Surface Heat Budget of the Arctic Ocean (SHEBA)

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The interaction of the ocean and the atmosphere is a key to understanding and ultimately predicting global climate. Our present understanding is that Arctic air-sea-ice processes influence global climate by modifying the surface albedo and the global thermohaline circulation. Both of these globally important aspects of Arctic climate are linked to the sea ice cover and its associated feedbacks. Although the sensitivity of global climate to processes occurring in the Arctic Ocean is widely acknowledged, there is great uncertainty about the magnitude and overall effect. Much of this uncertainty can be traced back to the basic model formulations of the surface heat and mass budgets of the sea ice cover and to the formation, maintenance, and dissipation of arctic clouds.

Intensified research efforts to elucidate the key physical processes and climatic feedbacks occurring in the Arctic climate system are necessitated by

- questions about possible amplification of global change in the Arctic and disagreement between models and observations
- questions concerning the stability of the Arctic ice pack
- the lack of accurate representation of the present-day Arctic climate by GCMs and the variations in Arctic climate predictions between different models the lack of *in situ* data to validate and improve satellite retrievals and general circulation model (GCM) performance in the Arctic.

To improve in our knowledge of Arctic and global climate requires multivariate data sets of two kinds:

1. An accurate climatology, including the monthly mean values and variances, for the major quantities that characterize the Arctic air-sea-ice system: surface air temperature; surface albedo; components of the surface energy balance; thickness and velocity of sea ice; surface radiation and energy balance components; surface winds; vertical structure of atmospheric temperature, humidity and cloud properties; temperature, salinity and depth of the ocean mixed layer; and outgoing longwave radiation and planetary albedo at the top of the atmosphere.
2. Detailed process-oriented data sets that document the simultaneous temporal variations of the coupled atmosphere-sea ice-ocean system on time scales of hours to a year. The process-oriented data sets are needed to formulate, test and implement improved parameterizations for the GCMS and to facilitate the development of a long-term monitoring system using satellites and buoys to improve the climatology.

Important information on the space and time variations of clouds, radiation and the surface energy balance is very sparse in the polar regions because of the paucity of conventional observations, difficulties in satellite remote sensing, and the lack of past field programs to address these issues. Remote sensing from space provides some of the temporal and spatial coverage needed for climate monitoring and, as the time period of continuous observations expands, should become increasingly valuable for detecting climatic trends. However, large discrepancies between surface- and satellite-derived climatologies exist. The lack of *in situ* data is the major obstacle to validating and improving satellite retrievals and GCM parameterization of polar physical processes.

To address these issues, a program, Surface Heat Budget of the Arctic Ocean (SHEBA) that will combine *in situ* observations, satellite remote sensing, analysis and modeling has been proposed.

In the context of global climate change, the consensus is that we are faced with five critical issues in the Arctic:

- documenting, understanding and predicting the sea ice-albedo feedback mechanism, including annual changes in surface albedo and snow/ice ablation and accretion, and the disposition of shortwave radiation in the ice and upper ocean
- documenting, understanding and predicting the Arctic cloud-radiation feedback mechanism, including changes in cloud fraction and vertical distribution, water vapor and cloud water content, cloud particle concentration and size, and cloud phase as atmospheric temperature and chemical composition change
- coupling the ice-albedo and cloud-climate feedbacks to understand the total sensitivity of the Arctic ocean/ atmosphere/sea ice system
- documenting, understanding and predicting the mechanisms that extend the influence of Arctic physical processes to the global climate system, and vice versa.

Within this context, SHEBA adopts two primary goals:

1. Develop, test and implement models of Arctic air-sea-ice processes that demonstrably improve GCM simulations of the present day Arctic climate, including its variability.
2. Improve the interpretation of satellite remote sensing data in the Arctic so that satellites can assist effectively in interpreting the Arctic climate system and provide reliable data for model input, model validation and climate monitoring.

The timeliness of SHEBA is established by

- *GCM assessments.* Recent increases in the number and quality of model simulations of current and doubled $C0_2$ climates highlight both the importance of Arctic processes and the large gaps in our knowledge about them.
- *Access.* The end of the Cold War has resulted in a beneficial exchange of ideas and data between scientists in the Soviet Union and western countries. In particular, areas previously inaccessible to western scientists have now been opened, and new options exist for logistical support in the Arctic Ocean.
- *New technology* to observe clouds and radiation has not yet been applied systematically to the Arctic Ocean. Recent instrumental developments allow ground-based observations of cloud properties and the vertical structure of the atmosphere that were previously possible only by using aircraft.
- *Satellite Sensors.* Upcoming launches and continued operation of satellite-borne active and passive microwave sensors, visible and infrared imagers, and remote sounders will provide unprecedented coverage of key variables, making 1995-2005 the “decade of polar remote sensing.”
- *Computational Capability.* Recent and continuing developments in computer technology make it possible to implement sophisticated formulations of Arctic air-sea-ice processes in global climate models and to perform improved simulations of the role of the Arctic in climate change scenarios.
- *Program Coordination.* Ongoing and proposed efforts could be enhanced through SHEBA. These programs include: NSF Arctic System Science (ARCSS) Ocean-Atmosphere-Ice Interactions (OAII) program; the DOE Atmospheric Radiation Measurement (ARM) program; the NASA Earth Observing System (EOS) initiative and the NASA polar ice and climate program; the Office of Naval Research (ONR) Arctic Program; the Global Ocean-Atmosphere-Land System (GOALS) program; the Arctic Climate System Study (ACSYS) of the World Climate Research Programme (WCRP); the

WCRP Global Energy and Water Experiment (GEWEX), the WCRP International Satellite and Cloud Climatology Program (ISCCP), and the WCRP Climate Variability and Predictability (CLIVAR) program.

To achieve the overall scientific goals of SHEBA, the following specific issues will be addressed in the program:

- Surface Heat and Mass Budget
  - surface fluxes of radiation, sensible and latent heat, and conduction in the heterogeneous ice cover
  - top and bottom surface mass balance, including bare ice, snow, melt ponds, and pressure ridge
  - internal heating, melting, and absorption and transmission of shortwave radiation within the ice
  - evolution of the ice thickness distribution and properties of leads and floes
  - impact of clouds on surface temperature, albedo, and fluxes of radiation, sensible heat, and latent heat.
- Arctic Clouds
  - formation, maintenance, and dissipation processes
  - cloud/atmosphere boundary layer interactions
  - cloud macrophysical and microphysical properties
  - cloud microphysical interactions with atmospheric chemistry
  - cloud radiative properties
  - response of clouds and atmospheric temperature, humidity, and wind to changes in surface state and temperature.
- Upper Ocean Interactions
  - response of upper ocean temperature and salinity to fluxes from sea ice and leads
  - horizontal exchange of heat and salt beneath the ice cover
  - disposition of shortwave radiative energy absorbed by the upper ocean
  - impact of ocean heat flux on ice mass balance.
- Coupled Sensitivity of Ice, Atmosphere, and Ocean
  - Mutual adjustments of the upper ocean, ice cover, and atmosphere to forcing functions and perturbations.

To meet the goals and scientific objectives of SHEBA, we envision the following components: a one-year field program over the Arctic Ocean pack ice, a satellite remote sensing component, and a modeling component.

A unique aspect of the proposed field program is the concurrent measurement of characteristics and physical properties of the atmosphere, sea ice and upper ocean, including the fluxes that occur at the air-ice, ice-ocean, and air-ocean interfaces. We plan to integrate the surface and aircraft measurements with satellite observations and model analyses. In designing the field program, we intend to draw on the experiences and measurement strategies from recent field experiments, including the Lead Experiment (LEADEX), the Atlantic Stratocumulus Transition Experiment (ASTEX), the Tropical Ocean Global Atmosphere (TOGA) Coupled Ocean Atmosphere Response Experiment (COARE), and previous sea ice experiments.

The SHEBA field experiment is a coordinated set of measurements on three different scales:

- a scale of about $(10\ \text{km})^2$, where we will make *in situ* and ground-based remote sensing measurements. This scale corresponds to an advanced very high resolution radiometer (AVHRR) footprint.
- a scale of about $(100\ \text{km})^2$, the scale of GCM grid box, using an aircraft, helicopter and an autonomous underwater vehicle. This scale is similar to the SSM/I footprint and the highest spatial resolution of the ISCCP cloud and radiation analysis.
- the extent of the Arctic Ocean, including surface buoys, satellite sensors, and the synoptic meteorological station network.

A camp on floating sea ice is an essential platform for making *in situ* and ground-based remote sensing measurements over the Arctic Ocean. For reasons of logistics, the southern Beaufort Sea is the most likely candidate. In developing the experimental design, we will emphasize making (nearly) continuous measurements where possible, so that the co-evolution of the coupled atmosphere/sea ice/ocean system can be understood.

In addition to surface *in situ* measurements, we anticipate making extensive use of ground-based remote sensing (passive and active). Recent technology, including millimeter (cloud detecting) radar, lidar, integrated sounding systems, and Fourier transform infrared radiometers, will provide unique time series data on atmospheric and cloud properties. We anticipate the use of one or more research aircraft and a helicopter. A tethered balloon has been suggested for making cloud physical and radiation measurements in boundary layer clouds. If available, a profiling sonar, mounted on a submarine or autonomous underwater vehicle, could provide invaluable areal coverage of ice thickness distribution and lead characteristics. Additional possibilities will be examined.

One of the goals of SHEBA is to provide ground truth for satellite remote sensing in the Arctic so that satellites can assist in the interpretation of the Arctic climate system, as well as provide data for model input and validation and for climate change monitoring purposes. During the field experiment, satellite remote sensing will be integrated with surface and aircraft observations. During SHEBA we will address three broad issues in the context of remote sensing: 1) provide ground truth for satellite retrievals so that their accuracy can be assessed and improved; 2) assess whether we can measure additional geophysical parameters in the Arctic using the current suite of satellite radiometers, particularly using multi-sensor algorithms; and 3) assess the potential utility of instruments that are currently not on satellites.

A long-term goal of SHEBA is to develop enhanced models of polar air-sea-ice interactions and to integrate these models in a fully coupled global atmosphere-ocean climate model than can address the climate processes of the Arctic and their impact on global climate. Toward this goal, a hierarchy of models will be developed and exercised as a part of the SHEBA program. The modeling activities in SHEBA will also contribute to the field experiment itself. Before the main field experiments, modeling will focus on the identification of key gaps in understanding and will assist in the development of the experimental design. For the period of the field experiment, modeling will provide a large-scale context for the field measurements.

We anticipate that SHEBA will be a 5-year program, with the field experiment to begin in April 1997 and continue through August 1998.