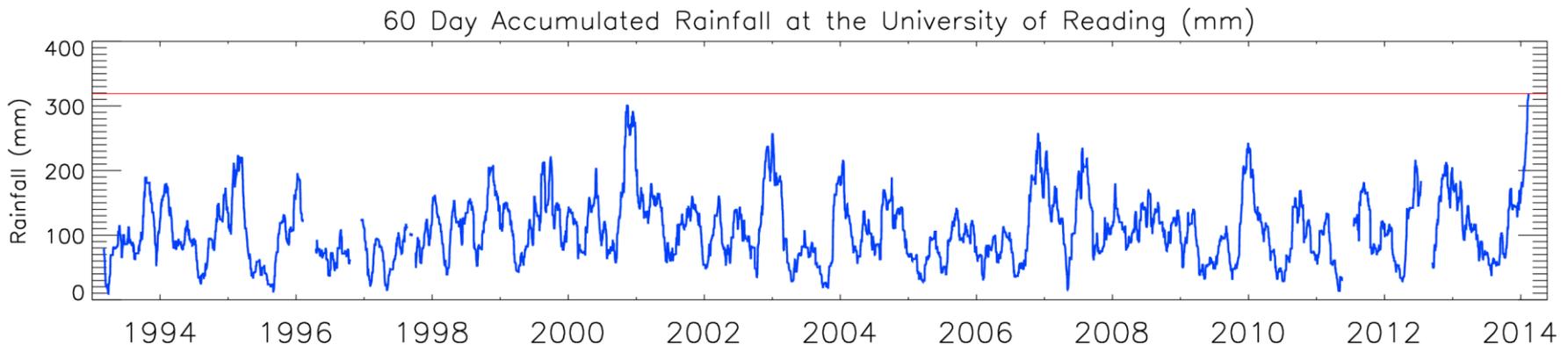


Extremes of Weather and the Latest Climate Change Science

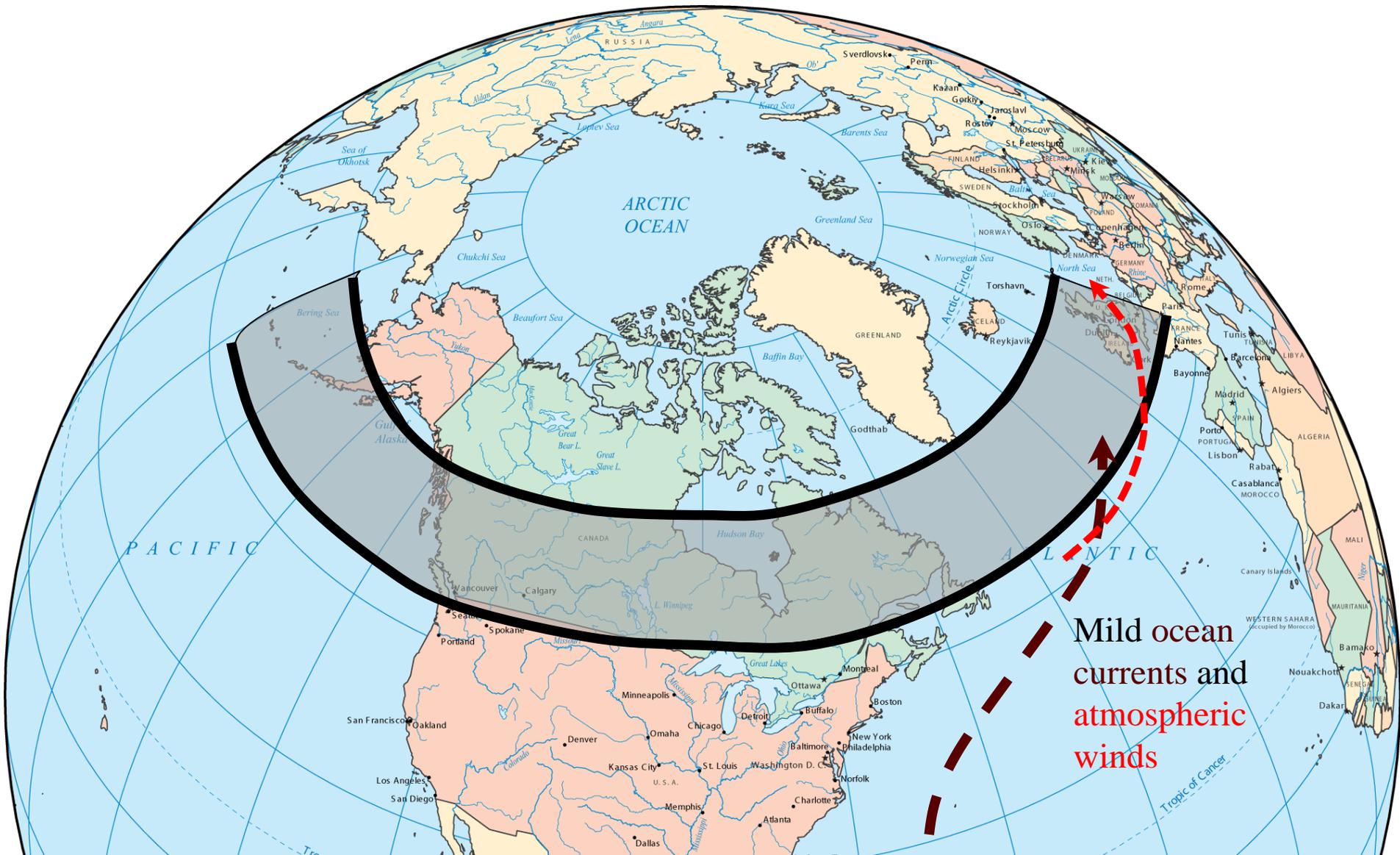
Prof. Richard Allan,
Department of Meteorology
University of Reading

Extreme weather climate change

- 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.



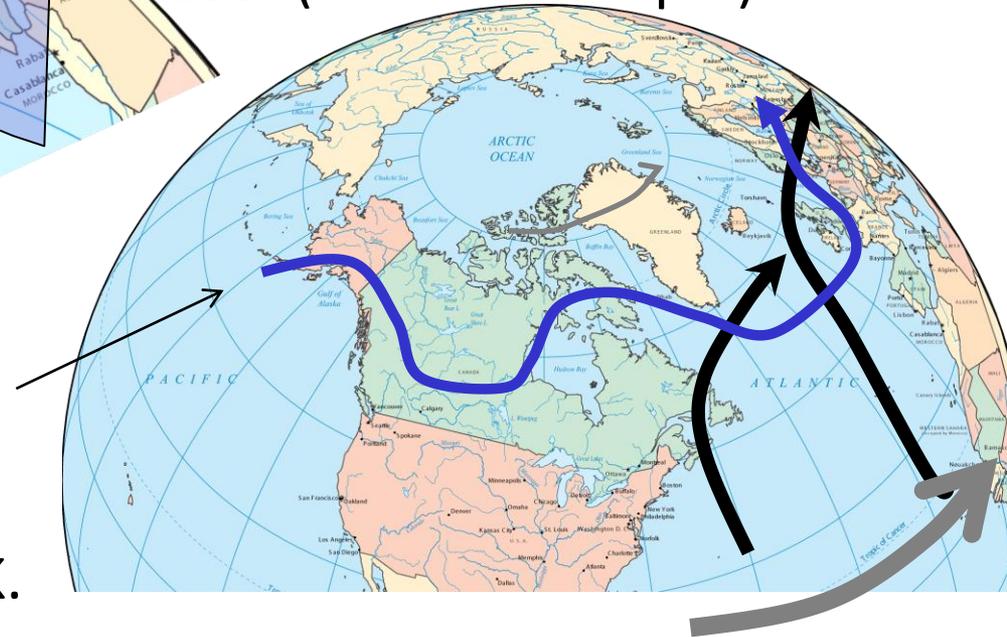
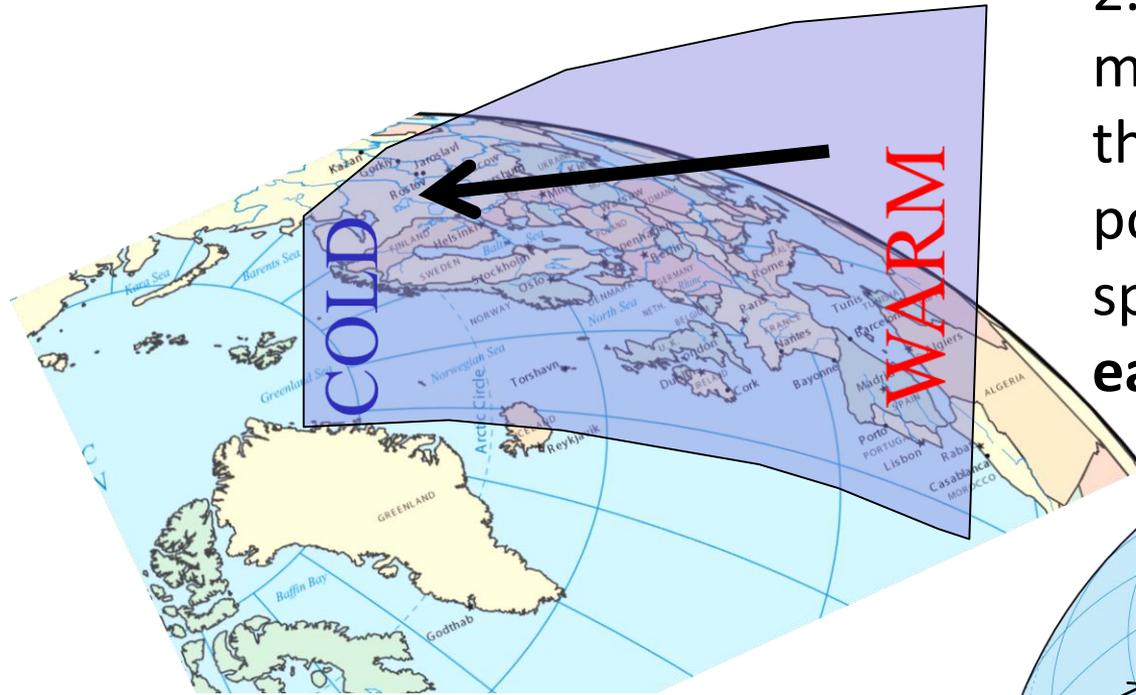
What explains the mild climate in the UK and its variations from year to year?



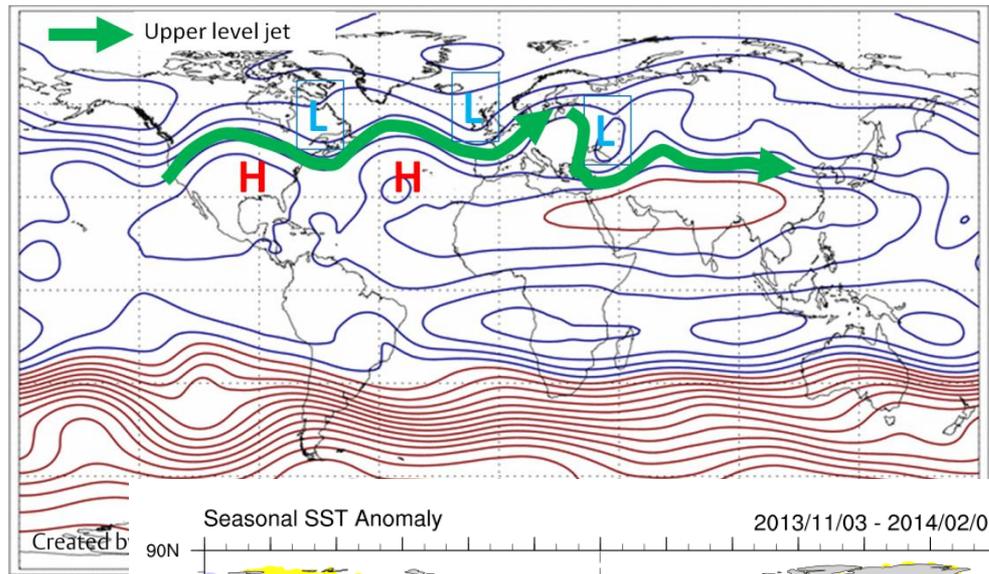
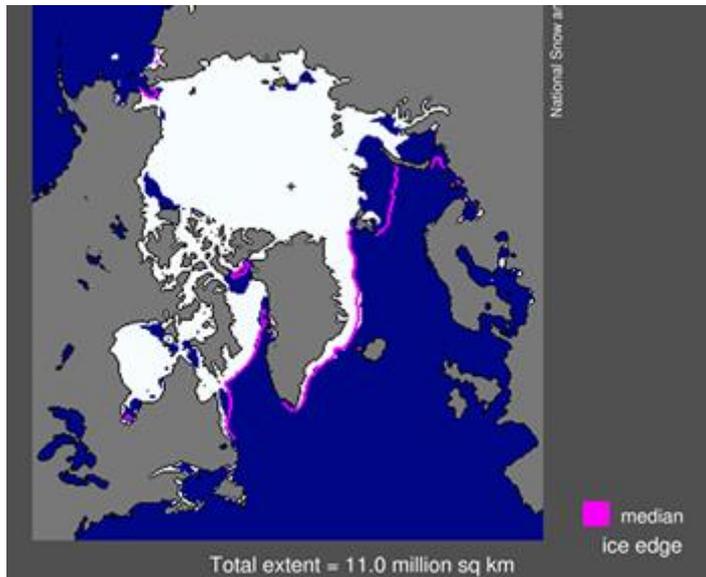
1. Air is **warmer** closer to the tropics (air expands) than at the poles (air contracts). This generates a **poleward flow of air** high up in the atmosphere

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)

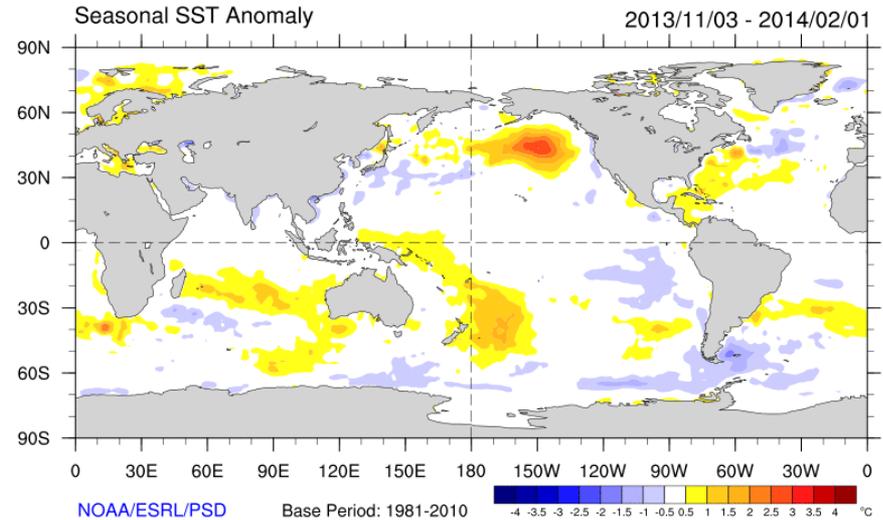
3. This high altitude (5-7km) fast moving ribbon of air is called the **jet stream**. It steers weather systems over or away from the UK.



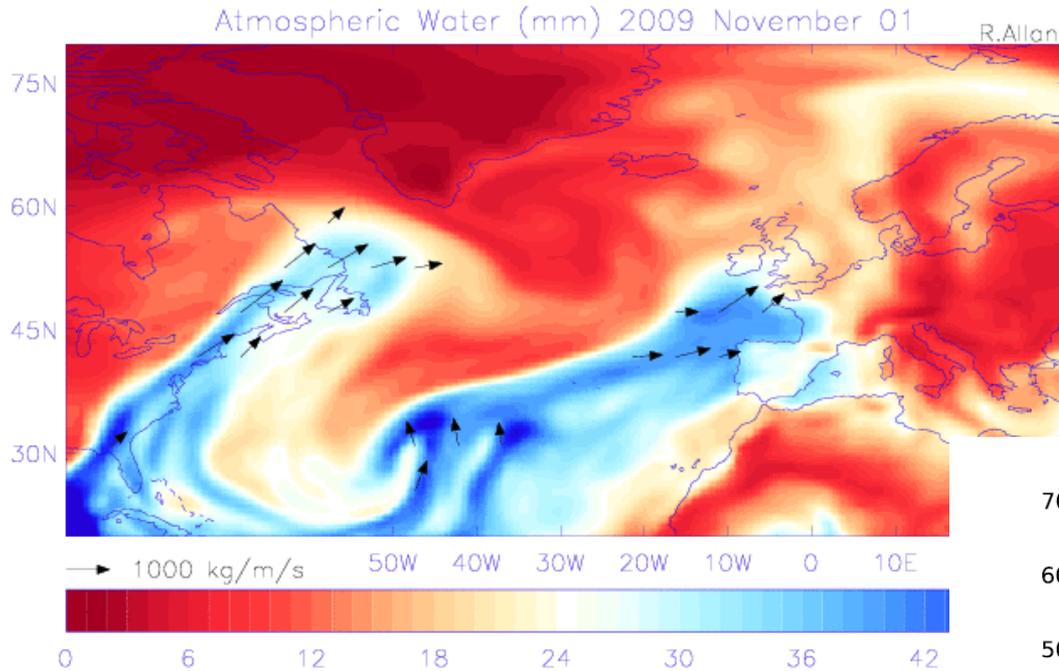
Remote influences on the jet stream



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.

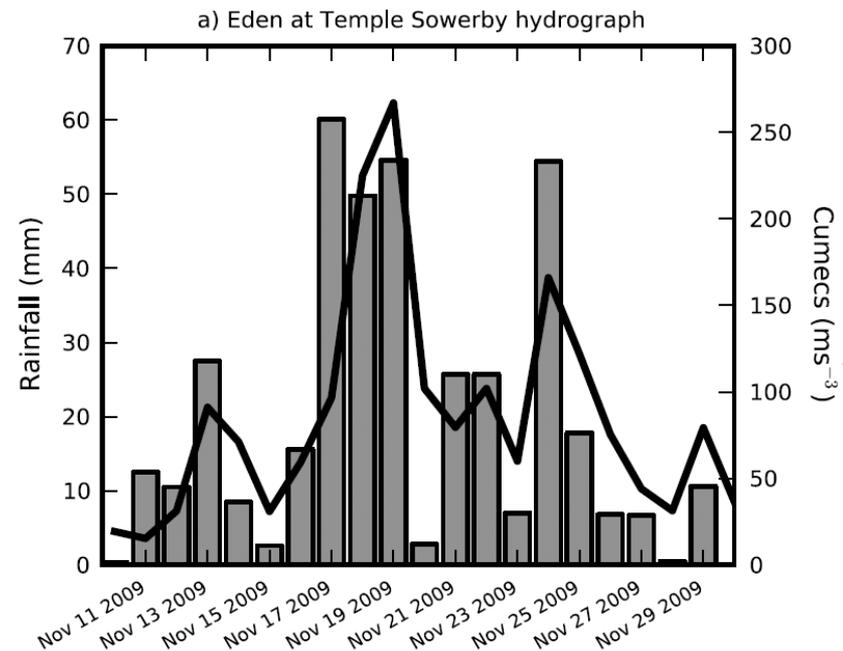


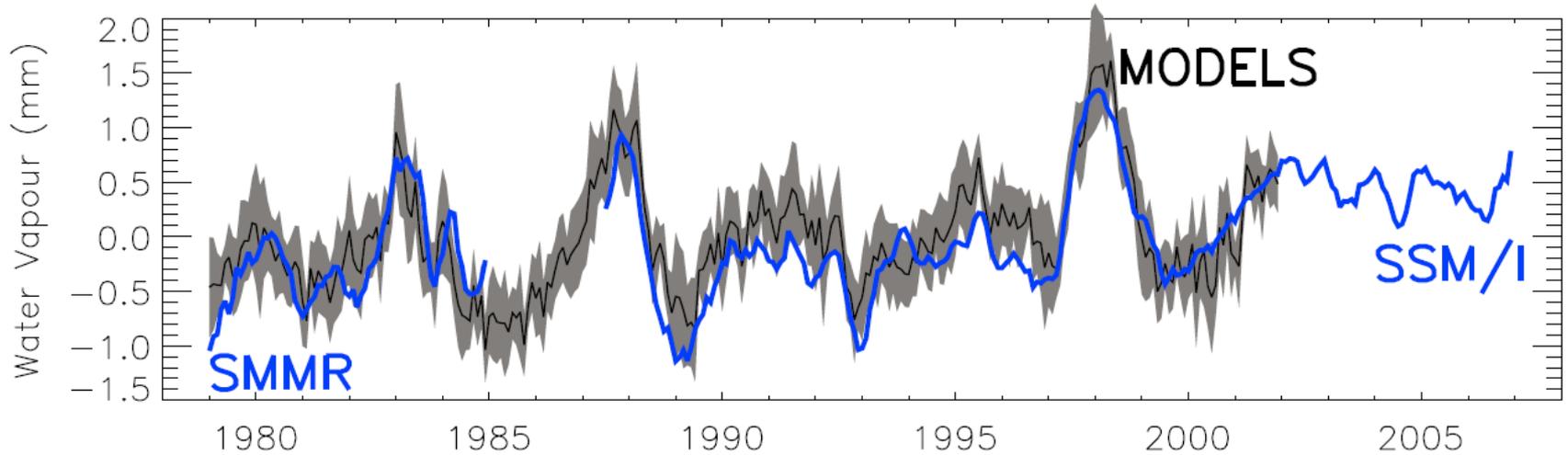
Cumbria flooding 2009: atmospheric river



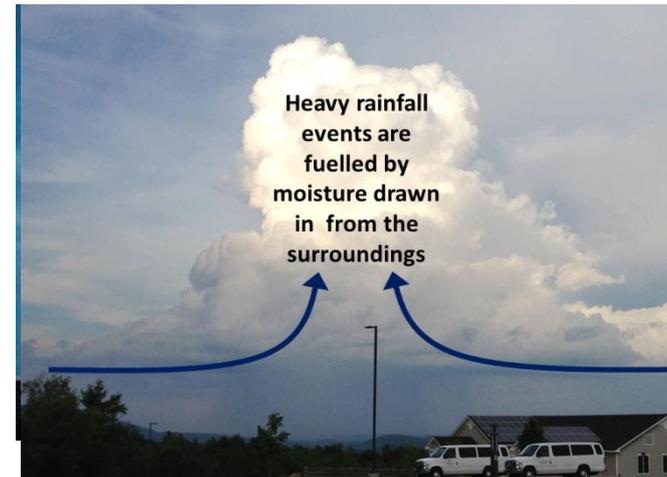
- Massive moisture transport
- Heavy rainfall over mountains
- River flooding

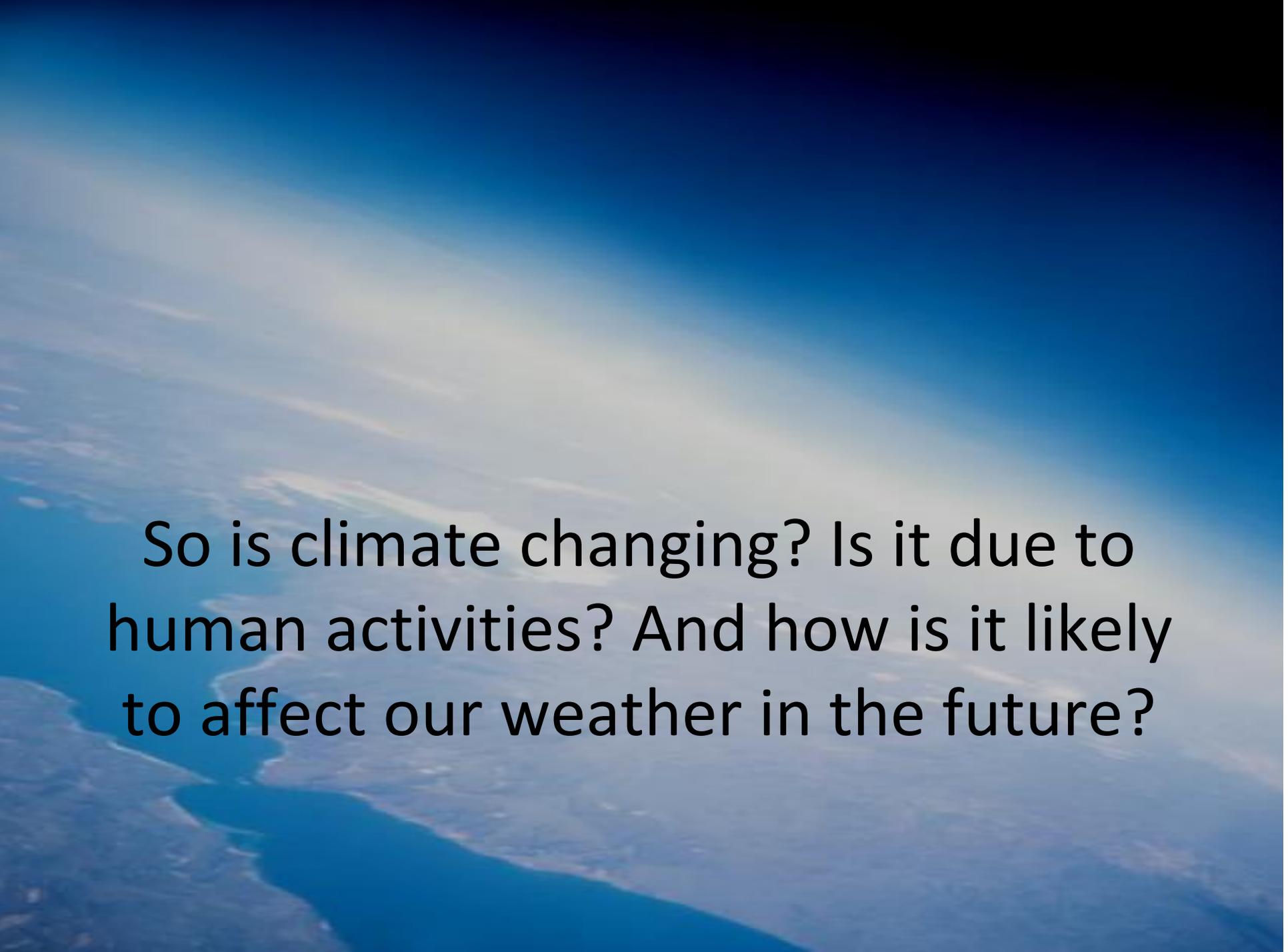
- Not only flood-generating mechanism
 - Summer flash flooding
 - Jet stream & wet seasons





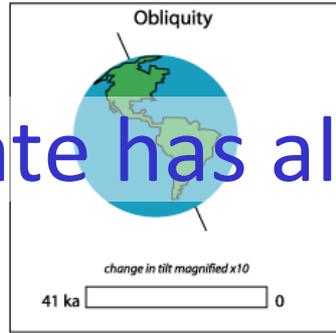
- Atmospheric **moisture** increases with **warming** in computer **simulations** and as detected by conventional and satellite **observations**
- The enhanced greenhouse effect **amplifies** climate change (+ve “feedback”)
- Additional moisture also fuels a greater **intensity** of rainfall



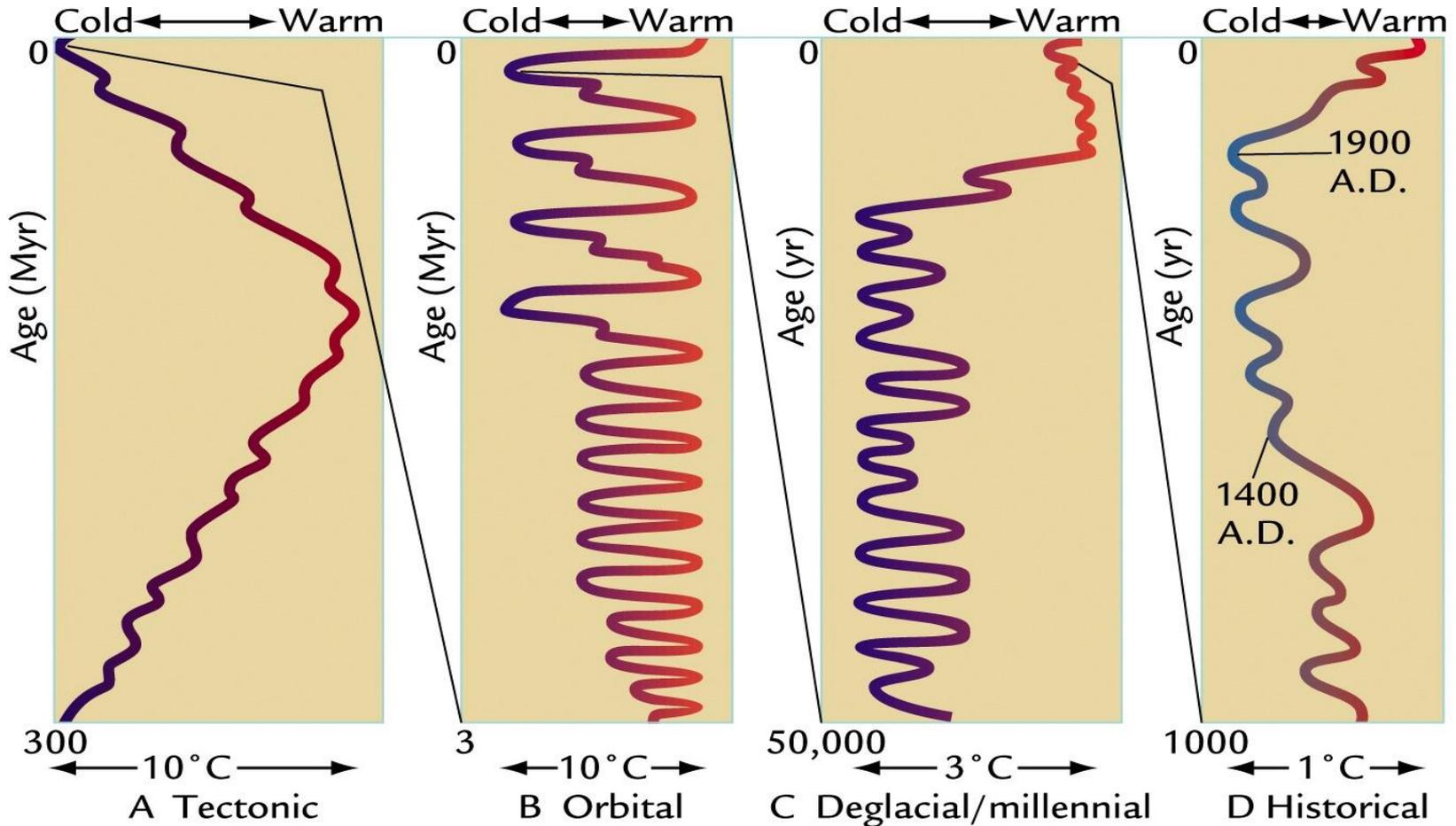
An aerial photograph of a coastline, showing a river delta flowing into the ocean. The water is a deep blue, and the land is a lighter, sandy or brownish color. The sky is a clear, pale blue. The text is overlaid on the image, centered horizontally and vertically.

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



Global temperature

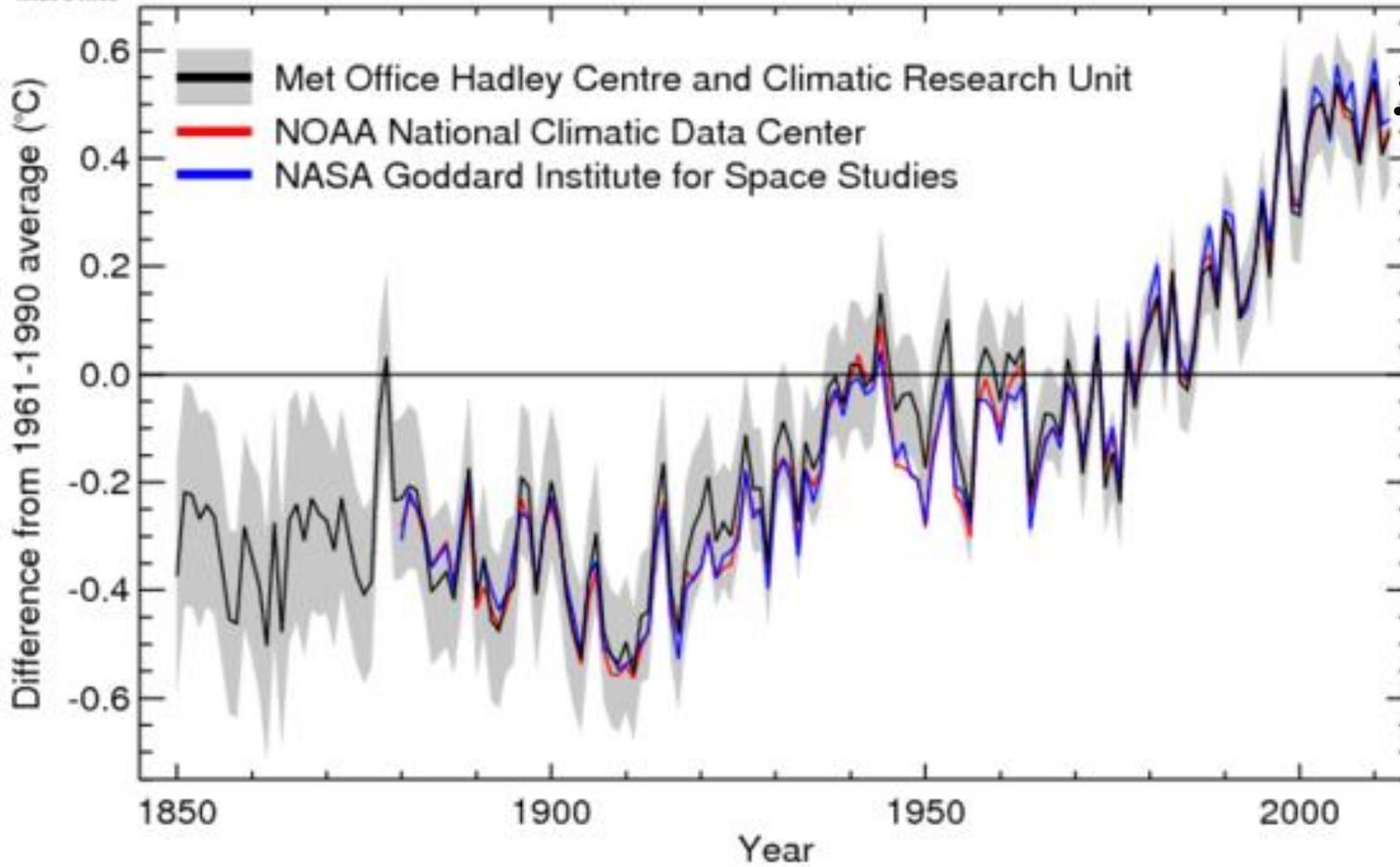


1) Is climate changing now?

The planet is warming

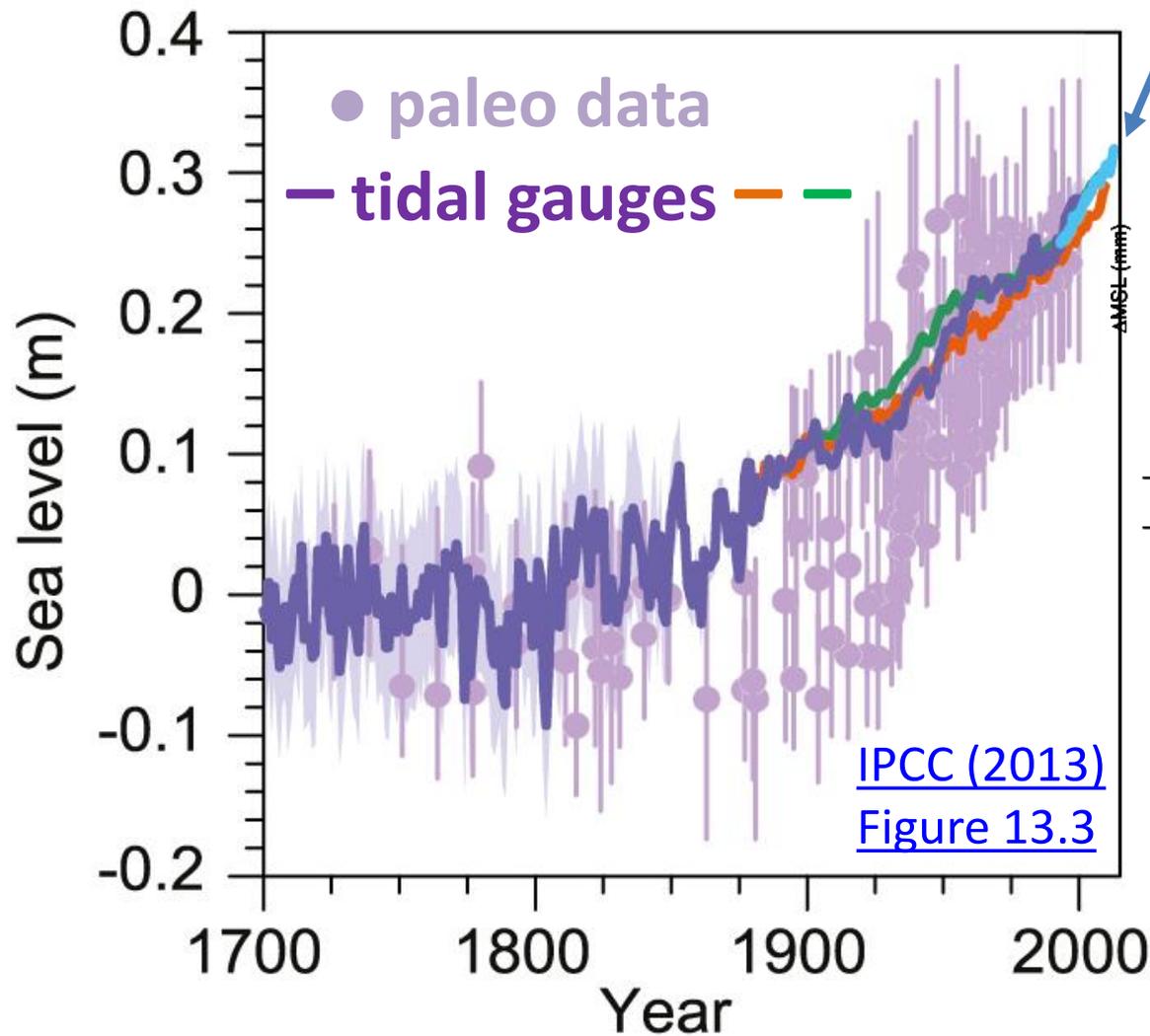


Global average temperature anomaly (1850-2012)

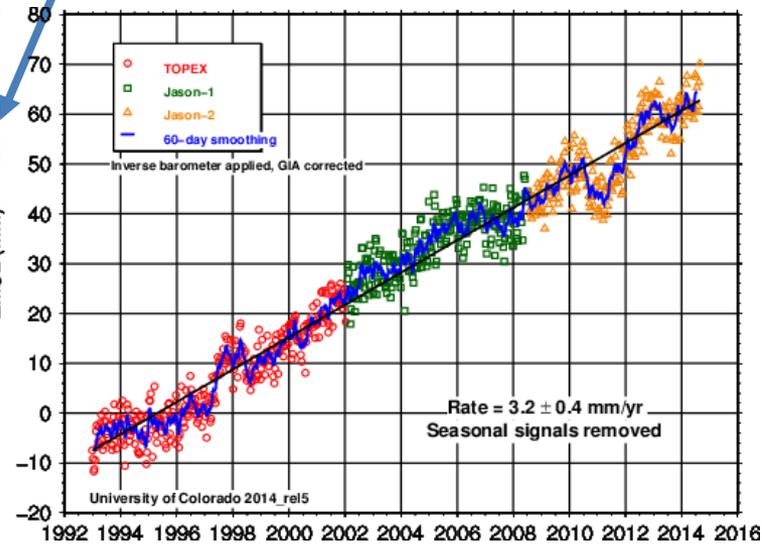


www.metoffice.gov.uk/research/monitoring/climate/surface-temperature

Global average sea level is rising...

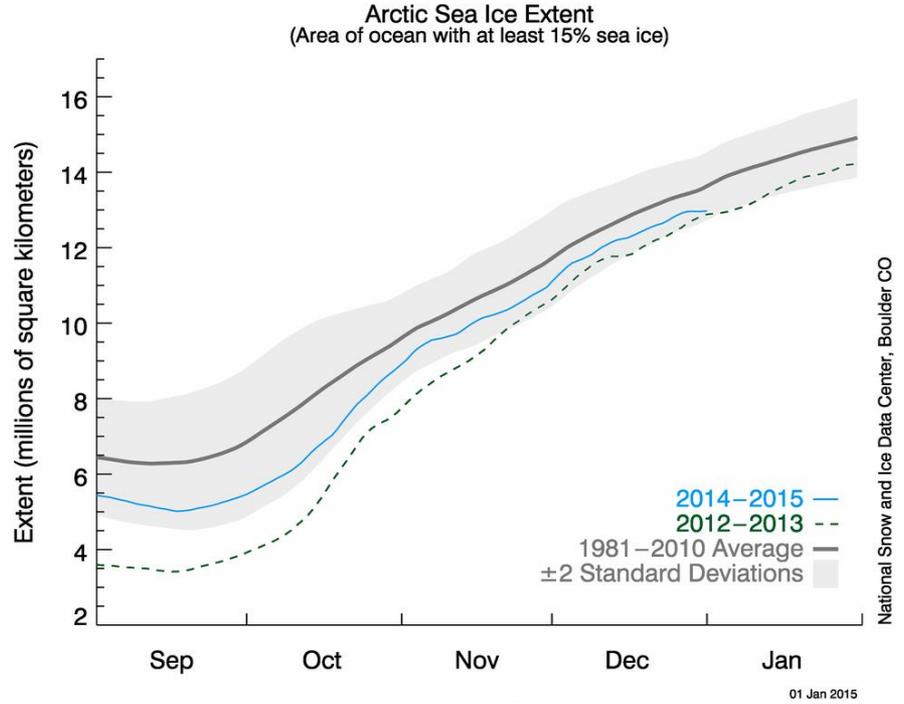
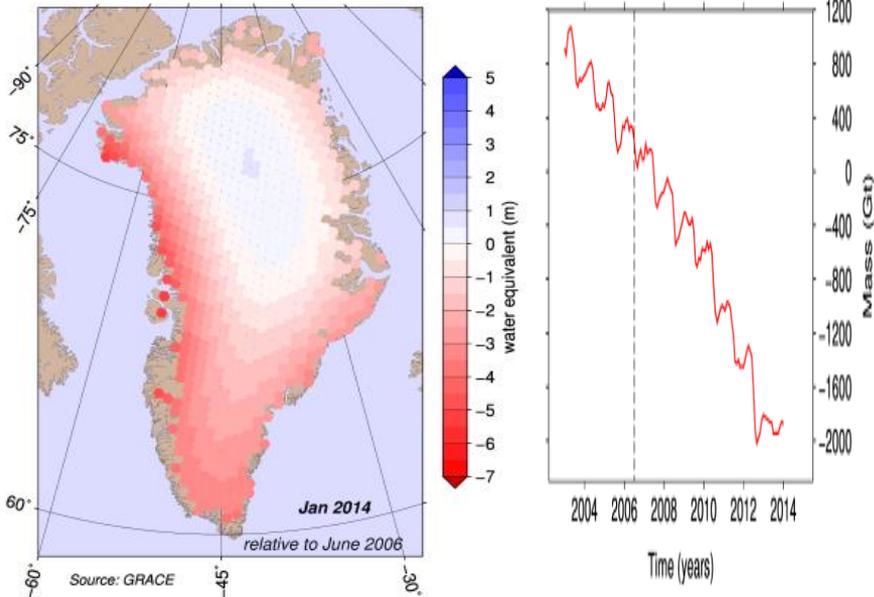


Satellite Altimeter data

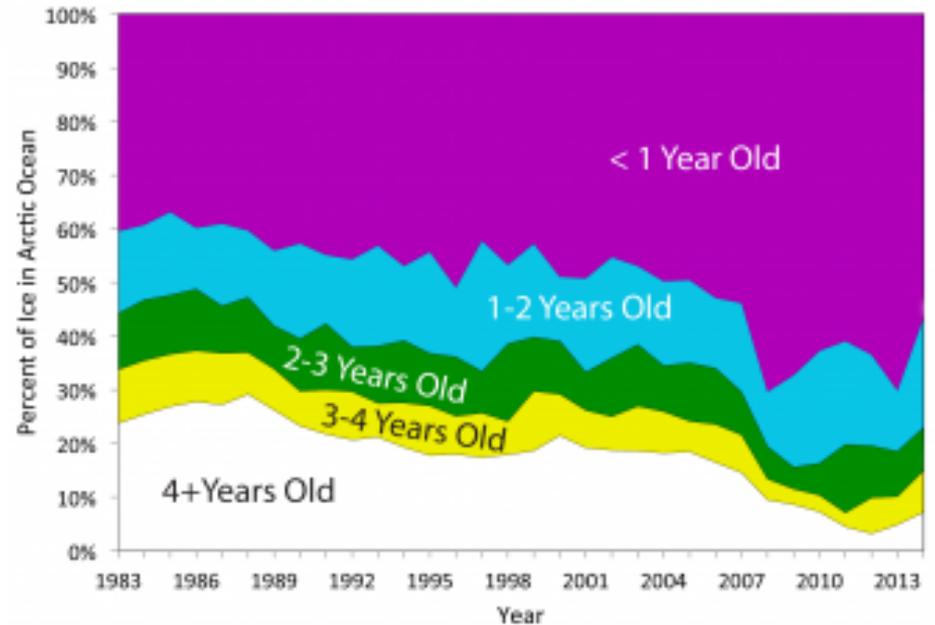
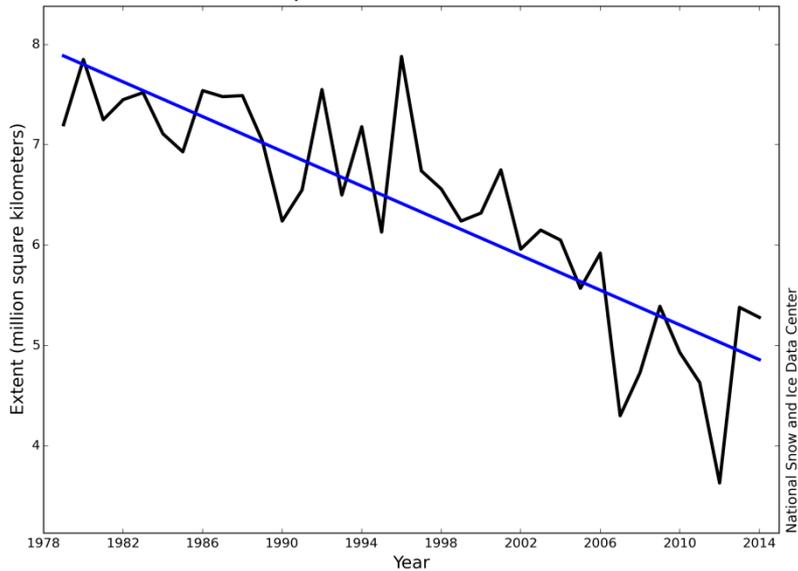


<http://sealevel.colorado.edu/>

Melting of Arctic Ice



Average Monthly Arctic Sea Ice Extent
September 1979 - 2014

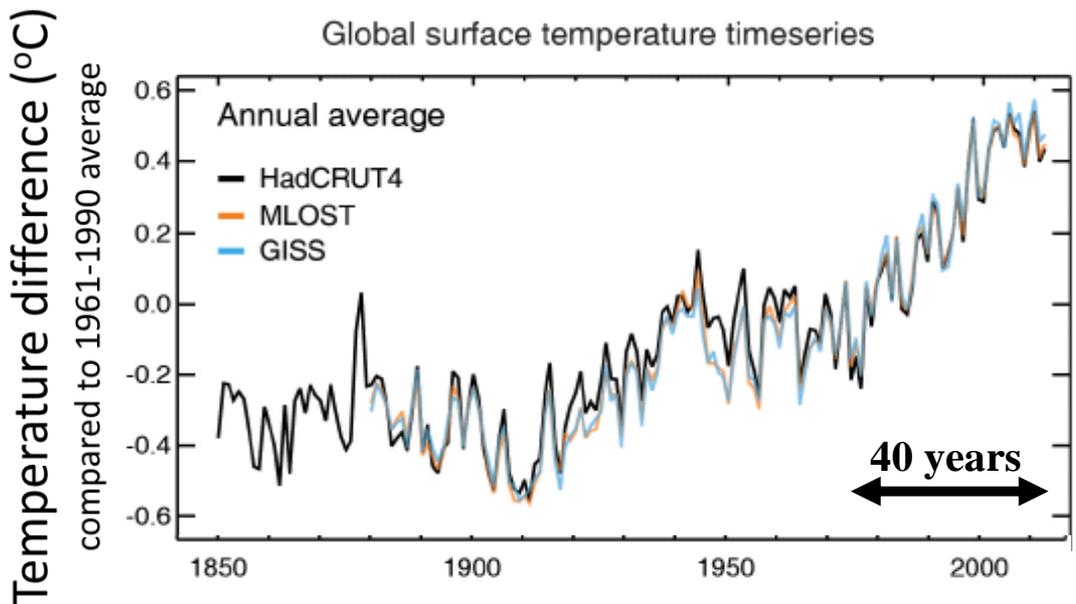


National Snow and Ice Data Center, Boulder CO

NSIDC, Courtesy M. Tschudi, University of C

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)

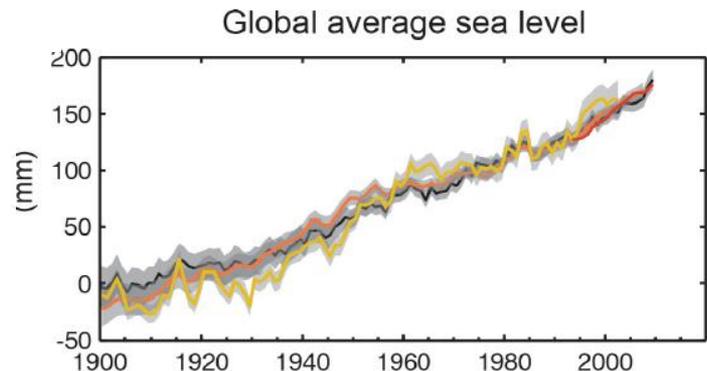
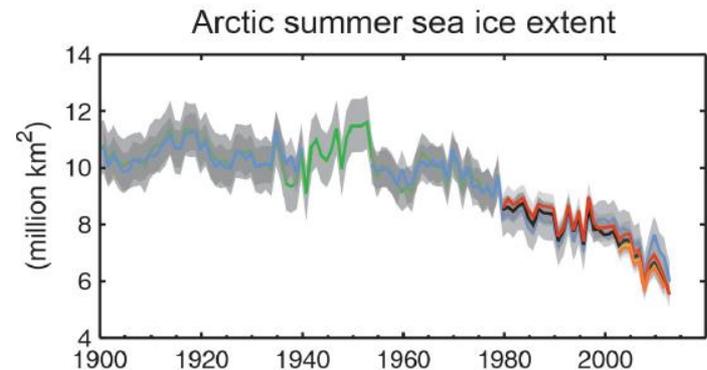


Top: Differences in global average surface temperature compared to the 1961-1990 average

Middle: Changes in the July-September average summer Arctic sea ice extent

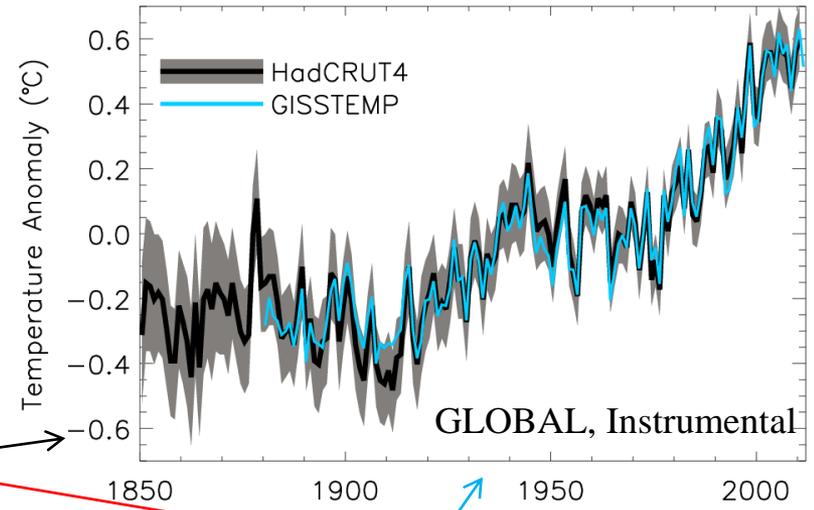
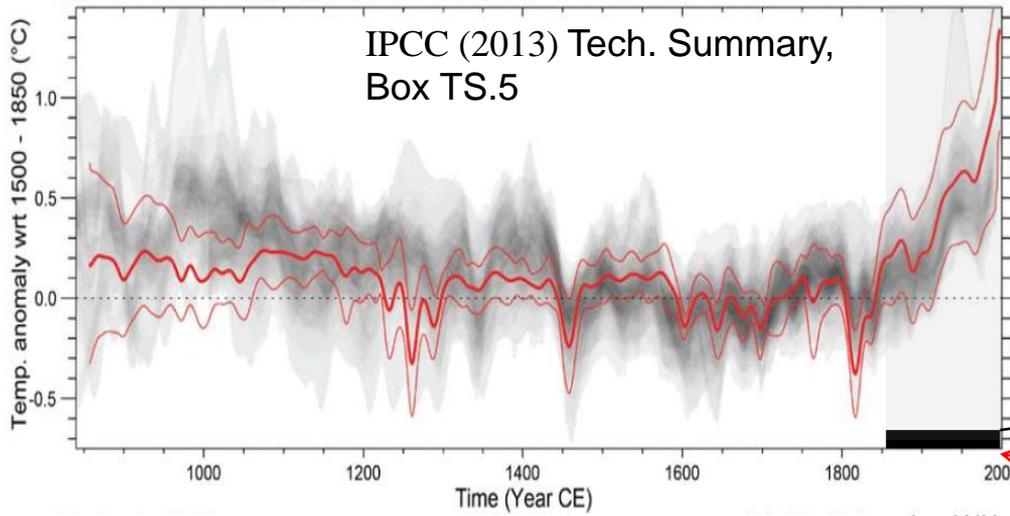
Bottom: Changes in global average sea level compared with 1900-1905 average

Source: IPCC WGI (2013) SPM

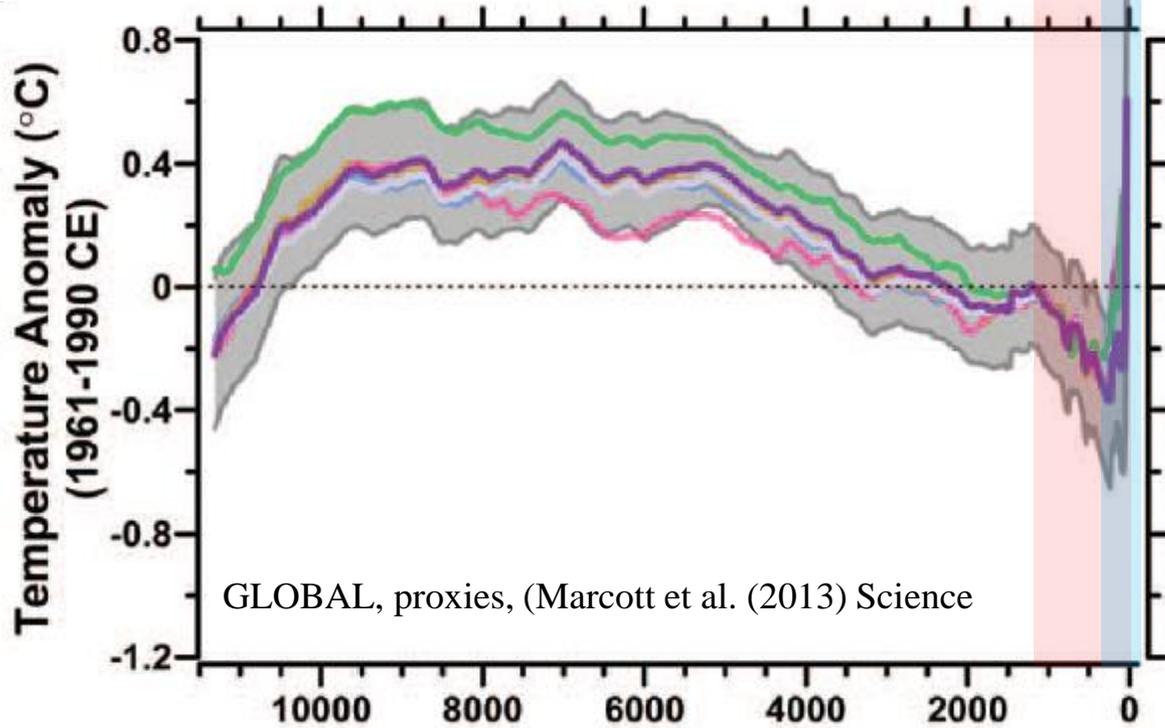


2) Is the warming unusual?

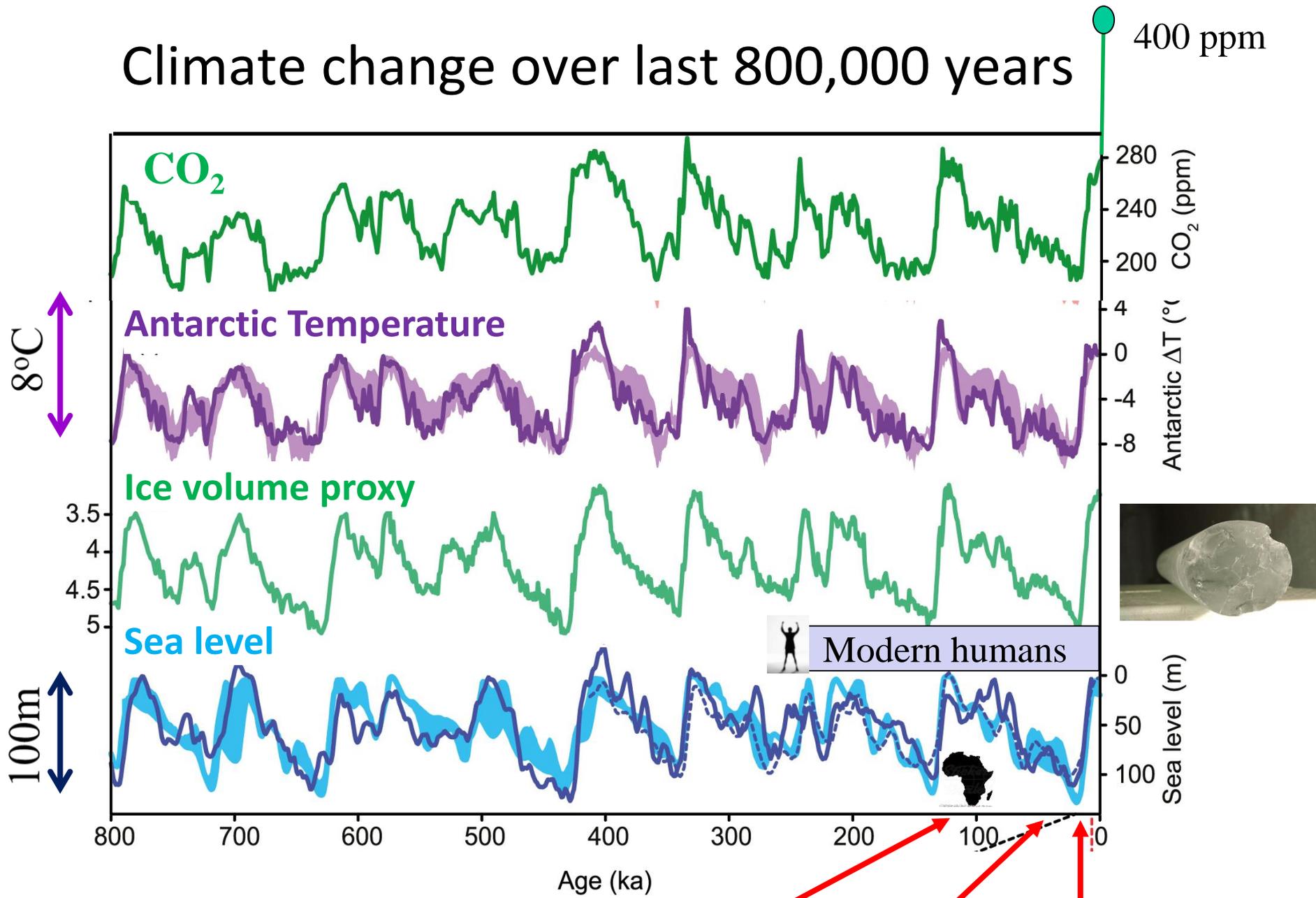
(b) Reconstructed (grey) and simulated (red) NH temperature



Northern hemisphere proxies



Climate change over last 800,000 years



IPCC (2013) Chap. 5 Fig 5.3

Africa Exodus Europe Agriculture

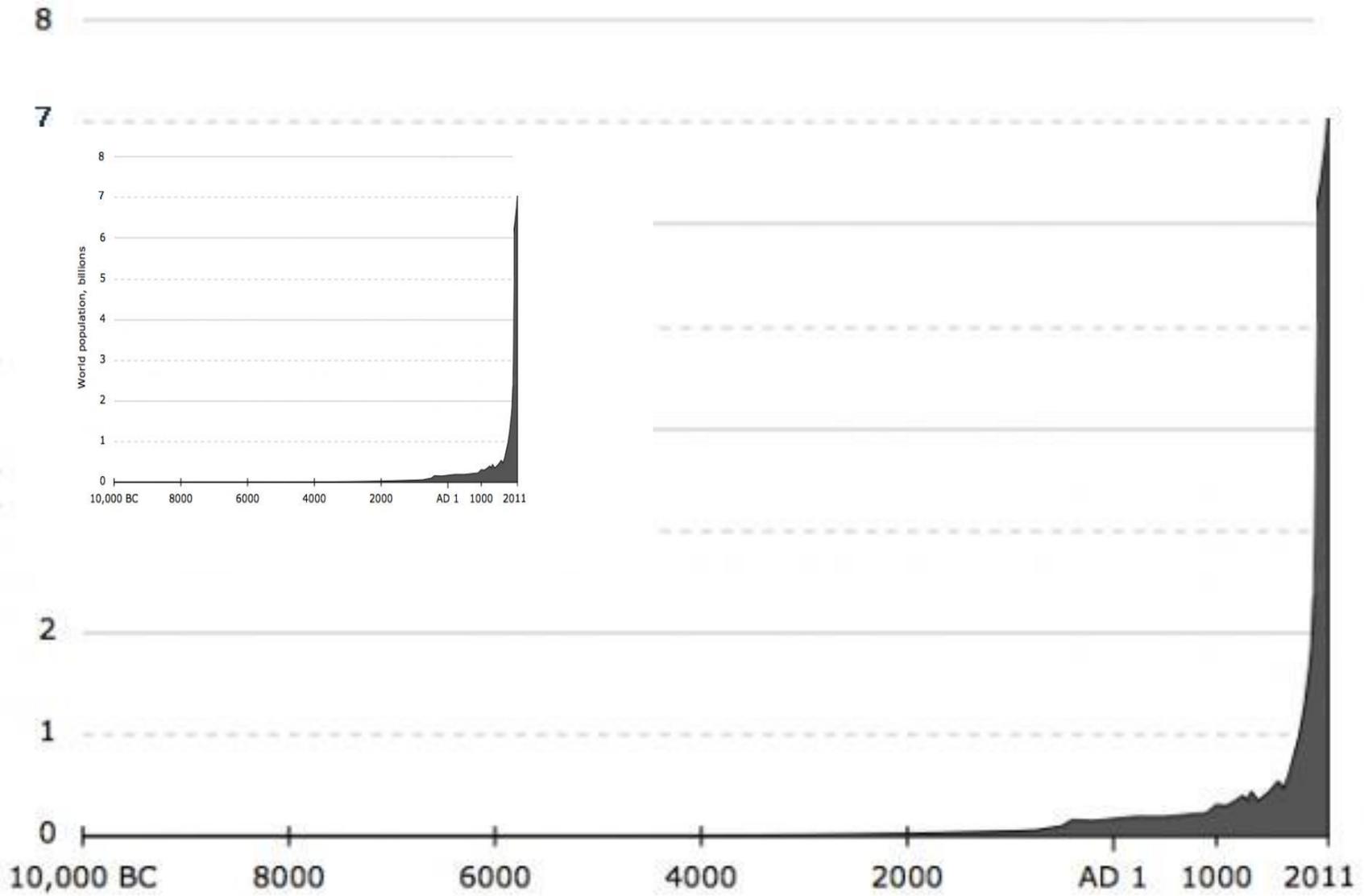
Is the warming unusual?

- Over the last 100 years the globe has warmed by about **0.8°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

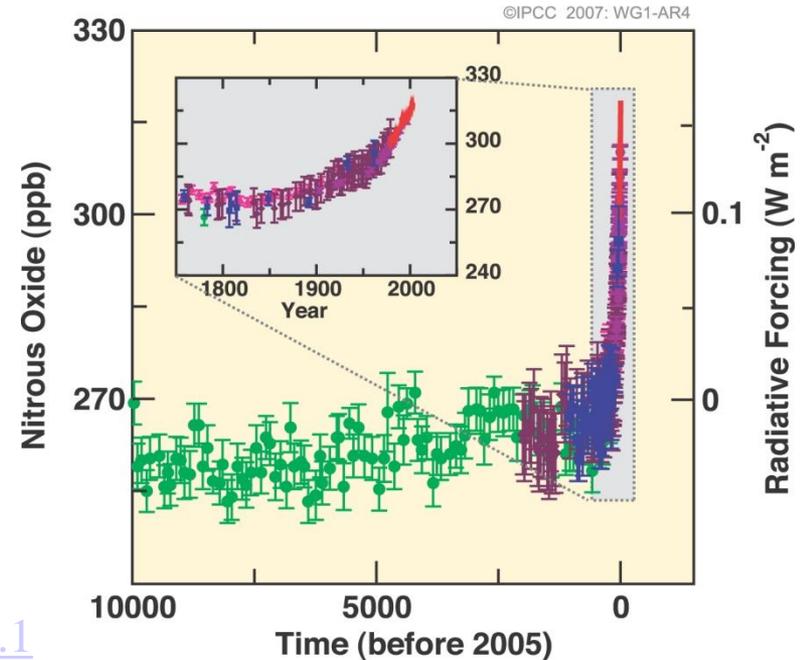
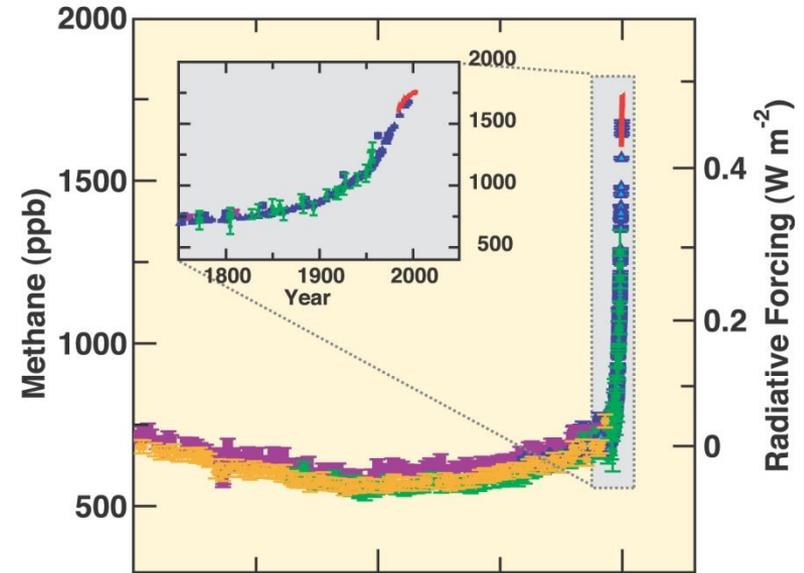
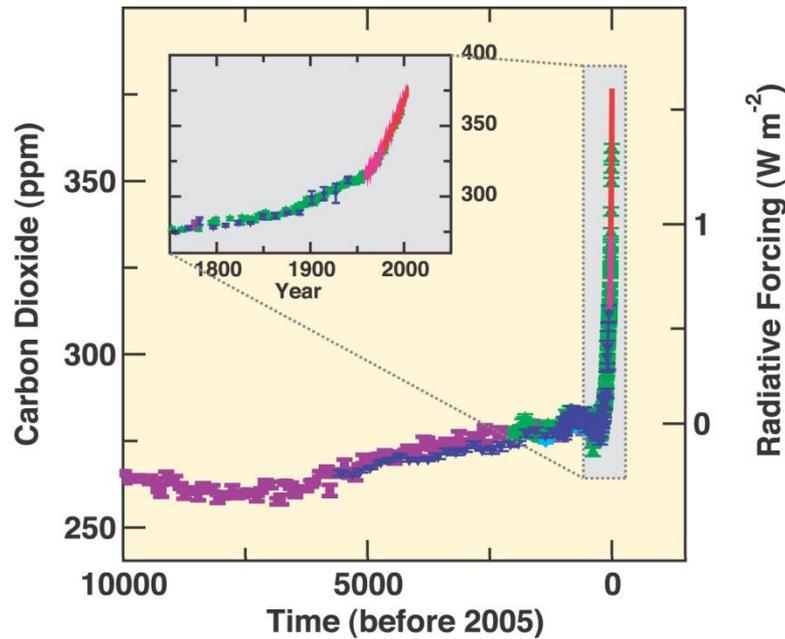


3) Why is it warming?

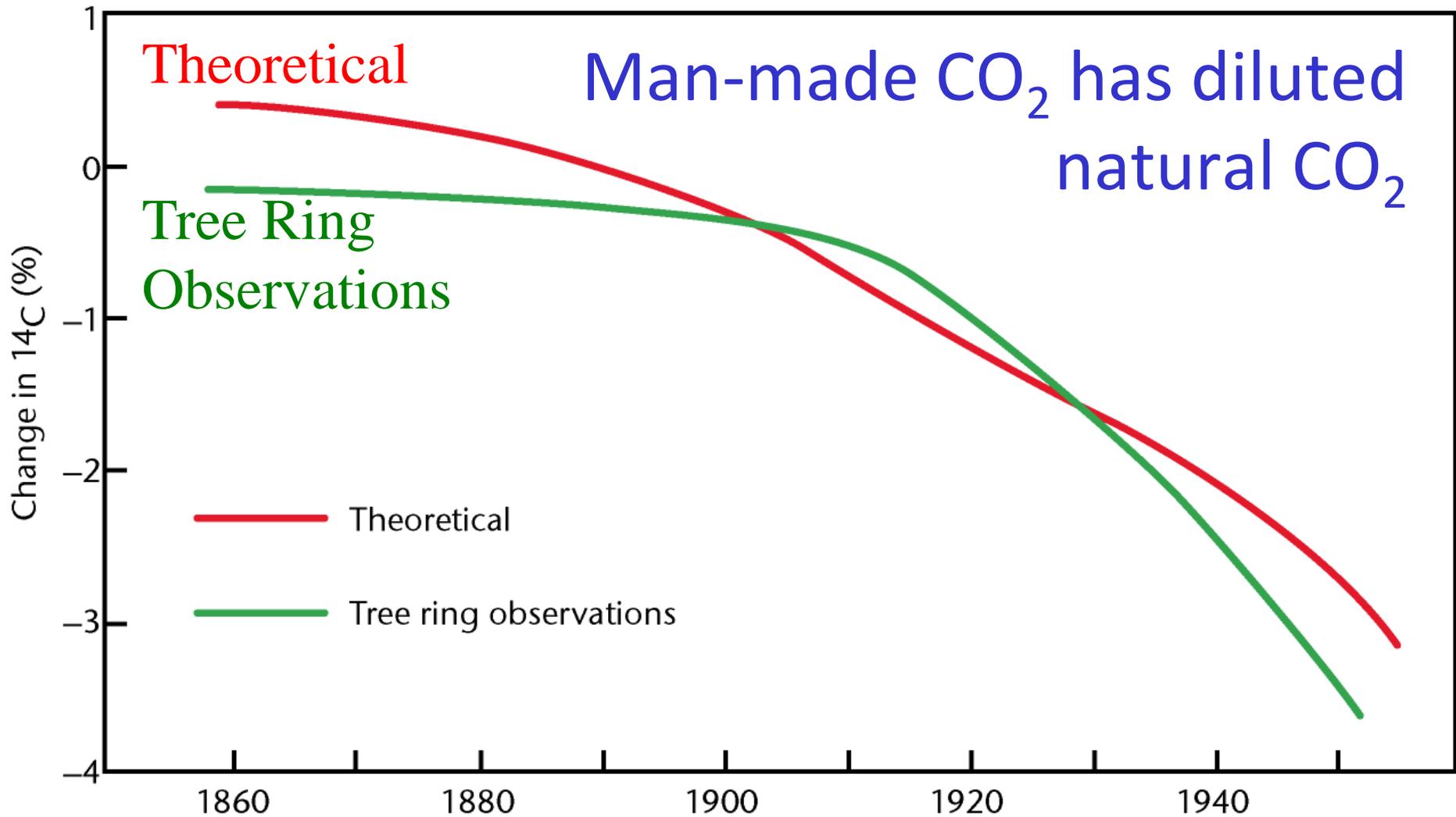
World population, billions



Changes in greenhouse gases from ice core and modern data



Carbon dioxide, methane
and nitrous oxide



Theoretical

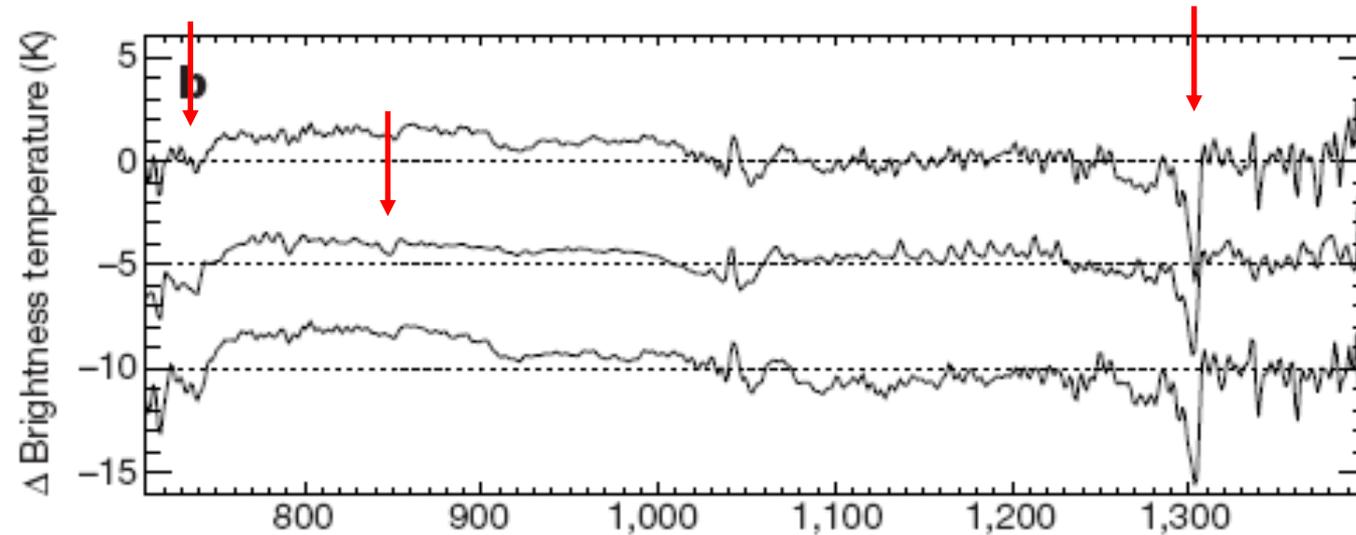
Man-made CO₂ has diluted natural CO₂

Tree Ring Observations

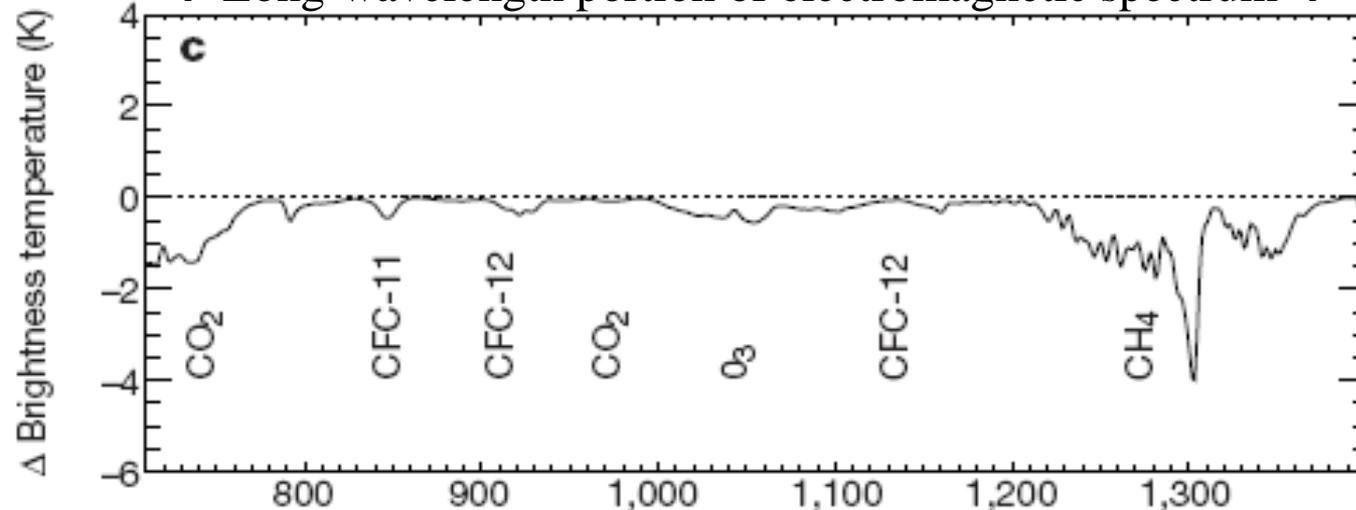
Theoretical
Tree ring observations

Satellite observations detect enhanced greenhouse effect: 1997-1970

Harries et al. 2001, Nature



← Long-wavelength portion of electromagnetic spectrum →

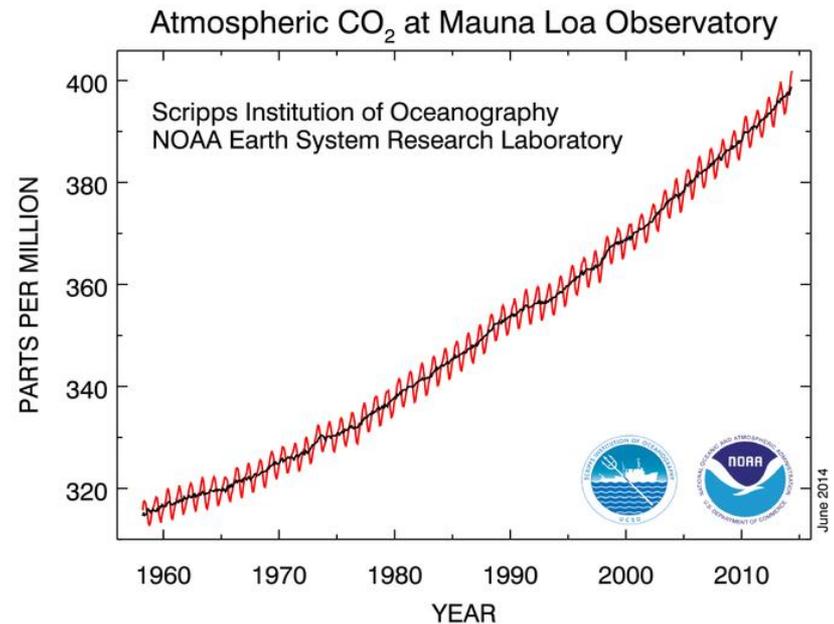


These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane

“Radiative forcing” of climate

- Increases in **greenhouse gases** **heat** the planet by reducing how easily Earth can cool to space through infra-red emission
- More small pollutant **“aerosol”** particles cool the planet by reflecting sunlight
- If more energy is arriving than leaving, Earth should heat up...

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



Solar Output Stable in last 15 years

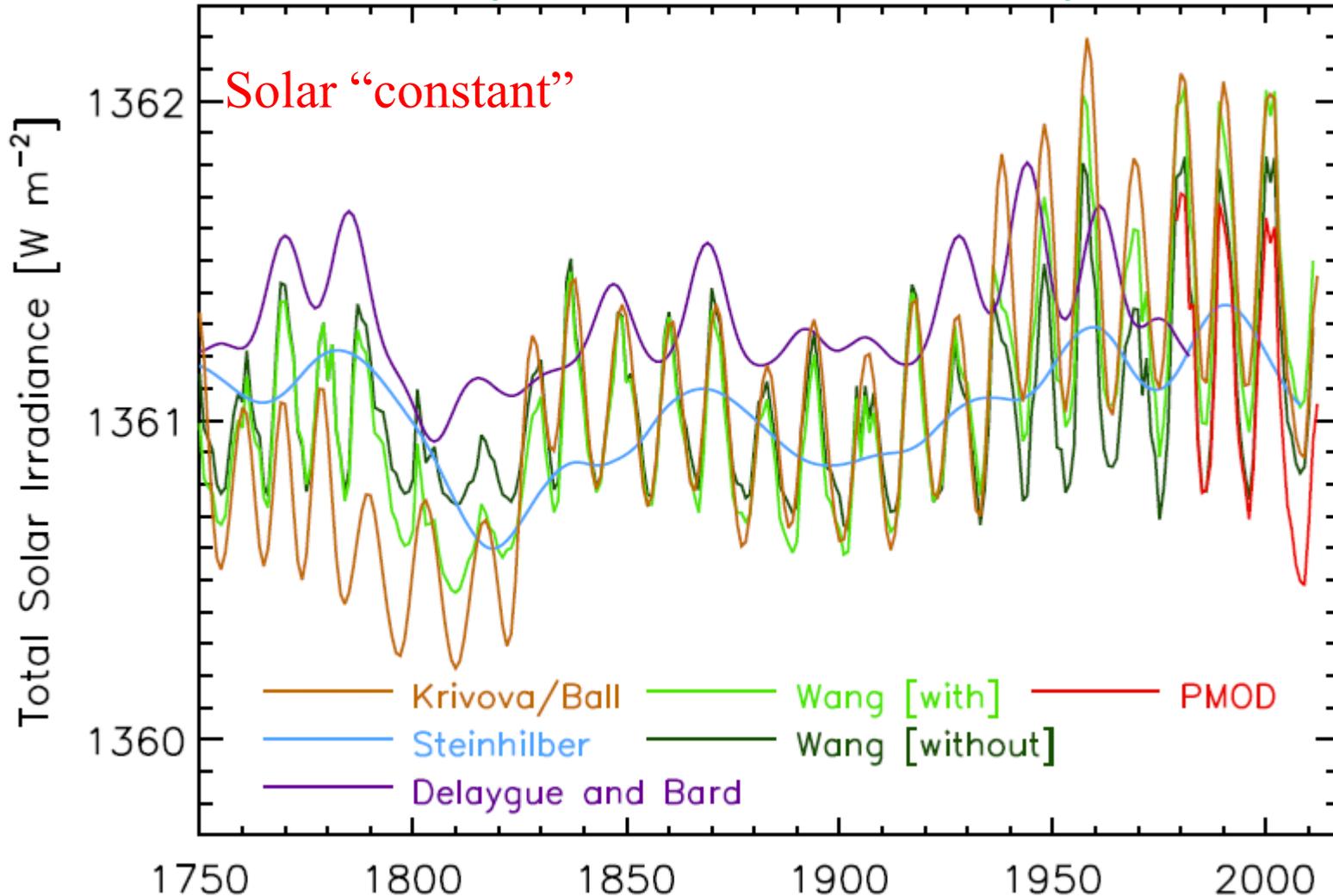
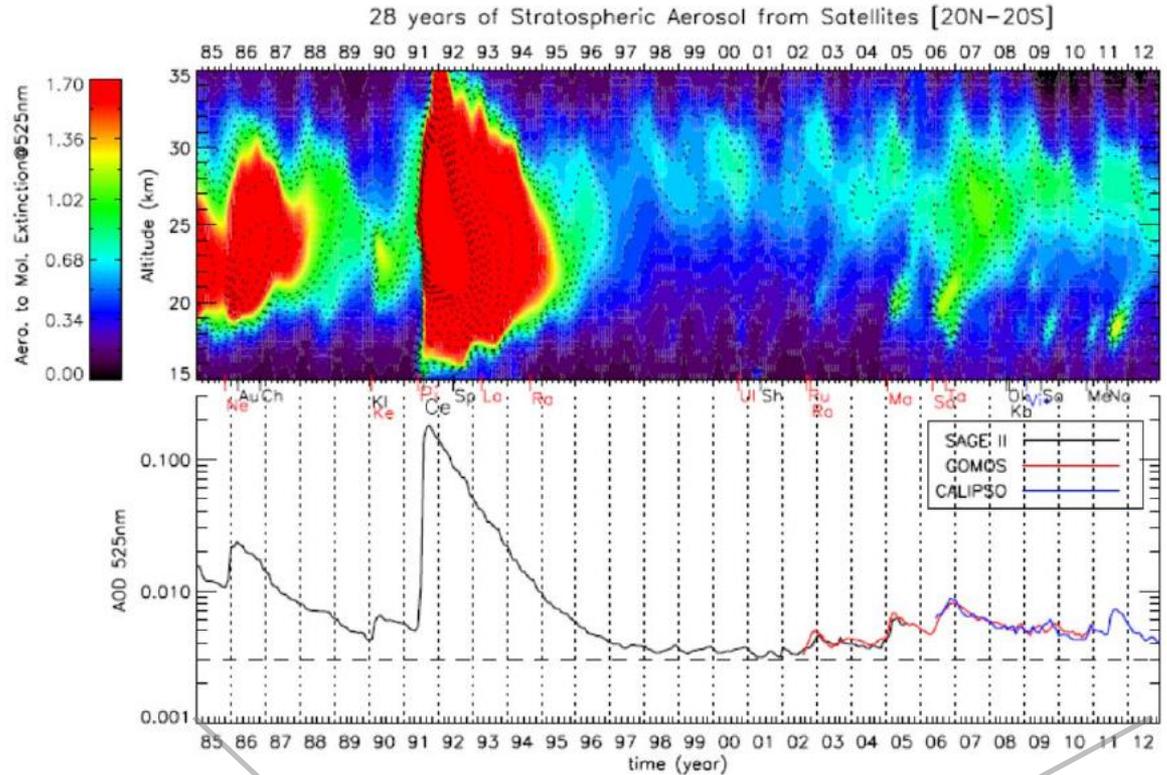
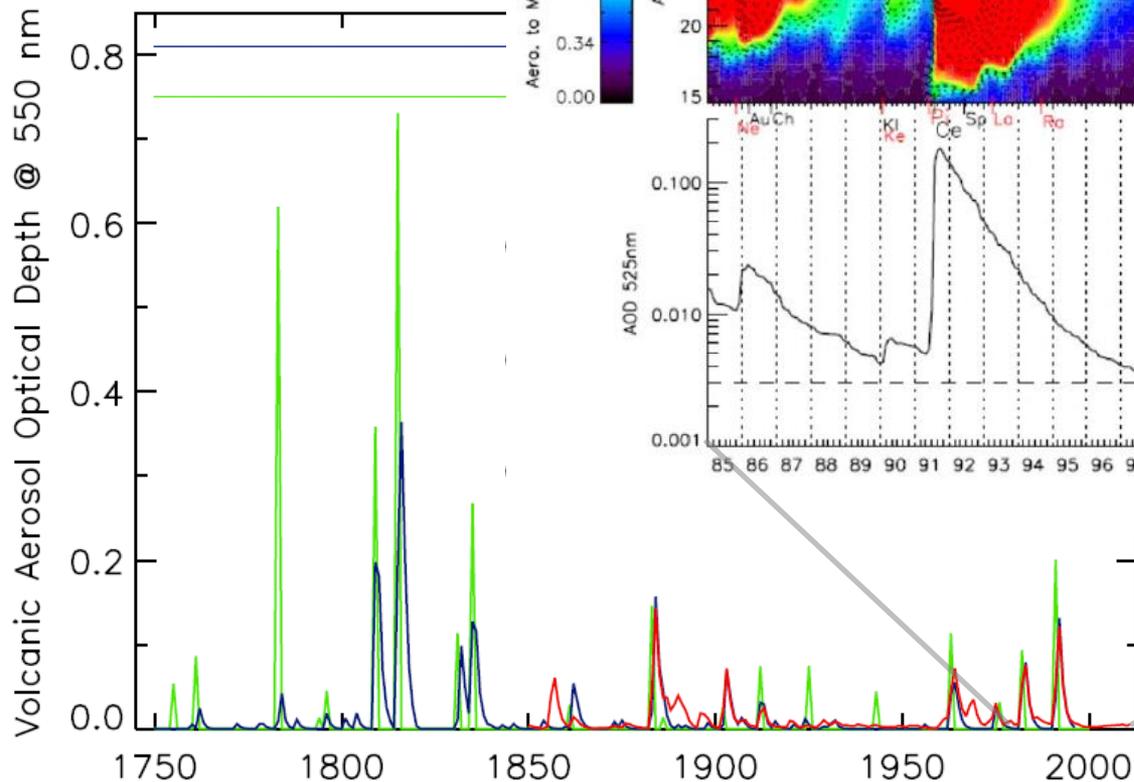


Figure 8.11 IPCC(2013) – Reconstruction of Total Solar Irradiance

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

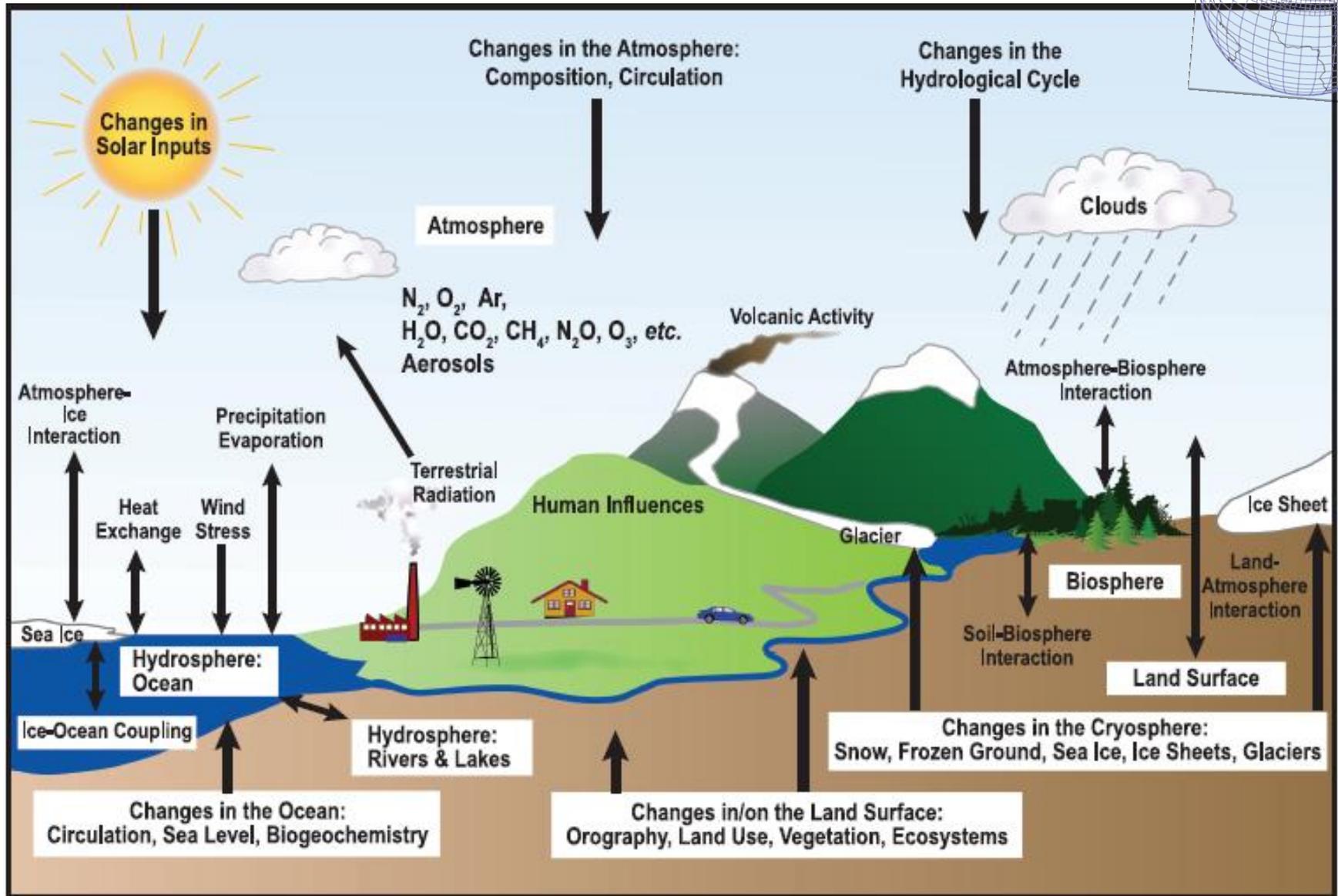
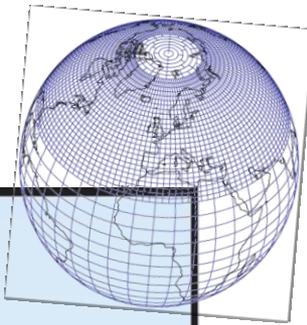
Changes in Volcanic Activity

Below: Reconstructed from observer reports & ice-core/sediments



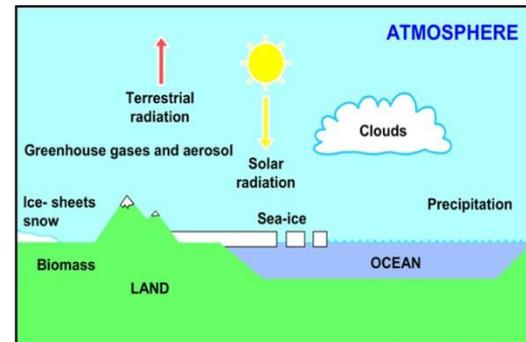
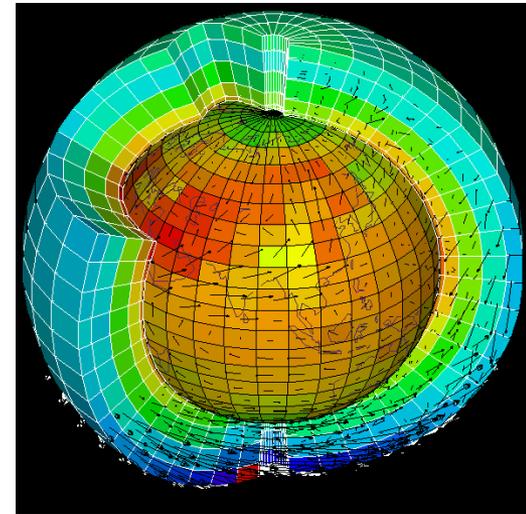
Above: Satellite era measured volcanic aerosol

Computer Simulations of Climate

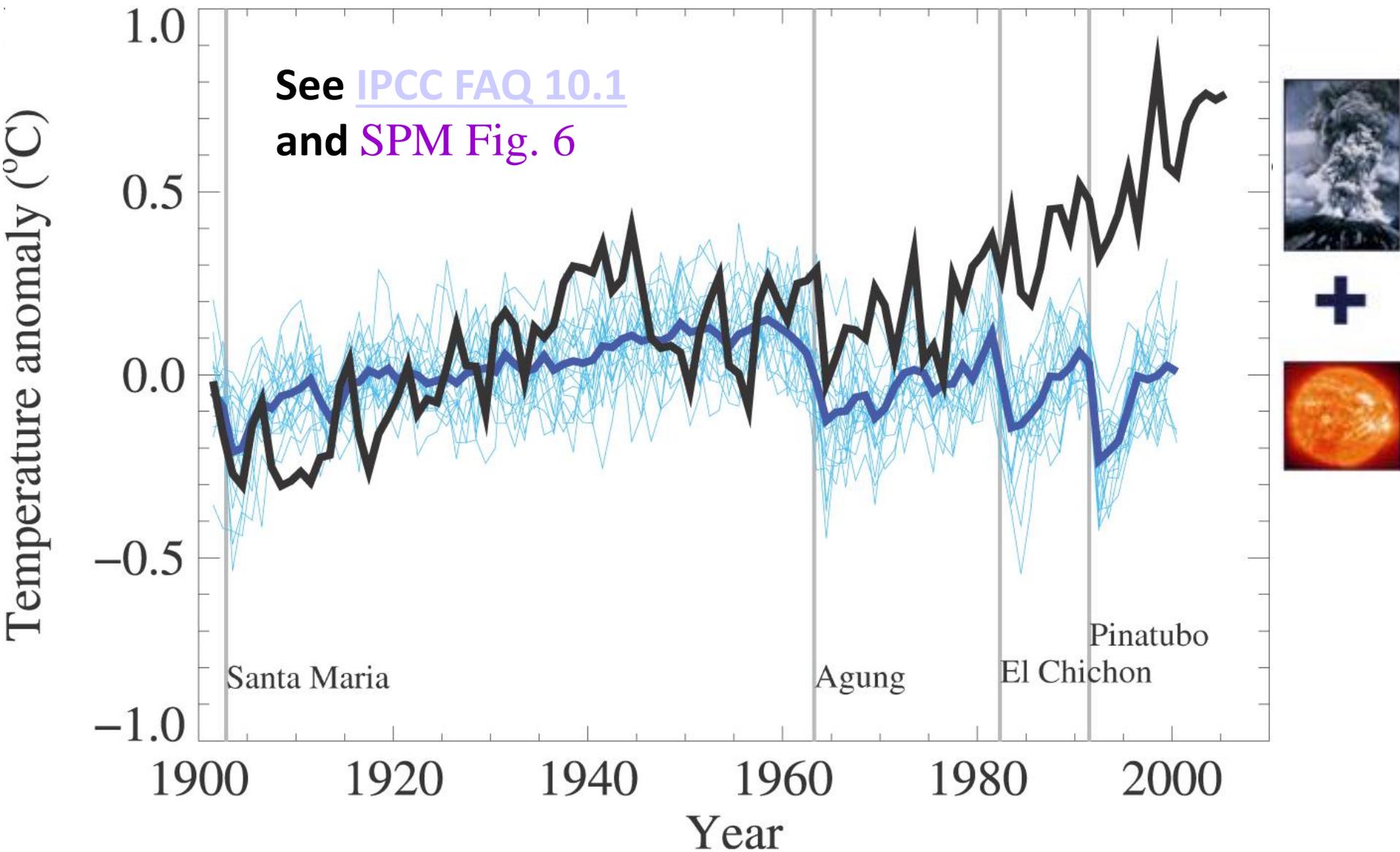


Experiments with climate models

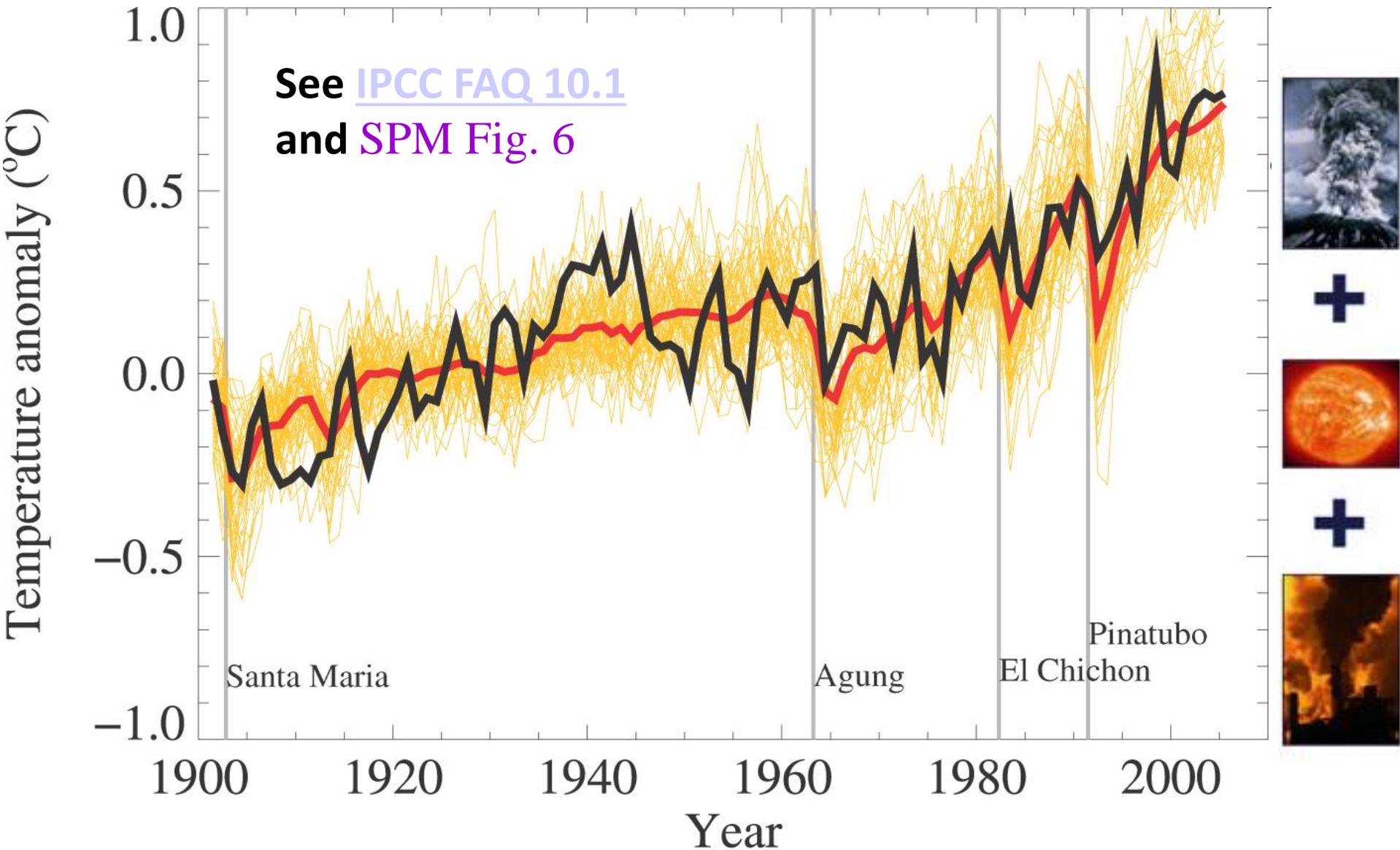
- How much of recent warming is explained by natural effects?
- To answer such questions, experiments can be performed with **climate simulations**
 - including just **natural factors** (ocean circulation, volcanic eruptions, changes in the sun, ...)
 - including **natural** and **anthropogenic factors**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



Natural factors cannot explain recent warming

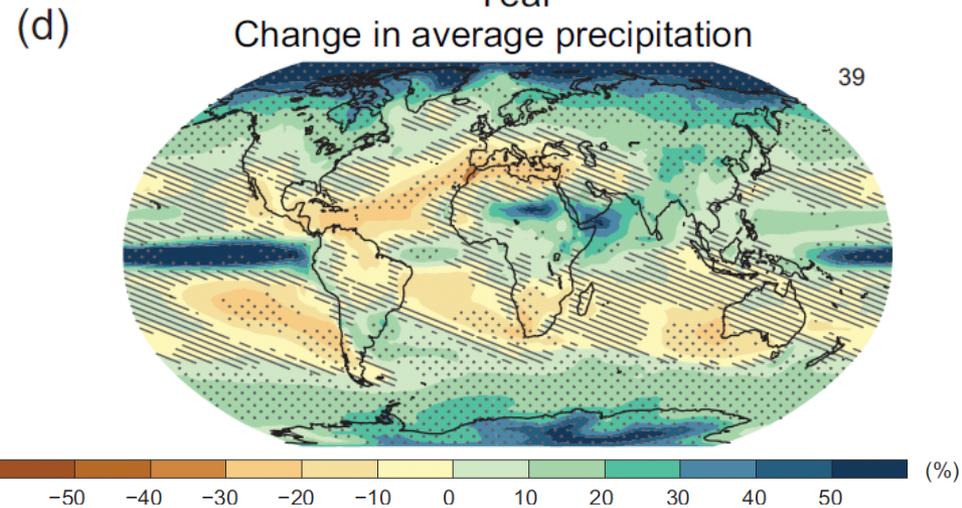
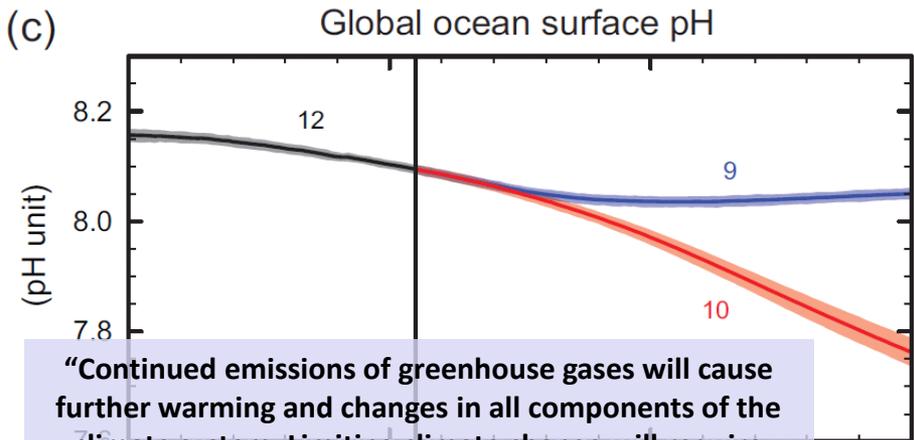
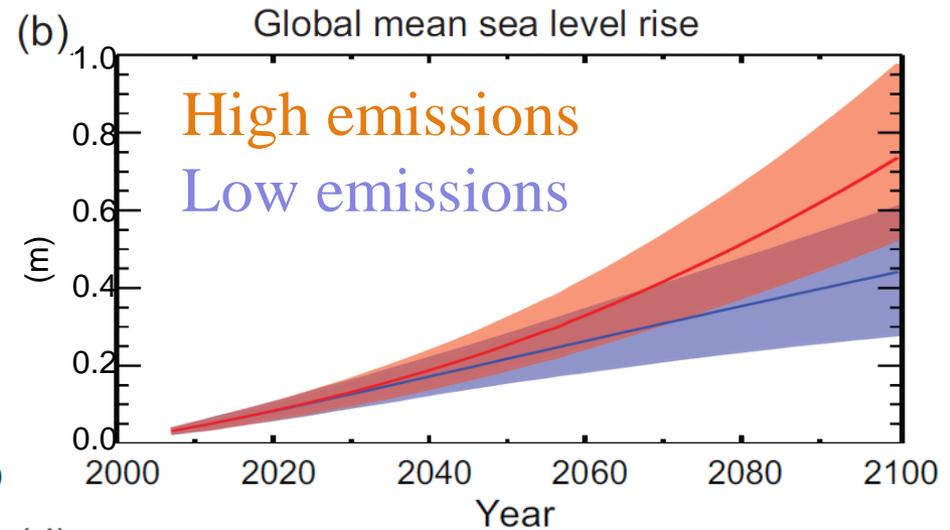
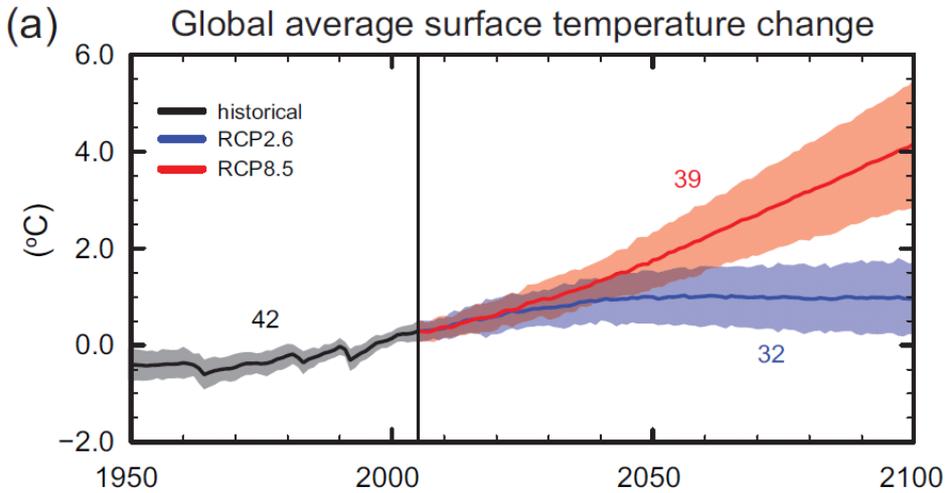


Recent warming can be simulated when man-made factors are included



4) What are the predictions?

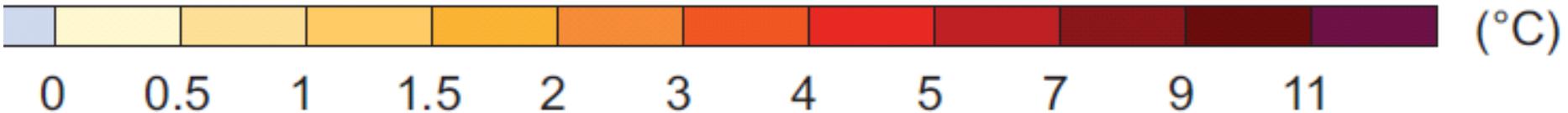
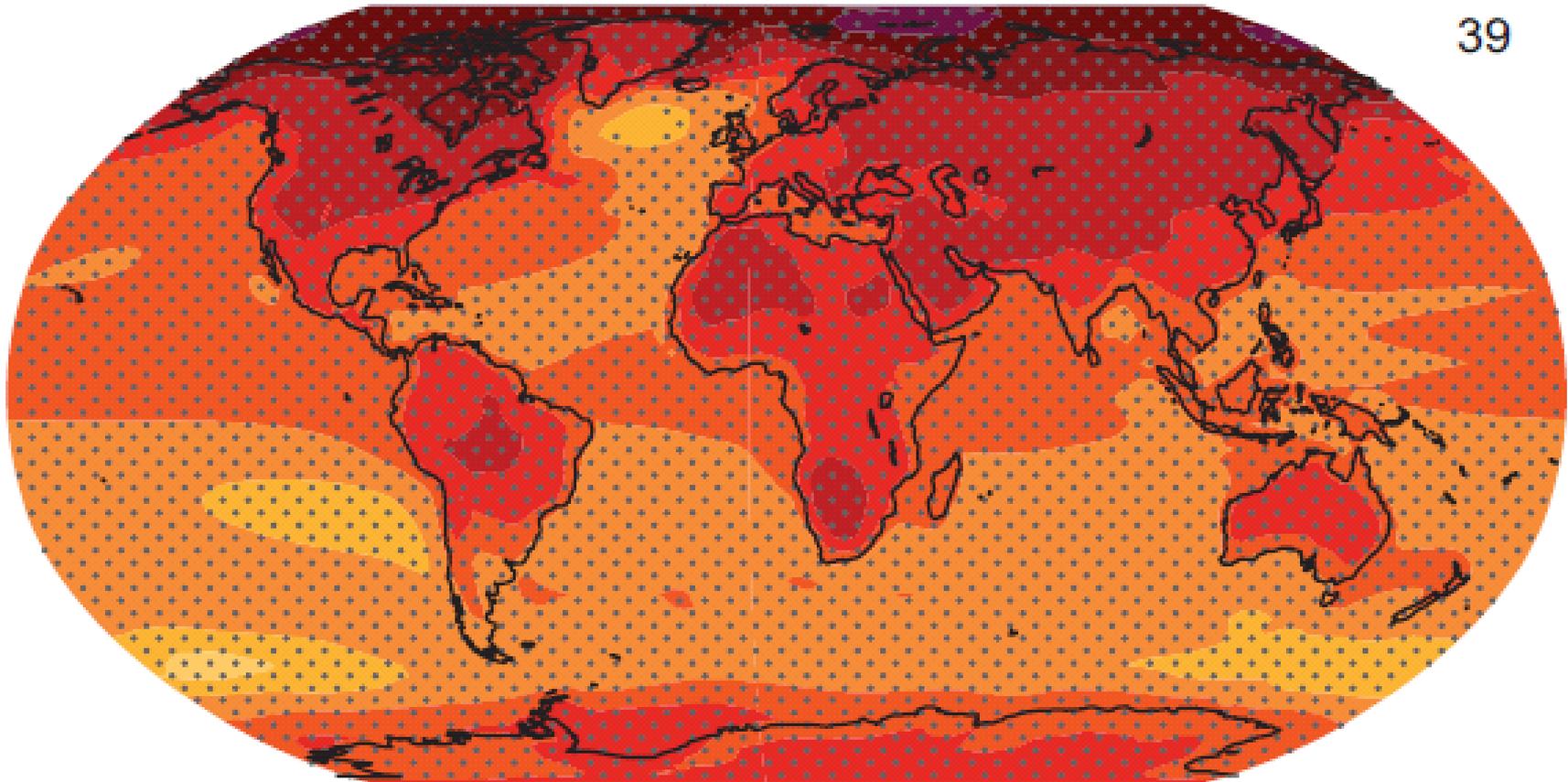
Future projections to 2100 from climate models



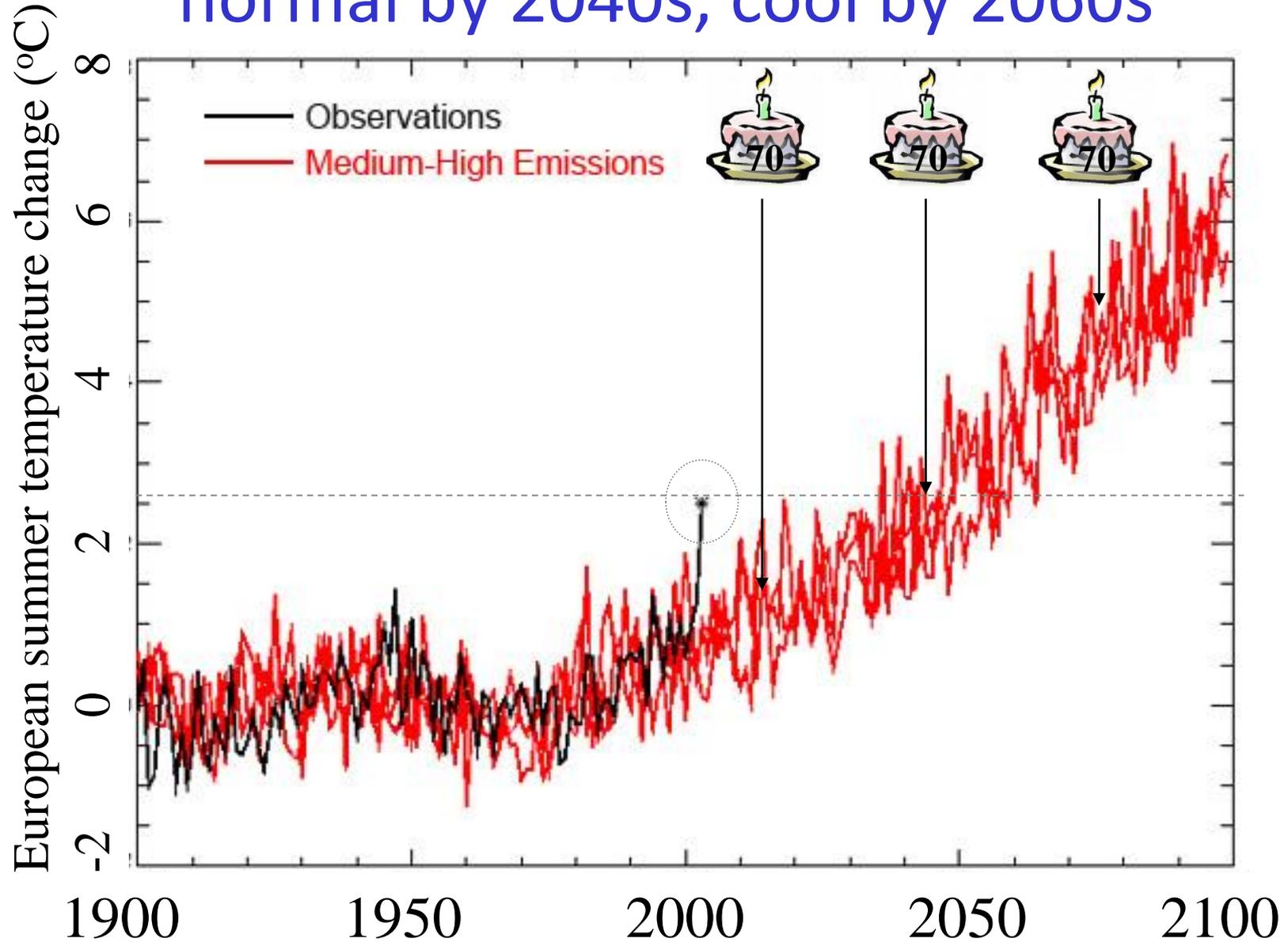
“Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.” [IPCC 2013 SPM]

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

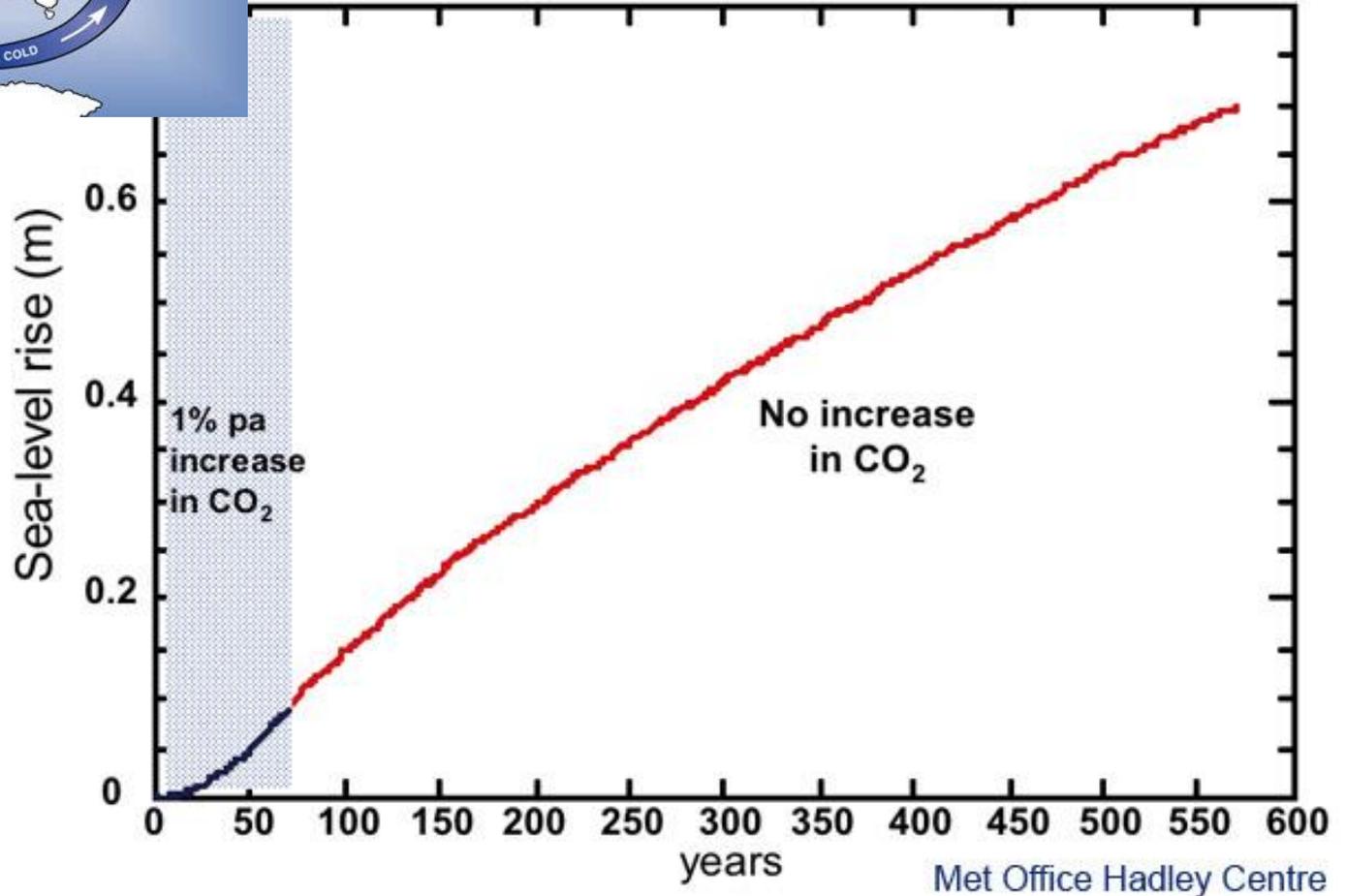
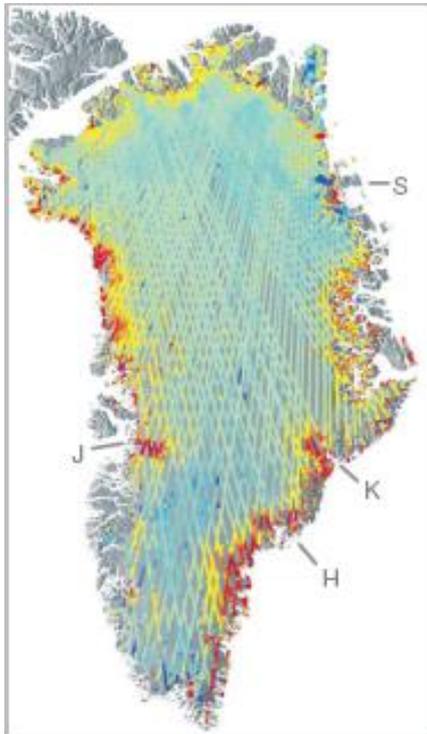
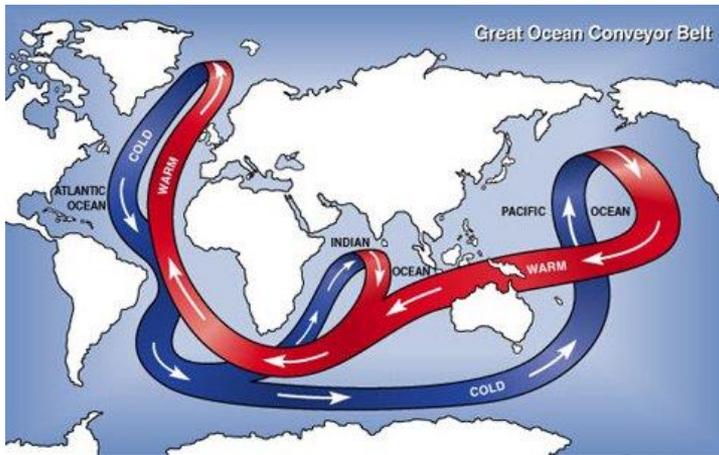
39



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



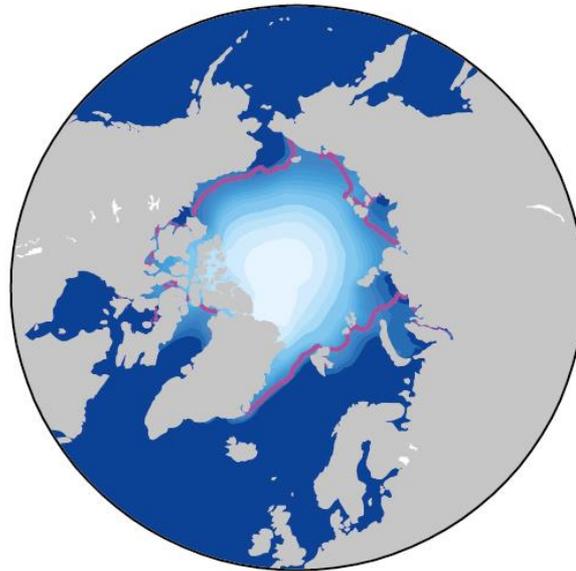
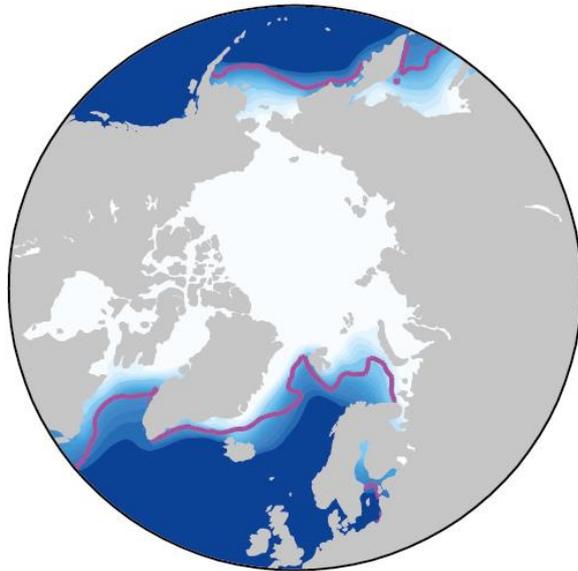
Long-term commitment to sea-level rise



February

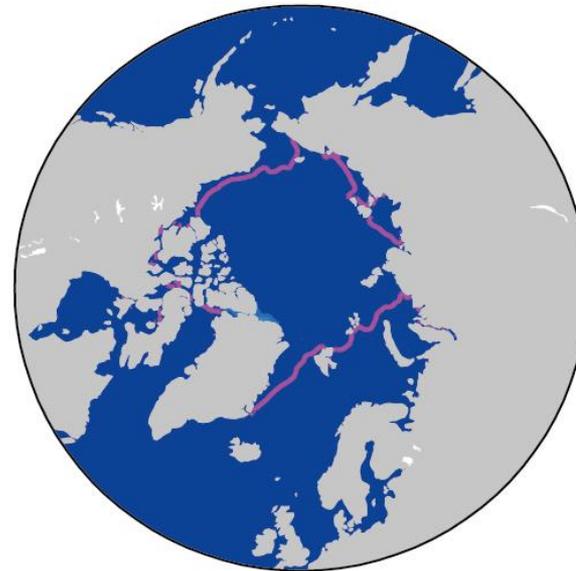
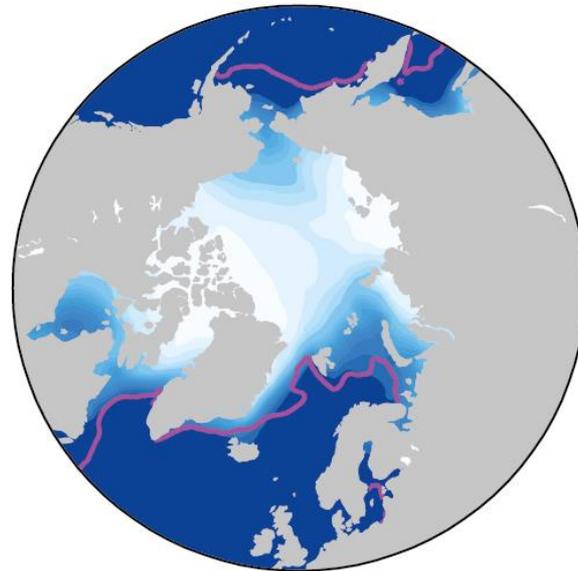
September

1986-2005

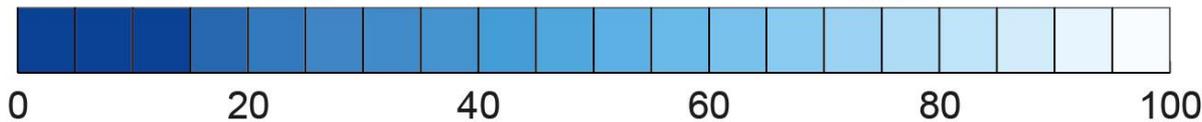


Arctic sea ice extent is projected to diminish over the 21st century

2081-2100 (RCP 8.5)



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



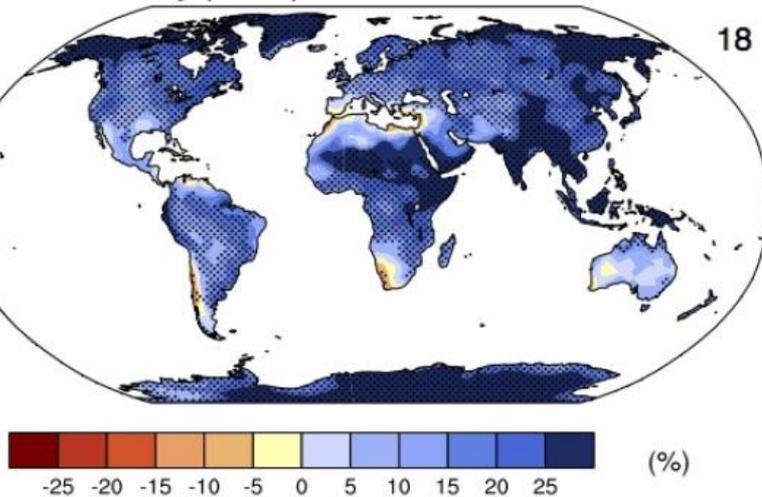
(%)

IPCC (2013)
WG1 Fig. 12.29

Projections of the water cycle

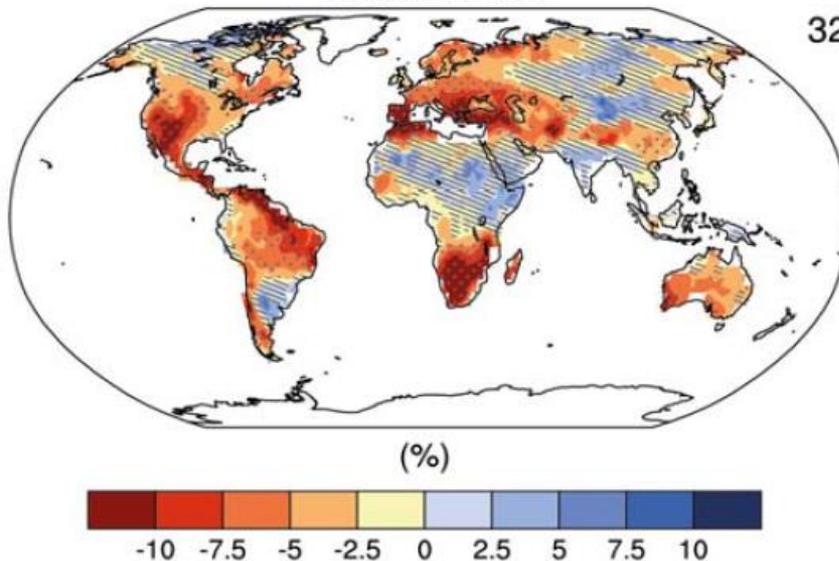
Precipitation intensity

18



Soil moisture

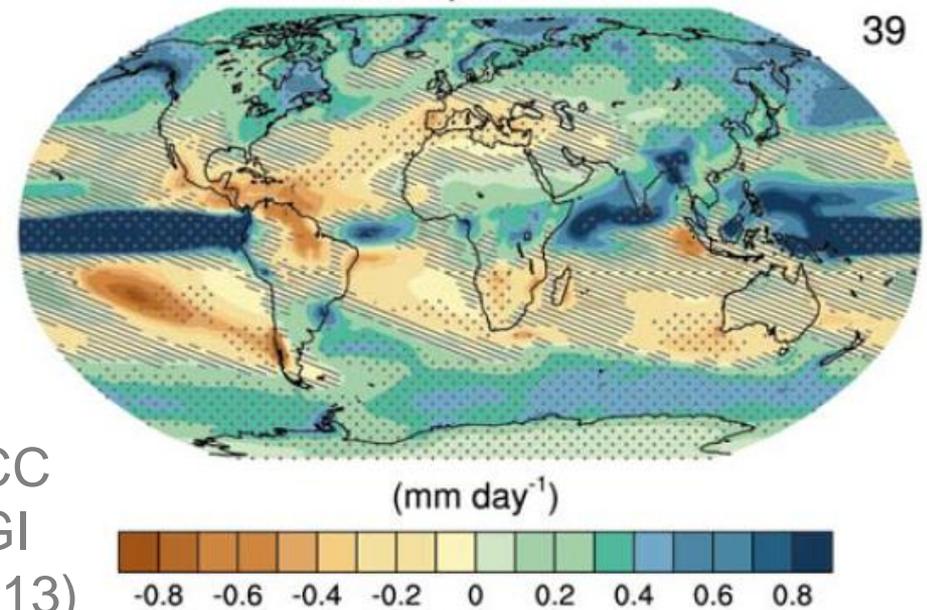
32



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

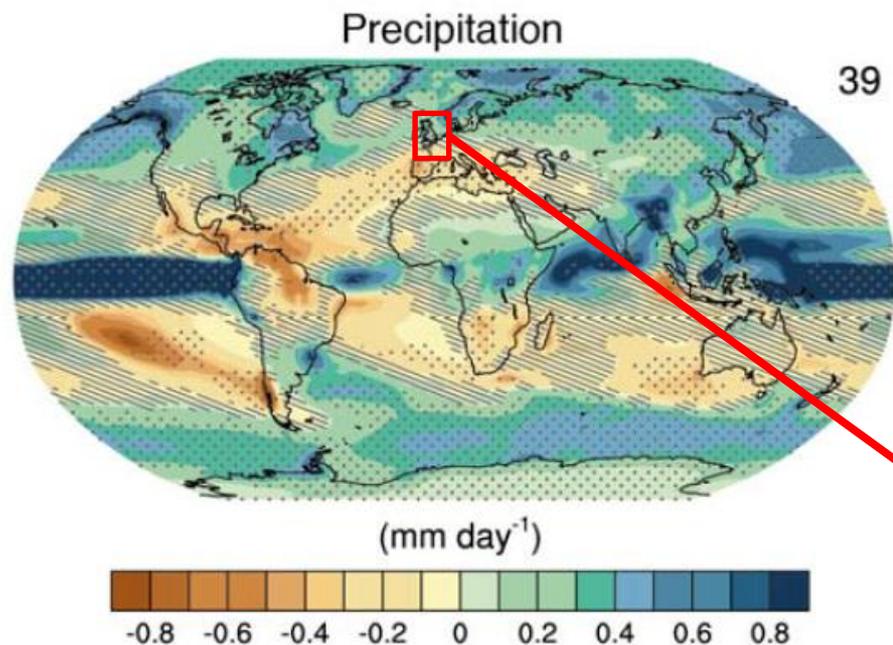
Precipitation

39



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.

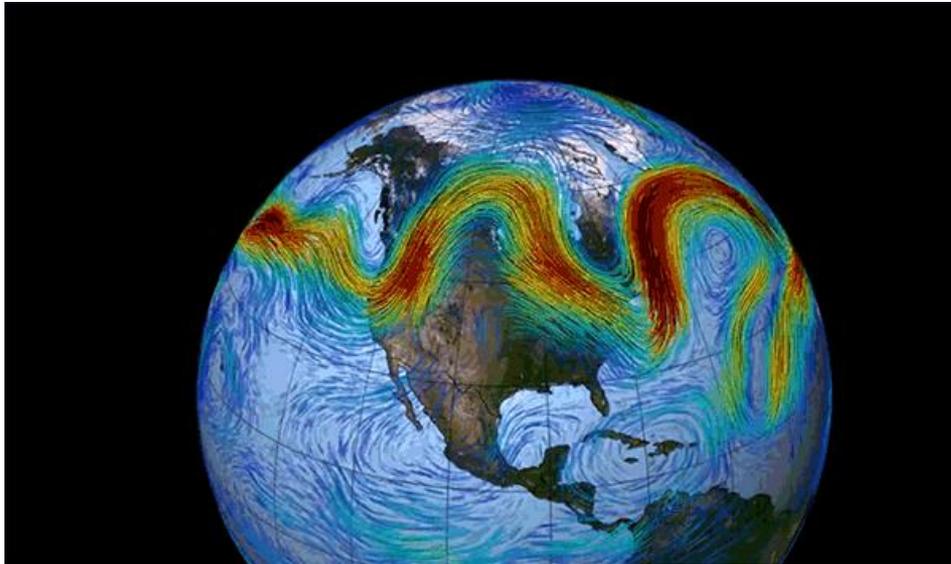
Small changes in the position and strength of the atmospheric circulation can have large influences on regional climate but are difficult to predict with any confidence.

Summer

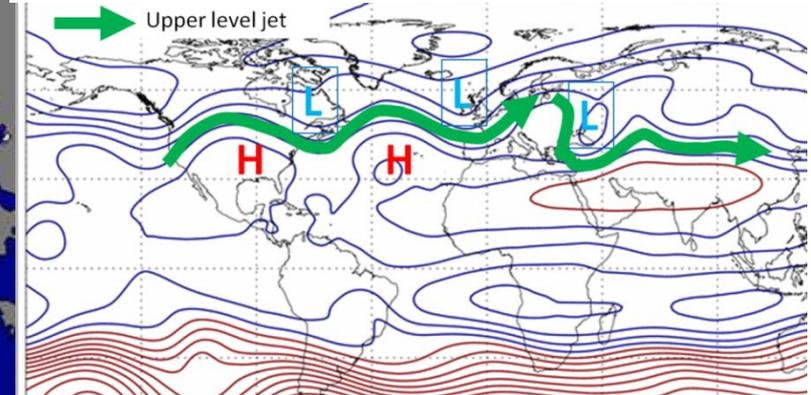
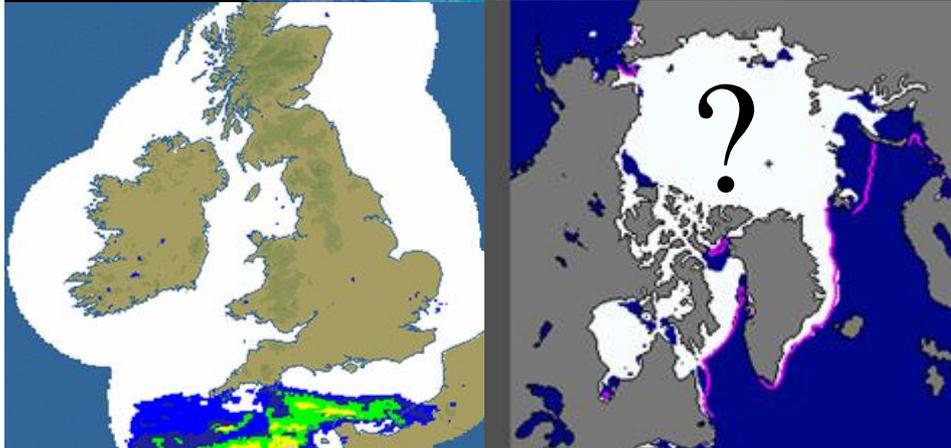
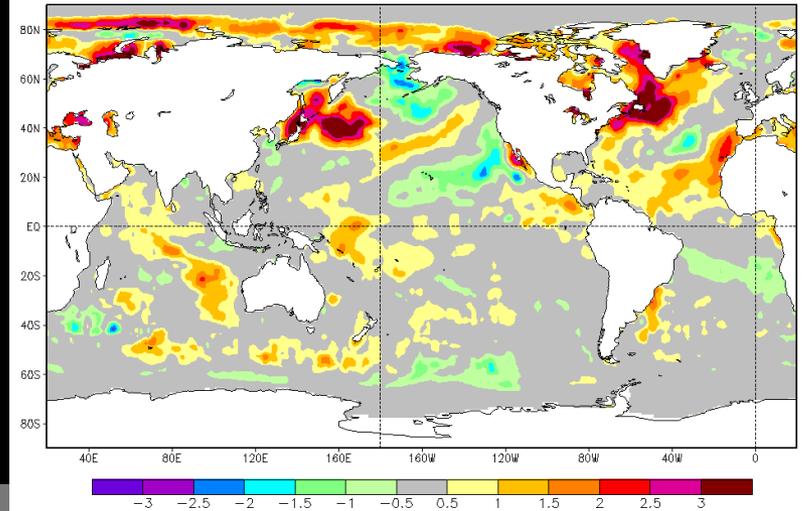
Winter



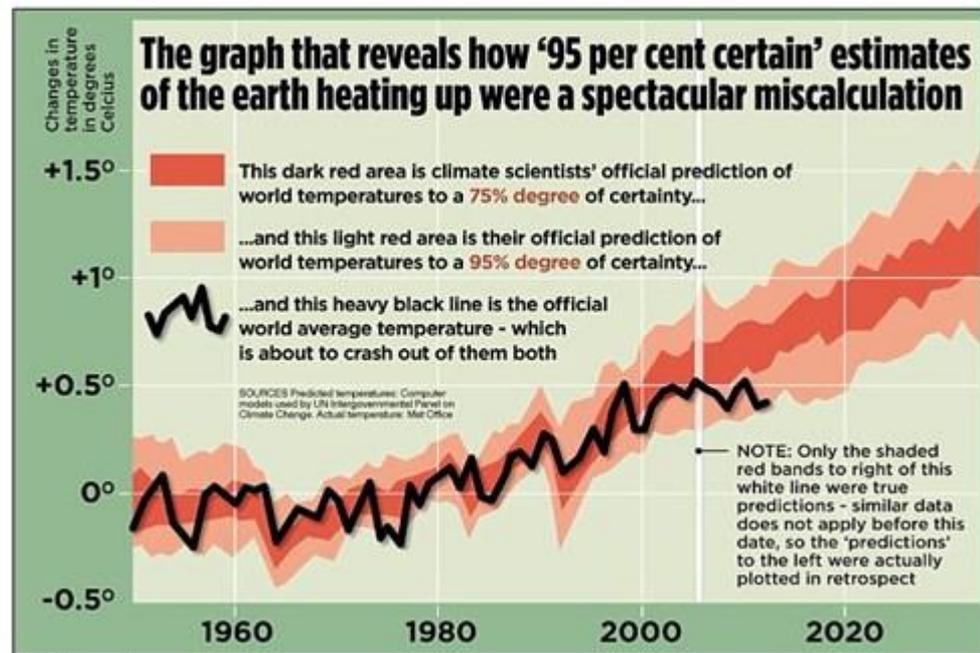
How will atmospheric and oceanic circulations change?



Sea Surface Temperature Anomaly (°C), Base Period 1971–2000
Week of 26 SEP 2012



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?