U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-15-040

ARM West Antarctic Radiation Experiment (AWARE) Science Plan

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October 2015

ARM
CLIMATE RESEARCH FACILITY

DISCLAIMER

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Summary

West Antarctica is one of the most rapidly warming regions on Earth, and this warming is closely connected with global sea level rise. The discovery of rapid climate change on the West Antarctic Ice Sheet (WAIS) has challenged previous explanations of Antarctic climate change that focused on strengthening of circumpolar westerlies in response to the positive polarity trend in the Southern Annular Mode. West Antarctic warming does not yet have a comprehensive explanation: dynamical mechanisms may vary from one season to the next, and these mechanisms very likely involve complex teleconnections with subtropical and tropical latitudes. The prime motivation for this proposal is that there has been no substantial atmospheric science or climatological field work on West Antarctica since the 1957 International Geophysical Year and that research continued for only a few years. Direct meteorological information on the WAIS has been limited to a few automatic weather stations for several decades, yet satellite imagery and meteorological reanalyses indicate that West Antarctica is highly susceptible to advection of warm and moist maritime air with related cloud cover, depending on the location and strength of low pressure cells in the Amundsen, Ross, and Bellingshausen Seas. There is a need to quantify the role of these changing air masses on the surface energy balance, including all surface energy components and cloud-radiative forcing. More generally, global climate model simulations are known to perform poorly over the Antarctic and Southern Oceans, and the marked scarcity of cloud information at southern high latitudes has so far inhibited significant progress. Fortunately, McMurdo Station, where the Atmospheric Radiation Measurement Facility's (ARM's) most advanced cloud and aerosol instrumentation is situated, has a meteorological relationship with the WAIS via circulation patterns in the Ross and Amundsen Seas. We can therefore gather sophisticated data with cloud radars and high spectral resolution lidar and a complete aerosol suite at McMurdo that have relevance to the WAIS as well. At the same time, we will send basic radiometric, surface energy balance, and upper air equipment directly to the WAIS to make the first well calibrated climatological suite of measurements seen in this extremely remote but globally critical region in more than 40 years.

Using the original concept of ARM field measurements, we refer to the McMurdo deployment of the second ARM Mobile Facility (AMF2) as our central facility, and the additional equipment sent to the WAIS as our extended facility. Logistical considerations with Antarctic field work permit a realistic field program with the AMF2 at McMurdo, but preclude deployment of the entire AMF2 on the WAIS. Our proposed subset of instruments for the WAIS is chosen realistically to accommodate the limited LC-130 (Ski Hercules) transport aircraft flights that can reach the site. We will analyze data from this Antarctic AMF deployment in three thrusts: (1) provide quantitative information on WAIS energy balance components and cloud-radiative forcing as they relate to changing air masses and warm air advection, which are ultimately related to lower latitude teleconnections; (2) provide cloud microphysical data to evaluate and improve climate model performance in the coldest and most pristine environment on Earth, particularly with respect to the orographically induced high vertical velocities that give rise to larger cloud ice water amounts over Antarctica; and (3) fully characterize an annual cycle of aerosol properties combining the microphysical information from AMF2 with chemical composition analysis of samples performed at the University of California, San Diego (UCSD) Scripps Institution of Oceanography (SIO).

Acronyms and Abbreviations

AMF	ARM Mobile Facility
AMF2	second ARM Mobile Facility
AOS	aerosol observing system
ARM	Atmospheric Radiation Measurement
ASC	NSF-PLR Antarctic Support Contractor (Lockheed Martin)
ASD	Analytical Spectral Devices (Inc.)
AWARE	ARM West Antarctic Radiation Experiment
BPRC	Byrd Polar and Climate Research Center at The Ohio State University
C-17	U.S. Air Force Globemaster III heavy lift turbofan transport airplane
CCN	cloud condensation nuclei
CHC	Christchurch Airport, New Zealand
CONUS	continental United States
CosRay	Cosmic Ray Research Facility, Building 84 at McMurdo Station, Antarctica
DOE	U.S. Department of Energy
IOP	intensive operational period
ISO	International Organization for Standardization
IT	information technology
LAN	local area network
LANL	Los Alamos National Laboratory
LC-130	Lockheed ski-equipped Hercules turboprop transport airplane
MCM	McMurdo Station, Antarctica
NASA	National Aeronautics and Space Administration
NSA	North Slope of Alaska
NSF	U.S. National Science Foundation
PI	principal investigator
PLR	NSF Division of Polar Programs
QuickSCAT	NASA Earth-looking satellite radar scatterometer
RSP	Research Support Plan (USAP required document)
SAM	southern annular mode
SIO	Scripps Institution of Oceanography
SIP	Support Information Package (USAP required document)
SKIP	Self-Kontained Instrument Platform
UCSD	University of California, San Diego
USAP	U.S. Antarctic Program
UTC	Coordinated Universal Time
WAIS	West Antarctic Ice Sheet

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1.0 Introduction

The Atmospheric Radiation Measurement Facility (ARM) West Antarctic Radiation Experiment (AWARE) will be the first climate-related field campaign in West Antarctica in more than 40 years and will use some of the most advanced instrumentation currently available for atmospheric research. The suite of U.S. Department of Energy (DOE) ARM instruments is advanced and extensive such that a successful AWARE campaign will provide a data set for Antarctic climate and atmospheric research that will have lasting value for decades. Approved in April 2015, support from the U.S. National Science Foundation (NSF) Division of Polar Programs (PLR) is essential because of PLR's role in governing the U.S. Antarctic Program (USAP). PLR makes direct awards for Antarctic research (and will support the ARM principal investigators [PIs] for preliminary data analysis), provides logistical support for science programs of other agencies, and manages all Antarctic installations and logistics involving U.S. assets. Cargo arrives at McMurdo Station either by sea or by heavy lift (Air Force C-17) aircraft, most often via New Zealand. From there, it may be distributed to any number of smaller part-time field camps throughout Antarctica. To cover longer distances, for example to the West Antarctic Ice Sheet (WAIS) Ice Camp (1600 km from McMurdo), only the largest aircraft available on the continent can be used, the LC-130 (Ski Hercules). A field campaign of AWARE's scope must involve close collaboration between DOE and PLR program managers. This situation offers a unique opportunity to advance Antarctic atmospheric science through the compelling combination of PLR's experience with logistical support and ARM's experience operating forefront in situ and remote sensing instrumentation in challenging environments, which includes continuous operations at the North Slope of Alaska (NSA) in Barrow, Alaska, since 1997 (Stamnes et al. 1999).

2.0 Relevance to the DOE Mission

AWARE will support the DOE's Atmospheric System Research (ASR) Program in furthering its mission to "quantify the interactions among aerosol, clouds, precipitation, radiation, dynamics, and thermodynamics to improve fundamental process-level understanding, with the ultimate goal to reduce the uncertainty in global and regional climate simulations and projections."

AWARE is entirely congruent with the mission of the ARM Climate Research Facility, whose primary objective is "improved scientific understanding of the fundamental physics related to interactions between clouds, aerosols, and radiative feedback processes in the atmosphere."

3.0 Background

One of the world's three great ice sheets, the WAIS provides a geographic and climatological contrast between both Greenland and the much higher East Antarctic Plateau. The WAIS is situated in a relatively warm marine geologic basin and transports mass via fast-moving ice streams and outlet glaciers to the Weddell, Bellingshausen, Amundsen, and Ross Seas (Bindschadler 2006). In contrast to East Antarctica, which to first order can be viewed as a zonally symmetric dome, West Antarctica exhibits more complex topography. The two regions of highest terrain elevation are the Executive Committee range near the western coastline and the Ellsworth and Whitmore mountain ranges at the eastern extremity. Between these two high points, Ellsworth Land to the northeast adjoining the Antarctic Peninsula and Marie Byrd Land to the west adjacent to the Ross Ice Shelf meet to form a saddle-shaped junction. Whereas the steep and symmetric topography of East Antarctica often prevents penetration of moisture from synoptic weather systems, the topography and lower elevation of West Antarctica often allows moisture to penetrate far inland. Annual accumulation of precipitation over West Antarctica is three times that of the East Antarctic Plateau (Bromwich 1988; Bindschadler 2006). Our ARM deployment will be on this saddle-shaped divide in the geographic center of West Antarctica (Figure 1).

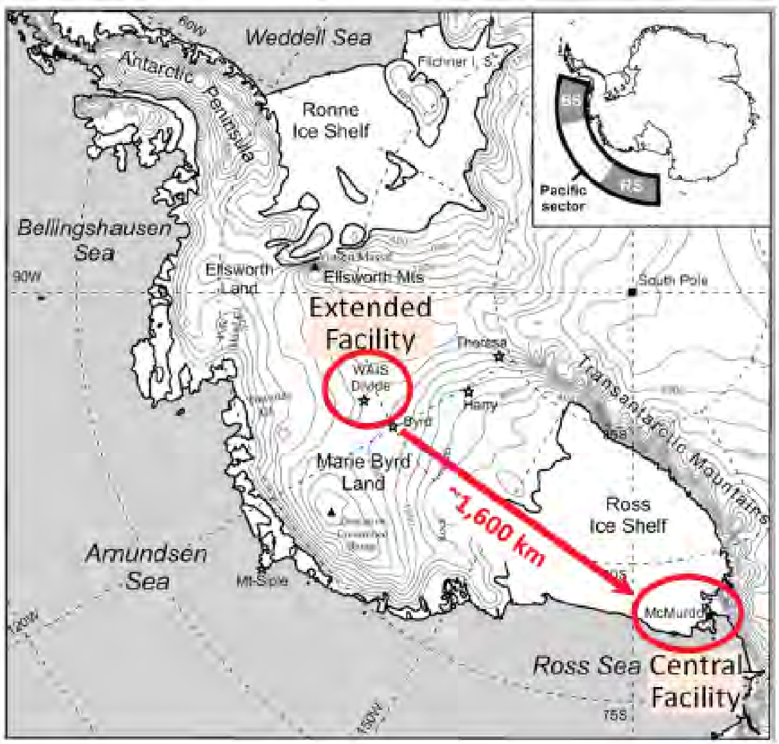

Figure 1. Locations for deployment of DOE AMF instrumentation for AWARE. Adapted from Nicolas and Bromwich (2011).

- Advection of warm air and moisture over West Antarctica is governed in large part by the location of cyclonic activity in the Bellingshausen versus the Ross and Amundsen Seas (Nicolas and Bromwich 2011). Low-pressure systems over the Ross Sea efficiently transport heat and moisture onto central West Antarctica, while lows over the Bellingshausen Sea tend to inhibit this transport (see the regions labeled BS and RS in the insert of Figure 1). Marine air masses steered by Ross and Amundsen Seas lows onto the WAIS manifest in an elongated pattern of increased cloud cover, pattern in 2-meter potential temperature, and snow accumulation. The saddle-shaped topography causes these marine air intrusions to descend onto both the Ronne-Filchner and Ross Ice Shelves, resulting in less cloud cover and precipitation farther away from the WAIS Divide in both directions. Intensification of the Ross Sea low pressure trough is directly linked to temperature over the grounded WAIS (Nicolas and Bromwich 2011).

For most of the previous two decades, climate change at high southern latitudes has been regarded in terms of pronounced multi-decadal warming on the Antarctic Peninsula (faster than the global average), a corresponding slight cooling over parts of the East Antarctic Plateau, and a slight net increase in Antarctic sea ice concentration integrated over the entire hemisphere. These contrasts with the high Arctic, which has exhibited pronounced warming and loss of sea ice throughout, have been reconciled with global CO_2-induced climate change by a radiative-dynamical interaction involving the Southern Annular Mode (SAM; Thompson and Solomon 2002; Kwok and Comiso 2002). However, as ice sheet loss has accelerated in the Antarctic Peninsula region (particularly the Larsen Ice Shelf), field work has extended farther south in this region into West Antarctica. By 2005, borehole thermometry revealed that the multi-decadal warming extended at least as far as the Rutford Ice Stream, which drains into the Ronne Ice Shelf (Barrett et al. 2009).

Steig et al. (2009) developed a reconstruction of surface temperature trends throughout West Antarctica by using satellite infrared imagery to bridge the sparse weather station records available since 1957. Between 1957 and 2006, the West Antarctic temperature trend was 0.17±0.06°C dec^{-1} (about 1°C warming in 50 years), according to this reconstruction. Focused on reconstructing the full temperature record from Byrd Station with the aid of meteorological reanalysis data, further analysis reveals a warming in central West Antarctica of 2.2±1.2°C between 1958 and 2010, with warming occurring in winter, spring, and mid-summer (Bromwich et al. 2013, 2014). These data indicate that West Antarctica is now established as one of the most rapidly warming regions on earth, requiring an urgent re-examination of governing mechanisms for climate change at high southern latitudes. For example, satellite-observed mass loss from the WAIS is equivalent to 0.28-0.56 mm yr^{-1} in sea level rise (Joughin and Alley 2011). It has long been understood (e.g., Mercer 1978) that the WAIS was not present during the last interglacial, in contrast to the higher East Antarctic Plateau, and that collapse of the WAIS was consistent with paleo-sea-level records from that period. Between 1996 and 2007, the Pine Island and Smith Glaciers have accelerated by 42% and 84% respectively, both becoming largely ungrounded, while the Thwaites Glacier has been widening. These rapid changes contrast with more modest losses recorded by field work in the 1970s. If the ungrounding progresses deeper inland (~250 km), it will extend over a subglacial floor that is well below sea level (Bindschadler 2006), increasing sea level rise to 1 mm yr^{-1} from the Pine Island Glacier alone (Rignot 2008; Favier et al. 2014).

As long as summer surface temperatures on the WAIS are below freezing, direct local atmospheric contribution to ice sheet loss should remain negligible (Joughin and Alley 2011), and the major source of stress on the WAIS will be oceanic (e.g., Pritchard et al. 2012). However, satellite microwave signatures in NASA QuickScat data over West Antarctica during summer 2005 are consistent with widespread surface melting (Nghiem et al. 2005) that, should it become more prevalent, could become a significant additional stress through enhanced growth of crevasses by hydrofracturing from the meltwater, as has been observed on the Larsen B Ice Shelf (Scambos et al. 2000) and in Greenland (Das et al. 2008).

For this now well documented West Antarctic warming to occur, the atmospheric connection between high southern and lower latitudes must be more complex than previously understood. For example, there is no simple relationship between West Antarctic warming and either the El Niño Southern Oscillation or the SAM (Ding et al. 2011). Different explanations may prevail in different seasons. In winter, a Rossby wave train linking anomalous central tropical Pacific sea surface temperatures to higher geopotential heights over West Antarctica appears to be a plausible mechanism (Ding et al. 2011). In spring, lower geopotential heights in the South Pacific related to the Pacific South American mode may have enhanced warm air advection over West Antarctica (Schneider, Deser, and Okumura 2012). Li et al. (2014) proposed that long-term warming of the Antarctic Peninsula in the non-summer months is primarily due to Atlantic Ocean surface warming transmitted by atmospheric Rossby wave propagation, and this impact may extend to West Antarctica, as similar results have been obtained by Simpkins et al. (2014). West

Antarctic warming during the height of summer has so far been more difficult to explain. Part of the time series (late 1980s) may result directly from a deepening and westward shift of low pressure over the Amundsen and Ross Seas, which would enhance northerly warm air advection, while in other parts of the time series, sea surface temperature trends in the subtropical South Pacific Convergence Zone may play an important role, particularly in offsetting SAM-induced cooling (Bromwich et al. 2013).

These hypotheses, which need further testing and confirmation, all imply that warm air advection drives much of the change over West Antarctica. At the same time, the moisture and cloud advection (Nicolas and Bromwich 2011) implies a concomitant positive cloud-radiative feedback. Moreover, these teleconnections with lower latitudes also affect winds at the edge of the continental shelf, which in turn impacts circumpolar deep water on West Antarctic ice shelves (Dutrieux et al. 2014). Thus, successfully explaining and confirming the atmospheric teleconnections have a bearing on the oceanic mechanism for stress on the WAIS.

The timeliness of these questions is underscored by a recent discovery (Nicolas and Bromwich 2014) that the spatial extent of West Antarctic warming is larger than that originally found by Steig et al. (2009). Figure 2 shows that the warming trend extends from West Antarctica through the Ross Ice Shelf, encompassing Ross Island and McMurdo Station, and onto significant portions of the higher East Antarctic Plateau. Squares denote the locations of the 15 stations used as anchor points for the spatial interpolation, and thick black lines encompass areas where trends are statistically significant at 95%.

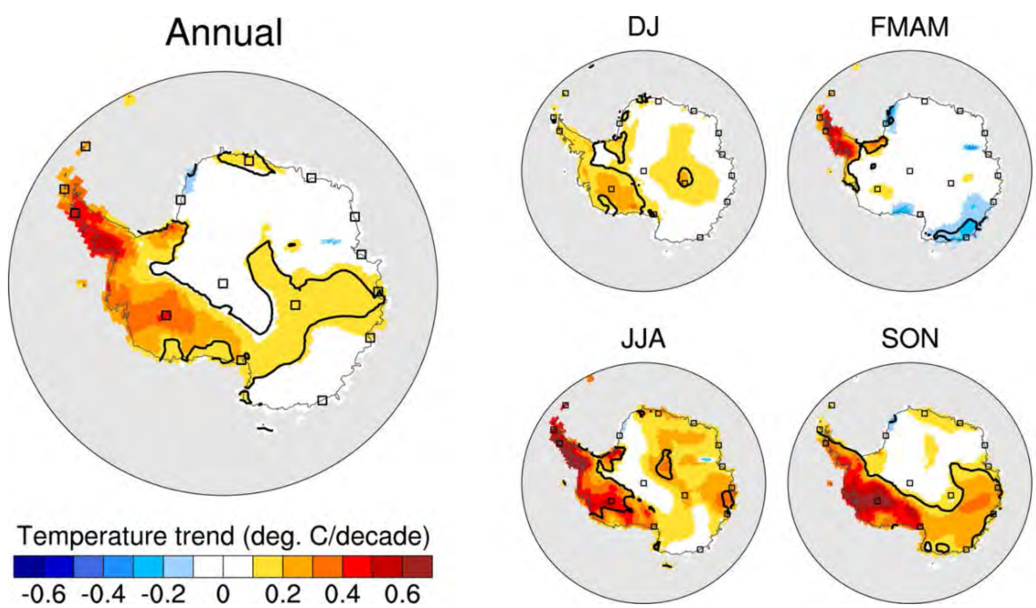

Figure 2. Linear trends in Antarctic near-surface temperature calculated for the 1958−2011 period and based on spatially interpolated monthly temperatures (Nicolas and Bromwich 2014).

The implication for this AWARE field program is that observations from both the WAIS and Ross Island have a climatic connection.

4.0 Deployment Strategy

Deploying significant instrumentation to a remote Antarctic site such as the WAIS is both expensive and highly constrained by limited USAP logistical resources. It is not as straightforward as previous international ARM AMF campaigns where, despite great distance from the mainland United States, major airport and overland transport infrastructure were available. For AWARE, we must adapt to the unique realities of Antarctic fieldwork. For example, the WAIS Ice Camp is a small summer-only facility, with between two and three LC-130 flights available to deploy AMF2 equipment. The entire AMF2 would require at least nine LC-130 flights each way. Even if this many flights were available, the WAIS Ice Camp would not be able to provide sufficient power for the entire AMF2. Therefore, we must select a subset of ARM equipment that provides the greatest impact for climate science on the WAIS and can also work within the stringent logistical constraints.

AWARE is comprised of two deployments: the full AMF2 at McMurdo Station, beginning operation in mid-October 2015 and continuing through the summer 2016-17 field season, and an additional, smaller suite of instruments on the WAIS, transported from McMurdo in October and operating for 75 days between November 2015 and January 2016. These two deployments can be regarded as the AWARE "Central Facility" and "Extended Facility," respectively. Although less capable than the full AMF2, the AWARE instruments slated for the WAIS have been chosen carefully to provide the greatest value for climate science given the transportation, power, and station operation constraints specific to the WAIS Ice Camp.

It is important to note that locating the full AMF2 at McMurdo is not just a choice for logistical convenience. Although McMurdo is one of the few locations in Antarctica that could possibly support the entire suite of AMF2 instrumentation, this area has direct meteorological connections with the WAIS. As discussed above, the West Antarctic warming trend is now known to extend spatially as far as Ross Island, and air masses containing moisture and cloud cover are often seen to transit the WAI to the Ross Ice Shelf and arrive at McMurdo, where they can be observed by the AMF2.

5.0 Science Objectives

The primary objective of AWARE on the WAIS is to characterize the atmospheric and surface energy budget, and atmospheric thermodynamic structure, as completely as possible with available logistics and instrumentation in order to garner a data set that can be interpreted in the context of large-scale atmospheric dynamics to understand specific warming mechanisms over West Antarctica. The primary objectives of AWARE at McMurdo are to understand empirically the unique Antarctic manifestations of mixed-phase clouds and aerosols and their effect on the radiation budget and, using the most advanced atmospheric instrumentation available, to examine microphysical properties of clouds that have recently descended from the WAIS to Ross Island via the Ross Ice Shelf. These goals require measurements of the following:

1. Surface energy balance, including downwelling and upwelling shortwave and longwave radiation, and surface fluxes of momentum, moisture, precipitation, and latent and sensible heat.

2. Spectral downwelling radiation measurements in the shortwave and longwave, to relate cloud microphysical properties and atmospheric aerosol and moisture content to the broadband radiation components at the surface, and to make independent retrievals of cloud optical properties for closure study in comparison with the active sensor data.
3. A complete inventory of cloud properties, including the basic properties of cloud type, cloud fraction, cloud base, and geometrical thickness (WAIS and McMurdo), and more advanced and altitude-dependent measurements of cloud particle size distribution, thermodynamic phase, cloud particle vertical velocity, and precipitation rate and type (McMurdo).
4. A complete inventory of aerosol properties (McMurdo), including chemical composition, particle size distribution, cloud condensation nuclei (CCN) behavior, hygroscopic behavior, and light-scattering properties.
5. The atmospheric state, including surface measurements and vertical profiles of temperature, pressure, relative humidity, wind speed, and direction.

6.0 Measurement Requirements

At McMurdo, measurements from the full suite of AMF2 instruments can be made essentially as at any land site where the AMFs have been situated, although there are some unique logistical challenges and minor restrictions on instrument operation to avoid radar interference with other station activities (see the Logistics section, below). At the WAIS, we need to deploy the most complete suite of instruments possible that can be operated from one small container and with power available at that small, summer-only research station. Because of the need to relate the WAIS energy budget measurements to large-scale dynamics, we require emphasis on vertical profiling both with a microwave vertical profiling radiometer and with sondes. The normal schedule for sondes at WAIS is at least twice daily, at 00:00 and 12:00 UTC, but we require a reserve so that we can increase the schedule to four times daily (00:00, 06:00, 12:00, 18:00) during intensive operation periods (IOPs) that may merge. One example of an IOP would be a warm, moist airmass being advected over West Antarctica from the Southern Ocean with a concomitant change in vertical profiles of temperature, moisture, and cloud properties. An IOP over the WAIS can only be identified by daily monitoring of large-scale atmospheric transport through global and regional modeling that will be done at Byrd Polar and Climate Research Center (BPRC, Bromwich 1988); therefore, we need daily communication with the WAIS station to adjust the sonde schedule as necessary.

7.0 Instruments

Table 1 and Table 2 list the instruments to be deployed at WAIS and McMurdo. Much of the WAIS equipment contains duplicate (additional) instruments of their counterparts with the main AMF2 at McMurdo. Some instruments (indicated by an asterisk) are singles that will be deployed first at WAIS and then reinstalled at McMurdo when the WAIS container is removed by late January 2016.

Table 1. Instruments Deployed to West Antarctic Ice Sheet.

Instrument Name	Instrument Acronym	Quantities Measured
Upward-looking precision spectral pyranometer	SKYRAD PSP	Downwelling total shortwave irradiance
Upward-looking Eppley model 8-48 diffuse pyranometer	SKYRAD 8-48	Downwelling diffuse shortwave irradiance
Upward-looking precision infrared radiometer	SKYRAD PIR	Downwelling longwave irradiance
Upward-looking Infrared thermometer	SKYRAD IRT	Sky equivalent blackbody temperature
Downward-looking precision spectral pyranometer	GRNDRAD PSP	Upwelling shortwave radiation reflected by surface
Downward-looking precision infrared radiometer	GRNDRAD PIR	Upwelling longwave radiation emitted by surface
Downward-looking Infrared thermometer	GRNDRAD IRT	Surface equivalent blackbody temperature
Cimel sunphotometer	CSPHOT	Multispectral direct solar irradiances
Multifilter rotating shadowband radiometer	MFRSR	Direct normal, diffuse horizontal, and total horizontal irradiances at six standard wavelengths
Analytical Spectral Devices (ASD) FieldSpec Pro shortwave spectroradiometer (SIO)	ASD	Downwelling spectral shortwave irradiance 350-2200 nm
Eddy correlation flux measurement system	ECOR	Surface turbulent fluxes of momentum, sensible heat, latent heat, and carbon dioxide
Total sky imager	TSI	Cloud fraction
Vaisala ceilometer	VCEIL	Cloud base height
Parsivel optical disdrometer	PARSIVEL	Precipitation particle size distribution and fall speed
Vaisala present weather detector	PWD	Visibility, precipitation detection
G-band vapor radiometer	GVRP	High-time-resolution water vapor and temperature profiling, and column-integrated liquid water and water vapor
Microwave radiometer, two channel	MWR, 2C	Column-integrated liquid water and water vapor
Balloon-borne sounding system	SONDE	Vertical profiles of T, P, RH, wind speed and direction
Meteorological instrumentation at AMF	MET	Near-surface (2 m) T, P, RH, wind speed and direction

Table 2. Instruments Deployed to Ross Island (McMurdo Station CosRay Site).

Instrument Name	Instrument Acronym	Quantities Measured
X-band and Ka-band scanning ARM cloud radar	SACR	Cloud particle co-polar and cross-polar radar reflectivity, Doppler velocity, linear depolarization ratio, differential reflectivity
Scanning W-band ARM cloud radar	SWACR	Cloud particle radar reflectivity, Doppler power spectrum
Ka-band ARM zenith radar	KAZR	Cloud particle Doppler moments (reflectivity, vertical velocity, spectral width) at high (30 m) range resolution
Atmospheric emitted radiance interferometer	AERI	Absolute thermal infrared spectral radiance emitted by the atmosphere down to the instrument
High spectral resolution lidar	HSRL	Aerosol optical depth, volume backscatter, cross section, cloud and aerosol depolarization
Micropulse lidar	MPL	Altitude of cloud layers
Vaisala ceilometer	VCEIL	Cloud base height
Beam-steerable radar wind profiler	BSRWP	Wind and virtual temperature profiles
Parsivel optical disdrometer	PARSIVEL	Precipitation particle size distribution and fall speed
CCN counter	CCN	Cloud condensation nuclei as function of supersaturation
Condensation particle counter	CPC	Total aerosol particle concentration down to diameter 10 nm
Hygroscopic tandem differential mobility analyzer	HTDMA	Aerosol size, mass, or number distribution as function of RH
Ambient nephelometer	NEPH AMB	Aerosol light scattering coefficient at ambient RH
Dry nephelometer	NEPH DRY	Dry aerosol light scattering coefficient
Ozone	O3	Ozone concentration
Particle soot absorption photometer	PSAP	Optical transmittance of aerosol particles
Aerosol filter sampling (SIO)	AER FLTR	Aerosol chemical composition
Upward-looking precision spectral pyranometer	SKYRAD PSP	Downwelling total shortwave irradiance
Upward-looking Eppley model 8-48 diffuse pyranometer	SKYRAD 8-48	Downwelling diffuse shortwave irradiance
Upward-looking precision infrared radiometer	SKYRAD PIR	Downwelling longwave irradiance
Upward-looking Infrared thermometer	SKYRAD IRT	Sky equivalent blackbody temperature
Downward-looking precision spectral pyranometer	GRNDRAD PSP	Upwelling shortwave radiation reflected by surface
Downward-looking precision infrared radiometer	GRNDRAD PIR	Upwelling longwave radiation emitted by surface
Downward-looking Infrared thermometer	GRNDRAD IRT	Surface equivalent blackbody temperature
Cimel sunphotometer	CSPHOT	Multispectral direct solar irradiances
Multifilter rotating shadowband radiometer	MFRSR	Direct normal, diffuse horizontal, and total horizontal irradiances at six standard wavelengths
Analytical Spectral Devices FieldSpec Pro shortwave spectroradiometer (SIO)	ASD*	Downwelling spectral shortwave irradiance 350−2200 nm

Table 2. (Cont).

Instrument Name	Instrument Acronym	Quantities Measured
Eddy correlation flux measurement system	ECOR	Surface turbulent fluxes of momentum, sensible heat, latent heat, and carbon dioxide
Total sky imager	TSI	Cloud fraction
Vaisala present weather detector	PWD	Visibility, precipitation detection
Hotplate total precipitation sensor	TPS	Precipitation amount
G-band vapor radiometer	GVRP*	High-time-resolution water vapor and temperature profiling, and column-integrated liquid water and water vapor
Microwave radiometer, two channel	MWR, 2C	Column-integrated liquid water and water vapor
Balloon-borne sounding system	SONDE	Vertical profiles of T, P, RH, wind speed and direction
Meteorological instrumentation at AMF	MET	Near-surface (2 m) T, P, RH, wind speed and direction
Local meteorology at top of aerosol observing system (AOS) stack	AOS MET	Wind speed, direction, T, RH, P
* These instruments are deployed first at WAIS November 2015-January 2016 and redeployed to CosRay for the remainder of the field program.		

8.0 Logistics

AWARE is one of the most challenging missions yet conceived for the AMF program. Its success requires a close relationship between the DOE instrument team led by Los Alamos National Laboratory (LANL) and the NSF Division of Polar Programs (PLR) operating through its primary contractor Lockheed Martin Antarctic Support Contractor (ASC), a collaboration that has been effective since DOE approved the AWARE project in October 2013. Logistical details have been gradually and carefully resolved, including a site visit to WAIS and McMurdo for AMF site selection even before PLR approved the NSF award for AWARE. Figure 3 details the AWARE project timeline and expected pre-deployment planning milestones.

Logistical details on site include heavy lift equipment to prepare and deliver the AMF2 equipment to the site, riggers to install and maintain meteorological and calibration towers, communications technicians to install a wireless link from the AMF2 site to the McMurdo Station LAN, McMurdo weather station support for sonde launches, field safety training for all participants, helium gas transport and storage to both McMurdo and WAIS Divide, and data communications to the mainland United States at an approximate bandwidth of 1-2 mbps on a best-effort basis.

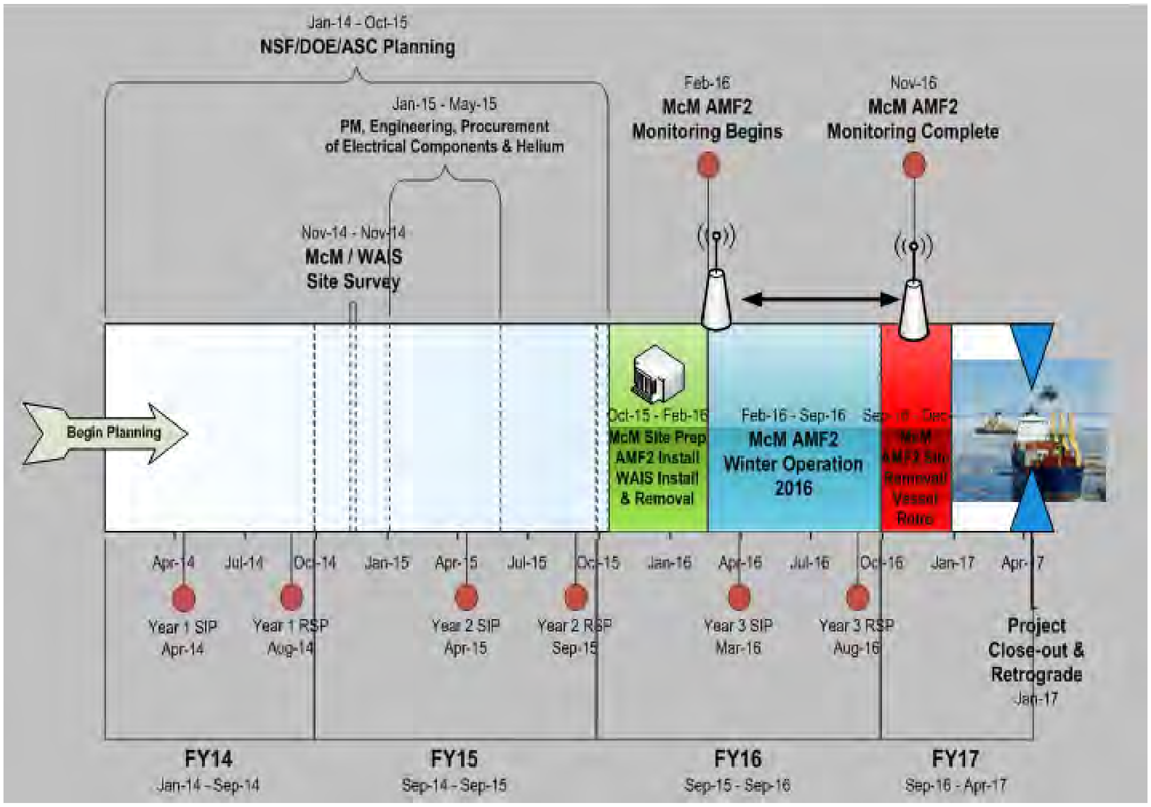

Figure 3. AWARE planning and deployment milestones (prepared by Judy Shiple, ASC).

With AWARE, the DOE ARM Facility will deploy the atmospheric measuring instruments listed in Table 2 to McMurdo Station to make the first observations of Antarctic cloud microphysics using advanced instrumentation over an entire annual cycle. Team members will deploy a subset of the ARM instrumentation (Table 1) to the WAIS Divide station to make complete surface and atmospheric energy balance measurements over one summer season. The ARM instruments are integrated into standard ISO containers or installed on meteorological towers. The project's McMurdo area Main Facility will comprise up to 12 ISO containers and one calibration tower, while the WAIS Divide facility comprises one ISO container and a number of helium gas cylinders. Radiosonde launching will also occur at both locations.

The AMF instrumentation at McMurdo and WAIS will be operated by a team of DOE personnel selected by LANL, who must then be physically qualified for Antarctic deployment by the ASC medical office. In addition, the AWARE lead PI (Lubin) and one SIO graduate student will deploy to WAIS Divide to operate the ASD instrument and assist with AMF instrument installation, operation, and retrograde.

A site selection visit conducted during the 2014-15 season in McMurdo identified an area near Building 84 (CosRay) for the Main Facility location. This area met siting requirements, including de-conflicted radar interference with USAP ground stations, airfields, and science projects. The site is in an area that typically receives lower snow accumulation and wind loads, which will simplify winter access and lessen maintenance requirements, and it provides easy road access for forklifts, cranes, and pickups. In addition, it is close enough to McMurdo Station that it will enable the group to use station power and IT connectivity. The site will accommodate a roughly 100 × 100 ft pad for the ISO containers with line-of-sight to a nearby location suitable for the calibration tower installation.

Major logistical support includes:

- Winter C-17 cargo flight for WAIS Divide SKIP container Christchurch Airport (CHC)-MCM in July
- Up to four C-17 missions to facilitate cargo movement from CHC to MCM in early 2015-16
- Fleet Operations support to prepare the Main Facility site and to place containers
- Provision of electrical service to the Main Facility
- Up to four LC-130 missions for the WAIS Divide facility put in and pull out.

The Support Agreement between PLR/ASC and AWARE covers all science projects related to these ARM facilities, including but not limited to the NSF-funded AWARE science project.

Aerosol filter samples will be collected from CosRay for return to Professor Lynn Russell's laboratory at the University of California, San Diego (UCSD)/Scripps Institution of Oceanography (SIO) using an air sampling line in the ARM aerosol ISO container. The maximum frequency will be one exposed filter per week. Filter installation and sampling in the field will be completed by DOE personnel. Return of small and lightweight exposed filters kept at freezing temperature will be coordinated with scheduled cargo flights northbound from McMurdo. Support for this aerosol sampling is part of the PI's award to UCSD/SIO.

At the end of the 2015-16 WAIS Divide camp season, the single ISO container of science instruments and equipment will be returned to McMurdo for over-winter storage. Any empty helium cylinders will be returned to CONUS via USAP cargo vessel in 2016 as they are being rented. The single ISO container and the Main Facility containers will be retrograded off continent via USAP cargo vessel in January 2017.

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