Observations of extreme wildfire enhancements of VOCs over the Canadian High Arctic



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Introduction

During August 2017, two independent large-scale wildfires occurred in British Columbia and the Northwest Territories of Canada. The B.C. wildfires were record-setting in their magnitude, affecting over 1.2x106 hectares of land (Fig. 1) [1]. Wildfires such as these are significant natural sources of many trace gases including reactive volatile organic compounds (VOCs). Four VOCs that are of particular importance are methanol (CH3OH), formic acid (HCOOH), peroxyacetyl nitrate (PAN), and ethylene (C2H4). These species have various negative impacts on the climate, air quality, and environment, particularly in sensitive remote regions such as the high Arctic [2, 3, 4, 5]. The plumes from the B.C. and NWT fires merged and were transported northwards to the Arctic where they led to the largest measured enhancement in ammonia measured by the Bruker IFS 125HR ground-based FTIR at the Polar Environment Atmospheric Research Laboratory (PEARL, Fig. 2) in Eureka, Nunavut (80.05°N, 86.42°W). This was the focus of a 2019 study by Lutsch et al. [6].

Here, we expand upon this previous study to incorporate ground-based measurements of CH₃OH, HCOOH, PAN, and C₂H₄, as well as measurements from the Infrared Atmospheric Sounding Interferometer (IASI) satellite instruments, and simulated columns from the GEOS-Chem chemical transport model. By using both ground-based and satellite datasets, in addition to global simulations from GEOS-Chem, we gain a broader perspective on this exceptional biomass burning event.





Figure 1: The smoke plume from the August 2017 B.C. wildfire seen from space by MODIS on NASA Terra.

Datasets and Methods

The FTIR retrievals are performed using the SFIT v0.9.4.4 retrieval software that is based on the optimal estimation method (OEM) of Rodgers (2000) [7]. The a priori trace gas profiles used in the retrievals are sourced from the average of a 40-year WACCM v4 simulation [8], and the daily pressure-temperature profiles at Eureka are taken from the US National Centers for Environmental prediction (NCEP). Total column trace gas abundances are obtained from IASI observations using v3.1 of the Artificial Neural Network for IASI (ANNI) retrievals [3].

A simulation for the full year of 2017 was performed using GEOS-Chem v13.1.1 at a spatial resolution of 2°x2.5° (latitude/longitude), with MERRA-2 meteorology and biomass burning emissions from the ECMWF Global Fire Assimilation System (GFAS). A model spin-up was performed at 4°x5° resolution for January to November 2016, and December was run at $2^{\circ}x2.5^{\circ}$ to smooth out the resolution differences. The current version of GEOS-Chem does not include a C₂H₄ simulation.

Comparisons between the PEARL FTIR and IASI were performed during the fire-affected period of August 2017. IASI-A & B measurements within 150km of PEARL were selected and daily averages were calculated for all species. For both the FTIR and IASI measurements, enhancement ratios (EnhR) of each VOC species relative to CO were computed from the slope of a linear regression of the retrieved total columns (Fig. 3). Furthermore, to correct for the plume travel time to Eureka we calculate the the emission ratio (ER) for each species following the methods of [9] using an estimate of the travel time of 5 days. Lastly, we calculate the emission factor (EF) for each species following [10] to allow for a direct comparison with previous studies and compilation works.

To compare GEOS-Chem with the FTIR, the nearest model grid-box to PEARL was selected and the corresponding volume mixing ratio and air density profiles were linearly interpolated to the pressure grid of the nearest FTIR measurement (within ±1 hour), converted to partial columns, and then smoothed using the FTIR averaging kernel following [11]. The final optimized model partial column profile is then summed to obtain a total column, allowing for a direct comparison with the FTIR.

Figure 2: (left) the location of PEARL in Eureka, NU, and (right) The PEARL Ridge Lab.



Results IASI and the PEARL FTIR both capture extreme enhancements in CO and the VOC species (Figs. 3 & 4) The EF's from IASI and the FTIR CH_3OH agree well (3.5 ± 2.05 g kg⁻¹ vs. 3.10 ± 1.47 g kg⁻¹ respectively). However, for C_2H_4 and HCOOH, the EF's derived from the IASI are significantly smaller than those from the FTIR (C_2H_4 : 0.99 ± 0.46 g kg⁻¹ vs. 6.56 ± 2.64 g kg⁻¹, HCOOH: 5.88 ± 2.68 g kg⁻¹ vs. 14.86 ± 6.00 g kg⁻¹ respectively). Since PAN is formed via secondary production, no EF was computed here. Discrepancies in the EF's may be a result of lower vertical sensitivities of the IASI retrievals.

GEOS-Chem CO columns display a slight underestimation relative to the FTIR and IASI, however for the short-lived VOC species the model does not capture a meaningful enhancement at Eureka (Fig. 5). These differences are the result of a transport error in the model coupled with a general underestimation of the biomass burning VOC emissions in GFAS. Despite this, both IASI and GEOS-Chem capture a fragment of the plume crossing the Atlantic towards Europe. The largest retrieved C₂H₄ columns from an FTIR at Jungfraujoch (JFG), Switzerland occur on 20 August 2017, which can be attributed to these fire plumes.





Conclusions JFG, demonstrating the exceptional long-range transport of these short-lived VOC species.

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