# Assessing wildfire emissions of Carbon Monoxide

USING 4D-VAR INVERSE MODELLING

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# INTRODUCTION

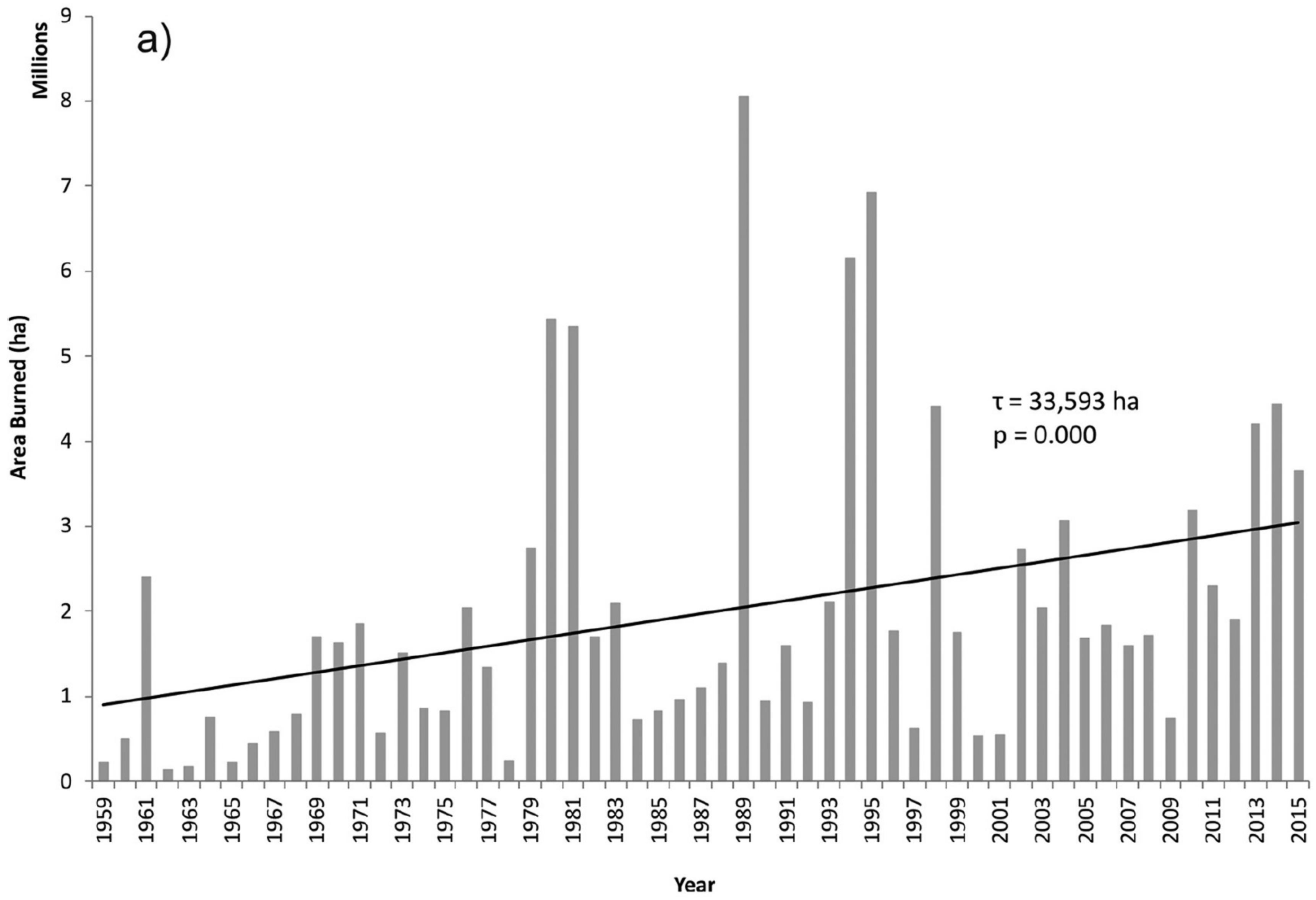
- The total area burned annually in Canada due to wildfires has increased during the past 50 years and is expected to continue increasing in the future due to climate change.

- Emissions from these fires will impact climate and Canadian air quality.

- The fires also affect the boreal net ecosystem carbon balance.

- Carbon monoxide (CO) is an ideal tracer of biomass burning. CO is also produced from FF combustion and the oxidation of methane and non-methane volatile organic compounds (NMVOCs).

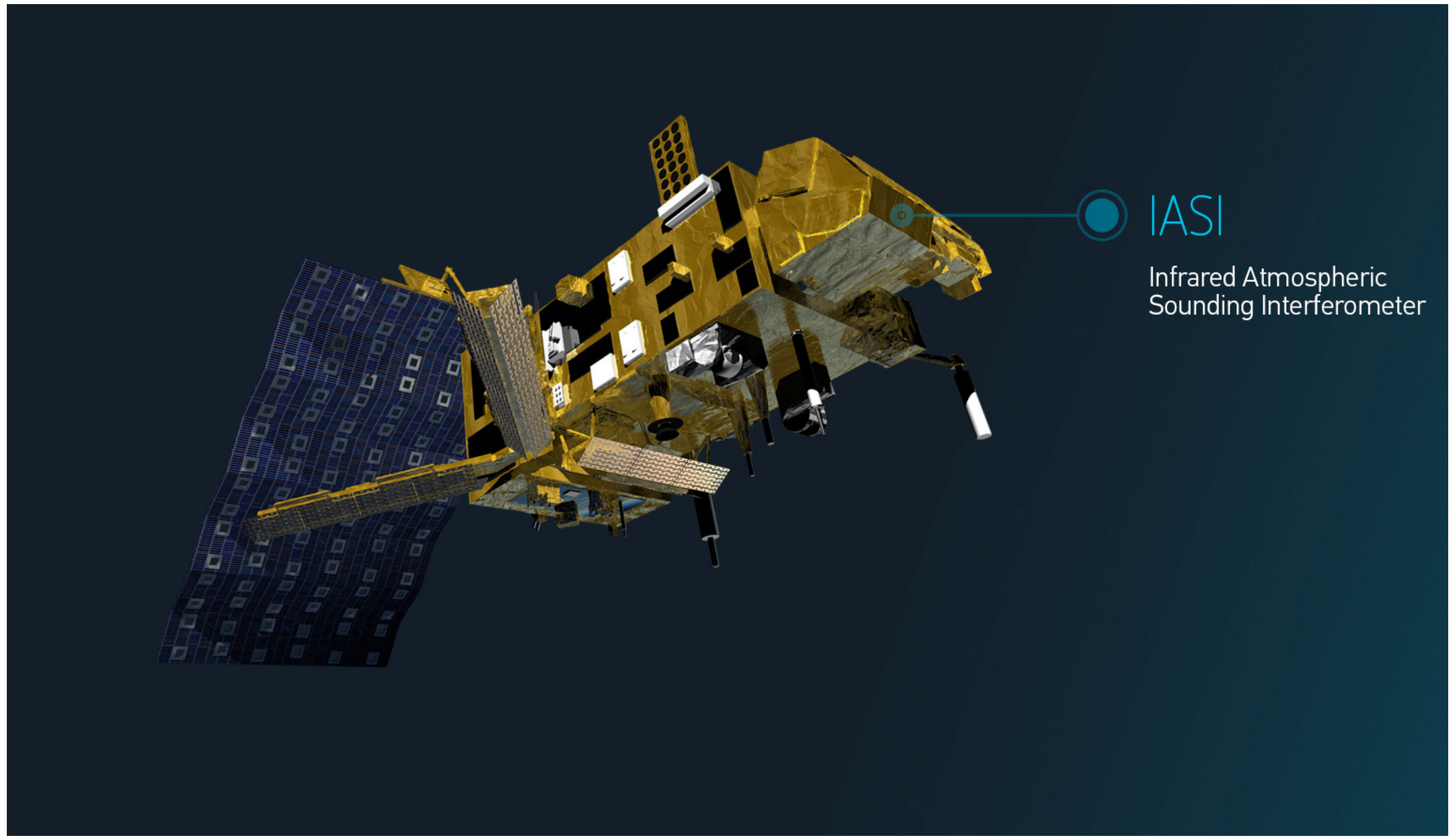
Trend in area burned in Canada (from the National Fire Database)




(Hanes et al., 2019)

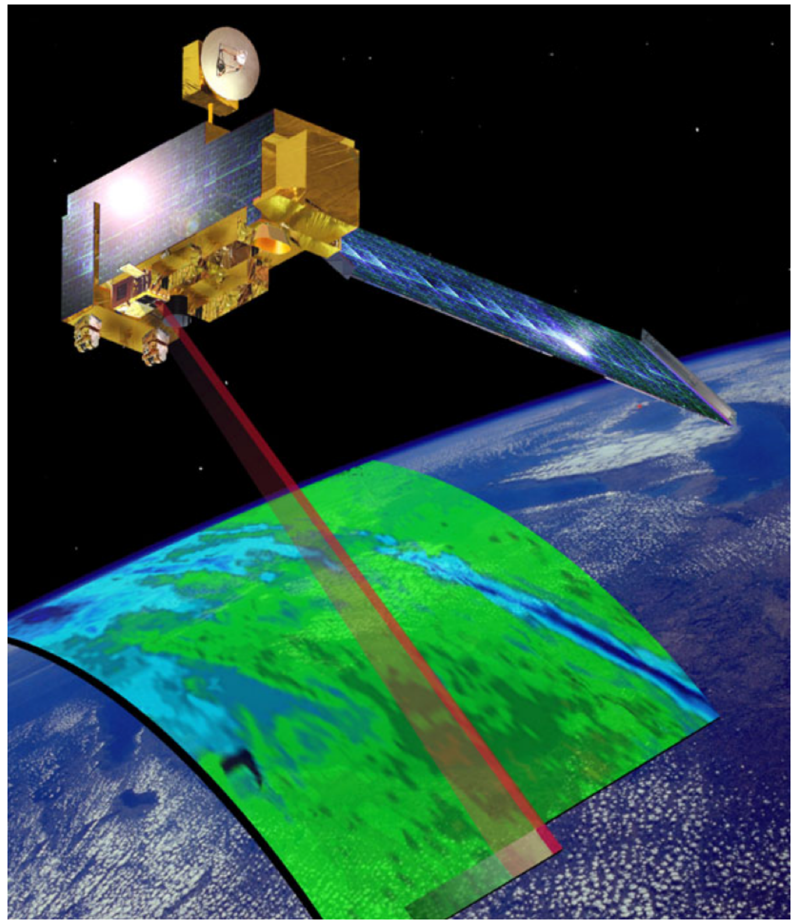
# SATELLITE OBSERVATIONS

Infrared Atmospheric Sounding Interferometer (IASI)




- Onboard the Meteorological Operational (Metop) Satellites.
- Measures in the thermal infrared region of the spectrum.
- In polar orbit, with an equatorial crossing time of about 9:30 am.
- With 14 orbits a day and the measurement consisting of a wide 2200 km swath, achieves global coverage daily.
- Nadir circular footprint with a 12 km radius.

Measurement Of Pollution In The Troposphere (MOPITT)



- Flying on the Terra spacecraft.
- Measures in the NIR and TIR.
- In polar orbit, repeats every 3 days with a 10:30 am local time equator crossing.
- Nadir footprint of 22 km x 22 km.

# GEOS-CHEM MODEL DESCRIPTION

- We use the CO-only simulation of GEOS-Chem, which uses prescribed OH fields to linearize the chemistry.
- The source of CO from the oxidation of NMVOC is no longer specified as a 2-D surface source.
- The CH4 source and the OH fields are also specified from the forward model.
- The OH fields are now consistent with all of the chemical sources specified in the CO-only simulation.

**Version 35j of the GEOS-Chem Adjoint**

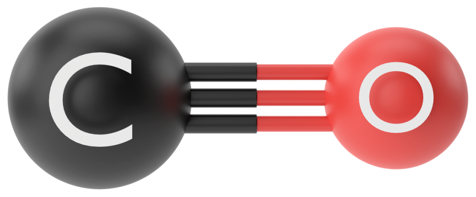
**Version 13 of the forward model**

**Resolution Horizontal (4 x 5 ) Vertical (47 levels)**

**GEOS-5 Meteorological fields**

# 4D-VAR ASSIMILATION SETUP

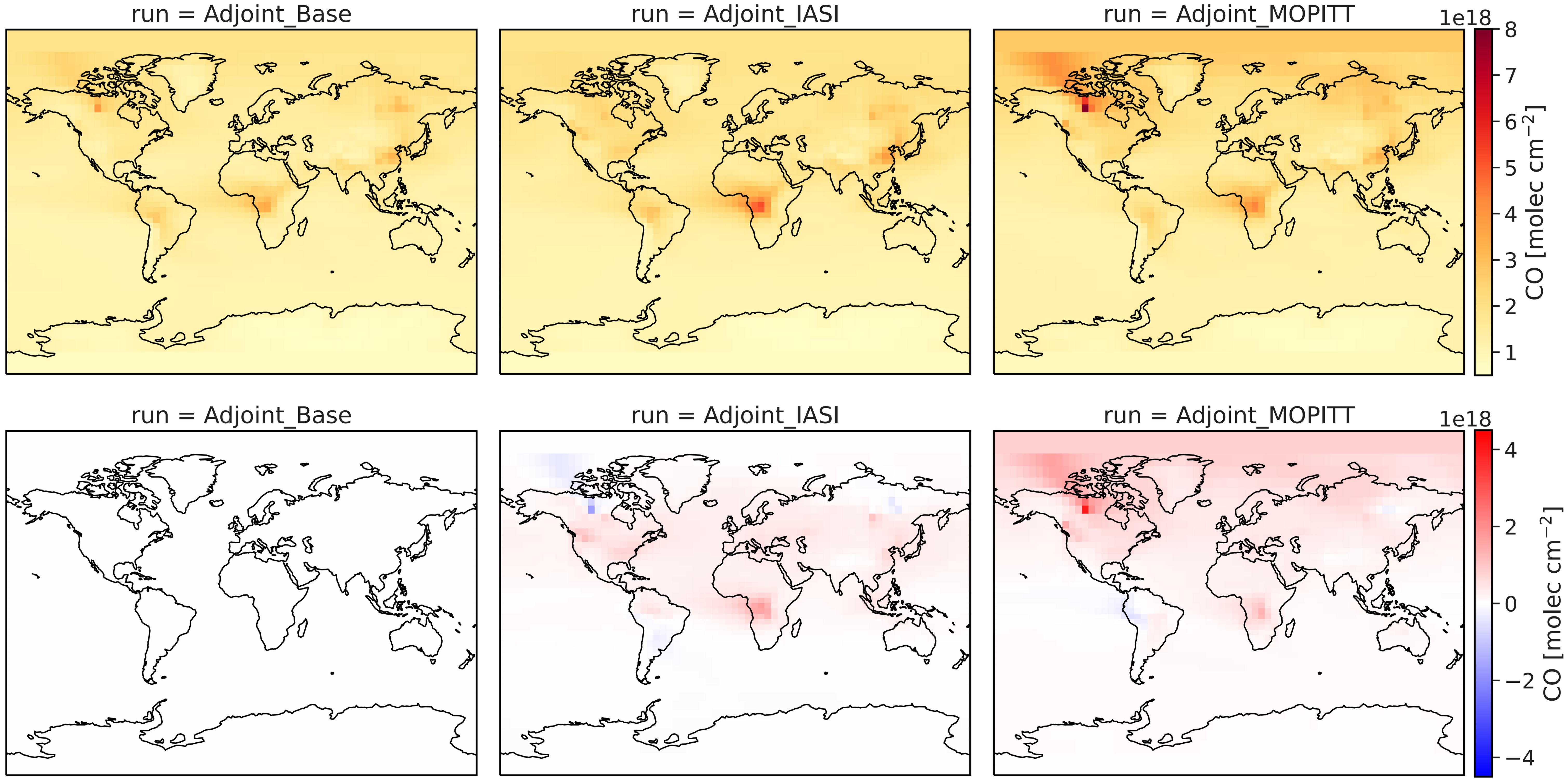
- We separately assimilate MOPITT CO columns and IASI partial columns to estimate CO emissions.
- Since CO is long-lived, we use a long window of four months (June - September) to quantify the emissions from the fires in western Canada in August 2017 and 2018.
- The initial conditions were optimized separately and generated for MOPITT and IASI CO measurements using weak constraint 4D-Var.
- Following previous studies, we initially focused on estimating monthly scaling factors for the emissions.
- Actual estimation of the emission scaling factors used strong constraint 4D-Var.
- We use the GFAS inventory as the a priori.



# RESULTS

- August 2017 Canadian wildfires
- August 2018 Canadian wildfires

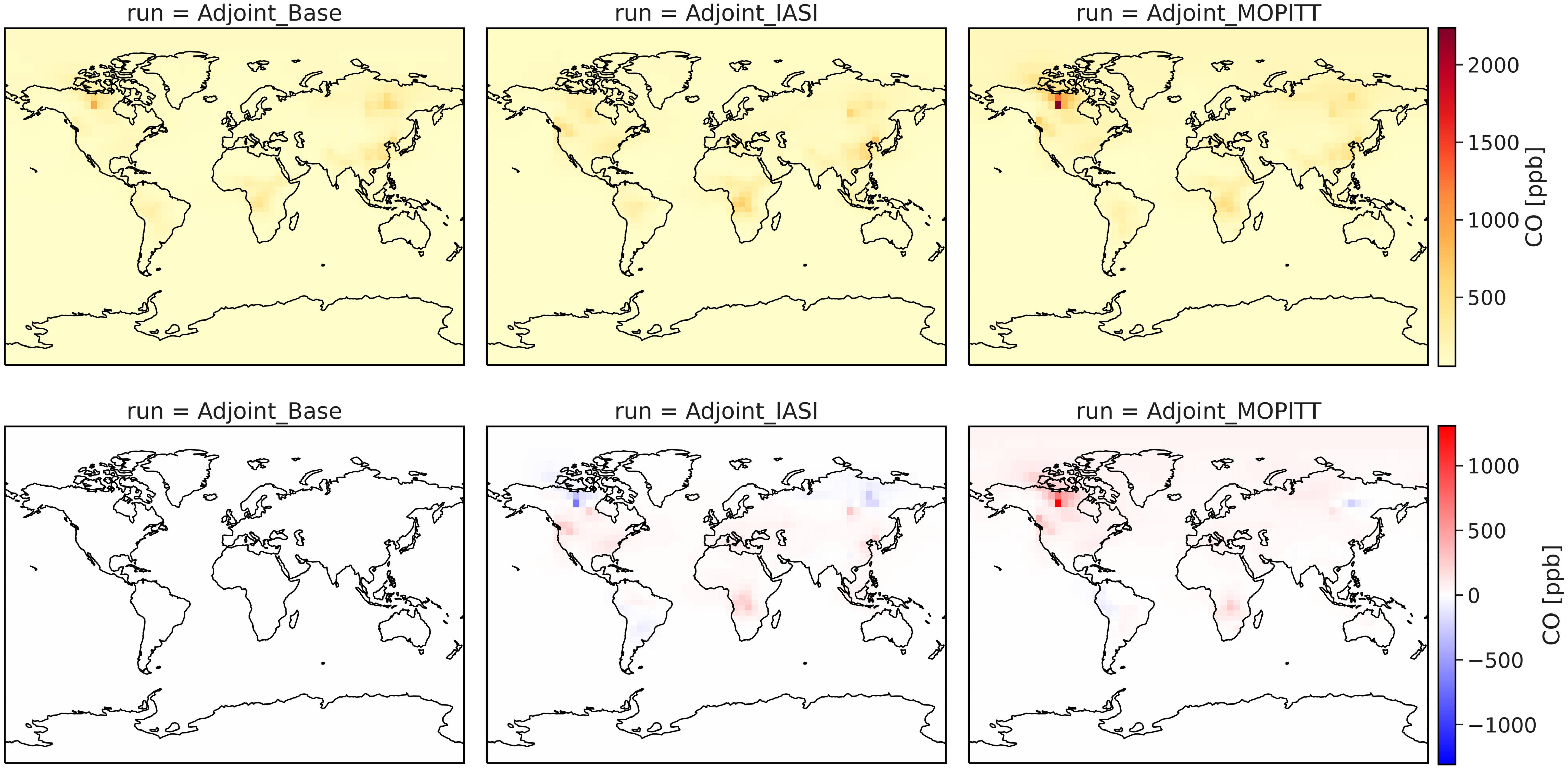
# CO COLUMNS (AUGUST 2017)




August 2017 mean CO total columns
Base - a priori state, IASI, MOPITT - a posteriori states

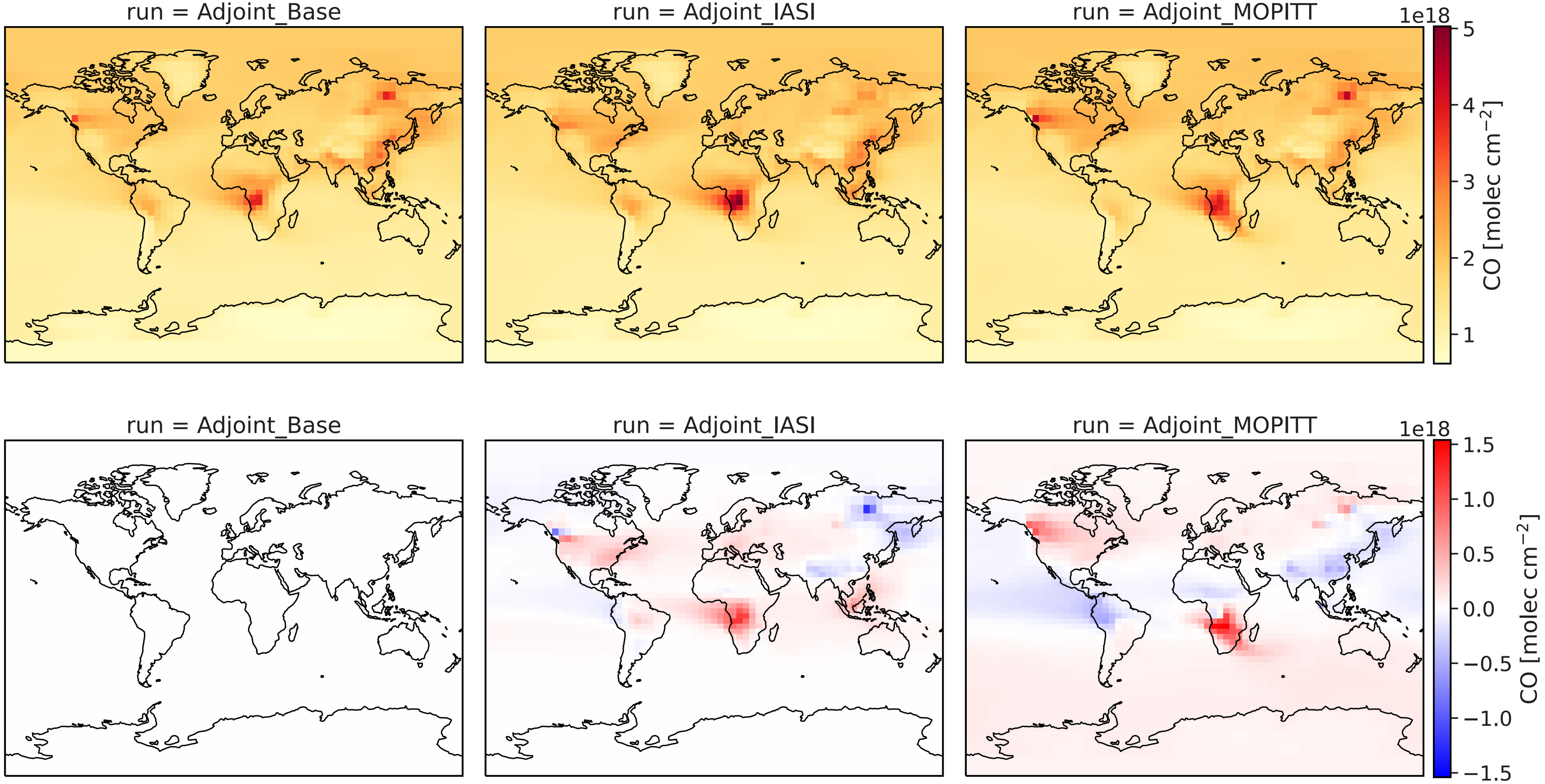
The MOPITT inversion scales up emissions in the Northwest Territories, whereas the IASI inversion scales down these emissions.

# SURFACE LEVEL CO (AUG. 2017)




August 2017 mean surface CO concentration
Base - a priori state, IASI, MOPITT - a posteriori states

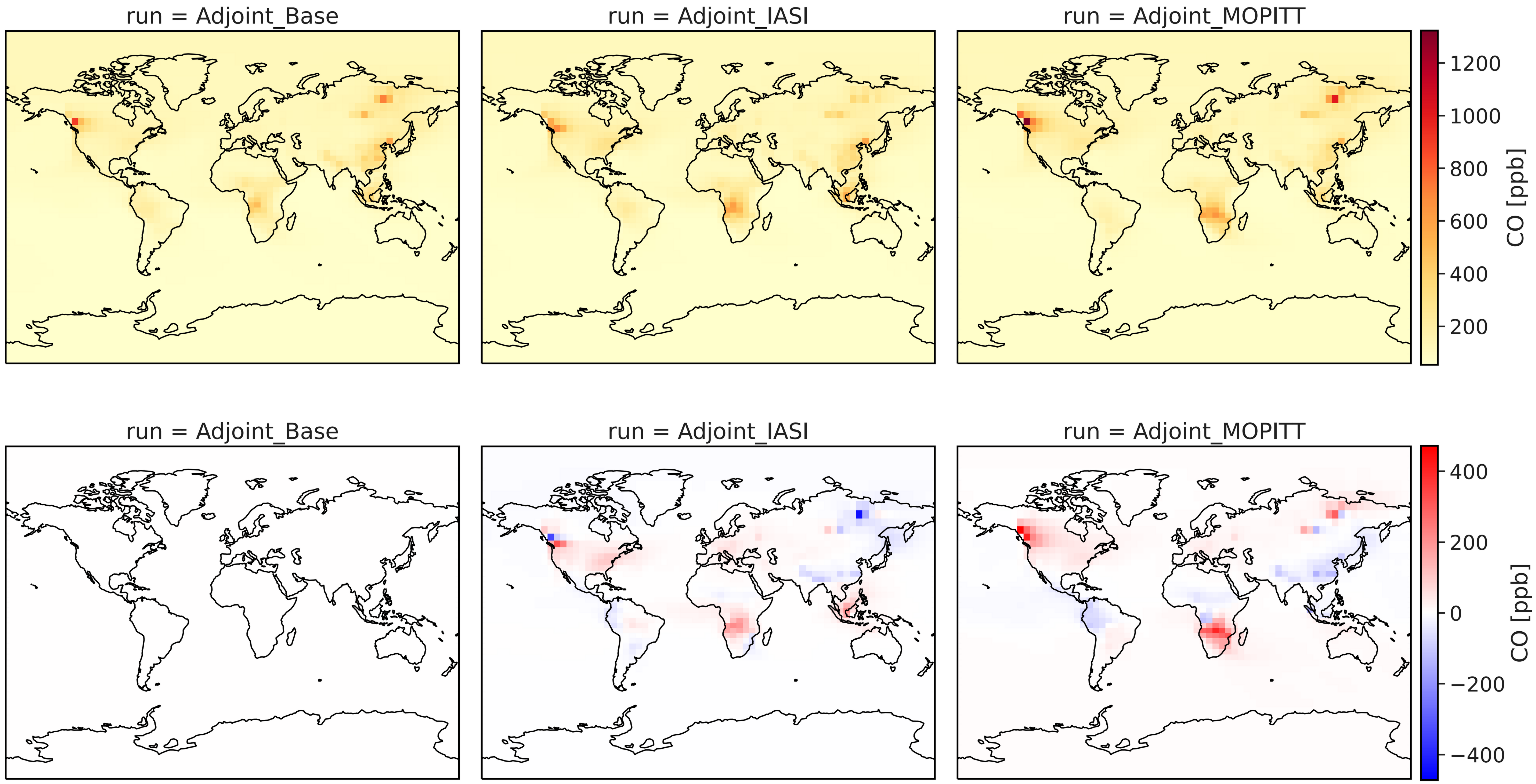
# CO COLUMNS (AUG. 2018)




August 2018 mean CO total columns
Base - a priori state, IASI, MOPITT - a posteriori states

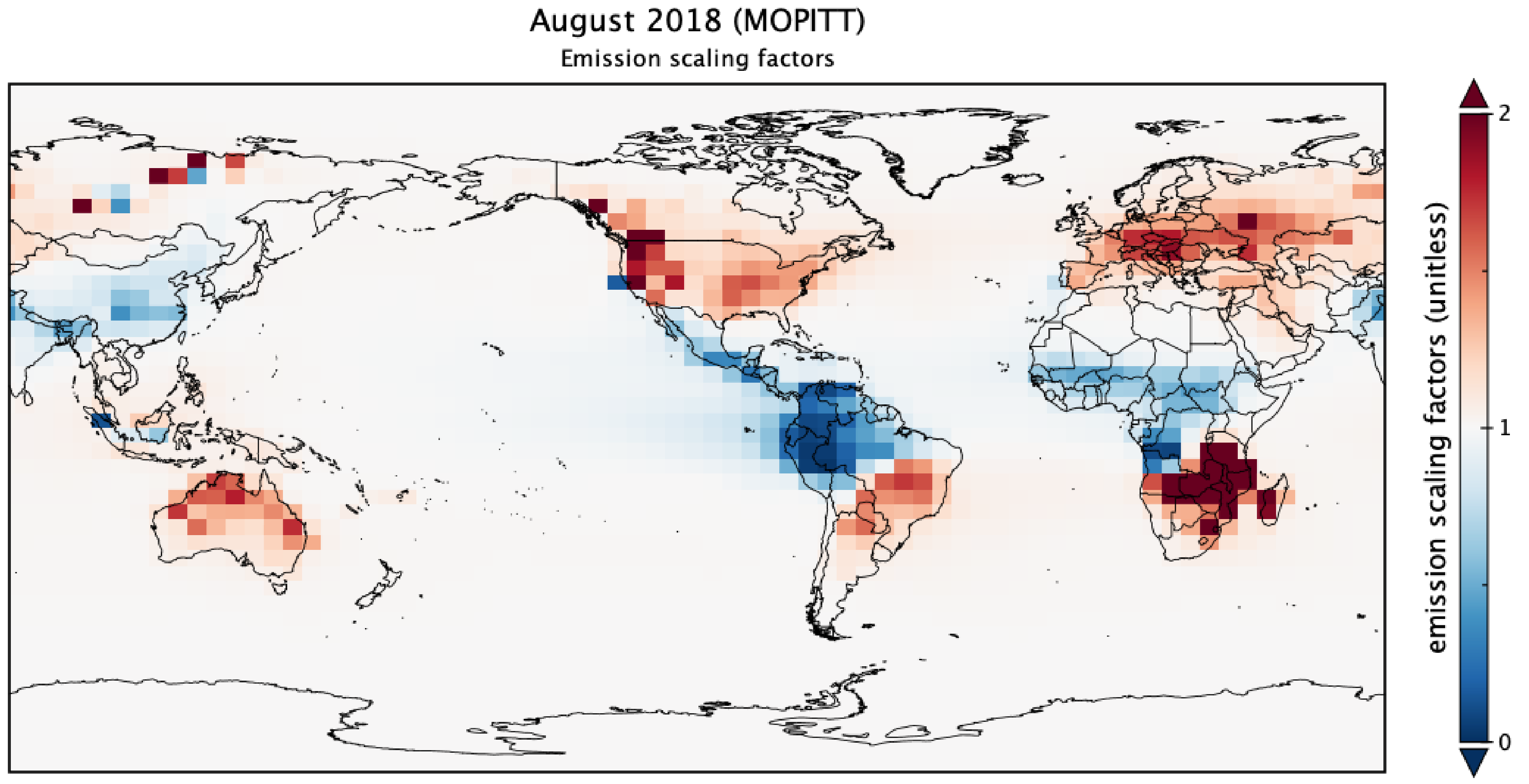
In BC, the estimated CO columns are higher for MOPITT compared to IASI.

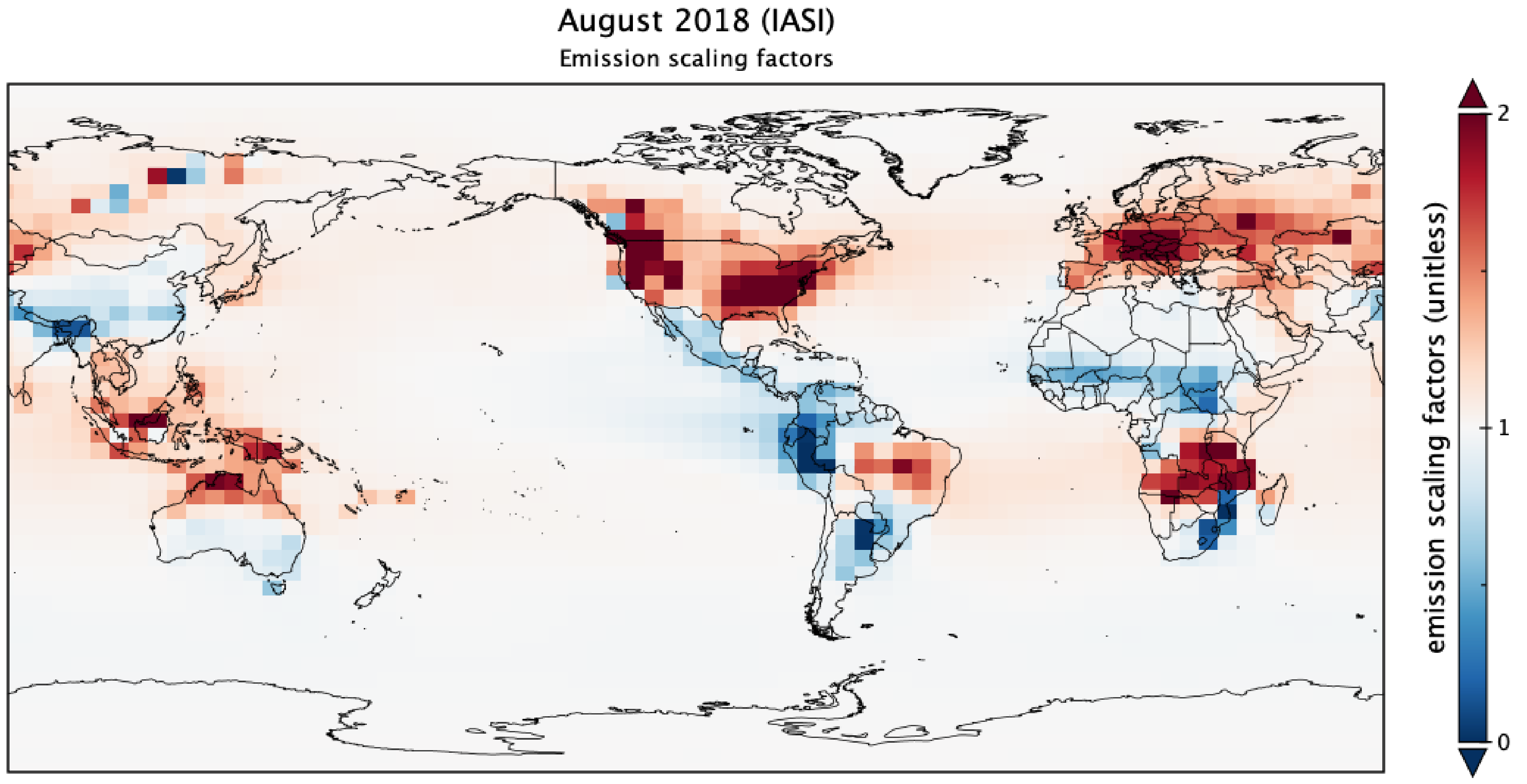
# SURFACE LEVEL CO (AUG. 2018)




August 2018 mean surface CO concentration
Base - a priori state, IASI, MOPITT - a posteriori states

# MONTHLY SCALING FACTORS (2018)




- Following previous studies, we initially focused on estimating monthly scaling factors for the emissions.
- The scaling factors are broadly consistent, but there are some large regional differences.

# MONTHLY EMISSION ESTIMATES

Prior and posterior CO emissions for MOPITT and IASI inversions for Boreal North America (2017 & 2018)

2017 emissions (Tg CO/month)

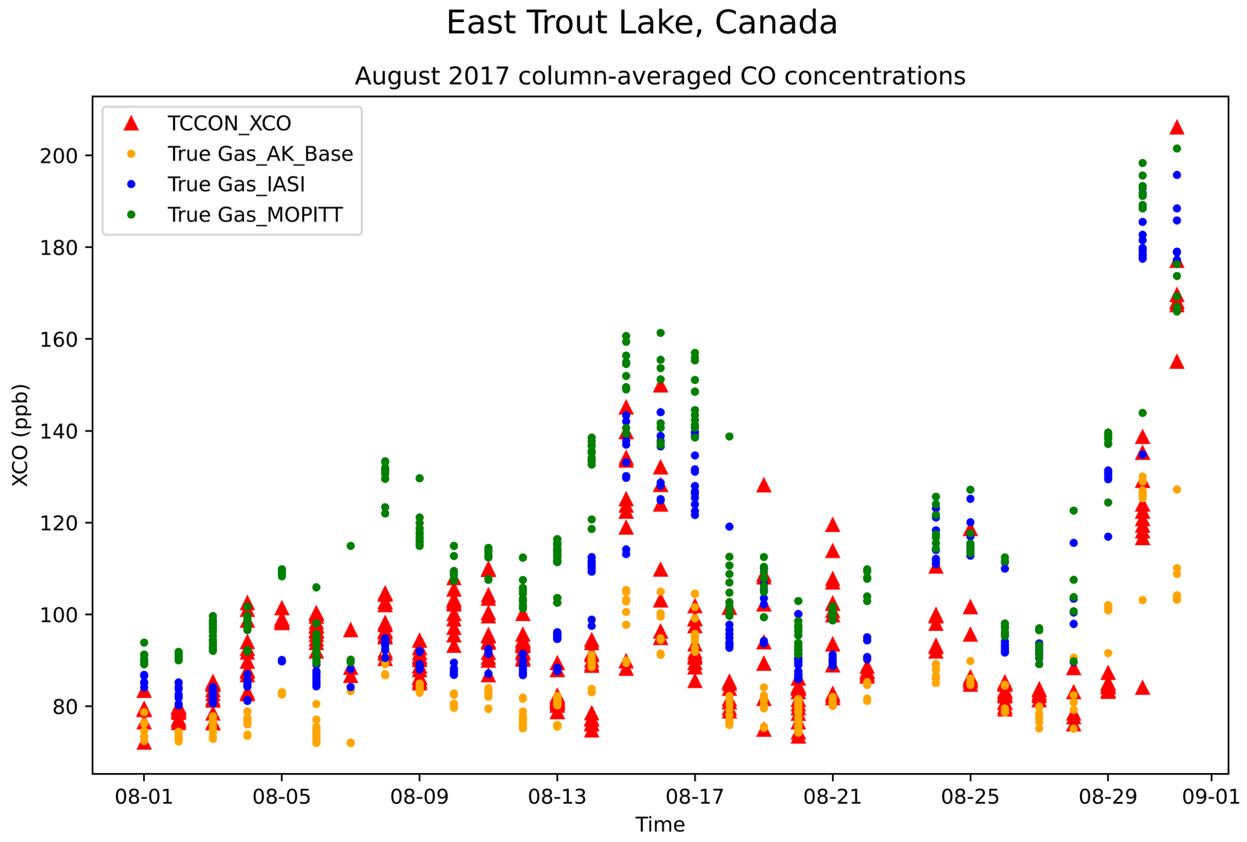
| Month | A priori | MOPITT a posteriori | IASI a posteriori |
|---|---|---|---|
| June | 1.3 | 1.8 | 1.2 |
| July | 5.2 | 9.2 | 7.3 |
| August | 12.8 | 30.0 | 13.1 |
| September | 3.0 | 4.8 | 2.5 |

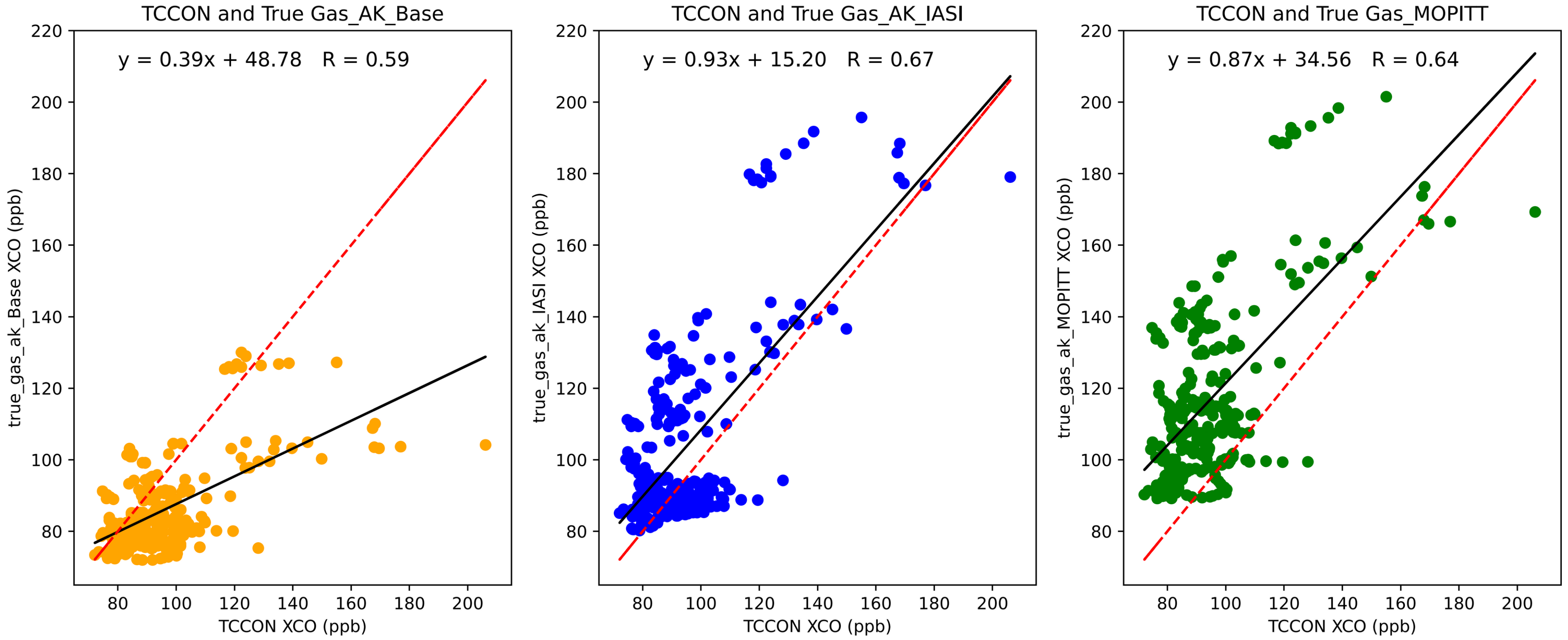
2018 emissions (Tg CO/month)

| Month | A priori | MOPITT a posteriori | IASI a posteriori |
|---|---|---|---|
| June | 1.1 | 0.7 | 0.1 |
| July | 1.8 | 2.6 | 2.6 |
| August | 8.3 | 15.1 | 10.0 |
| September | 0.4 | 0.6 | 0.2 |

- The MOPITT inversion suggests much higher emissions during August when the emissions are high.
- Emissions in June 2017, and in June, July, and September 2018 are likely too weak for the observations to constrain.

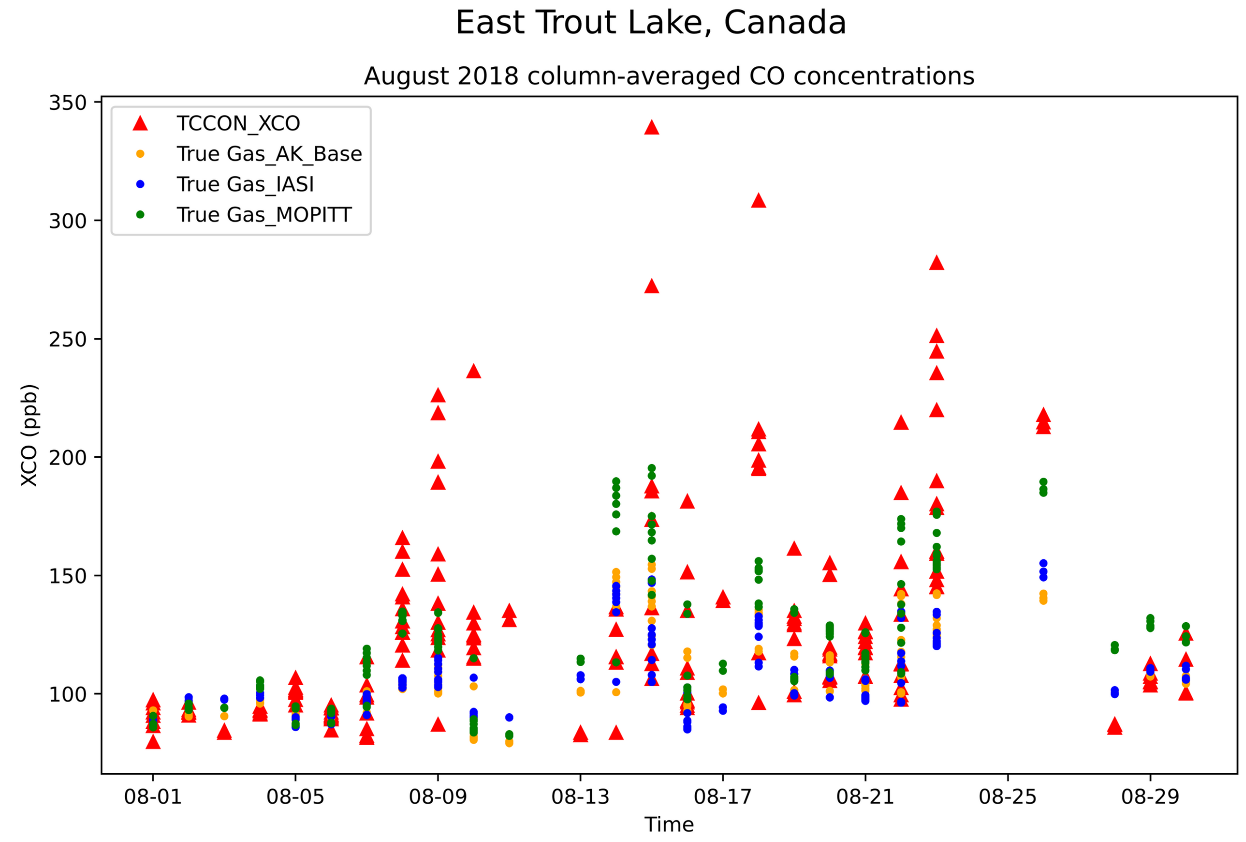
# TCCON COMPARISON (AUG. 2017)

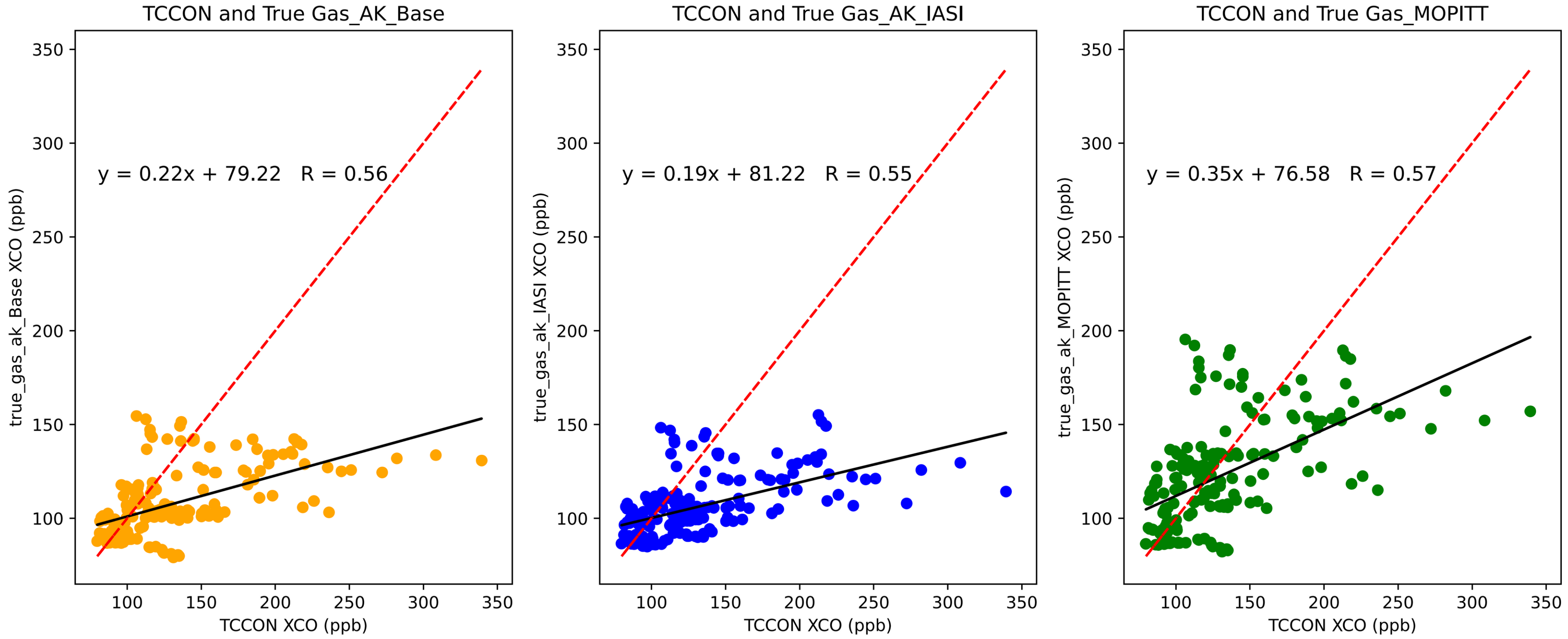



- High CO concentrations in the middle of the month and at the end.
- Note both inversions match the observations well, despite noticeable differences.
- Also, the regression plots suggest there is a similar agreement between the IASI and MOPITT inversion estimates at ETL.
- However, they have substantially different monthly CO estimates over BONA in August.

# TCCON COMPARISON (AUG. 2018)



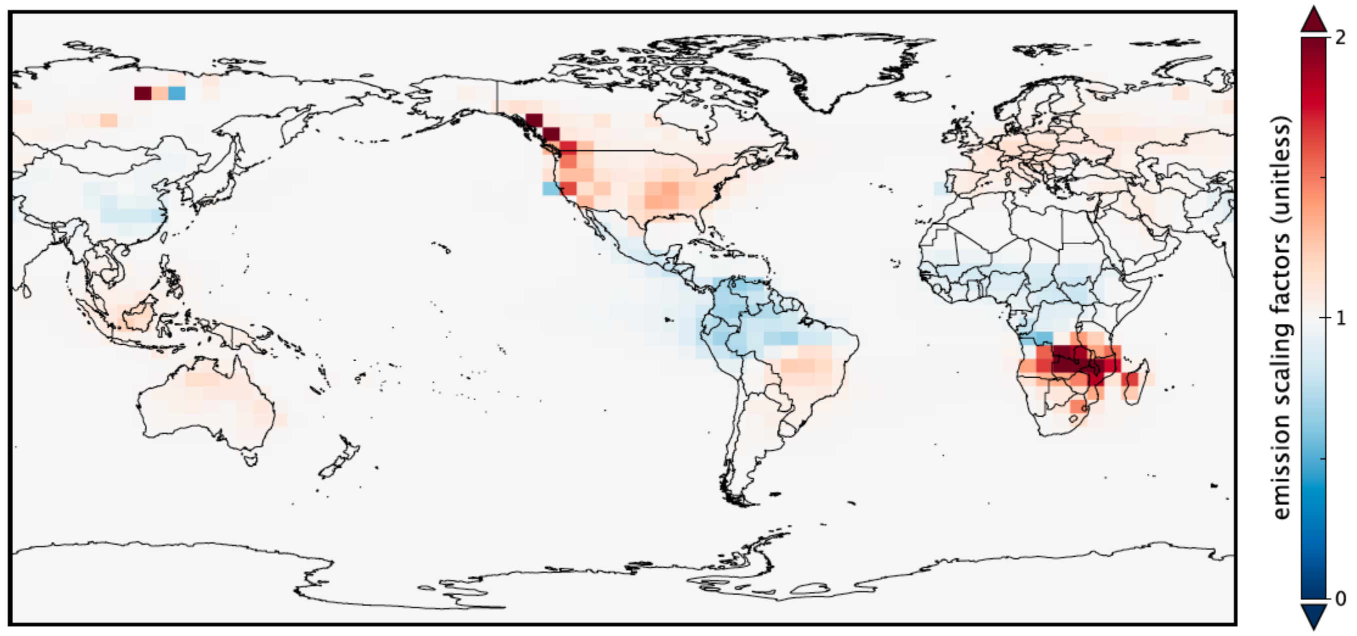




- Poor agreement.
- Both MOPITT and IASI inversions do not capture the peaks in CO.
- The MOPITT inversion CO have an overall better agreement with TCCON.
- These CO emission estimates were computed using monthly scaling factors.

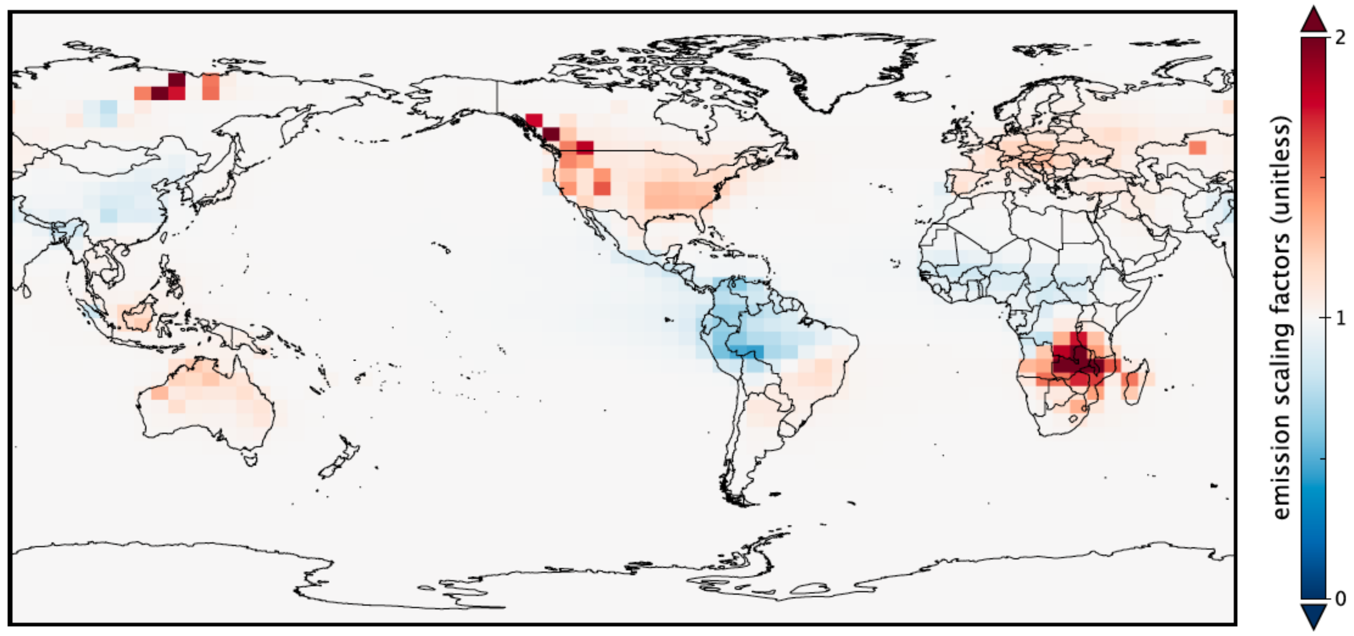
# WEEKLY SCALING FACTORS (2018)

## MOPITT

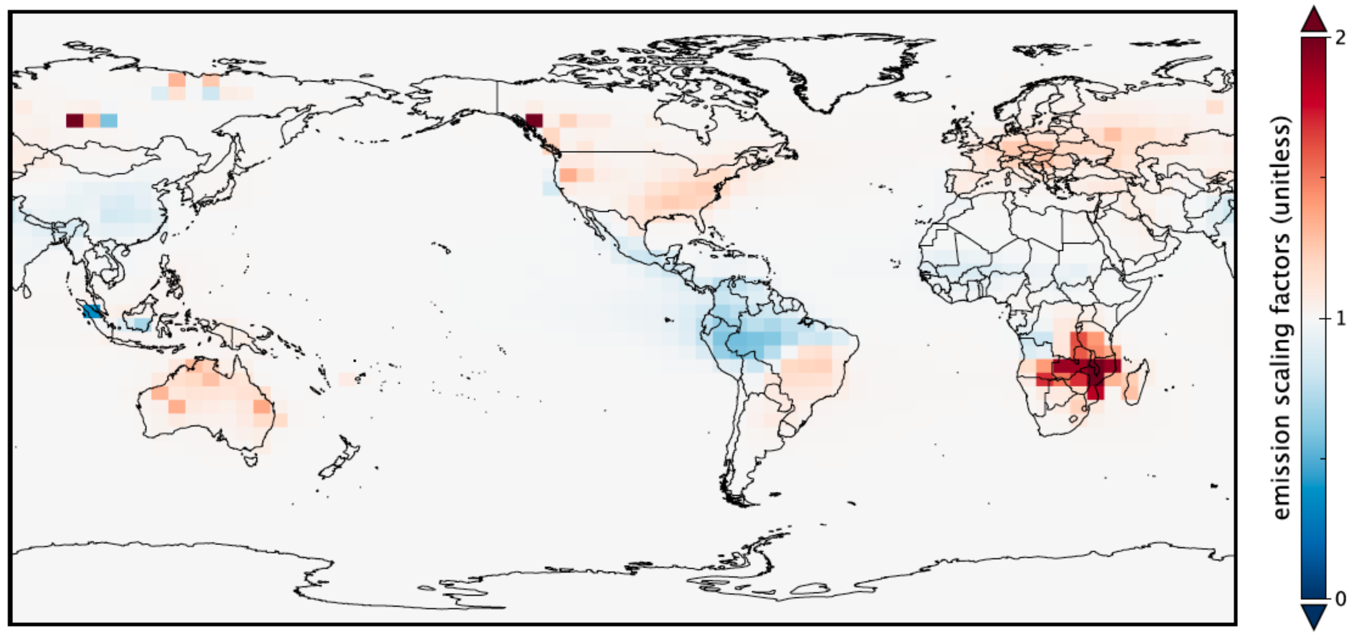
Week 1, August 2018 (MOPITT)
Emission scaling factors



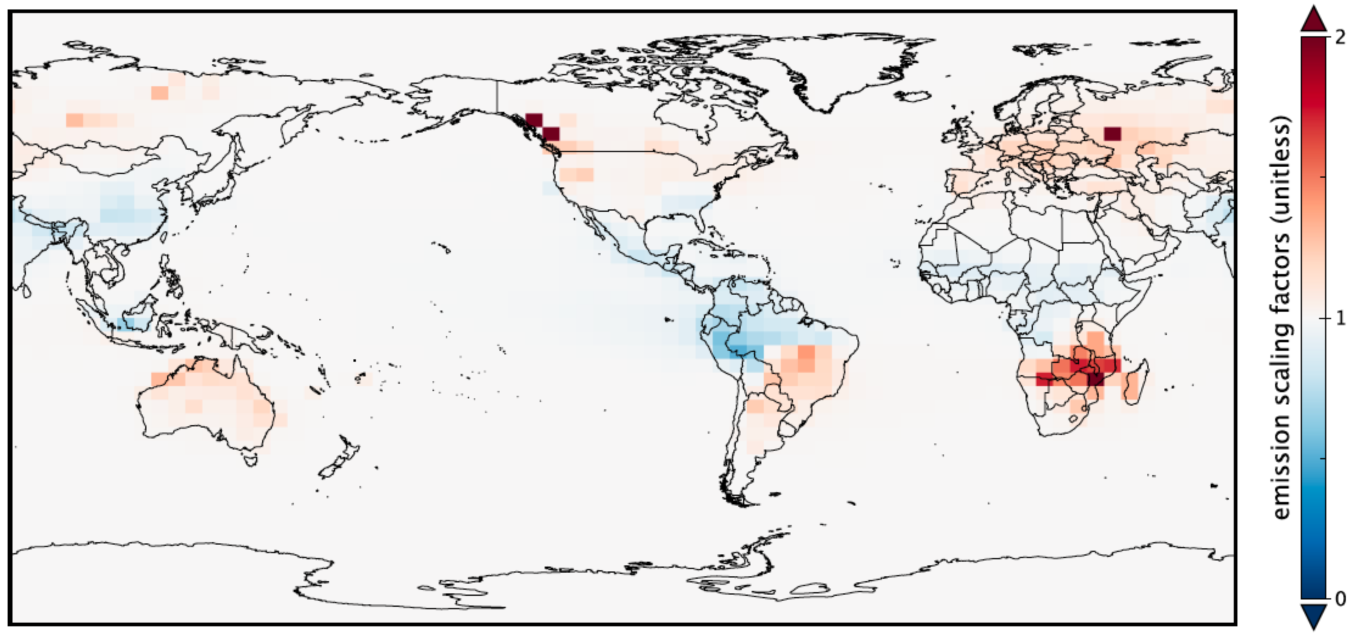

Week 2, August 2018 (MOPITT)
Emission scaling factors




Week 3, August 2018 (MOPITT)
Emission scaling factors

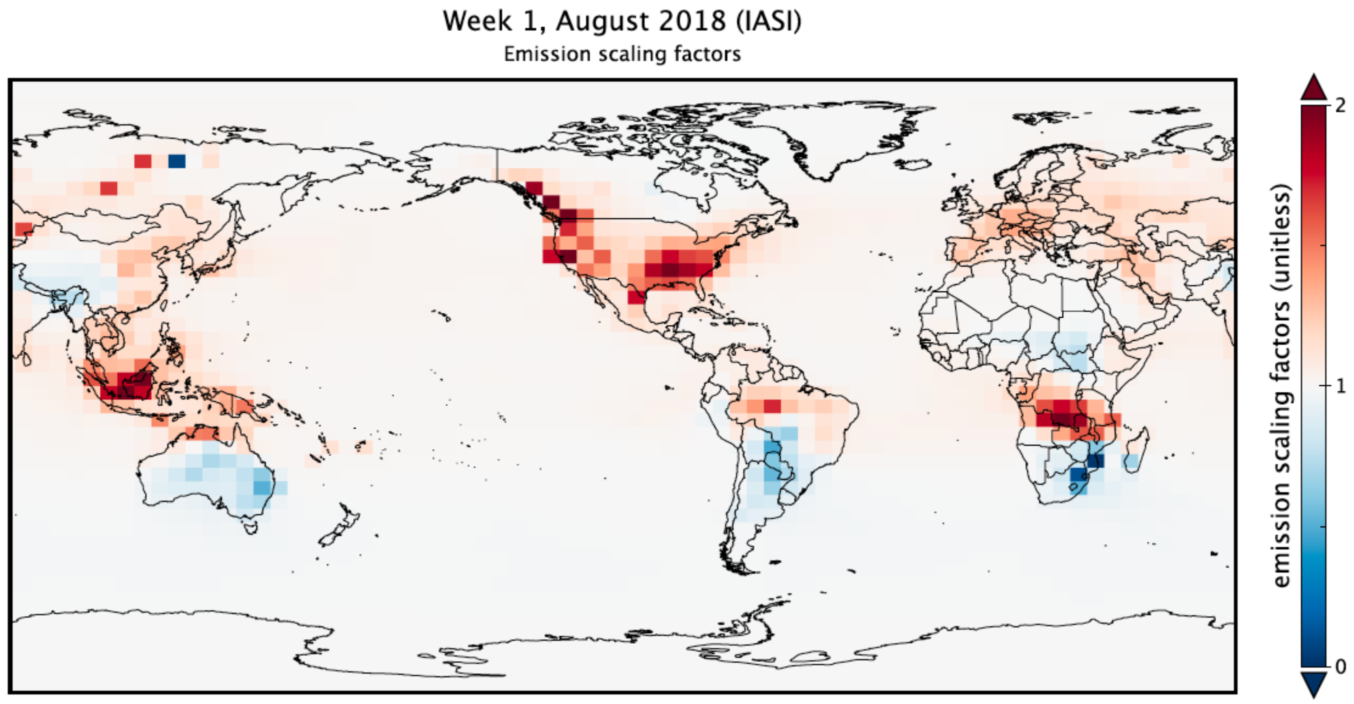


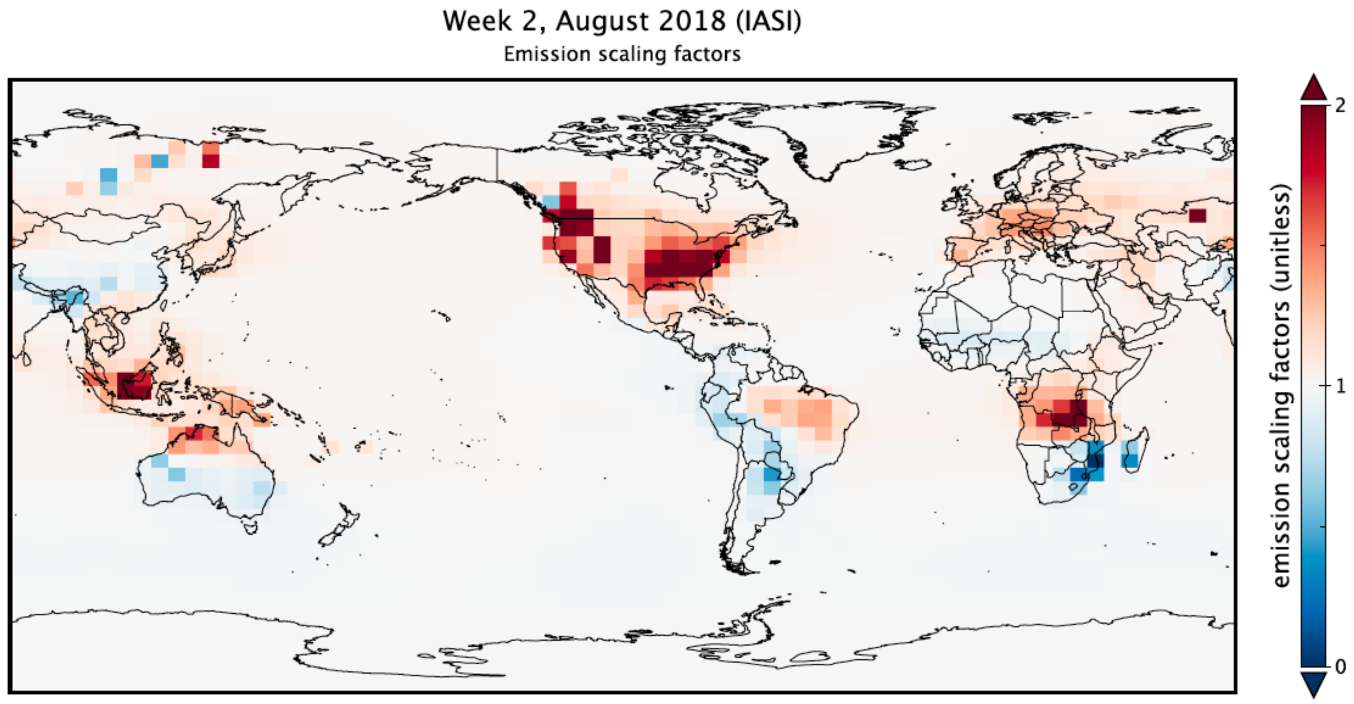

Week 4, August 2018 (MOPITT)
Emission scaling factors

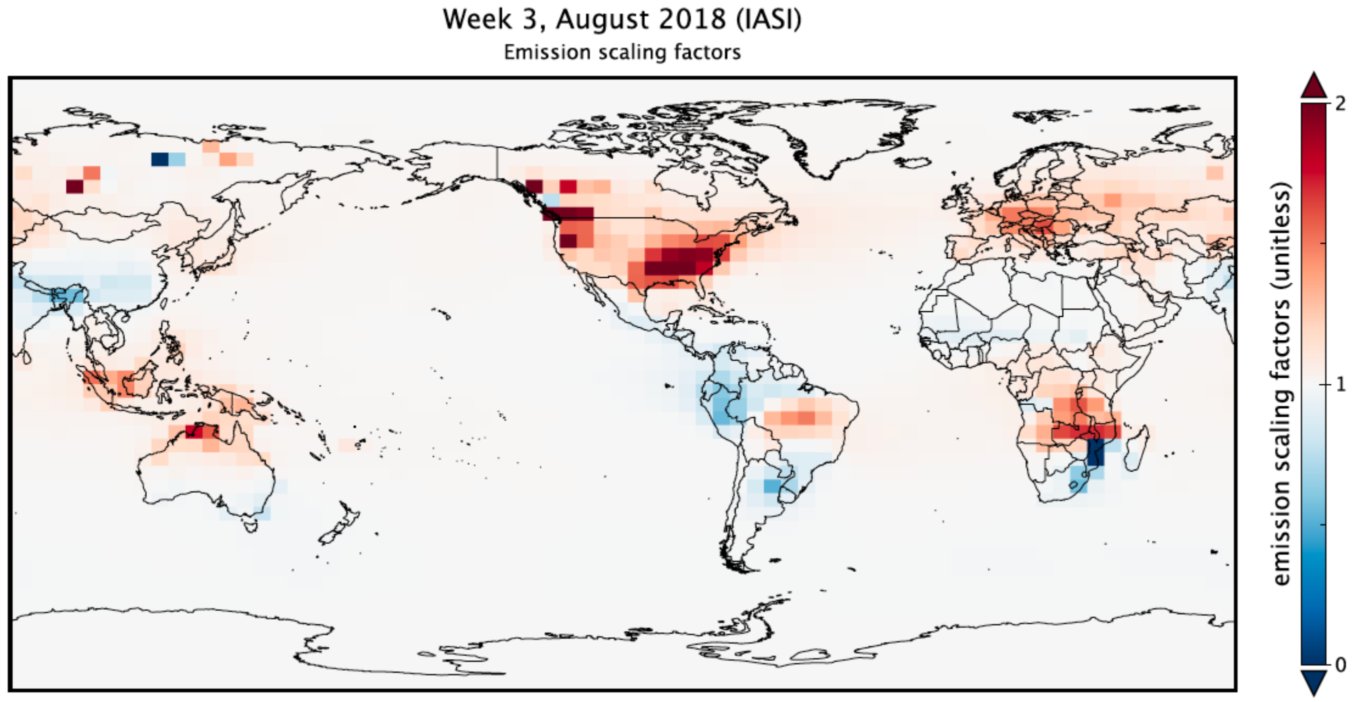


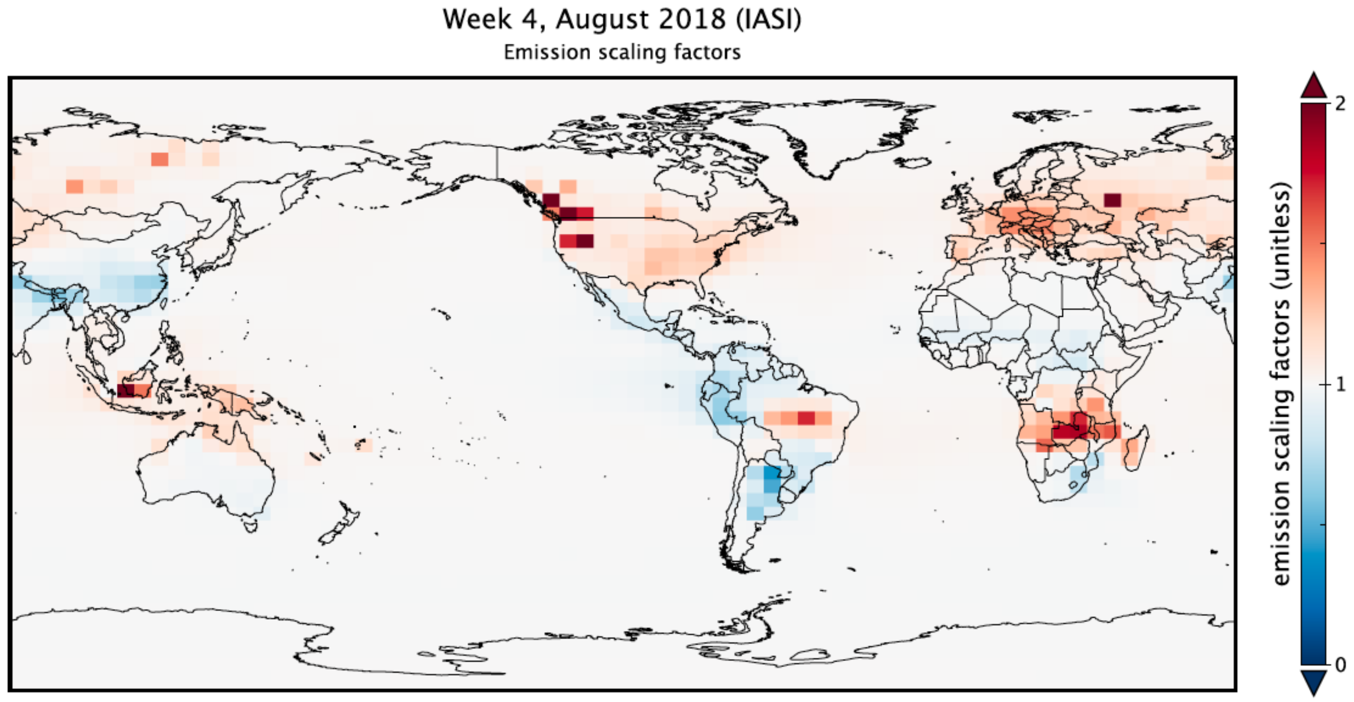
# WEEKLY SCALING FACTORS (2018)

IASI



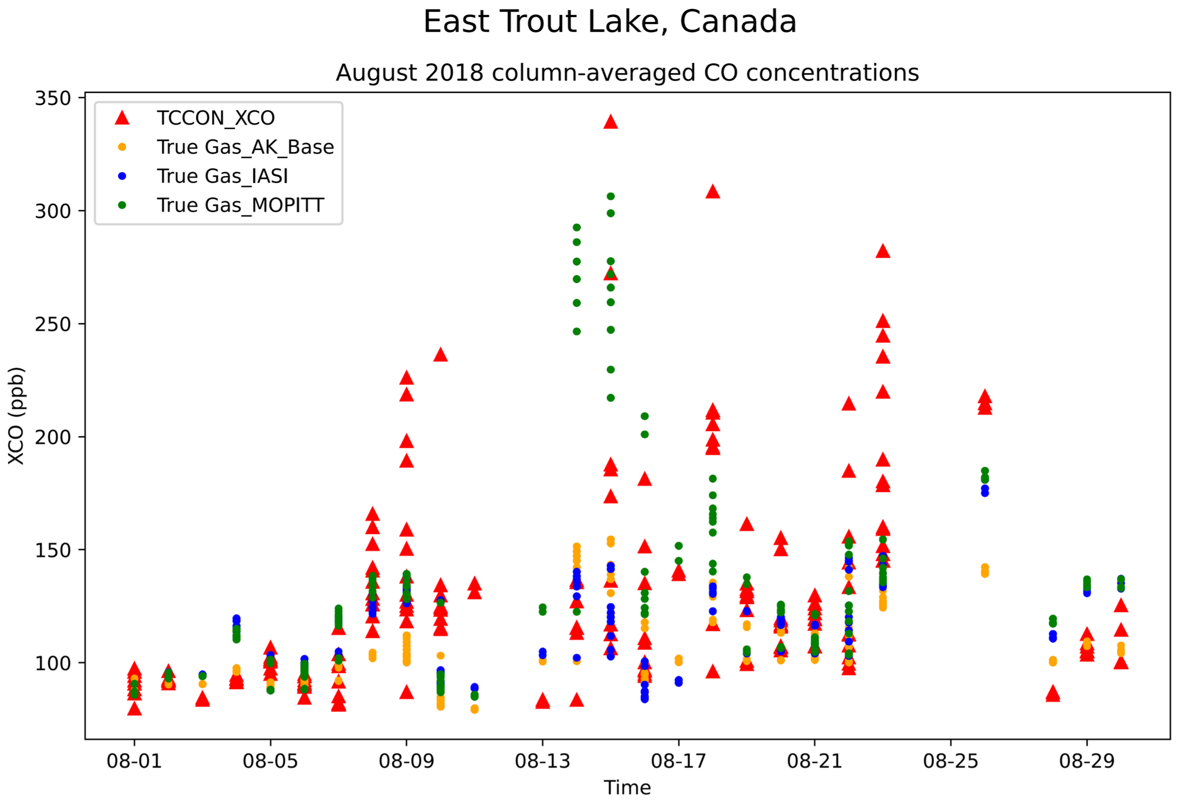



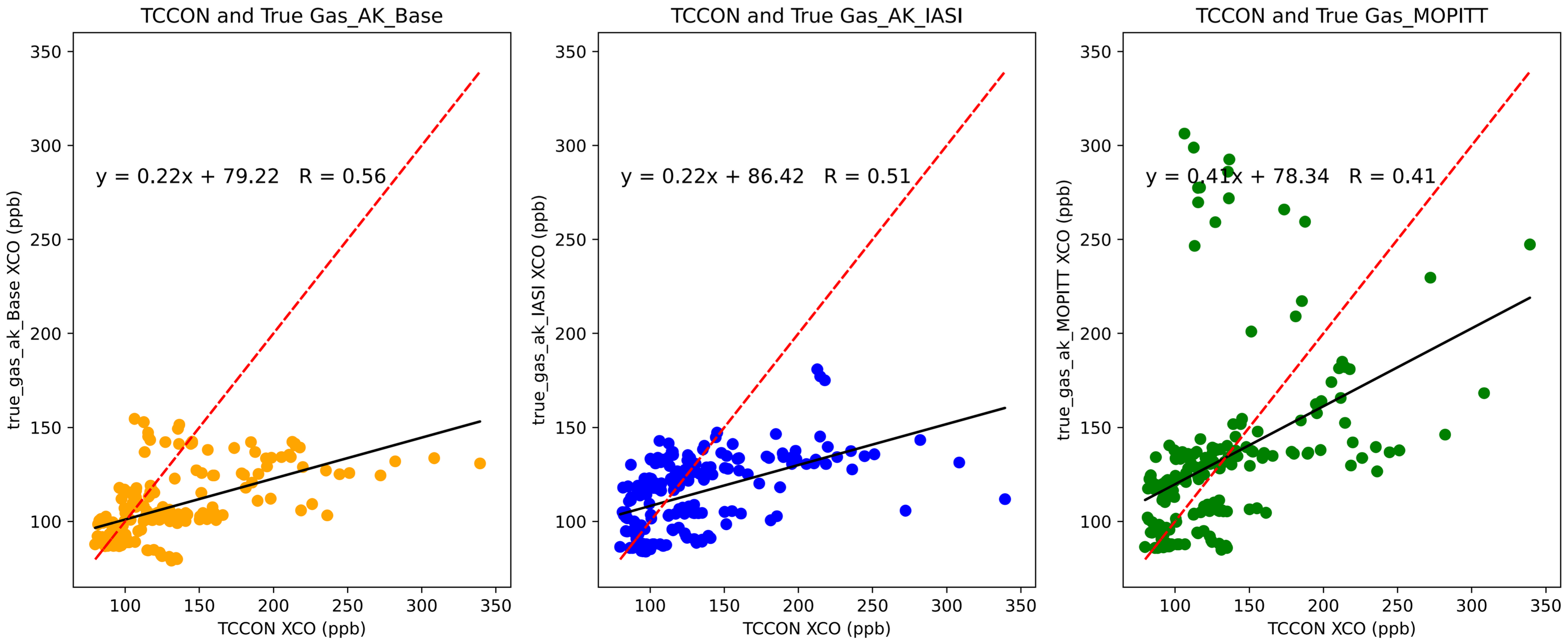



# TCCON COMPARISON (AUG. 2018)

## With Weekly Scaling

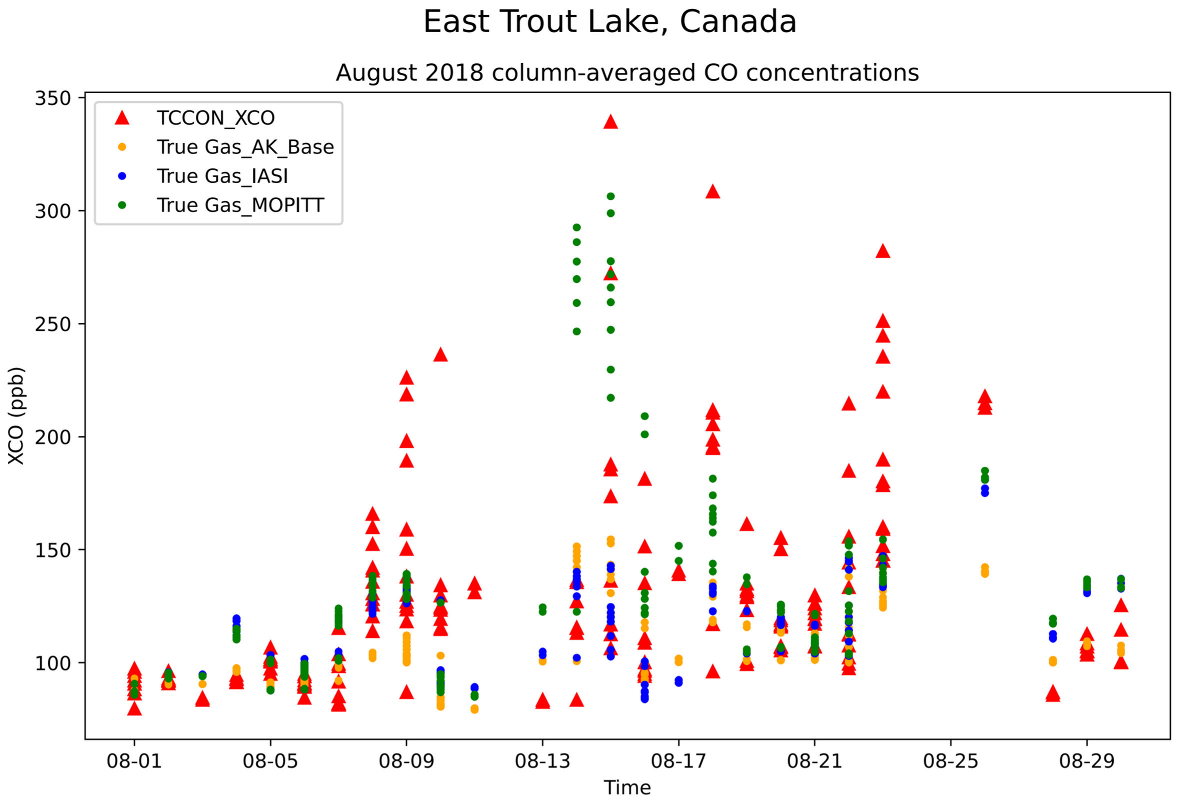


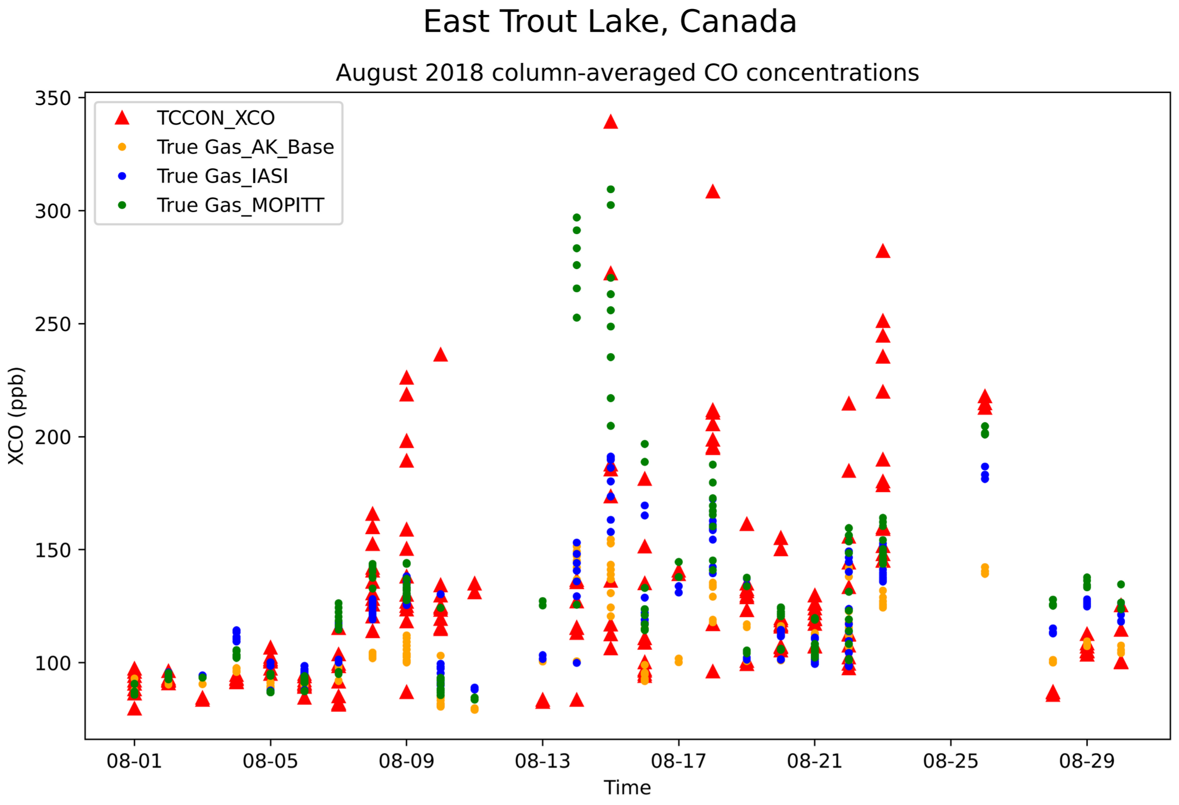



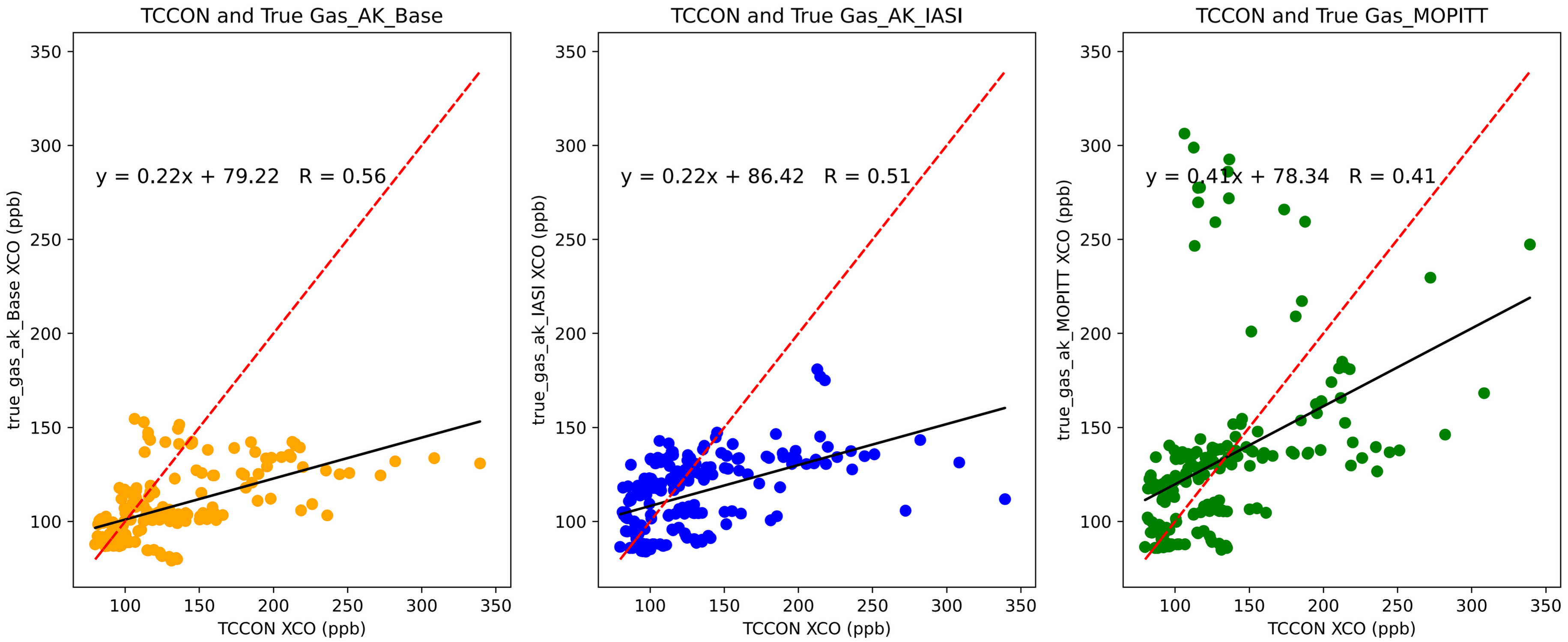

- GEOS-Chem MOPITT emissions are noticeably scaled higher, with better agreements during CO peaks.
- Small changes in GEOS-Chem IASI, suggest that the weekly scaling has a negligible impact on the assimilation.

# TCCON COMPARISON (AUG. 2018)

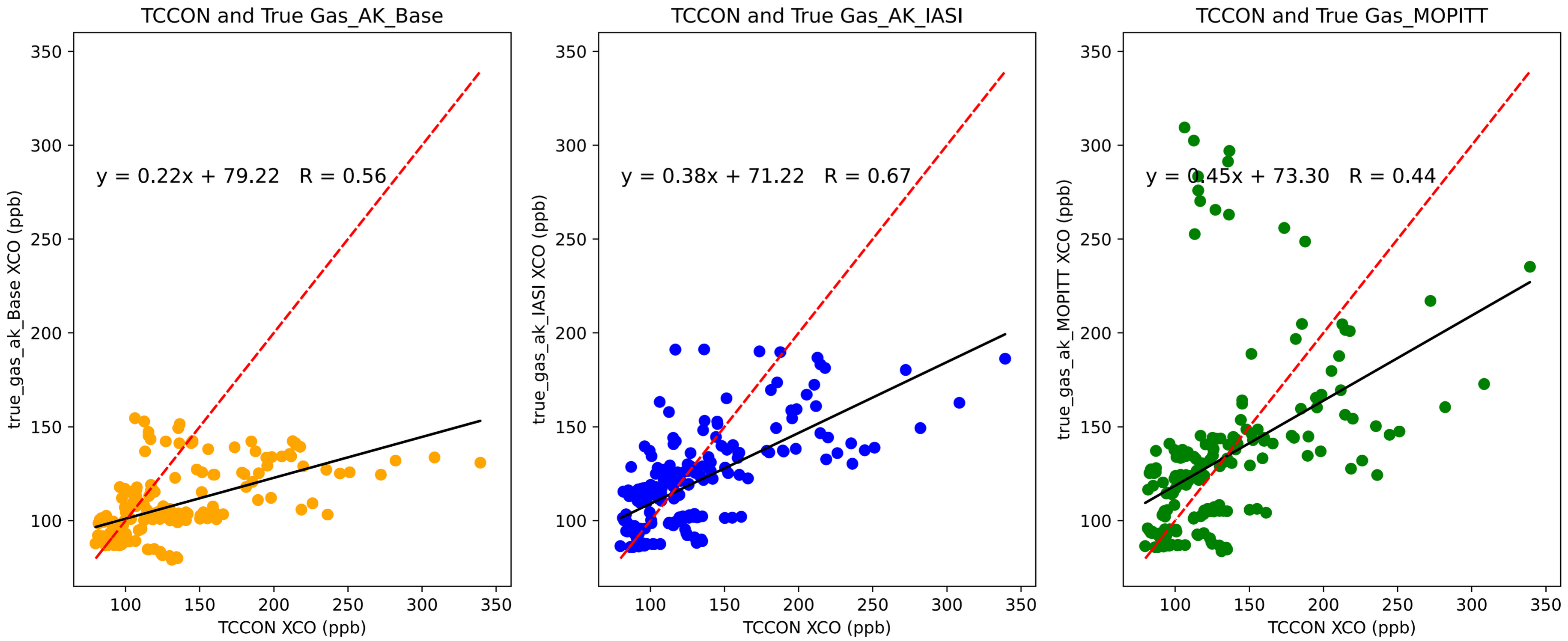
## With Weekly and 4-day Scaling




with weekly scaling




with 4-day scaling factors

ASSESSING WILDFIRE EMISSIONS OF CO

# Conclusions

- Wildfires are episodic; thus, quantifying these emissions with scaling factors on coarse temporal (and spatial) scales is challenging.
- Ideally, we should quantify these emissions on daily temporal scales, but it is unclear whether the observations have sufficient information for this. TROPOMI data might be valuable in this context.
- Biases in the observations due to aerosols from the fires could contribute to some of the differences in the inversions obtained here.
- The inversions will be sensitive to the altitude at which the model injects the fire emissions and the different vertical sensitivities of the observing instruments. GEOS-Chem uniformly, and perhaps, incorrectly, injects the emissions between the surface and the mean altitude of maximum injection specified in GFAS.

# Future Work

- Assimilate TROPOMI CO data
- GFAS injection heights
- Nested model

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