# Success and limitations of current climate models

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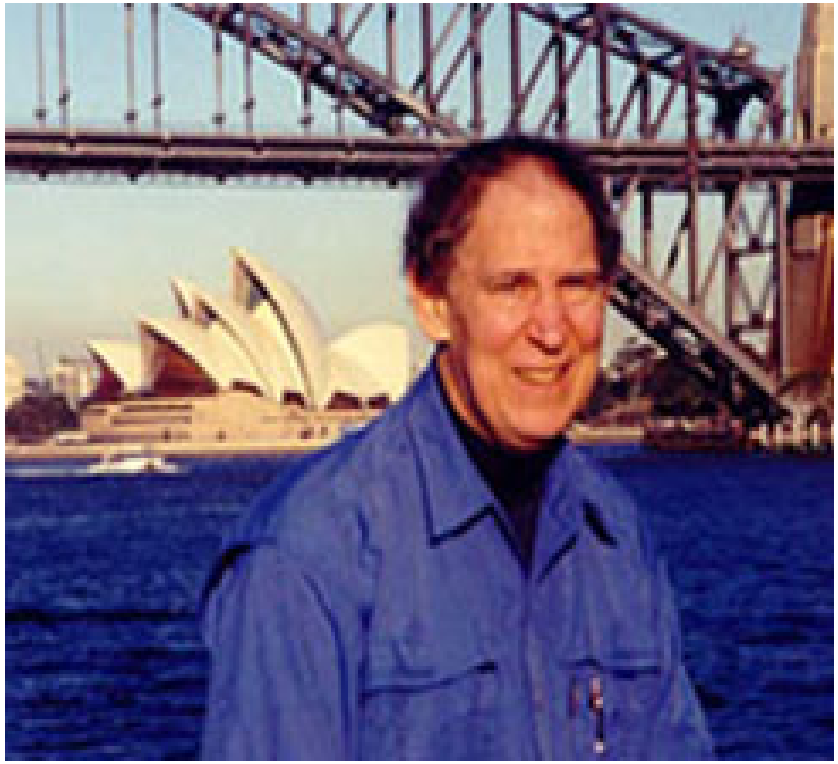
Askö, Sweden, 23rd-30th 2015

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

Warming is unequivocal, that's true. But that's not a sophisticated question. A much more sophisticated question is how much of the climate Ma Earth, a perverse lady, gives us is from her, and how much is caused by us. That's a much more sophisticated, and much more difficult question.



***Stephen Schneider, 1945-2010***

"I keep arguing, don't be too arrogant about the belief in your models; what you do is make projections, and then you crank a knob to try to avoid the more catastrophic outcomes or the outcomes that don't match your values, but we better be reflexive".

# S.Arrhenius predicted global warming by greenhouse gases in 1896

An increase of atmospheric concentration of **$CO_2$ of 300ppm**
causes a global surface waring of about **1 K**,
**when everything else remains unchanged**

The climate reacts to the warming. cloud cover, sea-ice, ocean currents, atmospheric flow, etc. all of the change with warming,
**enhancing or weakening** the initial warming. These the **feedbacks.**

**Feedbacks are very difficult to simulate correctly .**
Before looking into a few examples, we need first to understand of a climate model is

# The Earth's energy balance

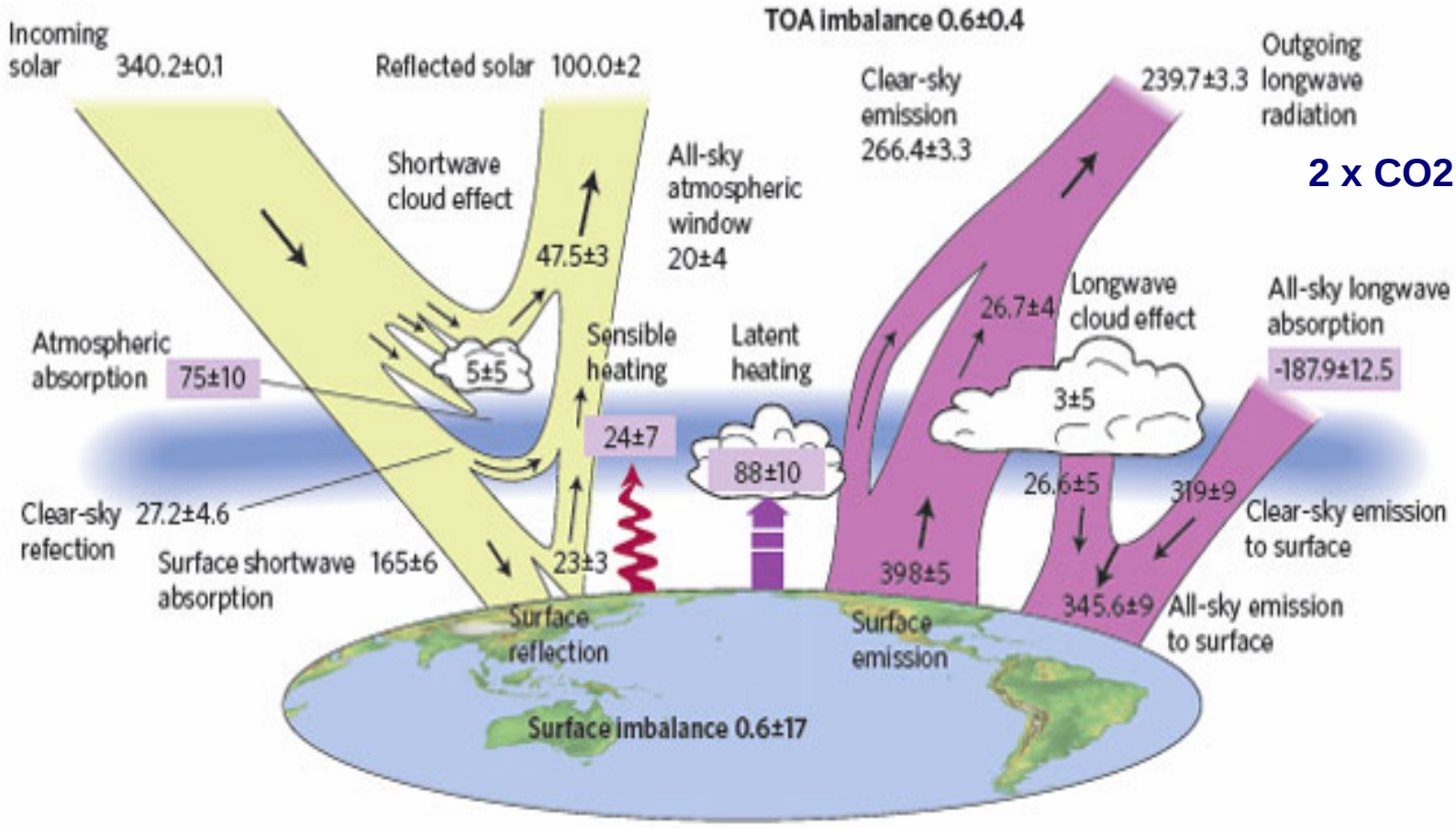
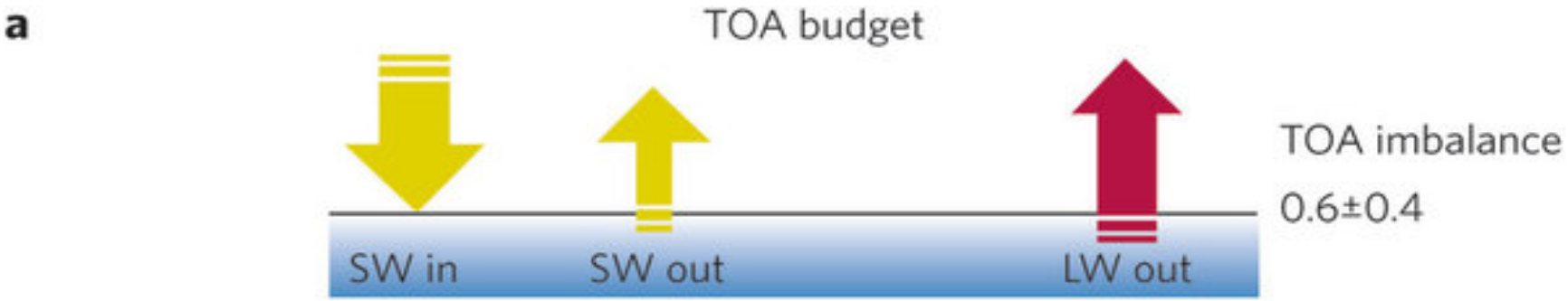
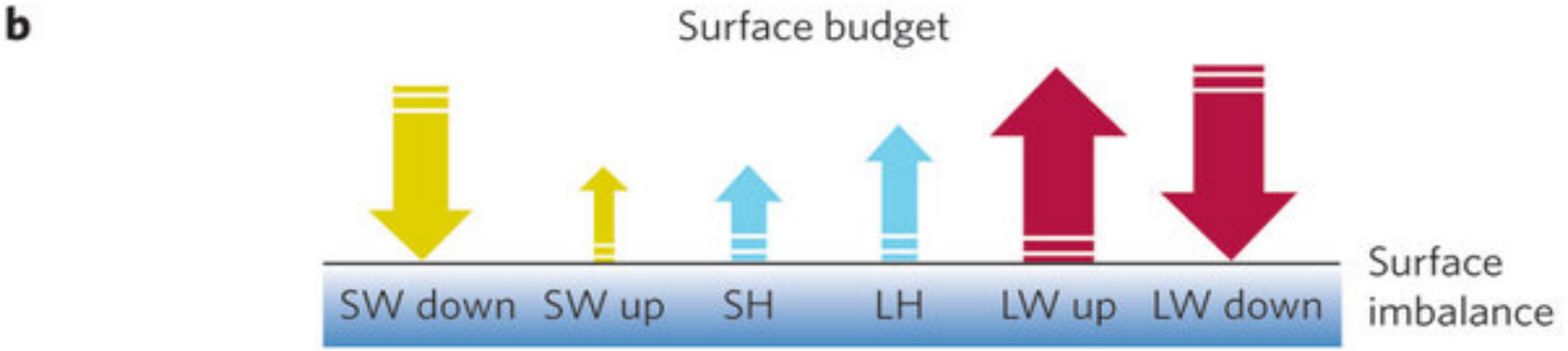



**Figure B1 | The global annual mean energy budget of Earth for the approximate period 2000–2010.** All fluxes are in $Wm^{-2}$. Solar fluxes are in yellow and infrared fluxes in pink. The four flux quantities in purple-shaded boxes represent the principal components of the atmospheric energy balance.




| | SW in | SW out | LW out |
|---|---|---|---|
| Observations | 340.2±0.1 | 100.0±2 | 239.7±3.3 |
| CMIP5 Min | 338.6 | 96.4 | 232.4 |
| (Mean) | (343) | (102.2) | (238.6) |
| Max | 343.7 | 106.5 | 243.5 |




| | SW down | SW up | SH | LH | LW up | LW down | Surface imbalance |
|---|---|---|---|---|---|---|---|
| Observations | 188±6 | 23±3 | 24±7 | 88±10 | 398±5 | 345.6±9 | 0.6±17 |
| CMIP5 Min | 181.9 | 21.1 | 17.6 | 78.4 | 391.9 | 326.4 | |
| (Mean) | (190.3) | (24.9) | (20.9) | (85.8) | (397.5) | (339.7) | |
| Max | 196.2 | 30.3 | 27.8 | 93.6 | 398.1 | 347.0 | |

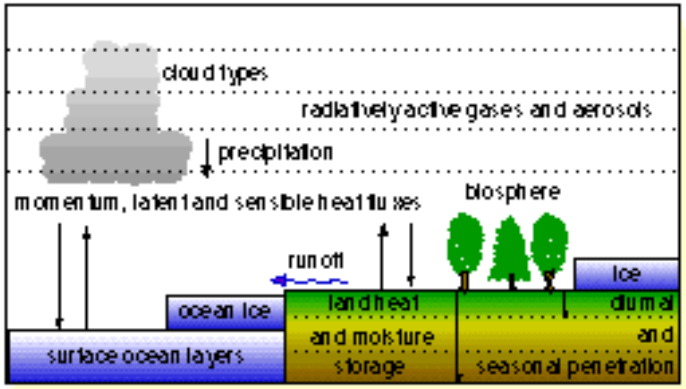
# Forced and unforced climate variations

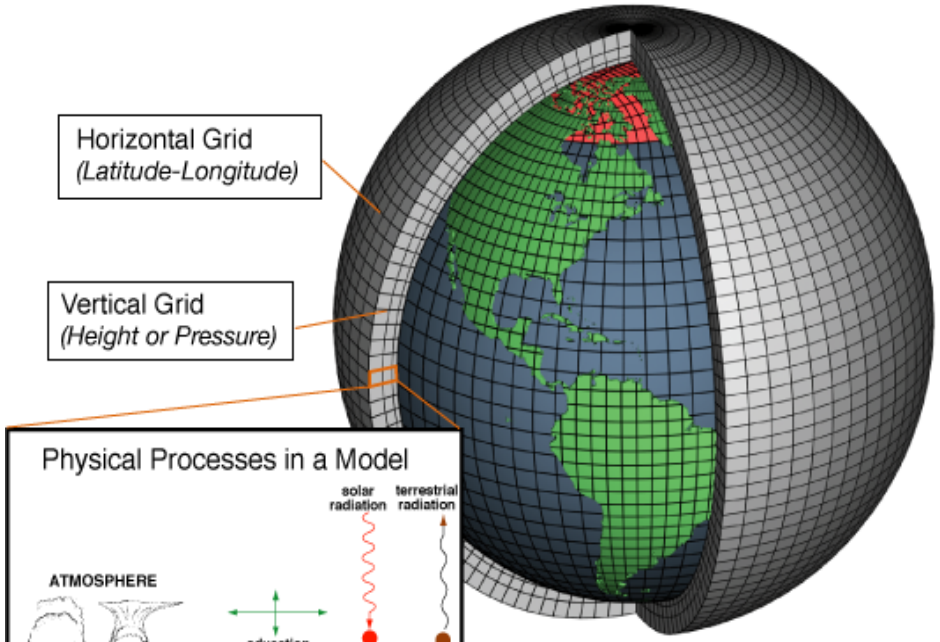
**Define our system of study,**
**e.g. *atmosphere-ocean-sea-ice***

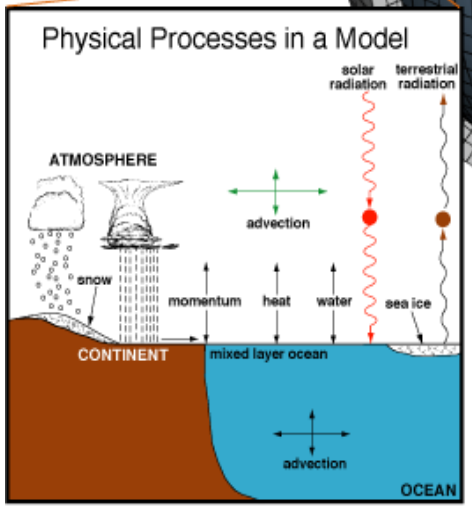
Forced variations:

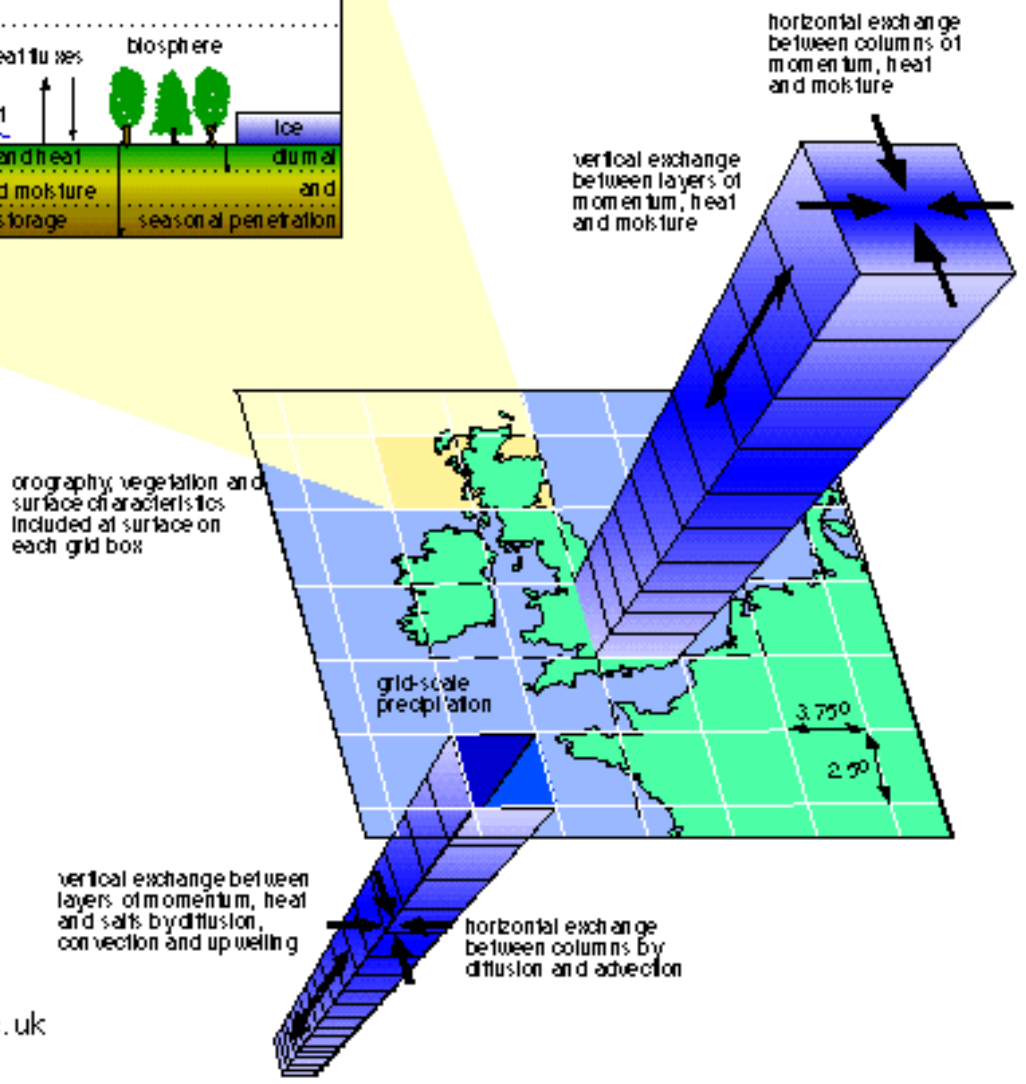
Unforced variations:

# Structure of a General Circulation Model



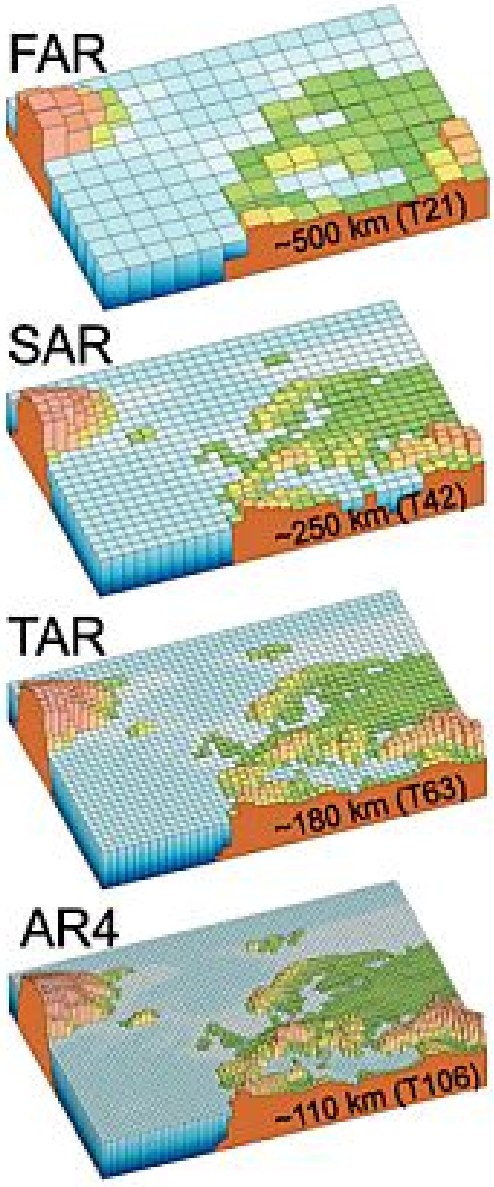



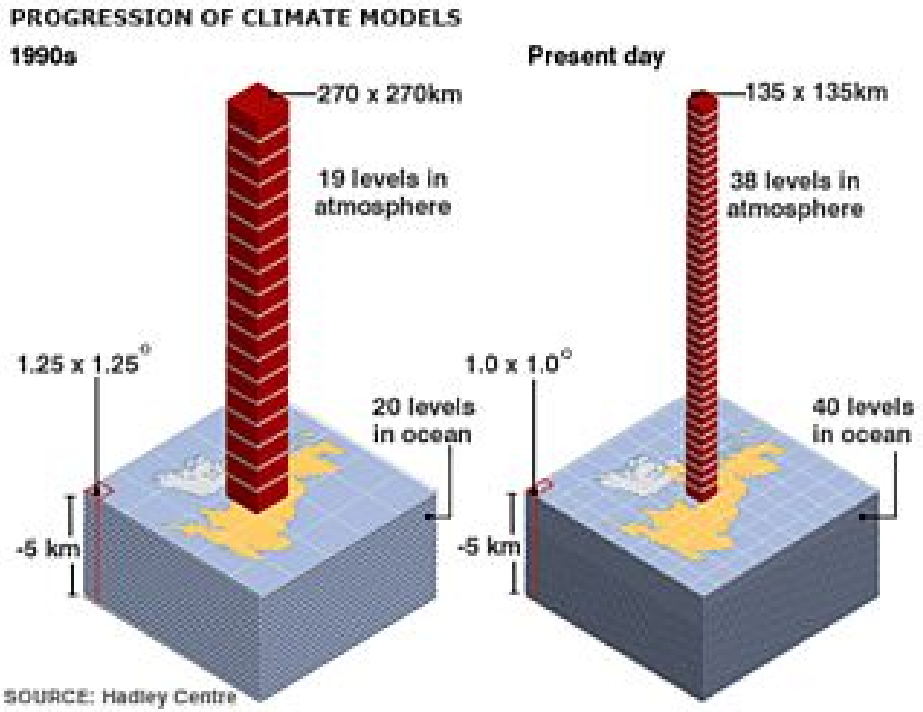




courtesy D. Vinner, CRU

# Increase in spatial resolution of global climate models

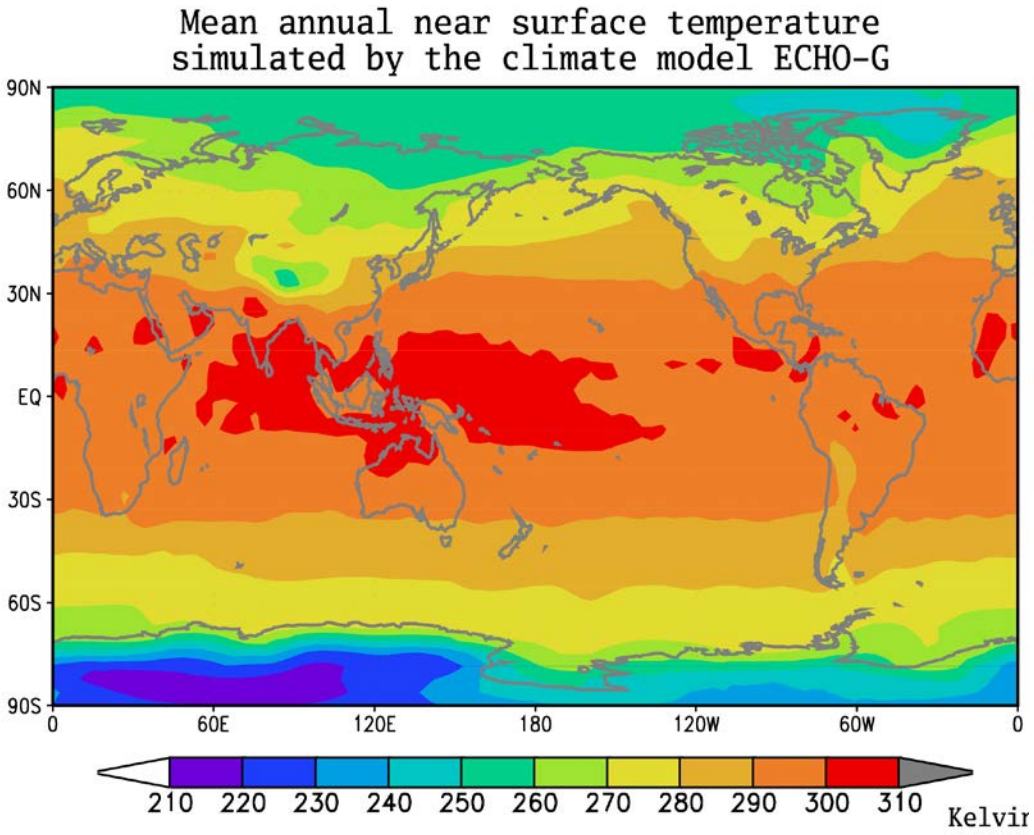
First Assessment Report ~1990

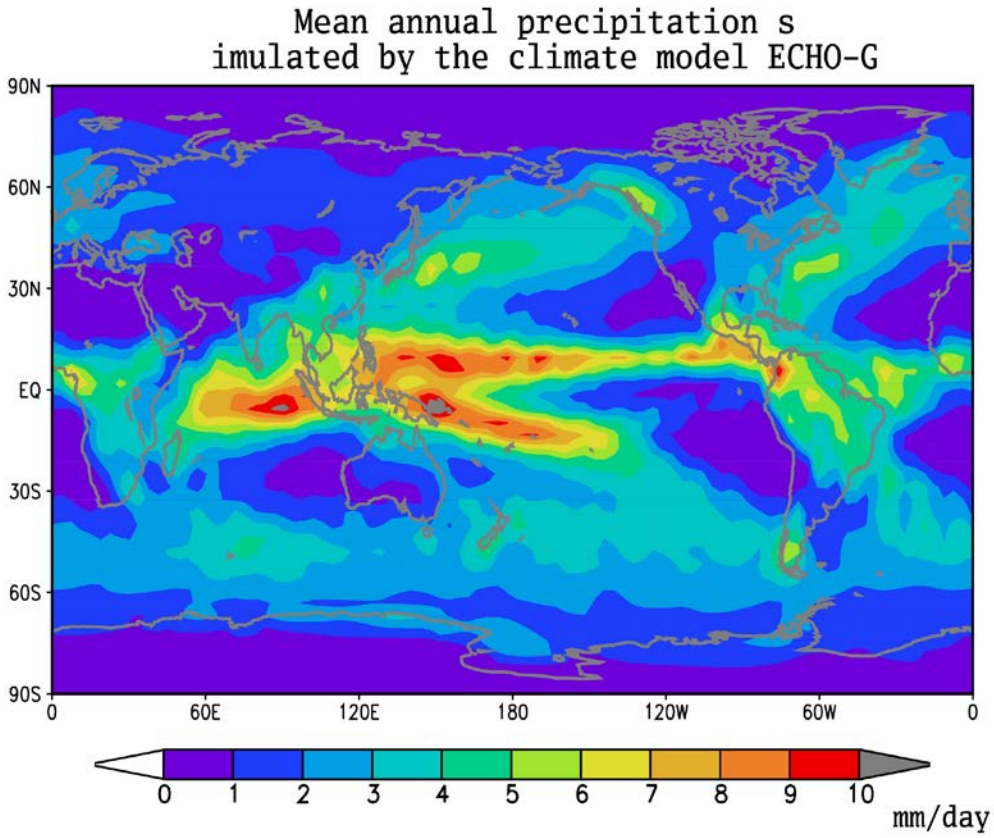



**AR5:** ~70km maximum horizontal resolution; up to 90 layers in the atmosphere and over 60 in the ocean.

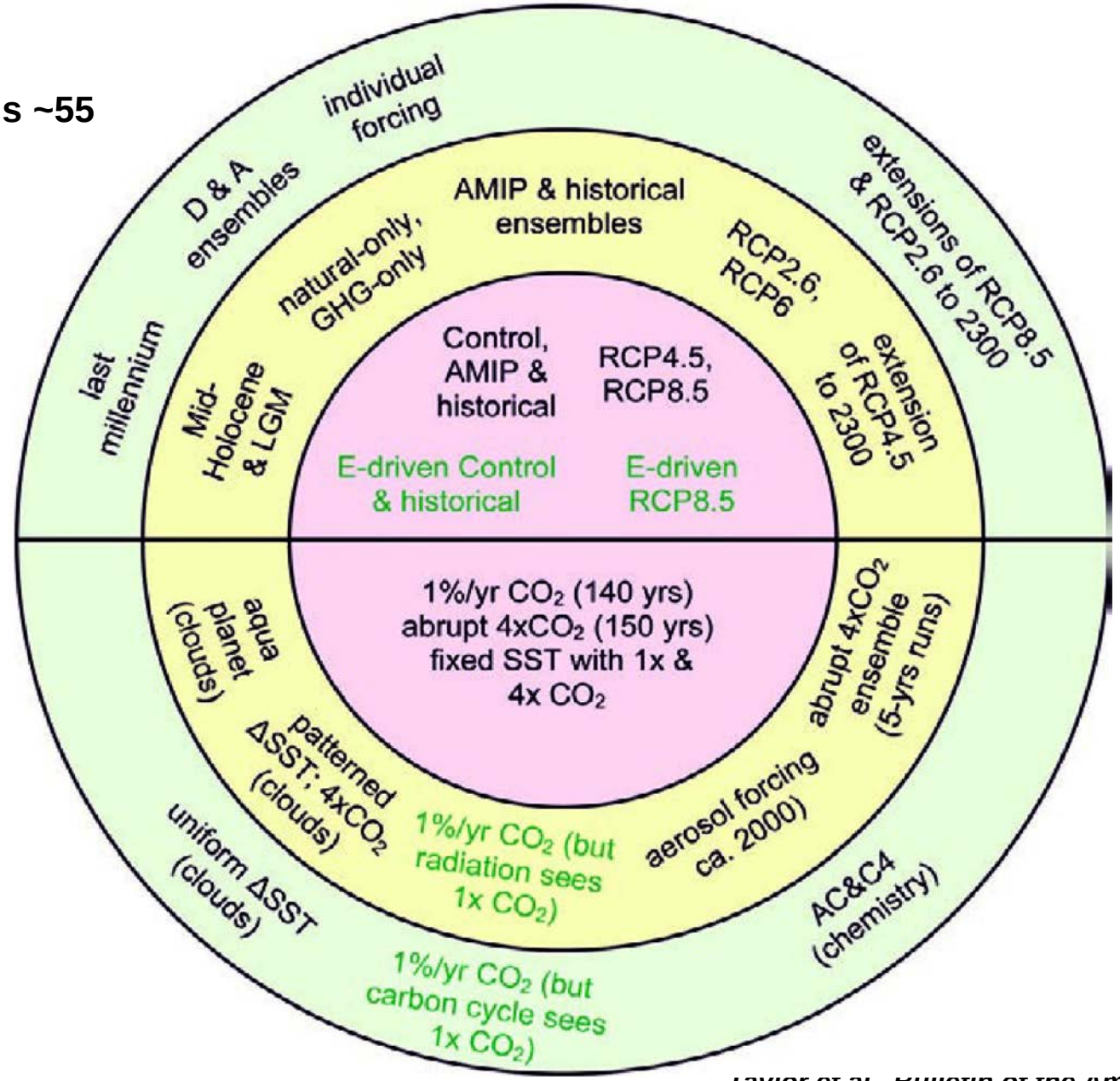
# Quite realistic simulations, but...



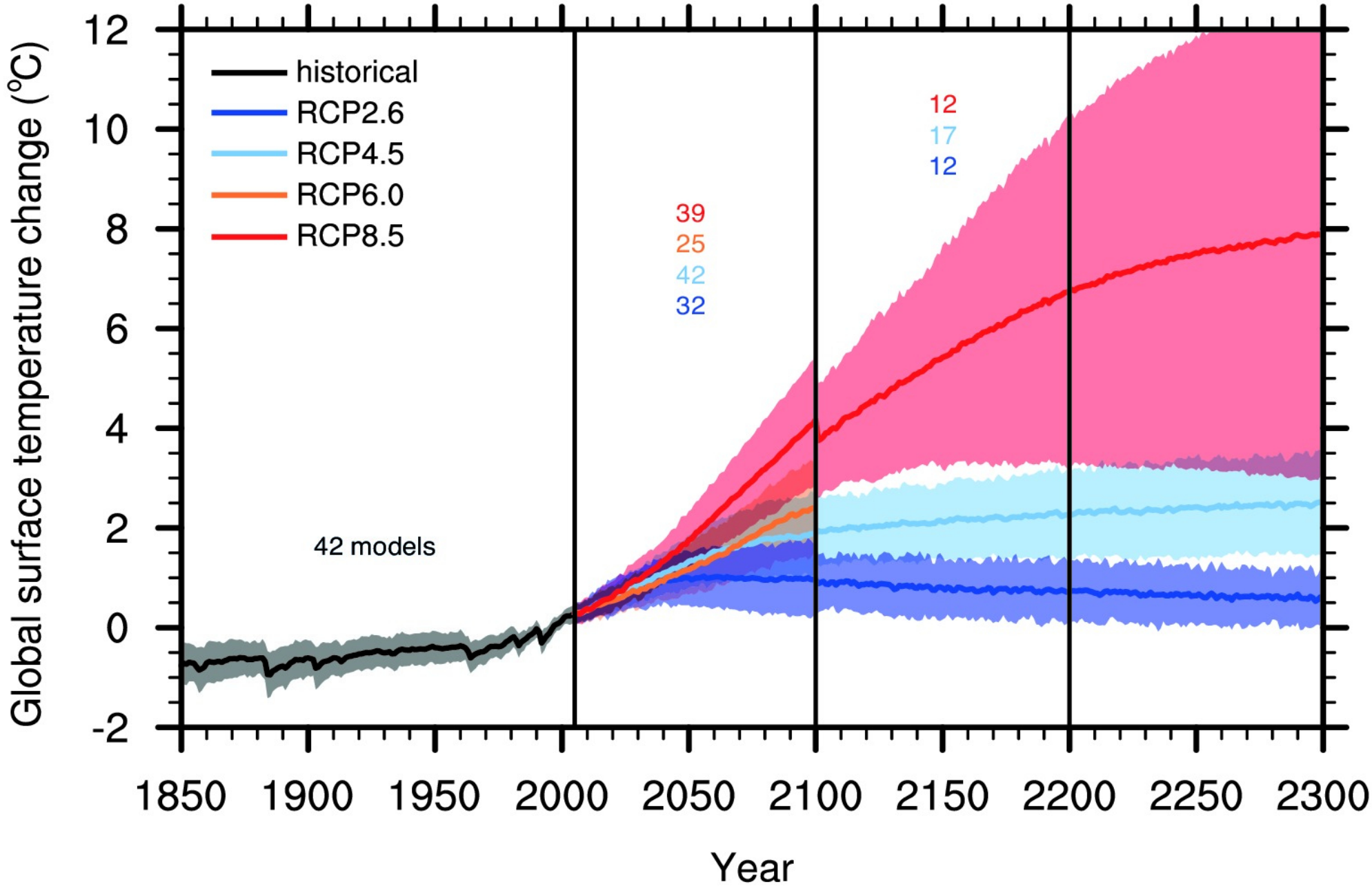



# The CMIP5 simulation scheme:
# different modelling groups providing simulations under the same protocol

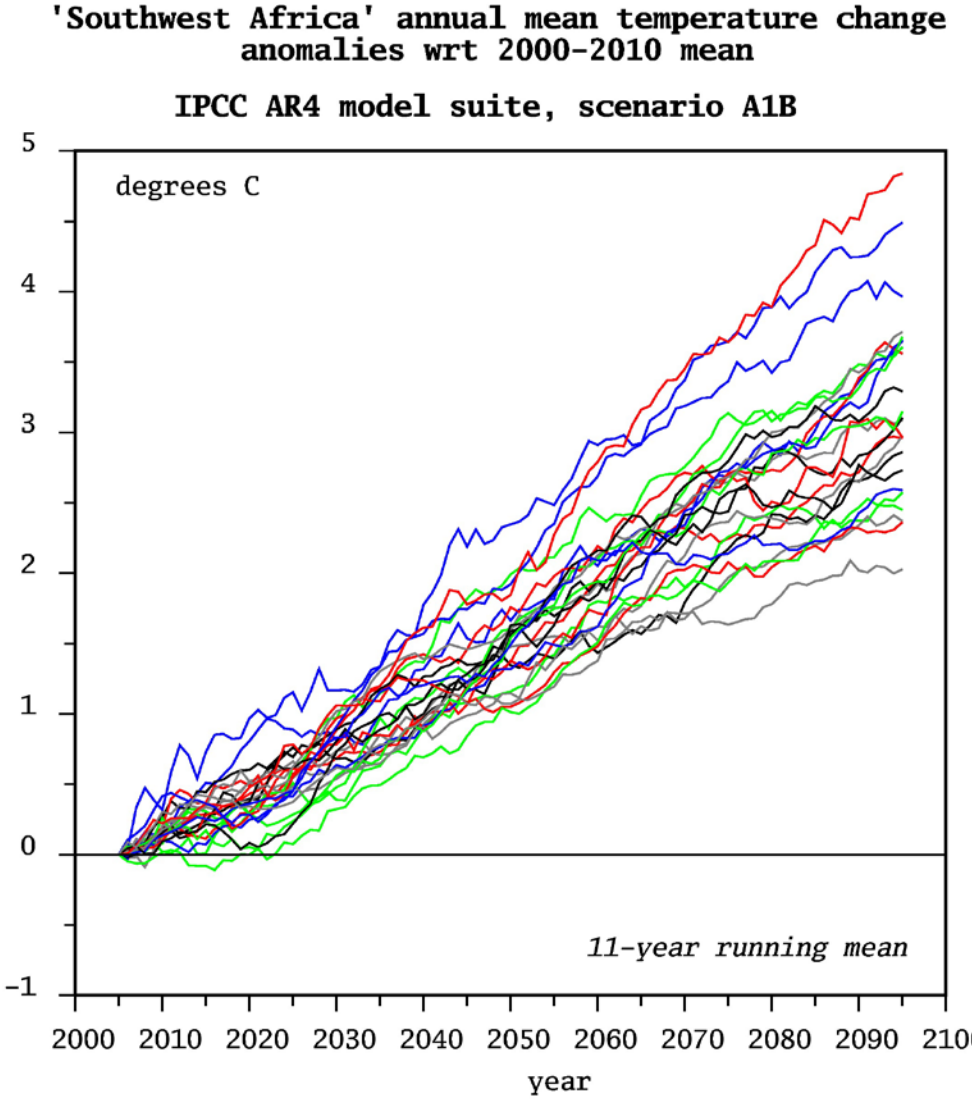
**Maximum number of models ~55**

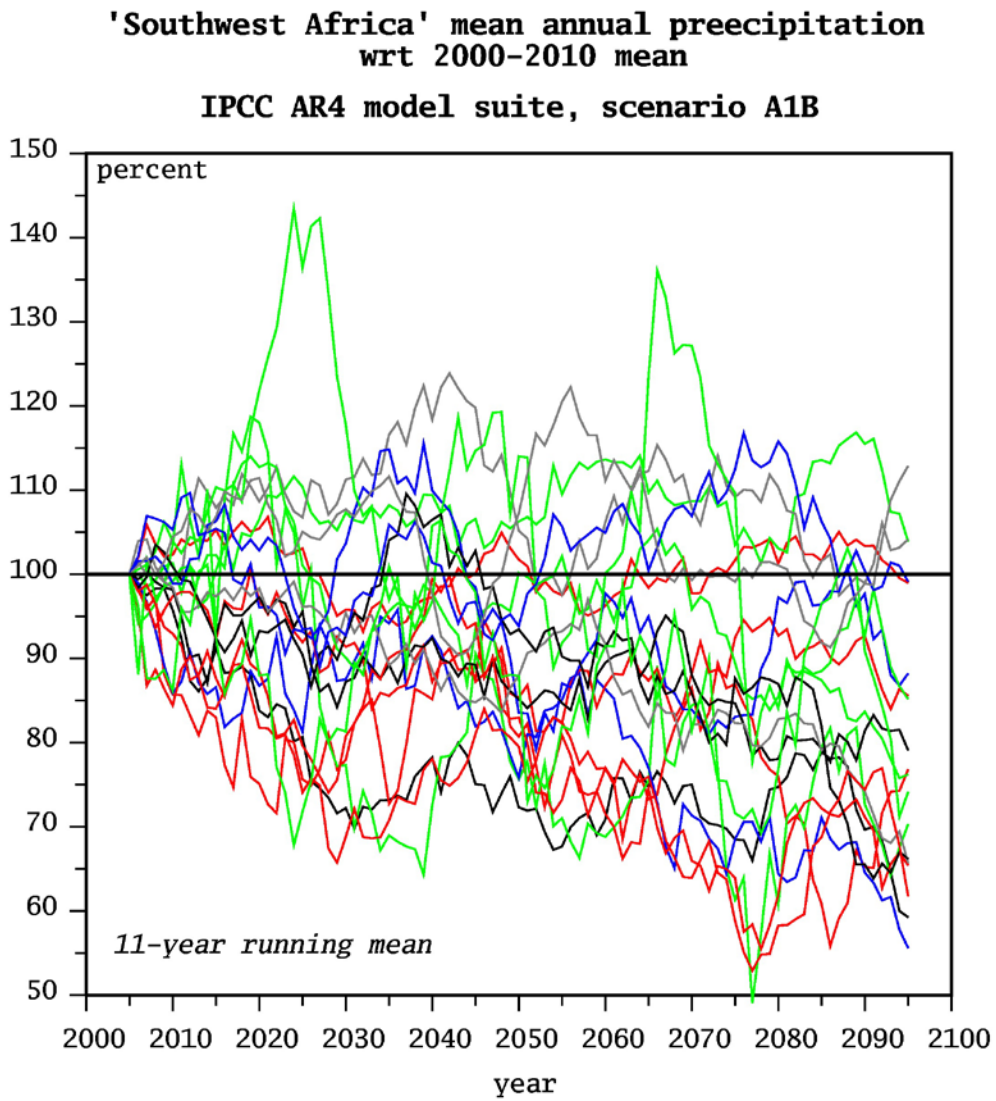



*Taylor et al., Bulletin of the American Meteor. Soc (2012)*

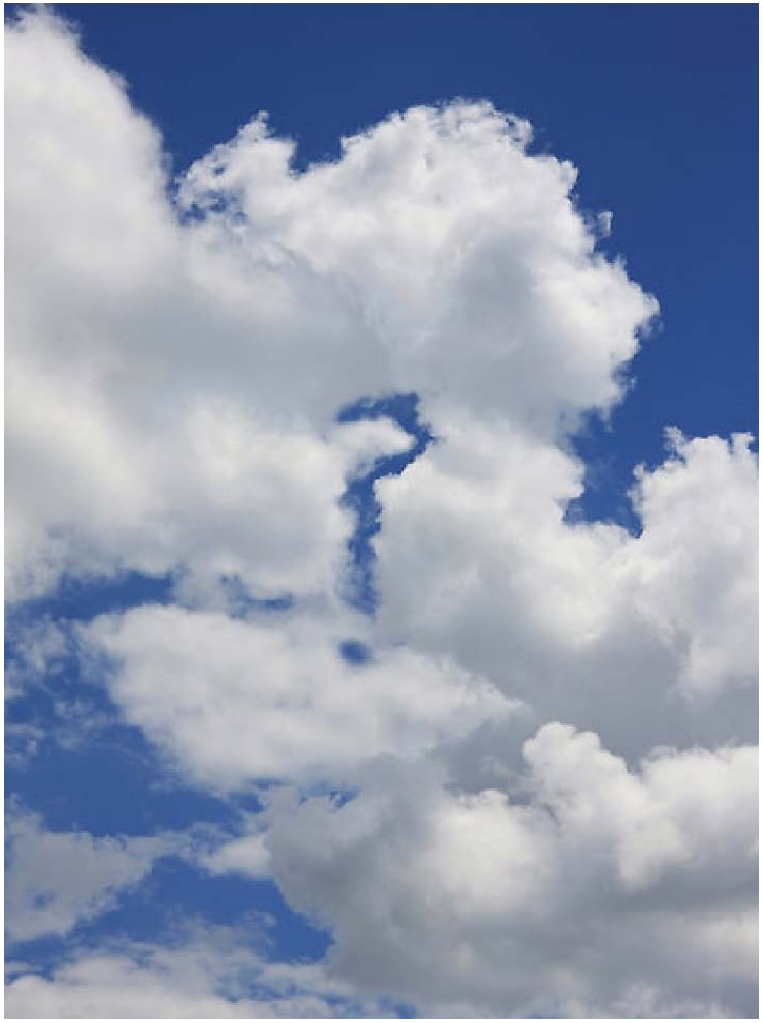

historical
RCP2.6
RCP4.5
RCP6.0
RCP8.5
42 models
39
25
42
32
12
17
12
Global surface temperature change (°C)
12
10
8
6
4
2
0
-2
1850
1900
1950
2000
2050
2100
2150
2200
2250
2300
Year

# Different models provide *the same (in some sense)* , *but different (in other sense)* answers



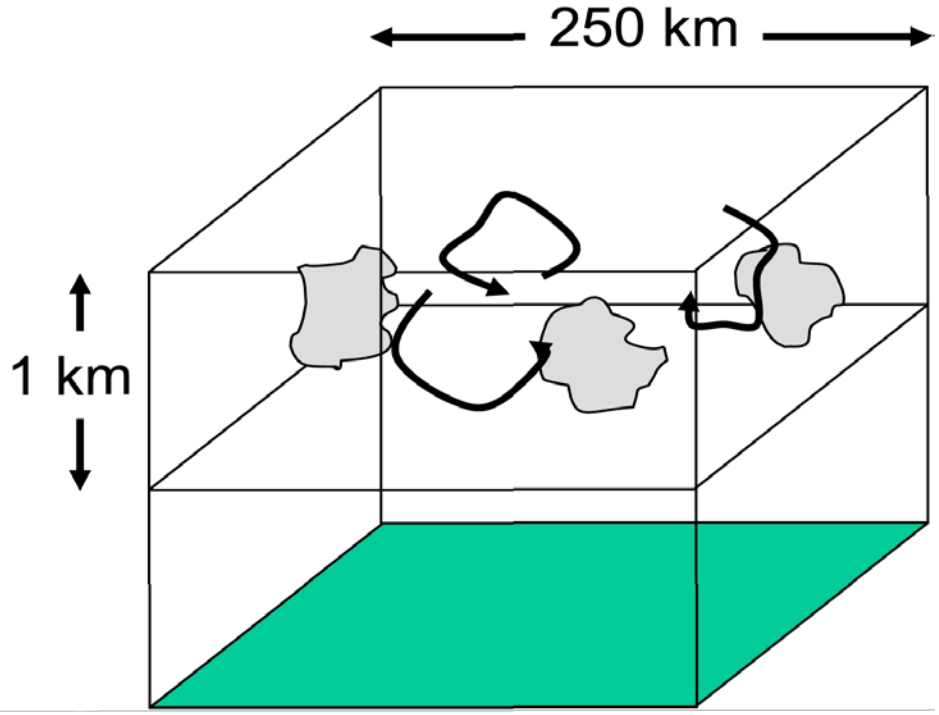
# What is the main source of climate model uncertainty



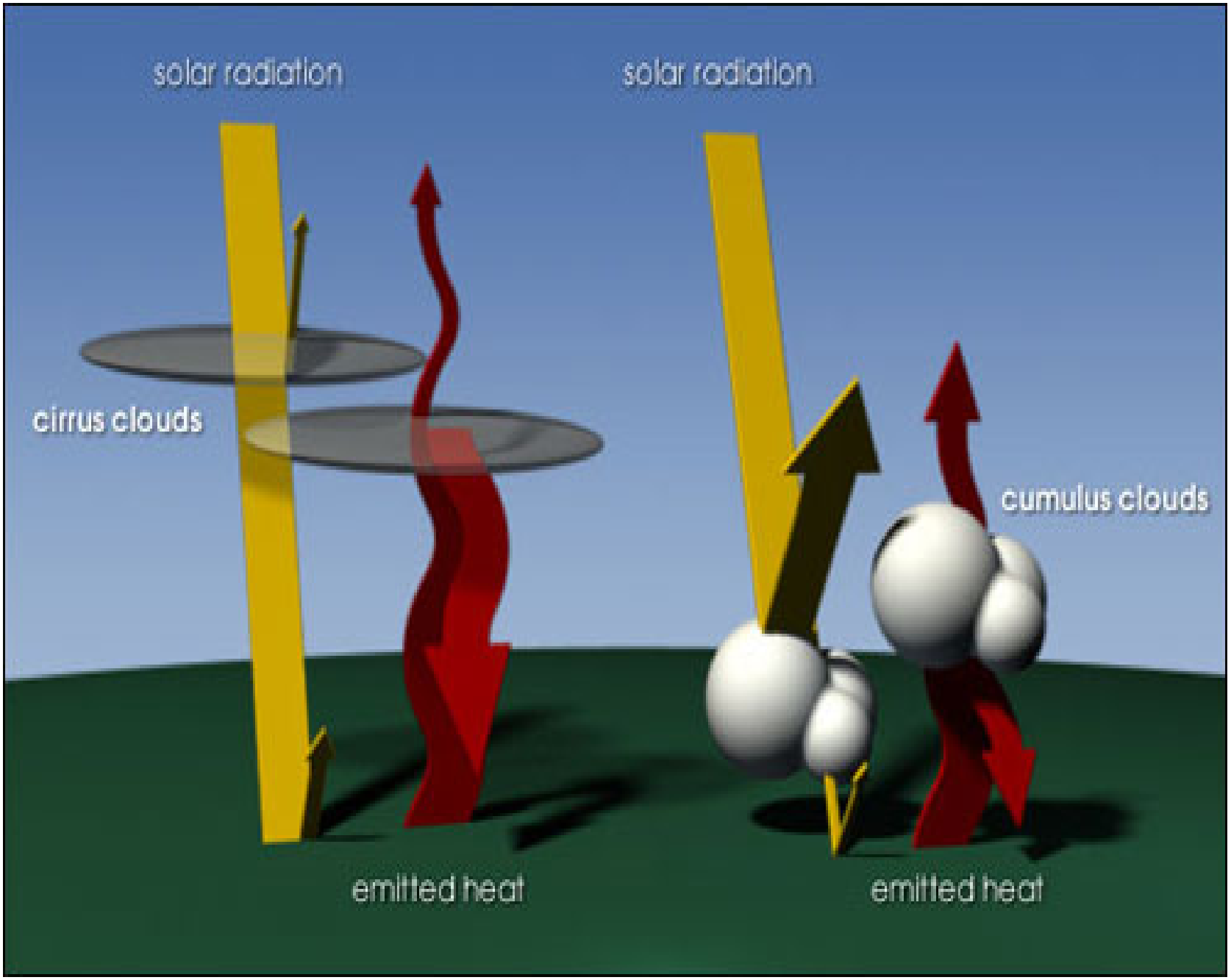
# GCM Resolution Difficulties

- grid boxes are typically 250 km wide and 1 km high
- processes important for cloud formation happen at much smaller scales
- it is very difficult to represent effects of clouds and small scale processes only in terms of grid box mean properties

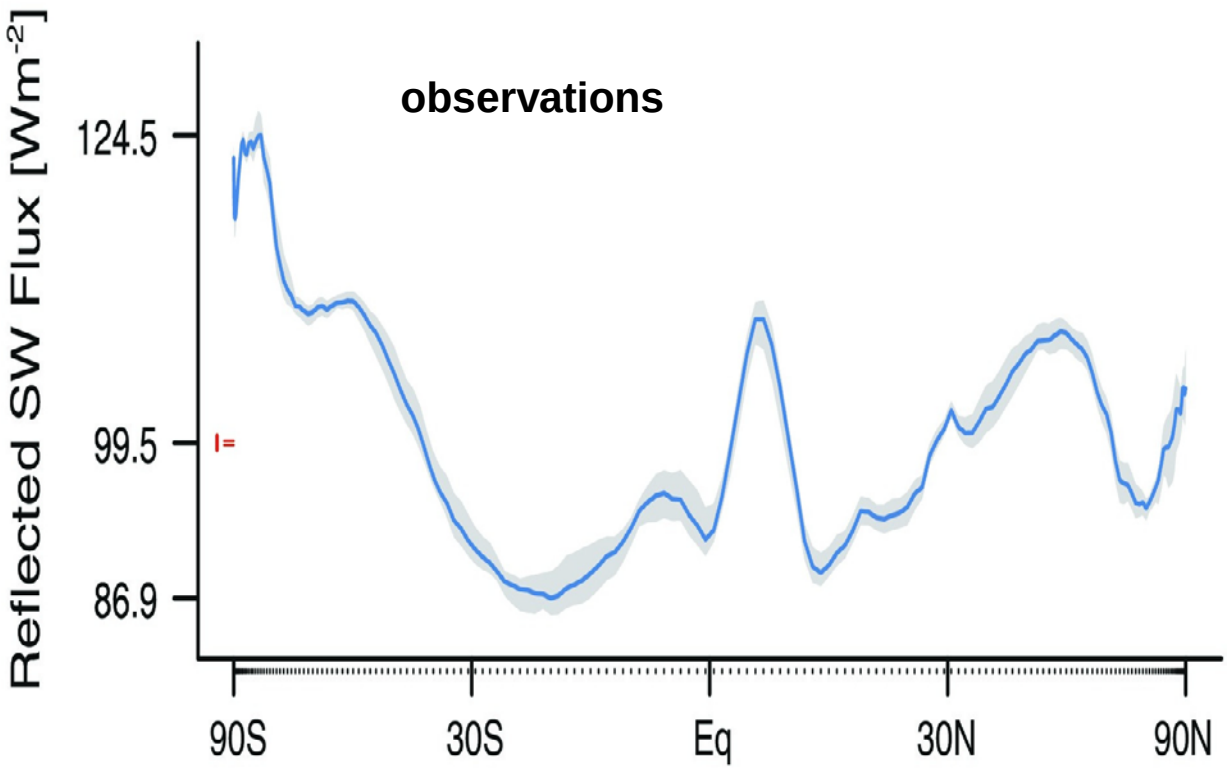
clouds and small-scale circulations



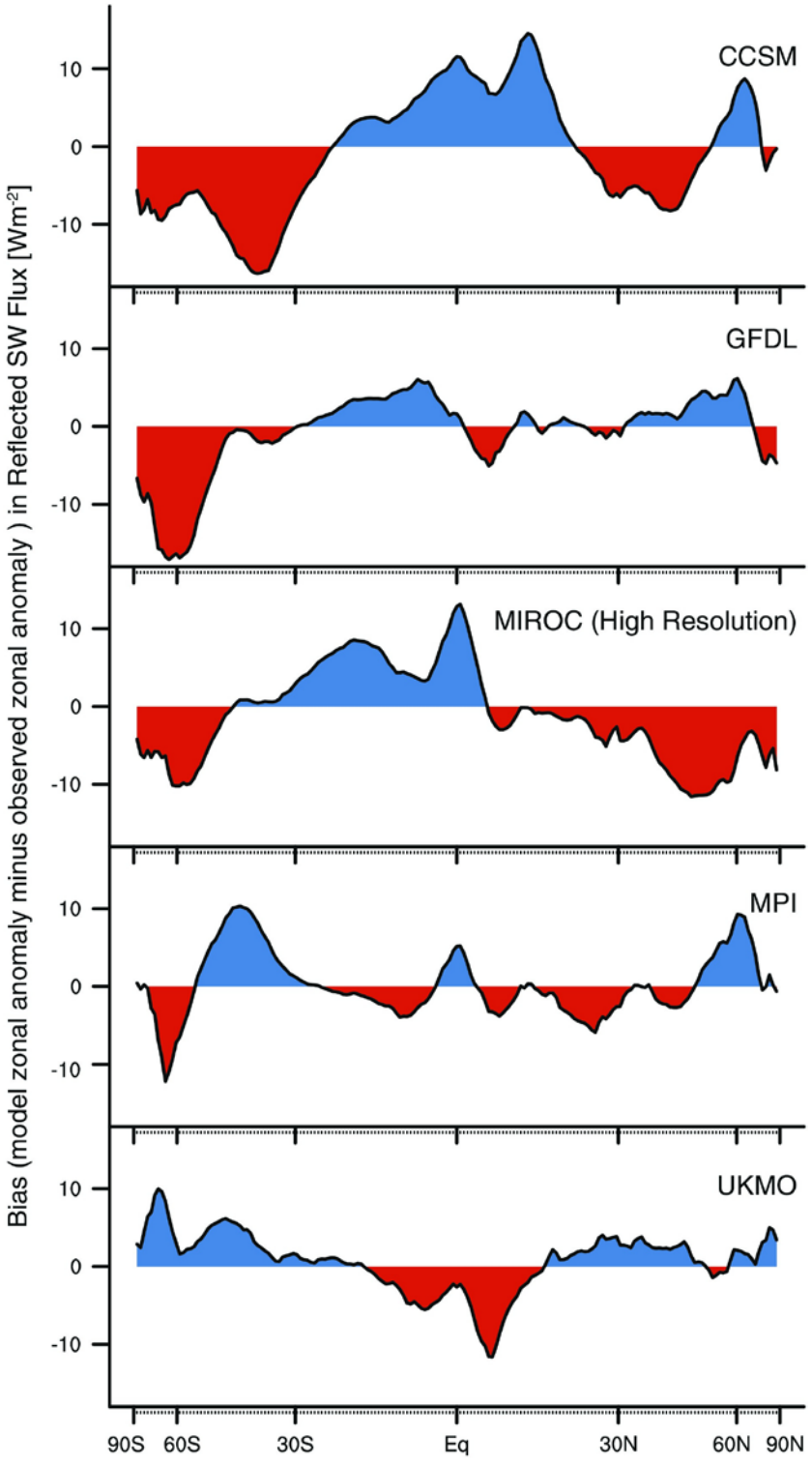
# Radiative properties of important cloud types



# Solar radiation reflected back to space



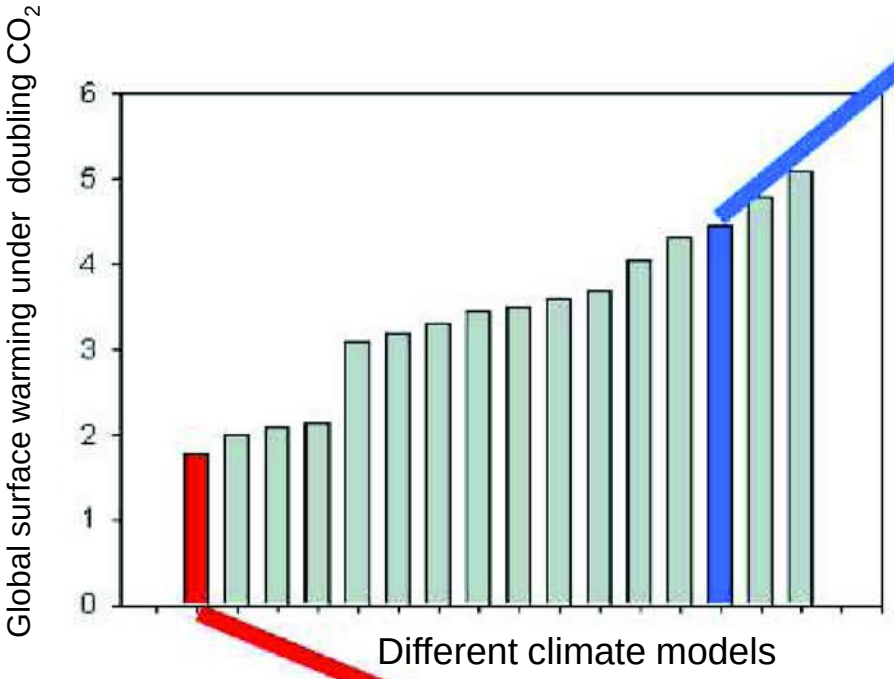

**Model bias:**
**mean difference between simulation and observations**

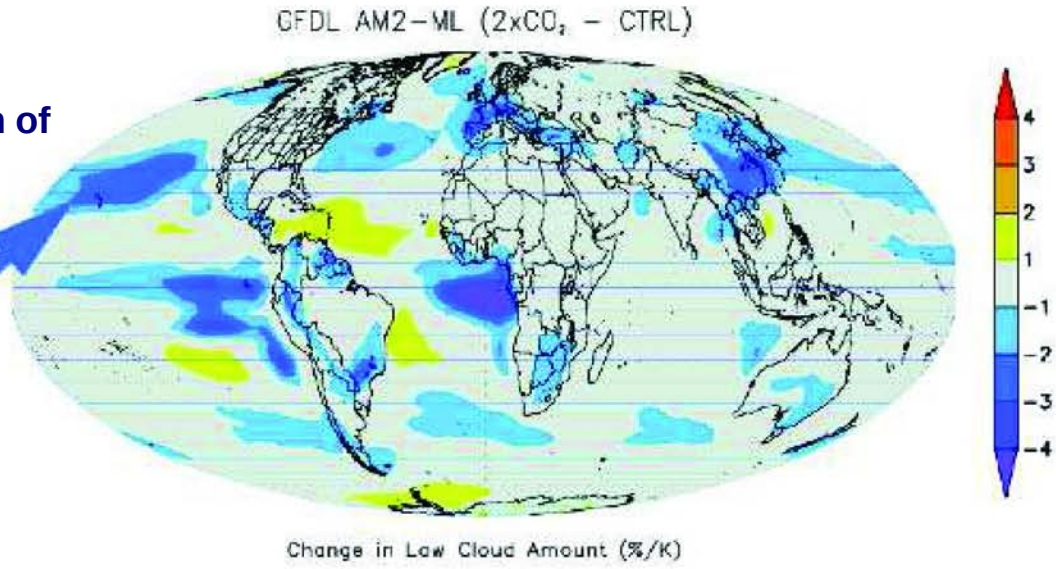


# Simulated changes in future cloud cover widely differ among models...

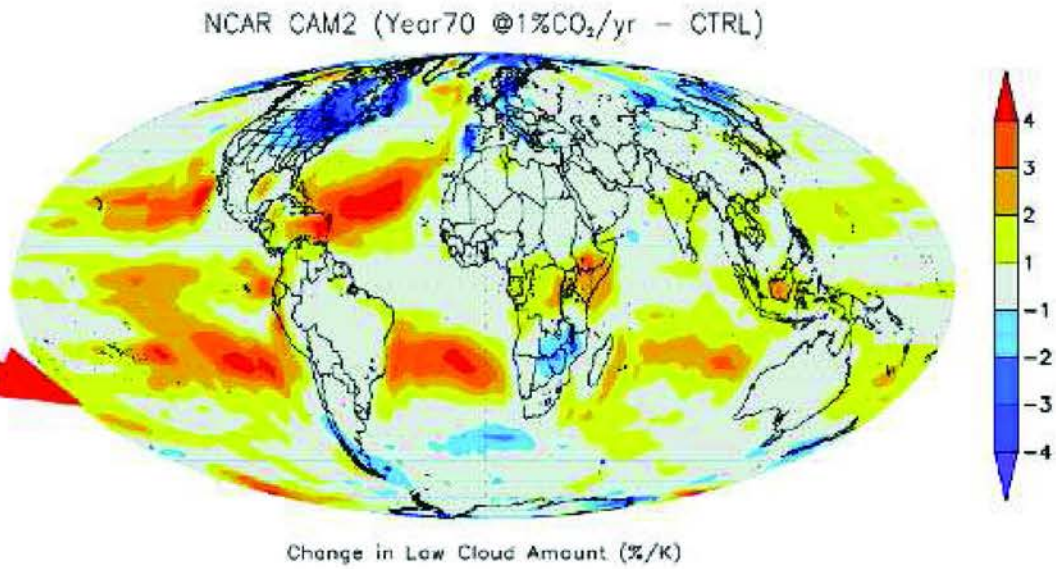
*Stephens, J. Climate 2005*

**.. and those differences are important for the simulation of global mean temperature changes**



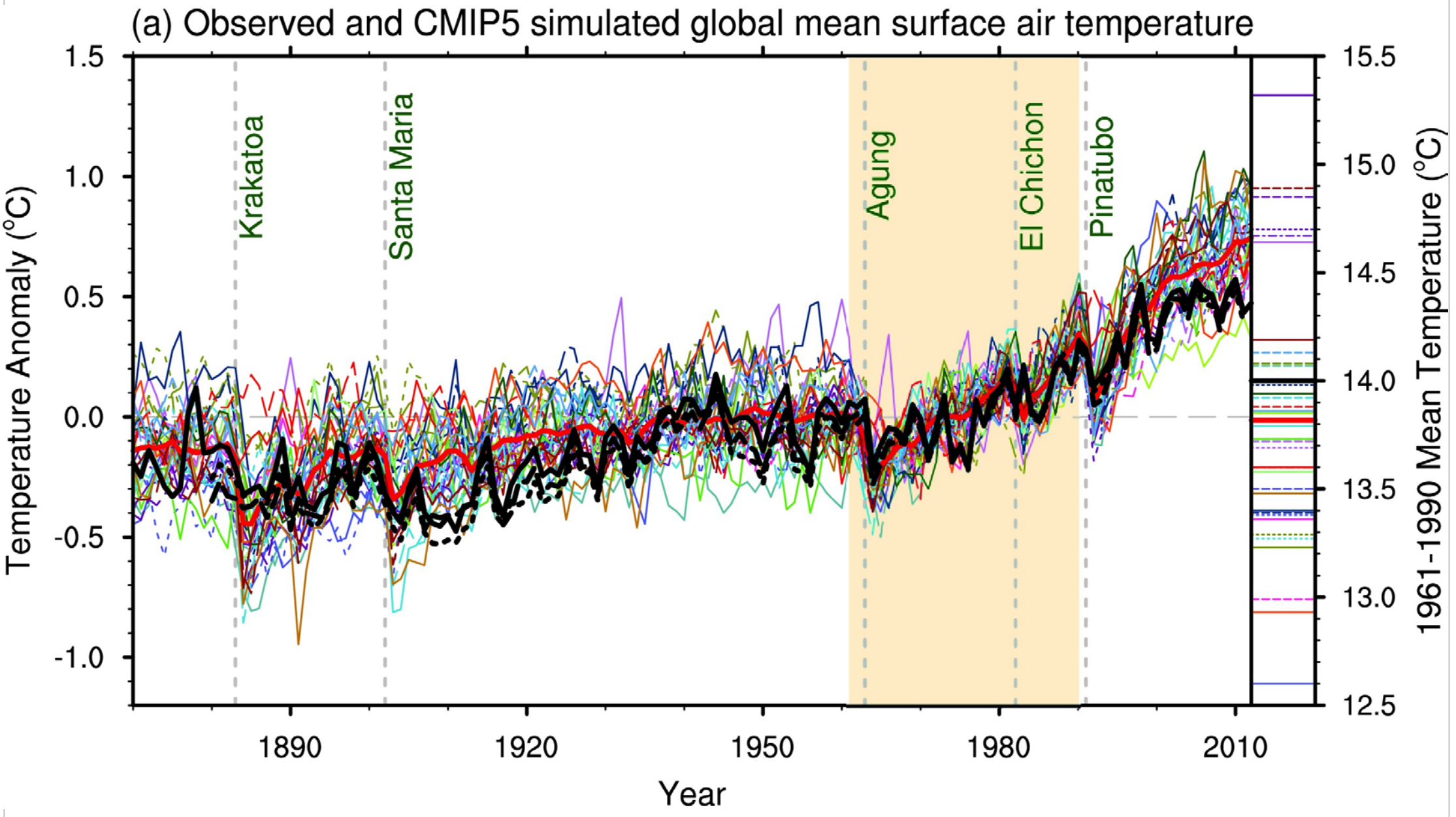




**Simulated changes in low-cloud cover**



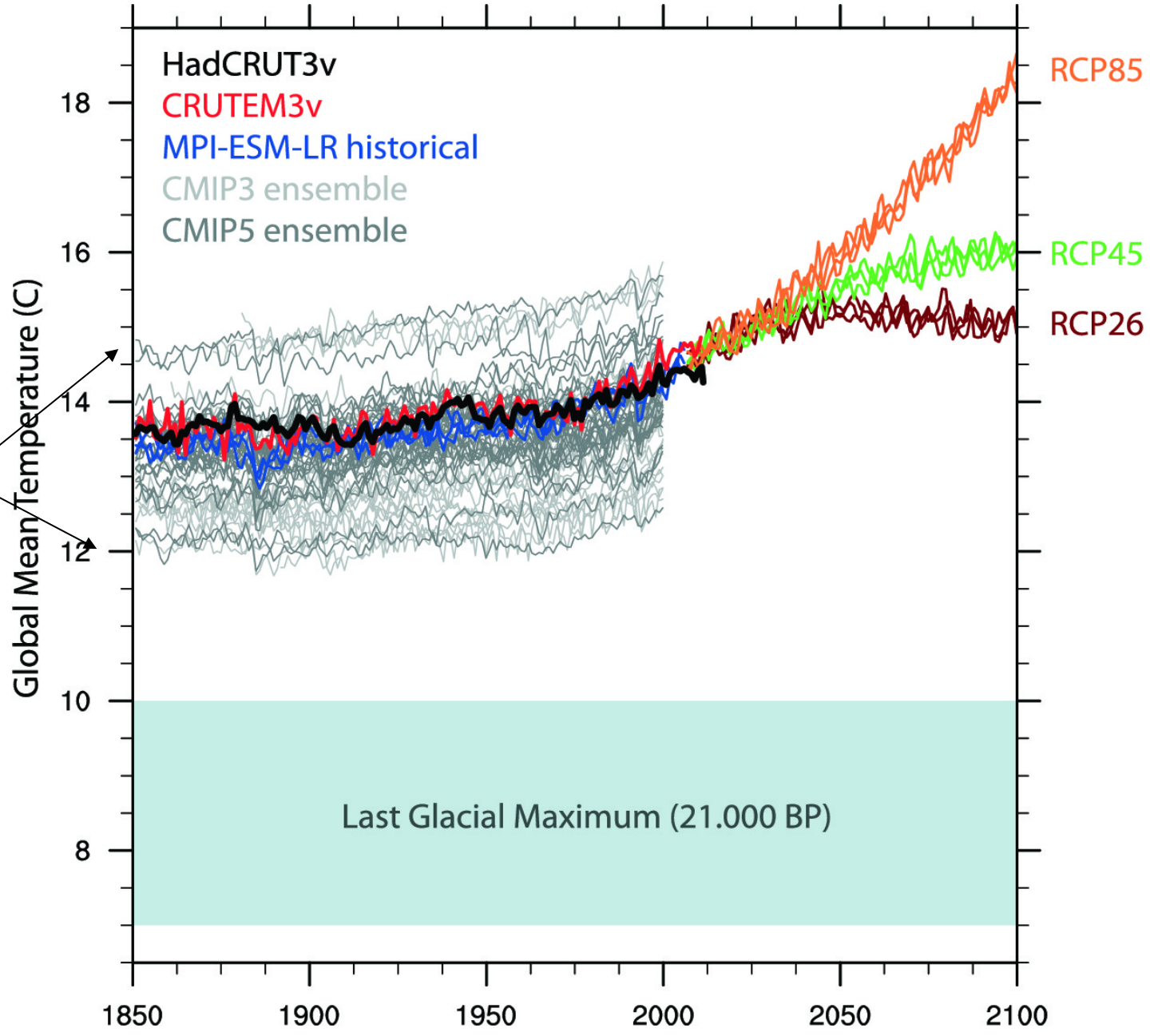

**Cloud feedback in action !**

# Can climate models simulate the observed climate ?



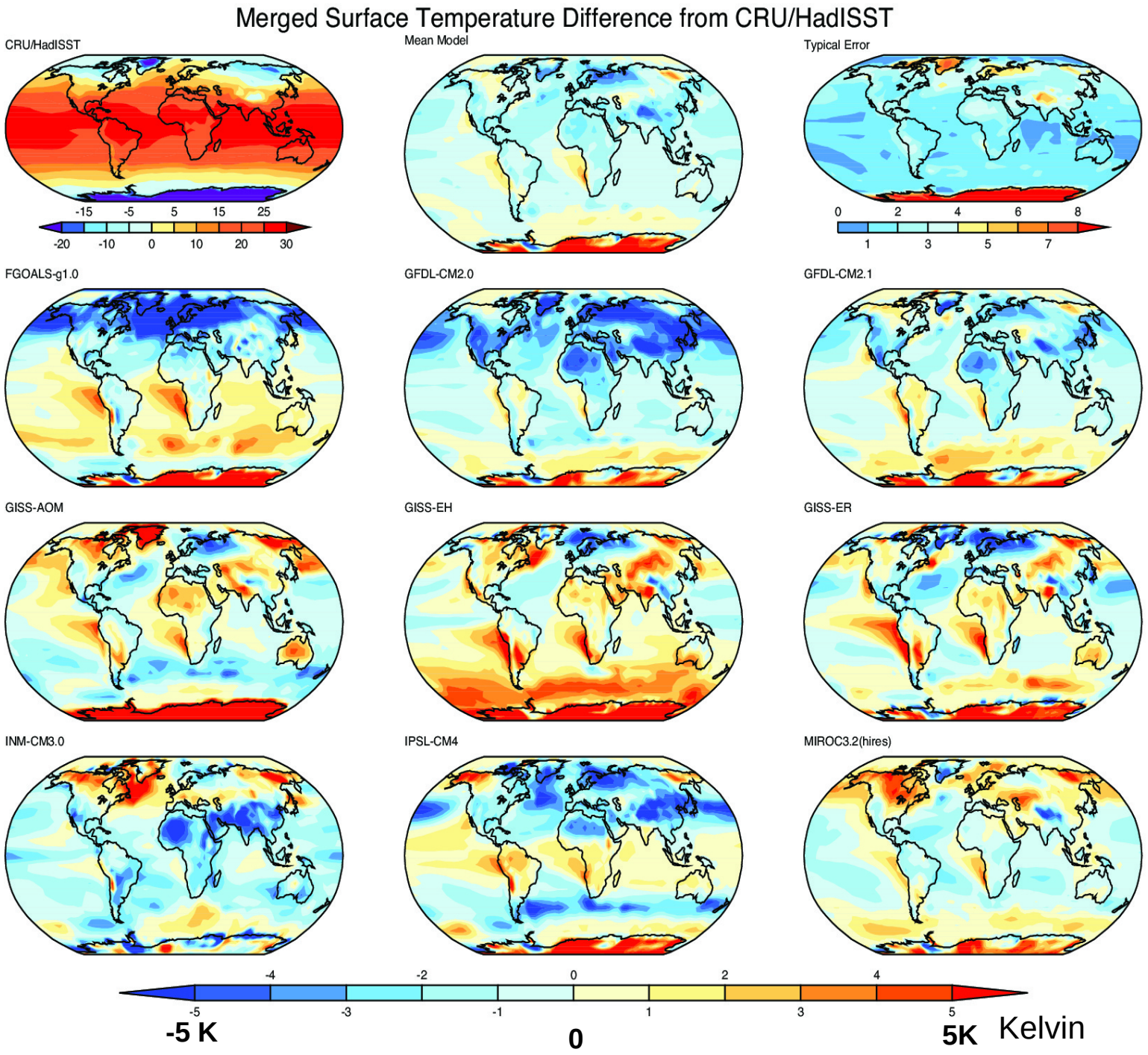
## Absolute global mean temperatures simulated by global climate models (Not changes from the mean)

Range of 2.5 degrees



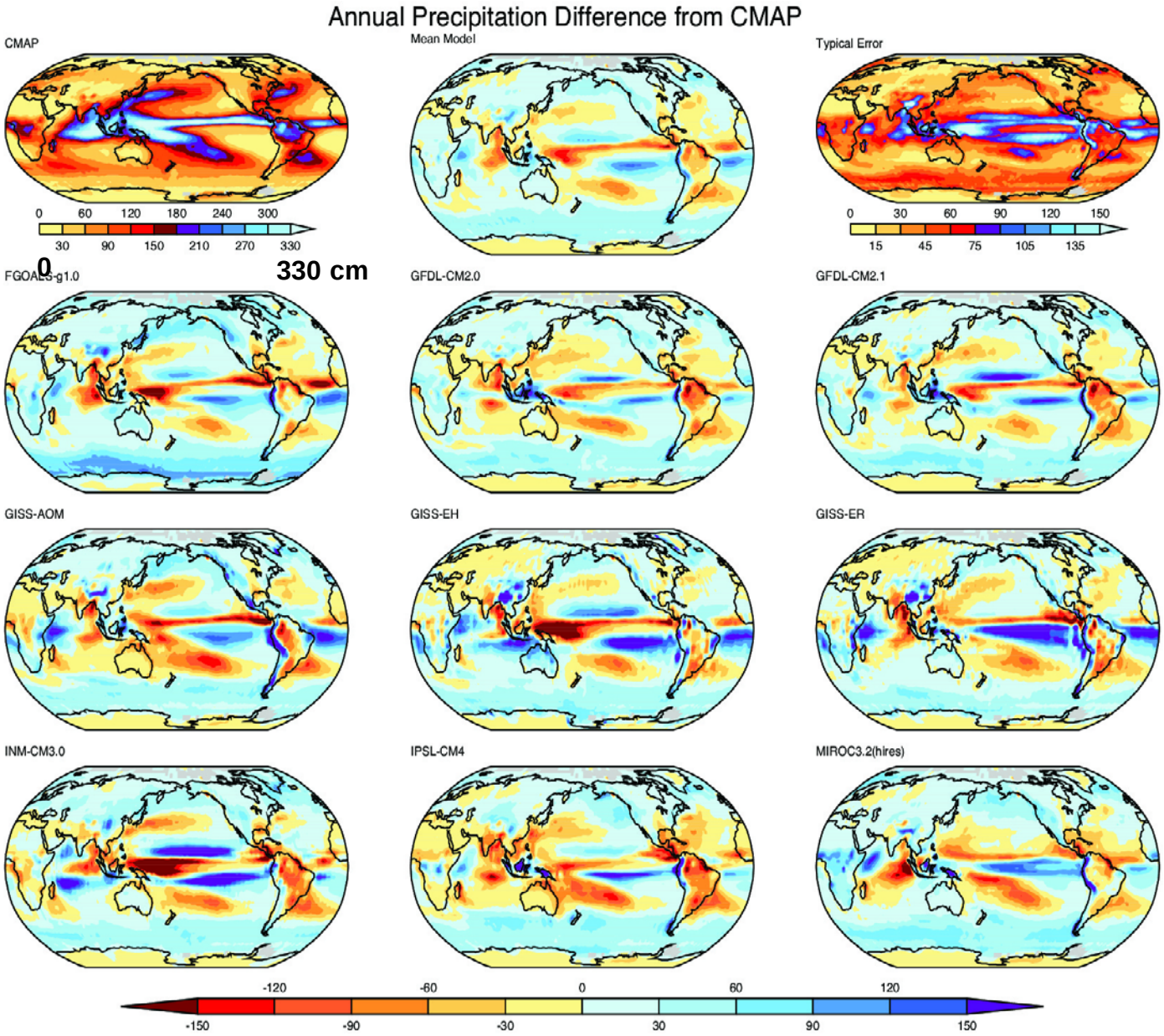

*Mauritsen et al., JAMS 2013*

# Bias in the annual mean temperature, some CMIP3 models

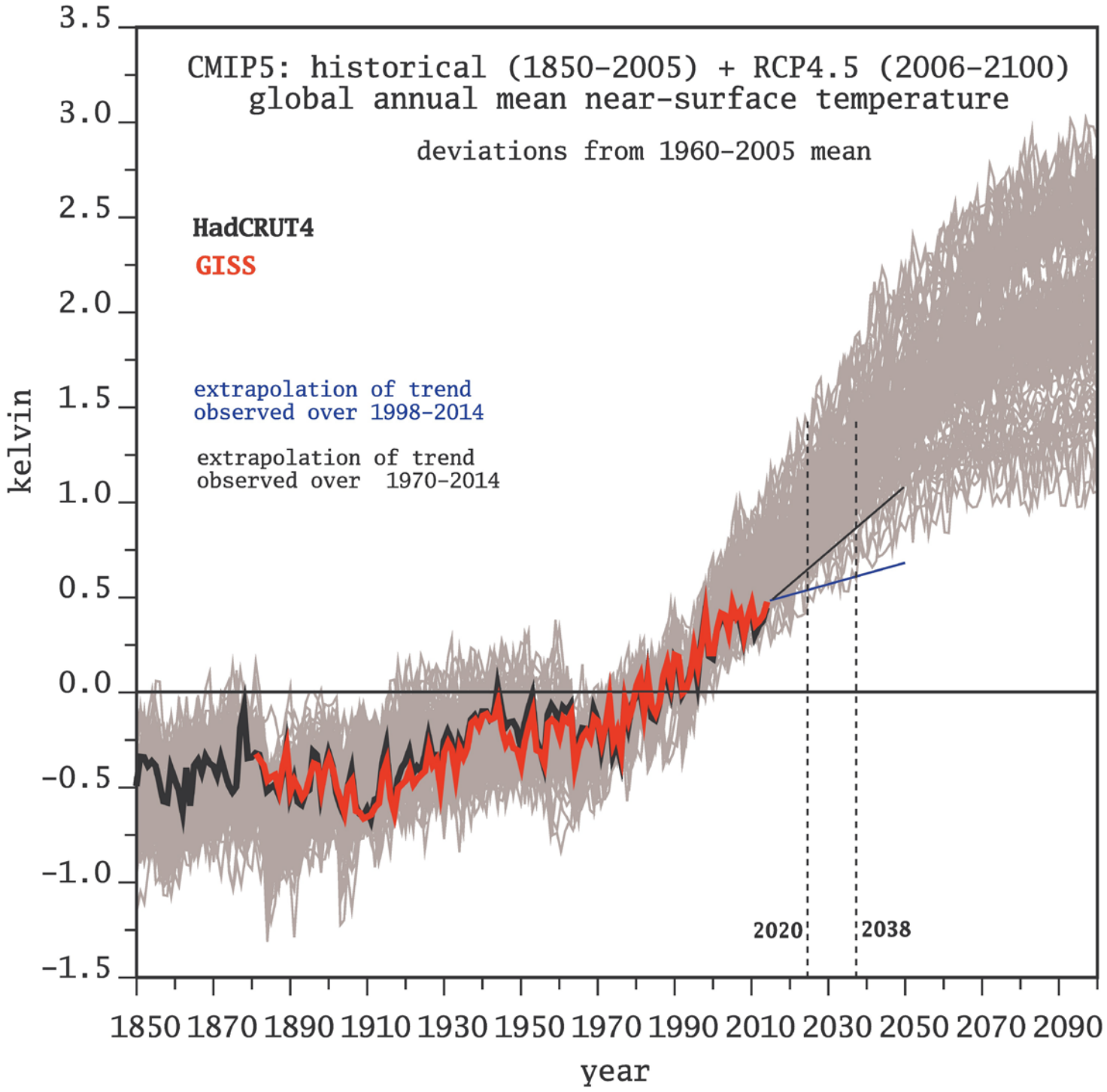


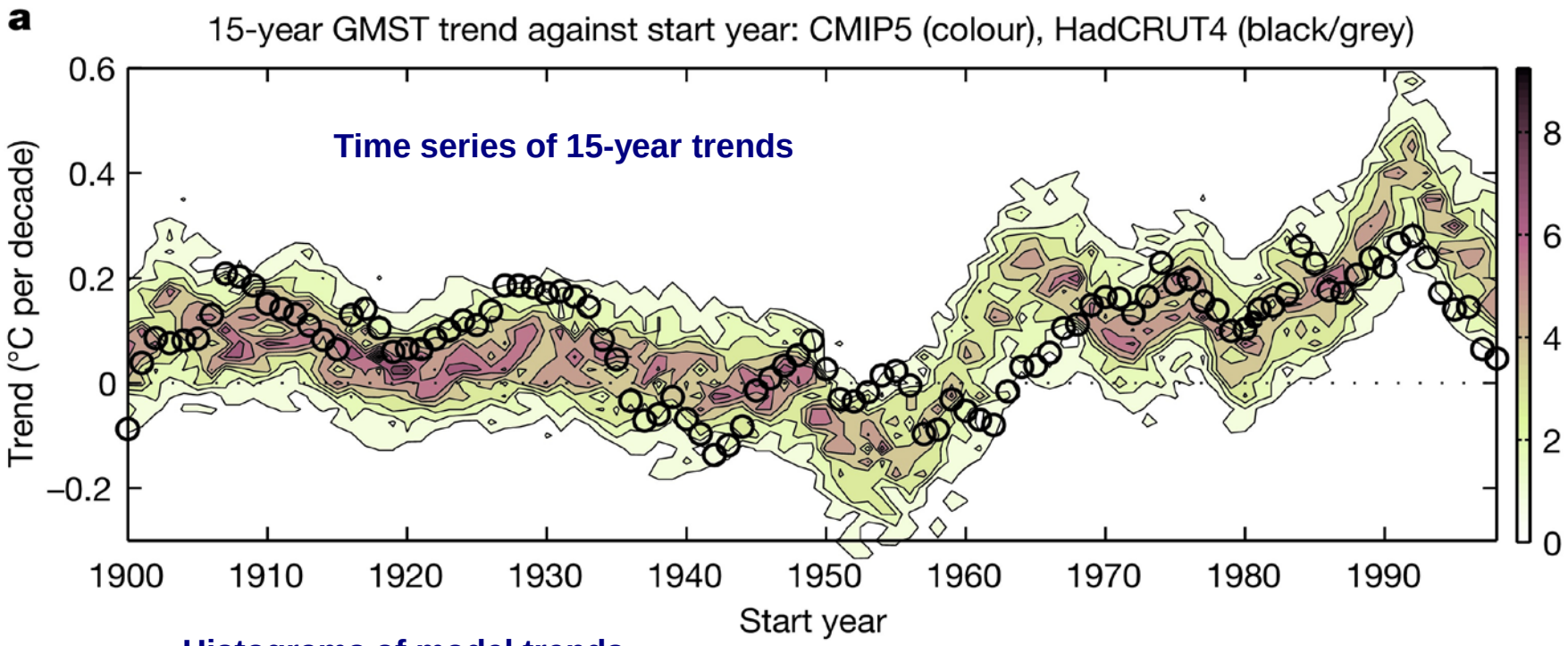

*IPCC Report, 2007*

# Bias in the annual mean precipitation, some CMIP3 models

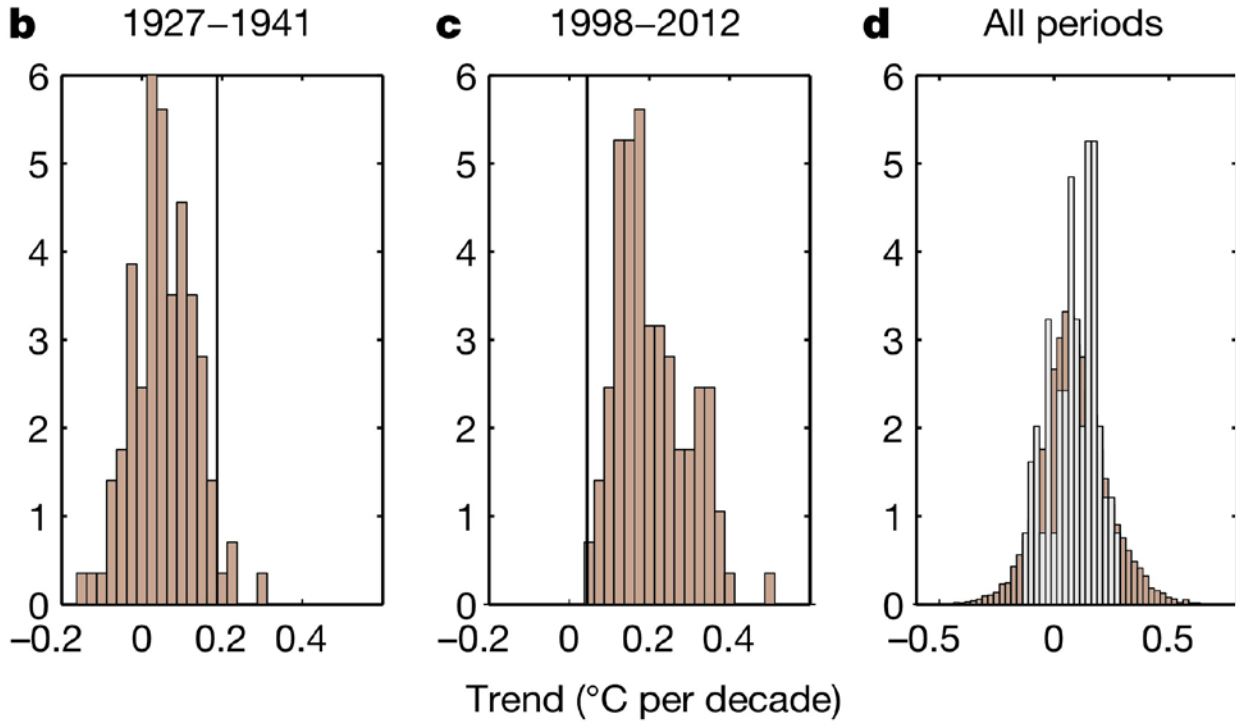



*IPCC Report, 2007*


CMIP5: historical (1850-2005) + RCP4.5 (2006-2100)
global annual mean near-surface temperature
deviations from 1960-2005 mean
HadCRUT4
GISS
extrapolation of trend
observed over 1998-2014
extrapolation of trend
observed over 1970-2014
2020
2038
kelvin
year
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
1850 1870 1890 1910 1930 1950 1970 1990 2010 2030 2050 2070 2090



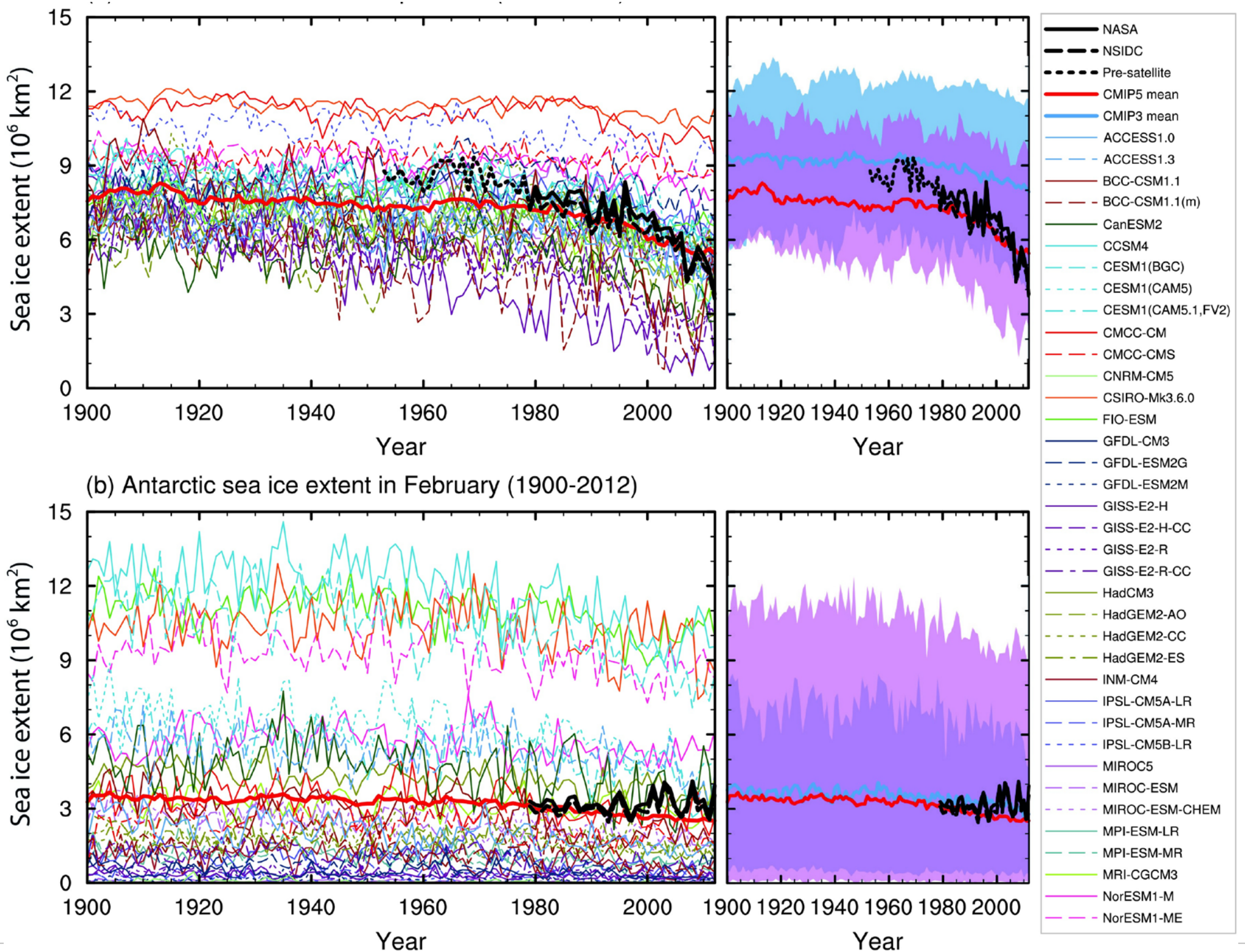

**Histograms of model trends**



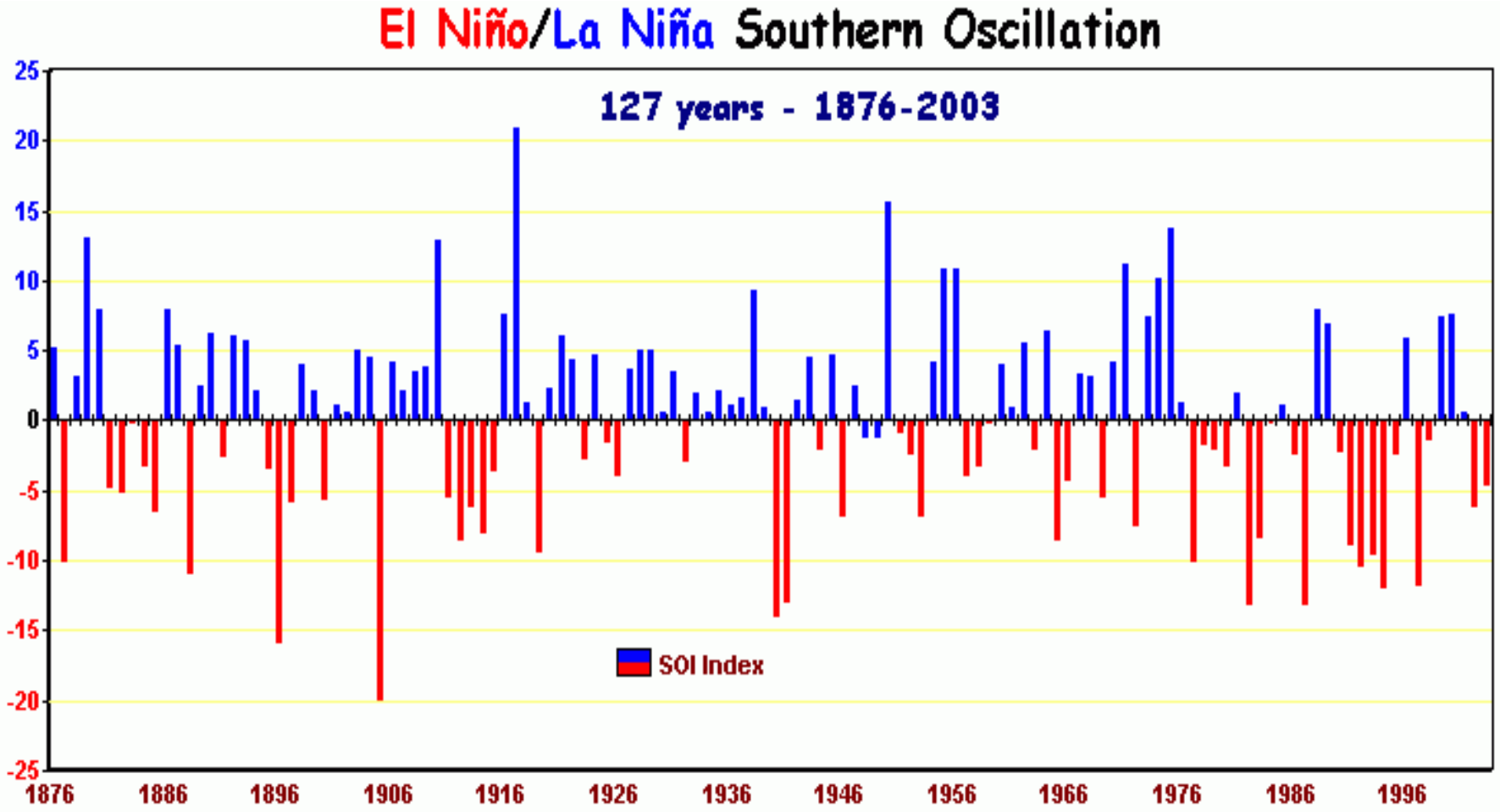

**Do models overestimate warming trends?**

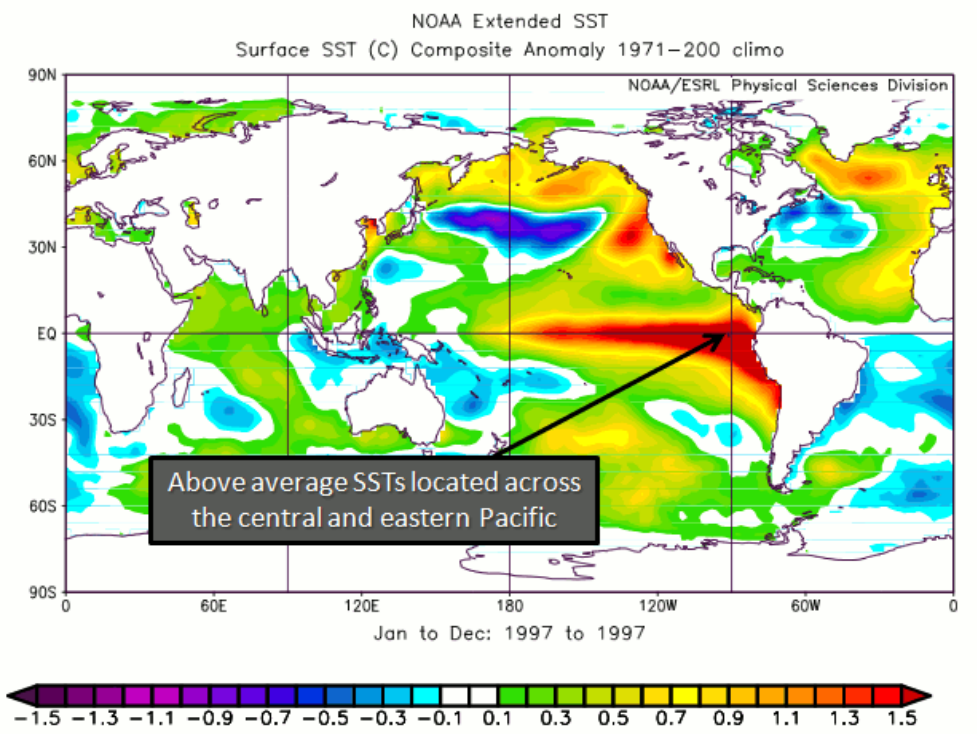
**Opinions vary**

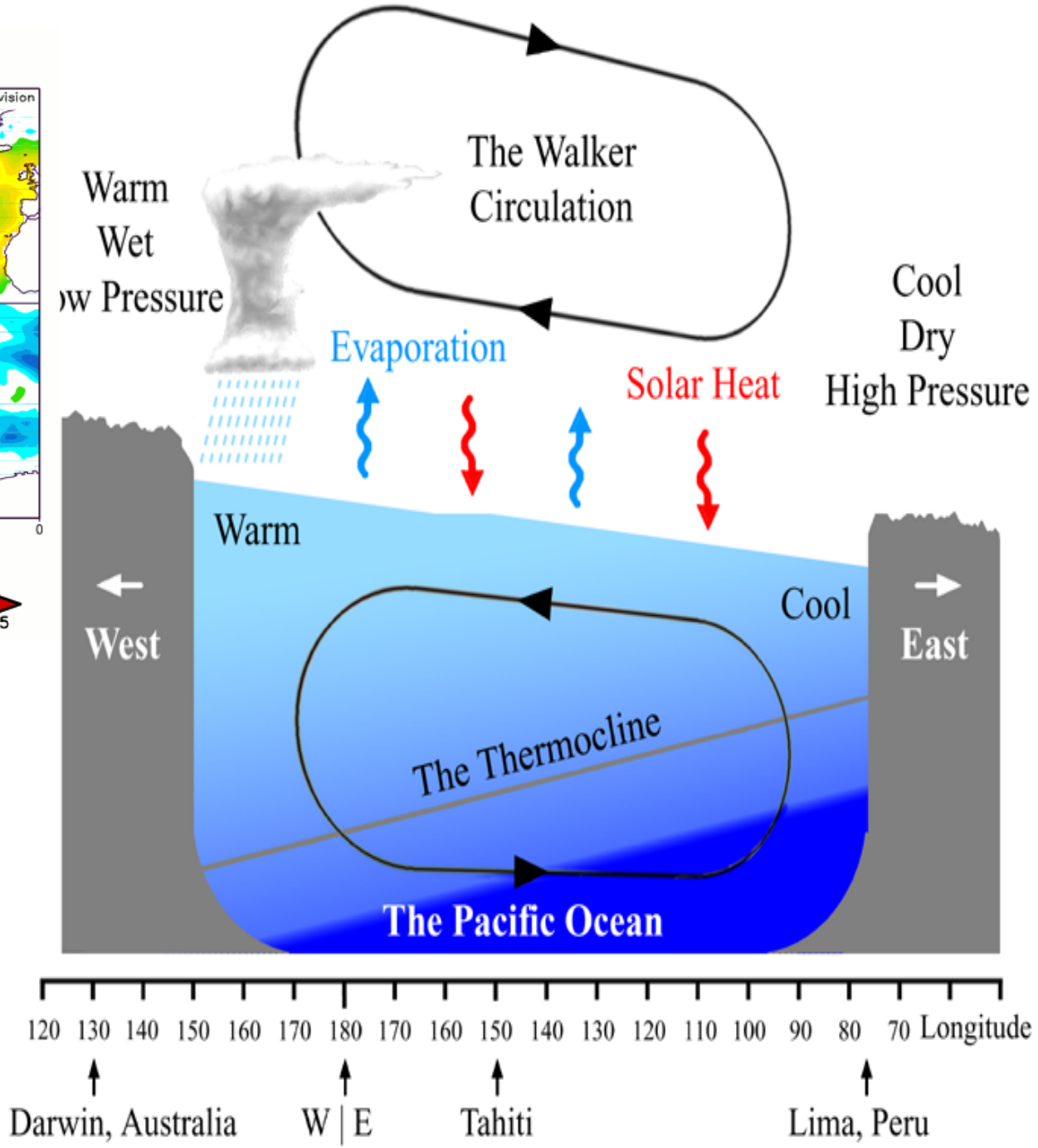
*Marotzle and Forster, Nature 2015*

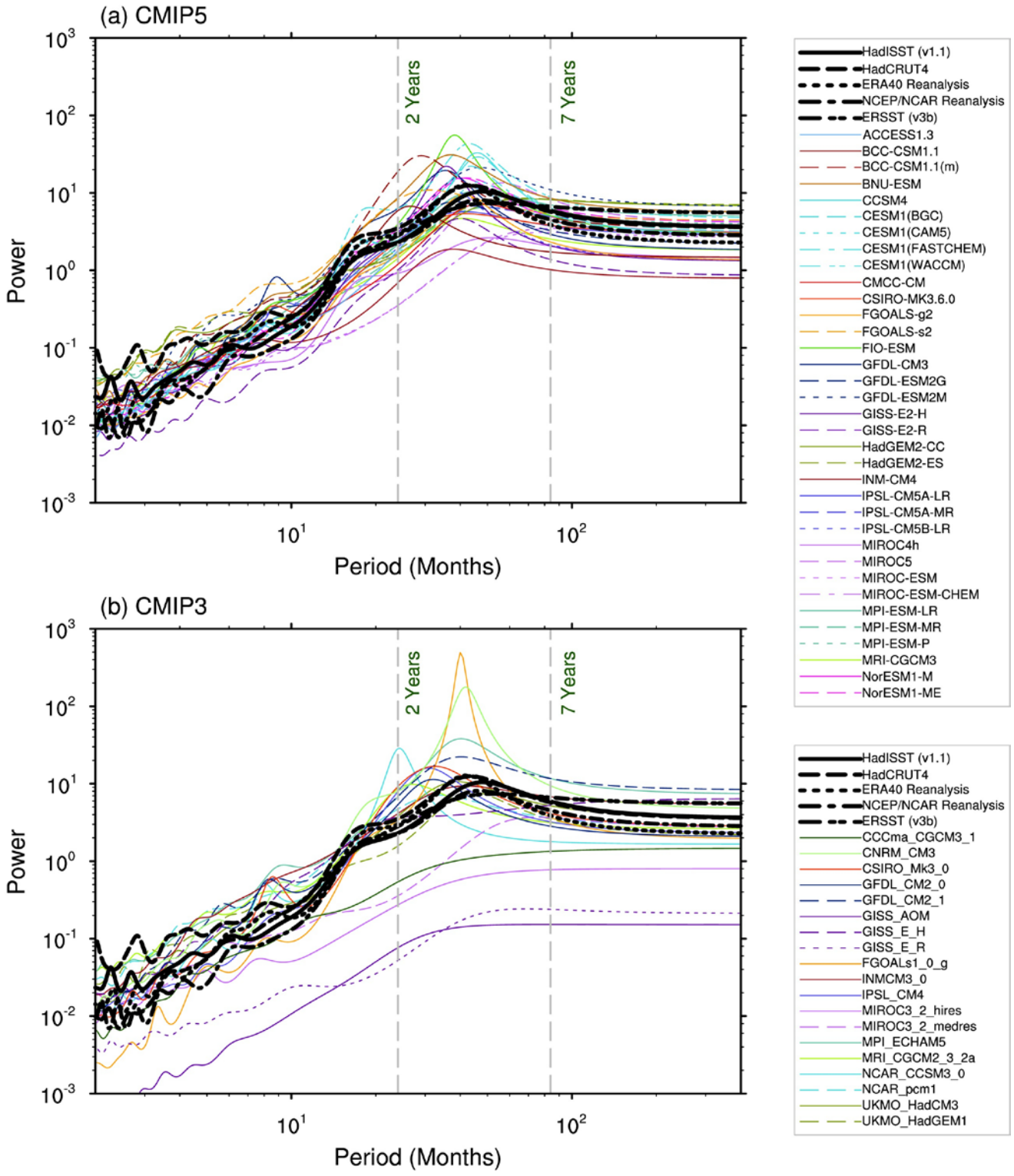

Sea ice extent ($10^6$ km$^2$)
15
12
9
6
3
0
1900
1920
1940
1960
1980
2000
Year
(b) Antarctic sea ice extent in February (1900-2012)
NASA
NSIDC
Pre-satellite
CMIP5 mean
CMIP3 mean
ACCESS1.0
ACCESS1.3
BCC-CSM1.1
BCC-CSM1.1(m)
CanESM2
CCSM4
CESM1(BGC)
CESM1(CAM5)
CESM1(CAM5.1,FV2)
CMCC-CM
CMCC-CMS
CNRM-CM5
CSIRO-Mk3.6.0
FIO-ESM
GFDL-CM3
GFDL-ESM2G
GFDL-ESM2M
GISS-E2-H
GISS-E2-H-CC
GISS-E2-R
GISS-E2-R-CC
HadCM3
HadGEM2-AO
HadGEM2-CC
HadGEM2-ES
INM-CM4
IPSL-CM5A-LR
IPSL-CM5A-MR
IPSL-CM5B-LR
MIROC5
MIROC-ESM
MIROC-ESM-CHEM
MPI-ESM-LR
MPI-ESM-MR
MRI-CGCM3
NorESM1-M
NorESM1-ME

# Can global models simulate internal variability well ?




NOAA Extended SST
Surface SST (C) Composite Anomaly 1971–200 climo
NOAA/ESRL Physical Sciences Division
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
Above average SSTs located across the central and eastern Pacific
Jan to Dec: 1997 to 1997
−1.5 −1.3 −1.1 −0.9 −0.7 −0.5 −0.3 −0.1 0.1 0.3 0.5 0.7 0.9 1.1 1.3 1.5


The Walker Circulation
Warm
Wet
w Pressure
Evaporation
Solar Heat
Cool
Dry
High Pressure
Warm
West
Cool
East
The Thermocline
The Pacific Ocean
120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 Longitude
Darwin, Australia
W | E
Tahiti
Lima, Peru




**Very few climate models are able to replicate the temporal variability of ENSO**

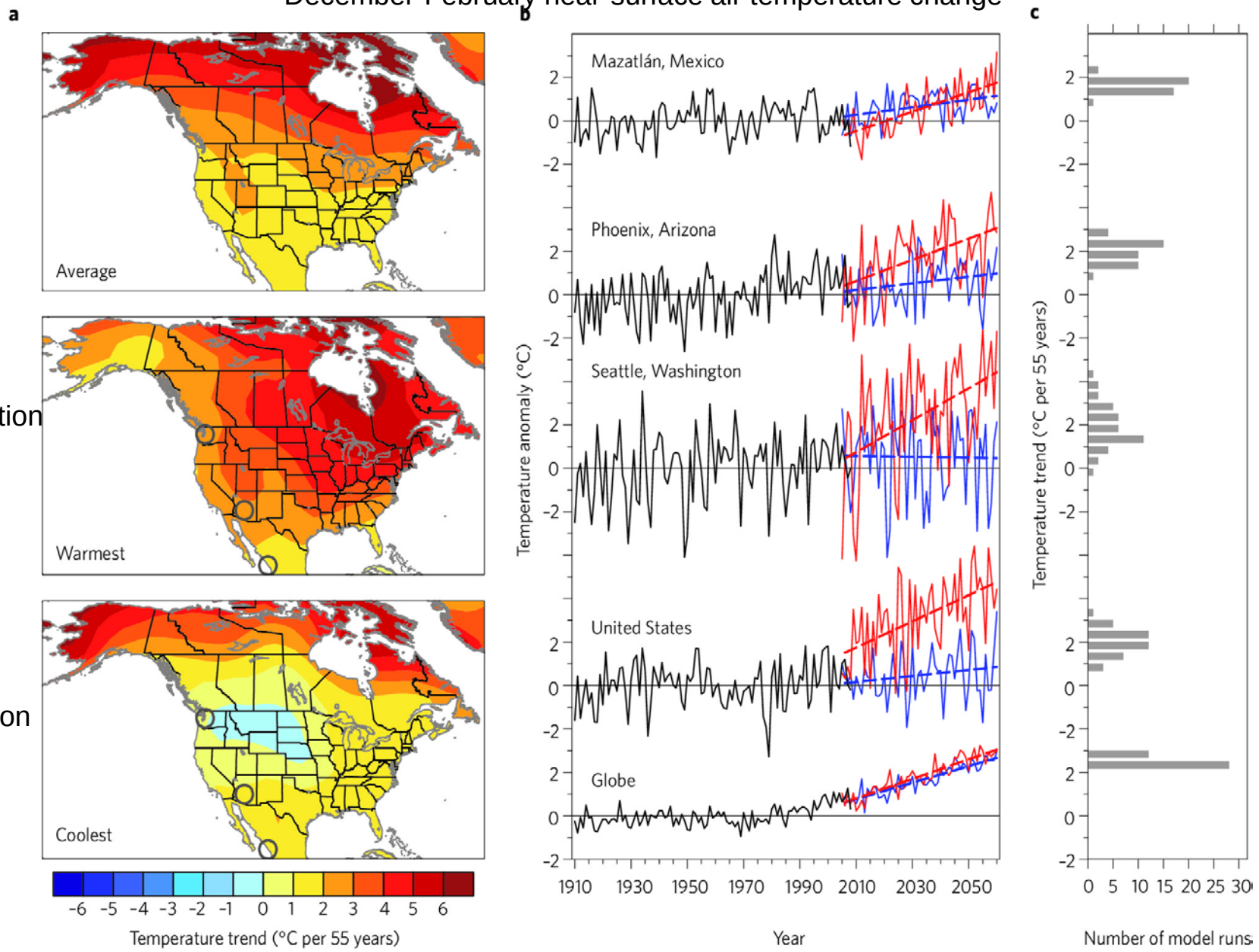
# The importance of internal variability: Same model (CCSM3) , same scenario (A1B), different conditions

December-February near-surface air temperature change

Mean of all simulations

'Warmes't simulation

Coldest simulation




*Deser et al., Nature Climate Change 2012*

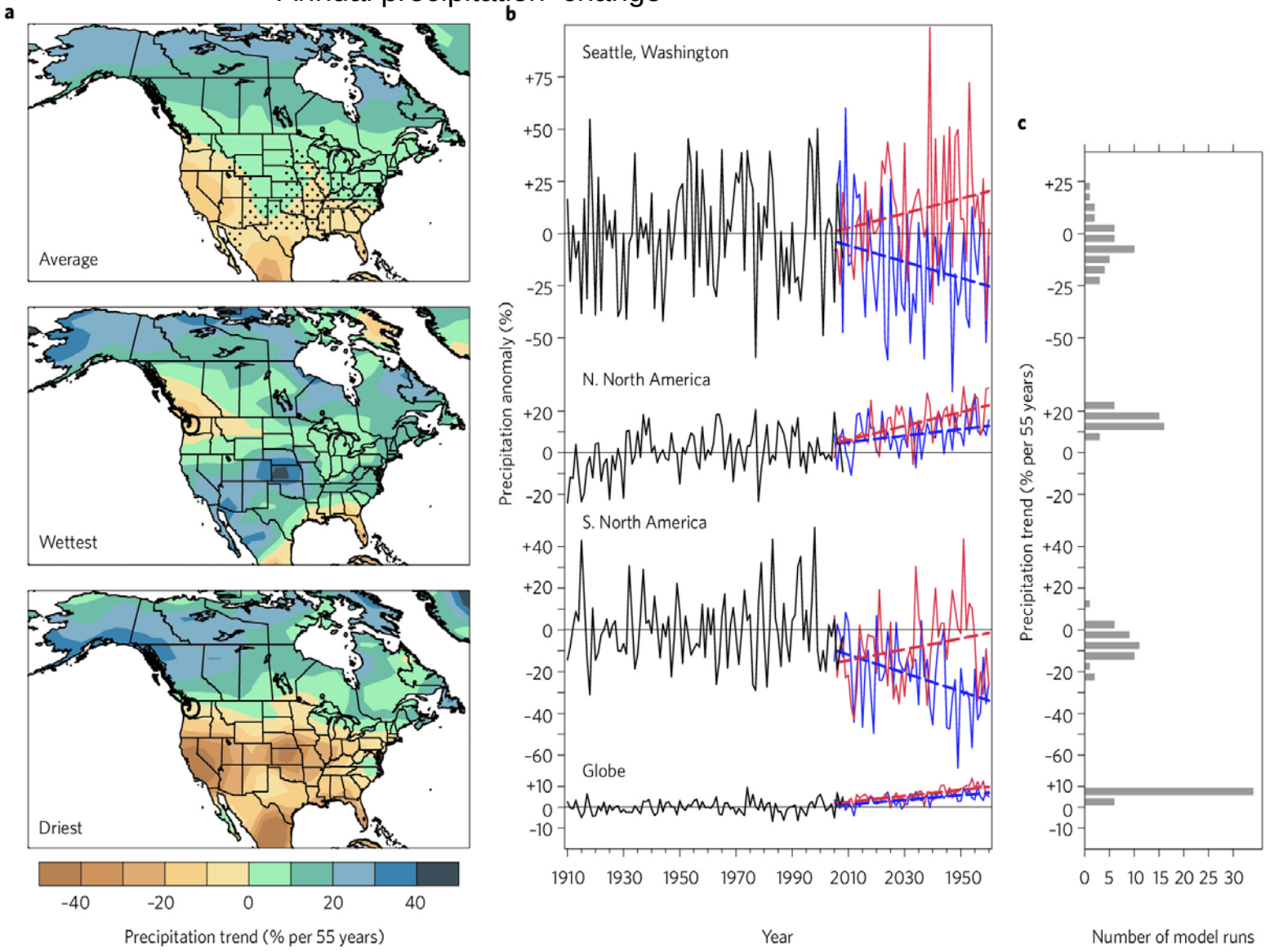
# The amplitude of internal variability: Same model (CCSM3) , same scenario (A1B), different conditions

Annual precipitation change

Mean of all simulations

Wettest simulation

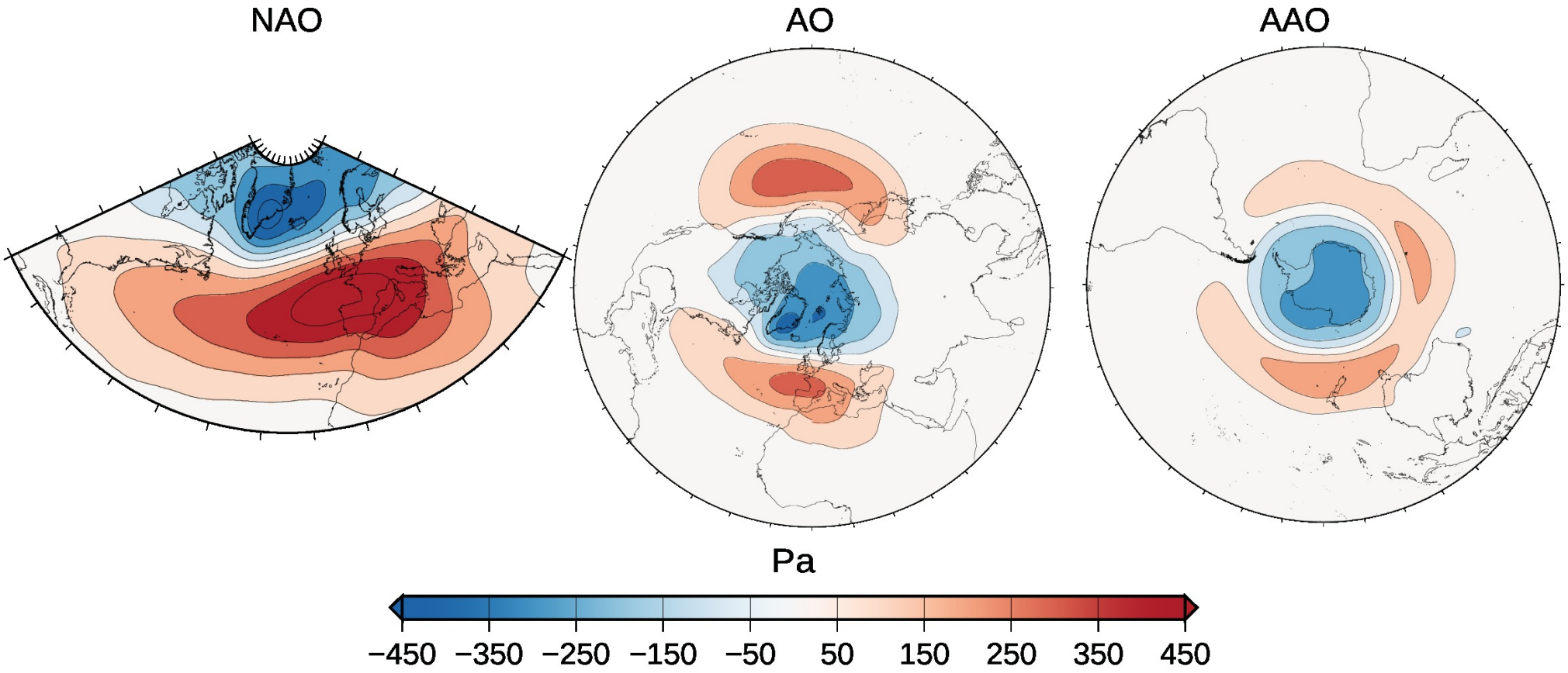
Driest simulation



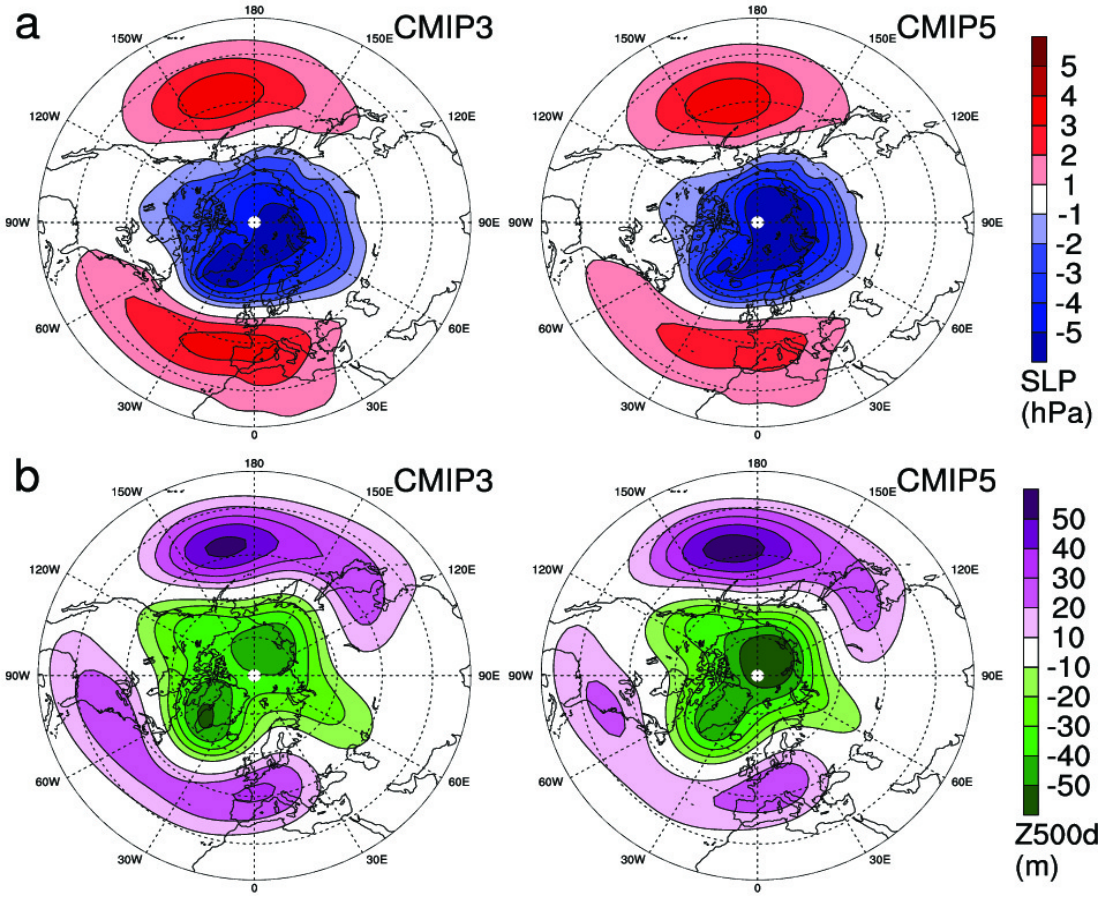

*Deser et al., Nature Climate Change 2012*

# The annular modes + NAO, simulated by a CMIP5 model

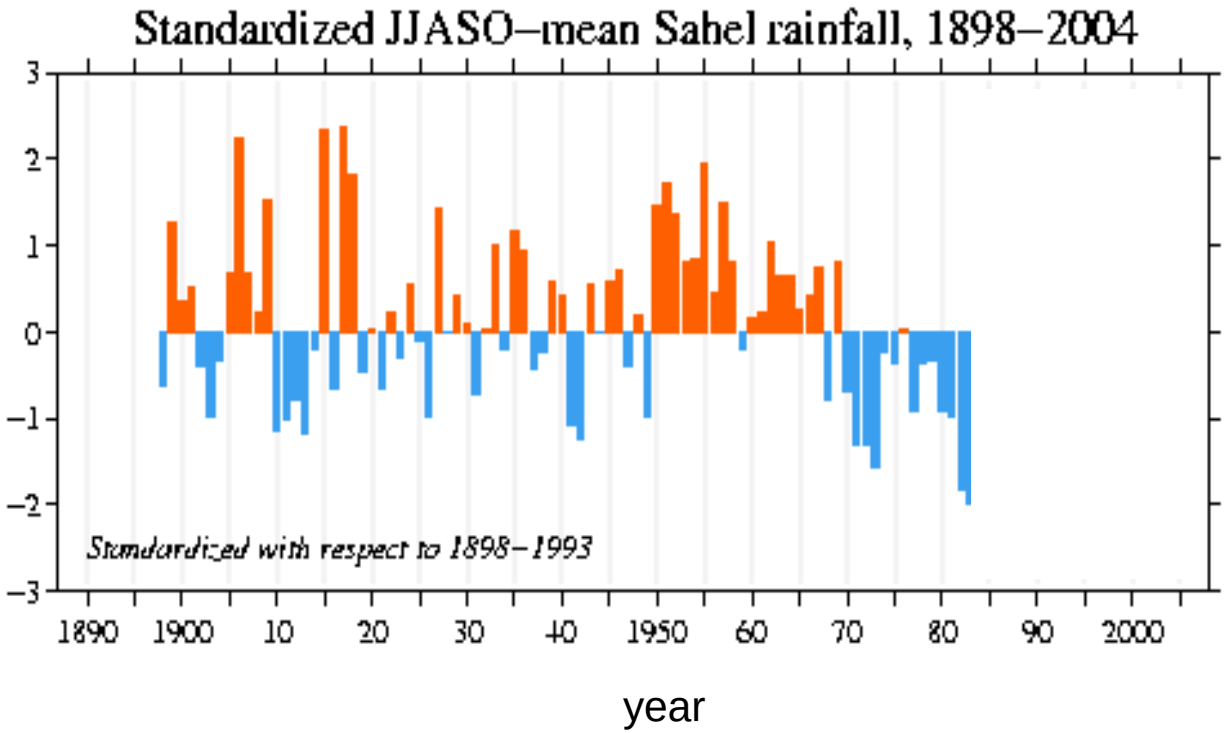
EOFs of the sea-level-pressure field in December-February

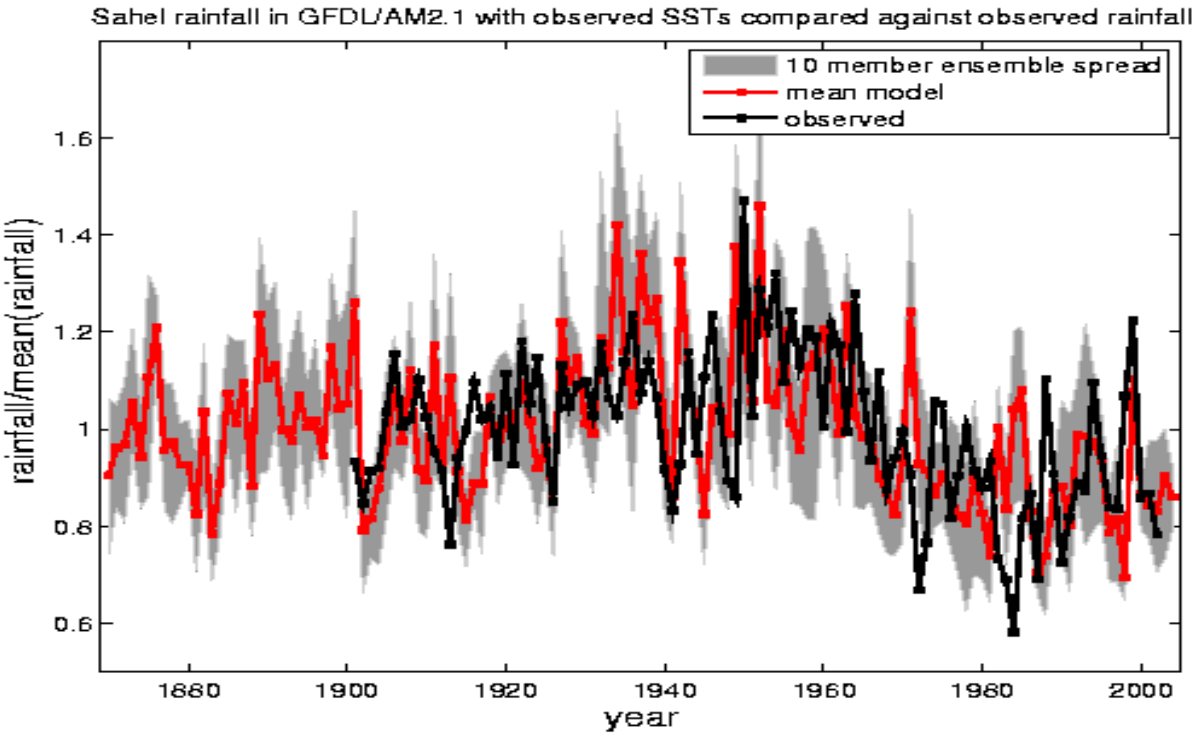


# Influence of model version



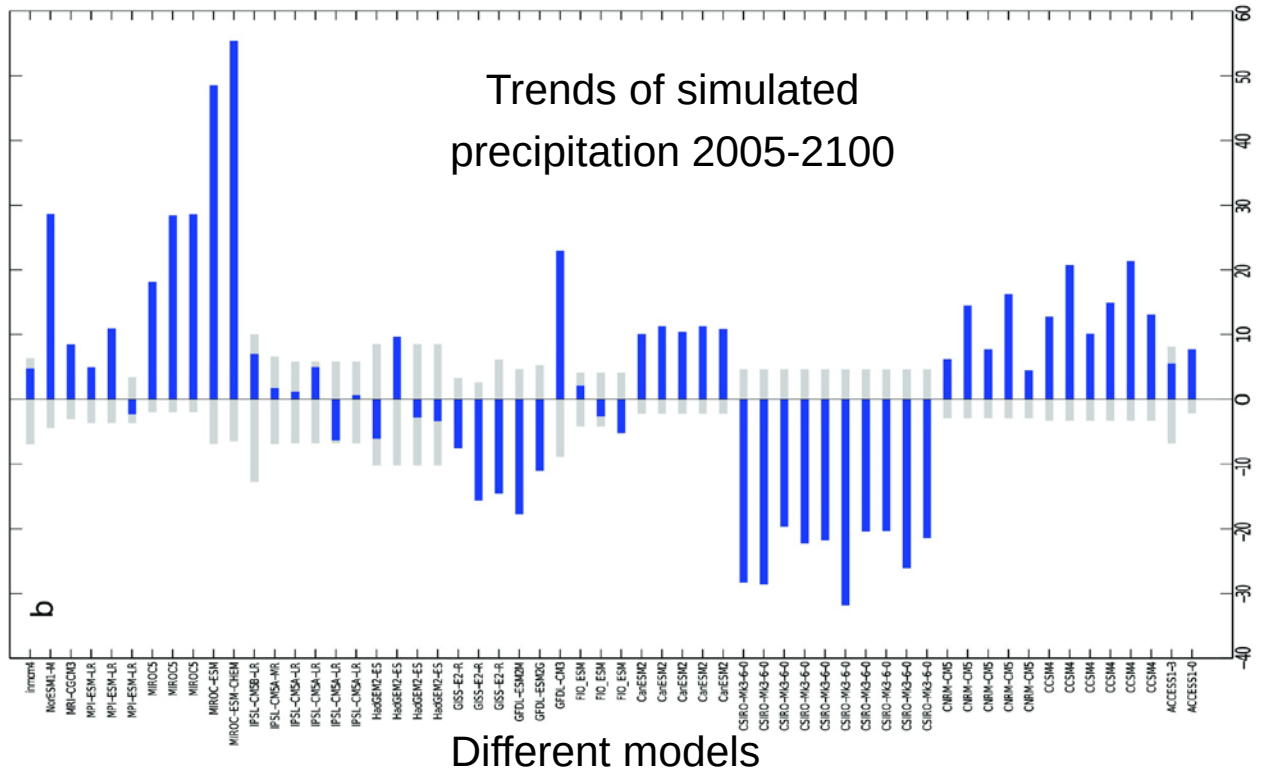

*Cattiaux and Casson, J. Geophys. Res. 2013*

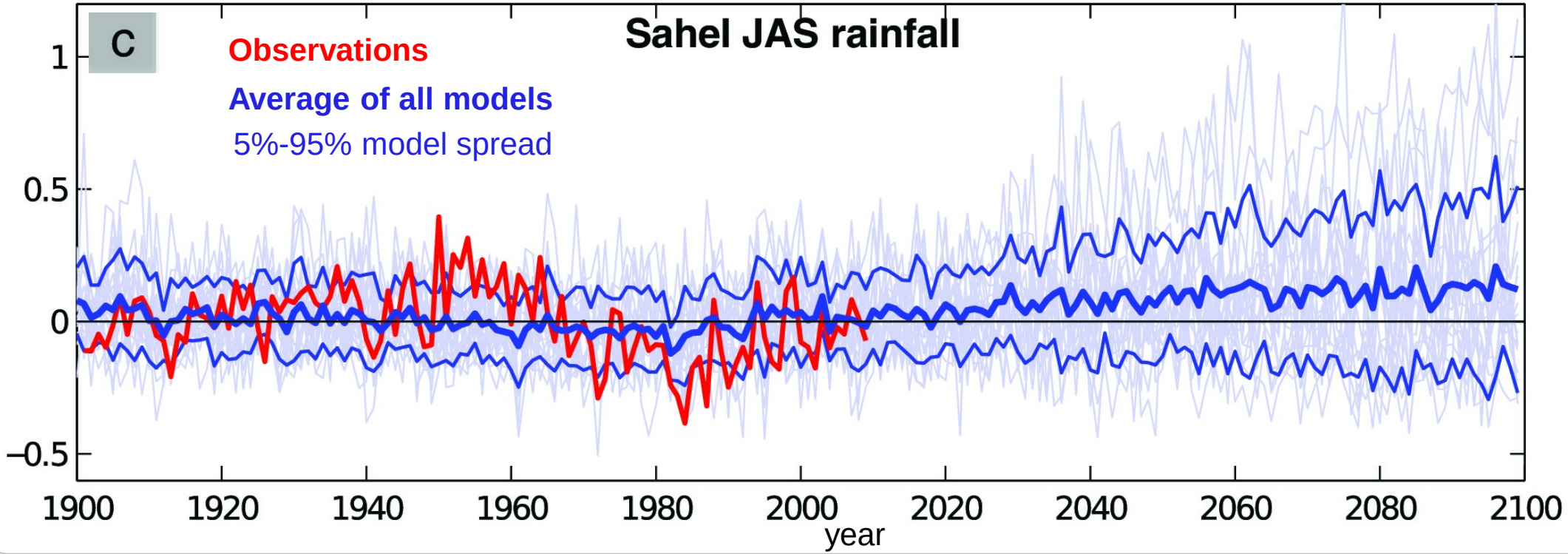



**Sahel rainfall:**
**an example of misidentified climate change**

# Model projections of Sahel summer rainfall, CMIP5



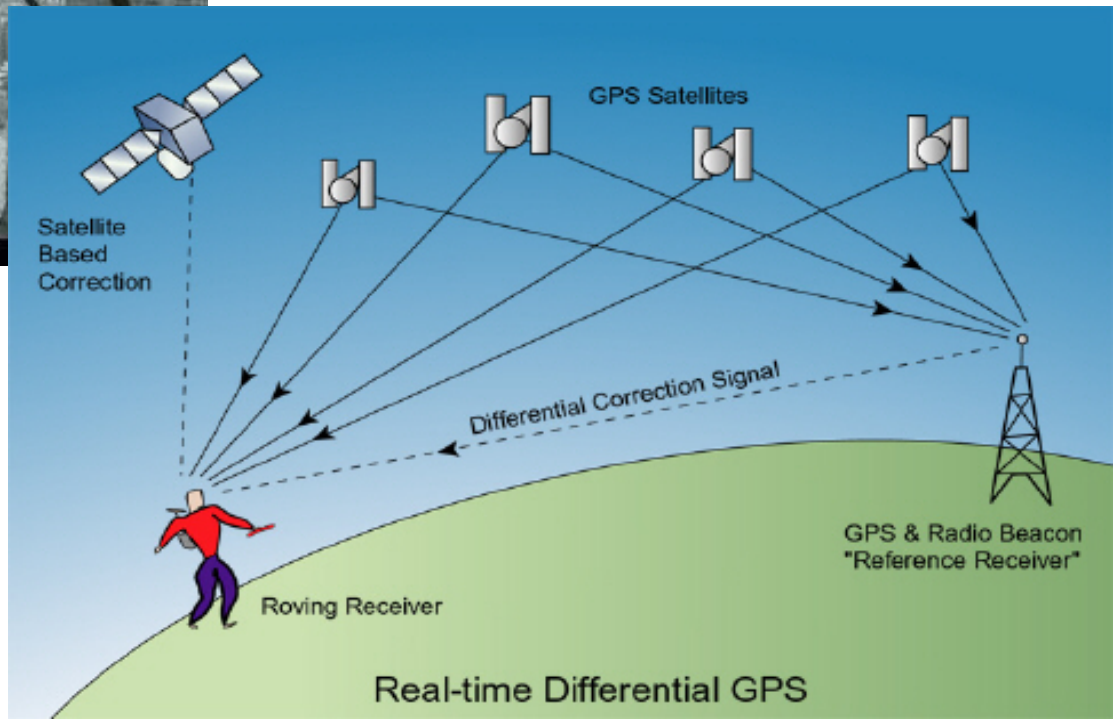
# Is Newton's theory of gravitation reliable ?


**Absolutely !!!**

**Just step forward, and I will fall**

**Absolutely not !!**

**Without Einstein's General Relativity, the accuracy of GPS devices is only 100 meters**



# All physical theories are incorrect... in some sense

In the history of science, all theories are sooner or later superseded by better

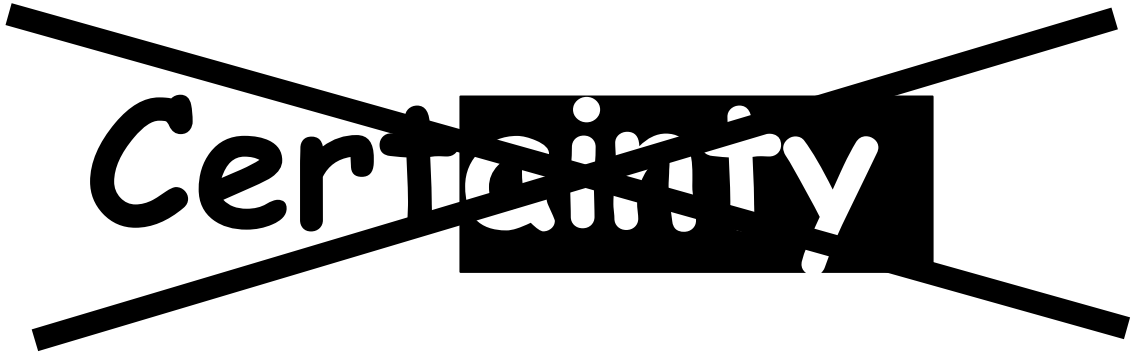
This happened also with the apparently most solid physical theory so far:

Newton's theory of gravitation, that was superseded by Einstein's General Relativity

From the scientific point of view, 'the science' is never ever settled.

This does not mean that science-based policy is impossible. The question is whether the science is good enough to warrant policy action

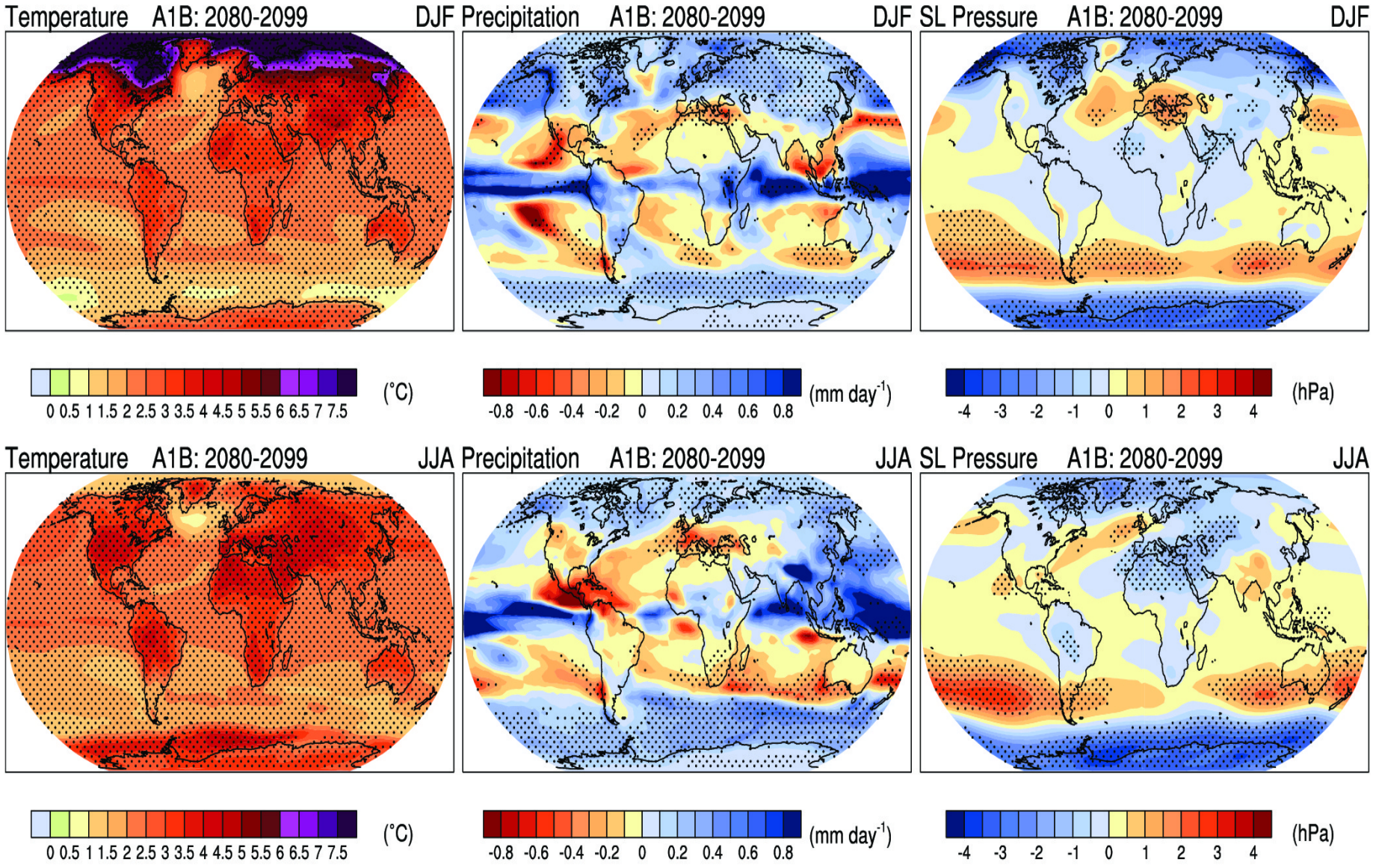
**But this does mean that uncertainty cannot be totally eliminated**




UnCertainty

# Summary of surface climate projections, including level of inter-model agreement

Stippled areas indicate agreement in sign by at least 80% of the models




*IPCC Report, 2007*