Note: This draft is meant to promote discussion on US SOLAS rather than a definitive plan. It was produced by Rik Wanninkhof, last revised 2/20/00. Comment can be addressed to any of the US SOLAS committee members listed below.

Prospectus

The United States efforts in the Surface Ocean Lower Atmosphere Study (US SOLAS)

Summary

The US component of the Surface Ocean Lower Atmosphere Study (US SOLAS) plans to study the controls and feedbacks of cycles of climate relevant compounds (CRCs) in the upper ocean and lower atmosphere. A process-oriented program is proposed that spans the air-sea interface rather than using it as a programmatic boundary. The program is geared to innovative research, or "high returns" efforts addressing specific hypotheses. US SOLAS will focus on studying the controls on mechanisms by natural and deliberate perturbations. Since many of the processes exert an interdependent control on the substances of interest, a strong multi-disciplinary approach is advocated. Key biogeochemical cycles of particular interest are those of carbon, water, sulfur, and nitrogen. These cycles either directly or indirectly influence the earth's climate and changes of the dynamics in the upper ocean and lower atmosphere can have a significant influence on future climate trends. Approaches will include field studies, modeling studies on different scales, and paleo-climate studies. The program implementation is envisioned as working groups taking charge of studies of intermediate size focusing on issues of relevance to SOLAS rather than a top down approach. The studies will contribute to answering the broader scientific questions relating to changes in the dynamic forcing affecting the cycles of CRCs and feedbacks in the earth system when perturbed by global change. US SOLAS anticipates a major role in quantification of air-sea CO_2 fluxes in order to estimate CO_2 update by the ocean on seasonal timescales as part of the US Carbon Cycle Science Plan.

Preamble

In the past decade rapid advances have been made in our understanding of physical and biogeochemical controls on climate and CRCs. Programs such as JGOFS and IGAC have provided new insights into the biogeochemical and physical interactions in the upper ocean and lower atmosphere. However, the lack of close collaborations between the predominantly oceanic effort (JGOFS) and atmospheric studies (IGAC/ACE) have impaired a comprehensive approach of study in this region. SOLAS hopes to stimulate scientific and programmatic interaction in this area. The air/sea boundary layer region exerts fundamental controls on biological and chemical cycling that have a direct influence on CRCs. These include processes such as deposition and transformation of aeolian input, notably iron, which controls biological productivity in High Nutrient Low Chlorophyll (HNLC) regions; oceanic emission of dimethylsulfide (DMS) that can act as a precursor of cloud condensation nuclei in remote marine environments; and the ability of nitrogen fixing organisms to supply new nitrogen to the surface ocean thus enhancing the biological pump in parts of the ocean. These recent insights have fundamentally changed our way of thinking about controls on upper ocean biogeochemistry, the influence of atmospheric processes on these controls, and, in turn, the influence of the processes on climate and the oxidizing capacity of the atmosphere. Large knowledge gaps on the processes surface ocean - lower atmosphere (SOLA) region remain, particularly in the area of climate feedbacks and the response of the chemistry, biology, and physics in the boundary layers.

Field studies and paleo-climate studies over the past several decades emphasized that an effective way to study processes is to determine response of the system to perturbations. Natural perturbations such as the seasonal progression have improved our understanding of spring blooms. Storms were shown to have an important effect on nutrient supply, sea salt/spray emissions, and dust deposition.   Eddies in the upper ocean were shown to have an important effect on productivity. The response of climate to longer scale perturbations has been studied in increasing detail from retrospective analysis and paleo-climate indicators. The first deliberate manipulation experiments showed that perturbations could be invoked "at will" thus offering a unique and definitive way to perform hypothesis driven research.

The last several decades have also offered increased evidence of man's influence on the natural environment along with indications of direct perturbations on the earth's climate. A prime example are fossil fuel emissions, which started in the mid-eighteenth century. The resulting increased atmospheric CO_2 burden appears to be warming the earth's surface. However, increased aerosol emissions by burning of fossil fuels have been suggested as a mechanism for localized cooling. This evidence of man-induced perturbations, which obviously have a direct effect on our lives, remains controversial and systematic investigations on controls and feedbacks of climate change are necessary to improve models and ultimately guide policy decisions.

The combination of increased awareness of the importance of the region encompassing the surface ocean and lower atmosphere on several CRCs, the appreciation that natural and manmade perturbations are a powerful way to improve our mechanistic understanding of the system, and the acute need to properly incorporate this understanding into prognostic models, precipitated the plans for a new study: the Surface Ocean Lower Atmosphere Study (SOLAS). US SOLAS is part of the international effort that started with a planning meeting in January 1997 in London. The resulting IGAC newsletter report authored by Prof. Watson of UEA states as overall goal for the effort:
"To address key interactions among the marine biogeochemical system, the atmosphere and climate, and how this system affects and is affected by past and future climate and environmental changes."

These goals will be attained by:
- Formulating and testing hypotheses about these key interactions
- Quantifying the cause and effect in these interactions, and
- Incorporating this new understanding into models

At the initial meeting five hypotheses were brought forth as examples of the scope of the program:

- Marine sulphur emissions have a substantial effect on climate by influencing cloud albedo.
- Atmospherically derived iron stimulates diatom and other phytoplankton growth in "high nitrate low chlorophyll" (HNLC) regions of the ocean, and this may exert significant feedback effects on climate.
- Changing patterns of atmospheric nitrogen deposition consequent of increasing industrialization will significantly influence the marine biota in some parts of the ocean.
- The influence of changes in marine biogeochemistry on ocean uptake of anthropogenic CO_2 in the next century will be small.
- The principal effect on marine production in a warmer world would be a decrease in global productivity, consequent on a slowing of the thermohaline circulation.

The importance of building on to what has been learned in previous programs was recognized at the initial meeting. US SOLAS plans to develop specific national science plans based on these general themes since the goals of the SOLAS program are broad and some of the hypotheses have been addressed or refuted through modeling and observational work in the past three years.

Both the proposed methods and the proposed interactions between groups who have historically not worked closely together create challenges in execution of the program. The US SOLAS planning group recognizes these issues and through judicial choice of membership and community input hopes to establish new working partnerships amongst disciplines, much like the interactions between the marine chemical and biological community facilitated through JGOFS. US SOLAS also will work closely with other planning efforts such as EDOCC and OCTET to provide a synergistic plan and joint efforts to address problems of high priority.

Scientific Questions

At the first US SOLAS planning meeting in San Francisco in December 1999 several general science questions were proposed to guide the overall planning of the program. They are closely aligned with the questions posed by the international SOLAS community and they will be fine-tuned and adapted as planning and implementation progresses. The questions can be roughly divided amongst two general themes.

I. The effect of changes in physical forcing on biogeochemical cycles in upper ocean and lower atmosphere.

- Can we improve quantification of air-sea fluxes and transport processes into the surface ocean boundary layer (SOBL) and lower atmospheric boundary layer (LABL) such that biogeochemical transformations can be determined quantitatively from mass balances in the region?
- What is the ocean biological contribution to cloud condensation nuclei?
- How do changes in surface forcing affect production and emission of trace gases and seasalt particles?
- Are changes in oceanic emissions affecting the oxidizing efficiency of the lower atmosphere?

II. Study of the nitrogen cycle and its effect on CO_2 uptake and release of biogenic gases.

- Is the oceanic nitrogen cycle in steady state?
- What is the impact of fertilization processes on emissions of biogenic gases such as DMS, halocarbons, hydrocarbons and N_2O, and uptake up CO_2?

The Scope of US SOLAS

With the development of new programs there is a strong impetus to make the objectives broad to satisfy a large constituency. This can lead to problems in implementation with objectives becoming too diffuse to address specific questions. Thus far the SOLAS planning revolves around a general concept that will have to be fine-tuned to create a coherent and doable program at national level. It should also dovetail into other [planning] efforts at national and international levels. The program should start out addressing tractable and provocative issues as outlined above for which we can make meaningful advances in process studies of finite duration. The research questions will likely satisfy two tenets. First, the program will fundamentally address the climate implications of changes in the relevant biogeochemical cycles. Second, the studies will take advantage of perturbation approaches to study processes. As general guidelines for the initial development US SOLAS should:

- Study CRCs for which the upper ocean plays a significant role.
- Follow a hypothesis based scientific approach.
- Limit its study region to the atmospheric marine boundary layer and euphotic zone.
- Be a true interdisciplinary project engaging researchers from different disciplines.
- Provide critical information and boundary conditions for other efforts and for models predicting future atmospheric levels of CRCs.

US SOLAS should focus on a critical boundary region for CRCs: the marine boundary layer comprised of the upper ocean and lower atmosphere. Although this region cannot be studied in isolation it is envisioned that other programs will provide the fluxes and concentrations of the compounds of interest at the boundaries of the SOLAS study domain. Through close inter-program interaction these " fuzzy boundaries" should be dealt with in a seamless fashion. US SOLAS should focus on gaining a comprehensive understanding of the processes controlling inventories and fluxes of the species of interest. Based on recent studies this means that conventional paradigms about C, S, N and H_2O cycling will be challenged.

The standard method of scientific inquiry will be followed in which the hypotheses will be formulated tested, and updated with aid of diagnostic models, historical observations and remote sensing observations. In advance of field studies diagnostic models will be run using climatological data or data obtained from specific field campaigns. The range of probable perturbation functions utilizing climatology and/or remotely sensed observations will be applied to the models to estimate the response of the natural system. The results of the field studies in turn will be analyzed in this framework. Likely differences will be investigated by updating models input functions based on observations that ultimately will lead to better parameterizations of prognostic modeling efforts.

A reasonable approach for mechanistic studies is to concentrate on specific geographic regions. By containing the temporal and spatial scale of the program the benefits of the multidisciplinary nature of the effort can be best illustrated. The geographic regional focus is much like the JGOFS process study effort with some important differences. The studies will focus on the response of the system of interest to perturbations and thus should be of sufficient scope to assure that the cause-and-effect is clearly illustrated and avoid ambiguous interpretation. For natural perturbation this means that several perturbation cycles should be investigated. For the seasonal cycle this would necessitate studies of several years duration. For deliberate perturbations the "forcing" and study of response should be long enough for the chemical and biological system to reach a new steady state.

A challenge for US SOLAS is to engage investigators from different disciplines such that the system can be studied comprehensively. The physical, biological, and chemical interactions controlling the levels of CRCs are often closely related and a systems approach is necessary. In particular, new interactions must be forged between experts in boundary layer physics and meteorology, atmospheric and marine chemists and biologists, and modelers studying processes on different scales. Some of these partnerships have been forged in previous programs, others, in particular those relating to boundary layer interactions, have to be initiated in the program both at scientific and programmatic levels.

An important goal for US SOLAS will be to offer the appropriate observational constraints and mechanistic input to improve global forecast models of climate relevant species. This will require a hierarchy of smaller scale process models to depict the trends of the perturbation studies properly. Conversely, large-scale models will also be used to guide the research efforts and point to particular gaps in our knowledge that will hamper prediction of the future.

Interaction with other Programs

By nature of the region of interest, the air-water boundary region, and because of its focus of determining the response of the biogeochemical system to [climate] perturbations it is imperative that US SOLAS forges close ties with other programs. Of direct relevance are GOOS, CLIVAR, CCSP, IGAC/ACE, EDOCC, and OCTET. The new efforts can be roughly divided as programs focusing on improving our mechanistic understanding of the relevant processes, and programs engaged in systematic observations of our current earth system and detection of changes therein. US SOLAS is primarily a process-oriented effort and close collaboration and interactions with programs of similar design are anticipated. Results from US SOLAS would be used in the observation based programs as boundary conditions for, amongst other things, prognostic modeling. The observational programs and accompanying global and regional models would in turn provide insights as to which oceanic regions exert or experience significant effects on climate change.

It is envisioned that the process-oriented programs would collaborate in several areas. The process studies in US SOLAS would be closely linked to efforts in for instance, OCTET and EDOCC, where the latter programs would focus on cycling and ecological changes in the water column while SOLAS effort would be geared to transfer between the ocean and atmosphere and projecting its effect on climate. In modeling and paleoclimate efforts the SOLAS efforts would focus on climate implications of changing atmospheric composition and fluxes while the OCTET studies likely concentrate on the oceanic manifestation and responses. In actual execution of programs it is envisioned that a "code share arrangement" of joint multi-agency announcements with general guidelines on partitioning of efforts would apply. An unique aspect of US SOLAS is that it does not concentrate solely on inventories and transformations of the compound of interest but rather takes broader systems approach.

The large-scale observational programs such as proposed under GOOS and CLIVAR and COAG will provide large-scale fields to extrapolate our results to large regions. An illustrative example is how US SOLAS hopes to contribute to the goals of the US Carbon Cycle Science Plan (CCSP) in an interactive fashion with other efforts. The overall goal of the CCSP is to determine where the anthropogenically produced carbon has been stored in the past and where it will be stored in the future. This objective requires quantification of inventories of carbon in the land biosphere and in the ocean over decadal time scales, and terrestrial uptake and air-sea CO_2 fluxes on seasonal time scales. To determine the global air-sea fluxes we must understand the controls on the gas transfer and surface water pCO_2 utilizing process studies and diagnostic modeling. The processes have to be related to hydrographic, hydrodynamic, and biological forcing which in turn should be related commonly measured parameters, particularly remotely sensed parameters that can be obtained globally over short time scales, such as SST, color, surface roughness, and wind speed. In this manner we can parameterize the air-sea CO_2 fluxes with environmental forcing. The studies in US SOLAS would provide the mechanistic information on gas transfer and controls on surface water pCO_2, while program being developed in the COAG in conjunction with CCSP would provide the global pCO_2 fields, including global information about forcing from, for instance, remote sensing. By combining the information from the proposed efforts with prognostic modeling, realistic flux estimates can be made to forecast future atmospheric CO_2 levels.

US SOLAS Organizational Structure

The implementation is envisioned to occur by small working groups of investigators who would take charge of the issue. International collaborations would be encouraged. The principal role of the US SOLAS committee would be to facilitate the efforts.

Implementation of scientific programs is often most efficient in a tightly structured top down approach. This is particularly advantageous for mission oriented projects with a clearly defined overall objectives. US SOLAS will be more of an exploratory program focusing on a variety of climate relevant processes and as such can benefit from a more participatory program management. Overall science planning will be closely coordinated with the international SOLAS effort to facilitate international collaborations on projects of mutual and global interest.

Because of the current thought for US SOLAS to focus on medium scale multidisciplinary studies, the implementation is well suited to take place by smaller groups of investigators. The

US SOLAS committee will facilitate inter-agency participation of the projects, and address gaps in overall scientific plans. Planning and execution of such medium scale interdisciplinary studies currently occurs in an ad hoc fashion often retarding speedy execution and sometimes excluding important or logical components for a variety of reasons. This is particularly true in studies such as proposed in SOLAS that involve different research communities.

Epilogue

US SOLAS is a program geared to studying processes and feedbacks controlling climate relevant species in the ocean and lower atmosphere. Its focus will be on integrated studies to investigate key mechanisms controlling the abundance of the species. A systems approach will be followed in which the overall impact of changes and perturbations of the cycles will be studied in unison rather than being a species-specific or reservoir specific effort. US SOLAS will encourage innovative studies and act as a conduit to streamline efforts to settle provocative hypotheses in the field and in the modeling arena. The effort should not be seen in isolation of other program developments but rather an integrated but unique aspect of the study of climate perturbations.

Acronyms

ACE	Atmospheric Chemistry Experiment
CCSP	Carbon Cycle Science Plan
CLIVAR	CLImate VARiability and prediction program
COAG	CO_2 Observations Advisory Group
EDOCC	Ecological Determinants of Oceanic Carbon Cycle
GOOS	Global Ocean Observing System
IGAC	International Global Atmospheric Chemistry
OCTET	Ocean Carbon Transport, Exchanges and Transformations
SOLAS	Surface Ocean Lower Atmosphere Study
UEA	University of East Anglia
US JGOFS	U.S. Joint Global Ocean Flux Study

Appendix

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