Sensitivity of Climate Effects of Hydrogen to Leakage size, Location, and Chemical Background

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Background:

Sand et al. (2023) calculated H_2 GWP100 by steady-state simulations of perturbed H_2 surface concentration in five atmospheric chemistry models. In addition, two models also perturbed anthropogenic H_2 emissions. Here, the sensitivity of the H_2 GWP100 to how H_2 is perturbed in the simulations is studied.

What we do:

We investigate the sensitivity of H2 GWP100 to:
1. Size of H_2 emission perturbation
2. Location of the H_2 emission perturbation
3. The atmospheric chemical background

Method:

Use the OsloCTM3 model, one of the models included in the study by Sand et al. (2023). Follow the same method as in Sand et al. (2023).
Three set of simulations:
- Control simulations
- Perturbed hydrogen emissions
- Perturbed methane concentrations – to account for methane induced effects on ozone and stratospheric water vapor.

Results:

1. Is the GWP100 sensitive to size of perturbation?

No. Enhancing the anthropogenic H_2 emissions (Fig. 1a) by 0.1, 1, 10 or 100 Tg yr^{-1} (antro01, antro1, antro10, antro100) resulted in very similar GWP100 (Fig. 5).

2. Does location matter?

Yes. 1 Tg yr^{-1} H_2 was added at seven different sites around the world (Fig 1b). The GWP100 ranges from 10.2 to 14.2 (Fig. 5).

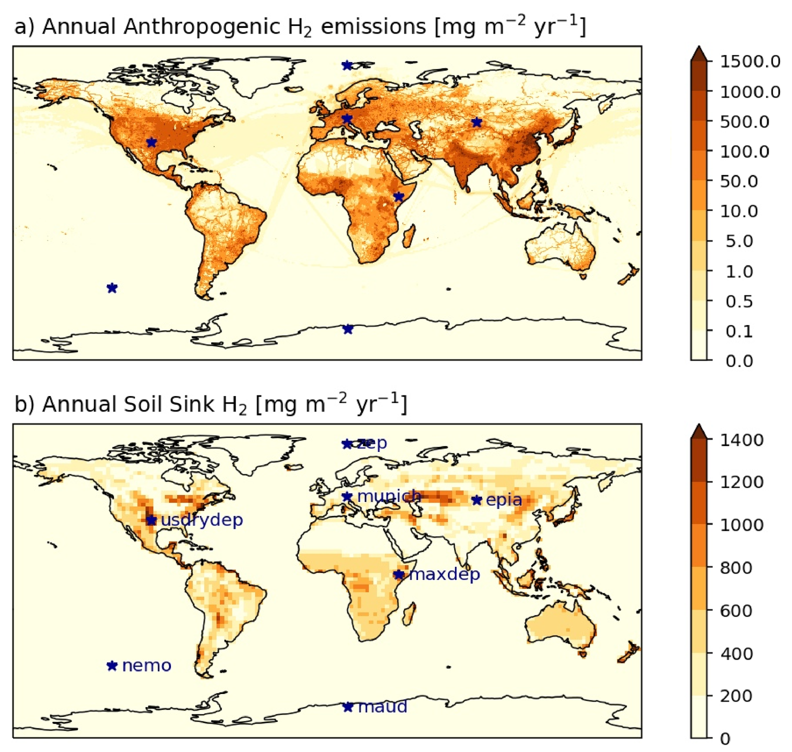


Figure 1: In a) the total anthropogenic emissions of H_2 (Paulot et al., 2021) for 2010 and in b) the total annual soil sink of H_2 from the present-day control simulation. In both figures, the sites where 1 Tg yr^{-1} is added is indicated by a blue star.

Increase in surface concentration per hydrogen flux is highly dependent on where the hydrogen perturbation is added in the simulation (Fig. 2).

Sites far away from soil sink areas (Fig. 1b) (nemo, maud) have larger increase in surface H_2 per H_2 flux than sites close to soil sink areas (usdrydep, maxdep).

Larger (smaller) increase in atmospheric H_2 for the same H_2 flux → larger (weaker) forcing and GWP100 (Fig. 5).

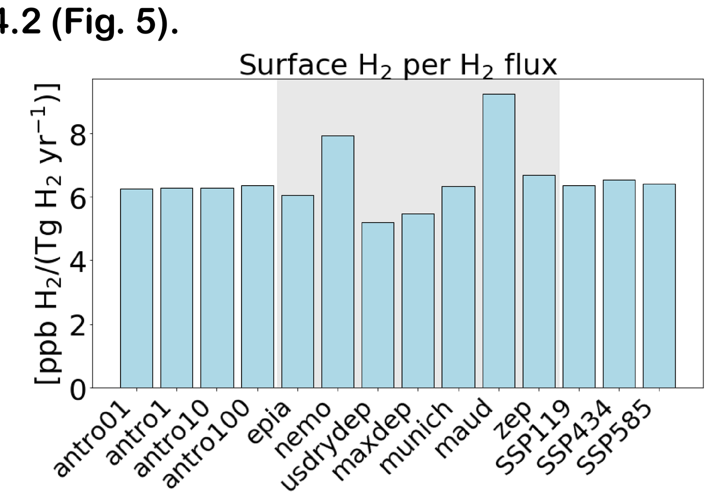


Figure 2: Changes in surface concentration due to 1 Tg yr^{-1} flux of H_2.

	Feedback factor	H2 total lifetime [yrs]	H2 perturbation lifetime [yrs]
antro1	0.92	2.35	2.17
nemo	1.09	2.35	2.56
epia	0.83	2.35	1.94
munich	0.89	2.35	2.08
usdrydep	0.76	2.35	1.77
maxdep	0.85	2.35	1.99
maud	1.10	2.35	2.59
zep	0.89	2.35	2.09

Emissions close to soil sink areas:
Soil sink enhanced
→ feedback factor < 1
→ perturbation lifetime shorter than total lifetime.

Emissions far from soil sink areas:
OH loss less efficient (as for methane)
→ feedback factor > 1
→ perturbation lifetime longer than total lifetime.

3. Will GWP100 be different in the future, with a different chemical composition of the atmosphere?

Yes, slightly larger GWP100 if the present day (antro10) chemical background is replaced by three SSPs for 2050 (Fig.5). Atmospheric lifetime increases in all the SSPs, by up to 0.9 years in SSP434. Because soil sink is the dominant loss term, total H_2 lifetime increases by only 0.1 year in SSP434.

Less OH, longer atmospheric lifetime of H_2 and CH_4

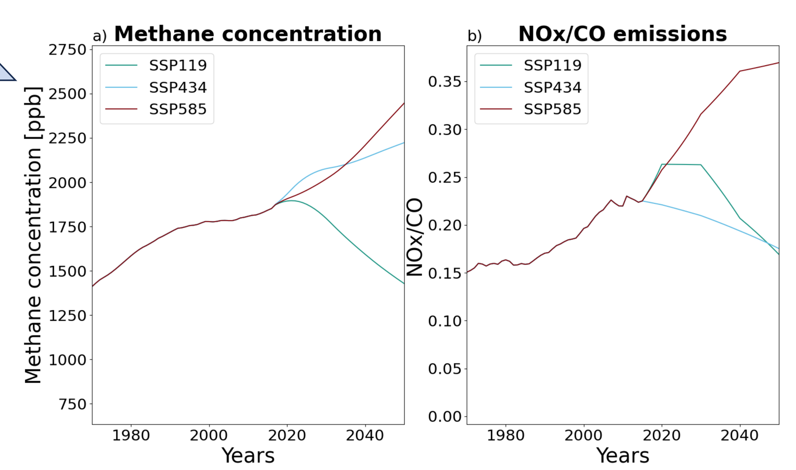
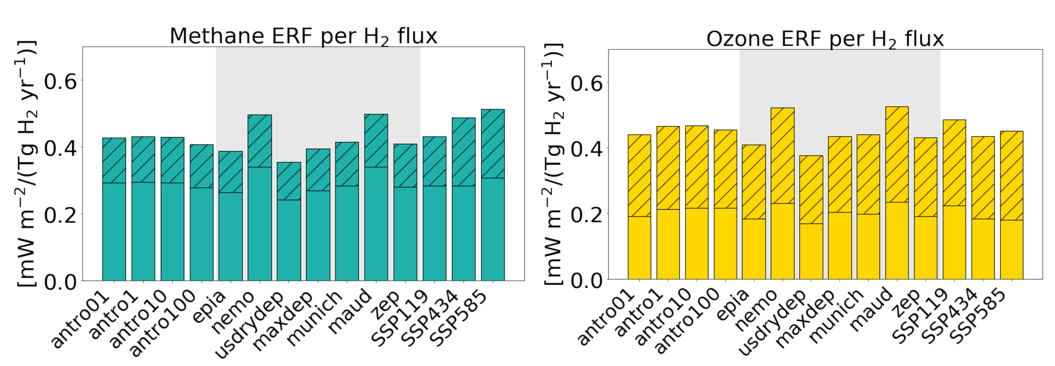


Figure 3: Historical and future methane concentrations (a) and anthropogenic NOx to CO emission ratios (b) for the three SSPs used.

Less OH, longer atmospheric lifetime of H_2 and CH_4

	H2 burden [Tg]	H2 atm prod [Tg/yr]	H2 atm lifetime [yrs]	H2 soil sink lifetime [yrs]	H2 total lifetime [yrs]
CNTR	205	55.8	7.02	3.53	2.35
diff. SSP119	-23.6	-10.8	0.24	-0.01	0.02
diff. SSP434	20.4	4.62	0.93	0.02	0.10
diff. SSP585	29.5	9.85	0.53	0.02	0.07



Ozone and Methane ERF per H_2 flux, compensating effect between the SSPs.

Figure 4: Changes in methane and ozone ERF due to 1 Tg yr^{-1} flux of H_2.

GWP100 of Hydrogen:

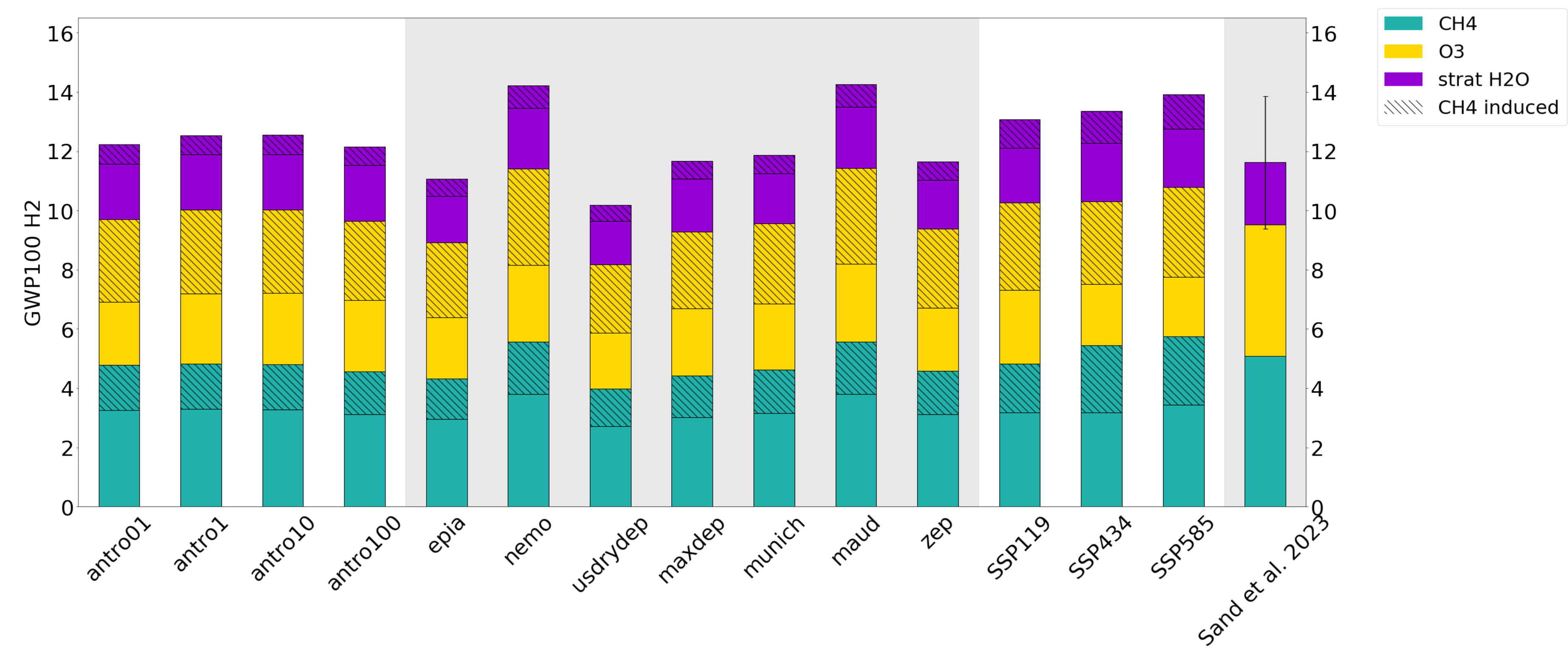


Figure 5: The GWP100 of hydrogen for the different sensitivity tests where the individual contributions from methane (green), ozone (yellow), and stratospheric water vapor (purple) as well as methane induced changes in these (hashed) are shown. The model mean with uncertainty range (one standard deviation) assessed in Sand et al. (2023) is shown to the right.

Take home messages:

- H_2 GWP100 is not dependent on the size of the emission perturbation
- H_2 GWP100 depends on emission location (distance to soil sink active areas)
- H_2 GWP100 slightly depends on the chemical background
- Overall, these changes are small compared to the uncertainty in the H_2 GWP100

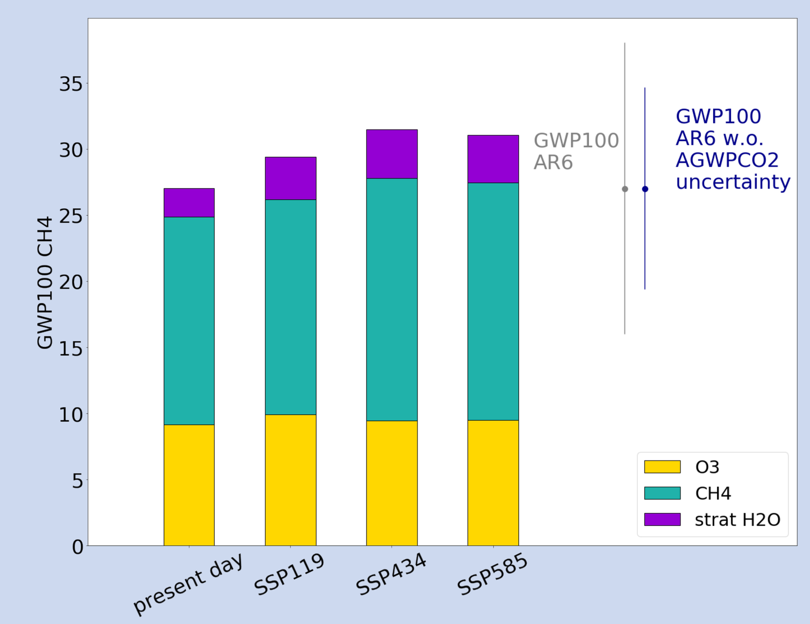
Implications for Methane:

Dominant loss for methane is reaction with OH. Total lifetime of methane increase in the three SSPs, by 0.25 to 0.90 years. Also, the methane feedback factor increases in all the SSPs, and in SSP434 the perturbation lifetime increase by 3.2 years.

The GWP100 for methane increase by 2.4, 4.4 and 4.0 for SSP119, SSP434 and SSP585 respectively, compared to present day atmospheric conditions.

	CH4 burden [Tg]	CH4 surface conc. [ppbv]	CH4 lifetime due to OH (whole atmosphere) [yrs]	Total CH4 lifetime [yrs]	Feedback factor	Perturbation lifetime
CTRL	4,975	1,813	7.38	6.85	1.46	10.0
diff.SSP119	-1,059	-386	0.29	0.25	0.05	0.72
diff.SSP434	1,129	410	1.05	0.90	0.25	3.24
diff.SSP585	1,738	633	0.61	0.52	0.21	2.31

GWP100 of Methane:



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Paulot, F. et al. .: Global modeling of hydrogen using GFDL-AM4.1: Sensitivity of soil removal and radiative forcing, Int. J. Hydrogen Energy, 46,13446-13460, https://doi.org/10.1016/j.ijhydene.2021.01.088, 2021.

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