Synthesis of Arctic System Science (SASS)
Summary Table: Projects and Investigators

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*Collaborative Projects

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Synthesis of Arctic System Science (SASS)
Project Abstracts

Collaborative Research: A Heat Budget Analysis of the Arctic Climate System

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The Arctic System can be viewed as a set of interconnected and interacting physical, biological and human components. Arguably the most integrating component of the full Arctic system is its climate system. The mean state, variability and change in the climate system exert strong controls on biological processes and human activities. Arctic climate is in turn tightly coupled to the global system. This is an effort towards synthesis of the Arctic climate system that distills the wealth of data assembled though ARCSS and other national and international efforts in a tractable, integrating heat budget framework.

While the Arctic climate system is certainly complex, in its most fundamental sense it has an elegant simplicity. One can consider the system in terms of a polar cap, defined by a hypothetical wall at 70°N, and comprising two columns separated by the surface interface – an atmospheric column extending from the surface to the top of the atmosphere, and an underlying column, extending from the surface down to some depth. Changes in the heat content of the atmospheric column depend on the net flux of energy coming into its sides (the heat flux from lower latitudes), the radiation budget at its top, and net heat transfers through the surface interface. These latter transfers include processes such as sea ice growth and melt, and exchanges of sensible heat. Similarly, the underlying column gains or loses heat via fluxes into its sides and communication with the atmosphere through the surface interface. The observed mean annual cycle, variability and change in the Arctic climate system can be essentially described in terms of these interactions, reflected in familiar climate elements such as the atmospheric circulation, surface, atmospheric and upper-ocean temperatures, snow cover and sea ice conditions. While the above example considers a simple polar cap, the heat budget framework can be applied to understand regional aspects of the climate system.

An advantage of this way of thinking is that it provides a common framework within which data from many sources, including atmospheric reanalyses, runs from coupled ice-ocean, land surface and global climate models, satellite remote sensing, and surface and oceanic observations, can be ingested. Different sources will give different realizations of a given budget term. This spread of realizations represents a measure of uncertainty. This group will compile gridded monthly time series of budget terms for a domain encompassing the Arctic Ocean and terrestrial drainage, emphasizing the data-rich period 1979 to present. Given the limitations of some records (e.g., observed ocean heat transports), they will also develop climatologies for simpler domains. These data sets will be applied in a series of studies, framed around key research questions, to clarify interactions shaping the annual cycles, variability and recent changes in the Arctic climate system. They will also assess consistency between recent changes and projected future states of the system.

Collaborative Research on Sunlight and the Arctic Atmosphere-Ice-Ocean System

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The distinct annual cycle of solar radiation is a defining feature of the Arctic system. The lack of sunlight in winter and the long daylight hours in summer control the seasonal cycle of the surface heat budget, structure both terrestrial and marine ecosystems, drive the seasonal build-up and sequestration of carbon and play a major role in the cycling of major atmospheric constituents. One of the most important aspects of the disposition of solar radiation within the Arctic system is the reflection, absorption and transmission of sunlight by the atmosphere-sea ice-ocean system (AIOS).

The overall goals of this study are to enhance our understanding of the present role that solar radiation plays in the Arctic AIOS and to improve our ability to predict the future role. This will be accomplished through an integrative and synthetic approach. Data will be collected from a wide range of sources including laboratory studies, field experiments, and satellite observations. An error analysis and data gap assessment will be a central component of the synthesis activity. Process models, ice-ocean models, and reanalysis products will be used to fill the gaps in the dataset. The primary product of this synthesis effort will be a 20-year, pan-Arctic description of the interaction of solar radiation with the AIOS. In particular, we will determine spectral values from 250 to 2500 nm of the incident solar energy, the reflected solar energy, and the solar energy absorbed in the snow, sea ice, and upper ocean. Values will be computed on a monthly, pan-Arctic basis from 1987 to 2007 using the 25 x 25 km Equal Area Scalable Earth Grid. The influx of (solar) heat into the Western Arctic through Bering Strait will also be examined in detail, since the largest changes in ice extent and ice thickness have been observed in this sector of the Arctic.

This proposed synthesis of solar radiation in the Arctic AIOS will contribute several key elements to the larger synthesis of the Arctic System including: an assessment of the recent changes in solar energy input to the Arctic Ocean in relation to the observed changes in ice cover and ice mass balance; an evaluation of polar amplification through the ice-albedo feedback; information on the distribution of solar energy available for driving the biological production in the under-ice and upper ocean environments; and insights into the potential changes in and impacts of solar energy distribution as predicted by climate change models.

Collaborative Research: Synthesis of Modes of Ocean-Ice-Atmosphere Covariability in the Arctic System from Multivariate Century-Scale Observations

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The project is an integrated statistical analysis of a comprehensive set of long time series from the Arctic and subpolar North Atlantic. These multivariate records include meteorological and oceanographic measurements, sea ice observations and climate indices. The project data set will comprise: a subset of the multidecadal to century-scale 'Unaami' Data Collection, and a set of relatively unknown, century-scale time series from the subpolar North Atlantic (Nordic Seas, Greenland, Iceland, Faroe Islands and Norway) and Arctic that is new to the US community. These data will be organized and analyzed using a comprehensive set of advanced time–frequency statistical methods including organized temporal and spatial patterns of variability and covariability in the ocean–ice–atmosphere system over the past 50–200 years. The work will focus on modes other than the Arctic / North Atlantic Oscillation (AO/NAO), including the multidecadal low-frequency oscillation. To further understanding of the mechanisms, the synthesis will use new output from multi-century model runs from the first coupled atmosphere–ocean general circulation model (AOGCM) with independent stretched-coordinate systems for the atmosphere and ocean that have been resolution-optimized for the Arctic and subpolar North Atlantic.

Arctic Surface Air Temperatures for the past 100 years: Analysis and Reconstruction of an integrated data set for Arctic System Science

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The Arctic has long been considered a harbinger of global climate change since increases in surface air temperature (SAT) over the globe are amplified in the Arctic. These increases in SAT have a profound impact on many other aspects of Arctic climate and ecology. For example, the thinning and decrease in area of Arctic sea ice has been attributed to increases in SAT, and many plant and animal species have been migrating further north.

In order to better understand these processes, accurate fields of SAT are required, but as of yet, a robust gridded data set of SAT of sufficient length is not available over the entire Arctic, e.g. the trends in SAT over the Arctic from 1954 – 2003 shown in the ACIA (2004) report exhibit a "data void" in SAT over the Arctic Ocean. The data sets that are currently available that provide estimates of SAT over the Arctic Ocean begin in 1979 with the increase in buoy observations and satellite derived surface temperatures. There are also some discrepancies between the *in situ* and satellite derived data sets, e.g. the satellite estimates of trends show cooling over the Arctic during winter where the *in situ* estimates show that temperatures have warmed. This research will produce authoritative SAT data sets, which cover the Arctic Ocean from 1901 – present, which will be used to better understand Arctic climate change. The primary goal of this study is to understand the causes and effects of the interdecadal variability in Arctic SAT on Arctic and global climate.

Collaborative Research: Synthesis of Arctic System Carbon Cycle Research Through Model-Data Fusion Studies Using Atmospheric Inversion and Process-Based Approaches

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A large release of CO_2 and CH_4 from high latitude terrestrial and marine systems to the atmosphere has the potential to affect the climate system in a way that may accelerate global warming. To improve our ability to predict the dynamics of carbon in high latitudes, this team analyze comprehensively the carbon cycle of the arctic system, guided by the following general questions: *What are the geographic patterns of fluxes of CO_2 and CH_4 over the Pan-Arctic region and how is the balance changing over time and What processes control the sources and sinks of CO_2 and CH_4 over the Pan-Arctic region and how do the controls change with time?*

To address these general questions, the group will integrate data on CO_2 and CH_4 dynamics of the Arctic System using a combination of prognostic and inverse approaches and provide an integrative approach to estimating and understanding the exchanges of CO_2 and CH_4 from terrestrial and marine components of the system.

Because the climate system is vulnerable to significant releases of CO_2 and CH_4 from high latitudes, the responses of these gases to climate change have global consequences. This study will bring together diverse regional data sets and understanding in the context of a linked set of numerical model studies. It will examine, and attempt to quantify, the fluxes and links between the terrestrial, atmospheric and oceanic components of the Arctic carbon and methane cycles.

Collaborative Research: Greening of the Arctic - Synthesis and Models to Examine the Effects of Climate, Sea-ice, and Terrain on Circumpolar Vegetation Change

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Changes to the vegetation of the Arctic are intimately linked to changes to the sea-ice cover, land surface temperatures, and a host of terrain variables.

The overarching goals of this research are to (1) explore the sea-ice/terrain/vegetation linkages by synthesizing a group of recently available long-term circumpolar databases, (2) examine how the vegetation of the circumpolar Arctic is responding to global climate change, and (3) use this information in combination with models to help predict future response of arctic vegetation.

The project will address directly the question of how the terrestrial vegetation of the Arctic has responded to climate change to date and how it will respond in the future as portions of the Arctic Ocean become seasonally ice free as indicated by current understanding of trends in sea ice. An average 17% increase in greenness, as measured by the normalized difference vegetation index (NDVI), occurred in northern Alaska from 1981 to 2001, concomitant with strong ice retreat in the Beaufort Sea and rising land-surface temperatures. The trend in NDVI is consistent with observations regarding shrub cover, modeling, and experimental evidence linking temperature increases to biomass increases. The group will synthesize 23+ years of data from Earth orbiting satellites in combination with detailed circumpolar maps of climate, vegetation, terrain, and substrate variables to determine how the ocean and land have interacted during the years of record, and then use this information to improve existing models of Arctic vegetation change. They will use primarily a time series of surface temperature, sea-ice, and NDVI data from the Advanced Very High Resolution Radiometers (AVHRR) aboard the NOAA satellites. A host of other remote sensing data will complement these to extend the length of the record and to look at finer scale changes. The primary region of study is the circumpolar Arctic as defined by the presence of tundra vegetation and an Arctic climate. A larger area defined by the arctic watershed will be studied in less detail. They will create a circumpolar integrated geographic information system for this region. The NDVI patterns will be analyzed spatially and temporally with respect to mapped variables including land-surface temperatures (LSTs), sea-ice patterns, the age of the terrain, substrate, topography, elevation, and regional floras. They will use vegetation change models to determine if the greening detected thus far can be used to project future patterns of vegetation change in the Arctic. A spatial analysis using BIOME4, a global model of vegetation change, will predict changes in the patterns of arctic and boreal plant communities, and ArcVeg, a model of arctic vegetation dynamics, will link the changes detected using remote sensing to ground-based measurements of plant species composition and structure to examine the rates at which changes can be expected.

Collaborative Research: A Synthesis of Rapid Meltwater and Ice Discharge Changes: Large Forcings from the Ice with Impacts on Global Sea Level and North Atlantic Freshwater Budgets

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Freshwater discharge from the Greenland ice sheet has a direct and immediate effect on global sea level, has the potential to impact global climate by perturbing nearby sensitive regions of oceanic deep-water formation, and is an important but as yet poorly quantified part of the pan-Arctic water balance.

The investigators will synthesize a range of extant data sets using numerous methods. Remote sensing and atmospheric modeling calibrated by surface data accurately reveal a spatially resolved history of surface melting on Greenland over decades, and coastal weather stations extend observations to more than a century. Sophisticated transfer techniques, including nonlinear approaches, will be used to downscale from these instrumental data to specific ice-core records of melt, learning how the widespread signal is archived. The derived transfer functions, the centuries-long ice-core records, and the century-length coastal-station records then will allow upscaling to determine meltwater variability over longer times than now available. Remotely sensed changes in ice shelves/tongues and outlet-glacier flow speeds will be combined with the contemporaneous histories of surface melting, and analyzed using diagnostic ice-flow modeling incorporating longitudinal stresses to learn how meltwater variability and ice shelf changes force ice-flow variability. If successful diagnosis is achieved, then the longer melt history from the ice-cores can be used to estimate the ice-flow variability over the same interval; the relations between ice-flow and melt changes also can be used prognostically in assessing future changes in the ice sheet affecting freshwater fluxes.

Collaborative Research: Humans and Hydrology at High Latitudes

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Data for the dynamics, uses and values of freshwater in the Arctic are rapidly accumulating. However, it is currently unknown which regions of the pan-Arctic are most vulnerable to future changes. In order to begin to address the future change to freshwater availability on a pan-arctic scale, this team will use a system of arctic typologies to enable the integration of biophysical data with socio-cultural data produced regionally, such as demographics and water values. They will use mature data sets to study the strategic transformations of the high latitude water cycle.

Recent studies suggest that climate change will have a significant impact on arctic hydrology. Changes in the hydrologic cycle will affect both the presence of surface water and the thermal balance in soil. While preliminary evidence suggests a changing climate will have a significant impact on the hydrologic cycle in arctic regions, very little evidence is available to predict how the quantity of freshwater used by people is likely to change. Even less is understood about how hydrologic changes will affect the sustainability and culture of arctic residents.

The overall objective of this research is to use a wide array of existing data sets in a synthesis effort to describe the vital role of freshwater in the lives of people in the pan-Arctic, how it has changed in the recent past, and how it is likely to change in the future. The group will use a model to predict climate-induced changes in the hydrologic cycle and the resultant water stress on people at these high latitudes. Water-related stress will involve all of the key agents of change: climate change, land use/cover change, and water management by humans. They seek to address water stress in the pan-Arctic by testing hypotheses related to the 1) dominant types of hydrologic change at local, regional and continental scales, 2) the interplay between humans and hydrology over the pan-Arctic, and 3) future prognostication of the high latitude water cycle under changing climate and populations. An important component of this research is an attempt to bridge the gap between large, continental scale processes with those processes acting at local scales.

Heterogeneity and Resilience of Human-Rangifer Systems: A Circumpolar Social-Ecological Synthesis

Award # 0531200

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The Human-*Rangifer* System is defined at the regional scale as the set of ecological-social processes underlying the human use of *Rangifer*. These processes include bio-physical interactions, socio-economic dynamics, the role of social institutions and organizations in shaping human adaptation. Resilience in these systems is the amount of disturbance to individual or multiple components that can be accommodated without change to alternative domains.

The overarching goal of this project is to improve understanding of the relative resilience and adaptability of regional Human-*Rangifer* Systems to forces of global change, and to derive generalized propositions about their functional properties as critical aspects of the Arctic System. This study of resilience goes beyond the regional analyses of Human-*Rangifer* Systems considered in past studies, to address the heterogeneity present in the drivers and responses found across the circumpolar North. This circum-arctic synthesis undertakes a comparative retrospective analysis of six regional case studies in North America and Russia. The project develops a conceptual framework for measuring and assessing resilience in three components of the Human-*Rangifer* System: ecological processes, socio-economic processes, and institutional processes. In addition, simple synthesis models will be developed and simulated to examine resilience in each subcomponent process interactions, as well as in the coupled social-ecological system. This project is the first to provide a comprehensive synthesis of heterogeneity and resilience of Human-*Rangifer* Systems, and the first such project to predict means of accommodating changes in drivers and enhancing resilience of Human-*Rangifer* systems in the circumpolar North.