Unprecedented NH_3 Enhancements Detected in the High Arctic from the 2017 North American Wildfires

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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

The Arctic is relatively free of NH_3 sources:

- 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., 2015*)
- 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

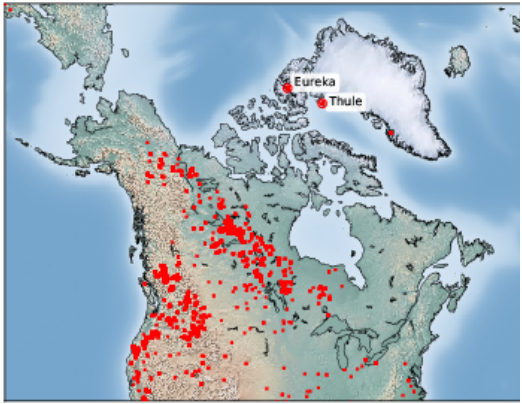
Eureka, Nunavut, Canada (80.05°N,86.42°W)

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

Thule, Greenland (76.53°,68.74°)

- In operation from 1999-Present

Separated by ∼500km



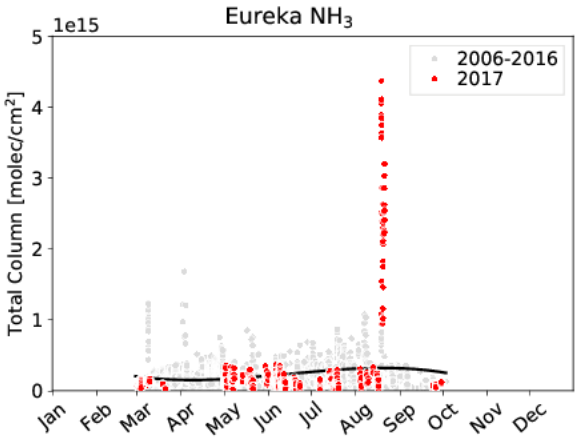
MODIS burned areas shown in red for Aug. 10-24, 2017

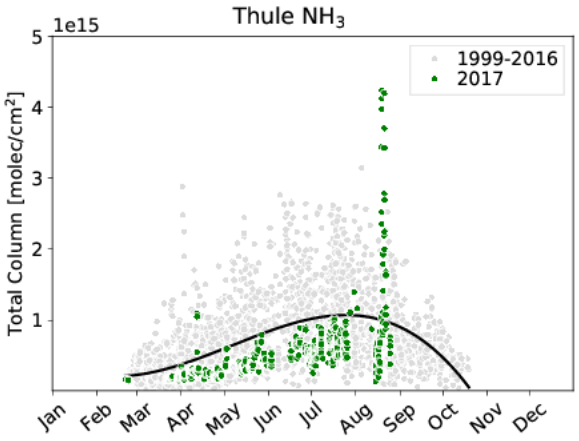
Retrieved Species

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

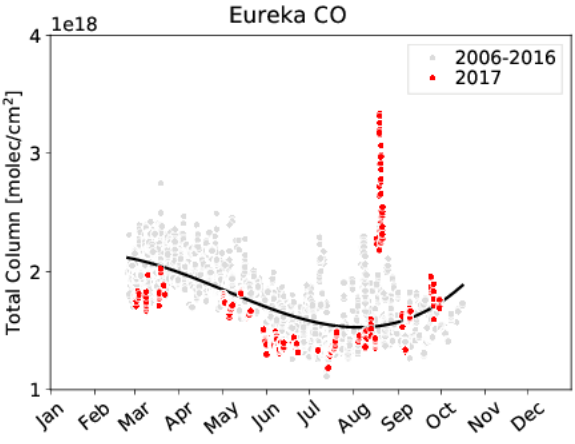
Species	Name	Sources	Sinks	Lifetimes
CO	Carbon Monoxide	BB, transport, steel industry, methane and VOC oxidation	reaction with OH	30 days
HCN	Hydrogen Cyanide	BB, industry, fungi and plant emission	reaction with OH and ocean uptake	75 days
C_2H_6	Ethane	BB, biofuel use, oil and gas extraction	reaction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

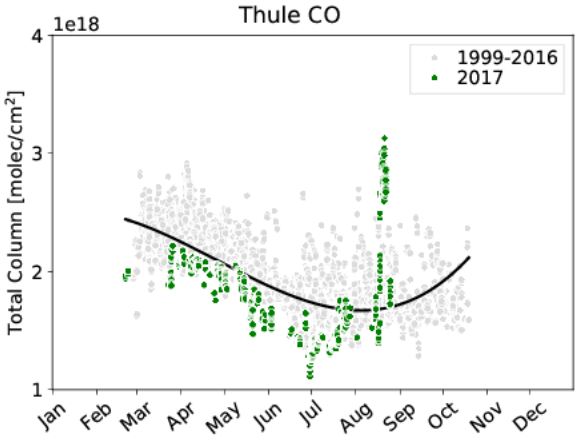
Time Series: NH_3



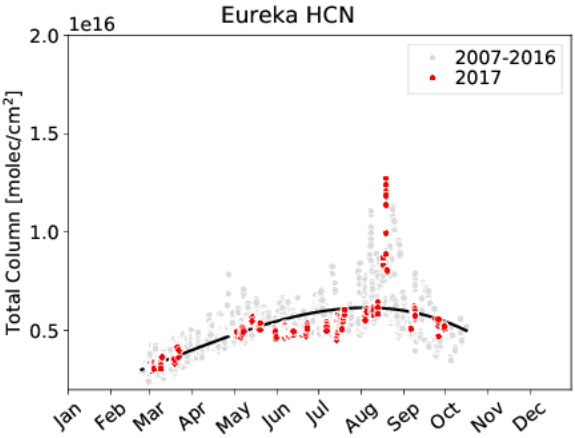


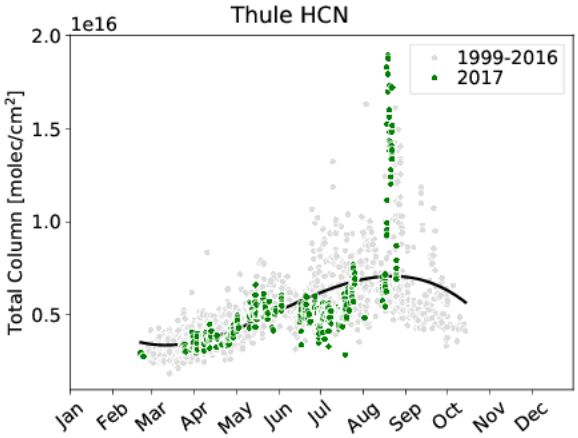
Time Series: CO



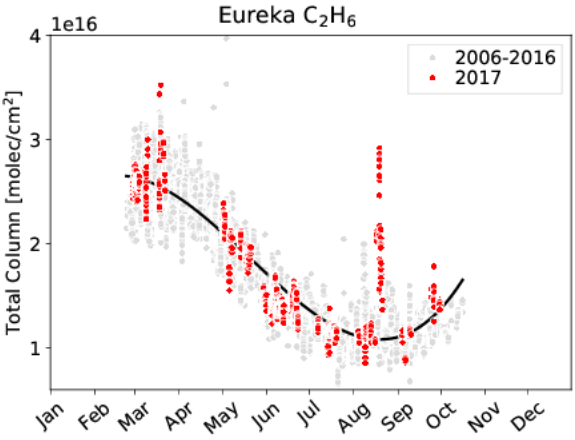


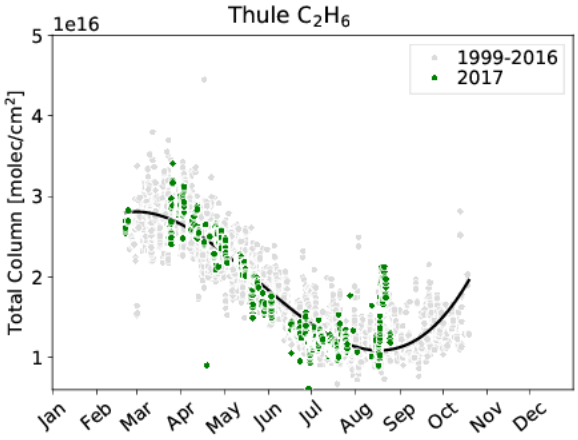
Time Series: HCN





Time Series: C_2H_6





Trace Gas Correlations

From FTIR measurements:

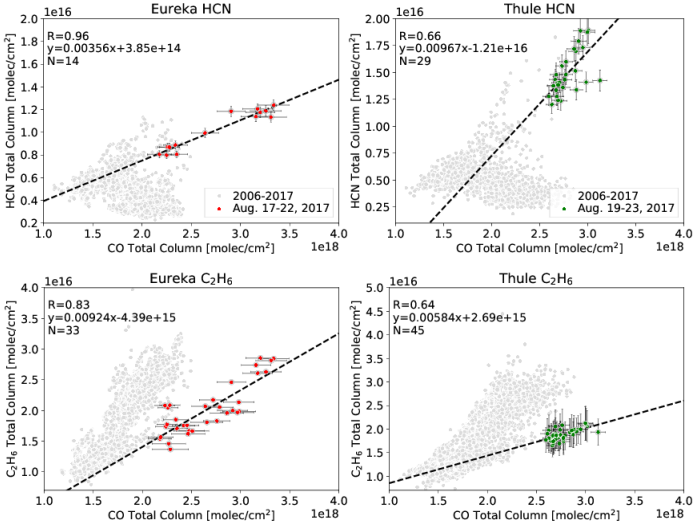
$$\mathrm{EnhR_X} = \mathrm{slope}\left(\frac{[\mathrm{X}]}{[\mathrm{CO}]}\right) \tag{1}$$

- EnhR - enhancement ratio
- [X] - total column amount
- Pair measurement of X with nearest CO measurement within 1 hr

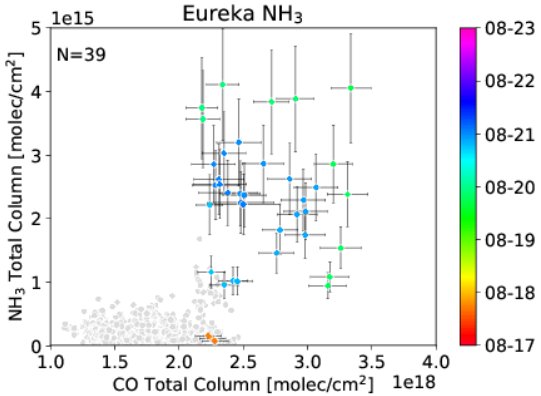
Enhancement Ratio

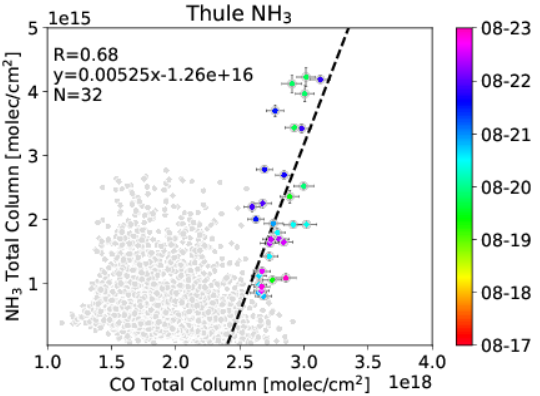
- Dependent on fuel type and burning phase of wildfire
- Also influenced by aging of smoke plume during transport

Enhancement Ratios: HCN and C_2H_6



Enhancement Ratios: NH_3

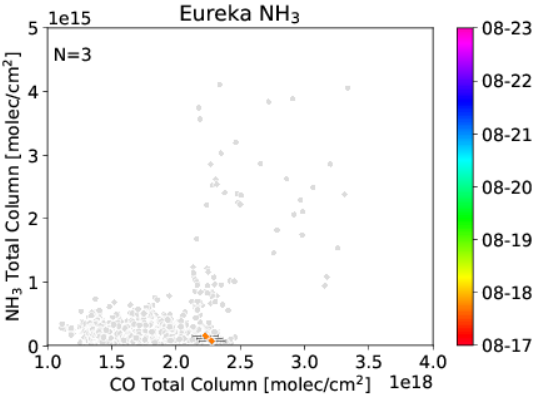




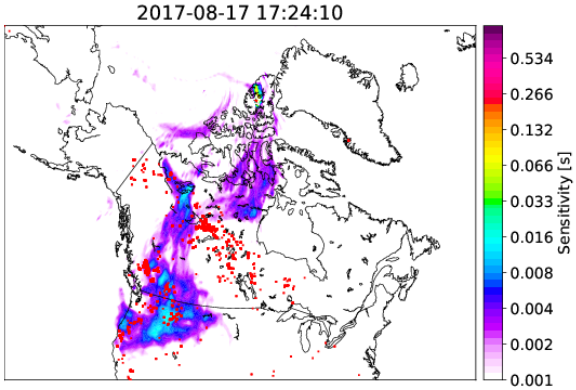
Eureka NH_3

- No correlation with CO; concentration highly variable with time

FLEXPART: August 17, 2017

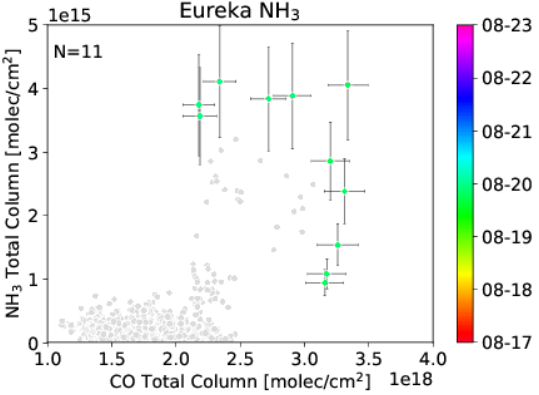


(a) Eureka NH_3:CO on Aug. 17, 2017

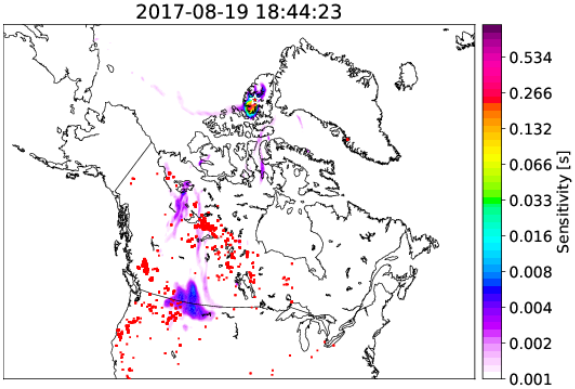


(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS fire hot-spots shown in red

FLEXPART: August 19, 2017



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



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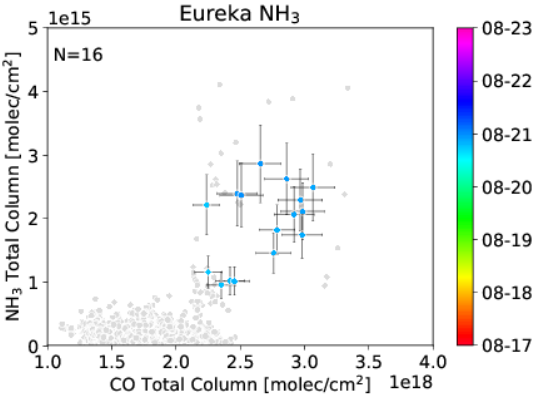
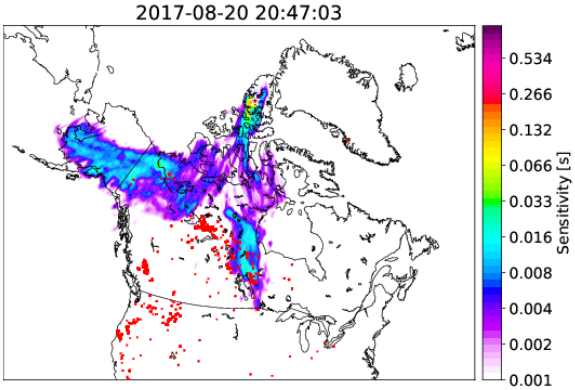
FLEXPART: August 20, 2017



(a) Eureka NH_3:CO on Aug. 20, 2017



(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS fire hot-spots shown in red

GEOS-Chem Model

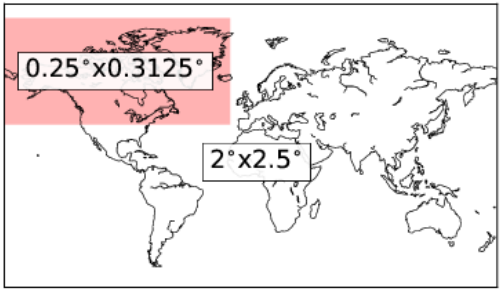
GEOS-Chem v11-01

- Custom nested domain: 40°N, 180°W to 86°N, 15°W:
  - Global spin-up at 2° × 2.5° to create boundary conditions
  - High-resolution nested run at 0.25° × 0.3125° from Aug. 10 - 24, 2017

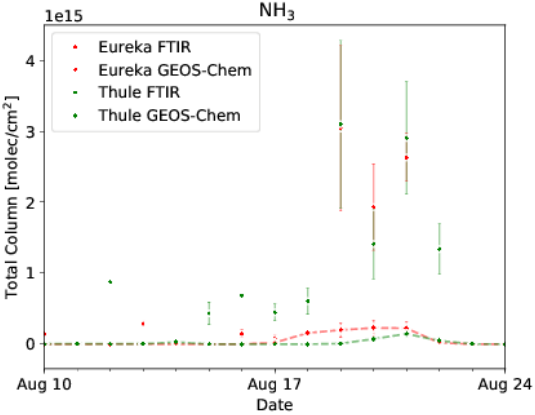
Model Inputs

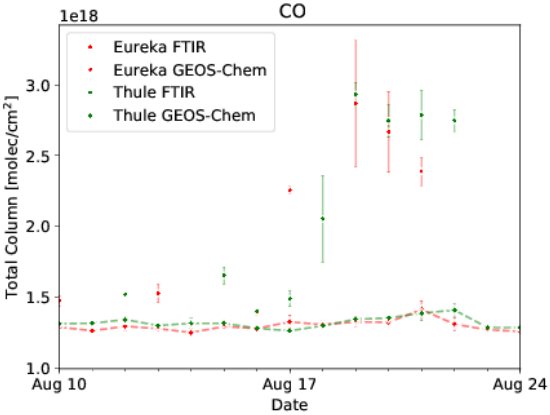
- GEOS-FP meteorological fields
- EDGAR anthropogenic emissions

1. FINN biomass burning emissions (*Wiedinmyer et al., 2011*)
   - Daily emissions at ∼1km resolution
2. GFAS biomass burning emissions (*Kaiser et al., 2012*)
   - Daily emissions at 0.1× 0.1 resolution



GEOS-Chem Time Series (FINN)





FINN underestimates NH_3 (short-lived) and CO (long-lived) in the high Arctic

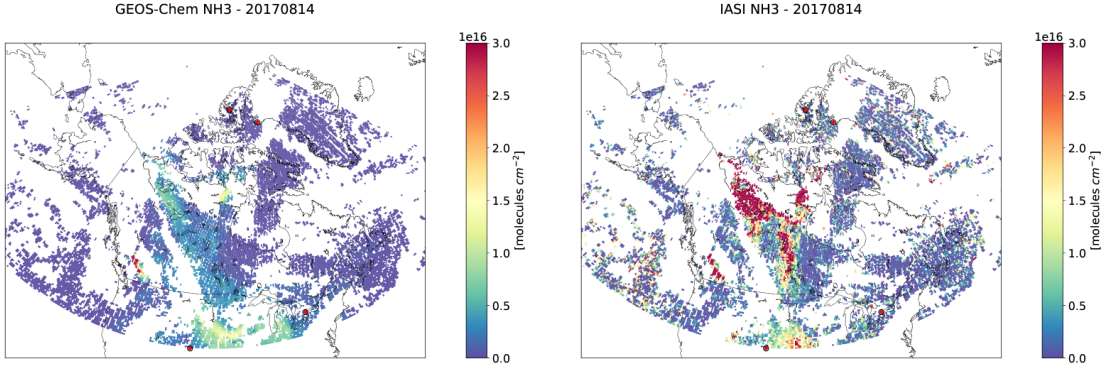
Satellite Observations of NH_3

Instrument	Global Coverage	Horizontal Resolution	Reference
IASI (Infrared Atmospheric Sounding Instrument)	2×daily	∼12 km	Whitburn et al., 2016
CrIS (Cross-track Infrared Sounder)	2×daily	∼14 km	Shephard et al., 2015

GEOS-Chem - Satellite Comparison Method

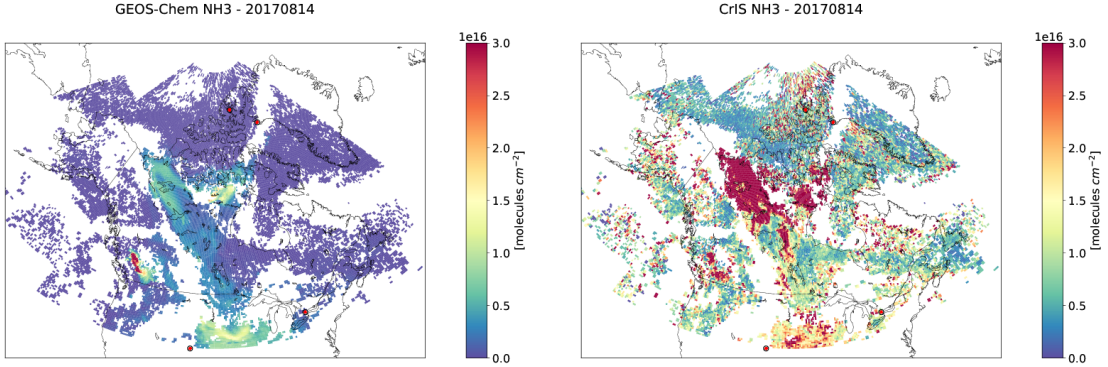
- Gridded satellite NH_3 measurement to the GEOS-Chem grid
- Interpolated GEOS-Chem hourly output to match the satellite overpass time

FINN vs. IASI NH_3



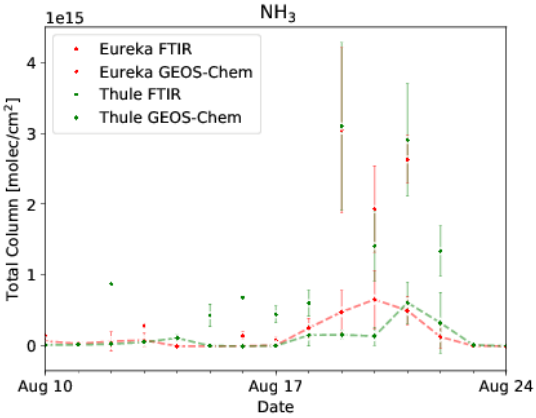
- Agreement is found in agricultural regions
- Fire plume is observed in IASI, missing in GEOS-Chem with FINN
- Arctic NH_3 below IASI sensitivity

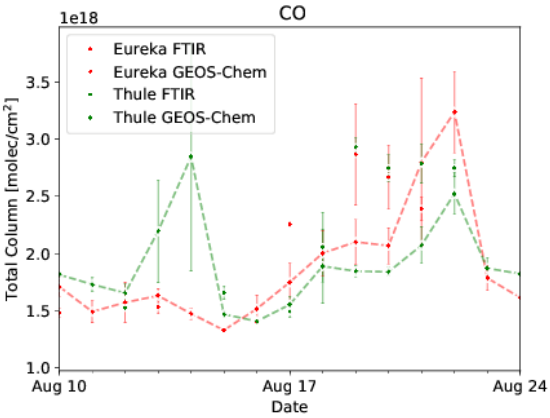
FINN vs. CrIS NH_3



- Comparable in agricultural regions
- Mid-latitude smoke plume underestimated in GEOS-Chem with FINN
- Higher sensitivity of CrIS reveals NH_3 in Arctic

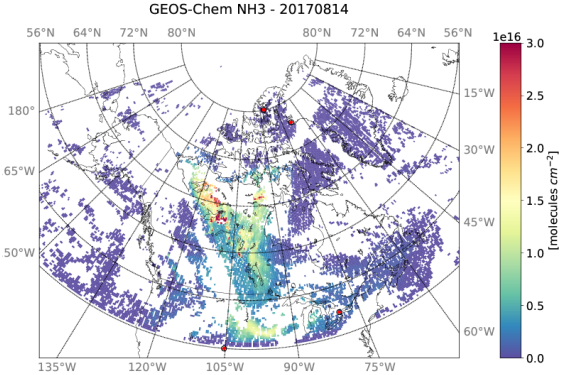
GEOS-Chem Time Series (GFAS)

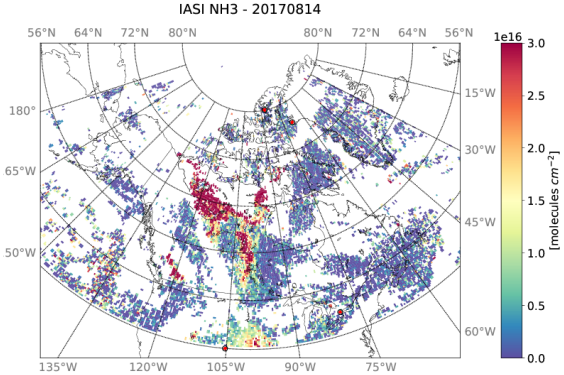




GFAS improves agreement with FTIR for NH_3 and CO in the high Arctic

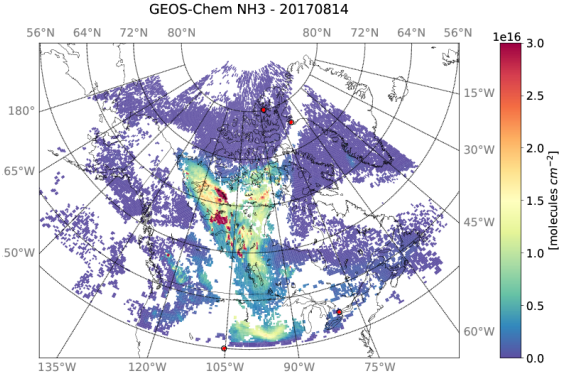
GFAS vs. IASI NH_3

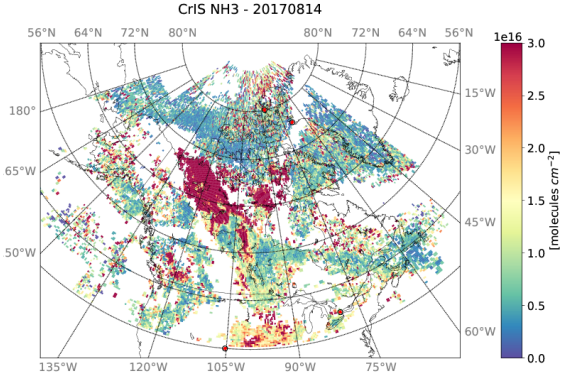




- Agreement is found in agricultural regions
- Fire plume is observed with IASI and in GEOS-Chem with GFAS
- Arctic NH_3 below IASI sensitivity

GFAS vs. CrIS NH_3





- Comparable in agricultural regions
- Mid-latitude plume better represented in GEOS-Chem with GFAS
- Higher sensitivity of CrIS reveals NH_3 in the Arctic

Conclusions

2017 North American 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

Satellite Observations

Transport of NH_3 in smoke plume observed with IASI and CrIS

- No NH_3 enhancements observed in Arctic with IASI
- Enhancements observed in Arctic with CrIS

GEOS-Chem

- GEOS-Chem underestimates transport of emissions with FINN
- Better agreement found with GFAS

Next Steps

GEOS-Chem

- Re-run GEOS-Chem when GFAS emissions are finalized.
- Estimate NH_3 deposition rates from model.
- Include seabird emissions (*Croft et al., 2016*, *Riddick et al., 2011*)
- Compare wildfire and seabird NH_3 deposition rates in Arctic.

Publish

- Manuscript is currently in progress.

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- PEARL site manager Pierre Fogal
- CANDAC data manager Yan Tsehtik
- CANDAC operators
- Team at the ECCC Weather Station

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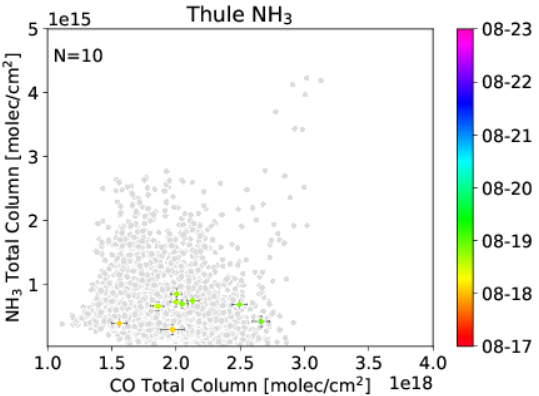
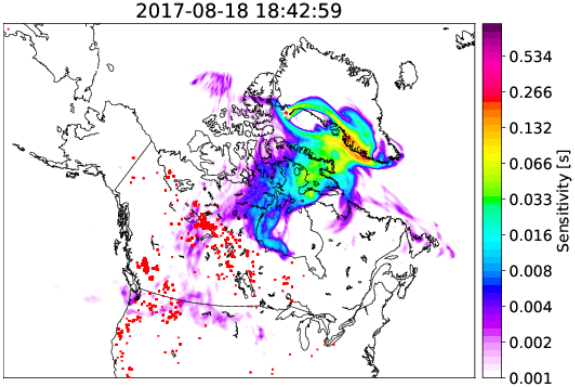
- PI Kaley A. Walker

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.

FLEXPART: August 18, 2017



(a) Thule NH_3:CO on Aug. 18, 2017



(b) FLEXPART surface sensitivity for 7 days backwards in time with MODIS fire hot-spots shown in red

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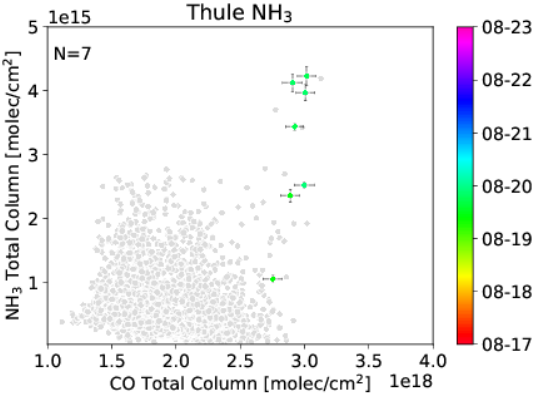

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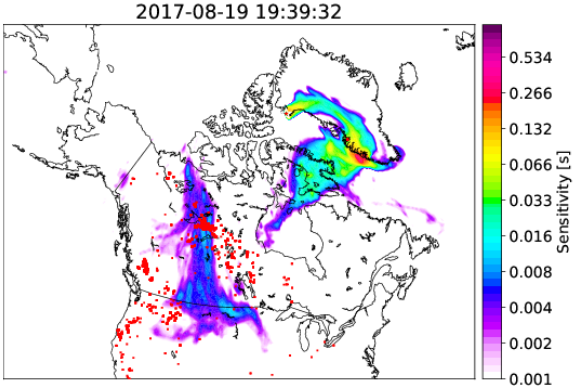

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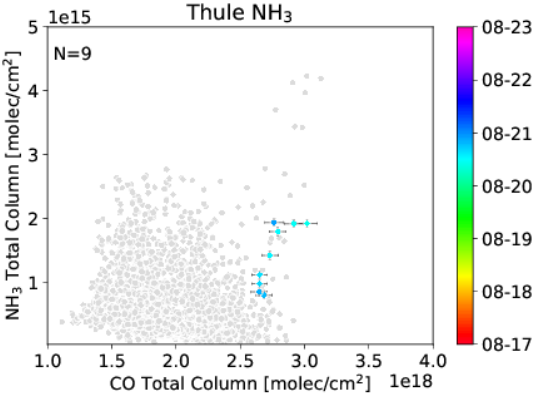

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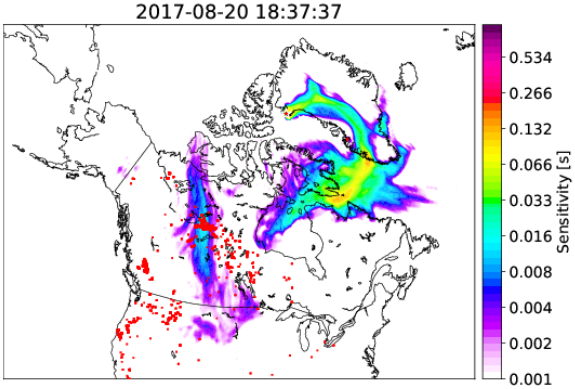

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