Validation Capacity in the Canadian High Arctic: The Polar Environment Atmospheric Research Laboratory (PEARL)

Kaley A. Walker¹, James R. Drummond², Pierre F. Fogal¹, and the CANDAC/PAHA Science Team

¹University of Toronto, Toronto, ON, Canada
²Dalhousie University, Halifax, NS, Canada

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Outline

- Polar Environment Atmospheric Research Laboratory (PEARL)
  - Why do satellite validation at PEARL?

- Atmospheric Data Product Validation from PEARL
  - Canadian and international missions

- PEARL: PAHA (Probing the Atmosphere of the High Arctic) Project
  - Collaborative project utilizing the PEARL dataset
Validation Motivation

• Why validate data sets?
  - To keep everyone honest and ensure on-going data quality

• Why validate satellite measurements in the Arctic?
  - Because the region is so large and sparsely populated, we need satellites to see the “whole picture”
  - Because the Arctic is “different” and we need appropriate validation (don’t assume all is good if it works at <50°N)

• Why long-term activities in the Arctic to support validation?
  - Because it is hard to do things well in the Arctic!
  - The comparison data has got to be at least as good as the validated satellite data
Polar Environment Atmospheric Research Laboratory (PEARL)

- Eureka, Nunavut, Canada (80N, 86W)
  - Three sites make up PEARL
- Goal to characterize the Arctic atmosphere from ground level to 100 km as thoroughly as possible.

Photos courtesy of Pierre Fogal

Photos courtesy of Paul Loewen
PEARL/Eureka
Resolute Bay
Grise Fiord

Halifax-Vancouver – 4,400km
Halifax – Eureka – 4,100km
Yellowknife – Eureka 2,000km
Resolute – Eureka 620km
Grise Fiord – Eureka 400km

Don’t forget your screwdriver!
PEARL’s nearest ‘neighbour’
Environment Canada’s Eureka Weather Station
25+ instruments are located across all three sites at PEARL

- **Trace gases measurements (columns and/or profiles):**
  - Solar absorption FTIR (Bruker 125HR - NDACC, TCCON)
  - Emitted radiation FTIR (E-AERI)
  - UV-visible grating (NDACC) and Brewer spectrometers
  - Tropospheric and stratospheric lidars
  - Including \(O_3\), NO, \(NO_2\), HNO\(_3\), NO\(_3\), \(N_2O\), ClONO\(_2\), HCl, OClO, BrO, HF, CFCs, \(CH_4\), \(H_2O\), CO, \(CO_2\) and OCS

- **Aerosol** measurement via lidar, sun photometer and star photometer instrumentation (AERONET/AEROCAN)

- **Upper atmospheric wind and temperature** measurements, tropospheric cloud and wind radars.

- **Longwave and shortwave radiation** are measured using Baseline Surface Radiation Network (BRSN) type instrumentation. Also, 10 m flux tower.
Percent deviation from 1978-1988 ozone mean for 20 March 2011
Why Satellite Validation at PEARL?

- Eureka is at the “sweet spot” for polar orbiting satellites
  - More overpasses at this latitude than any other location on the planet
- Possible to validate
  - “A-train” (Cloudsat)
  - SCISAT/ACE
  - Terra/MOPITT
  - Envisat and Odin
  - Any sun synchronous satellite
Satellite Validation at PEARL

- Focus on atmospheric missions - both limb profilers and nadir viewing
  - Canadian limb sounders
    • SCISAT/ACE and Odin/OSIRIS
  - Nadir-viewing greenhouse gas monitoring
    • Japanese GOSAT and US OCO-2
  - Also, used for Envisat, NPP Suomi, MetOp...
Recent Northern Hemisphere stratospheric HCl increase due to atmospheric circulation changes

Increase in HCl in lower stratosphere (46 hPa) diagnosed using satellite profile measurements including SCISAT/ACE

ACE/OSIRIS Arctic Validation Campaign Project

- To obtain validation measurements for ACE and OSIRIS in the Canadian Arctic (Eureka, Nunavut - 80°N, 86°W) from February to April 2004 - 2014 for all baseline species
- To make daily measurements at high temporal resolution to give context to the sparse (in time and space) ACE occultation measurements (Arctic science is priority 1)
- To use data to validate OSIRIS and other satellite missions
- To provide spectral, as well as trace gas, measurements from ground-based versions of ACE-FTS and ACE-MAESTRO
- To maintain the continuity of measurements from the NDSC-validated FTIR at Eureka, which have been made since 1993
Comparisons of NO\textsubscript{2} Partial Columns

- Correlation plots used to examine consistency of measurements from satellite and ground-based instruments at PEARL (~2004-2011)
- Fits for partial columns from 17-40 km from each instrument
- All measurements scaled to local noon using photochem. box model

ACE-FTS (v3.0)

OSIRIS (OE v3.0)

GBS - Visible

GBS - UV

SAOZ

Adams et al., AMT, 5, 927–953 (2012)
Validating Stratospheric Measurements

Comparisons of ACE-FTS versus FTIR for stratospheric species important in understanding ozone chemistry

Partial columns calculated from
6-43 km (O₃)
8- 38 km (HCl)
15-26 km (ClONO₂)
8-29 km (HNO₃)
10-43 km (HF)

Top plot - all observations within 12 hours, 1000 km
Bottom - further selected by air mass (sPV, T)

Batchelor et al., AMT, 3, 51-99 (2010)
Impact of ACE Campaigns at PEARL

- Goal is to continue a time series of measurements with consistent set of instruments throughout the life of SCISAT
  - Use to identify changes in satellite instrument performance (50% of ACE measurements >60 degrees lat.)

- Understanding differences between instruments has improved data processing for ground-based instruments and comparison techniques
  - FTS results very important for atmospheric species not often measured from satellites - HCl, HF, CH₄, CFCs etc.
  - GBS results valuable for BrO as well as O₃ and NO₂
  - Balloon sondes and DIAL very useful for providing profiles of O₃ and temperature

- Used O₃ and temperature sonde profiles for refinement of ACE-FTS data products and development of MAESTRO T retrievals
PEARL Participation in Global Networks

NDACC: Network for Detection of Atmospheric Composition Change

TCCON: Total Carbon Column Observing Network

Figure courtesy of E. Sepúlveda, M. Schneider

AERI deployed systems Worldwide network

Figure courtesy of ABB

www.ndacc.org

https://tccon-wiki.caltech.edu/

ERC project MUSICA: Multi-platform remote Sensing of Isotopologues for investigating the Cycle of Atmospheric water

Figure courtesy of E. Sepúlveda, M. Schneider
Evaluation of GOSAT XCO$_2$ Retrievals

- Two different data processors used on same near-IR data set
- ACOS-GOSAT compared with TCCON to show bias correction improvement for total column dry-air mole fraction XCO$_2$

Wunch et al., ACP, 11, 12317-12337 (2011)

Yoshida et al., AMT, 6, 1533-1547 (2013)

- NIES SWIR L2 comparing time series of XCO$_2$ to evaluate product versus TCCON
GOSAT Aerosol Comparisons

- Aerosol Optical Depth (AOD) using 15 AEROCAN sites (including PEARL) comparing with GOSAT overpasses
  - $\delta \text{AOD} = \text{AOD}_{\text{GOSAT}} - \text{AOD}_{\text{AEROCAN}}$
  - $\sigma(\text{AOD})$: std dev. ($\text{AOD}_{\text{GOSAT}}$)
- $\delta \text{AOD}^* = a + b \sigma(\text{AOD}) + c \text{NDVI}$ as a predictor of $\delta \text{AOD}$
- This is obtained by multi-regression
  - $a = 0.076; b = 1.71; c = -0.19$
- Used to estimate and model AOD bias error. Being compared over different years of observations

A. Saha, N. O’Neill, U. Sherbrooke
Orbiting Carbon Observatory-2 (OCO-2)

- Launched July 2014
- Initial calibration and validation is focusing on making target measurements over TCCON stations
  - Using an alert system to decide when to get optimal observations over sites
  - PEARL in Eureka was the initial test target for system

- Measurements have focused on TCCON near-IR observations over summer and fall for OCO
  - Until sunset 21 October

http://www.nasa.gov
Probing the Atmosphere of the High Arctic

- PEARL: PAHA is a five-year project primarily funded by the Natural Sciences and Engineering Research Council Canada (NSERC) Canadian Climate and Atmospheric Research (CCAR) Program
  - Funding began on 1 February 2013 and continues to end of January 2018
  - PI: Jim Drummond; deputy PI: Kim Strong

- Collaborating Agencies:
  - Dalhousie University - Funding
  - Environment Canada - Personnel time, In-kind support for PEARL
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PI/Co-Is:
- Jim Drummond, Dalhousie U.
- Kim Strong, U. Toronto
- Kaley Walker, U. Toronto
- Bob Sica, U. Western Ontario
- Alan Manson, U. Saskatchewan
- Norm O'Neill, U. Sherbrooke

Collaborators:
- David Hudak, EC
- Gloria Manney, North West Research Associates
- Saroja Polavarapu, EC

Collaborators (cont.):
- David Tarasick, EC
- William Ward, U. New Brunswick
- Ray Nassar, EC
- Yves Rochon, EC
- Doug Worthy, EC
- Taneil Uttal, NOAA SEARCH
- Wayne Hocking, U. Western Ontario
- Jim Sloan, U. Waterloo
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- Taneil Uttal, International representative
- Jamesse Moulton, Nunavut Dept. of Environment
- Barry Goodison, Member at large
- Sandy Starkweather, U.S. National Oceanic and Atmospheric Administration
What are We Doing?

- Addressing the issue of the variability of the atmosphere in the Canadian High Arctic.
- Three major themes: Composition Measurements (CM), Polar Night (PN) and Satellite Validation (SV).
- The strength of this proposal is the extent to which a comprehensive, well-calibrated set of measurements from the High Arctic will be used in multiple ways to produce multiple outcomes.
- Emphasis on the Polar Night
Initial Validation of GOSAT TIR CH$_4$

- Working with GOSAT (TANSO-FTS) retrieval team to intercompare their new version 1.0x CH$_4$ from the thermal-IR channel (not main one) with PEARL FTIR

Need to account for different sensitivities of instruments - “smoothing” brings products to state for better comparison

Wider altitude sensitivity for PEARL versus GOSAT TIR

Work in progress by G. Holl, PAHA; N. Saitoh, GOSAT team
Summary

- PEARL in Eureka, Nunavut is an excellent station for satellite validation studies
  - Measurements available to users and provided through international networks (NDACC, TCCON, AERONET/AEROCAN)

- Suite of atmospheric measurements that can be used for assessment of satellite data
  - Primary focus on composition - ozone-related species, greenhouse gases, aerosols, tropospheric pollutants
  - Used for Canadian, Japanese, European, US missions

- Need to find methods for sustained support of validation stations
  - Currently funded by national science, environmental, space agencies in piecemeal manner
  - Often “assumed” that stations will be there when needed
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