Extremes of Weather and the Latest Climate Change Science

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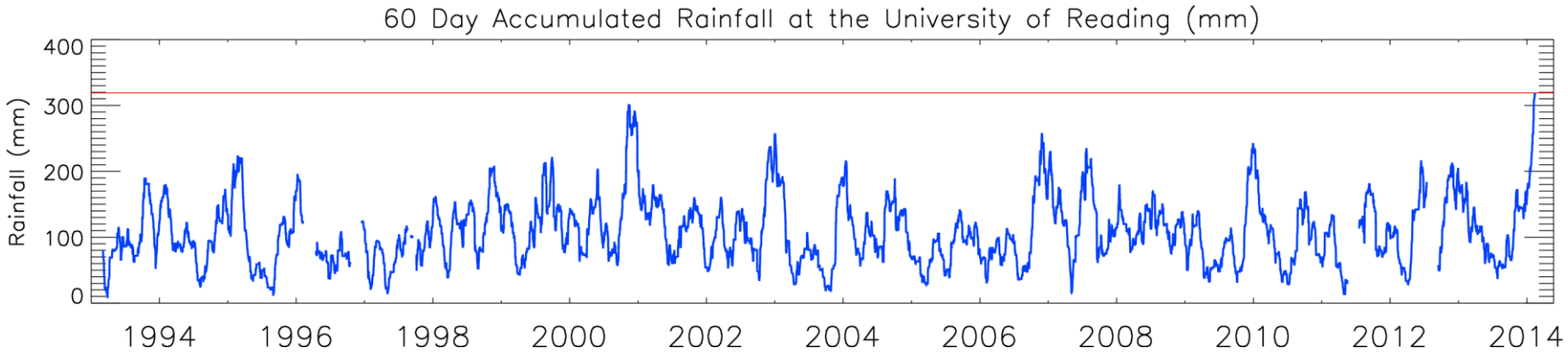
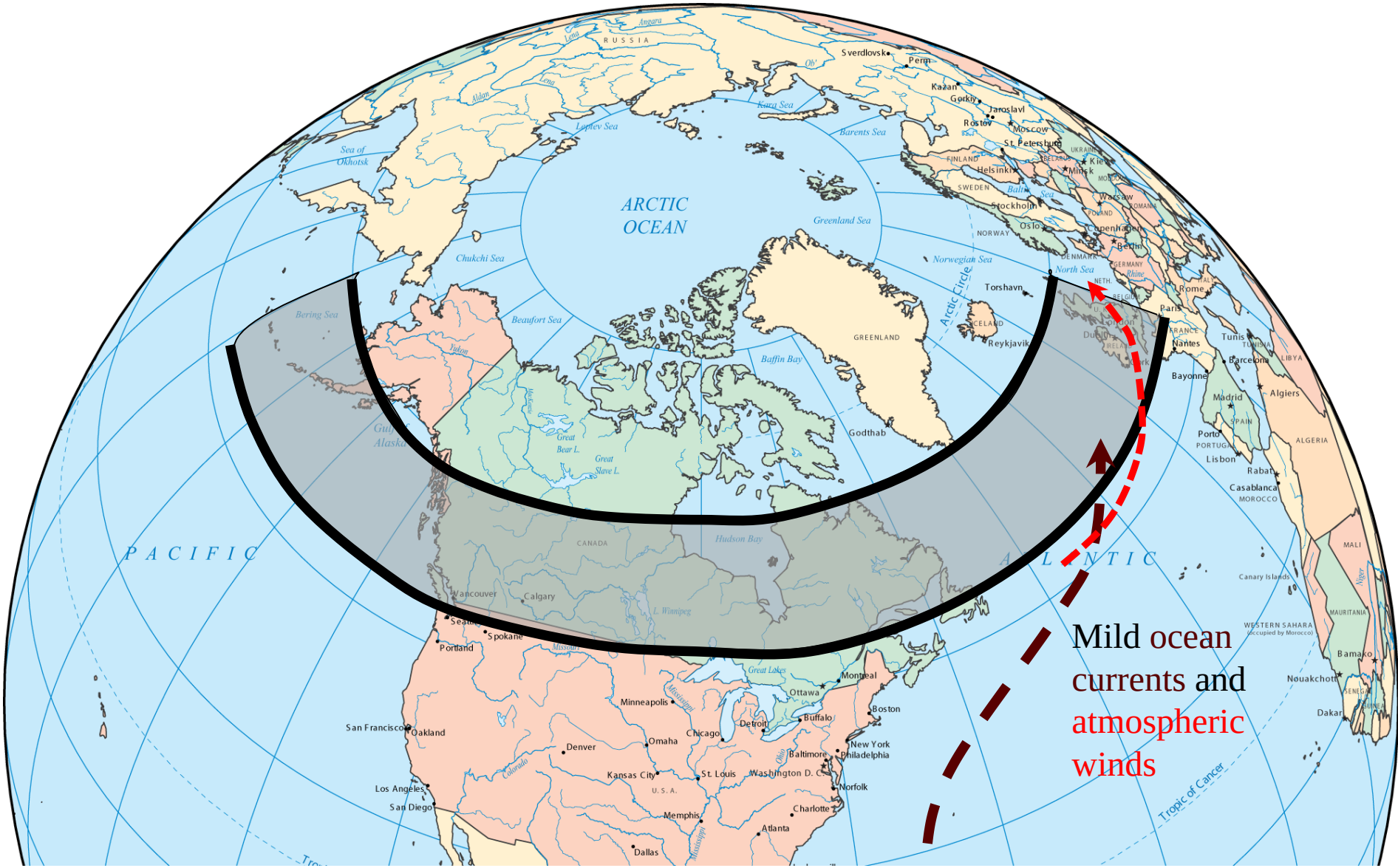
Extreme weather climate change

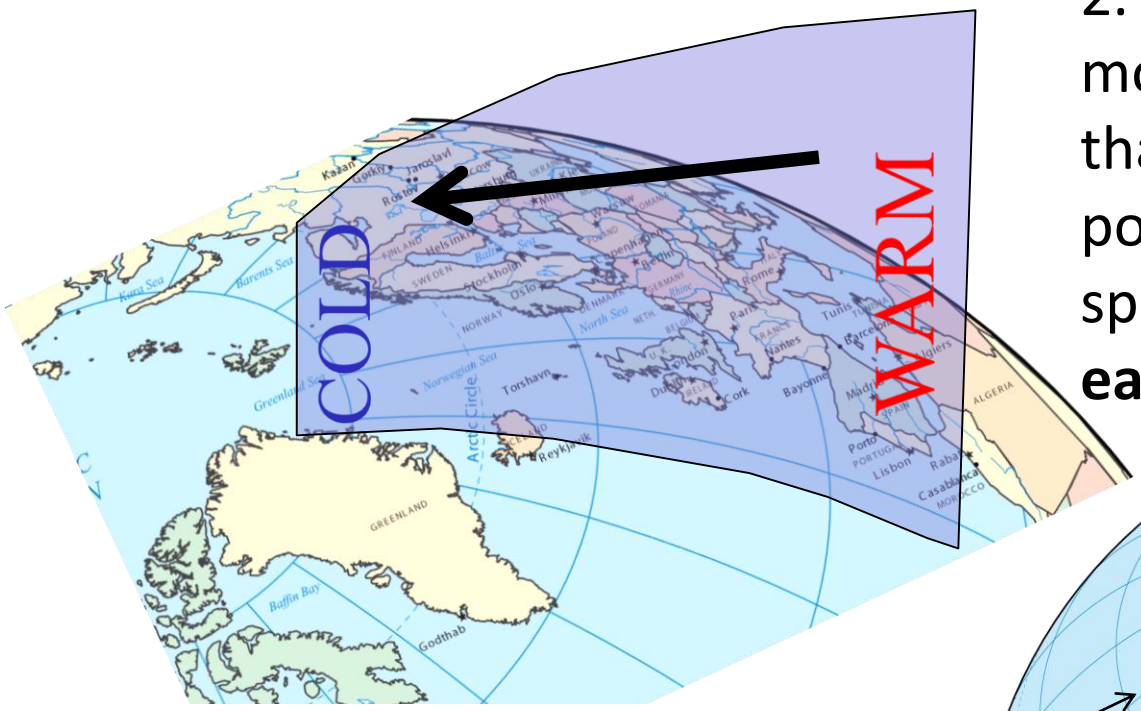
- Recent extreme weather focusses debate on climate change
- Can we expect more or worse in the future?
- First we need to establish what generates our weather extremes



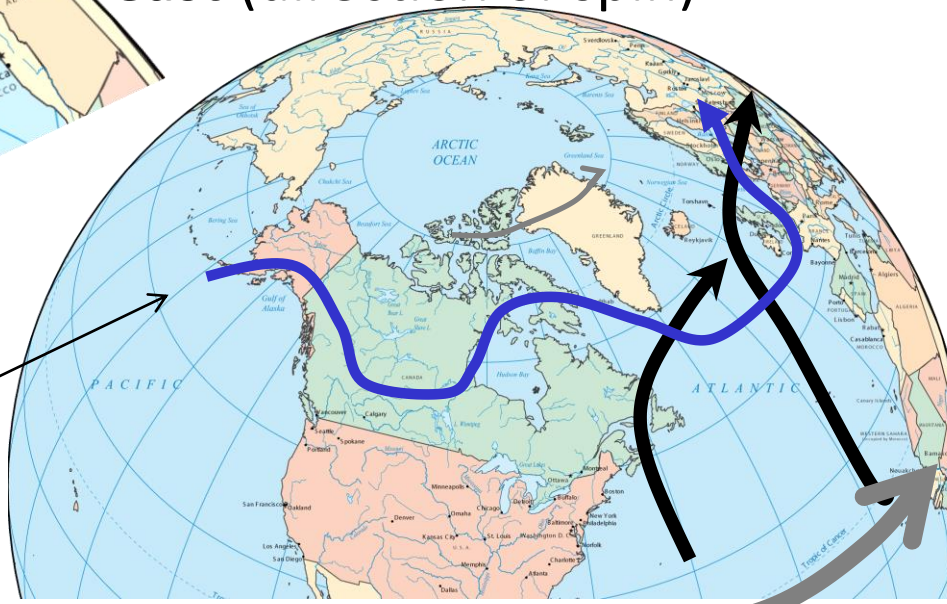
What explains the mild climate in the UK and its variations from year to year?



1. Air is warmer closer to the tropics (air expands) than at the poles (air contracts). This generates a **poleward flow of air** high up in the atmosphere

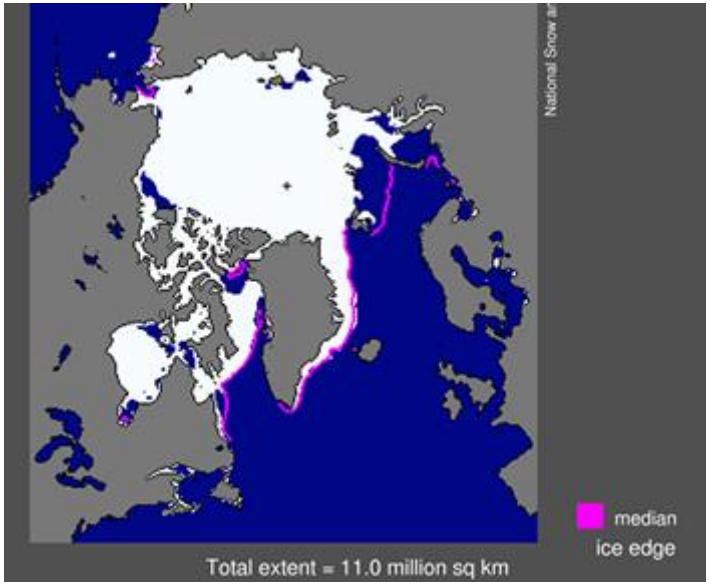


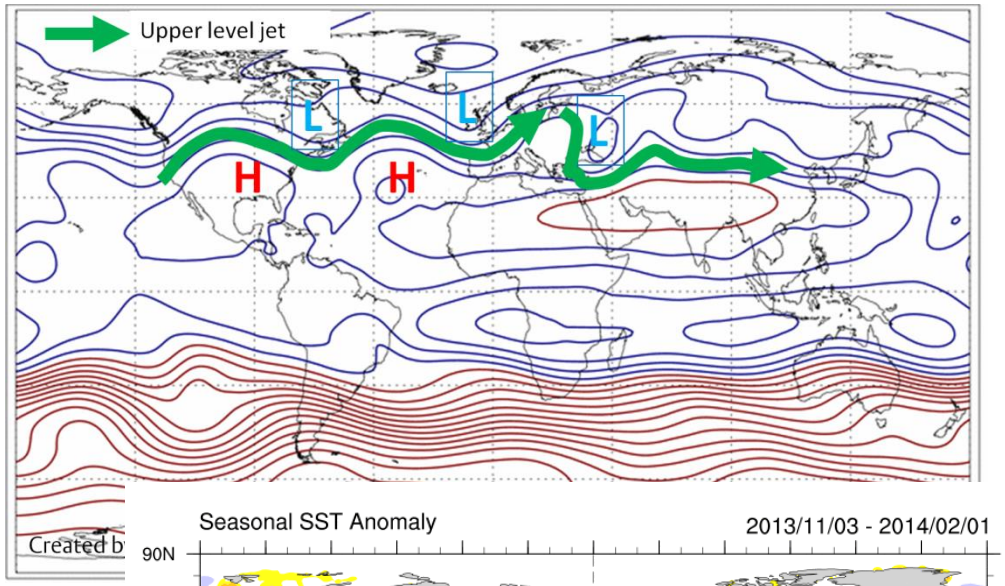
2. The Earth spins: the surface moves quicker near the equator than at higher latitudes. So poleward-flowing air retains this speed and is deflected to the **east** (direction of spin)

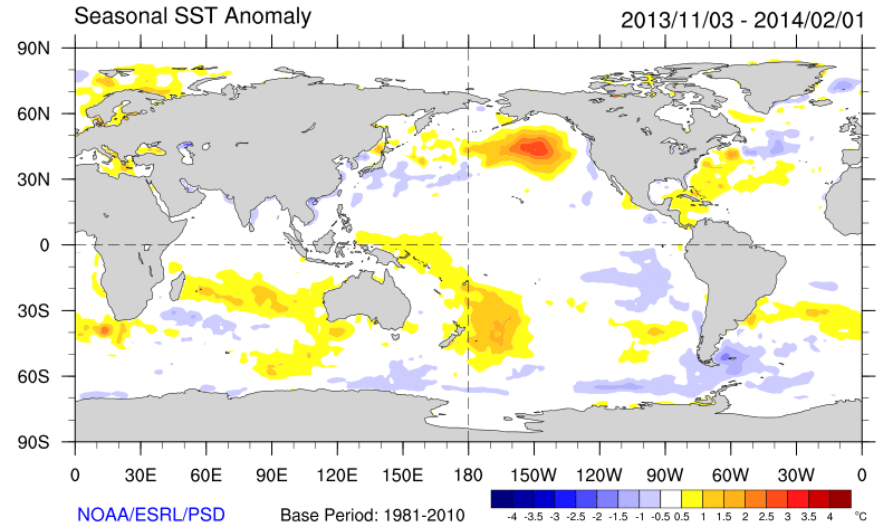


3. This high altitude (5-7km) fast moving ribbon of air is called the jet stream. It steers weather systems over or away from the UK.

Remote influences on the jet stream

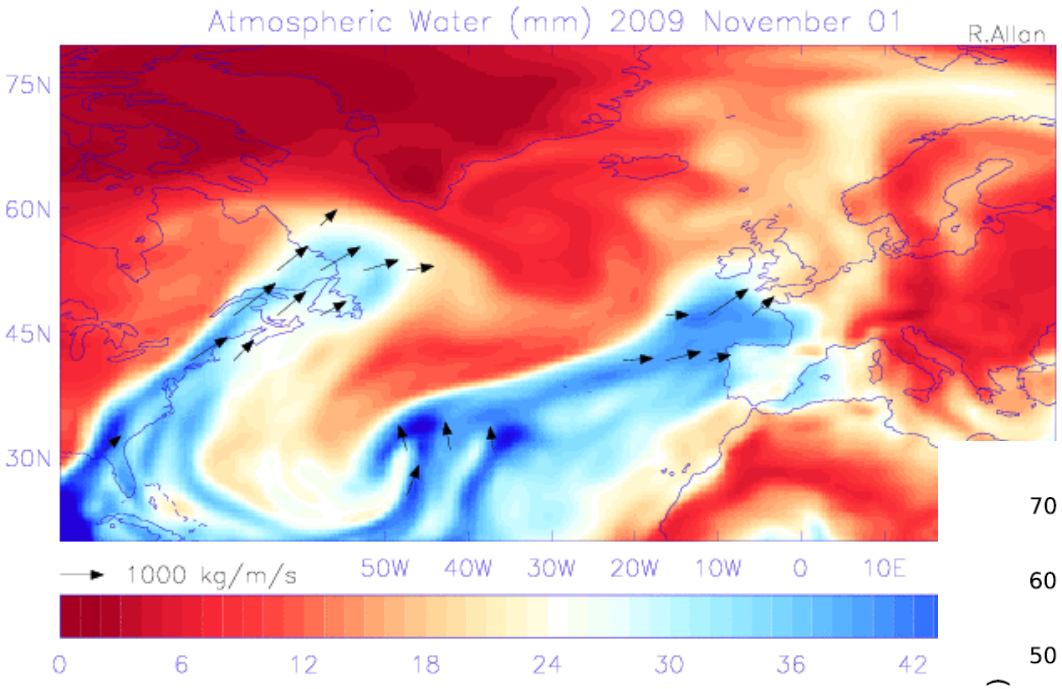




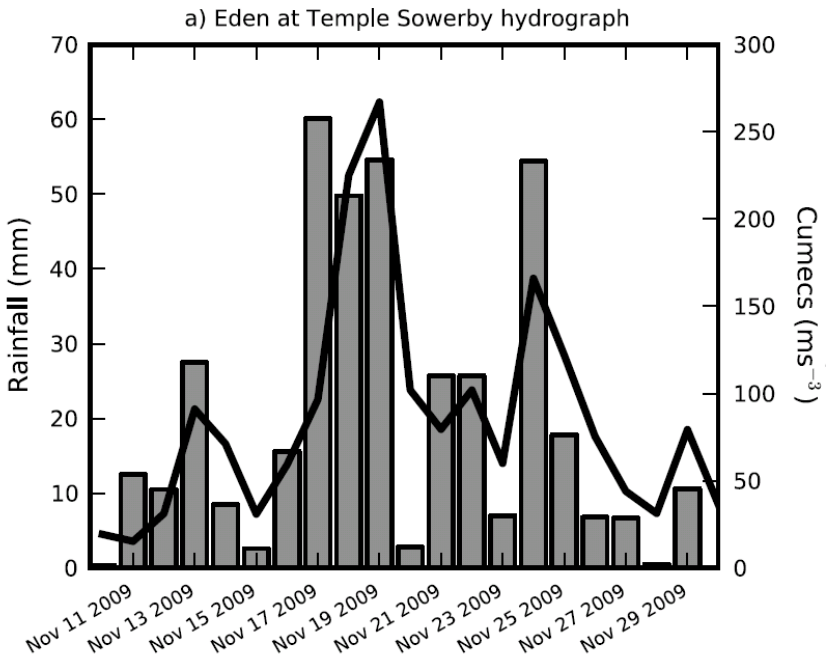


4. Changes in this temperature difference between equator and pole can alter the position and strength of the jet stream. This and other **natural** and **human-caused** effects influence our weather patterns and extremes.

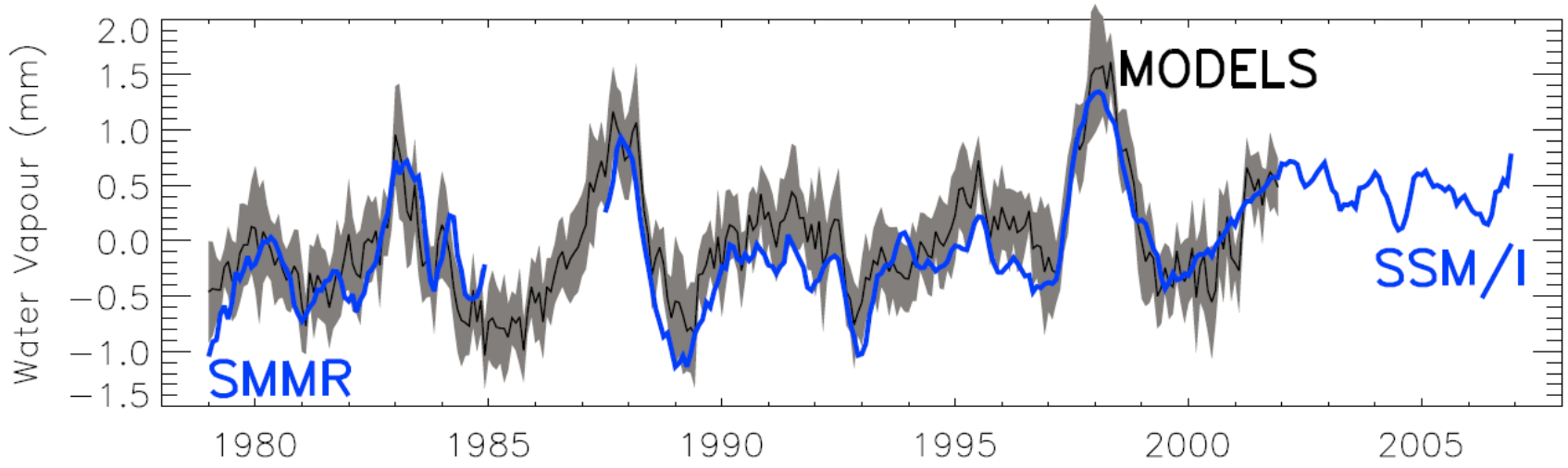
Cumbria flooding 2009: atmospheric river

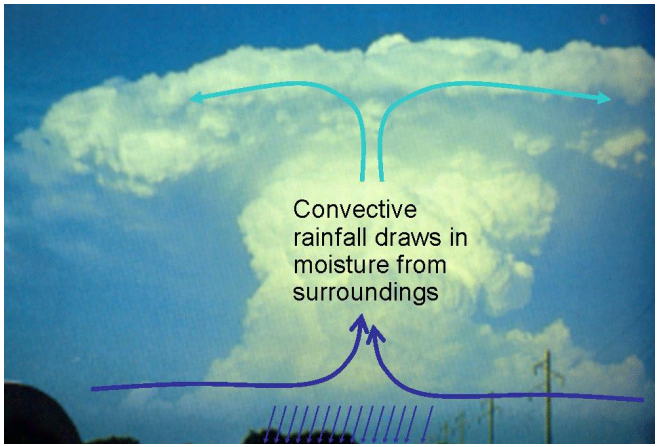


- Massive moisture transport
- Heavy rainfall over mountains
- River flooding



- Not only flood-generating mechanism
  - Summer flash flooding
  - Jet stream & wet seasons





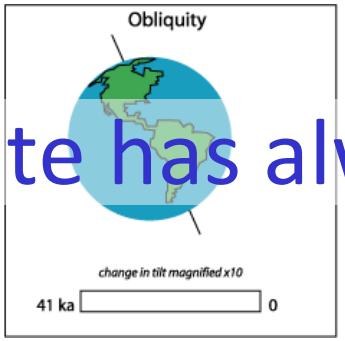
- Atmospheric moisture increases with warming in computer simulations and as detected by conventional and satellite observations

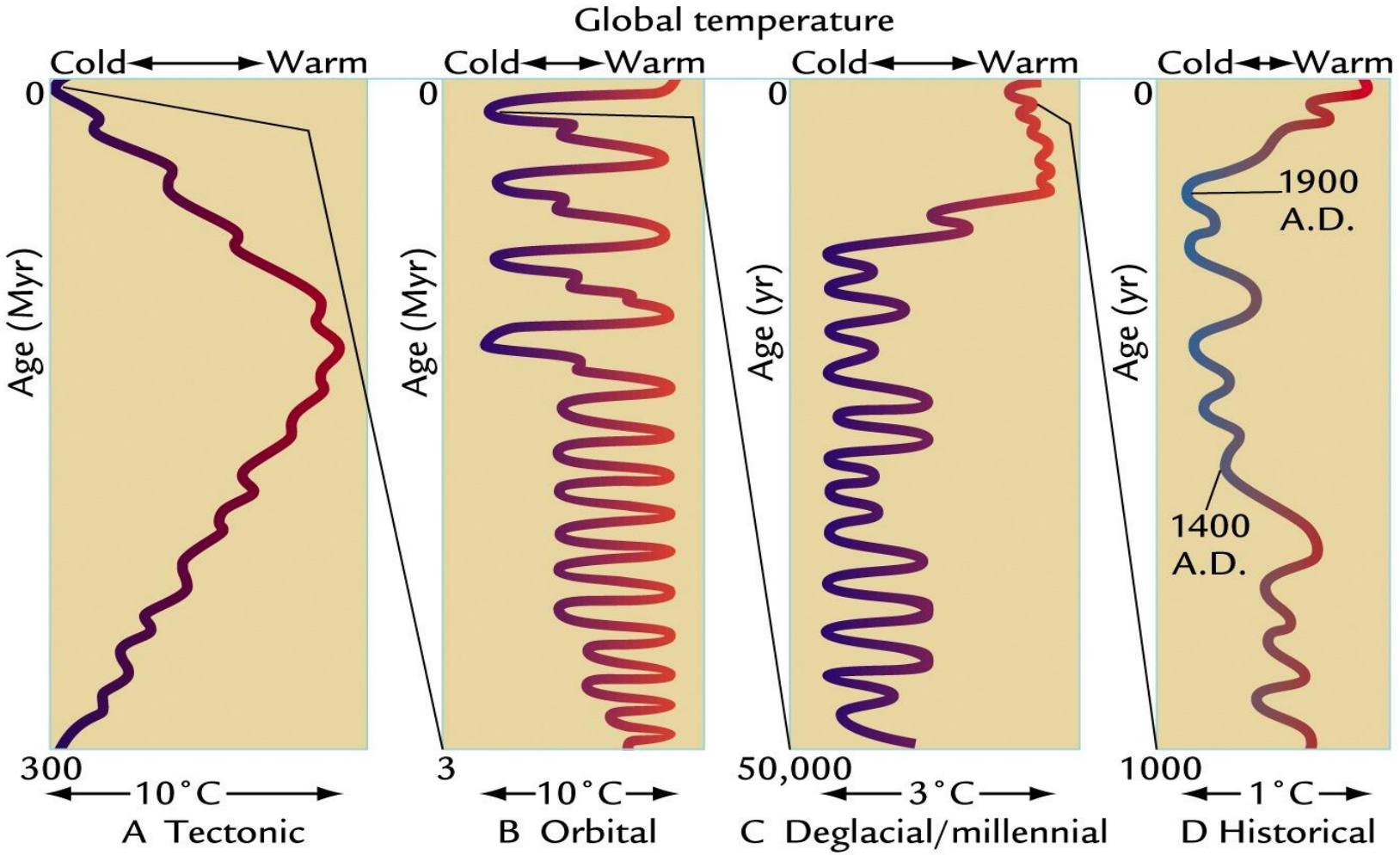
- The enhanced greenhouse effect amplifies climate change (+ve “feedback”)

- Additional moisture also fuels a greater intensity of rainfall

So is climate changing? Is it due to human activities? And how is it likely to affect our weather in the future?

Earth's Climate has always been changing





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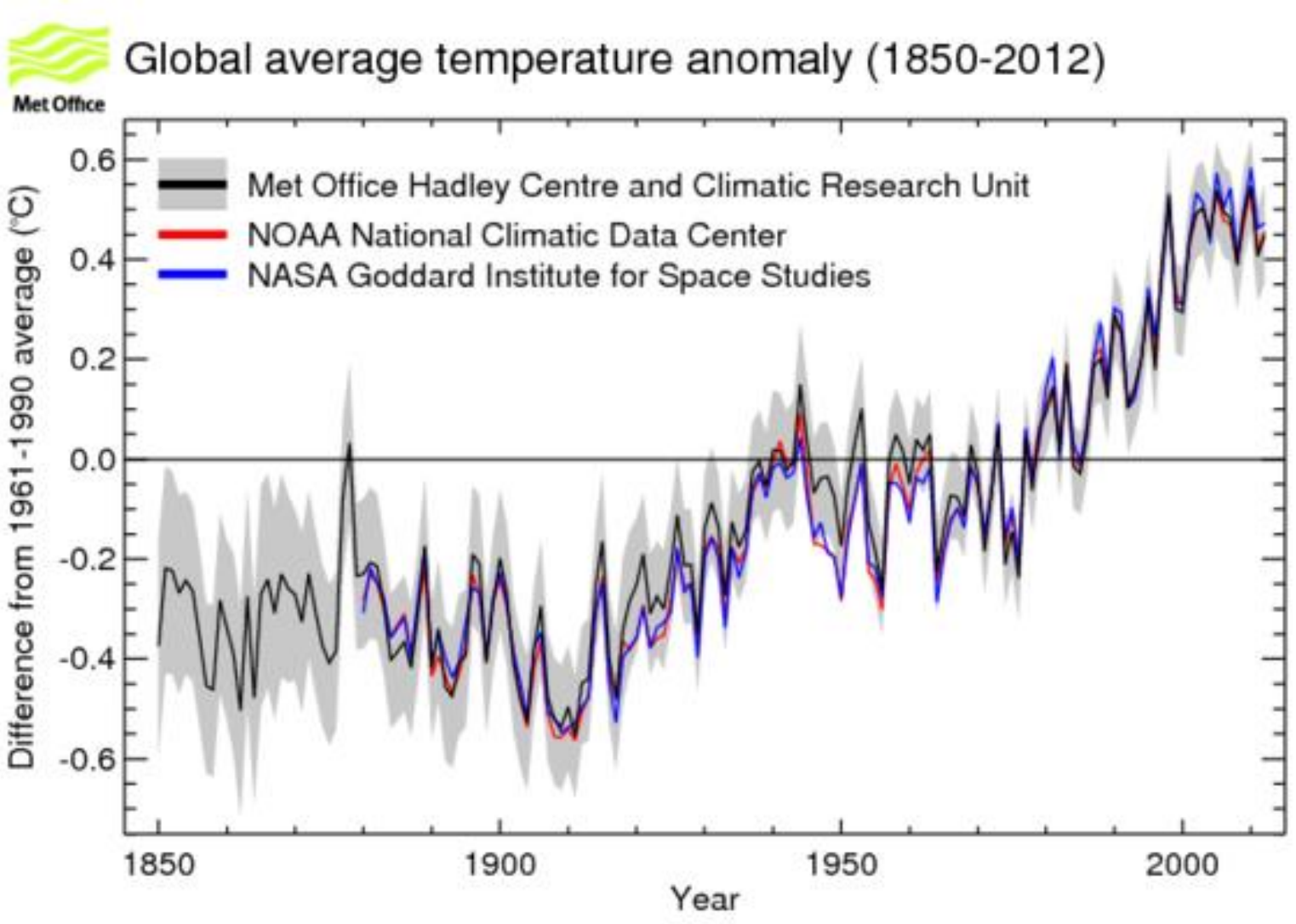
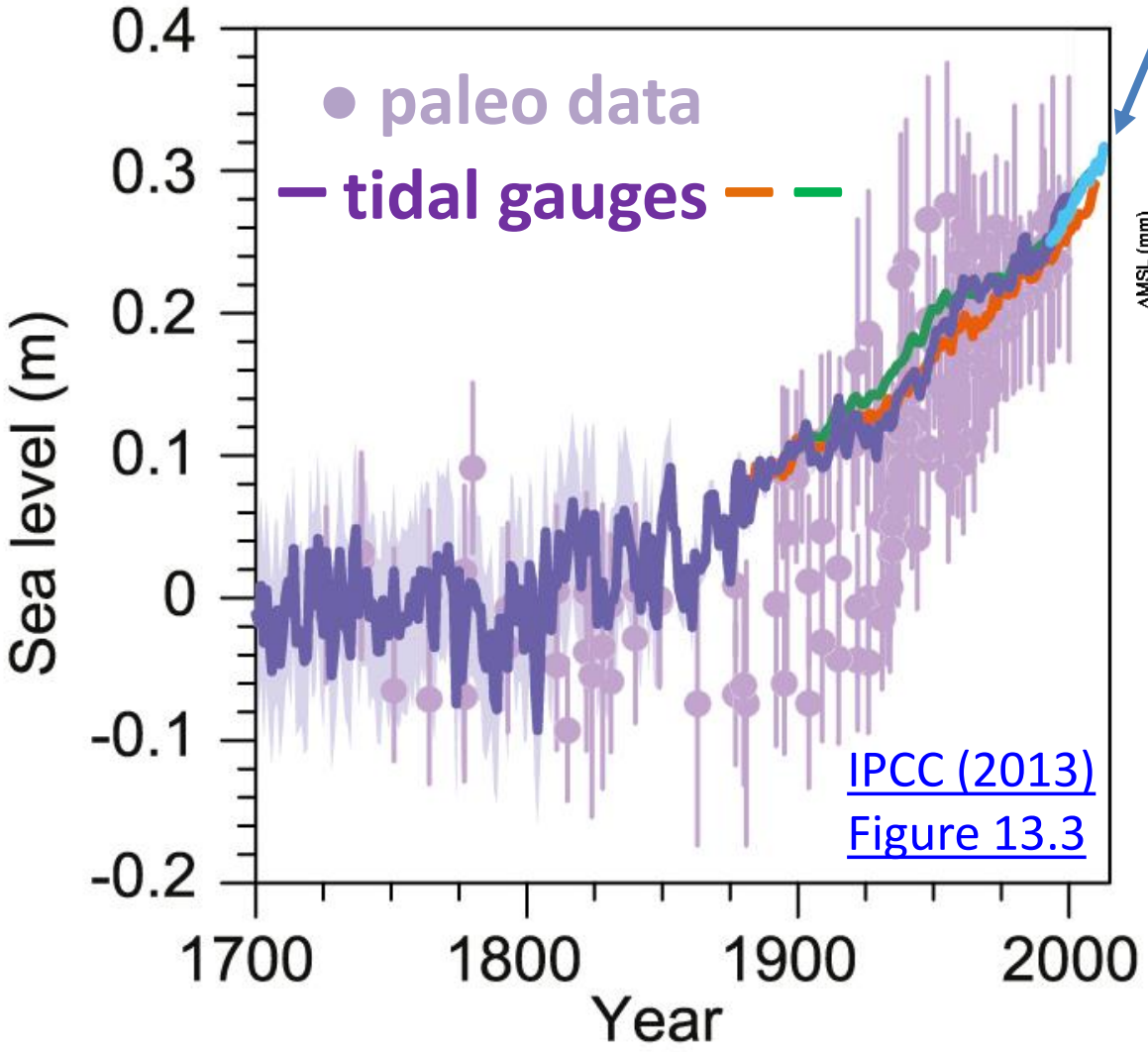
1) Is climate changing now?

The planet is warming



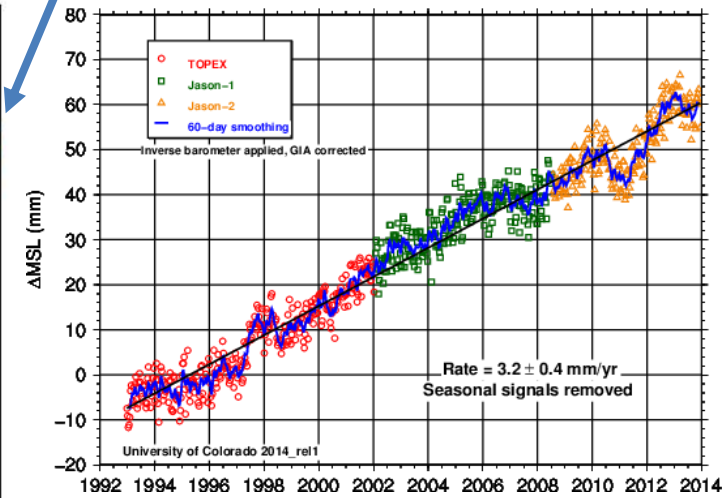
www.metoffice.gov.uk/research/monitoring/climate/surface-temperature

Global average sea level is rising…



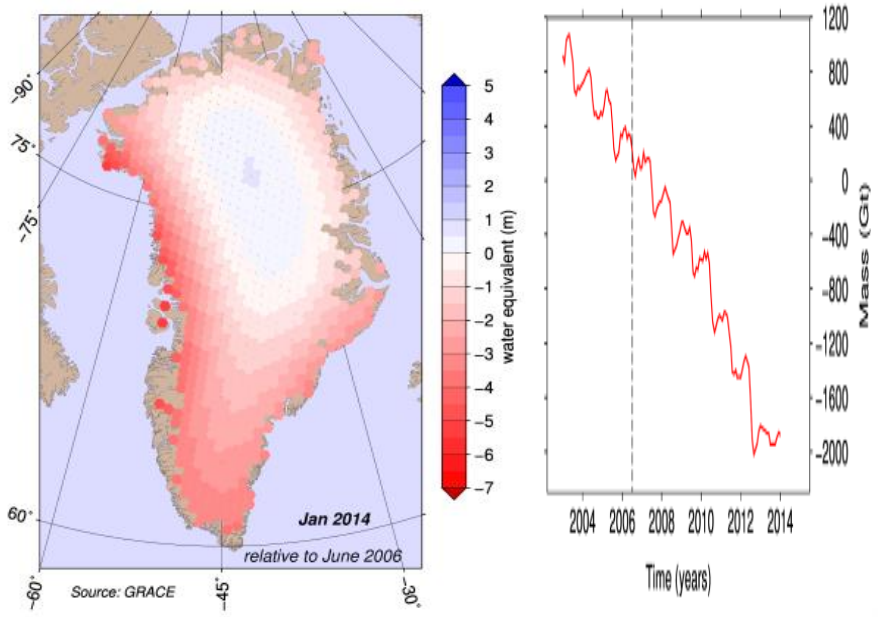
IPCC (2013)
Figure 13.3

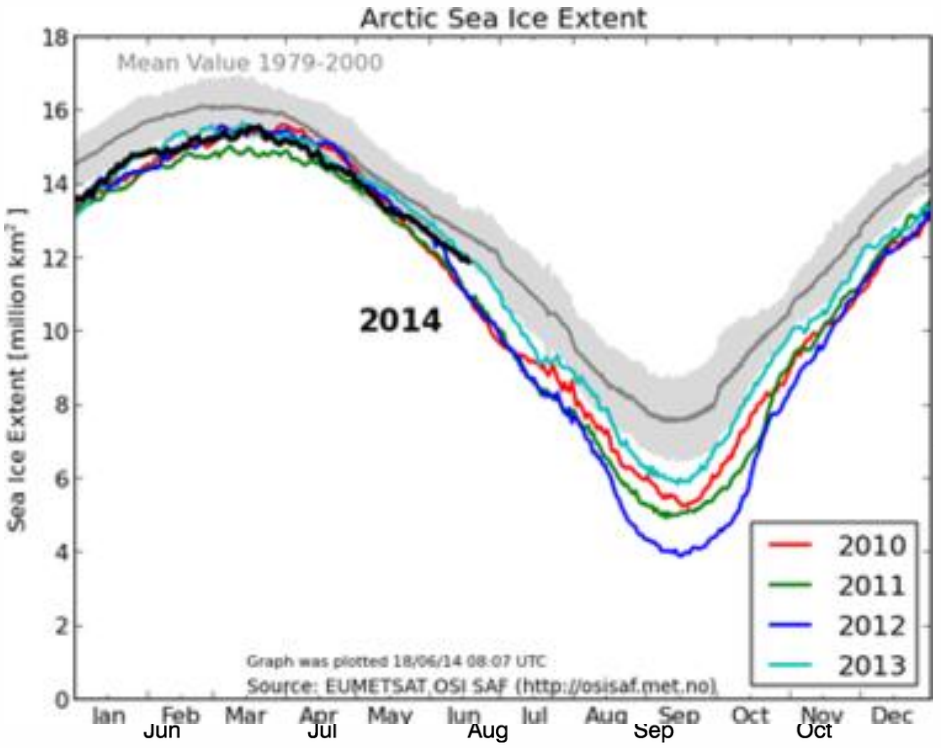
Satellite Altimeter data

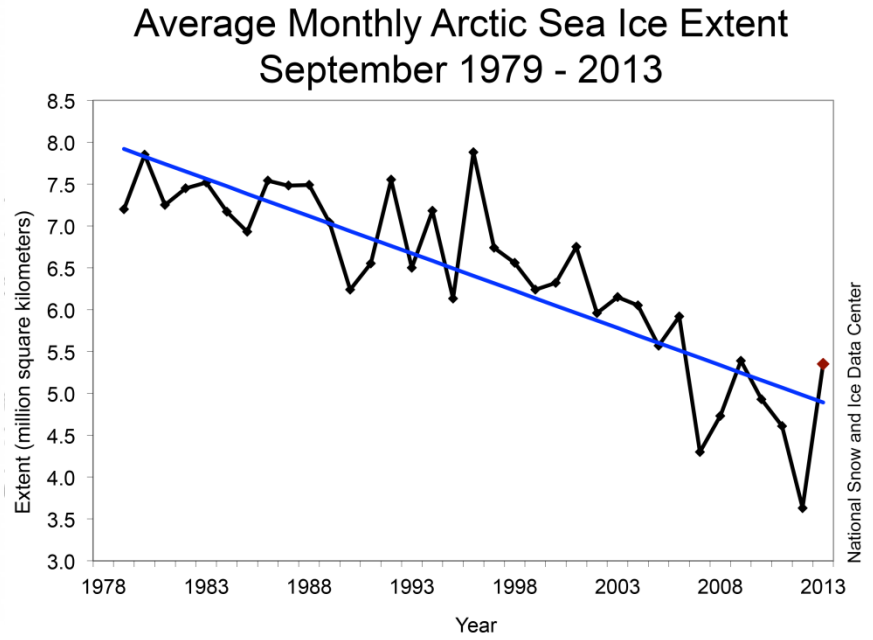


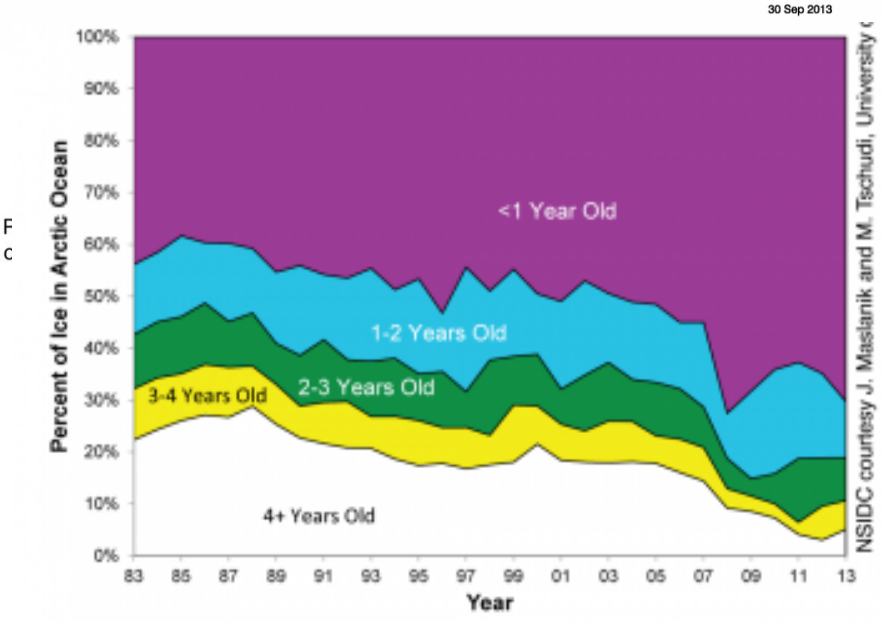
http://sealevel.colorado.edu/

Melting of Arctic Ice



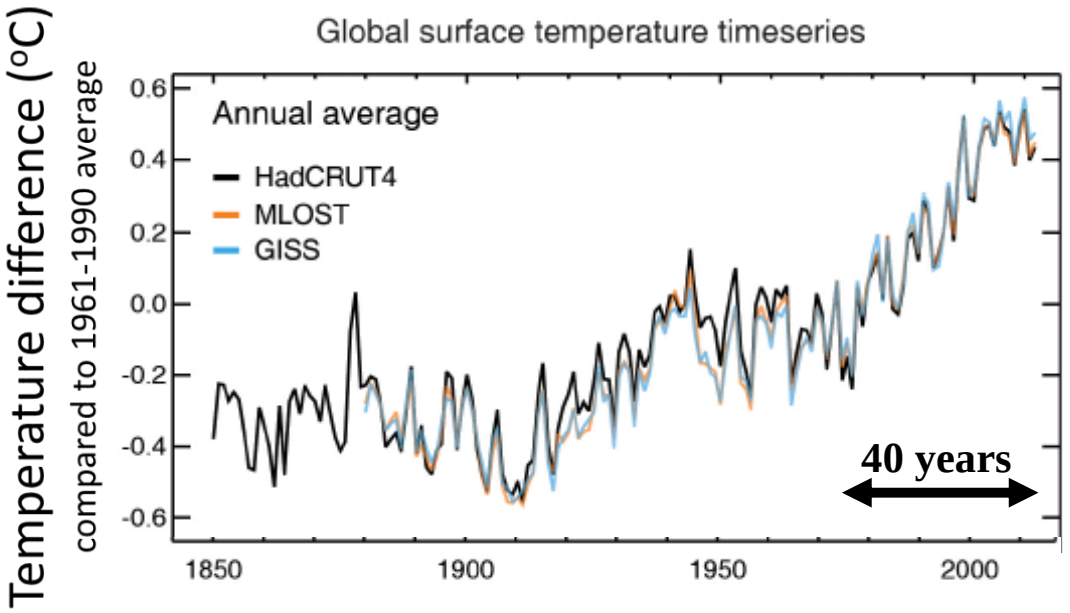




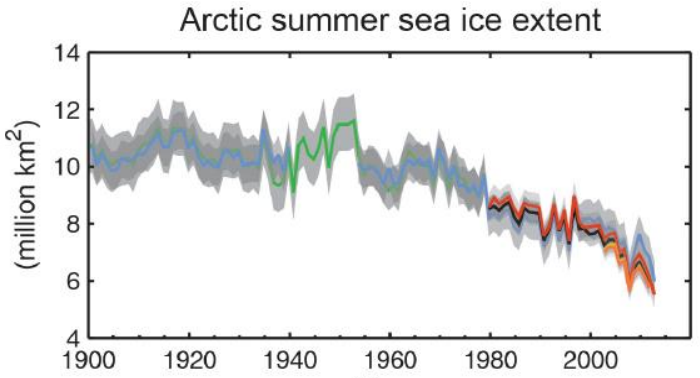


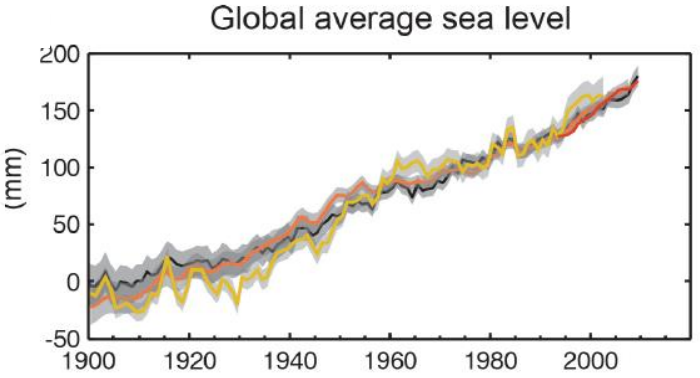
Evidence for current climate change

"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." IPCC (2013)



Top: Differences in global average surface temperature compared to the 1961-1990 average
Middle: Changes in the July-September average summer Arctic sea ice extent
Bottom: Changes in global average sea level compared with 1900-1905 average
Source: IPCC WGI (2013) SPM





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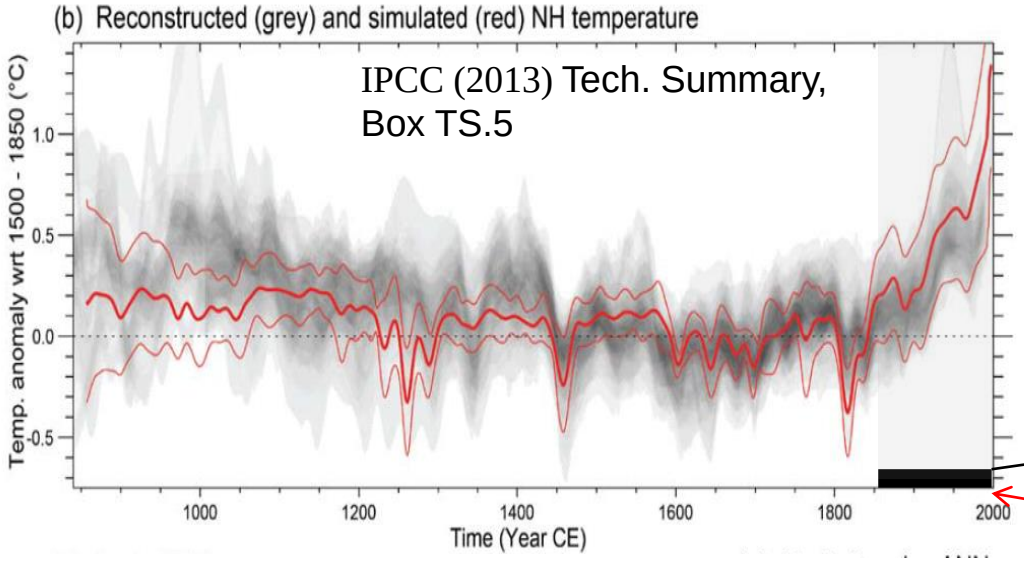
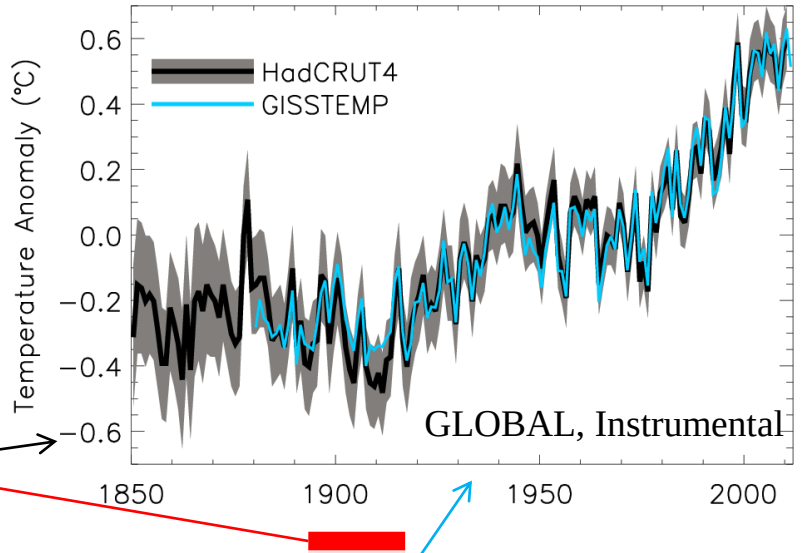
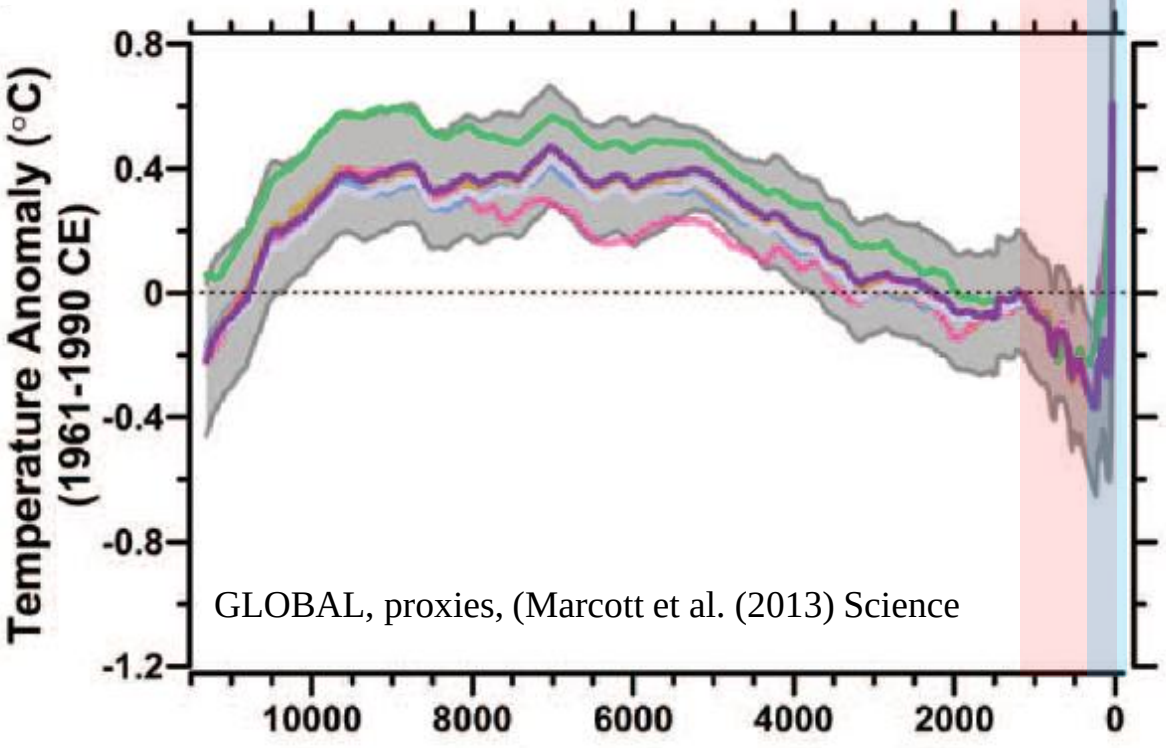
2) Is the warming unusual?

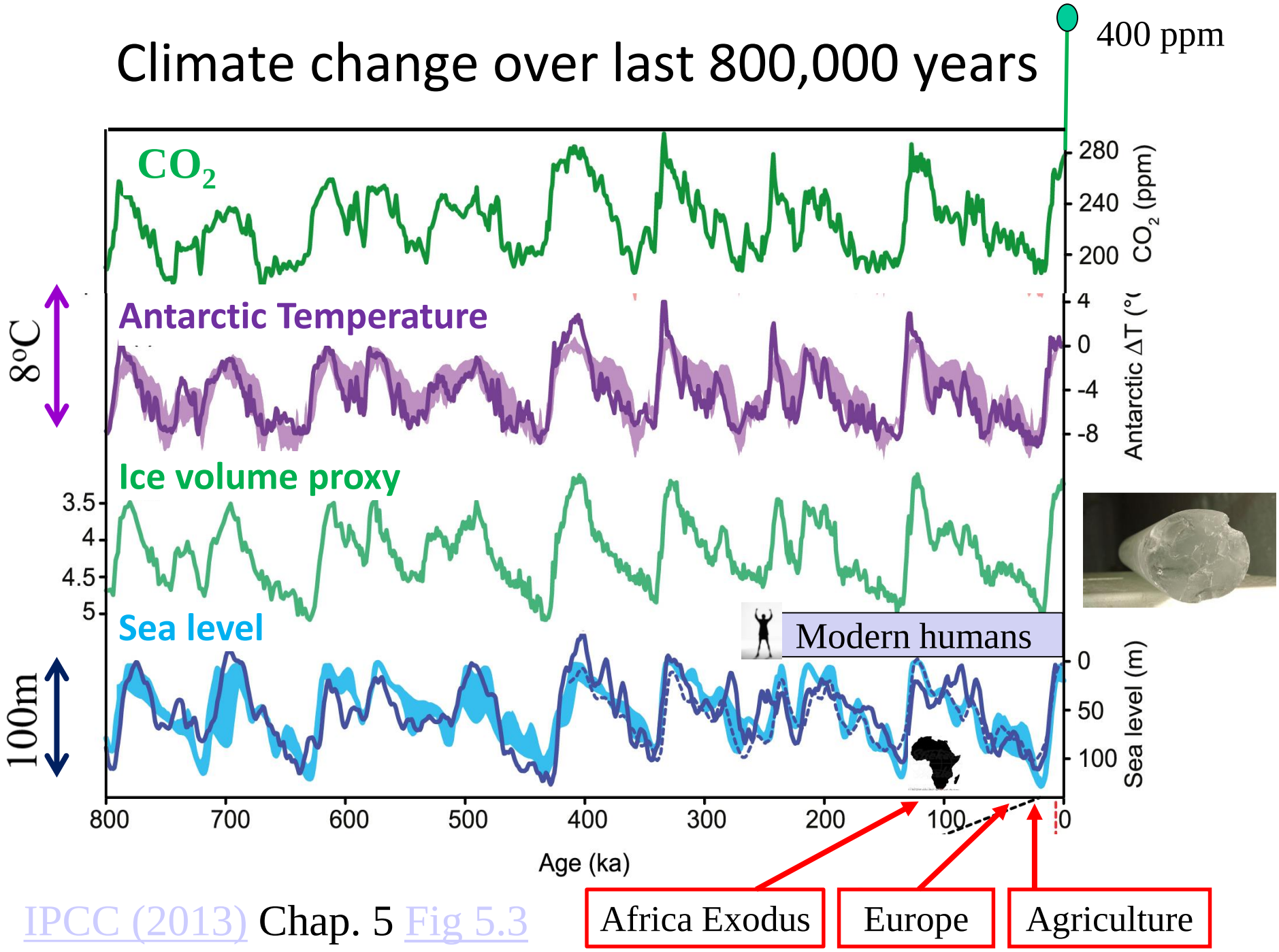




Northern hemisphere proxies



Climate change over last 800,000 years



IPCC (2013) Chap. 5 Fig 5.3

Is the warming unusual?

- Over the last 100 years the globe has warmed by about 0.8^{o}C
- Warming in northern hemisphere unprecedented in last 1400 years
- The last time polar regions were warmer than today was more than 125 000 years ago
  - sea level was 4-7m higher than today

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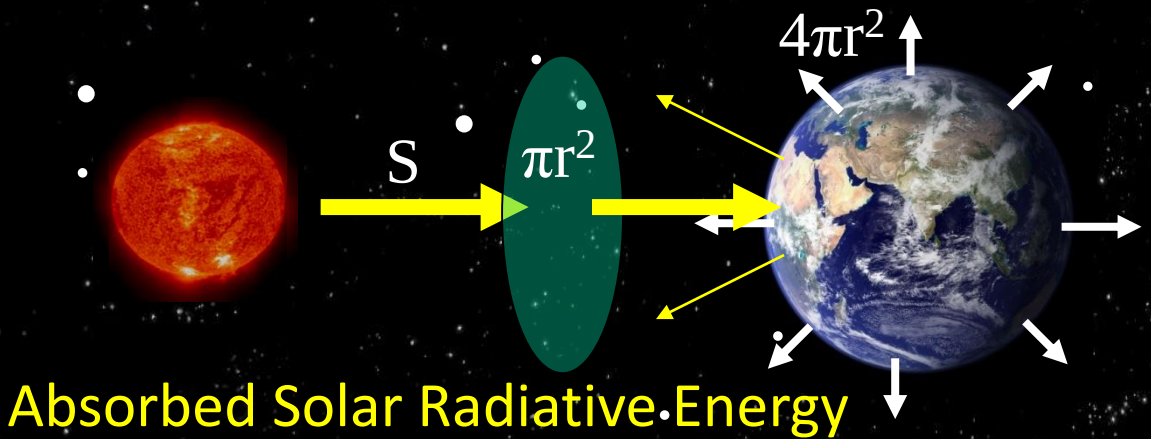
3) Why is it warming?

Earth's energy balance in space



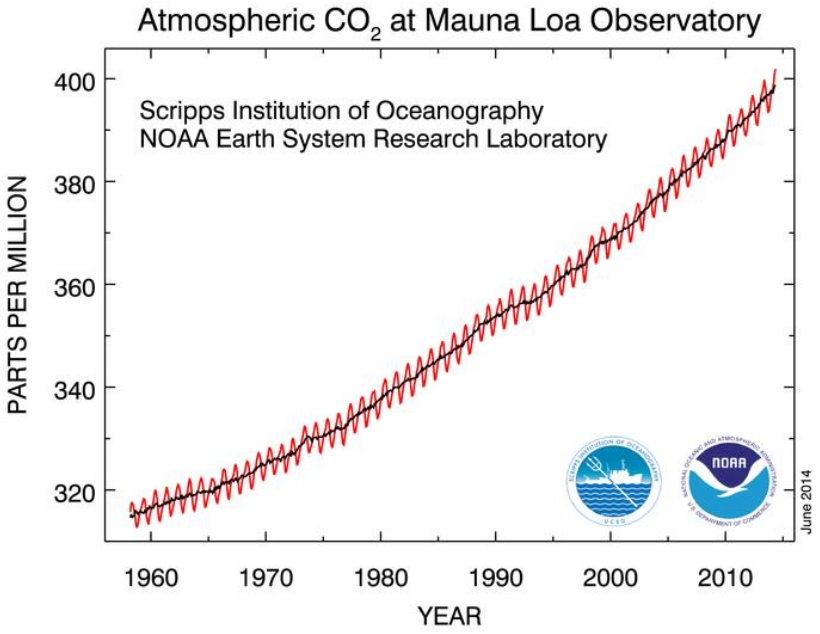
- There is a balance between the absorbed sunlight and the thermal radiative cooling of the planet
- Without the greenhouse effect, this balance would occur at a frigid global temperature of –18°C

Fourier (1824); Tyndall (1858); Arhenius (1896); Lacis et al. (2011)

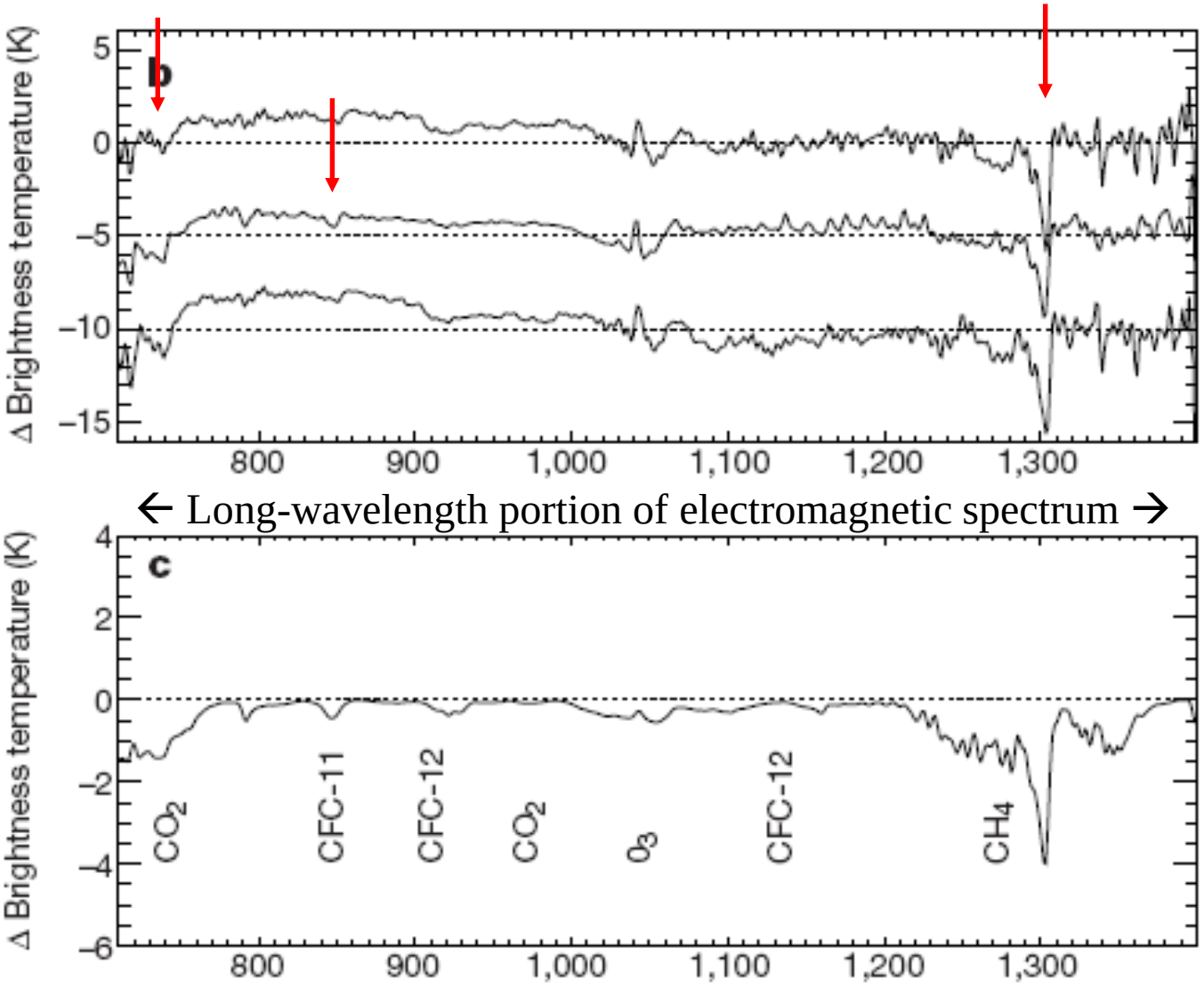
“Radiative forcing” of climate

- Increases in greenhouse gases heat the planet by reducing how easily Earth can cool to space through infra-red emission
- Small pollutant particles “aerosols” cool the planet by reflecting sunlight
- If more energy is arriving than leaving the planet, Earth’s surface should warm…

Currently energy is accumulating at rate equivalent to 300 billion electric heaters (1 kilo Watt) over the globe

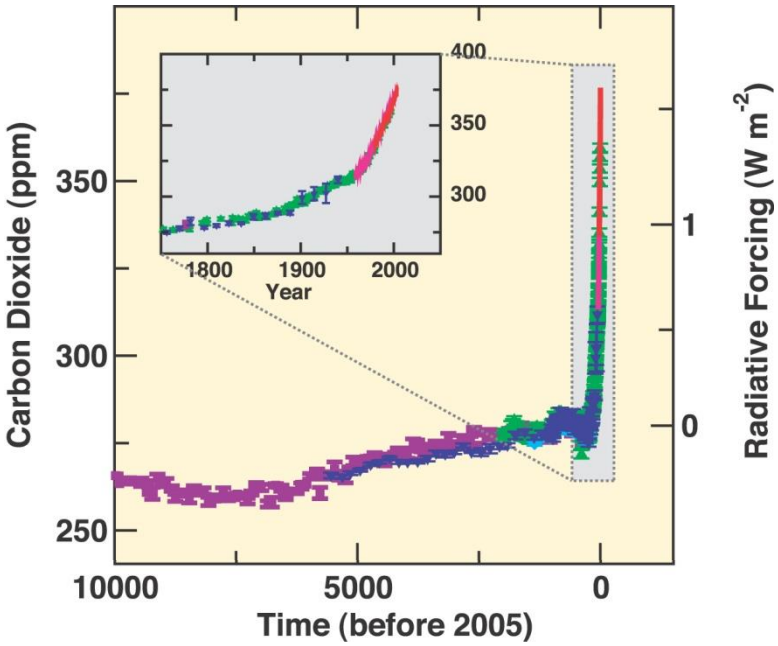


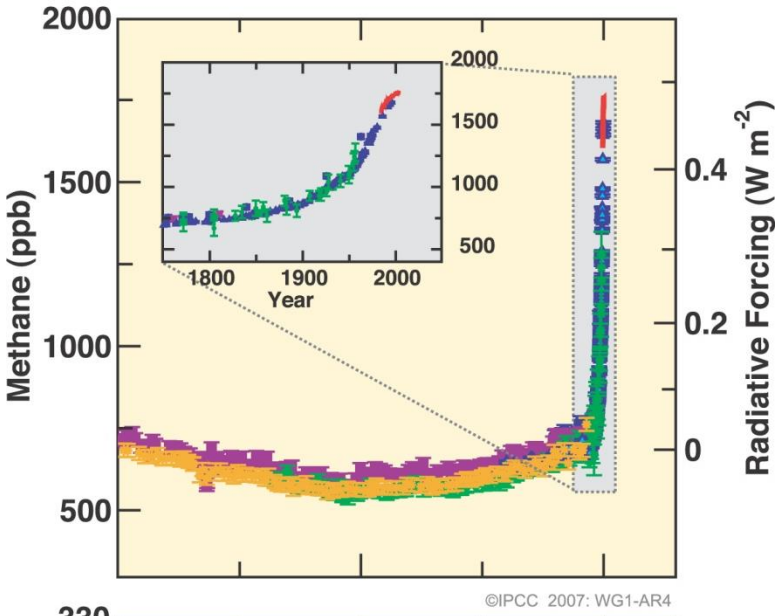
Satellite observations detect enhanced greenhouse effect: 1997-1970 Harries et al. 2001, Nature

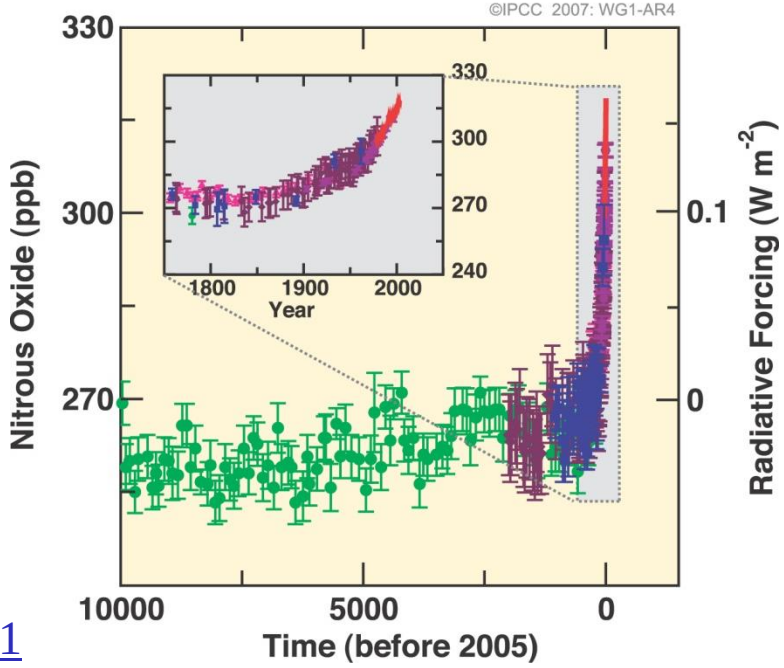


These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane

Changes in greenhouse gases from ice core and modern data

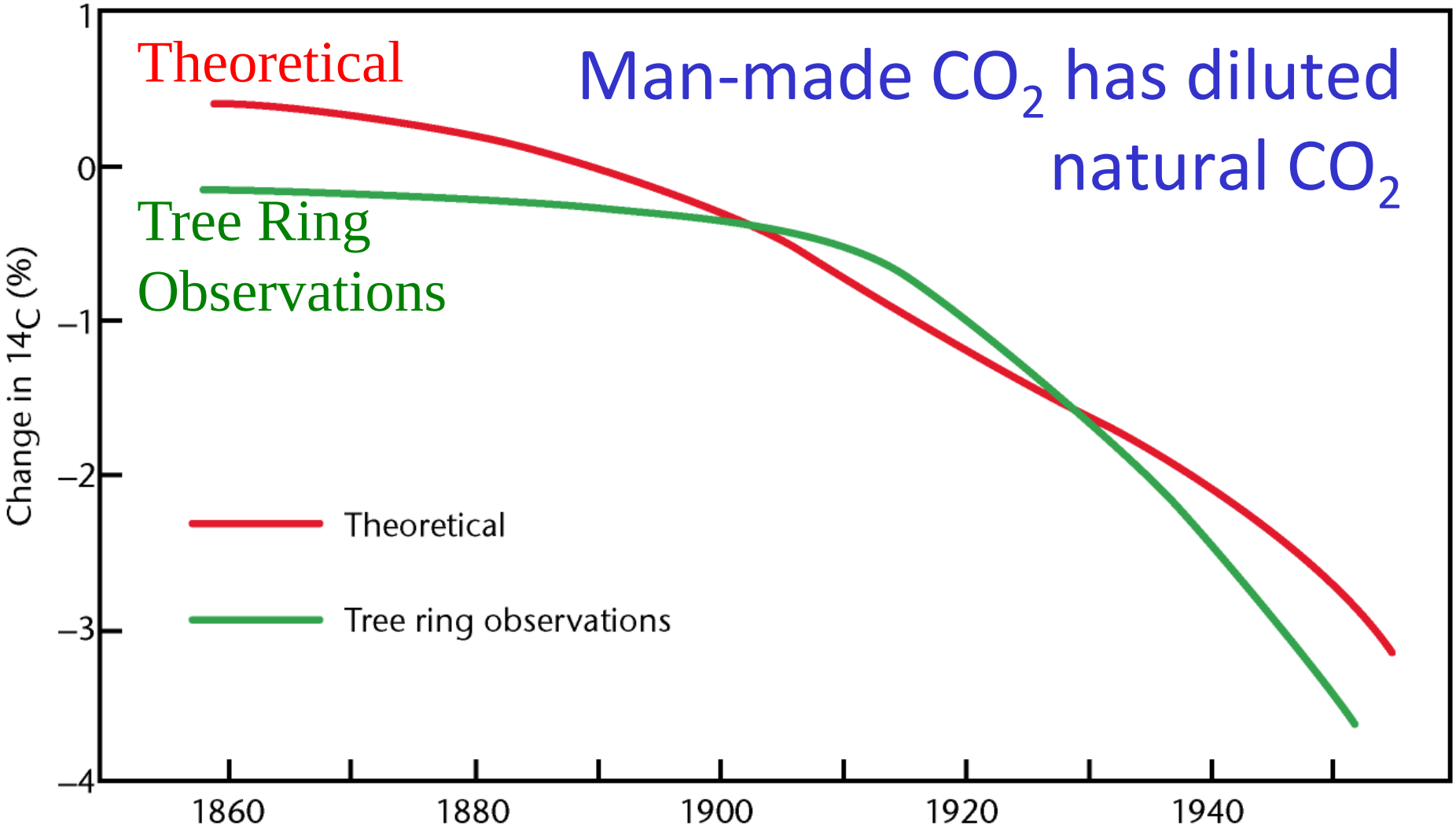




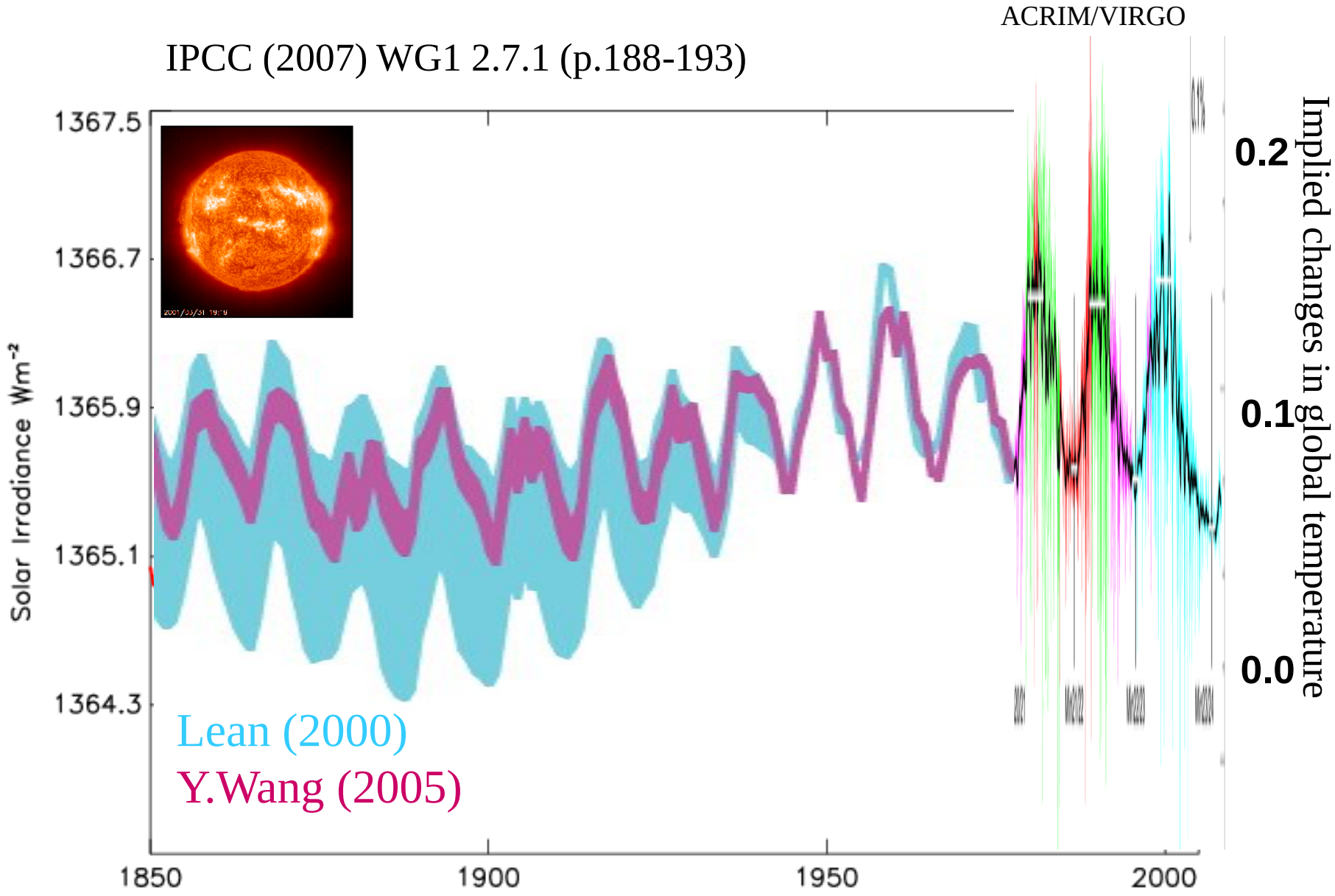


Carbon dioxide, **methane** and **nitrous oxide**

IPCC (2007) Summary for Policy Makers Fig. SPM.1


Theoretical
Man-made CO_2 has diluted natural CO_2
Tree Ring Observations
Change in ^{14}C (%)
1
0
−1
−2
−3
−4
1860
1880
1900
1920
1940
Theoretical
Tree ring observations

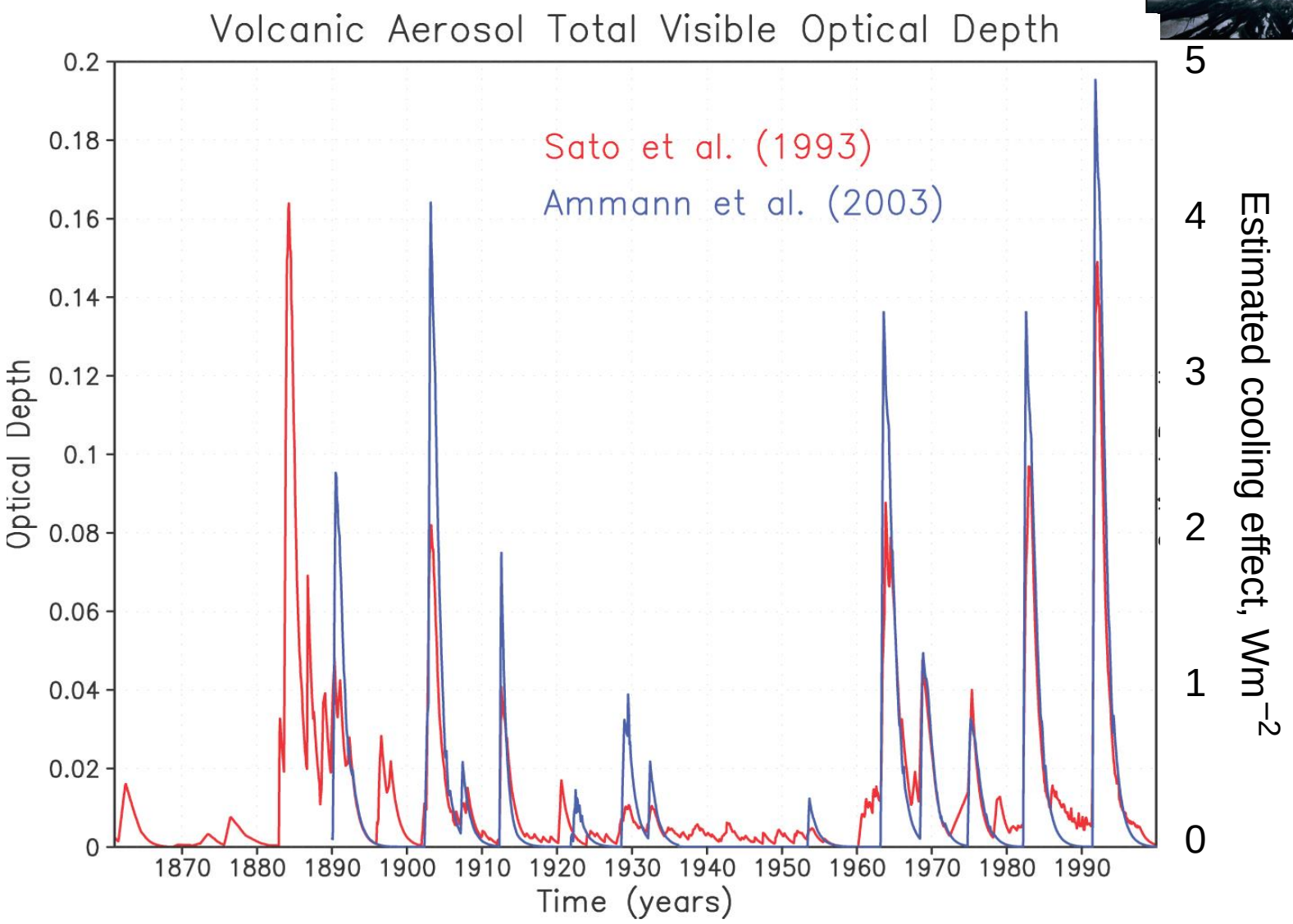
Energy from the Sun; stable over last 50 years



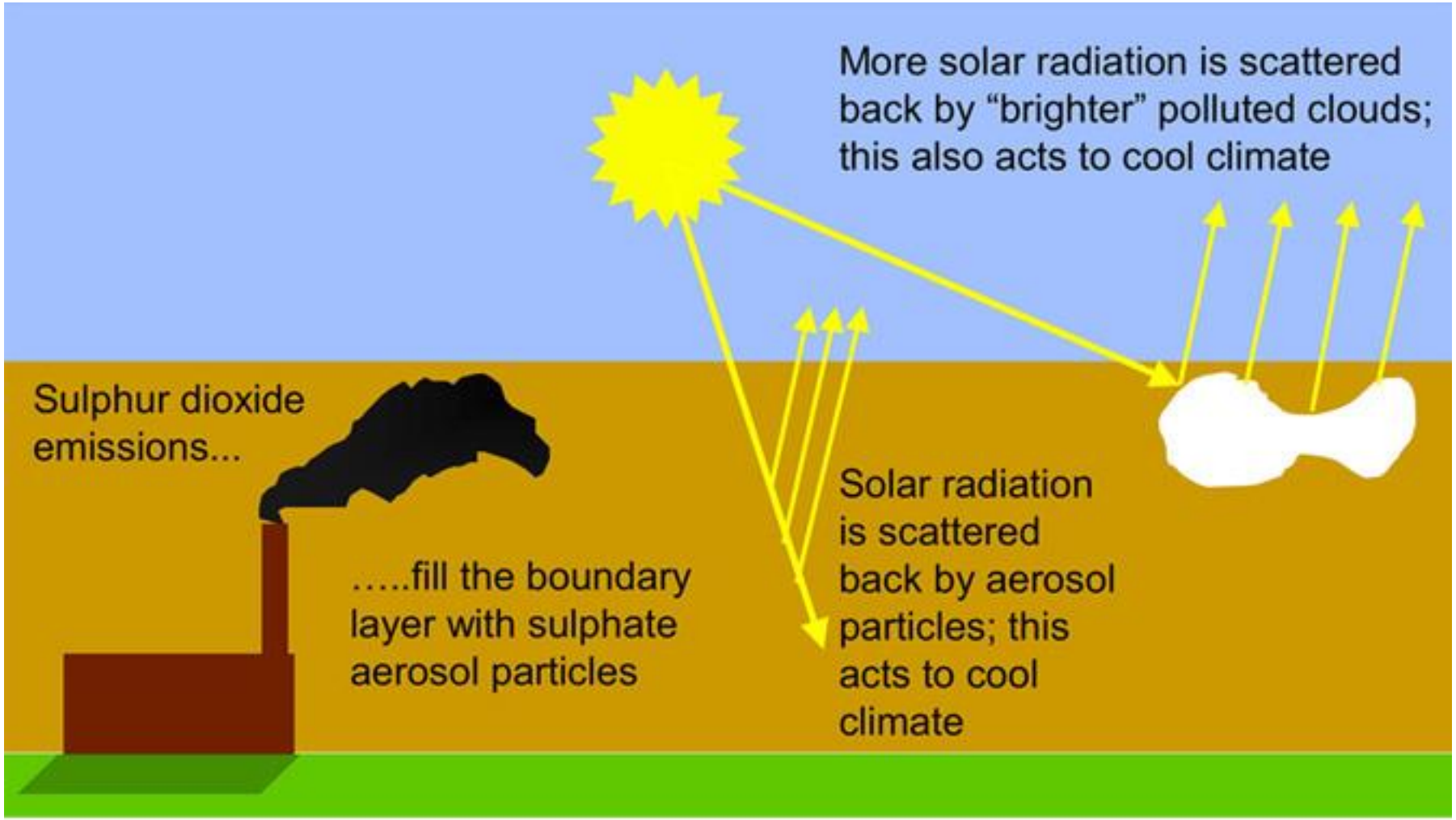
See also: http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant

Changes in volcanic activity

IPCC (2007) WG1 2.7.2 (p.193-195)



Sulphur aerosols cool climate directly and indirectly



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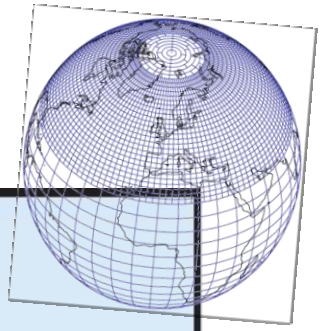
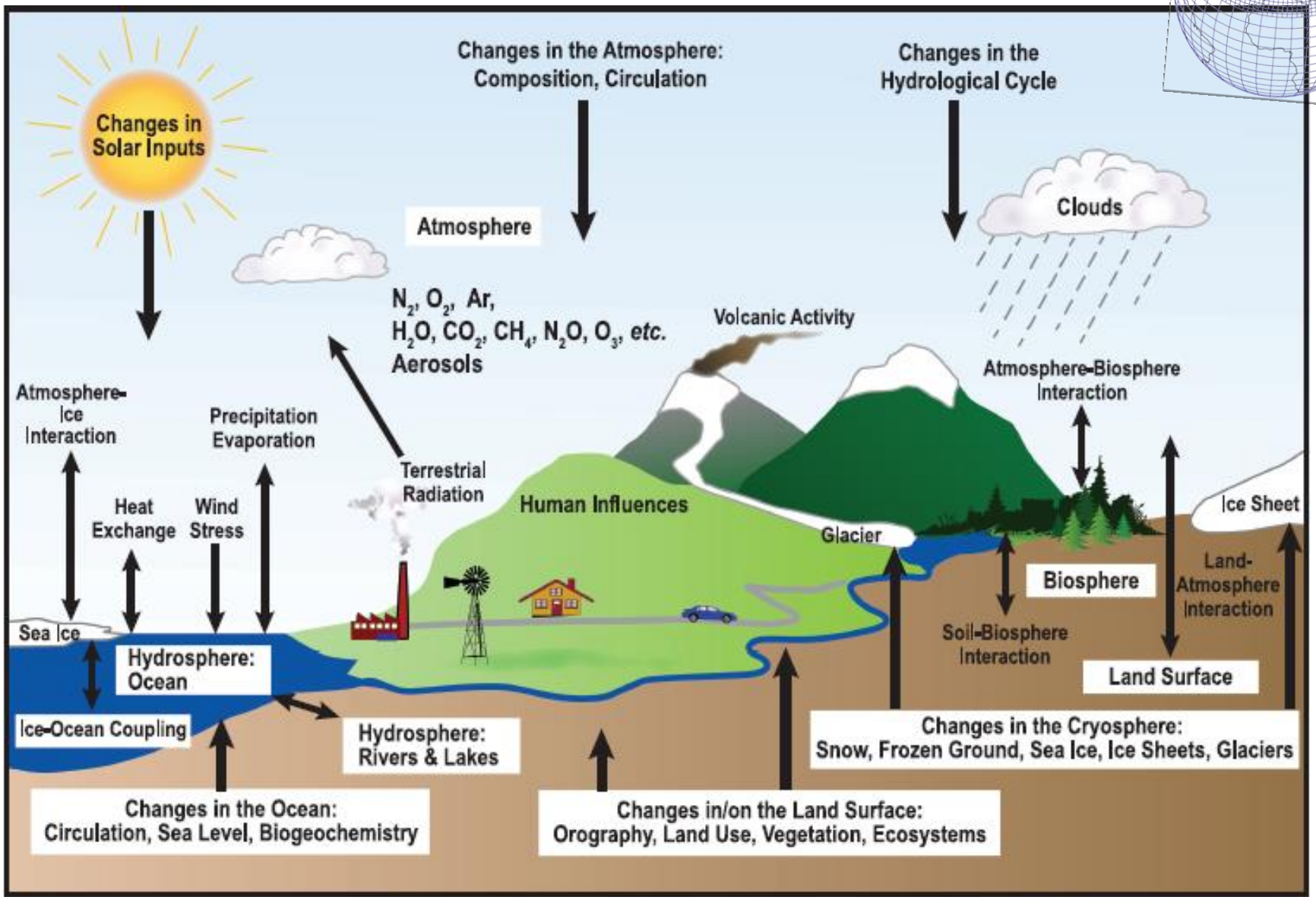
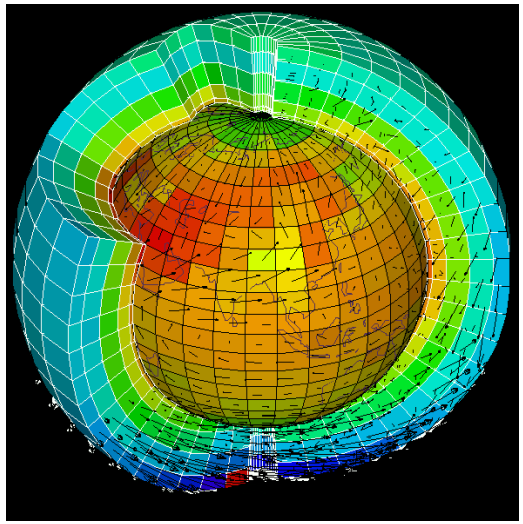
Computer Simulations of Climate

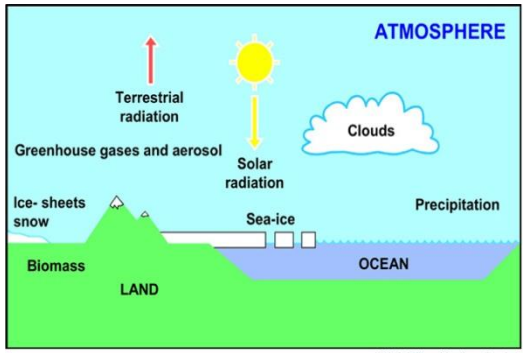




Experiments with climate models

- How much of recent warming is explained by natural effects?
- To answer such questions, experiments can be performed with climate simulations
  - including just natural factors (ocean circulation, volcanic eruptions, changes in the sun, …)
  - including natural and anthropogenic factors (e.g. greenhouse gas emissions which cause heating + sulphate aerosol pollutant particles which cause cooling)





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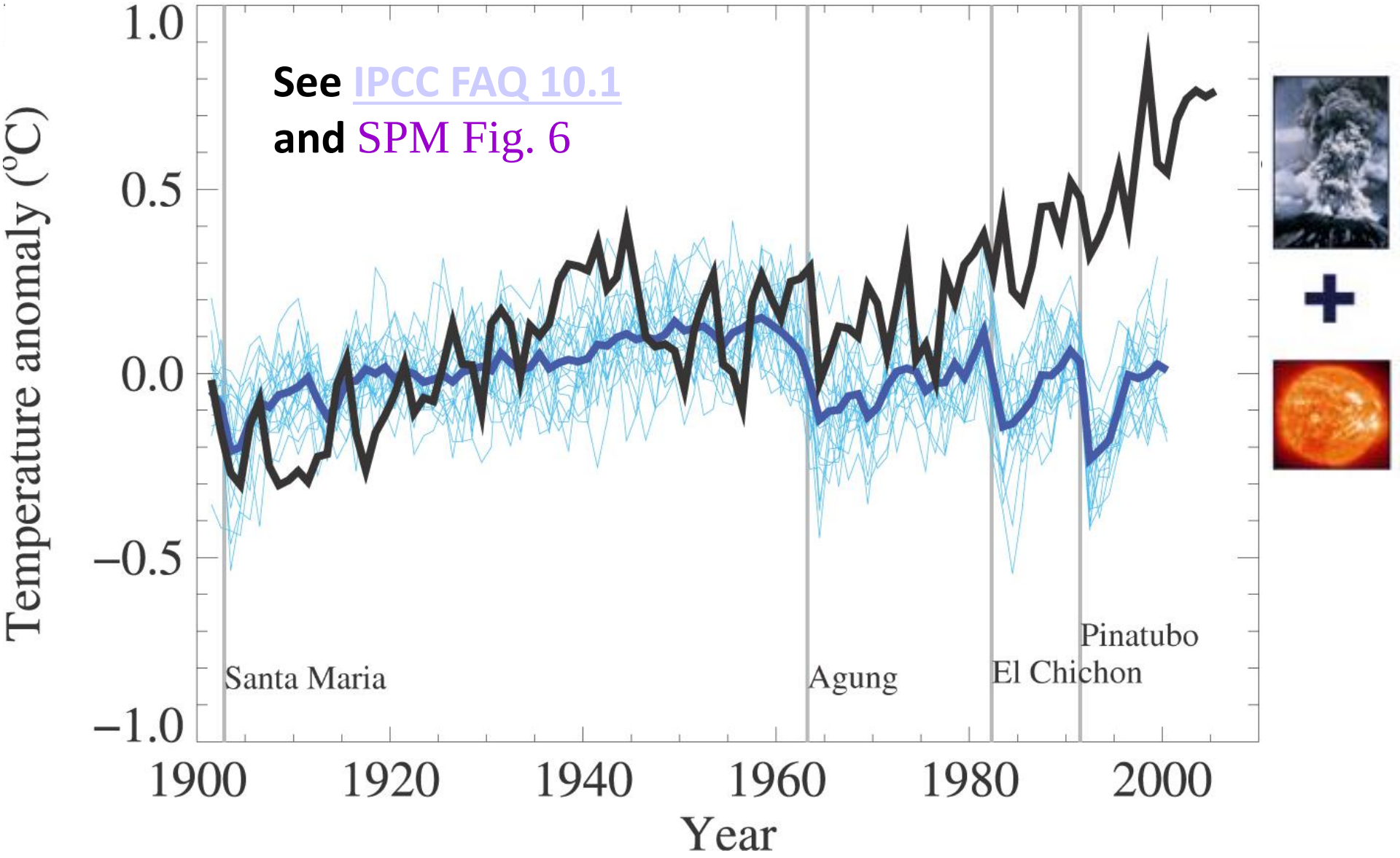
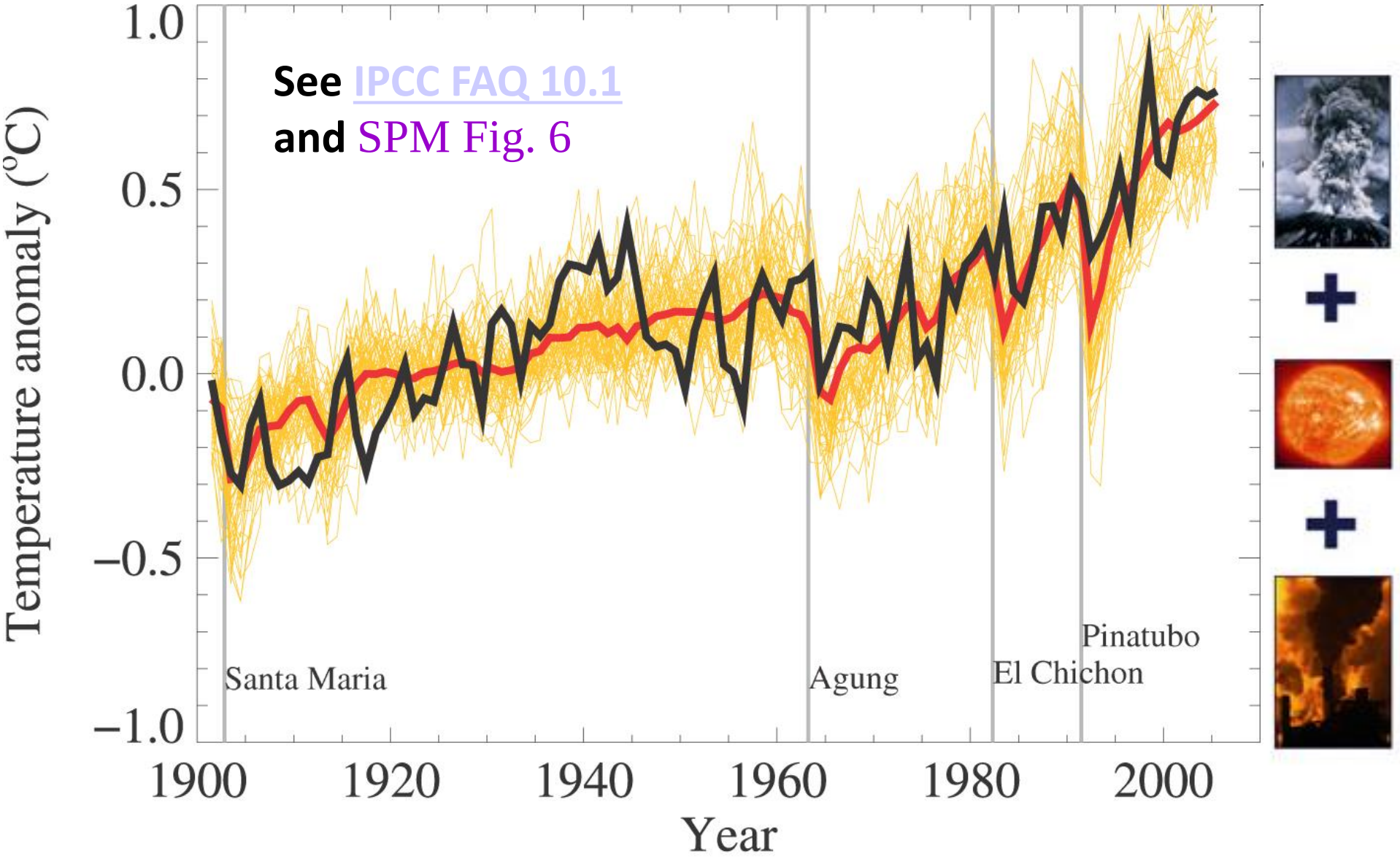
Natural factors cannot explain recent warming



Recent warming can be simulated when man-made factors are included



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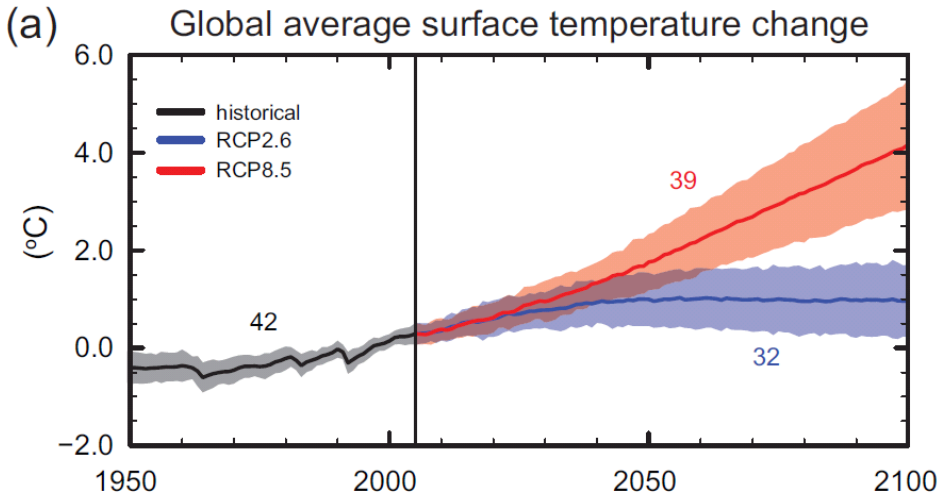
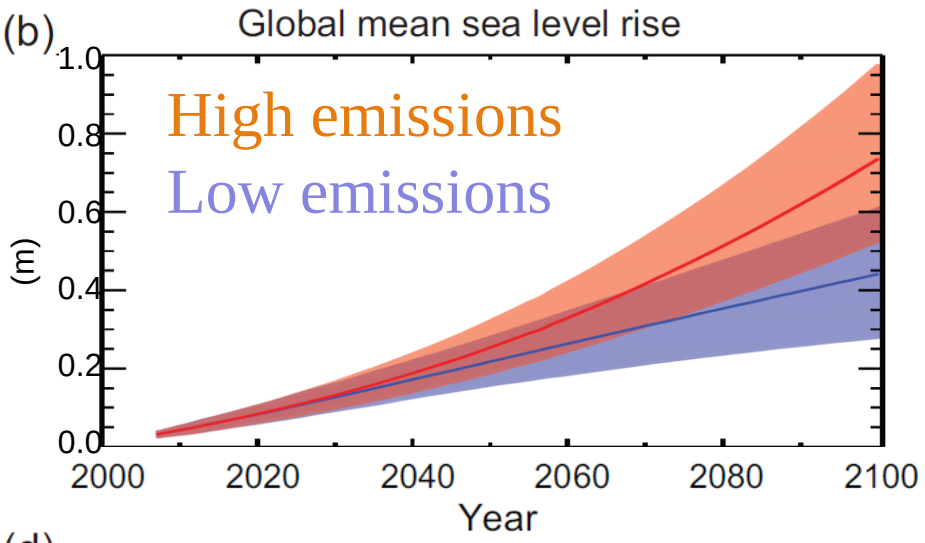
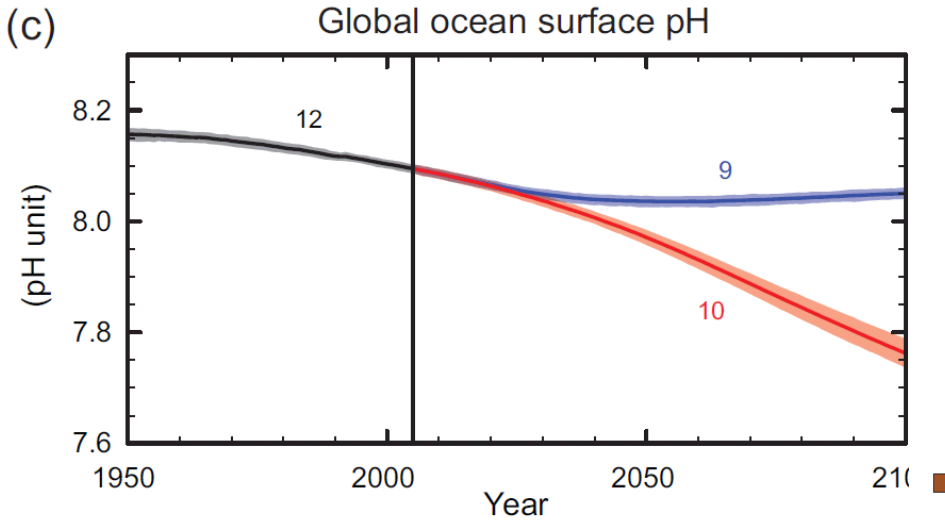
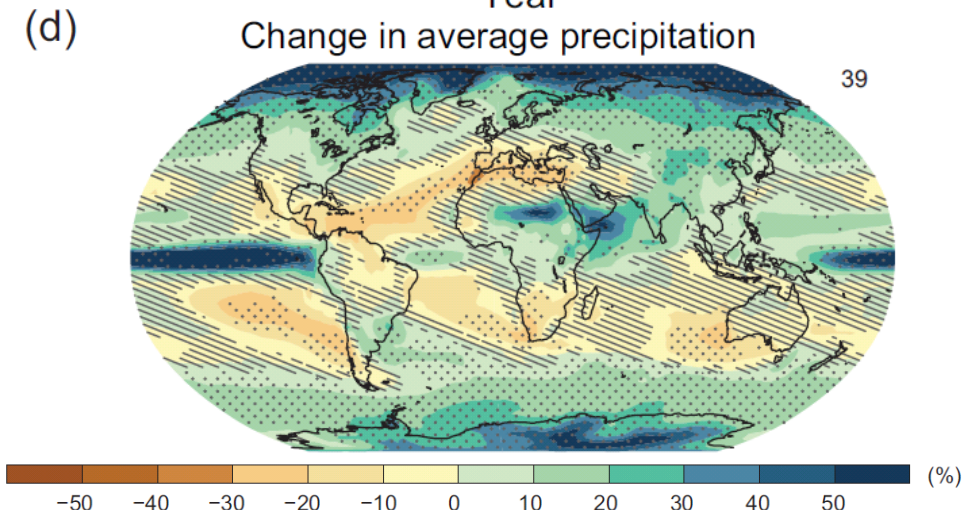
4) What are the predictions?

Future projections to 2100 from climate models



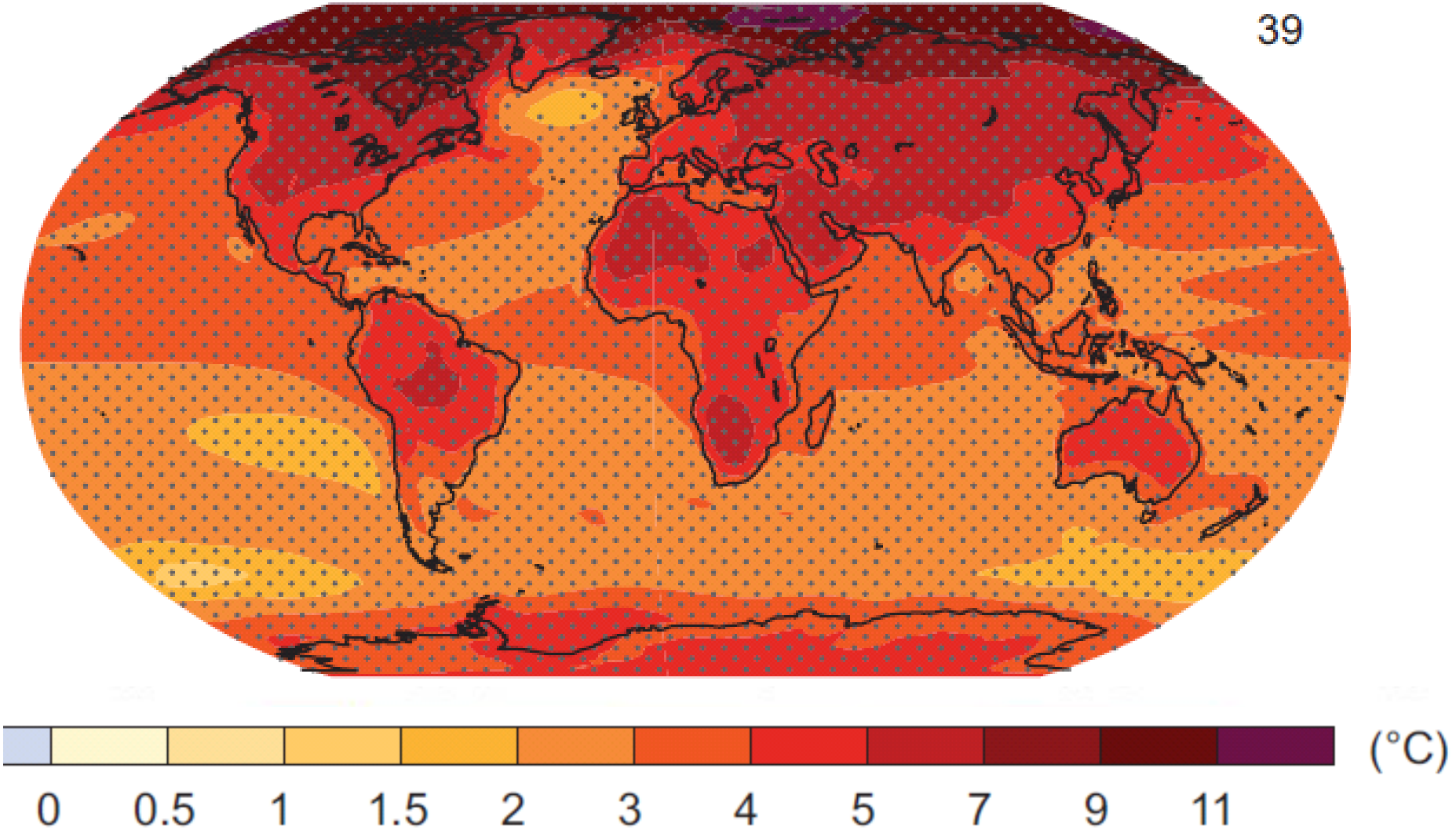




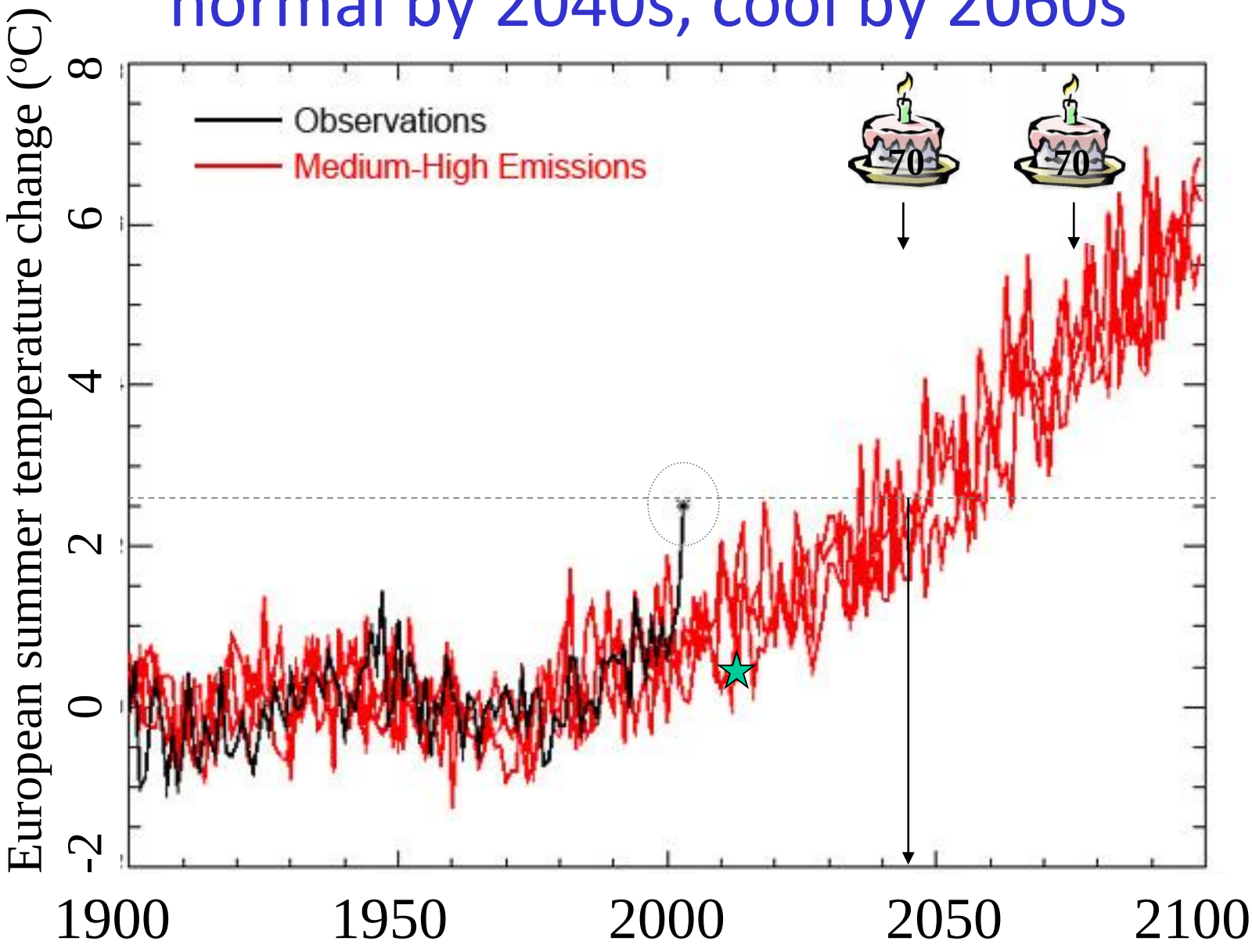


IPCC (2014) WG1 Summary for Policy Makers

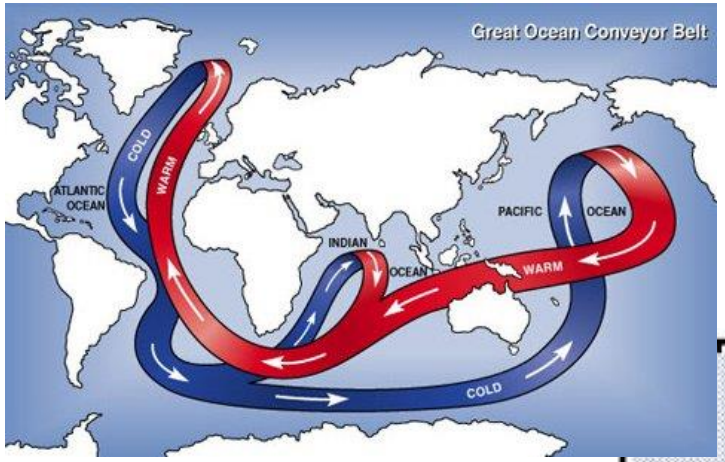
Change in average surface temperature (1986–2005 to 2081–2100) RCP 8.5 Scenario

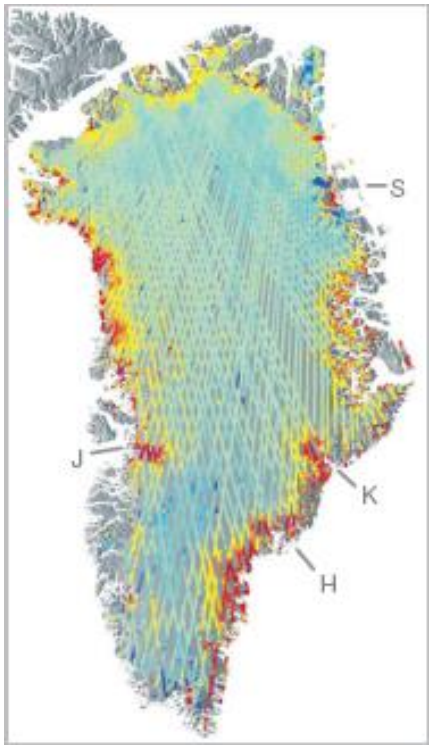


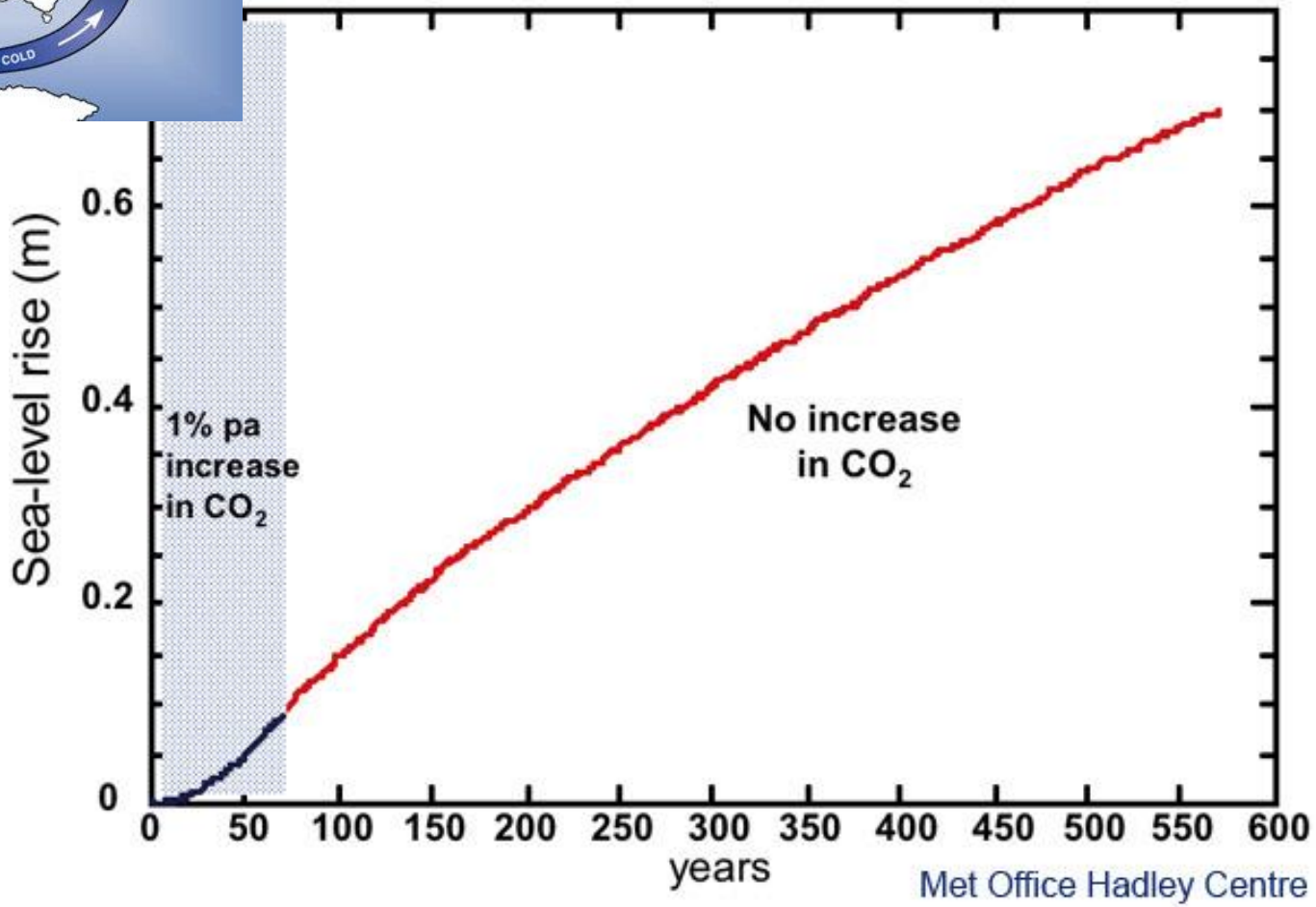
European 2003 summer temperatures could be normal by 2040s, cool by 2060s

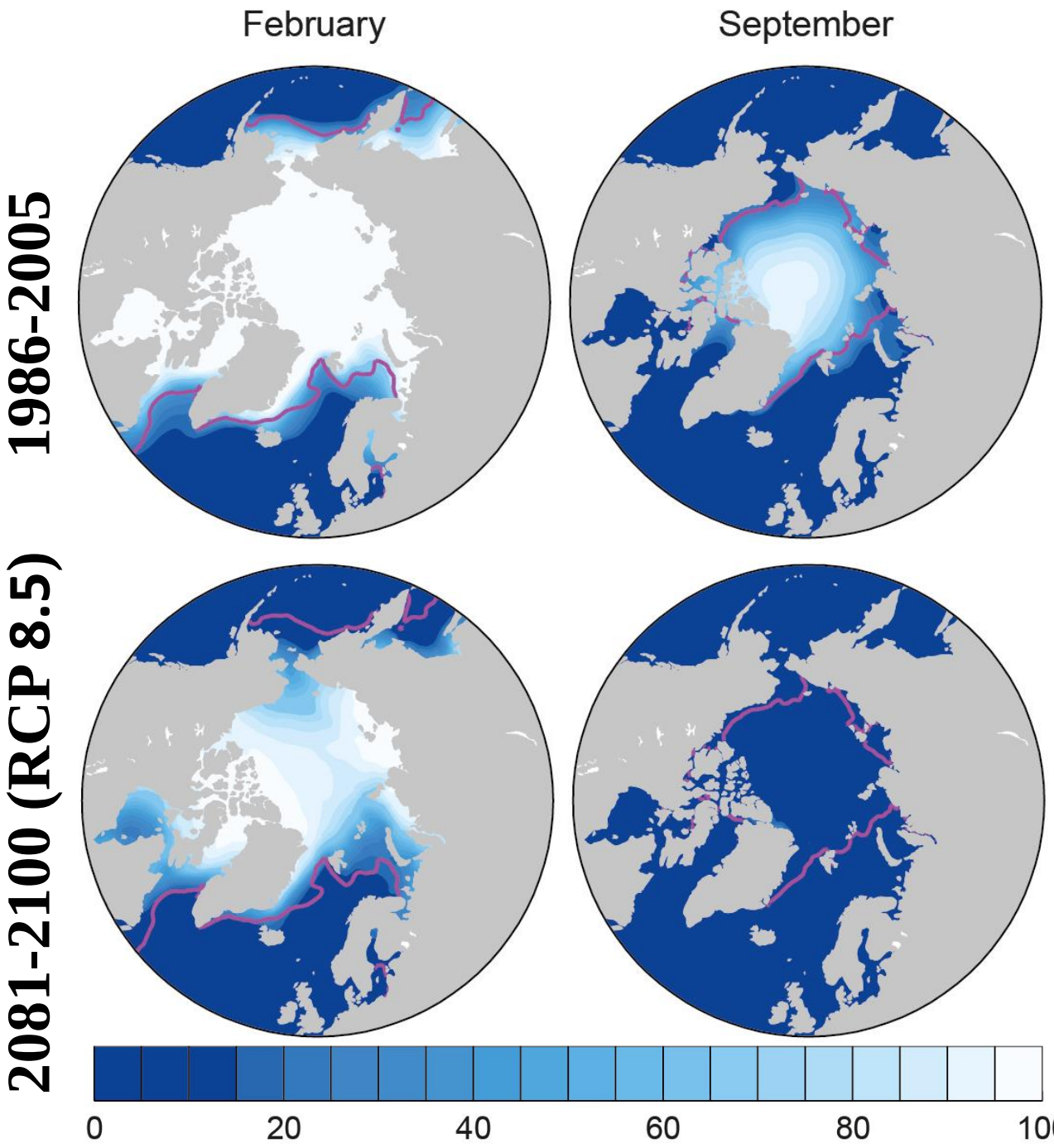


Long-term commitment to sea-level rise









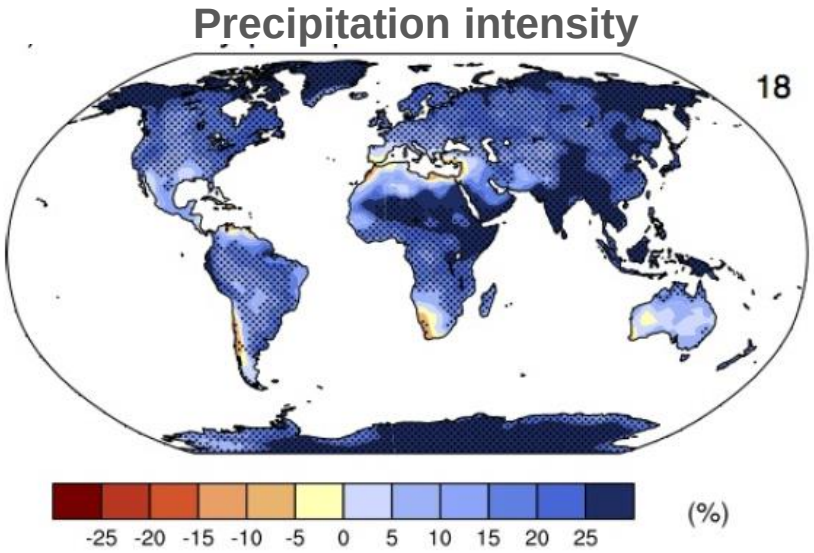
Arctic sea ice extent is projected to diminish over the 21st century

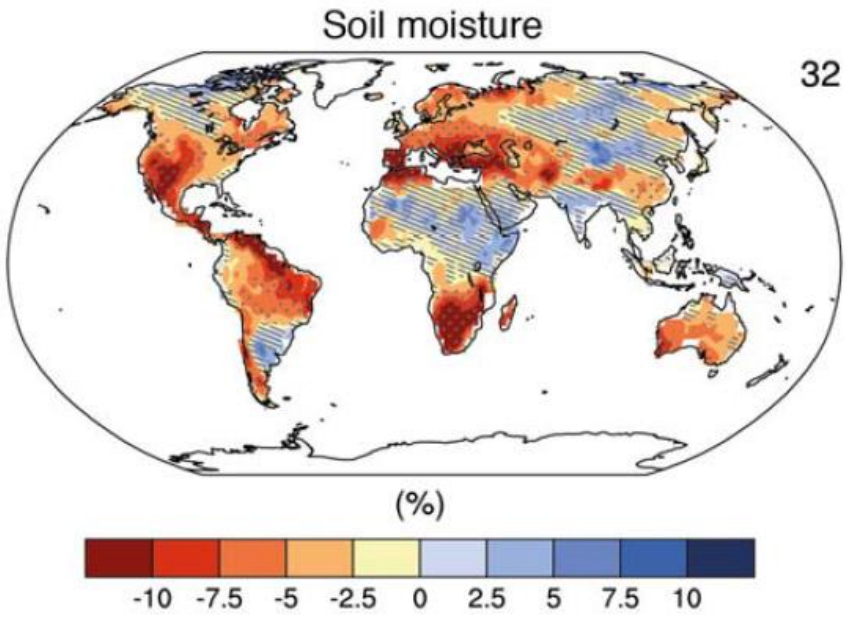
94% decrease in September and 34% decrease in February for the RCP8.5 scenario

IPCC (2013)
WG1 Fig. 12.29

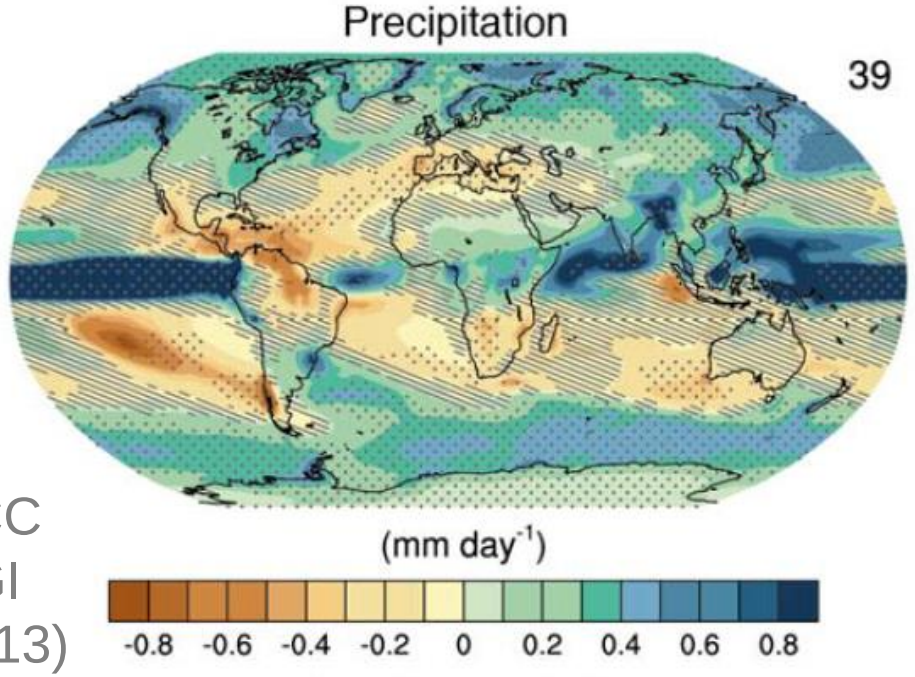
Projections of the water cycle

University of Reading



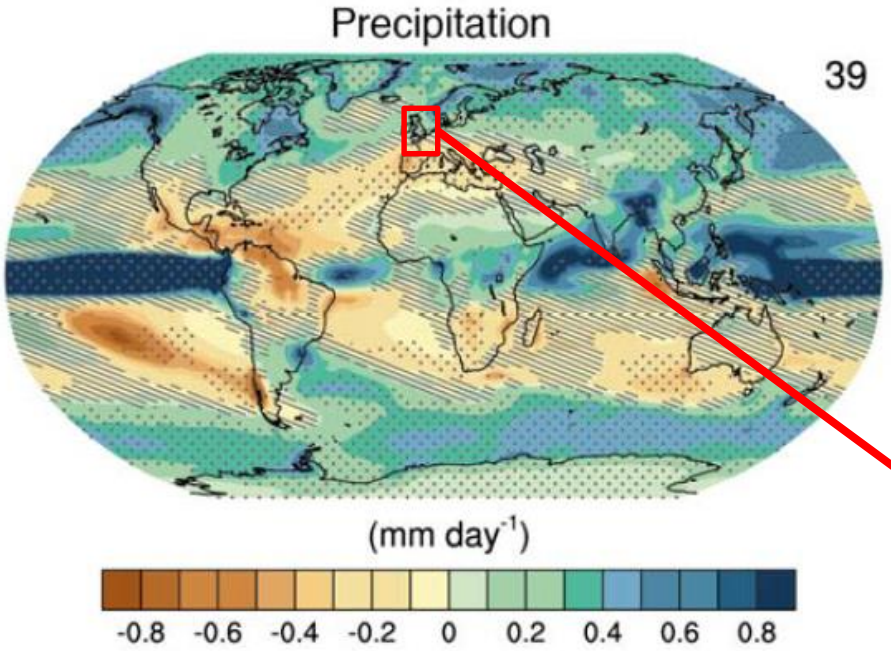


- Increased Precipitation
- More Intense Rainfall
- More droughts
- Wet regions get wetter, dry regions get drier?
- Regional projections??



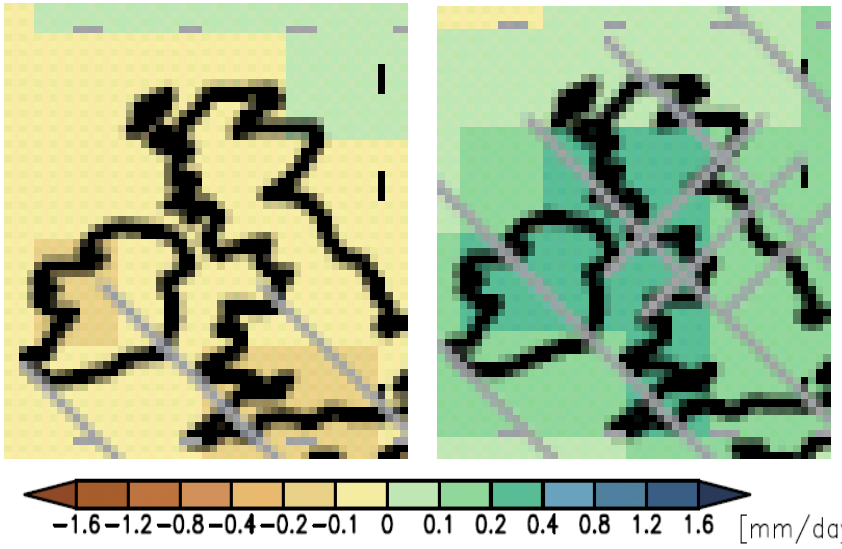
IPCC WGI (2013)

Challenge: Regional projections



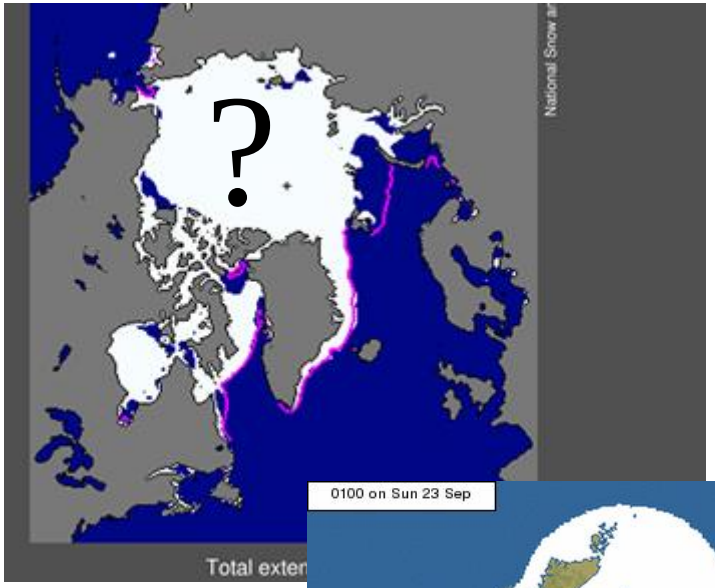
General changes in rainfall patterns are quite well understood **but** changes at regional scales – countries, even river catchments – are much less certain.

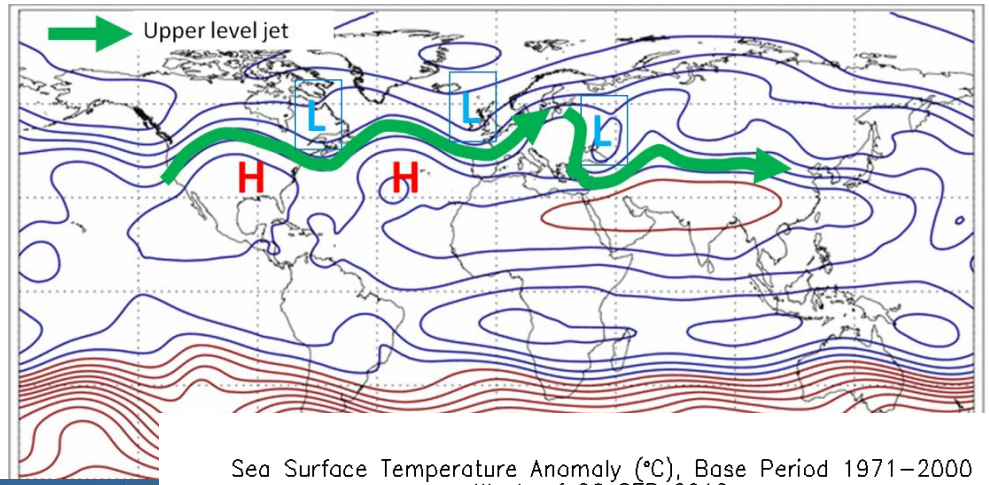
Summer Winter

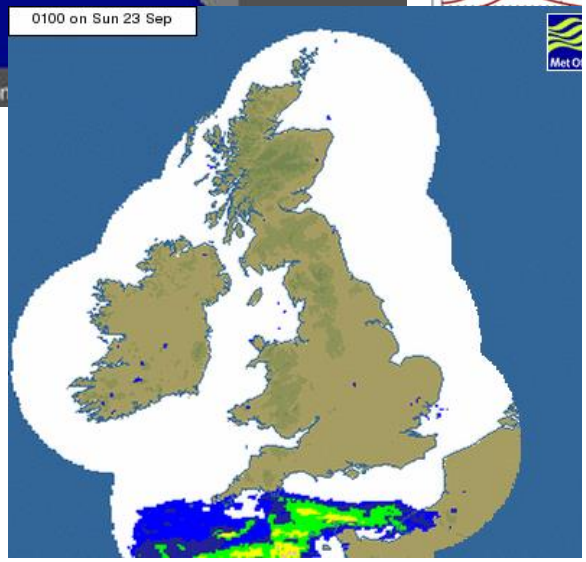


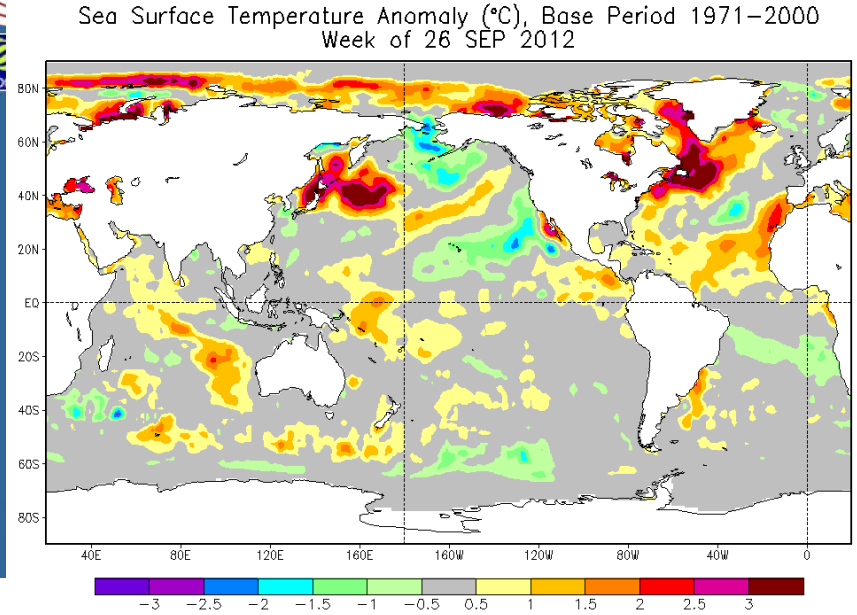
Small changes in the position and strength of the atmospheric circulation can have large influences on regional climate but are difficult to predict with any confidence.

How will atmospheric and oceanic circulations change?

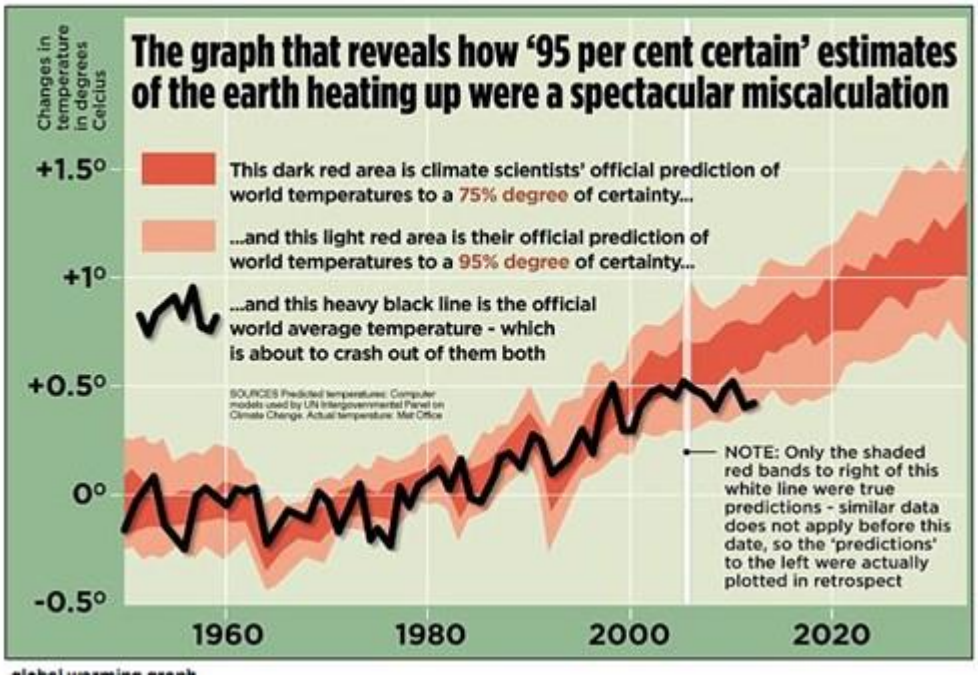








Outstanding questions



From the Mail on Sunday 16th March 2013

- Has global warming stopped (above)?
- Are computer predictions reliable?
- Why have we had such odd weather in recent years?

Summary

- The evidence for warming is unequivocal
- Northern hemisphere warming unusual in context of last 1400 years and for 100,000 years in the Arctic
- Greenhouse gases at highest levels for > 800,000 yrs
- Physics of greenhouse effect well understood
- Substantial changes in global temperature and rainfall patterns are projected using computer simulations
- Predicting regional climate change is a challenge…
  - How much more greenhouse gases will we emit?
  - Will "knock on effects" of the warming involving the land surface or clouds to amplify or oppose the warming?
  - How will atmospheric and oceanic circulations change?