

# The Science of Climate Change - Facing the facts

**EPA Climate Change Lecture Series**

Dublin

20 November 2007

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# Introduction

1. What changes are occurring
2. What drives climate change
3. Is there really a human contribution
4. What can we say about the future?

# The Working Group I Report



- Started 2003
- Completed February 2007
- 152 Authors
- ~450 other contributors
- ~600 expert reviewers
- 30,000+ review comments

## Contents

You can get it at: <http://ipcc-wg1.ucar.edu/>

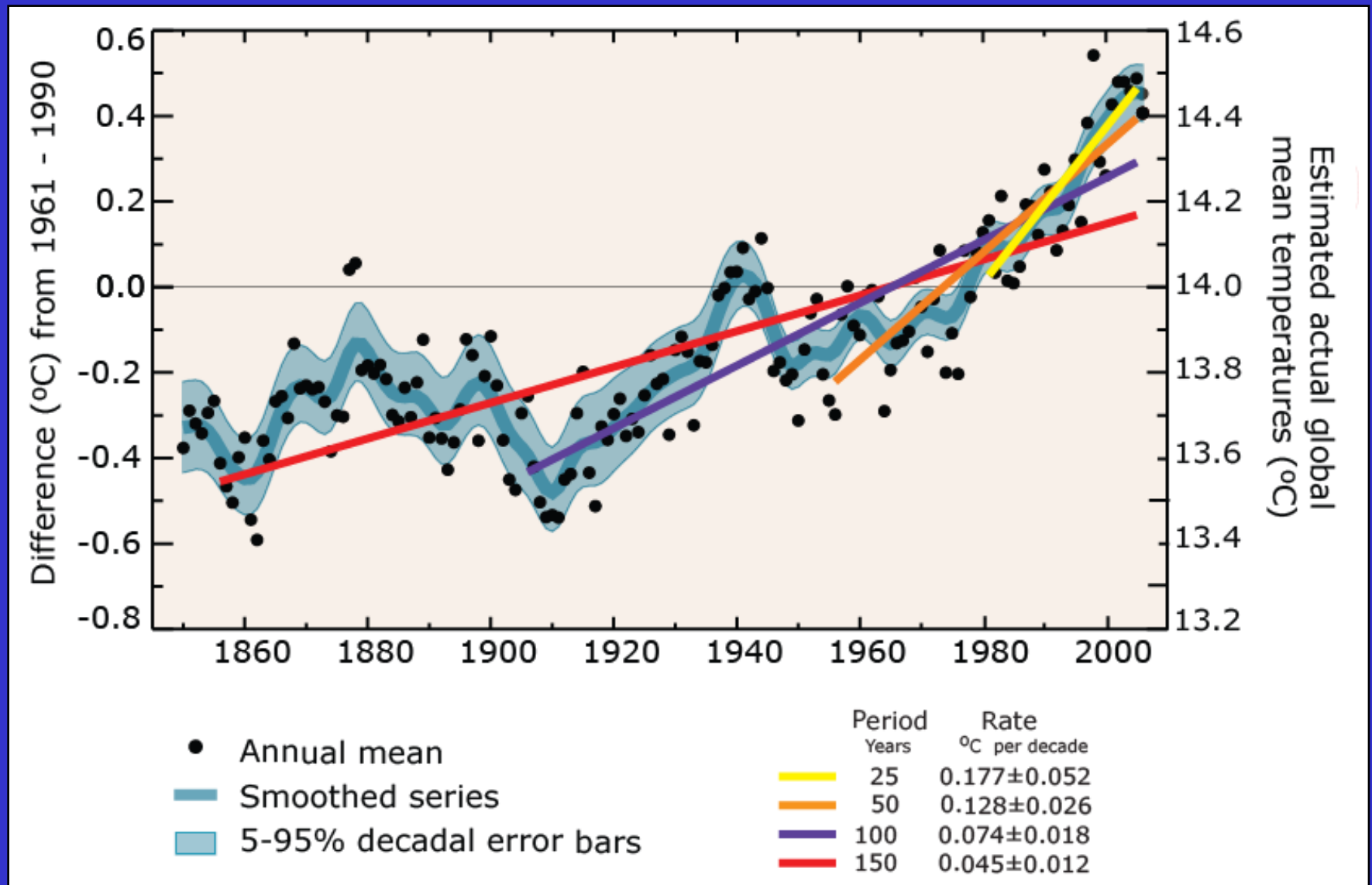
All figures available in PowerPoint format.

All review comments & author responses publicly available



- ~5000 literature references
- ~1000 pages

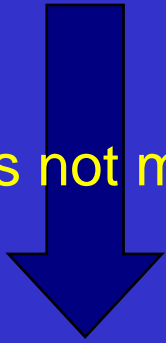
# Global average temperature



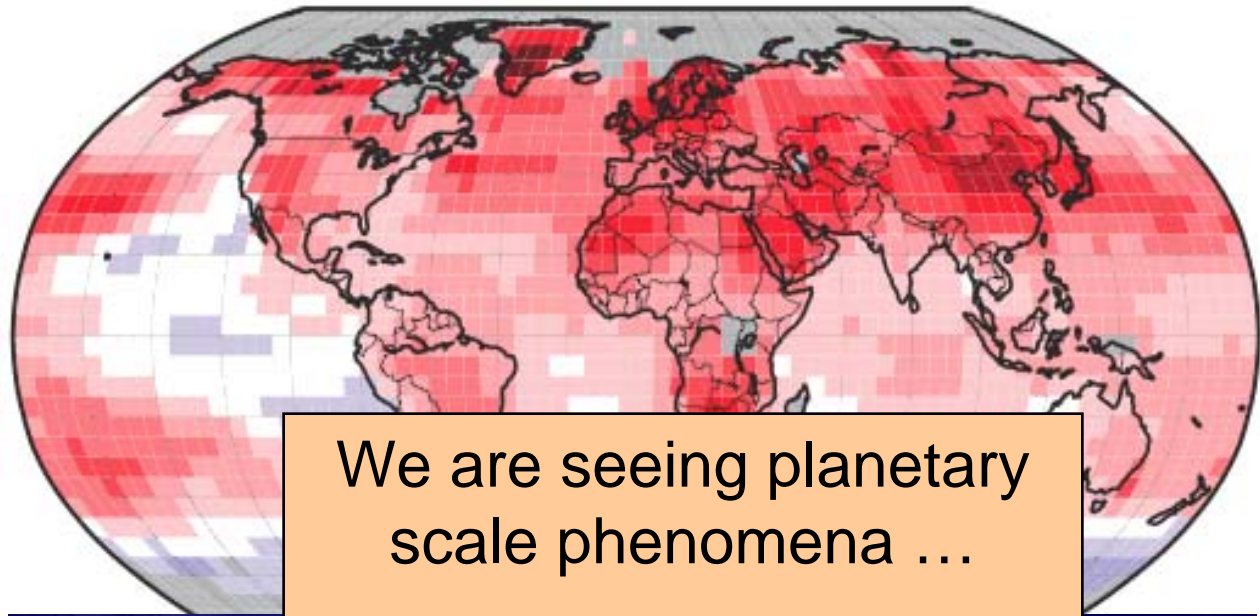
# Warming is truly global

The pattern of  
surface warming  
trends ...

does not match



The pattern of  
global night lights  
(indicating population  
and industrial centers)

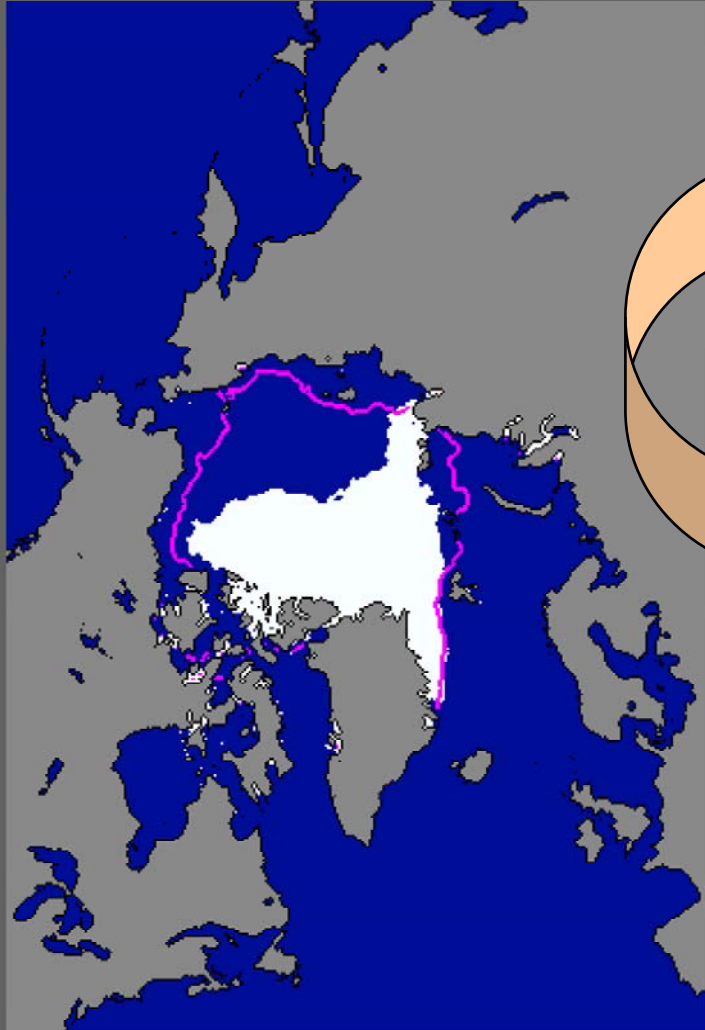


We are seeing planetary  
scale phenomena ...  
... NOT local effects



# Changes in Arctic Sea Ice Cover

Current Ice Extent  
09/16/2007



Total extent = 4.1 million sq km

median  
ice edge

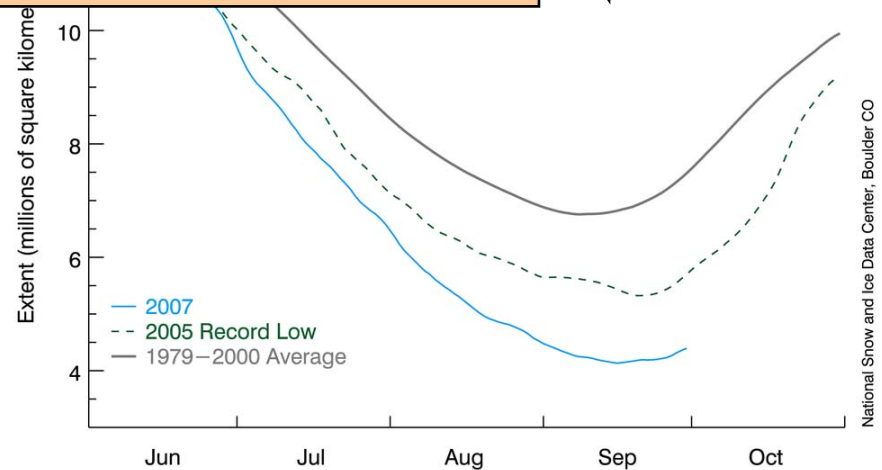
National Snow and Ice Data Center, Boulder, CO

Average Arctic sea ice extent decreased by 2.7% per decade since 1978. Larger decreases in summer

Less ice

2007 record low sea ice extent

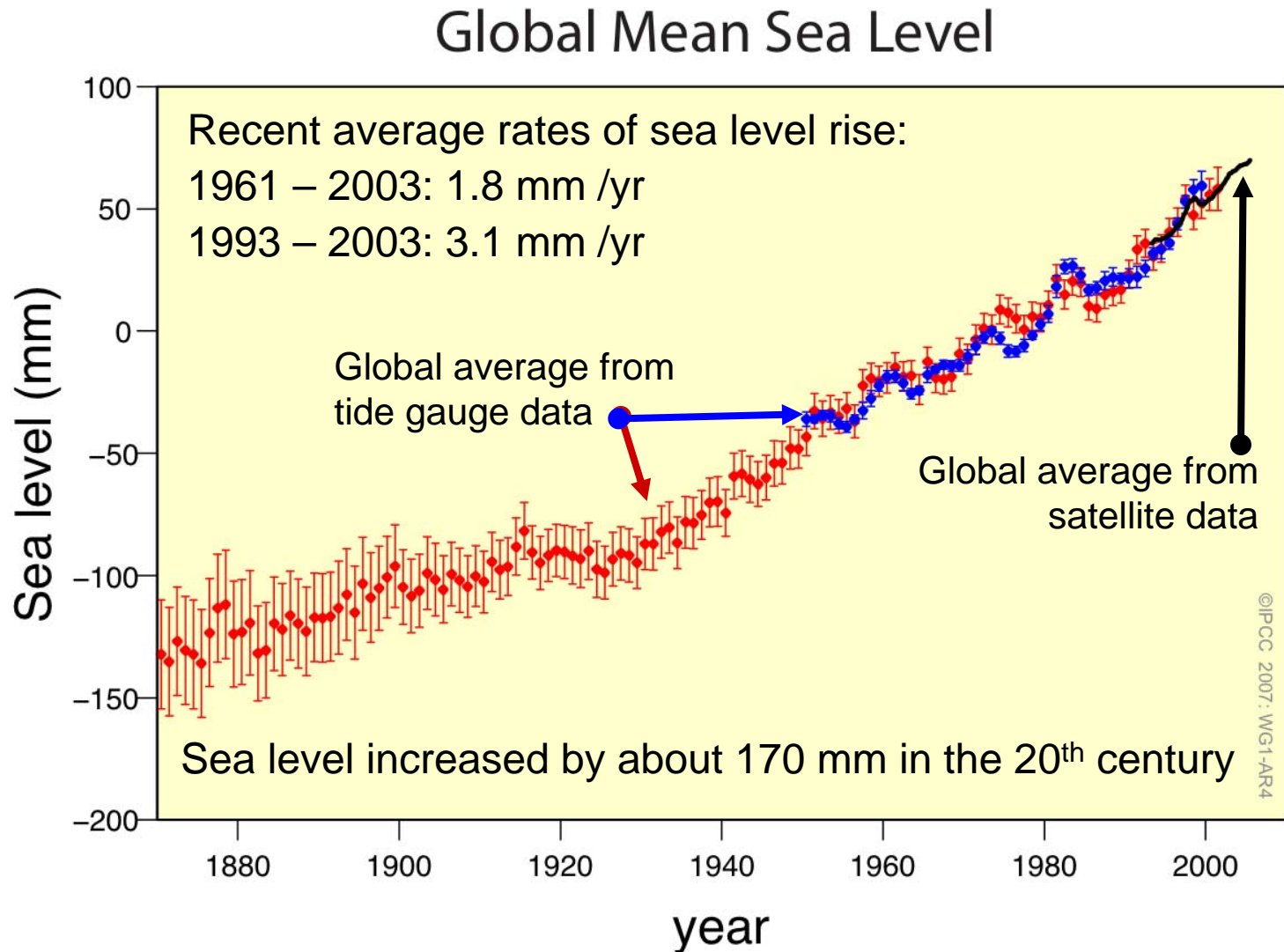
Ocean absorbs more heat



National Snow and Ice Data Center, Boulder, CO

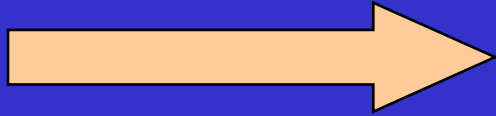


# Tide gauge and satellite data on sea level

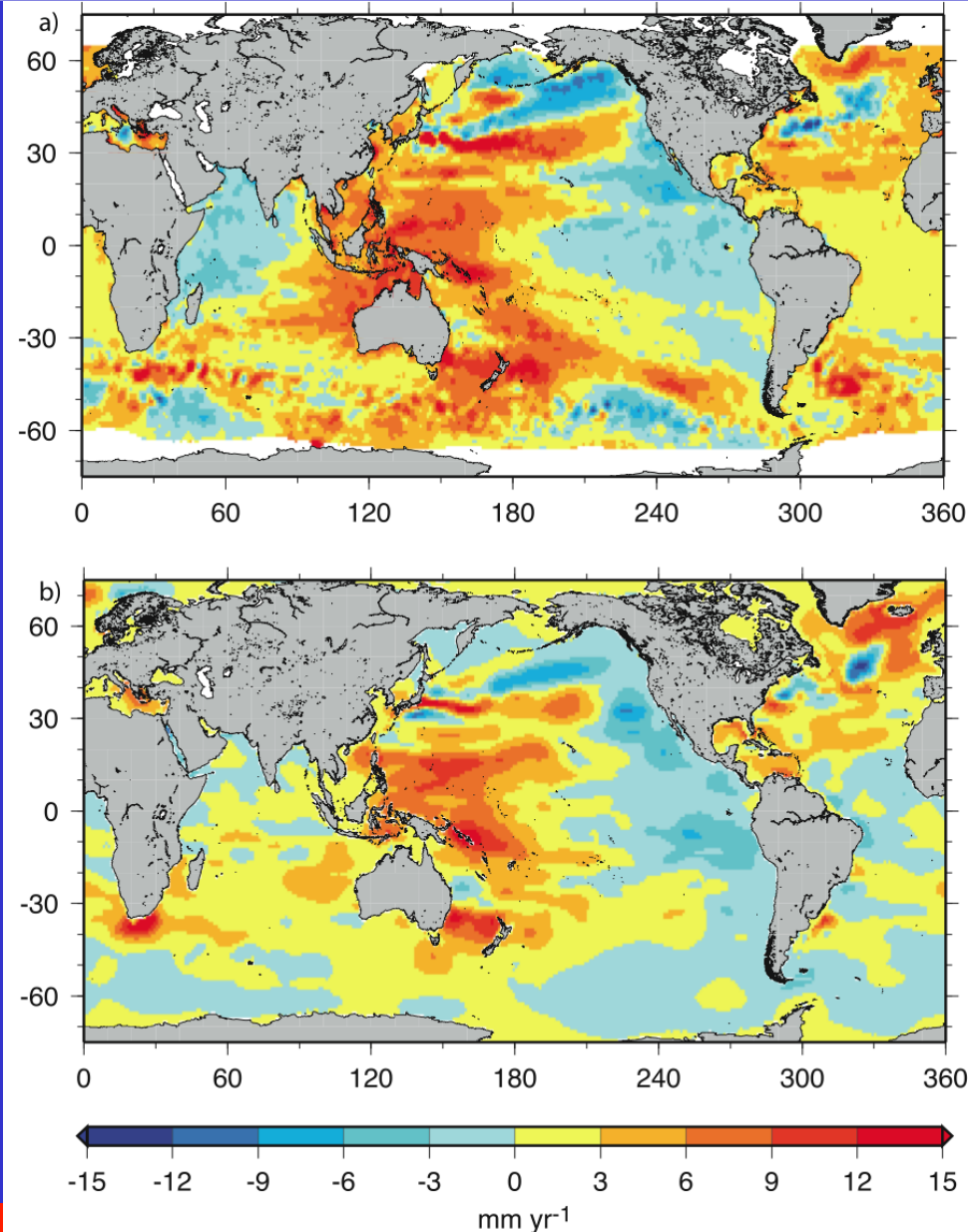
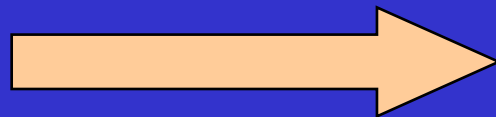


# Sea level rise and ocean warming

Satellite measurements show patterns of decadal sea level rise (1993 – 2003)



Sea level rise estimated from expansion due to observed ocean warming to depth of 700 m over same period





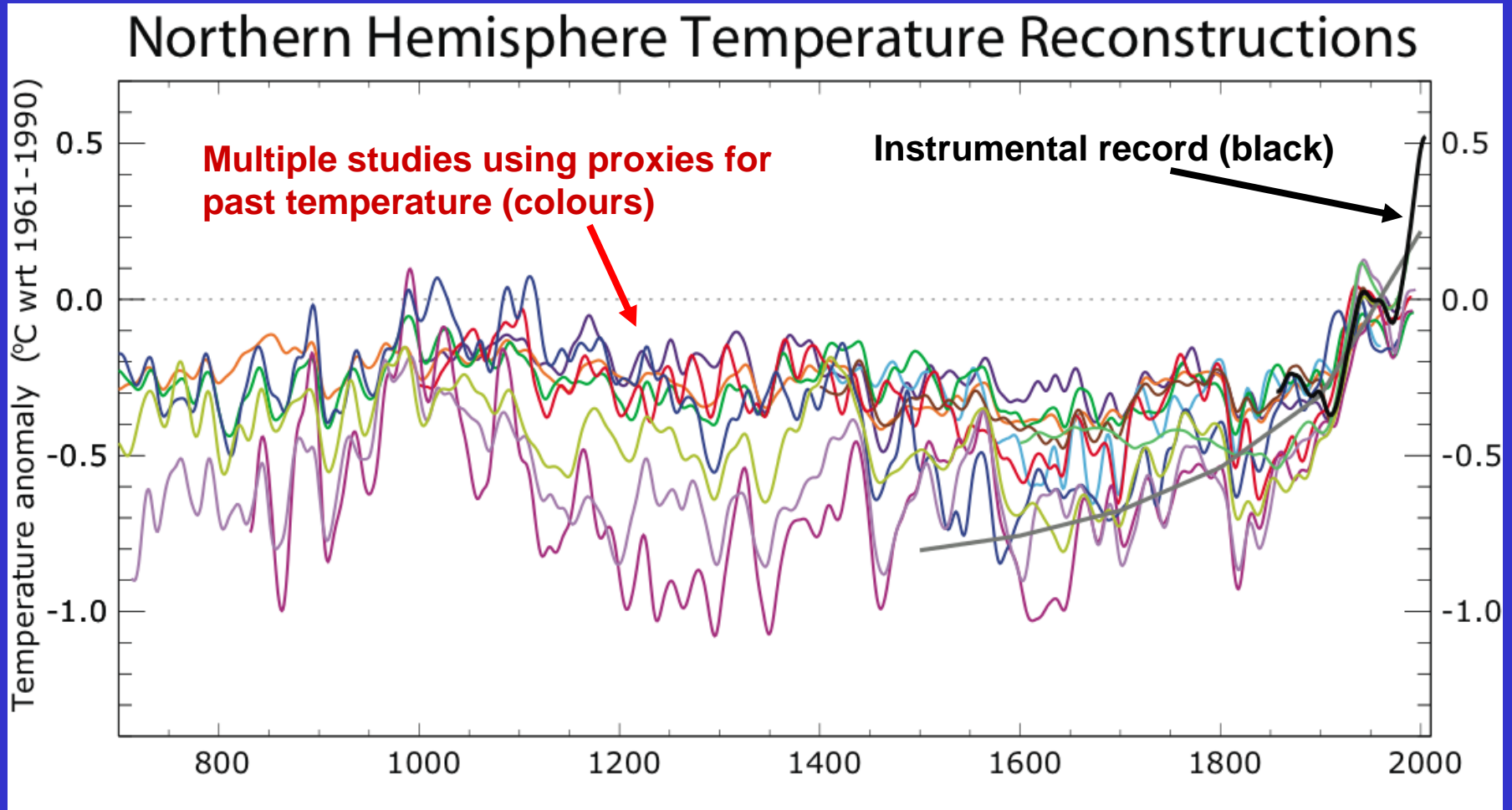
# Consistent pattern of warming

- Surface temperatures increasing
- Tropospheric temperatures increasing
- Atmospheric water vapour content increasing
- Ocean heat content increasing ...
- ... now directly linked to sea level rise
- Greenland and Antarctic Ice Sheets losing mass
- Glaciers and snow cover retreating
- Arctic sea ice extent decreasing
- Area of seasonally frozen ground decreasing
- Mid-latitude wind patterns/ storm tracks shifting poleward
- More intense and longer droughts
- More frequent heavy precipitation events over land
- Extreme temperatures increasing
- Tropical cyclone intensity increasing (in North Atlantic)

**Unequivocal**

# A longer term perspective

Warmth of the last half century is unusual  
in at least the previous 1300 years.



# Icarus and Daedalus

The Greeks knew a lot about the geosciences;

And that the sun heated the planet;

But not how the greenhouse effect worked!

The Fall of Icarus  
Jacobi Gowi



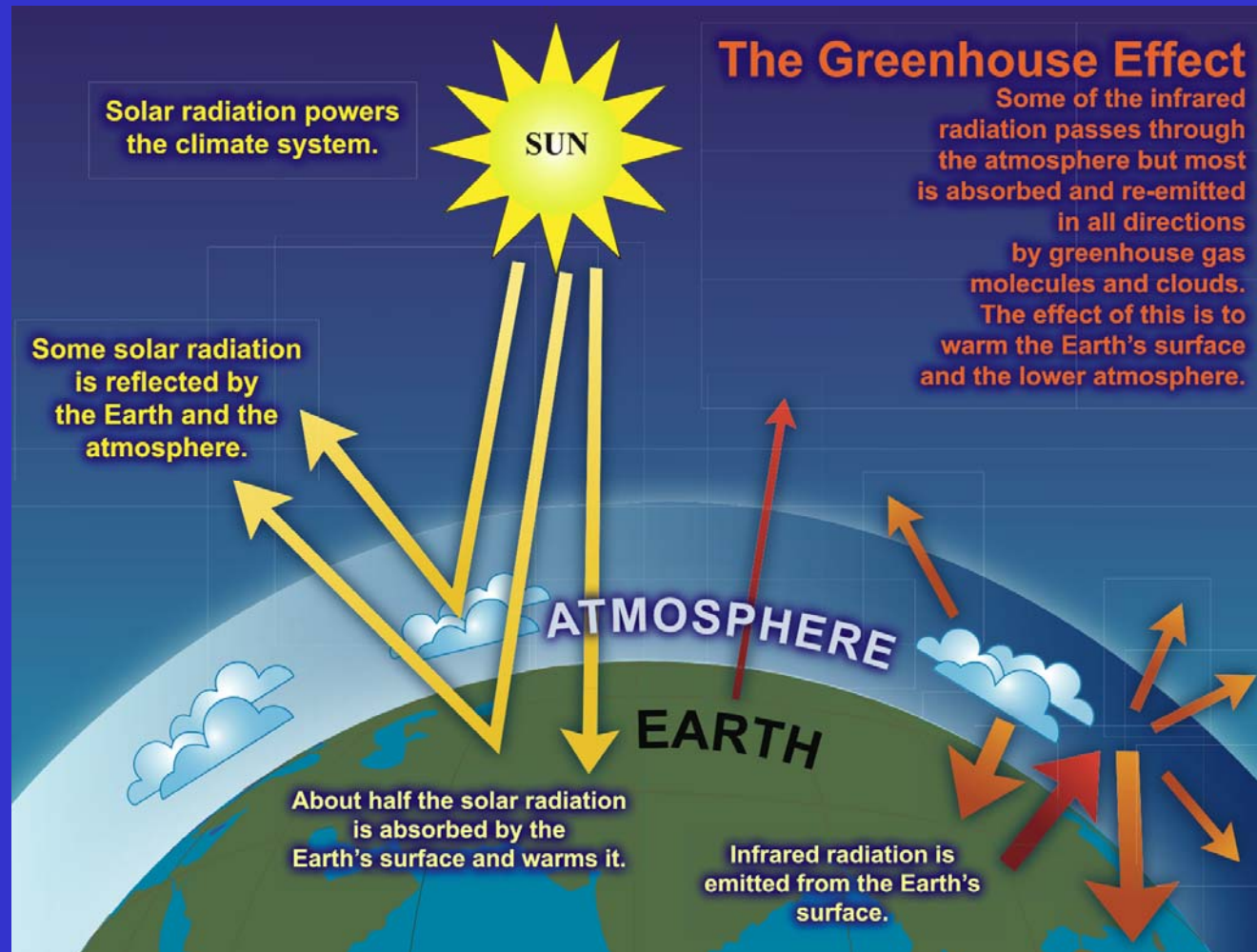


# The greenhouse effect

The planet is warmed by the Sun - but air is warmed by the Earth.

The natural greenhouse effect increases surface temperatures by about 30°C.

Increasing greenhouse gas concentrations tends to increase surface temperatures.

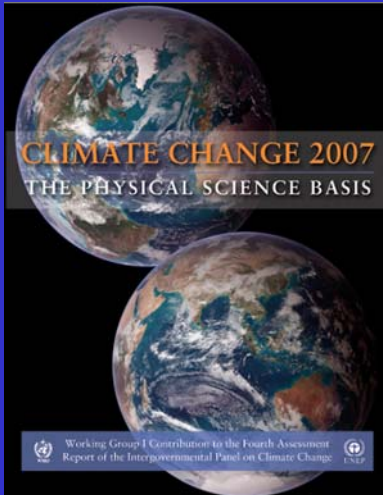


# Projections of climate change



## Svante Arrhenius, “Verldamas Utveckling”, 1906

- ... any doubling of the percentage of carbon dioxide in the air would raise the temperature of the Earth's surface by 4°C.
- ... the percentage of carbonic acid in the atmosphere may, by the advances of industry, be changed to a noticeable degree in the course of centuries.



## Intergovernmental Panel on Climate Change 2007

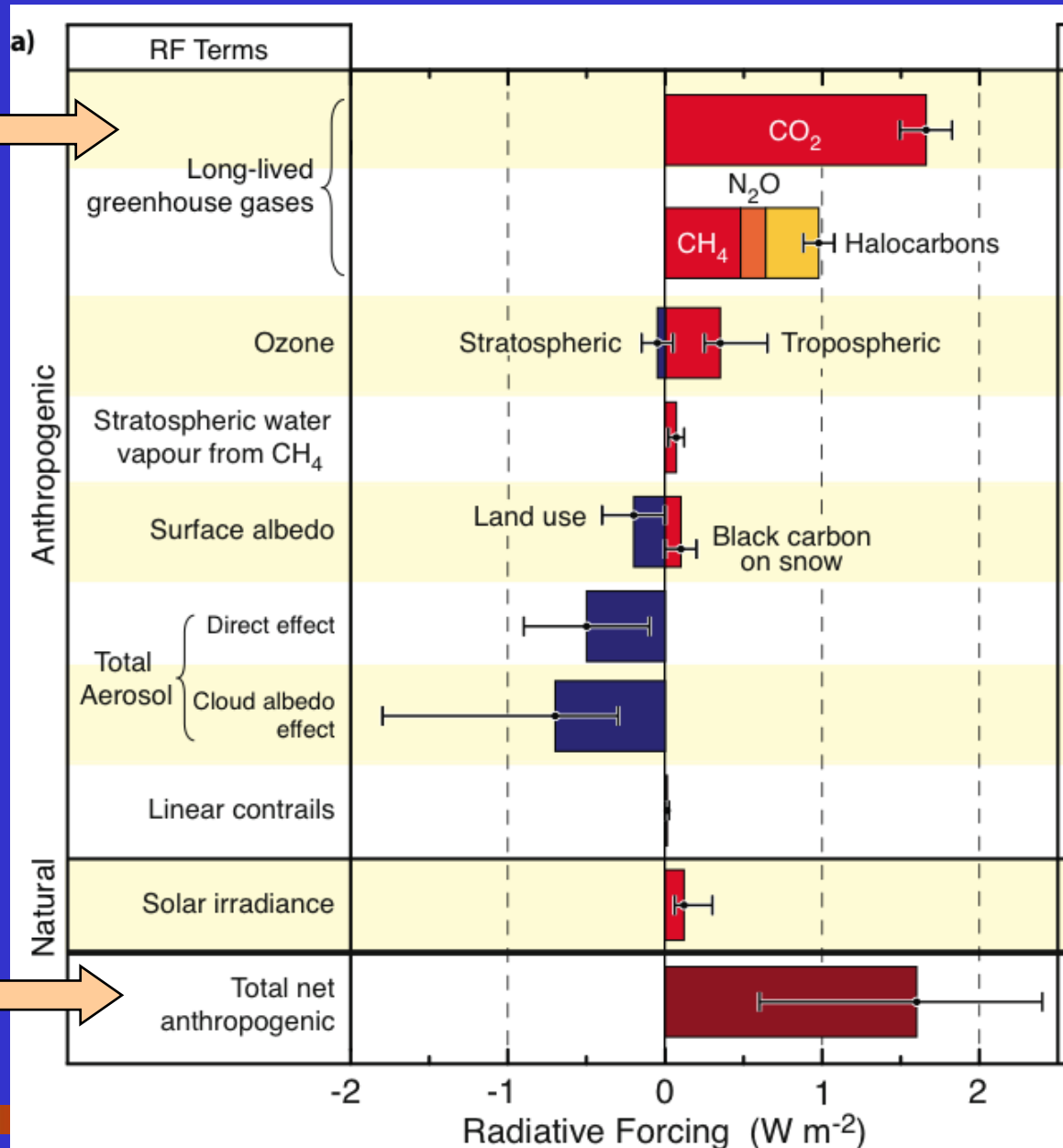
- ... the best estimate of climate sensitivity to a CO<sub>2</sub> doubling is a warming of 3°C, with a likely range of 2 to 4.5°C.
- ... “business as usual” scenarios lead to CO<sub>2</sub> doubling over pre-industrial levels between 2050 and 2100.

# Comparing different drivers of change

Increased by 20%  
over 1995 - 2005

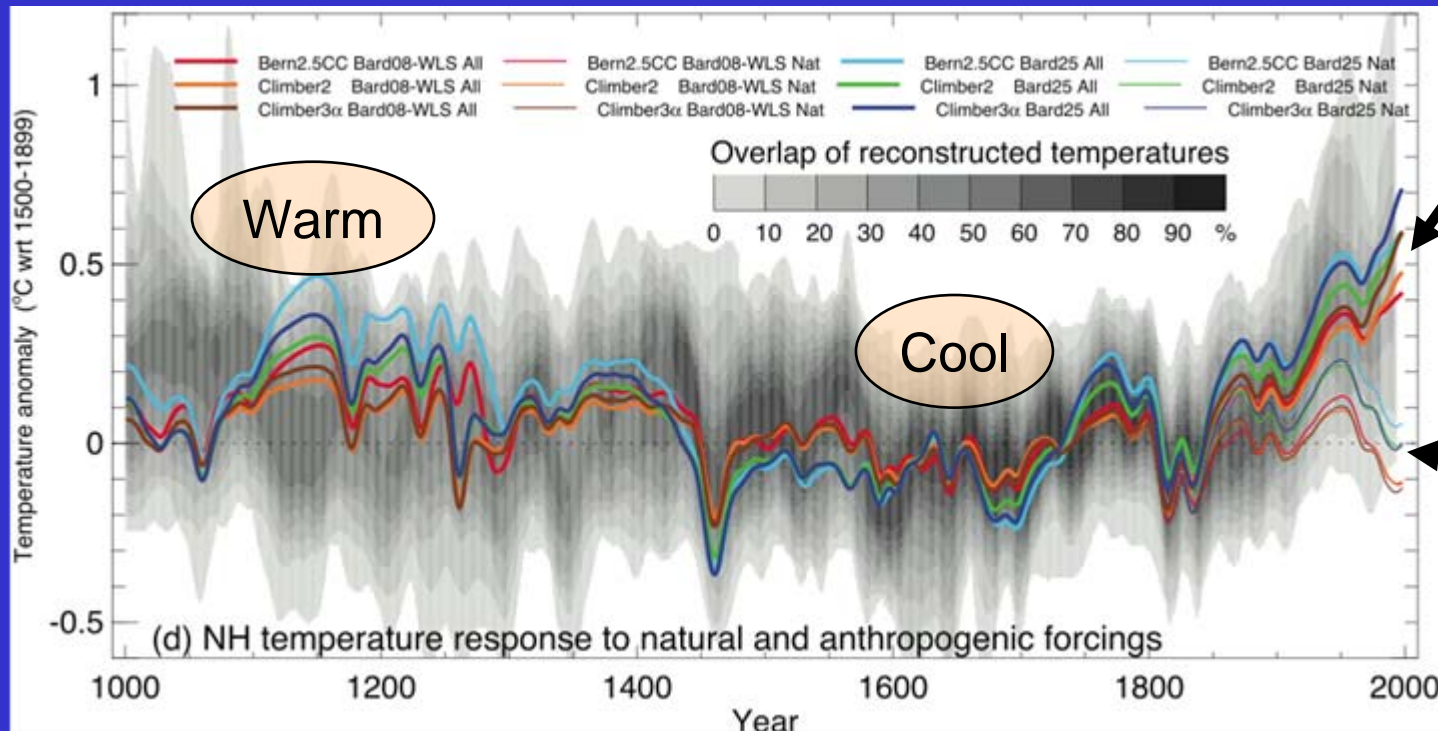
Radiative forcing:  
measures the change  
in the Earth's energy  
balance due to different  
causes of climate  
change.

Equivalent to about 50  
times world primary  
energy production.





# Climate models track much of past temperature change

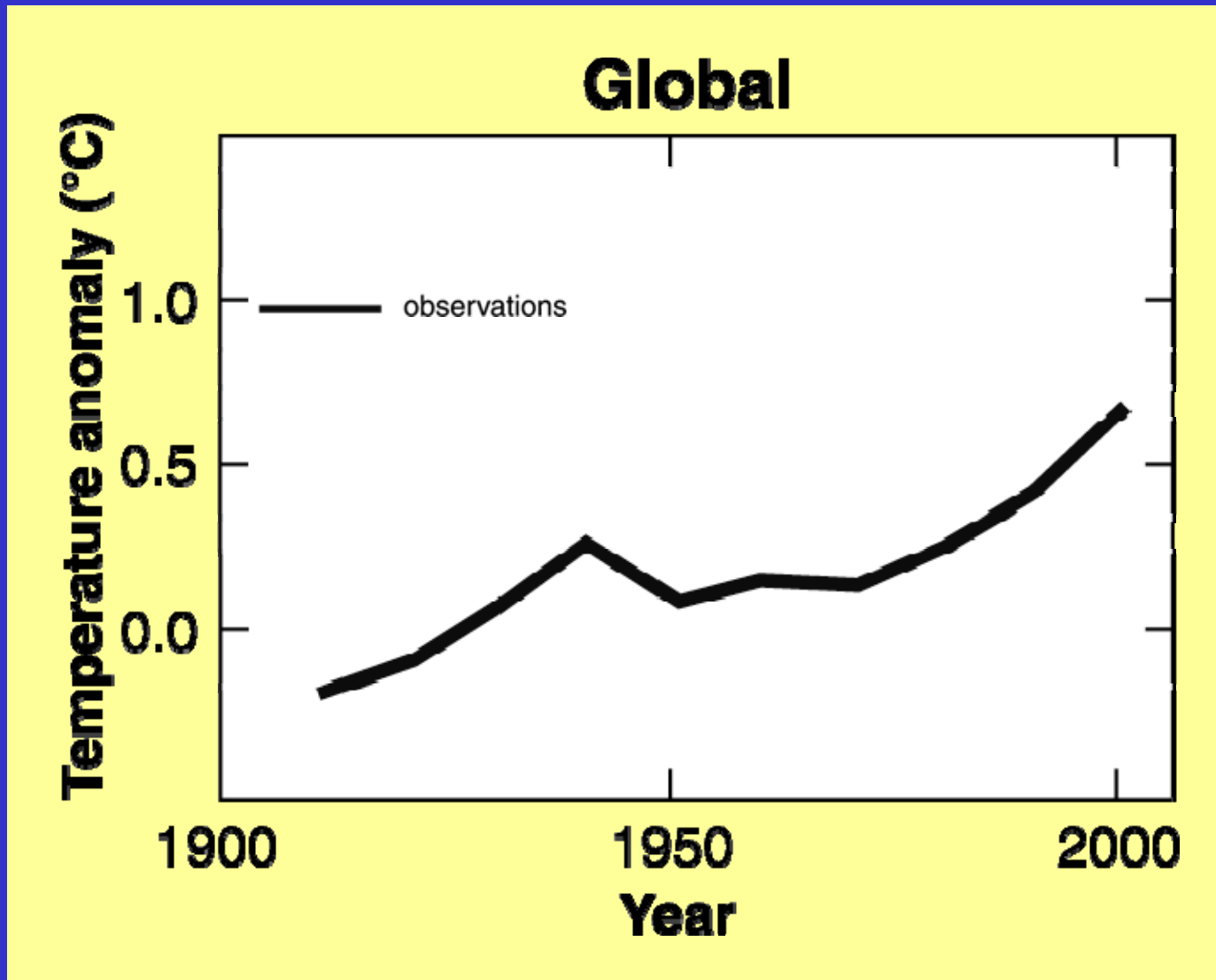


Thick lines include increasing greenhouse gases

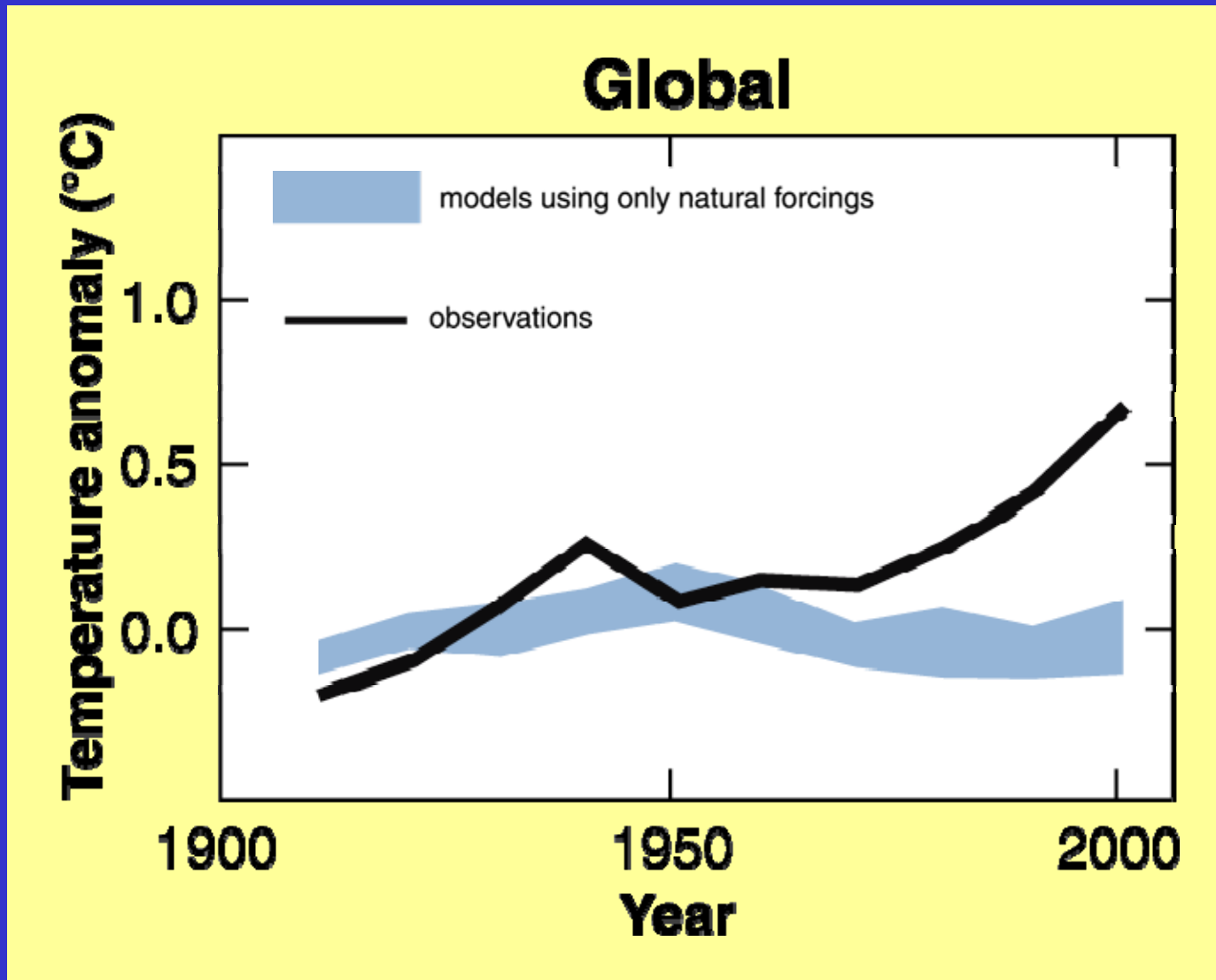
Thin lines do not

While there is uncertainty in reconstructed temperatures for the past, models using best estimates of solar change and volcanic eruptions reproduce warm and cool periods for which there is broad evidence.

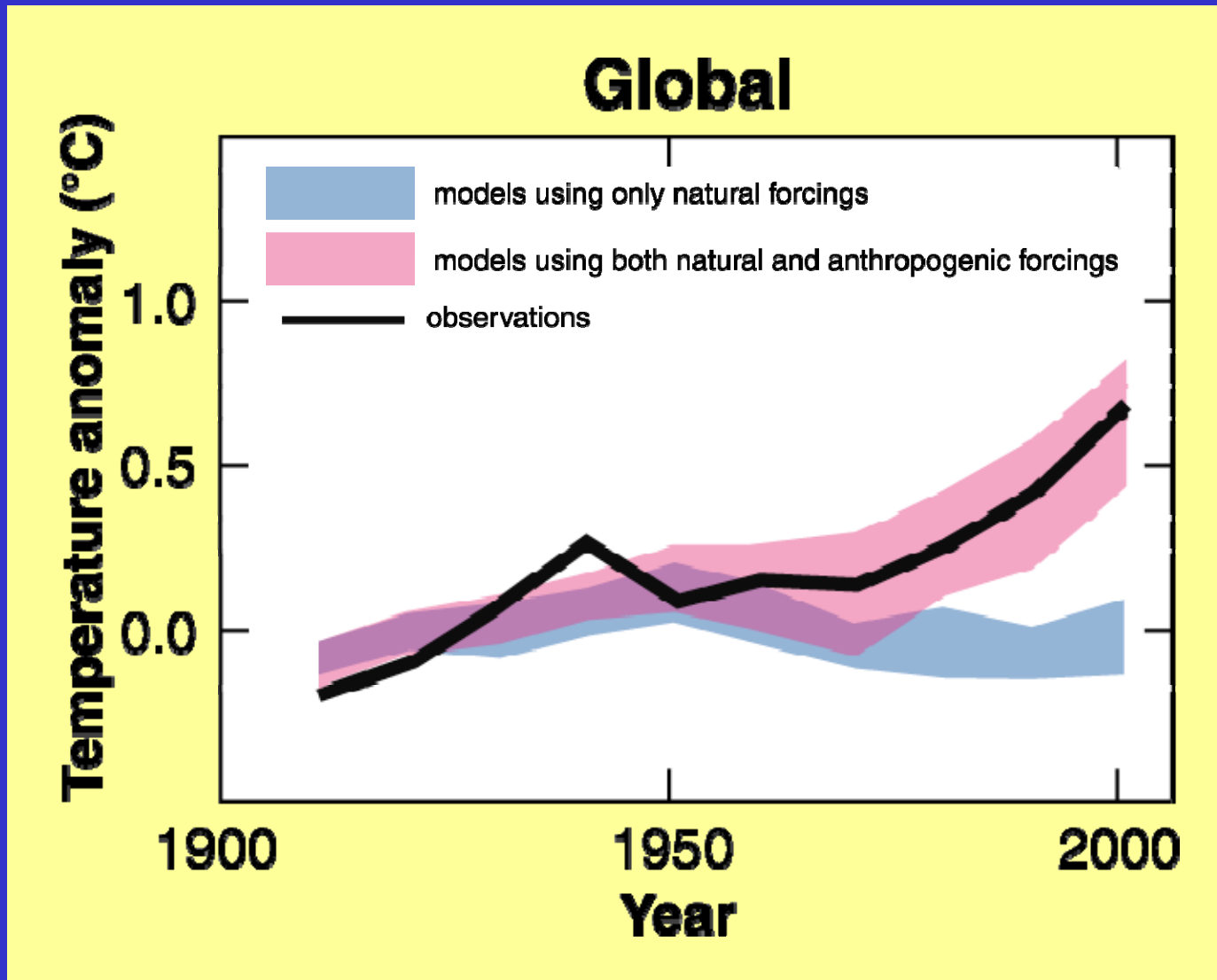
# Recent warming is due to greenhouse gases



# Recent warming is due to greenhouse gases

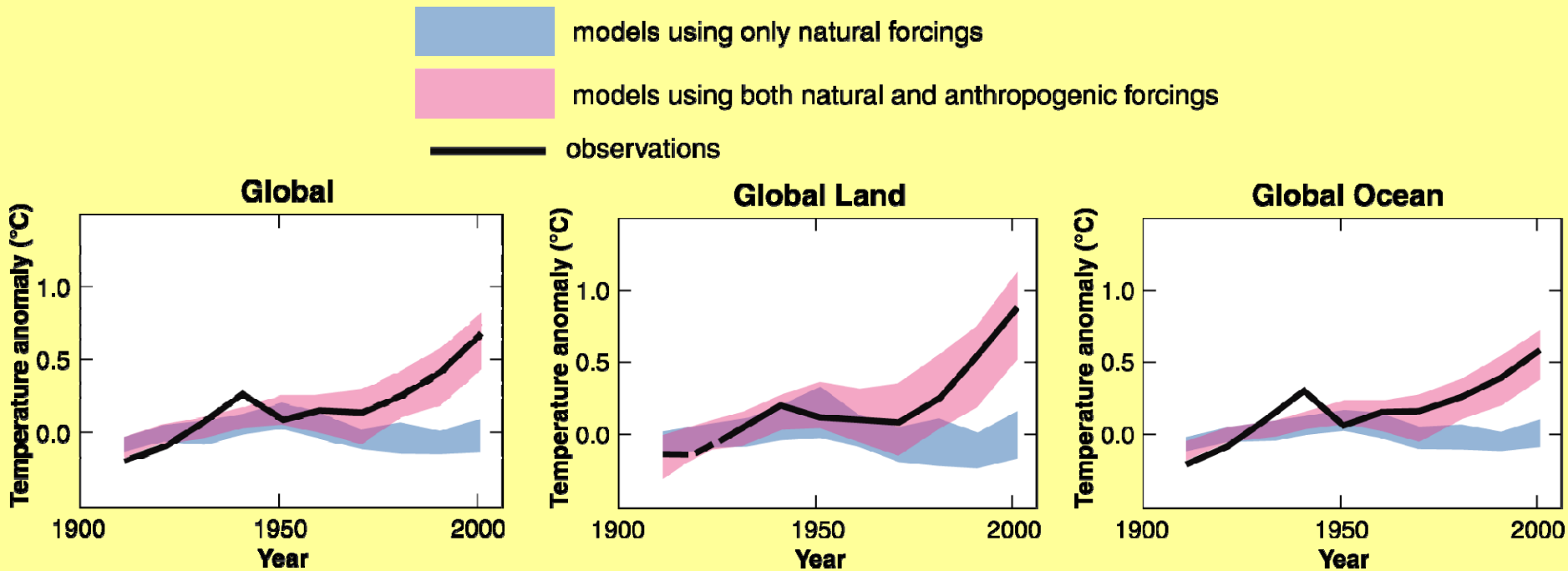


# Recent warming is due to greenhouse gases



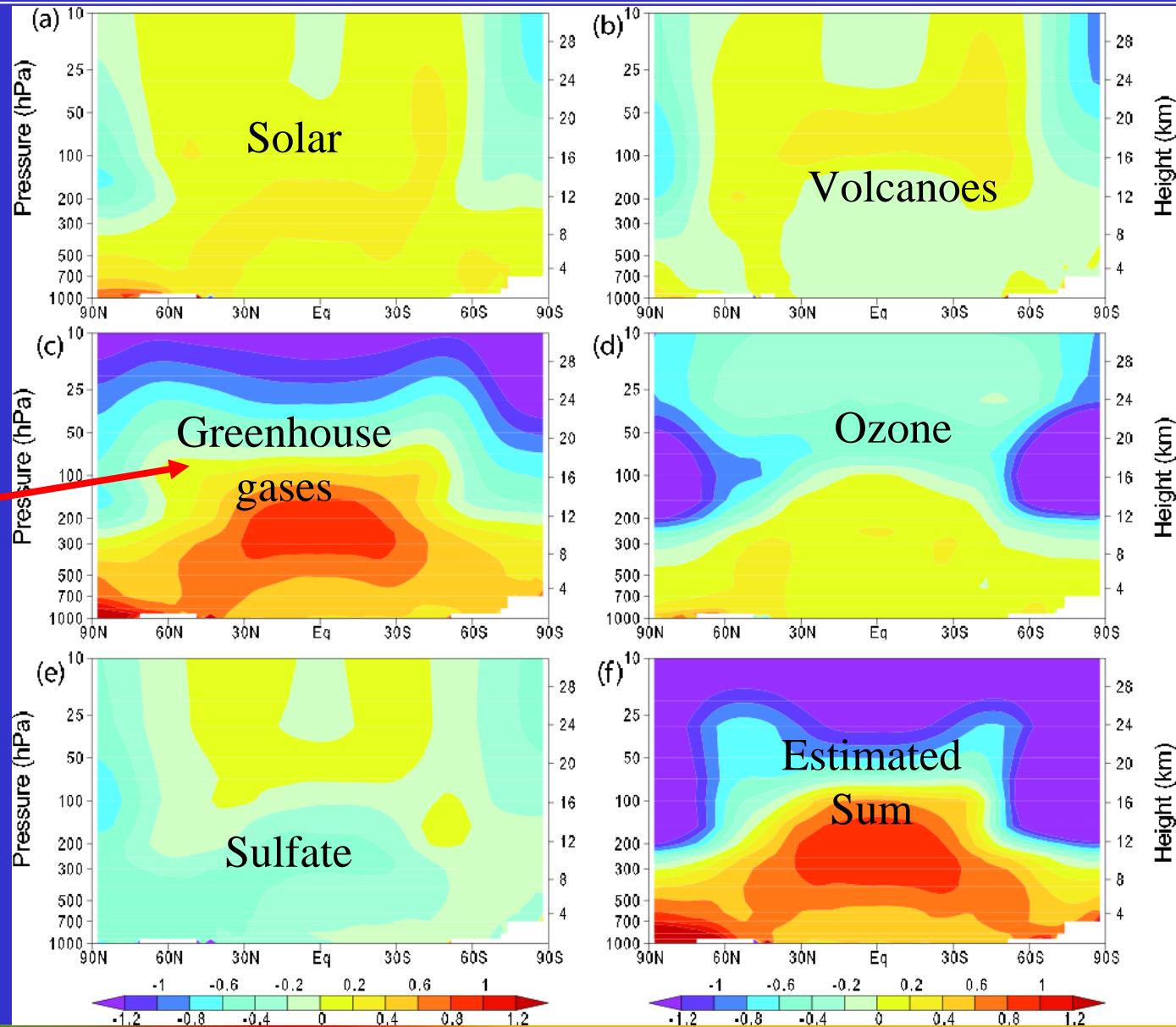
# Recent warming is due to greenhouse gases

Warming due to greenhouse gases explains many observed features – such as the land warming faster than the oceans



# Different causes - different fingerprints

We can not explain the observed distribution of warming without this component.





# Identifying cause and effect

**“Most of the observed increase in global average temperatures since the mid-20th century is *very likely*\* due to the observed increase in anthropogenic greenhouse gas concentrations.”**

\* *Very likely* means an assessed likelihood of being correct greater than 90%

# Scenarios used

Based on pre-2000 literature

No additional climate change policy (i.e. no mitigation)

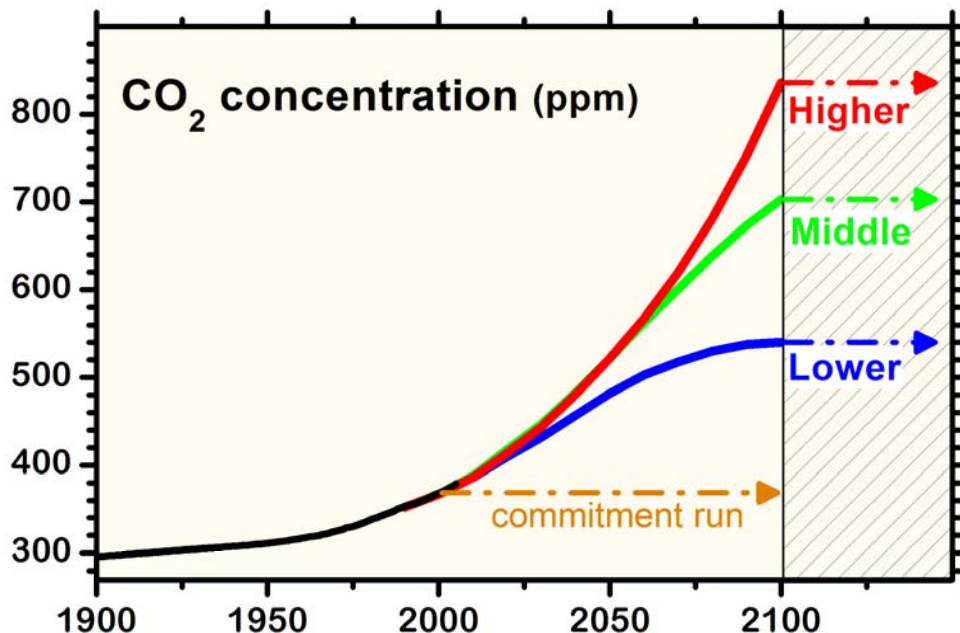
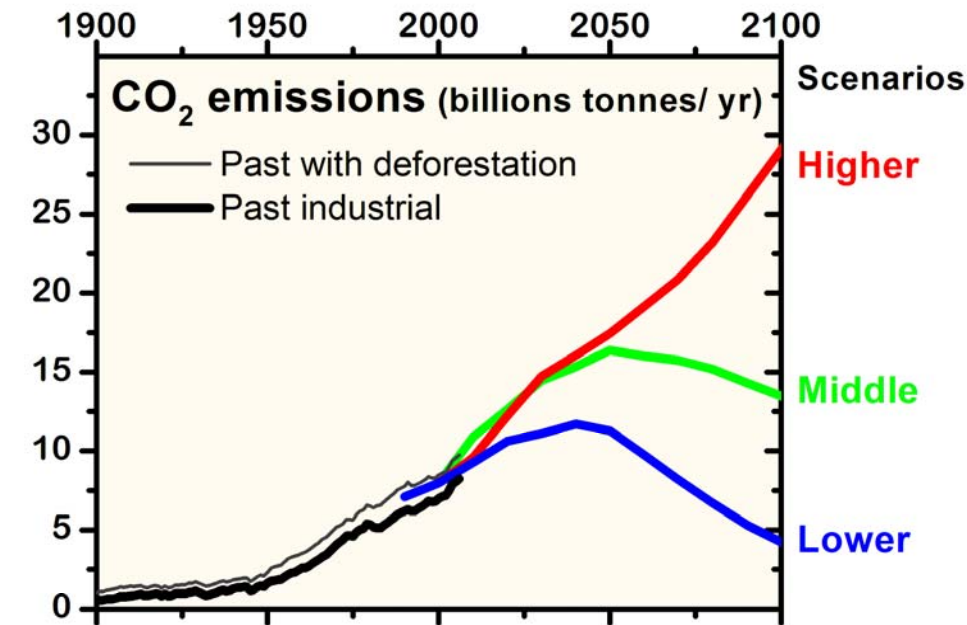
Lower, Middle, and Higher emission scenarios.

“Physics tests” kept atmospheric composition constant.

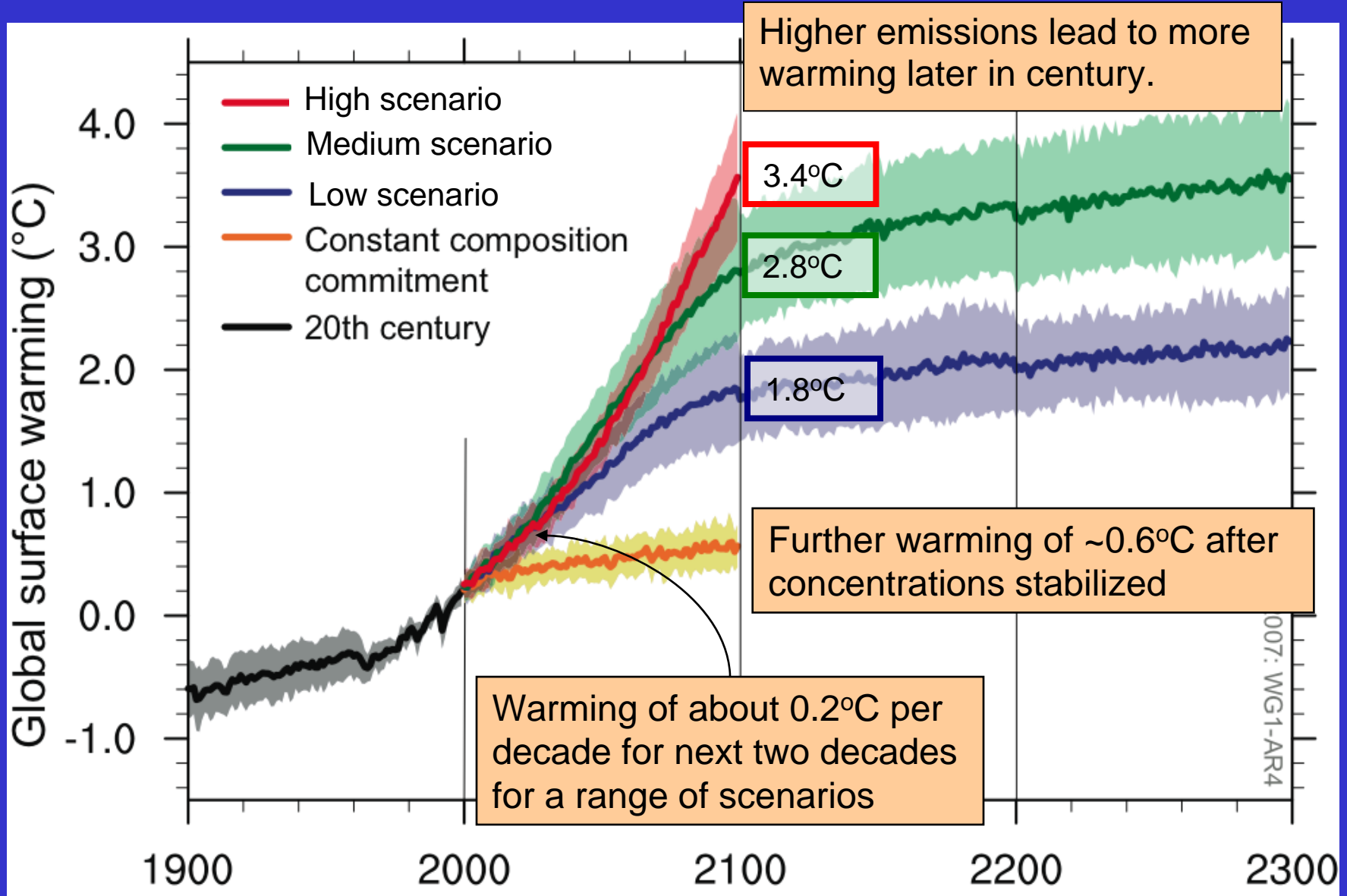
Compare doing so in 2100 vs doing so in 2000.

Results from

- 14 modelling groups
- 23 models



# Projected global average warming



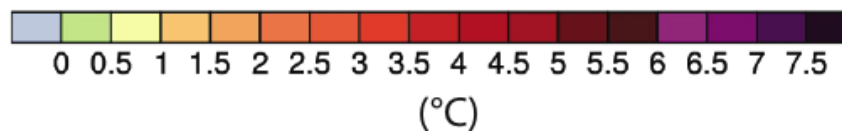
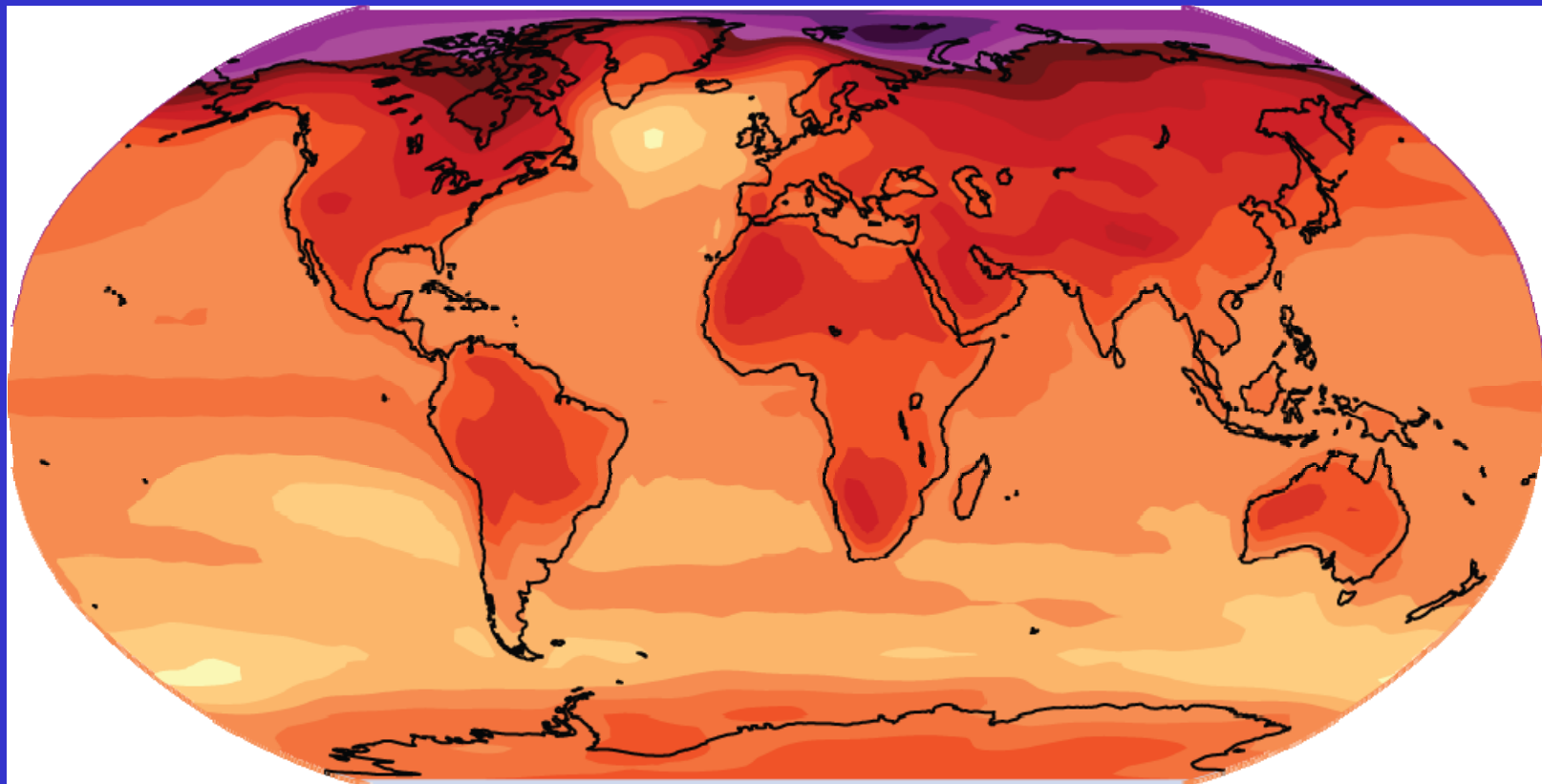
# No one lives at the global average

Medium (A1B) scenario (2090-2099): Global mean warming 2.8°C;

Much of land area warms by ~3.5°C

Arctic warms by ~6°C.

A 550 ppm CO<sub>2</sub>-eq world would *more likely than not* be warmer.



# Projected precipitation change

Underlying physics of precipitation change is better understood.

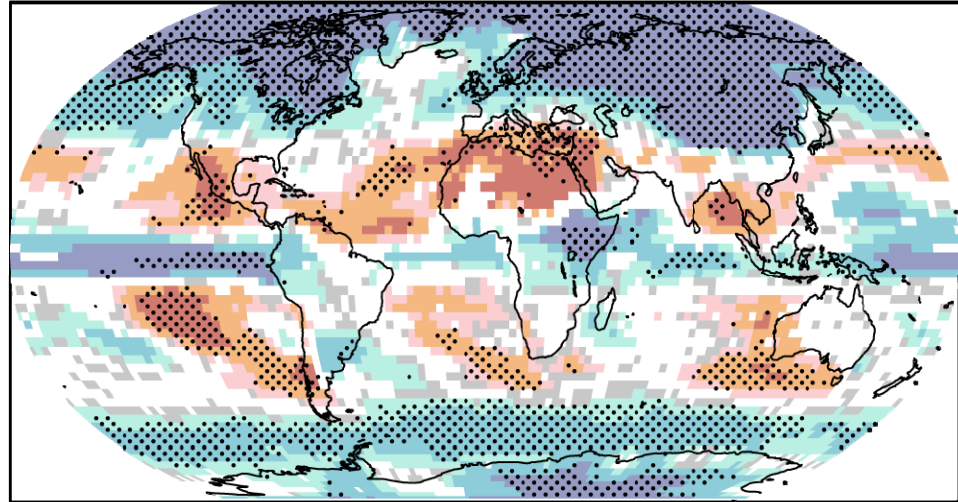
Pattern is:  
increases in tropics  
and high latitudes;  
decreases in  
sub-tropics.

Consistent with  
observed trends.

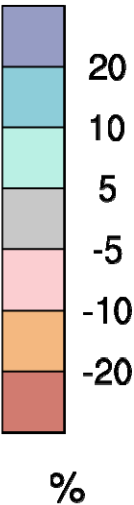
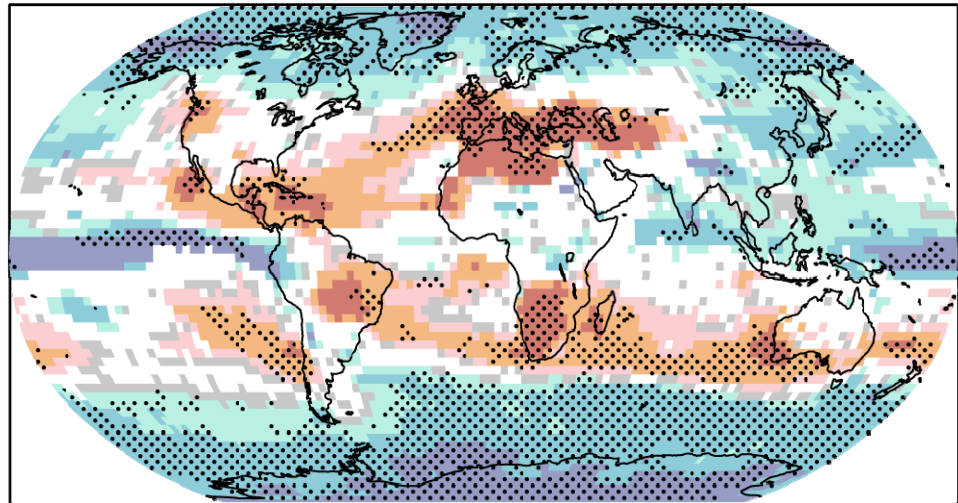
Multi-model mean change  
shown where >66% of models  
agree in sign; >90% of  
models agree in stippled areas.

Projected percent change in precipitation  
in 2090-2099 (Medium scenario)

DJF



JJA

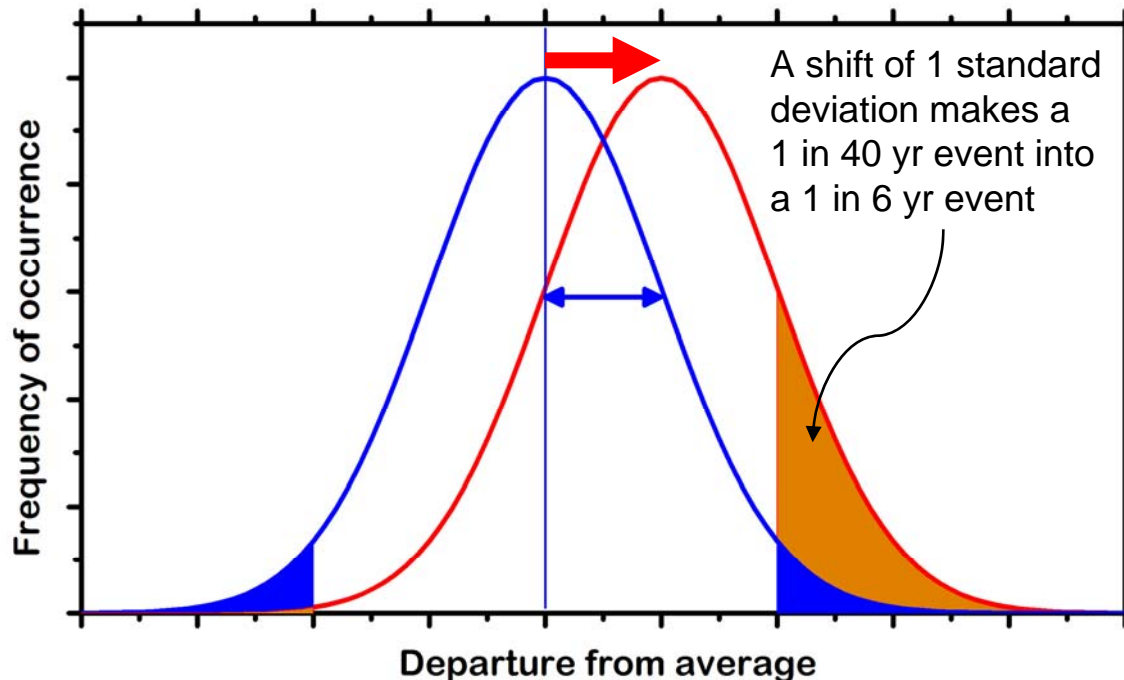


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# Calculus of extremes

The distribution of weather events around the climatic average follows a 'bell-shaped' curve.

Climate change can involve change in the average, or the spread around the average (standard deviation), or both.



A shift in the distribution of temperatures has a much larger relative effect at the extremes than near the mean.



# Extremes will increase

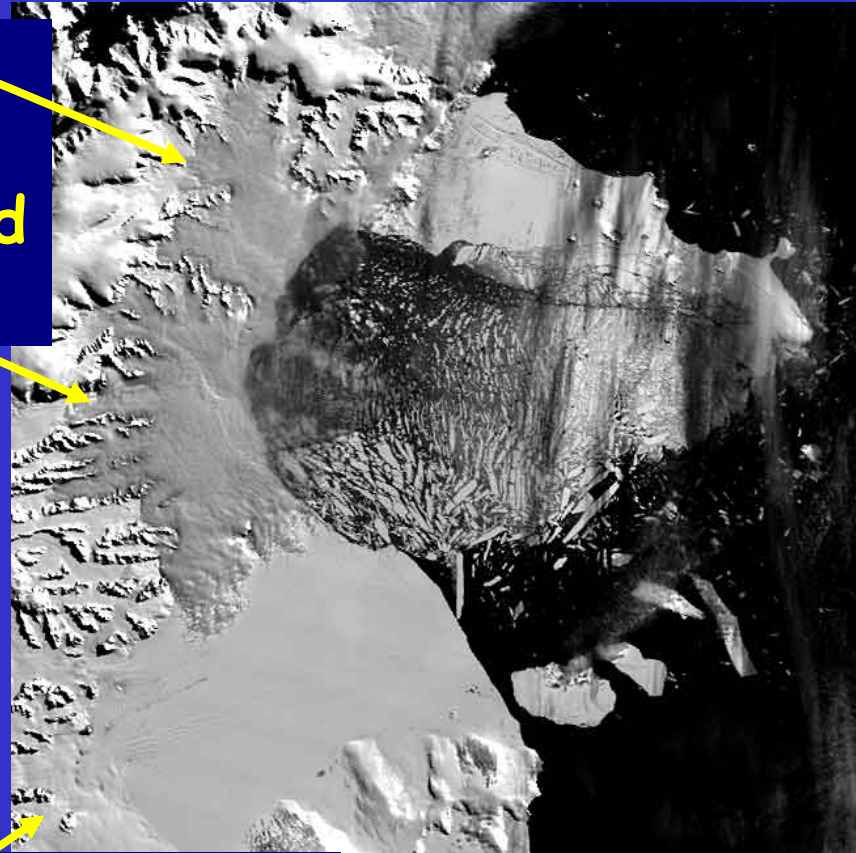
- Projected increases in heavy precipitation and drought are linked to physical processes – principally increased absolute humidity and patterns of convergence and divergence in atmospheric transport.
- Precipitation intensity increases - even where total precipitation decreases.
- Risk of 2003 type heat wave doubled in Europe due to current level of greenhouse gases (single study).
- Extreme summer temperatures become at least 20 times more frequent by end of century (average for 3 scenarios and for multiple models).

# Ice shelves influence glacier flow

The break up of the **Larsen B ice shelf** off the Antarctic Peninsula in February 2002 is illustrative of the speed up of glaciers after the blocking of the ice shelf is removed.

Other examples, such as **Jakobshavn Glacier (Greenland)**, show speed up in flow after collapse of the floating glacier tongue.

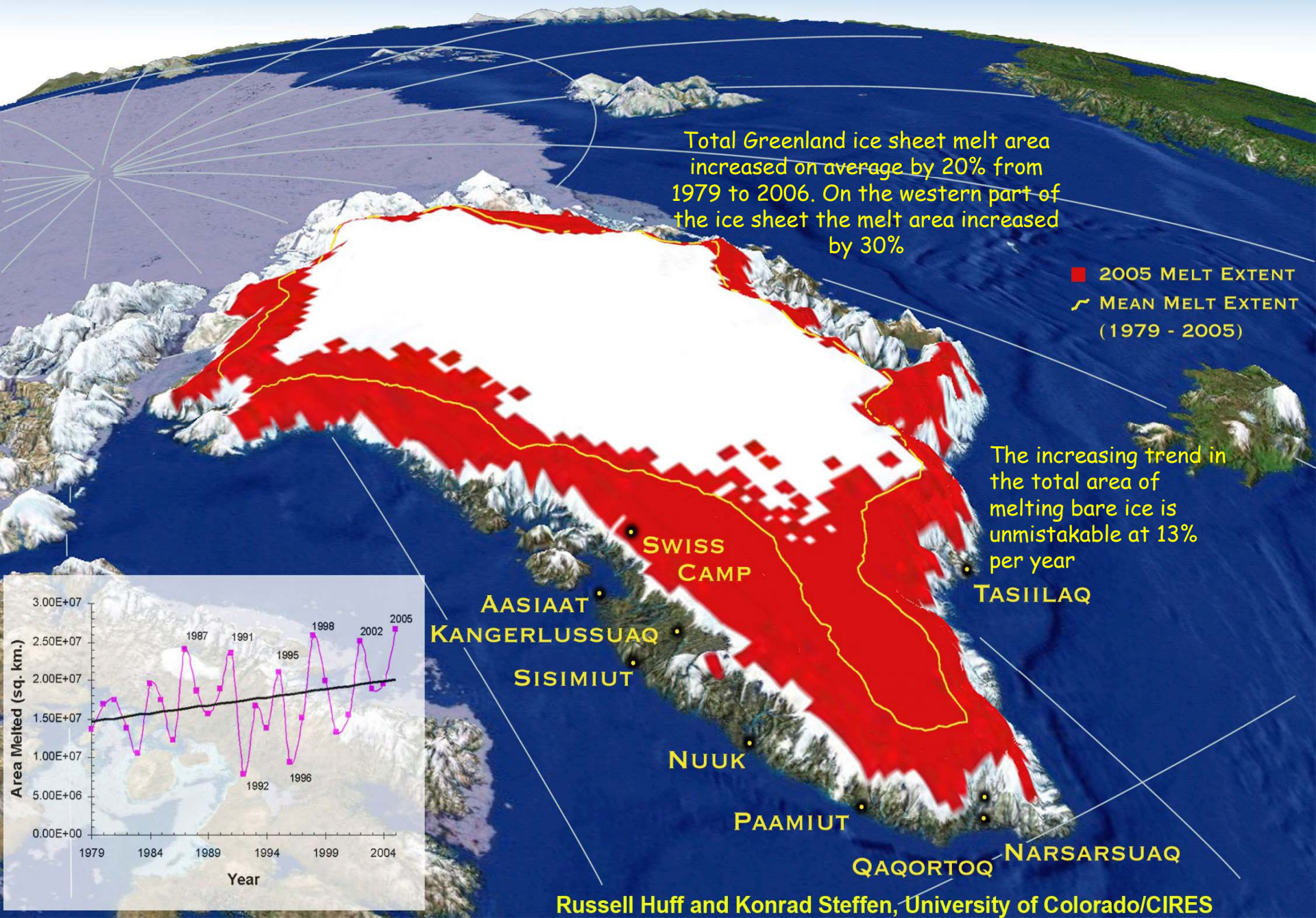
**Glaciers lost ice shelf and sped up**



**Glacier still has ice shelf and did not speed up**



# GREENLAND 2005 MELT EXTENT





# Sea level rise - limits to knowledge

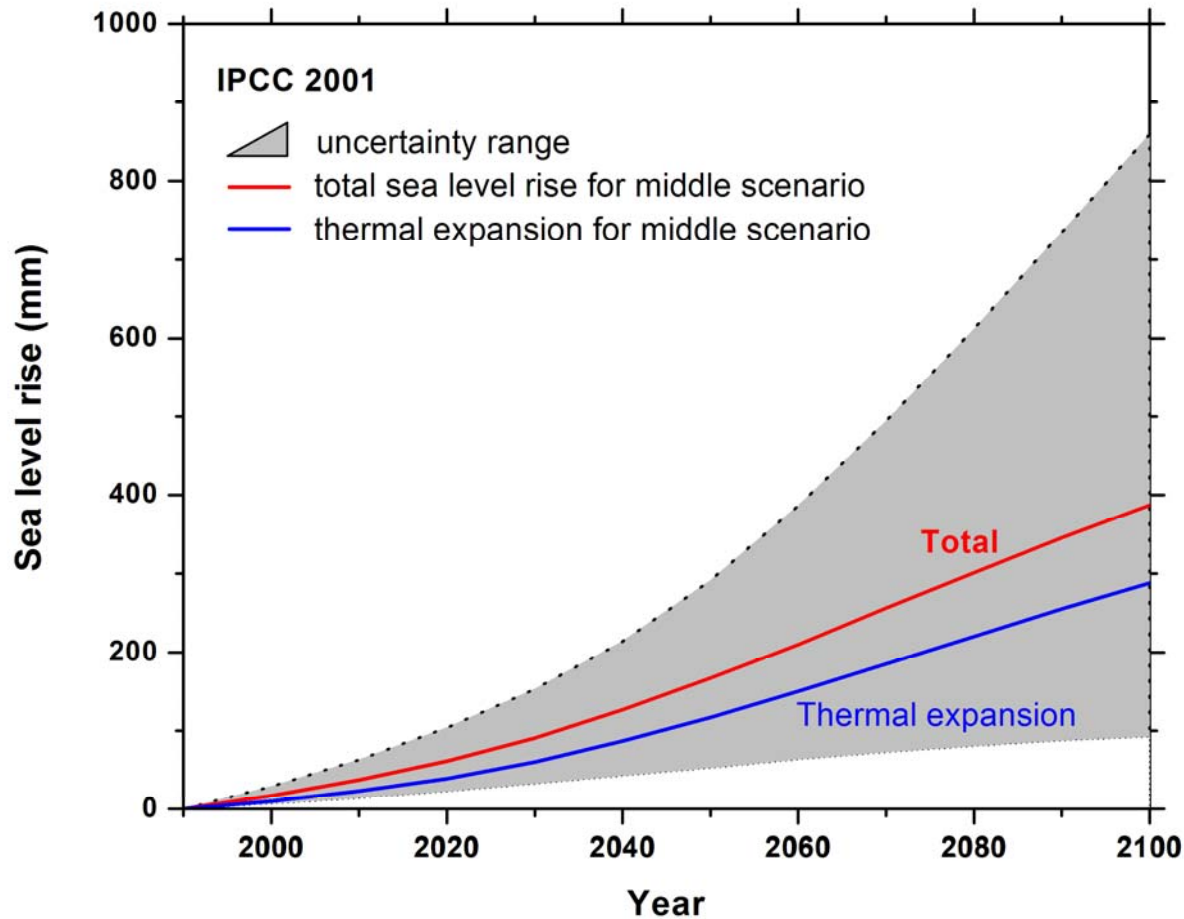
In the last 5 years seeing new ice sheet phenomena that may significantly affect ice discharge into the ocean.

As yet corresponding processes are not in any ice sheet models.

Surface melt on Greenland ice sheet descending into moulin, a vertical shaft carrying the water to base of ice sheet.  
Photo credit: Roger Braithwaite

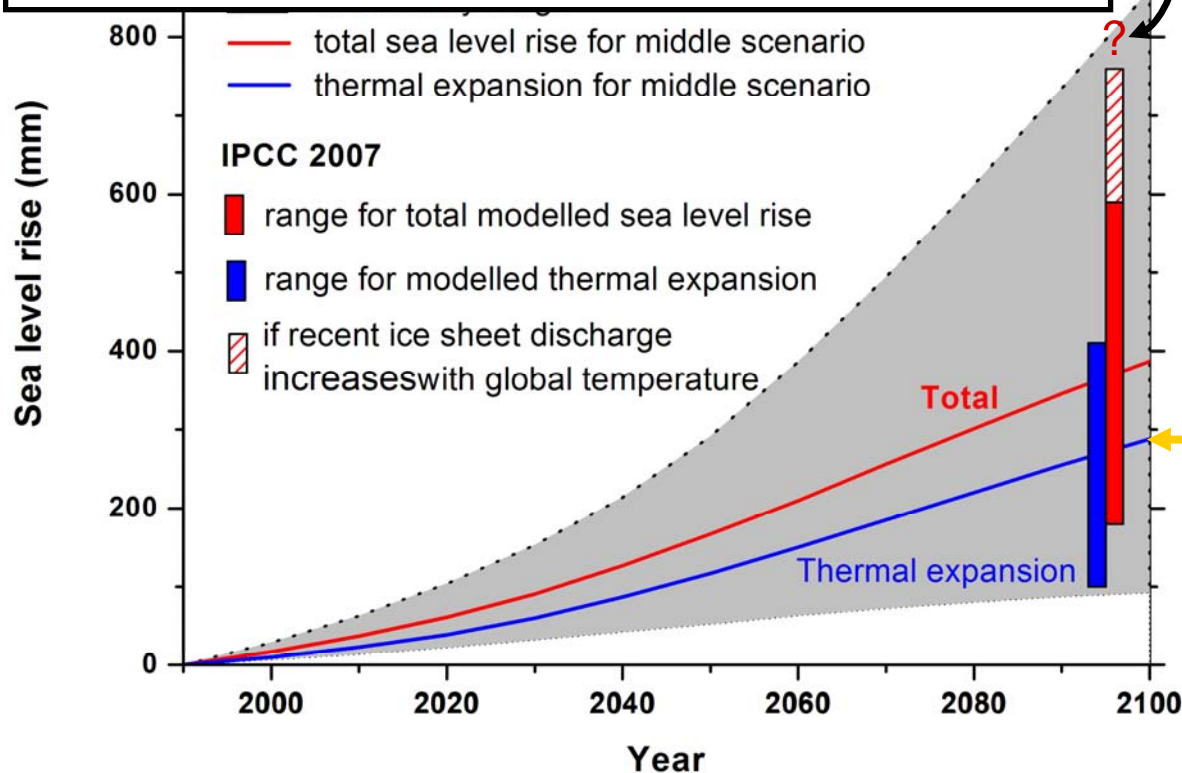


# IPCC assessments of sea level rise



# IPCC assessments of sea level rise

*Larger values cannot be excluded, but understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise.*

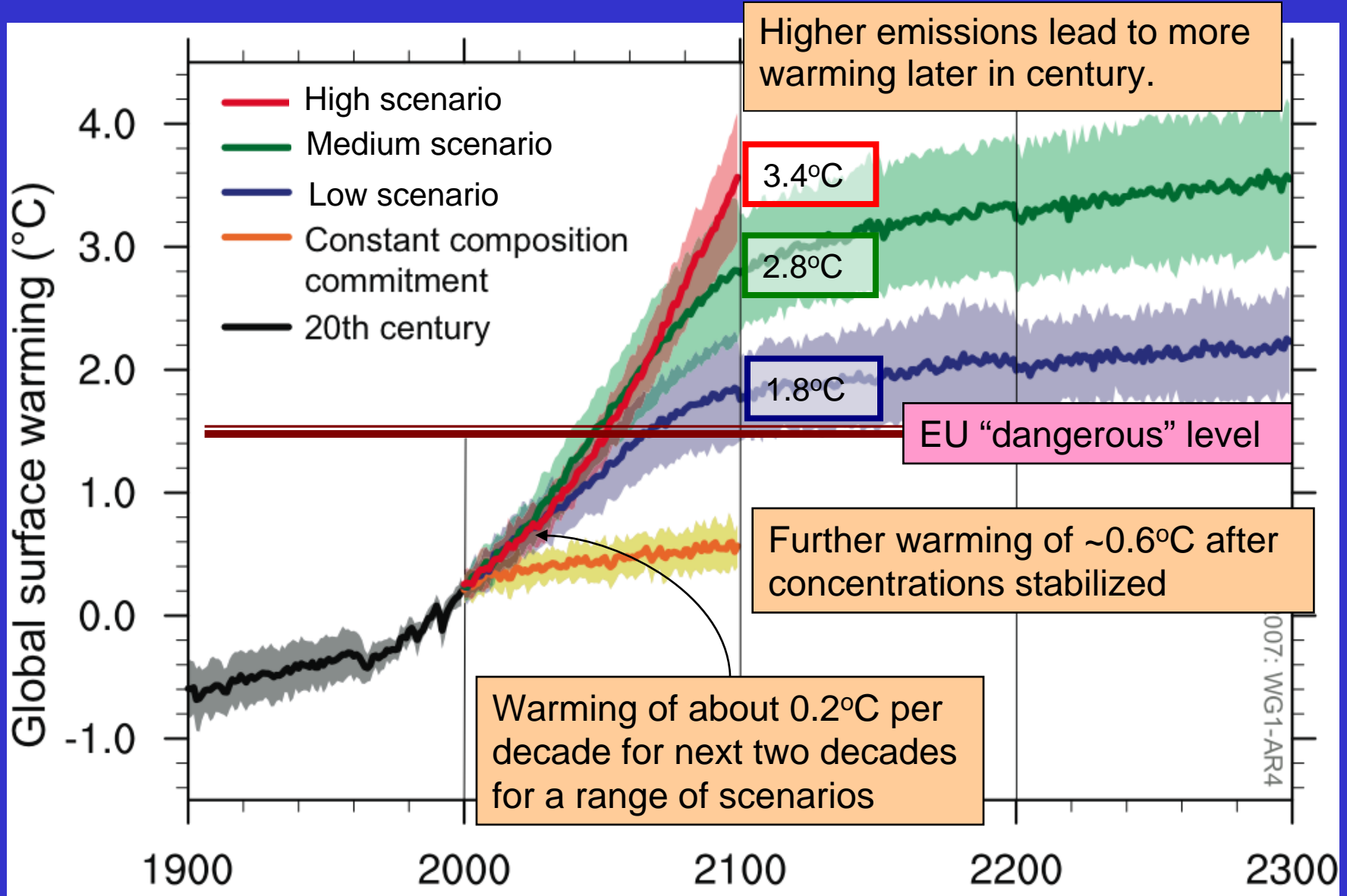


The last time polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 m of sea level rise.

Thermal expansion continues for many centuries.



# Projected global average warming



# Summary

Evidence for warming of the climate system is now unequivocal.

In the 21<sup>st</sup> century, Earth's climate will be different from anything experienced during human civilization.

This climate change is different from past natural changes because it is happening faster, because it will affect humans, and because we are doing it.

Reducing carbon emissions to the atmosphere can limit the magnitude of change.