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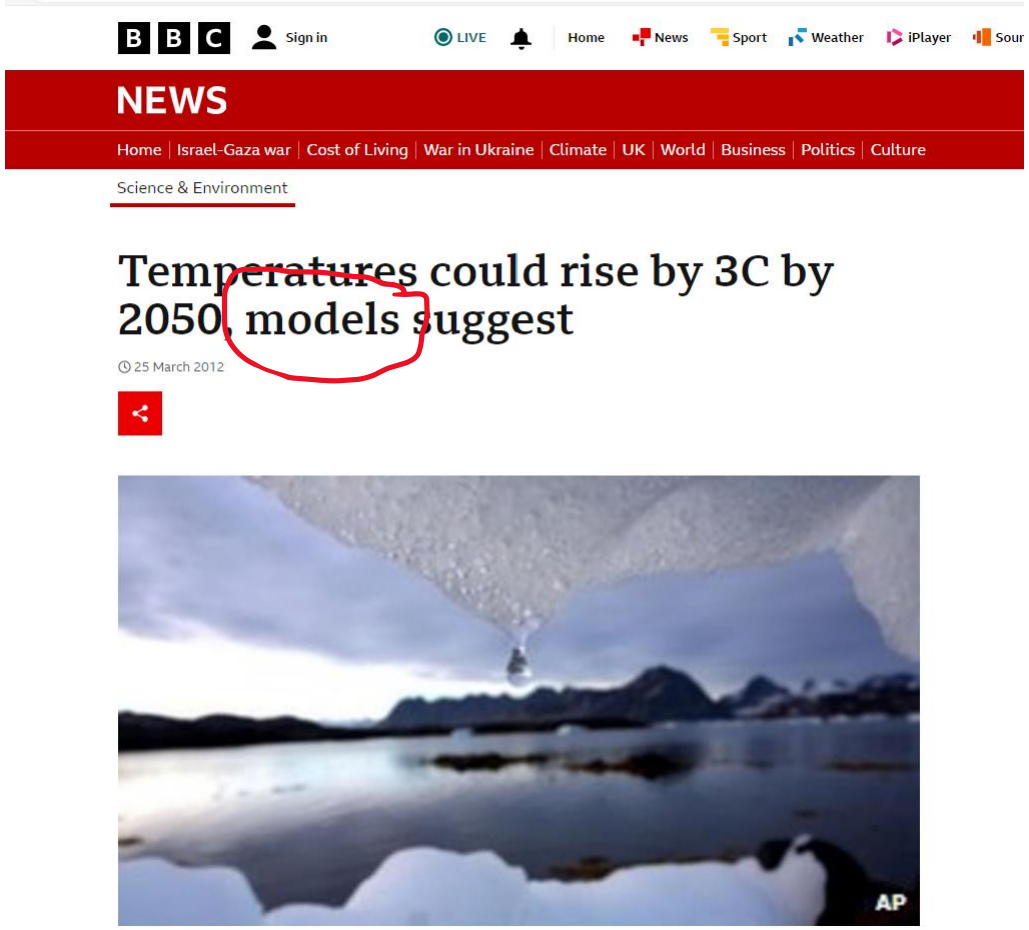
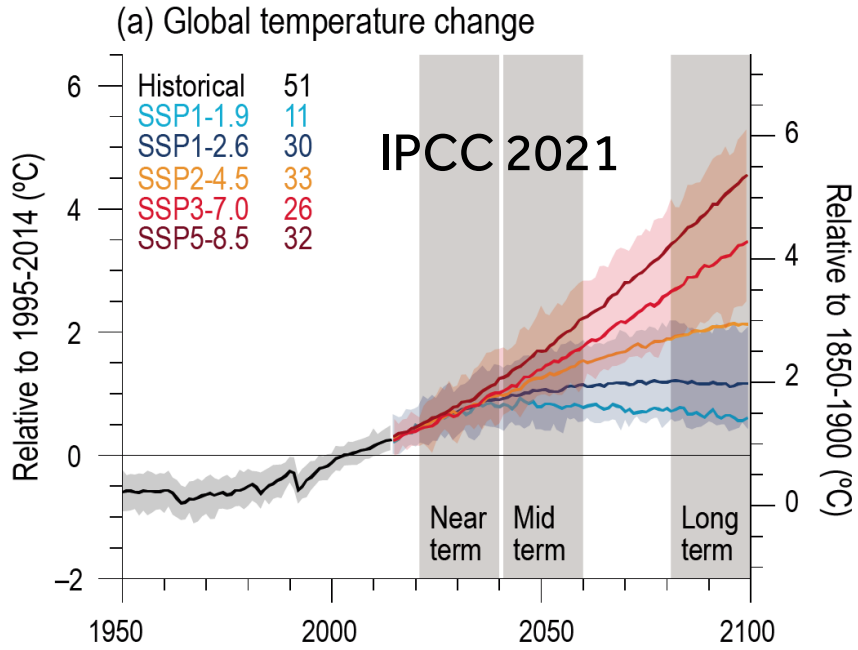
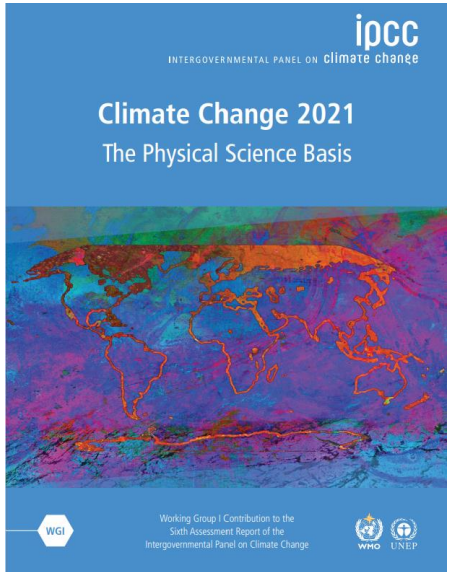
THE SCIENCE BEHIND CLIMATE MODELS

Bill Collins

CAN CLIMATE MODELS PREDICT THE FUTURE?







- Can climate models tell us what the climate is going to do?
- How do they do it?

CLIMATE PROJECTIONS

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- What is a climate model?
- What is in the black box?

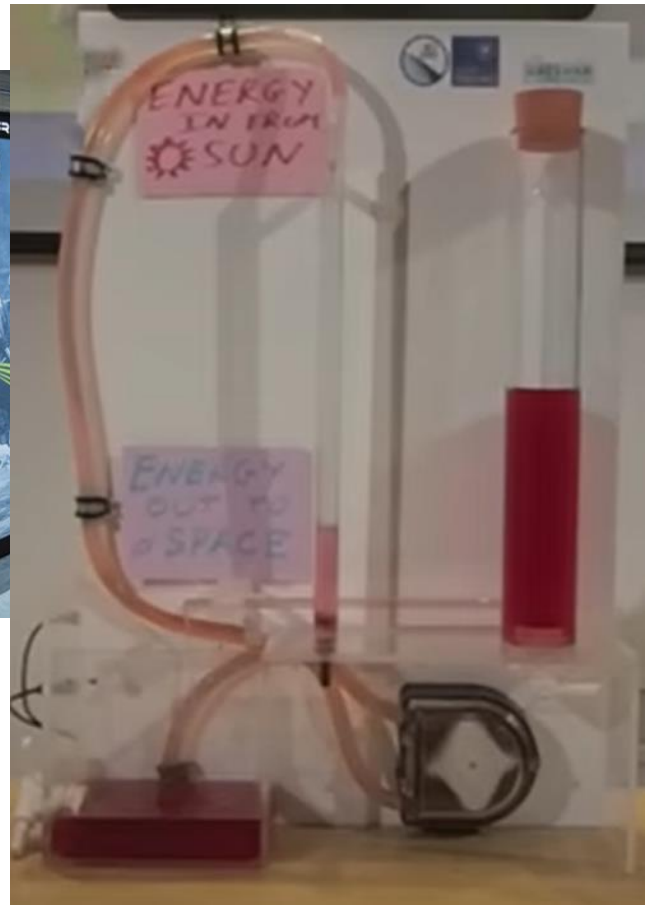
CLIMATE MODELS

- Simply a way of putting together our scientific knowledge of climate process in a useful form.
- Can be very simple and run on a laptop

- Can be very complex requiring months of calculations on a supercomputer

- Can even be mechanical!

MAGICC



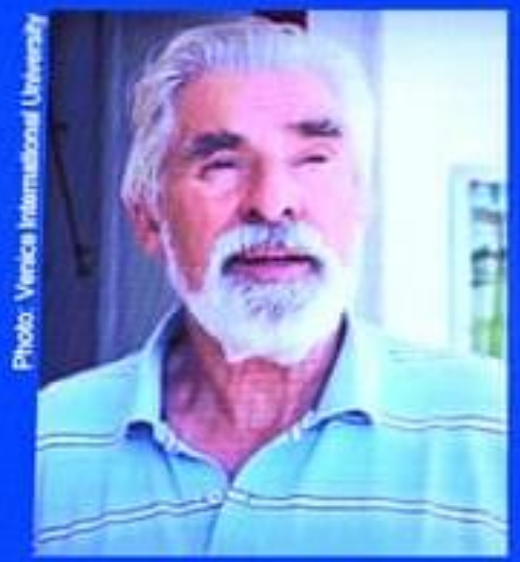
Gresham College Why Net Zero? Prof. Myles Allen

NOBELPRISET I FYSIK 2021
THE NOBEL PRIZE IN PHYSICS 2021

KUNGL. VETENSK AKADEM
THE ROYAL SWEDISH ACADEMY OF

"för banbrytande bidrag till vår förståelse av komplexa fysikaliska system"
"for groundbreaking contributions to our understanding of complex physical systems"

Syukuro Manabe, USA



Klaus Hasselmann, Germany

Giorgio Parisi, Italy

"för fysikalisk modellering av jordens klimat, kvantitativ analys av variationer och tillförlitlig förutsägelse av global uppvärmning"

"for the physical modelling of Earth's climate, quantifying variability and reliably predicting global warming"

"för upptäckten av hur oordning och fluktuation i fysikaliska system från atomära till planetä

"for the discovery of the interplay of disorder a in physical systems from atomic to planet

ONE OF THE FIRST CLIMATE MODELS

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Manabe and Wetherald **1967**

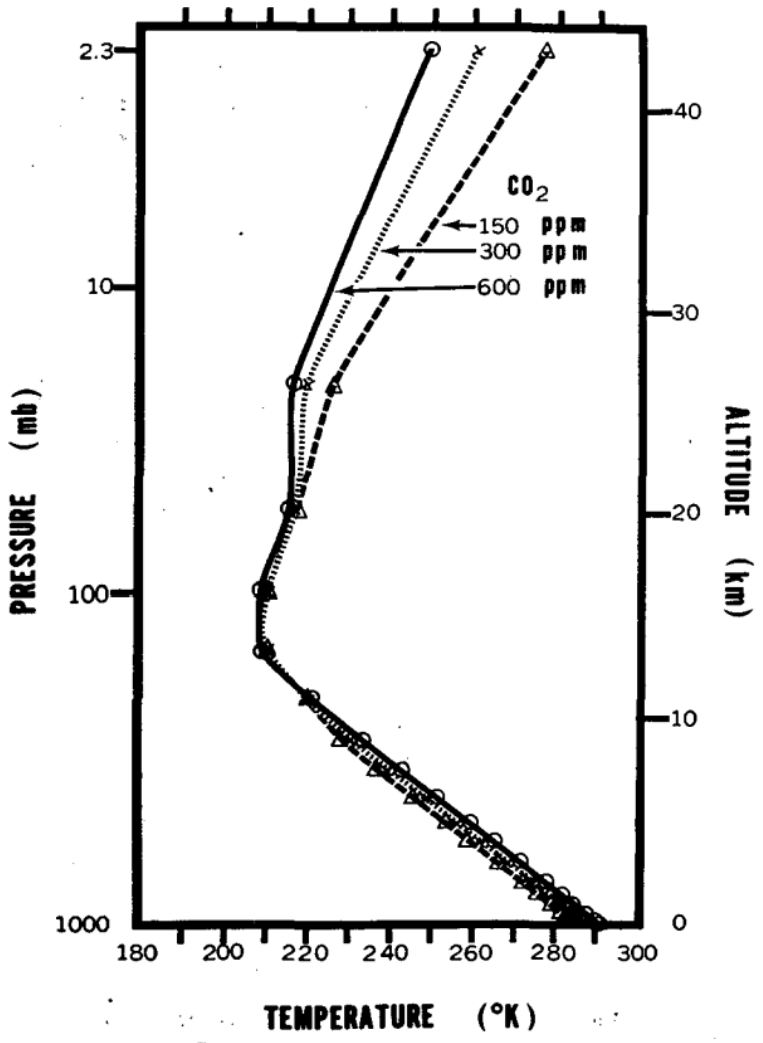

FIG. 16. Vertical distributions of temperature in radiative convective equilibrium for various values of CO_2 content.

do not always indicate the extreme sensitivity of the actual earth's climate. The basic shortcoming of this line of argument may be that it is based upon the heat balance only of the earth's surface, instead of that of the atmosphere as a whole. In Fig. 15, the net upward long-wave radiation at the top of the atmosphere, together with that at the earth's surface, are plotted against the temperature of the earth's surface. As we have already discussed in Section 3b, the former increases significantly with increasing temperature in contrast to the latter. In order to compensate for the decrease of net outgoing radiation at the top of the atmosphere due to the increase of CO_2 content, it is necessary to increase the atmospheric temperature. Therefore, one may expect that the larger the CO_2 content in the atmosphere, the warmer would be the temperature of the earth for the ordinary range of atmospheric temperature. This result is not in agreement with the conclusion which we reached based upon the earth's surface.

TABLE 5. Change of equilibrium temperature of the earth's surface corresponding to various changes of CO_2 content of the atmosphere.

Change of CO_2 content (ppm)	Fixed absolute humidity		Fixed relative humidity	
	Average cloudiness	Clear	Average cloudiness	Clear
300 → 150	−1.25	−1.30	−2.28	−2.80
300 → 600	+1.33	+1.36	+2.36	2.92

THE CLIMATE SYSTEM IS COMPLICATED

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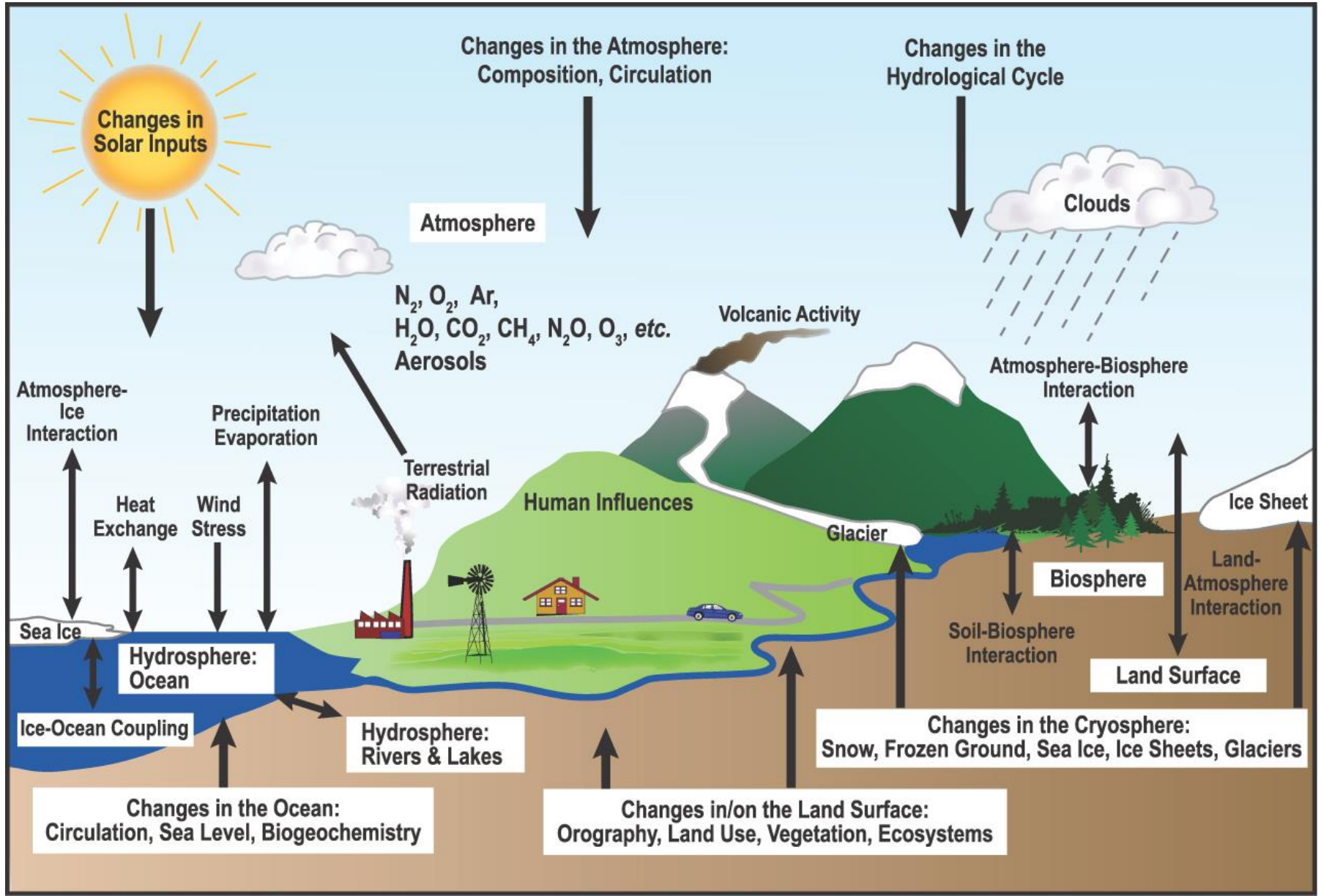

BUILDING A CLIMATE MODEL

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Schematic for Global Atmospheric Model

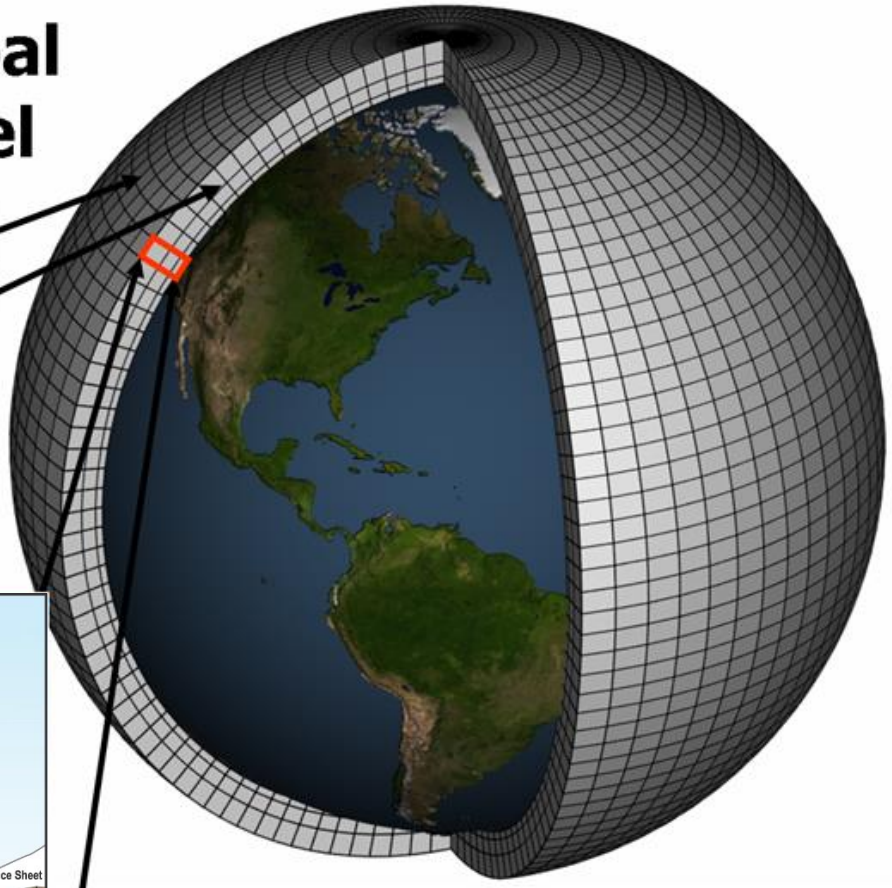
Horizontal Grid (Latitude-Longitude)

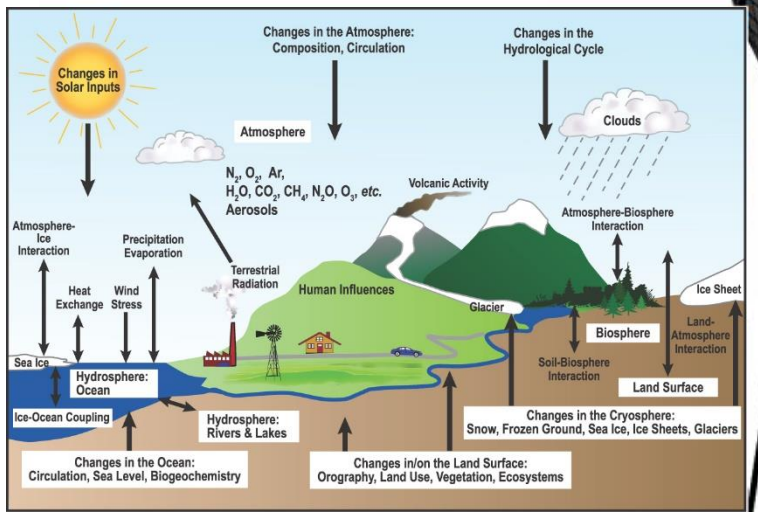
100 km x 100 km

Vertical Grid (Height or Pressure)

500 m

> 2 million cubes for atmosphere





$$
\begin{aligned}
\frac{Du}{Dt} &= -\frac{\partial \Pi}{\partial R} + v\left(2\Omega + \frac{v}{R}\right) + \Omega^2 R\frac{\Delta\rho}{\rho_0} + \Delta^2(\nu, u) \\
&\quad + \frac{1}{R}\frac{\partial(Ru)}{\partial R}\frac{\partial \nu}{\partial R} + \frac{\partial w}{\partial R}\frac{\partial \nu}{\partial z} - \frac{2}{R^2}\frac{\partial(\nu v)}{\partial \phi} + \frac{1}{R^2}\frac{\partial(vR)}{\partial R}\frac{\partial \nu}{\partial \phi} \\
\frac{Dv}{Dt} &= -\frac{1}{R}\frac{\partial \Pi}{\partial \phi} - u\left(2\Omega + \frac{v}{R}\right) + \Delta^2(\nu, v) \\
&\quad + \frac{1}{R}\frac{\partial u}{\partial \phi}\frac{\partial \nu}{\partial R} + \frac{1}{R^2}\frac{\partial v}{\partial \phi}\frac{\partial \nu}{\partial \phi} + \frac{1}{R}\frac{\partial w}{\partial \phi}\frac{\partial \nu}{\partial z} + \frac{2}{R^2}\frac{\partial(u\nu)}{\partial \phi} \\
\frac{Dw}{Dt} &= -\frac{\partial \Pi}{\partial z} - \frac{g\Delta\rho}{\rho_0} + \tilde{\Delta}^2(\nu, w) \\
&\quad + \frac{\partial u}{\partial z}\frac{\partial \nu}{\partial R} + \frac{\partial w}{\partial z}\frac{\partial \nu}{\partial z} + \frac{1}{R}\frac{\partial v}{\partial z}\frac{\partial \nu}{\partial \phi}
\end{aligned}
$$

CLIMATE COMPUTING

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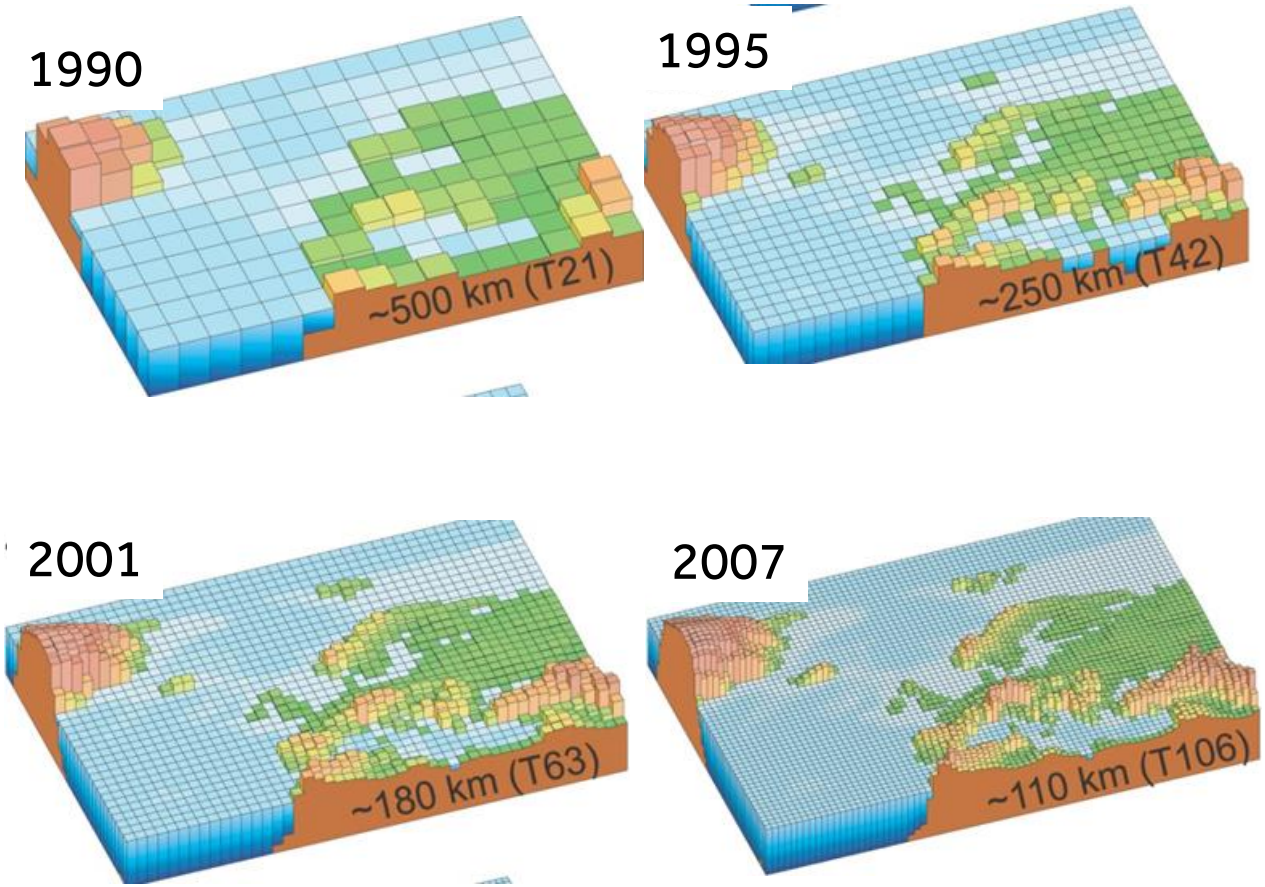
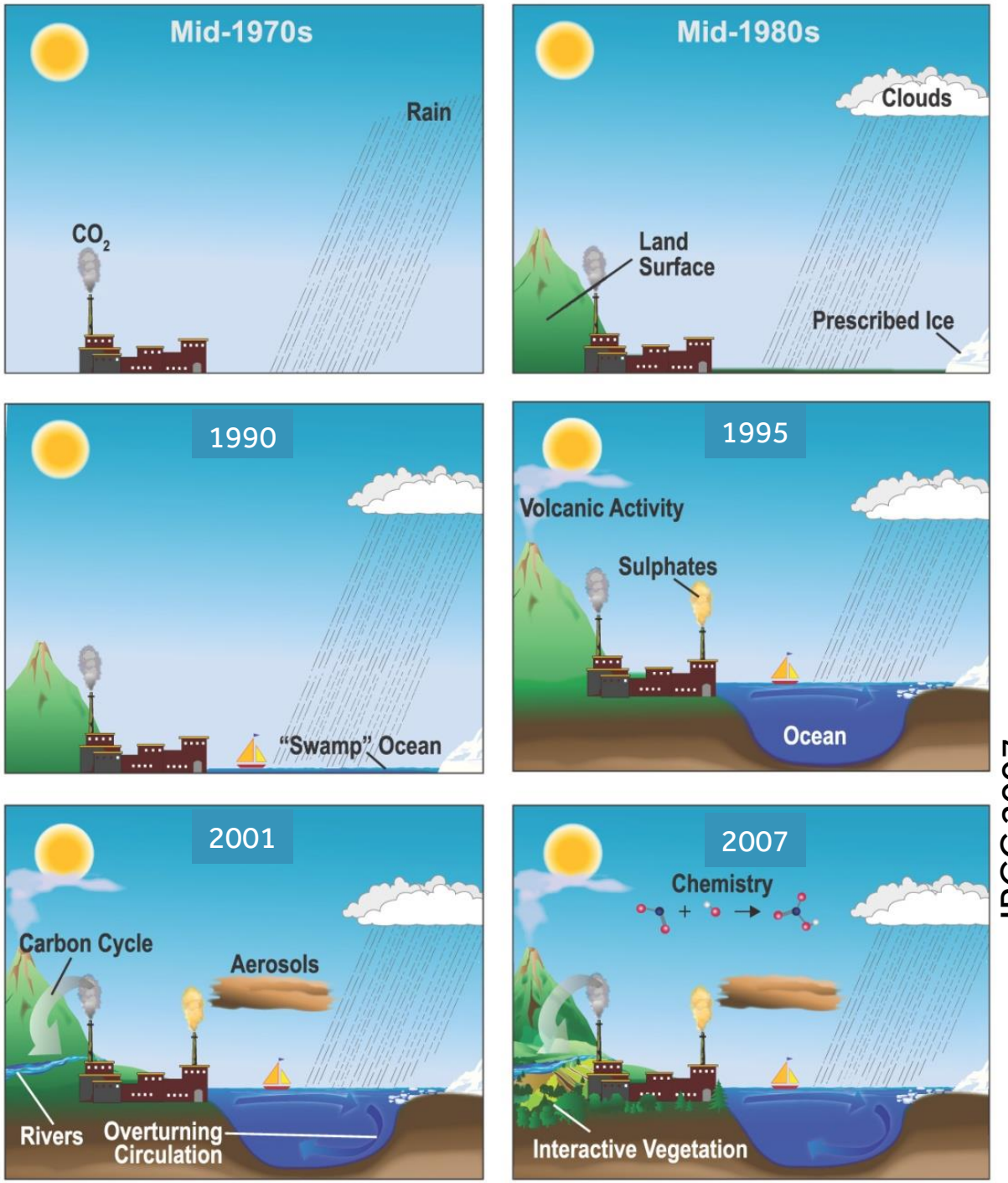
- A powerful computer is needed to do climate change simulations.

- Even on such a powerful computer, is takes a month to simulate 100 years of Earth system changes.

A SHORT HISTORY





IPCC 2007

WHY AREN'T MODELS PERFECT?

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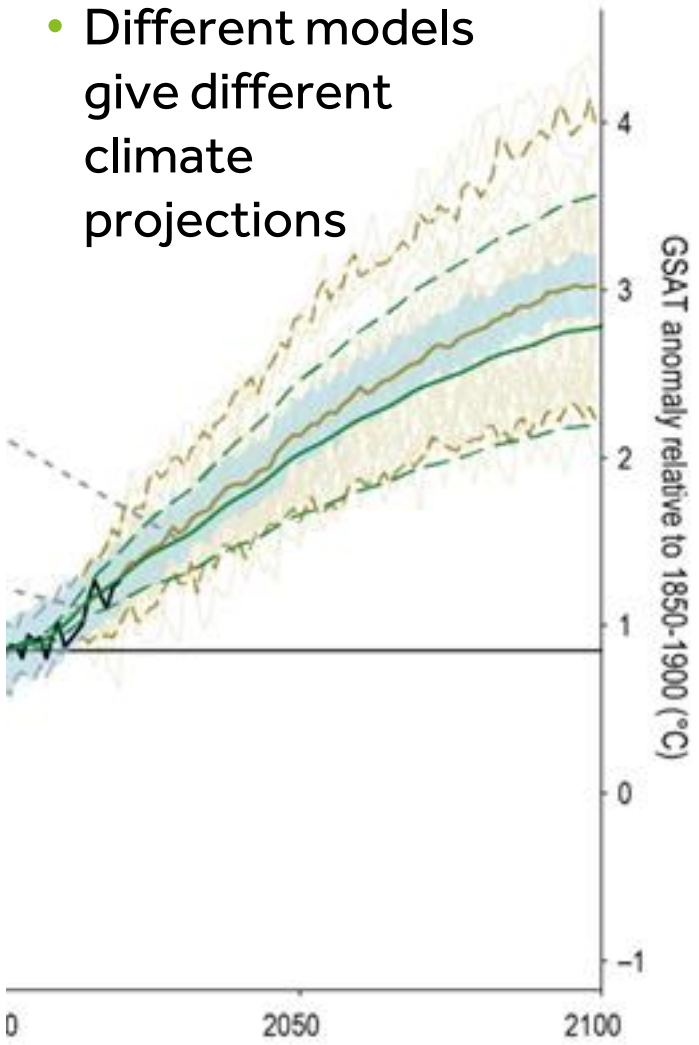
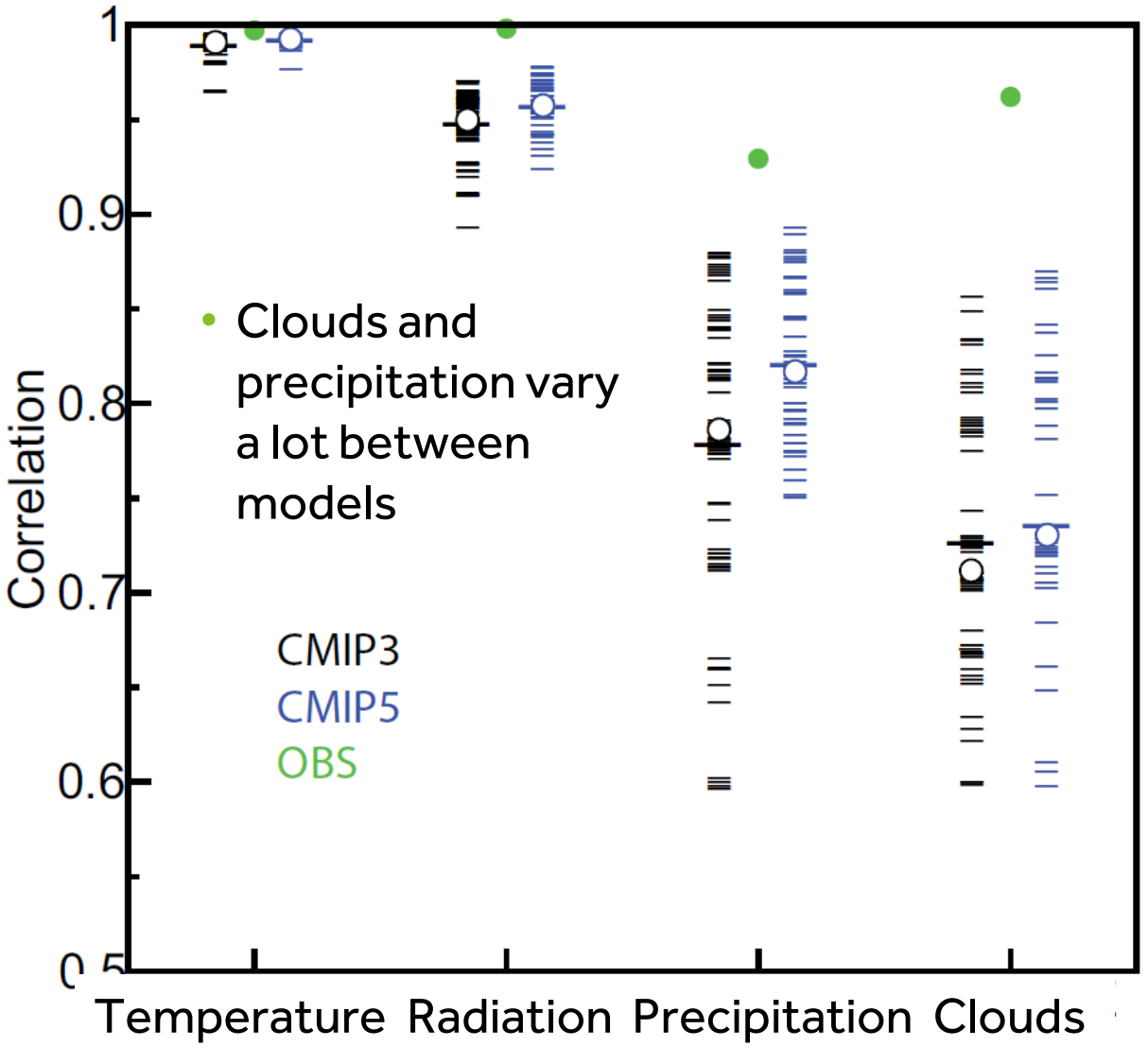
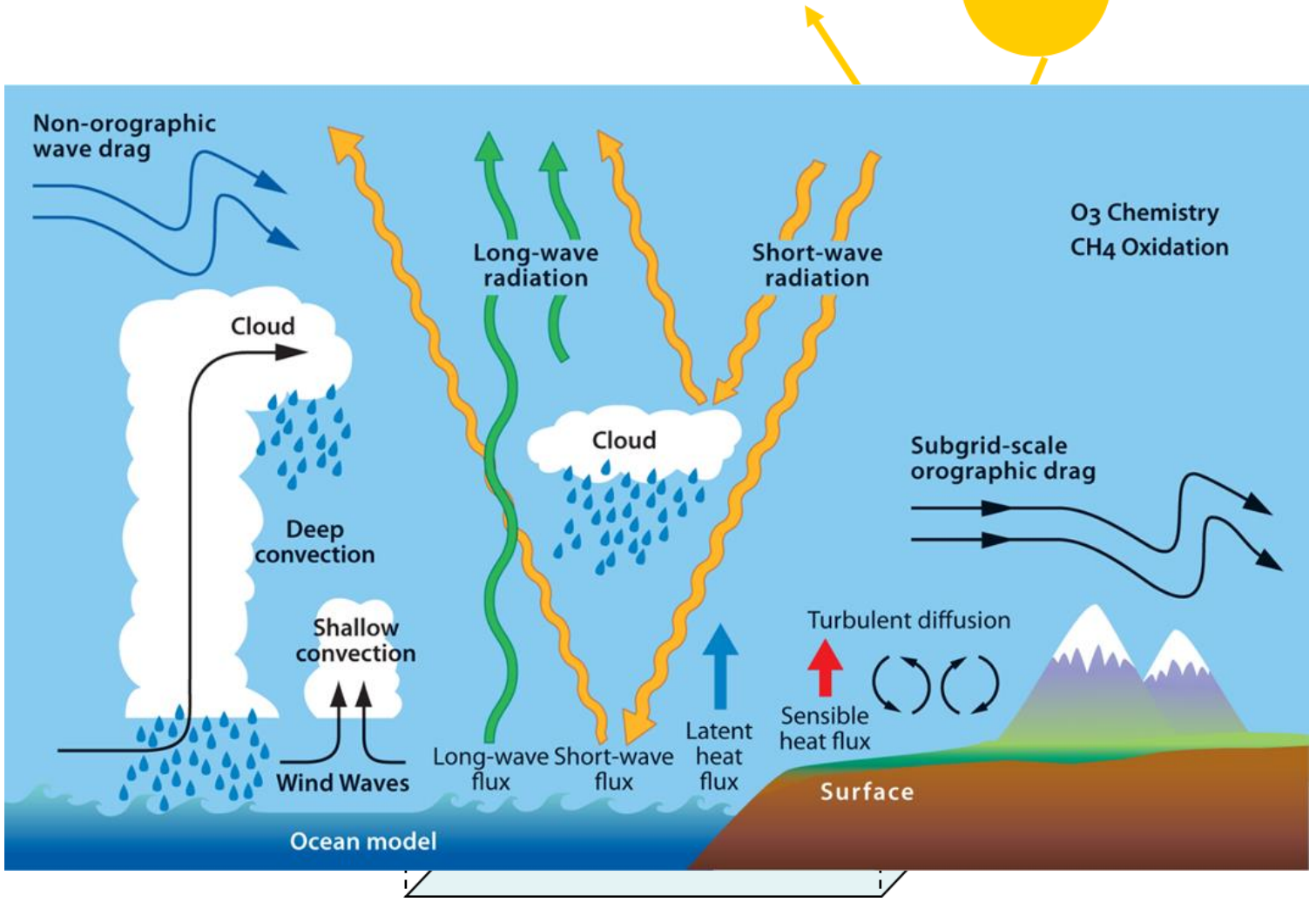
- Different models give different climate projections





INSIDE A MODEL GRID BOX

- Clouds are much smaller than a 100 km x 100 km grid box
- Can't write definitive equations for clouds
- Every modelling centre treats clouds differently
  - Hence models behave differently
- Not just clouds …



25 km CLIMATE MODEL SIMULATION

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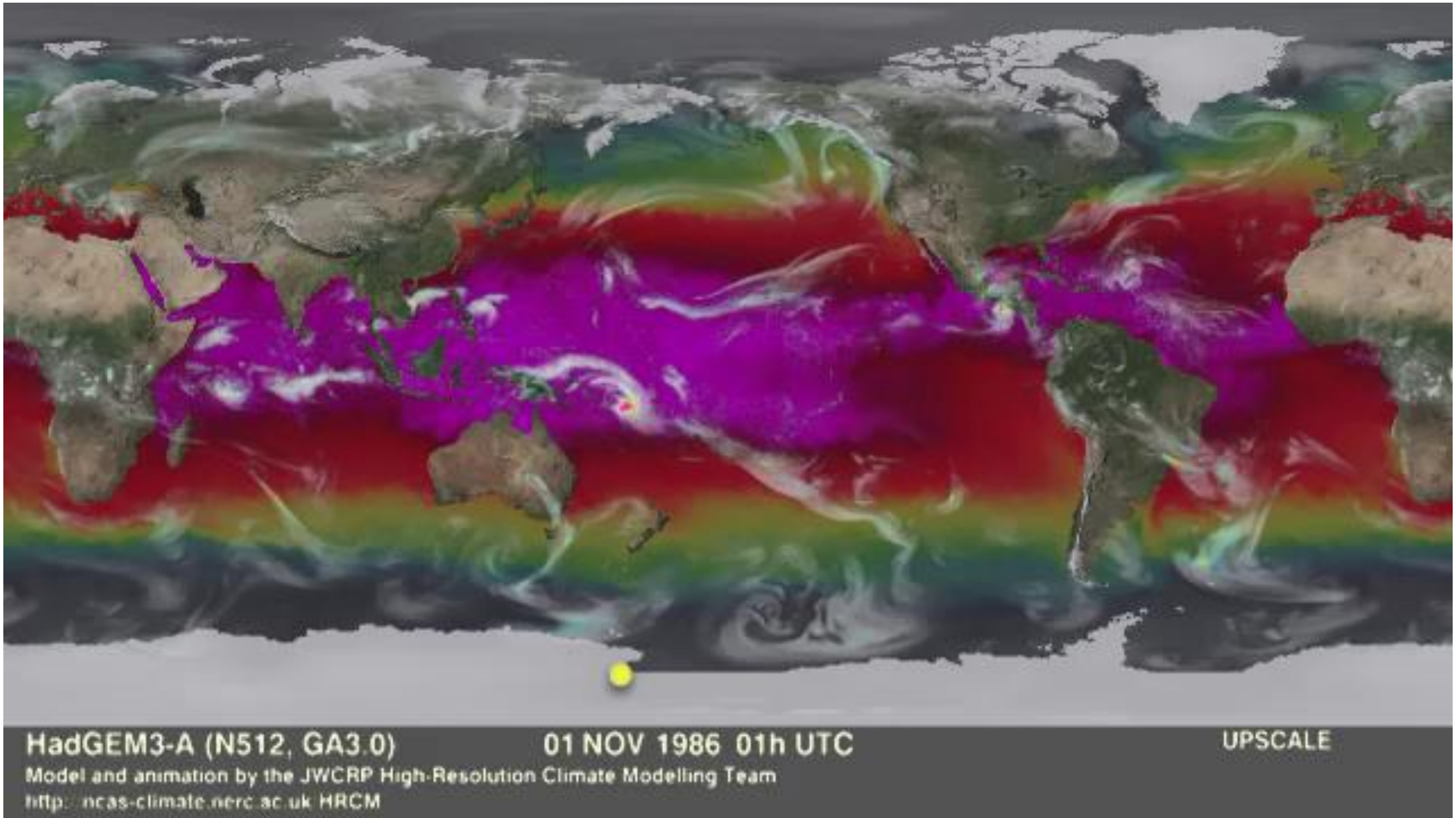

HOW DO WE KNOW THE MODELS WORK?

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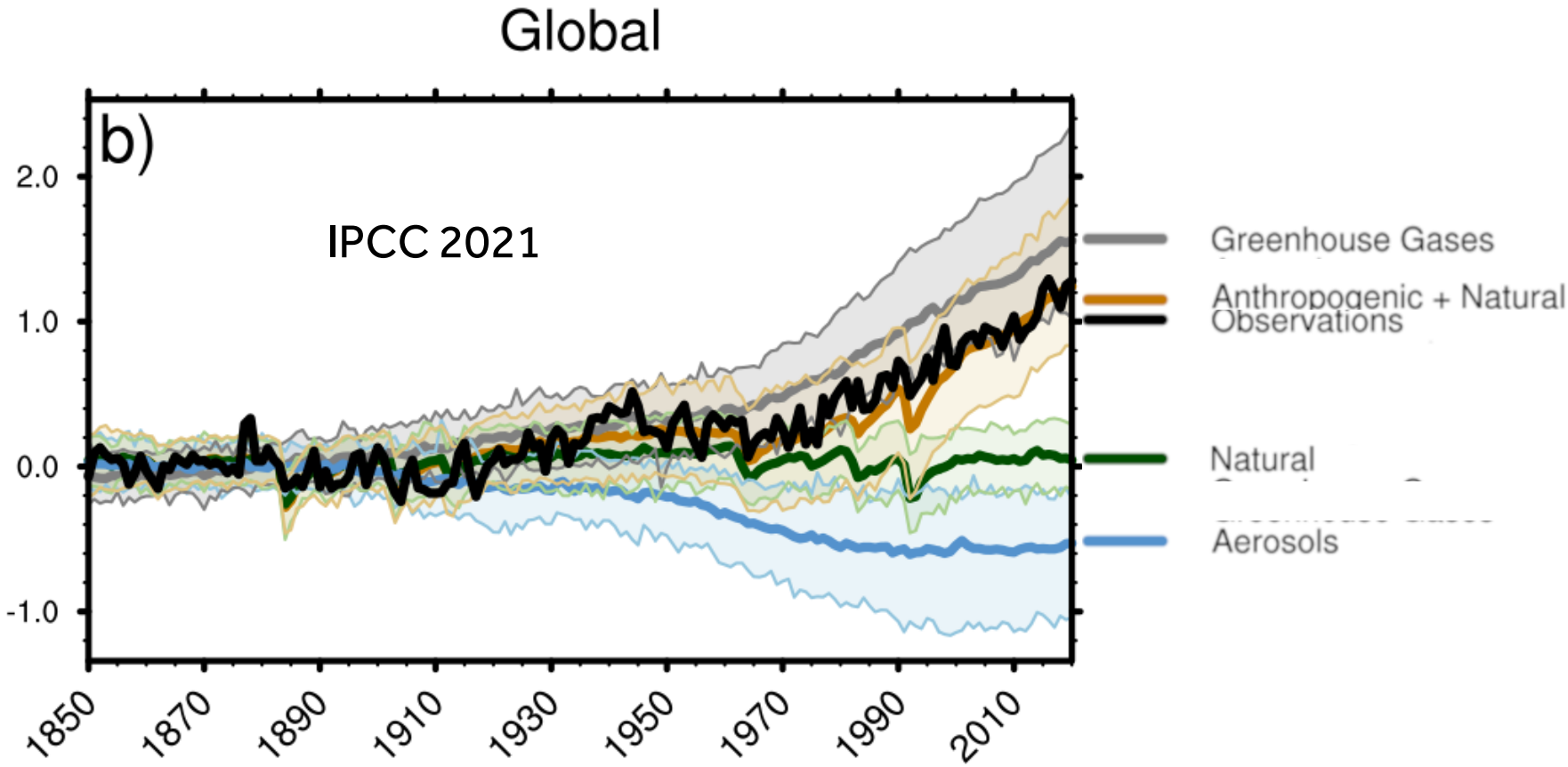
- Compare them against the past
- But is that cheating?
  - We already know the answer we want



HOW DO WE KNOW THE MODELS WORK?

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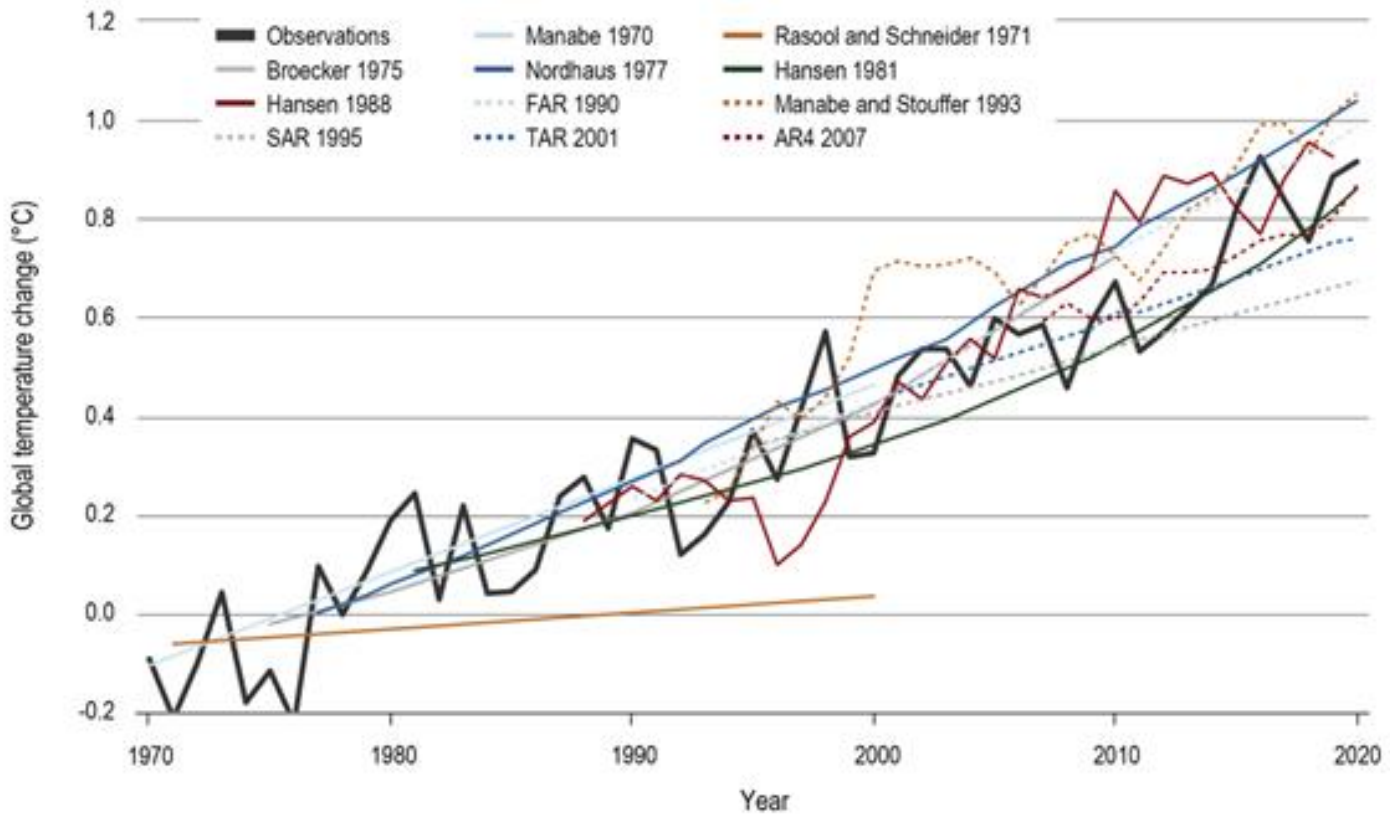
- Can now test predictions from the first models against what actually happened.



'***All models are wrong, but some are useful***'

George Box, 1976

So what are climate models useful for?

WHAT CAN MODELS TELL US?

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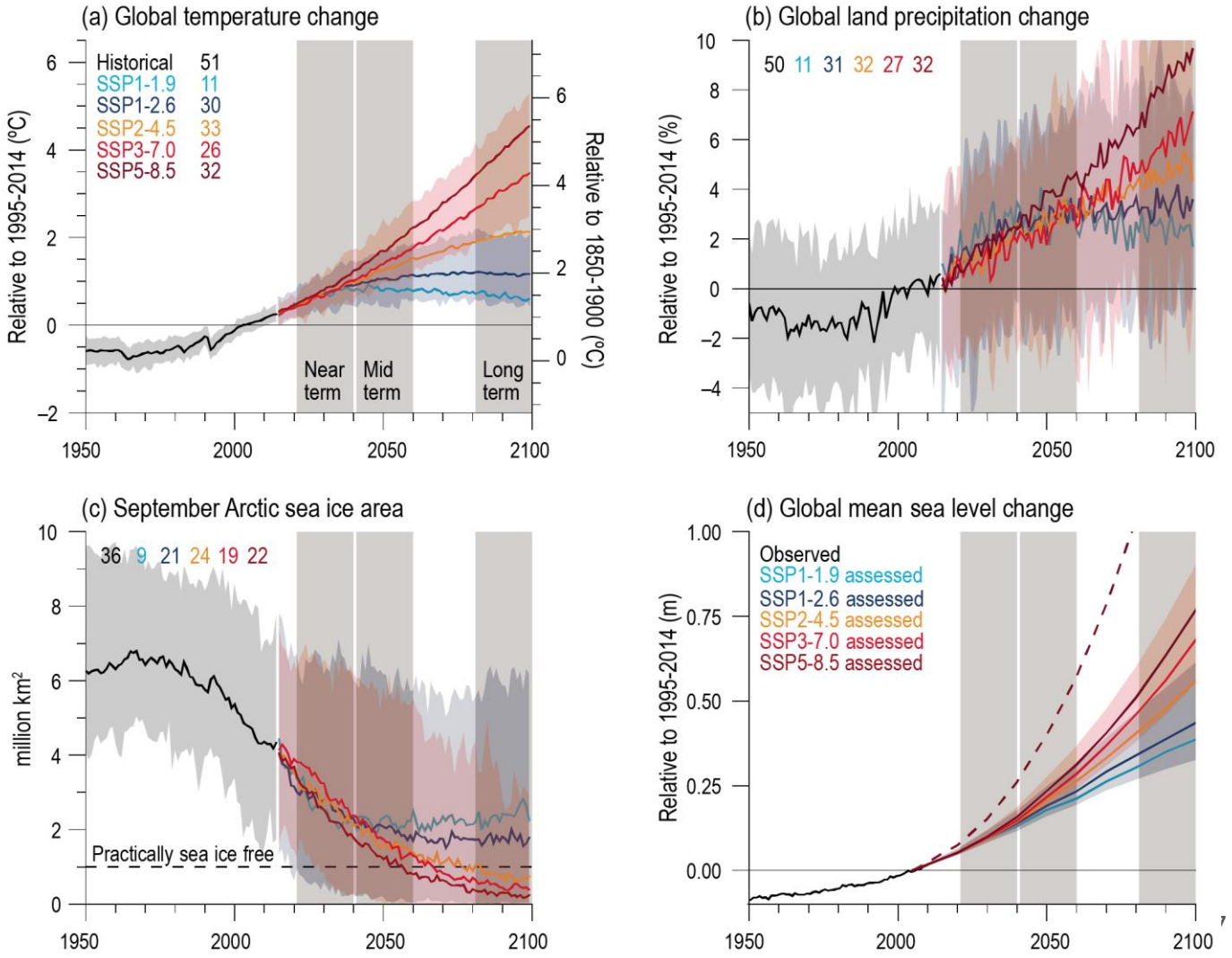
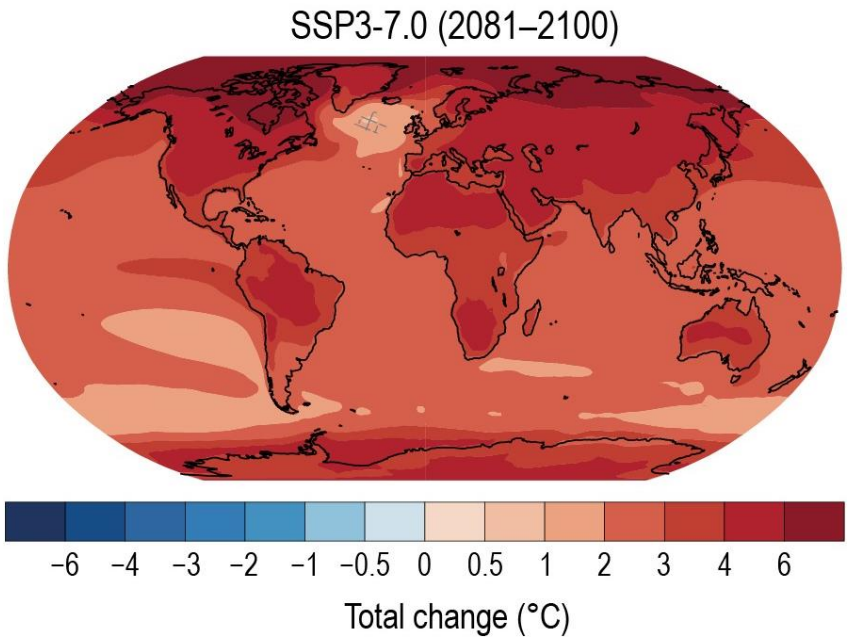
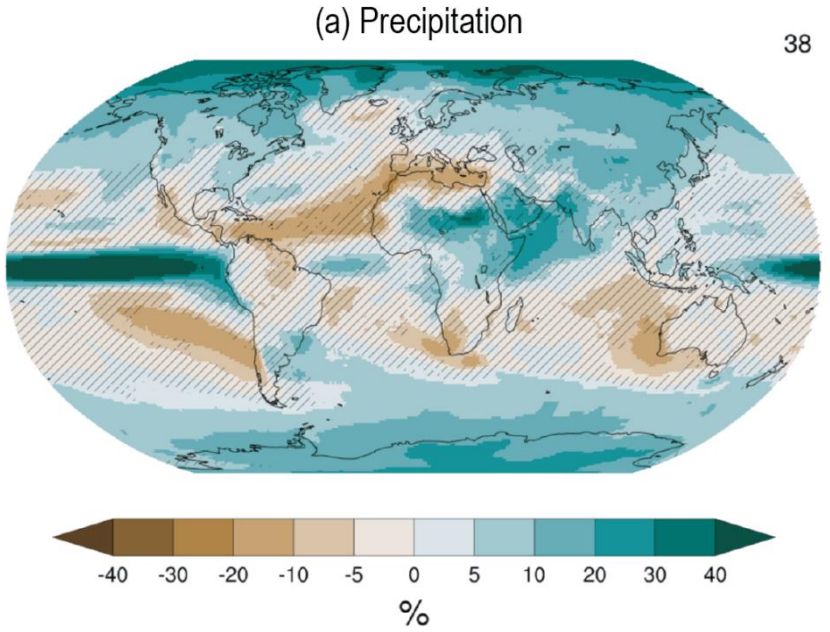
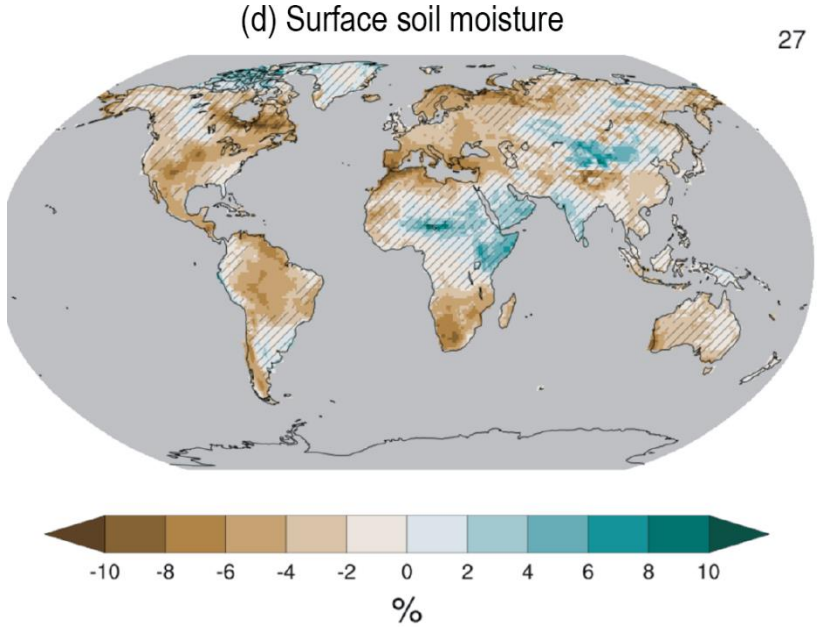
- Global changes in climate



WHAT CAN MODELS TELL US?







- Local changes in climate

EARTH SYSTEM MODELLING

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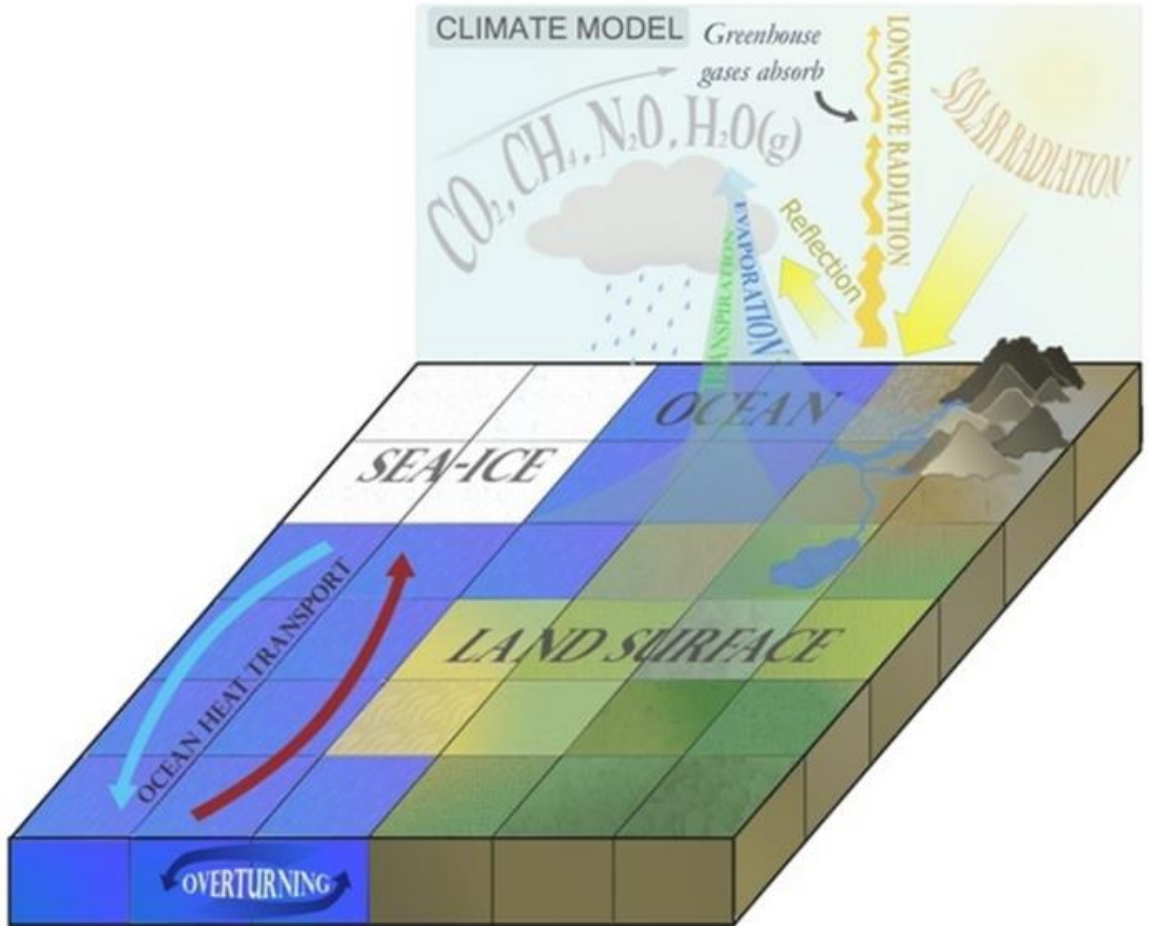

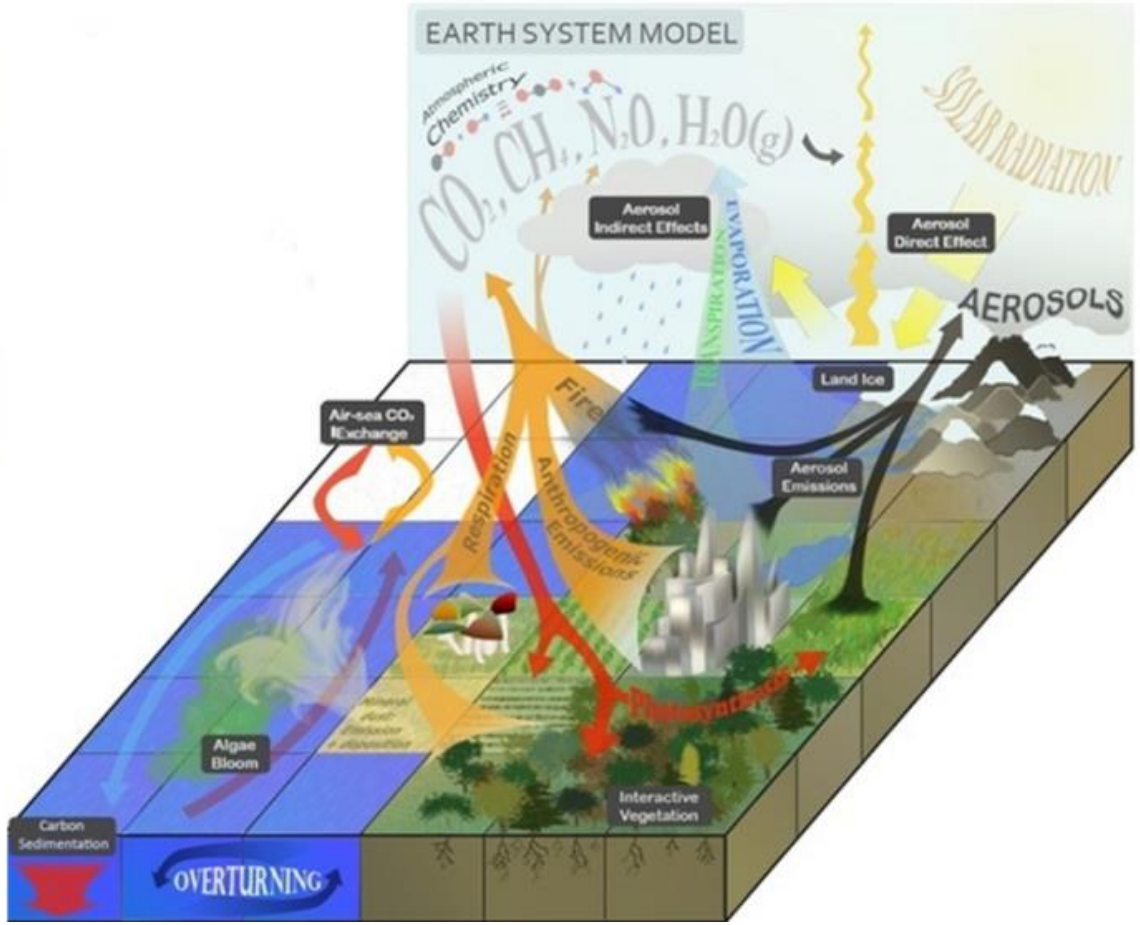

OFFSETTING CARBON

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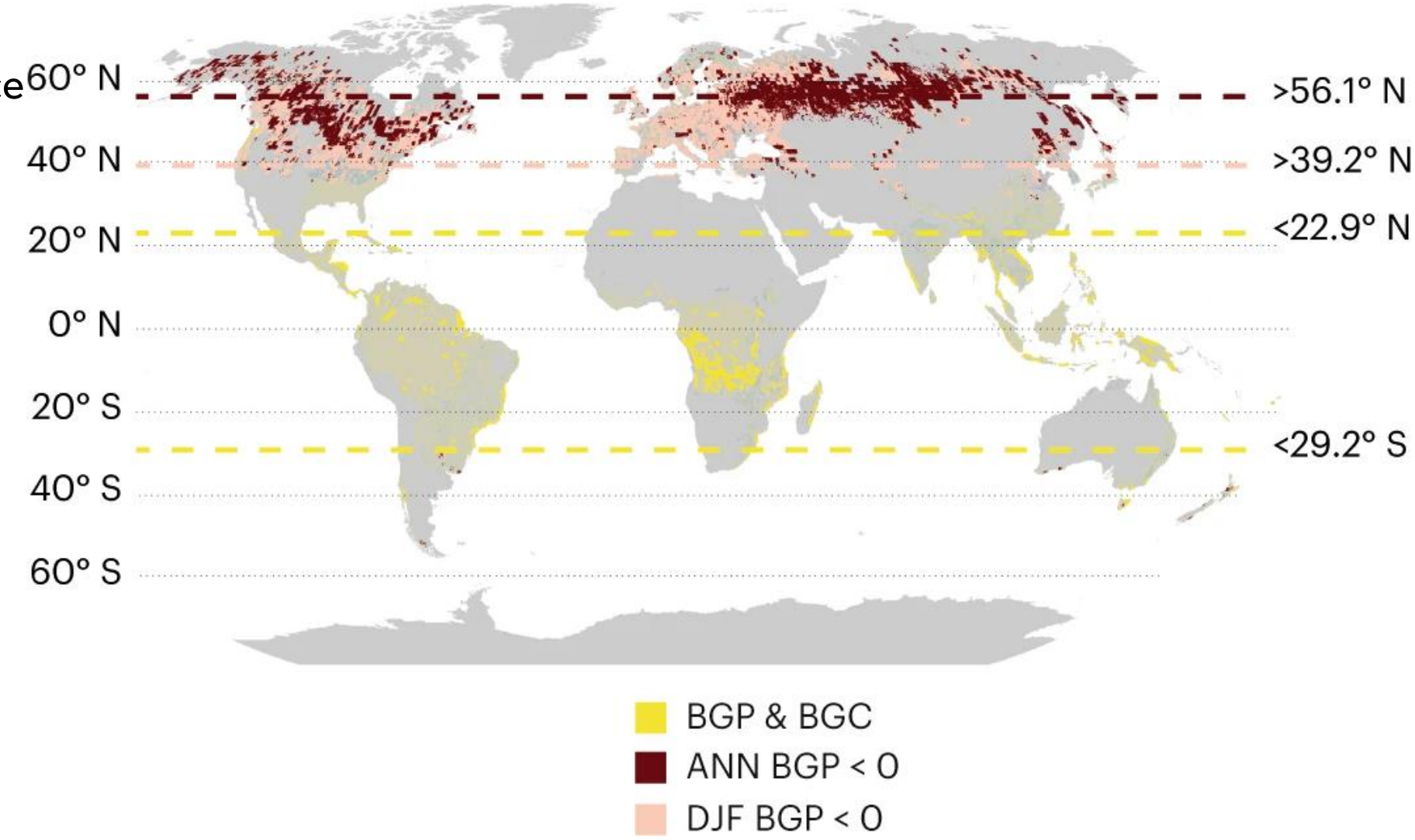
- Earth system models can tell us the best place to plant trees to offset carbon emissions



HIGH RESOLUTION

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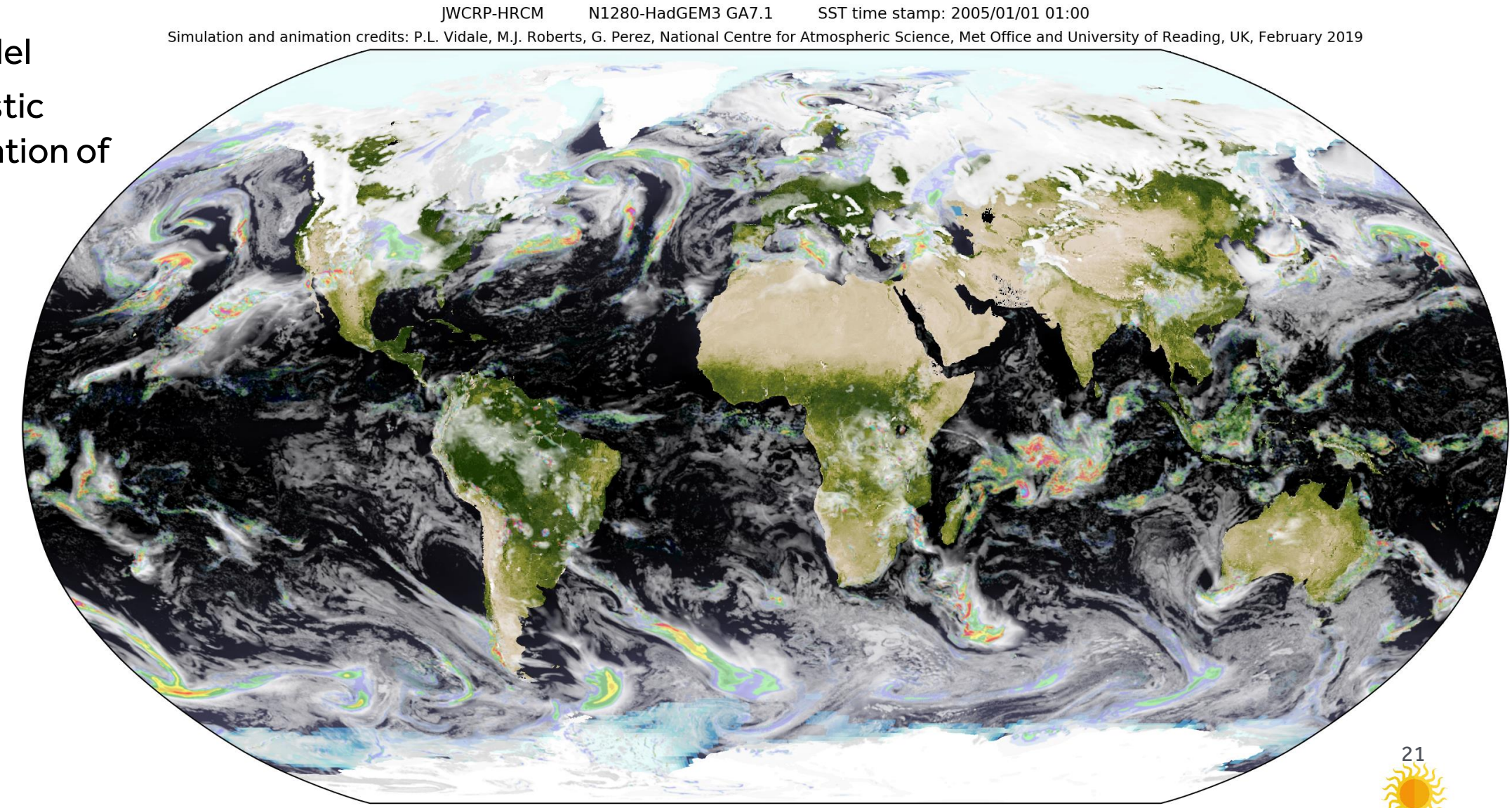
- 10 km model
- More realistic representation of clouds



DIGITAL TWIN EARTHS

NOT A BLACK BOX

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CLIMATE PROJECTIONS

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- What is a climate model?
- What is in the black box?

CLIMATE MODELS ARE (VERY) USEFUL!

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'***All models are wrong, but some are useful***'

George Box, 1976