

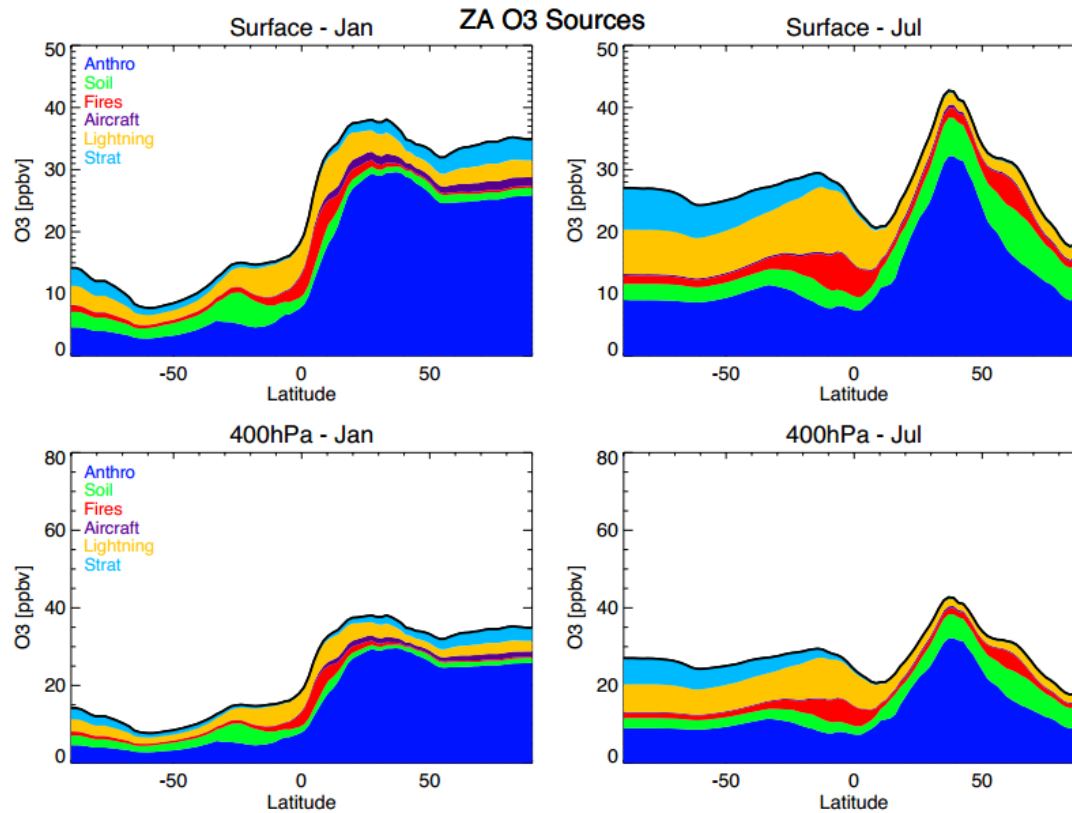
# **TOAST**

## **Tropospheric Ozone Attribution of Sources with Tagging in CAM4-chem**

Tim Butler, Aurelia Lupascu, Aditya Nalam

Institute for Advanced Sustainability Studies, Potsdam  
([tim.butler@iass-potsdam.de](mailto:tim.butler@iass-potsdam.de))

Chemistry-Climate WG meeting, NCAR, 21.02.2019



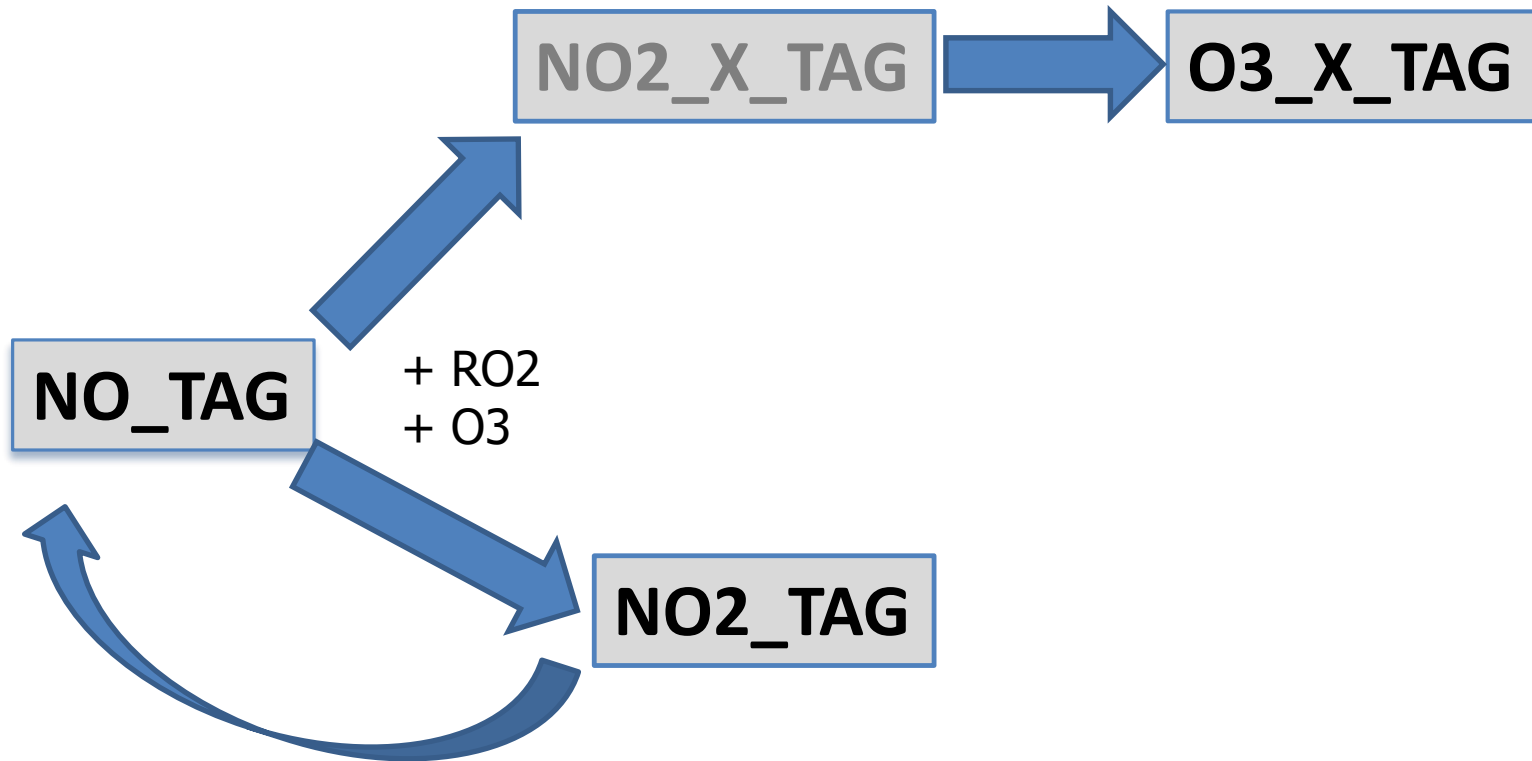
**Fig. 6.** Zonal average of tagged ozone source contributions at the surface and at 400 hPa, for January and July of 2008. Stratospheric contribution is determined as the difference between total ozone and tagged ozone from all tropospheric sources combined. Emmons et al. (2012)

# Benefits of TOAST

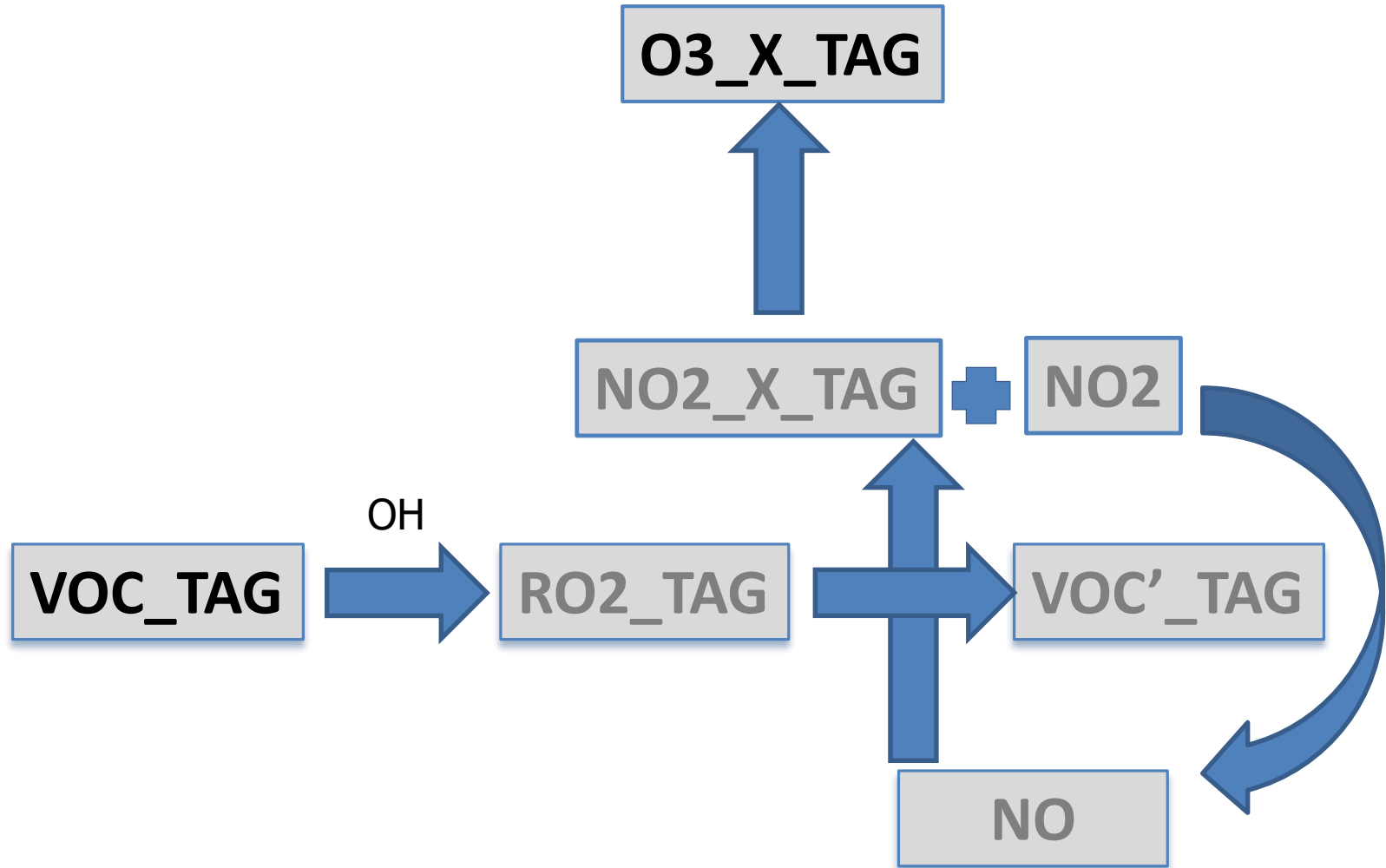


- Multiple tags in one model run
- Explicitly tagged stratospheric ozone
  - Oxygen photolysis
  - Upper boundary adjustment
- 100% closed ozone budget
  - User's responsibility to provide tagged emissions
- Tagging of VOCs (!)
  - Separate run required
- O<sub>3</sub>-NO<sub>x</sub> "null cycle" does not overwrite tags
  - $\text{NO} + \text{O}_3 \rightarrow \text{NO}_2 \rightarrow \text{NO} + \text{O} \rightarrow \text{O}_3$
  - $\text{NO}_A + \text{O}_3_B \rightarrow \text{NO}_2_{??}$

# NO<sub>x</sub> tagging schematic



# VOC tagging schematic



For more details...



Geosci. Model Dev., 11, 2825–2840, 2018  
<https://doi.org/10.5194/gmd-11-2825-2018>  
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## TOAST 1.0: Tropospheric Ozone Attribution of Sources with Tagging for CESM 1.2.2

Tim Butler<sup>1</sup>, Aurelia Lupascu<sup>1</sup>, Jane Coates<sup>1</sup>, and Shuai Zhu<sup>1,a</sup>

<sup>1</sup>Institute for Advanced Sustainability Studies, Potsdam, Germany

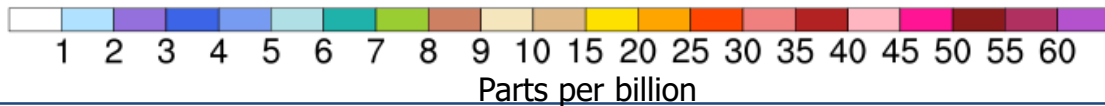
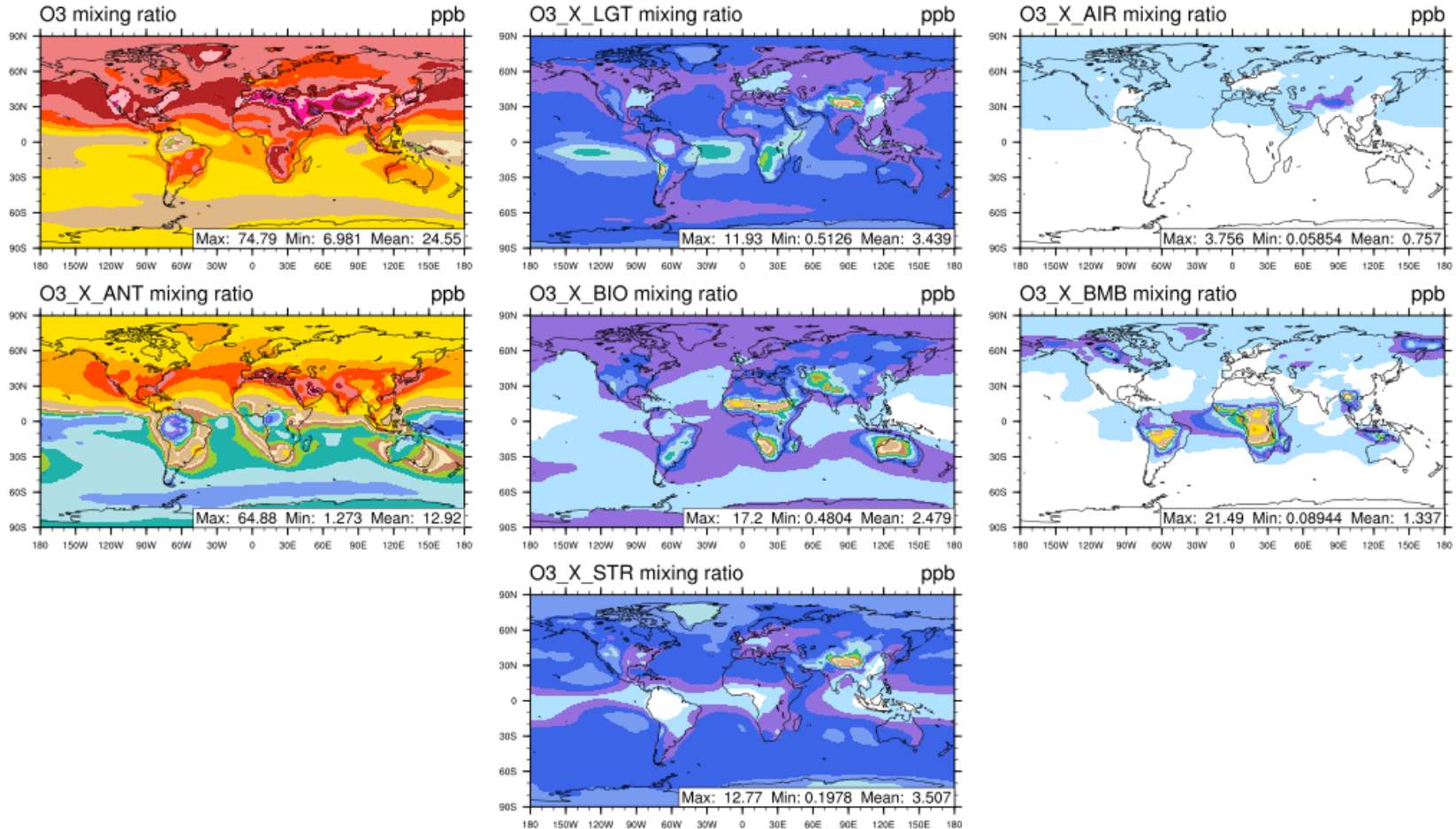
<sup>a</sup>now at: China Unicom System Integration Limited Corporation, Beijing, China

**Correspondence:** Tim Butler ([tim.butler@iass-potsdam.de](mailto:tim.butler@iass-potsdam.de))

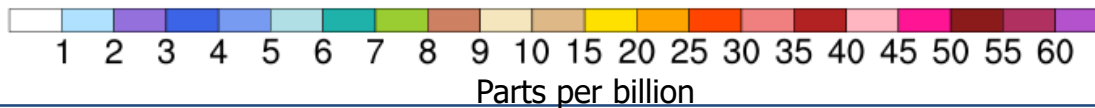
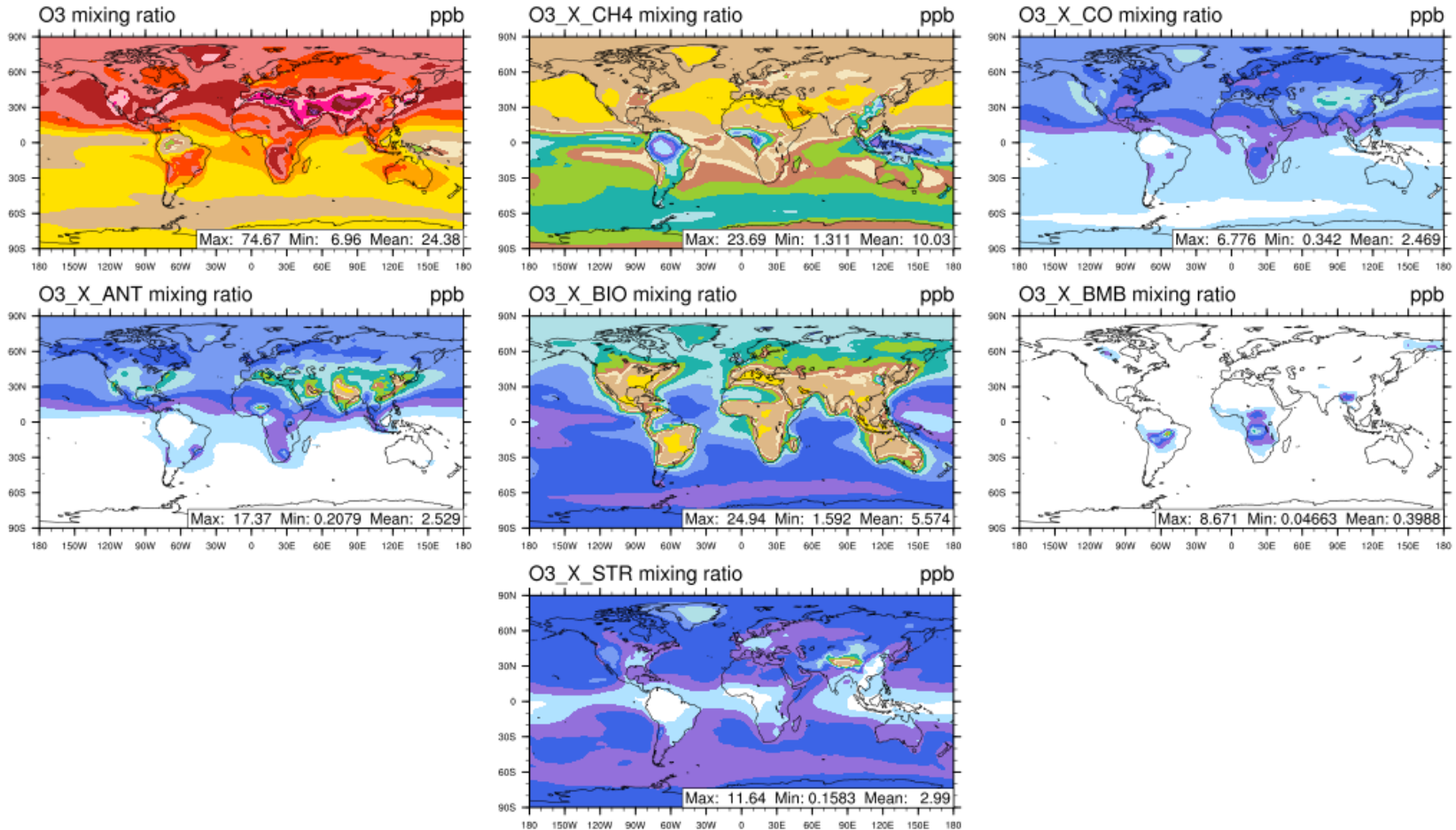
Received: 26 February 2018 – Discussion started: 12 March 2018

Revised: 5 June 2018 – Accepted: 13 June 2018 – Published: 13 July 2018

# Annual average surface ozone: NO<sub>x</sub>-tagged



# Annual average surface ozone: VOC-tagged



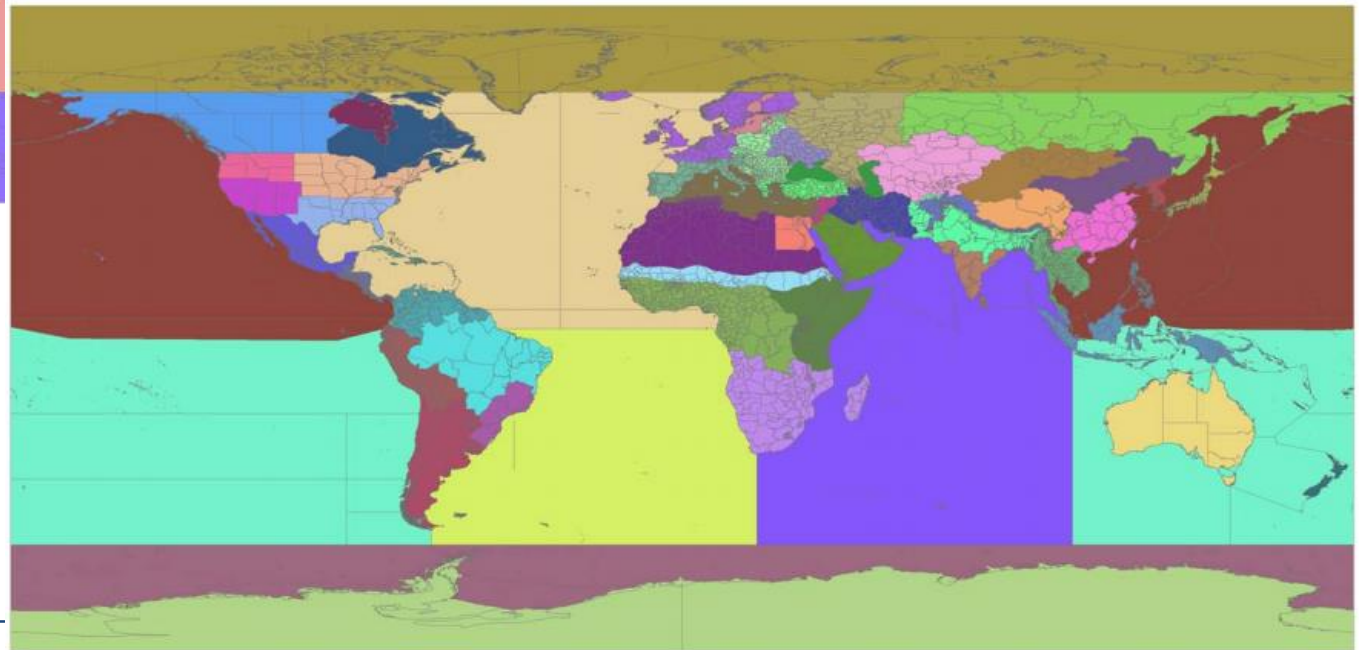
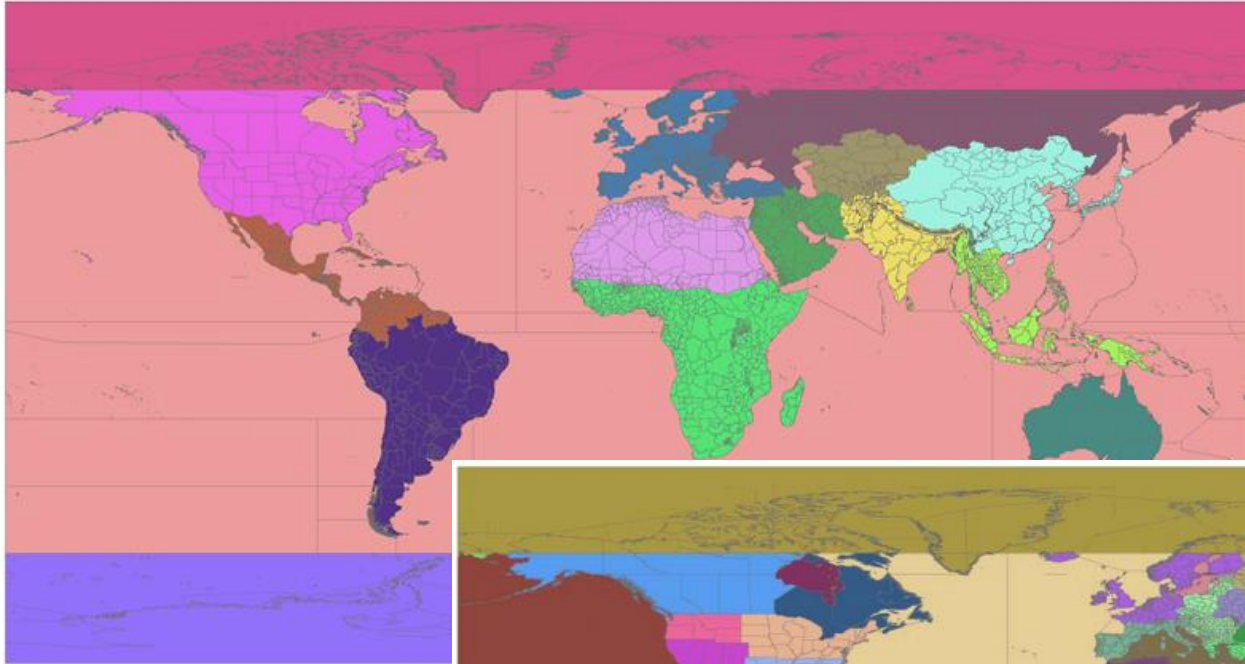


## Contribution to tropospheric ozone burden

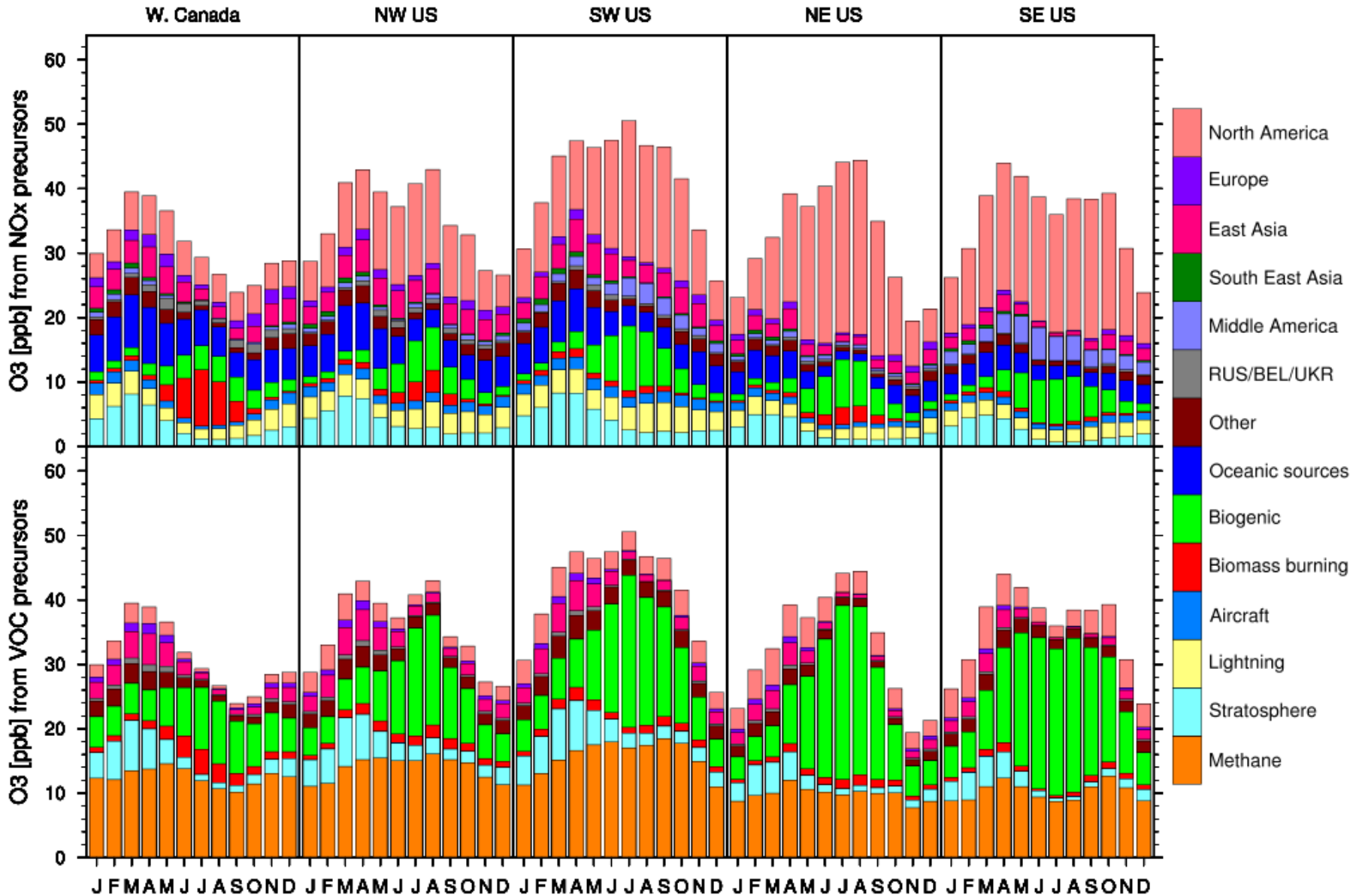
Source tag (NO <sub>x</sub> tagging)	Contribution to tropospheric ozone burden (Tg)	Percent contribution
Stratosphere	75.7	23.7
Anthropogenic	111	34.9
Lightning	81.2	25.4
Biogenic	26.1	8.17
Aircraft	12.3	3.84
Biomass burning	11.5	3.59
Other	1.47	0.46

Source tag (VOC tagging)	Contribution to tropospheric ozone burden (Tg)				Percent contribution
	Anthropogenic	Biogenic	Biomass burning	Total	
Stratosphere	–	–	–	66.9	20.9
Methane	–	–	–	113	35.4
NMVOC	26.4	73.1	4.25	104	32.5
CO	18.6	3.24	9.43	31.3	9.78
Other	–	–	–	4.65	1.45

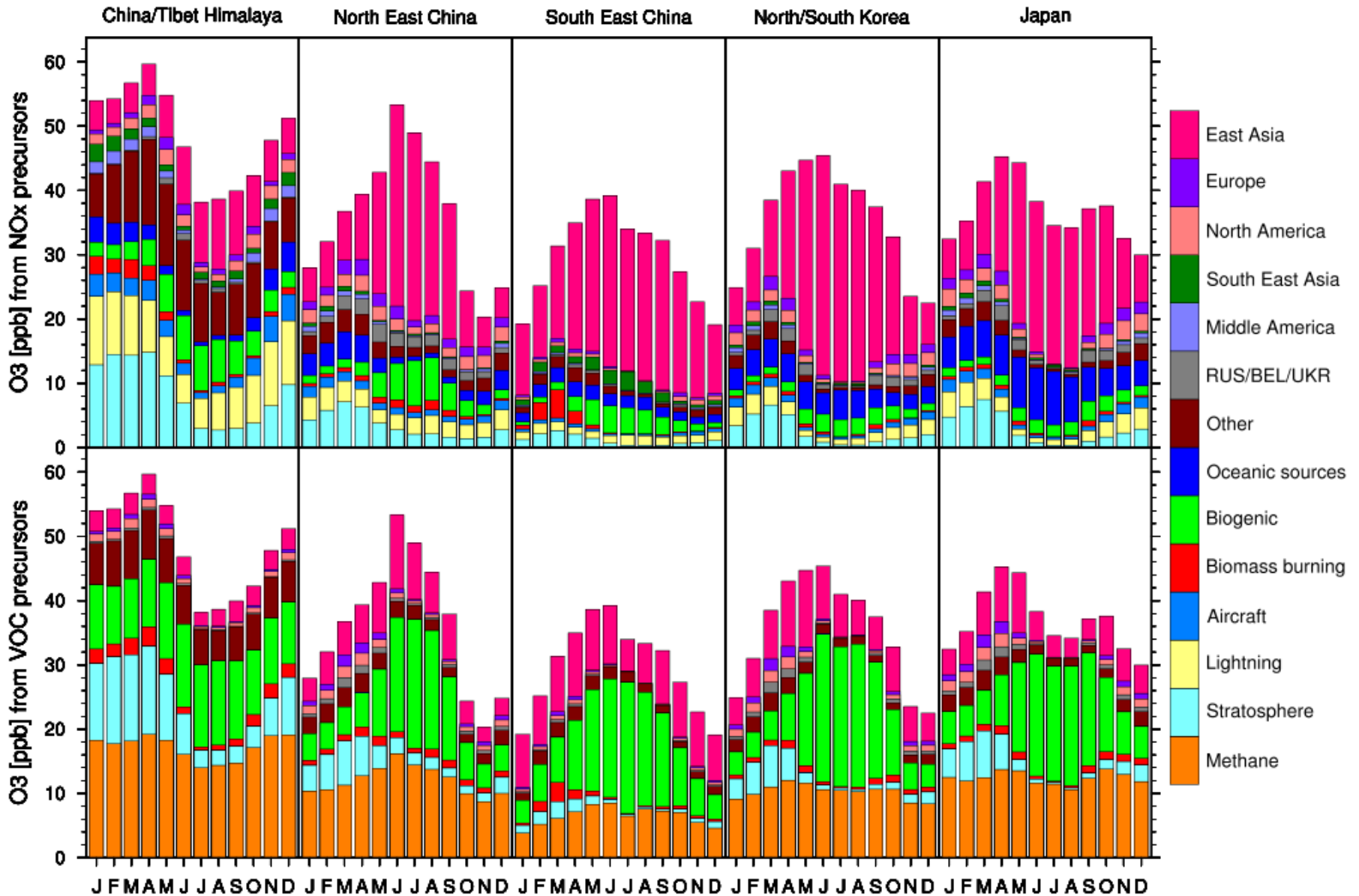
# Application: HTAP source/receptor relationships



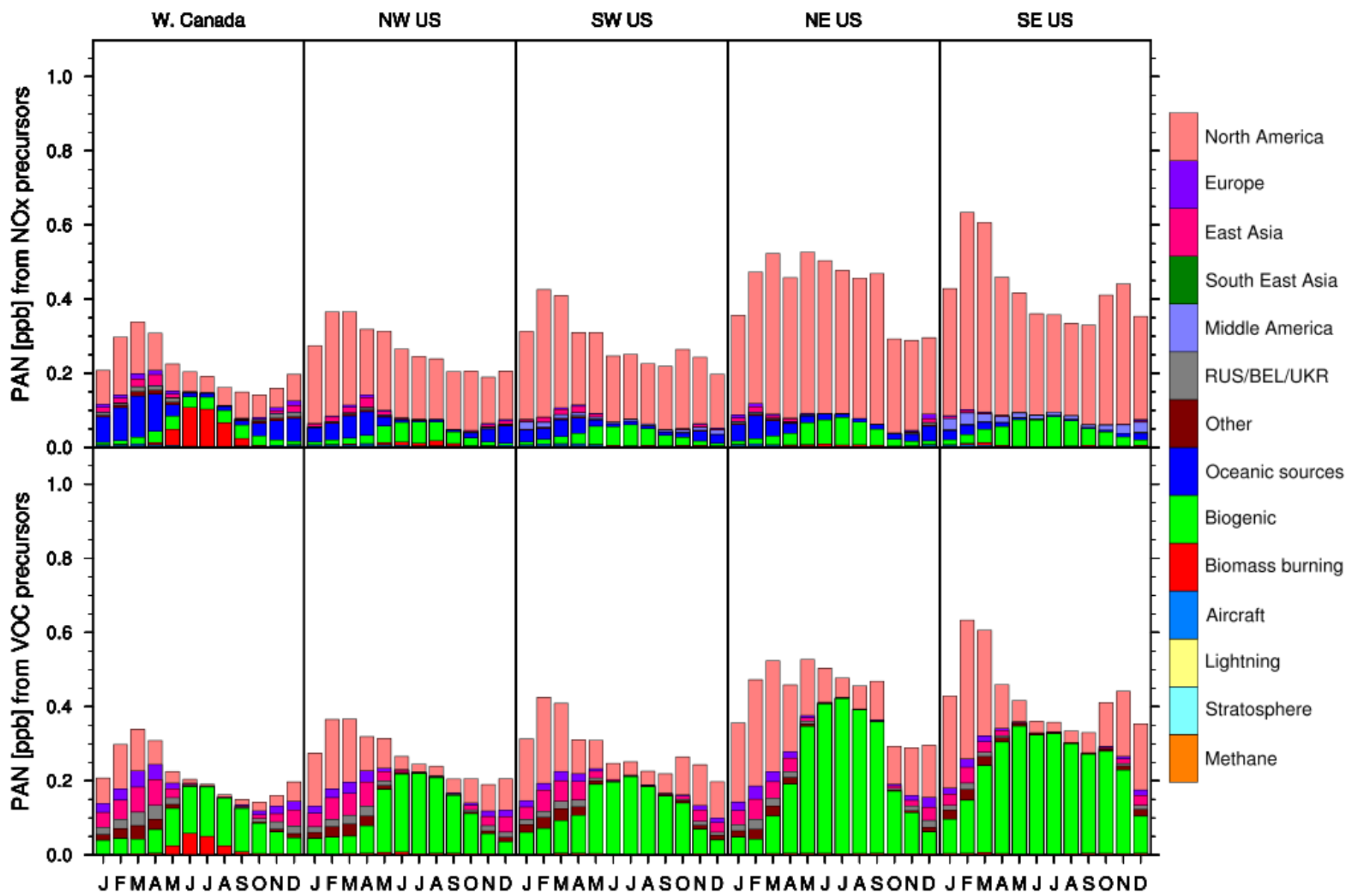
# Seasonal cycle of surface ozone: North America



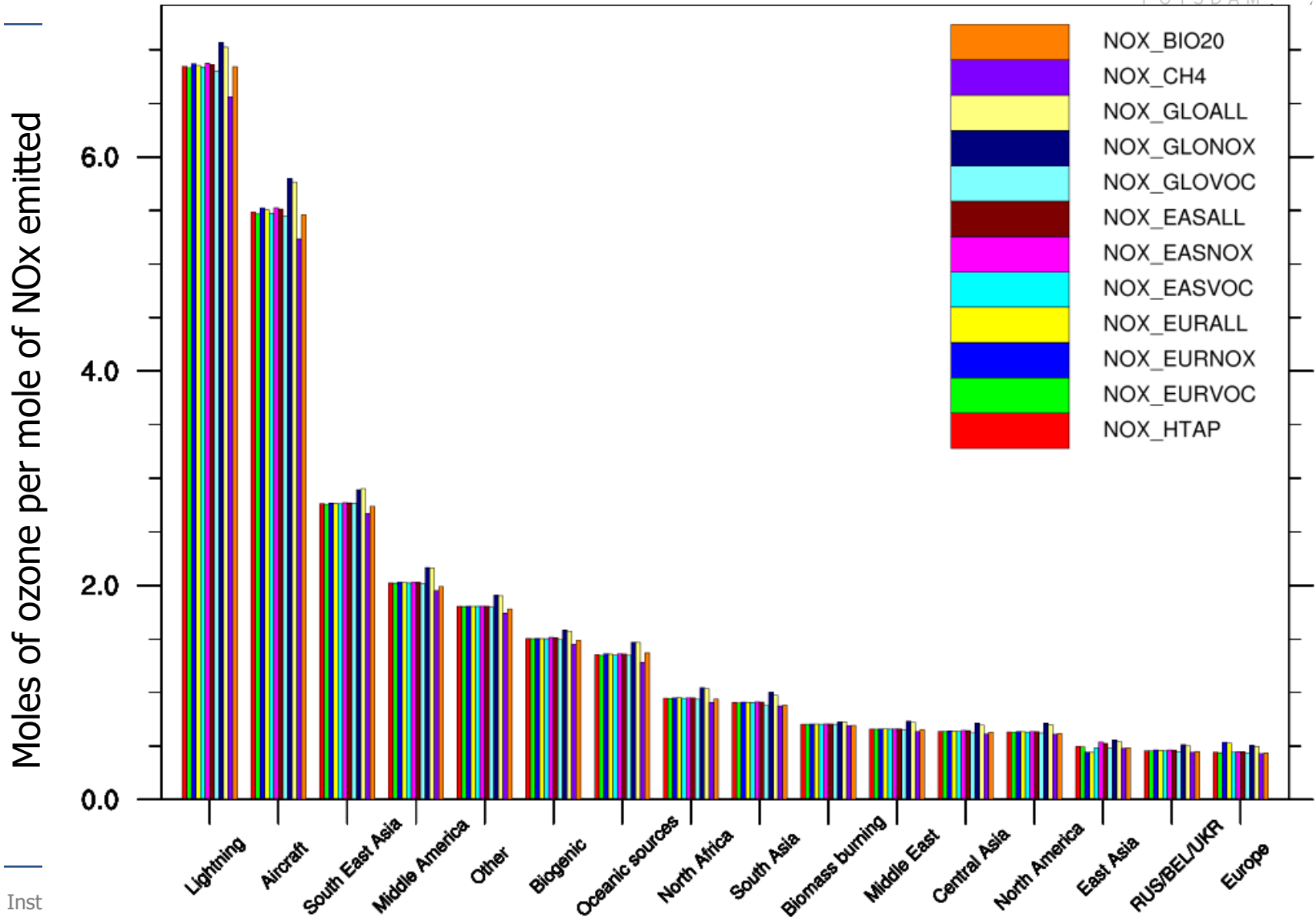
# Seasonal cycle of surface ozone: East Asia



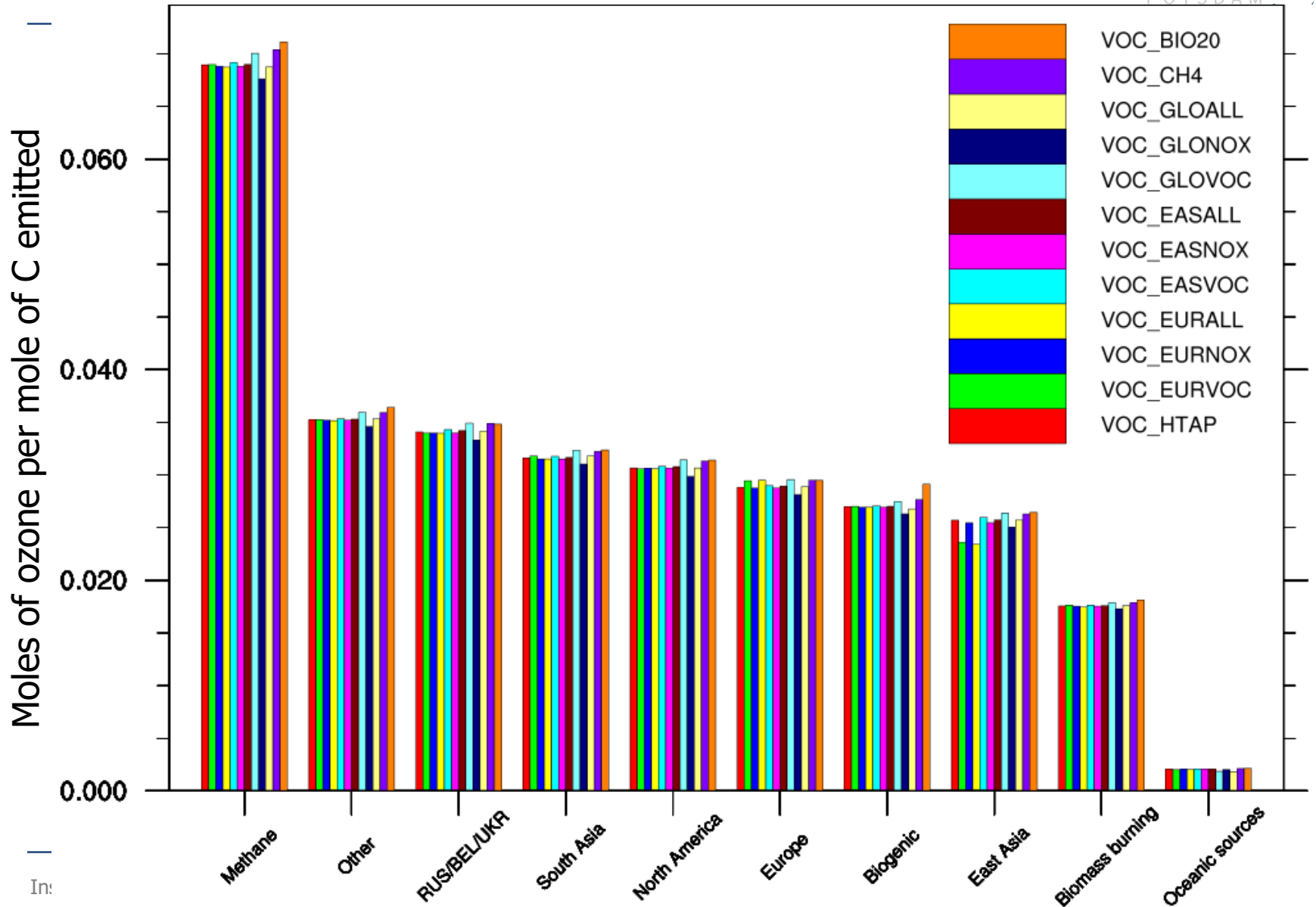
# Seasonal cycle of surface PAN: North America



# Ozone production efficiency of NOx precursors



# Ozone production efficiency of VOC precursors



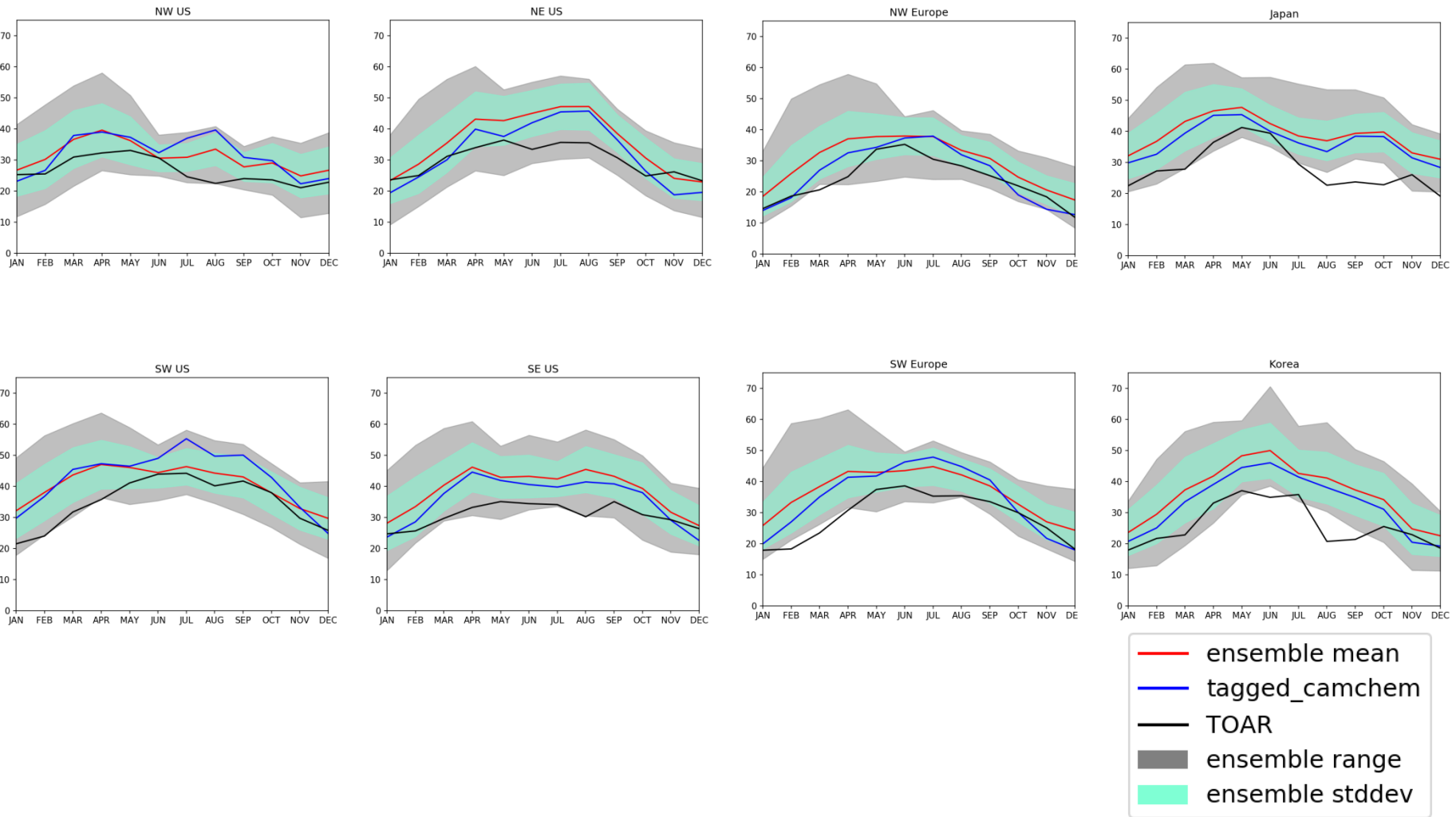
# Conclusion

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- Extended version of existing tagging in CAM-chem
- Quantification of VOC precursor contributions to O<sub>3</sub>
- Long-range anthropogenic VOC influence on springtime O<sub>3</sub>
- Uses beyond just O<sub>3</sub>
  
- Next steps:
  - HTAP2 paper: source/receptor, tagging/perturbation
  - Ozone source/receptor relationships in future climates
  - HTAP3
  - Implement in CESM2
    - CAM4 -> CAM6
    - TS1 chemistry
  - Convince other modelers to use this too



# Comparison with TOAR and HTAP ensemble



- Introduce a new set of odd-oxygen tracers "X\_TAG" species
- $\text{NO} + \text{RO}_2 \rightarrow \text{NO}_2 + \text{RO}$
- $\text{NO\_TAG} + \text{RO}_2 \rightarrow \text{NO}_2\_TAG + \text{NO}_2\_X\_TAG$ 
  - $\text{NO}_2\_TAG + h\nu \rightarrow \text{NO\_TAG}$
  - $\text{NO}_2\_X\_TAG + h\nu \rightarrow \dots \rightarrow \text{O}_3\_X\_TAG$
- Null cycle
  - $\text{O}_3 + \text{NO} \rightarrow \text{NO}_2$
  - $\text{O}_3 + \text{NO\_TAG} \rightarrow \text{NO}_2\_TAG \quad (+ h\nu \rightarrow \text{NO\_TAG})$
  - $\text{O}_3\_X\_TAG + \text{NO} \rightarrow \text{NO}_2\_X\_TAG \quad (+ h\nu \rightarrow \dots \rightarrow \text{O}_3\_X\_TAG)$

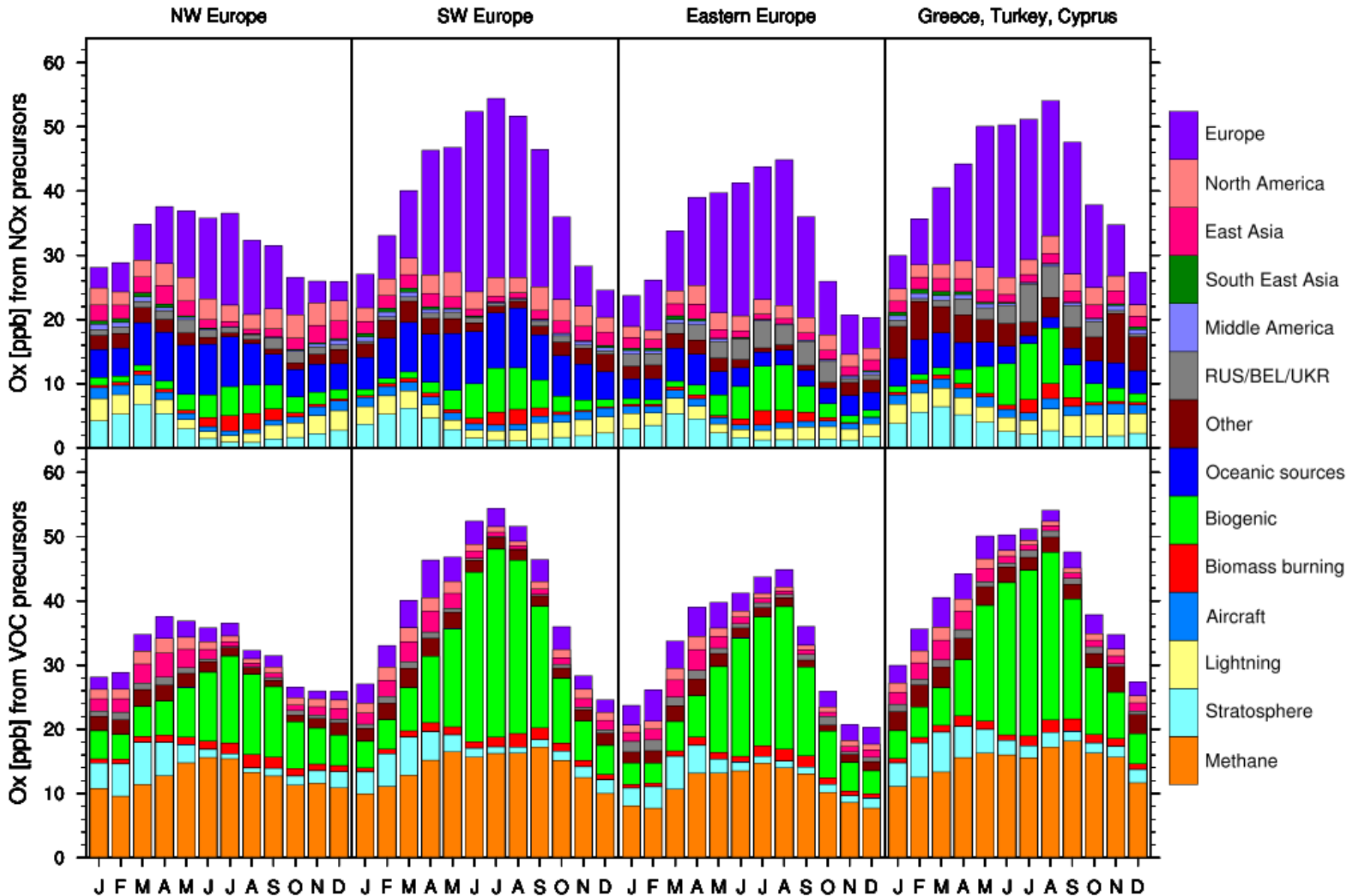
- Perl Scripts
  - Specify a list of tags to apply (eg. "TAG", "FOO", "BAR")
  - Rewrite the mechanism file, adding new reactions and tracers
  - Rewrite model source code (tracers, reaction rates, etc...)
  
- Each tag adds:
  - 155 reactions
  - 26 tracers

- Original code:

```
if( jno2a_ndx > 0 .and. jno2_ndx > 0 ) then
    photos(:, :, jno2a_ndx) = photos(:, :, jno2_ndx)
end if
```
- Manually modified “template” code:

```
! BEGIN TAGGING CODE
if( jno2_tag_ndx > 0 .and. jno2_ndx > 0 ) then
    photos(:, :, jno2_tag_ndx) = photos(:, :, jno2_ndx)
end if
! END TAGGING CODE
```
- Template code is then automatically processed to produce compiler-ready code...

# Seasonal cycle of surface ozone: Europe



# Seasonal cycle of surface ozone: oceans and seas

