The Atmospheric Physics behind Net Zero

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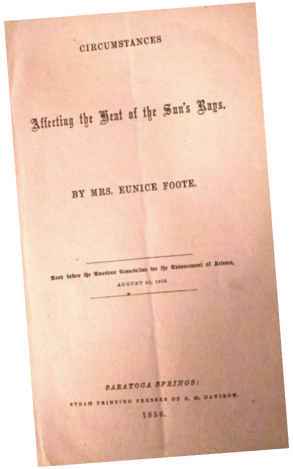
Joseph Fourier, Eunice Foote and John Tyndall

- Identified CO_2 as one of the trace gases responsible for the blanketing effect of the atmosphere, absorbing and emitting infrared light, keeping Earth's surface warm.



CIRCUMSTANCES

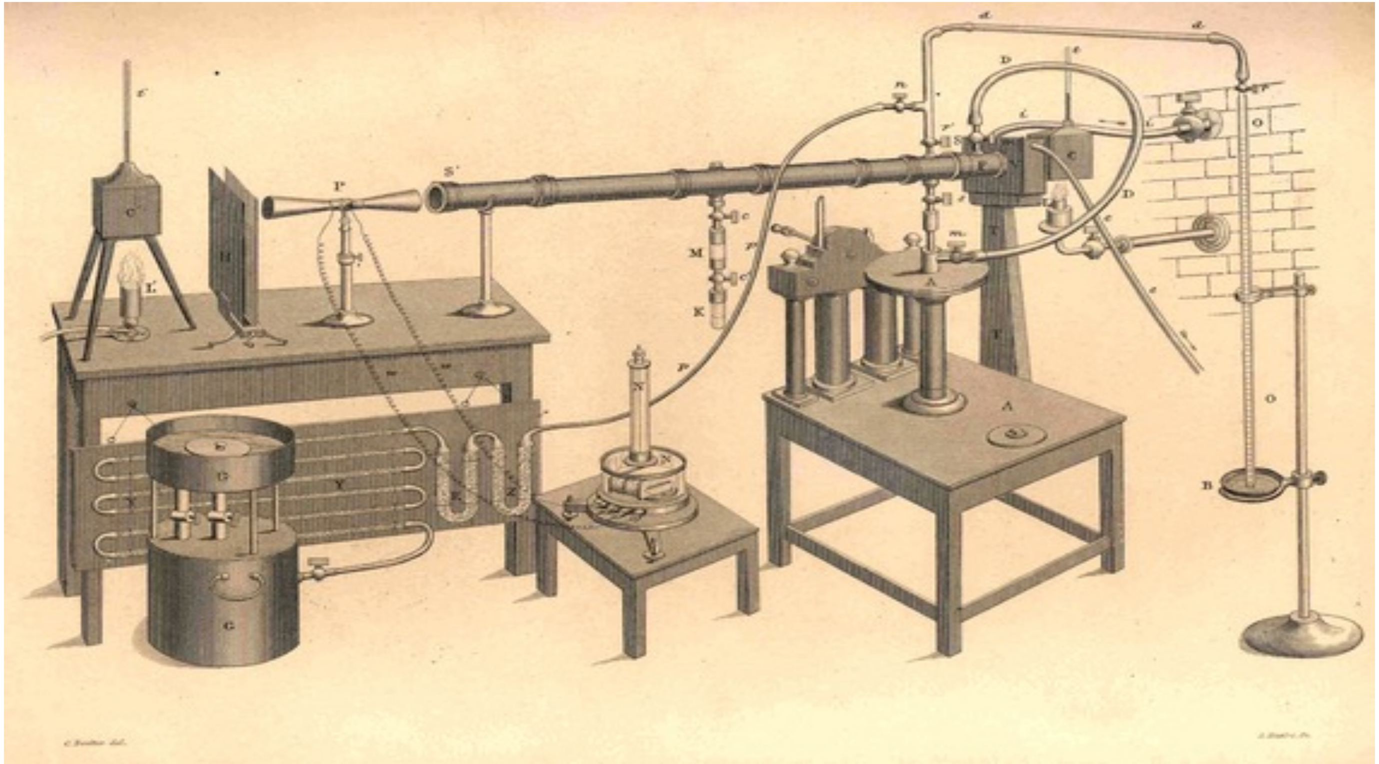
Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

Read before the American Association for the Advancement of Science,
AUGUST 23, 1856.

SARATOGA SPRINGS:
STEAM PRINTING PRESSES OF G. M. DAVISON.
1856.

Tyndall’s experiments



The first quantitative account of the impact of rising CO_2 on temperature: Svante Arrhenius

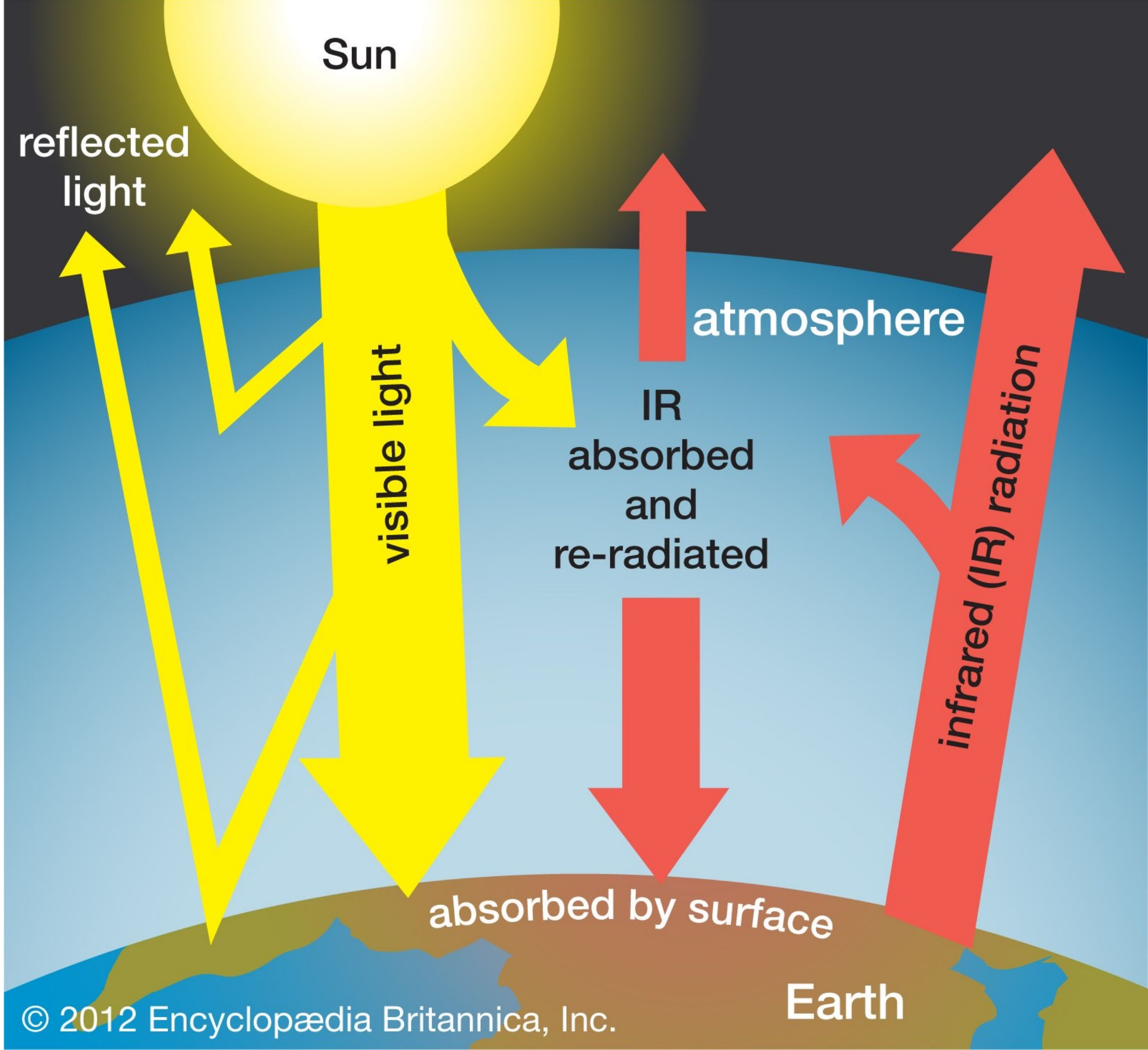
- “Any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4° C; and if the carbon dioxide were increased fourfold, the temperature would rise by 8° C.”

Ångström intervenes

- Repeated a variant of Tyndall’s experiment, varying the amount of CO_2 in the tube, and showed very little change in infrared absorption: the “CO_2 band saturation” argument, still very popular today.

The standard "greenhouse" picture

Implies the infra-red opacity of the atmosphere determines Earth's surface temperature



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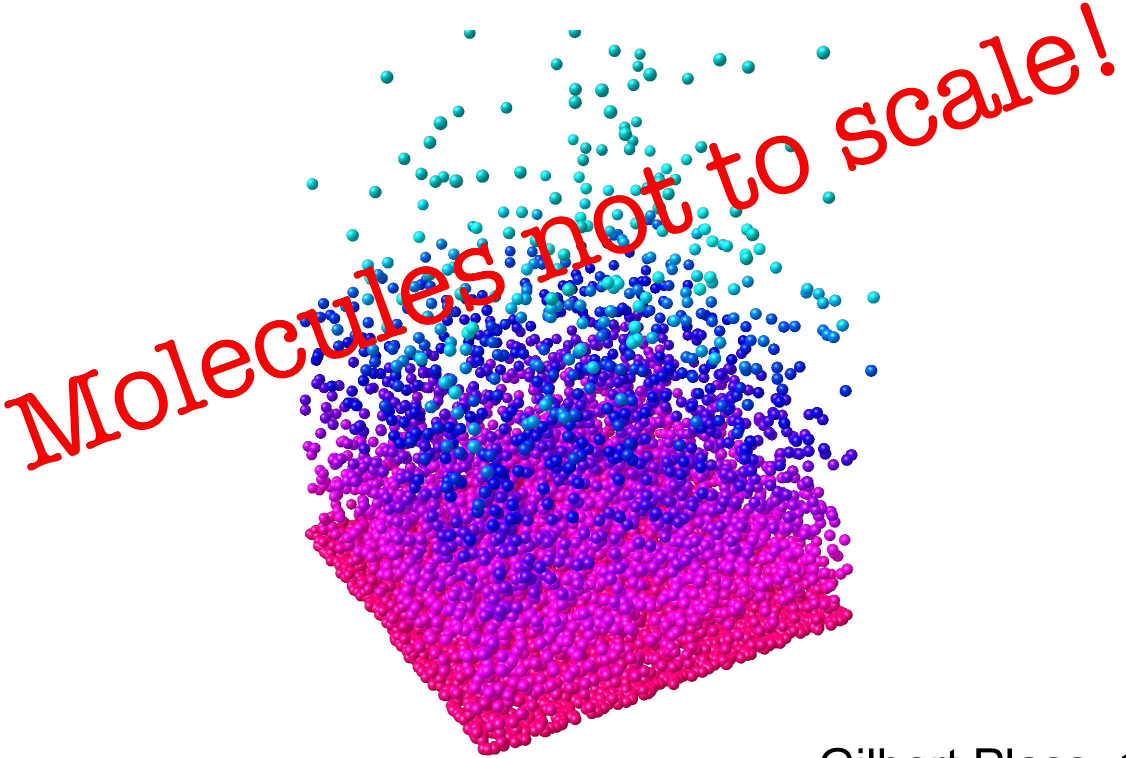
But if the atmosphere is already opaque in the infrared, how can adding more CO_2 make a difference?

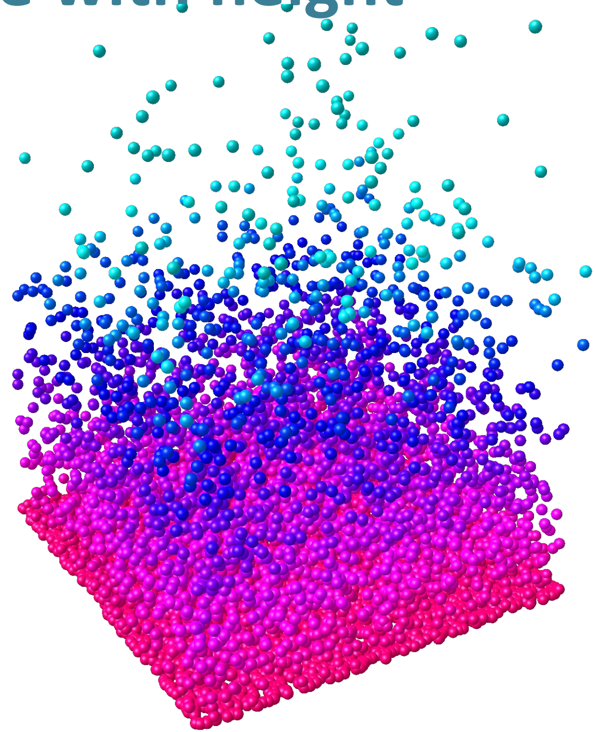
Carbon dioxide molecules in the atmosphere: colour=temperature, density=absorption density

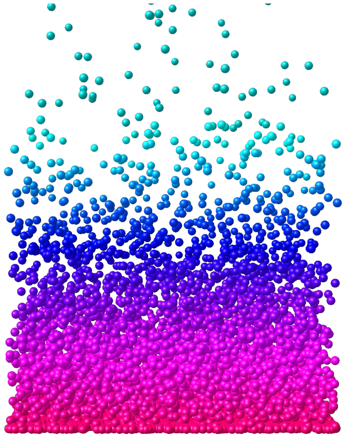


Gilbert Plass, 1955

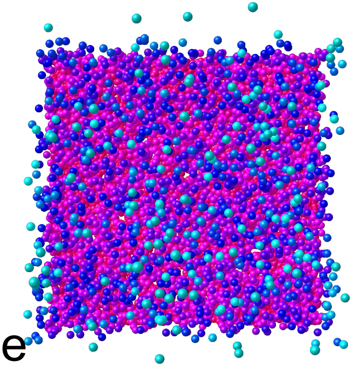

Scanned at the American Institute of Physics

Both temperature and density of CO_2 molecules decrease with height





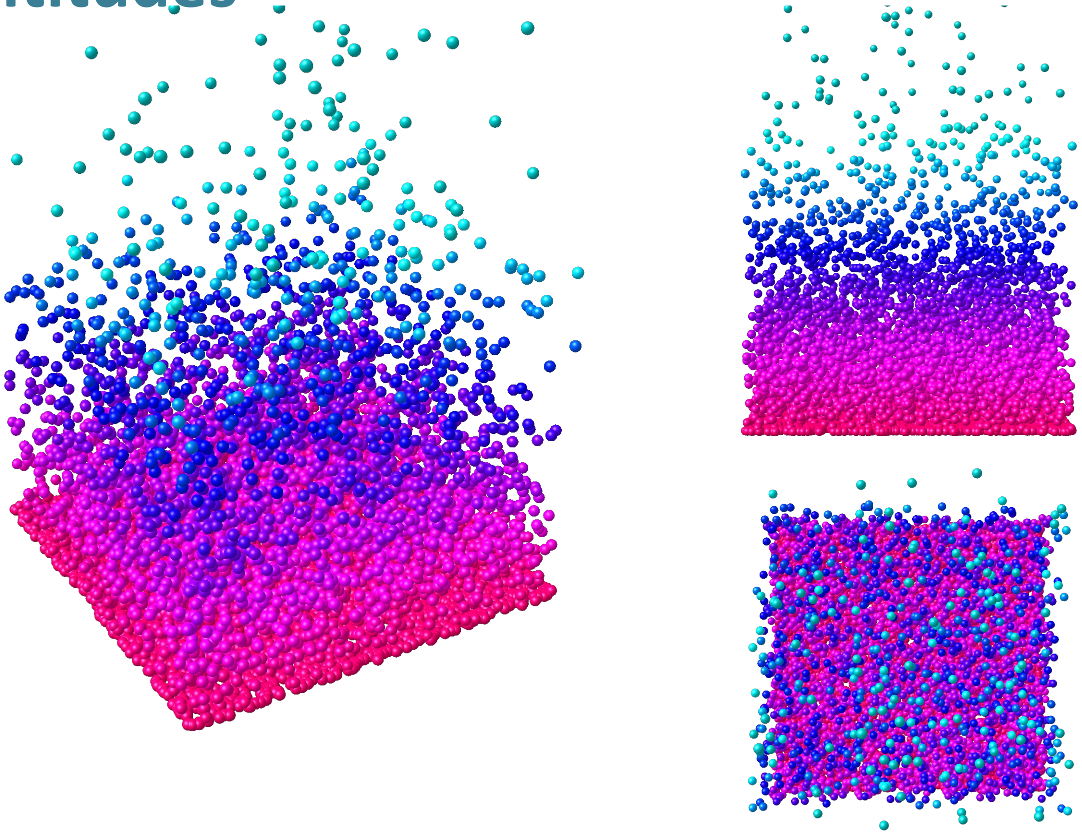
View
from
side



View
from
above

Rate of energy emitted to space depends on average temperature of molecules seen from above

Increasing CO_2 forces energy to escape from higher altitudes



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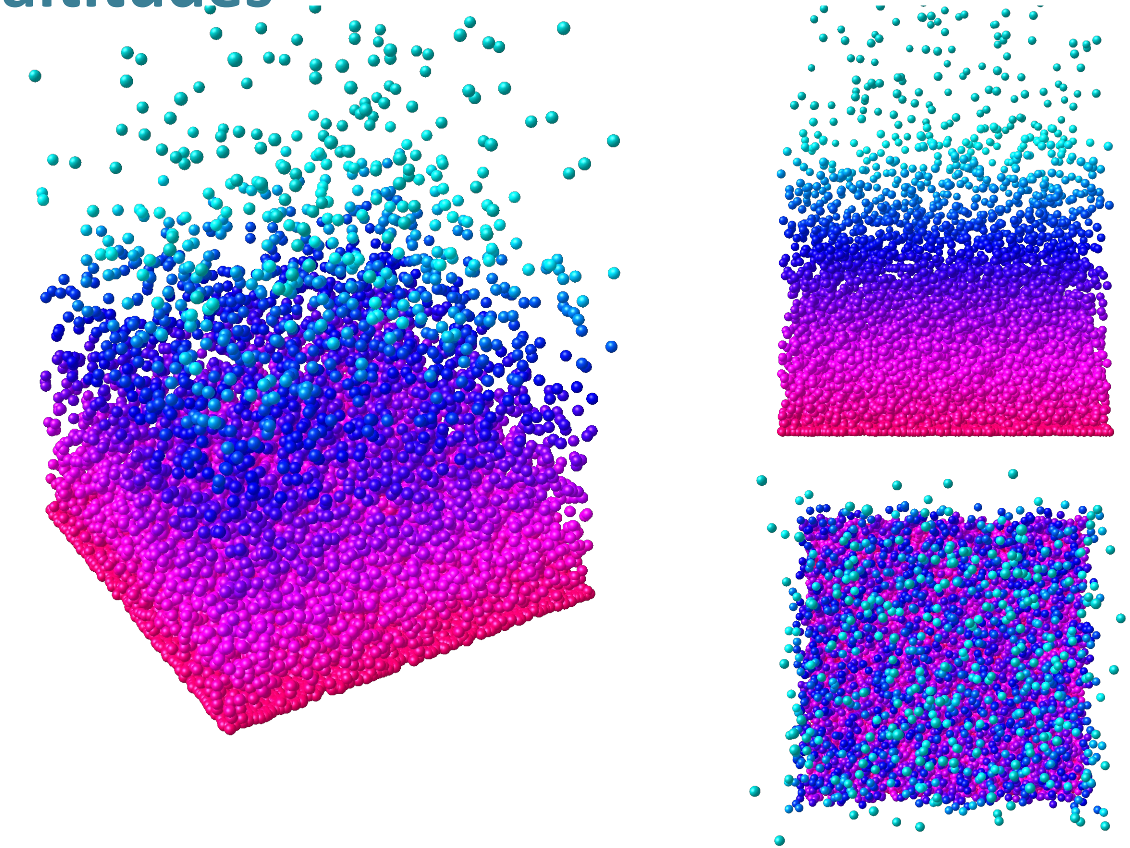
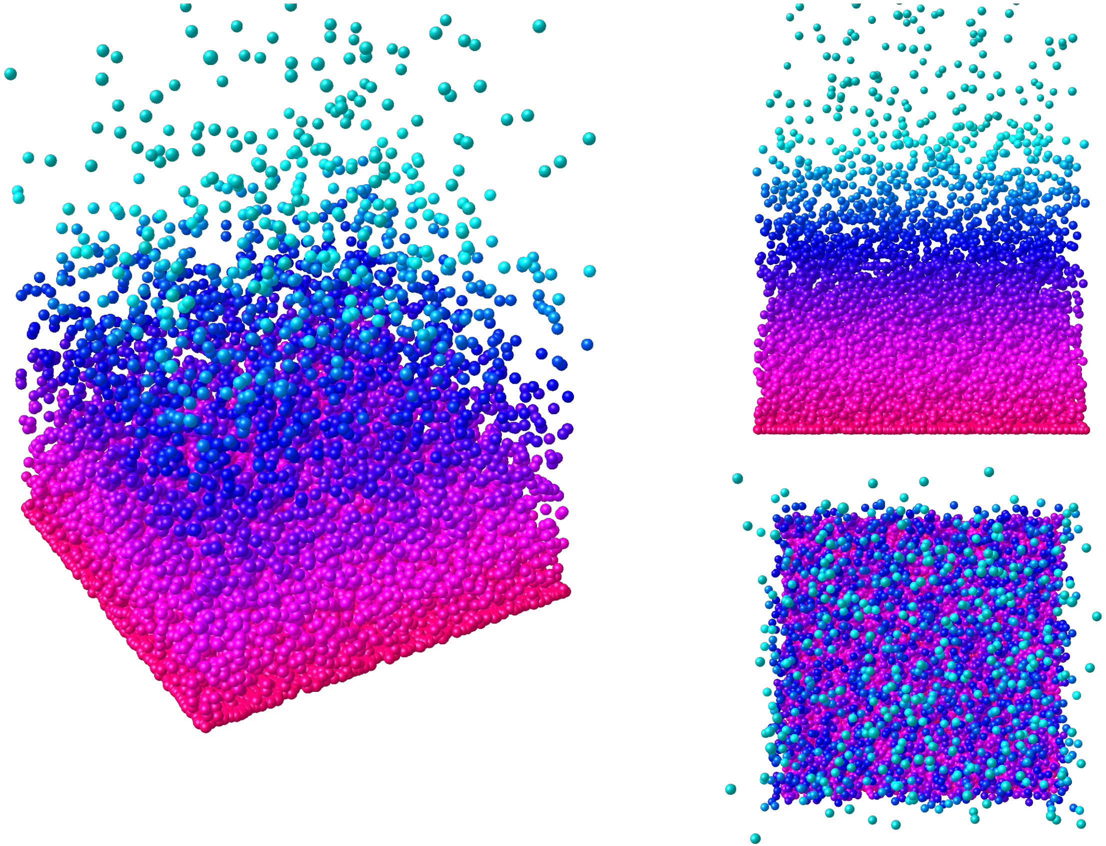
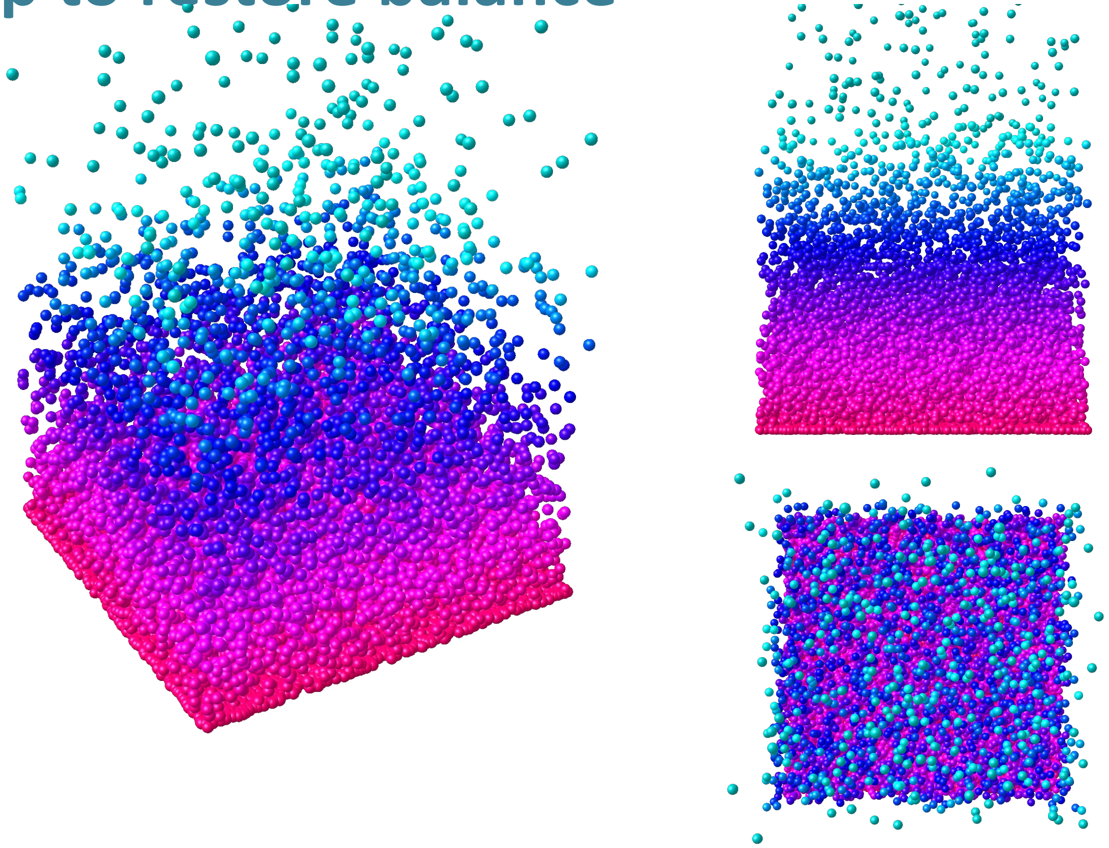


Higher air is colder, and so radiates less energy



So the surface and lower atmosphere have to warm up to restore balance



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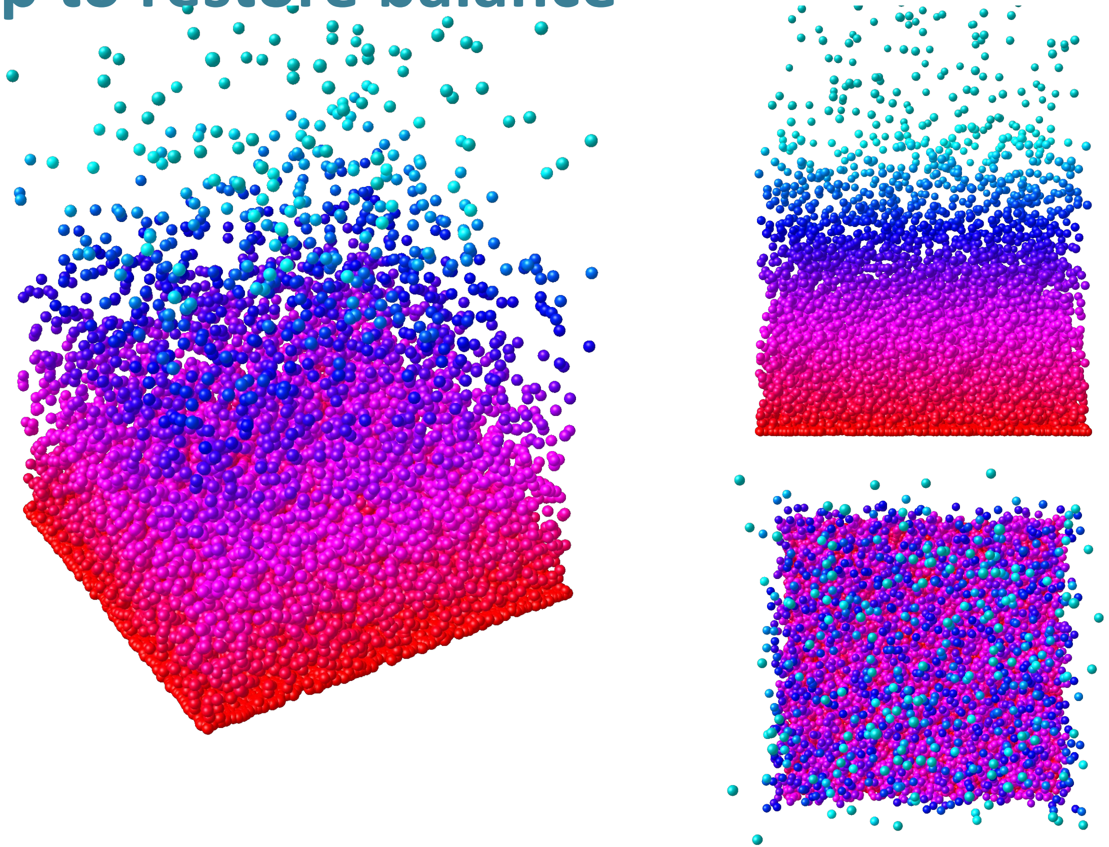

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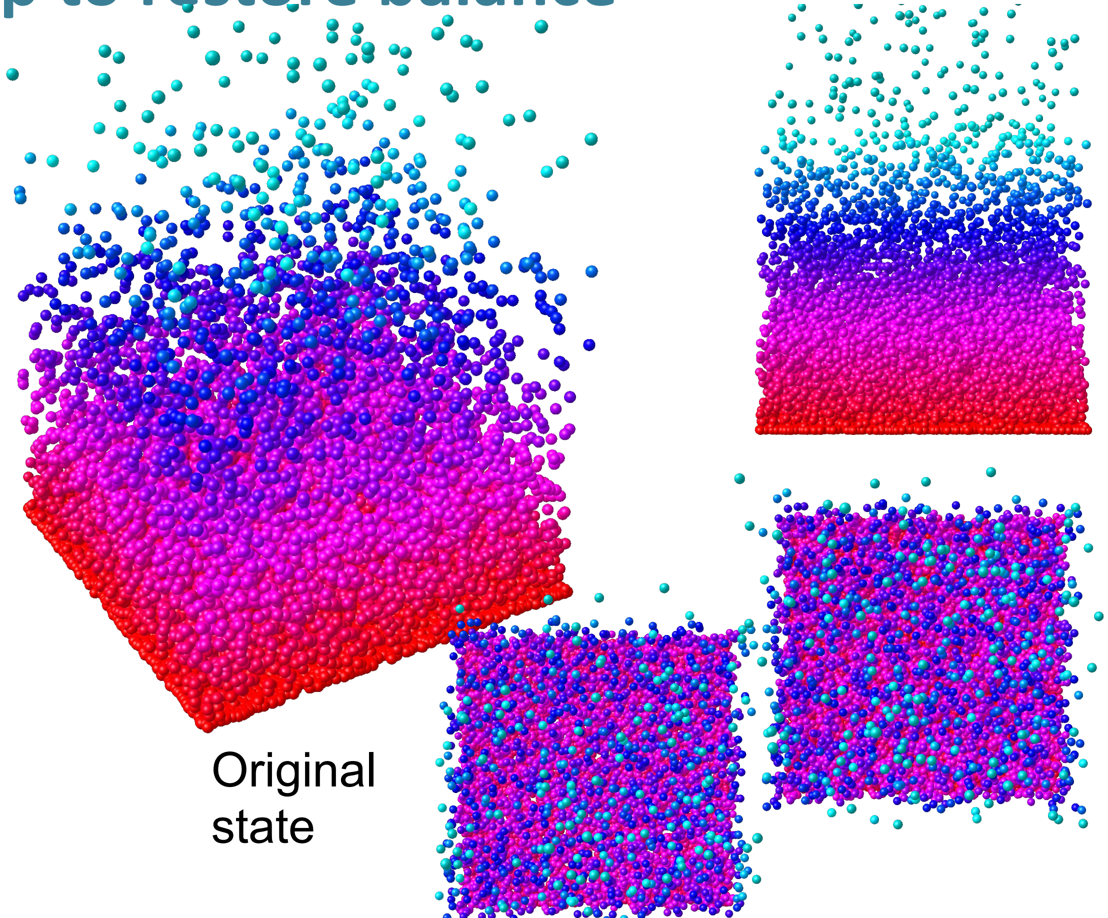
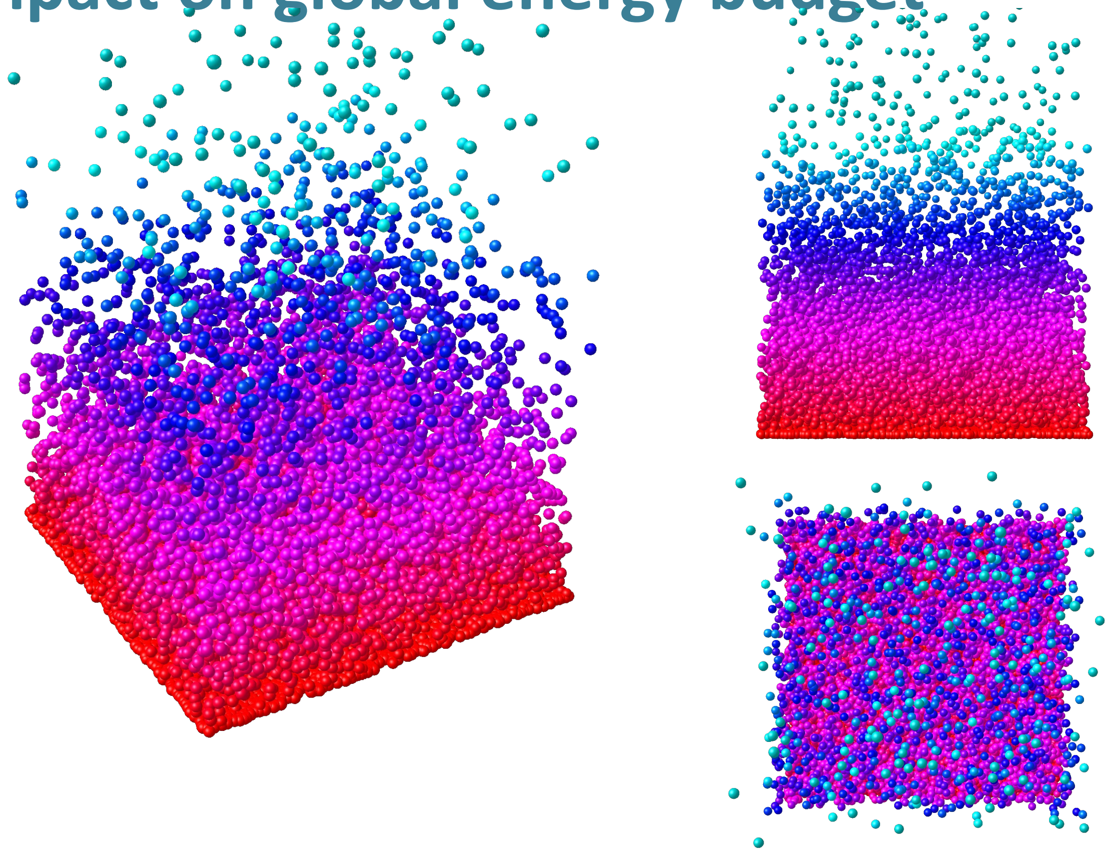


Original state

And successive CO_2 doublings have about the same impact on global energy budget



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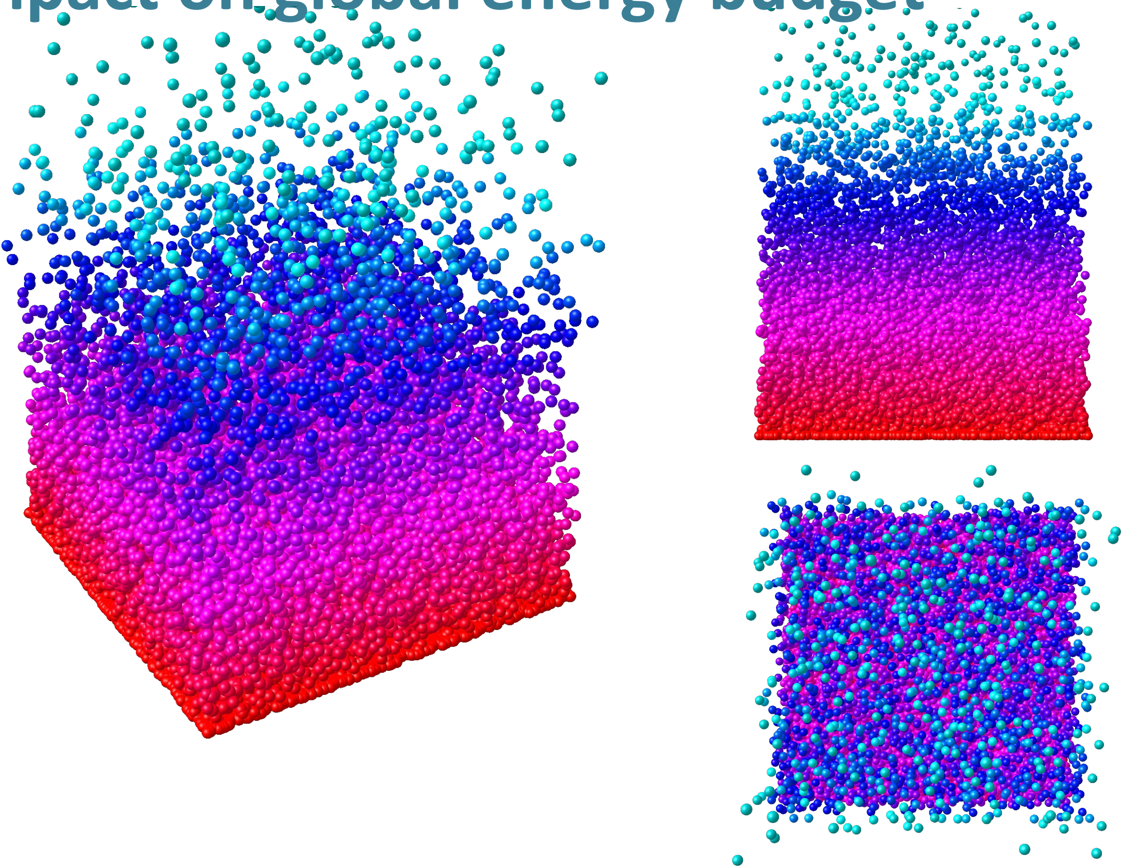
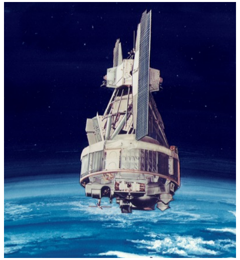
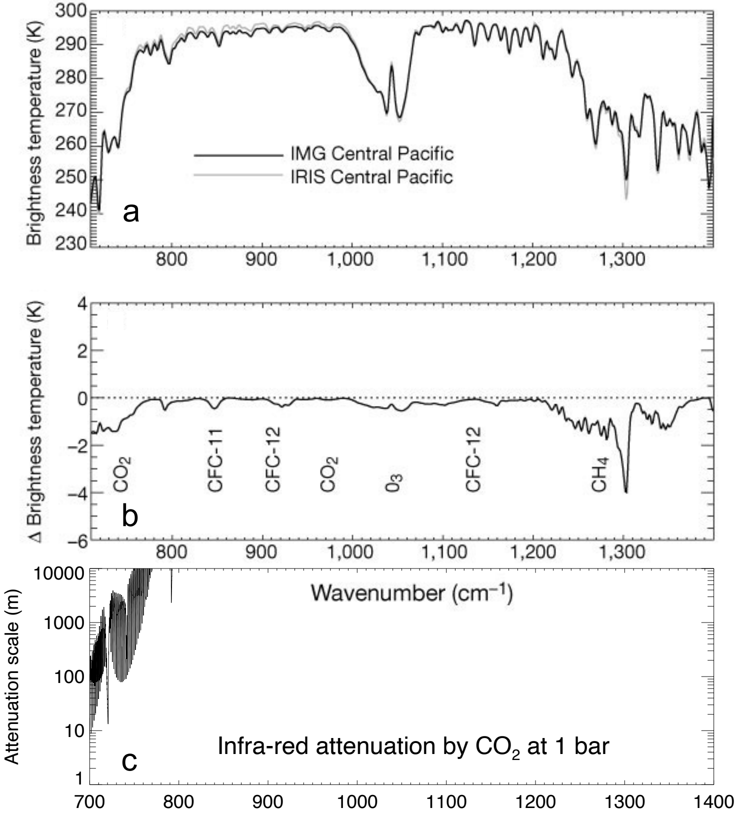


Impact of rising greenhouse gases on outgoing infrared light has been directly observed



Nimbus 4 spacecraft, 1970



a) Comparison of outgoing spectra, from IMG (1997, 367 ppm CO_2) versus IRIS (1970, 323 ppm CO_2).

b) Change in outgoing spectrum after correcting for impact of temperature.

c) CO_2 absorption spectrum.

Harries et al (2001)

To understand the response, we will need a climate model

YaleEnvironment360

Published at the Yale School of Forestry & Environmental Studies

Can We Trust Climate Models? Increasingly, the Answer is 'Yes'

Forecasting what the Earth's climate might look like a century from now has long presented a huge challenge to climate scientists. But better understanding of the climate system, improved observations of the current climate, and rapidly improving computing power are slowly leading to more reliable methods.

BY MICHAEL LEMONICK · JANUARY 18, 2011

Why you don't need to "trust" climate models

- A plastic tube with an open outlet pipe in equilibrium:
$$F = k \times h$$
- F is the externally-driven additional rate of fluid flowing into the tube above the initial equilibrium flow rate.
- h is the increased water depth above the initial equilibrium level.
- k is the "openness" of the outlet pipe, depends on the viscosity (syrupiness) of the fluid & dimensions of the pipe.

Why you don’t need to “trust” climate models

- The Earth’s climate system in equilibrium:

$$F = \lambda \times T$$

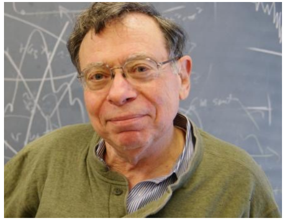
- F is the net additional rate of energy flowing into the climate system due, e.g., to increased greenhouse gas levels.
- T is global average surface temperature increase above pre-industrial equilibrium (“level of global warming”).
- λ is the “sensitivity parameter”, the efficiency with which Earth gets rid of excess energy, in Watts per square metre per degree of surface warming.

The “Equilibrium Climate Sensitivity”

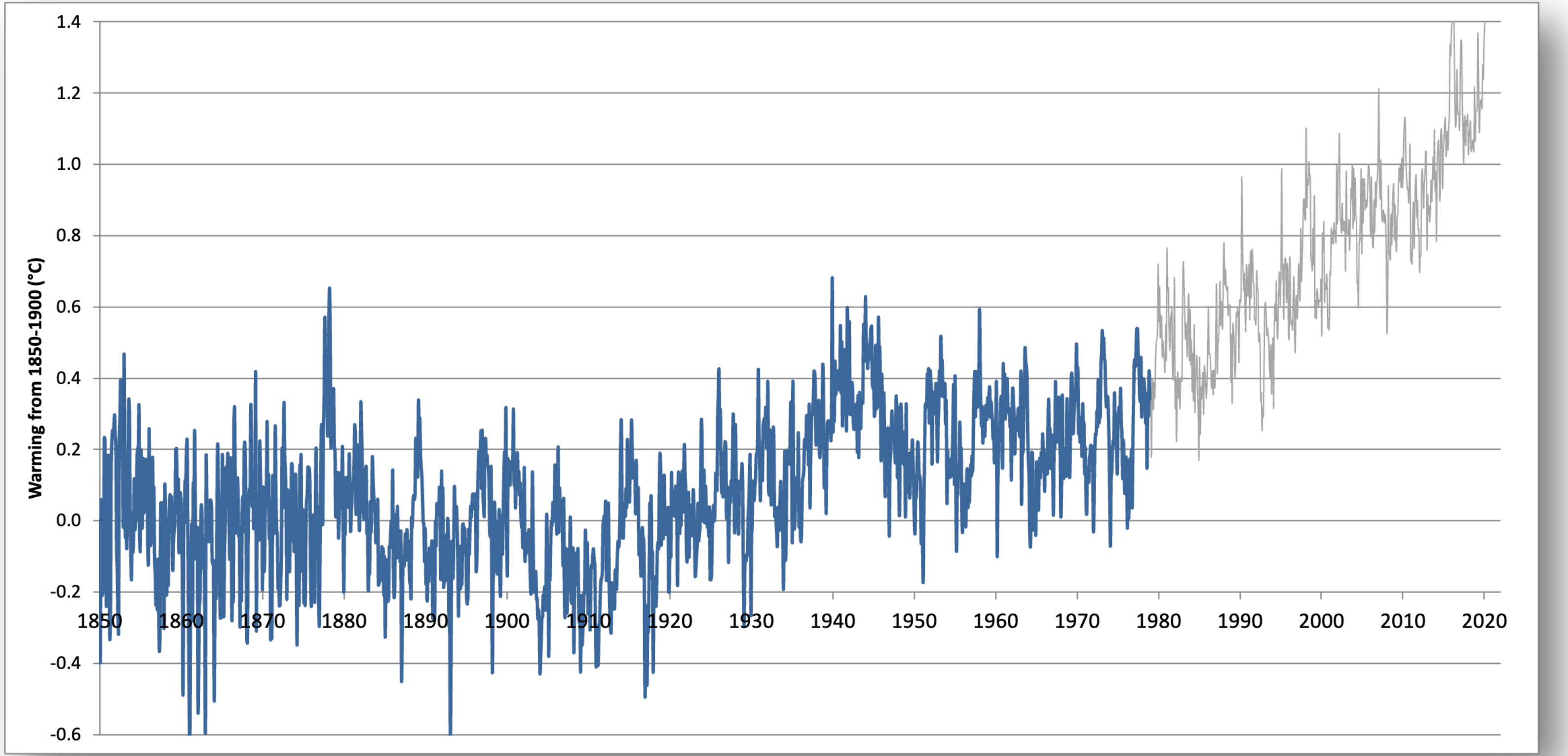
- Equilibrium warming in response to doubling carbon dioxide:
$$F_{2\times \mathrm{CO2}} = \lambda \times T_{2\times \mathrm{CO2}}$$
- $F_{2\times \mathrm{CO2}}$ is the net additional rate of energy flowing into the climate system due to a doubling of CO_2 concentrations.
- $T_{2\times \mathrm{CO2}}$ is global average surface temperature increase due to a doubling of CO_2 concentrations.
- λ is the sensitivity parameter again. Depends on lots of uncertain processes, because many things change as the world warms.

The 1979 National Academy of Sciences Report chaired by Jules Charney

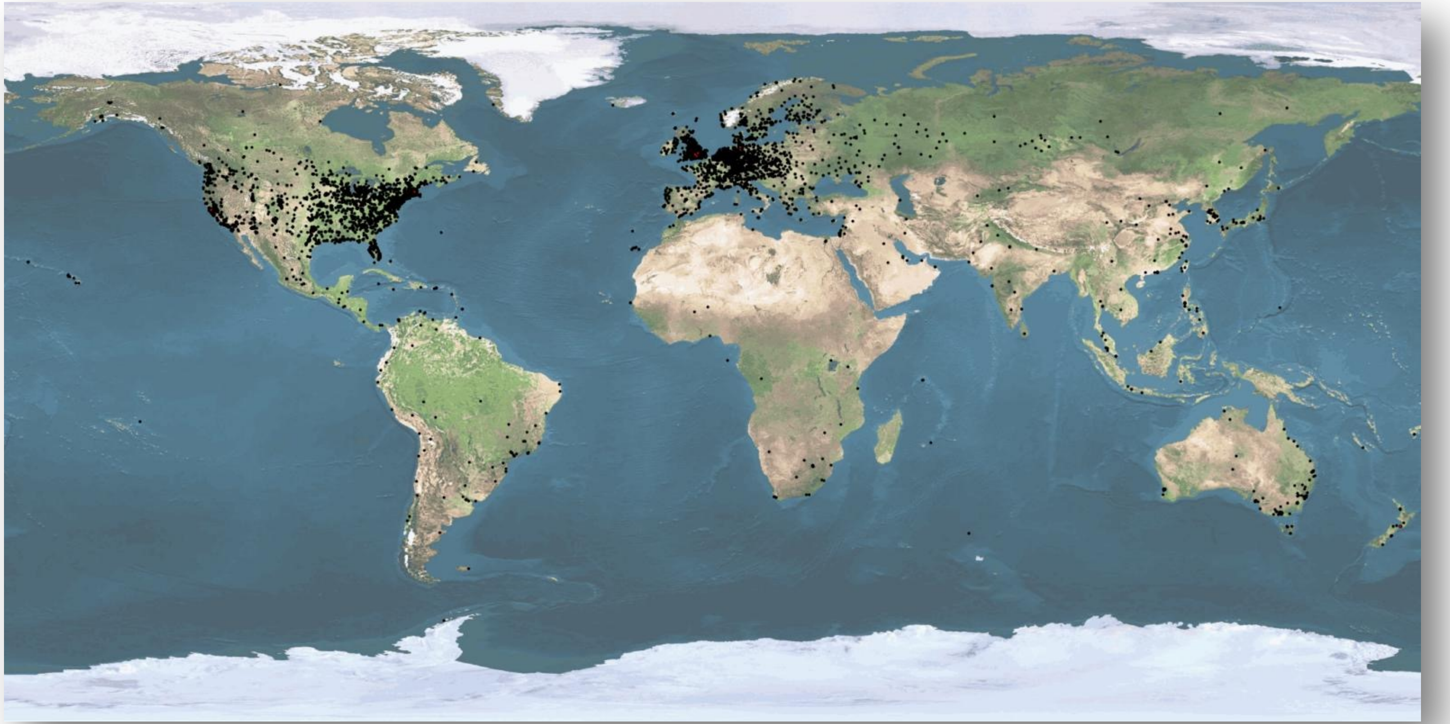
- Gave a range of 1.5-4.5°C for T_{2xCO2}, emphasizing:
    - Oceans “could delay the estimated warming for several decades” (warming reached 1°C around 2017)
    - “We may not be given a warning until the CO_2 loading is such that an appreciable climate change is inevitable.”



The Charney Report was an entirely model-based prediction (two climate models)

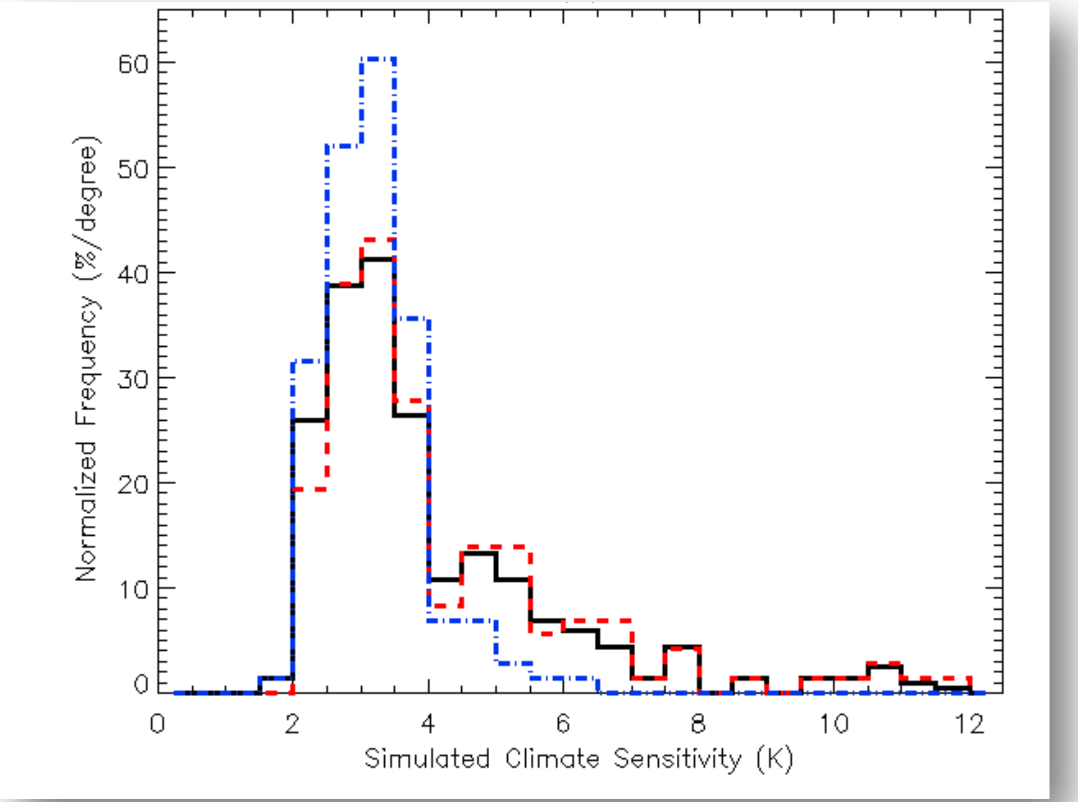


Can we pin down the equilibrium climate sensitivity using lots of climate models?



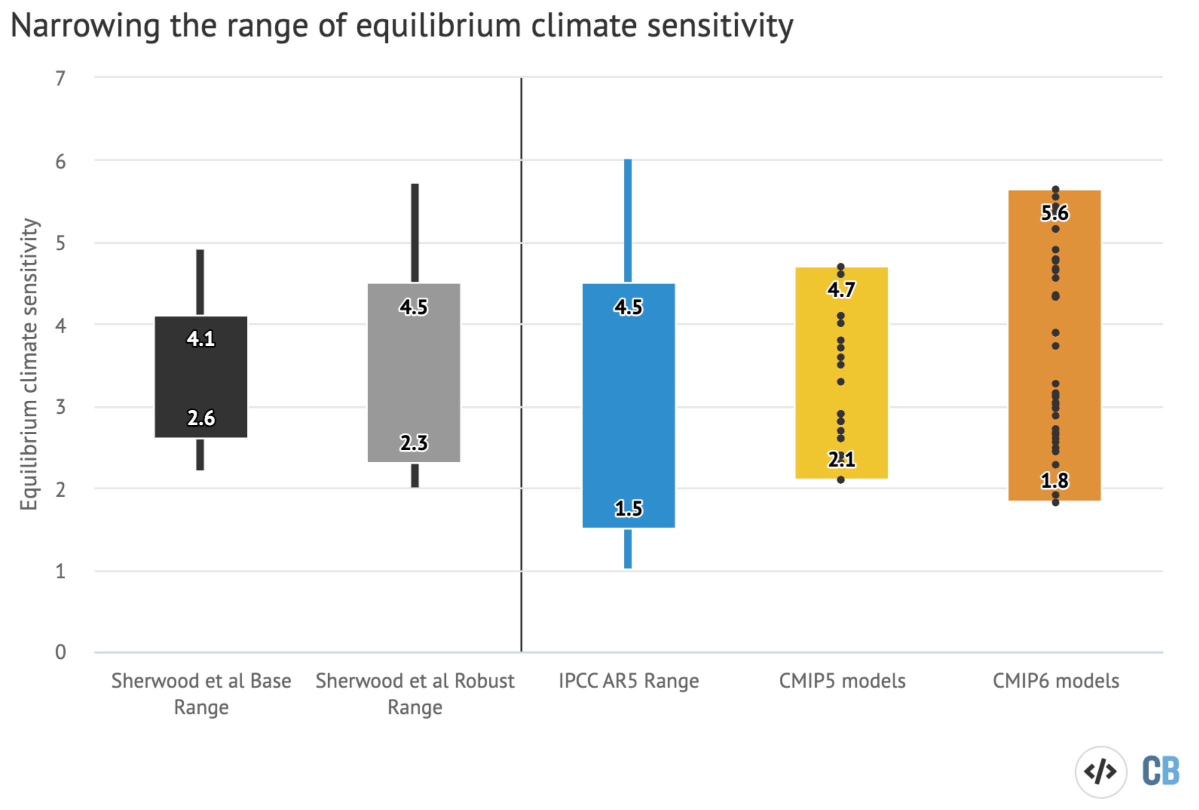
>300,000 volunteers, >140 countries, >29M model-years

Equilibrium climate sensitivities, T_{2xCO2}, from the climate*prediction*.net experiment



Stainforth et al, 2005

The latest generation of models aren't really helping…



https://www.carbonbrief.org/guest-post-why-low-end-climate-sensitivity-can-now-be-ruled-out/

The problem with the Equilibrium Climate Sensitivity

- Suppose you are driving a car with a dodgy speedometer:

  Distance = speed x journey-time

- You have 40 miles to go, the speedometer says your speed is somewhere between 20 and 40 miles per hour, so the journey will take between one and two hours.
- You are meant to arrive in 1½ hours: what are the odds you will be late?
- All arrival times in range equally likely: 50%
- All speeds in range equally likely: 33%

The problem with the Equilibrium Climate Sensitivity

- Suppose you are driving a car with a dodgy speedometer:

  Distance = speed x journey-time

- You have 40 miles to go, the speedometer says your speed is somewhere between 20 and 40 miles per hour, so the journey will take between one and two hours.
- You will be fired if you take more than 1.9 hours: what are the odds you will be fired?
- All arrival times in range equally likely: 10%
- All speeds in range equally likely: 5.2%

The problem with the Equilibrium Climate Sensitivity

- Today's level of energy imbalance due to human activity:

  $$F_{now} = 2.8 \text{ Watts per square metre}$$

- Equilibrium warming if all concentrations remain as they are.

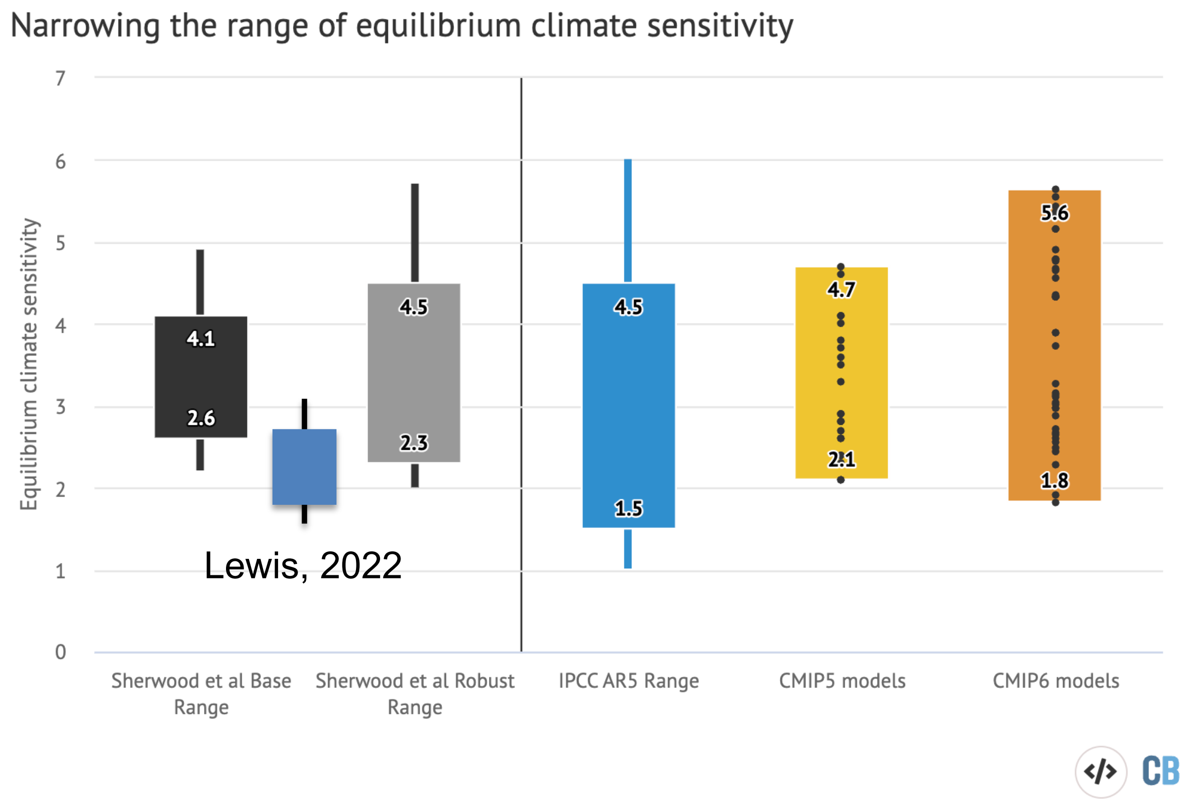
  $$T_{eqm} = F_{now}/\lambda = F_{now} \times T_{2\times\mathrm{CO2}}/F_{2\times\mathrm{CO2}}$$

- Suppose $T_{2\times\mathrm{CO2}}$ is 1.5-4.5^{o}C & $F_{2\times\mathrm{CO2}} = 3.7$ W/m^{2} : what are the odds of T_{eqm} greater than 3^{o}C?
- All λ values in range equally likely: 7%
- All $T_{2\times\mathrm{CO2}}$ values in range equally likely: 18%

The problem with the Equilibrium Climate Sensitivity

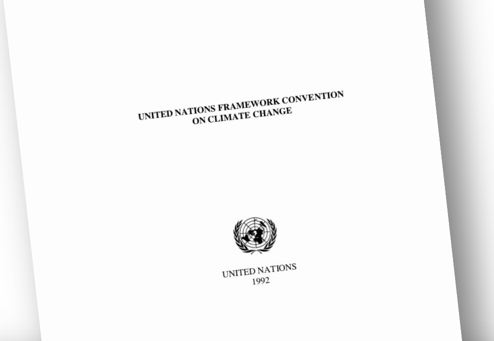
- Is not just that it’s uncertain: lots of things are uncertain.
- It’s that the uncertainty itself is *contestable*, because the answer seems to depend on subjective decisions.
- It is even contested whether or not it is contestable.
  - This is an example of Bertrand’s Paradox, resolved (?) by Edwin Jaynes (1970), Jaynes’ solution contested by Alon Drury (2015), and the story continues…

So the argument continues…



Why care about equilibrium warming?

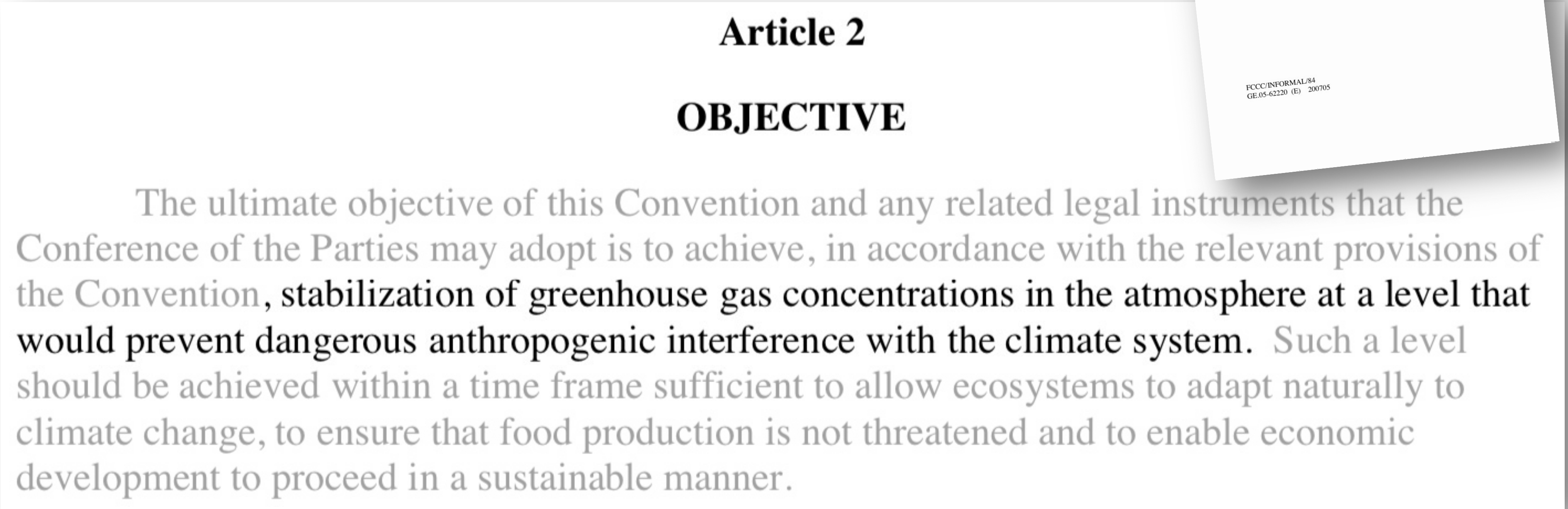
Stabilization in Rio, 1992



UNITED NATIONS FRAMEWORK CONVENTION
ON CLIMATE CHANGE

UNITED NATIONS
1992

FCCC/INFORMAL/84
GE.05-62220 (E) 200705



Article 2

OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, **stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.** Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

Why care about equilibrium warming?
Stabilization redux, 2022

- The equilibrium climate sensitivity only matters if we actually stabilize atmospheric concentrations of greenhouse gases and allow the climate to re-equilibrate over centuries.
- The breakthrough in the late 2000s was the realization that we can stop the warming well before restoring climate equilibrium if we reduce anthropogenic emissions to net zero.
- Unless, of course, we count enhanced uptake of CO_2 due to past emissions as a “negative emission” – as carbon offset markets are just starting to do…

The Atmospheric Physics behind Net Zero

NET ZERO

UNIVERSITY OF OXFORD

How rising carbon dioxide concentrations actually cause global warming.

Why the equilibrium climate sensitivity is still so hotly contested.

How basic probability theory affects global climate policy, and offset markets.

22nd November 2022

EST. 1597

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