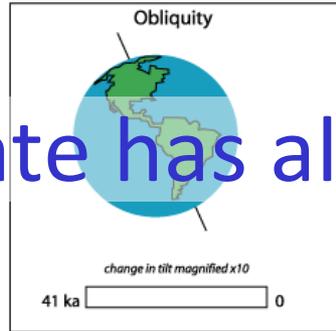


Introduction to Climate Change

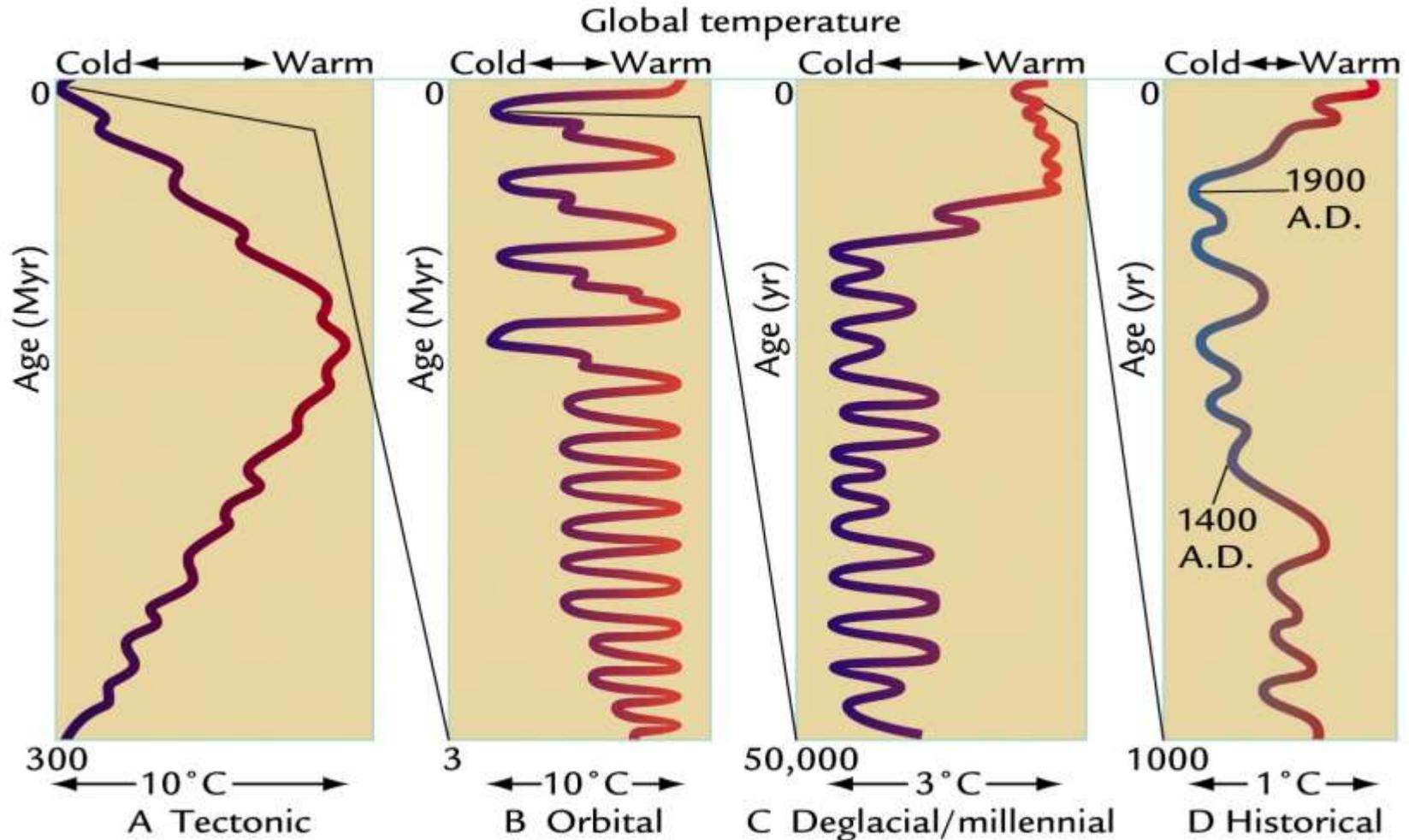
Mathematics of Planet Earth CDT Kick Off Camp, September 5th 2016



Professor Richard Allan,
Department of Meteorology, University of Reading



Earth's Climate has always been changing

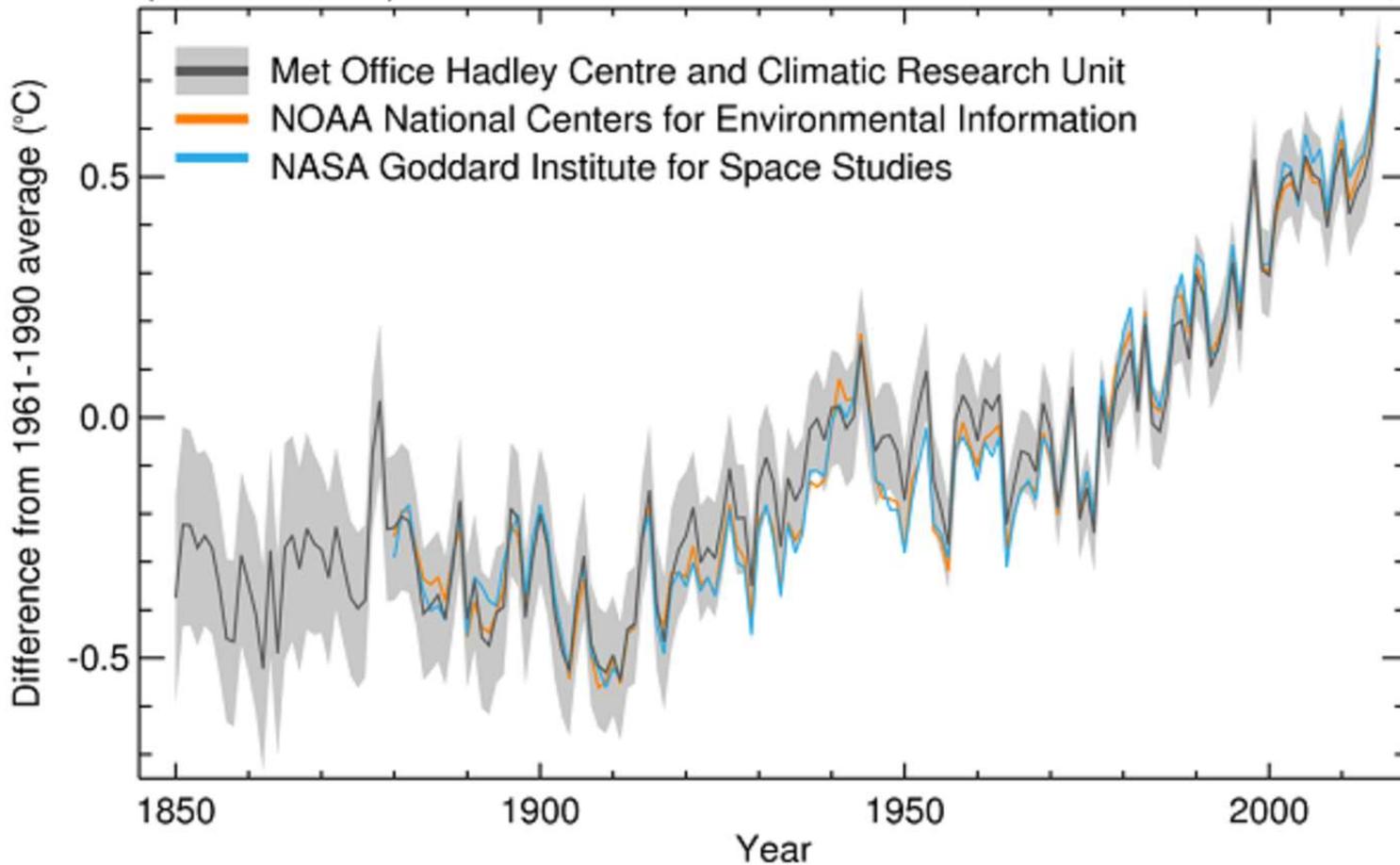


1) Is climate changing now?

The planet is warming

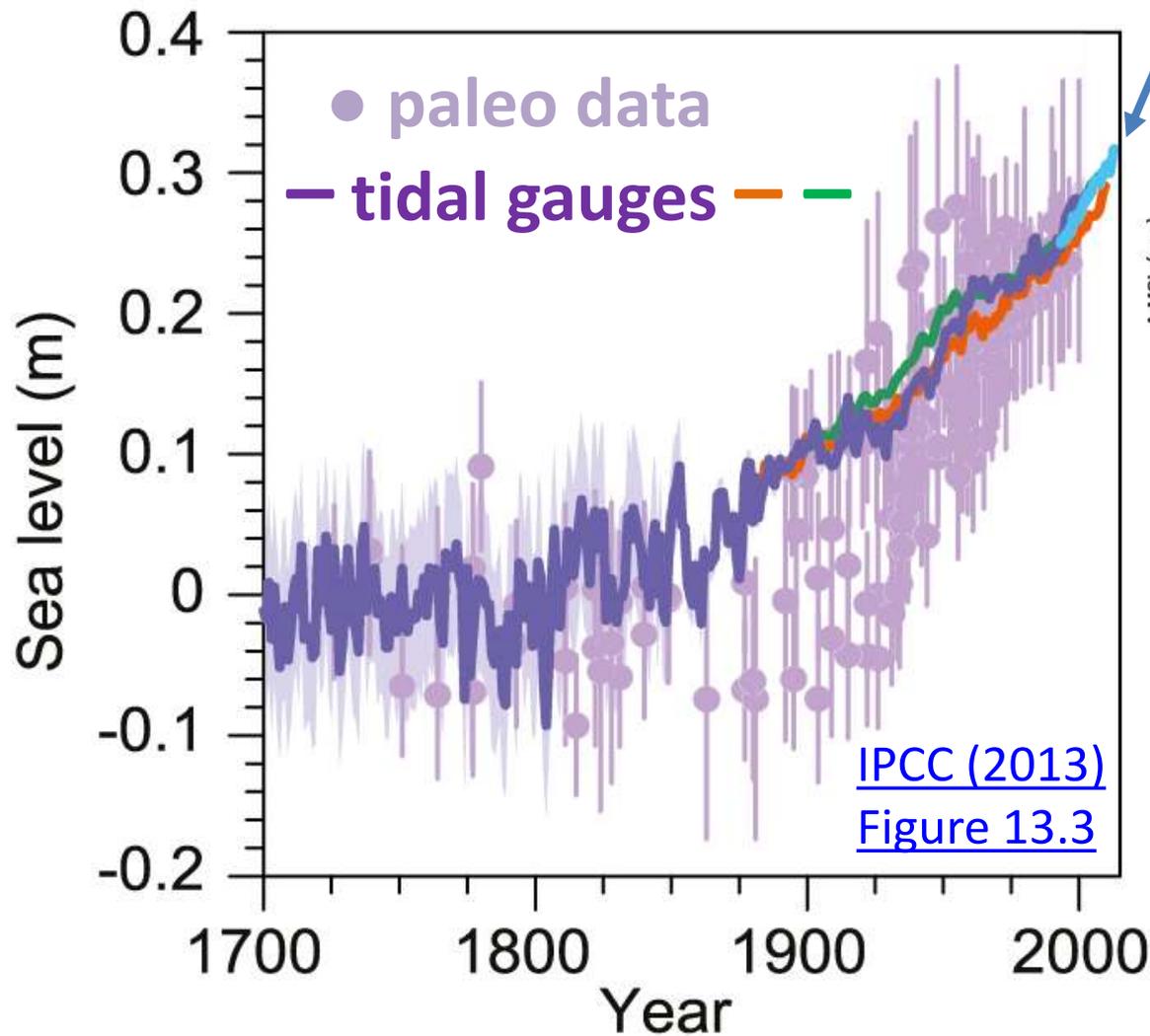
Global average temperature anomaly
(1850-2015)

2016? ●

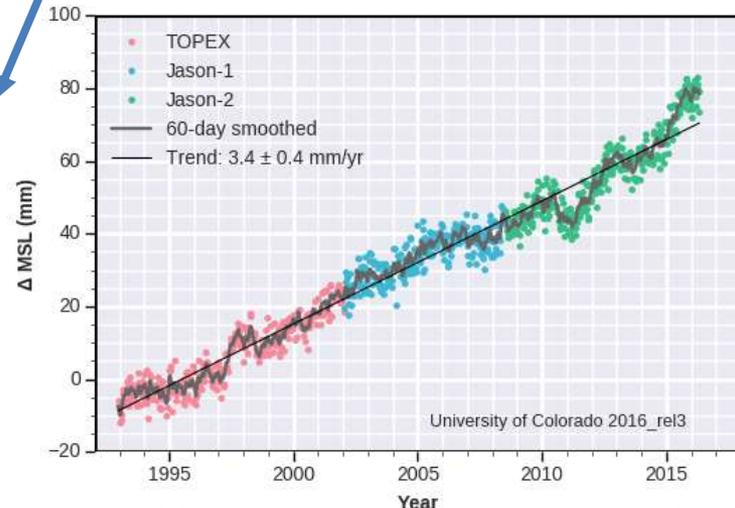


www.metoffice.gov.uk/research/monitoring/climate/surface-temperature

Global average sea level is rising...

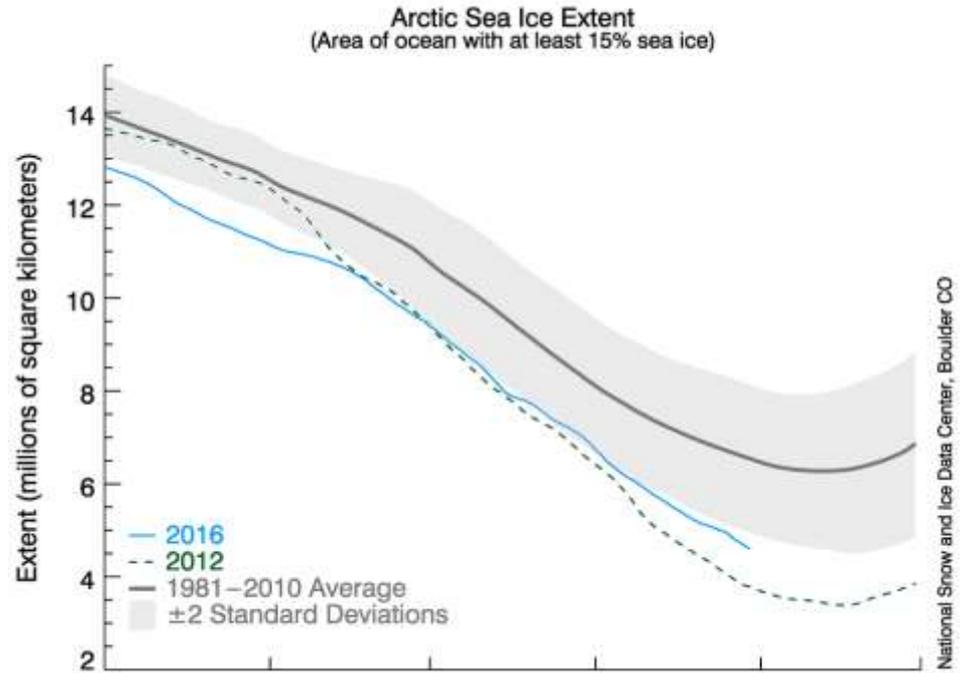
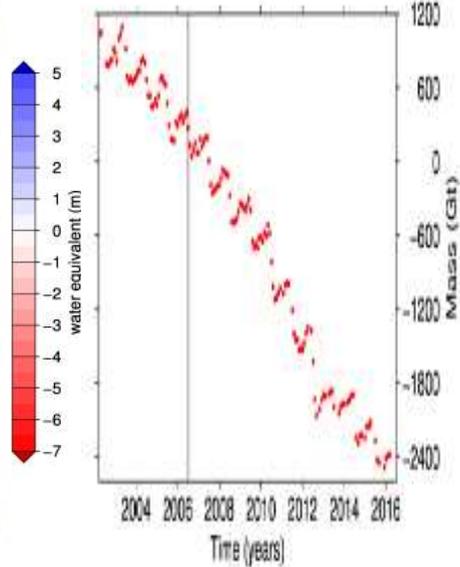
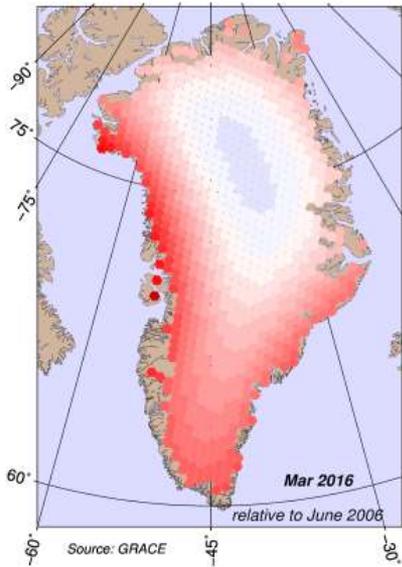


Satellite Altimeter data

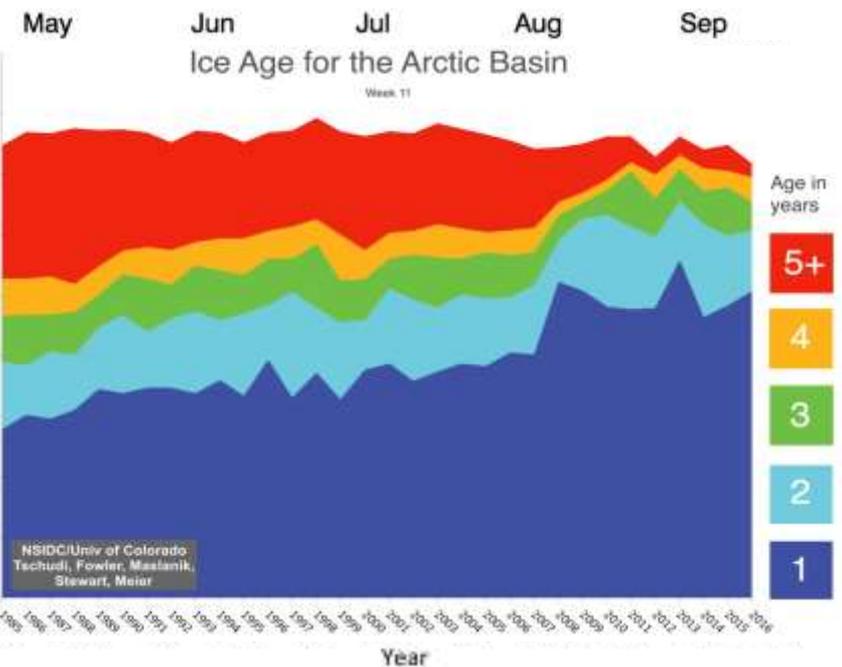
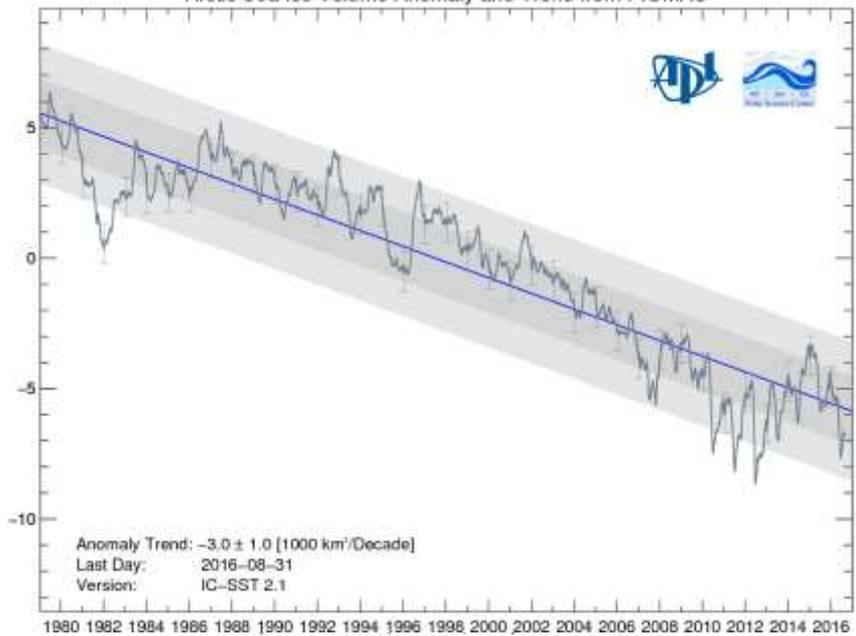


<http://sealevel.colorado.edu/>

Melting of Arctic Ice

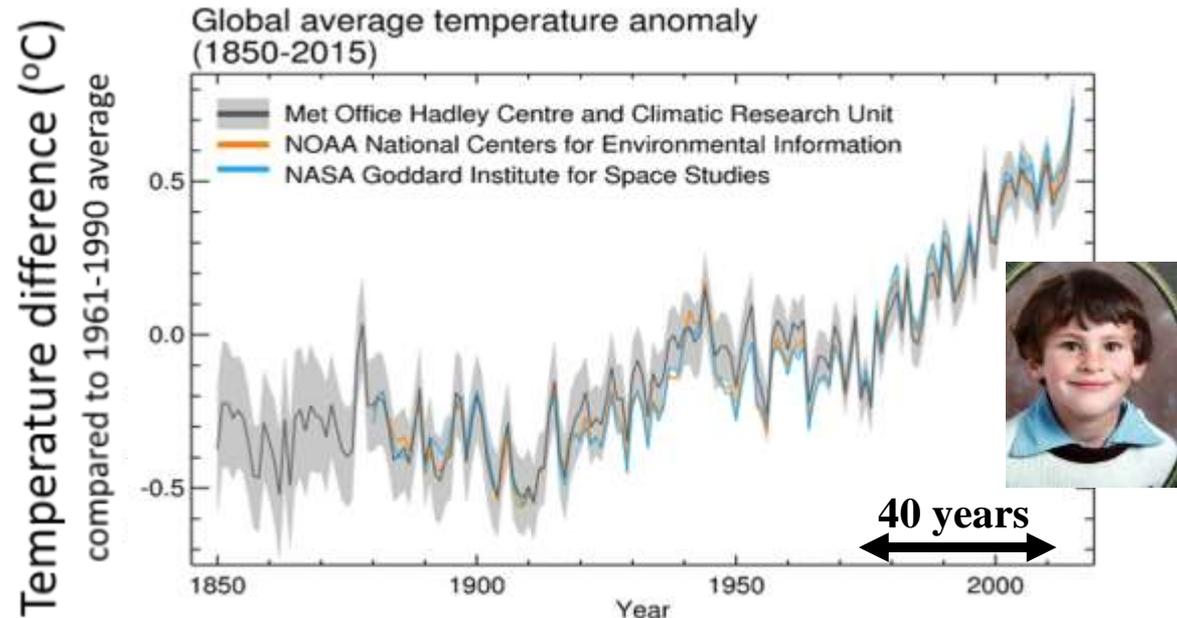


Arctic Sea Ice Volume Anomaly and Trend from PIOMAS



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)

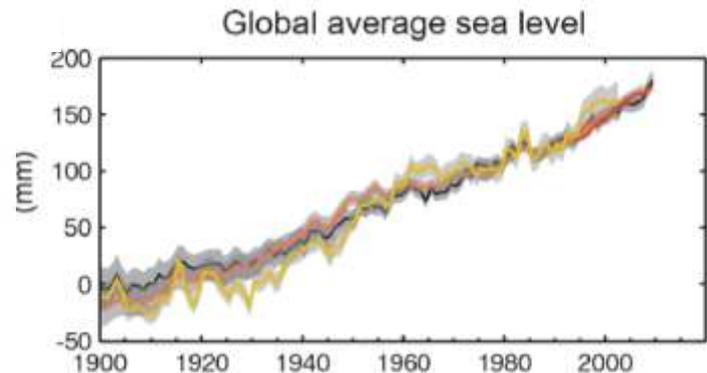
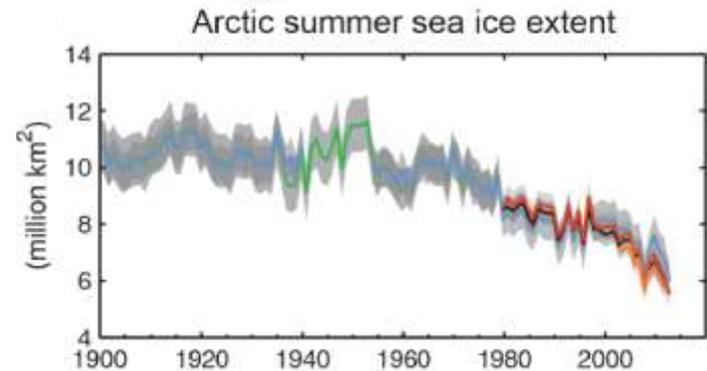


Top: Differences in global average surface temperature compared to the 1961-1990 average

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

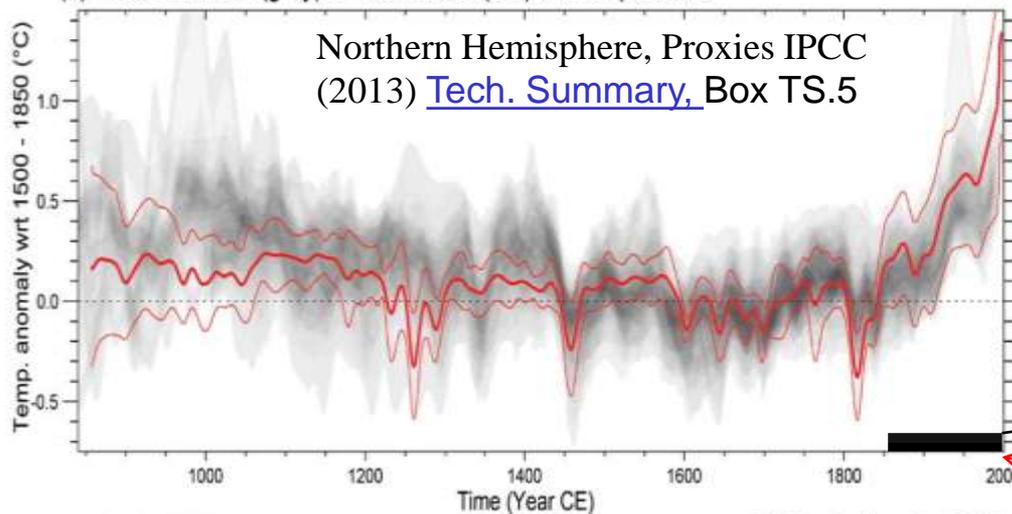
Bottom: Changes in global average sea level compared with 1900-1905 average

Source: IPCC WGI (2013) SPM



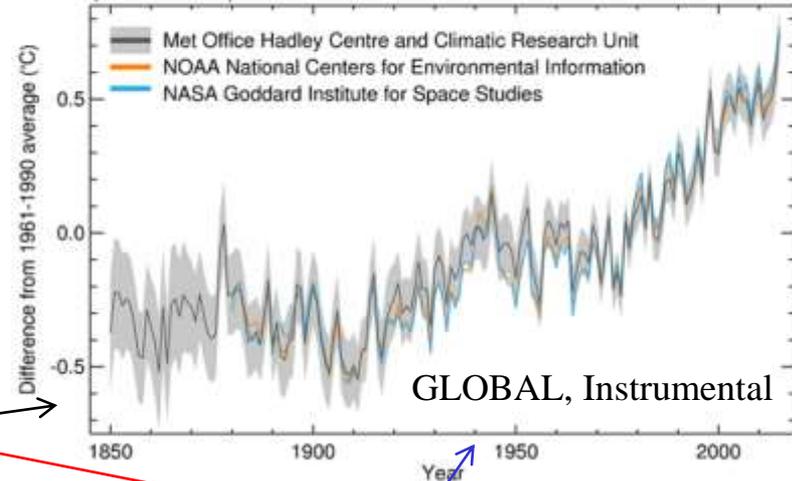
2) Is the warming unusual?

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



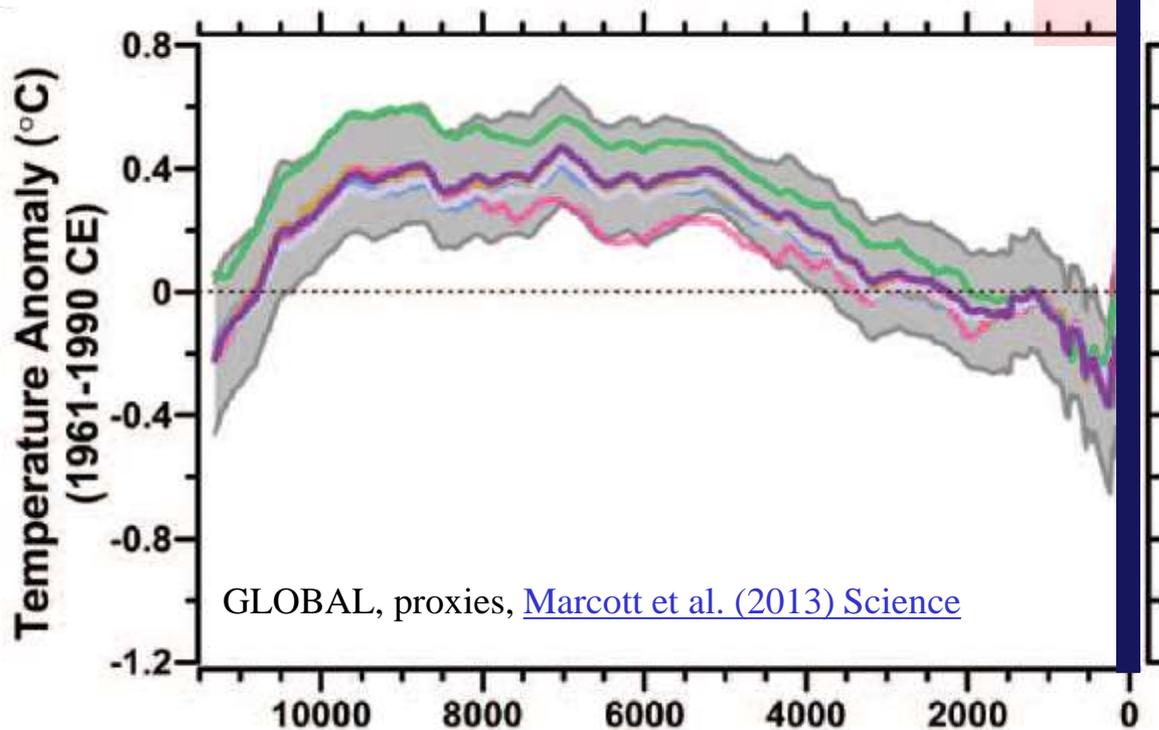
Northern Hemisphere, Proxies IPCC (2013) [Tech. Summary](#), Box TS.5

Global average temperature anomaly (1850-2015)



GLOBAL, Instrumental

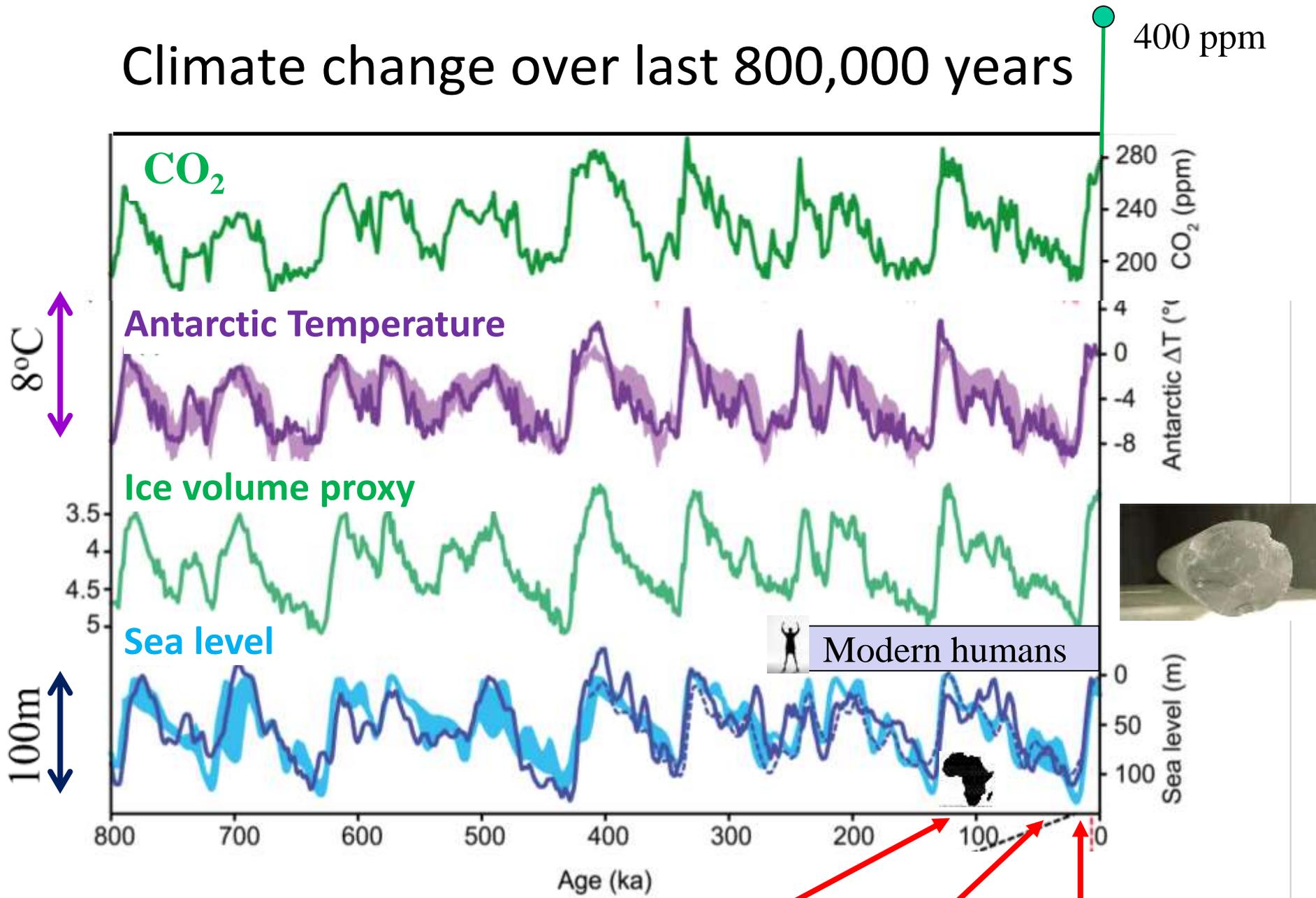
Northern hemisphere proxies



GLOBAL, proxies, [Marcott et al. \(2013\) Science](#)



Climate change over last 800,000 years



[IPCC \(2013\) Chap. 5 Fig 5.3](#)

Africa Exodus

Europe

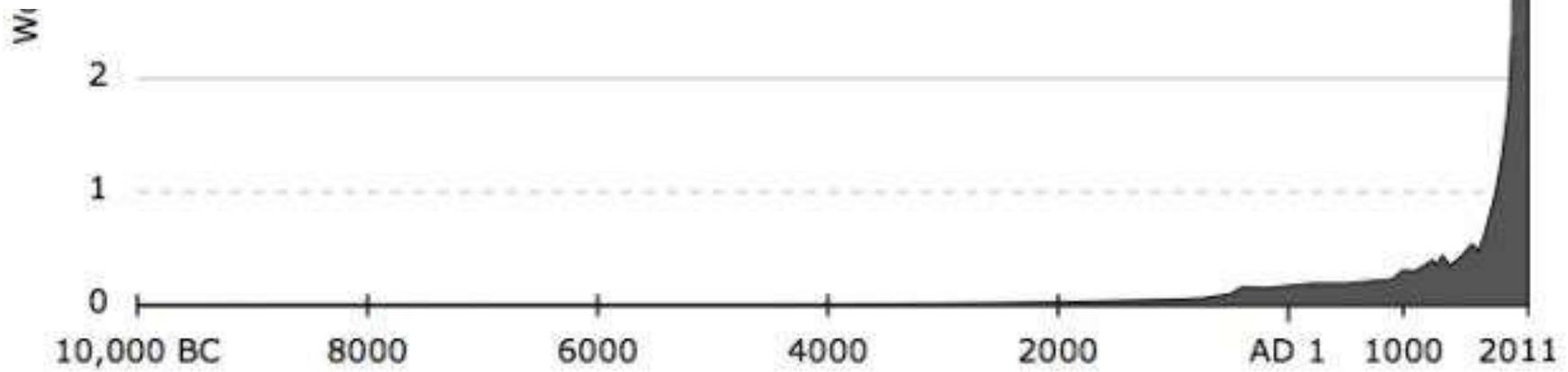
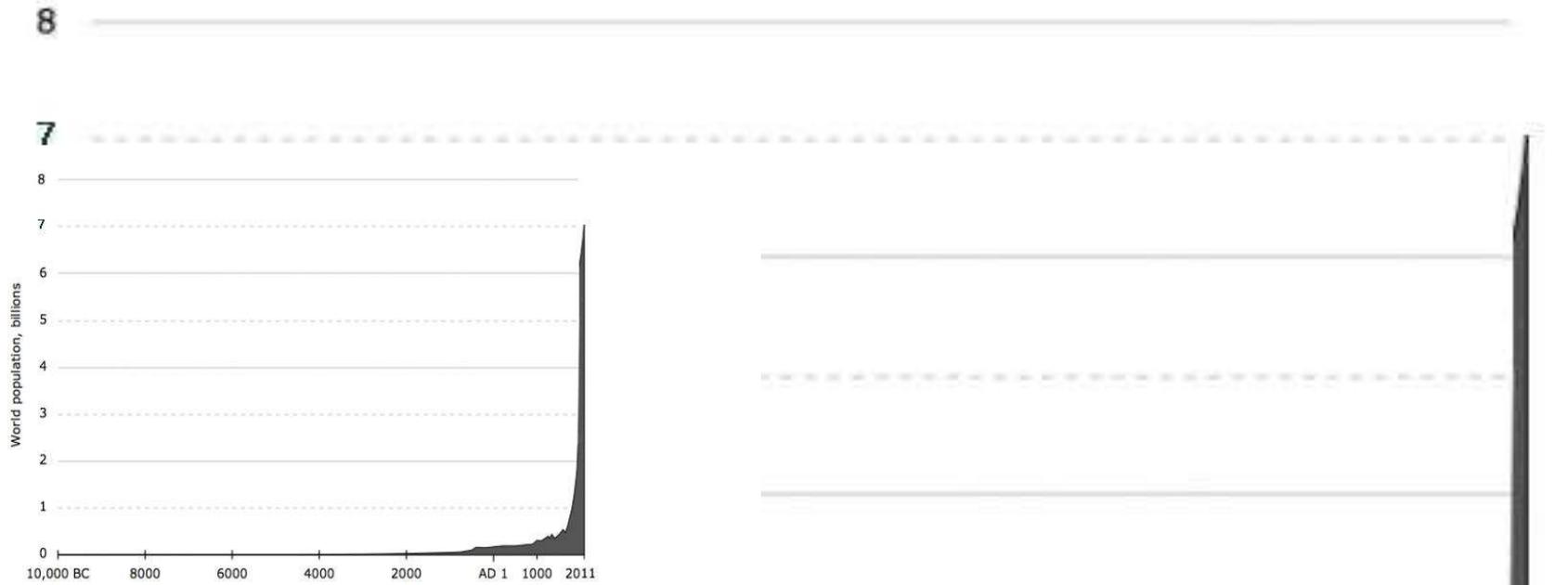
Agriculture

Is the warming unusual?

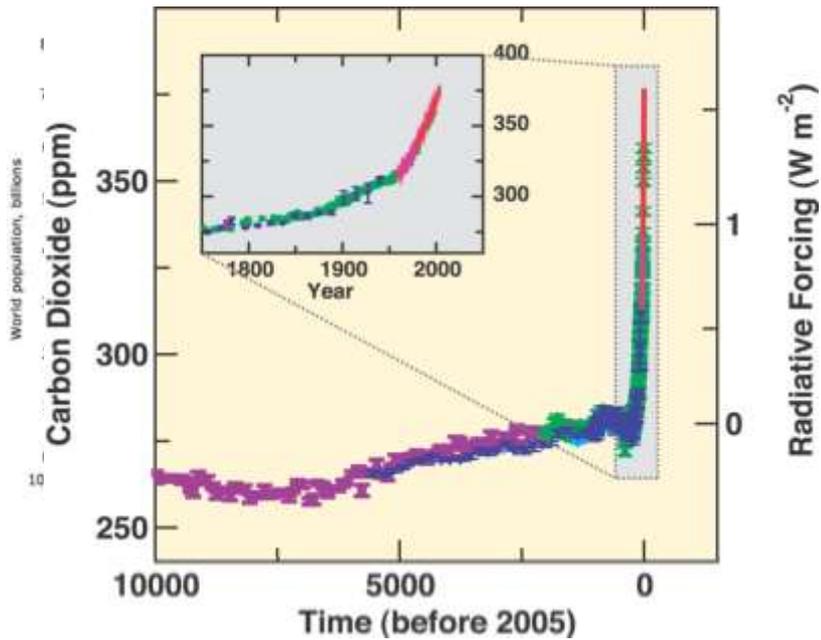
- Over the last 100 years the globe has warmed by around **0.9°C**
- 1983-2012 likely the **warmest 30 year** period in N. Hemisphere in past 1400 yrs
 - Comparable warmth in last 1400 years not as coherent in space or time as now
- Last time Arctic was warmer than today was probably **125,000 years ago**
 - Previous (very different) interglacial when sea level was 4-7m higher than today



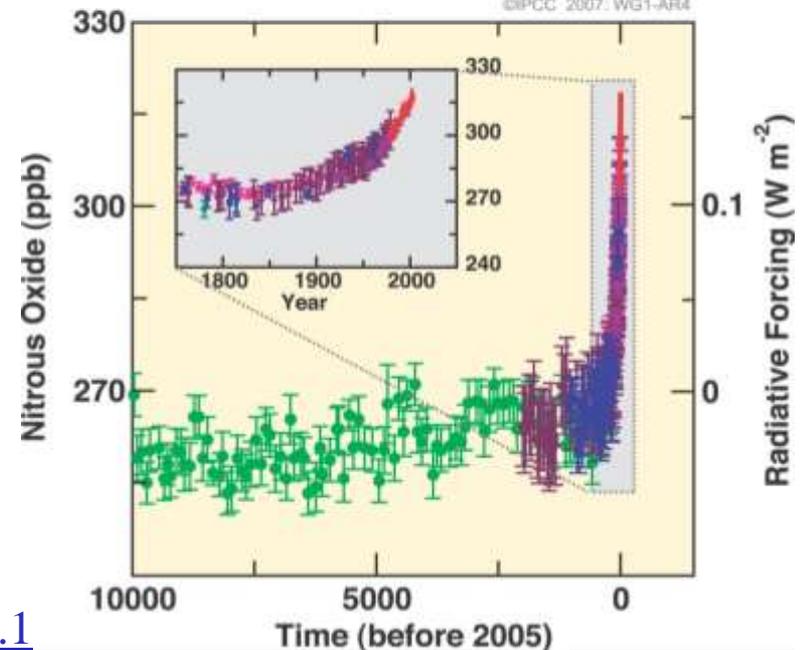
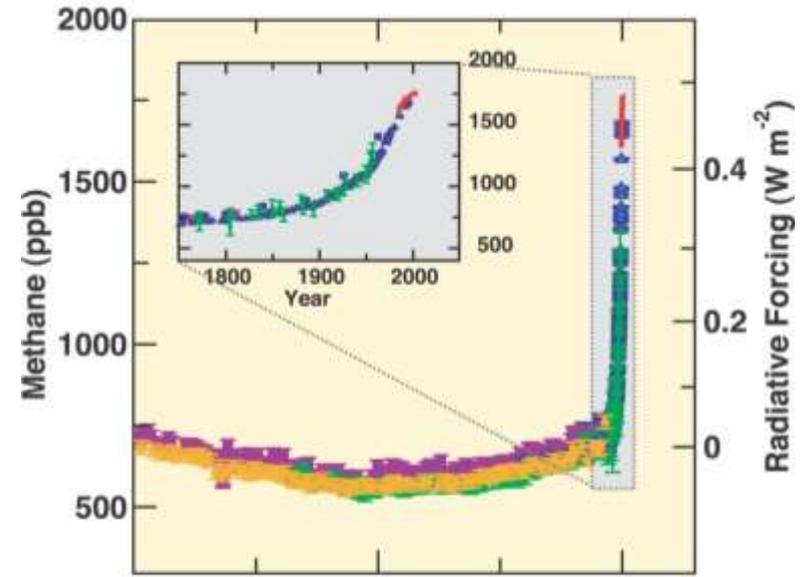
3) Why is it warming?

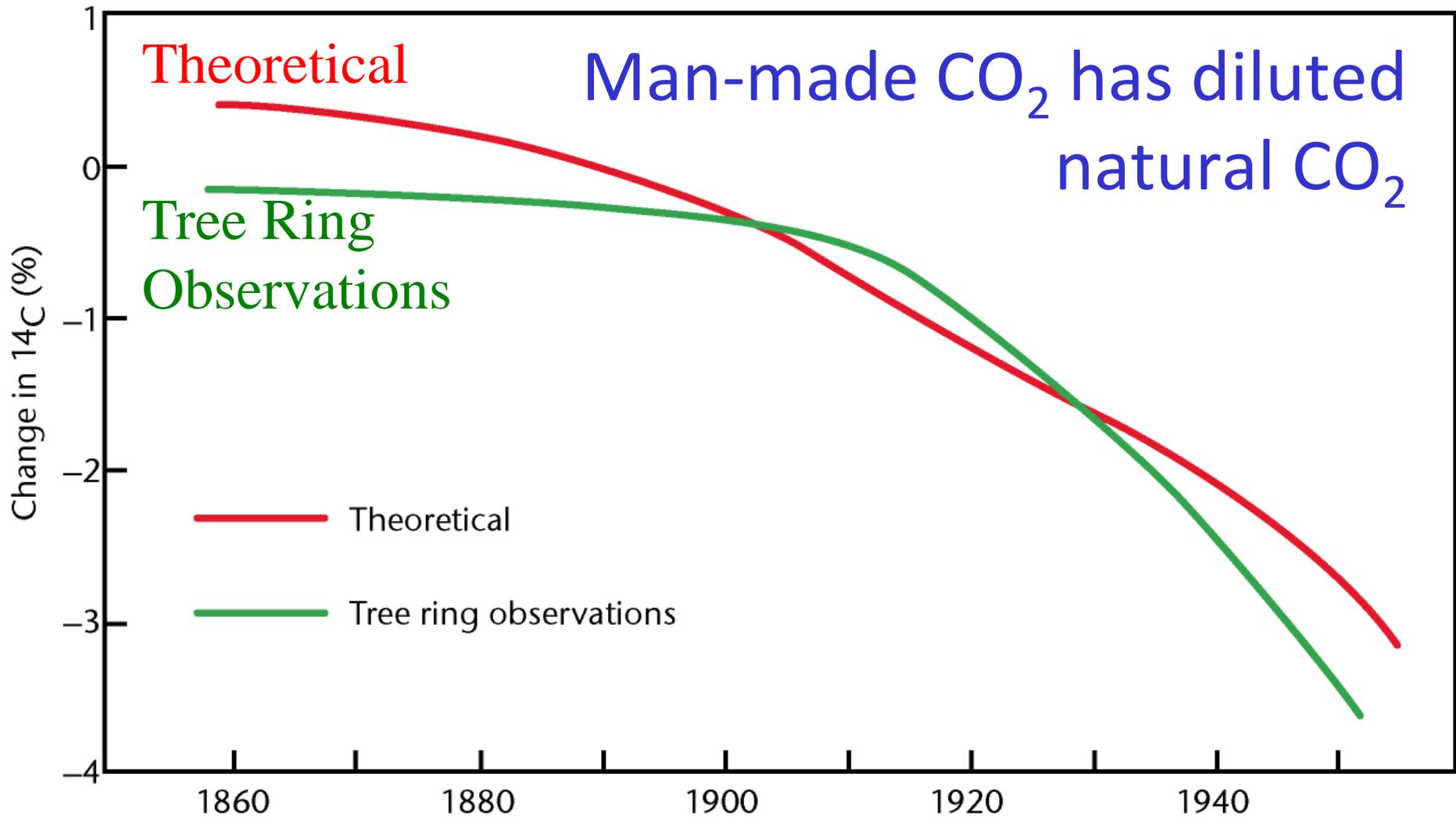


Changes in greenhouse gases from ice core and modern data



Carbon dioxide, methane
and nitrous oxide





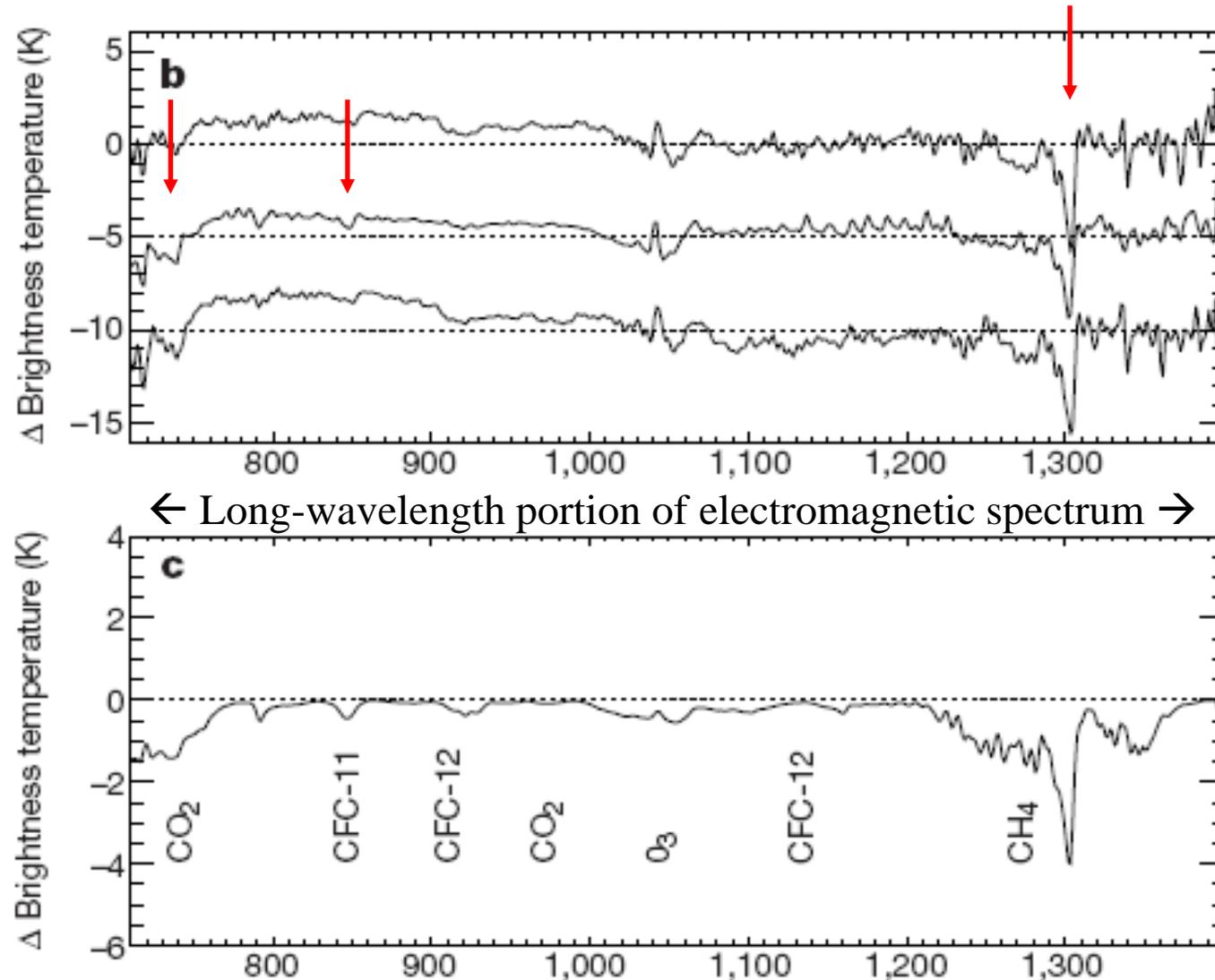
Theoretical

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](#)

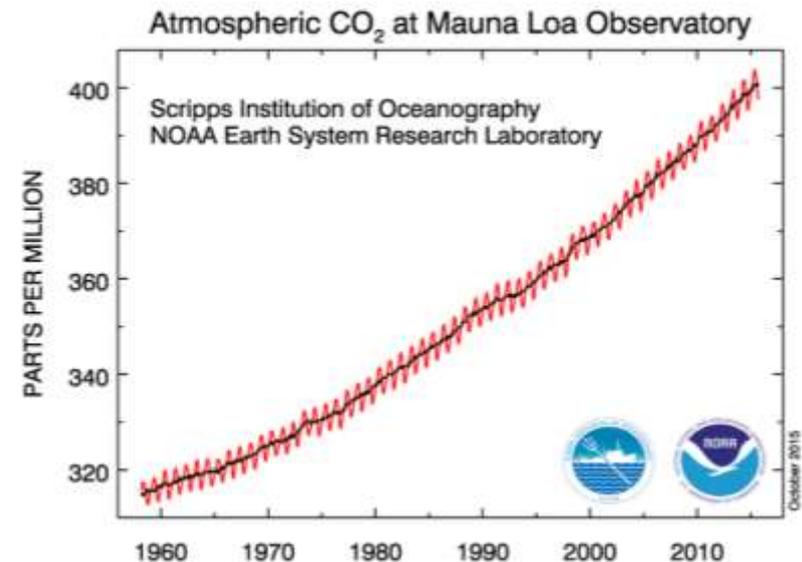


These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane

“Radiative forcing” of climate

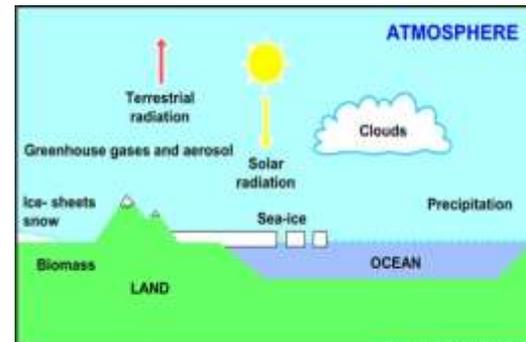
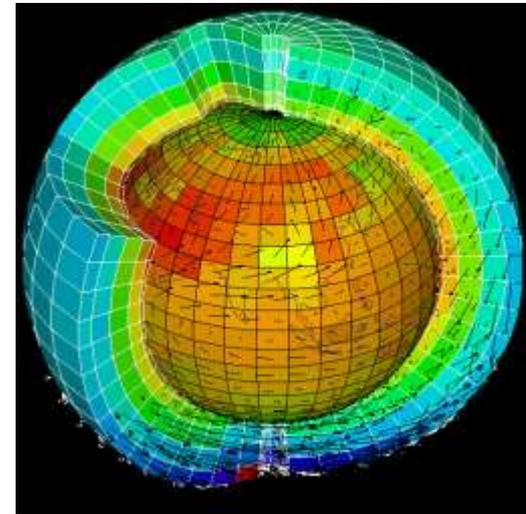
- Increases in **greenhouse gases** **heat** the planet by reducing how easily Earth can cool to space through infra-red emission
- More small pollutant “**aerosol**” particles cool the planet by reflecting sunlight
- If more energy is arriving than leaving, Earth should heat up...

Currently energy is accumulating at rate equivalent to every person currently alive using 20 kettles (2kW) each to boil oceans (or about 300 trillion watts) [Allan et al. \(2014\)](#)

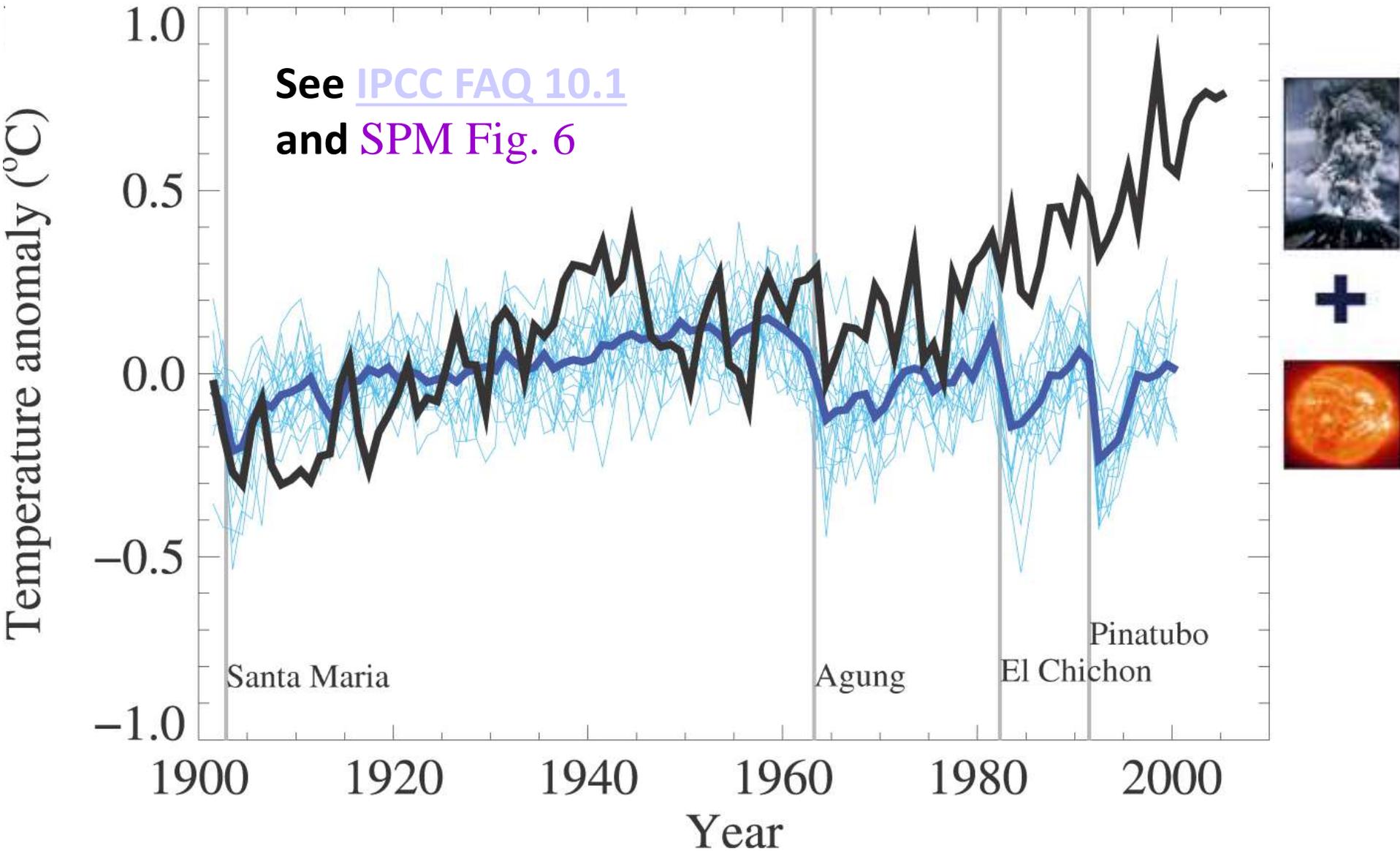


Attributing causes of climate change

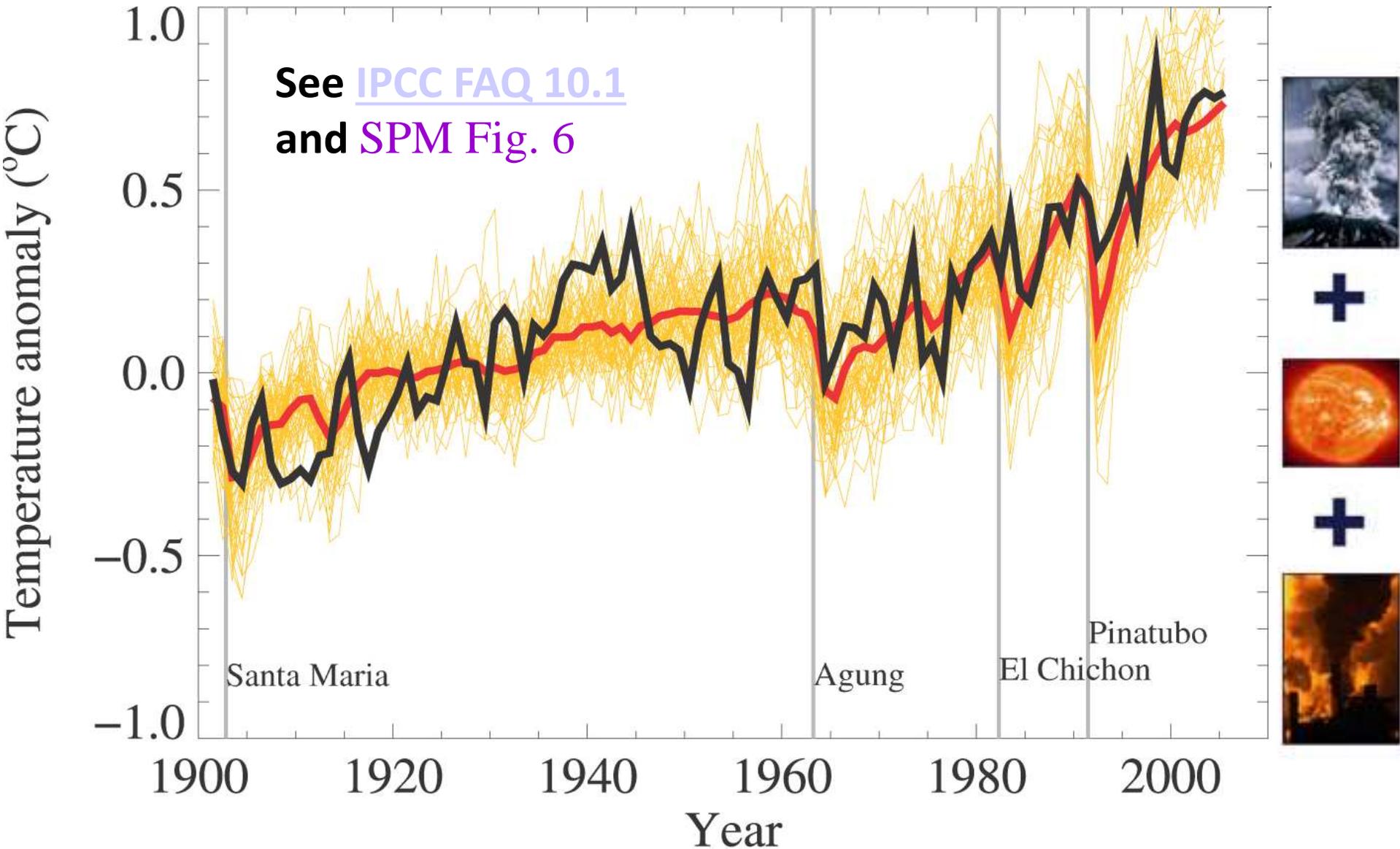
- How much of recent warming is explained by natural effects?
- To answer such questions, experiments can be performed with **climate simulations**
 - including just **natural factors** (ocean circulation, volcanic eruptions, changes in the sun, ...)
 - including **natural** and **anthropogenic factors**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



Natural factors cannot explain recent warming

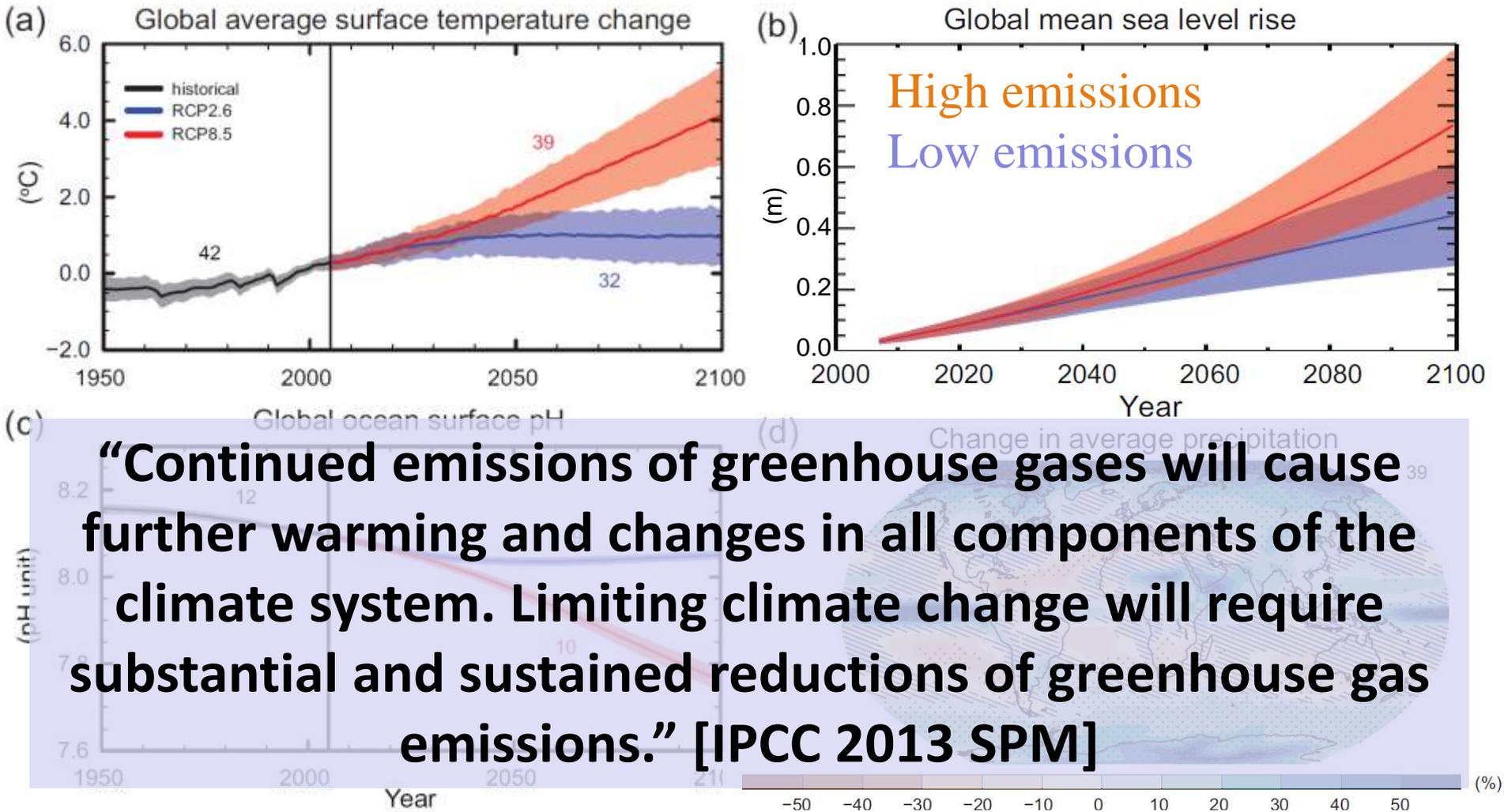


Recent warming can be simulated when man-made factors are included



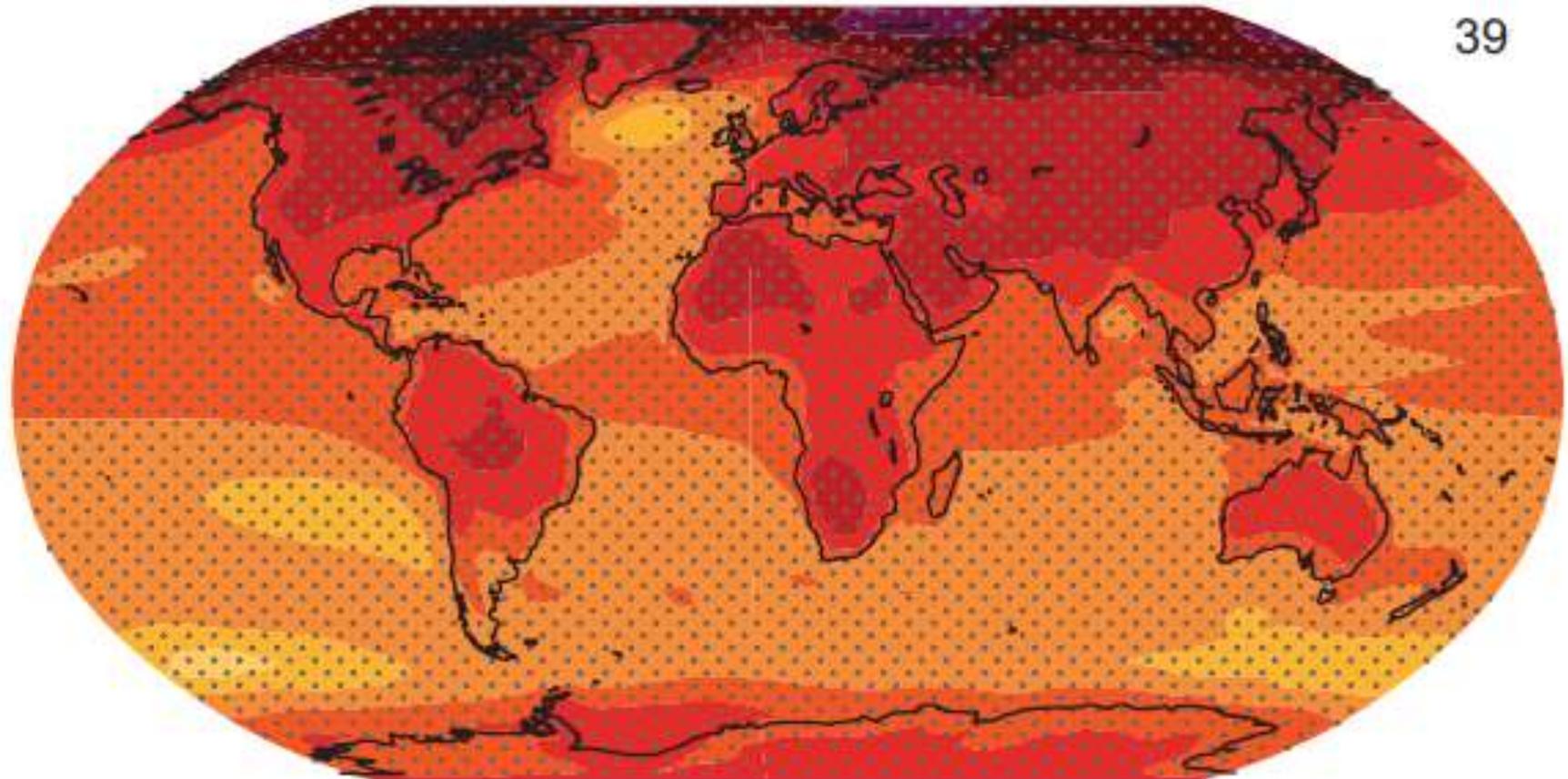
4) What are the predictions?

Future projections to 2100 from climate models

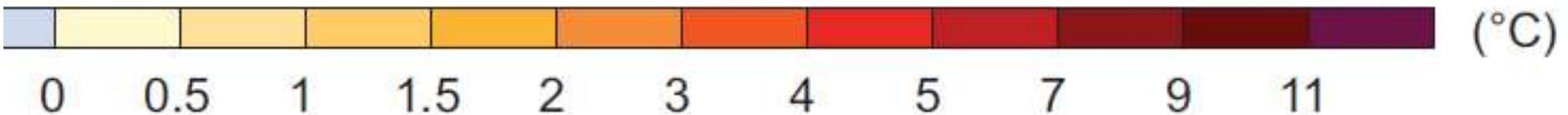


“Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.” [IPCC 2013 SPM]

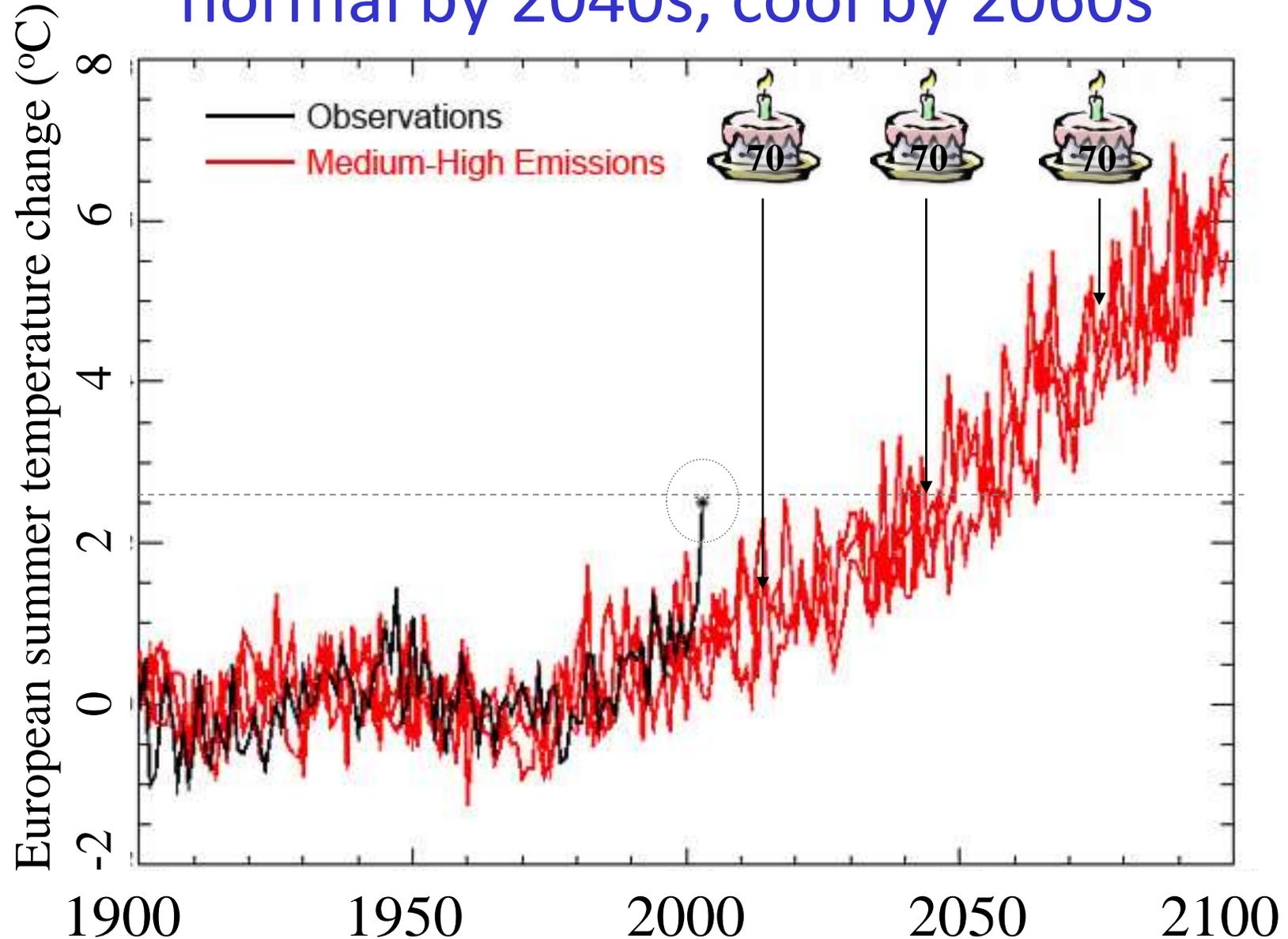
Change in average surface temperature (1986–2005 to 2081–2100) RCP 8.5 Scenario



39



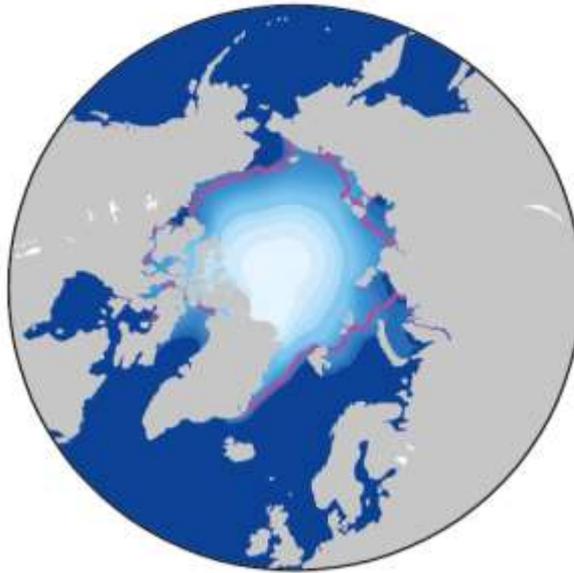
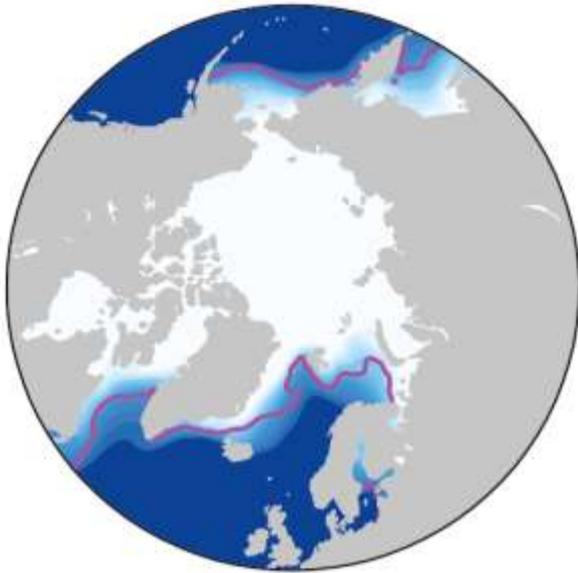
European 2003 summer temperatures could be normal by 2040s, cool by 2060s



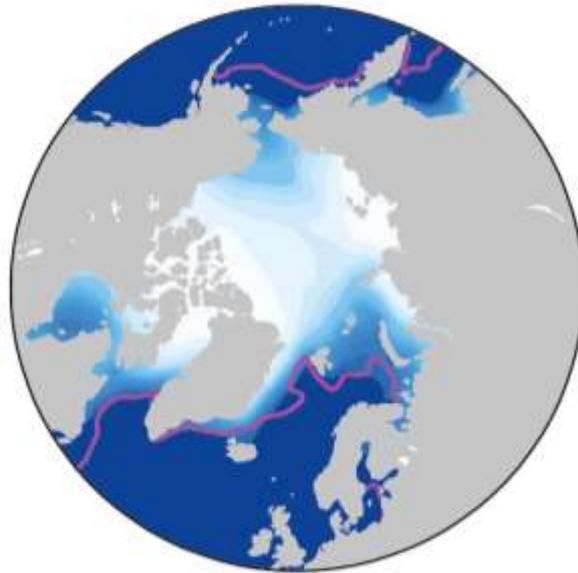
February

September

1986-2005

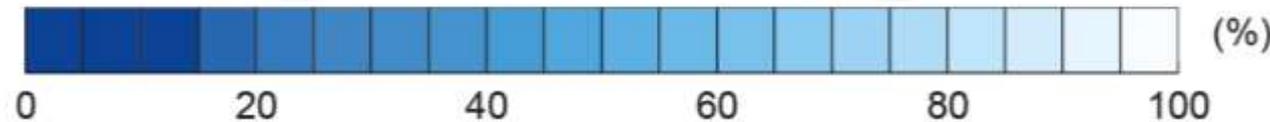


2081-2100 (RCP 8.5)



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



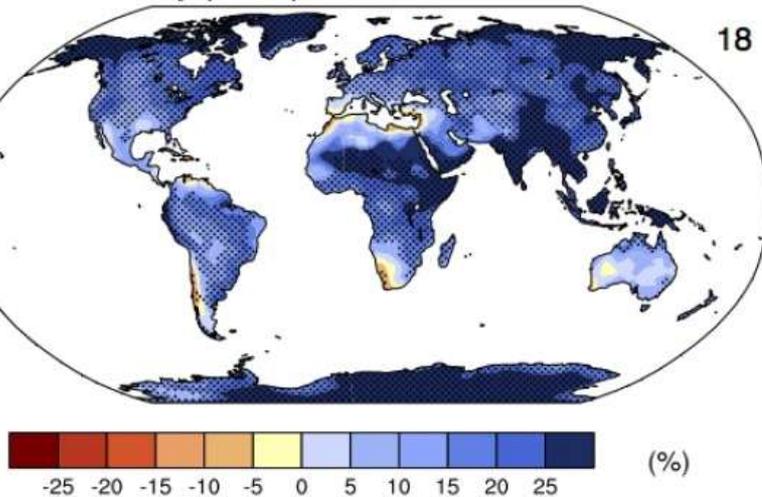
(%)

IPCC (2013)
WG1 Fig. 12.29

Projections of the water cycle

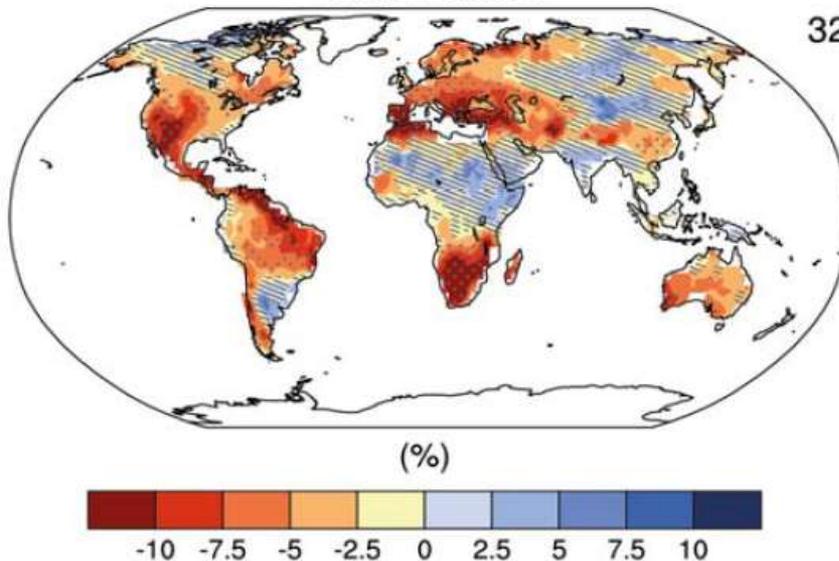
Precipitation intensity

18



Soil moisture

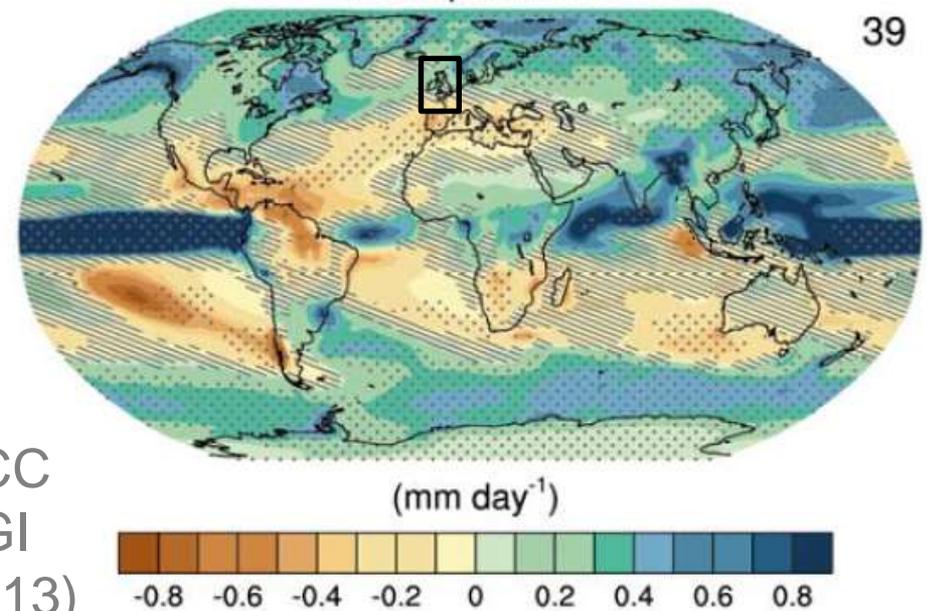
32



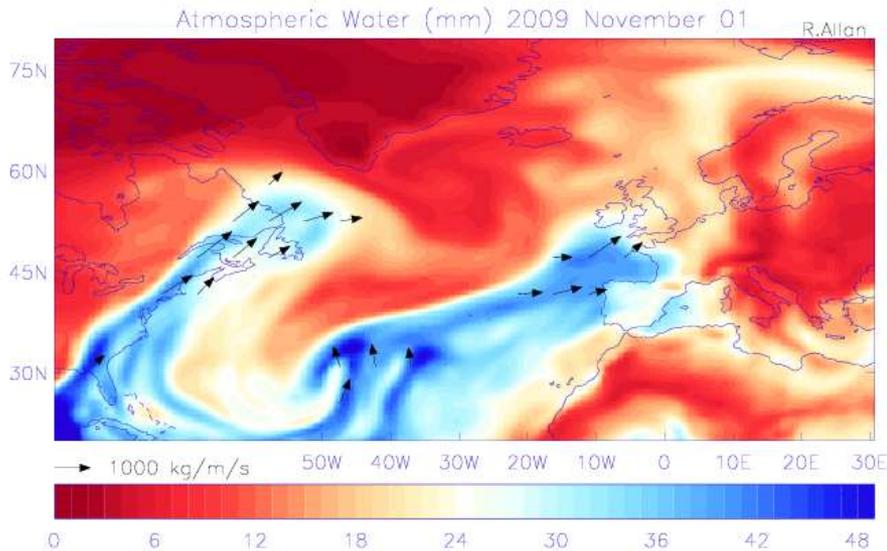
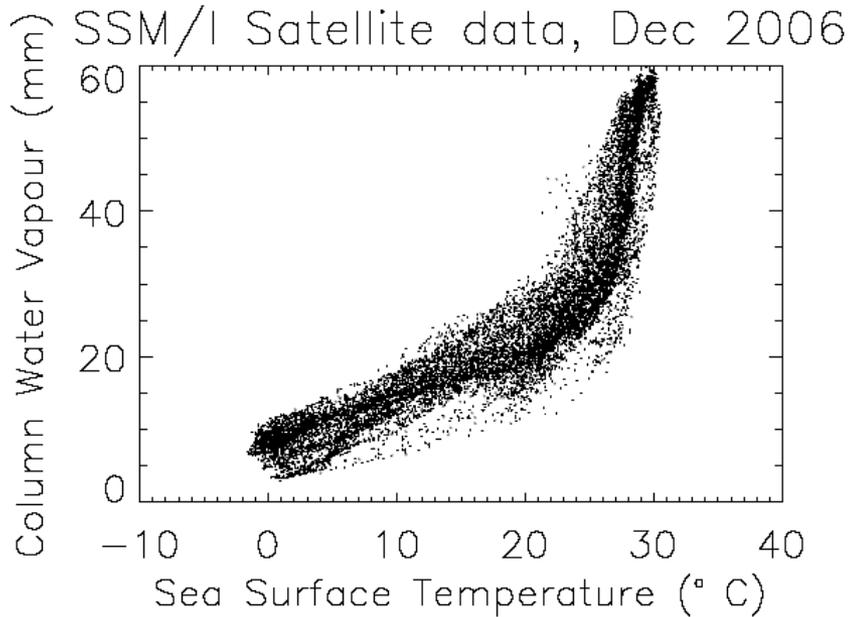
- Increased Precipitation
- More Intense Rainfall
- More droughts
- Intensification of wet and dry seasons?
- Regional projections??

Precipitation

39



IPCC
WGI
(2013)

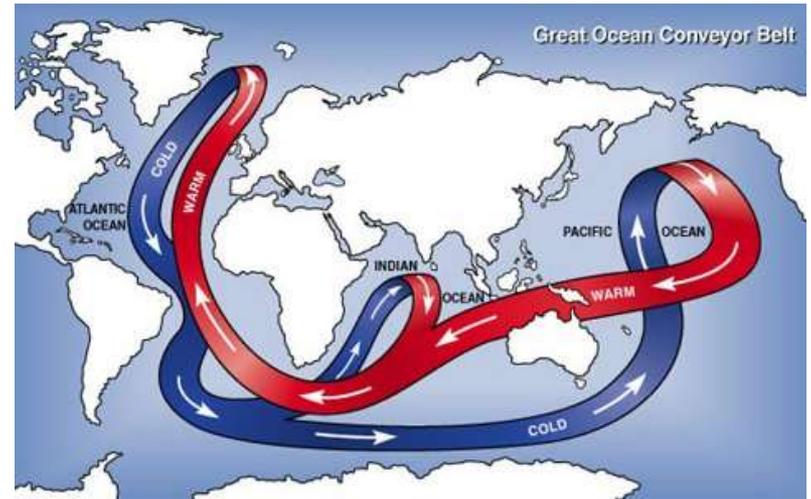
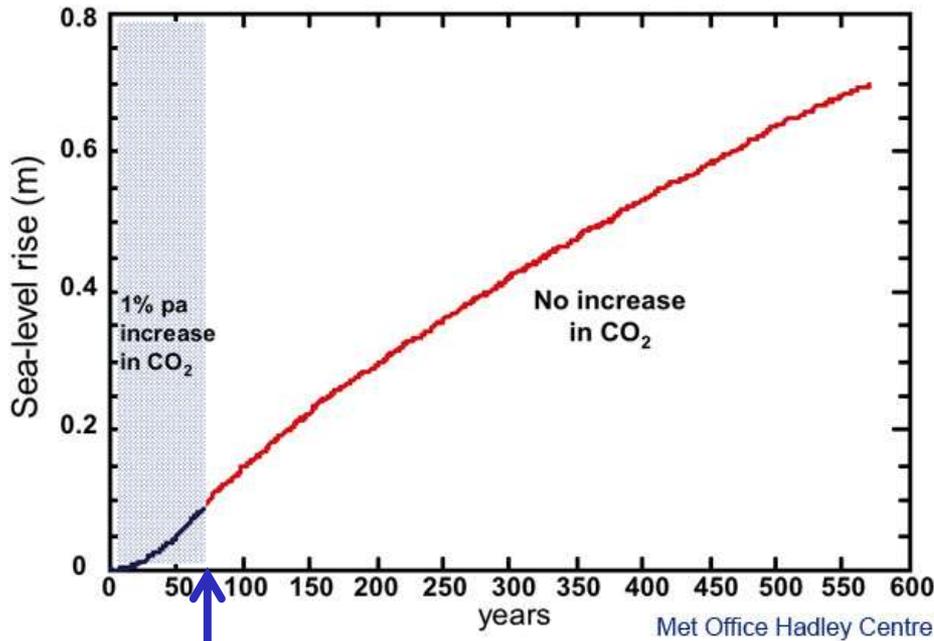


Water vapour & climate change

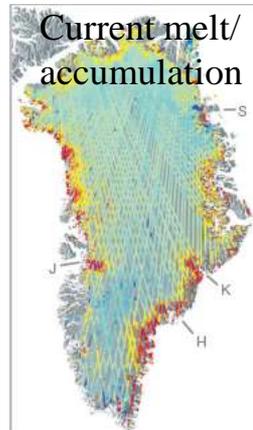
- Water vapour is a powerful greenhouse gas
 - Water vapour in the air increases with warming
 - This increases magnitude of climate change
 - Also drives intensification of extreme rainfall events
- ← Nov 2009 Cumbria flooding event
- The weather will always generate extreme rainfall events but warming of climate will increase their severity*

[Lavers et al. \(2013\) Environ. Res. Lett.](#)

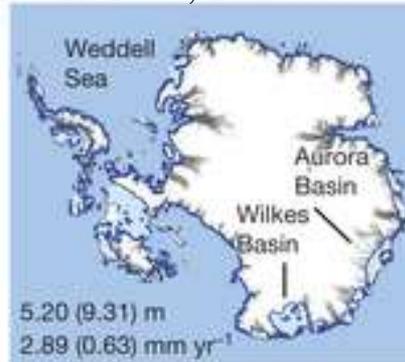
Long-term commitment to sea-level rise



CO₂ increase stops here



RCP 8.5, Year 5000

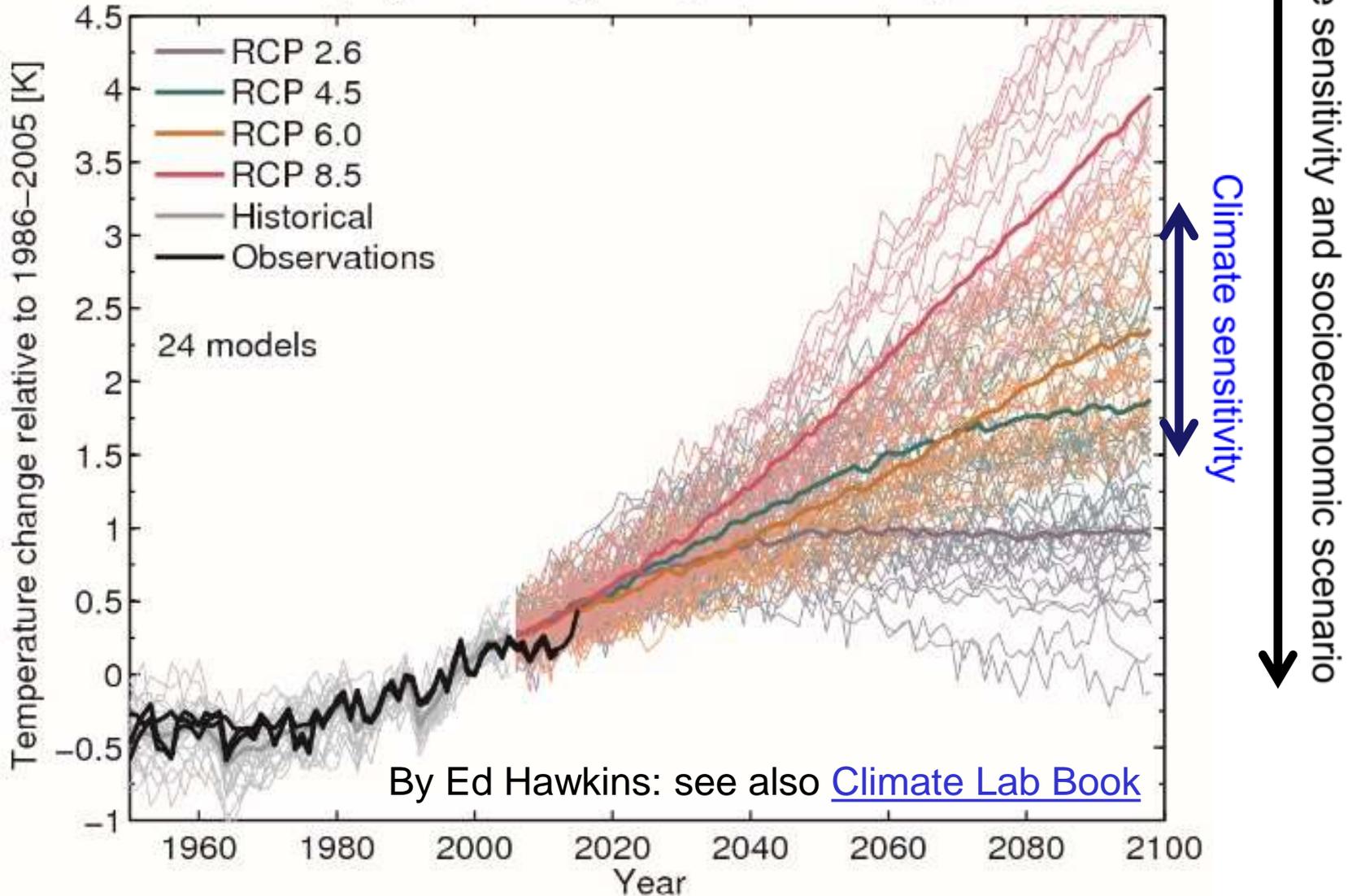


2.3m sea level rise per °C warming over long term (e.g. 2000 years) [\[IPCC Fig. 13.14\]](#)

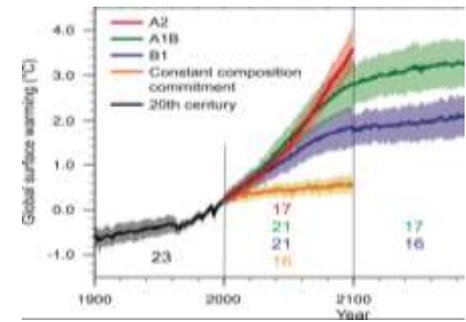
[Golledge et al. \(2015\) Nature](#)

How much will planet warm?

CMIP5 projected changes in global mean temperature



Summary



- The planet is warming and this is primarily attributable to rising greenhouse gas concentrations
- 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...
 - Will substantial greenhouse gas emissions continue?
 - Are “knock on effects” of warming amplifying or reducing the magnitude of change (e.g. clouds, land surface, ...)?
 - Changes in atmospheric and oceanic circulations change are crucial for local impacts yet challenging to predict