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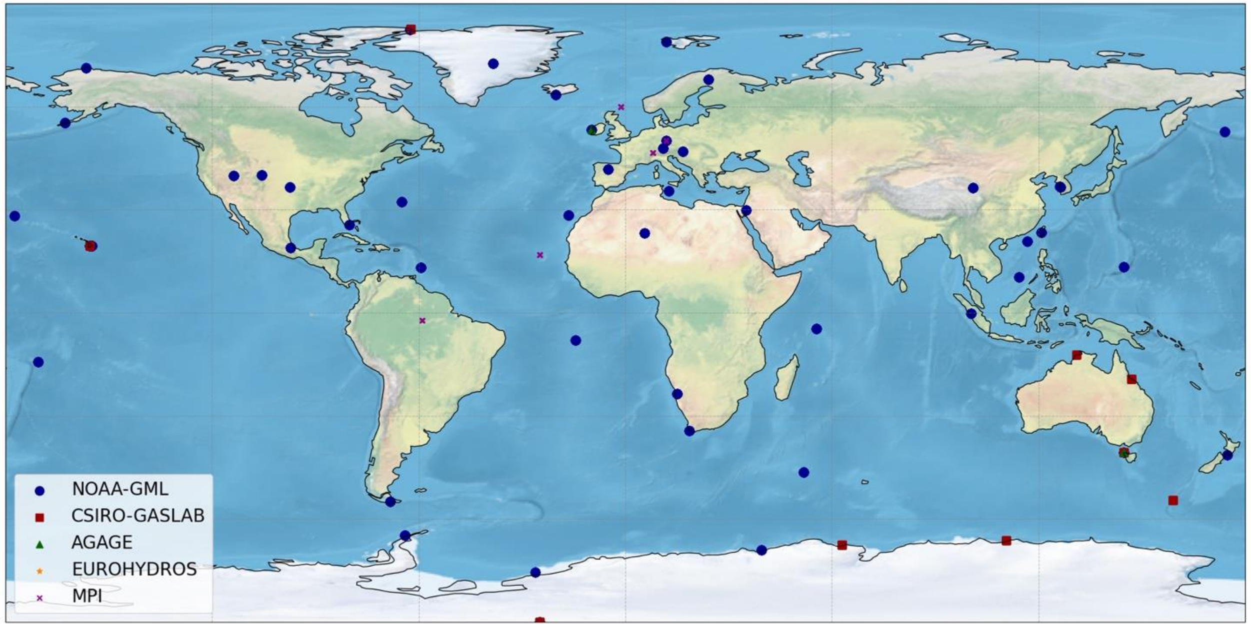
Changes in atmospheric hydrogen during the energy transition



Firmin Stroo
Supervisors: Wouter Peters and Harro Meijer

Atmospheric composition and climate impacts of a future hydrogen economy

Nicola J. Warwick[1,2], Alex T. Archibald[1,2], Paul T. Griffiths[1,2], James Keeble[1,2], Fiona M. O'Connor[3,4], John A. Pyle[1,2], and Keith P. Shine[5]

ARTICLE

https://doi.org/10.1038/s43247-022-00626-z OPEN

Check for updates

Climate benefit of a future hydrogen economy

Didier Hauglustaine[1✉], Fabien Paulot[2], William Collins[3], Richard Derwent[4], Maria Sand[5] & Olivier Boucher[6]

Climate consequences of hydrogen emissions

Ilissa B. Ocko and Steven P. Hamburg

Environmental Defense Fund, New York, NY, USA

Correspondence: Ilissa B. Ocko (iocko@edf.org)

Received: 3 February 2022 – Discussion started: 18 February 2022
Revised: 20 May 2022 – Accepted: 13 June 2022 – Published: 20 July 2022

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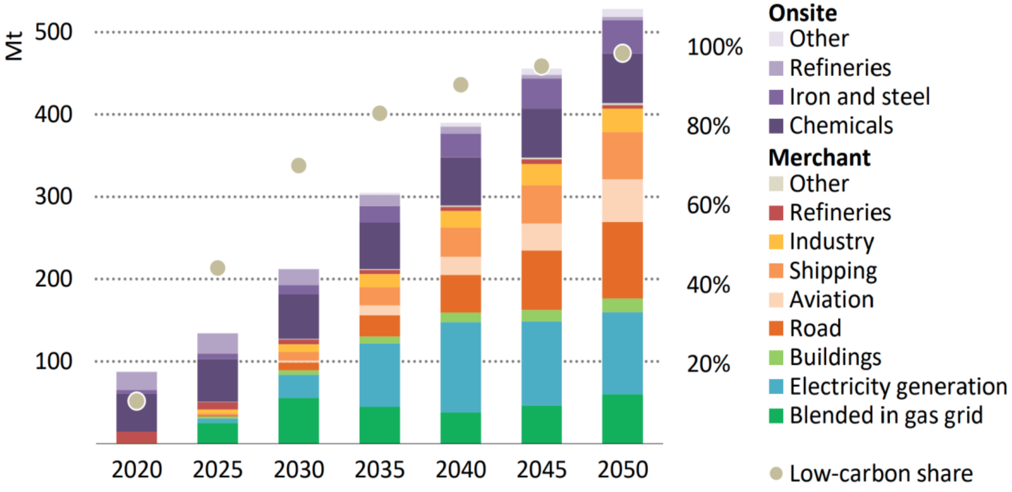
Introduction

- Molecular Hydrogen (H_2)
- Second most abundant reactive trace gas (530 ppb)
- Energy transition (decarbonisation)
- Energy carrier (grey, blue, green)

- Papers warning about climate impact (losses)



Global hydrogen production under the Net Zero emissions by 2050-scenario. Taken from International Energy Agency, 2021.

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Article | Open access | Published: 15 October 2024

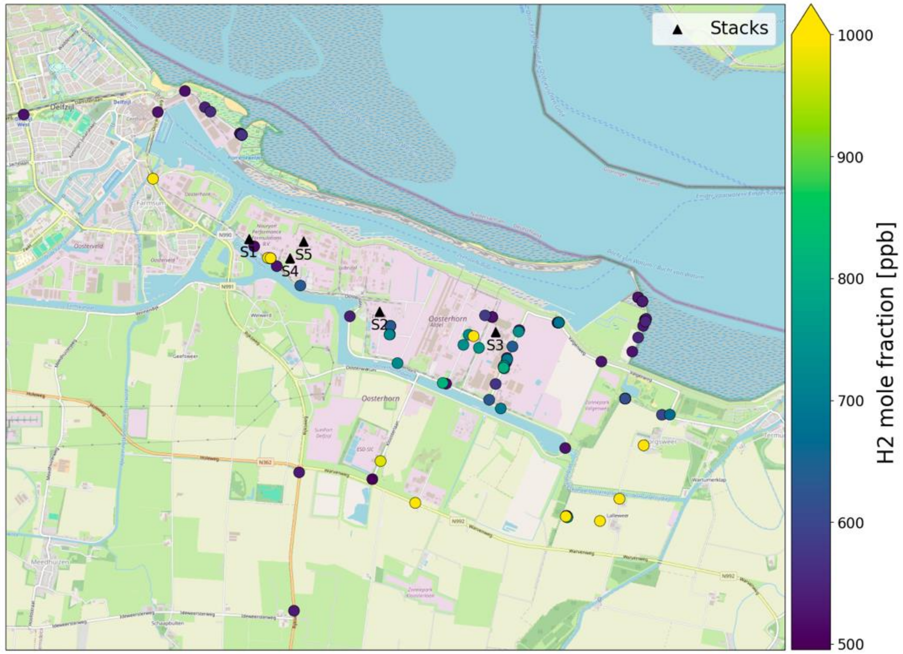
First detection of industrial hydrogen emissions using high precision mobile measurements in ambient air

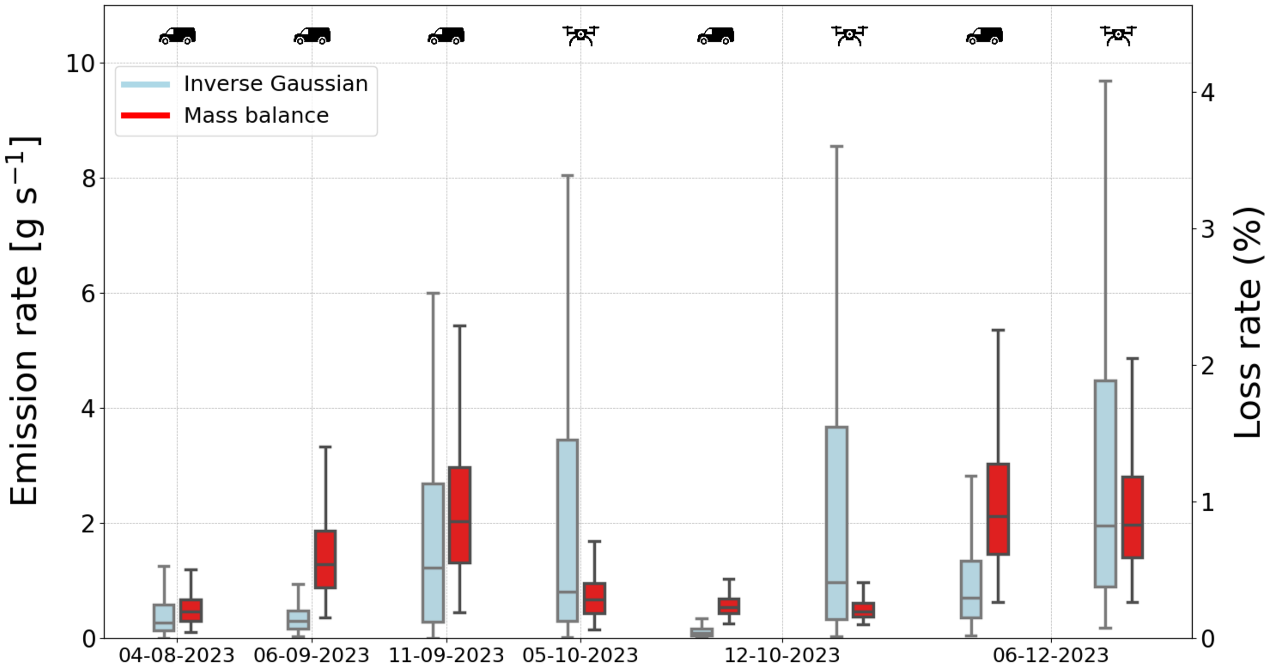
Iris M. Westra, Hubertus A. Scheeren, Firmin T. Stroo, Steven M. A. C. van Heuven, Bert A. M. Kers, Wouter Peters & Harro A. J. Meijer

Scientific Reports **14**, Article number: 24147 (2024) | Cite this article

First detection of H_2 emissions

- Delfzijl chemistry park Groningen
- Car and drone measurements using Active AirCore + Analysis with Gas chromatograph (GC)
- Clear enhancements on all days






ARTICLE
https://doi.org/10.1038/s43247-023-00857-8 OPEN

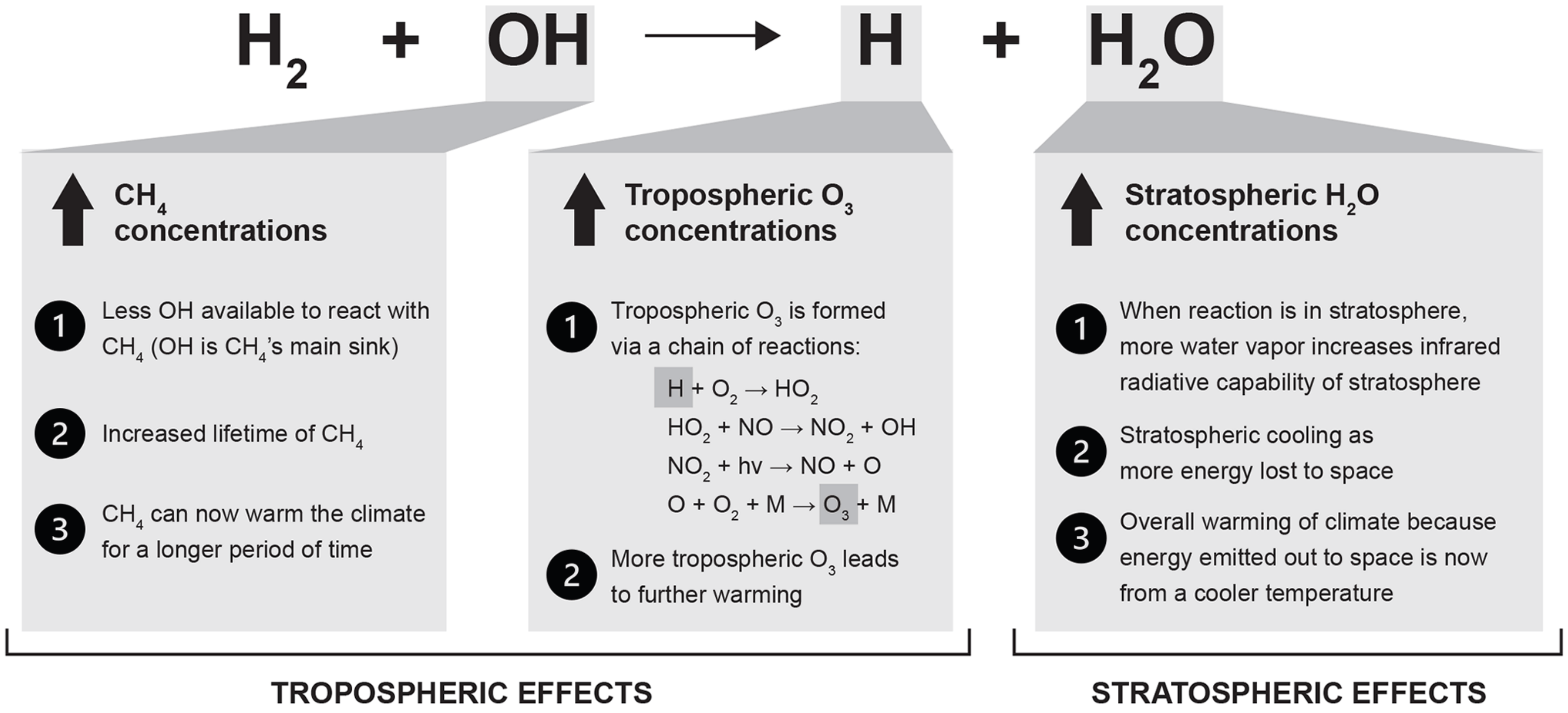
A multi-model assessment of the Global Warming Potential of hydrogen

Maria Sand[1], Ragnhild Bieltvedt Skeie[1], Marit Sandstad[1], Srinath Krishnan[1], Gunnar Myhre[1], Hannah Bryant[2], Richard Derwent[3], Didier Hauglustaine[4], Fabien Paulot[5], Michael Prather[6] & David Stevenson[2]

Climate impact of H_2

- H_2 itself is no pollutant or GHG
- Interaction with OH radical

- Consensus emerging on GWP
- GWP_{100} = 11.8
- GWP_{20} = 37.3
- Policy timescales



My PhD

1. How large are industrial hydrogen leakages?

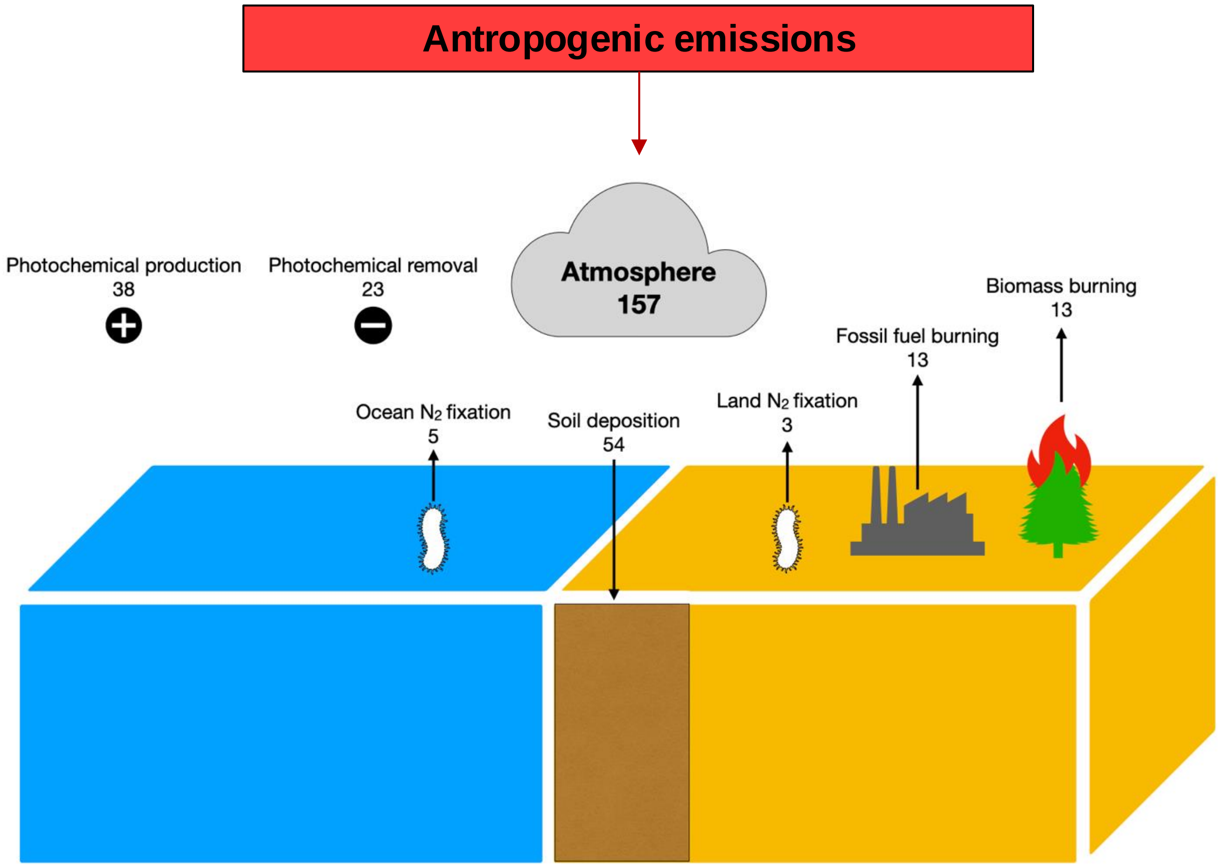
2. Constraining the Global H_2 budget

Understand impact of H_2 on atmospheric composition during energy transition

The global H_2 cycle

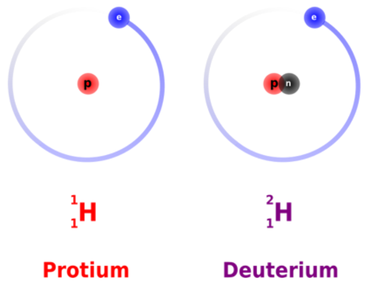
- Photochemical production (CH_4, VOCs)
- Fossil fuel burning (incomplete combustion)
- Biomass burning (breakdown organic material)
- Ocean & Land (H_2 producing bacteria)

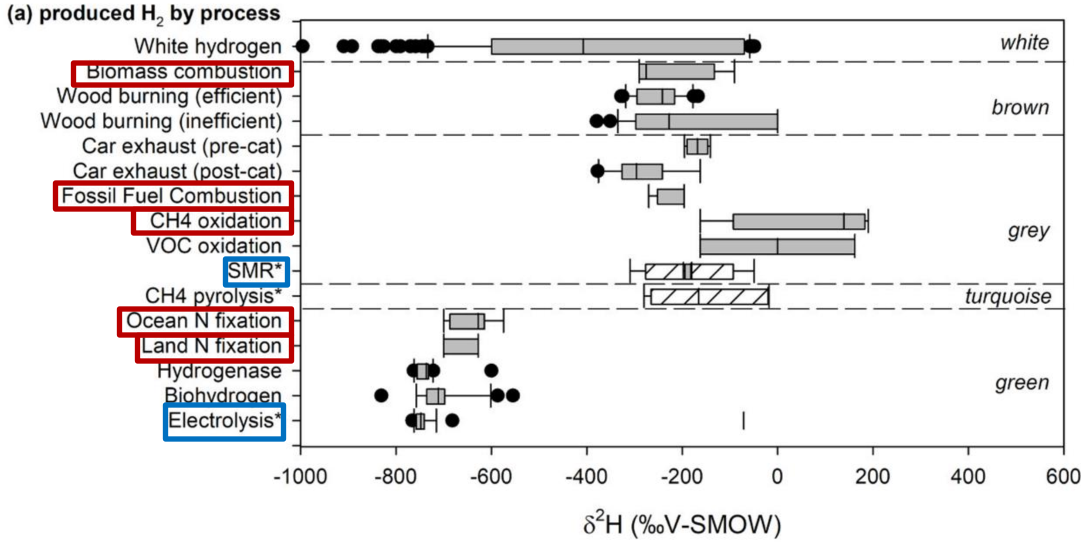
- Soil deposition (H_2-oxidizing bacteria, enzymes)
- Photochemical removal (OH, climate impact)

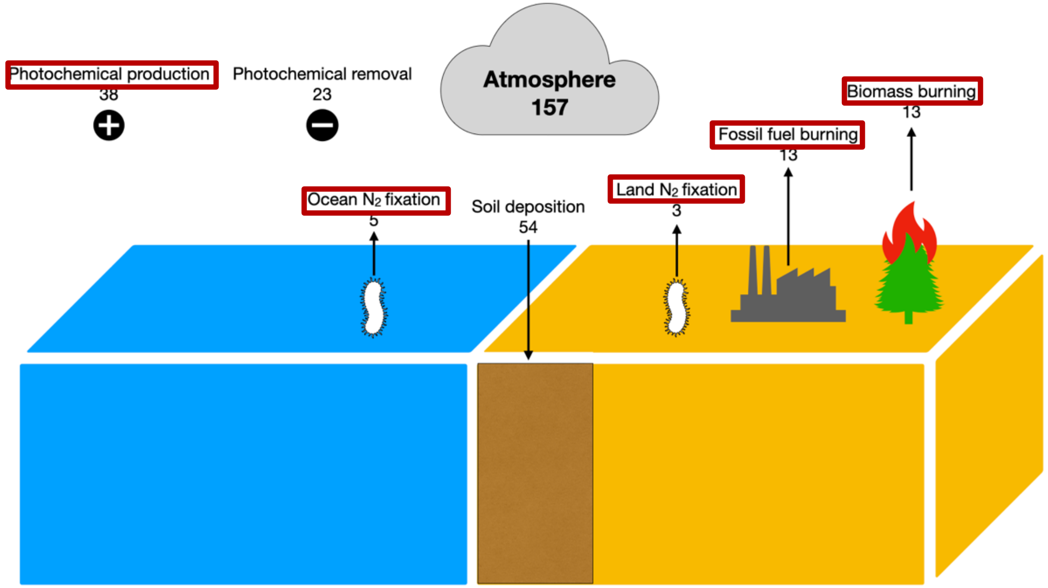


H_2 isotopes

- Large kinetic isotope effects per process
- Large mass difference between H_2 and HD
- Natural and manmade!







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Global modelling of H_2 mixing ratios and isotopic compositions with the TM5 model

G. Pieterse[1], M. C. Krol[1,2], A. M. Batenburg[1], L. P. Steele[3], P. B. Krummel[3], R. L. Langenfelds[3], and T. Röckmann[1]
[1]Institute for Marine and Atmospheric Research Utrecht (IMAU), Utrecht, The Netherlands
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Received: 1 December 2010 – Published in Atmos. Chem. Phys. Discuss.: 17 February 2011
Revised: 10 July 2011 – Accepted: 12 July 2011 – Published: 20 July 2011

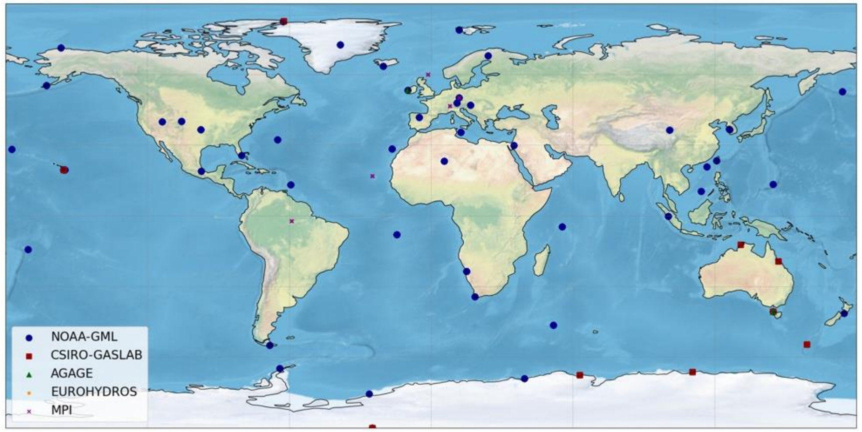
TM5: Global simulations of H_2

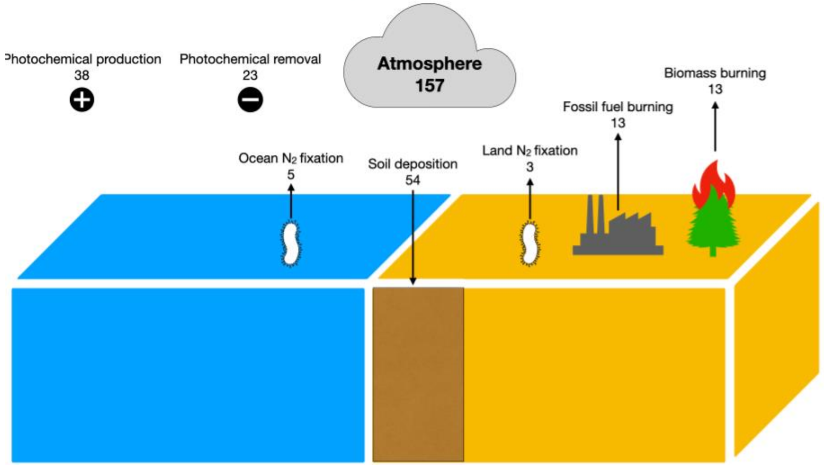
- Goal: constraining global budget via inversion

- Forward model (TM5-MP CTM)
- ECMWF meteorological fields + CMIP6 emissions
- Added H_2 sources and sinks (Pieterse)
- Plan to add HD
- Spatial resolution: 6x4 degrees, 34 levels
- Simulation time: 2007-2020

- Observations (flask networks)

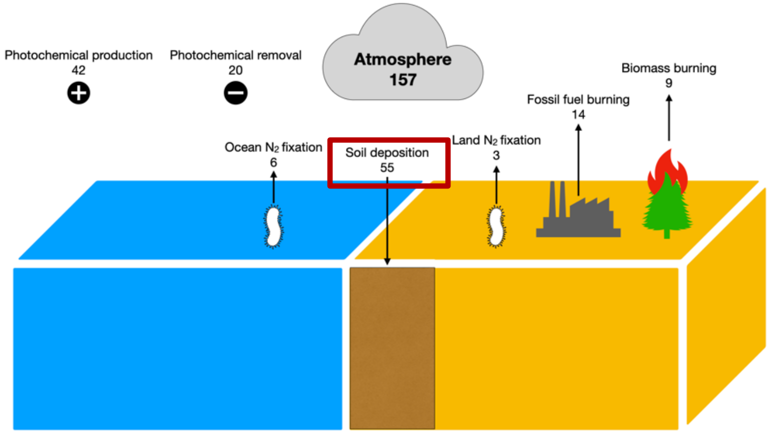
Flask measurement stations active in 2023



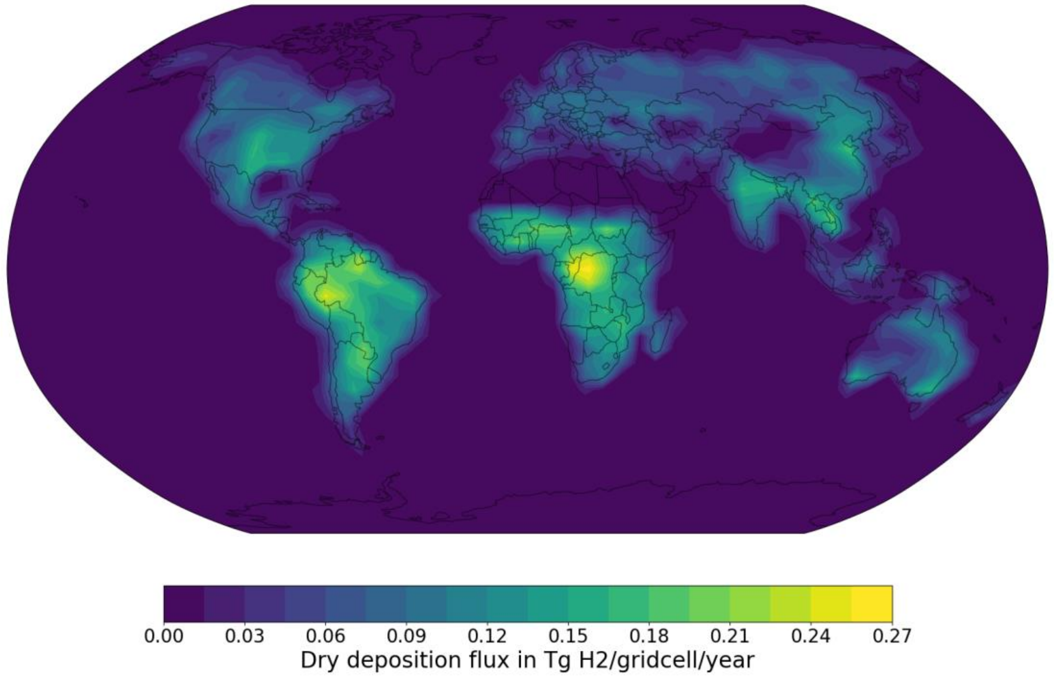


Dry deposition

- Added H_2 to deposition module
- Soil resistance: Sanderson et al. (2003) parameterisation
- 8 Ecosytem types. Relations based on soil moisture

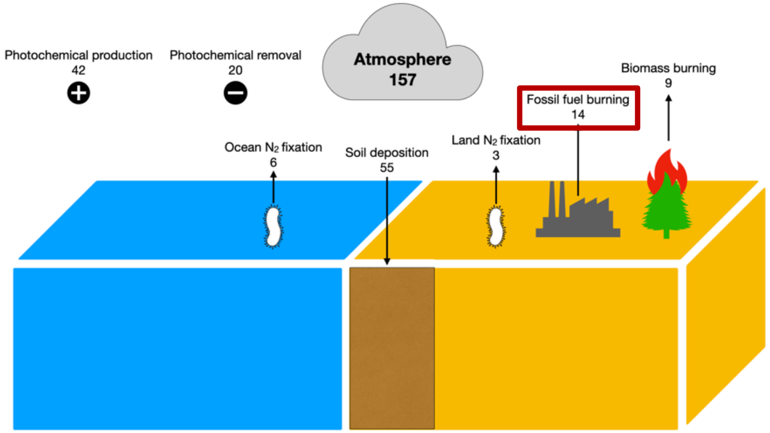


Average annual soil deposition for 2020

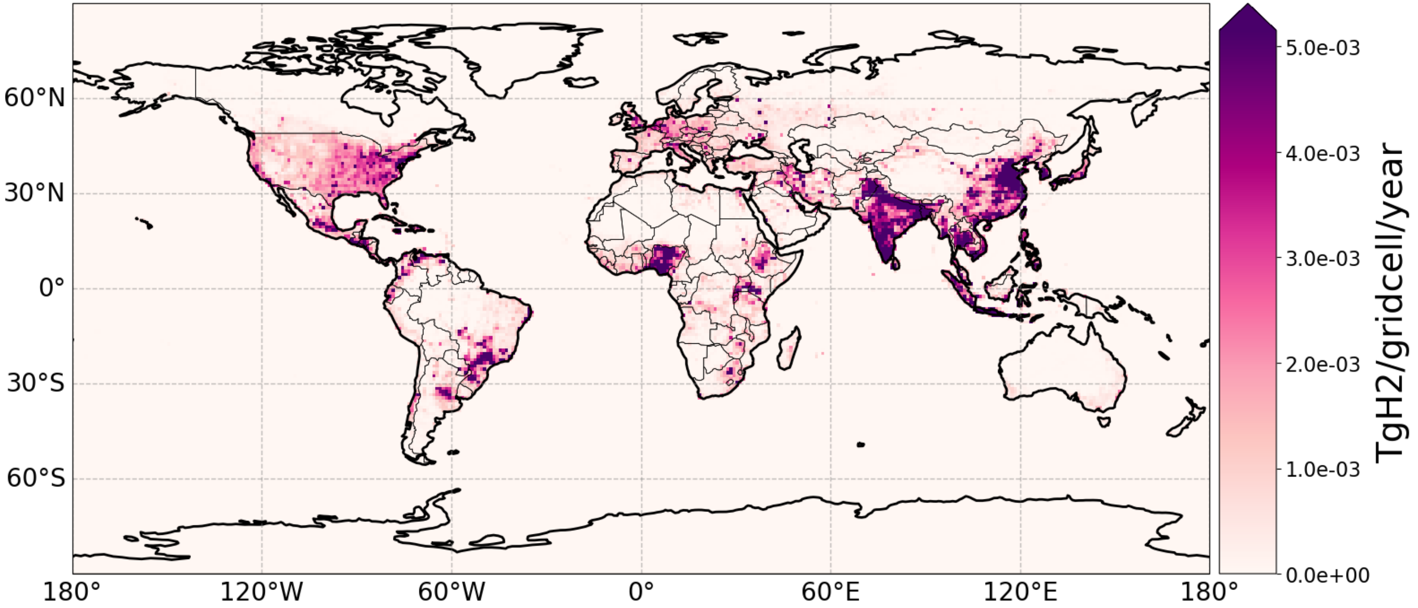


Fossil fuel burning

- CAMS v6.2 CO
- $CO_2 + H_2 \rightleftharpoons CO + H_2O$
- Sector specific emission factors (Paulot et al., 2021)

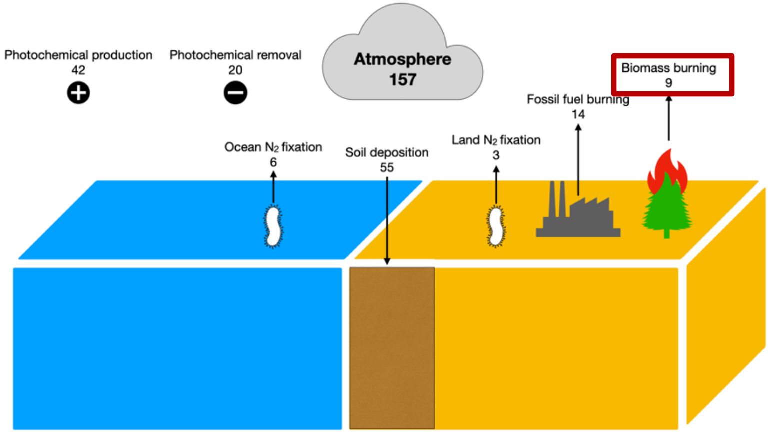


Average annual fossil fuel burning source for 2000-2023.

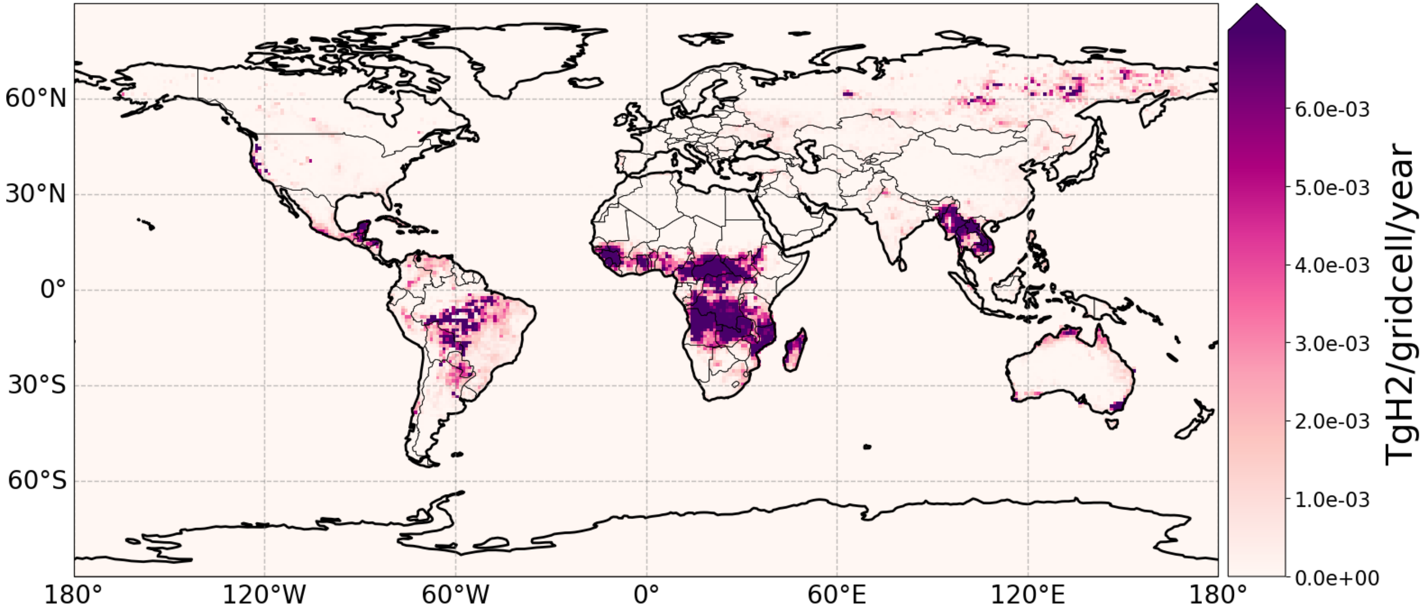


Biomass burning

- GFED5 Beta (Van der Werf et al., 2024)
- Dry matter burnt
- Experimentally derived emission factors.

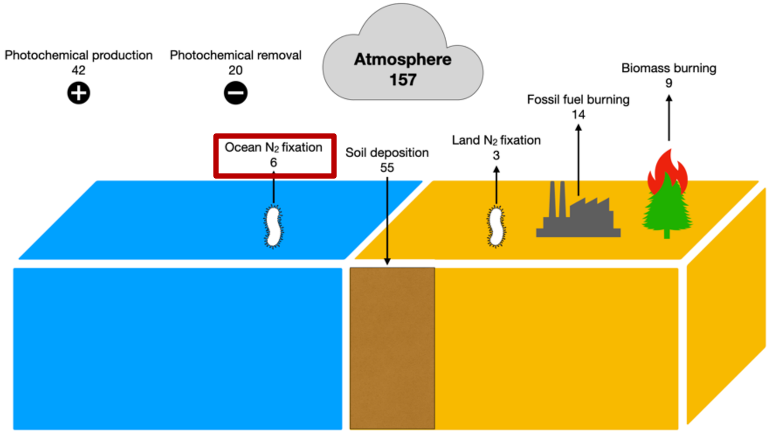


Average annual biomass burning source for 2002-2020.

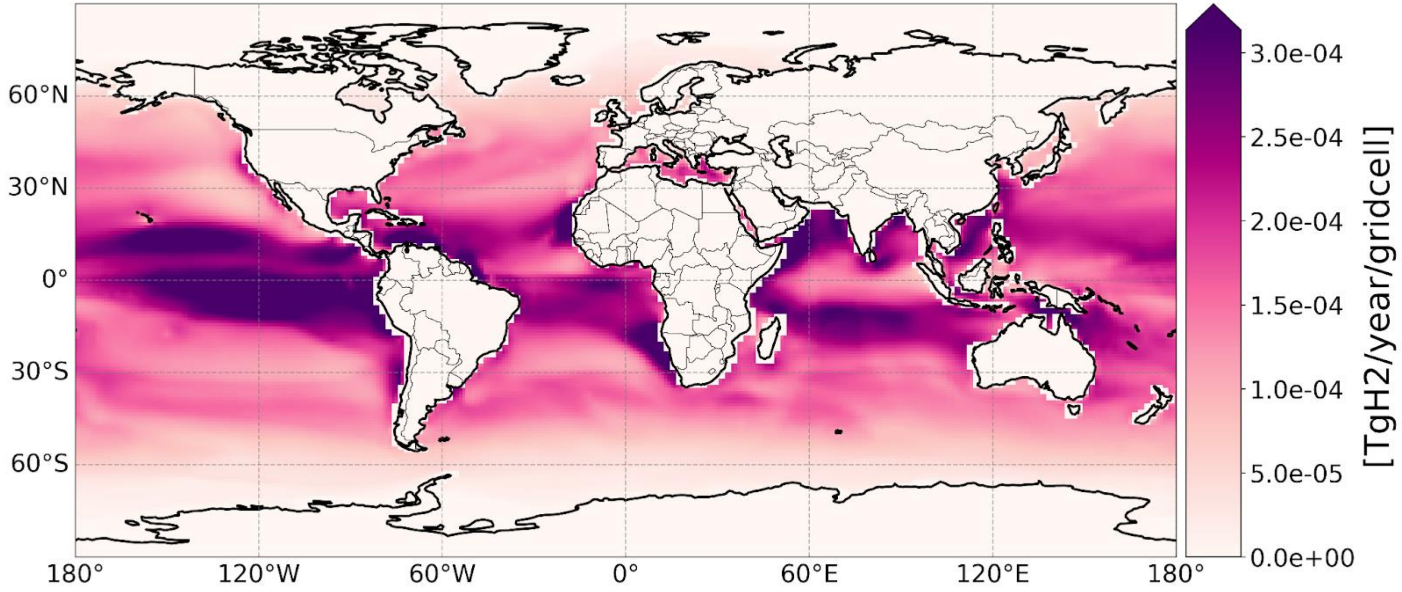


Ocean N_2 fixation

- 5 TgH_2 per year from Price et al. (2007)
- Spatial and temporal distribution of oceanic CO fluxes from Conte et al. (2019)
- Hypothesis: both H_2 (Walter et al., 2016) and CO (Gros et al., 2009) biologically produced in oceans

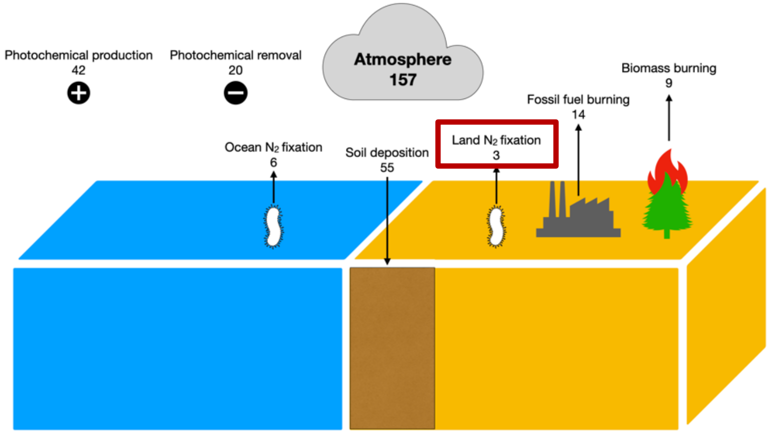


Average annual ocean source

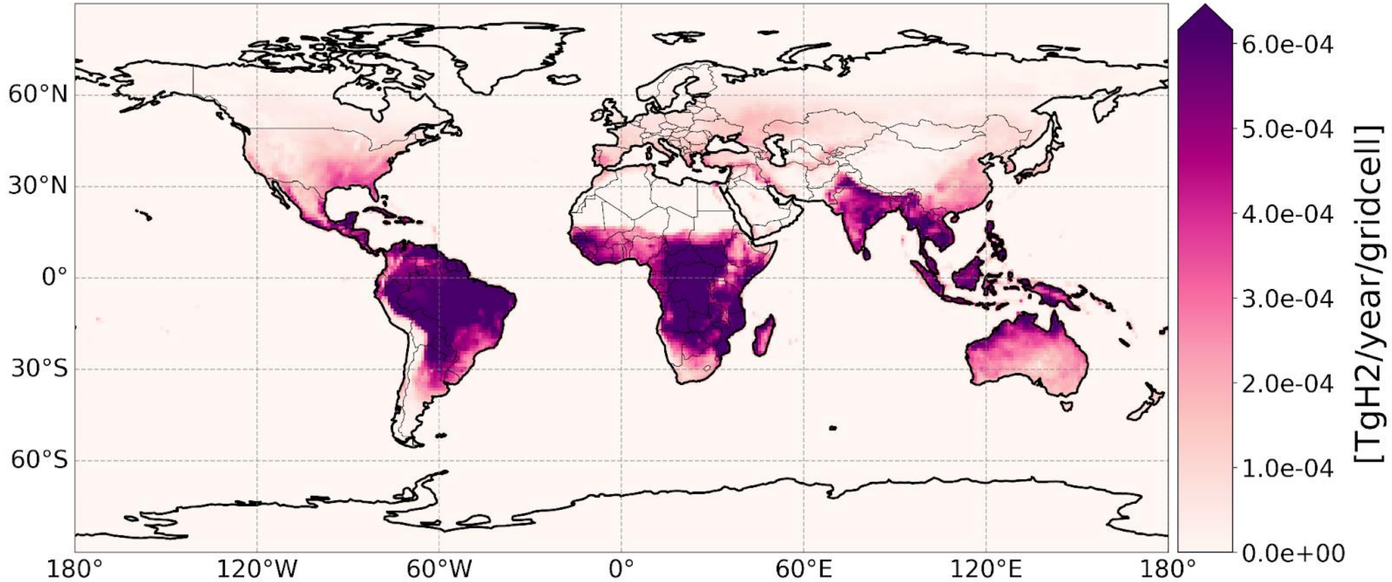


Land N_2 fixation

- 3 TgH_2 per year from Price et al. (2007)
- Spatial and temporal distribution of biogenic CO fluxes from MEGAN (2010) model
- Assumption: proxy for biological activity



Average annual land source



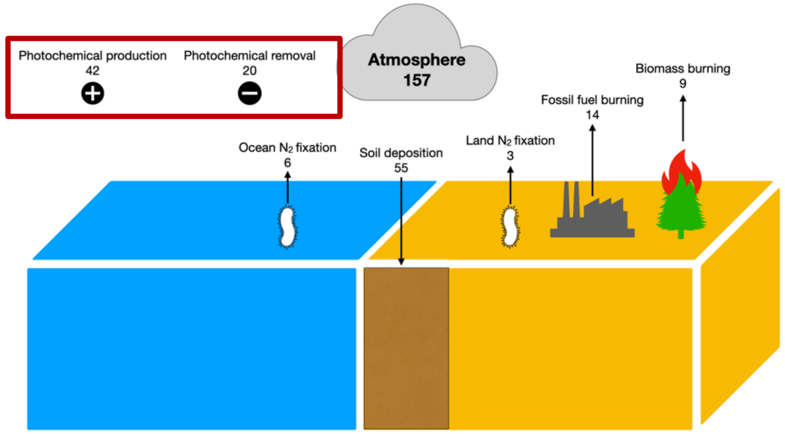
Photochemical production and removal

- CB05: (51 species and 156)
- H_2 concentrations were originally fixed
- Modified two reactions:

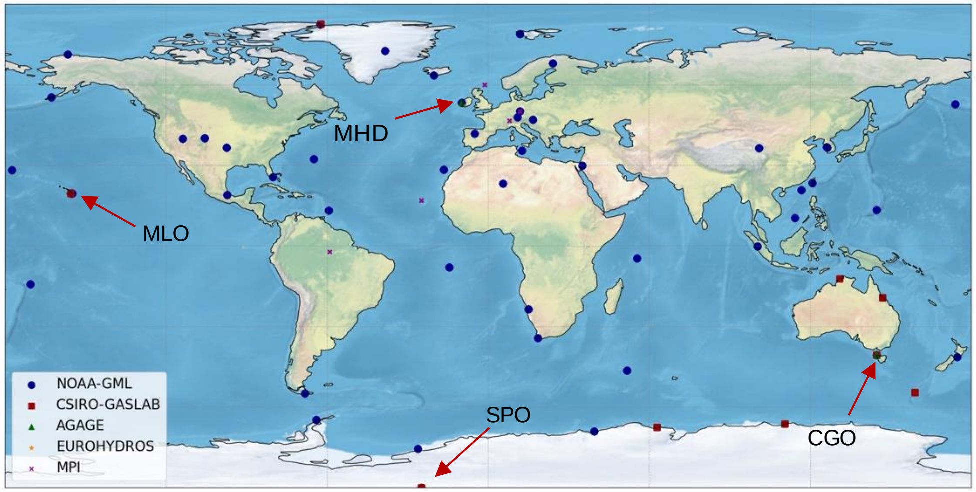
1.) HCHO + hv = H_2 + CO

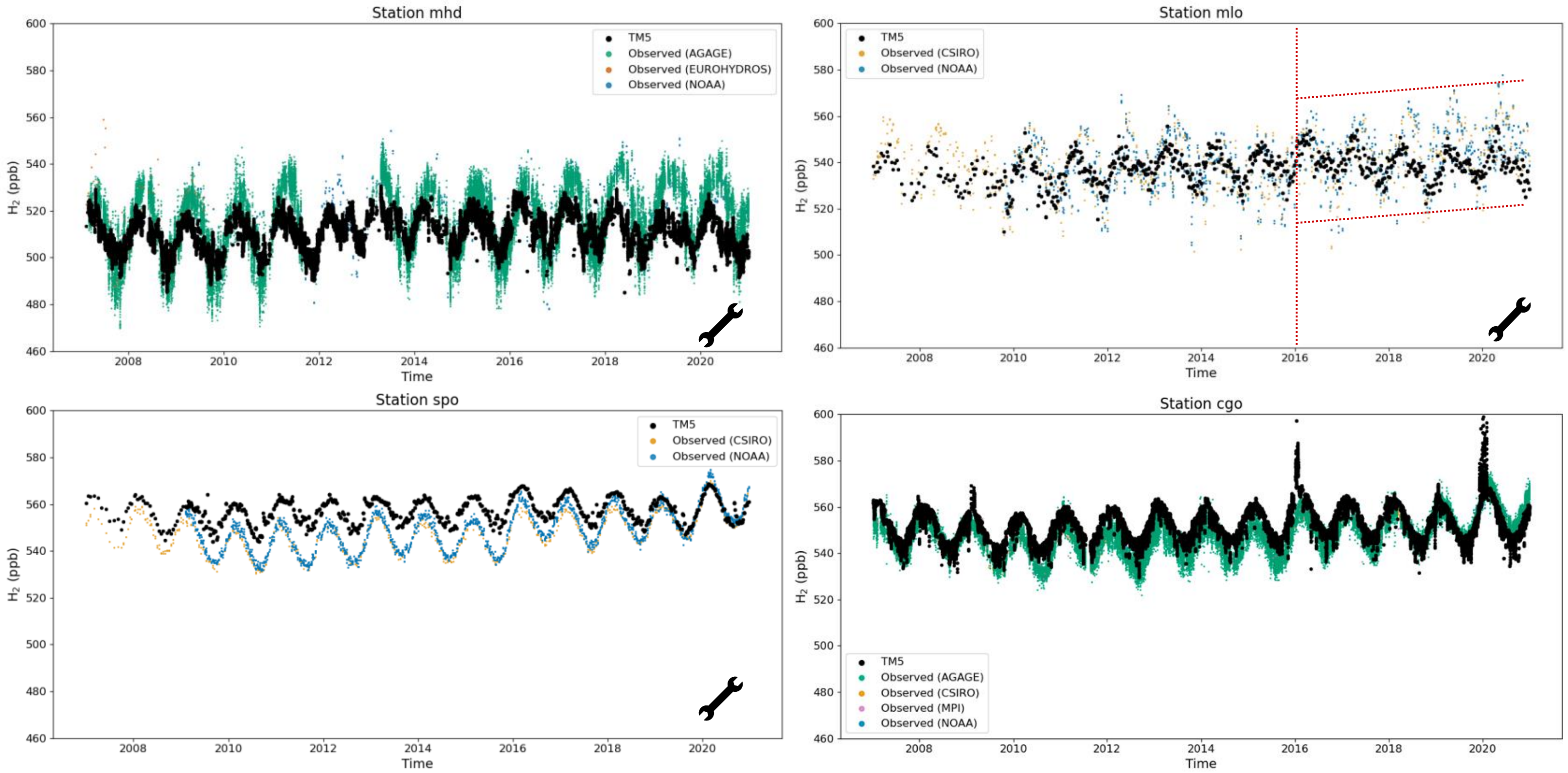
2.) H_2 + OH = H2O + H

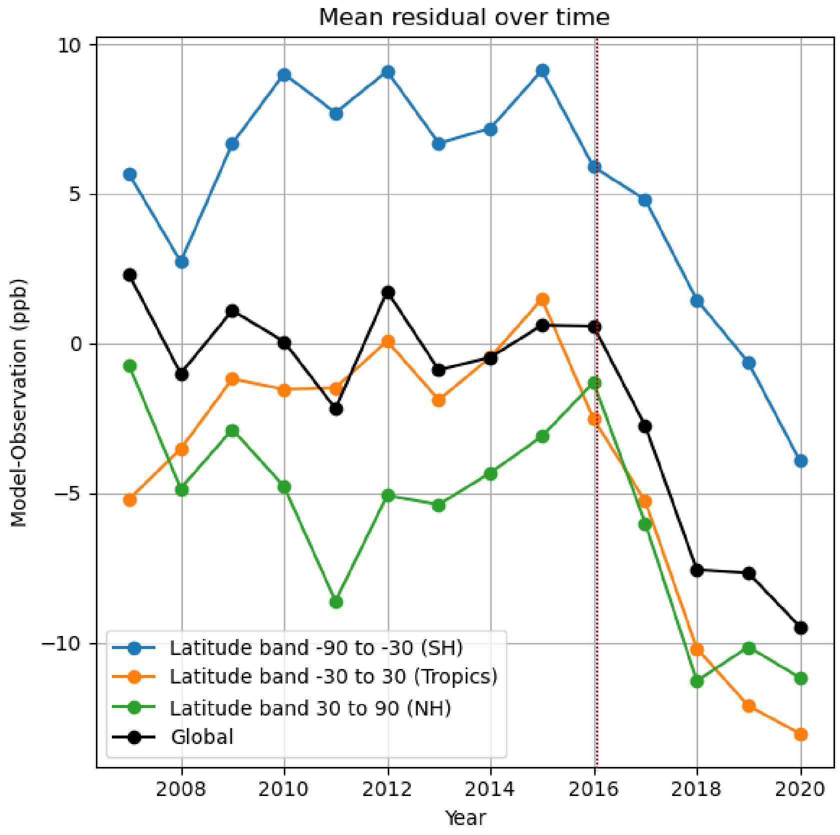
- Reaction 1: largest source term in budget
- Reaction 2: responsible for climate impact!



TM5: Station timeseries







- Mean, seasonality, growth rate

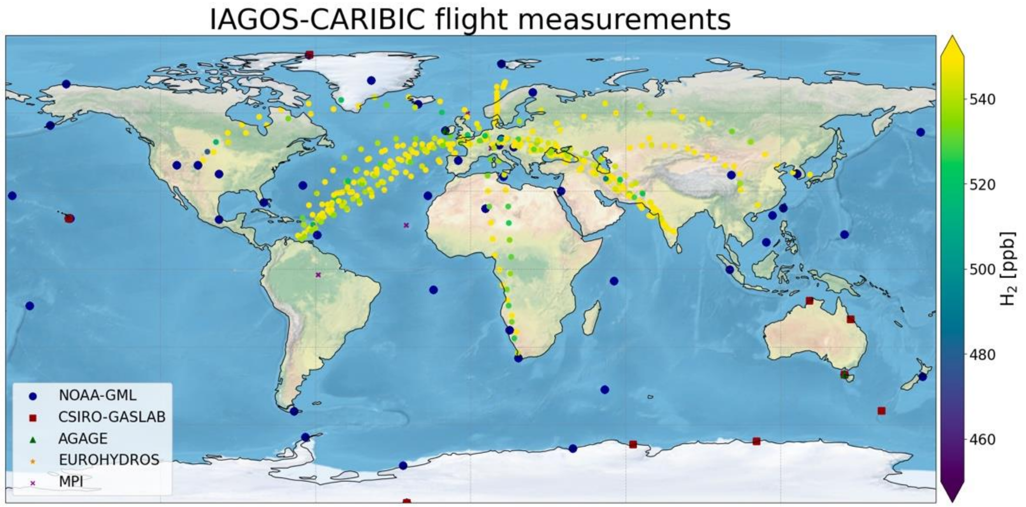
Optimal estimation of the soil uptake rate of molecular hydrogen from the Advanced Global Atmospheric Gases Experiment and other measurements

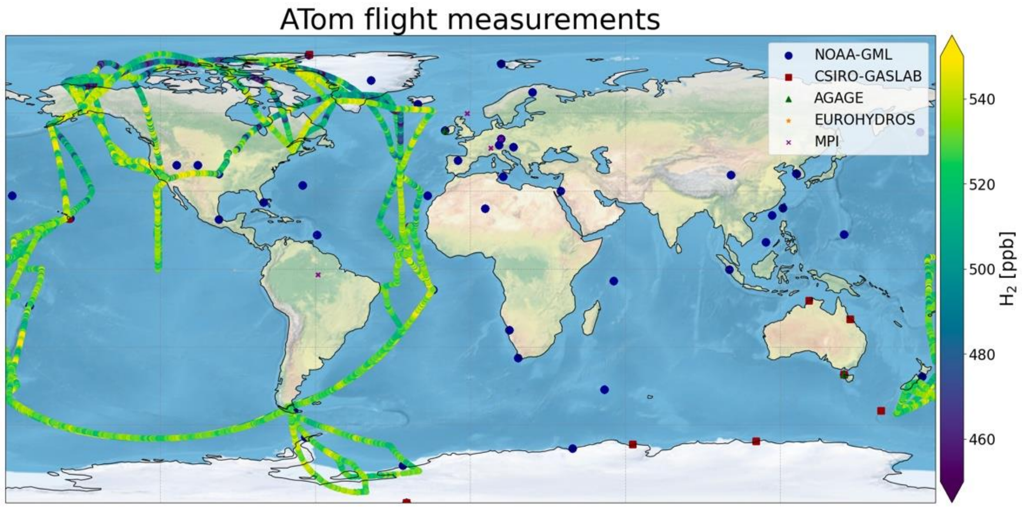
X. Xiao,[1] R. G. Prinn,[1] P. G. Simmonds,[2] L. P. Steele,[3] P. C. Novelli,[4] J. Huang,[1] R. L. Langenfelds,[3] S. O'Doherty,[2] P. B. Krummel,[3] P. J. Fraser,[3] L. W. Porter,[5] R. F. Weiss,[6] P. Salameh,[6] and R. H. J. Wang[7]

Received 28 February 2006; revised 12 September 2006; accepted 22 November 2006; published 3 April 2007.

Planned development 1: Inversions

- Use (flask) observations to constrain the H_2 budget
- Carbon tracker long-window (CO_2)
- Independent validation with 3D-aircraft profiles
- IAGOS-CARIBIC: 2007-2010 (H_2 and HD)
- ATom: 2016–2018 (H_2)

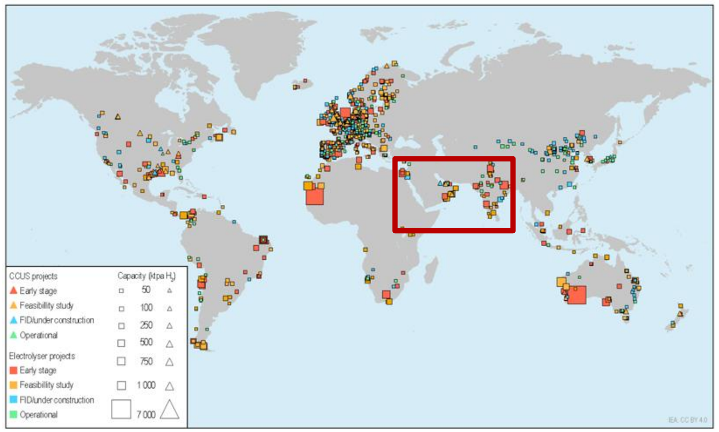


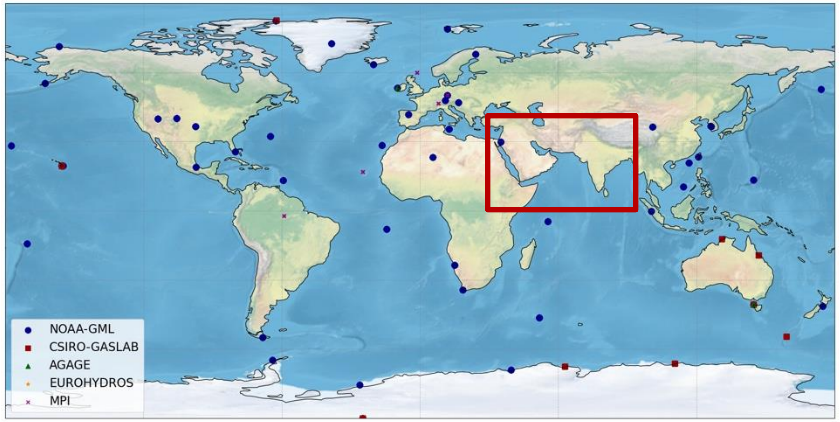


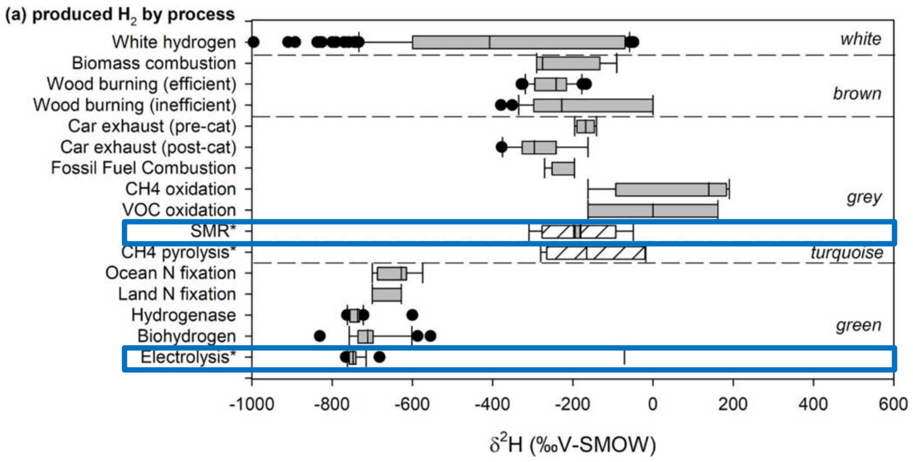
Planned development 2: future monitoring network

- Future emissions vs measurement locations
- India and Saudi-Arabia: almost no active stations in 2023
- But large announced green H_2 production projects (solar)!
- Future emission scenario, evaluate current monitoring capacity, design future network
- Verification using HD (grey vs green)
- Claim: x amount of green H_2 produced: check with HD-measurements

Map of announced low-emissions hydrogen production projects, 2024







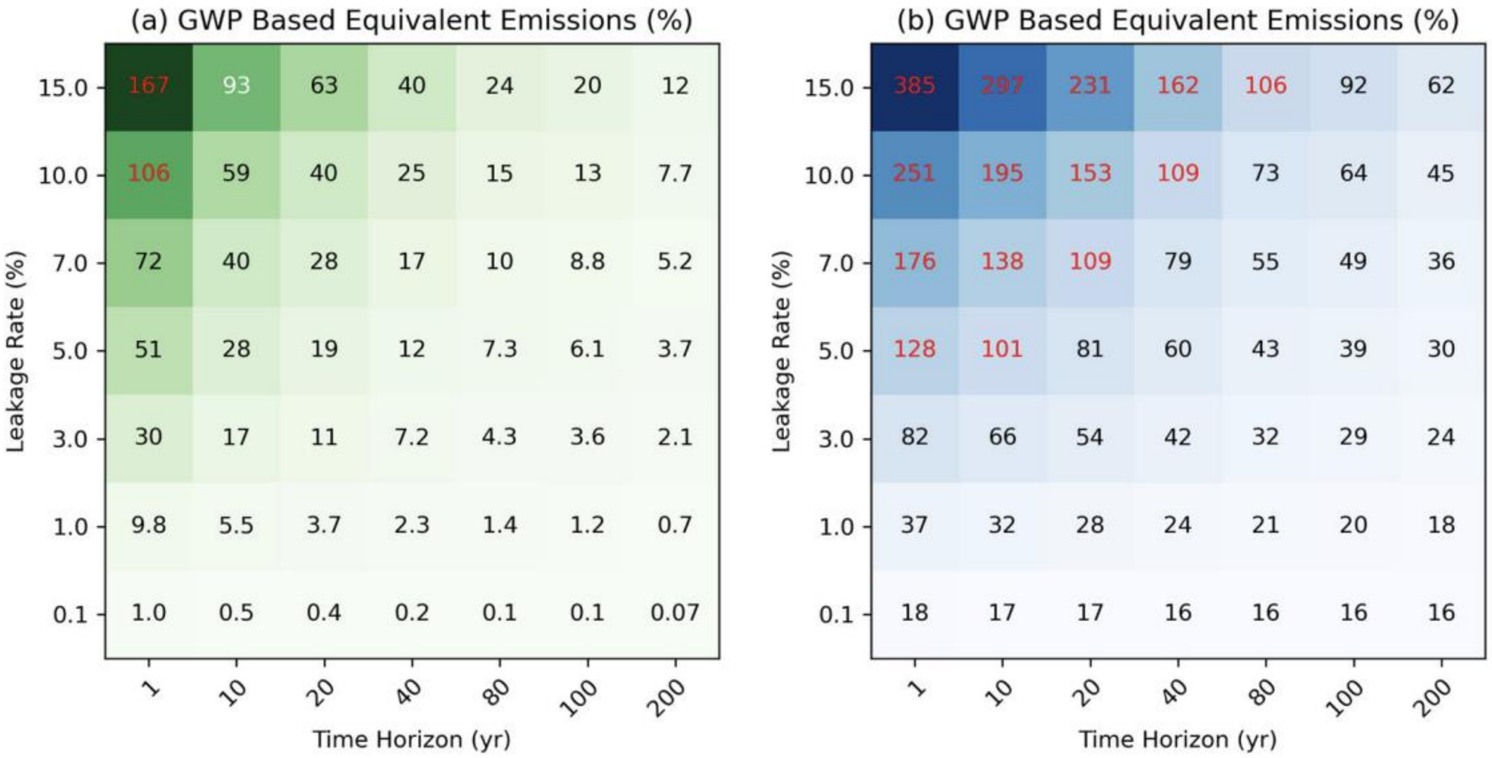
Take-Home messages & Questions

1. **Hydrogen is an indirect greenhouse gas**, meaning that minimizing leakages is essential to ensure its full climate benefits.
2. **Atmospheric inversions help constrain the global hydrogen budget**, improving our ability to predict the impact of future emissions on atmospheric composition.
3. **Current monitoring infrastructure may not be future-proof,** given the low observational density in potential future emission hotspots

Firmin Stroo
Supervisors: Wouter Peters and Harro Meijer

Additional slide: Climate impact of H2

Ratio (in %) of CO2 equivalent emissions associated with a hydrogen economy to the avoided CO2 emissions for green (a) and blue (b) hydrogen. Taken from Hauglustaine et al., 2022.



Additional slide: TM5 Budget vs literature

TM5

	2020
Fossil fuel	13.0
Biomass burning	13.4
Ocean N2 fixation	5.0
Land N2 fixation	3.0
Photochemical production	37.6
Stratospheric correction flux	4.3
Photochemical destruction	23.5
Dry deposition	54.4

Paulot et al., 2021

Table 1 – Global tropospheric budget of H_2[a].

	This work	Other estimates[b]
Source		
Emission	32.3 [29.9–37.1]	28–48
Anthropogenic	14.3 [13.4–15.8]	11–25
Biomass burning	9 [7.3–12.6]	8–20
Nitrogen fixation	9	
Soil	3	1–11
Ocean	6	3–6
Chemical production	42.1 [40.7–43.3]	30–41[b], 64–77[c]
Tropospheric loss		
Dry deposition	54.7 [53.5–56.3]	55–60[b], 85–88[c]
Chemical loss	20.4 [19.5–20.9]	15–19