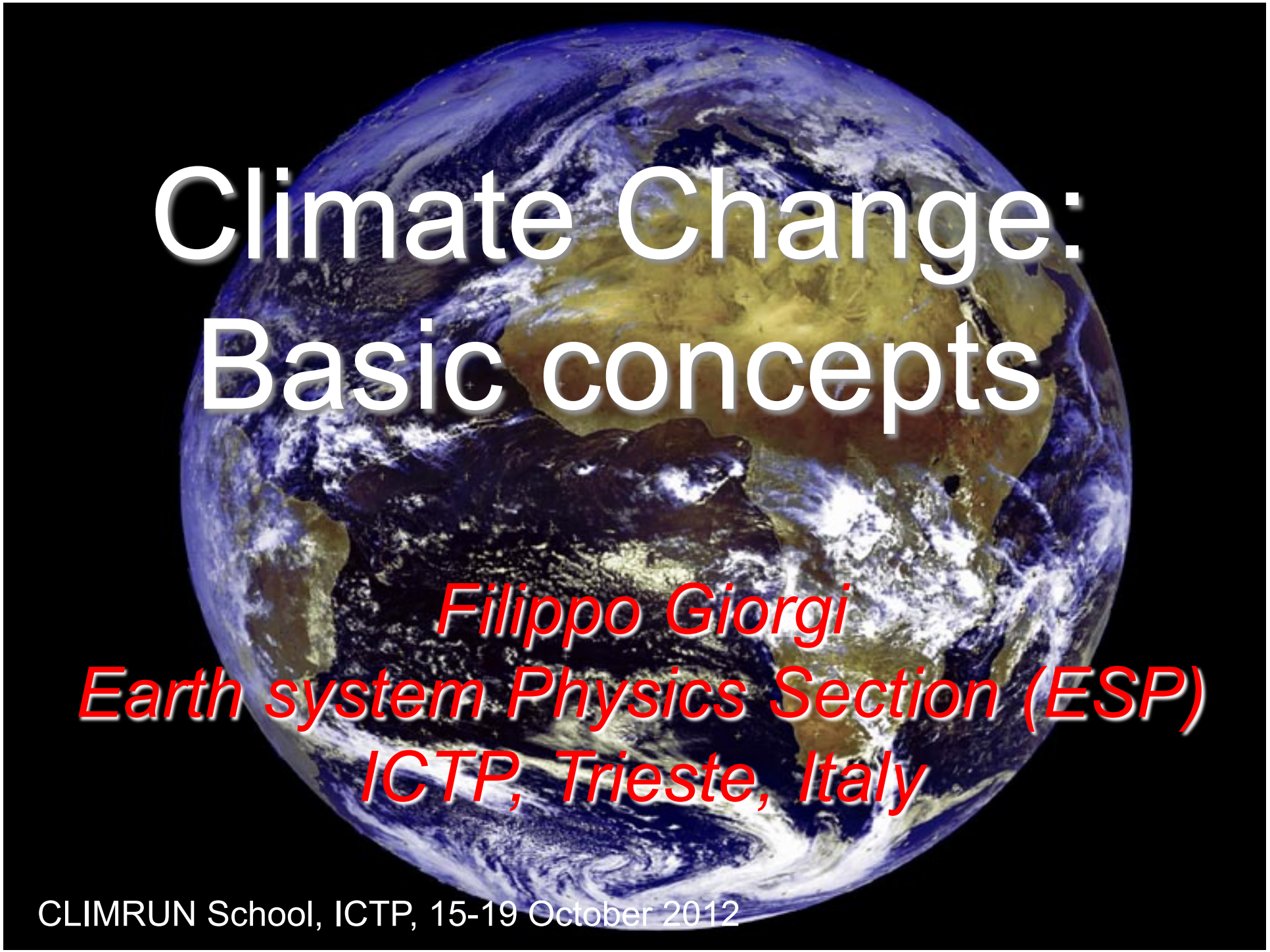

Climate Change: Basic concepts

Filippo Giorgi
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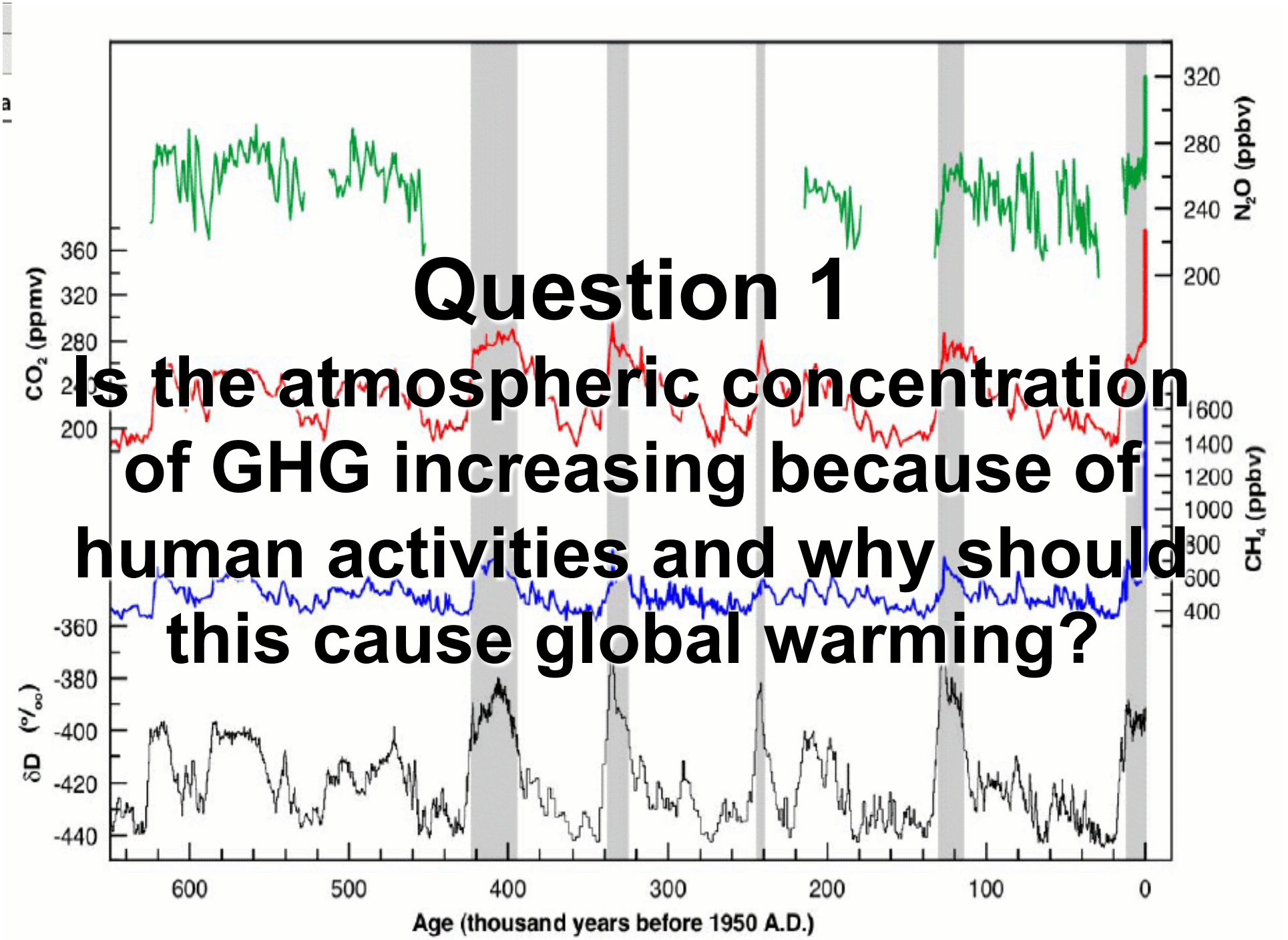
ICTP, Trieste, Italy

CLIMRUN School, ICTP, 15-19 October 2012

Lecture outline: 6 Questions

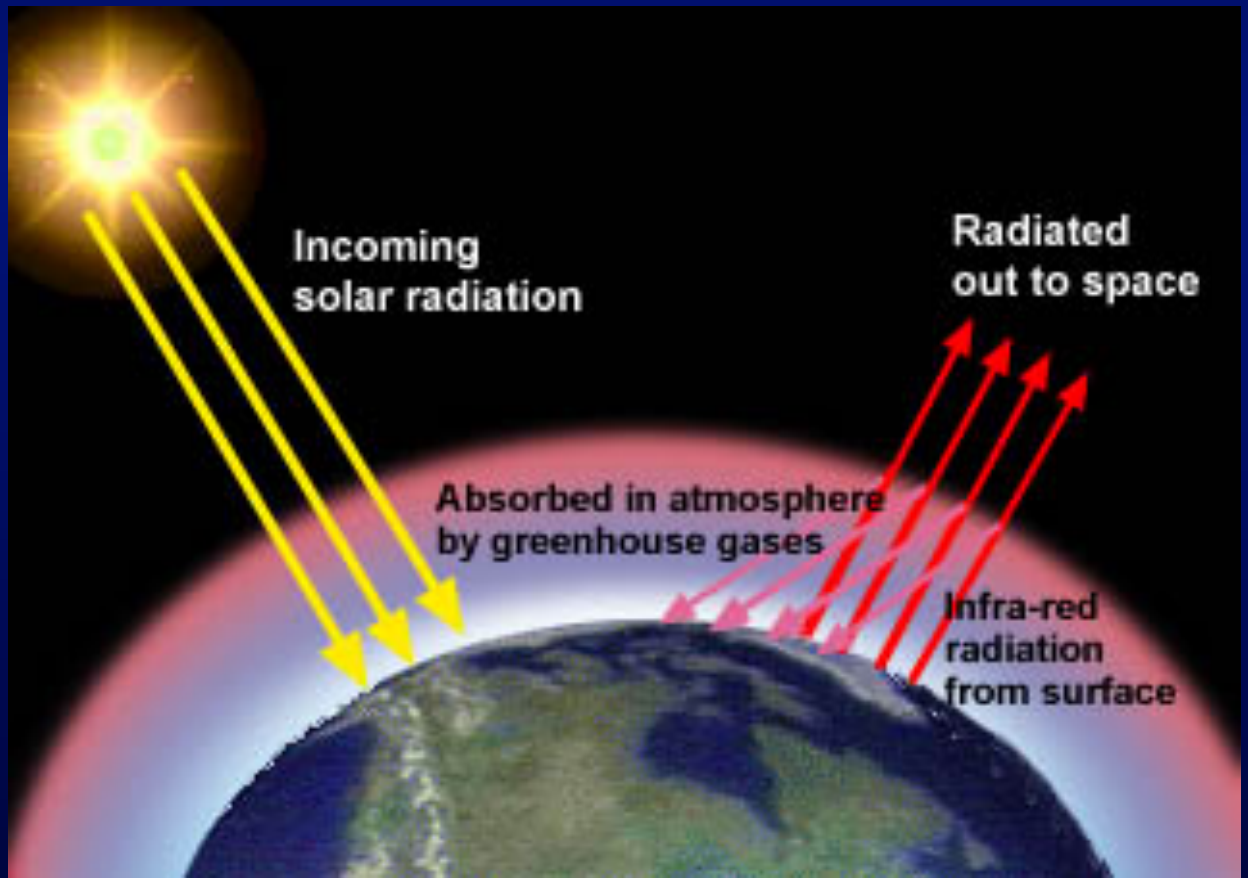
- Is the atmospheric concentration of greenhouse gases (GHG) increasing because of human activities and why should this cause global warming?
- Is global warming (and other related climatic changes) happening?
- Is the observed global warming due to increases in anthropogenic GHG concentrations or to natural factors?
- Are climate models good for anything?
- What can we expect for the future (climate change projections)?
- What are key uncertainties?

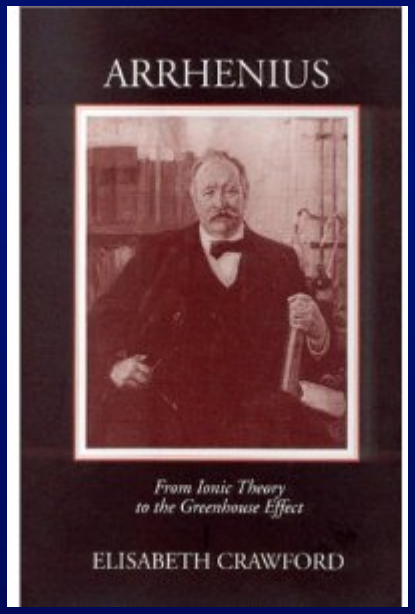

Question 1
Is the atmospheric concentration of GHG increasing because of human activities and why should this cause global warming?
CO2 (ppmv)
360
320
280
200
N2O (ppbv)
320
280
240
200
CH4 (ppbv)
1600
1400
1200
1000
800
600
400
δD (°/oo)
-360
-380
-400
-420
-440
600
500
400
300
200
100
0
Age (thousand years before 1950 A.D.)

The Greenhouse Effect

Greenhouse gases absorb the infrared radiation emitted by the surface of the Earth thereby warming the atmosphere and oceans

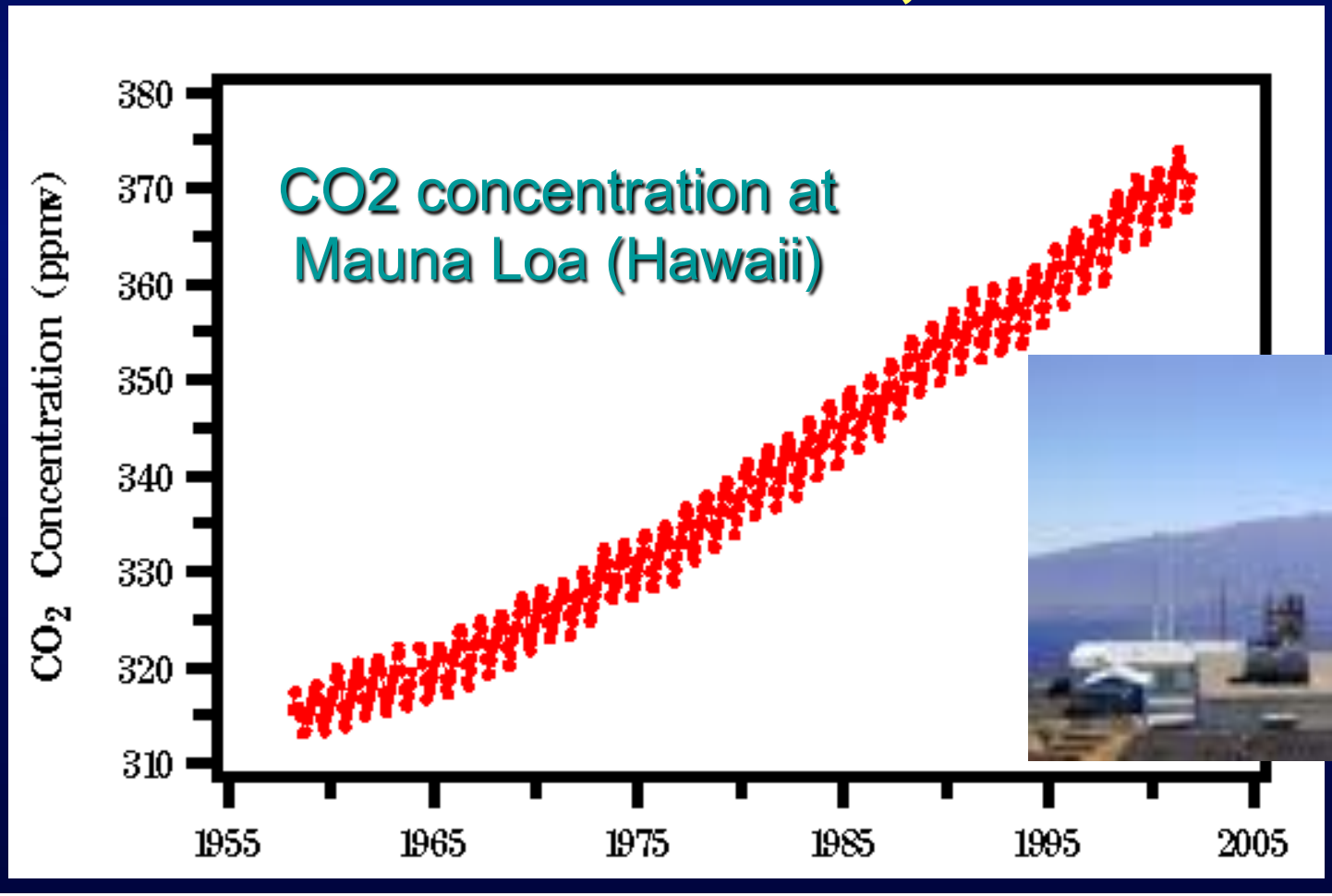
The main GHG are H2O, CO2, O3, CH4,N2O, CFCs





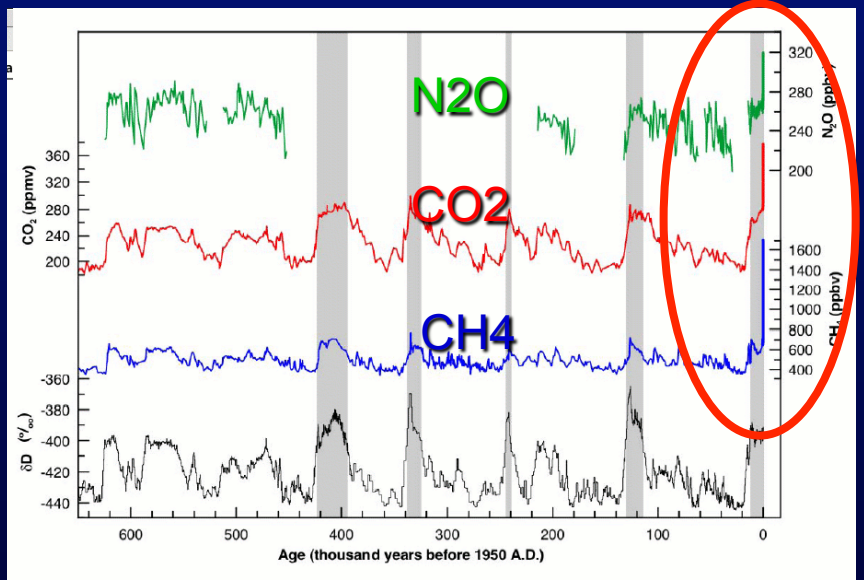
In 1896 Arrhenius estimated that doubling of CO2 would lead to a global warming of 5-6 ° C

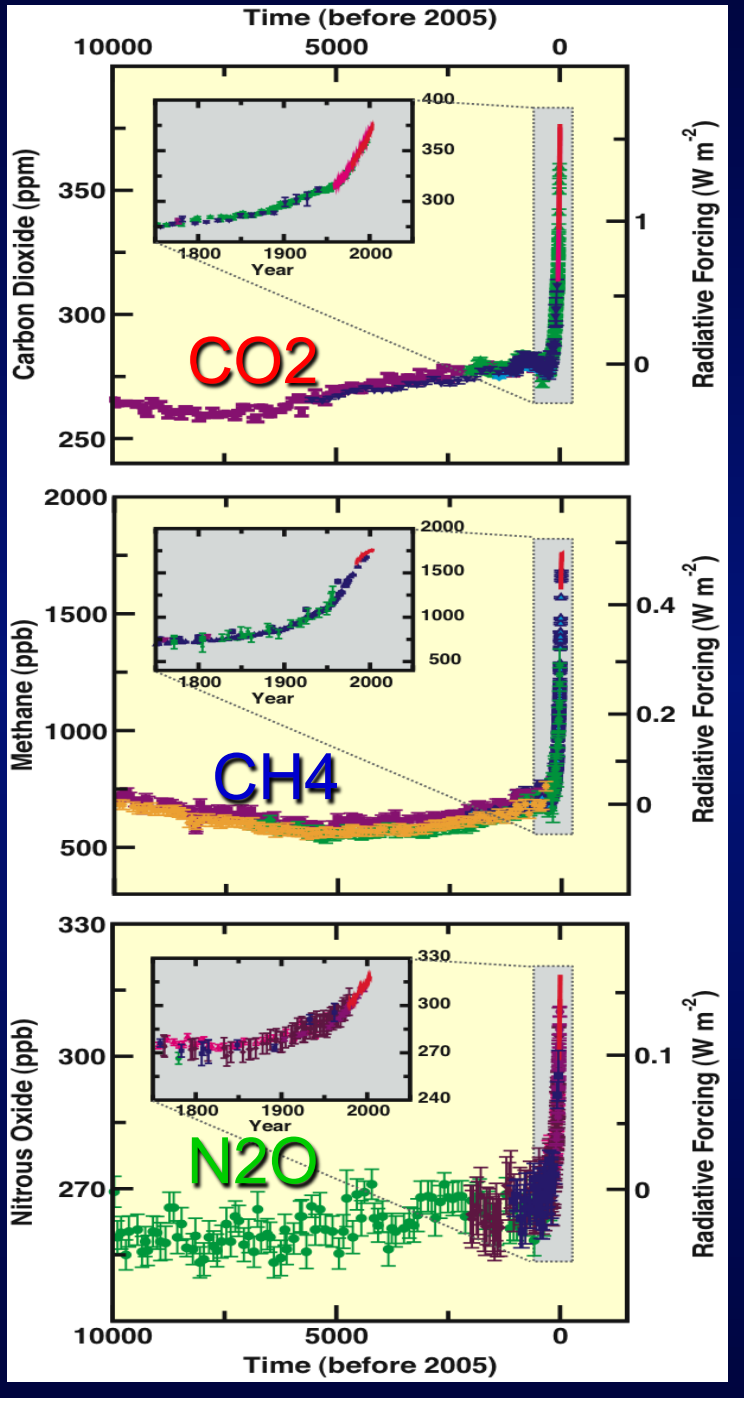
The beginning of the story: C. Keeling's measurements at Mauna Loa, Hawaii



Variation of greenhouse gas concentration in the atmosphere

Trends in the isotopic composition of CO2 and in the ratio of oxygen to nitrogen confirm that the increase in CO2 is mostly from fossil fuel burning





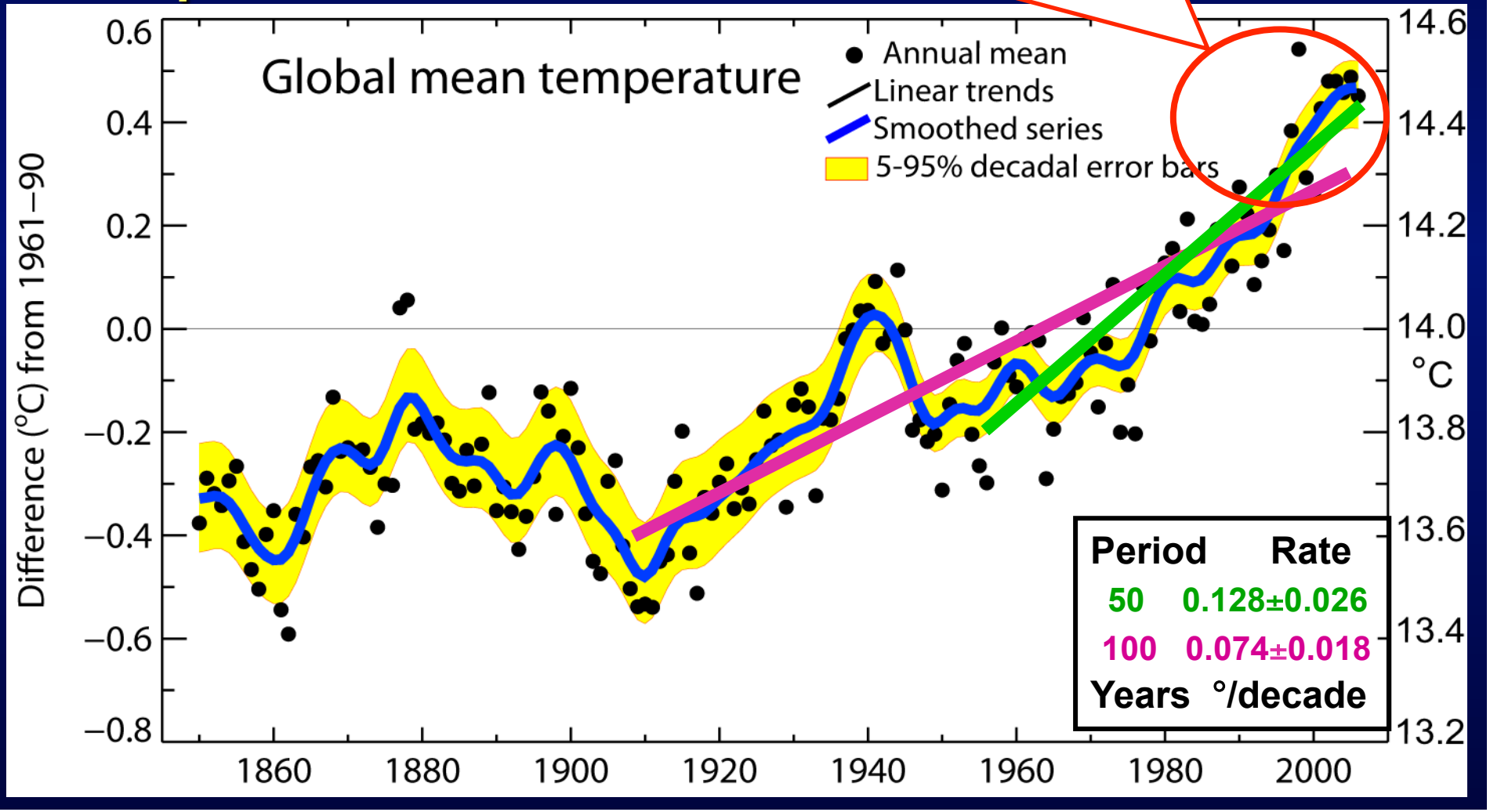
Why does the increase in GHG concentrations cause global warming?

- Direct radiative forcing by the increased GHG amounts (positive) - Greenhouse effect
- Water vapor feedback mechanism (positive)
- Ice-albedo feedback mechanism (positive)
- Carbon feedback mechanism (positive)
- Cloud feedback mechanism (positive or negative)

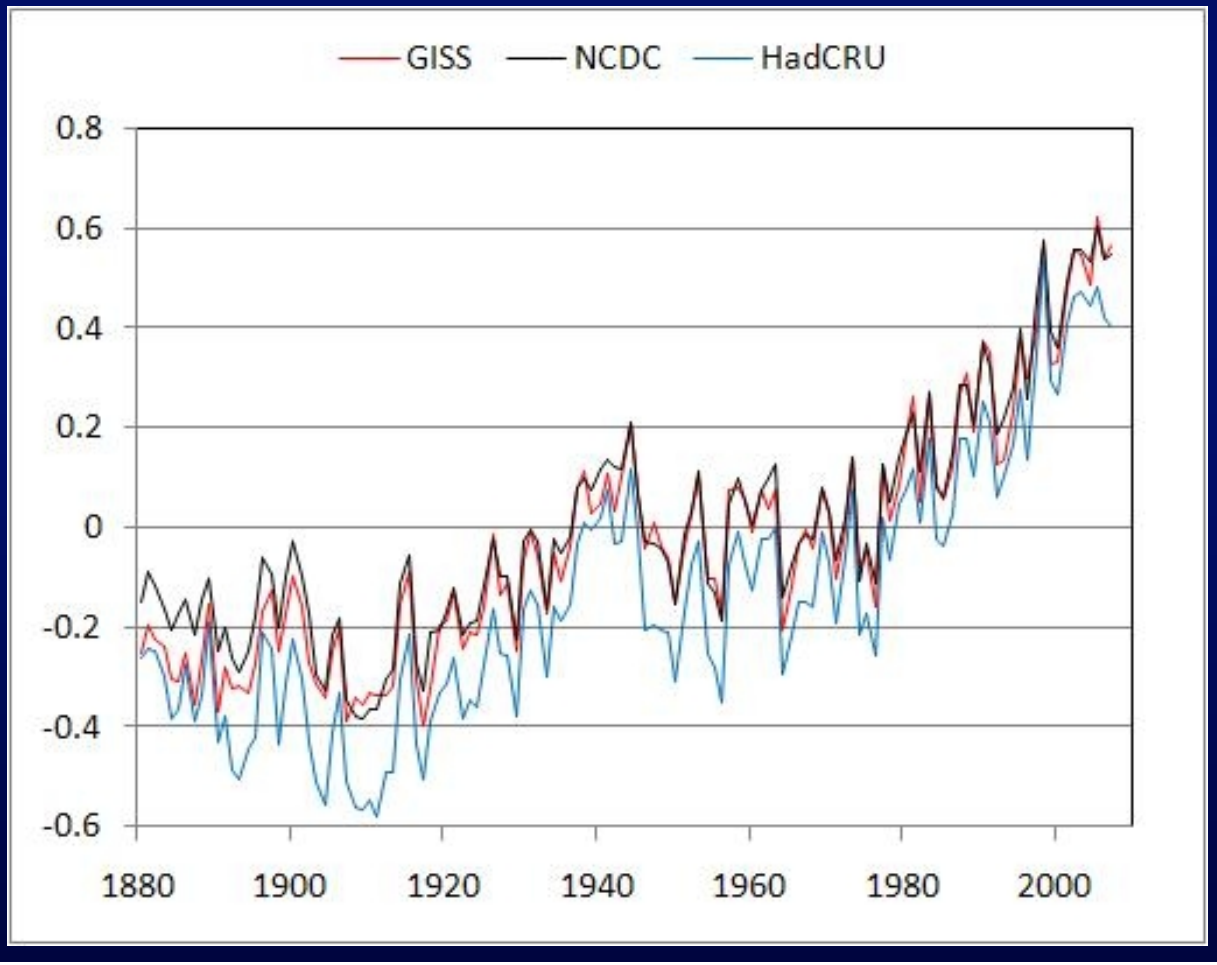

Thursday September 01 07:53:22 AM CDT
sea ice concentration (%)
100
80
60
40
20
0
Question 2:
Is global warming
Happening?
University of Illinois - The Cryosphere Today

Evidence I: Observed change in global surface temperature

Warmest 12 years:
1998, 2005, 2003, 2002, 2004, 2006,
2001, 1997, 1995, 1999, 1990, 2000

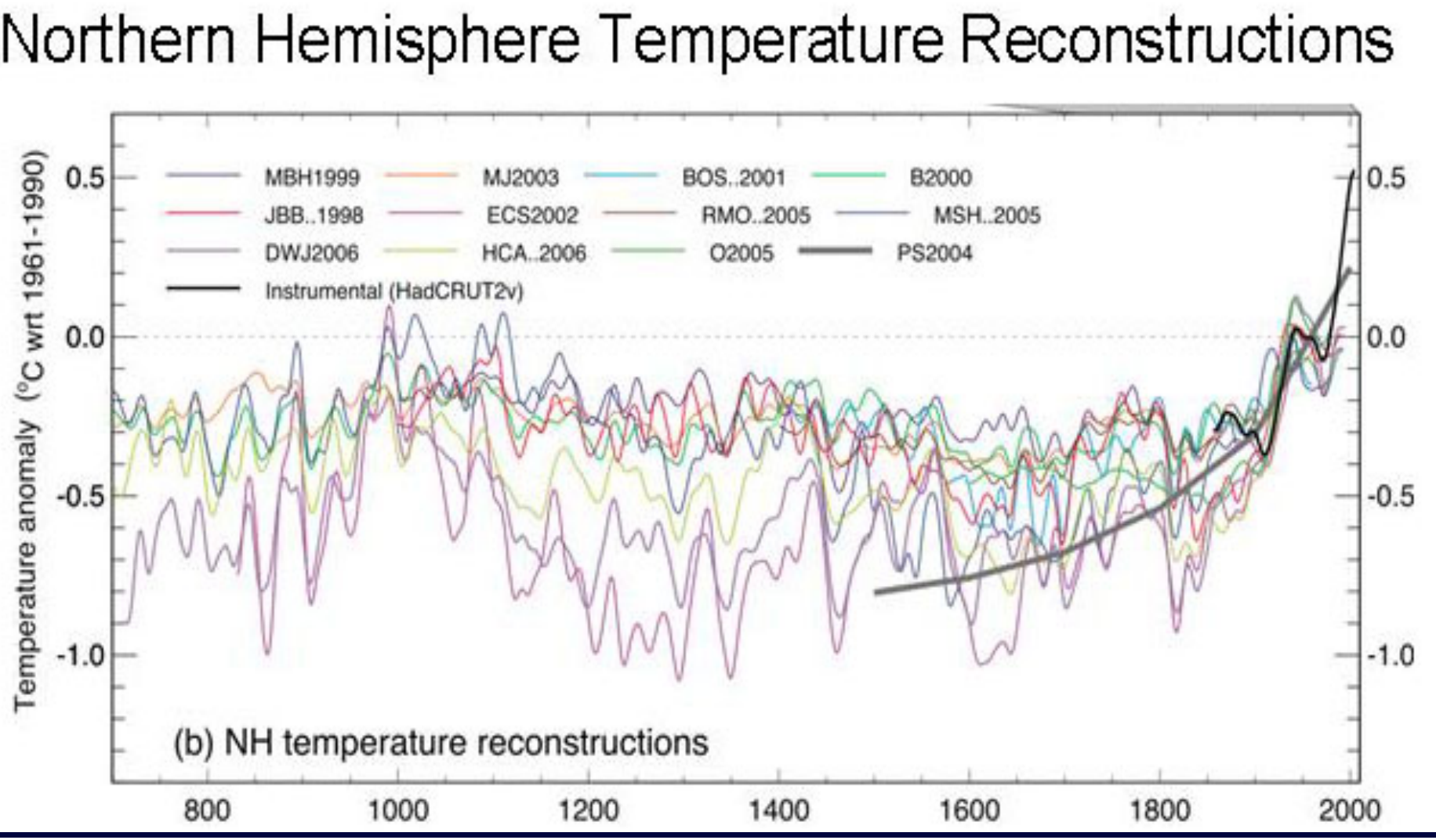


Different datasets show consistent trends superposed to natural temporal variability

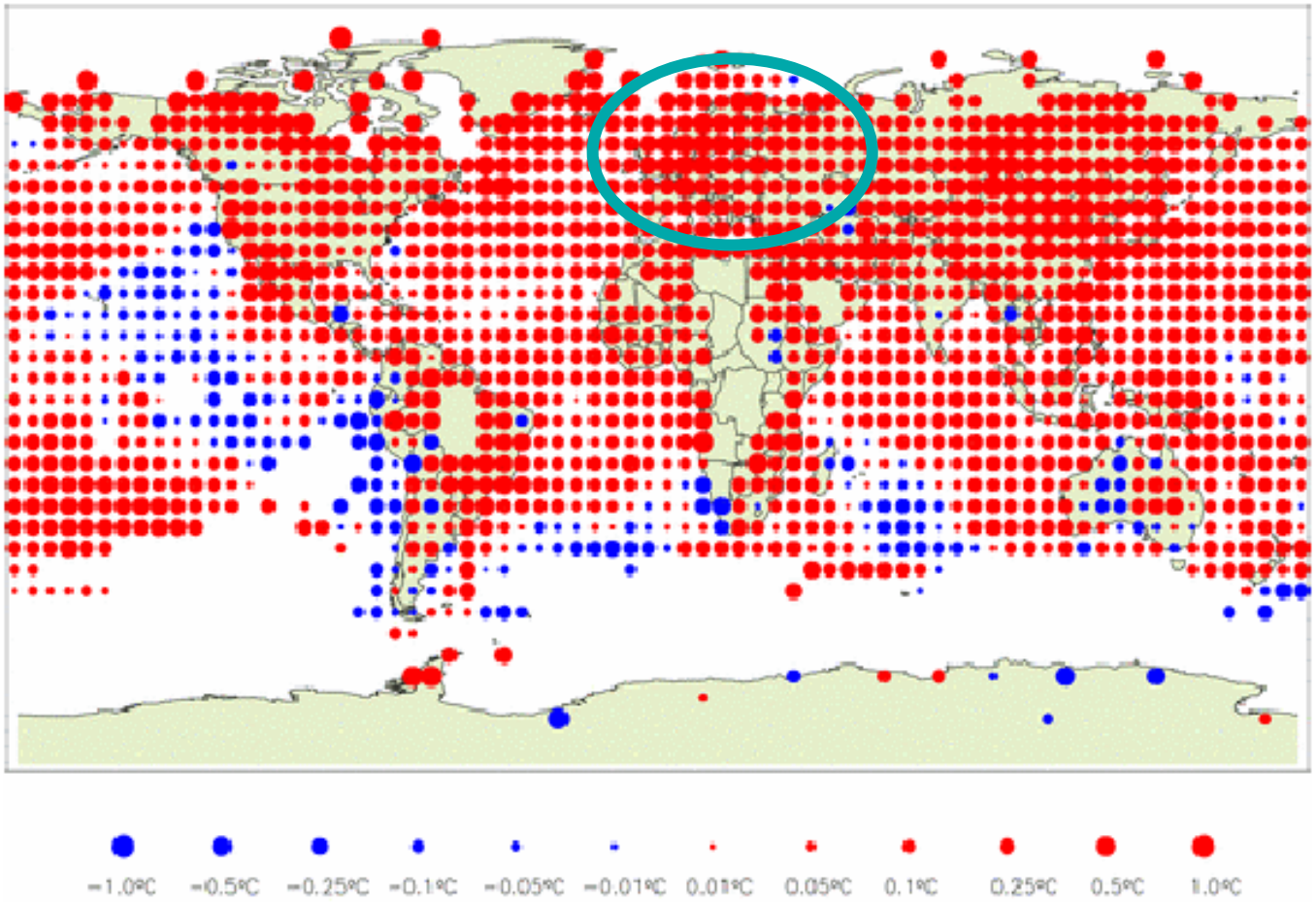


Putting present temperatures into a longer term context

The last 50 years are likely the warmest during the past 1300 years

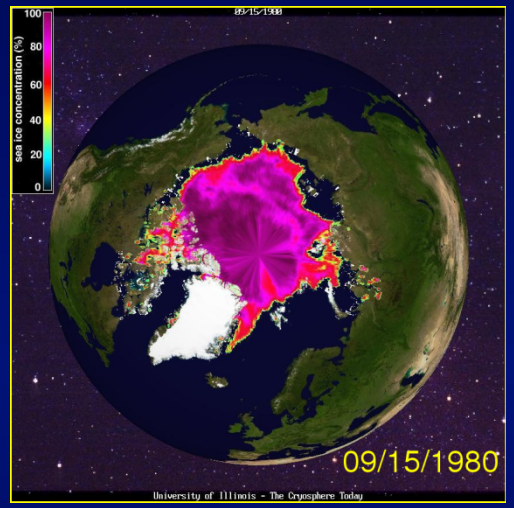


Observed temperature trends are not homogeneous in space (1979-2003)

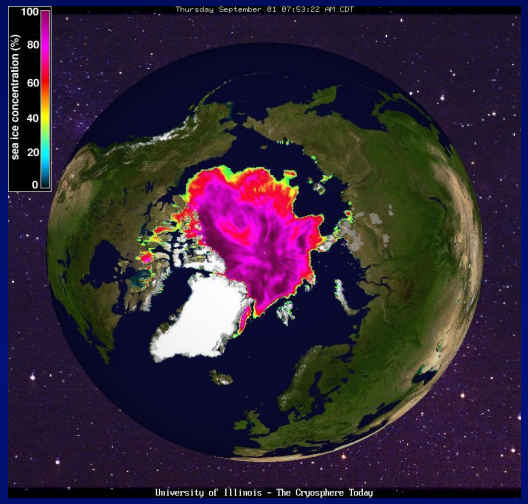


Evidence 2: Decrease of sea ice

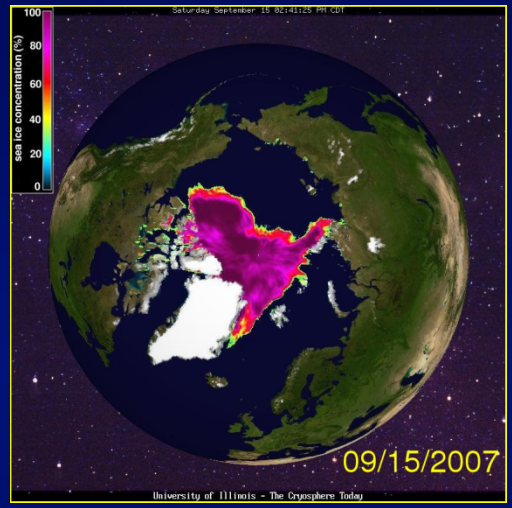
15 September 1980



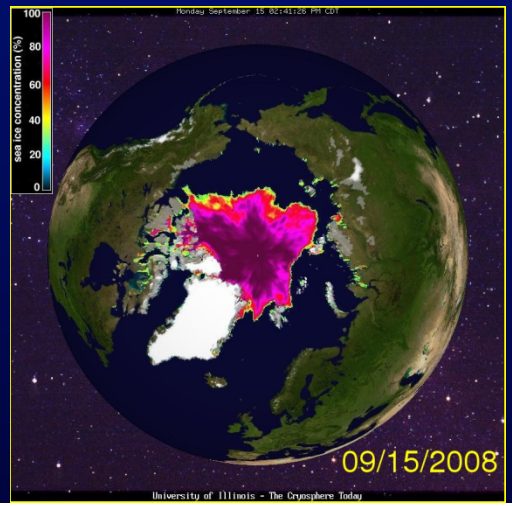
15 September 2005

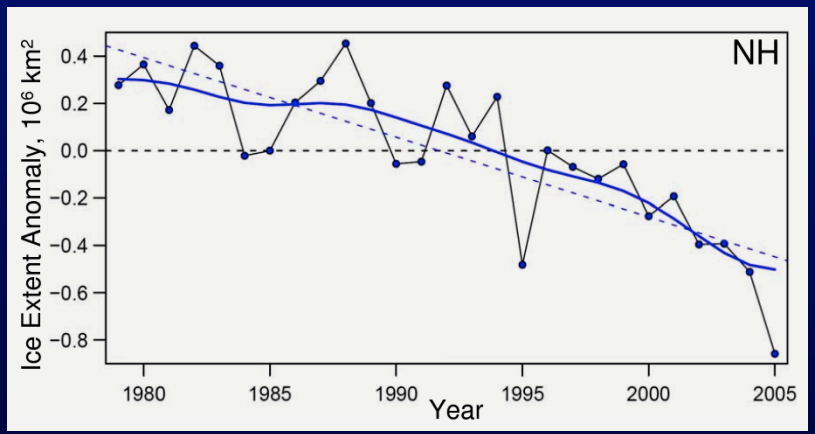


15 September 2007

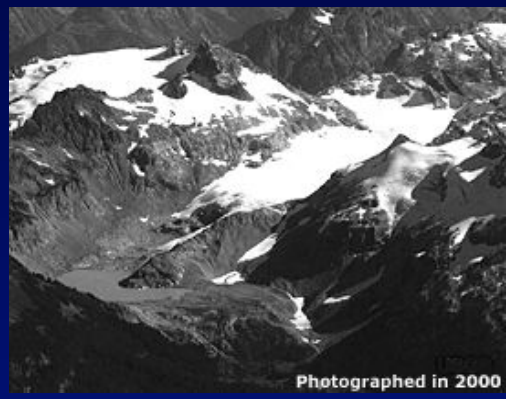


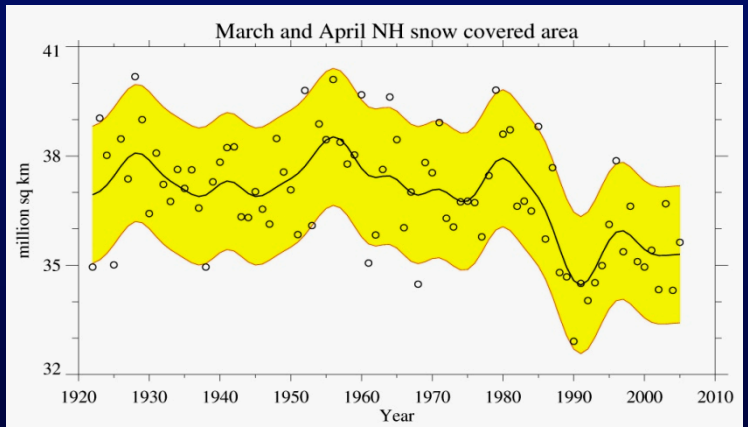
15 September 2008

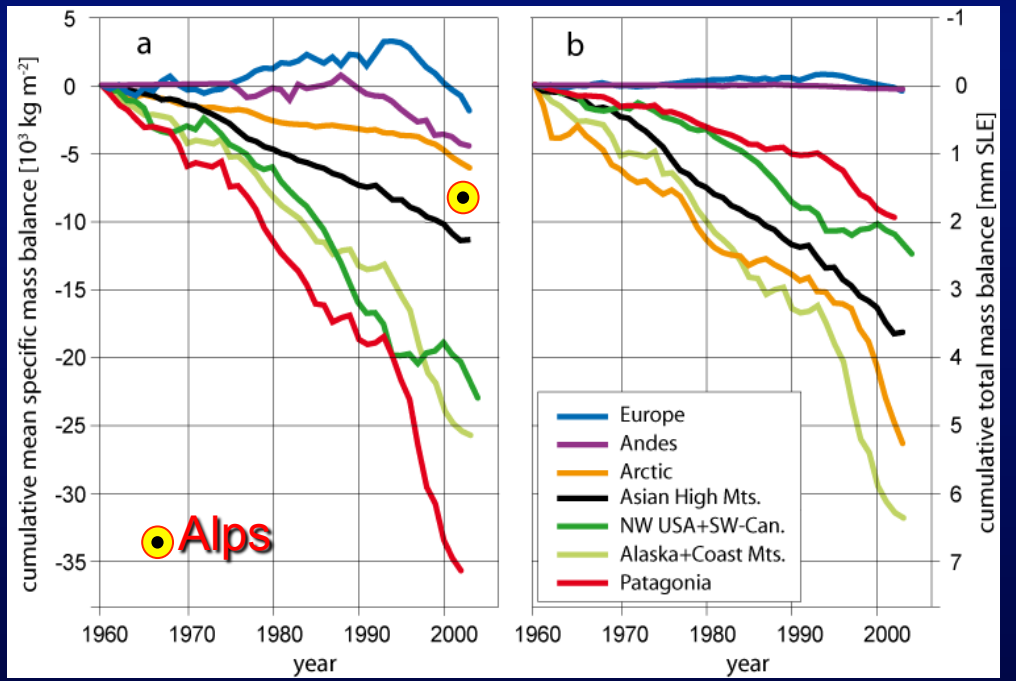




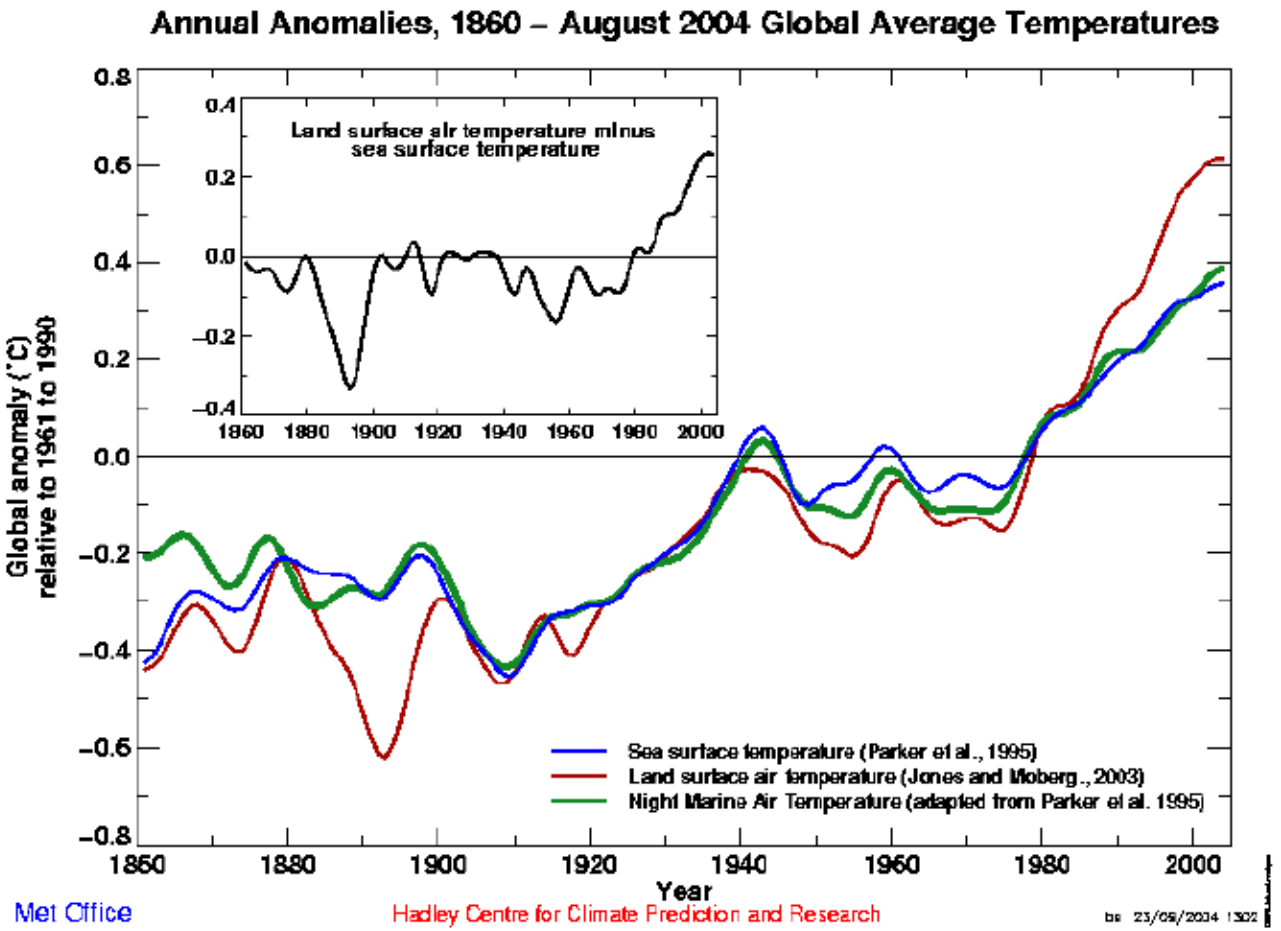
Evidence 3: Melting of glaciers and snow







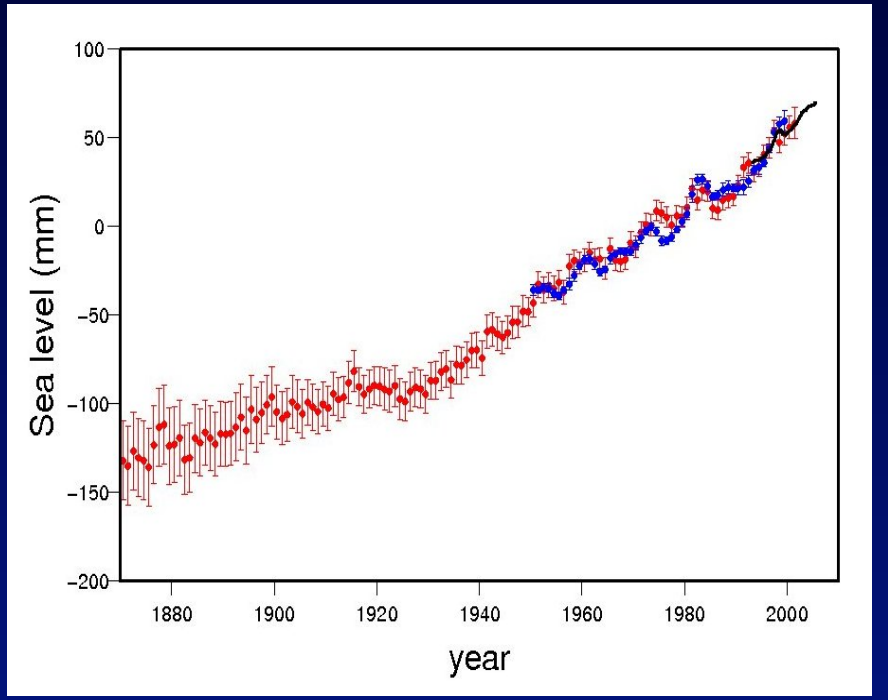
Evidence 4: Ocean warming



Evidence 5:

Sea level rise

~ 20 cm since 1880



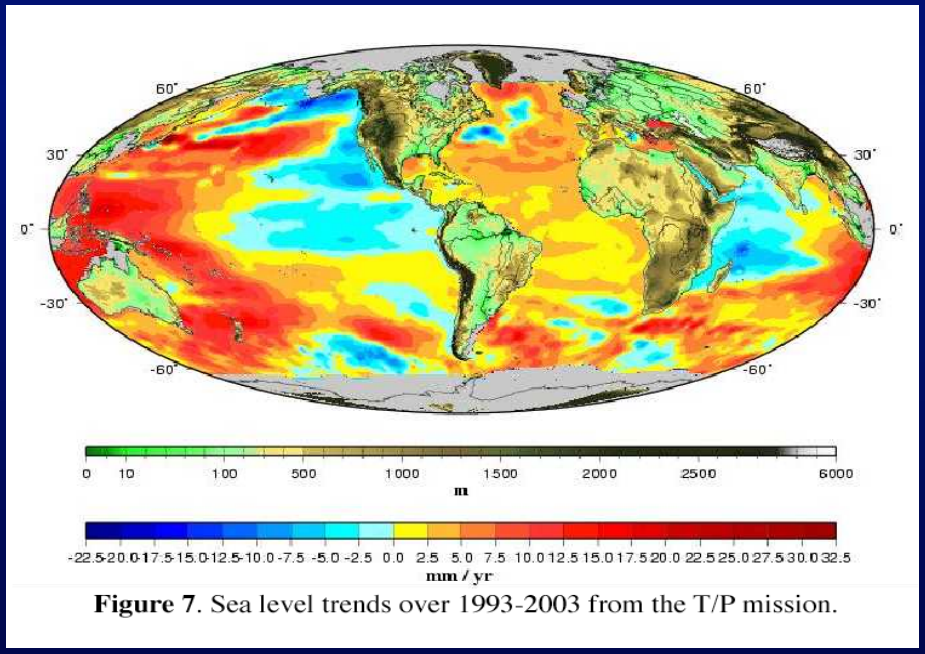


Figure 7. Sea level trends over 1993-2003 from the T/P mission.

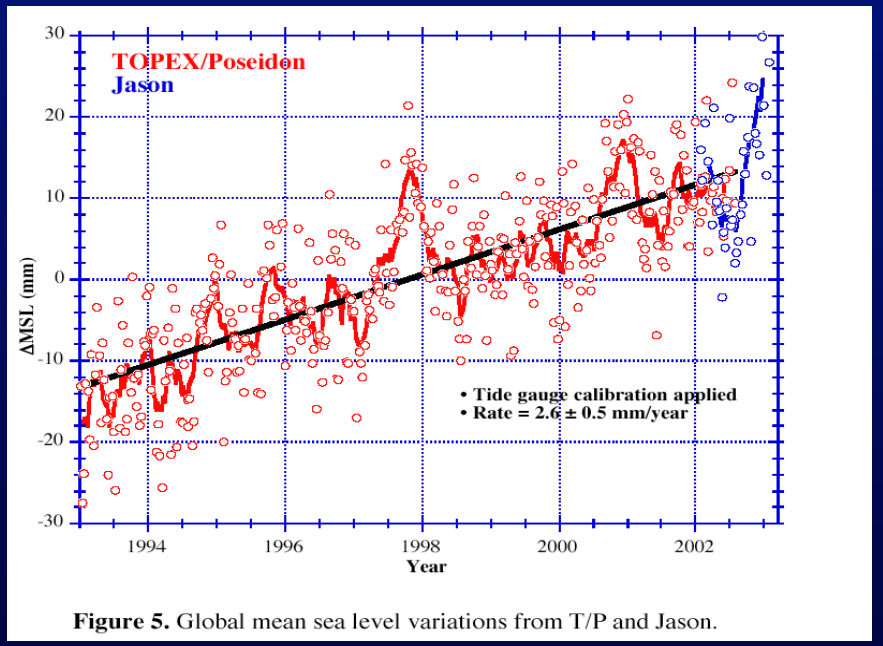
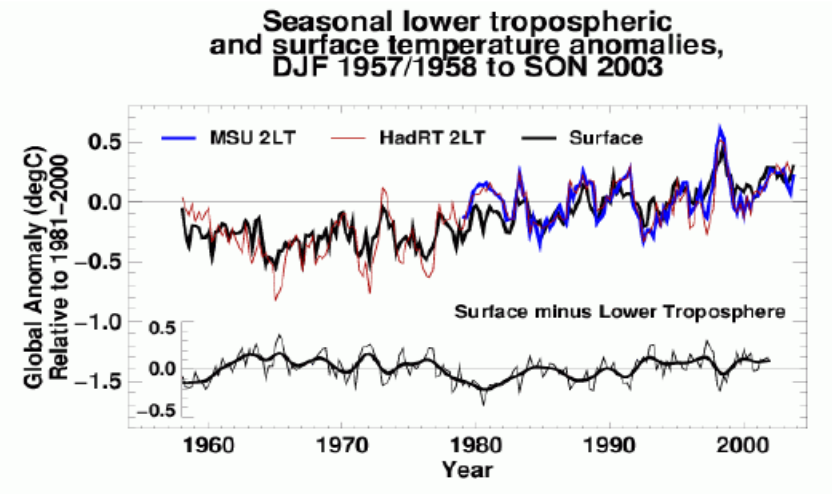
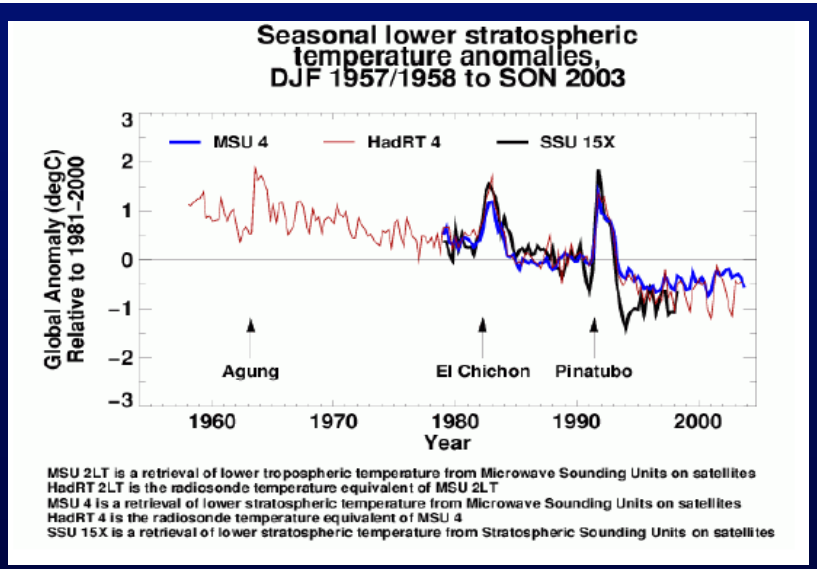


Figure 5. Global mean sea level variations from T/P and Jason.

Evidence 6: Tropospheric warming and stratospheric cooling

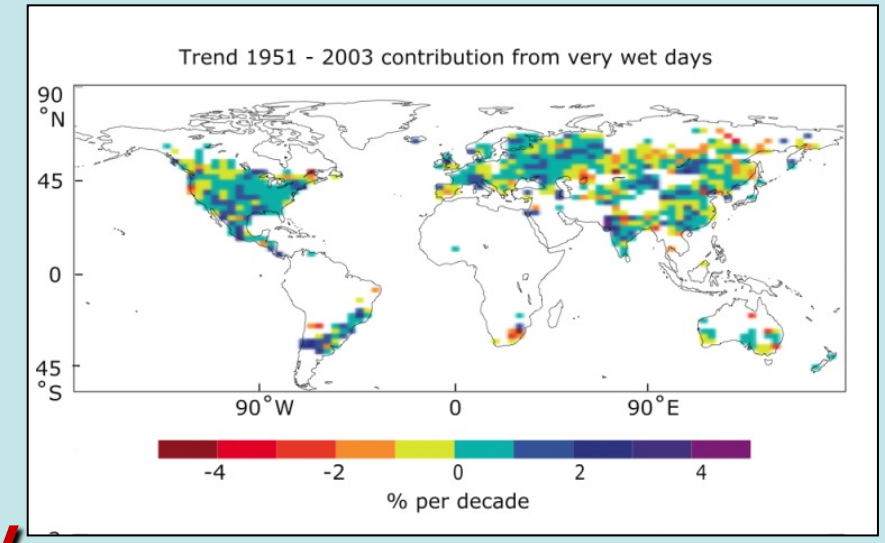


Satellite measurements since 1979 show a global tropospheric warming consistent with the surface warming



Lower stratospheric cooling is observed, which is consistent with the effects of increased GHG concentrations

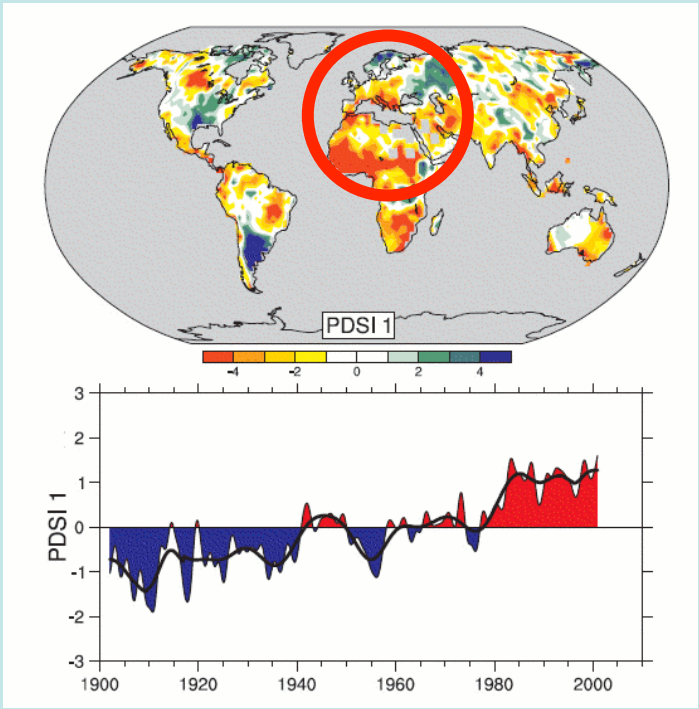
Observed trends in the hydrologic cycle IPCC (2007)



It rains less frequently but more intensely

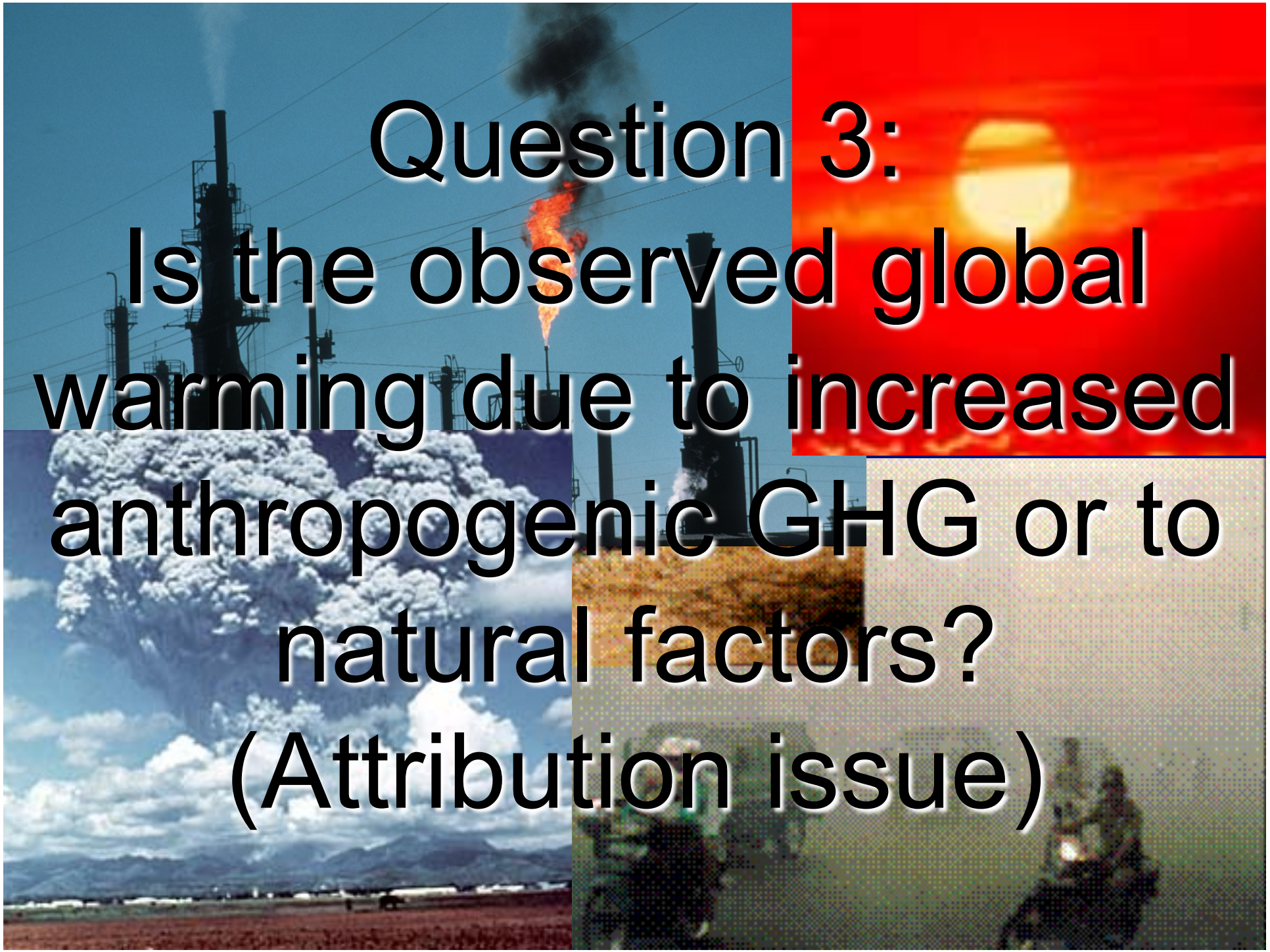
IPCC 2007: “More intense and longer droughts have been observed over wider areas since the 1970s”

IPCC 2007: “The frequency of heavy precipitation events has increased over most land areas”

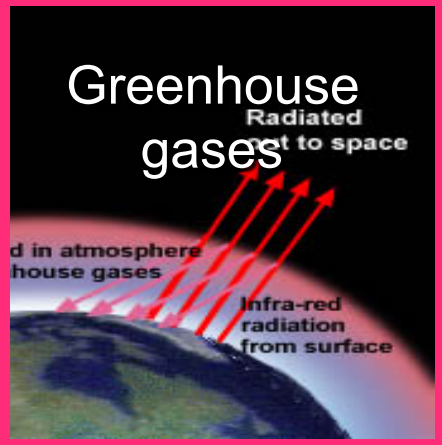


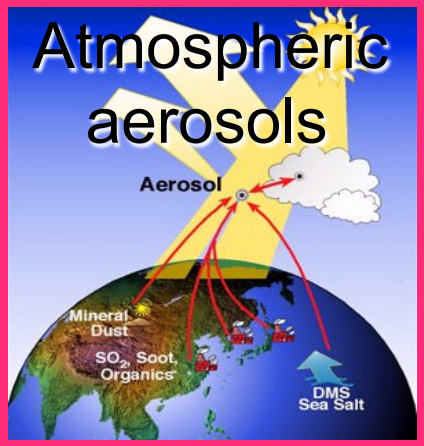
IPCC-2007

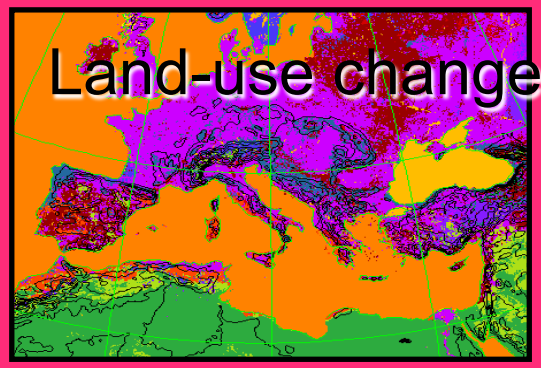
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level


Question 3:
Is the observed global warming due to increased anthropogenic GHG or to natural factors?
(Attribution issue)

Human factors

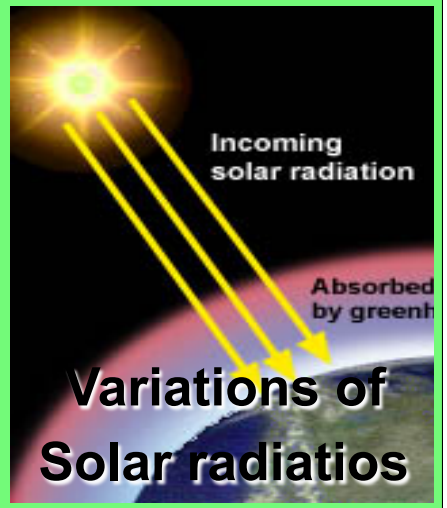


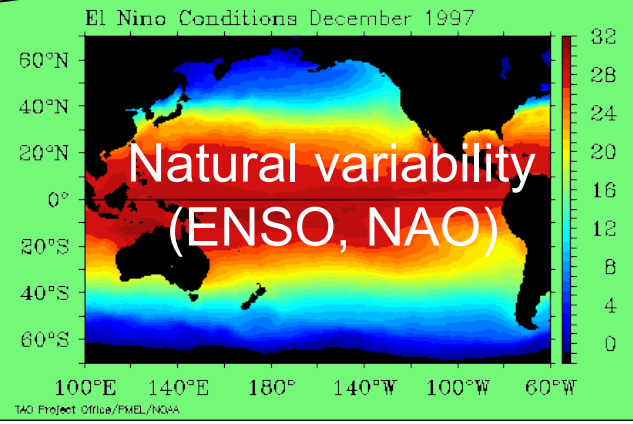




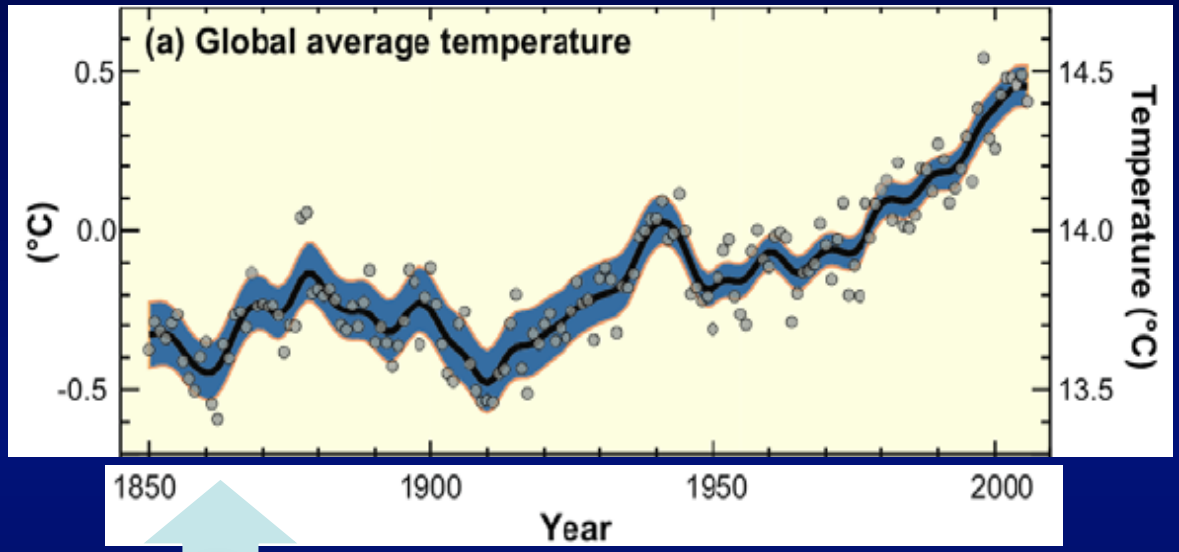
The earth's climate can change because of anthropogenic or natural factors

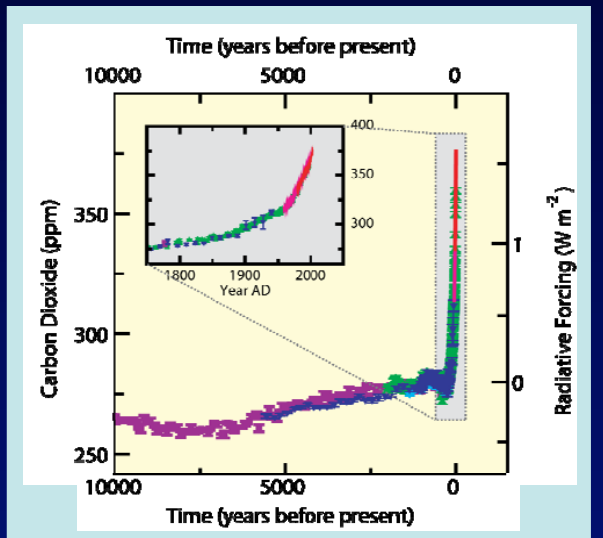
Natural factors





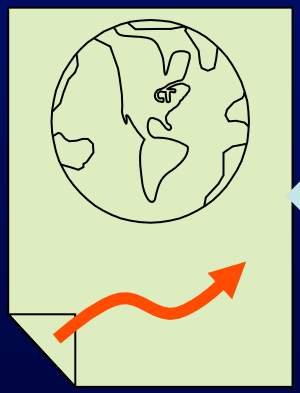
“Fingerprinting” of the anthropogenic effects

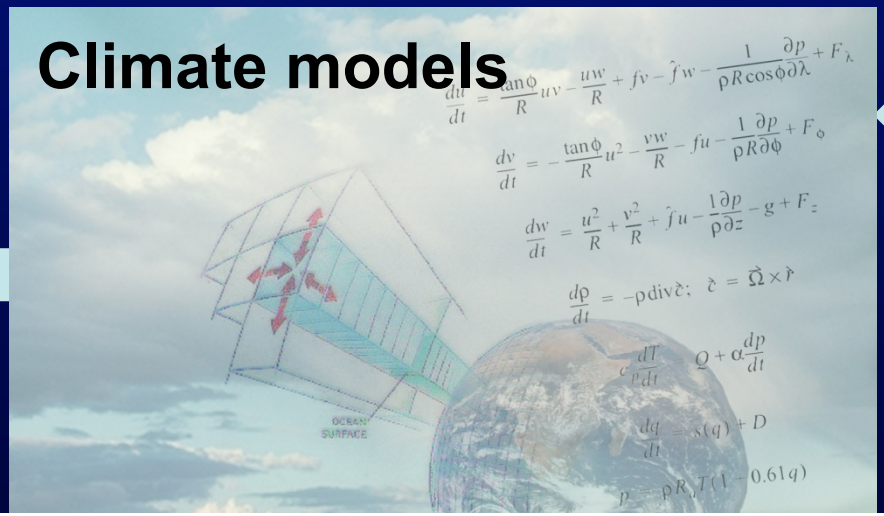


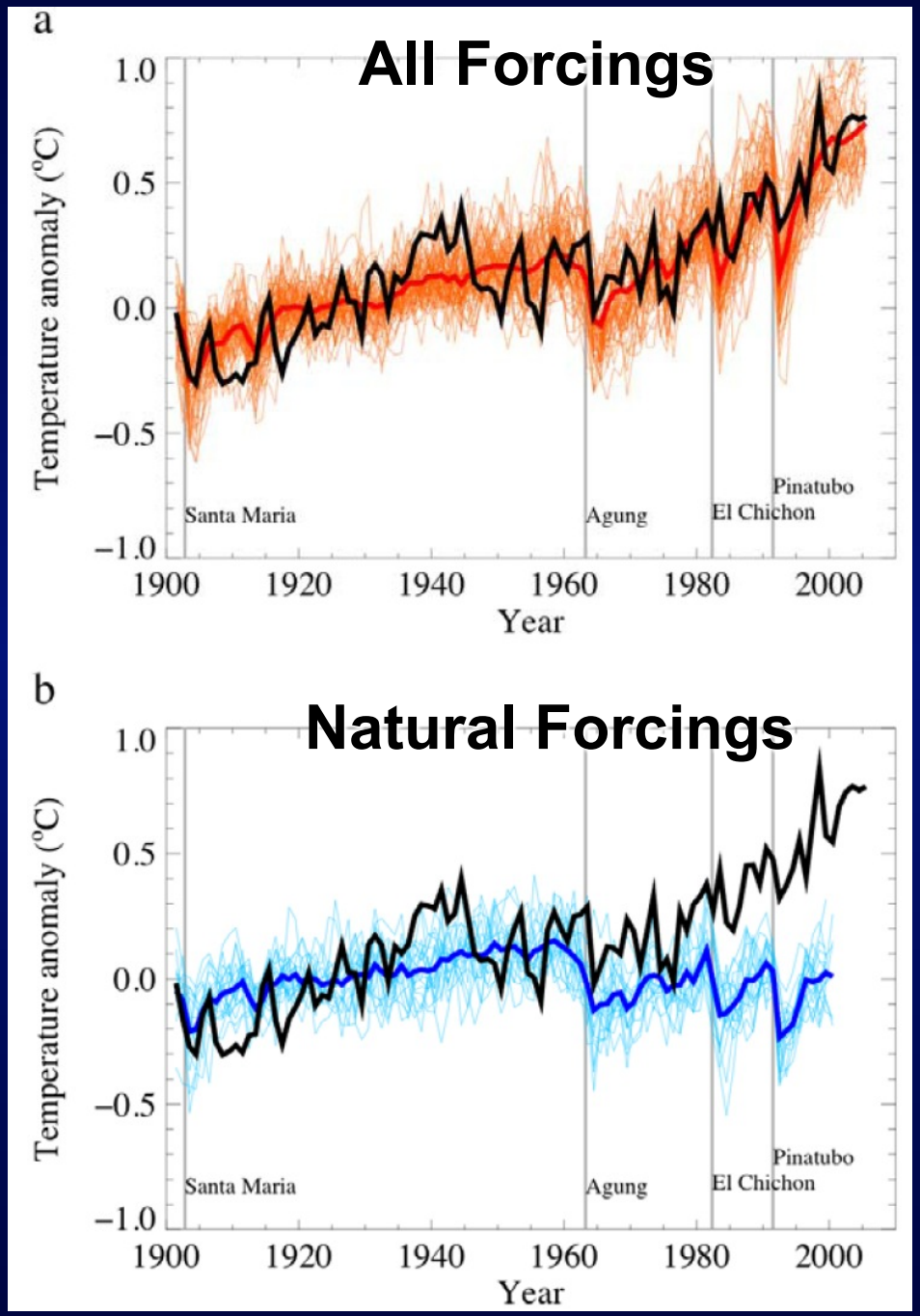


- other GHGs
- aerosols
- volcanic
- solar
- natural internal

?

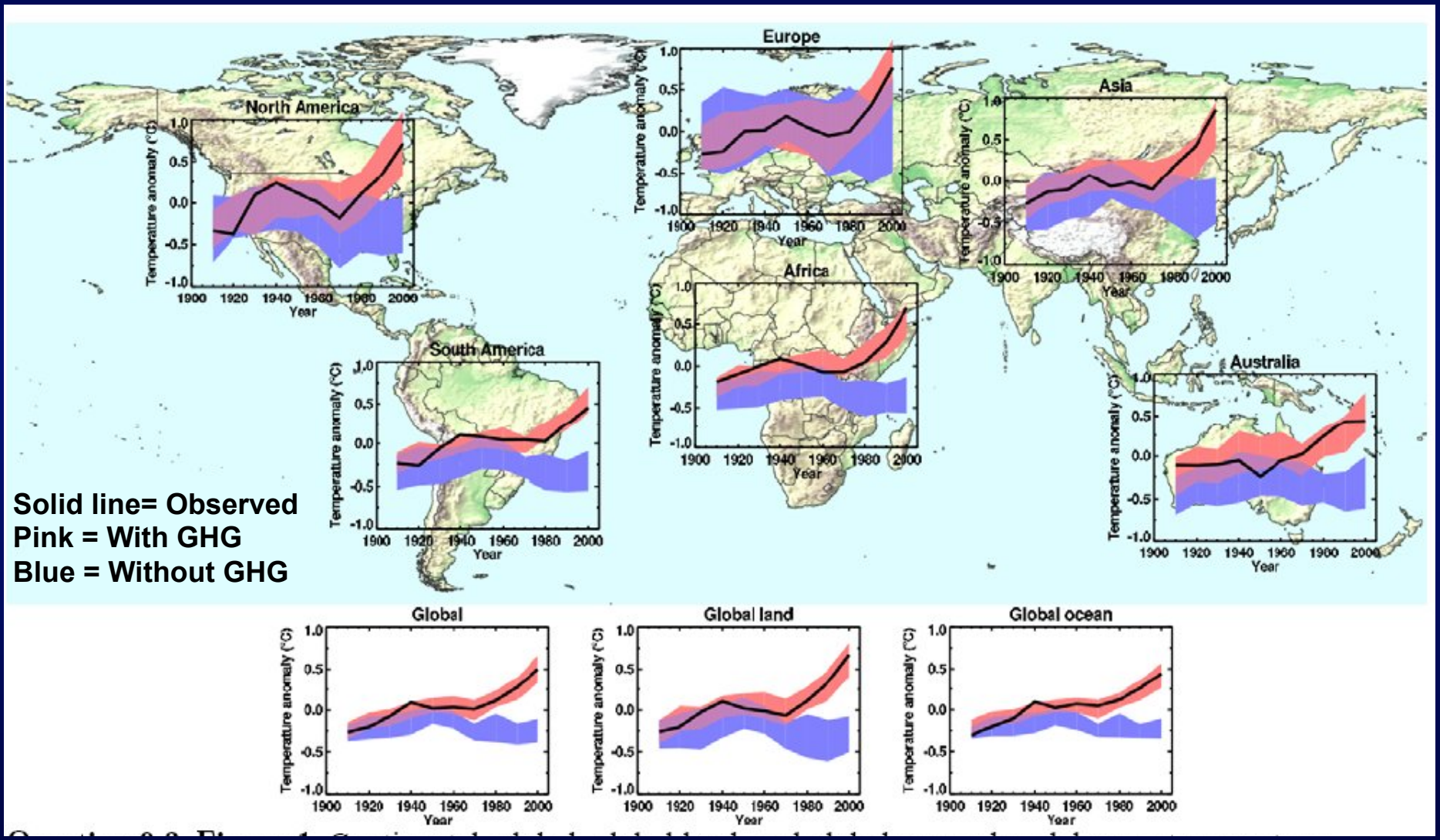




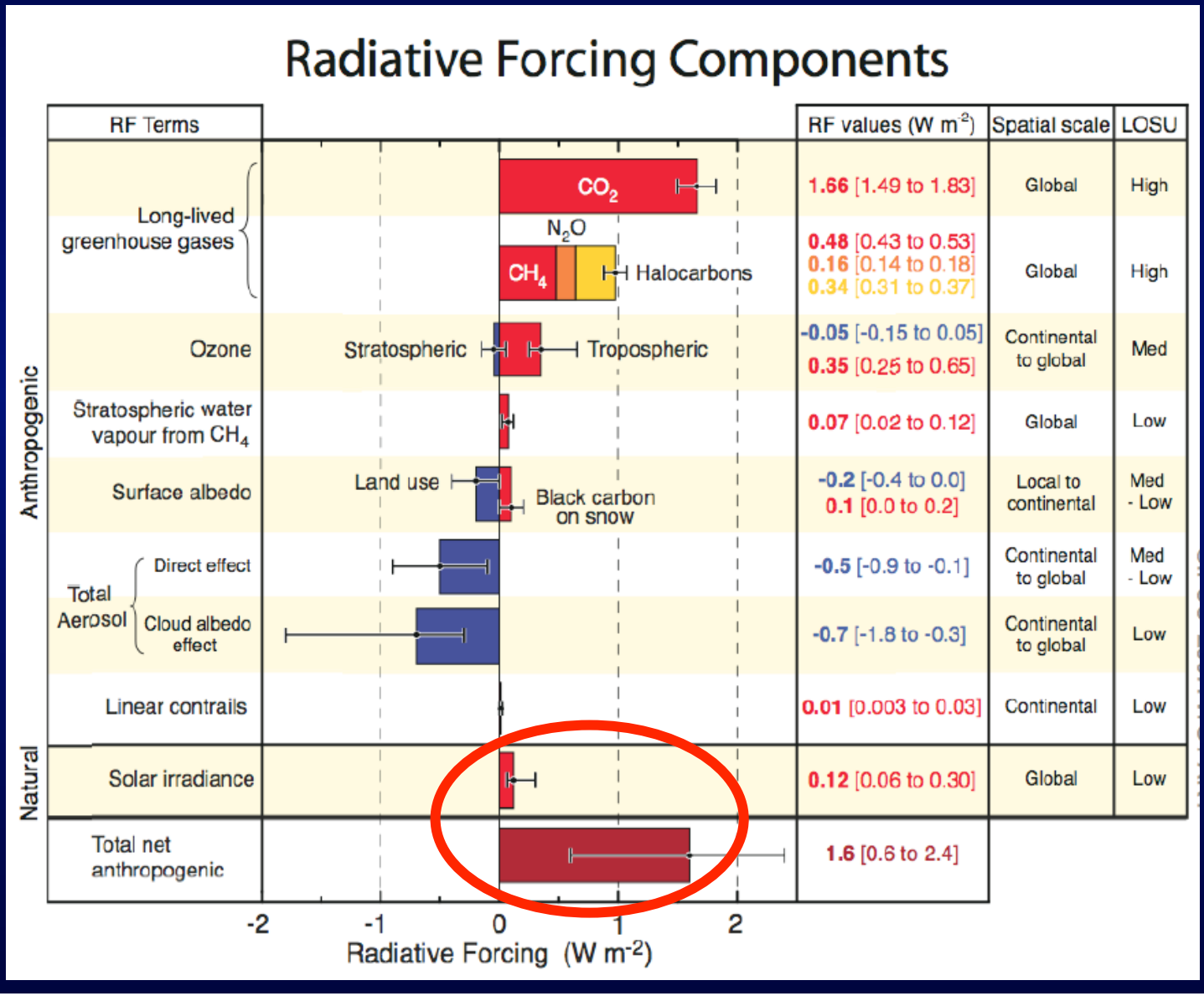


Identification of the anthropogenic effects on global warming

Identification of the anthropogenic effect on regional and ocean warming

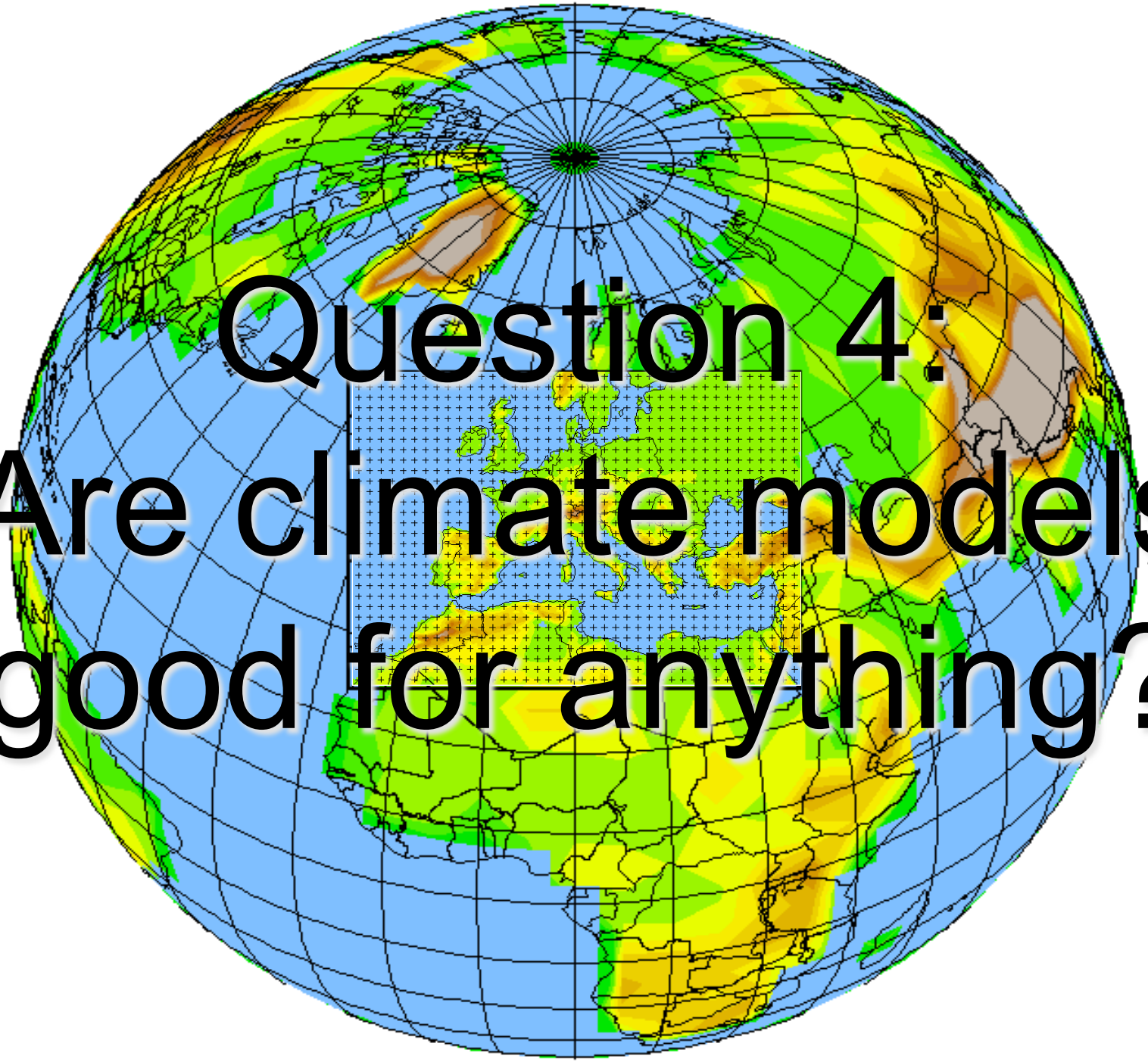


Anthropogenic and natural forcings from 1750 to 2005



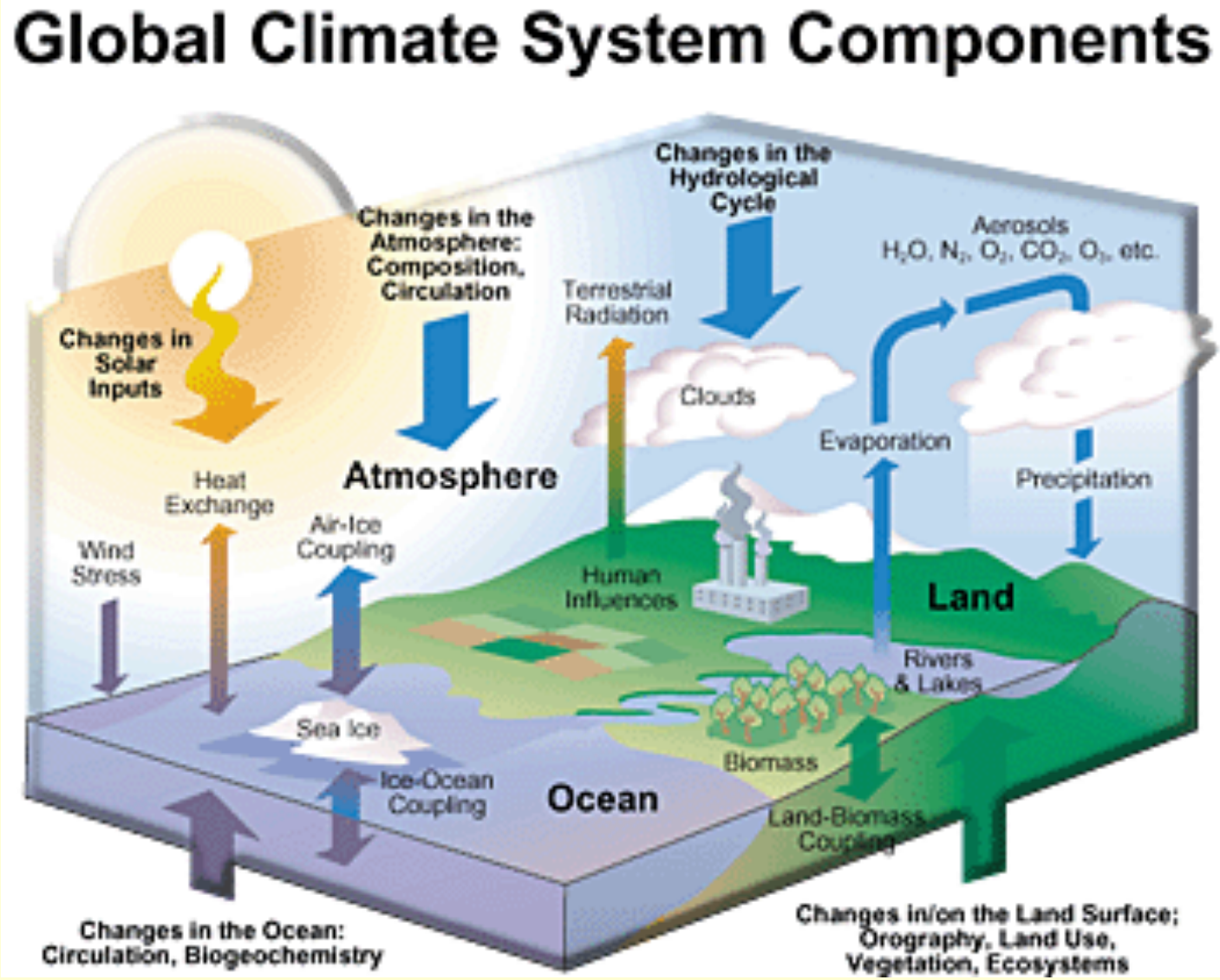
IPCC-2007

Most of the observed increase in globally averaged temperature since the mid-20th century is very likely (90-95%) due to the observed increase in anthropogenic greenhouse gas concentrations. Discernible human influences now extend to other aspects of climate, Including ocean warming, continental average temperatures, temperature extremes and wind patterns.



Question 4:
Are climate models good for anything?

The Global Climate System



The equations of an atmospheric model

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{\nabla p}{\rho} - 2\overline{\Omega} \times \overline{V} + \overline{g} + \overline{F}_{\overline{V}}$$

Conservation of momentum

$$C_p\left(\frac{\partial T}{\partial t} + \overline{V} \cdot \nabla T\right) = \frac{1}{\rho}\frac{dp}{dt} + Q + F_T$$

Conservation of energy

$$\frac{\partial \rho}{\partial t} + \overline{V} \cdot \nabla \rho = -\rho \nabla \cdot \overline{V}$$

Conservation of mass

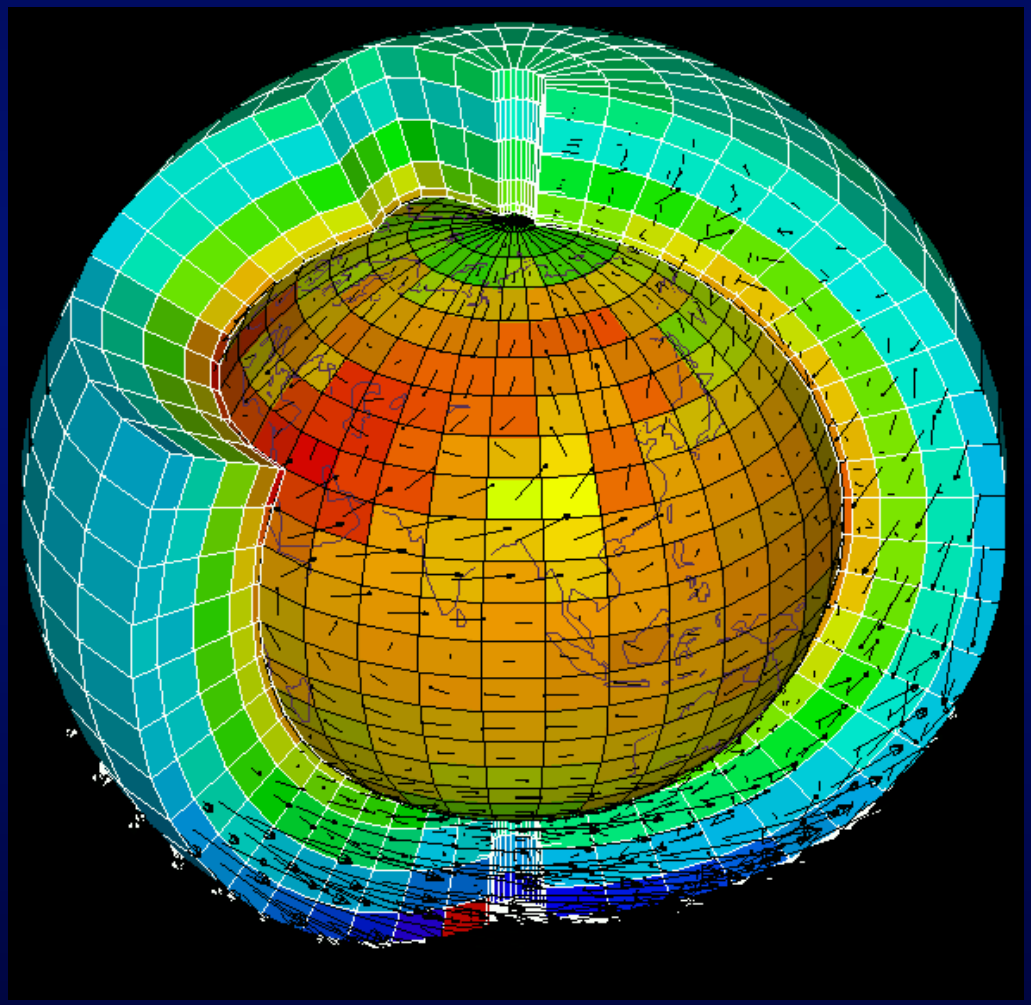
$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

Conservation of water

$$p = \rho R T$$

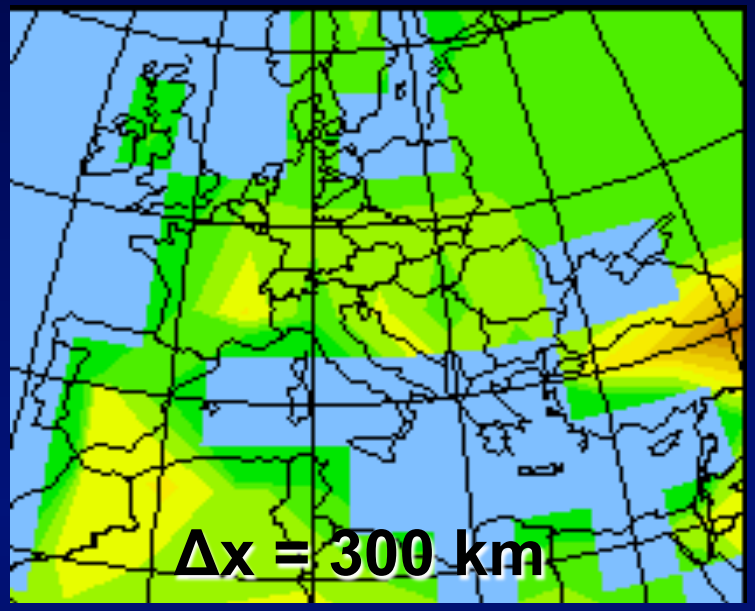
Equation of state

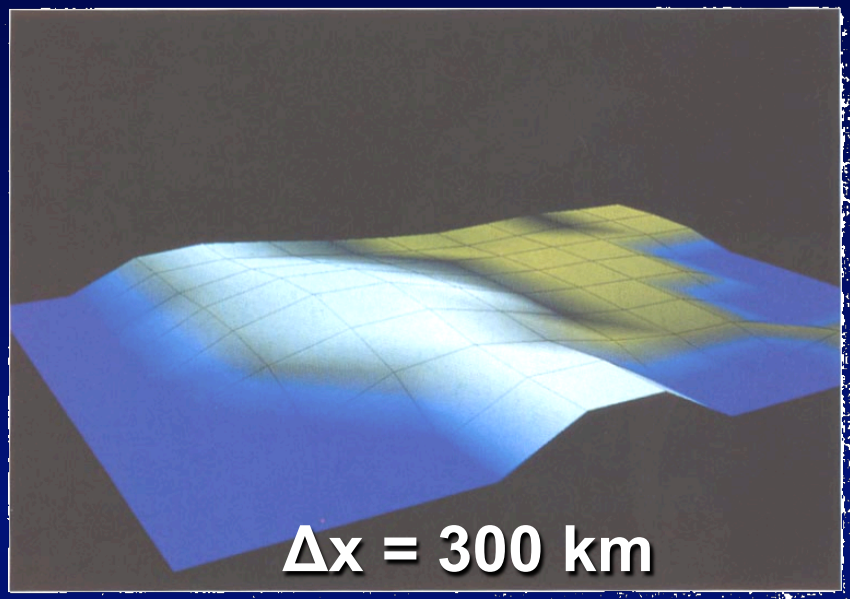
The equations of a climate model cannot be solved analytically and therefore they are discretized on a three-dimensional grid, where all the model variables are defined (wind, temperature etc.)

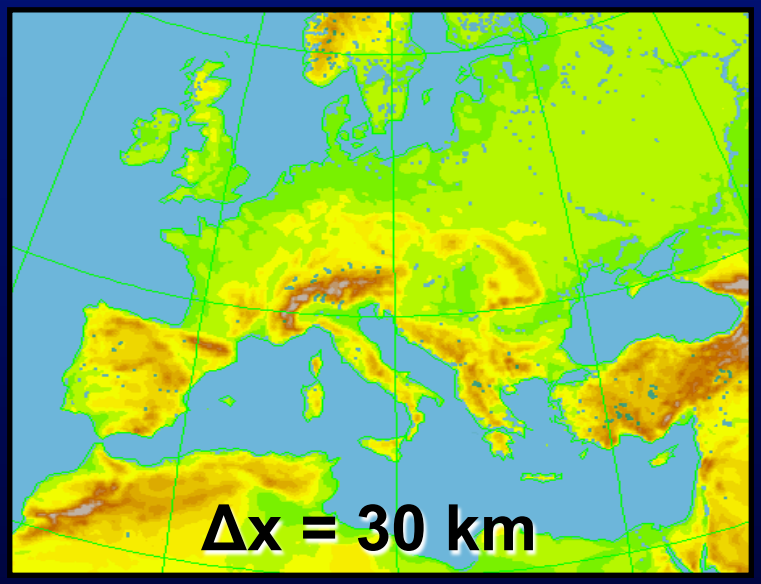


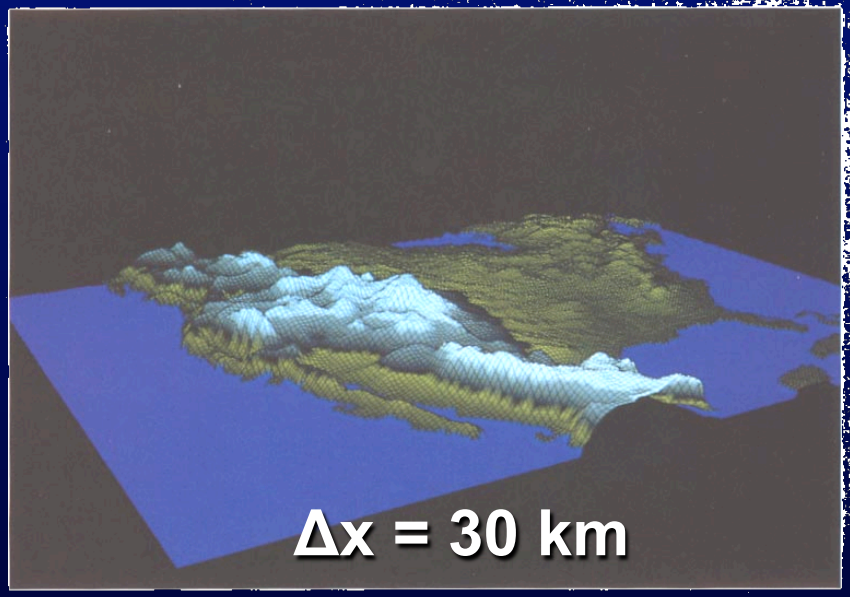
The distance between grid points determines the model resolution. Processes occurring at scale smaller than this distance are not resolved explicitly and must be “parameterized”

The importance of resolution

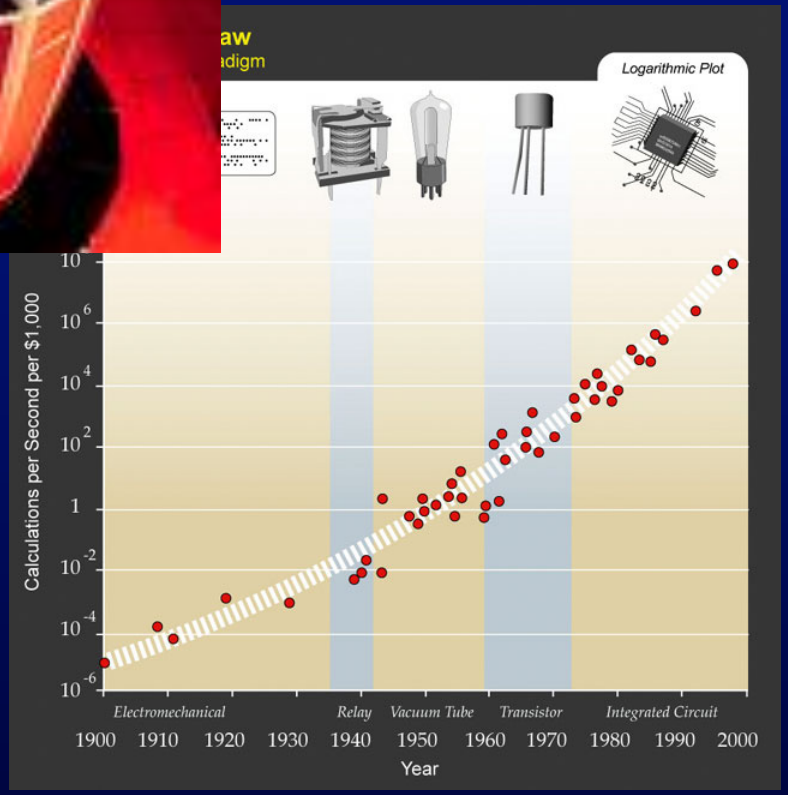


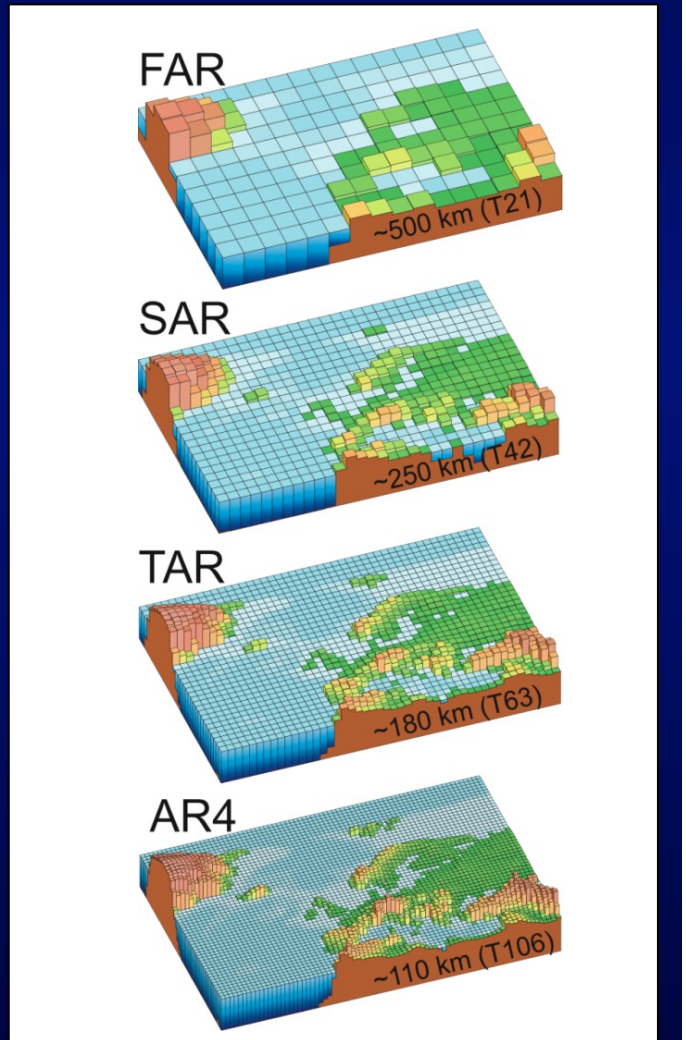






The model resolution depends on the availability of computer resources. The resolution of global climate models has increased from about 500 km in the 80s to about 100 km today





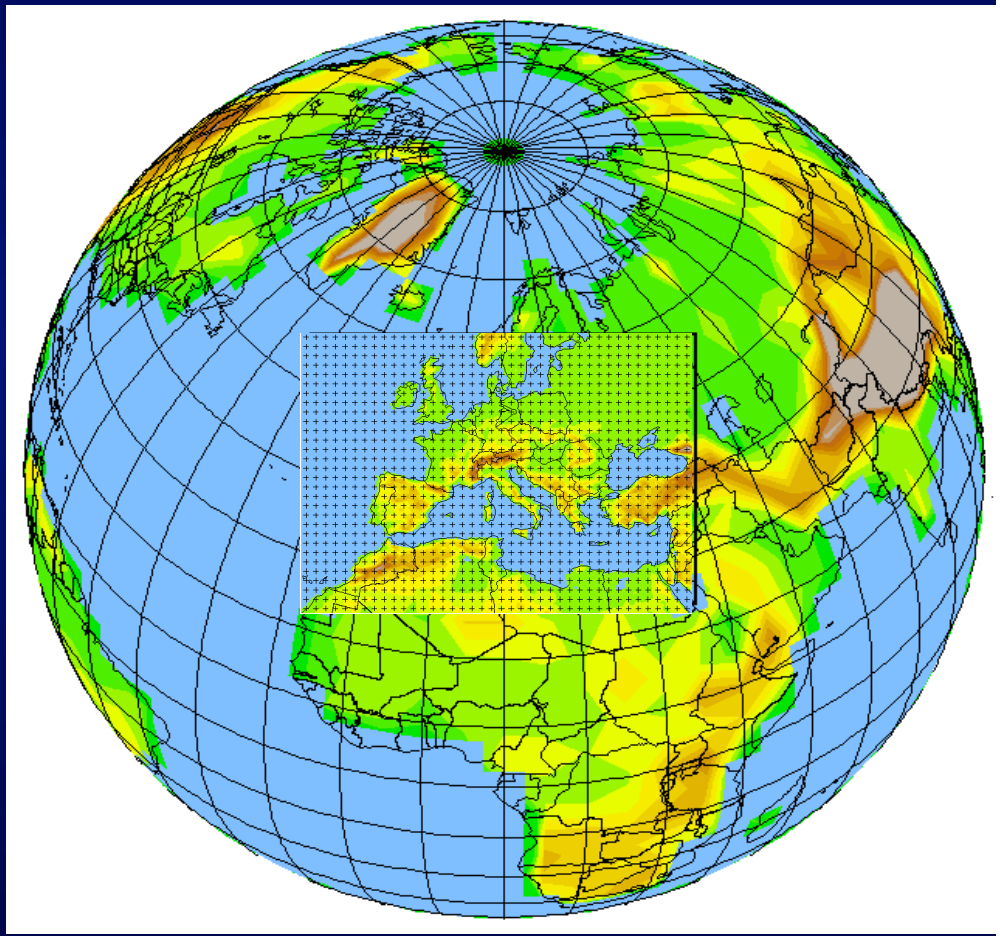
Regional Climate Modeling

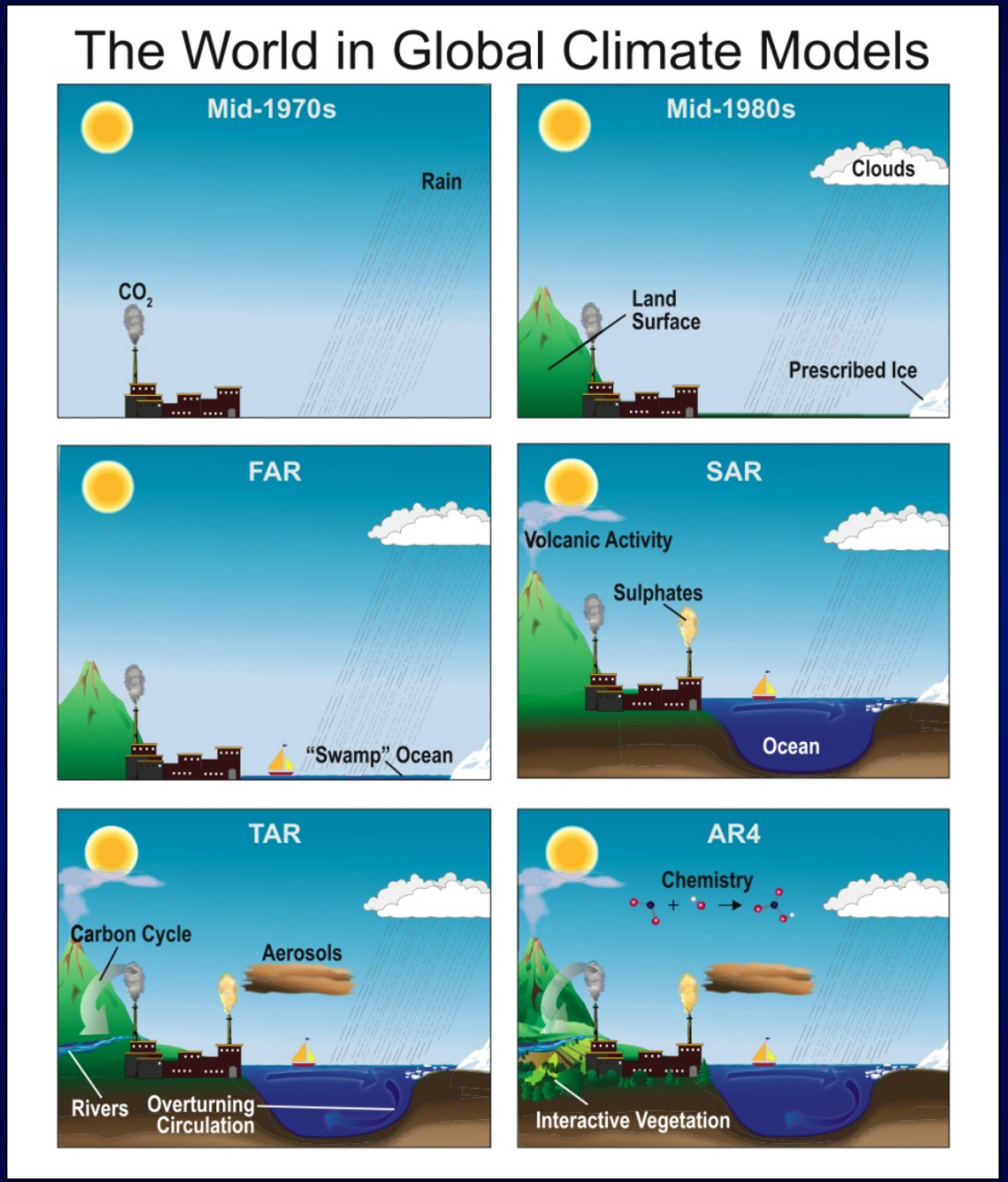
Motivation: The resolution of AOGCMs is still too coarse to capture regional and local climate processes (e.g. topography, coastlines)

Technique: A limited area "Regional Climate Model" (RCM) is "nested" within a GCM in order to locally increase the model resolution.

- Initial conditions (IC) and lateral boundary conditions (LBC) for the RCM are obtained from the GCM ("One-way Nesting").

Strategy: The GCM simulates the response of the general circulation to the large scale forcings (e.g. GHG), the RCM simulates the effect of sub-GCM-grid scale forcings and provides fine scale regional information

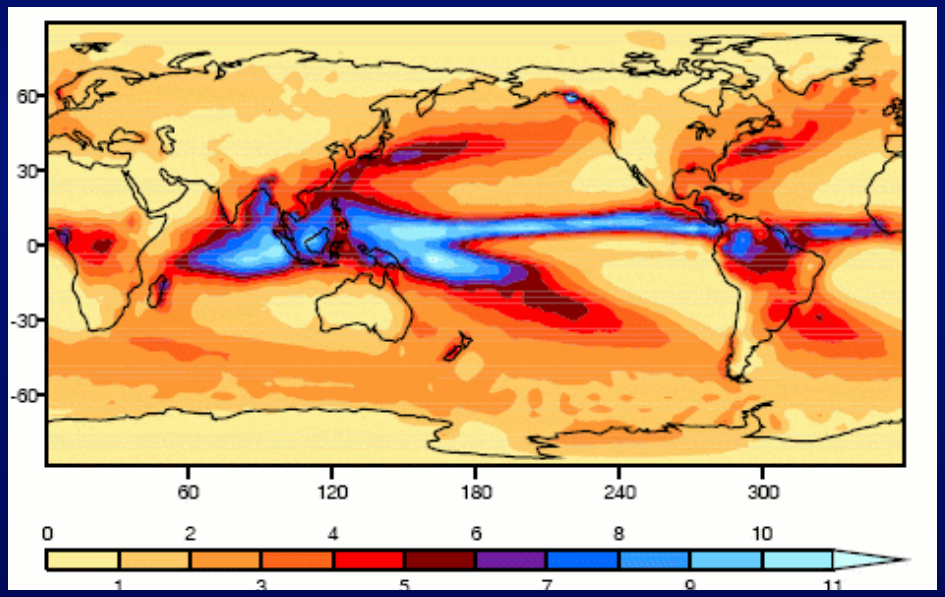




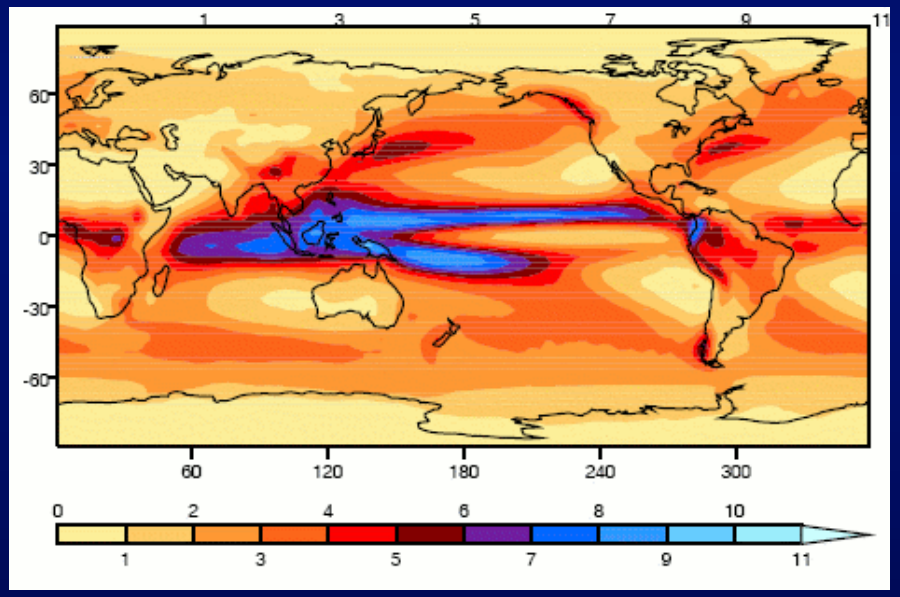
The evolution of global model complexity in the last decades

Performance of AOGCMs
Annual precipitation, 20 models

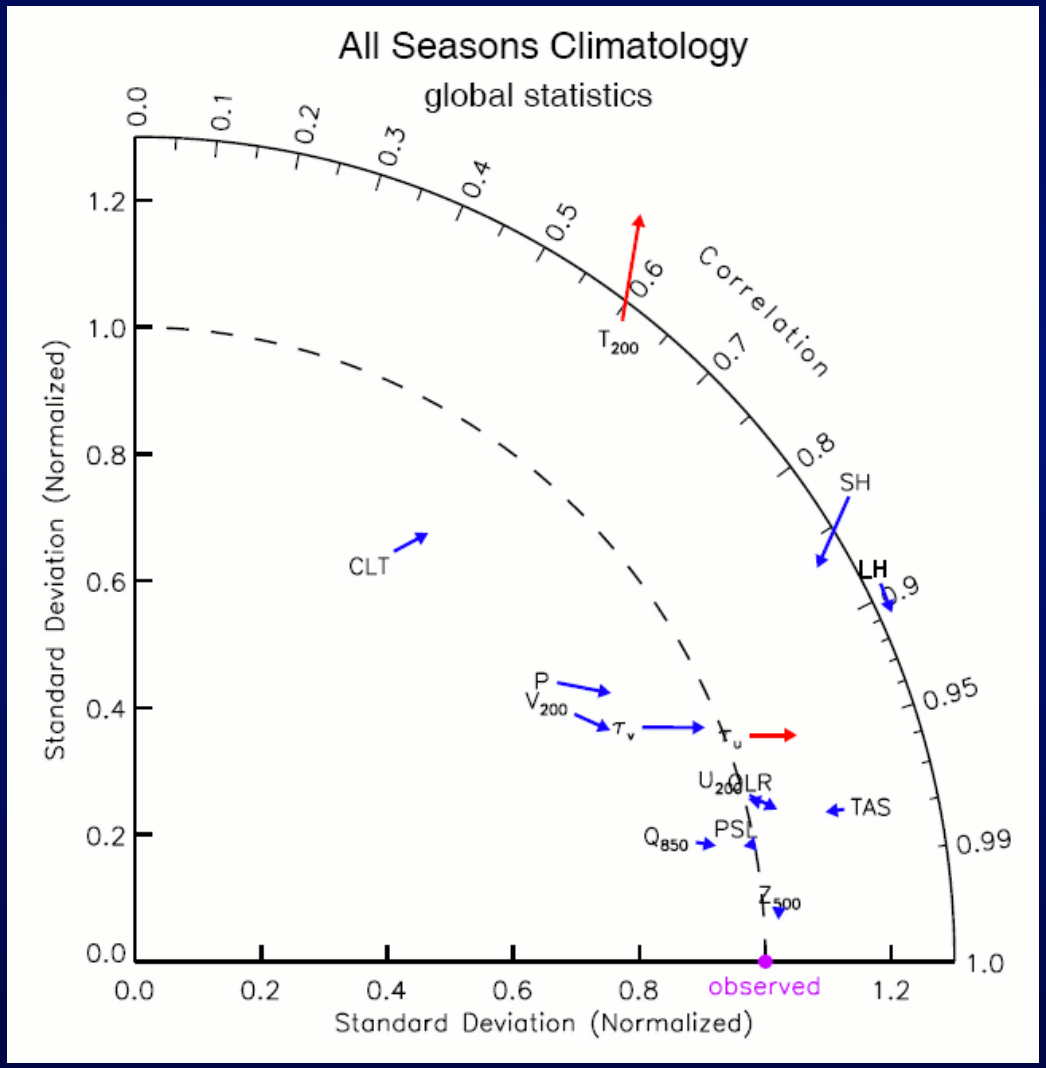
Observations



Model ensemble mean



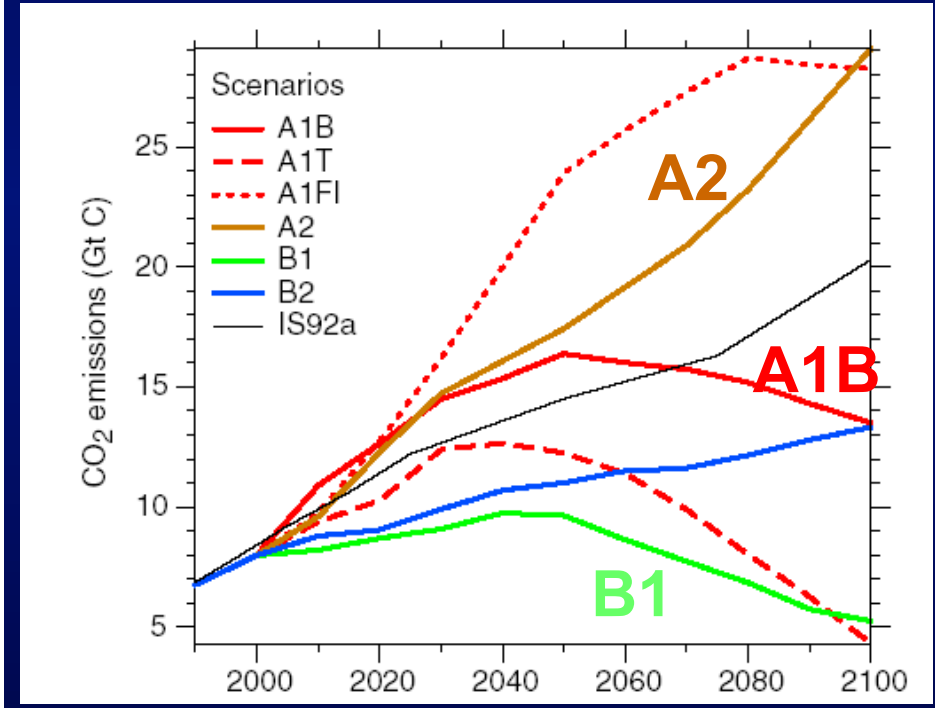
Global Performance of AOGCMs
CMIP3 models



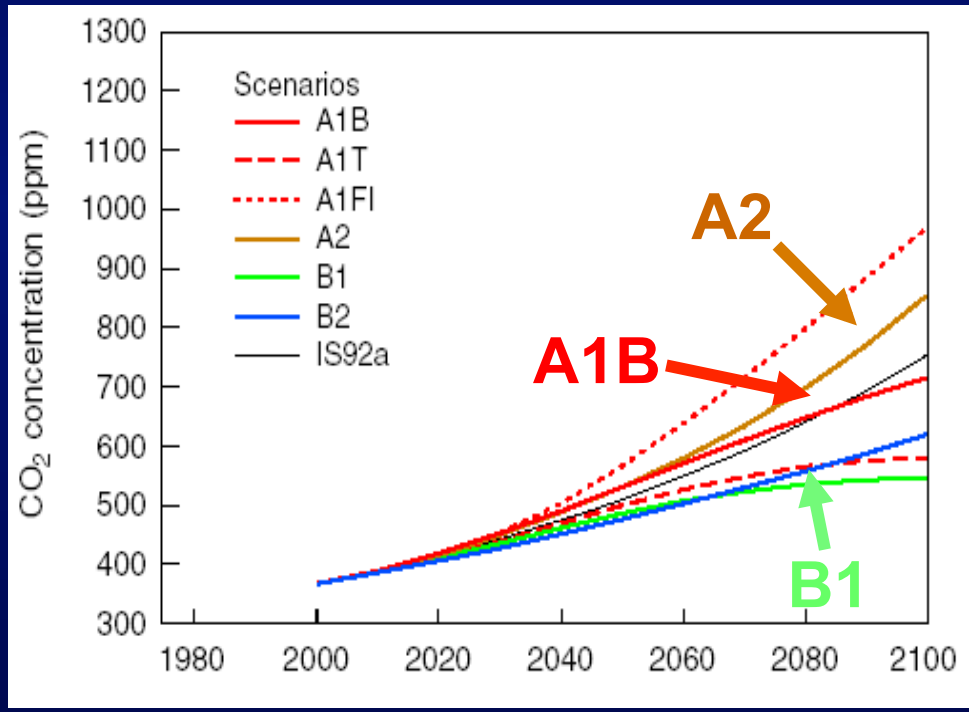

Question 5:
What can we expect in the future?

Greenhouse gas emission and concentration scenarios (IPCC-2000)

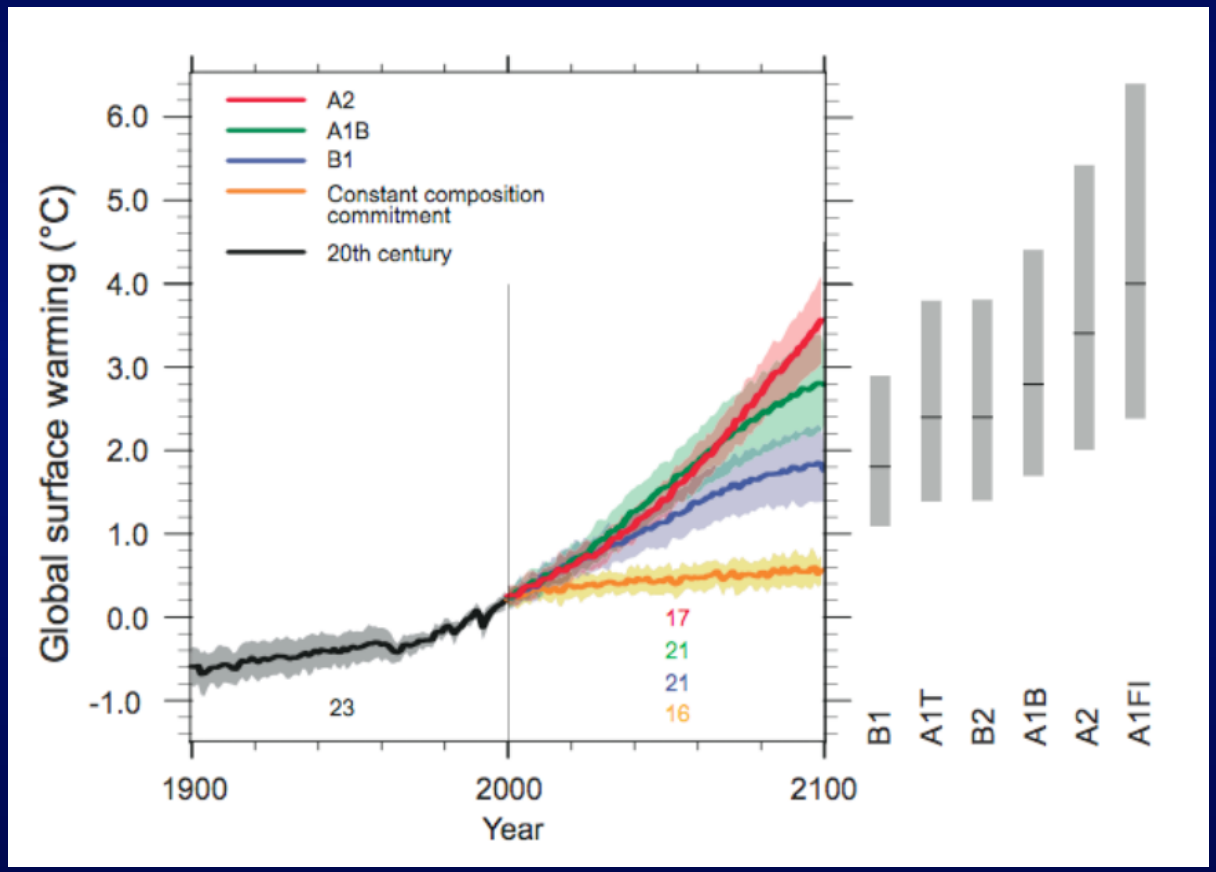
CO2 emissions

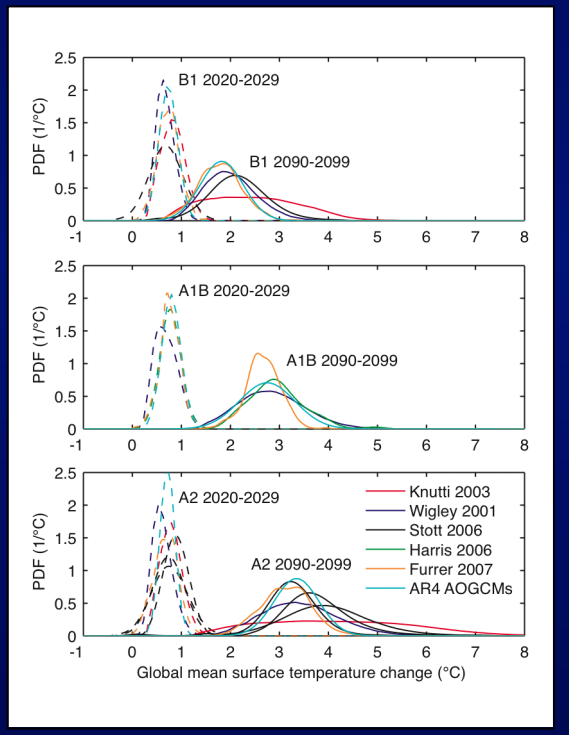


CO2 Concentrations



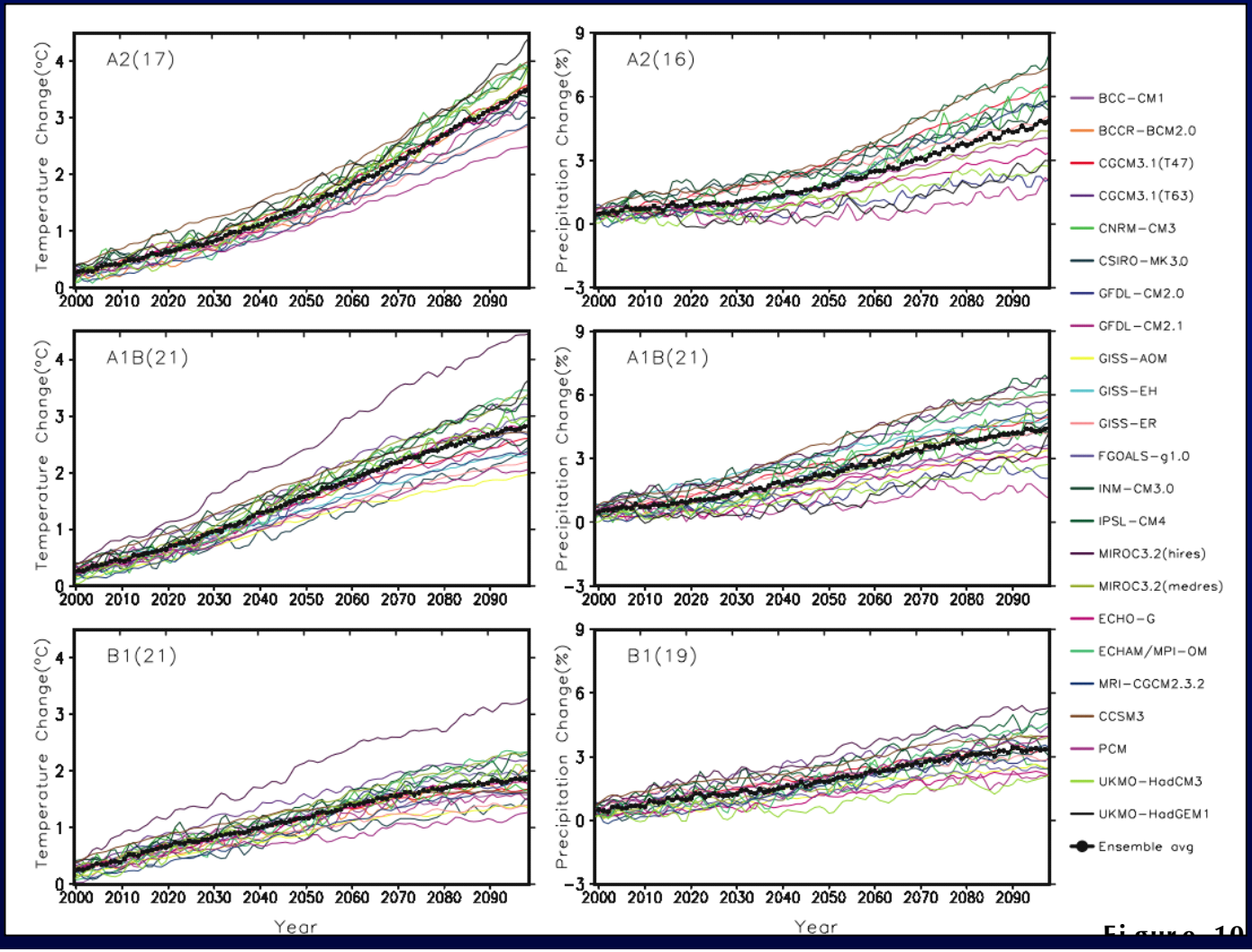
IPCC – 2007: Global temperature change projections for the 21st century





Corresponding changes in sea level rise are 19-58 cm

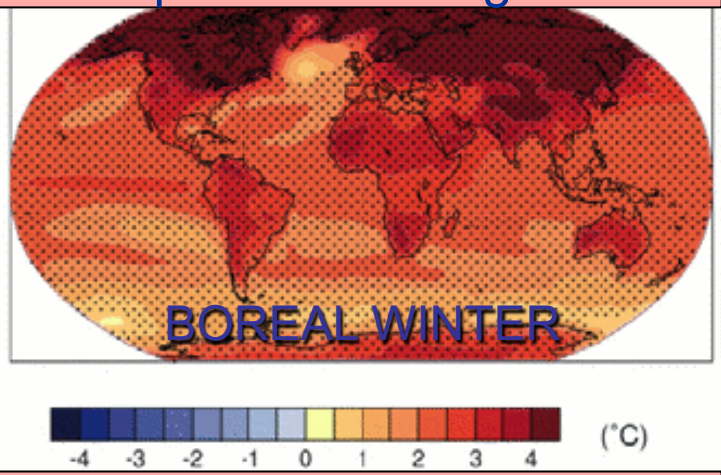
Different models respond differently to the same greenhouse gas concentration increase because of different parameterizations of physical processes. This characteristics of models is called "climate sensitivity"



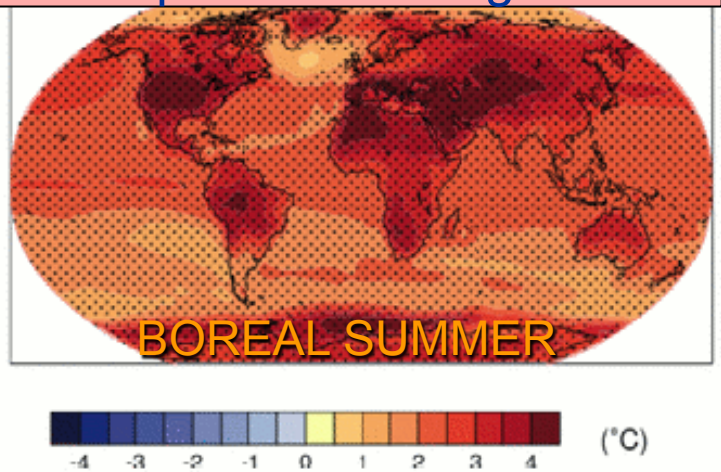
Regional distribution of projected temperature and precipitation change

(A1B scenario, 2090-2100)

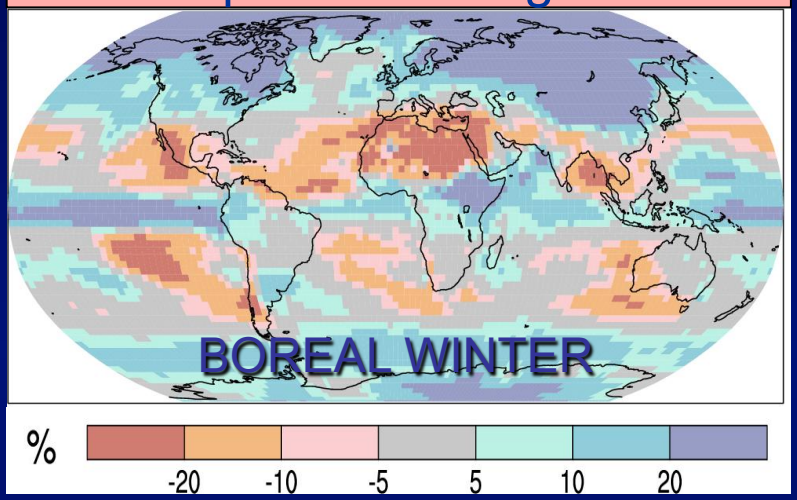
Temperature change DJF



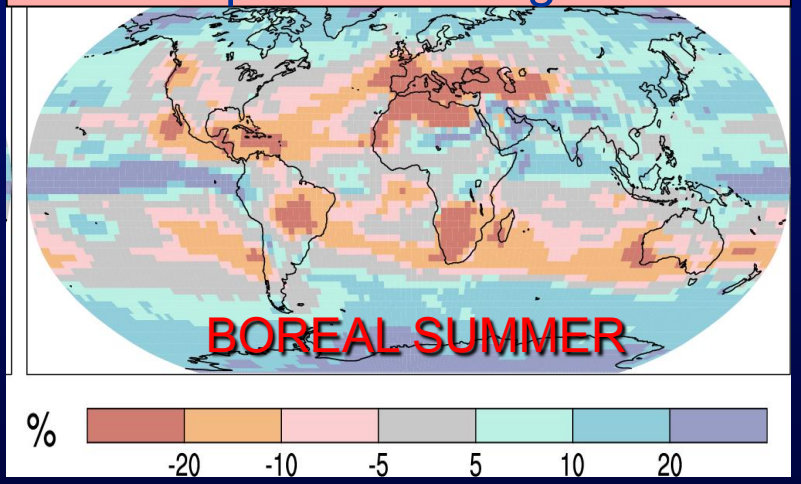
Temperature change JJA



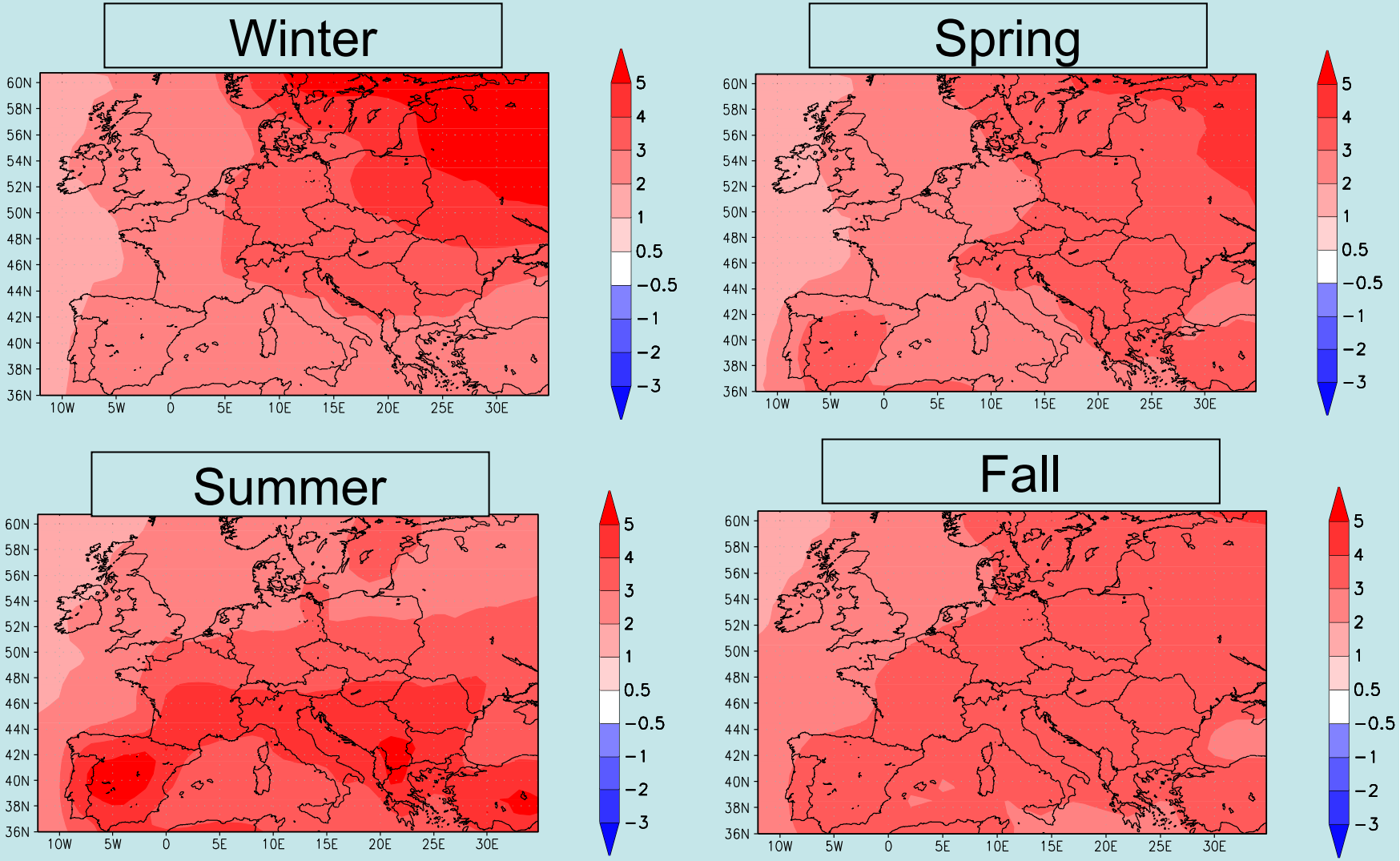
Precipitation change DJF



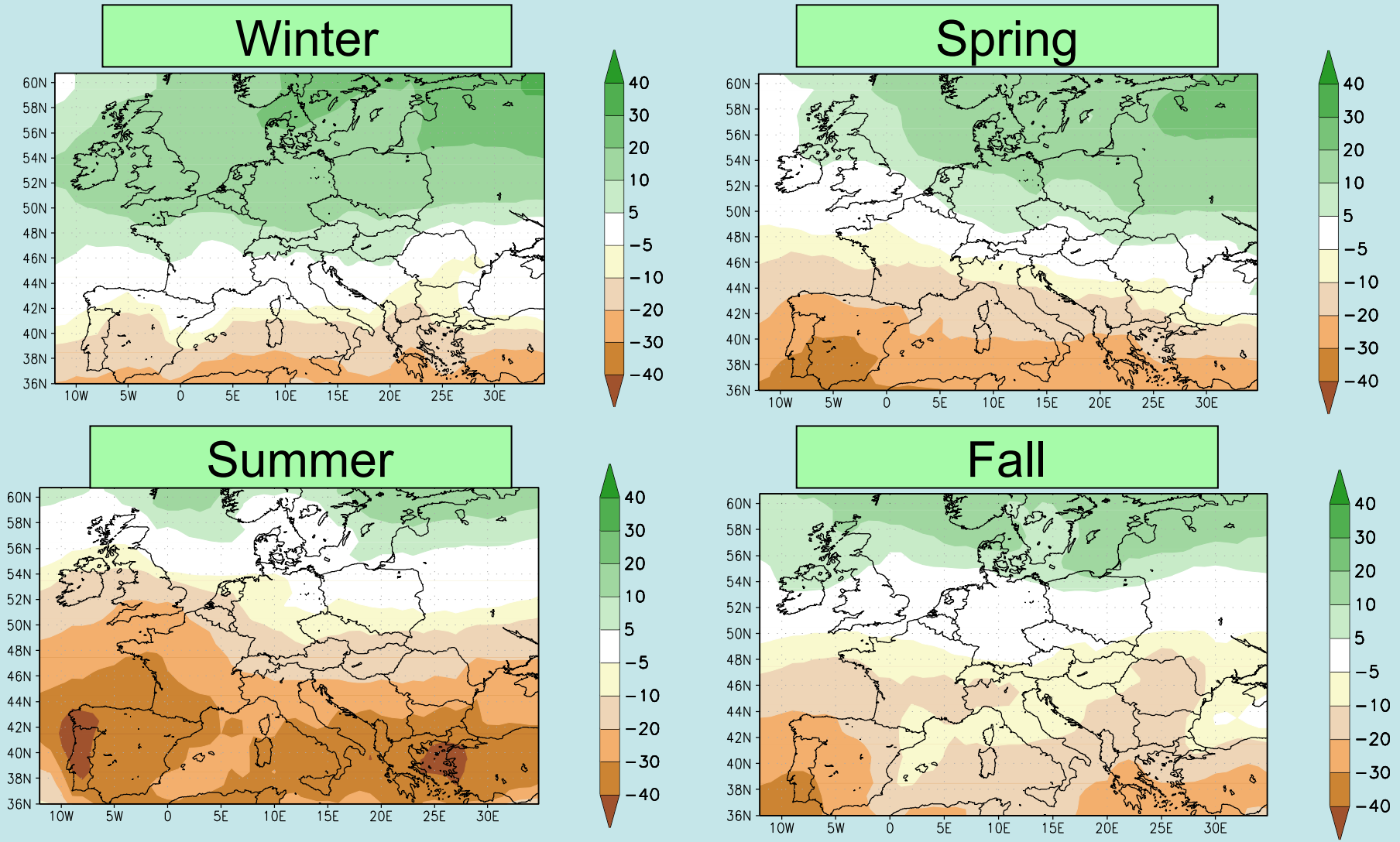
Precipitation change JJA



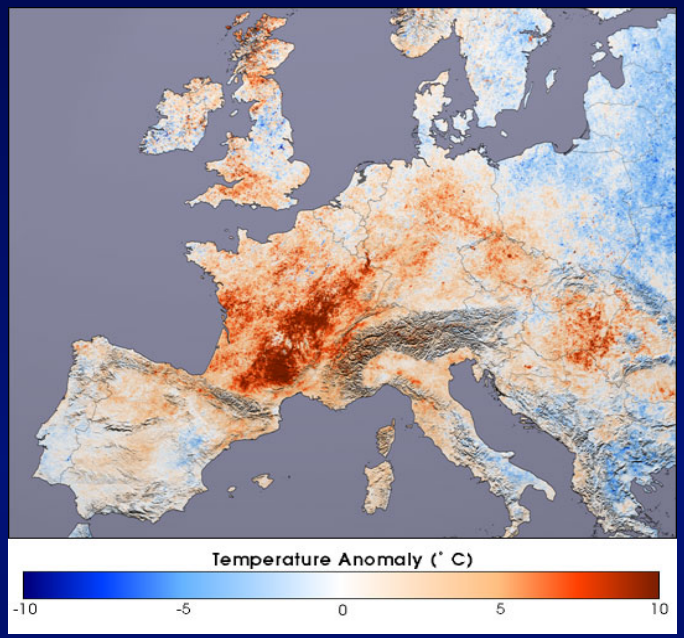
Temperature change, CMIP3
A1B Scenario, 20 AOGCMs

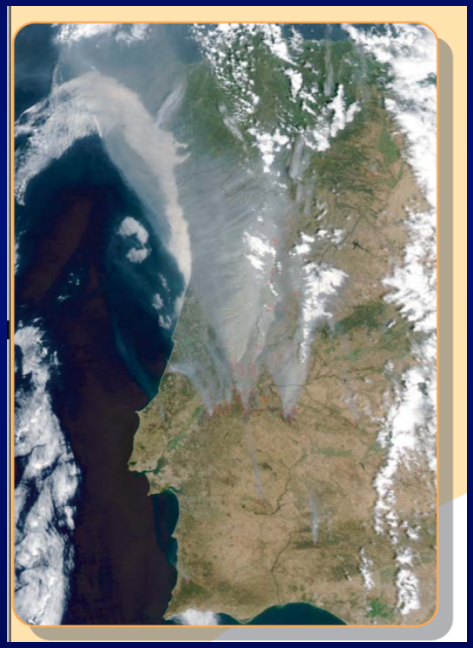


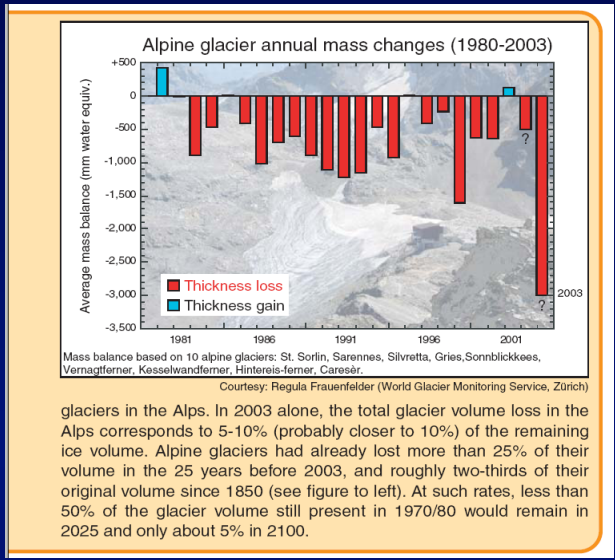
Precipitation change, CMIP3
A1B Scenario, 20 AOGCMs



The summers we can expect in Europe?
Summer of 2003



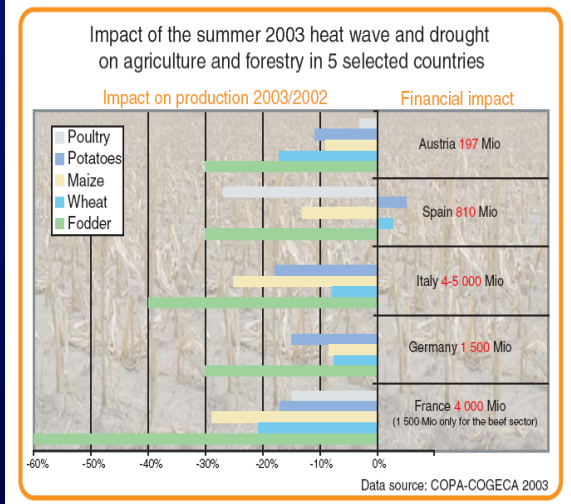




glaciers in the Alps. In 2003 alone, the total glacier volume loss in the Alps corresponds to 5-10% (probably closer to 10%) of the remaining ice volume. Alpine glaciers had already lost more than 25% of their volume in the 25 years before 2003, and roughly two-thirds of their original volume since 1850 (see figure to left). At such rates, less than 50% of the glacier volume still present in 1970/80 would remain in 2025 and only about 5% in 2100.

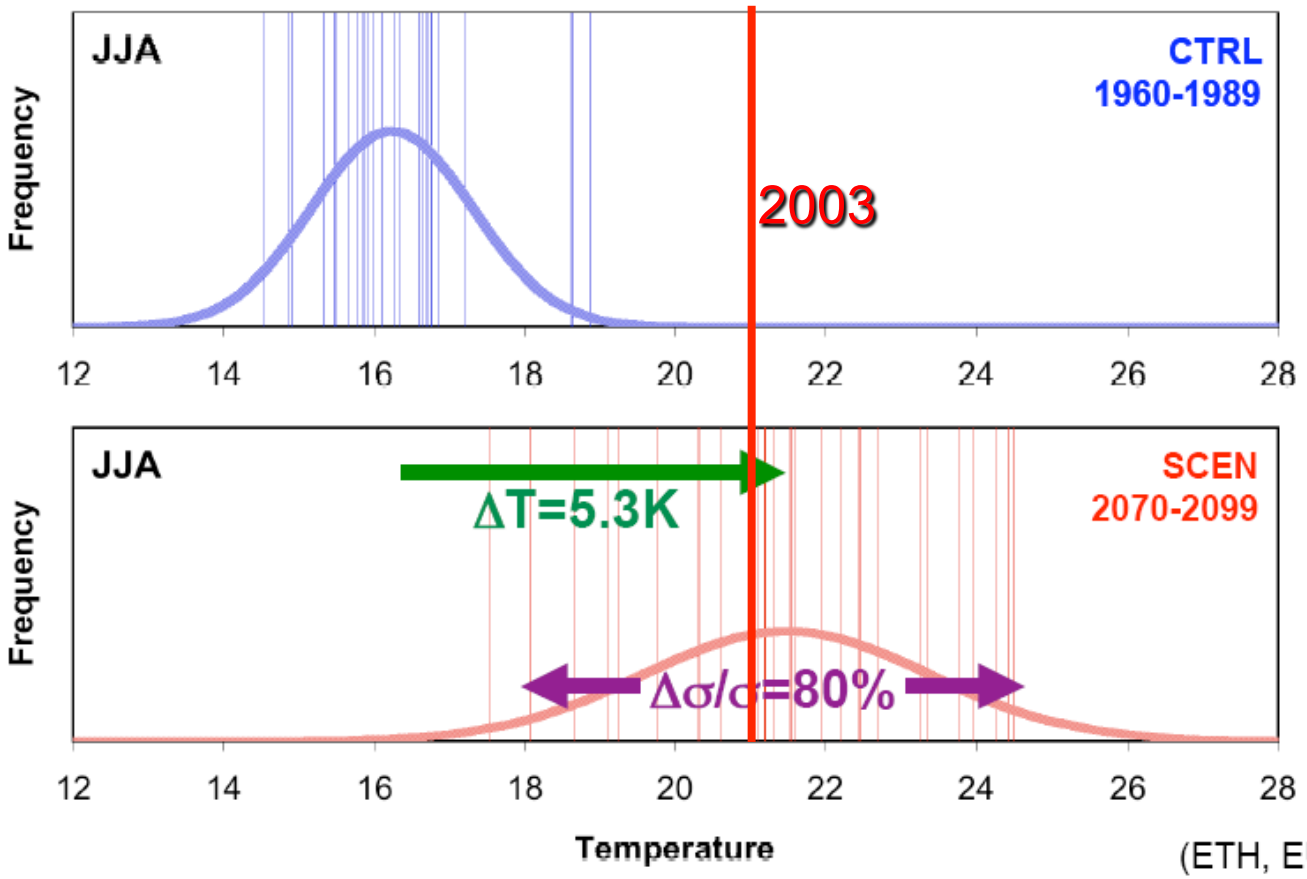
Country	Casualties
France	14 082
Germany	7 000
Spain	4 200
Italy	4 000
UK	2 045
Netherlands	1 400
Portugal	1 300
Belgium	150

INSERM: "Surmortalité liée à la canicule de l'été 2003", AP September 25, 2003



The summer of 2003 may become the norm in the future

Summer Temperatures



Gridpoint near Zurich

Simulated:
T = 15.8 °C
σ = 0.97 °C

Observed:
T = 17.2 °C
σ = 0.94 °C

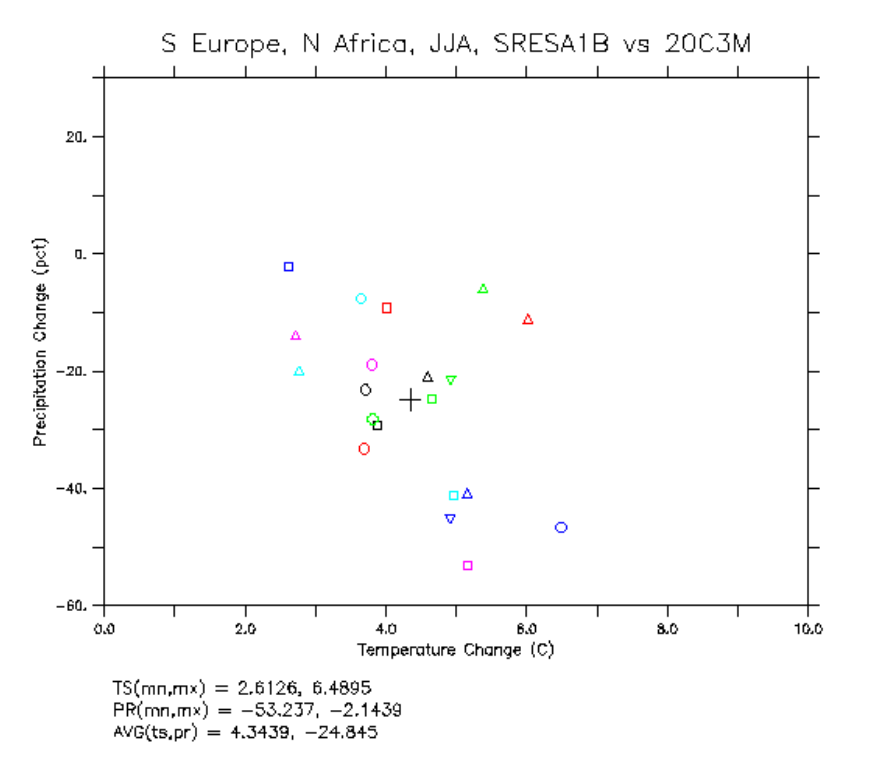
Dramatic increase in variability

(ETH, EU-Project PRUDENCE)

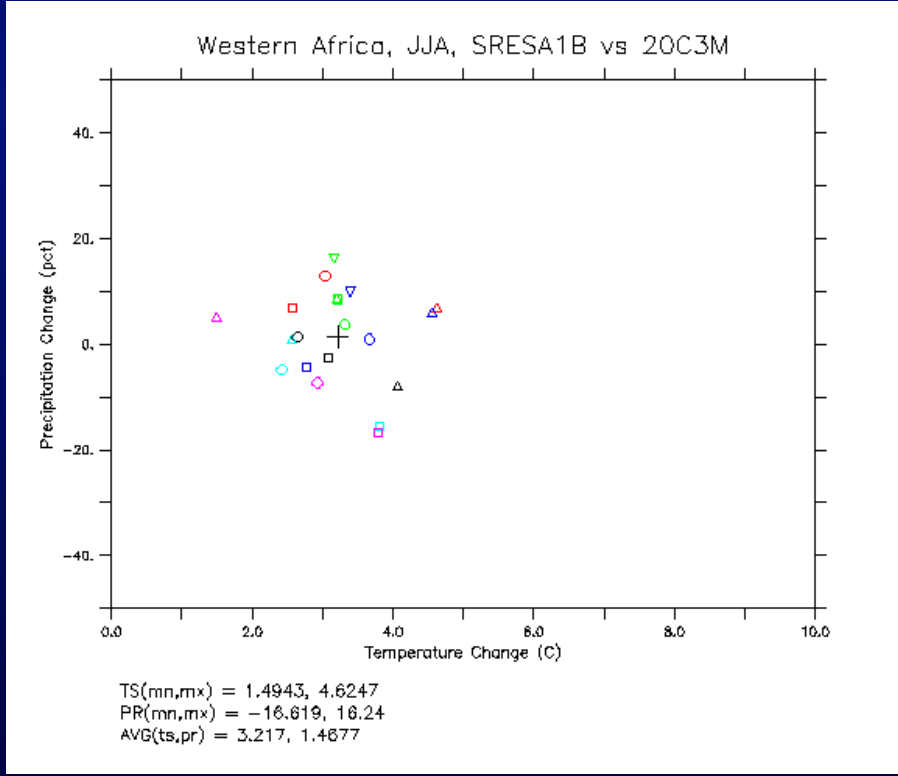
Inter-model uncertainty can be large at the regional scale

Regional precipitation vs. temperature change

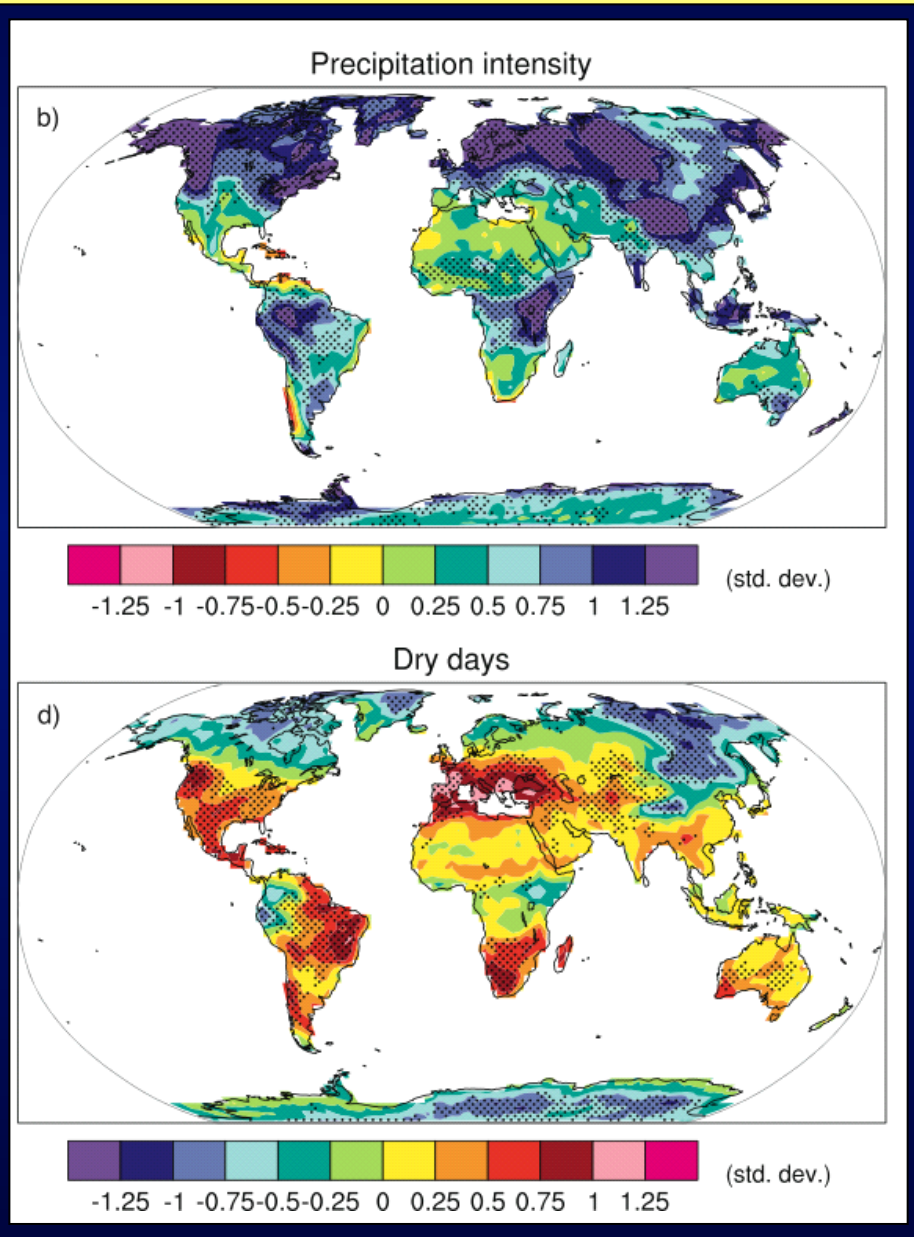
Mediterranean warm season

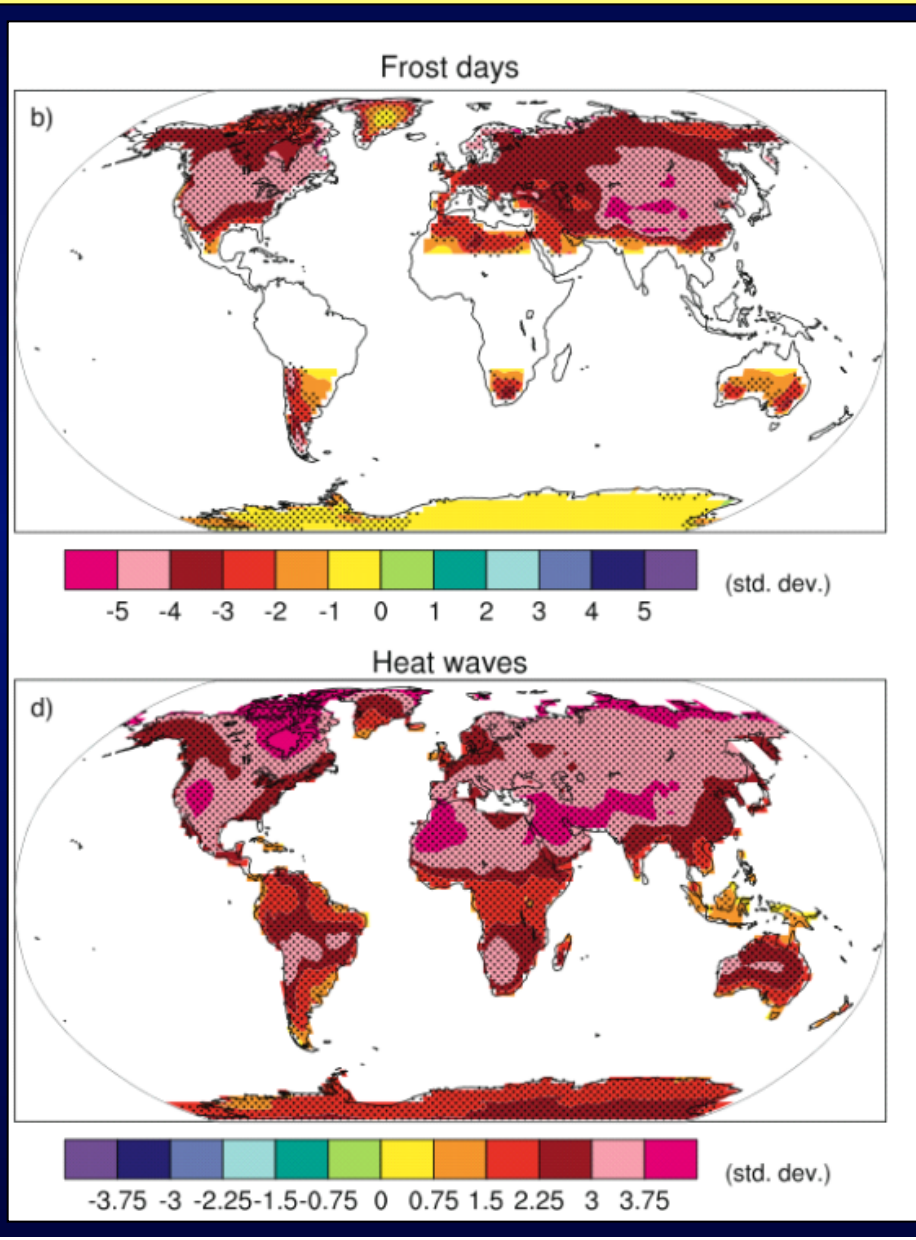


West Africa monsoon season



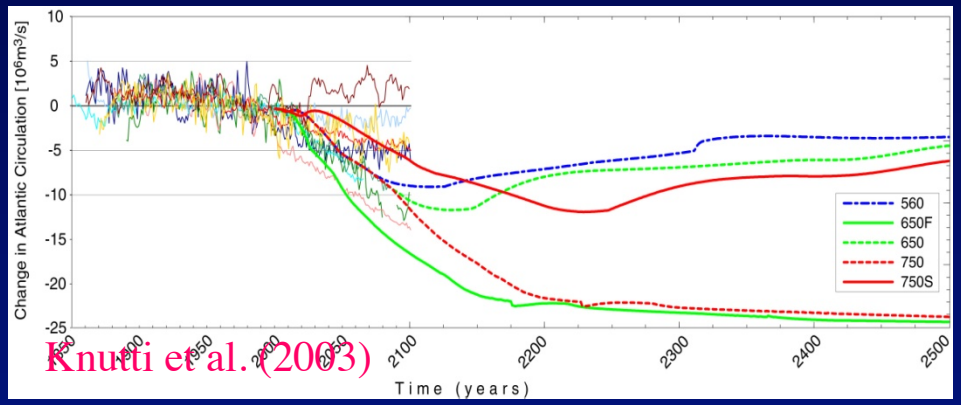
Changes in precipitation characteristics





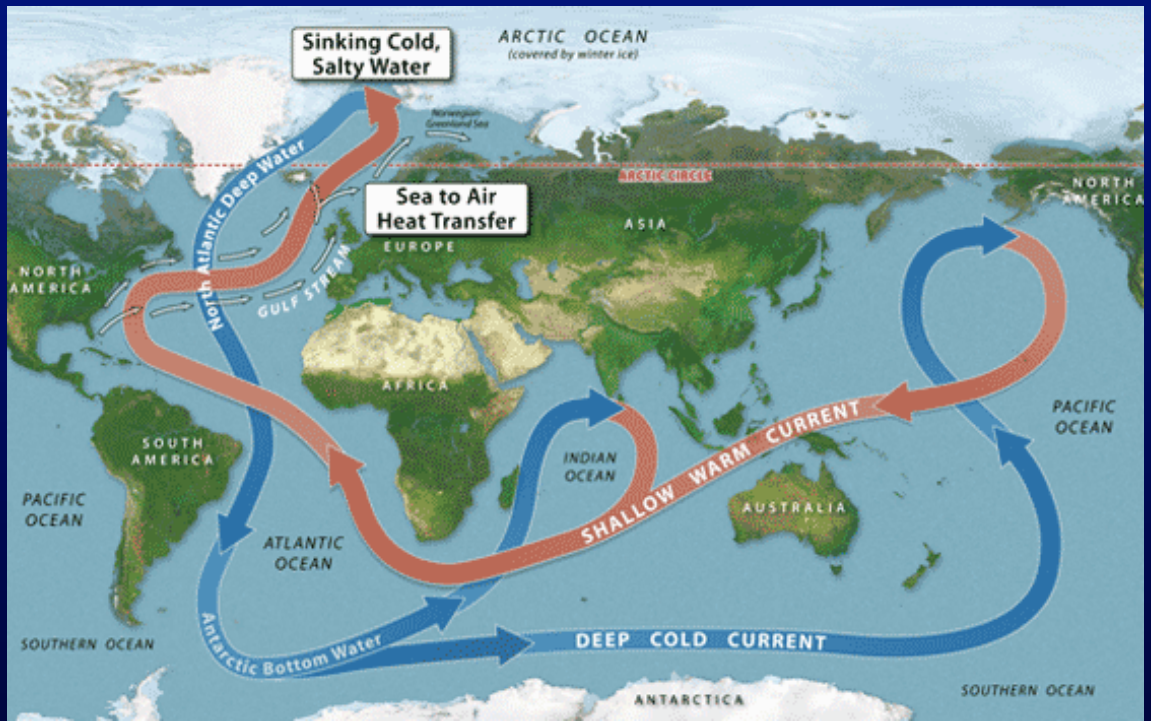
Another glimpse of the future?
August 2010

Sustained warming beyond the 21st century might lead to semi-irreversible changes



Knutti et al. (2003)

Shut down of the oceanic circulation



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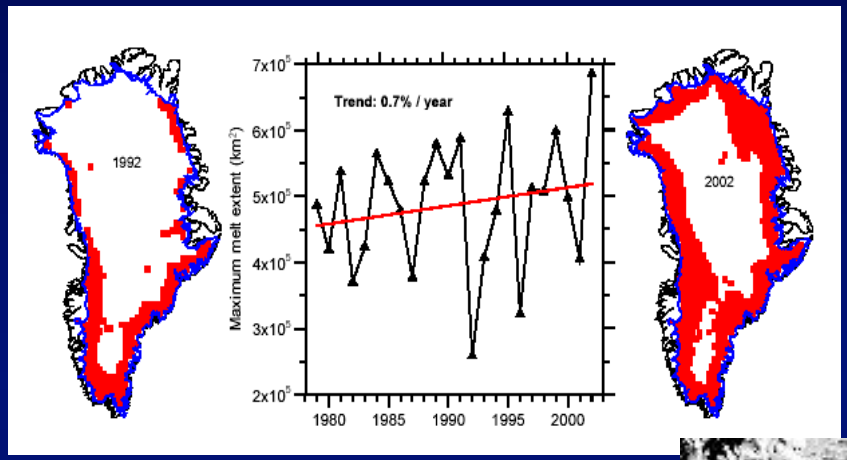
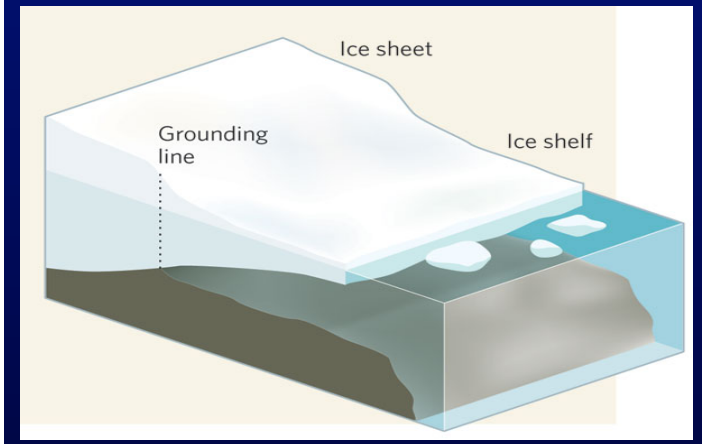
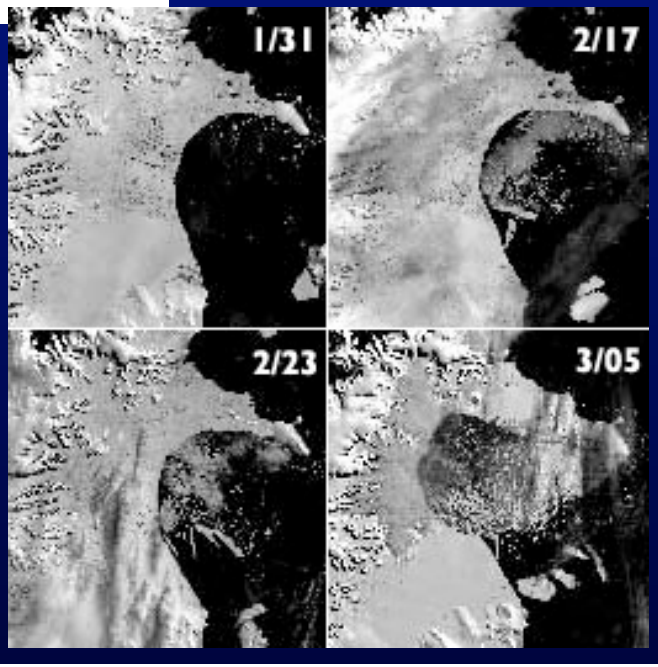


Melting of Greenland and the West Antarctica ice sheet (sea level rise > 12 m)

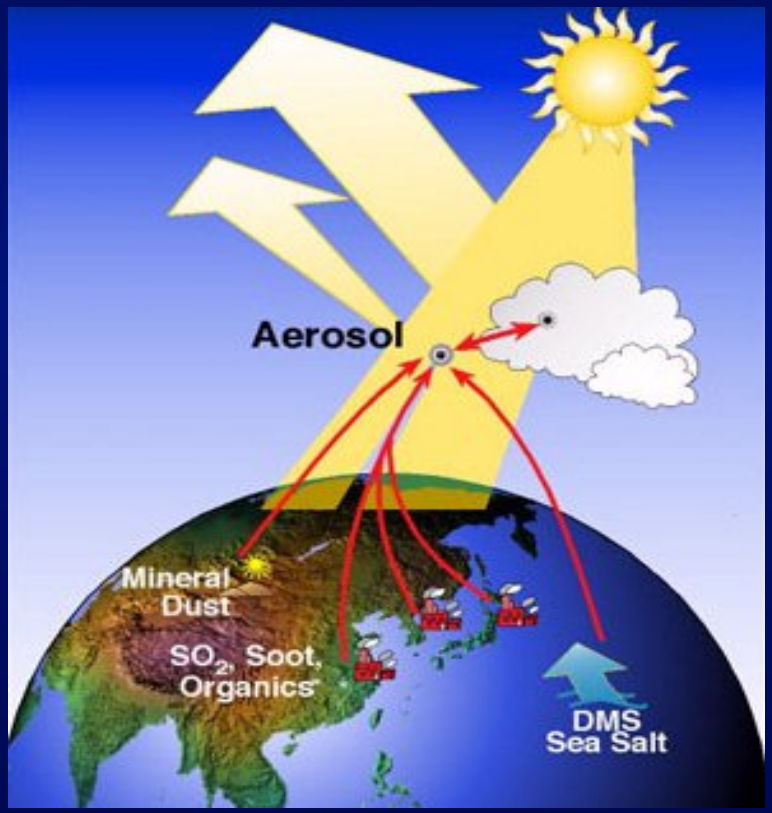


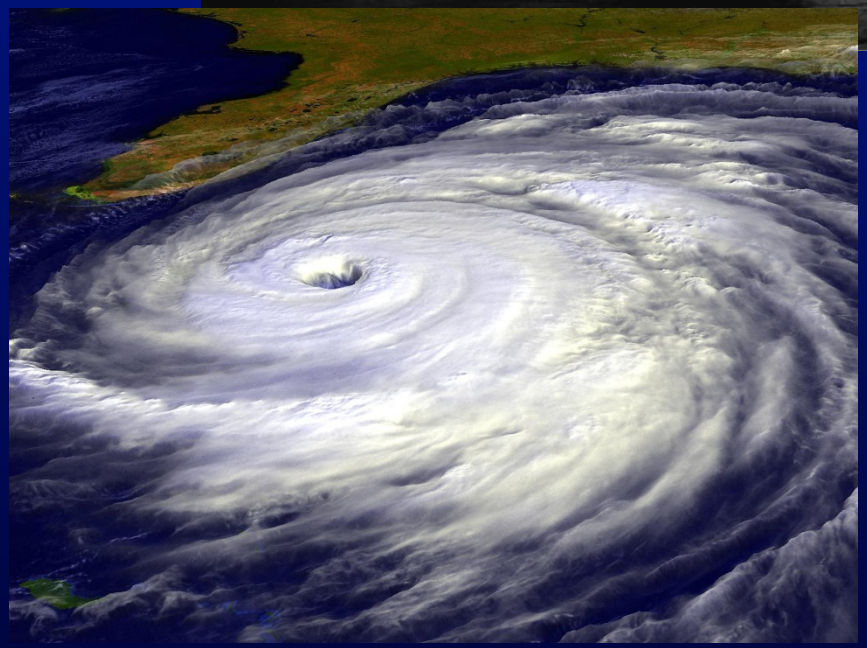


2002: Collapse of the Larsen-B Ice-Shelf

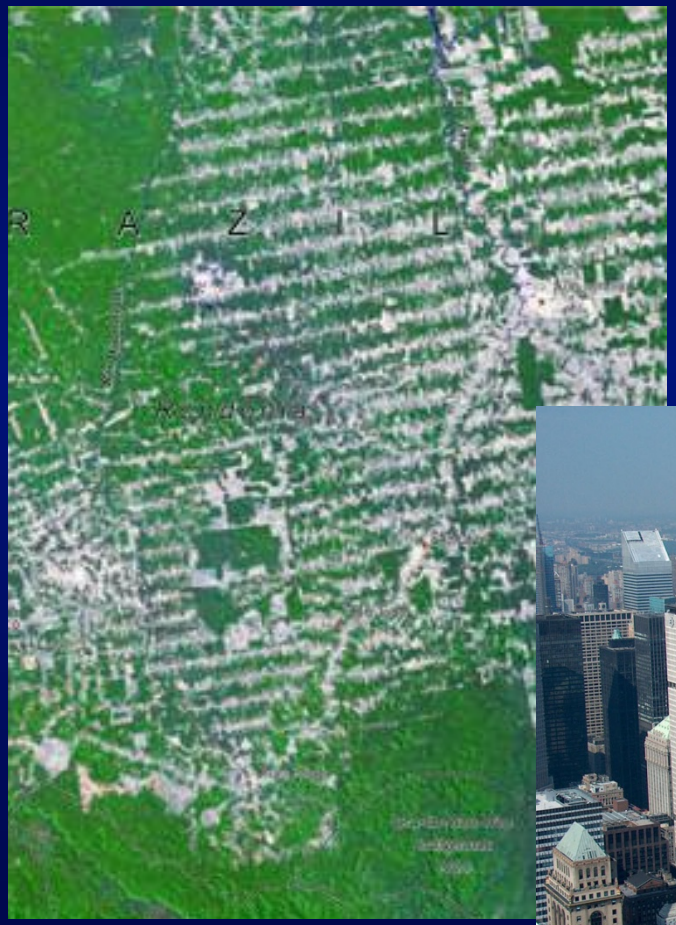
Question 6: What are key uncertainties ?

Effects of clouds, aerosols and tropical convection

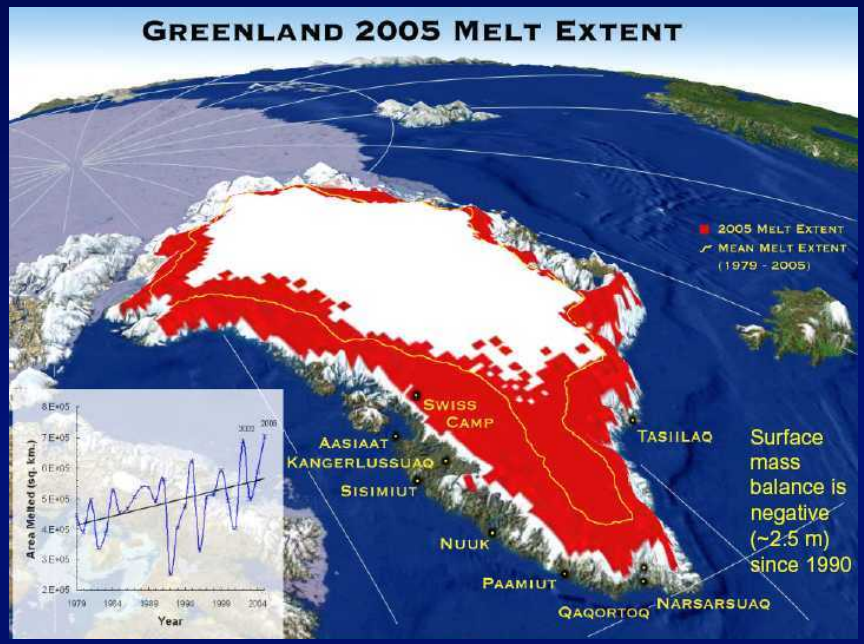


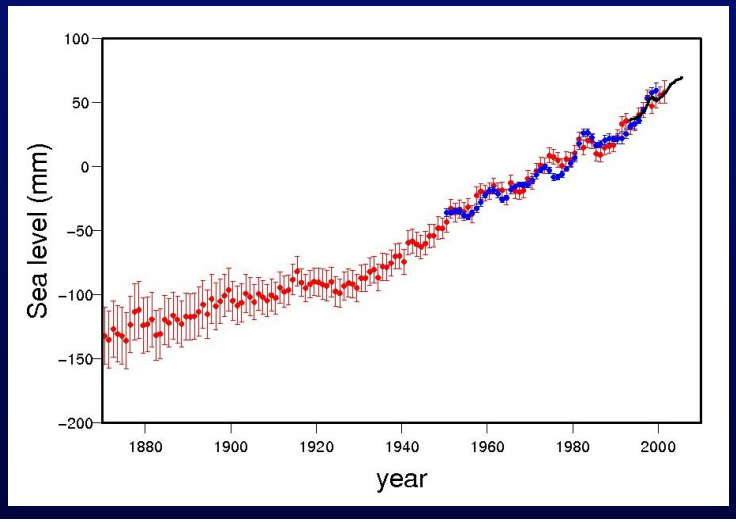


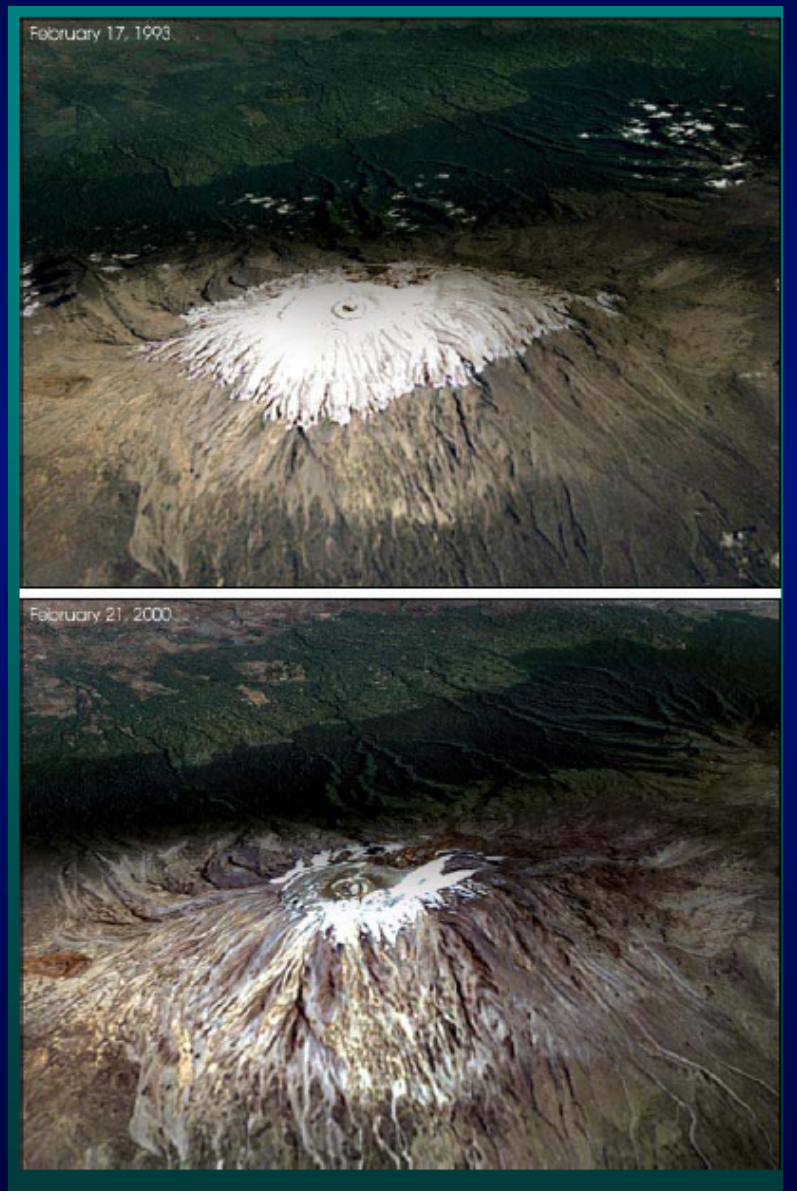
Land use change and carbon cycle



Sea level rise

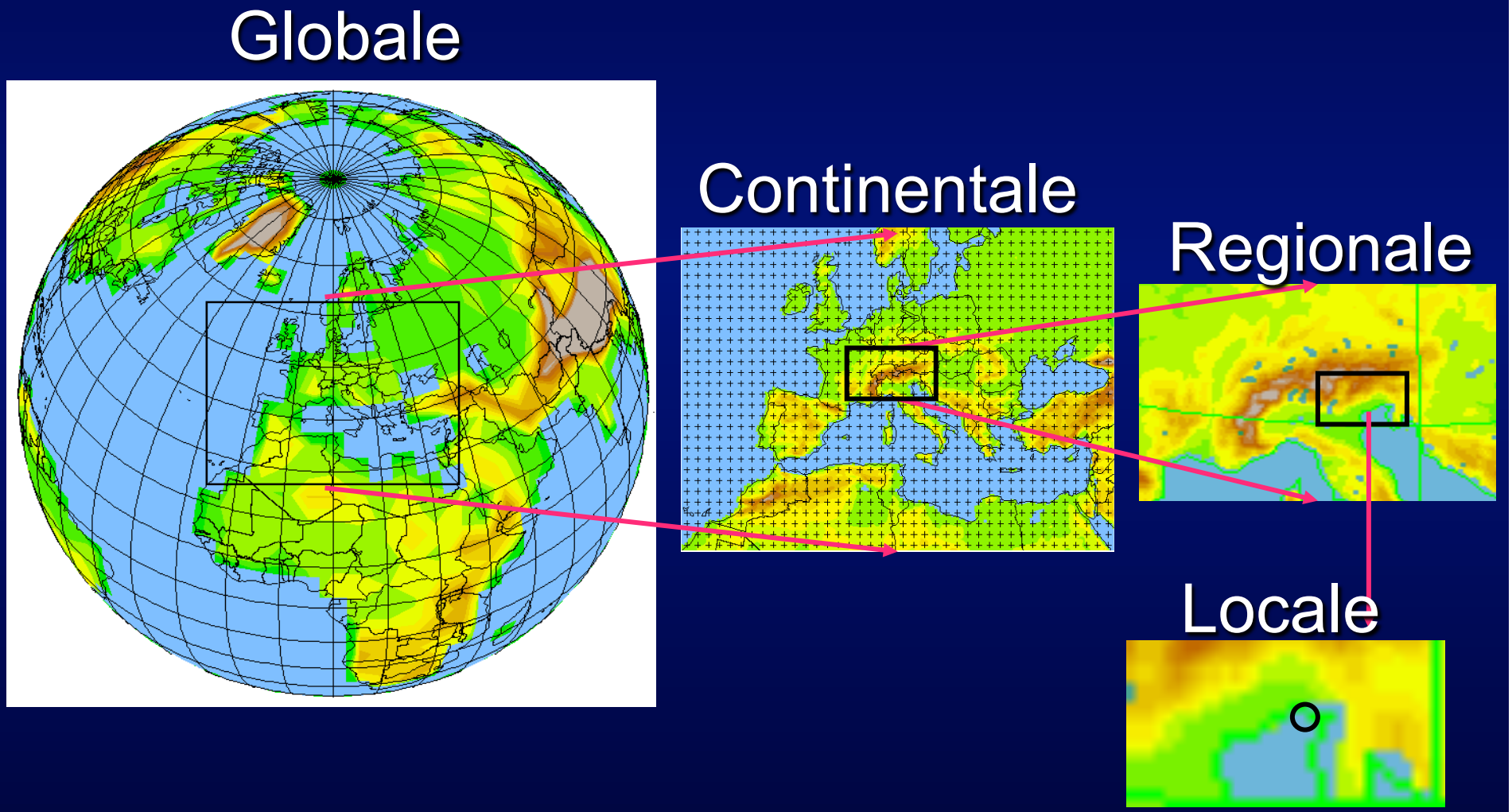






Greenhouse gas emission scenarios

Projections at regional to local scales



Lecture outline: 6 Answers

- Is the atmospheric concentration of greenhouse gases (GHG) increasing because of human activities and why should this cause global warming? **YES**
- Is global warming (and other related climatic changes) happening? **YES**
- Is the observed global warming due to increases in anthropogenic GHG concentrations or to natural factors? **Very likely to anthropogenic GHG**
- Are climate models good for anything? **YES, but they do have problems**
- What can we expect for the future (climate change projections)? **Serious effects depending on the path of GHG emissions.**
- What are key uncertainties? **There still a number of them**

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THANK YOU