2

A Strategy for Detecting and Understanding Arctic Hydrological Change: Arctic-CHAMP

We recommend development of a pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) to provide the structure and framework for synthesis studies of the pan-arctic water cycle. Arctic-CHAMP would provide a focal point for cross-disciplinary research that focuses on the linkages between land, atmosphere, ocean, and biota.

The overall structure of Arctic-CHAMP is shown conceptually in Figures 2-1 and 2-2. It consists of three basic, interacting components:

1. compilation and evaluation of monitoring data on the hydrologic cycle,
2. field observations and focused process studies, and
3. simulation models operating over local to regional to pan-arctic domains.

We will focus on the individual contributions of these primary scientific elements but also discuss how they should be integrated for maximum benefit. The execution of Arctic-CHAMP, which requires a consideration of its organizational structure, specific program activities, and links to ongoing NSF, U.S., and international research programs, is detailed in Chapter 6.

Arctic-CHAMP Basic Long-Term Monitoring

We recommend that steps be taken immediately to reconstitute, sustain, and improve upon the basic hydrologic monitoring systems of the Arctic. The long-term observations necessary to understand the consequences of global change on the hydrosphere are currently

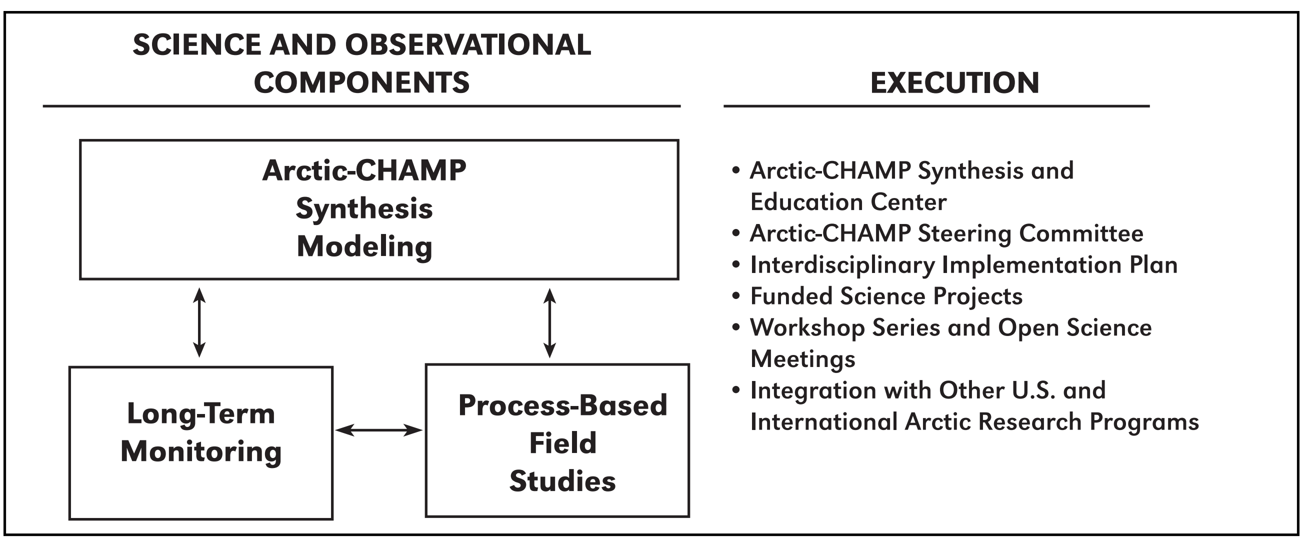


Figure 2-1. Overall framework of the Arctic Community-Wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP). The science and technical goals of the project are considered in Chapter 2. Execution of the program is described in Chapter 6.

unavailable. The Arctic is where we will best be able to measure the early signs of global change. A sustained commitment of resources will be necessary to develop the infrastructure necessary to capitalize on this unique scientific opportunity.

The value of documenting long-term changes in arctic temperature, precipitation, snow cover, sea ice, and storms has been demonstrated (Serreze et al. 2000). These progressive changes are occurring across the very region where general circulation models (GCMs) have predicted the earliest and largest greenhouse warming (Houghton et al. 1996, 2001) and where observed changes are consistent with predicted trends. Unfortunately, at precisely the time we need these records most, the quality and extent of arctic monitoring networks have diminished substantially (IAHS Ad Hoc Group on Global Water Data Sets 2001; Shiklomanov et al. in review) (Box 2-1).

The existing network of hydrometeorological stations devoted to long-term monitoring needs to be aggressively reconstructed and optimized in order to detect and accurately track the unique signature of global change on the Arctic. Consideration needs to be given to deploying instruments for observing the system as a whole. This is a fundamental goal of the new interagency Study of Environmental Arctic Change (SEARCH) Program (SEARCH SSC 2001), which goes well beyond hydrology per se. To support continued availability of hydrologically relevant monitoring data, we recommend the following steps, all of which require a commitment to free and open data exchange (Box 2-2):

1. ***Rescue Data:*** Critical data from past monitoring and measurement programs needs to be identified, recovered, and made available. Support for translation, documentation, accuracy checking, and conversion of paper archives to electronic media is needed. In vast areas of Eurasia, monitoring networks continue to deteriorate and every effort should be made to rescue critical data from these stations. Some of this effort (Holmes et al. 2000, Lammers et al. 2001; cf. National Snow and Ice Data Center) is underway, but much more needs to be done.

2. ***Sustain/Augment Observational Networks:*** Ground-based arctic hydrological and meteorological sites where long-term observations are most valuable need to be identified and steps taken to ensure that measurements will be continued at these sites. Threatened sites can be found not only in Eurasia but in North America as well. For example, atmospheric moisture fluxes determined from numerical weather prediction model reanalyses ultimately depend on the routine rawinsonde network which has been in decline since the early 1990s.

3. ***Improve Autonomous Instrumentation:*** Because much of the Arctic is remote and uninhabited, there is a pressing need for better and more reliable autonomous instrumentation for collecting hydrological and meteorological parameters. Critical improvements are needed in communications, power, and in the measurement of precipitation, notorious for gauge-related bias.

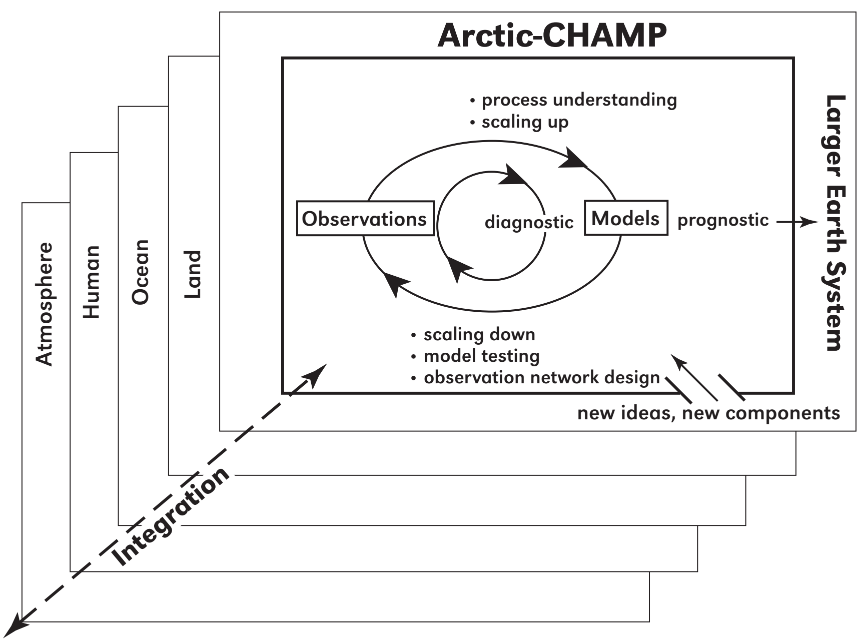


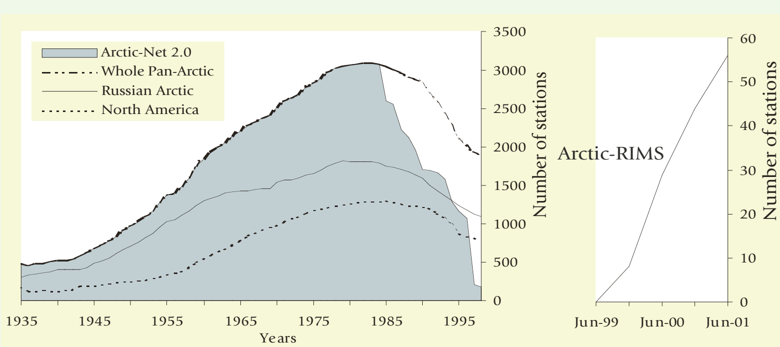
Figure 2-2. Overall conceptual framework of the pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP).

Box 2-1. The Deterioration of Arctic Hydrographic Monitoring Networks

Despite sensitivity of the pan-arctic region to global change and mounting evidence of its response expressed through the arctic water cycle, we see an increasing number of obstacles to the timely and broad distribution of *in situ* monitoring data. Precipitation data are threatened for several reasons. In spite of the universal importance and high value of accurate measurements of rain and snowfall, the number of measurement stations continues to decrease. The data that does exist is not always usable due to gauge undercatch that occurs (particularly for snow) in windy areas (Benson 1982, Goodison et al. 1998, Yang et al. 2000).

The situation has been particularly troublesome with respect to discharge data, which are viewed as a strategic information resource subject to formal and informal data policy restrictions and commercialized for cost-recovery (National Research Council 1999, IAHS Ad Hoc Committee on Global Data Sets 2001). Time series of available pan-arctic discharge monitoring station data sets is shown below (Lammers et al. 2001), and the problem is obvious. In the Russian Arctic, we have seen a 30% decline in operational capacity since 1990. Delays in data reduction and release, in many countries amounting to several years, greatly exacerbate the problem. Large quantities of otherwise reliable data exist in difficult-to-use paper formats, warehoused for years and in grave risk of damage. Canada has seen a 20% reduction in the number of discharge stations since 1990, many in the Arctic (B. Goodison, Environment Canada, Downsview ONT, personal communication, 2000). In Canada there has been a push to establish instrumented monitoring stations that are untended during the winter. Much data such as snow depths are now not collected and other data are compromised by instrument failure during winter. The U.S. also has lost river station time series, including the vital lowermost station on the Yukon River, which fortunately has just been reopened. Accurate water chemistry data over the pan-arctic are even more fragmentary (Holmes et al. 2000).

The situation is in stark contrast to the real-time availability of meteorological and oceanological data for weather forecasting. The mismatch between river discharge and meteorological data availability interferes with the timely identification and interpretation of a changing hydrology of the pan-arctic. A good example is the most recent estimate of present-day freshwater inflow to the Arctic Ocean, based on six-year-old observations (I. Shiklomanov et al. 2000). A temporally harmonized data set for pan-arctic hydrology and meteorology will be essential to the future monitoring of global change in the region.



Time series of station holdings from a pan-arctic hydrographic archive (R-ArcticNet) (Lammers et al. 2001) and an operational data bank (Arctic-RIMS). Both net declines in operating stations (lines) and multiyear delays in data access (unshaded area) are apparent in the panel on the left. Arctic-RIMS represents a concerted effort to obtain timely hydrographic records for a set of key stations (from Shiklomanov et al. in review).

Arctic-CHAMP Field-Based Process Studies

We recommend that a commitment be made toward establishing a core set of pan-arctic watershed study sites where a tightly integrated set of process-based measurements and monitoring can be systematically carried out over a long time frame. An interdisciplinary perspective is central to the success of these field studies.

There is a conspicuous lack of fully coordinated studies of hydrological processes in the Arctic. Decades-long watershed studies like Coweeta, Hubbard Brook, and H. J. Andrews have made major contributions toward our process-based understanding of temperate ecosystems and provide essential calibration and validation data to a wide spectrum of hydrological and hydrological-biogeochemical models. From these sites has emerged critical information on water cycle dynamics, for instance, how precipitation and evapotranspiration interact to regulate runoff throughout the year. Comparable facilities dedicated to integrated analyses of arctic hydrological processes must be established.

To fill current gaps in our process-based knowledge and to improve our capacity to simulate and predict arctic hydrologic and ecosystem change, research at these sites would comprise:

- experiments to uncover hydrologic mechanisms through the conjunction of fieldwork and modeling;
- measurements allowing comparative analyses with other watersheds; and
- research to improve the transferability of site-specific process studies and measurements to unmonitored sites, larger drainage basins, and the entire pan-arctic.

The coordinated set of activities would constitute hydrological as well as biogeochemical and biological measurements, including seldom-made winter observations (Table 2-1). Since permafrost is the single most dominant control on arctic terrestrial hydrological pro-

Box 2-2. Open Data Policy

The success of CHAMP will depend heavily on a policy of free and unrestricted data exchange. In light of the continued loss of hydrometeorological monitoring capacity (Box 2-1) this continues to be of critical importance. The arctic scientific community has only recently compiled an adequate historical archive of data sets that can be combined to detect systematic changes to the arctic system. When this has been done for the issue of change detection (Serreze et al. 2000), it has provided compelling evidence of major warming trends, atmospheric circulation changes, and a host of associated impacts. The NSF Arctic System Science Program has already invested heavily in community-wide databases by supporting the National Snow and Ice Data Center in Boulder, Colorado.

An Arctic-CHAMP Hydrometeorological Data Archive (HDA), representing an integrated community data resource, should be created as part of the overall CHAMP effort. HDA should serve as a repository not only for station-based measurements (such as meteorological and hydrological data) but also for second-generation data (gridded interpolations of point measurements and thematic interpretations of spatially distributed data sets) and model input and output files (such as associated with GCMs or regional climatic models). Each of these data sets should be organized in standard formatting, distributed through the Internet, and accompanied by appropriate metadata to explain the methodology used to create each data product.

Contributions of data to the archive should be an obligation of every scientist who receives funding under NSF ARCSS programs, and in particular Arctic-CHAMP. Charging a fee to use data or limiting access to that data places obstacles in the path of rapid scientific advancement (IAHS Ad Hoc Group on Global Water Data Sets 2001, Kanciruk 1997). Data should be freely distributed to anyone upon request. However, in keeping with the long-standing tradition in the NSF-funded geosciences, an exclusive right to data providers to first complete their analyses and publish those data as appropriate should be granted before release to the general community.

cesses, it is important that the sites span a latitudinal gradient extending southward from the Arctic Ocean into the region of discontinuous permafrost. The sites must also encompass both tundra and boreal forest biomes because there is evidence that these ecosystems are changing rapidly and that the change is intimately linked to hydrology. As shrub invades tundra, or spruce follows shrubs, a variety of hydrologic consequences and feedbacks are operating, all of which impact humans and potentially the global system.

We recommend that a joint NSF working group consisting of researchers from LAII, OAII, HARC, PARCS, SIMS, and LTER be convened to study the costs and benefits of establishing and maintaining an integrated set of well-instrumented small arctic catchments. The group should advise on an optimal set of measurements that would support process understanding, process modeling, and pan-Arctic extrapolation, as well as on-site location to encompass the full range of landscapes typical of the pan-arctic land mass. The group should include observationalists, modelers, and researchers from Canada, Scandinavia, and Russia and international scientific programs so that the choice of sites augments existing networks and is of greatest value to modeling.

Arctic-CHAMP Synthesis Modeling

We recommend that an Arctic-CHAMP Integrated System Model (ARC-ISM) be developed. One way to promote synthesis in arctic hydrology is to integrate existing models and develop a simulation system that can provide a formal mechanism for mass and energy balance accounting, process-level testing, hypothesis generation, and pan-arctic application. ARC-ISM is intended to provide such a mechanism. It also provides a framework for integrating the long-term monitoring and process-based experimental elements of Arctic-CHAMP.

ARC-ISM (Figure 2-3) is an earth system model focused on the Arctic. It should treat in an integrated fashion the Arctic's climate, land surface hydrology, ocean, vegetation, biogeochemical, and human systems. Equally as important, it must be able to quantitatively articulate the pan-arctic's connection to the larger earth system, which will be critical for analyzing feedbacks in response to global change. Retrospective, contemporary, and future time frames need to be analyzed, with ARC-ISM cast as a *diagnostic* as well as *prognostic* modeling tool. ARC-ISM should be considered to be a numerical modeling *framework* serving as a flux coupler to which various component models (land, ocean,

Table 2-1. Examples of the coordinated set of measurements that might be made at an Arctic-CHAMP study site. Efforts should be made to expand the number of sites and the number of variables routinely observed.

Hydrological and Other Geophysical Measurements

- Precipitation Amount (Year Round)
- Evapotranspiration and Sublimation
- Solar Flux and Surface Energy Measurements
- Snow Pack
- Snow Redistribution
- Snow Melt
- Soil Thermal Properties and Their Variation
  - Temperature Profiles
  - Active Layer Depth
  - Permafrost Temperature
  - Thermal Conductivity
- Infiltration on Frozen and Unfrozen Soils
- Soil Moisture
- Runoff Flow Paths
- Stream and Large River Discharge
- High-Resolution and Accurate Digital Elevation Models

Biological and Biogeochemical Measurements

- Precipitation Chemistry
- Vegetation Surveys
- Soil Mapping
- Monitoring of Vegetation, Soil, and Groundwater Chemistry
- Stream and River Constituent Concentration
- Aquatic Ecosystem Surveys
- Isotope and Other Tracers for Discharge Entering Arctic Ocean

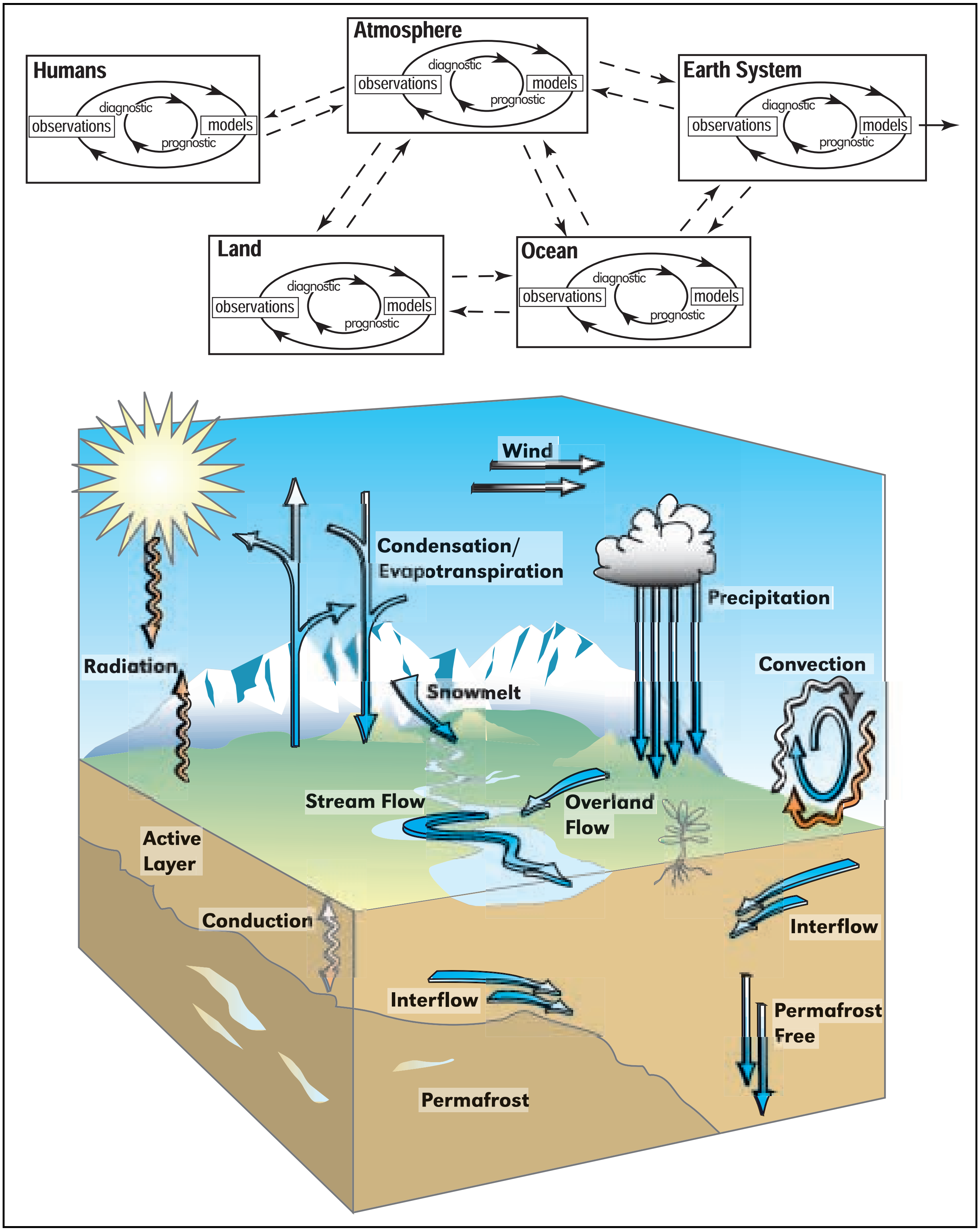


Figure 2-3. Major features of the Arctic-CHAMP Integrated System Model (ARC-ISM) showing (top) the overall conceptual domains of the model and (bottom) the land surface hydrological component in more detail. The land includes vegetation, soils, river corridors, wetlands, and aquatic ecosystems. Carbon, nutrient, and other constituent fluxes will be modeled in tandem with the simulated water cycle dynamics.

atmosphere) could be attached. This would allow for the necessary flexibility to make the overall modeling scheme accessible to the broadest user community. Success will require strict adherence to rules governing module coupling and documentation.

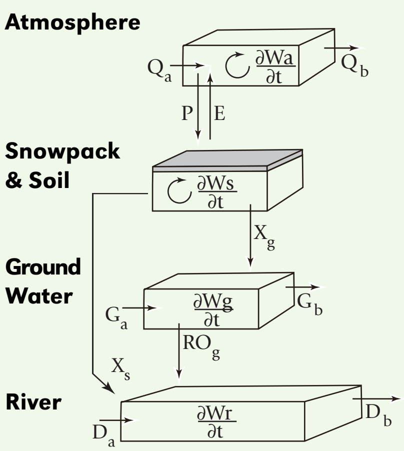
ARC-ISM in diagnostic mode should be used to analyze retrospective and near-real time water cycle dynamics, drawing on experience and techniques developed through state-of-the-art atmospheric modeling. These models include the current generation of General Circulation Models (GCMs) and Regional Climate Models (RCMs). "Reanalysis" efforts by the National Centers for Environmental Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) constitute a promising method for obtaining relevant fields for the pan-Arctic. Atmospheric transports of water vapor provide the fastest and most direct link between the pan-arctic and global climates and are therefore of great value in articulating the coupling of the Arctic to the earth system. Such models provide us with the necessary tools for analyzing this linkage and for quantitatively assessing changes to the pan-arctic water budget. An emphasis on improving the accuracy of such models is clearly warranted (e.g., Gutowski et al. 1997). Data assimilation for all key variables of the hydrologic cycle should also be fostered explicitly.

The diagnostic ARC-ISM can also offer an important resource in the design of optimal monitoring networks for hydrological variables. Precipitation, for example, remains one of the most crucial but difficult-to-estimate hydrologic measurements. Precipitation fields can be obtained through spatial interpolation techniques that produce high-resolution gridded data sets (e.g., Willmott and Rawlins 1999, Willmott and Matsuura 1995, Hutchinson 1998) based on station data, topography and/or existing climate information. The techniques are sensitive to station density, which is in decline over much of the Arctic. The diagnostic version of ARC-ISM could be used in numerical experiments to identify critical stations requiring formal protection and to formulate an optimal deployment strategy for new sites. Identification of the appropriate level of spatial and temporal detail necessary to capture the salient features of hydrological processes—working from the intensive field site models up to the domain of the pan-arctic—would be a major activity of the ARC-ISM modeling group.

An important opportunity presents itself to the arctic research community through a rapidly emerging suite of remote sensing data resources provided by U.S. and international space agencies. Given its pan-Arctic perspective, ARC-ISM could provide an important testbed for satellite sensors specifically targeted at the hydrology of high-latitude landscapes. Its initial use could be in testing data sets in existing remote sensing repositories (Alaska SAR Facility [http://www.asf.alaska edu], National Snow and Ice Data Center [http://nsidc.org]), which have not yet been adequately exploited for hydrological studies (Walsh et al. 2001). One particularly important data set for high-latitude runoff simulation would be an accurate and high-resolution digital elevation model (DEM), which has yet to be collected for the pan-Arctic despite major investments to obtain this information for other parts of the world (i.e., recent NASA Shuttle Radar Topography Mission). Space-borne sensors that show promise in delineating critical seasonal transitions in the arctic hydrologic cycle (McDonald et al. 1999, Running et al. 1999, Frolking et al. 1999, Kimball et al. 2001) could be investigated and rigorously tested in the context of ARC-ISM. It could also be used to create specific new sensor science requirements that could be acted upon in the design phase of these sensors (Cline et al. 1999).

ARC-ISM should also be configured to run in prognostic mode over the pan-Arctic. Current arctic regional climate models incorporate several interacting components of the hydrologic system, including atmosphere, ocean, land surface, and biosphere (e.g., Lynch et al. 2001, Wei et al. in review). These regional climate models operate at much higher spatial resolutions than global climate models, but their boundaries are provided by the coarse-scale GCMs into which they are nested. Such models may eventually provide detailed spatial descriptions of climate change scenarios. The models could thus be used to gauge the impacts of greenhouse warming on plant community structure or altered runoff generation and river discharge to the Arctic Ocean. Some specific applications of the ARC-ISM integrated modeling

Box 2-3. Arctic-CHAMP Framework Application: Atmosphere/Land Surface Hydrology Reanalysis



$$\frac{\partial Wa}{\partial t} = -\nabla\vec{Q} + E - P$$

$$\frac{\partial Ws}{\partial t} = P - E - X_g - X_s$$

$$\frac{\partial Wg}{\partial t} = -\nabla\vec{G} + X - RO_g$$

$$\frac{\partial Wr}{\partial t} = -\nabla\vec{D} + RO_g + X_s$$

Atmosphere

Observations	Processes
Water Vapor	Cloud Micro Physics
Aerosol Profiles	Boundary Layer Processes
Wind Profiles	Moisture Convergence
Temperature Profiles	Modulation/Influence by AO, NAO, ENSO, PNA
Cloud Cover	
Precipitation	
Evaporation	

Land

Observations	Processes
Precipitation	Infiltration
Evaporation	Snow Melt
Snow Cover	Freeze
Soil Moisture	Thaw
Permafrost	Thermokarsting
Discharge	Runoff (X_s + RO_g)

W_a = precipitable water (vertically integrated)
$\nabla\vec{Q}$ = horizontal water vapor flux divergence
E = evaporation + transpiration
P = precipitation
W_s = snowpack/soil water storage
X_g = excess water to groundwater pool
X_s = excess water to river/surface pools
W_g = groundwater storage
$\nabla\vec{G}$ = horizontal groundwater flux divergence
RO_g = runoff from groundwater
W_r = river water storage
$\nabla\vec{D}$ = horizontal discharge divergence
t = time

As the sophistication of atmospheric modeling has increased, it is now possible to begin quantifying a wide array of hydrologically relevant components of the overall climate system—for example, the troposphere, land surface, ocean, and stratosphere. New techniques for assimilating meteorological observations directly into Numerical Weather Prediction (NWP) models fosters the improvement of operational products as well as the reanalysis of long time series of historical archive data. These are important data sets because they provide us with the raw material for analyzing quasi-periodic phenomena such as ENSO, AO, and NAO. Working with U.S. (NCEP) and European (ECMWF) meteorological services, ARC-ISM researchers would be well positioned to develop an optimal land surface model for Arctic NWP. Improved representations of specific processes would include runoff generation at the surface and at depth, storage in the soil in liquid and solid forms, surface sublimation or evapotranspiration, surface storage in the form of snow, river routing, etc. When combined with atmospheric and oceanic models that contain an optimal representation of arctic physical processes (e.g., sea ice, arctic stratus, arctic haze, etc.), a reanalysis designed specifically for arctic hydrology could be realized. Hydrologic predictions constrained by all available observations would be obtained with high time resolution for a period of many years using an appropriate data assimilation scheme. Such a project would have to be a combined effort of the arctic hydrology community and experts in NWP. Improved reanalysis parameterizations have a major additional benefit: the enhancement of near-real-time, operational weather forecasts for the pan-arctic using versions of the same NWP models. An application of the equations shown here can be found in Box 2-4.

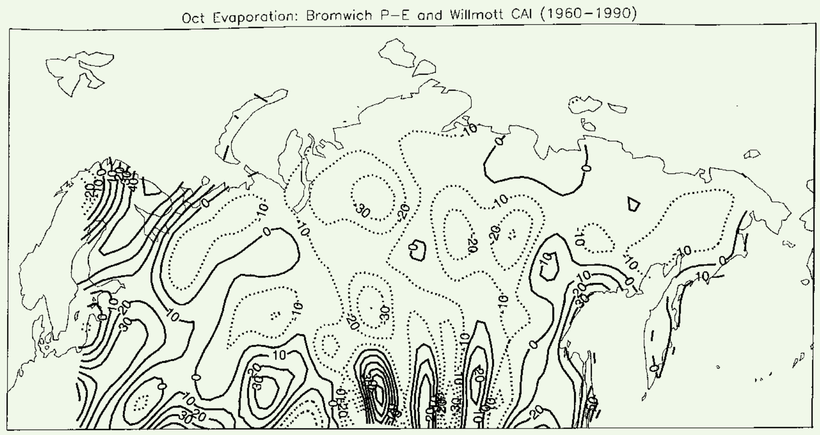
framework are given in Boxes 2-3 through 2-8.

Execution of Arctic-CHAMP

While each element of Arctic-CHAMP is important in its own right, we believe their integration will be the key to significant and rapid progress. To that end, Arctic-CHAMP has been structured to provide facilities and synthesis support activities linking the three components of the initiative—monitoring, process studies, and synthesis modeling. To afford pan-arctic integration, a multiscale approach will be fundamental, incorporating under a single framework broad-scale monitoring network data sets, site-specific hydrologic research, and simulation.

Successful synthesis will not be automatic, and the otherwise independent monitoring, field experimentation, and simulation components of Arctic-CHAMP will require a continual and concerted effort at integration. The management of the program will thus be a key to its success. The overall program goals can be achieved by incorporating guidance from a steering committee, providing support to targeted science and technology projects, entraining promising young investigators, funding expanded monitoring, coordinating with existing arctic research programs, and making a strategic investment in science infrastructure. These programmatic elements are detailed in Chapter 6.

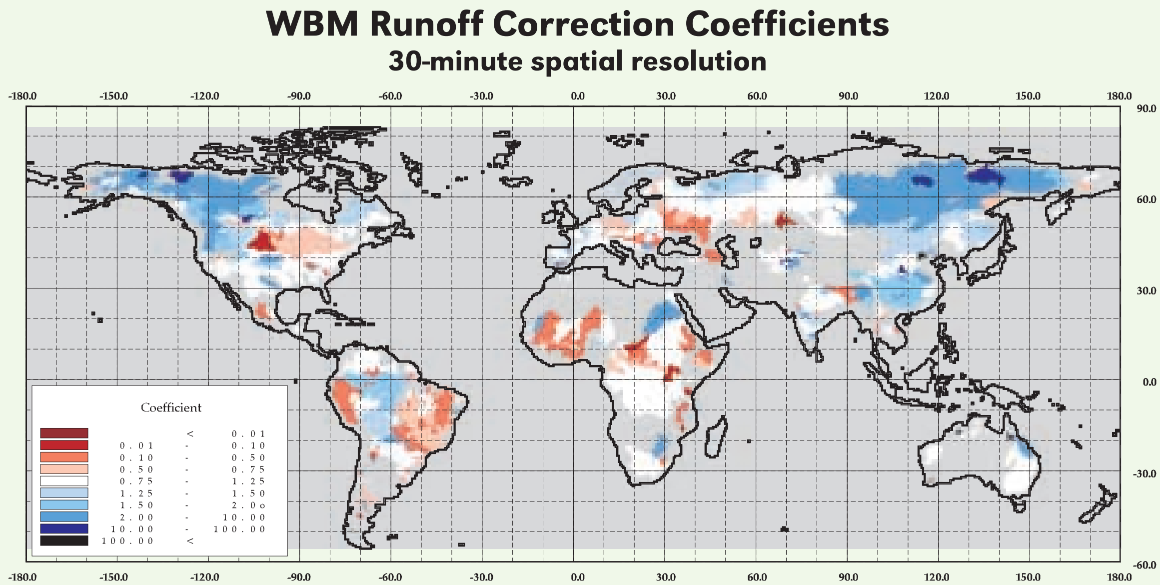
Box 2-4. Arctic-CHAMP Framework Application: Diagnosing the Performance of Model Outputs



Computed evapotranspiration from the combination of aerological budgets from NWP reanalysis and an independent precipitation data set (Willmott and Matsuura 2000). Note the negative values, incongruent with our current understanding of system dynamics. The framework for combining such data sets is at the heart of the ARC-ISM algorithm and Arctic-CHAMP more generally.

In its diagnostic mode, Arctic-CHAMP should be designed to maximize our ability to judge the consistency among individual data sets, both against themselves and observational archives. Thus, Arctic-CHAMP would be a test bed for intercomparison studies using equations of the form shown in Box 2-3. An example would be testing for disparities among several existing precipitation data sets and the translation of these discrepancies into runoff uncertainty. In another example, preliminary assessment by M. Serreze (University of Colorado, Boulder, unpublished data) demonstrates that when NCEP atmospheric divergence fields and station-based, interpolated precipitation fields are blended to generate estimates of spatially varying evapotranspiration, these estimates give wholly unrealistic, large negative evapotranspiration values (see Figure). Ongoing work demonstrates that fields can be somewhat improved by accounting for gauge undercatch of solid precipitation (Serreze et al. in review). Such sensitivity tests allow the community to judge the degree to which observations of individual water cycle elements contribute uncertainty to the overall water budget closure across the pan-Arctic. Identification of such "weak links" is a necessary step in identifying fertile areas for future research.

Box 2-5. Arctic-CHAMP Framework Application: Design of Optimal Monitoring Networks



Potential bias in river basin precipitation as inferred from closure experiments on global water budgets. For much of the arctic drainage basin there are strong negative biases (blue color), which are likely associated with underestimates of regional precipitation (from Fekete et al. 1999).

River discharge is one of the more accurate observations associated with the global hydrological cycle. However, real-time river discharge data has been underutilized within the ocean-atmosphere modeling community due to typical three-to-five-year delays in data posting (GRDC 1996), network closure, and data policy restrictions.

Recent work (Fekete et al. 1999) has demonstrated the capacity to identify possible sources of error in particular elements of the water cycle when judged objectively against the instrumental record. The figure above shows the spatial distribution of potential biases in precipitation when compared against observed discharge and a physically consistent water budget model. It is noteworthy that the Arctic, when analyzed from the standpoint of river discharge records over large river basins, shows sizable underestimation. This corroborates, from an independent perspective, the well-known problems with gauge catch and interpolation bias in both liquid and solid precipitation measurements in such harsh environments (Groisman 1991, Groisman et al. 2001, Willmott and Matsuura 1995).

The experiment shown in the figure indicates that by combining otherwise decoupled data sets and models, we can assess the degree of uncertainty and potential bias (see also Box 2-4). In addition, it lends hope that the synergy embodied in these data sets can yield a mutually consistent picture of water and energy budget closure. ARC-ISM should be used to optimize such an integration of data and model results and could beneficially be applied in the design of future monitoring systems for the pan-arctic system. These should be optimized to retrieve information of direct value to the scientific objectives of Arctic-CHAMP. However, of particular note would be the additional use of ARC-ISM derived products to help improve operational forecast and reanalysis products from weather prediction services. A coherent pan-arctic observational program in support of Arctic-CHAMP thus would provide an important framework for improving our capacity to monitor change over the Arctic and to interpret its impact.

Box 2-6. Remote Sensing Support for Pan-Arctic Synthesis

Comparison of maximum air temperature, interpolated from measurements acquired from 72 meteorological stations in Alaska with freeze/thaw index maps derived from two-day NASA Scatterometer (NSCAT) satellite sensor composite mosaics. NSCAT was extremely sensitive to the presence of unfrozen water on the surface of the snow or ground and is therefore a promising platform for determining hydrologic conditions over wide areas. The bottom four graphs show temporal series of NSCAT backscatter at four locations along a north-south transect extending (1) from Toolik Lake on the north slope of the Brooks Range, (2) to the Dietrich Valley, surrounding Coldfoot, Alaska, near the northern limit of the boreal forest, (3) through the Bonanza Creek Experimental Forest in the central interior, and (4) to Denali National Park in the Alaska Range. Each point on the four graphs represents mean NSCAT backscatter computed over a 50 km region centered at the respective ground location. The broken vertical lines mark the times initiating the two-day NSCAT composite mosaics. Remote sensing will provide critical observational support to Arctic-CHAMP synthesis studies. From the unique vantage point of space, satellite-based sensors constitute an important monitoring asset for constructing comprehensive views of the changing biogeophysical character of the entire pan-arctic domain (see Walsh et al. 2001). Use of such remote sensing data sets will be critical to observational support for pan-arctic synthesis studies as part of Arctic-CHAMP and to afford pan-arctic coverage.

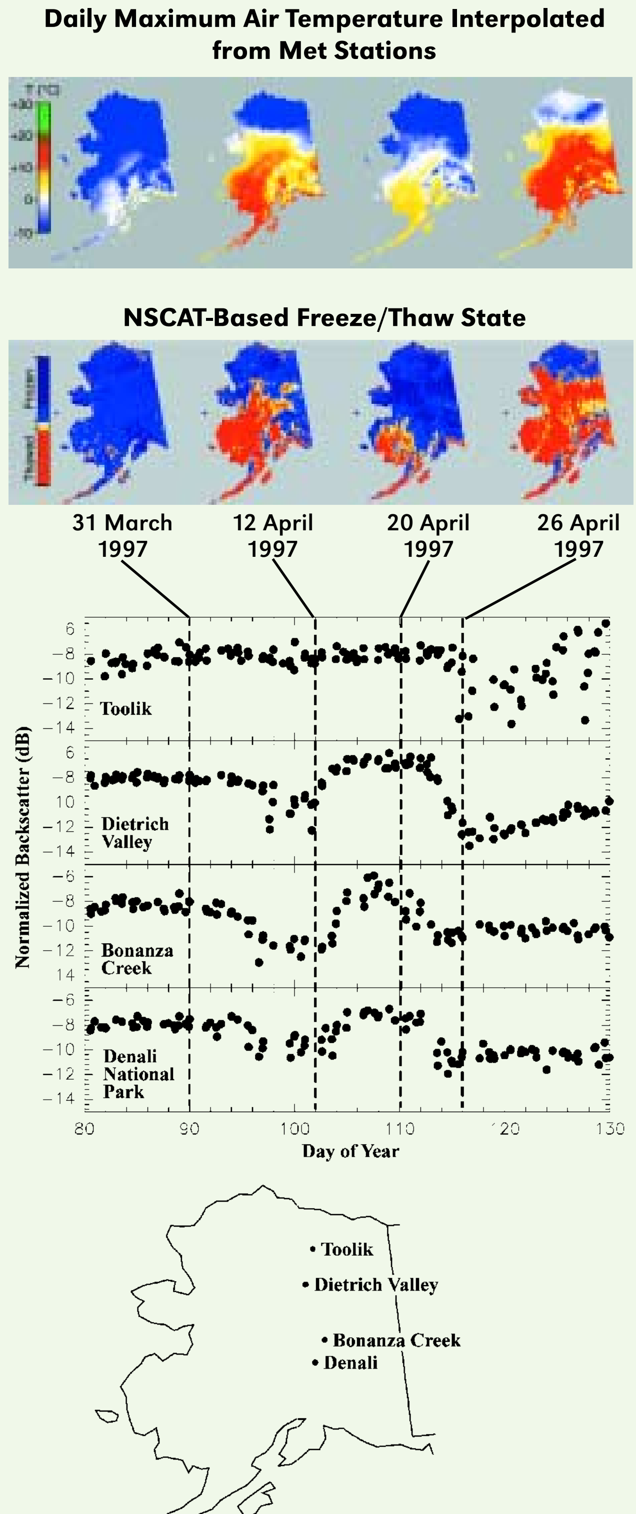
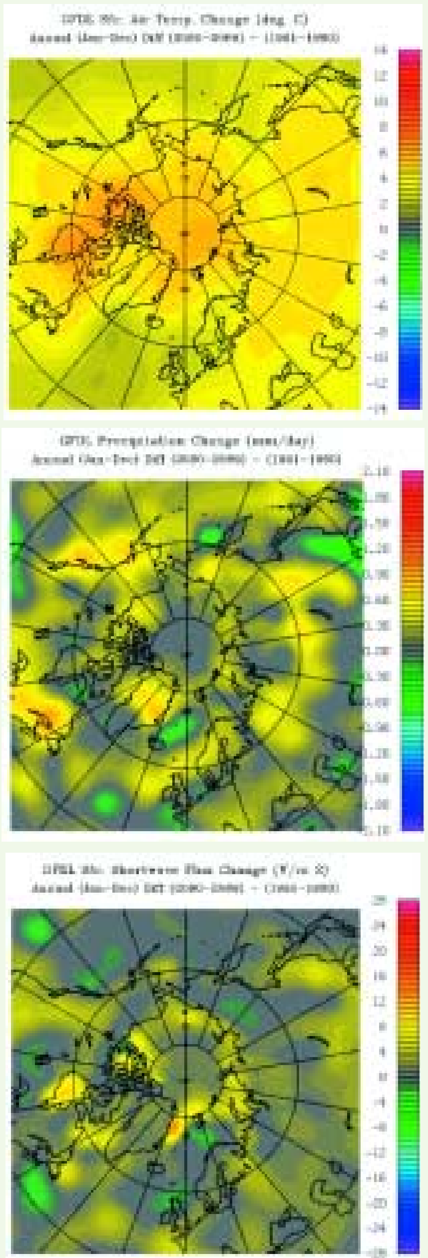


Figure from Running et al. 1999.

Box 2-7. Arctic-CHAMP Framework Application: Prognostic Simulation



The Arctic-CHAMP model can be used in a prognostic mode to produce high-resolution sets of scenarios on the potential future state of the pan-arctic system. The ARC-ISM model could easily be envisioned to represent a regional simulation nested within a larger earth system model, but with higher detail in its physical representation of land surface hydrology, ecosystem and vegetation state, coastal and Arctic Ocean, sea ice, and the dynamic atmosphere. The coupling has several advantages. It permits the full-system behavior to be assessed, as well as any subcomponents that would be the targets of more focused studies, thereby enabling feedbacks to be better elucidated. In addition, through scenario analysis it could be used to test for system sensitivities. And, using results derived from the error analysis developed under the diagnostic mode, ARC-ISM could be used to predict the impact of uncertainties in our understanding of possible future trajectories of environmental change.

Changes in annual mean surface air temperature (top), precipitation (center), and surface solar radiation (bottom) over the 100 years from 1961–1990 to 2061–2090, according to a greenhouse simulation by the GFDL coupled global climate model. Units are degrees C, mm per day, and Watts per square meter, respectively. Yellow and red denote increases; green and blue denote decreases, and gray denotes little or no change (IPCC Data Distribution Center, http://www.dkrz.de/ipcc/ddc/html/dkrzmain.html).

Box 2-8. Arctic-CHAMP Framework Application: Human Dimensions

The interactions between humans and the hydrological cycle in the Arctic are an integral part of the Arctic-CHAMP concept. Humans are responsible for damming rivers, deforestation, and agriculture, which alter the timing, amount, and quality of runoff to the ocean. Conversely, arctic hydrological conditions affect humans inhabiting the Arctic in many other ways (see Table 5-2). Ice and snow affect the everyday lives of arctic residents, including their commercial activities as well as traditional hunting and fishing. Permafrost changes affect the stability of engineering works such as roads, hospitals, schools, houses, pipelines, and industrial structures. Sea ice conditions affect both coastal hunters and commercial shipping along Alaska's arctic and Chukchi coasts, Canada's Northwest Passage, and the Northern Sea Route of Russia.

These issues have a fundamental geophysical underpinning which will be integrated within Arctic-CHAMP. The necessary links to these dynamics must be made by a consortium of physical and biological scientists and socioeconomic experts. Human dimension considerations have sometimes been treated merely as speculative or as anecdotal adjuncts to natural-science research. Arctic-CHAMP could serve as a vehicle for more empirical, observational research aimed at understanding the links between human systems variables and arctic hydrology. Documenting changes observed by indigenous populations would be especially important in this context, owing to the strong dependence of native residents on the arctic environment. Physical science and modeling work will seek to identify aspects of arctic hydrological systems that have varied substantially in the recent past, and/or appear likely to exhibit substantial change in the future. Researchers can then use this information as a starting point to systematically investigate the societal implications, including human responses to the hydrological variations that are already being observed.

A tundra pond was created among the Prudhoe Bay oil fields after a short gravel road was removed. Anthropogenic influences may have direct or indirect impacts on the hydrologic system (photo by L. Hinzman).