

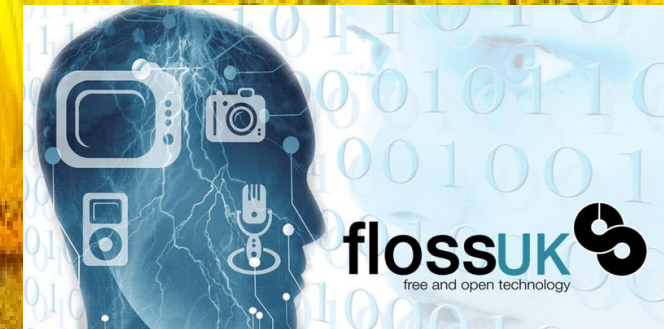
# Climate Change in One Line:

Can Open Data and Open Source  
Solve Humanity's  
Greatest-Ever  
Environmental  
Threat?

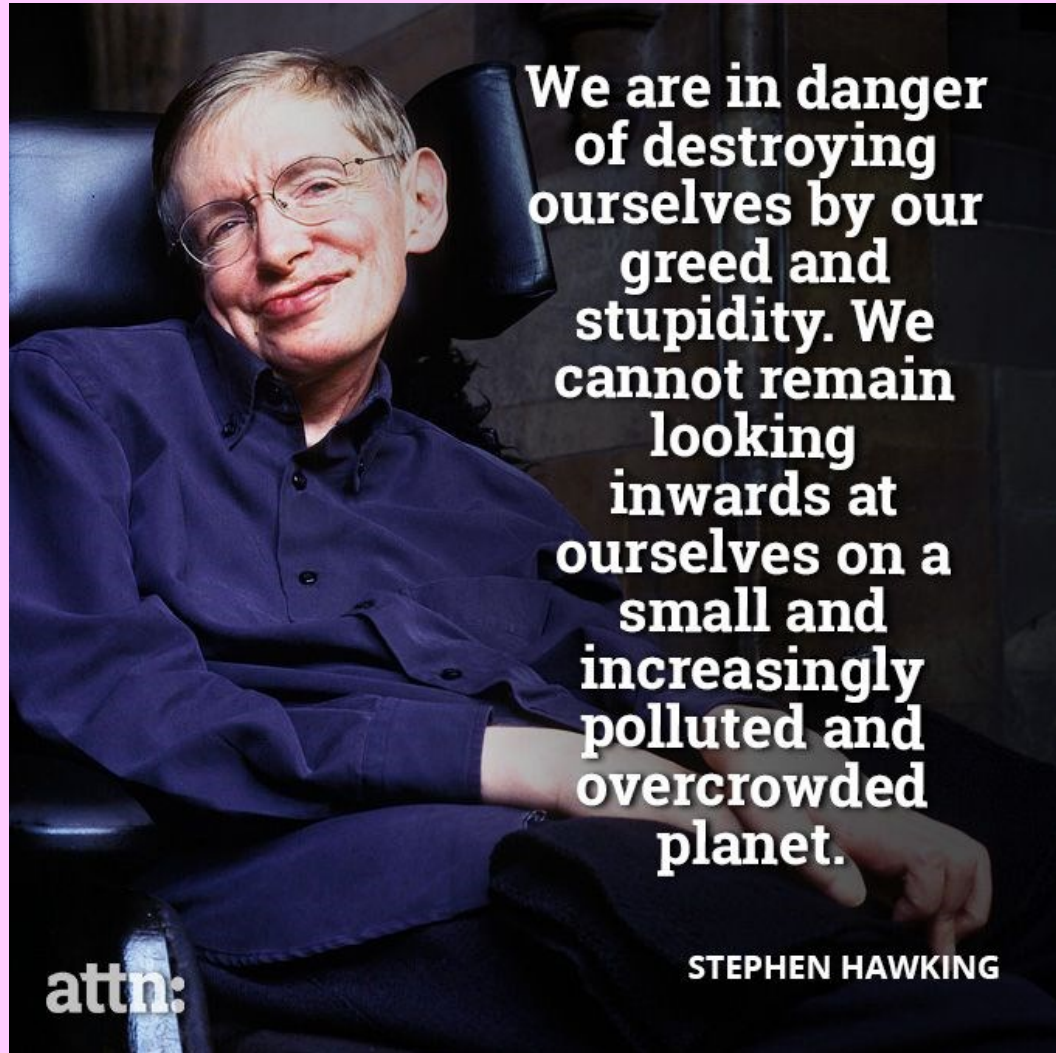
*Prof. Roy Thompson*

**GeoSciences**

**Edinburgh University**



***"Next time you meet a climate-change denier, tell them to take a trip to Venus; I will pay the fare".***



**Donald J. Trump has tweeted climate change scepticism over 115 times.**



We hold a wealth of publicly accessible marine data.

### Our data policy

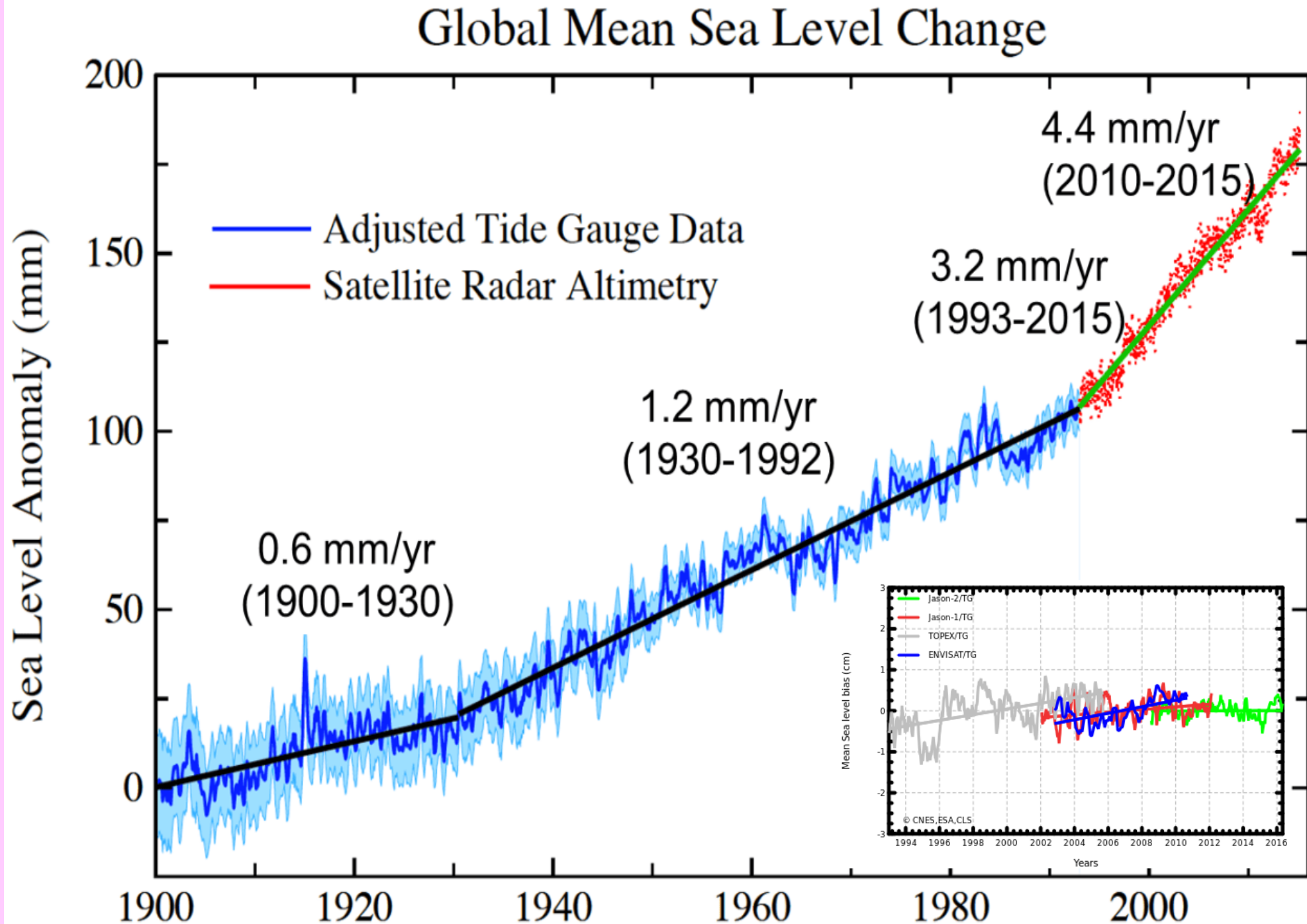
We encourage the use of our data holdings. BODC makes data available under a licence agreement.

### Our data delivery

BODC strives to make our data holdings retrievable directly from our web site.

### Data display

Software is available to download under licence. You are required to have a BODC web user account.



# The problem

$\text{SO}_2$

$\text{CO}_2$

$\text{CO}_2$

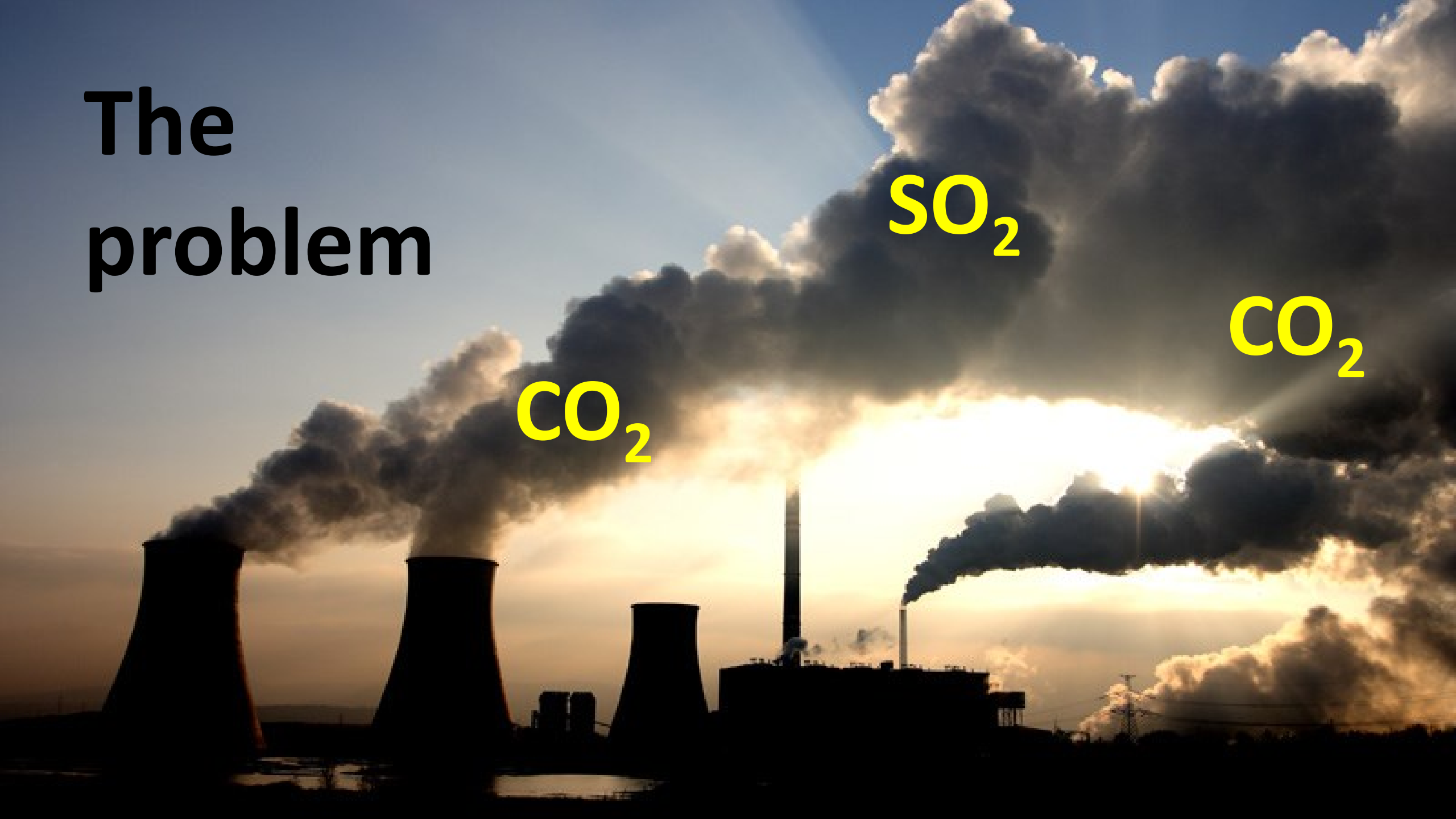


Illustration is a conceptualisation of the scale of emissions from the UK's oil and gas sector. The image is not intended to be taken literally.

# IMAGINE CAPTURING THIS MUCH CO<sub>2</sub> EVERY DAY

Find out how Shell plans to capture CO<sub>2</sub> at [shell.co.uk/peterheadccs](http://shell.co.uk/peterheadccs)

LET'S GO





# *The Scottish Enlightenment*

*Black*

1728–1799

*CO<sub>2</sub>*



*Hutton*

1726–1797

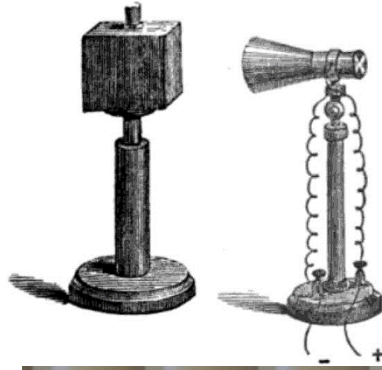
*Earth Sys Sci*



*Leslie*

1766–1832

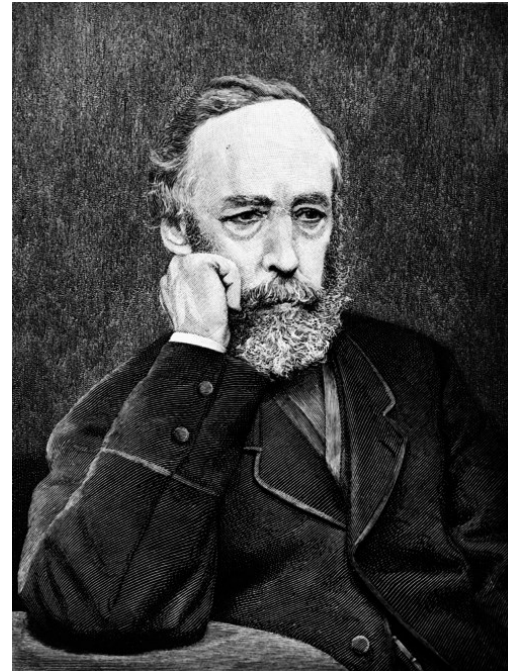
*Cube*



*Croll*

1821–1890

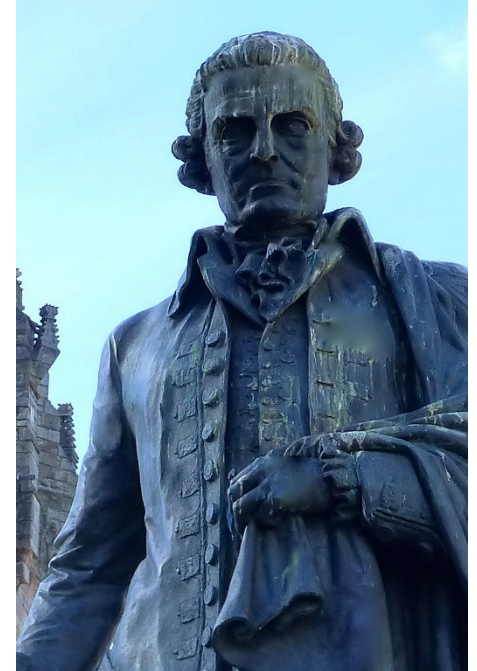
*Positive Feedback*



*Smith*

1723–1790

*Invis Hand*

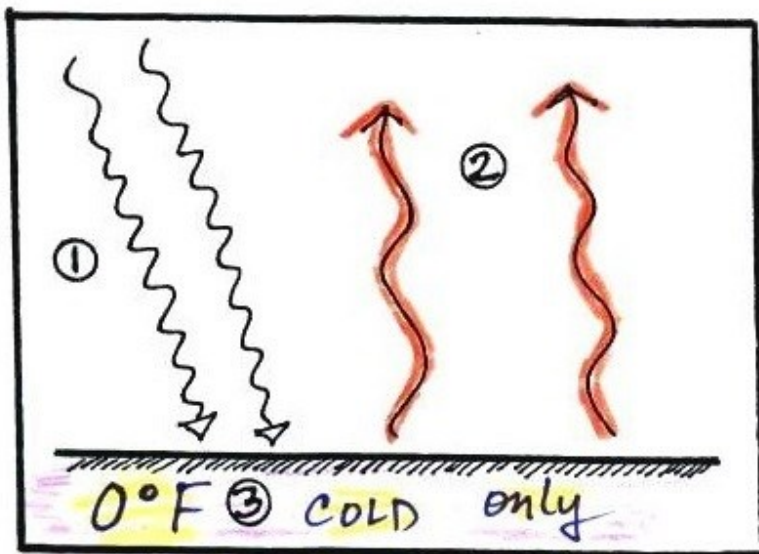


# Greenhouse gases

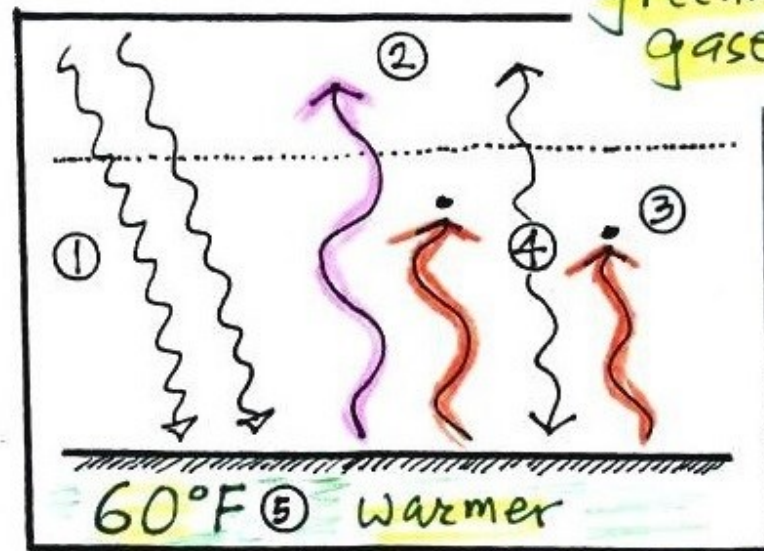
no  
atmosphere

atmosphere  
with  
greenhouse  
gases

Under  
normal  
conditions  
the Sun's  
heat is  
radiated  
back into  
space

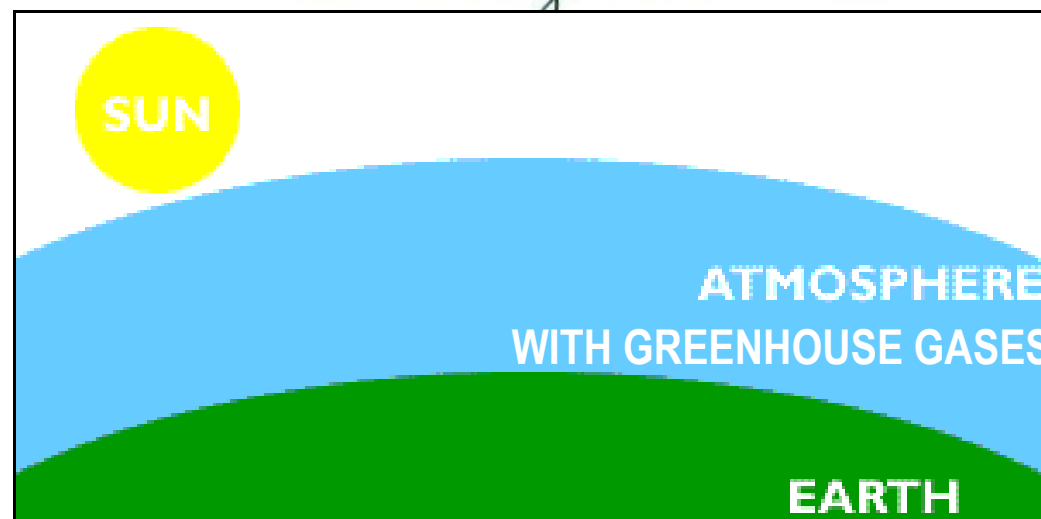
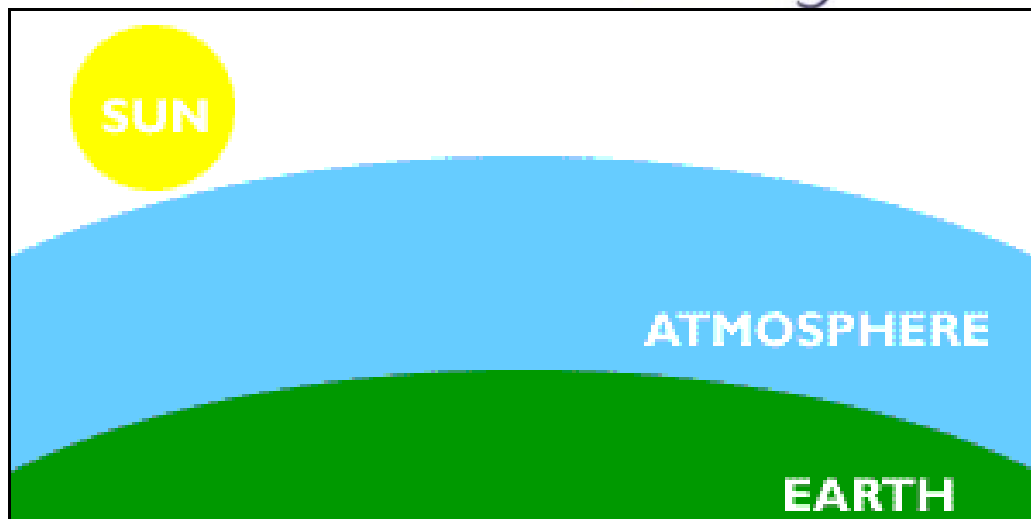


emitting 2 arrows



emitting 3 arrows

The man-made  
greenhouse effect  
occurs when heat  
is trapped in the  
atmosphere by  
unnaturally high  
levels of CO<sub>2</sub>





# Understanding aerosols

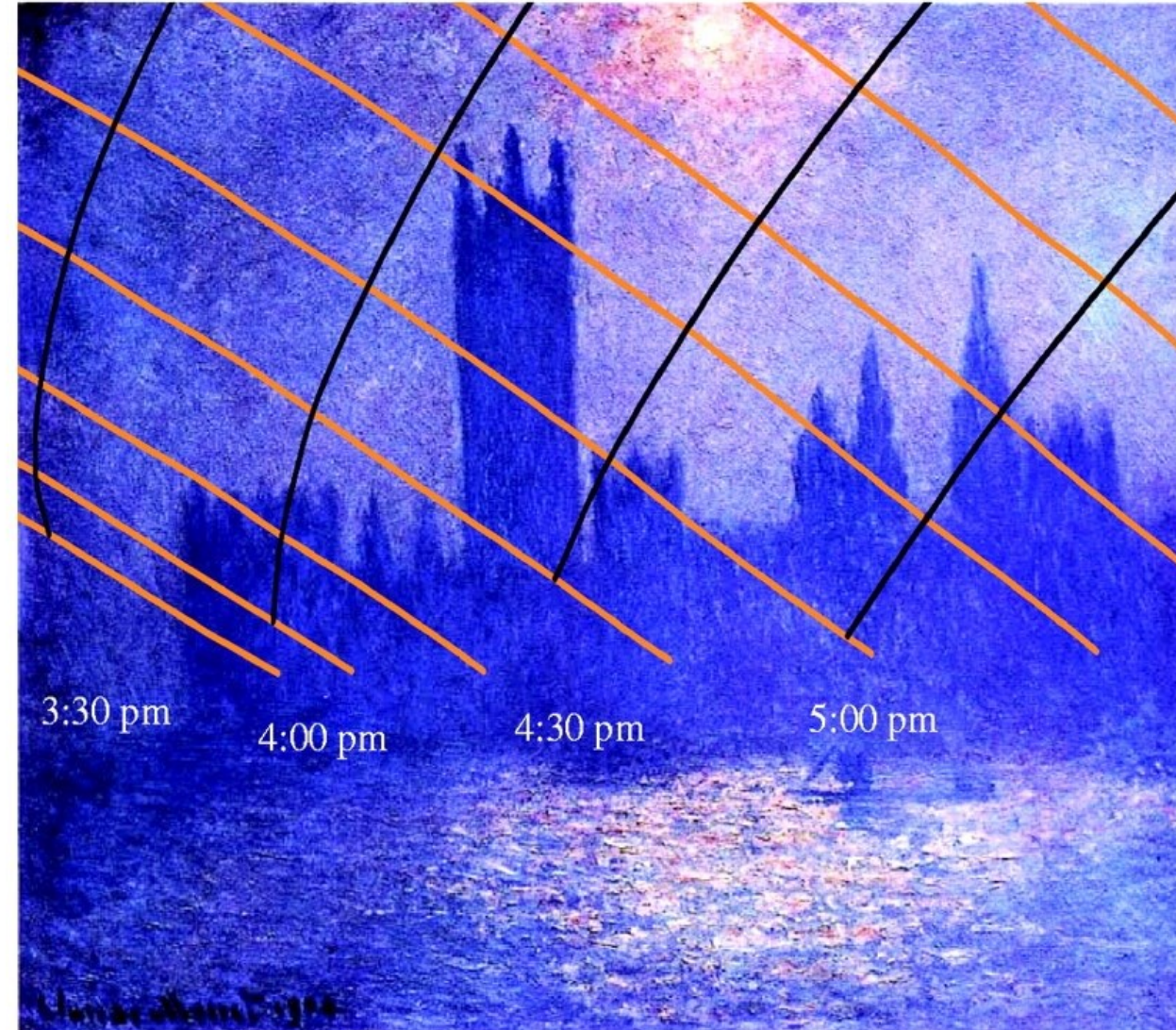
The colours in works by famous artists can be used to estimate aerosol optical depths.

20th

28th

10th Mar

20th



Example of volcanic sunset by J. M. W. Turner with R/G ratio of  $1.76 \pm 0.03$ , following the eruption of Babuyan (1831).

Monet's London series depicts the atmospheric state at the turn of the twentieth century

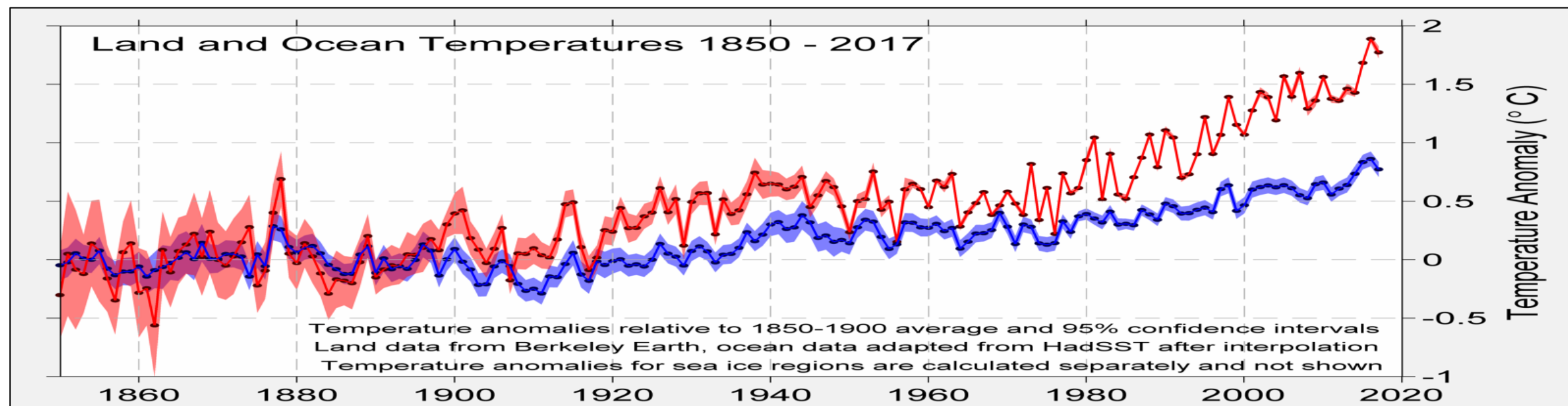
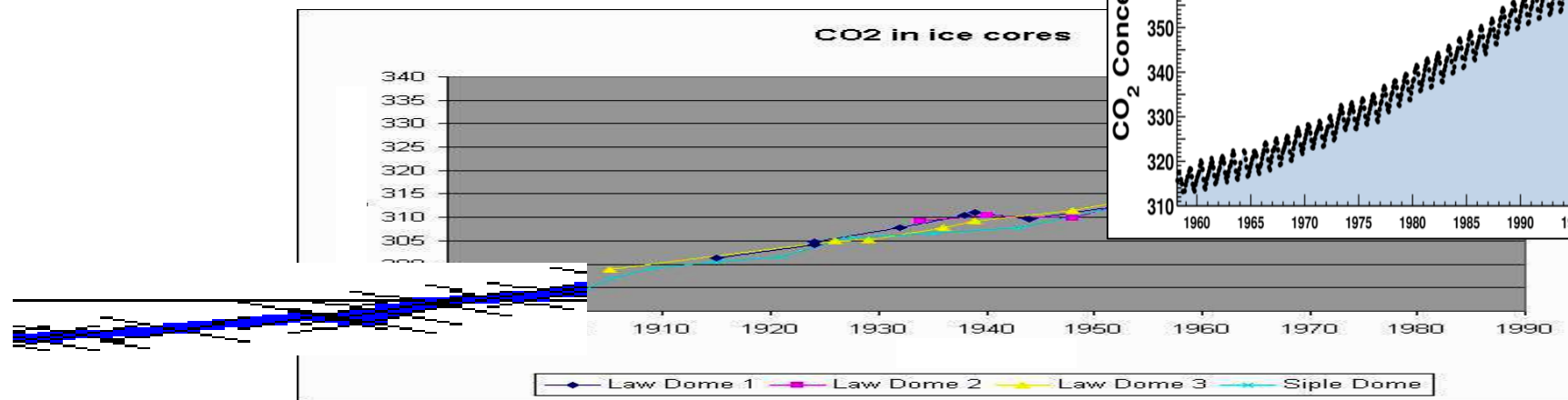
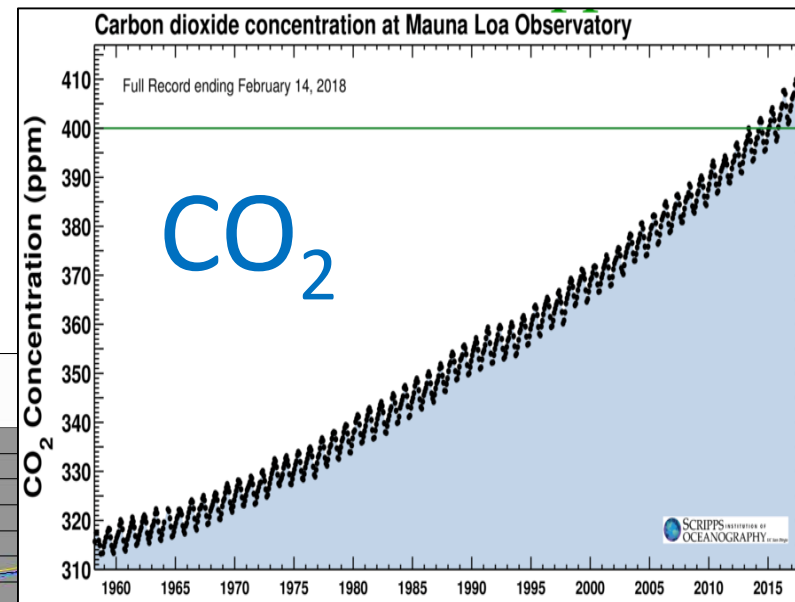


WORLD METEOROLOGICAL DAY  
23 MARCH 2017

# UNDERSTANDING CLOUDS



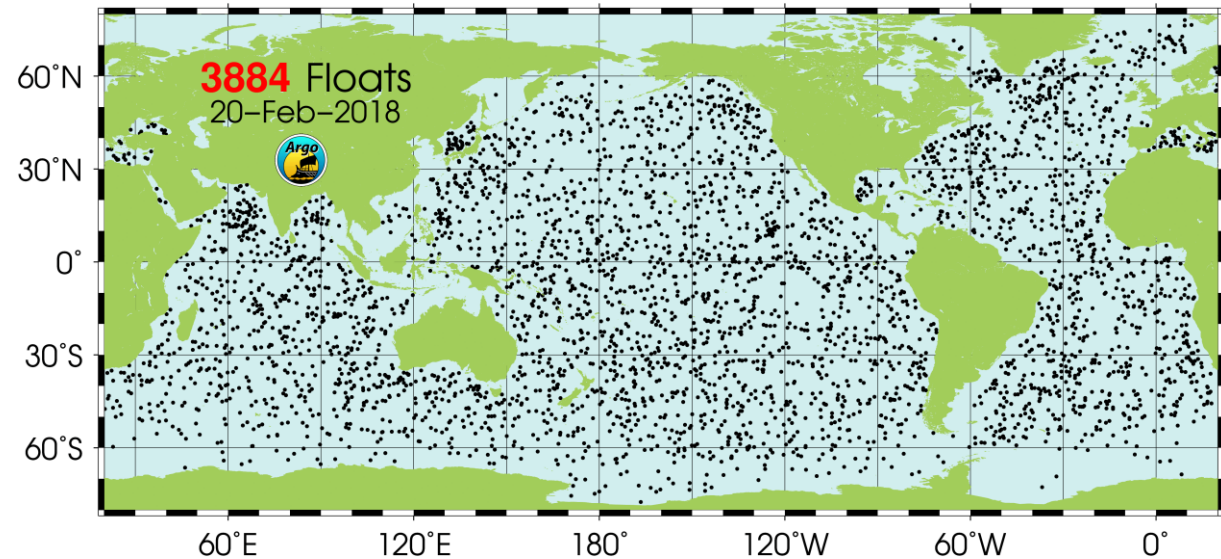
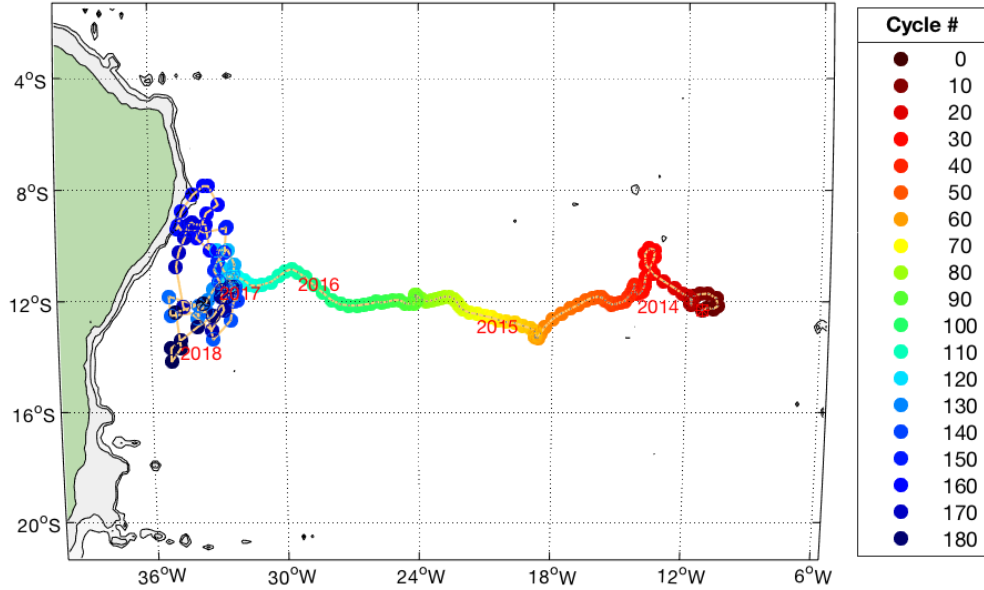
# Open Data





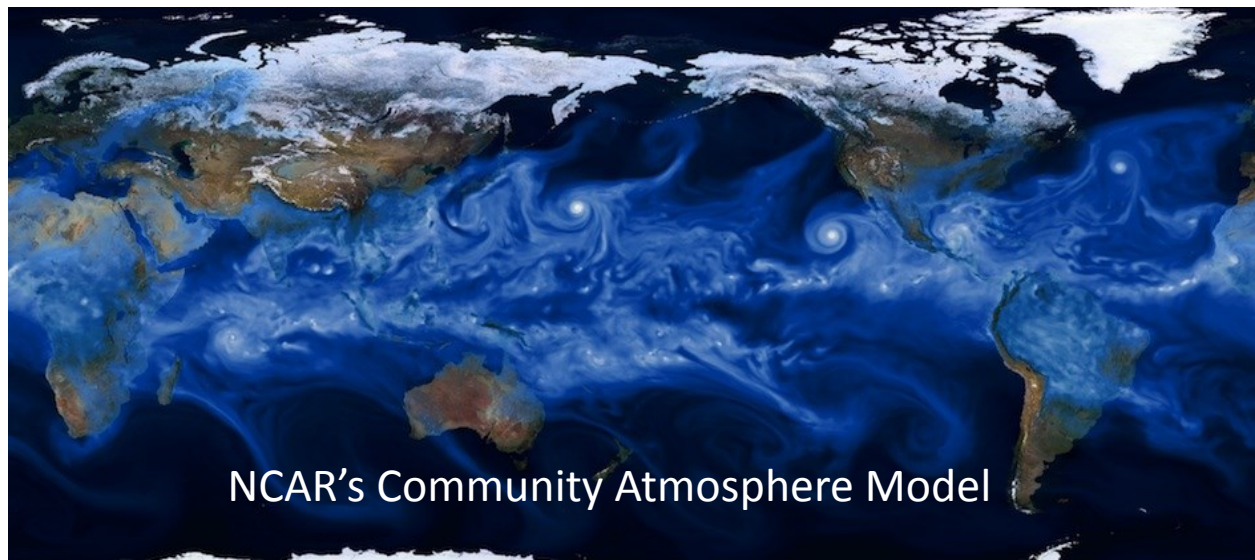
**Argo** – a global array of 4,000 free-drifting floats measuring ocean temperatures.  
**All data is made publicly, freely available within hours of collection.**

1901646: Profile Positions & Trajectory

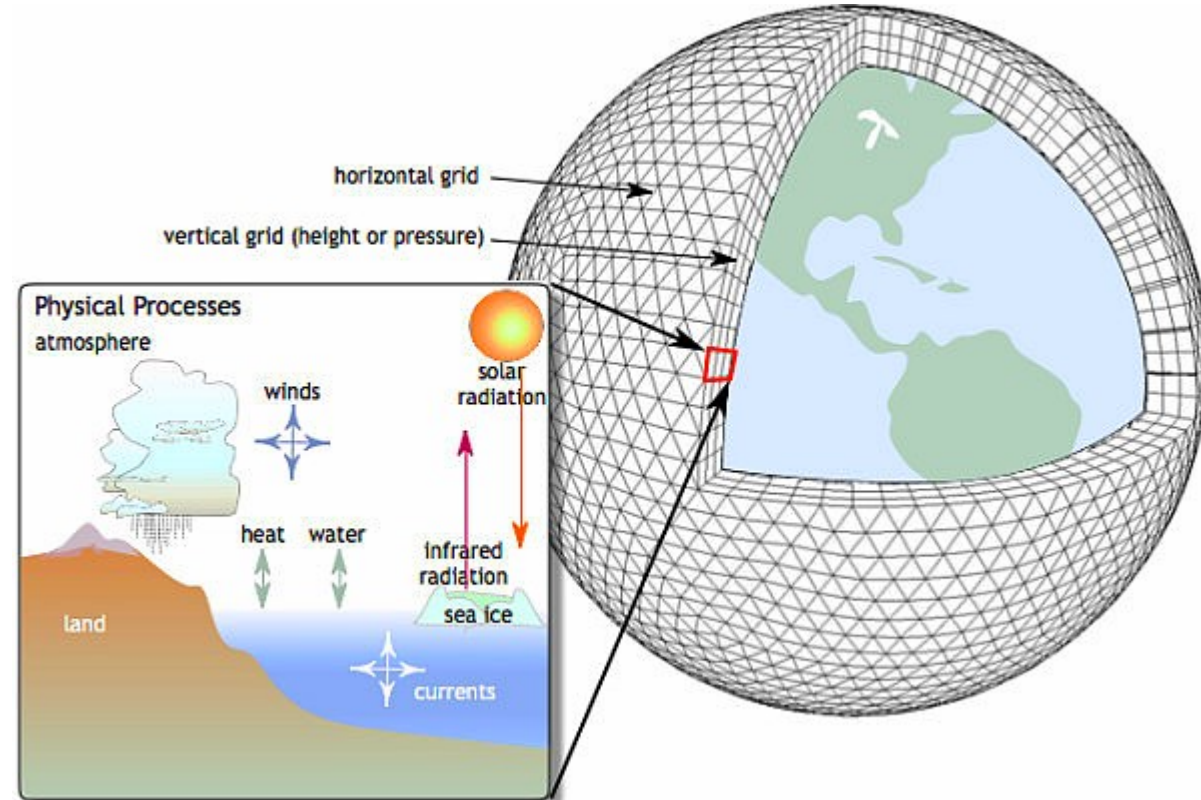
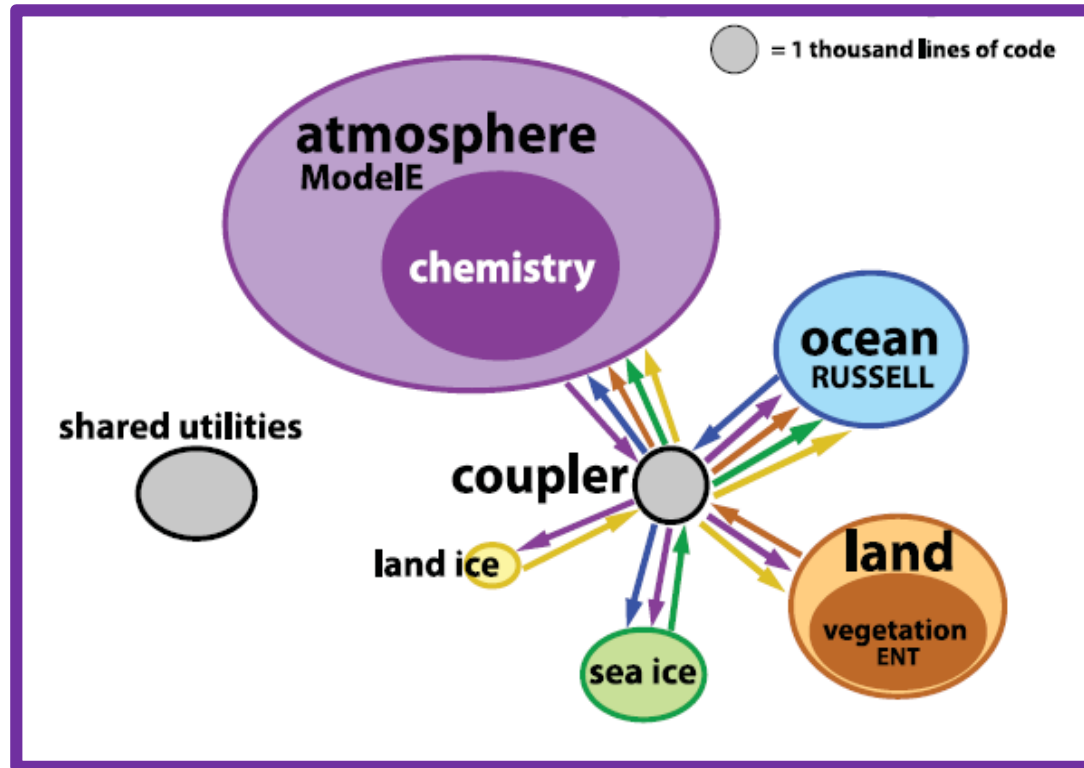


**Four Argo floats adopted by South African schools**





# Open Source Models

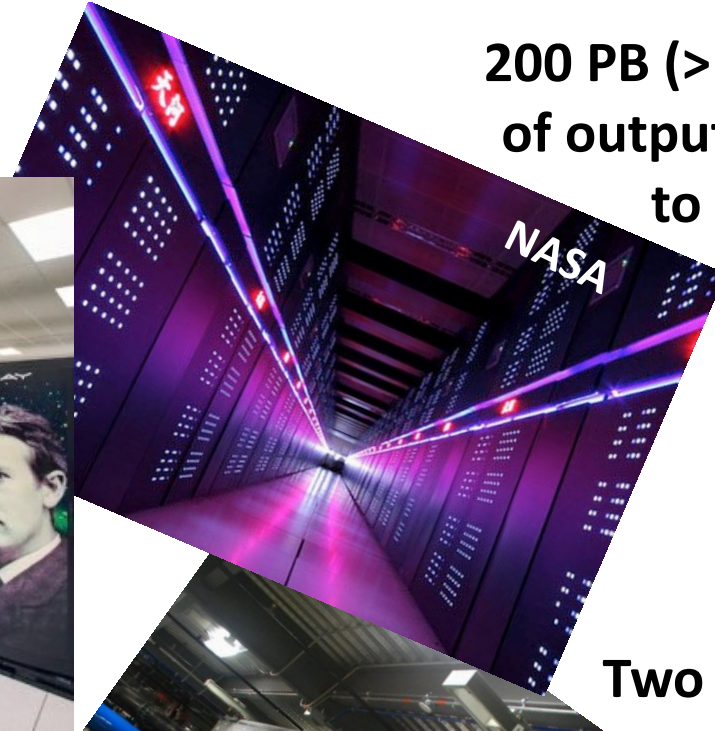




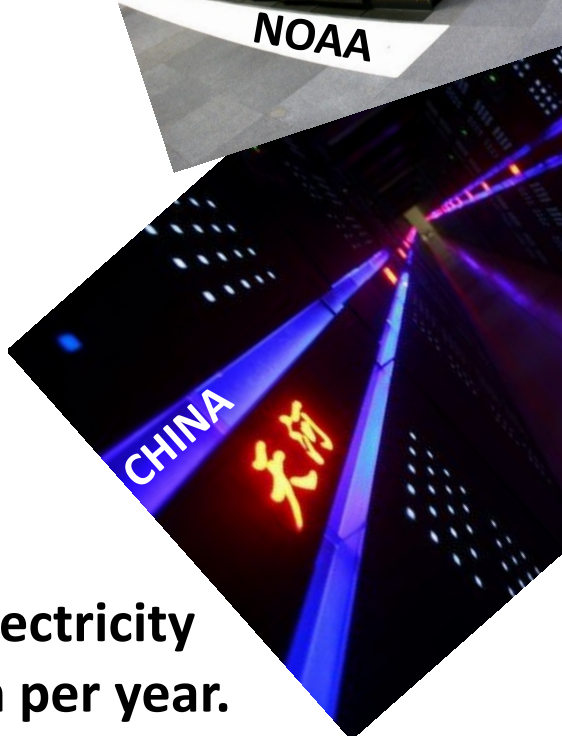
# CMIP

## Coupled Model Intercomparison Project

Over 1.2 million lines of FORTRAN growing at  $10^5$  lines per year.



200 PB ( $>10^{17}$  bytes) of output. Impossible to ingest every 6 years.



Two dozen centres in Europe, USA, Asia, Australia, Canada, Russia, China, Korea

Hamburg's electricity bill €2 million per year.



**IPCC: created 1988**

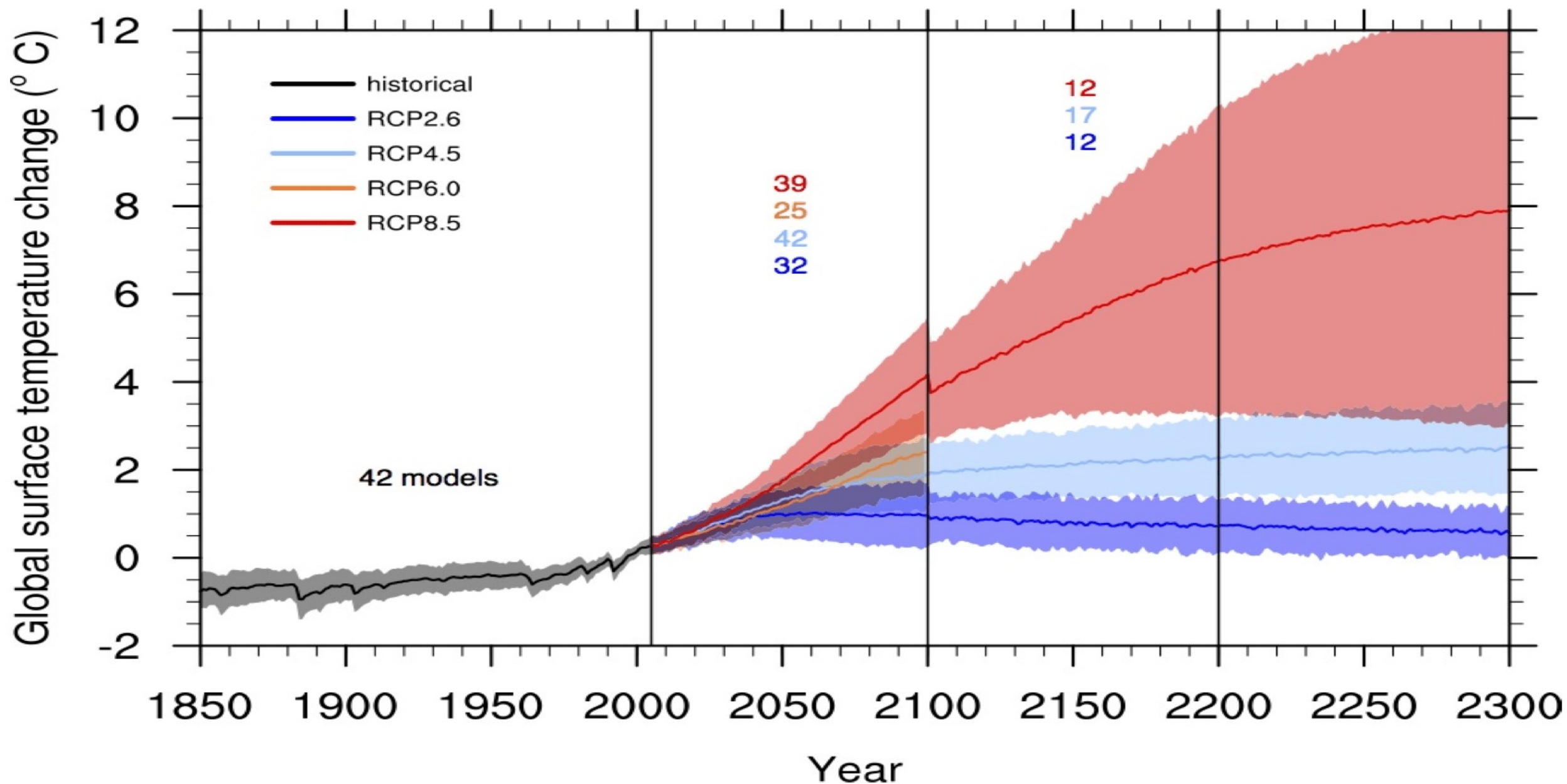
**Remit: to prepare a comprehensive review of the state of knowledge of the science of climate change.**

***"No best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies."***

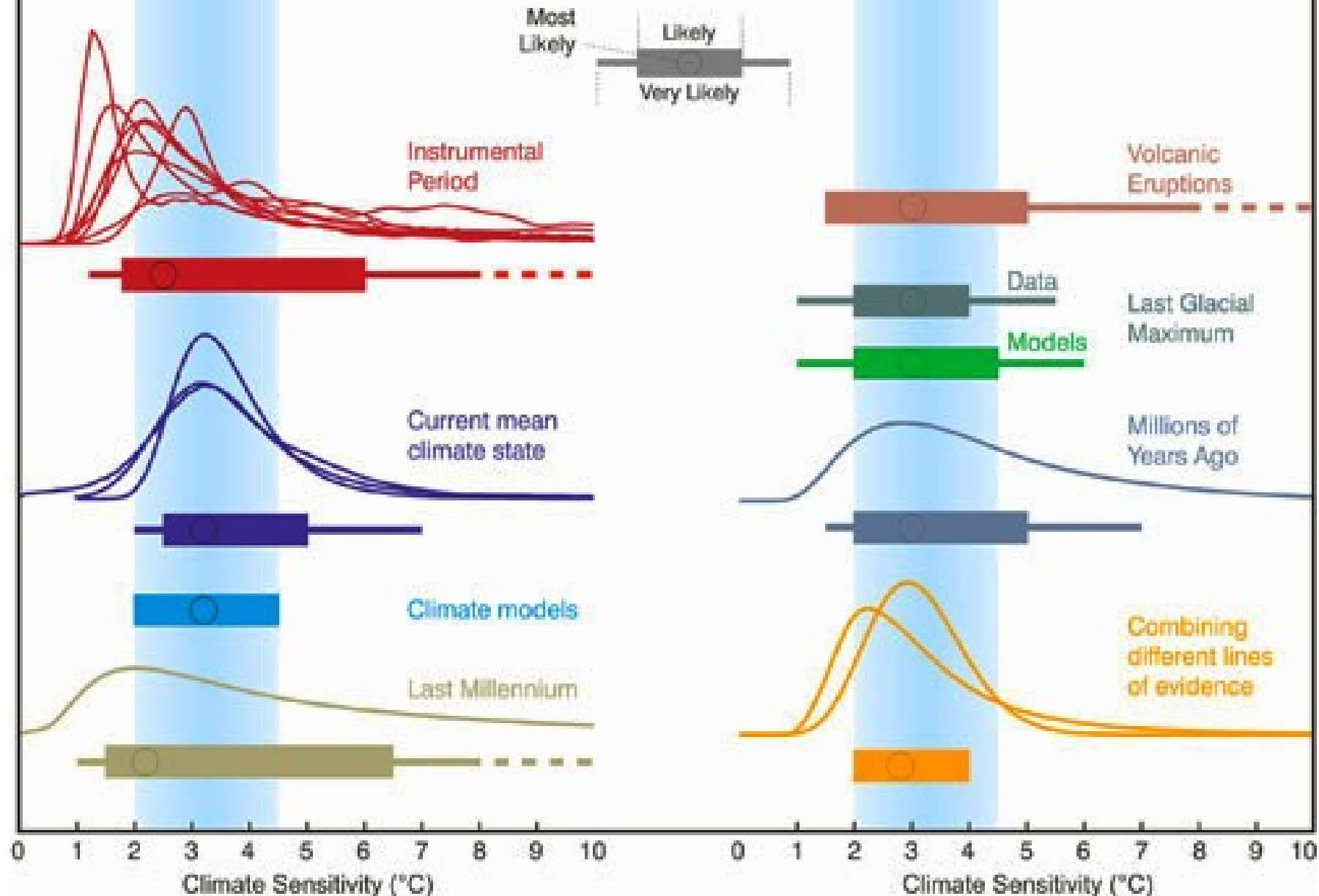
***IPCC-AR5, p14, 2014***



# Uncertainties in global temperature projections



# Various Estimates of Climate Sensitivity



## History

**Climate sensitivity** (the equilibrium surface temperature increase for carbon dioxide doubling) has more than a century of history. First estimated by Arrhenius (1896).

**Budyko and Sellers (1969)** improved Arrhenius's calculations using a mean annual, zonally averaged energy-balance climate model. They too found a high sensitivity.

**Charney's report (1979)** established the canonical range of 1.5 to 4.5 °C.

**Today** No best estimate can be given.



# One line of code - heat balance model

```
library(nlme)
library(stats)
```

```
gnls(y ~ HoltWinters(b0 + b1*x1 + b2*x2, alpha = plogis(b3)),
     start = list(b0 = 1, b1 = 1, b2 = 1, b3 = 1),
     corr = corAR1()
)
```

# y	temperature (1880 to present day)
# x1, x2	forcings (change in CO <sub>2</sub> , aerosols, volcanic dust, El Niño)
# gnls()	generalised nonlinear maximum likelihood additive model
# HoltWinters()	filter
# plogis()	transform (of real values to the logit scale)
# b0, b1, b2	unknowns (pre-industrial temperature, sensitivities ( $\lambda^{-1}$ ))
# alpha	exponential smoothing coefficient (ocean response time $\sim C/\lambda$ )
# corAR1	autocorrelation structure (of order 1)

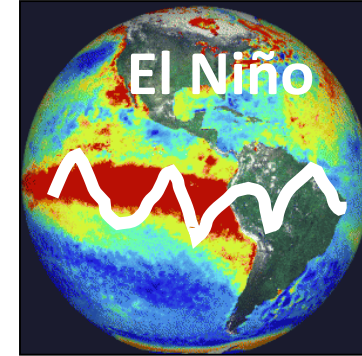
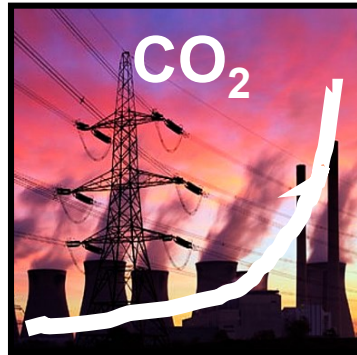
# A Simple Energy Balance Model of Climate

$$C \frac{dT}{dt} + \lambda T = F(t)$$

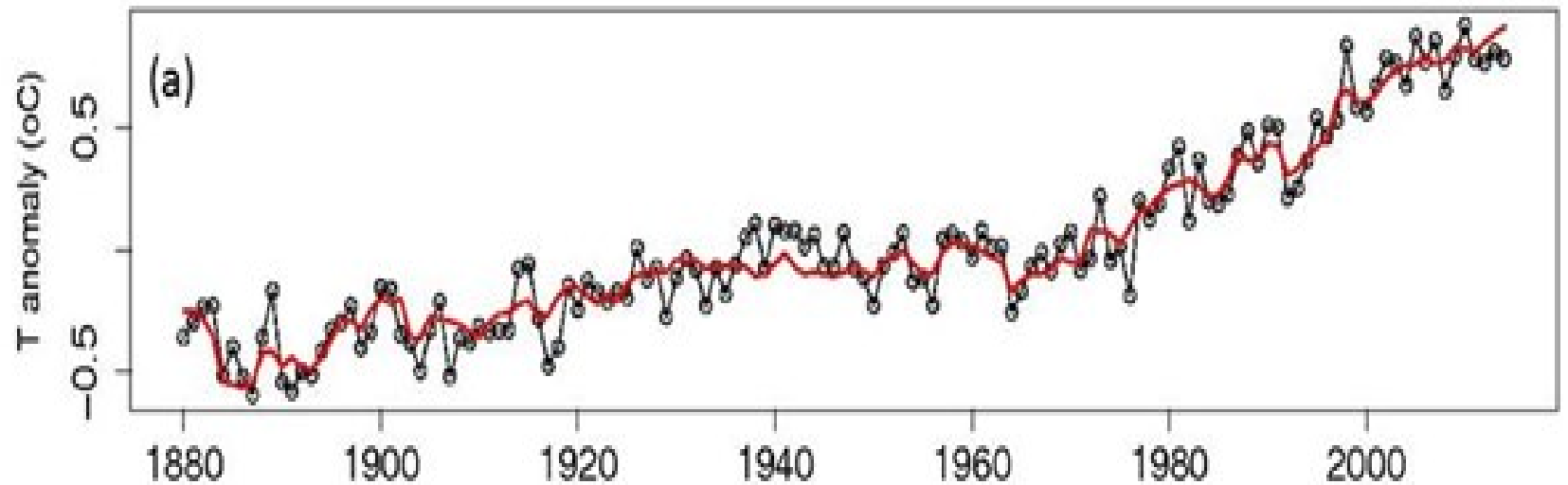
Units for  $C$ :  $\text{W yr m}^{-2} \text{K}^{-1}$   
Units for  $\lambda$ :  $\text{W m}^{-2} \text{K}^{-1}$   
Units for  $F(t)$ :  $\text{W m}^{-2}$

Units for  $T$ :  $\text{K}$   
Units for  $dt$ :  $\text{yr}$

- $C$  Heat capacity
- $T$  Temperature change
- $\lambda$  Equilibrium response
- $F(t)$  Change in net energy flux



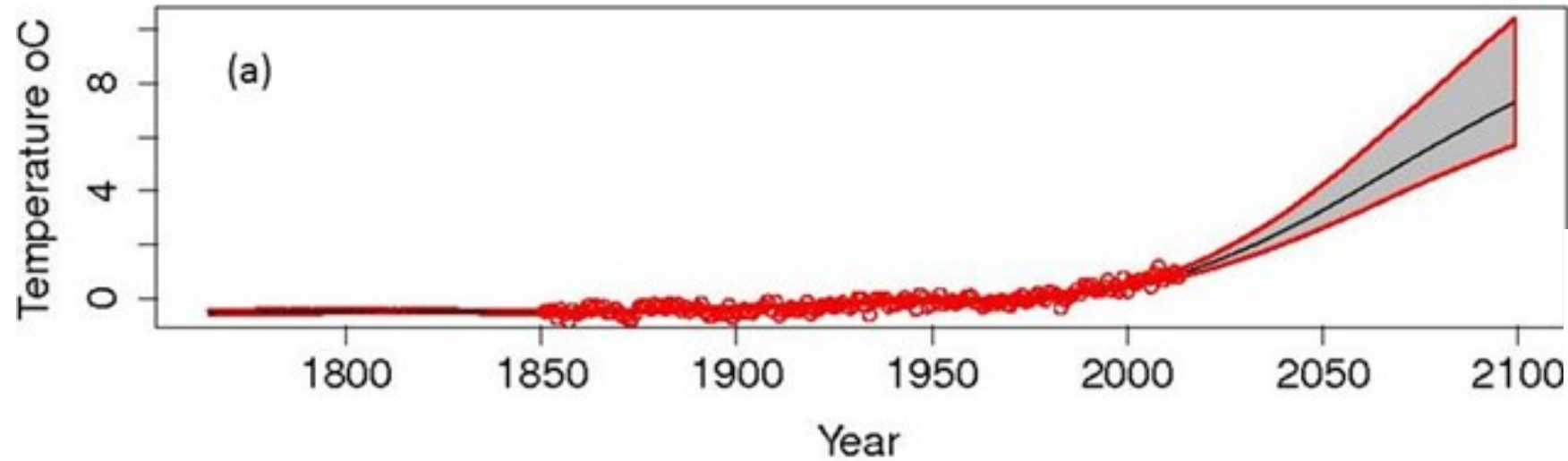
Temperature  $\sim$  Greenhouse gases + aerosols + ENSO + Volc



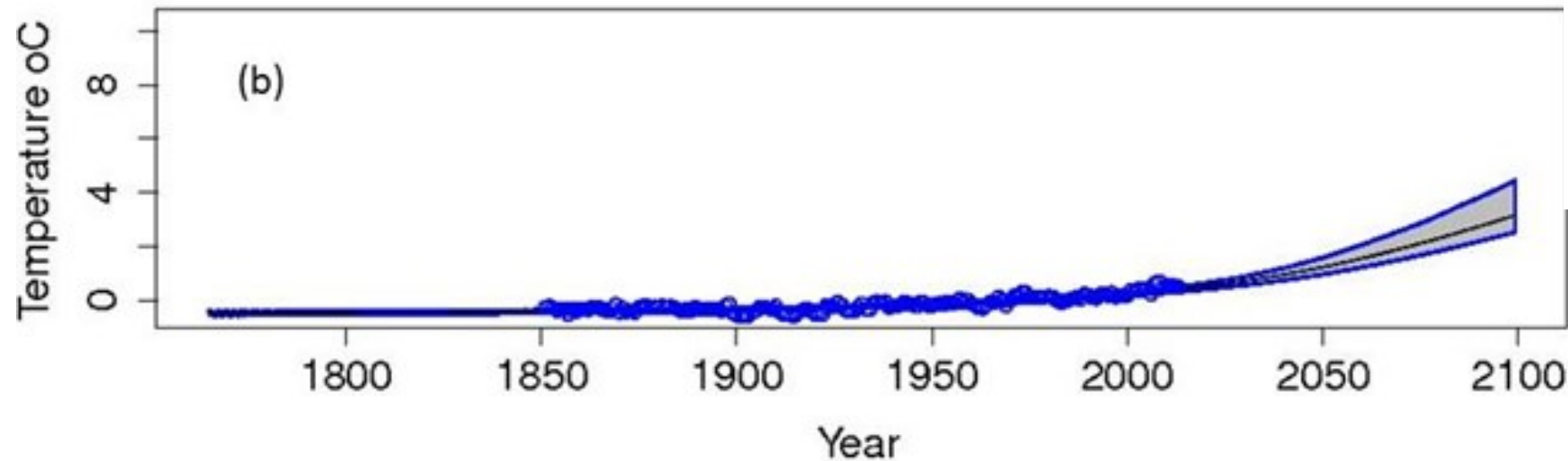
(Thompson, Trans. R. Soc. Ed., 2015)



Land (RCP\_8.5)



Ocean (RCP\_8.5)



My 'purely' data driven estimate  
of climate sensitivity (x2 CO<sub>2</sub>) is

**+4°C**

with 95% confidence intervals of

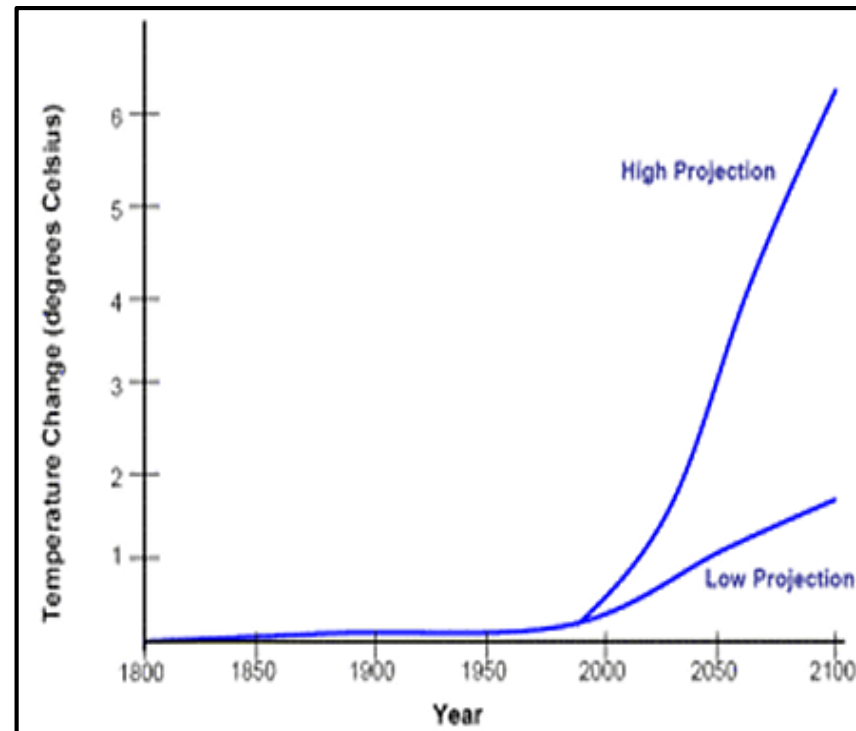
**3.0 to 6.3°C**

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

Anthony Watts From the UNIVERSITY OF EDINBURGH comes yet another ... way to “limit” ~~our wallets~~ climate change

**Colin** • [7 days ago](#) "I have too much time on my hand along with a massive grant. Here's some mad ramblings to get the public worked over nothing."

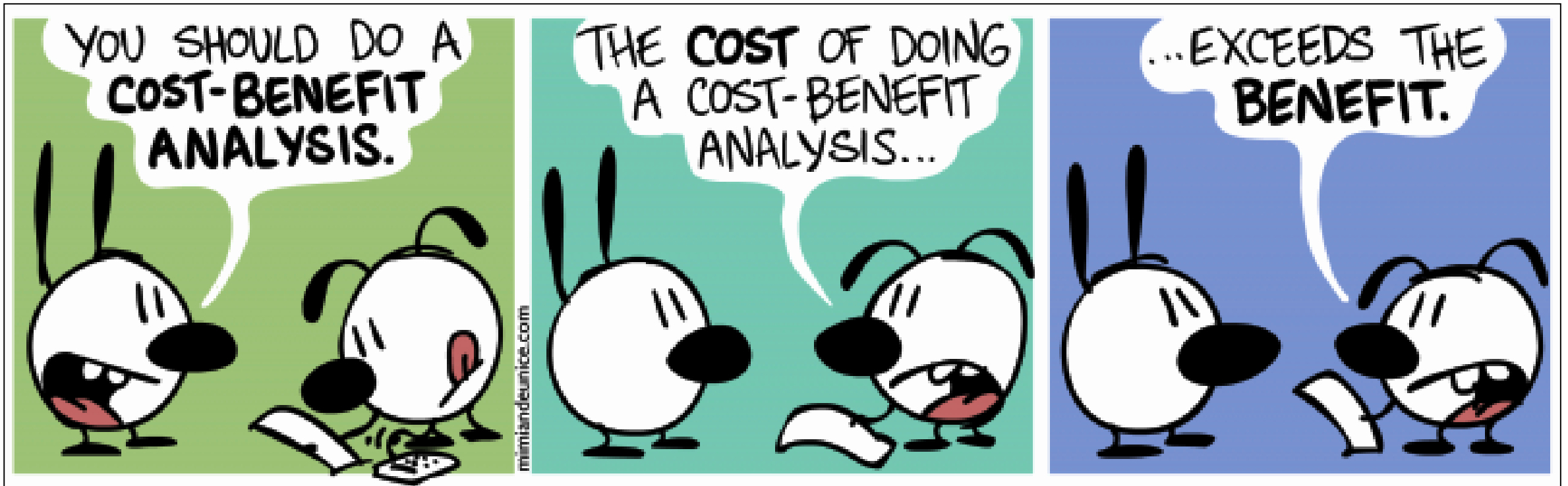
**Eugene WR Gallun** • [November 2, 2016 at 2:31 am](#) The hotheads say that CO<sub>2</sub> is warming the earth — and they believe it! But the truth is that it is space aliens projecting thoughts into the minds of the hotheads making them believe in global warming.



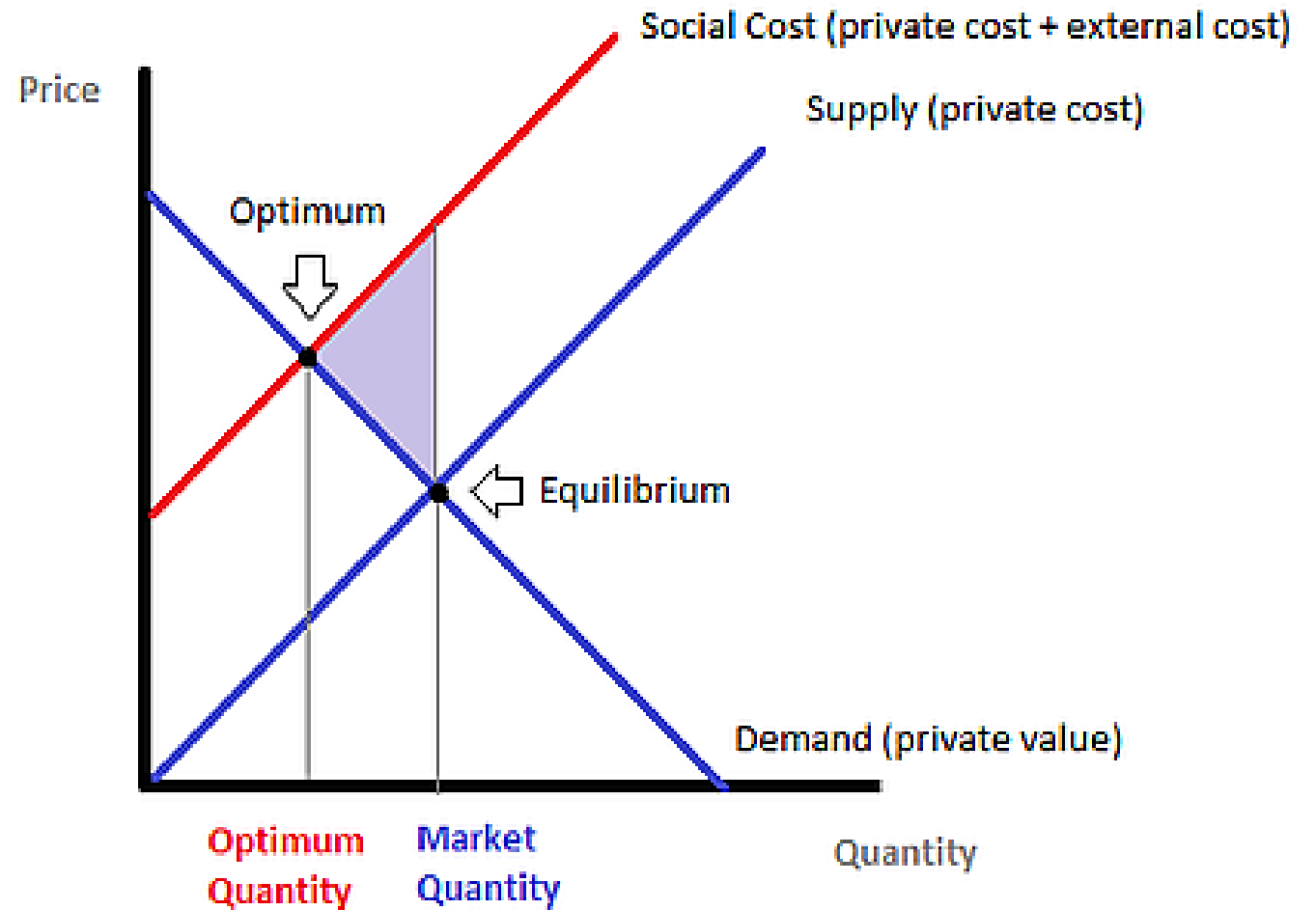
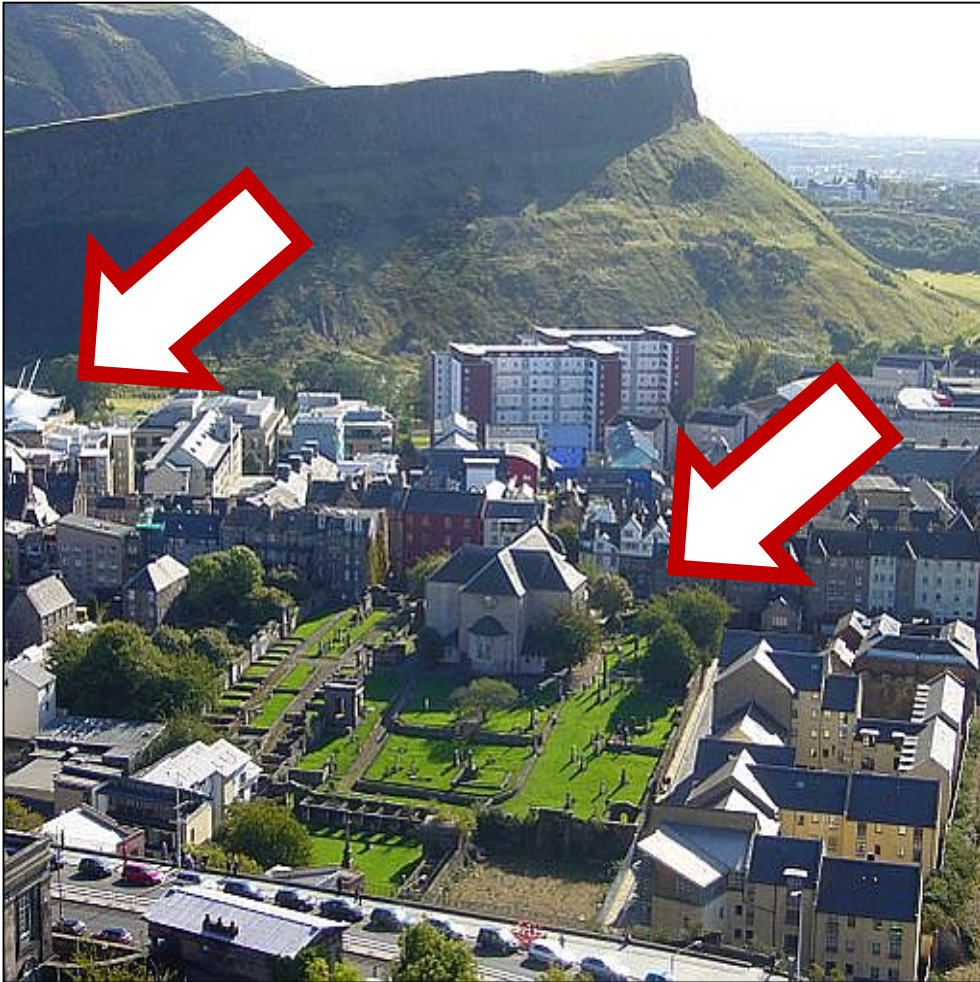
**Editor of the Fabius Maximus website** • [December 11, 2015 at 7:11 am](#) I have a copy of the paper. Calling this a “business as usual” scenario is misrepresentation. Or outright deceit. RCP8.5 is the scenario used for almost all of the doomster studies published in the past several years.



# Cost-benefit analysis

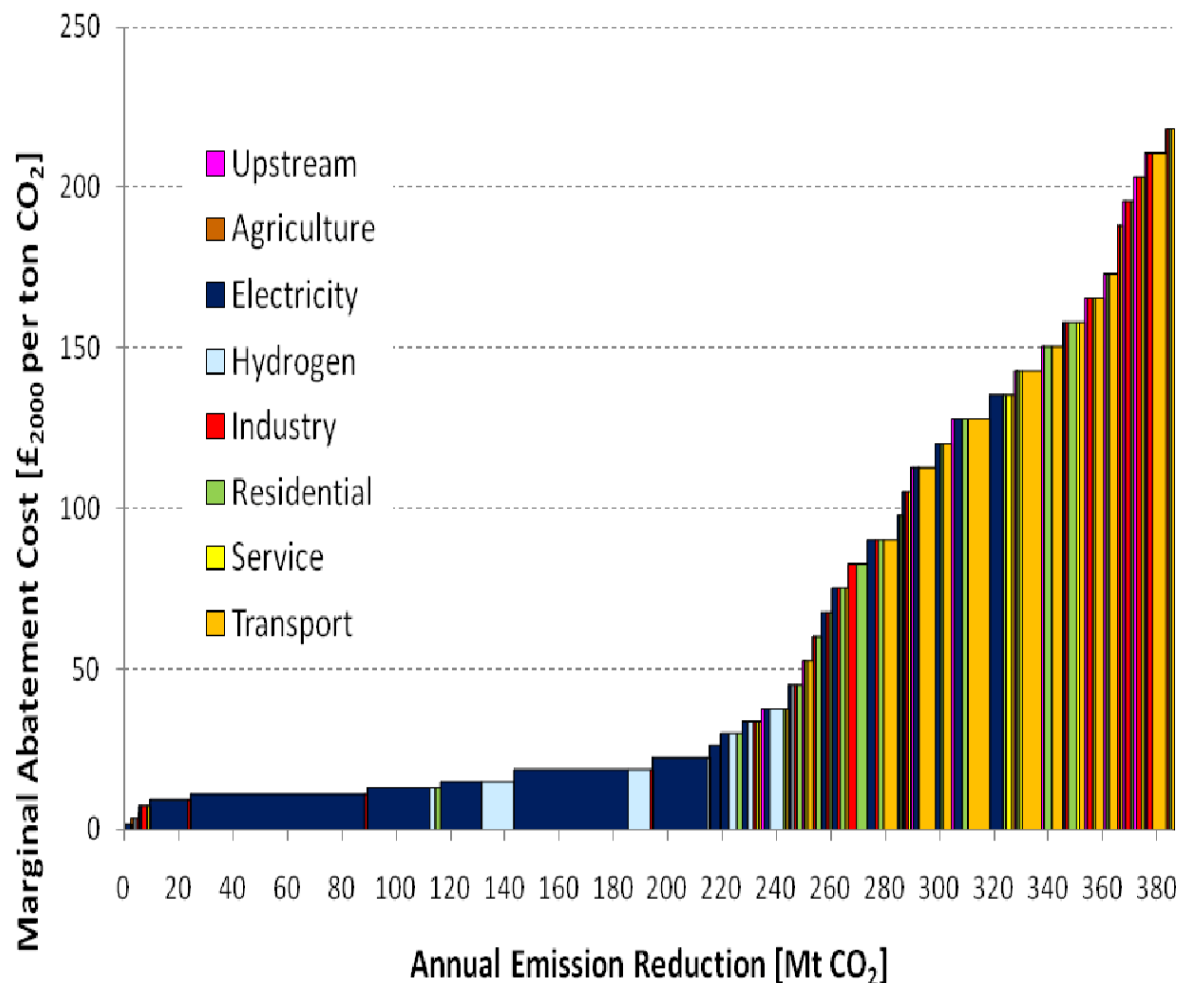


# Adam Smith's “invisible hand” in the presence of externalities



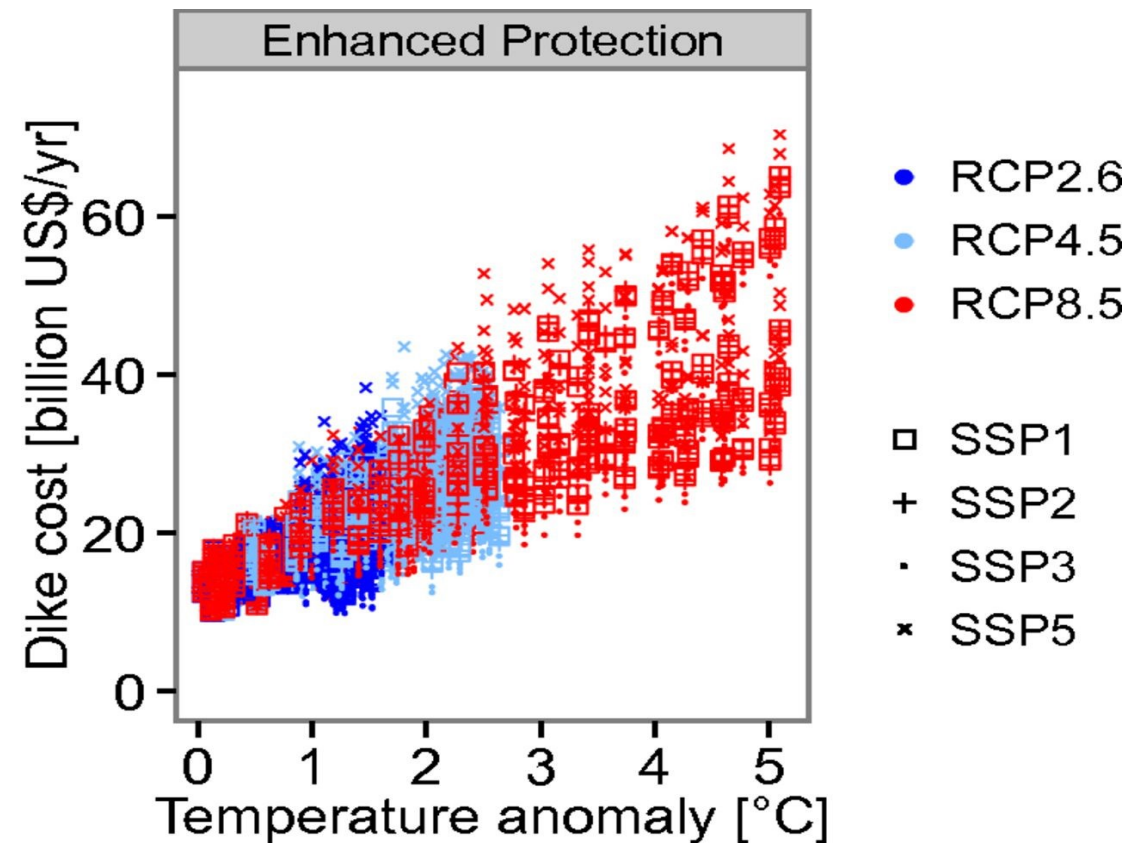


# CO<sub>2</sub> emission reduction costs



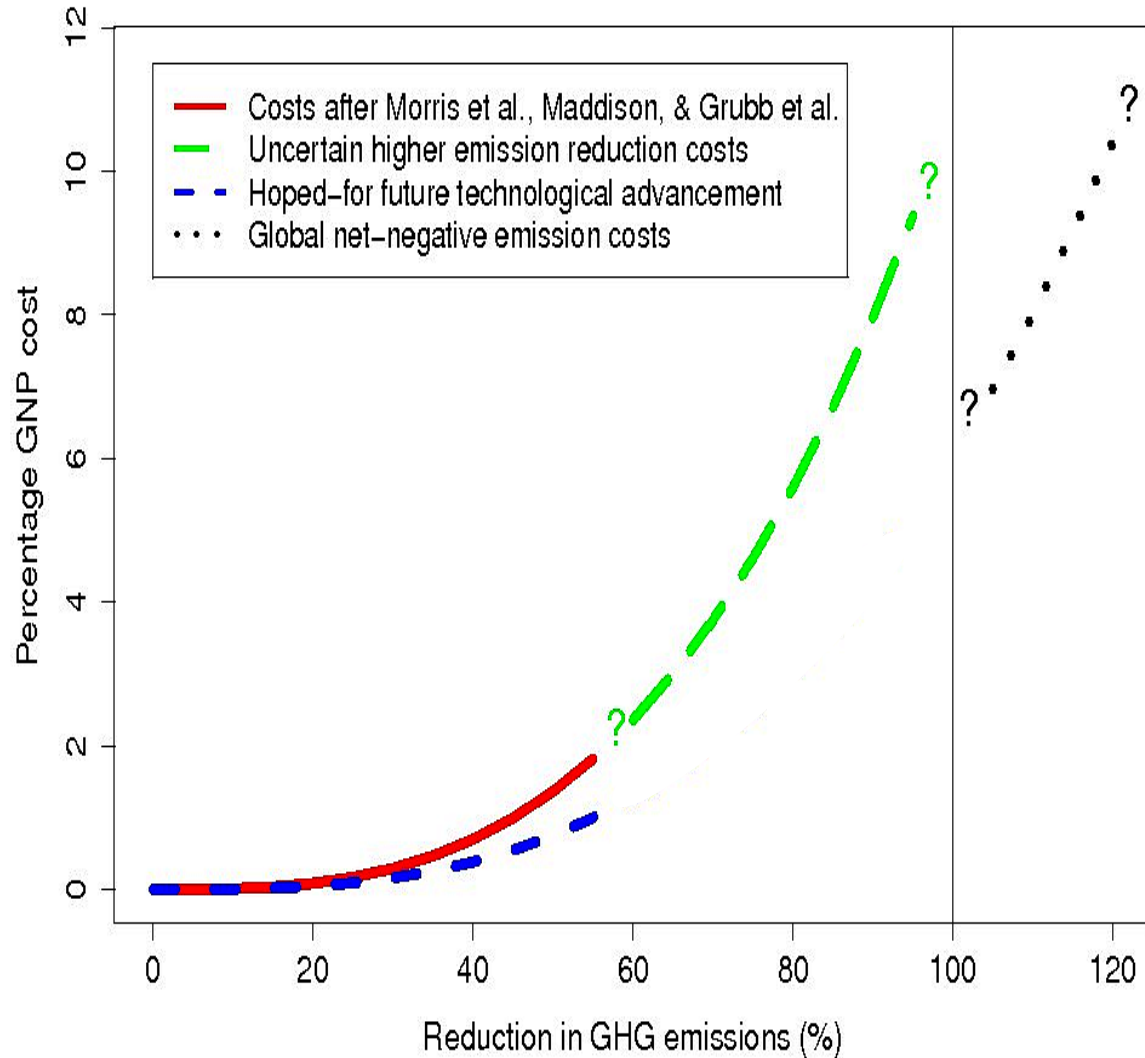
Abatement Costs for the UK Energy Sector in 2030

# Flood damage costs

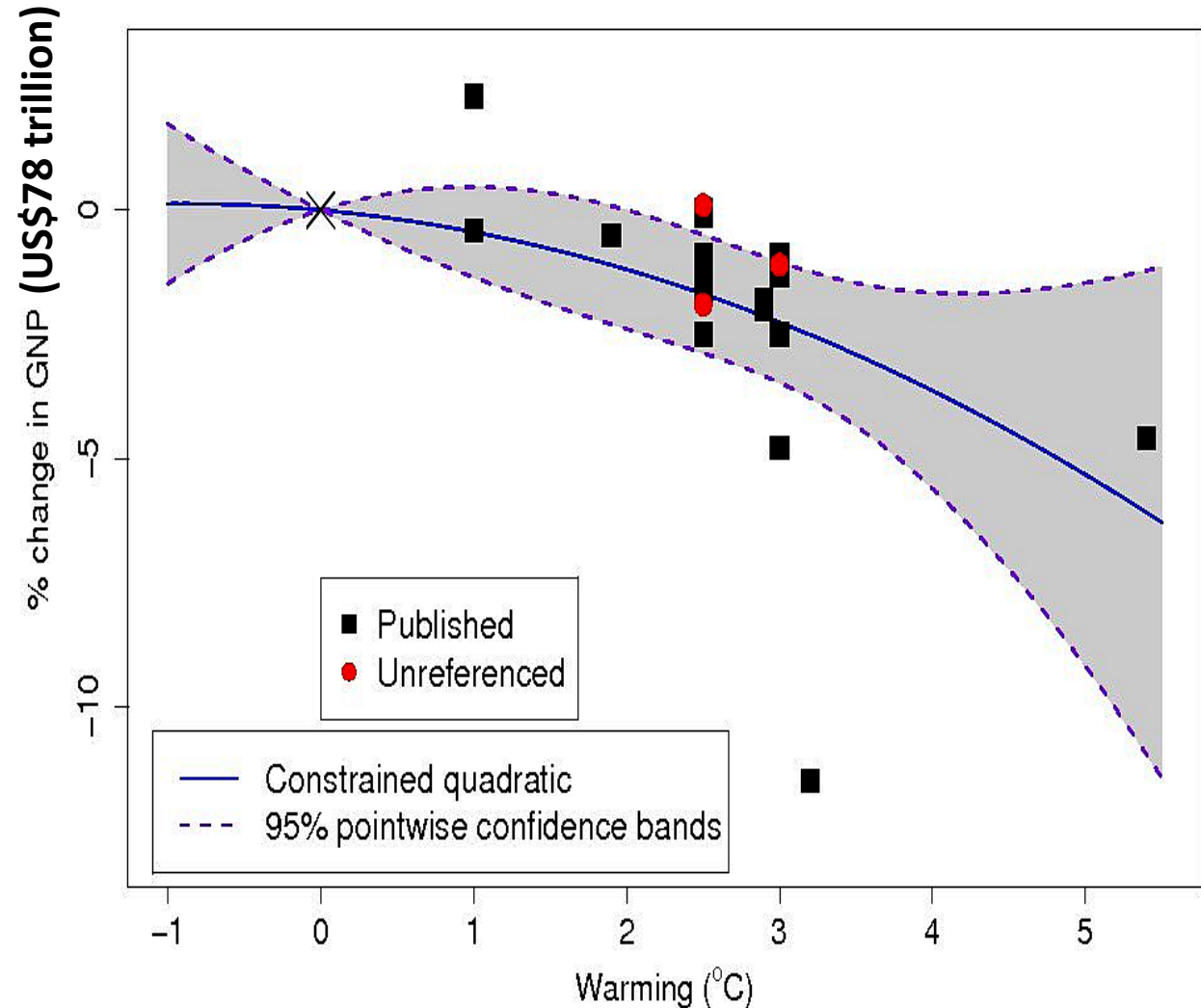


Global costs to 2100

# Costs of global emissions reduction



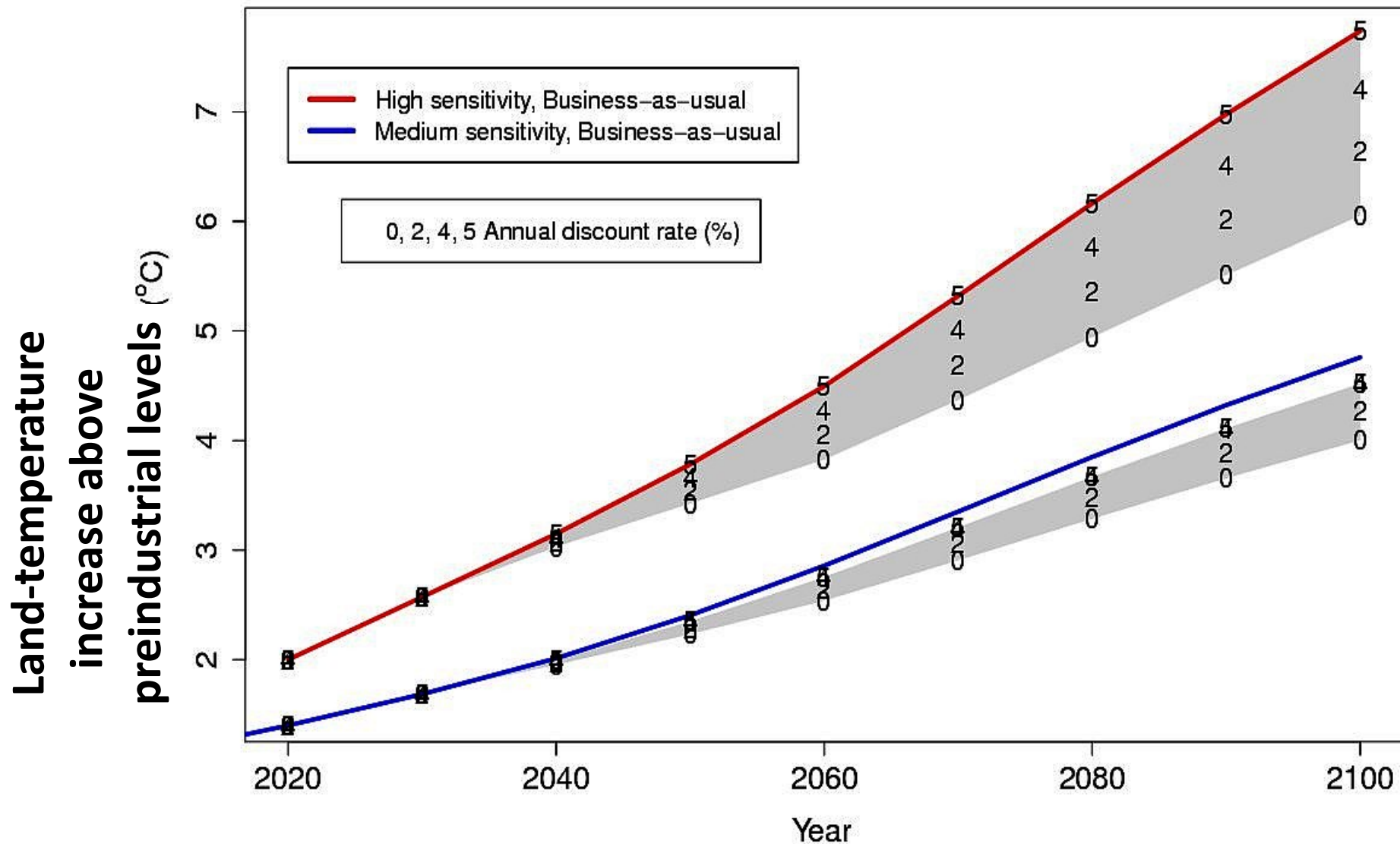
# Damage from global warming



(Thompson, Anthropocene Review, 2016)

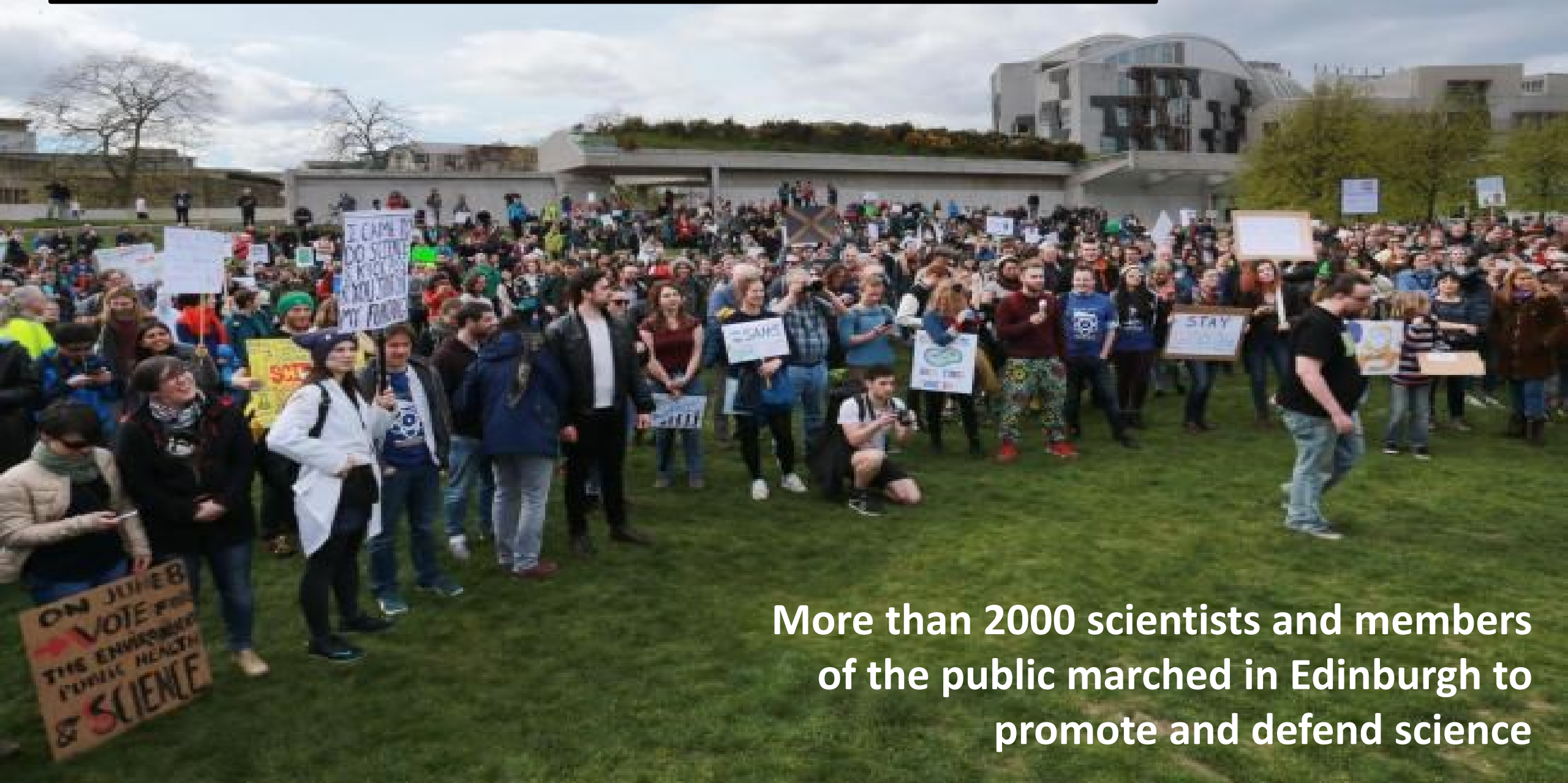


# Optimisation of the economic/energy-balance analysis



(Thompson, Anthropocene Review, 2016)

# Public acceptance of climate change science

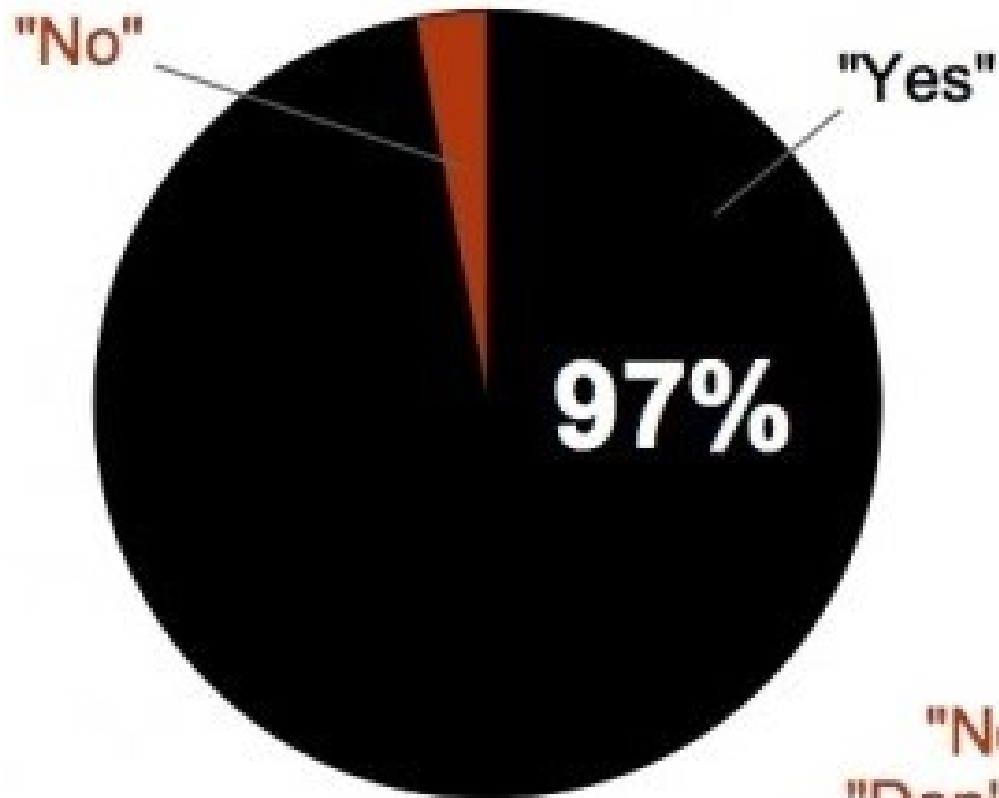


More than 2000 scientists and members of the public marched in Edinburgh to promote and defend science

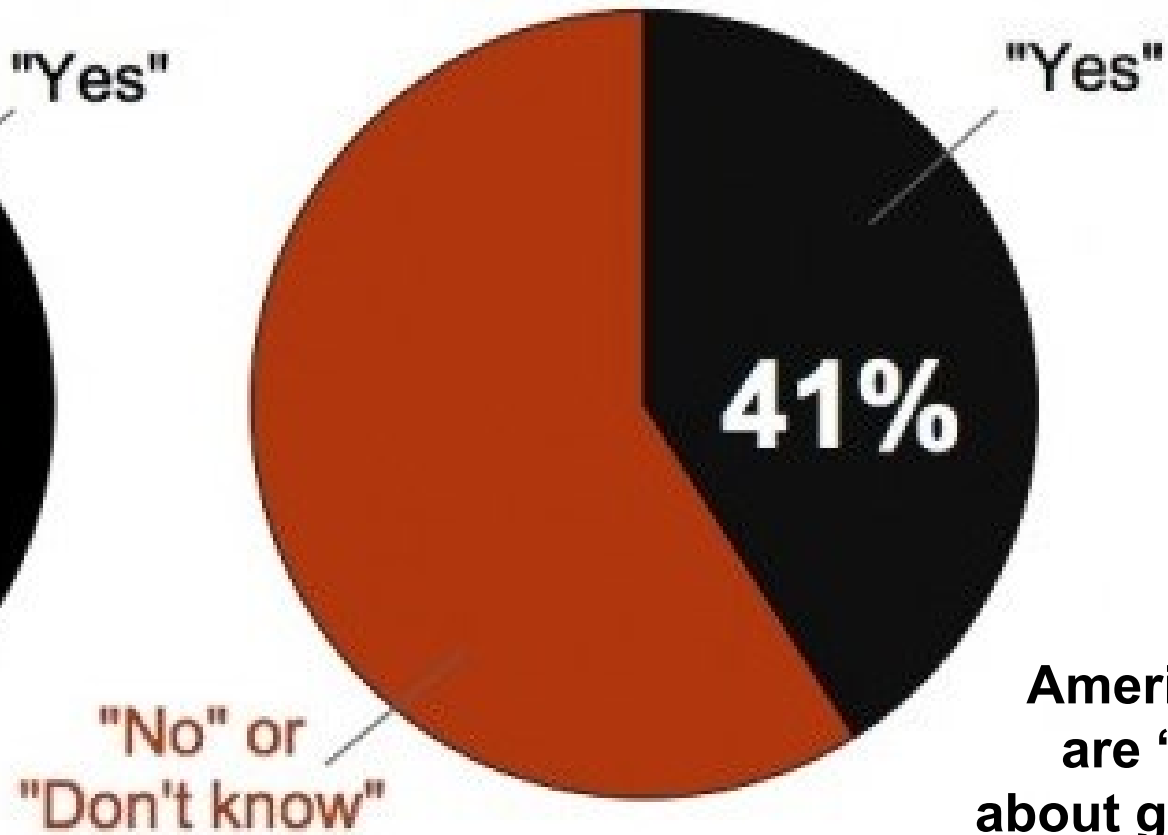
# Belief in climate change

Climate Change is Happening and Human Caused

Climate Scientists



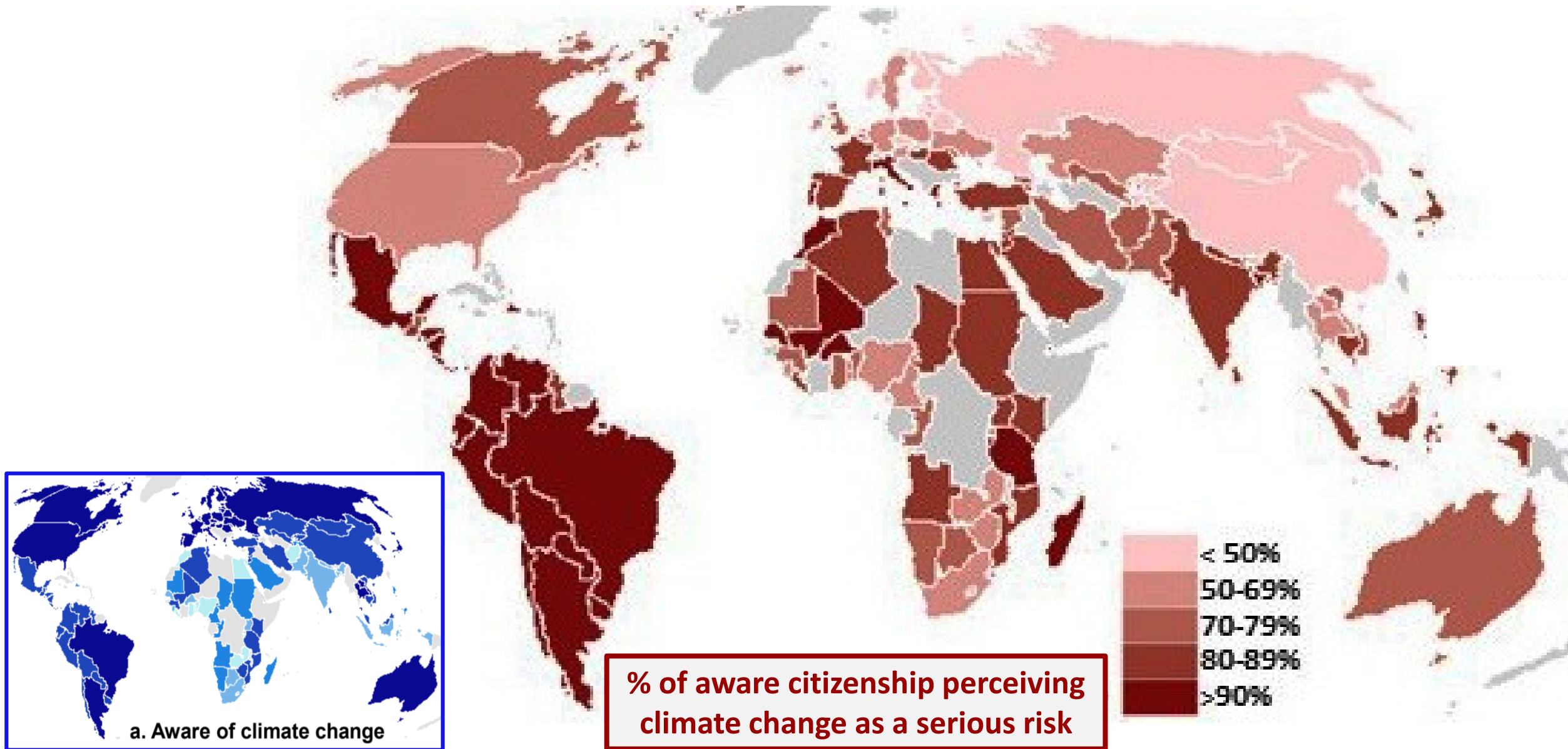
American Public



Only 16% of Americans say they are *"very worried"* about global warming



# Public awareness of climate change around the world



As 5p charge starts in England, shoppers face tangle of red tape

# PLASTIC BAG CHARGE

5p bag bid causes... But the many... becoming... bizarre... by minister... Police show... which follow... Bags campaign... age to the end... of plastic bags... However, critic... ing the scheme... shoppers, meanin...

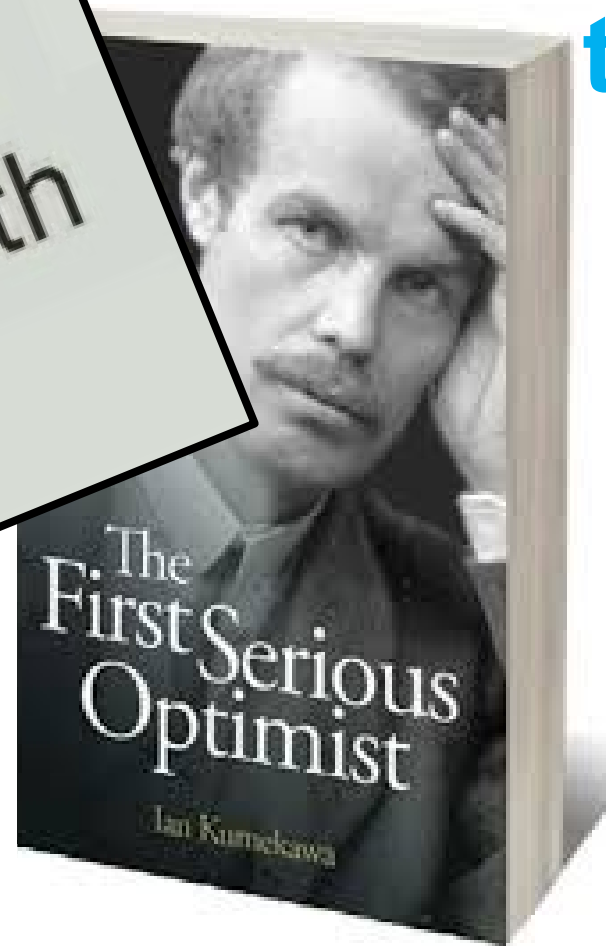
**BANK**  
**THE B**  
**Daily N**

reduction in bags issued a... don bags a year - will not be... said the 'totally superfluous... exemptions to the charge w... items for both retailers and cus... There are also concerns the... frustrations could be taken out... While 4p of each charge will go to... Chancellor George Osborne has... campaigners by insisting that the... will take the remaining 1p in VAT... The new charge excludes paper b... will be payable on each plastic bag... out in major stores - those with mor... Turn to Page 4

The best thing about the 5p plastic bag charge is that the cupboard next to my sink is now worth £672,348.

on Saturday  
**...on misery**  
**... Cup humiliation** PAGE SEVEN

**A. C. Pigou**  
**(the father of**  
**environmental**  
**taxes)**



# Concluding observations

## State of play

- A growing hierarchy of well-used, open-access climate models has been created.
- Much, open, high-quality climate data is readily available at the click of a button.
- In contrast - econometric data, and code, is much scarcer and not as freely available.

## Quo vadis ?

- The public remains highly sceptical.
- Many large corporations remain firmly behind climate disinformation campaigns.
- CO<sub>2</sub> continues to rise.
- Governments set ambitious targets - but genuine political will remains woefully insufficient.



# Final thought

**Yes**, while a one-line energy-balance model forecasts calamitous change in the absence of carbon-pricing, **Pigouvian rebating** offers a straightforward solution by promoting behavioural change.

## 1-line code

✓ Aerosols	-ive
✓ Clouds	+ive
✓ $T_{\text{land}}$	$\sim +2\text{ }^{\circ}\text{C}$
✓ $\times 2\text{ CO}_2$	$= 4\text{ }^{\circ}\text{C}$
✓ $T_{2100}$	$= +7.9\text{ }^{\circ}\text{C}$
✓ C pricing	$= \$200/\text{tonne}$