2017 Connaught Summer Institute in Arctic Science

Poster Session Winners

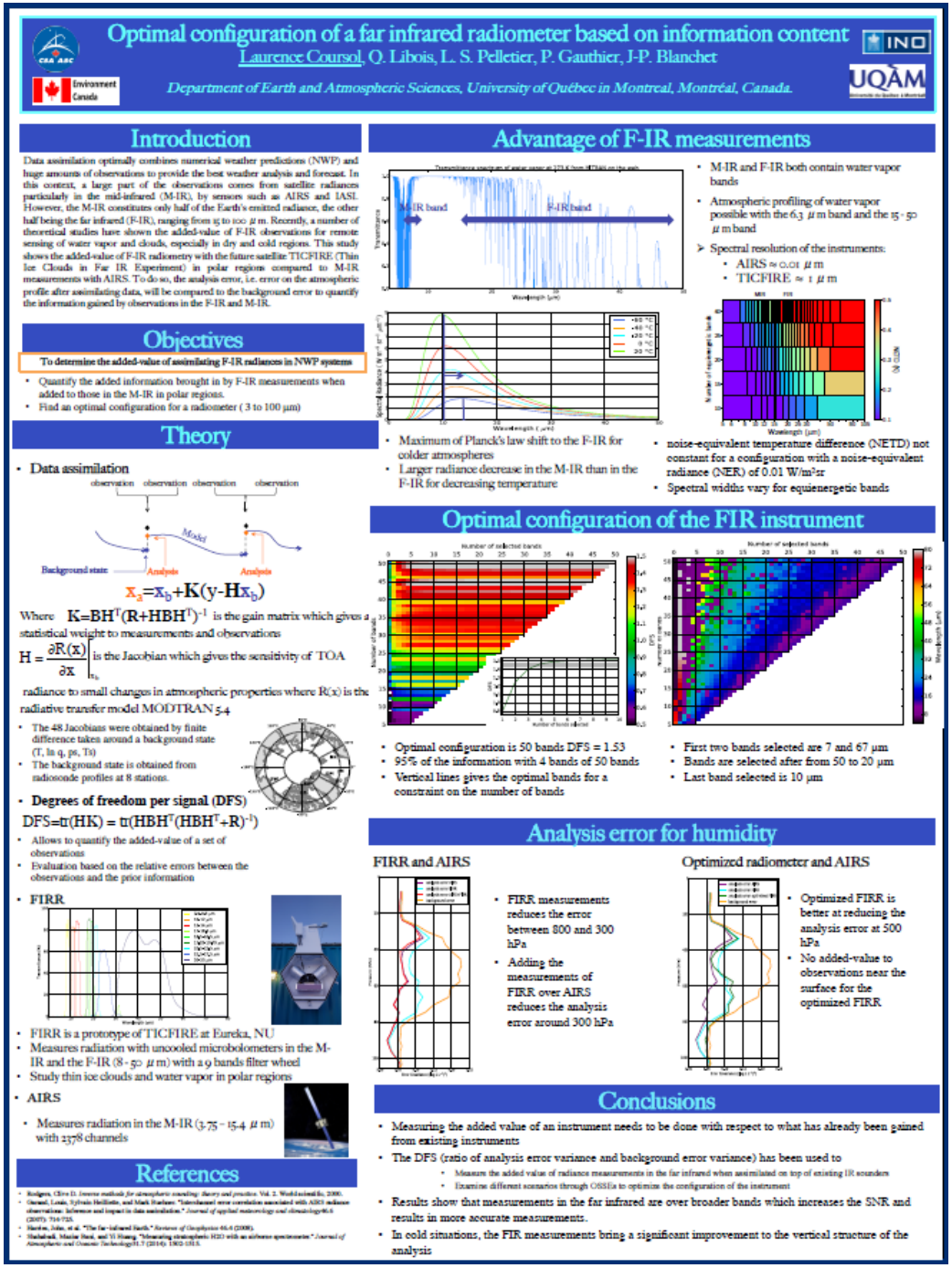
MSc Winner (1)

Winner

Laurence Coursol

(UQAM)

Impact of far infrared measurements on analyses of temperature and humidity



Optimal configuration of a far infrared radiometer based on information content

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Introduction

Data assimilation optimally combines numerical weather predictions (NWP) and huge amounts of observations to provide the best weather analysis and forecast. In this context, a large part of the observations comes from satellite radiances particularly in the mid-infrared (M-IR), by sensors such as AIRS and IASI. However, the M-IR constitutes only half of the Earth's emitted radiance, the other half being the far infrared (F-IR), ranging from 15 to 100 μm. Recently, a number of theoretical studies have shown the added-value of F-IR observations for remote sensing of water vapor and clouds, especially in dry and cold regions. This study shows the added-value of F-IR radiometry with the future satellite TICFIRE (Thin Ice Clouds in Far IR Experiment) in polar regions compared to M-IR measurements with AIRS. To do so, the analysis error, i.e. error on the atmospheric profile after assimilating data, will be compared to the background error to quantify the information gained by observations in the F-IR and M-IR.

Objectives

To determine the added-value of assimilating F-IR radiances in NWP systems

- Quantify the added information brought in by F-IR measurements when added to those in the M-IR in polar regions.
- Find an optimal configuration for a radiometer (3 to 100 μm)

Theory

- **Data assimilation**

observation observation observation observation

Model

Background state Analysis Analysis

$$x_a = x_b + K(y - Hx_b)$$

Where $K = BH^T(R+HBH^T)^{-1}$ is the gain matrix which gives a statistical weight to measurements and observations

$H = \left.\frac{\partial R(x)}{\partial x}\right|_{x_b}$ is the Jacobian which gives the sensitivity of TOA radiance to small changes in atmospheric properties where R(x) is the radiative transfer model MODTRAN 5.4

- The 48 Jacobians were obtained by finite difference taken around a background state (T, ln q, ps, Ts)
- The background state is obtained from radiosonde profiles at 8 stations.

- **Degrees of freedom per signal (DFS)**

$$DFS = \mathrm{tr}(HK) = \mathrm{tr}(HBH^T(HBH^T+R)^{-1})$$

- Allows to quantify the added-value of a set of observations
- Evaluation based on the relative errors between the observations and the prior information

- **FIRR**

- FIRR is a prototype of TICFIRE at Eureka, NU
- Measures radiation with uncooled microbolometers in the M-IR and the F-IR (8 - 50 μm) with a 9 bands filter wheel
- Study thin ice clouds and water vapor in polar regions

- **AIRS**

- Measures radiation in the M-IR (3.75 - 15.4 μm) with 2378 channels

References

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Advantage of F-IR measurements

- M-IR and F-IR both contain water vapor bands
- Atmospheric profiling of water vapor possible with the 6.3 μm band and the 15 - 50 μm band
- Spectral resolution of the instruments:
  - AIRS ≈ 0.106 μm
  - TICFIRE ≈ 1 μm

- Maximum of Planck's law shift to the F-IR for colder atmospheres
- Larger radiance decrease in the M-IR than in the F-IR for decreasing temperature

- noise-equivalent temperature difference (NETD) not constant for a configuration with a noise-equivalent radiance (NER) of 0.01 W/m²sr
- Spectral widths vary for equienergetic bands

Optimal configuration of the FIR instrument

- Optimal configuration is 50 bands DFS = 1.53
- 95% of the information with 4 bands of 50 bands
- Vertical lines gives the optimal bands for a constraint on the number of bands

- First two bands selected are 7 and 67 μm
- Bands are selected after from 50 to 20 μm
- Last band selected is 10 μm

Analysis error for humidity

FIRR and AIRS

- FIRR measurements reduces the error between 800 and 300 hPa
- Adding the measurements of FIRR over AIRS reduces the analysis error around 300 hPa

Optimized radiometer and AIRS

- Optimized FIRR is better at reducing the analysis error at 500 hPa
- No added-value to observations near the surface for the optimized FIRR

Conclusions

- Measuring the added value of an instrument needs to be done with respect to what has already been gained from existing instruments
- The DFS (ratio of analysis error variance and background error variance) has been used to
  - Measure the added value of radiance measurements in the far infrared when assimilated on top of existing IR sounders
  - Examine different scenarios through OSSEs to optimize the configuration of the instrument
- Results show that measurements in the far infrared are over broader bands which increases the SNR and results in more accurate measurements.
- In cold situations, the FIR measurements bring a significant improvement to the vertical structure of the analysis

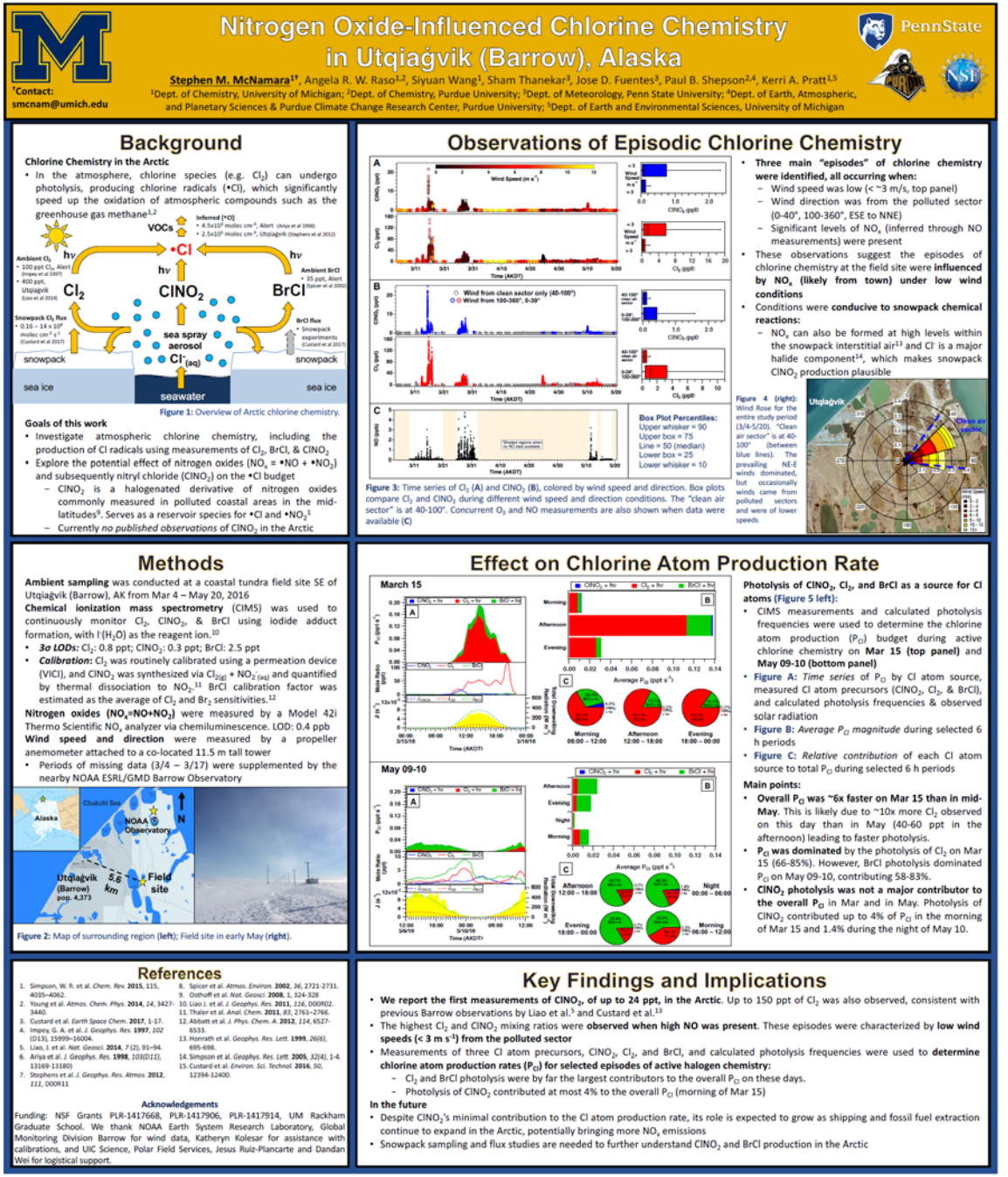
PhD Winners (2)

Winner

Stephen McNamara

(U Michigan)

Nitrogen Oxide-Influenced Chlorine Chemistry in Utqiaġvik (Barrow), Alaska



Nitrogen Oxide-Influenced Chlorine Chemistry in Utqiaġvik (Barrow), Alaska

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Background

Chlorine Chemistry in the Arctic

- In the atmosphere, chlorine species (e.g. Cl_2) can undergo photolysis, producing chlorine radicals (•Cl), which significantly speed up the oxidation of atmospheric compounds such as the greenhouse gas methane[1,2]

Figure 1: Overview of Arctic chlorine chemistry.

Goals of this work

- Investigate atmospheric chlorine chemistry, including the production of Cl radicals using measurements of Cl_2, BrCl, & $ClNO_2$
- Explore the potential effect of nitrogen oxides (NO_x = •NO + •NO_2) and subsequently nitryl chloride ($ClNO_2$) on the •Cl budget
  - $ClNO_2$ is a halogenated derivative of nitrogen oxides commonly measured in polluted coastal areas in the mid-latitudes[9]. Serves as a reservoir species for •Cl and •NO_2[1]
  - Currently *no published observations* of $ClNO_2$ in the Arctic

Observations of Episodic Chlorine Chemistry

Figure 3: Time series of Cl_2 (A) and $ClNO_2$ (B), colored by wind speed and direction. Box plots compare Cl_2 and $ClNO_2$ during different wind speed and direction conditions. The "clean air sector" is at 40-100°. Concurrent O_3 and NO measurements are also shown when data were available (C)

- **Three main "episodes" of chlorine chemistry were identified, all occurring when:**
  - Wind speed was low (< ~3 m/s, top panel)
  - Wind direction was from the polluted sector (0-40°, 100-360°, ESE to NNE)
  - Significant levels of NO_x (inferred through NO measurements) were present
- These observations suggest the episodes of chlorine chemistry at the field site were **influenced by NO_x (likely from town) under low wind conditions**
- Conditions were **conducive to snowpack chemical reactions:**
  - NO_x can also be formed at high levels within the snowpack interstitial air[13] and Cl^- is a major halide component[14], which makes snowpack $ClNO_2$ production plausible

Figure 4 (right): Wind Rose for the entire study period (3/4-5/20). "Clean air sector" is at 40-100° (between blue lines). The prevailing NE-E winds dominated, but occasionally winds came from polluted sectors and were of lower speeds

Methods

Ambient sampling was conducted at a coastal tundra field site SE of Utqiaġvik (Barrow), AK from Mar 4 – May 20, 2016

Chemical ionization mass spectrometry (CIMS) was used to continuously monitor Cl_2, $ClNO_2$, & BrCl using iodide adduct formation, with $I^-(H_2O)$ as the reagent ion.[10]

- ***3σ LODs:*** Cl_2: 0.8 ppt; $ClNO_2$: 0.3 ppt; BrCl: 2.5 ppt
- ***Calibration:*** Cl_2 was routinely calibrated using a permeation device (VICI), and $ClNO_2$ was synthesized via $Cl_{2(g)}$ + $NO_2^-{}_{(aq)}$ and quantified by thermal dissociation to NO_2.[11] BrCl calibration factor was estimated as the average of Cl_2 and Br_2 sensitivities.[12]

Nitrogen oxides (NO_x=NO+NO_2) were measured by a Model 42i Thermo Scientific NO_x analyzer via chemiluminescence. LOD: 0.4 ppb

Wind speed and direction were measured by a propeller anemometer attached to a co-located 11.5 m tall tower

- Periods of missing data (3/4 – 3/17) were supplemented by the nearby NOAA ESRL/GMD Barrow Observatory

Figure 2: Map of surrounding region (**left**); Field site in early May (**right**).

Effect on Chlorine Atom Production Rate

Photolysis of $ClNO_2$, Cl_2, and BrCl as a source for Cl atoms (Figure 5 left):

- CIMS measurements and calculated photolysis frequencies were used to determine the chlorine atom production (P_{Cl}) budget during active chlorine chemistry on **Mar 15 (top panel)** and **May 09-10 (bottom panel)**
- **Figure A:** *Time series* of P_{Cl} by Cl atom source, measured Cl atom precursors ($ClNO_2$, Cl_2, & BrCl), and calculated photolysis frequencies & observed solar radiation
- **Figure B:** *Average P_{Cl} magnitude* during selected 6 h periods
- **Figure C:** *Relative contribution* of each Cl atom source to total P_{Cl} during selected 6 h periods

Main points:

- **Overall P_{Cl} was ~6x faster on Mar 15 than in mid-May**. This is likely due to ~10x more Cl_2 observed on this day than in May (40-60 ppt in the afternoon) leading to faster photolysis.
- **P_{Cl} was dominated** by the photolysis of Cl_2 on Mar 15 (66-85%). However, BrCl photolysis dominated P_{Cl} on May 09-10, contributing 58-83%.
- **$ClNO_2$ photolysis was not a major contributor to the overall P_{Cl}** in Mar and in May. Photolysis of $ClNO_2$ contributed up to 4% of P_{Cl} in the morning of Mar 15 and 1.4% during the night of May 10.

References

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Acknowledgements

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Key Findings and Implications

- **We report the first measurements of $ClNO_2$, of up to 24 ppt, in the Arctic**. Up to 150 ppt of Cl_2 was also observed, consistent with previous Barrow observations by Liao et al.[5] and Custard et al.[13]
- The highest Cl_2 and $ClNO_2$ mixing ratios were **observed when high NO was present**. These episodes were characterized by **low wind speeds (< 3 m s^{-1}) from the polluted sector**
- Measurements of three Cl atom precursors, $ClNO_2$, Cl_2, and BrCl, and calculated photolysis frequencies were used to **determine chlorine atom production rates (P_{Cl}) for selected episodes of active halogen chemistry:**
  - Cl_2 and BrCl photolysis were by far the largest contributors to the overall P_{Cl} on these days.
  - Photolysis of $ClNO_2$ contributed at most 4% to the overall P_{Cl} (morning of Mar 15)

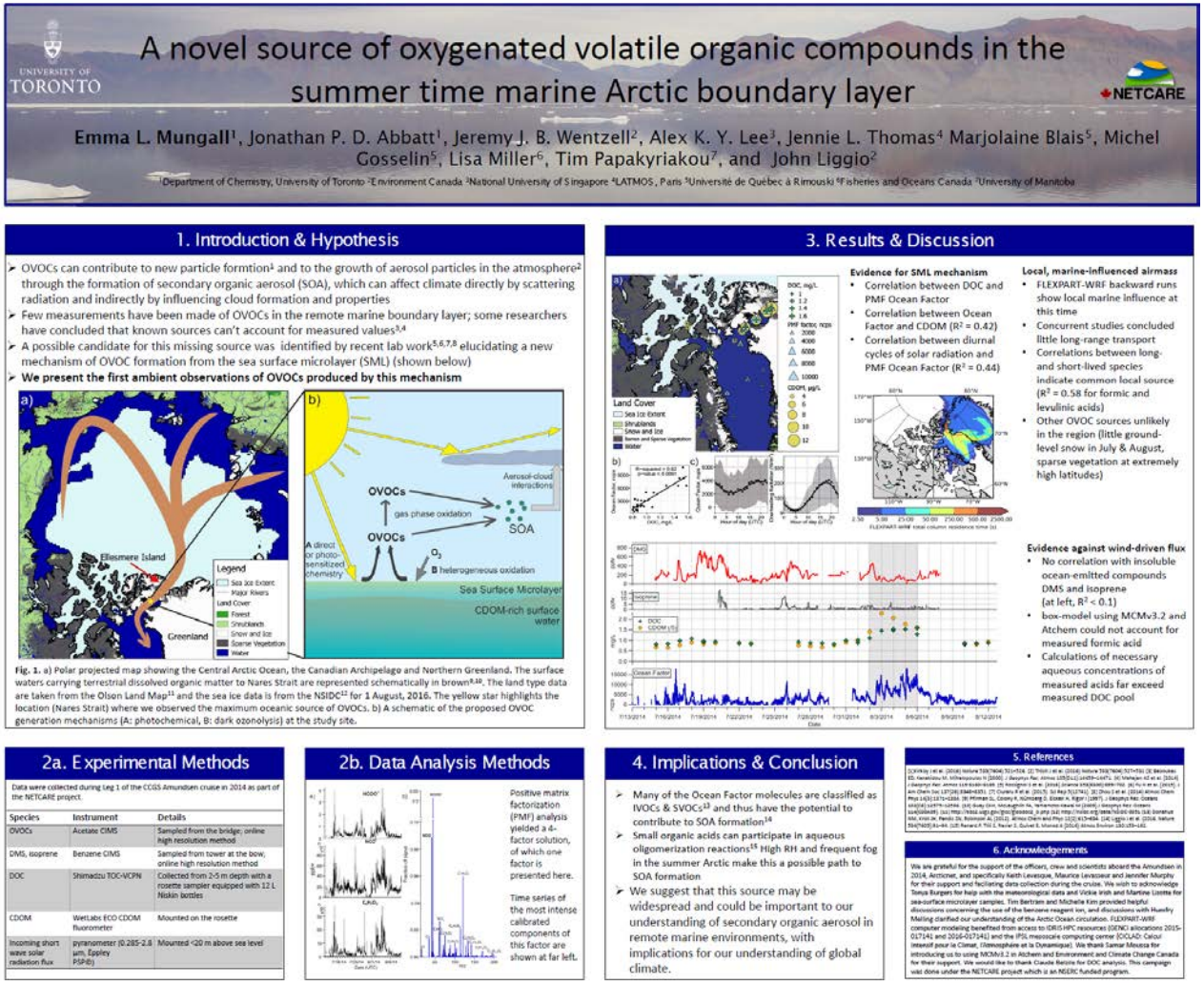
In the future

- Despite $ClNO_2$'s minimal contribution to the Cl atom production rate, its role is expected to grow as shipping and fossil fuel extraction continue to expand in the Arctic, potentially bringing more NO_x emissions
- Snowpack sampling and flux studies are needed to further understand $ClNO_2$ and BrCl production in the Arctic

Winner

Emma Mungall

(U Toronto)



A novel source of oxygenated volatile organic compounds in the summertime marine Arctic boundary layer

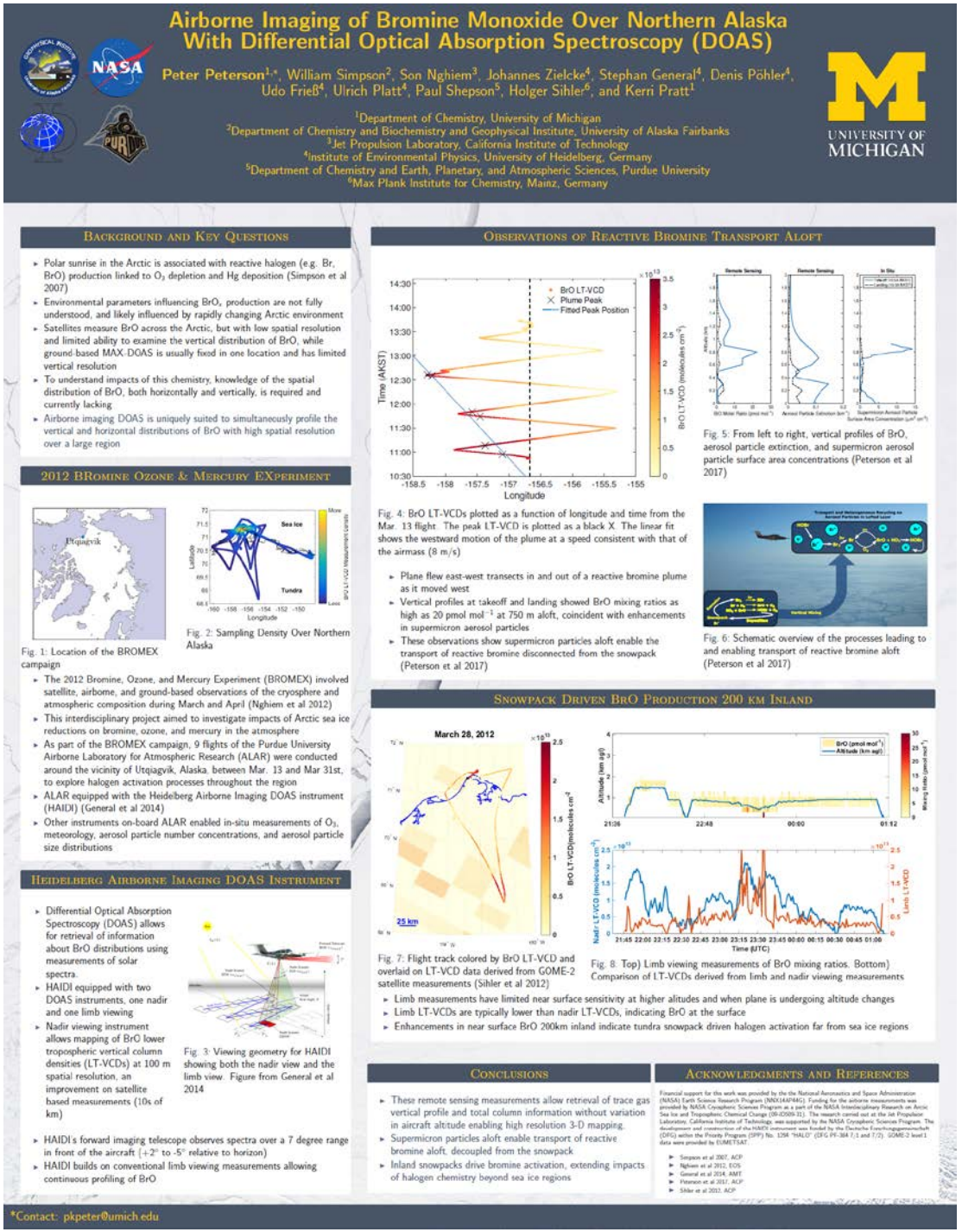
PDF Winner (1)

Winner

Peter Peterson

(U Michigan)

Airborne Imaging of Bromine Monoxide Over Northern Alaska With Dierential Optical Absorption Spectroscopy (DOAS)



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