Assessment of Hydrogen's Climate Impact Is Affected by Model OH Biases

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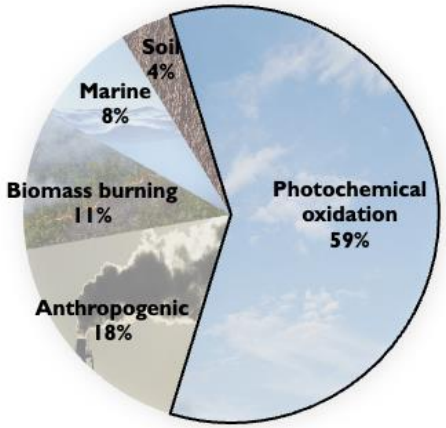
Hydrogen (H_2) is an indirect climate forcer due to its atmospheric oxidation by OH



$H_2 + OH \rightarrow H + H_2O$

↑ CH_4 40% → ↑ Trop. O_3 40%

↑ Strat.H_2O 20%

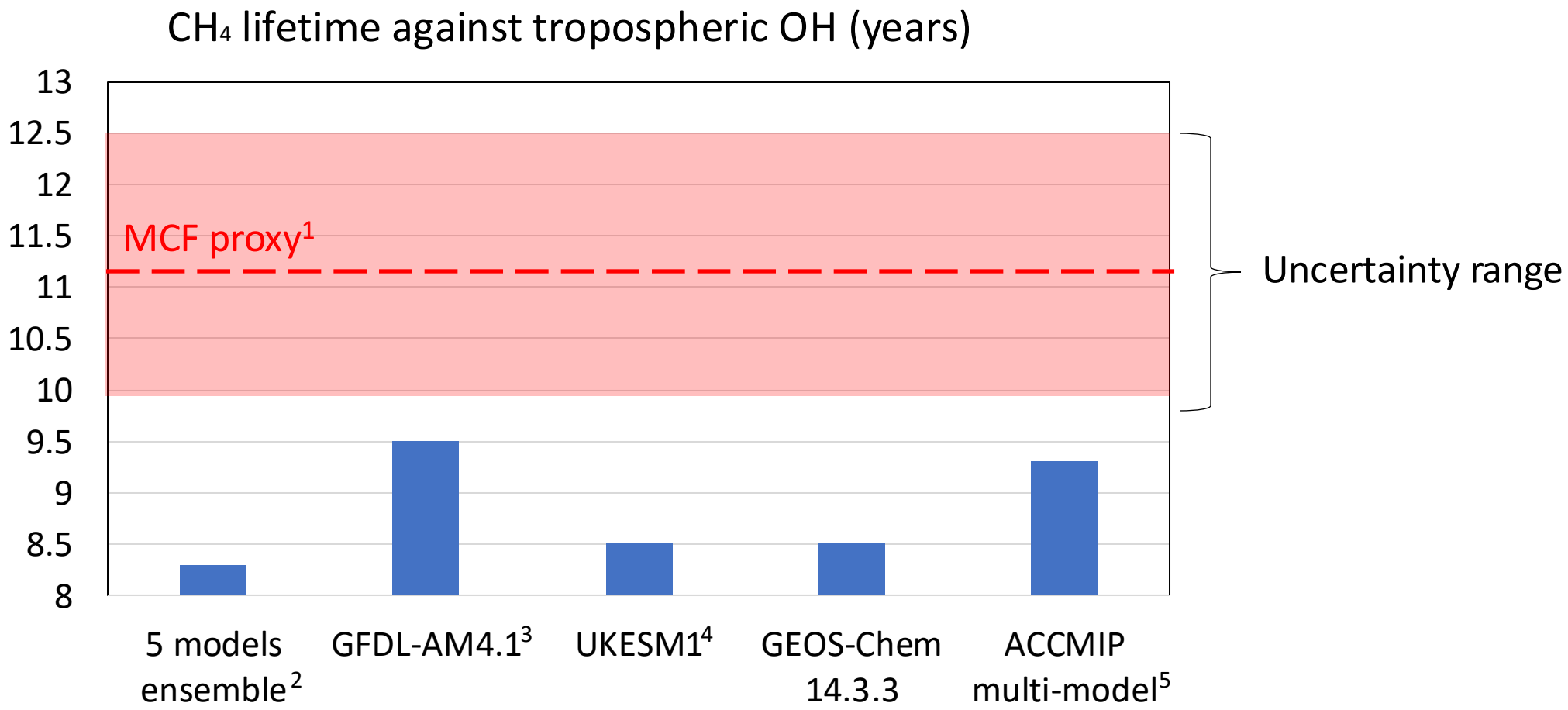
Future source: H_2 leakage in a hydrogen economy

Deposition to soils

H_2 total lifetime: 2.4±0.3 years

H_2 GWP-100	Model	References
8 ± 2	2-D model	Derwent et al. (2023)
10^{+7}_{-4}	Box model	Chen et al. (2024)
11.6 ± 2.8	Ensemble of five 3-D models	Sand et al. (2023)

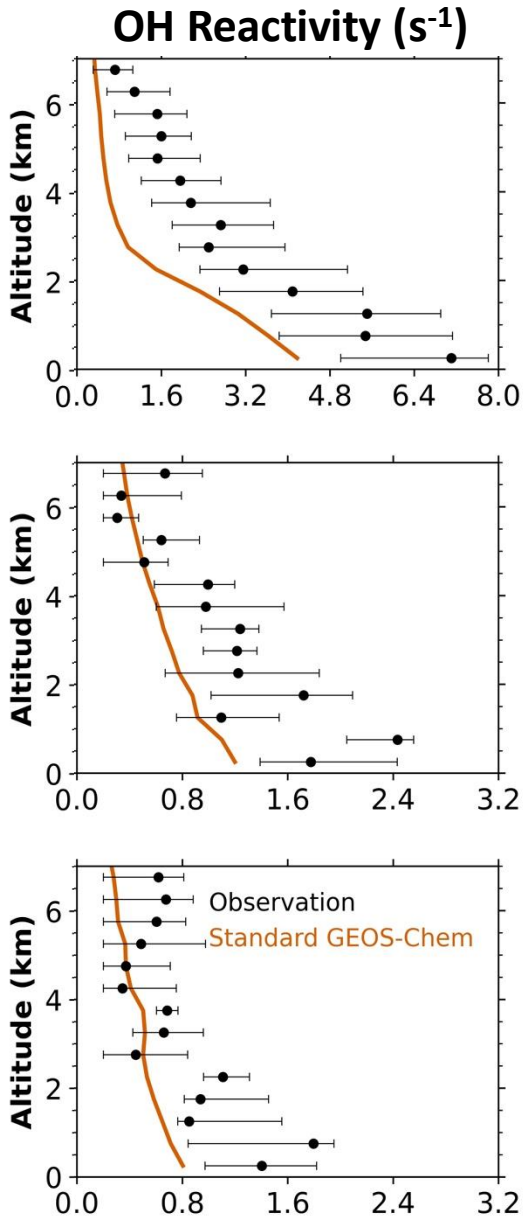
Global 3-D models overestimate tropospheric OH by 10-30% as inferred by the methyl chloroform (MCF) proxy



The OH biases in current models may lead to biases in the GWP estimates

[1]: Prather et al. (2012), [2]: Sand et al. (2023), [3]: Hauglustaine et al. (2022), [4]: Warwick et al. (2023), [5]: Naik et al. (2013)

Underestimated OH reactivity (OHR) in the models may be driving an overestimation of OH and H_2 GWP



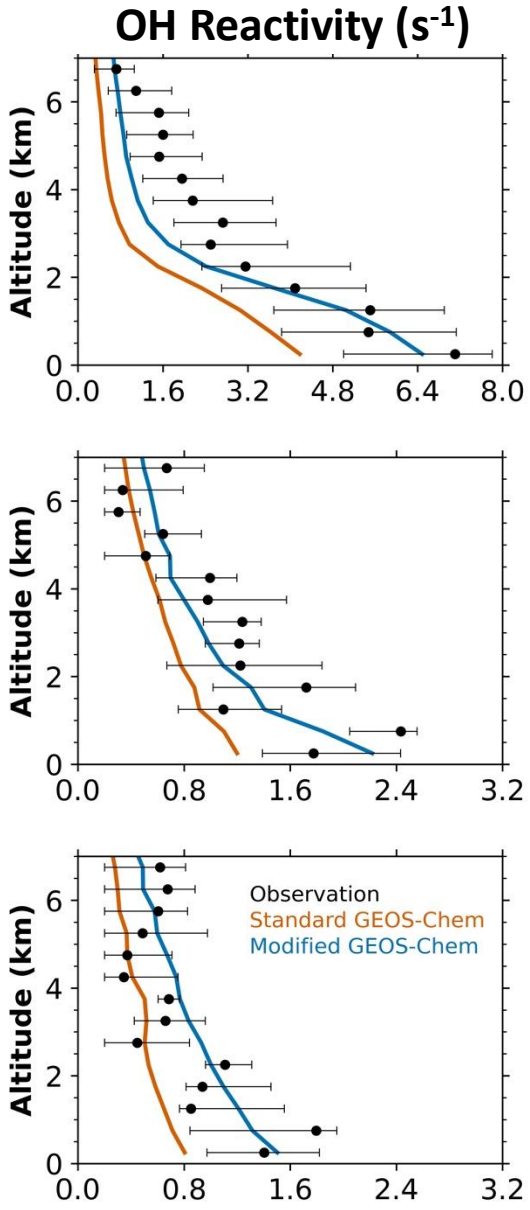
OH reactivity (OHR): OH loss frequency

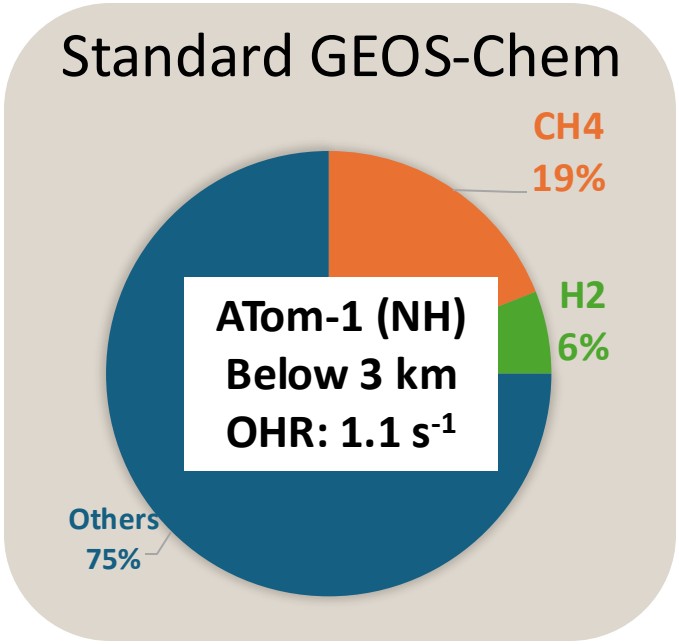
$$OHR = k_{H_2+OH}[H_2] + \sum k_{VOC+OH}[VOC] + \ldots$$

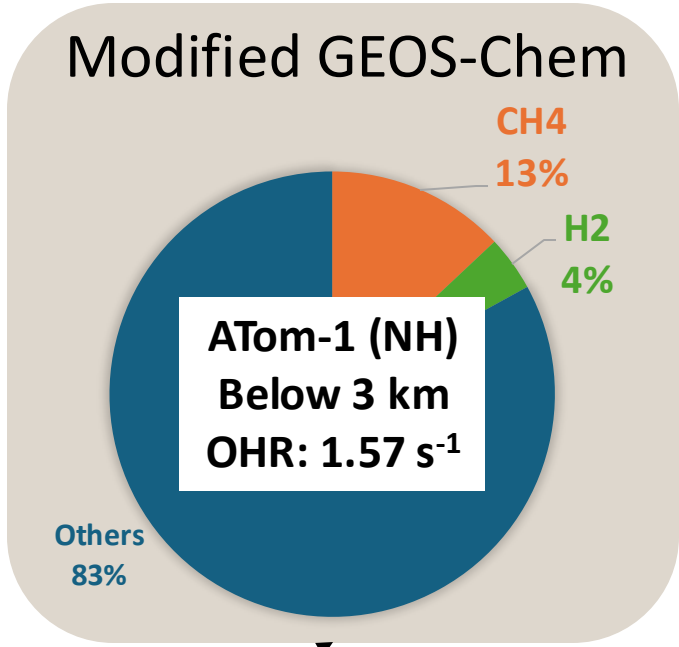
Missing/ under-accounted species → OHR underestimate → ↑ importance of H_2 for affecting τ_{CH_4} & P_{O_3} → Overestimate of H_2 GWP

τ_{CH_4}: Lifetime of methane
P_{O_3}: O_3 production

Modified GEOS-Chem with increased OHR makes H_2 less of a driver for OH loss and relaxes CH_4-H_2 coupling







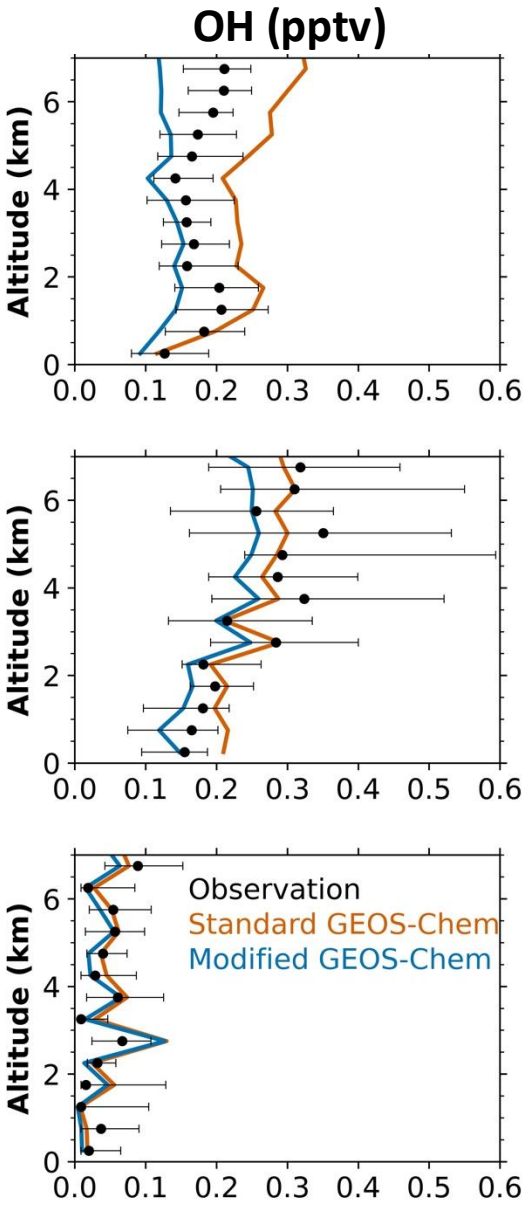
1) Added volatile chemical product[1,2] & oceanic[3] emissions of NMVOCs
2) Added terminal OH sink over continents

* *The change in O_3 concentration is minor*

NMVOCs: Non-methane volatile organic compounds

[1]: Yang et al. (2023), [2]Coggon et al. (2024), [3]: Travis et al. (2020)

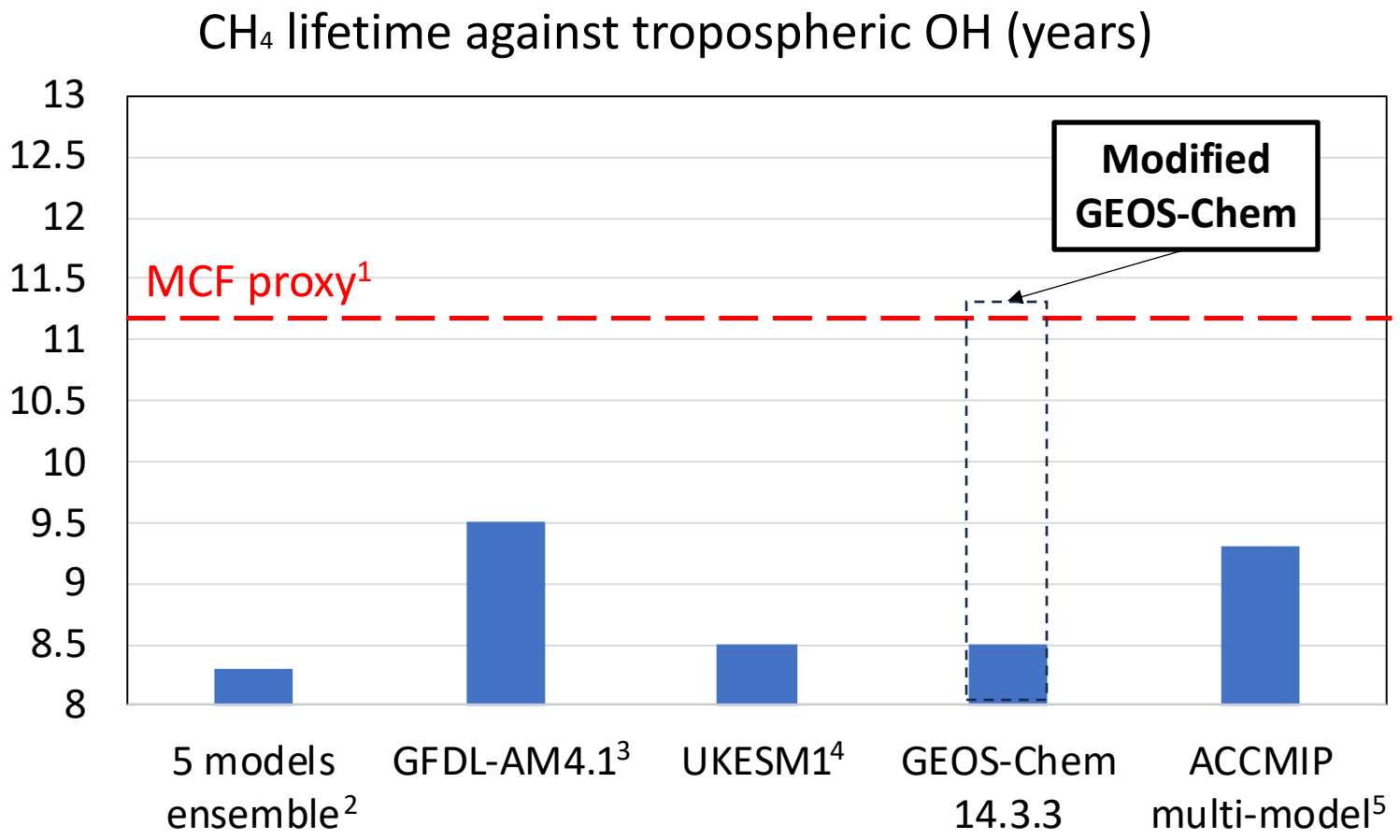
Modified GEOS-chem shows improved agreement with observationally constrained OH values



KORUS-AQ
May – June 2016

ATom-1 NH
July – Aug 2016

ATom-1 SH
July – Aug 2016



[1]: Prather et al. (2012), [2]: Sand et al. (2023), [3]: Hauglustaine et al. (2022), [4]: Warwick et al. (2023), [5]: Naik et al. (2013)

The roles that H_2 and CH_4 play in ozone production decrease in the modified GEOS-Chem

	Standard GEOS-Chem	Modified GEOS-Chem
Chemical source (Tg O_3 equivalent a^{-1})		
$NO + HO_2 \rightarrow NO_2 + OH$	3970	3590
$NO + CH_3O_2 \rightarrow NO_2 + CH_3O$	1420	1320
$NO + RO_2 \rightarrow NO_2 + RO$	330	900
Total	5720	5810
Chemical loss (Tg O_3 equivalent a^{-1})		
$O(^1D) + H_2O \rightarrow 2OH$	2170	2290
$O_3 + HO_2 \rightarrow OH + 2O_2$	1340	1360
$O_3 + OH \rightarrow HO_2 + O_2$	660	500
Others	1050	1140
Total	5220	5290
Lifetime against chemical loss (days)		
	24.2	24.8
Tropospheric O_3 burden (Tg)		
	346	359

Modified GEOS-Chem

Increased contribution of RO_2 to P_{O_3} due to added NMVOCs

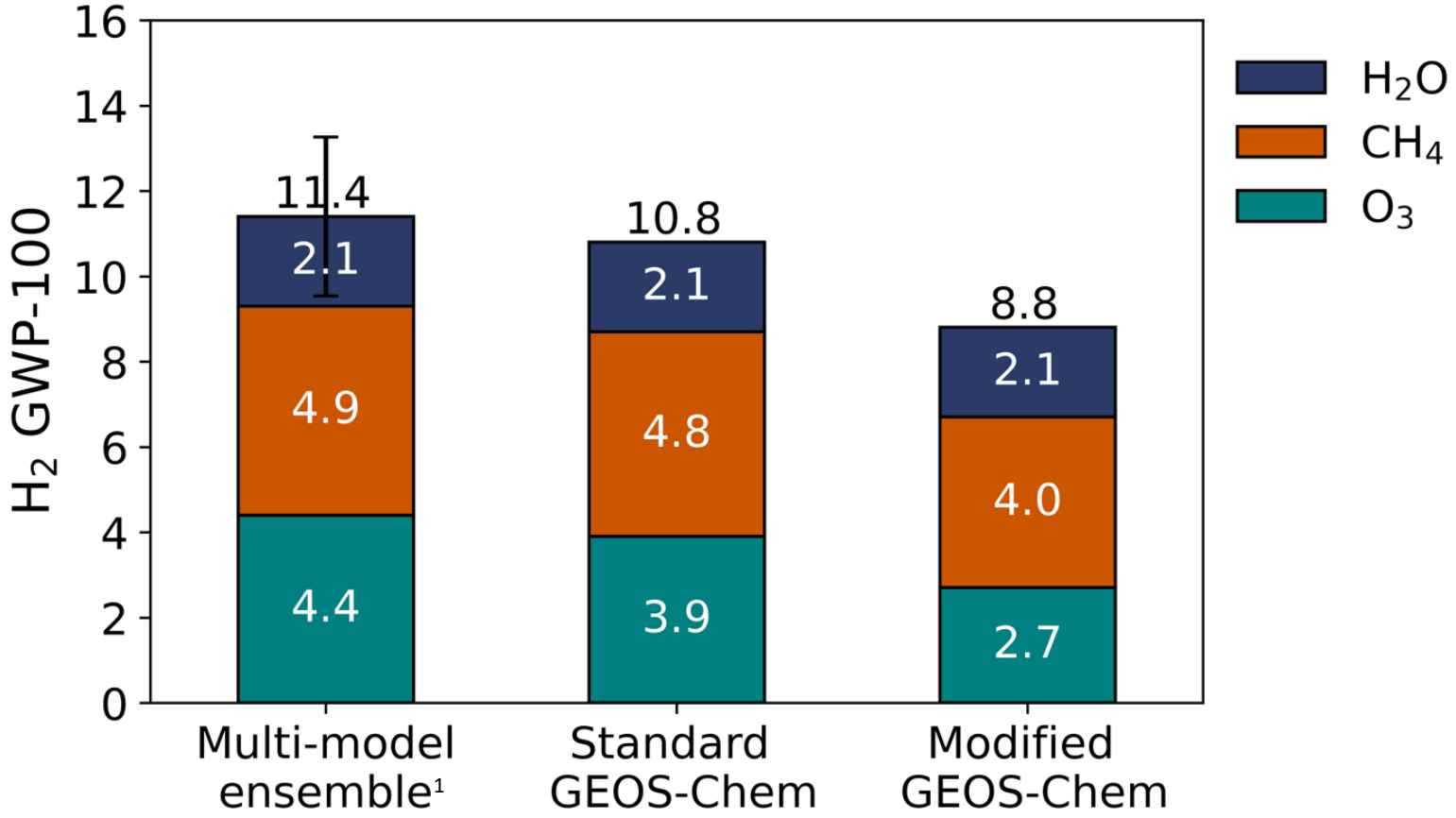
↓

Decreased contributions of H_2 and CH_4 to P_{O_3}

O_3 concentrations in the modified model show little change from the standard model

RO_2: Organic peroxy radicals
NMVOCs: Non-methane VOCs
P_{O_3}: O_3 production

Correcting OHR and OH biases in modified GEOS-Chem leads to 20% smaller hydrogen GWP-100



- GWP-100 calculation method, soil sink, and stratospheric H_2O follow Sand et al. (2023)
- Increasing OHR to match observations decreases the GWP regardless of how this OHR increase is implemented

[1]: Sand et al. (2023)

Takeaways

Correcting the OHR underestimate in global 3-D models
decreases the coupling between CH_4 and H_2 and reduces the effect of H_2 on O_3

OH and OHR biases may lead to a 20% overestimation of H_2 GWP-100
in current 3-D atmospheric chemistry models

Better understanding of the factors controlling global OH concentrations and OHR is needed for GWP estimates

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The views expressed in this work are solely those of the authors.