Detection of Wildfire Pollution in the Arctic: Pan-Arctic FTIR Observations and Model Results

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Uncertainty of Wildfire Influence

- Wildfire emissions are highly variable and dependent on fuel type and burning phase (*Andreae et al., 2001, Akagi et al., 2011, Sekimoto et al., 2018, Andreae et al., 2019*)
- Events are spatially and temporally variable which can influence transport pathways (*Ikeda et al., 2017*)
- Aging of the plume during transport influences composition (*Franklin et al., 2014, Konovalov et al., 2017*)
- Wildfire activity and intensity is expected to increase in the future (*Flannigan et al., 2009, Wotton et al., 2010, Boulanger et al., 2014*)

Photo Credit: BC Wildfire Service

Wildfire Impact on the Arctic

- Contribution to aerosol and reactive trace gases:
  - Direct and indirect radiative forcing (*Randerson et al, 2006*)
  - Implications for surface albedo (*Kim et al., 2005*)
  - Negative impact on air quality (*Ikeda et al., 2015*)

The Problem

Observational coverage of the Arctic is scarce, resulting in great uncertainty in assessing the wildfire impact in high-latitude remote regions

Photo Credit: BC Wildfire Service

Global Chemical Transport Models

- Global models have been used extensively to investigate wildfire impacts on the Arctic
- All models have uncertainties and biases:
  - Emissions are estimated and may be highly uncertain
  - Coarse resolution results in transport and chemistry errors (*Eastham and Jacob, 2017*)
  - Model parameterizations lead to further errors (*Phillip et al., 2016*)

The Problem

Models provide global coverage of atmospheric constituents, but is only an estimate based on prior knowledge and a number of assumptions

Photo Credit: Meagan Wohlberg

Focus of Study

Ground-based FTIR Observations

- Measurements of wildfire tracers CO, HCN and C_2H_6
- Long-term time series and coverage of high-latitude regions
- Detect wildfire pollutions events at high and mid-latitude sites

GEOS-Chem Tagged CO Simulation

- Source attribution for FTIR measurements
- Long-term, continuous and global time series
- Evaluate model performance in the Arctic using FTIR

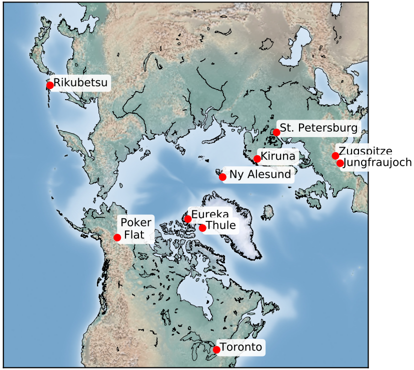
Retrieved Species

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

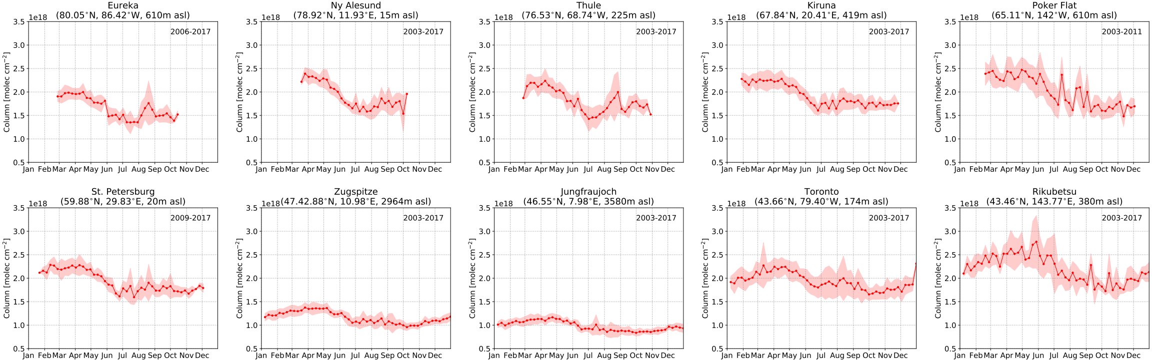
Species	Name	Sources	Sinks	Lifetimes
CO	Carbon Monoxide	BB, transport, steel industry, methane and VOC oxidation	reaction with OH	30 days
HCN	Hydrogen Cyanide	BB, industry, fungi and plant emission	reaction with OH and ocean uptake	75 days
C_2H_6	Ethane	BB, biofuel use, oil and gas extraction	reaction 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
Rikubetsu	44°N,144°E	380	1995-present



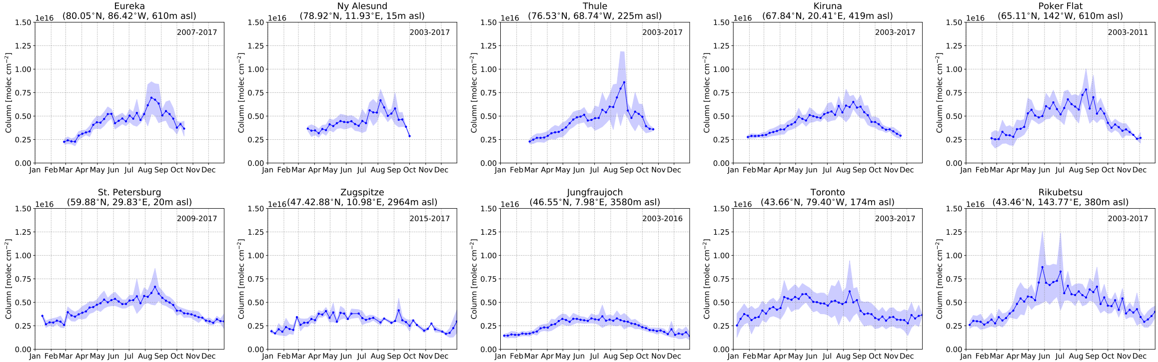
CO Time Series



CO Seasonal Cycle

- Seasonal cycle driven by transport and OH production
- Summer influence from boreal wildfires and biogenic sources (ie. VOC oxidation)

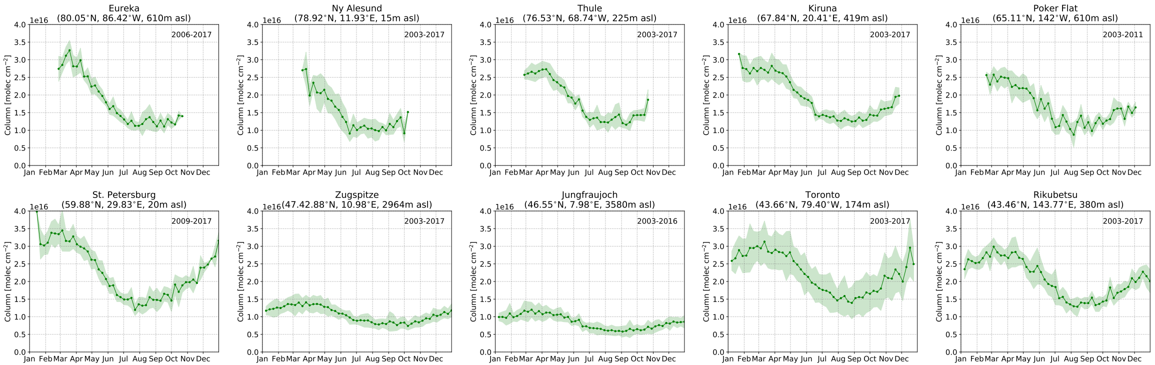
HCN Time Series



HCN Seasonal Cycle

- Seasonal cycle driven by natural sources and boreal wildfires
- Long lifetime allows HCN to accumulate

C_2H_6 Time Series



C_2H_6 Seasonal Cycle

- Similar seasonal cycle to CO as result of their common sources and sinks
- Less influence from boreal wildfires in the summer months

GEOS-Chem Chemical Transport Model (v12.1.1)

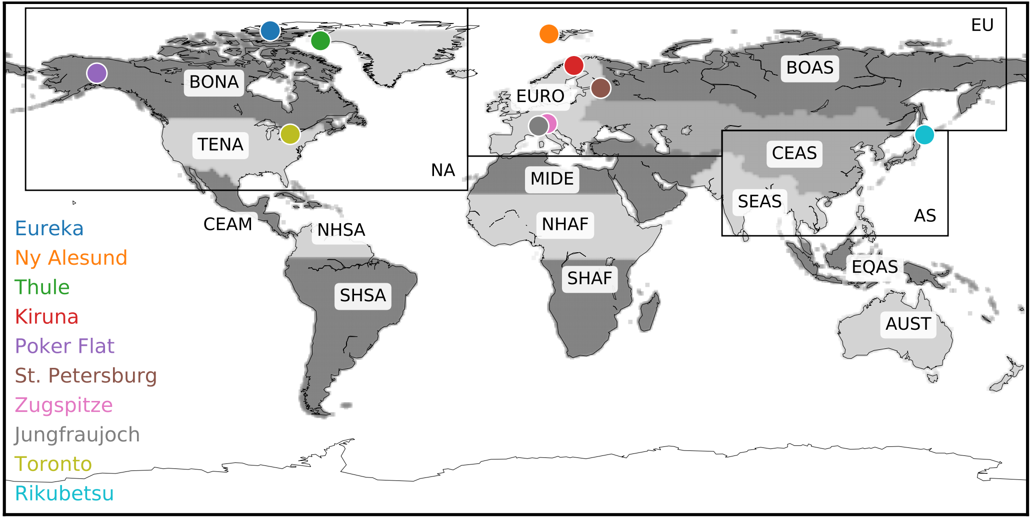
Tagged CO Simulation

- 14 B.B. source regions from GFED (Giglio et al., 2013)
- 3 anthropogenic source regions (N. America, Europe, Asia)
- CO from CH_4 and NMVOC oxidation

Model Inputs

- **MERRA-2** meteorological fields at $2^\circ \times 2.5^\circ$ horizontal resolution
- **EDGAR** global anthropogenic emissions
- **GFAS** biomass burning emissions (*Kaiser et al., 2012*)
- **TransCom** prescribed OH fields (*Patra et al., 2011*)

GEOS-Chem Tagged CO Source Regions



FTIR Fire Detections

Method

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

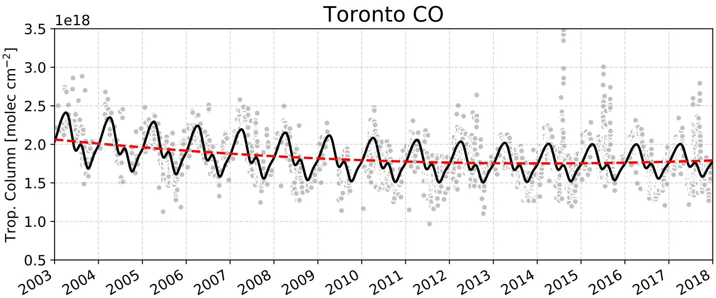
$$f(t) = a_0 + a_1 t + a_2 t^2 + \sum_{n=1}^{4} b_n \cos(2\Pi n t) + c_n \sin(2\Pi n t)$$

Thoning et al., JGR, 1989

Procedure

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

Toronto CO Time Series

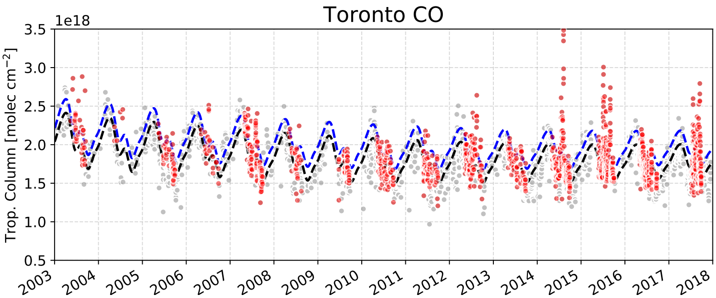


- **Fitted CO time series**
- **Inter-annual trend**
- **FTIR CO measurements**

CO Trends

- Seasonal cycle driven by transport, seasonality of emissions and OH production
- Declining trend due to a reduction of anthropogenic emissions

Detection of Pollution Events



- **Fitted CO time series**
- **Mirrored negative residual standard deviation**
- **Detected pollution events**
- **FTIR CO measurements**

Detection of CO Enhancements

- Enhancements only considered during boreal fire season from April-September
- All measurements considered fire-affected between start and end of detected 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] measurement within 1 hr

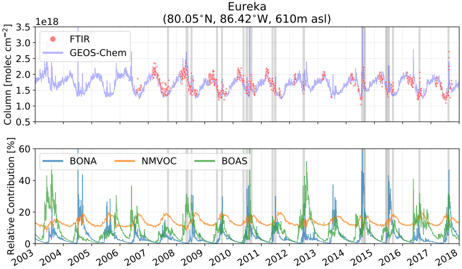
Enhancement Ratio

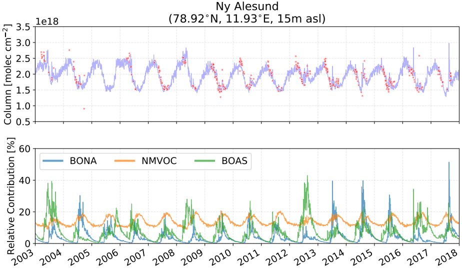
- Dependent on fuel type and burning phase of wildfire
- Also influenced by aging of smoke plume during transport

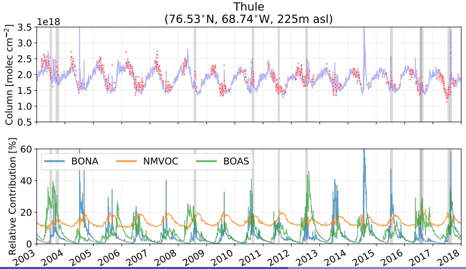
Fire Detection Criteria

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

High-Arctic Sites



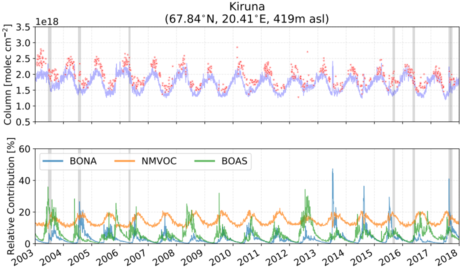


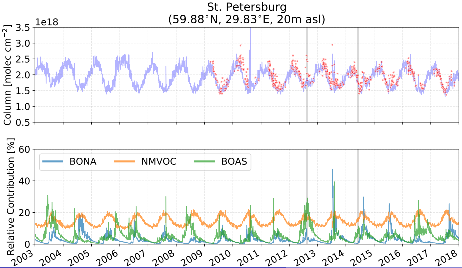


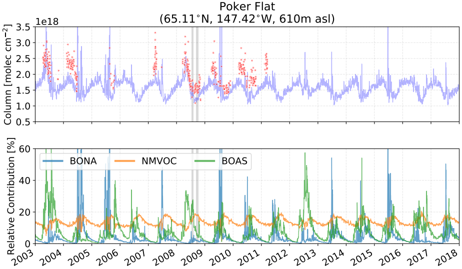
Top Panel: Daily-averaged CO tropospheric column from FTIR and GEOS-Chem
Bottom Panel: GEOS-Chem relative contribution from B.B. sources

BONA and BOAS greatest B.B. contribution (∼10-60% of CO total column)

Arctic Sites



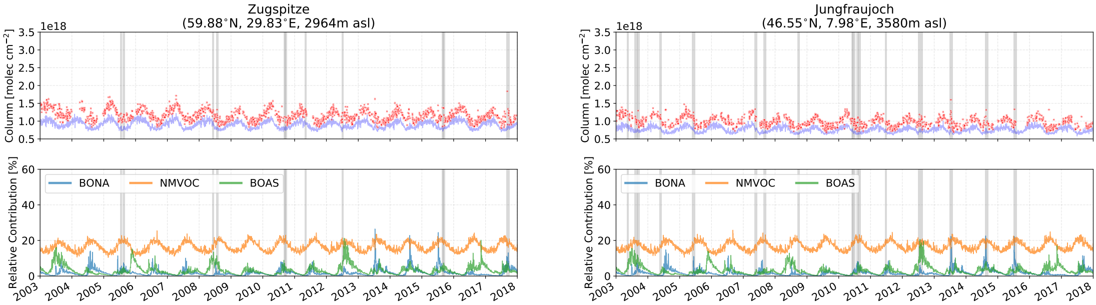




BONA and BOAS greatest B.B. contribution (∼20% of CO column) for Kiruna and St. Petersburg

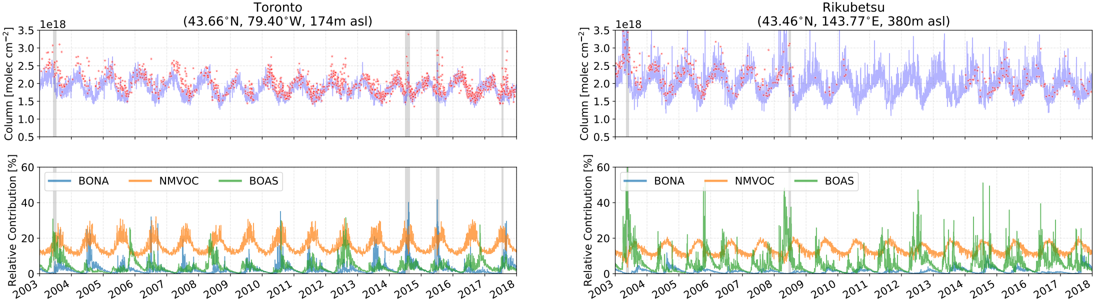
Large contribution (>60%) for Poker Flat from BONA and BOAS

Alpine Sites



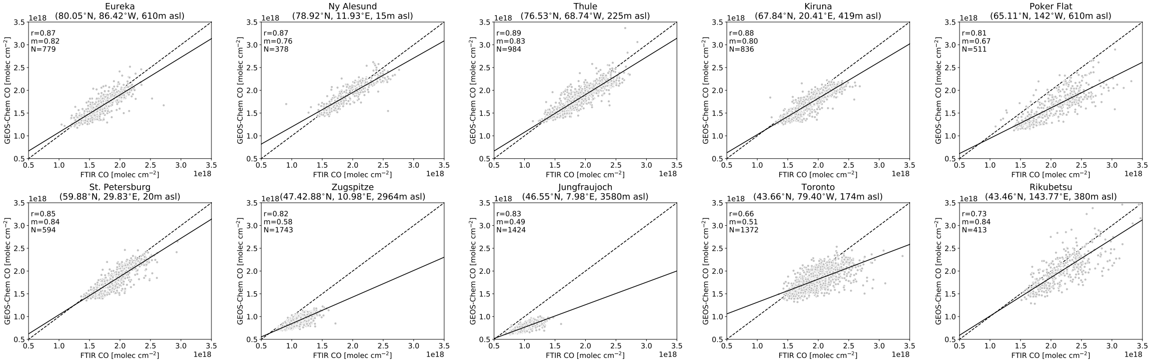
- Neither site largerly influenced by B.B. emissions
- BONA and BOAS greatest contribution at both sites (∼10%)

Mid-latitude Sites



- Toronto largely influenced by BONA emissions
- Rikebetsu predominately influenced by BOAS and Asian sources

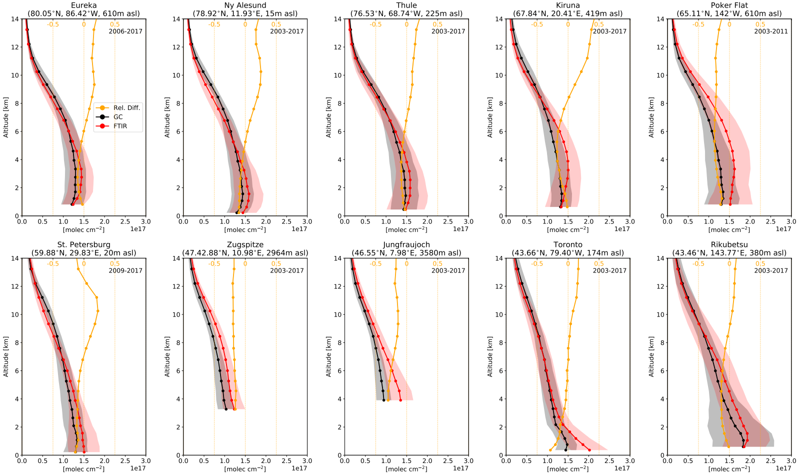
GEOS-Chem vs. FTIR Correlation



GEOS-Chem vs. FTIR

- Good correlations at all sites, *r*-value generally greater than 0.8
- GEOS-Chem shows low bias at all sites, magnitude varying by site

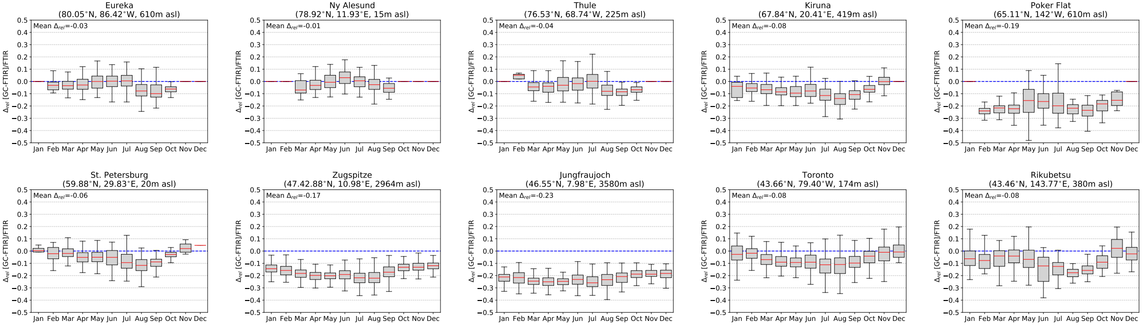
CO Profile Comparison



GEOS-Chem Bias

- General high bias in upper-troposphere
- Low bias near surface
- Likely due to
  - OH distribution
  - Model vertical transport

GEOS-Chem vs. FTIR Bias



GEOS-Chem Bias

- Generally greater low bias in summer months at all sites
- Suggests underestimation of wildfire emissions/plume transport and biogenic sources.

Summary

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

Influence of wildfires on CO vary by location:

- All sites influenced by episodic emissions from North American and Russian fires (From April-Sept. in 2003-2017)
  - ~10-50% of high-Arctic (Eureka, Thule and Ny Alesund) CO column
  - ~5-40% of Arctic (Kiruna, Poker Flat and St. Petersburg) CO column
    - Alaskan fires greatest contribution for Poker Flat (~40-60% of CO column)
- Zugspitze and Jungfraujoch comparable contributions from North America, Russia and Asia (~10% of CO column)
- Toronto mainly influenced by North American wildfires (~10-20% of CO column)
- Rikubetsu subject to outflow from Asia, mostly Boreal Asia (~10-50% of CO column)

Summary

Good agreement of GEOS-Chem tagged CO simulation to FTIR:

- Underestimation of GEOS-Chem observed at all sites
- General low bias of 8%
- Greater underestimation at Jungfraujoch (23%) and Zugspitze (17%)
  - Possibly due to unresolved topography and underestimation of vertical transport
- Poker Flat underestimated by 19%, possible underestimation of:
  - Transport of Asian pollution
  - Local biogenic CO sources
- All sites illustrate great low bias in the summer which suggests:
  - Underestimation of boreal wildfire emissions and plume transport
  - Biogenic contribution to CO also underestimated

Manuscript in Progress

Manuscript currently in late stage of preparation

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