Biomass Burning: A Comparative Study Between ACE-FTS Observations and the GEOS-Chem High Performance Model

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Objectives

- Compare the climatological means and timeseries of key biomass burning products as measured by the Atmospheric Chemistry Experiment – Fourier Transform Spectrometer (***ACE-FTS***) satellite and as modelled by the GEOS-Chem High Performance (***GCHP***) model over the ***2004-2021*** period for the upper troposphere-lower stratosphere ***(UTLS) region***
- Assess the biases between ACE-FTS and GCHP to better understand the model performance
- Biomass burning species to be examined include: carbon monoxide (***CO***), acetylene (***C_2H_2***), ethane (***C_2H_6***), formic acid (***HCOOH***), and peroxyacetyl nitrate (***PAN***)

Methodologies

- The cubed-sphere coordinate grid of GCHP is converted to a standard latitude-longitude grid using the Python-based toolkit, GCPy
- GCHP model output is sampled at the times and locations of ACE-FTS accounting for the change in geographical location with altitude (using method of [2])
- Quality control flags are used to remove outliers in ACE-FTS data as recommended by [8] (note that the corresponding GCHP sampled at these times and locations are also removed)
- ACE-FTS and model data (sampled as ACE-FTS) are placed into 5˚ latitude bins and interpolated to 28 pressure levels (300, 250, 200, 170, 150, 130, 115, 100, 90, 80, 70, 50, 30, 20,15, 10, 7, 5, 3, 2, 1.5, 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1 hPa) as used in the SPARC Data Initiative [9]

Climatologies

- Monthly mean zonal mean climatologies are determined for each species by year
- At least three observations at any given latitude and pressure level are required to determine each monthly climatology and at least five years in which this condition is met is required to determine the 2004 - 2021 multi-year mean climatology
- Monthly mean climatologies are used to calculate seasonal climatologies

Data and Background Information

ACE-FTS (Version 5.2 – Level 2 Data) [1]

- Highly inclined (74˚) limb-viewing satellite instrument that records solar absorption spectra twice per orbit with up to 15 sunrise and 15 sunset measurements taken per day
- ACE-FTS has a broad spectral coverage in the mid-infrared (750-4400 cm^{-1}) with a spectral resolution of 0.02 cm^{-1}
- Measurement altitude coverage extends from cloud tops to 150 km with a vertical resolution of ~2-3 km in the UTLS
- Latitude coverage is between 85˚N – 85˚S with more than 50% of observations occurring poleward of 60˚

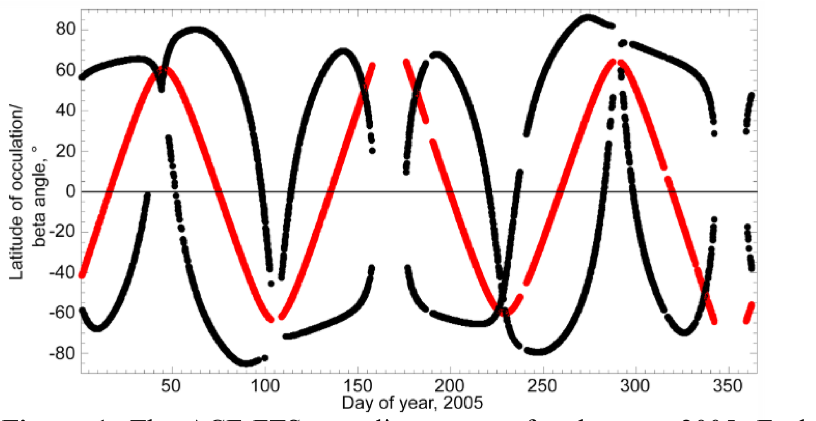

Figure 1: The ACE-FTS sampling pattern for the year 2005. Each black circle is the latitude of the 30 km tangent height of the occultation and each red circle is the corresponding beta angle of the occultation. Imagine and caption taken from [2].

GCHP (Version 14.1.1)

- Model resolution of C48 (~2˚x2.5˚) with 72 vertical layers from the surface to 0.01 hPa (~ 80 km)
- Emissions are configured using Harmonized Emissions Component (HEMCO) [3]
- Global anthropogenic emissions for the 1980-2019 period are provided by Community Emissions Data System v2 (CEDSv2) [4]. The 2019 emissions are applied for the 2020-21 period
- Biogenic emissions provided by Model Emissions of Gases and Aerosols from Nature v2.1 (MEGAN2.1) [5]
- Biomass burning emissions for CO, C_2H_6, and PAN are provided by the Global Fire Assimilation System v1.2 (GFASv1.2) [6]
- C_2H_2 and HCOOH emissions determined by calculating the ratio of the emission factor relative to CO (i.e. EF_{C2H2} / EF_{CO}, in molar units) using values from [7] for various biomass burning types
- Biomass burning emissions from GFAS are distributed evenly between the surface and the "mean altitude of maximum injection" (MAMI) – determined using 1-D plume-rise model

Note: GCHP model runs performed by Tyler Wizenberg

Results – *Climatologies (Dec. – Feb., DJF)*

- In this section, we compare the 2004 – 2021 multi-year mean DJF climatologies for CO, C_2H_2, C_2H_6, HCOOH, and PAN from ACE-FTS to GCHP
- Depicted in each plot are the climatologies, the difference between the climatologies and the percent difference GCHP is from ACE-FTS relative to ACE-FTS
- We find that **CO is well represented in GCHP**, however there is a **negative bias in C_2H_2**, and **C_2H_6** and a **large positive bias in HCOOH** and **PAN** in GCHP
- Note: though GCHP model output extends up to ~80 km, there is no mesospheric intrusion of CO into the underlying stratosphere which results in a significant discrepancy. As such, we have chosen to only investigate pressure levels from 10 – 300 hPa

CO

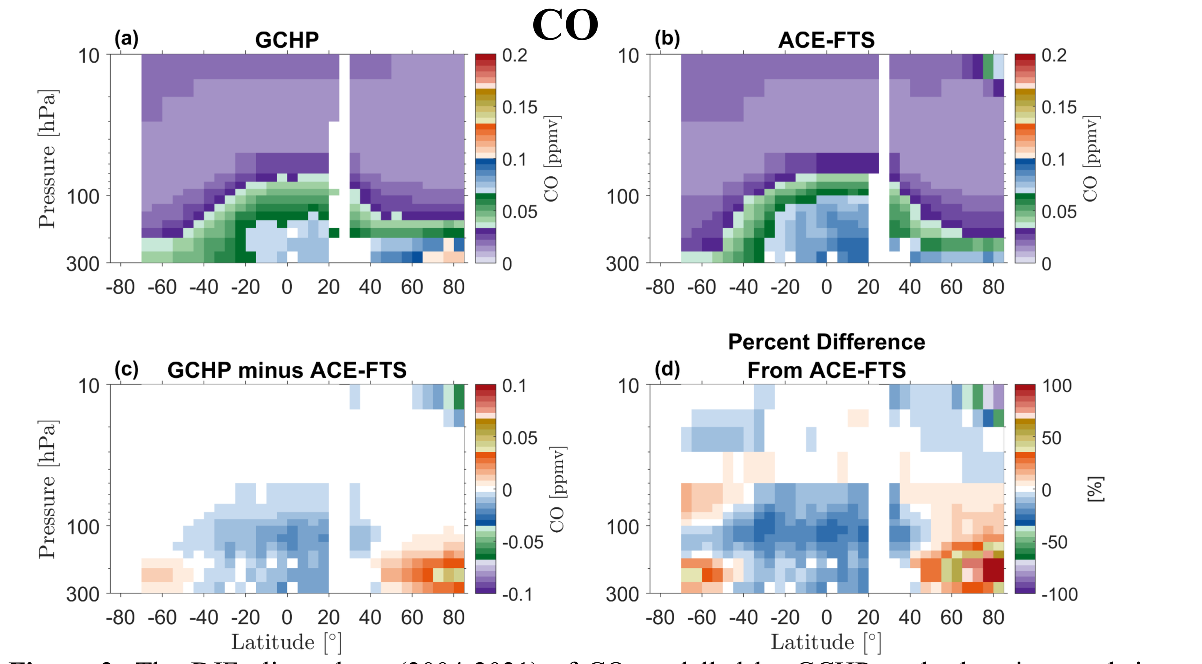

Figure 2: The DJF climatology (2004-2021) of CO modelled by GCHP at the locations and times specified by ACE-FTS (a) and measured by ACE-FTS (b). The difference between GHCP and ACE-FTS (c) and the percent difference GCHP is from ACE-FTS (d) are also presented. Note that units for (a)-(c) are in ppmv. Areas with missing data correspond to regions that did not meet the threshold requirement for determining the climatology of CO. Also, due to the rounding of GCHP data to the closest latitude that ACE-FTS measures at any given time, the regions with missing data in Figs. 2a and b will not match exactly.

C_2H_2

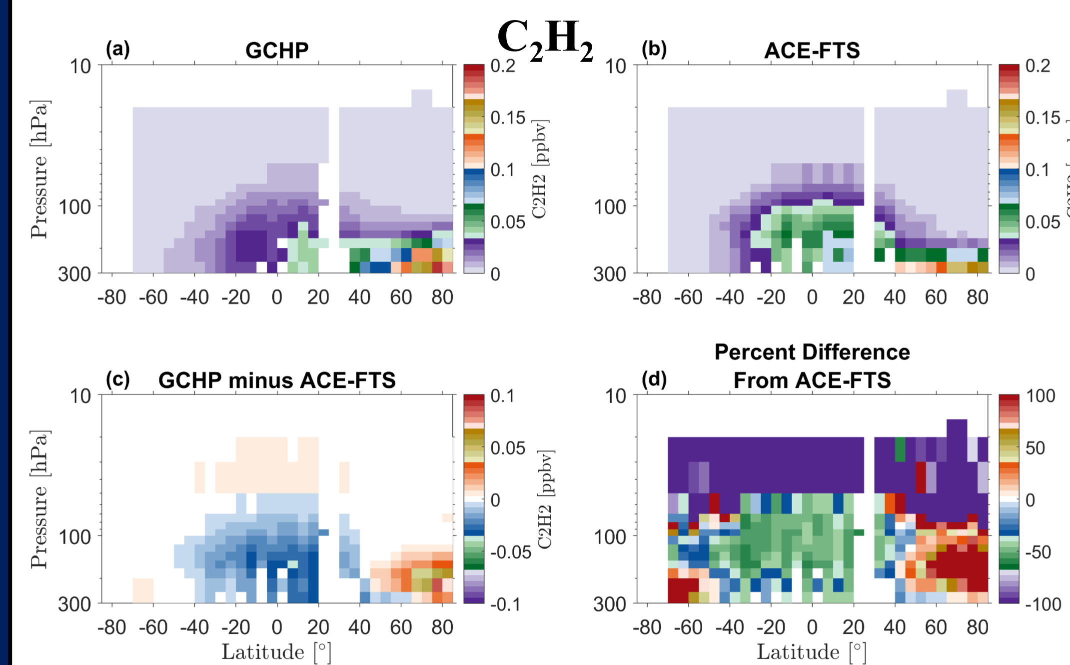

Figure 3: The same as Figure 2 except for C_2H_2. Note the units for (a)-(c) are in ppbv.

C_2H_6

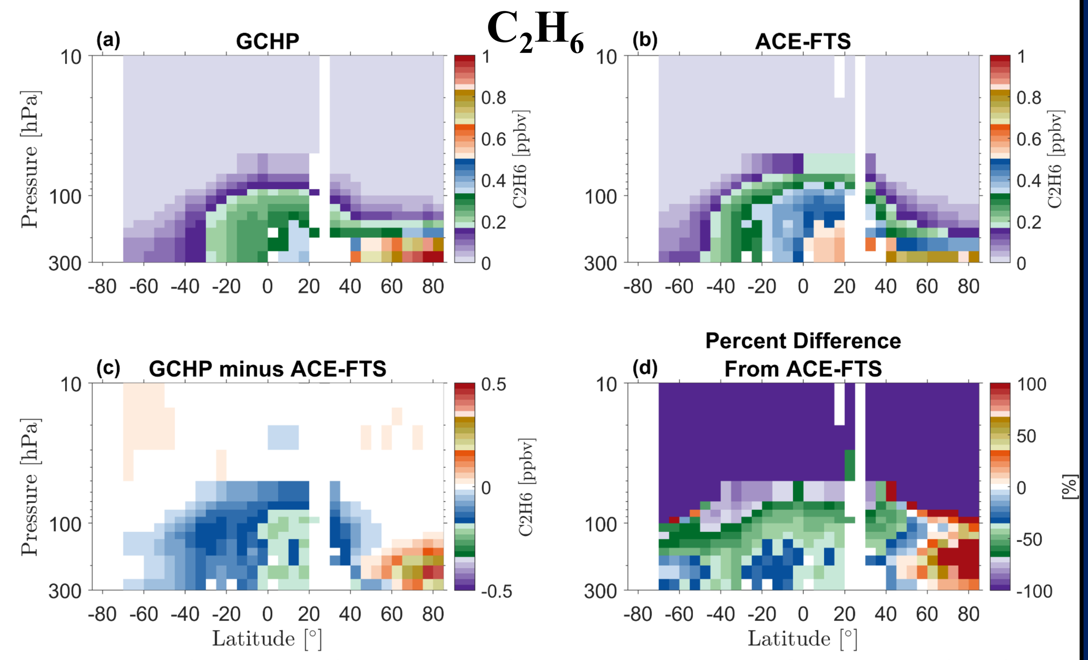

Figure 4: The same as Figure 2 except for C_2H_6. Note the units for (a)-(c) are in ppbv.

HCOOH

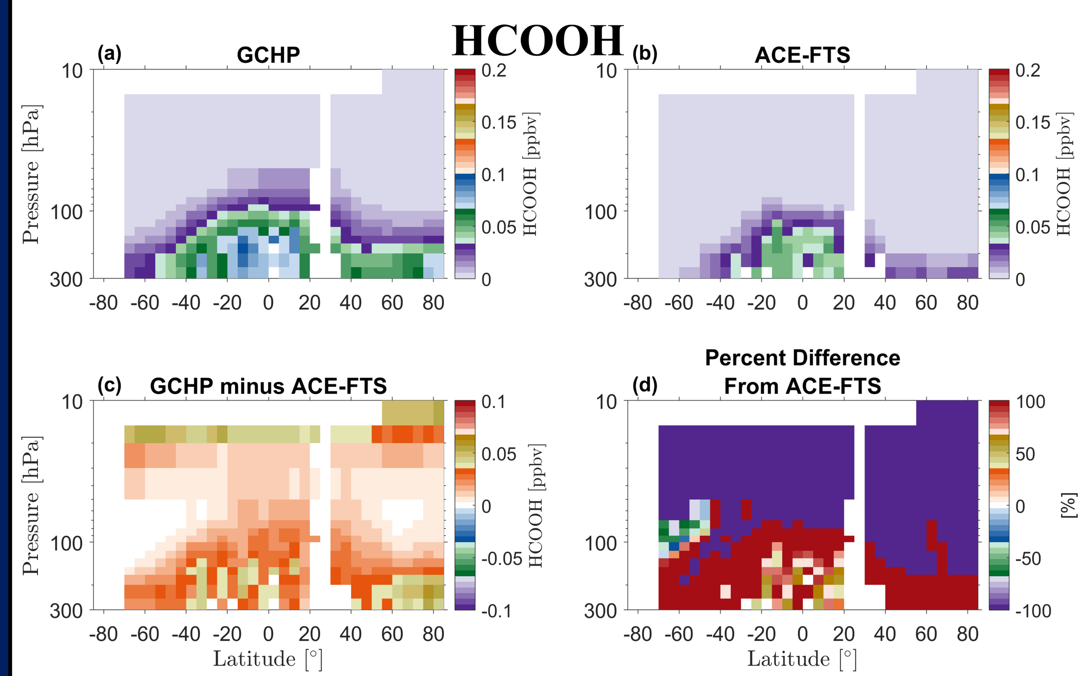

Figure 5: The same as Figure 2 except for HCOOH. Note the units for (a)-(c) are in ppbv.

PAN

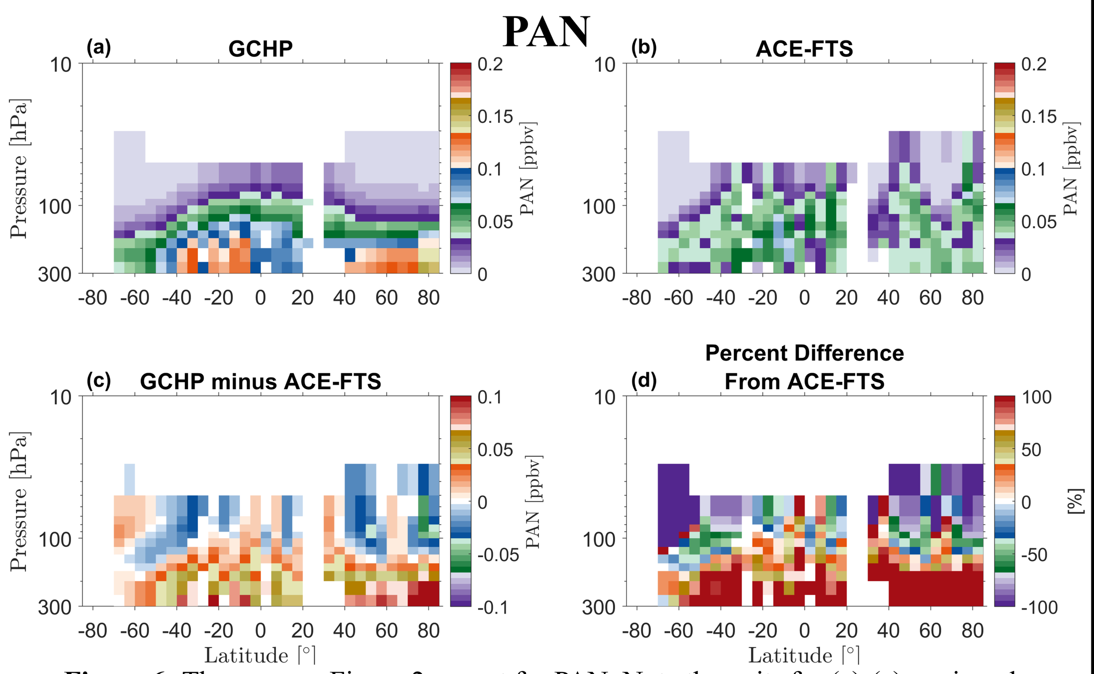

Figure 6: The same as Figure 2 except for PAN. Note the units for (a)-(c) are in ppbv.

Results – *Monthly Timeseries of CO*

- While the climatological comparisons provide insight into the performance of GCHP compared to ACE-FTS, they do not demonstrate differences in the interannual variability of the species
- Here we present a timeseries comparison between ACE-FTS (red) and GCHP (blue) of CO divided by month
- Overall, the monthly interannual variability of CO is well captured by GCHP
- However, **there are a few discrepancies such as Oct./Nov. 2015.** It is interesting that this is the same year that the Indonesian wildfires occurred

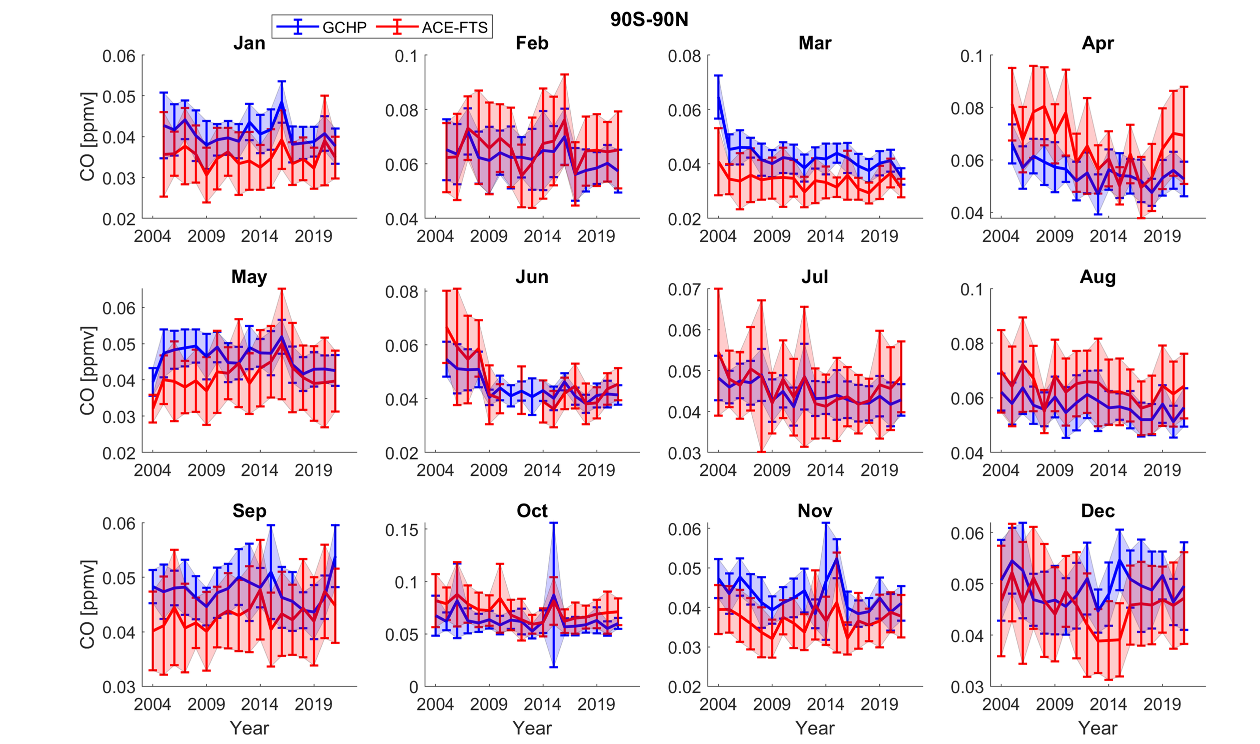

Figure 7: Cosine-latitude weighted average of global CO concentrations averaged over the 100-300 hPa atmospheric layer broken up according to month for GCHP (blue) and ACE-FTS (red) with shading representing the standard deviation. Units are in ppmv. Note the difference in the scale of the y-axis for each plot. This plot requires at least three observations within the specified latitudinal range and for each month.

Results – *Interannual Variability of CO*

- Here we focus on the year surrounding the Indonesian wildfires of 2015 to examine in more detail the observed difference between GCHP and ACE-FTS (Figs. 8-10)
- The vertical profiles of CO from ACE-FTS and GCHP are also compared to examine the relative position of the CO maximum

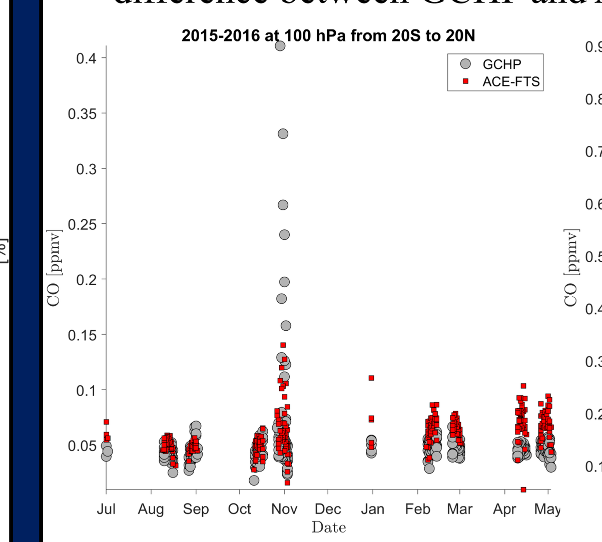

Figure 8: CO concentrations observed by ACE-FTS (red) and modelled by GCHP (grey) from 20˚N–20˚S at 100 hPa over the June 2015–May 2016 period. Units are in ppmv.

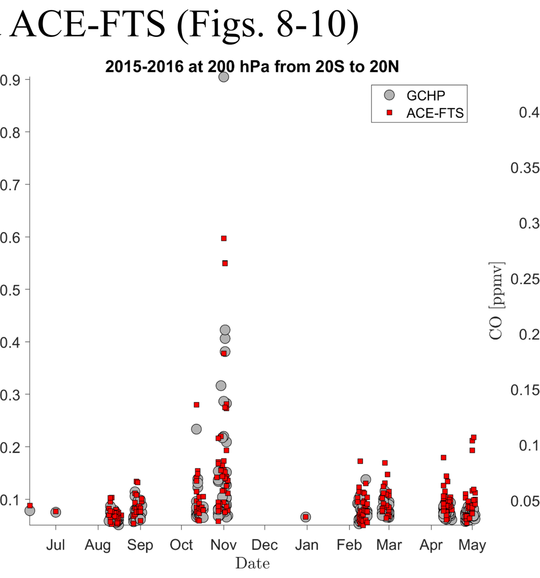

Figure 9: The same as Figure 8 but for 200 hPa

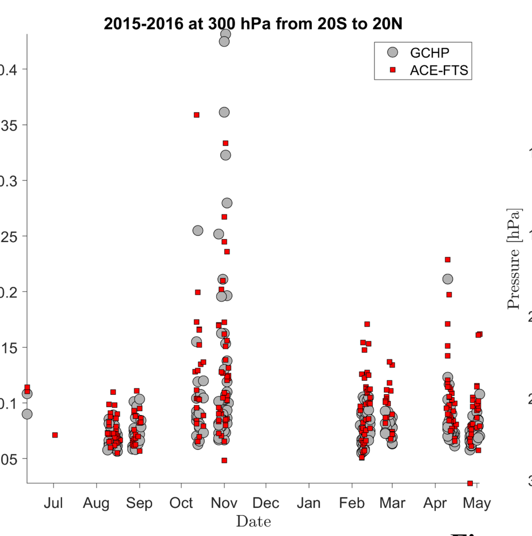

Figure 10: The same as Figure 8 but for 300 hPa

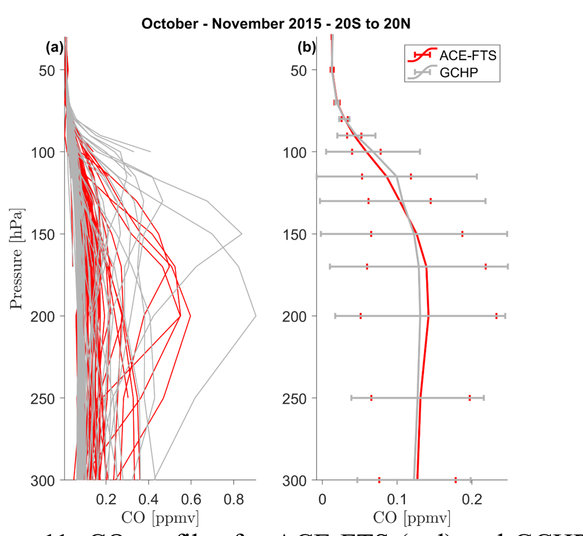

Figure 11: CO profiles for ACE-FTS (red) and GCHP (grey) from 20˚N–20˚S over the Oct.–Nov. 2015 period (a). The cosine-latitude weighted average and standard deviation of the profiles (b). Units are in ppmv.

Conclusions

- ***Good agreement*** found between ACE-FTS measurements of ***CO*** and GCHP model output in the UTLS region
- ***Negative bias*** of ***C_2H_2*** and ***C_2H_6*** and ***large positive bias*** of ***HCOOH*** and ***PAN*** in GCHP compared to ACE-FTS in the UTLS region
- ***Noticeable discrepancy of CO*** measurements by ACE-FTS and GCHP model output in ***October/November 2015***

Future Work

- Investigate why the Indonesian wildfire of 2015 caused such a discrepancy at 300-100 hPa between ACE-FTS observations and GCHP model output and not for other biomass burning events (such as the Australian wildfires of 2020/21)
- Investigate other species during biomass burning events / how the biomass burning species correlate with one another
- Establish a methodology of detecting anomalous injections of biomass burning species into the atmosphere including spatial and altitude coordinates and use this to compare biomass burning events

Acknowledgements

This work is supported by a grant (21SUASABBC) from the Canadian Space Agency (CSA). The Canadian-led ACE satellite mission is mainly supported by CSA. We thank Peter Bernath for his leadership of the ACE mission. The MERRA-2 data used in GCHP is provided by the Global Modeling and Assimilation Office (GMAO) at NASA Goddard Space Flight Center.

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