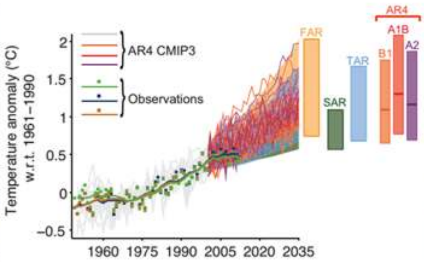
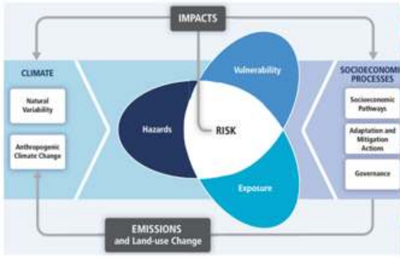
# Energy Systems & Climate Change

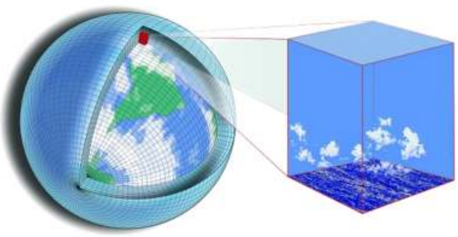




## Topic 4: Climate – Science and Policy

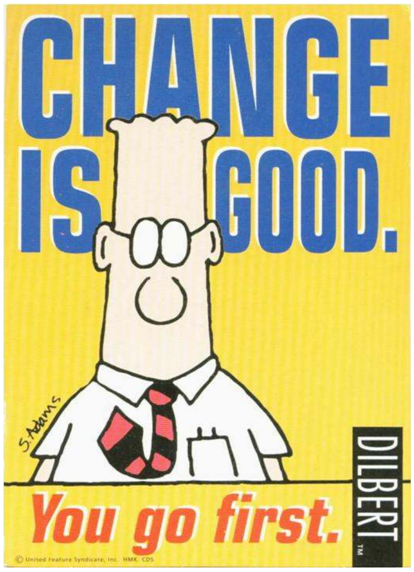

Material covered in this Topic:

- 4a. What is climate?
- 4b. Modelling earth's climate



- 4c. The global response: UNFCCC, IPCC, and the Paris Agreement

## Observed changes in climate: some conclusions




1. The earth's climate is changing    (but it always has, and it probably always will).

2. Globally averaged, it's probably getting warmer – but the definition of average global temperature is ambiguous, and its usefulness is questionable.

3. The relationship between average global temperature and atmospheric concentration of $CO_2$ is complicated: $CO_2$ is not a simple "control knob" for climate.

4. Regional climate changes will be significantly larger, and more relevant, than the globally-averaged change.



## Modelling earth's climate

# What models do (how models work)

## Modelling earth's climate

The underlying assumption for all models is that the pre-industrial climate was in equilibrium.

ALL changes from that initial state are then attributed to specific phenomena – either natural or anthropogenic.

"Better" models incorporate:

- More phenomena
- More detailed physics of existing phenomena
- More spatial resolution



## Modelling earth's climate

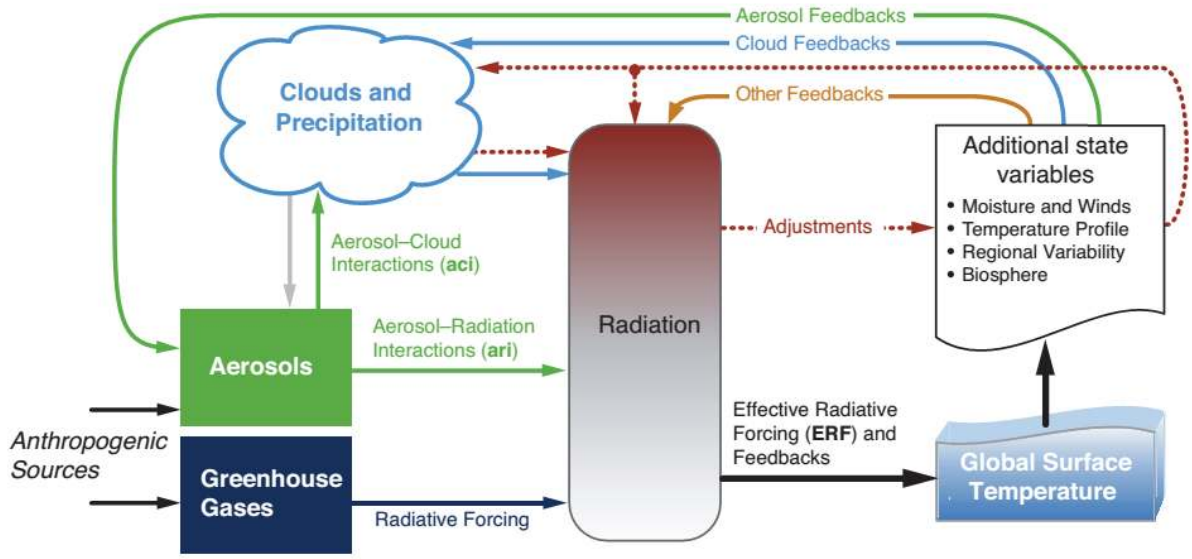
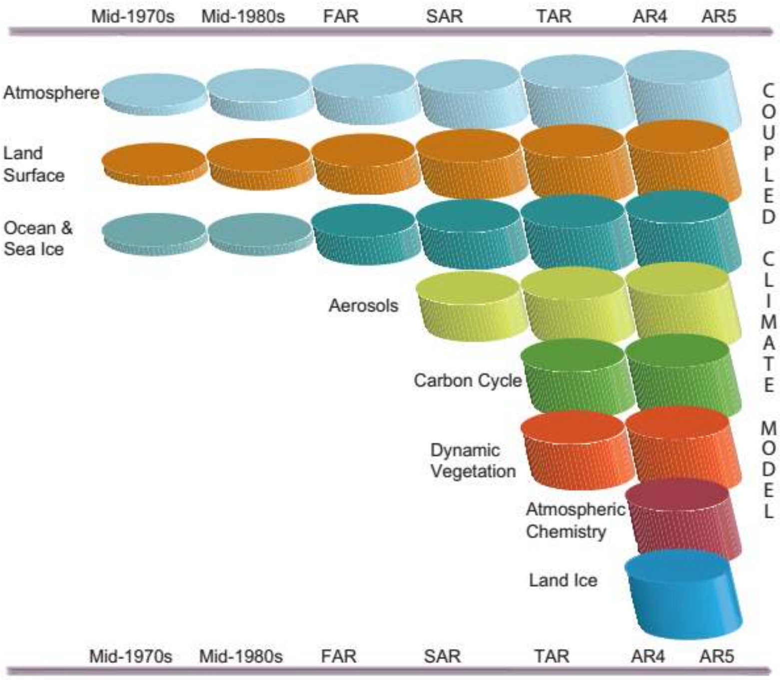



**Figure 7.1 |** Overview of forcing and feedback pathways involving greenhouse gases, aerosols and clouds. Forcing agents are in the green and dark blue boxes, with forcing mechanisms indicated by the straight green and dark blue arrows. The forcing is modified by rapid adjustments whose pathways are independent of changes in the globally averaged surface temperature and are denoted by brown dashed arrows. Feedback loops, which are ultimately rooted in changes ensuing from changes in the surface temperature, are represented by curving arrows (blue denotes cloud feedbacks; green denotes aerosol feedbacks; and orange denotes other feedback loops such as those involving the lapse rate, water vapour and surface albedo). The final temperature response depends on the effective radiative forcing (ERF) that is felt by the system, that is, after accounting for rapid adjustments, and the feedbacks.

*Source: Fig 7.1, AR5 WG1 The Physical Science Basis. IPCC (2014)*

## Modelling earth's climate



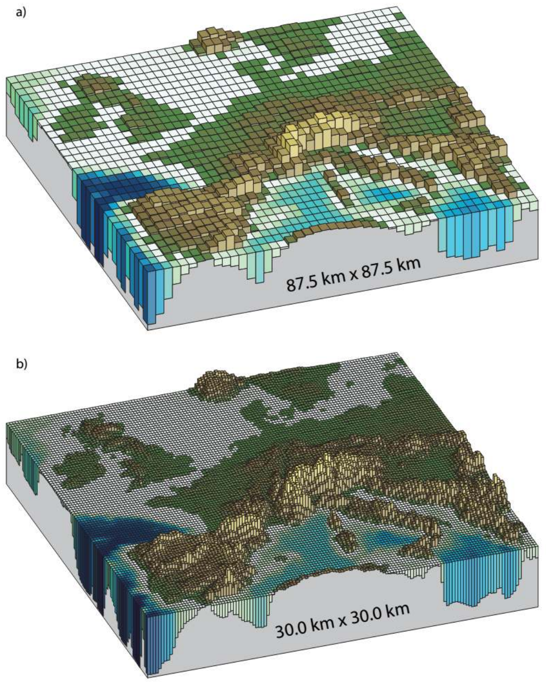
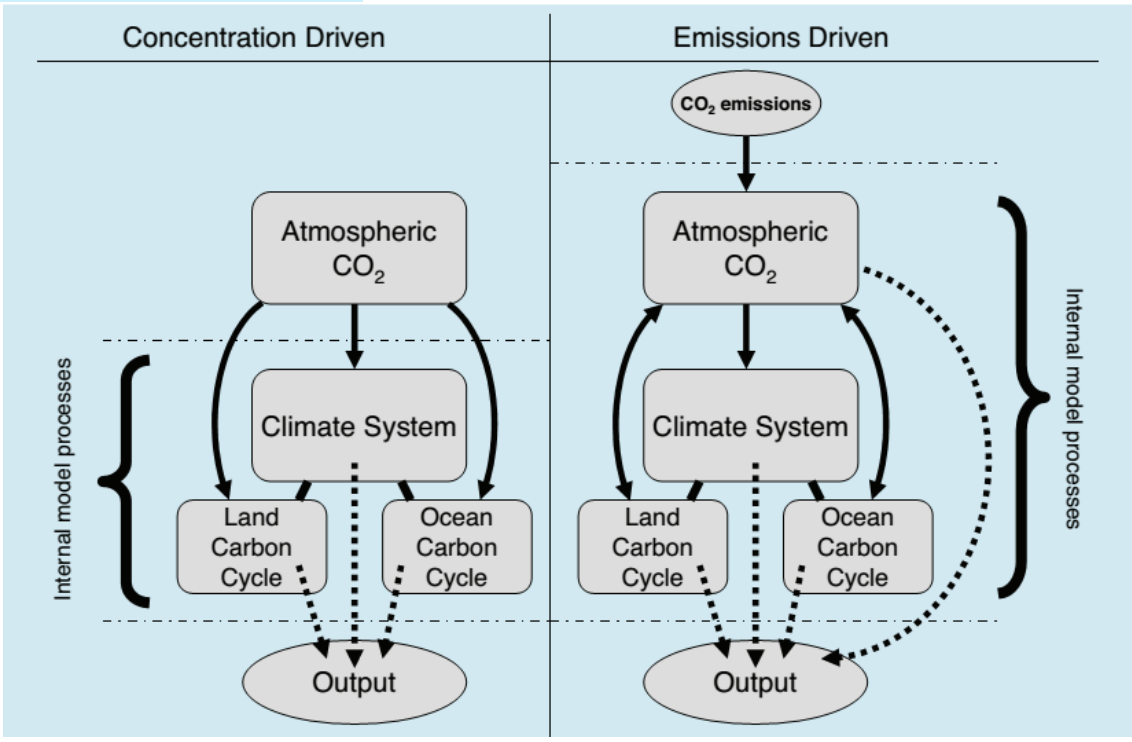




**Figure 1.14** | Horizontal resolutions considered in today's higher resolution models and in the very high resolution models now being tested: (a) Illustration of the European topography at a resolution of 87.5 × 87.5 km; (b) same as (a) but for a resolution of 30.0 × 30.0 km.

*Source: Figures 1.13 and 1.14, AR5 WG1 The Physical Science Basis. IPCC (2014)*




## Modelling earth's climate


*Source: Box 6.4 Fig. 1, AR5 WG1 The Physical Science Basis, p517. IPCC (2014)*

## Modelling earth's climate

RCP: Representative Concentration Pathway

Temporal evolution of:

- atmospheric concentration of all GHG, aerosols, and chemically-active gases
- land use / land cover

Each RCP leads to a specific increase in Radiative Forcing (RF) by 2100, relative to 1750

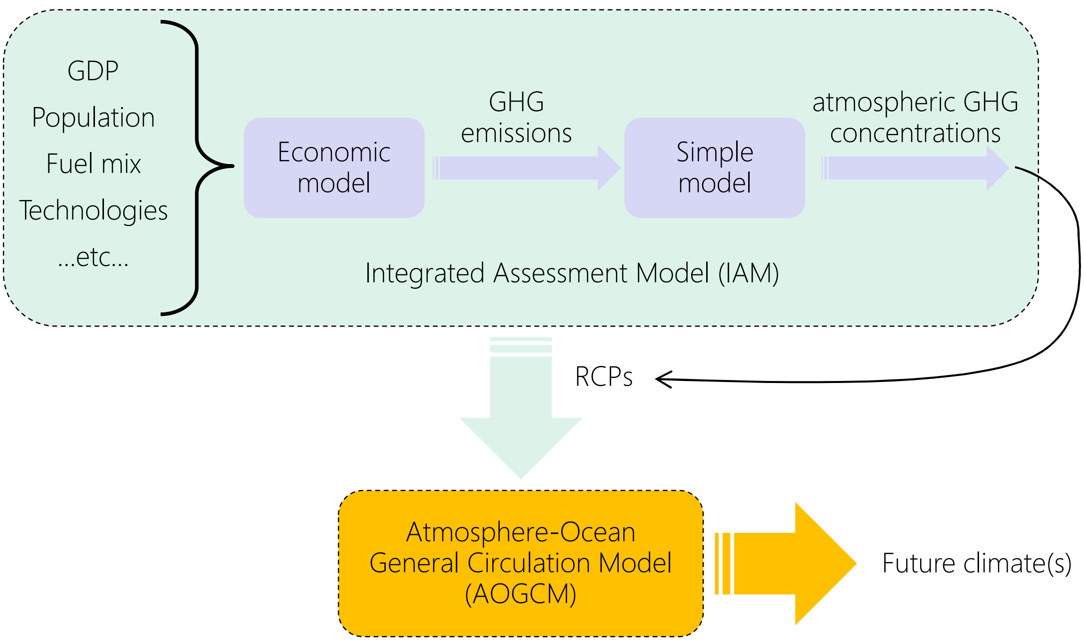
4 RCPs considered in AR5

| Model | RF in 2100 | Estimated $CO_2$ concentration in 2100 | Scenario Context | Assumed Fossil Fuel GtC/y in 2100 | Approx GtC/y in 2100 versus now |
|---|---|---|---|---|---|
| RCP2.6 | 2.6W/m$^2$ | 421ppm | Stringent mitigation | 0Gt/y | -100% |
| RCP4.5 | 4.5W/m$^2$ | 538ppm | Intermediate – low | 5GtC/y | -50% |
| RCP6.0 | 6.0W/m$^2$ | 670ppm | Intermediate – high | 12.5GtC/y | +25% |
| RCP8.5 | 8.5W/m$^2$ | 936ppm | Very high emissions | 25GtC/y | +250% |

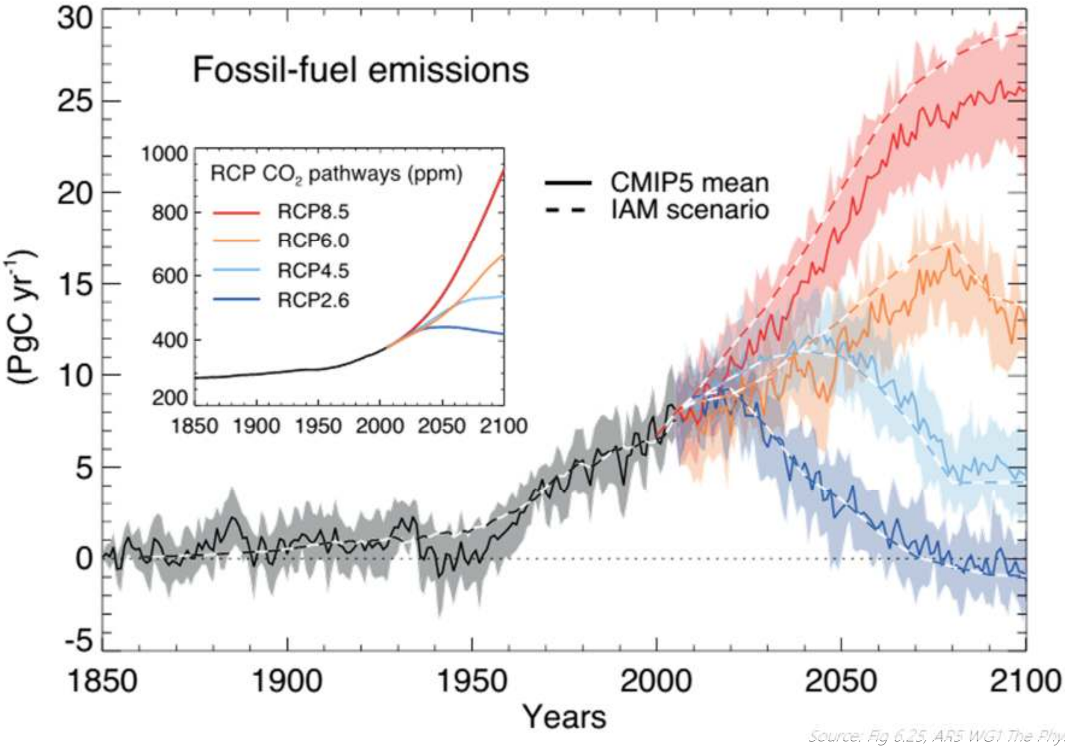
Intended as indicative of policy impacts: these are projections, not forecasts.



## Modelling earth's climate



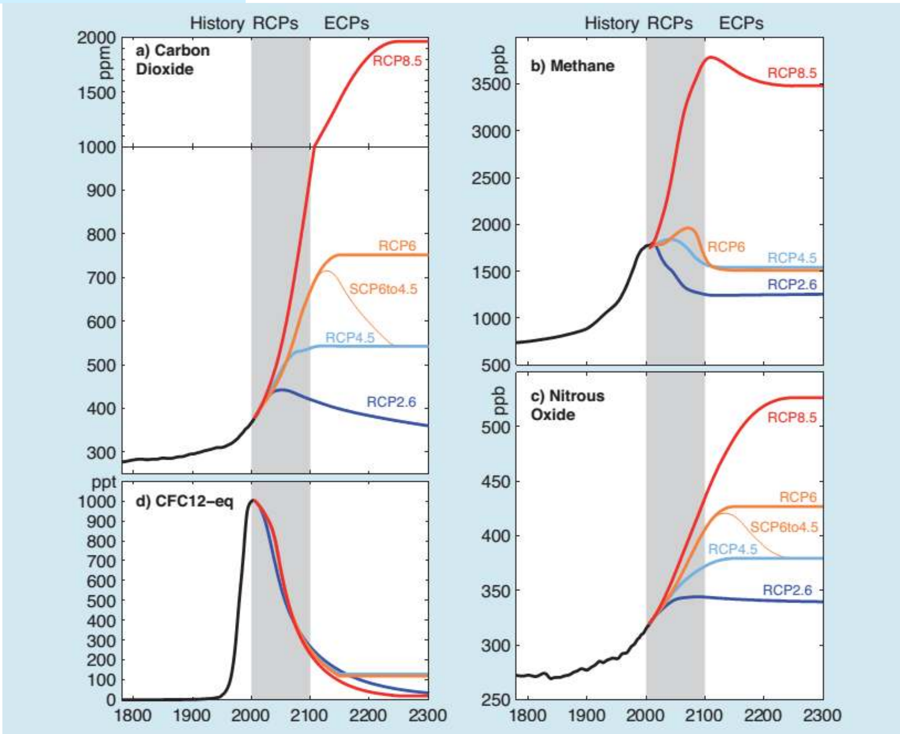
## Modelling earth's climate




Source: Fig 6.25, AR5 WG1 The Physical Science Basis. IPCC (2014)

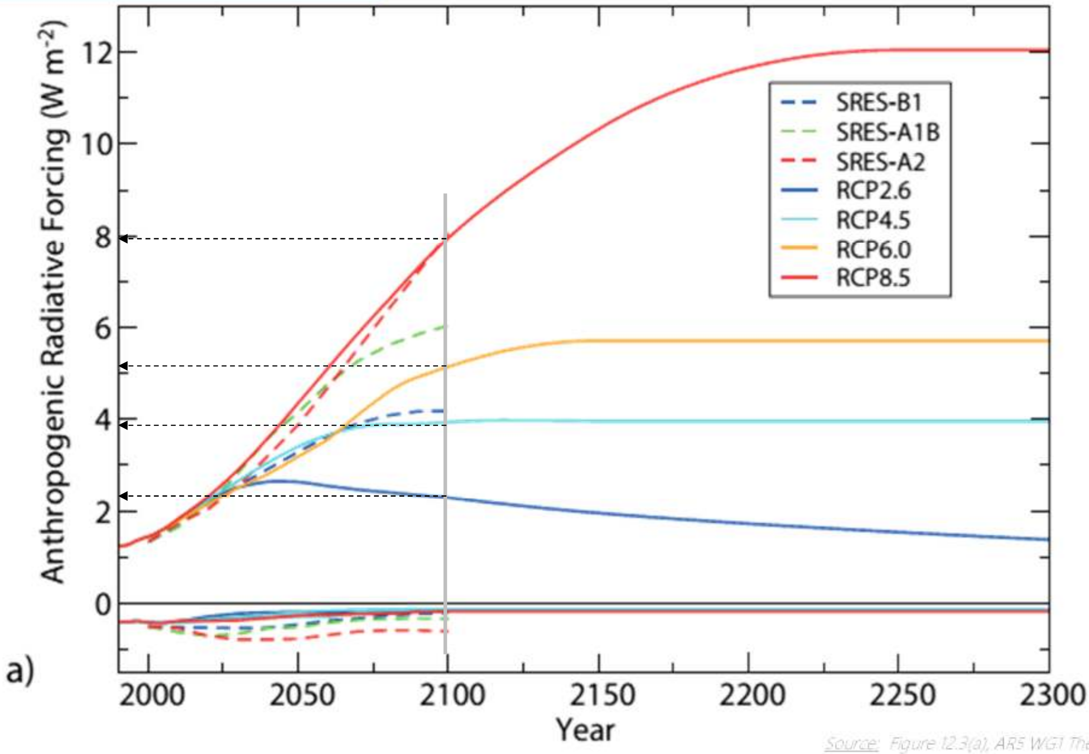


## Modelling earth's climate




Source: Box 1.1 Figure 2, AR5 WG1 The Physical Science Basis. IPCC (2014)

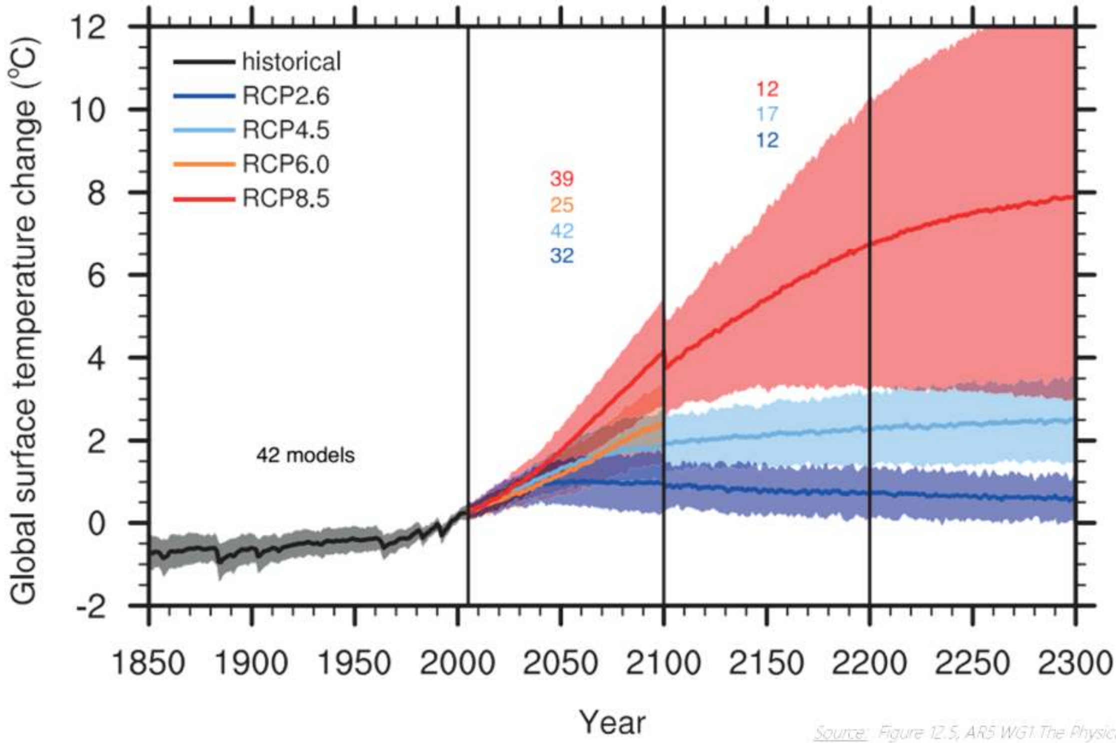
## Modelling earth's climate




Source: Figure 12.3(a), AR5 WG1 The Physical Science Basis. IPCC (2014)

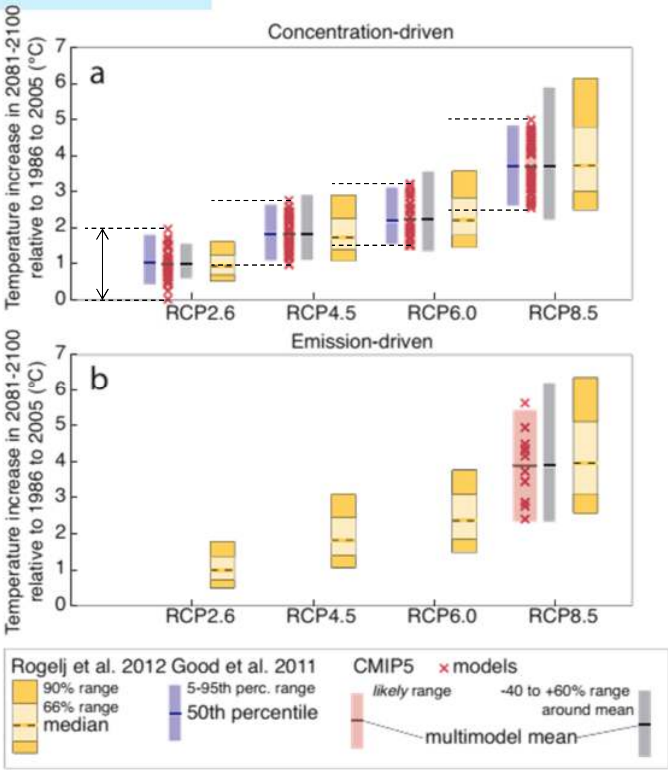


## Modelling earth's climate




Source: Figure 12.5, AR5 WG1 The Physical Science Basis. IPCC (2014)

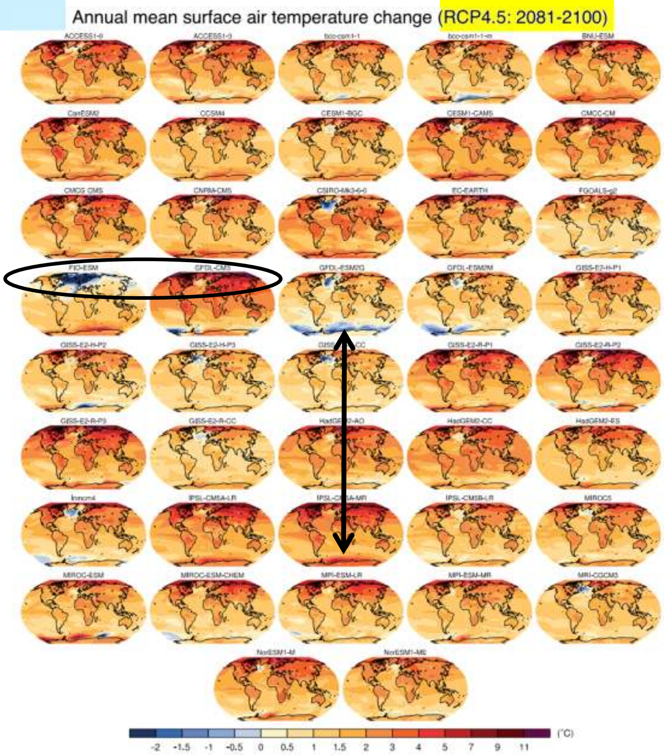
## Modelling earth's climate




Source: Figure 12.8, AR5 WG1 The Physical Science Basis. IPCC (2014)



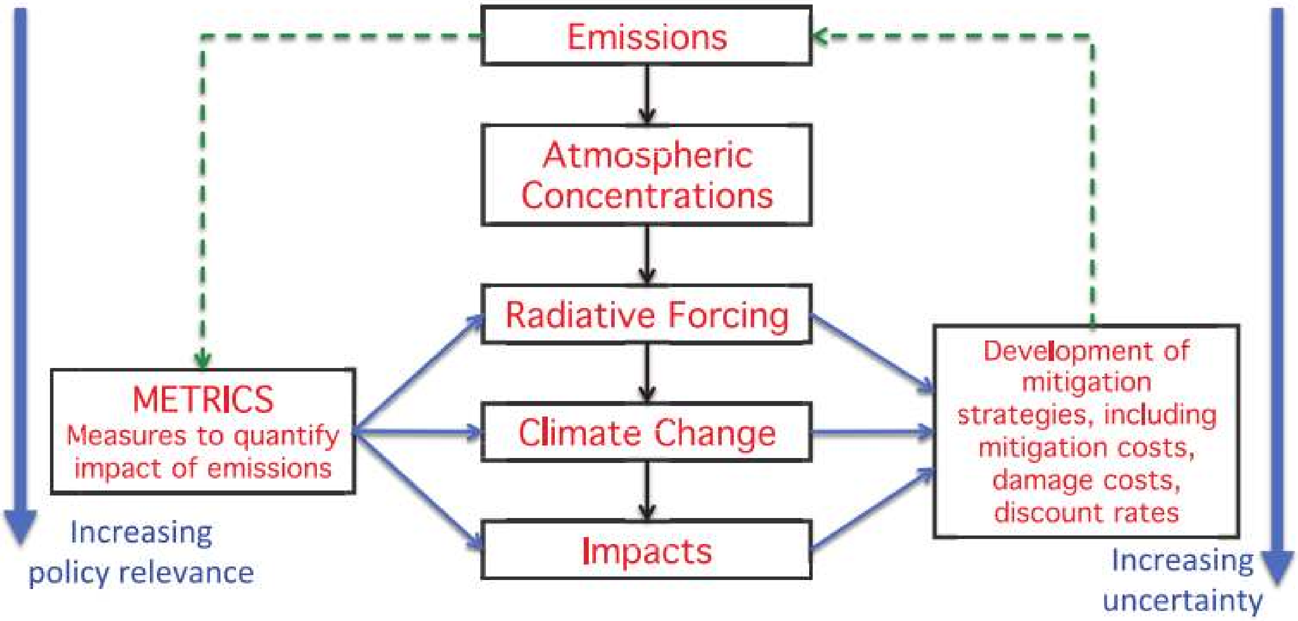
## Modelling earth's climate




Source: Figure 12.9, AR5 WG1 The Physical Science Basis. IPCC (2014)

## Modelling earth's climate

Impacts and uncertainty




Source: *Figure 8.27, AR5 WG1, The Physical Science Basis. IPCC (2014)*



## Modelling earth's climate

Summary to date:

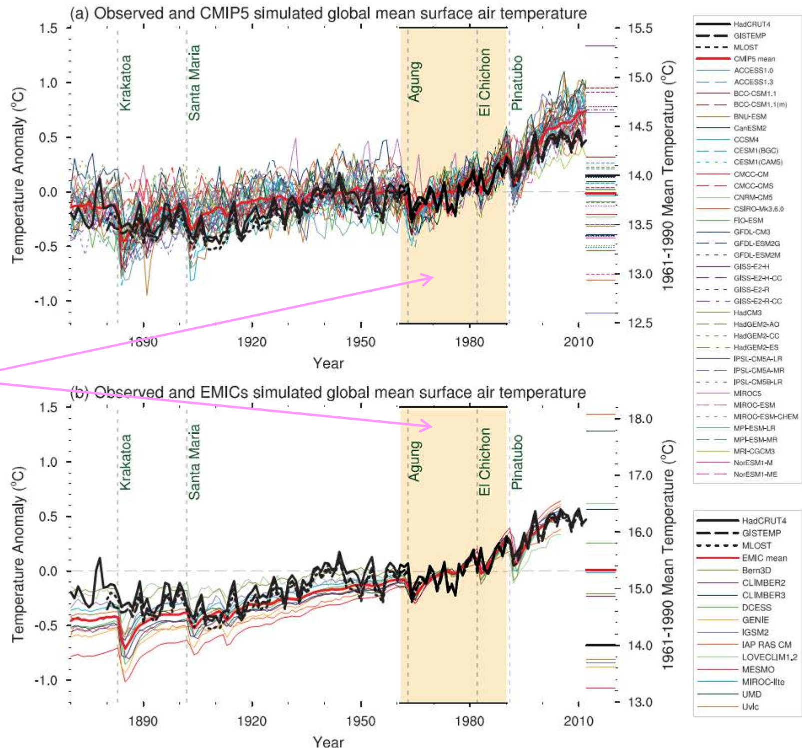
1. Modelling earth's climate is extremely challenging.
2. Each new generation of models incorporates additional physics, and improved spatial resolution. However, many processes are still poorly understood or crudely modelled.
3. Although all CMIP models are based on the same physics, projections of regional climate can differ very substantially between models – even when starting from the same initial conditions and driven by the same $CO_2$ forcing.
4. The more policy-relevant the information sought from a model, the greater the uncertainty associated with that information.

# Comparing models and measurements

versus



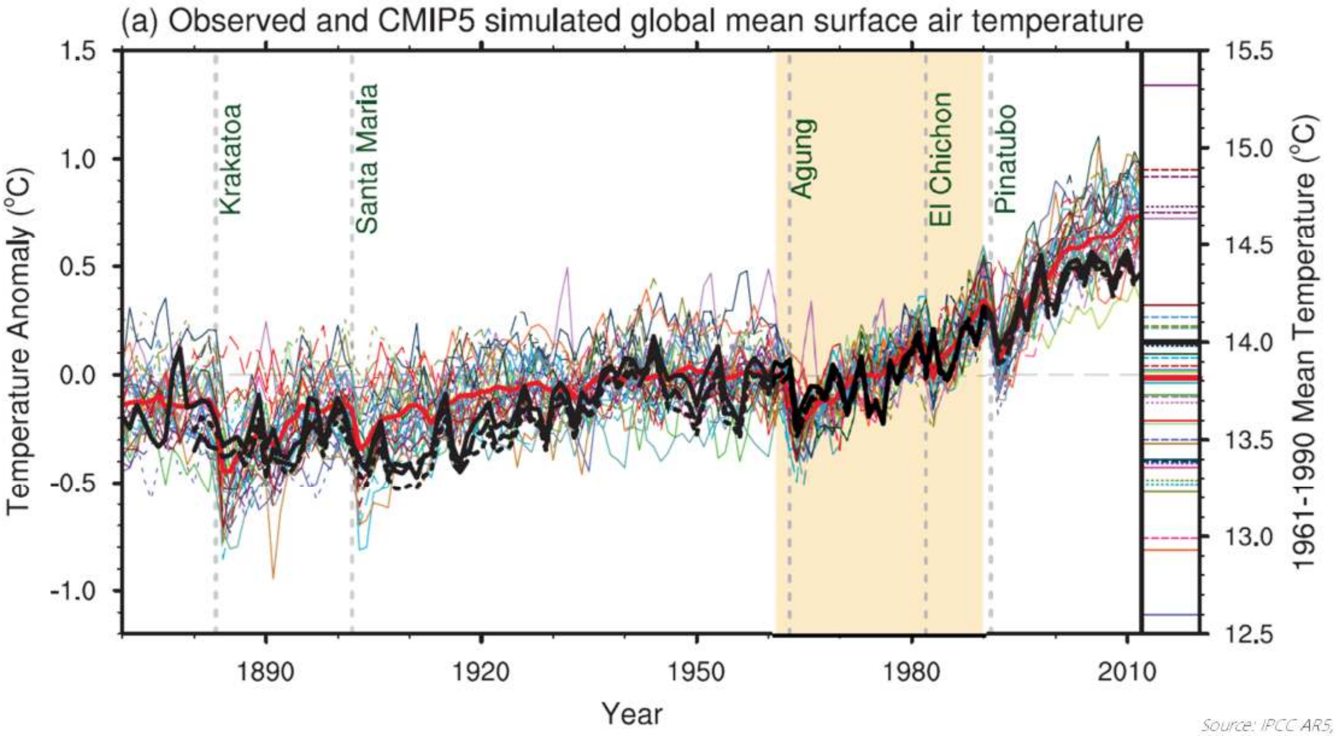
## Comparing models and measurements




Temperature averaging period, 1961-1990

*Source: IPCC AR5, WG1, Fig. 9.8*

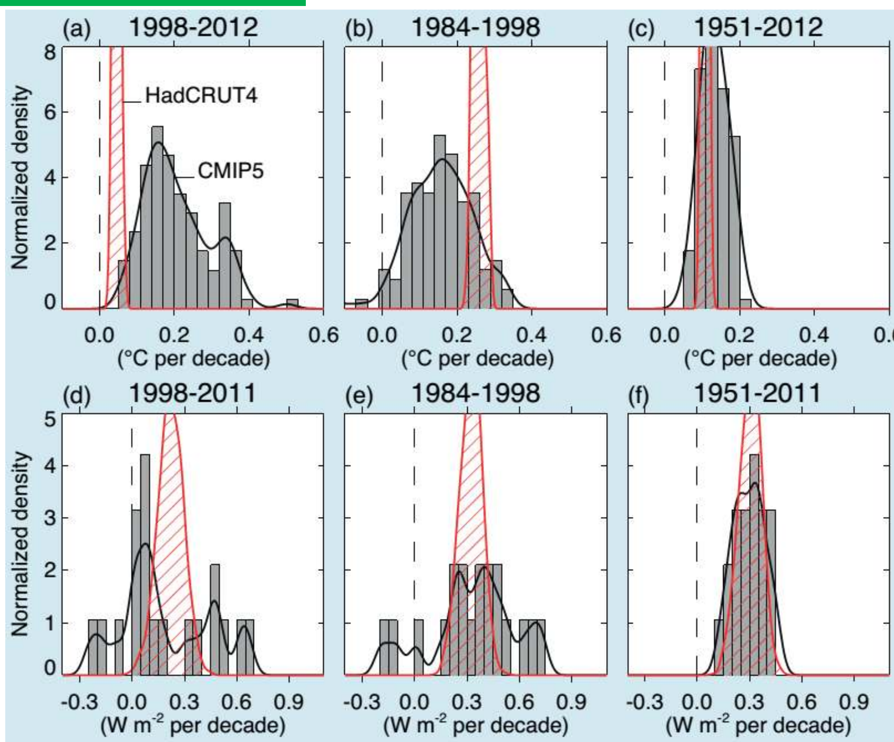
# Comparing models and measurements




*Source: IPCC AR5, WG1, Fig. 9.8*

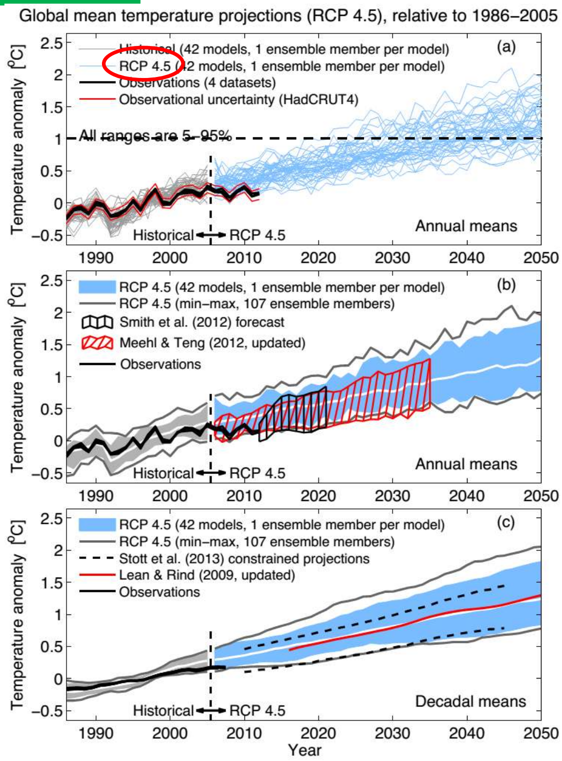


# Comparing models and measurements




*Source: IPCC AR5, WG1, Box 9.2, Fig. 1*

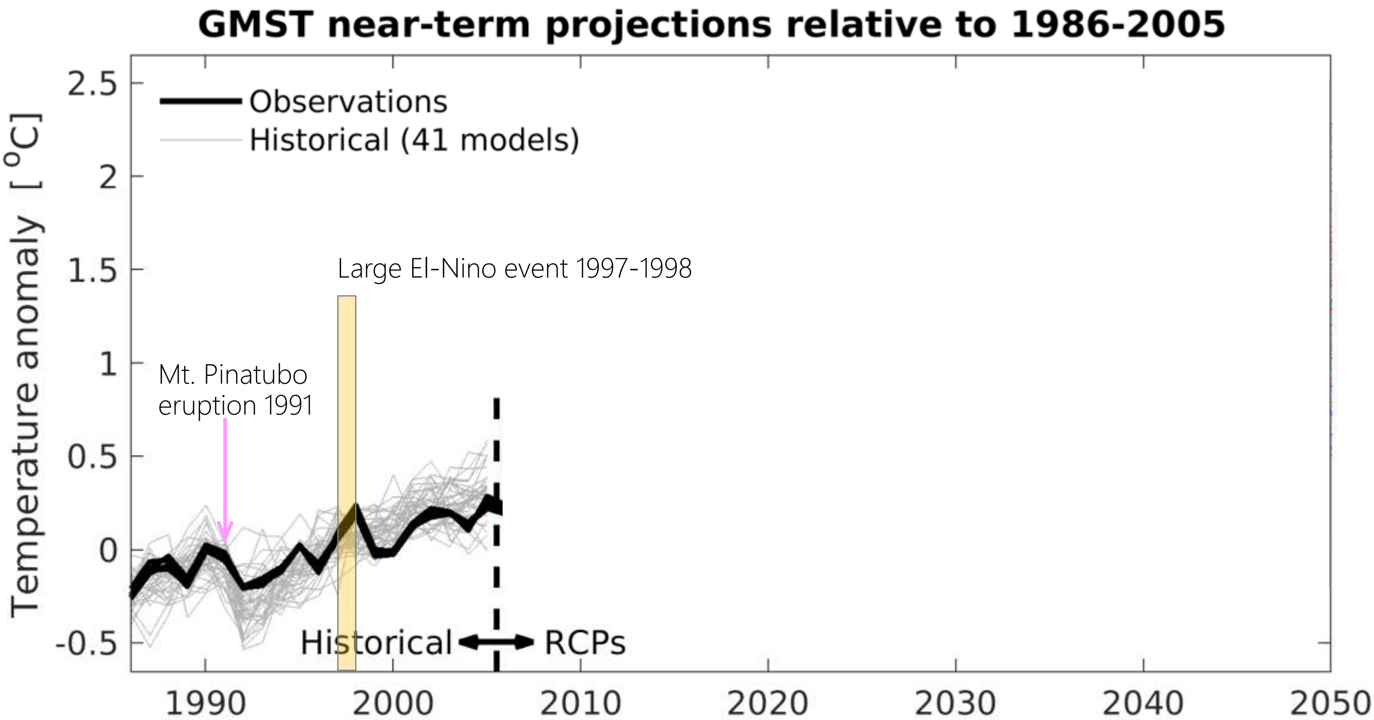
## Comparing models and measurements




*Source: IPCC AR5, WG1, Fig. 11.9*

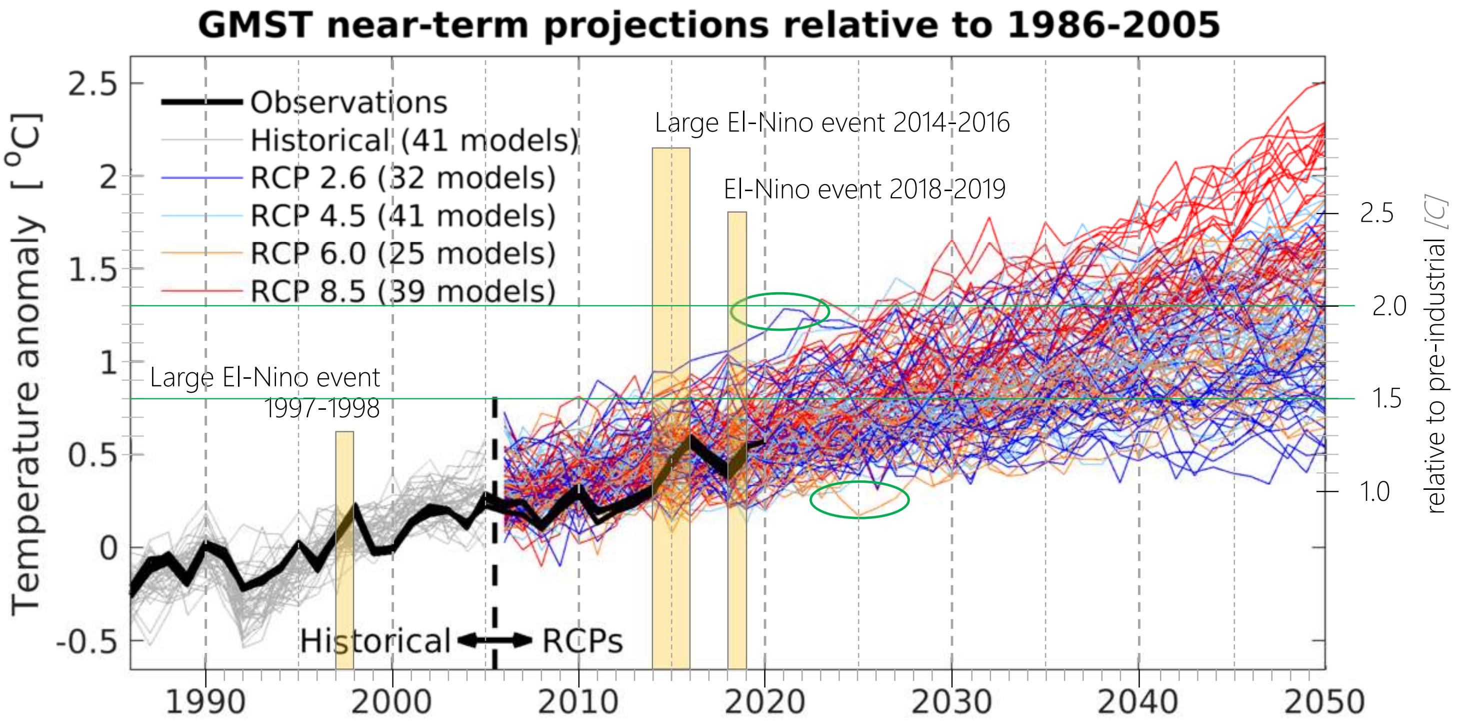


## Comparing models and measurements




*Source: https://www.climate-lab-book.ac.uk/comparing-cmip5-observations/ (Last update: Sep 2020)*

## Comparing models and measurements




*Source: https://www.climate-lab-book.ac.uk/comparing-cmip5-observations/ (Last update: May 2021)*



## Back to basics

How much will earth's temperature increase, due to increased $CO_2$ in the atmosphere?

<u>Climate sensitivity:</u> defined as the temperature increase associated with a <u>doubling</u> of atmospheric $CO_2$.

From GHG effect of $CO_2$ alone: ~ 1 C per doubling of $CO_2$ This is relatively easy to measure, and not disputed.

Paris Climate Agreement targets:
- < 2 C increase in global mean surface temperature (GMST), relative to pre-industrial;
- try to limit the increase to ≤ 1.5 C

Based on a climate sensitivity of 1 C per doubling: $\Delta T = 1.5\ \mathrm{C}\ \boxed{\leftrightarrow}\ 790\ \mathrm{ppm}_{\mathrm{CO_2}}$

$\Delta T = 2.0\ \mathrm{C}\ \boxed{\leftrightarrow}\ 1120\ \mathrm{ppm}_{\mathrm{CO_2}}$

So why the concern...?



## Back to basics

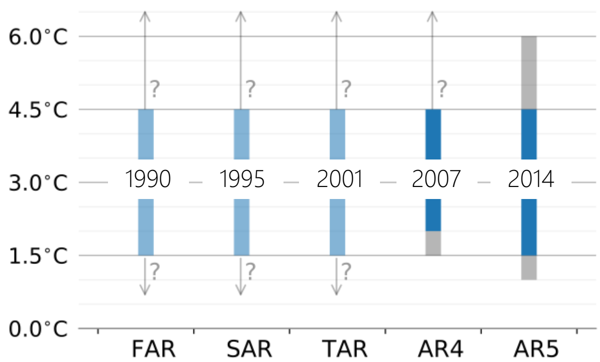
How much will earth's temperature increase, due to increased $CO_2$ in the atmosphere?

<u>Climate sensitivity:</u> defined as the temperature increase associated with a <u>doubling</u> of atmospheric $CO_2$.

From GHG effect of $CO_2$ alone: ~ 1 C per doubling of $CO_2$

When feedbacks are included: 1979 estimate (Charney) 1.5 – 4.5 C per doubling of atmospheric $CO_2$

Inferred from models:



## Back to basics

### How much will earth's temperature increase, due to increased $CO_2$ in the atmosphere?

<u>Climate sensitivity:</u> defined as the temperature increase associated with a <u>doubling</u> of atmospheric $CO_2$.

From GHG effect of $CO_2$ alone: ~ 1 C per doubling of $CO_2$

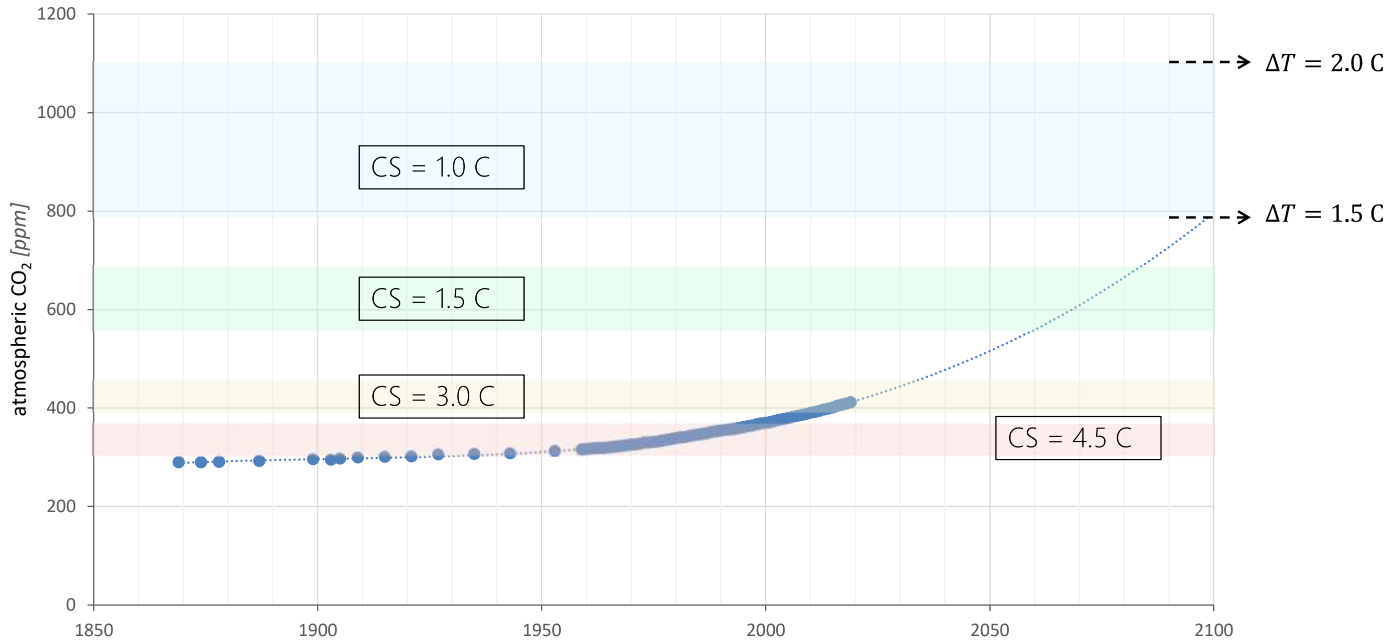
When feedbacks are included: 1979 estimate (Charney) 1.5 – 4.5 C per doubling of atmospheric $CO_2$

| Climate sensitivity → | 1.0 C | 1.5 C | 3.0 C | 4.5 C |
|---|---|---|---|---|
| $\mathbf{CO_2}$ **for** $\mathbf{\Delta T = 1.5\ C}$ | 790 ppm | 560 ppm | 396 ppm | 353 ppm |
| $\mathbf{CO_2}$ **for** $\mathbf{\Delta T = 2.0\ C}$ | 1,120 ppm | 706 ppm | 444 ppm | 381 ppm |

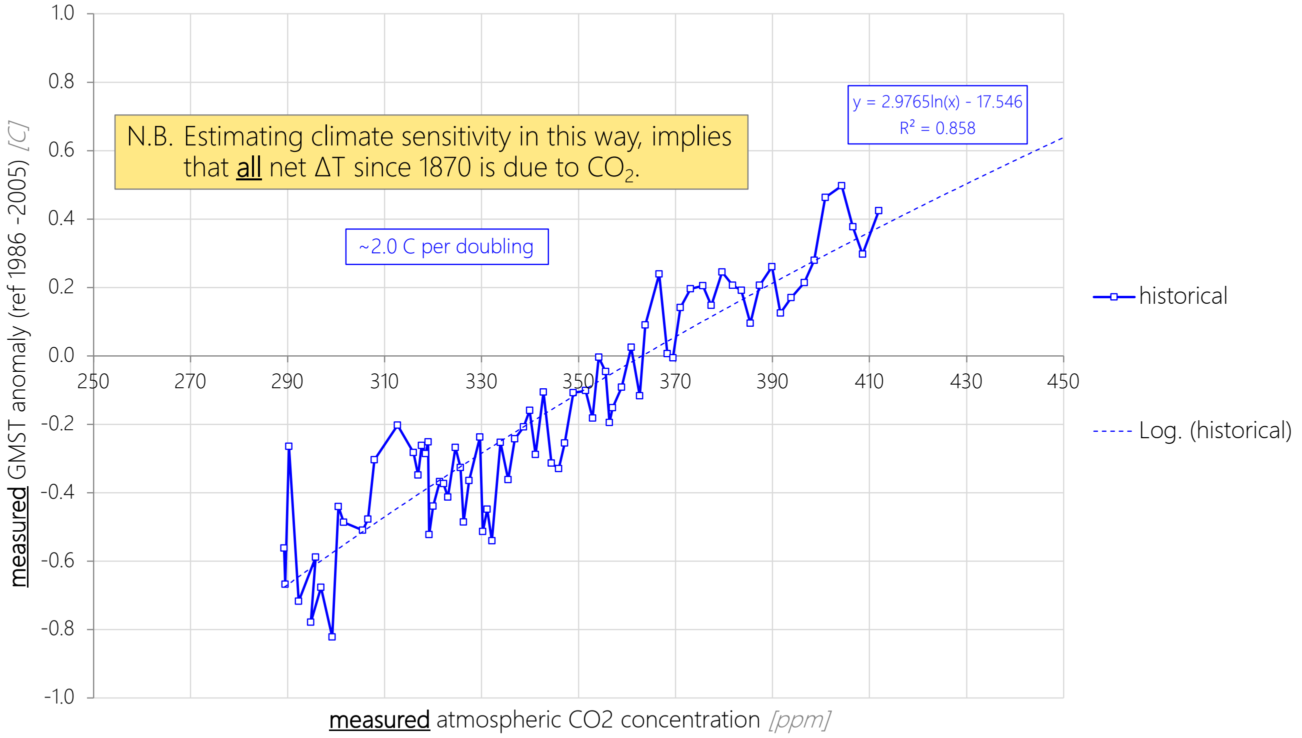


## Back to basics

### How much will earth's temperature increase, due to increased $CO_2$ in the atmosphere?

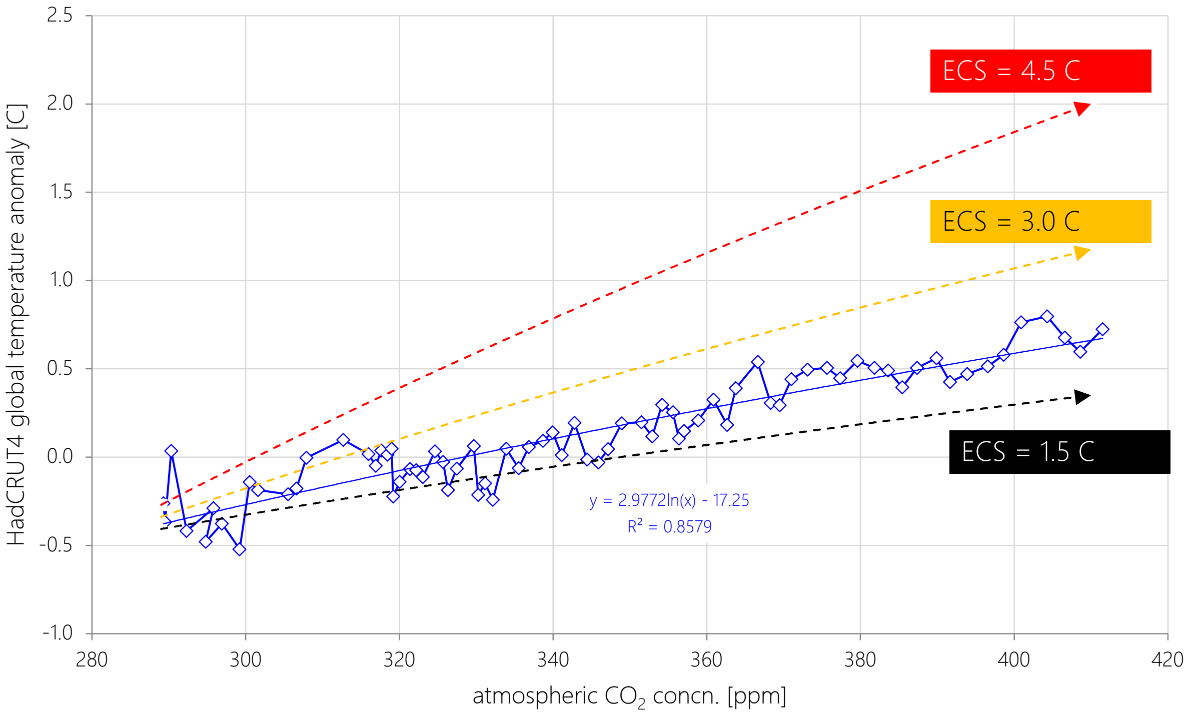


## Back to basics

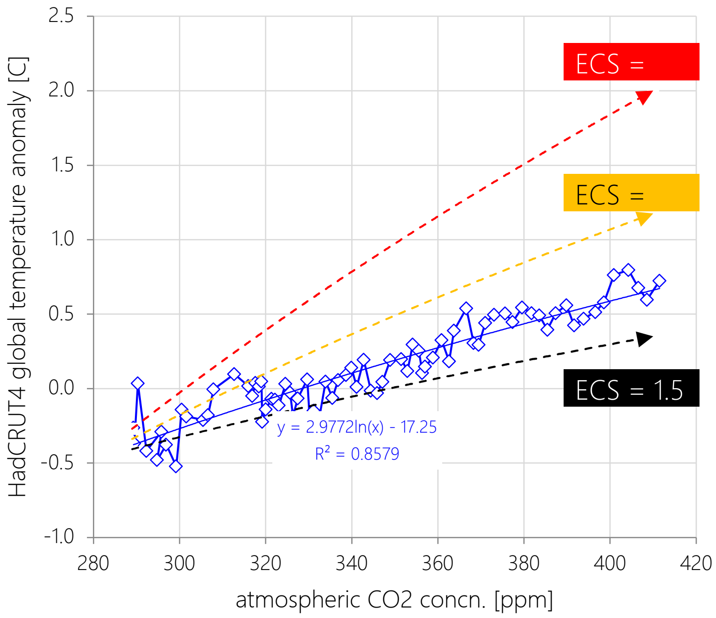





## Back to basics



## Back to basics

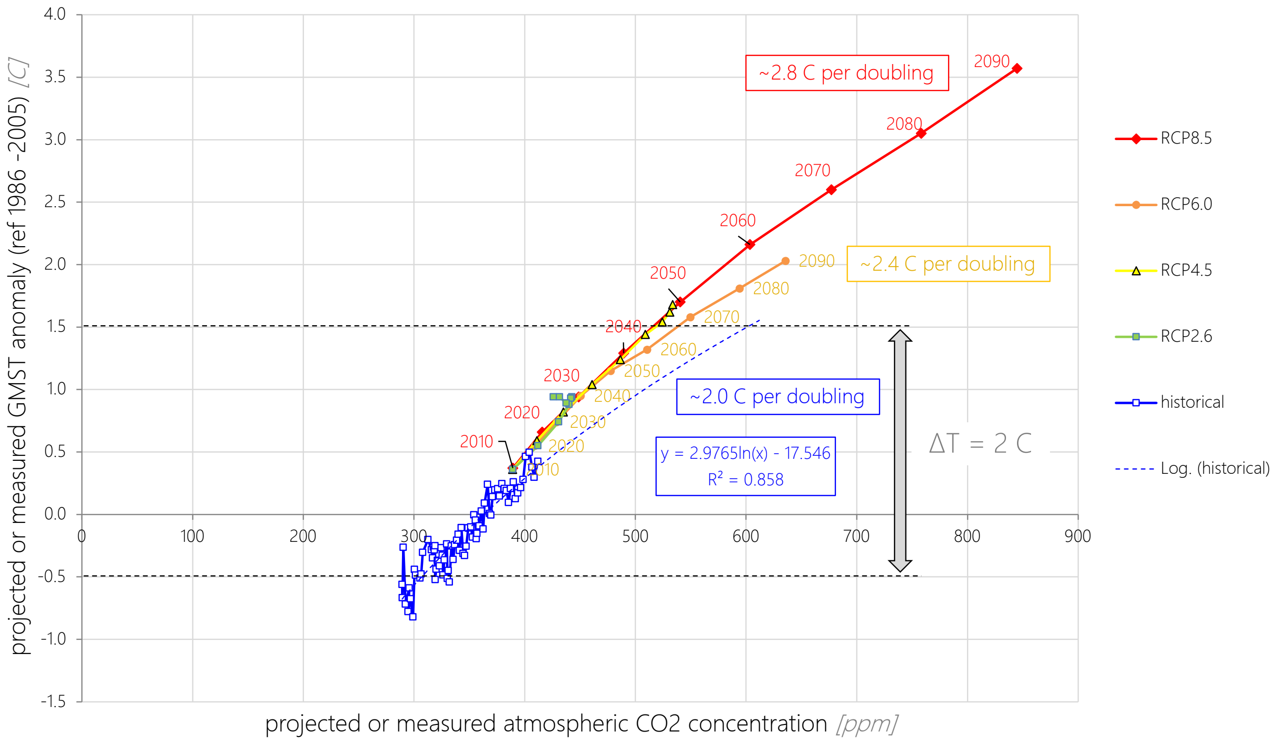



Why do model estimates of climate sensitivity not match observations?

- Some physics missing from models?
- Some physics over-simplified in models?
- Exaggerated positive feedbacks in models?
- Under-estimates of some negative feedbacks in models?
- Errors in temperature observations?
- Comparing apples with oranges?



## Back to basics



## Questioning voices

Professor Richard Lindzen.

1972-1982: Professor of Dynamic Meteorology, Harvard

1983-2013: Alfred P. Sloan Professor of Meteorology, at MIT.

2001: One of ten Lead Authors of Chapter 7, 'Physical Climate Processes and Feedbacks,' of the IPCC Third Assessment Report (TAR).

Professor Judith Curry.

2001: One of fifty-six Contributing Authors of Chapter 7, 'Physical Climate Processes and Feedbacks,' of the IPCC TAR.

2002 - 2018: Chair of the School of Earth and Atmospheric Sciences, Georgia Tech.

Professor John Christy.

1987 - : Distinguished Professor of Atmospheric Science, UAH

2000 - : Alabama State Climatologist.

2001: One of eight Lead Authors of Chapter 2, 'Observed Climate Variability and Change,' of the IPCC TAR.

Professor Steven Koonin.

1995 - 2004: Provost, Caltech

2004 - 2009: Chief Scientist, BP

2009 - 2011: U.S. Under-Secretary for Science

*"Scepticism is the first step towards truth."*
*Denis Diderot (1713-1784)*

*"Science is the belief in the ignorance of experts."*
*Richard P Feynman (1918-1988)*



## Back to basics

### Precautionary Principle:

*"In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."* *(UN 1993)*

Is this reasonable?

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