The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2022-9

Workshop on Theoretical Ecology and Global Change

2 - 18 March 2009

Climate Change

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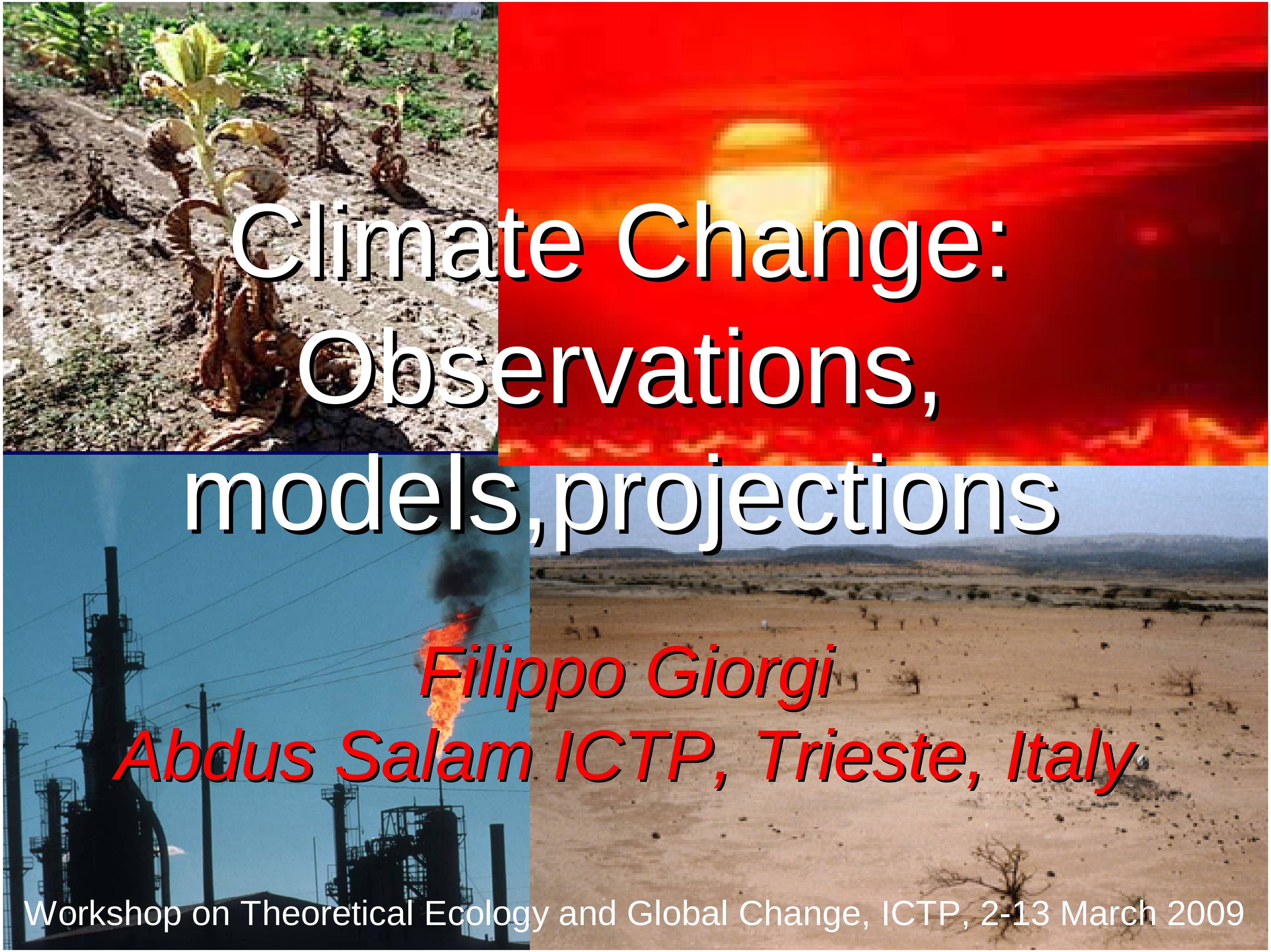
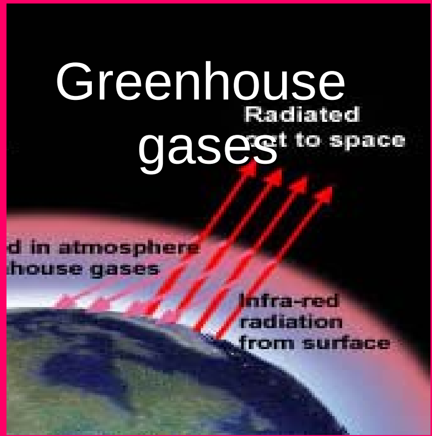


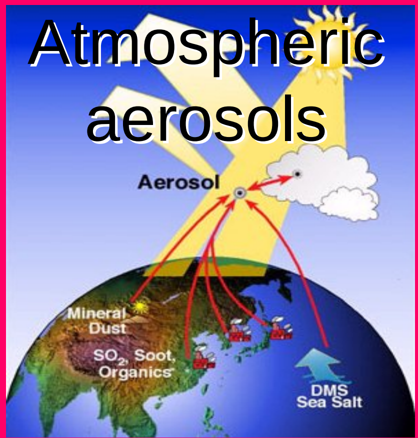
Climate Change: Observations, models,projections

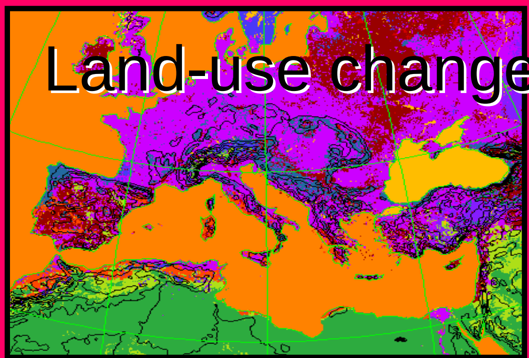
Filippo Giorgi
Abdus Salam ICTP, Trieste, Italy

Workshop on Theoretical Ecology and Global Change, ICTP, 2-13 March 2009

Human factors

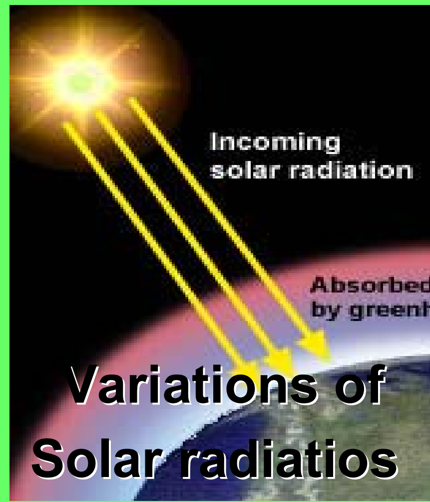


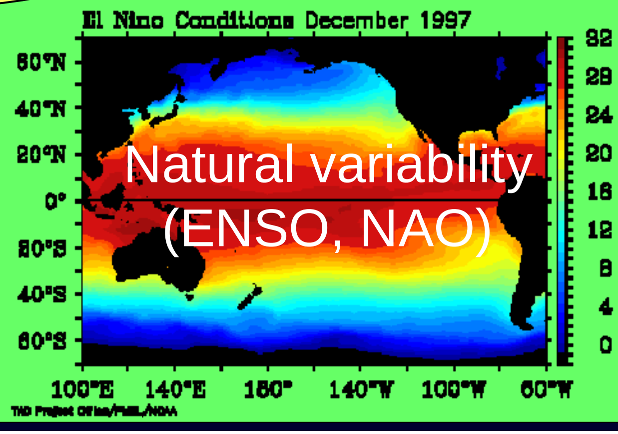




The earth's climate can change because of anthropogenic or natural factors

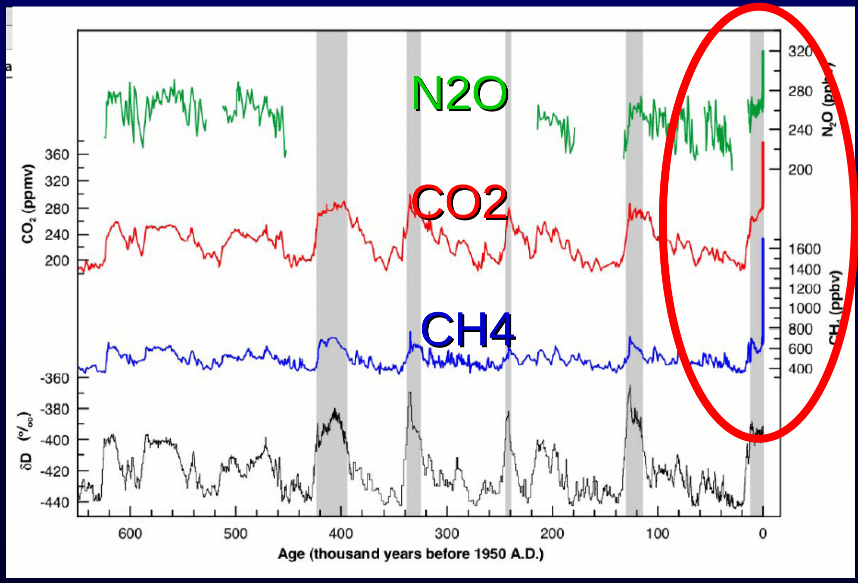
Natural factors

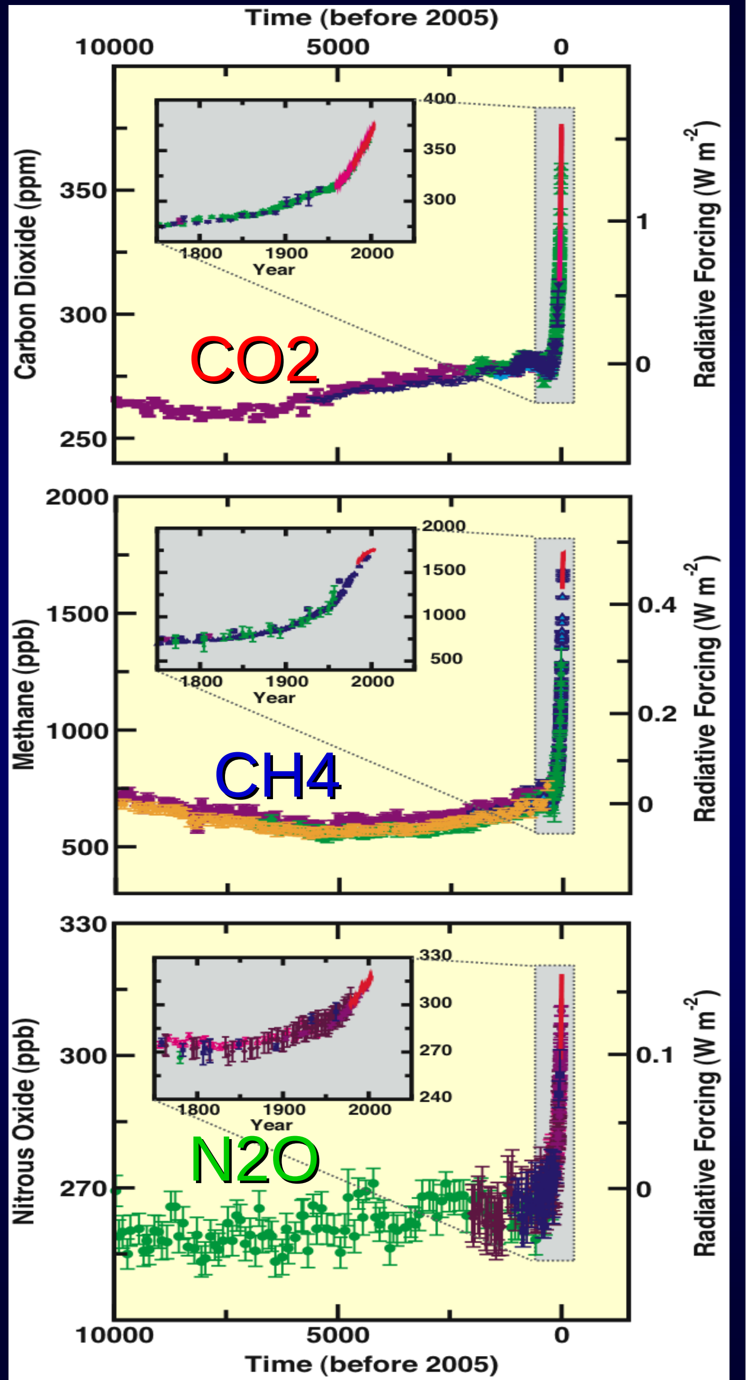




Climate has changed naturally in the past but a new perturbation has occurred since the beginning of the industrial revolution

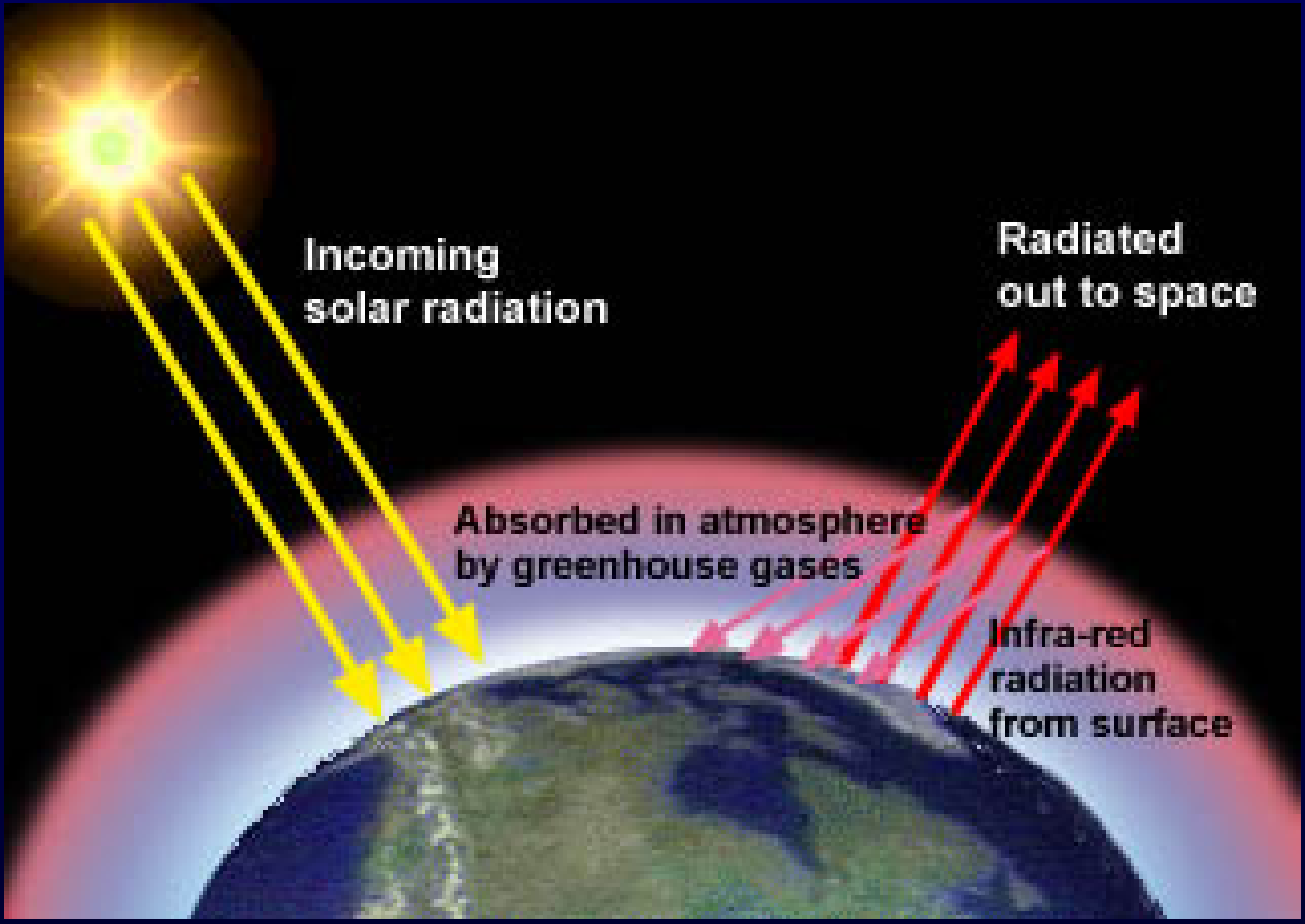
The greenhouse gas concentration
is higher than in the last 650000 years
and continues to increase
mostly due to human activities.



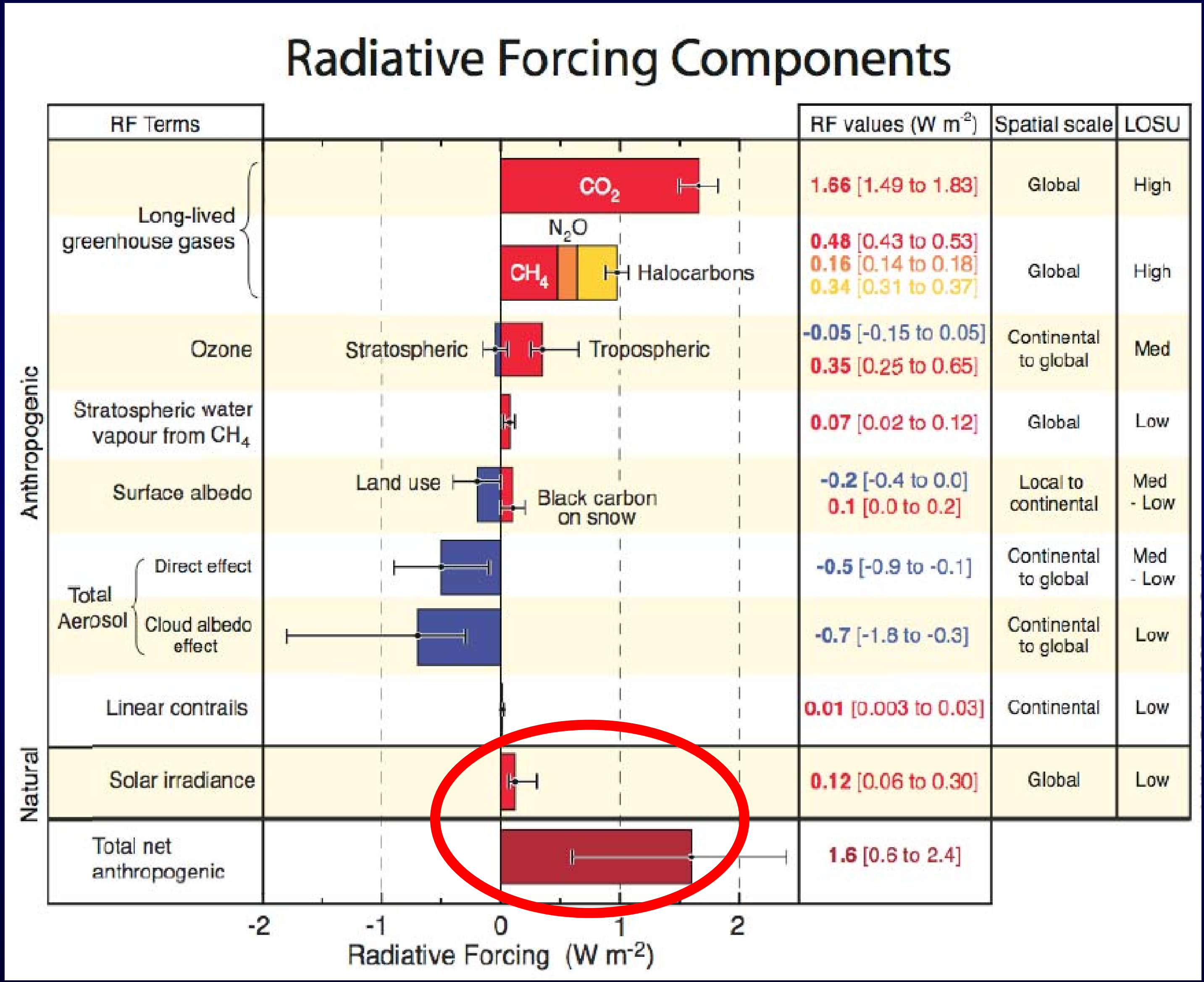


The Greenhouse Effect

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



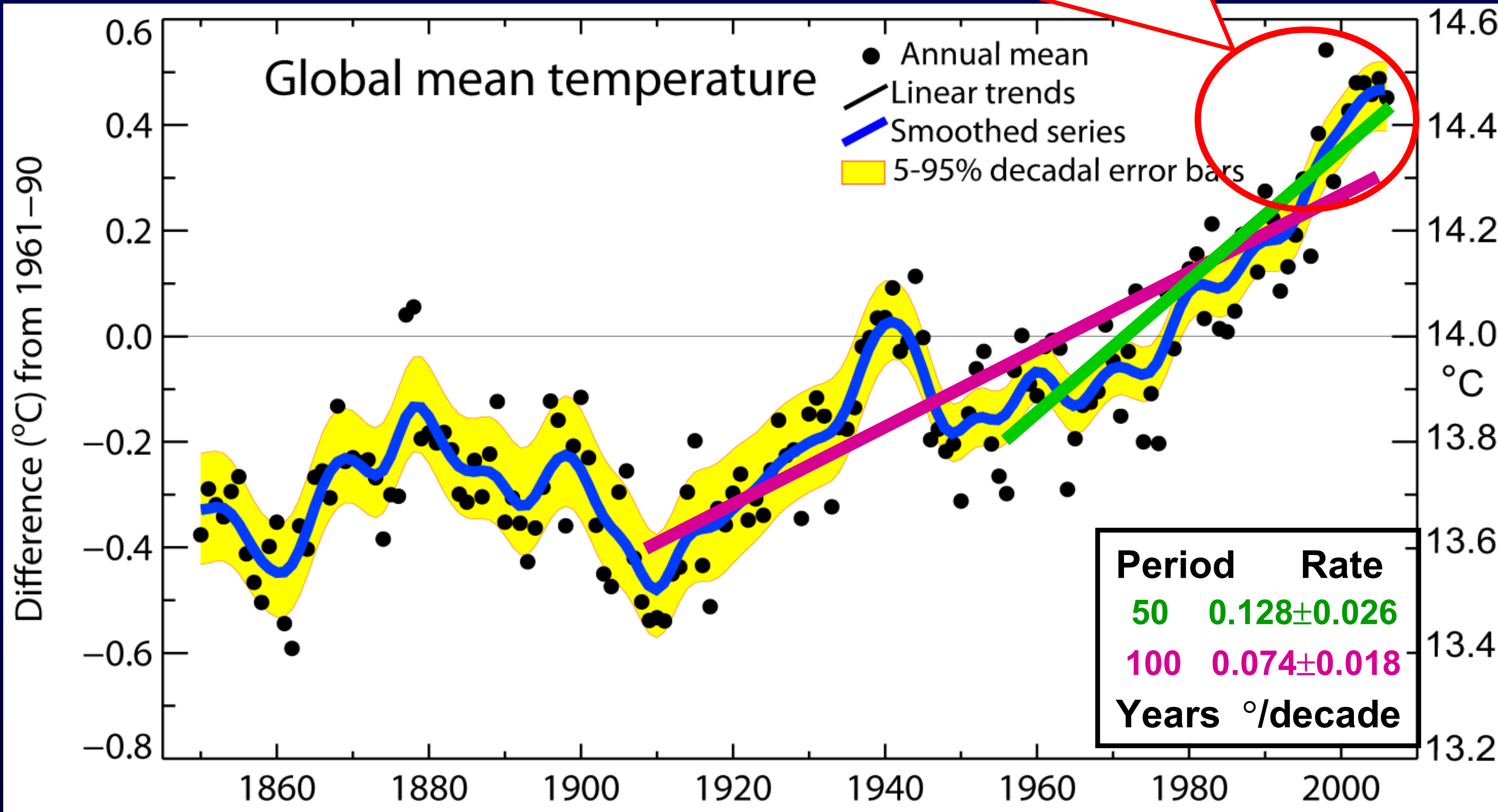
Anthropogenic and natural forcings from 1750 to 2005



The observational evidence of climate change

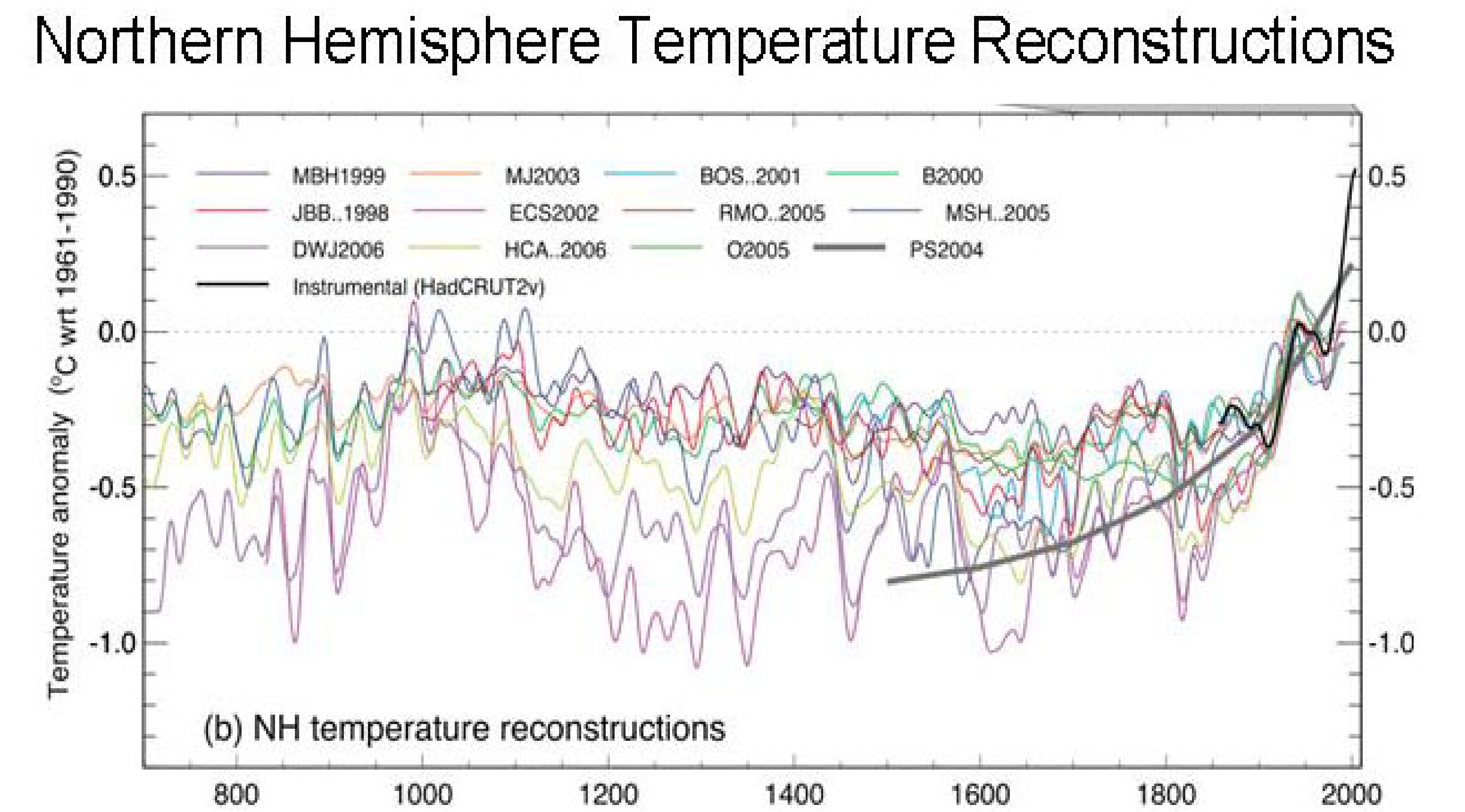
Observed change in global surface temperature

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

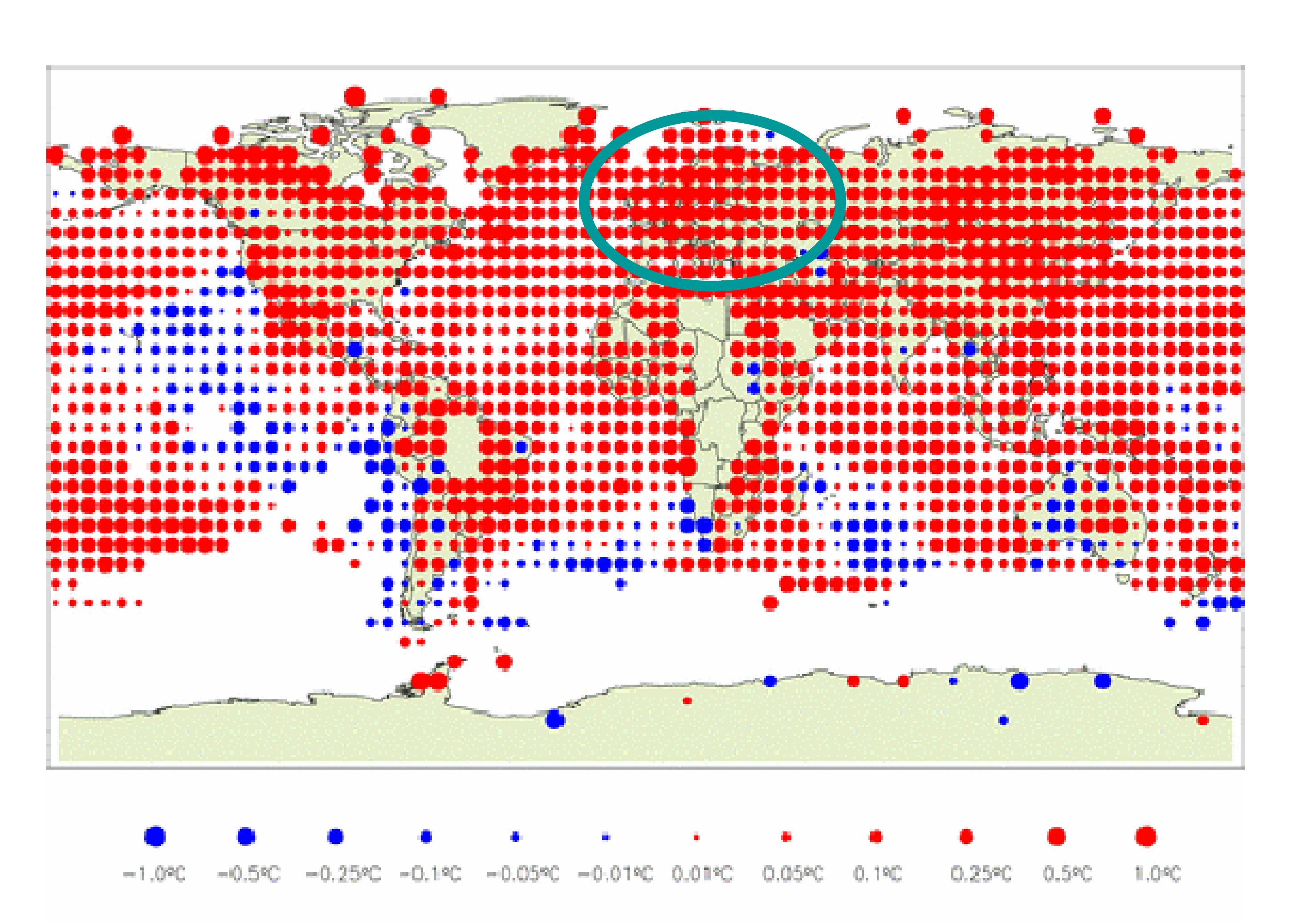


Paleoclimate: Evidence from different types of past data

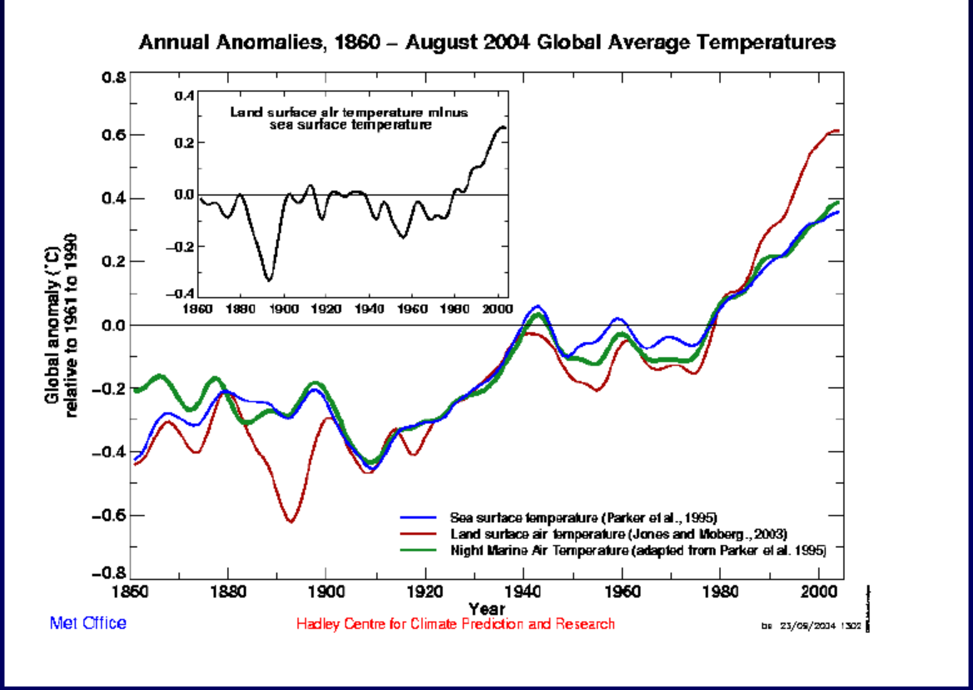
The last 50 years are likely the warmest during the past 1300 years



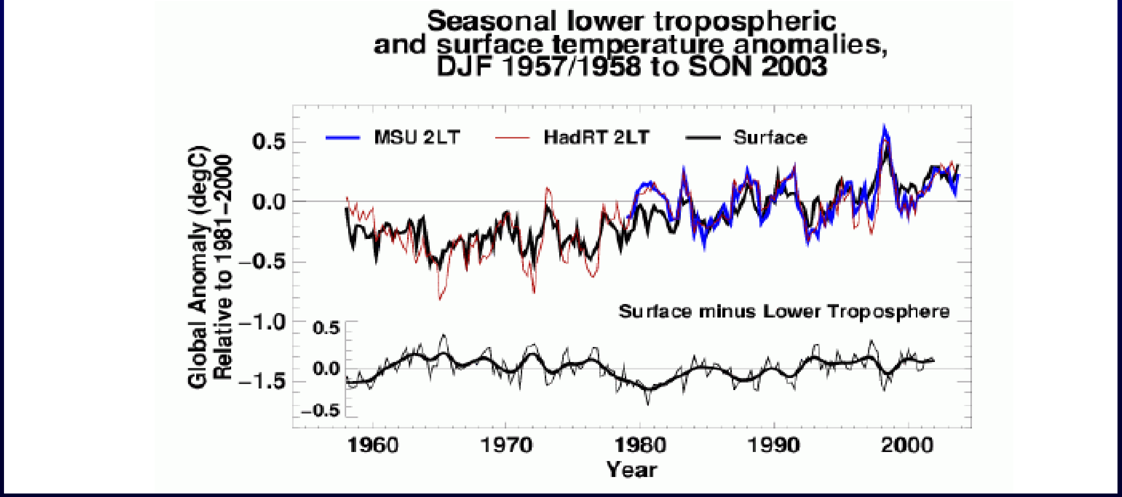
Regional scale: Observed temperature change for the period 1979-2003



Global tropospheric and ocean warming



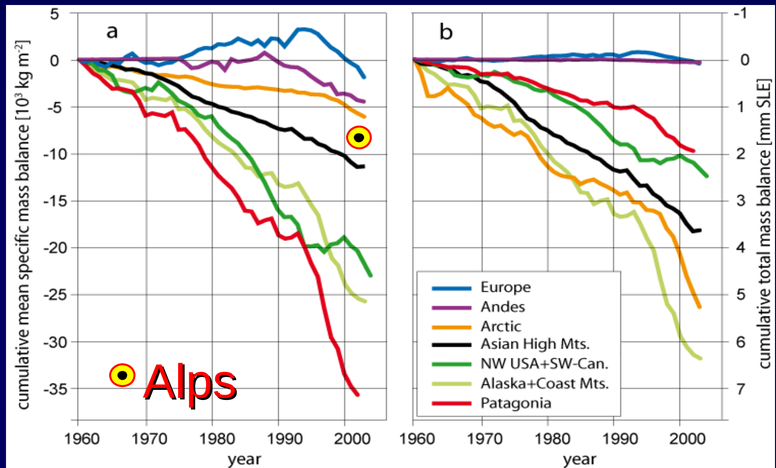
The global ocean warming (blue line) is slightly less than the continental warming (red line)



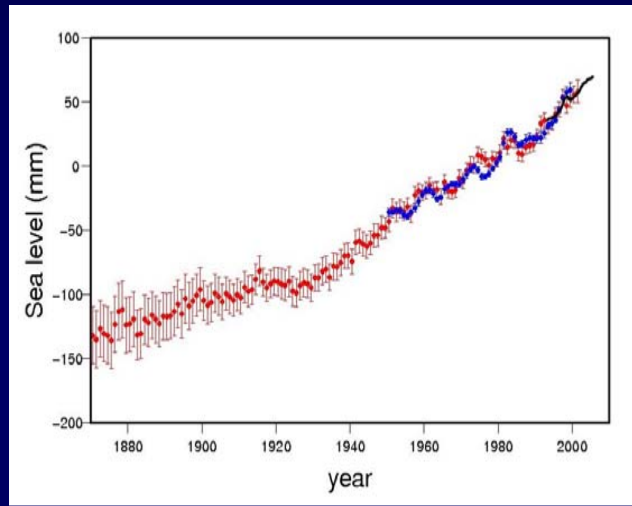
The global tropospheric warming is consistent with the surface warming

Decrease of snow cover, sea ice and glaciers, sea level rise

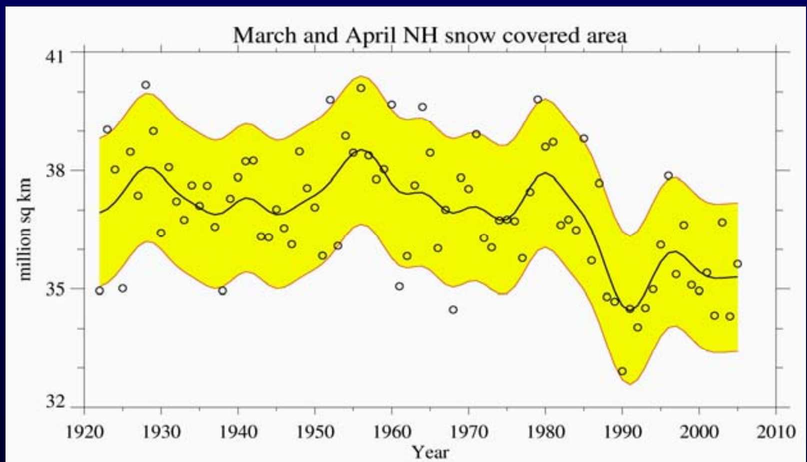
Melting of glaciers



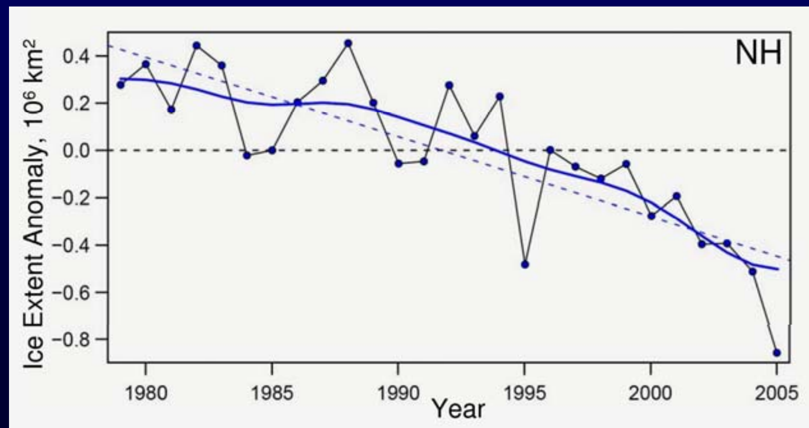
Sea level rise



Decrease of snow cover

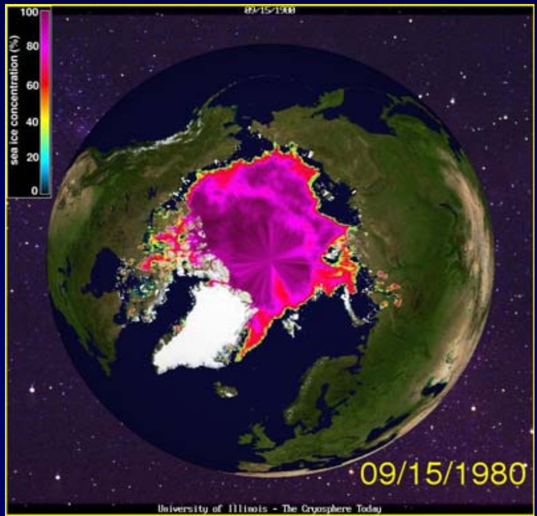


Decrease of sea ice

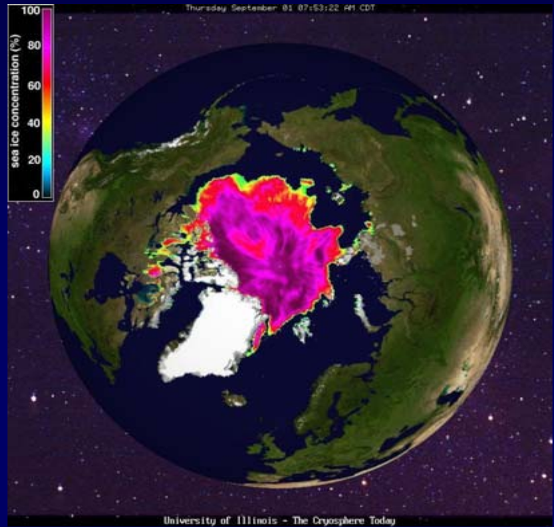


Melting of the Arctic cap

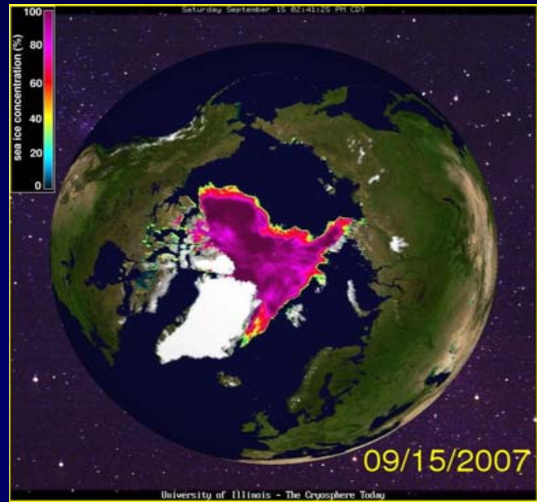
15 September 1980

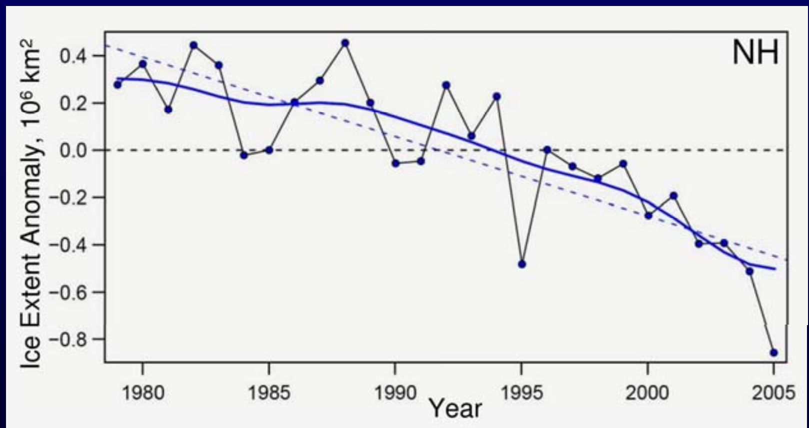


15 September 2005

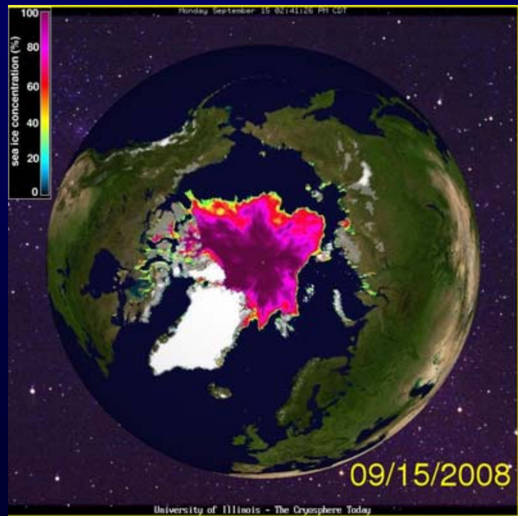


15 September 2007

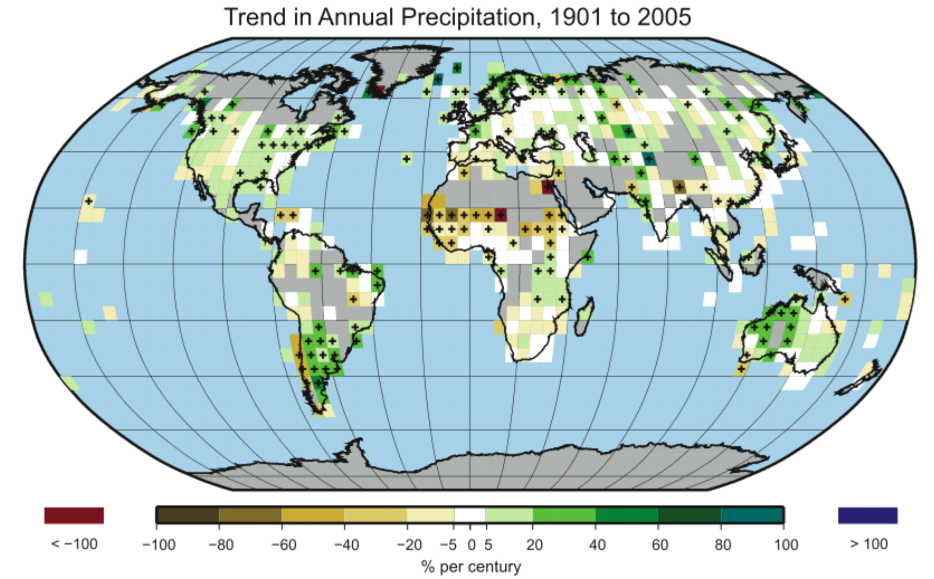


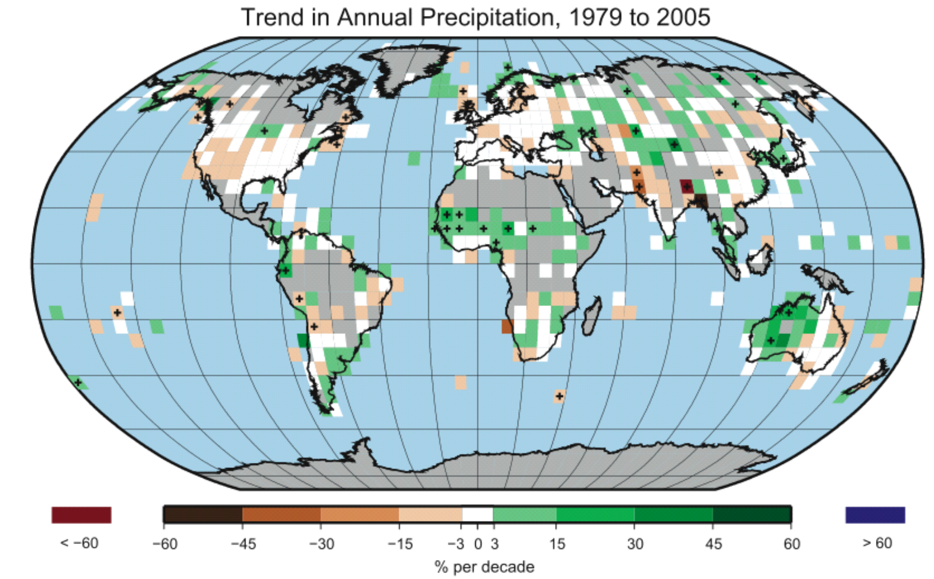


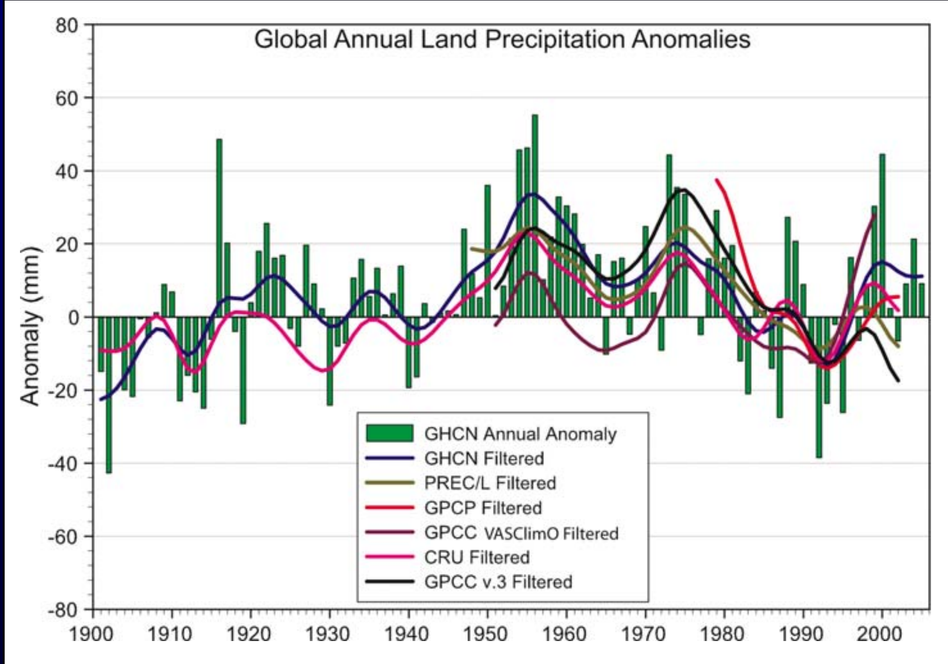
15 September 2008



Observed precipitation trends







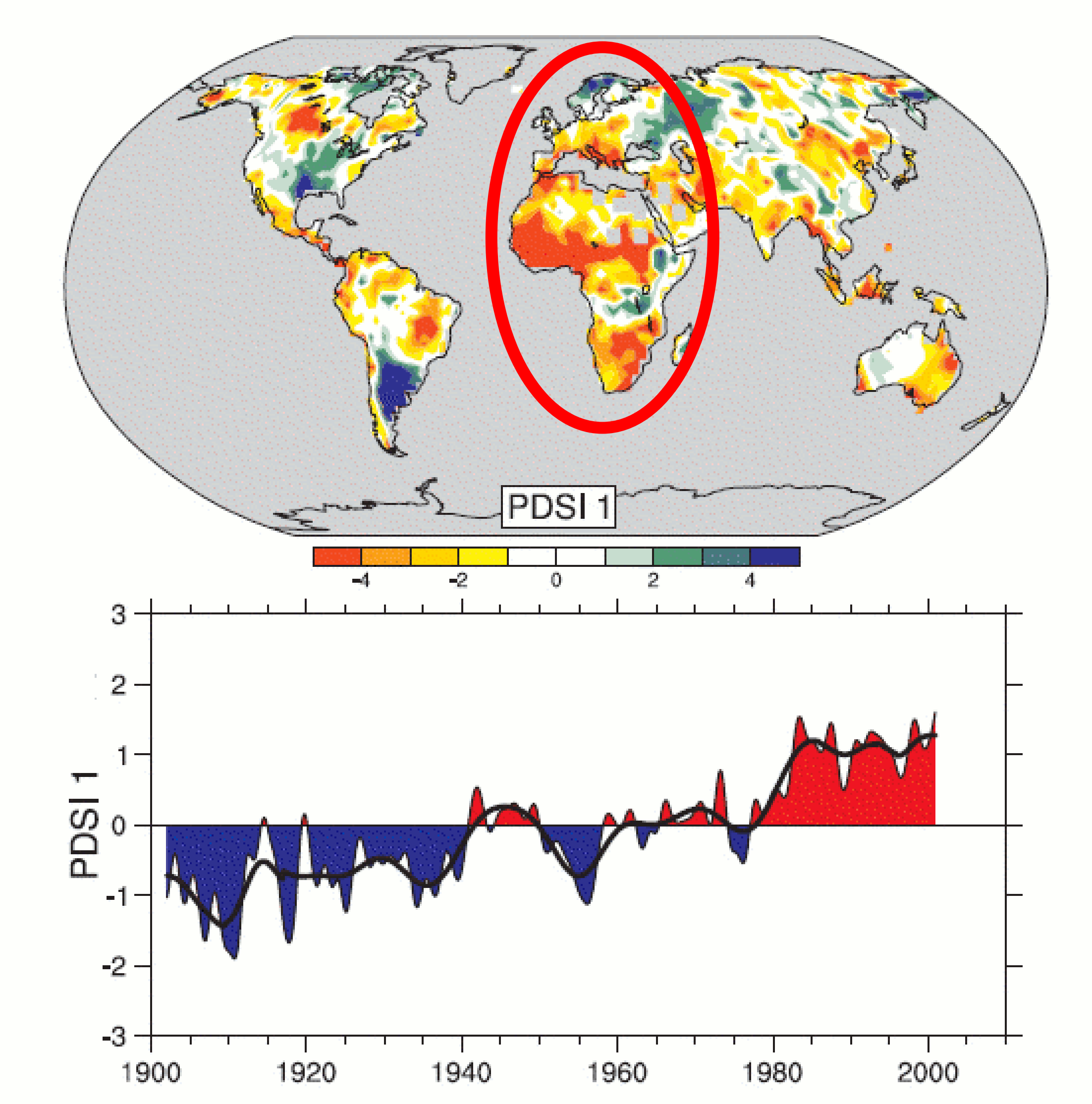
Other observed changes
Temperature and precipitation extremes

Increased frequency
of heavy precipitation events

Warmer and more hot days,
warmer and fewer cold days

Increased frequency of
heat waves

Other observed changes
Droughts



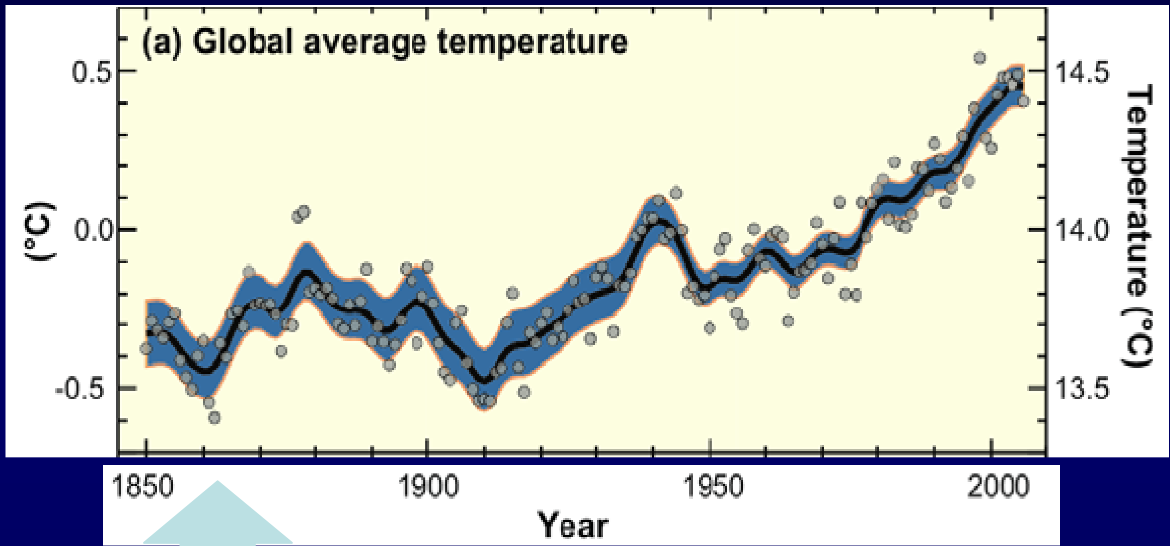
Increase in length and intensity of droughts as measured by the PDSI

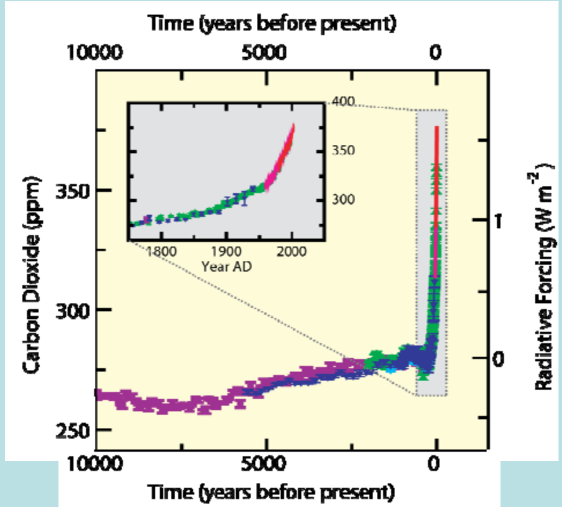
IPCC-2007

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

What has caused 20th Century global warming?

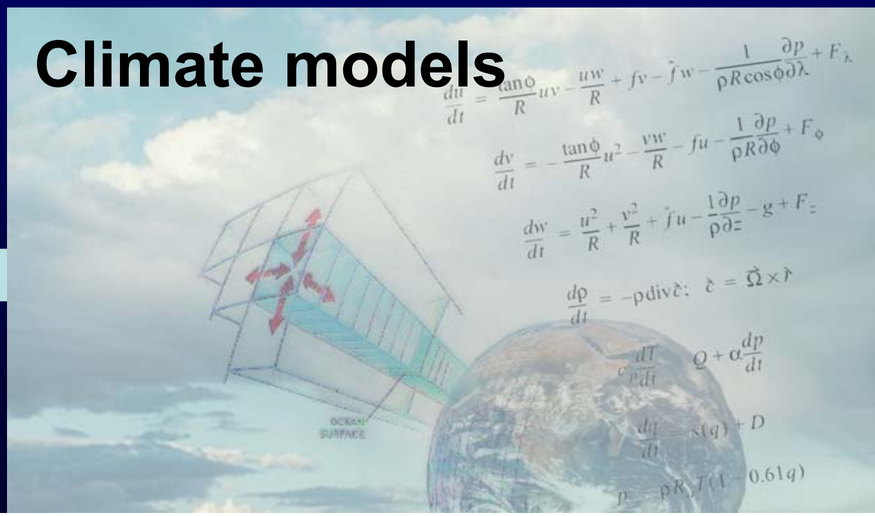
"Fingerprinting" of the anthropogenic effects

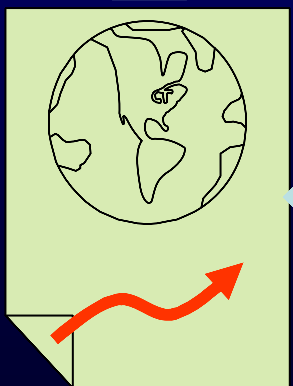




- other GHGs
- aerosols
- volcanic
- solar
- natural internal

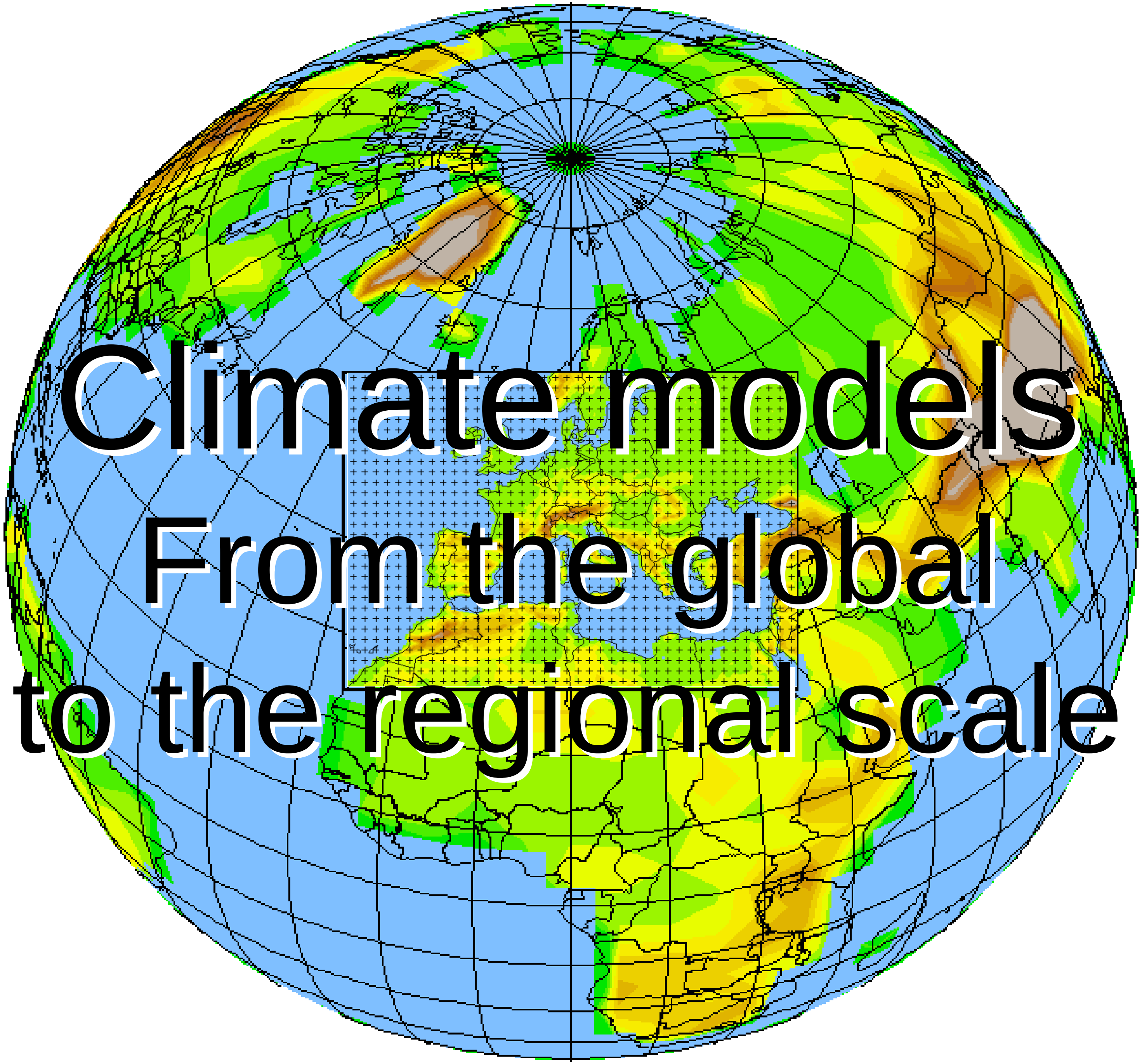
Climate models





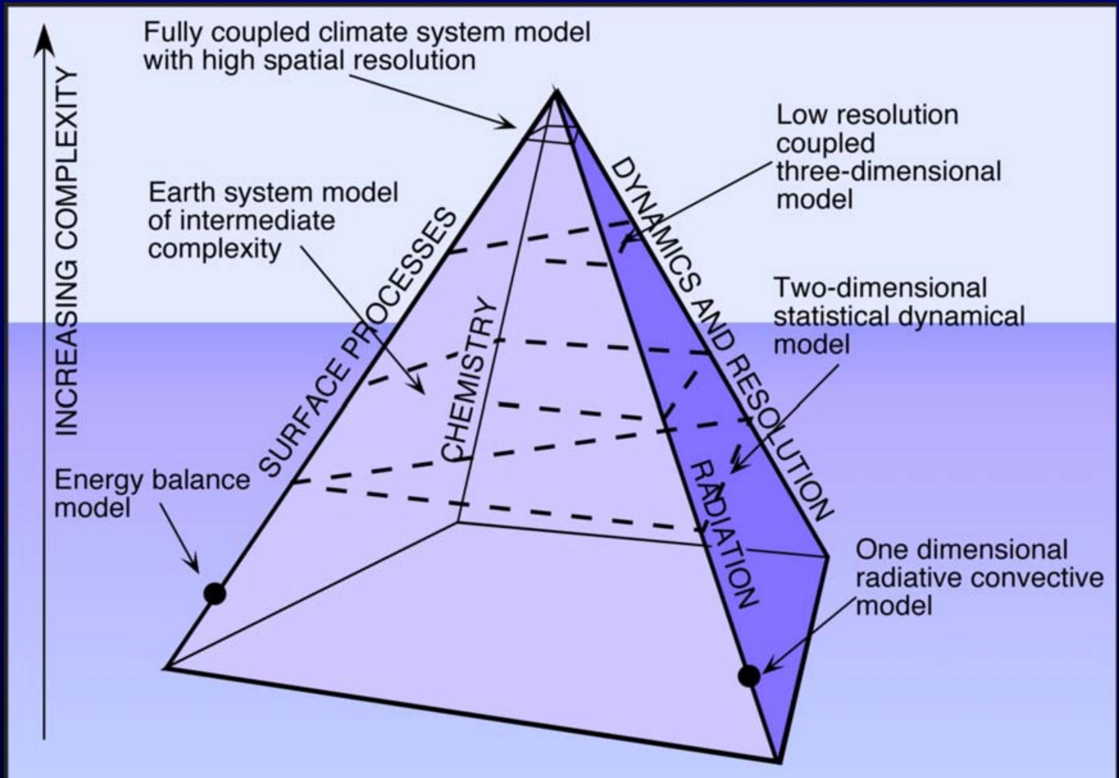
Climate models

From the global
to the regional scale



A hyerarchy of models of increasing complexity is currently used to study climate variability and change

The climate modeling "Pyramid"



Earth System Models

↑

General Circulation Models (GCMs)

↑

Intermediate complexity models

↑

Simple models

The equations of a climate 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

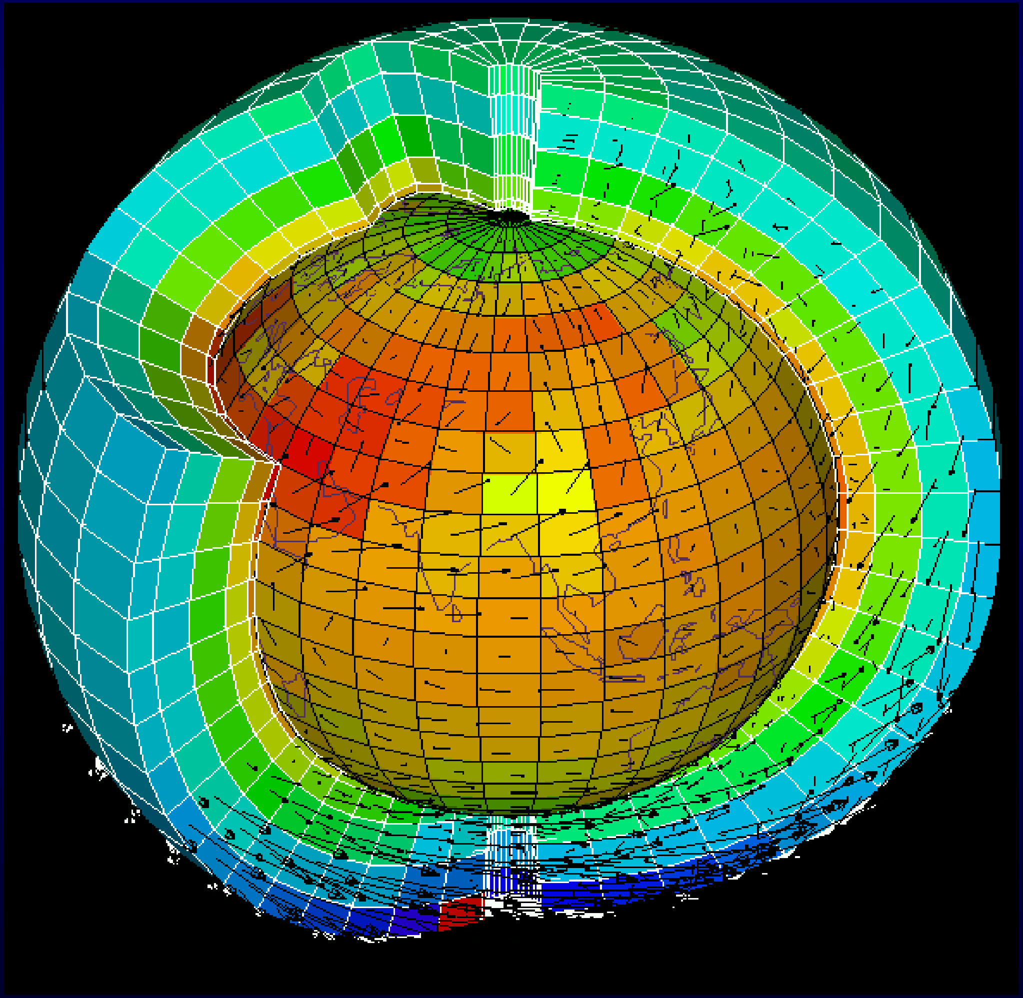
$$\frac{\partial q}{\partial t} + \overline{V} \cdot \nabla q = \frac{S_q}{\rho} + F_q$$

Conservation of water

$$p = \rho R T$$

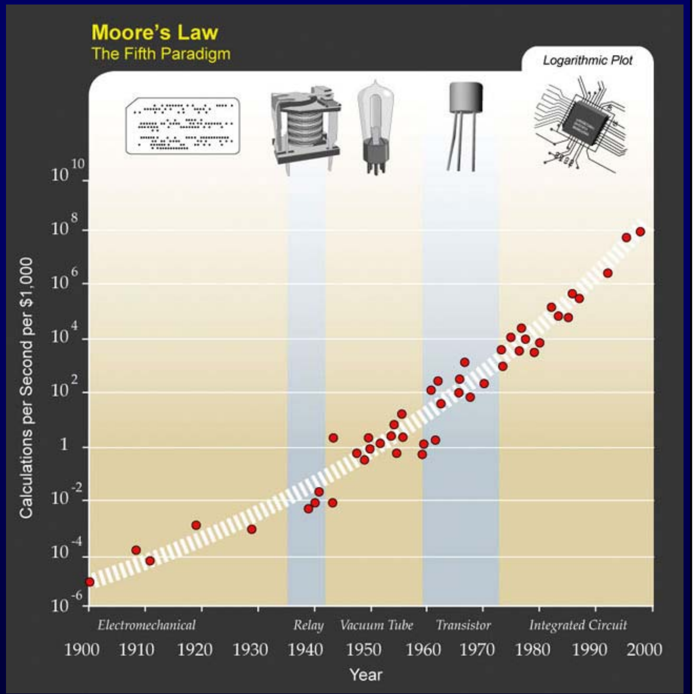
Equation of state

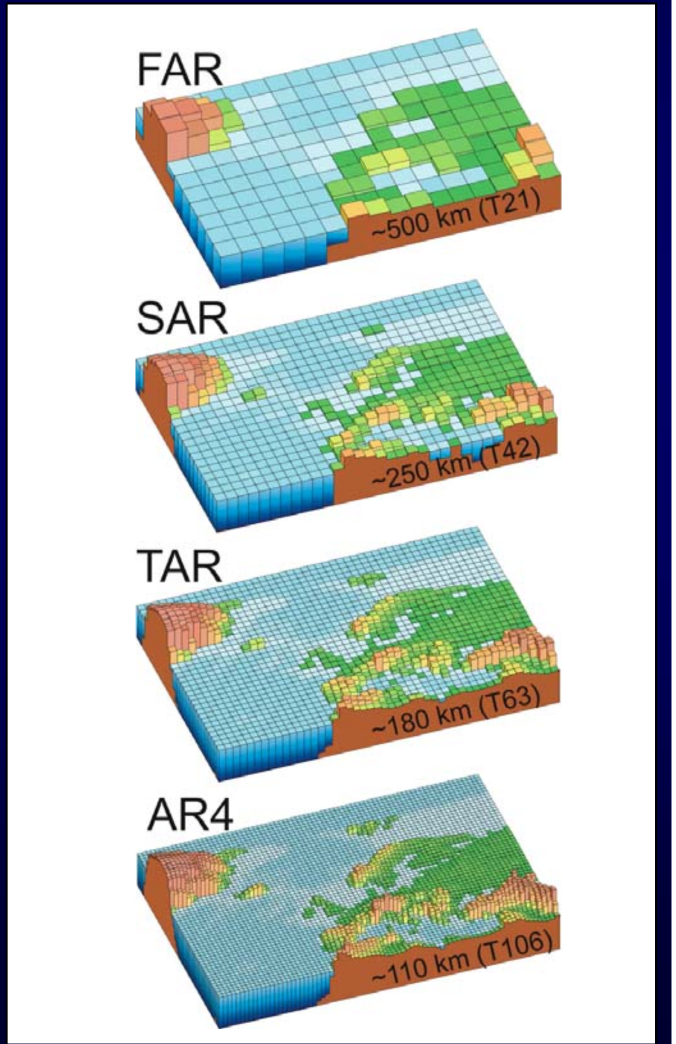
The equations of a climate model cannot be solved analytically and therefore they are discretized on a three-dimensional grid, where all the model variables are defined (wind, temperature etc.)

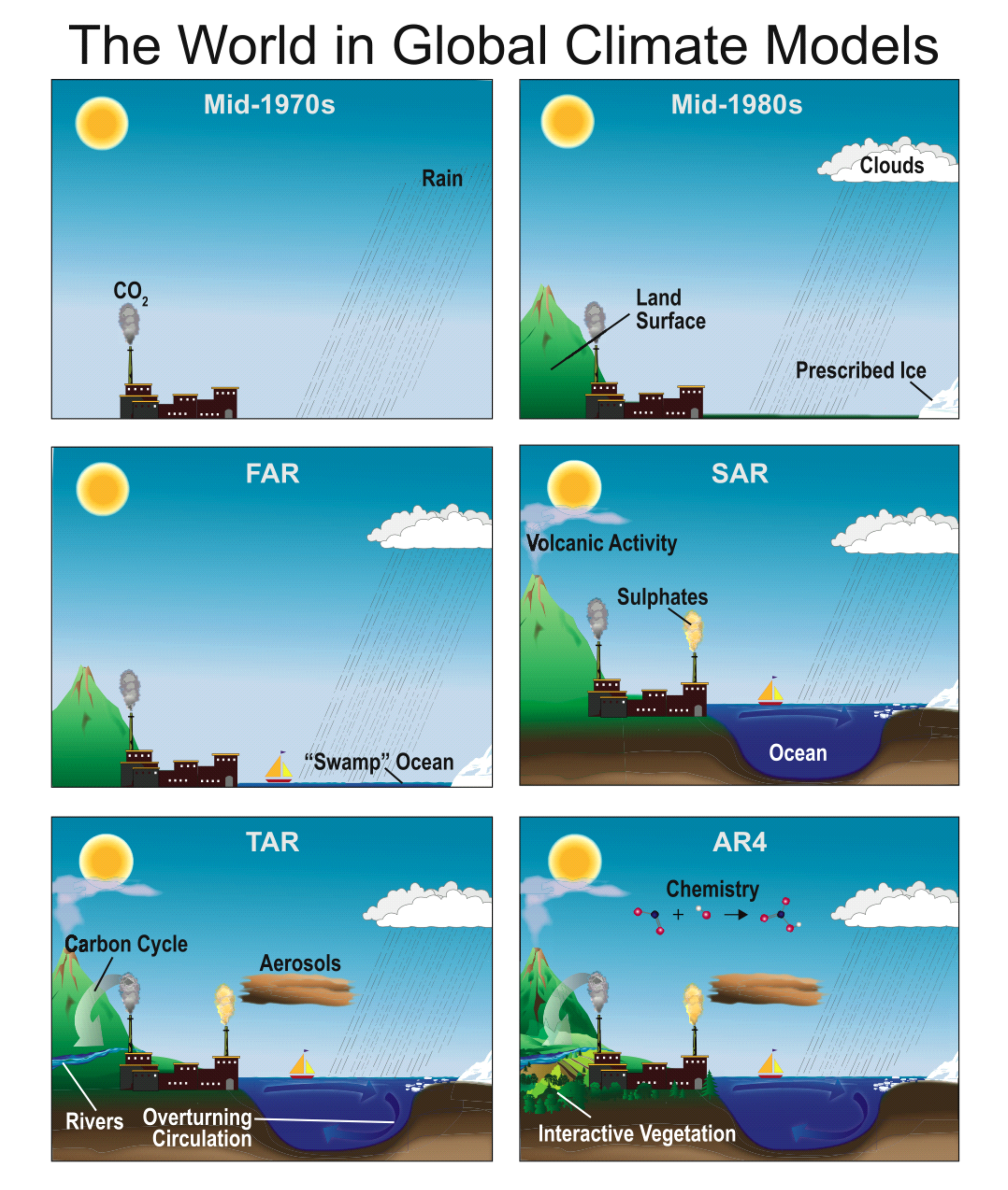


The distance between grid points determines the model resolution. Processes occurring at scale smaller than this distance are not risolved explicitly and must be “parameterized”

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

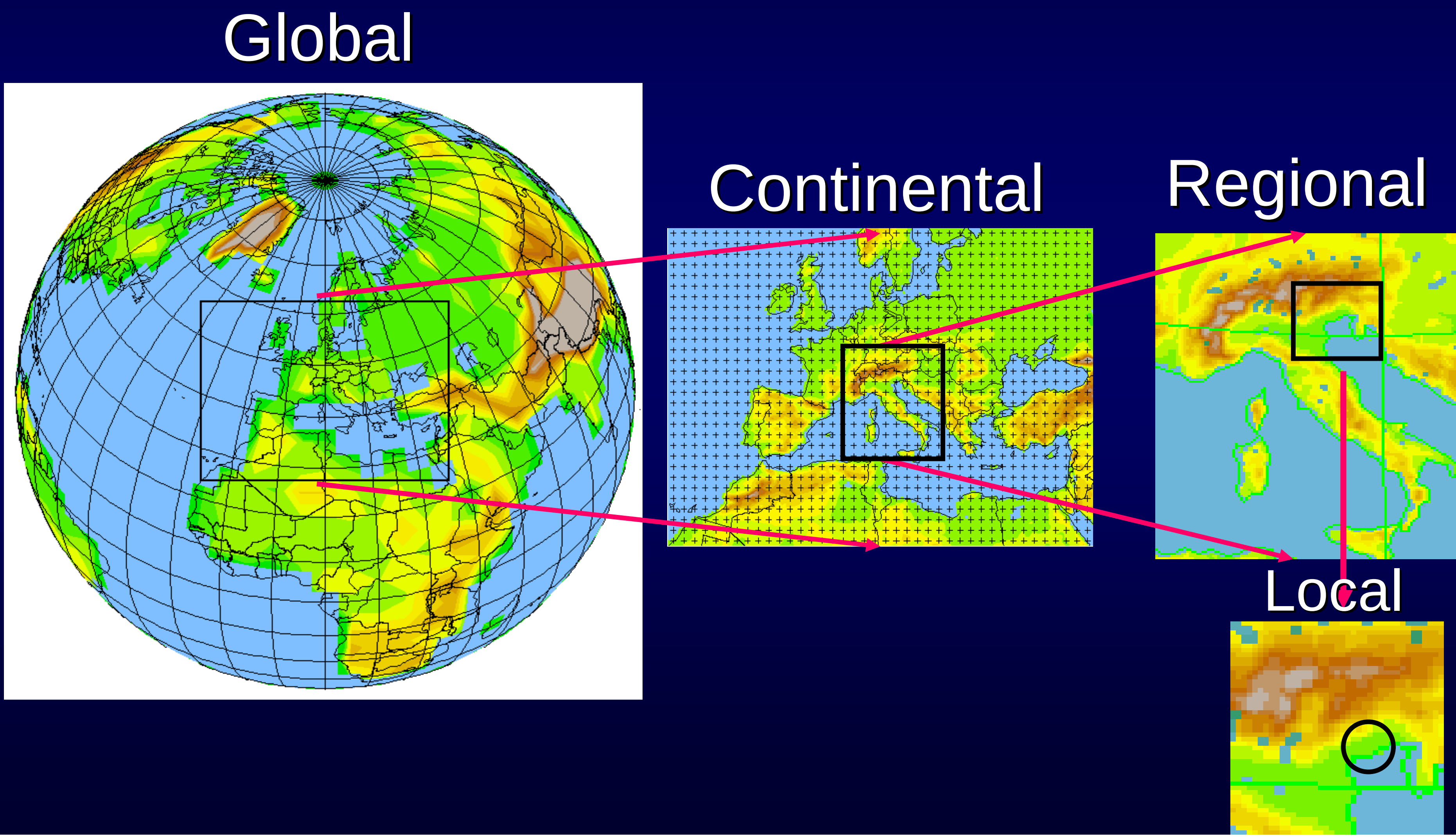




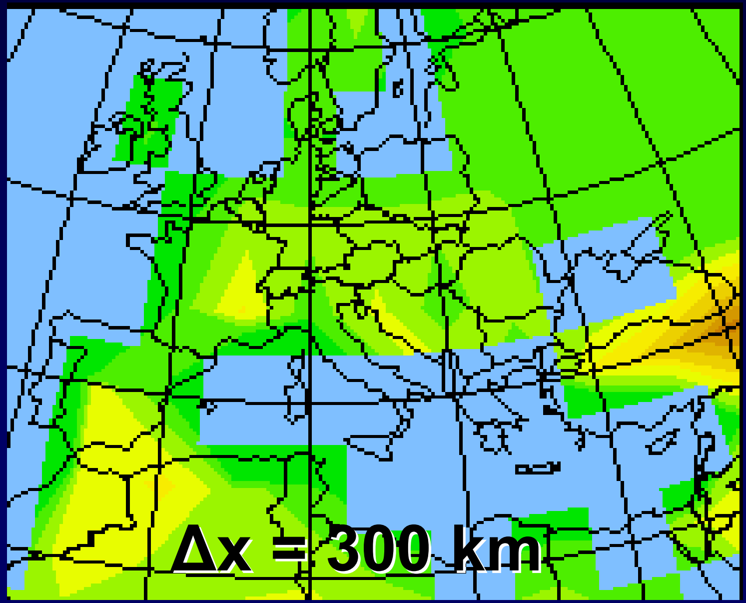


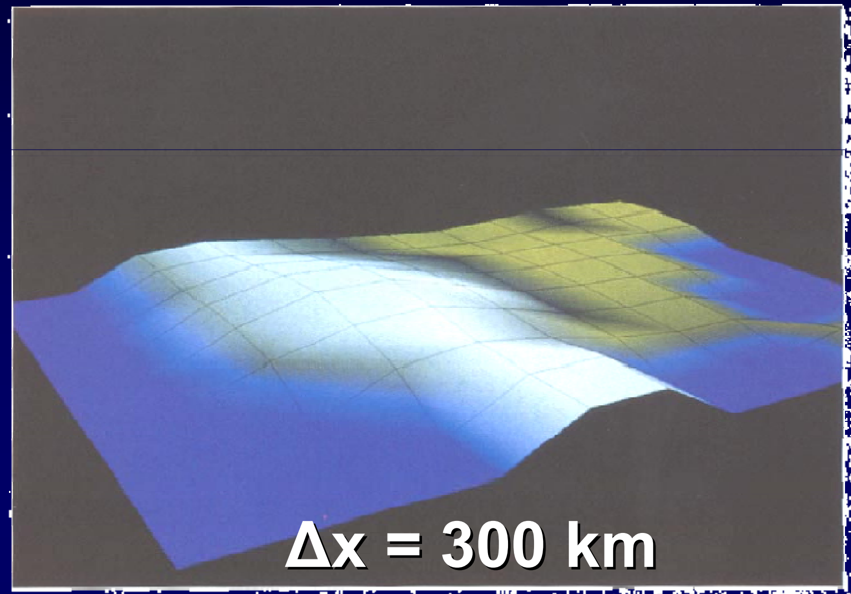
The evolution of global model complexity in the last decades

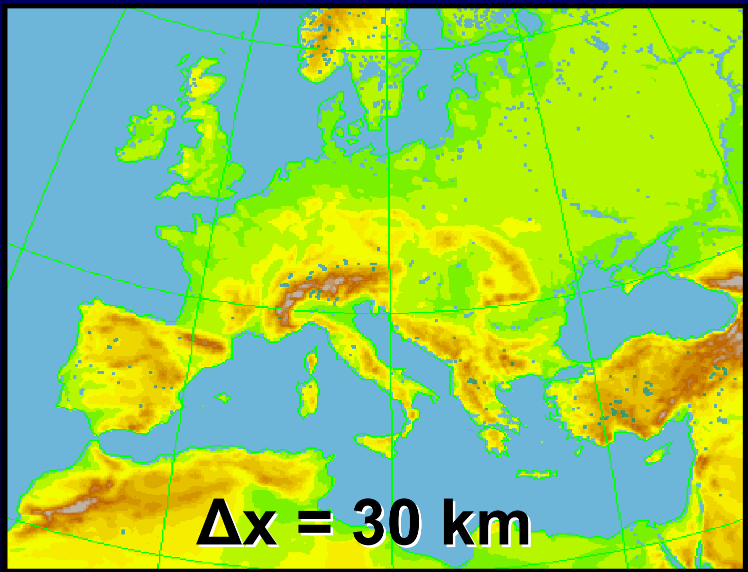
From global to regional climate
The spatial scales of climate processes

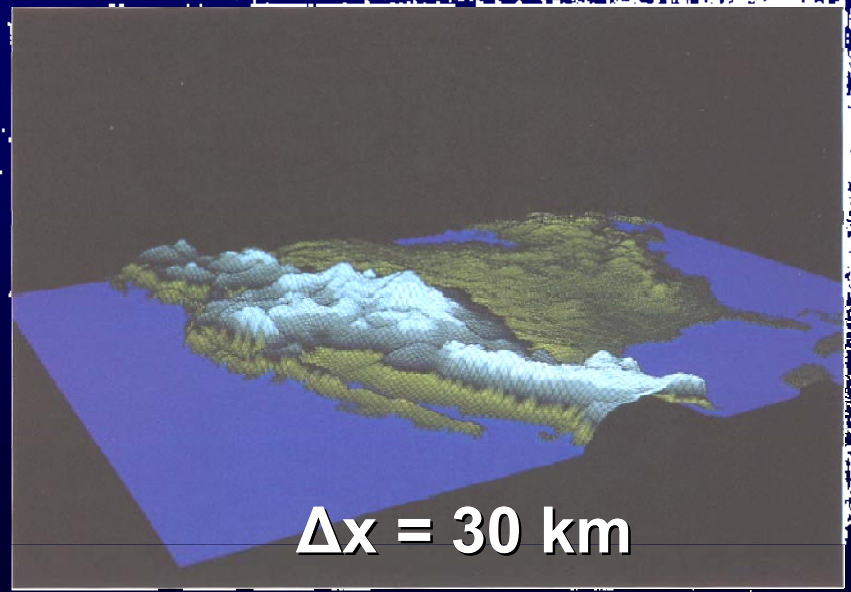


The importance of resolution



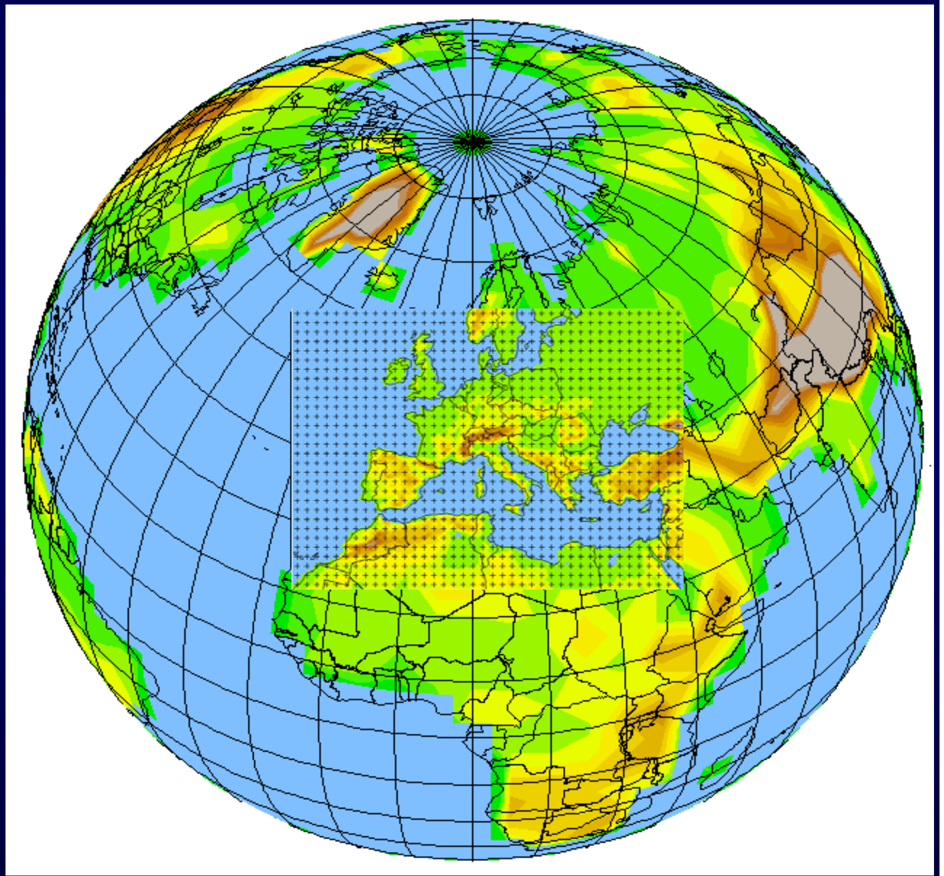






"Nested" Regional Climate Modeling: Technique and Strategy

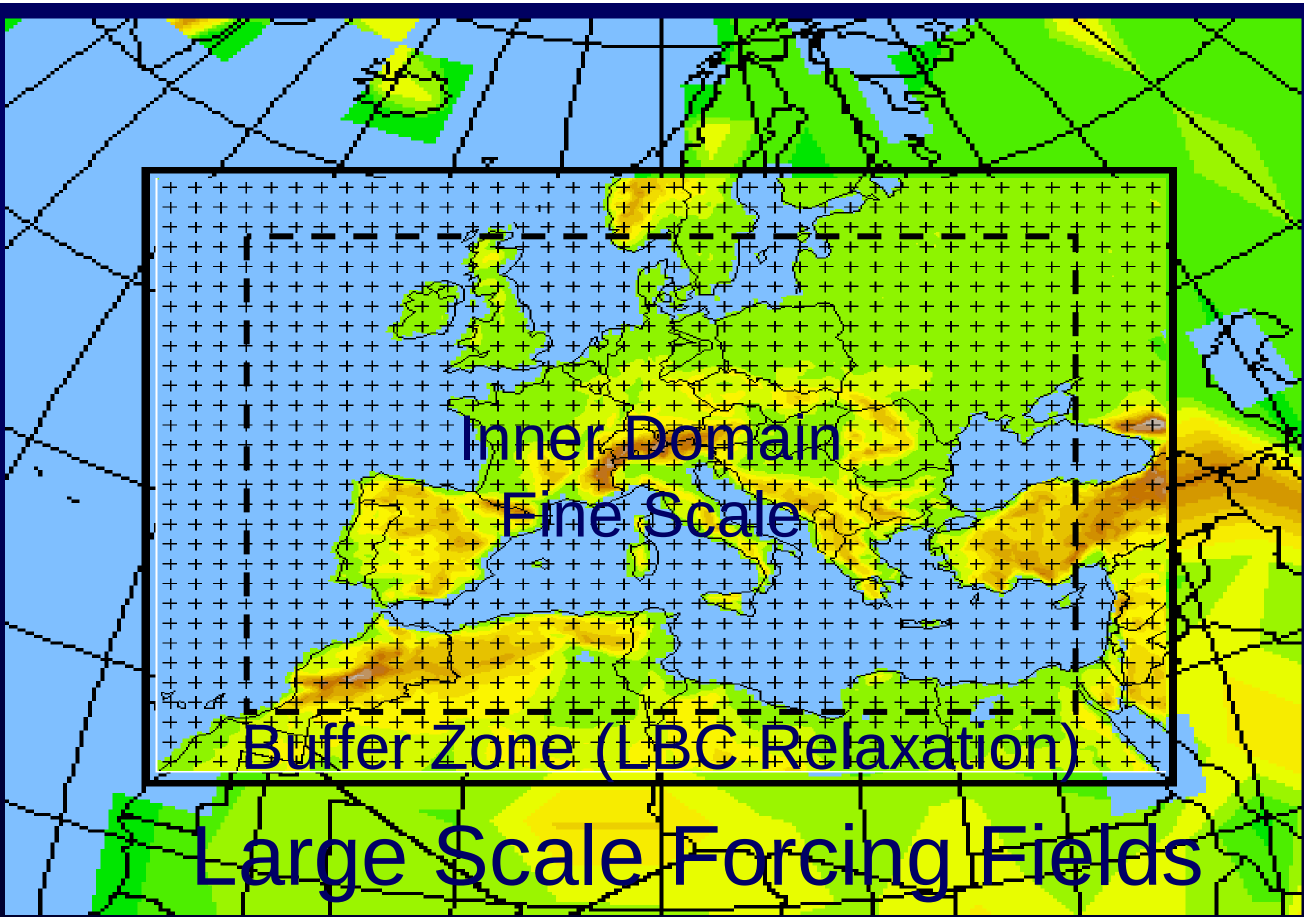
- Motivation: The resolution of AOGCMs is still too coarse to capture regional and local climate processes (e.g. topography, coastlines)
- Technique: A limited area "Regional Climate Model" (RCM) is "nested" within a GCM in order to locally increase the model resolution.
  - Initial conditions (IC) and 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



RCM Nesting procedure

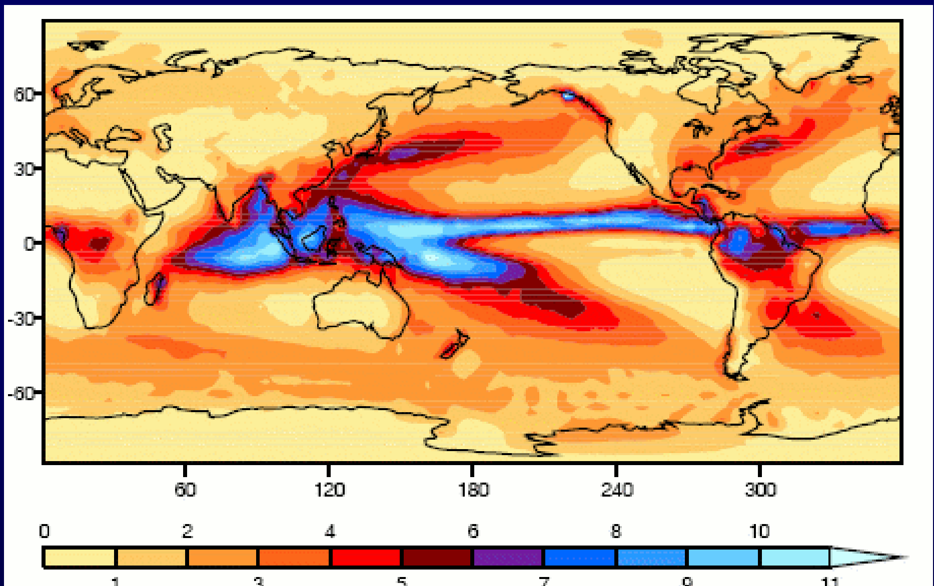
Different model prognostic variables are "relaxed" toward the large scale forcing fields in a lateral "buffer zone"

$$\frac{\partial \alpha}{\partial t} = F(n)F_1 \cdot (\alpha_{LBC} - \alpha_{mod}) - F(n)F_2 \cdot \Delta_2(\alpha_{LBC} - \alpha_{mod})$$

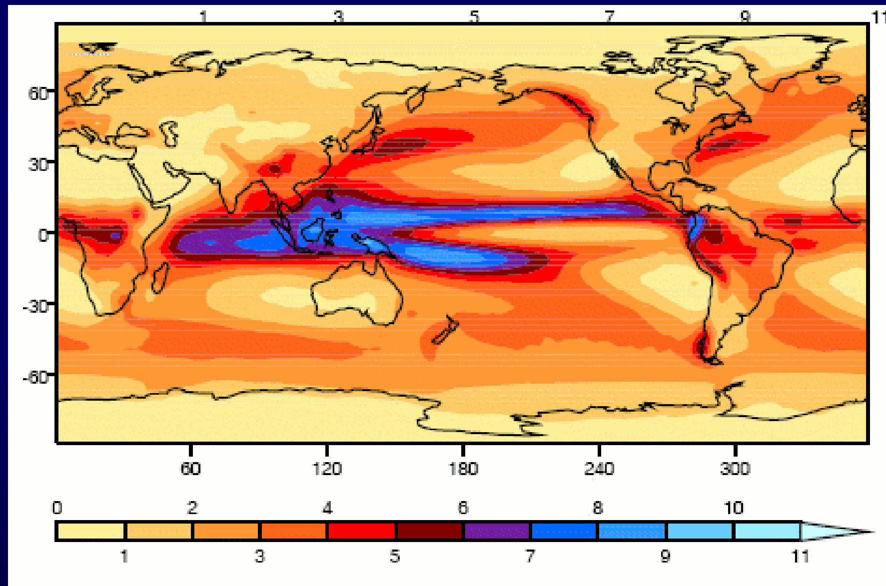


Performance of AOGCMs
Annual precipitation, 20 models

Observations



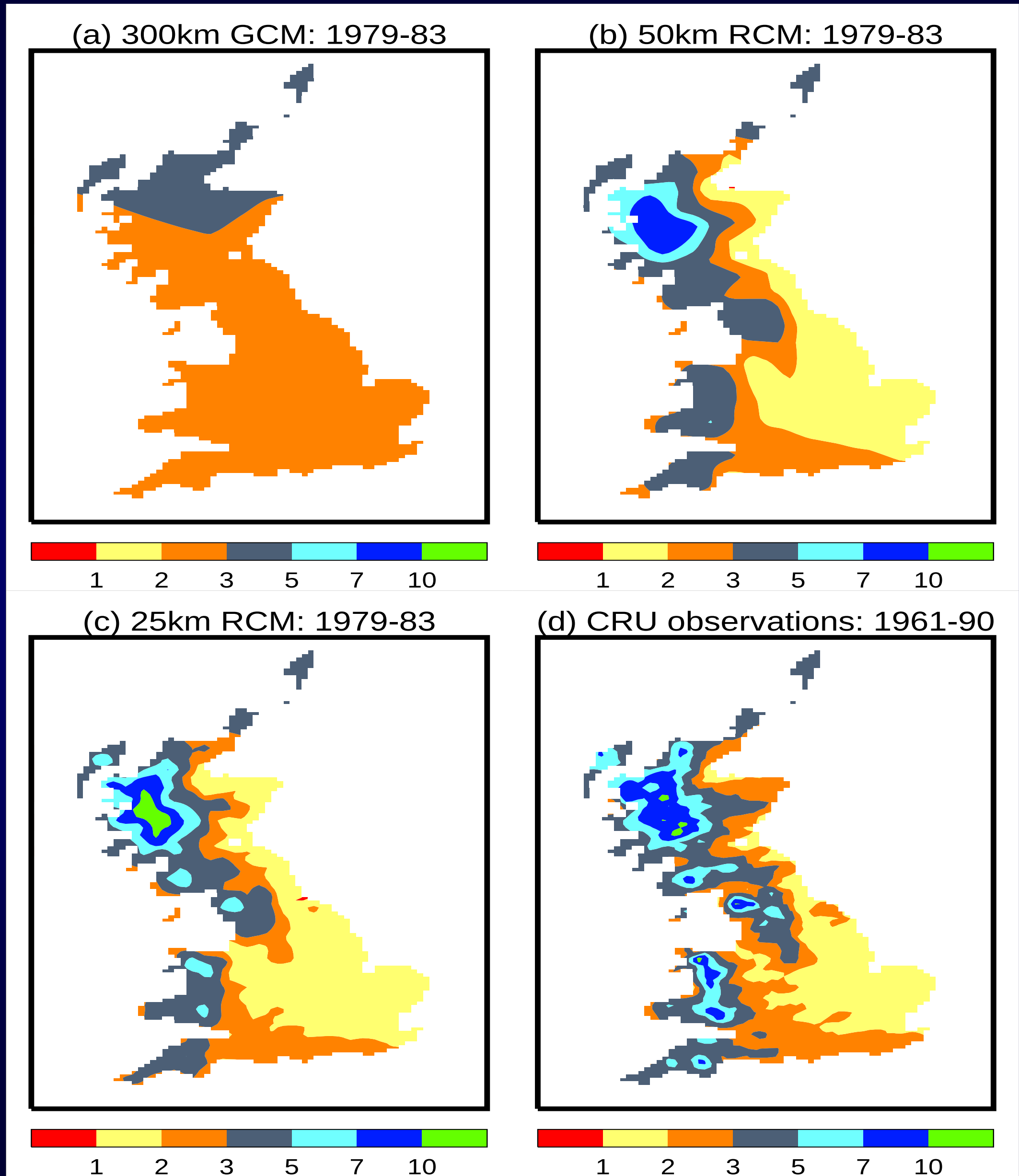
Model ensemble mean



WINTER PRECIPITATION OVER BRITAIN

300km Global Model

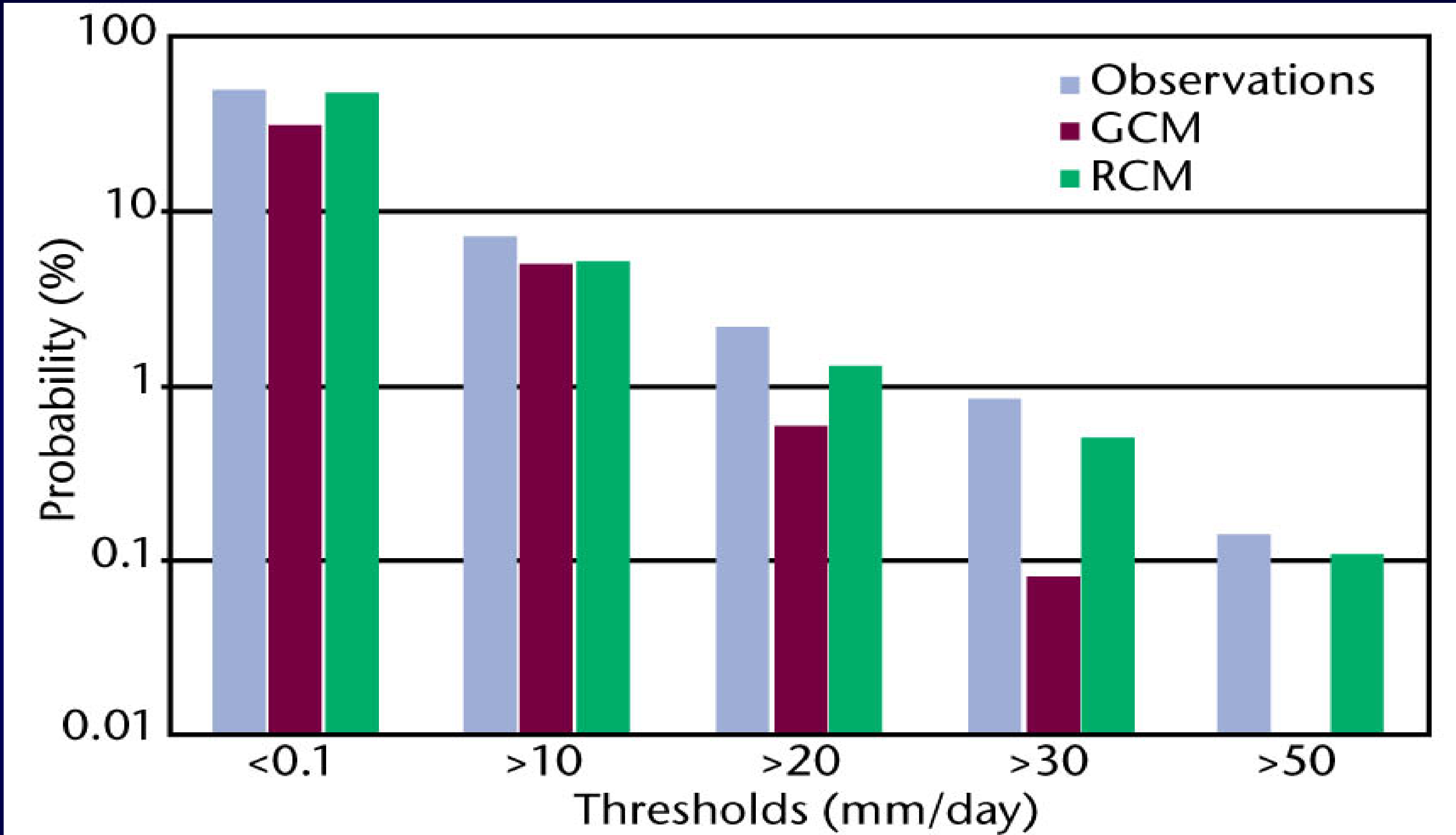
50km Regional Model



25km Regional Model

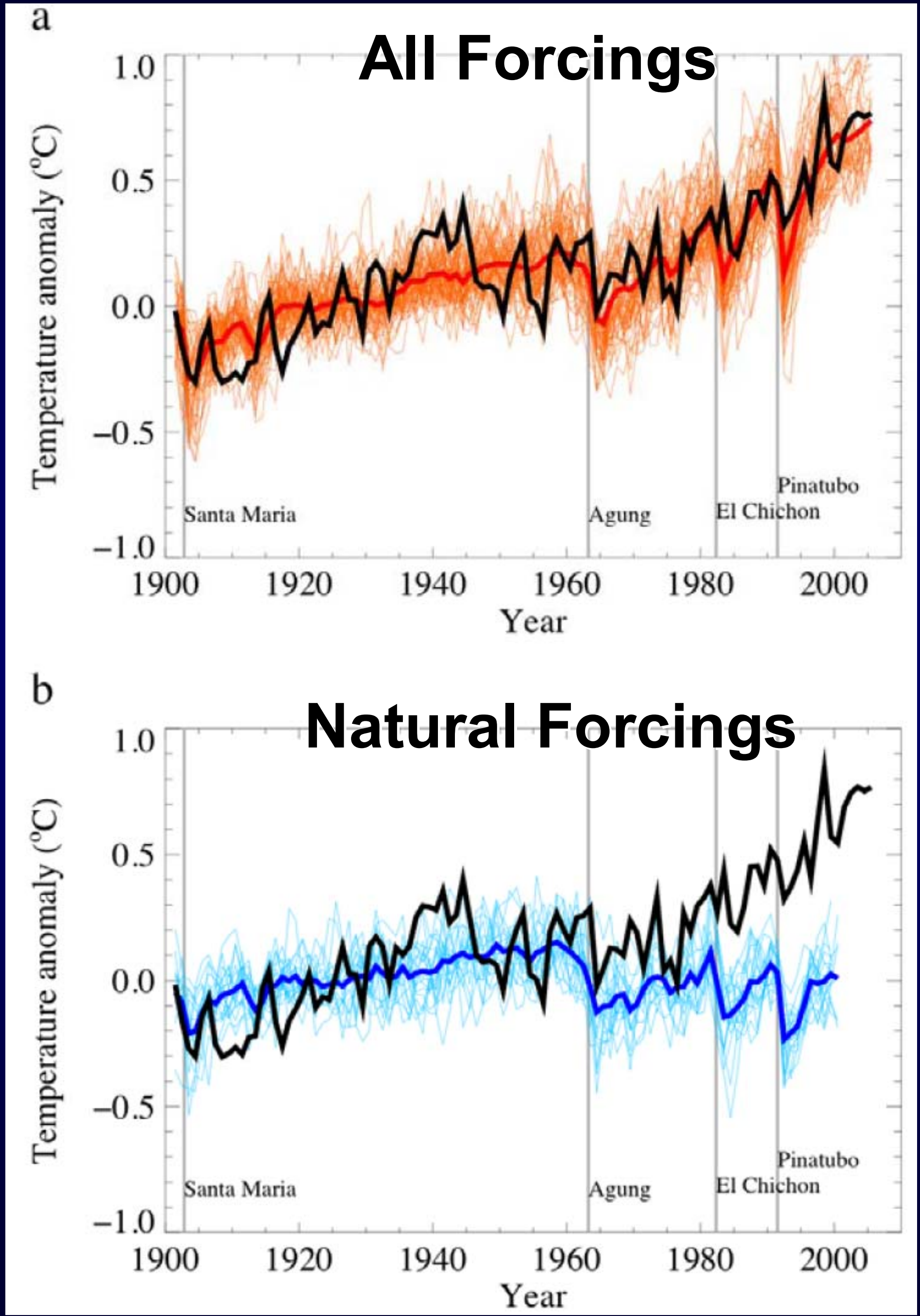
Observed

WINTER DAILY RAINFALL OVER THE ALPS



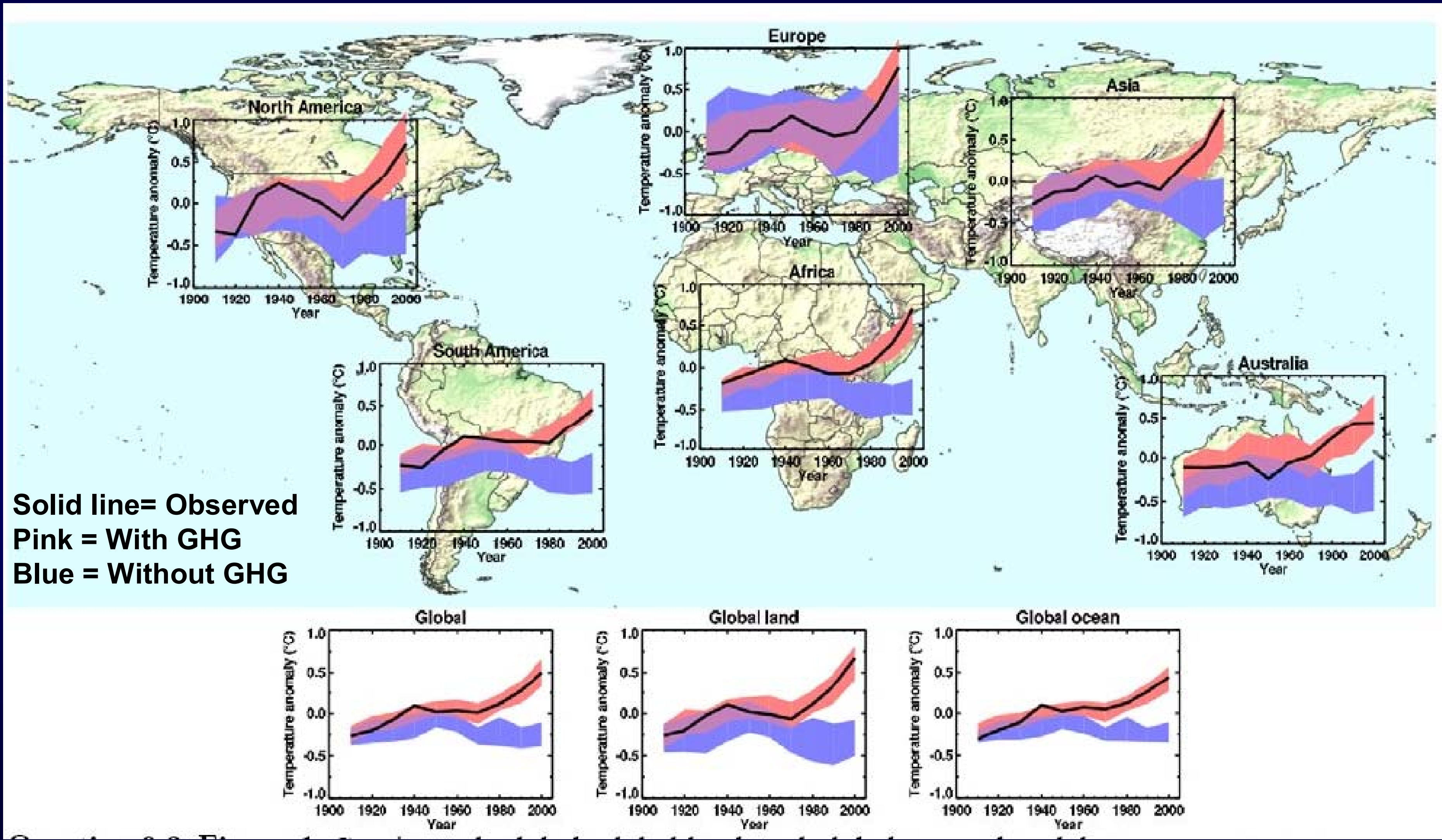
RCMs simulate extreme rainfall much better than GCMs

Back to the attribution problem



Identification of the anthropogenic effects on global warming

Identificaton of the anthropogenic effect on regional and ocean warming



Solid line= Observed
Pink = With GHG
Blue = Without GHG

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.

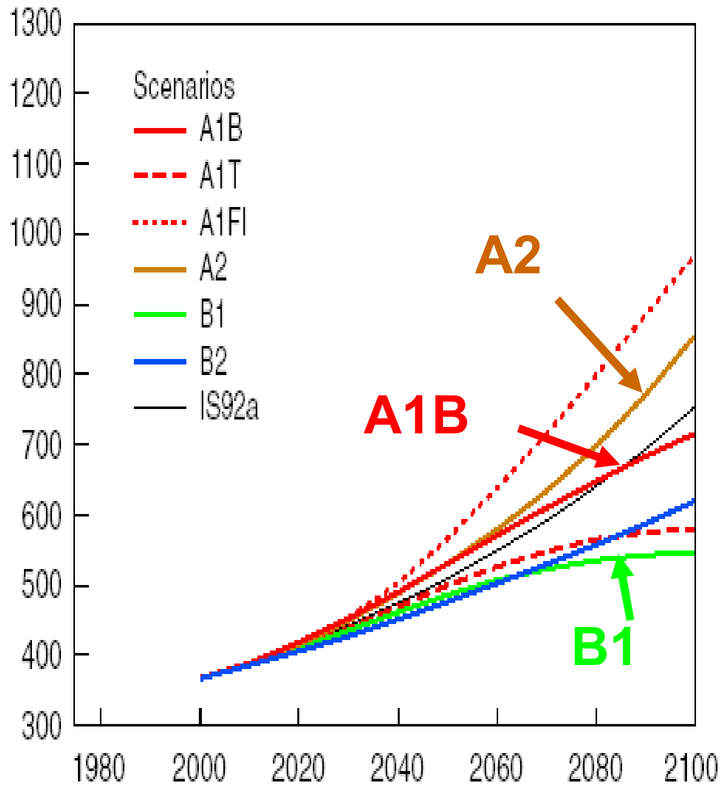

Projections of future climate change

The CMIP3 Ensemble

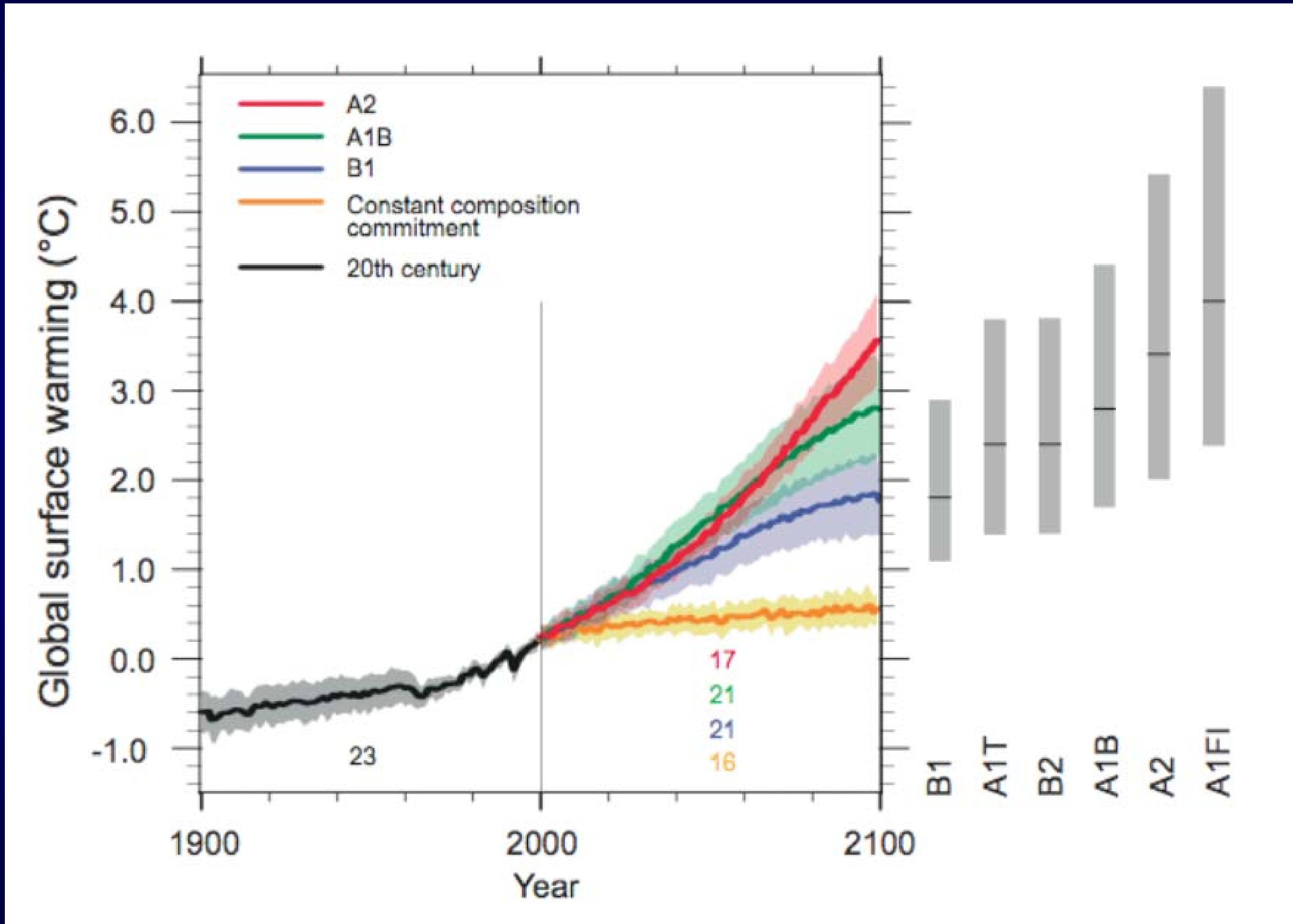
Models and simulations

Model	20 Cent.	A1B	A2	B1
BCCR-BCM2-0	1	-	1	1
CCMA-3-T47	5	4	2	4
CNRM-CM3	1	1	1	1
CSIRO-MK3	2	1	1	1
GFDL-CM2-0	3	1	1	1
GFDL-CM2-1	3	1	1	-
GISS-AOM	2	2	-	2
GISS-EH	5	4	-	-
GISS-ER	1	2	1	1
IAP-FGOALS	3	3	-	2
INMCM3	1	1	1	1
IPSL-CM4	1	1	1	1
MIROC3-2H	1	1	-	1
MIROC3-2M	3	3	3	3
MIUB-ECHO-G	5	3	3	3
MPI-ECHAM5	3	2	3	3
MRI-CGCM2	5	5	5	5
NCAR-CCSM3	8	6	4	8
NCAR-PCM1	4	3	4	2
UKMO-HADCM3	1	1	1	1

Scenarios



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

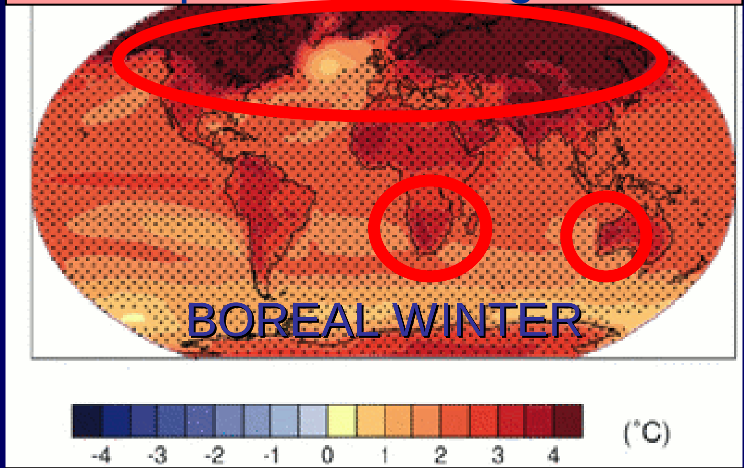


Corresponding changes in sea level rise are <u>19-58</u> cm

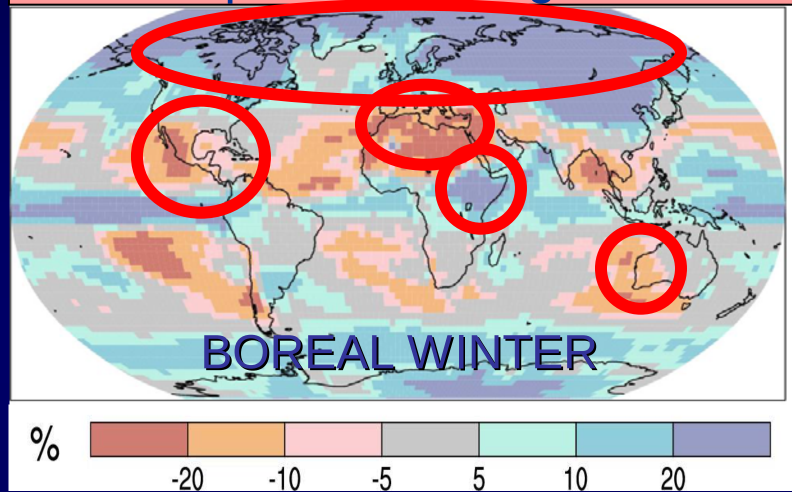
Regional distribution of projected temperature and precipitation change

(A1B scenario, 2090-2100)

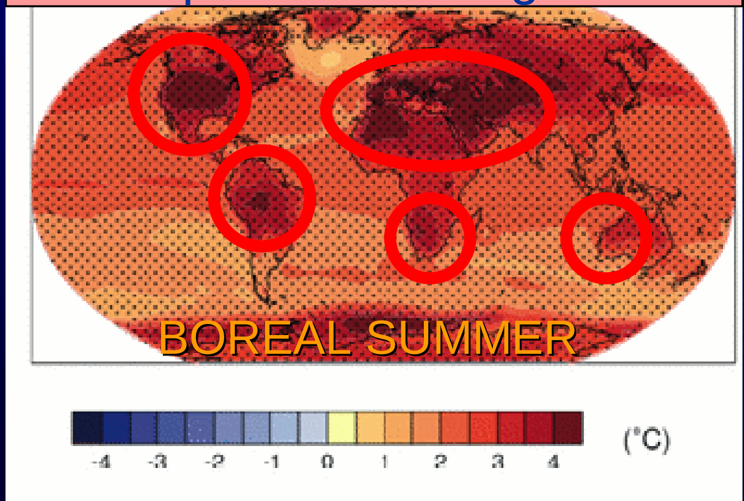
Temperature change DJF



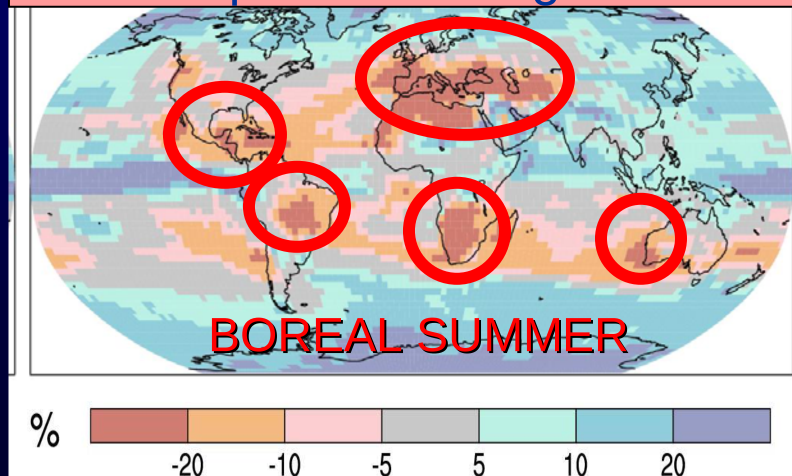
Precipitation change DJF



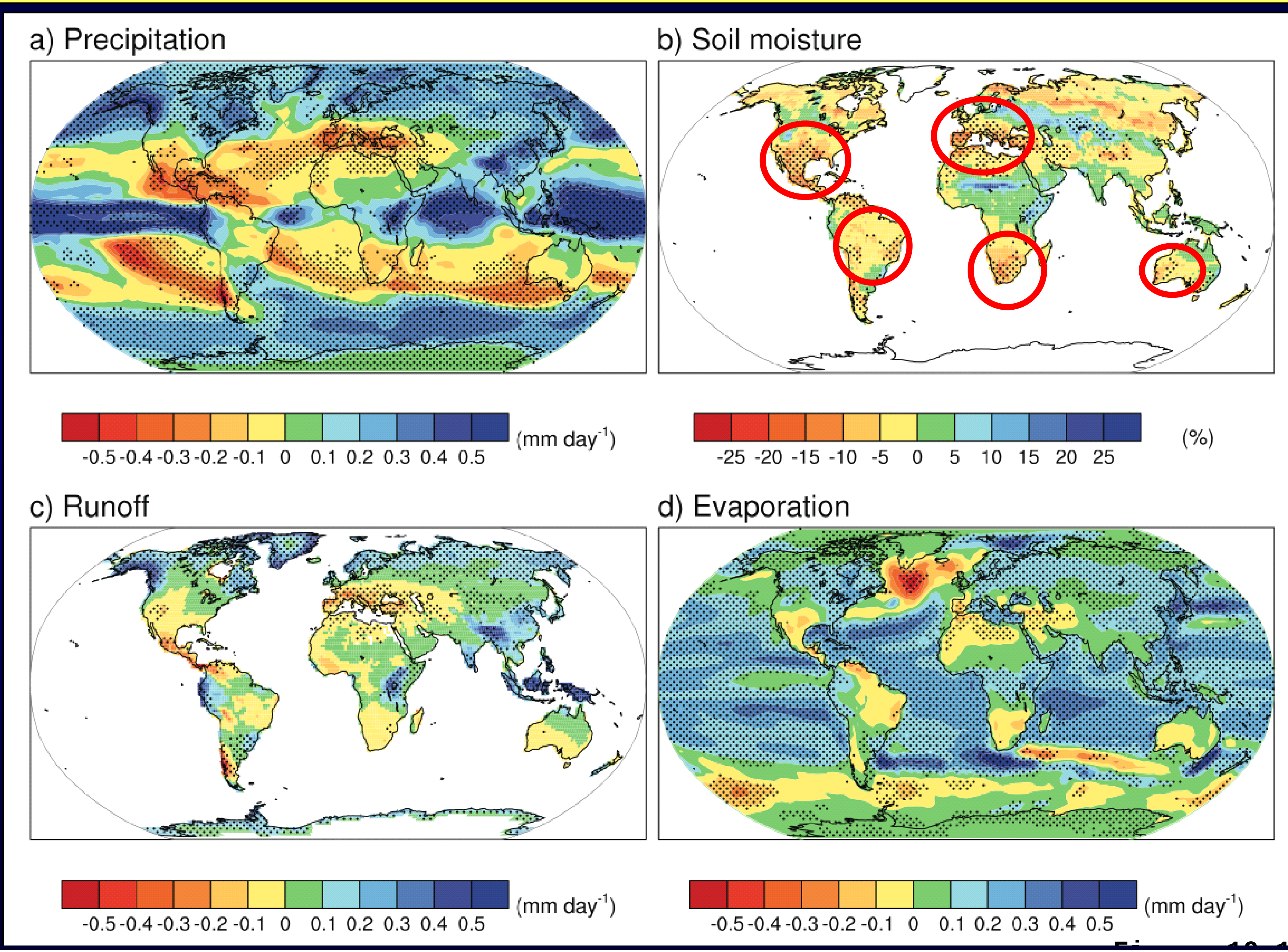
Temperature change JJA



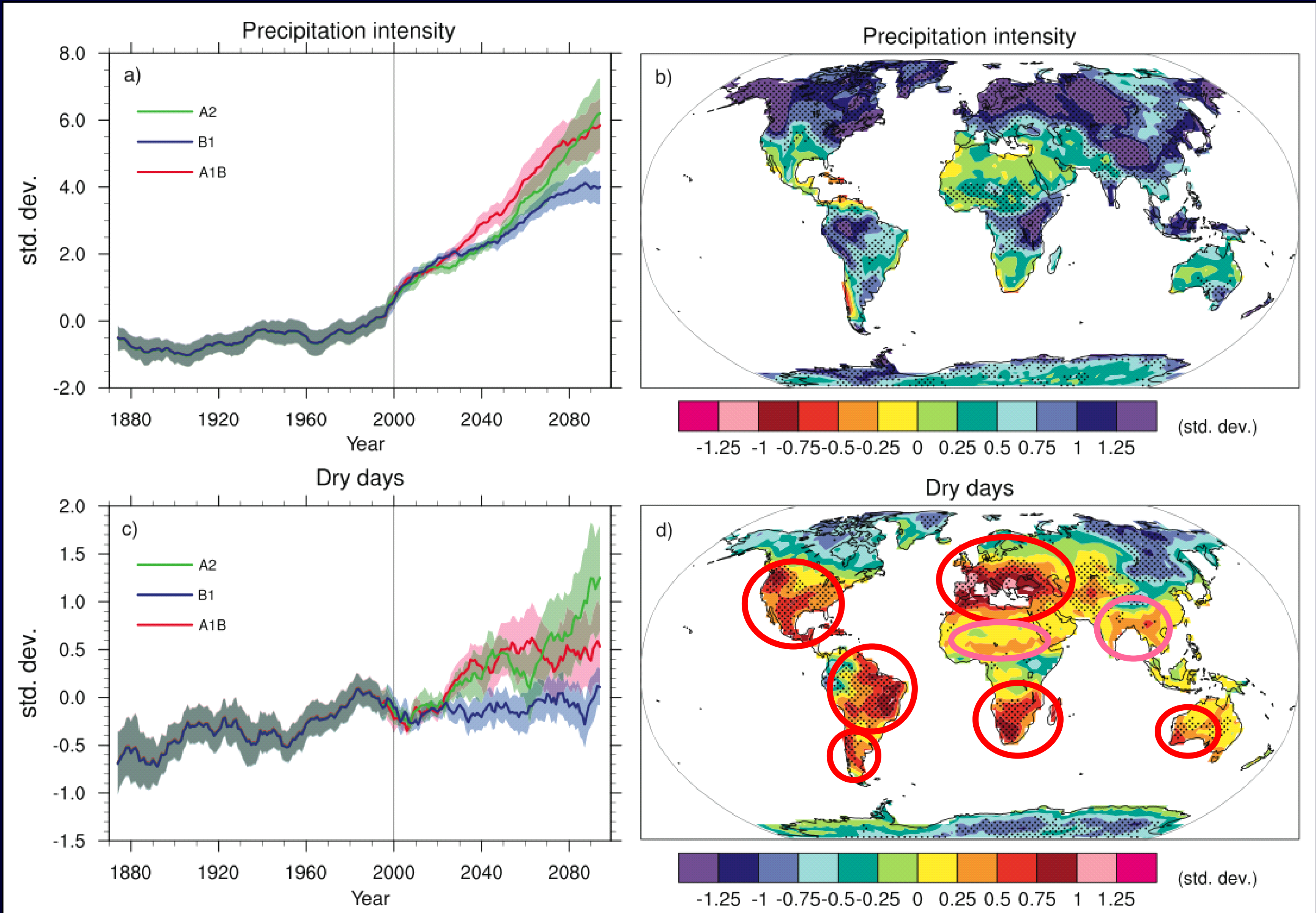
Precipitation change JJA



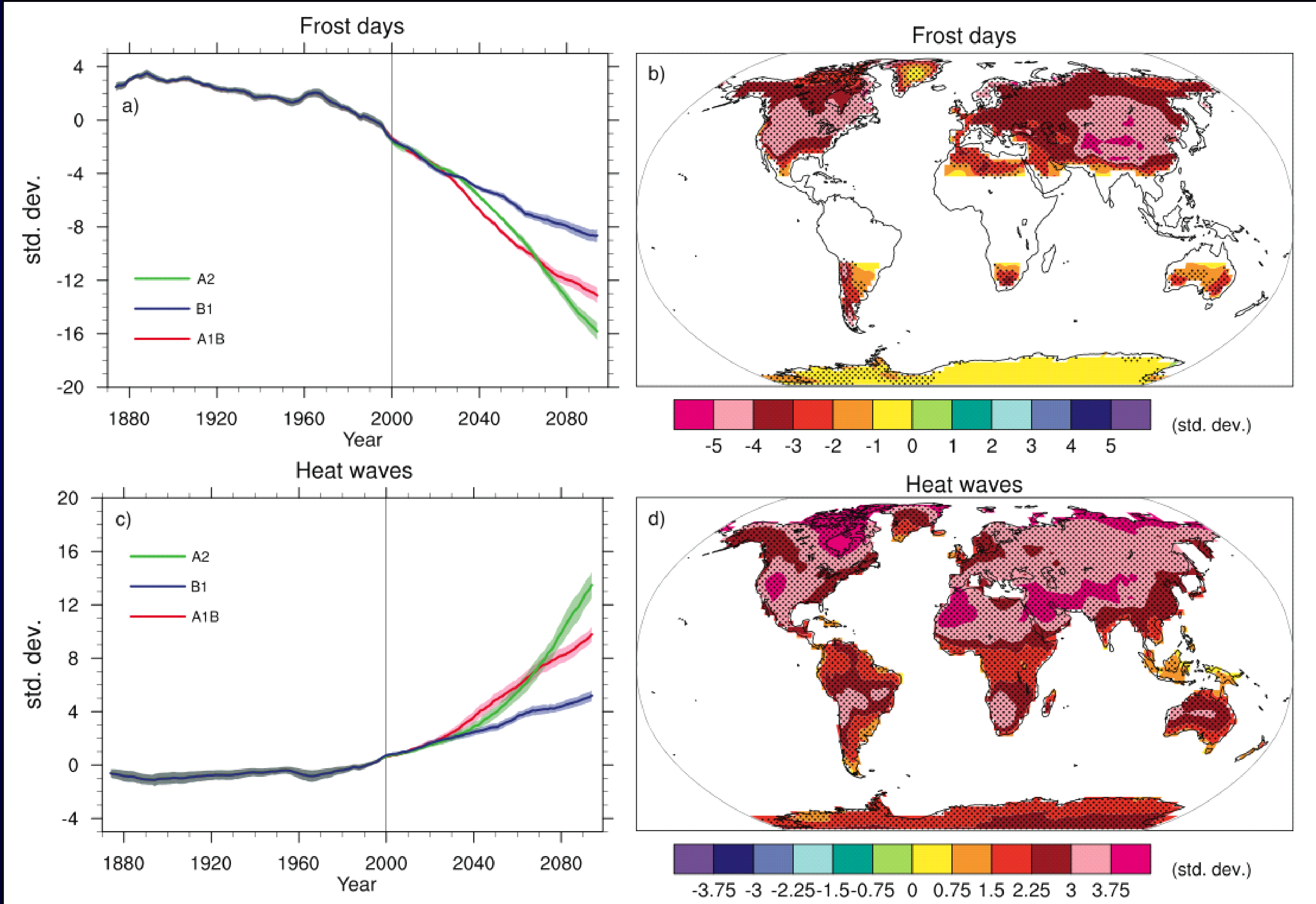
Projected changes in the hydrologic cycle



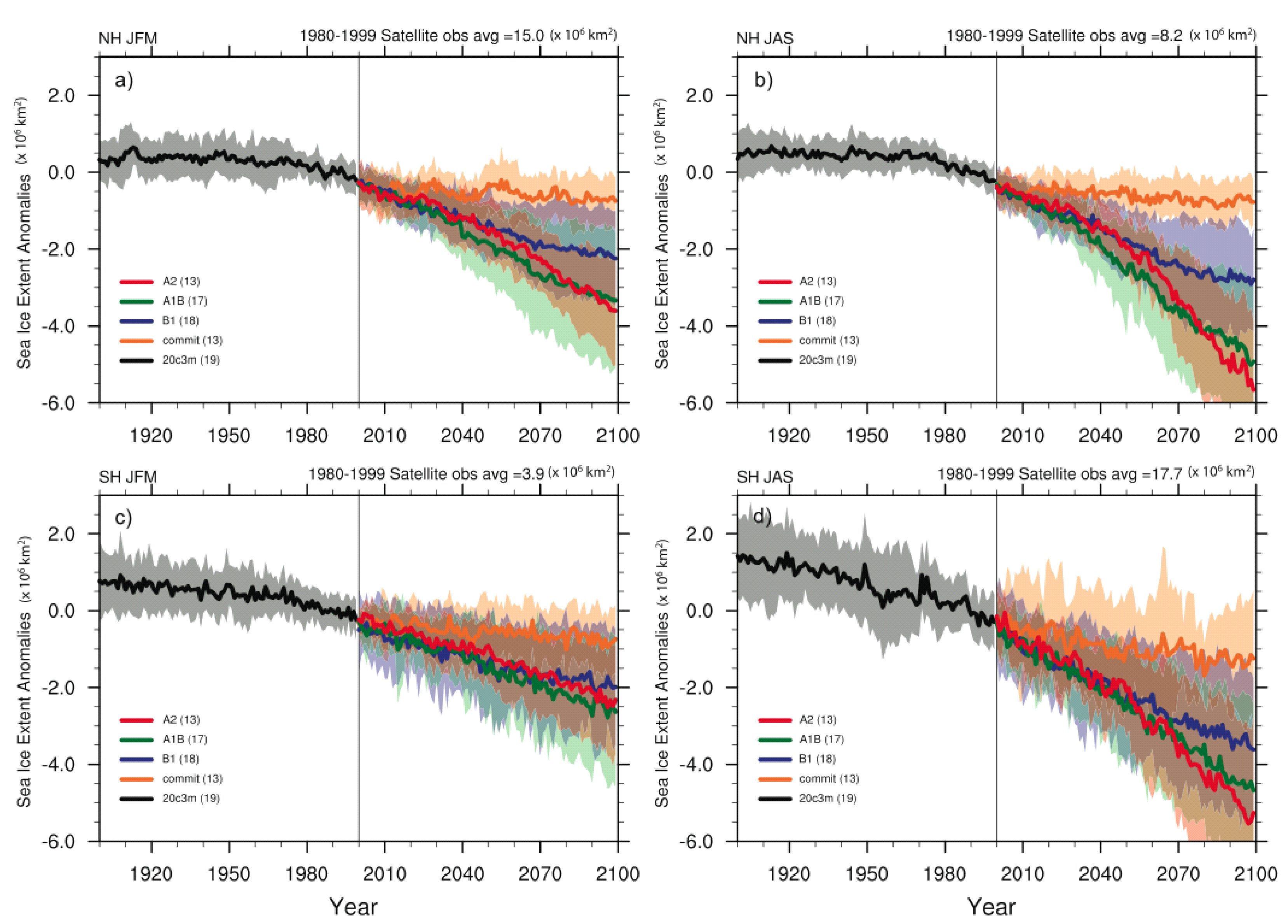
Changes in precipitation characteristics



Projected changes in extremes

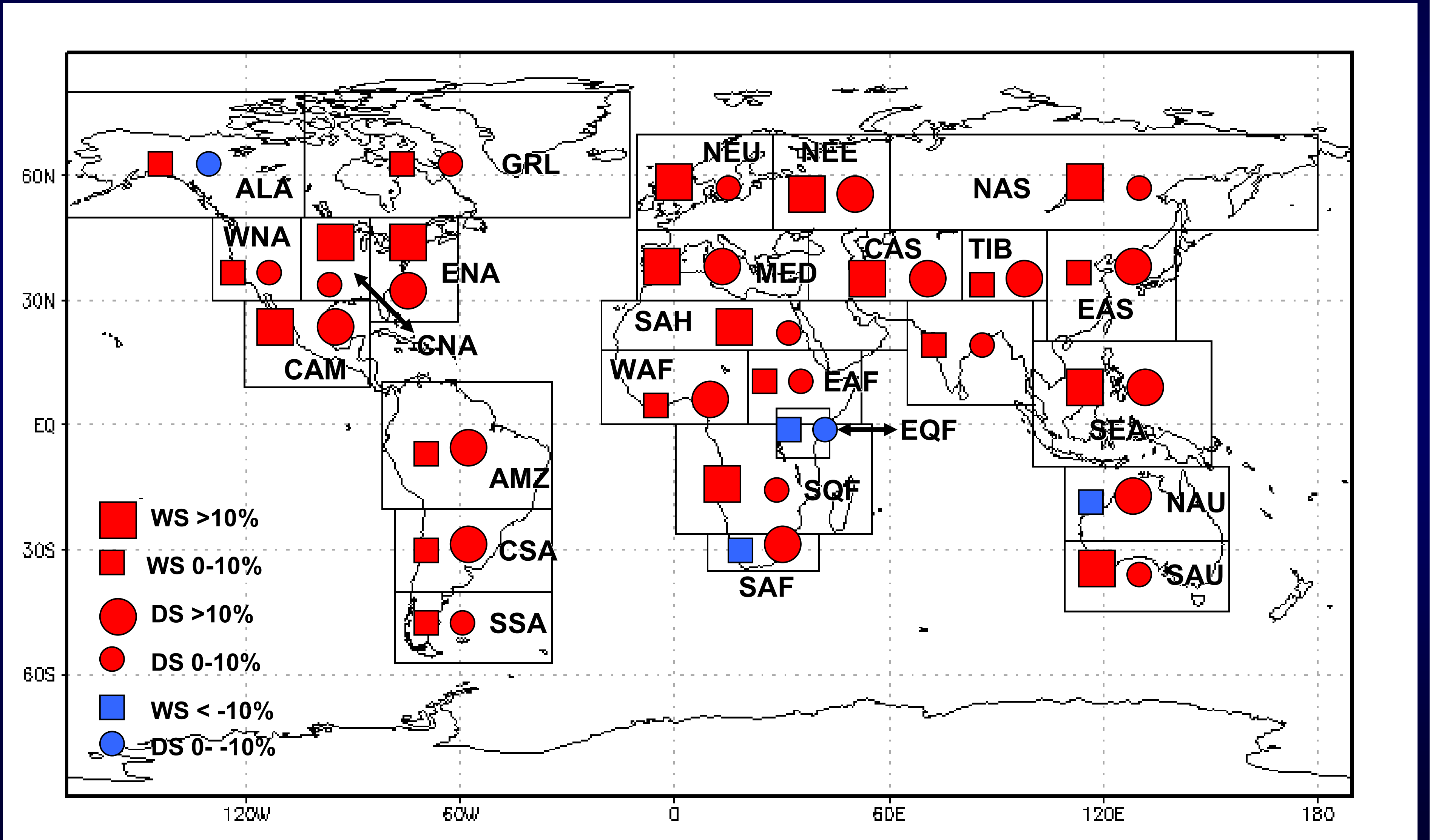


Projected changes in sea ice cover



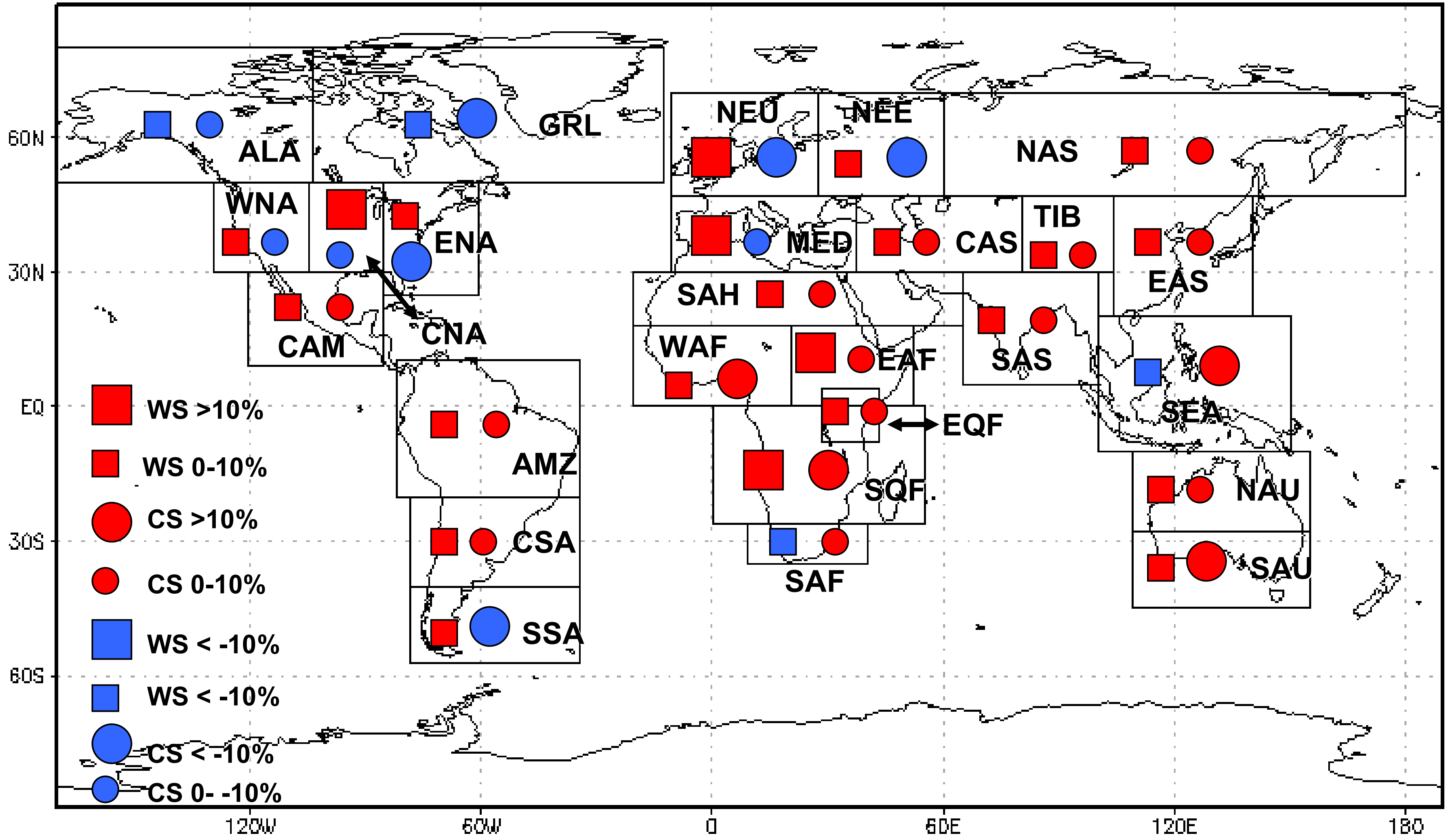
Change in precipitation interannual variability

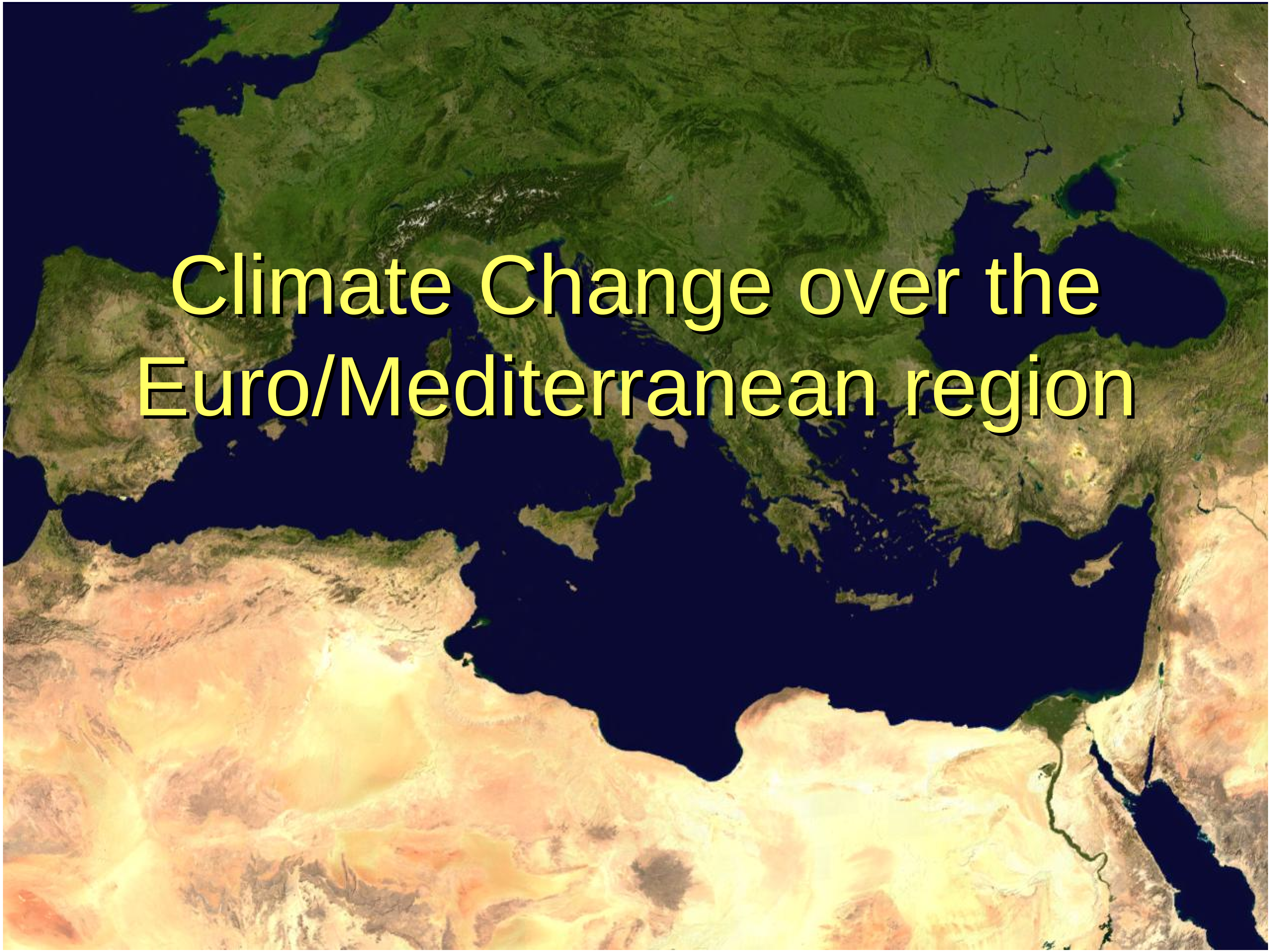
(CV, 2080-2099 minus 1960-1979, A1B-A2-B1)



Change in temperature interannual variability

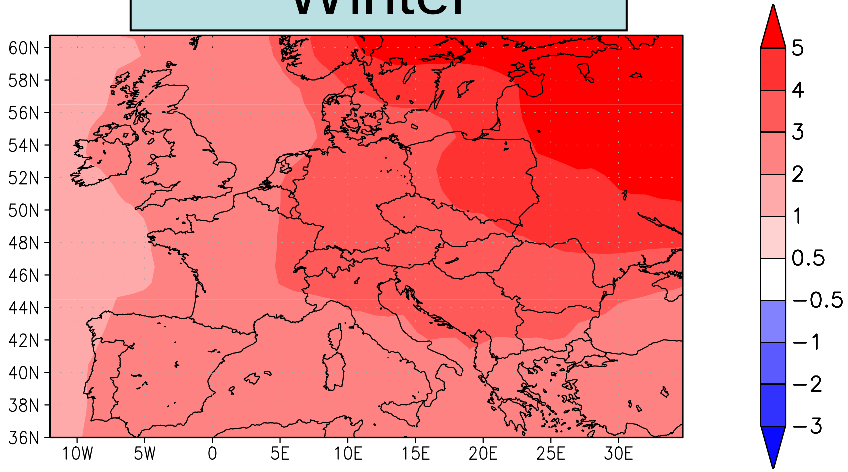
(SD, 2080-2099 minus 1960-1979, A1B-A2-B1)



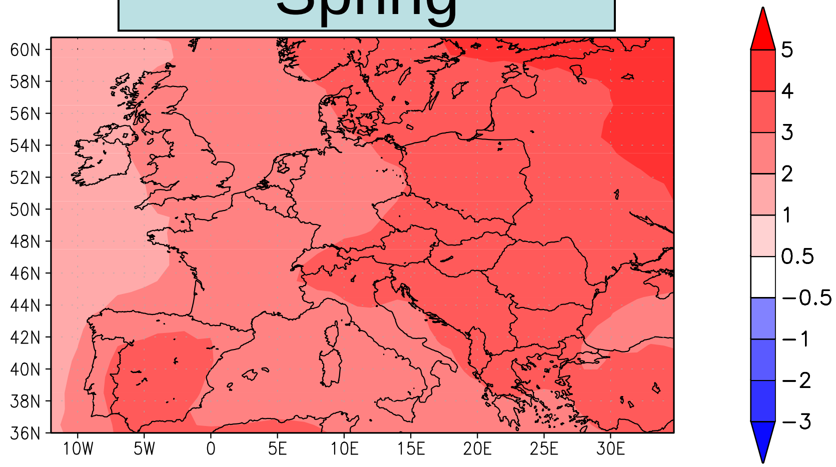

Climate Change over the
Euro/Mediterranean region

Temperature change, CMIP3
A1B Scenario, 20 AOGCMs

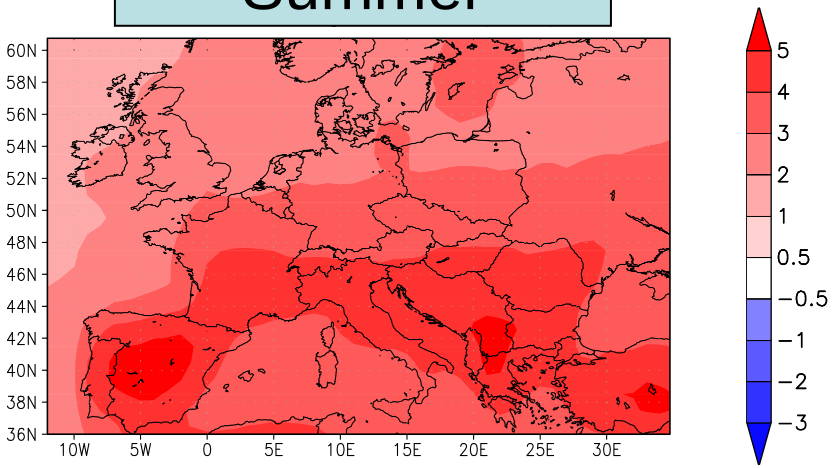
Winter



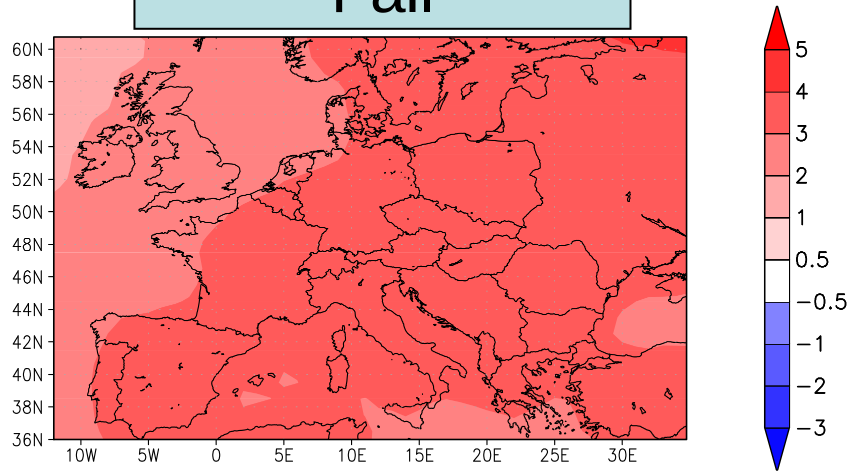
Spring



Summer

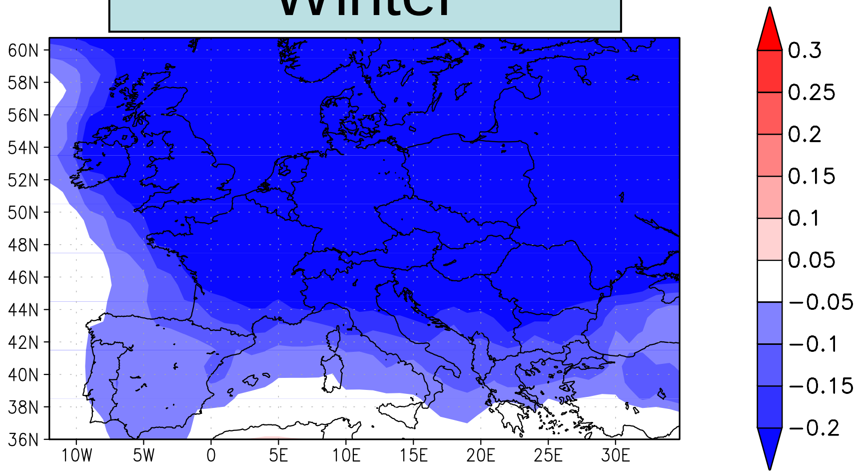


Fall

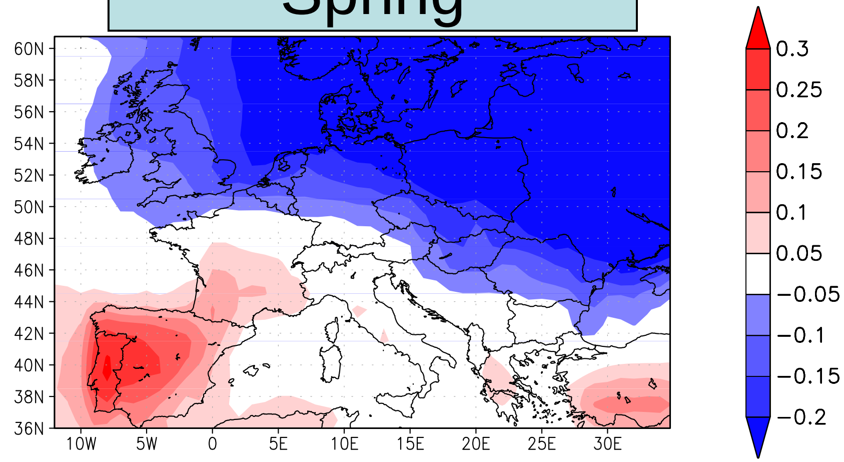


Temperature variability change, CMIP3 A1B Scenario, 20 AOGCMs

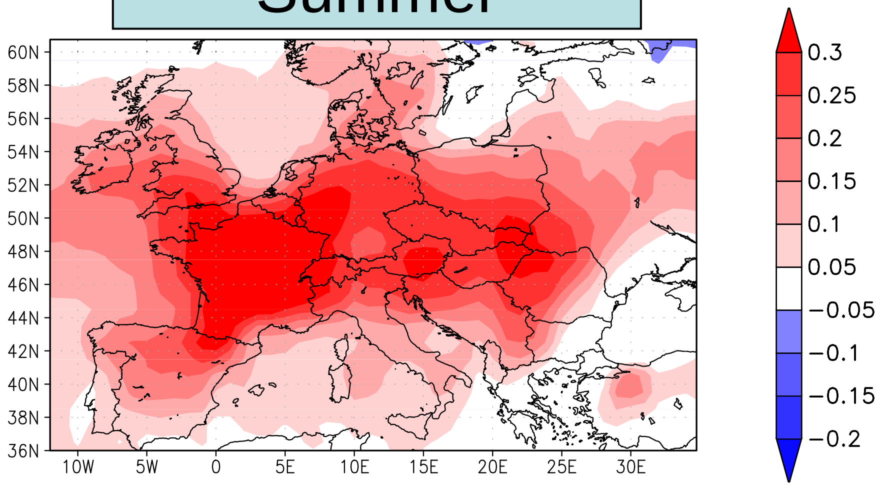
Winter



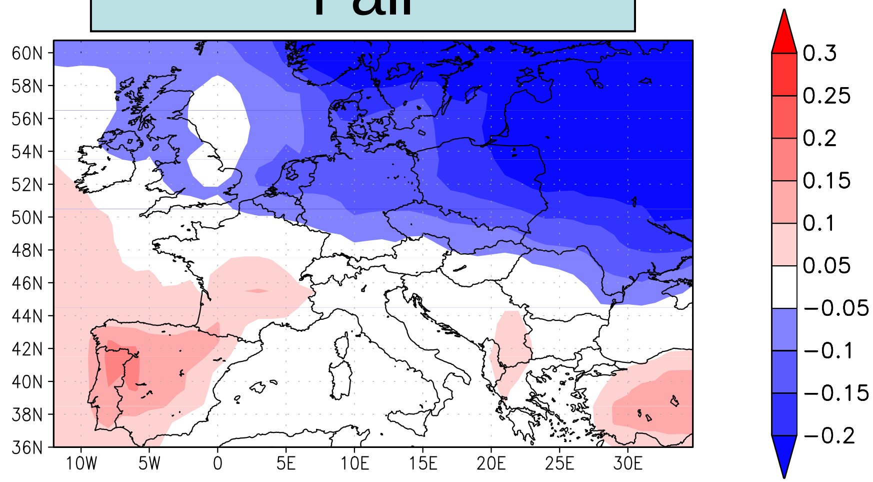
Spring



Summer

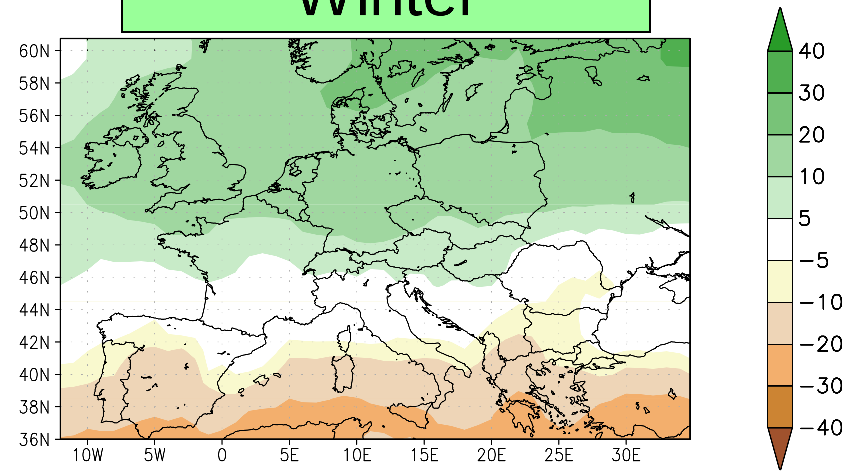


Fall

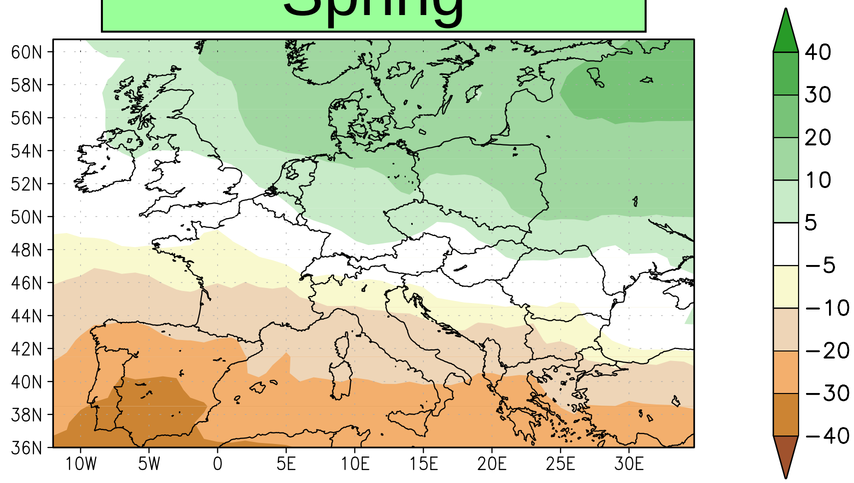


Precipitation change, CMIP3 A1B Scenario, 20 AOGCMs

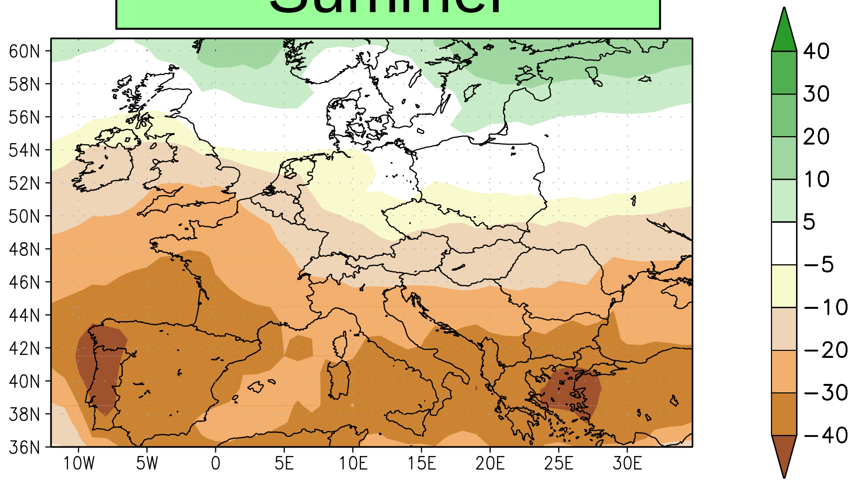
Winter



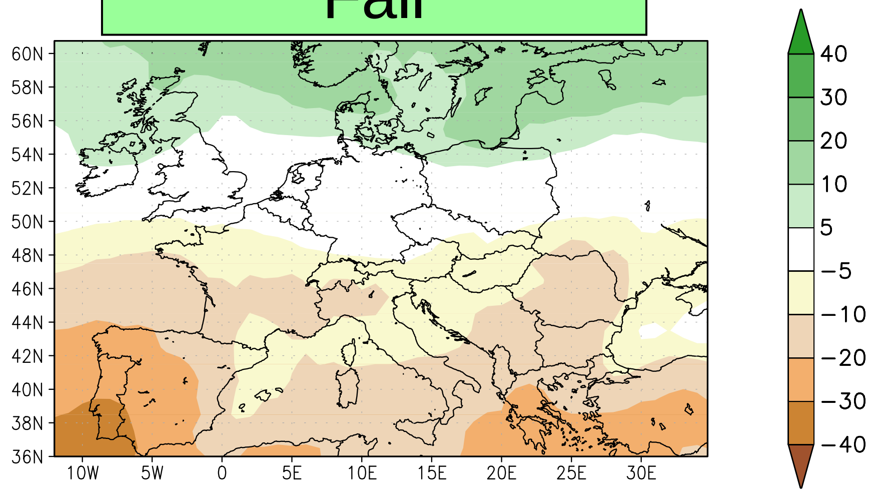
Spring



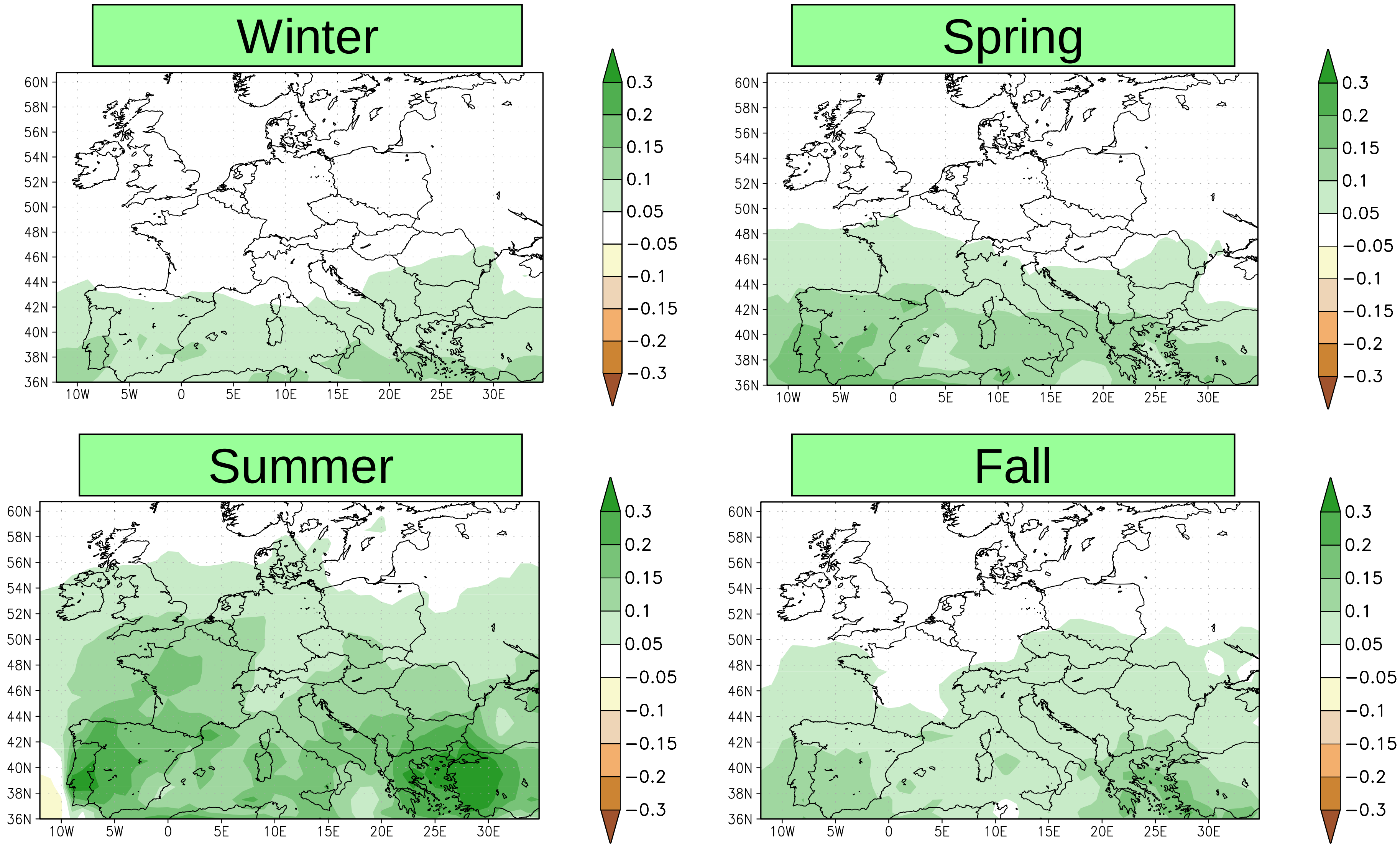
Summer



Fall



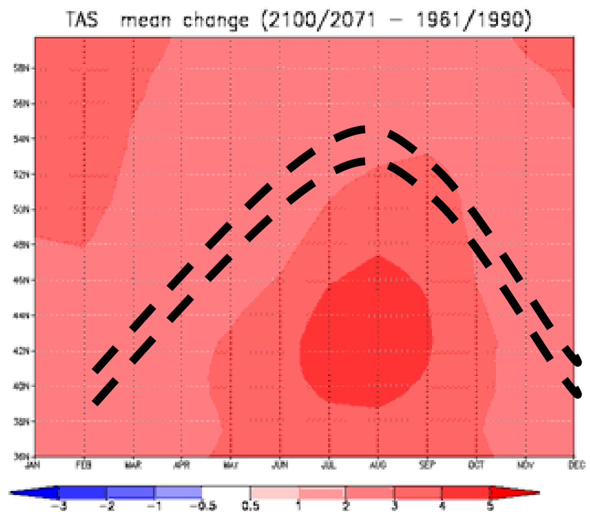
Precipitation variability change, CMIP3 A1B Scenario, 20 AOGCMs

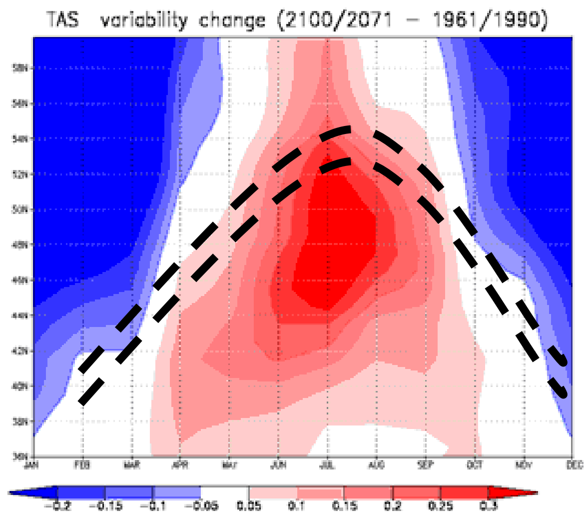


The European Climate Change Oscillation (ECO)

(A1B, 2071-2100 minus 1961-1990, Giorgi and Coppola, GRL 2007)

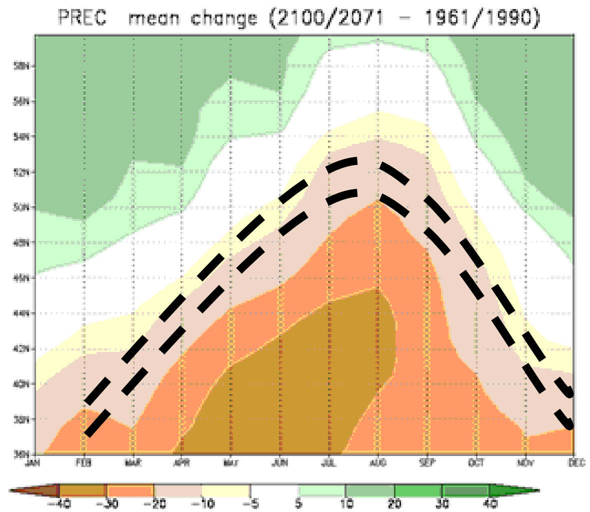
T-Mean

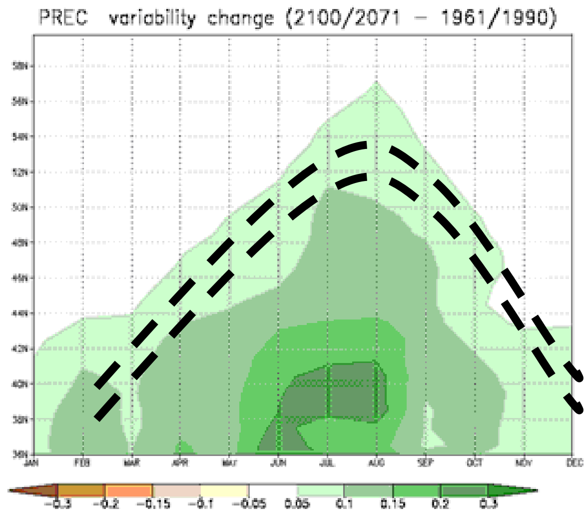




T-Var

P-Mean

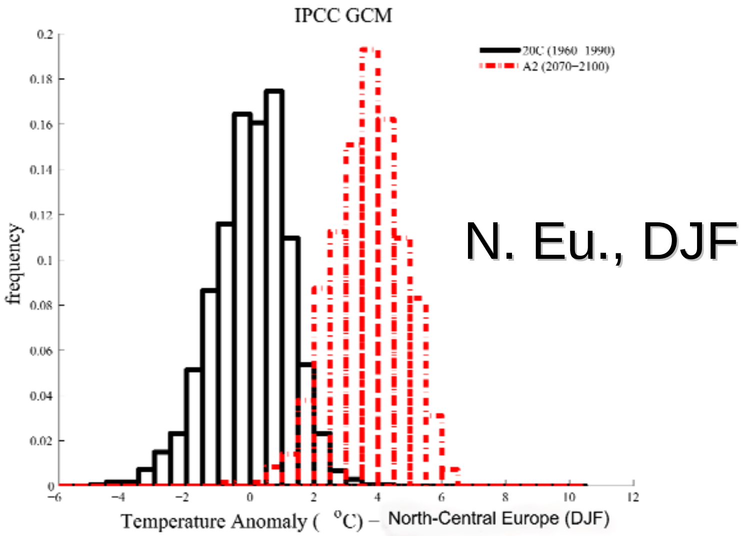


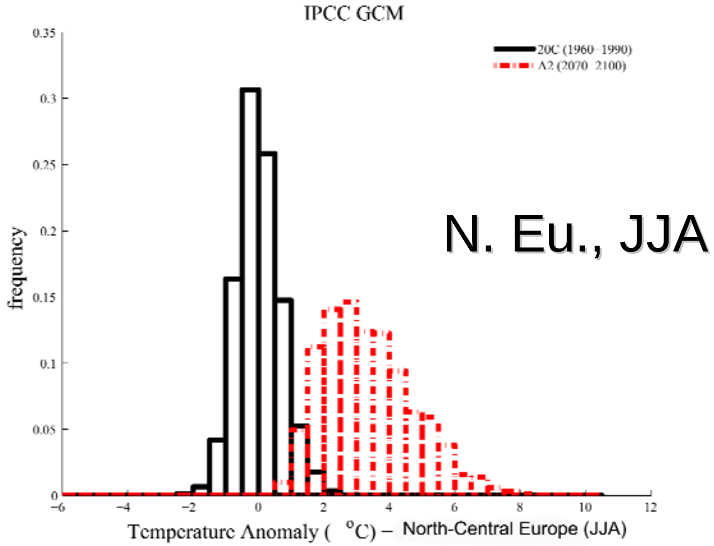


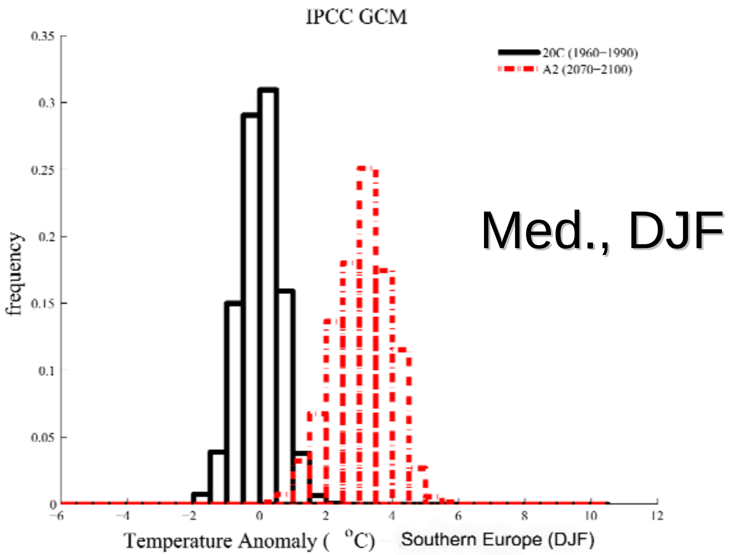
P-Var

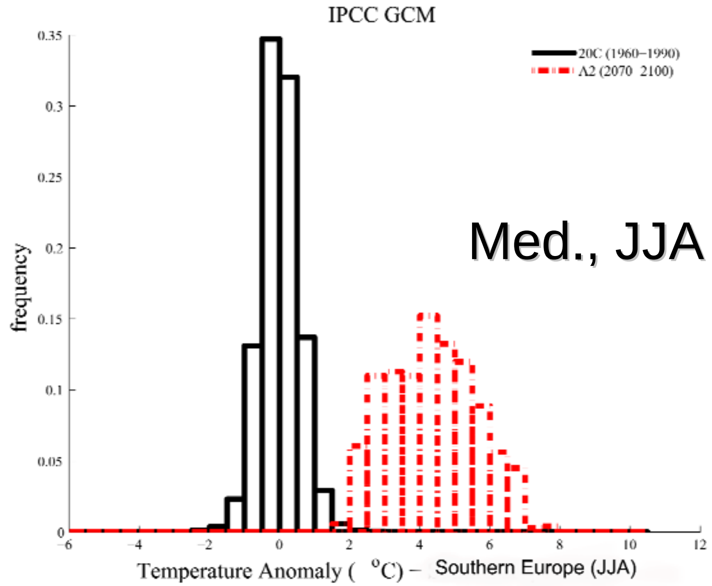
Change in seasonal temperature distribution

CMIP3 Ensemble (%, 2071-2100 minus 1961-1990),



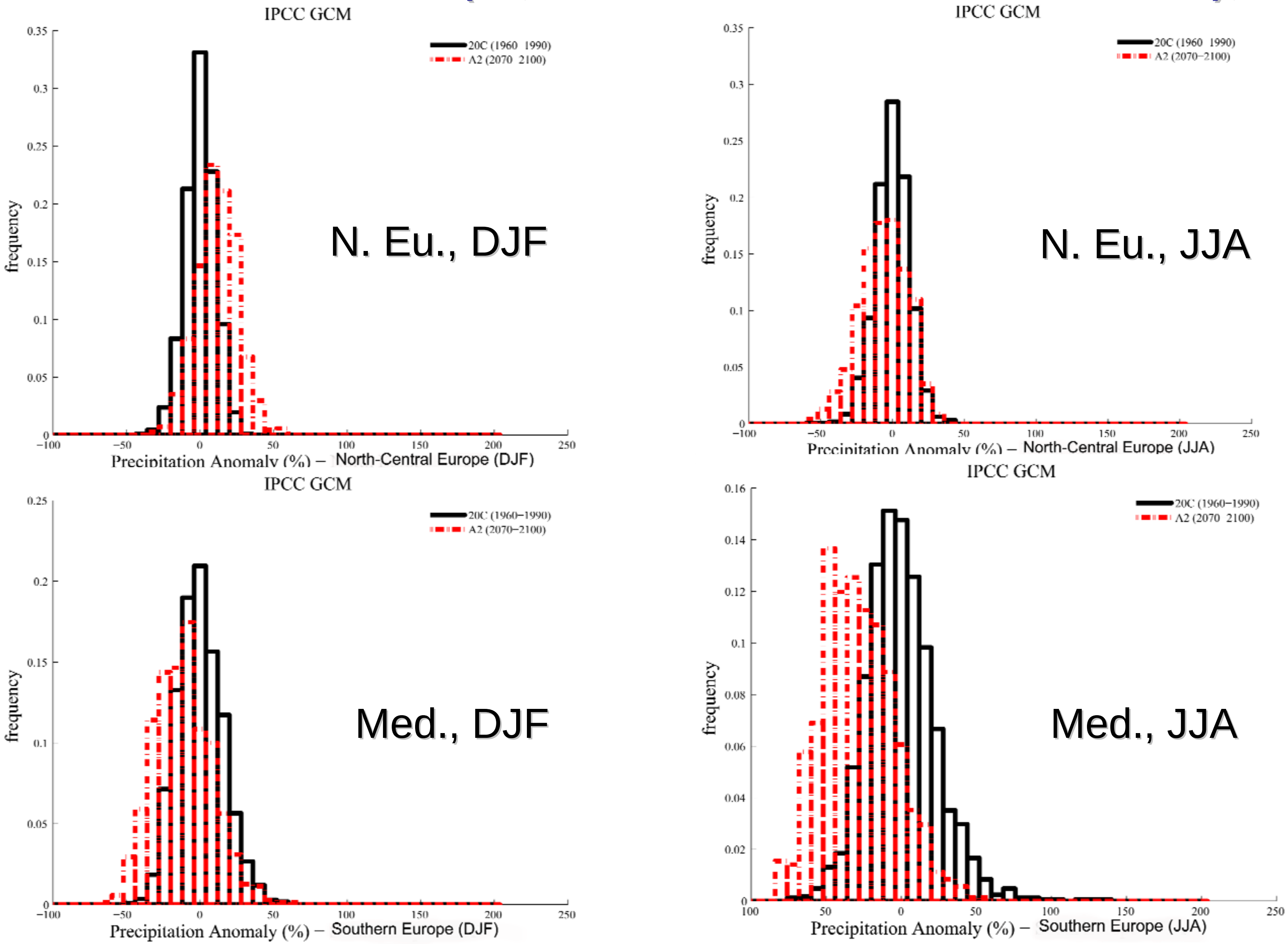




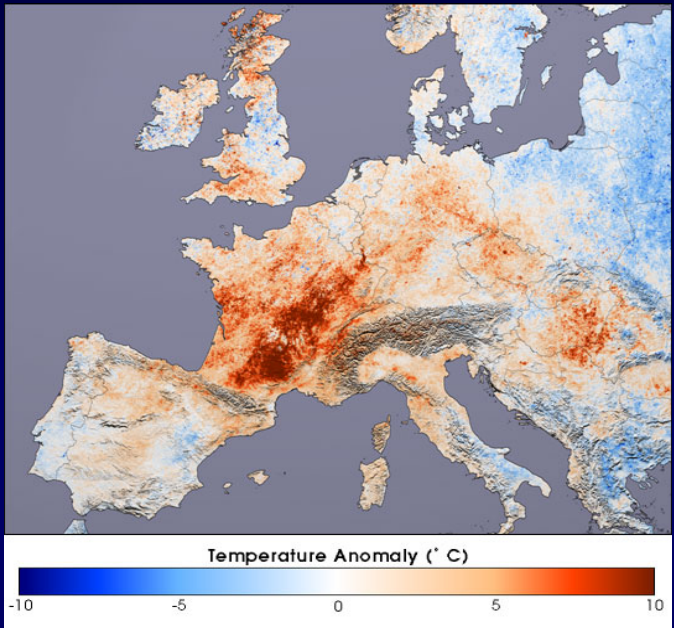


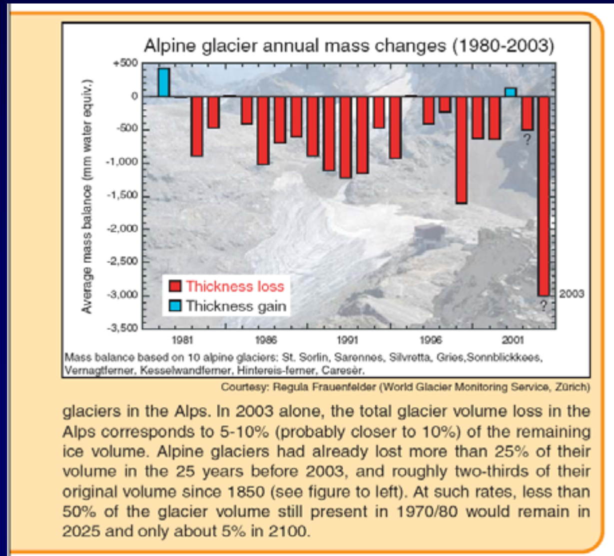
Change in seasonal precipitation distribution

CMIP3 Ensemble (%, 2071-2100 minus 1961-1990),



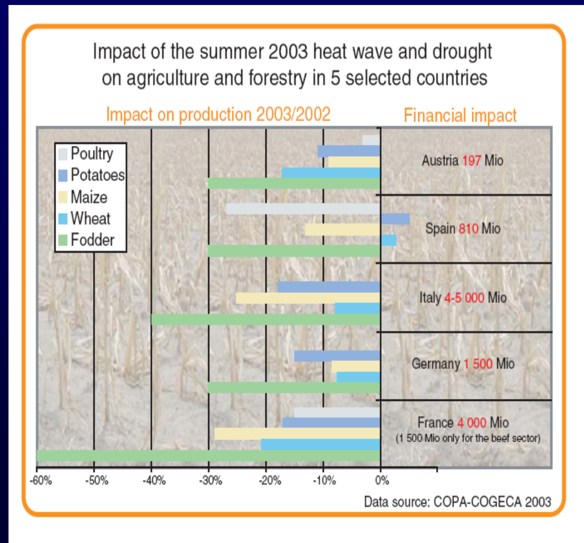
The summers we can expect in Europe?
Summer of 2003



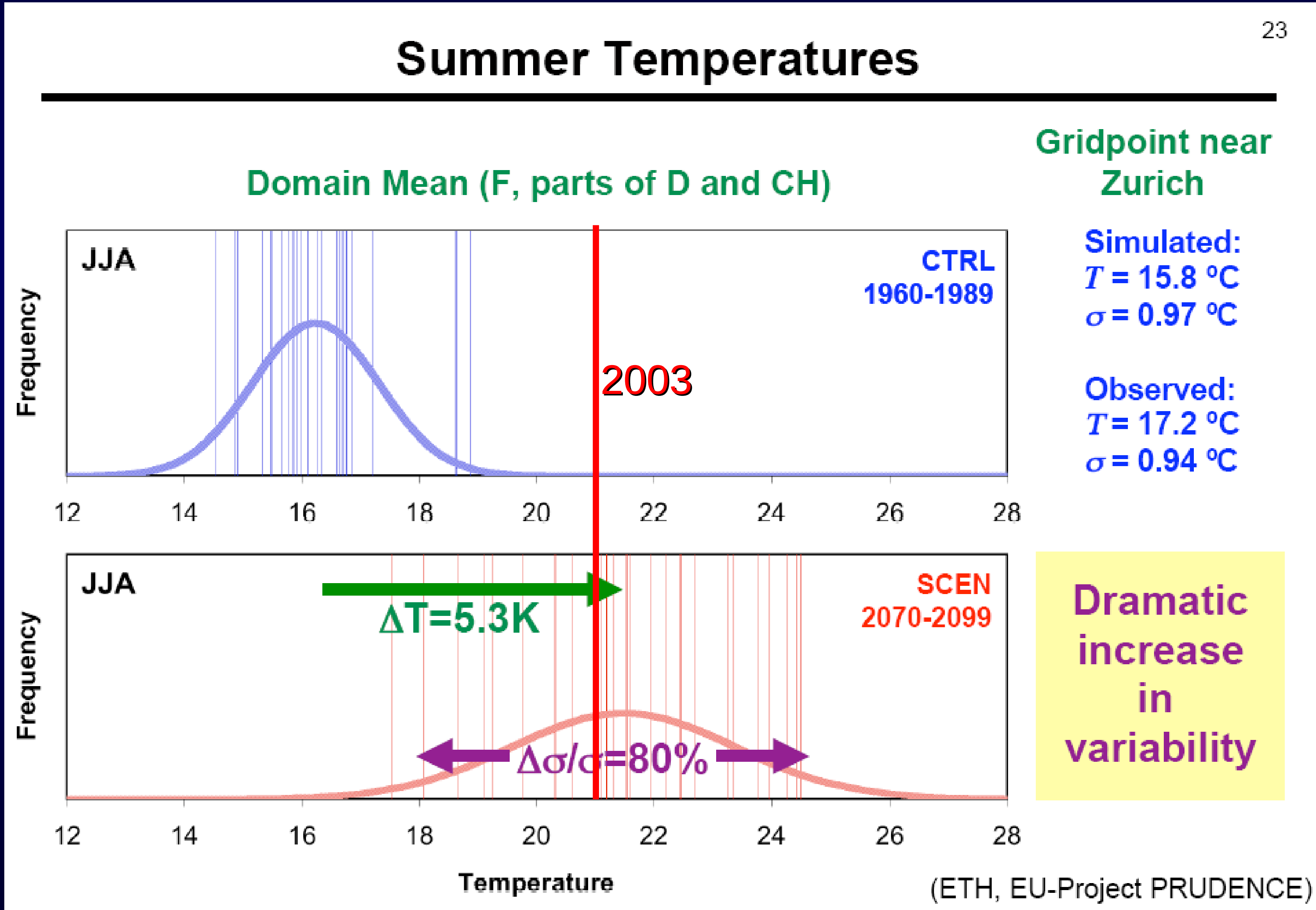


Country	Casualties
France	14 082
Germany	7 000
Spain	4 200
Italy	4 000
UK	2 045
Netherlands	1 400
Portugal	1 300
Belgium	150

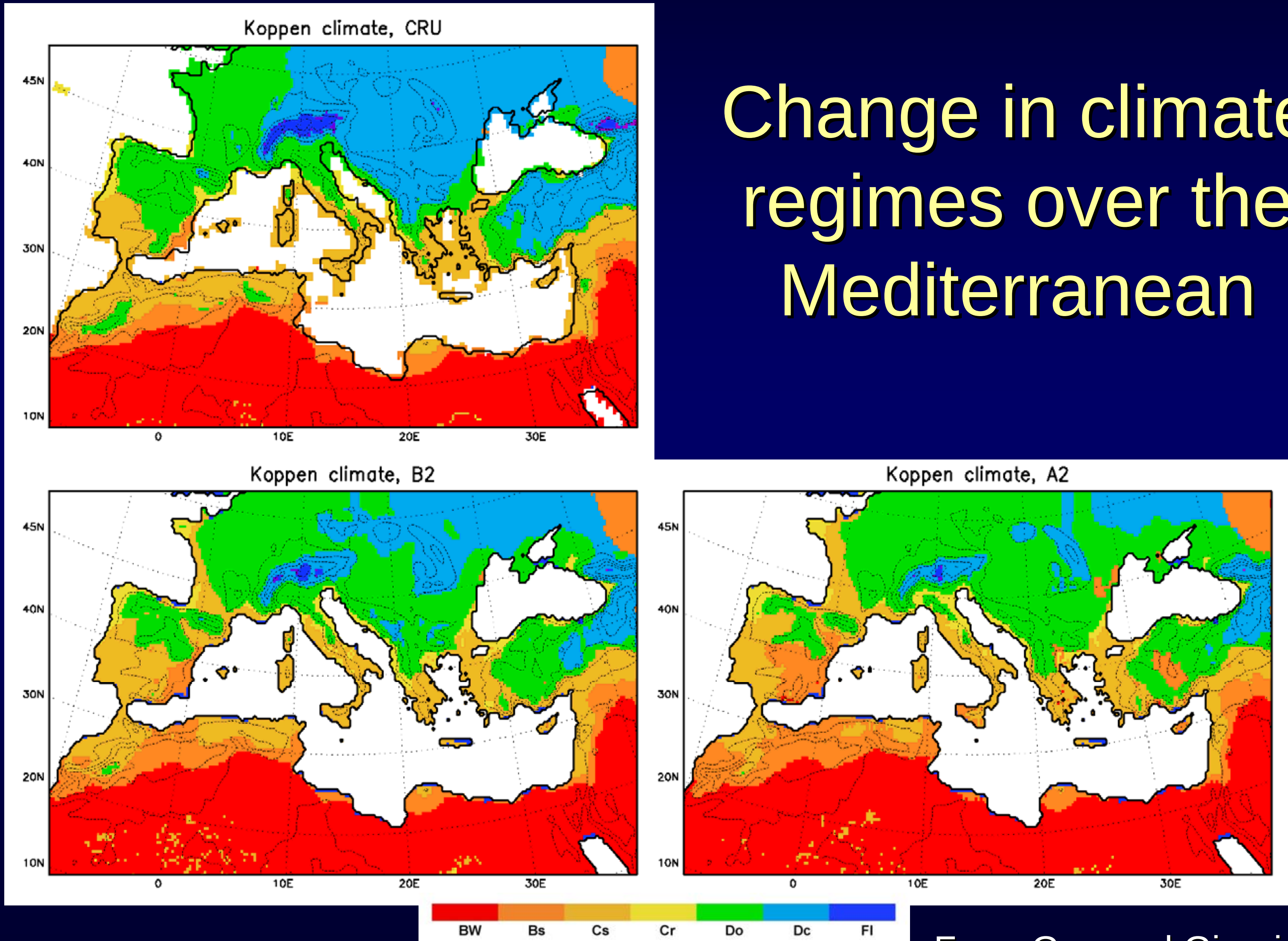
INSERM: "Surmortalité liée à la canicule de l'été 2003", AP September 25, 2003



The summer of 2003 may become the norm in the future

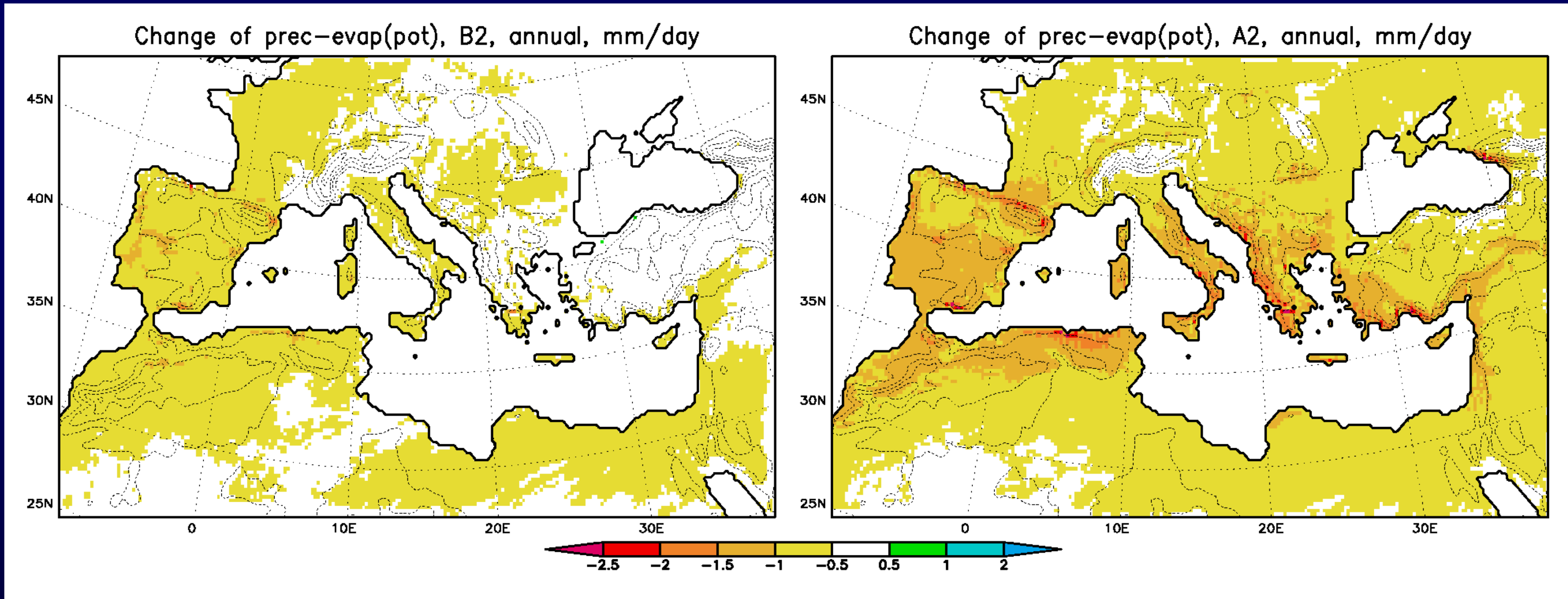


Change in climate regimes over the Mediterranean



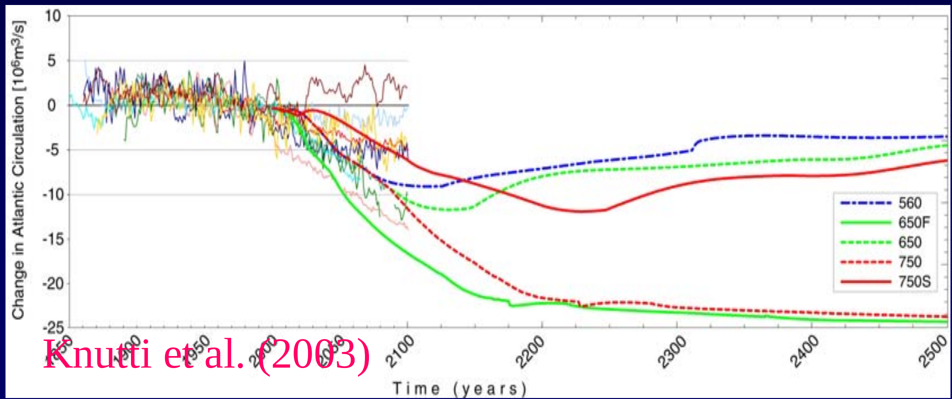
From Gao and Giorgi (2007)

Change in water stress
Change in precipitation – evapotranspiration



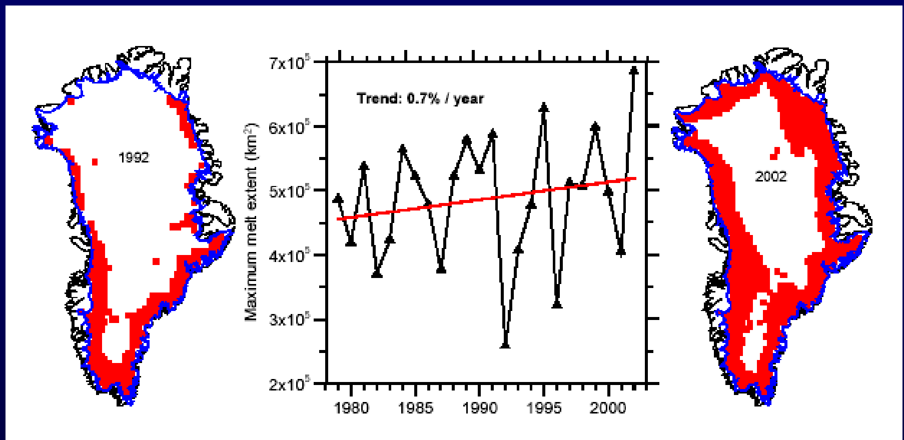
From Gao and Giorgi (2007)

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



Knutti et al. (2003)

Shut down of the oceanic circulation

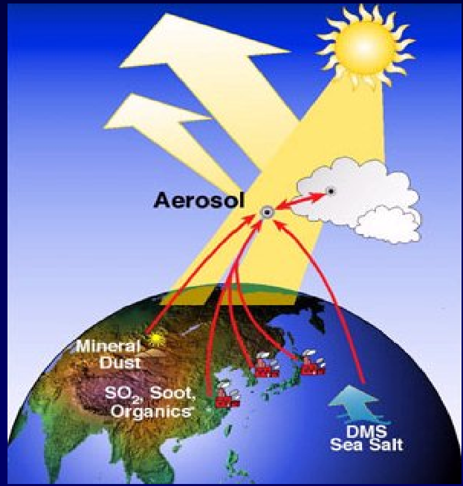


Melting of Greenland and the West Antarctica ice sheet (sea level rise > 12 m)

Die-back of the Amazon forest

Some key uncertainties

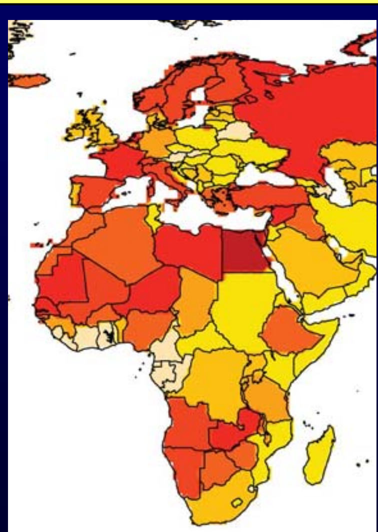
Aerosol and clouds



Emission scenarios

Carbon feedbacks and landuse change

Regional projections



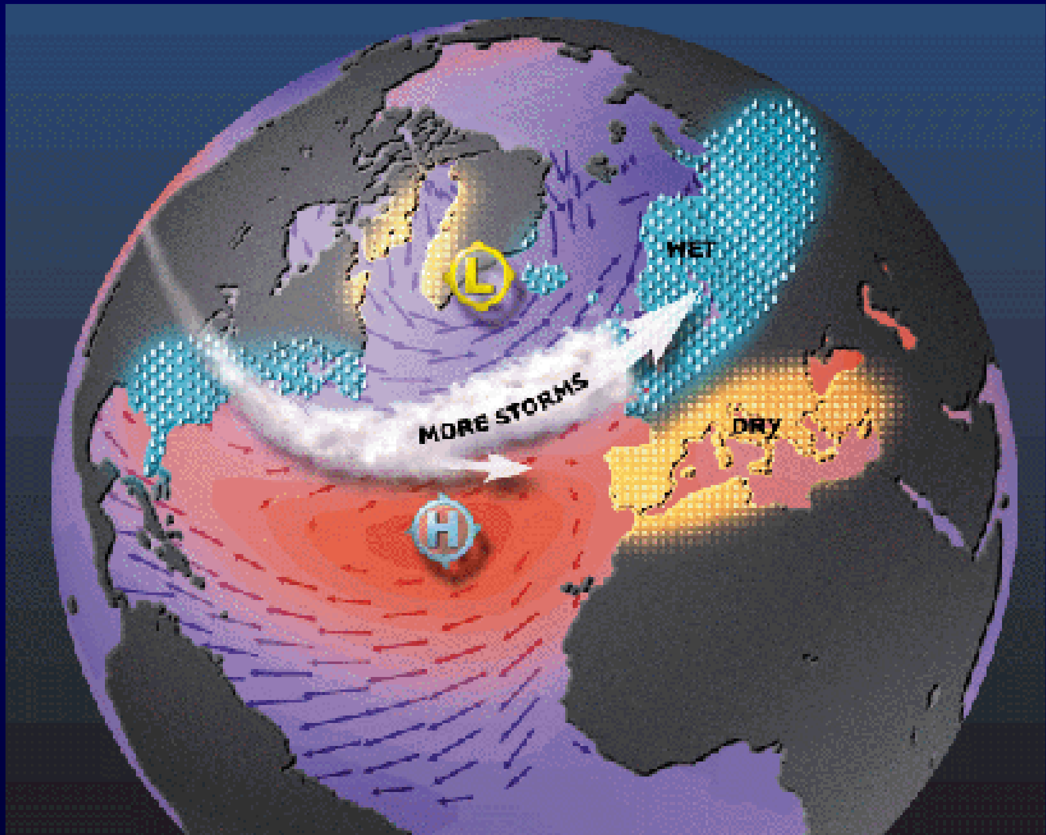
Sea level rise

Some new aspects of the AR5

- Decadal predictions
  - Predictions to 2035
  - High resolution global models
  - Initialized ocean conditions
- Inverse scenario approach
  - Reference concentration pathways (RCP)
  - Climate simulations for the RCPs
  - Emission scenarios consistent with the RCPs
- Greater focus on regional climate change scenarios
  - Coordinated regional climate modeling experiment


THANK YOU

Other observed changes
Circulation

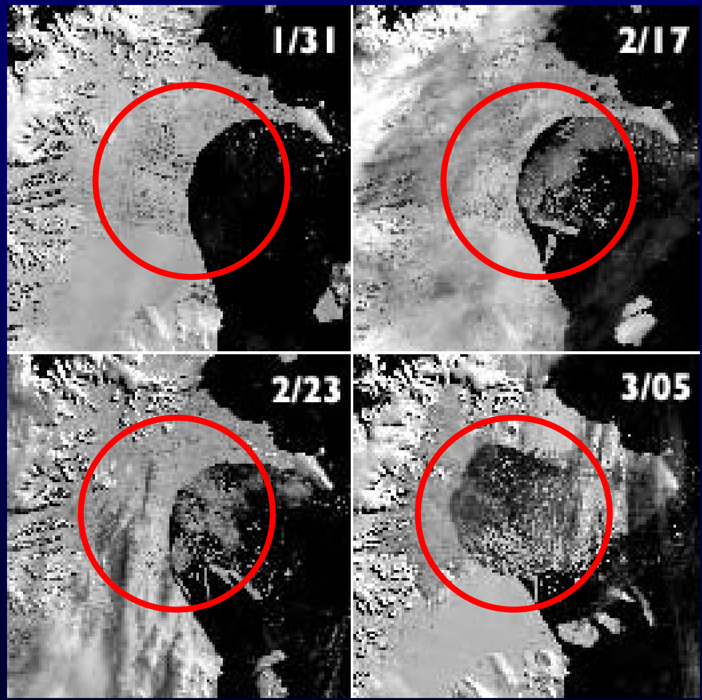


Poleward shift of mid-latitude storm tracks

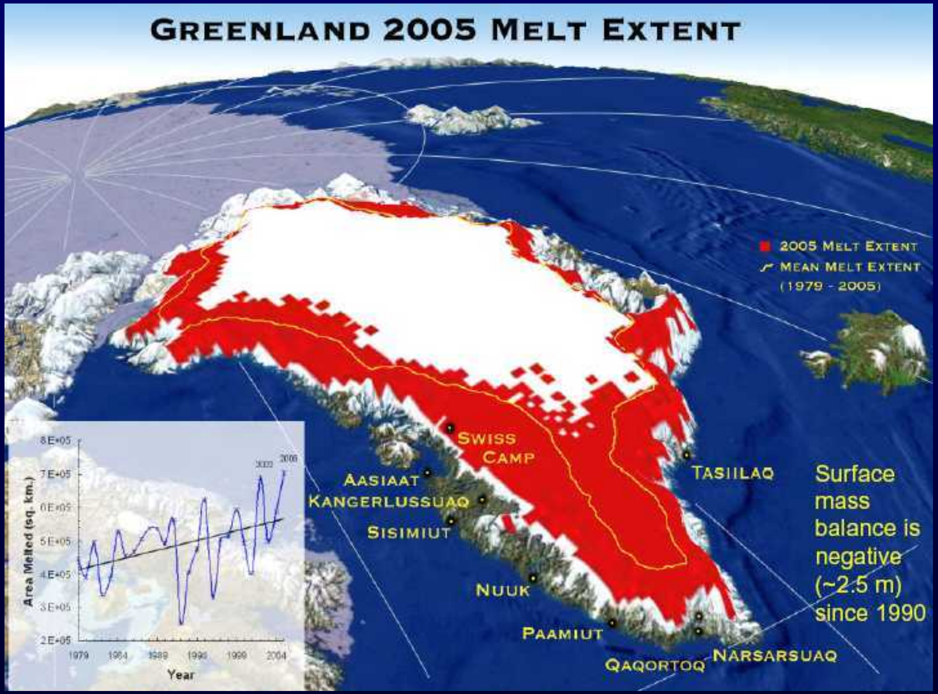
More intense westerlies

Reality or science fiction ?

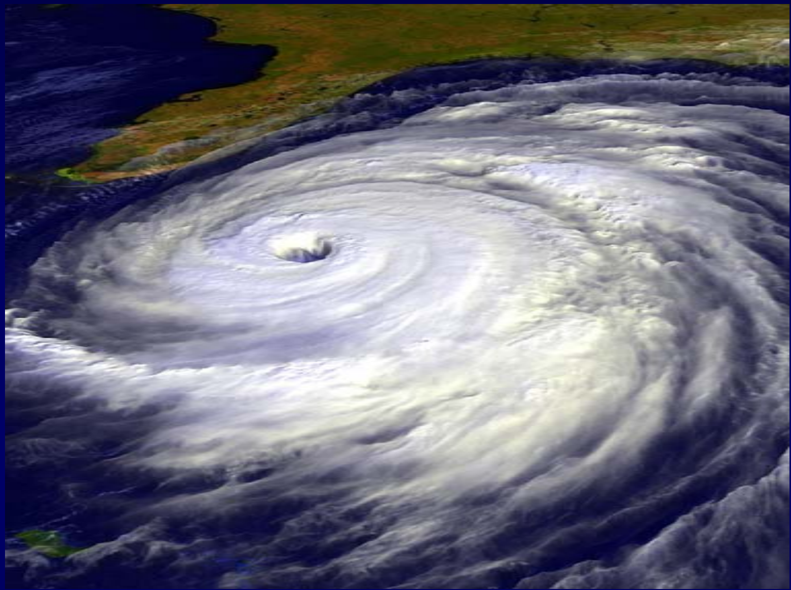
2002: Collapse of the Larsen-B Ice Shelf



Reality or science fiction: The melting of Greenland



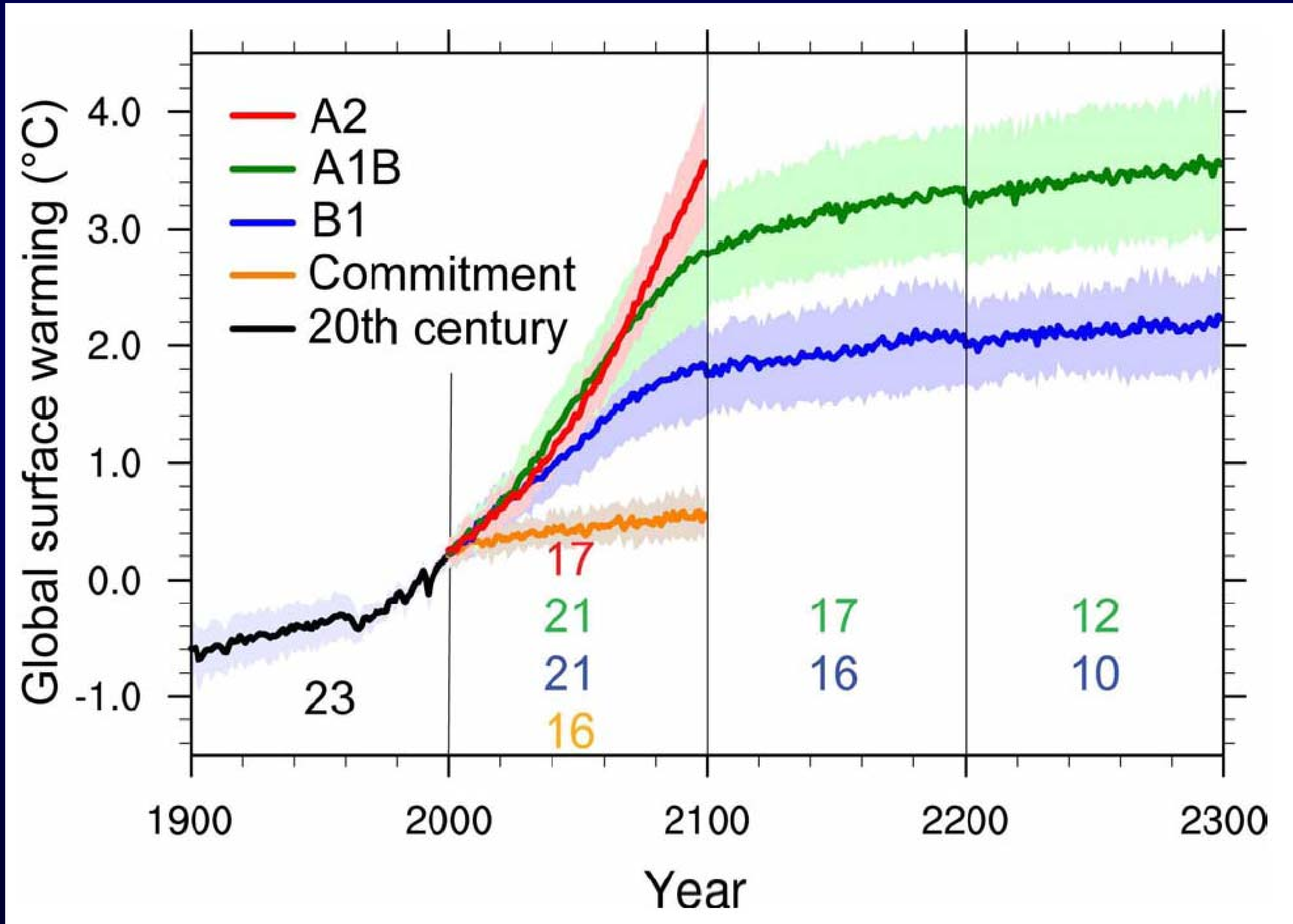
Other observed changes
Storms



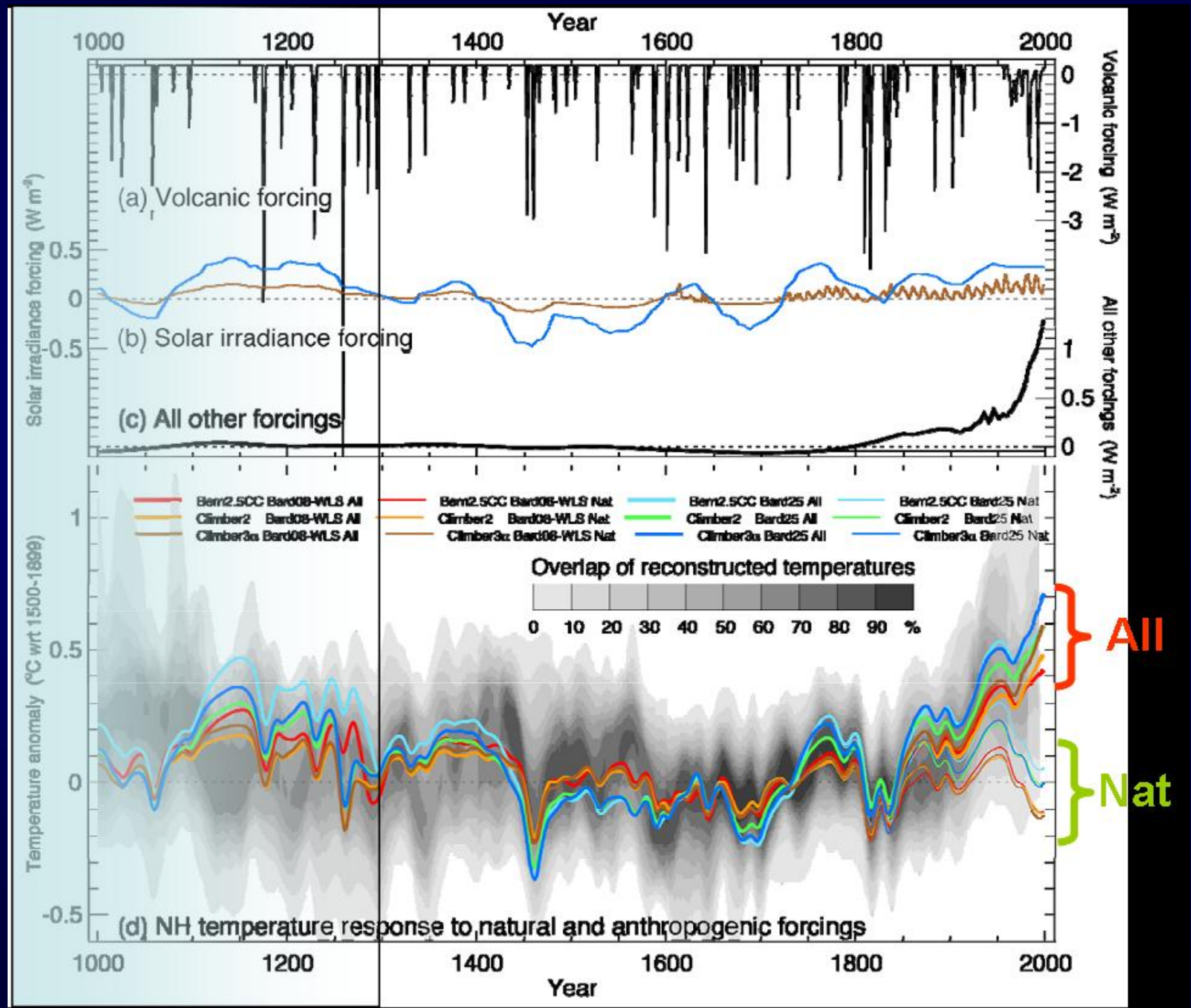
Increase in intense tropical cyclone activity in the North Atlantic since ~ 1970 correlated with increases in tropical SSTs

Insufficient evidence to determine whether trends exist in small scale phenomena such as tornadoes hail, lighting and dust storms

Global temperature change projections after stabilization

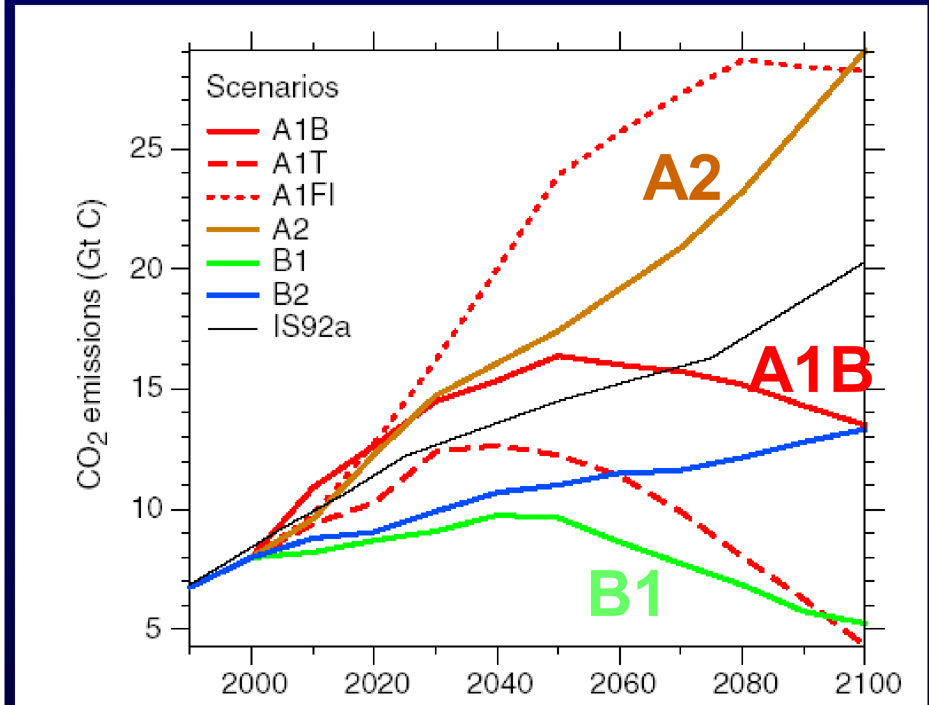


Temperature reconstruction for the last millennium



Greenhouse gas emission and concentration scenarios (IPCC-2000)

CO2 emissions



CO2 Concentrations