Understanding and quantifying future climate change

SPAT PG Lectures, Autumn 2017

Mike Byrne

Outline

1. A brief intro to climate models
2. Feedback processes
3. Quantifying global climate change: equilibrium climate sensitivity
4. Regional climate change: focus on δT and δP patterns
5. Detection & attribution of climate change

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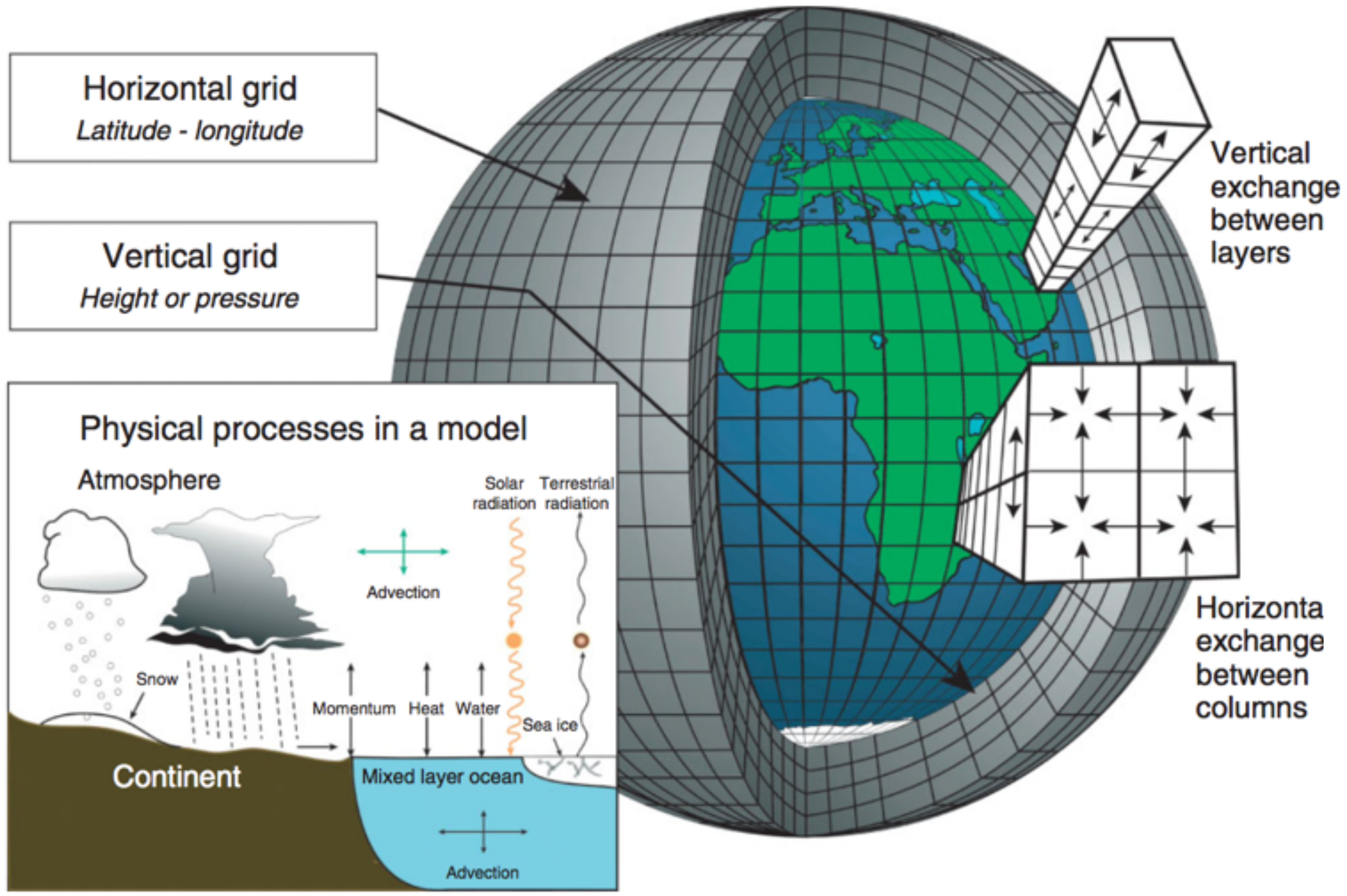
1. A brief intro to climate models
2. Feedback processes
3. Quantifying global climate change: equilibrium climate sensitivity
4. Regional climate change: focus on δT and δP patterns
5. Detection & attribution of climate change (spoiler alert: we're doing it)

Climate models are used for fundamental research *and* future predictions



- A **'computational lab'** for fundamental research + a **'prediction tool'** for future climate
- **Attempt to simulate many processes:** fluid dynamics, radiation, biosphere, ice physics, atmospheric chemistry, ocean biology…

Edwards (2011)

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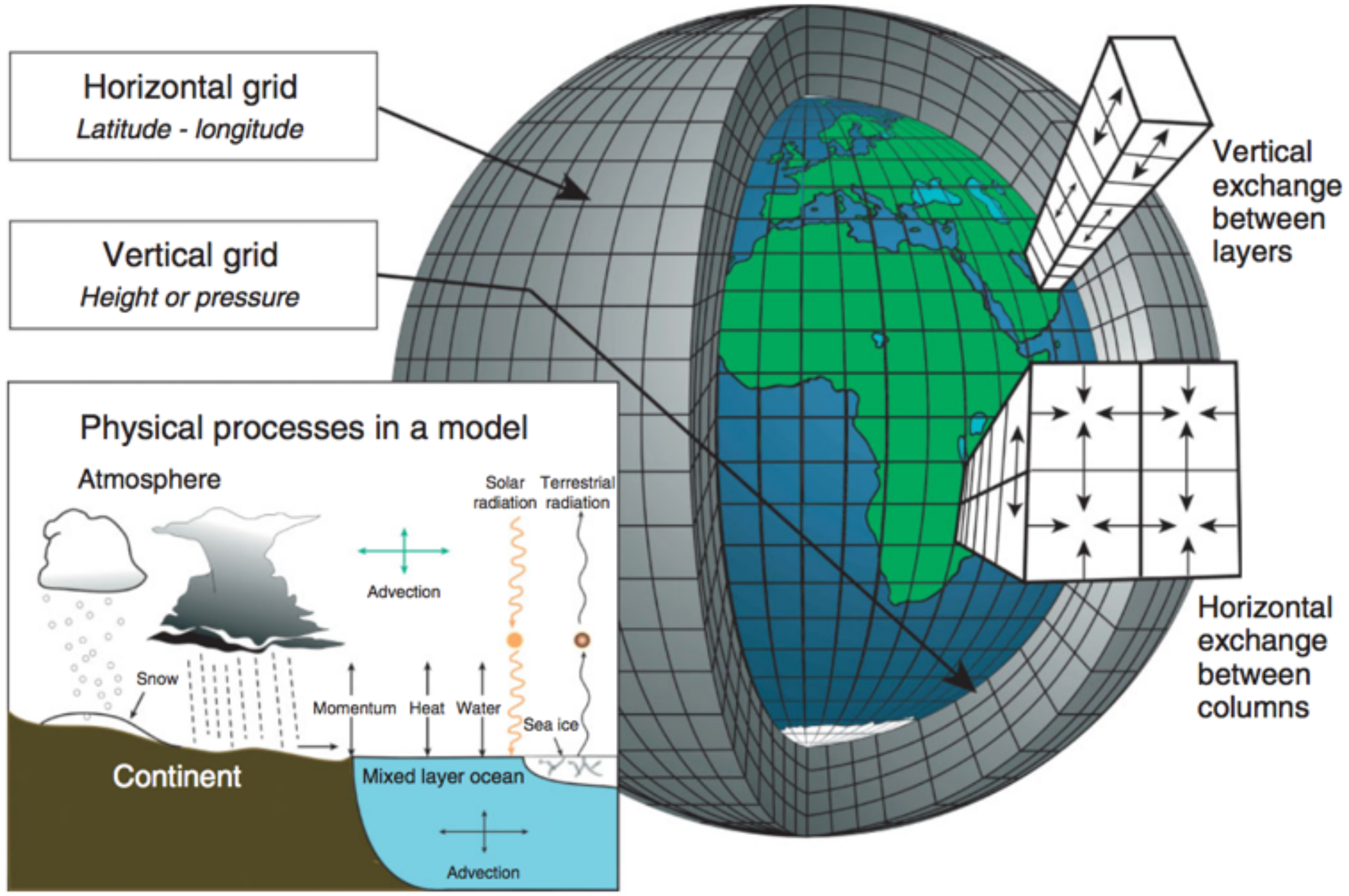


Edwards (2011)

- A **'computational lab'** for fundamental research + a **'prediction tool'** for future climate
- **Attempt to simulate many processes:** fluid dynamics, radiation, biosphere, ice physics, atmospheric chemistry, ocean biology…
- **Many timescales:** convection (hours), midlatitude cyclones (days), radiation (month), upper ocean (months/years), deep ocean (>100 years), ice sheets (1000 years), chemical weathering (1,000,000 years)
- **Useful but uncertain!**

Evolution of climate models over time

1970

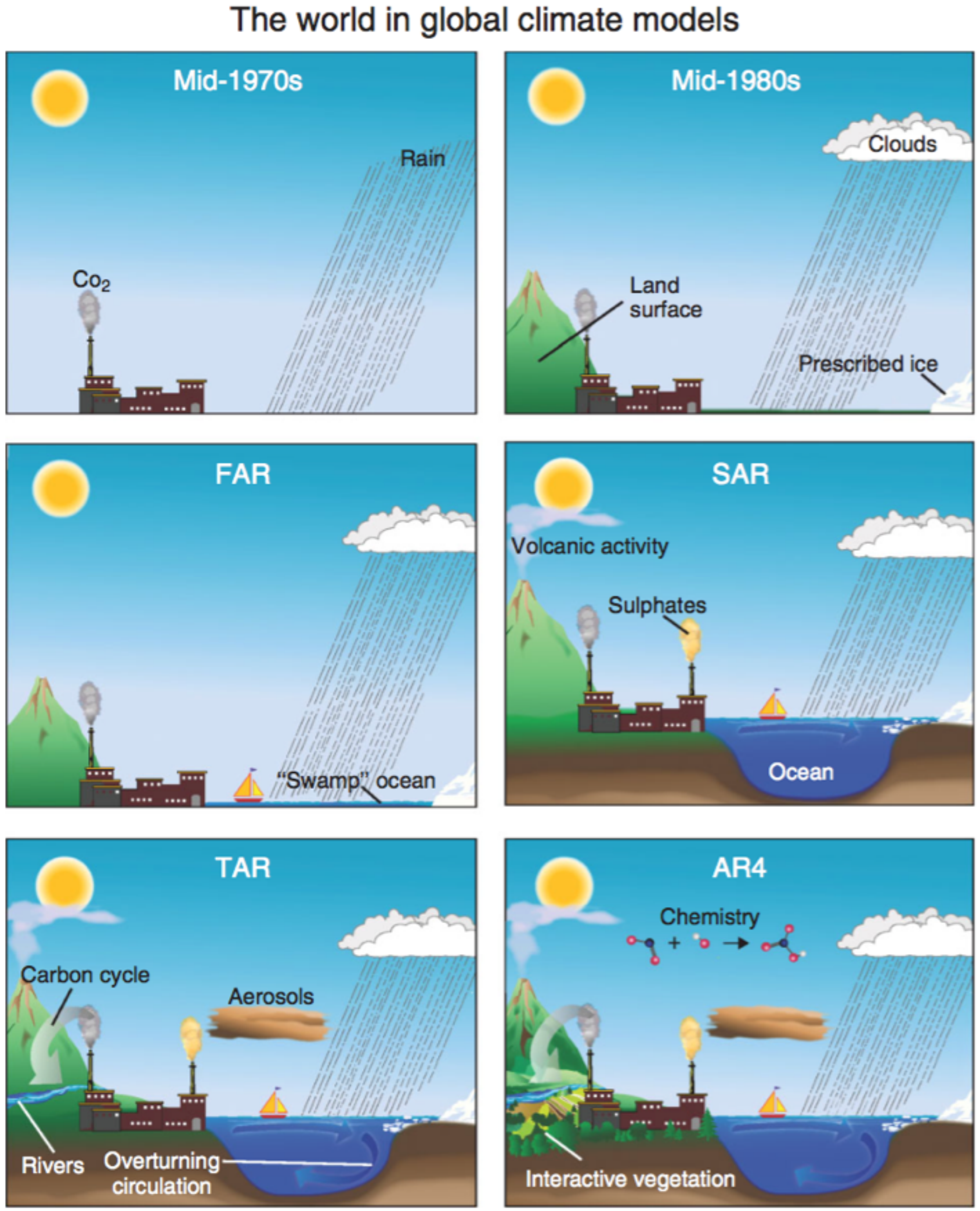
1980

1990

1995

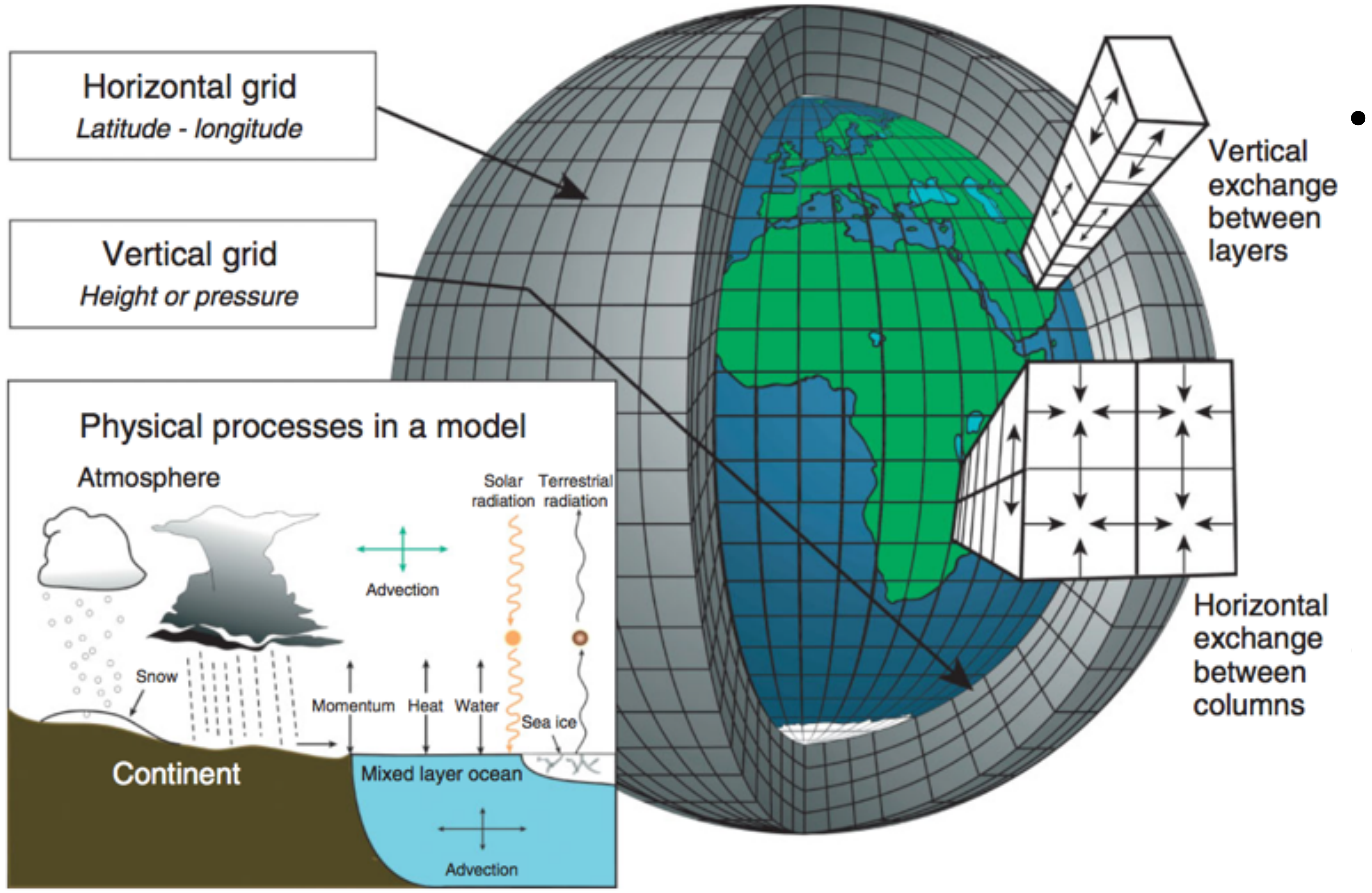
2001

2007



Edwards (2011)

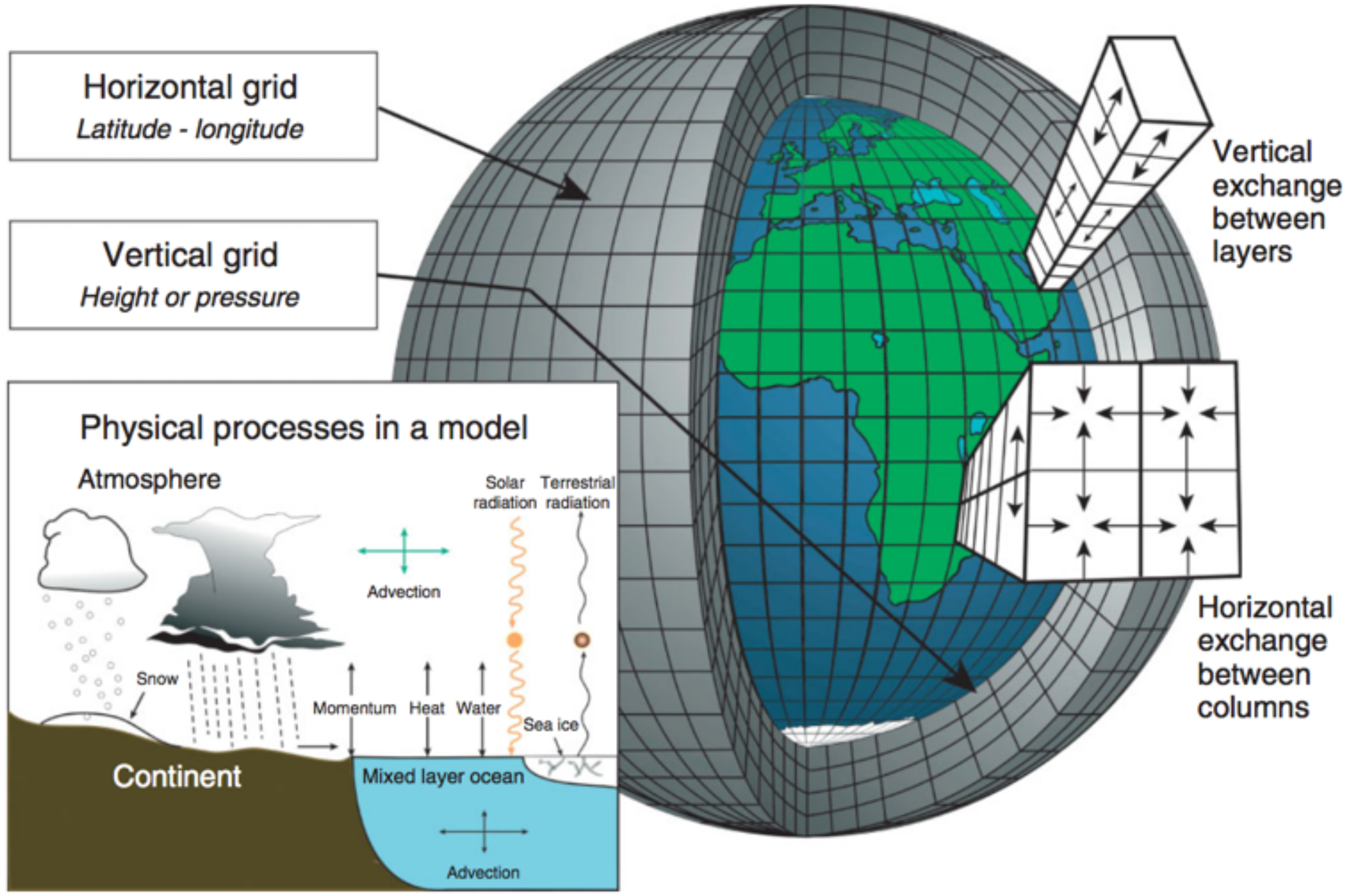
Useful but uncertain: Challenges in climate modelling



- **Insufficient resolution:** Limited computational capacity -> important processes cannot be resolved by global models so need to be "parameterised" (e.g. clouds)

Edwards (2011)

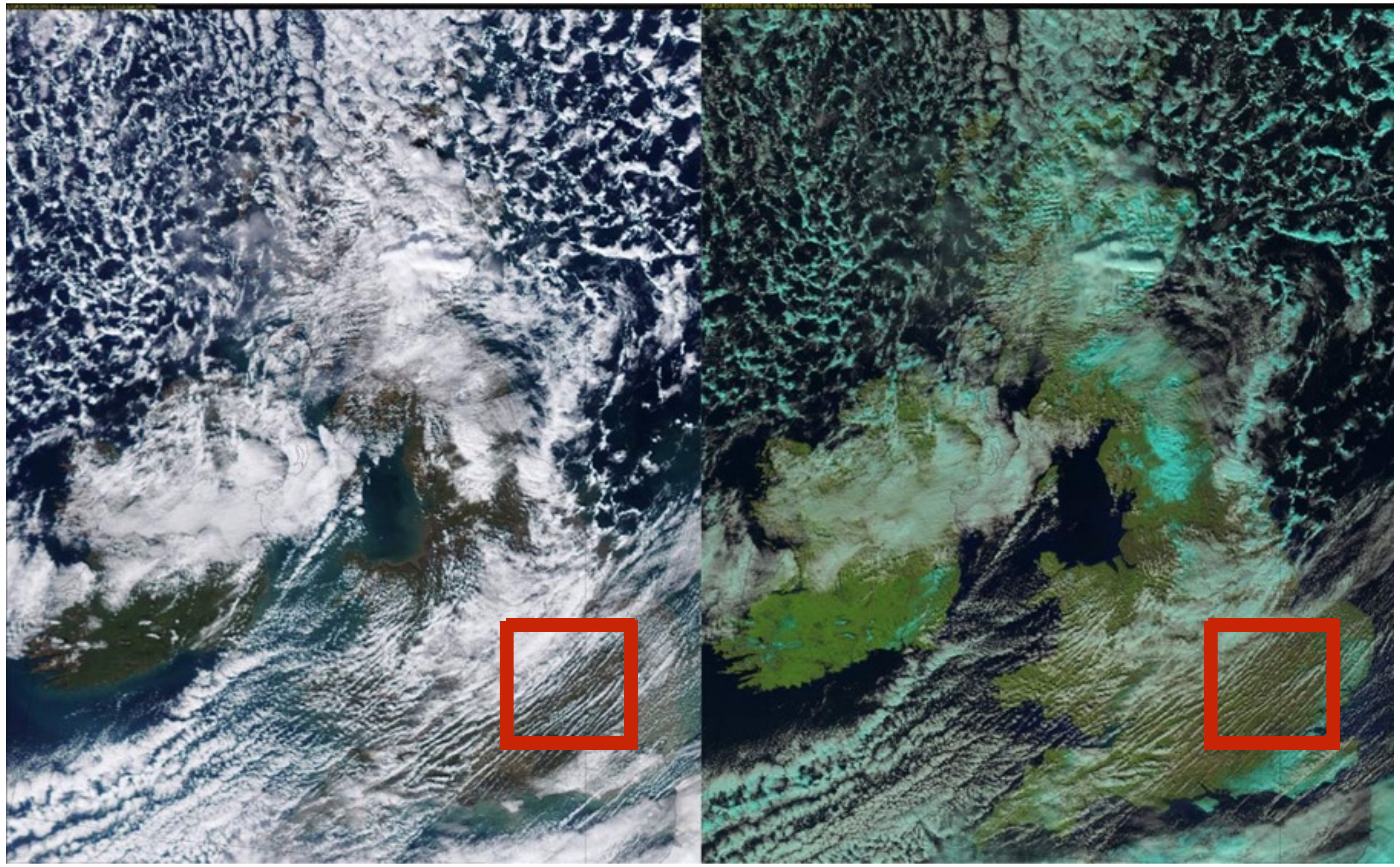
Useful but uncertain: Challenges in climate modelling



- **Insufficient resolution:** Limited computational capacity -> important processes cannot be resolved by global models so need to be "parameterised" (e.g. clouds)
- **Structural uncertainty:** We know exact mathematical description of fluid motion (Navier-Stokes) but not of vegetation, phytoplankton, ice dynamics…

Edwards (2011)

Problem of limited resolution in global climate modelling



typical atmosphere-ocean climate model resolution

- **Atmosphere:** Can simulate midlatitude cyclone, planetary circulations (e.g. Hadley cell) *but not* convection, clouds, hurricanes, etc.

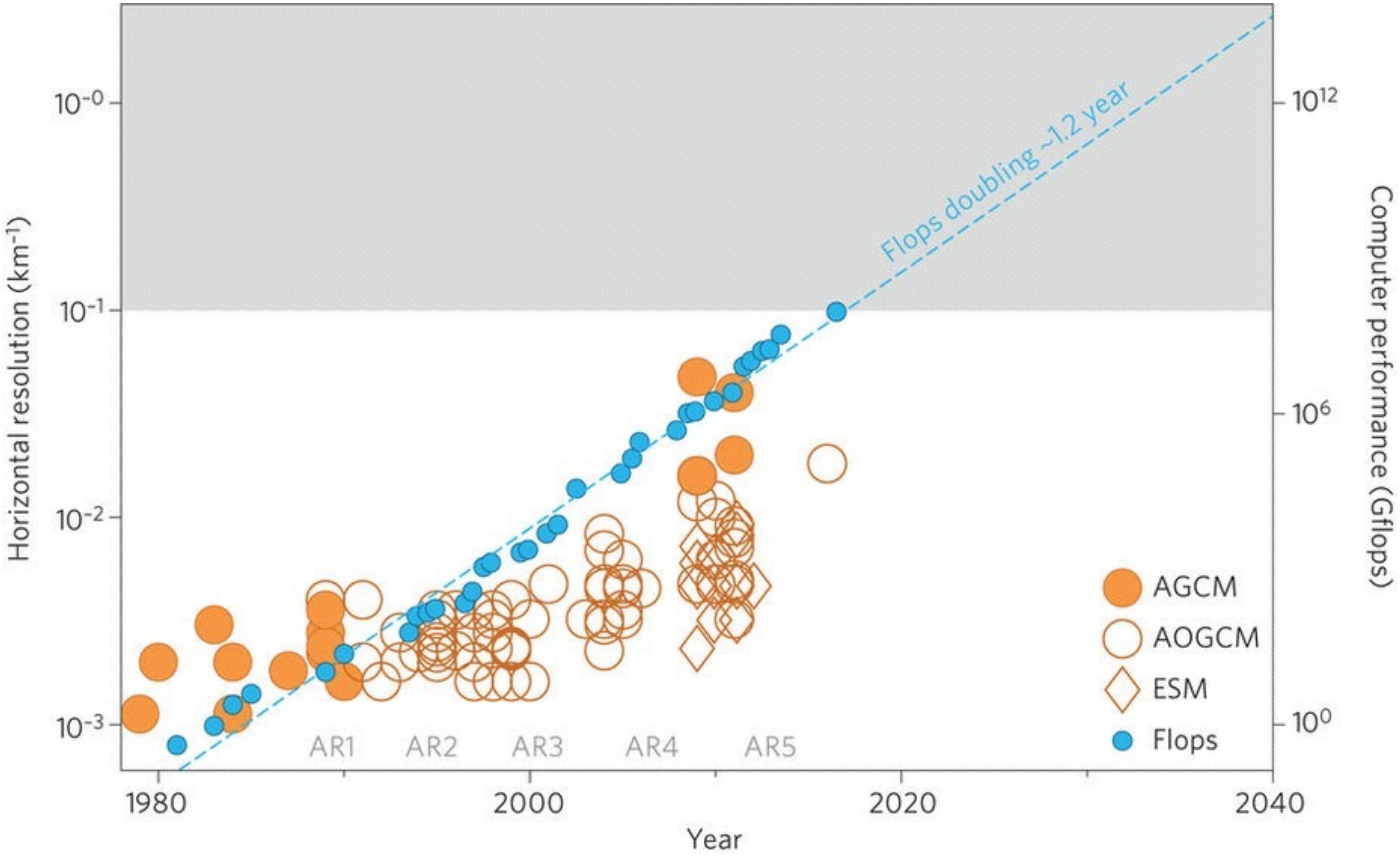
- Clouds and convection particularly important for determining magnitude of future climate change — their effects are crudely paramaterised, which introduces large uncertainties

Problem of limited resolution in global climate modelling

- **Ocean:** Full of macro turbulence and eddies which cannot be resolved by global climate models. Again, need paramaterisations to capture effects of these eddies on climate (e.g. heat transport, Gent-McWilliams)

video of ocean eddies

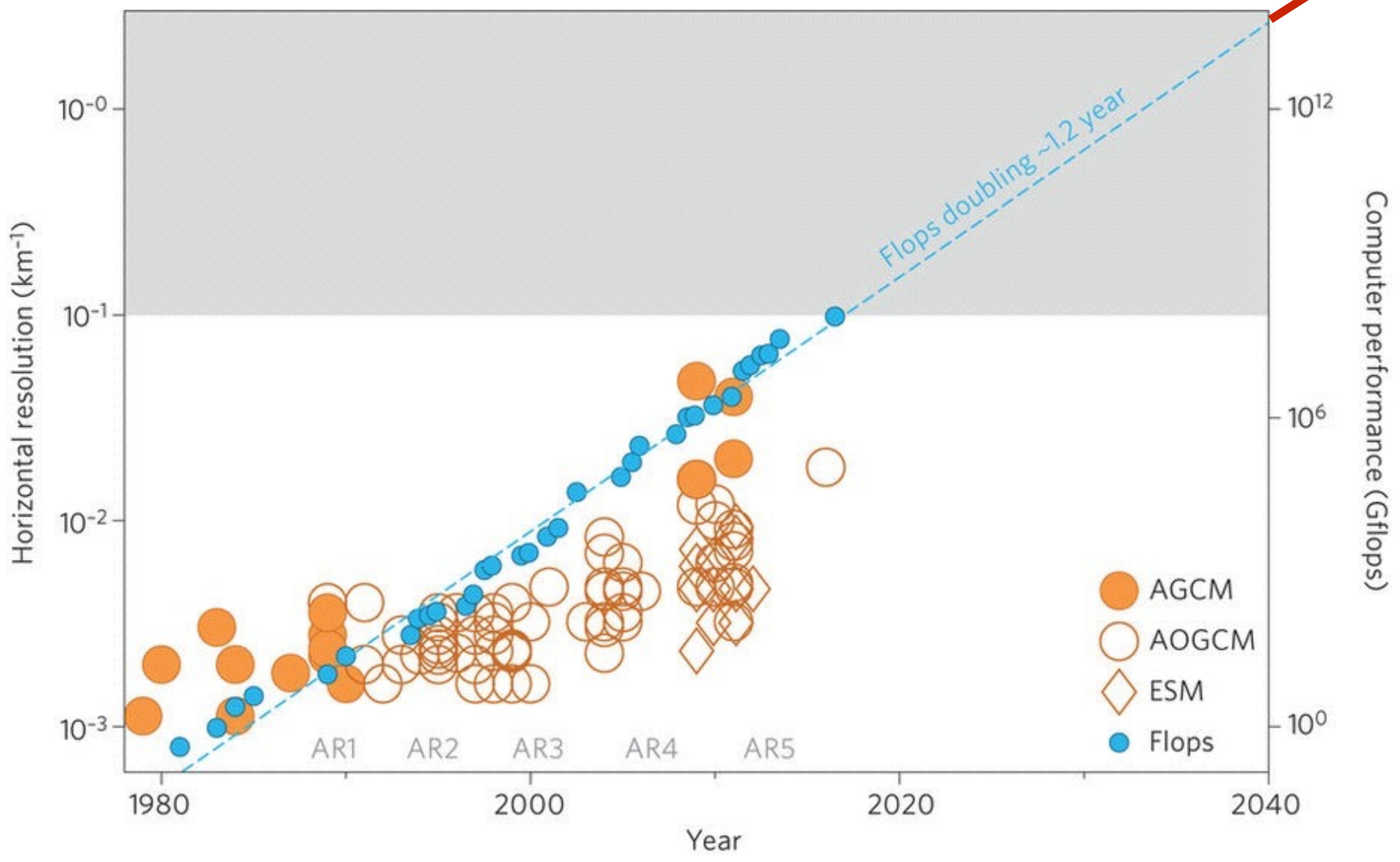
Climate change: We will not be able to compute the exact answer anytime soon (because of low subtropical clouds)



Schneider et al. (Nat. Climate Change, 2016)

Climate change: We will not be able to compute the exact answer anytime soon (because of low subtropical clouds)

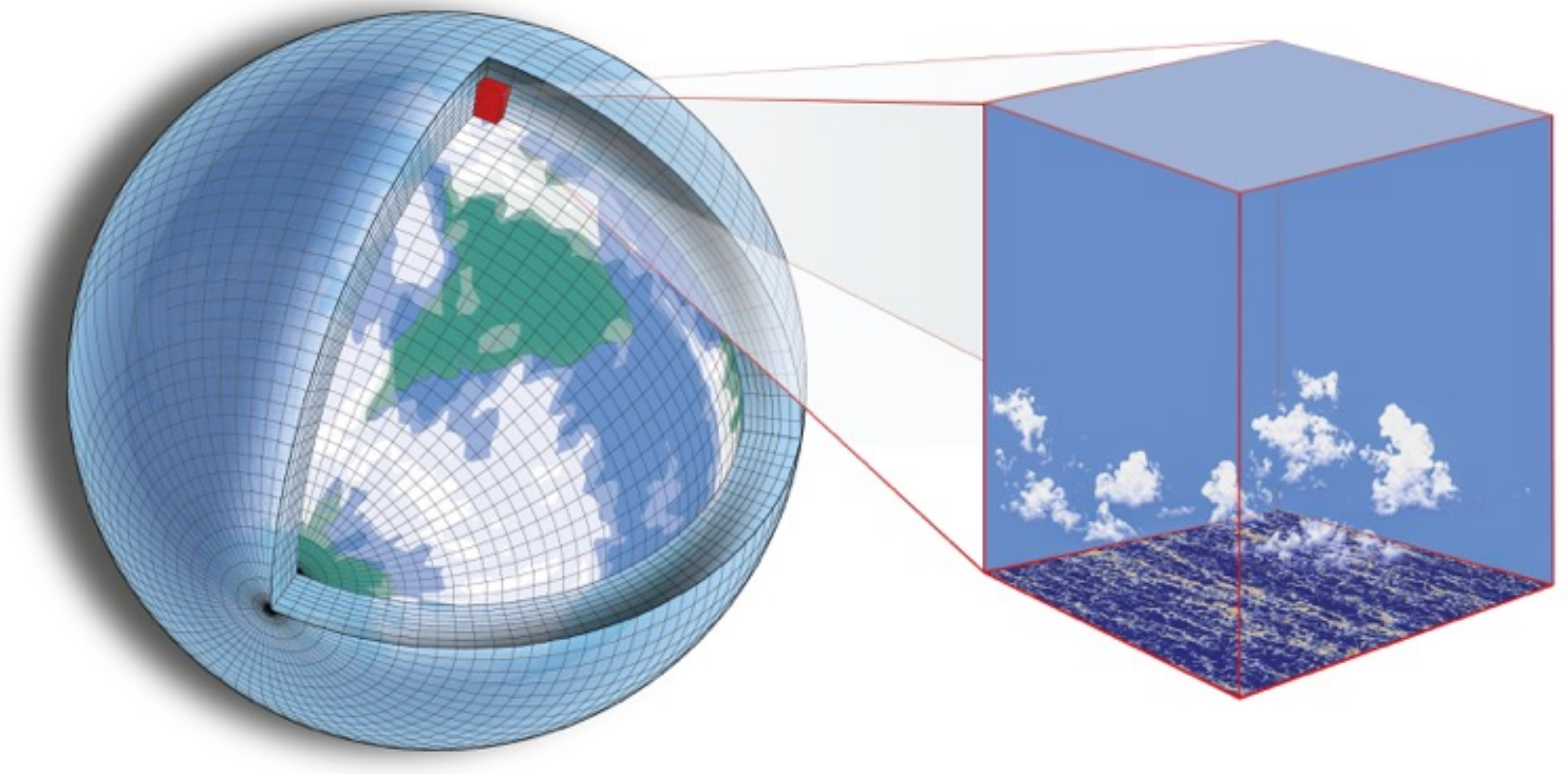
resolving low clouds
(10m resolution)



>2060 (!)

Schneider et al. (Nat. Climate Change, 2016)

Climate modelling is not only about making detailed predictions of the future: fundamental research with simplified models

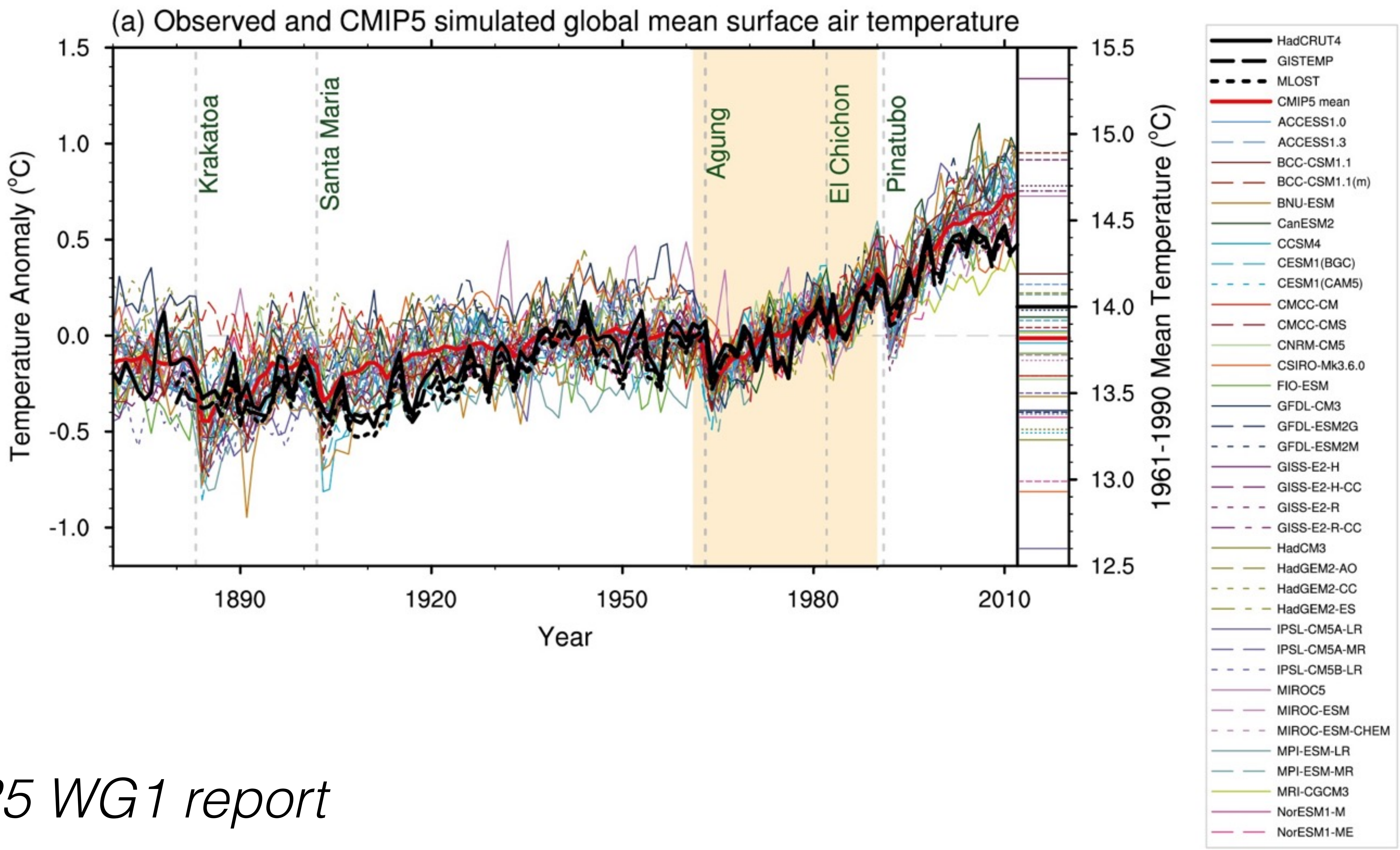


Some examples of simplified models used in climate research:

- Small-domain cloud-resolving models (sacrifice global coverage in order to simulate small-scale processes)
- Ocean-only models
- Atmosphere-only "aquaplanet" models

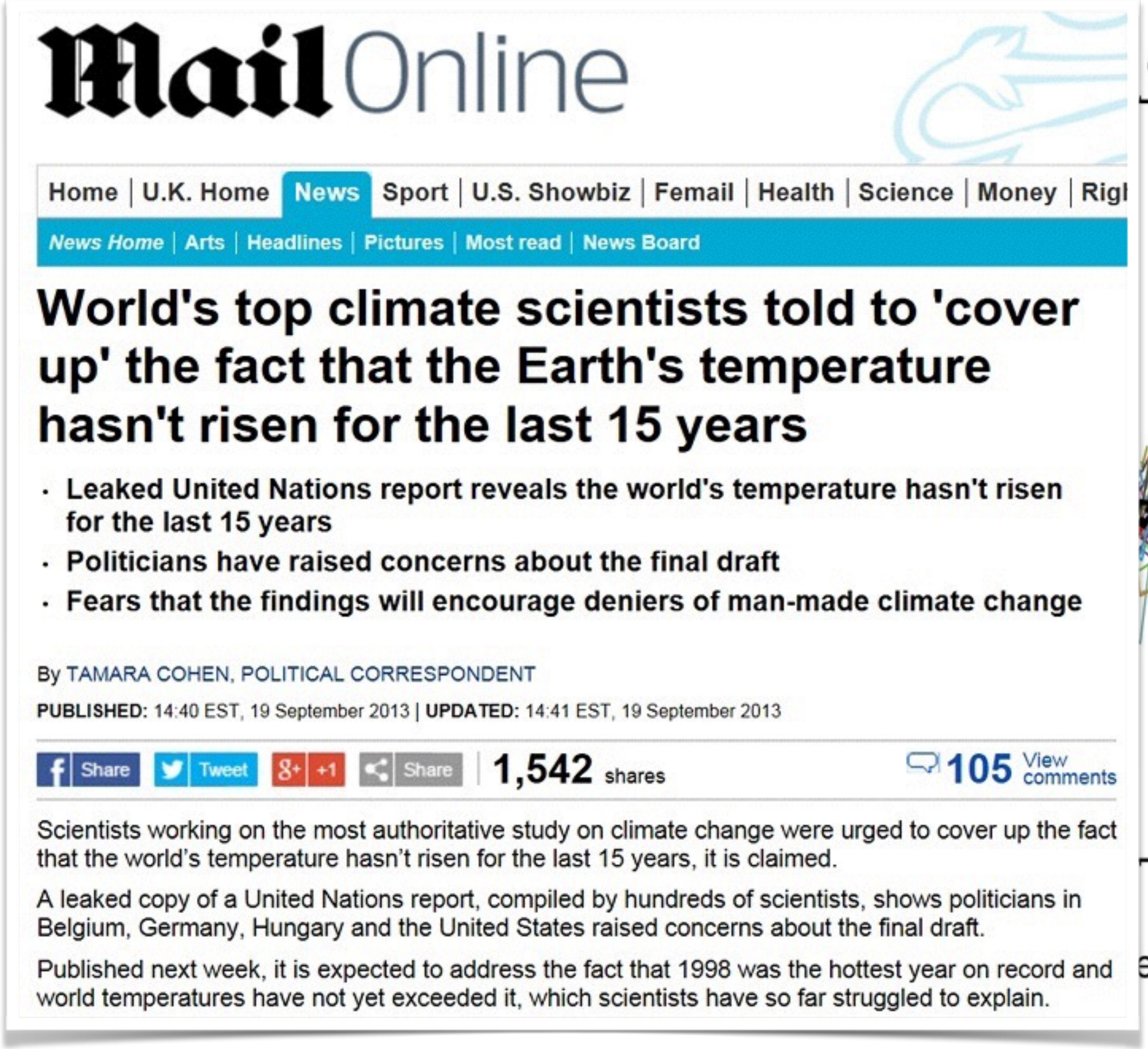
video of a "large-eddy simulation"

Evaluation of climate models: They capture historical global warming reasonably well



IPCC AR5 WG1 report

Evaluation of climate models: They capture historical global warming reasonably well



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World's top climate scientists told to 'cover up' the fact that the Earth's temperature hasn't risen for the last 15 years

- Leaked United Nations report reveals the world's temperature hasn't risen for the last 15 years
- Politicians have raised concerns about the final draft
- Fears that the findings will encourage deniers of man-made climate change

By TAMARA COHEN, POLITICAL CORRESPONDENT

PUBLISHED: 14:40 EST, 19 September 2013 | UPDATED: 14:41 EST, 19 September 2013

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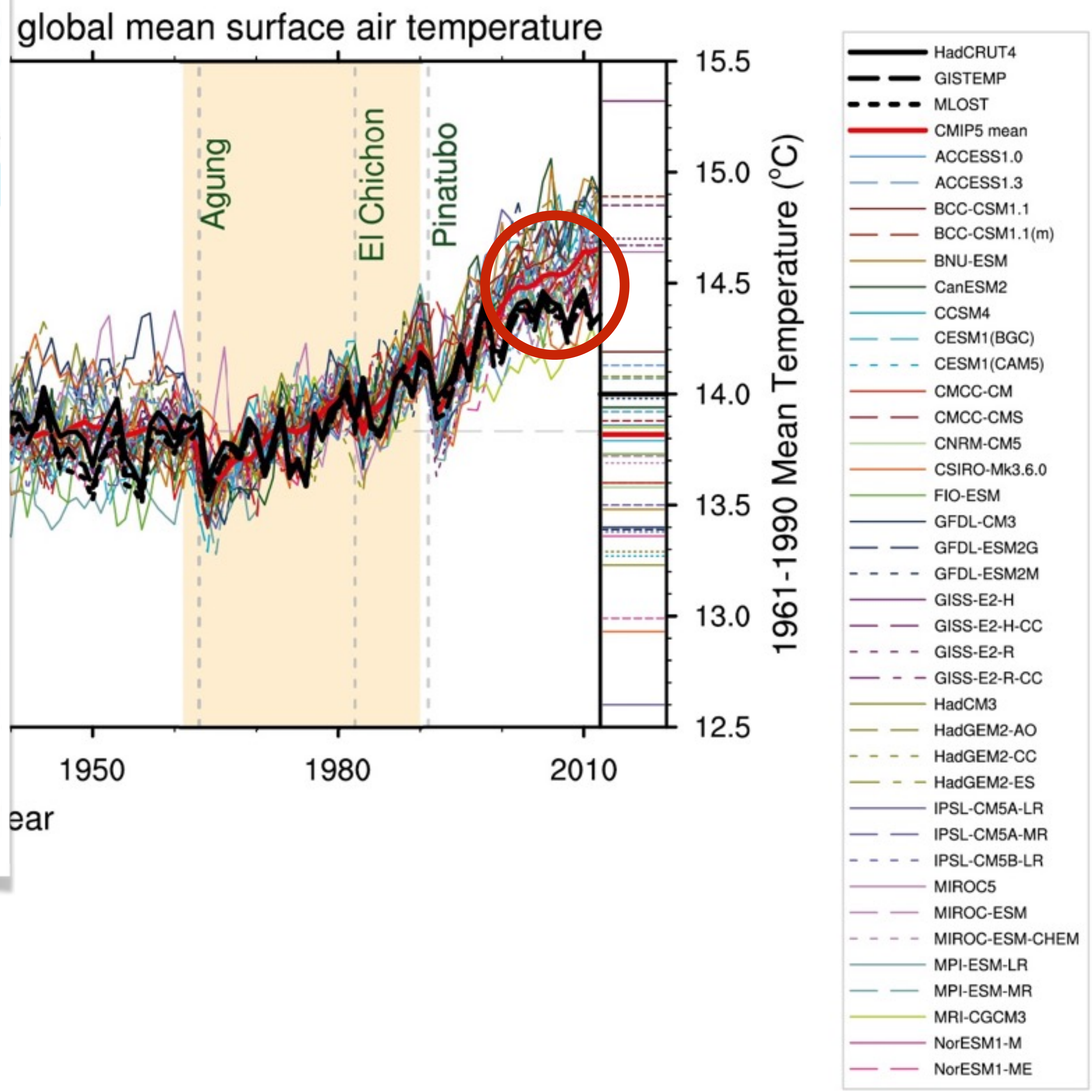
Scientists working on the most authoritative study on climate change were urged to cover up the fact that the world's temperature hasn't risen for the last 15 years, it is claimed.

A leaked copy of a United Nations report, compiled by hundreds of scientists, shows politicians in Belgium, Germany, Hungary and the United States raised concerns about the final draft.

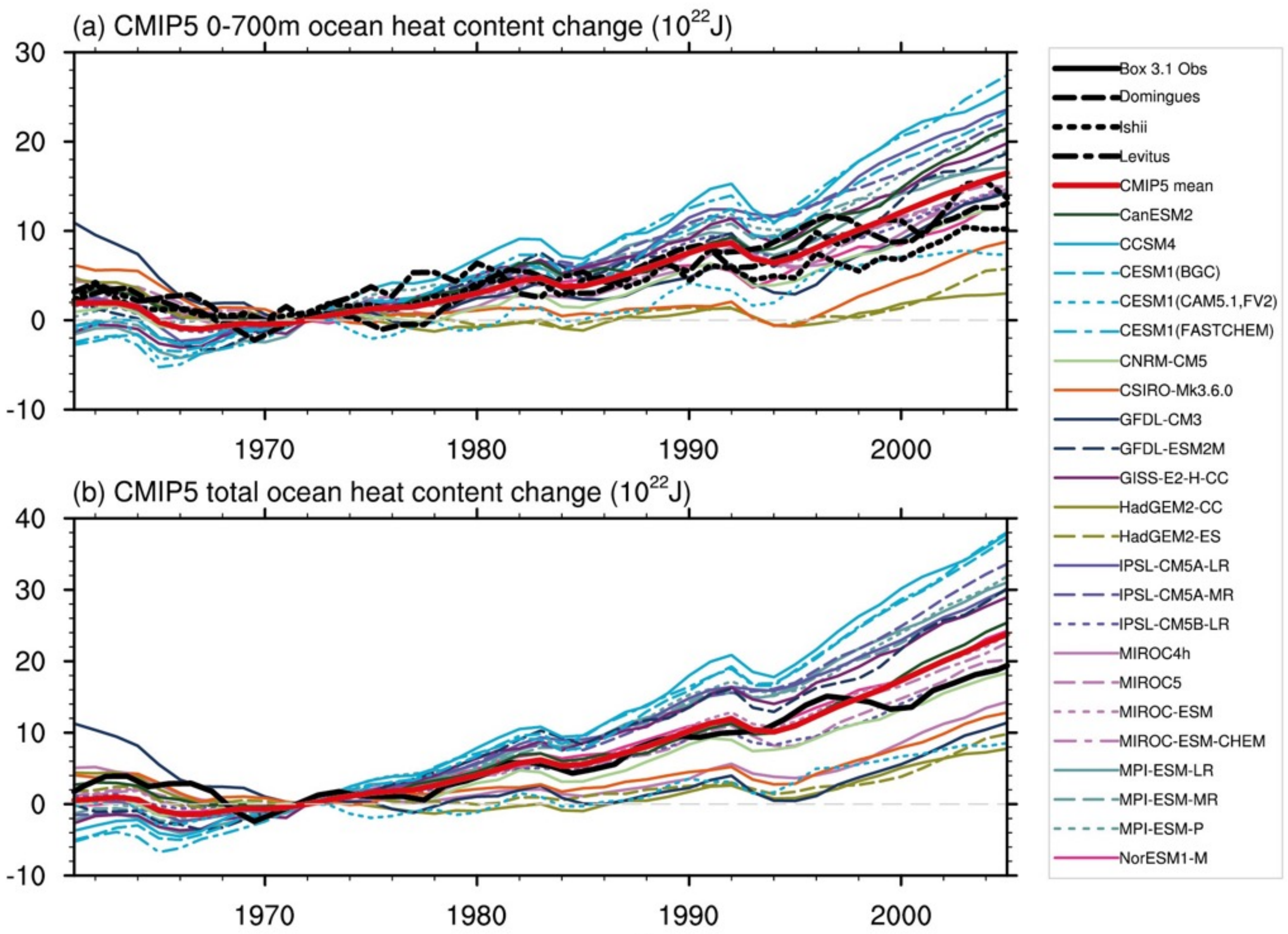
Published next week, it is expected to address the fact that 1998 was the hottest year on record and world temperatures have not yet exceeded it, which scientists have so far struggled to explain.



"warming hiatus"

IPCC AR5 WG1 report

Evaluation of climate models: Not all historical climate trends are well simulated



IPCC AR5 WG1 report

How large is the global climate response to radiative forcing (e.g. CO_2)? Feedback processes

top-of-atmosphere energy imbalance [W/m²/K]

surface temperature change

Climate change equation: $$\text{Forcing} = R_{\text{TOA}} - \lambda\delta T$$

climate feedback parameter [W/m²/K]

Key assumption for climate feedback analysis: Radiative response is linearly proportional to *δT*

How large is the global climate response to radiative forcing (e.g. CO_2)? Feedback processes

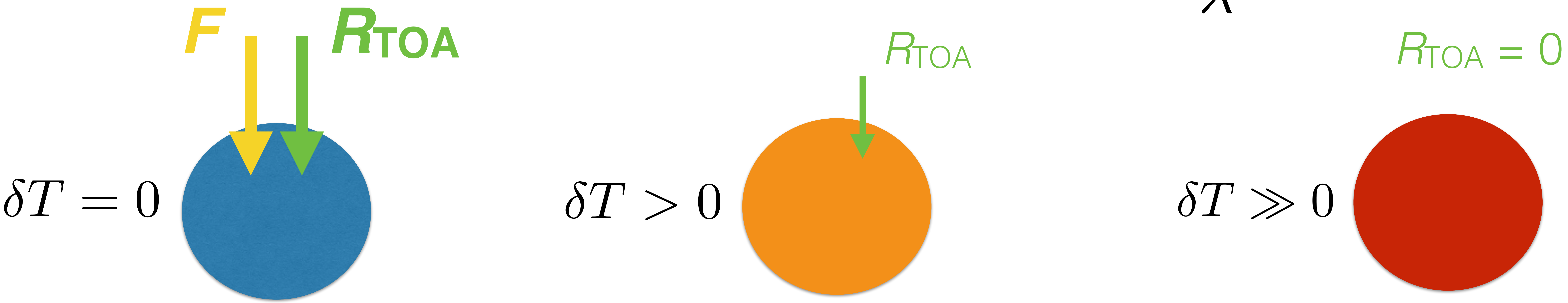
top-of-atmosphere energy imbalance [W/m²/K]

surface temperature change

Climate change equation:

$$\text{Forcing} = R_{\text{TOA}} - \lambda \delta T$$

$$\Rightarrow \delta T = \frac{R_{\text{TOA}} - \text{Forcing}}{\lambda}$$



"Gregory plot": Response of climate system to an abrupt radiative forcing is roughly linear

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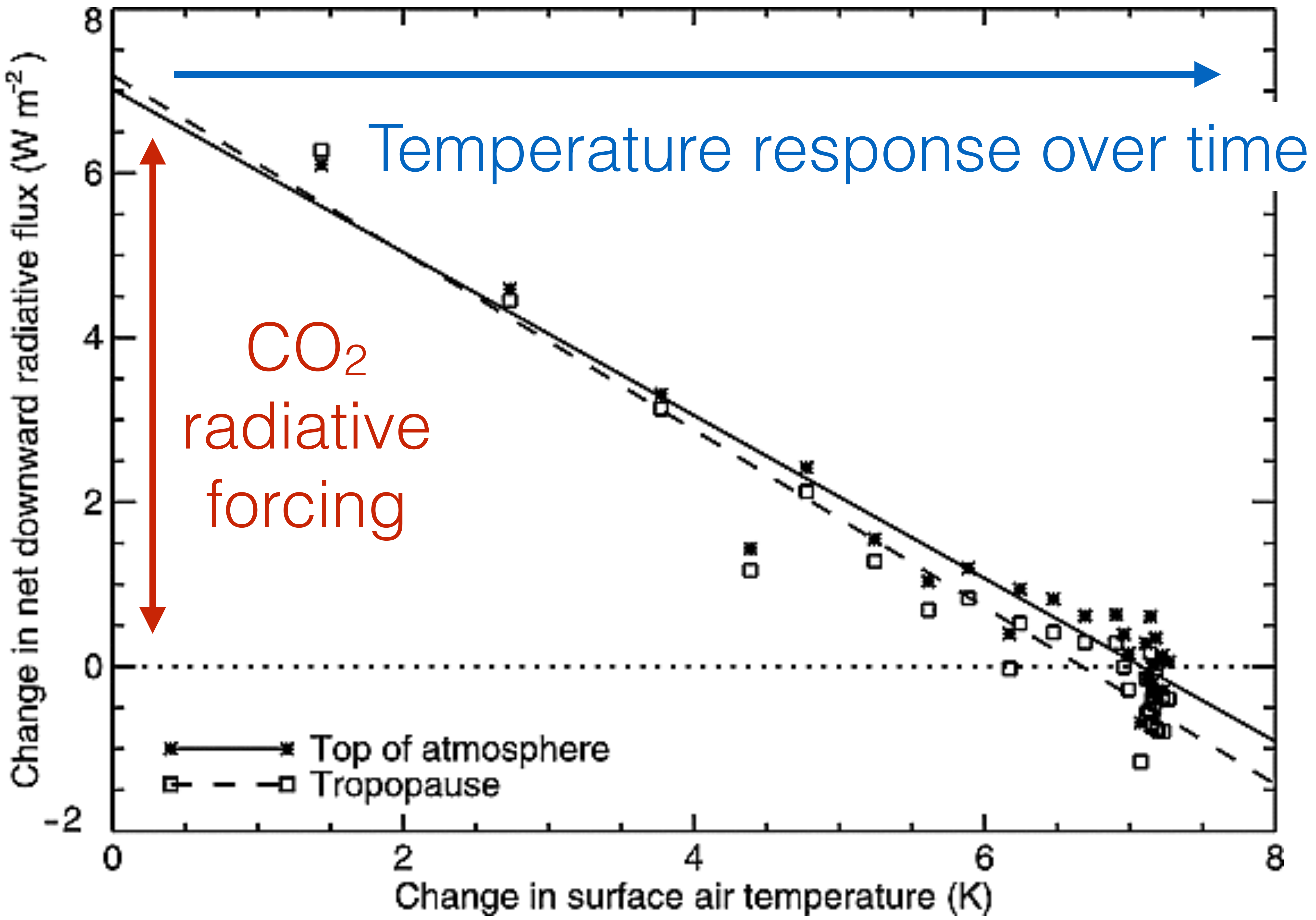

Gregory et al (2004)

"Gregory plot": Response of climate system to an abrupt radiative forcing is roughly linear

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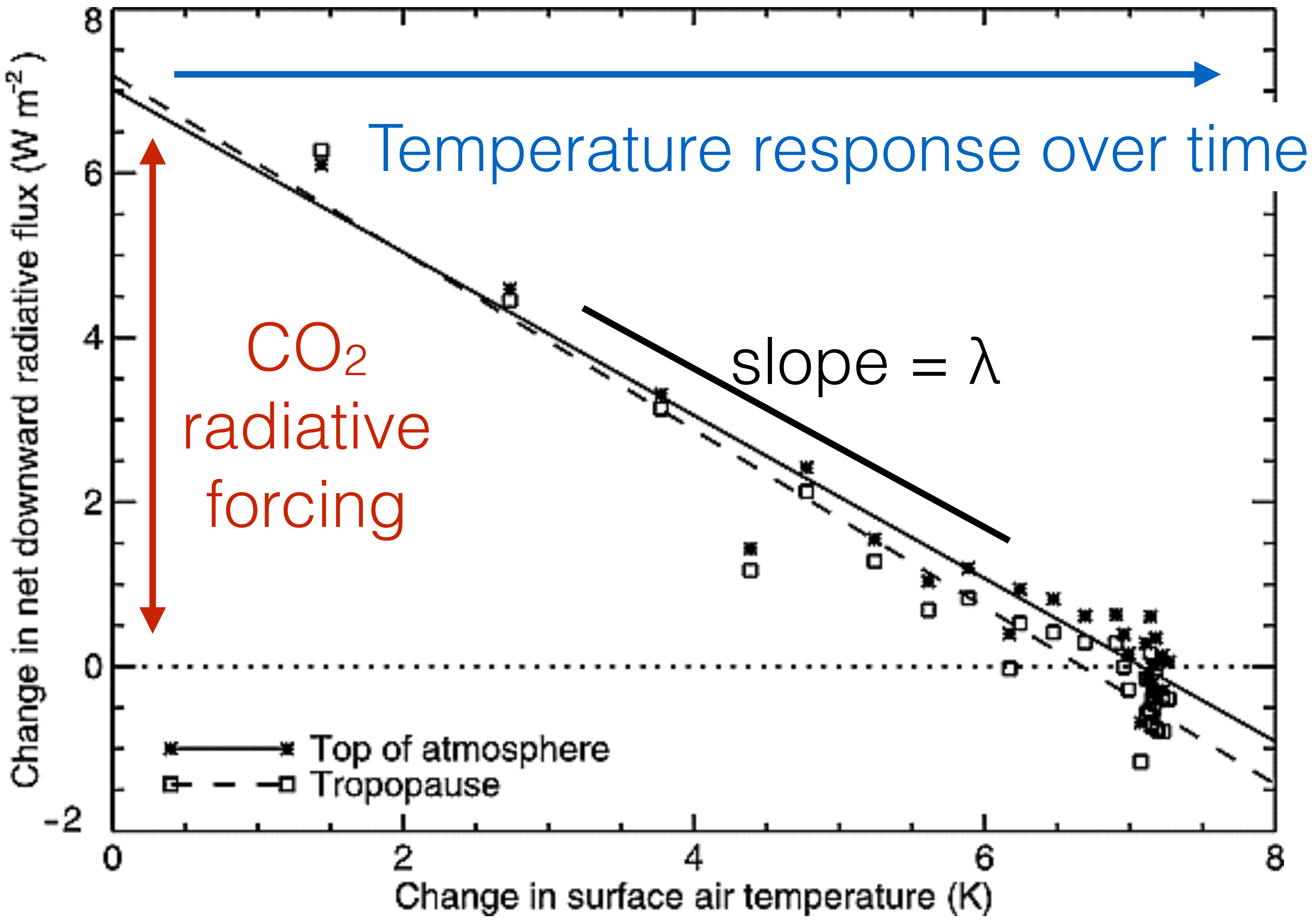

Feedback: Change in net TOA radiation per degree temperature change

Gregory et al (2004)

Climate feedback parameter determines the temperature response to radiative forcing, includes many positive and negative feedback processes

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \cdots = \sum_{i=1}^{n} \lambda_i$$

total feedback parameter ("the slope")

individual feedback processes

Positive or negative feedback processes in the climate system?

Climate feedback parameter determines the temperature response to radiative forcing, includes many positive and negative feedback processes

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \cdots = \sum_{i=1}^{n} \lambda_i$$

1. Negative (cooling) feedback: Planck feedback

$$\lambda_{\text{Planck}} = \frac{\partial(\sigma T^4)}{\partial T} = 4\sigma T^3$$
$$\approx 3\,\text{W}/\text{m}^2/\text{K}$$

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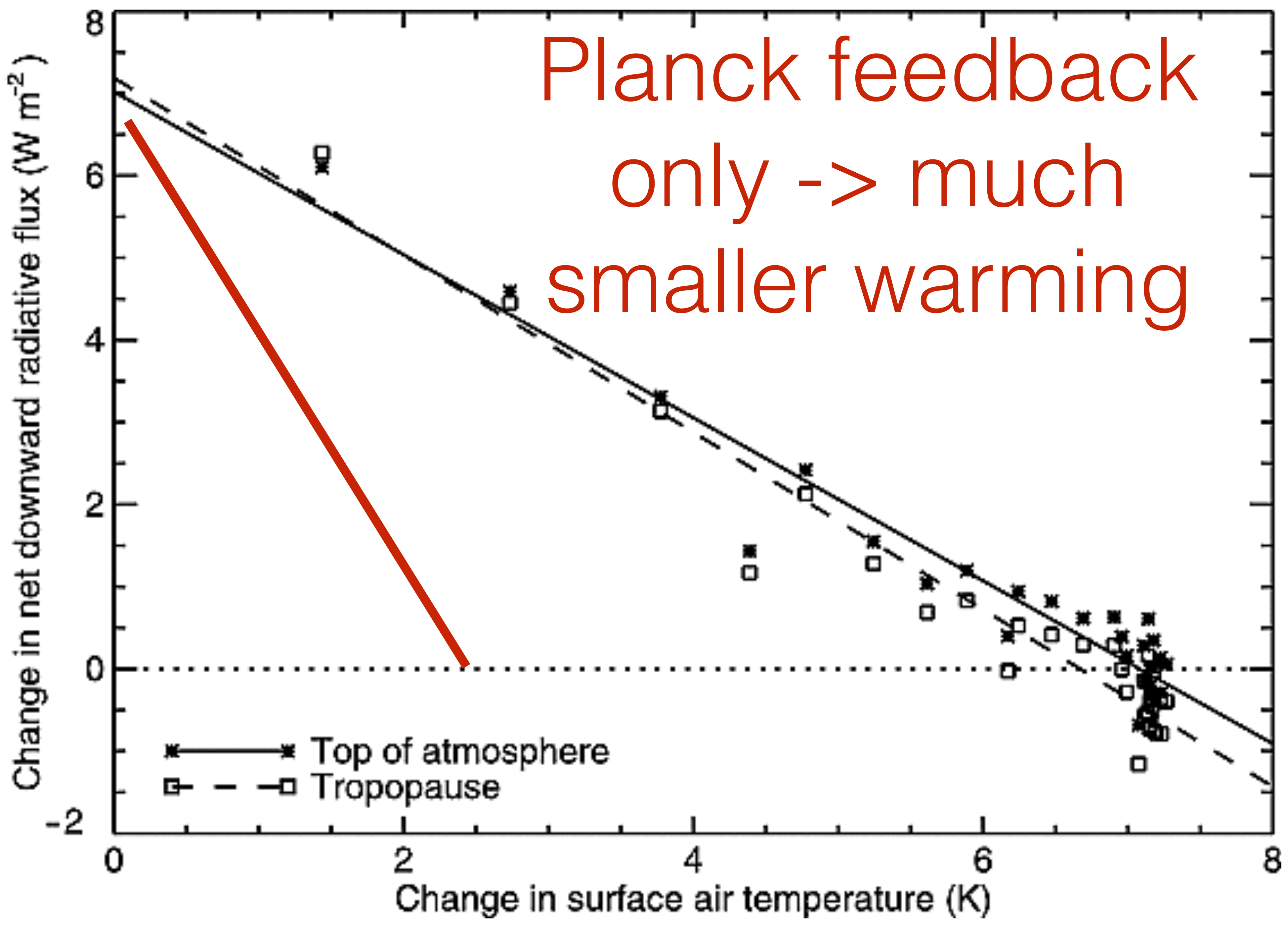
$$\approx 3\,\mathrm{W/m^2/K}$$

$$\delta T_{\text{eq.}} = F/\lambda \approx 2.5\,\mathrm{K}$$

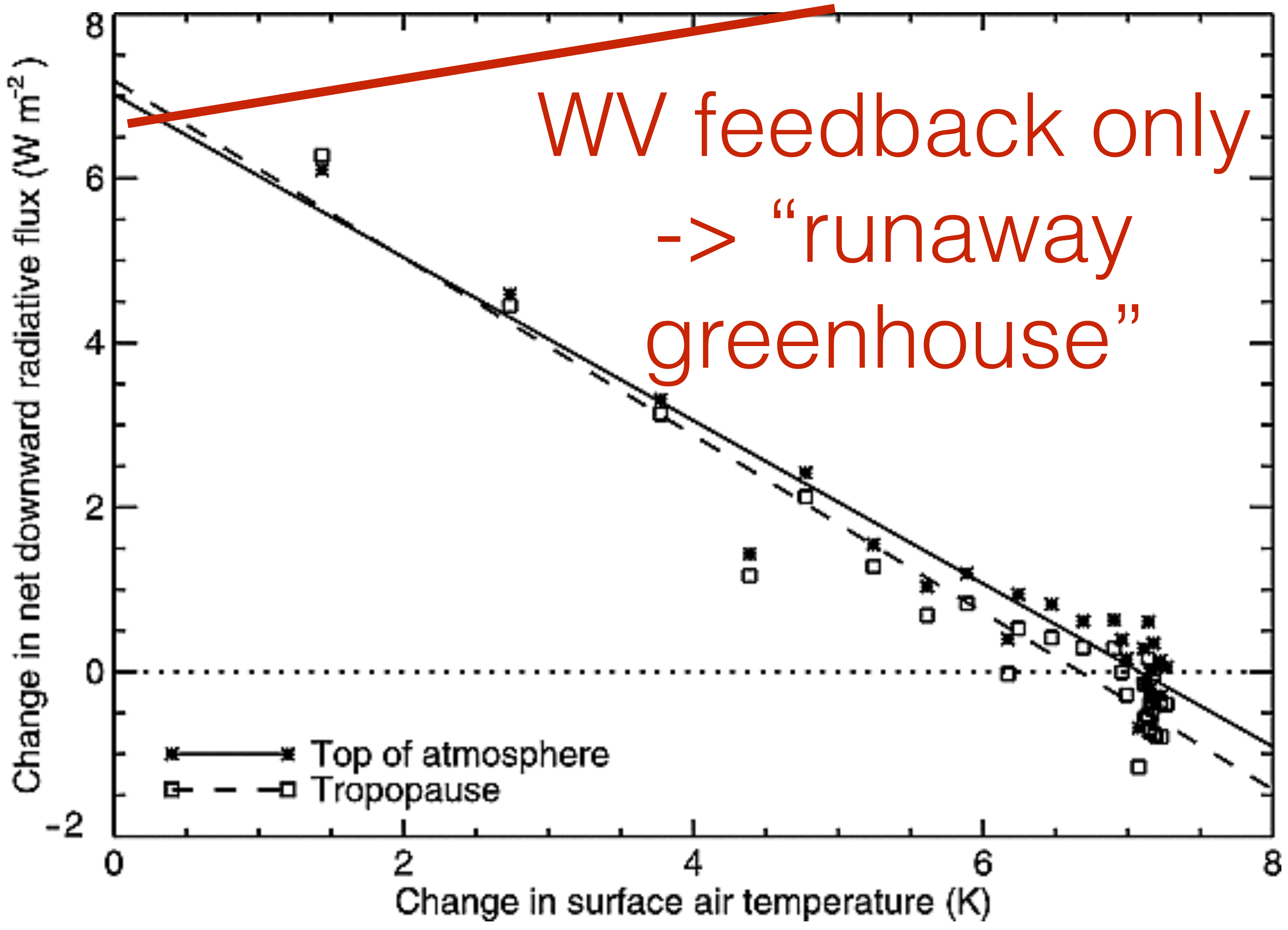


Climate feedback parameter determines the temperature response to radiative forcing, includes many positive and negative feedback processes

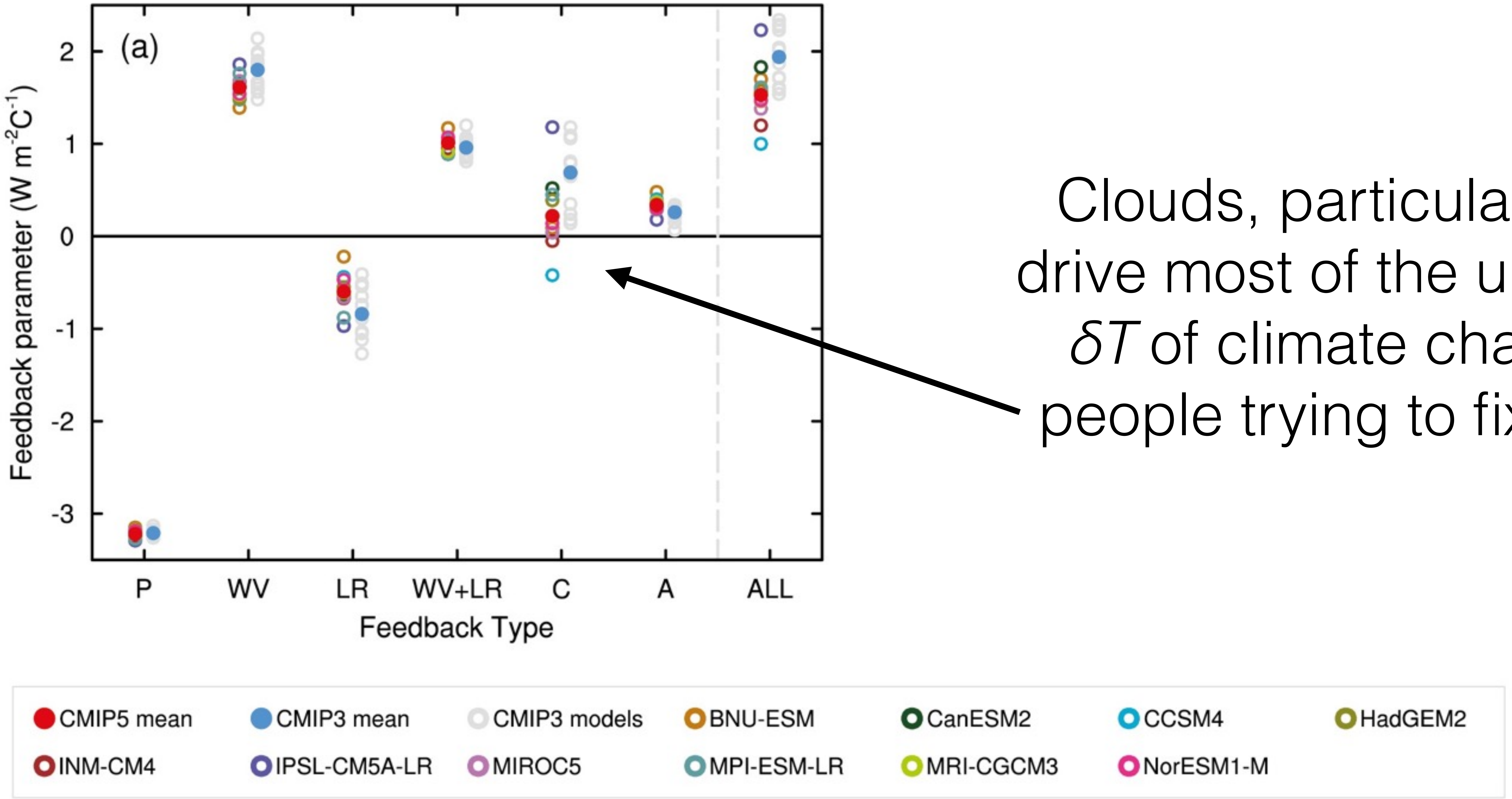
$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \cdots = \sum_{i=1}^{n} \lambda_i$$

1. Positive (warming) feedback: Water vapour feedback

$$\lambda_{\text{water vapour}} \approx -1.5\,\mathrm{W/m^2/K}$$



Climate system has a variety of physical feedback processes, some more certain than others

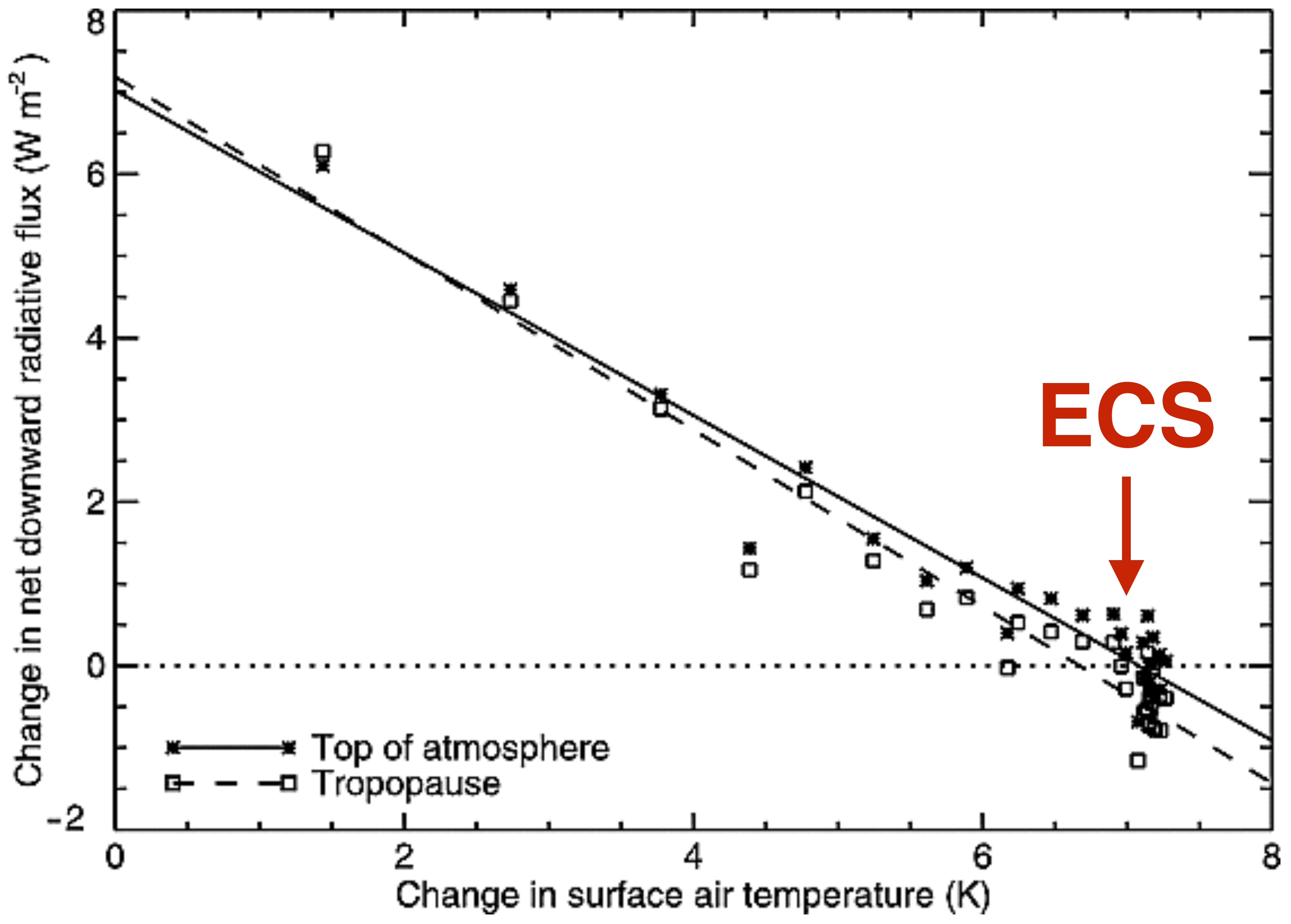


Clouds, particularly low clouds, drive most of the uncertainty in the δT of climate change… Lots of people trying to fix this (e.g. Ed!)

Courtesy of Brian Rose

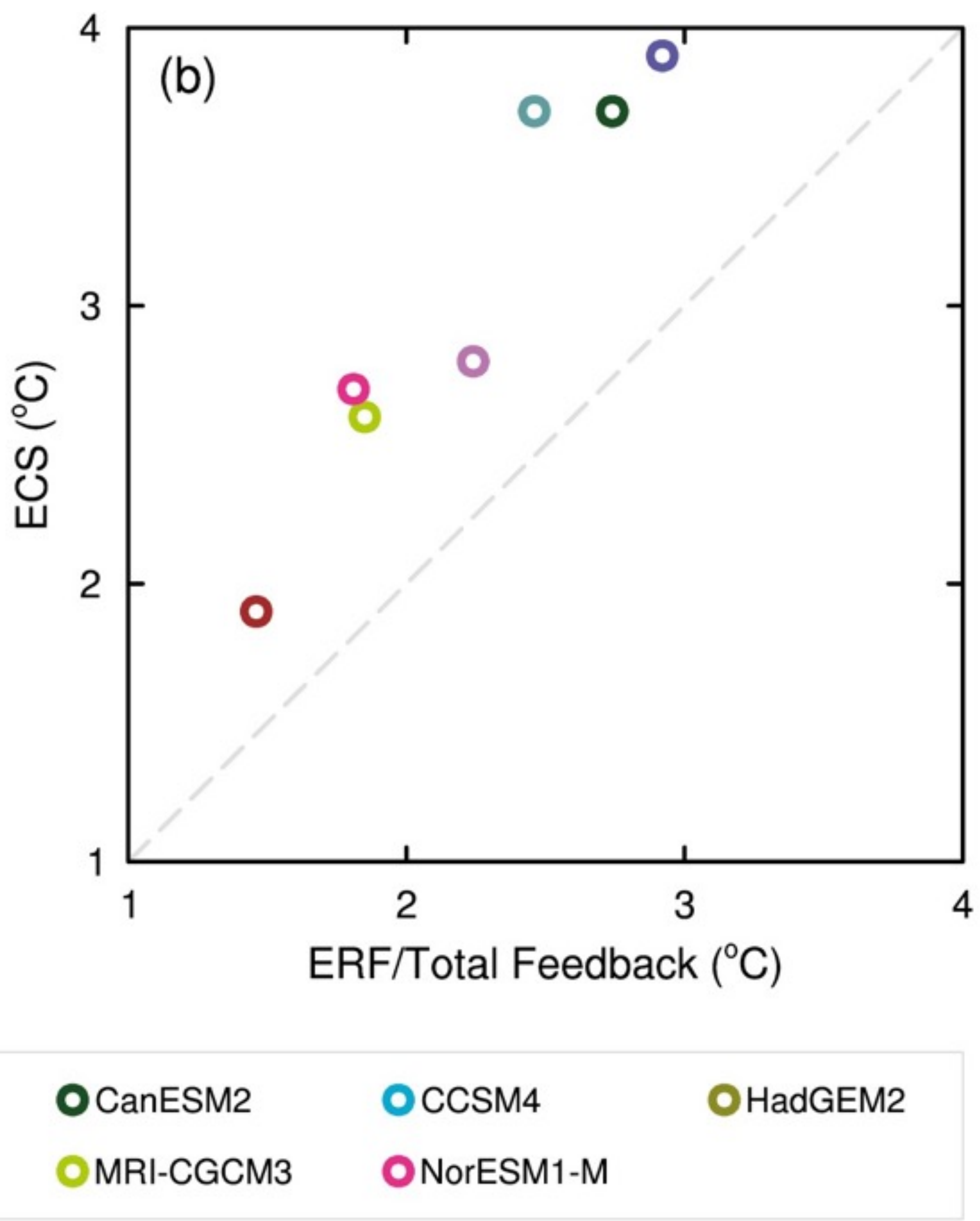
Quantifying climate climate: The "equilibrium climate sensitivity" (ECS)

ECS: Change in global-mean surface temperature *at equilibrium* following a doubling of CO_2



Uncertainty in ECS is large…

According to state-of-the-art climate models, ECS is “likely” in the range 1.5K to 4.5K (IPCC AR5)



Courtesy of Brian Rose

What have we actually learned about climate change over the last 40 years?!

When it is assumed that the CO_2 content of the atmosphere is doubled and statistical thermal equilibrium is achieved, the more realistic of the modeling efforts predict a global surface warming of between 2°C and 3.5°C, with greater increases at high latitudes. This range reflects both uncertainties in physical understanding and inaccuracies arising from the need to reduce the mathematical problem to one that can be handled by even the fastest available electronic computers. It is significant, however, that none of the model calculations predicts negligible warming.

"Carbon dioxide and climate: a scientific assessment" (J. Charney et al, 1979)

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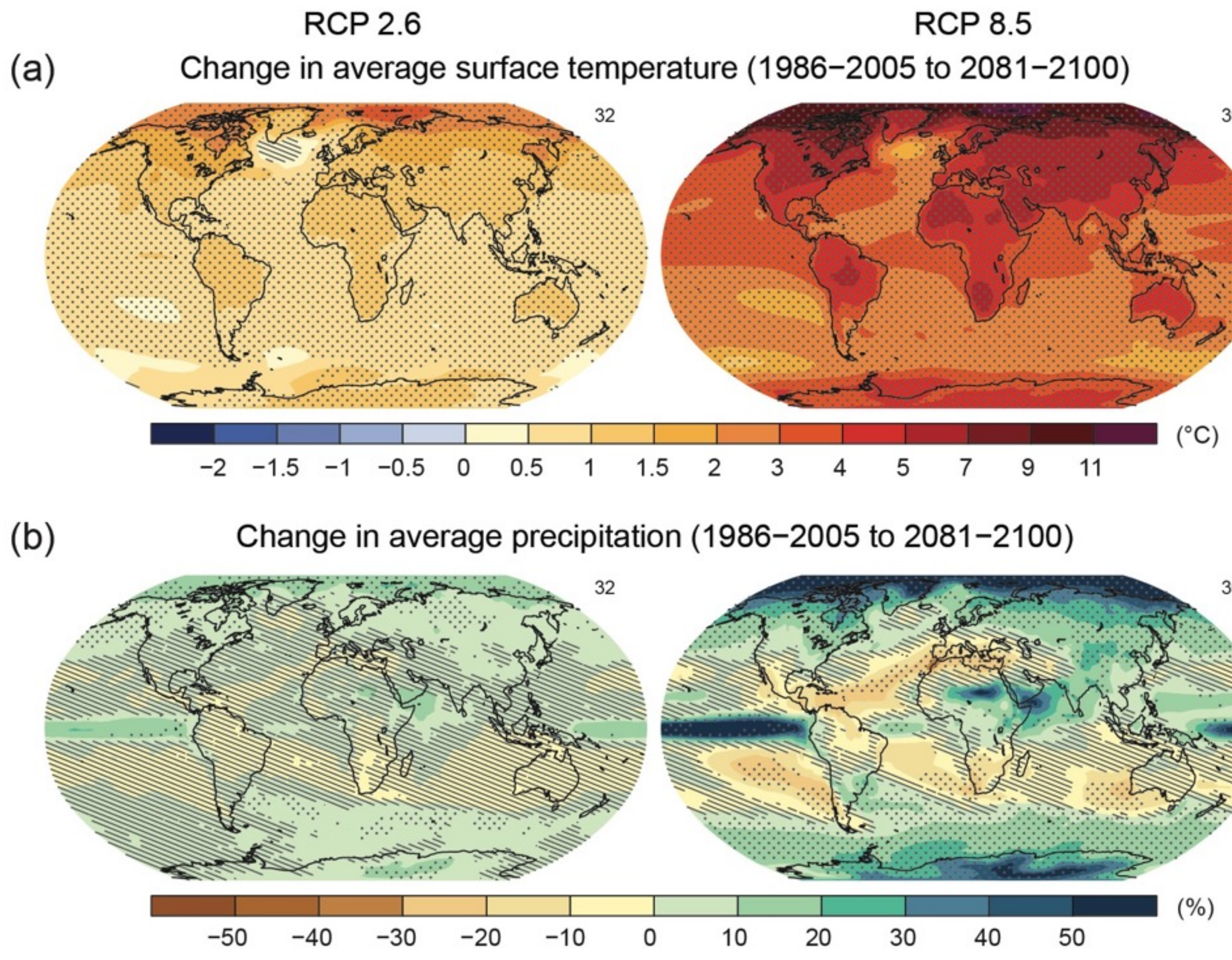
IPCC AR5: 1.5K to 4.5K

"Carbon dioxide and climate: a scientific assessment" (J. Charney et al, 1979)

Patterns of climate change: Surface temperature and precipitation

δT **δP**

Different emissions scenarios:
RCP 2.6 vs 8.5 depends on technology, policy, economics, human behavior…

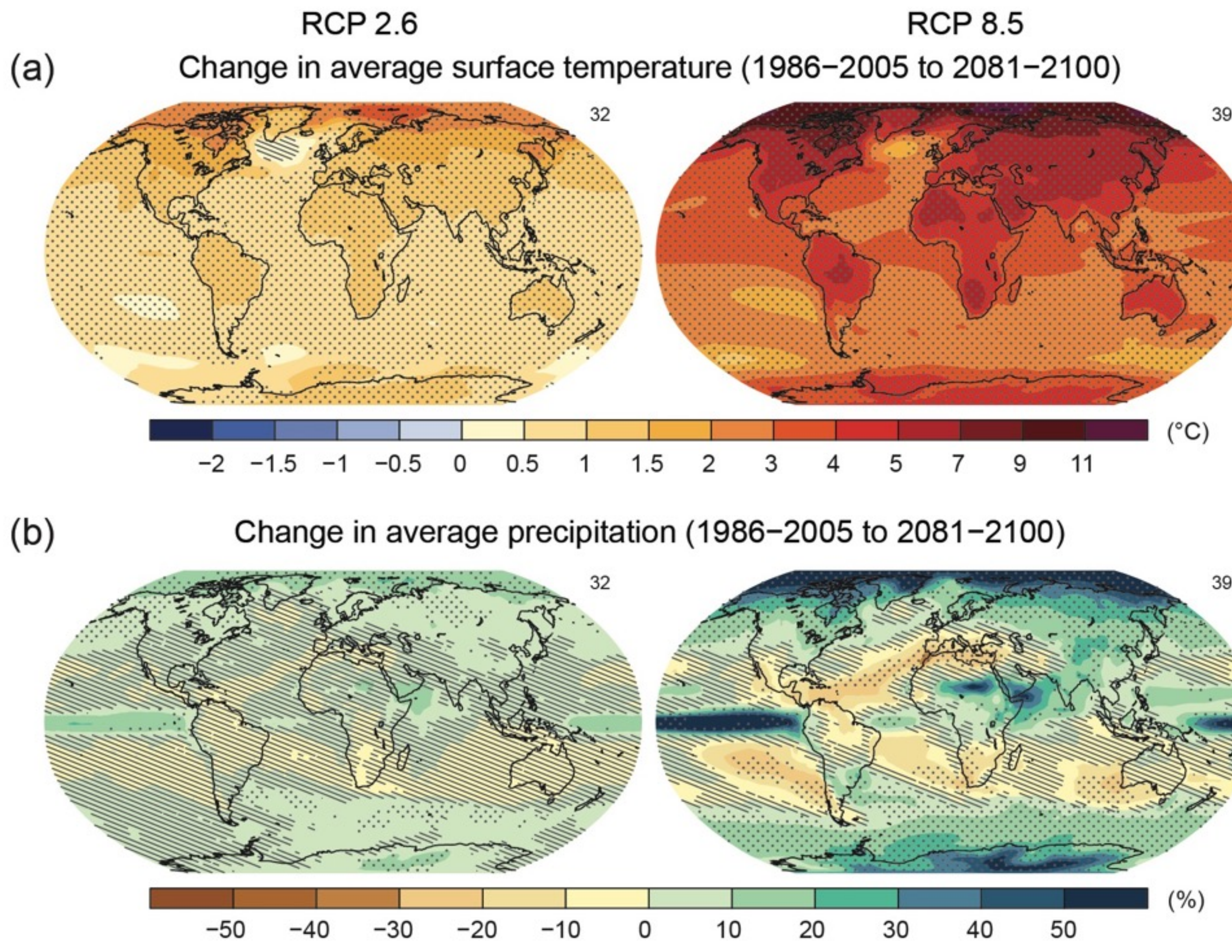


IPCC AR5

Patterns of climate change: Surface temperature and precipitation

δT **δP**

Dominant large-scale spatial patterns??



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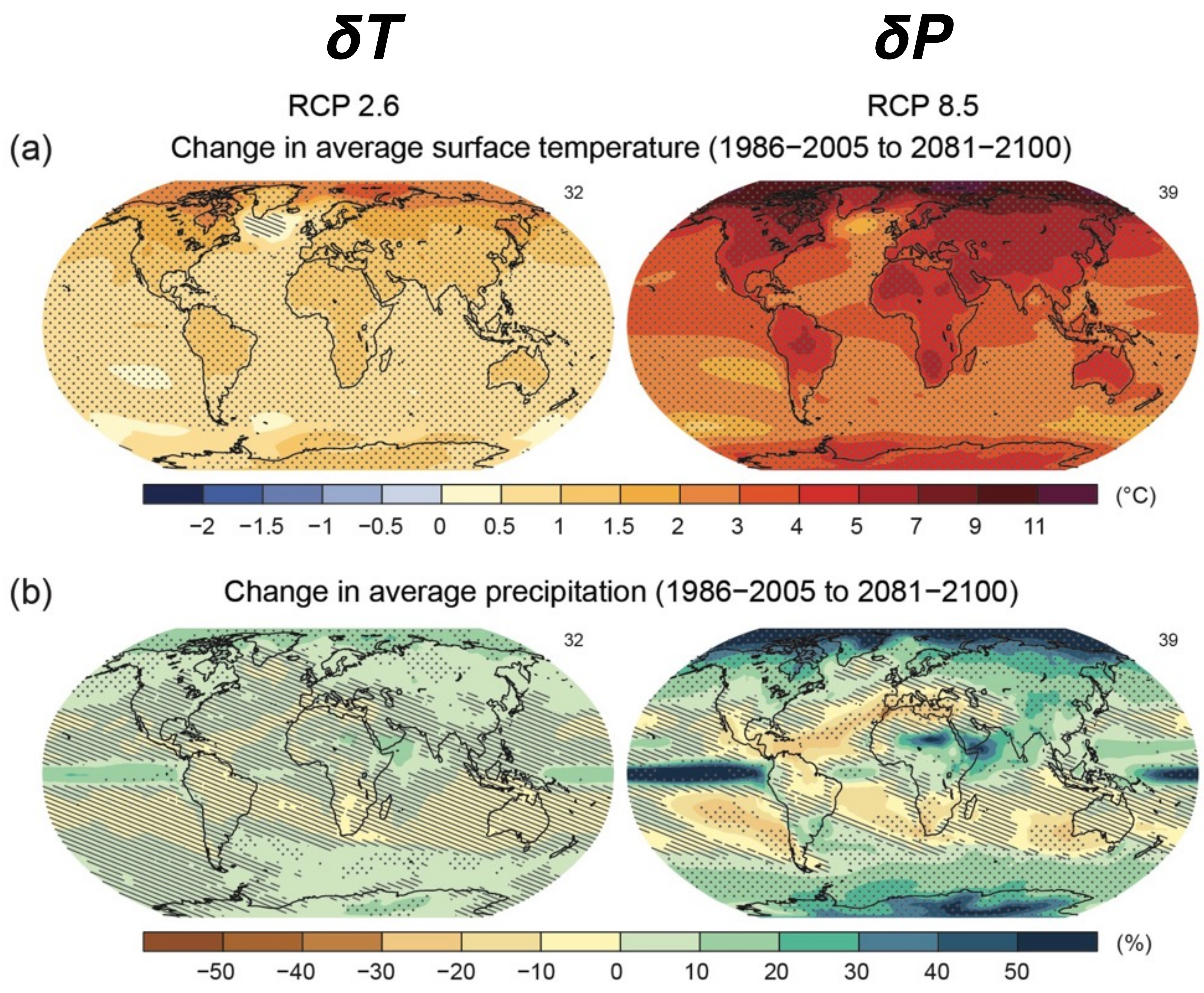
Patterns of climate change: Surface temperature and precipitation

Dominant large-scale spatial patterns??

1. Land-ocean warming contrast



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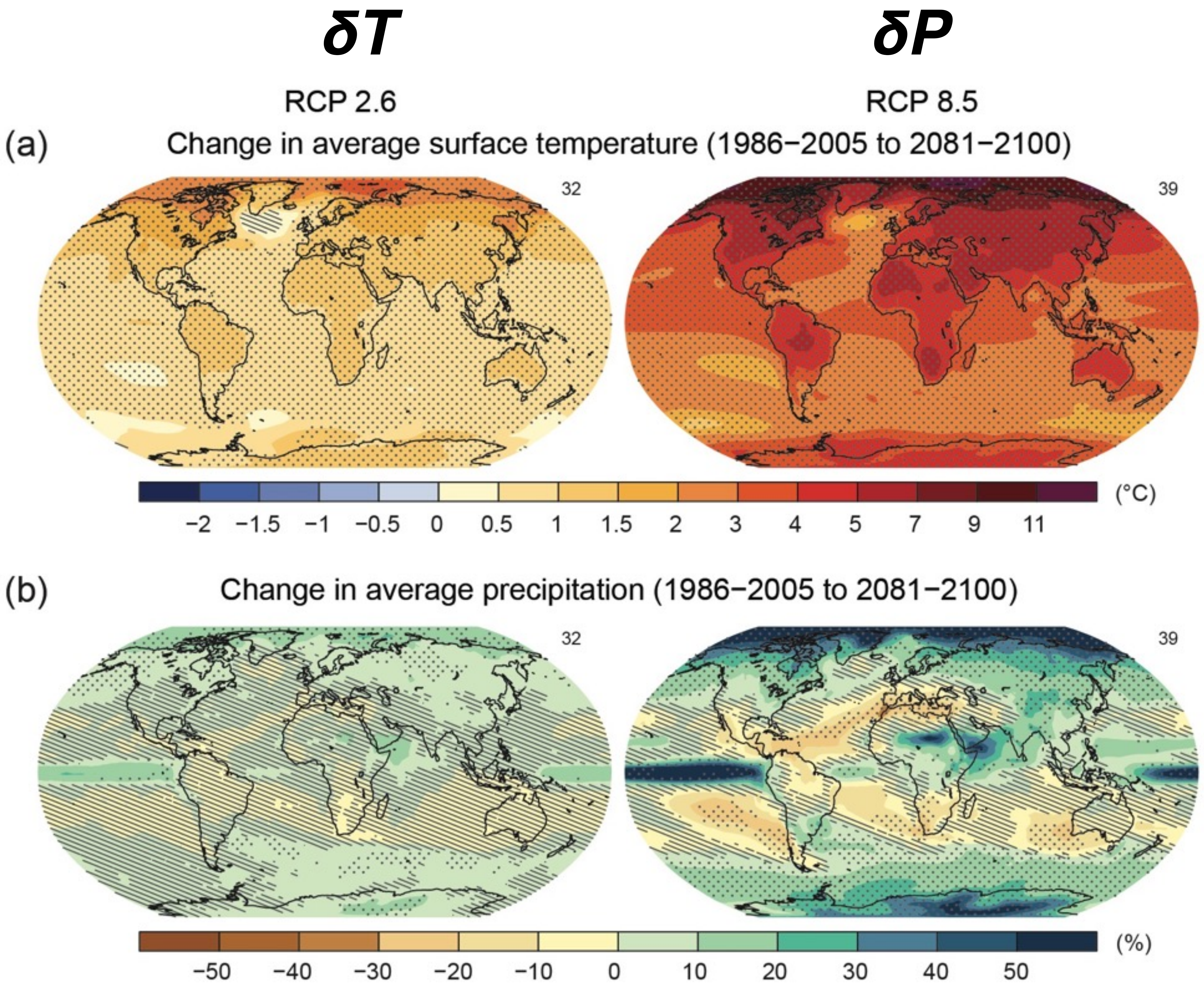
Patterns of climate change: Surface temperature and precipitation

Dominant large-scale spatial patterns??

1. Land-ocean warming contrast
2. Polar-amplified warming



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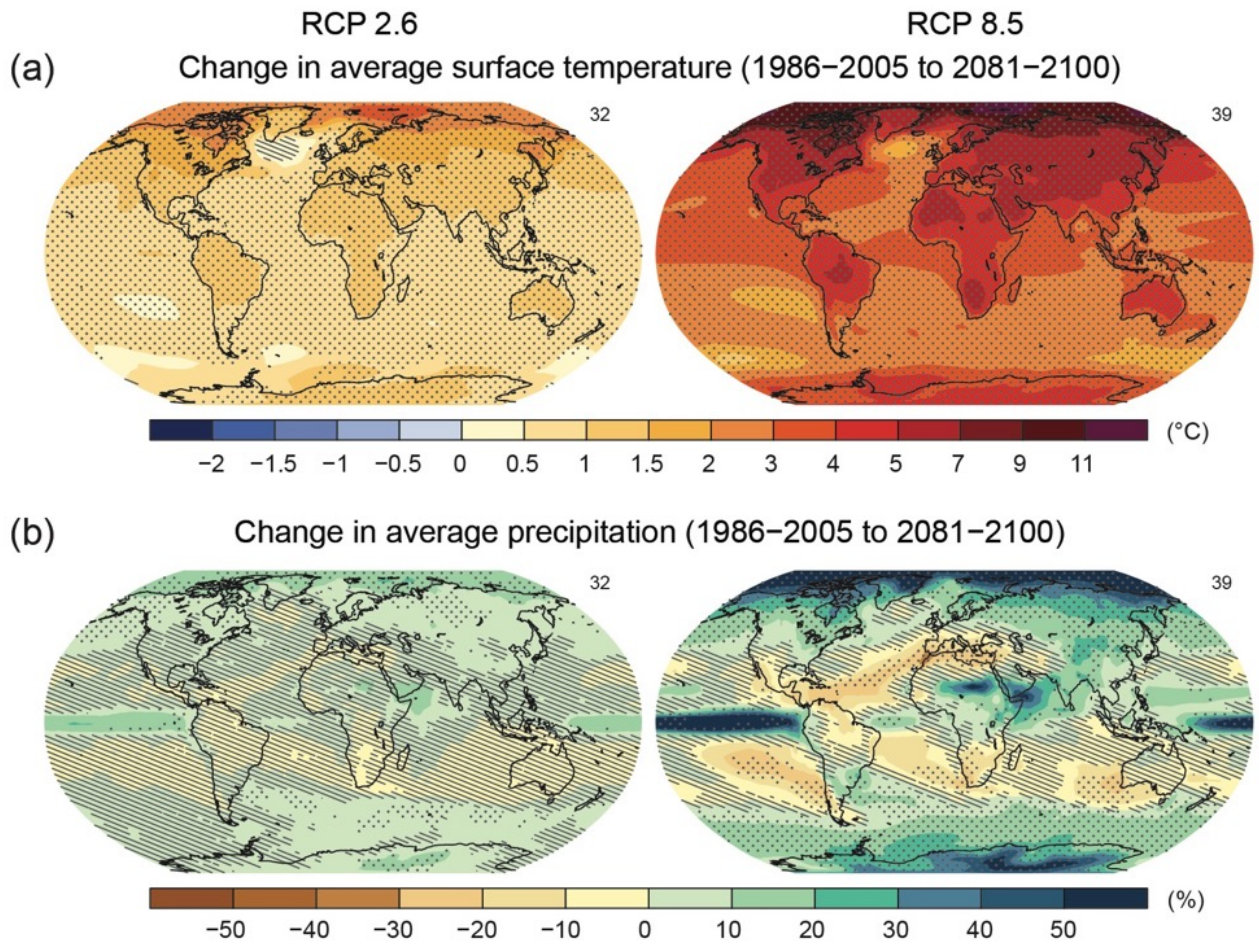
Patterns of climate change: Surface temperature and precipitation

δT ***δP***

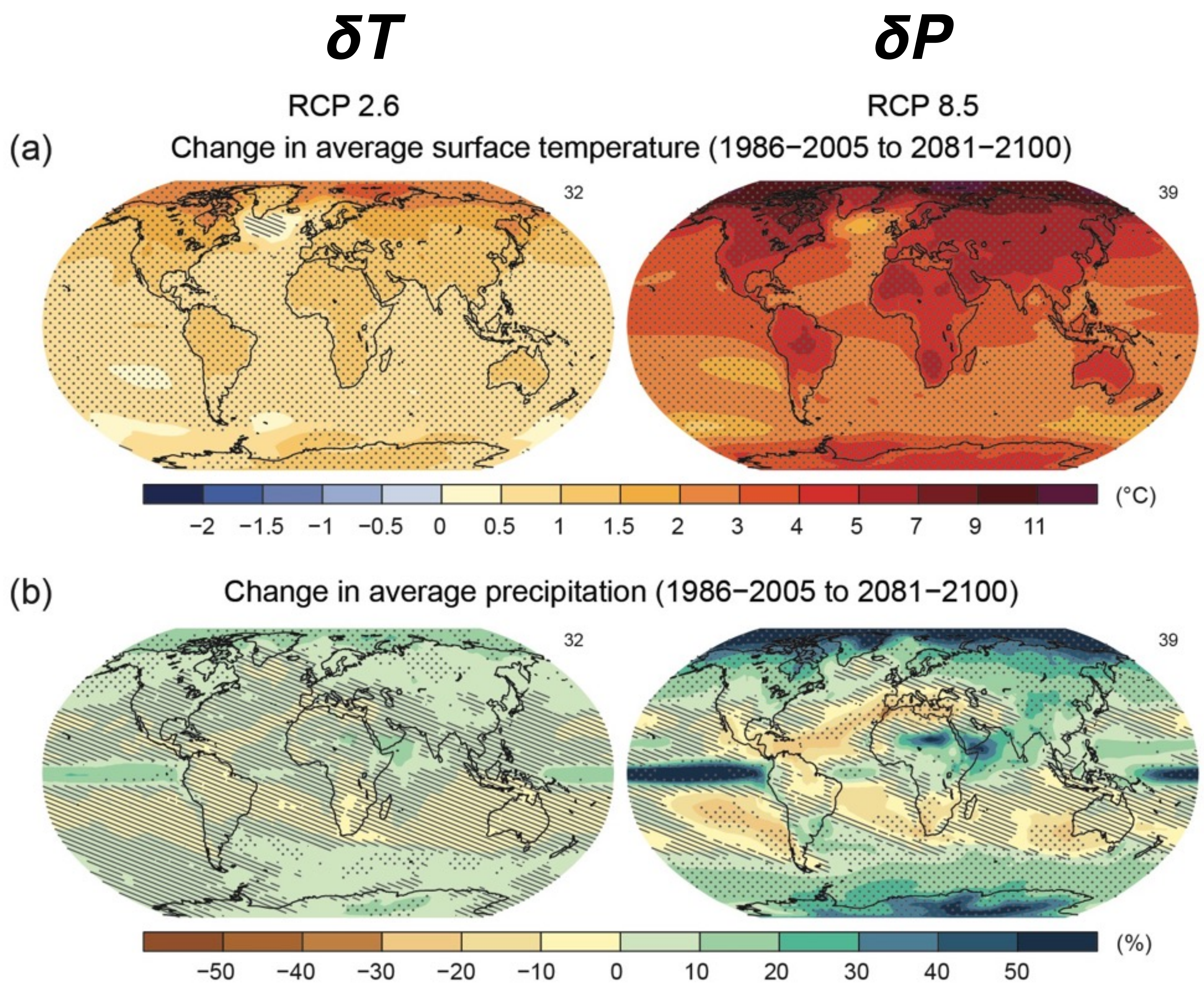


Dominant large-scale spatial patterns??

1. Land-ocean warming contrast
2. Polar-amplified warming
3. “Wet get wetter, dry get drier”

IPCC AR5

Patterns of climate change: Surface temperature and precipitation

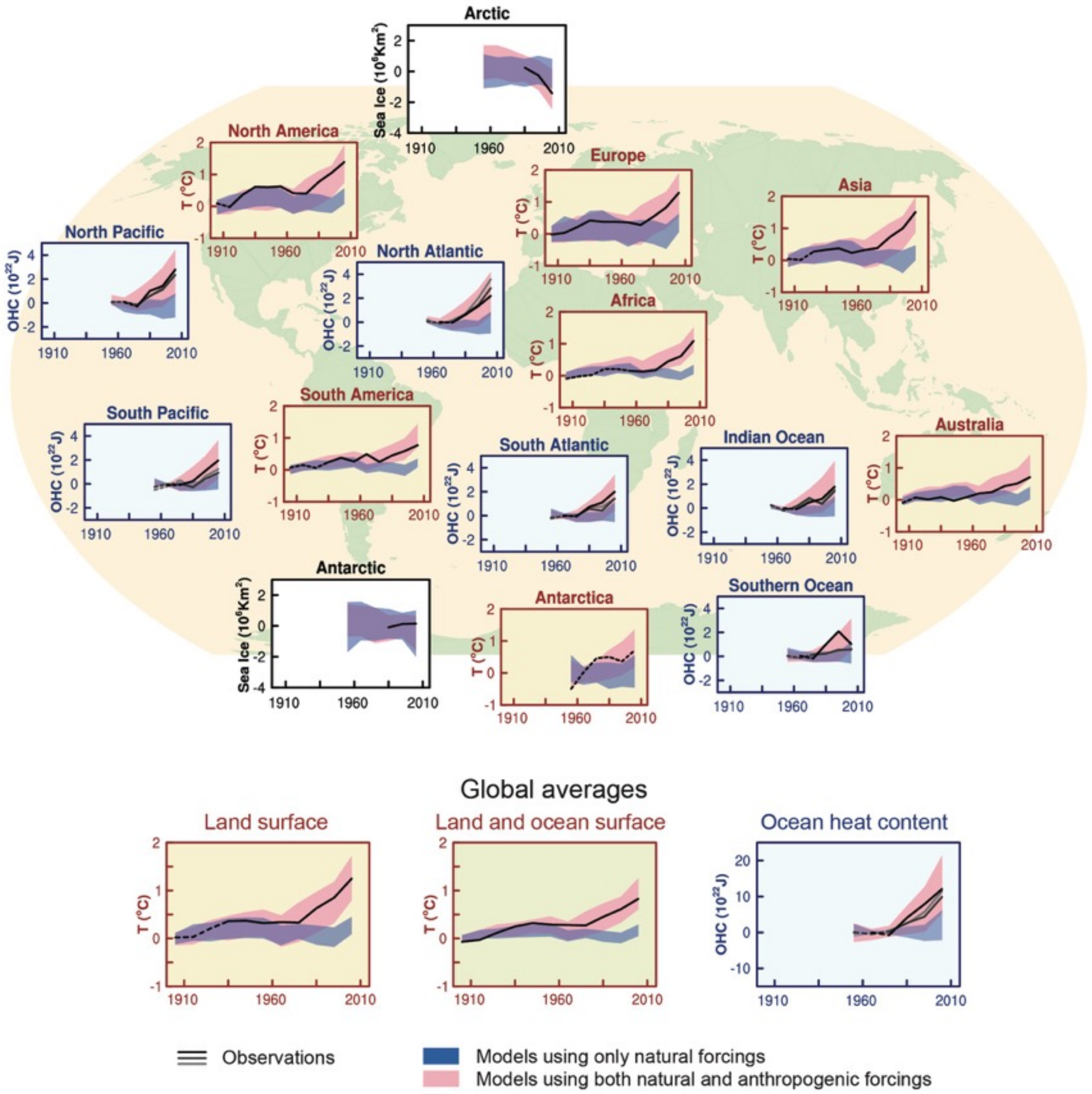


Dominant large-scale spatial patterns??

1. Land-ocean warming contrast
2. Polar-amplified warming
3. "Wet get wetter, dry get drier"
4. Lots of regional aspects of climate change still to be figured out…

IPCC AR5

How do we know that humans are responsible?
“Detection & attribution”



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