How sensitive is the climate to greenhouse gases?

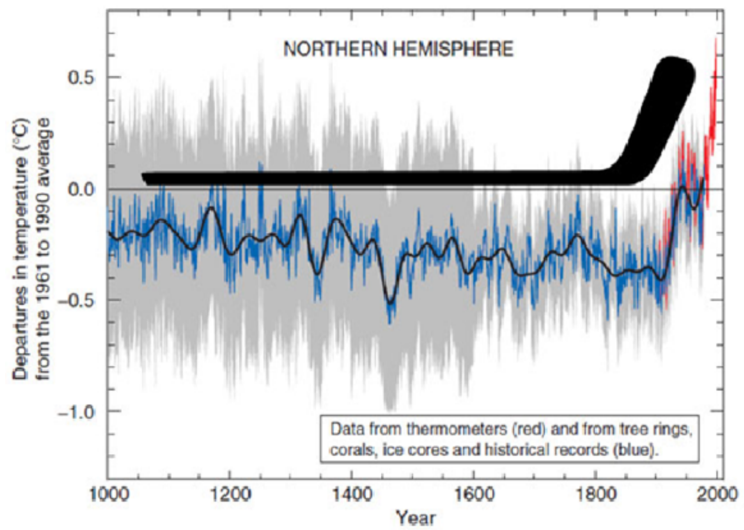
Is it really necessary to reach zero emissions in 2050?

Nicholas Lewis

March 2019, Amsterdam

How I became a climate scientist

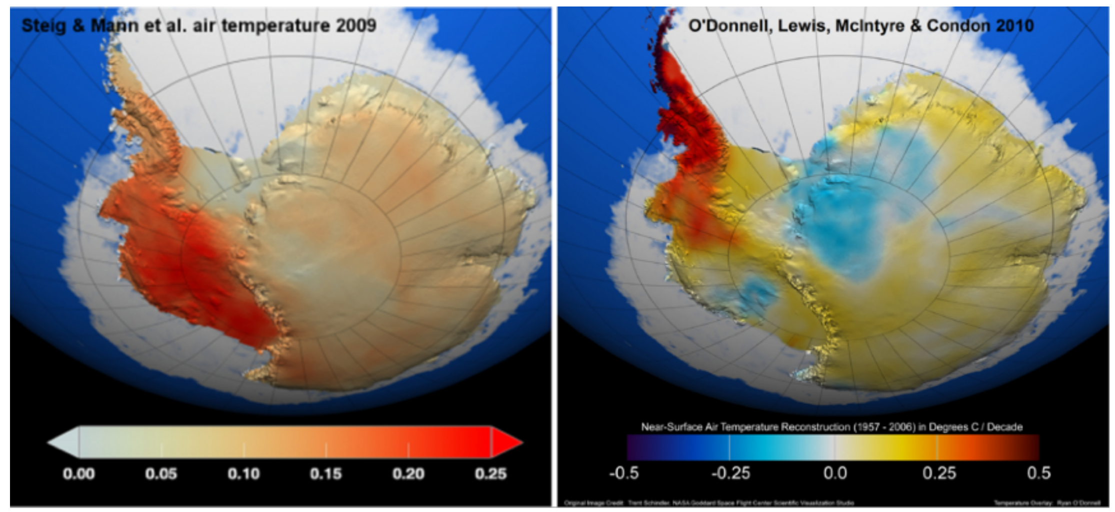
- Hooked on Climate Audit blog – Steve McIntyre



Much in climate science seemed to me questionable and calling out for investigation.
This is Michael Mann's 'Hockey Stick', showing unprecedented warmth – debunked by Steve M, a superb Canadian analyst and blogger who has inspired others.
Steve & I are both competitive, independent people, who are willing to publicly challenge poor work and consensus views.
Happily today's technology enables independent researchers like myself to work effectively.

Why climate science?

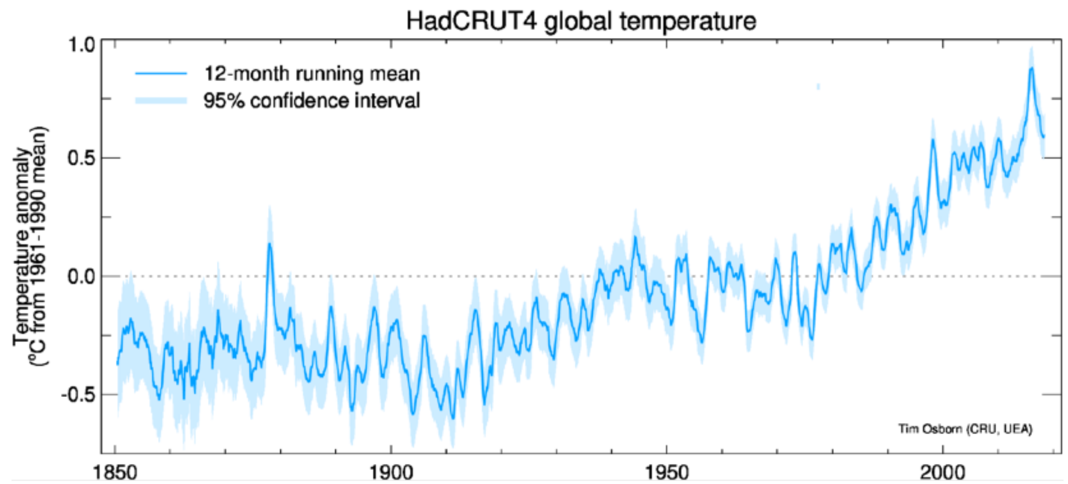
- I started off working with Steve M and others
- We debunked a hyped Antarctic temperature paper
- Our improved record paper was published in 2010



I had a steep learning curve - tough but very intellectually stimulating!
LHS= front cover of January 2009 Nature – West Antarctice warming rapidly (red area). RHS= our results: same data, proper maths ans statistics, resulting in warming being spread over a much smaller area and a much lower average Antartic warming rate. Published in Journal of Climate in 2010.
By then I had become addicted to climate science and started to look into it other areas of it, starting with historical warming.

My current views on climate science

- Much of the basic science is OK
- IPCC: 'It is extremely likely that human activities caused more than half of the observed increase in GMST from 1951 to 2010.' [Best estimate ~100%]



- I remain sceptical of climate model simulations

IMO the basic science is mainly sound, and disputing it loses credibility. Best to focus on issues that can sensibly be challenged.
The chart shows warming since 1850. Some people may think this warming is mainly a recovery from the LIA, and maybe overstated. I've dug into this and now accept the IPCC view. Indeed, my studies assume that post-1850 warming is almost all anthropogenic , with recovery from the LIA and volcanic activity earlier in the 1800s making a modest contribution.

Why I focus on climate sensitivity

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Research

CrossMark

The $10 trillion value of better information about the transient climate response

Chris Hope

Judge Business School, University of Cambridge,

- Very valuable to know climate sensitivity accurately
- I saw serious statistical errors in published studies

Climate sensitivity is a measure of how much global average temperature will go up, in the long run or shorter term, as greenhouse gases rise.
Climate sensitivity is a key area: society can't properly calibrate very expensive emission reduction policies if climate sensitivity is poorly known.
Steve M dominated scrutiny of paleoclimate work; I saw serious errors being made in the more critical climate sensitivity area and decided to focus there.

It is an exciting area, as scientific understanding is poor & evidence conflicting, so I could hope to make a real contribution.

My publication record

- 8 peer reviewed climate sensitivity papers

JOURNAL OF CLIMATE

1 August 2018 LEWIS AND CURRY 6051

The Impact of Recent Forcing and Ocean Heat Uptake Data on Estimates of Climate Sensitivity

Nicholas Lewis

Bath, United Kingdom

Judith Curry

Climate Forecast Applications Network, Reno, Nevada

I'm fairly unusual for an outsider, in that I generally aim to get my research published in good peer-reviewed journals.
This is my latest major study, an update of my 2015 study with well-known co-author Judith Curry – just-retired as a climate science prof.essor.
As well as estimating climate sensitivity to be low, Lewis & Curry 2018 (LC18) refutes various critiques of the methods it and its predecessor 2015 study use.
Observational estimates that I give in this talk are consistent with the results in this 2018 study.

Engagement with other scientists

Unlike most people who approach climate change from a sceptical viewpoint, I meet with & give talks to other climate scientists.
Schloss Ringberg was the unusual setting for a week long 2015 meeting on climate sensitivity; I was lucky to be one of 35 scientists worldwide invited. I am glad to find that I am taken seriously.

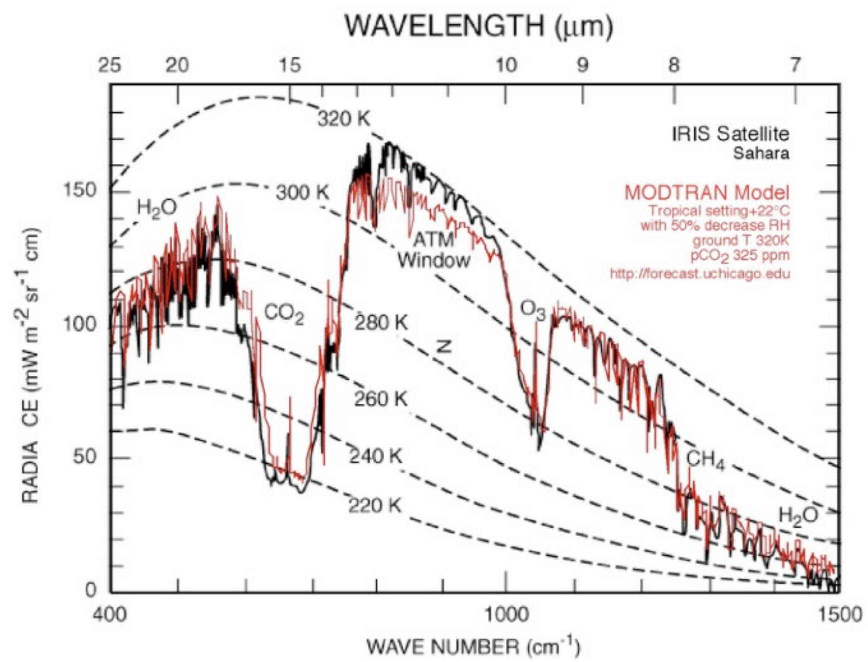
What my talk will cover

- How sensitive the climate system is to CO_2
  – in the long term
  – over 50-100 years
- What this implies for warming this century
- Some personal views on policy implications

My focus on sensitivity to CO_2 is standard: climate sensitivity in climate models is measured by altering just the CO_2 level, and CO_2 accounts for ~90% of projected future greenhouse gas warming.
The main other anthropogenic emission-linked GHGs are methane, nitrous oxide, CFCs and the short-lived gas ozone.

Greenhouse effect

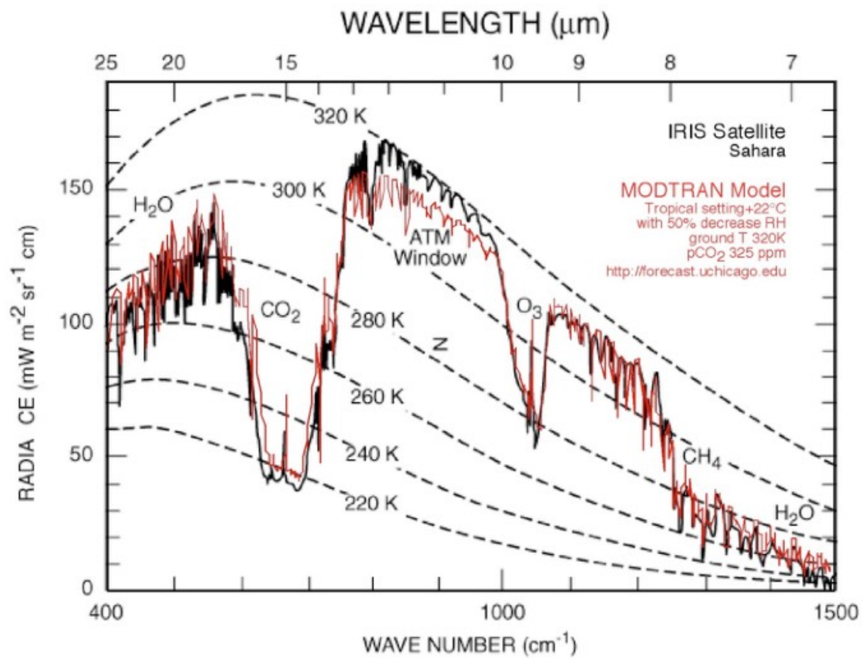
- GHGs impede radiation emitted by the Earth
- Basic radiative physics – not to be disputed



Modelled and measured thermal radiation out into space – a near perfect match between observations and model results.
GHGs reduce radiation to space from the Earth's surface and atmosphere. The radiative effect of GHGs – their '**radiative forcing**' – is a solid part of climate science.

Greenhouse effect

- Big CO_2 trough in radiation to space: grows as level ↑
- Water vapour – key gas but temperature-governed



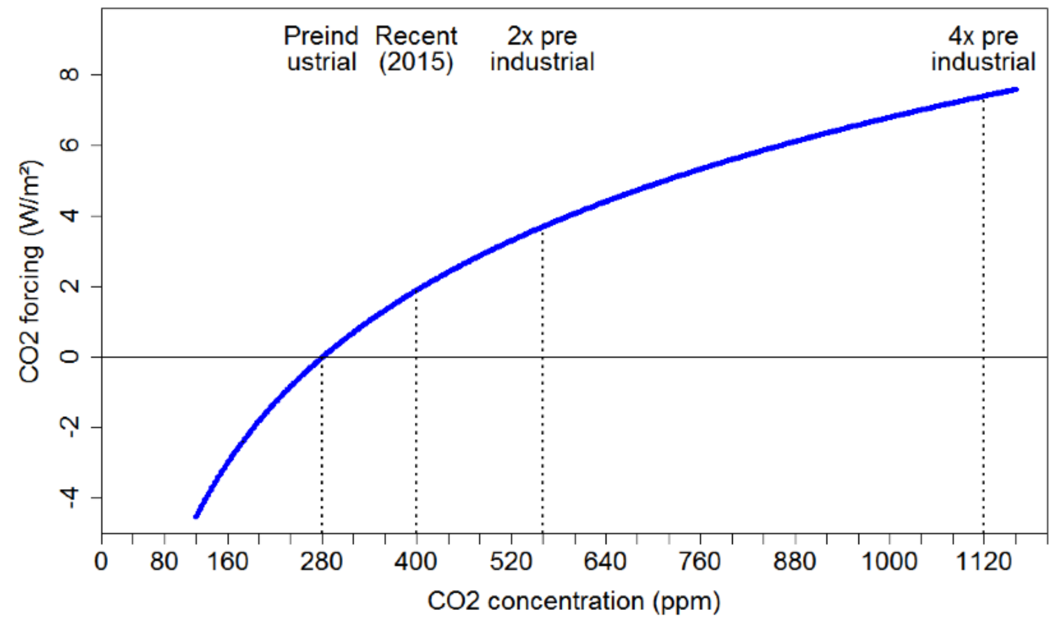
CO_2 reduces outgoing radiation by ~75% in a band around 15 microns wavelength: it only escapes from cool upper atmosphere

Higher atmospheric CO_2 => even deeper & wider trough in outgoing radiation.

Water vapour absorbs at many wavelengths, but is not directly affected by humans – it comes from ocean etc. evaporation, and its concentration depends on surface temperature.

Is CO_2 absorption saturated?

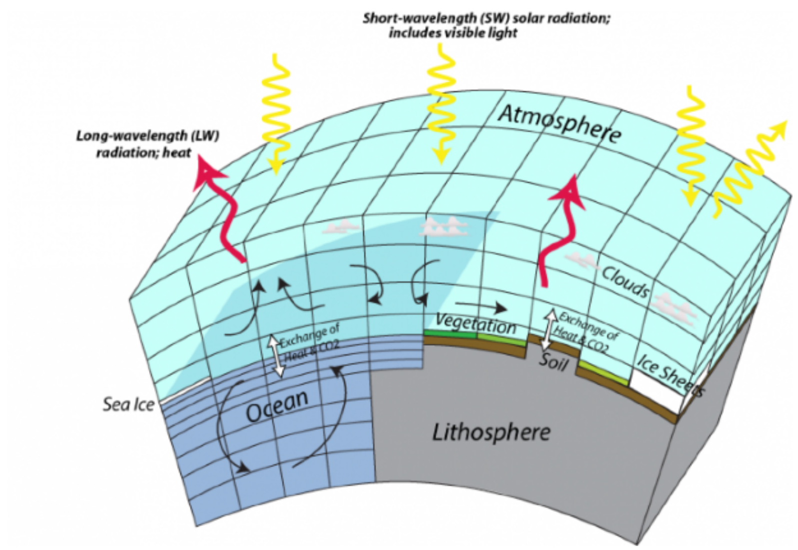
- Effect of CO_2 is logarithmic – same for each 2x



The radiative effect of CO_2 is not saturated. Outgoing radiation is reduced more as CO_2 concentration rises – its radiative forcing increases – but increasingly slowly.

Global climate models

- 3D simulation models (GCMs) – key in science & policy
- GCMs physically-based but use huge approximations



GCMs are very impressive achievements, but their results vary hugely between different GCMs and they may all be wrong.
GCMs simulate large scale 3D atmospheric & ocean circulation, and some other things, from basic physics. The remainder are approximated – 'parameterised' . Treatment of key cloud and convection behavior is poor.

Climate sensitivity

- Basic surface warming ~1°C per CO_2 doubling
- +/– ‘feedbacks’ increase/reduce basic warming
- Main feedbacks: water vapour, clouds, snow/ice
- Equilibrium climate sensitivity: metric used to quantify resulting long term warming

  ECS = resulting long-term warming if 2x CO_2

Warming due to GHG causes other changes in the climate system that affect outgoing radiation & hence warm or cool the Earth additionally – called ‘feedbacks’.
Warmer => more evaporation => more WV => stronger GH effect => higher warming : strong positive feedback. Most uncertain feedback is form changes in clouds: they both reflect sunlight & have a greenhouse effect, and their behaviour is very complex.
Snow/ice albedo feedback is positive but small.

I’ll be using these acronyms for equilibrium climate sensitivity and transient climate response a lot, so please try to remember them!

Long term climate sensitivity - ECS

- ECS range unchanged since 1979; mainly GCM-based
- IPCC (AR5) ECS range is 1.5–4.5°C: very uncertain
- Typical GCM ECS ~3°C : 1°C basic, 2°C feedbacks

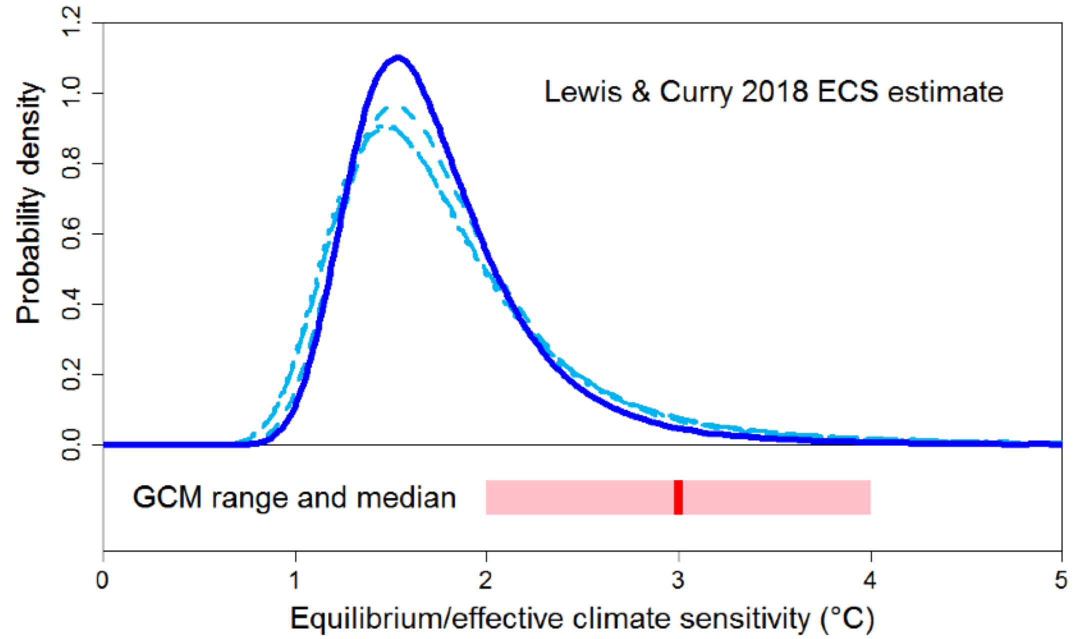
	ECS Range (°C)	ECS Best estimate (°C)	TCR Range (°C)
Charney Report 1979	1.5–4.5	3.0	
NAS Report 1983	1.5–4.5	3.0	
Villach Conference 1985	1.5–4.5	3.0	
IPCC First Assessment 1990	1.5–4.5	2.5	
IPCC Second Assessment 1995	1.5–4.5	2.5	
IPCC Third Assessment 2001	1.5–4.5	None given	1.1–3.1[a]
IPCC Fourth Assessment 2007	2.0–4.5	3.0	1.0–3.0
IPCC Fifth Assessment 2013	1.5–4.5	None given	1.0–2.5

[a]Range based on models only.

The equilibrium climate sensitivity range in the 5th and latest IPCC Assessment Report, AR5, was the same as in 1979.
Model–observation disagreement => no best estimate given in AR5.
Wide sensitivity range => can't tell what policy action is best
Equilibrium climate sensitivity in GCMs varies over a range of 2 °C to 4+°C, as it always has. Feedbacks are strong in most GCMs.

Long term sensitivity – Observations

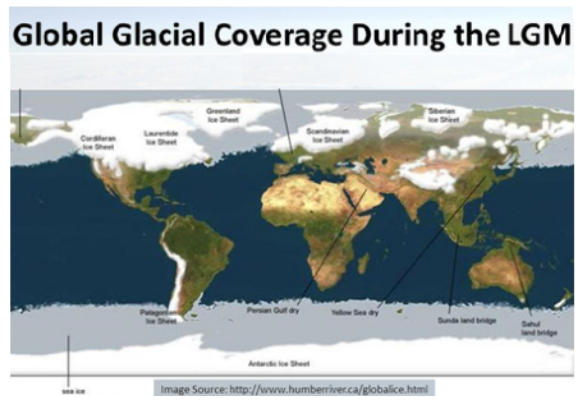
Last 150 years observations => ECS 1.7°C (1–3°C)

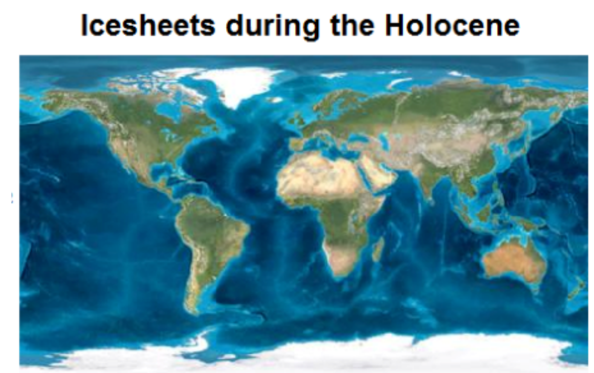


One can also estimate ECS using observations of real climate system. Doing so doesn't give very precise estimates, but they are improving.
The LC18 estimate is based on comparing estimated changes in global temperature, in ocean heat uptake and in radiative forcing from GHG and other drivers of climate change, between windows early and late in the historical record. Some limited input from models is required to provide the radiative forcing estimates. LC18 uses radiative forcing estimates given in the IPCC 5th Assessment Report (AR5), updated to 2016 (and in a few cases revised to reflect more recent understanding).
X-axis is sensitivity, Y-axis is probability.
Main estimate is the dark blue line; dashed cyan lines are estimates based on alternative time windows.
The median observational equilibrium climate sensitivity estimate of 1.7°C is 45% below the GCM median of 3.0°C.

Long term climate sensitivity – ECS

- Paleoclimate proxy data: IPCC ECS range 1–6°C
- LGM (best studied paleoclimate): 1.8°C (1–3.4°C)

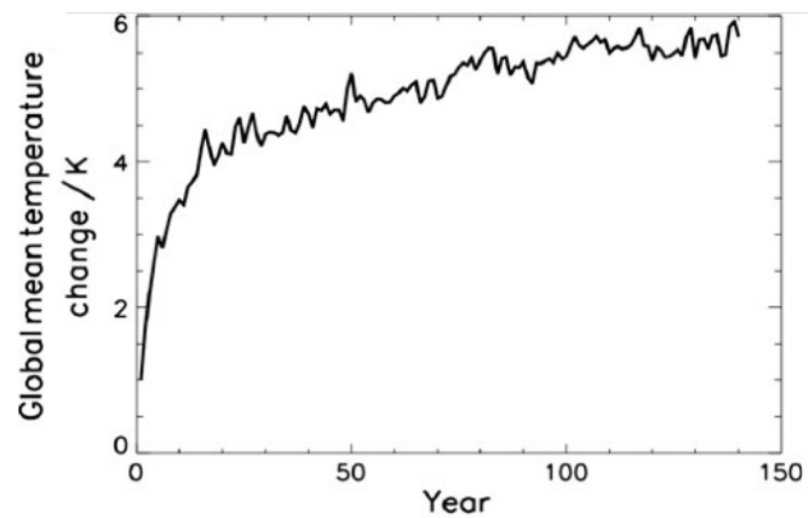




Can also estimate equilibrium climate sensitivity in the same way from ancient periods, using proxy data – ice cores, isotopes, etc.
But uncertainties are very large, so usefulness of paleoclimate ECS estimates is limited.
Least uncertain estimates are probably from the Last Glacial Maximum (LGM), 20,000 years ago. See LC18 for details of the 1.8°C ECS estimate from the LGM to preindustrial Holocene transition.

Multidecadal climate sensitivity - TCR

- Large ocean heat capacity slows rise towards ECS
- Most warming occurs by year 20, then flattens out
- So ECS not a good metric for multidecadal warming



Warming in a typical GCM after CO_2 is abruptly quadrupled

Takes > 1000 years to fully warm ocean and reach new equilibrium.
In abrupt CO_2 increase simulations, warming over years 1-20 usually accounts for half to two-thirds of the ultimate, equilibrium wraming.
Warming on a multidecadal timescale is not very sensitive to the exact timeframe.

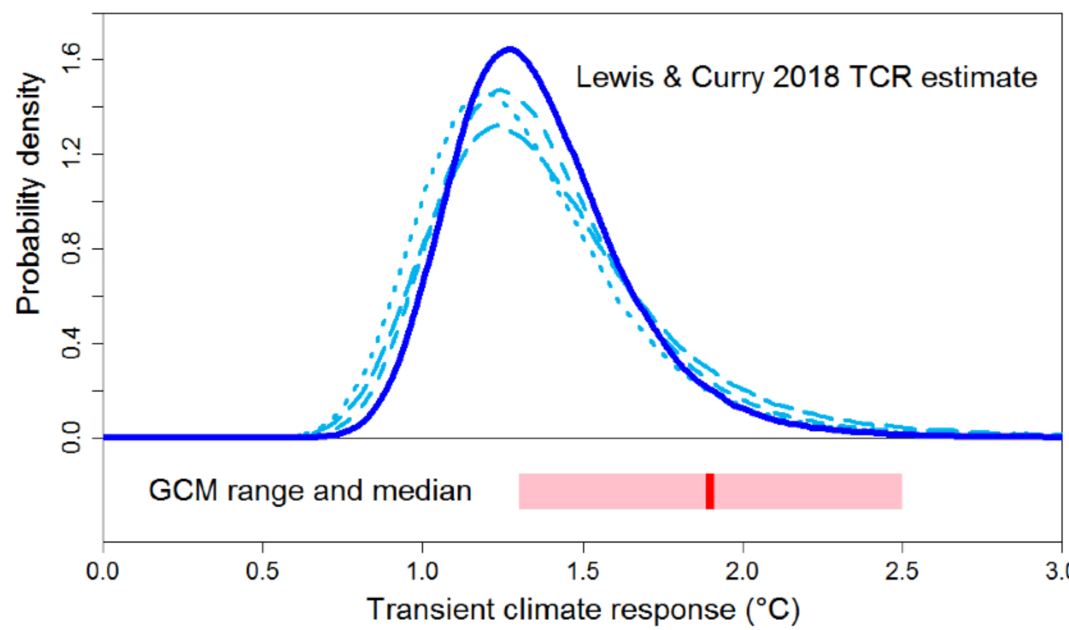
Multidecadal climate sensitivity - TCR

- Metric used is the Transient climate response
- TCR: warming at year 70 if gradual CO_2 rise to 2x
- TCR is lower and less uncertain than ECS
- < 2100 warming depends more on TCR than ECS
- IPCC AR5 TCR range: 1.0–2.5°C
- GCM TCR range 1.3–2.5°C; average 1.8–1.9 °C

TCR < ECS because some of the heat that increased GHGs trap is absorbed by the ocean

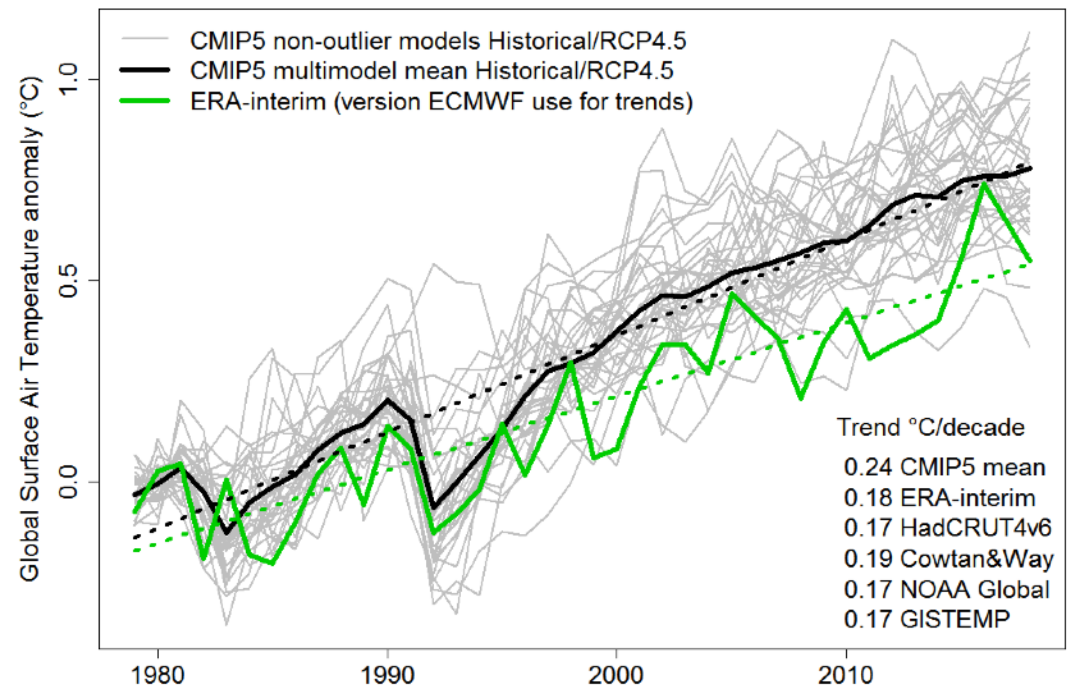
Multidecadal sensitivity - Observations

Last 150 years observations => TCR 1.35°C (1.1–1.6°C)



Typical GCMs have a 35–40% higher transient climate response than the median observational estimate.
Same estimation method as for equilibrium climate sensitivity, but don't need to know ocean heat uptake.

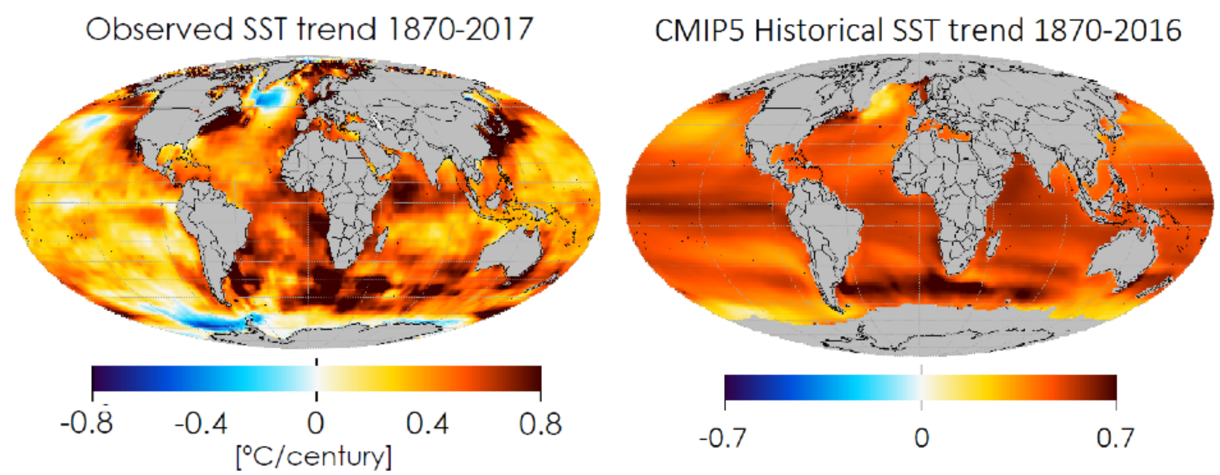
Models over-warmed 1979–2018



My graph of warming from 1979-2018: on average current generation (CMIP5) GCMs warmed 1/3 more than the exactly comparable ERA-interim 40-year long record; much as expected from the ratio of their TCRs.
All observational records have similar trends over 1979 – 2018.
Changes in radiative forcing in GCMs and per the IPCC's primarily observation-based best estimates are only similar over last 40 years.
Growth rate in radiative influence of emissions (i.e., radiative forcing) in models is close to recent best estimates since 1979, but lower until then.
GCMs were trained on observations up to ~2005. Until 1990s their higher sensitivity was offset by lower forcing – especially from aerosols, with the result that their overall warming was similar to that observed.

Why do observations & GCMs differ?

- GCM-simulated historical warming patterns ≠ actual
- GCM ECS low if follow observed warming pattern!
- Did natural variability depress historical warming?



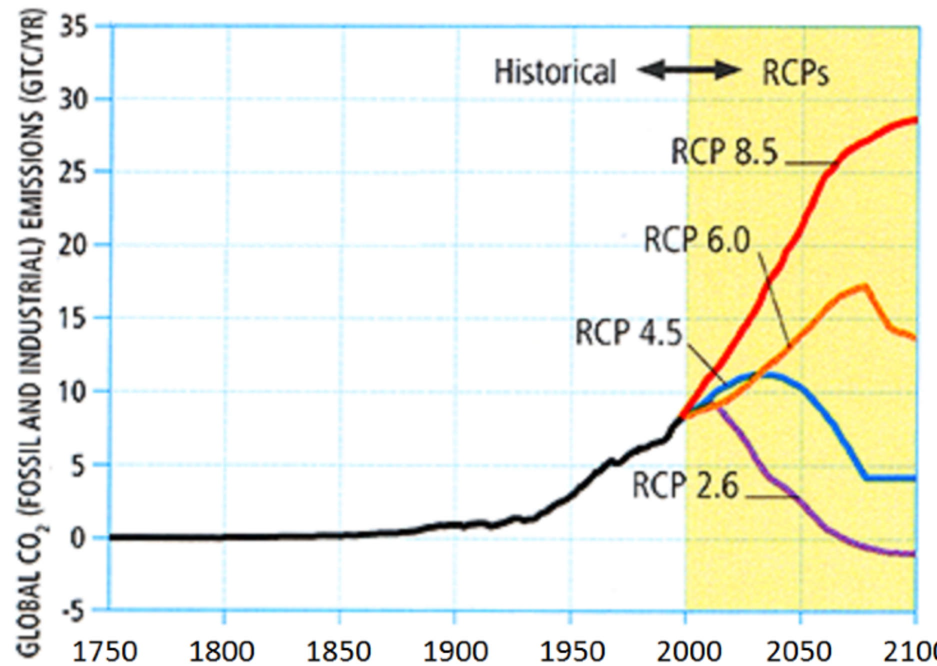
These maps compare 1870-on observed warming trends per the UK Met Office sea-surface temperature record and as simulated by the average current GCM.
If GCMs are forced to warm with the same pattern of SST trends as observed, they exhibit substantially lower climate sensitivity than when they are, as is usual, free to generate their own patterns of ocean surface warming when simulating the historical period.
Many sceptics claim natural variability caused a good part of observed warming; many scientists now claim the opposite! Both are wrong in my view.

Relating warming to CO_2 emissions

- 40% of human CO_2 emissions remain in atmosphere
- Airborne CO_2 fraction will very slowly fall, to 15-20%
- ESMs project no cooling after emissions cease
  ESM = GCM with carbon etc. cycle model added
- In ESMs, warming **μ** cumulative CO_2 emissions
- This is why people talk about ‘carbon budgets’
- Carbon budget: cumulative emissions for ≤ 2°C (say)
- ESM-derived carbon budgets are driving policy

Dutch climate law 95% emissions reduction by 2050 is I think driven by aim to limit cumulative emissions, to meet 1.5/2°C target
NB Political 1.5 & 2°C targets are warming from preindustrial , which the IPCC usually treats as being the average over the 2nd half of C19

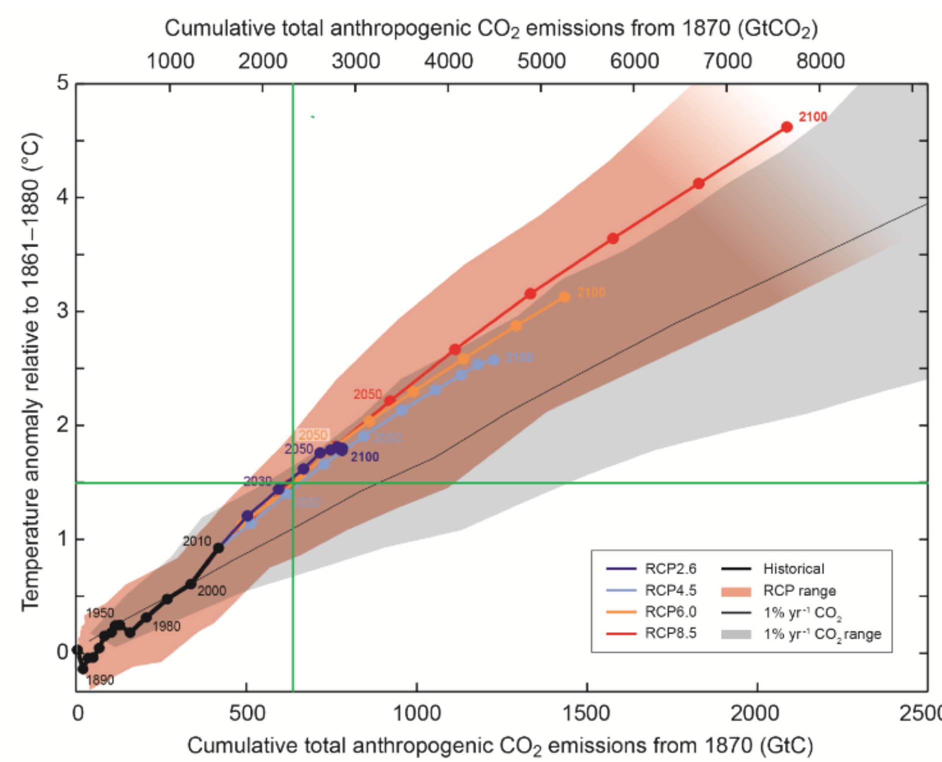
RCP emission scenarios to 2100



IPCC AR5 used four socio-economic scenarios to project future emissions, CO_2 concentration & warming – Representative Concentration Pathways 2.6, 4.5, 6 & 8.5
RCP8.5 is a pessimistic worst case scenario – not business-as-usual (BAU) as is often claimed.
RCP6.0 is closest to a BAU scenario with little further mitigation. On RCP6, FF emissions rise until after 2050, then fall.
Based on 40% airborne fraction, on RCP6 CO_2 concentration reaches ~580 ppm in last decade of the century

Warming relative to emissions in AR5

On RCP6.0 scenario, 3.2°C rise in 2090s; green lines show 1.5°C rise for 625 GtC emissions



The most important graph in AR5 as regards policy. Earth System Model-based projections. Almost same warming at same emissions on all scenarios – supports carbon budget idea. Slightly higher warming relative to cumulative emissions on the RCP8.5 scenario reflects much higher methane emissions in RCP8.5.

CO_2 emissions are measured either in gigatonnes of teir carbon content, GtC, or in $GtCO_2$.

We have now reached 625 GtC emissions, but warming is only ~1°C! High TCRs + too high airborne CO_2 => AR5 ESMs run too hot

AR5 carbon budgets (50% probability) & warming targets are both from ~1870.

Transient climate response to emissions

- AR5 ESM-derived carbon budgets ridiculously low
- There is a simpler way to project future warming
- Use the Transient Climate Response to Emissions
- TCRE = warming per 1000 GtC cumulative emissions
- TCRE estimated over ~70 yrs; ESMs or observations

The main reason why Earth system models project that we have already hit 1.5°C warming is their high TCRs.
But also the land biosphere and ocean don't absorb enough CO_2 in ESMs, so atmospheric CO_2 too high.
The acronym for the Transient Climate Response to Emissions is TCRE.

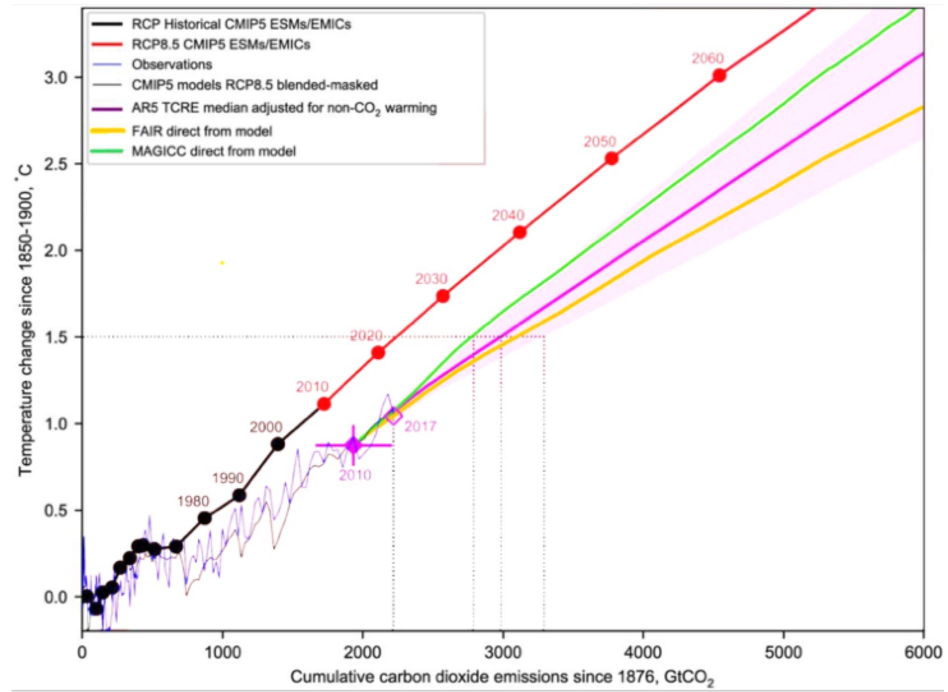
Projecting future warming using TCRE

- TCRE = warming per 1000 GtC cumulative emissions
- In ESMs TCRE averages ~1.65°C, but ranges widely
- AR5 assessed a 0.8–2.5°C TCRE range; mainly ESMs
- Observational TCRE estimate 1.05°C, range 0.7–1.6°C
- Project future warming as: Future emissions x TCRE + warming from human non-CO_2 emissions etc.
- This is what IPCC SR1.5 did – link to ESMs is indirect

The 2018 IPCC SR1.5 Report used the largely ESM-derived IPCC AR5 TCRE range and midpoint.

SR1.5: 15-20% cooler than AR5 /1000 GtC

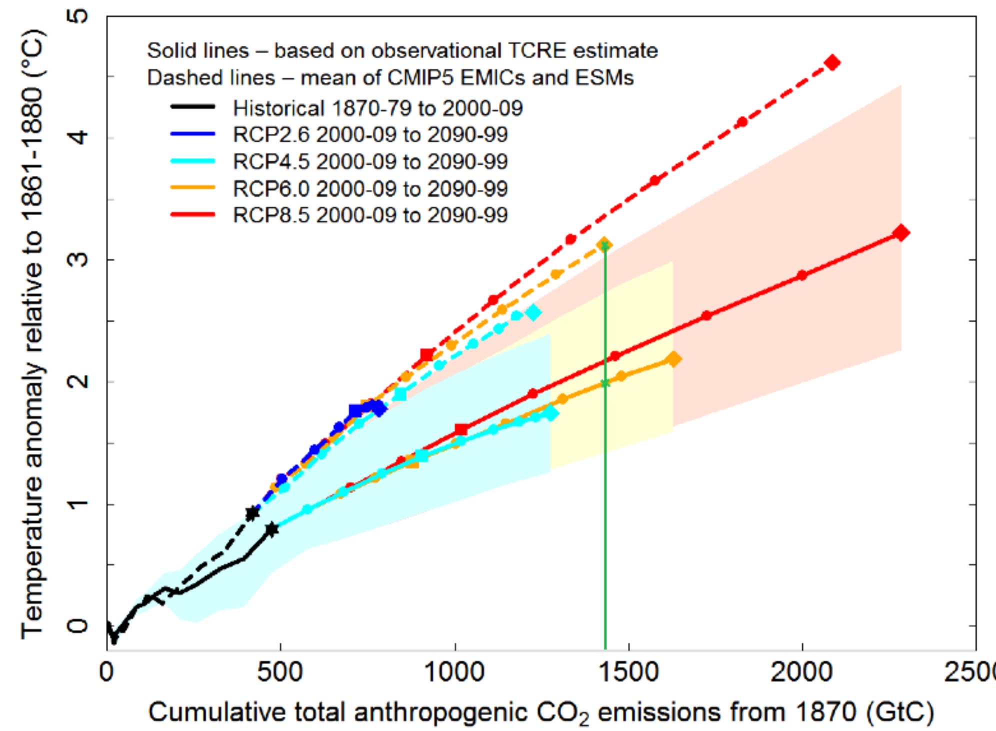
SR1.5 warming: AR5 TCRE + simple model for non-CO_2



Key figure in IPCC Special Report on Global Warming of 1.5°C (SR1.5). Projections are for a range of scenarios.
Red line = old AR5 ESM-based RCP8.5 projection.
Green line = SR1.5 projection based on 1.65°C TCRE + old simple model for non-CO_2 : ~ parallel to red line because this old model has a TCR and ECS that match a typical AR5 ESM's TCR and ECS.
The projction lines are shifted down as warming to date is much smaller relative to emissions than AR5 ESMs projected.
Yellow line: using a less sensitive new model for future non-CO_2 warming. CO_2 warming is same as for green line.
Magenta line = SR1.5 projection – average of old & new model projections for non-CO_2 warming. ~2.6°C (vs 3.2°C) warming at 2090s point on RCP6 scenario per AR5.

Warming from observed TCRE, TCR, ECS

Warming on RCP6.0 (yellow lines) at AR5 2090s emissions (green line) is 2.0°C vs 3.2°C per IPCC AR5



Solid lines: my observation-based projections using 1.05°C TCRE for future CO_2-driven warming & simple model with TCR 1.33°C, ECS 1.7°C for non-CO_2.

Dashed lines are AR5 ESM central projections. NB AR5 RCP6 emissions are slightly lower than those in RCP6 scenario, because they are converted to concentrations by a simple model and then back again to emissions by the ESMs.

Policy implications

- IPCC AR5 ESM projections linking warming to cumulative emissions are driving climate policies
- IPCC projections => rapid reductions in CO_2 emissions needed to meet ≤ 2°C (or 1.5°C) target
- Observation-based projections => slower CO_2 emission reductions will meet ≤ 2°C target
- Low net emissions needed post-2100 if want ≤ 2°C

The little-further-mitigation RCP6 scenario likely to meet ≤ 2°C target if emissions peak sooner after 2050
Slower emission reductions => time to develop & deploy new, better/cheaper, technology & to adjust policy to new knowledge
Costs of reducing emissions fast is much higher. I doubt it is sensible to try to meet the ≤ 1.5°C target – but it is not very important to do so IMO.

Policy issues

- Many climate change policies wasteful/harmful
- Unclear how serious problems are if warming 2–3°C
- AGW a long term problem; adjust policy adaptively
- Maybe not the most serious environmental problem

Diesel vehicles, biofuels, carbon dioxide-reduction policy-driven environmental / health disasters; woodburning stoves are now a major source of PM2.5 pollution.
If the rate of warming is slower then the cost of adaptation will be much lower.
Nothing very bad is at all likely to occur soon IMO. It makes sense to adjust policy, as to both mitigtion and adaptation, in the light of developing knowledge and problems experienced.
Environmental damage is linked primarily to population growth, and other human impacts could turn out more serious than GHG emissions.

Conclusions

- Best observational estimates of climate sensitivity are (for doubled CO_2 concentration):
  – long term: 1.7°C, 45% below typical GCMs
  – multidecadal: 1.35°C, 25%+ below typical GCMs
- Likely warming to 2100: 60-65% of AR5 projection
- Near zero emissions in 2050 not vital: if still high but then drop, likely warming in 2100 is only 2°C

Thank you for listening

Nic Lewis

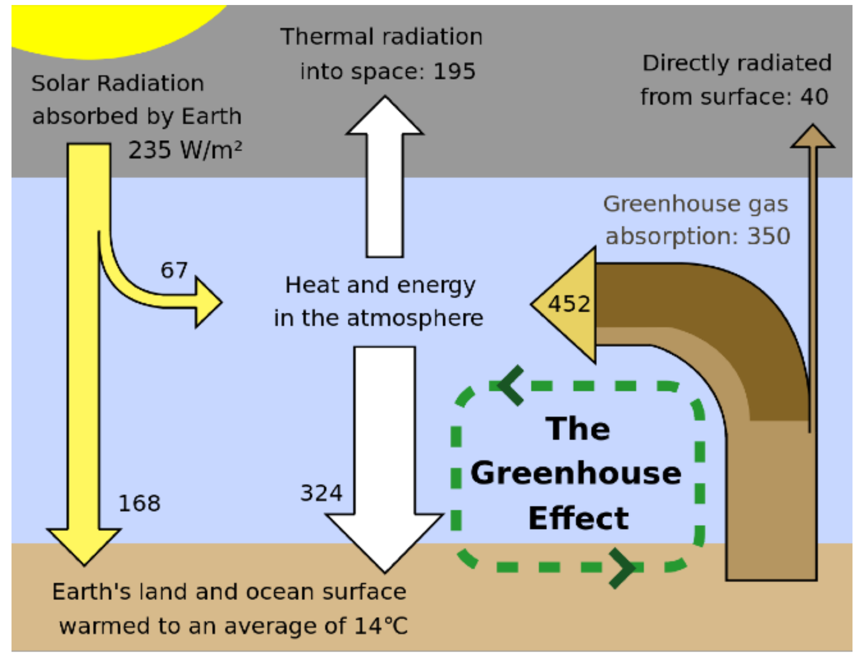
Presentation slides and notes will be available, together with papers and articles by me, at

www.nicholaslewis.org

Additional slides

Greenhouse effect

- Greenhouse gases affect Earth's temperature



Most thermal radiation from the surface is intercepted by atmospheric greenhouse gases and re-emitted – down as well as up.
Increased greenhouse gases mean that radiation escapes to space nearer the top of the atmosphere, where it is cooler than the surface. Cooler => lower thermal radiation. The surface and atmosphere therefore warm until sufficient thermal radiation escapes.

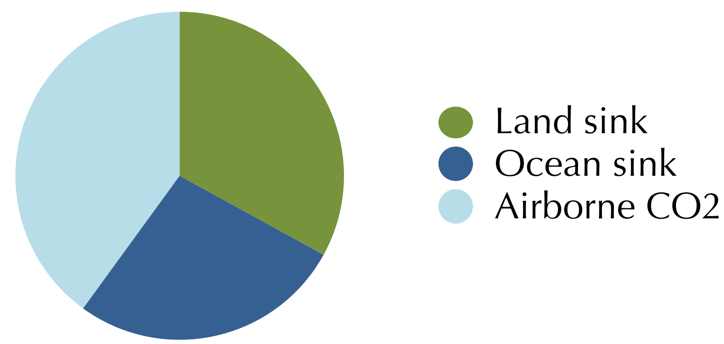
Uncertainty in climate sensitivity

- Spread in GCM TCR & ECS values: mainly clouds
- Uncertainty in observational TCR & ECS estimates: mainly the cooling effect of aerosols

Clouds are too small-scale for GCMs to simulate them, so they use crude approximations, which vary between models
Observed warming is a net effect: part of GHG warming offset by cooling from aerosols, whose effect is poorly measured

How much emitted CO_2 stays airborne?

- Higher CO_2 => more plant/tree growth & soil C
- Land biosphere absorbed 30-35% of emitted CO_2
- Ocean absorbs 25-30% of emitted CO_2
- So ~40% remains airborne – has varied modestly



CO_2 is plant food. Plants and trees grow faster at higher the atmospheric CO_2 levels, provided other nutients are adequate.
This leads to the land carbon pool – carbon stored in woody parts and the soil – becoming larger, with a lag, as CO_2 increases.
Ocean carbon chemistry is well understood and ocean CO_2 uptake is now reasonably well measured.
The speed of future carbon uptake by the ocean is somewhat less certain, not least since ocean biology is poorly understood.

How much emitted CO_2 stays airborne?

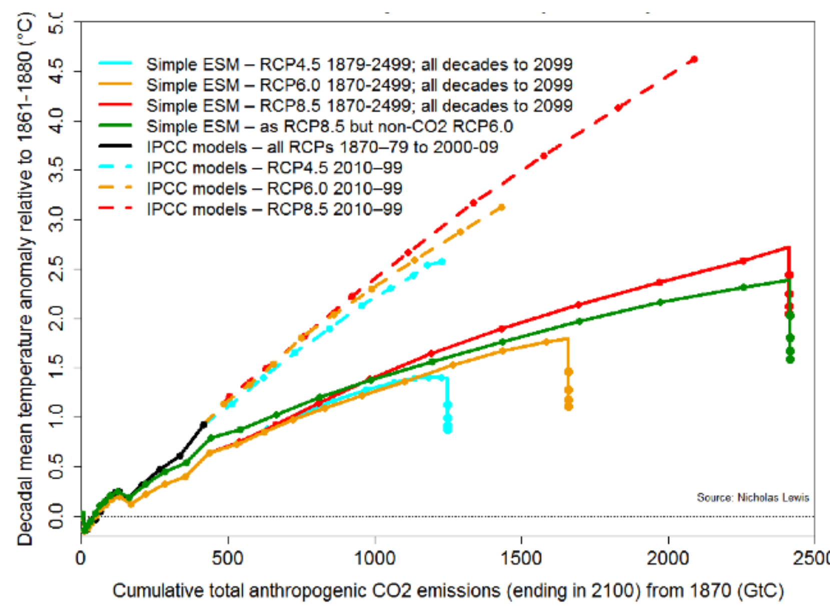
- IPCC AR5 used ESM projections: ~45% airborne now
- ESM => airborne fraction rises to 50-60% in 2100
- Simple model: airborne fraction still ~40% in 2100

IPCC and thus policymakers rely almost entirely on simulations by Earth System Models (ESMs), which already overproject CO_2 levels. AR5 ESMs project a rising airborne fraction: their land biospheres are oversensitive to temperature but undersensitive to the CO_2 level (see, e.g., Friedlingstein 2015). The AR5 ESMs were developed using now superceded observational estimates of past emissions and land biosphere sensitivity.

Originally most human CO_2 emissions were from forest clearance and other land use changes, but today only 10–15% is. Past land use change emissions are quite uncertain, but from now on they are expected to be a very minor source

Warming per simple ESM, not TCRE

- Simple ESM warms 1.8°C for same RCP6 emissions
- Warming 45% below IPCC AR5 projections



My simple ESM has proper physically-based coupled carbon-cycle and climate modules, calibrated to match observations.
TCRE method assumes warming remains unchanged after emissions cease, as in AR5 ESMs; simple ESM => cools ~20% in 100 years after CO_2 emissions cease (highest blob on descending vertical lines at RH end of projection curves; subsequent blobs show slower cooling at end of each subsequent 100 years).
Fairest comparison is of dashed yellow AR5 line & green simple ESM line, at same cumulative emissions. < 2°C w/o tighter policy
Simple ESM incorporates a standard 2-time constant simple climate model with a TCR of ~1.35°C and an ECS of ~1.75°C, and a simple carbon cycle model with separate surface and deep ocean compartments, each of which are consistent with ocean physical chemistry, and a single land biosphere compartment.