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North Slope of Alaska and Adjacent Arctic Ocean Cloud and Radiation Testbed: Science, Siting and Implementation Strategies

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Forward

This is the most recent version of a document that has gone through many versions. The first draft of this document was written in the early 1990s. At the present (August, 2001), it is primarily of historical interest, revealing the thinking that led to the decisions now long since implemented.

Summary

The long-term goal of the Atmospheric Radiation Measurement (ARM) Program is to improve the performance of GCMs (General Circulation Model; also Global Climate Model)—to make them more accurate, and hence, to make their regional climate predictions more useful. This requires that GCMs be developed to the point that they are able to simulate energy flows with a statistical accuracy of better than one percent. The treatment of clouds and their effects on radiative transfer represents the largest uncertainties in current atmospheric GCMs. To improve the treatment of clouds in GCMs, ARM is establishing three primary Cloud and Radiation Testbed (CART) sites throughout the world. The purpose of these sites is to provide suitable facilities for conducting the process-oriented research required to understand the role of clouds in climate, and to use that new knowledge to develop and incorporate accurate mathematical descriptions of cloud behavior into GCMs.

The first CART site is located in the Southern Great Plains (SGP) of the U.S. There, substantial weather-related instrumentation was already in place because of the National Oceanographic and Atmospheric Administration's (NOAAs) role in predicting and monitoring the severe storms that frequently occur in the area. The second site, the Tropical Western Pacific, is located in the equatorial regions where a disproportionate share of the solar energy fueling the atmospheric general circulation is received by the Earth. The North Slope of Alaska (NSA) was chosen for the third CART site, mainly because it represents a locale where radiant energy lost to space greatly exceeds the energy received from the Sun (averaged over the year), and because water occurs primarily in solid form there, fundamentally changing radiative transfer and other cloud-related processes. Because climate depends upon the balance between the incoming energy received from the Sun and the outgoing energy emitted by the Earth over its whole surface, an understanding of the atmospheric processes that determine cloud behavior and the effects of clouds on radiative transfer, at low, mid and high latitudes is necessary. The choice of CART sites reflects this need.

This document describes the most important science issues to be addressed at the NSA and Adjacent Arctic Ocean (AAO) CART site. The science strategies adopted for this site are based on the recognition that fundamentally different atmospheric and surface processes are important in cold regions. Thus, the scientific objectives focus primarily on cold region phenomena, but these phenomena have global implications. Ice clouds frequently occur near the surface in the Arctic, which makes them easily accessible with ground-based platforms: tethered balloons, towers, and low-flying aircraft. On a global scale, ice clouds in the form of cirrus occur high in the atmosphere—another cold region but one not so easily accessible for study with in situ probes. Not just ice clouds, but also cold and dry environments in general are typically experienced near the surface in the Arctic during winter. Globally, such conditions also occur high in the atmosphere, where the planet effectively emits energy to space. Thus, understanding the radiative impact of water vapor under cold and dry conditions becomes a global climate issue of high priority. In addition, highly-reflective snow- and ice-covered surfaces during winter, and highly variable surface reflectance and emissivity during the spring and summer melt season in the Arctic also raise issues associated with modeling the temporal evolution of surface optical properties which are important globally wherever snow cover occurs for some part of the year.

This document also describes the scientific priorities and practical implementation strategies designed to accomplish the scientific objectives in a timely and cost-effective manner. These involve instrument selection, location and maintenance, construction of appropriate facilities, establishment of proper data collection and quality assurance procedures, site operation and scheduling, and operator selection and training. Project management structure is also covered.

Acronyms

AAO	Adjacent Arctic Ocean (to the North Slope of Alaska)
ACSYS	Arctic Climate System (WCRP Program)
ADEOS	Advanced Earth Observing System (Japanese satellite program)
ARM	Atmospheric Radiation Measurement (DOE program)
ARCS	Atmospheric Radiation and Cloud Station
ARCSS	Arctic System Science (NSF program)
ASIC	Arctic Sivunmun Ilisagvik College
BRDF	Bidirectional Reflectance Distribution Function
CAT	Caterpillar - hauled Train
CB	Cloud Behavior
CART	Cloud and Radiation Testbed
CIRES	Cooperative Institute for Research in Environmental Sciences (UCo/NOAA)
CMDL	Climate Monitoring and Diagnostic Laboratory (NOAA)
DEW	Distant Early Warning
DOE	(U.S.) Department of Energy
EA	Environmental Assessment
EOS	Earth Orbiting System (a NASA program)
FIRE	First ISCCP Regional Experiment (NASA Program)
GCM	General Circulation Model; Global Climate Model
IOP	Intensive Observational Period
IPCC	Intergovernmental Panel on Climate Change
IR	Infra Red
IRF	Instantaneous Radiative Flux
ISCCP	International Satellite Cloud Climatology Program
IT	(ARM) Instrument Team
LAII	Land Atmosphere Ice Interaction (NSF/ARCSS sub-program)
MFRSR	Multi-Filter Rotating Shadowband Radiometer
MMWR	Milli Meter Wave Radar
MWR	Micro Wave Radiometer
NAC	Northern Air Cargo
NARL	(former) Naval Arctic Research Lab—for decades, the largest arctic research facility in the world

NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NOAA	National Oceanic and Atmospheric Administration
NPRA	National Petroleum Reserve Alaska
NSA	North Slope of Alaska
NSB	North Slope Borough
NSF	National Science Foundation
NWS	(U.S.) National Weather Service
OAII	Ocean Atmosphere Ice Interaction (Subprogram of NSF ARCSS)
PAARCS	Portable Arctic ARCS
PNNL	(Battelle) Pacific Northwest National Laboratory
QA	Quality Assurance
QC	Quality Control
RASS	Radio-Acoustic Sounding System
SCM	Single Column Model
SGP	Southern Great Plains (CART Site)
SHEBA	Surface Heat Budget of the Arctic Ocean (Subprogram of NSF ARCSS OAII)
SNL/CA	Sandia National Laboratories, Livermore, California
SNL/NM	Sandia National Laboratories, Albuquerque, New Mexico
SOM	Surface Optical Model
SPM	Site Program Manager
SPO	Sheba Program Office
SWG	(SHEBA) Science Working Group
TWP	Tropical Western Pacific (CART Site)
UAF	University of Alaska Fairbanks
UAV	Unmanned Aero Vehicle
UCo	University of Colorado
UI	University of Illinois
UIC	Ukpeagvik Inupiat Corporation
UMd	University of Maryland
USAF	U.S. Air Force
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
UWa	University of Washington
WCRP	World Climate Research Programme

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1.0 Introduction

1.1 Atmospheric Radiation Measurement Program

The U.S. Department of Energy (DOE) initiated the Atmospheric Radiation Measurement (ARM) Program as a major part of the U.S. Global Change Research Program (USGCRP) in 1990 (DOE 1990). ARM focuses on the improvement of climate change predictive capability through development of better means of treating the Earth's radiation budget in GCMs (General Circulation Model; also Global Climate Model), especially with regard to clouds. Clouds and their effects on radiative transfer have been identified as the source of the largest known uncertainties in atmospheric GCMs (IPCC 1990). A major thrust of ARM is the establishment and operation of three primary Cloud and Radiation Testbed (CART) sites, each with a planned life of about ten years.[a] The CART sites will provide the means to acquire the necessary data to test and further develop the mathematical models that relate the characteristics of the atmosphere and the underlying surface with the magnitude and spectral dependence of solar and thermal radiant energy fluxes.

The CART concept, involving process-focused research sites with a projected ten-year life[a] represents a significant departure from traditional climate and weather-related research. Climate and weather research efforts involving specific field data acquisition (as opposed to analysis of standard weather station data) have traditionally fallen into two categories: monitoring, and short-term field studies. The objective of monitoring efforts has been to acquire information on the long-term trends of some important geophysical parameters, for instance, the composition of the atmosphere. Because monitoring efforts have well-defined, limited objectives, they have modest instrumentation requirements. Short-term field studies, typically 3–12 weeks in duration, have focused instead on increasing our understanding of specific phenomena and related geophysical processes, for instance, large-scale storms and related mesoscale convection. The process-focus of ARM greatly increases the number and variety of parameters that must be measured, and hence, the instrumentation and effort requirements. Cost is the main reason such studies have remained short-term.

The ARM Program recognizes that the development of the needed improvements in GCMs requires a much larger process-focused database than can be obtained in short-term field studies. ARM's long-term goal is to facilitate development of GCMs capable of making regional climate change predictions of sufficient accuracy and credibility to be of direct use in policy-making. Because of the small relative size of the changes in energy flows that underlie global climate change, GCMs must be improved to the point where they are able to simulate those energy flows to significantly better than one percent on average (Hansen 1994). This represents approximately an order of magnitude improvement over the current (mid 1990s) situation. It is unlikely that short-term field studies can bring about such dramatic improvement. This level of improvement requires that the statistics of large numbers be brought to bear. In the present context, this implies the acquisition of detailed information on the evolution of large numbers of meteorological situations, which in turn translates directly into long CART Facility life.

(a) The ARM Program was subsequently extended to an anticipated lifetime of 20 years.

ARM does not question the value of short-term field studies. They are exploratory forays. CART sites are climate process observatories. Combining both research strategies at CART sites results in optimum cost-effectiveness.

The currently implemented CART locales are part of a set of such locales put forward by the CART Locale Recommendation Team on the basis of specified selection criteria and extensive study (DOE 1991). The first CART site is located in the Southern Great Plains (SGP) of the U.S., north of Oklahoma City. It began operations in June 1992. The second CART site is in the Tropical Western Pacific (TWP). It began operations in the fall of 1996. The third CART site, the North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO), and began operations in late 1997, and is the subject of this report.

2.0 Motivation for NSA/AAO CART Site

2.1 Scientific

2.1.1 Rationale for a High Latitude/Cold Region CART Site

Although many more specific climate-related issues can and will be discussed, the broad rationale for a high latitude/cold region CART site can be summarized as follows:

- Cold regions strongly influence global climate.

The major drivers for the global ocean currents (thermohaline circulation) are located in high latitude cold regions. Coupled ocean-atmosphere GCM results suggest that the operation of these drivers, which depend upon cold region radiative and other processes, could be seriously affected by the ongoing changes in the composition of the atmosphere (Delworth et al. 1993). Ocean currents are known to have profound climatic influence. The effect of the "Atlantic Conveyor" on the habitability of Northern Europe is a case in point—without the conveyor, Northern Europe would have a climate similar to that of Northern Canada. Changes in the strength and distribution of ocean currents provide a mechanism for global influence of high-latitude climate change, which is strongly influenced by radiative effects such as snow/ice albedo feedback. Although the ocean currents themselves are not within the charter of the ARM Program, the changes in radiative transfer phenomena, which could cause or result from the ocean current changes are.

The ocean thermohaline circulation is not the only way in which high-latitude climate change may affect lower latitudes. The atmosphere itself is involved, both through the advection of heat and water vapor, and through the advection of trace gases. Differential regional warming and/or cooling are expected to modify atmospheric flow patterns. Also, high-latitude warming appears to be responsible for release into the atmosphere of carbon stored in the tundra (Oeschel et al. 1994). If true, this would result in another positive feedback influencing global surface temperatures.

The cold region occurring globally in the upper troposphere and stratosphere also has profound influence on the overall energy balance of the earth, and hence, on global climate.

- Fundamentally different atmospheric and surface physics are important in cold regions.

If geophysical conditions did not differ too much over the entire Earth and throughout the atmosphere, one could conceive of a situation in which one CART site, at some convenient location, would be adequate to achieve ARM objectives. However, such is not the case. In cold regions, the temperature is below freezing most of the time, so ice is the predominant form of condensed water, both in the air (ice clouds, diamond dust and snow) and on the surface. Ice and snow scatter, transmit, and absorb visible and infrared (IR) radiation much differently than liquid water and bare soil.

In addition, in cold regions (in spite of 24-hour-a-day sunlight at high latitudes in summer), the annual average radiative energy absorbed is negative. That is, averaged over an annual cycle, more energy is radiated to space than is absorbed from the sun. This difference causes heat to flow from the warm low latitude regions to the cold high latitude regions. Thus, the cold regions serve as “heat sinks” for the global climate engine.

Furthermore, because of the low temperatures in cold regions, the water vapor mixing ratio in the atmosphere is very low, and that changes the character of radiant heat flows (Stamnes et al. 1996). More specifically, the occurrence of a window in the water vapor rotational band, in the 16–28 μm wavelength region, plays a significant role in radiative cooling in contrast to warm regions which support high water vapor concentrations, where that window is essentially closed. The low temperatures also shift more of the radiant energy distribution (Planck function) into the spectral region of the 16–28 μm window.

The surface energy balance is affected in other ways by the fact that this window is largely open in high latitude cold regions. For instance, computations for an actual winter case at Barrow indicated that as the sky became overcast, 45 percent of the increased energy received by the surface came from the 16-28 μm window region (Stamnes et al. 1998).

The high latitude cold region environment differs from warm regions in many other ways as well. One of these is that strong and persistent surface-based temperature inversions exist much of the year, even in the presence of wind, and this greatly influences the dynamics of the atmosphere.

- Interpretation of satellite remote sensing data to differentiate between high-latitude clouds, snow and sea ice is an important, but poorly solved problem.

Satellite data have proven to be invaluable for global climate monitoring and process studies, but the use of satellite data for high latitude cold regions is impeded by an array of interpretation problems (Key and Barry 1989; Key and Haefliger 1992; Schweiger and Key 1992; Schweiger and Key 1994). Because of the similarity of cloud and snow/ice surface reflectance and temperature, it is difficult to distinguish between low cloud and snow- and/or ice-covered surfaces.

2.1.2 Rationale for an Arctic Rather than an Antarctic Site

The Arctic is largely an ocean surrounded by continents, whereas the Antarctic is a continent covered by thousands of meters of ice, surrounded by the Southern Ocean. This difference makes the Arctic much more sensitive to climate change. In the Arctic, a small warming or cooling brings surface albedo-surface temperature feedback (as well as surface temperature-cloud cover, ice export, and other feedbacks) into play almost immediately. In the Antarctic, it would take thousands of years to melt the ice and produce feedbacks of similar strength. As a result of these feedbacks, current GCMs predict that the Arctic will experience two to three times more warming than mid latitudes. Much less warming is predicted for the Antarctic (Delworth et al. 1993). Paleoclimate proxy data also indicate that small changes in northern high latitude solar insolation invoked by orbital effects are well correlated with global (not just Northern Hemisphere) ice volumes. Thus, the Arctic appears to have a stronger influence on global climate than the Antarctic (Crowley and North 1991; Alley 1995).

2.1.3 Why Specifically the NSA/AAO?

Recent analyses of nearly all available data sets (Walsh 1992; Figure 2.1) indicate that over the last several decades, there is strong evidence for Arctic warming, especially over land areas other than Greenland. Analysis of the former Soviet Central Arctic Ocean ice island meteorological data by Kahl et al. (1993) gives no evidence of surface warming in the Central Arctic ice pack, but rather, perhaps minor cooling The Arctic ice pack results conflict with the predictions of most GCM simulations, and provide additional evidence that high latitude ocean-atmosphere-ice interactions are poorly simulated in GCMs. The discrepancies may be due in part to inadequate vertical resolution near the surface in the atmospheric component of coupled GCMs, but the source of the discrepancy is not well established. In general, high latitude land-ice-ocean-atmosphere interactions are treated quite primitively in GCMs, (Lynch et al. 1995).

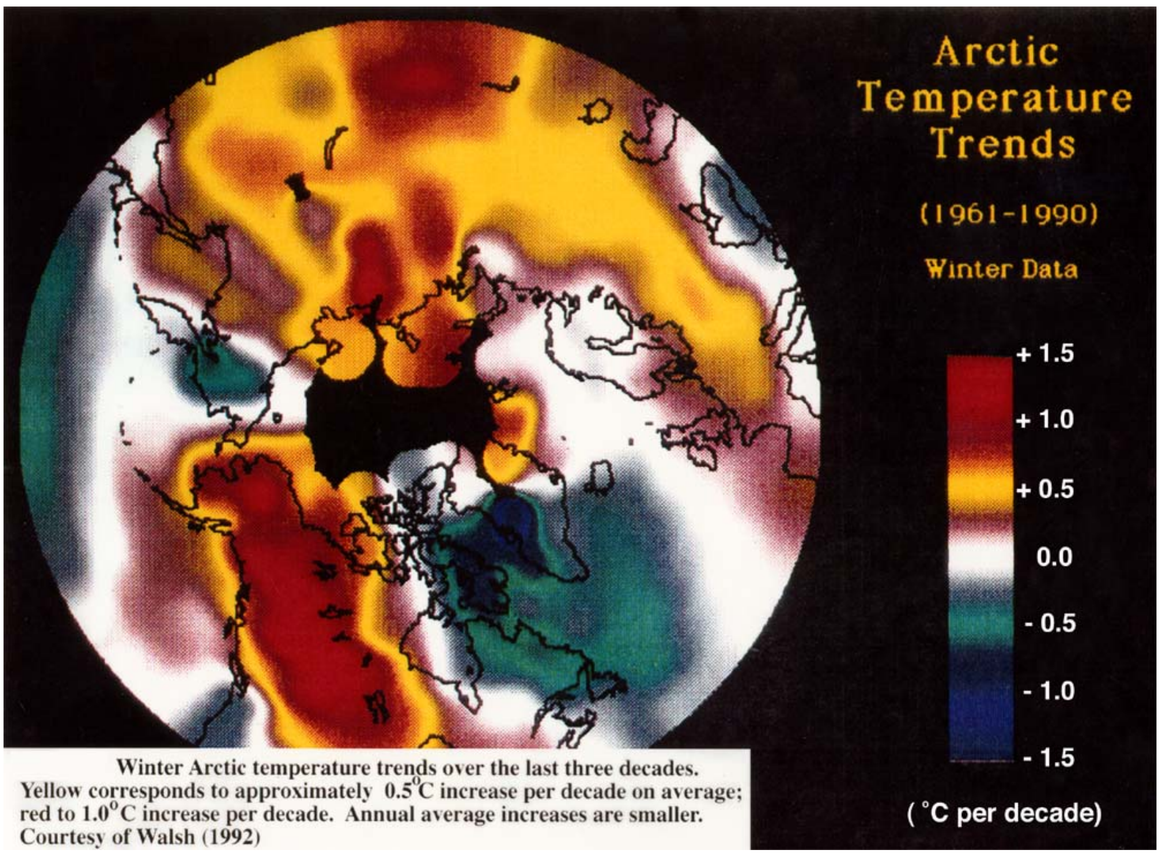


Figure 2.1. Arctic Temperature Trends, 1961 to 1990

In light of these facts, to accomplish the goals of ARM, one must learn more about high latitude cold region climate processes over both land and sea. So if there is to be only one high latitude CART site, an area that straddles an arctic coast is needed. Furthermore, the land area should be relatively flat, to simplify interpretation of experimental results. Among the areas in the Arctic that meet these criteria, the NSA and AAO is the area that permits the most cost-effective scientific operations—where a given number of dollars buys the greatest increase in understanding. The excellent existing infrastructure lowers costs, and collaboration with other U.S. and international agencies make cost sharing and synergism possible. The principal facility for the NSA/AAO CART is near Barrow, Alaska, the farthest north community in the U.S. It is within a few kilometers of Pt. Barrow, the northernmost point of U.S. territory, which extends out into the Arctic Ocean.

2.2 Policy Relevance

The NSA/AAO locale was selected for implementation in response to scientific, budgetary and policy issues, which overlap to a considerable degree. The principle element of policy relevance is that the NSA/AAO CART site supports the improvement of GCM climate change predictions for all regions worldwide, not just the Arctic. However, there are additional elements of policy relevance.

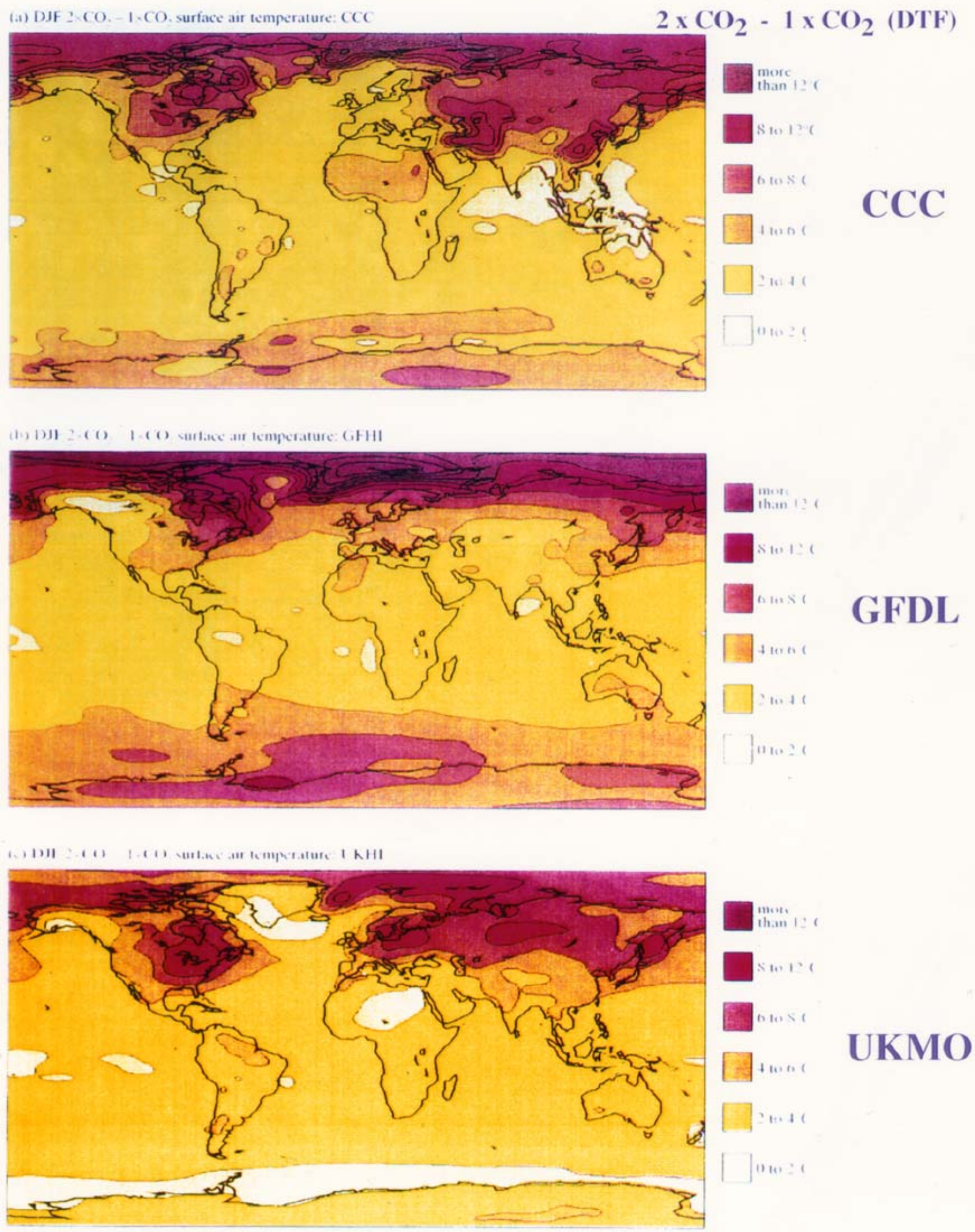
- Amplified Effect of Global Warming on the Alaskan Arctic.

Most global climate models predict that the Arctic as a whole will experience at least twice as great a warming as the mid latitudes (Figure 2.2). These models specifically predict that the Alaskan Arctic will experience amplified warming. Thus, of all U.S. land, the greatest and probably the earliest significant climate changes are expected to occur here. The predicted changes would have major consequences for the economy and for the social fabric of the region. In addition, the accuracy with which these early changes can be predicted will have a strong influence on the policy debate concerning how the U.S. should respond to the challenge of global climate change.

To put predicted climate changes into perspective, we note that the so-called "Little Ice Age," a period marked by worldwide glacial advance which began in the 15th century and which put an end to the pre-Columbian Norse settlement in the New World, represented an average cooling of only about 2–3°C. If the Little Ice Age had not occurred, the history of Europeans in the Americas would likely have been very different. The predicted average global warming is of the same order, but the predicted changes in the Arctic are as much as three times greater.

- Strategic Influence of the Arctic.

The Arctic is a treasure trove of natural resources. The NSA has already produced more oil than any other region of the U.S., and is currently the source of about a quarter of U.S. domestic oil production. The mineral wealth of the Alaskan Arctic precipitated a gold rush over a century ago, and vast deposits of natural gas, coal and other minerals underlie the North Slope. While much of the natural wealth of the Alaskan Arctic has already been located, the cost of exploiting these known deposits in an environmentally acceptable manner has slowed development. Similar situations exist in the Canadian, European, and Russian Arctic, as well. Recognition that the climate of the Arctic is changing, but in a manner and to an extent that is not yet well understood, poses a further barrier to development. The cost, and hence the feasibility, of transportation and extractive technologies, as well as their environmental impacts, depends critically on climate (permafrost annual cycle, presence or absence of ice along water transportation



Predicted increase in winter surface air temperature of a doubling of carbon dioxide concentration for the Canadian Climate Center, the Geophysical Fluid Dynamics Laboratory and the United Kingdom Meteorological Office High Resolution atmospheric GCMs (IPCC, 1990). Yellow corresponds to a 2-4°C increase; red to a 8-12°C increase. Courtesy of J. Walsh.

Figure 2.2. Predicted Changes in Arctic Surface Temperatures

routes, river levels, availability of adequate water supply, etc.). It may be that in this context, the net effect of global warming will be positive, but at the present time, there is inadequate information available to reach firm conclusions. Thus, understanding future climate in the Arctic is important for making economically and environmentally sound national and international natural resource development decisions. In a world of shrinking resources, those decisions are of strategic importance.

3.0 Scientific Objectives

3.1 Primary Focus: Cold Region Phenomena

The primary objective for the NSA/AAO CART Site is the development, improvement and statistical testing of models and model parameterizations for radiative transfer-related processes that are believed to be significantly affected by the cold region environment. Restated, the primary objective of the NSA/AAO is the elucidation of cold region atmospheric and surface processes in such a way that improved mathematical descriptions can be accurately and cost-effectively incorporated into GCMs.

3.1.1 Atmospheric Radiative Transfer

It is widely recognized that the melting of snow and ice cover results in a sharp change in surface albedo, and that this change triggers a whole suite of feedback mechanisms. The initiation and rate of melting is strongly influenced by the presence of clouds. Clouds play a critical role in nearly all cold region near-surface feedback mechanisms as a modulator of the timing and rate of change of surface albedo. In addition, at high latitudes, cloud cover tends to be stratified, nearly continuous and persistent, and hence plays an even larger role in influencing energy transfer than in most other locales. Thus, accurate modeling of radiative energy flows in the presence of clouds is critical.

In order to model radiative energy fluxes accurately, it is necessary to understand the relationships between cloud optical properties and cloud microphysics. In the context of global warming, this requires consideration of questions such as the following: Will a warmer Arctic imply:

(i) Increased or decreased cloudiness?
(ii) higher- or lower-altitude clouds?
(iii) an increase or decrease in column water, liquid or solid?
(iv) bigger or smaller cloud particles?
(v) a change in the appropriate parameterization of the optical properties of ice clouds in terms of particle geometry?
(vi) a change in the annual fraction of clouds that are glaciated (frozen)?
(vii) significant changes in the surface energy balance, and thereby the annual average period during which the surface is covered with ice and snow and therefore exhibits high albedo?

Quantitative answers to these questions should be implicitly contained in the models and model parameterizations that we develop, test and improve using the data collected at the NSA/AAO CART site.

In connection with surface melting in spring and summer, there is a major change in surface water vapor flux, which brings water vapor feedback into play. Since the high latitude atmosphere is quite dry on an absolute basis, even this modest increase in water vapor has proportionately greater effects on radiative transfer and possibly on other processes than at lower latitudes. The increase in humidity also contributes to cloud feedback (Meehl and Washington 1988; Ramanathan et al. 1989). In contrast to stratus clouds at lower latitudes, stratus clouds over the Arctic have a net warming effect at the surface (Tsay et al. 1989). The annual cycle of cloud-radiative forcing indicates warming at all times except for a few weeks in mid-summer (Curry 1992; Curry et al. 1996).

Finally, we note that surface albedo has a pronounced impact on radiative transfer, under both clear and cloudy sky conditions (Barry et al. 1993; Jin et al. 1994). Since the albedo of snow is typically greater than the albedo of cloud, clouds over snow-covered surfaces may actually decrease the fraction of shortwave radiation reflected to space (Tsay et al. 1989), which is just the reverse of their effect over lower albedo surfaces.

3.1.2 Cold Cloud Formation, Evolution, and Dissipation

It is true everywhere that, for climate modeling purposes, modeling of cloud formation, evolution and dissipation processes is just as important as modeling radiative transport through clouds. In cold regions, however, the predominance of ice and mixed phase clouds much of the year considerably complicates the problem of modeling cloud behavior.

Cloud 'particles' (liquid or solid) are formed typically by heterogeneous rather than homogeneous nucleation. Thus, either cloud condensation nuclei (CCN) or ice nuclei (IN) may be more important for cloud formation, depending upon ambient conditions. Related critical questions include the following:

(i) What is the relationship between aerosol particle size/chemical composition and its likelihood of being activated as CCN or IN?
(ii) Given the cloud condensation and ice nuclei spectra (number density activated vs. supersaturation), the available water vapor abundance, the temperature and the rate of change of temperature, what will be the resulting cloud phase (liquid or solid) and particle size spectrum?

Although a large number of CCN spectra have been measured, such measurements were typically made at supersaturations much higher than those found in clouds in the Arctic. In addition, we know very little about ice nucleation anywhere in the real atmosphere.

3.1.3 Behavior of Surface Radiative Characteristics

Depending upon the season, "surface" in the Arctic includes tundra, lakes and ponds (melted or frozen), snow, sea ice (bare or snow-covered, with or without leads), ocean with partial ice coverage, sea ice with melt ponds, and ice-free ocean. In the winter, the land surface is quite homogeneous, being completely covered with snow, although the character of the snow varies spatially (Benson and Sturm 1993). The ocean surface is less homogeneous because of pressure ridges and leads in the sea ice (centimeter to several kilometer-wide cracks that expose ocean water). During melting and freeze-up periods, the surface is heterogeneous on a scale of meters to hundreds of meters, but may look reasonably homogenous on larger scales, as observed from airborne platforms or satellites. Determining the associated radiative parameters and the dependence of those parameters on surface history is a major challenge. The need is to model with accuracy the behavior of high latitude surface characteristics.

3.1.4 Direct and Indirect Aerosol Radiative Effects

The arctic atmosphere is polluted, especially in late winter. The basic reason is that, although the total output from Arctic pollutant sources is modest relative to those at lower latitudes, pollutant removal from the cold Arctic atmosphere by natural processes in winter is very slow. Thus, accumulated pollution leads to significant direct perturbation of the radiation budget (Shaw et al, 1993). As has already been pointed out, aerosol also influences cloud condensation, evolution and evaporation, and hence, cloud optical properties (Twomey 1977; Twomey et al. 1984).

3.1.5 Development and Testing of Satellite Remote Sensing Algorithms

Satellite remote sensing plays a crucial role in understanding energy flows over large areas—even areas the size of CART sites, and in extending what is learned at CART sites to the Earth as a whole. Furthermore, satellite remote sensing depends critically upon an accurate understanding of atmospheric radiative transfer. Hence, improvement of high latitude satellite remote sensing is a relevant and important scientific objective of the NSA/AAO CART site.

Snow- and ice-covered surfaces greatly complicate satellite remote sensing data interpretation. Since clouds, snow and ice all have high albedo, it is particularly difficult to distinguish between them. For sea ice coverage determination, it is also important to be able to make distinctions on the basis of ice thickness, but snow cover over thin ice produces images that are hard to distinguish from snow cover over thick ice. Surface temperature is particularly difficult to measure when there is partial coverage by low-lying clouds whose temperature may not differ too much from that of the surface. These and other high latitude remote sensing data interpretation problems are the subject of very active research efforts in the satellite remote sensing community (Key and Barry 1989; Schweiger and Key 1994). The NSA/AAO CART site will contribute directly to the solution of these problems by providing surface and profile validation data, both over high latitude land and sea. This latter point is important because it is virtually certain that algorithms for interpretation of satellite remote sensing data for high latitude land areas will not work well without modification over high latitude sea, and vice versa. National Aeronautics and Space Administration (NASA) plans to use all of the ARM CART sites as primary remote sensing validation facilities.

3.2 Secondary Focus: Other Climate-Related Phenomena

It has been recognized that the NSA/AAO CART site offers attractive opportunities to study certain phenomena which are believed to be important to the achievement of ARM goals, but which are not limited to cold regions. Of particular interest are phenomena not easily studied at the other CART sites. These phenomena form a secondary focus.

3.2.1 Generic Marine Stratus

On average, marine stratus covers 18 percent of the Earth's surface (DOE 1991). Since it occurs mostly over open water, it greatly increases the albedo of most of the regions of the Earth it covers. The importance of this fact was recognized by the Locale Recommendation Team in recommending that an

Eastern Ocean Margin (Marine Stratus) locale be developed as one of five primary CART sites. Since anticipated resource constraints have limited ARM to only three primary CART sites, it would be helpful to the achievement of ARM objectives if the issues associated with marine stratus were addressed to the extent possible at the NSA/AAO. Clearly, the NSA/AAO is well positioned to focus on marine stratus for part of the year. In summer and fall, when open water is present offshore, marine stratus occurs with great regularity. During the rest of the year, stratus occurs somewhat less frequently but is still common, and varies from fully glaciated to totally unglaciated. Hence, marine stratus over a wide range of temperatures and glaciation conditions is a secondary focus of the NSA/AAO CART.

3.2.2 High Heat and Water Vapor Fluxes

The Locale Recommendation Team felt that the high latent and sensible heat fluxes and their resulting effects on cloud systems in the Gulf Stream merited special study. The Gulf Stream was the fifth recommended primary CART site. While the NSA/AAO does not exhibit such high latent and sensible heat fluxes over the entire region, in winter, leads and polynyas locally do exhibit extraordinarily high fluxes, and these fluxes are of critical importance to the high latitude climate system. Especially in connection with lee polynyas, which occur conveniently close to shore, the NSA/AAO offers an attractive opportunity for studying this phenomenon. Of course, the limited areas over which these fluxes occur in the NSA/AAO locale constrain the extent to which the NSA/AAO CART site can address the issues associated with the originally proposed Gulf Stream site. Thus the NSA/AAO does not routinely give birth to the equivalent of North Atlantic storms. The NSA/AAO CART will address a subset of the high-flux-related issues, specifically as they apply to cold regions, but the results will be more generally applicable.

3.2.3 Transition Zones

Site homogeneity was one of the selection criteria used by the Locale Recommendation Team in choosing candidate CART site locales (DOE 1991). Initially, the high latitude/cold region CART site was envisioned as a land site located entirely on the arctic coastal plain. However, as the necessity of confronting the ARM-related issues associated with sea ice became apparent, it was decided to act on a suggestion of the Locale Recommendation Team and extend the site to include the AAO. During the part of the year that the Arctic Ocean is ice-covered, the coast represents only a modest discontinuity. However, in summer and fall, the discontinuity is dramatic. The presence of the coast provides both a complication and an opportunity. Treatment of discontinuities needs improvement in GCMs. For that reason, the Locale Recommendation Team had also suggested that ARM consider developing a CART site specifically incorporating a discontinuity. A secondary effect of extending the NSA site to include the AAO is to accommodate this recommendation as well. This permits the NSA/AAO CART to be used as a testbed for models that better accommodate discontinuities.

Mountains are another type of discontinuity and involve transition zones as well. Although no mountain ranges are within the NSA/AAO, the Brooks Range is adjacent - some 150 km to the south. Thus, the NSA/AAO is much closer to a substantial mountain range than either of the other two primary CART sites. At some time in the future, it may prove desirable to exploit this proximity.

4.0 NSA/AAO Siting Strategy: Phased Implementation

To begin, we address the most frequently asked question: Why not locate the land component of the NSA/AAO CART site around Prudhoe Bay? The road network that supports the oil fields and pipelines would simplify travel to, from and within the area, and reduce costs. Our answer is that the oil field operations in and around Prudhoe Bay constitute an enormous industrial area. These operations affect the natural environment in many poorly understood ways. The ARM project needs to gain an understanding of the Arctic environment not significantly affected by local industrial operations, so the Prudhoe Bay area is not satisfactory. Even if it were eventually learned that the industrial activities at Prudhoe did not significantly affect the results, the project would have to shoulder the burden of proof, and the results might always be regarded with an extra measure of skepticism.

As to the main topic: because of anticipated resource constraints, development of the NSA/AAO CART site needs to be implemented in a phased manner. The phasing described here seeks to take maximum advantage of opportunities for interagency synergism as well as to make optimum use of work already done for earlier CART sites. It is designed so that each phase is a building block for successive phases, but also so that each phase produces results of independent value.

4.1 Phase I: Radiative Transfer—the Perennial Arctic Ice Pack versus Coastal Environments (SHEBA and Barrow)

We focus initially on radiative transfer rather than cloud behavior, adopting the Instantaneous Radiative Flux (IRF) measurement strategy described elsewhere (Stokes and Schwartz 1994). Although radiative transfer experiments require costly and sophisticated instrumentation, IRF experiments can be done with all instrumentation concentrated at one location. Cloud behavior experiments must take into account the fact that clouds move. To understand how clouds evolve in time, it is necessary to have multiple instrumentation sets spread over a large area. Since the two types of experiments share much of the same instrumentation, more instrumentation sets translates into higher cost. By focusing initially on radiative transfer experiments, one can begin acquiring one class of needed data at a lesser cost while building towards the capability of acquiring the more expensive class of data as well. That is the major thrust of the strategy that has been adopted for the NSA/AAO.

Another element of the strategy recognizes the need to model and measure high latitude/cold region radiative processes accurately over both land and sea, as well as over the transition region in between. The proposal was to acquire radiative transfer experimental data (in which both radiative energy flows and the surface and atmospheric characteristics that influence them are measured) in the coastal environment of Barrow and simultaneously within the perennial Arctic ice pack as part of the Surface HEat Budget of the Arctic Ocean (SHEBA) project.

SHEBA was a year-long field experiment focused on a manned drifting ice station in the Arctic Ocean perennial ice pack (Moritz et al. 1993). That station was centered on a Canadian Coast Guard ice breaker (Des Groseilliers) intentionally frozen into the arctic ice pack during fall, 1997 (Figure 4.1). The

Figure 4.1. Aerial View of SHEBA

SHEBA effort was led by the National Science Foundation as part of its Arctic System Science (ARCSS) program, and by the Office of Naval Research. The SHEBA observational effort emphasized the interactions of the surface radiation balance, the resulting growth and decay of the sea ice, the storage and retrieval of energy and salt in the mixed layer of the ocean, the formation and radiative properties of low level clouds and their interplay with the radiation balance, and the relationships between the atmosphere-ocean-ice system and the data acquired by satellite remote sensors. There was considerable commonality between ARM and SHEBA. With the two efforts being carried out collaboratively, they complemented each other and avoided unnecessary duplication.

An important question that ARM participation in SHEBA addressed is whether the relevant radiative processes and phenomena in the vicinity of Barrow are sufficiently similar to the same processes and phenomena within the central Arctic Ocean (the arctic ice pack) to make Barrow atmospheric and radiative data an adequate surrogate for similar data over the Arctic Ocean. The costs of a significant presence within the central ice pack are such that SHEBA offered the only viable opportunity for such a presence to ARM, and that opportunity was short-lived. When all the data are analyzed, should the question be answered in the affirmative, the long term ARM data from Barrow will be of even greater value than if such were not the case.

Participation in SHEBA also brought with it the benefit of collaboration with First ISCCP Regional Experiment (FIRE); International Satellite Cloud Climatology Project (ISCCP) Phase III (which focuses on Arctic clouds), a NASA-led effort that emphasizes satellite and airborne data.

Of course, SHEBA offered much more than the opportunity to take advantage of logistical support provided by other programs. It also offered the opportunity to exercise ARM radiometric expertise (Figure 4.2) in a situation in which researchers supported by other agencies were measuring the direct results of the radiative energy flows on the sea ice and on the ocean, which in turn influenced the evolution of surface radiative properties, an area critical to ARM. Simultaneously, FIRE researchers

Figure 4.2. Subset of ARM/SHEBA Hardware on Flight Deck of Des Groseilliers

provided much needed in situ airborne data, and both airborne and satellite remote sensing data, which would be very costly to acquire independently. Thus, in a SHEBA-ARM-FIRE collaboration (called SAFIRE by some), each agency contributed its special capabilities and expertise, and each received much more than it contributed.

4.2 Phase II: Radiative Transfer, Coastal versus Inland Environments (Barrow and Atqasuk)

After SHEBA, the Phase II proposal is to move the ARM instrumentation that was part of SHEBA to a site approximately 100 km inland from Barrow, in the vicinity of the village of Atqasuk (Figure 4.3). This proposal has now been implemented. The ARM instrumentation from SHEBA may need to be augmented somewhat to more nearly replicate the instrumentation at Barrow. At SHEBA, some of the data needed by ARM came from instruments operated by researchers supported by other agencies. Based on previous studies (Haugen and Brown 1980) we can anticipate that the inland site will have a signify-cantly more continental character than Barrow (colder and dryer in winter, warmer in summer; less low cloud year-around). The higher probability of conditions in which low clouds are absent favors investiga-tion of radiative transfer through cold dry air, and of comparison of the radiative effects of high altitude cirrus with those of glaciated arctic stratus. Together, Phases I and II will have jointly produced a transect

Figure 4.3. NSA/AAO CART Site Location

of radiometric experimental data from the arctic ice pack, through the coastal transition zone to the inland region. These data should go a long way towards providing the needed understanding of radiative transfer in cold regions everywhere.

The timing of the proposed deployment of the ARM/SHEBA instrumentation to the vicinity of Atqasuk is coordinated with the schedule of the NSFs Land-Atmosphere-Ice Interactions (LAII) Program. LAII is scheduled to begin measurements along a transect from Barrow to Atqasuk and beyond to the foothills of the Brooks Range beginning in summer 1998. The measurements will continue at least till the summer of the year 2000. Trace gas fluxes, snow coverage and depth, water vapor and sensible heat fluxes and some meteorological measurements will be routinely made along this transect. An instrumented ultralight aircraft will be among the measurement platforms used. LAII and ARM will both benefit from the spatial and temporal overlap of the two projects.

4.3 Phase III: Cloud Formation, Evolution, and Dissipation (Extended CART Site)

In phase III, we propose to broaden the focus of the NSA/AAO CART site to include cold region cloud behavior. ARM recognizes that understanding radiative transport through clouds of known location and optical properties is of little value if GCMs cannot accurately predict the formation, evolution, and evaporation of clouds as well as their optical properties as they evolve. Hence ARM generally, and the NSA/AAO specifically, will address cloud temporal and spatial behavior as well through the “single column model” and related measurement strategies (Stokes and Schwartz 1994). Because clouds move while evolving, these strategies necessarily involve an extended CART site: an additional boundary facility is proposed on the east near Oliktok Point, as are several augmented automated weather stations over the triangle formed by the three facility locations. It is an open question if or how severely budgetary constraints will limit cloud formation, evolution and dissipation experiments at the NSA/AAO, but the need for such experiments is undisputed.

5.0 Implementation Strategies

5.1 Implementation Priorities

To achieve the objectives described in this document, the effort is divided into near-term and long-term priorities. These priorities were formulated based on several ARM project and interagency meetings.

5.1.1 Early Priorities

As the result of these meetings, a set of NSA/AAO early priorities and required measurements was formulated: a temporally prioritized set of scientific issues to be addressed at the NSA/AAO site. That set is given below, along with a set of associated required measurements. The required measurements affect the feasibility of addressing these issues in the near term, and the temporal priority assigned here gives weight to both intrinsic importance and near-term feasibility. These priorities are likely to be addressed iteratively as the NSA/AAO CART site measurement capabilities grow. Each new measurement capability opens up new possibilities for model verification and refinement, possibilities, which may fall within more than one priority category.

It should be noted that the required measurements listed are in addition to the gas and aerosol measurements already being made by NOAA/Climate Monitoring and Diagnostics Laboratory (CMDL)[a] within a 100 m or so of the ARM sensors. The required meteorological measurements listed are to be supplied by some combination of new ARM/NSA/AAO measurements, existing NOAA/CMDL measurements, and existing (and perhaps modified) National Weather Service (NWS)/Barrow upper air soundings.

1. *Infrared radiative transfer under cloudless skies for very cold, dry conditions. This issue pertains to both high latitudes and high altitudes (Instantaneous Radiative Flux [IRF] Experiment).*

Measurements:

- Infrared spectral radiances (zenith) at the surface from at least 4–25 µm.

- Broadband infrared upwelling and downwelling hemispherical irradiances at the surface.

(a) CMDL measures all of the usual greenhouse gas concentrations, condensation nuclei concentration, volume scattering coefficient (at 4 wavelengths), volume absorption coefficient (at one wavelength), as well as wind speed and direction, temperature and humidity. For a current complete list of Barrow/CMDL measurements, contact Dan Endres, the NOAA/CMDL Barrow Station Chief at Dendres@CMDL.NOAA.gov.

- Temperature and humidity profiles from the surface to at least 10 km altitude (including surface temperature); vertical resolution under inversion conditions, 10 m 0-50 m, 50 m 50-1000 m; 300 m above 1 km; under non-inversion conditions, 100 m below 1 km, 300 m above 1 km; ±0.5 K; ±5% absolute humidity.

- Optical backscatter vertical profiles and optical depth in the visible to assure that the sky really is clear (no subvisible cloud or diamond dust; minimal aerosol).

2. *Influence of stratus clouds on near UV, visible and near IR (<1 μm) radiative transfer near the surface. Start with liquid water clouds; next go to ice clouds; attack mixed phase clouds last (in order of increasing measurement challenges). This issue pertains to the influence of stratus clouds, and to high altitude ice (cirrus) clouds worldwide (IRF Experiment).*

Measurements:

- Direct and diffuse spectral irradiances at the surface throughout the visible and near infrared.

- Broadband solar upwelling and downwelling hemispherical irradiances at the surface.

- Spectral solar upwelling hemispherical irradiance at the surface.

- Cloud vertical structure from lidar and radar backscatter (perhaps other techniques as well) to include cirrus as well as stratus.

- Cloud liquid water, ice water profiles to 3 km (or top of stratus).

- Cloud particle effective radius profiles to 3 km (or top of stratus).

3. *Influence of stratus clouds on infrared radiative transfer near the surface. Start with liquid water clouds; next go to ice clouds; address mixed phase clouds last. This issue has the same broad applicability as number 2 above (IRF Experiment).*

Measurements:

At least zenith and nadir spectral radiances from 4-25 μm (preferably more downward angles, and coverage to longer wavelengths).

- Solar spectral transmission at the surface from 1–5 μm wavelength.

- Broadband upwelling and downwelling IR hemispherical irradiances at the surface.

- Temperature and humidity profiles from the surface to at least 10 km; vertical resolution, 50 m, surface-1000 m; 300 m above 1 km; ±0.5 K; ±5% absolute humidity.

- Cloud vertical structure from lidar and radar backscatter (perhaps other techniques as well); to include cirrus as well as stratus.

- Cloud liquid water, ice water profiles to 3 km (or top of stratus).

- Cloud particle effective radius profiles to 3 km (or top of stratus).

4. *Solar radiative transfer to the surface under cloudless skies (IRF Experiment).*

Measurements:

- Direct and diffuse spectral radiances at the surface throughout the visible and near infrared.

- Solar spectral transmission at the surface from 1–5 µm wavelength.

- Broadband solar upwelling and downwelling hemispherical irradiances at the surface.

- Spectral solar upwelling hemispherical irradiance at the surface.

- Surface Bidirectional Reflectance Distribution Function (BRDF) and albedo (at local sites selected to span the range of representative surface types; BRDF and albedo need not be measured continuously).

- Local aerosol specific scattering and absorption coefficients (scattering and absorption per unit mass).

5. *Interactions of surface albedo and related optical and physical factors with surface heating (Surface Optical Model [SOM] experiments).*

Measurements (at local sites selected to span the range of representative surface types; slowly-varying parameters like BRDF need not be measured continuously):

- Surface BRDF and albedo.

- Spectral emissivity to cover at least 4–25 µm.

- Determination of forms and profiles of snow, ice, water and temperature within the active layer.

- Determination of vegetation and other relevant surface physical characteristics.

- Precipitation at the surface, for all forms of water.

- Direct and diffuse spectral irradiances at the surface throughout the visible and near infrared.

- Broadband solar upwelling and downwelling hemispherical irradiances at the surface.

- Spectral solar upwelling hemispherical irradiance at the surface.
- Broadband infrared upwelling and downwelling hemispherical irradiances at the surface.
- Surface fluxes of sensible and latent heat.
- Standard surface meteorological parameters.

6. *Local factors affecting the formation and properties of stratus clouds (Cloud Behavior [CB] experiments; horizontal measurement scale, few km; e.g. coastal, open lead, snow cover edge, lake and other discontinuity effects).*

Measurements:

- Broadband solar upwelling and downwelling hemispherical irradiances at the surface (this and subsequent measurements span a several km scale).
- Broadband infrared upwelling and downwelling hemispherical irradiances at the surface.
- Solar and IR optical depth of cloud.
- Surface fluxes of sensible and latent heat.
- Standard surface meteorological parameters.
- Temperature, humidity and wind profiles from the surface to approximately 3 km (or top of stratus); vertical resolution, 50 m; ±0.5 K; ±5% absolute humidity.
- Cloud vertical structure from lidar and radar backscatter (perhaps other techniques as well).
- Cloud liquid water, ice water profiles to 3 km (or top of stratus).
- Cloud particle effective radius profiles to 3 km (or top of stratus).

7. *Stratus cloud formation and evolution processes on GCM grid cell scales Cloud Behavior/Single Column Model [CB/SCM] experiments).*

Measurements (to be made at 3-4 locations separated by 100 km or so):

- Temperature and humidity profiles from the surface to approximately 10 km; vertical resolution under inversion conditions, 50 m 0-300 m; 300 m above; under non-inversion conditions, 100 m below 1 km, 300 m above; ±0.5 K; ±5% absolute humidity.

- Horizontal wind speed and direction from surface to 10 km.
- Cloud vertical structure from lidar and radar backscatter (perhaps other techniques as well).
- Cloud liquid water, ice water profiles to 3 km (or top of stratus).
- Cloud particle effective radius profiles to 3 km (or top of stratus)
- Column precipitable water vapor and liquid water measurements.
- At the 3–4 boundary and selected additional intermediate sites:
  - Surface meteorology
  - Broadband solar and IR upwelling and downwelling hemispherical irradiances at the surface

5.1.2 Longer Term Priorities

The later early priorities blend into the longer-term priorities. Cloud Behavior and CB/SCM experiments mentioned in items 6 and 7 above are at the heart of the longer-term priorities.

It is believed that Single Column Model (SCM) experiments will be in some ways easier at the NSA/AAO than at the other CART sites for a number of reasons:

- During winter, the surface is covered with snow and ice. Thus,

  - surface temperatures are more nearly horizontally uniform
  - surface albedo is more nearly uniform
  - vertical heat, moisture, and aerosol fluxes to and from the surface are more nearly uniform
  - snow machines provide relatively easy access to the entire extended site.
- Horizontal advection may be relatively simple to define because the air sweeping in off the Arctic Ocean appears typically to be fairly homogeneous. This hypothesis is supported by NWS data from Barrow and Barter Island, which indicate that monthly averages of temperature, relative humidity, and water vapor mixing ratio over an extended period of time look very similar at the two sites. Sky cover and inversion depth are also very similar (Kahl 1990). Barter Island is located on the Arctic Ocean shore, about 250 miles east of Barrow. Since the airflow is generally from the east-northeast, these data suggest that the air is reasonably horizontally homogeneous upwind of the NSA/AAO site, at least on a statistical basis.
- Clouds are relatively simple at the NSA/AAO site. They consist mostly of low stratus clouds, (low cloud is the norm), although middle and high clouds frequently occur as well. Therefore, the cloud physical and microphysical properties are more easily measured and modeled.

- Over much of the year, atmospheric stability does not have a strong diurnal cycle. During the polar night, the sun has no influence on the planetary boundary layer; during the summer, when the sun is up 24 hours per day, the influence of the sun is strong, but more nearly constant than elsewhere. The sun never climbs very high in the sky. Thus, flux measurements are more easily parametrized.

- The tropopause height over the NSA/AAO site is low, about 7 km. Thus, there would be little need for high altitude aircraft to measure vertical fluxes above the single column volume, or to deploy dropsondes from above 7 km (23,000 ft).

While these facts make it more probable that SCM experiments succeed at the NSA/AAO, the remoteness of the area imposes somewhat greater logistical challenges than at the SGP CART site, but not nearly so great as at the TWP CART site. As we shall see later, the logistics at the NSA/AAO site are far better than one would imagine.

In the process of carrying out the CB/SCM experiments, it is likely that the ambient aerosol present during each experiment will need to be better characterized than has been the case using the instrumentation formerly in place at NOAA/CMDL. Indeed, NOAA/CMDL Barrow aerosol instrumentation has already been enhanced (with ARM funding) in support of the ARM/NSA/AAO effort. But additional measurements are still expected to be needed eventually:

- Aerosol properties (size distribution and chemical composition), cloud condensation nuclei (CCN) and ice nuclei (IN) concentrations versus supersaturation.

- Cloud droplet and ice crystal concentrations, size distributions and other characteristics.

- Aerosol specific scattering and absorption coefficients (scattering and absorption per unit mass).

To determine the relationship between aerosol properties, CCN and IN, and cloud/fog/diamond dust characteristics, these measurements need to be co-located.

We note that pollution from Prudhoe Bay or Barrow will occasionally intrude into the proposed study volume, but this will be identifiable from ARM and CMDL instrumentation. When such an intrusion occurs, it is both an additional complication and an opportunity to investigate the effects of higher levels of fresh pollutants in the Arctic.

5.2 Instrumentation Locations

There are several considerations for the selection of instrumentation locations. First, the instrumentation needs to be positioned so that it usually measures the environment unperturbed by nearby human activity. In this context, the wind rose is relevant (Figure 5.1). For coastal or near-coastal sites, the closer the site is to the coast, the greater its capability to determine the character of the air incoming from over the Arctic Ocean as a function of time. There are, of course, also regulatory, logistical other practical considerations: compliance issues, ease of access, availability of utilities, and cost among others.

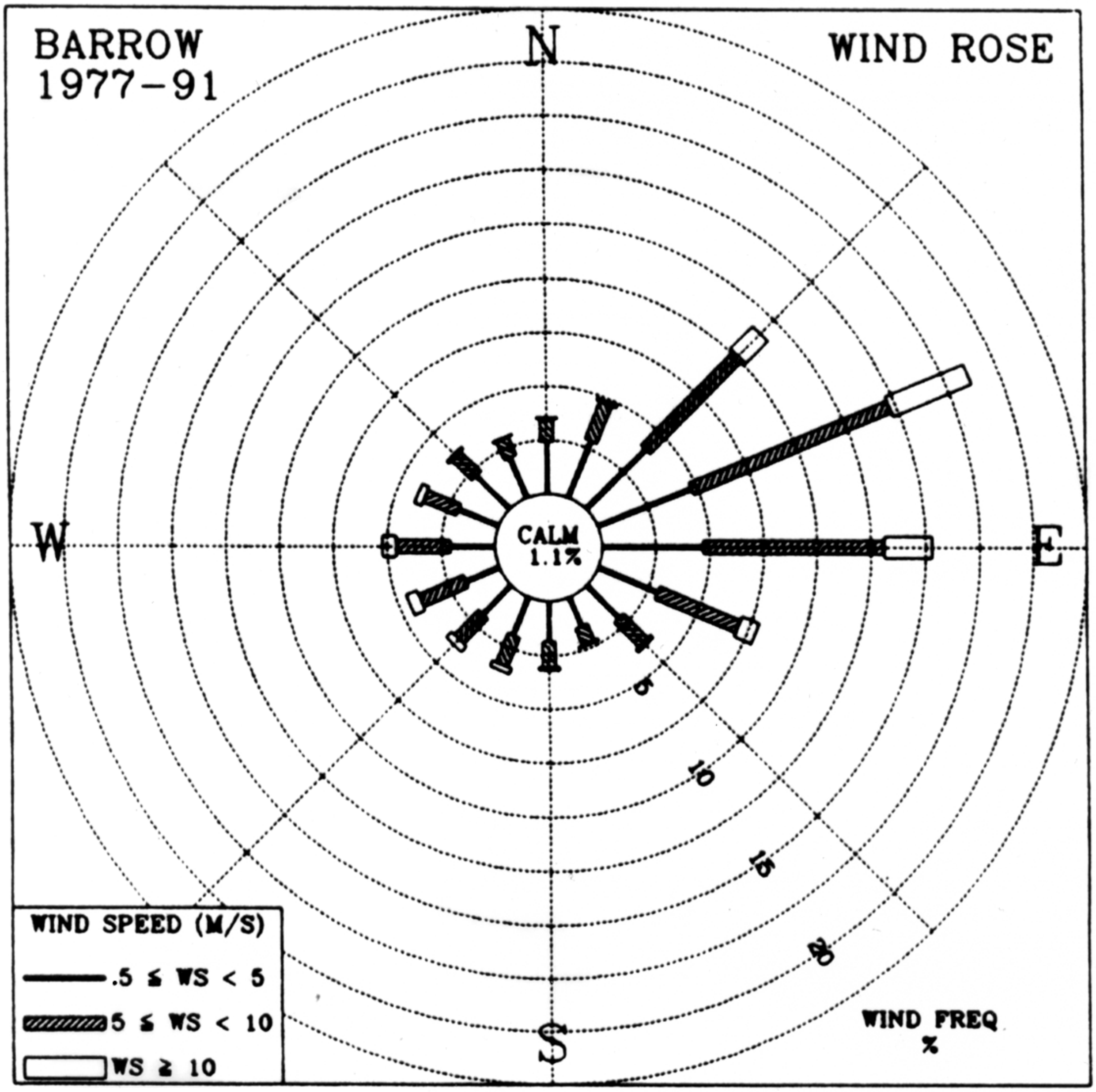


Figure 5.1. Barrow Wind Rose

Figure 5.2 shows the general location of the Barrow NSA/AAO instrumentation site. The instrumentation is on federal land controlled by the NOAA CMDL. The pre-existing structures on this land (Figures 5.3–5.5) house one of four NOAA CMDL global background atmospheric monitoring stations. The other CMDL stations are near the top of Mauna Loa on the big island of Hawaii, in American Samoa, and at the South Pole. The synergism with the NOAA CMDL station is a great plus for the NSA/AAO CART site. The structures on the adjacent USGS land to the west comprise a magnetic

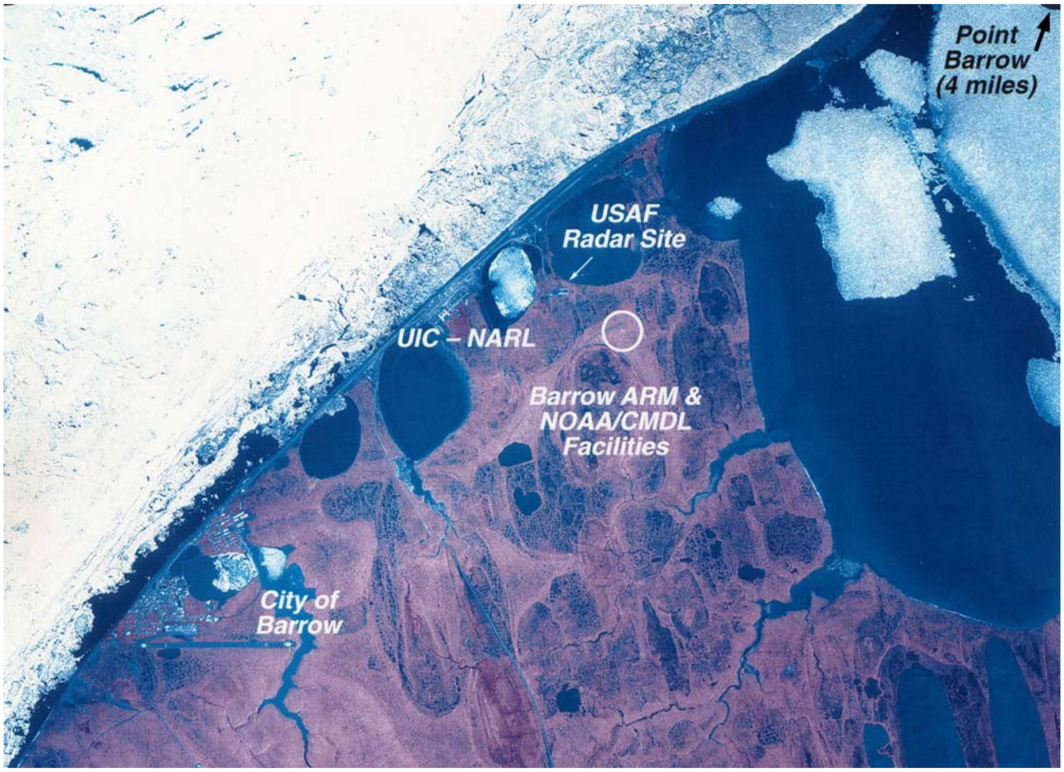


Figure 5.2. Aerial Photo of Barrow Area

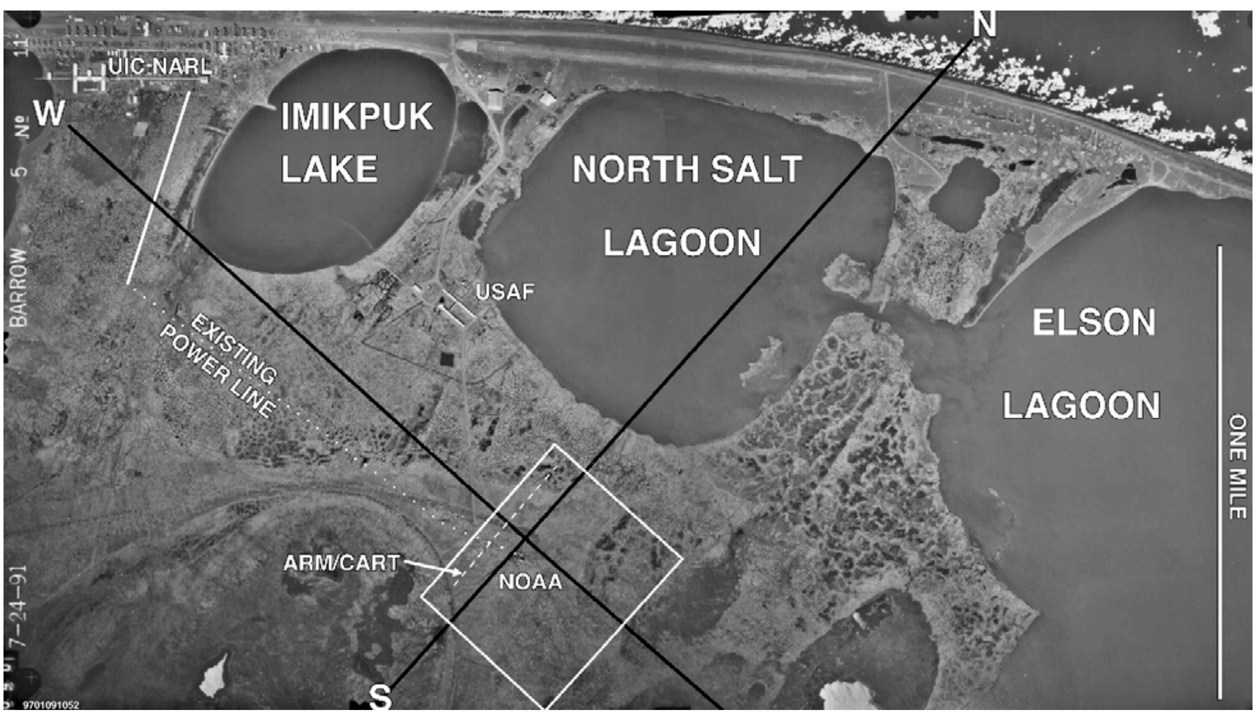


Figure 5.3. NSA/AAO ARM/CART Barrow Facility Location Detail

observatory routinely serviced by the staff of the NOAA CMDL Barrow station. The eleven square mile parcel of land adjacent on the south and east comprises the Barrow Environmental Observatory (BEO), an area protected from development set aside for environmental research. BEO land is owned by Ukpeagvik Inupiat Corporation (UIC), a corporation owned by the native people of Barrow, and is administered by the Barrow Arctic Science Consortium (BASC). BASC facilitates environmental and ecological research at the BEO and elsewhere on the North Slope in part through a cooperative agreement with the National Science Foundation.

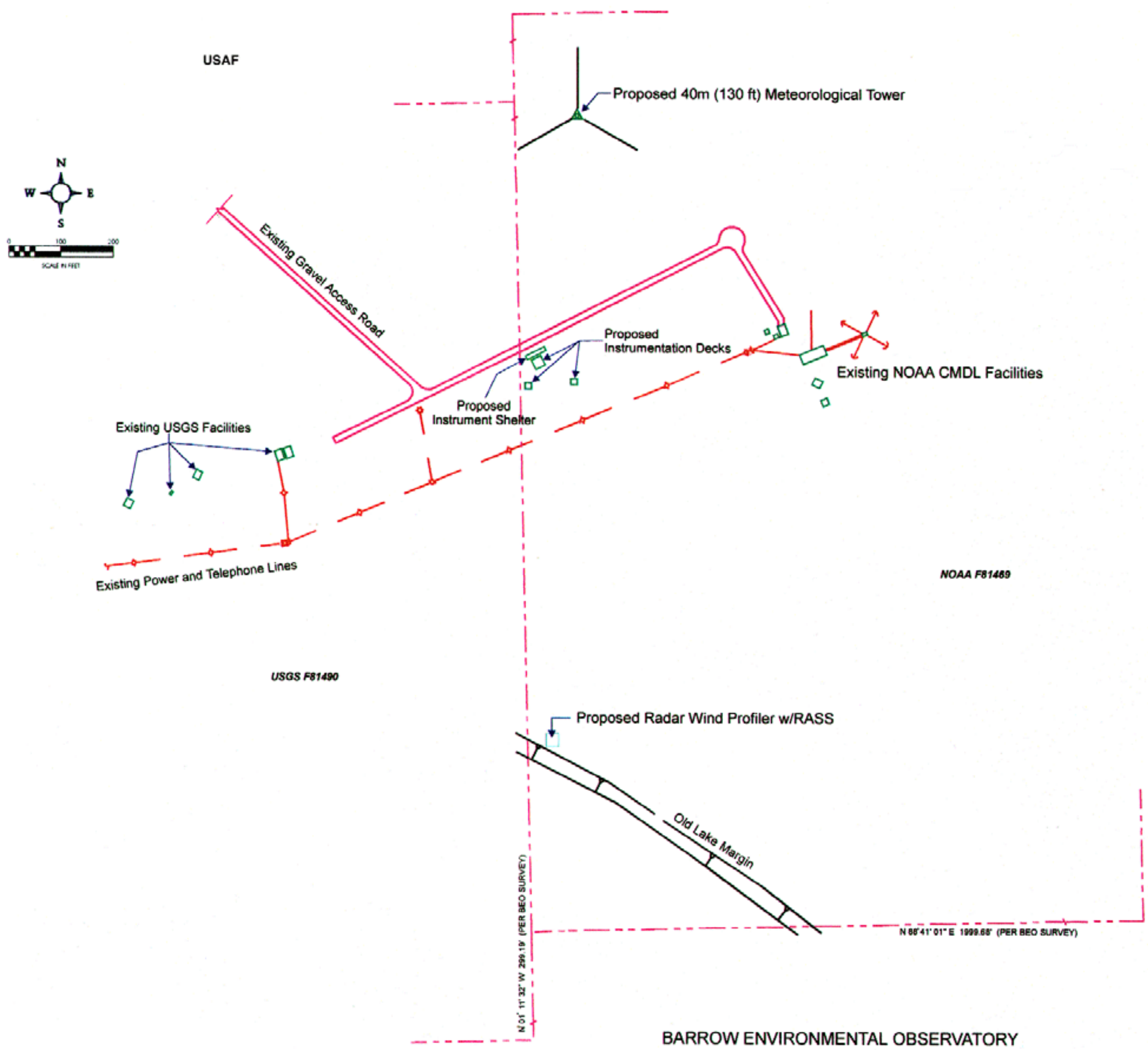


Figure 5.4. Layout of the NSA/AAO Barrow Central Facility

Figure 5.5. NOAA CMDL Barrow Station

Although the ARM instrumentation is located on NOAA land, the necessary office and light laboratory space is leased within the UIC-NARL (UIC -former Naval Arctic Research Laboratory) complex about two kilometers away. From October through May, it was not unusual for the road to CMDL to be closed by blowing snow. Once it was closed, the most practical way to get out to the NOAA land was by snowmobile. Since the main NSA/AAO data acquisition system is located in the UIC-NARL complex, ARM technicians can carry out most of their duties within UIC-NARL, and only go out to the sensor site itself for instrumentation maintenance and service. (In recent years, the road has been improved to the point that now, even in winter, travel to the instrumentation is usually by truck rather than snowmobile).

The NARL and its predecessors operated at what is now the UIC-NARL site from the late 1940s to the early 1980s. After NARL was closed for budgetary reasons, the facilities were transferred to UIC ownership. The NARL facility was of great importance to U.S. Arctic research over several decades, and much useful research data came from the NARL period. UIC-NARL is now continuing that tradition.

The main UIC-NARL building houses the administrative offices of Ilisagvik Community College (an affiliate of the University of Alaska supported by the North Slope Borough), as well as other offices, conference rooms, and a number of research laboratories. It serves as the hub of activity for both resident and visiting researchers. It has central heating, indoor plumbing, and a cafeteria. There is a hardware store and a lumberyard within the UIC-NARL complex. Ilisagvik classrooms and workshops occupy several of the other buildings in the UIC-NARL complex. Since more than 100 people work at UIC-NARL, the road from Barrow to UIC-NARL is very seldom allowed to remain closed for more than a few hours, even under near blizzard conditions. There is even scheduled bus service from Barrow to UIC-NARL.

The facility in the vicinity of Atqasuk (Figure 5.6) does not enjoy the same quality of infrastructure as the Barrow ARM facility. Whereas Barrow, the seat of government for the North Slope Borough, is a town with a population of nearly 4000 and has 737 jet service from Anchorage and Fairbanks, Atqasuk is a village of about 225 residents. It has an airport, power plant, water system, school, health clinic, community center, a couple of grocery stores and two police officers. Atqasuk is served daily from Barrow by three commuter airlines. Fortunately, Atqasuk is also a center for NSF research. NSF has put in place limited housing facilities at Atqasuk, which are now also available to ARM.

The third potential major instrumentation site has been proposed for the vicinity of Oliktok Point (Figure 5.7). Oliktok Point is on the Arctic Ocean to the east of Atqasuk and Barrow. That is desirable for CB/SCM experiments. It is further away than one would like, but the logistical support available there makes it much to be preferred over the alternatives. It is at the extreme western end of the road network that serves the Prudhoe Bay oil field complex. So it can draw upon the excellent logistical facilities available in Deadhorse and Prudhoe. Yet it's location and the wind rose are such that it's seldom downwind of the oil field facilities themselves. An appropriate instrumentation location near the point would effectively be in the arctic marine environment. So even if Barrow should prove not to be an adequate surrogate site for the Arctic Ocean marine environment, there is some probability that Oliktok could still serve that function. Oliktok is the location of an active USAF radar site, and an ARCO/British Petroleum water filtration plant. It is also the only logistically convenient place at the NSA/AAO CART site where the Federal Aviation Administration (FAA) is comfortable with the use of tethered balloons. Both Barrow and Atqasuk are within FAA-defined instrument approach zones. Oliktok is sufficiently far from Deadhorse-Prudhoe Bay and other airports that tethered balloons flown here pose little hazard to air traffic.

5.3 Structures

As part of the TWP CART effort, ARM designed and procured structures which together make up an ARCS: Atmospheric Radiation and Cloud Station (not to be confused with ARCSS - the National Science Foundation's Arctic System Science program). The ARCS is based on an 8'×8'×20' customized shipping container. This generic approach has been used by NOAA for several year for sheltering instrumentation in remote locations with good success. One of its virtues is that it makes shipping very straightforward. The shelter is also the shipping container for the instrumentation.

Figure 5.6. Aerial View of Atqasuk

The ARCS container designed for the TWP has been extensively modified for application to the NSA/AAO, while preserving the basic concept. This new version is called the Portable Arctic ARCS (PAARCS). The modified design will serve ARM needs at SHEBA, Barrow, and elsewhere at the NSA/AAO site. It is fabricated from 4’×8’ insulated panels and can be assembled and disassembled as needed to accommodate shipping size and weight limitations.

For the NSA/AAO land locations, structures (Figures 5.8, and 5.9) will be mounted on pilings rather than gravel pads (except perhaps for the most part where gravel pads already exist). Pilings and gravel pads are the two principal options for construction on the permafrost that underlies the entire North Slope of Alaska to an approximate depth of 300 m. Dependence on pilings rather than pads avoids certain potential environmental pitfalls and wetlands permitting requirements.

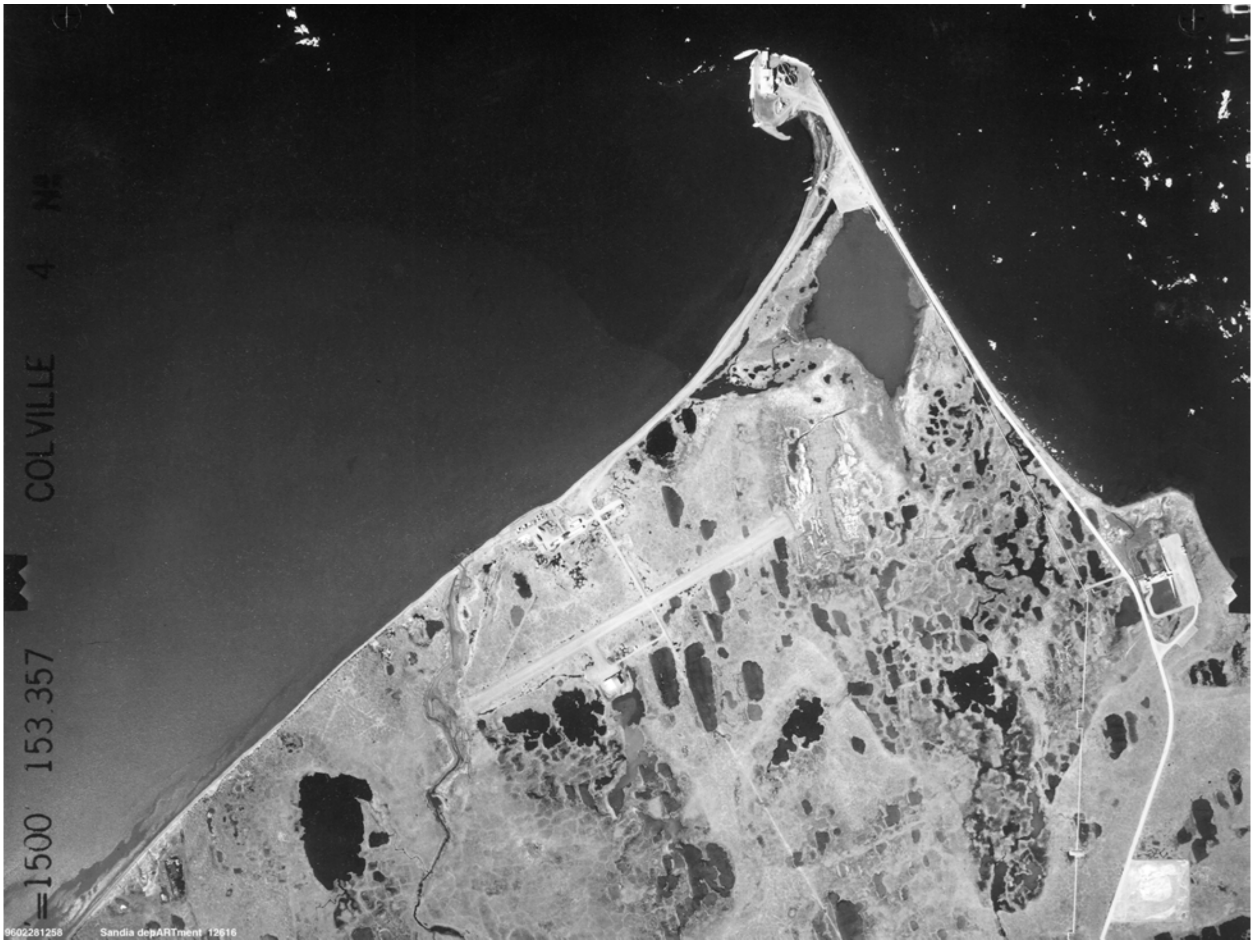


Figure 5.7. Aerial View of Oliktok Point

5.4 Instrumentation Selection

The initial selection of the instrumentation that was installed at the NSA/AAO CART site resulted from a negotiation between the scientists funded to carry out research there and members of the ARM infrastructure, including the NSA/AAO Site Scientist (Stamnes), the ARM Instrument Team, the ARM Program Office, the NSA/AAO Site Manager (Zak), and the DOE ARM Program Managers (Ferrell, and earlier, Lunn), and was made with additional input from the NSA/AAO Advisory Panel. The selection is based on the requirements of the experiments to be performed, technical feasibility, and budgetary constraints. A list of the initial instrumentation already deployed and which will be deployed in the near term is given in Table 1. This list addresses primarily the needs of instantaneous radiative flux experiments.

Figure 5.8. Aerial View of PAARCS and Instrument Platforms (W/O Instrumentation)

Comparison of the measurement needs given in Section 5.1 with the capabilities of the instruments in Table 1 reveals that there are some as yet unresolved measurement issues. A few are pointed out here. Cloud liquid water and ice water profiles are called for. Liquid water profiles are obtainable from in situ probes on instrumented aircraft, but instrumented aircraft will only occasionally be available. There is a prospect of obtaining similar profile data under some conditions from a combination of remote sensing measurements, including the millimeter wave doppler cloud radar, but the technique is still under development. Ice water profiles are even more difficult to obtain. Few instrumented aircraft are equipped to make this measurement even in fully glaciated clouds, and there are no accepted in situ techniques for mixed phase clouds. Remote sensing is less well developed for ice water profiles. In both cases, however, the approach adopted is to use instrumented aircraft to assist in the development of the remote sensing measurement techniques, and if the approach is successful, to infer these profiles subsequently from the remote sensing results.

Figure 5.9. PAARCS During Recent Installation of jER-AERI

Temperature and humidity profiles are also called for. Routine NWS radiosonde soundings provide these data, but at low temperatures, not with the specified accuracy for humidity. The soundings are also only routinely taken twice a day. A number of approaches are being pursued on this front. We are working with the NWS to see if their radiosonde hardware at Barrow can be upgraded or augmented, and to determine if, on request, more frequent soundings can be taken. In addition, ground based in situ and remote sensing systems at the sensor site have been installed that will help with the first several hundred meters of the atmosphere.

Finally, the influence of the arctic environment on the performance of all instrumentation not specifically developed and/or hardened for arctic application has been found to be strongly negative. Low temperatures (to - 50°C) and hoarfrost on optical instrumentation (Figure 5.10) are the major difficulties. To the extent possible, instrumentation is being sheltered in such a way as to protect it from the cold. In addition, provisions have been added to several instruments for ventilation and modest heating to prevent frost accumulation. The strategy here has been threefold. First, prior to SHEBA, the NSA/AAO Site Scientist (Stamnes) deployed selected ARM instrumentation at Fairbanks to gain experience with the problems likely to be encountered at the NSA/AAO, and to develop solutions. Second, most of the ARM/SHEBA hardware was deployed for a cold test at Barrow during February to April 1997. Additional problems were identified and potential solutions implemented during the cold test. Third, subsequent to the deployment of the ARM/SHEBA hardware, yet more problems were encountered and fixes implemented. The process of ameliorating and/or eliminating instrumentation problems is intrinsically iterative with each iteration moving one asymptotically closer to the desired data quality.

Table 5.1. NSA/AAO Near Term Instrumentation

	SHEBA	Barrow
Surface Meteorological Sensors		
Wind Speed, Wind Direction, Temperature, Humidity (1 level)	SPO	NOAA/CMDL
(2m, 10, 25m, 40m)	No	Yes
Dew Point/Frost Point Hygrometer (1 level fixed)	SPO	NOAA/CMDL
(1 level moveable)	No	Soon
Optical Precipitation Gauge	No	Soon
Standard Precipitation Gauge	NOAA	NOAA/CMDL
Wind, Temperature and Humidity Sounding Systems		
Microwave Radiometer (MWR) – column liquid water and vapor	Yes	Yes
915 MHz Wind Profiler w/RASS (WS, WD, T profiler)	No	Soon
Millimeter Wave Temperature Profiler (MMTP- to 600 m)	Yes	Soon
Radiosondes	SPO	W/NWS
Raman Lidar (water vapor, T profiles)	No	Maybe?
Cloud Observation Instruments		
Millimeter Wave Cloud Radar	NOAA	Yes
Micropulse Lidar (MPL)	NOAA	Yes
Vaisala Ceilometer (VCEIL)	Yes	Yes
Whole Sky Imager	Yes	Soon
Downwelling Radiation		
Extended Range Atmospheric Emitted Radiance Interferometer (ER-AERI, 4-26 microns)	Yes	Yes
Solar Spectral Flux Radiometer (SSFR)	NASA	No
UV Spectrometer	No	Yes
Infrared Thermometer	Yes	Yes
Cimel Sunphotometer (CSPHOT; 8 Wavelengths)	No	NASA
Multi-filter Rotating Shadowband Radiometer (MFRSR)	Yes	Yes

	SHEBA	Barrow
Downwelling Radiation (contd)		
Normal Incidence Multi-filter Radiometer	Yes	Yes
Precision Solar Pyranometer, Unshaded (PSP/DS)	Yes	Yes
Precision Solar Pyranometer, Shaded (PSP/DD)	Yes	Yes
Normal Incidence Pyranometer (NIP; pyrheliometer)	Yes	Yes
Precision Infrared Radiometer, Unshaded (PIR/DI)	Yes	Yes
Precision Infrared Radiometer, Shaded (PIR/DDI)	Yes	Yes
Ultraviolet B Radiometer (UVB)	Yes	Yes
Net Radiometer (RN)	Yes	Yes
Duplicate PSPs and PIRs	Yes	NOAA/CMDL
Upwelling jRadiation		
Infrared Thermometer	Yes	Yes
Precision Solar Pyranometer (PSP/US; 1.5 m)	Yes	Yes
Precision Infrared Radiometer (PIR/UI; 1.5 m)	Yes	Yes
Multi-filter Radiometer	Yes	Yes
Precision Solar Pyranometer (PSP/US; 40 m)	No	Soon
Precision Infrared Radiometer (PIR/UI; 40 m)	No	Soon
Aerosol Instrumentation		
Multi-wavelength Integrating Nephelometer	No	NOAA/CMDL
Condensation Nuclei Counter (CNC)	No	NOAA/CMDL
Filter Samplers	No	NOAA/CMDL
Gas Instrumentation		
Flask Samplers	No	NOAA/CMDL
Gas Chromatography for Greenhouse Gases	No	NOAA/CMDL
UV Ozone Monitor	No	NOAA/CMDL
Column Ozone Monitor	No	NOAA/CMDL

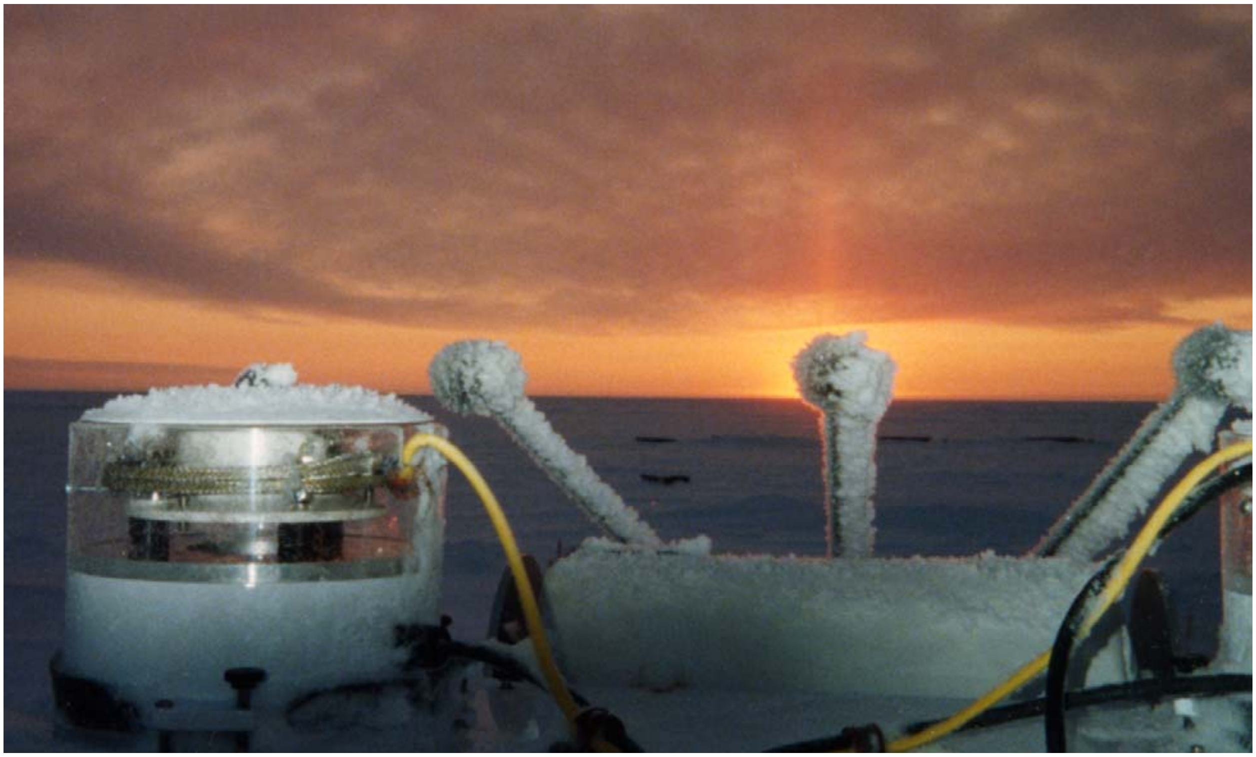


Figure 5.10. Hoarfrost on ARM/SHEBA Instrumentation

5.5 Communications

The data communications to and within the NSA/AAO Barrow facility are very good. A 256 kB line connects the NSA/AAO data system located at UIC-NARL with the ARM Experiment Center at Battelle Pacific Northwest National Laboratory (PNNL). A T1 line connects the data system at UIC-NARL with the sensors on NOAA land. This arrangement permits the main data system as well as the individual instruments to be addressed or reprogrammed (password protected) via the Internet.

For SHEBA, the situation was not nearly as convenient. The Inmarsat B satellite service provided limited state of health data reporting on a daily basis, but the principal means of transmitting data were by removable hard disk and other media physically transported every six weeks between SHEBA and PNNL (with full onsite backup). Fortunately, the Site Scientist had an individual charged with monitoring data quality physically located at SHEBA, so that when problems arose, they were noted, and usually fixed quite promptly.

For communications around the SHEBA and Barrow facilities (and subsequently, other facilities), away from phone-equipped structures, handheld radio transceivers are used. At Barrow, the transceivers are backed up with cellular phones. Satellite-based fixed location phone service is available in Barrow and in all of the villages. Cellular service is limited to Barrow and the oil fields.

5.6 Site Operations Personnel

At SHEBA, the NSA/AAO equipment was operated by carefully-selected technicians, engineers and scientists each of whom served a six-week shift. The SHEBA project office contracted for crew change aircraft operations with this frequency. The quality assurance(QA) operator on the ARM Site Scientist team changed on the same schedule. At Barrow, the ARM NSA/AAO facility manager and chief operator are provided under contract by UIC Science Division. All of the operators at both locations have been or are being trained by the NSA/AAO team. An instrument specialist at the Geophysical Institute at the University of Alaska Fairbanks is a part of that team. At Atqasuk, part time operators are also provided by UIC.

5.7 Instrument Maintenance

For the ARM/SHEBA instrumentation, the operators were chosen in large part on the basis of the depth of their electronics and computer experience. This was so because it was recognized that relatively little help could be provided when instrument or computer problems arose at SHEBA between shift changes. Several of the designated operators had advanced technical degrees and many years of experience. Of necessity, these operators at SHEBA handled both the routine maintenance and the repair functions. At Barrow, at first only routine maintenance was handled by the onsite operators. But as the local staff's experience has grown, a greater and greater proportion of problems are being handled locally with input by telephone from Sandia, UAF or mentors elsewhere. Just as at the other CART sites, if the onsite (and nearby) personnel are unable to fix problems, instrument mentors and instrument vendors are brought into play as needed. At Barrow, Federal Express or other rapid delivery service may be used to send out the failed components instead of bringing repair personnel to Barrow. If telephone consultation is not adequate, an ARM operations support person from UAF is brought to bear.

5.8 Transportation

The most striking feature of transportation in the vicinity of Barrow is that neither Barrow nor the villages are connected to Alaska's highway network. Furthermore, the villages are not connected to Barrow by road either. Hence, except for very heavy cargo, air transportation is routinely used. In winter, travel by snowmobile by local people between Barrow and all of the villages is not unusual. However, use of air transportation is even more common. Heavy cargo (like the winter's supply of diesel fuel for a village), or heavy equipment not compatible with air transport typically moves by barge in August and/or by specially commissioned rolligon train across the frozen tundra in winter. Rolligons are very large tire heavy vehicles designed for crossing the snow-covered tundra with minimum environmental impact.

Air transportation to and from the North Slope is very good. Most days of the week there are three Boeing 737 flights to Barrow from Anchorage and Fairbanks (weather permitting), and there are many flights each day between these cities and the lower 48. It is possible to leave many cities in the lower 48 and arrive in Barrow the same day. It is also possible to leave Barrow and arrive at West Coast cities the same day. Barrow is connected to the villages by scheduled commuter airlines. There are two or more flights a day to each of the villages mentioned.

Northern Air Cargo (NAC), Southern Air Transport, Alaska Airlines, and Linden all run air cargo operations into Barrow. NAC operates scheduled cargo flight to Barrow 5 days a week. Most of the Alaska Airlines passenger flights into Barrow also carry cargo. All of the villages have runways capable of handling the C-130 Hercules aircraft operated by Southern, and the DC6 swing-tail transport operated by NAC.

5.9 Instrumented Aircraft

With the exception of the FIRE period during SHEBA, in situ measurements aloft by dedicated instrumented aircraft in support of the ongoing experiments are likely to be less frequent than one would like because of the costs involved. Ferrying costs alone for an instrumented aircraft from the lower 48 to the North Slope will run $30–50K. As part of the budget for a several week long Intensive Observation Period (IOP), these ferrying costs are not prohibitive, but they make dedicated aircraft support significantly more expensive.

However, there are alternatives. Cape Smythe Air typically has about a half dozen aircraft stationed in Barrow for passenger and cargo service including a pair of Cessna 206s (large single engine aircraft), a pair of Beech 99s (approximately a 10 passenger twin engine aircraft), and a DC3 (1950s vintage medium size twin). Cape Smythe is willing to consider using one or more of these aircraft for in situ measurements aloft when they are not otherwise committed. In fact, they have already been used by NSF and EPA researchers.

6.0 Program Management

6.1 Program Environment

As part of the ARM Program, the NSA/AAO CART site is embedded in a distributed infrastructure. The ARM Program is directed by Wanda Ferrell of the DOE Environmental Sciences Division (SC-74), of the Office of Health and Environmental Research. She is assisted by Tom Ackerman, ARM Chief Scientist, by Ted Cress, ARM Technical Director, and by Jimmy Voyles, Head of ARM Engineering, all at Batelle Pacific Northwest National Laboratory (PNNL), and by Doug Sisterson, Head of Operations at Argonne National Laboratory (ANL), Argonne, Illinois. PNNL also coordinates the ARM Science Team, the group of all funded ARM Principal Investigators. As ARM Chief Scientist, Ackerman plays that role. Each of the above draws upon expertise from throughout the DOE laboratory complex and, to a lesser extent, the laboratories of other agencies, and universities. A more detailed description of the ARM infrastructure, as it existed in the early 1990s, is given by Stokes and Schwartz (1994).

6.2 NSA/AAO Site Management Structure

The NSA/AAO CART Site Manager is B. D. Zak of Sandia National Laboratories. He is responsible for the planning, development and operation of the NSA/AAO CART Site. Zak reports to DOE through the ARM Operations Manager, Doug Sisterson, of Argonne National Laboratory (ANL). Zak is assisted by Wayne Einfeld, Deputy Site Manager, and by Hugh. Church under contract who, until his recent retirement, served as Associate NSA/AAO Site Manager. Zak is also assisted by Jean Burstein, the NSA/AAO Administrative Assistant. Other key members of the ARM NSA team include: Site Engineer, Kevin Widener; Technical Operations Task Manager, Jeff Zirzow; NSA Facilities Manager, Walter Brower; NSA Chief Operator, Jimmy Ivanoff and Site Data System and Related Computer Operations Manager, Dick Eagan.

The NSA/AAO CART Site Scientist is Knut Stamnes of the Stevens Institute of Technology and the Geophysical Institute of the University of Alaska Fairbanks (UAF). Stamnes reports to the ARM Chief Scientist. Stamnes is assisted by Rune Storvold at UAF and Hans Eide at Stevens. The Site Scientist is responsible for data quality assurance and quality control (QA/QC) on a routine and ongoing basis. QA/QC will be covered in detail in a separate document.

On NEPA (National Environmental Policy Act) affairs, Zak, Church and Widener were originally assisted by Nancy Finley of Sandia. After Finley's untimely passing, that task was undertaken by Sharon Walker, also of Sandia. An Environmental Assessment (EA) was prepared by the project team together with an oversight team from DOE Kirtland Area Office. In March 1997, after extensive review of the EA by federal, state and local North Slope of Alaska officials, DOE issued a Finding of No Significant Impact (FONSI). In the same time frame, a Development Permit for the project was issued by the North Slope Borough Planning Department.

General Environment, Safety and Health overview is provided by Wayne Einfeld and Jaci Hernandez of Sandia. Monte Brandner of Argonne oversees safety at all three ARM CART sites. Safety planning had been undertaken by Ernie Sanchez (firearms for polar bear defense) and Mark Semonisck (general safety engineering), with the help of Hugh Church. DOE's Central Training Academy in Albuquerque has handled polar bear defense and firearms safety training.

Any required permit applications are prepared by Zak and Church, and are formally submitted by the DOE Kirtland Area Office.

Anne Jensen of UIC Real Estate Science Division is the resident North Slope NSA/AAO CART operations and support coordinator.

During the development phase of the NSA/AAO, extensive use was made of the NSA/AAO Advisory Panel. It has since been replaced by the NSA/AAO Users Group, a less formal body of time - varying composition. The former NSA/AAO Advisory Panel membership is listed in Appendix A.

6.3 Schedule

Dates beyond 2000 are approximate.

ARM/SHEBA Cold Test	February-April 97	done
Barrow CART site preparations	March-June 97	done
Barrow Instrumentation and data system integration and test	May 97 to March 98	done
NSA/AAO Formal Site Dedication	July 1, 1997	done
SHEBA data acquisition begun	October 97	done
Barrow data acquisition scheduled to begin	April 98	done
ARM/SHEBA instrumentation Recovery	October 98	done
Redeployment to Atqasuk	Calendar year 00	done
Development of Oliktok Pt Site		

The formal NSA/AAO CART site dedication took place on schedule on July 1, 1997, presided over by the Mayor of the North Slope Borough, Ben Nageak, the President of UIC, Max Ahgeak, and by Martha Krebs, Director of the DOE Office of Energy Research (Figure 6.1).

Figure 6.1. NSA/AAO Site Dedication Ceremony. Left to Right: Peter Lunn (DOE ER74), Kenneth Toovak (NARL, retired), Max Ahgeak (President, Ukpeagvik Inupiat Corporation, behind Toovak), Dr. Martha Krebs (DOE ER1), and Ben Nageak (Mayor, North Slope Borough). July 1, 1997.

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Appendix A

NSA/AAO Advisory Panel

Appendix A

NSA/AAO Advisory Panel

The NSA/AAO Advisory Panel consisted of two subgroups. One subgroup consisted of individuals working in areas relevant to the scientific objectives of the NSA/AAO site, and well positioned to advise on the NSA/AAO science and siting strategy, who may or may not have personal arctic experience. The other subgroup consisted of members who have extensive experience in the Arctic who are well positioned to advise on NSA/AAO implementation plans, although their personal research interests may not be directly relevant to ARM. Of course, there is overlap between these subgroups.

The membership of the ARM/NSA/AAO Advisory Panel was:

Carl Benson, UAF
Ellsworth Dutton, NOAA/CMDL
Judy Curry, UCo
Bob Ellingson, UMd
Richard Glenn, NSB
Jeff Key, Boston U.
Mike King, NASA/EOS
Dick Moritz, UWa/SHEBA
F. Nishio, UHokkaido/ADEOS
Steve Krueger, UUtah
Ed Westwater, UCo (CIRES)
John Walsh, UI

Appendix B

Other Synergistic Research Programs

Appendix B

Other Synergistic Research Programs

As discussed in Section 4.1 the extension of the NSA ARM effort to the Adjacent Arctic Ocean (AAO) occurred in conjunction with SHEBA, a one-year field experiment based at a manned drifting sea ice station based on a Canadian Coast Guard icebreaker frozen into the perennial pack ice of the Arctic Ocean. This experiment was led by the National Science Foundation as part of its Arctic System Science (ARCSS) program and by the Office of Naval Research. The SHEBA observational effort emphasized the relationship between radiative fluxes (especially as affected by surface- and cloud-radiative interactions), the mass balance of sea ice, and the storage and retrieval of energy and salt in the mixed layer of the ocean. SHEBA and the ARM NSA/AAO efforts were designed to maximize their synergism.

Another ARCSS effort that is of direct relevance to ARM NSA/AAO is the arctic trace gas "Flux Study" of the Land-Atmosphere-Ice-Interactions (LAII) component of ARCSS. The Flux Study involves flux measurements of carbon dioxide and methane to the atmosphere and of water-transported materials to the ocean. It also involves determination of the origin of the fluxes, as well as scaling and synthesis to the regional scale (Alaskan North Slope and beyond. Measurements of snow cover, thickness and characteristics are also periodically undertaken. The ultimate goal of this study is to assess the feedbacks between climatic change and the release of greenhouse gases from arctic land. The LAII Flux Study interfaces with the ARM/NSA effort both geographically through field measurements in adjacent regions of the North Slope, and scientifically through the link between surface radiative fluxes, soil/vegetation temperature and wetness, and rates of trace gas flux from/to terrestrial ecosystems. The "scaling and synthesis" component of the LAII Flux Study utilizes the Arctic Regional Climate System Model (ARCSYM), which is now being run over a domain that encompasses both the LAII Flux Study area and the proposed ARM/NSA/AAO CART site. LAII plans to extend the flux study to a transect from Barrow to Atqasuk and beyond to the Brooks Range beginning in 1998 and ending in the year 2000. The presence of ARM NSA/AAO instrumentation at both Barrow and Atqasuk for most of the period while this transect is operational will be of considerable benefit to both programs

The Arctic Climate System Study (ACSYS) is an initiative of the World Climate Research Program. ACSYS is expected to span a period of approximately ten years. This initiative emphasizes the climate component of the arctic system through its focus on the Arctic Ocean, its sea ice cover, and its energy and water budgets. A topic of particular emphasis in ACSYS is the cloud-radiative interaction that is crucial to a quantitative description and understanding of the surface energy budget in the Arctic. Both ARM/NSA/AAO and SHEBA are considered to be U.S. contributions to ACSYS. It is expected that the findings of ARM and SHEBA will directly impact the ACSYS-coordinated ice-ocean modeling, which will likely be the key to an assessment of the stability of arctic sea ice in a changing climate.

NASA will conduct a major aircraft campaign in the Arctic in spring 1998. Thus, Phase III of the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment (FIRE III) is a NASA-led effort that is planned to take place in conjunction with SHEBA and NSA/AAO. The emphasis of FIRE is to provide in situ data on cloud radiative and microphysical properties to test and improve ground-based and satellite remote sensing retrievals and GCM performance in the Arctic. The use of instrumented aircraft will play a major role in FIRE. Coordination between the FIRE III, ARM and SHEBA programs in the Arctic is being facilitated by the presence of several members of the FIRE III Science Team on the SHEBA Science Working Group, the ARM Science Team Executive Committee, and the ARM NSA/AAO Advisory Panel.

Appendix C

Barrow Climate Record

Appendix C

Barrow Climate Record

We have analyzed data obtained from the National Weather Service and NOAA - Climate Monitoring and Diagnostics Laboratory (CMDL) sites at Barrow, Alaska to define monthly averages of meteorological parameters for the ARM North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO) site.

The monthly average temperature over the period from 1977 through 1995 at the NOAA/CMDL site ranges from near 0oC in the summer to about - 26°C in the winter. However, a minimum of about -50°C and a maximum of about 22°C have been recorded. The monthly average water vapor mixing ratio ranges from 0.28 to 3.9 g kg^{-1}. These values are within 82 to 92 percent of the saturation-mixing ratio at the surface air temperature. The prevailing winds are from the east-northeast with average monthly velocities in the range of 5.2 to 6.9 m s^{-1} with a maximum of about 33 m s^{-1} having been recorded.

Based on ceilometer charts, the monthly average cloud base ranges from about 400 to 1600 m above the ground. Higher cloud bases, recorded in the winter, are associated with lower mixing ratios. Comparing cloud base with temperature inversion height, we find that the cloud base is above the top of the inversion about 50 percent of the time. In the winter, when the water vapor mixing ratios are low, cloud base is considerably higher than the top of the inversion. Cloud frequency ranges from about 45 percent in the winter to about 92 percent in the summer. Stratus clouds are most common. Cirriform clouds are reported more frequently in the winter and spring than during summer and fall, perhaps because of the prevalence of low cloud during the latter period.