The Influence of Wildfires on the Arctic: Pan-Arctic FTIR Observations and Model Results

E. Lutsch[1], S. Conway[1], K. Strong[1], D. B. A. Jones[1], J. R. Drummond[2], I. Ortega[3], J. W. Hannigan[3], M. Makarova[4], M. Palm[5], J. Notholt[5], T. Blumenstock[6], R. Sussmann[7], E. Mahieu[8], Y. Kasai[9], C. Clerbaux[10], J.A. Fisher[11]

[1]Department of Physics, University of Toronto, Toronto, Ontario, Canada
[2]Department of Physics and Atmospheric Science, Dalhousie University, Halifax, Nova Scotia, Canada
[3]National Center for Atmospheric Research, Boulder, Colorado, USA
[4]St. Petersburg State University, St. Petersburg, Russia
[5]Institute of Environmental Physics, University of Bremen, Bremen, Germany
[6]Karlsruhe Institute of Technology, IMK-ASF, Karlsruhe, Germany
[7]Karlsruhe Institute of Technology, IMK-IFU, Garmisch-Partenkirchen, Germany
[8]Institute of Astrophysics and Geophysics, University of Liege, Liege, Belgium
[9]National Institute for Information and Communications Technology, Tokyo, Japan
[10]LATMOS/IPSL, UPMC Univ. Paris 06 Sorbonne Universites, UVSQ, CNRS, Paris, France
[11]Centre for Atmospheric Chemistry, University of Wollongong, Wollongong, Australia

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Introduction

- Biomass burning presents significant contributions to pollution in the Arctic (*Shindell et al., ACP, 2008, Saha et al., GRL, 2010*)
- Emissions of radiatively and photochemically active species may affect climate (*Amiro et al., CGFR, 2001*)
- Quantifying emissions is difficult due to the spatial and temporal variabilities of events.
- Emissions are also highly dependent on fuel type and burning stage

Photo Credit: BC Wildfire Service

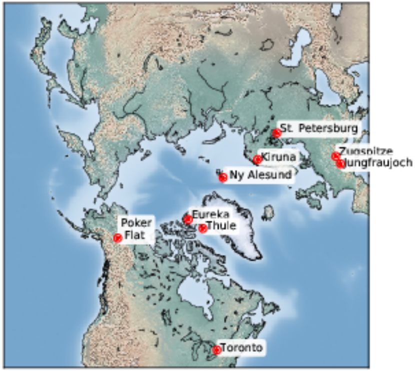
Retrieved Species

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

FTIR Sites

Site	Lat., Lon.	Elev. [m]	Years of Measurement
Eureka	80°N, 86°W	610	2006-present
Ny Alesund	79°N, 12°E	15	1992-present
Thule	77°N, 69°W	225	1999-present
Kiruna	68°N, 20°E	419	1996-present
Poker Flat	65°N, 142°W	610	1999-2011
St. Petersburg	60°N, 30°E	20	2009-present
Zugspitze	47°N, 11°E	2964	1995-present
Jungfraujoch	47°N, 8°E	3580	1984-present
Toronto	44°N, 79°W	174	2002-present



Fire Detections

Method

Fit the data to account for seasonal variabilities and inter-annual trends

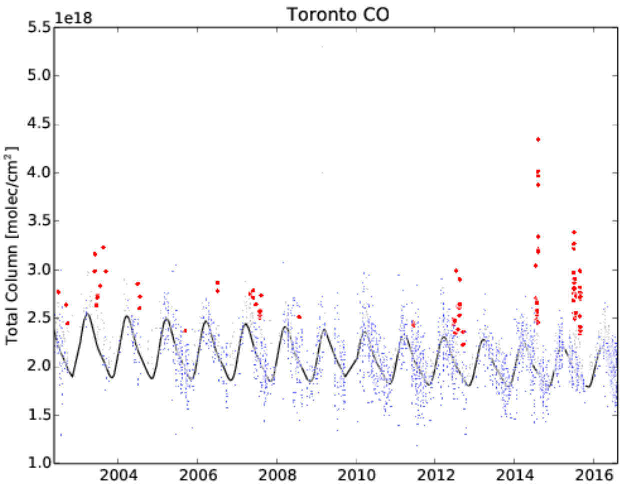
$$f(t) = a_0 + a_1 t + a_2 t^2 + \sum_{n=1}^{4} b_n \cos(2\Pi nt) + c_n \sin(2\Pi nt)$$

Thoning et al., JGR, 1989

Procedure

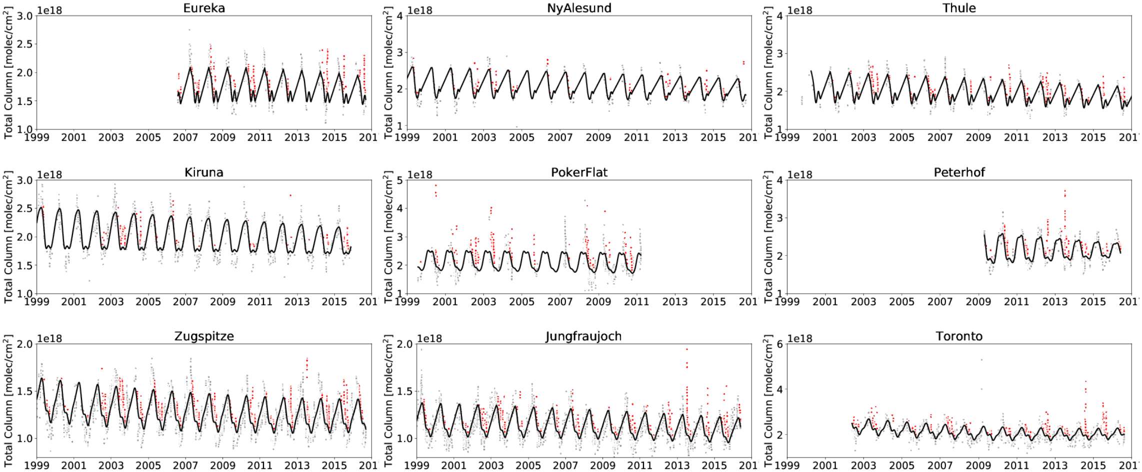
1. Fit CO time series for each site.
2. Negative residuals defines natural variability.
3. Negative residuals are mirrored into positive.
4. Measurements greater than 0.5σ indicate possible events.

Toronto CO Enhancements



- **Fitted CO time series.**
- Mirrored negative residuals
- 0.5σ indicate possible events.

CO Enhancements



Enhancement Ratio

$$\text{EnhR}_X = \text{slope}\left(\frac{[X]}{[CO]}\right)$$

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

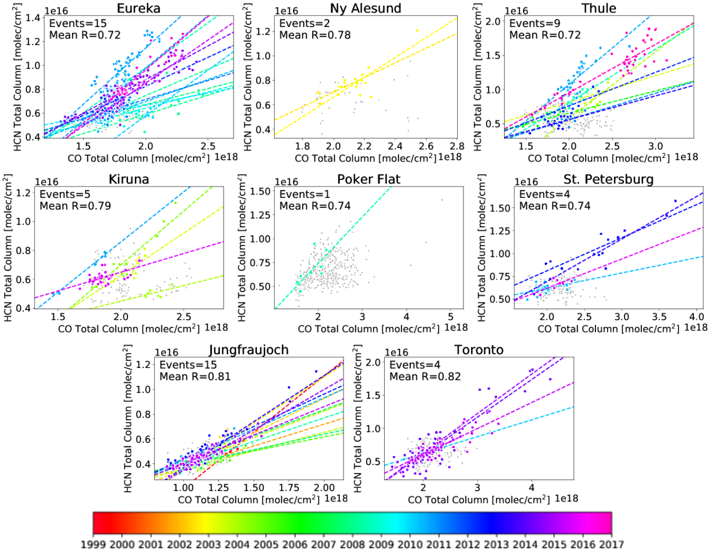
Enhancement Ratio

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

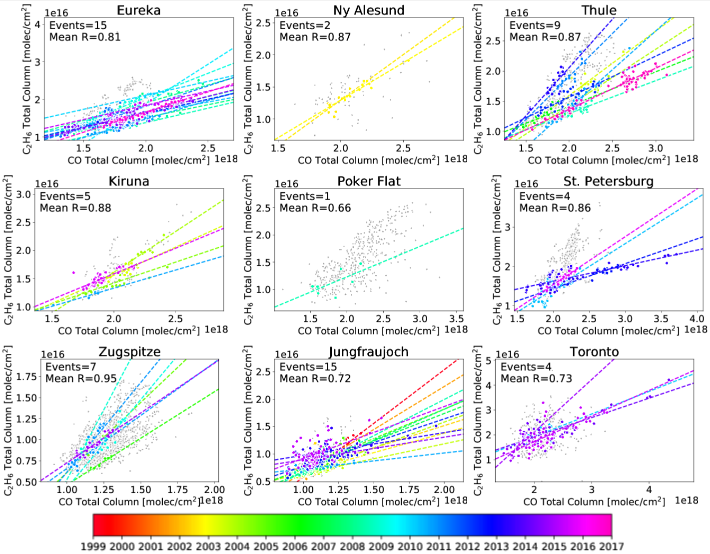
Fire Detection Criteria

1. Number of measurements > 5
2. Linear correlation of $R > 0.5$
3. Number of measurements > 5 and $R > 0.5$ for EnhR of both HCN and C_2H_6

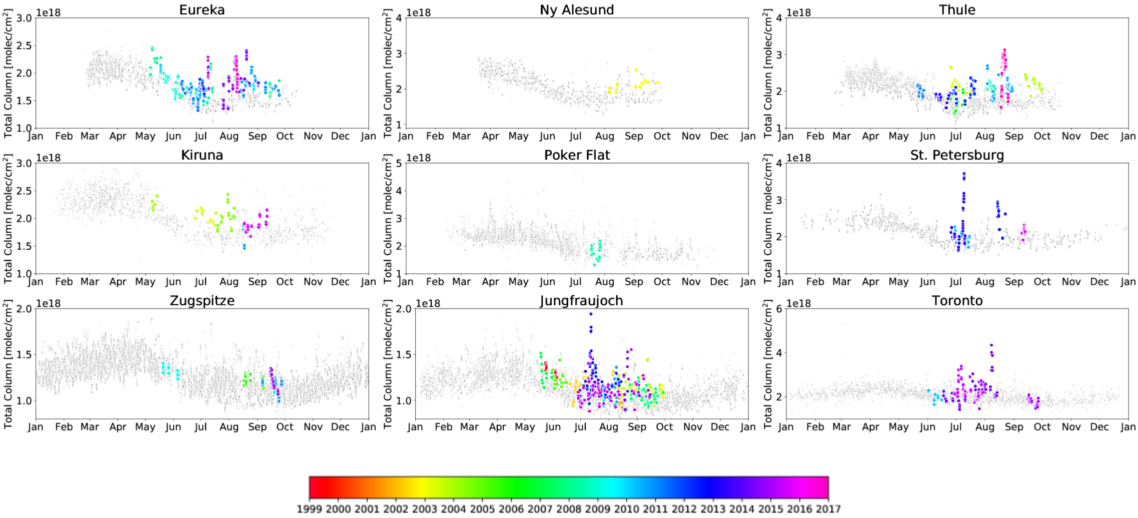
EnhR HCN


Eureka
Events=15
Mean R=0.72
Ny Alesund
Events=2
Mean R=0.78
Thule
Events=9
Mean R=0.72
Kiruna
Events=5
Mean R=0.79
Poker Flat
Events=1
Mean R=0.74
St. Petersburg
Events=4
Mean R=0.74
Jungfraujoch
Events=15
Mean R=0.81
Toronto
Events=4
Mean R=0.82
HCN Total Column [molec/cm²]
CO Total Column [molec/cm²] 1e18
1e16
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

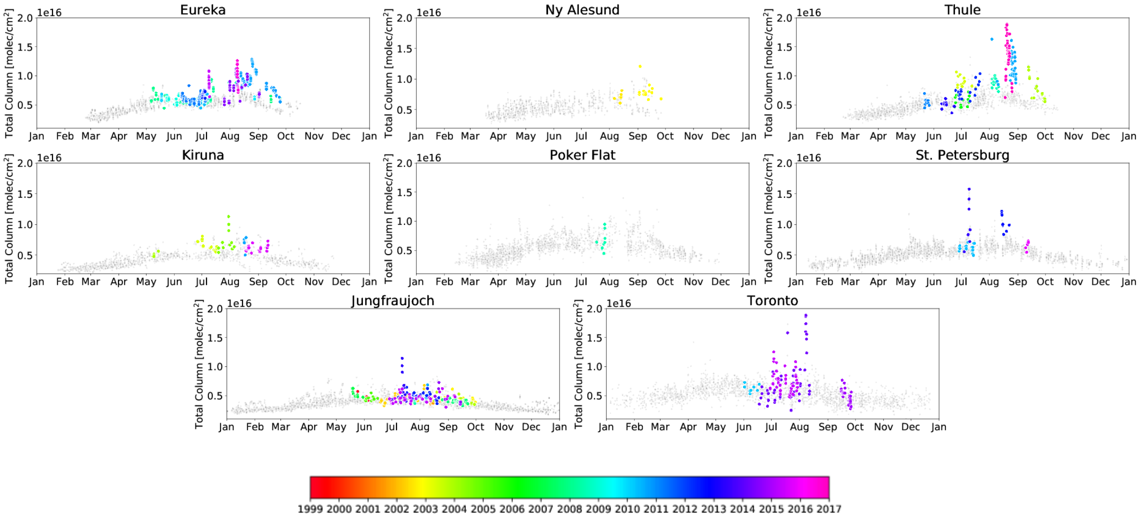
EnhR C_2H_6


Eureka
Events=15
Mean R=0.81
Ny Alesund
Events=2
Mean R=0.87
Thule
Events=9
Mean R=0.87
Kiruna
Events=5
Mean R=0.88
Poker Flat
Events=1
Mean R=0.66
St. Petersburg
Events=4
Mean R=0.86
Zugspitze
Events=7
Mean R=0.95
Jungfraujoch
Events=15
Mean R=0.72
Toronto
Events=4
Mean R=0.73
C2H6 Total Column [molec/cm2] 1e16
CO Total Column [molec/cm2] 1e18
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

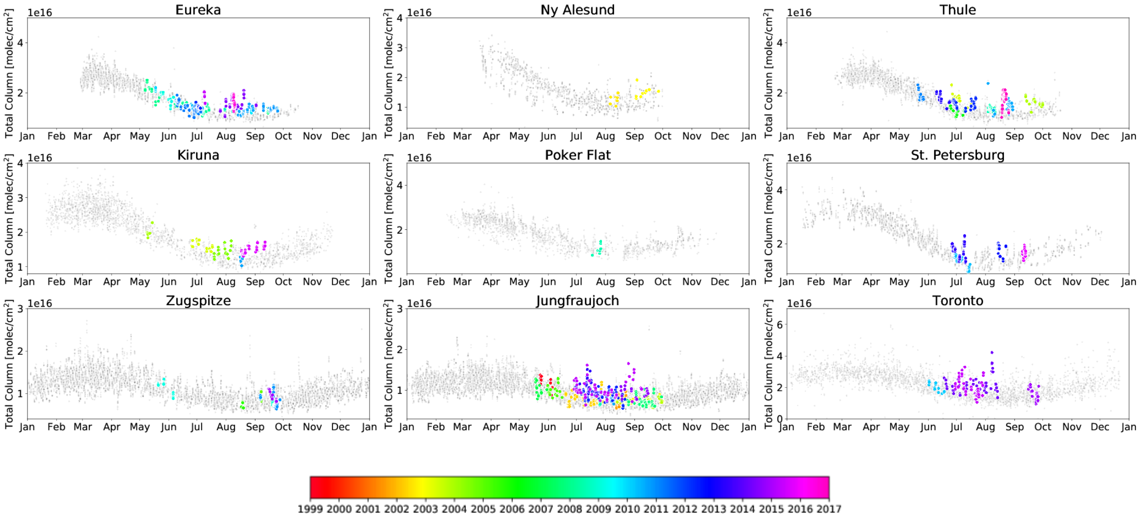
CO


Eureka
Ny Alesund
Thule
Kiruna
Poker Flat
St. Petersburg
Zugspitze
Jungfraujoch
Toronto
Total Column [molec/cm^2]
1e18
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

HCN


Eureka
Ny Alesund
Thule
Kiruna
Poker Flat
St. Petersburg
Jungfraujoch
Toronto
Total Column [molec/cm^2]
1e16
2.0
1.5
1.0
0.5
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

C_2H_6

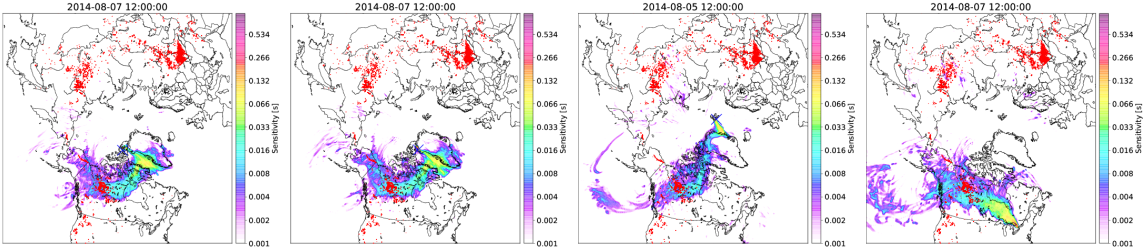

Eureka
Ny Alesund
Thule
Kiruna
Poker Flat
St. Petersburg
Zugspitze
Jungfraujoch
Toronto
1e16
Total Column [molec/cm^2]
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017

Summary of Events

Site	Number of Events	Dates
Eureka	15	2007-09-14, 2008-05-05 ,2008-06-05, 2008-07-29, 2009-05-23, 2009-08-27, 2010-05-17, 2010-05-17, 2010-06-19, 2010-08-12, 2010-09-09, 2011-06-08, 2012-06-28, **2014-07-25**, 2015-07-08, 2016-08-07
Ny Alesund	2	2016-08-07, 2002-09-02
Thule	8	2003-06-25, 2003-09-12, 2006-06-23, 2008-08-02, 2010-08-03, 2011-05-20, 2012-06-23,2013-06-09
Kiruna	5	2003-06-25, 2004-05-07, 2004-07-18, 2010-08-16, 2015-08-17
Poker Flat	1	2008-07-16
St. Petersburg	2	2010-06-28, 2012-08-13, 2013-06-25, 2015-09-09
Zugspitze	7	1998-05-07, 2004-09-06, 2005-08-17, 2008-09-18, 2009-05-20, 2010-09-06, 2010-09-20, 2014-09-15
Jungfraujoch	15	1999-05-23, 2001-08-11, 2002-06-18, 2002-08-28, 2003-08-11, 2003-09-12, 2005-05-31, 2007-05-18, 2007-08-24, 2008-07-23, 2010-08-07, 2012-07-05, 2013-06-30, **2014-08-17**, 2015-06-28
Toronto	4	2010-06-01, **2014-07-22**, 2014-09-16, 2015-06-29

FLEXPART: 2014 Canadian Wildfires

Eureka Thule Ny Alesund Toronto

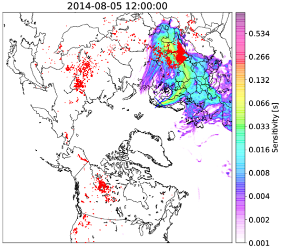


FLEXPART Surface Sensitivity

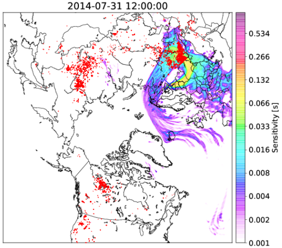
- Particles released at measurement site from surface to ∼12 km.
- Particles transported backwards in time for 10 days.
- Surface residence time shown with MODIS burned areas in red.
- **Enhancements detected at Eureka and Toronto**, no measurements at Thule and Ny Alesund.

FLEXPART: 2014 Russian Fires

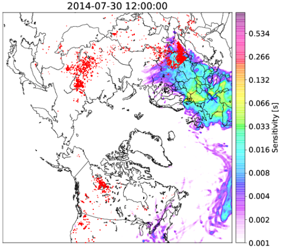
Kiruna



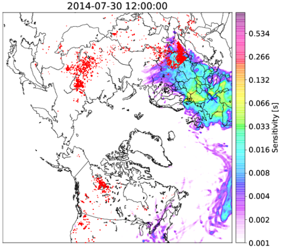
St. Petersburg



Zugspitze



Jungfraujoch



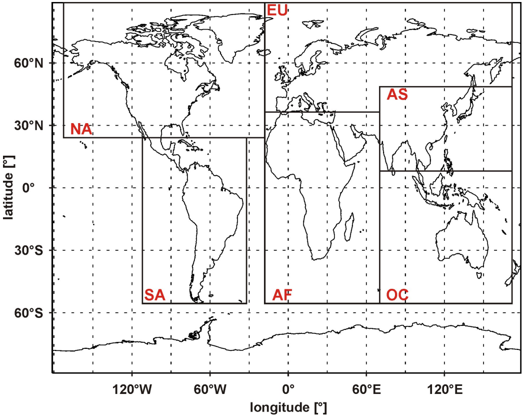
FLEXPART Surface Sensitivity

- Particles released at measurement site from surface to ∼12 km.
- Particles transported backwards in time for 10 days.
- Surface residence time shown with MODIS burned areas in red.
- **Enhancements detected at Jungfraujoch**, no measurements at Kiruna, Peterhof and Zugspitze.

GEOS-Chem Tagged CO

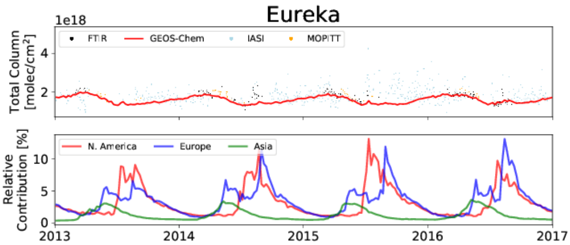
GEOS-Chem v11-01

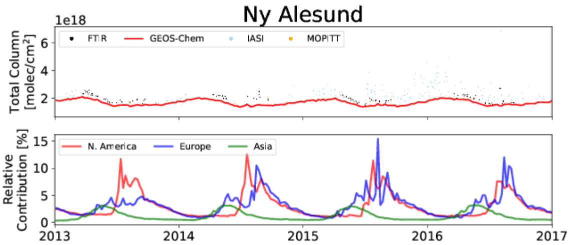
- $2^\circ \times 2.5^\circ$ GEOS-FP meteorological fields
- EDGAR anthropogenic emissions
  - Monthly emissions at $0.1^\circ \times 0.1^\circ$ resolution
- QFED biomass burning emissions (*Darmenov et al., 2015*)
  - Daily emissions at $0.1^\circ \times 0.1^\circ$ resolution

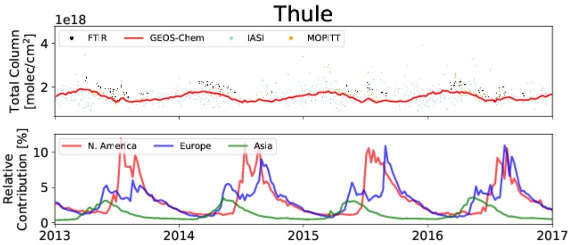


Ridder et al., 2012

High-Arctic Sites



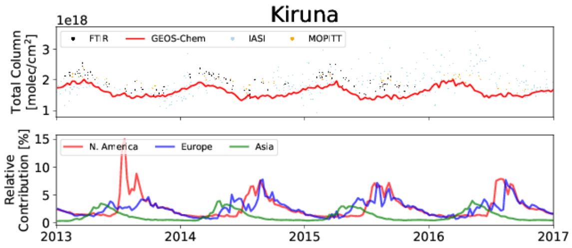


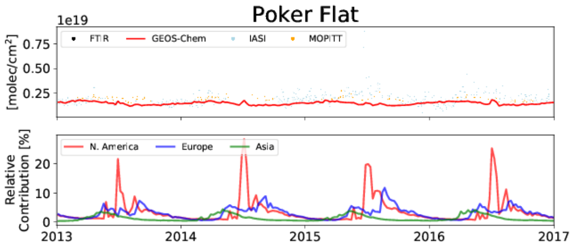


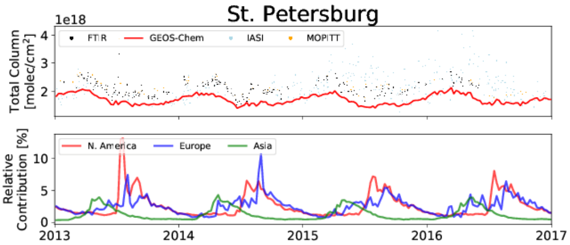
Top Panel: CO total column from FTIR, GEOS-Chem, IASI and MOPITT
Bottom Panel: GEOS-Chem relative contribution from biomass burning sources

North America and Europe greatest biomass burning contribution (∼5-15% of CO total column)

Arctic Sites





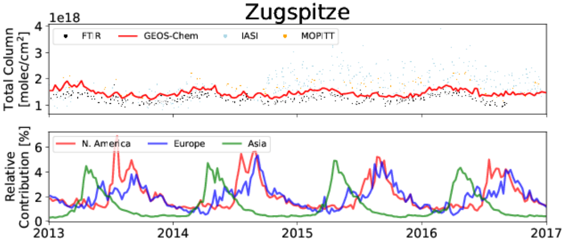


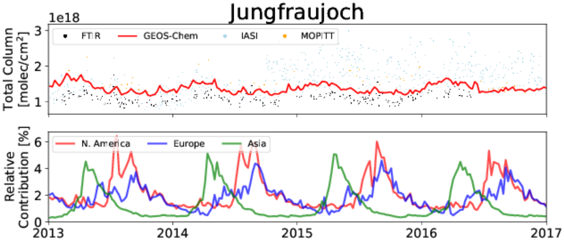
Top Panel: CO total column from FTIR, GEOS-Chem, IASI and MOPITT

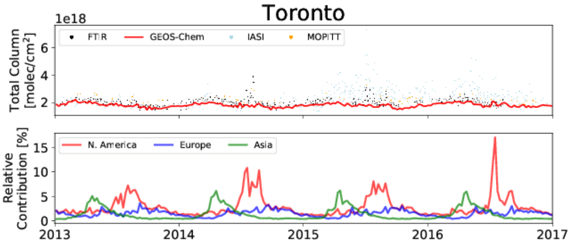
Bottom Panel: GEOS-Chem relative contribution from biomass burning sources

North America and Europe biomass burning: ∼5-20% of CO total column

Mid-latitude Sites







Top Panel: CO total column from FTIR, GEOS-Chem, IASI and MOPITT
Bottom Panel: GEOS-Chem relative contribution from biomass burning sources

Toronto: up to ∼15% contribution from North American wildfires
Zugspitze and Jungfraujoch: ∼5% from each biomass burning source

Conclusion

Episodic enhancements observed at all sites:

- Detections in CO confirmed by correlation with HCN and C_2H_6
- Number of events detected dependent on measurement density
- FLEXPART and MODIS confirm detections
- Can be applied to other species measured by FTIR including C_2H_2, HCOOH, CH_3OH, H_2CO and NH_3

Influence of wildfires on CO vary by location:

- All sites influenced by episodic emissions from North American and Russian fires (From May-Sept. in 2013-2016)
  - ~10-15% of high-Arctic (Eureka, Thule and Ny Alesund) CO total column
  - ~5-10% of Arctic (Kiruna, Poker Flat and St. Petersburg) CO total column
    - Alaskan fires greatest contribution for Poker Flat (~15-20% of CO total column)
- Zugspitze and Jungfraujoch comparable contributions from North America, Russia and Asia (~5% of CO total column)
- Toronto mainly influenced by North American wildfires (~5-15% of CO total column)

Next Steps

GEOS-Chem Tagged CO Runs

- Update biomass burning emissions (GFED or GFAS).
- Custom tagged tracers to separate Siberia/Eurasia from Europe.

AERONET Observations

- Include AERONET observations for co-located or nearby sites.
- AERONET shows enhanced aerosol optical depth for enhanced FTIR measurements.

GEOS-Chem Adjoint

- Use GEOS-Chem adjoint to characterize measurement sensitivity to emissions.

Publish

- Manuscript currently in progress.

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- CANDAC data manager Yan Tsehtik
- CANDAC operators
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