The North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO) Cart Site Begins Operation: Collaboration with SHEBA and FIRE

B. D. Zak, H. Church, M. Ivey, L. Yellowhorse, and J. Zirzow
Sandia National Laboratories
Albuquerque, New Mexico

K. B. Widener, P. Rhodes, C. Turney, and A. Koontz
Pacific Northwest National Laboratory
Richland, Washington

K. Stamnes, R. Storvold, H. A. Eide, and P. Utley
Geophysical Institute
University of Alaska
Fairbanks, Alaska

R. Eagan, D. Cook, D. Hart, and M. Wesely
Argonne National Laboratory
Argonne, Illinois

Introduction

Since the 1997 Atmospheric Radiation Measurement (ARM) Science Team Meeting, the North Slope of Alaska and Adjacent Arctic Ocean (NSA/AAO) Cloud and Radiation Testbed (CART) site has come into being. Much has happened even since the 1998 Science Team Meeting at which this paper was presented. To maximize its usefulness, this paper has been updated to include developments through July 1998.

Barrow Site

On July 1, 1997, the ARM NSA/AAO CART site was dedicated by local North Slope officials and by Dr. Martha Krebs, who heads the U.S. Department of Energy's (DOE's) Office of Energy Research. The main facility is located near Barrow, Alaska, and has its sensors on National Oceanic and Atmospheric Administration (NOAA) land adjacent to the NOAA Climate Monitoring and Diagnostics Laboratory (CMDL) Barrow station (Figure 1). The NOAA land borders the Barrow Environmental Observatory (BEO) (Figure 2), an area protected from development and set aside for environmental research by the Ukpeagvik Inupiat Corporation (UIC), the corporation owned by the native residents of Barrow. Management of the BEO is supported in part

Figure 1. Location of the Barrow ARM NSA/AAO facility. Atqasuk and Olikotok are other locations within the ARM NSA/AAO locale where additional ARM instrumentation may eventually by located.

by the National Science Foundation (NSF). Over the past several decades, much high latitude environmental research has been conducted on this land. The NSA/AAO's data acquisition system and offices are in the UIC-(former) Naval Arctic Research Laboratory (NARL) complex about 2 km from the sensors. The basic instrumentation for the Barrow ARM facility was installed during 1997 and early 1998. The CART site began routinely producing data streams in April of 1998.

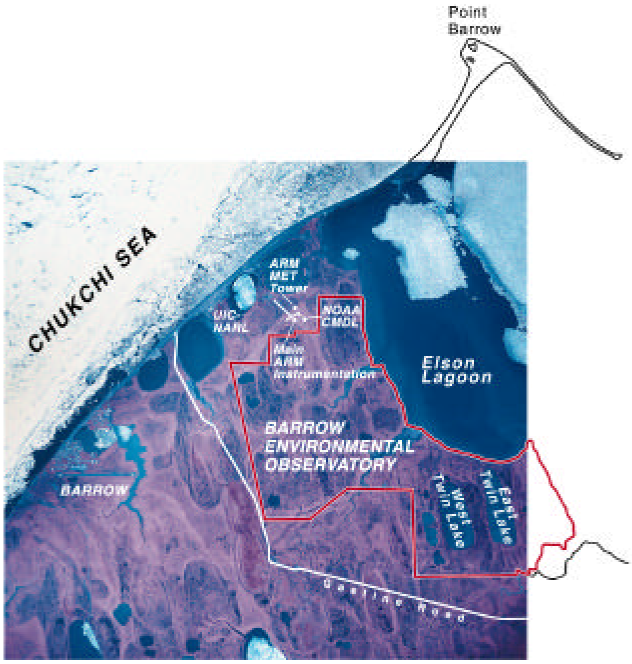

Figure 2. Aerial view of the Barrow region, showing the locations of the ARM and NOAA instrumentation relative to the BEO and the UIC-(former) NARL. (For a color version of the figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zak-98.pdf*.)

Figure 3. The main ARM instrument shelter on NOAA land as the instrumentation was being installed. (For a color version of the figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/zak-98.pdf*.)

The ARM instrumentation at the NSA/AAO site includes both broadband and spectral radiometric instrumentation covering the near UV (ultraviolet), the visible, and the IR (infrared)—that is, both the solar and the thermal segments of the spectrum (Table 1). The principal spectral instrument acquiring data in the IR is the extended range atmospheric emitted radiance interferometer (AERI-ER). This instrument covers the IR from below 4 to up to 26 micrometers with one wavenumber resolution. This broad coverage is necessary because in cold regions, the concentration of water vapor in the atmosphere is sufficiently low that the longer wavelength portion of this range (18-26 micrometers) opens up for atmospheric radiant energy transfer.

In addition, both in situ and remote sensing instrumentation is in place to document the instantaneous state of the atmosphere above the CART site (Figure 3). This instrumentation includes a micropulse lidar (MPL) for measuring cloud base, cloud and atmospheric characteristics; a zenith-staring millimeter cloud radar (MMCR) for recording the vertical distribution of clouds even when multiple layers are present; a multi wavelength whole sky imager (WSI) for documenting cloud coverage and type; and a dual channel microwave radiometer (MWR) for measuring integrated column water vapor and liquid water over the site. A 40-m meteorological tower provides data on the near-surface environment, where strong temperature inversions are frequently found in the Arctic. NOAA CMDL also makes continuous and episodic measurements on the gaseous and aerosol composition of the atmosphere, as well as on other climate-relevant parameters. In addition, the National Weather Service (NWS) routinely launches radiosondes at its Upper Air Sounding Station in Barrow, measuring profiles of temperature, humidity, and winds with altitude. The NWS sondes can be augmented, if needed, either at the NWS Barrow Station a few miles away, or at the ARM site itself.

The NSA/AAO CART site is ARM's cold region climate research facility. In cold regions, water vapor concentrations in the atmosphere are very low, and typically condensed water occurs not as liquid, but as solid: ice crystals, snow. These two facts fundamentally affect both radiative transfer and cloud behavior, both of which are within ARM's purview. It has long been known that the interplay of snow cover (which reflects much of the incoming solar energy) and surface temperature (which determines if the snow melts away or not) gives rise to several climate feedback mechanisms that together make high latitude regions particularly important to global climate.

Table 1. NSA/AAO current and near-term instrumentation.

Surface Meteorological Sensors	SHEBA	Barrow
-Wind Speed, Wind Direction, Temperature, Humidity (1 level)	SPO	NOAA/CMDL
-Tower, WS, WD, T, RH (2 m, 10 m, 20 m, 40 m)	No	Yes
-Dew Point/Frost Point Hygrometer (1 level)	SPO	NOAA/CMDL
-Dew Point/Frost Point Hygrometer (profiling, 2 m to 40 m)	No	Yes
-Optical Precipitation Gauge	No	Yes
-Standard Precipitation Gauges	NOAA	NOAA/CMDL
Wind, Temperature and Humidity Sounding Systems		
-MWR – column liquid water & water vapor	Yes	Yes
-915-MHz Wind Profiler w/RASS (WS, WD, T profiles)	No	Yes
-Millimeter Wave Temperature Profiler (MMTP- to 600 m)	No	Yes
-Radiosondes	SPO	W/NWS
-Raman lidar (water vapor, T profiles)	No	IOP
Cloud Observation Instruments		
-Millimeter Wave Cloud Radar	NOAA	Yes
-Micropulse Lidar (MPL)	NOAA	Yes
-Vaisala Ceilometer (VCEIL)	Yes	Yes
-Whole Sky Imager	Yes	Yes
Downwelling Radiation		
-AERI-ER, 4-26 microns	Yes	Yes
-Solar Spectral Flux Radiometer (SSFR)	NASA	No
-UV spectrometer	No	NSF/NARL
-Infrared Thermometer	Yes	Yes
-Cimel Sunphotometer (CSPHOT; 8 Wavelengths)	No	NASA
-Multi Filter Rotating Shadowband Radiometer (MFRSR)	Yes	Yes
-Normal Incidence Multi Filter Radiometer	Yes	Yes
-Precision Solar Pyranometer, Unshaded (PSP)	Yes	Yes
-Precision Solar Pyranometer, Shaded	Yes	Yes
-Normal Incidence Pyranometer (NIP; pyrheliometer)	Yes	Yes
-Precision Infrared Radiometer, Unshaded (PIR)	Yes	Yes
-Precision Infrared Radiometer, Shaded	Yes	Yes
-Ultraviolet B Radiometer (UVB)	Yes	Yes
-Net Radiometer (RN)	Yes	Yes
-Duplicate PSPs and PIRs	Yes	Yes
	Yes	NOAA/CMDL
Upwelling Radiation		
-Infrared Thermometer	Yes	Yes
-Precision Solar Pyranometer (PSP/US; 10 m)	Yes	Yes
-Precision Infrared Radiometer (PIR/UI; 10 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
-Particulate Carbon Concentration	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

Legend: SPO: Fielded by SHEBA Project Office; NOAA/CMDL: At NOAA/CMDL Laboratory, within 100 m of ARM instrumentation; W/NWS: Vaisala sondes flown for ARM by National Weather Service in Barrow, or can be launched at site for IOPs; IOP: for Intensive Observation Periods – typically 2-6 weeks; NOAA, NASA: fielded by these agencies at the respective sites; NSF/NARL: National Science Foundation Instrument at UIC-(former) NARL; RASS: Radio-Acoustic Sounding System.

But cold regions occur not only at high latitudes, but at high altitudes as well—not just on mountain tops, but high in the atmosphere over the entire surface of the earth. Thus, cold region phenomena are operative over the entire globe, not just at high latitudes. However, relatively little is known of radiative transfer and cloud processes under cold conditions, because the regions where they occur—high latitudes and high altitudes—are difficult for researchers to access. The ARM NSA/AAO CART site ameliorates this difficulty.

ARM Participation in SHEBA

SHEBA stands for Surface Heat Budget of the Arctic (Ocean). SHEBA is supported principally by the NSF's Arctic Systems Science (ARCSS) program and the Office of Naval Research, but other elements of the NSF and other agencies as well are also participating. The SHEBA experiment involves instrumenting a region of the Arctic ice pack, and collecting data on that region through one full year as it drifts with the pack ice. The instrumentation is designed to better quantify the energy flows between the ice and water at the surface, and the atmosphere above, as well as the ocean below. The objective is to learn how to more accurately incorporate Arctic climate processes in general circulation models (GCMs). The underlying question which SHEBA addresses is how the Arctic ice pack will respond to the ongoing and projected global warming.

There are many participants in SHEBA, one of which is the ARM NSA/AAO effort. ARM is participating in SHEBA by measuring the components of the radiative energy balance at SHEBA with instrumentation similar to that at Barrow. After being cold-tested at Barrow during winter 1996-1997, the ARM instrumentation for SHEBA was deployed the following fall. The SHEBA site is centered on the Canadian Coast Guard icebreaker Des Groseilliers frozen into and drifting with the Arctic ice pack since October 2, 1997 (Figure 4). A suitable ice flow to serve as the focus of SHEBA was found in the vicinity of 75° N and 143° W, and the Des Groseilliers was moored within it. This initial location was about 500 km north of Prudhoe Bay, Alaska. Since then, the flow drifted primarily west and then north, and as this is written, it is north of the Bering Strait at above 78° N latitude.

ARM Participation in FIRE

FIRE [First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment] Arctic Cloud is a National Aeronautics and Space Administration (NASA) project coordinated with both SHEBA and ARM that focuses on in situ measurements aloft using instrumented aircraft. During the spring and summer of 1998, a succession of FIRE aircraft made measurements over both SHEBA and the ARM site at Barrow. The Atmospheric Environment Service of Canada Convair 580 was the first to arrive on the scene in early April. It was followed by the University of Washington Convair 580 and the NASA ER-2 high altitude aircraft. The NSF's instrumented C130 came later. Each aircraft is differently equipped and undertook different missions. Some had multi-agency support.

Figure 4. Aerial view of the Canadian icebreaker Des Groseilliers with the SHEBA encampment growing around it shortly after it was moored to the ice. (For a color version of the figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/alberta-98.pdf*.)

Unlike the other aircraft, the University of Washington plane was based at Barrow. Consequently, it was ideally positioned to acquire data over the Barrow ARM facility. It flew a total of 23 research flights between mid-May and the end of June. Of these, ten included a focus on the Barrow ARM site. Most of the other flights focused on SHEBA.

Simultaneous data acquisition of atmospheric characteristic profiles by surface-based remote sensing techniques and by in situ aircraft within the same atmospheric column is essential for the validation of both surface and satellite-based remote sensors. For this reason, NASA looks to the ARM sites for much of the validation data for its remote sensing satellites. In the FIRE Arctic Cloud experiment, many of the University of Washington flights were also coordinated with high altitude overflights by the ER 2, which carried downward-looking remote sensors, essentially emulating a satellite. Satellite data as such were brought to bear as well.

Early Results

Although much of the data from ARM, SHEBA and FIRE have not been fully processed and analyzed as yet, certain observations already stand out. The models developed over the past several decades for radiative transfer in the 18-to-26 micrometer portion of the IR spectrum—a part of the spectrum particularly important for cold regions—represent the data poorly. Modifications have already been made to those models based on ARM NSA/AAO early results. At SHEBA, it was noted that the surface layer of the Arctic Ocean is significantly warmer and less saline than had been observed in the Arctic Ice Dynamics Joint Experiment (AIDJEX) two decades ago. In addition, to no one's surprise, the ice is now considerably thinner. The extent to which these latter observations represent permanent changes rather than variability is not yet certain.

Looking Ahead

These and the flood of results yet to be realized from "The Year of the Arctic" represented by SHEBA, the coming online of the ARM NSA/AAO CART site, and FIRE Arctic Cloud, will take years to be completely digested by the climate research community. But we're off to an exciting start. It is our anticipation that these results will probably raise as many questions as they answer. As new questions about cold regions arise, however, the ARM NSA/AAO site and its associated facilities will be in place to help future researchers address them.

Acknowledgments

Many of the U.S. Department of Energy (DOE) laboratories making important contributions to ARM and to the NSA/AAO CART site effort in particular, include Argonne National Laboratory, Brookhaven National Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, and Sandia National Laboratories. Several academic institutions do as well, the most notable being the Geophysical Institute at the University of Alaska Fairbanks. In addition, private and governmental organizations in the area play pivotal roles—here, especially UIC, the Barrow Arctic Science Consortium, and the North Slope Borough. Other agencies heavily involved include NSF, NOAA, NASA and NWS. The ARM NSA/AAO effort is included in the Arctic Climate System (ACSYS) program fostered by the International Arctic Science Committee (IASC).