Methane Time Bombs, Leaky Pipelines and Scientists Doing Their Best to Stay Warm

Vasilii Petrenko, University of Rochester

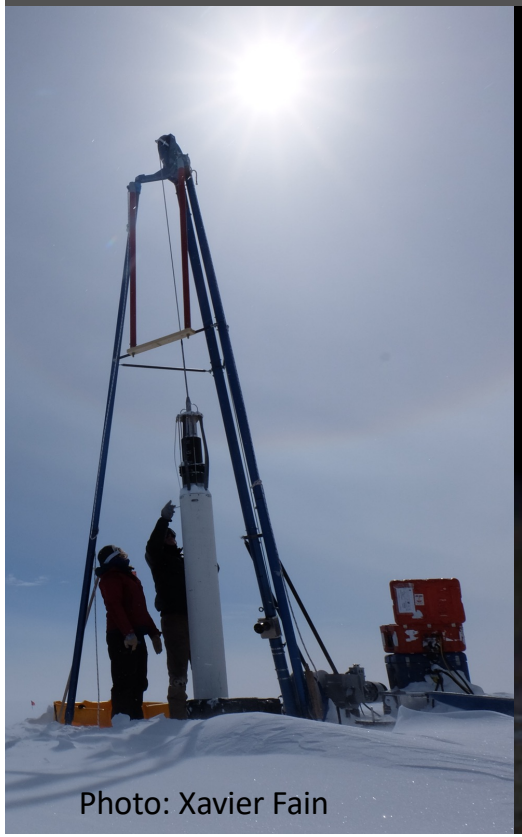


Photo: Xavier Fain

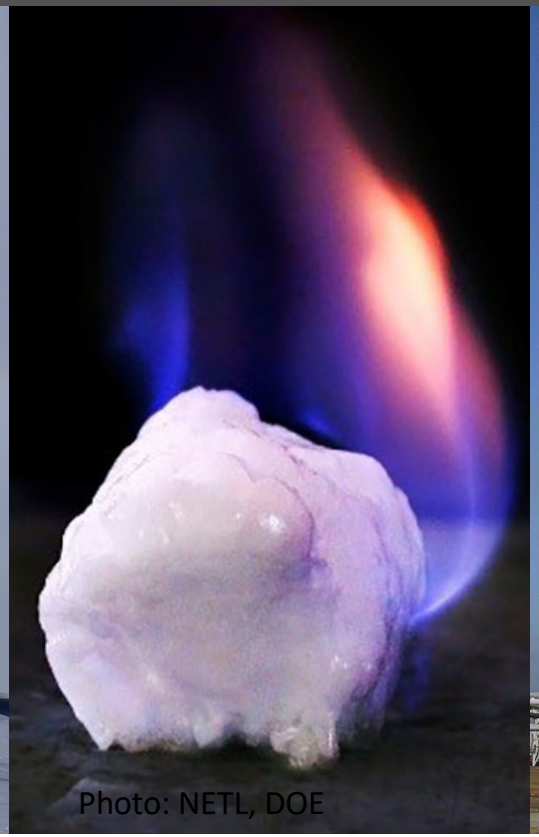
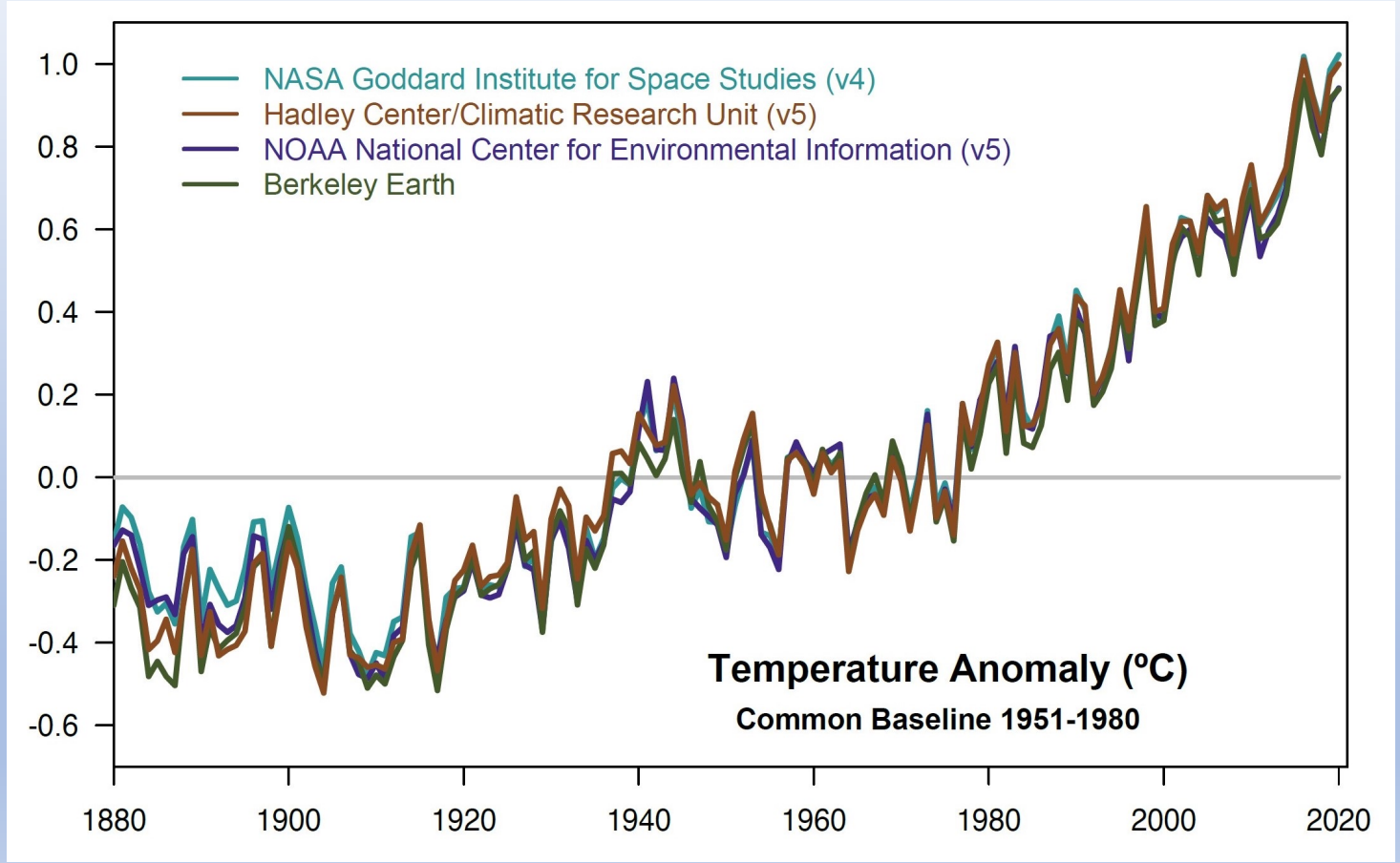


Photo: NETL, DOE


Photo: Terry Joyce

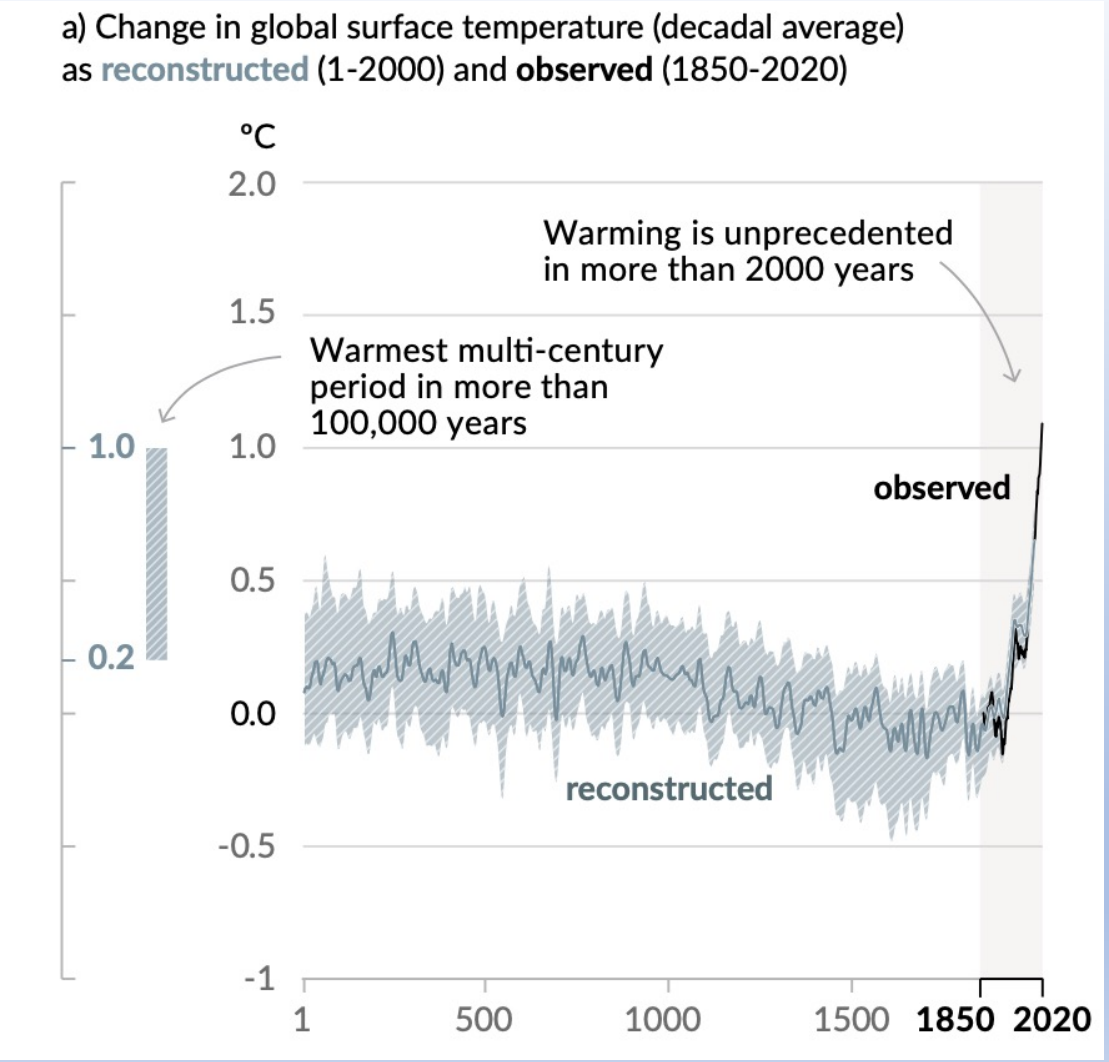

Photo: USGS

WE LIVE IN A RAPIDLY WARMING WORLD



- 2020 was the 2nd warmest year on record
- Each of the last four decades has been successively warmer than any decade that preceded it since 1850
- Global average surface temperature for 2011 – 2020 was 1.1˚C higher than for 1850 - 1900

Image: NASA

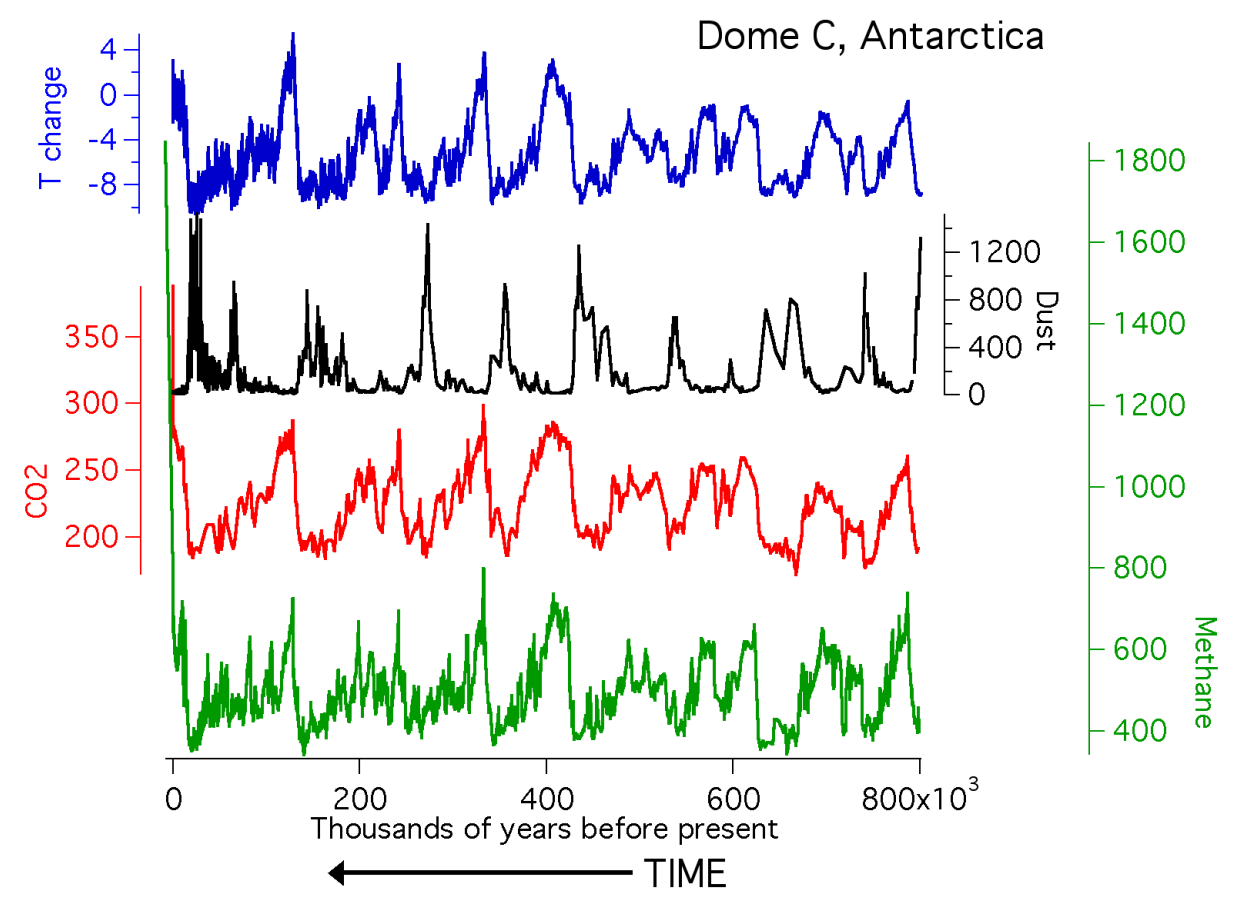


THIS WARMING IS HIGHLY UNUSUAL

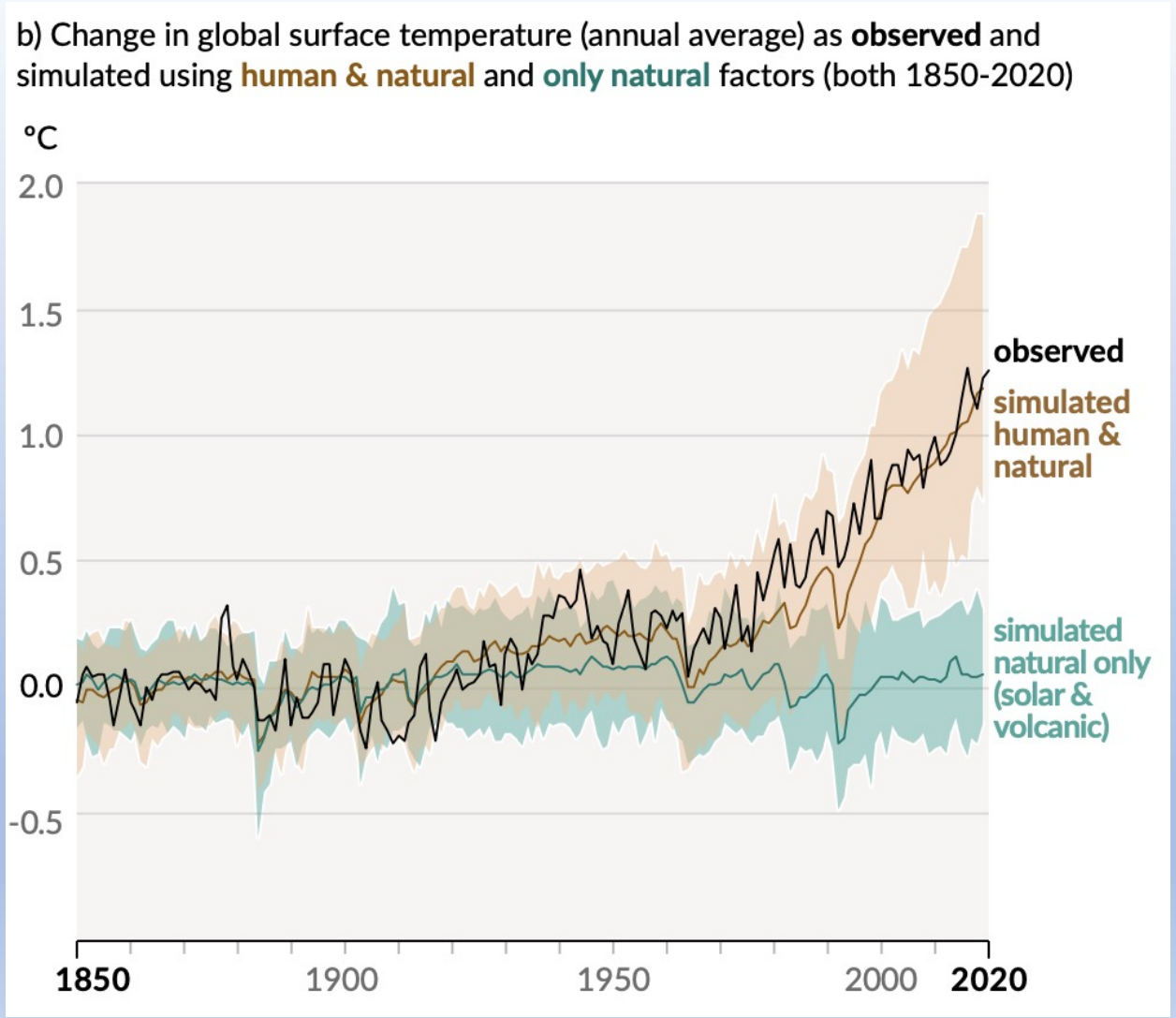
- Already slightly warmer than at any extended period during the last 100,000 years
- Rate of global warming seems unprecedented in the last several million years of Earth history

Image: IPCC 2021, WG I

OUR EMISSIONS OF GREENHOUSE GASES ARE THE MAIN CAUSE



- We're way outside the natural variability for at least the last 800,000 years
- It is basic physics that more of these gases in the atmosphere would cause the Earth to warm



"It is unequivocal that human influence has warmed the atmosphere, ocean and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere and biosphere have occurred"

- IPCC 2021, WG I, Summary for Policymakers

Image: IPCC 2021, WG I

IMPACTS DEPEND ON WARMING MAGNITUDE

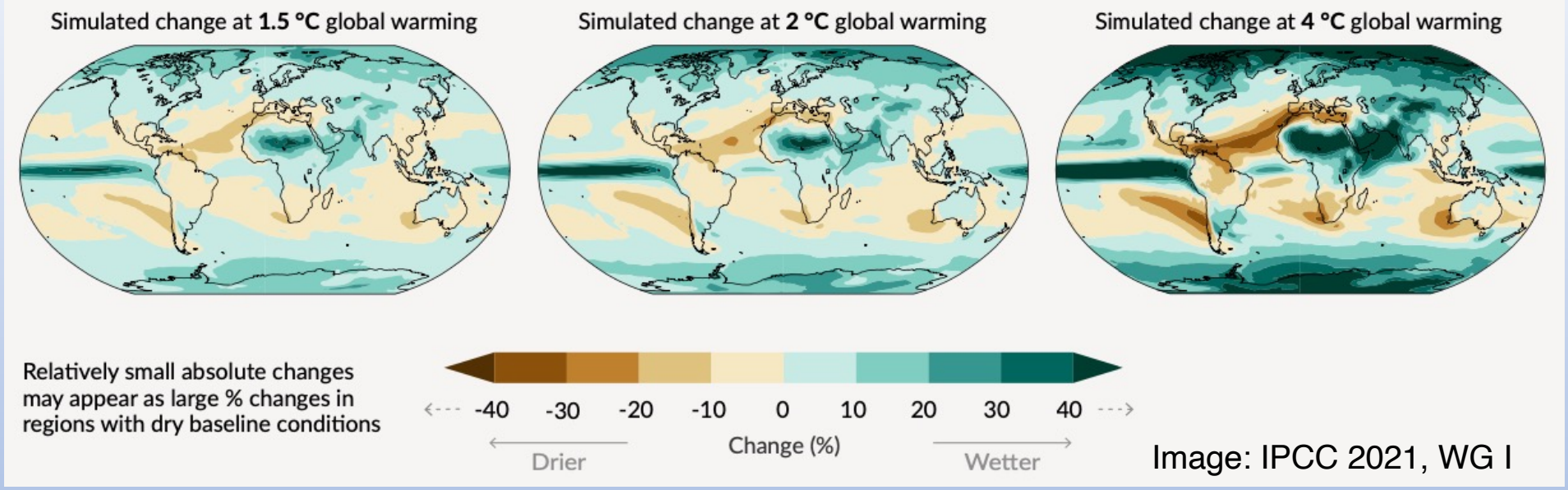
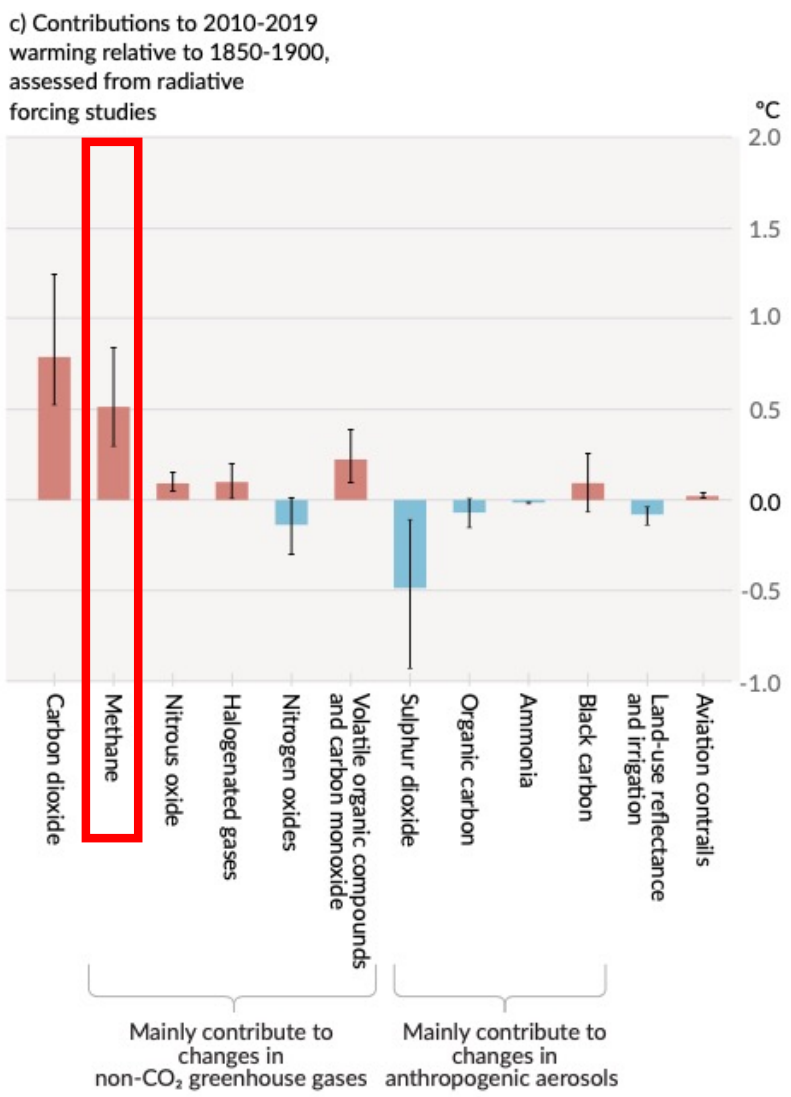


Image: IPCC 2021, WG I

- Heat waves
- Extreme storms
- Sea Level Rise
- Food production
- Many others…

Scientists agree that we must limit global warming to about 1.5˚C (or, at worst, 2˚C) to avoid very large impacts

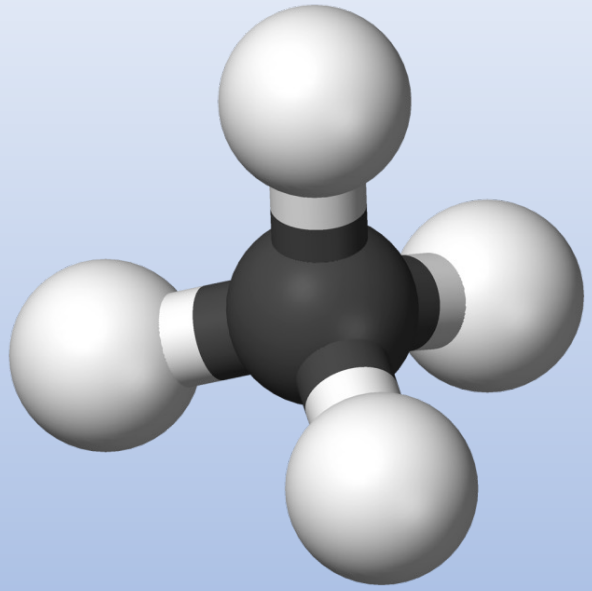


CONTRIBUTORS TO WARMING

"From a physical science perspective, limiting human-induced global warming to a specific level requires limiting cumulative CO_2 emissions, reaching at least net zero CO_2 emissions, along with strong reductions in other greenhouse gas emissions. ***Strong, rapid and sustained reductions in CH_4 emissions would also limit the warming effect resulting from declining aerosol pollution and would improve air quality."***

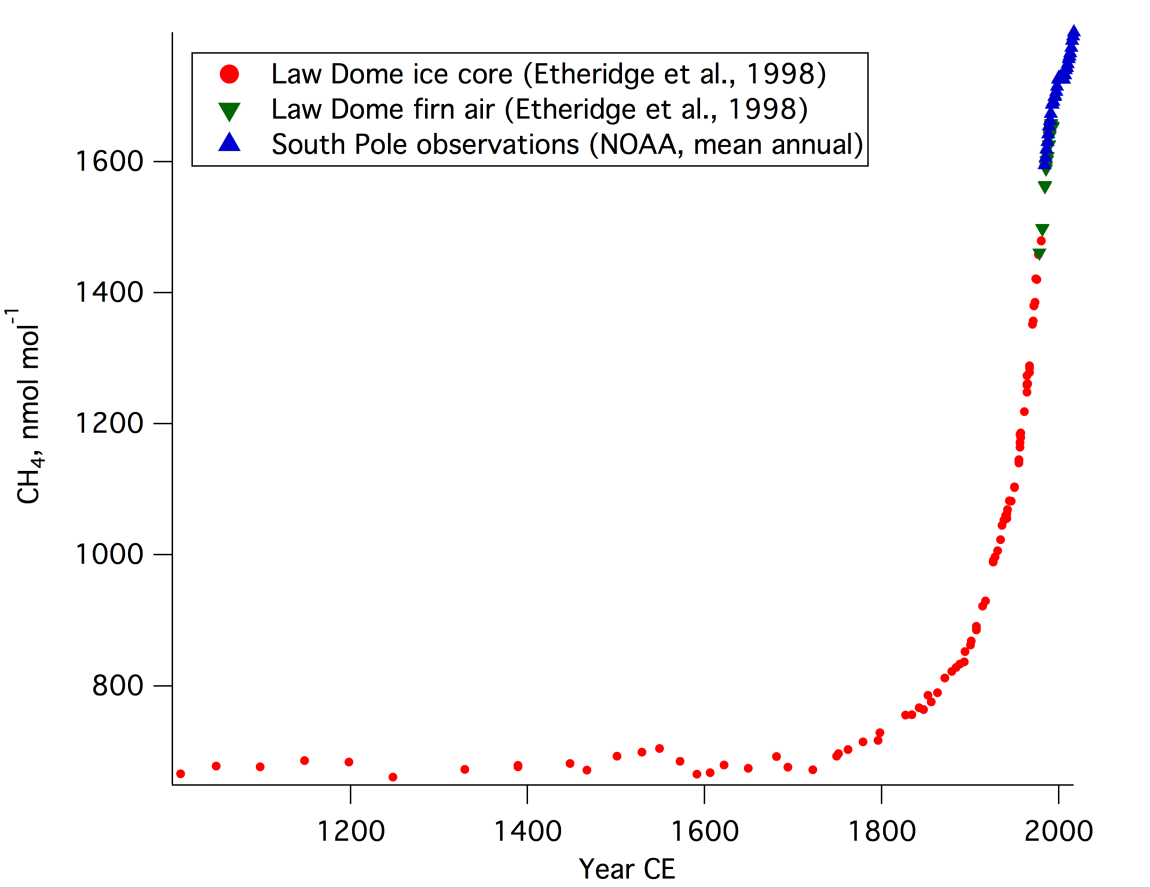
- IPCC 2021, WG I, Summary for Policymakers

INTRODUCTION TO METHANE (CH_4)



- Colorless, odorless gas
- Main component of natural gas (fossil fuel)
- Minor atmospheric component (≈ 2 methane molecules per million air molecules)
- Good at absorbing infrared radiation (greenhouse gas)
- Emitting 1 kg of CH_4 causes about 28 times more warming than emitting 1 kg of CO_2 over a period of 100 years after emission

THE RISE OF ATMOSPHERIC CH_4 SINCE THE PREINDUSTRIAL ERA



- Rapid increase since ≈1800
- Driven by human activities

The Global Atmospheric Methane Budget

Natural Sources (≈ 40%):

wetlands

termites and wild animals

natural geologic

Anthropogenic Sources (≈ 60%):

ruminants

energy

rice

landfills

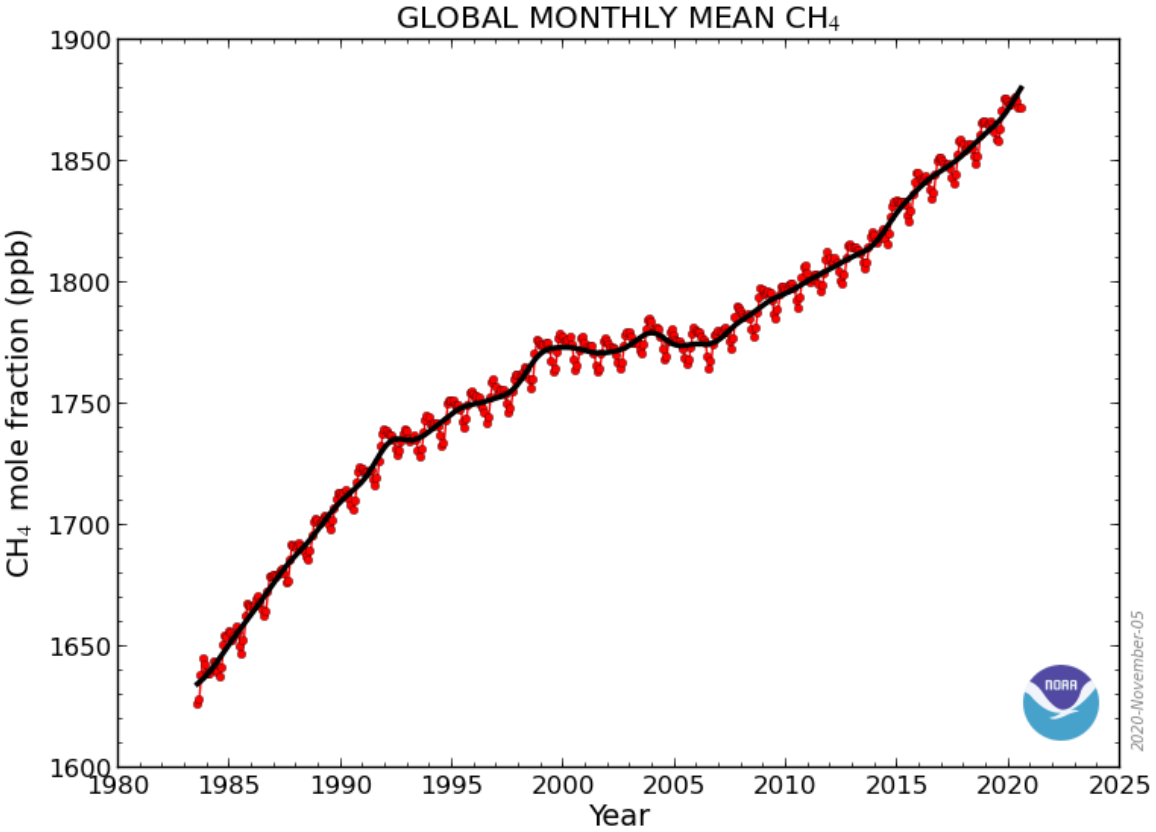
Biomass burning

Main removal process: atmospheric OH radicals (≈90 %)

Methane atmospheric lifetime is ≈ 9 years (compare with >100 yrs for CO_2)

Images: Wikipedia

ATMOSPHERIC CH_4 IS CONTINUING ITS RAPID RISE TODAY



- No consensus among scientists about the causes of the most recent methane rise
- Are fossil fuel emissions going up?
- Are natural sources increasing due to warming?
- Is methane lifetime changing due to changes in atmospheric chemistry?

Ice Core Basics

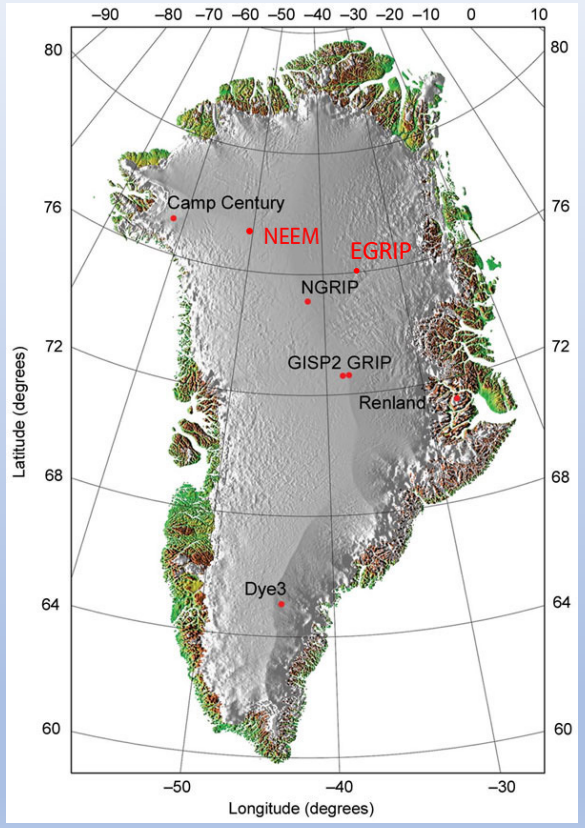


Image: NEEM Project

Greenland:

- up to 3 km thick
- 120,000+ yr old

Antarctica:

- up to 4 km thick
- 800,000+ yr old

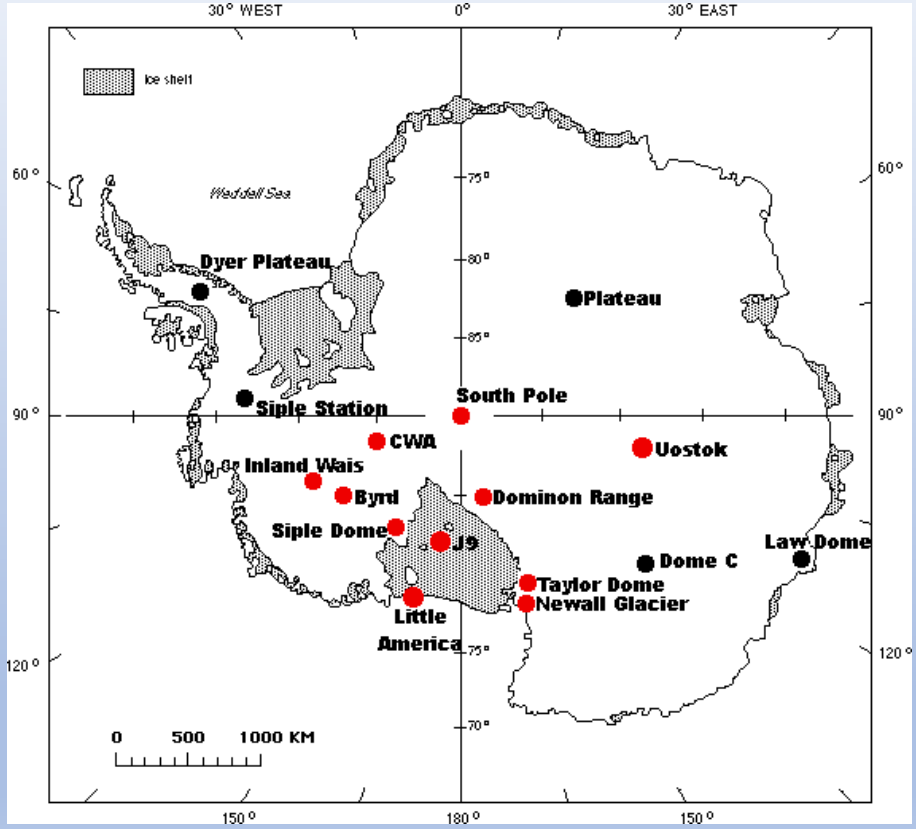
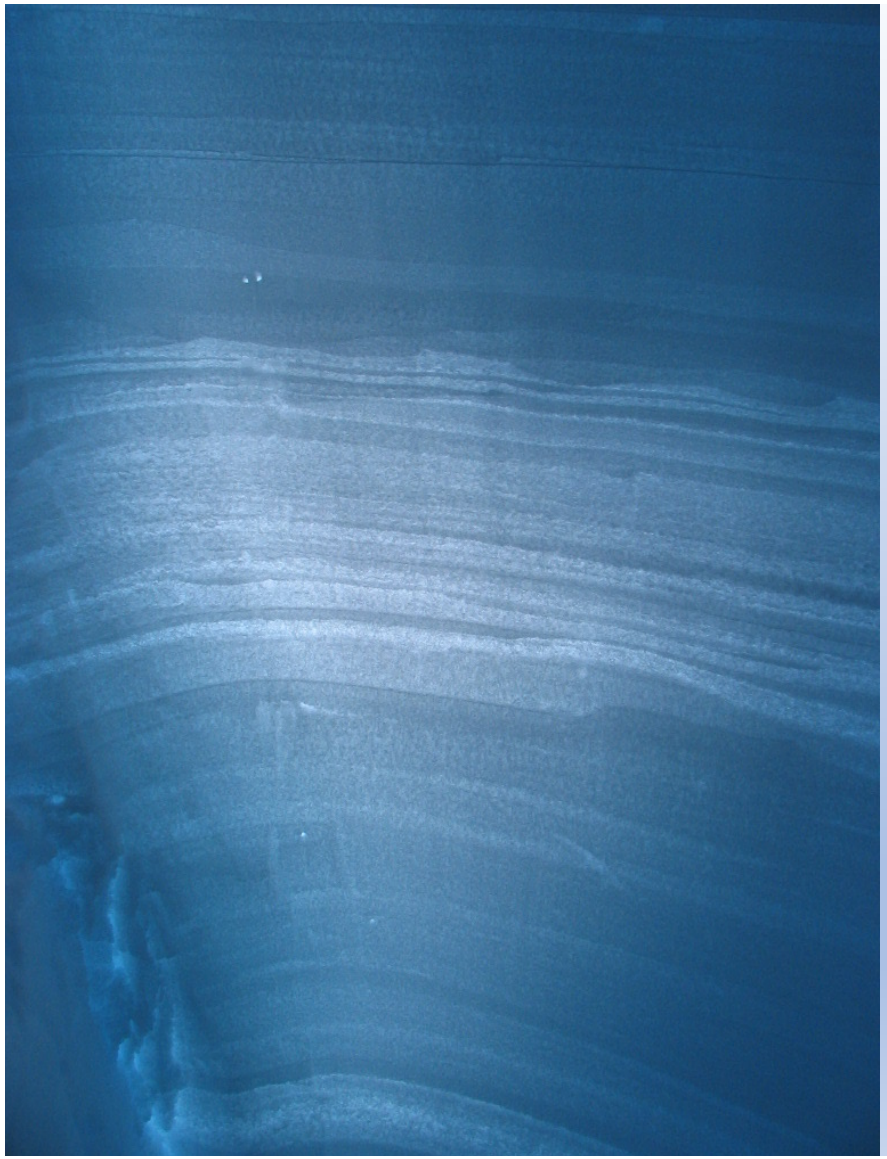
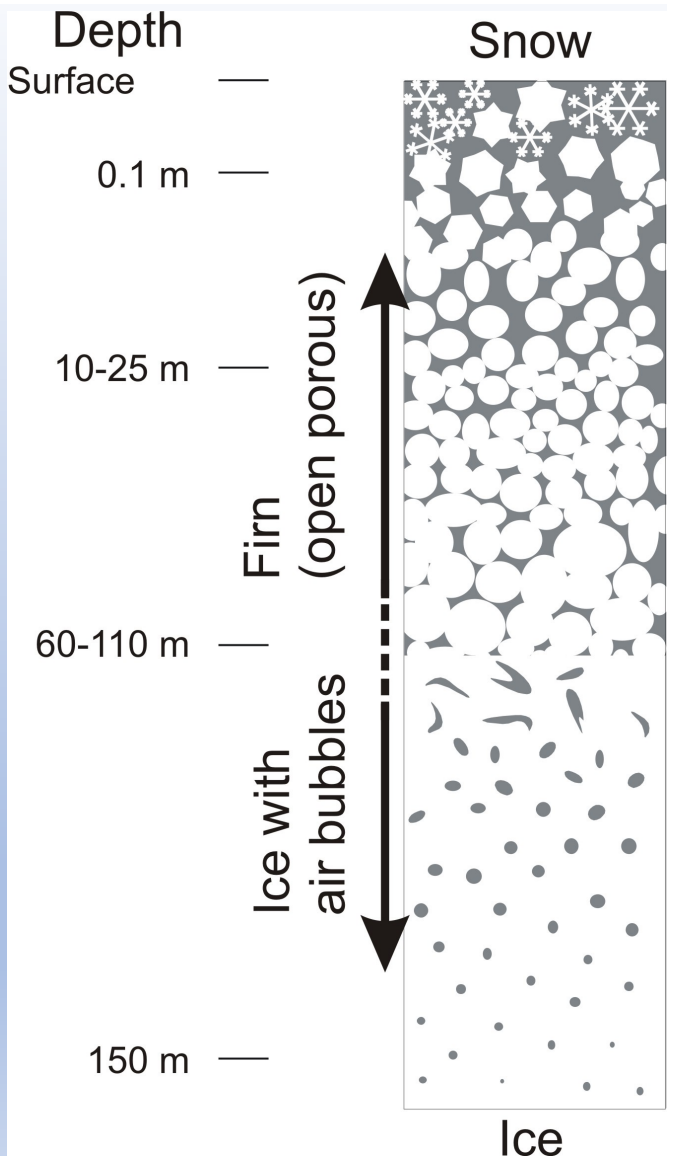


Image: National Ice Core Lab



Ice Core Basics

Center for Ice and Climate,
U Copenhagen



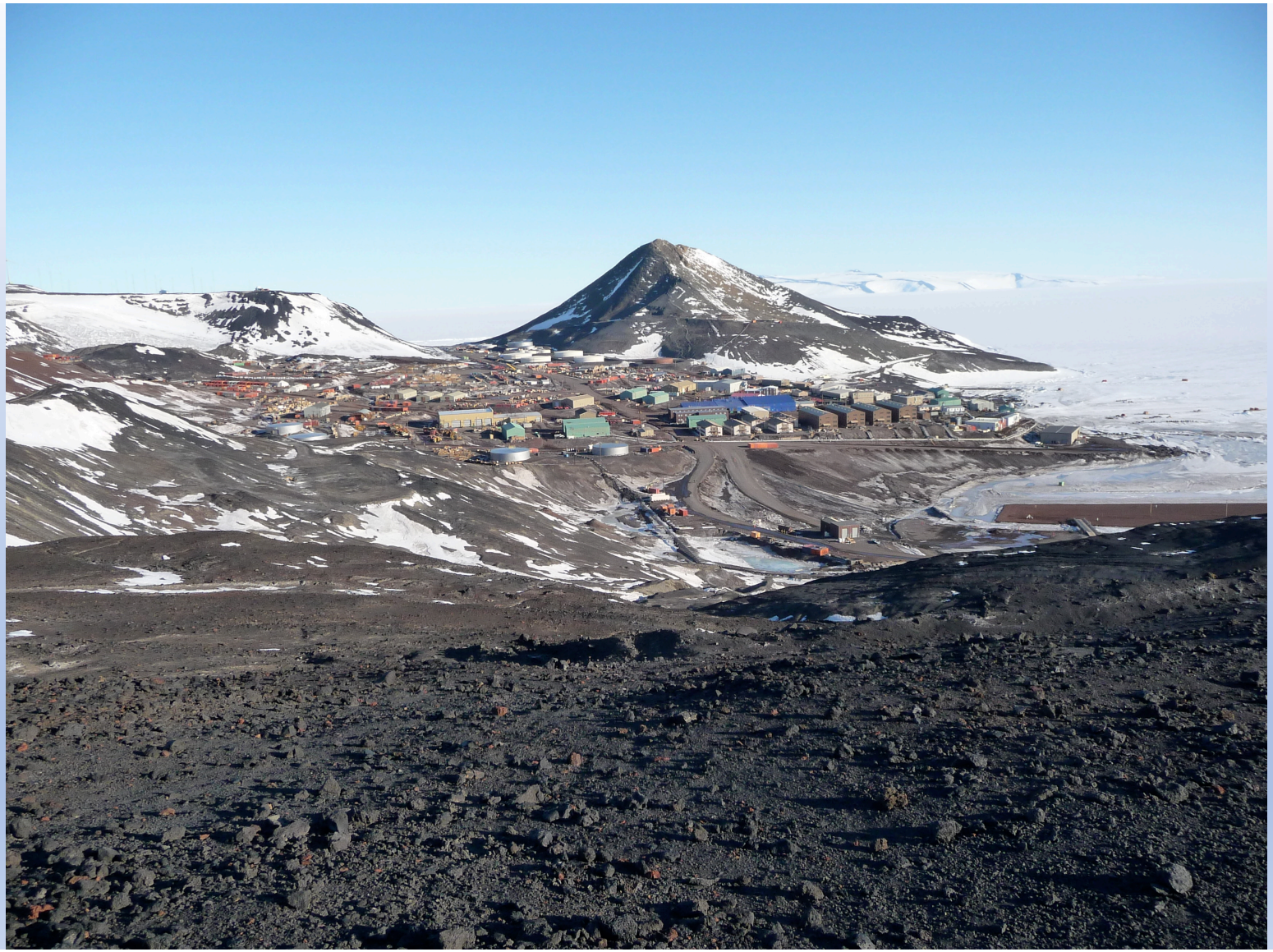
Ice Core Basics

Traditional site

Ice Margin site


DO NOT
PUNCTURE
ROLLER


U.S. AIR FORCE
8203
62ND AW
446TH AW

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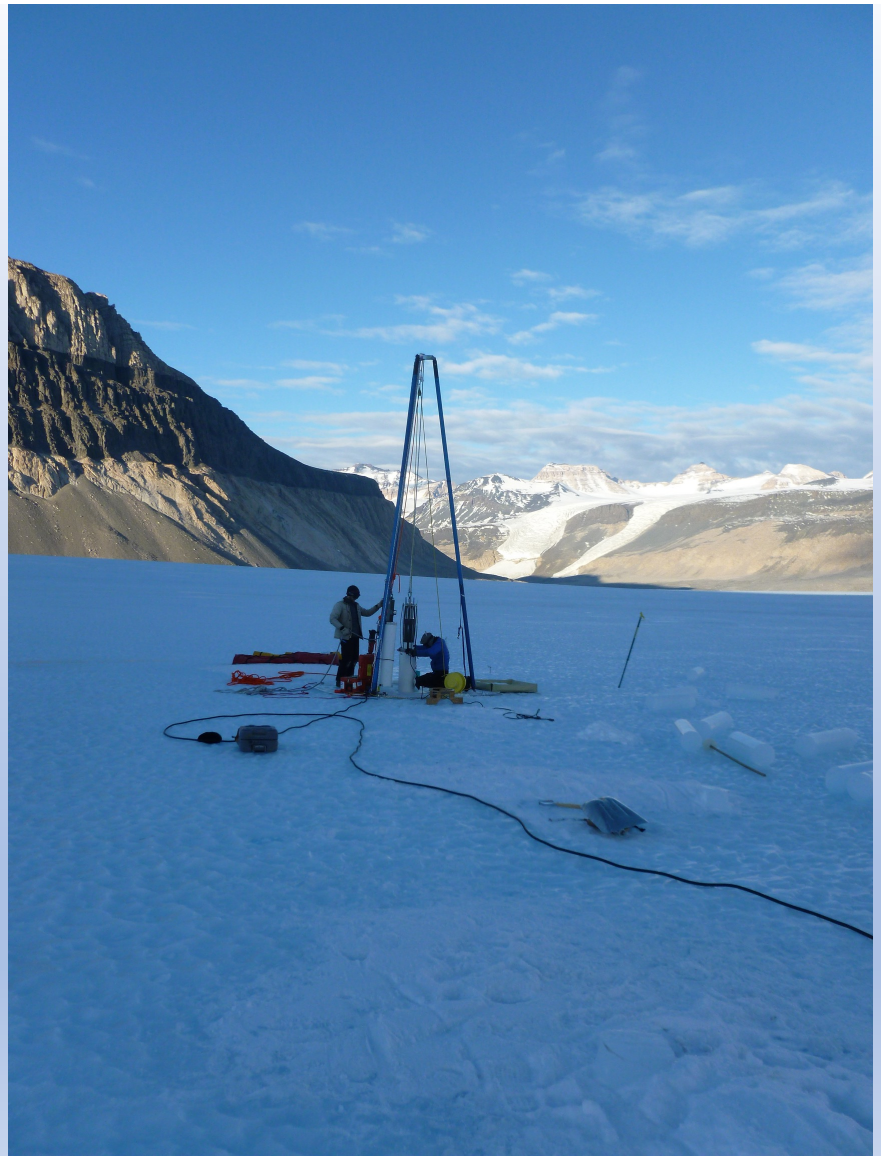
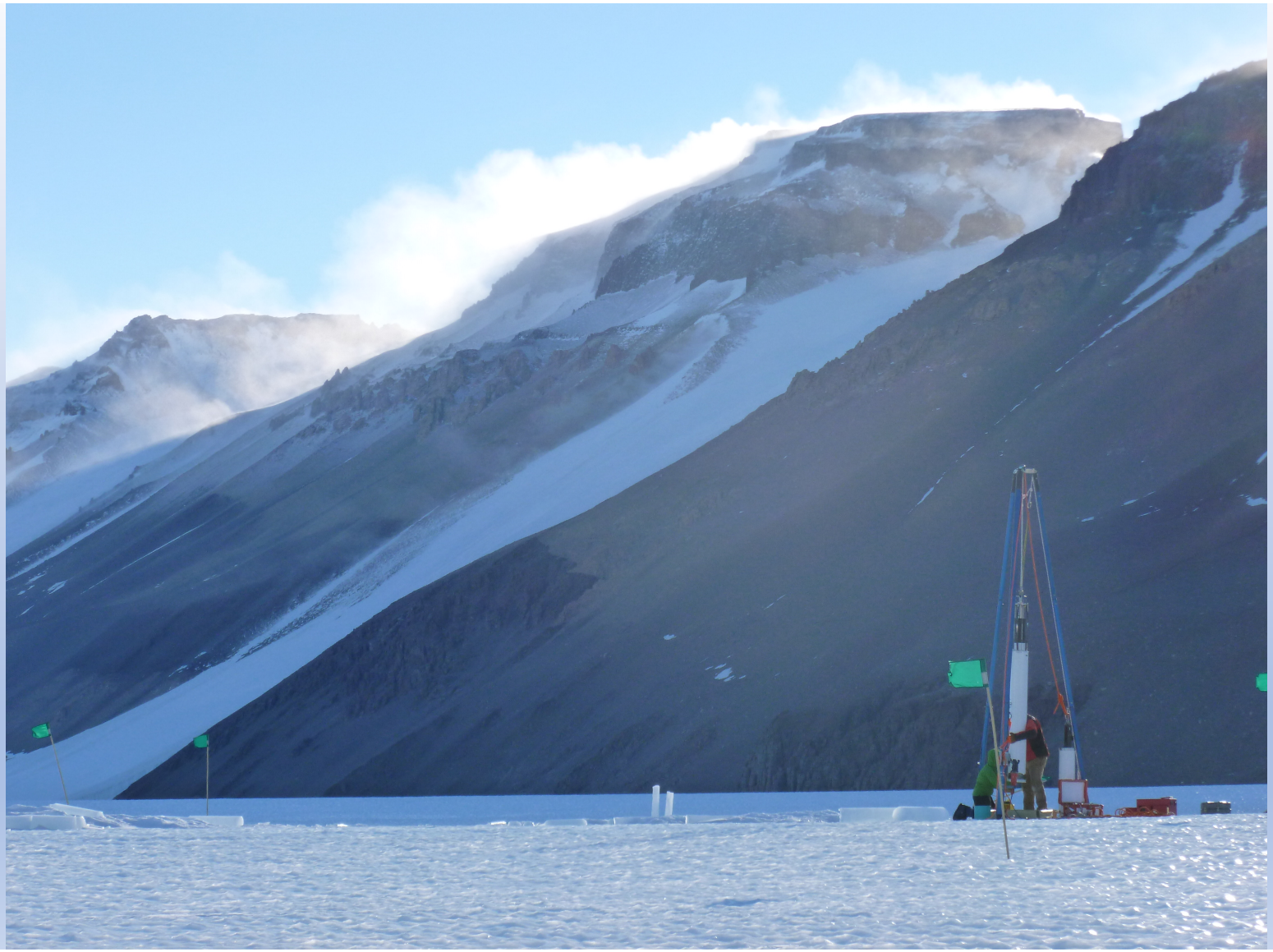
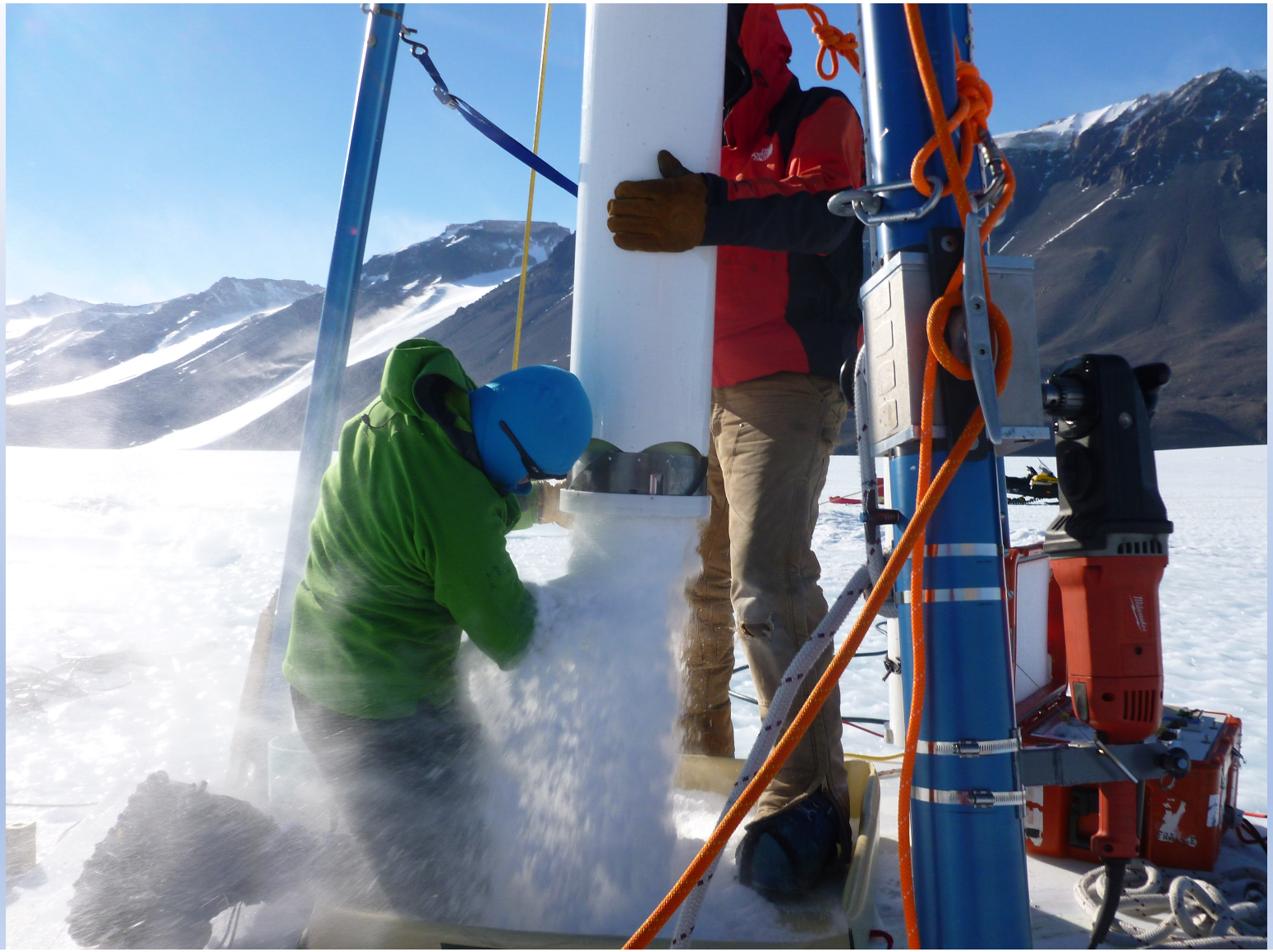
Fire
Blanket


Columbia
Six Flags
SAVE $25








WARNING
SENSITIVE
SCIENTIFIC
EQUIPMENT
DO NOT FUMIGATE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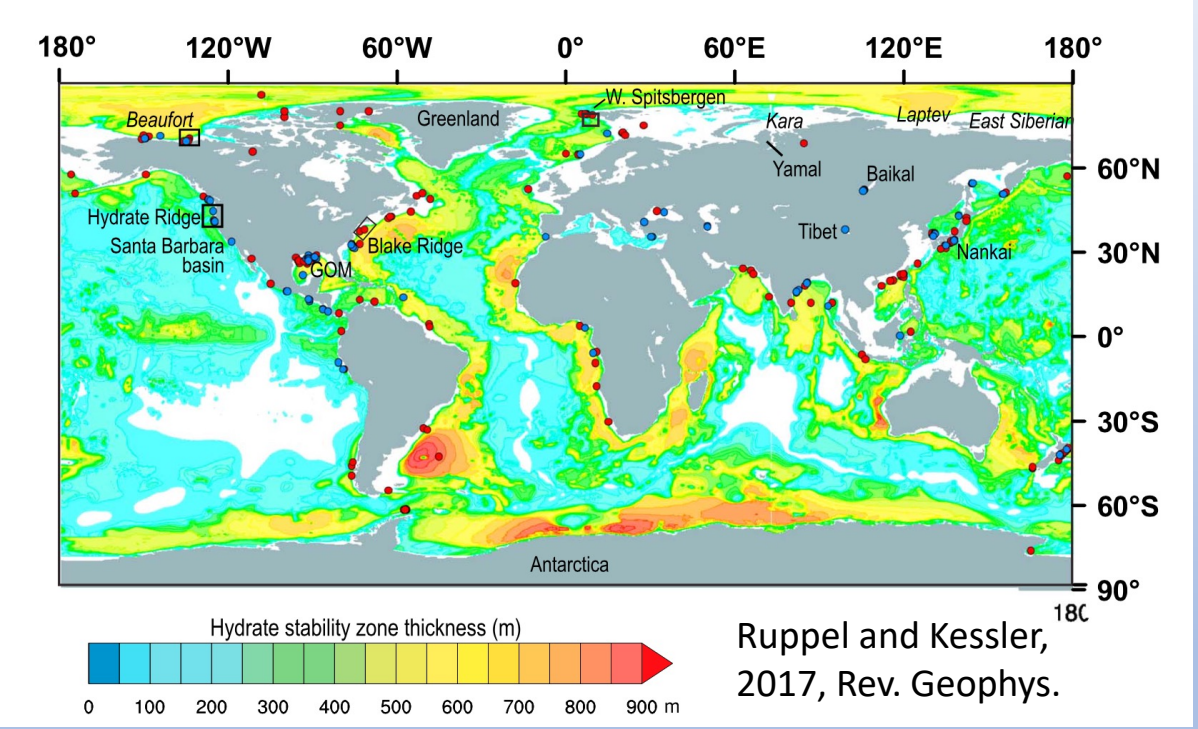
Question 1: How Concerned Should We Be About Methane – Climate Feedbacks from Old Carbon Reservoirs?

Methane - Climate Feedbacks: Marine Methane Hydrates



Ruppel and Kessler, 2017, Rev. Geophys.

NETL, Department of Energy

- Approx. 1800 Gigatons of carbon as methane (compare to 4 Gigatons in atmosphere)
- Destabilizes and releases methane gas in response to warming

Methane - Climate Feedbacks: Permafrost

- Approx. 1500 Gigatons of organic carbon in permafrost
- Becomes bioavailable when permafrost thaws
- Methane can be produced and released

Studying the Past to Learn About the Future

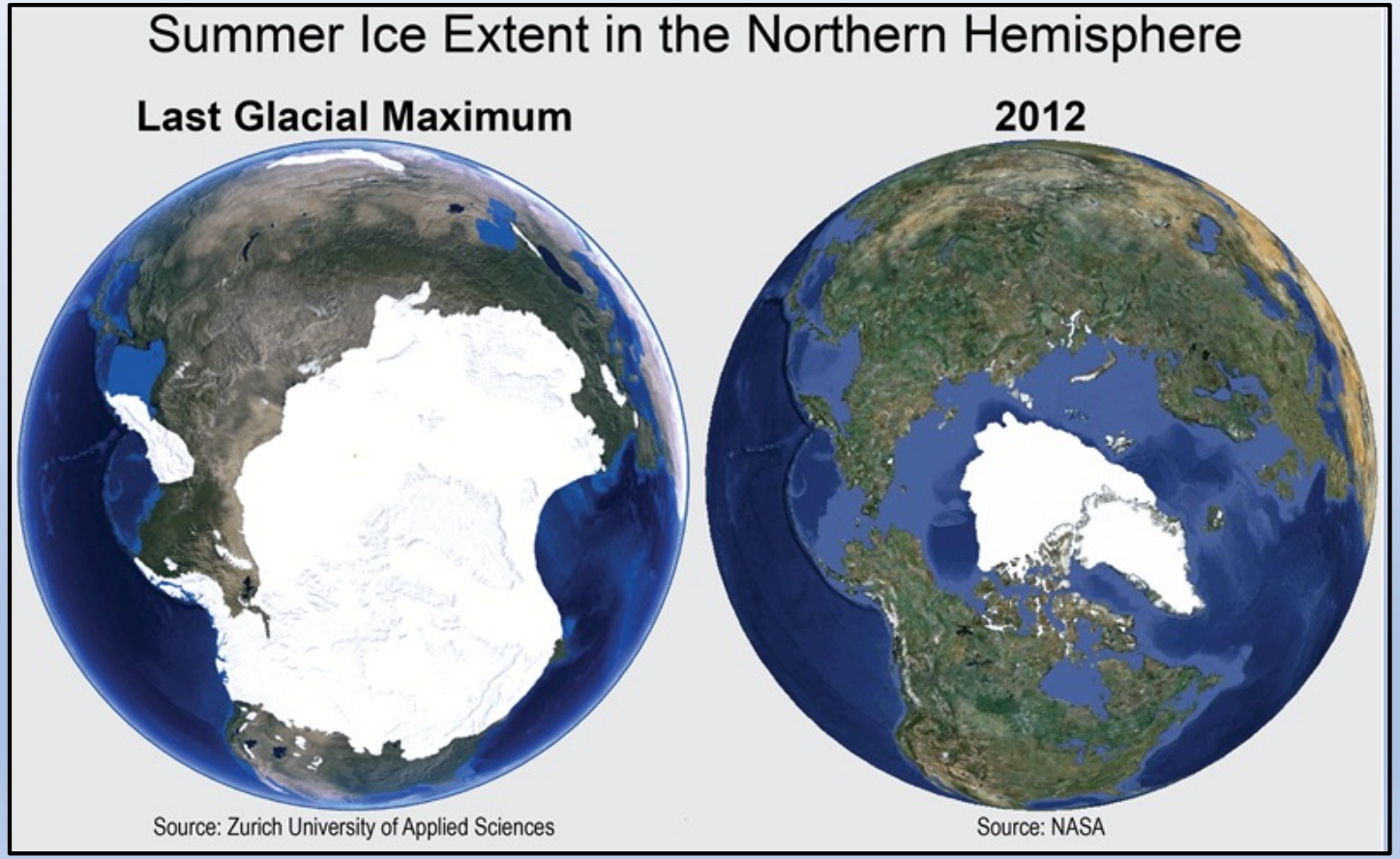
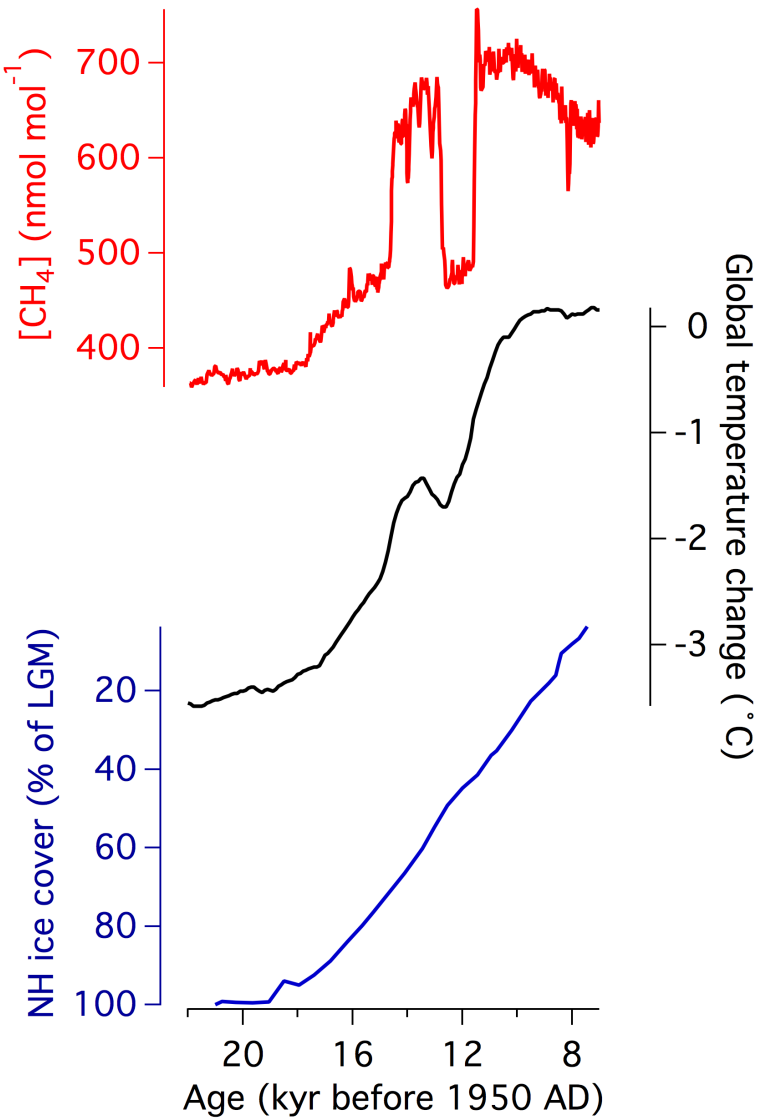


Figure from Georgia State University, Department of Geosciences



The Last Deglaciation as a Partial Analogue to Current Global Warming

- Magnitude of global warming was similar to what is predicted for the future under a mid-range emissions scenario
- Large methane increase (factor of 2)
- Periods of rapid methane increase at times of very rapid regional warming in North Atlantic / Greenland
- Which of the natural methane sources were responsible? Did old carbon reservoir feedbacks play a role?

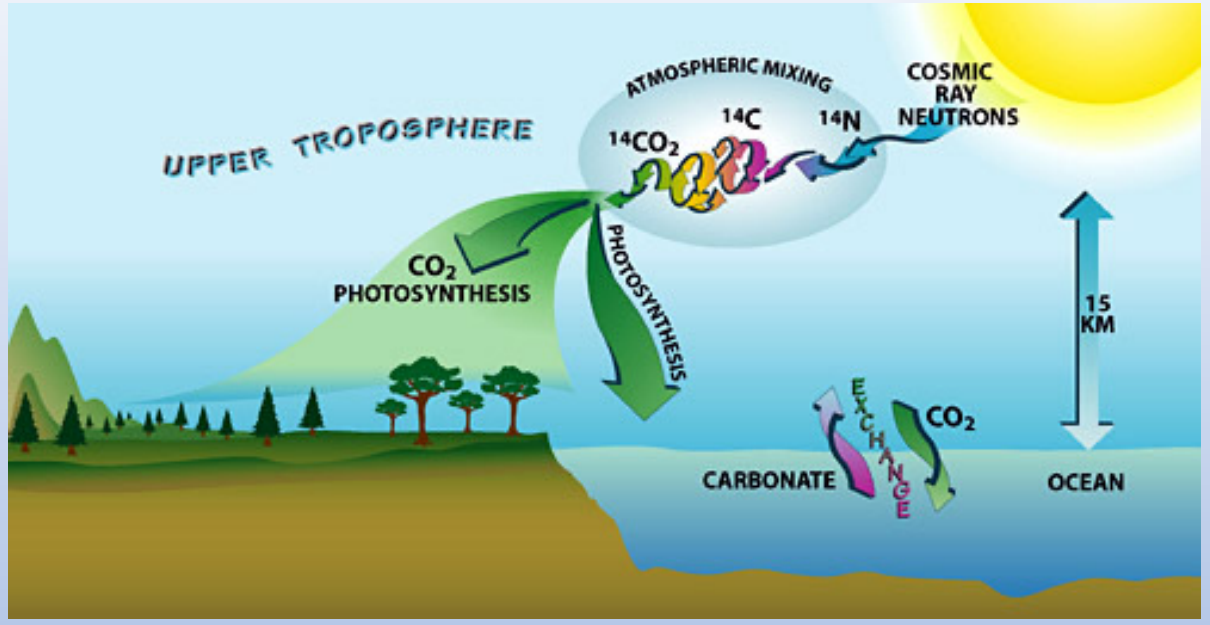


Image: Jane Doucette, Woods Hole Oceanographic Institution

$$\Delta = \left[\frac{A_{SN} e^{\lambda(1950-y)}}{A_{ON}} - 1 \right] \times 1000$$

^{14}C Basics

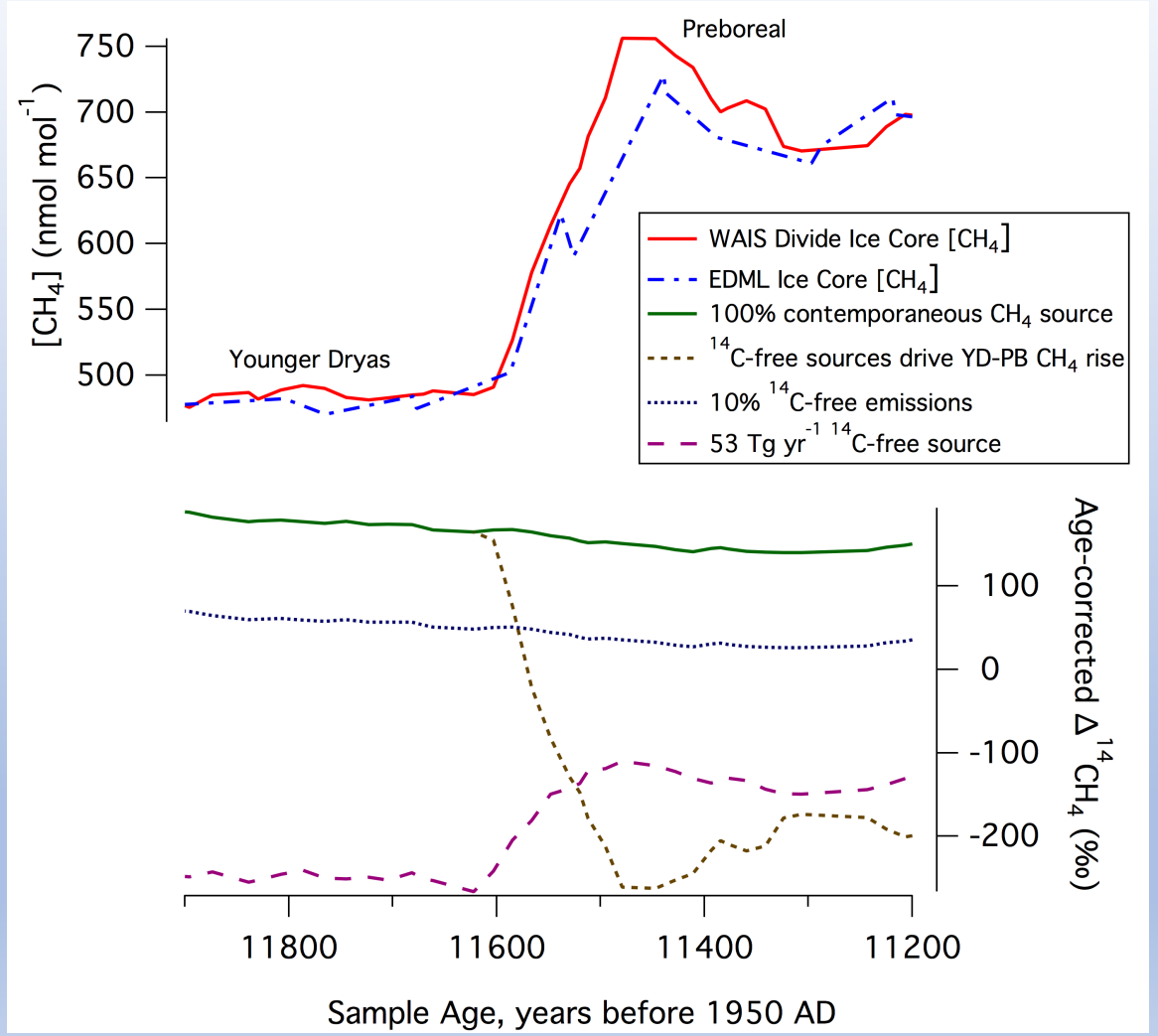
Natural source in atmosphere: cosmic rays

$^{14}C \rightarrow {}^{14}CO \rightarrow {}^{14}CO_2 \rightarrow$ Biosphere $\rightarrow {}^{14}CH_4$, other organic gases

^{14}C half-life: 5730 years

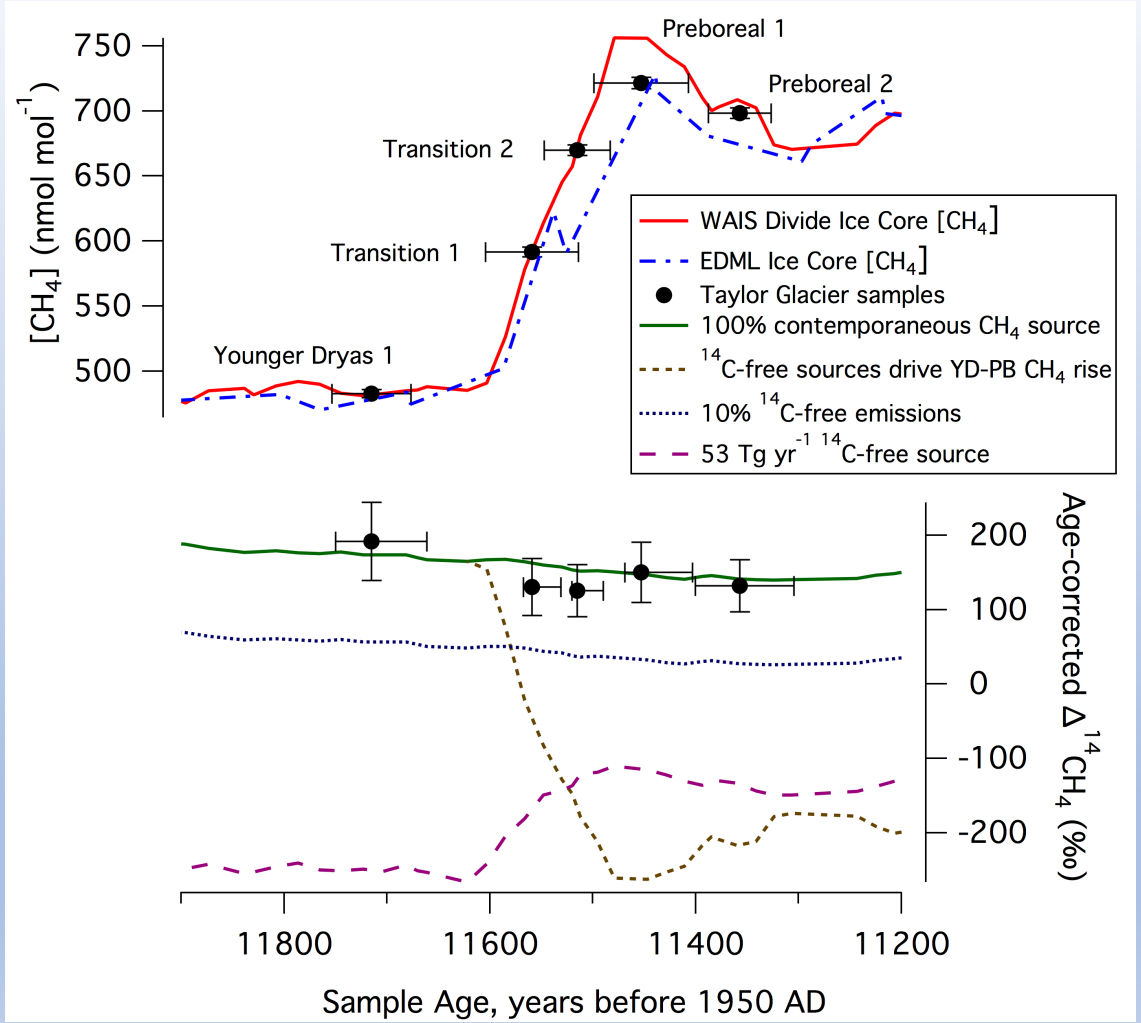
Anthropogenic sources:

- Nuclear weapons testing ($^{14}CO_2$)
- Nuclear energy ($^{14}CH_4$)



^{14}C as a Tracer

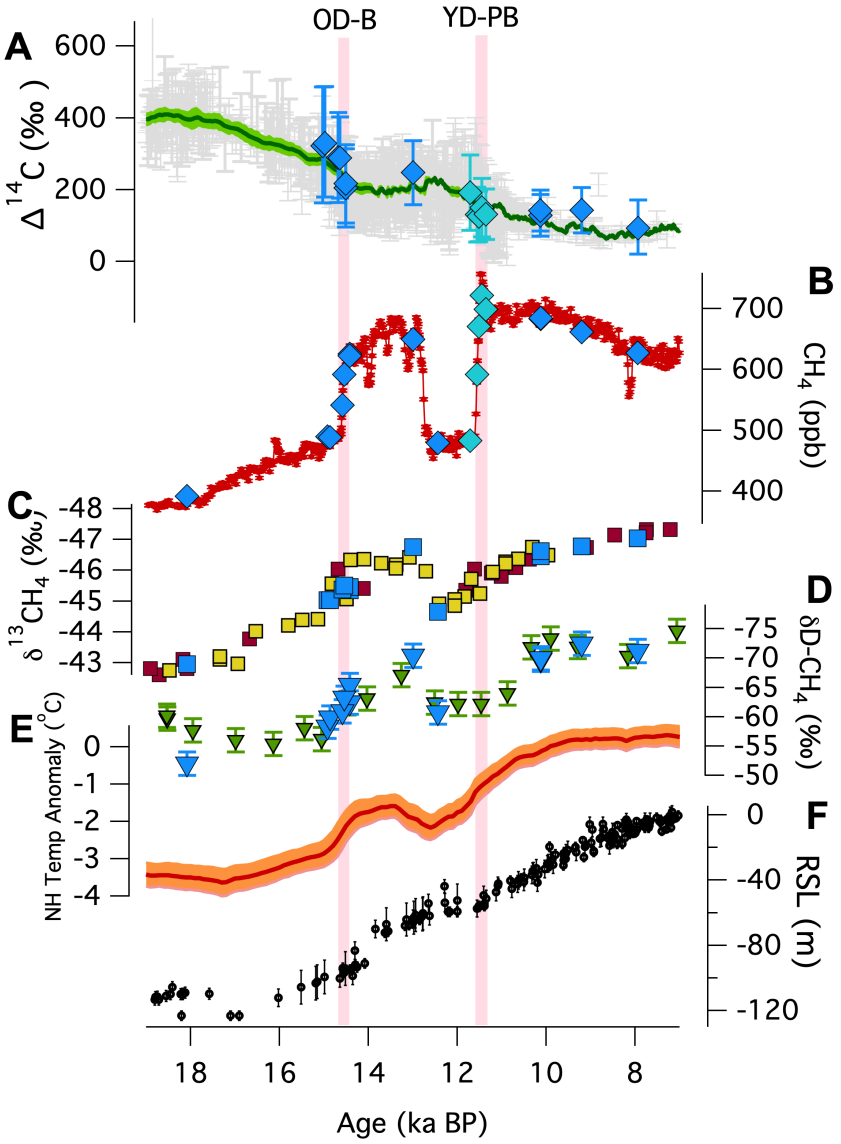
- CH_4 emissions from wetlands, animals, wildfires: $^{14}CH_4$ follows $^{14}CO_2$ ("contemporaneous")
- CH_4 emissions from methane hydrates, natural geologic seeps: no ^{14}C
- CH_4 emissions from permafrost: intermediate ^{14}C, depends on relative age of thawing C



First Study: the Younger Dryas – Preboreal Transition

- All $\Delta^{14}CH_4$ values agree with the atmospheric $^{14}CO_2$ history within 1σ
- Contemporaneous biogenic sources (mainly wetlands) were driving the atmospheric CH_4 budget

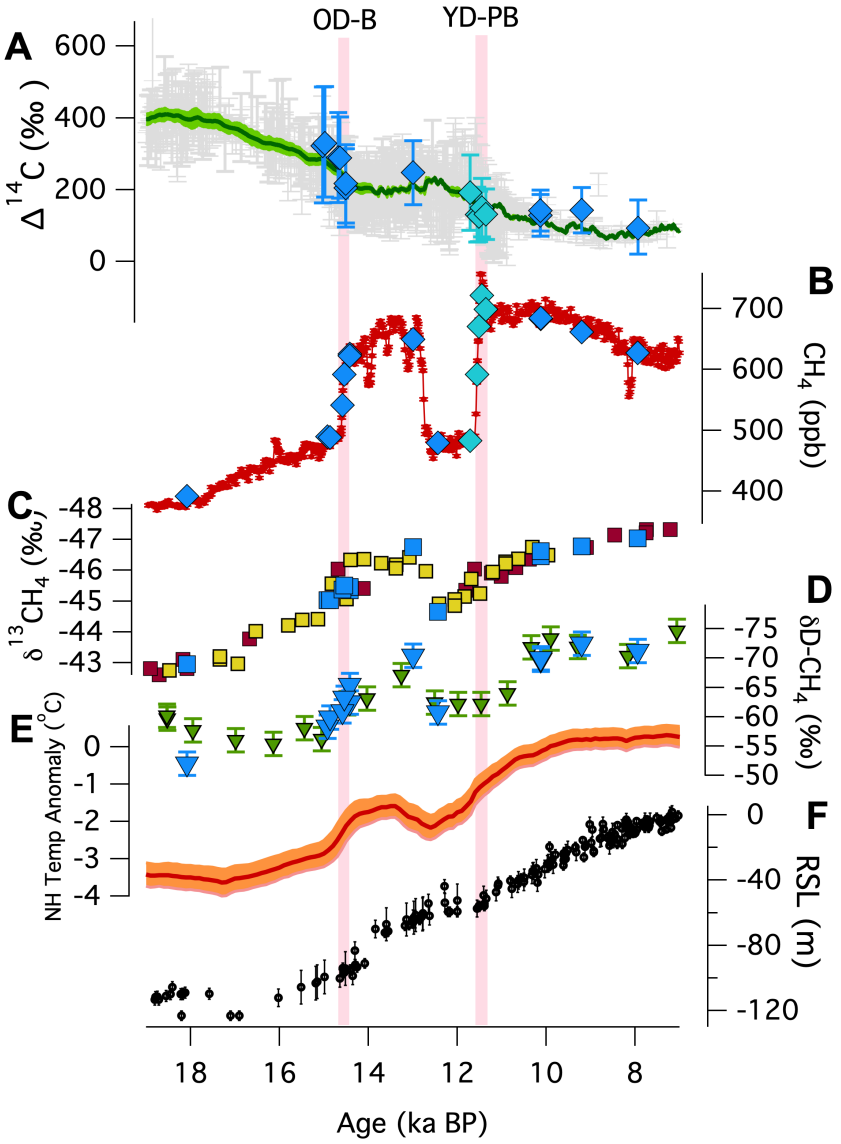
Petrenko et al., 2017, *Nature*



Newer $^{14}CH_4$ Results from Last Deglaciation and Early Holocene

- $^{14}CH_4$ again follows ^{14}C of atmospheric CO_2 within uncertainties
- Almost all methane emissions were contemporaneous biogenic

Dyonisius et al., 2020, Science



Observations and Conclusions

- No large increase in ^{14}C-free CH_4 emissions at abrupt warming / CH_4 rise events
  - No evidence for hydrate CH_4 bursts
  - Strong support for wetland hypothesis
- No evidence for delayed CH_4 release from hydrates
  - Ice retreat
  - Early Holocene warmth

Dyonisius et al., 2020, Science

Summary: What Does This Mean In Terms Of Old Carbon Reservoir Methane – Climate Feedbacks?

- Neither the gradual global warming of the last deglaciation nor the abrupt regional warming events were able to trigger large methane releases from hydrates and permafrost

- Makes such releases seem less likely for current and future warming
  - We should be more concerned about our own methane emissions

- The ^{14}C results are consistent with the hypothesis that natural wetland methane emissions would increase as the world warms

Question 2: How Much Fossil Methane Are We Emitting?

Natural:

natural geologic

≈50 Tg CH_4 / year estimated by bottom-up methods (large uncertainty)

Anthropogenic:

energy

100 – 150 Tg CH_4 / year estimated

1 Tg = 10^{12} g

- Methane isotope measurements (mainly $^{13}C/^{12}C$ and $^{14}C/^{12}C$) in atmosphere: "top-down" constraints
- ^{14}C: great tracer in principle, but with complications:
  - There are also natural fossil emissions
  - Isotopes of natural geologic and anthropogenic fossil sources look very similar
  - Nuclear power plants emit $^{14}CH_4$ directly

Images: Wikipedia

Much Simpler for the Pre-Industrial Period (pre ≈1800 AD)

Natural:

natural geologic

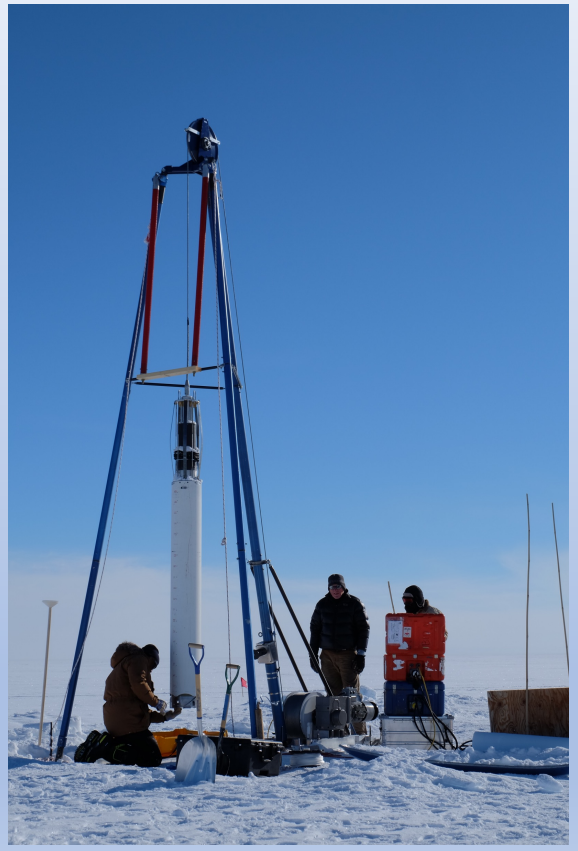
≈50 Tg CH_4 / year estimated (large uncertainty)

- ^{14}C-free methane only comes from natural geologic sources
- No ^{14}C interference from nuclear power plants
- Can quantify natural geologic emissions using ice core methane ^{14}C measurements
- Then use $^{13}C/^{12}C$ today for improved estimates of anthropogenic fossil emissions

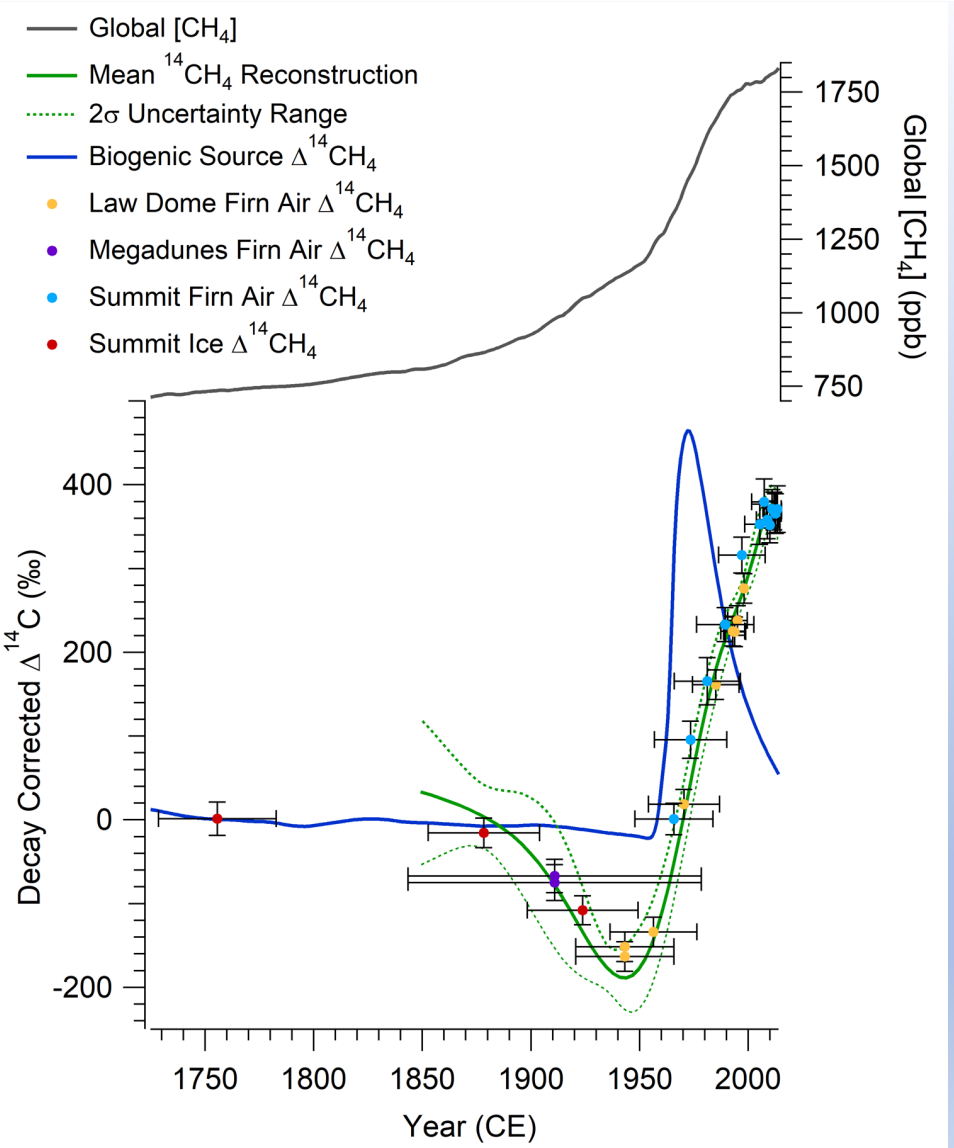
Image: Wikipedia

Obtaining a $^{14}CH_4$ record from 1750 AD - Today

Image: World Data Center for Paleoclimatology



Photos: Xavier Fain



Atmospheric $^{14}CH_4$ History, 1750 AD - Present

- $^{14}CH_4$ follows ^{14}C of CO_2 prior to ≈1880 AD (not much room for fossil CH_4)
- Drop after 1880 AD: ramp up of fossil fuel use
- Rise after 1950: interference from nuclear bomb testing and nuclear reactors

Hmiel et al., *Nature*, 2020

What Does This Mean For Anthropogenic Fossil Methane Emissions?

- Most prior estimates of natural geologic methane emissions:
  ≈40 – 60 Teragrams CH_4 $year^{-1}$, or ≈10% of today's global CH_4 budget

- Ice core $^{14}CH_4$ Preindustrial estimate:
  ≤ 6 Teragrams CH_4 $year^{-1}$ (agrees well with data from last deglaciation also)

- This means prior atmospheric isotope-based estimates of anthropogenic fossil methane emissions (≈100 – 150 Teragrams CH_4 $year^{-1}$) were too low and must be increased **by 25 - 40%** (new estimate based on $^{13}C/^{12}C$ ratio: 177 ± 37 Tg CH_4 yr^{-1})

  - We are emitting more fossil methane than we thought

  - Greater leverage for mitigating emissions of this greenhouse gas

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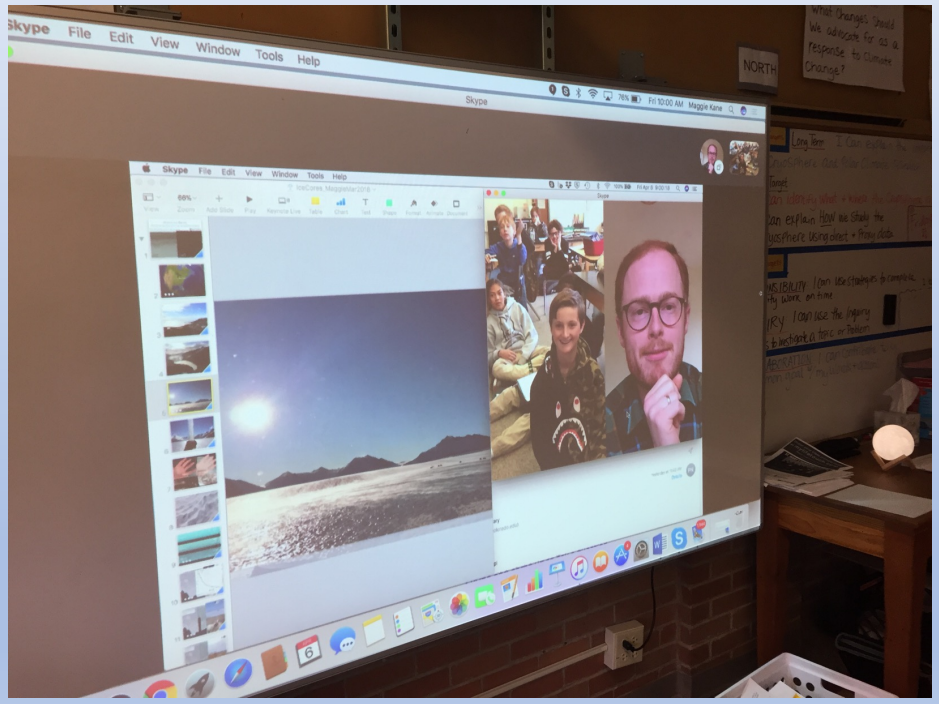
Outreach



Questions?

vasilii.petrenko@rochester.edu
http://www.sas.rochester.edu/ees/petrenko/index.html