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The Polar Environment Atmospheric Research Laboratory (PEARL): Sounding the Atmosphere at 80˚ North

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INTRODUCTION

Making atmospheric measurements in the High Arctic is challenging because of the remoteness of the area, the difficult transportation, the inconsistent communications, and the extreme environmental conditions. In 2003, after the Environment Canada (EC) Arctic Stratospheric Ozone Observatory (AStrO) closed, the Canadian Network for the Detection of Atmospheric Change (CANDAC), a group of university and government scientists, identified a High Arctic observatory as a high-priority need to improve research measurements over the Canadian portion of the Arctic. Significant effort was given to selecting a site and acquiring the required funding to populate it. This activity gained fresh urgency with the planning of the International Polar Year (IPY) in 2007–08. A High Arctic observatory would directly respond to the IPY intention not only to make intensive measurements throughout the IPY time frame, but also to "leave a legacy of observing sites, facilities and systems to support ongoing polar research and monitoring" (ICSU, 2004:10).

After some consideration of alternative sites, CANDAC decided to concentrate activities at Eureka (80˚ N, 86˚ W, see Fig. 1). The research site was designated the Polar Environment Atmospheric Research Laboratory (PEARL), and CANDAC began to seek funding for equipment and operations. PEARL, which formally began operations in 2005, supports research in three broad areas: air quality, ozone, and climate change. Subsequent experience has amply demonstrated the appropriateness of the site, and several advantages that were not apparent at the time of site selection affirm Eureka as a uniquely suitable location for atmospheric (and now other) measurements in the Canadian sector of the High Arctic.

EUREKA AS A LOCATION FOR MEASUREMENTS

The major advantages of the PEARL site at Eureka are good viewing conditions for making atmospheric measurements; the possibility of geostationary contacts for communications and data transfer; the many overflights of polar orbiting satellites; and the availability of aircraft landings, power, accommodation and other logistical support. An additional advantage was the possibility of using the existing AStrO building and continuing the time series of ozone-related measurements that were in progress at the site. The major disadvantage is the expense of access, since charter aircraft and a once-per-year sealift are the only means of getting materials and personnel to the site.

General Site Characteristics

PEARL is located near EC's Eureka Weather Station (79˚59′ N, 85˚56′ W) (Fig. 2). When the laboratory was first established, the former AStrO Observatory (the iconic principal building with the red siding) was usually referred to as PEARL. However, since PEARL is actually more than one building location, this led to confusion as to what exactly was meant by "PEARL"—the building, the observatory, or the site. In this paper we will refer to the principal building as the PEARL Ridge Laboratory (PRL) or just the "Ridge Lab."

Eureka is an important site not only for atmospheric measurements and research, but also as a support site for all manner of operations to locations in the surrounding area and farther north. Both civilian and military groups come and go through the station, mainly during the summer months. The gravel runway is 1474 m long and can accommodate large aircraft, including a Hercules C-130 or 737 equipped for landing on gravel runways. However, most traffic involves more modest aircraft, the Twin Otter and similar planes being the norm.

The Eureka Weather Station (EWS) provides accommodation and meals to science and technical personnel, maintains the airport and the road, and supplies electrical power to PEARL.

Weather and Climate

Climate data for Eureka can be found at Environment Canada (2013). Average temperatures range from −38.4˚C (1971–2000 February average) in winter, with a record low of −55.3˚C on 15 February 1979, to +5.7˚C (1971–2000 July average) in summer, with a record high of +20.9˚C on 14

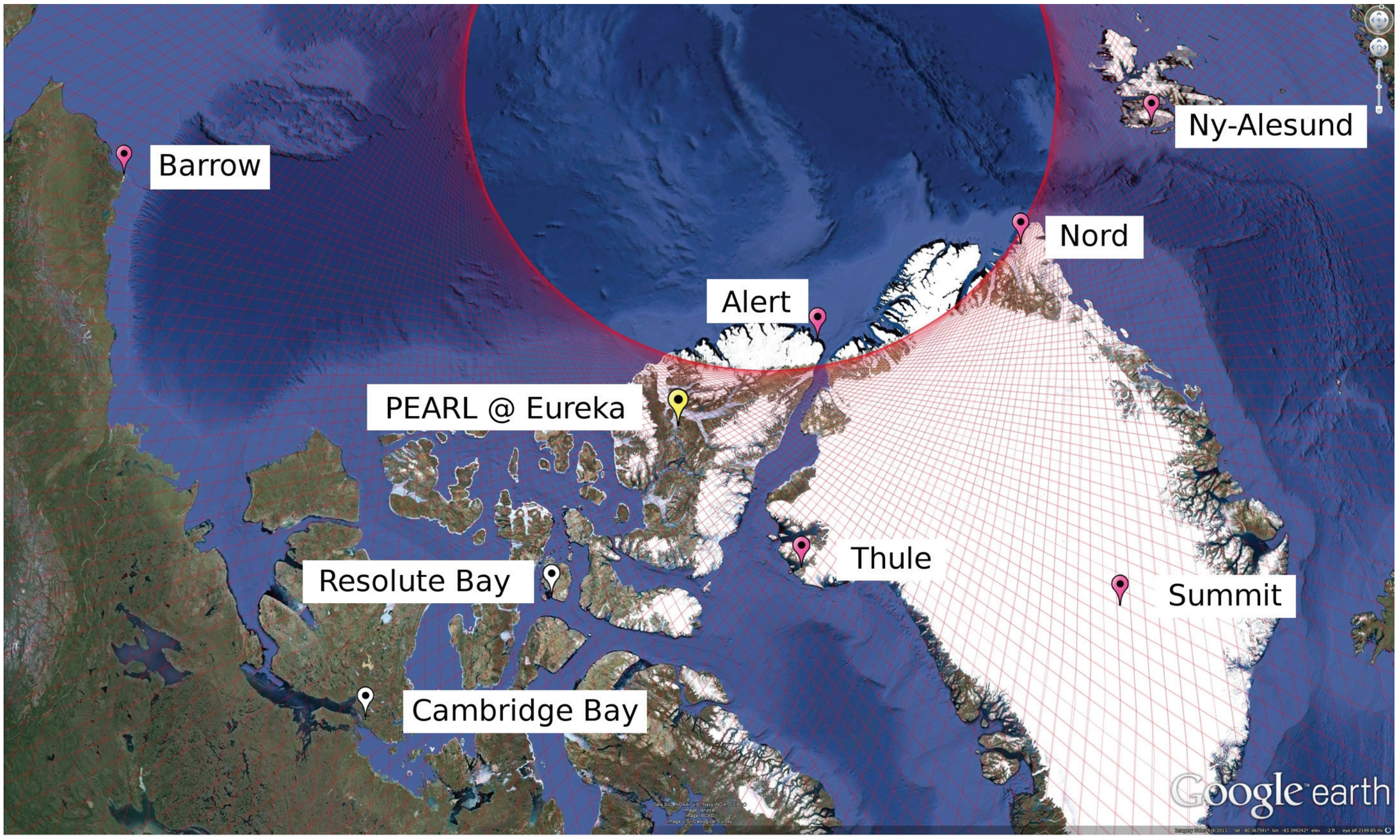

FIG. 1. A map of the Canadian sector of the Arctic showing some observing sites. Superimposed on the image is the ground track for 16 days of the CloudSat satellite. Image courtesy of Google Earth.

July 2009. The area is classified as semi-arid; annual precipitation for 1971–2000 averaged 75.5 mm, two-thirds of which was frozen. The record daily precipitation is 41.7 mm (rain, 17 August 1953). Winds are generally from the east in winter and from the west in summer but are quite variable. Annual average wind speed for 1971–2000 is 11 km/h, with a record hourly wind speed of 113 km/h (15 March 1953) and a maximum recorded gust of 126 km/h (4 January 1977).

The availability of clear skies for remote sounding measurements using solar absorption spectrometers, LIDARs, and optical imaging devices is particularly important for atmospheric measurements. A reasonable proxy for clear skies during daylight hours is the hours of sunlight that were recorded by the Meteorological Service of Canada up until June 2005. The results for a number of Arctic sites from EC Climate data for 1971–2000 are shown in Table 1. The theoretical maximum number of hours of direct sunlight in a year is 4376. Of all of these sites, Eureka shows the largest number of hours of direct sunlight, 50% of the maximum.

For some instrumentation, such as solar absorption spectrometers, only daylight hours are relevant, but other instrumentation operates exclusively at night or in both day and night. However, there are no long-term measurements of atmospheric clarity during the polar night. Recently there has been interest in the use of Eureka as a site for a polar astronomical telescope, and several studies on optical properties of the atmosphere at night are in progress (Steinbring et al., 2010).

Communications

A reliable communications system in the High Arctic is a major issue. There are no landlines to Eureka, and the military and EWS communications are handled by the High Arctic Data Communications System (HADCS; jproc.ca/rrp/alert.html). PEARL's data requirements are significant, and the communications system has evolved considerably even over the comparatively short time that the laboratory has been operational. Since the elevation angle for a geostationary satellite at Eureka is very close to zero, the atmospheric path is extremely long, making it a considerable challenge to achieve a reliable connection. In 2005 a C-band (~3.6–6.5 GHz) communications system was installed by Telesat under contract, using two 3.2 m antennas and three signal beams, two that transmit and one that receives, in a "vertical diversity" configuration (Strickland, 1981). This system performs extremely well throughout the year.

In 2008, with the help of the Canadian Space Agency, a Ka-band (~27–40 GHz) satellite communications was installed at Eureka. In 2010, under the Government of Canada Arctic Research Infrastructure Fund (ARIF) program,

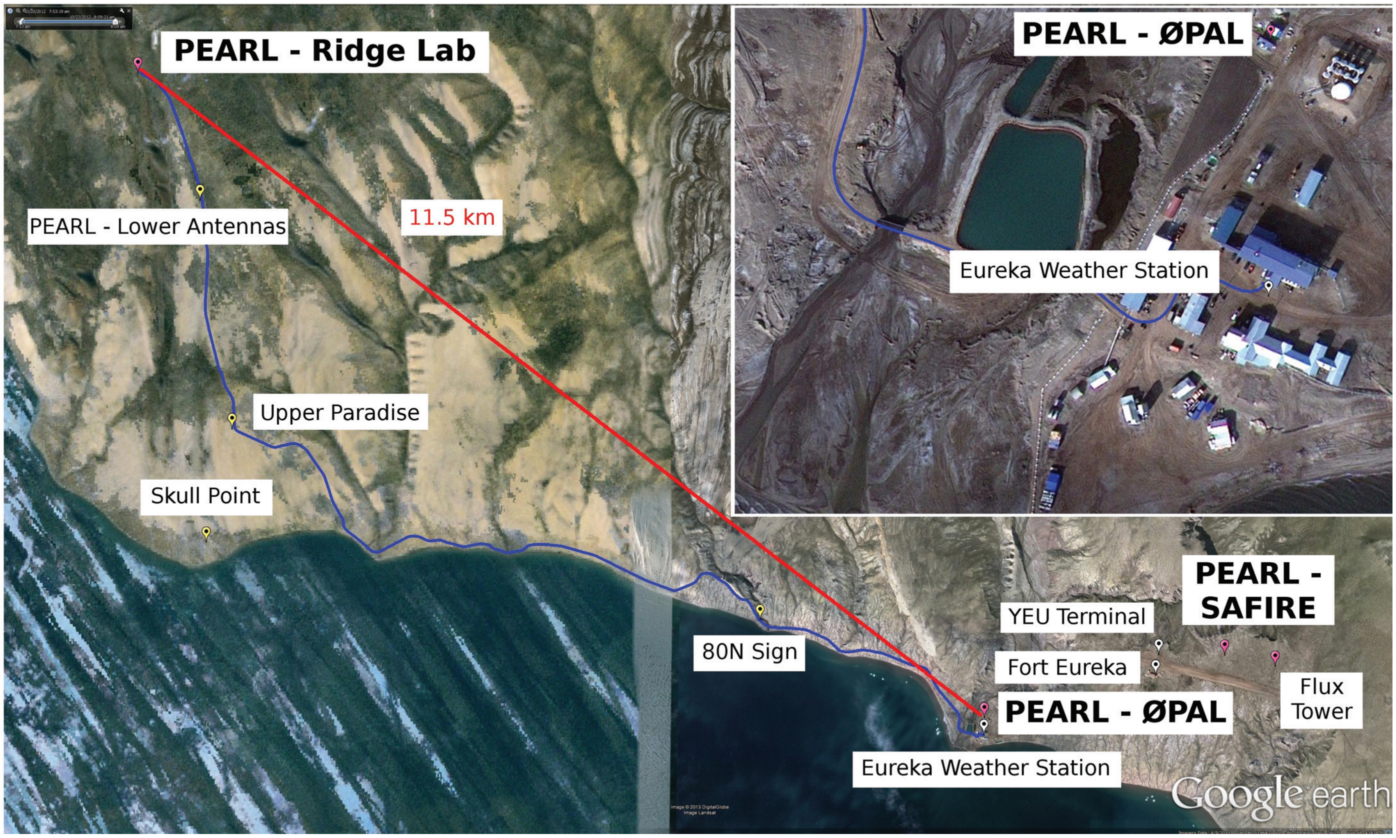

FIG. 2. The Eureka site, showing its major features, including the three PEARL facilities: the Ridge Lab, ØPAL, and SAFIRE. The blue line follows the approximately 15 km road between the Ridge Lab and the Eureka Weather Station (EWS) and the red line indicates that the straight-line distance between the two is 11.5 km. Inset image is an enlarged image of the area immediately surrounding the EWS, showing the location of ØPAL in relation to the EWS. Image courtesy of Google Earth.

TABLE 1. Hours of direct sunshine (average 1971–2000) for some Arctic locations.

Location	Latitude (N)	Hours of direct sun/year	Rank
Alert	82.5	1795	3
Eureka	79.9	2068	1
Resolute Bay	74.7	1578	5
Pond Inlet	74.7	1887	2
Cambridge Bay	69.1	1703	4

an additional three Ka-band 2.4 m antennas were installed and are being operated under the Anik F2 Government of Canada Capacity Credit Initiative. Although these links are still being tested, the initial findings are that Ka-band communications are possible for most of the year except in the summer months, mainly July and August.

Satellite Overpasses

The PEARL site is also significant in terms of satellite overpass frequency. Many of the atmospheric-sensing satellites (e.g., Terra, Aqua, Aura, the “A-train”) are in sun-synchronous orbits and this geometry leads to a maximum overpass latitude of about 80˚. This pattern is depicted for Cloudsat (part of the A-train) in Figure 1, where the northern limit is clearly visible. Figure 3 shows the total time in a year that the sub-satellite point is within a given distance of the station for a number of Canadian Arctic sites at a range of latitudes. It can be seen that PEARL has more satellite overpass time than any of the other sites, making PEARL an exceptionally good site for satellite validation.

Unique Challenges

All fieldwork has unique challenges, in the High Arctic no less than in other locations. Some of the more unique challenges to working on this site are issues with temperatures, both of the environment and of the equipment, issues with the local terrain and wildlife, and issues with communications, networks and computers.

Exposed items can undergo large (> 50˚C) repeated temperature cycles. This can result in fasteners “unfastening” and similar events. It is a common occurrence for nuts to come loose on bolts. At one point the main power feed to the PRL failed because of the loosening of the screws in the main power breaker! Positive retention and frequent torque checks are required.

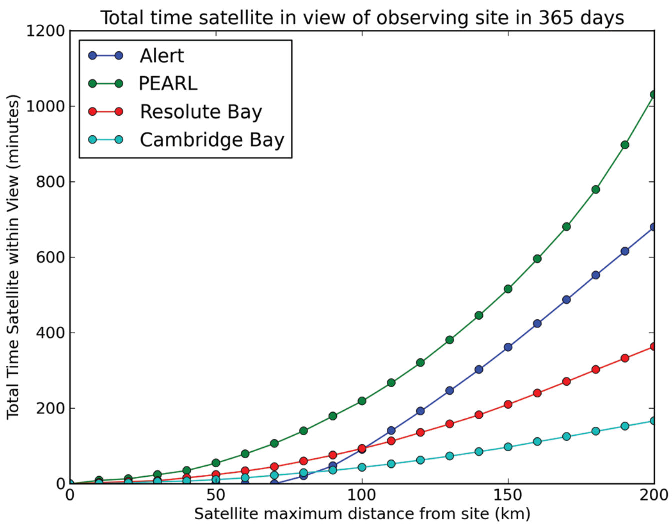

FIG. 3. The total time per year that the CloudSat satellite (as a representative polar orbiting satellite) is within a certain distance of the observing station. For Alert the satellite never comes closer than ~70 km of the site (see Fig. 1). PEARL/Eureka is seen to have the highest overpass time of all the Canadian locations.

For equipment that is heat sensitive or generates significant internal power, dissipating the heat and maintaining lower temperatures in summer prove to be more challenging than keeping things warm in the winter. There is a minimal diurnal cycle in summer, and buildings can be in sunlight for many hundreds of hours at a time. This can lead to overheating. In the winter, sufficient heat can be applied, but the temperature gradients in laboratories can be very high. Freezing floors and hot ceilings are common. Aggressive air circulation equalizes temperatures, but brings its own problems with drafts and dust. All external cable must be rated for low temperatures.

Four-season operation in the High Arctic involves coping with a wide variety of physical conditions. Snow and ice are obvious issues. Repeated frost and ice build-up on loose cables, feed horns, and equipment is a factor in the autumn. Travel between sites is also affected by winter storms.

Less obvious issues occur in the summer, when the fine soils of the region are exposed. If they are dry, they form a fine dust that can impact instrument operation; if they are wet, the mud impedes travel between sites and can destabilize equipment and structures installed on the surface. The gravel roads are highly susceptible to damage when wet. There are times when intra-site movement has to be restricted for safety and to preserve the road. The terrain away from roads and building sites, which are often on built-up gravel pads, is susceptible to washout and ponding, as the soil has almost no mechanical retention given the absence of root systems or other restraints. Mudslides in summer are common.

Interaction with wildlife is inevitable. The main issues are personal safety around the larger animals and equipment safety from all wildlife, whether it is muskoxen tramping through an antenna field, ravens attacking the cover of a microwave sounder, or Arctic hares or wolves chewing the insulation of cables. This latter issue particularly affects cables laid on the ground, and our practice has been to lightly bury them (although on occasion we have seen them dug up), or more often, to use armouring or conduit. There have been many cases of cables being severed, and if this happens in winter, repair may have to wait until spring.

The PEARL observatory has an extensive internal network: the three sites are linked by microwave systems at speeds up to 100 Mbps. However, although internal communications are fast, communication with the rest of the planet is slow, which affects activities such as data downloading, remote control and diagnostics, and computer maintenance.

It is not possible to download an entire large dataset to the South quickly, but it is desirable to ensure that the equipment is operational from a remote site. In this case the use of "quick-look" data subsets can be important, as these can be available quickly at the home institution. Datasets at PEARL are handled by a central archiving system to ensure that the data are archived properly and that the communications links are efficiently used.

Many remote communications protocols make hidden assumptions about network bandwidth and delay time that are inappropriate for PEARL. Care must be taken to ensure that these protocols will work within the necessary restrictions.

Many personal computer operating systems also have built-in assumptions about communications and bandwidth. Automatic updates are appropriate with fast, high-bandwidth communications, but not with PEARL's restricted conditions. Besides the bandwidth issues, two other problems can arise: first, an update can produce some incompatibility that makes the computer system inoperable; second, and this has happened several times, an update may require an operator confirmation to complete ("press OK to continue") that can be provided only from the computer keyboard. Experience suggests that shutting off updates is the best response. Security issues are dealt with at the facility level with a comprehensive firewall.

PEARL SITES

Several of the instruments that CANDAC installed have requirements not met by the PRL, including a need to be as low in the atmosphere as practical, and so PEARL expanded from a single site to three sites: The PRL, the Zero Altitude PEARL Auxiliary Laboratory (ØPAL), and the Surface Atmospheric Flux and IRradiance Experiments (SAFIRE) site mapped in Fig. 2 and shown in Fig. 4.

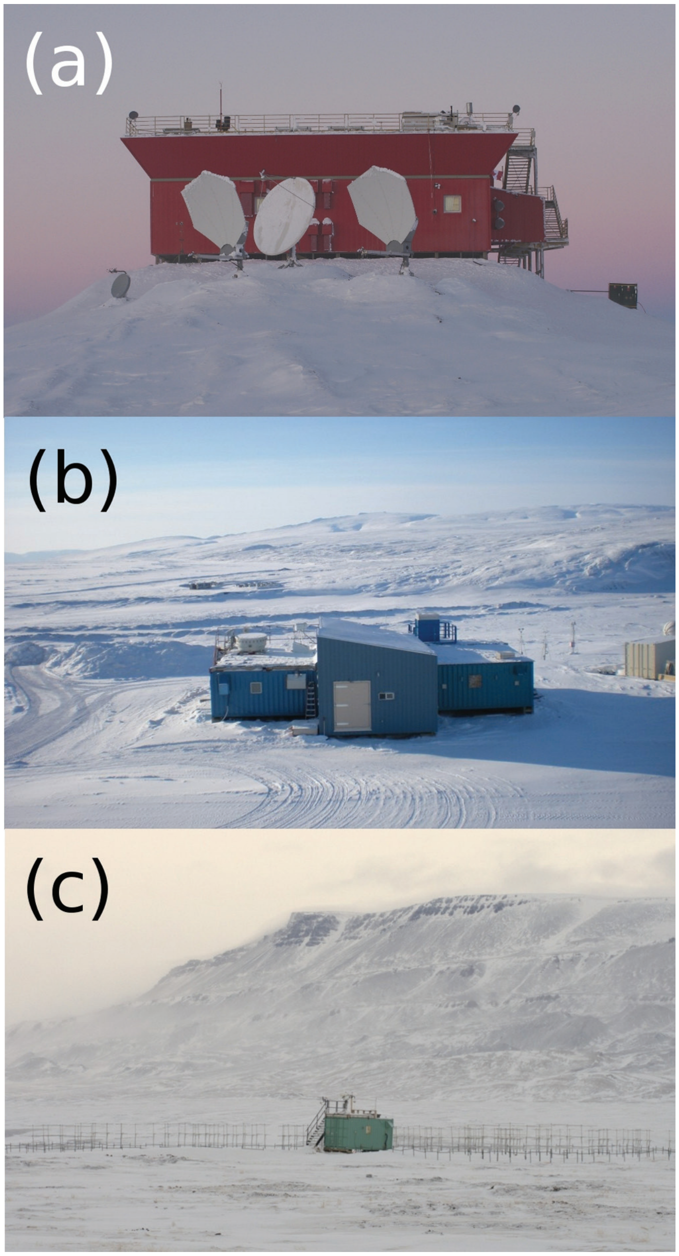

FIG. 4. Photographs of the three PEARL sites: (a) the Ridge Lab from the south side, showing the outside instrument deck on the roof and the communication antennas. (b) ØPAL from the east side. The PRL is located approximately 11.5 km distant in the centre of the photograph. (c) SAFIRE, the green container with the antenna array for the VHF radar across the right of the picture. Photos (a) and (c) courtesy of Pierre F. Fogal; (b) courtesy of Alexei Khmel.

The PEARL Ridge Laboratory (PRL)

The PRL (Fig. 4a), opened as the Arctic Stratospheric Ozone Observatory (AStrO) in 1993, has two purpose-made LIDAR laboratories, complete with cold rooms with retractable hatches for their telescopes. In addition, there are two other laboratories that also have roof hatch access to the atmosphere. These laboratories also have access ports in the wall. In total, there is ~350 m^2 of laboratory space. CANDAC added ~80 m^2 of additional space through the addition of mezzanine levels in two of the laboratories. These mezzanines also provide much safer and easier access to the roof hatches in those laboratories. A "penthouse" has been placed on the roof. This is a small (~3 m × ~2 m) "walk-in freezer." The insulation properties of this structure, nominally designed to keep cold inside and warm outside, are equally applicable to this purpose. Viewing apertures have been cut into the walls and ceiling.

Besides power and space, the building has wired and wireless internet and a small liquid nitrogen generator that extracts nitrogen from the air and liquefies it using a closed-cycle helium refrigerator.

There is office space, a full kitchen, and a pair of bedrooms and a "safe hut" for emergency use. The PRL is powered from the Eureka generating station via a 15 km long "extension" cord, ensuring that the site generates the minimum possible local pollution. In the case of a power failure, the PRL has a backup generator to support the essential subsystems.

The location of the PRL ensures that pollution from Eureka is minimized. It often experiences very different local weather conditions than the EWS. Its location in the free troposphere makes it a suitable site for sampling instruments such as an aerosol mass spectrometer. Being at a higher altitude affords the site a large improvement in viewing the upper atmosphere by being above the boundary layer. This advantage is important for stratospheric measurements such as those of the solar absorption Fourier transform spectrometer and the stratospheric ozone LIDAR. The separation in altitude between the PRL and the other PEARL sites also provides us with an opportunity to compare and contrast measurements made at different altitudes (O'Neill et al., 2008; Mariani et al., 2012). These include extinction measurements such as those carried out by sunphotometers and radiance measurements carried out by both spectrometers and radiometers.

The ØPAL Site

The Zero Altitude PEARL Auxiliary Laboratory (ØPAL; Fig. 4b) was constructed ~300 m from the main weather station building at ~10 m above sea level. ØPAL is a site for instruments that need to be as low in the atmosphere (near sea level) as possible. In particular, cloud and aerosol measurements fit into this category. ØPAL is a collection of interconnected ISO standard 20 × 8 × 8.5 foot (6.1 × 2.4 × 2.6 m) modified sea containers. The 20-foot limit on size is imposed by the capacity of transport by aircraft or sealift. These containers were modified to provide an insulated, fully wired laboratory space with access to the outside for instruments and cables. Each container has a roof hatch, main door, window, four 15 cm square ports at bench level, and eight three-inch circular ports, at the top of the container. There are four containers at ØPAL joined together in pairs. The first pair was joined by an unheated

TABLE 2. Roster of PEARL instruments as of the end of 2012.

Instrument	Location	Date(s) in service	Seasons[1]	Principal measurement
Aerosol Mass Spectrometer	PRL	2006–	A	aerosol composition
All Sky Imager	PRL	2007–	W	airglow images
Fourier Transform Spectrometer	PRL	2006–	S	trace gas partial column amounts
Brewer Ozone Spectrophotometer	PRL	2005–	A	ozone column amounts and Umkehr profiles
CIMEL Sunphotometer	PRL	2007–11	S	aerosol optical depth
DIAL (stratospheric ozone) Lidar	PRL	1993–2008	W	ozone, water vapour, aerosol and temperature profiles
E-Region Wind Instrument	PRL	2008–	W	mesospheric winds
Spectral Airglow Temperature Interferometer	PRL	2007–	W	mesospheric temperatures
UV-Visible Grating Spectrometer	PRL	2006–	S	ozone, NO_2, BrO, and OClO column amounts
High Spectral Resolution Lidar	ØPAL	2005–10	A	cloud and aerosol properties
CIMEL Sunphotometer	ØPAL	2007–	S	aerosol optical depth
Millimetre Wave Cloud Radar	ØPAL	2005–	A	cloud properties
Microwave Water Radiometer	ØPAL	2006–	A	water profiles
ABB Extended (Polar) Atmospheric Emitted Radiance Interferometer	ØPAL	2006–	A	atmospheric down welling radiance and some trace gas amounts
Precipitation Sensor Suite	ØPAL	2007–	A	precipitation amount and type
Rayleigh-Mie-Raman lidar	ØPAL	2007–	A	water vapour, aerosol and temperature profiles
SKiYMET Meteor radar	ØPAL	2006–	A	mesospheric temperatures
Starphotometer	ØPAL	2007–	W	aerosol properties
Tropospheric Ozone lidar	ØPAL	2007–	A	tropospheric ozone profiles
Baseline Radiation Suite	SAFIRE	2007–	A	surface radiation budget
Flux tower	SAFIRE	2007–	A	wind, CO_2, P, T, RH to 10 m
Windtracker VHF radar	SAFIRE	2007–	A	wind vectors 400 m to 12 km

[1] Indicates whether the instrument is operated all year (A) or only during the Summer/Daylight (S) or Winter/Dark (W).

wooden breezeway that houses the power distribution network for the ØPAL site, and the second pair was connected in a similar fashion. Later, under ARIF funding, the intervening space, measuring approximately 7 × 9 m, was filled by a freestanding building of wooden construction that tied the four containers together and provided additional work and meeting space. The roof area of the first container pair has been covered with metallic grating so that it can house external instruments.

The SAFIRE Site

The Surface Atmospheric Flux and IRradiance Experiments (SAFIRE; Fig. 4c) site was created to support experiments that either needed a great deal of space outside (e.g., a large antenna field) or needed to be located far from structures and landforms that might affect the measurements. SAFIRE is located in a large, flat, open area north of the Eureka runway. Shelter for the instruments is provided by a sea container identical to those at ØPAL. SAFIRE also has a roof deck for instruments. Nearby, the U.S. National Atmospheric and Oceanic Administration (NOAA) Study of Environmental Arctic Change (SEARCH) program erected a 10 m tall tower that carries a collection of instruments to measure fluxes at and near the surface.

INSTRUMENTATION

Some of the past and current instruments installed at PEARL are among very few of their kind operating in an Arctic environment (Table 2). For example, the Aerosol Mass Spectrometer instrument for measuring aerosol particles (Kuhn et al., 2010) is unique to this sector of the Arctic. Its uniqueness not only increases the challenge of the operation, since there is little operating experience under these conditions, but also makes the data acquired more valuable.

In other cases, the CANDAC/PEARL team uses standard instruments or instruments that have been certified to meet certain standards. Thus, we use standard CIMEL instruments that provide data to the AERONET database, and we have certified several instruments to the standards of the Network for the Detection of Atmospheric Composition Change (NDACC) for use in the NDACC datasets (Batchelor et al., 2009; Fraser et al., 2009). The NDACC certification process is rigorous, and in one case, it was somewhat complicated by the need to ensure that the measurements were properly validated from one generation of instruments (a BOMEM DA8) to another (a Bruker IFS 125HR). These actions are essential if long-term datasets are to be consistent.

The ABB Extended range Atmospheric Emitted Radiance Interferometer (ABB E-AERI) instrument is particularly noteworthy, in that it is adapted for Arctic temperatures. This instrument measures the spectrum of downward-directed radiation. Cold temperatures shift the peak of this radiation towards the long wave, and the dryness of the atmosphere reduces water-vapor absorption, opening the so-called "dirty window" of atmospheric transparency in the range 17–33 µm. At more southern latitudes, this region is highly opaque because of water vapor absorption. The ABB E-AERI instrument is adapted by an extended range detector for the longest wavelengths, giving sensitivity to ~25 µm.

The ideal PEARL instrument is autonomous, self-diagnosing, and self-repairing. Instrumentation varies widely in the approach to that ideal. Several instruments, e.g., the CIMEL instruments, are autonomous, but require setup and adjustment. Some instruments, such as the stratospheric ozone DIAL LIDAR are run manually, and those that require frequent replenishment of supplies, such as liquid nitrogen, also need frequent manual intervention. As an intermediate step towards full autonomy, some instruments, such as the CANDAC Raman-Mie-Rayleigh LIDAR (Nott et al., 2012) are operated remotely. Even during the comparatively short time that PEARL has been operating, the increasing sophistication of equipment and the increase in affordable computer power has allowed noticeable progress in autonomous operation and remote diagnosis of problems (sometimes using webcams and other external remote monitoring tools). This trend is expected to continue both to ensure that the maximum amount of data is collected and to keep costs under control.

SITE OPERATIONS

CANDAC operations are based on the concept that all instruments should be as automated in their daily operations as is practical. Highly automated instruments tend in the long run to acquire more data in a more consistent fashion. Bridging the gap between "as automated as possible" and full operations requires personnel on site and available at all times. This goal was achieved from 2005 to early 2011. In general, these "operators" are responsible for the oversight of normal instrument operation, any scheduled maintenance that does not require highly specialized training, site maintenance, and general support. In addition to these regular duties, they are key personnel in any special scheduled or unanticipated measurement programs such as might be carried out during events like eclipses, volcanic eruptions, and research aircraft overflights. In general, this strategy has been successful, resulting in most instruments gathering data most of the available time. Analysis of the instrument availability over the last four years (2008–12) shows a high (average ~90%) availability when there was operator support and a significant decline (average ~50%) in 2012 when support was no longer possible.

CANDAC has always emphasized the participation of students in the hands-on aspects of measurements and science. This grounding in Arctic fieldwork is a key part of CANDAC's vision of sustaining Canadian science and scientists in the Arctic and so students are heavily involved in the commissioning, use, and maintenance of the instruments.

Operations also include the transportation of both goods and people, the overall re-supply of PEARL, as well as the interface between PEARL, the EWS and other organizations. In all such endeavours, communication between individuals and organizations is a key aspect of a successful operation.

DATA MANAGEMENT AND AVAILABILITY

CANDAC data management begins at each instrument's controlling computer. Data are moved from that computer to a central data storage unit and from there scheduled for transmission south for storage and access by instrument teams. This system reduces the need for each team to download the data from the instruments and permits more efficient use of the communication links.

The CANDAC Data Management Policy provides data to all users, while giving first use of it to the research teams involved in its collection. Metadata for all CANDAC-operated instruments at PEARL have been provided to the Canadian Polar Data Catalogue (www.polardata.ca).

Data are also being submitted to appropriate international databases, e.g., the Baseline Surface Radiation Network (BSRN), the World Ozone and Ultraviolet Data Centre (WOUDC), the Network for the Detection of Atmospheric Composition Change (NDACC), and the Total Carbon Column Observing Network (TCCON). The CANDAC website (www.candac.ca) is the major data dissemination resource for other PEARL data. It provides meteorological information from the PEARL Weather Station, near real-time and archive data from the Millimeter Wave Cloud Radar, SKiYMET VHF Meteor Wind and Temperature Radar, and ØPAL Precipitation Sensor Suite. The website also provides information about installed instruments and systems and their current status, as well as the CANDAC Data Inventory.

BEYOND ATMOSPHERIC SCIENCE

Many research groups use Eureka as a base of their operations because of the facilities offered by the EWS. Studies have included topics such as permafrost, glaciers, and the wolf pack. With the establishment of PEARL and an expanded communication system based at Eureka, more groups have been able to take advantage of expanded infrastructure and increased general activity to aid in their research. Some groups are primarily atmospheric in focus, such as the U.S.-based Study of Environmental Arctic

Change (SEARCH), but others have a broader focus, and PEARL has gradually expanded from being primarily an atmospheric research site to occupying a more general role. In 2008, CANDAC was asked to host and maintain a pollen counter at PEARL. This has resulted in a unique dataset of the sparse pollen concentrations in this region. In the winter of 2010 – 11, astronomers at the Herzberg Institute for Astrophysics installed instrumentation at the PRL to evaluate the suitability of the site for a polar astronomical telescope. The results (Steinbring et al., 2010, 2012) have been extremely encouraging, with the "seeing" over the PRL shown to be comparable to some of the best international telescope sites. Other examples of co-operative research are support of seismographic instrumentation, ionosondes through the Canadian High Arctic Ionospheric Network (CHAIN; Jayachandran et al., 2009), and logistical support for activities in support of the UN Convention on the Law of the Sea (UNCLOS).

RESULTS

The results of the PEARL initiative are measured in the new scientific knowledge that is generated by the activity. Because of the long-term nature of much of the research, some knowledge is acquired only incrementally through long-term datasets. However, specific results that have been achieved through the PEARL can be identified. Four of them are summarized here. For more details, please consult the papers referred to below.

One unexpected diffuse result is an increasing understanding of the importance of the polar night in determining the overall state of the atmosphere. For example, it has been found that the temperature rise in the High Arctic is occurring through warming in the polar night rather than the polar day (Lesins et al., 2010, 2012). It was realized as the project unfolded that many datasets are biased towards the polar day for the simple reason that making measurements is easier then. These results emphasize the importance of PEARL's unique atmospheric measurements, particularly during the polar night.

Particulate measurements at Eureka indicate episodic transport of pollutants from lower latitude regions into the area, often on quite short timescales. Particulates specific to volcanic activity (O'Neill et al., 2012), biomass burning (Eck et al., 2009), and industrial activity (O'Neill et al., 2008; Kuhn et al., 2010) have been repeatedly observed.

One of the several specific events that occurred during this initial observation period was a sudden stratospheric warming (SSW) that occurred in the winter of 2008 – 09 (Shepherd et al., 2010). During such events, stratospheric temperatures increase by up to 70 K, and the winter circulation pattern—the polar vortex—becomes very disturbed. This breakdown of the circulation patterns has significant influence on the dynamics and chemistry of the whole polar atmosphere for the remainder of the winter.

In 2011, the largest ozone depletion ever recorded in the Arctic (Manney et al., 2011) occurred when the polar vortex was situated above PEARL. Fortunately, this happened during one of our intensive observing campaigns and thus data were acquired not only on the ozone itself, but on the chemicals that influence the ozone. Subsequent analysis has shown that the depletion was due to longer than normal cold conditions in the winter Arctic stratosphere, with average ozone losses above Eureka in the range of 27% – 35% and a peak loss of 47%, coupled with corresponding changes in, for example, NO_2, HNO_3, HCl, and OClO. (Adams et al., 2012; Lindenmaier et al., 2012).

By the end of 2012, 86 papers had been published using PEARL, and additional papers are being written or are under review.

LESSONS LEARNED

There is a great deal of difference between doing research in a remote field station and doing research in or near a university campus. The facilities for power, communications, sleeping accommodation, water, and sewage are completely different. Recognizing the differences is critical to successful planning and funding of Arctic research.

With limited times when equipment and supplies can be moved and limited options for transport, forward planning is essential, but planners face the problems of random but frequent equipment failure and sometimes the late arrival of funding. Periodic equipment failures that are merely a nuisance in a university laboratory become catastrophic for instrumentation at PEARL, since the time to locate and transport a spare can be measured in months rather than days. Spare parts must be kept on site in profusion. It is sometimes more cost effective to procure and ship two full sub-systems to the site to provide a full spare.

Co-operation and flexibility are essential. Different groups can provide different resources, and combining those resources can multiply effectiveness and expedite research timescales. Two areas where this is especially important are transport (sharing charter planes) and communications. This flexibility must be carried over to the accounting to permit cost-sharing and other ways to reduce overall costs where appropriate.

Autonomy and automation are important. The more equipment that can be automated, then the more time is available to deal with equipment failure and other problems. Even within the few years that PEARL has been operating, the degree of automation of the equipment has increased, and this trend is being emphasized in our future planning.

PEARL was and is a highly successful project because of the hard work and co-operation of many individuals and groups. A significant amount of scientific equipment was designed, built, delivered, and operated in a relatively short time and is delivering meaningful scientific results as evidenced by science papers in the literature and science data in major databases.

THE FUTURE

With changes in the funding universe, the future of research at this site has been in considerable doubt for the last several years. However, recently a group of researchers has been awarded a five-year grant from the Natural Sciences and Engineering Research Council (NSERC) for the Probing the Atmosphere of the High Arctic (PAHA) project. It is hoped that support from this grant and from other government agencies will allow atmospheric and other research at this important northern outpost to continue.

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