Seventeen Years of the Canadian Arctic ACE/OSIRIS Validation Project at PEARL

Kaley A. Walker[1], Kimberly Strong[1], Pierre F. Fogal[1], James R. Drummond[2]

and the Canadian Arctic ACE/OSIRIS Campaign Team

[1]University of Toronto; [2]Dalhousie University

(contact: kaley.walker@utoronto.ca)

EGU General Assembly 2020, Sharing Geoscience Online, 4 May 2020

Introduction & Campaign Motivation

- Ground-based measurements provide critical data to validate satellite retrievals of atmospheric trace gases and to assess the long-term stability of these measurements.
    - Validation in the Arctic is needed for satellite measurements, because the region is so large and sparsely populated only satellites can see the "whole picture".
- As of February 2020, the Canadian-led Atmospheric Chemistry Experiment (ACE) satellite mission has been making measurements of the Earth's atmosphere for sixteen years and Canada's Optical Spectrograph and InfraRed Imager System (OSIRIS) instrument on the Odin satellite has been operating for over eighteen years.
- As ACE and OSIRIS continue to operate far beyond their planned two-year missions, there is an ongoing need to validate the trace gas profiles from the ACE-Fourier Transform Spectrometer (ACE-FTS), the Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation (ACE-MAESTRO) and OSIRIS.
    - In particular, validation comparisons are needed during Arctic springtime to understand better the measurements of species involved in stratospheric ozone chemistry.

Campaign Location: PEARL at Eureka

- To this end, seventeen Canadian Arctic ACE/OSIRIS Validation Campaigns have been conducted during the spring period (February - April in 2004 - 2020) at the Polar Environment Atmospheric Research Laboratory (PEARL).
  - The spring period coincides with the most chemically active time of year in the Arctic, as well as a significant number of satellite overpasses.
- The PEARL Ridge Lab, pictured at right, is one of the three PEARL sites [Fogal et al., 2013]. Since 2005, this facility has been operated by the Canadian Network for the Detection of Atmospheric Change (CANDAC).
- Eureka is located on Ellesmere Island in the Canadian high Arctic (80 °N, 86 °W). PEARL is situated near the Environment Canada Weather Station (that has been in operation since 1947).

ACE on SCISAT

Launched: August 2003

Orbit: 74° inclination at 650 km

Measurement mode:
solar occultation (~6-150 km)

ACE-FTS [Bernath et al., 2005]**:**
- FTIR spectrometer, 2-13 microns at 0.02 cm^{-1} resolution
- 2-channel visible/NIR imager, 0.525 and 1.02 microns

MAESTRO [McElroy et al.,2007]**:**
- dual UV / visible / NIR grating spectrophotometer, 285 to 1030 nm at ~1-2 nm resolution

Pointing: suntracker in ACE-FTS

OSIRIS on Odin

Launched: February 2001

Orbit: 98° inclination at 600 km

Measurement mode (in limb):
scattered sunlight (10-100 km)

OSIRIS [Llewellyn et al., 2004]**:**
- Optical grating spectrograph (280-810 nm, 1 nm resolution)
- Narrow horizontal slit (1 arc minute)
- Three channel filtered vertical imager (1.26 and 1.27 micron $^1\Delta$ O_2; 1.53 micron OH Meinel)

Pointing: Odin moves to point OSIRIS instrument

Campaign Measurements

IR Fourier Transform Spectrometers (FTSs): CANDAC Bruker 125HR FTS, EM27/SUN, E-AERI, PARIS-IR, and EC DA8 FTS
- Total and partial columns of O_3, CH_4, H_2O, NO, NO_2, $ClONO_2$, HNO_3, N_2O, HCl, CCl_3F, CCl_2F_2, HF, CO and CO_2

UV-Visible Spectrometers: SPS-G, SAOZ, MAESTRO-G, UT-GBS, PEARL-GBS, Pandora spectrometer, and Brewer spectrometers
- Total columns and (some) partial columns of O_3, NO_2, H_2O, OClO, BrO, SO_2

Profiling Lidars: Ozone Differential Absorption Lidar (DIAL) and Rayleigh-Mie-Raman (CRL)
- Profiles of O_3, H_2O, temperature, aerosols, and clouds

Balloon Sondes: Ozonesondes and radiosondes
- Profiles of O_3, H_2O and temperature

Campaign Data Set

- **Pre-campaign phase:** early February – mid February (pre-sunrise lidar measurements)
- **Intensive phase:** mid February – early-mid March (full team on site, daily ozonesondes)
- **Extended phase:** early-mid March – early-mid April (operators only, weekly ozonesondes)

Instrument	Type	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
ECCC DA8 FTS	IR FTS	√	√	√	√	√	*											
PARIS-IR	IR FTS	√	√	√	√	√	√	√	√	√	√	√	√	√	√			
CANDAC Bruker FTS	IR FTS				√	√	√	√	√	√	√	√	√	√	√	√	√	√
CANDAC E-AERI	IR FTS						√		√	√	√	√	√	√	√	√	√	√
EM27/SUN	IR FTS																√	√
EC/CANDAC Ozone DIAL	Lidar	√	√	√	√	√	√	**					**	√	√	√	√	√
CANDAC RMR Lidar (CRL)	Lidar								√	√	√	√		√	√	√	√	√
York/ECCC MAESTRO-G	UV/Vis	√	√	√	√	√	√	√	***	√	√	√	****	√	√	√		
York/ECCC SPS-G	UV/Vis	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
CANDAC UT-GBS	UV/Vis	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
ECCC Brewer Spectrometer	UV/Vis	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
SAOZ	UV/Vis		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
CANDAC PEARL-GBS	UV/Vis				√	√	√	√	√	√	√	√	√	√	√	√	√	√
ECCC Pandora Spectrometer	UV/Vis																√	√
ECCC Ozonesondes	Balloon	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Abbreviations for spectral regions are as follows: IR: infrared; UV: ultra-violet; Vis: Visible

* Following extensive intercomparisons with Bruker FTS, DA8 FTS was removed in February 2009

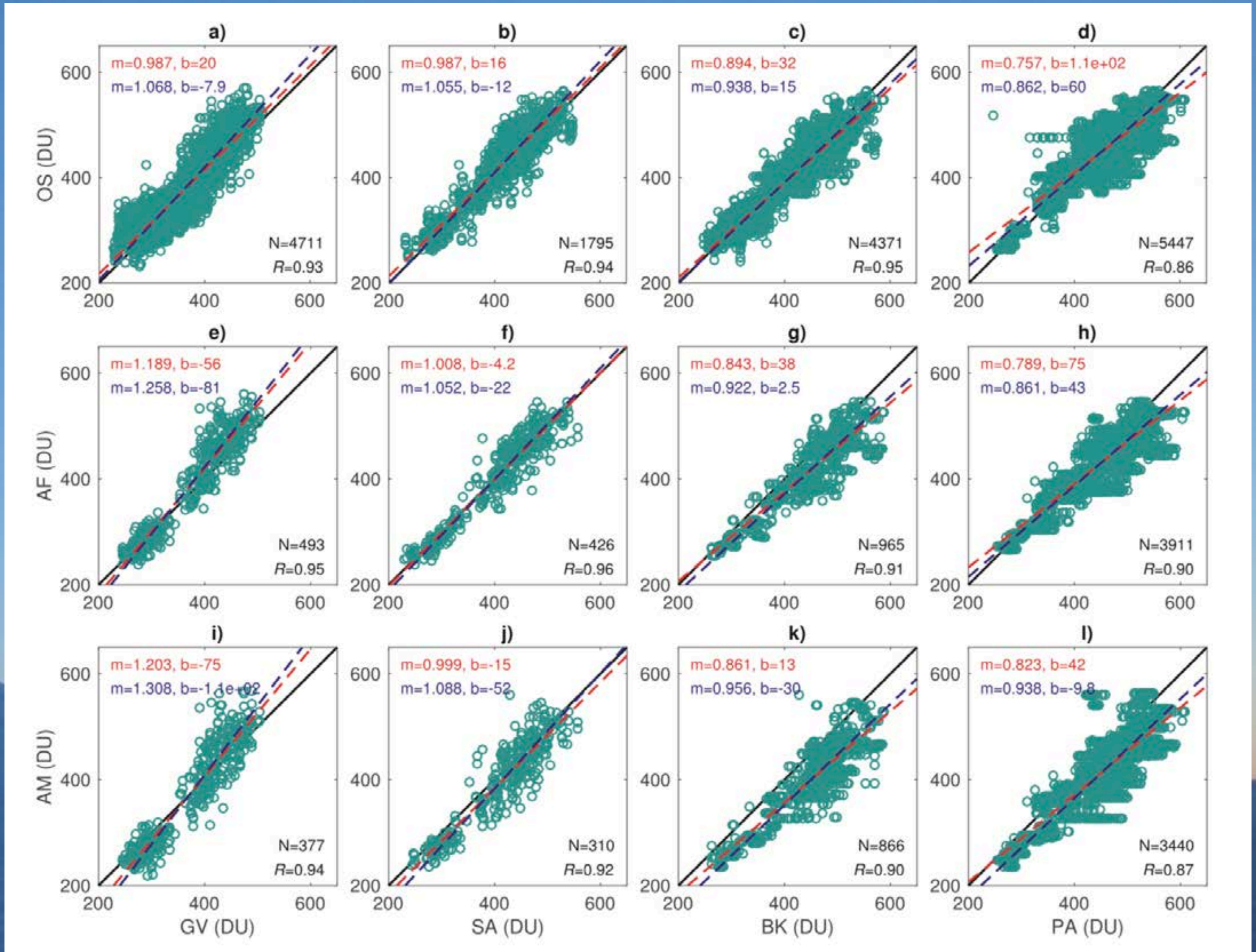
** Laser failed at end of 2009 campaign and repair / rebuilding of lidar was tested during 2015 campaign

*** On balloon campaign in Kiruna during spring 2011

**** Being prepared for balloon campaign in Timmins during late summer 2015

Recent validation comparison results

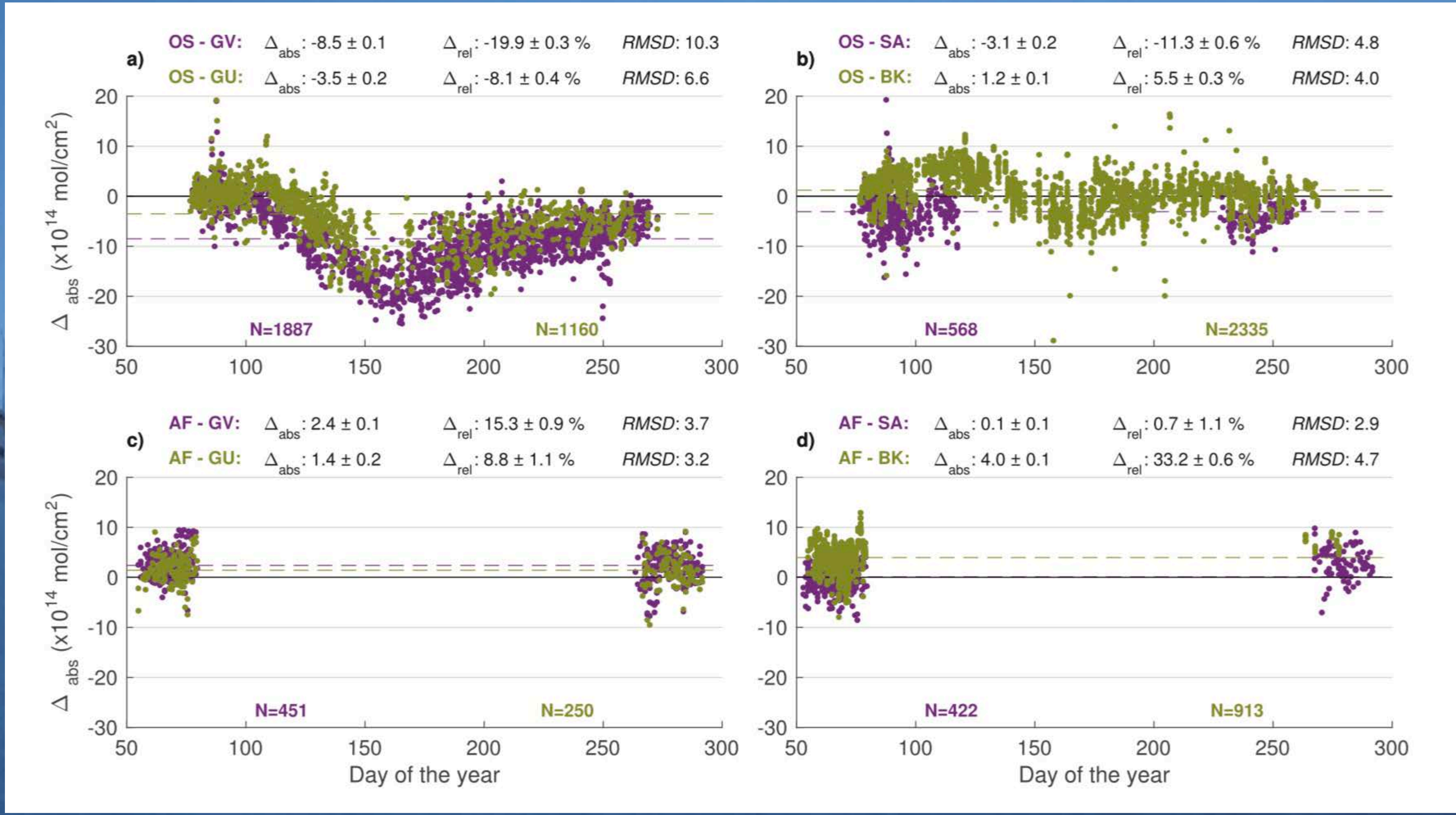
- Comparison of ozone total columns from GBS (GV), SAOZ (SA), 125HR FTS (BK) and PARIS-IR (PA) to satellite-derived columns from OSIRIS (OS), ACE-FTS (AF) and MAESTRO (MA)
- Nearest ozonesonde profile is used for altitudes below lowest satellite measurement to produce a satellite-plus-sonde total column
- Best fit lines (dashed) are shown from both ordinary least squares (red) and reduced major axis (blue) methods



Results from Bognar et al. [2019].

Recent validation comparison results

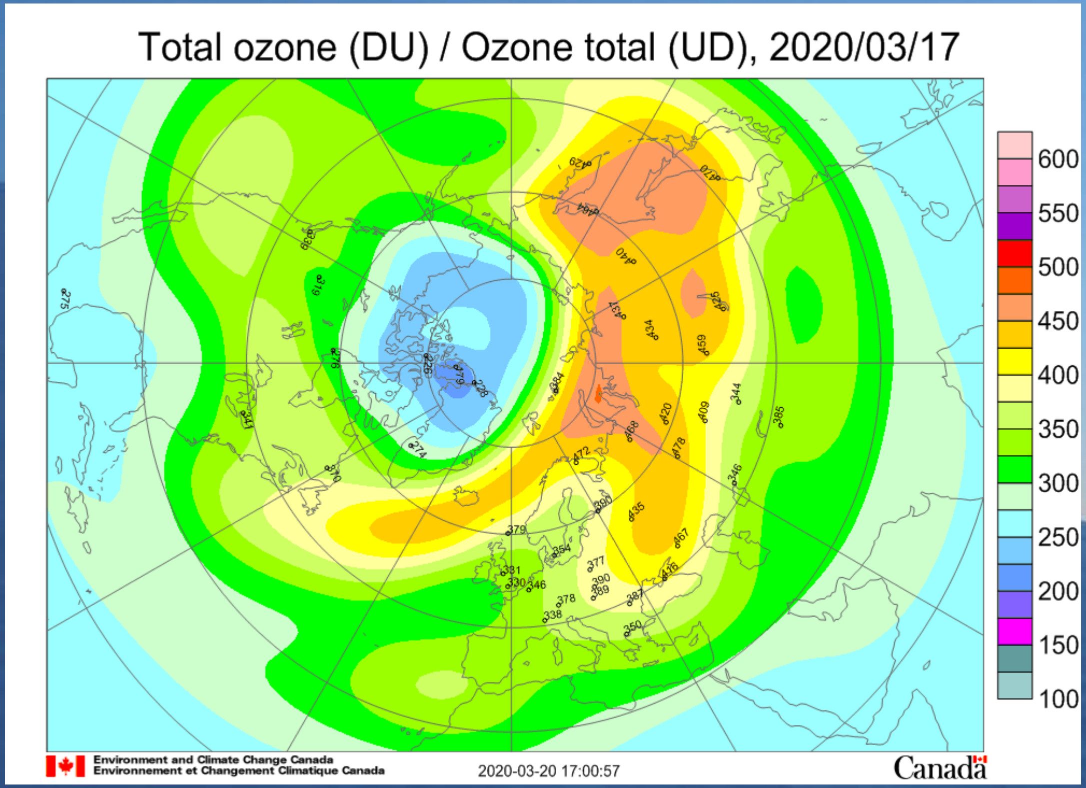
- Seasonal comparison of 12-40 km partial columns of NO_2
- Absolute differences between OSIRIS (OS) or ACE-FTS (AF) and UV-GBS (GU), Vis-GBS (GV), SAOZ (SA) and 125HR FTS (BK) are shown
- Dashed lines show mean absolute differences
- Errors shown for the mean differences and *RMSD* values are the standard error

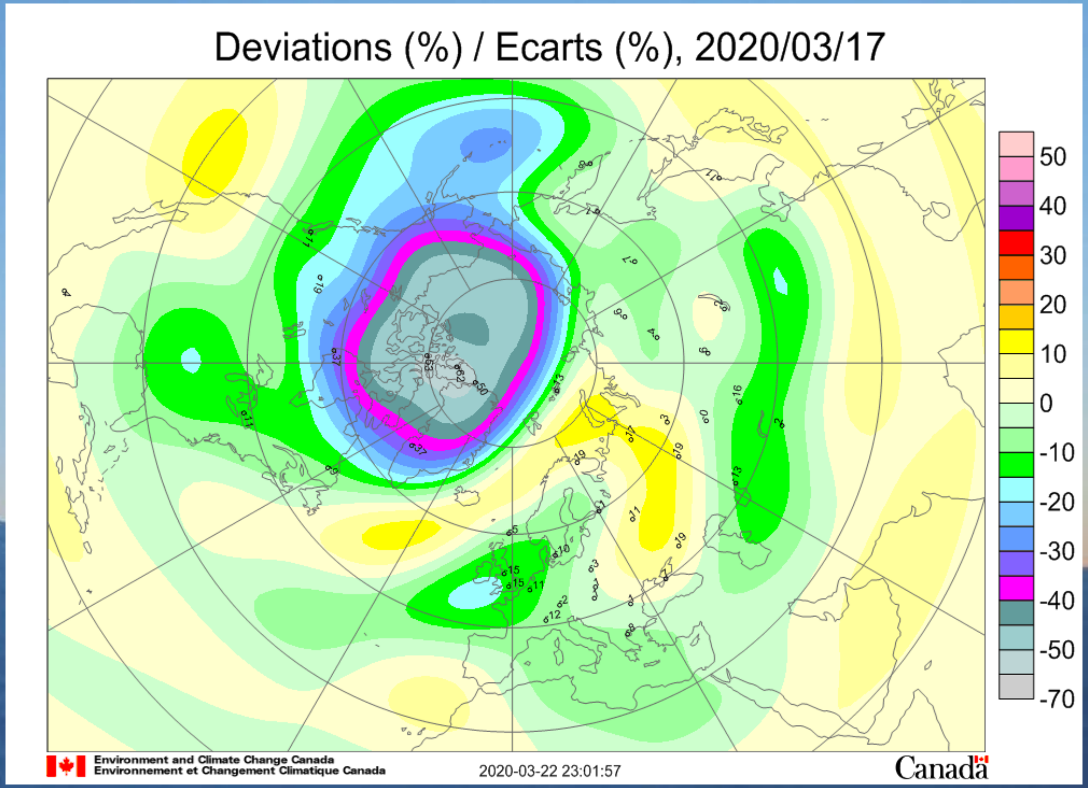


Results from Bognar et al. [2019].

Interesting 2020 Conditions at Eureka

- The polar vortex was over Eureka for a significant portion of the 2020 ACE/OSIRIS Arctic Campaign – through March and into April
- Data from the campaign are in the process of being analyzed to explore ozone depletion and chemistry during this interesting winter!





Source: ECCC World Ozone Monitoring and Mapping site; https://exp-studies.tor.ec.gc.ca/clf2/e/ozoneworld.html

Summary

- The goal of the Canadian Arctic Validation Campaign project is to build a time series of measurements with a well characterized set of instruments that will extend throughout the life of ACE and OSIRIS.
  - To use these in identifying and investigating changes in satellite instrument performance and in assessing new data versions and data products.
  - To utilize these in collaborative validation efforts for international missions such as Envisat, GOSAT/GOSAT-2, OCO-2/OCO-3 and TROPOMI.

- Characterizing and understanding differences between instruments has improved data processing techniques for the ground-based instruments and has furthered satellite comparison techniques.

- **Please get in touch if you are interested in the campaign data sets.** We are very happy to collaborate on validation and scientific studies using these high Arctic data!

2004 – 2020 Campaign Team

ACE Validation Team Co-Leaders
- Kimberly Strong, U. Toronto
- Kaley Walker, U. Toronto

Campaign Co-Investigators
- Adam Bourassa, U. Saskatchewan
- Doug Degenstein, U. Sask.
- James R. Drummond, Dal. U.
- Tom Duck, Dalhousie U.
- Hans Fast, ECCC
- Pierre Fogal, PEARL Site Manager
- Florence Goutail, LATMOS
- C. Thomas McElroy, York U.
- Richard Mittermeier, EC
- Andrea Pazmiño, LATMOS
- Mahesh Kumar Sha, BIRA-IASB
- Robert Sica, Western U.
- Kevin Strawbridge, ECCC
- David Tarasick, ECCC
- Corinne Vigouroux, BIRA-IASB
- Debra Wunch, U. Toronto

Team Members
- Cristen Adams, U. Toronto
- Ramina Alwarda, U. Toronto
- Rebecca Batchelor, U. Toronto
- Richard Berman, Spect. Appl. Res.
- Kristof Bognar, U. Toronto
- Lin Dan, U. Toronto
- Ellen Eckert, KIT/U .Toronto
- Ghazal Farhani, Western U.
- Bernard Firanski, ECCC
- Jonathan Franklin, Dalhousie U.
- Annemarie Fraser, U. Toronto
- Dejian Fu, U. Waterloo
- Shayamila Gamage, Western U.
- Debora Griffin, U. Toronto
- Michael Harwood, ECCC
- Beatriz Herrera, U. Toronto
- Shannon Hicks, Western U.
- Ali Jalali, U. Toronto
- Paul Jeffery, U. Toronto
- Tobias Kerzenmacher, U. Toronto
- Felicia Kolonjari, U. Toronto
- Rodica Lindenmaier, U. Toronto
- Lei Liu, U. Toronto
- Erik Lutsch, U. Toronto
- Zen Mariani, U. Toronto
- Emily McCullough, Dalhousie U.
- Joseph Mendonca, U. Toronto
- Andrea Moss, Western U.
- Clive Midwinter, U. Toronto
- Chris Perro, Dalhousie U.
- Sebastien Roche, U. Toronto
- Volodya Savastiouk, ECCC
- Keeyoon Sung, U. Waterloo
- Alexey Tikhomirov, Dalhousie U.
- Sophie Tran, U. Toronto
- Zahra Vaziri Zanjani, York U.
- Jennifer Walker, U. Toronto
- Dan Weaver, U. Toronto
- Tyler Wizenberg, U. Toronto
- Mareile Wolff, U. Toronto
- Hongjiang Wu, U. Toronto
- Xiaoyi Zhao, U. Toronto/ECCC

CANDAC/PEARL Operators
- Suzy Bingham, U. Toronto
- John Gallagher, Dalhousie U.
- Andrew Hall, Dalhousie U.
- Ashley Harrett, U. Toronto
- Paul Loewen, U. Toronto
- Keith MacQuarrie, U. Toronto
- Michael Maurice, Dalhousie U.
- Peter McGovern, Dalhousie U.
- Oleg Mikhailov, U. Toronto
- Matt Okraszewski, U. Toronto

ACE Mission Scientist
- Peter Bernath, U. Waterloo

Acknowledgments

Funding and support for the ACE/OSIRIS Campaigns and this work was provided by:

- Canadian Space Agency (CSA)
- Environment and Climate Change Canada (ECCC)
- Natural Sciences and Engineering Research Council Canada (NSERC)
- Northern Scientific Training Program (NSTP)
- Centre National d'Etudes Spatiales (CNES)
- Canadian Network for Detection of Atmospheric Change (funding/partners including: ARIF, AIF/NSRIT, CFCAS, CFI, CSA, ECCC, GoC-IPY, NDACC, NSERC, NSTP, OIT, ORF, PCSP, SEARCH)

Special thanks to the Eureka Weather Station staff for their support during our seventeen campaigns.

References

Bernath, P. F., et al. (2005), Atmospheric Chemistry Experiment (ACE): Mission overview, *Geophys. Res. Lett.*, 32, L15S01.

Bognar, K. et al. (2019), Updated validation of ACE and OSIRIS ozone and NO_2 measurements in the Arctic using ground-based instruments at Eureka, Canada, *J. Quant. Spectrosc. Ra.*, 238, 106571.

Fogal P.F., et al. (2013), The Polar Environment Atmospheric Research Laboratory (PEARL): Sounding the Atmosphere at 80° North, *Arctic*, 66, 377-86.

Llewellyn, E. J., et al. (2004), The OSIRIS instrument on the Odin spacecraft, *Can. J. Phys.*, 82, 411-422.

McElroy, C.T., et al., (2007), The ACE-MAESTRO instrument on SCISAT: description, performance, and preliminary results, *Appl. Opt.*, 46, 4341-4356.