ARM-00-003

Background for the DOE/ARM North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART) Site Scientific Mission Plan

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Disclaimer

Abstract

A detailed description of the site and its scientific context is given here. We start by giving a general perspective on climate change, and then go on to the Atmospheric Radiation Measurement (ARM) Program as a whole, and the North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART) site in particular. We describe the long-term areas of scientific focus for the site, and present the temporal priorities that have driven site planning. We then proceed to discuss the existing and planned facilities associated with the site, and wrap up with a discussion of the NSA/AAO educational outreach program and site management. Companion reports (the NSA/AAO Site Scientific Mission Plans) to this document provide an up-to-date snapshot of current scientific priorities for the NSA/AAO CART site, as well as recent progress and near-term plans. Those brief reports are updated twice yearly. This report will be updated significantly less frequently. The information in these reports is expected to be most useful to current and prospective users of site data, and to the personnel who help develop, operate, and maintain the site throughout the ARM infrastructure. For points of contact and the most current information, see “NSA” under “Sites” at www.arm.gov.

Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement (DOE program)
ARCS	Atmospheric Radiation and Cloud Station
ARCUS	Arctic Research Consortium of the U.S.
ATDD	Atmospheric Turbulence & Diffusion Division (NOAA)
ATV	all terrain vehicle
BASC	Barrow Arctic Science Consortium
BEO	Barrow Environmental Observatory
CART	Cloud and Radiation Testbed
CB	Cloud Behavior (experiment)
CMDL	Climate Monitoring and Diagnostic Laboratory (NOAA)
CNC	condensation nuclei counter
CSPHOT	Cimel sunphotometer
DOE	U.S. Department of Energy
DRI	Desert Research Institute (University of Nevada, Reno)
FAA	Federal Aviation Administration
FTIR	Fourier transform infrared spectrometer
GI	Geophysical Institute (UAF)
IOP	intensive operational period
IR	infrared (portion of the spectrum)
IRF	Instantaneous Radiative Flux (experiment)
MFRSR	multi-filter rotating shadowband radiometer
MMCR	millimeter cloud radar
MPL	micropulse lidar
MWR	microwave radiometer
NARL	(former) Naval Arctic Research Lab—for decades, the largest Arctic research facility in the world
NASA	National Aeronautics and Space Administration
NIMFR	normal incidence multi-filter radiometer
NIP	normal incidence pyranometer
NSF	National Science Foundation
NOAA	National Oceanic and Atmospheric Administration
NSA/AAO	North Slope of Alaska/Adjacent Arctic Ocean
NSB	North Slope Borough

NSBSD	North Slope Borough School District
NSF	National Science Foundation
NWS	National Weather Service
ONR	Office of Naval Research
PAARCS	Portable Arctic ARCS
PIR	precision infrared radiometer
PNNL	Pacific Northwest National Laboratory
PSP	precision solar pyranometer
QA	quality assurance
QC	quality control
RASS	radio-acoustic sounding system
RESET	Regional Service Team
SCM	Single-Column Model (experiment)
SGP	Southern Great Plains (CART site)
SHEBA	Surface Heat Budget of the Arctic Ocean [Subprogram of Arctic System Science (NSF Program)]
SOM	Surface Optical Model (experiment)
SPEC	Stratten Park Engineering Consultants
TWP	Tropical Western Pacific (CART site)
UAF	University of Alaska, Fairbanks
UIC	Ukpeagvik Inupiat Corporation
USGCRP	U.S. Global Change Research Program
UV	ultraviolet (portion of the spectrum)
UVB	ultraviolet B radiometer
WCRP	World Climate Research Programme
WSI	whole sky imager
VCEIL	Vaisala ceilometer

Preface

There is reason to believe that the accumulation in the atmosphere of carbon dioxide, primarily from the burning of fossil fuels, and of other “greenhouse gases” may be causing significant modifications in the global climate on a time scale of decades. Carbon dioxide concentrations in the atmosphere have been observed to be steadily increasing ever since routine monitoring began during the International Geophysical Year (1957). Presently, those concentrations are believed to stand at the highest levels attained during the last few million years. Global climate models predict that high concentrations of carbon dioxide and other greenhouse gases will lead to a global climate significantly different from the climate regime of the recent past. Studies of ice cores and other data sets from the paleoclimate record have provided evidence that high concentrations of atmospheric carbon dioxide are strongly correlated with warm climatic periods. There is also evidence in the paleo record for a correlation between higher carbon dioxide concentrations and greater climatic instability.

Compelling evidence has accumulated that tell us the earth’s climate has warmed over the past several decades. While the case for anthropogenic global climate change has not yet been proven beyond doubt, there is sufficient evidence to support a conclusion of probable cause that deserves further investigation. Because of the seriousness of the potential impacts of a significantly changed climate, a World Climate Research Program (WCRP) has been put in place and now serves as an umbrella for national and international climate change research. The U.S. Global Change Research Program (USGCRP) is formally a constituent of the WCRP. The Atmospheric Radiation Measurement (ARM) Program is the U.S. Department of Energy’s (DOE’s) principal effort contributing to the USGCRP. ARM focuses on the radiative energy balance of the earth, the primary determinant of global climate, and especially on the influence of clouds on that balance. The North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART) is ARM’s cold region climate process research site.

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1. Introduction

The U.S. Department of Energy's (DOE's) Atmospheric Radiation Measurement (ARM) Program seeks to improve the performance of global climate models. Its goal is to make their global and regional climate predictions more accurate and credible, and hence, more useful. Because clouds and their effects on radiative energy transfer have been identified as the source of some of the largest uncertainties in global climate models, ARM focuses on cloud-radiation interactions, and on developing mathematical descriptions of those interactions for global climate models that more faithfully represent reality. To facilitate comparison with the real world, ARM has established three primary Cloud and Radiation Testbed (CART) sites, each with a planned programmatic life of ten years or more.

The first CART site was established on the Southern Great Plains (SGP) of the United States and began operation in 1992. The second CART site was deployed in the Tropical Western Pacific (TWP). Operations at the TWP site began in 1996. The third CART site, the North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO), was dedicated in July of 1997. Routine data acquisition at the NSA/AAO began in October 1997 as part of the Surface Heat Budget of the Arctic Ocean experiment [SHEBA; primarily sponsored by the National Science Foundation (NSF) and the Office of Naval Research (ONR)]. Routine data acquisition began at the ARM facility in the vicinity of Barrow, Alaska, in April 1998. SHEBA involved freezing an icebreaker into the perennial arctic ice pack north of the arctic coast of Alaska for a year, and using that icebreaker as a research base for improving our understanding of energy flows to and from the ice from both the atmosphere above and the ocean below. SHEBA addressed the fact that the eventual impact of the current warming on the ice pack is highly uncertain. It needs to be better understood because of the importance of the polar ice for the climate system as a whole. ARM provided most of the detailed radiometric measurements for SHEBA, and NSF and ONR provided ARM with an otherwise unaffordable research platform in the arctic ice pack, as well as with an array of supporting measurements.

As part of the TWP CART effort, ARM designed and procured transportable structures that make up an Atmospheric Radiation and Cloud Station (ARCS). The ARCS is based on 8 x 8 x 20-foot customized shipping containers. The ARCS container designed for the TWP site has been extensively modified for application at the NSA/AAO. This new version, the Portable Arctic ARCS (PAARCS) served ARM needs at SHEBA. A larger version is deployed at Barrow, and the PAARCS used for ARM instrumentation at SHEBA has been redeployed at Atqasuk on the North Slope.

These PAARCS include an extensive suite of solar and thermal infrared radiometers, in situ and remote sensing cloud and water vapor instruments, and other meteorological sensors. The sensors currently operating at the site are listed later in this report. An instrumentation list for each CART site is also available from the ARM home page at www.arm.gov.

2. NSA/AAO Science

2.1 Primary Focus: Cold Region Cloud and Radiation Phenomena

The NSA/AAO CART site provides data about cloud and radiative processes at high latitudes, and by extension, about cold and dry regions of the atmosphere in general. These data will be used to refine models and parameterizations for high latitude regions and for the upper atmosphere. More specifically, the issues of principal interest as they apply to cold regions are as follows:

- Atmospheric Radiative Transfer
- Ice and Mixed Phase Cloud Formation, Evolution, and Dissipation
- Behavior of Surface Radiative Characteristics
- Direct and Indirect Aerosol Radiative Effects
- Development and Testing of Satellite Remote Sensing Algorithms.

Atmospheric radiative transfer in cold regions differs in two major ways from radiative transfer in warmer regions. The first is that the cold temperatures severely limit the concentration of water vapor in the air. Since water vapor is a very strong IR absorber (hence a strong greenhouse gas), this has profound effects on radiative transfer. Whereas the concentration of water vapor in warm, moist regions effectively makes the atmosphere a black body beyond a wavelength of 16 micrometers, such is not the case in cold regions. Atmospheric radiative transfer in cold regions must take into account the 16-26 micrometer "window," as well as in the IR region below 16 micrometers.

The second way that atmospheric radiative transfer differs between cold regions and warmer regions is that, in cold regions, the clouds are either entirely or partly composed of ice particles. This fact dramatically changes radiative transfer in the presence of clouds. Not only are the optical properties of ice much different than those of liquid water, but ice is a solid that enables ice particles to exist in a variety of shapes. Hence, the Mie scattering theory (developed for spherical particles) does not apply. Ice and mixed phase clouds occur worldwide year-around in the stratosphere and upper troposphere, as well as near ground level in winter in high latitude regions.

Ice and mixed phase cloud formation, evolution and dissipation also differ considerably from similar processes for water clouds. For these clouds, in modeling as in measurements, one needs to keep track of the concentrations of three forms of water, rather than just two: water vapor, liquid water, *and ice water*. In addition, the chemical and ionic species capable of nucleating ice particles are different than those that nucleate water droplets. So in principle, one needs to keep track of the concentration and characteristics of two different types of nucleating species as well.

It may seem incongruous to include surface radiative characteristics as an issue of major interest in a program that focuses on atmospheric radiative transfer, but at high latitudes, it's not. Here, because the albedo of the surface changes dramatically when the snow and ice melt, the radiative characteristics of the surface are tightly coupled to atmospheric radiative transfer, as well as to surface sensible heat and water vapor fluxes. Hence, surface melting and freezeup are major drivers of atmospheric cloud and radiation feedbacks at high latitudes.

The direct and indirect influence of aerosol particles on radiative transfer in warm regions has been a subject of research for decades. However, aerosol behavior in cold regions relative to clouds is markedly different where the clouds may consist of super cooled water droplets, ice particles, or a dynamic mixture. Arctic haze, diamond dust, and ice fog are just a few of the phenomena that reflect these differences. Dry aerosol has a direct effect on atmospheric radiative transfer that is relatively insensitive to temperature. But if the aerosol particles are also capable of nucleating water droplets and/or ice particles under ambient conditions, the secondary effect through the aerosol's influence on the optical properties of clouds may be much greater than the direct effect. With the growing utilization of the Arctic, understanding the impacts of aerosols on cold cloud behavior is becoming increasingly important.

The interest ARM has in satellite remote sensing stems in part from the fact that what is learned at the CART sites will be most readily applied globally through that technology. But in order to make that application, the algorithms used to interpret satellite data must be validated over areas where what is happening in the atmospheric column and on the surface is well documented by independent means. The CART sites are presently the most appropriate sites available for that purpose in the United States, and probably the world. At high latitudes, validation of remote sensing algorithms is particularly important because the presence of snow and ice on the surface introduces many difficulties for satellite remote sensing.

2.2 Secondary Focus: Targets of Opportunity Important to ARM

The ARM Locale Identification Report (DOE 1991) reviewed what ARM seeks to accomplish, and then surveyed the world to find a suite of generic locales for ARM CART sites that, taken together, would allow ARM to achieve its goals. Unfortunately, budgetary constraints have forced ARM to cut back from the number of CART sites originally proposed. So cloud and radiative phenomena that were originally thought to be of sufficient importance to merit a separate CART site were left unrepresented. This makes it imperative that, if at all possible, the remaining CART sites stretch their original charters to include phenomena of importance to ARM that would otherwise be left unstudied. The phenomena that fall in this category that can be conveniently studied at the NSA/AAO site include the following:

- Generic Marine Stratus
- High Heat and Water Vapor Fluxes Over Water
- Transition Zones.

Marine stratus occurs in the Arctic as well as over many other areas of the earth. It is estimated that at any given time, about 18% of the earth's surface is covered by marine stratus. By happenstance, the NSA/AAO is now the only CART site located where this globally important cloud type can be easily studied. It is true that the character of marine stratus is likely a strong function of temperature. So even in summer, the marine stratus at the NSA/AAO site will not be identical to that at warmer latitudes. Nevertheless, the NSA/AAO currently provides ARM with its best marine stratus research site. Of course, marine stratus is not entirely different from other low lying stratus. So stratus investigations at both the NSA/AAO and the SGP site may be required to satisfy marine stratus research needs.

Understanding the high heat and water vapor fluxes that occur when a water surface is exposed to much colder air is important for the Arctic. High fluxes occur in winter when the sea ice fractures and the fractures form leads. The air advecting over the leads may be at –40°C or colder, but the water is near 0°C. The air-water interface, although it probably accounts for only 1-2% of the surface area of the Arctic Ocean in winter, is estimated to account for around 50% of the flux of heat and water vapor to the atmosphere over the ice pack. Thus, understanding these high flux situations is critical to understanding winter cloud formation processes in the Arctic. It turns out, however, that high fluxes are also important in the North Atlantic where warm water transported by the Atlantic Conveyor meets cold air from the North. There these fluxes are critical for the formation of North Atlantic storms and for the heat transfer to the atmosphere that accounts for the relatively mild climate of Northern Europe. Tromso, on the Arctic coast of northern Norway, is at approximately the same latitude as Barrow. Yet, Tromso is ice free year around, whereas Barrow is icebound 8 months of the year.

Transition zones were and are considered an important type of region for ARM to study. While there are several different types of transition zones, coastal transition zones are certainly of global importance. The NSA/AAO site incorporates a transition zone—from the Arctic Ocean to the North Slope proper. This transition zone has an unusual feature that makes it of particular value to ARM. The strength and character of the discontinuity represented by the coast changes with time of year. During winter, when both the land and the sea are covered with snow and ice, the discontinuity is very weak. In late spring, the snow on land melts long before the sea ice. The resulting coastal discontinuity is very strong, with much warmer land than ice. After the sea ice disappears and for the few months before it returns, the coast represents much the same type of discontinuity as coasts farther to the south. Then in fall, the land freezes and acquires a mantle of snow long before the sea ice returns. So again, one has a very strong coastal discontinuity, but here with cold land and warm sea, there is a reverse of this situation in spring. If algorithms can be developed that handle all of these situations well, it is likely that they will go a long way towards meeting global climate model coastal transition zone algorithm needs worldwide.

For discussions in greater depth of the scientific issues to be addressed at the NSA/AAO CART site, please refer to Stamnes et al. (1999) and Zak et al. (2000).

2.3 Temporal Priorities

Planning involves the setting of priorities. For ARM, priorities are set in part on the basis of science, and in part on the basis of cost considerations. As an output of several ARM NSA/AAO project-wide and interagency meetings, a more detailed set of NSA/AAO early priorities was formulated to guide subsequent planning. The temporally-prioritized set of scientific issues to be addressed at the NSA/AAO site that emerged from these meetings is given below (Zak et al. 2000). The temporal priority assigned gives weight to both perceived intrinsic importance and near-term feasibility. Note however that these priorities are likely to be addressed iteratively as the NSA/AAO CART site measurement capabilities grow. Each new measurement capability opens up a set of new possibilities for model verification and refinement, possibilities that typically fall within more than one priority category. These priorities are listed as follows.

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].

2. Influence of stratus clouds on near ultraviolet (UV), visible, and near IR (<1 μm) radiative transfer, especially in the troposphere. 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).

3. Influence of stratus clouds on IR radiative transfer beyond the near IR, especially in the troposphere. Start with liquid water clouds; next go to ice clouds; address mixed phase clouds last. This issue has the same broad applicability as priority 2 above (IRF Experiment).

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

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

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

7. Stratus cloud formation and evolution processes on global climate model grid cell scales [CB/Single-Column Model (SCM) experiments].

As of now, priorities 1-4 and 6 are being addressed. Priorities 5 (SOM experiments) and 7 (SCM experiments), will be addressed in the future. More on these later.

2.4 Siting Strategy

The siting strategy for the NSA/AAO site was formulated in light of the basic scientific objectives, the temporal priorities, and logistical considerations. In the near term, the strategy calls for data acquisition at locations that form a transect from the Arctic Ocean ice pack, through the coastal region and on to the inland environment. Thus, siting has explicitly taken into account priority 6. Initial instrumentation at these locations focuses on the needs of IRF experiments (priorities 1-4). Priority 5 (SOM experiments) was covered by NSF- and ONR-funded researchers in the context of SHEBA, but the majority of the instrumentation necessary to address this priority is yet to be selected, procured, and deployed for the ARM NSA facilities. Provisions for meeting SCM measurement needs at the NSA/AAO are currently being explored (priority 7).

The NSA/AAO is centered at Barrow and extends 100 km to the south to the vicinity of the village of Atqasuk, and east to the vicinity of Oliktok Point (Figure 2.1). During the period October 1997 through September 1998, the AAO to the north was probed during the SHEBA experiment. SHEBA involved the deployment of an instrumented ice camp within the perennial Arctic Ocean ice pack around the Canadian Ice Breaker Des Groseilliers (Figure 2.2).

The ARM instrumentation originally deployed as part of SHEBA was redeployed at Atqasuk in the summer of 1999. Once in place, the Atqasuk facility will complete the transect of the Arctic Ocean coast (SHEBA-Barrow-Atqasuk). This arrangement is aimed at providing an understanding of the coastal transition zone. It does not, however, adequately address the needs of SCM experiments. For that, one needs data over an extended area.

Figure 2.1. Map of Alaska with NSA/AAO CART facility locations.

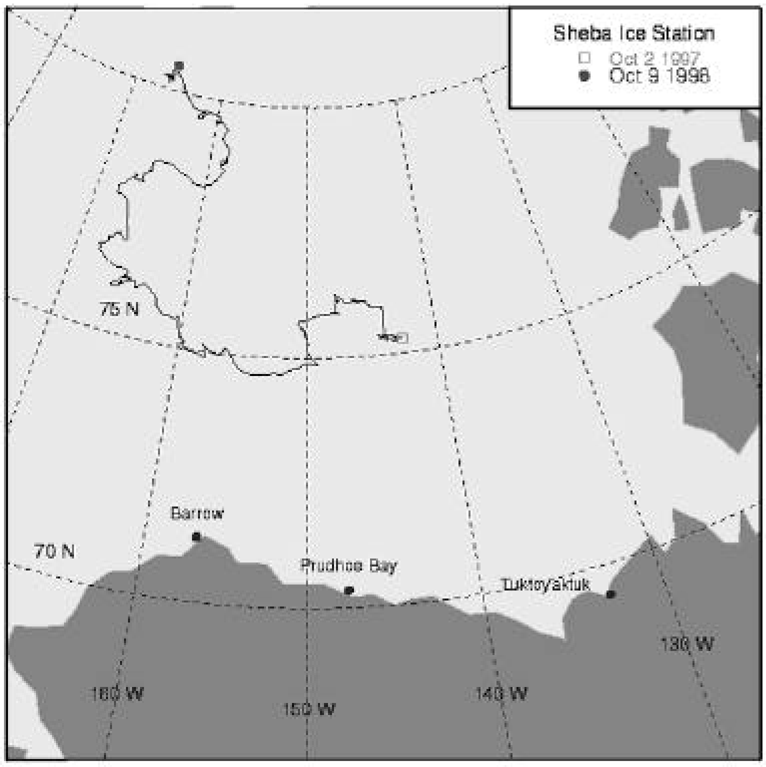

Figure 2.2. The year-long drift of the SHEBA ice camp.

3. Barrow

3.1 Instrumentation

The present instrumentation at Barrow is given in Table 3.1. The rationale for this instrument suite is given in Zak et al. (2000). The location of the facilities relative to Barrow and the instrumentation layout are shown in Figures 3.1 and 3.2. The ARM Barrow sensor array is located on National Oceanic and Atmospheric Administration (NOAA) land adjacent to the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) Barrow Observatory about 6 km to the northeast of the City of Barrow, and about 10 km southwest of Point Barrow, the northern tip of Alaska. Views of the ARM Barrow and NOAA/CMDL facilities are given in Figures 3.3 and 3.4, respectively. The NOAA/CMDL Barrow station has been in operation since the mid 1970s. The primary data acquisition system for the Barrow ARM facility (Ugruk) is located in a duplex on the UIC/NARL [Ukpeagvik Inupiat Corporation/(former) Naval Arctic Research Laboratory] campus. A T1 high-bandwidth data line from the lower 48 states comes into the duplex. Another T1 line runs from the duplex to the instrumentation site. The duplex also provides limited housing and work space for visiting ARM infrastructure and research personnel. Note that the NOAA/CMDL land is contiguous with the Barrow Environmental Observatory (BEO), about 25 square kilometers of tundra set aside by the land owner (UIC) for environmental research. This land had been used extensively for similar purposes while the NARL was in operation (1950s through 1981).

Table 3.1. ARM and related instrumentation at Barrow and Atqasuk (Spring 2000).

Surface Meteorological Sensors	Barrow Location	Atqasuk
Wind Speed, Wind Direction, Temperature, Humidity	NOAA/CMDL and NWS[(a)]	Yes
Same as Above, but at 2 m, 10 m, 20 m, and 40 m	ARM	No
Dew Point/Frost Point Hygrometer (1 level fixed)	NOAA/CMDL	No
Same as Above, but Elevation Scannable Over Tower Height	ARM, soon	No
Optical Precipitation Gauge	ARM	No
Standard Precipitation Gauges	NOAA/CMDL and NWS	No
Wind, Temperature, and Humidity Sounding Systems		
Microwave Radiometer (MWR; column liquid water and water vapor)	ARM	Yes
915-MHz Wind Profiler w/RASS (WS, WD, T profile)	ARM	No
Radiosondes	NWS and ARM	IOPs
Cloud Observation Instrumentation		
Millimeter Cloud Radar (MMCR)	ARM	No
Micropulse Lidar (MPL)	ARM	No
Ceilometer (VCEIL)	ARM and NWS	Yes
Whole Sky Imager (WSI)	ARM	Soon
Downwelling Radiation		
Extended-Range Atmospheric Emitted Radiance Interferometer [ER-AERI; Fourier transform infrared spectrometer (FTIR), 4-26 micrometers]	ARM	IOPs
UV Spectrometer	NSF/NARL	No
Infrared Thermometer	ARM	Yes
Cimel Sunphotometer (CSPHOT; 8 Wavelengths)	NASA/ARM	No
Multi-Filter Rotating Shadowband Radiometer (MFRSR)	ARM	Yes
Normal Incidence Multi-Filter Radiometer (NIMFR)	ARM	Yes
Precision Solar Pyranometer, Unshaded (PSP/DS)	ARM	Yes
Normal Incidence Pyranometer (NIP; pyrheliometer)	ARM	Yes
Precision Infrared Radiometer, Unshaded (PIR/DI)	ARM	Yes
Precision Infrared Radiometer, Shaded (PIR/DDI)	ARM	Yes
Ultraviolet B Radiometer (UVB)	ARM	No
Duplicate PSPs and PIRs	NOAA/CMDL	No
Upwelling Radiation		
Infrared Thermometer	ARM	Yes
Precision Solar Pyranometer (PSP/US; 1.5, soon 10 m)	ARM	Yes
Precision Infrared Radiometer (PIR/UI; 1.5, soon 10 m)	ARM	Yes
Multi-Filter Radiometer	ARM	Yes

Table 3.1. (contd)

Upwelling Radiation (contd)	**Barrow Location**	**Atqasuk**
Downward-Pointing Video Camera (snow cover)	ARM, soon	Soon
Duplicate PSPs and PIRs	NOAA/CMDL	No
Aerosol Instrumentation		
Multi Wavelength Integrating Nephelometer	NOAA/CMDL	No
Condensation Nuclei Counter (CNC)	NOAA/CMDL	No
Filter Samplers	NOAA/CMDL	No
Micropulse Lidar (MPL)	ARM	No
Gas Instrumentation		
Flask Samplers	NOAA/CMDL	No
Gas Chromatography for Greenhouse and Ozone-Destroying Gases	NOAA/CMDL	No
UV Ozone Monitor	NOAA/CMDL	No
Column Ozone Monitor	NOAA/CMDL	No
(a) NOAA/CMDL and ARM sensors are collocated on NOAA land northeast of Barrow; the NSF sensor at NARL is 2 km to the west; the NWS sensors and Upper Air Sounding Station are 6 km to the southwest near the Barrow airport. IOP - intensive operational period. NASA - National Aeronautics and Space Administration. RASS - radio-acoustic sounding system.		

Hence, the ecology of a number of plots on the BEO have been periodically characterized for nearly a half century, a period during which significant climate change has taken place. Management of the BEO is supported by the NSF.

3.2 Operations

Instrumentation at the NSA/AAO Barrow facility operates 7 days a week, 24 hours a day, year around. The instrumentation is routinely maintained using an extensive “daily rounds” checklist five days a week, except during intensive operational periods (IOPs), when the needs of the IOP determine if some other schedule of checks is needed. The daily rounds call for the launch of a balloon-borne temperature and humidity sonde once a day from the vicinity of the ARM instrumentation on NOAA land. The NWS launches two standard upper air soundings per day at Barrow.

Routine operations at the Barrow facility are conducted by local site operators employed through UIC/Science Division, under the direction of the NSA/AAO Onsite Facilities Manager (Walter Brower), who also serves as a backup site operator. The Chief Operator is George Leavitt. The UIC/Science Division, under the direction of Anne Jensen, also supplies the site with a range of supporting services, including utilities, additional manpower, and heavy equipment as needed. A non-profit affiliate of UIC, the North Slope Borough (NSB) and Ilisagvik College, the Barrow Arctic Science Consortium (BASC) provides the CART site with leased space (the duplex, outdoor and indoor storage and work space). The BASC is directed by Glenn Sheehan.

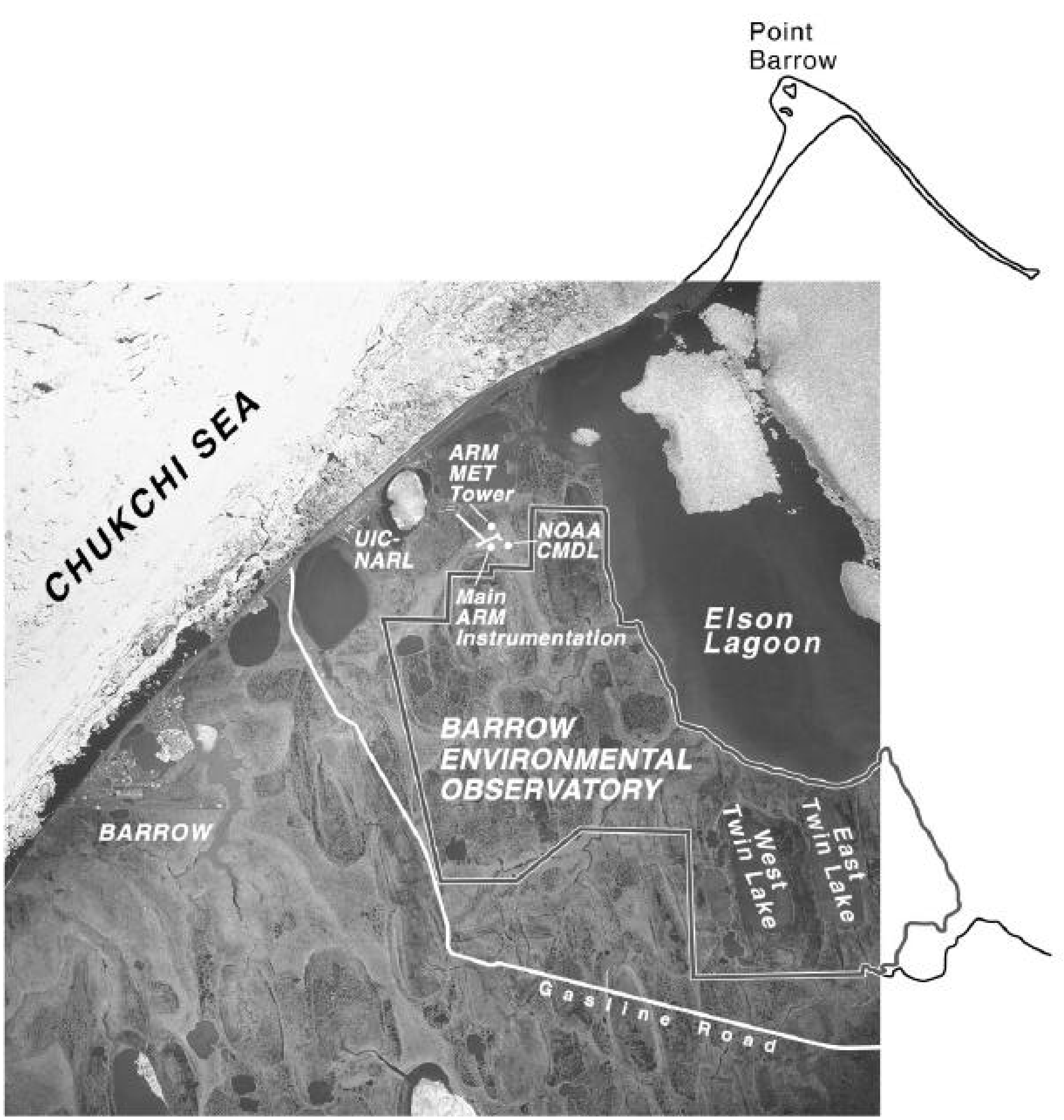

Figure 3.1. Aerial photo of Barrow vicinity with location of Barrow ARM facility.

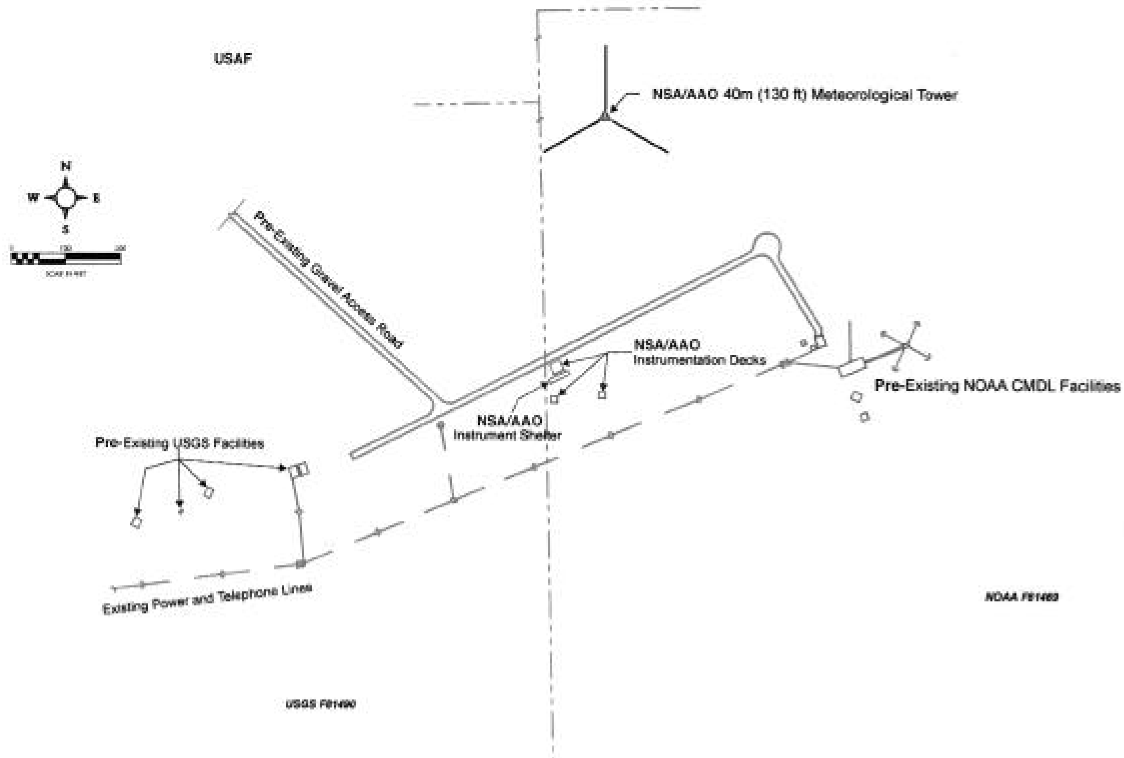

Figure 3.2. Layout of Barrow ARM facility.

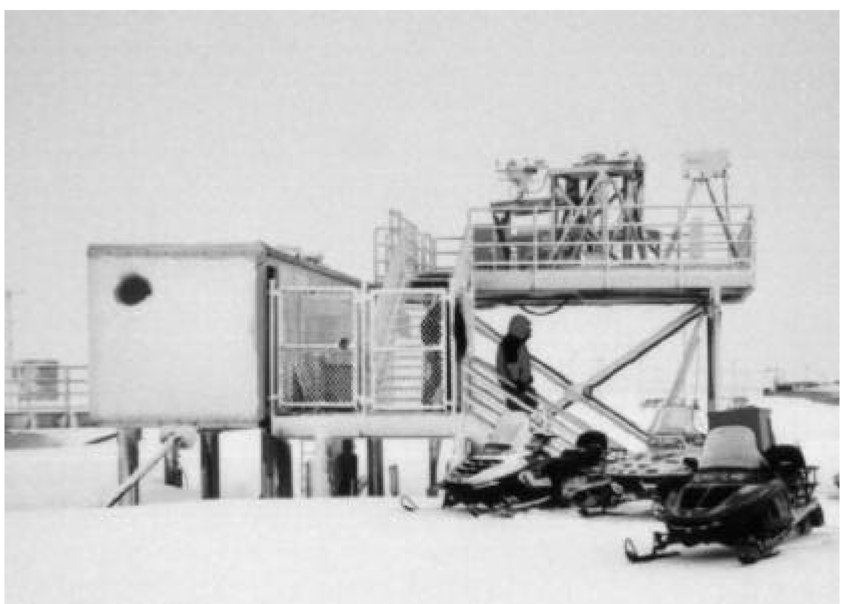

Figure 3.3. The PAARCS on NOAA/CMDL land near Barrow.

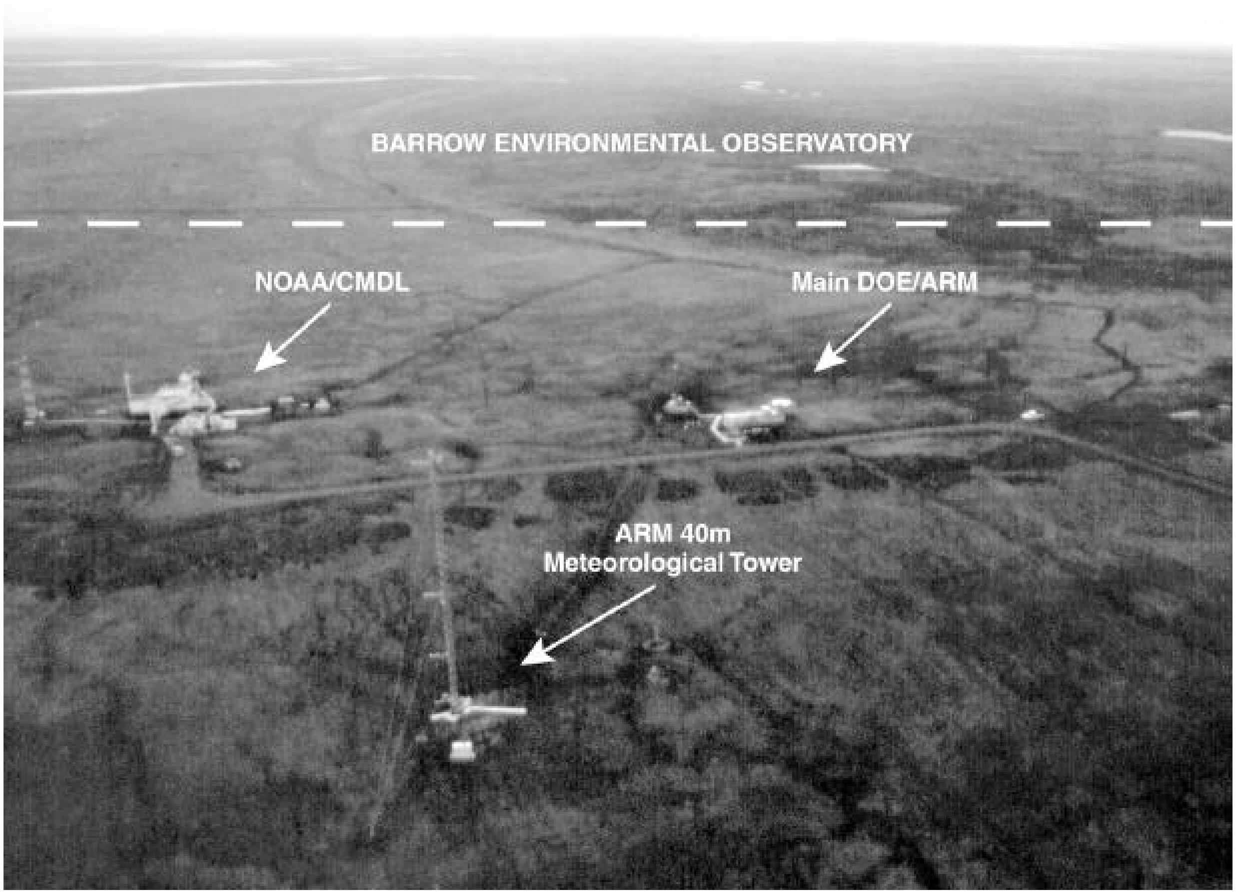

Figure 3.4. NOAA and ARM facilities adjacent to the BEO.

As at the other CART sites, instrumentation and equipment maintenance is handled in a stratified manner. The onsite operators handle many maintenance tasks either independently, or with telephone consulting support from Regional Service Team (RESET) members, instrument mentors, or data system engineers. However, the onsite operators are not expected to undertake maintenance procedures that exceed their expertise. For more demanding troubleshooting and other procedures, additional help is supplied. The second line of defense comes from the Geophysical Institute (GI) at the University of Alaska, Fairbanks (UAF): Rune Storvold and his assistant(s) form an analog to the TWP's RESET. It should be noted, however, that since the NSA/AAO RESET is only a little over an hour's flight from Barrow, visits by members of the team are managed on an "as-needed" basis, rather than having to be scheduled far in advance as at the TWP. RESET members also assist in instrumentation deployment and in the conduct of IOPs. For IOPs, the RESET can be augmented with graduate student help from UAF.

The third line of defense is the instrument mentor system. When neither the site operators nor the RESET team can find and fix a problem, the instrument mentors come more strongly into play. Each ARM instrument deployed at a CART site has an "instrument mentor" assigned to it who is particularly knowledgeable regarding their instruments. Marv Wesely at Argonne National Laboratory is responsible for mentor assignments and management of the instrument mentor system. The Site Data System requires the analog to instrument mentors as well. The group of data system engineers for the NSA/AAO CART site is managed by Cindy Turney of Pacific Northwest National Laboratory (PNNL). Depending upon the circumstances, the instrument mentors or data system engineers either come to the site to do the repairs in place, or arrange for the instrumentation or data acquisition hardware to be shipped to them at their home institutions. For software problems, the necessary changes can be made remotely using the T1 line. The final line of defense consists of the original equipment manufacturers.

3.3 Data Quality Assurance

A team of academic researchers under the direction of a Site Scientist is charged with assuring data quality at each CART site. To ensure that the data collected by the ARM instrumentation are of "known and reasonable quality" (an explicit goal of ARM), the quality assurance (QA) operators within the Site Scientist's group at GI, UAF, routinely carry out specified tasks to implement the Data Quality Plan. This plan is presented in a manual titled *ARM NSA/AAO Data Quality Assurance* (Storvold et al. 2000; in preparation) that describes the procedures developed to implement QA for the NSA/AAO site. The QA procedures for the NSA/AAO were modeled after the QA procedures developed for the TWP site, appropriately extended and modified for the changed circumstances. These procedures are implemented on a daily basis, 5 days a week. A weekly status report is prepared by the QA team at UAF that incorporates all of the status information they have acquired from all sources, including their own observations, onsite operators, instrument mentors, and data users. Standardized summary reporting on data status is also being developed through the ARM Metadata System. That system is not yet fully in place.

4. Atqasuk

4.1 Instrumentation

The instrumentation presently being deployed at Atqasuk is the same as that deployed at SHEBA, but with minor additions. There is no ARM instrumentation presently scheduled to be deployed at Atqasuk that is not also deployed at Barrow. Rather, the Atqasuk instrumentation is a subset of that at Barrow (see Table 3.1). The differences in instrumentation at Atqasuk, which are noted in Table 3.1, are as follows:

- Under the heading Surface Meteorological Sensors: no 40-m tower (instead, a 10-m tip tower with wind speed, wind direction, temperature and humidity at 2 m and 10 m); no present schedule for deployment of either an optical precipitation gauge or a standard precipitation gauge.

- Under Wind, Temperature, and Humidity Sounding Systems: no 915-MHz Radar Wind Profiler with radio-acoustic sounding system (RASS); radiosondes only during IOPs.

- Under Cloud Observation Instrumentation: no Millimeter Cloud Radar; no Micropulse Lidar.

- Under Downwelling Radiation: no UV instrument; no CIMEL sunphotometer; no duplicate PSPs and PIRs (only one set to be on site). The issue of whether to deploy the extended-range atmospheric emitted radiance interferometer to Atqasuk is not yet firmly decided.

- Under Upwelling Radiation: no current schedule for deployment of a downward-pointing video camera; no duplicate PSPs and PIRs (only one set to be on site).

- Under Aerosol Instrumentation: none.

- Under Gas Instrumentation: none.

The location for the instrumentation in the vicinity of Atqasuk is indicated in Figure 4.1. The original proposal was for the PAARCS and associated shelters to be located on the pad at the end of the spur road for the long term. That would have been the most cost effective. However, the Atqasuk Corporation indicated that this proposal would not be acceptable for the long term. Although the spur road ends at the pad at the present time, it is planned that the road be extended at a later date. So, the ARM shelters must not block passage through the pad area. For the longer term, the instrumentation will be deployed adjacent to the pad on land leased from the Atqasuk Corporation either on pilings or on an extension of the gravel pad which forms the turn around.

Power and phone service were available along the main road connecting Atqasuk with its airport. Power poles and a power line as well as phone service were installed along the spur road from the main road to the pad area to support the PAARCS deployment.

It should be clear from the aerial photo that Atqasuk is a small community with a population of about 225. However, it does have a police station, power plant, and water delivery and sewage pickup service, thrice daily air service to and from Barrow, telephone and cable television service, a health clinic, a hotel, restaurant and store—altogether, a remarkable infrastructure considering Atqasuk's size and location. Note, however, that there is no year-round road to Barrow.

4.2 Operations

Although it would be highly desirable to have the Atqasuk facility be a mirror image of that at Barrow, and to operate it in the same manner as Barrow, anticipated budgetary constraints make that infeasible. So, the issue is how to operate the Atqasuk facility in a manner that yields the most favorable cost-benefit ratio, while still holding costs in the affordable range. The present plan is to operate the low maintenance meteorological and radiometric instrumentation continuously, but to only operate the facility in a "full up" condition during IOPs and other scheduled periods. Since the inland Arctic Slope environment is not well known, even the limited subset of data streams that it is planned to acquire continuously will be of great value. These data streams will provide a unique data set on which modelers can begin to build.

Figure 4.1. Aerial photo of Atqasuk with instrumentation location.

Individuals living in Atqasuk who are willing and able to serve as part-time local site operators have been identified. One of these individuals, James Ivanoff, manages the physical plant operated by NSB Village Services in Atqasuk (power plant, water plant, airport, etc.). The other individual, Melvin Wong, is also an NSB employee at the power plant. It is planned that an abbreviated set of daily rounds be implemented at Atqasuk, 5 days a week, as at Barrow. It is expected that the abbreviated rounds will take one to two hours per day.

Maintenance of the instrumentation at Atqasuk would be largely handled as an extension of Barrow. Maintenance experience would be taken into account in determining which instrumentation would be operated continuously and which would operate only during IOPs.

4.3 Data Quality Assurance

Data Quality Assurance will be handled in very much the same way as for Barrow. However, the satellite data line will not allow all data during IOPs to be checked in real time. Hence, some limited sampling scheme will need to be worked out for those few instruments that may be deployed with high bandwidth requirements. Very likely, the whole sky imager (WSI) will be one such instrument. Currently, the bulk of data transfer from Atqasuk is by removable hard disks shipped out weekly.

5. Oliktok Point and Beyond

The third potential instrumentation site has been proposed for the vicinity of Oliktok Point (Figure 5.1). Oliktok Point is on the Arctic Ocean to the east of Atqasuk and Barrow, and climatologically upwind from Atqasuk. That’s because over the North Slope, the wind direction rose peaks sharply from the east northeast (Figure 5.2). Oliktok’s location is desirable for transition zone and CB/SCM experiments (priorities 6 and 7). Oliktok 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. It is the only NSA/AAO facility site accessible by road from the lower 48 states. Hence, certain instrumentation that could not cost-effectively be brought into Barrow or Atqasuk for an IOP could be brought to Oliktok. For instance, it appears that the University of Utah scanning lidar falls into this category.

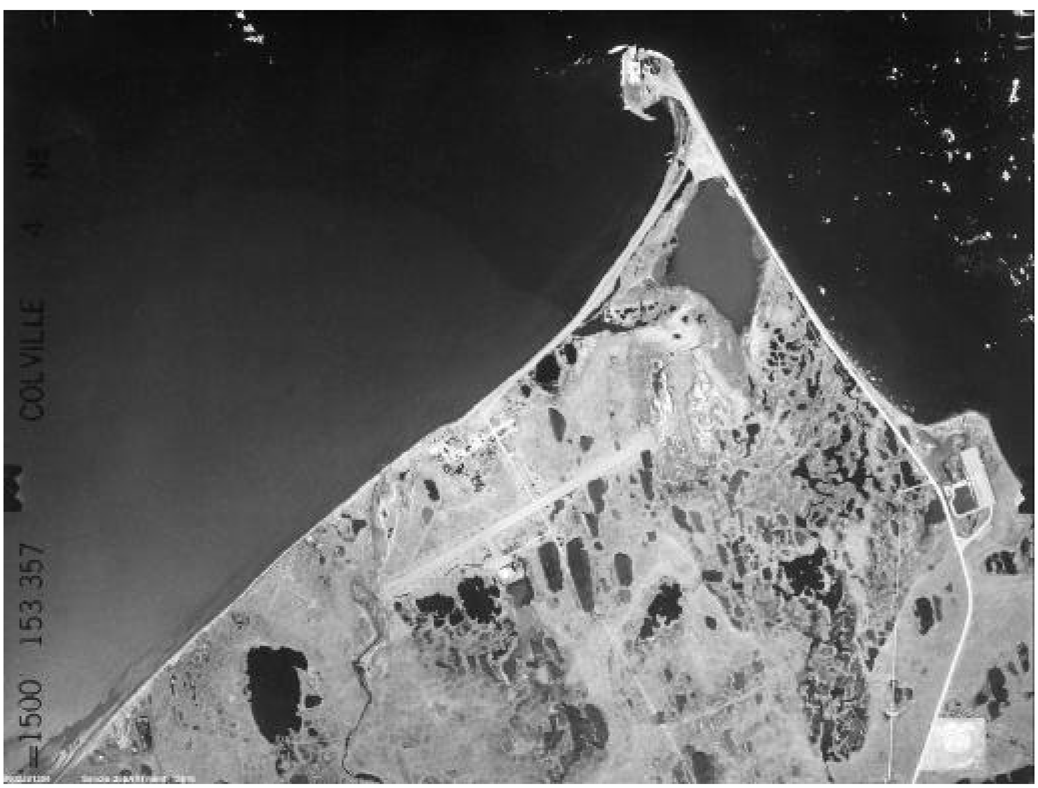

Figure 5.1. Oliktok Point with potential instrumentation location.

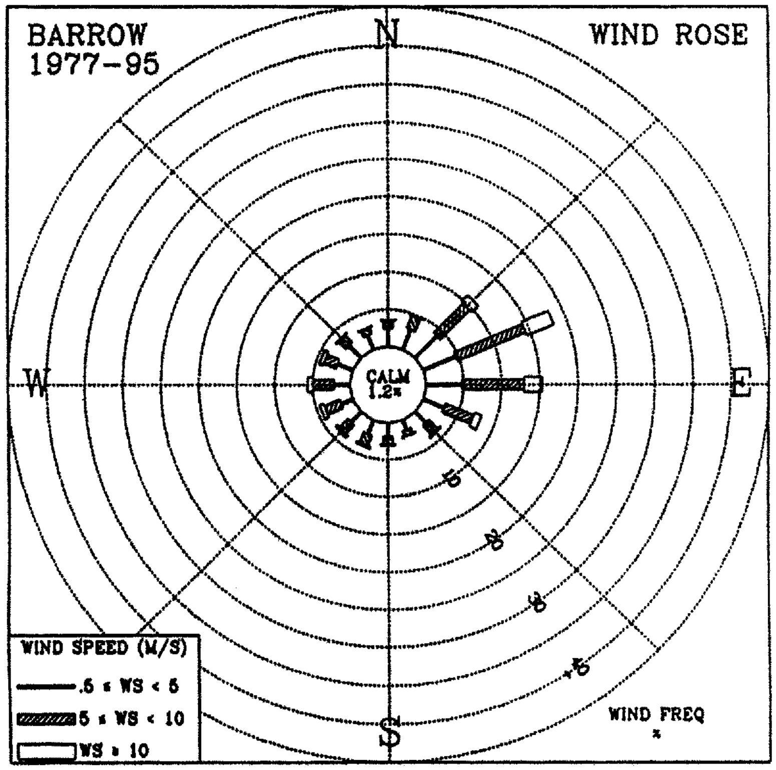

Figure 5.2. Barrow wind rose. Wind-determined shape of North Slope lakes suggests that this wind rose may be roughly applicable over the whole NSA/AAO CART site.

Oliktok's location and wind rose are such that most often, the air passing over Oliktok is coming in directly from the Arctic Ocean. An appropriate instrumentation location near the point would effectively be in the Arctic marine environment, and hence, measurements made there would be directly relevant to the "Adjacent Arctic Ocean," part of the NSA/AAO charter. Very likely, instrumentation could be located within 100 m or closer to the coast. This is in contrast to the situation at Barrow where the instrumentation is a mile from the coast of Elson Lagoon, which itself is several miles across. Oliktok Point also tends to create lee polynyas—areas of open water downwind of points or islands that remain open for extended periods during winter. Ice motion is responsible for this phenomenon. Hence, Oliktok could be an excellent location for the study of high heat and moisture fluxes—one of the "targets of opportunity of importance to ARM" that the NSA/AAO offers.

Oliktok also is the only logistically convenient place at the NSA/AAO CART site where the Federal Aviation Administration (FAA) is relatively comfortable with the use of tethered balloons. Barrow is within an FAA-defined instrument approach zone, and the FAA tells us that Atqasuk soon will be. Oliktok is sufficiently far from Deadhorse-Prudhoe Bay and other airports that tethered balloons flown here pose little hazard to air traffic. The FAA recommends that we seek restricted air space designation at Oliktok for use with tethered balloons. This possibility is being explored. With restricted air space, the "owner" can declare the area "active" (with appropriate lead time) at their own discretion. When the area is active, there are very few restrictions on the use of tethered balloons. Most FAA rules do not apply in active restricted air space (e.g., that tethered balloons may not fly in or near clouds, or that tethered balloons may not exceed an altitude of 500 ft).

With NSF/SHEBA funding, the Site Scientist's group at UAF together with Paul Lawson of Stratten Park Engineering Consultants (SPEC) and Randy Borys of Desert Research Institute (DRI) have developed a tethered balloon instrumentation system with a powered tether that would make stratus cloud microphysical characterization much more affordable than using instrumented aircraft. A tethered balloon can stay aloft continuously for days, gathering far more data than is feasible with an instrumented aircraft costing in excess of $1,000/hour for flight time alone. Furthermore, for the comparison of in situ cloud measurements with ground-based remote sensing profile measurements, the balloon-borne package is always in the right place—above the remote sensors.

Just as for Atqasuk, it would be highly desirable to have an Oliktok facility be a near mirror image of that at Barrow, and to operate it continuously in the same manner as Barrow. However, anticipated budgetary constraints for Oliktok are likely to be even more severe than for Atqasuk. So the challenge is to develop an operational concept that preserves as much as possible the benefit from an Oliktok facility while minimizing the cost. Interpreting Oliktok as an IOP and/or campaign instrumentation site only seems most realistic at this point in time.

Barrow, Atqasuk, and Oliktok can be viewed as boundary facilities for SCM experiments. In the traditional SCM view, multiple simple (automated weather station) measurement sites distributed over the enclosed area would also be needed for SCM experiments. While deploying many such sites at the NSA/AAO would be physically possible, it is doubtful that under present circumstances, it would be financially feasible. An alternative may be a few such sites augmented with repeated surface characterization measurements on an IOP-only basis using an ultralight aircraft, frequently deployed on the North Slope by San Diego State University (Walt Oechel) and NOAA/Atmospheric Turbulence & Diffusion Division (ATDD) (Steve Brooks).

6. Educational Outreach

Each CART site has an educational outreach component to its program. While there are several motivations for ARM educational outreach, a particularly strong motivation at the NSA/AAO site is to help build a mutually supportive relationship with the communities in which we operate. In the Arctic, both individuals and organizations really need each other. Here, functioning in a supportive social environment could be only slightly more difficult than functioning in a less environmentally hostile locale. But if the social environment here were not supportive, functioning could be nearly impossible.

The underlying assumption for the NSA/AAO educational outreach program is that people cannot support what they do not understand. Hence, there is a strong effort to disseminate information on what the ARM NSA/AAO effort is all about. This effort consists of ARM participants making presentations as part of the regular BASC-sponsored lecture series, and on request at schools and to other local groups; making visiting ARM researchers available for interviews to the news staffs of the local public radio station (KBRW) and North Slope print media; participating in the local scientific community;

involvement with the Inupiat Heritage Center; offering public site tours in connection with local celebrations; providing general openness and responsiveness to any and all inquiries from both official sources and the general public; as well as supporting more formal programs for K-12, and through the community college as described below.

A principle we've adopted for the educational outreach effort is that the effort should be driven by the desires of the people to whom we are reaching out. The effort should not be designed by project personnel and imposed from outside. Rather, the outreach effort should evolve with the full participation of the local community.

With these considerations in mind, a white paper on the outreach program was prepared, and meetings were held with various representatives of the North Slope Borough School District (NSBSD). A program suggested by the teachers evolved in which small "contracts" (Sandia National Laboratories does not have granting authority) were let to individual teachers and groups of teachers for science project support. Support was limited to $2,000 per teacher, and was awarded on the basis of brief competitive proposals submitted in response to an announcement of opportunity. This approach addresses a problem that the teachers have. While the school district has been relatively affluent (because of North Slope oil revenues), it has been nonetheless difficult for teachers to obtain any funds to pursue innovative science projects for their students. Roughly a dozen such projects have now been funded over the last few years through ARM.

Within a year or so of starting this effort, it became clear that it would work best if the individual science projects were on a two-year cycle. What is proposed one year is to be carried out the next. This schedule allowed the initiation of a parallel effort in alternate years through Ilisagvik College, the community college for the North Slope located in Barrow. Ilisagvik reaches out to the more remote villages on the North Slope through distance learning techniques (primarily teleconference courses). We have now completed one year of the effort through the community college. Three of the more interesting projects are noted below. One involved seeking out stands of dwarf trees on the North Slope. Trees are not generally found on the North Slope, but there are reports that small stands of trees are beginning to be found here, perhaps as a result of climatic warming. Another project involved the construction of a "model solar system" in Barrow, with the sun located at the elementary school, and signs for the various planets at appropriate distances from the sun located around Barrow (Figure 6.1). A third involved the procurement of a 7-inch Meade telescope for an astronomy class offered to the community through the college. For each project, connections are made to what is being done in the ARM program. The astronomy connection is particularly interesting. It is now generally believed that the cycling between full ice age and interglacial climatic conditions that has occurred about every 100,000 years over the last two million years is driven largely by astronomical effects on the earth's orbit and the orientation of the earth's axis (Milankovitch theory).

The Arctic Research Consortium of the U.S. (ARCUS) staff in Fairbanks, Alaska, administers the ARM educational outreach program for the NSA/AAO site.

Figure 6.1. Earl Finkler with the sign for the sun, part of the model solar system deployed around Barrow as he proposed.

7. Management and Personnel

The NSA/AAO CART Site Manager is Bernie Zak of Sandia National Laboratories. He is responsible for the planning, development, and operation of the NSA/AAO CART site. He is assisted part time by Associate Site Manager Wayne Einfeld, and administrative assistants Jean Burstein and Michelle Nelson, under contract to Sandia. Einfeld has taken on responsibility for site environment, safety and health. The NSA/AAO Site Scientist is Knut Stamnes of the GI, UAF. He is responsible for data QA and data quality control (QC) on a routine and ongoing basis. The Site Scientist team assisting Stamnes in the development and implementation of the QA/QC procedures, consists currently of Sharon Kessey (administrative assistant), Gus Lindquist (programmer/ analyst), Wei Li (research associate) and research assistants, Hans Eide, and Rune Storvold. The Site Scientist operation is under the direction of the ARM Chief Scientist, Tom Ackerman of PNNL. Storvold and others at UAF also assist in site operations, serving as a nearby emergency response (RESET) team when problems arise. The NSA/AAO Site Engineer is Kevin Widener of PNNL. He is responsible for implementing the site scientific design in hardware. Until recently, Widener served as Technical Operations Task Leader, assuring that the site instrumentation and supporting hardware function properly on a day-to-day basis. In this role, he oversaw the efforts of the NSA/AAO Site Operations Contractor, UIC Science Division. Jeff Zirzow of Sandia recently assumed the Technical Operations Task Leader role to permit Widener to undertake larger responsibilities within ARM. Cindy Turney of PNNL is responsible for the NSA/AAO site data system. She and her associates are part of the ARM Engineering Team which serves the SGP and TWP CART sites as well. Operations onsite at Barrow and Atqasuk were described in Sections 3 and 4, respectively. The ARM Operations Manager at the NSA/AAO site is Doug Sisterson of Argonne National Laboratory.

8. References

DOE, 1991: Identification, Recommendation and Justification of Potential Locales for ARM Sites. U.S. Department of Energy Report 0495T.

Stamnes, K., R. G. Ellingson, J. A. Curry, J. E. Walsh, and B. D. Zak, 1999: Review of Science Issues, and Deployment Strategy for the ARM North Slope of Alaska/Adjacent Arctic Ocean (NSA/AAO) Climate Research Site. *J. Climate*, **12**, 46-63.

Zak, B. D., K. Stamnes, and K. Widener, 2000: North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART): Science, Siting and Implementation Strategy. U.S. Department of Energy Report (in press).