The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1867-67

College of Soil Physics

22 October - 9 November, 2007

Prediction of climate change: from global to regional scales.

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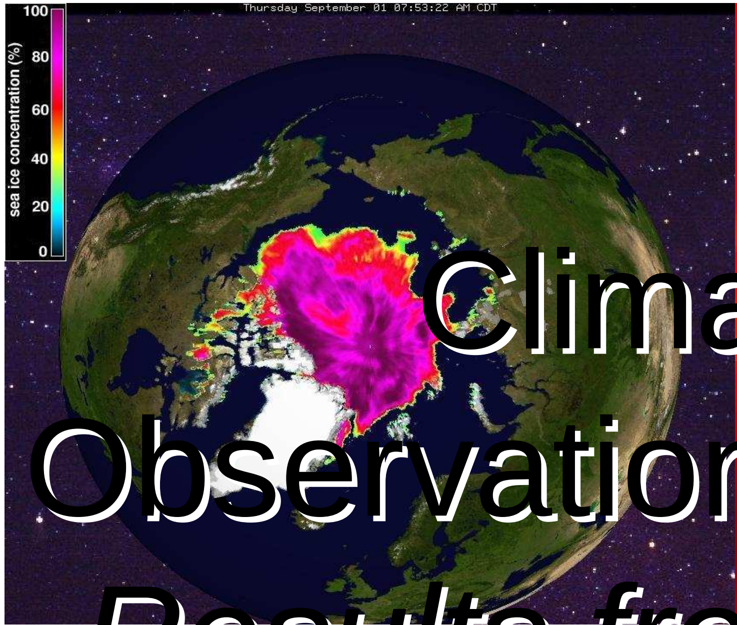
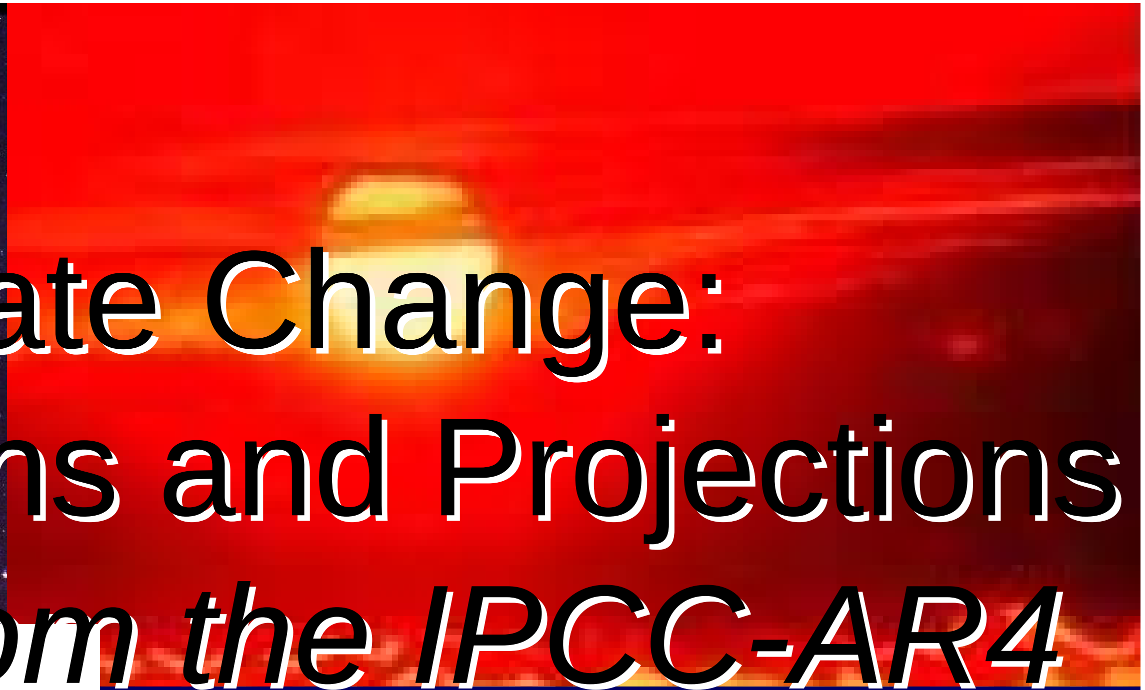
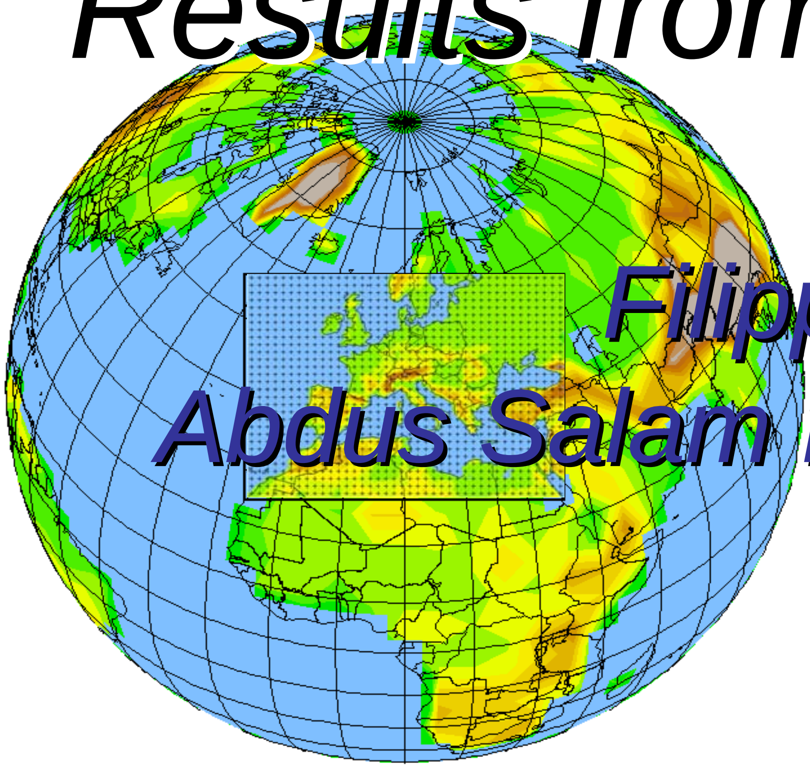
the Abdus Salam International Centre For Theoretical Physics
Earth System Physics Section
Physics of Weather and Climate Group
Trieste
ITALY

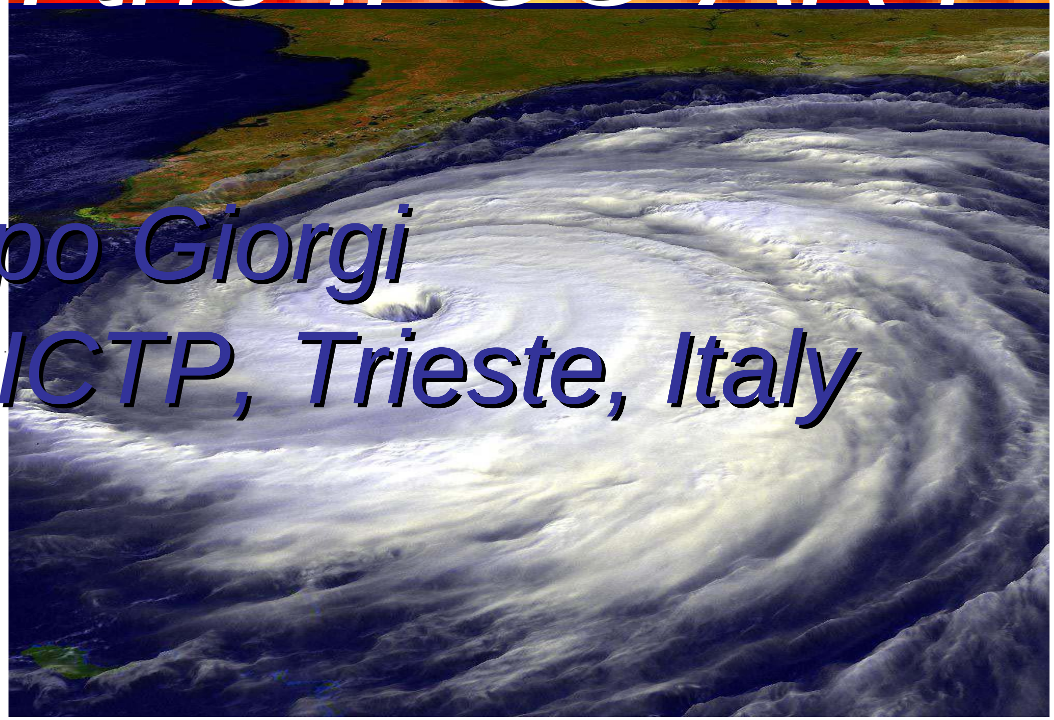
Climate Change: Observations and Projections

Results from the IPCC-AR4







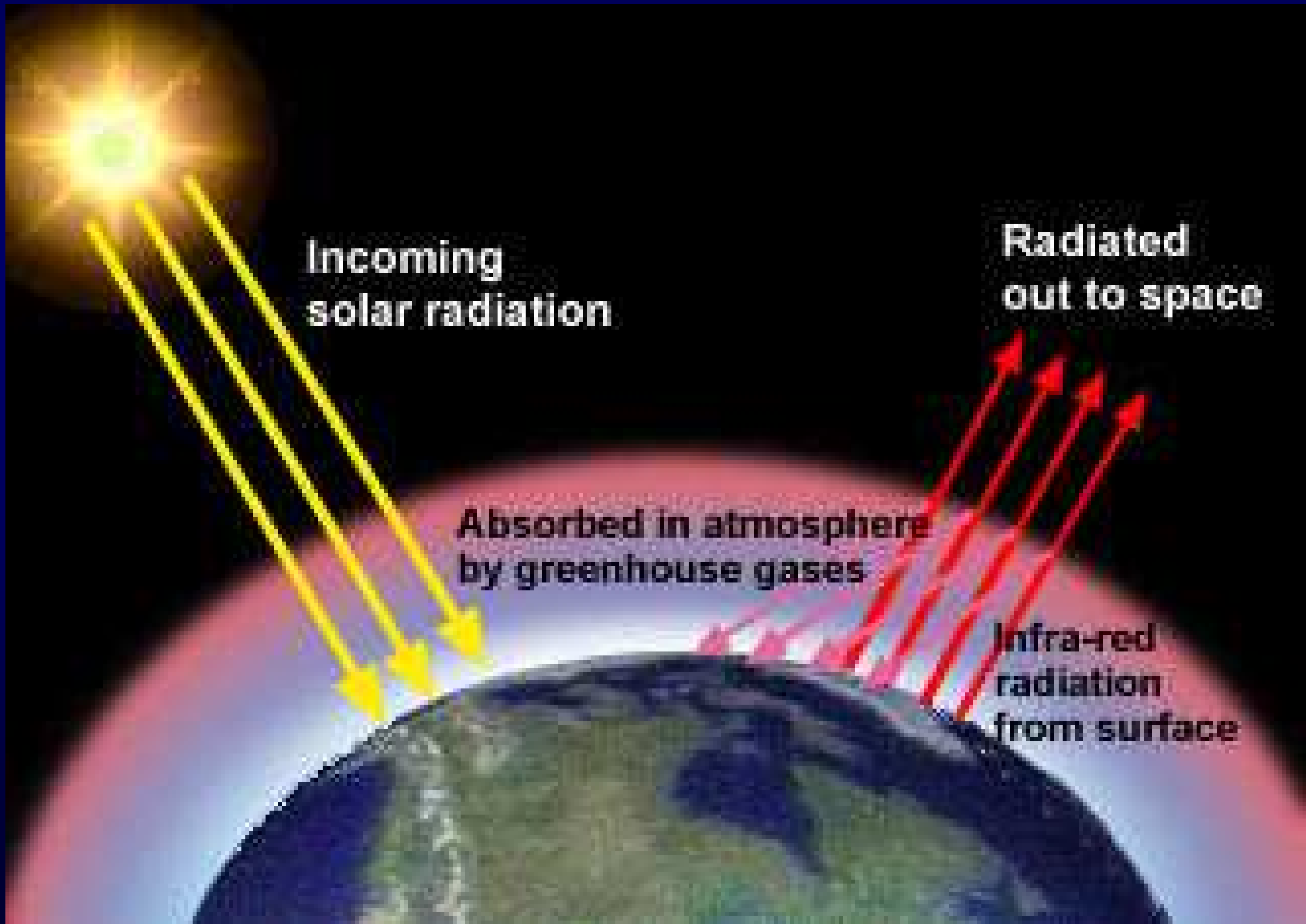


Filippo Giorgi

Abdus Salam ICTP, Trieste, Italy

The Greenhouse Effect

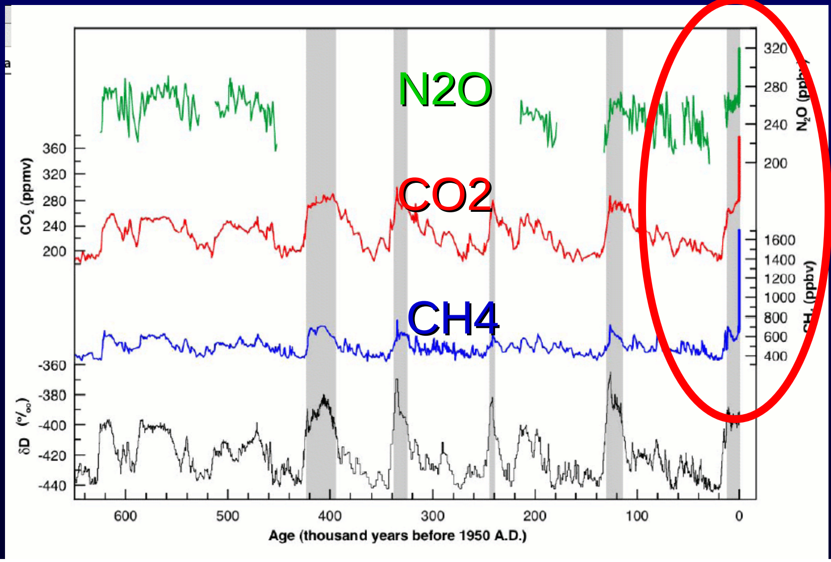
Greenhouse gases absorb the infrared radiation emitted by the surface of the Earth thereby warming the atmosphere and oceans

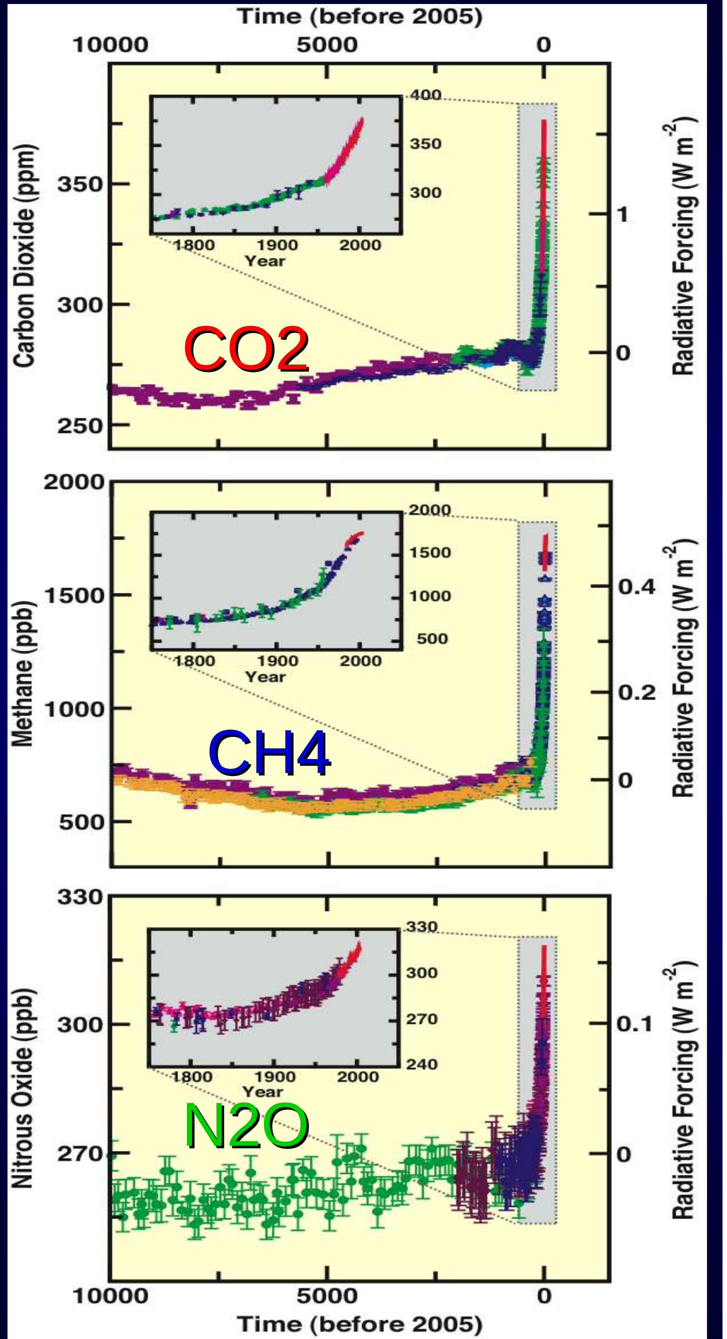


Changes in atmospheric composition and radiative forcing

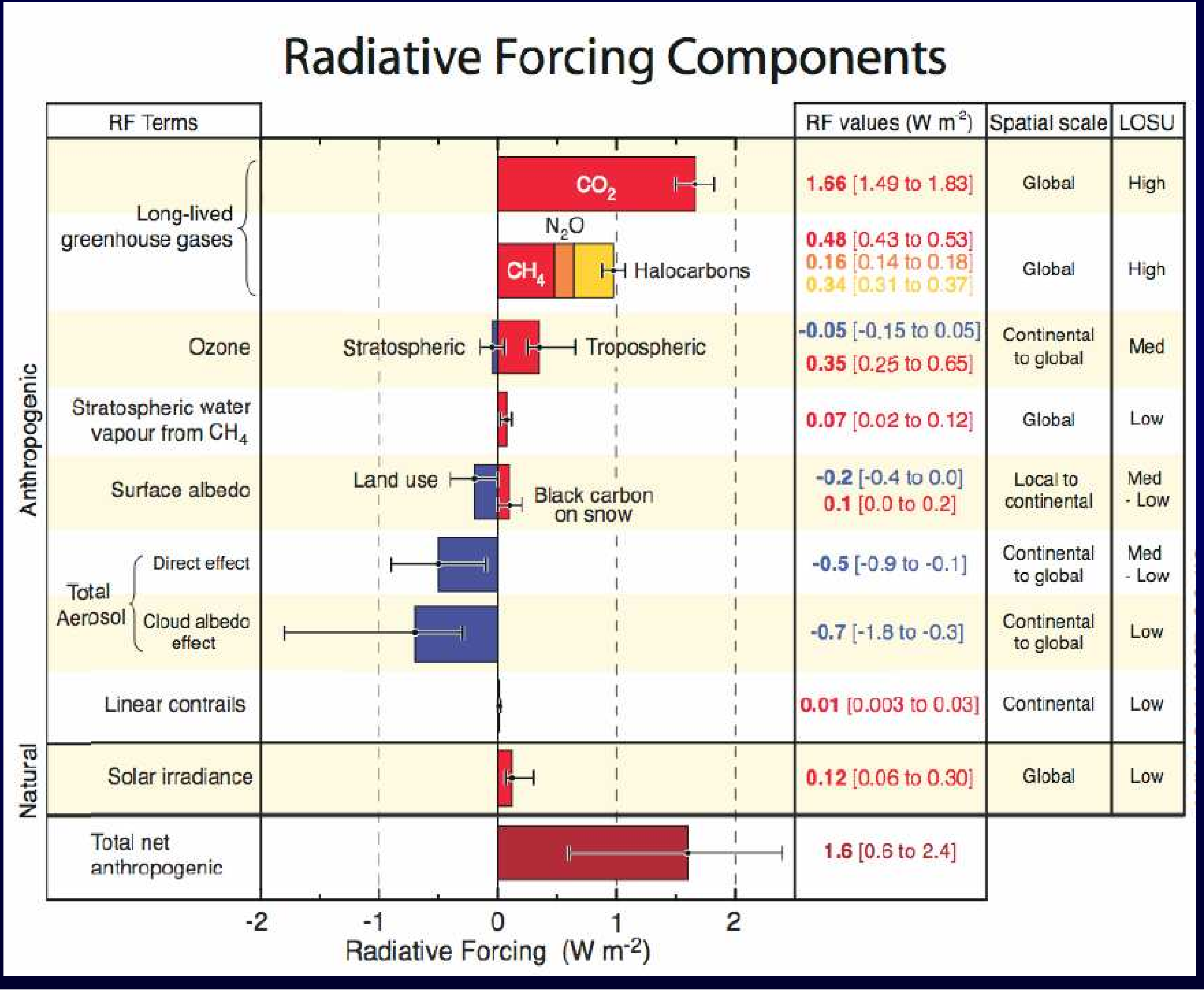
Variation of greenhouse gas concentration in the atmosphere

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





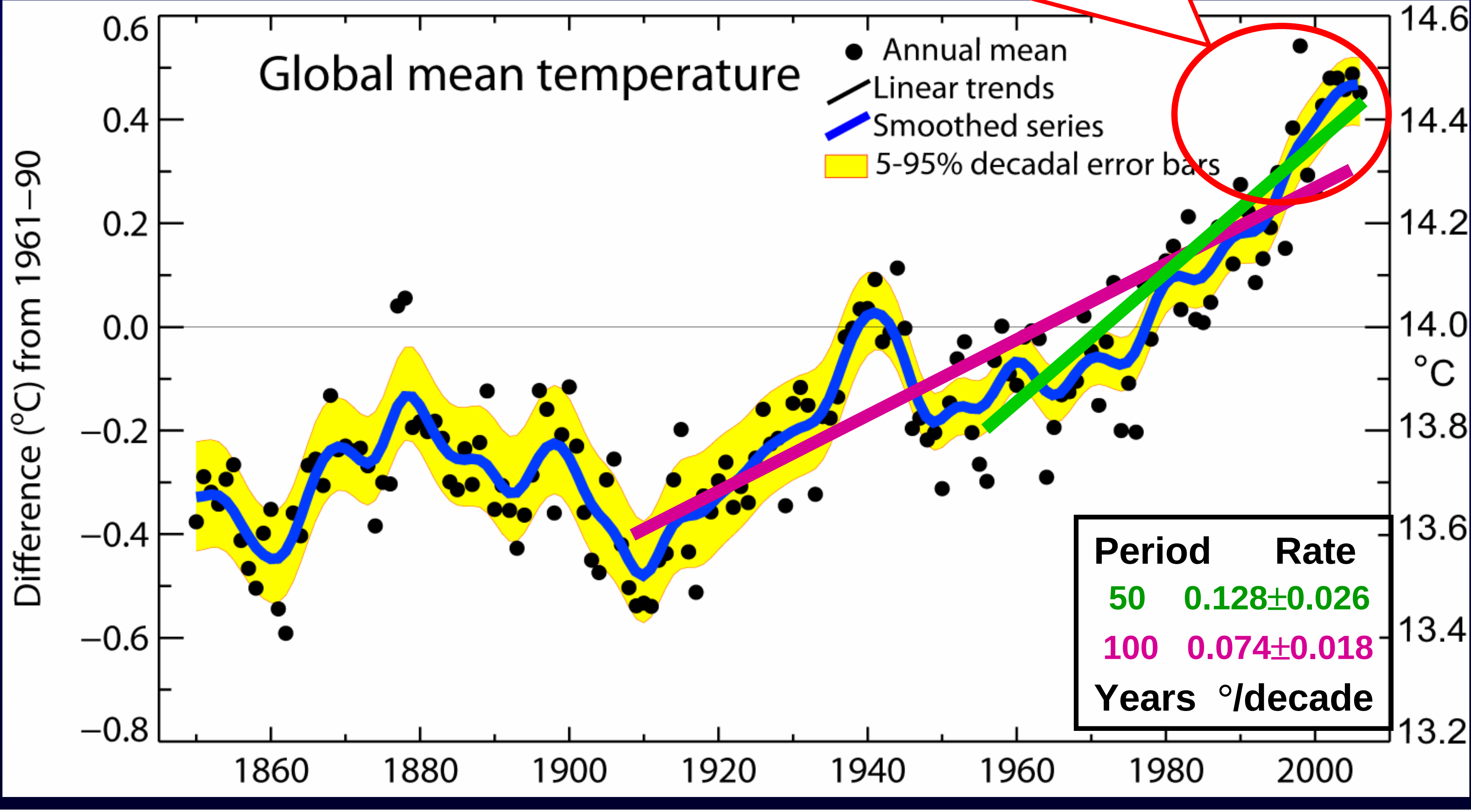
Anthropogenic and natural forcings from 1750 to 2005



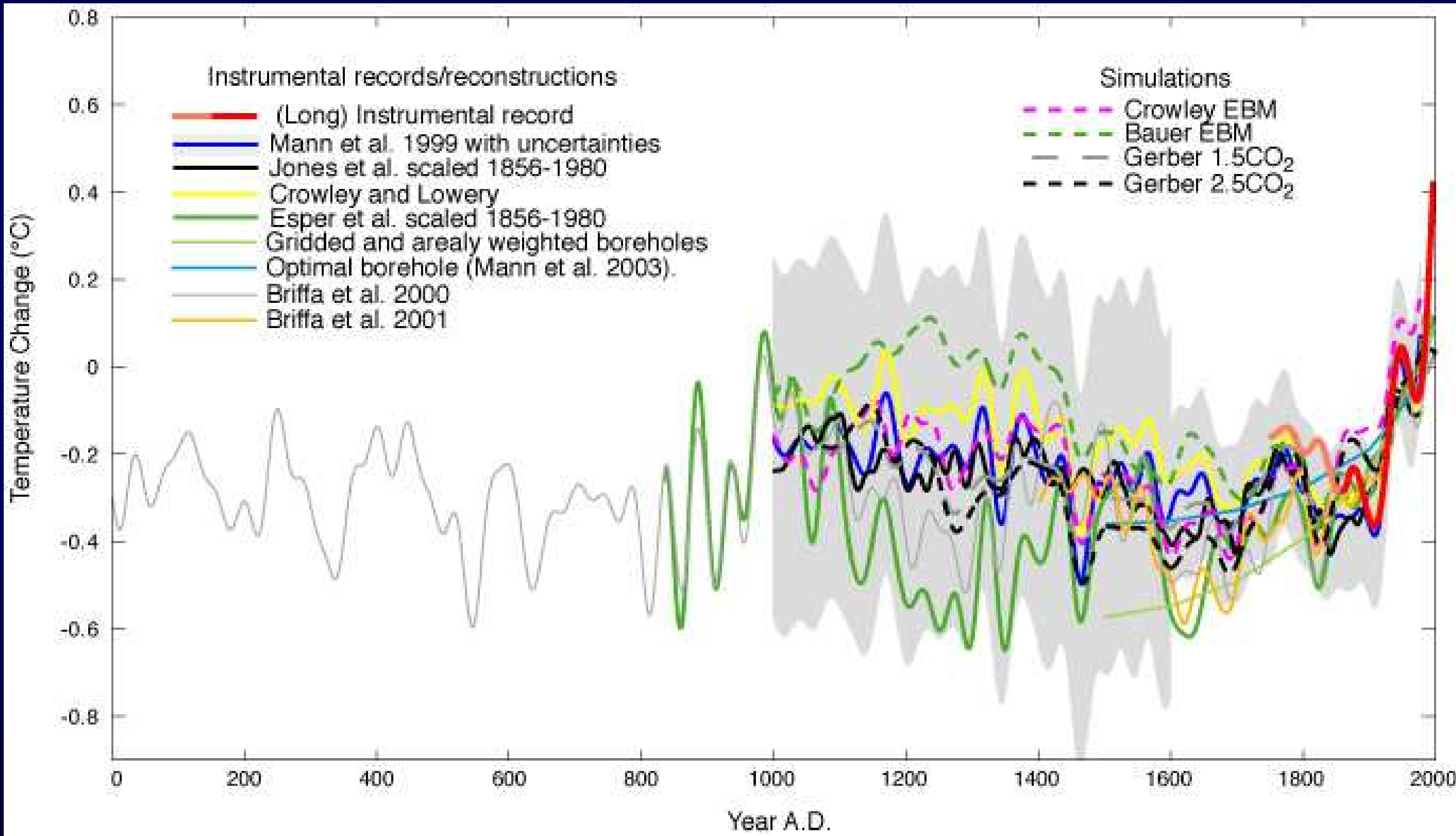
The observational evidence of climate change

Observed change in global surface temperature

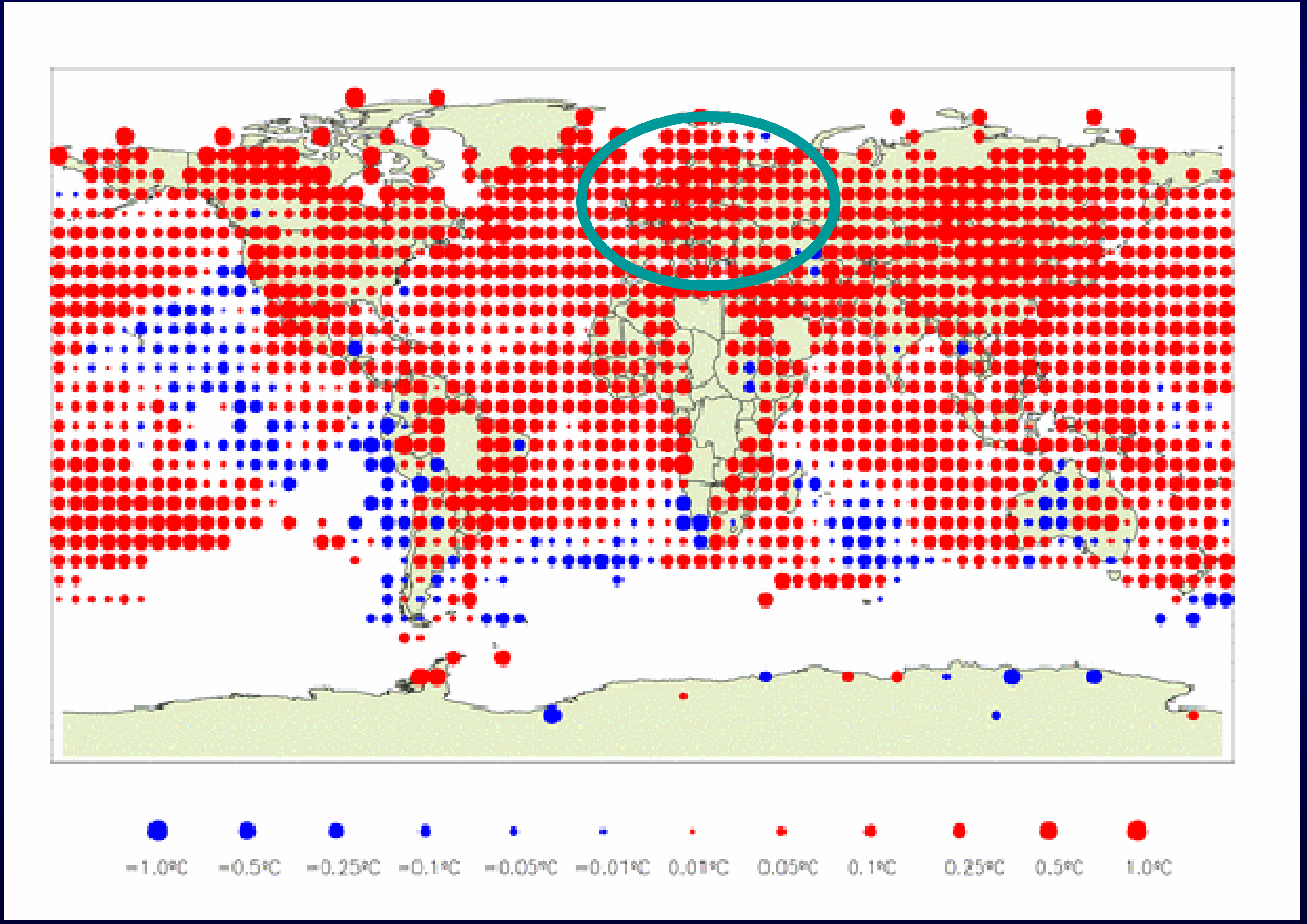
Warmest 12 years:
1998,2005,2003,2002,2004,2006, 2001,1997,1995,1999,1990,2000



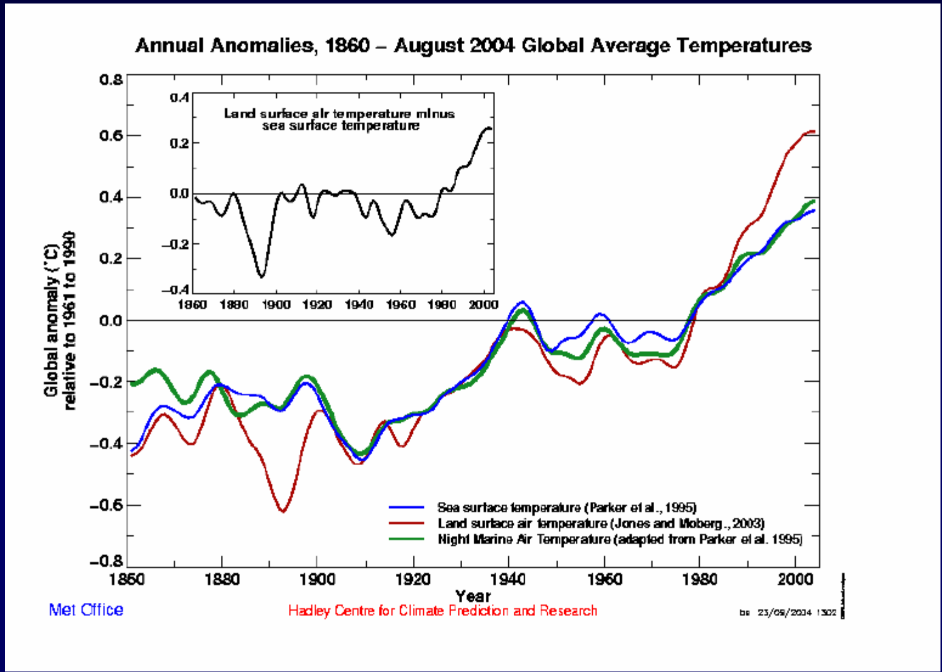
Northern hemisphere temperature reconstructions for the last 2000 years



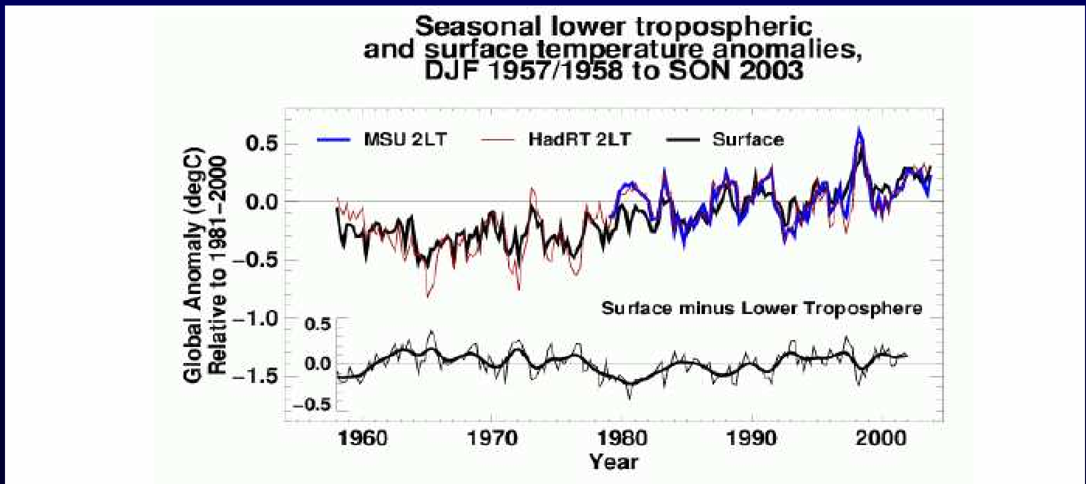
Regional scale: Observed temperature change for the period 1979-2003



Global tropospheric and ocean warming

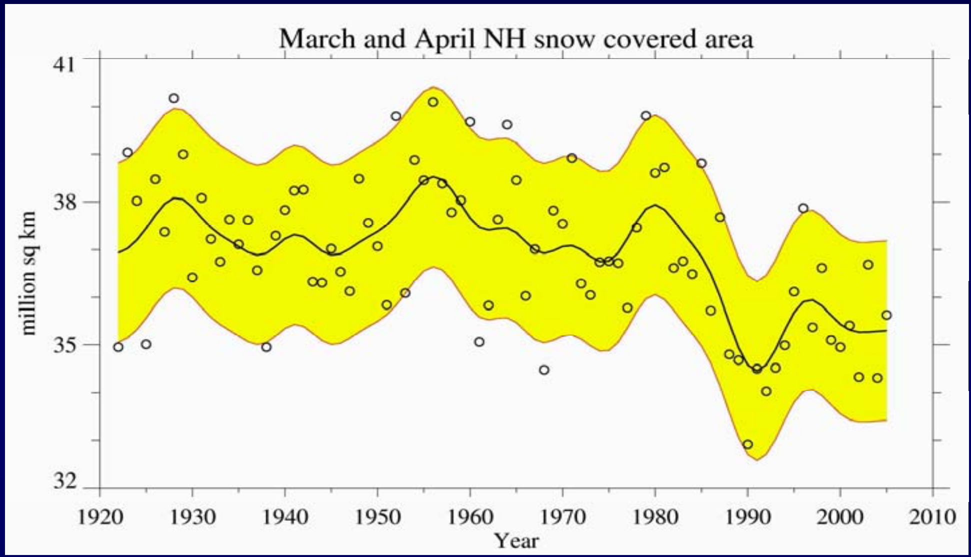


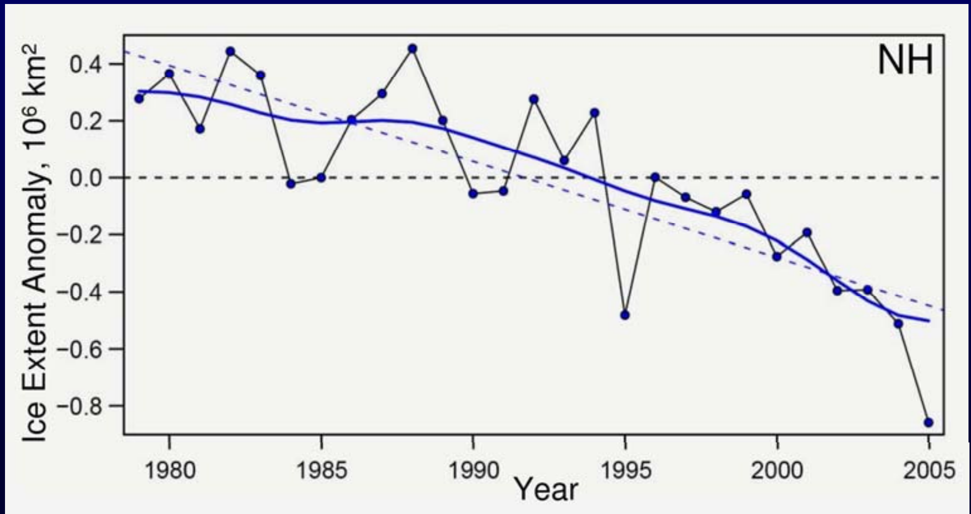
The global ocean warming (blue line) is slightly less than the continental warming (red line)



The global tropospheric warming is consistent with the surface warming

Decrease of snow cover and sea ice





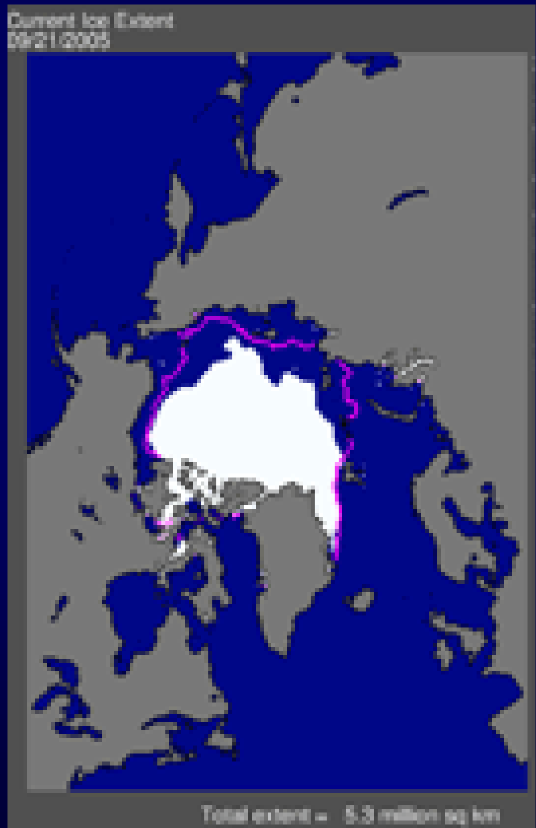
Decrease of snow cover

Decrease of sea ice

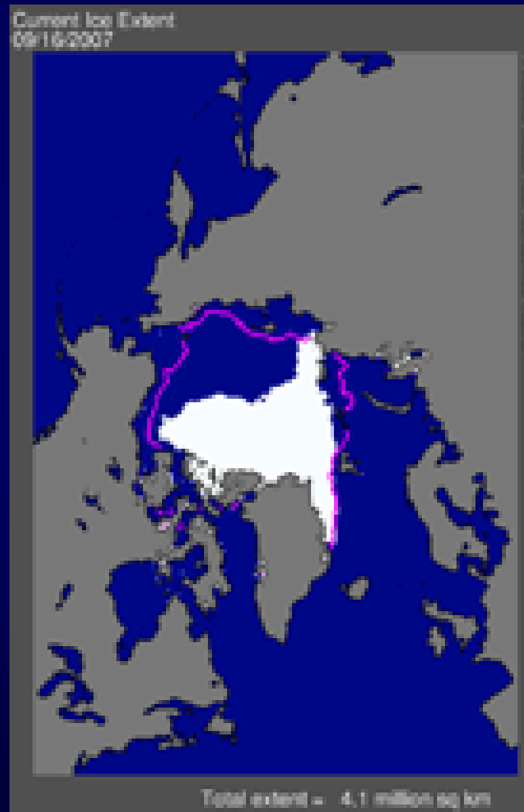
Extension of the Arctic ice cap

September 1979

September 2005



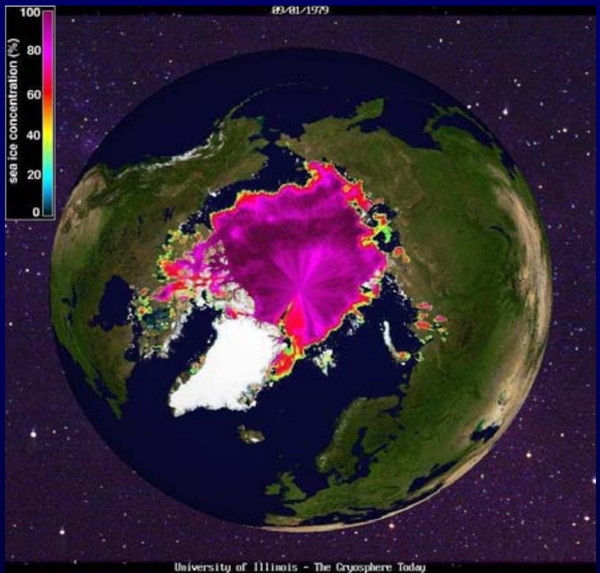
September 2007



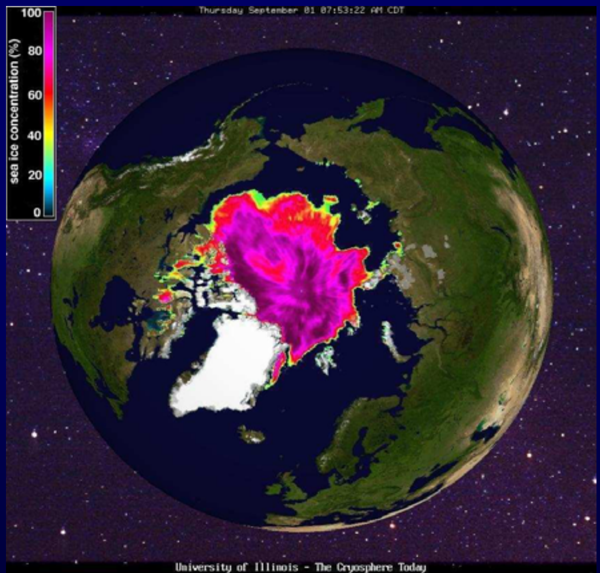
The pink line indicates the average ice cap extension since 1979

Extension of the Arctic ice cap

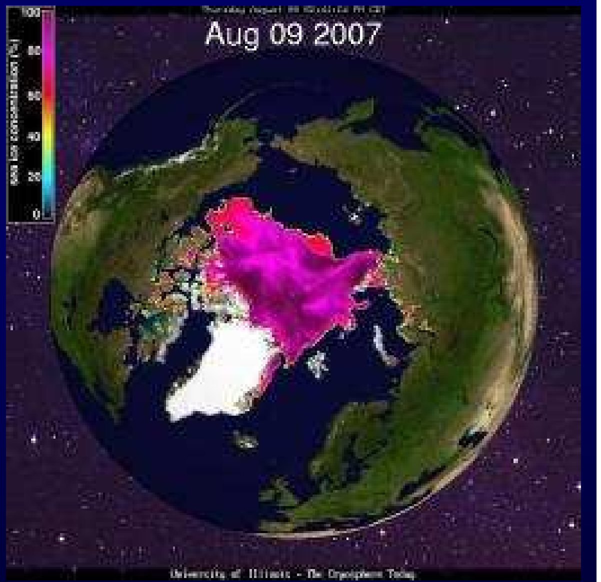
1 September1979



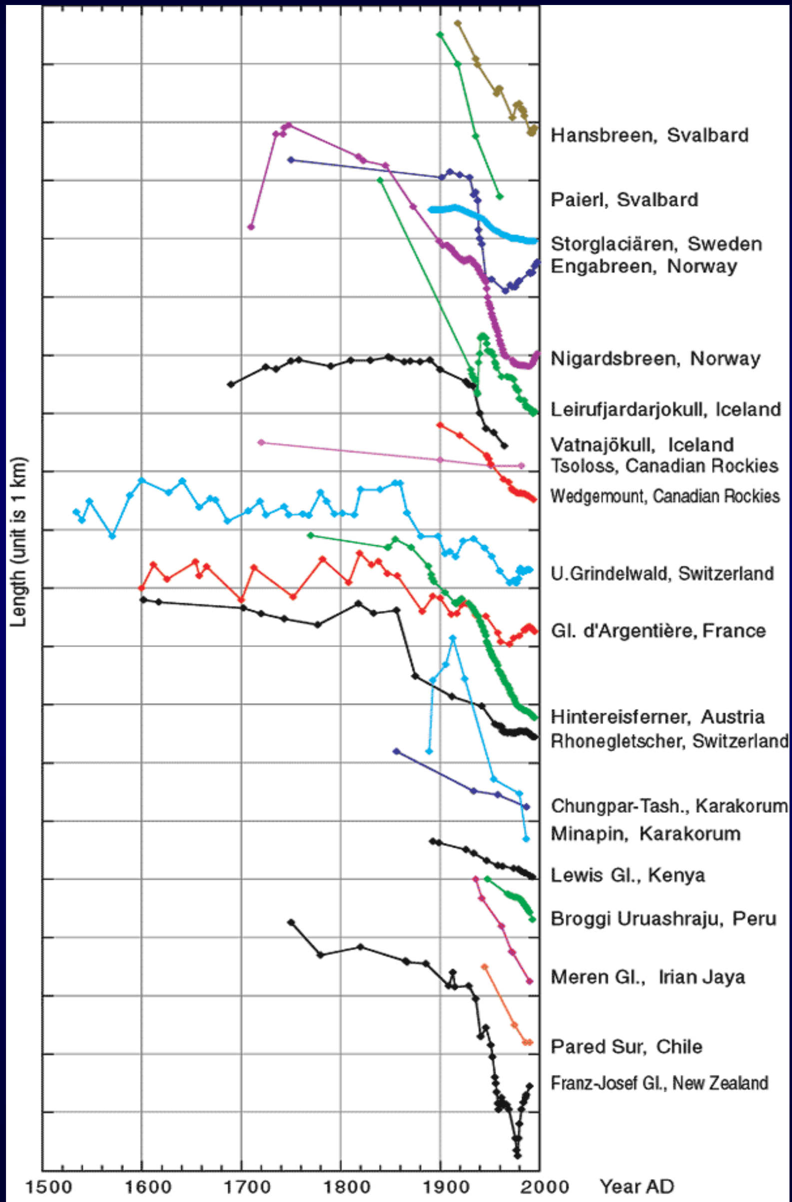
1 September 2005

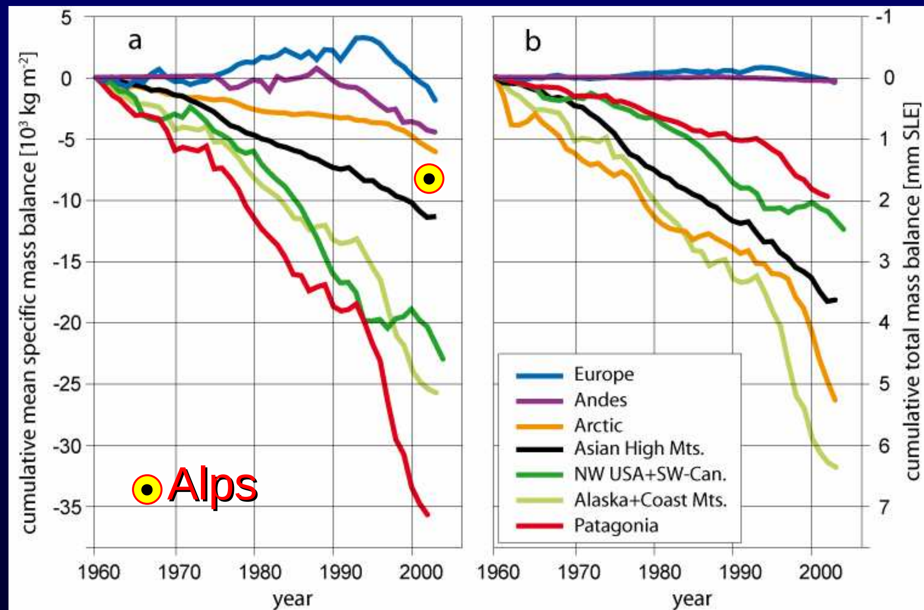


9 August 2007

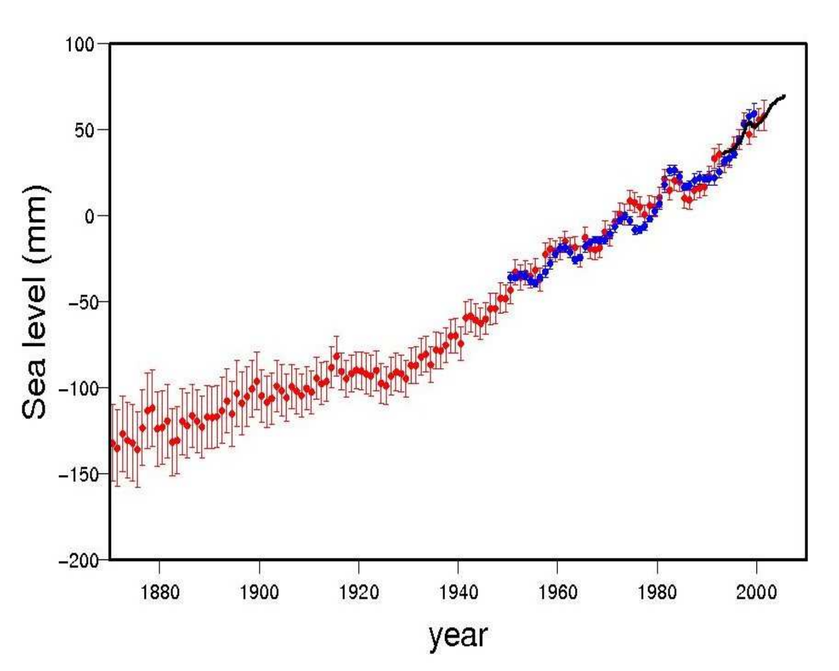


Melting of glaciers





Sea level rise



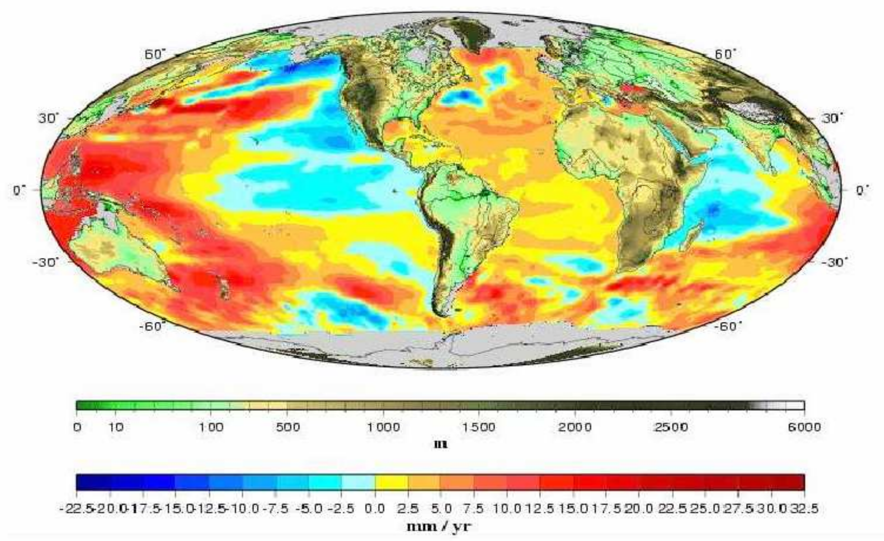


Figure 7. Sea level trends over 1993-2003 from the T/P mission.

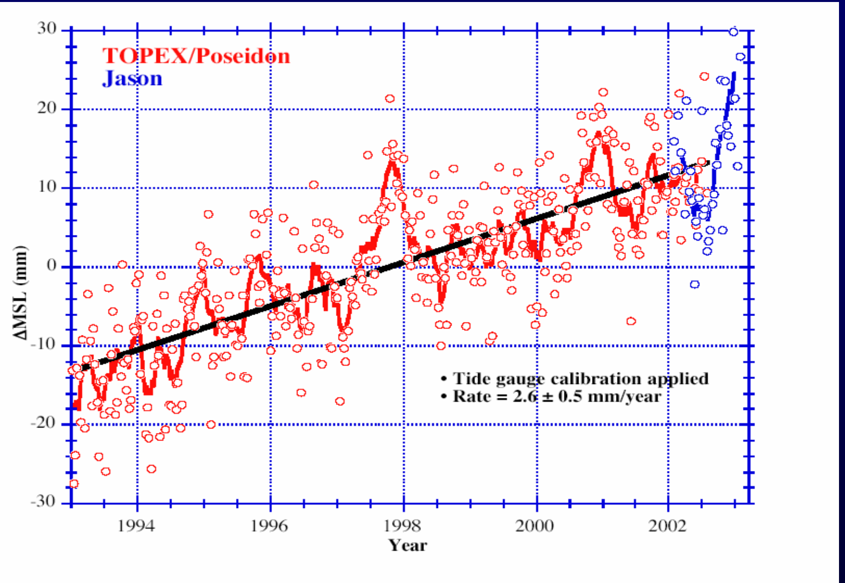
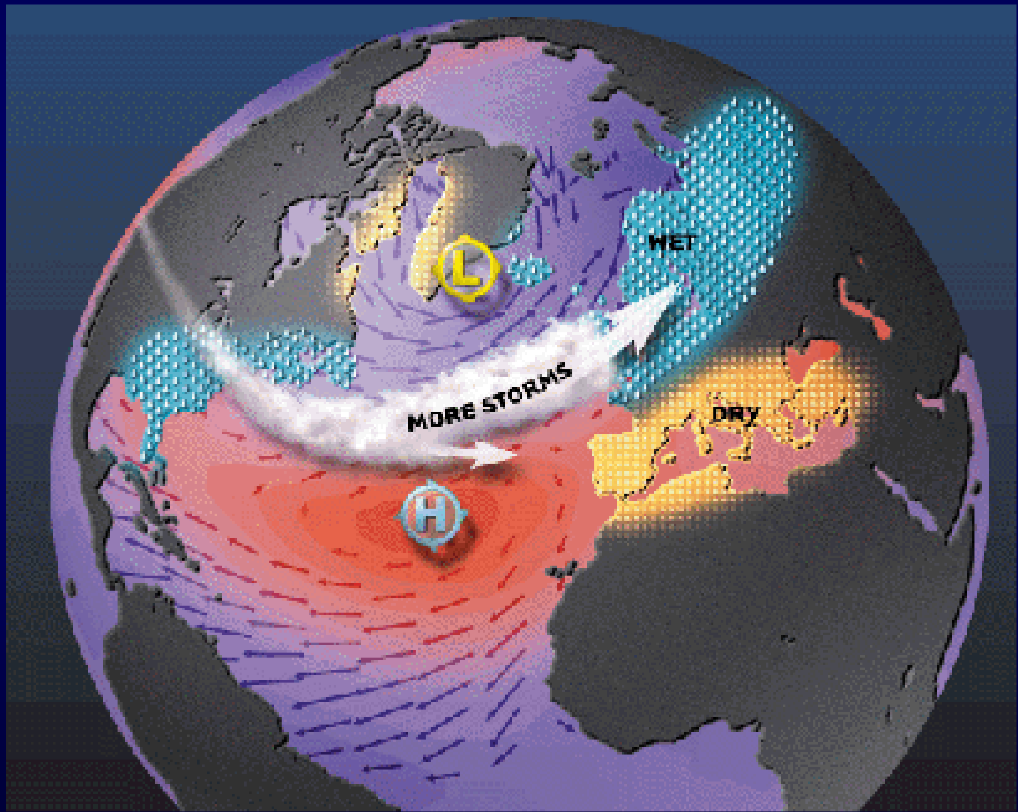


Figure 5. Global mean sea level variations from T/P and Jason.

Other observed changes
Circulation



Poleward shift of mid-latitude storm tracks

More intense westerlies

Other observed changes
Temperature and precipitation extremes

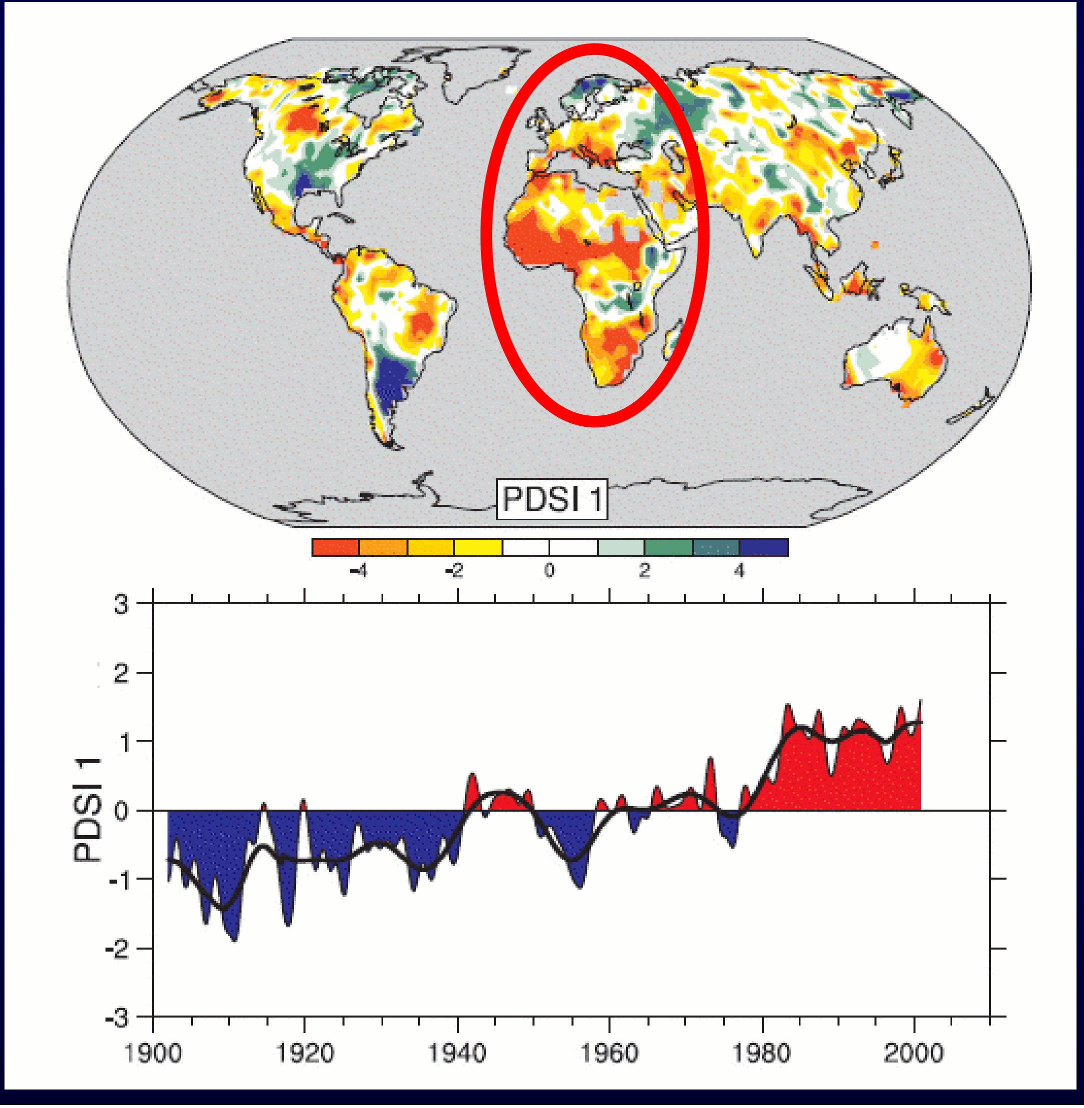
Increased frequency
of heavy precipitation events

Warmer and more hot days,
warmer and fewer cold days

Increased frequency of
heat waves

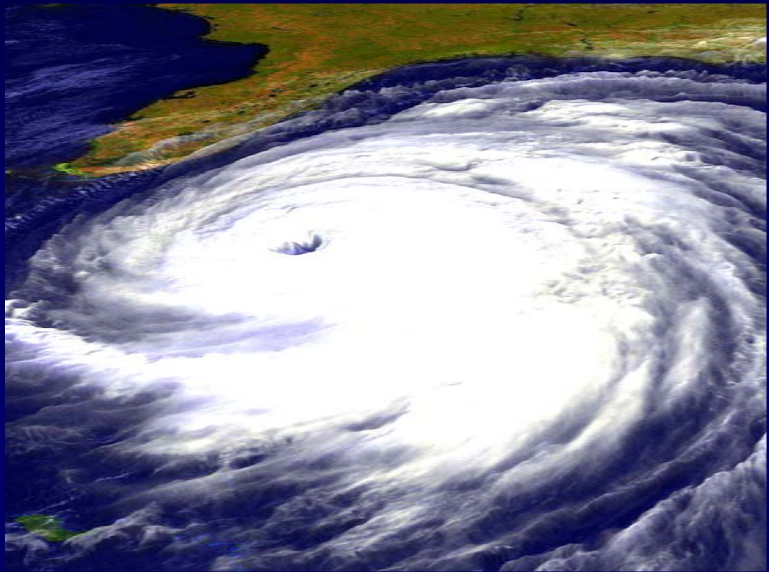
Other observed changes

Droughts



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

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

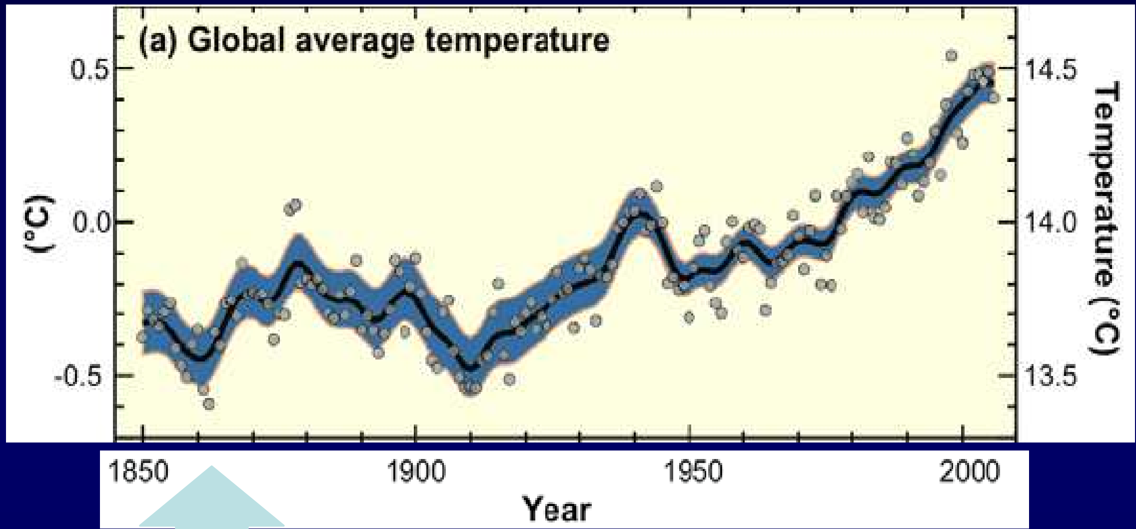
IPCC-2007

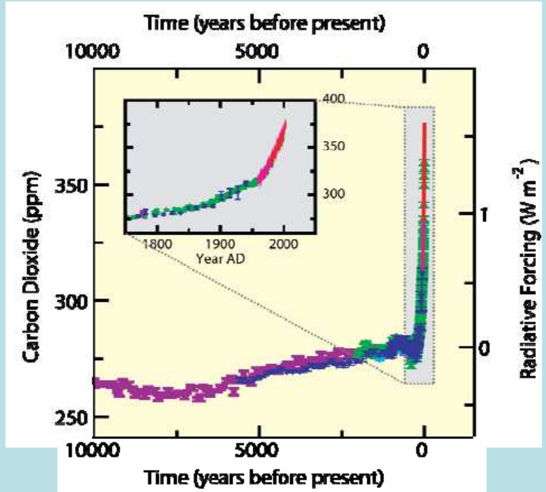
Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level

The attribution of climate change

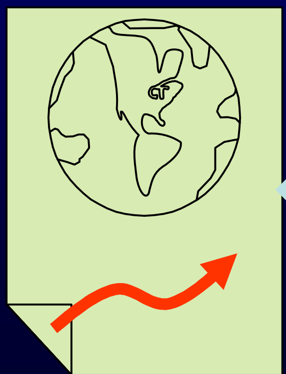

Human factors
Greenhouse gases
Radiated out to space
Infra-red radiation from surface
Atmospheric aerosols
Aerosol
Mineral Dust
SO2, Soot, Organics
DMS Sea Salt
Land-use change
The earth's climate can change because of anthropogenic or natural factors
Volcanic activity
Natural factors
Incoming solar radiation
Variations of Solar radiatios
El Nino Conditions December 1997
60°N
40°N
20°N
0°
20°S
40°S
60°S
100°E
140°E
180°
140°W
100°W
60°W
32
28
24
20
16
12
8
4
0
Natural variability (ENSO, NAO)
TAO Project Office/PMEL/NOAA

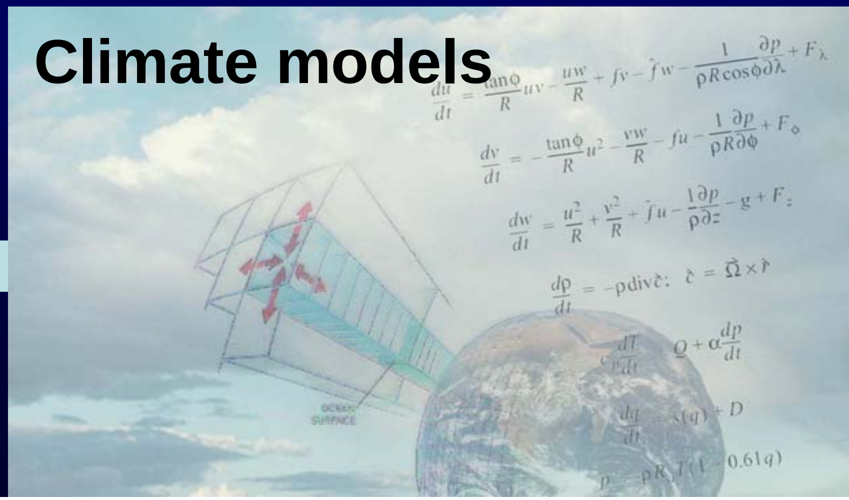
"Fingerprinting" of the anthropogenic effects





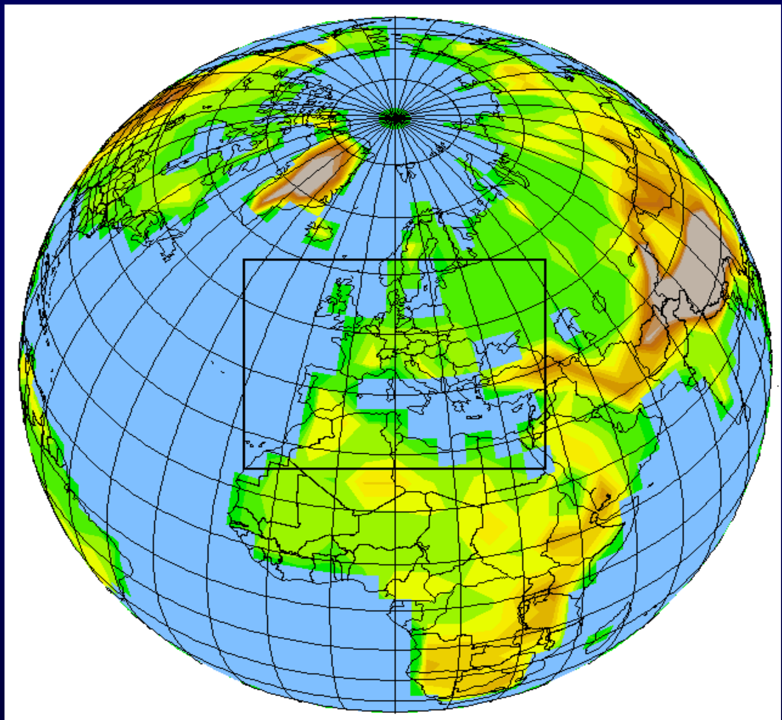
- other GHGs
- aerosols
- volcanic
- solar
- natural internal

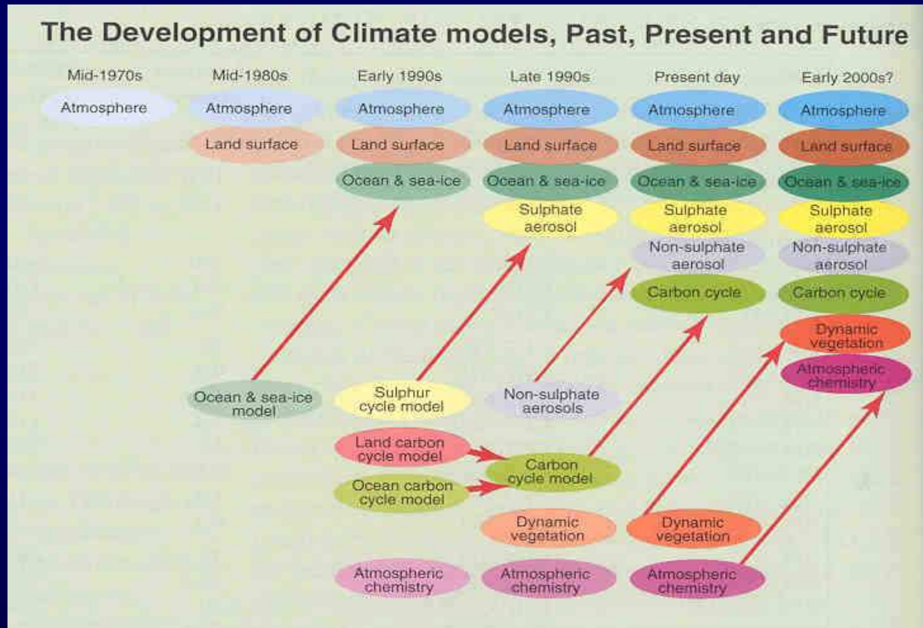




The basic tool for climate modeling

Coupled Atmosphere-Ocean General Circulation Model or AOGCM



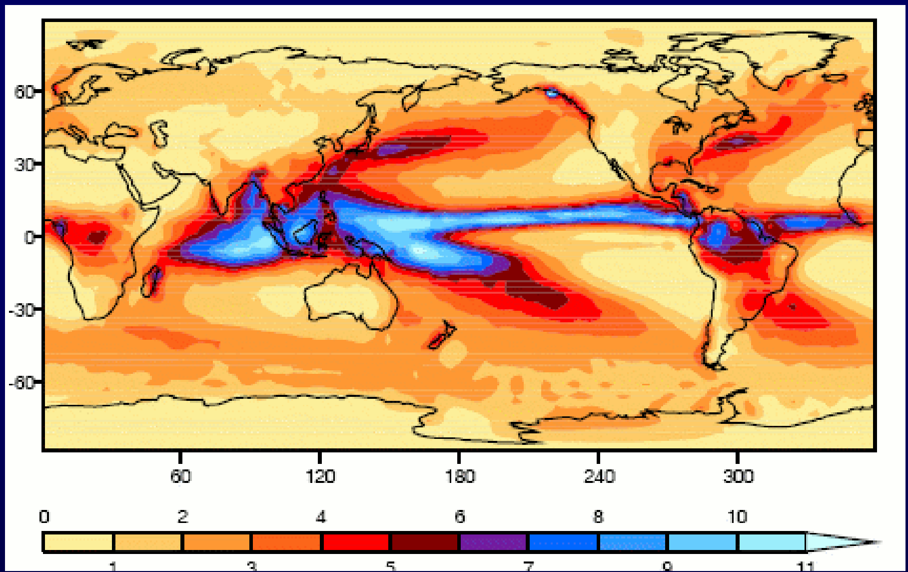


Box 3, Figure 1: The development of climate models over the last 25 years showing how the different components are first developed separately and later coupled into comprehensive climate models.

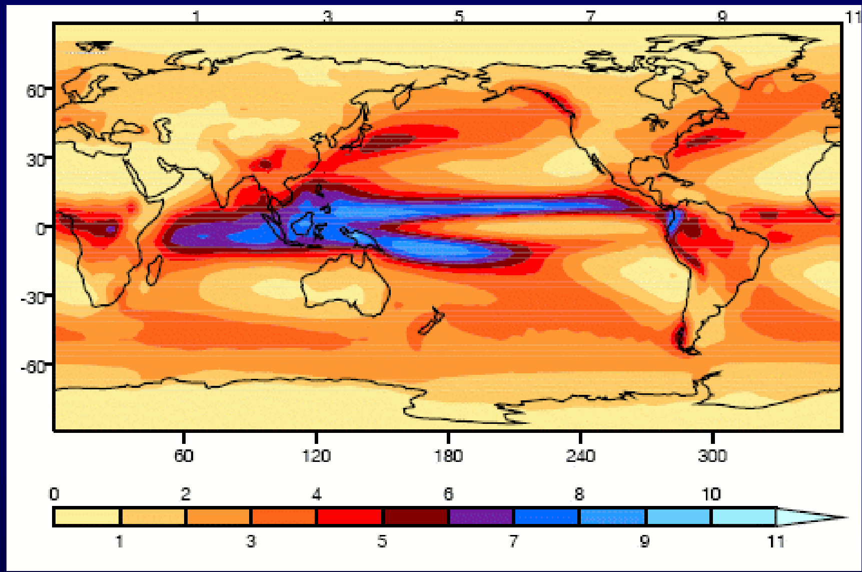
AOGCMs are numerical representations of the global climate

Performance of AOGCMs
Annual precipitation, 20 models

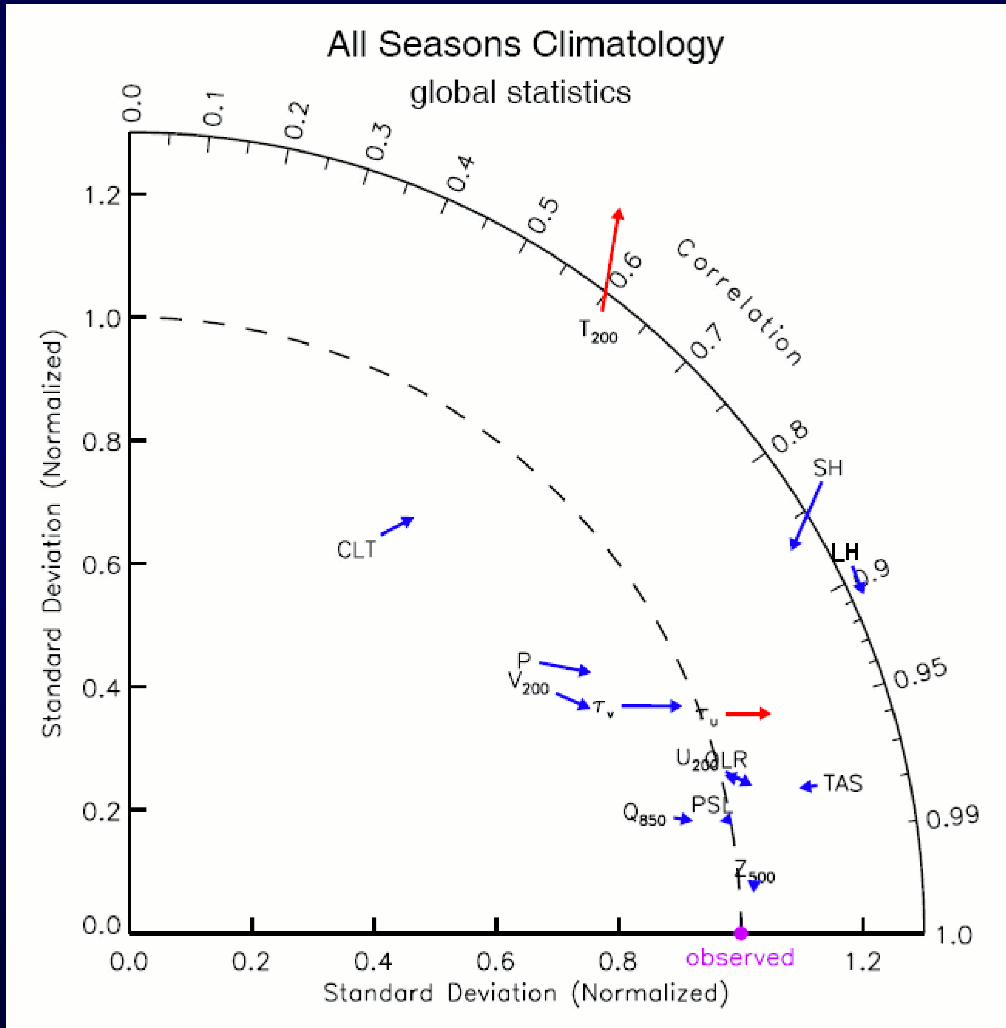
Observations

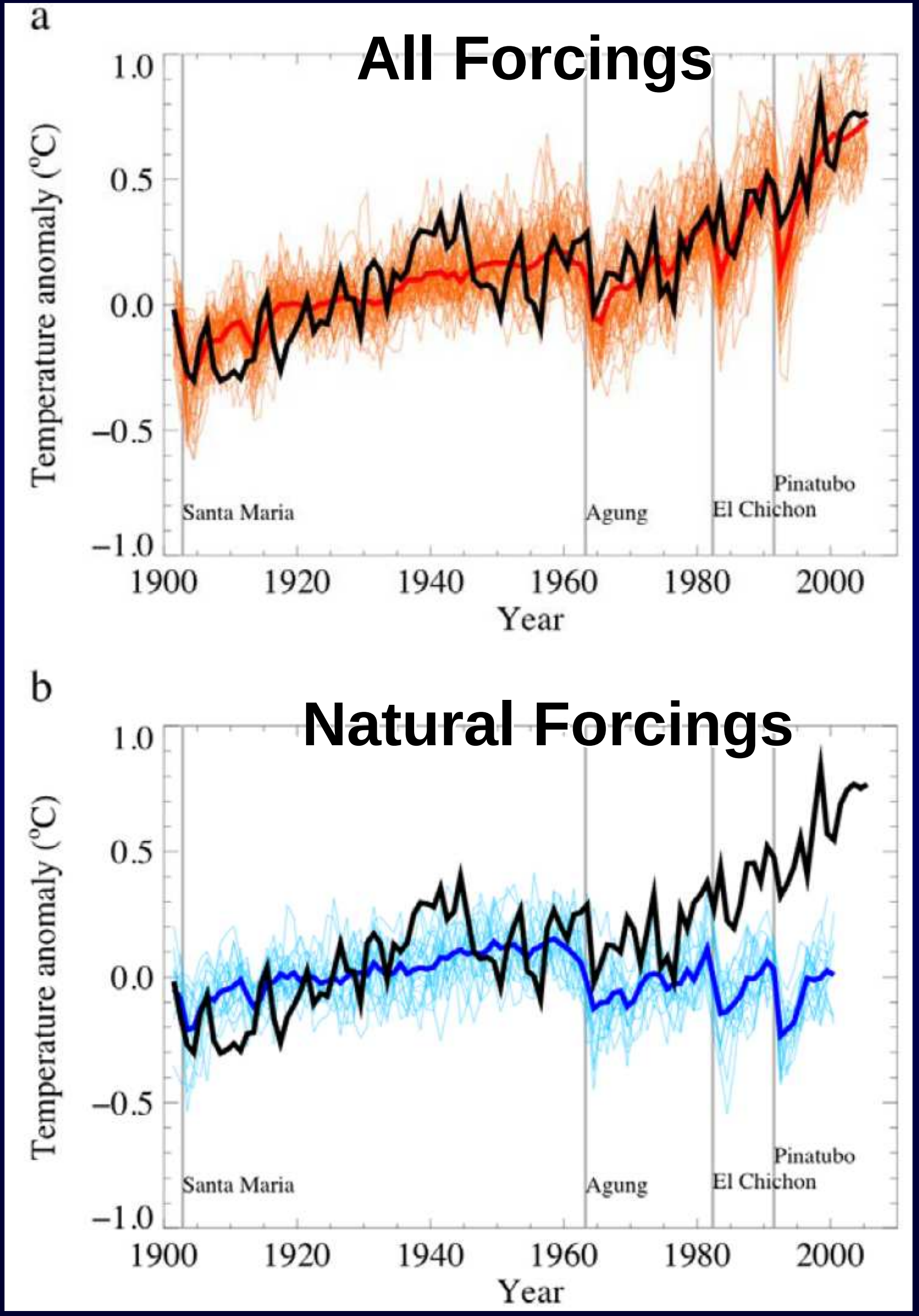


Model ensemble mean



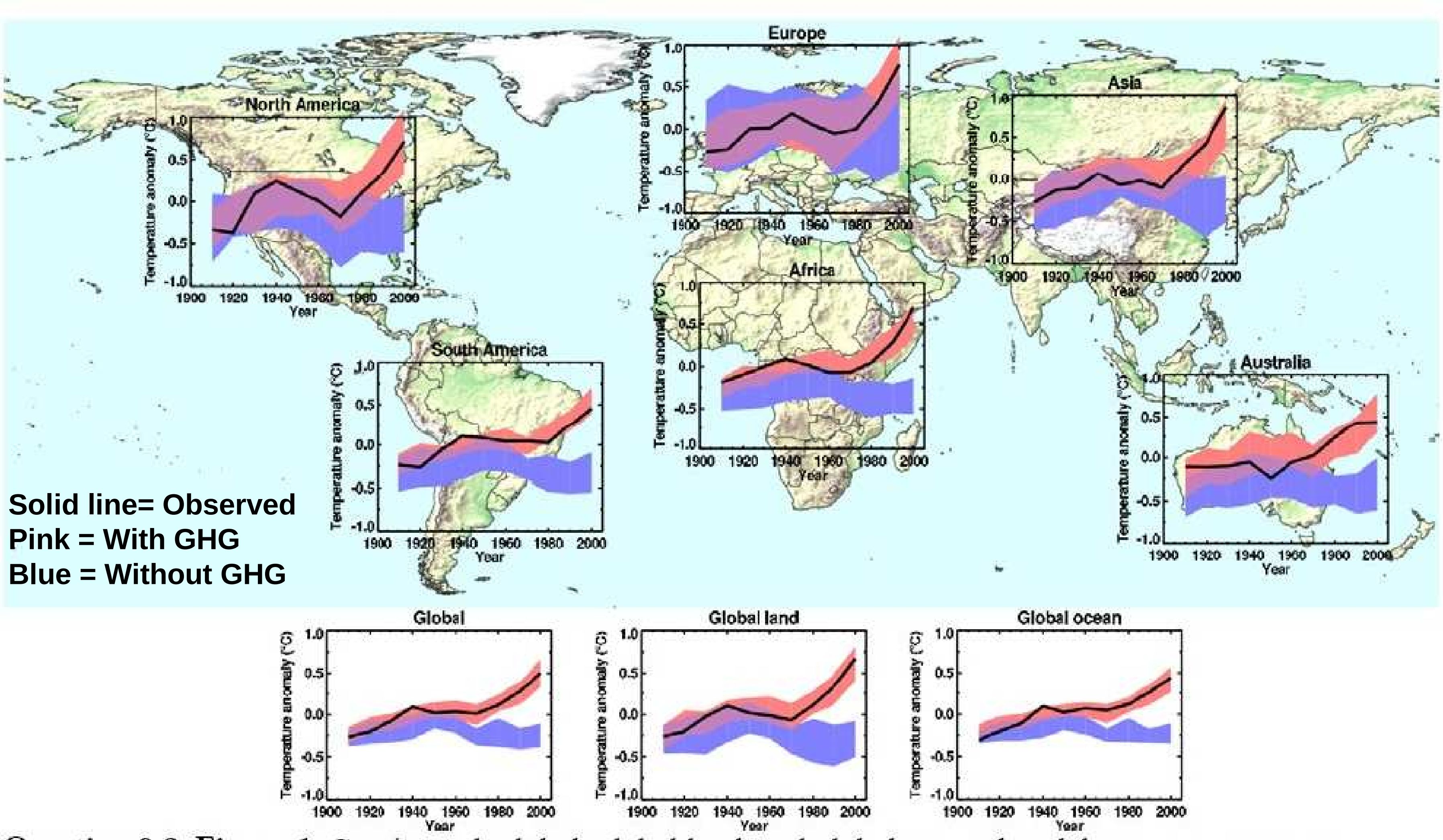
Global Performance of AOGCMs
20 models





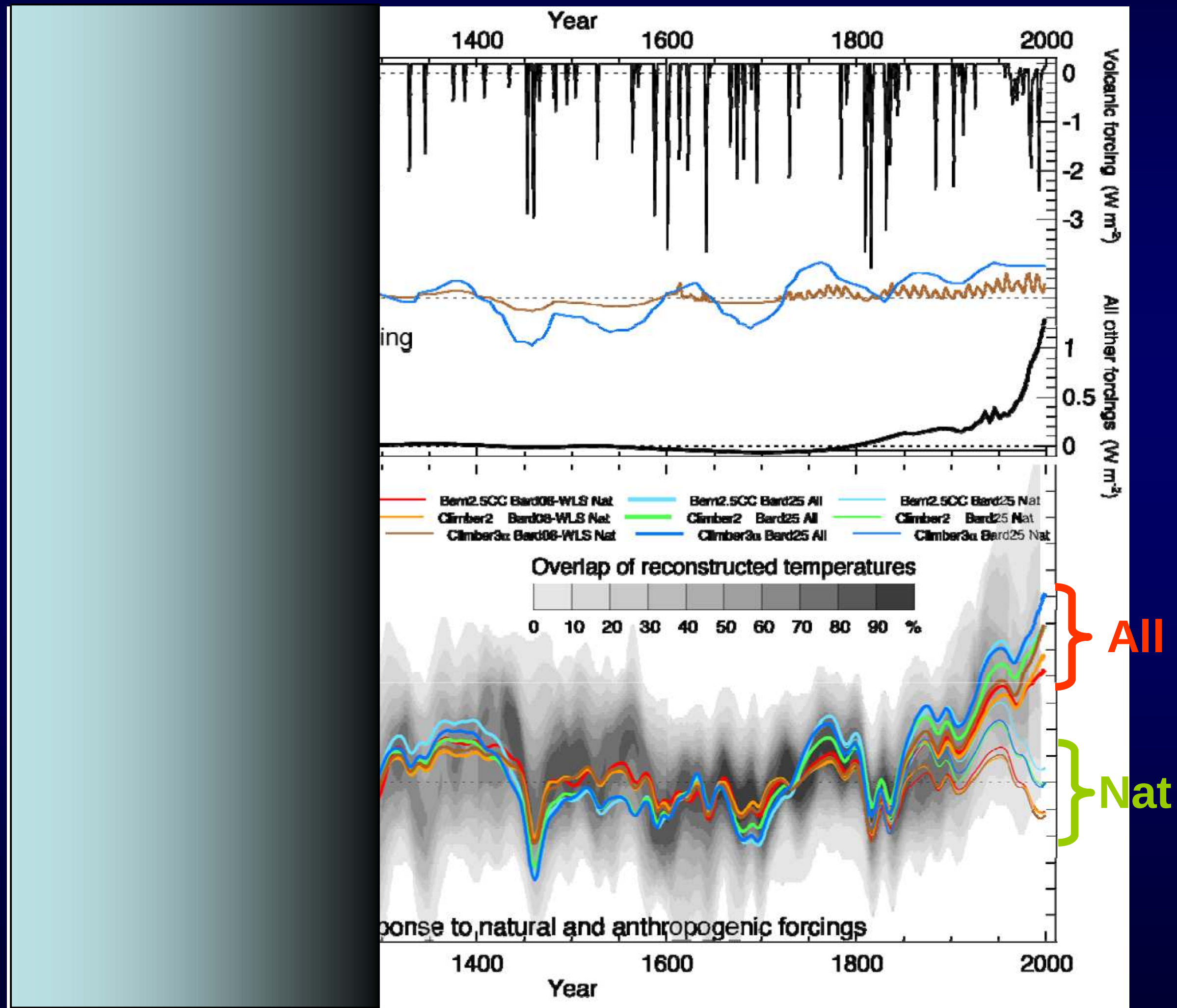
Iidentification of the anthropogenic effects on global warming

Identificaton of the anthropogenic effect on regional and ocean warming



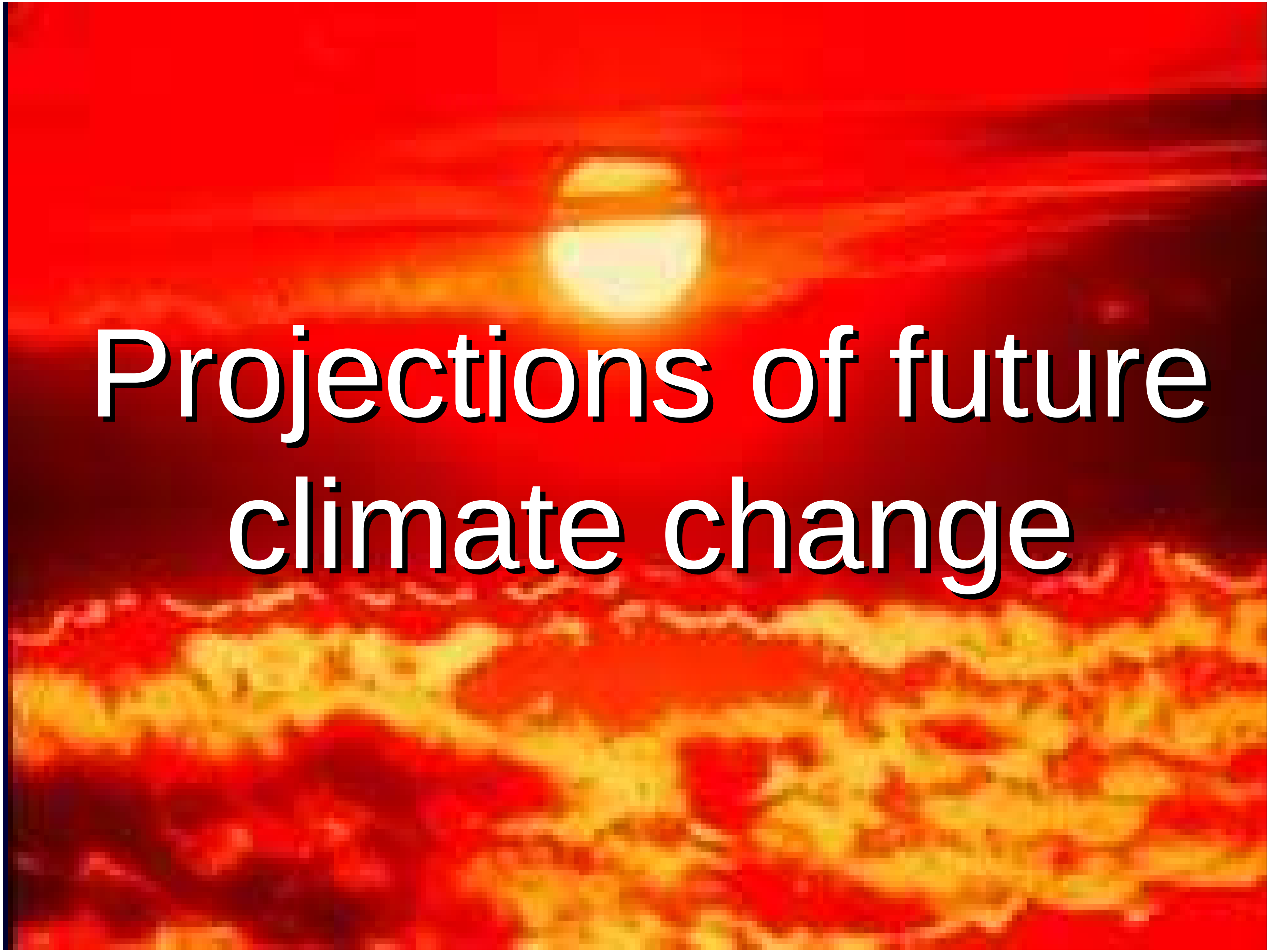
Solid line= Observed
Pink = With GHG
Blue = Without GHG

Temperature reconstruction for the last millennium



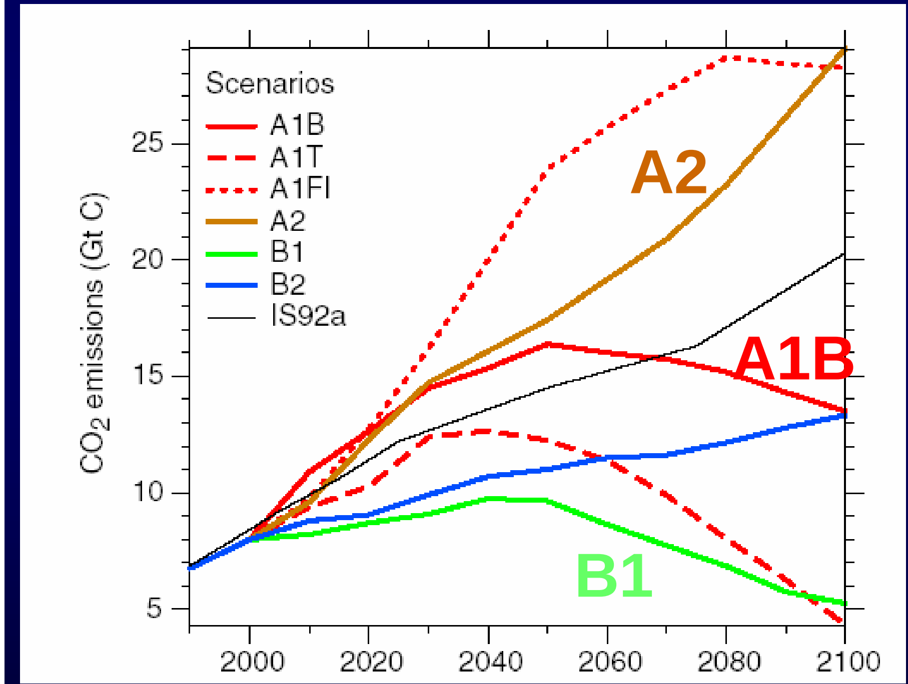
IPCC-2007

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.

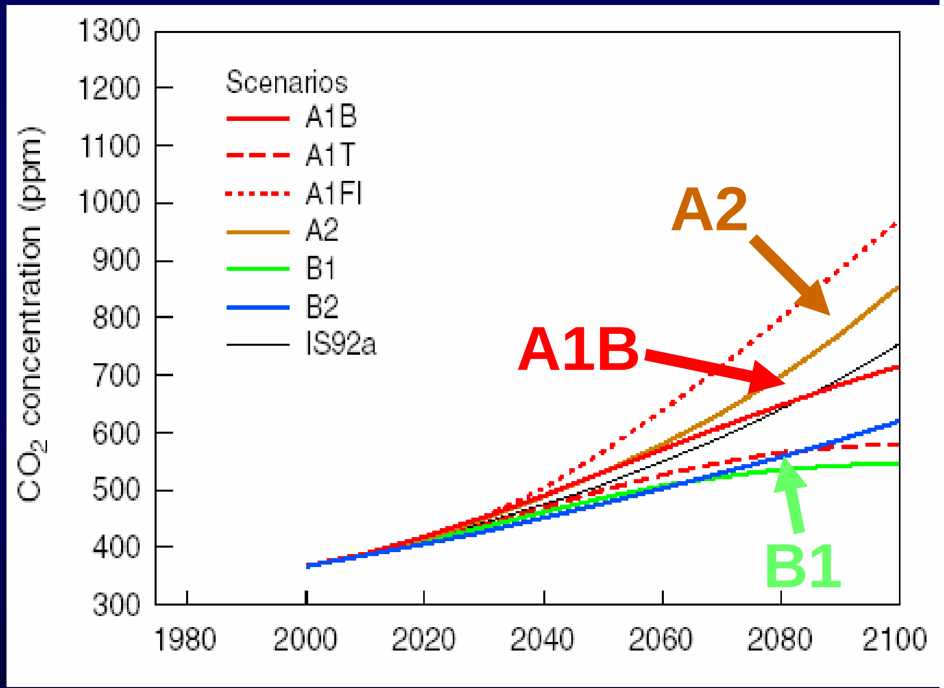

Projections of future
climate change

Greenhouse gas emission and concentration scenarios (IPCC-2000)

CO2 emissions



CO2 Concentrations

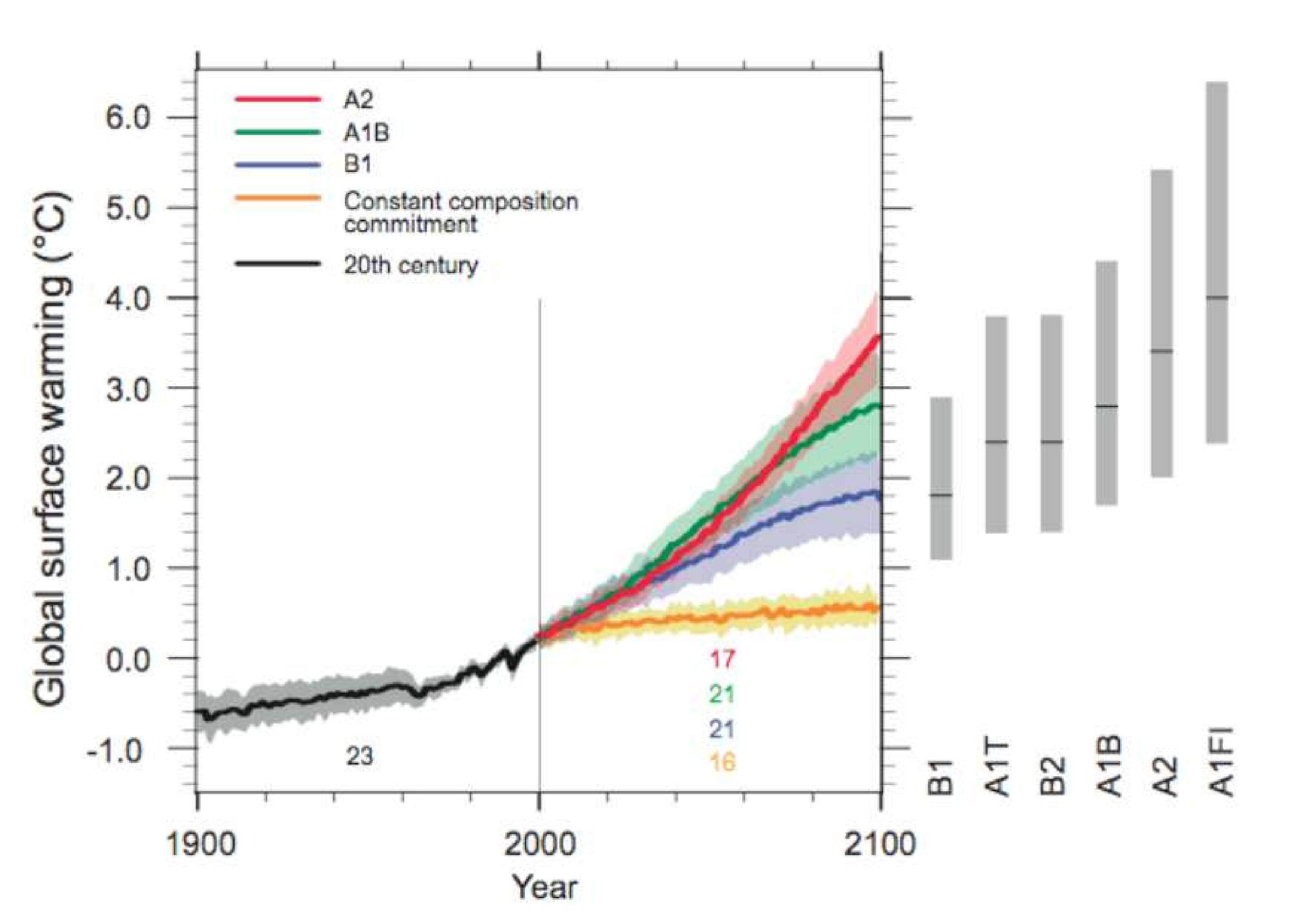


More than 20 models worldwide have been used to simulate the climate response to the GHG scenarios (CMIP3 – PCMDI, http://www-pcmdi-llnl-gov)

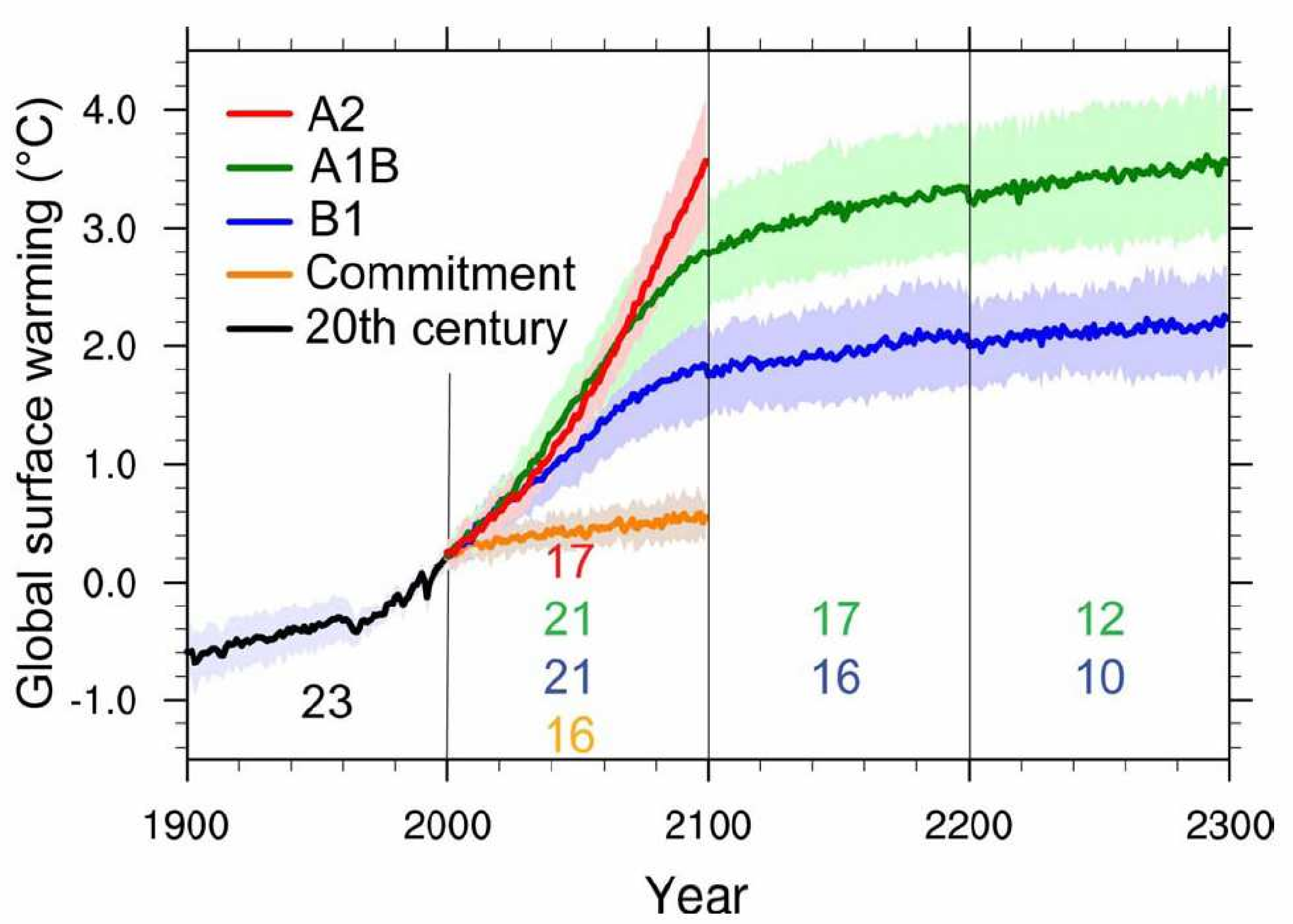
Table 1. List of models and simulations used in the analysis.

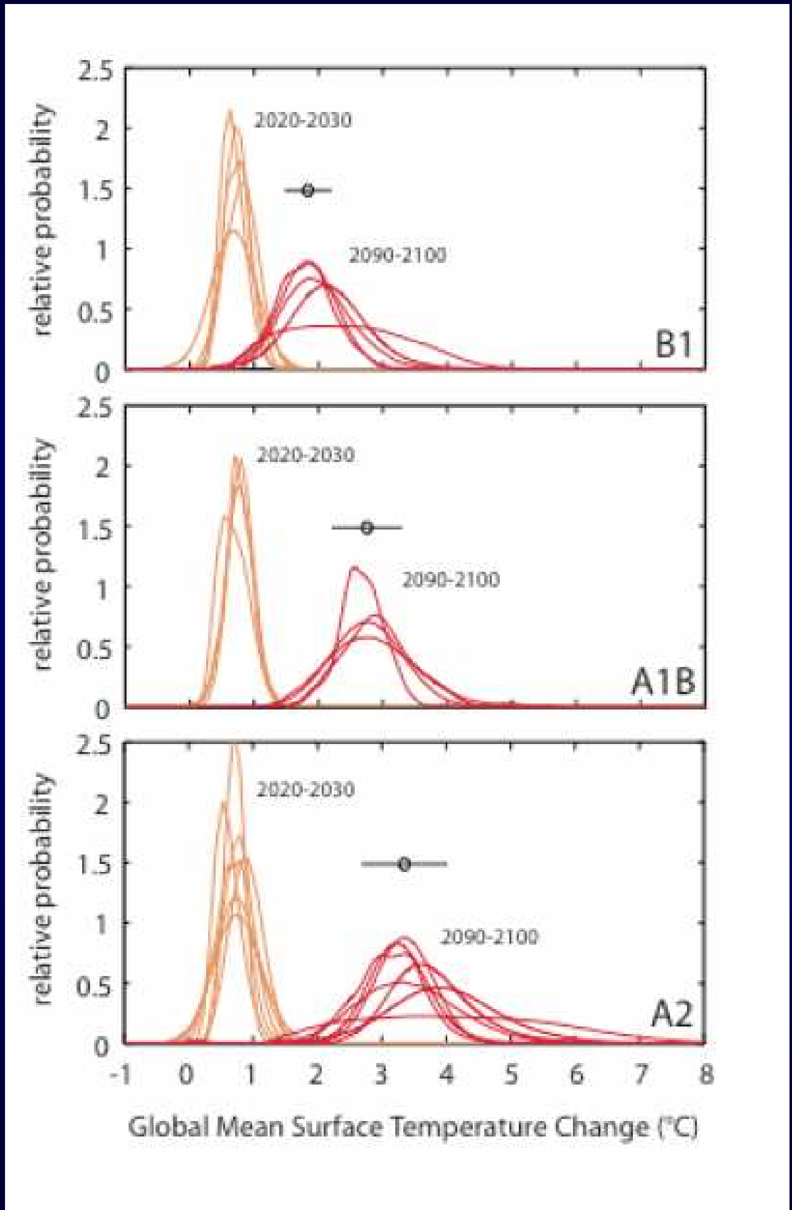
Model	20 Cent.	A1B	A2	B1
BCCR-BCM2-0	1	-	1	1
CCMA-3-T47	5	4	2	4
CNRM-CM3	1	1	1	1
CSIRO-MK3	2	1	1	1
GFDL-CM2-0	3	1	1	1
GFDL-CM2-1	3	1	1	-
GISS-AOM	2	2	-	2
GISS-EH	5	4	-	-
GISS-ER	1	2	1	1
IAP-FGOALS	3	3	-	2
INMCM3	1	1	1	1
IPSL-CM4	1	1	1	1
MIROC3-2H	1	1	-	1
MIROC3-2M	3	3	3	3
MIUB-ECHO-G	5	3	3	3
MPI-ECHAM5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

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



Global temperature change projections after stabilization





IPCC-AR4

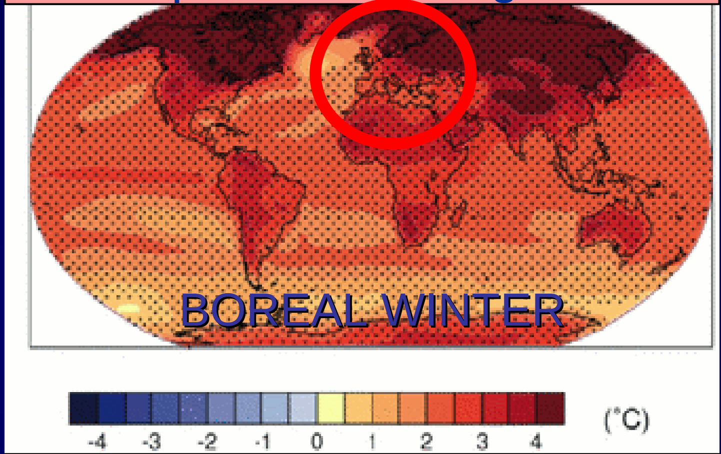
More emphasis on probabilistic predictions of climate change based on large multi model ensembles

Global mean sea level rise (cm) for 2099-2100 with respect to 1980-1999 for different emission scenarios

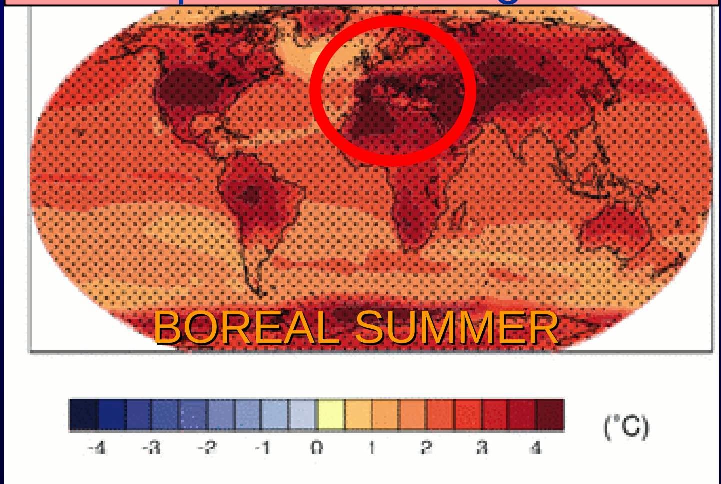
Scenario	Model range
B1	19 - 37
A1T	22 - 44
B2	21 - 42
A1B	23 - 47
A2	25 - 50
A1FI	28 - 58

Regional distribution of temperature and precipitation change (A1B scenario, 2090-2100)

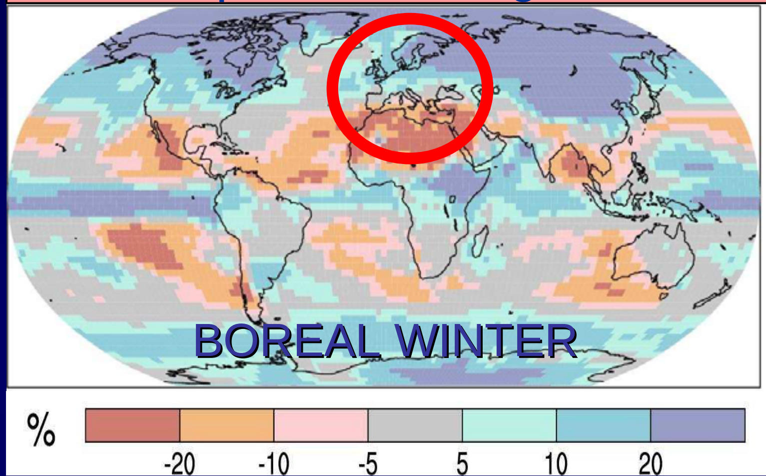
Temperature change DJF



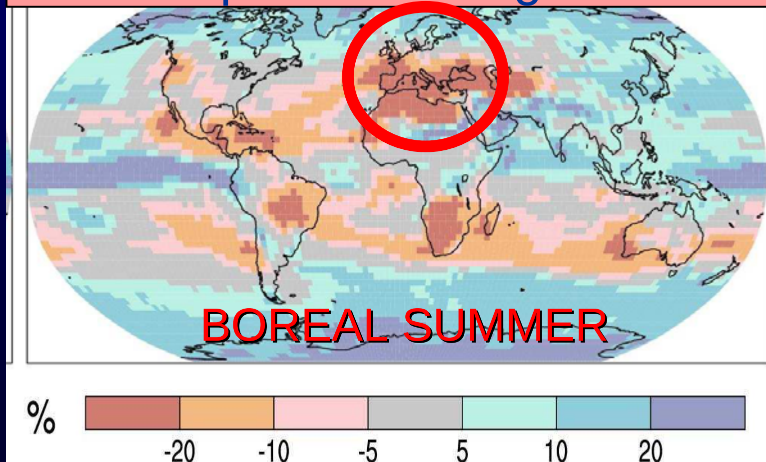
Temperature change JJA



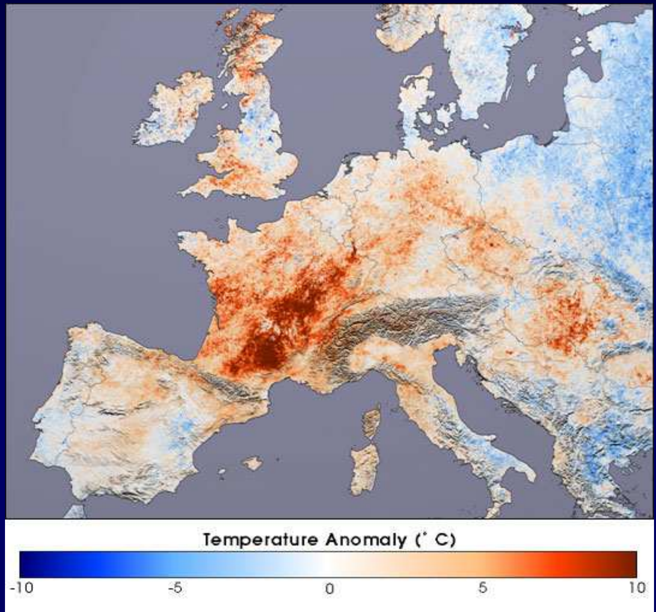
Precipitation change DJF

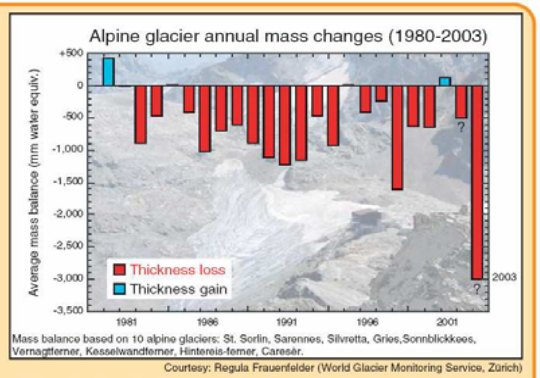


Precipitation change JJA



The summers we can expect in Europe?
Summer of 2003

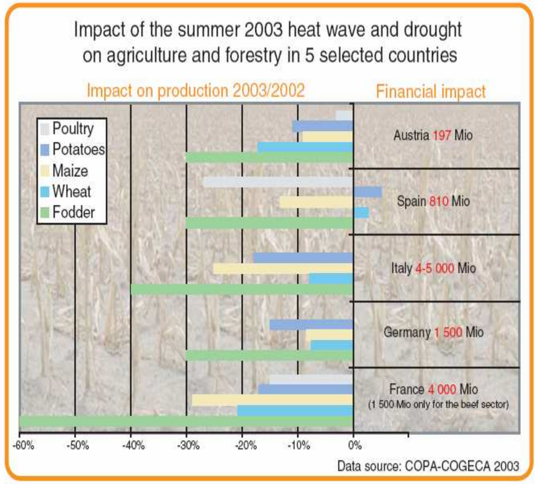




glaciers in the Alps. In 2003 alone, the total glacier volume loss in the Alps corresponds to 5-10% (probably closer to 10%) of the remaining ice volume. Alpine glaciers had already lost more than 25% of their volume in the 25 years before 2003, and roughly two-thirds of their original volume since 1850 (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



Other projected changes for the 21st Century

-> Poleward shift of mid-latitude storm tracks

-> Greater intensity of tropical and extratropical cyclones

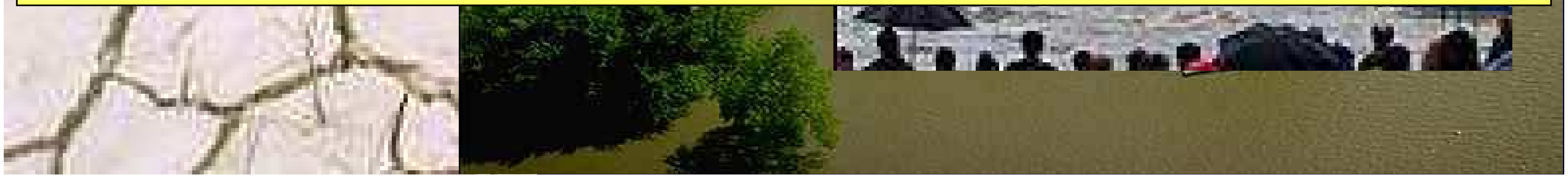
-> Increase of heat-waves and droughts

-> Greater intensity of precipitation

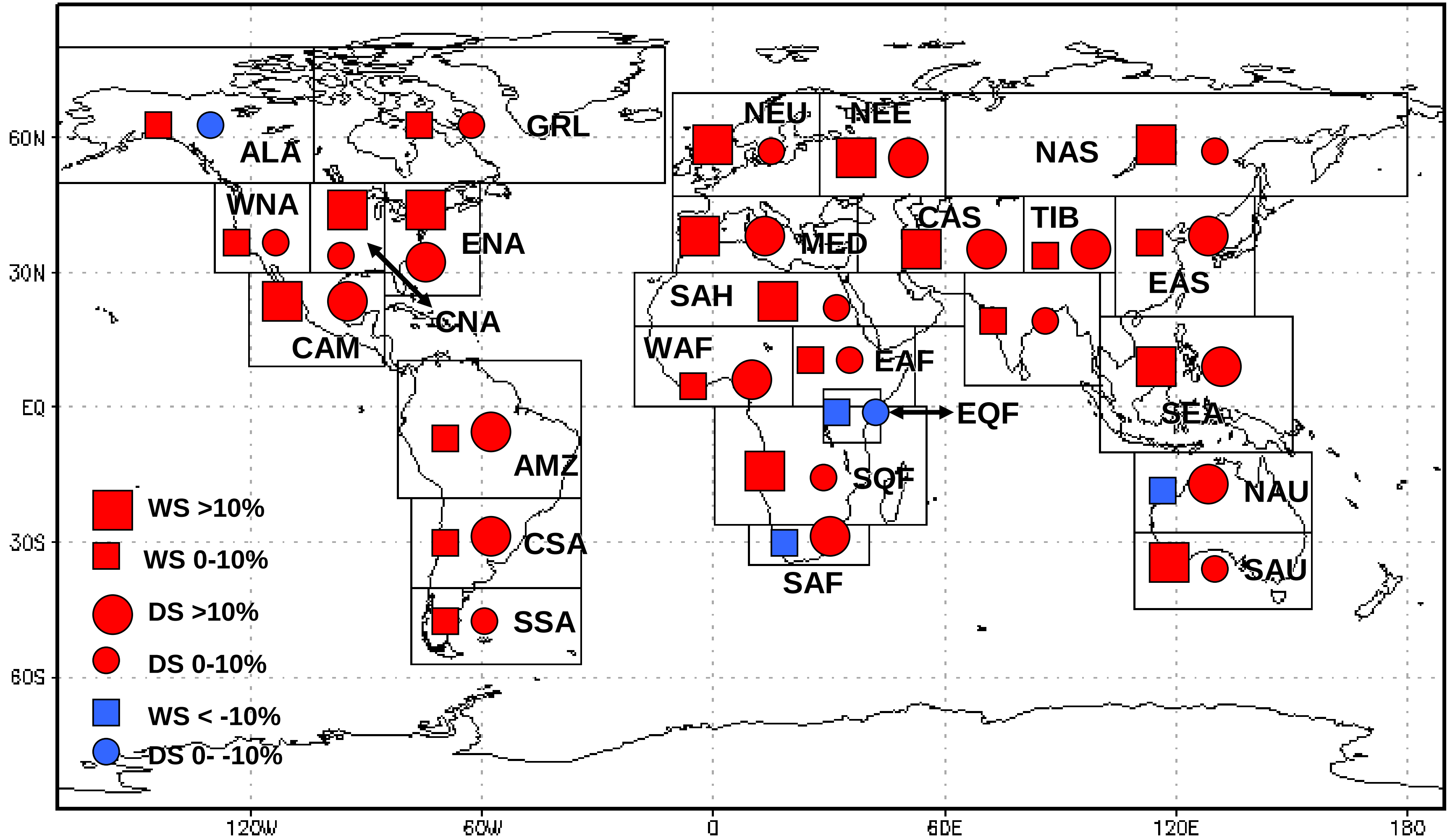
-> Increased warm season interannual variability

-> Further widespread melting of glaciers and sea ice

-> Slow down (but not collapse) of the MOC



Change in precipitation interannual variability (CV, 2080-2099 minus 1960-1979, A1B-A2-B1)



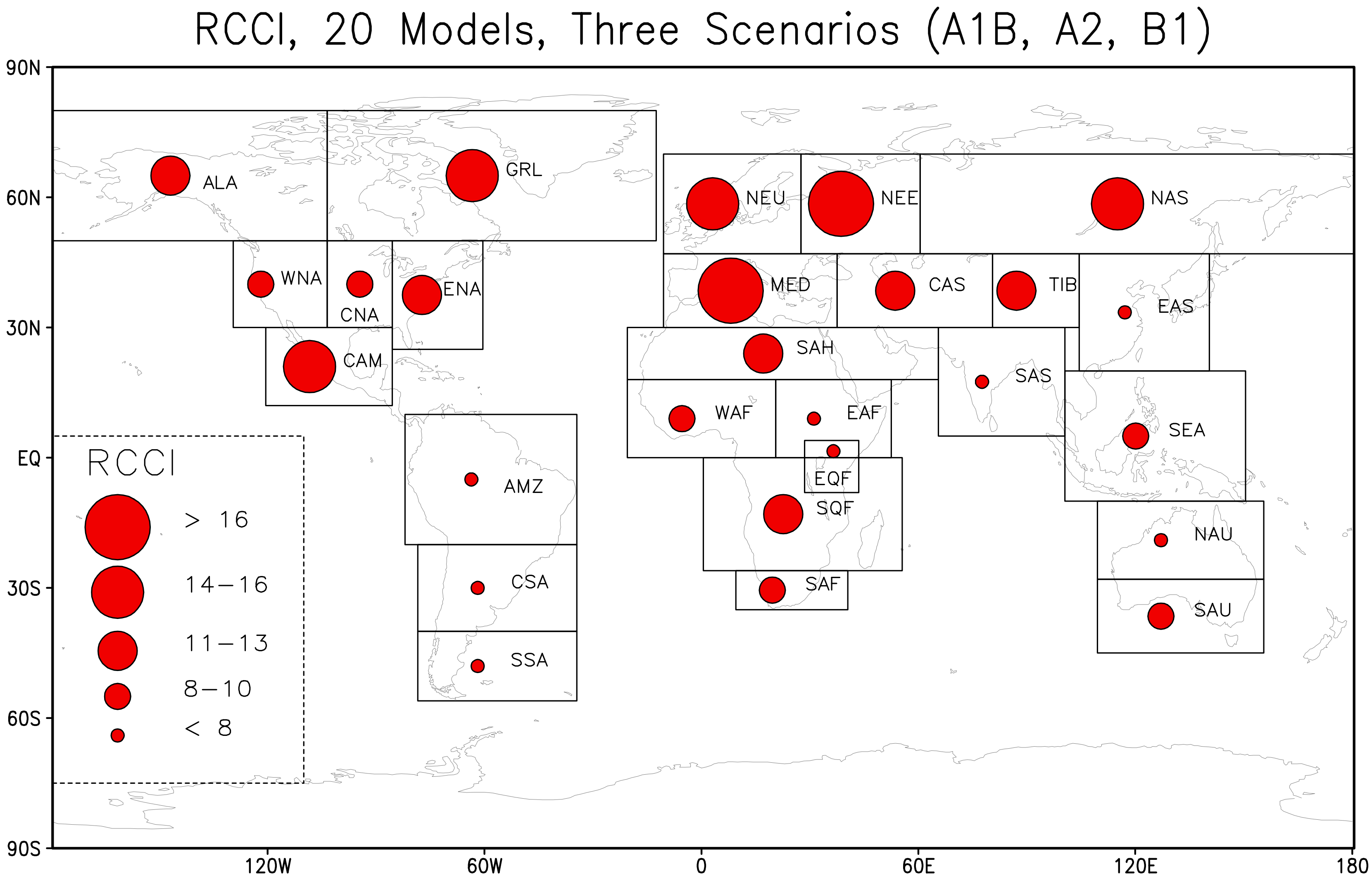
Regional Climate Change Index (RCCI)
The RCCI is a comparative index

$$RCCI = [n(\Delta P)+n(\Delta\sigma_P)+n(RWAF)+n(\Delta\sigma_T)]_{WS} +$$

$$[n(\Delta P) + n(\Delta\sigma_P) + n(RWAF) + n(\Delta\sigma_T)]_{DS}$$

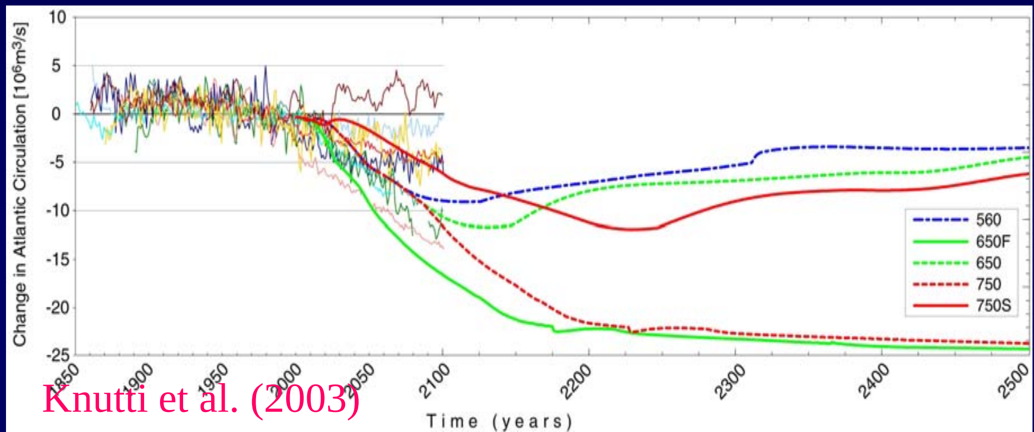
n	ΔP	$\Delta\sigma_P$	RWAF	$\Delta\sigma_T$
0	$< 5\%$	$< 5\%$	< 1.1	$< 5\%$
1	$5 - 10\%$	$5 - 10\%$	$1.1 - 1.3$	$5 - 10\%$
2	$10 - 15\%$	$10 - 20\%$	$1.3 - 1.5$	$10 - 15\%$
4	$> 15\%$	$> 20\%$	> 1.5	$> 15\%$

Climate change Hot-Spots



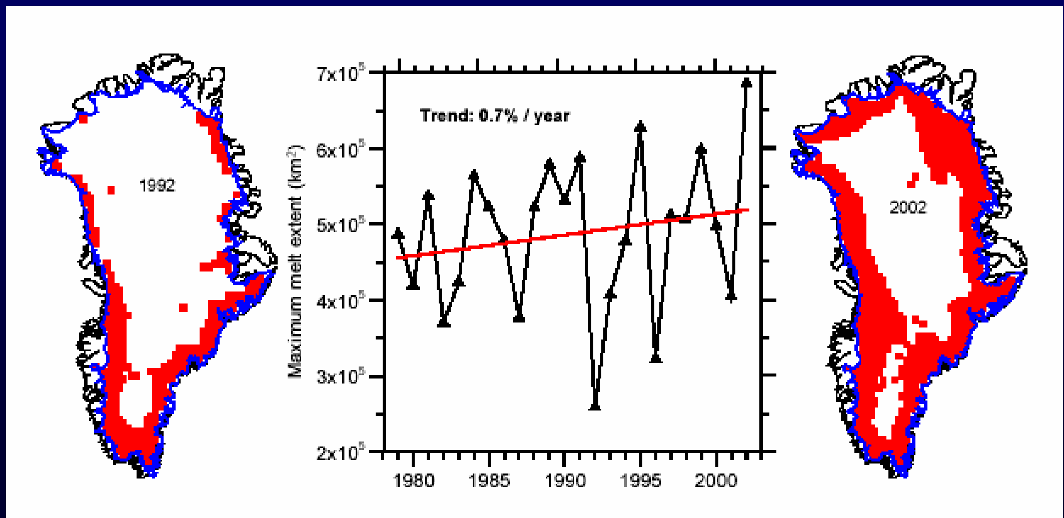
From Giorgi, GRL, 2006

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



Knutti et al. (2003)

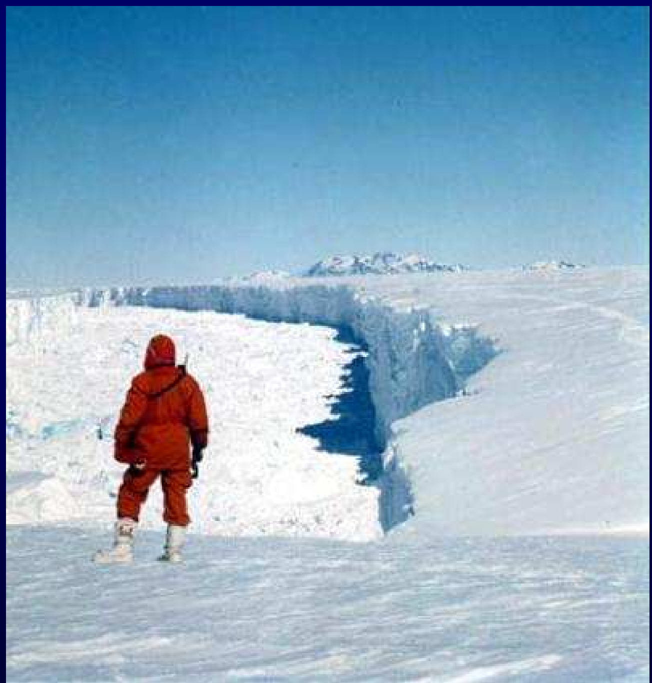
Shut down of the deep oceanic circulation (and of the Gulf Current)

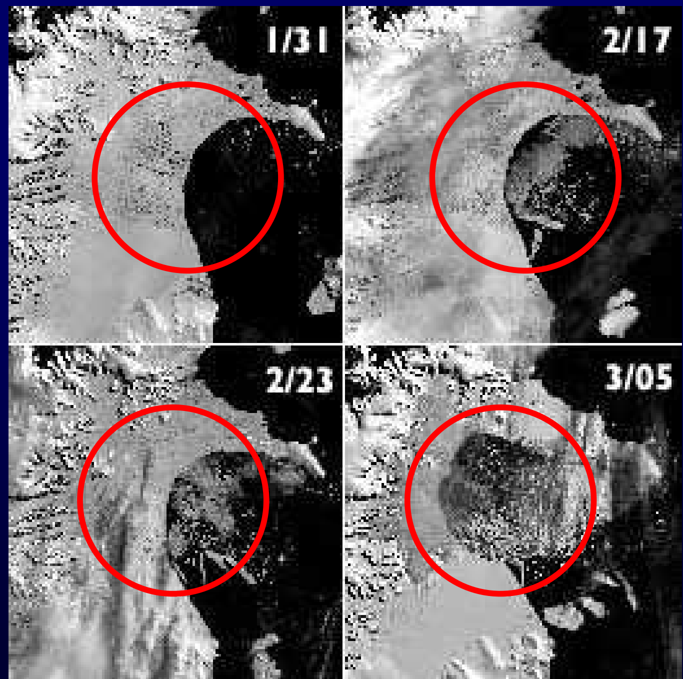


Melting of Greenland and the West Antarctica ice sheet (sea level rise of more than 15 m)

Reality or science fiction ?

2002: Collapse of the Larsen-B Ice Shelf



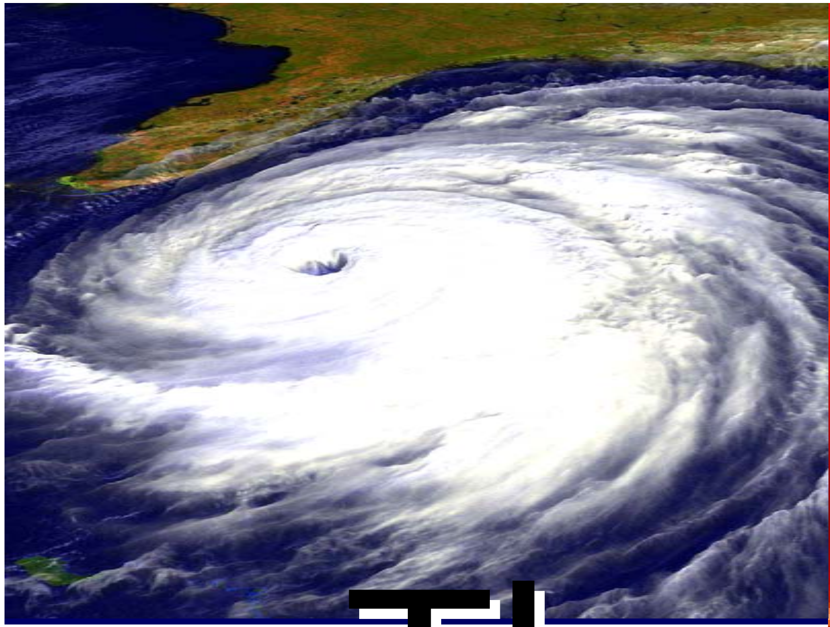


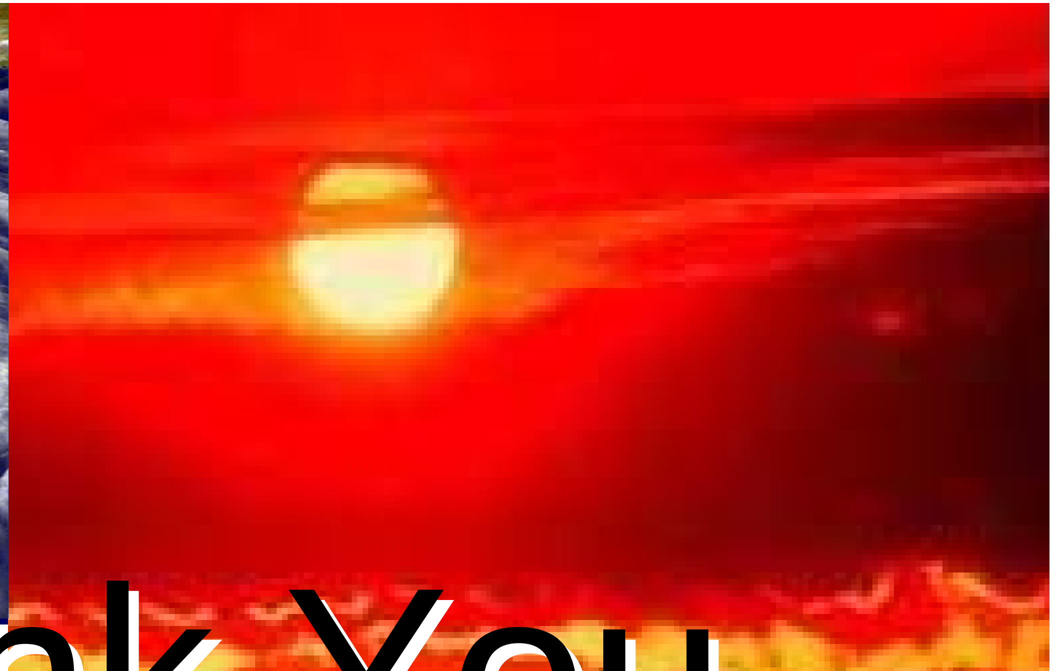
Some key uncertainties

- Greenhouse gas emission scenarios
  - Discussion ongoing on how to update the SRES and deal with emission scenarios in the AR5
- Limitations in climate models
  - Wide spread of climate sensitivity
  - Cloud representation still main contributor to the uncertainty
- Role of atmospheric aerosols
- Carbon cycle feedbacks and landuse change
- Sea level rise estimates
- Regional to local climate change information

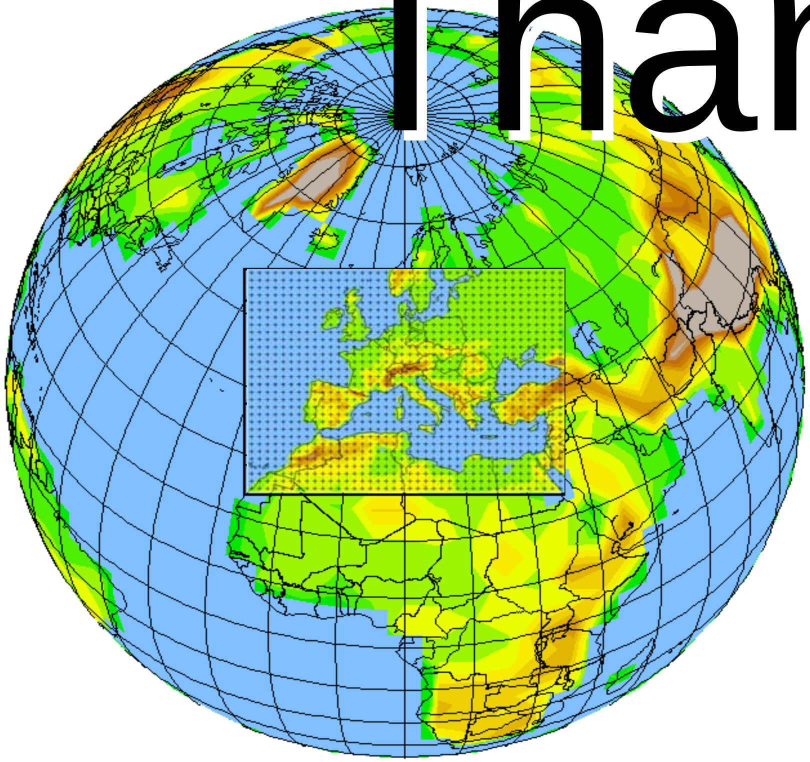
Summary of key messages

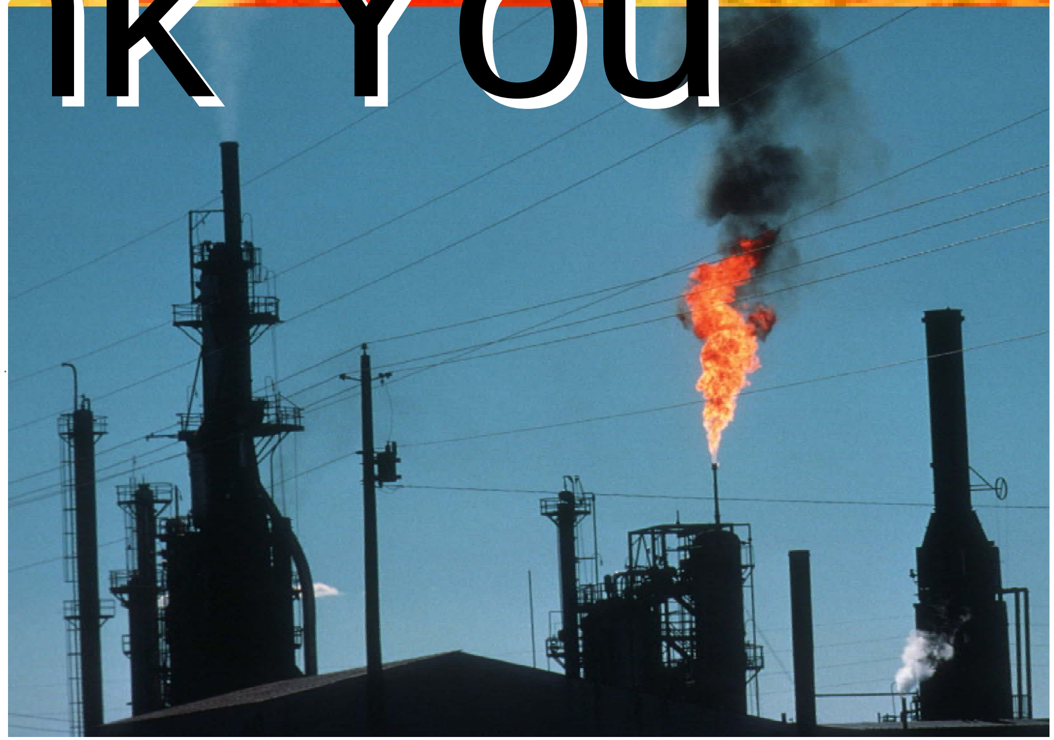
- Global warming is unequivocal
- Warming since the mid of the 20 century is mostly due to human activities (90-95% likelihood)
- Climate change projections are generally in line with previous assessments.
  - Uncertainty depends on emission scenarios and climate sensitivity.
  - Probabilistic predictions based on large multi-model ensembles
- Abrupt changes are not projected to occur in the 21st century, but they could occur at longer time scales under sustained warming
- Some further climate change is unavoidable so we will need to manage the unavoidable (adaptation) but avoid the unmanageable (mitigation).





Thank You



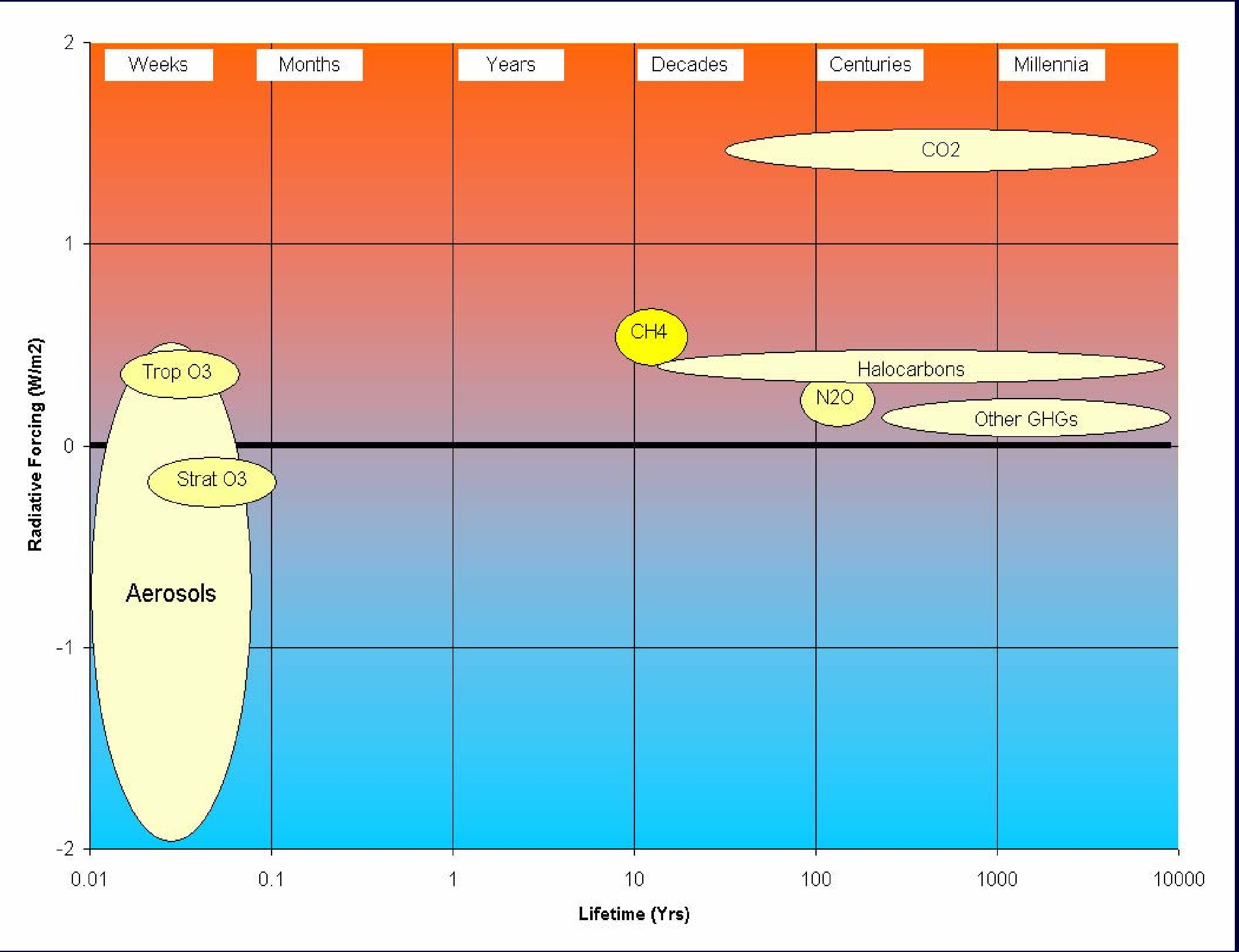


Temporal scales of forcings

Many key warming agents live for decades or more

All known cooling agents are relatively short-lived

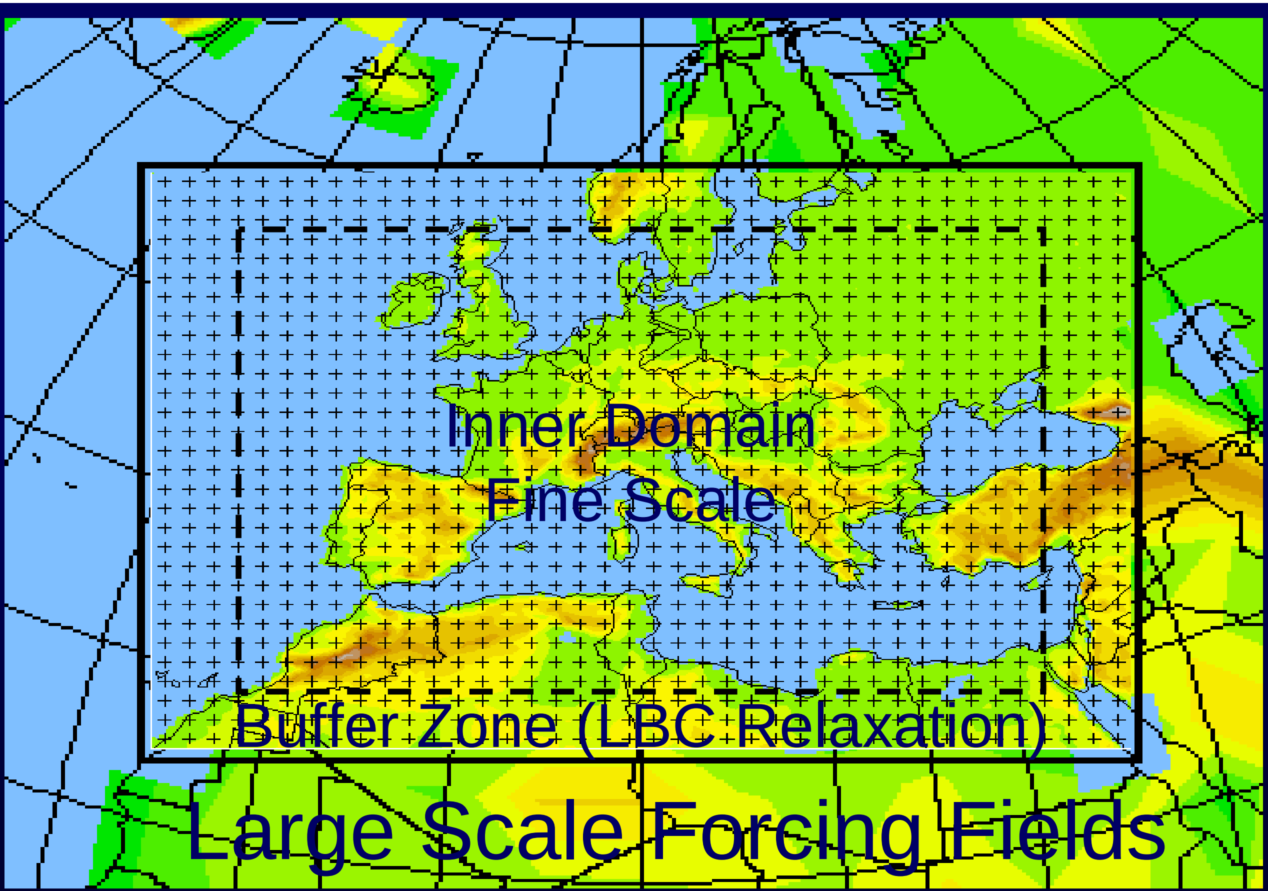
-> implications for short and long-term effects and options



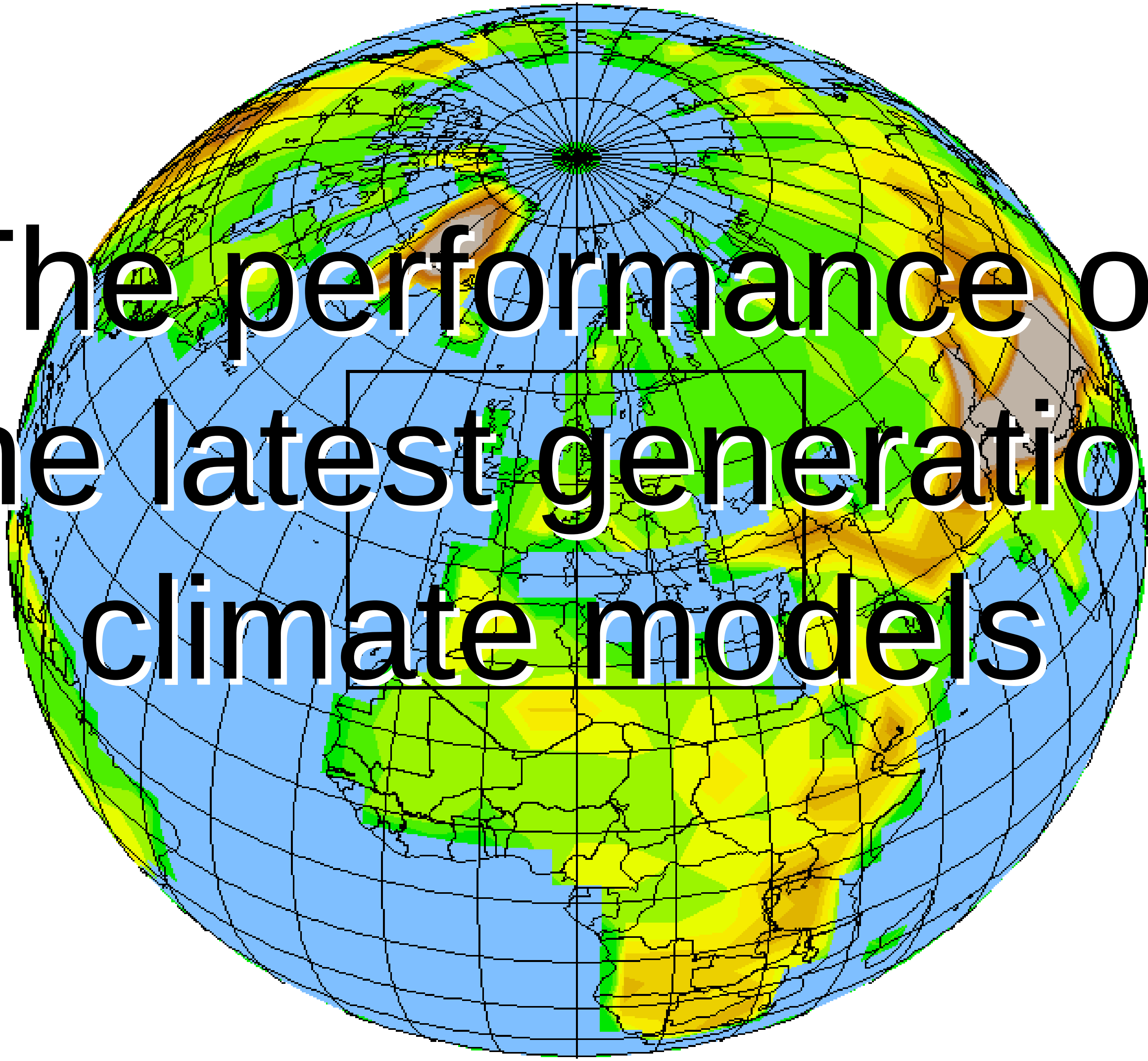
Regional modeling

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

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

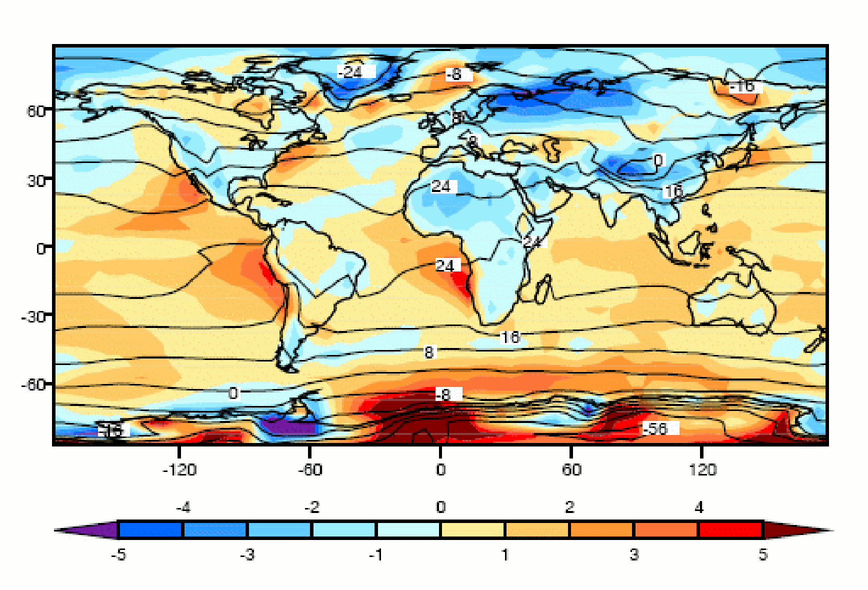


The performance of the latest generation climate models

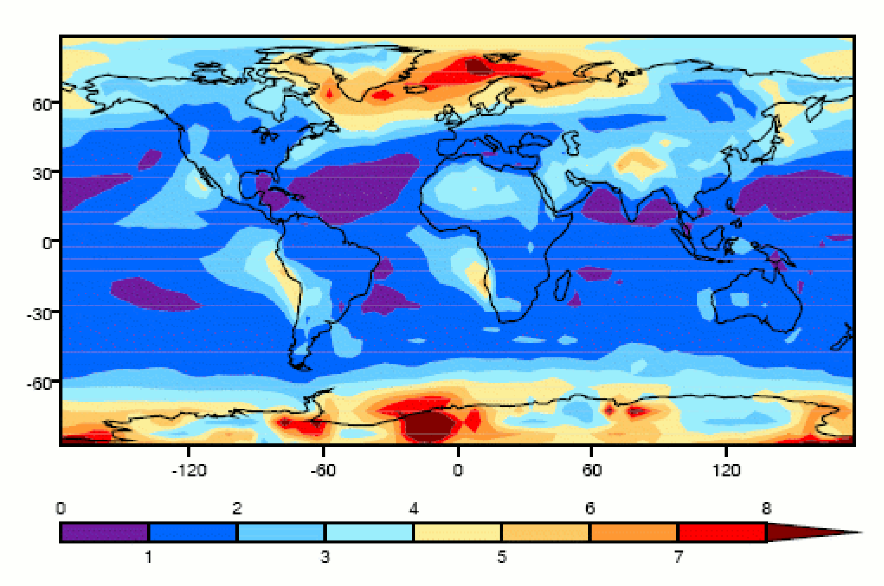


Performance of AOGCMs
Annual temperature, 20 models

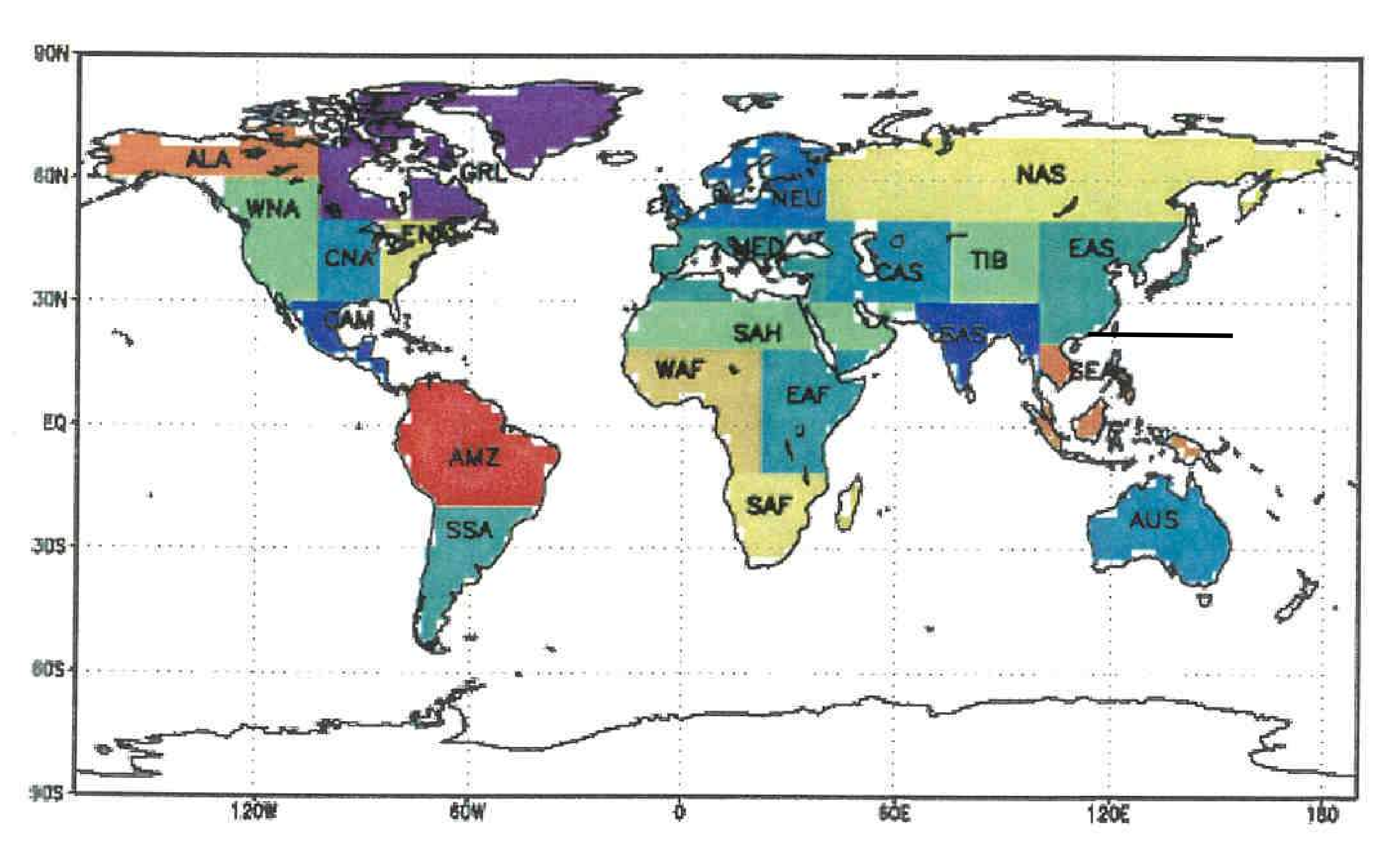
Observed annual temperature (lines) and multi-models ensemble bias (colors)



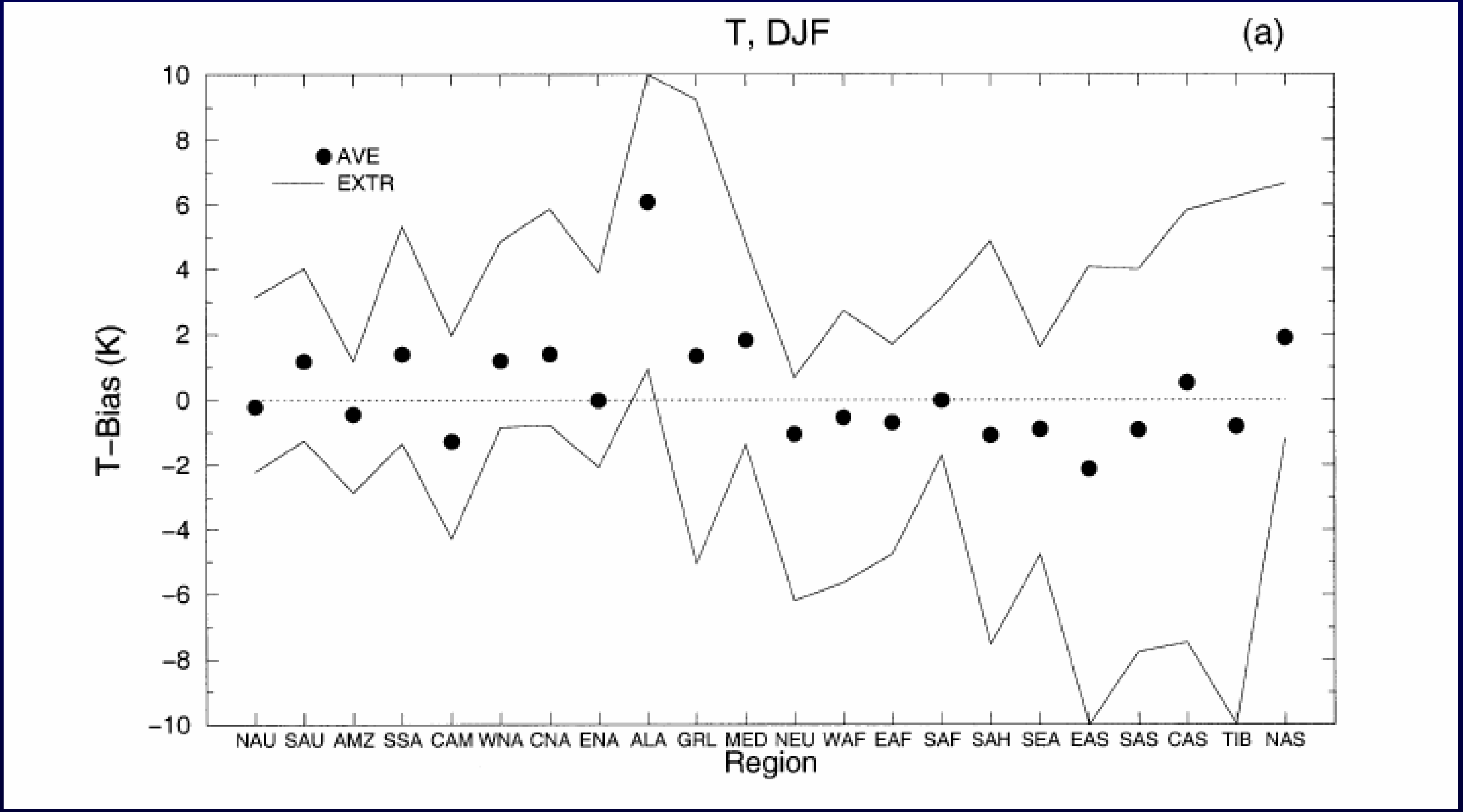
Annual temperature multi-model ensemble Average root mean square error



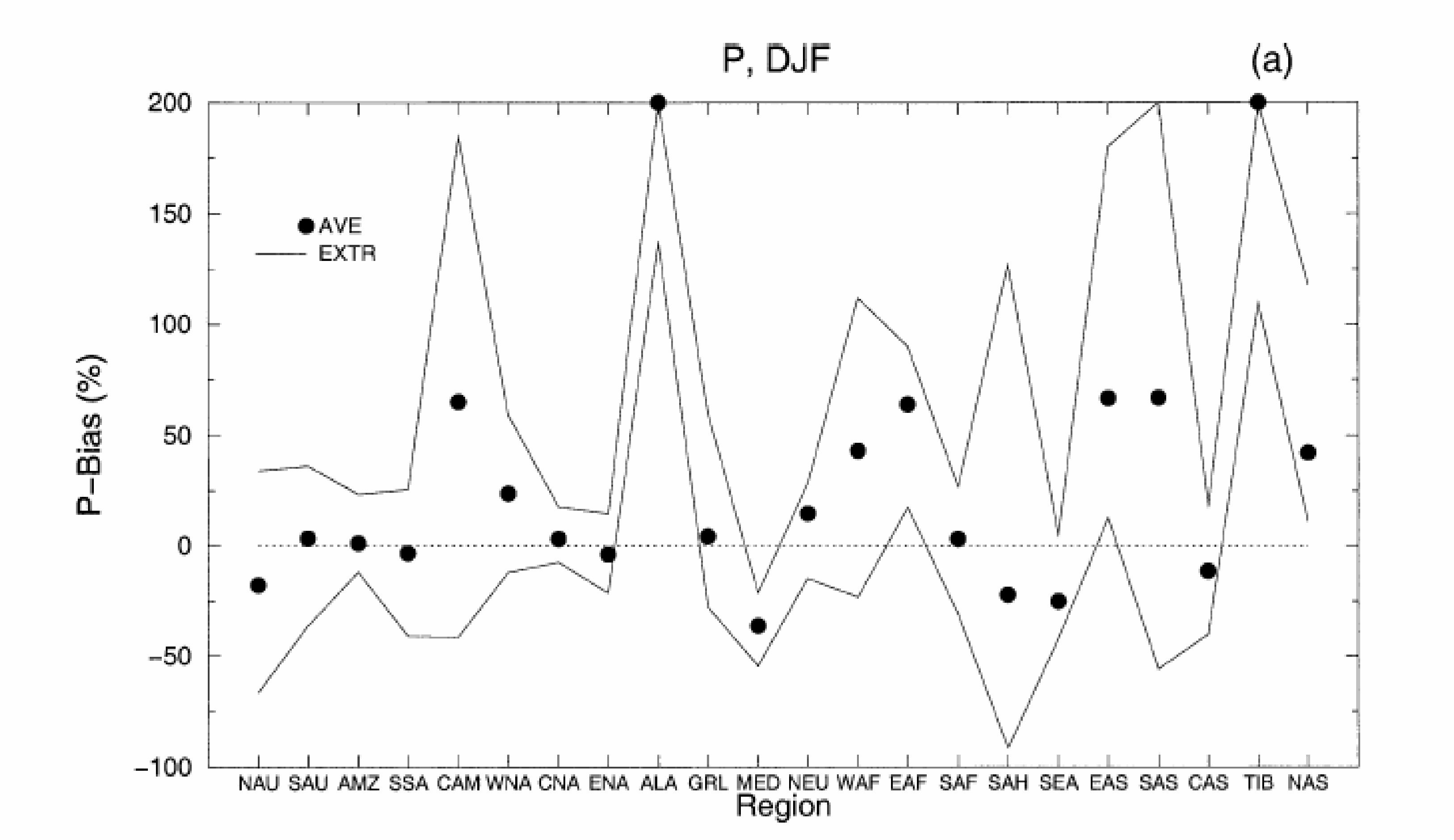
Regional performance of AOGCMs



Regional performance of AOGCMs
Temperature Bias, 9 AOGCMs



Regional performance of AOGCMs
Precipitation Bias, 9 AOGCMs



Other observed changes

-> Poleward shift of mid-latitude storm tracks

-> Greater intensity of tropical and extratropical cyclones

-> Increase of heat-waves and droughts

-> Greater intensity of precipitation

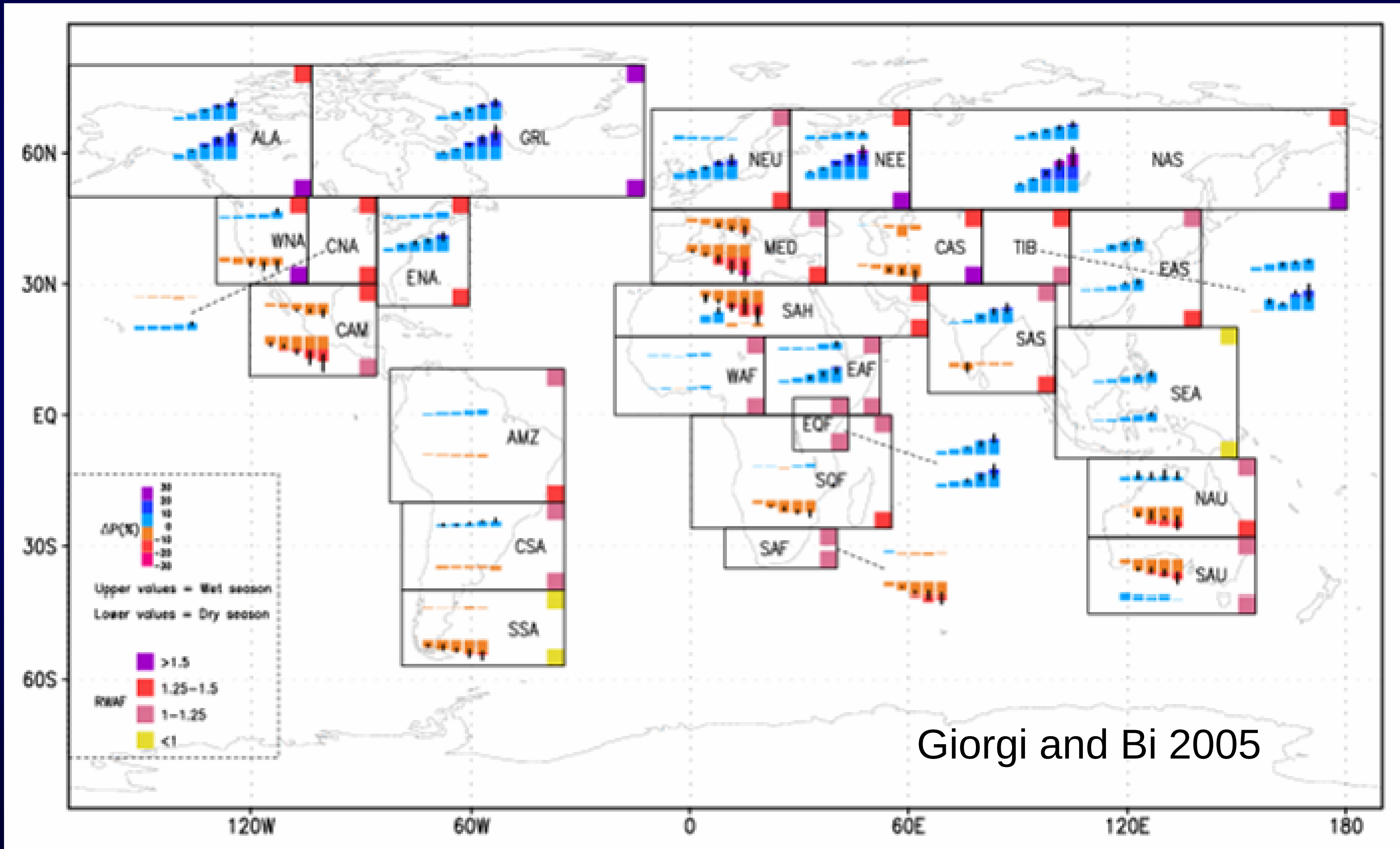
Projected changes in extremes

Phenomenon	*Likelihood that trend occurred in late 20th century (typically post 1960)*	*Likelihood that observed trend is due to human influence*	*Confidence[a] in trend predicted for 21st century*
Cool days / cool nights / frosts: decrease over mid- and high-latitude land areas	Very likely	Likely	High
Warm days / warm nights: increase over mid- and high-latitude land areas	Very likely	Likely (warm nights)	High
Warm spells / heat waves: increase	Likely	*More likely than not*	High
Proportion of heavy precipitation events: increase over many areas	Likely	*More likely than not*	High (but a few areas with projected decreases in absolute number of heavy events)
Droughts: increase over low-latitudes (and mid-latitudes in summer)	Likely	More likely than not	Moderate – mid-latitude continental interiors in summer (but sensitive to model land-surface formulation)
Tropical cyclones: increase in intensity	More likely than not since 1970	*More likely than not (but with low confidence)*	Moderate (few high-resolution models)
Mid- and high-latitude cyclones: increase in most intense storms; storm tracks move polewards	More likely than not	*Not assessed*	Moderate (intensity not explicitly analysed for all models)
High sea level events: increase (excludes tsunamis)	More likely than not	*Not assessed*	Moderate (most mid-latitude oceans)

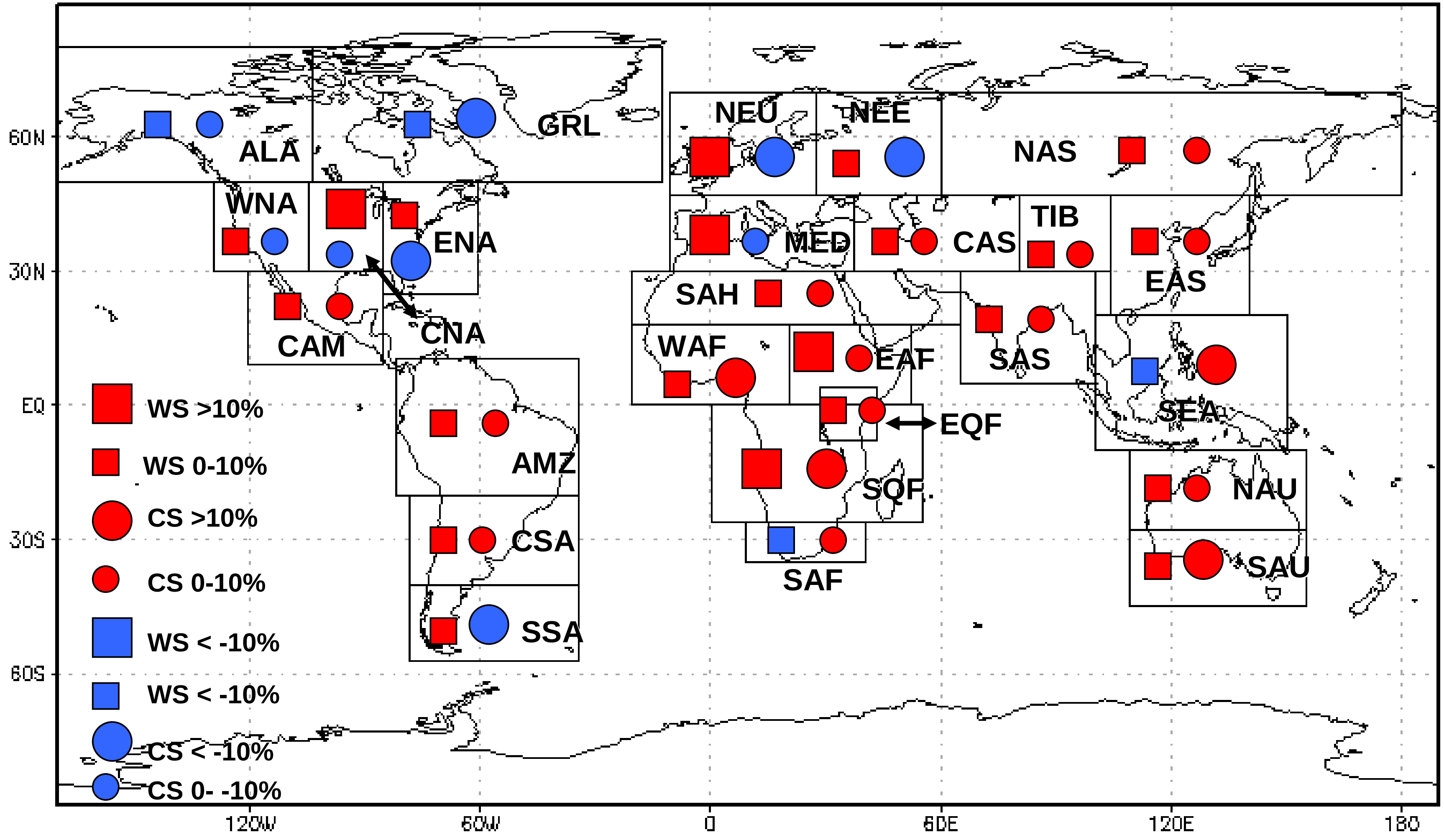
Notes:

(a) Confidence terms for projected trends are as follows: "high" means consistency across model projections and/or consistent with theory and/or changes in mean; "moderate" indicates some inconsistencies across model projections or only a few relevant model projections available or analysed.

Regional temperature and precipitation change for the 21st century (ensemble average 20 AOGCMs)



Change in temperature interannual variability (SD, 2080-2099 minus 1960-1979, A1B-A2-B1)



Ensemble average changes
A1B scenario, 20 AOGCMs