Response to Reviewer #1

We are grateful to the reviewer for the valuable comments that facilitate the important improvements of the original manuscript. We list the point-by-point responses below. The reviewer's comments are marked black and our responses are marked dark blue. Line numbers refer to the discussion paper egusphere-2023-1431.

It is a very interesting article and an alert for future impacts from global warming that will certainly contribute to HCHO emissions.

However, I am not familiar with the methodology used to acquire data.

The OMPS-SNPP, OMI and OCO-2 satellite data are acquired from public online archive or contacting the authors. The GEOS-Chem simulation is based on GEOS-Chem codes acquired online from GEOS-Chem github. We describe the code and data availability after Sect. 6 (Conclusions and discussions):

"**Code and data availability.**
The OMPS-SNPP HCHO L2 V1 product is available at https://disc.gsfc.nasa.gov/datasets/OMPS_NPP_NMHCHO_L2_1/summary (González Abad, 2022). The OMI HCHO L2 product is available at https://waps.cfa.harvard.edu/sao_atmos/data/omi_hcho/OMI-HCHO-L2/ . The OCO-2 SIF is available at https://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1863 (Yu et al., 2021). Data used in this work is available at https://doi.org/10.6084/m9.figshare.23599566.v1 (Zhao, 2023a). Data processing and plotting codes are available at https://doi.org/10.5281/zenodo.8094844 (Zhao, 2023b). The GEOS-Chem model is publicly available at: https://doi.org/10.5281/zenodo.3701669 (GEOS-Chem, 2020).

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Abstract must contain quantitative results.

Lines 30-32 could use traditional references for HCHO formation, as those from Atkinson, Seinfeld, Pitts and Carter.

Rewrite abstract to be: "
The northern high latitudes (50-90°N, mostly including boreal forest and tundra ecosystem) has been undergoing rapid climate and ecological changes over recent decades, leading to significant variations in Volatile Organic Compounds (VOCs) emissions from biogenic and biomass burning sources. Formaldehyde (HCHO) is an indicator of VOC emissions, but the interannual variability of HCHO and its main drivers over the region remain unclear. In this study, we use the GEOS-Chem chemical transport model and satellite retrievals from Ozone Monitoring Instrument (OMI) and Ozone Mapping and Profiler Suite (OMPS), to examine the interannual variability of HCHO vertical column density (VCD) during the summer seasons spanning from 2005 to 2019. Our results show that in 2005-2019 summers, wildfires contribute 75-90% of the interannual variability of HCHO VCD over Siberia, Alaska, and Northern Canada, while

biogenic emissions and background methane oxidation accounts for ~90% of HCHO interannual variability over Eastern Europe. We find that monthly Solar-induced chlorophyll fluorescence (SIF) from Orbiting Carbon Observatory-2 (OCO-2), an efficient proxy for plant photosynthesis, shows a good linear relationship (R=0.6-0.7) with modelled biogenic HCHO column ($dVCD_{Bio,GC}$) in Eastern Europe, Siberia, Alaska and Northern Canada, indicating the coupling between SIF and biogenic VOC emissions over the four domains on a monthly scale. In Alaska, Siberia and Northern Canada, SIF and $dVCD_{Bio,GC}$ both show a relatively lower interannual variabilities (SIF: CV=1-9%, $dVCD_{Bio,GC}$: CV=1-2%. CV: Coefficient of Variation) comparing to wildfire-induced HCHO (CV=8-13%), suggesting that the high interannual variabilities of OMI HCHO VCD (CV=10-16%) in these domains are likely driven by wildfires instead of biogenic emissions.

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We change the line 30-32 to be “HCHO is mainly produced from atmospheric VOC oxidation with a short photochemical lifetime on the order of hours, serving as an indicator of non-methane VOC (NMVOC) emissions and photochemical processes (Finlayson-Pitts and Pitts, 1986; Carter, 1994; Atkinson, 1997; Fu et al., 2007; Millet et al., 2008; Seinfeld and Pandis, 2016).”

It is not possible to use other molecules as wildfires tracers as carbon monoxide, and other type of molecules to help to understand the results as COS?

In this work, since COS is not in the standard simulation, it has not been studied yet.

After reorganization the paragraphs, this figure is now Figure 3, and is mainly discussed in Sect.4. We updated this figure to show the contribution of wildfire CO emission in the wildfire carbon emission.

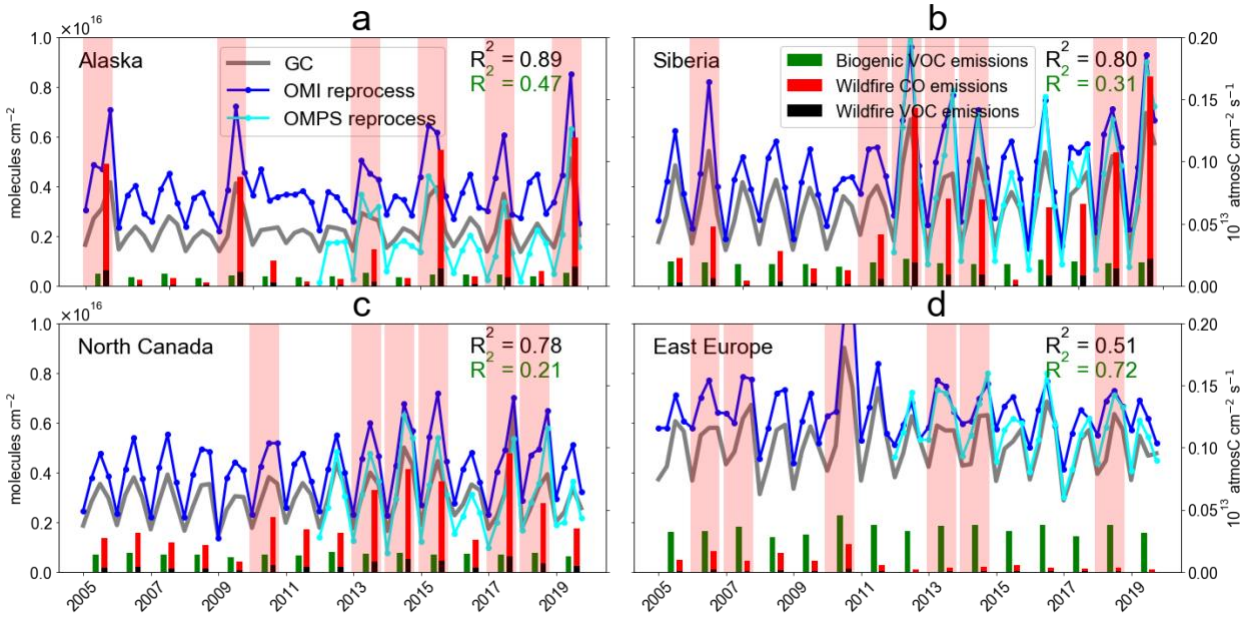

Figure 3. *Timeseries of HCHO VCD, biogenic and wildfire emissions over (a) Alaska, (b) Siberia, (c) Northern Canada and (d) Eastern Europe, May 1-August 31, 2005-2019. The blue lines are monthly HCHO VCD from reprocessed OMI, cyan lines are from reprocessed OMPS-SNPP, grey lines are from GEOS-Chem. Red and black bars are area-normalized wildfire CO and VOC emissions during the summer of each year; green bars are area-normalized biogenic VOC emissions. Wildfire emissions are calculated from GFED4.1s inventory; biogenic VOC emissions are calculated by MEGAN2.1 model. Pink shade indicates high HCHO VCD years (definition see Sect. 2.2 and Table S1). The R^2 between reprocessed OMI HCHO VCD and biogenic VOC emission (green) / wildfire VOC emission (black) is shown at top right of each panel.*

We change the paragraph in Sect. 4 describing Figure 3 to be: "Figure 3 shows that in Alaska, Northern Canada and Siberia, high HCHO years are often associated with strong wildfire VOC emissions (R^2=0.78-0.89) and to a lesser extent associated with biogenic VOC emissions (R^2=0.21-0.47). The interannual variability of wildfire VOC emission is further supported by CO emissions from both GFED4 and satellite-based estimation (Yurganov and Rakitin, 2022). The high correlation between OMI HCHO VCD and GFED wildfire VOC emissions in Alaska, Siberia and Northern Canada indicates a strong wildfire impact on interannual variabilities of HCHO VCD in these domains. In Eastern Europe, high HCHO years are associated with large biogenic emissions (With wildfire VOC emissions: R^2=0.51; With biogenic emissions: R^2=0.72), indicating the important role of biogenic emission in interannual variability of HCHO in Eastern Europe.

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The results can be extrapolated to South Pole?

According to Riedel et al 1999, HCHO in the Antarctic region is mainly from methane oxidation with OH radicals, with other possible yet unknown HCHO sources. It can be hard to extrapolate our results to the South Pole.

In the introduction, we add the reference about HCHO variability in Antarctic region "
Several studies suggest that biogenic VOC emissions are largely responsible for interannual variabilities of HCHO on a global scale (Palmer et al., 2001; De Smedt et al., 2008; González Abad et al., 2015; De Smedt et al., 2018). Stavrakou et al. (2009) attributes Biogenic VOCs (BVOCs) emissions as the predominant source of global HCHO columns, in which isoprene alone contributes to 30% of global HCHO. Isoprene emissions were also found to be the major driver of HCHO interannual variability (Bauwens et al., 2016; Stavrakou et al., 2018; Morfopoulos et al., 2022). During wildfire seasons, pyrogenic emission is the secondary important controlling factor of HCHO over the whole Amazon (Zhang et al., 2019) and contributes to 50-72% of HCHO total column in Alaskan summer fire seasons (Zhao et al., 2022). Over Antarctic region, HCHO is produced mainly from methane oxidation with hydroxyl radicals (OH), with possible unknown HCHO sources and long-range transport (Riedel et al., 1999). The interannual variability of HCHO over this region is still unclear.
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