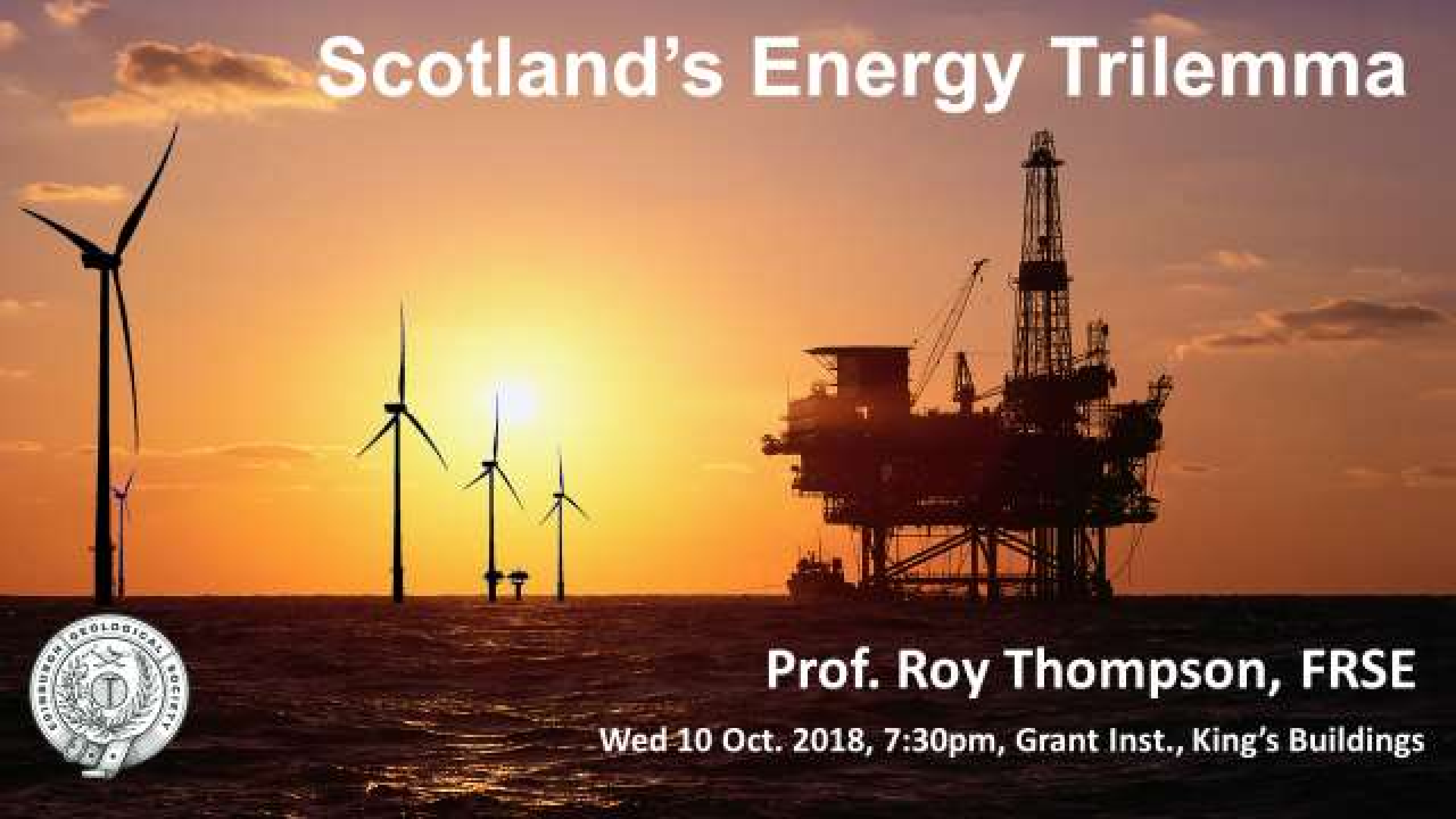
Scotland's Energy Trilemma



Prof. Roy Thompson, FRSE

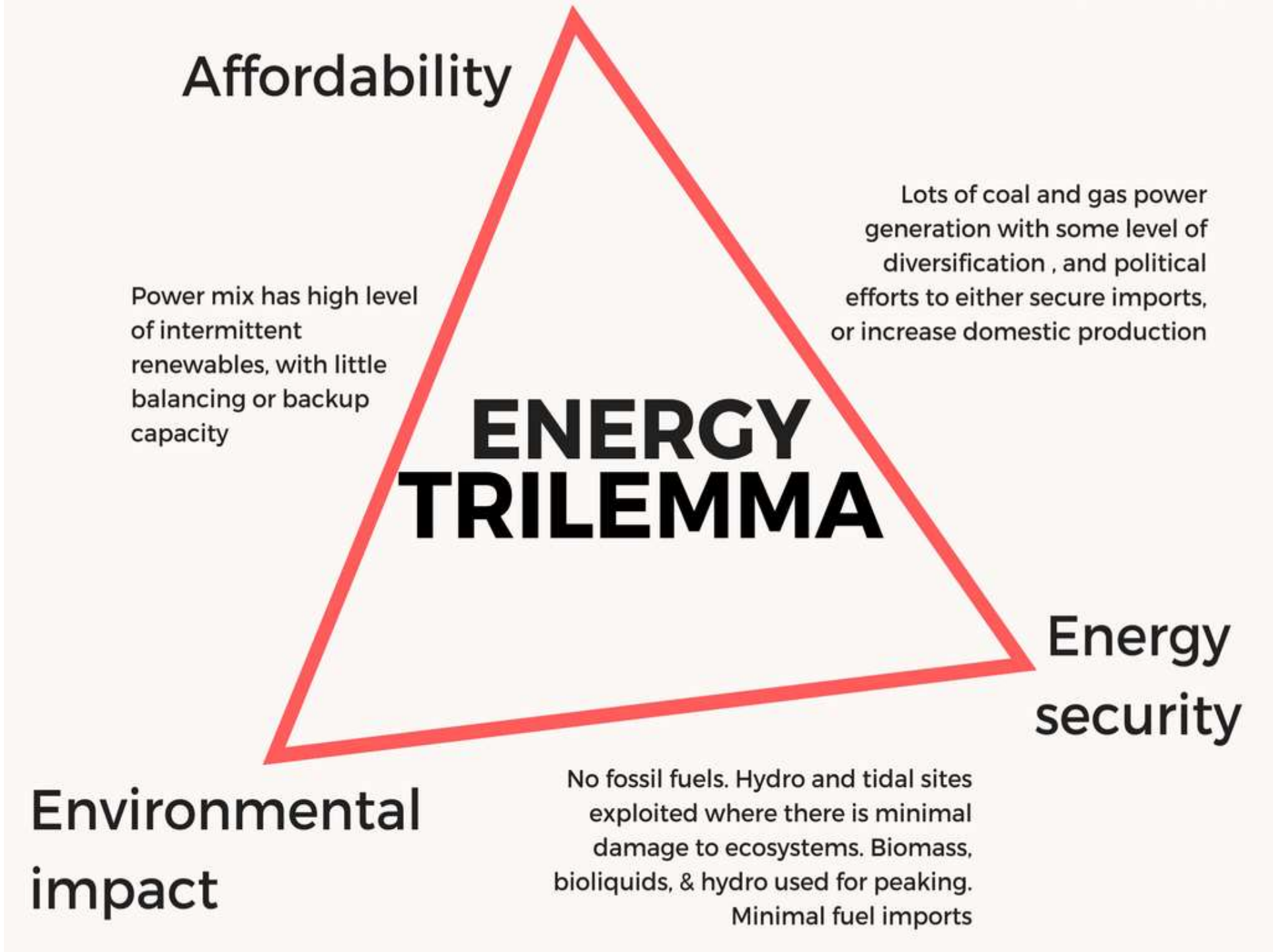
Wed 10 Oct. 2018, 7:30pm, Grant Inst., King's Buildings

Synopsis

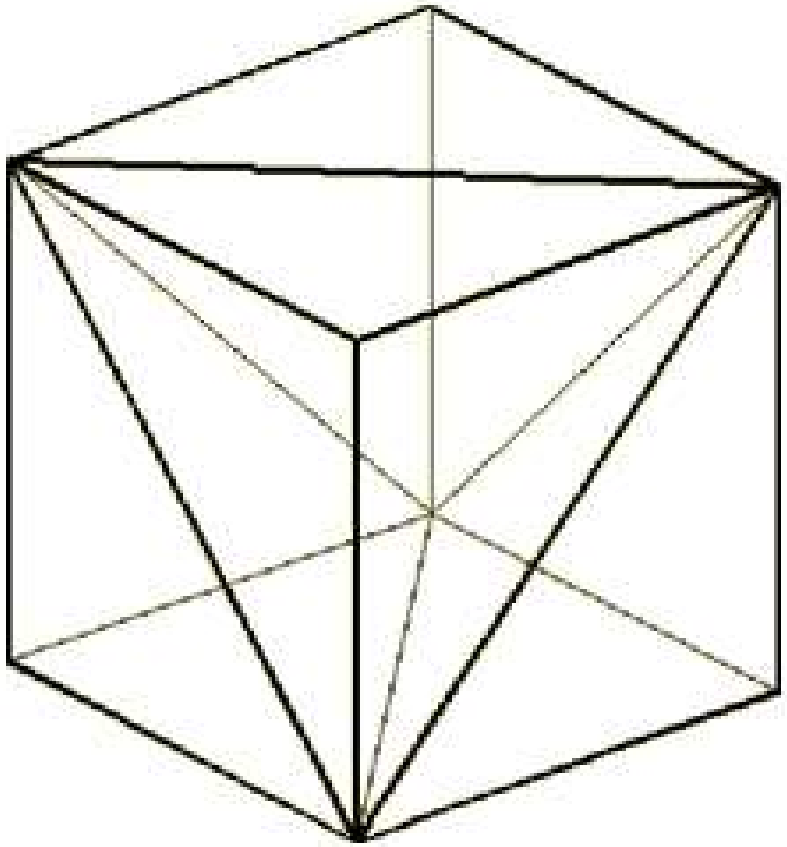
The energy trilemma is the problem of striking a balance between costs, security and environmental impact. Scotland is creating an unnecessarily difficult position for itself by aiming for 90% reduction in greenhouse emissions at a time when UK oil and gas is rapidly running out and by adopting a 'no new nuclear energy' policy.

The lecture spells out why Scotland should instead be targeting reductions of only around 50%. This level of change is feasible, unlike the Paris 1.5 °C temperature limit which is hopelessly overoptimistic. A 50% reduction target strikes the best balance between the high costs (of replacing fossil fuels by clean energy) and the likely financial damage (that will be caused by continuing to burn fossil fuels). The lecture describes and emphasises the key role of geology in the energy trilemma.

The solution is to introduce carbon pricing (using a Pigouvian rebate system) thereby maximising the World's overall economic development and wellbeing.


Affordability
Lots of coal and gas power generation with some level of diversification , and political efforts to either secure imports, or increase domestic production
Power mix has high level of intermittent renewables, with little balancing or backup capacity
ENERGY TRILEMMA
Energy security
Environmental impact
No fossil fuels. Hydro and tidal sites exploited where there is minimal damage to ecosystems. Biomass, bioliquids, & hydro used for peaking. Minimal fuel imports

Energy quadrilemma - the need to simultaneously



- Reduce carbon emissions
- Cut consumer costs
- Ensure security of supply
- Achieve public acceptability

Outline

1. Energy supplies

Fossil fuels – 80% Coal, oil, gas, fracking

Nuclear – 7% Radioisotope stratigraphy, geological disposal

Clean energy – 12% Renewables, geological storage (CCS)

2. Climate change

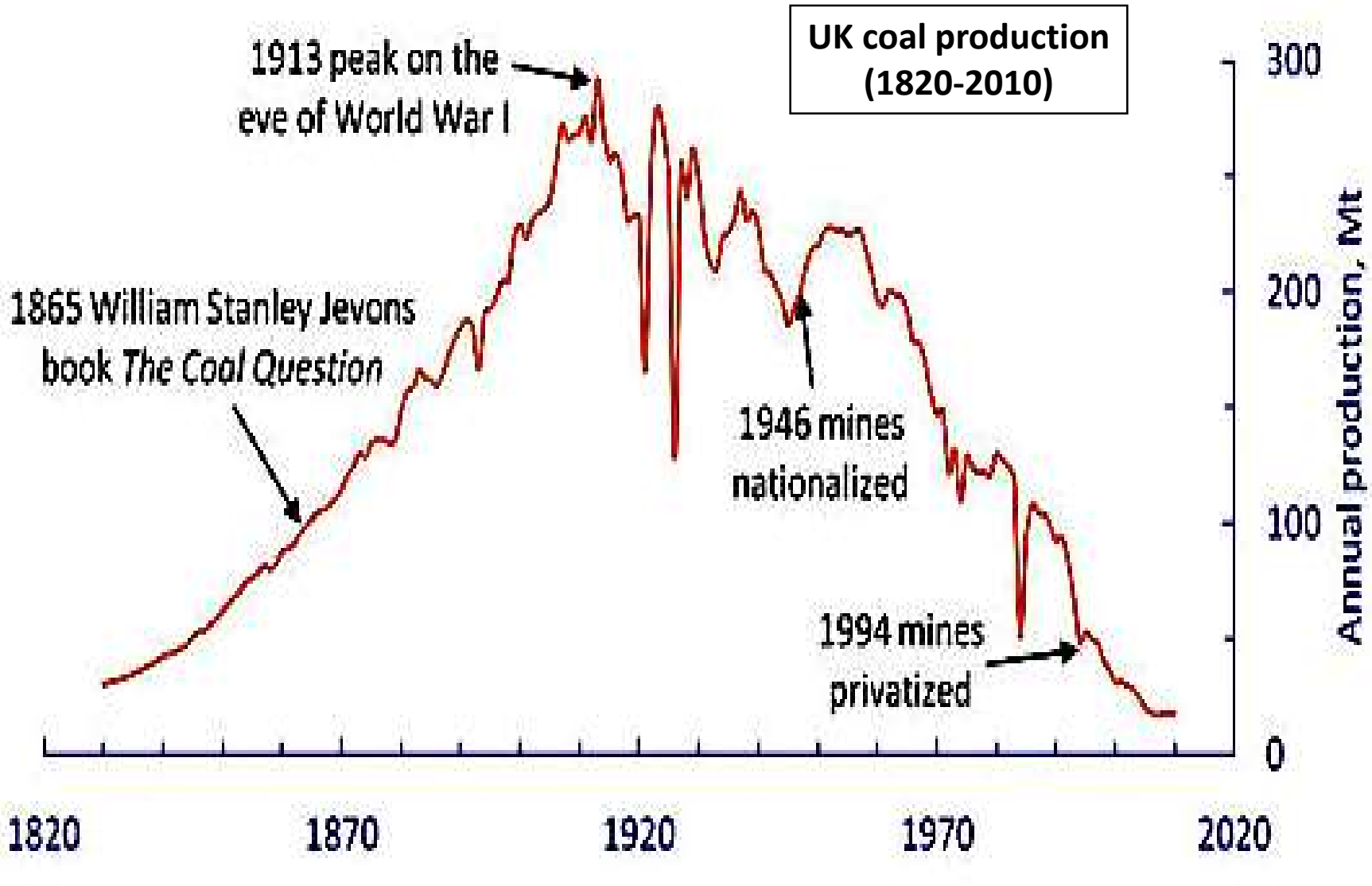
Climate sensitivity – Palaeoclimates, models, historical data

Recent trends – CO_2, temperatures (land & ocean)

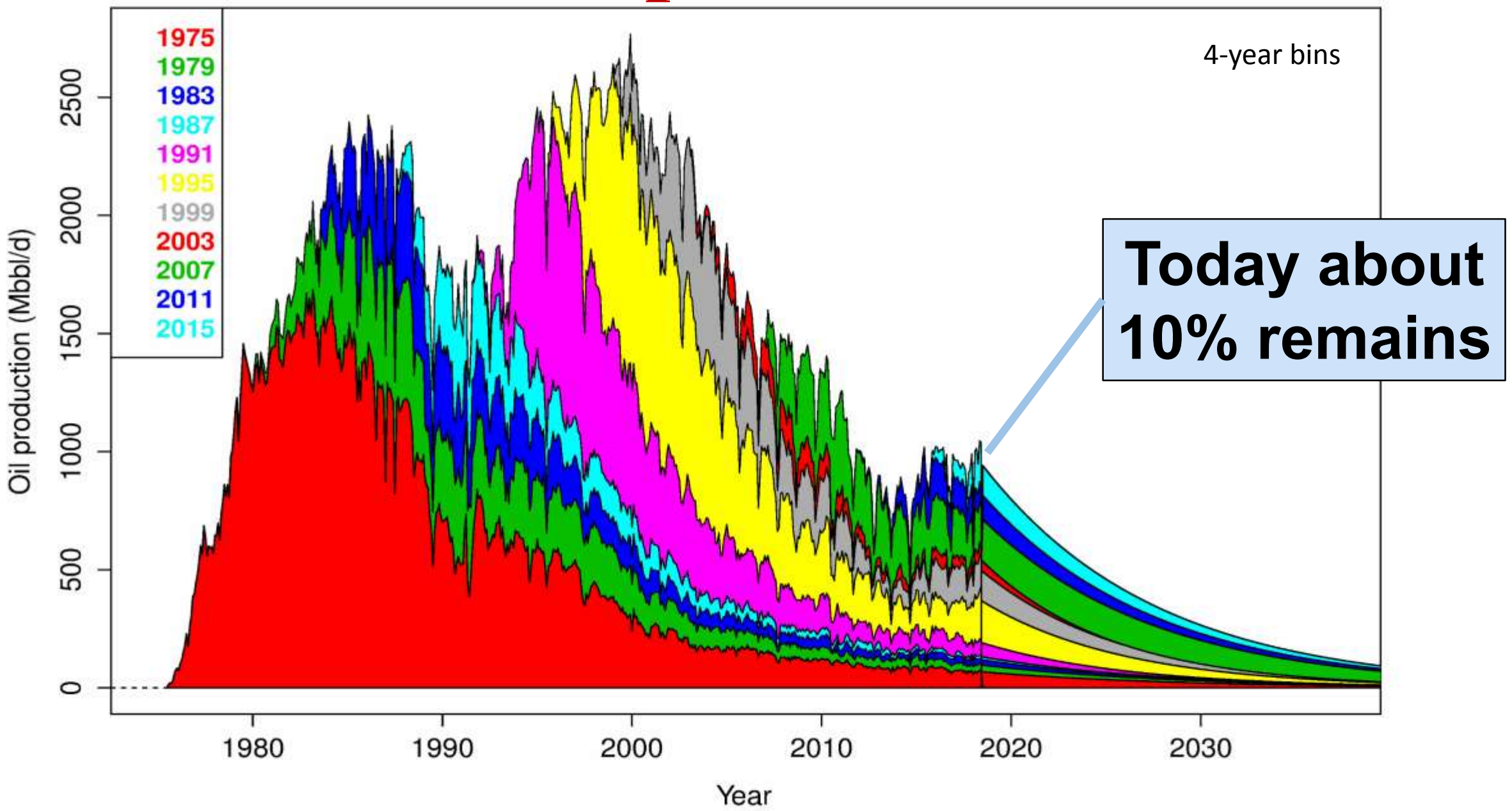
3. Behavioural change

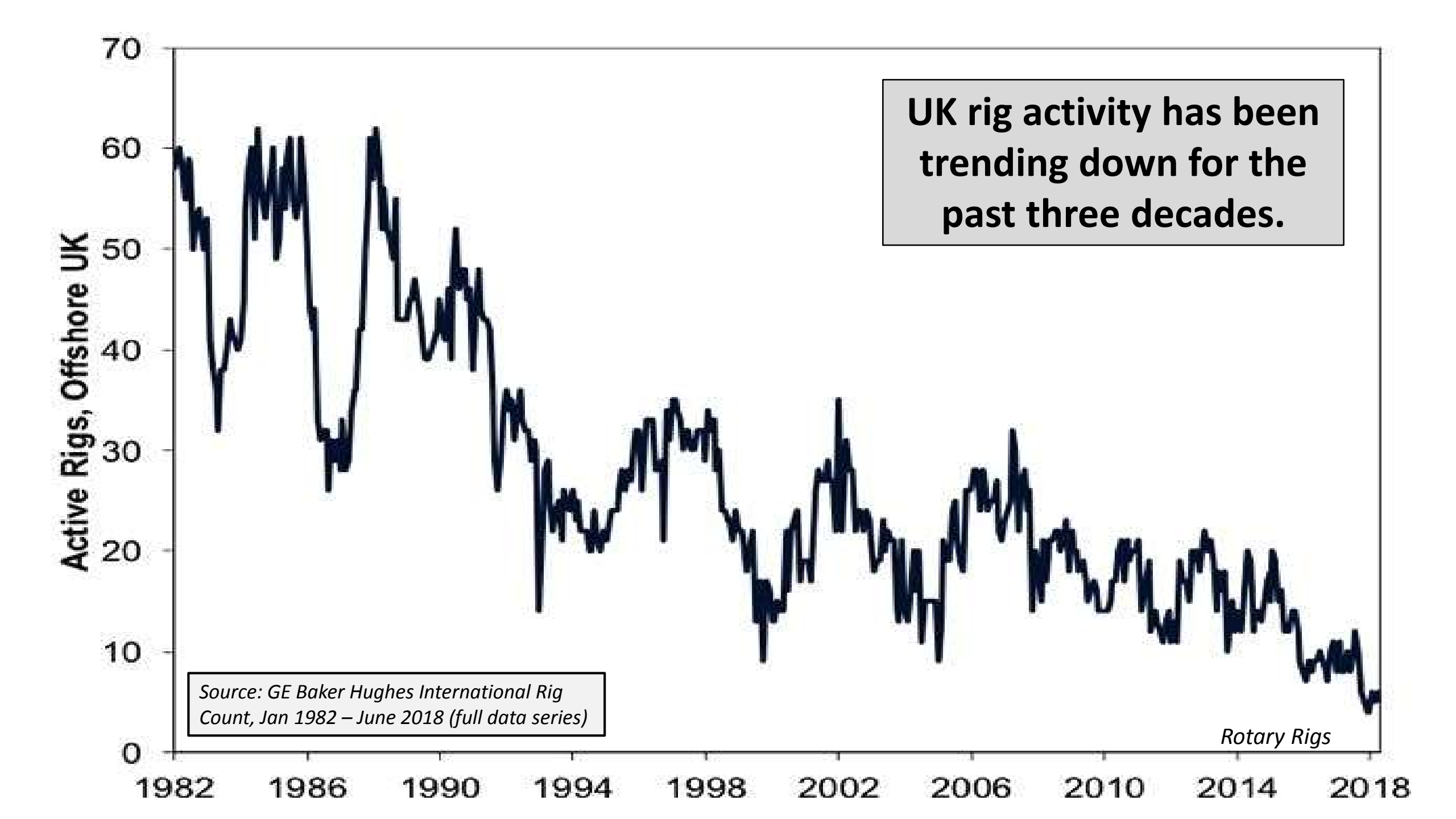
Carbon economics – Solving the trilemma

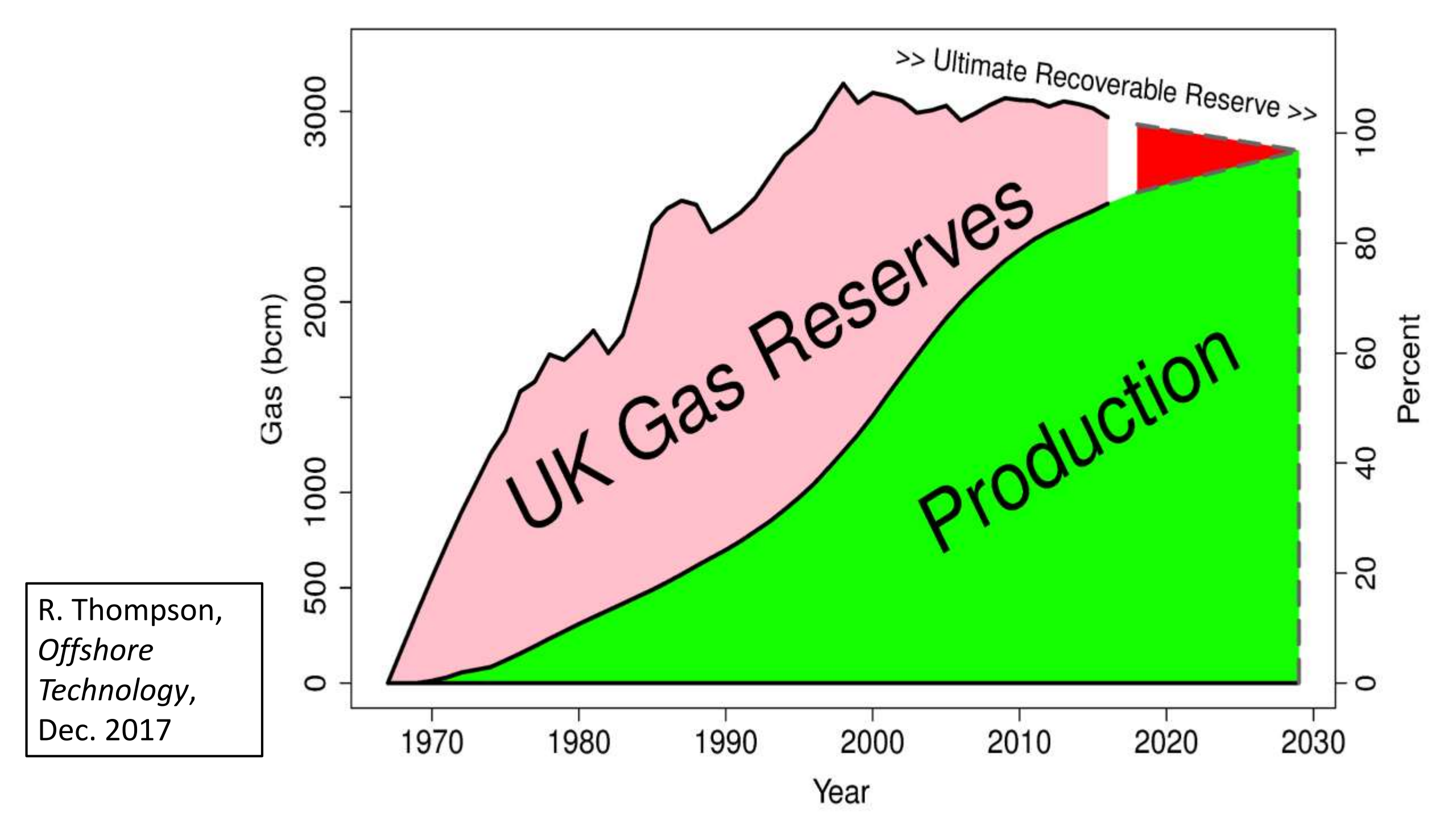
UK Coal Production



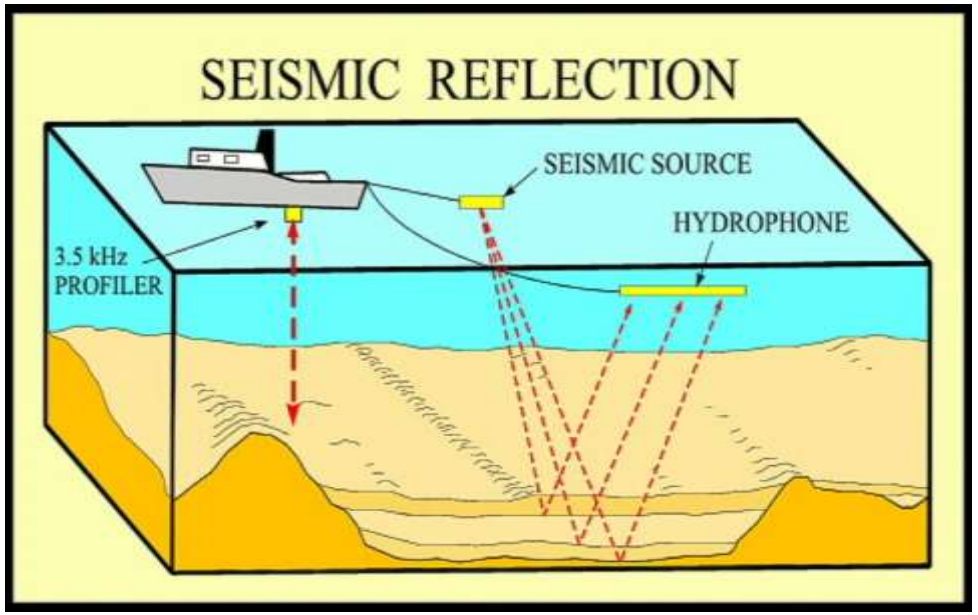
UK oil production




UK rig activity has been trending down for the past three decades.
Active Rigs, Offshore UK
70
60
50
40
30
20
10
0
1982
1986
1990
1994
1998
2002
2006
2010
2014
2018
Source: GE Baker Hughes International Rig Count, Jan 1982 – June 2018 (full data series)
Rotary Rigs

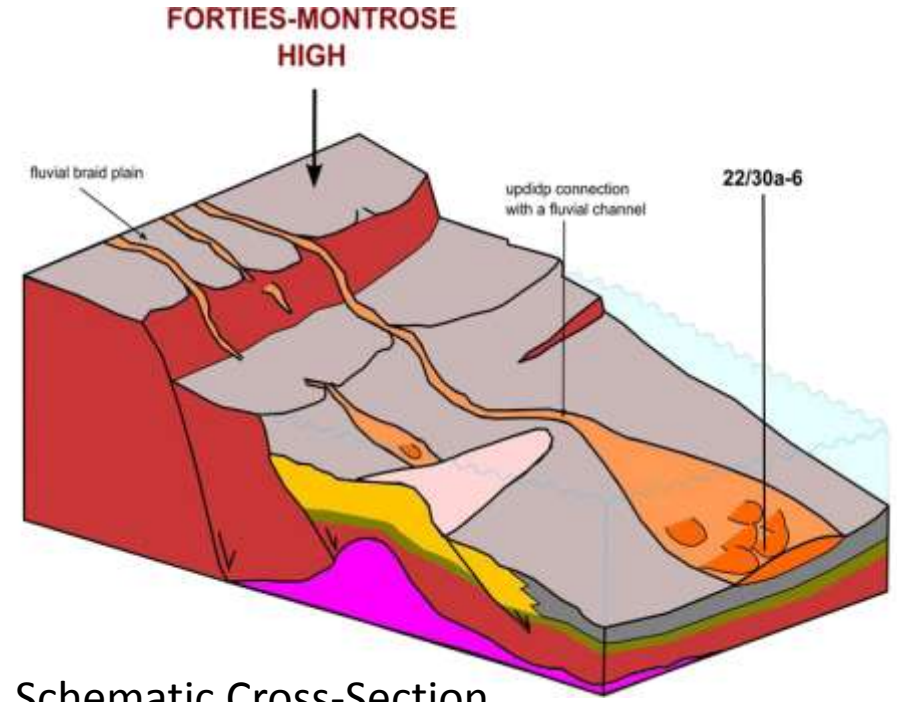


R. Thompson, *Offshore Technology*, Dec. 2017



A recent success story:

4D-seismics in Forties Field



Schematic Cross-Section

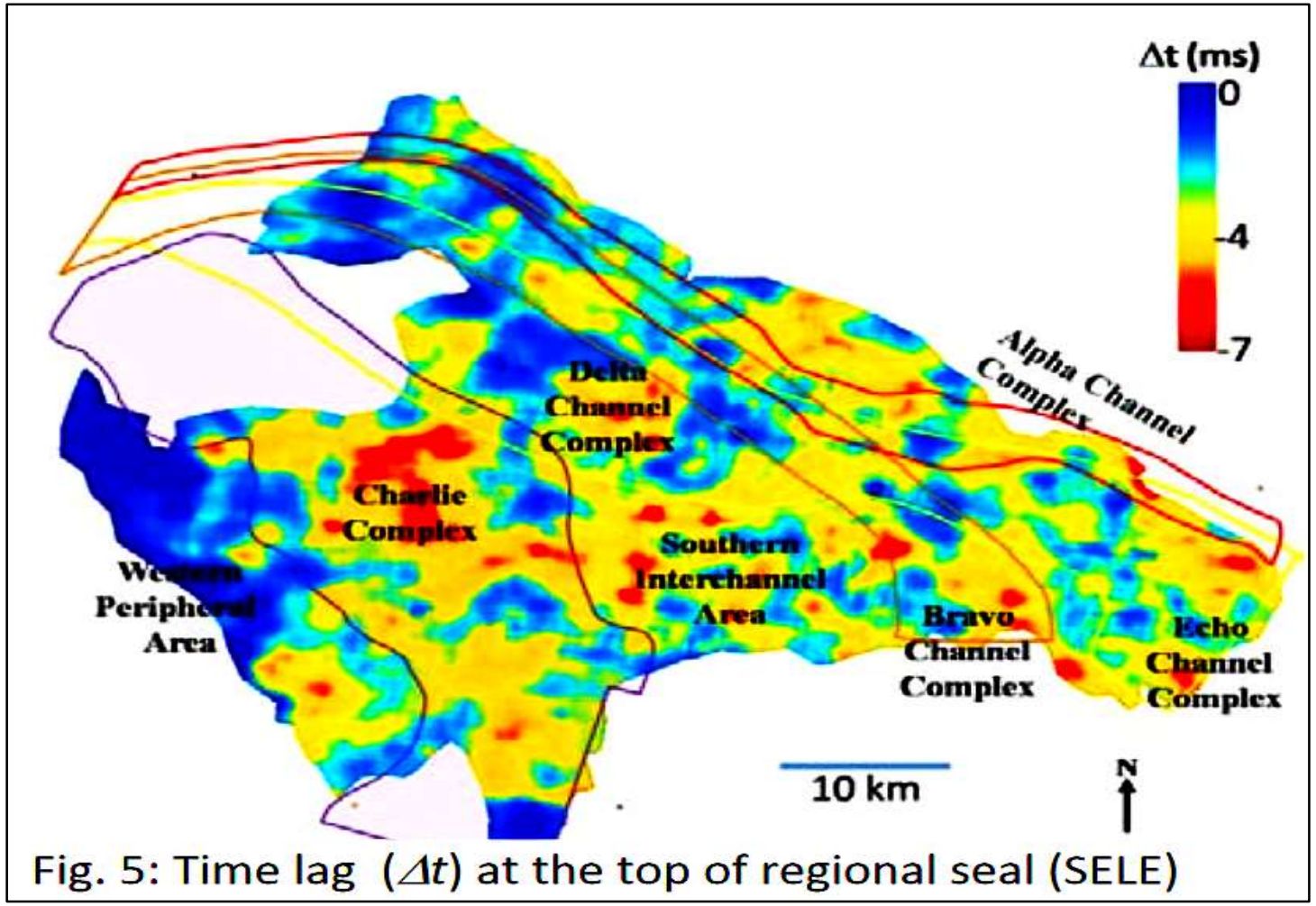
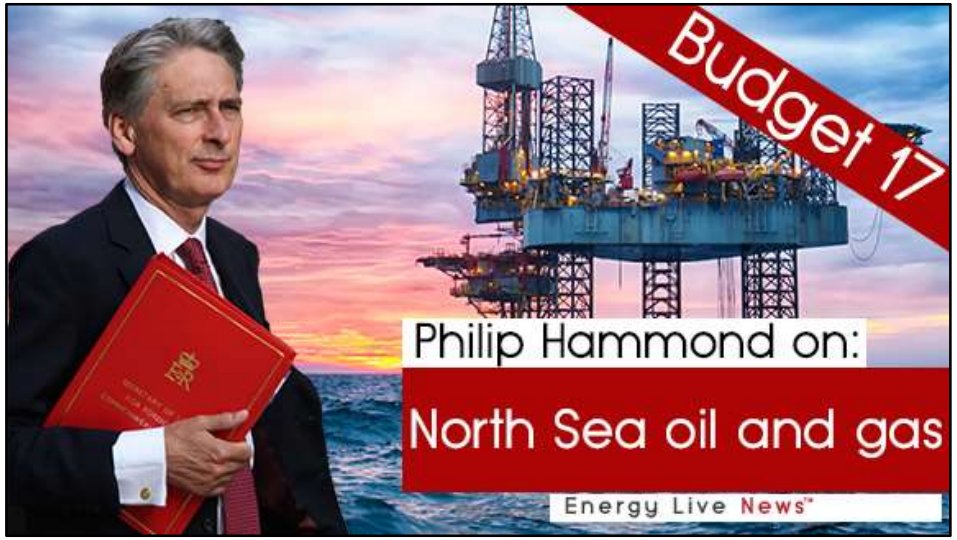


Fig. 5: Time lag (Δt) at the top of regional seal (SELE)

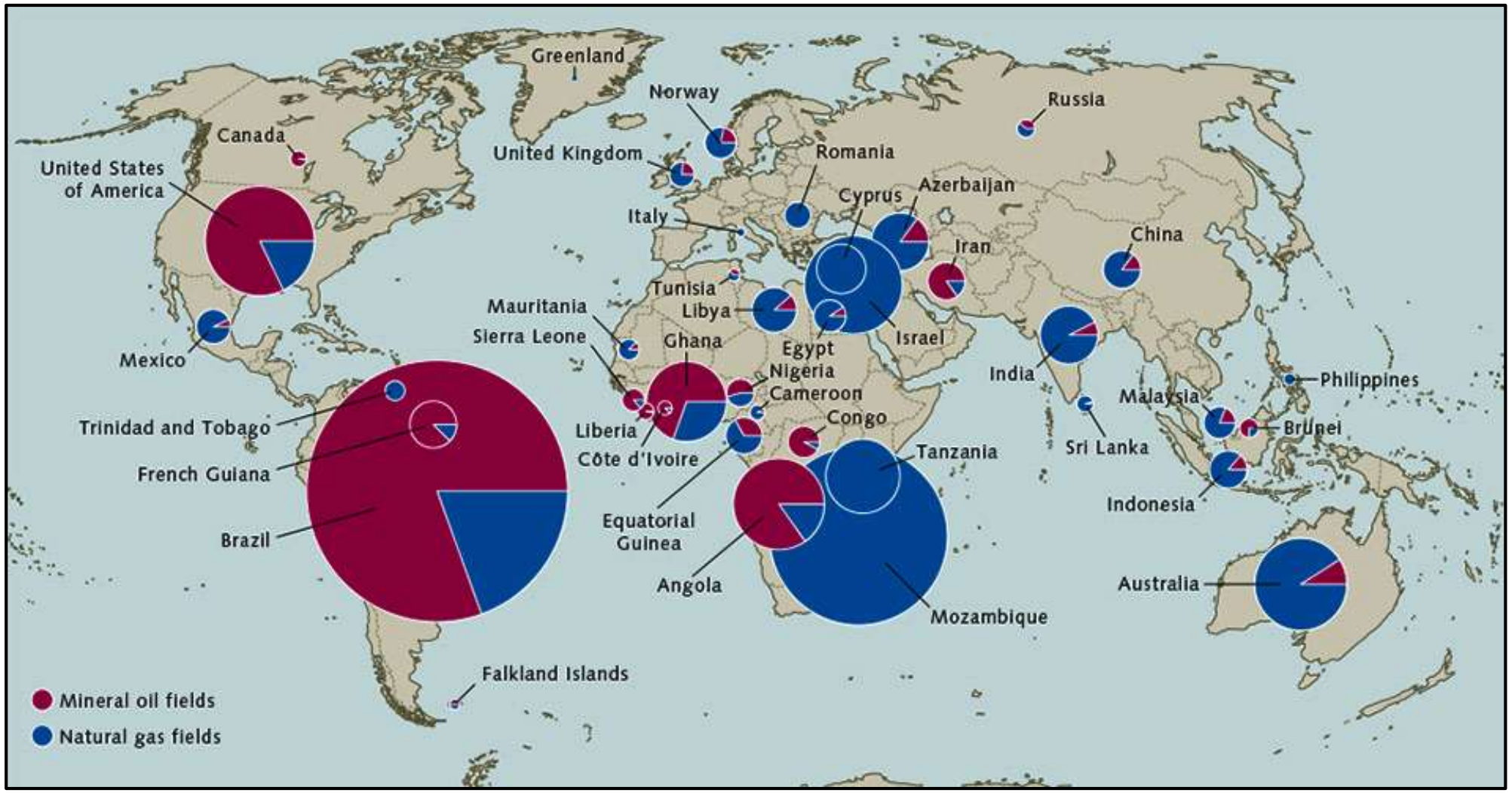
Chancellor Philip Hammond said the basin "*still holds up to 20 billion barrels of oil*"



Paul Wheelhouse "*The North Sea has a bright future, with up to 20 billion barrels of oil equivalent of known reserves*"

Regional organiser Tommy Campbell (Unite) believes *"further help from Westminster is needed to ensure the remaining 20 billion barrels of oil are recovered"*

Global offshore oil and gas - the future

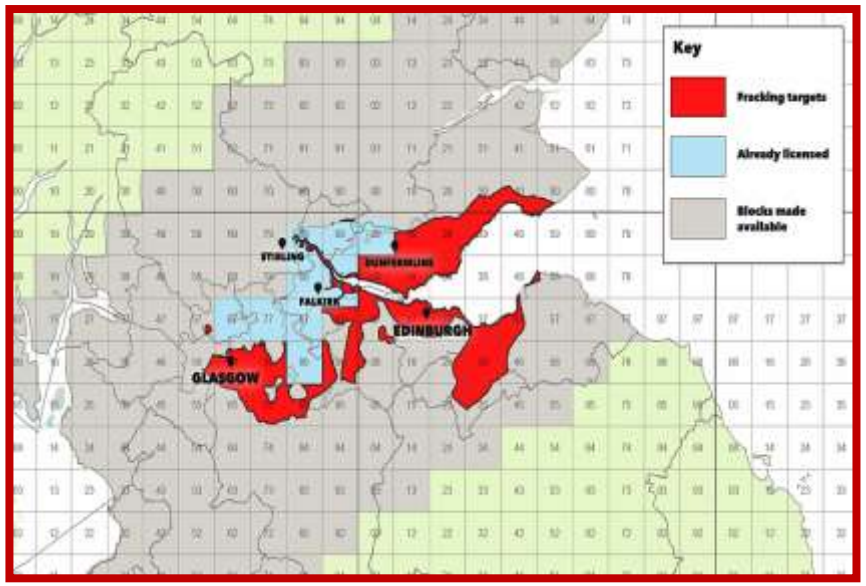


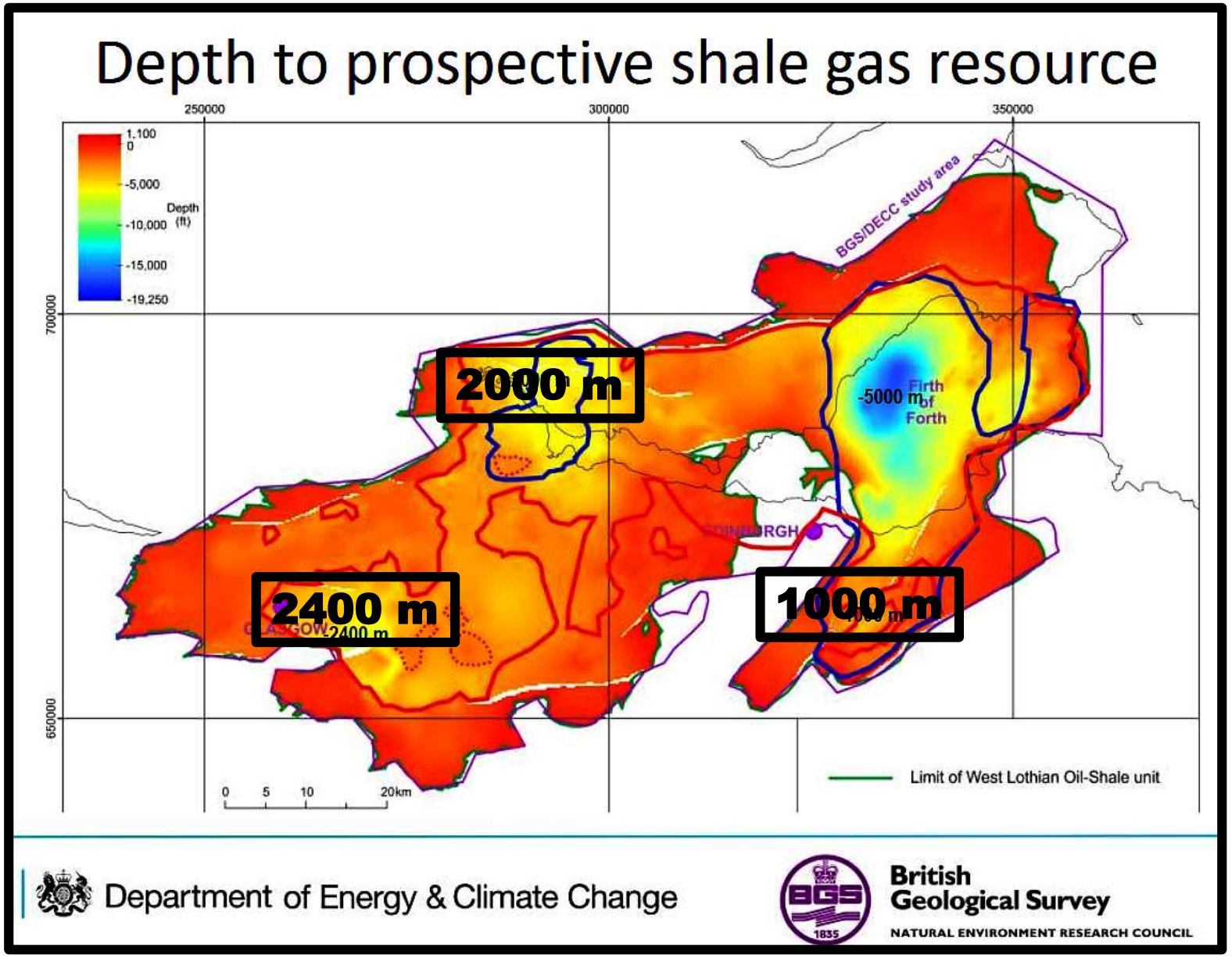
Fossil fuels are nearly limitless on the time-scales that matter for climate change.


Fracking
Pad 63-K Horn River Basin (Oct. 2, 2010) NE British Columbia


<<<<<Pumpherston oil-shale >>> >>

Where do companies want to frack in Scotland?

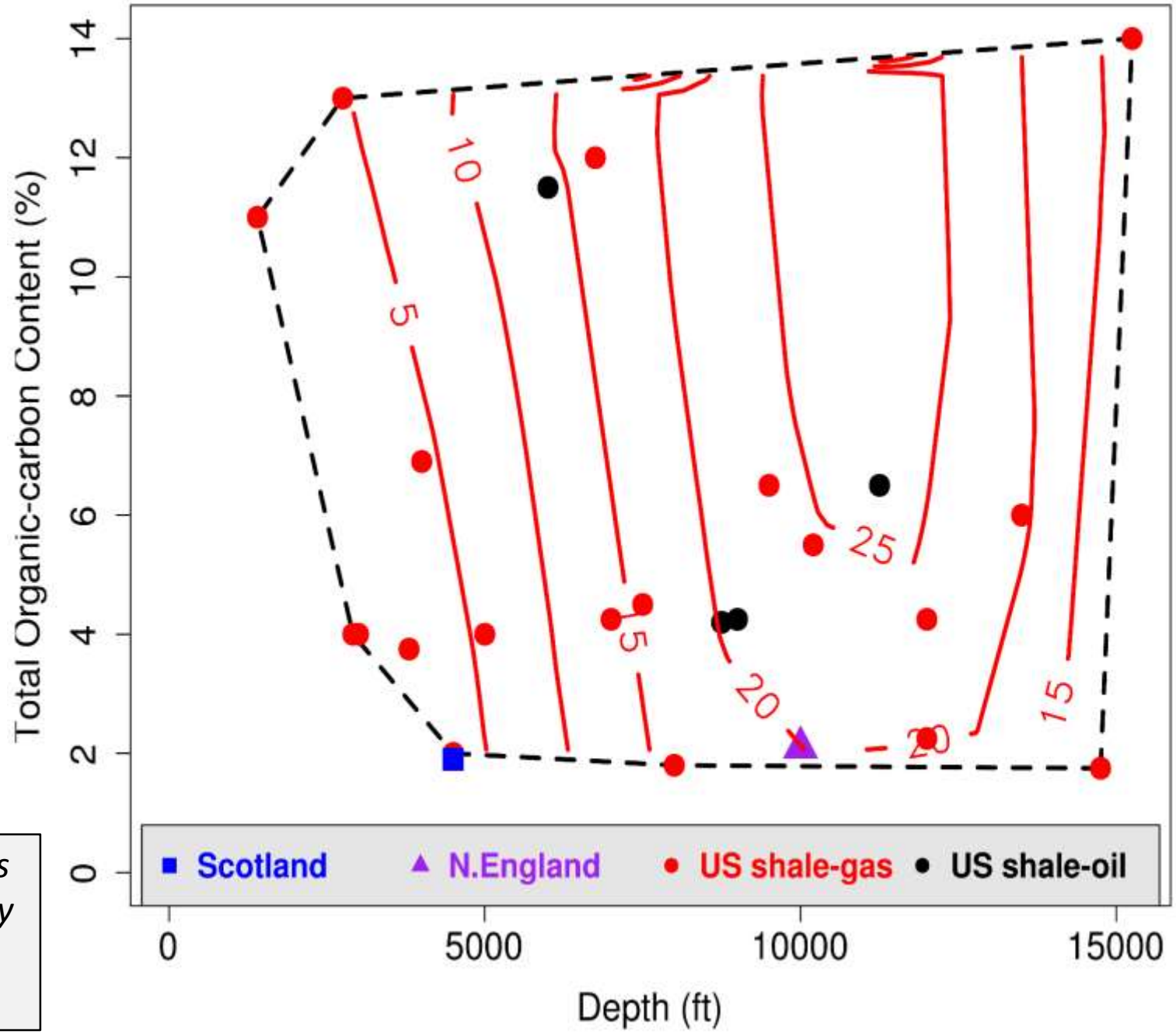




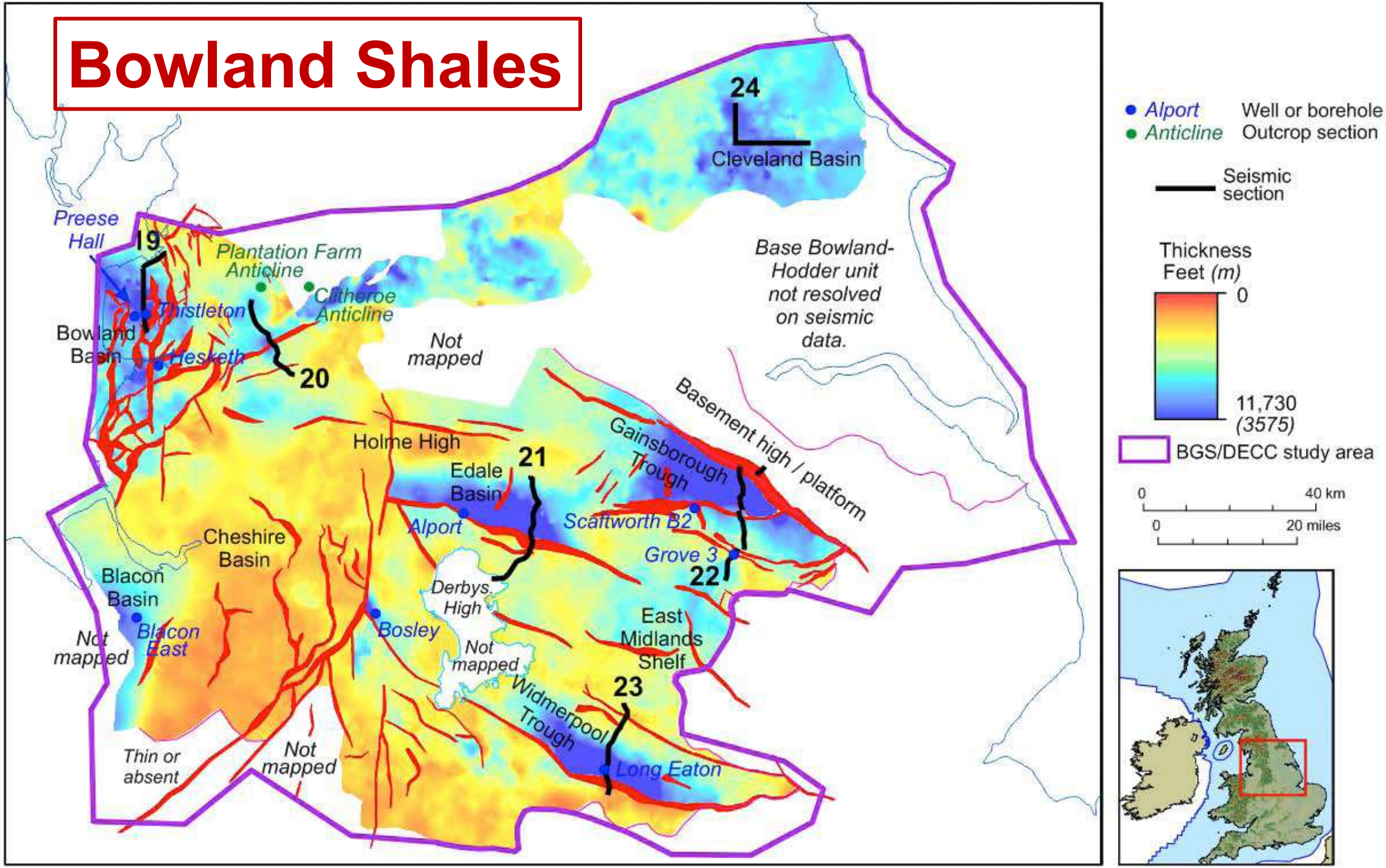
The Midland valley: A geological analogue study

"*Can fracking, for gas and oil, power the Scottish economy?*"

By R. Thompson in The Edinburgh Geologist, 62 20-27; Discussion, 5-7.



Depth vs. total organic content. Contours (red lines) of estimated ultimate recovery (Bcf/sq. mile) in 24 US shale-systems. Dashed line (US convex hull).

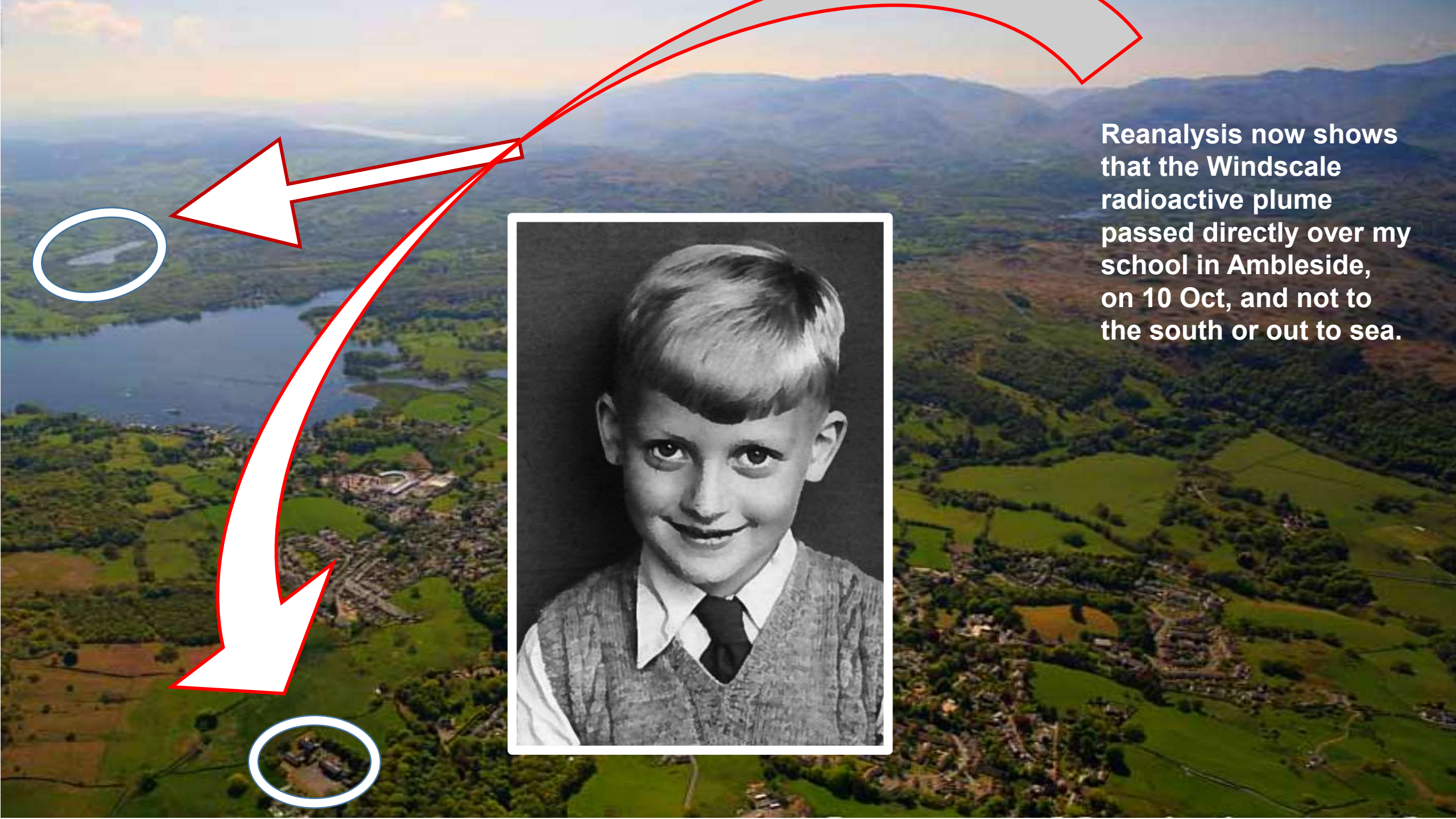

Bowland Shales
24
Cleveland Basin
Preese Hall
19
Plantation Farm Anticline
Clitheroe Anticline
Thistleton
Bowland Basin
Hesketh
20
Not mapped
Base Bowland-Hodder unit not resolved on seismic data.
Basement high / platform
Gainsborough Trough
Holme High
Edale Basin
21
Alport
Scaftworth B2
Grove 3
22
Cheshire Basin
Blacon Basin
Blacon East
Not mapped
Derbys. High
Bosley
Not mapped
East Midlands Shelf
Widmerpool Trough
23
Long Eaton
Thin or absent
Not mapped
Alport Well or borehole
Anticline Outcrop section
Seismic section
Thickness Feet (m)
0
11,730 (3575)
BGS/DECC study area
0 40 km
0 20 miles

Preston New Road

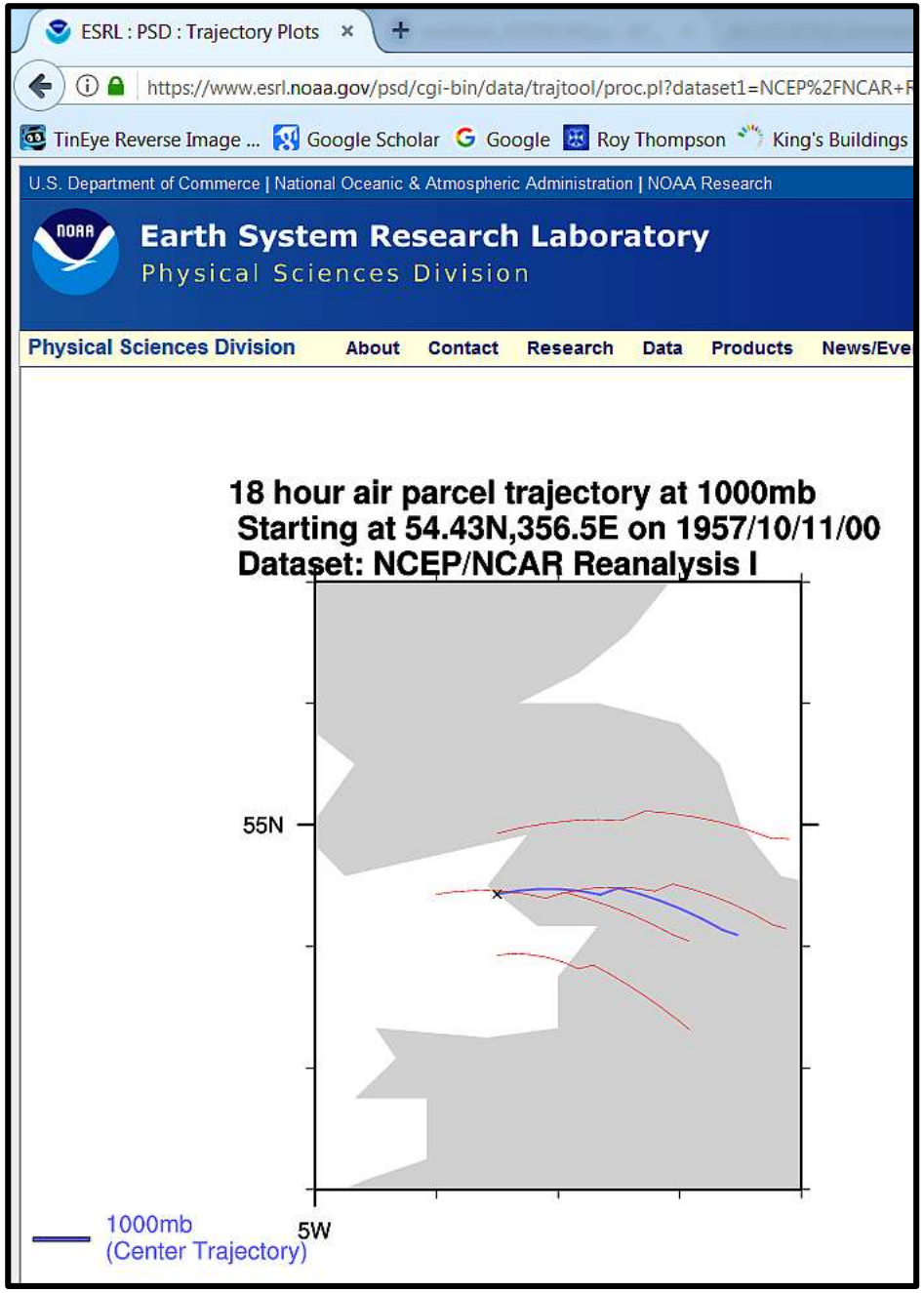
On the last day of parliament, before the 2018 summer recess, the government gave Cuadrilla the green light to begin hydraulic fracturing.


Nuclear


34,000 TBq
of ^{131}I, ^{90}Sr, ^{106}Ru, ^{129}I,
^{137}Cs, ^{239}Pu & ^{133}Xe,
plus an originally
undisclosed quantity
of polonium-210
10 October 1957



Reanalysis now shows that the Windscale radioactive plume passed directly over my school in Ambleside, on 10 Oct, and not to the south or out to sea.

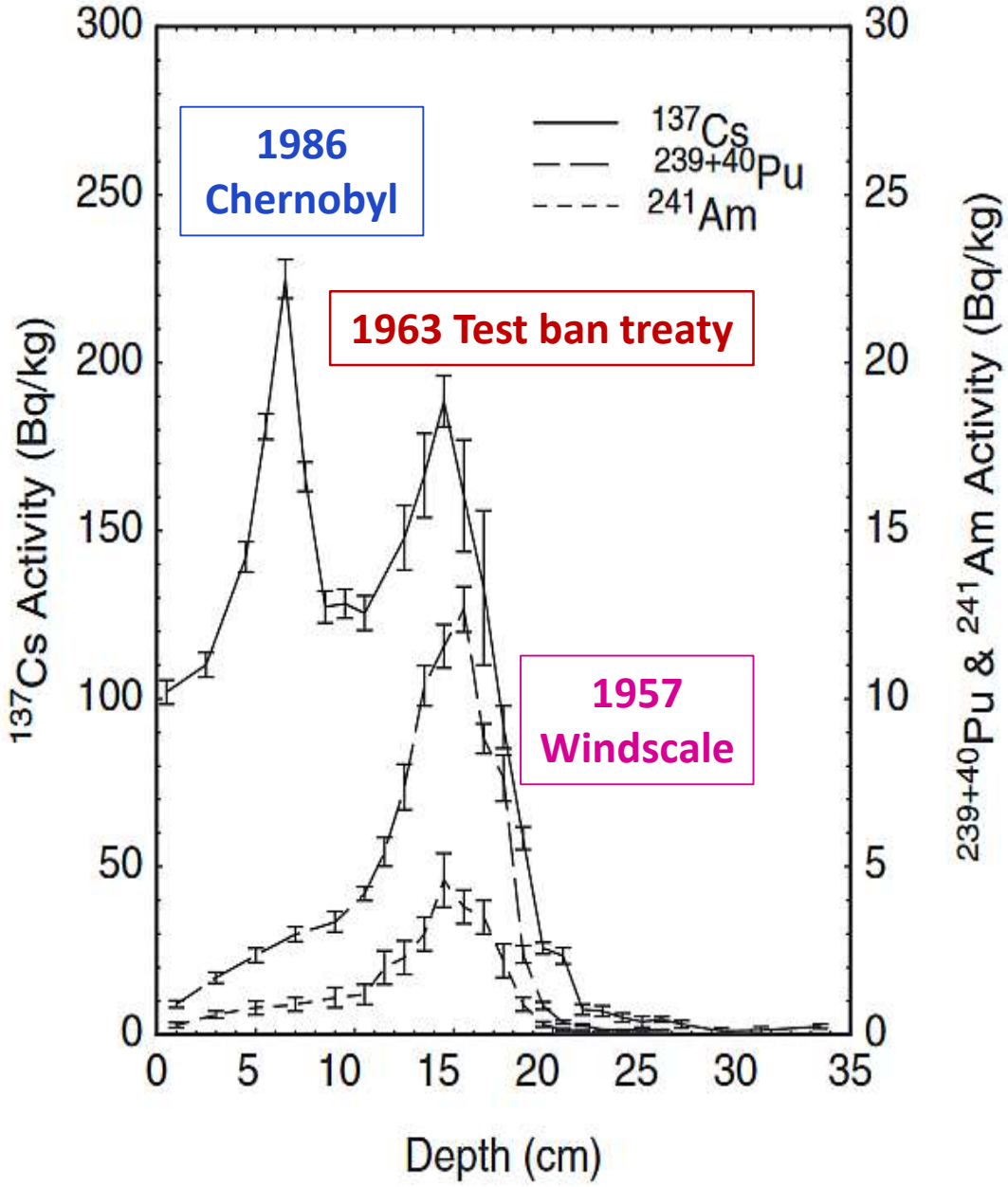


The NCEP/NCAR 40-Year Reanalysis Project:

by Eugenia Kalnay - 1996. **Cited by 26,242**

Reanalysis generates a physically complete estimation of the past state of geophysical systems. It has become a widely used tool in weather and climate.

Distribution of $^{239+240}$Pu, ^{137}Cs and ^{241}Am in the sediments of Belham Tarn




USA
The Yucca Mountain, national geological nuclear waste repository has been indefinitely delayed

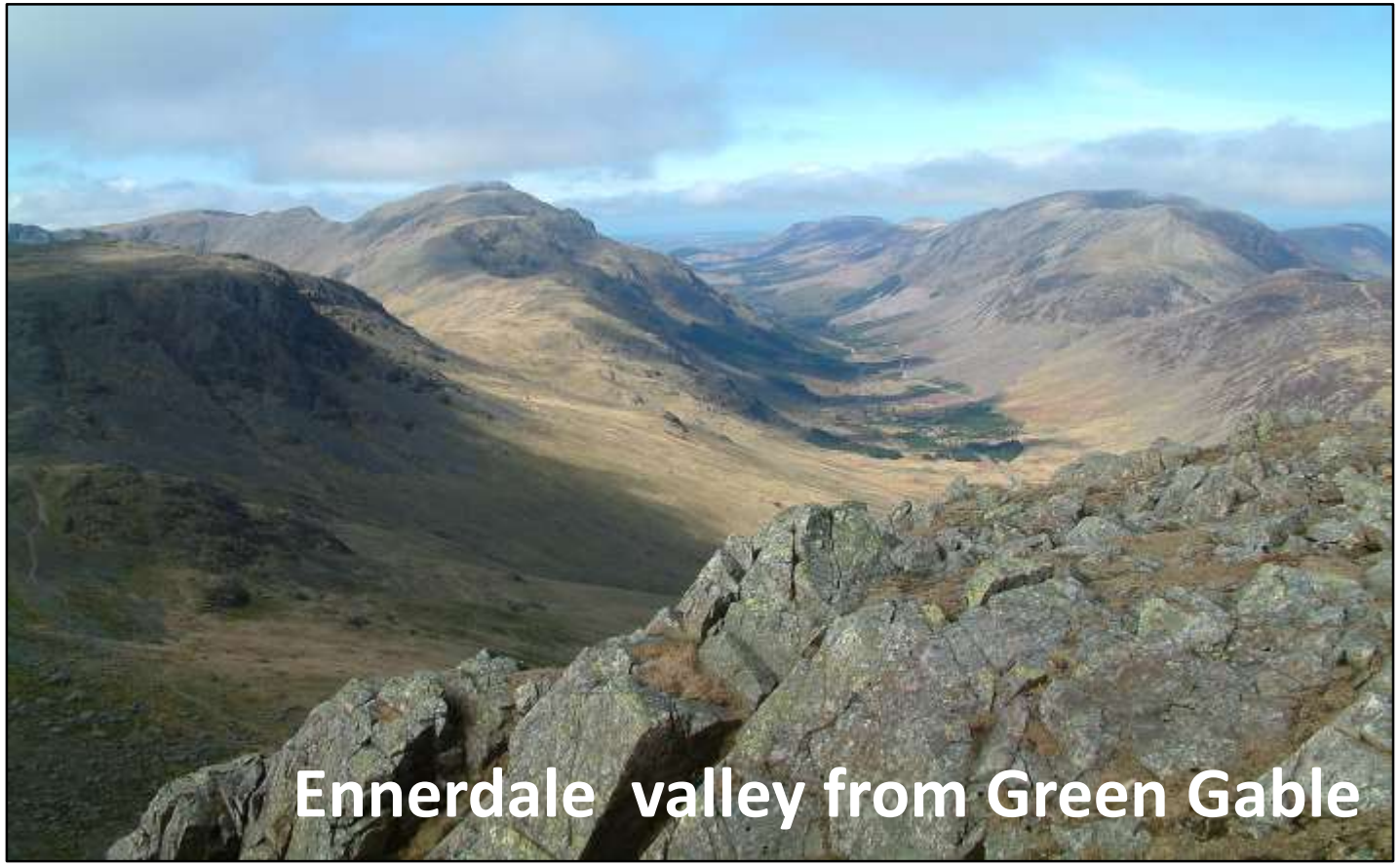
Germany's Nuclear Waste Disaster

126,000 drums of nuclear waste dumped at the Asse II salt mine are now threatened by water leaking through collapsing and cracked walls. The race is on to dig it all up before radioactive residues are flushed to the surface.

UK geological disposal

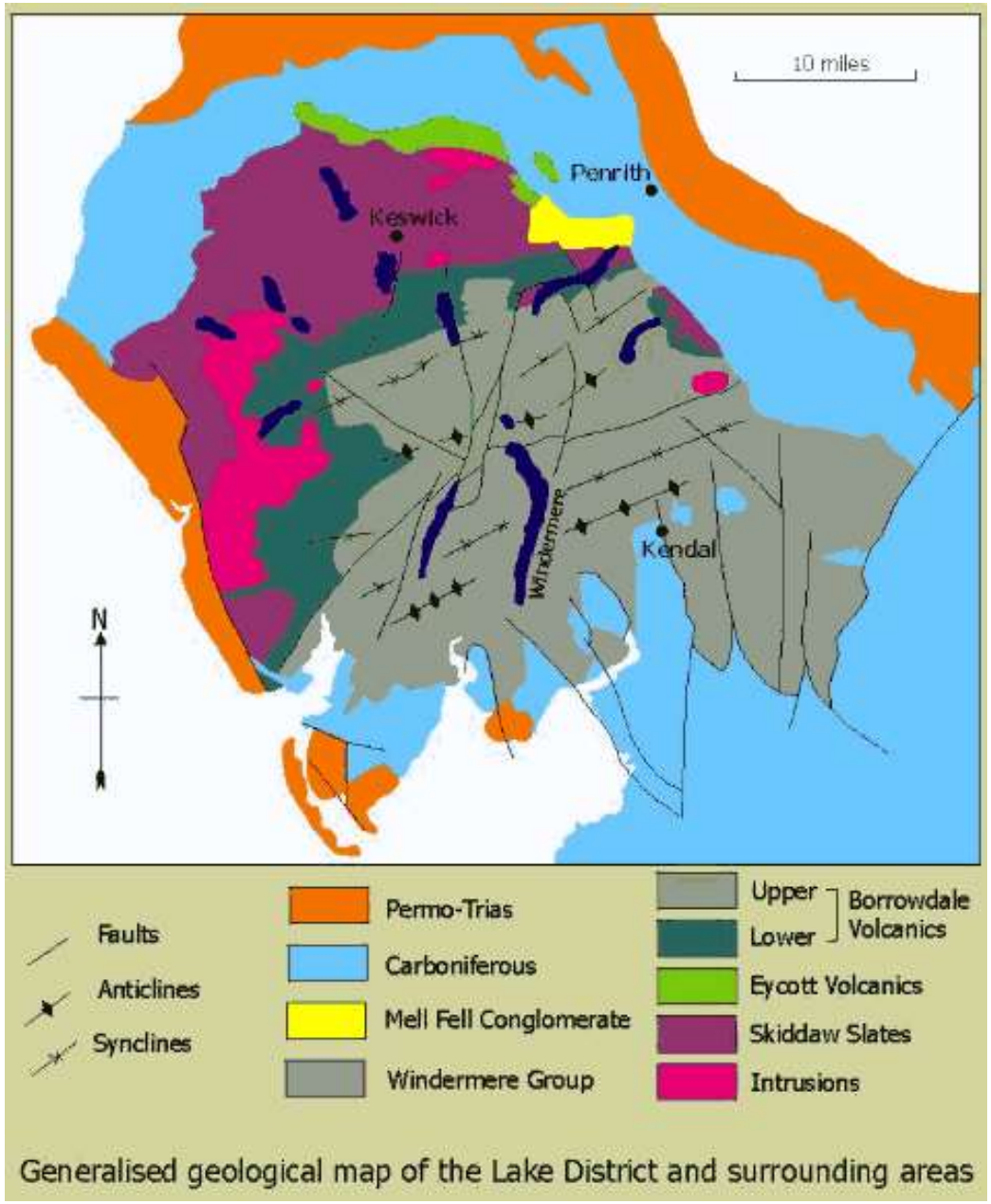
(*'Bury-and-forget'*)

Local communities are being offered £2.5m a year to host underground facilities in a rebooted (2018) government programme.



Ennerdale valley from Green Gable

Unlike other developed countries, the UK has placed the principle of voluntarism ahead of geological suitability.



Generalised geological map of the Lake District and surrounding areas

Scotland: The Government does not support geological disposal.

Its policy is that "*long-term management should be in near-surface facilities*"

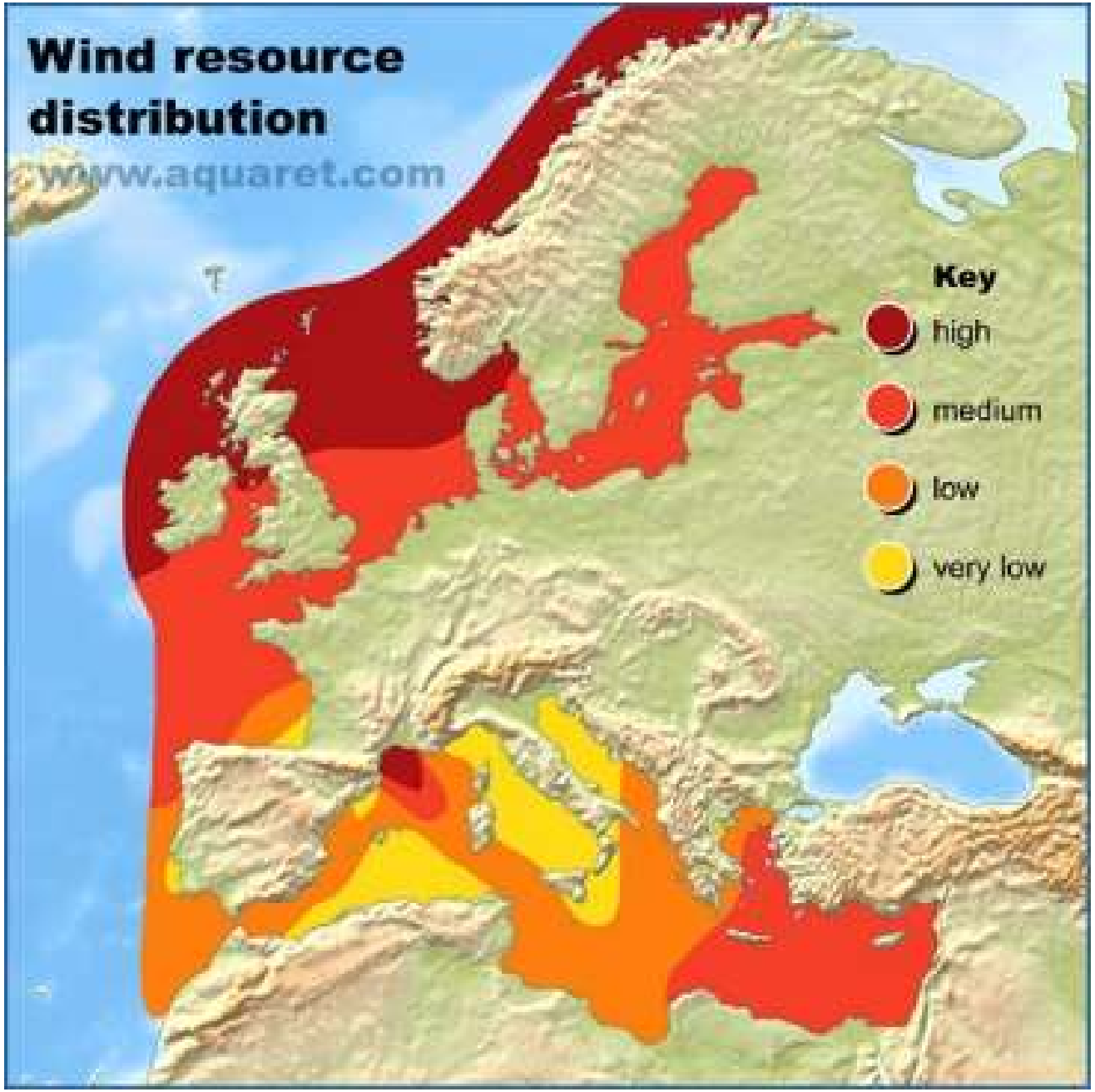
The Press and Journal

"US Air Force flight carrying Dounreay's nuclear waste to South Carolina,

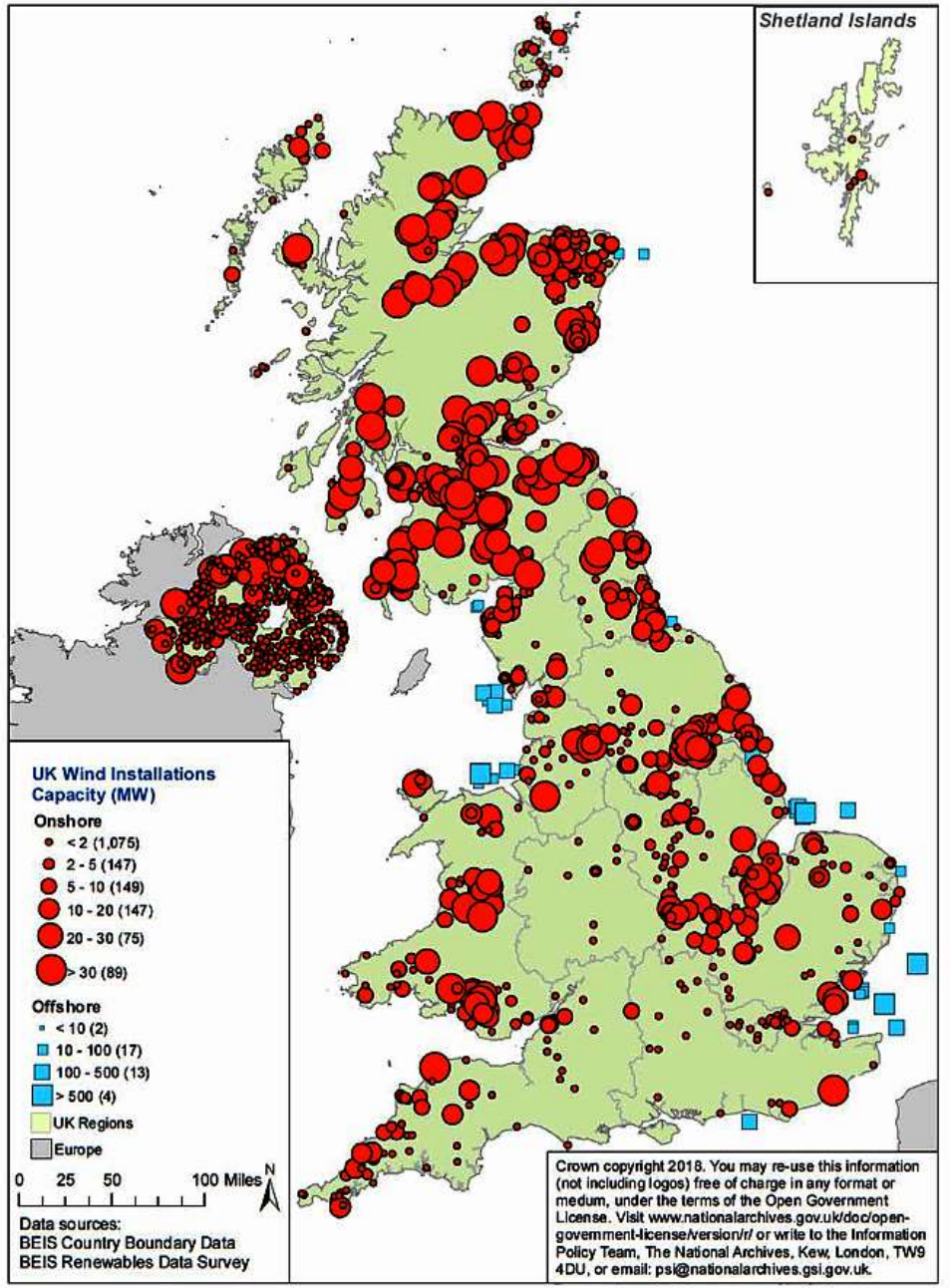
May 7, 2018

Clean energy

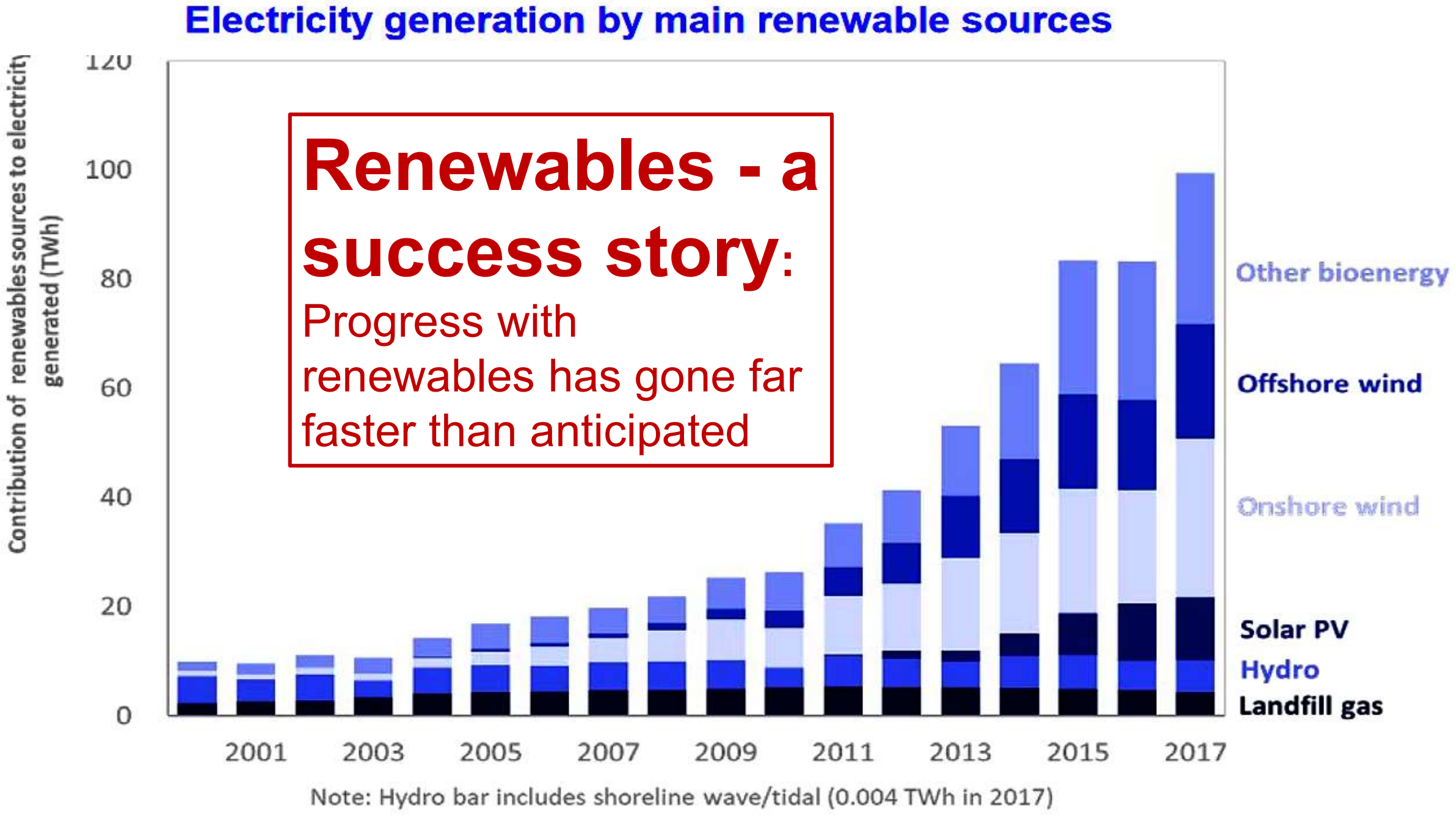
UK's largest onshore windfarm Whitelee 551 MW East Renfrewshire



UK Onshore and Offshore Wind Capacity

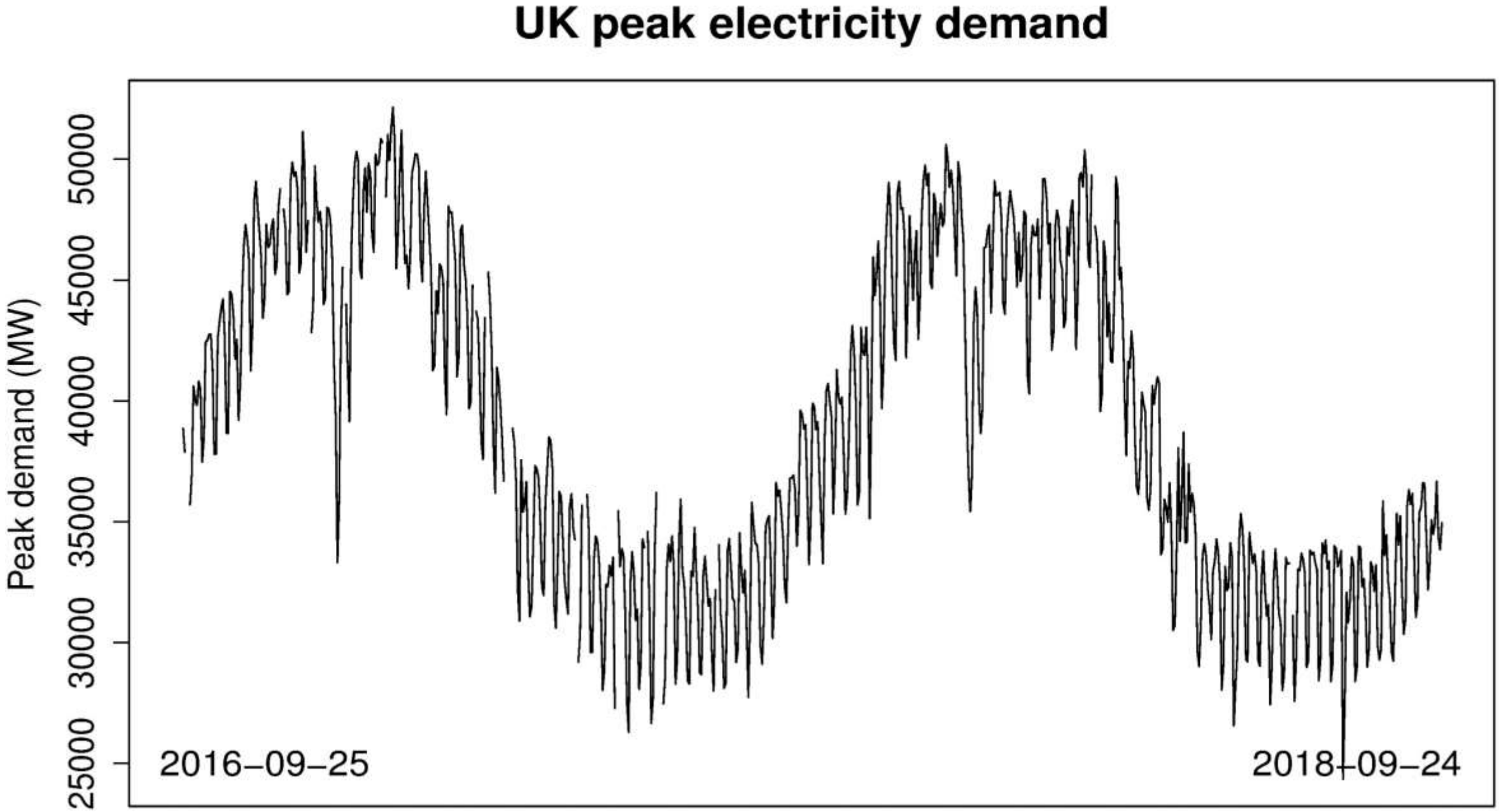



Scotland’s largest solar farm
55,000 panels give 13 MW
Errol Estate in Perthshire

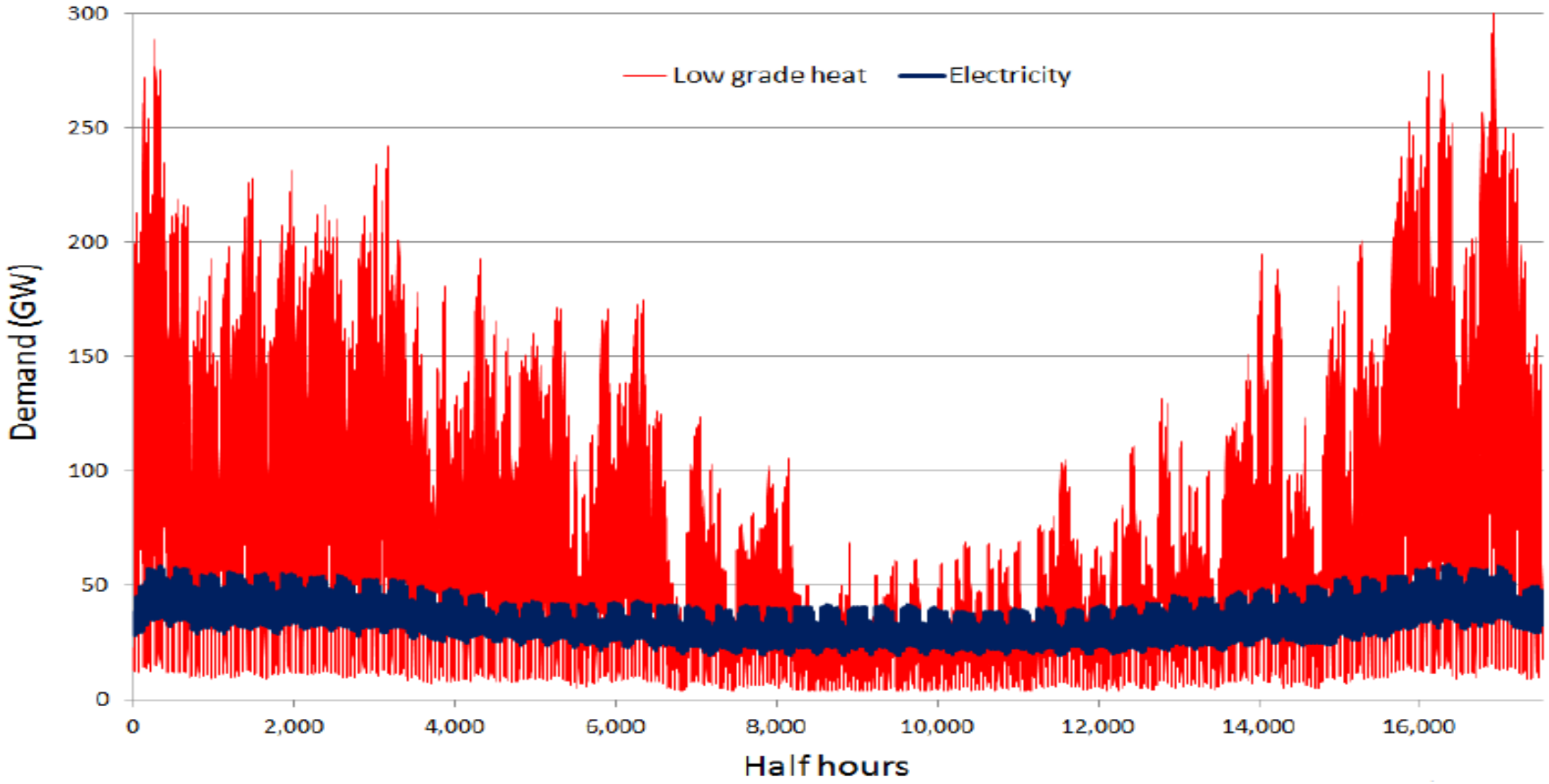


Renewables - a success story:

Progress with renewables has gone far faster than anticipated


UK peak electricity demand
Peak demand (MW)
25000
30000
35000
40000
45000
50000
2016–09–25
2018–09–24

UK half-hourly heat and electricity demand profile - 2010



Heat presents a much bigger problem, with substantial opportunities for storage and demand-side participation

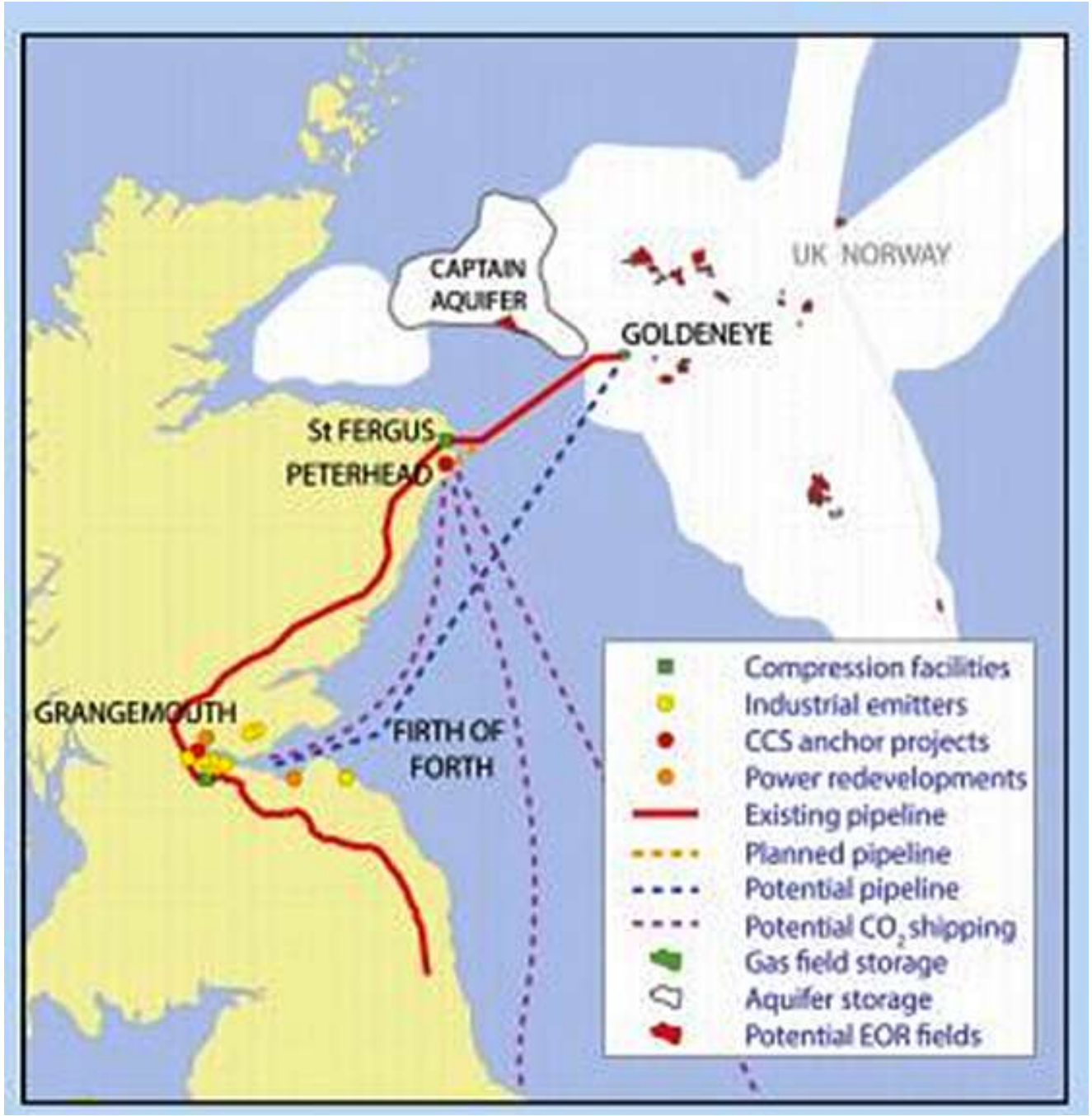

Scottish Ministers have
granted approval of a 400 MW
pumped-storage scheme at the
Glenmuckloch surface coal mine.

Compressed-air storage plant, Huntorf, Germany

A 310,000m^3 cavern at 600m depth, in a converted salt mine, runs on a daily cycle and provides 290MW for 2 hours.

Carbon capture & storage

"Scotland could become Europe's carbon capture and storage hub, building on existing pipelines and offshore infrastructure and saving on oil decommissioning costs."

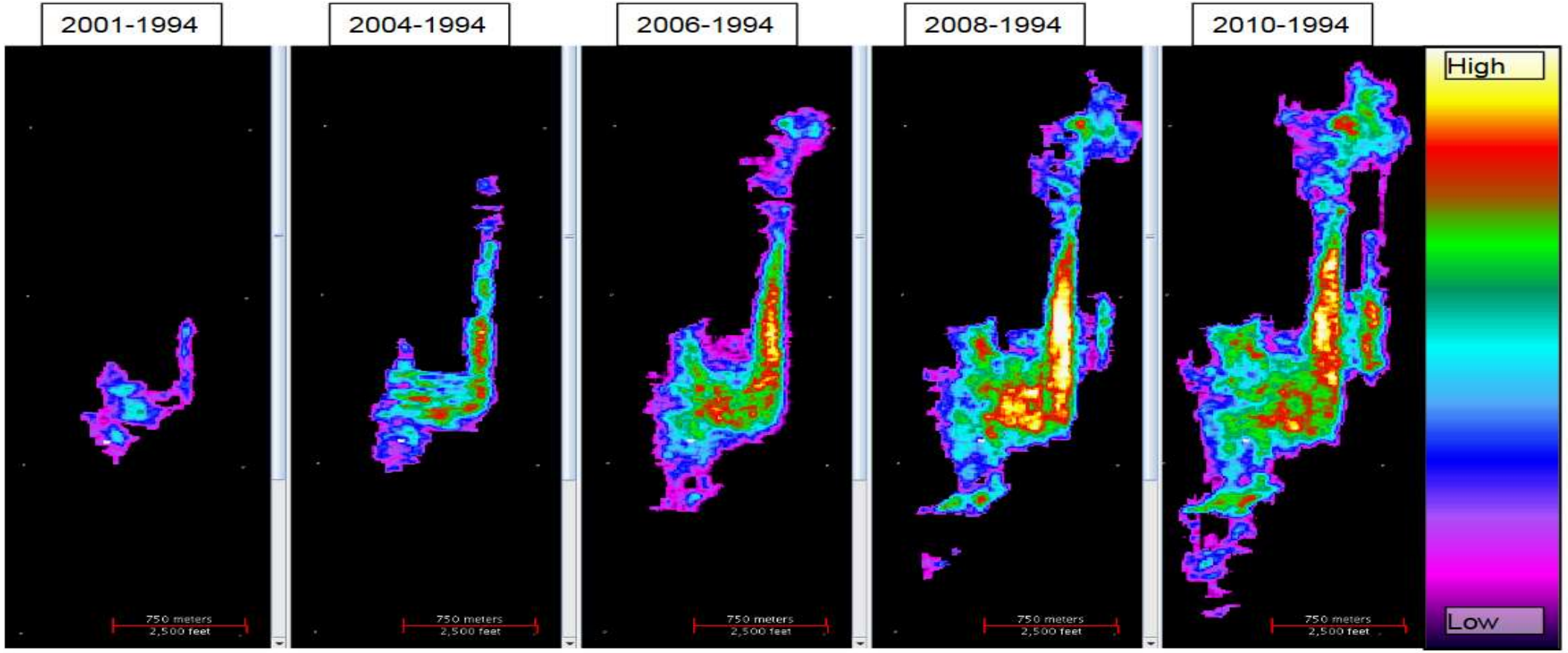


Source: Scottish CO_2 Hub


Century plant, Texas (largest CO_2 capture & usage facility in North America) 5 Mt/yr used for EOR projects throughout the Permian Basin.
Carbon Capture Facility
Cogeneration Plant (power for CCS system)
Cooling Tower
Flue Gas Duct

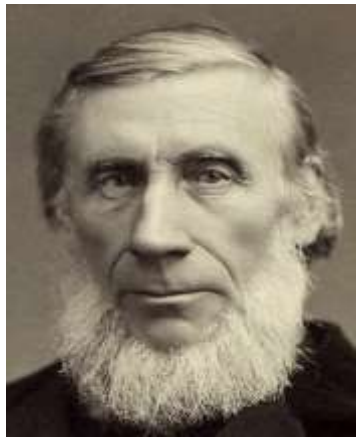
22 years of successful operations at Sleipner

CO_2 plume - 4D seismic



Seismic time-lapse monitoring shows that CO_2 stays in place in the Utsira Fm at Sleipner and gives a detailed description of where the CO_2 is

The basic climate-change problem

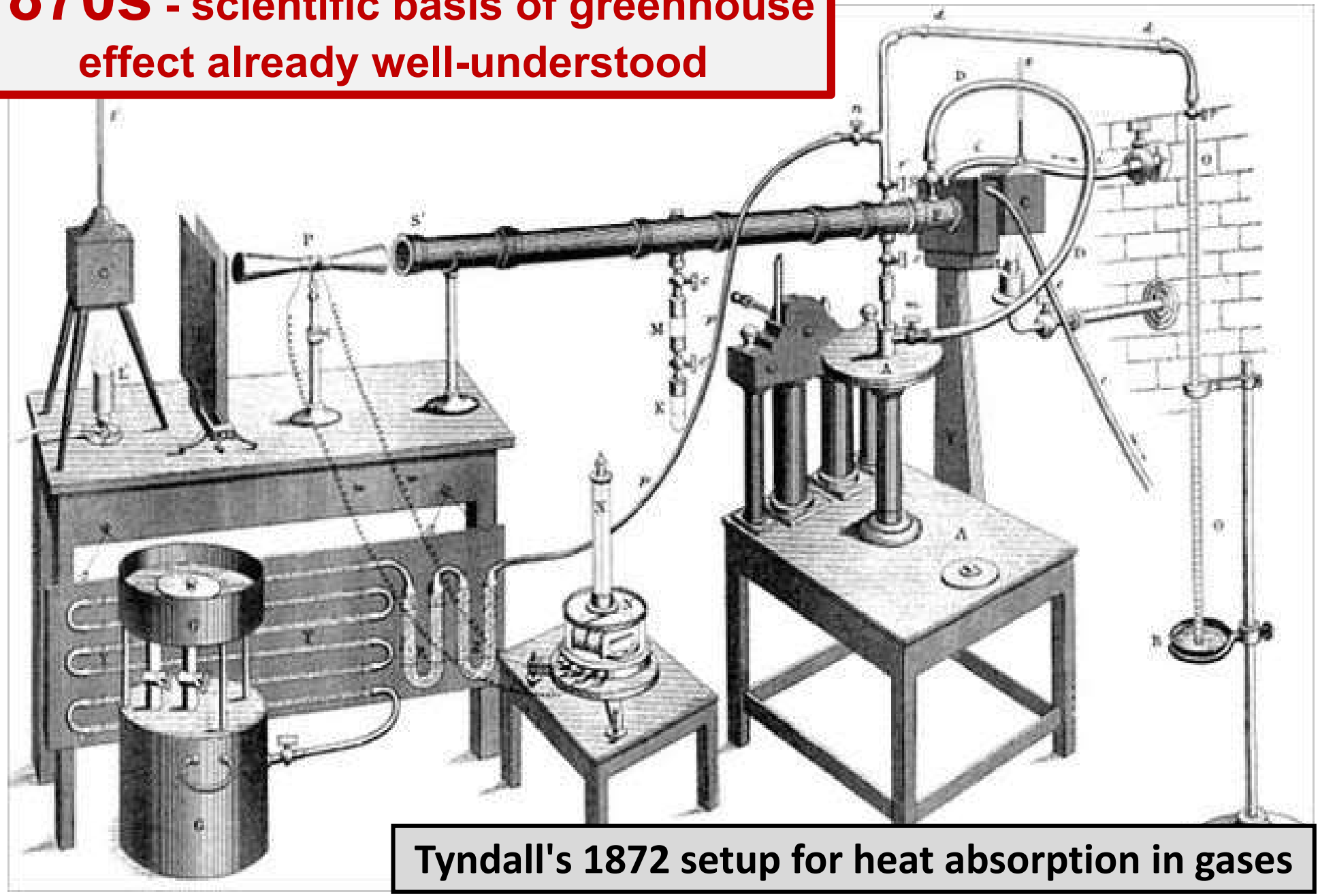


Tyndall

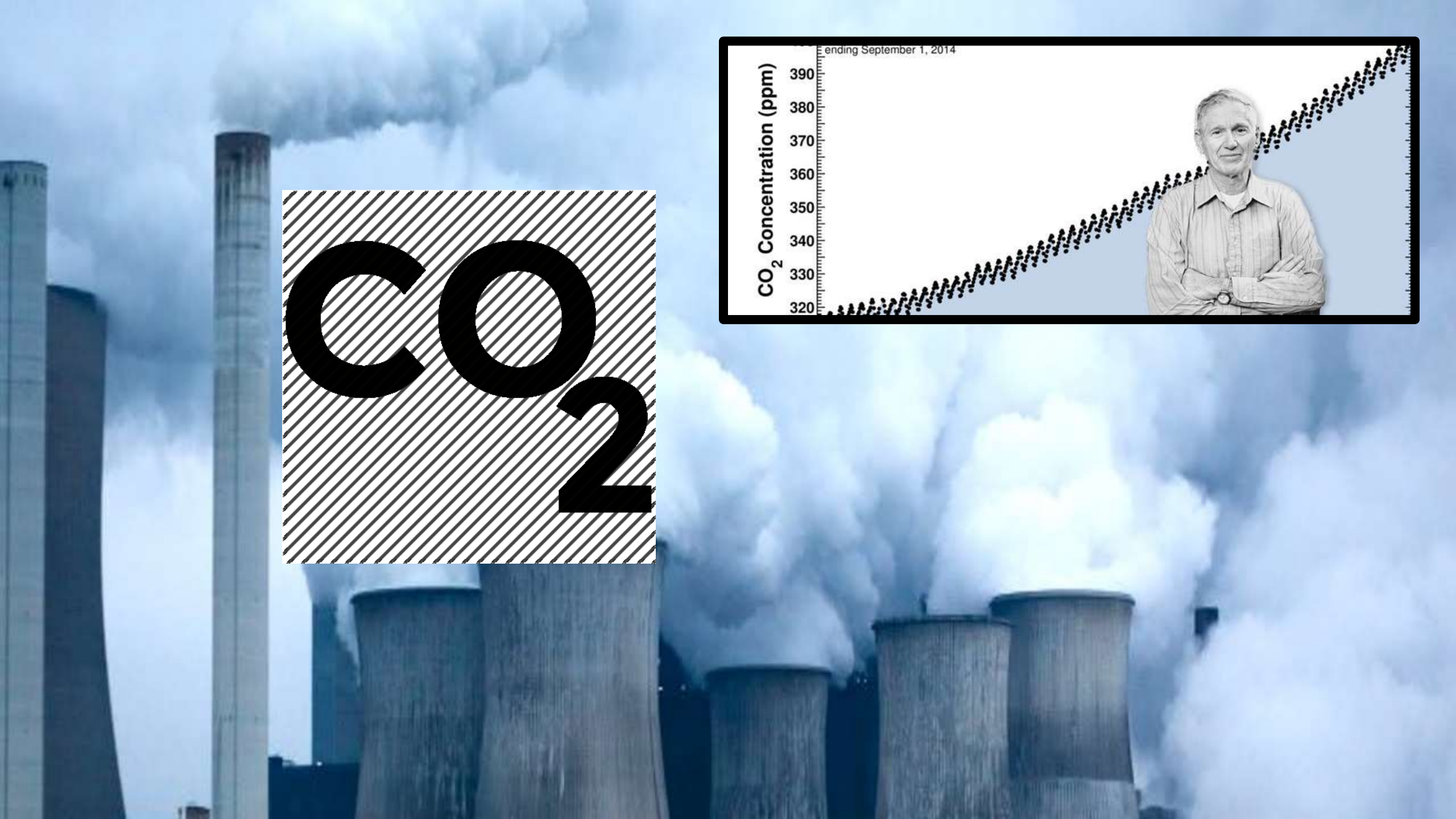
1870s - scientific basis of greenhouse effect already well-understood

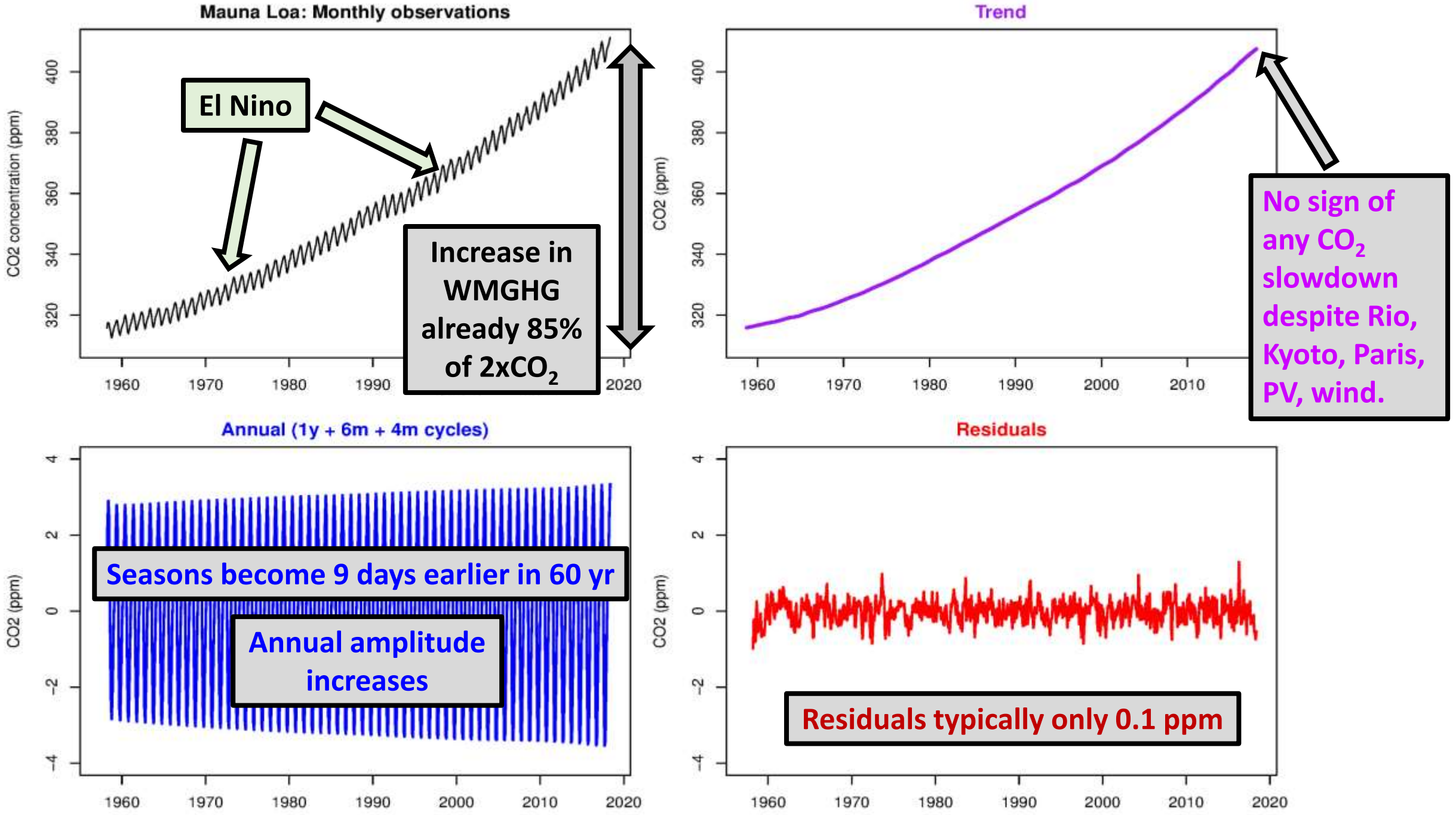
Croll

Arrhenius

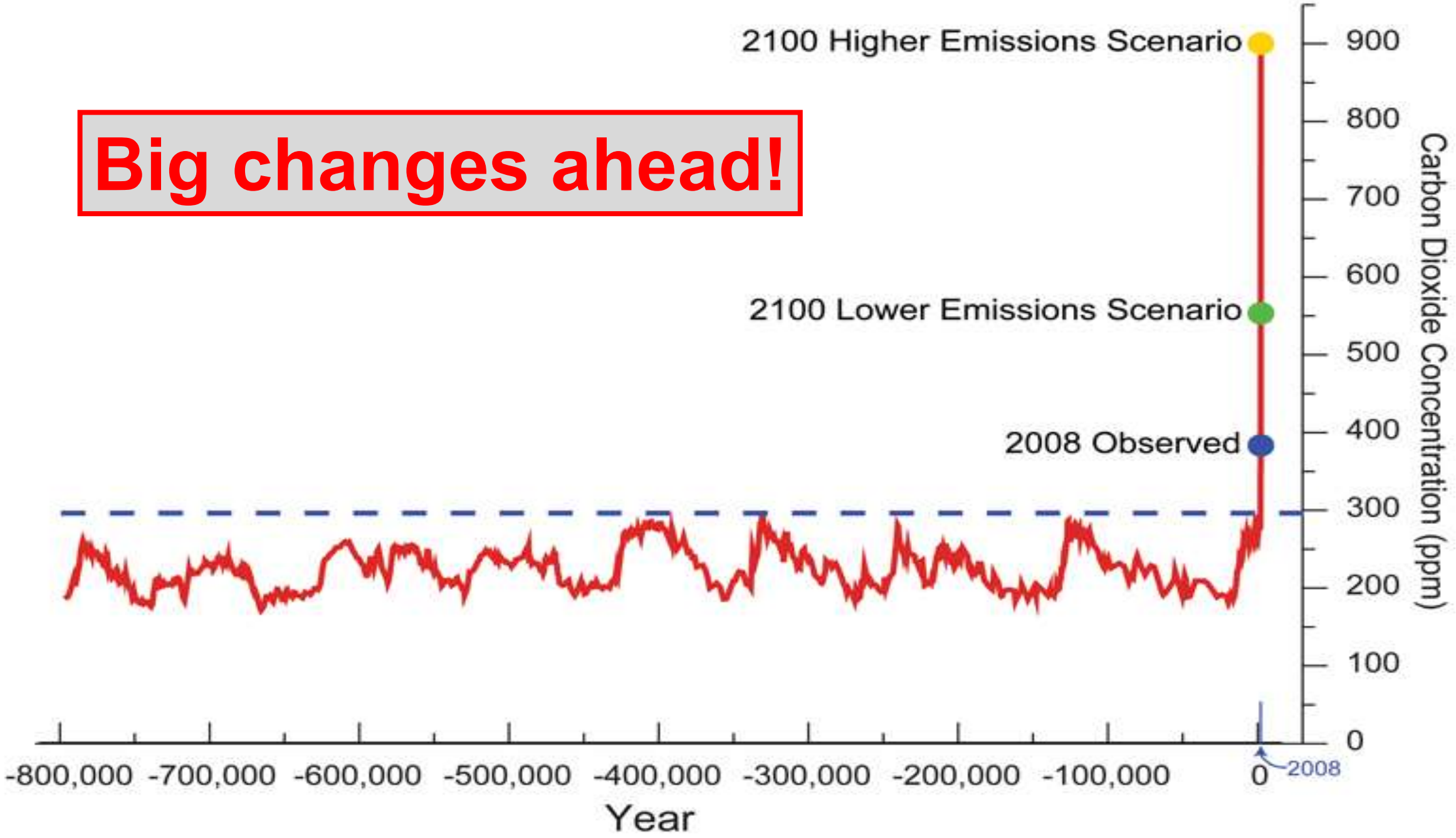


Tyndall's 1872 setup for heat absorption in gases

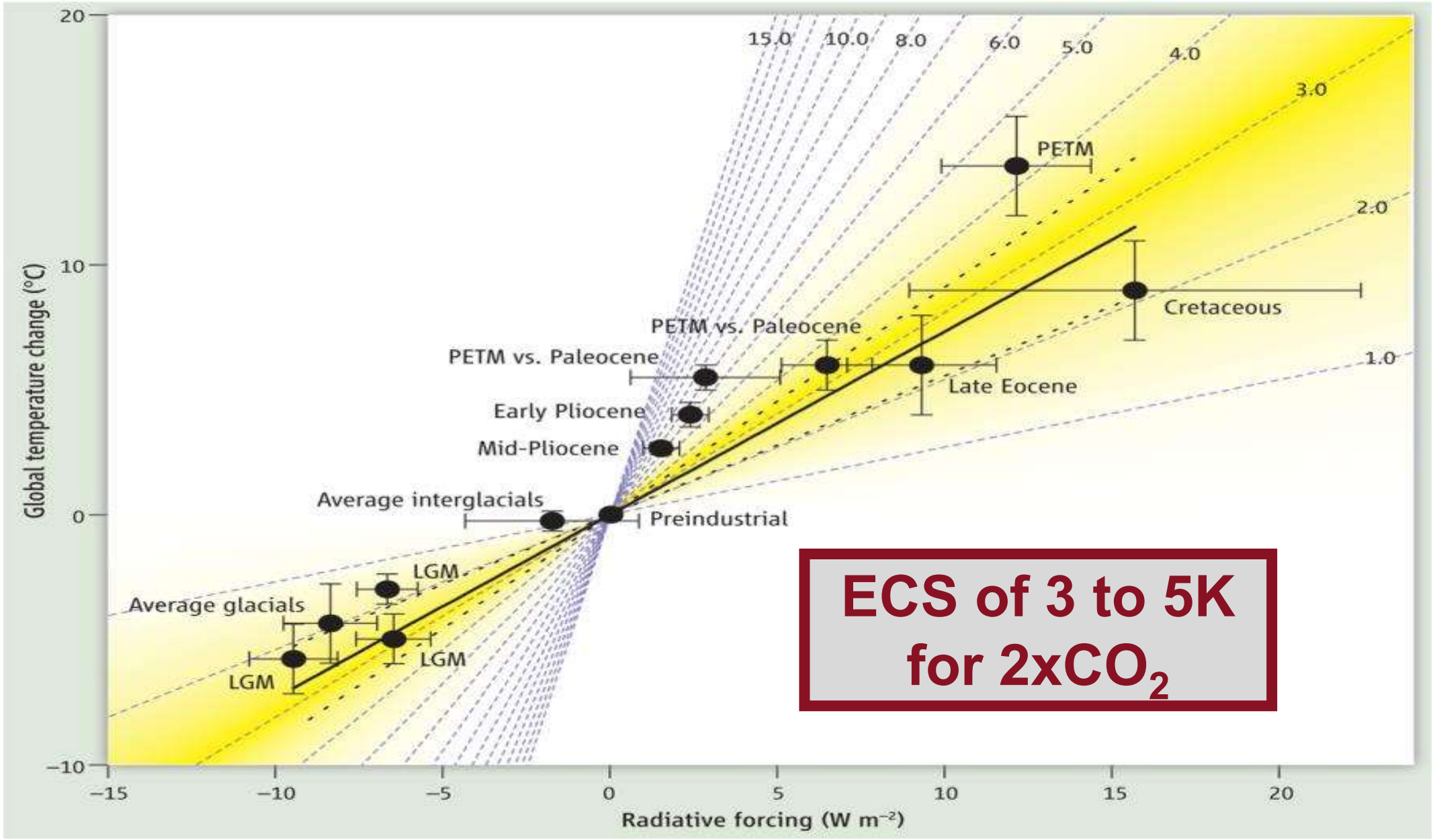

CO_2
ending September 1, 2014
CO_2 Concentration (ppm)
390
380
370
360
350
340
330
320


Mauna Loa: Monthly observations
CO2 concentration (ppm)
320
340
360
380
400
1960
1970
1980
1990
2020
El Nino
Increase in WMGHG already 85% of 2xCO2
CO2 (ppm)
Trend
2000
2010
No sign of any CO2 slowdown despite Rio, Kyoto, Paris, PV, wind.
Annual (1y + 6m + 4m cycles)
Seasons become 9 days earlier in 60 yr
Annual amplitude increases
Residuals
Residuals typically only 0.1 ppm

Big changes ahead!



Climate Sensitivity Estimated From Earth's Climate History



Antarctic ice: the world's air museum

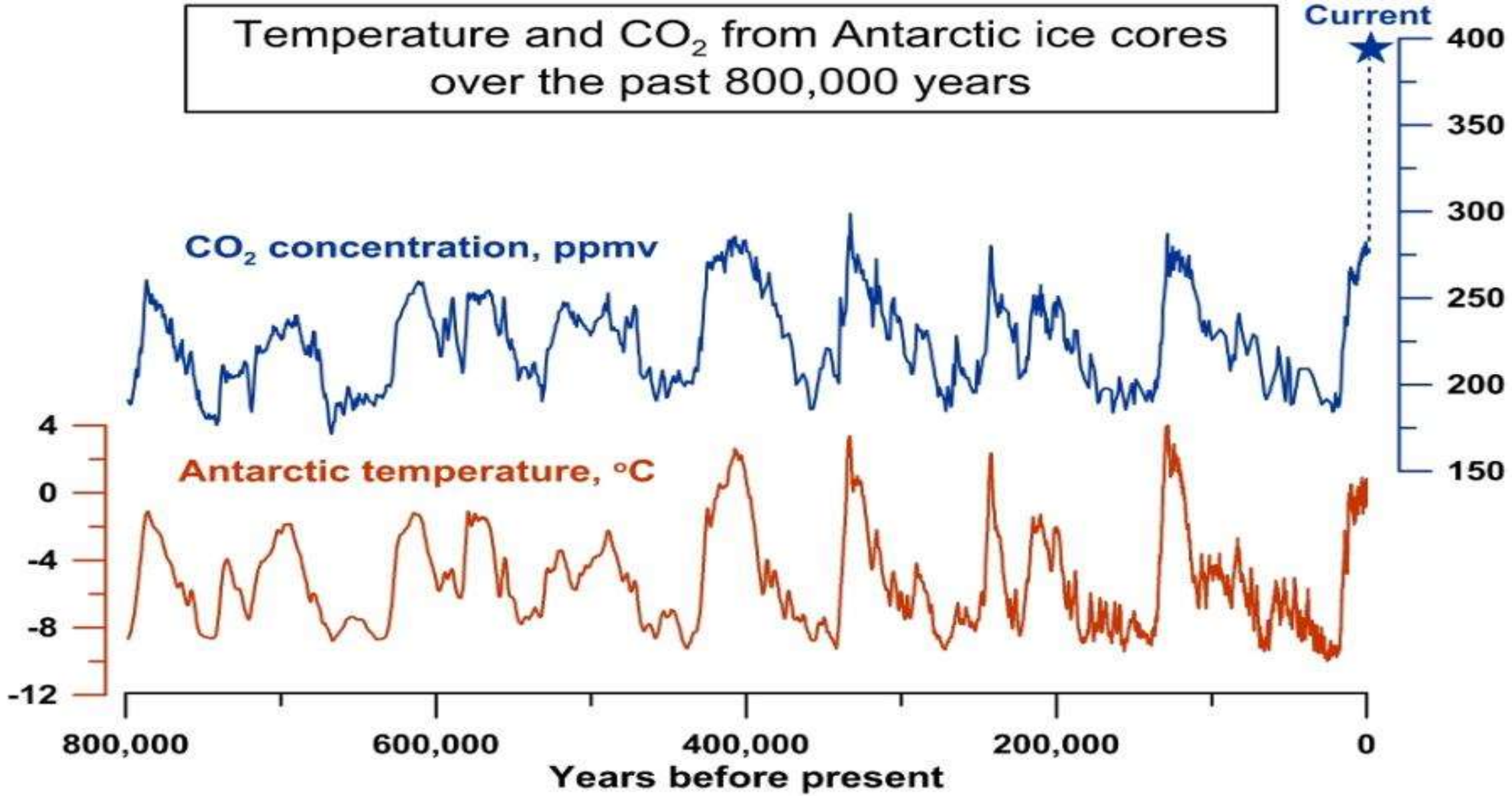
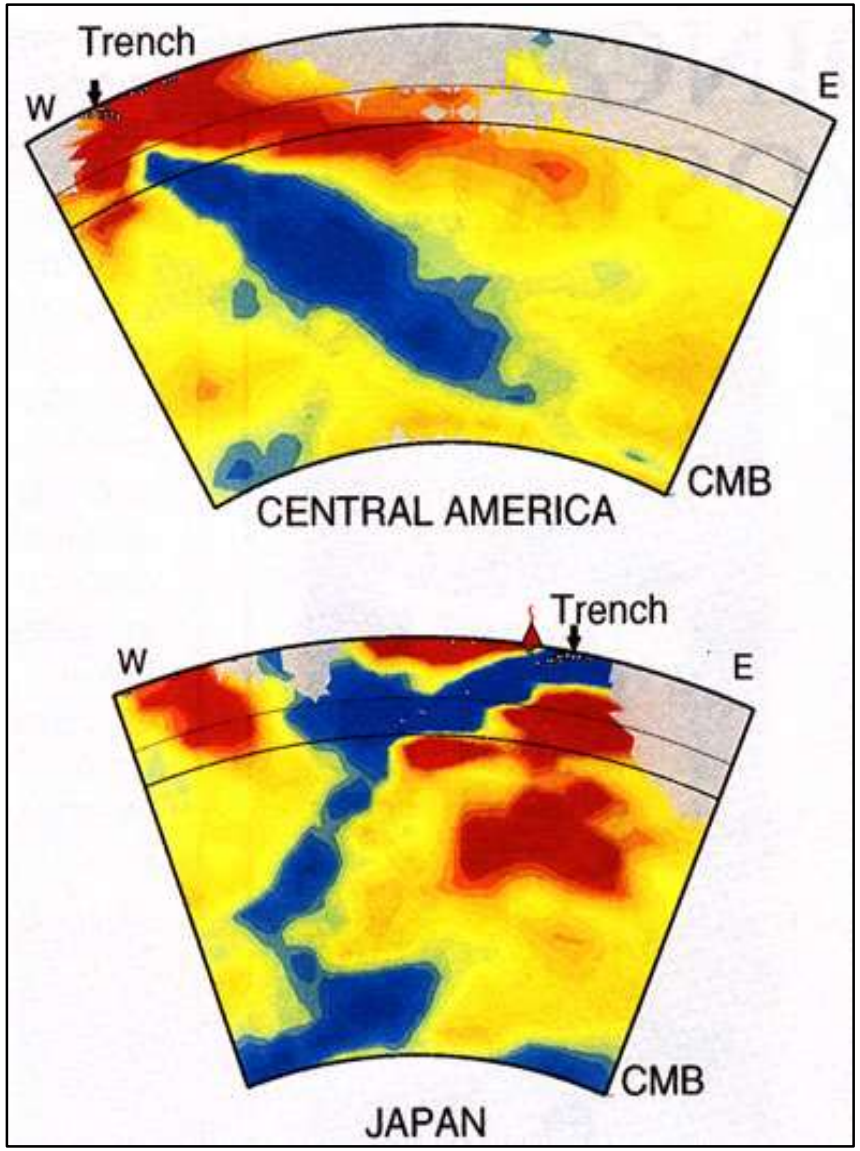
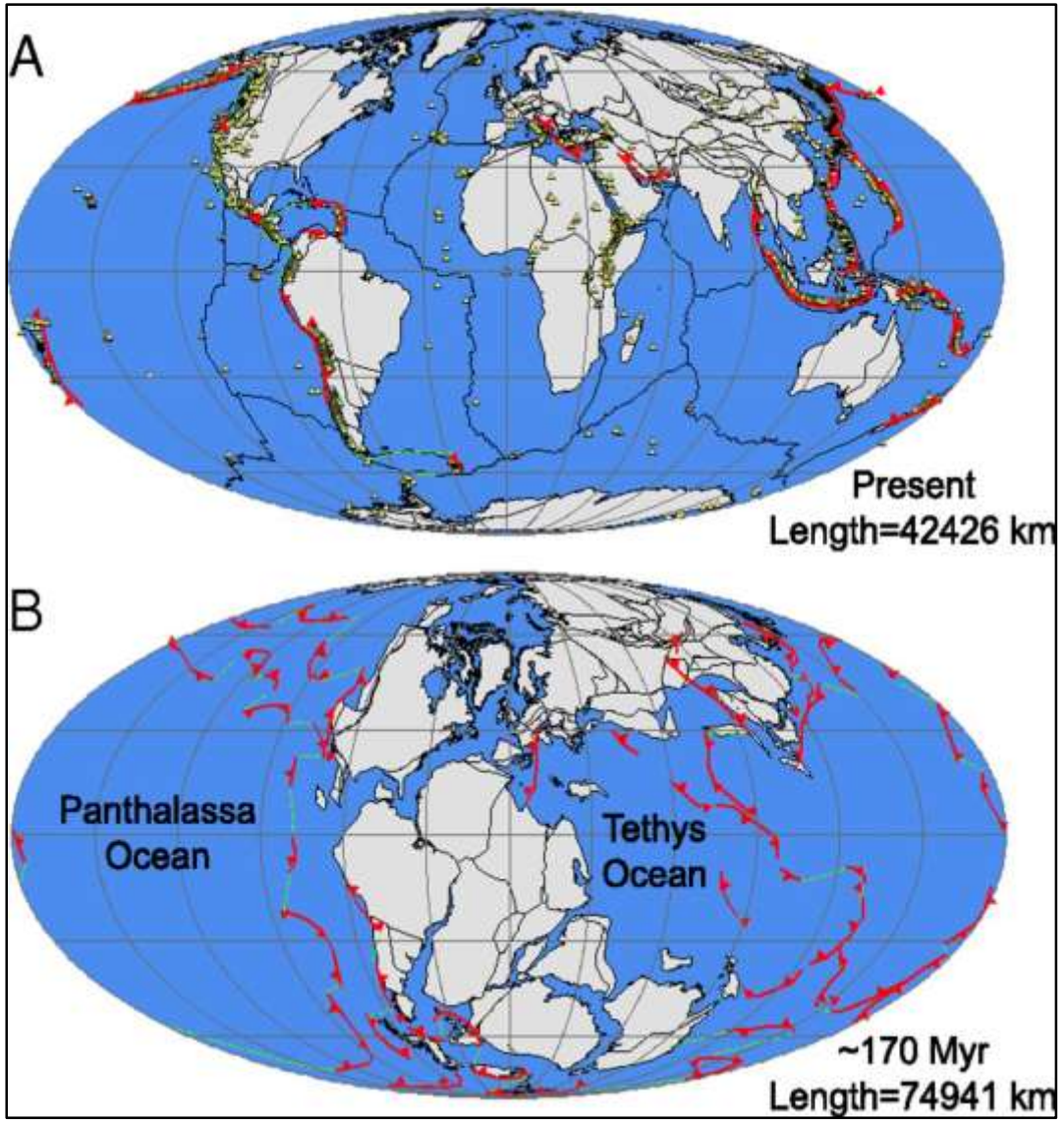


Plate tectonic controls on atmospheric CO_2 levels






Met Office
New supercomputer 2012
Photo © timpestridge.co.uk

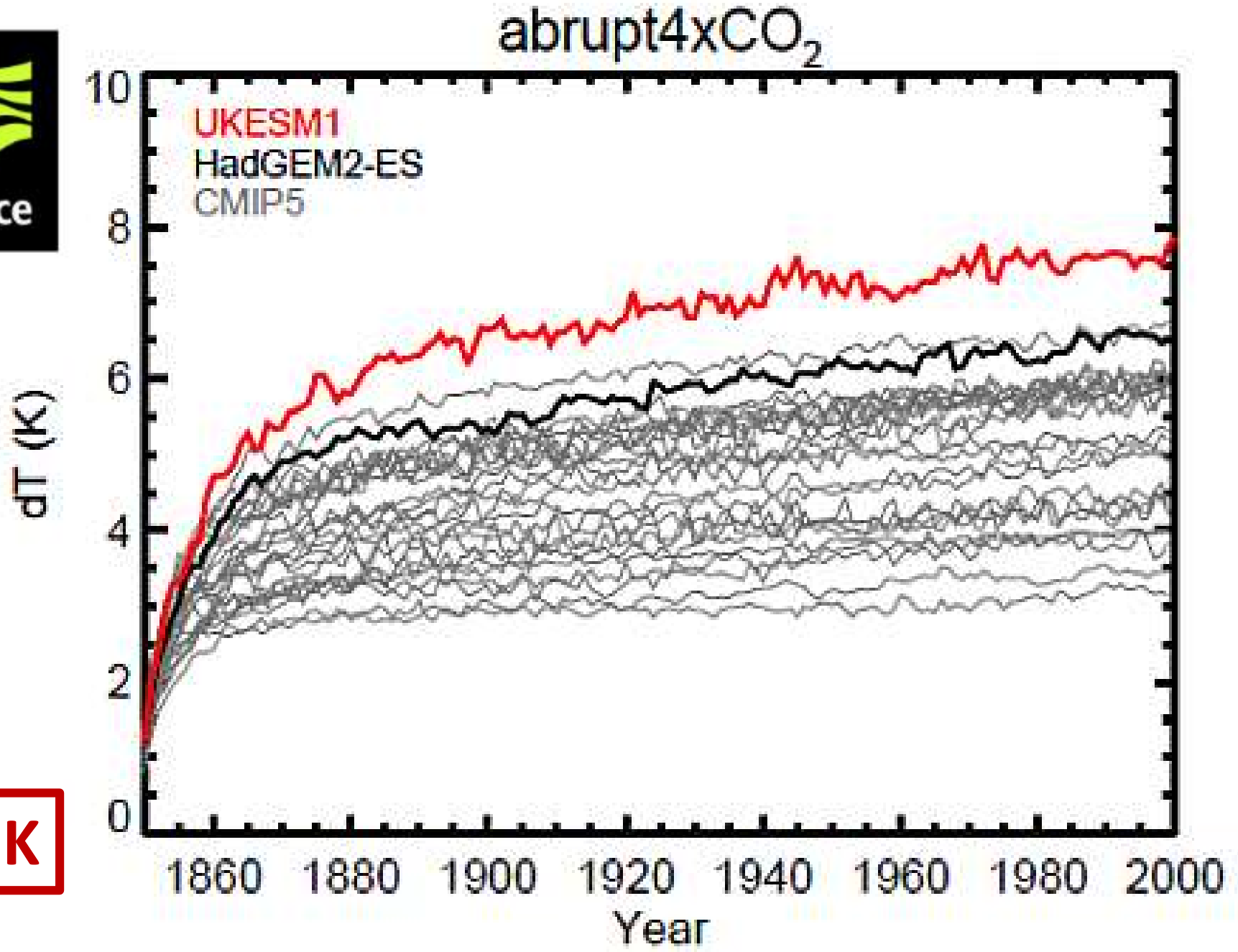
National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

NERC SCIENCE OF THE ENVIRONMENT

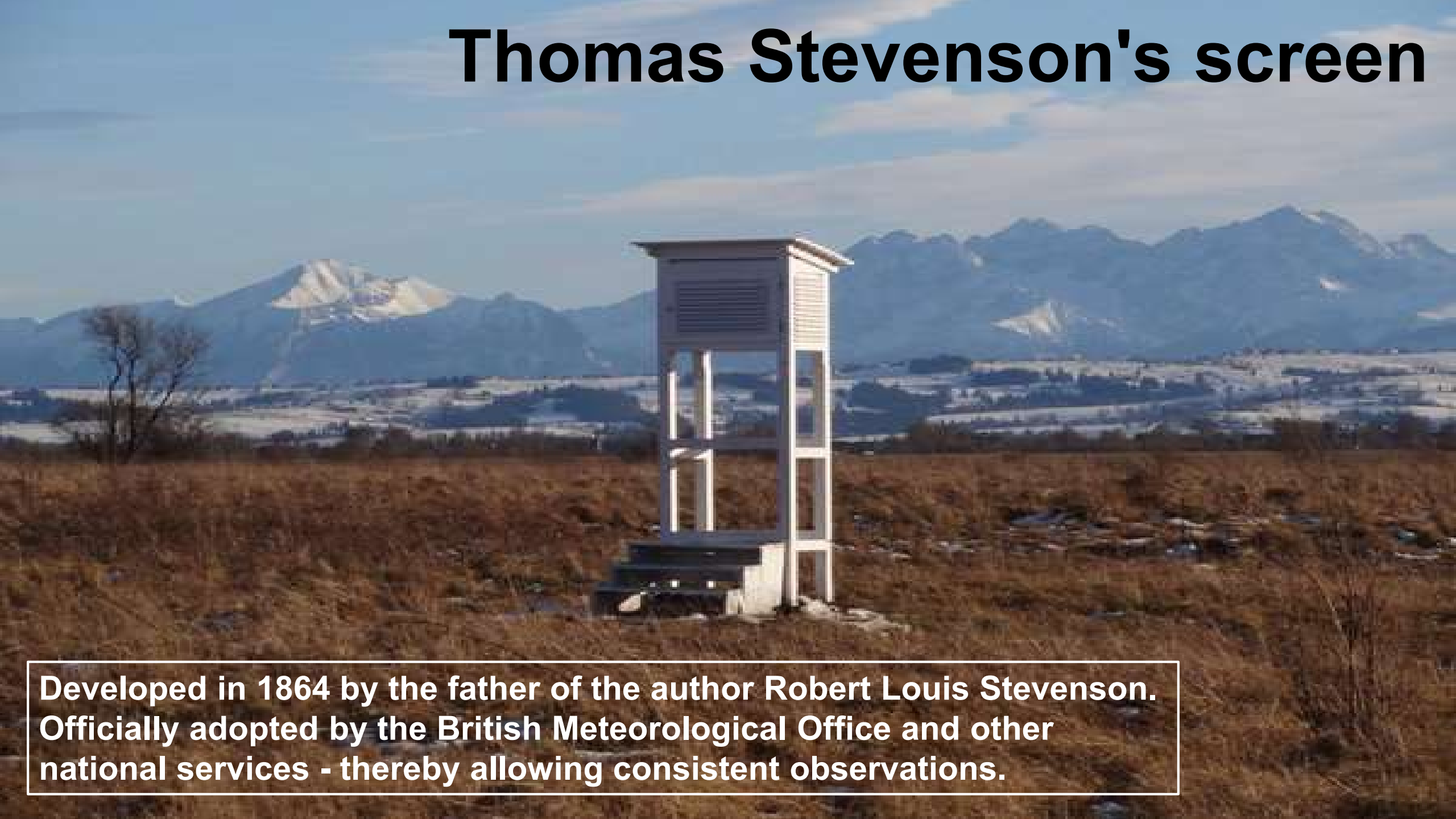
Met Office

Abrupt 4xCO_2 Experiment

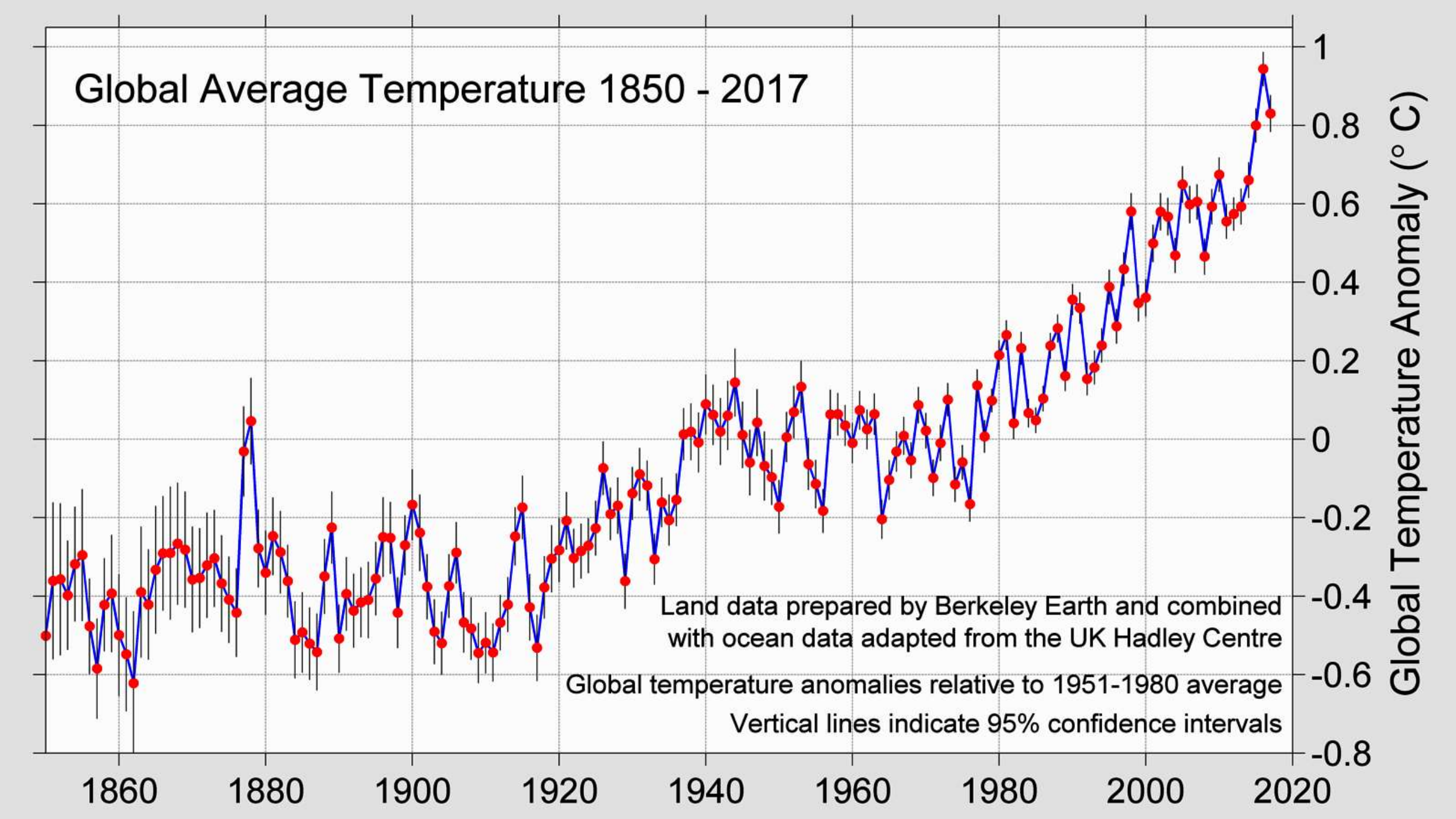
UKESM1 ECS ~ 5.2K



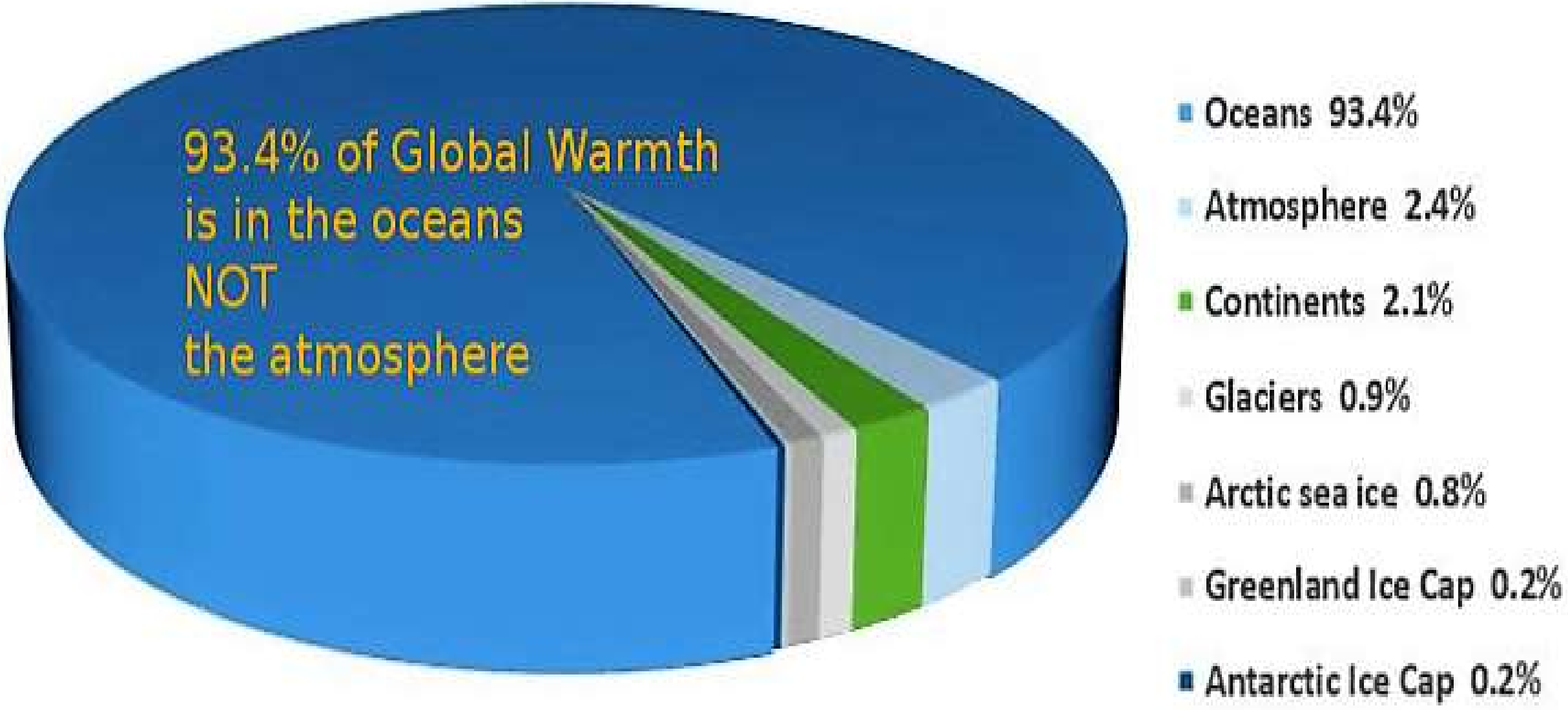
Thomas Stevenson's screen



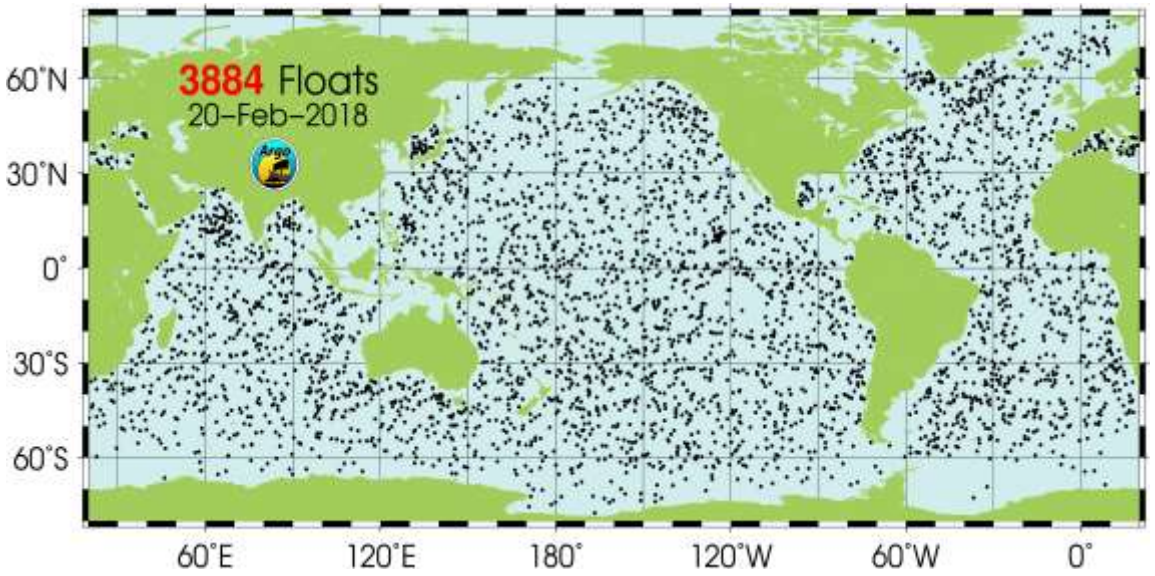
Developed in 1864 by the father of the author Robert Louis Stevenson. Officially adopted by the British Meteorological Office and other national services - thereby allowing consistent observations.

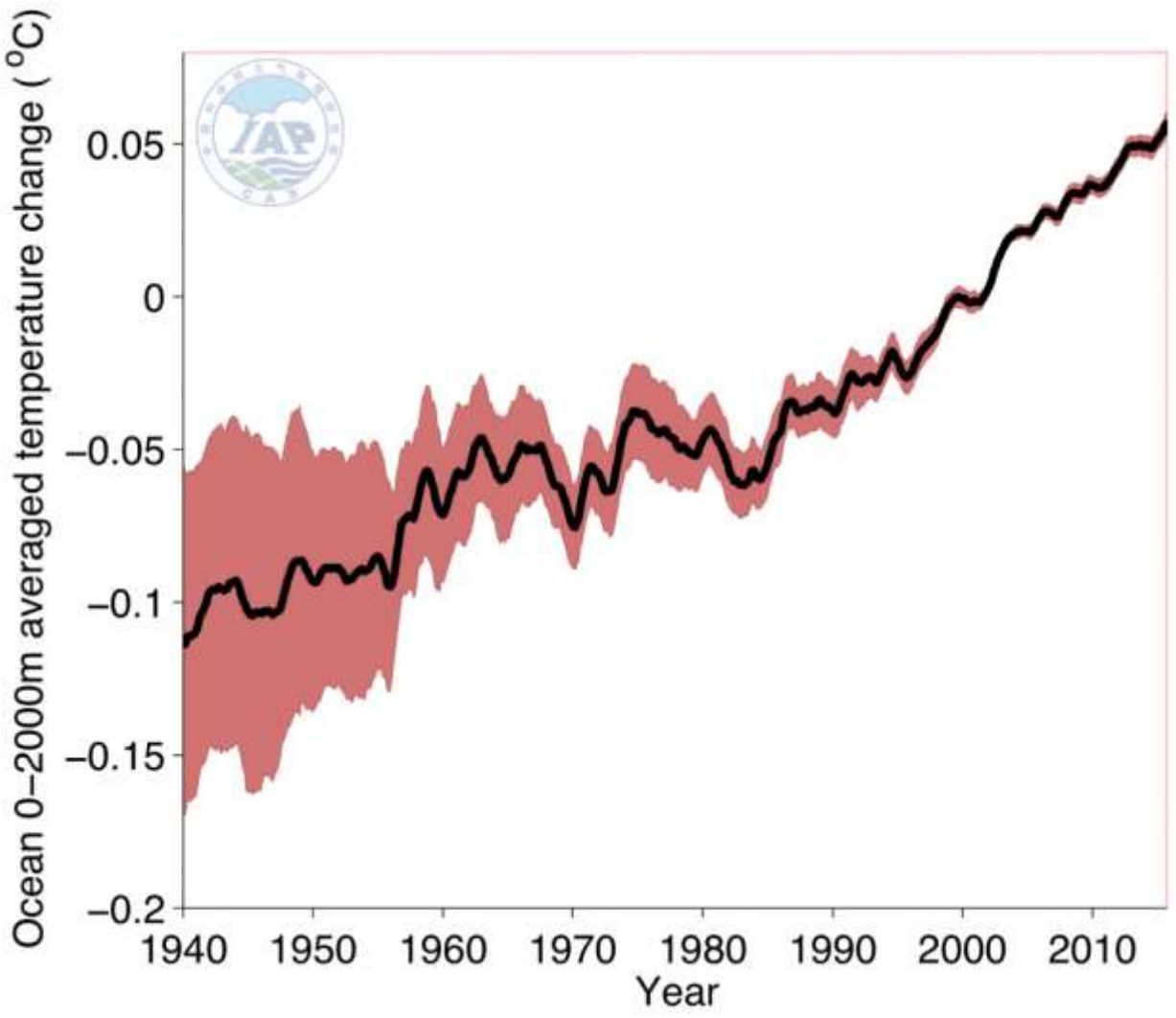

Global Average Temperature 1850 - 2017
Land data prepared by Berkeley Earth and combined
with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1951-1980 average
Vertical lines indicate 95% confidence intervals
Global Temperature Anomaly (° C)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1860
1880
1900
1920
1940
1960
1980
2000
2020

Where is global warmth going?

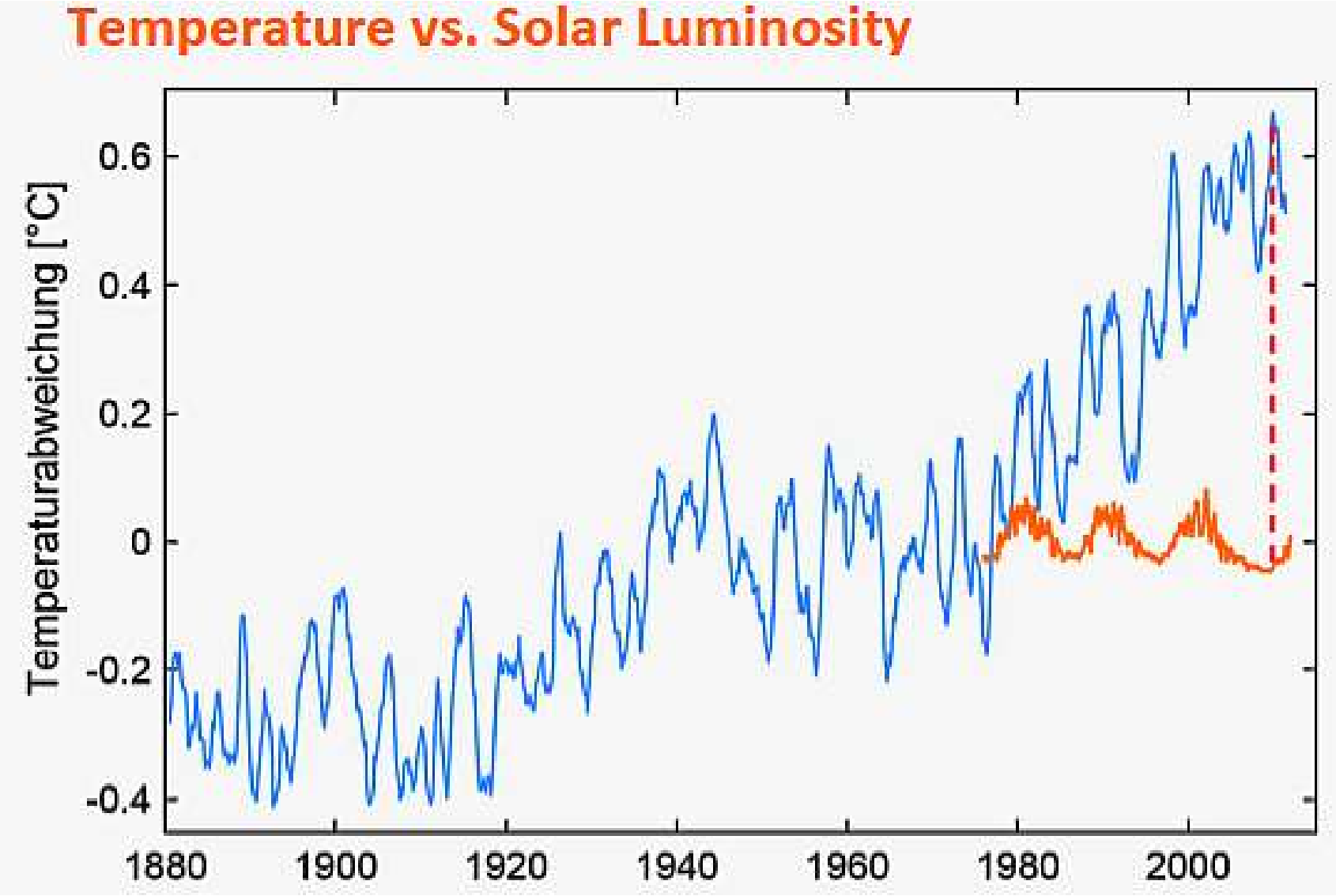


Argo a global array of 4,000 free-drifting floats measuring ocean temperatures.



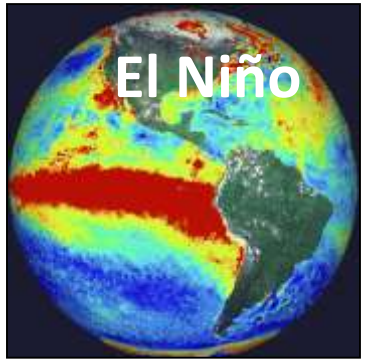


Modern space-borne observations (daily, 1976-2017) do not support the old idea of changing solar output contributing to accelerated global warming.



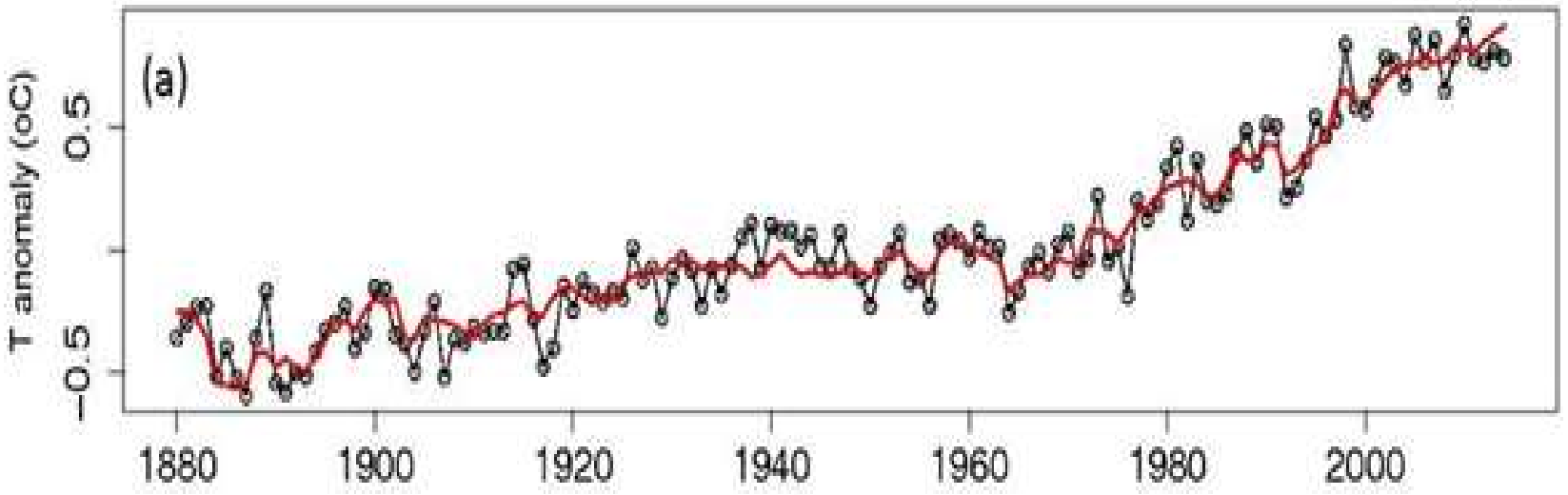
A Simple Energy Balance Model of Climate

$$C\,dT/dt + \lambda T = F(t)$$

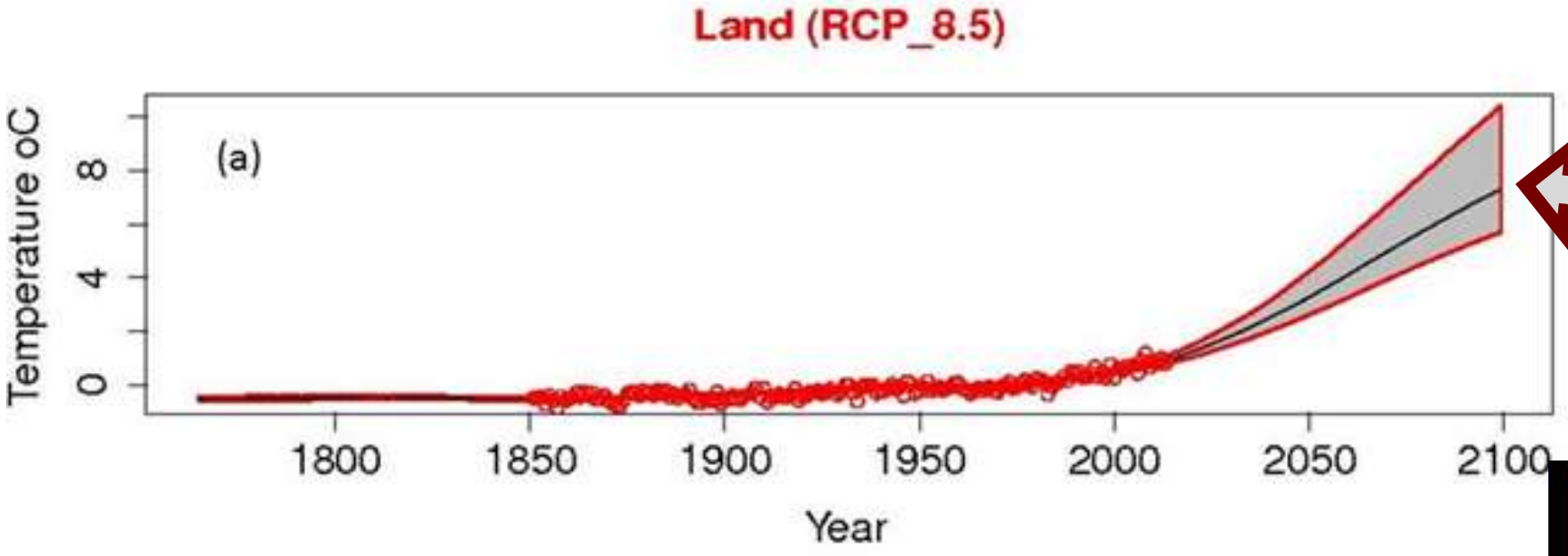


The 1st law of thermodynamics allows the key parameter of climate sensitivity, along with Earth's heat storage capacity, to be estimated directly from changes in historical temperature and energy flux

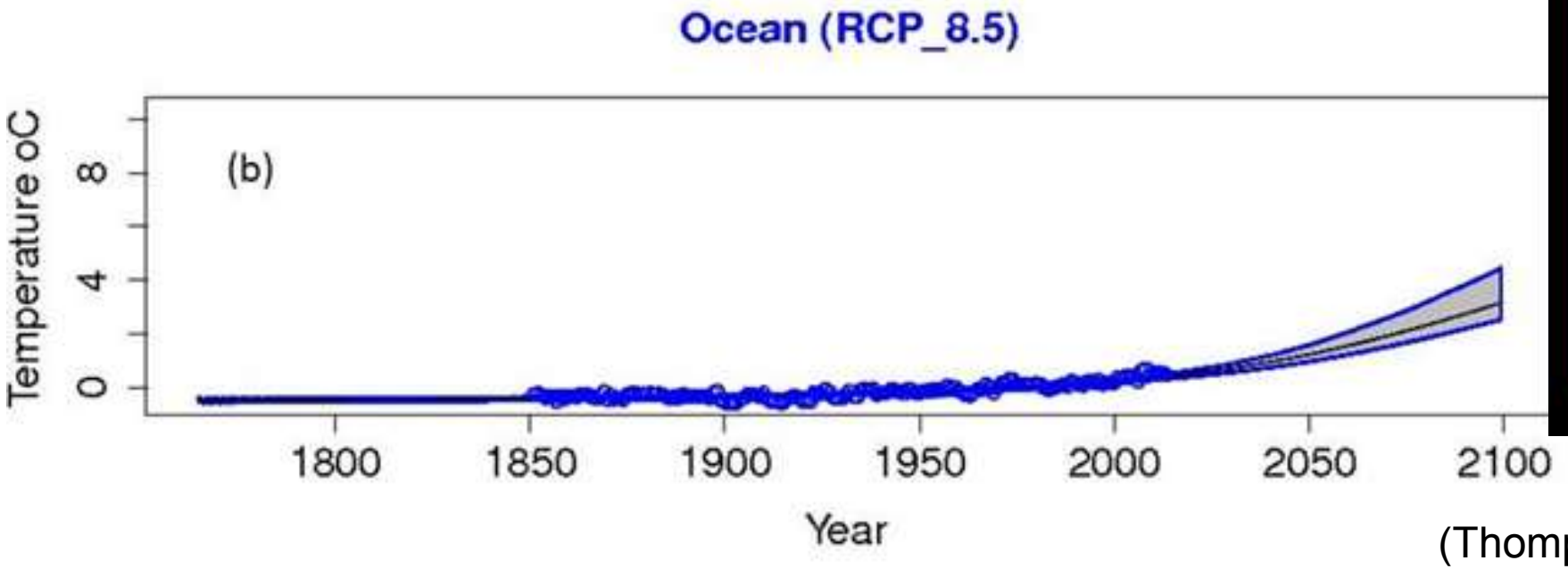
Temperature ~ Greenhouse gases + aerosols + ENSO + Volc



(Thompson, Trans. R. Soc. Ed., 2015)



Land +7.9K by 2100



My 'purely' data driven estimate of climate sensitivity (x2 CO_2) is

+4°C

with 95% confidence intervals of

3.0 to 6.3°C

(Thompson Trans. R. Soc. Ed., 2015)

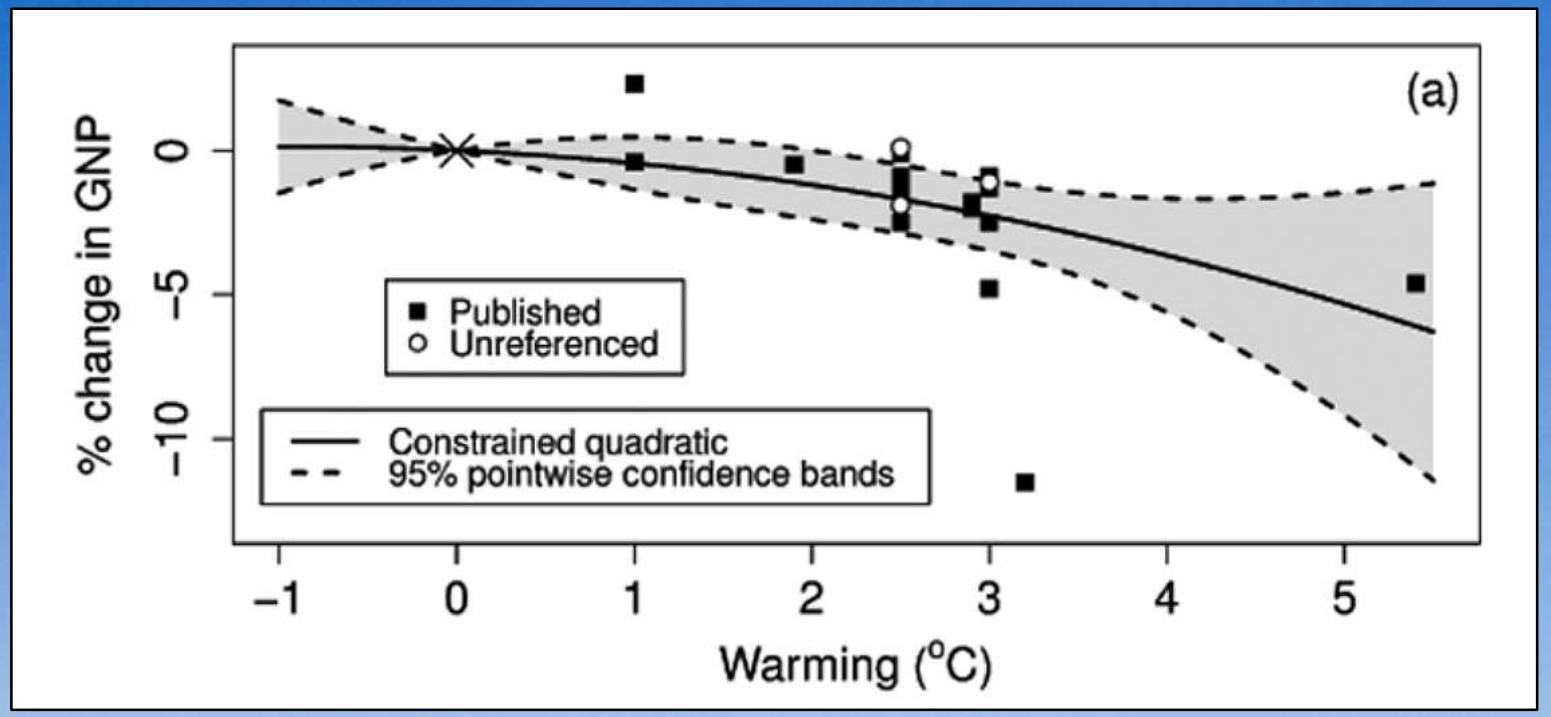
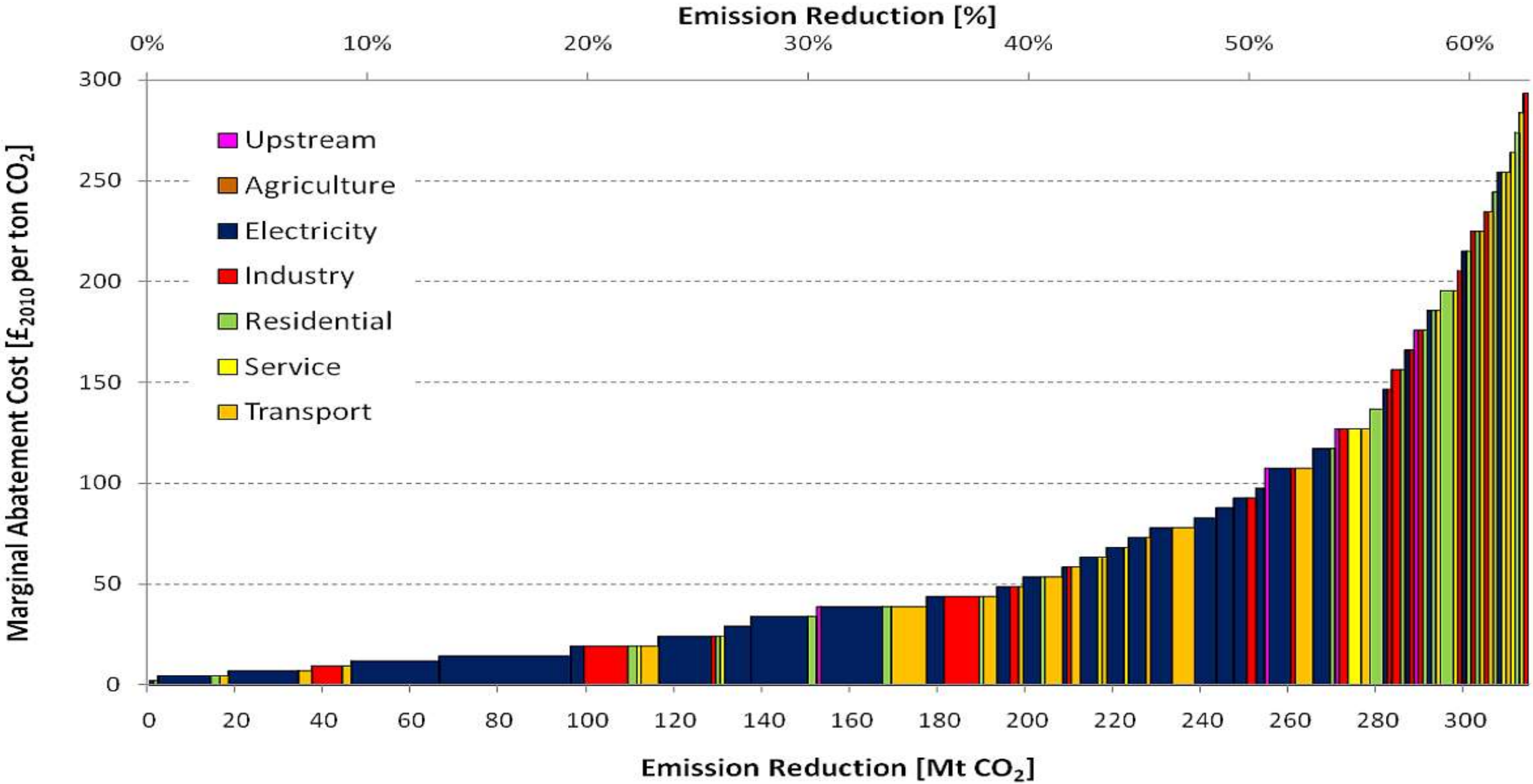
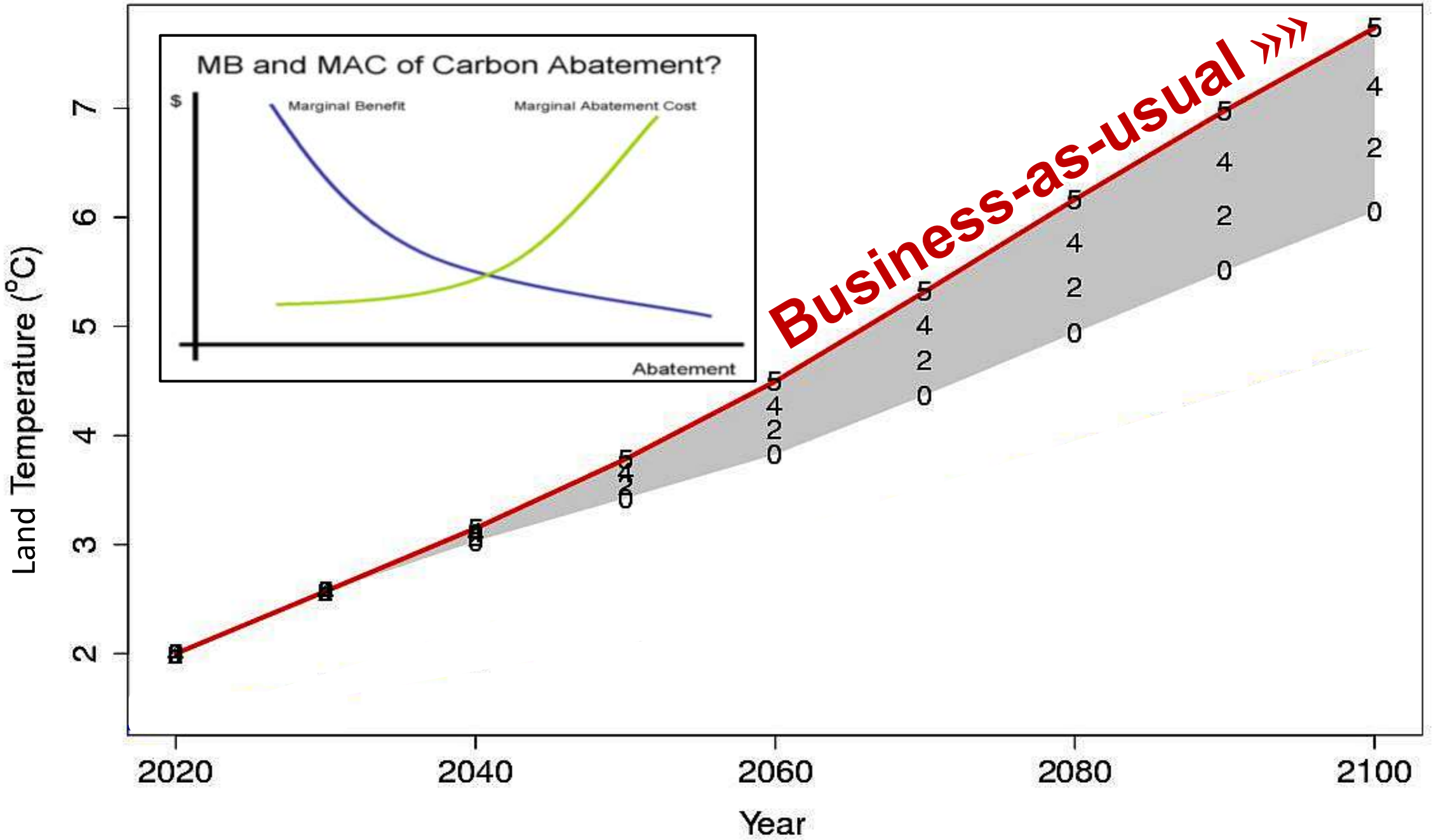
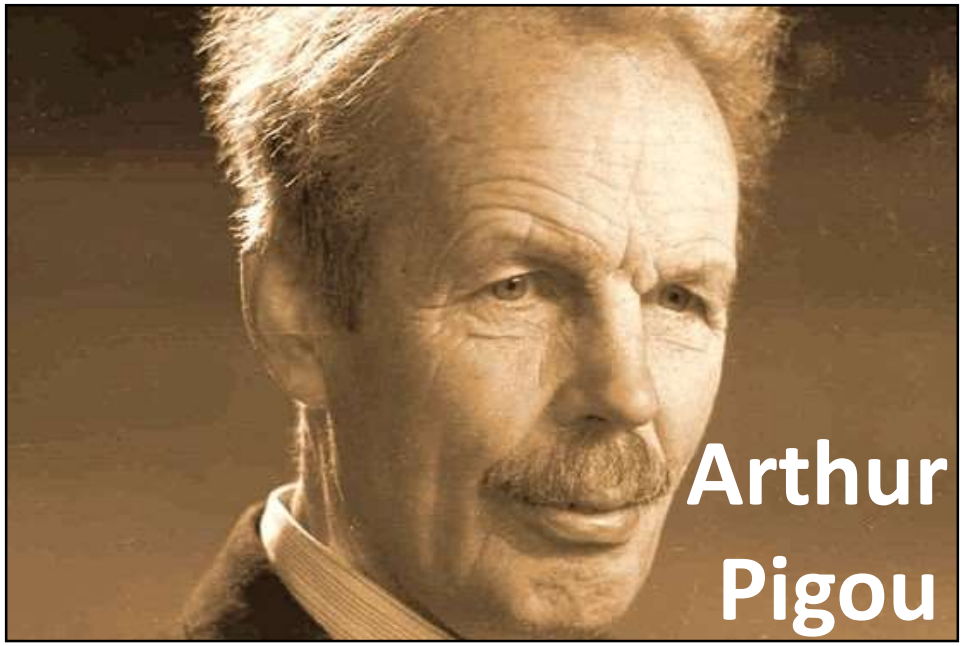


Figure 1. Schematic damage and cost functions. (a) Damage curve. Constrained (no constant) quadratic fit to the 21 currently available data points, as garnered by Tol (2015). Damage expressed as percentage of global GNP.

Marginal Abatement Cost Curve for the UK Energy Sector

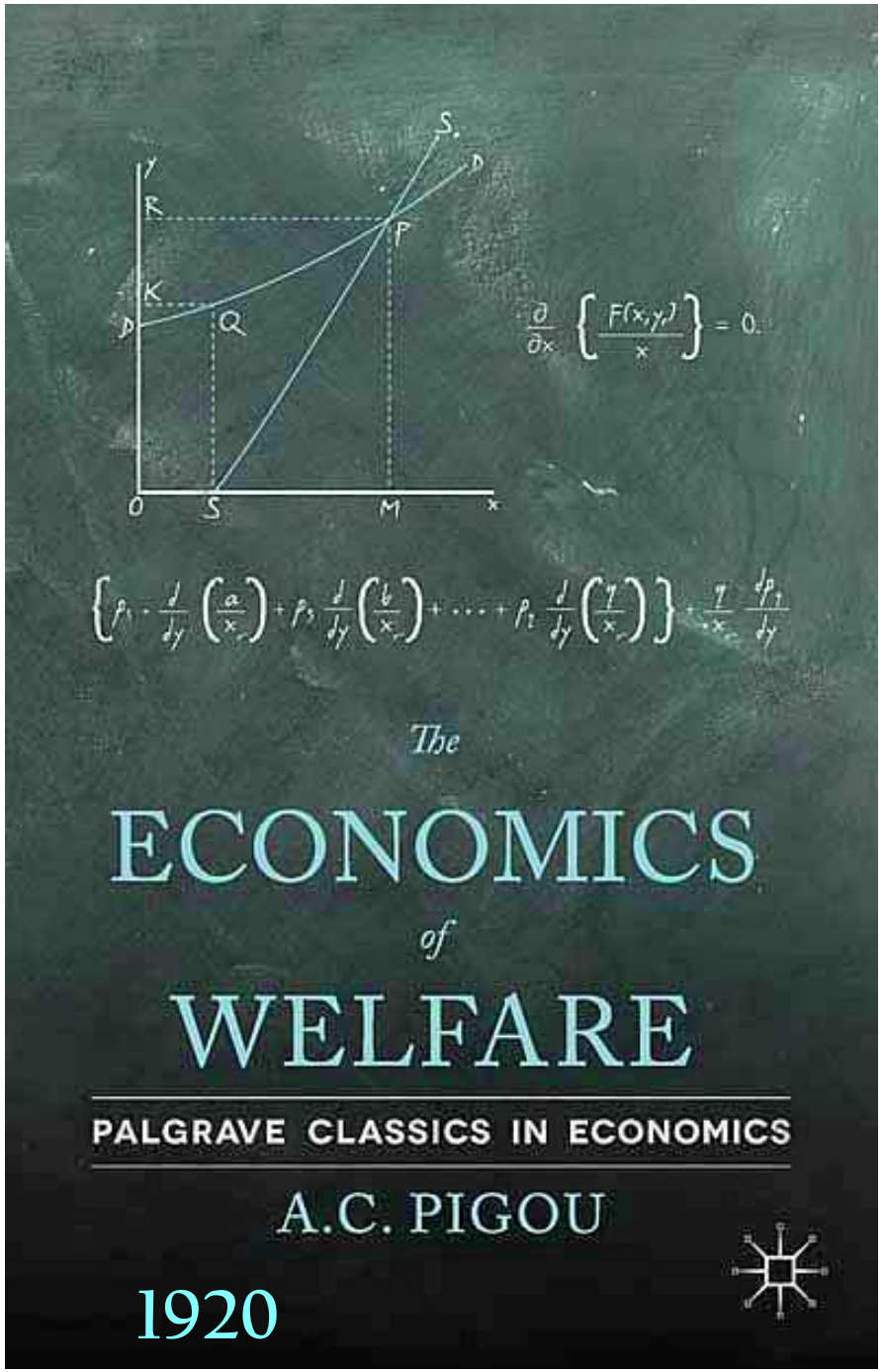



MB and MAC of Carbon Abatement?
$
Marginal Benefit
Marginal Abatement Cost
Abatement
Business-as-usual »»
Land Temperature (°C)
2
3
4
5
6
7
2020
2040
2060
2080
2100
Year



A Pigovian levy,

in a true market economy, is the most effective way to correct an environmental (negative) externality and avert its unnecessary costs on society.



- **All revenues returned to households**
  Innovation & investment stimulated by Adam Smith's invisible hand.
- **Simple and inexpensive to administer**
  Scope for corruption / lobbying greatly reduced.
- **Gradual**
  Predictable for business.

David G. Wilson:

The unsung inventor of the revenue-neutral energy tax

The 2018 Nobel prize in economics was awarded to Nordhaus and Romer for their research into how to create sustained long-term economic growth.


Following Nordhaus, rebating of Pigovian pricing would encourage innovation such as cost-effective air capture of CO_2 for geological disposal

Summary

1. Global warming

- Geology => CO_2 + feedbacks => powerful greenhouse warming
- Climate sensitivity => 3-4 ^oC / 2xCO_2
- Business-as-usual => +7.9 ^oC by 2100
- Oceanography => ~ 10^{22} joules yr^{-1} [World energy consumption 6 × 10^{20} J]

2. Scotland's energy trilemma

- Cost => Oil & gas in terminal decline, fracking improbable
- Security => Renewables + storage, or nuclear, else gas imports
- Environment => 90% emissions cut by 2050 is fanciful without CCS

3. Economics

- Pigou => Tax the externality
- Wilson => Rebate => invisible hand => innovation