Wildfire Emission Factor Uncertainty and Modeled Atmospheric CO and O3

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Abstract

Wildfire emissions can vary substantially between different inventories due to the assumptions made in the emission creation process, including the defined vegetation type, fire detection, fuel loading, fraction of vegetation burned and emissions factors. Here, we focus on the uncertainty in emission factors and the resulting impact on modeled composition. We use the Community Atmosphere Model with chemistry (CAM-chem) to simulate 2014 atmospheric composition and focus on carbon monoxide (CO), a trace gas emitted from incomplete combustion and also produced from secondary oxidation of volatile organic compounds (VOCs). Fire is a major source of atmospheric CO and VOCs. Multiple simulations are compared, from an ensemble using four fire emission inventories (CMIP6/GFED4s, QFED2.5, GFAS1.2 and FINN1.5) and a range of sensitivity tests based on CO and VOC emission factor uncertainties. We compare model output and evaluate against CO observations from the Measurements of Pollution in the Troposphere (MOPITT) satellite-based instrument. For some regions, emission factor uncertainty spans the results found by using different inventories. Finally, we use modeled ozone (O3) to investigate how emission factor uncertainty influences the atmospheric oxidative environment. Overall, accounting for emission factor uncertainty lends a range of uncertainty to simulated results.

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Fire emissions impact air quality, weather and climate

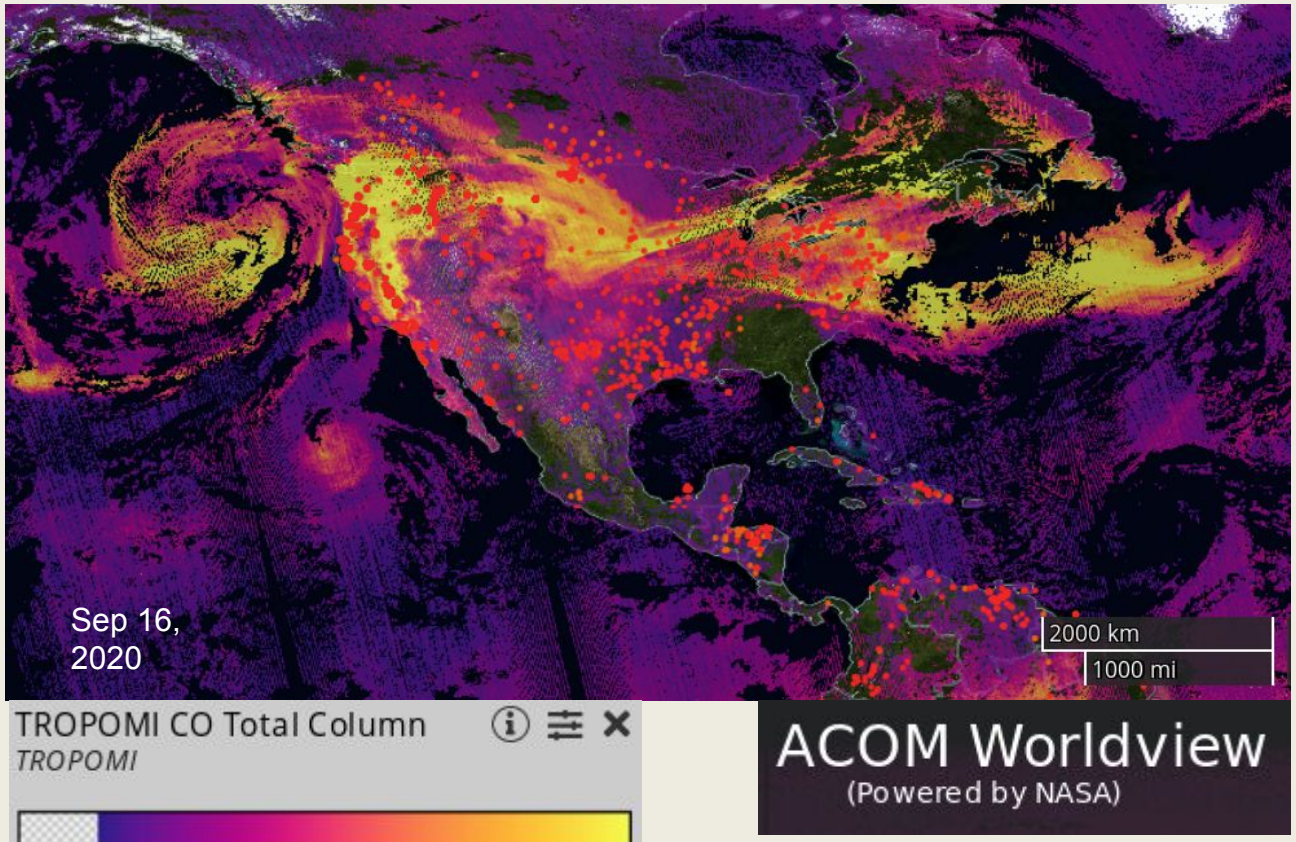
Trace gases and aerosols emitted from fires degrade air quality: tropospheric ozone (O_3), $PM_{2.5}$

Fire aerosols change weather properties: clouds, precipitation

Two-way climate feedback

Large differences have been found between global inventories of emissions

- **Quantify the role of uncertainty in fire emission factors**



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Creating global fire emissions

Method 1

Burned area
x
Biomass loading and fraction burned

CMIP6 a.k.a GFED FINN (active fire)

Fuel consumption
(kg C burned)

x

Biome-specific
Emission Factors
kg/kgC

Determined from field and laboratory studies
(e.g. [1] Akagi et al. 2011)

Emissions
(2014)

Method 2

Fire radiative power (FRP)
x
Biome-specific conversion factors

GFAS QFED

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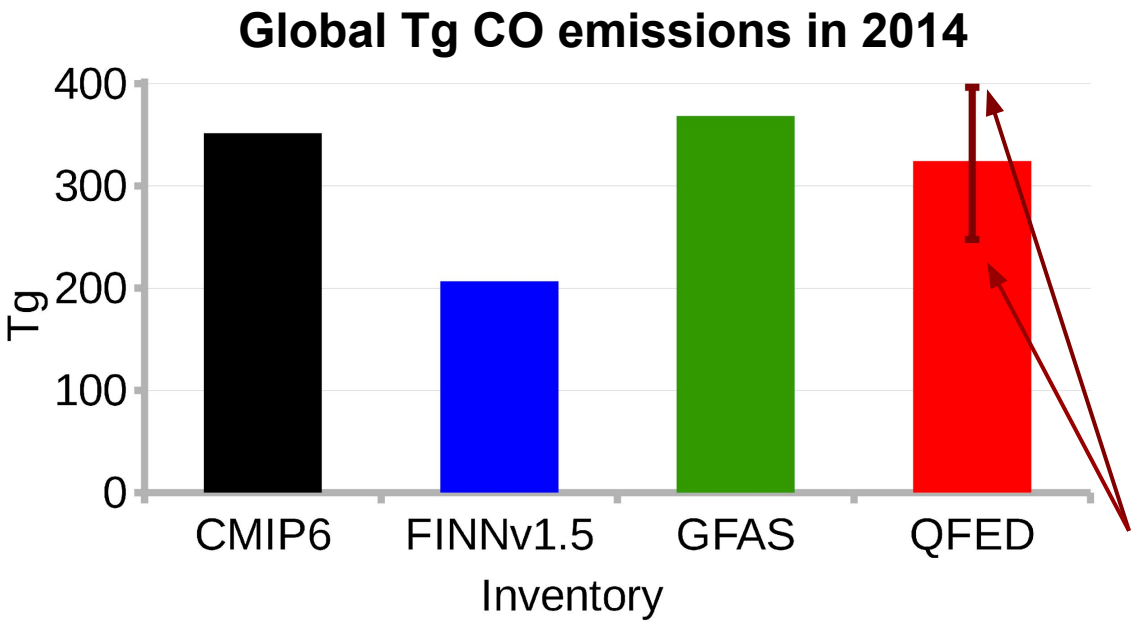
Comparing carbon monoxide (CO) emissions globally, 2014



CO from four inventories:

- **CMIP6 v1.2** - Coupled Model Intercomprison Project (based on GFED4s)[2]
- **FINN v1.5** - Fire INventory from NCAR [3]
- **GFAS v1.2** - Global Fire Assimilation System (ECMWF-CAMS) [4,5]
- **QFED v2.5** - Quick Fire Emissions Dataset (NASA/NCAR hybrid)[6]

CO emission factor uncertainties are used to create minimum and maximum emissions for the QFED inventory

- 6 simulations of CO-only changes

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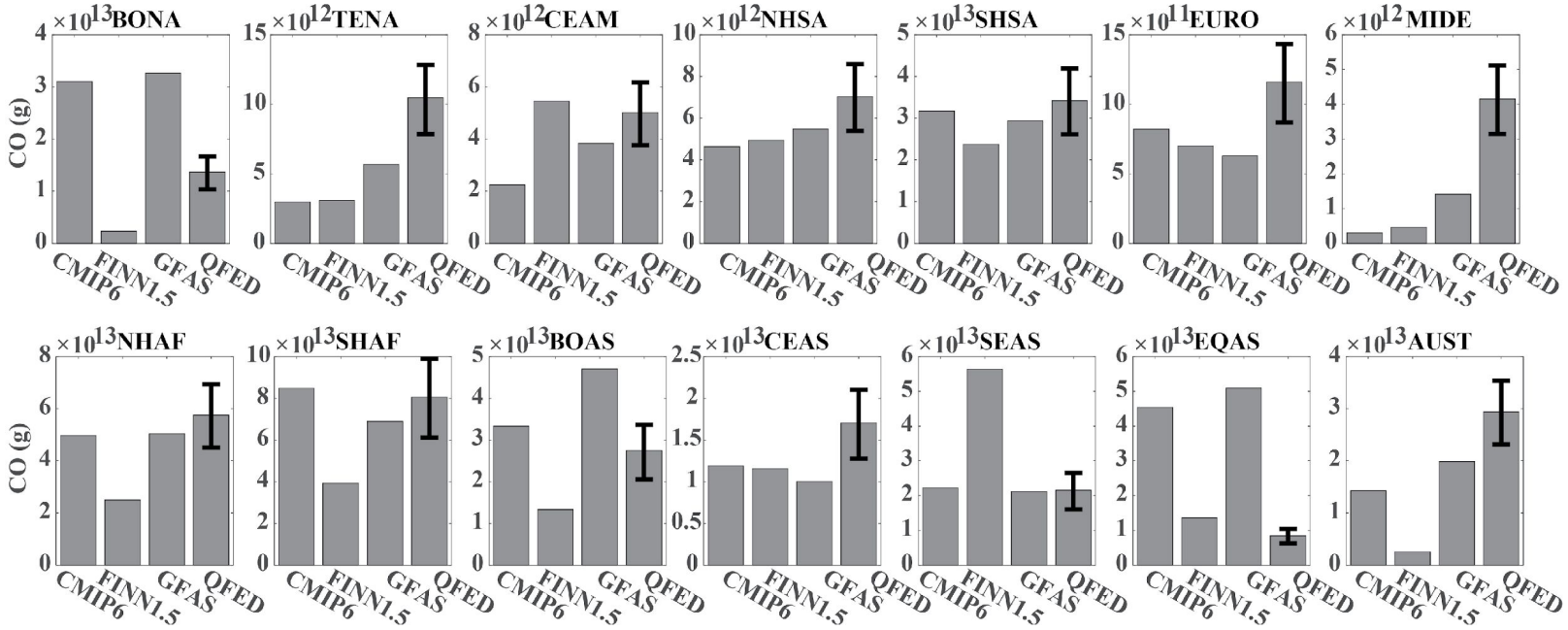
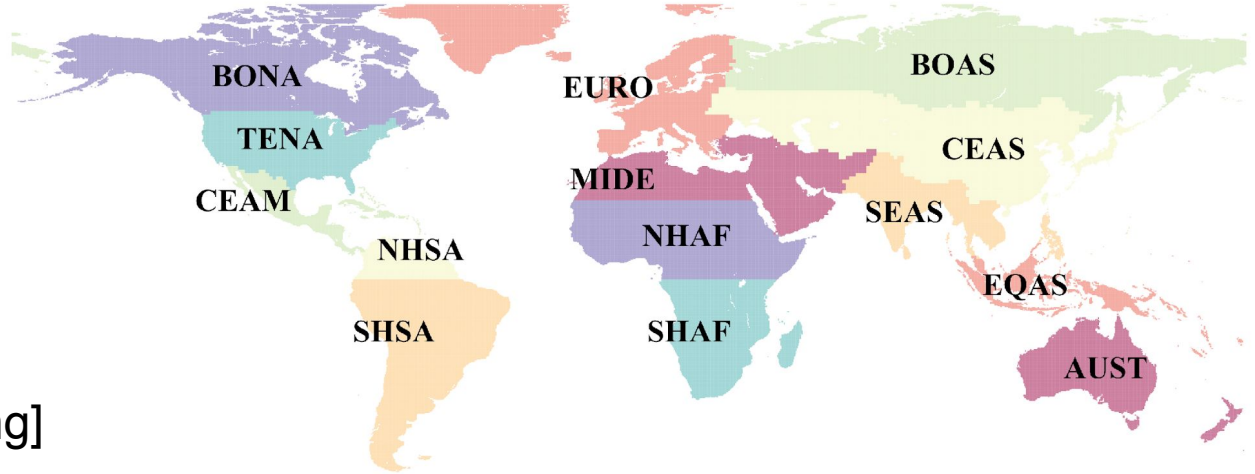
CO emissions in different regions





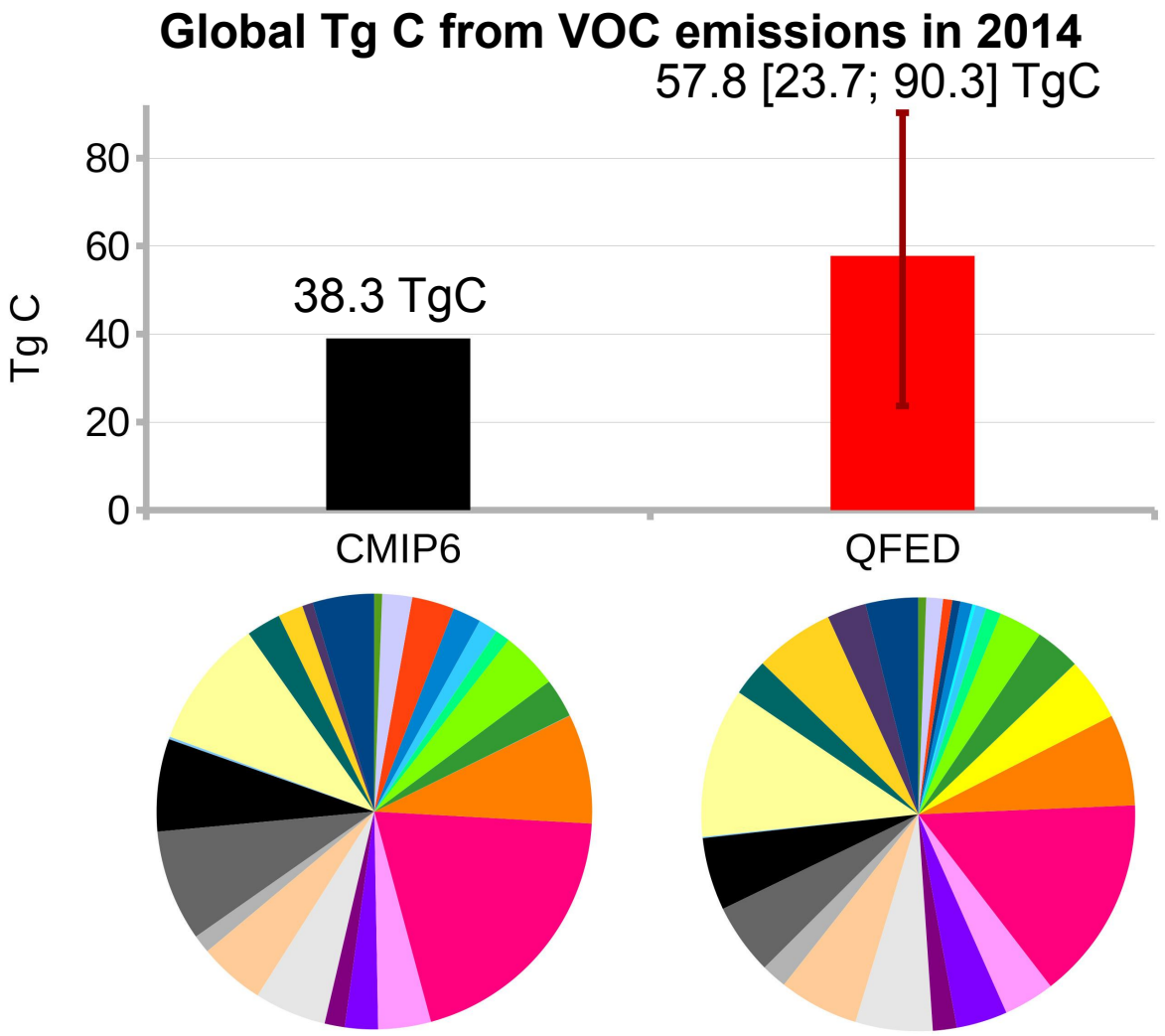
[W. Tang]

2014 emissions in the 14 GFED regions

([7] Giglio et al., 2006)

Different regions → different inventories have the highest fire CO emissions

Volatile organic compounds (VOC) global emissions, 2014



- Species co-emitted with CO will impact the atmospheric oxidation capacity
- All QFED emissions, plus their respective emission factor uncertainties (all + or all -)
- 3 extra simulations

BENZ
BIGALK
BIGENE
C2H2
C2H4
C2H5OH
C2H6
C3H6
C3H8
CH2O
CH3CHO
CH3CN
CH3COCH3
CH3COCHO
CH3COOH
CH3OH
CRESOL (QFED only)
DMS
GLYALD
HCN
HCOOH
ISOP
MACR (QFED only)
MEK
MVK (QFED only)
TERPENES
TOLUENE
XYLENE

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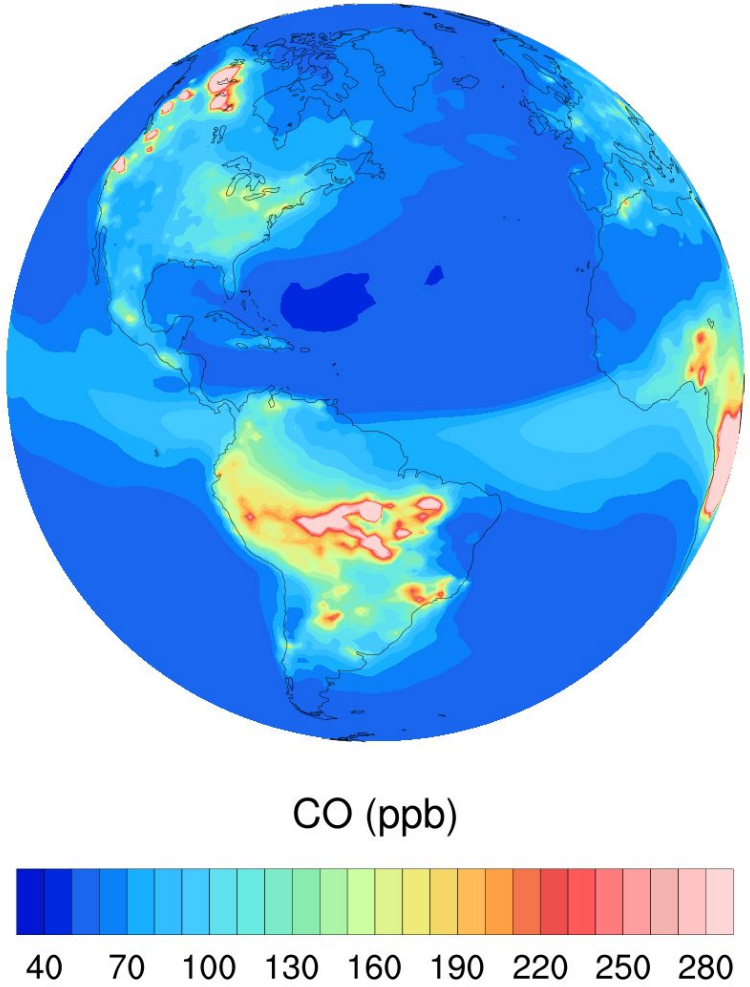
Exploring chemistry using a global model

- CESM2.0 full chemistry
- 0.92° ×1.25° horizontal resolution
- 32 level vertical resolution
- T1 Chemistry ([8] Emmons et al., 2020)
- Specified dynamics: MERRA2 nudged at 1%
- Emissions:
  - Biogenic - MEGAN coupled to CLM
  - Anthropogenic - CMIP6
  - Fire - sensitivity studies, mainly look at QFED

CAM-chem surface CO, August 2014



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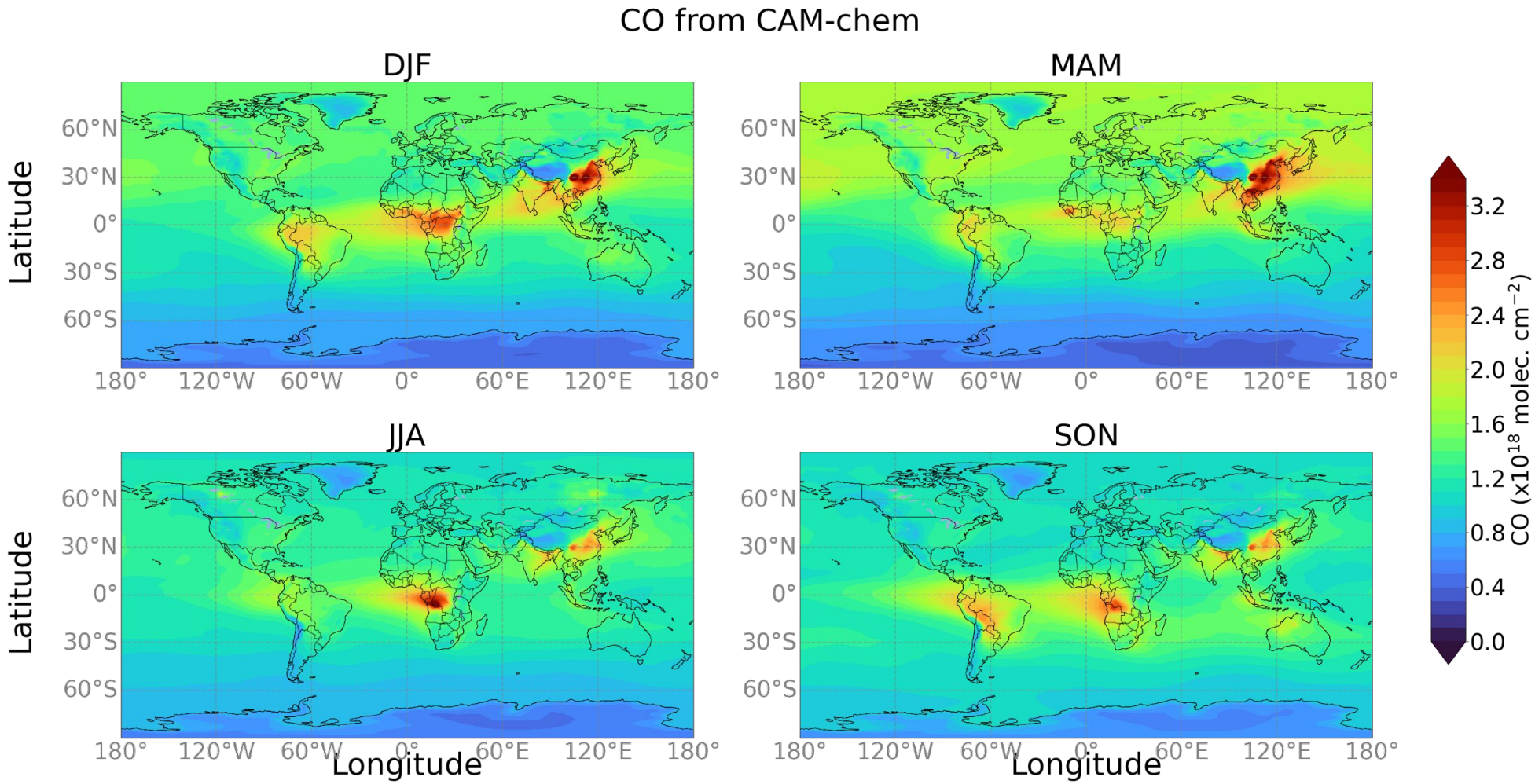
Simulated column CO seasonal averages: using QFED emissions

CO is produced by incomplete combustion

Large amounts of column CO over regions dominated by fire emissions or large sources of anthropogenic emissions



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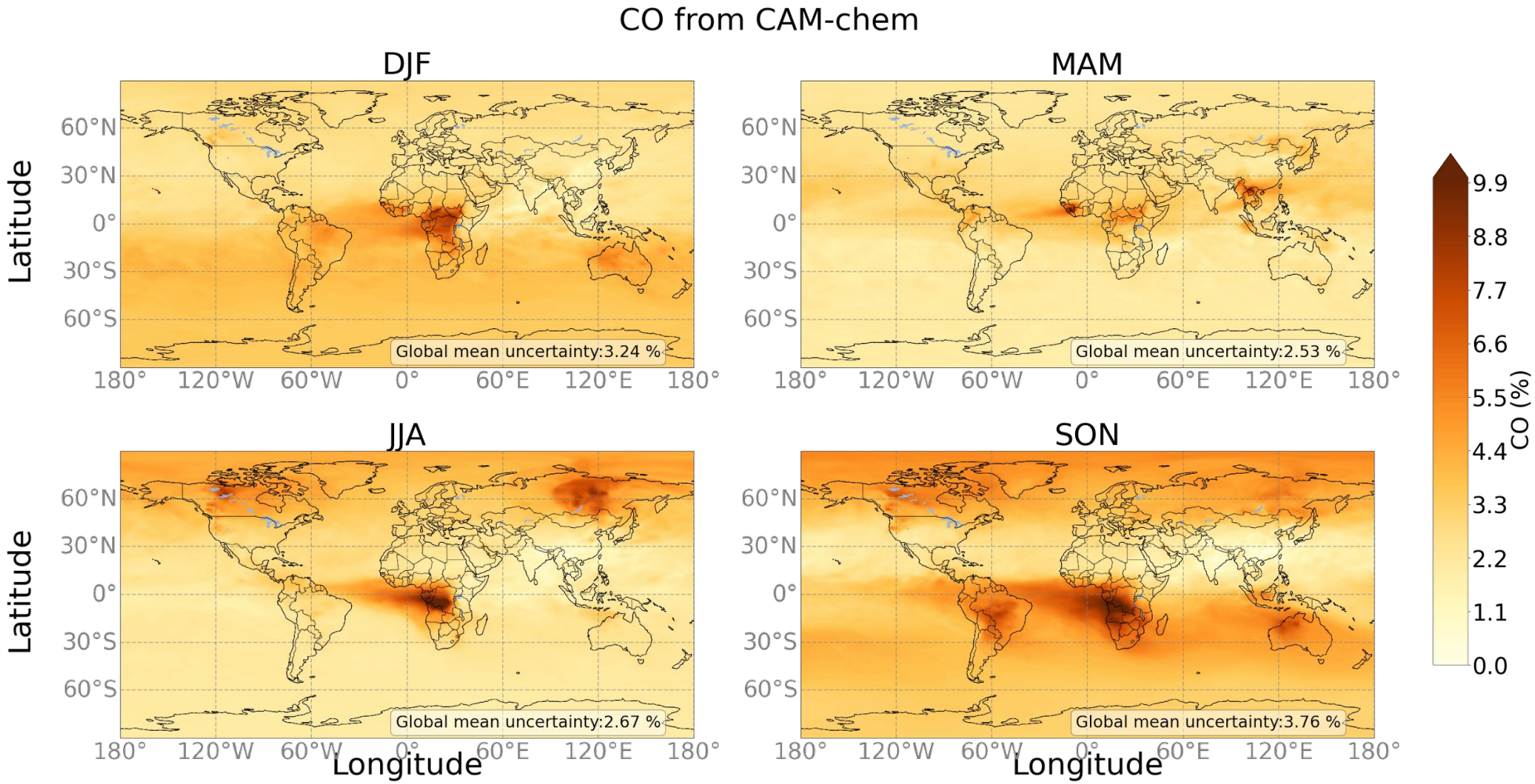
Seasonal uncertainty in column CO

Only including uncertainty in CO fire emission factors

Global:

CO E.F uncert: 3.1%



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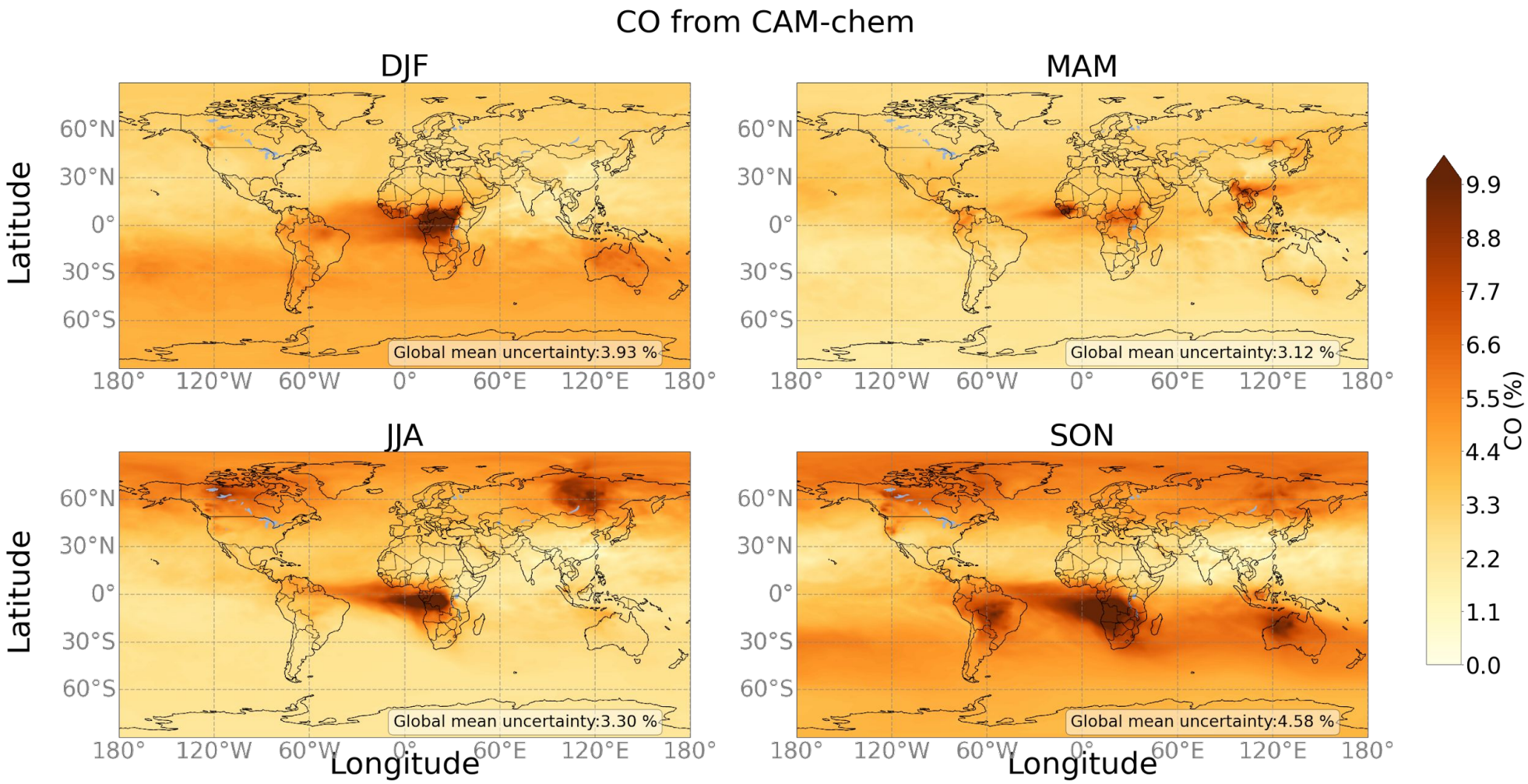
Seasonal uncertainty in column CO

Including uncertainty in all fire emission factors

Global:
CO E.F uncert: 3.1%
All E.F uncert: 3.7%



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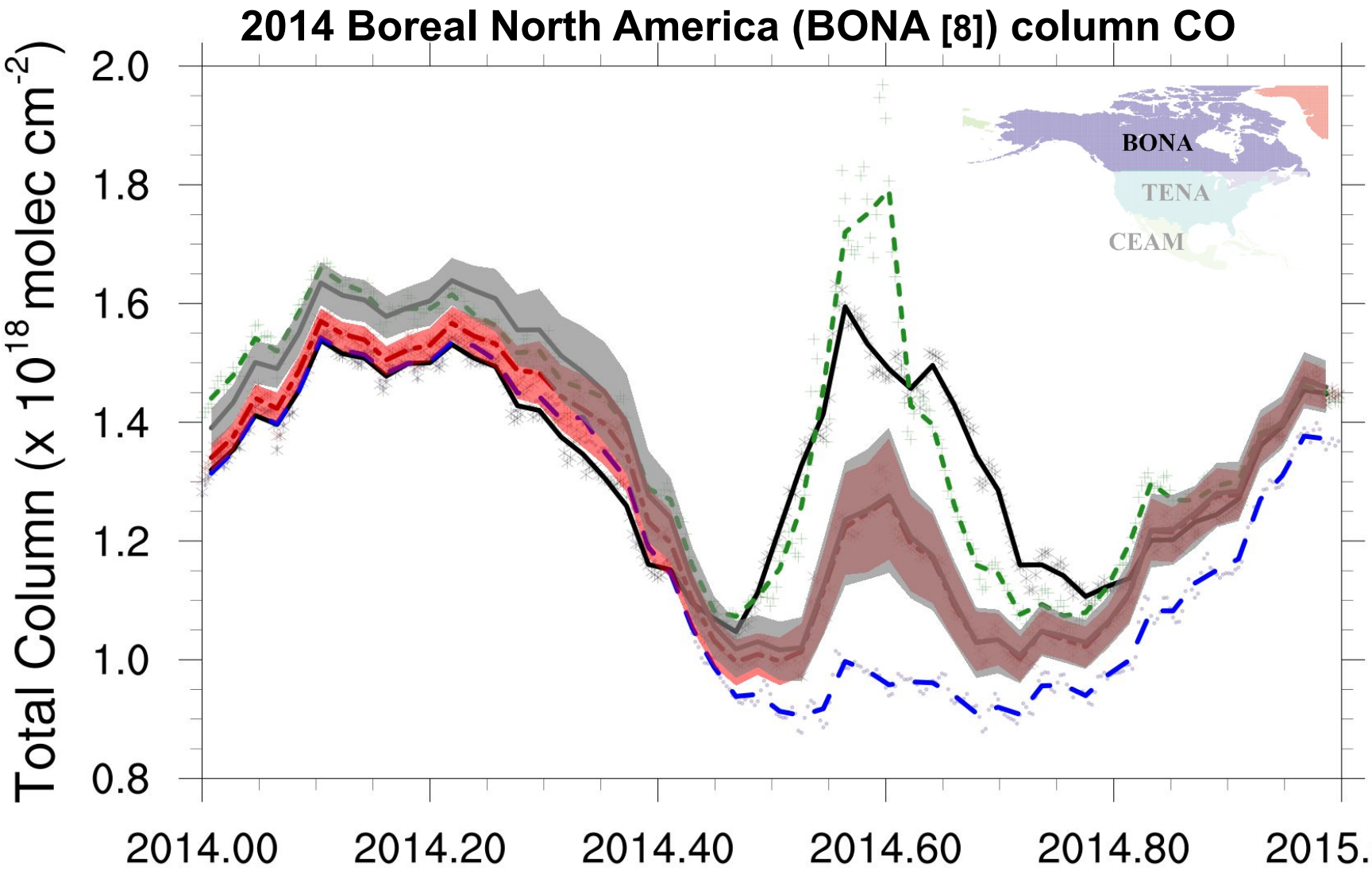
Temporal evolution of uncertainty



- **CMIP6 v1.2**
- **FINN v1.5**
- **GFAS v1.2**
- **QFED v2.5**
  +/- CO uncert
- **QFED v2.5**
  +/- all uncert

Outside the fire season, emission factor uncertainty bounds inventory differences.

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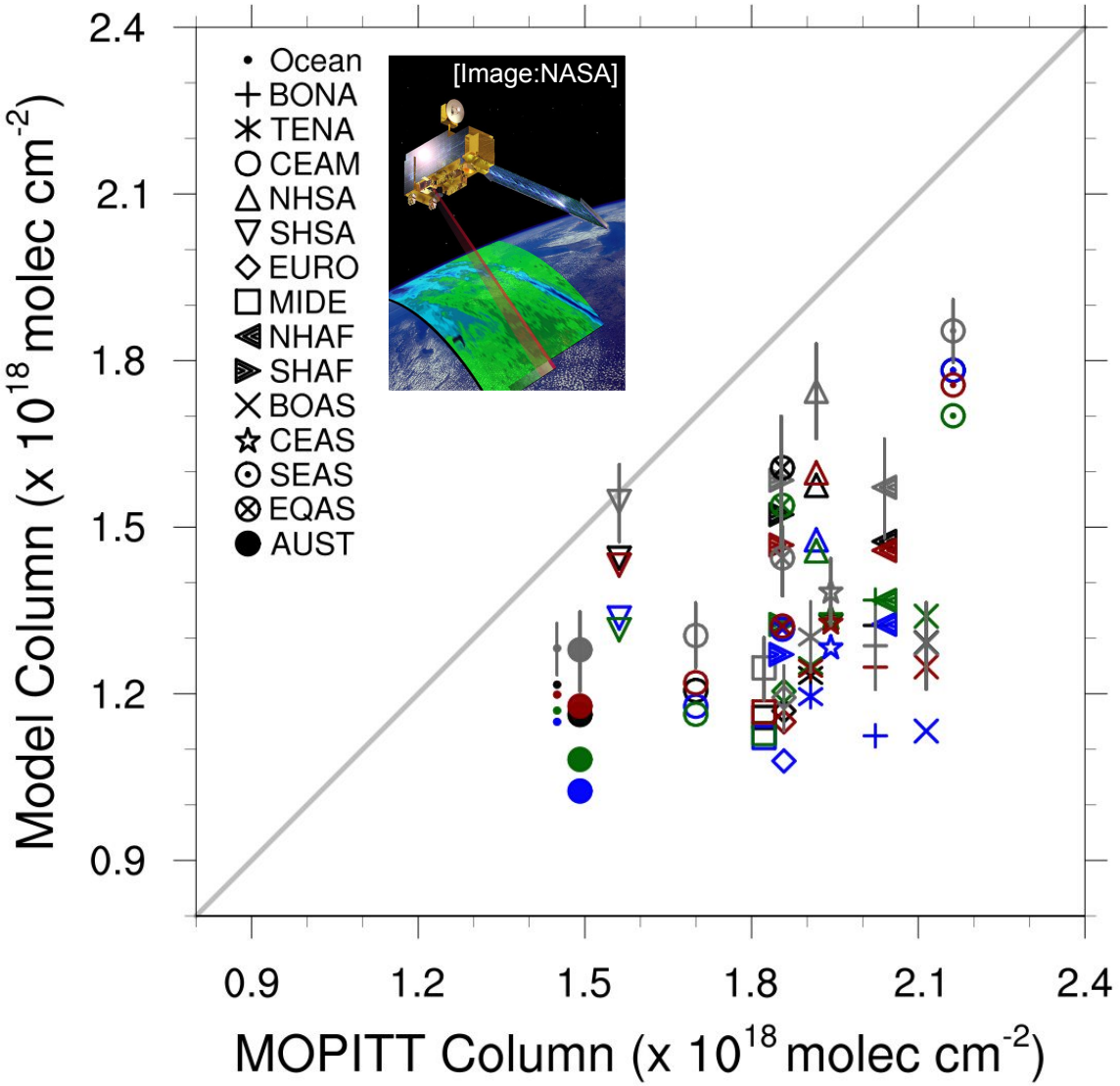
Regional annual CO comparisons with Terra/MOPITT



Model underestimates measurements

Regional differences

- **CMIP6 v1.2**
- **FINN v1.5**
- **GFAS v1.2**
- **QFED v2.5 +/- CO uncert**
- **QFED v2.5 +/- all uncert**

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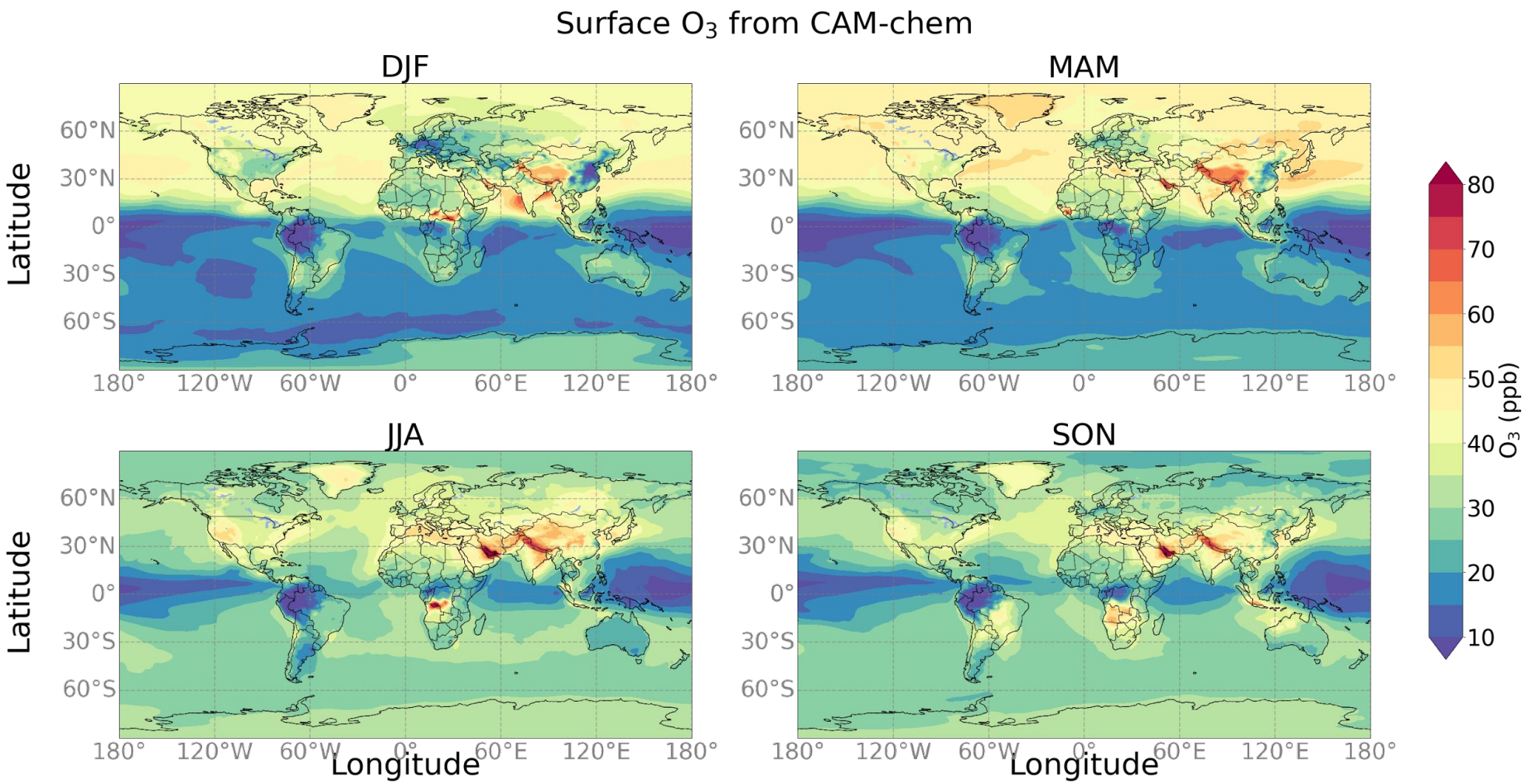
Surface layer ozone (O_3) from simulations with QFED

O_3 is created photochemically

Relationship to emissions is complex



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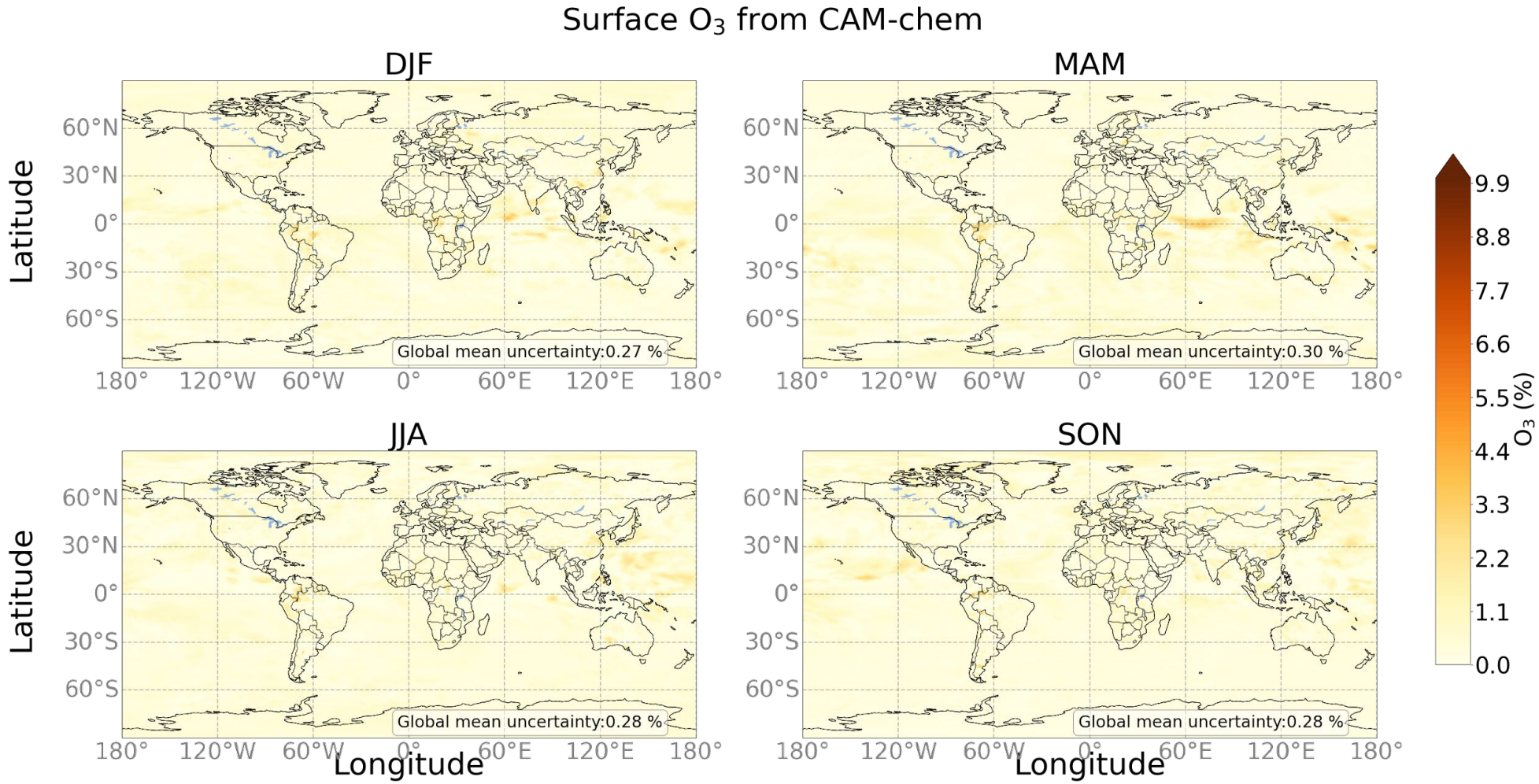
Seasonal uncertainty in surface O_3

Only including uncertainty in CO fire emission factors

Global:

CO E.F uncert: 0.3%



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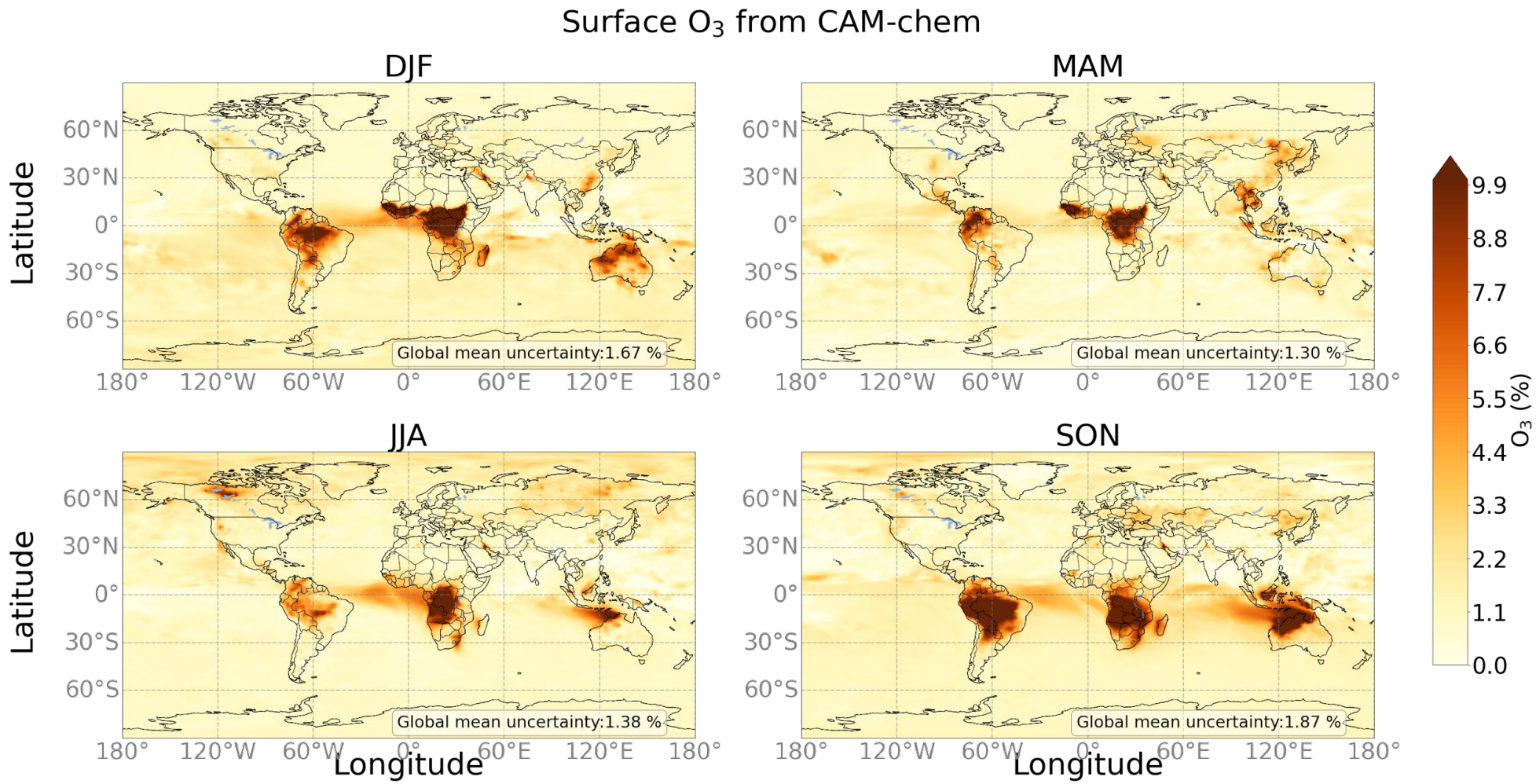
Seasonal uncertainty in surface O_3

Including uncertainty in all fire emission factors

Global:

CO E.F uncert: 0.3%

All E.F uncert: 1.6%



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Summary

Fire emission factor uncertainty can explain some differences between global inventories. Remaining differences are likely due to algorithm differences such as land cover used, fire detection and cloud handling.

CO emission factor uncertainty results in global average ~3.1% uncertainty in modeled column CO. All emission factor uncertainties adds an extra ~0.6%.

Most uncertainty in surface O_3 originates from all fire emission factor uncertainties, which contributes ~1.6% uncertainty globally.

Regional evaluation of modeling with global inventories is essential.

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References

Emission Factors: **[1]** Akagi, S. K., et al. (2011), Atmos. Chem. Phys. 11, 4039-4027

CMIP6: **[2]** van Marle, M. J. E.,et al., (2017), Geosci. Model Dev., 10, 3329-3357, https://doi.org/10.5194/gmd-10-3329-2017.

FINN: **[3]** Wiedinmyer, C., et al., (2011): Geosci. Model Dev., 4, 625-641, https://doi.org/10.5194/gmd-4-625-2011.

GFAS: **[4]** Kaiser, J. W., et al. (2012), 9, 527–554, Biogeosciences https://doi.org/10.5194/bg-9-527-2012.
[5] Di Giuseppe, F., et al., (2018), Atmos. Chem. Phys., 18, 5359–5370, https://doi.org/10.5194/acp-18-5359-2018.

QFED: **[6]** Darmenov, A. & da Silva, A.(2015), NASA GMAO Technical Report, Vol. 38, 183 pp., available at: https://gmao.gsfc.nasa.gov/pubs/docs/Darmenov796.pdf

Region definitions: **[7]** Giglio, L., et al., (2006), Atmos. Chem. Phys., 6, 957-974, https://doi.org/10.5194/acp-6-957-2006.

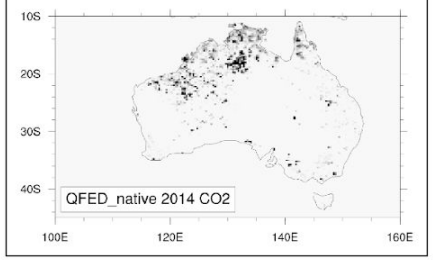
CAM-chem T1 Chemistry: **[8]** Emmons, L. K., et al., (2020). JAMES, 12, e2019MS001882, https://doi.org/10.1029/2019MS001882.

Artwork on slide 3 by Caparelli ArtNScience

Extra: Creating emission bounds

How emission bounds are created using emission factor uncertainties

QFED CO_2 emissions



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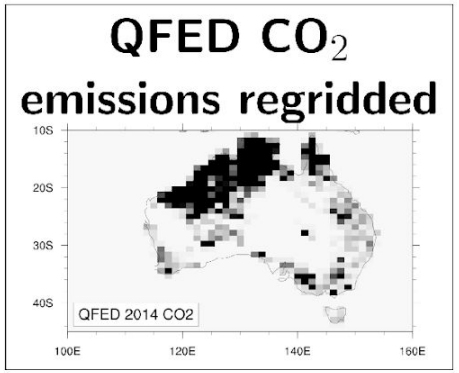
QFED CO_2 emissions regridded



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Emission Ratios:

$$\frac{\text{Species E.F.} \pm \sigma_s}{\text{CO}_2\ \text{E.F.} \pm \sigma_{CO_2}}$$

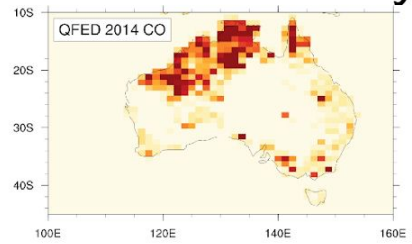
E.F. = emission factor

$\sigma = uncertainty$

Created using emission factors compiled for FINN.
Applied separately over four biomes.

→

QFED emissions for CAM-chem Three files: mean, max = + uncertainty, min = -uncertainty



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