Report on CANDAC Activities at Eureka, Nunavut during 2016

submitted to

The Nunavut Research Institute

Prepared by:

Pierre F. Fogal, Ph.D

PEARL Site ManagerUniversity of Toronto

Department of Physics

60 St. George Street

Toronto, Ontario

M5S 1A7

and

Professor James Drummond FRSC

PEARL/CANDAC/PAHA Principal Investigator

Dalhousie Universality

Department of Physics & Atmospheric Science

Halifax, Nova Scotia

B3H 4R2

on behalf of

The Canadian Network for the Detection of Atmospheric Change

NRI Research License #02 009 16R-M

31 December 2016

Executive Summary

The Canadian Network for the Detection of Atmospheric Change (CANDAC) continues to operate under the grant funded by the Natural Sciences and Engineering Research Council (NSERC) Canadian Climate and Atmospheric Research (CCAR) entitled "Research related to the Polar Environment Atmospheric Research Laboratory (PEARL): Probing the Atmosphere of the High Arctic (PAHA)". The PAHA grant permits CANDAC to continue a significant presence in Eureka with approximately 742 person-days in Eureka for 2016. As has been the case for several years, not all of our Memoranda of Understanding (MoUs) with Environment and Climate Change Canada (ECCC) are in place but this has not proven to be a significant problem.

Our operation has stabilized at approximately 320 manned days per year, and we continue to remotely operate as many instruments as possible. We also continue our efforts directed at putting as much of our data as possible into national and international data catalogues. The Polar Sunrise campaign was once again run in combination with the Atmospheric Chemistry Experiment (ACE) satellite validation campaign in late winter – early spring. Additionally, we supported the deployment and operation of the Far-Infrared Radiometer (FIRR) a ground-based version of the instrument proposed for the Canadian Space Agency Thin Ice Clouds in the Far Infra Red Experiment (TICFIRE) project that will measure thin ice clouds which may play an important role in the planetary radiation budget.

In 2016, we had 21 visitors to the laboratory, 11 of them students (Appendix A). Additionally, we continue to publish research papers in peer-reviewed journals and to make numerous presentations at national and international conferences and workshops (Appendix C), and are members of multiple multi-nation Arctic research coordination efforts such as SAON, the Sustaining Arctic Observing Network, and IASOA, the International Arctic Systems of Observing the Atmosphere.

CANDAC continues to refine the resources for teachers available on our website (http://www.candac.ca) as well as continuing to participate in teacher training conferences and science outreach events for students. Based on the positive feedback we have received on our Student-Researchers Atmospheric Collaboration outreach project in past years we Continue to look for opportunities to do so and are pleased to report that we will again visit a Nunavut school in early February 2017.

In 2016 our funding allowed us to maintain the number of days of operator manned operation at over 300. However, current funding is insufficient for re-establishing full-time on-site operations. We also ran extended summer and fall campaigns to operate instruments, take new CANDAC members to Eureka, and carry our necessary repairs.

CANDAC instrumentation continues to operate as anticipated and have not experienced any new failures in 2016. We have made improvements to instruments such as the Meteor Radar and Aerosol Mass Spectrometer, both of which had returned to operation in 2015, but in compromised configurations.

We continue to experience typical challenges including the normal turn-over in personnel from graduate students to instrument mentors. We had designated Professor Kimberly Strong of the

University of Toronto as a deputy Principal Investigator (PI) to strengthen our management structure. At the end of 2015, James Drummond the CANDAC/PEARL/PAHA principal investigator suffered a heart-attack and Professor Strong stepped in to keep the group moving. We are happy to say that Professor Drummond has recovered well. Our efforts to maintain CANDAC as a thriving scientific group saw us add three new instrument mentors/co-investigators Rachel Chang of Dalhousie University, Jean-Pierre Blanchet of Université du Québec a Montréal (UQÀM), and Patrick Hayes of Universite de Montreal. As a group we continue to work diligently to service our existing instrumentation while adding new instruments that will add to our relevance and scientific output. In 2017 we expect to put significant effort into continuing these efforts to renew and improve our PEARL operations and our scientific output. We are also always seeking funding to extend our outreach activities into Nunavut communities.

Introduction

2016 marked the third year of near full operation for the Canadian Network for the Detection of Atmospheric Change (CANDAC) at the Polar Environment Atmospheric Research Laboratory (PEARL) after having received further funding under the Natural Sciences and Engineering Research Council (NSERC) Canadian Climate and Atmospheric Research (CCAR) program. Our program of research entitled: Probing the Atmosphere of the High Arctic (PAHA) has seen us continue with the core observations and enables us to continue to maintain and improve our instruments.

In 2016 all but one of our instruments were in near continuous operation whether autonomous, remotely operated, or operated on site. We have maintained where applicable, the joint operation capability of instruments so that science teams in southern Canada -particularly graduate students- can participate in the active collection of data with the assistance of the on-site operator. This year we experienced a moderate rate of instrument problems and failures. The increasing age of many of them continues to be a concern and we monitor them very carefully. This year we have added new instruments from outside of the original PAHA scope that will expand our aerosol measuring capabilities, thereby expanding the scientific output of PEARL. The two instruments returned to service in 2015; the meteor radar and the aerosol mass spectrometer (AMS) have required further work. After its move from 0PAL to SAFIRE, one of the meteor radar receive antennas experienced a higher level of noise and so it was moved to an alternate location, and the radar is now functioning well. The AMS was brought back on line, but earlier this year suffered a failure of the chopper servo control loop which remains unresolved. During 2016, we introduced (first time visits)10 graduate students, post-doctoral fellows, and faculty to arctic operations .

Our research program continues to be highly relevant and our collaborators in various global efforts such as the Total Column Carbon Observing Network (TCCON), the Network for the Detection of Atmospheric Composition Change (NDACC) and the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) are increasingly interested in our data and science products. TCCON in particular seeks to be very interested in PEARL data as part of the Orbiting Carbon Observatory (OCO)-2 satellite validation program, and directed a DC-8 CO_2 profiling instrumentation to overfly PEARL in August of 2016. PEARL continues to be an important site for satellite validation, and the Canadian Space Agency continues to support our operations by contributing to the infrastructure costs and have committed to continued support for 0PAL and SAFIRE power. We continue to invest in our infrastructure through the upgrading of the local network that links the various sites. We continue to host several guest instruments and remain open to discussions non CANDAC/PAHA scientists who are looking for Arctic research sites.

Data and metadata of results from PEARL continue to be included in the Polar Data Catalogue as well as various national and international databases.

Within the purview of our Outreach Program, we were delighted to be able to continue our Student-Researchers Atmospheric Collaboration with a school in Toronto, Ontario, and to continue our project where students measure atmospheric aerosols. As will be discussed later, we were unable to visit schools in Nunavut during 2016 but plans are in place for 2017. In addition to these larger projects, we

continue to visit schools in southern Canada to educated students about the research done at PEARL.

Instrument Installations, Removals, and Modifications

Ridge Laboratory
In July 2016 two photo-acoustic extinctiometers were installed to complement the aerosol mass spectrometer measurements program and to support that we installed a scanning mobility particle sizer (SMPS) and an optical particle counter (OPC).

The Zero-Altitude PEARL Auxiliary Laboratory (ØPAL)
In October 2015, we installed the Far Infrared Radiance Radiometer (FIRR) at ØPAL. The FIRR will be attempting to detect the presence of ice clouds in the atmosphere. It is the proto-type of a satellite instrument that may be selected for launch in the next few years. The FIRR remained in operation at 0PAL until April 2016 and was returned to the CSA in July. In August a Thermo Scientific TEI49i ozone sensing instrument was installed in one of the ØPAL containers. This instrument will help us monitor surface level ozone events. A Cimel Moonphotometer was installed in March. This instrument is also capable of taking solar measurements, and the expectation was that it would remain in operation throughout the year, complementing the aerosol measurements made by the star photometer during polar night-time, and re-instituting the ØPAL sunphotometer measurements that had halted in 2012. However, this instrument must be regarded as still under development as its pointing and tracking device has been unable to cope with temperatures significantly below -20C. We will be continuing to work with Cimel and ECCC on the deployment of this instrument.

The Surface and Atmospheric Flux, Irradiance and Radiation Extension (SAFIRE) Laboratory
There were some additions to the Flux tower installation at SAFIRE as two new anemometers were added. The rest of the site was stable in terms of instrument additions or removals.

On-going Research

Once again for what was the 12th consecutive year, the Intensive Phase of the Canadian Arctic ACE Validation Campaign 2016 (aka the Polar Sunrise Campaign) took place from 25 February to 19 March at PEARL, with the Extended Phase immediately following between 13 March and 1 April. 2016 also had some “pre-campaign” activity as team members went in late January and mid February to establish LIDAR operations. As per the previous campaigns, the team of researchers from the University of Toronto, Western University, York University and CANDAC collected atmospheric composition measurements using a suite of 11 instruments, some of which are permanently installed on-site and some of which were brought in for the campaign. These observations will be used to verify results obtained by two Canadian scientific satellite missions, the Atmospheric Chemistry Experiment (ACE) on SciSat and the Optical Spectrograph and InfraRed Imager System (OSIRIS) on ODIN. The

measurements are made at polar sunrise when sunlight returns to Eureka and which is the period when ozone depletion processes are occurring. These measurements continue to be of great importance in the validation of the satellite instruments, that have now exceed their planned life-time by a decade.

On-site operations for 2016 match those of 2015, a significant increase over the 2012-2014 time frame with on-site operator coverage from early January through to mid December. Michael Maurice and Peter McGovern continue as our on-site operators. Through out 2016 the weather was not generally a negative factor allowing for a "normal" slate of activities. We also continue to assist NavCan in their efforts to upgrade the Eureka airport weather and runway conditions reporting in any way that we can.

Most of the activity of our summer campaign dealt with instrument repairs and new installations. After moving the meteor radar to the SAFIRE site in 2015, it returned to operation. However, a noise issue was discovered with one of the antennas being too close to the building enclosure for the electronics, and so that antenna needed to be relocated. The VHF Wind tracker radar had a maintenance visit, with damaged radio frequency feed-lines repaired. Much work was done in modernizing the instrumentation mounted on the flux tower. Two new anemometers were added and several wiring issues that had evolved over the years were repaired. The communication to the tower was also moved from a 900 MHz radio system to the microwave system that is used everywhere else on site. Data monitoring and distribution has also been improved. The flux tower work was carried out primarily by our collaborators at the American National Oceanic and Atmospheric Administration (NOAA) in close cooperation with CANDAC. The CANDAC/PAHA micro-barometer located at the base of the flux tower worked very well through much of 2015-2016 but at some point its cabling was damaged and subsequently repaired.

The fall sunset campaign was held from 25 October to 14 November. During this visit we carried out several maintenance and instrument repair activities to the Bruker FTIR vacuum subsystem, All Sky imager power supply, and E Region Wind (ERWIN) instrument calibration lamps. We also began operating the PEARL RidgeLab Differential Absorption Lidar (DIAL) system to monitor the ozone and temperature profile and improved the measurement capability of the of the ØPAL CANDAC Raman lidar (CRL) which had been operating without one of its channels. We also re-activated several of the night-time operating instruments. We also had a test flight of a small unmanned aerial vehicle (UAV) to study the features of the polar night-time atmospheric temperature inversion near Eureka. Our UAV is Matrice 100 quad-copter made by DJI. This model can fly with up 1 kg of payload for about 20 minutes. The UAV has been equipped with a data acquisition system which includes Raspberry Pi 2 microcomputer, GPS receiver, pressure sensor and three resistance temperature detectors to monitor atmospheric conditions during the flight. There are no cameras or other sensors included.For the most part, all our instruments have been working as expected and the results are being reported in the scientific literature as well as being presented at various national and international conferences and workshops. In addition, we now hold monthly telecons with scientists and managers at Environment Canada to ensure they are kept current with our efforts and that we are responding to their requirements as dictated by the PAHA grant. These are increasingly well attended by ECCC scientists.

PEARL and the Eureka Weather Station continue to be excellent examples of how the existence of quality facilities provides synergies that lead to research projects not previously considered, and that may have a real impact on the lives of Canadians in remote communities. Both the FIRR and OMTI collaborations may yield significant understandings to atmospheric processes affecting daily life in the Arctic.

Outreach Activities

Our outreach program continued to be active in 2016. The main program we undertook this year was the Student-Researcher Atmospheric Collaboration with kindergarten to Grade 5 students in 12 classes at West Preparatory School in Toronto, Ontario [five kindergarten, two grade 1, three grade 2, one grade 4 and one grade 5 classes]. These elementary school students monitored the atmosphere using a variety of scientific instruments and shared and compared their data and analyses. The student researchers made and recorded daily measurements using thermometers (kindergarten) and anemometers (grades 1 and 2) and pyronometers (grades 4 and 5). At the end of the eight-week measurement program, they shared their results in a collaborative event at the school. The PAHA participants included Aubyn O'Grady, Shayamila Gamage, Ghazal Farhani, and Orfeo Colebatch (also Alex Geddes, Ja-Ho Koo, Kevin Olsen). In addition, Ralf Bauer and Alex Geddes visited one kindergarten class (including parents) at Da Vinci Public School in Ajax, Ontario on 30 March 2016 to talk about weather measurements; and Aubyn O'Grady, Ralf Bauer and Luke Collins participated in the Science Rendezvous festival at the University of Toronto (presenting demonstrations and hands-on activities for the public on atmospheric science). For the University of Toronto "Science Unlimited Summer Camp", we provided a half-day of activities (PAHA participants: Kaley Walker, Aubyn O'Grady, Ralf Bauer, Kristof Bognar, Luke Collins, Dan Weaver and other participant: Kanupria Seth).

In past years, our outreach program has travelled to various locations in Nunavut to interact with interested schools. We will be doing so again in 2017. Detail is provided in the section describing our 2017 plans.

Summary of Plans for 2017

As has been the case for some years, at the time of the writing of this report, we are still in the process of negotiating our Memorandum of Understanding with Environment Canada. We are hopeful that the process will be completed in at some point but do not expect that its completion will result in a materially different operating scenario. Aside from the standard operations, measurements, and maintenance, we will be continuing the effort We continue to develop the remote controlled drone capability for measurements of the temperature field at a greater spatial extent in the vicinity of the flux

tower. We continue to refine the automation of instrument operation with the goal of general improvement to, and expansion of the measurement capabilities. We continue to find ourselves in discussion with multiple new groups beyond the CANDAC family that are considering installing instruments at PEARL. 2017 will also see the advent of on-site activity in support of the CSA funded "Arctic Validation And Training for Atmospheric Research in Space" (AVATARS) program based largely at PEARL. AVATARS is lead by PAHA Deputy PI Professor Kimberly Strong and includes many of the PEARL/CANDAC/PAHA team. This program is aimed at building Canadian capacity in support of science and technology. Over the next 3 years, this will result in further development of PEARL instrumentation and operation.

While we do not have a full year-round operator presence at PEARL, we are aiming to maintain a presence for approximately10 months of the year to facilitate acquiring more data with those instruments (mostly daytime instruments) that are least automated. We continue to work towards decreasing the amount of human intervention required by those instruments. With the anticipated return of operation of the DIAL we will increase our manned days on site during the polar night in support of our polar night theme. In 2016 we achieved 322 days on site. We have chosen to not have an operator on site during the period spanning roughly mid December to mid January as this tends to be a quiescent period for both instruments and operations

The ACE/OSIRIS team is funded for 2017 and so we expect to host the Canadian Arctic Validation Campaign, at PEARL for the thirteenth operation. The time period will be very similar as in previous years and we will be continuing to validate the ACE/OSIRIS results during polar sunrise.

CANDAC will be resuming its outreach effort in the form of contact with Nunavut communities principally through school visits. The CANDAC Student-Researcher Collaboration project is designed to enable students to become co-investigators in atmospheric research. The program gives students an opportunity to gather data and conduct inquiry-based investigations about current atmospheric conditions using scientific instruments located at their own school. CANDAC researchers partner with students and staff to provide training and assistance and ensure that the data collected throughout the project is analysed and understood. Beginning in February 2017, we will be running the Student-Researcher Collaboration program with Joamie Elementary School and Inuksuk High School in Iqaluit, Nunavut. Over a period of eight weeks, grade four and five students at Joamie will be gathering daily temperature and wind speed measurements using a thermometer, an anemometer and a weather vane. High School students at Insukuk will be taking daily pyranometer (solar radiation) and sun photometer (aerosol optical thickness) measurements.

Concluding Remarks

Making state of the art scientific measurements in the Arctic is challenging and keeping equipment on line continues to be our major concern. CANDAC continues to push forward with the PAHA project, demonstrating that it has a solid core complement of instrumentation, facilities and personnel. Operationally, 2016 is characterized by a high level of instrument operation with expanded measurement capabilities. We continue to have a significant amount of research dissemination while

continuing with our development of highly qualified personnel. We have continued to improve instrument automation and our continued partnerships with NOAA, ECCC and various universities both in Canada and abroad show that we remain well-equipped to support both our own research and other research that might benefit from our facilities. PEARL based research results are continuously making their way into the scientific world and are contributing to a greatly-improved understanding of the Arctic atmosphere. We continue to extend the PEARL data record and for many instruments it is approaching a significant length such that they will be useful for trends analyses. This is where the benefits of an enduring and well-instrumented site such as PEARL will become apparent as we continue with our efforts. Our outreach activities continue to educate future generations of Canadians. We are determined to continue our small part in asserting that the Arctic is an important part of Canada through our presence, our research, and through education. As always, the CANDAC team is working hard to ensure a continuation of these efforts in the future.

Appendix A: Visitors to PEARL in 2016

** denotes first time visitors*

Non-CANDAC Personnel visiting PEARL in 2016

1. Ludovic Pelletier, grad student, UQAM*
2. Zahra Vaziri, grad student, York U.
3. Ellen Eckert, grad student, Karlsruhe Institute of Technology*
4. Sergio Dempsey, grad student, Western U.*
5. Taneil Uttal, government scientist, NOAA
6. Christopher Cox, government scientist, NOAA*

CANDAC Personnel visiting PEARL in 2016

1. Patrick Hayes, Assistant Professor, McGill U
2. Pierre Fogal, PEARL Site Manager, U Toronto
3. Wayne Hocking, CANDAC Co-Investigator, U Western Ontario
4. Liviu Ivanescu, graduate student, U Sherbrooke
5. Sam Kristoffersen, graduate student, UNB
6. Michael Maurice, operator, Dalhousie U
7. Peter McGovern, operator, Dalhousie U
8. Alexey Tikhomirov, Research Associate, Dalhousie U
9. Sebastien Roche, graduate student, U Toronto *
10. Samantha Tremblay, grad student U. Montreal*
11. Emily McCullough, Dalhousie
12. Kristof Bognar, grad student, U. Toronto*
13. Eric Lutsch, grad student, U. Toronto*
14. Ghazal Farhani, grad student, Western U.*
15. William Ward, professor, UNB*

Appendix B: Glossary of Acronyms

0PAL	Zero-altitude PEARL Auxiliary Laboratory
ACE	Atmospheric Chemistry Experiment
AVATARS	Arctic Validation And Training for Atmospheric Research in Space
CANDAC	Canadian Network for the Detection of Atmospheric Change
CCAR	Canadian Climate and Atmospheric Research
CSA	Canadian Space Agency
DIAL	DIfferential Absorption Lidar
ECCC	Environment and Climate Change Canada
FIRR	Far-Infrared Radiometer
IASOA	International Arctic Systems for Observing the Atmosphere
MoU	Memoranda of Understanding
NDACC	Network for the Detection of Atmospheric Composition Change
NSERC	Natural Sciences and Engineering Research Council of Canada
OCO	Orbiting Carbon Observatory
OMTI	Optical Mesosphere and Thermosphere Imager
OSIRIS	Optical Spectrograph and InfraRed Imager System
PAHA	Probing the Atmosphere of the High Arctic
PEARL	Polar Environment Atmospheric Research Laboratory
PI	Principal Investigator
SAON	Sustaining Arctic Observing Network
SMPS	Scanning Mobility Particle Sizer
OPC	Optical Particle Counter
SAFIRE	Surface and Atmospheric Flux, Irradiance and Radiation Extension
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
TCCON	Total Carbon Column Observing Network
TICFIRE	Thin Ice Clouds in the Far Infra Red Experiment
UAV	Unmanned Aerial Vehicle
UQAM	Université de Quebéc à Montréal

Appendix C: Publications:

The dissemination list is provided as a separate document.