Observations of tropospheric species from NDACC IRWG stations: impact of covid-19 lockdowns

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& many participants from the IRWG

2021 NDACC IRWG Virtual Meeting

Motivation

- The COVID-19 outbreak is a health crisis that we have never seen in modern life - it disrupted our way of typical life, which translates directly to an opportunity to study the unprecedent changes in emissions & air quality world-wide.

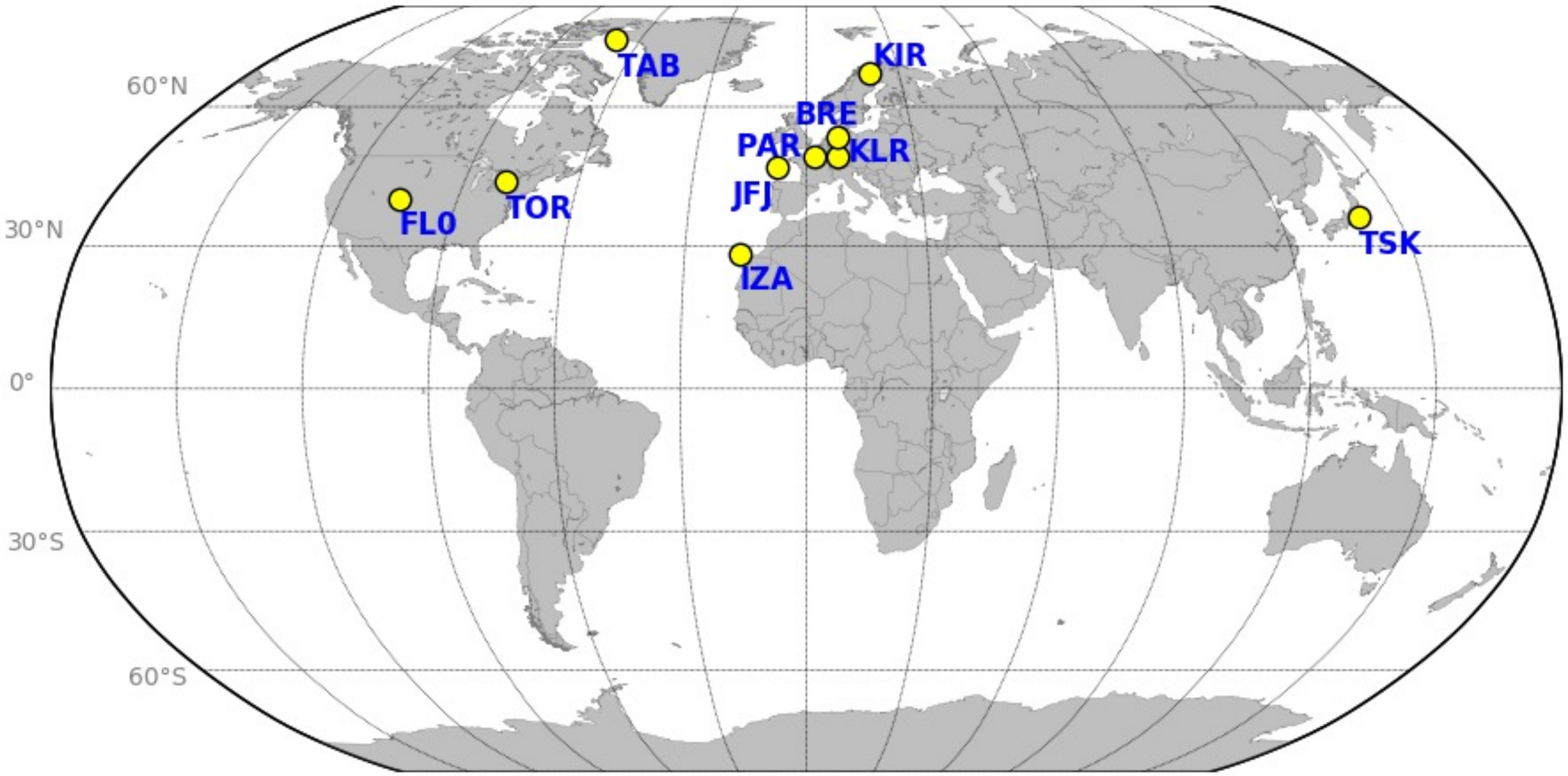
- There are several studies/papers reporting changes in the spatial and temporal distributions of atmospheric species during intensive 2020 lockdowns. These studies have focused primarily in either surface pollutants, e.g., O_3, NO_2, PM or satellite (NO_2) observations. --> https://amigo.aeronomie.be/

- Multiple species are missing. Intensive field campaigns were suspended.

- Near-surface in-situ may be different than tropospheric and/or free tropospheric observations.

- In this study, we try to contribute to these studies by using ground-based FTIR observations & model simulations. Do we see clear changes in 2020 during stringent lockdowns? Do model simulations capture similar patterns?.

Map of participating stations



Urban (& sub-urban) stations

Site	Lat, Lon, Alt (km asl)
BREMEN (BRE)	53.10° N, 8.85° E, 0.03
KARLSRUHE (KLR)	49.10° N, 8.44° E, 0.12
PARIS (PAR)	48.85° N, 2.36° E, 0.06
TORONTO (TOR)	43.60° N ,79.36° W, 0.17
BOULDER (FL0)	40.04° N, 105.24° W, 1.61
TSUKUBA (TSK)	36.05° N 140.12° E 0.03

Remote stations

Site	Lat, Lon, Alt (km asl)
THULE (TAB)	76.52° N 68.77° W 0.22
KIRUNA (KIR)	67.84° N 20.40° E 0.42
JUNGFRAUJOCH (JFJ)	46.55° N 7.98° E 3.58
IZAÑA (IZA)	28.30° N 16.50° W 2.37

- Data set covering 2010 -2020
- Tropospheric weighted mixing ratios are used – below TPP height.

Species of interest/retrieved as part of NDACC/IRWG

Species	Sources	Sinks	Lifetime
CO	**BB, industry, CH_4/VOC oxidation**	**Reaction with OH**	**30 days**
C_2H_2	**Fossil fuel burning, industry**	**Reaction with OH**	**60 days**
CH_2O	**CH_4/VOC oxidation, direct from fossil fuel burning**	**Reaction with OH And photolysis**	**3 hours**
O_3	**Interaction of sunlight with CH_4/VOC + nitrogen oxides**	**Deposition, uptake by plants**	**Hours to weeks**
HCN	BB, industry, plants	Reaction with OH Ocean uptake	75 days
C_2H_6	BB, O&NG extraction, biofuel use	Reaction with OH	45 days

Species that would or may be affected by an economic slowdown, a shutdown of certain sectors, consequent reduced automobile activity, reduced industrial production.

Methods – *How can we disentangle the Impact of the COVID-19 from natural/met variability?*

With aim to understand different conditions currently we are testing different methods to interpret changes in 2020. Typically, the time frames of stringent lockdowns around the world have been carried out for a couple of months (March-May 2020), hence we try to determine differences in these months.

(1) Compare 2020 vs 2019.
- pros: will reduce uncertainty due to sza (months) and trends.
- cons: weather patterns could be very different.

(**2) Compare long-term (2010-2019) vs 2020.**
- **pros: will reduce uncertainty due to sza (months) and perhaps dimmish weather condition differences.**
- **cons: Enhanced/extraordinary values from past months may change the overall shape of the climatology. Significant linear trends may bias the comparison.**

(3) Use predicted 2020 monthly values using long-term (2010-2019) and compare with actual 2020.
- **pros: will reduce uncertainty due to sza (months), perhaps dimmish weather conditions differences, and diminish trends.**
- **cons: fit needs to capture well observations.**

Assess findings with model simulations (CAM-Chem) using control and estimated covid-19 emissions.

Model simulations with CAM-Chem

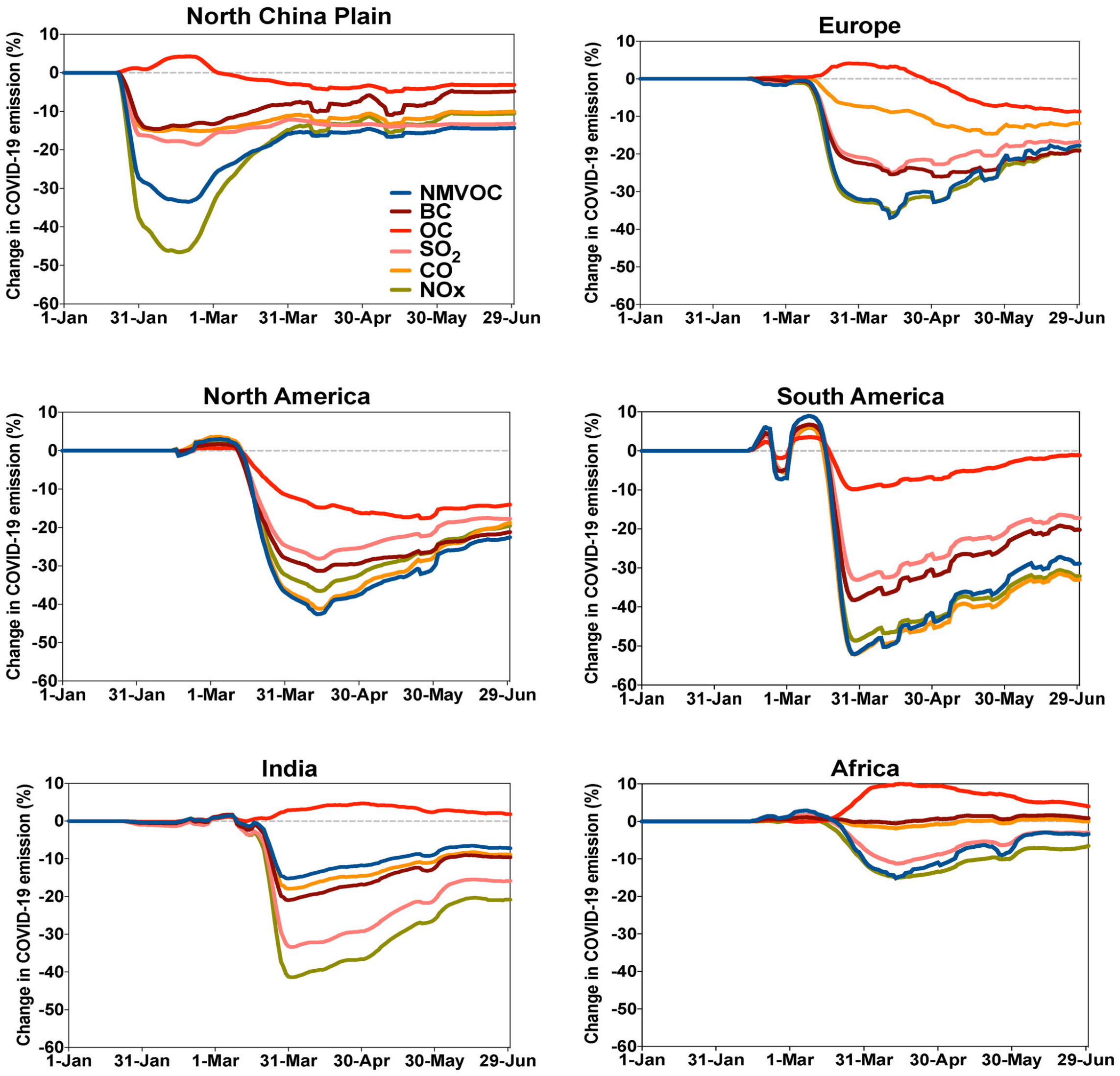
JGR Atmospheres

Research Article | Open Access

Global Changes in Secondary Atmospheric Pollutants During the 2020 COVID-19 Pandemic

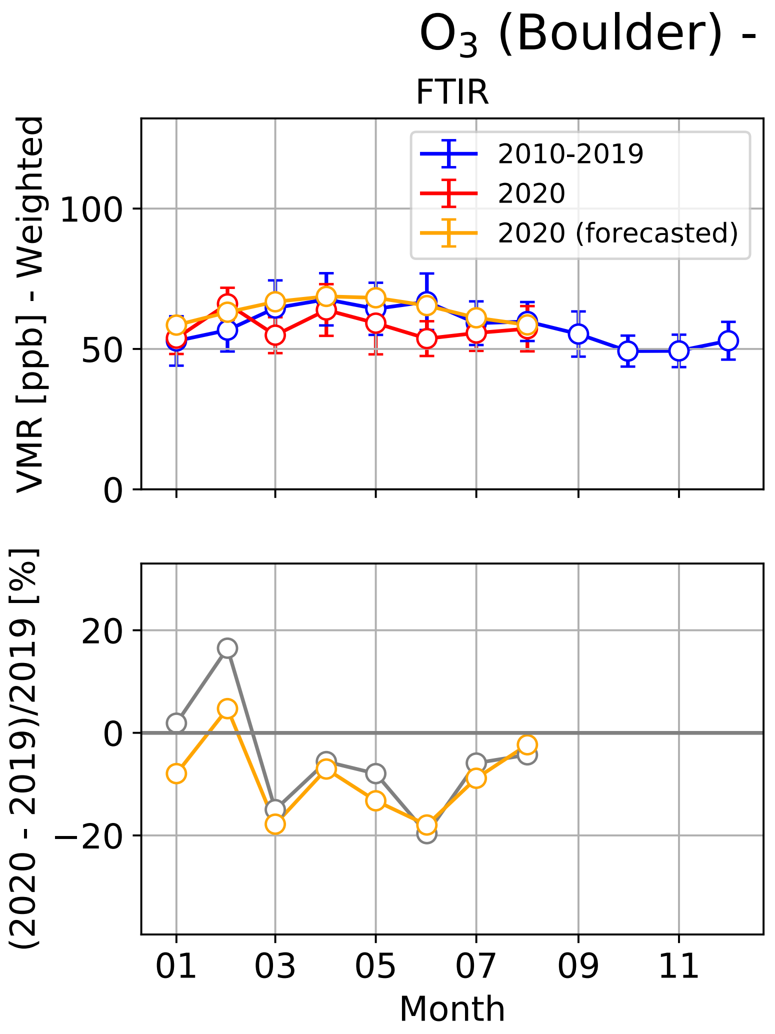
Benjamin Gaubert, Idir Bouarar, Thierno Doumbia, Yiming Liu, Trissevgeni Stavrakou, Adrien Deroubaix, Sabine Darras, Nellie Elguindi, Claire Granier, Forrest Lacey, Jean-François Müller ... See all authors

- **China: Reduction starts in February 2020 (40% for NOx, 25% for VOCs)**
- **Rest of the world: Reduction is highest on March-April 2020.**
- **In this study we use same years (2020-2020)**
- **For 2020 using 2 different simulations:**
  - **Control (business as usual)**
  - **covid19**



Results: Comparison with CAM-Chem using control and estimated covid-19 emissions.

O_3



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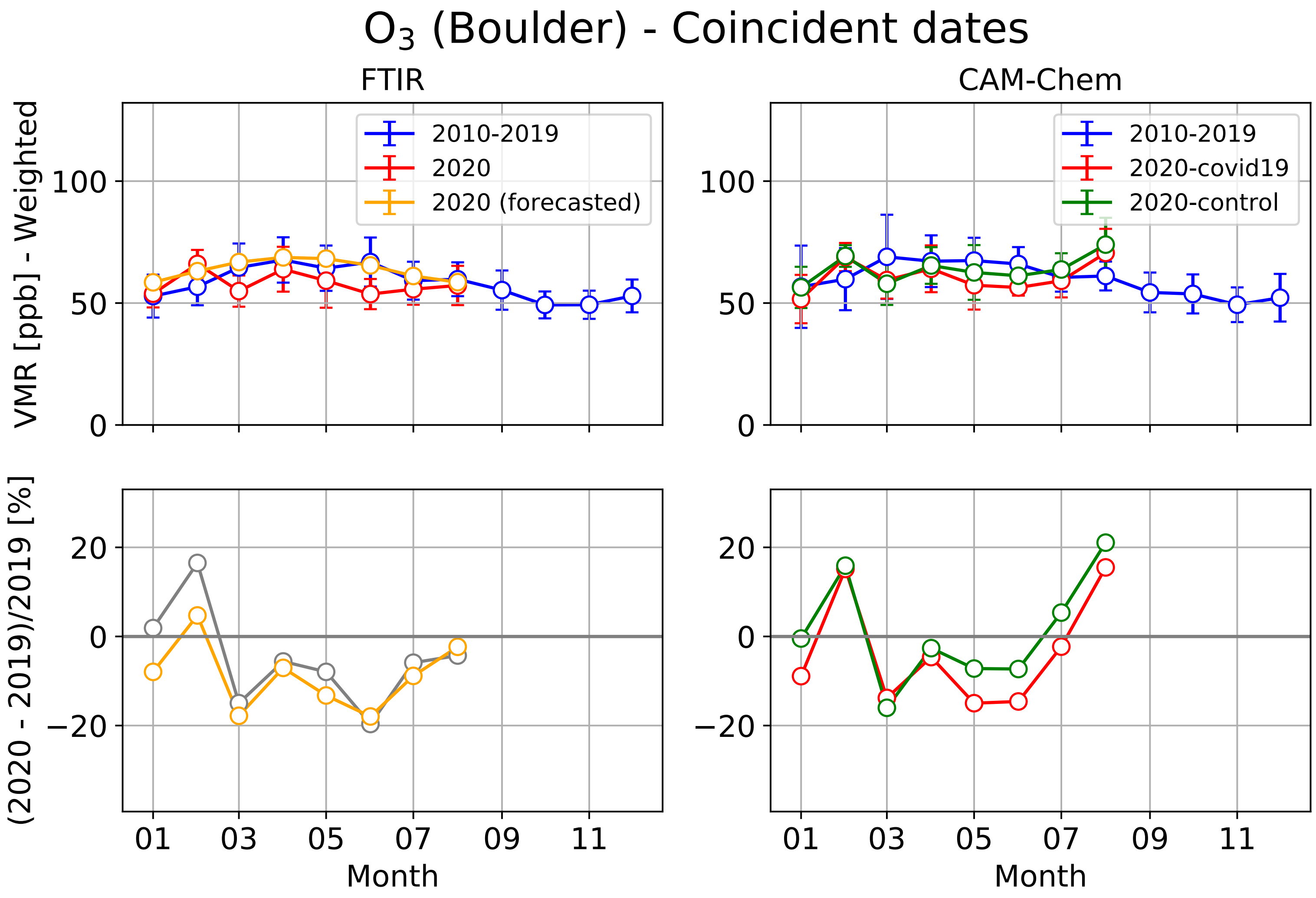
O_3



Excellent agreement in the shape of the difference.

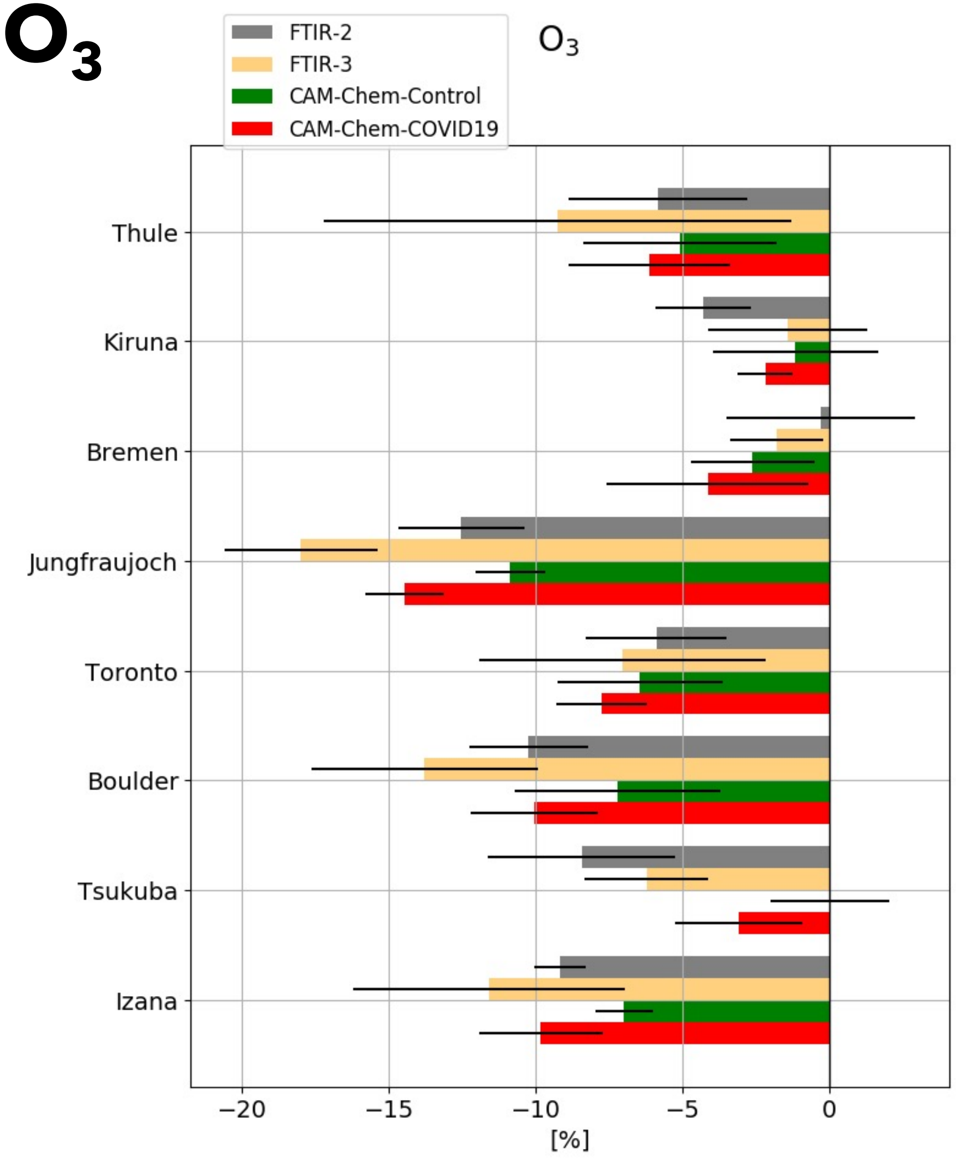
CAM-Chem control and covid19 (2020) show differences of about 5% in April but overall they are similar, does that mean the decrease is a combination of both met & covid19 restrictions?

Note high O_3 in August in the model. However FTIR does not capture O_3 enhancement within fire plumes.

Results: Using all participating FTIR sites

% Change of 2020 (March – May) wrt climatology using method 2 (gray) and 3 (orange) from NDACC/FTIR sites & CAM-Chem

O_3



The % change is defined as:

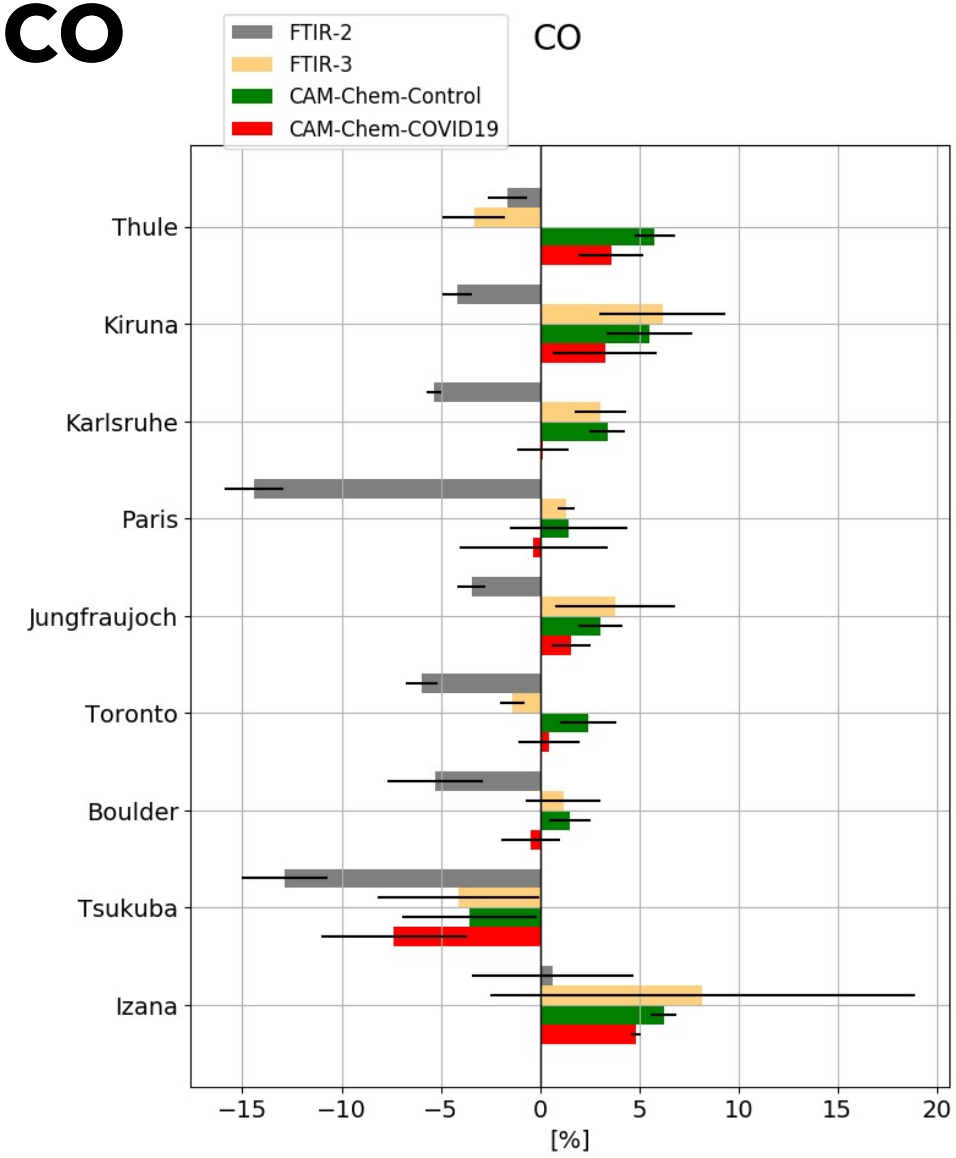
(cov – cnt)/cnt x100

where cov is the mean value of March-May 2020 and cnt is the mean value of March-May climatology using method 2 and 3. Same is applied to simulations using both control and covid emissions in 2020.

- TPP height is taken into account
- Methods 2 & 3 are are consistent.
- Both FTIR and simulation show ozone decrease in 2020 among all sites (consistent with Steinbrecht et al. (2021, GRL).
- In general reductions are greater using covid emissions but control shows also a significant decrease. Does that mean is primarily dynamical + a bit of covid related?

Results: Using all participating FTIR sites

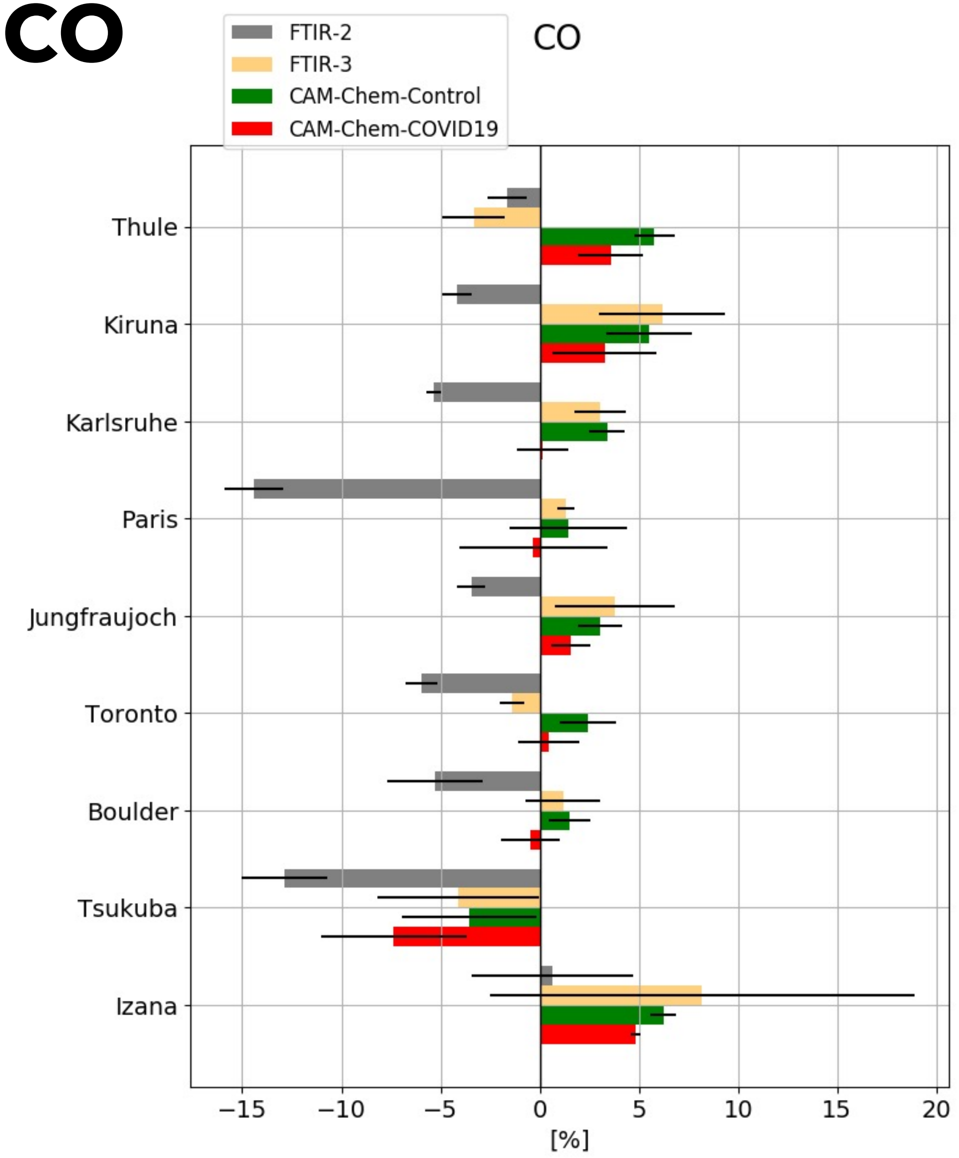
CO



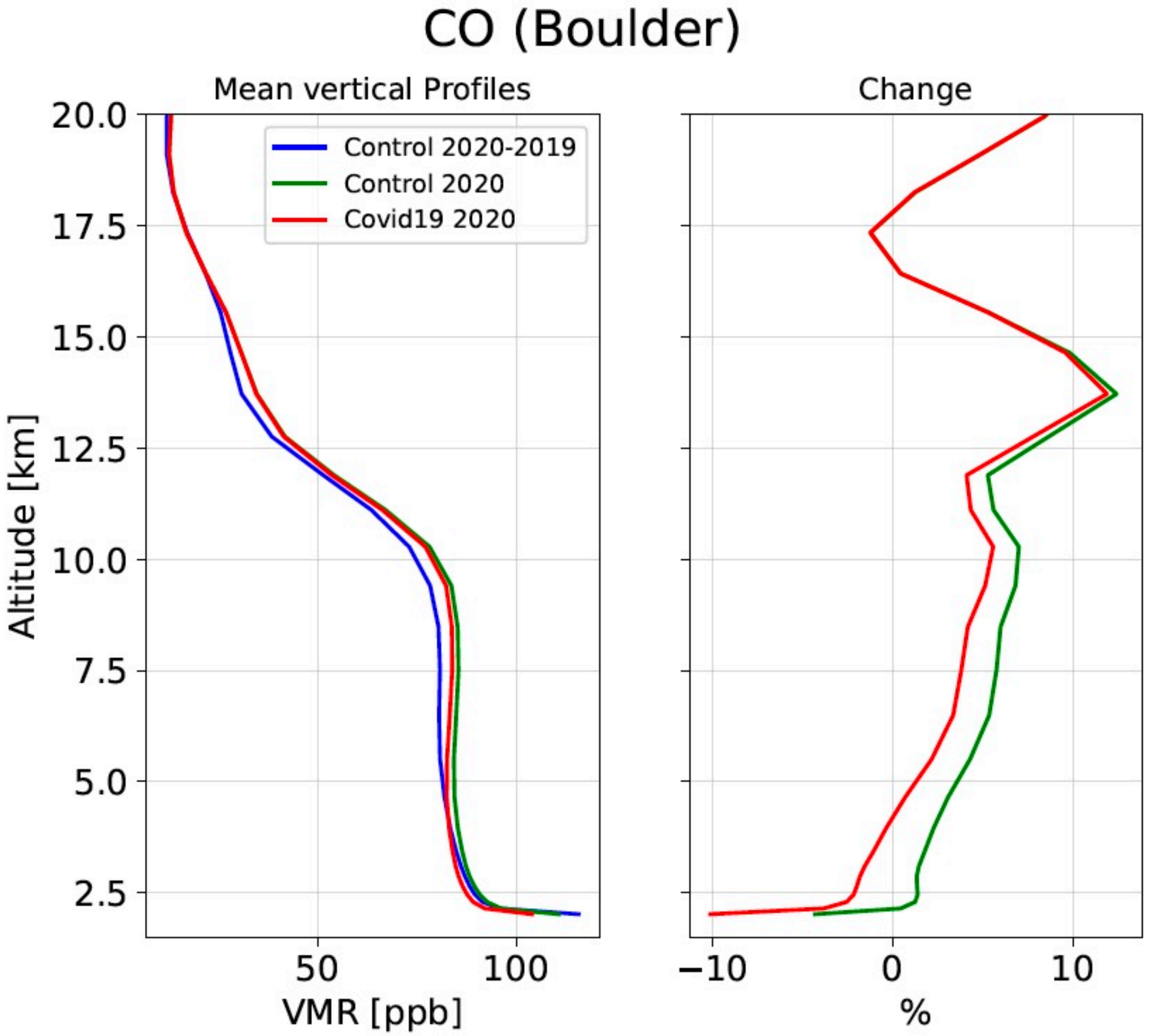
- Methods 2 & 3 show significant difference. This is due that CO has decreased substantially in the past 10 years, hence monthly mean values from climatology would be bias high.
- In this case the predicted (method 3) would be preferably.
- Both control & covid emissions show positive change in agreement with observations (method 3).
- Interestingly, the only site with significant negative change is Tsukuba and it is capture well in the model.

Results: Using all participating FTIR sites

CO



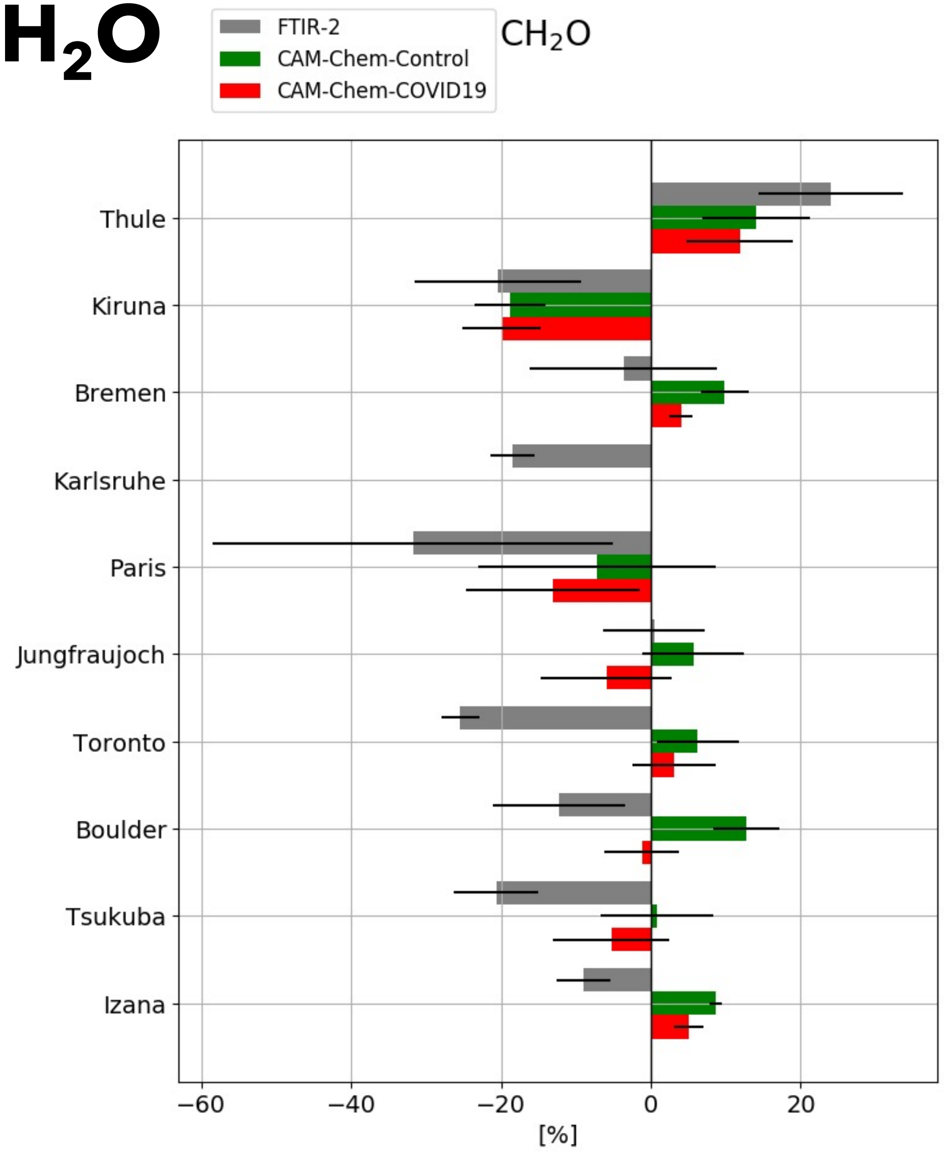
Would surface values and trop columns show similar patterns?



FTIR observations complement surface measurements.

Results: Using all participating FTIR sites

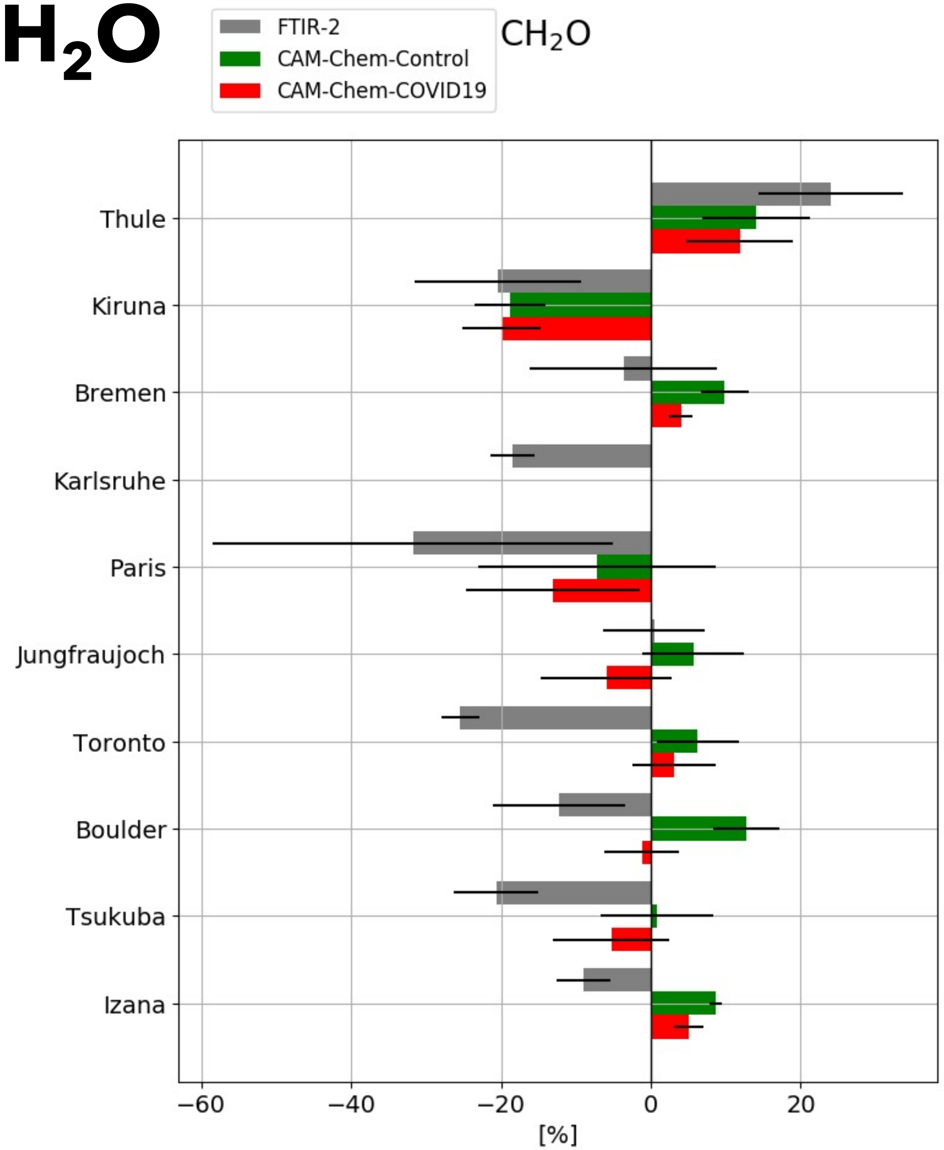
CH_2O



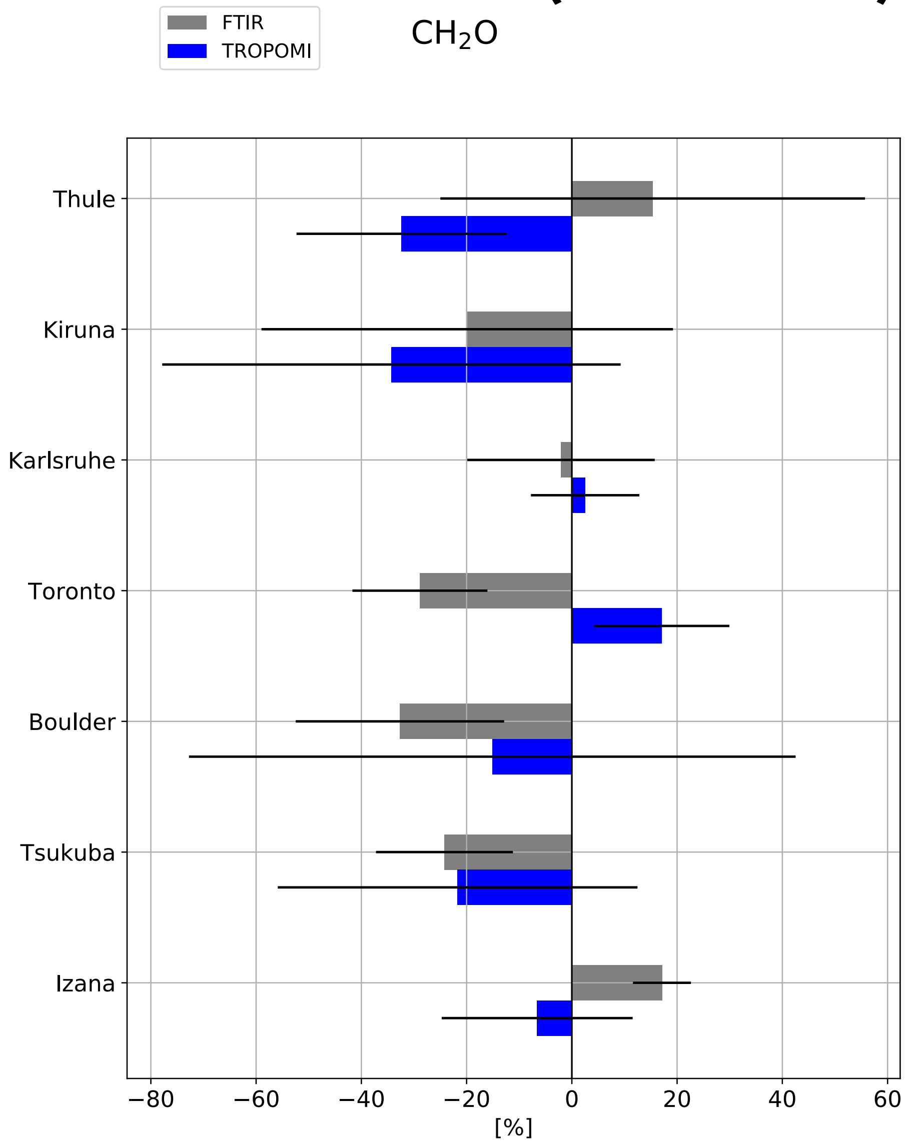
- Except for Thule, all other sites show significant decrease.
- Simulations with Covid emissions agree with observations while control indicates many sites with positive change.

Results: Using all participating FTIR sites

CH_2O



TROPOMI & FTIR (2019-2020)



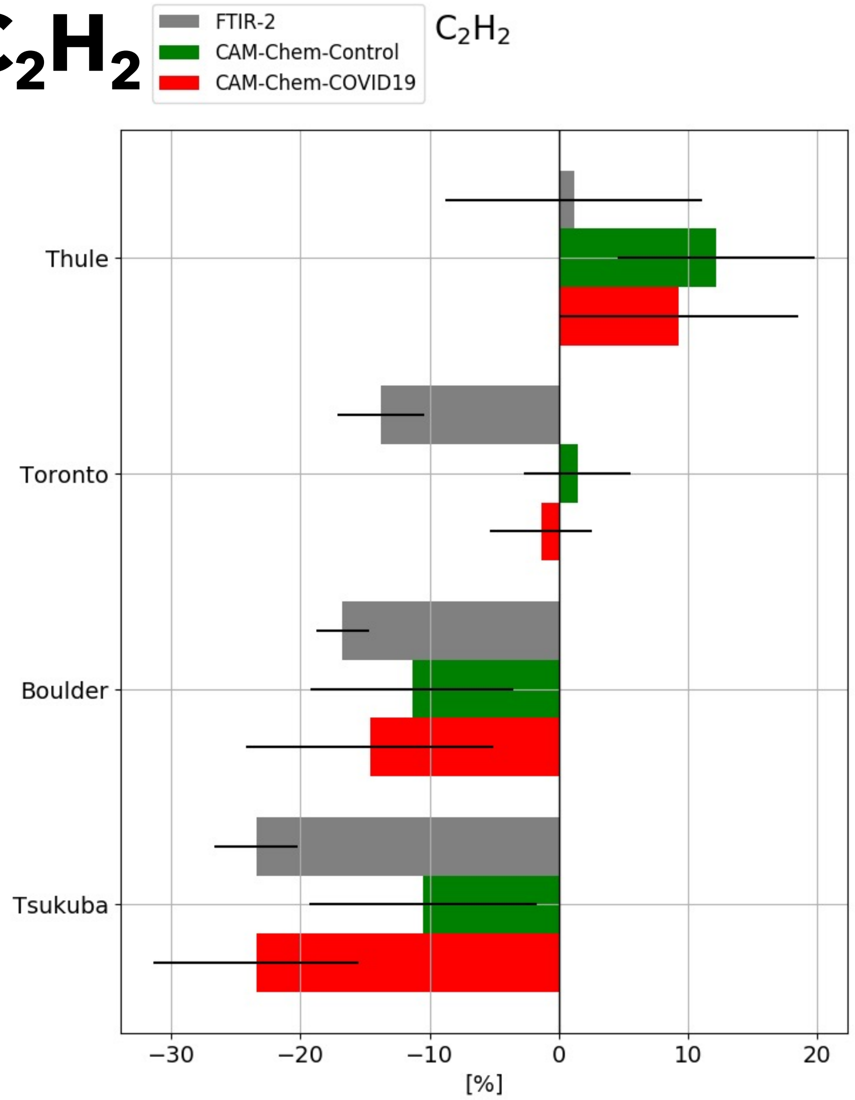
Next steps

- The end goal is to publish and contribute to the already long-list of covid19 related papers using IRWG sites.
- Digest in more detail model simulations, e.g., OH reactivity, NOx regime, transport.
- Characterize near-surface vs tropospheric columns using model simulations or both.
- Develop a better way to characterize uncertainties.
- If someone wants to participate I encourage to submit at least these four gases (CO, O_3, H_2CO and C_2H_2) and with good coverage in 2020 (March – May).
- Thanks all participating sites.

Additional Slides

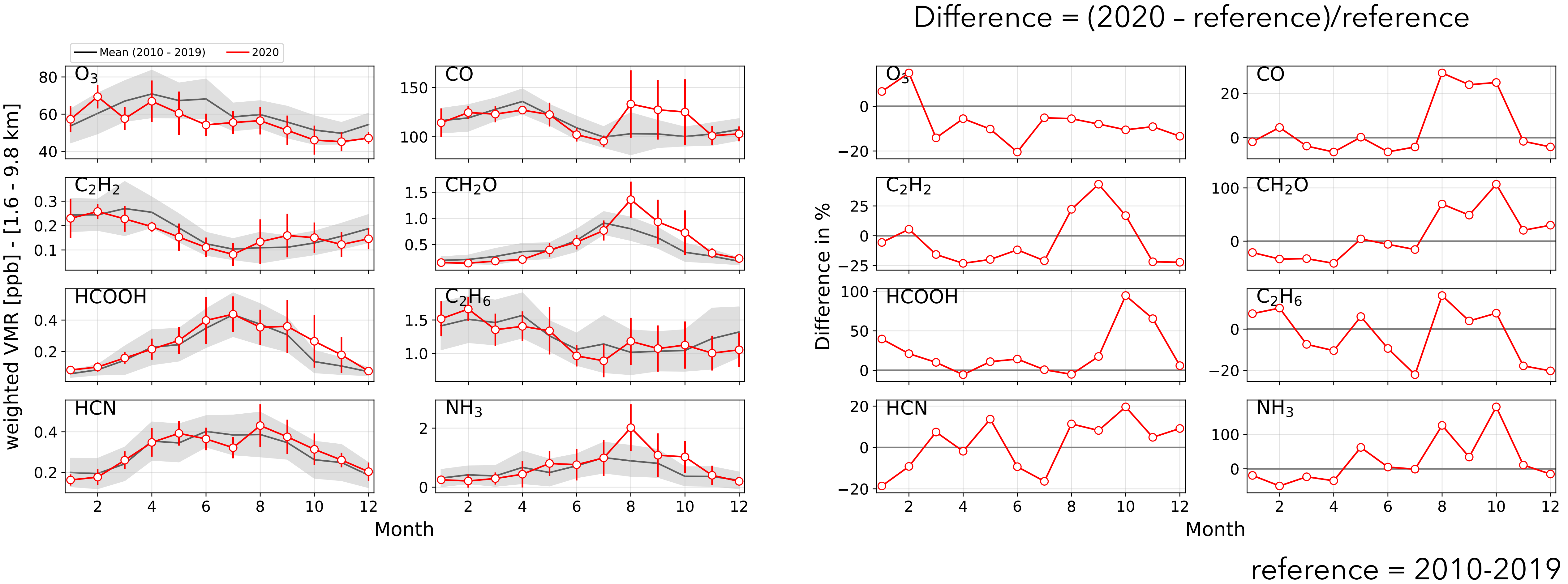
% Change of 2020 (March – May) wrt climatology using method 2 and 3 (slide 6) from NDACC/FTIR sites & CAM-Chem

C_2H_2



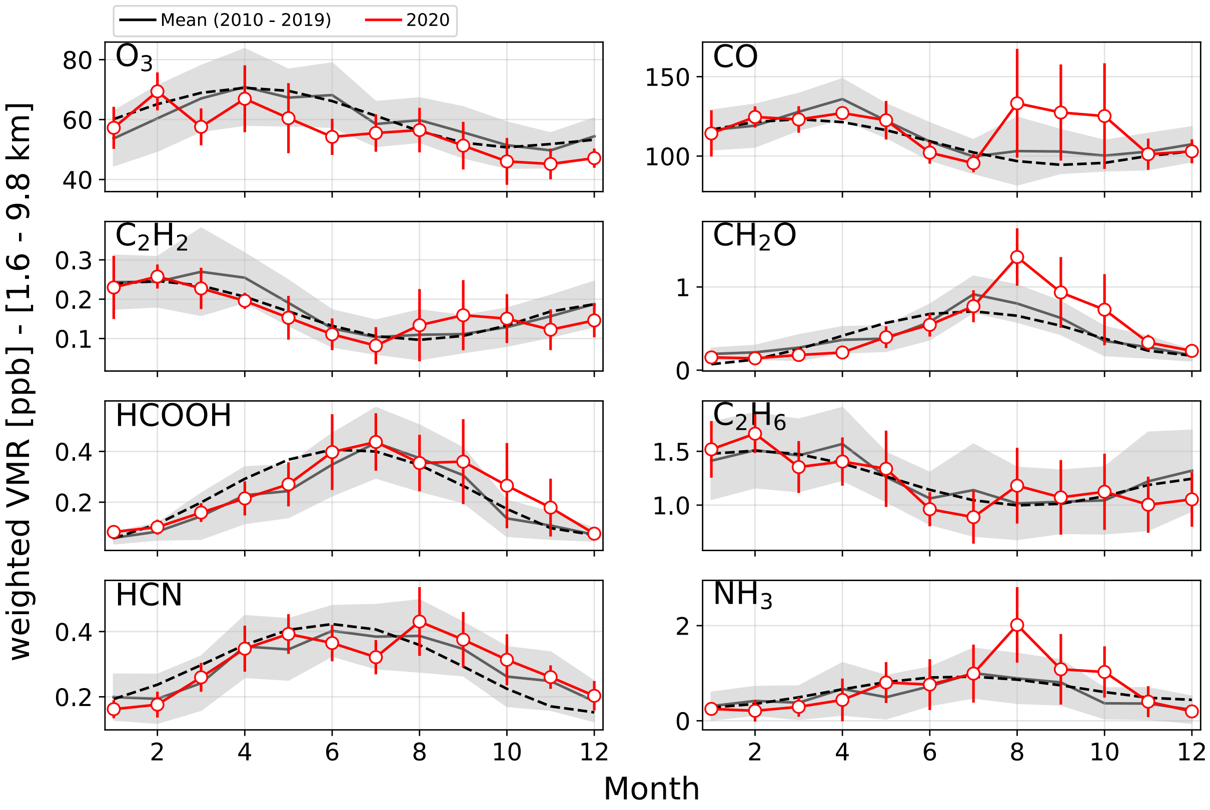
- Significant decrease of C2H2 is captured with observations.
- Good agreement between obs and simulations, especially with covid emissions.

(2) Compare 2020 vs 2010-2019.

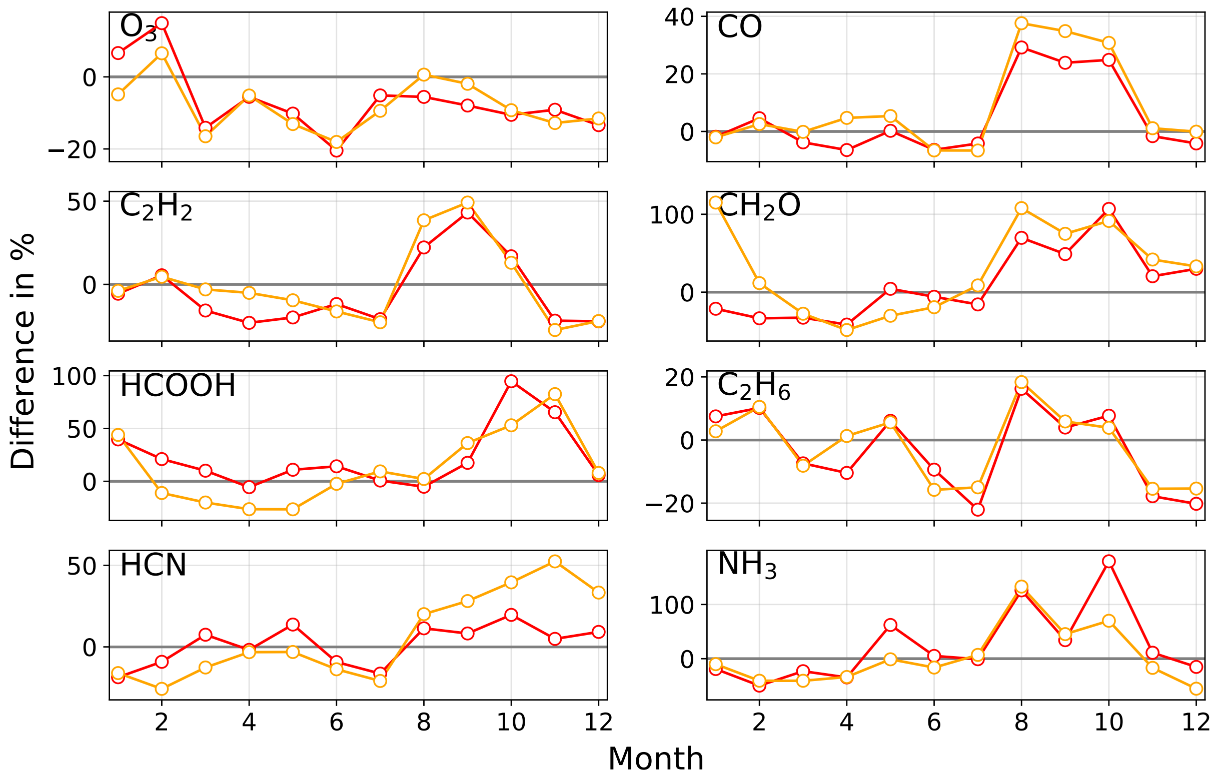


- O3 is lower in 2020. Note absence of O3 within the fire plumes. However, other gases increased within the plumes.
- Enhancements of CO were captured in Aug (fires far from Boulder) but h2co, hcooh increased in Sep (local fires).

(3) Use predicted 2020 monthly values using long-term (2010-2019) and compare with actual 2020.



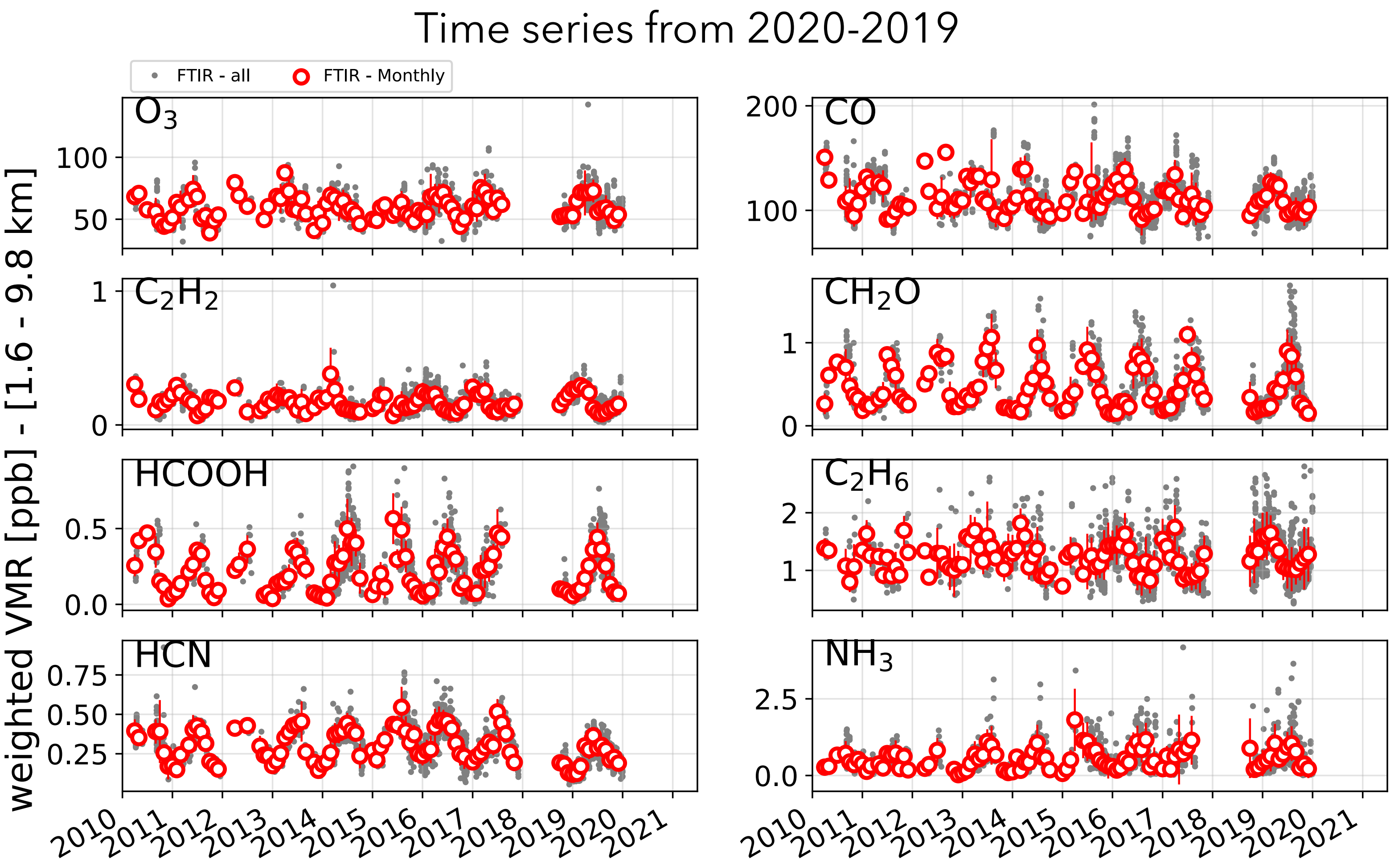
Difference = (2020 – reference)/reference



reference = 2010-2019

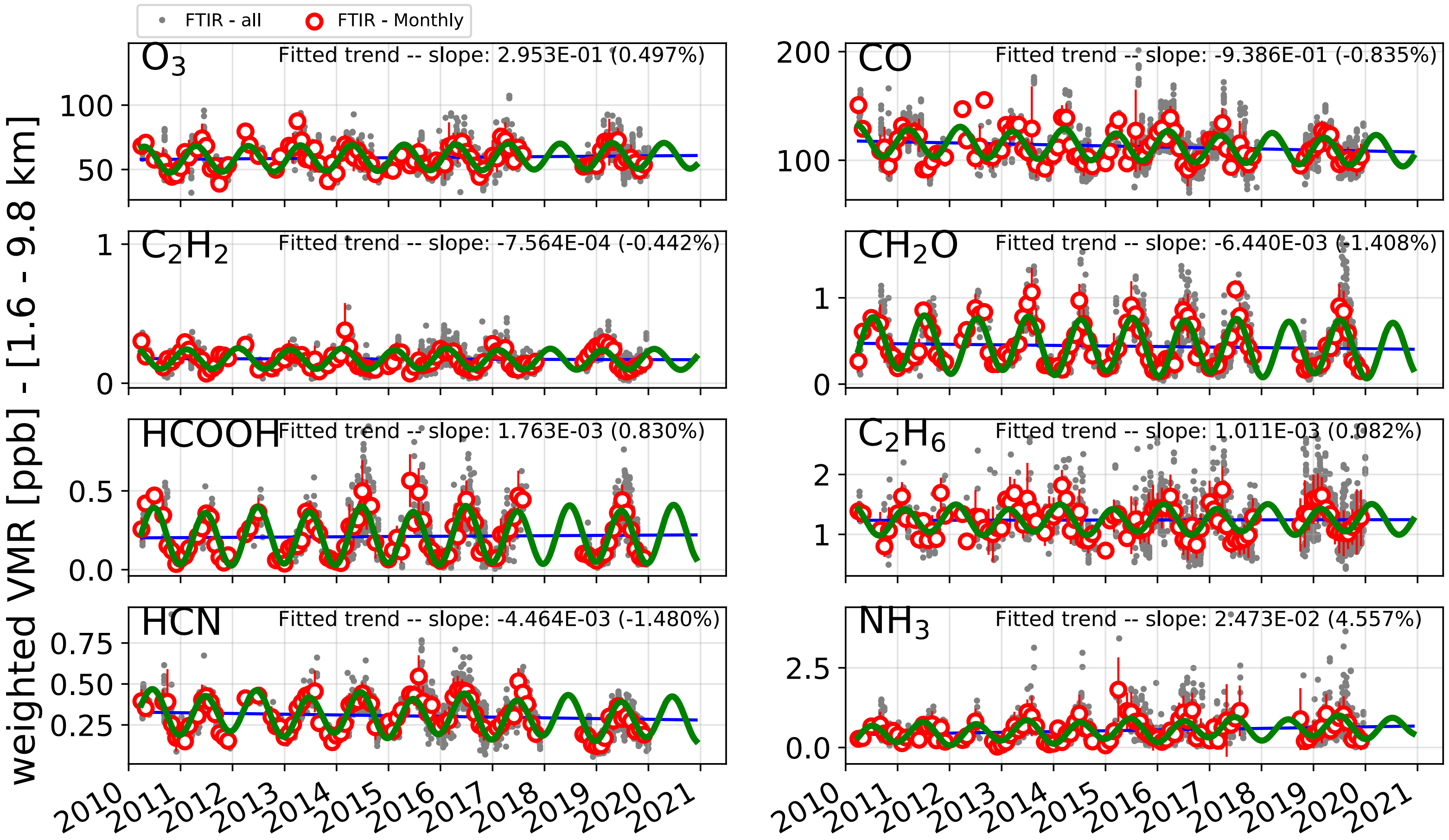
- Left panel: same as before dotted line included showing the predicted monthly value in 2020.
- Right panel: same as before; orange line represents the difference of observation and predicted values.

(3) Use predicted 2020 monthly values using long-term (2010-2019) and compare with actual 2020.



(3) Use predicted 2020 monthly values using long-term (2010-2019) and compare with actual 2020.

Time series from 2020-2019



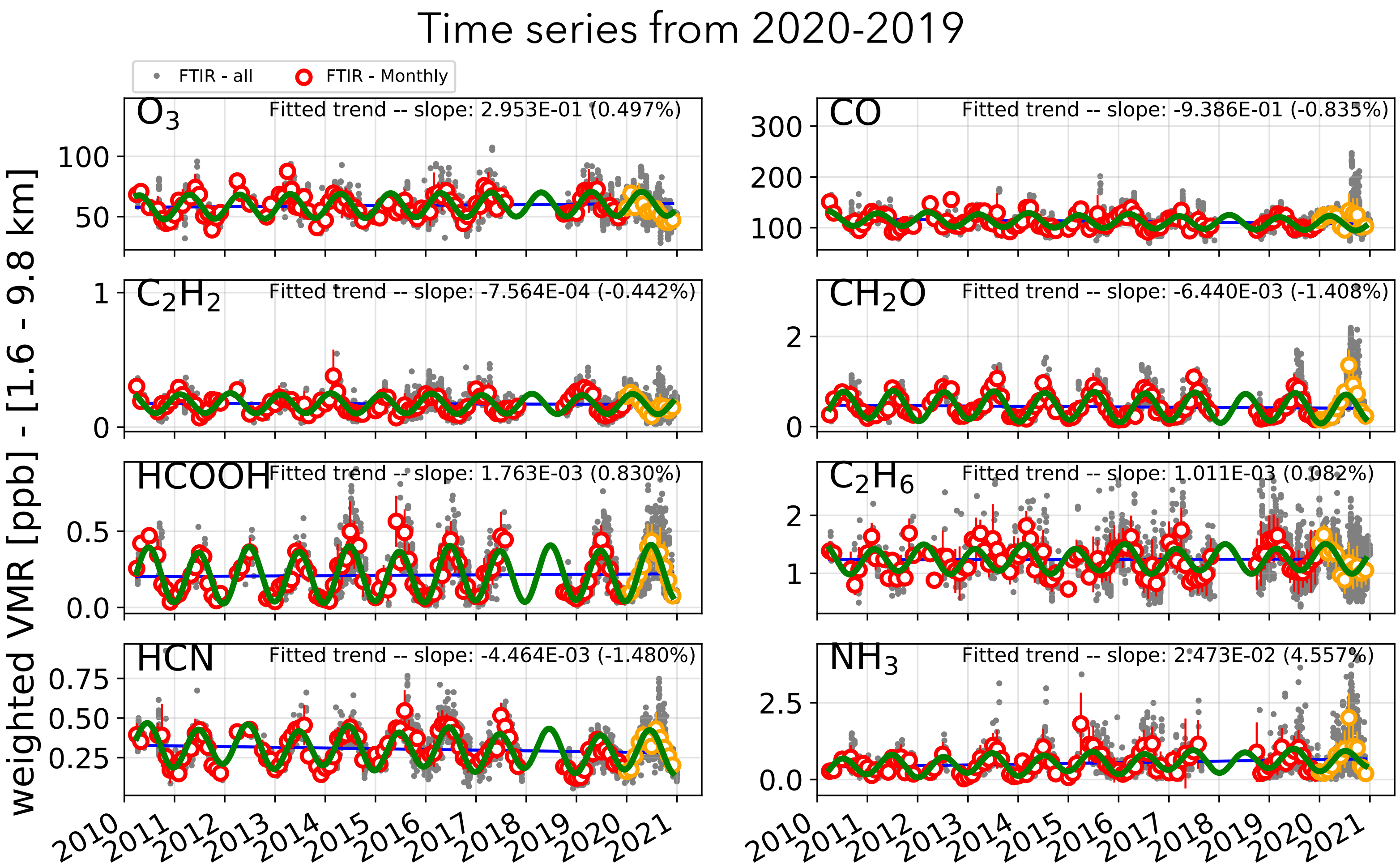
Long-term trend and the seasonal modulation

$$\overbrace{\underbrace{f(t) = a_0 + a_1(t - t_0)}_{\text{Linear component}} + \underbrace{\sum_{n=1}^{N} b_n \cos\left(\frac{n\pi x}{L}\right) + \sum_{n=1}^{N} c_n \sin\left(\frac{n\pi x}{L}\right)}_{\text{Fourier series}}}^{\text{Long-term trend and the seasonal modulation}}$$

Linear component

Fourier series

(3) Use predicted 2020 monthly values using long-term (2010-2019) and compare with actual 2020.



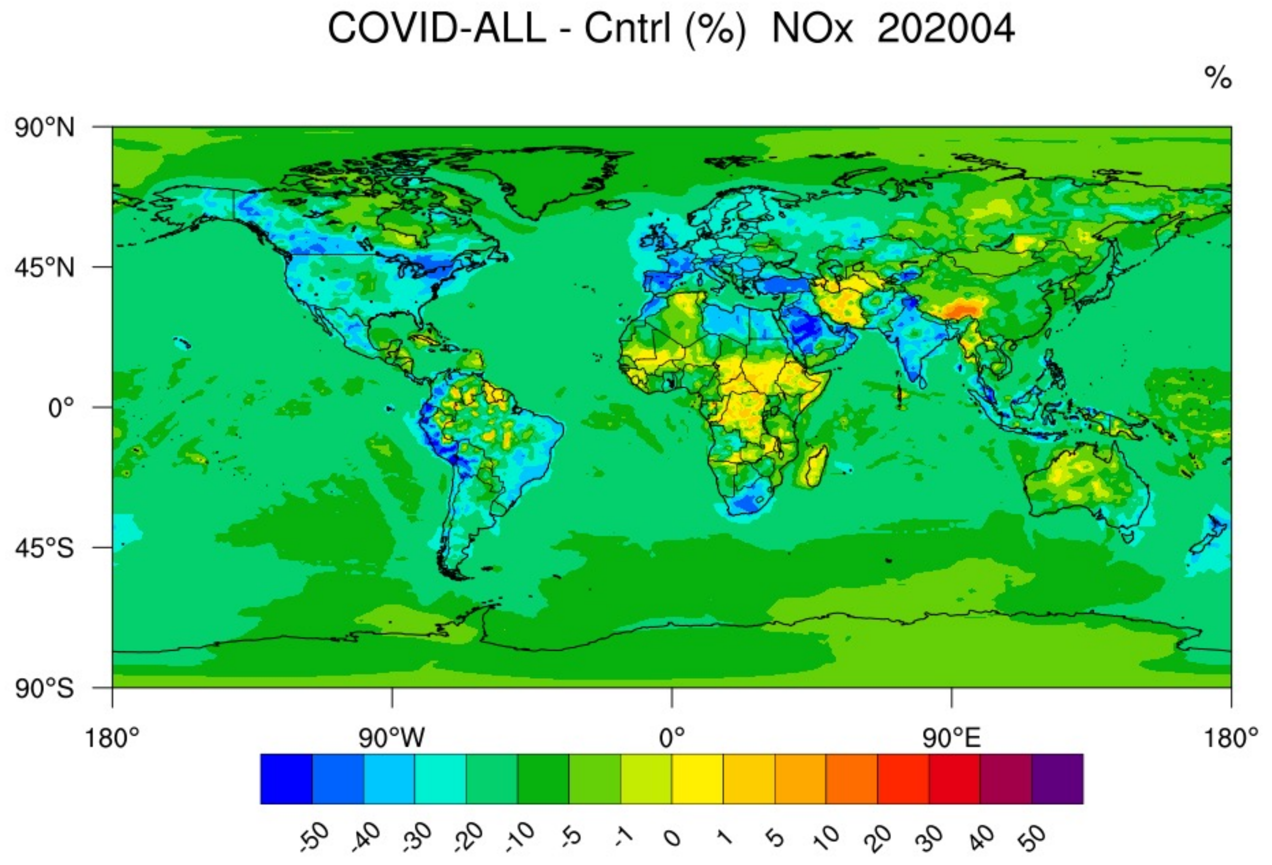
$$f(t) = \overbrace{\underbrace{a_0 + a_1(t - t_0)}_{\text{Linear component}} + \underbrace{\sum_{n=1}^{N} b_n \cos\left(\frac{n\pi x}{L}\right) + \sum_{n=1}^{N} c_n \sin\left(\frac{n\pi x}{L}\right)}_{\text{Fourier series}}}^{\text{Long-term trend and the seasonal modulation}}$$

2020

Global CAM-chem simulations

- ❖ Daily 2020 fire emissions (QFED 2.5)
- ❖ Daily CAMS-CONFORM
- ❖ MOZART-TS1 chemistry
- ❖ MAM4 VBS aerosols
- ❖ Climatological SSTs
- ❖ Strong nudging of winds and temperature to 3 hourly MERRA-2 outputs (Modern-Era Retrospective analysis for Research and Applications, Version 2)

- ❖ Climatological SSTs
- ❖ Specified dynamics
- ✓ 3 hourly MERRA-2 outputs
- ✓ U,V,T (Coef. of 0.5 or 6 hours relaxation time)

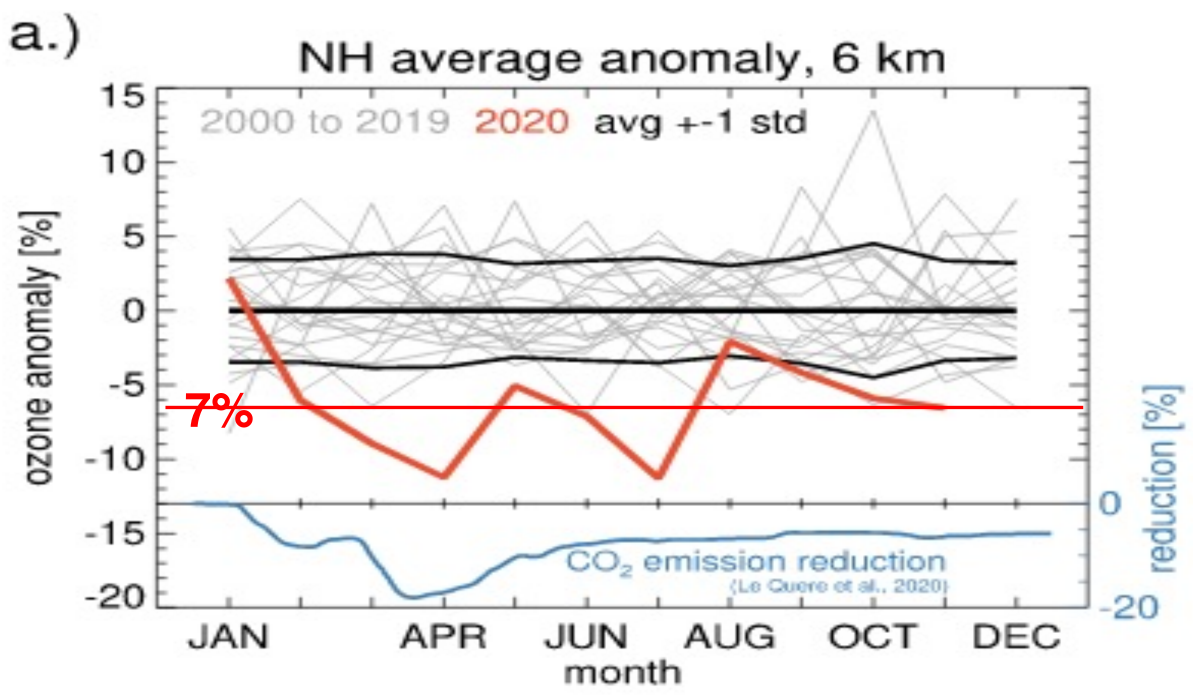


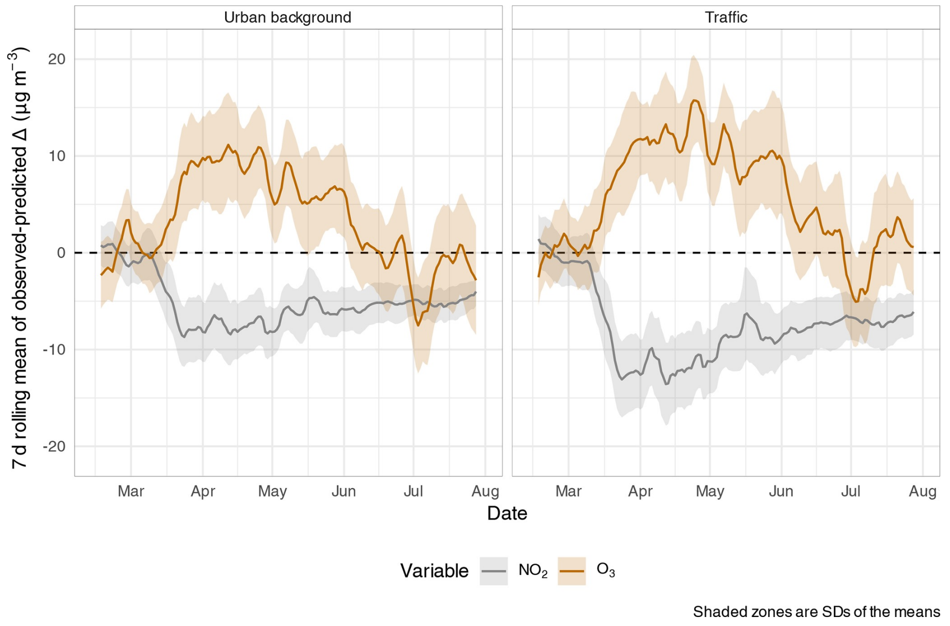
O_3

- Steinbrecht et al. (2021, GRL): observations (sondes, NDACC) indicates ozone was on average 7% below 2000 to 2020
  - ✓ April to August
  - ✓ 1 to 8 kilometers altitude

- Grange et al. (2021, ACP):

NO_2 concentrations decreased by 34% at roadside location. However, the widespread reductions in NO_2 concentrations were accompanied by increases in O_3 (30%).

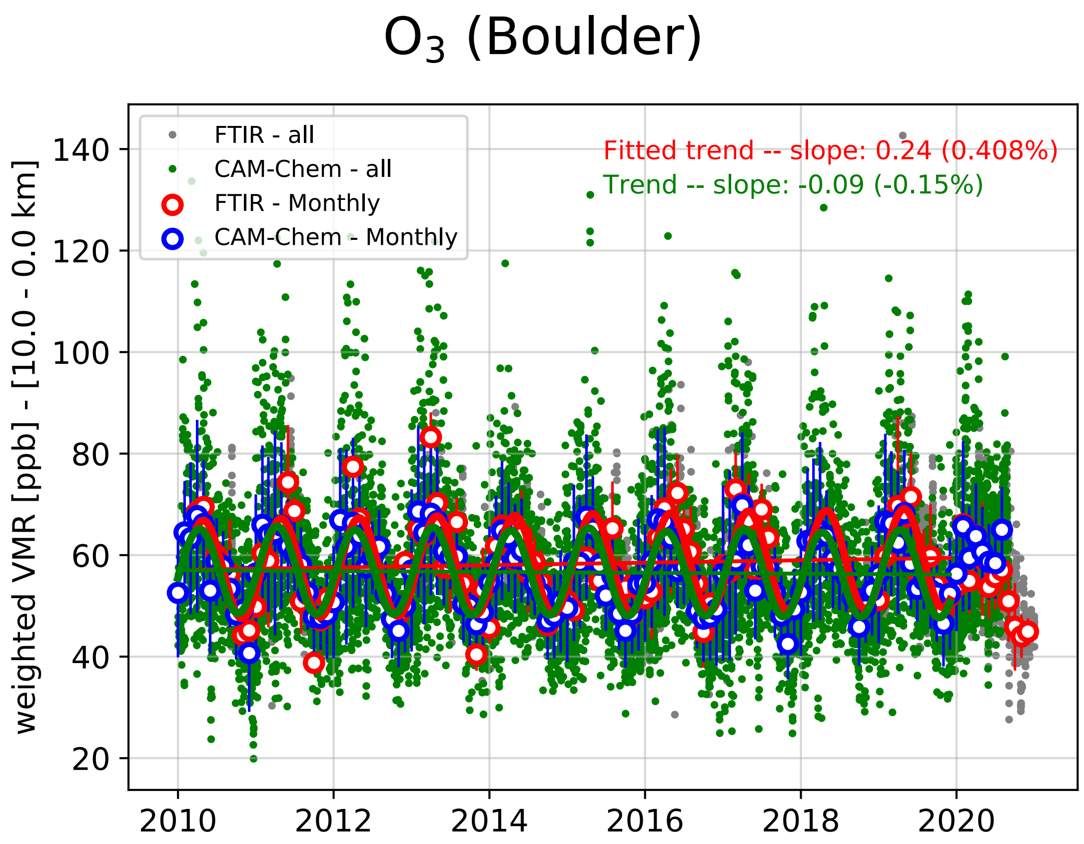




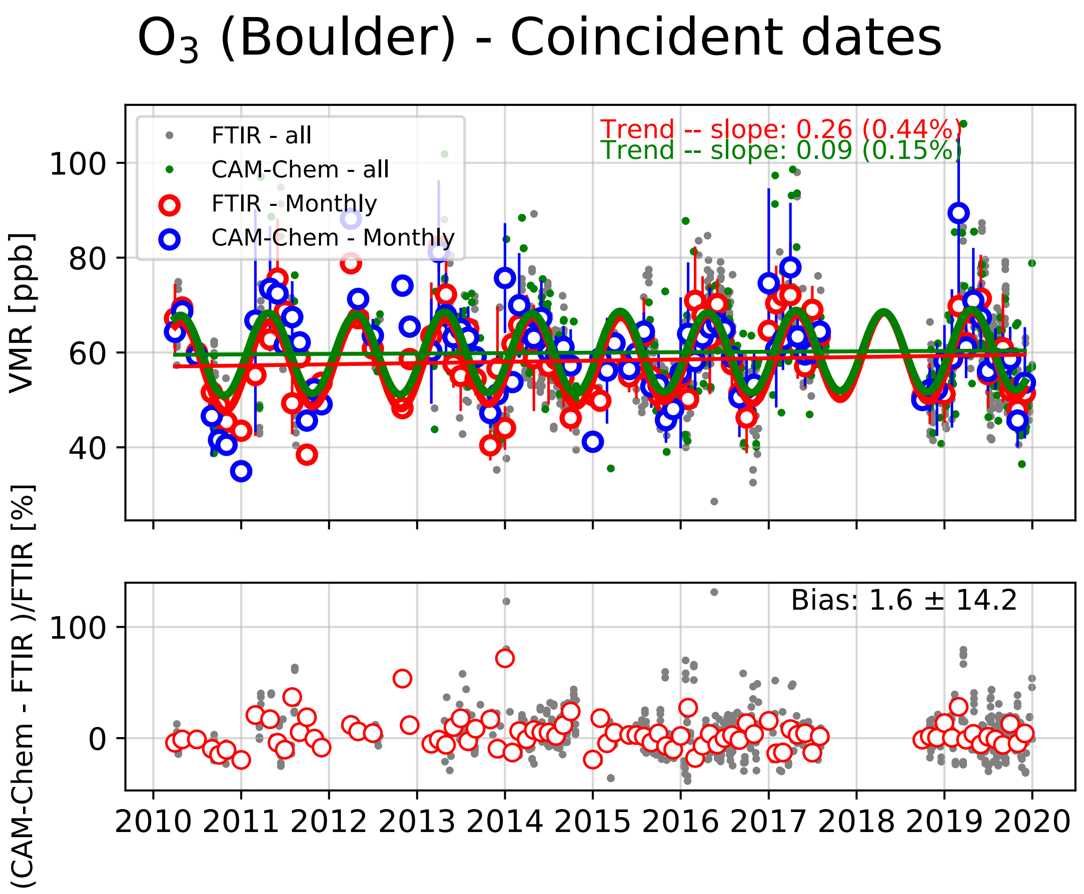
Comparison with CAM-Chem using control and estimated covid-19 emissions.

O_3

Time series from 2010-2020



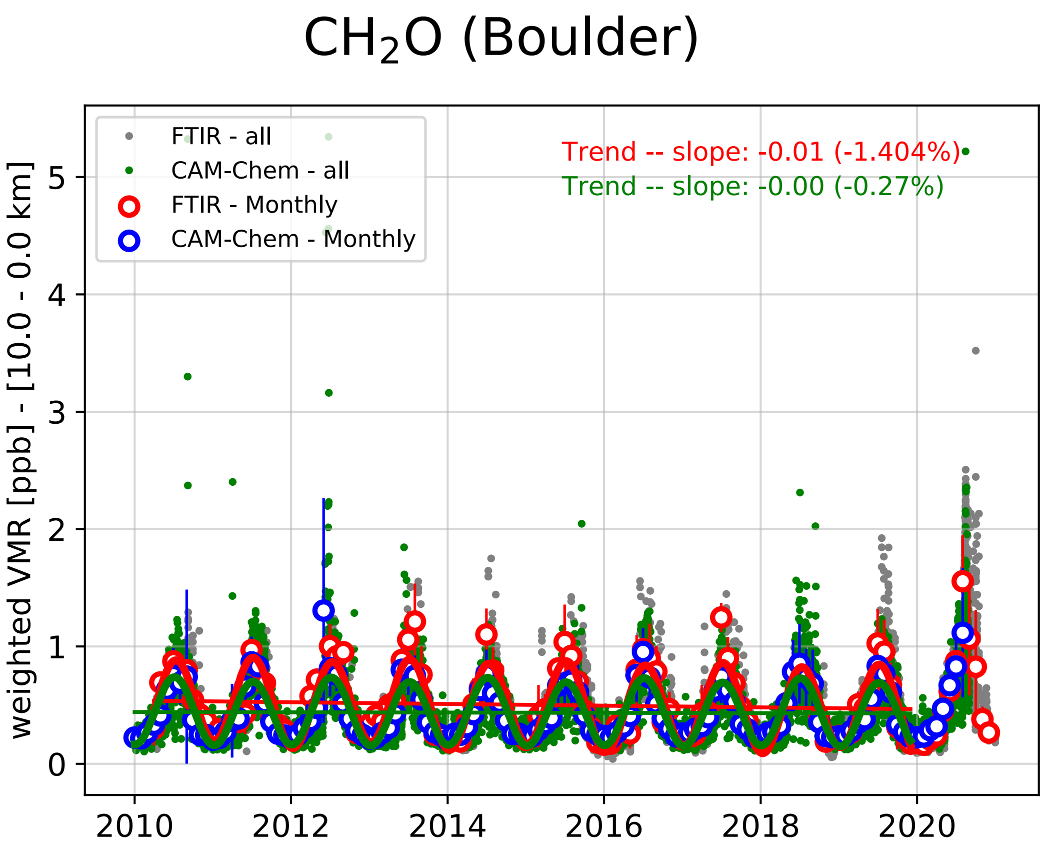
Time series from 2010-2019



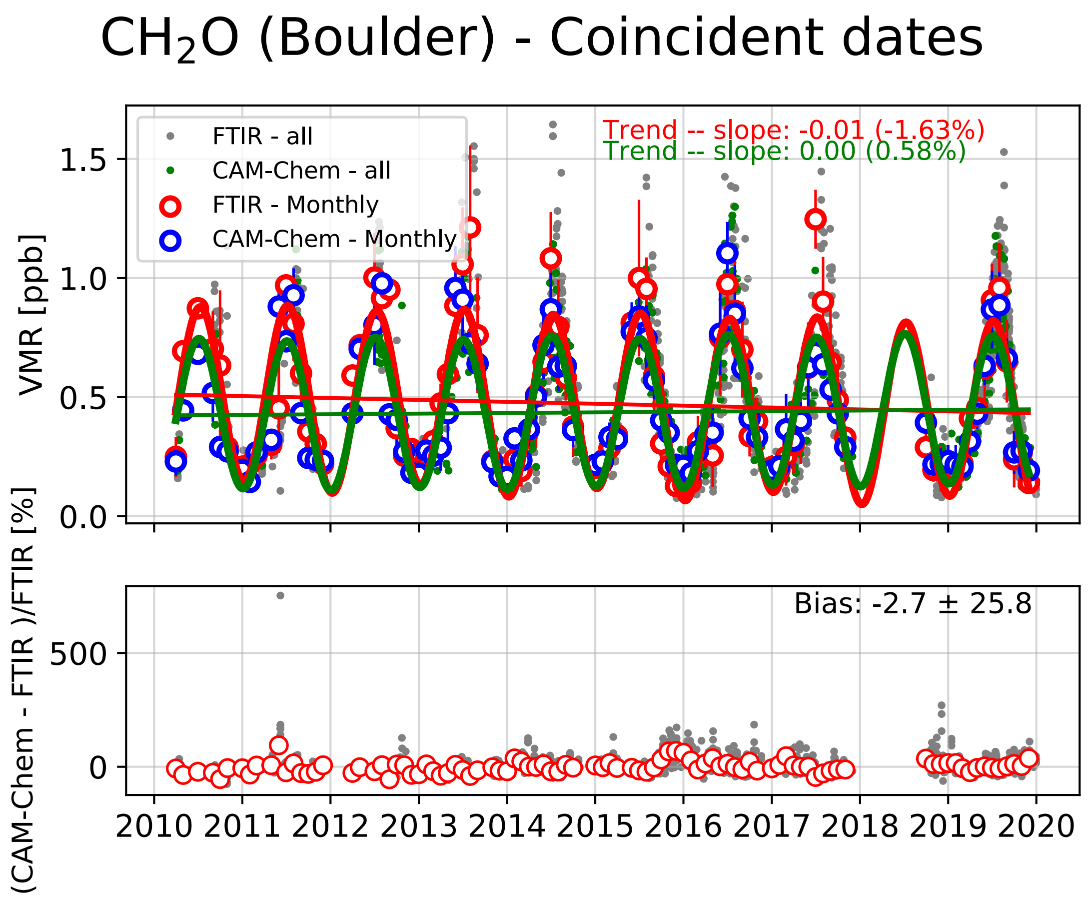
Comparison with CAM-Chem using control and estimated covid-19 emissions.

CH_2O

Time series from 2010-2020

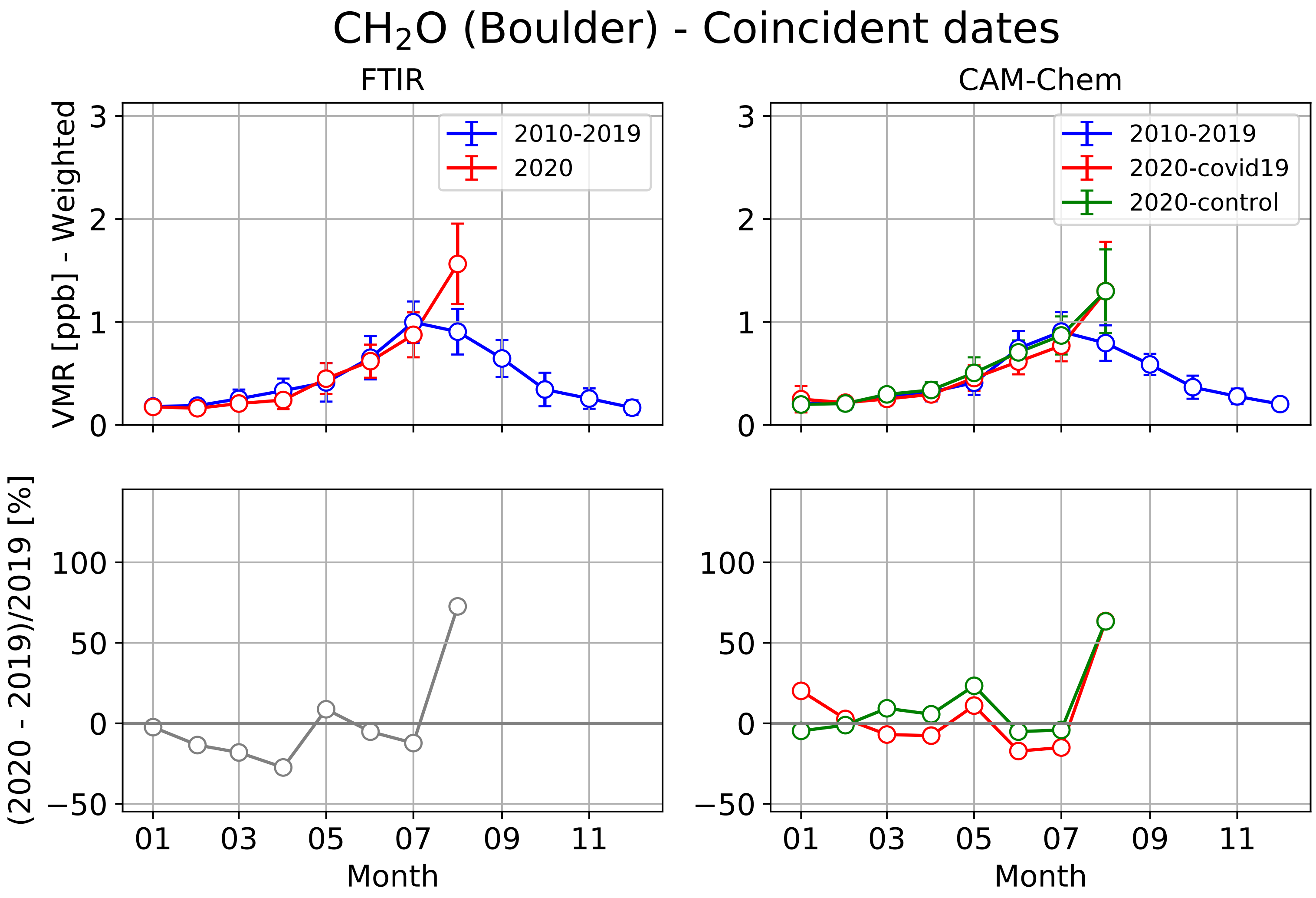


Time series from 2010-2019



Comparison with CAM-Chem using control and estimated covid-19 emissions.

CH_2O



Excellent agreement in the shape of the difference.

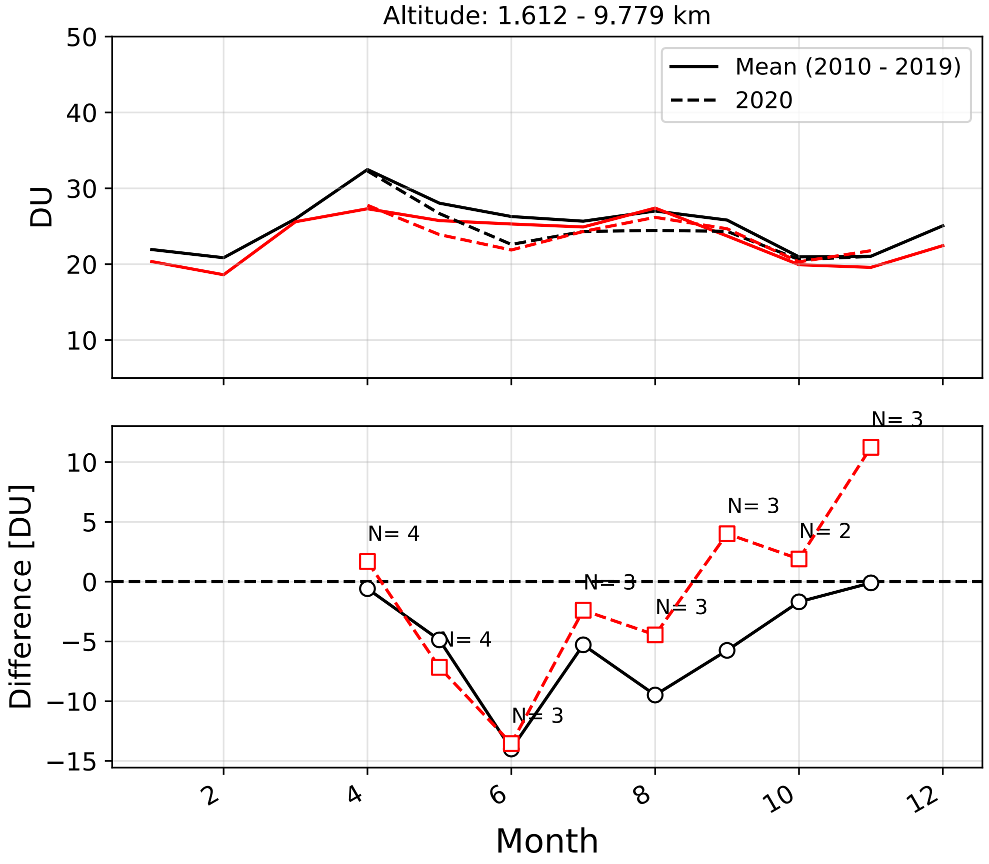
CAM-Chem control and covid19 (2020) show differences of about 5% in April but overall they are similar, does that mean the decrease is a combination of both met & covid19 restrictions?

How well can we retrieve some species, e.g., O_3

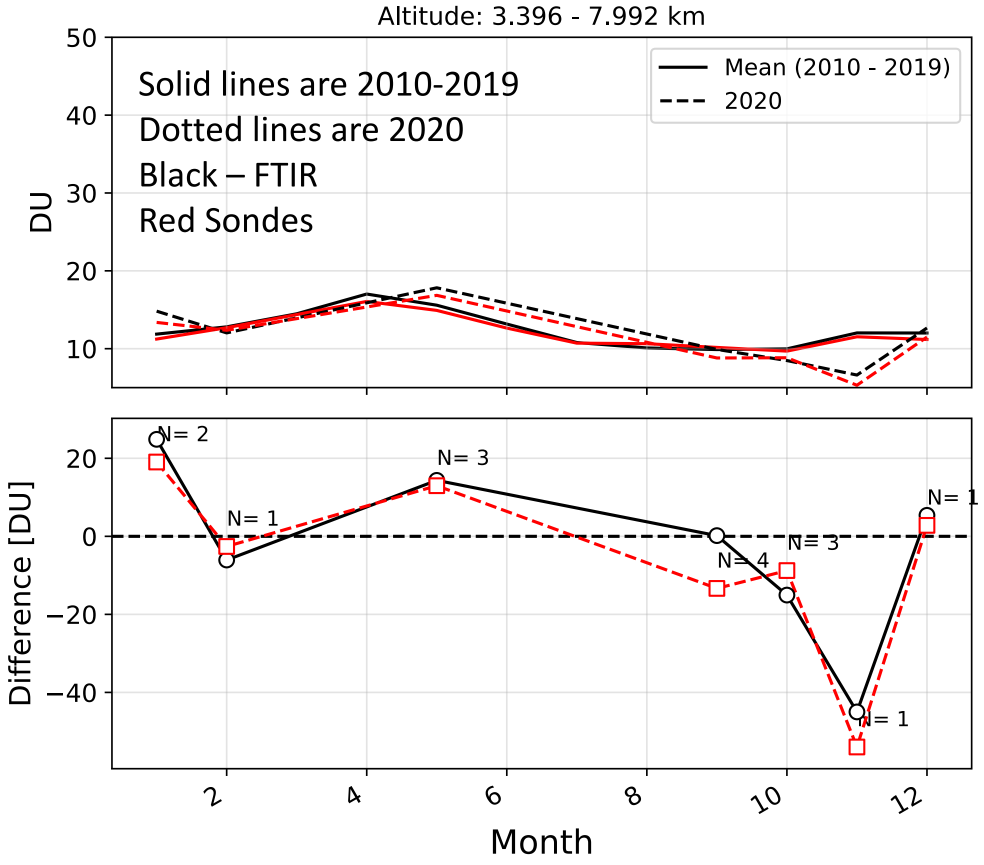
- O_3 is retrieved with ~3-4 DOFs (low trop, upper trop/low strat and stratosphere)
- Balloon-borne O_3 profiles are measured weekly at Boulder (and other sites) and can be used to characterize these Partial columns.

We use mean O_3 from FTIR measurements of coincident dates within +/- 2h of the sonde launch

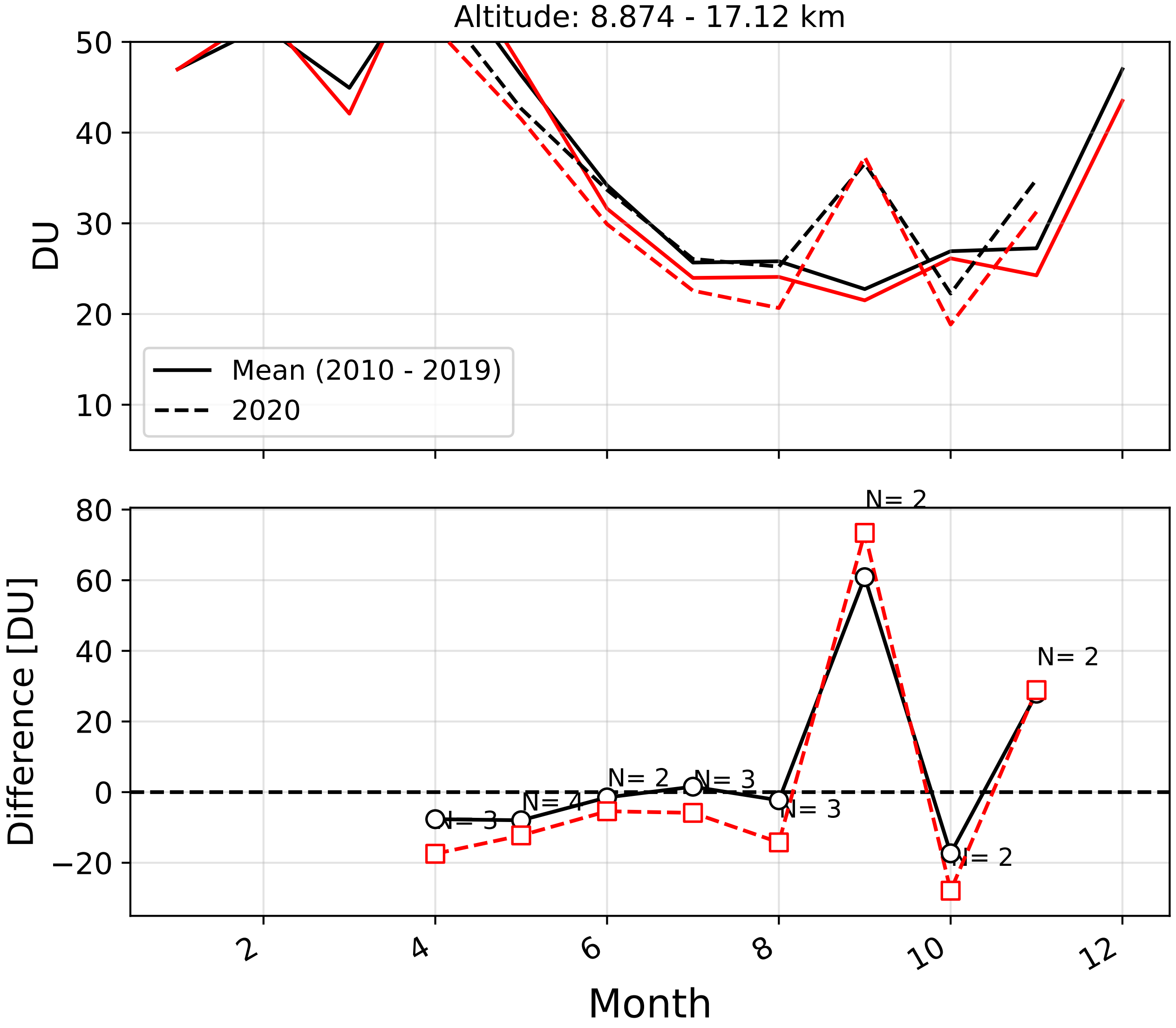
Boulder



MLO



Boulder



Altitude: 8.874 - 17.12 km
50
40
30
20
10
DU
Mean (2010 - 2019)
2020
80
60
40
20
0
−20
Difference [DU]
N= 2
N= 2
N= 2
N= 3
N= 4
N= 3
N= 3
N= 2
2
4
6
8
10
12
Month

Conclusions

- ❖ **CAM-chem reproduces observed ozone features with great accuracy.**
- ❖ **Free tropospheric ozone reduction of 6-7% (observations are 7%).**
- ❖ **Emission test alone suggest aircraft contributes to more than half of the free tropospheric ozone reduction.**
- ❖ **Investigation and quantification of the role of stratospheric ozone change is on-going.**
- ❖ **Uncertainties in emission reduction can be large, but not larger than error in emissions.**

Perspectives:

- ❖ **MUSICA simulations will allow to take full advantage of the spatial resolution of the anthropogenic emissions (~0.1 degree), including for biomass burning.**
- ❖ **Assimilation of CO and AOD to improve combustion emissions (CO, VOCs, black carbon and organic aerosols).**