Biogenic Emissions Modulate the Tropospheric Hydroxyl Radical (OH) Response to Climate Warming

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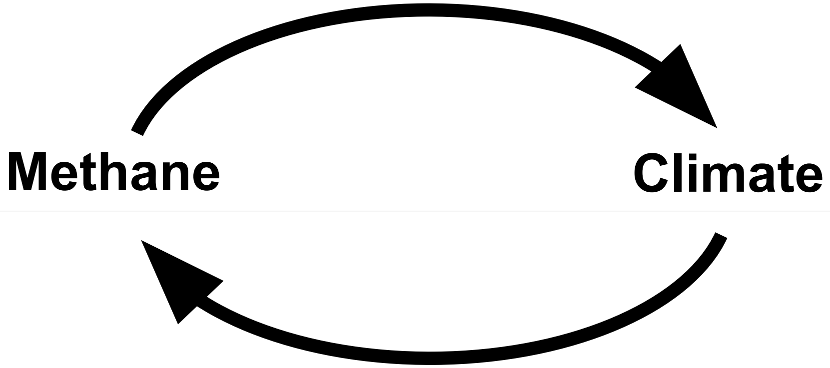
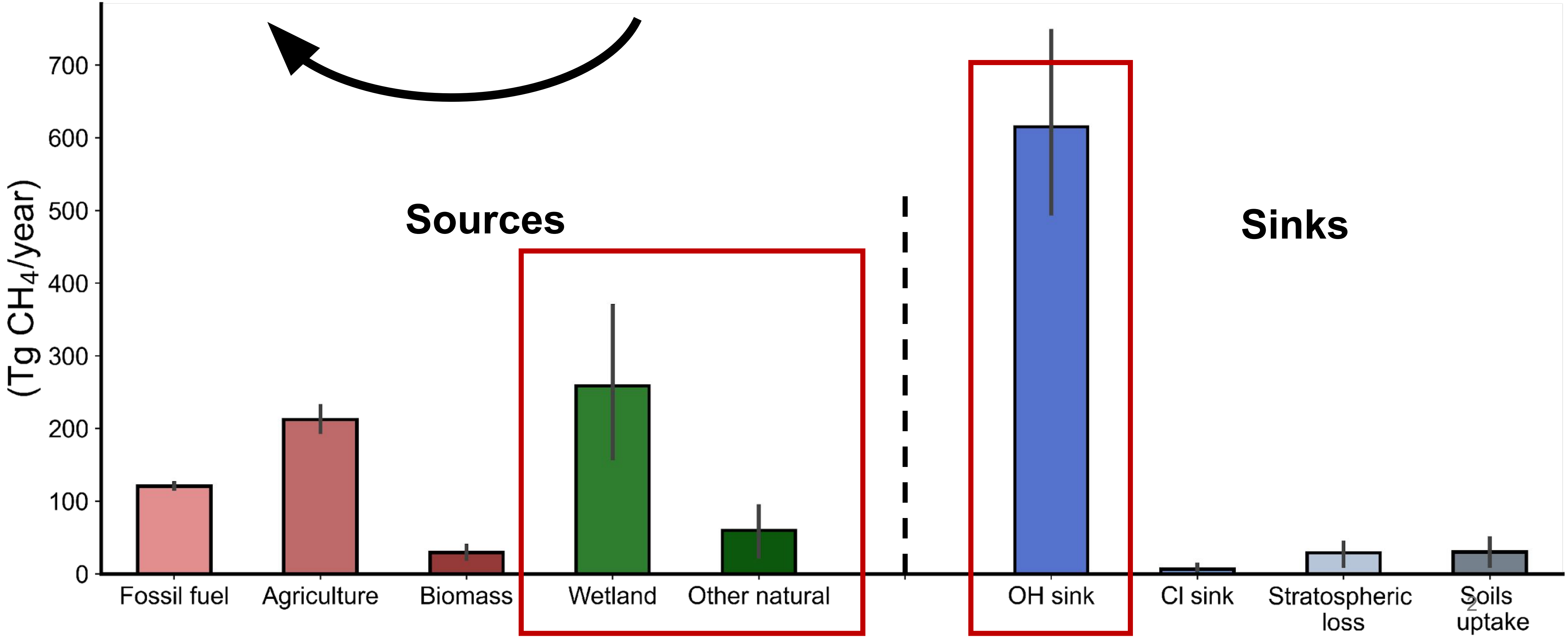
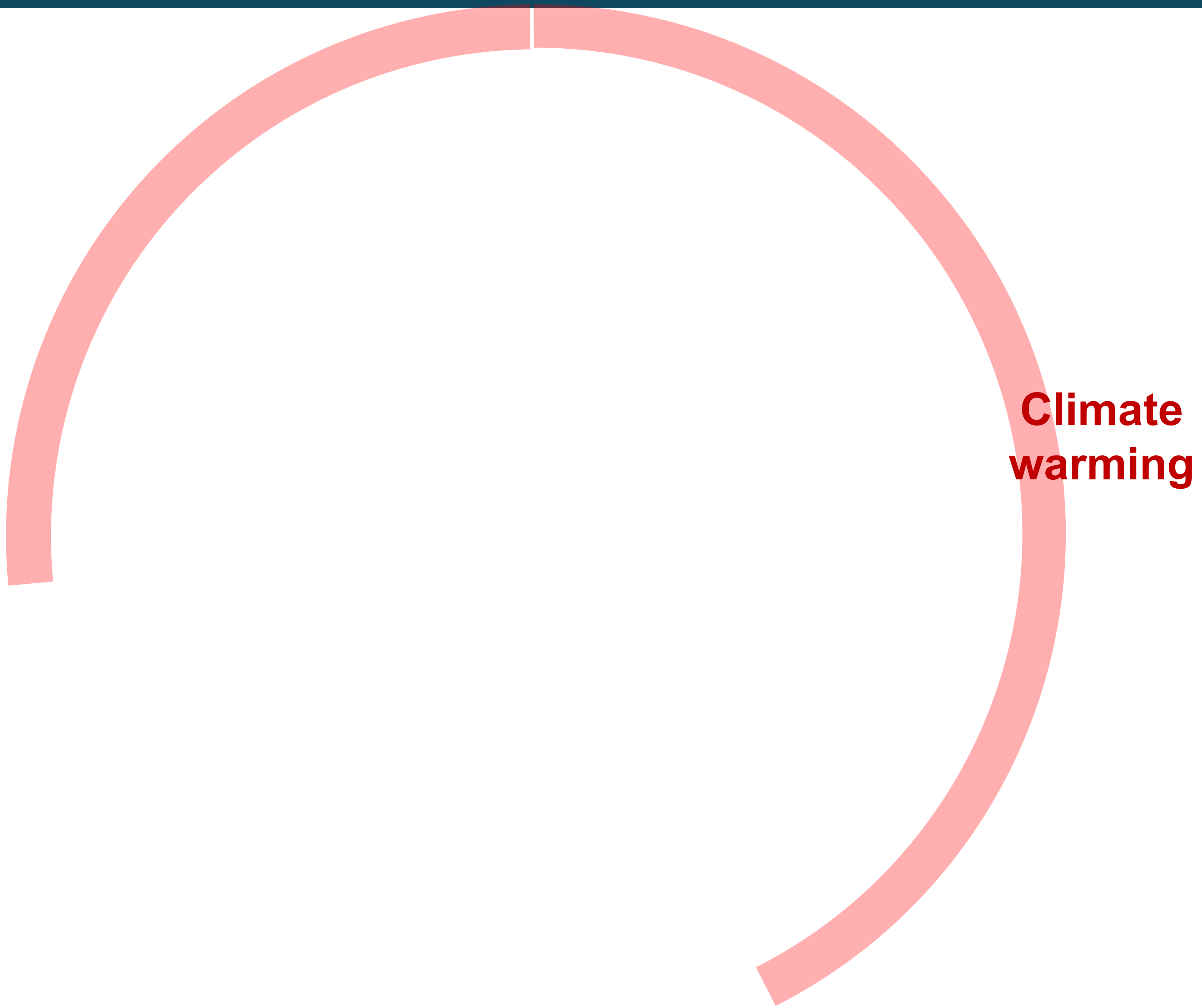
The climate feedback of methane is determined by both natural methane emissions and OH chemistry



- Methane natural emissions.
- OH.



How does OH respond to climate warming?

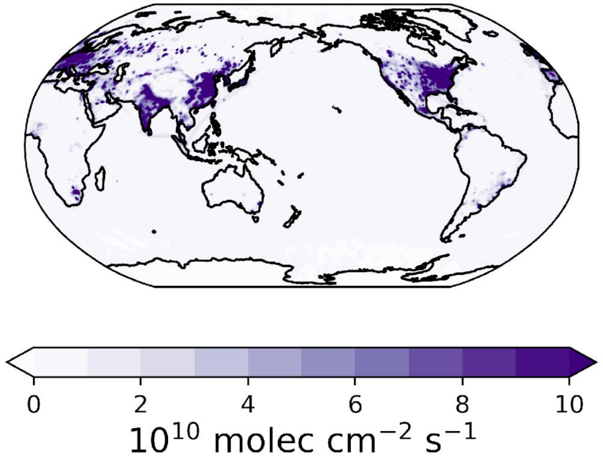


- Direct response: meteorology.
- Indirect response: biogenic volatile organic compounds (BVOC) emissions.

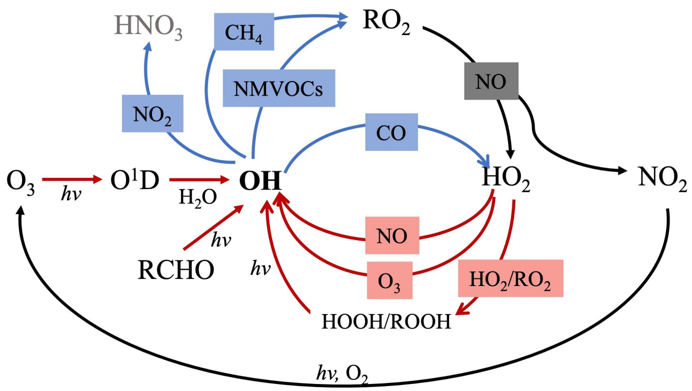
Zhu et al., 2025, In prep

The coupling between climate dynamics and emissions makes interpreting OH challenging

Emissions (103 in total, e.g. NO anthropogenic)

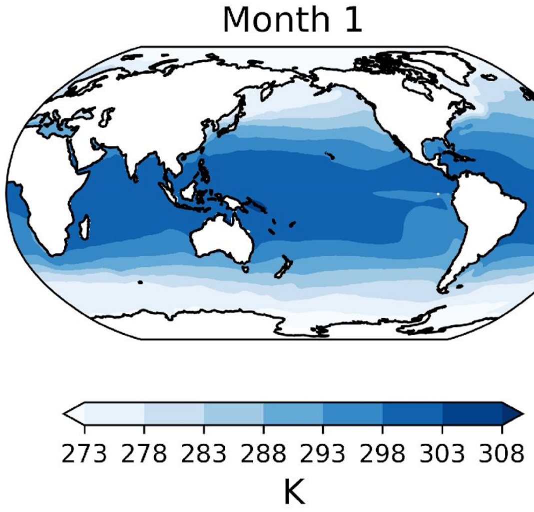


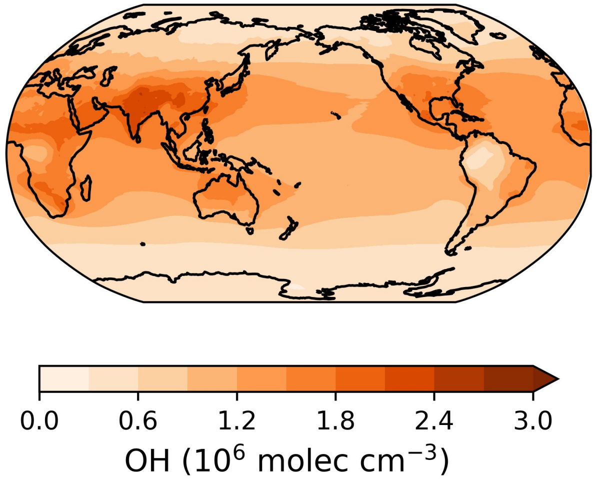
Chemistry



287 reactions

Sea surface temperature (SST)



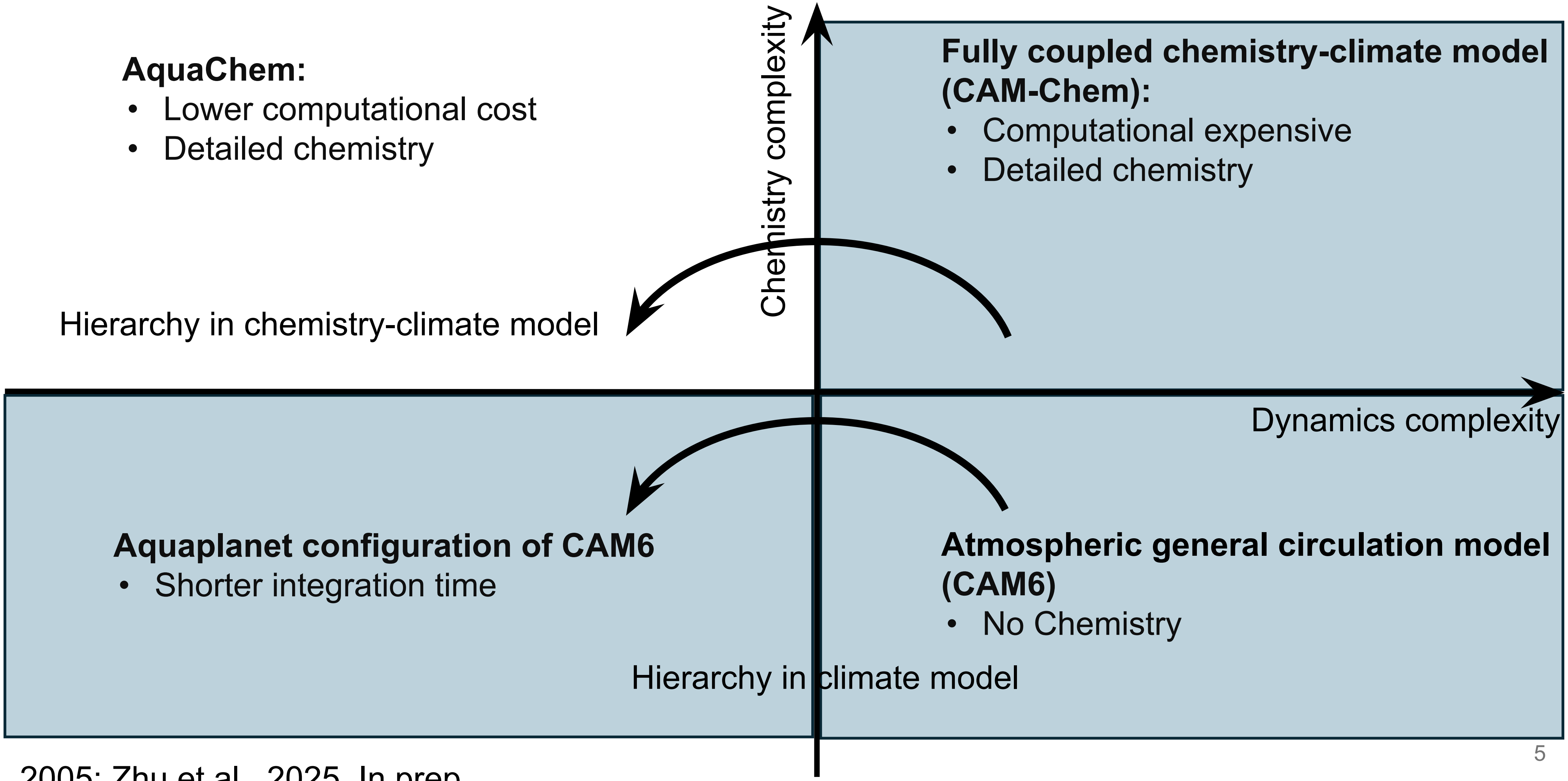


- CAM-Chem
- 0.94° x 1.25° x 30 vertical layers

- **Computationally intensive.**
- **Hard to isolate the impact of emissions/climate.**

Zhu et al., 2025, In prep

Build a step in the model hierarchy to study chemistry-climate interaction



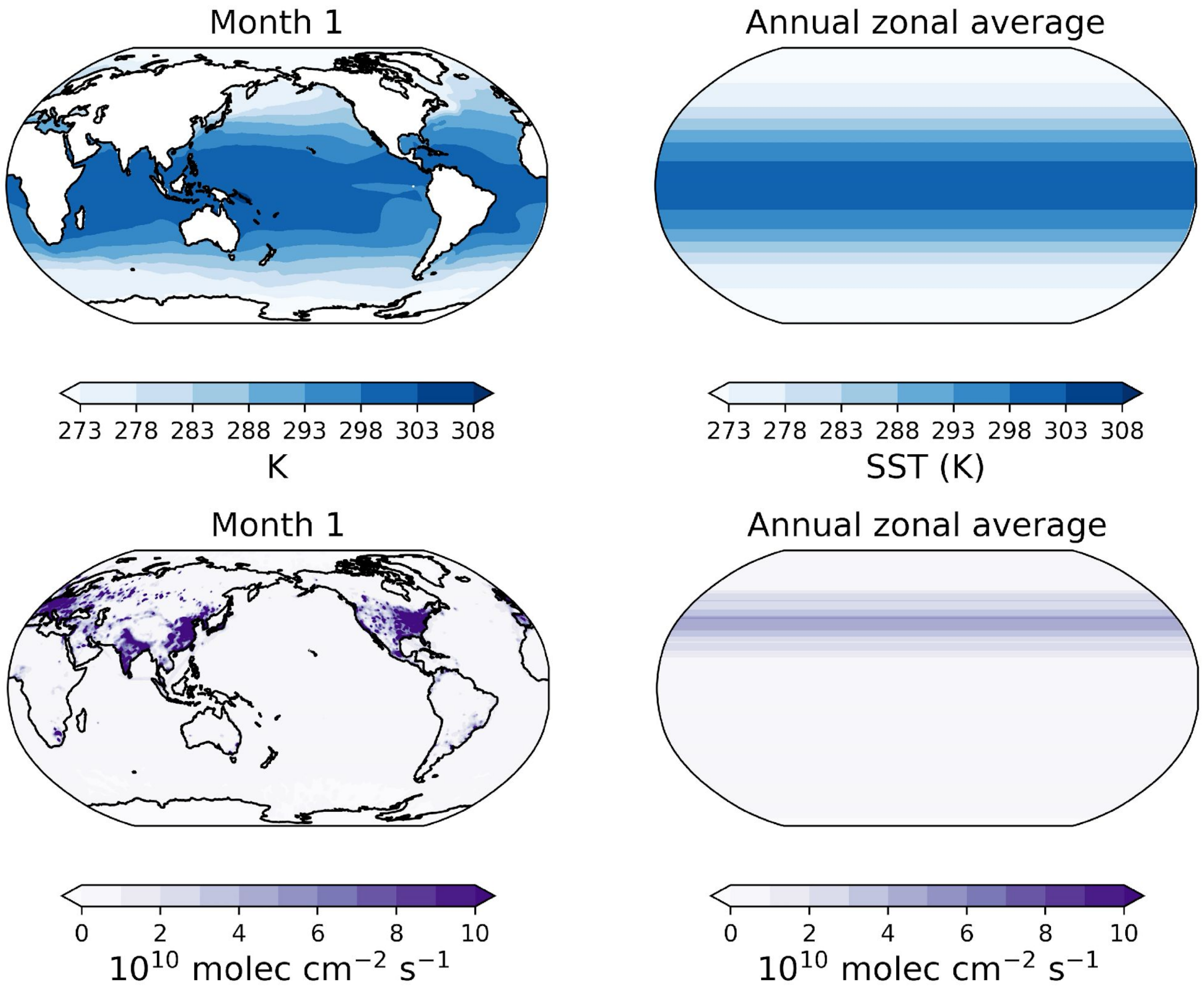
Held, 2005; Zhu et al., 2025, In prep

AquaChem: a simplified chemistry-climate model retaining full complexity in chemistry

CAM-Chem | **AquaChem**

Sea surface temperature (SST)

Emissions (103 in total, e.g. NO anthropogenic)



- **Simplified dynamics**
- Hadley Cell
- Upper tropospheric jet

- **Simplified emissions**
- 103 in total
- No spatial and seasonal variation

Zhu et al., 2025, In prep

AquaChem reproduces the contribution of individual OH **production** and **loss** pathways simulated in CAM-Chem

- OH is at the steady state.
- [OH] = R(prod) / f(loss).
- Integrated between -60° and 60° latitudes.

CAM-Chem AquaChem

Zhu et al., 2025, In prep

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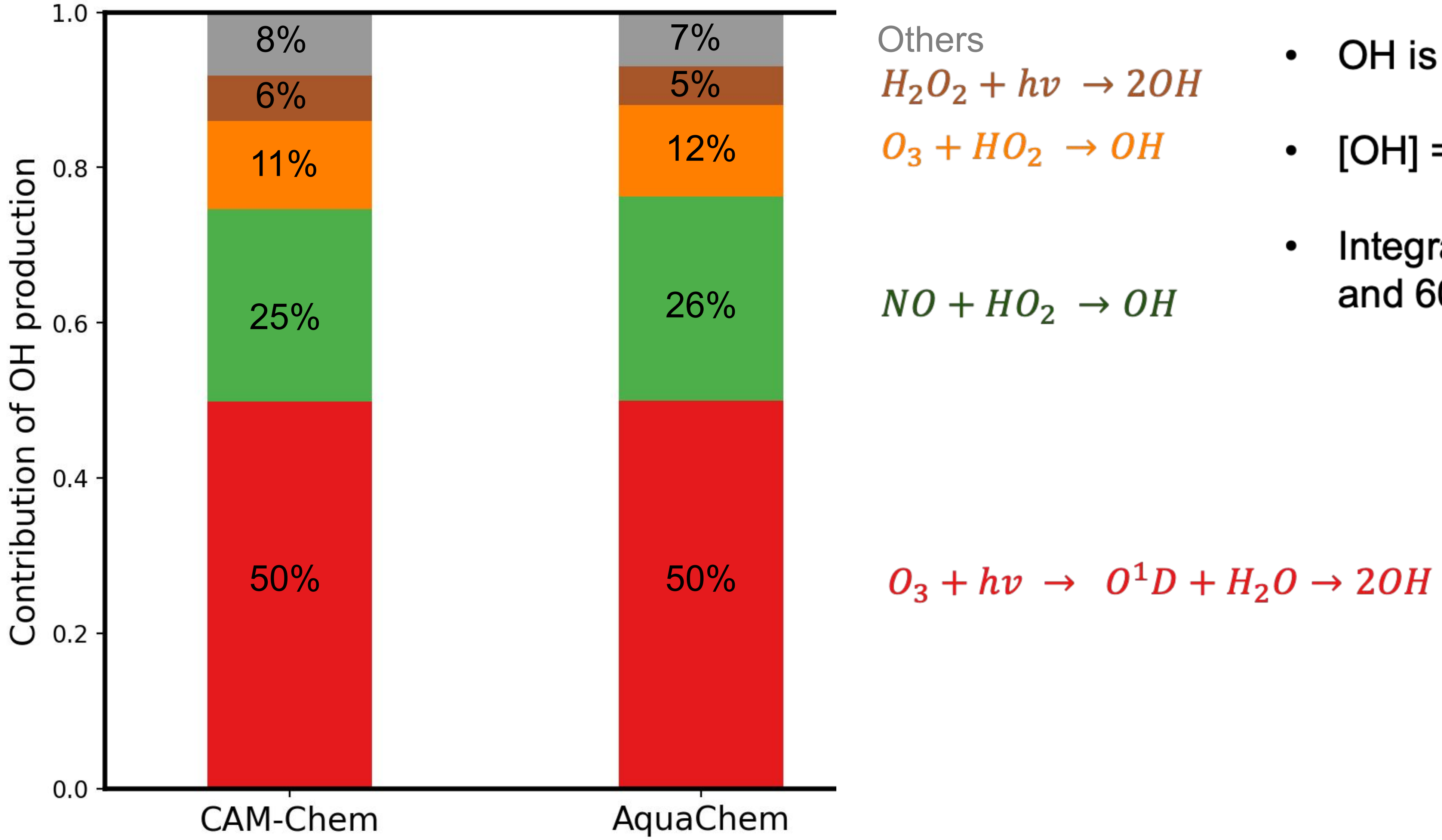

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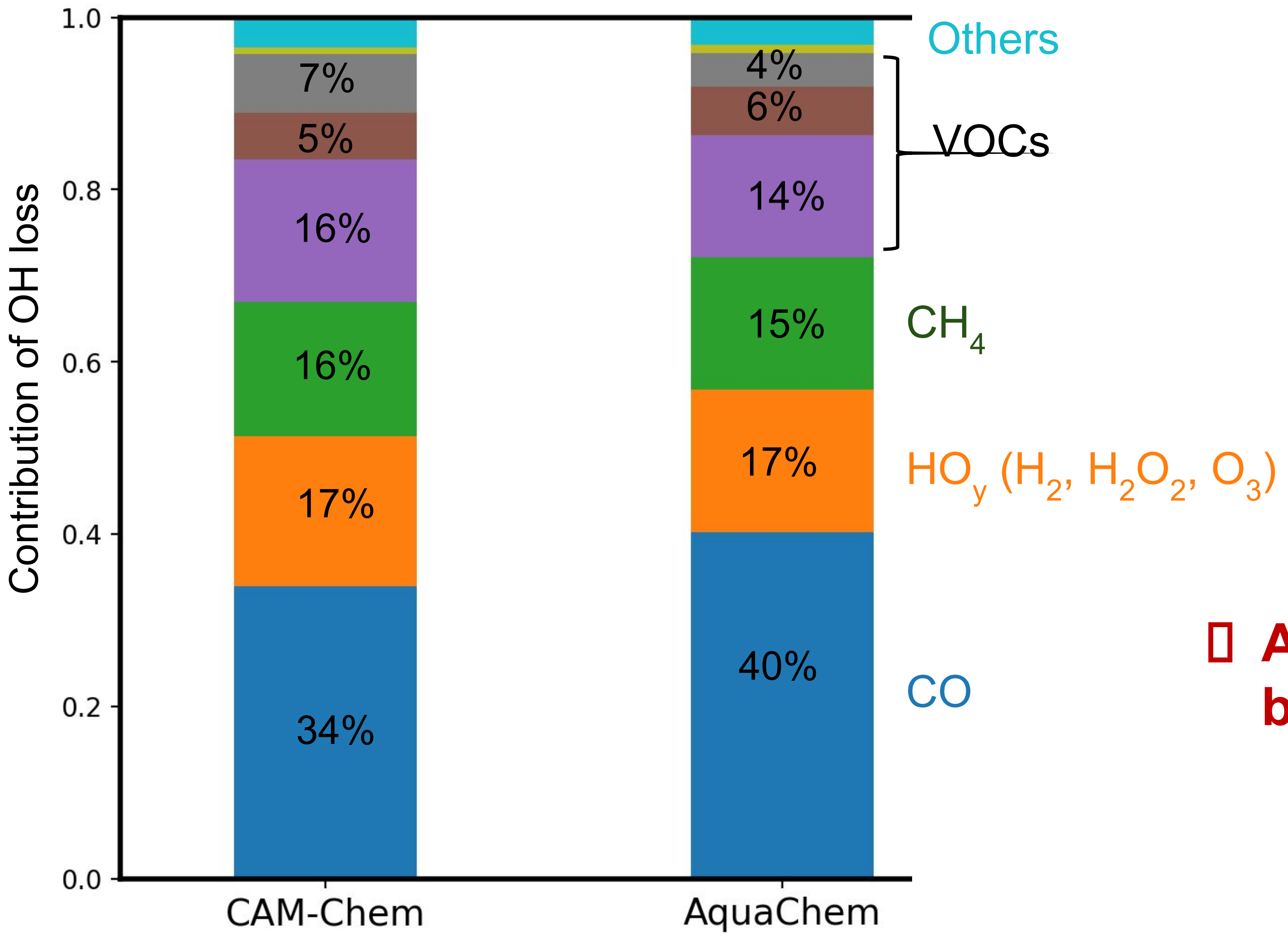

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AquaChem: individual OH budget terms.

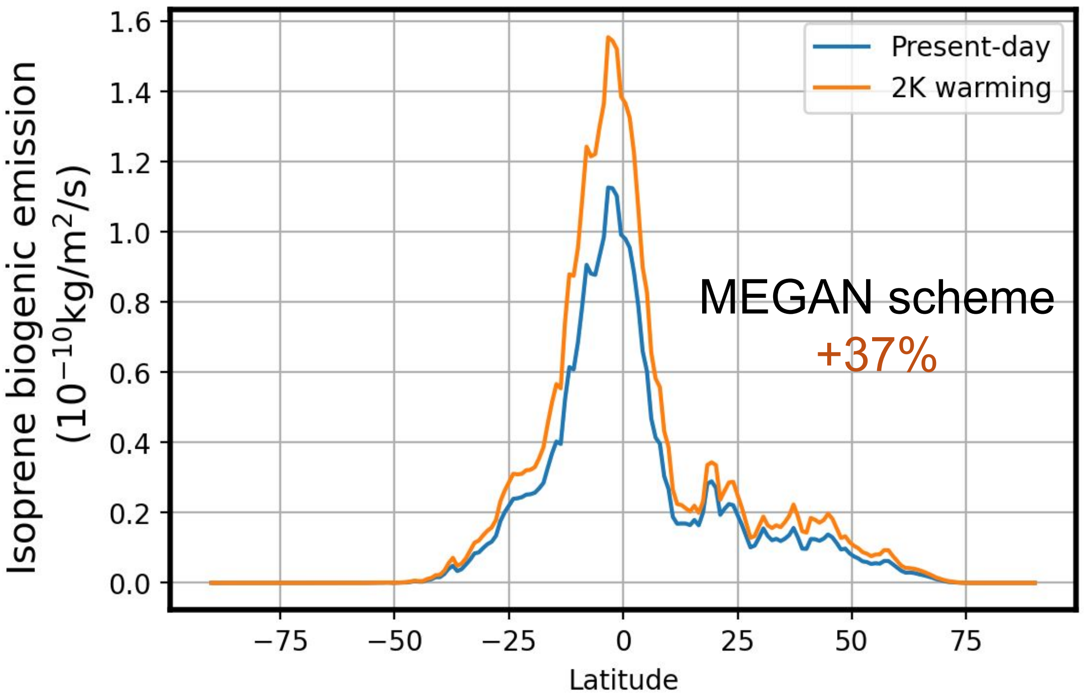
Zhu et al., 2025, In prep

Characterize the OH response to warming using idealized +2 Kelvin SST experiments in AquaChem

OH response to +2K idealized warming

	Present-day	Idealized-warming (Met only)
SST	PD	+2K
Anthro. emission	PD	PD
Biogenic emission	PD	PD

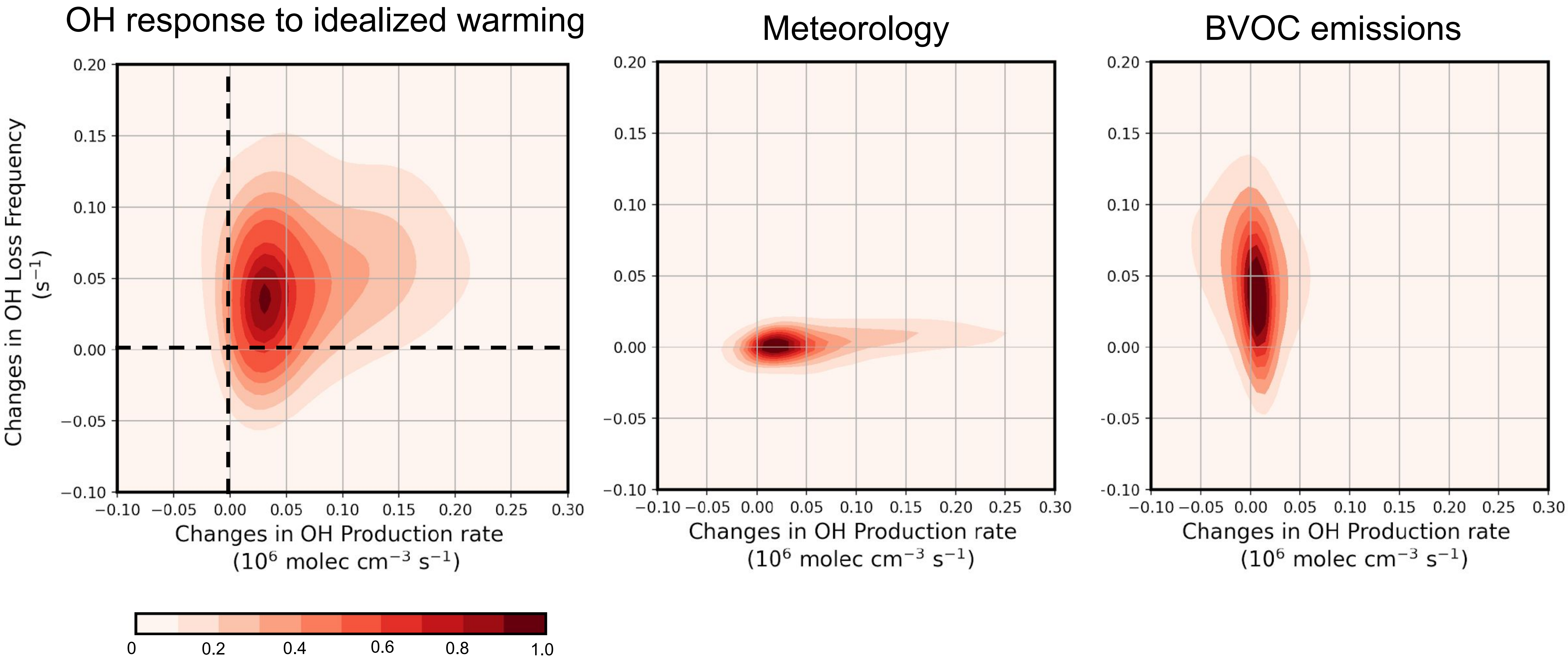
Meteorology   BVOC emissions



BVOC: biogenic volatile organic compounds

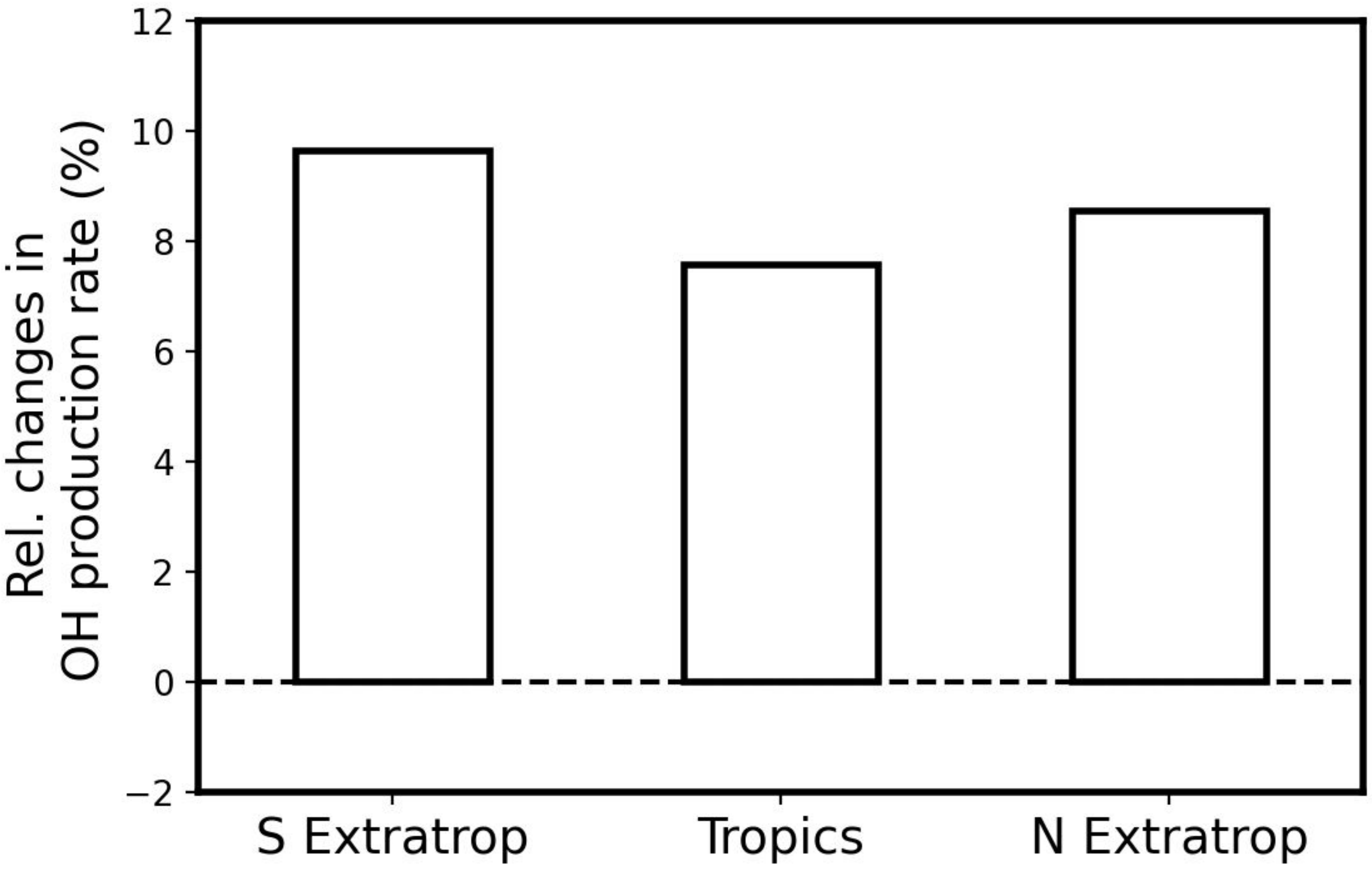
Zhu et al., 2025, In prep

The meteorology and BVOC emissions impacts OH through OH production and loss pathways, respectively



Zhu et al., 2025, In prep

Direct OH response to idealized warming is dominated by moistening



- OH production rate: 7.6-9.6%.

Zhu et al., 2025, In prep

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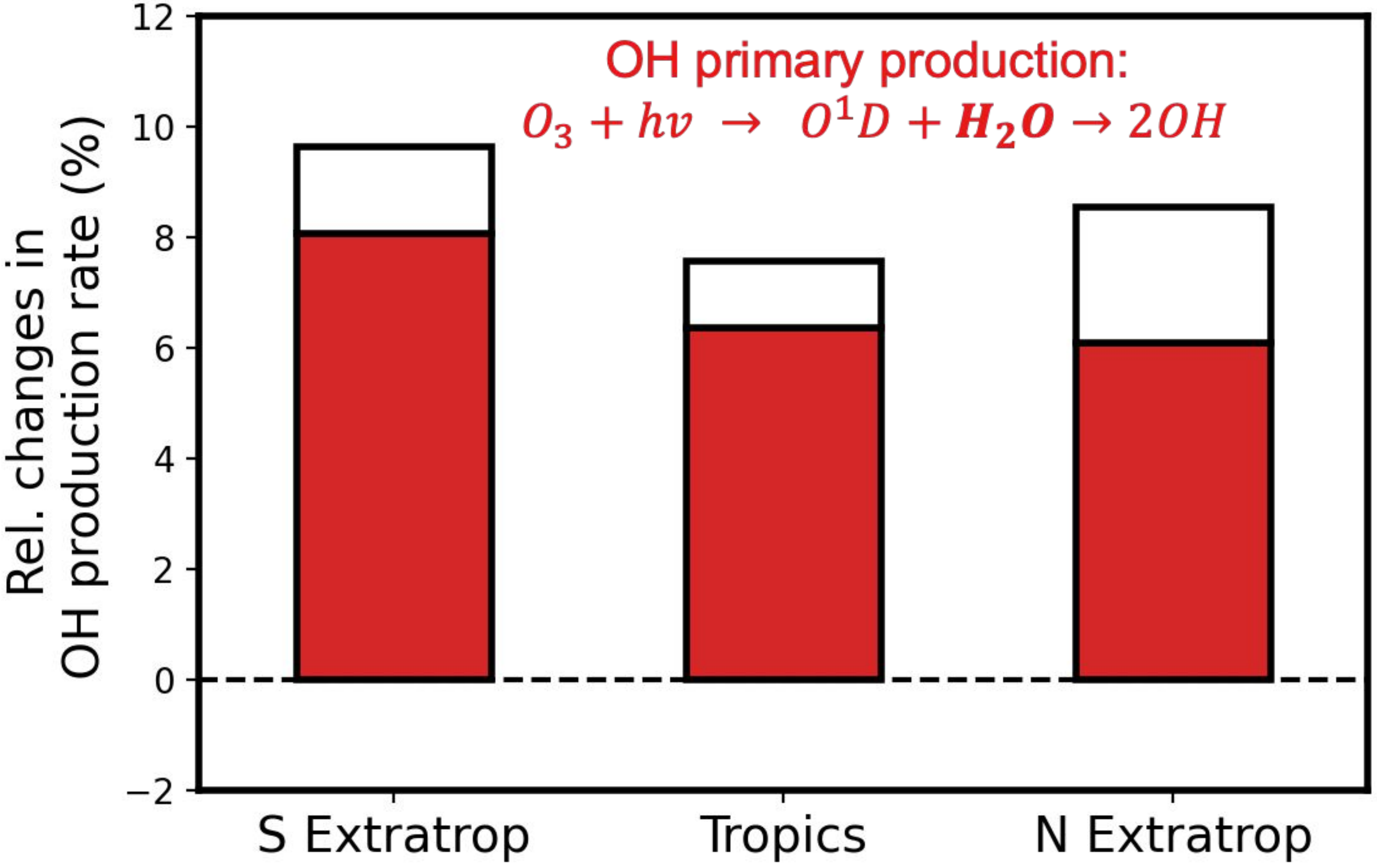
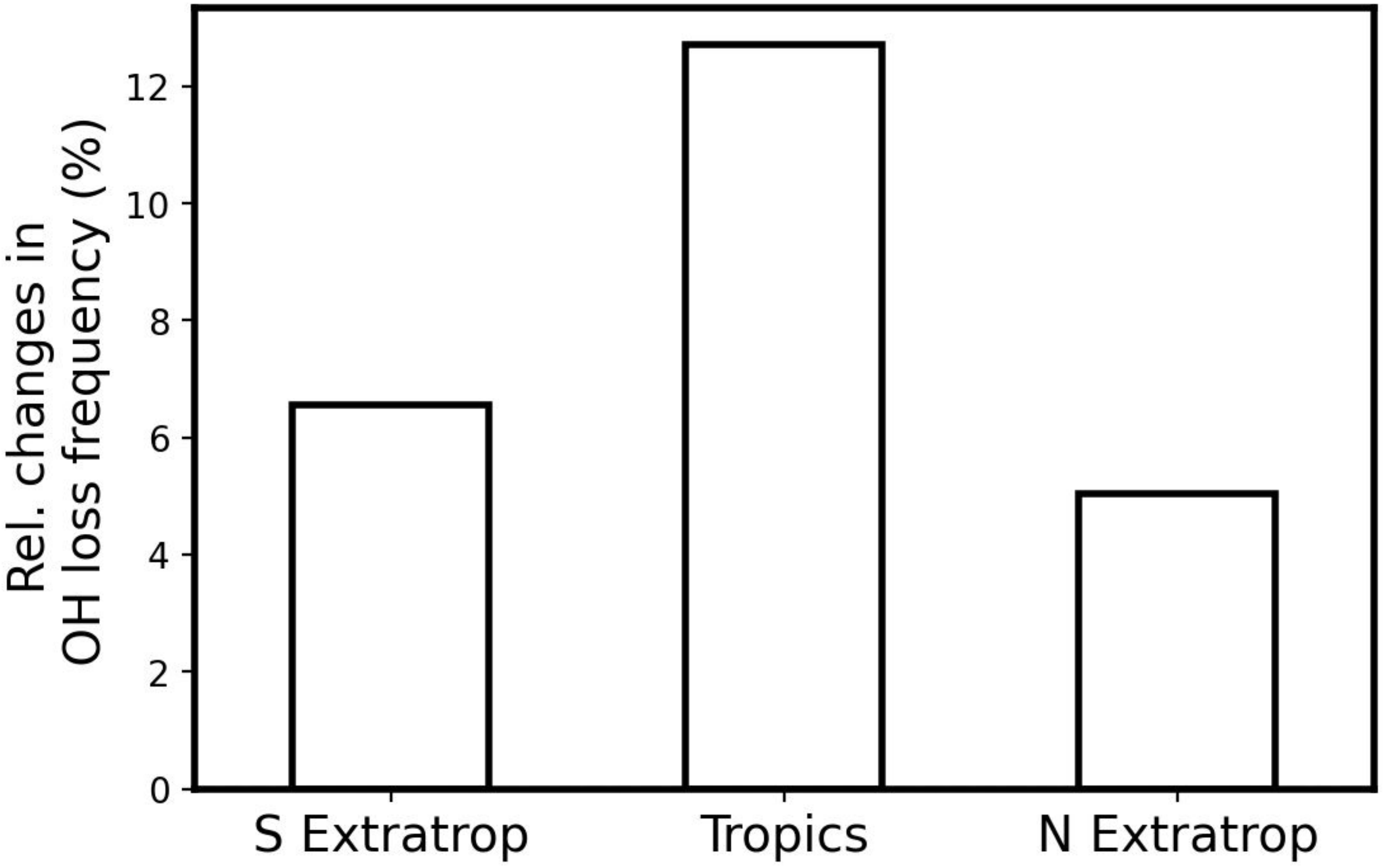


- OH production rate: 7.6-9.6%.
- Primary production pathway: 6.1-8.1%.
- 7%/K increase in H_2O (Clausius-Clapeyron).

Zhu et al., 2025, In prep

Temperature-sensitive BVOC emissions contributes to OH losses through BVOC and its oxidation products



- OH loss frequency: 5.0-12.7%.

Zhu et al., 2025, In prep

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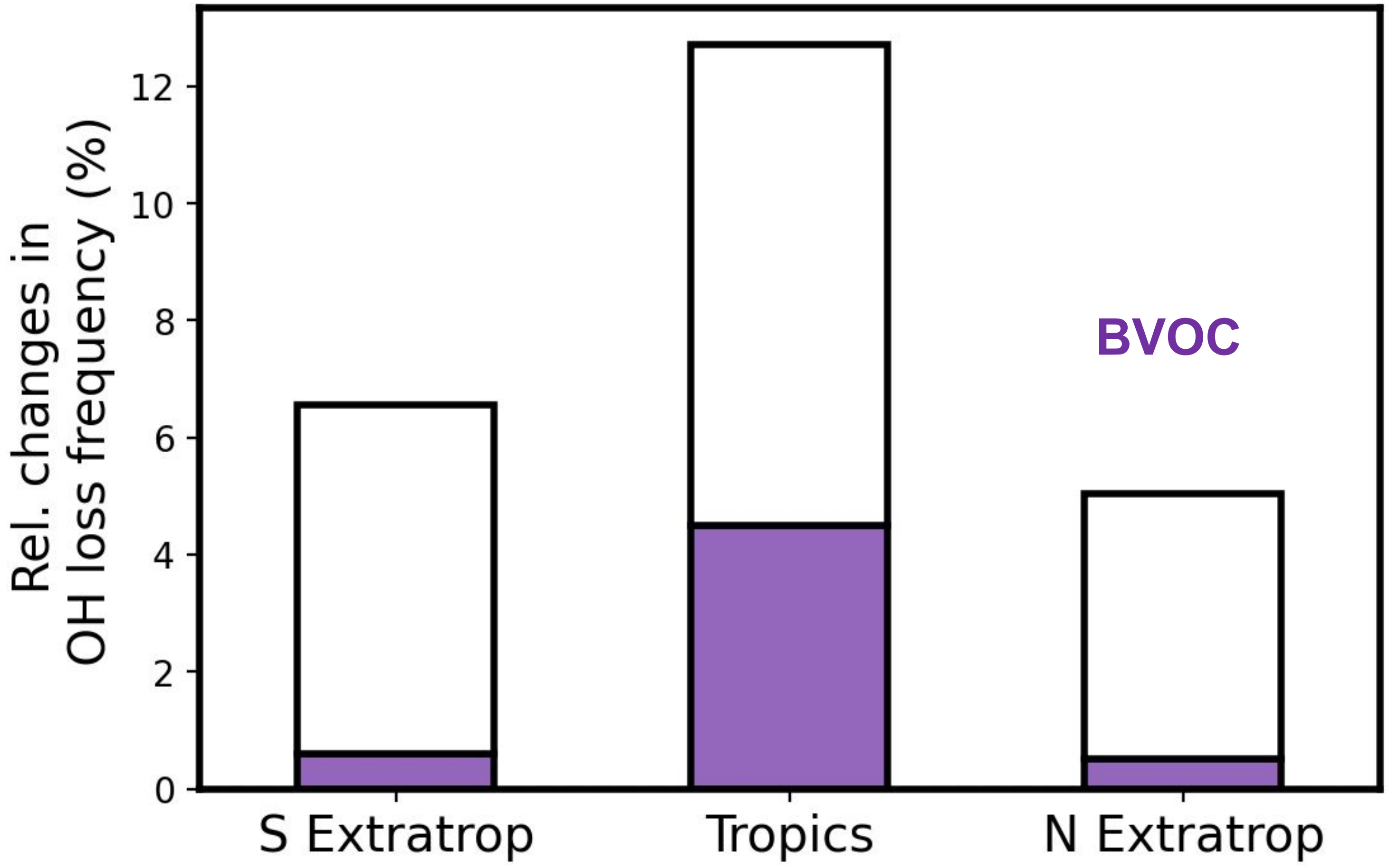
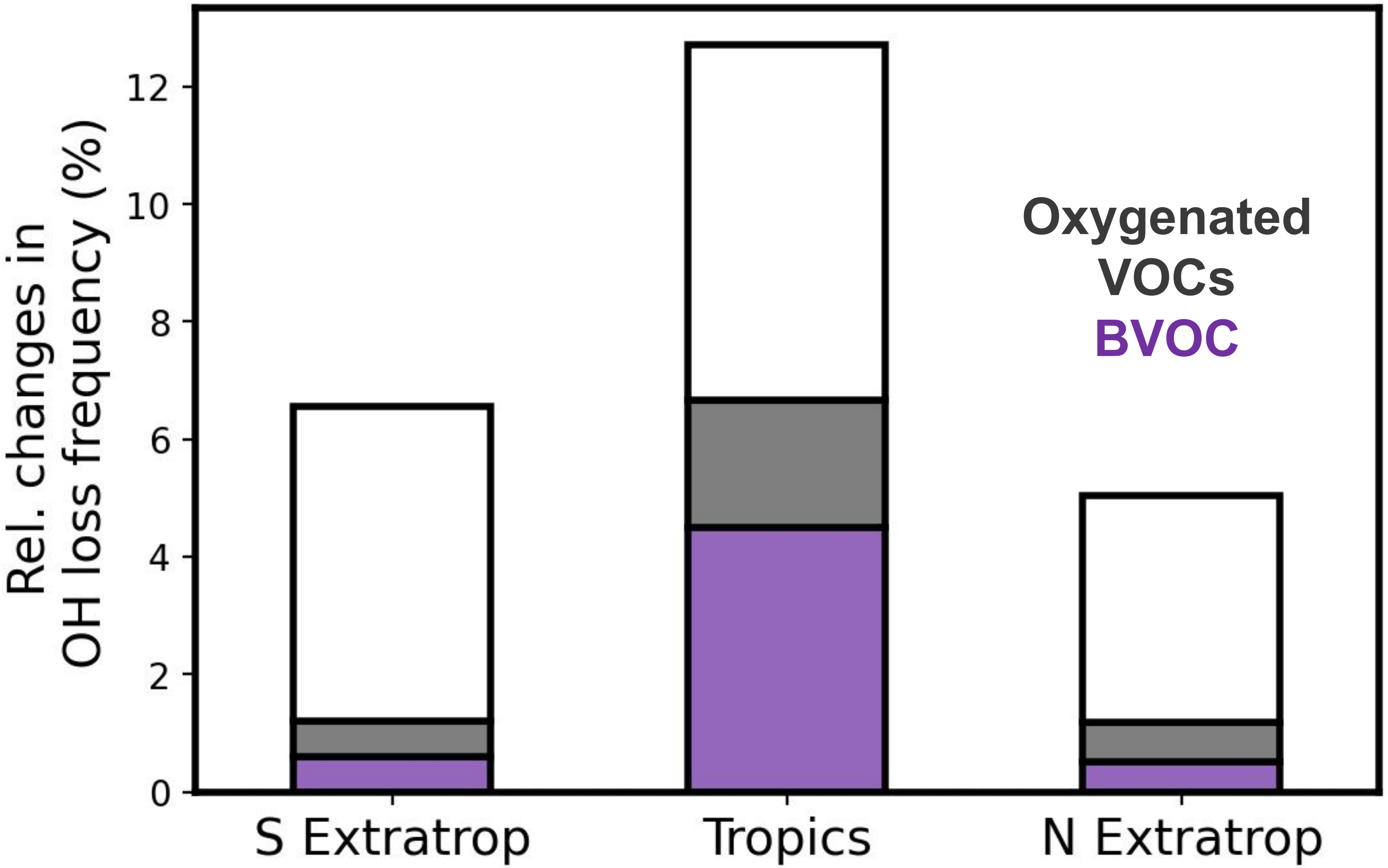


BVOC oxidation products: oxygenated VOCs and CO

- OH loss frequency: 5.0-12.7%.
- OH + BVOC reaction: 4.5% in the tropics.

Zhu et al., 2025, In prep

Temperature-sensitive BVOC emissions contributes to OH losses through BVOC and its oxidation products



- OH loss frequency: 5.0-12.7%.
- OH + BVOC reaction: 4.5% in the tropics.
- OH + oxygenated VOCs: 2.2% in the tropics.

BVOC oxidation products: oxygenated VOCs and CO

Zhu et al., 2025, In prep

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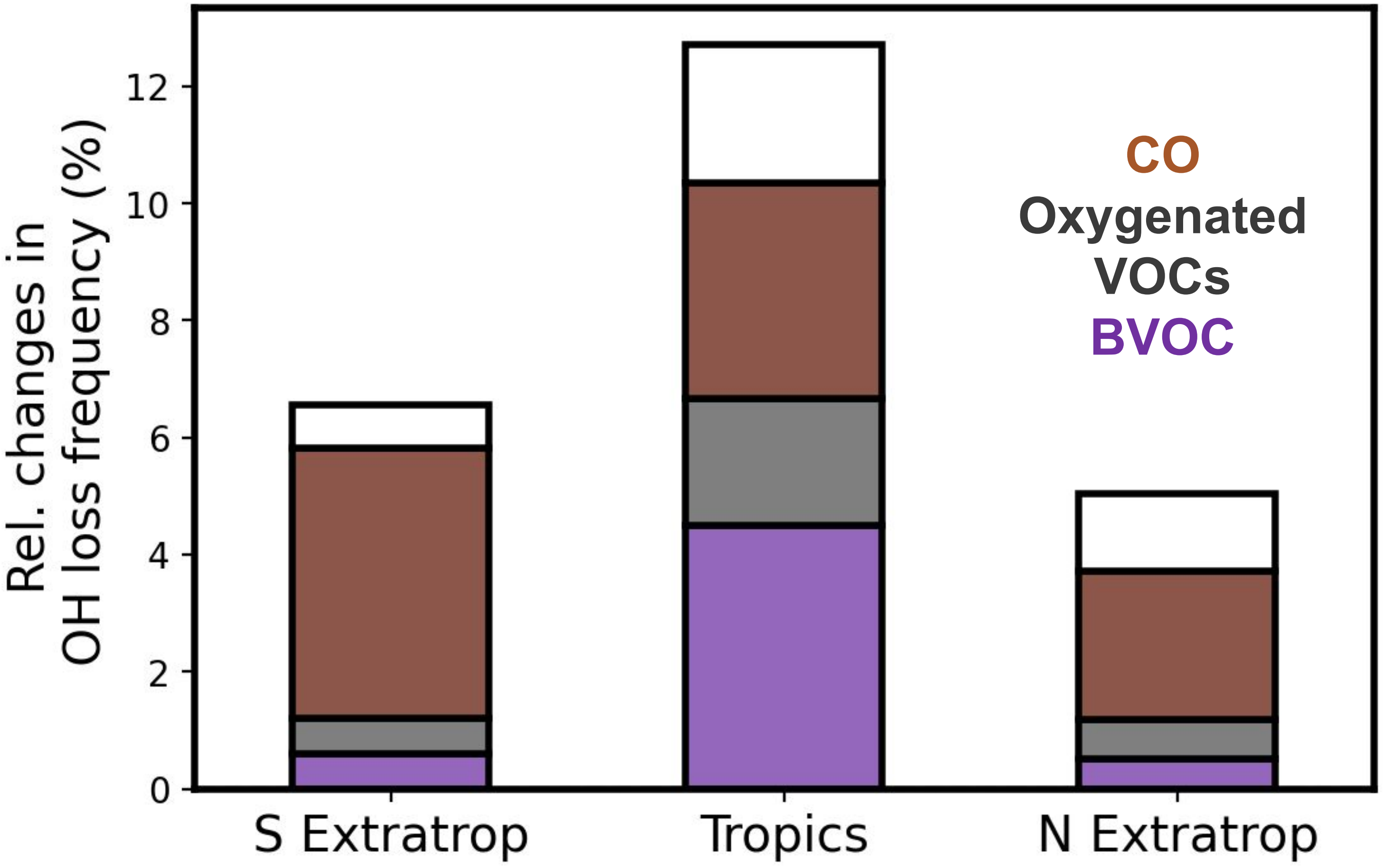


- OH loss frequency: 5.0-12.7%.
- OH + BVOC reaction: 4.5% in the tropics.
- OH + oxygenated VOCs: 2.2% in the tropics.
- OH + CO reaction: 2.5-4.6%.

BVOC oxidation products: oxygenated VOCs and CO

Zhu et al., 2025, In prep

OH response to idealized warming depends on competing processes through moistening and BVOC emissions

- Moistening: well-constrained.

- BVOC emissions: highly uncertain.

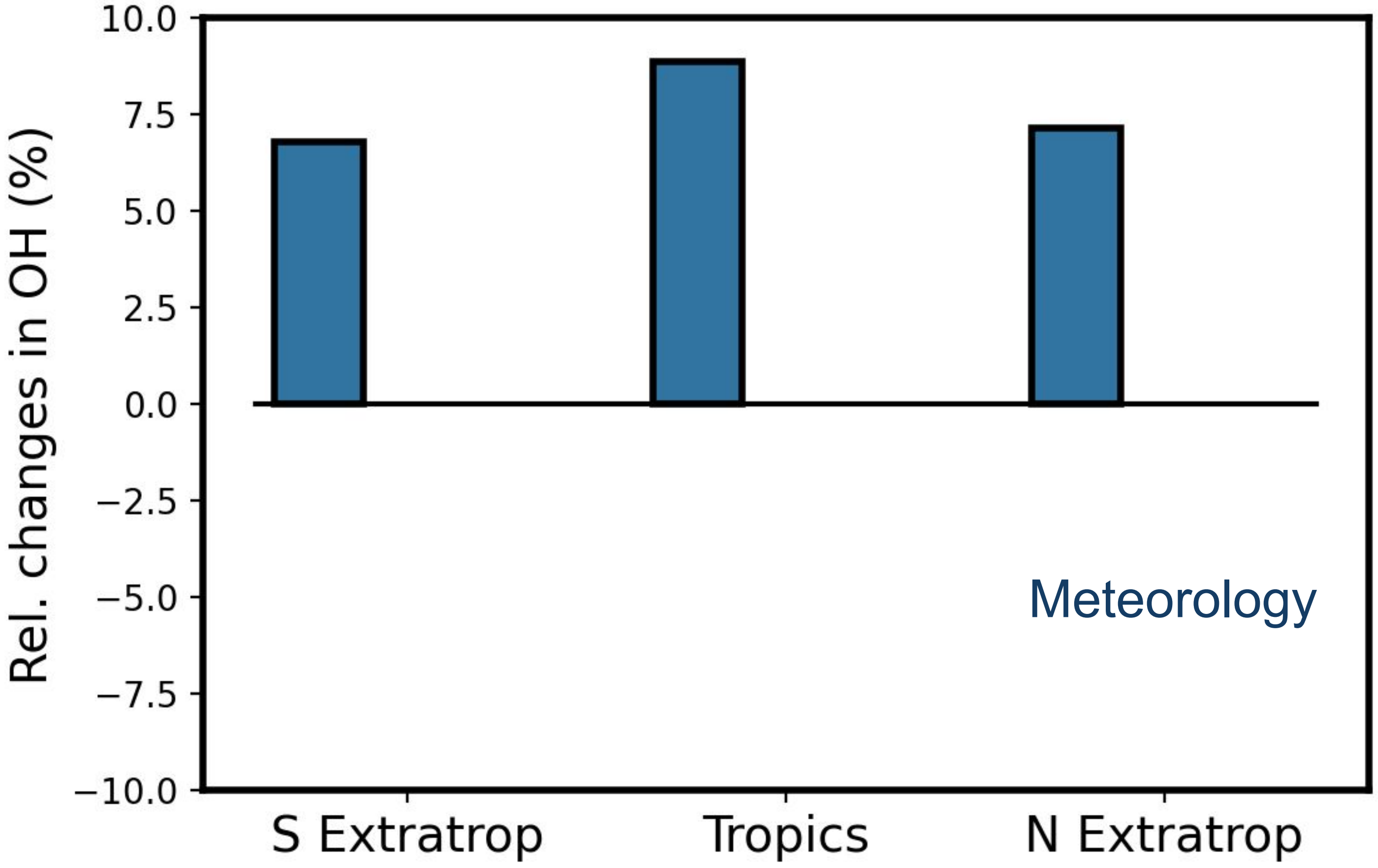
Take-away messages

Climate warming

OH response to idealized warming

- Idealized chemistry-climate model AquaChem.
- Process-level understanding of OH chemistry.
- Moistening vs BVOC emissions.

OH response to idealized warming depends on competing processes through moistening and BVOC emissions



- Moistening: 6.8% to 8.5%.

Zhu et al., 2025, In prep

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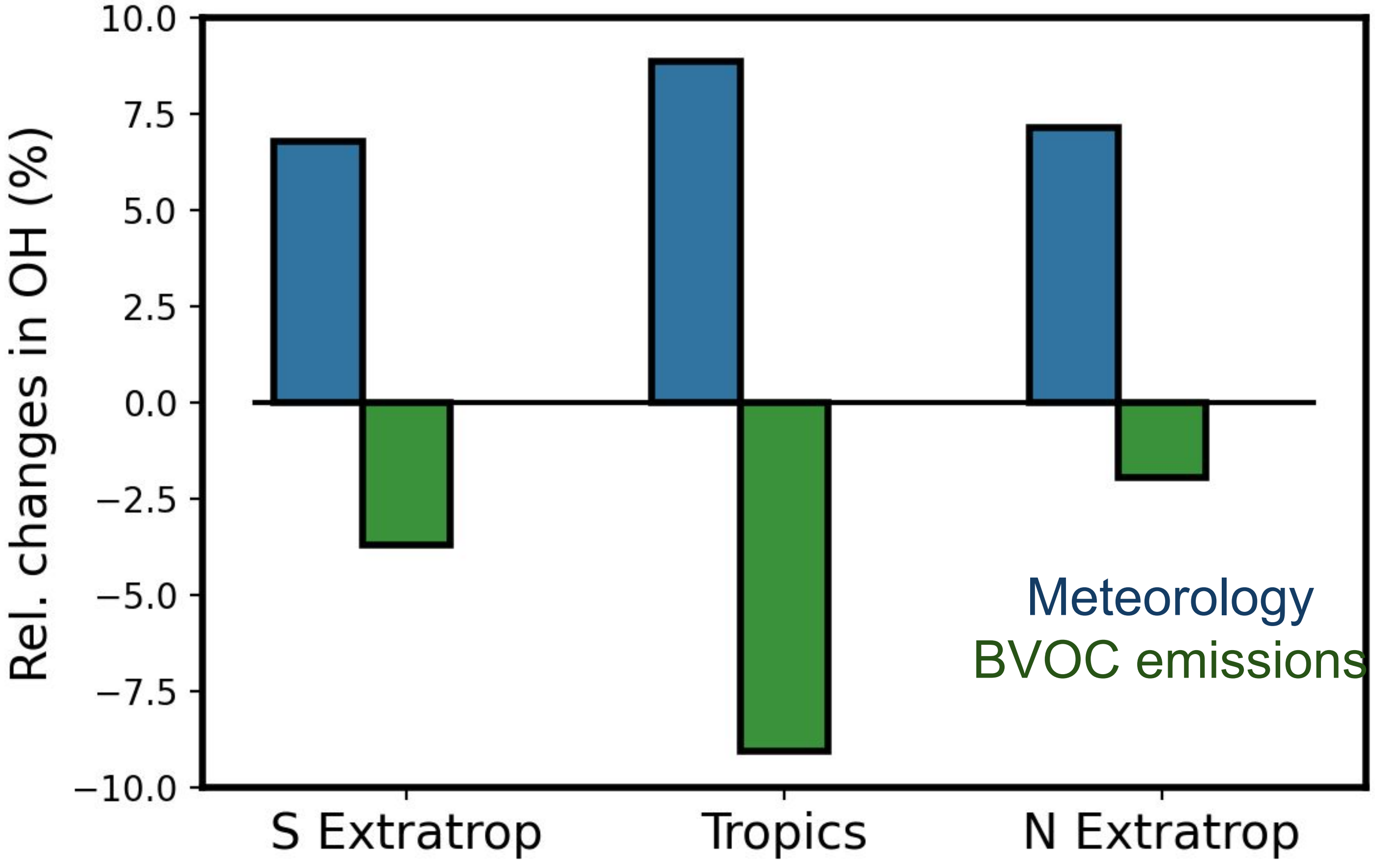

- Moistening: 6.8% to 8.5%.
- Temperature-sensitive BVOC emissions: -9.1% to -2.0%.

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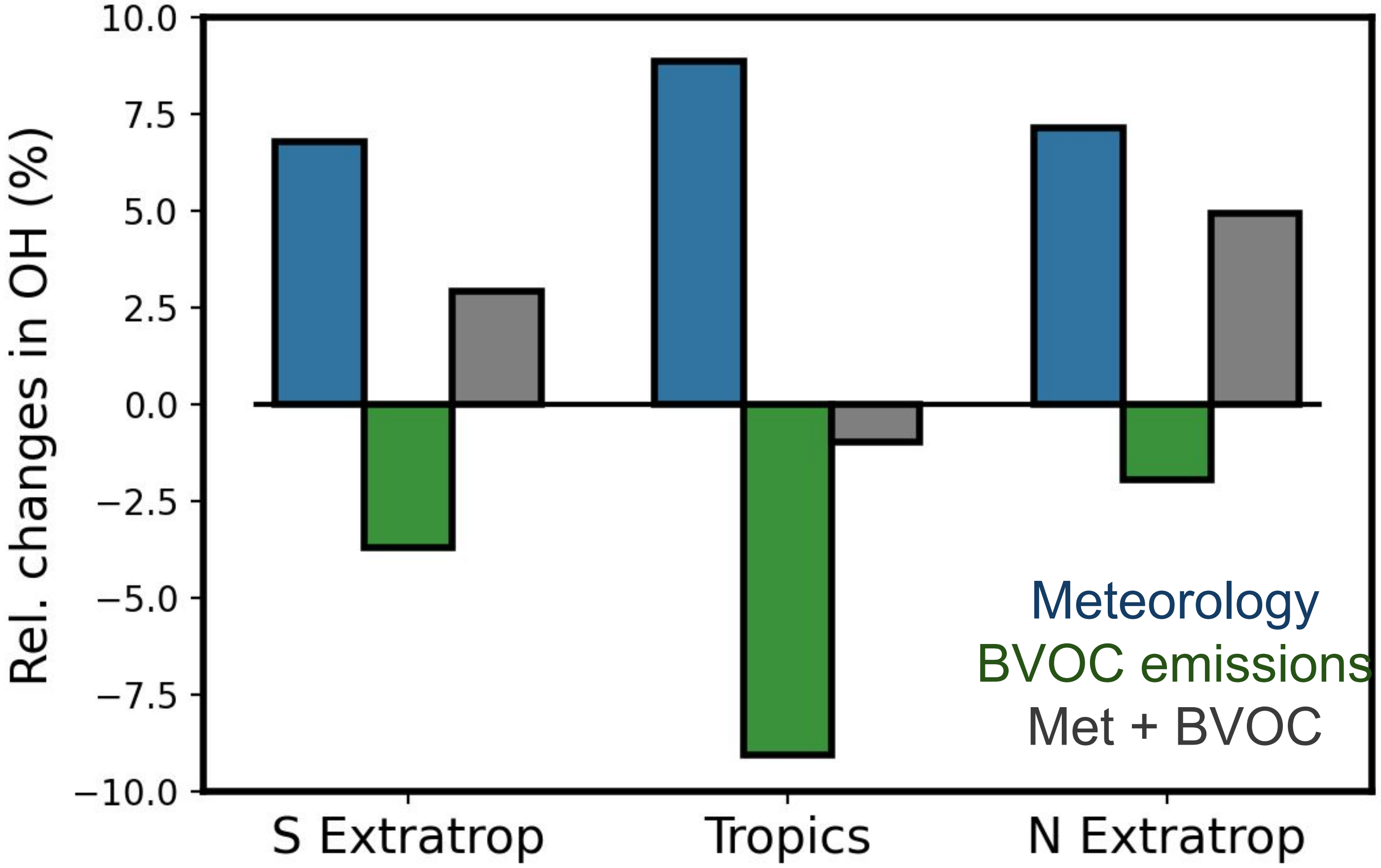
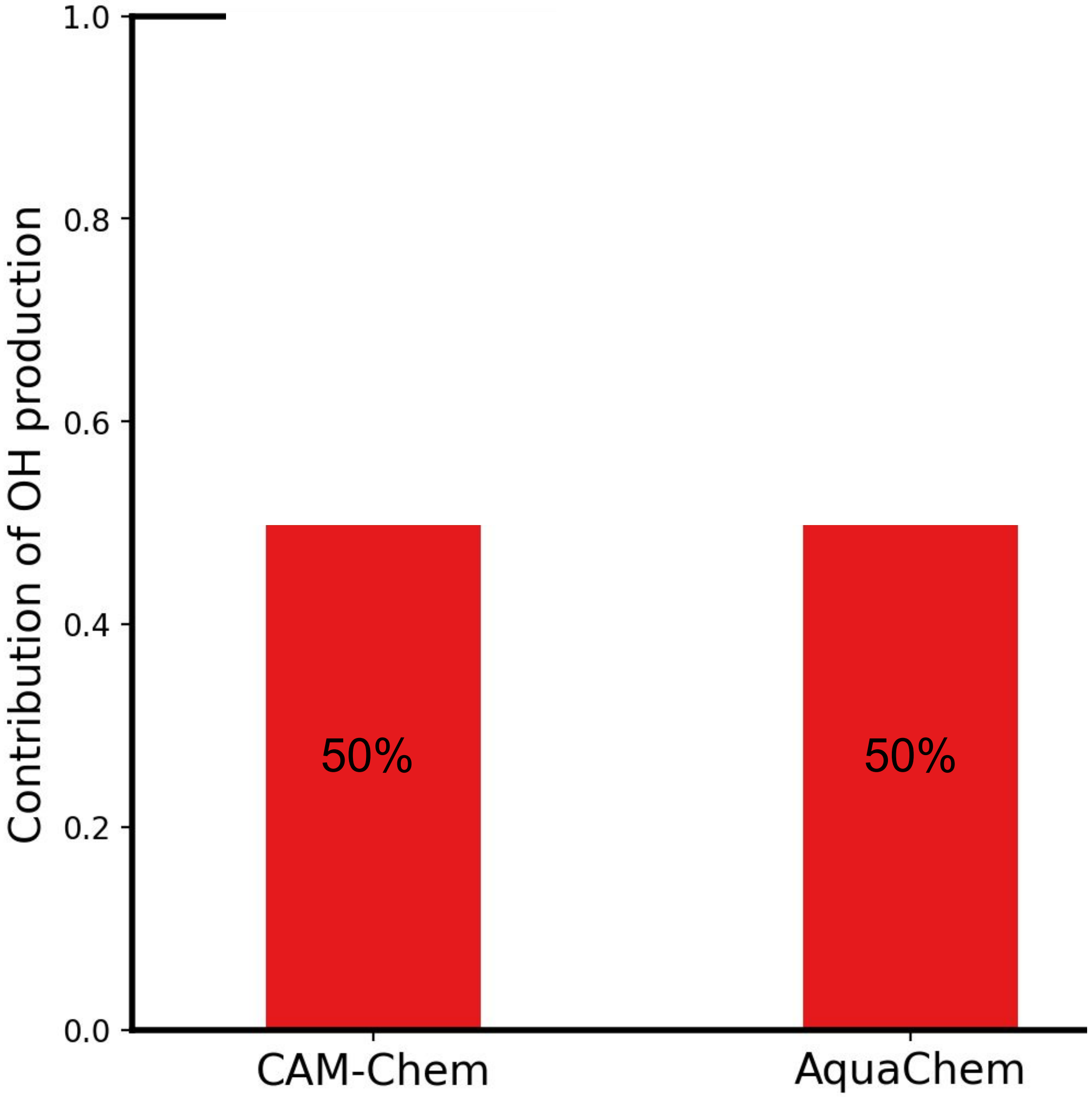


- Moistening: 6.8% to 8.5%.
- Temperature-sensitive BVOC emissions: -9.1% to -2.0%.
- OH response to idealized warming: -1.0% to 4.9%.

Zhu et al., 2025, In prep

AquaChem reproduces the contribution of individual OH production and loss pathways simulated in CAM-Chem



- OH is at the steady state.
- [OH] = R(prod) / f(loss).
- Integrated between -60° and 60° latitudes.

Primary OH production pathway

$O_3 + hv \rightarrow O^1D + H_2O \rightarrow 2OH$

Zhu et al., 2025, In prep

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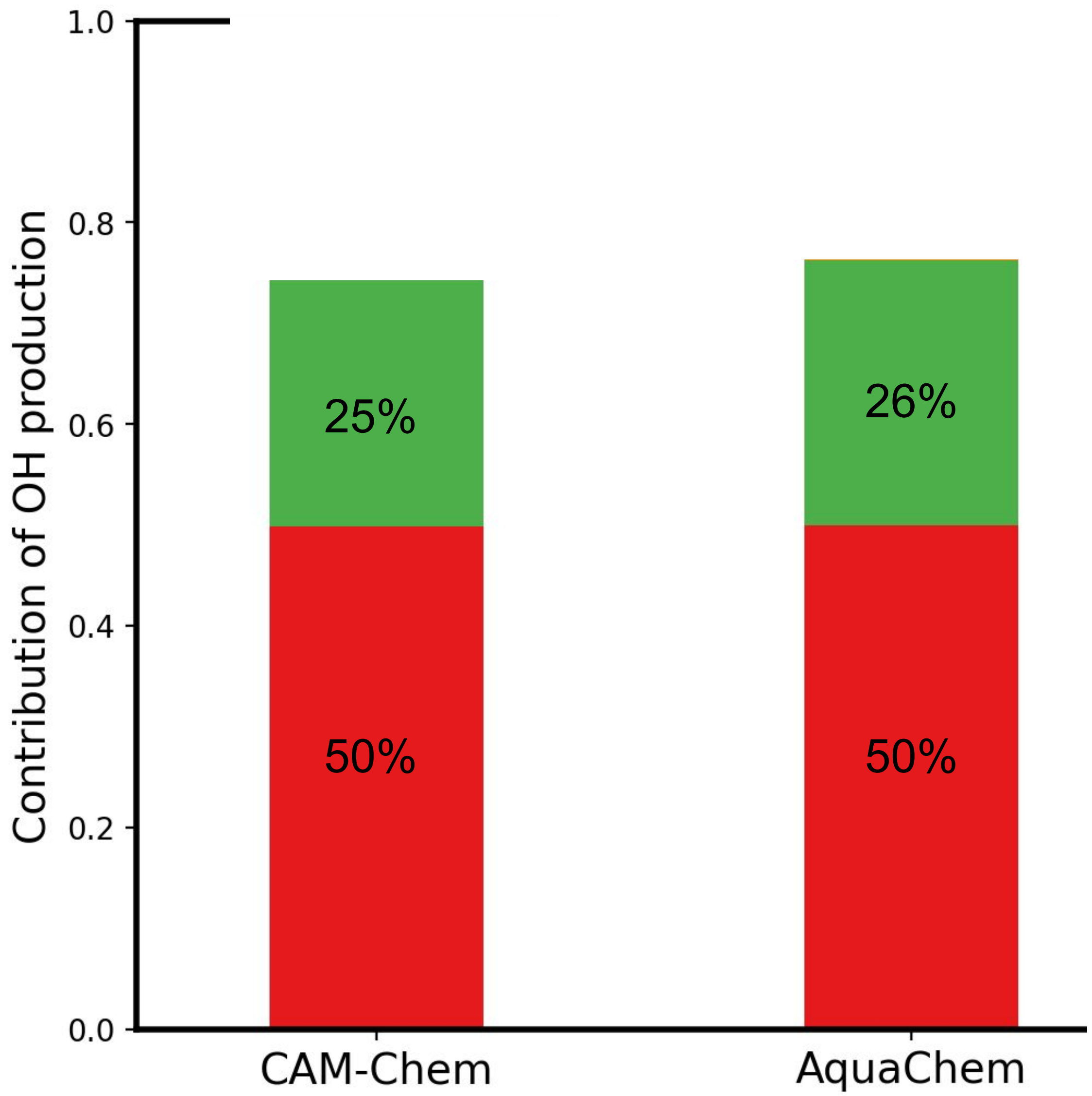

$NO + HO_2 \rightarrow OH$

$O_3 + h\nu \rightarrow O^1D + H_2O \rightarrow 2OH$

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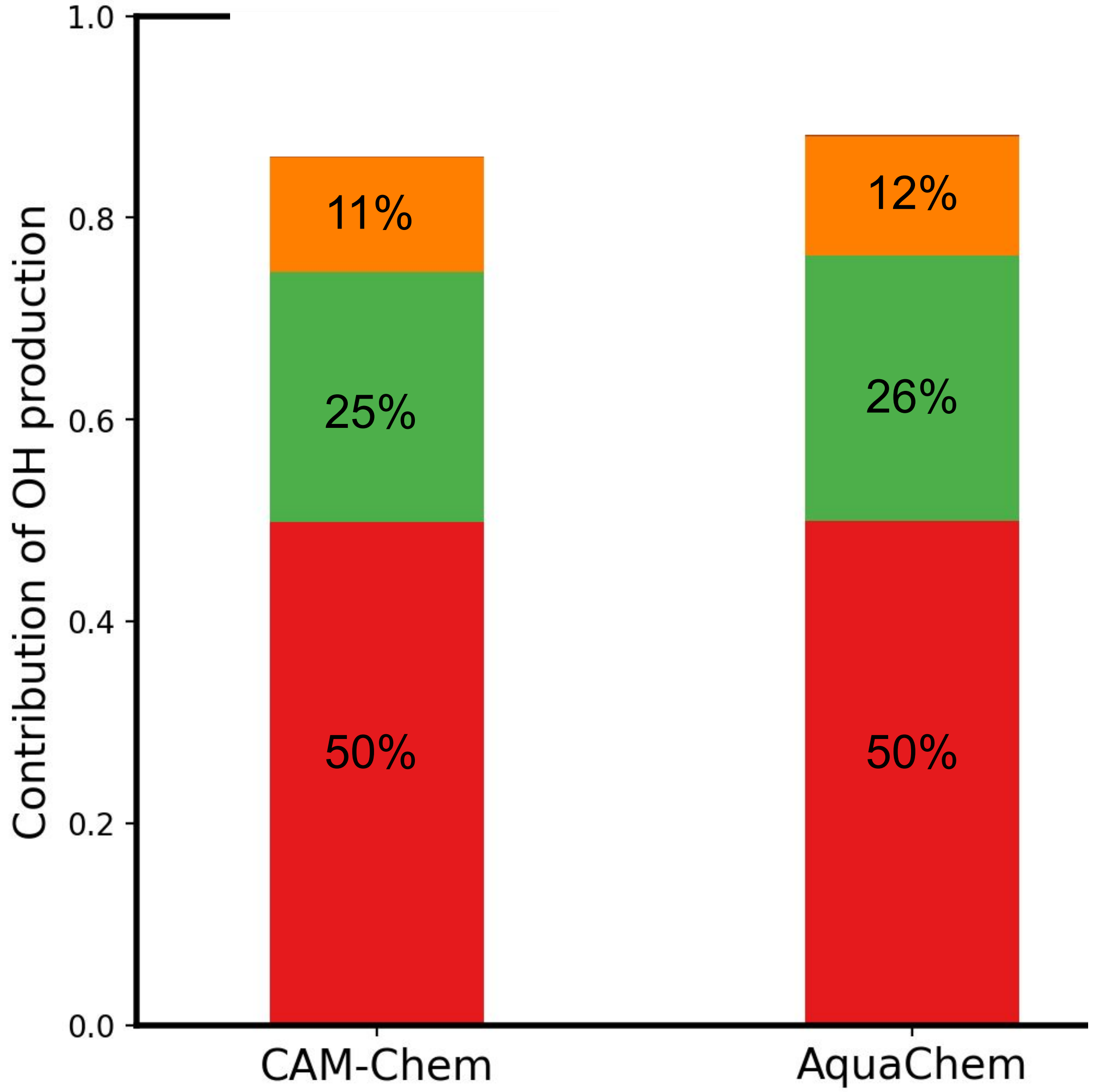

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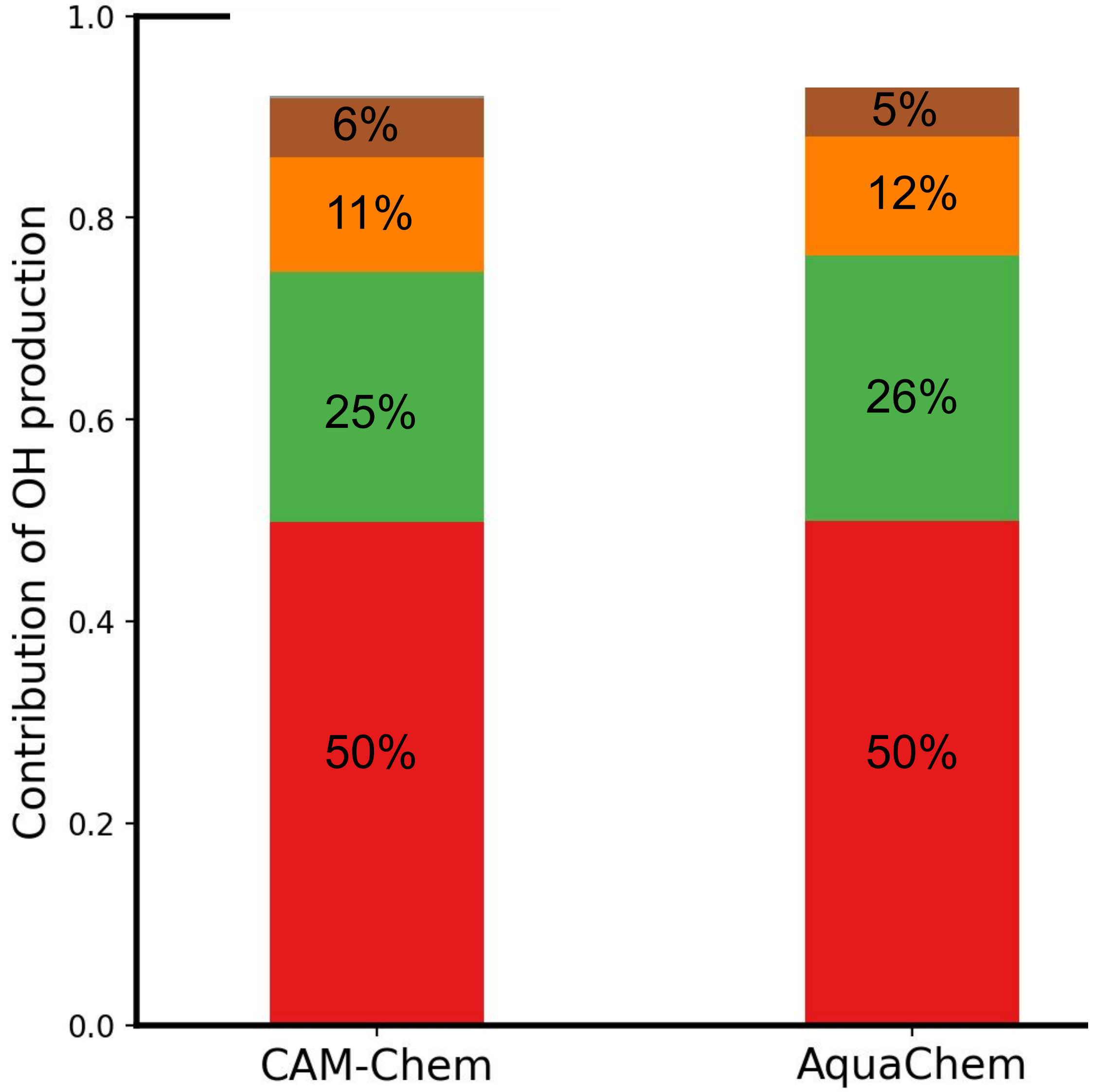

$H_2O_2 + hv \rightarrow 2OH$

$O_3 + HO_2 \rightarrow OH$

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$O_3 + hv \rightarrow O^1D + H_2O \rightarrow 2OH$

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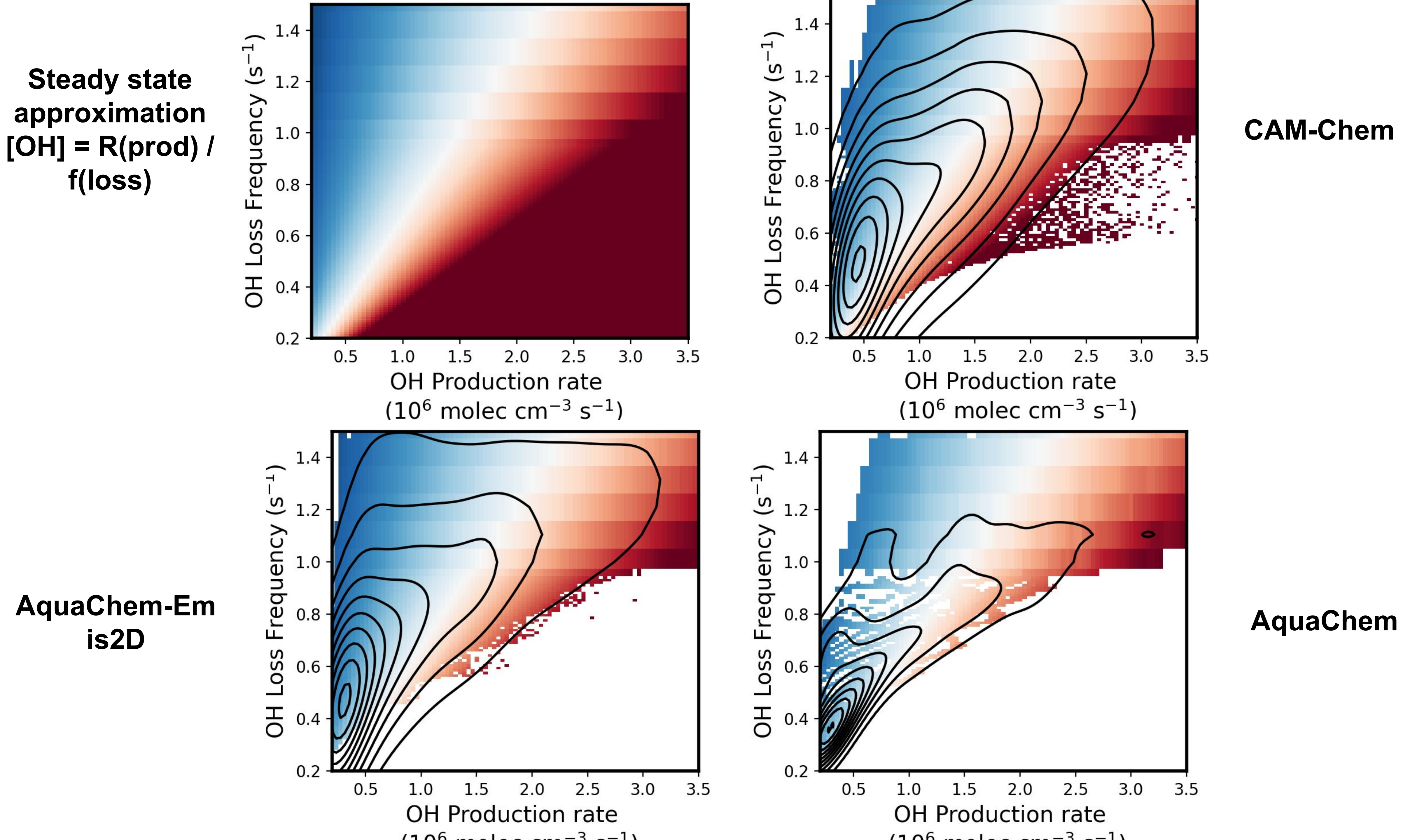
Steady state approximation [OH] = R(prod) / f(loss)
CAM-Chem
AquaChem-Emis2D
AquaChem
OH Loss Frequency (s^{-1})
OH Production rate
(10^6 molec cm^{-3} s^{-1})
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0.5
1.0
1.5
2.0
2.5
3.0
3.5