

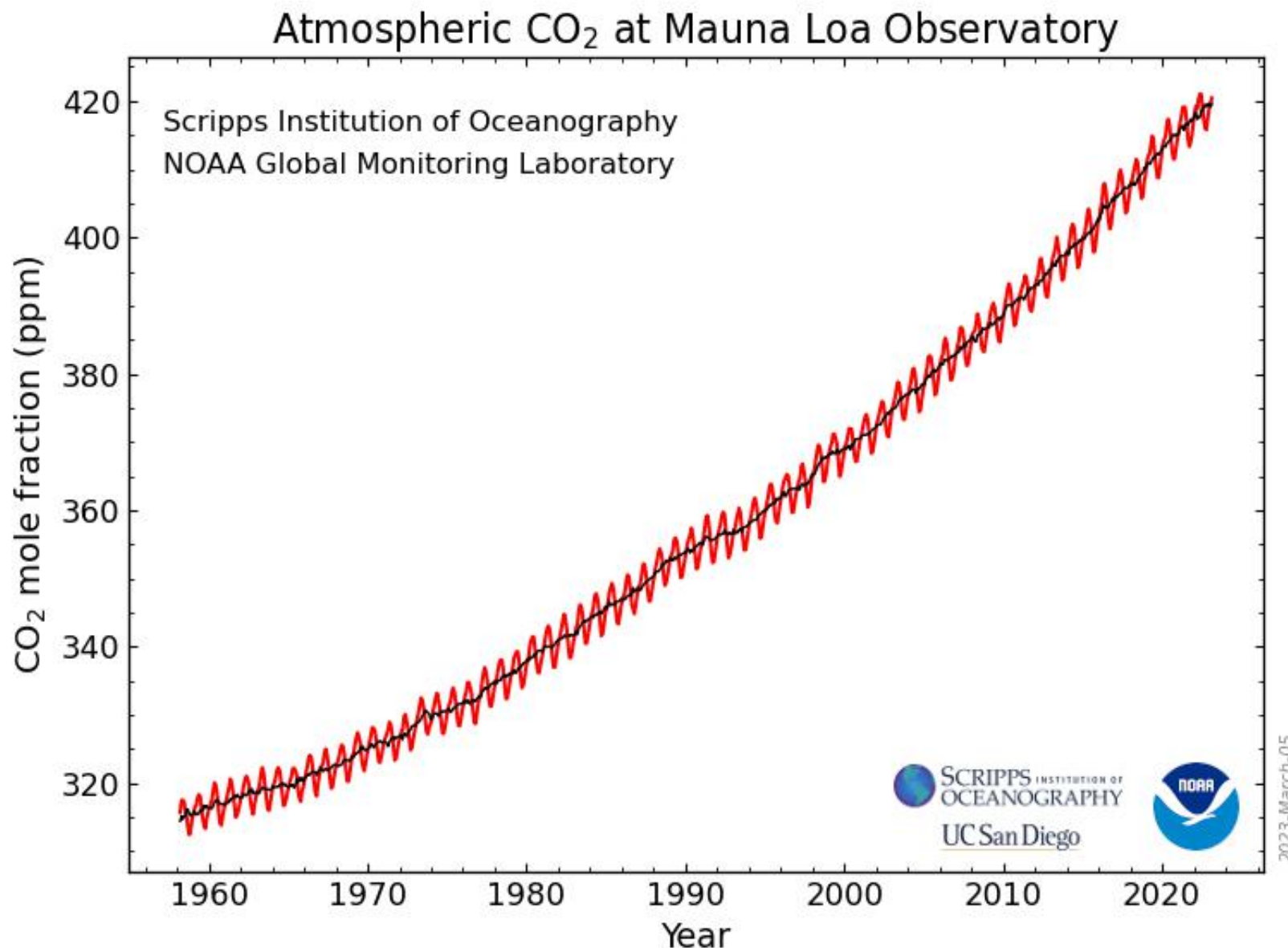


Edinburgh: 1770 CO₂ discovery

Managing carbon and climate for engineered climate repair

Professor Stuart Haszeldine
GeoSciences, University of Edinburgh

CO₂ – continual increase



Keeling curve – direct air measurement since 1956 on Hawaii

World's longest purposeful measure of CO₂ in well-mixed atmosphere.

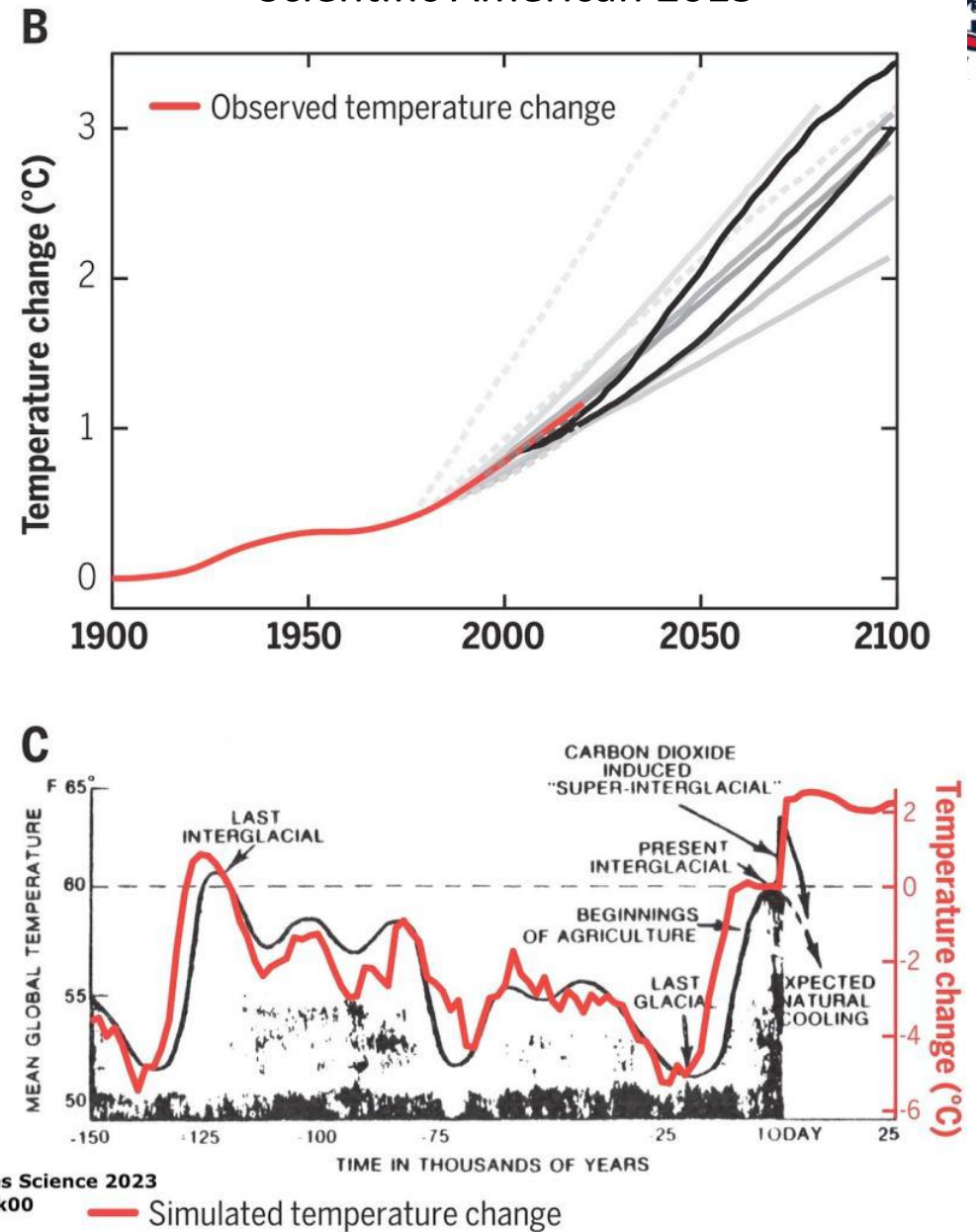
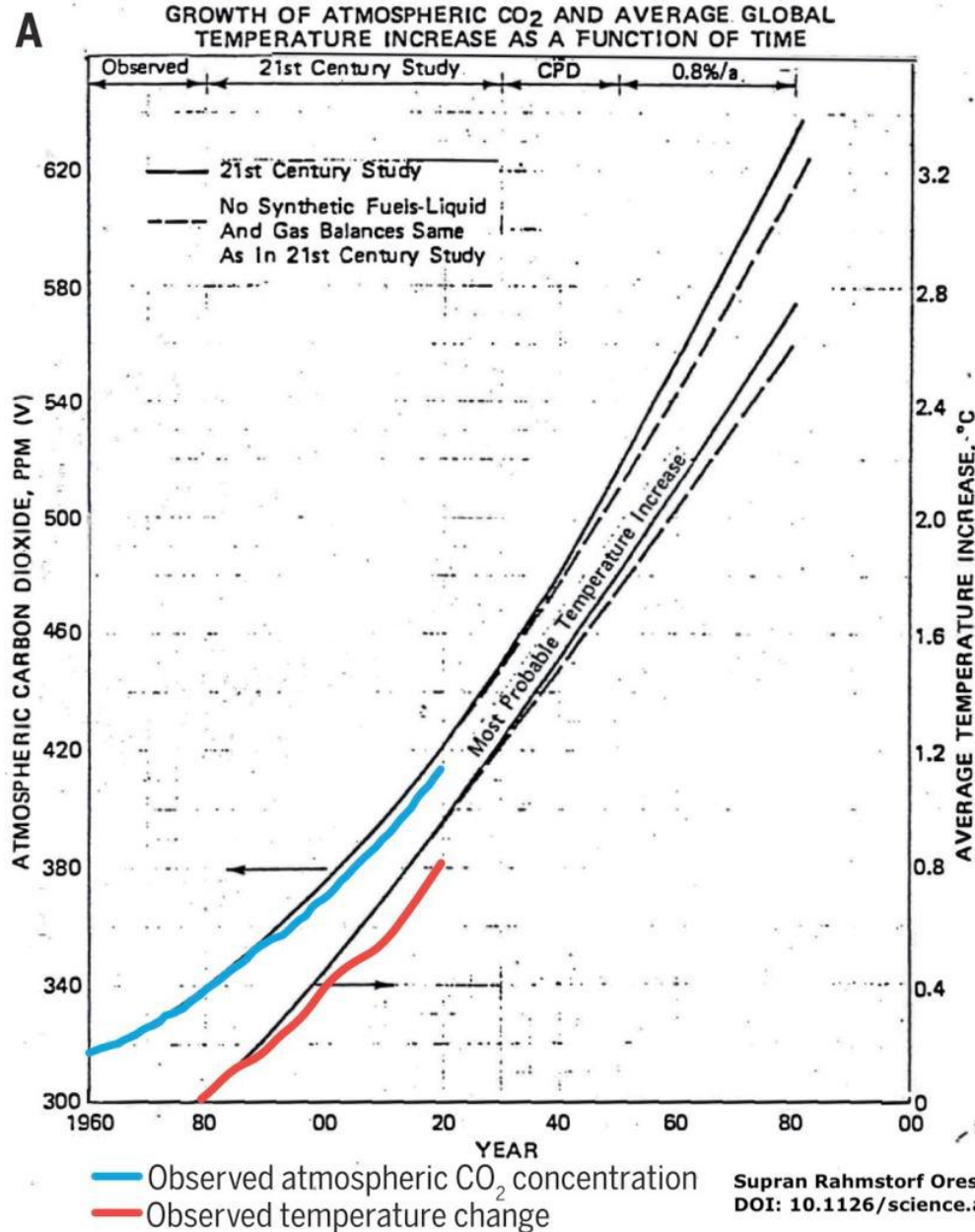
Distant from industrial sites

CO₂ release 20x faster than Paleocene-Eocene

And 50x faster than 2023 volcanoes

Exxon knew

Inside Climate News 2014
Scientific American 2015



Hansen 1988 evidence USA Congress



Freedom to comment
Personal commitment



And at pipeline protests
Arrested (multiple times)

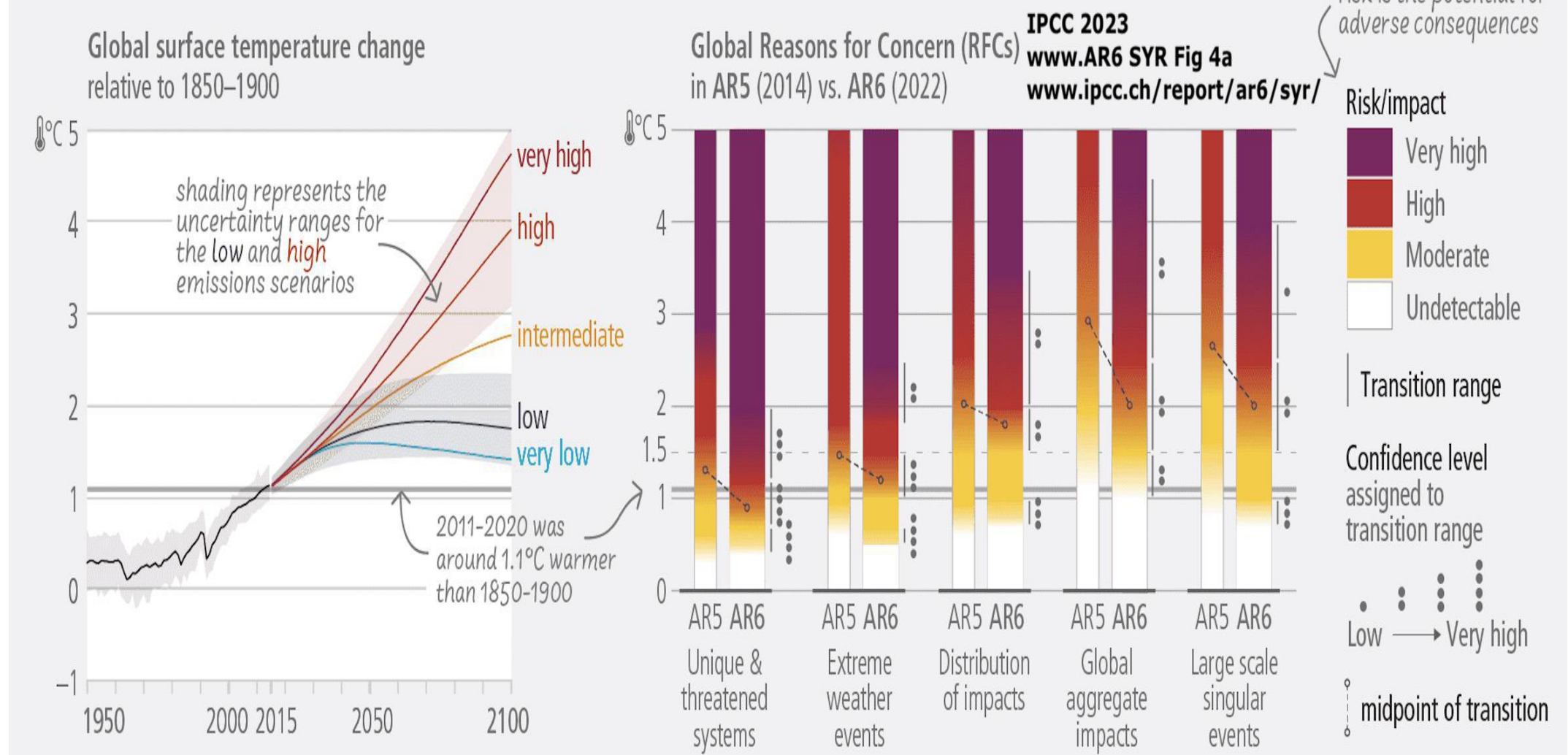
IPCC

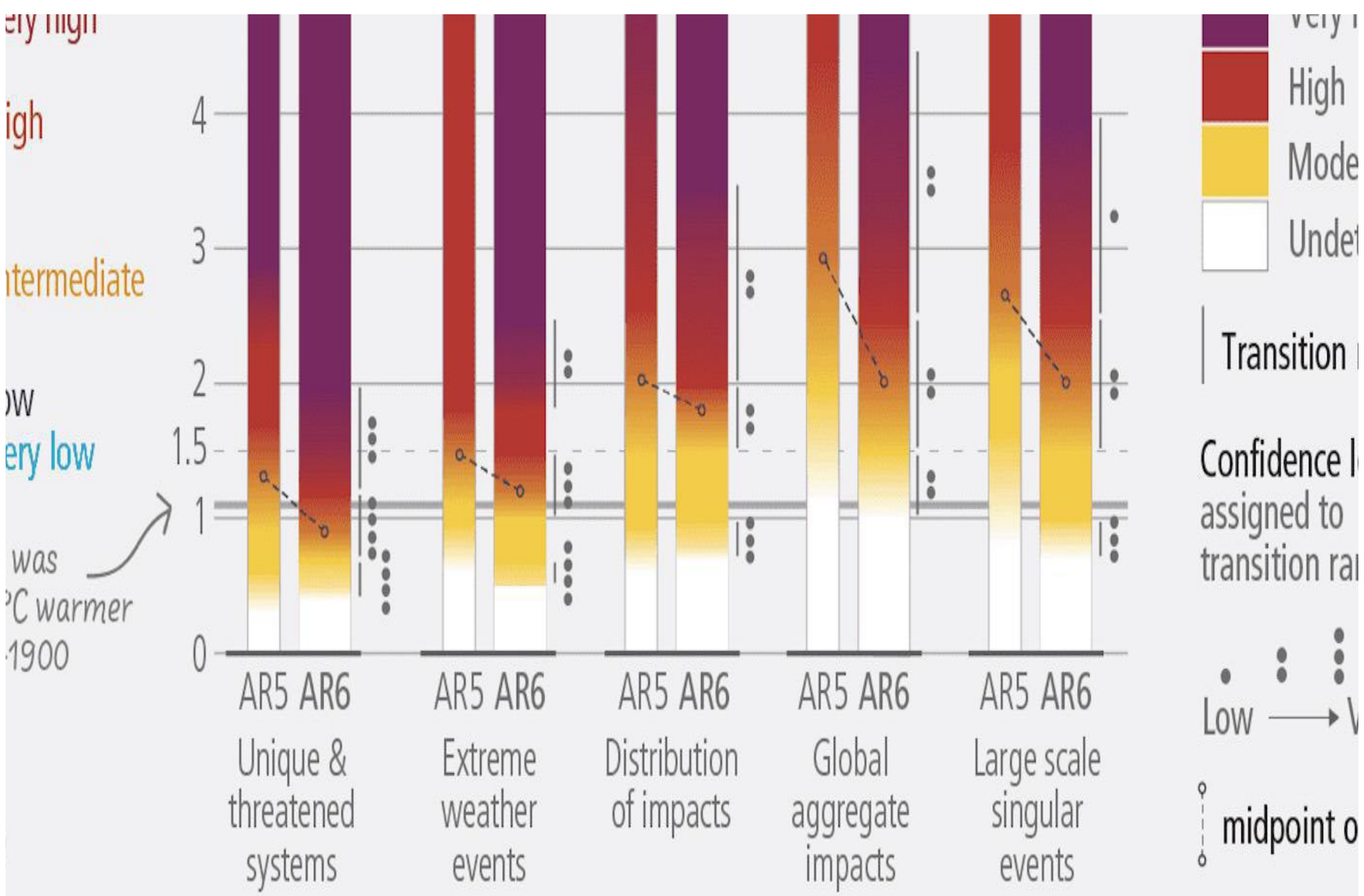


IPCC More risk at less heating comparing AR5 (2014) and AR6 (2023)

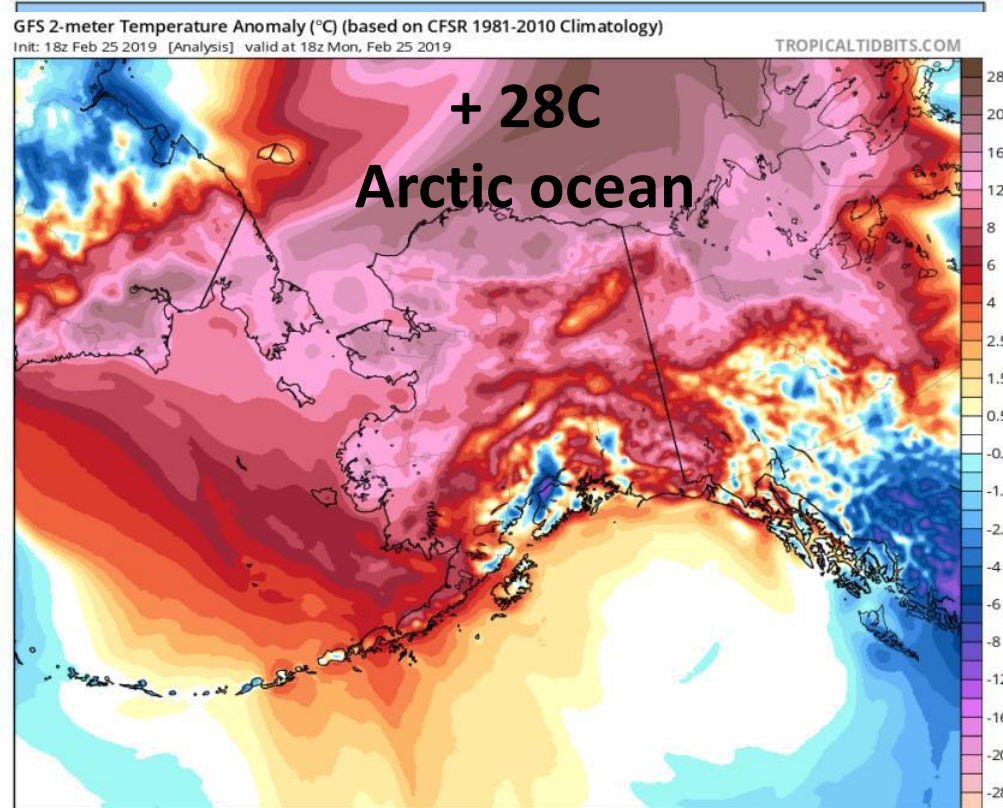


a) High risks are now assessed to occur at lower global warming levels



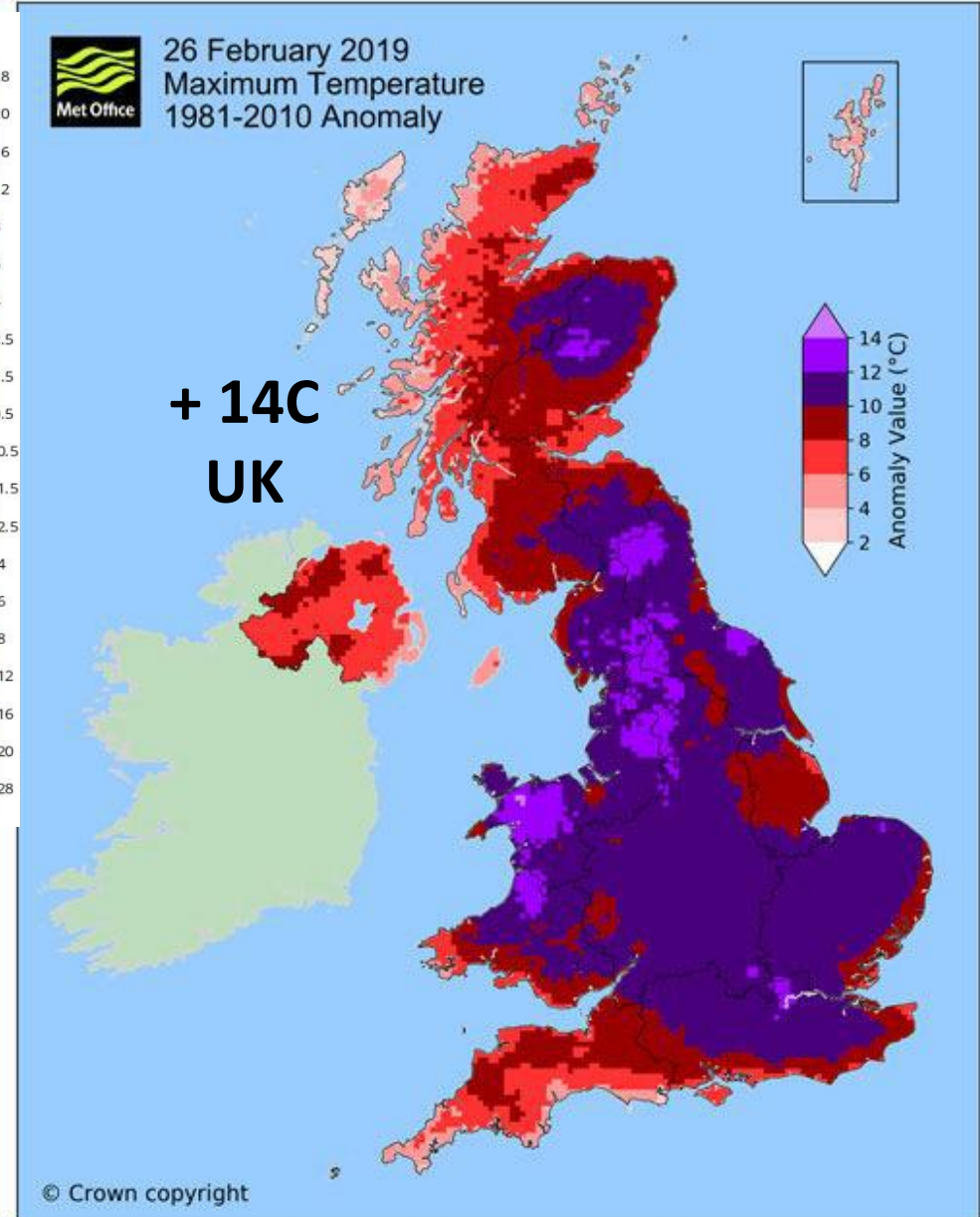


Warming effects well established: 25 Feb 2019



Faster heating in temperate north and south → unprecedented warming

IPCC reports on AVERAGE global temperatures. Not MAXIMUM local





Feedbacks and tipping points

Tipping points

a small amount of extra global warming
Can trigger a qualitative change in part of
the climate system. That becomes abrupt
and/or irreversible beyond the tipping point.

Policy-relevant tipping elements have been
identified in three types of climate sub-
system:

the cryosphere,

circulation of the atmosphere/ocean,

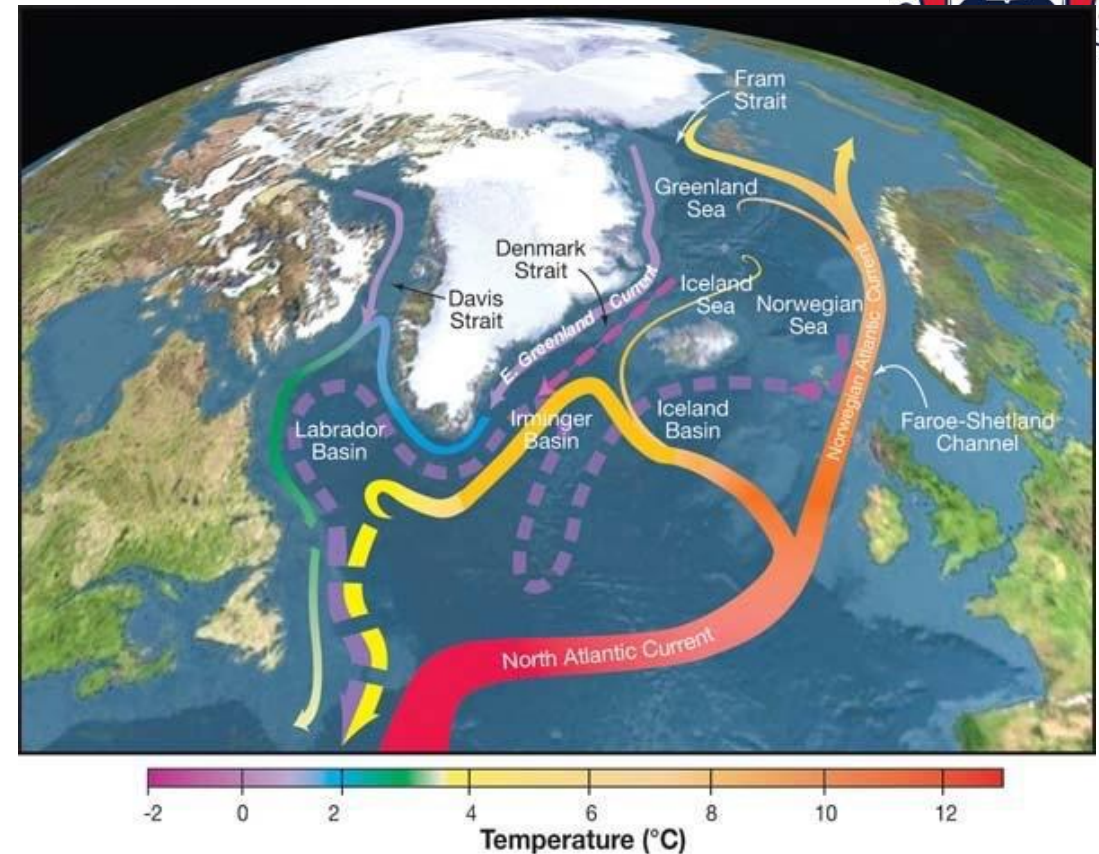
and the biosphere

West Antarctic ice sheet may already be
experiencing the onset of an irreversible ice
sheet instability (IPCC, [2019](#)). Accelerating
changes in the Wilkes Basin, the Greenland
ice sheet, the Amazon rainforest, the AMOC,
and coral reefs

Jenga tower
collapse

Lenton 2021 Weather

<https://doi.org/10.1002/wea.4058>



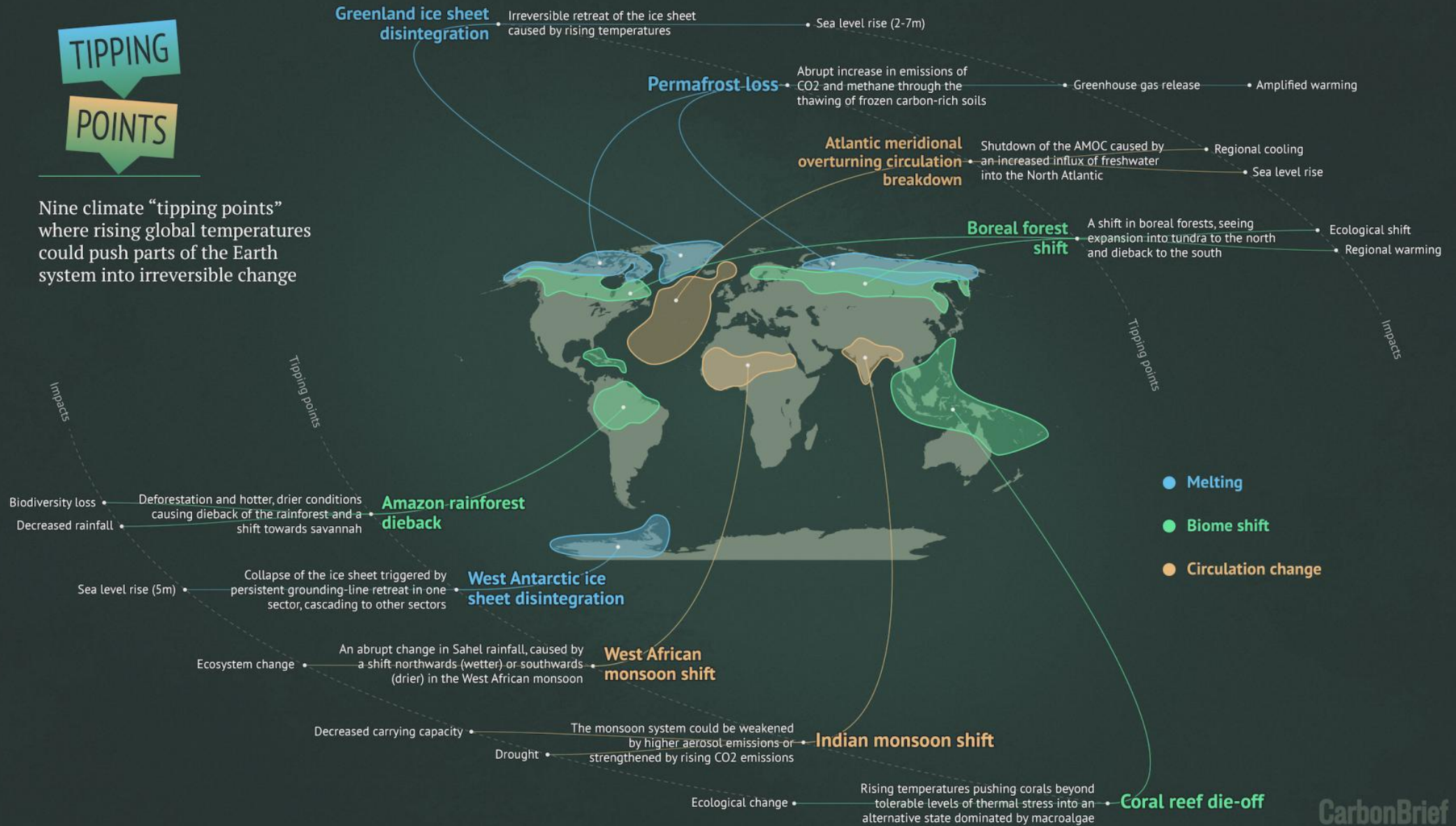
The Atlantic Meridional Overturning Circulation (AMOC) is a system of Atlantic Ocean currents that brings warm water up to Europe from the tropics and beyond. Shallow warm flow, return deep cold flow

most climate models are unrealistically insensitive to freshwater injected by melting ice and also that ice sheet models are unrealistically lethargic in the face of rapid, large climate change.

Nine tipping points

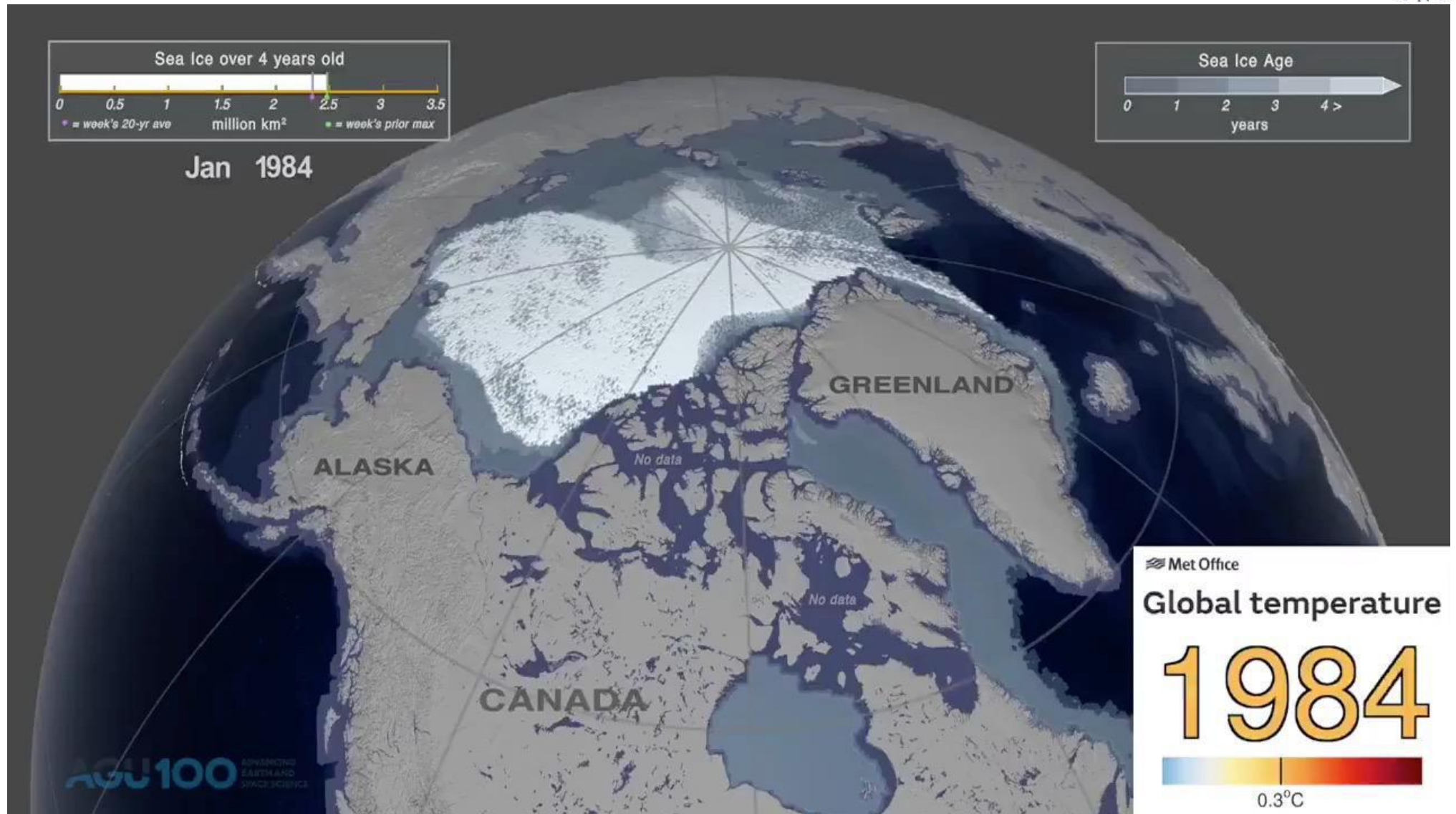
TIPPING POINTS

Nine climate “tipping points” where rising global temperatures could push parts of the Earth system into irreversible change



Force to tipping imminent

Floating ice 4yr< = blacker sea more absorption



CO₂ reduction of output or removal

Coal CCS. Boundary Dam, Sask.

Post-combustion amine
110MW, 1Mt CO₂/yr, 2nd Oct 2014

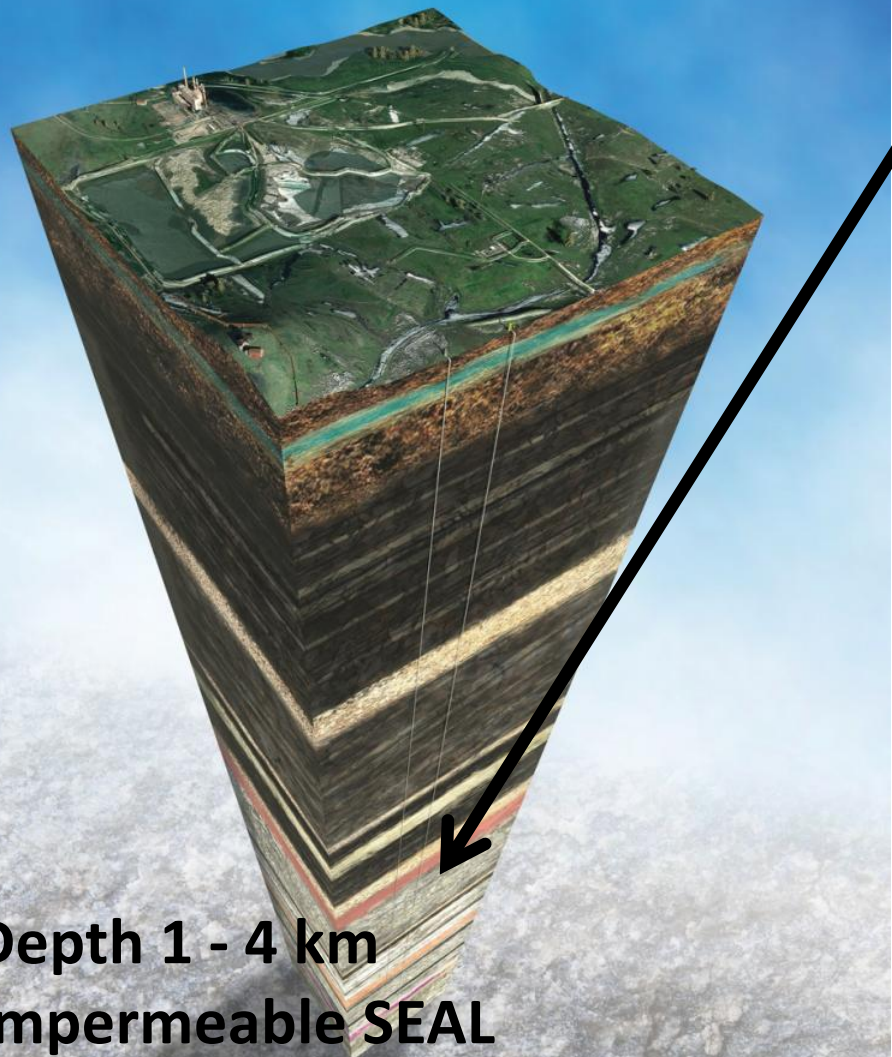
CCS projects
exist and work,
since 1972

Gas processing
ExxonMobil's Shute Creek gas
processing plant near LaBarge,
Wyoming, was ordered in 2008 by
State Government.

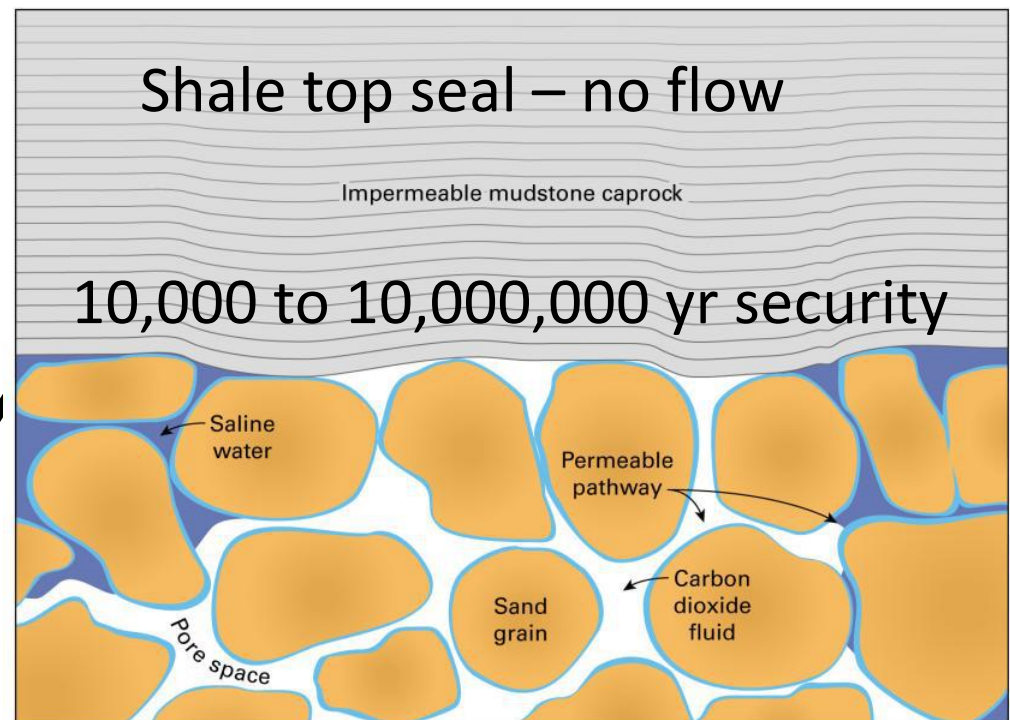
Currently capturing **around 7 million
tonnes per annum of CO₂**



CO2 storage is a long way down



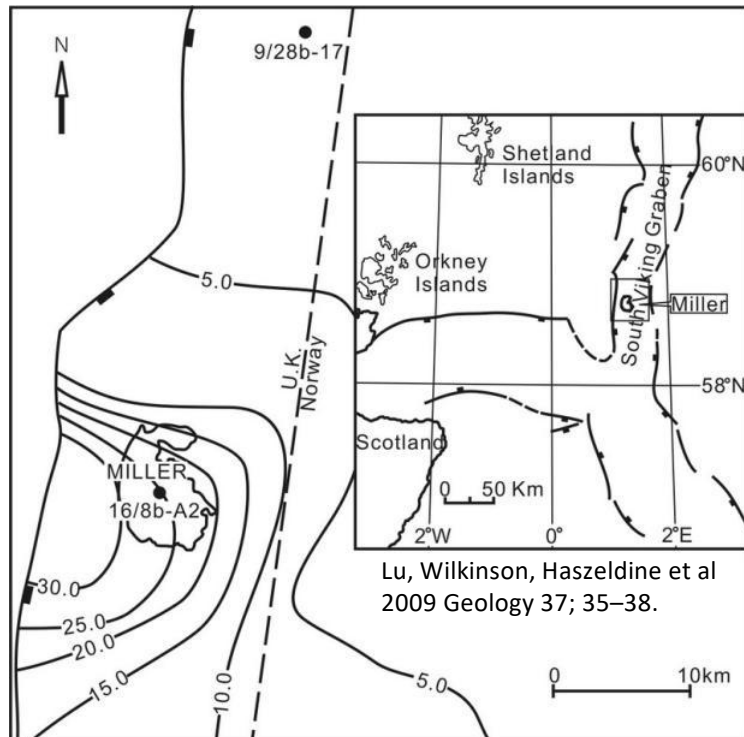
Depth 1 - 4 km
Impermeable SEAL
Overlies
Porous RESERVOIR



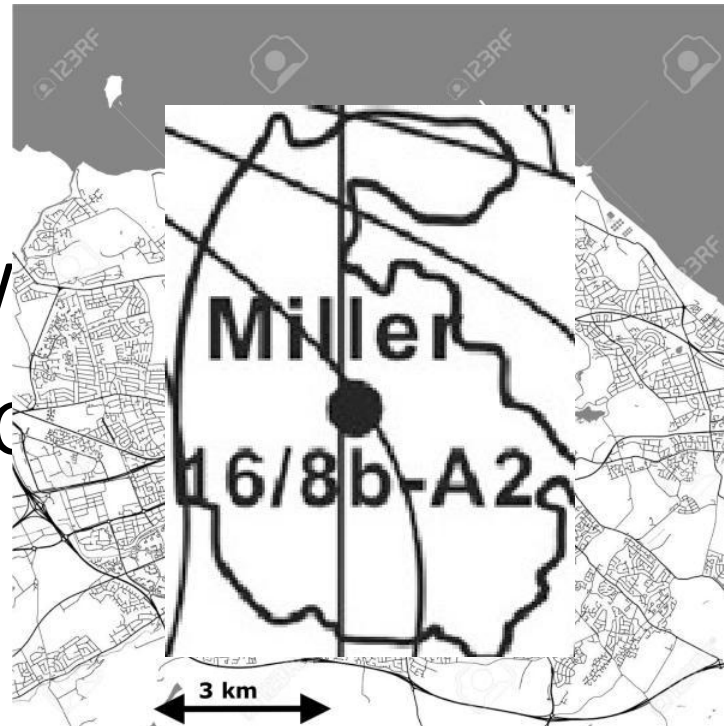
CO2 storage for UK is offshore – large size and high quality information



Miller field, North Sea
Natural CO2 content



Edinburgh city and permeability streetmap



Typical small CO2 storage site represented by Miller oilfield (BP project DF1) injecting 1.3 Mt CO2/yr for 20 years. Similar size to Edinburgh city. Spacing of boreholes 500m requires interpolation of reservoir



Nature



Industry



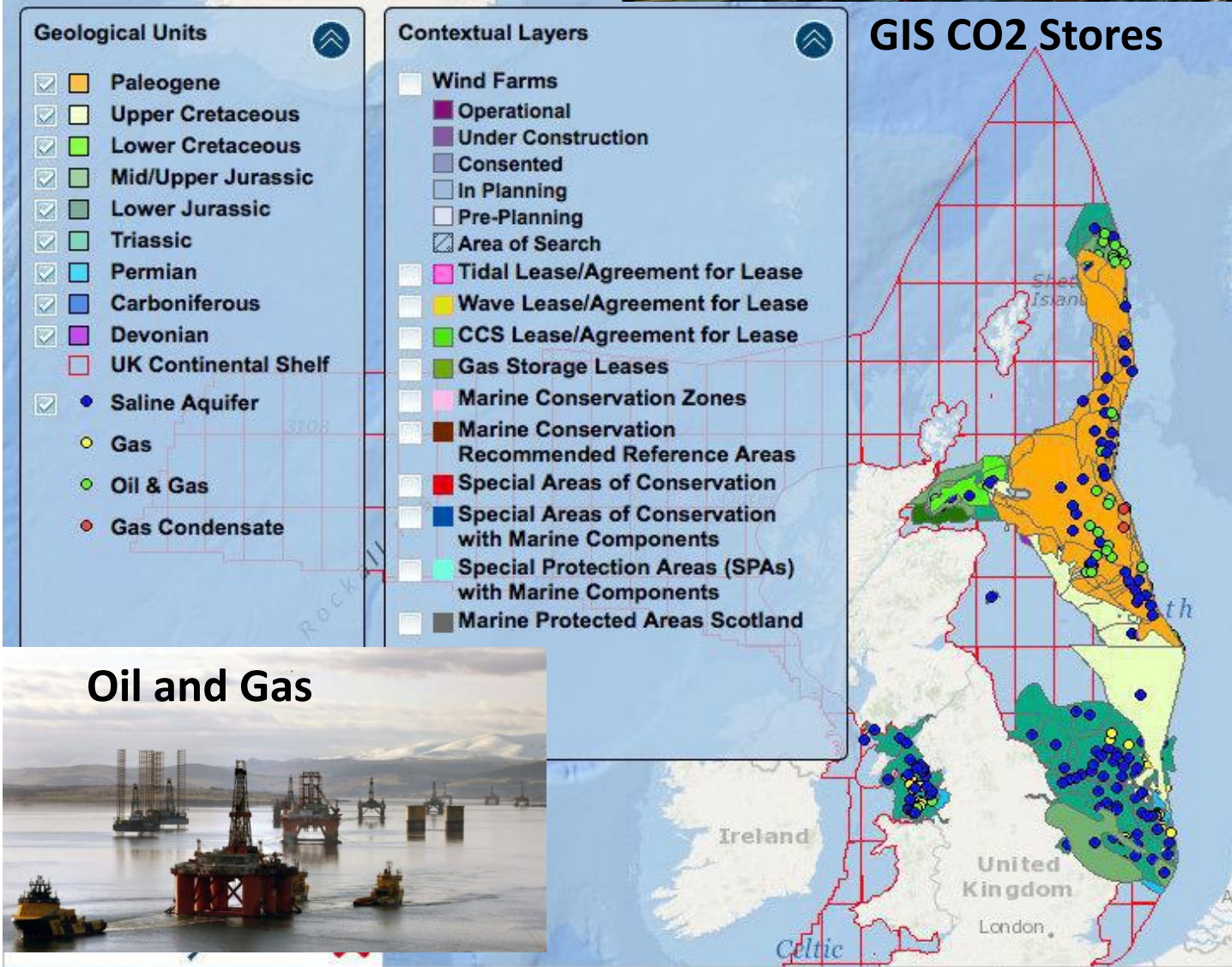
UK has abundant high quality CO₂ storage

Norway 80 Gt CO₂

UK 78 Gt CO₂

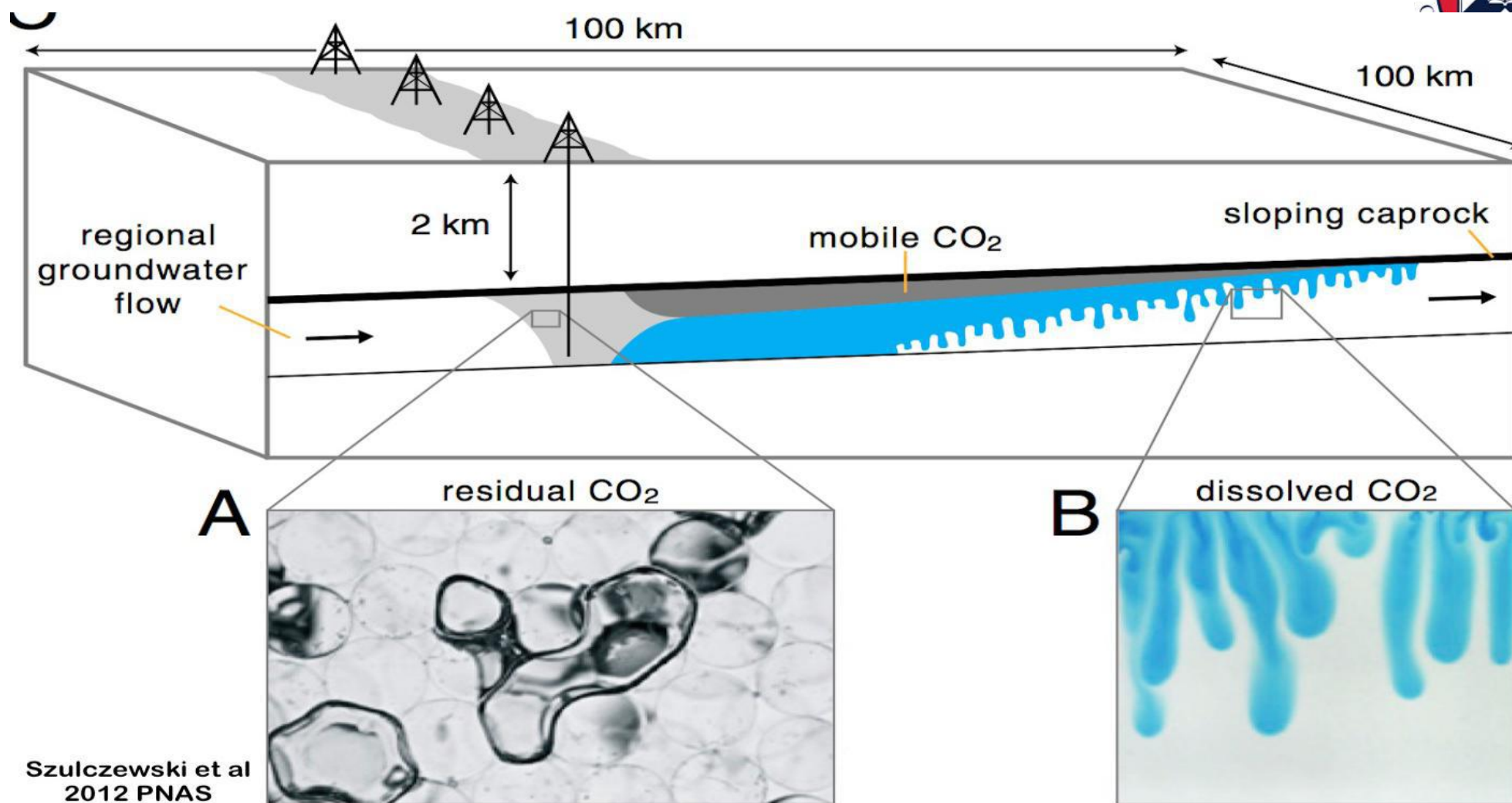
Of which Scotland has 65%

10—200 years EU storage



Oil and Gas

Geological storage CO₂ by fluid injection

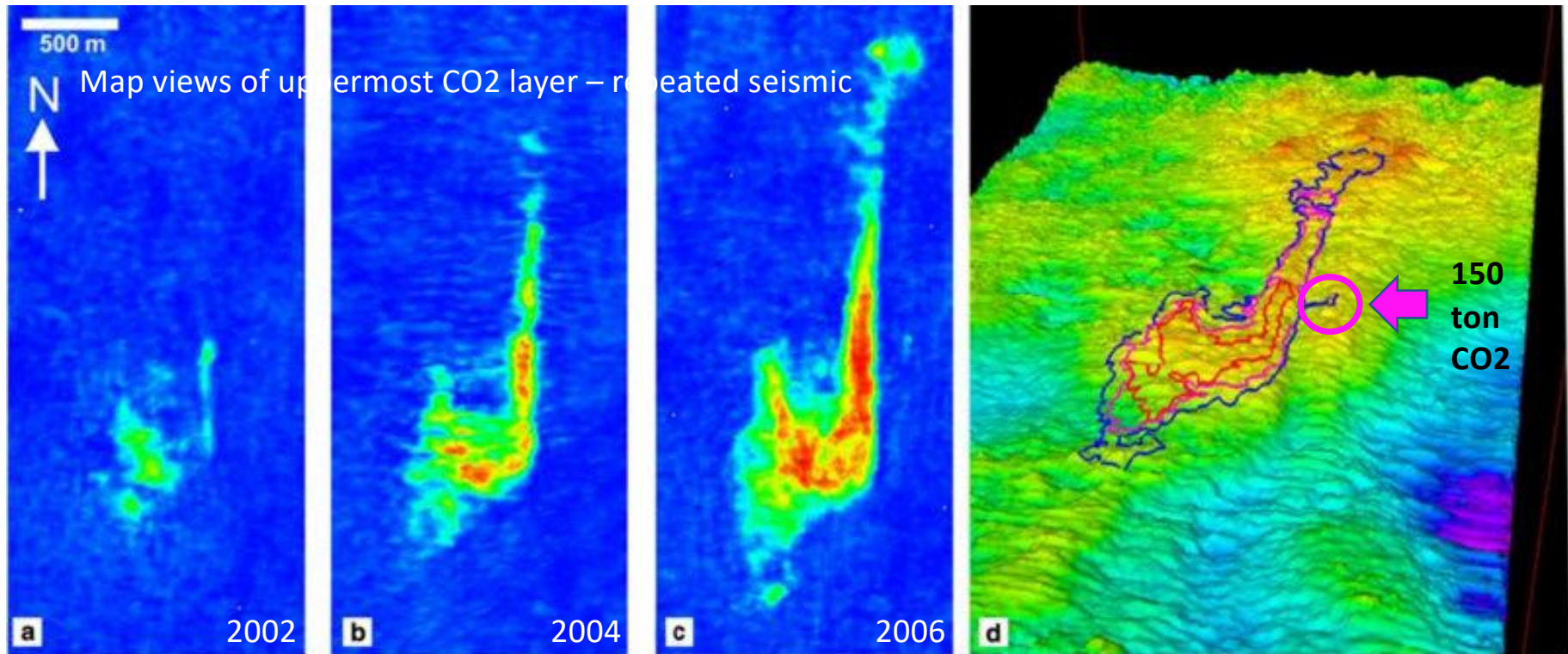


10¹² size scale

Good understanding needed from small, to mid, to large for prediction

Science: Laboratory measurement and process. Theory maths, Field calibration

Monitoring - location & resolution



Since 1996 CO₂ produced from the Sleipner field, has been separated offshore, and 1MtCO₂/yr injected safely

Seismic reflection surveys have been acquired for the Sleipner field condensate production – these accidentally include the Sleipner storage site. Repeat differences **detection is excellent - 150 tonnes CO₂**. Lateral migration 1m/day. Buoyant CO₂ fills uppermost reservoir topography. Also measure **PRESSURE**

Iceland: Direct CO₂ injection, mineral storage



Carb Fix cost

CO₂ already separated

No transport

Secure store

Potential capacity immense

Single business

**£20-30
tonne CO₂**

**How to scale-up?
How to validate
storage ?**

Slow pace V Big Ask for green tech



Carbon capture – need 20 GtCO₂ /yr by 2050
Current operations 0.02 Gt/yr



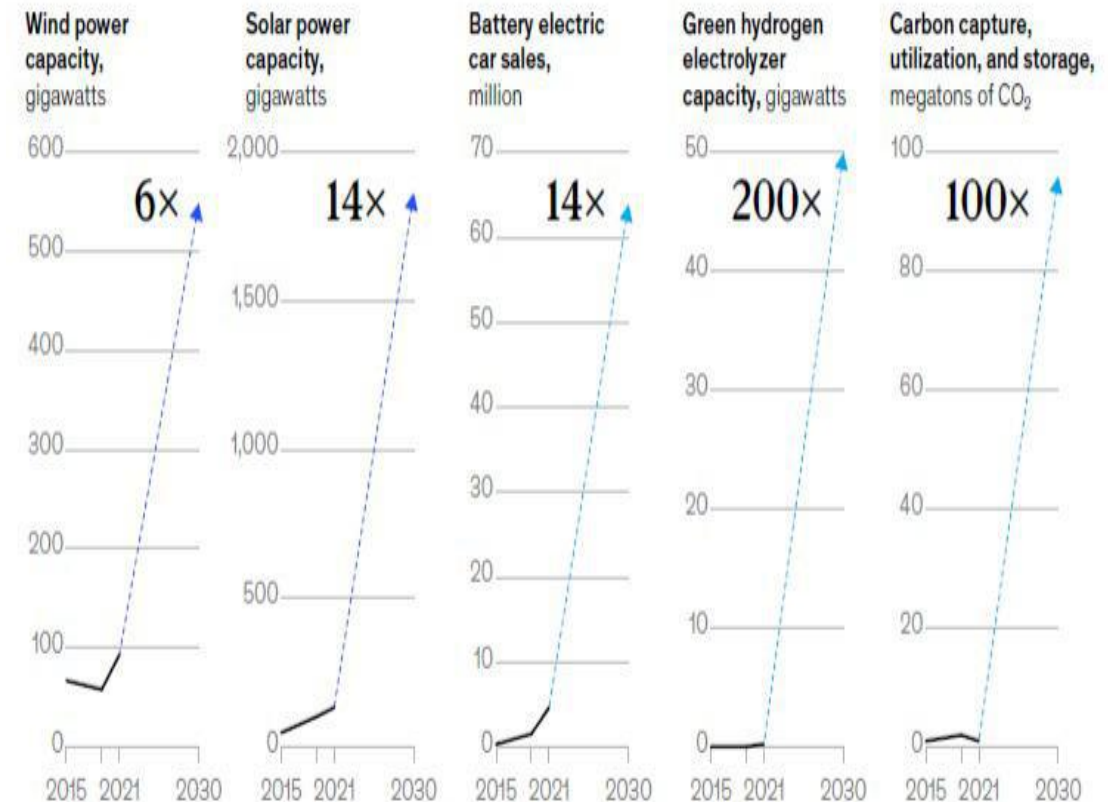
Direct air capture – need 10GtCO₂ /yr by 2050
Current operations 0.00004 Gt/yr



To reach net-zero targets, a set of existing climate technologies would need to scale exponentially by 2030.

Annual deployment of climate technologies needed,¹
multiples of current supply

-----> Mature -----> Early adoption




¹Based on the McKinsey 1.5°C achieved commitments scenario, which represents existing commitments from companies and policies from countries. To conduct this analysis, we estimated the current trajectory of supply of key climate technologies (based on historical and current activity), factored in current emissions-reductions commitments from countries and governments, and assessed the supply of these technologies that would be required by 2030 to stay on track for a 1.5° pathway.

Source: EV-Volumes; IEA; International Renewable Energy Agency; McKinsey analysis

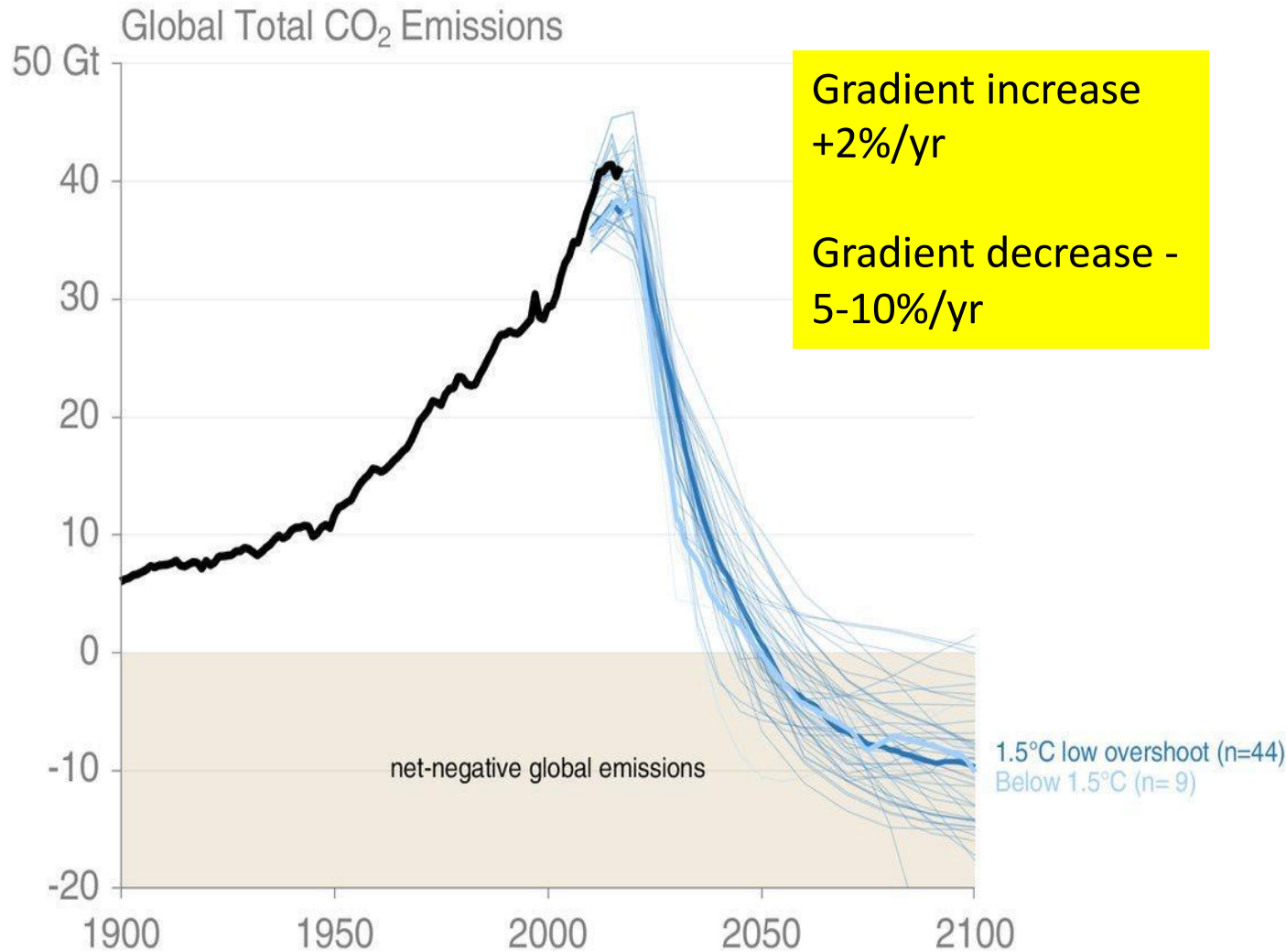
McKinsey 2023

Money and Policy

£ or  ?

Staying below 1.5C ???

Rate of decrease IPCC SR15C



© Data: IAMC 1.5°C Scenario Explorer (hosted by IIASA) • Figure: @Peters_Glen

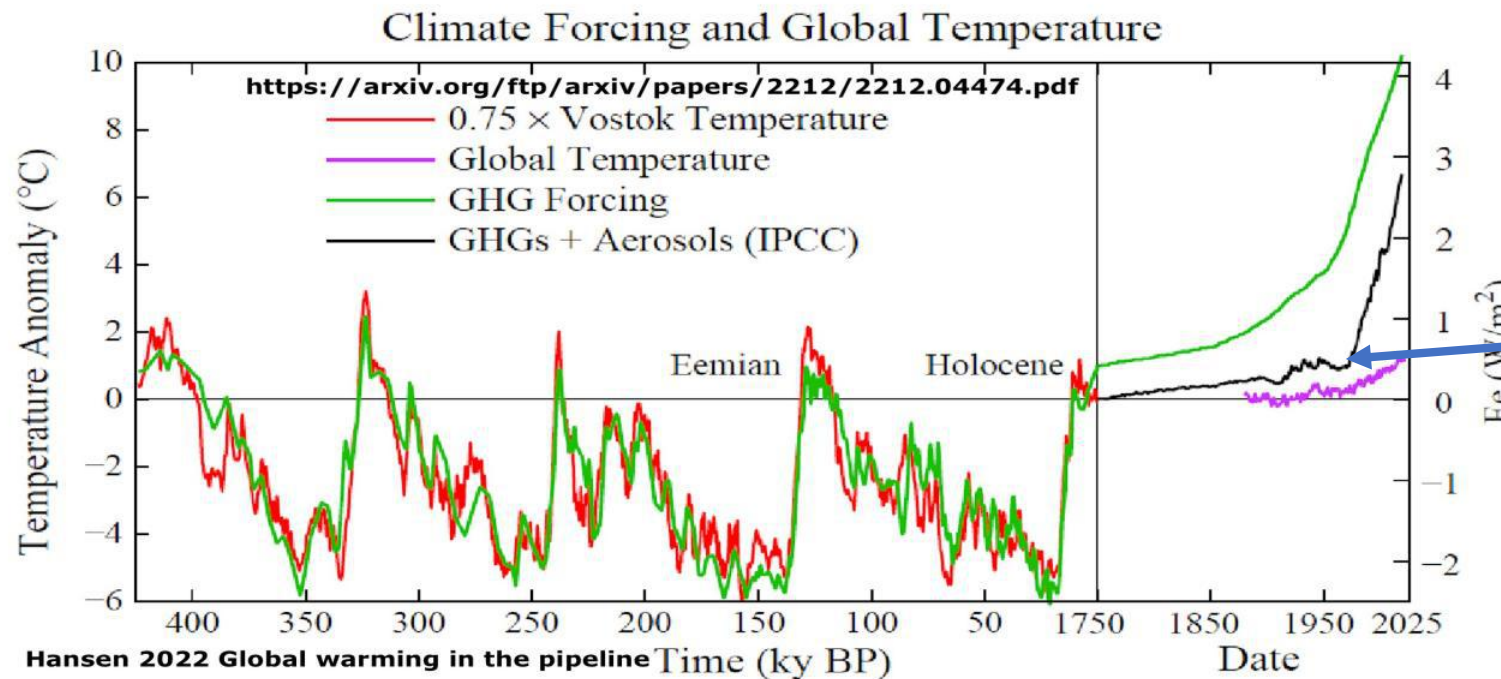
PLAN - Paris

- CO₂ emissions down 50% by 2030 (40-60%)
- Net-zero by 2050-2060
- Around 10GtCO₂ (net) negative emissions by 2100

ACTION

- Minimal

Hansen – no aerosols, predicts 10C by 2100



Greenhouse gas (GHG) climate forcing is 4.1 W/m² larger in 2021 than in 1750, equivalent to 2×CO₂ forcing.

Decreased aerosol 1970, increased warming

Global warming in the pipeline is greater than prior estimates. 2023 GHG – after slow feedbacks operate – warms about 10°C.

If there is a long delay of feedback, the system breaks down, unless there is anticipation built into the loop

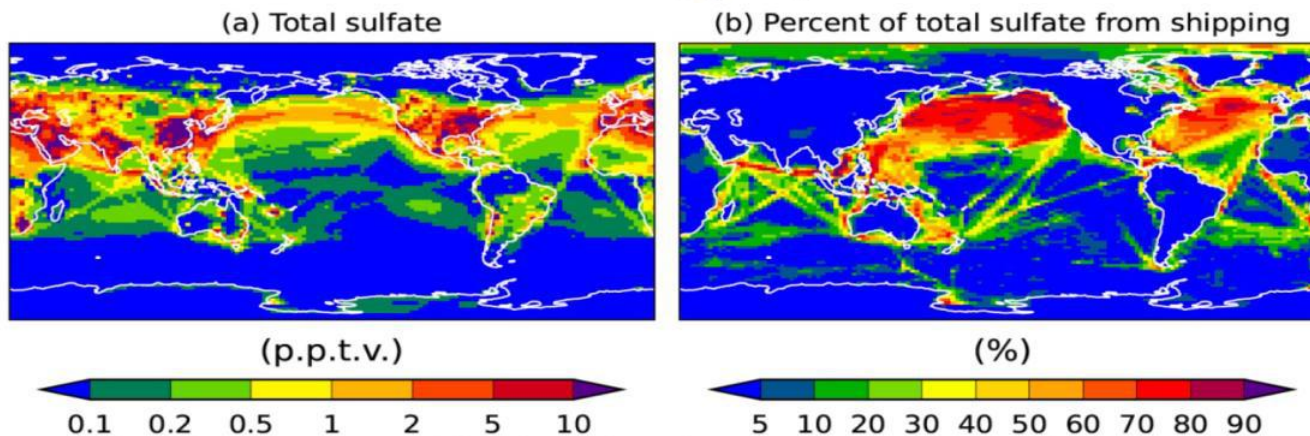


Fig. 16. Total sulfate (parts per trillion by volume) and percentage of total sulfate provided by shipping in simulations of Jin et al.¹²³ prior to IMO regulations on sulfur content of fuels.

Shipping sulphur cloud increased albedo

<https://arxiv.org/ftp/arxiv/papers/2212/2212.04474.pdf>

Engineered albedo management marine cloud brightening MCB



Existing cloud trails from ships, size of cloud depends on drop size,

Latham... Salter ... Phil Trans Royal society

<https://doi.org/10.1098/rsta.2012.0086>

Controlled autonomous ships spraying seawater – for low energy, multiweek voyages



IMPACT OF CLOUD SEED SIZE ON MCB



Problems
Making the droplets – at different sizes

Climate model prediction of rainfall effects

First trials 2021 : SCOPEX



8 Feb 2021

In June, a team of Harvard scientists is planning to launch a high-altitude balloon from Kiruna in Lapland to test whether it can carry equipment for a future small-scale experiment on radiation-reflecting particles in the Earth's atmosphere.

Frank Keutsch, Harvard

"I'm really worried about the world we are heading towards. For me, that is a reason to do research on solar radiation management."

Raymond Pierrehumbert, Oxford

"You go into this death spiral, where you try to keep the Earth habitable in the face of ever-increasing CO2 and set ourselves up for a bigger and bigger risk of catastrophe."



<https://www.theguardian.com/environment/2021/feb/08/solar-geoengineering-test-flight-plan-under-fire-over-environmental-concerns-aoe>

DIY solar radiation management



January 2023 Flights

We plan to fly at least 3 balloons in January 2023. Here's some details. Anyone can comment [here](#), and we'll consider input before finalizing launch plans!

Where/When:

Southern Baja, Mexico. We'll plan exact location based on weather conditions, utilizing [SondeHub Predictor](#) to decide exactly where and when. Target will be near a road but away from any population center.

Balloons:

These flights will be latex weather balloons rated at 1200g.

Lift Gas:

These flights will utilize helium.

Clouds:

We will utilize sulfur dioxide generated by burning sulfur in the presence of oxygen. Each launch will include between 10g and 500g of clouds (target 100g+).



And doing nothing,
means others will do it

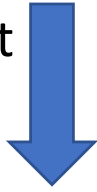


[makesunsets.com](#)

Changing basic technology takes time



Carbon management is here



Tesla electric 2019



Model T Ford 1910



Two horsepower plus two drivers 1750

Summary

CO₂ in atmosphere increases relentlessly

Global heating models ignore extremes, feedbacks, and tipping points

Links of temperature to doubling CO₂ are poorly calculated (ECS)

Slowing heating by GHG decrease to removal is too slow

Much more heating is in the pipeline – climate repair is needed

Engineering albedo may decrease heating
And is low cost, reversible, low risk

MORE WORK on
cloud physics
and aerosols

MORE WORK ECS –
Equilibrium Climate Sensitivity
calibration of climate to past
times

Model fossil fuel
forcing Sea level
Xmetres rapid rise