Seasonal impacts of biomass burning on ozone air quality across Southeast Asia

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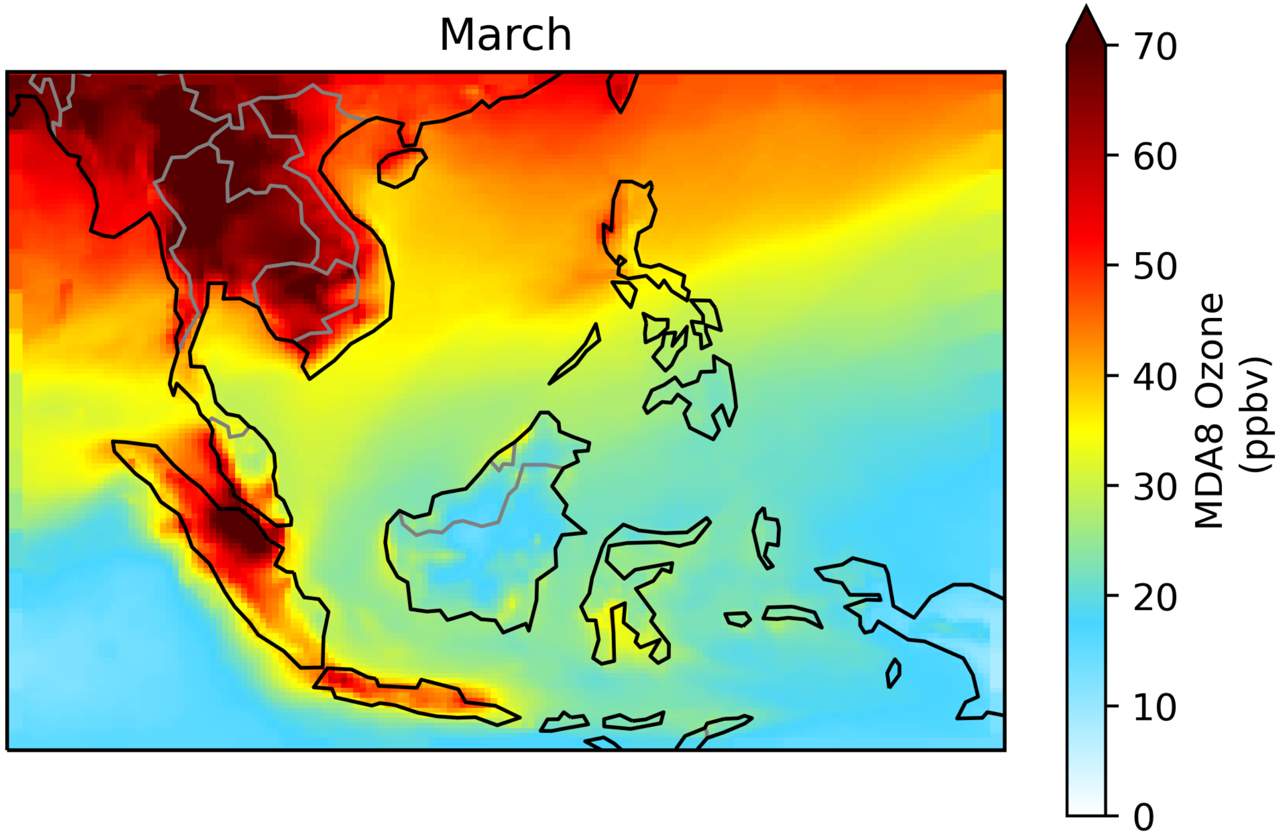
Ozone exposure guideline (WHO, 2005):
100 µg m^{-3} (≈ 50 ppbv)



Biomass burning is known to cause unhealthy air quality in Southeast Asia

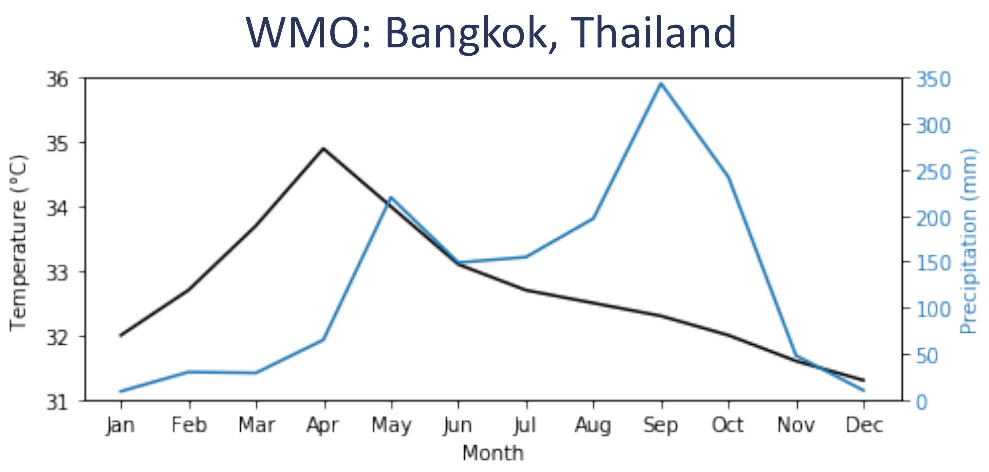
- Related literature emphasizes the impacts of particulate matter (PM)
- Fires emit enough PM to exceed public health guidelines (WHO, 2005)
- Severe fires are estimated to cause up to 100,000 excess premature deaths
- How does biomass burning impact **surface ozone** across the region?

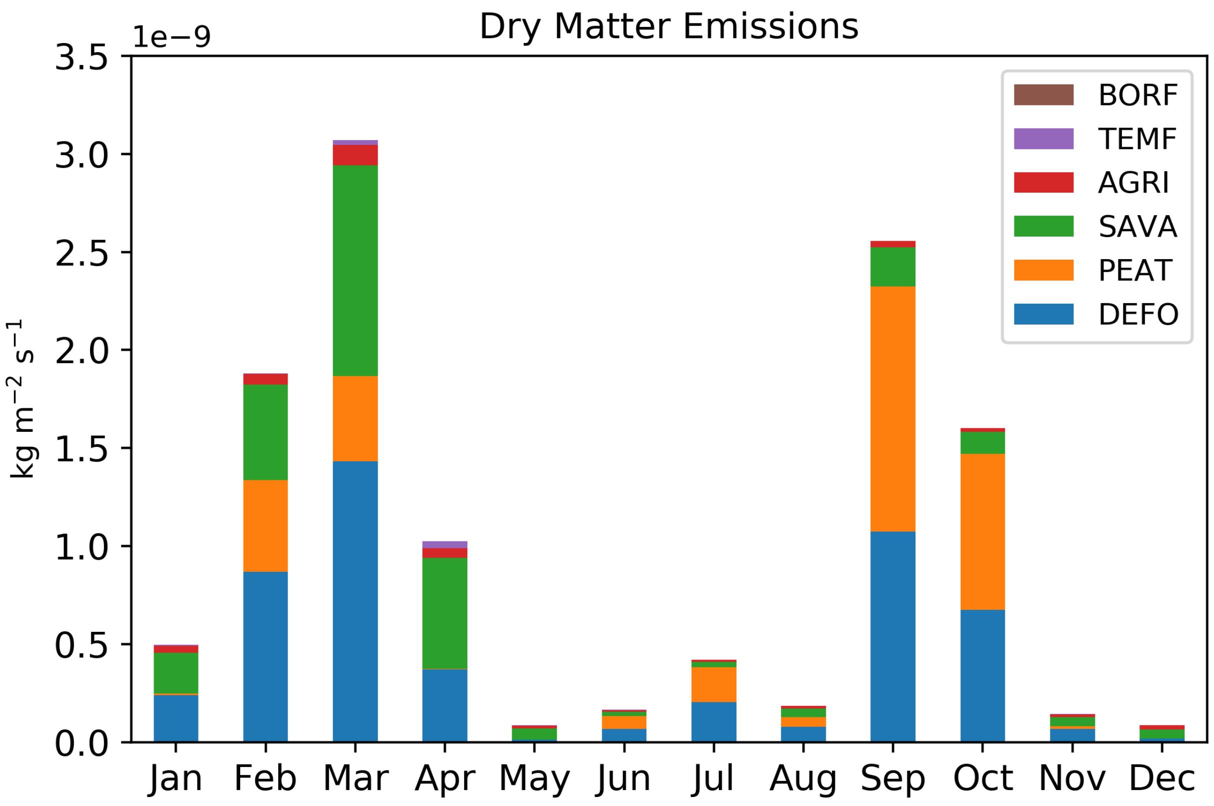
Photograph: M. Wooster

Photograph: D. Gaveau

Wooster et al. (2018)

Seasonality of biomass burning emissions from Southeast Asia in 2014





Calculated from GFED4.1s biomass burning inventory

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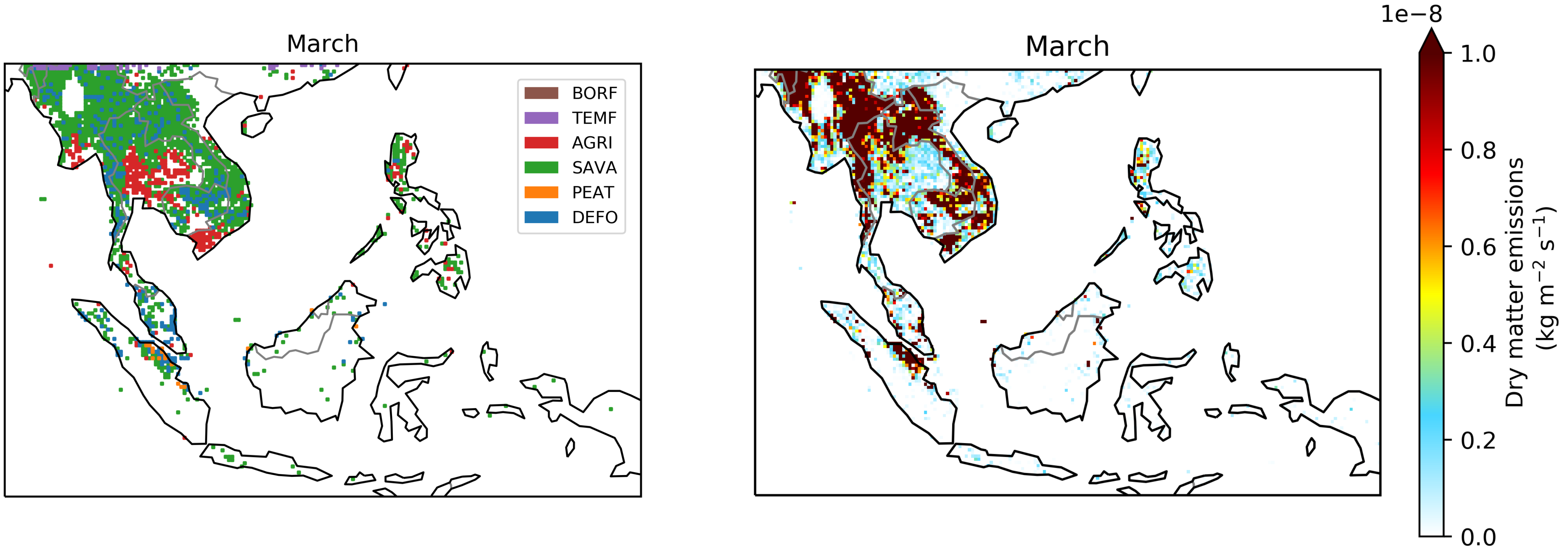
Two distinct biomass burning regimes

1. Burning of DEFO (47%), SAVA (35%), and PEAT (14%) vegetation on mainland Southeast Asia peaking in March



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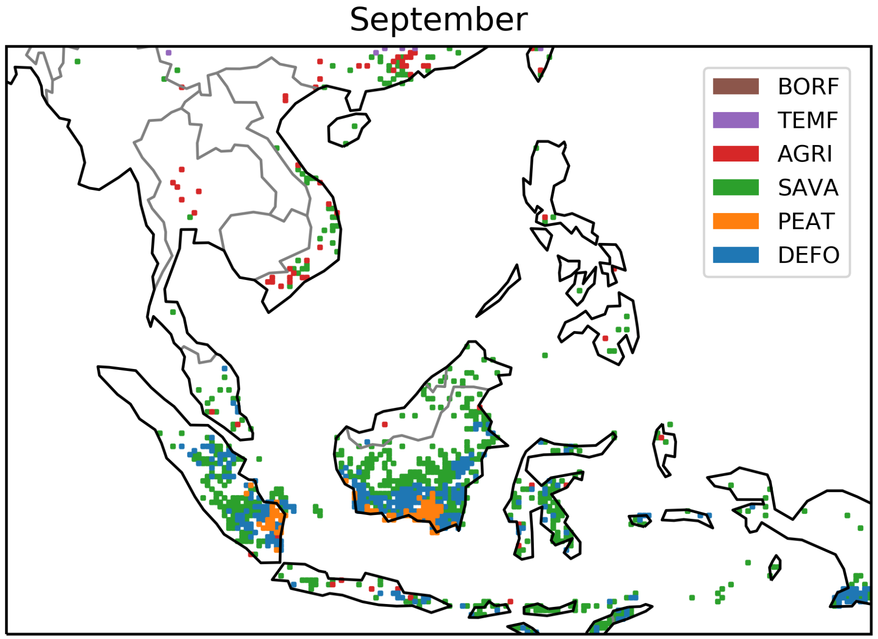
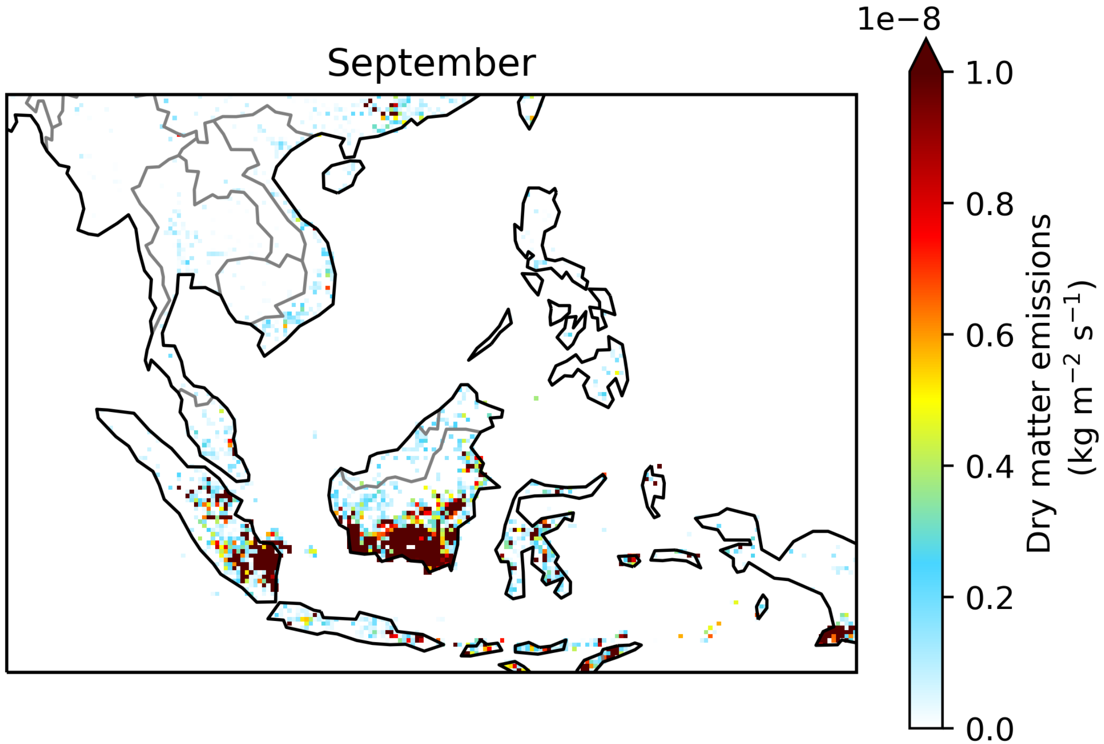
Two distinct biomass burning regimes

2. Burning of DEFO (42%), SAVA (8%), and PEAT (49%) vegetation on mainland Southeast Asia peaking in September





Model and emissions

Atmospheric Chemistry Model

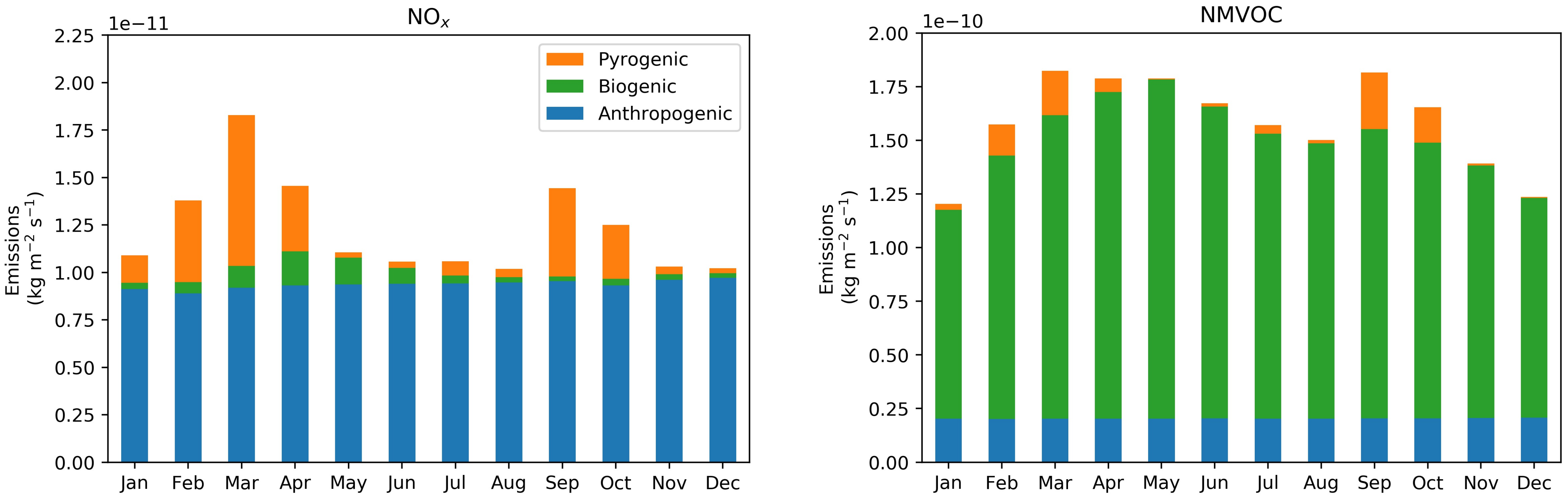
- GEOS-Chem v12.5.0 (geos-chem.org)
- Global and nested model
- Nested resolution: 0.25°x0.3125°
- Meteorology from GEOS-FP
- Full gas and aerosol chemistry

GEOS-Chem

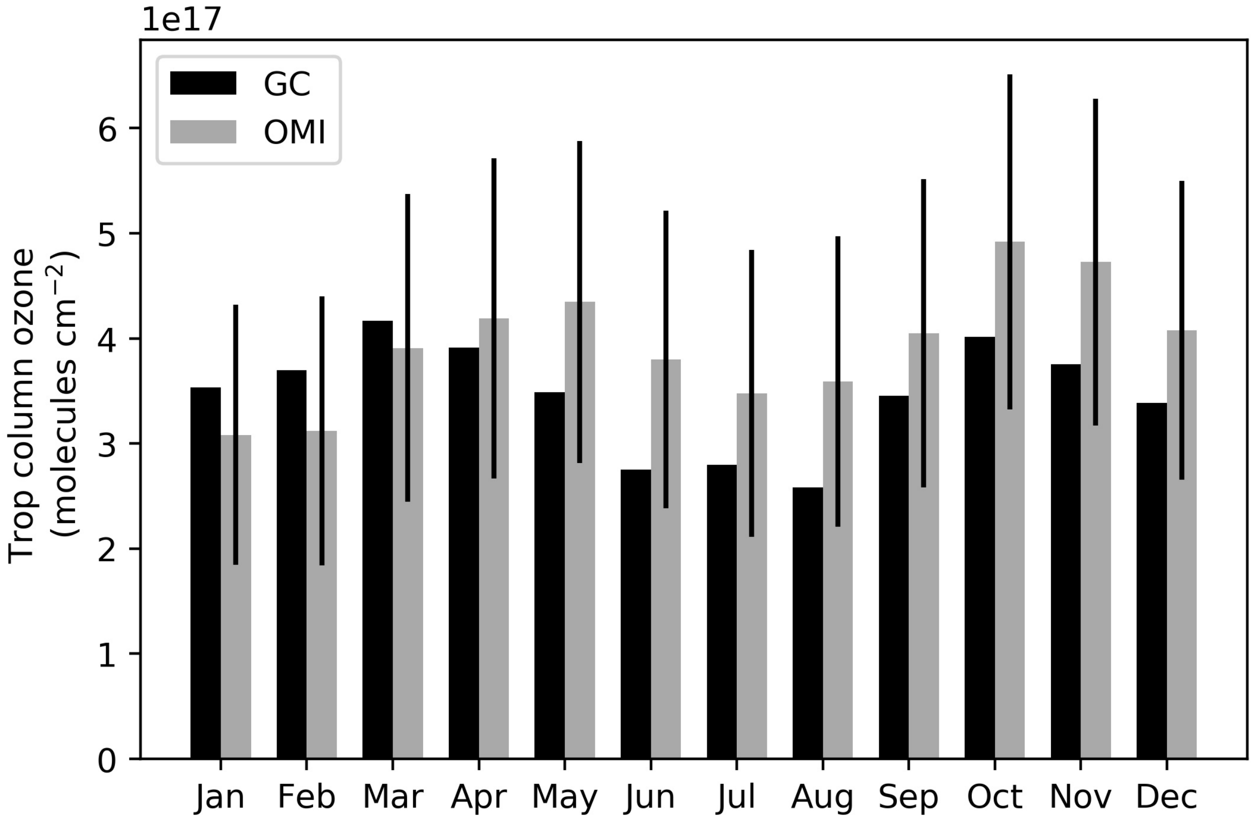
Emission Inventories

- Anthropogenic: MIX 2010 (Li et al., 2017)
- Biogenic: MEGAN v2.1 (Guenther et al., 2012)
- Pyrogenic: GFED v4.1 (van der Werf et al., 2017)

Seasonal trends in emissions of ozone precursors



Seasonal variation in tropospheric ozone reflects trends in the precursor emissions



EO Data

- RAL OMI L2 fv0214
- Gridded to match model
- Daily overpass at 13:30 LT
- Averaging kernels applied
- Filtered for good data
  - Passed all retrieval quality checks
  - Effective cloud fraction < 0.2

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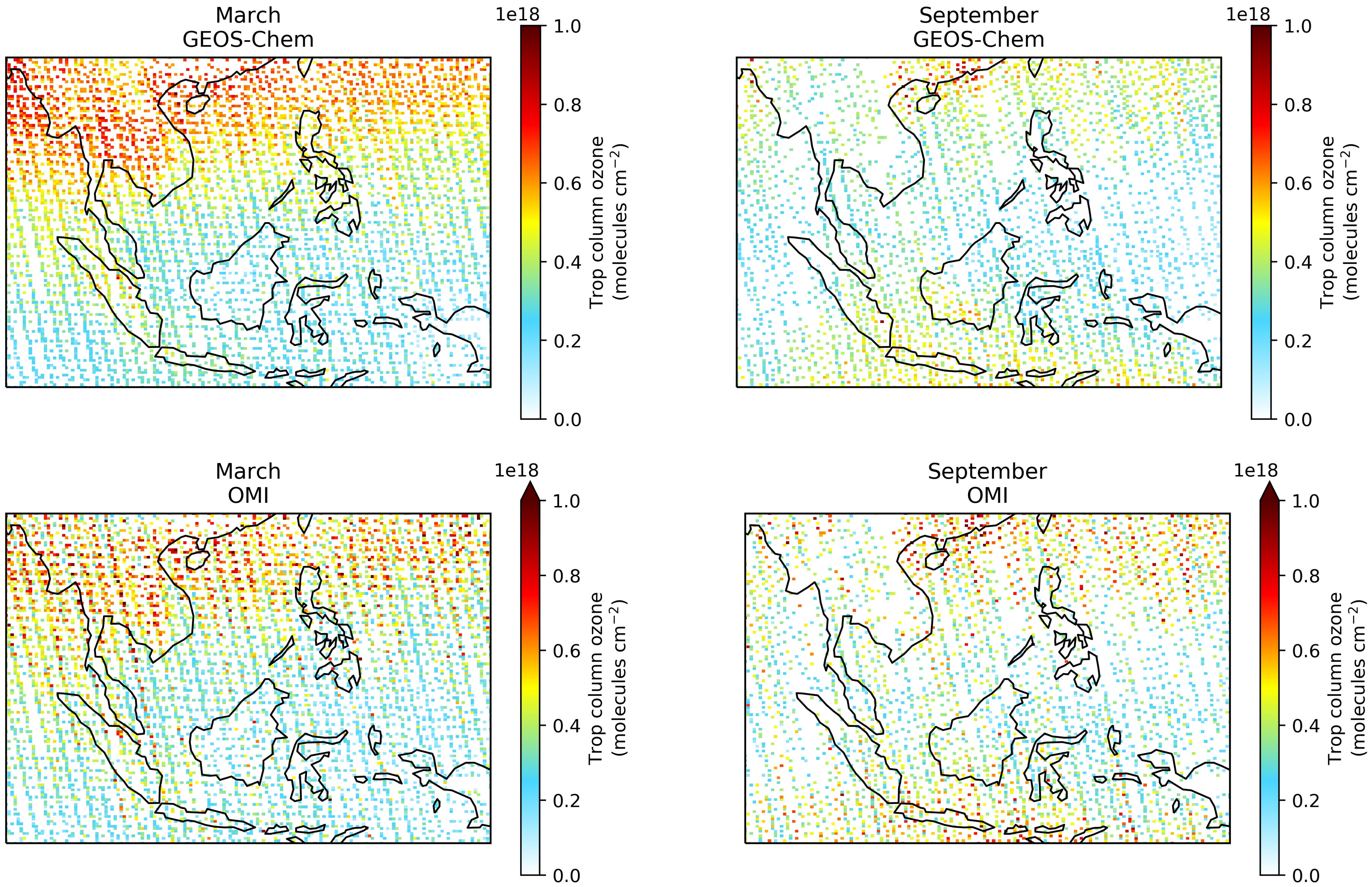


March
GEOS-Chem
September
GEOS-Chem
March
OMI
September
OMI
1e18
1.0
0.8
0.6
0.4
0.2
0.0
Trop column ozone
(molecules cm^{-2})

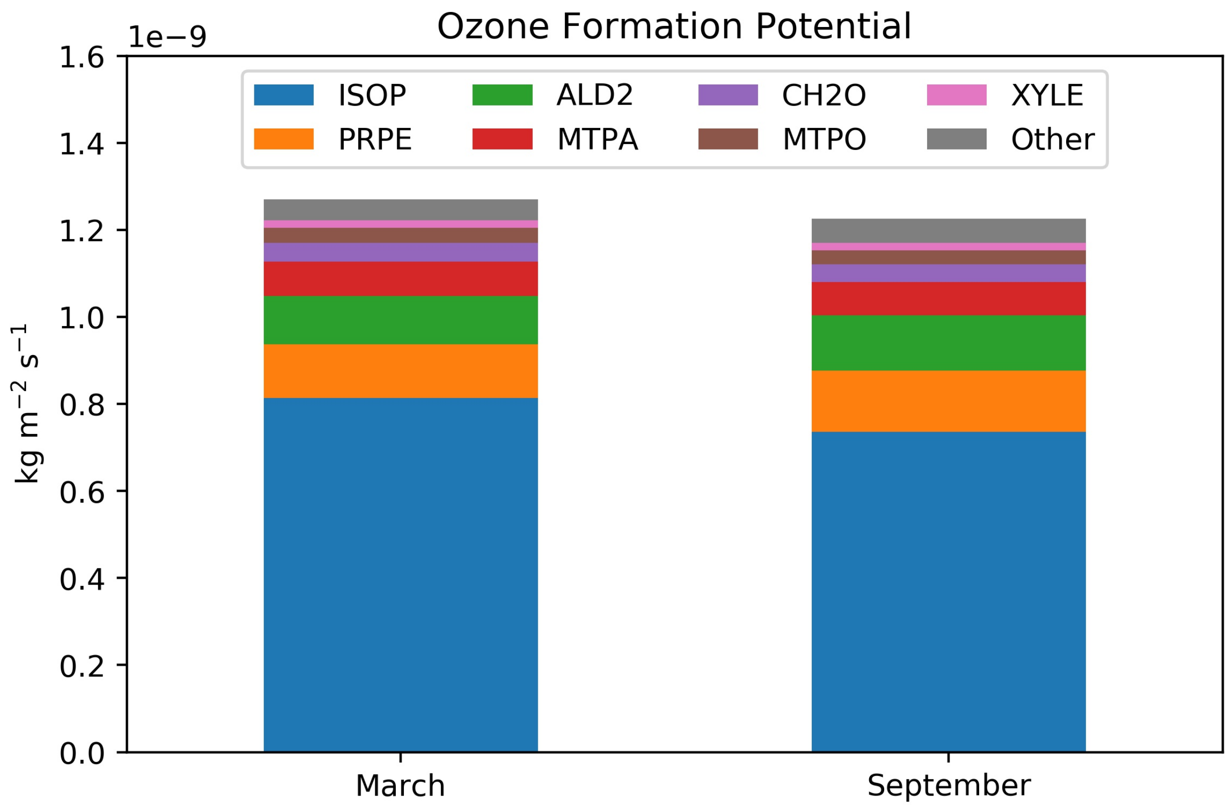
Ozone Formation Potential (OFP) links ozone directly to precursor emissions

$$OFP_{VOC} = E_{VOC} \times MIR_{VOC}$$

E: Emission rate ($kg\ m^{-2}\ s^{-1}$)
MIR: Maximum Incremental Reactivity

Top Contributing VOC	MIR*
Isoprene (ISOP)	10.61
Propene (PRPE)	11.66
Acetaldehyde (ALD2)	6.54
Monoterpenes (MTPA/MTPO)	4.04
Formaldehyde (CH2O)	9.46
Xylene (XYLE)	4.00

*g ozone per g VOC emitted
Carter (2010)



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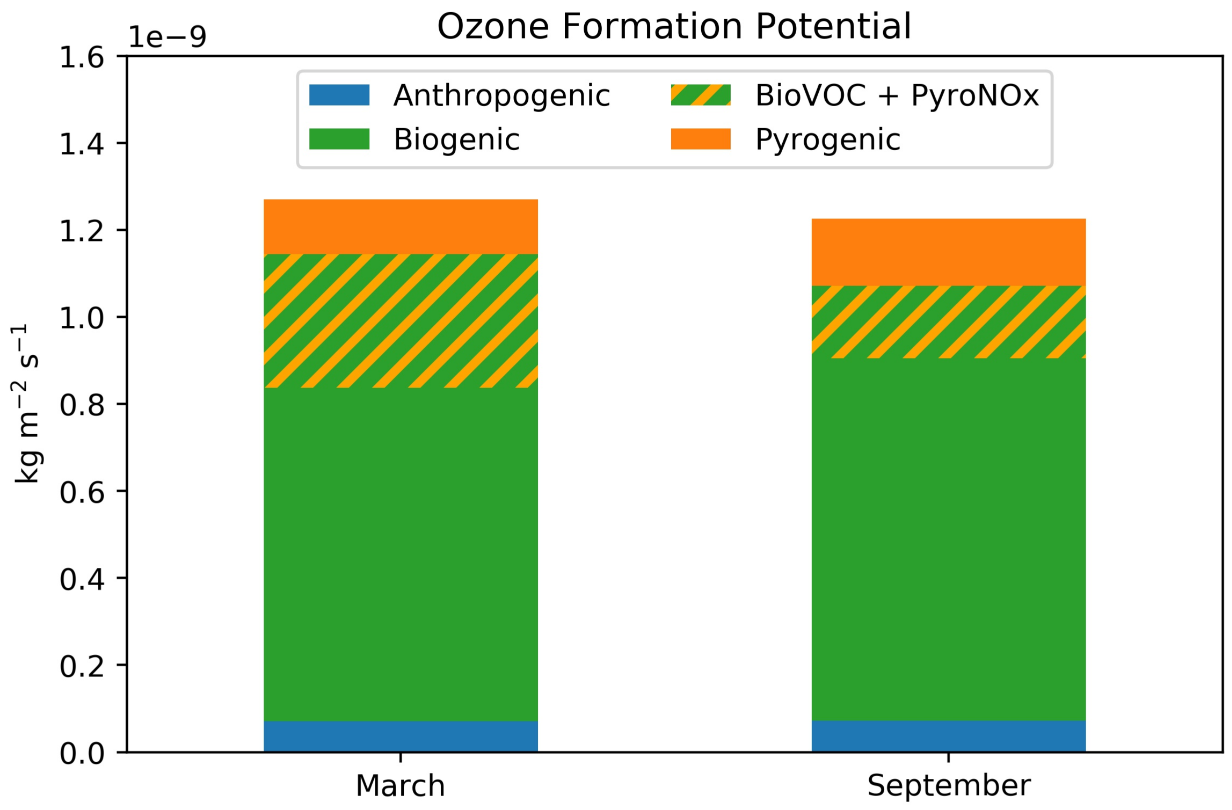

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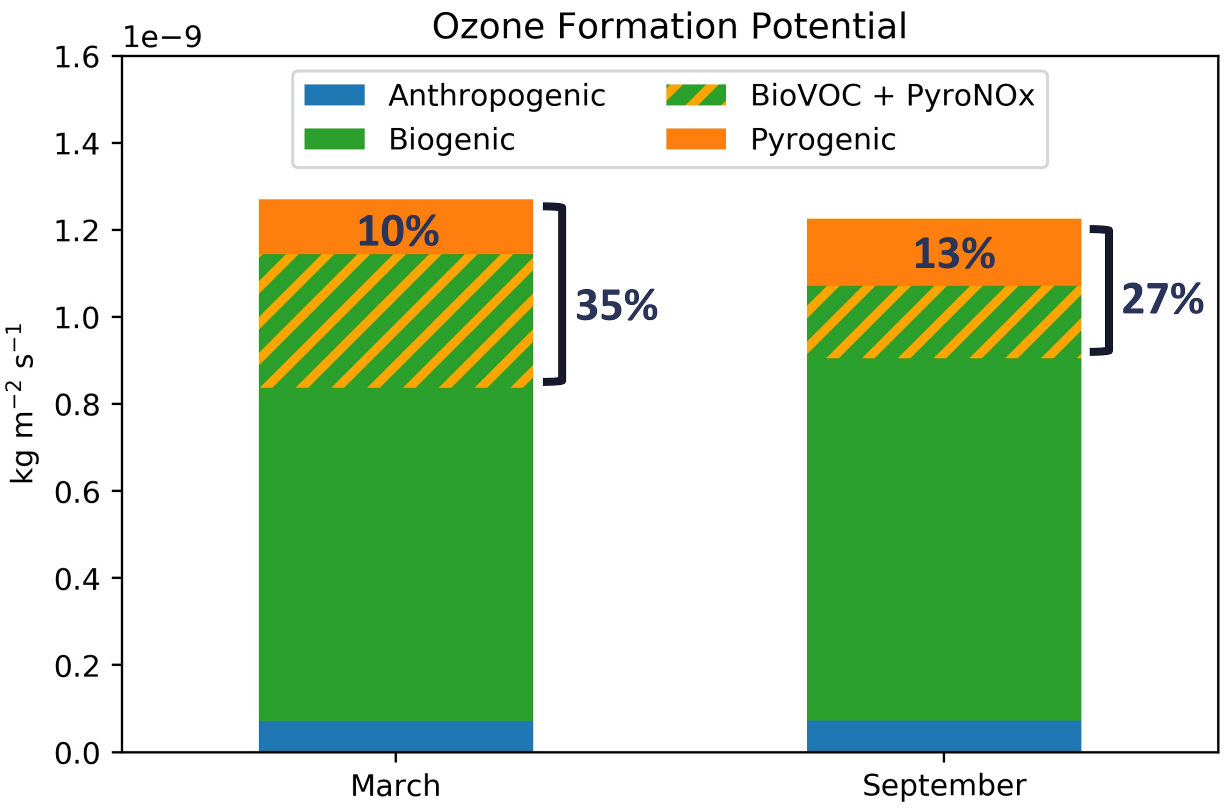

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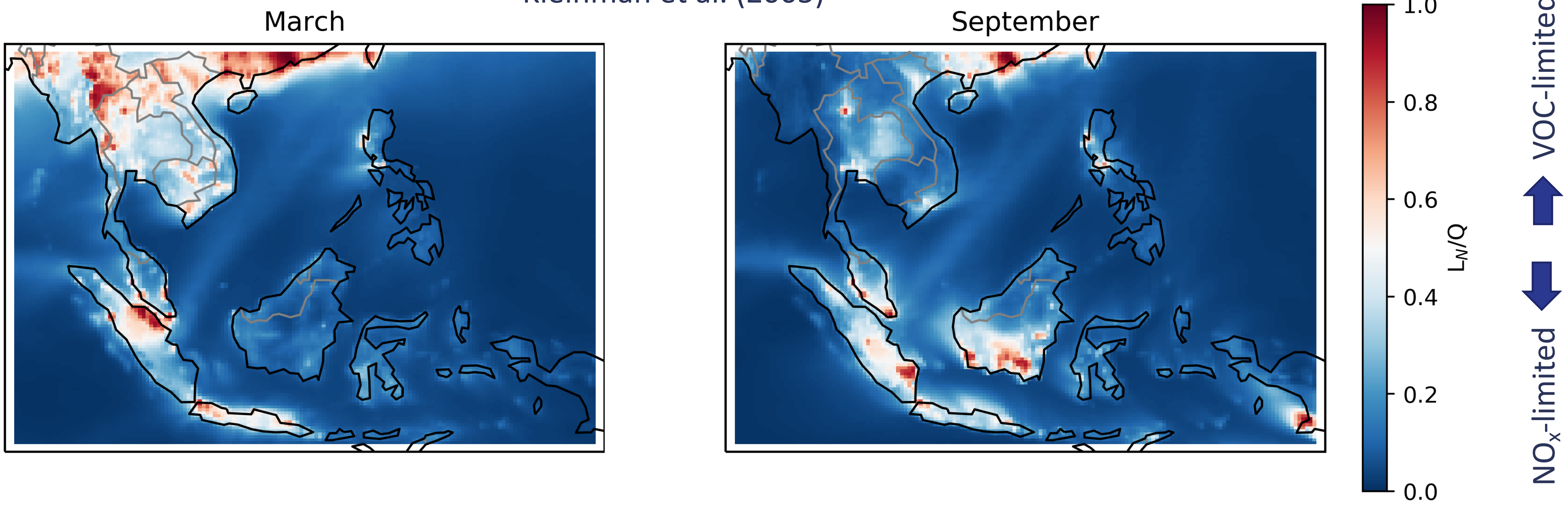
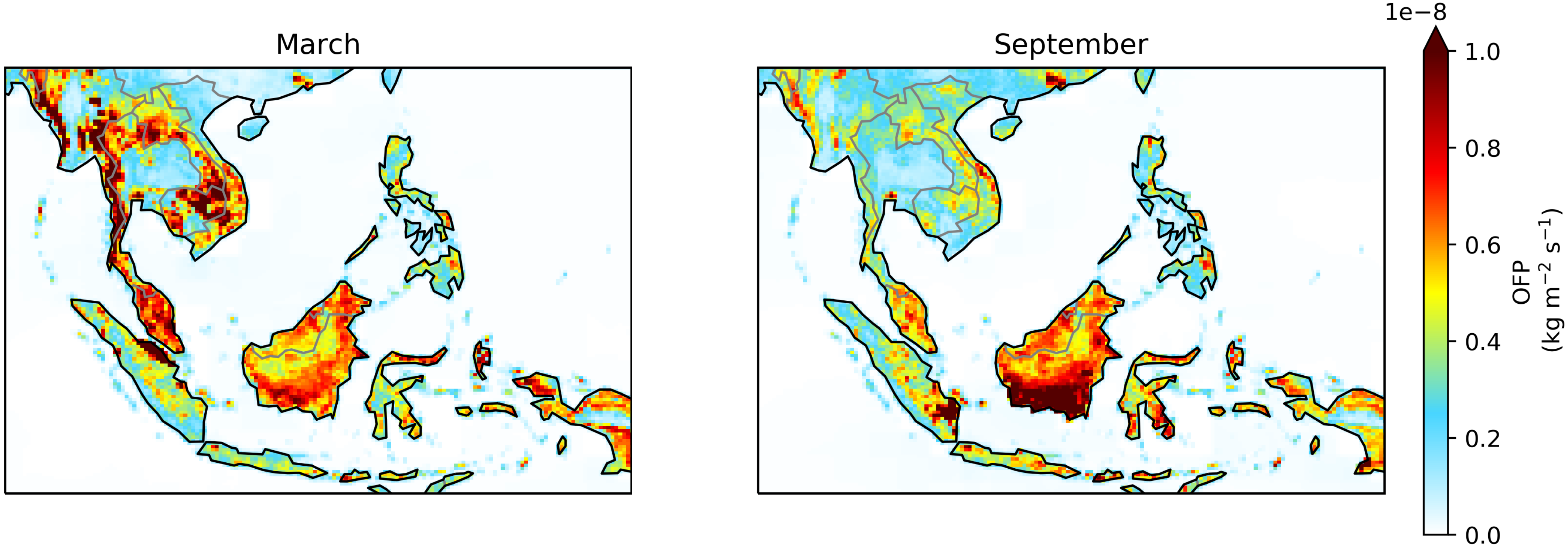
Assumption: Ozone production is VOC-limited

$$L_N/Q = \frac{P(\mathrm{HNO3})}{P(\mathrm{H2O2}) + P(\mathrm{HNO3})}$$

Kleinman et al. (2005)



Spatial distribution of estimated OFP



- OFP likely provides an <u>upper limit</u> on the yield of ozone from emitted VOC
- May underestimate the relative contribution of pyrogenic precursors

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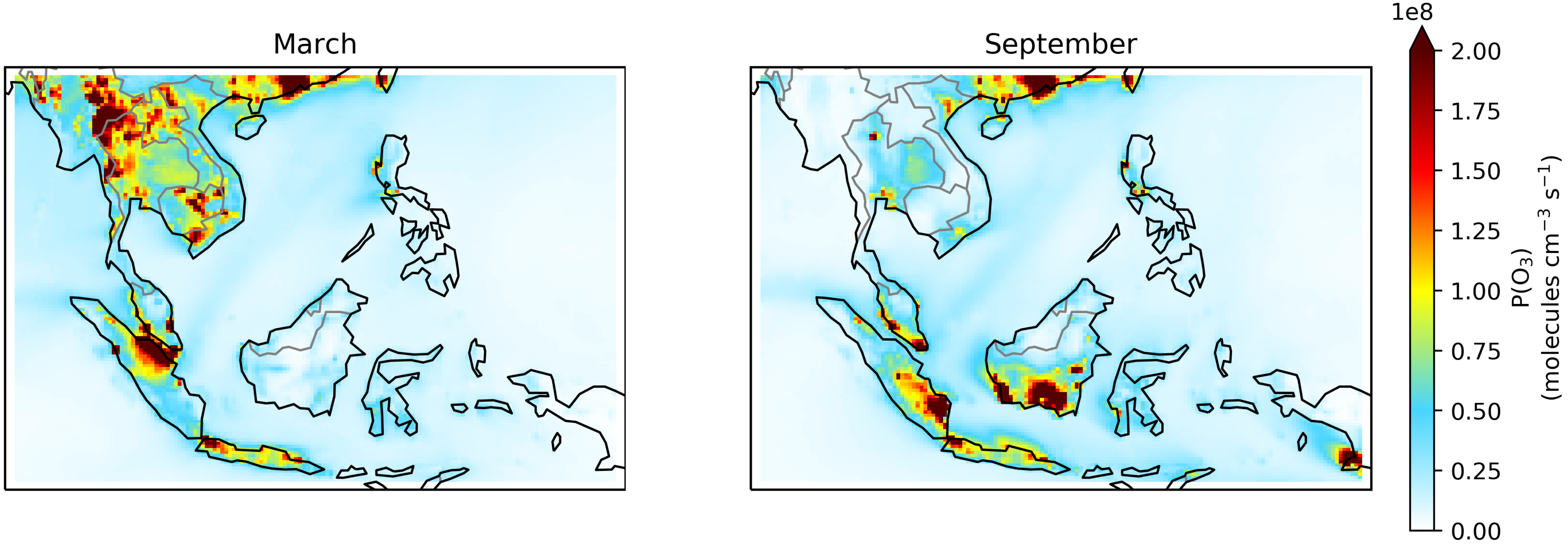
Spatial distribution of modeled $P(O_3)$

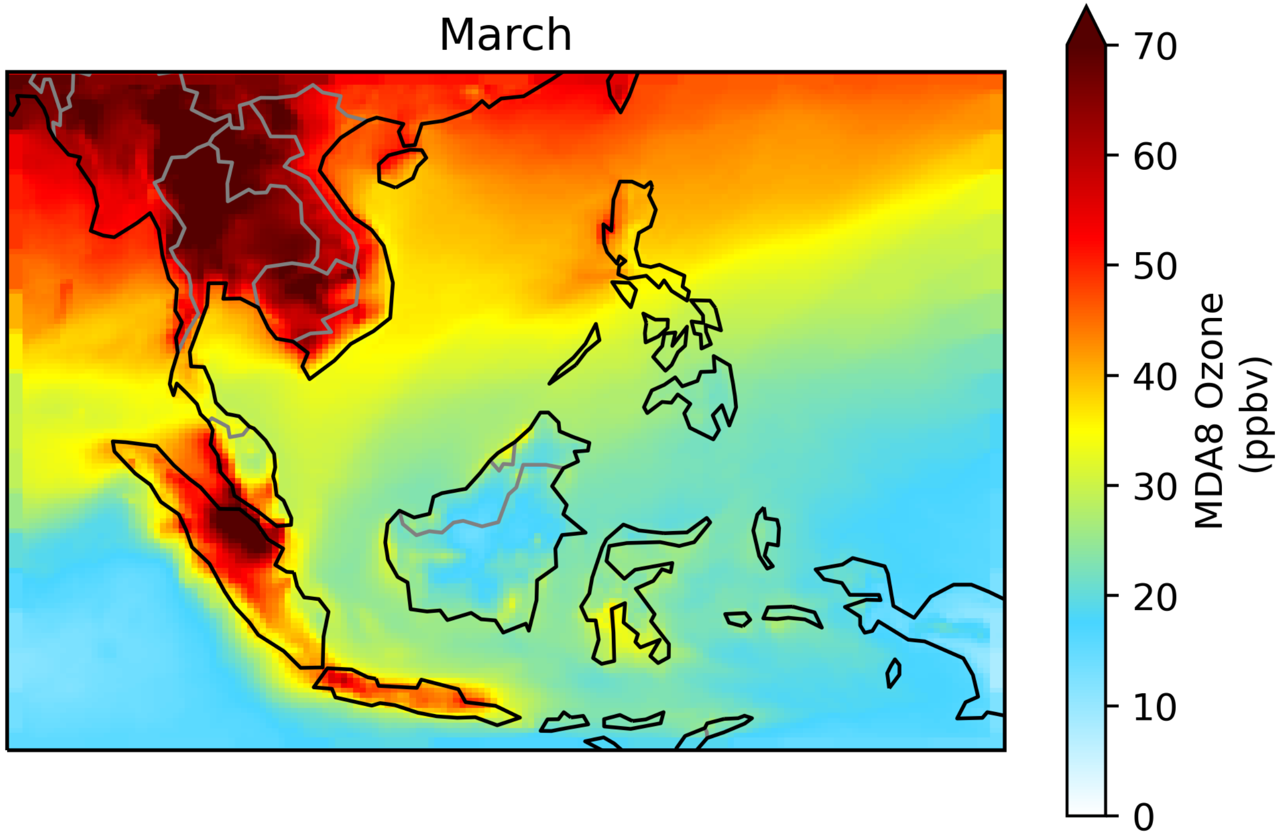


- Magnitudes of OFP and $P(O_3)$ are not directly comparable
- $P(O_3)$ confirms ozone production is enhanced over areas of biomass burning

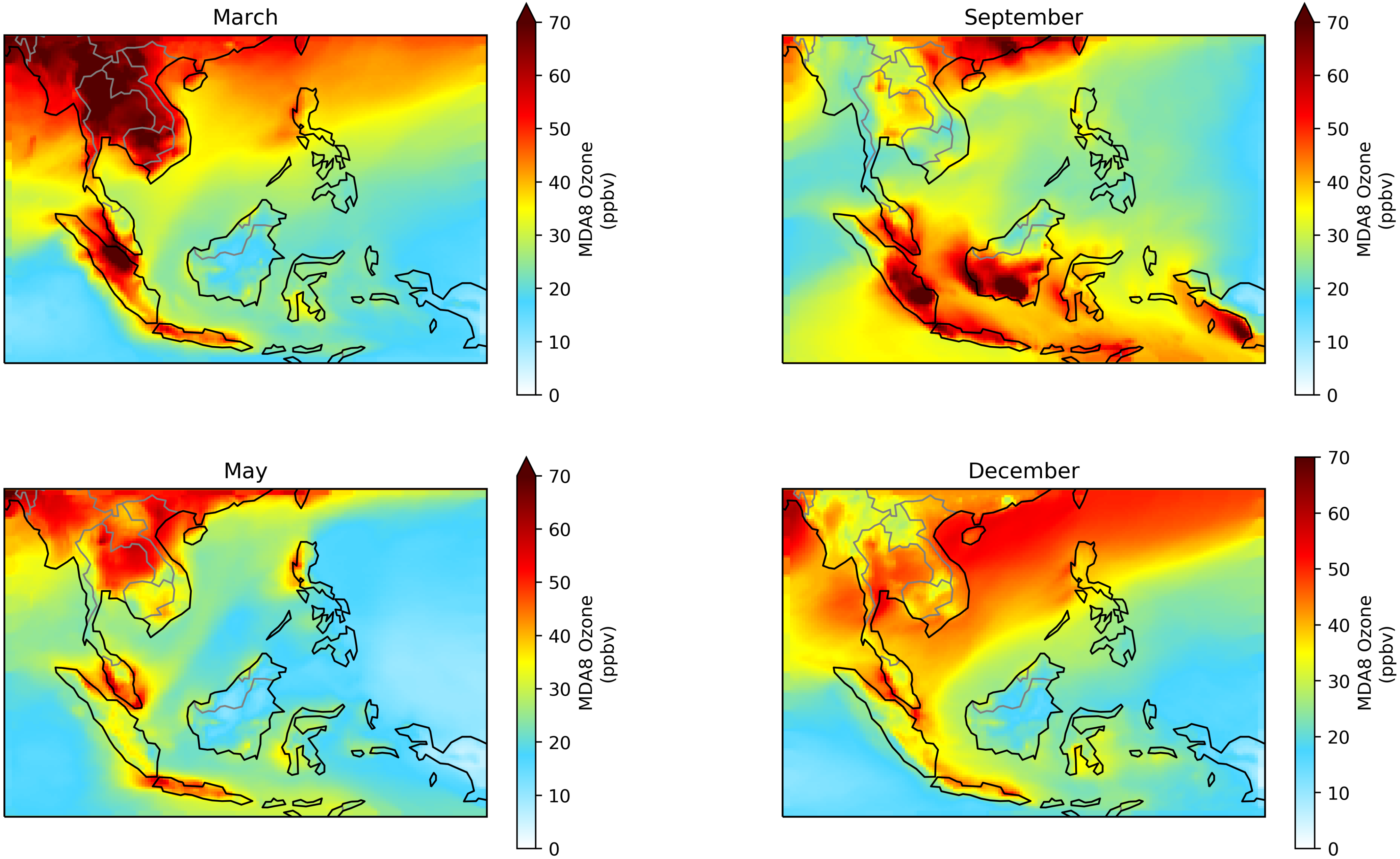
Implications for public health

MDA8: Maximum Daily 8-Hour Average Ozone (ppb)

- WHO guideline (2005): 100 µg m^{-3} (≈ 50 ppbv)
- Short term exposure above the WHO guideline accounts for 0.2% of total mortality* (Vicedo-Cabrera et al., 2020)
- Ozone responsible for nearly **300 excess premature deaths** on mainland Southeast Asia in March of 2014

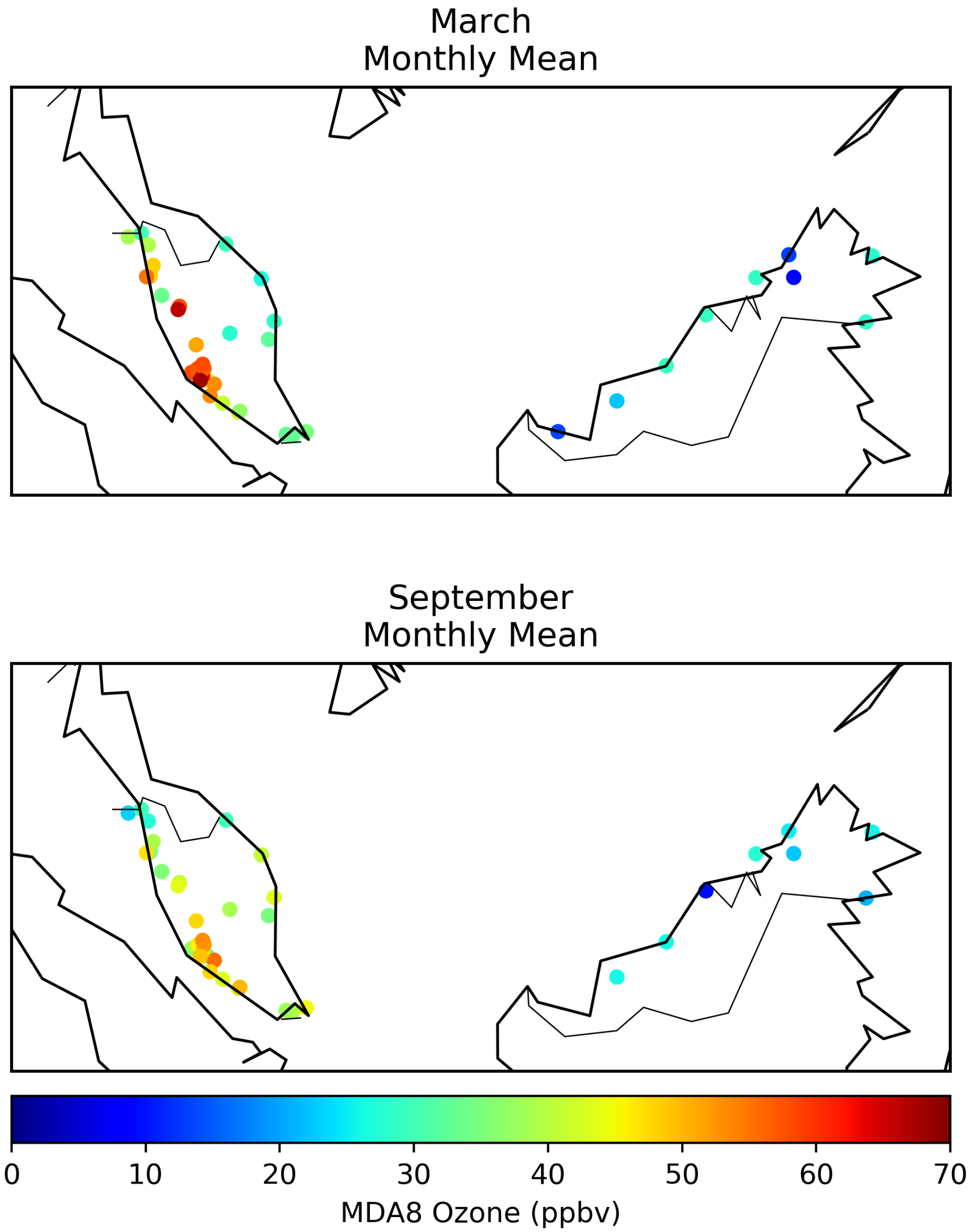


*Compared to exposure below 70 µg m^{-3}


March
September
May
December
MDA8 Ozone
(ppbv)
0
10
20
30
40
50
60
70

Ground-based data from Malaysia

- Collected by the Malaysian Department of Environment
- Provided by the Universiti Kebangsaan Malaysia
- Includes observations from 40 stations across Malaysia in 2014
- Ozone measurements:
  - UV absorption at 254 nm (Teledyne API Model 400/ 400E)
  - Precision: 0.5%
  - Detection limit: 0.4 ppb



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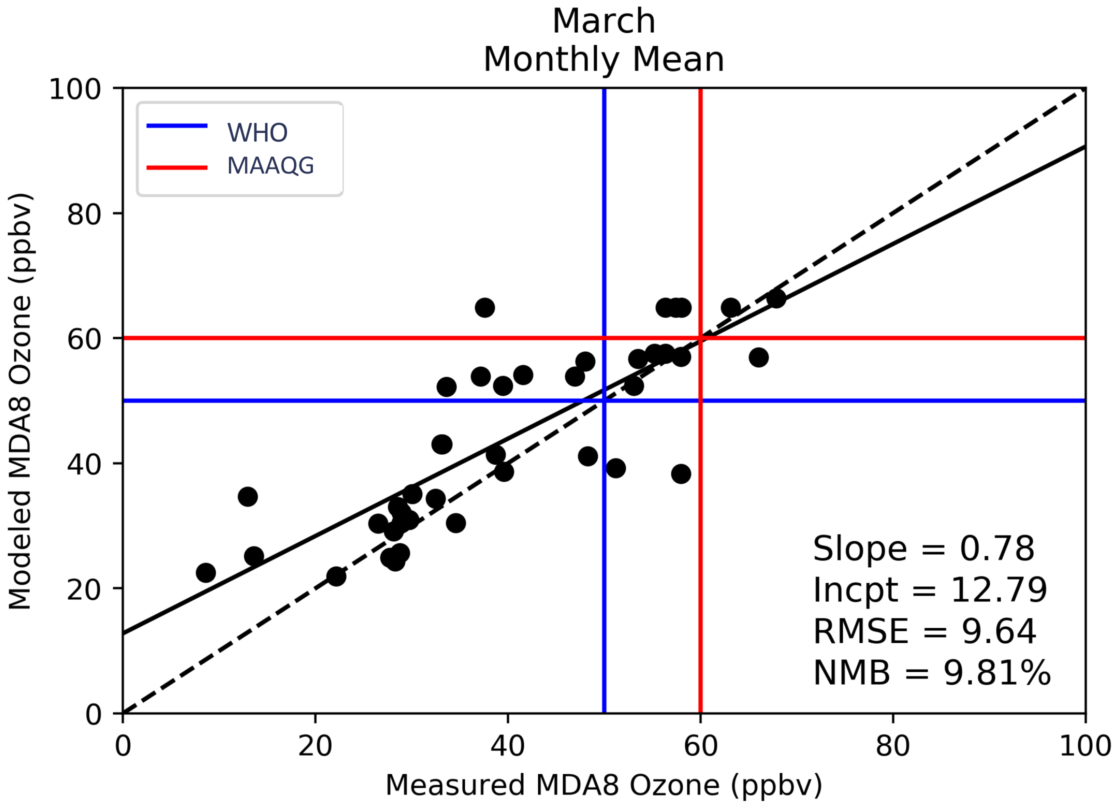
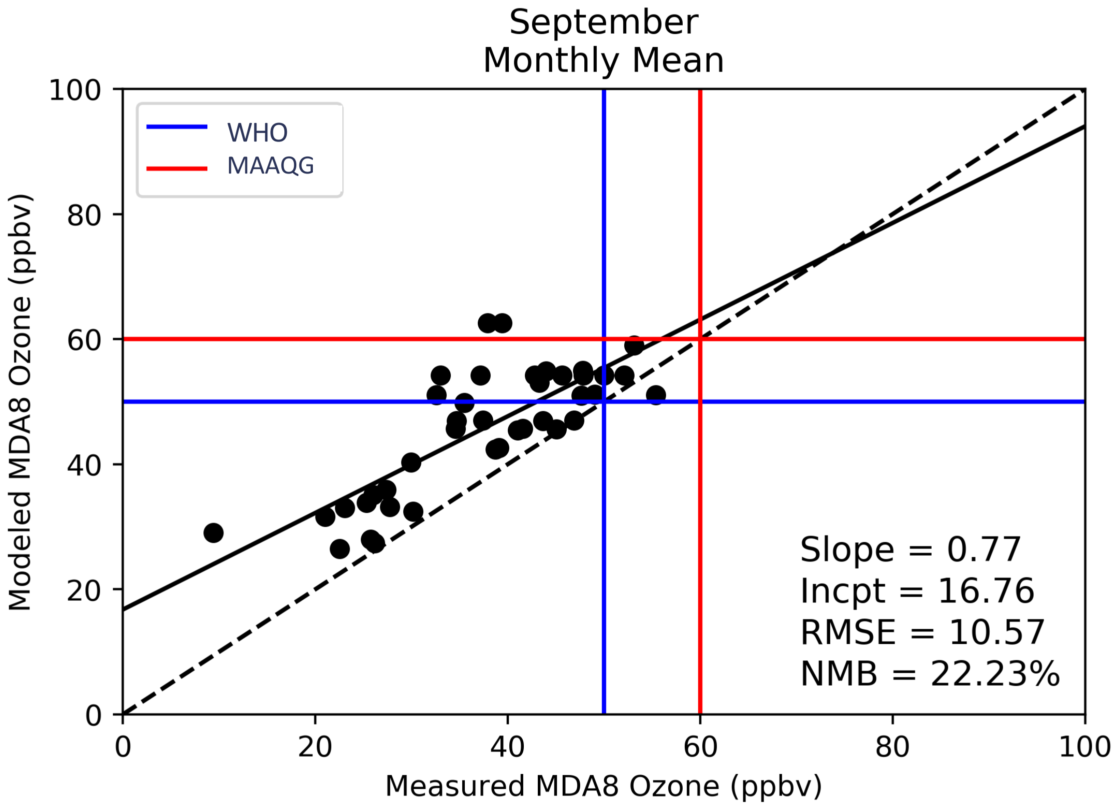
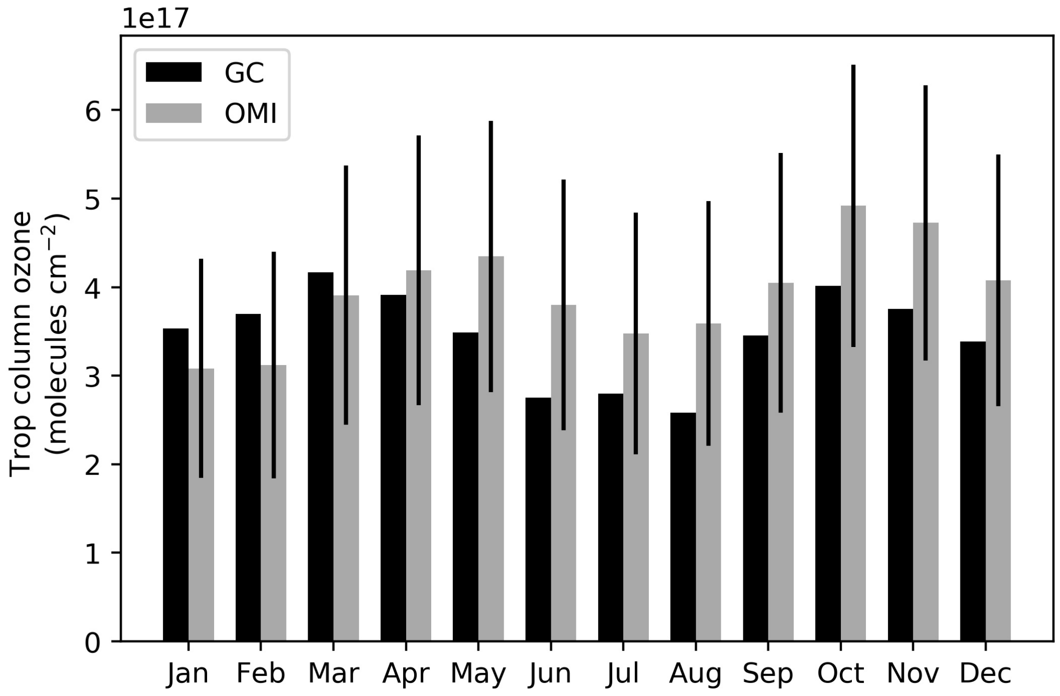
NATURAL ENVIRONMENT RESEARCH COUNCIL

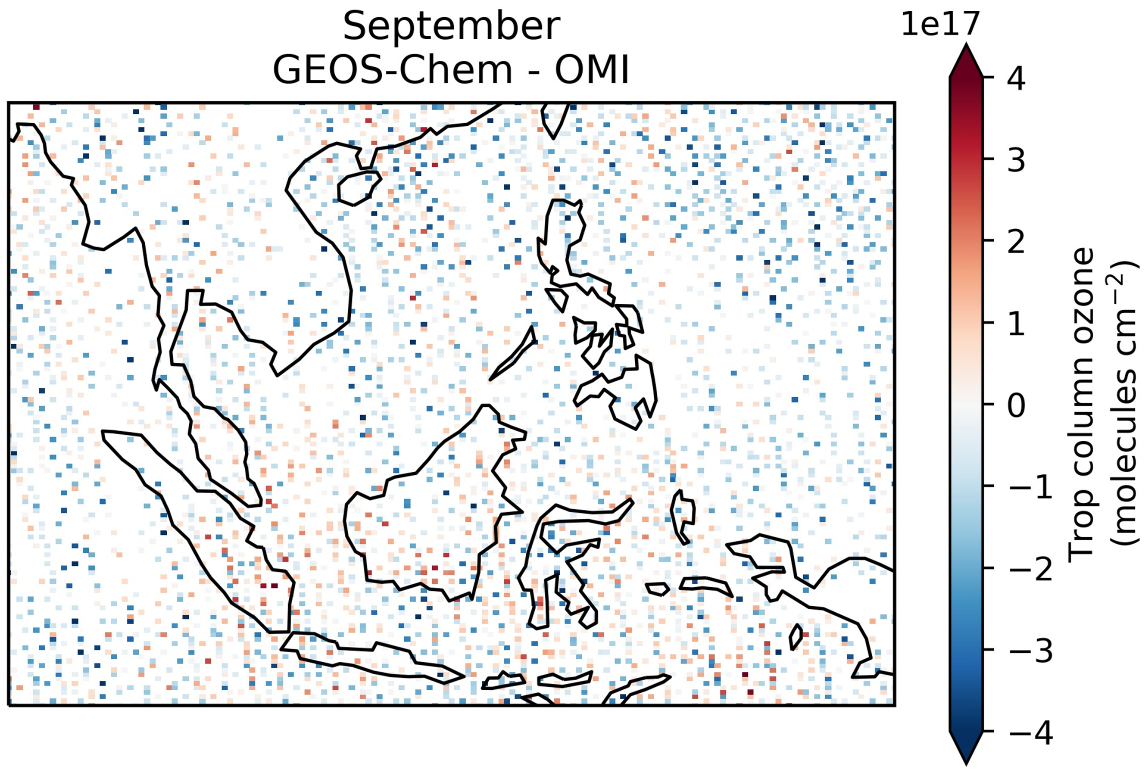
Model ozone biased high compared to ground observations





Ground-based observations support EO evaluation





- In September, the model underestimates tropospheric ozone from EO overall
- Overestimates tropospheric ozone over parts of Malaysia where ground data collected

Conclusions

- Differences in the dry season and the type of land burned distinguish two different biomass burning regimes in Southeast Asia
- Each regime has a unique distribution of precursors that drives regional ozone production
- Pyrogenic precursors may produce ozone directly or indirectly through interactions with the biogenic sector
- Biomass burning accounts for **35%** and **27%** of regional OFP in March and September, respectively
  - Could make the difference between “healthy” and “unhealthy” ozone air quality for millions of people across Southeast Asia

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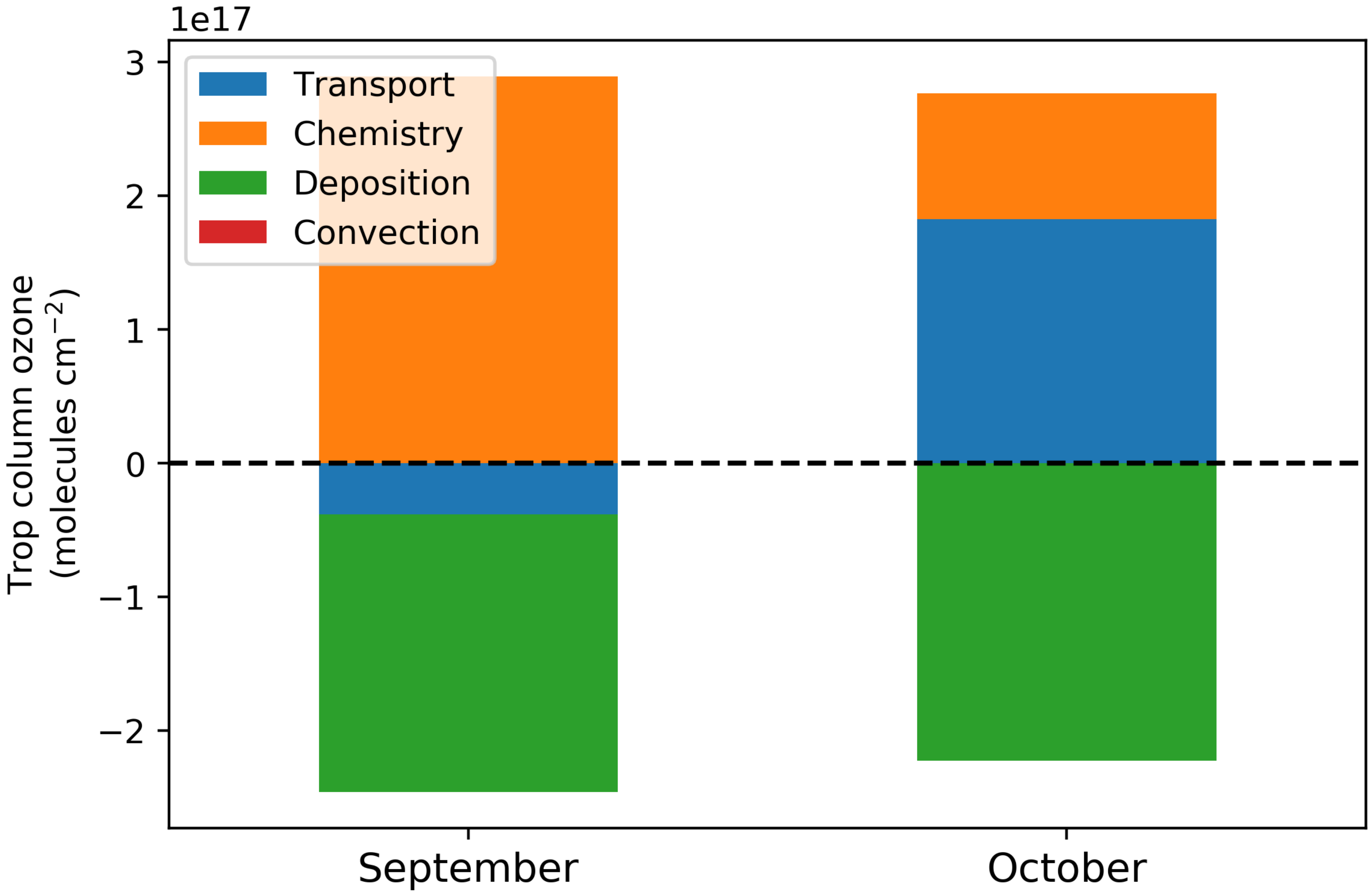

1e17
3
2
1
0
−1
−2
Trop column ozone (molecules cm−2)
Transport
Chemistry
Deposition
Convection
September
October