value by improving process understanding in both the surface ocean and the lower atmosphere, as well as the mechanisms of exchange between them. This will lead to improved parameterisation of air-sea transfer rates and processes within both fluids. In turn, this will feed into better models for upscaling local results to regional and global scales. Finally, the improved understanding of biogeochemical interactions between atmosphere and ocean to be achieved in SOLAS will be vital components in the construction of Earth System models of various degrees of complexity. A current example is the strong involvement of SOLAS in the SCOR/IGBP Fast Track Project 'Global Iron Connections', which will produce an integrative assessment of the global iron cycle.

The Structure of the SOLAS Science Plan and Implementation Strategy

SOLAS consists of 3 Foci, each containing several Activities, as shown in Figure 4. In the main part of the Plan, the Activities are introduced and a review of the present state of understanding is presented. This leads to definition of the major issues requiring resolution, which have been classified in terms of essential (⏩) and complementary (▶); these are followed by a statement of the specific goals of each Activity. Finally, promising approaches to tackling the identified issues are discussed, together with a strategy for implementation. The Plan concludes with a description of the organisation and management of SOLAS.