Unprecedented Atmospheric NH_3 Concentrations Detected in the High Arctic from the 2017 Canadian Wildfires

E. Lutsch[1], **T. Wizenberg**[1], K. Strong[1], D.B.A. Jones[1], I. Ortega[2], J.W. Hannigan[2], E. Dammers[3], M.W. Shephard[3], E. Morris[4], K. Murphy[4], M. Evans[4], M. Parrington[5], S. Whitburn[6], M. Van Damme[6], L. Clarisse[6], P.-F. Coheur[6], C. Clerbaux[6,7], B. Croft[8], R.V. Martin[8], J.R. Pierce[9], J.A. Fisher[10]

[1]Department of Physics, University of Toronto, Toronto, ON, Canada
[2]National Center for Atmospheric Research, Boulder, CO, United States
[3]Air Quality Division, Environment and Climate Change Canada, Toronto, ON, Canada
[4]Department of Chemistry, University of York, York, United Kingdom
[5]European Center for Medium-Range Weather Forecasts, Reading, United Kingdom
[6]Service de Chimie Quantique et Photophysique,
Spectroscopie de l'Atmosphère, Université Libre de Bruxelles (U.L.B.), Brussels, Belgium
[7]LATMOS/IPSL, Sorbonne Universités, UVSQ, CNRS, Paris, France
[8]Department of Physics and Atmospheric Science, Dalhousie University, Halifax, NS, Canada
[9]Colorado State University, Department of Atmospheric Science, Fort Collins, CO, USA
[10]Centre for Atmospheric Chemistry, University of Wollongong, Wollongong, Australia

May 22, 2019

Atmospheric NH_3

NH_3 is mainly emitted from agricultural practices; biomass burning is a significant source (*Bouwman et al., 1997, 2012*)

NH_3 is an important form of reactive nitrogen:

- Reacts rapidly with acidic gases to form aerosols (*Aneja et al., 2007*)
- Aerosol formation affects air quality and climate (*Sutton et al., 2011*)
- Contributes to eutrophication and acidification of soil and precipitation (*Erisman et al., 2007*)

Photo Credit: BC Wildfire Service

NH_3 in the Arctic

- Short lifetime (<24hr) prevents long-range transport from lower latitudes
- Primary source of Arctic NH_3 from seabird guano (*Blackall et al., 2009, Wentworth et al., 2016*)
- Arctic tundra NH_3 emissions (*Croft et al., 2019, Murphy et al., 2019*)
- Indirect radiative cooling from seabird NH_3 emissions (*Croft et al., 2016)*

Photo Credit: The Canadian Press/Andrew Vaughan

NH_3 Measurements in the Arctic

First long-term NH_3 measurements using FTIR at Eureka, Nunavut (*Lutsch et al., 2016*)

- Enhancements detected from 2014 Canadian Wildfires
- NH_3 lifetime of ∼2 days in a wildfire smoke plume

Ground-based Measurements

FTIR Sites

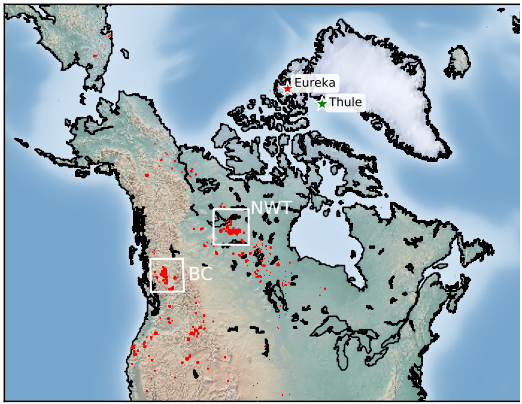
Eureka, Canada (80.05°N, 86.42°W)

- Located at the Polar Environment Atmospheric Research Laboratory (PEARL)
- In operation from 2006-Present

Thule, Greenland (76.53°N, 68.74°W)

- Located at the Thule Air Base (TAB)
- In operation from 1999-Present

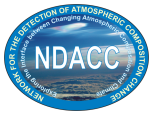
Separated by ∼500km



MODIS burned areas shown in red for Aug. 10-24, 2017

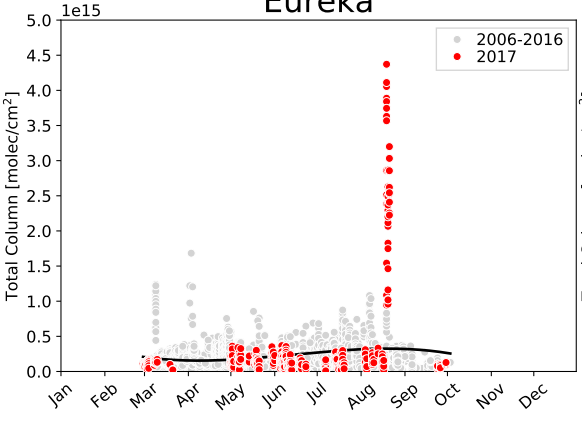
Retrieved Species

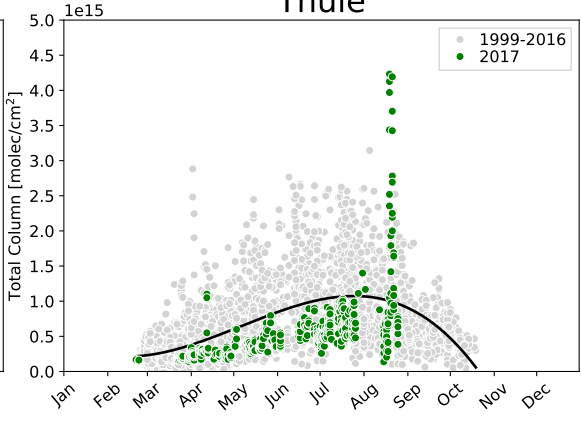
CO, **HCN** and $\mathbf{C_2H_6}$ retrieved using the **Network for Detection of Atmospheric Composition Change** (**NDACC**) **Infrared Working Group** (**IRWG**) recommendations



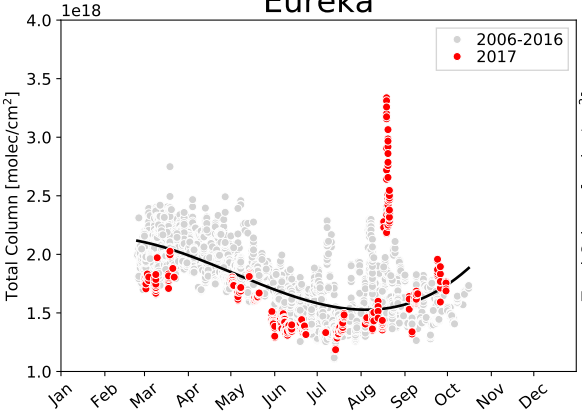
Species	Name	Sources	Sinks	Lifetimes
CO	Carbon Monoxide	BB, transport, steel industry, methane and VOC oxidation	reaction with OH	30 days
HCN	Hydrogen Cyanide	BB, industry, fungi and plant emission	reaction with OH and ocean uptake	75 days
$\mathbf{C_2H_6}$	Ethane	BB, biofuel use, oil and gas extraction	reaction with OH	45 days
$\mathbf{NH_3}$	Ammonia	BB, agriculture, seabirds, natural emission	reaction with acidic gases, dry and wet deposition	$<$1 day

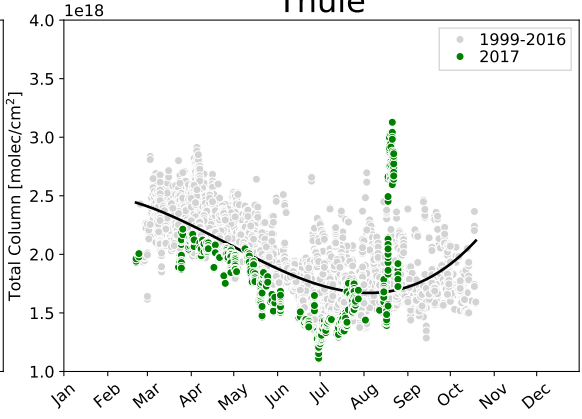
Time Series: NH_3



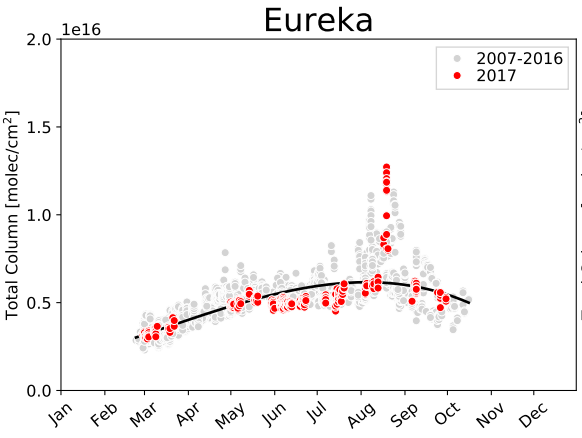


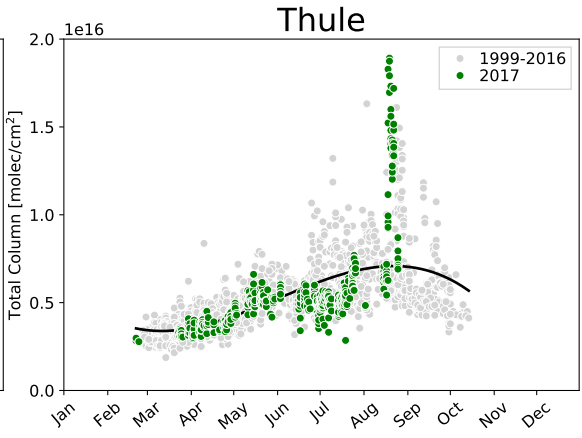
Time Series: CO



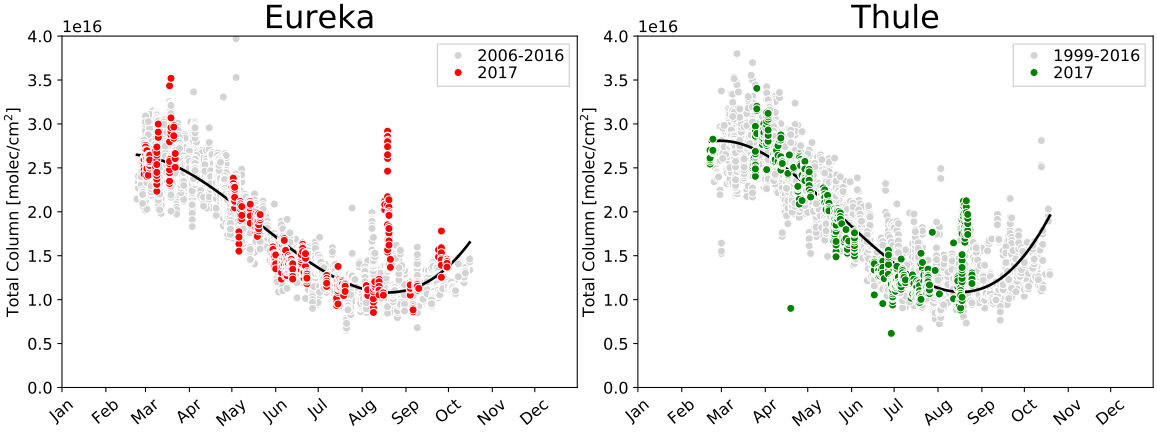


Time Series: HCN





Time Series: C_2H_6



Trace Gas Correlations

From FTIR measurements:

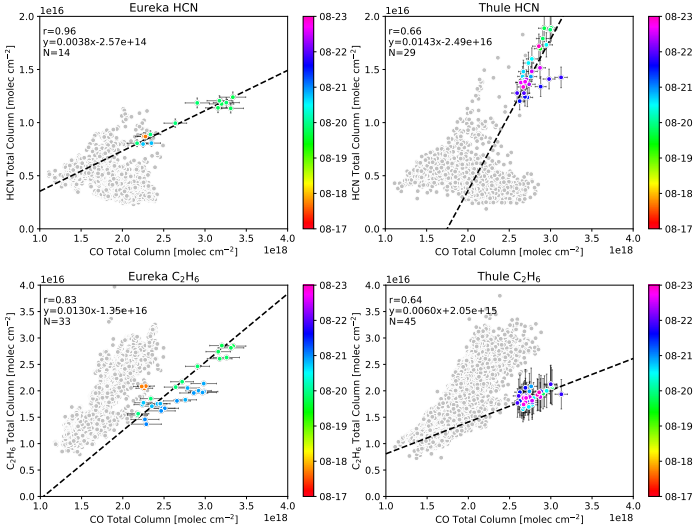
$$\mathrm{EnhR_X} = \mathrm{slope}\left(\frac{[\mathrm{X}]}{[\mathrm{CO}]}\right) \tag{1}$$

- EnhR - enhancement ratio
- [X] - total column amount
- Pair measurement of X with nearest CO measurement within 1 hr
- Apply weighted least-squares fitting (*York et al., 2004*)

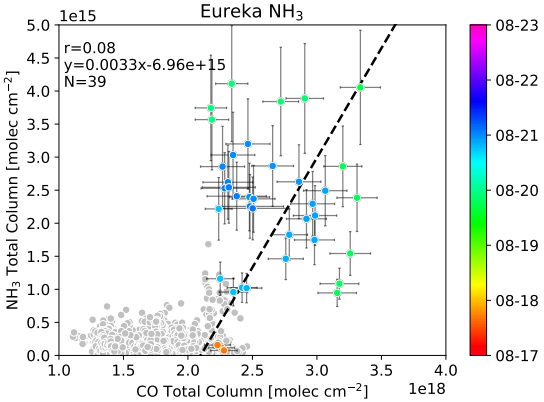
Enhancement Ratio

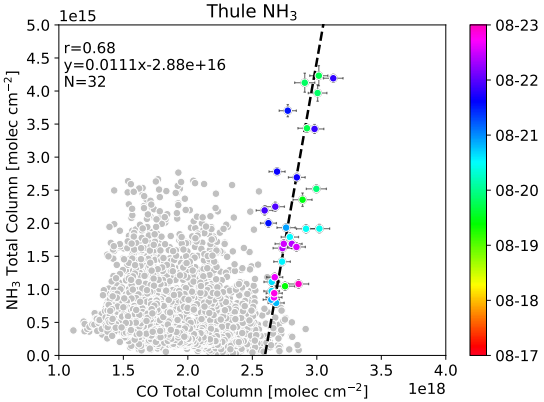
- Dependent on fuel type and burning phase of wildfire
- Also influenced by aging of the smoke plume during transport

Enhancement Ratios: HCN and C_2H_6



Enhancement Ratios: NH_3

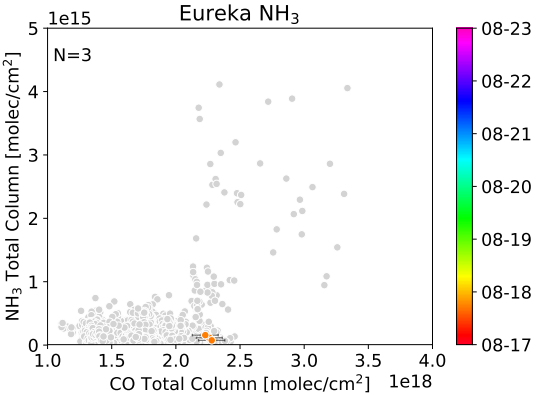




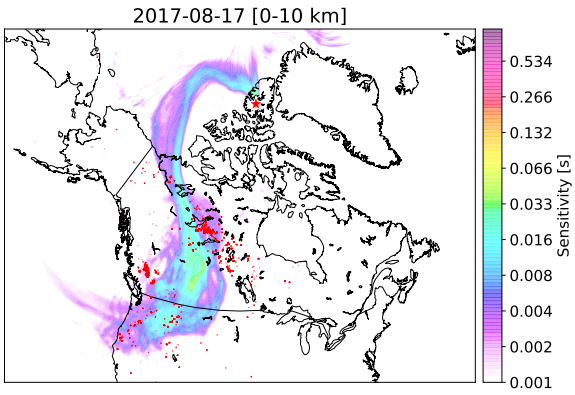
Eureka NH_3

- No correlation with CO; concentration highly variable with time

FLEXPART: August 17, 2017

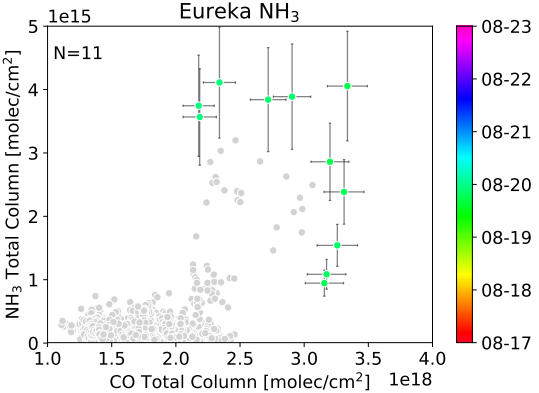


(a) Eureka NH_3:CO on Aug. 17, 2017

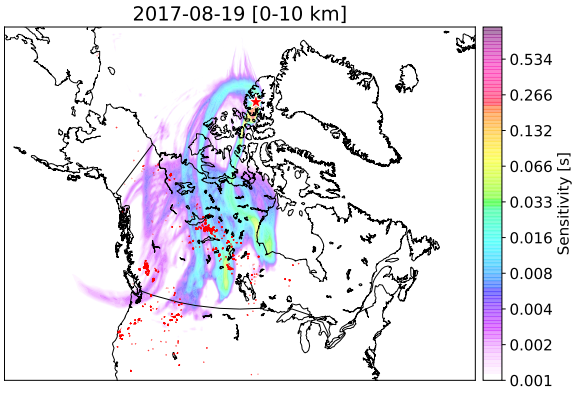


(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS burned areas in red

FLEXPART: August 19, 2017

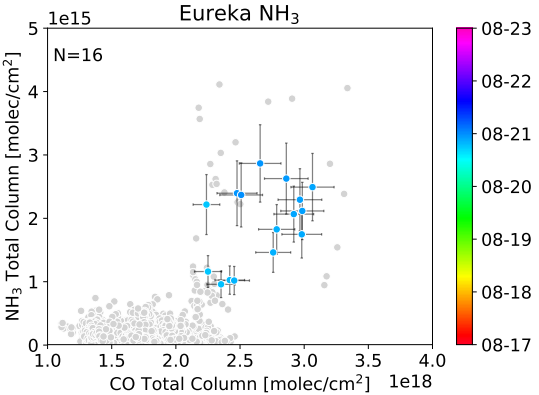


(a) Eureka NH_3:CO on Aug. 19, 2017

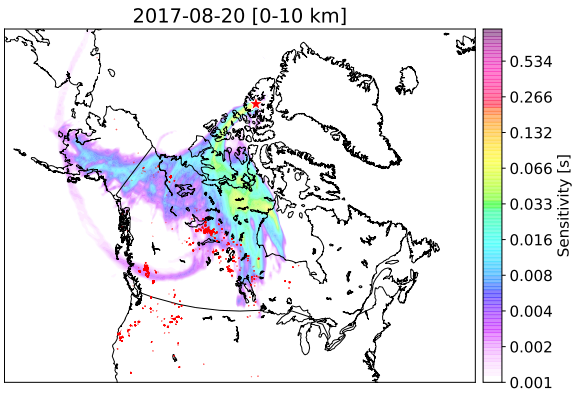


(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS burned areas in red

FLEXPART: August 20, 2017



(a) Eureka NH_3:CO on Aug. 19, 2017



(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS burned areas in red

GEOS-Chem Chemical Transport Model (v11-01)

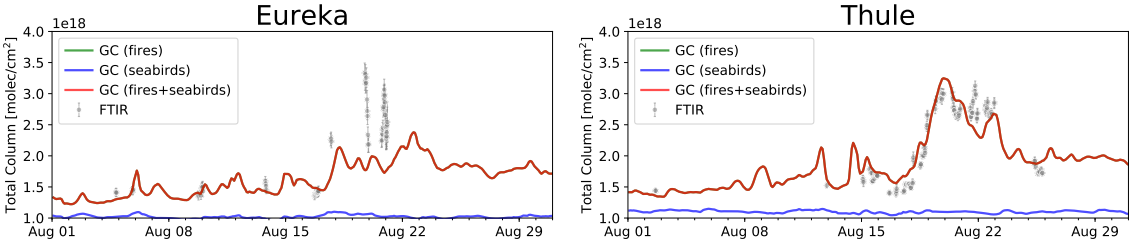
Simulation Scenarios (with anthropogenic emissions)

1. Wildfire emissions only
2. Seabird-colony emissions only
3. Wildfire and seabird-colony emissions

Model Inputs

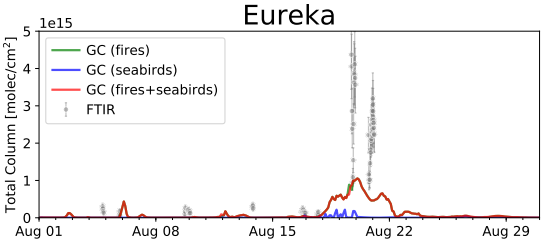
- **GEOS-FP** meteorological fields at $2^\circ \times 2.5^\circ$ horizontal resolution
- **GFAS** biomass burning emissions (*Kaiser et al., 2012*)
  - Daily emissions at $0.1^\circ \times 0.1^\circ$ resolution
- **Seabird-colony NH_3** emissions
  (*Riddick et al., 2012, Wentworth et al., 2016, Croft et al., 2016*)
  - Monthly emissions at $0.25^\circ \times 0.25^\circ$ resolution

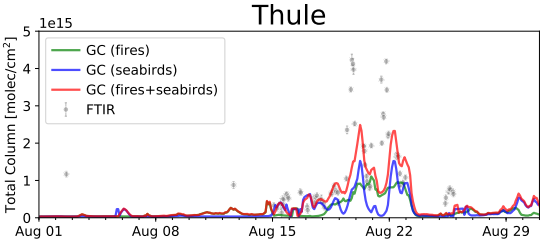
GEOS-Chem CO



- Seabird-colony NH_3 has no influence on CO
- GEOS-Chem wildfire CO underestimated at Eureka, good agreement at Thule
- CO total columns enhanced at both sites due to wildfire emissions

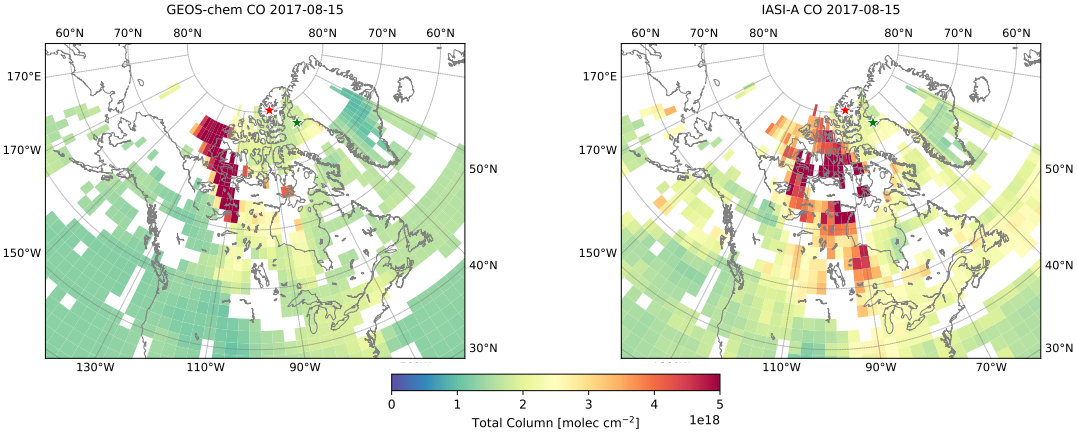
GEOS-Chem NH_3





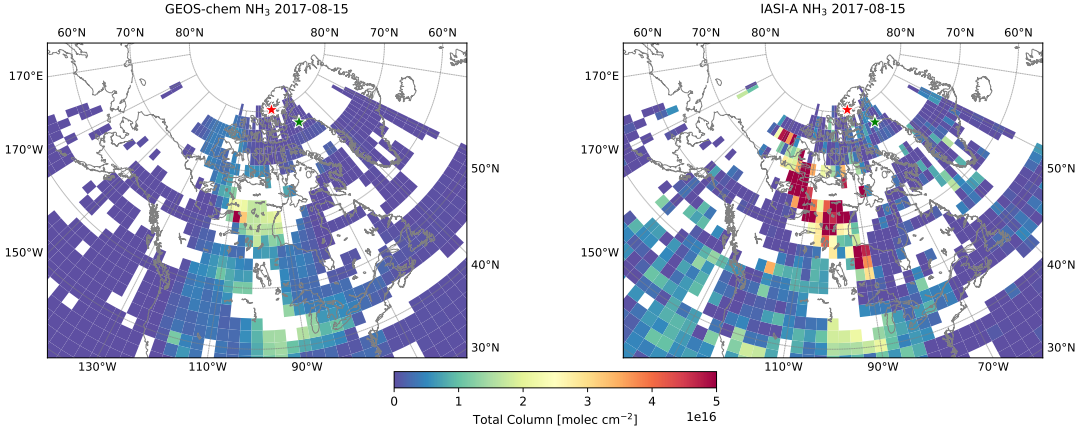
- GEOS-Chem wildfire NH_3 underestimated at both sites
- Seabird-colony NH_3 has a minor influence at Eureka
- Inclusion of seabird-colony NH_3 emissions improves agreement at Thule

GEOS-Chem vs. IASI CO (August 15, 2017)



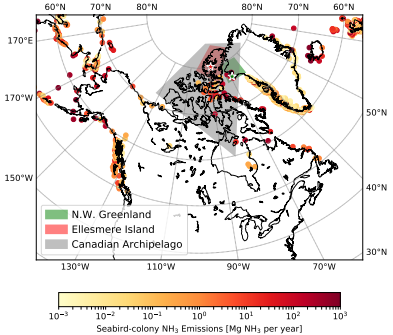
- IASI-A CO gridded onto GEOS-Chem horizontal grid and daily averaged
- Transported CO plume underestimated in GEOS-Chem

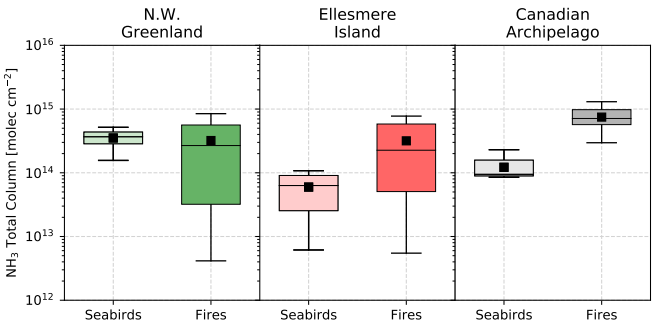
GEOS-Chem vs. IASI NH_3 (August 15, 2017)



- IASI-A NH_3 gridded onto GEOS-Chem horizontal grid and daily averaged
- GEOS-Chem NH_3 underestimated in comparison to IASI-A

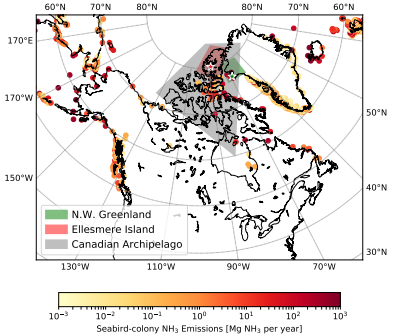
GEOS-Chem Total Column NH_3

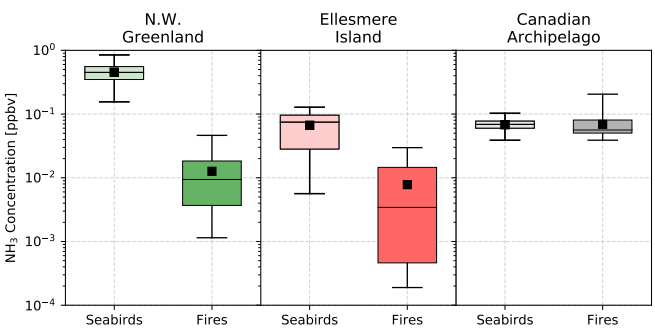




- Total column NH_3 spatially averaged during fire-affected period from **Aug. 15-23, 2017**
- Wildfire total column NH_3 exceeds background contribution from seabird colonies
- Mean wildfire NH_3 of $\sim 7.5 \times 10^{14}$ molec/cm^2 in Canadian Archipelago

GEOS-Chem Surface-layer NH_3





- Surface-layer NH_3 spatially averaged during fire-affected period from **Aug. 15-23, 2017**
- Seabird-colony NH_3 predominates near colonies in N.W. Greenland
- Wildfire NH_3 comparable to seabird-colony NH_3 in Canadian Archipelago ($\sim$0.07 ppbv)

Conclusions

2017 Canadian Wildfires

- Greatest NH_3 enhancements observed in Eureka and Thule time series
- NH_3 concentrations more variable at Eureka than Thule
  - Possible plume aging and influence of multiple fire sources
  - Variable source sensitivity observed at Eureka from FLEXPART

GEOS-Chem

- Transported wildfire emissions underestimated in comparison to FTIR and IASI:
  - Underestimation of wildfire emissions; emitted from boundary layer, no injection heights
  - Plume diffusion in the model (*Eastham et al., 2017*)
  - Loss of NH_3 due to chemical processing, dry and wet deposition
- Wildfire NH_3 comparable to seabird-colony NH_3 in the Canadian Archipelago
  - Mean surface-layer concentration of 0.07 ppbv for both wildfires and seabird colonies
- The 2017 Canadian wildfires were a considerable episodic NH_3 source to the high Arctic

Acknowledgements

This work was supported by the Canadian Space Agency (CAFTON and AVATARS) and NSERC (PAHA). CANDAC and PEARL are supported by: ARIF, AIF/NSRIT, CFCAS, CFI, CSA, ECCC, GOC-IPY, INAC,

NSERC, NSTP, OIT, ORF, PCSP, SEARCH Logistical and operational support at Eureka:

- CANDAC/PEARL PI James R. Drummond
- PEARL site manager Pierre Fogal
- CANDAC data manager Yan Tsehtik
- CANDAC operators
- Team at the ECCC Weather Station

Canadian Arctic ACE Validation Campaigns supported by:

- CSA, ECCC, NSERC, and NSTP
- PI Kaley A. Walker

NCAR is sponsored by the US NSF. The NCAR FTS at Thule is supported under contract by NASA. We wish to thank DMI for support at Thule.