H_2 in polar Ice: atmospheric reconstructions and interpretation

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Why is H_2 important?

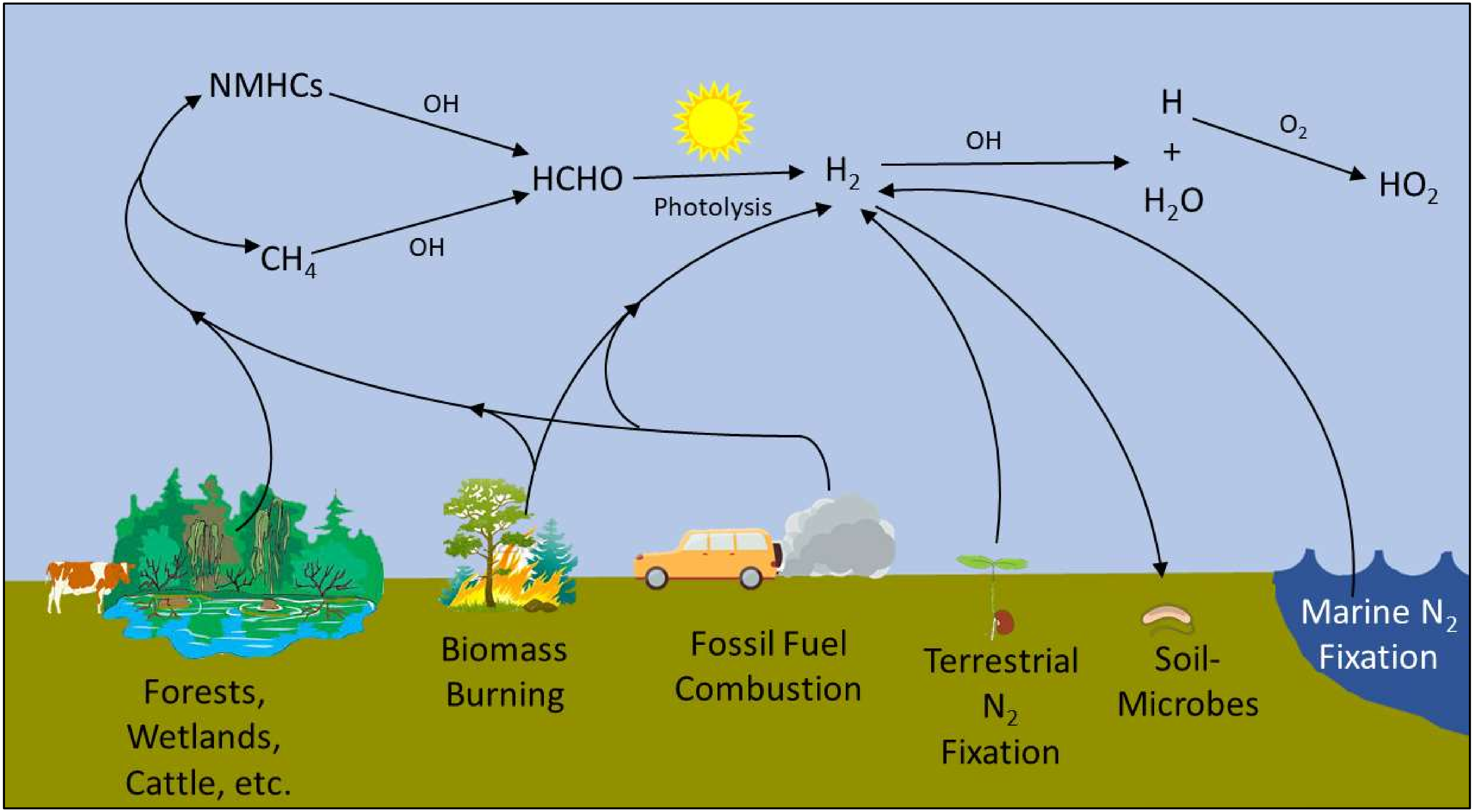
H_2 is the third most abundant trace gas in the atmosphere (after CO_2 and CH_4).

H_2 is important for climate and background ozone

H_2 has a complex and interesting biogeochemical cycle.

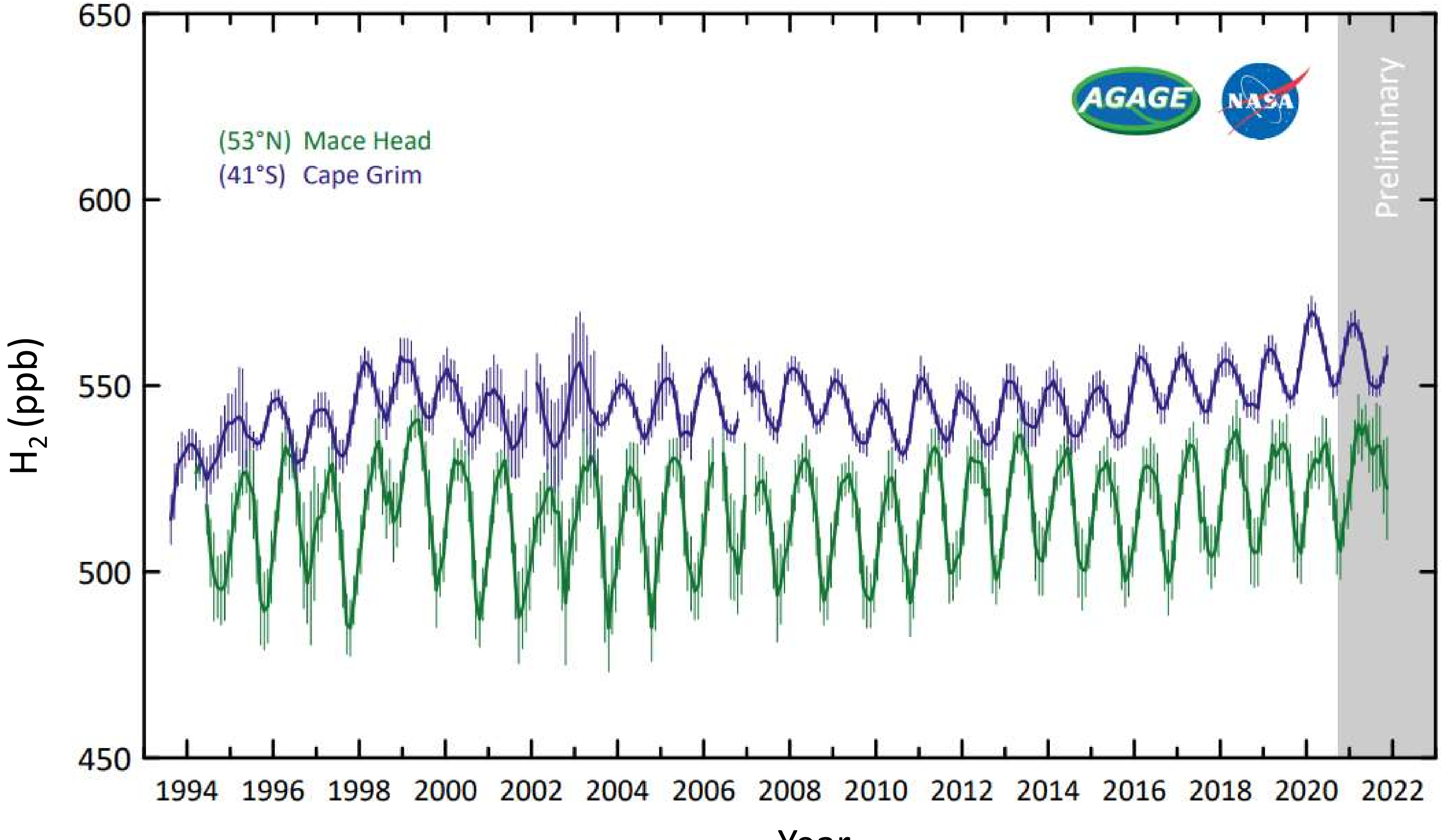
As the "hydrogen economy" expands, H_2 levels in the atmosphere will likely increase due to leakage.

Biogeochemical cycle of H_2



Modern atmospheric H_2 distribution

- Globally averaged mixing ratio ~530 ppb
- Atmospheric lifetime ~ 2 years
- Average mixing ratio 3% higher in SH than NH
- Seasonal Cycle



Prinn et al.

Motivating questions

What were preindustrial levels of H_2?

How have humans already altered atmospheric H_2?

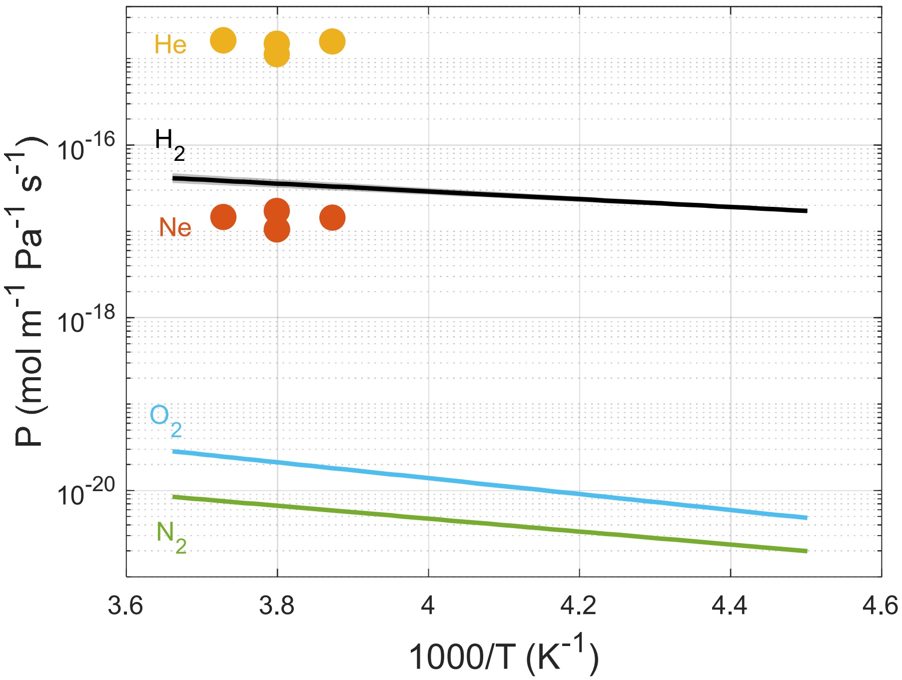
What does natural variability in atmospheric H_2 look like?

How does climate variability affect atmospheric H_2? How might H_2 affect climate?

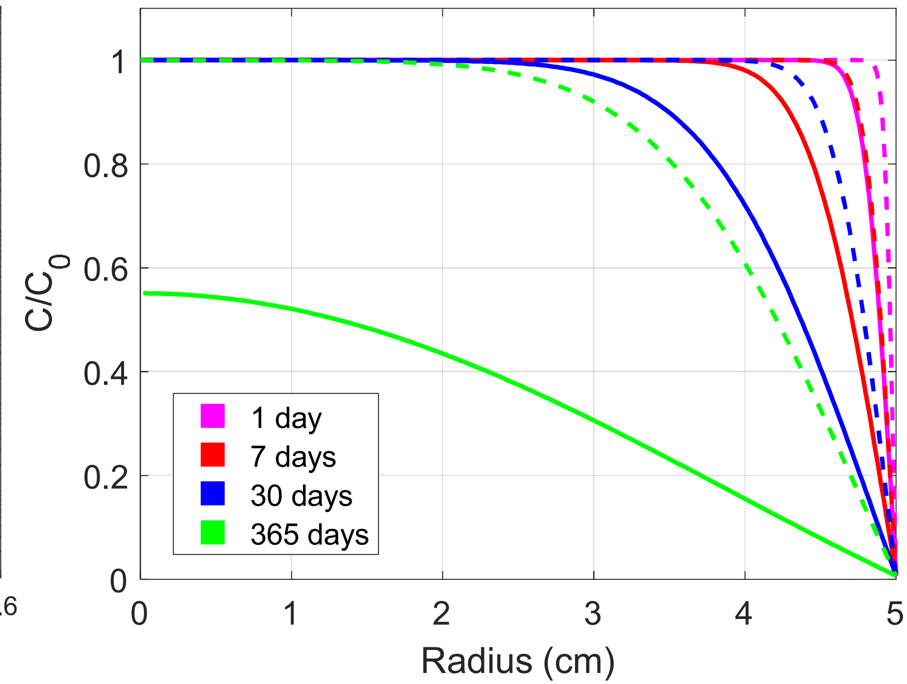
<u>Establish past changes to atmospheric H_2 and understand the drivers of those changes</u>

Why can't we use stored ice cores?

Permeability



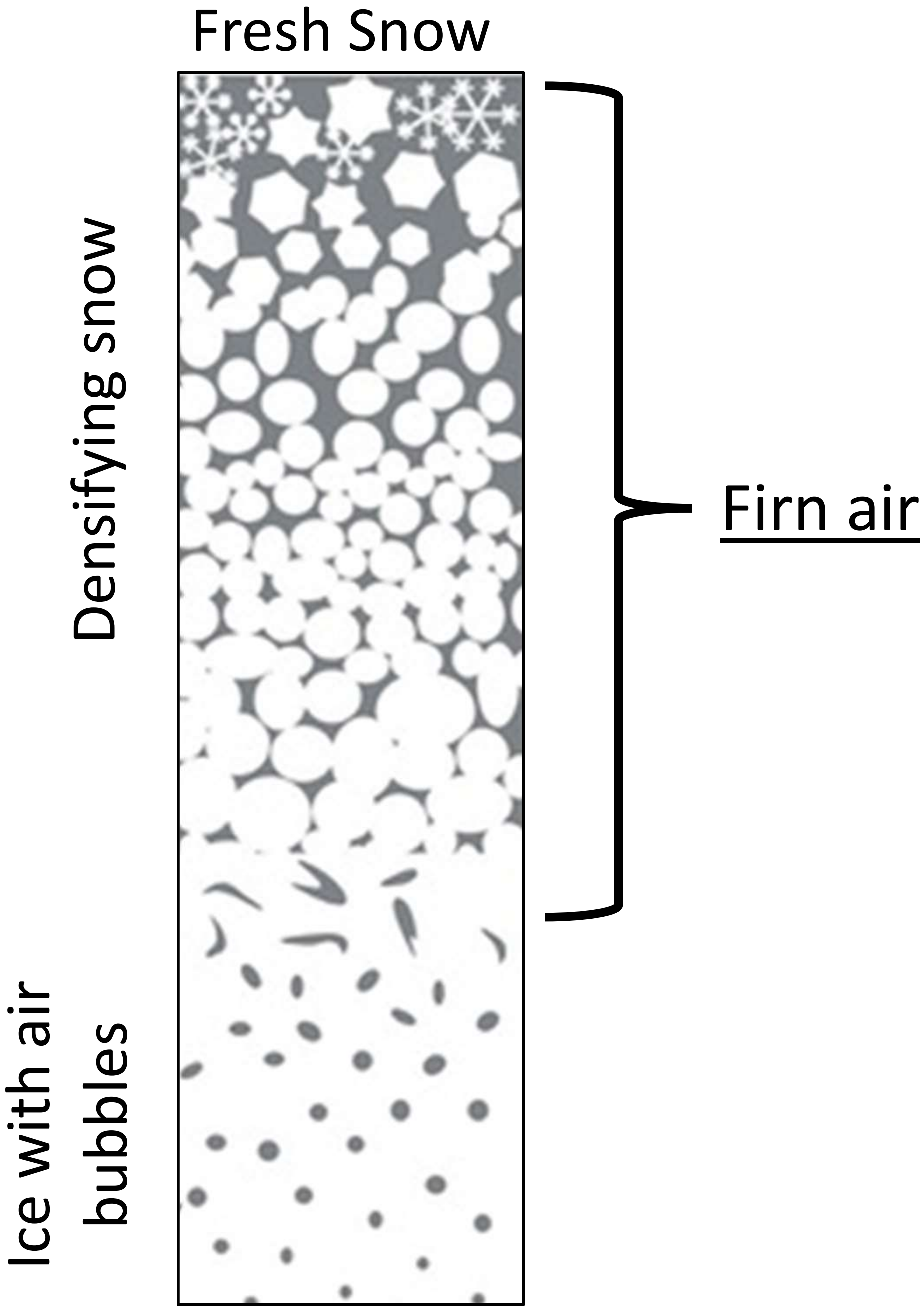
Diffusive Losses



Unlike most gases, H_2 can dissolve into and diffuse through the ice matrix

- The existing ice core archive has equilibrated with the modern atmosphere
- Mobility also influences how atmospheric signals are preserved in polar ice

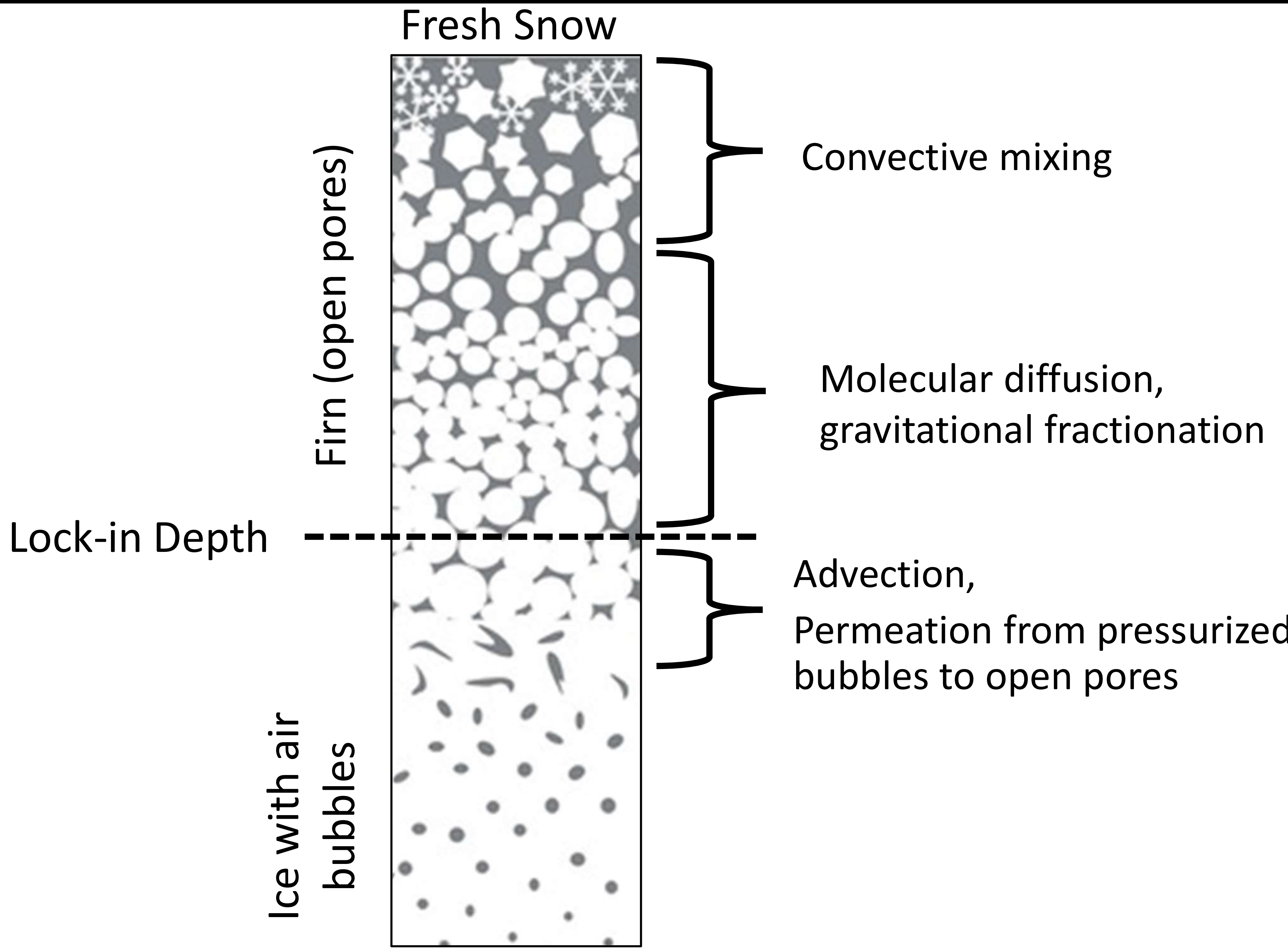
How else could we answer these questions?



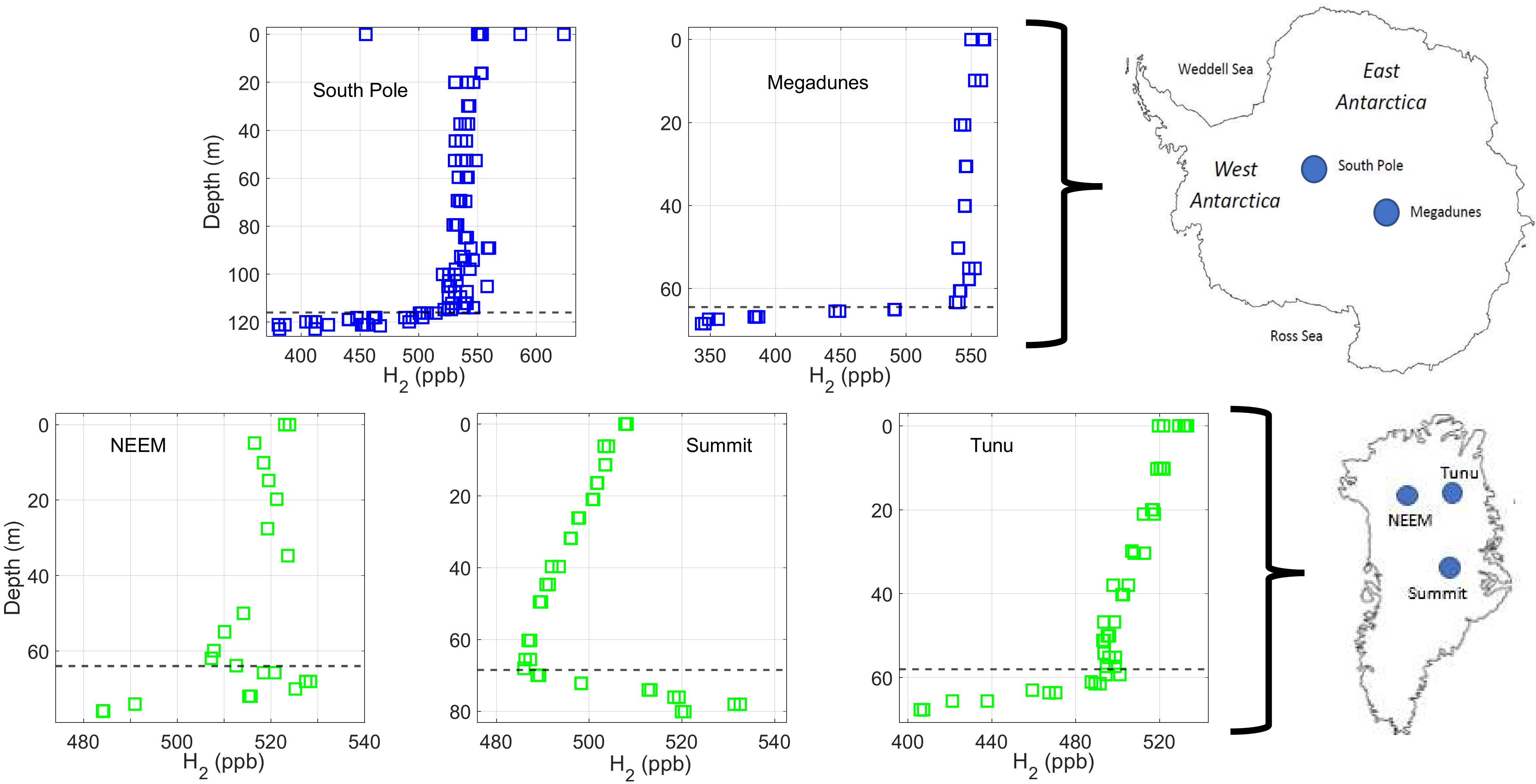
New ice cores

NOAA/GML & CSIRO

Firn air and ice cores

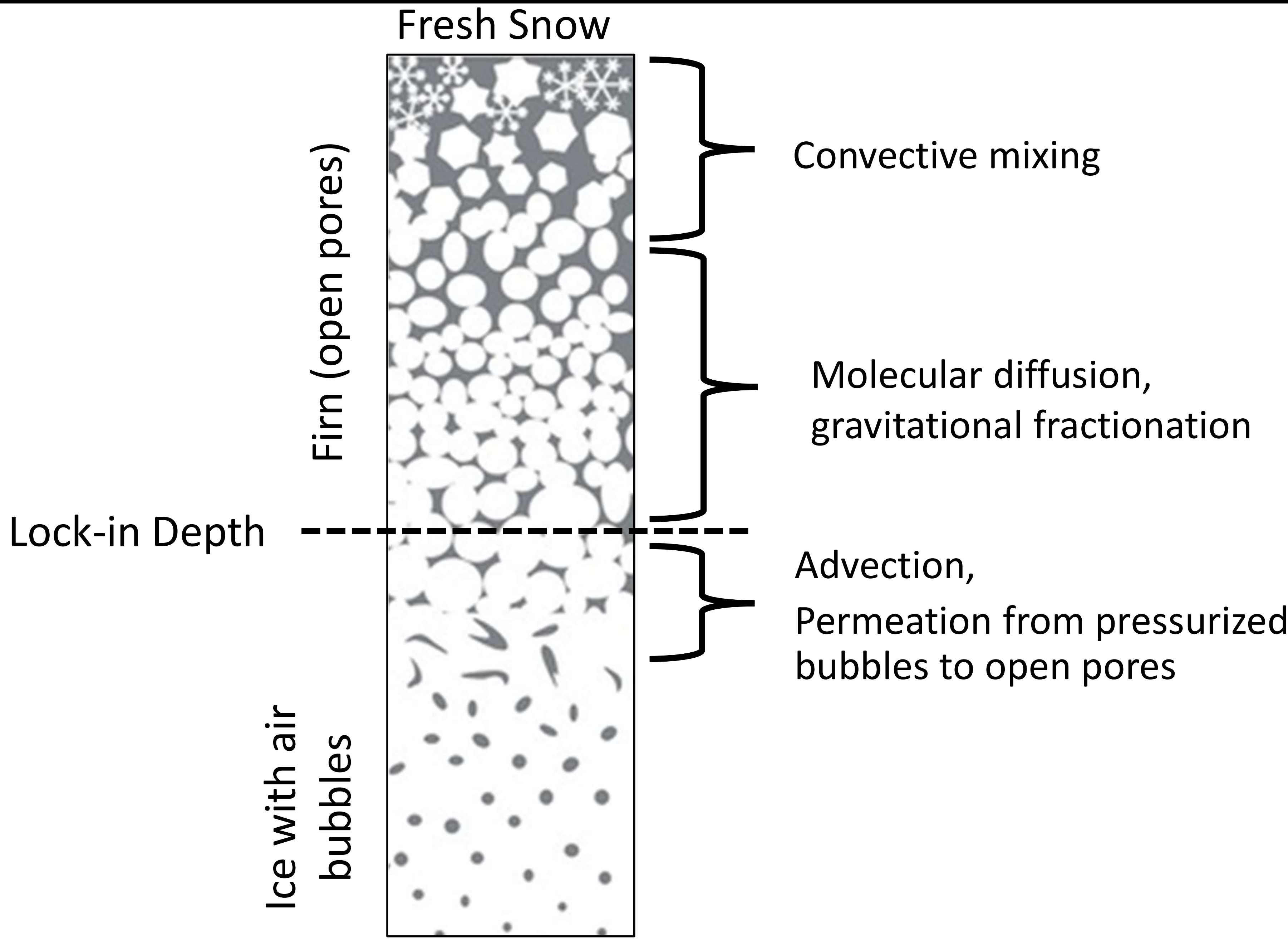


Firn air



NOAA/GML & CSIRO

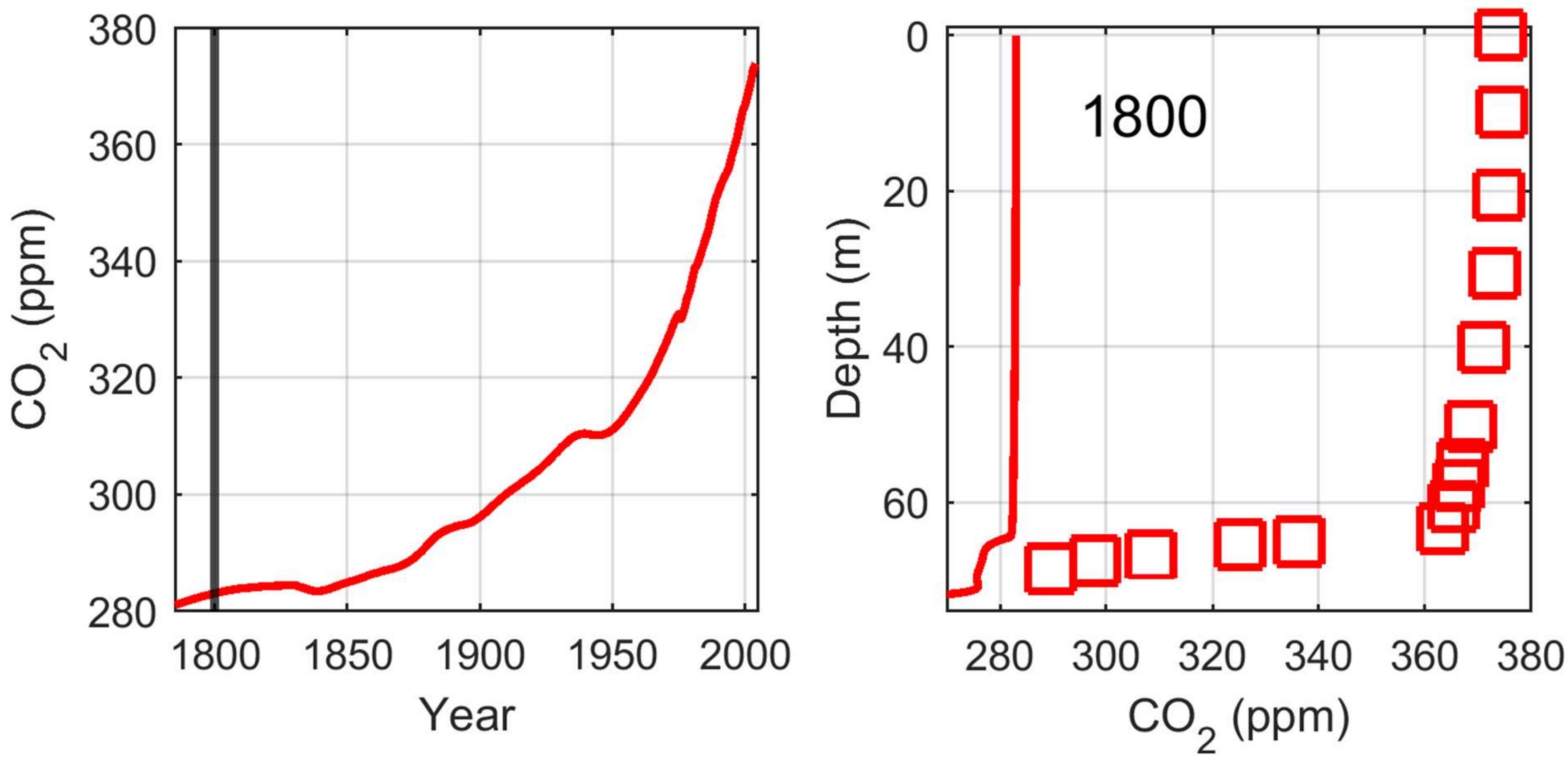
Firn air



Fresh Snow
Firn (open pores)
Lock-in Depth
Ice with air bubbles
Convective mixing
Molecular diffusion,
gravitational fractionation
Advection,
Permeation from pressurized bubbles to open pores

Relating firn air measurements to atmospheric histories

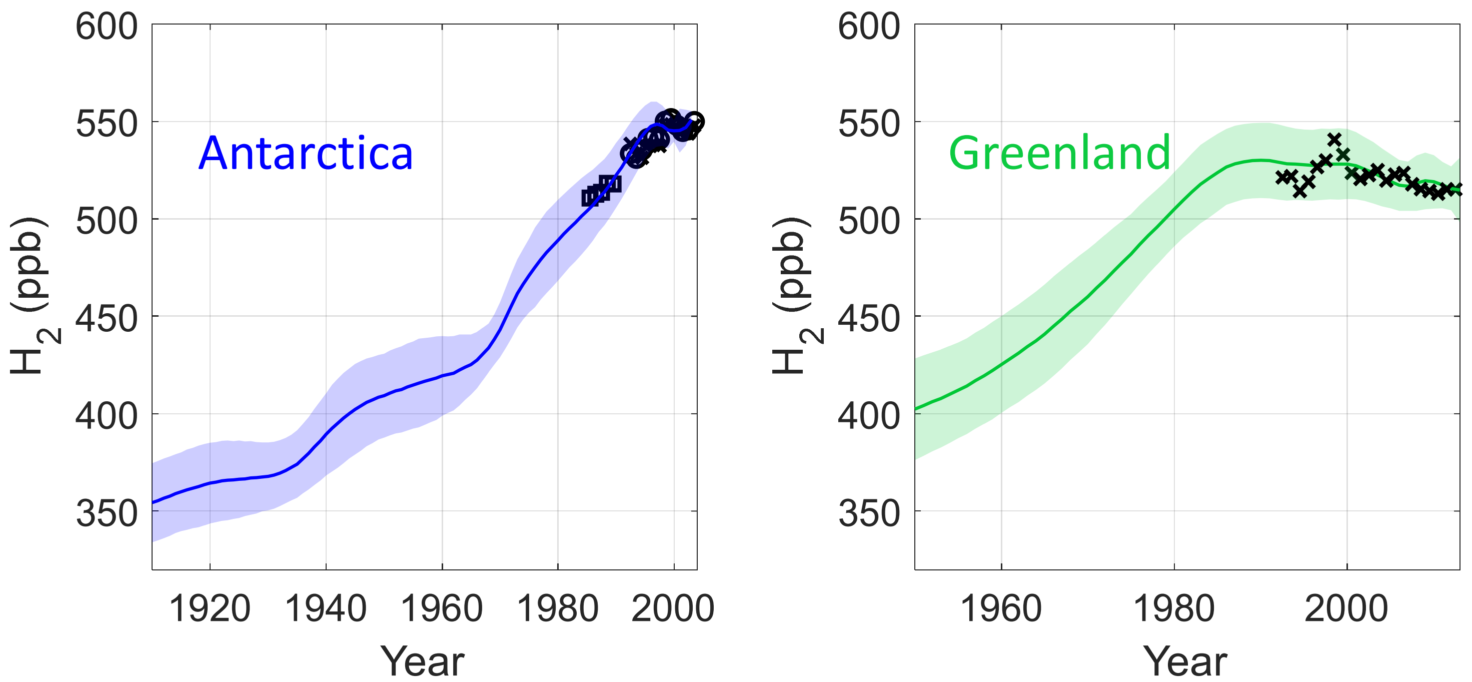
Firn air models: Megadunes



The diffusivity profile of the firn air model is tuned to reproduce the measured depth profile when forced with the known atmospheric history CO_2

Etheridge et al., 1996

Atmospheric reconstructions



Antarctic H_2 levels rose from 350 ppb to 550 ppb over the 20^{th} century

Greenland H_2 levels rose from 400 ppb to 530 ppb in in 1990

Reasonable agreement with modern flask measurements in both hemispheres

Patterson et al., 2023

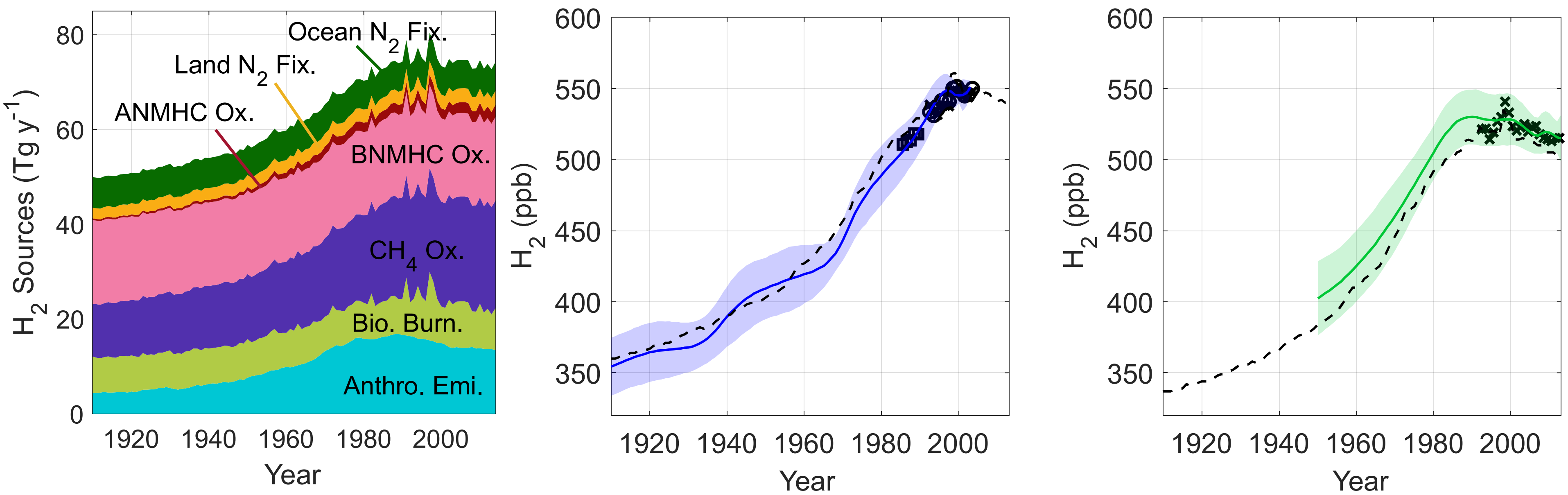
Active research: 20th century changes in H_2 biogeochemistry

Bottom-up historical H_2 budget to force GFDL-AM4.1 (Fabien Paulot)

Reconstructed trends are well-explained by changing anthropogenic emissions and increasing CH_4 oxidation

Reconstruction shows some systematic differences with modeled H_2 levels prior to mid 1990's

Why?



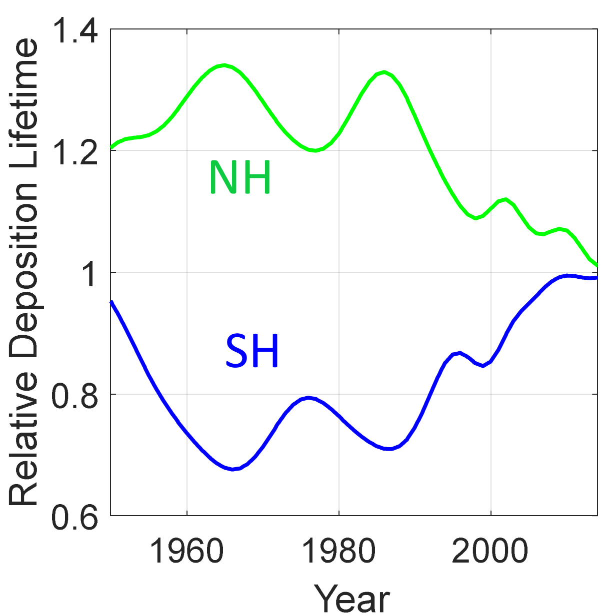
Active research: 20th century changes in H_2 biogeochemistry

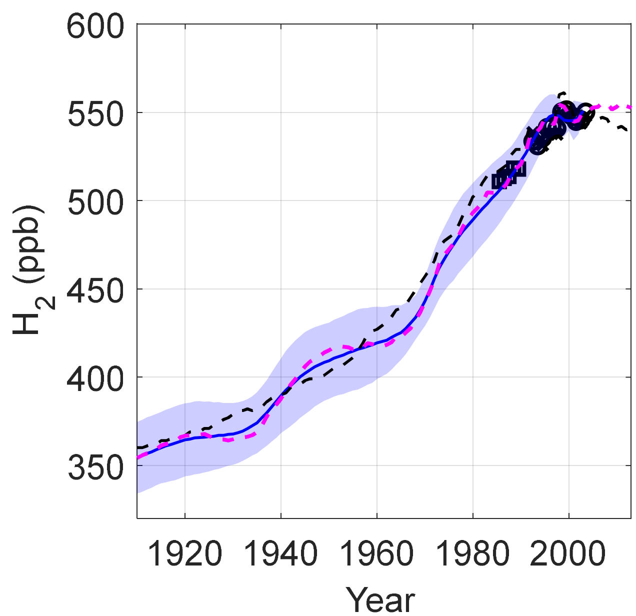
Adapted GFDL-AM4.1 to a 6-box atmospheric model (tagged tracers)

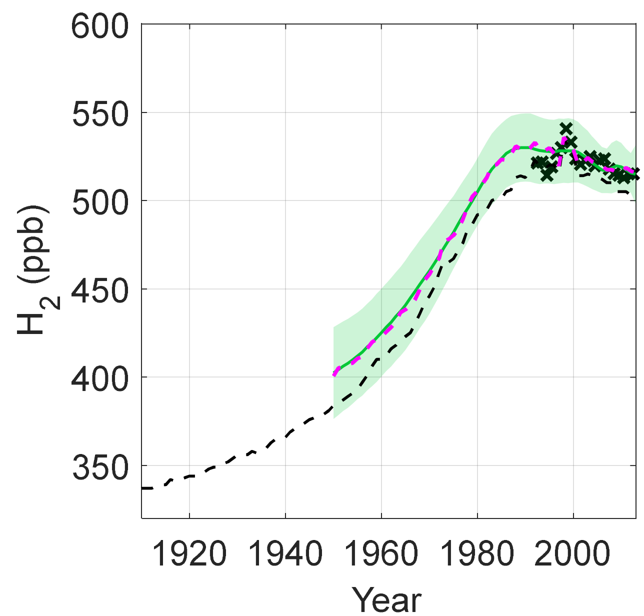
Inverted 6-box model to find the budget perturbations which could produce better agreement with atmospheric reconstruction

Difficult to achieve agreement by perturbing only one term

- One interesting result: the soil sink







Summit, 2024 field campaign

New ice core drilled at Summit Station, Greenland during the summer of 2024

Elevation: 10,551 ft.

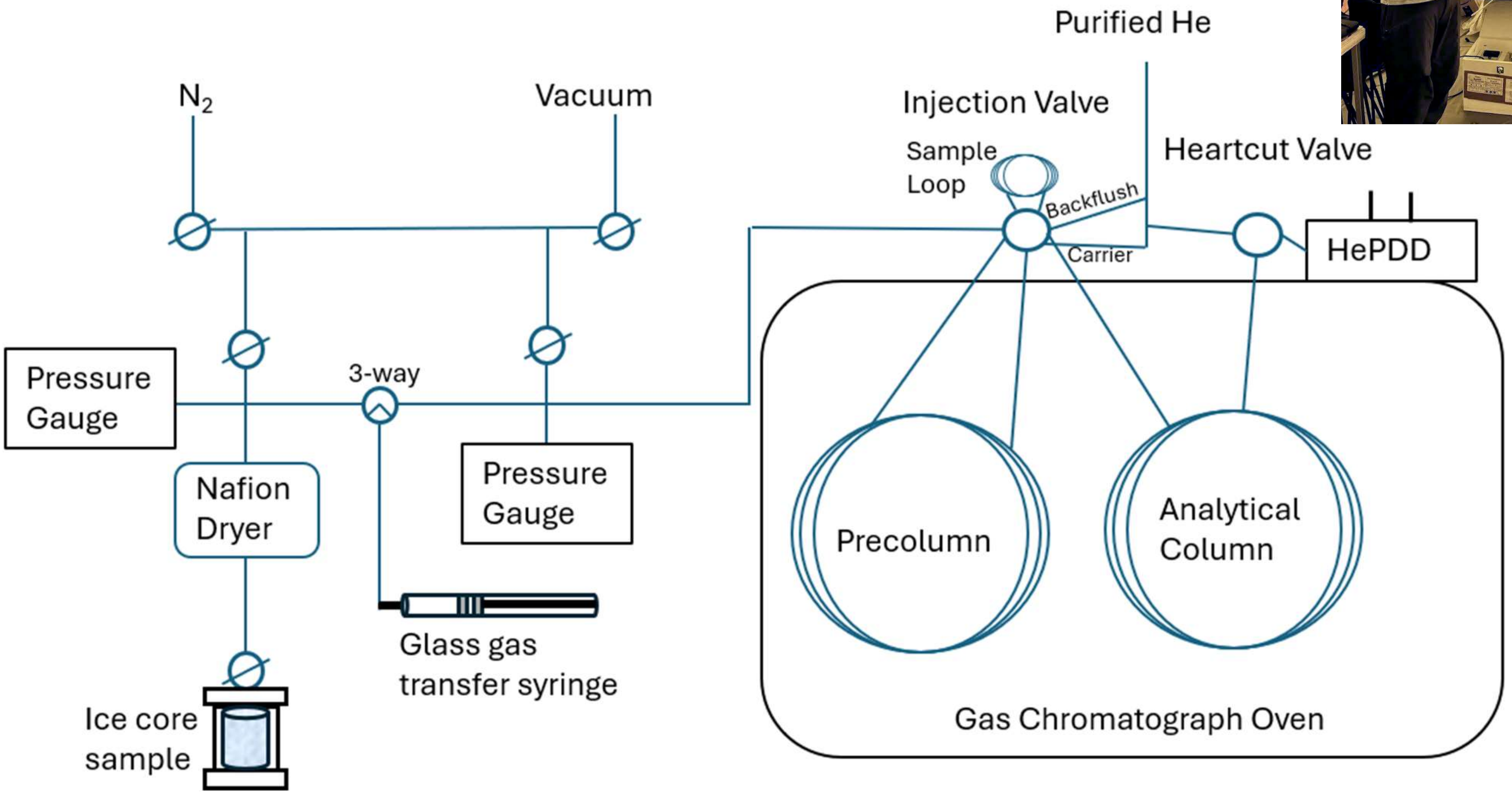
Reached a depth of 330 m

Field analytical system

Melt extraction

Custom glass gas transfer syringe

GC-HePDD

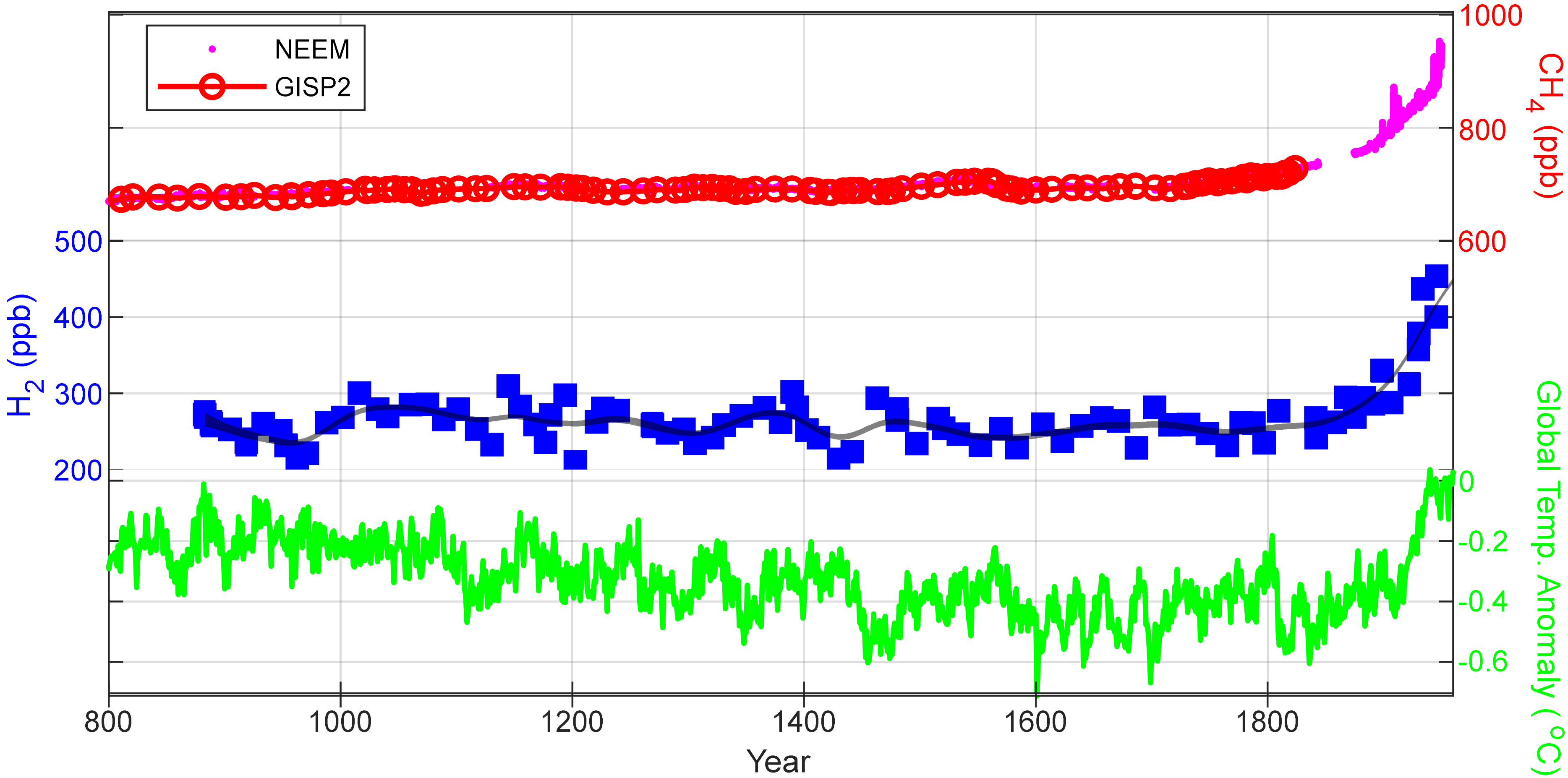


New ice core measurements

89 total field measurements spanning 880-1945 CE

Preindustrial levels of 250-300 ppb- roughly consistent with reduced production from CH_4 and no fossil fuel emissions

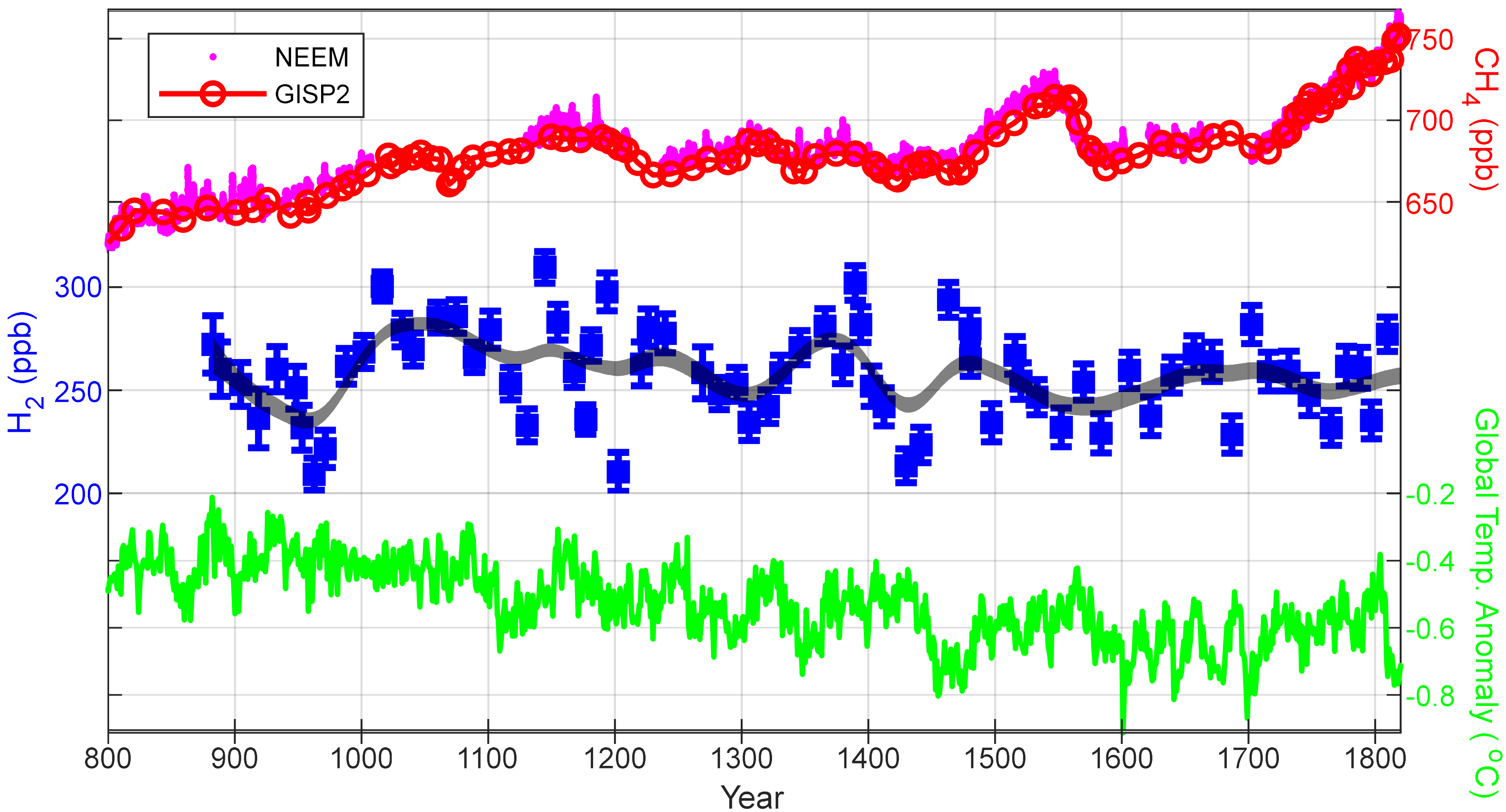
Anthropogenic rise begins around 1830, shortly after CH_4



New ice core measurements

Centennial-scale variability superimposed on a long-term decreasing trend, mirroring global temperature

Interesting differences with reconstructed CH_4

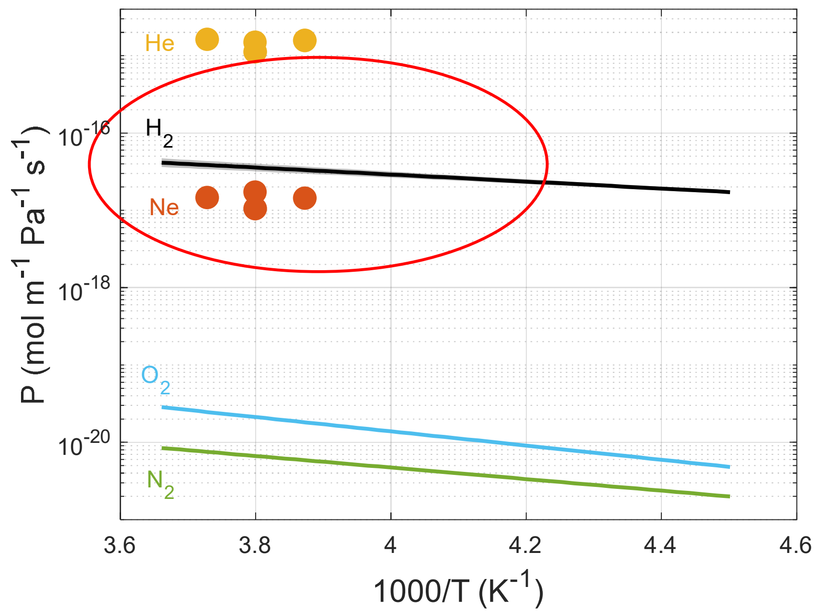


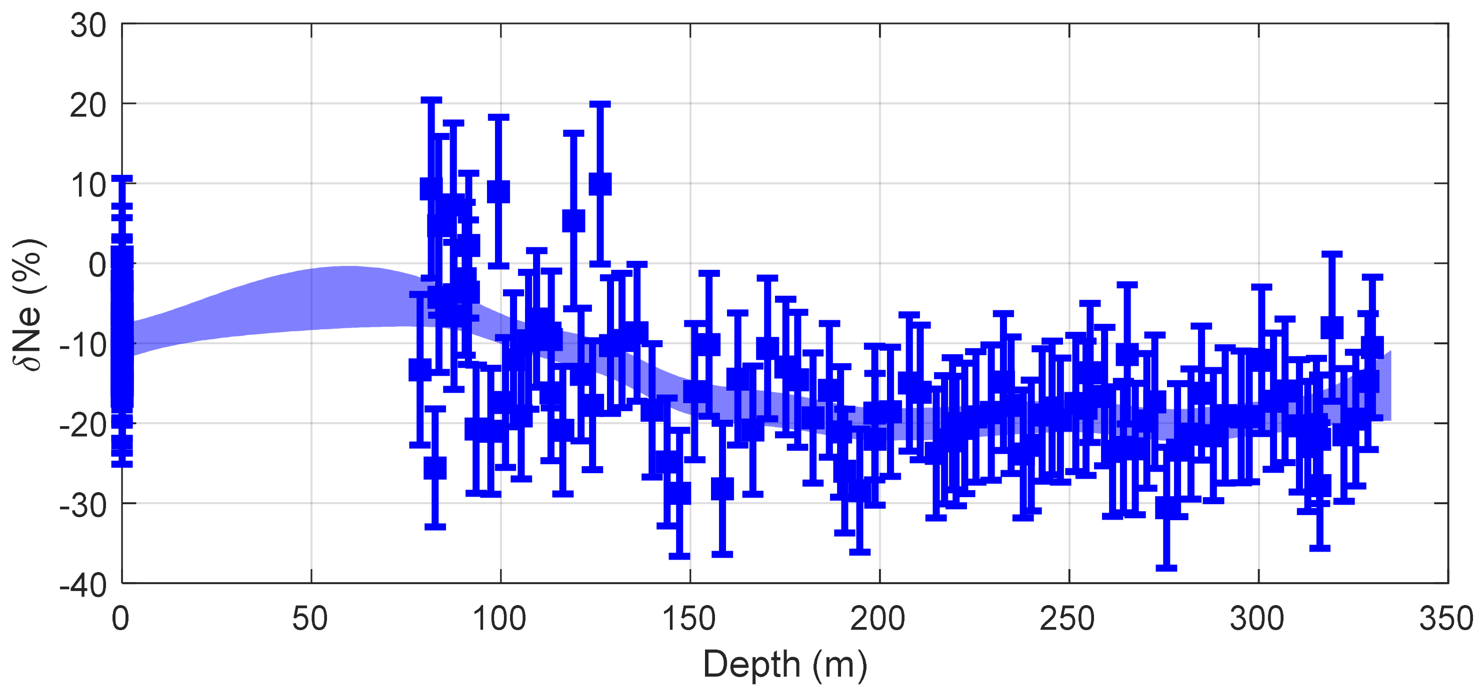
Possible corrections to the data

These measurements are preliminary!

Improve age-depth scale with CH_4 measurements

Correct for diffusion in the ice sheet using neon as a proxy





Takeaways and future directions

Takeaways

- Atmospheric H_2 levels increased by ~60% over the 20^{th} century
- General trends in atmospheric H_2 over 20^{th} century are explained by changing anthropogenic emissions and increasing production from atmospheric CH_4
- Reconstructed 20^{th} century H_2 levels show a surprising reversal in the interpolar difference that is difficult to explain by perturbing only one budget term
- New measurements of H_2 from a Greenland ice core show preindustrial levels of 250-300 ppb, in rough agreement with reduced production from CH_4 and no anthropogenic emissions

Future directions

- Develop a bipolar record by drilling a new ice core in Antarctica (preindustrial interpolar difference?)
- Understand the biogeochemical implications of the reconstructions
- Analyze HD measurements in Greenland firn air for better constraints on biogeochemistry

Questions?