The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

1986-10

WCRP and ICTP Interpreting Climate Change Simulations: Capacity Building for Developing Nations Seminar

26 - 30 November 2007

IPCC (2007) Working Group I. Scientific Basis.

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IPCC (2007) WGI

IPCC (2007) Working Group I: Scientific Basis

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[on behalf of the Authors/ Contributors/ Review Editors and Reviewers of the Report]

Presentation: ICTP, Trieste; November 27, 2007

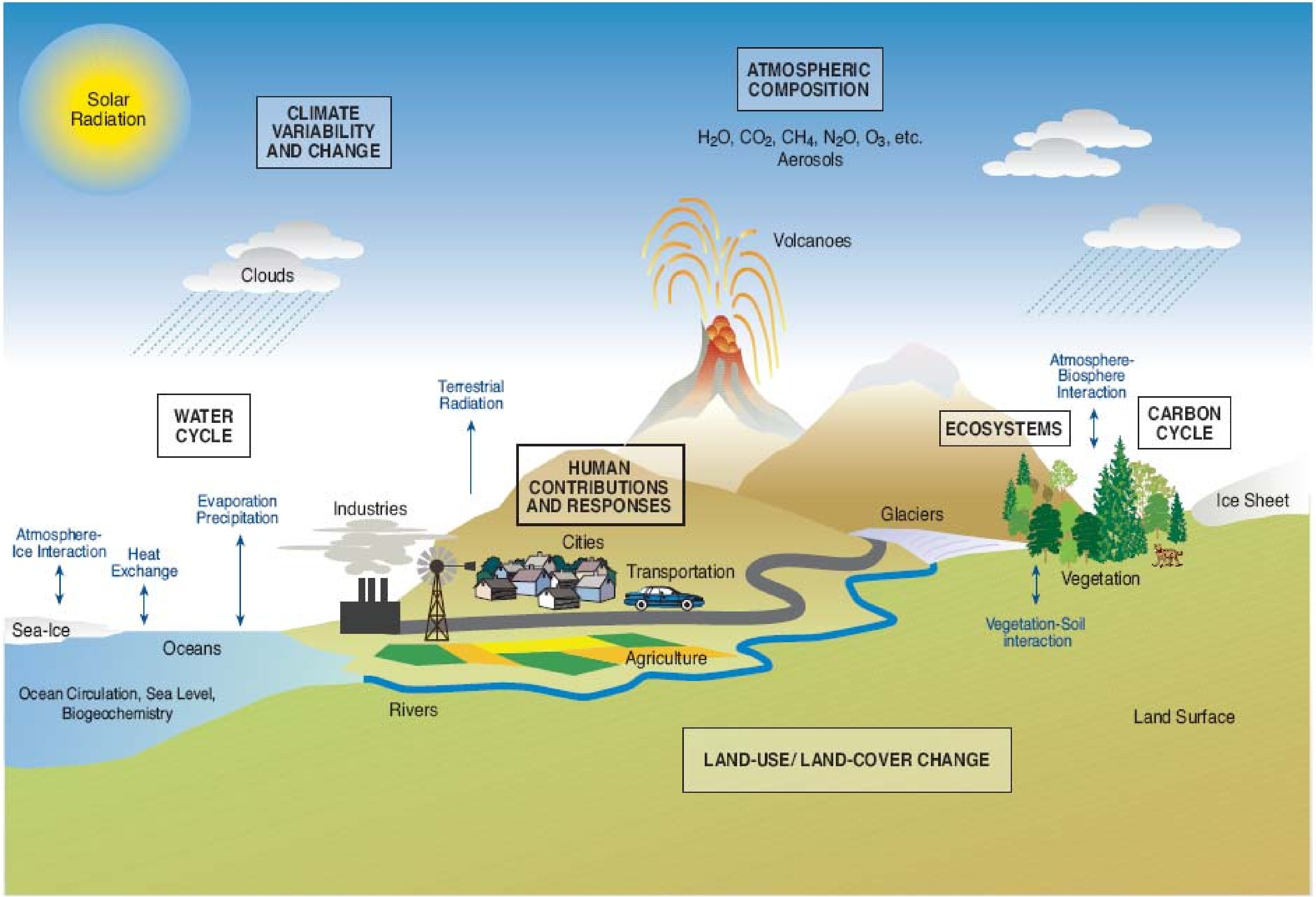


Figure 1: Major components needed to understand the climate system and climate change.

Scope

Key findings from the IPCC (2007) Working Group I report:

- “Drivers” of climate change
- Observed changes in the climate system
- Understanding and attribution of the 20th Century climate changes
- Projections of future climate changes

“Drivers” of climate change

RADIATIVE FORCING (RF) [1750-2005]

{Global-average estimates and ranges; typical geographical extent and assessed level of scientific understanding}

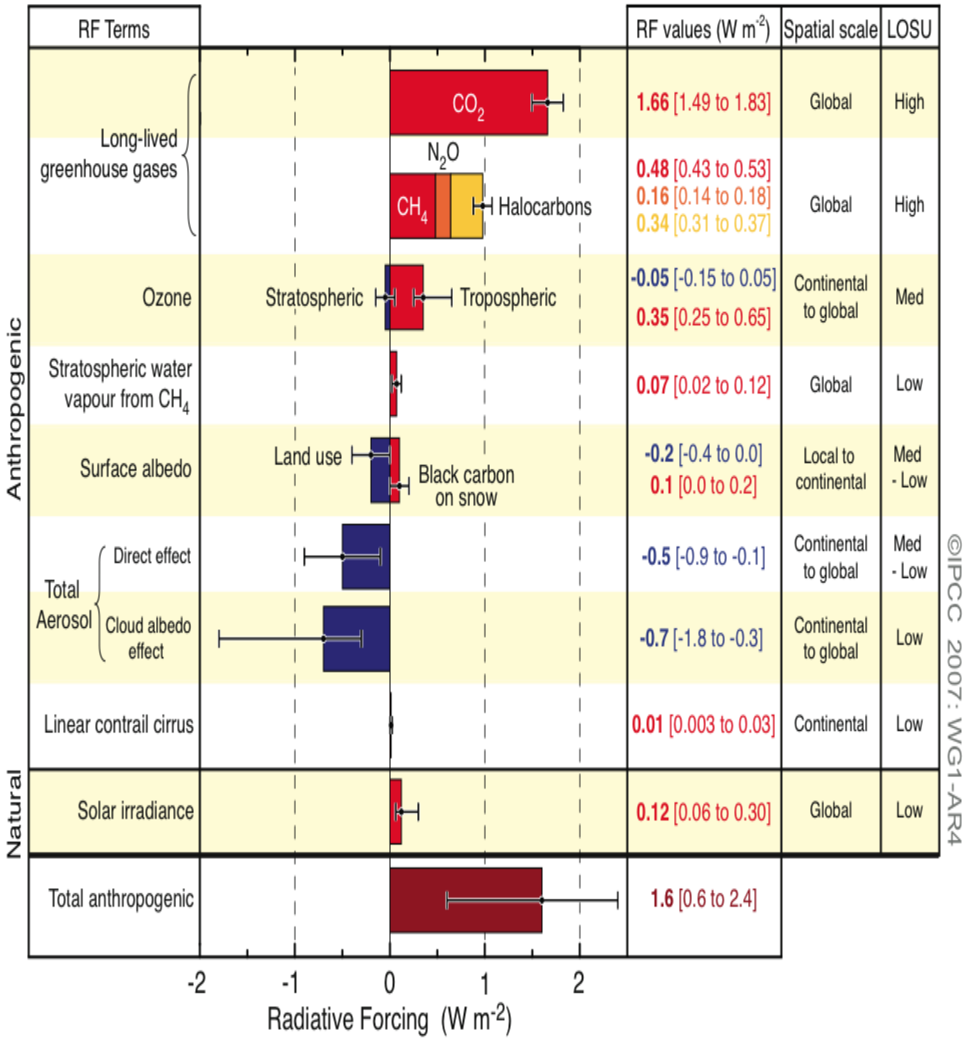


Fig. SPM-2

ANTHROPOGENIC

Long-lived greenhouse gases
-dominant forcing, with high scientific understanding

Other greenhouse gases: ozone

▪Aerosol Direct forcing: better constrained since TAR

▪Best estimate for cloud albedo forcing given for first time. Note large and asymmetric uncertainty range.

▪Land-surface forcings

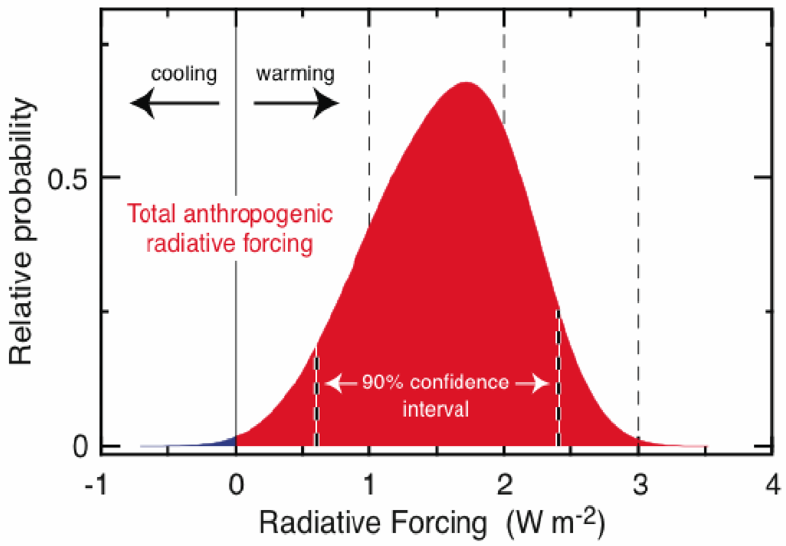
{forcings less than +/- 0.1 Wm^{-2} not discussed}

NATURAL

Revised solar forcing less than half of that in TAR
- from re-evaluation of the change in the long-term irradiance

-Volcanic forcing not shown on figure as it is episodic

Combining anthropogenic forcing estimates



Panel B.

Fig. 2.20

Figure TS-5
(Panel B)

Combined anthropogenic forcing **is not straight sum of individual terms.**

Tropospheric ozone, cloud-albedo, contrails → asymmetric range about the central estimate

Uncertainties for the agents represented by normal distributions except: contrail (lognormal); discrete values → trop. ozone, direct aerosol (sulphate, fossil fuel black and organic carbon, biomass burning), cloud albedo

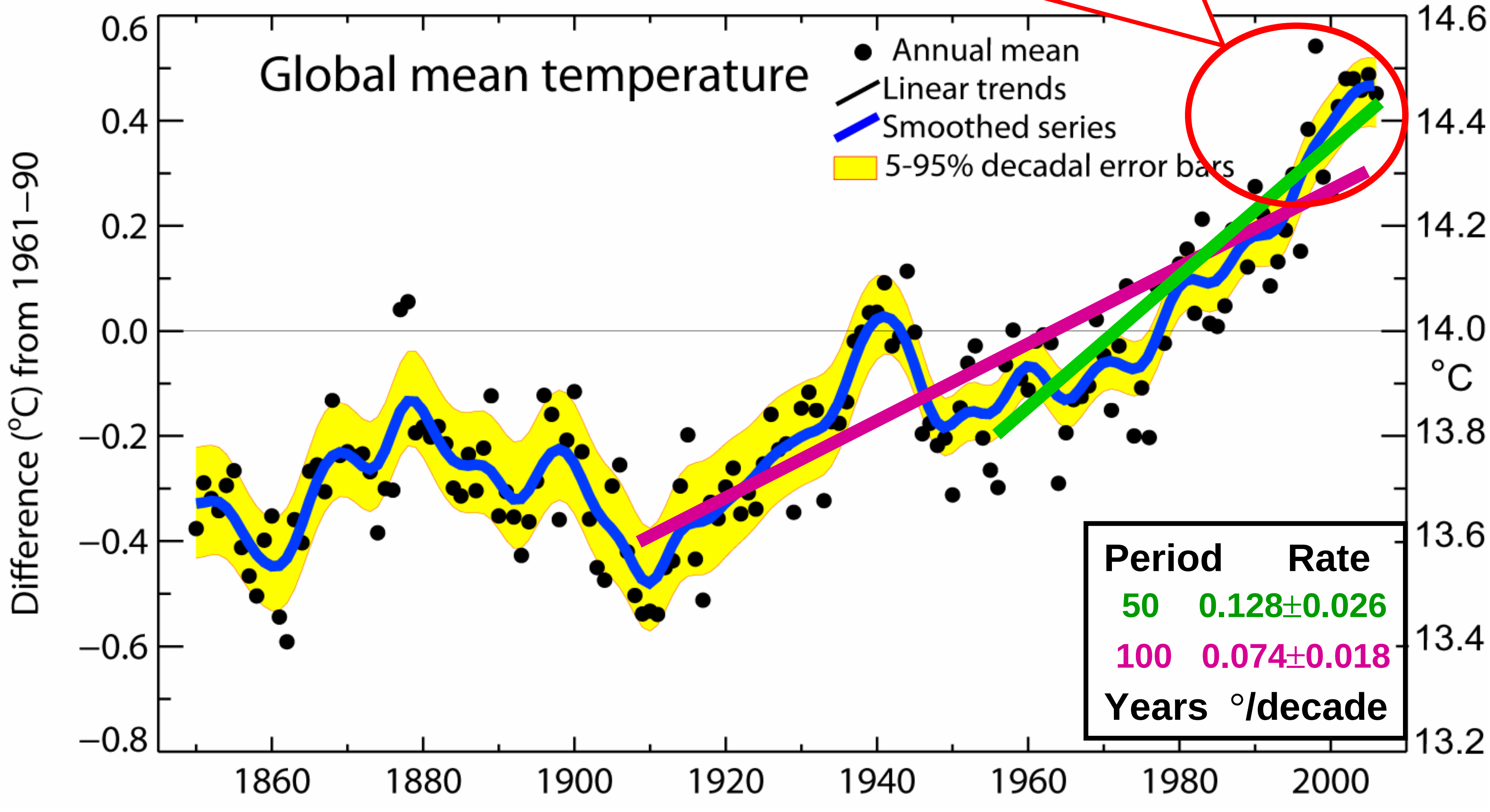
Monte Carlo calculations to derive probability density functions for the combined effect

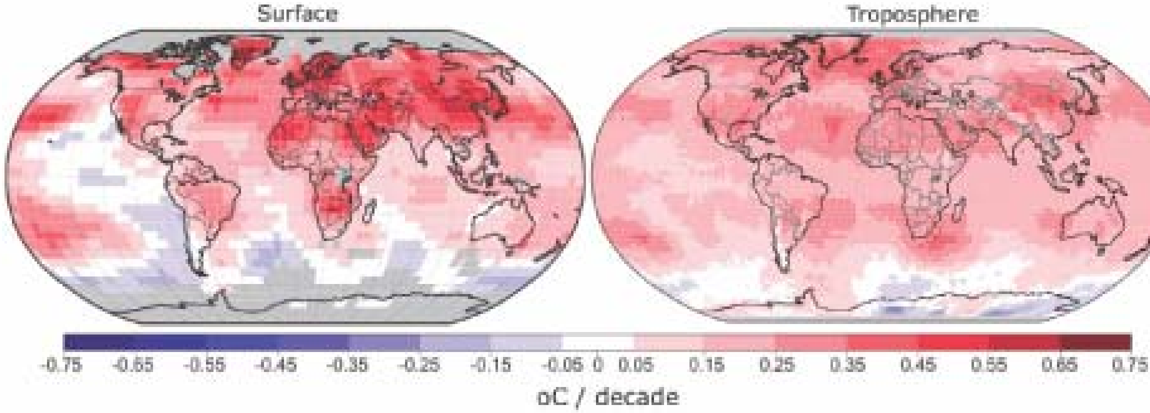
Only derived for the global-mean

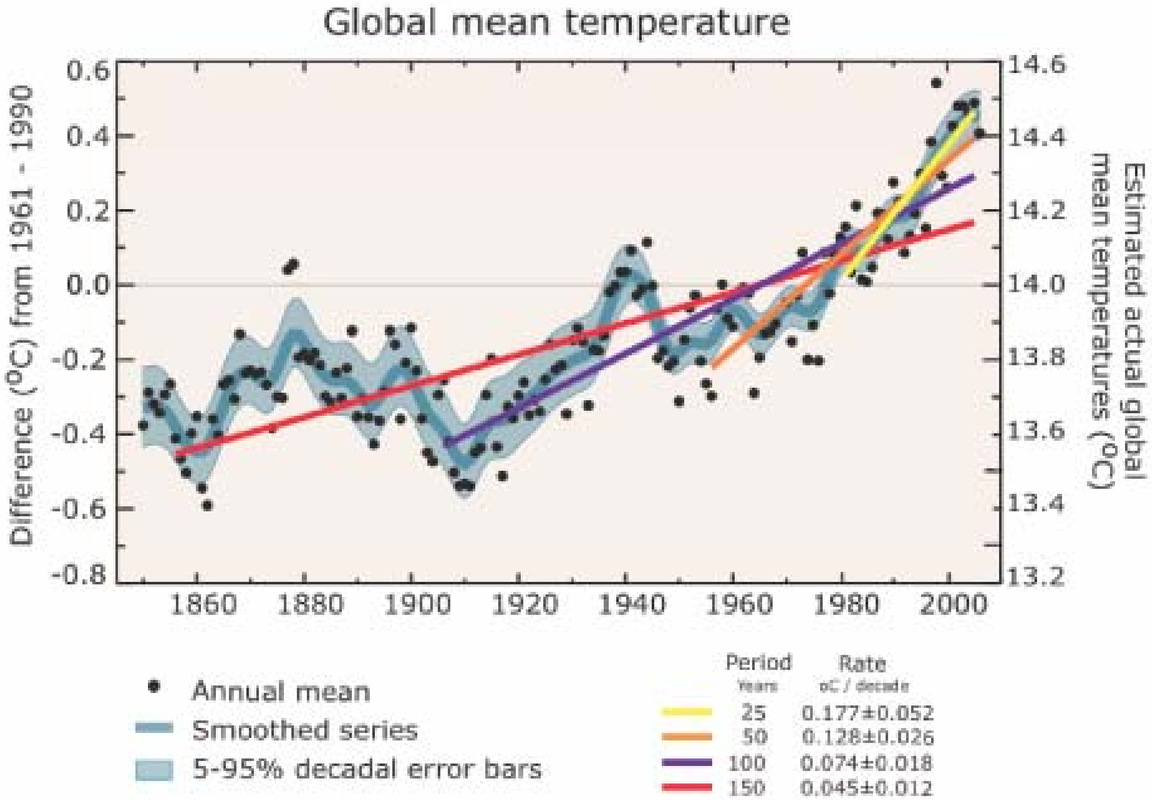
Observed climate changes

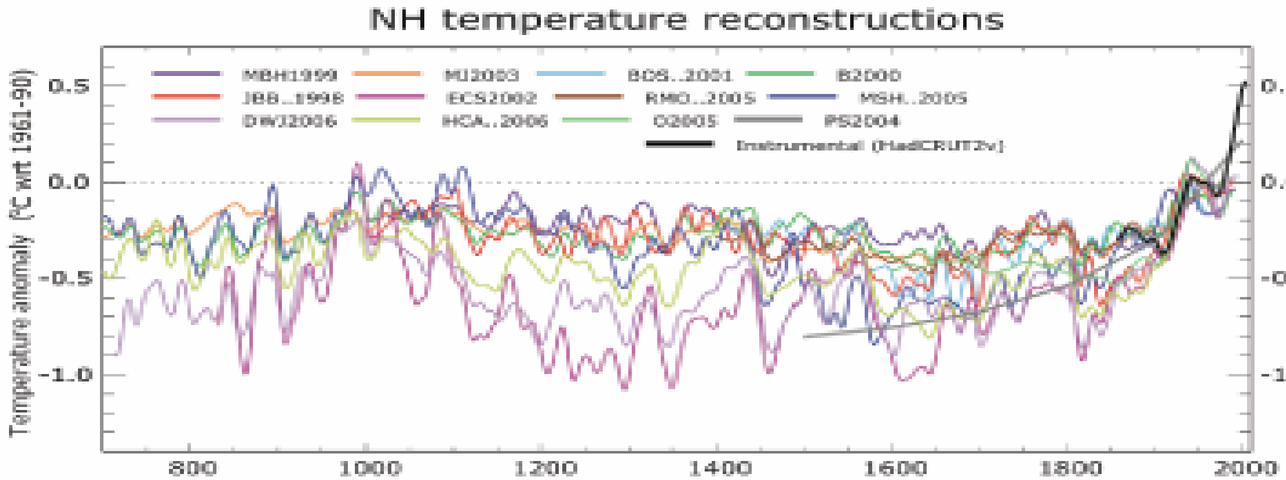
Global mean temperatures are rising faster with time

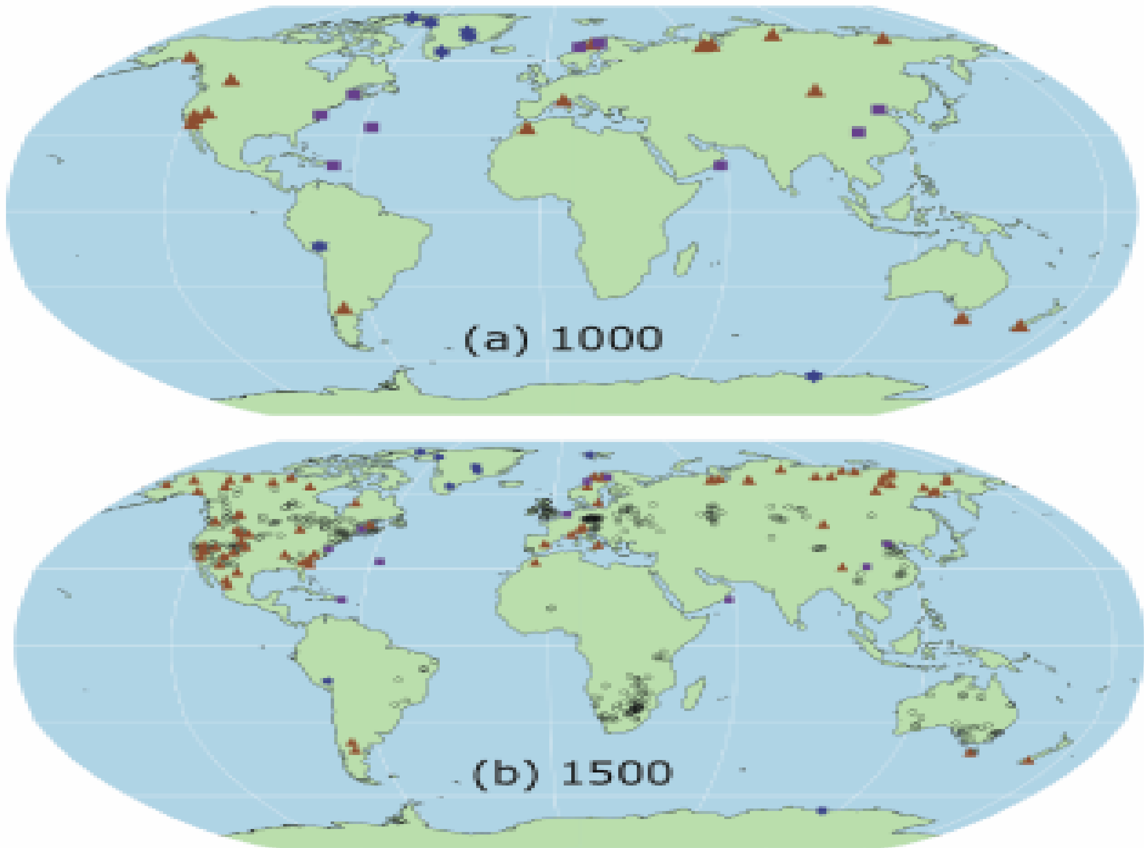
Warmest 12 years:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000




Surface
Troposphere
-0.75 -0.65 -0.55 -0.45 -0.35 -0.25 -0.15 -0.05 0 0.05 0.15 0.25 0.35 0.45 0.55 0.65 0.75
oC / decade


Global mean temperature
Difference (°C) from 1961 - 1990
Estimated actual global mean temperatures (°C)
0.6 0.4 0.2 0.0 -0.2 -0.4 -0.6 -0.8
14.6 14.4 14.2 14.0 13.8 13.6 13.4 13.2
1860 1880 1900 1920 1940 1960 1980 2000
Annual mean
Smoothed series
5-95% decadal error bars
Period Years
Rate oC / decade
25 0.177±0.052
50 0.128±0.026
100 0.074±0.018
150 0.045±0.012


NH temperature reconstructions
MBH1999
MJ2003
BOS..2001
B2000
JBB..1998
ECS2002
RMO..2005
MSH..2005
DWJ2006
HCA..2006
O2005
PS2004
Instrumental (HadCRUT2v)
Temperature anomaly (°C wrt 1961-90)
0.5
0.0
-0.5
-1.0
800
1000
1200
1400
1600
1800
2000

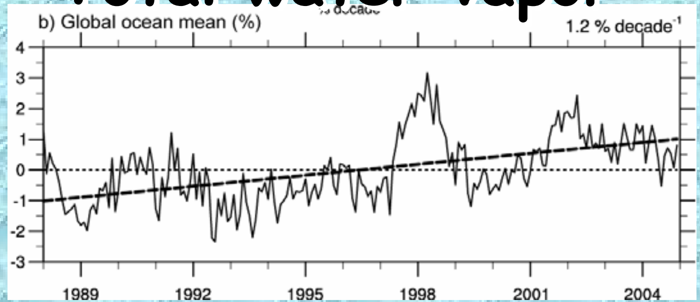

(a) 1000
(b) 1500

Air holds more water vapor at higher temperatures

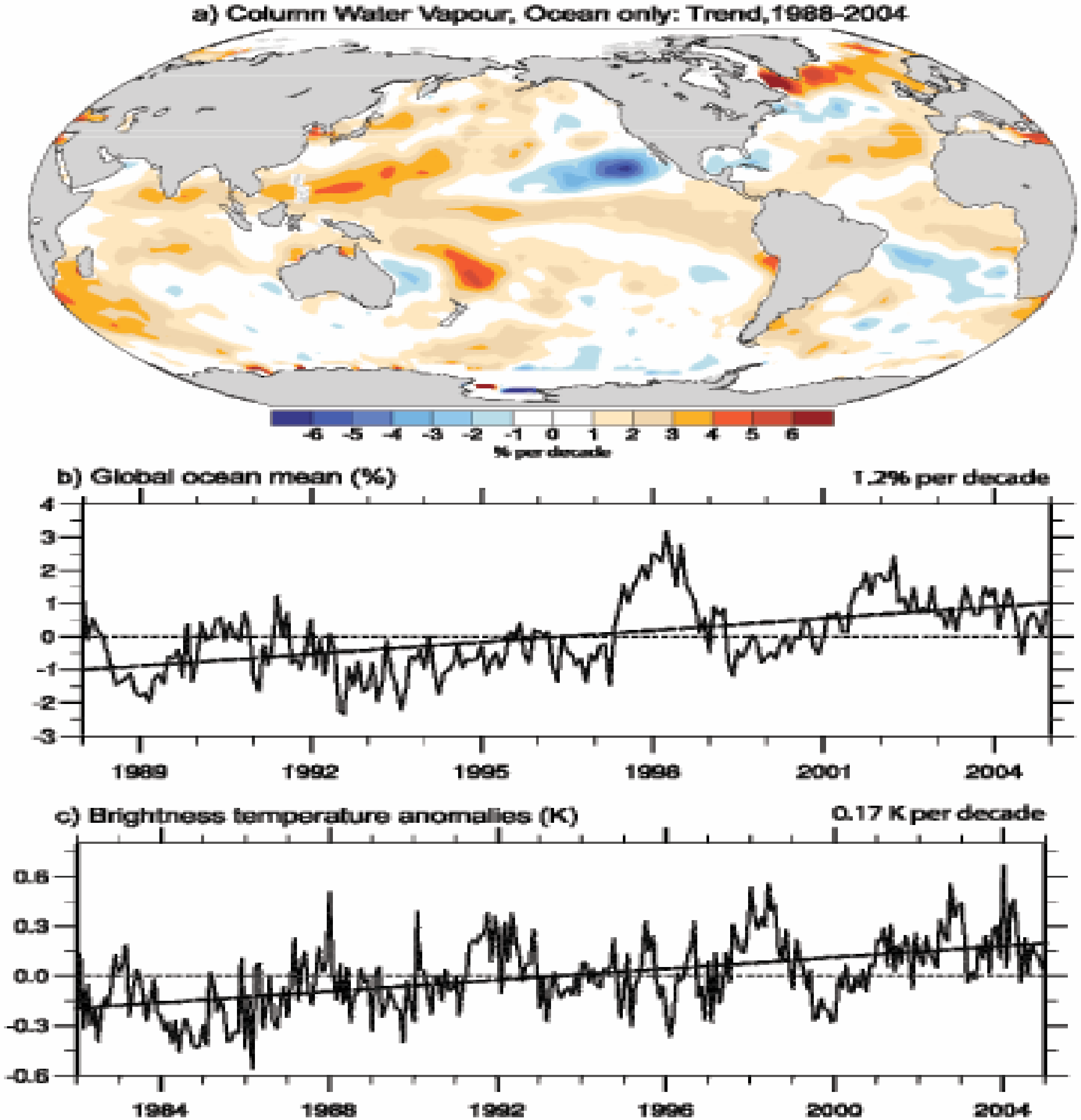
A basic physical law tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature.

Observations show that this is happening at the surface and in lower atmosphere: 0.55°C since 1970 over global oceans and 4% more water vapor.

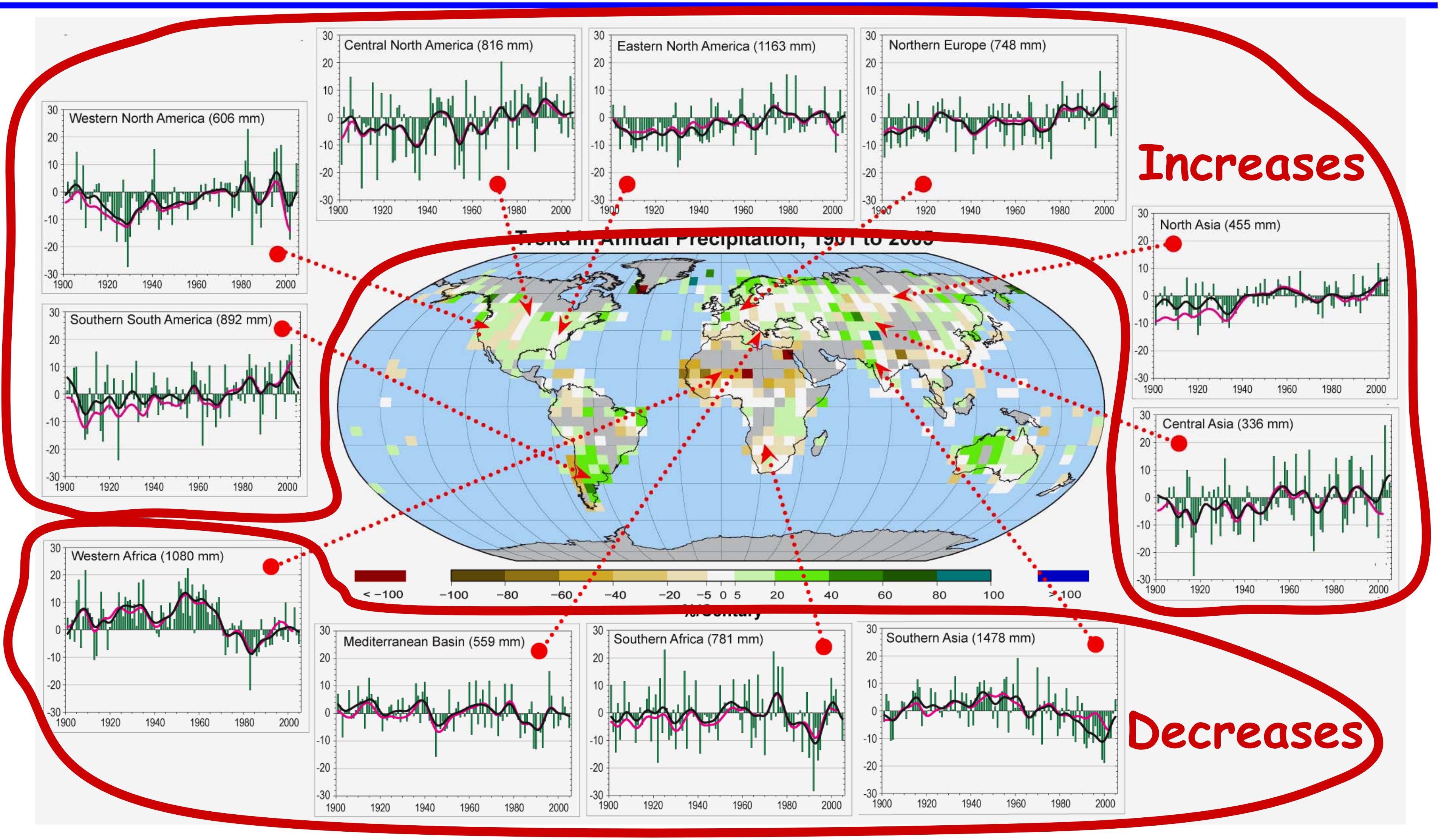
Total water vapor



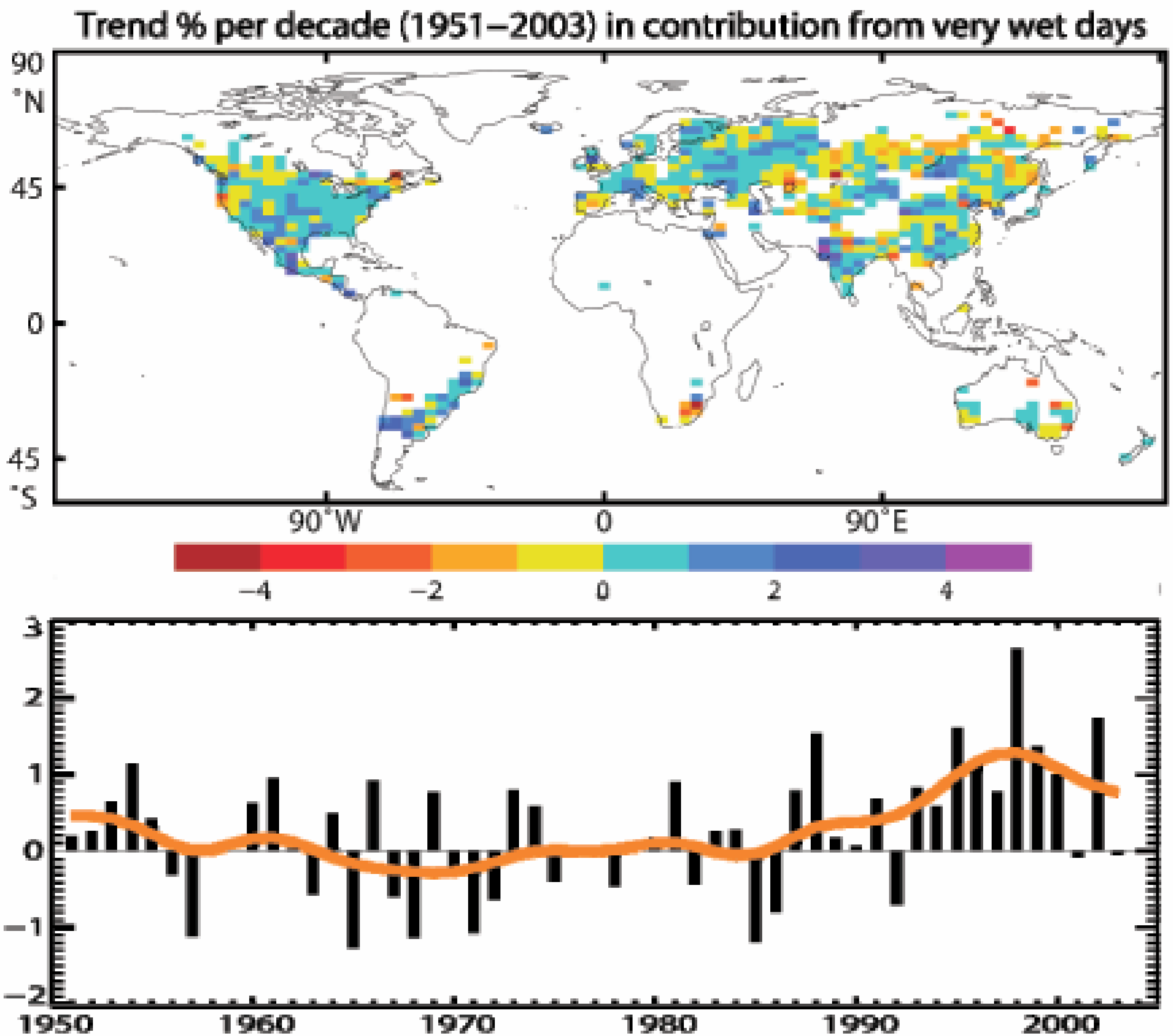
This means more moisture available for storms and an enhanced greenhouse effect.


a) Column Water Vapour, Ocean only: Trend,1988-2004
-6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6
% per decade
b) Global ocean mean (%)
1.2% per decade
4
3
2
1
0
-1
-2
-3
1989
1992
1995
1998
2001
2004
c) Brightness temperature anomalies (K)
0.17 K per decade
0.6
0.3
0.0
-0.3
-0.6
1984
1988
1992
1996
2000
2004

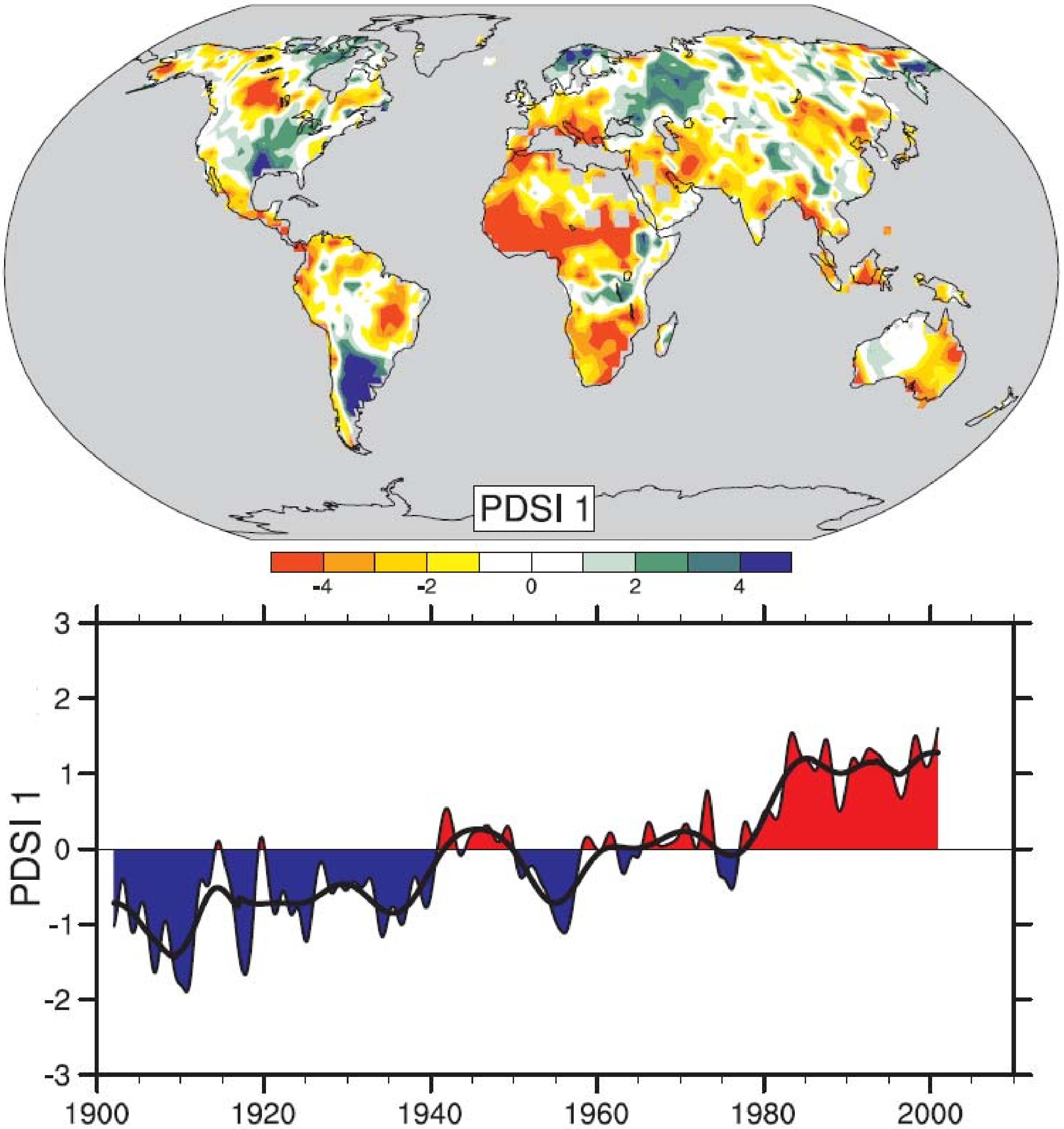
Land precipitation is changing significantly over broad areas



Smoothed annual anomalies for precipitation (%) over land from 1900 to 2005; other regions are dominated by variability.



Trend % per decade (1951–2003) in contribution from very wet days
90 °N
45
0
45 °S
90°W
0
90°E
−4
−2
0
2
4
3
2
1
0
−1
−2
1950
1960
1970
1980
1990
2000



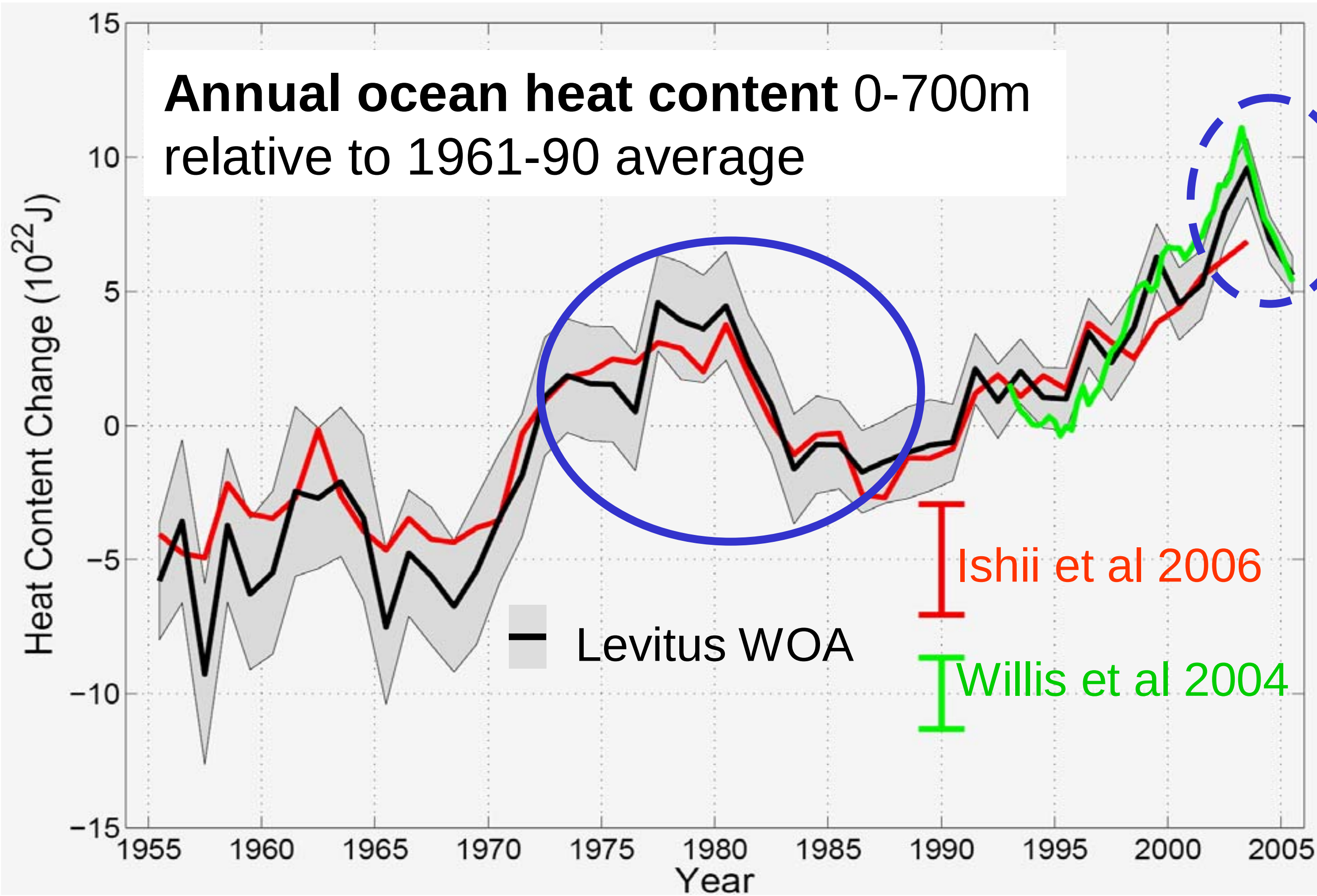
PDSI 1
-4
-2
0
2
4
3
2
1
0
-1
-2
-3
PDSI 1
1900
1920
1940
1960
1980
2000

Is ocean warming accelerating?

Causes of decadal variability not well understood

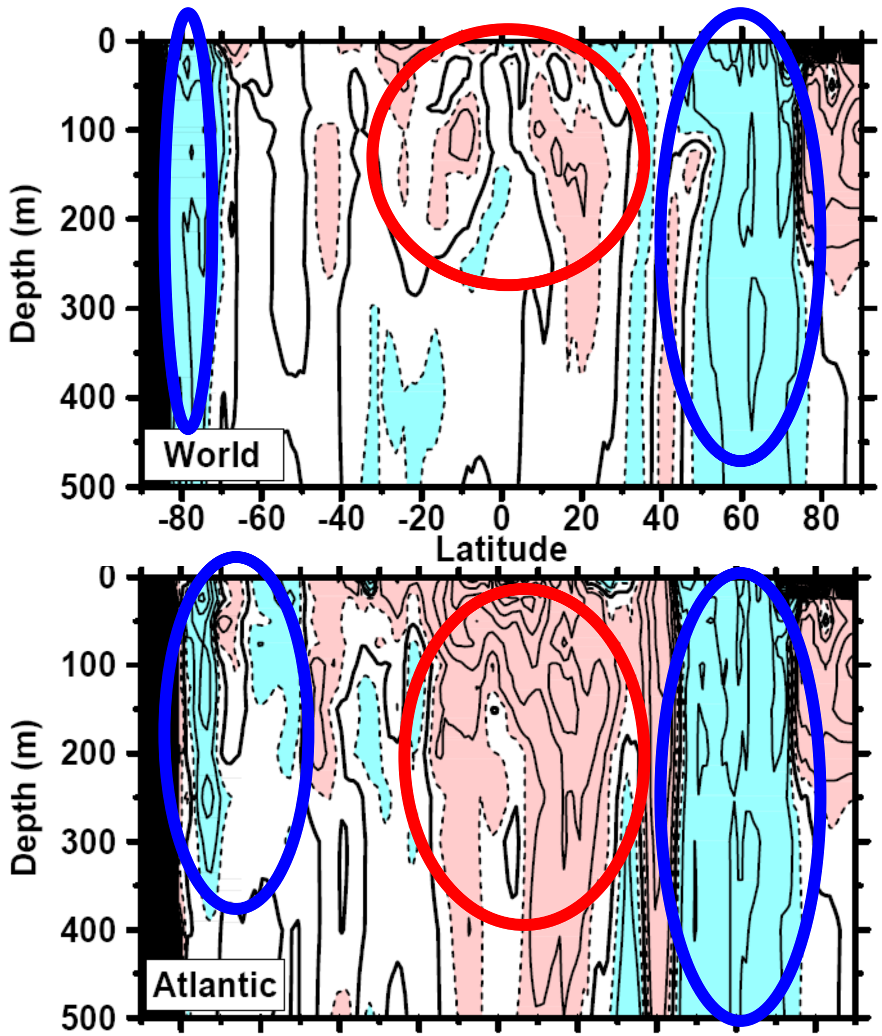
- **cooling due to volcanism?**
- **artefact due to temporally changing observing system?**

→ **No statement on acceleration possible**



Ocean salinities are changing, indicating changes in evaporation and precipitation

Zonally averaged salinity trend 1955–1998



Tropics in upper oceans are becoming saltier, in particular in Atlantic/Indian

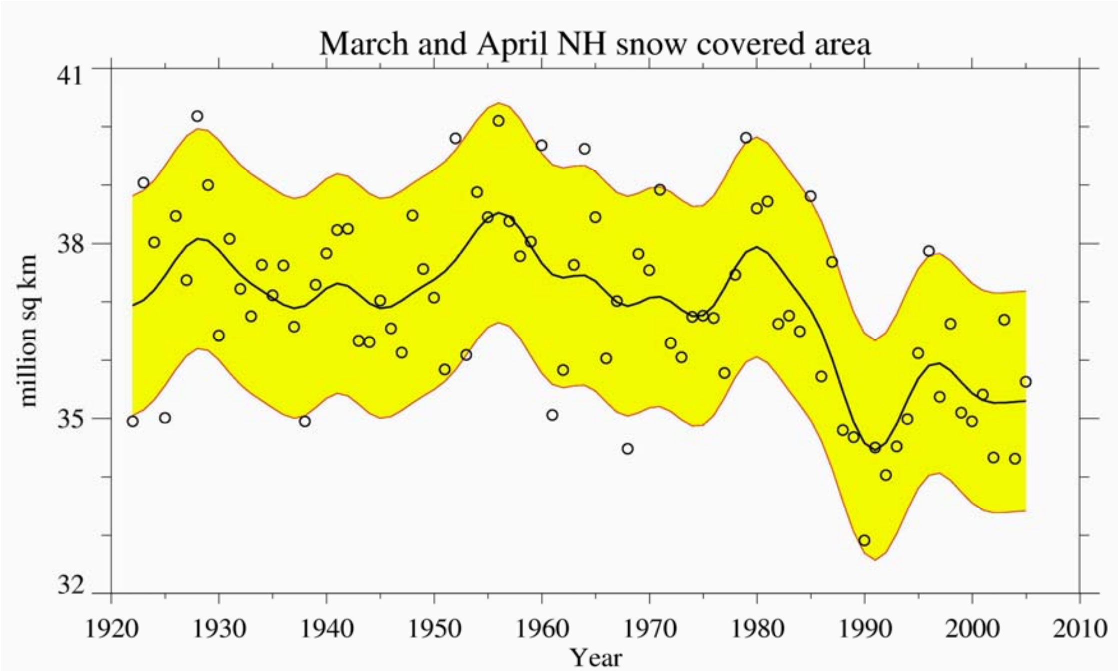
Mid-to-high latitudes are becoming fresher, in particular in N-Pacific/N-Atlantic

Consistent with increase in atmospheric water transport

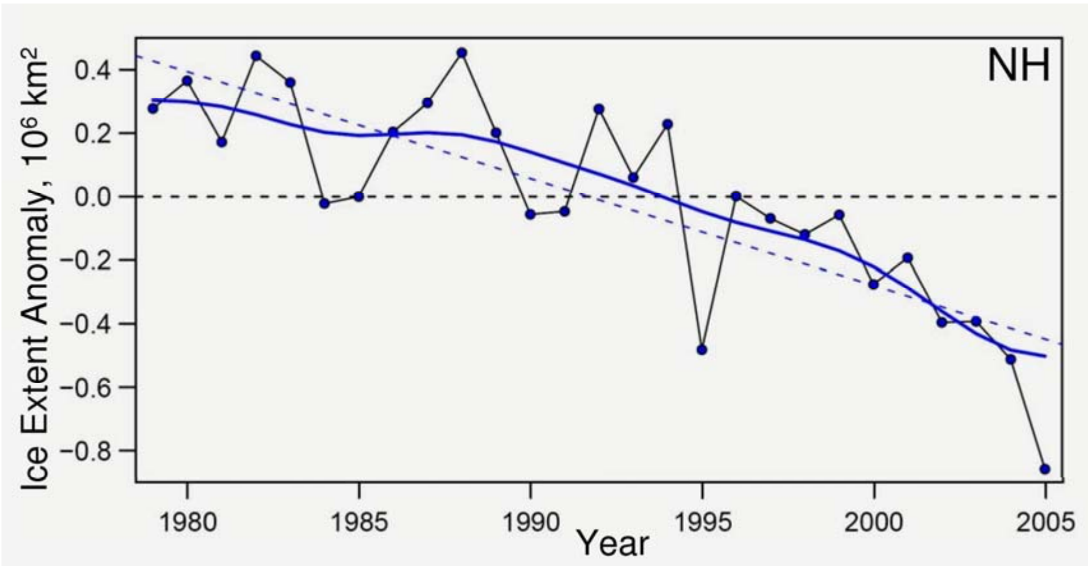
saltier
> 0.005psu per decade

fresher
< - 0.005psu per decade

Snow cover and Arctic sea ice are decreasing



Spring snow cover shows 5% stepwise drop during 1980s



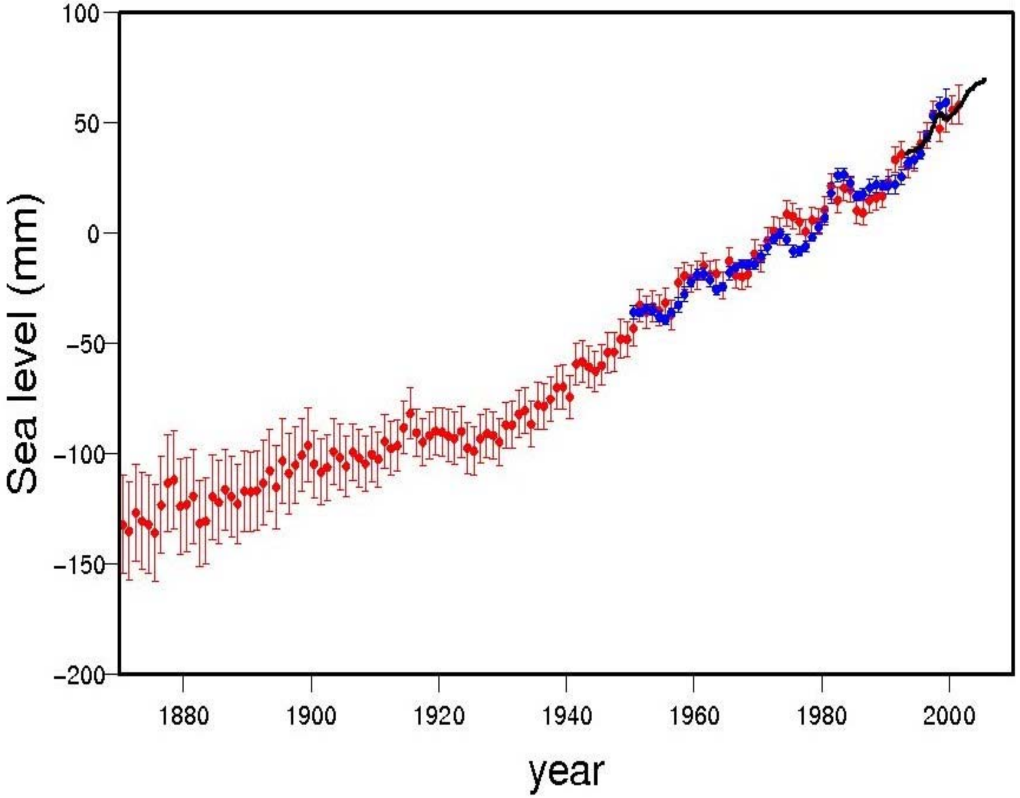
Arctic sea ice area decreased by 2.7% per decade (Summer: -7.4%/decade)

Changes in atmospheric circulation alter temperatures and precipitation

When the North Atlantic Oscillation (NAO) and Northern Annular Mode (NAM) indices become more positive, storm tracks, temperatures and precipitation change as indicated.

Sea Level Rise Observations

20th century sea level

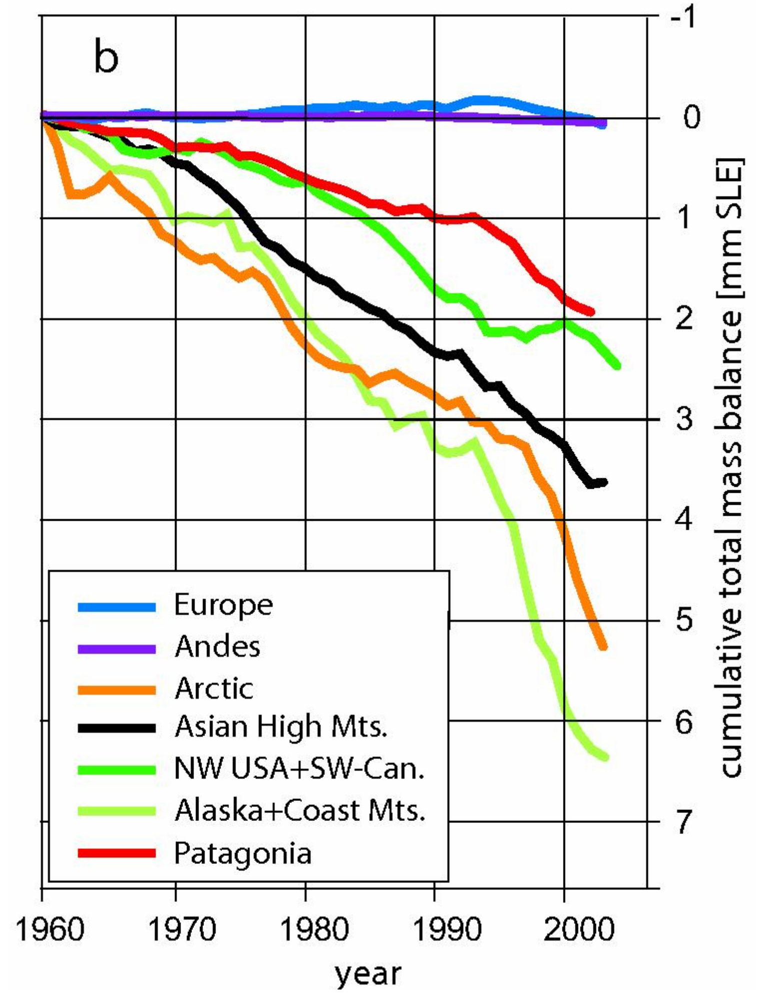


Rates of sea level rise:

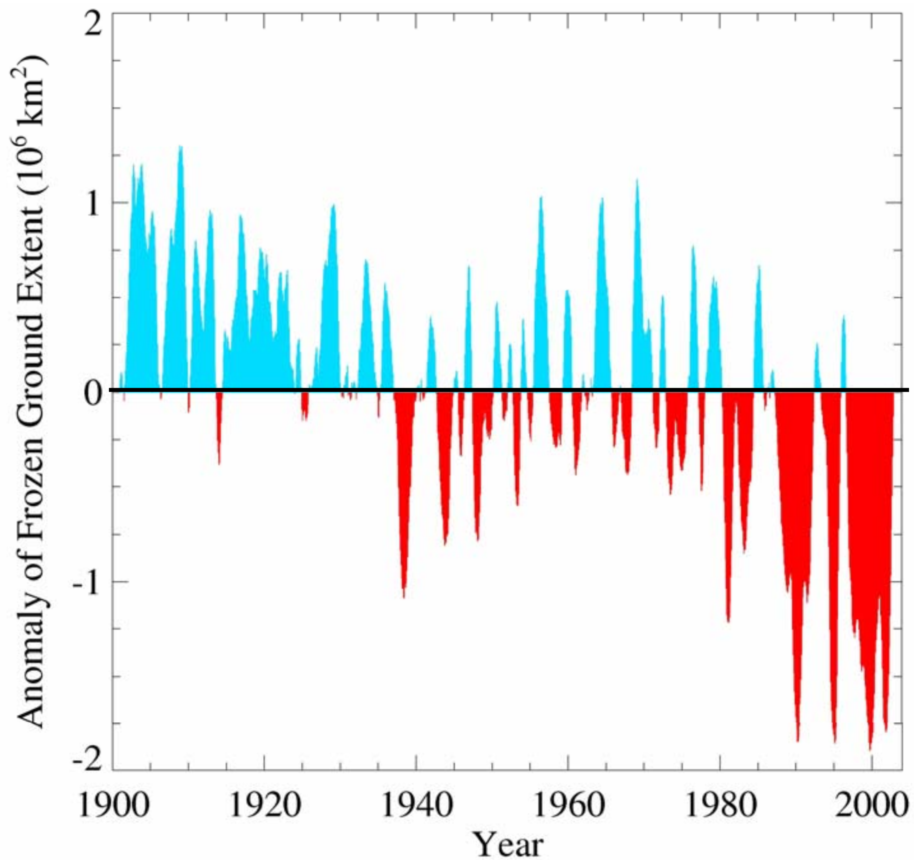
- 1.8 ± 0.5 mm yr^{-1}, 1961-2003
- 1.7 ± 0.5 mm yr-1, 20th Century
- 3.1 ± 0.7 mm yr^{-1}, 1993-2003

- Consistency of sea level data
- Variability of sea level data
- Are rates increasing?

Glaciers and frozen ground are receding

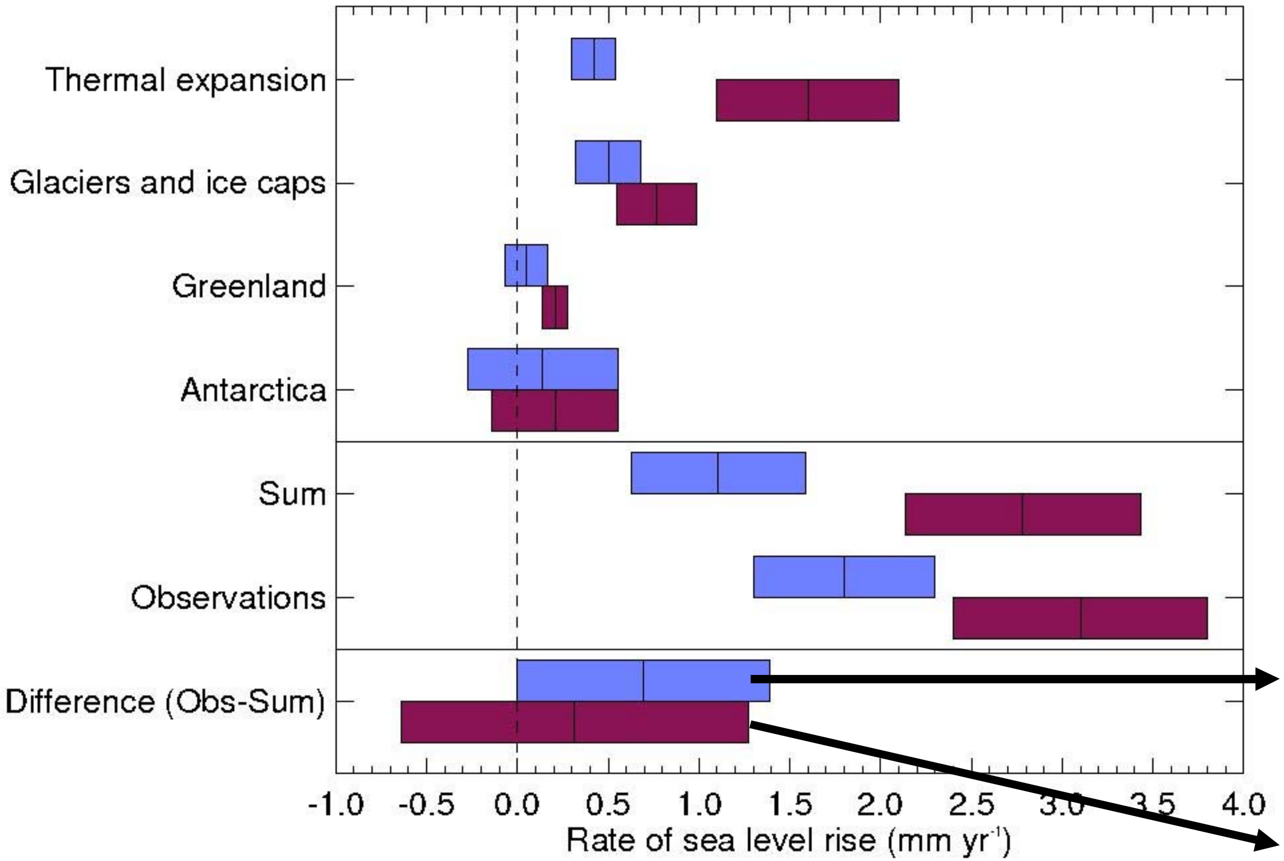


Increased Glacier retreat since the early 1990s



Area of seasonally frozen ground in NH has decreased by 7% from 1901 to 2002

Accounting for observed sea level rise



1961-2003: **Sea level budget not quite closed.**

1993-2003: **Sea level budget is closed.**

Warming is unequivocal

Since 1970, rise in:

- Global surface temperatures
- Tropospheric temperatures
- Global SSTs, ocean Ts
- Global sea level
- Water vapor
- Rainfall intensity
- Precipitation extratropics
- Hurricane intensity
- Drought
- Extreme high temperatures
- Heat waves

Decrease in:

NH Snow extent
Arctic sea ice
Glaciers
Cold temperatures

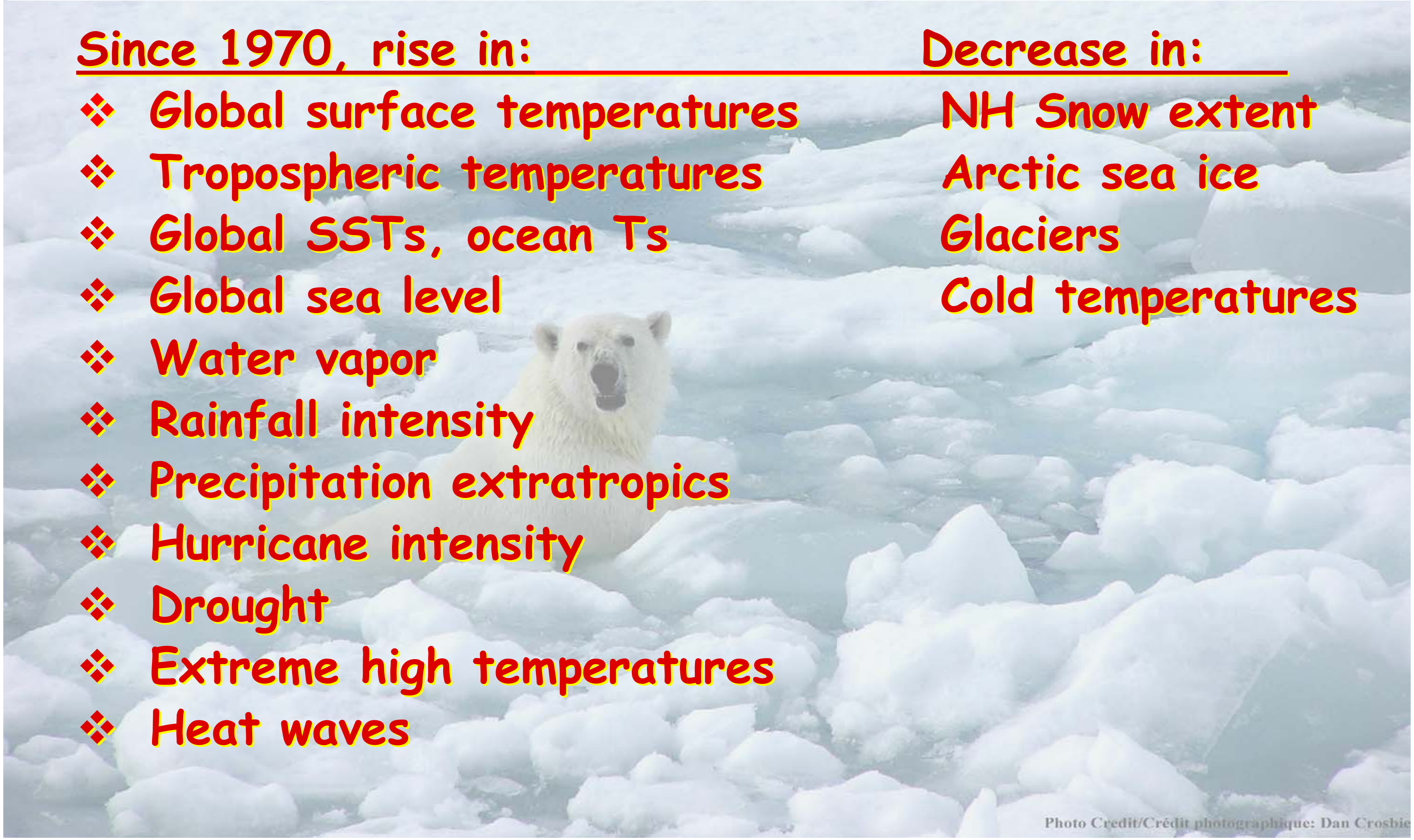


Photo Credit/Crédit photographique: Dan Crosbie

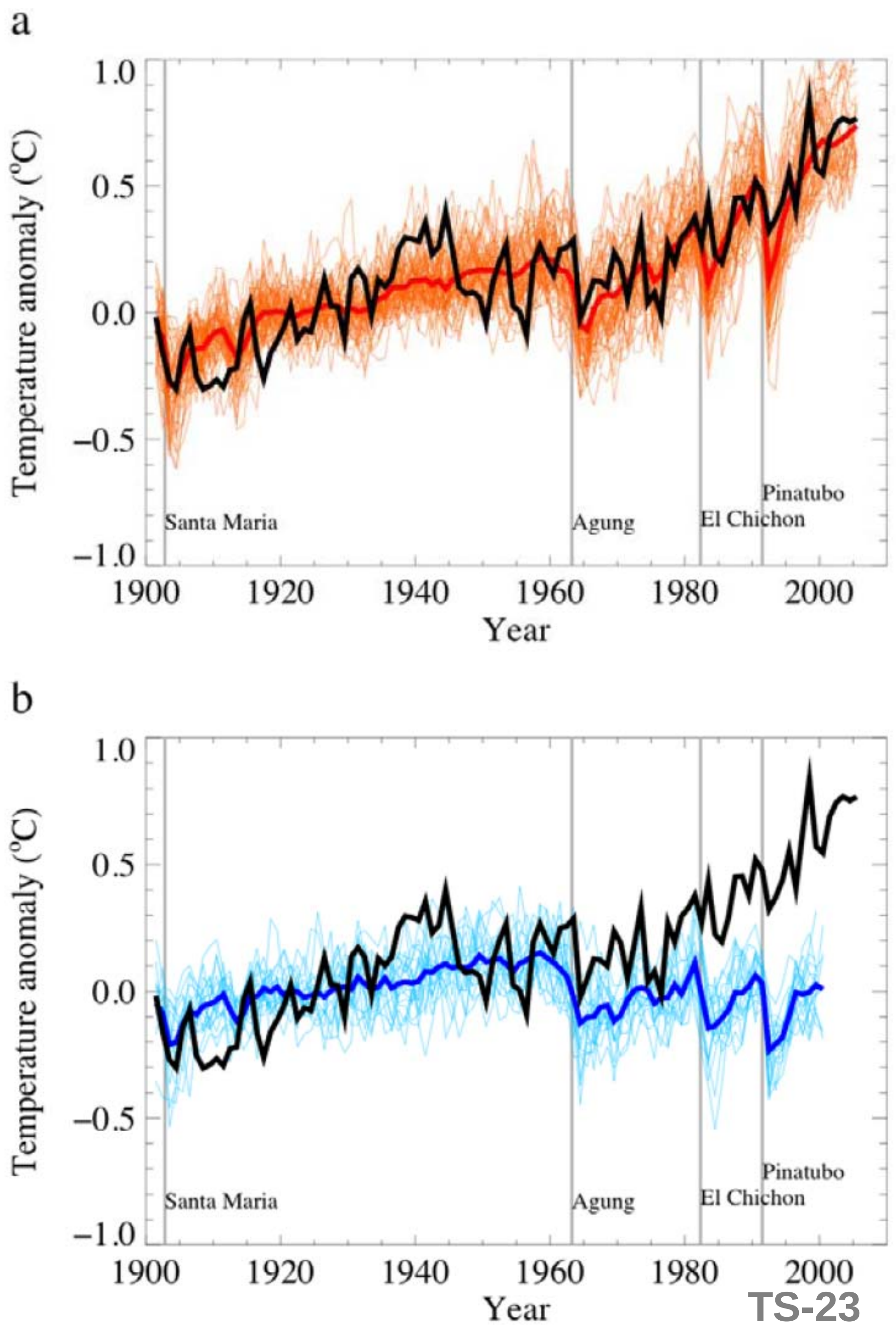
Understanding and Attribution of climate changes

Attribution

- Asks whether observed changes are consistent with

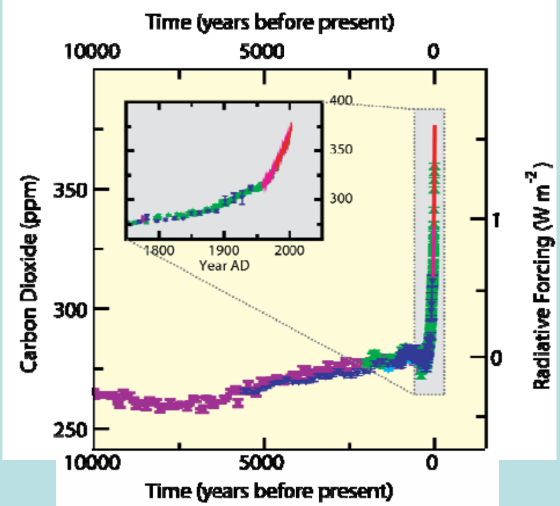
☑ expected responses to forcings

☒ inconsistent with alternative explanations



Attribution Process

SPM-1



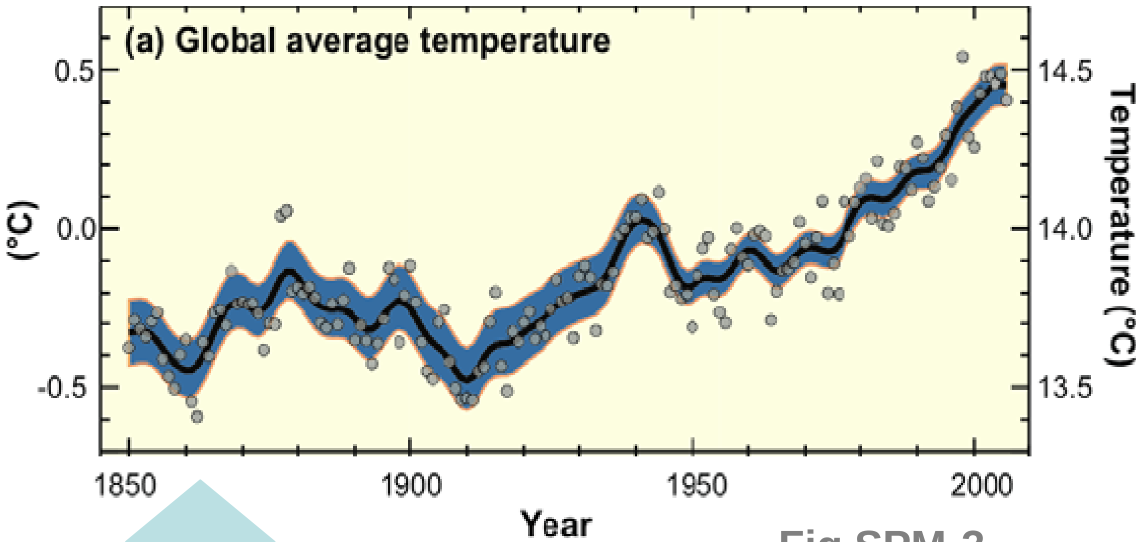
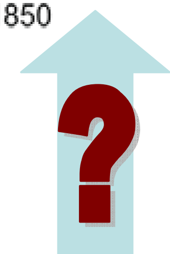
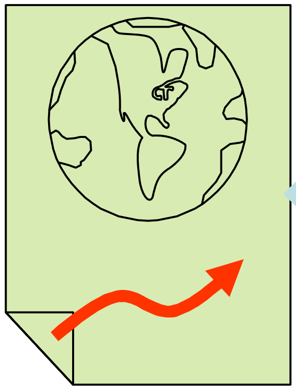
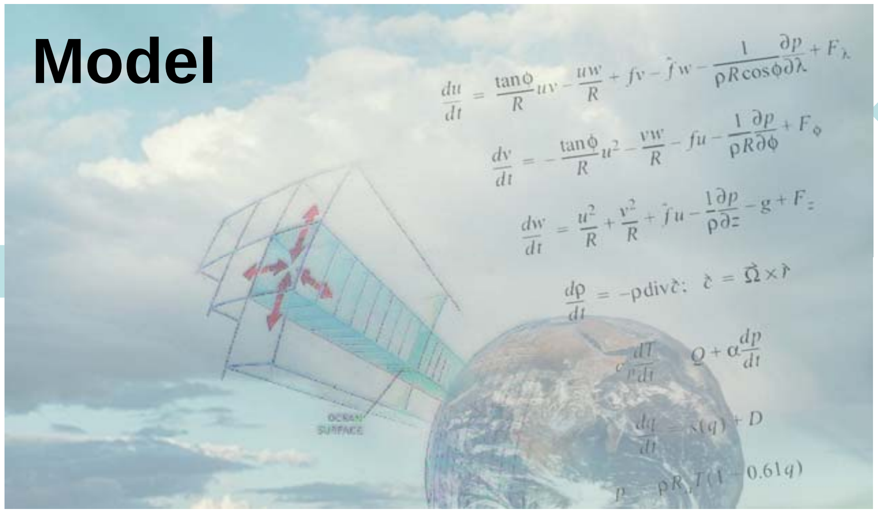


Fig SPM-3

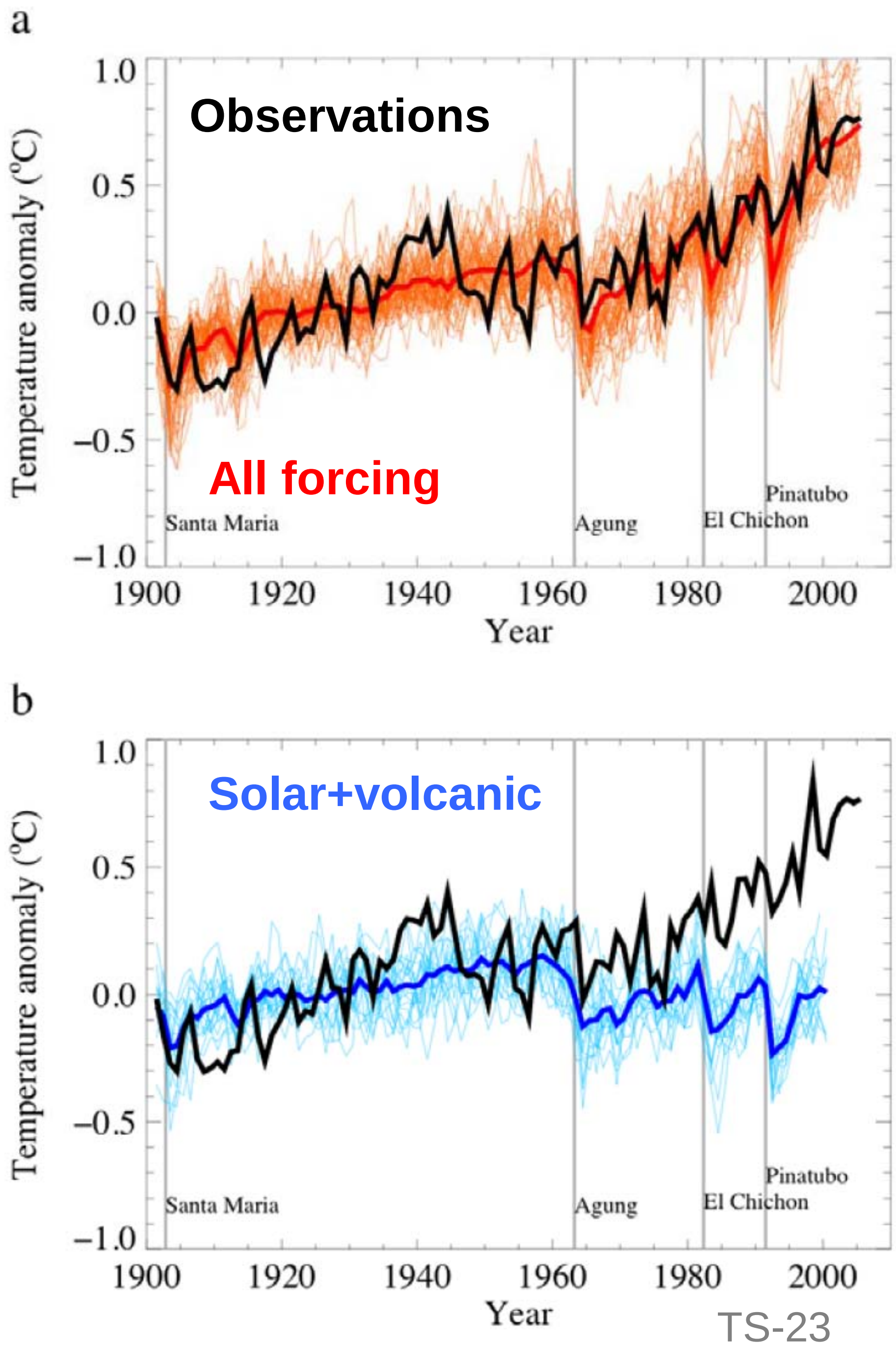
- other GHGs
- aerosols
- volcanic
- solar
- natural internal







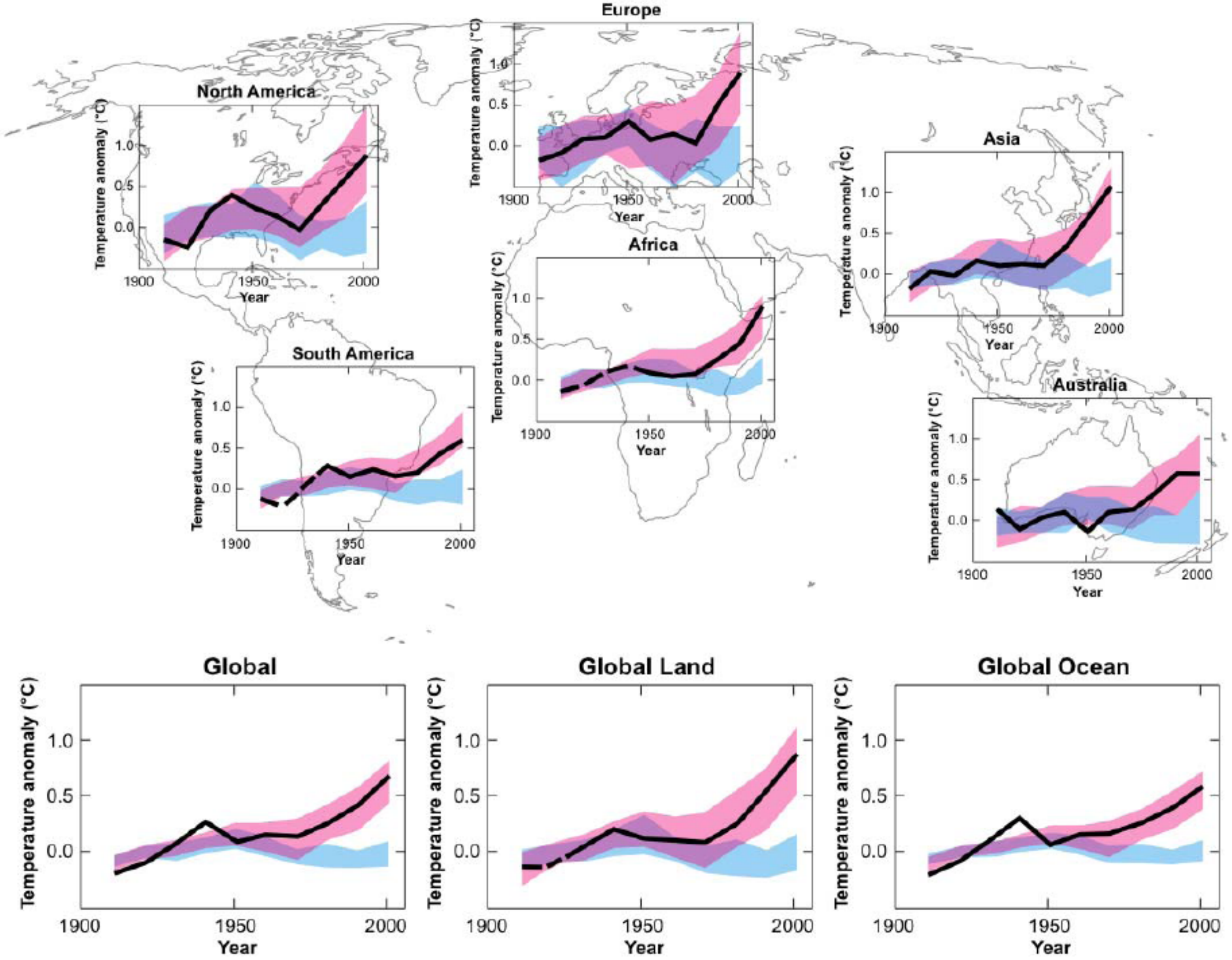
- Anthropogenic greenhouse gas increases *very likely* caused most of the observed warming since mid-20th century



Continental warming

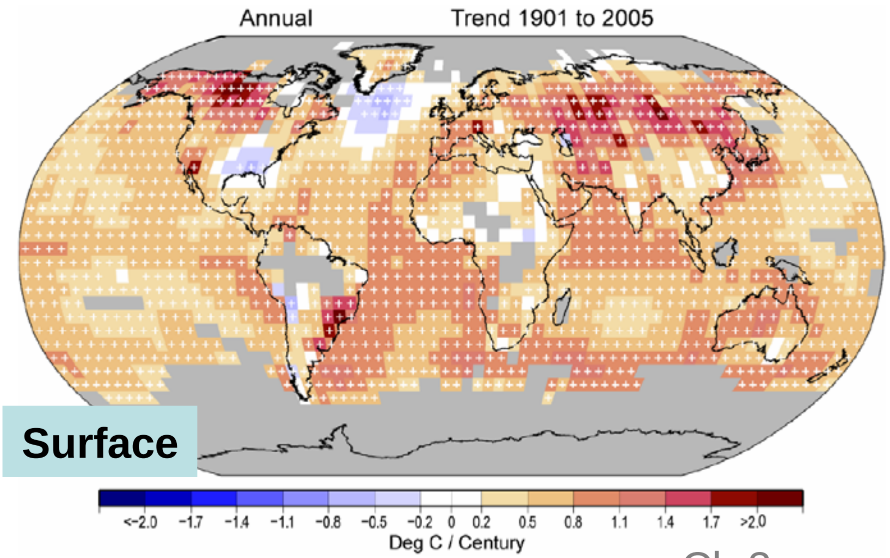
SPM-4

likely shows a significant anthropogenic contribution over the past 50 years

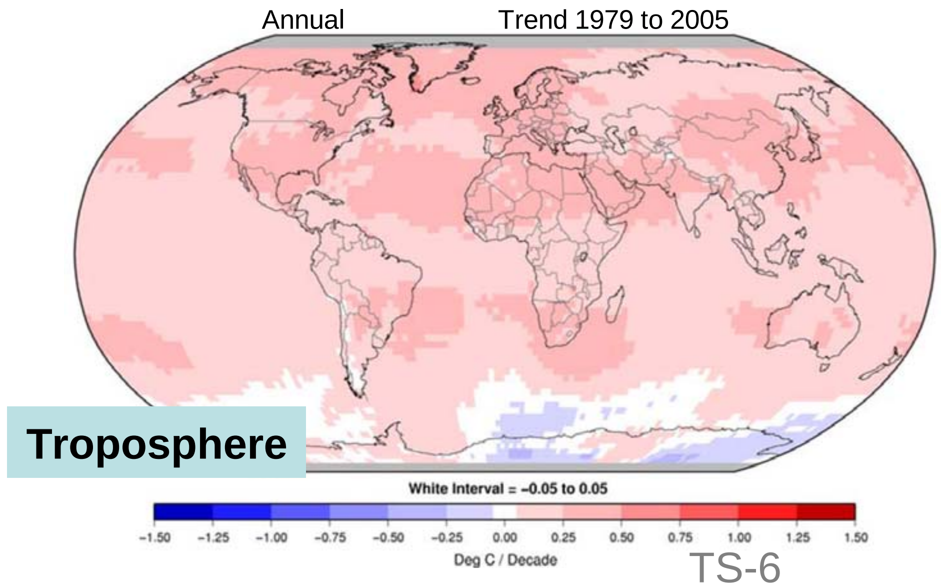


— Observations
All forcing
natural forcing

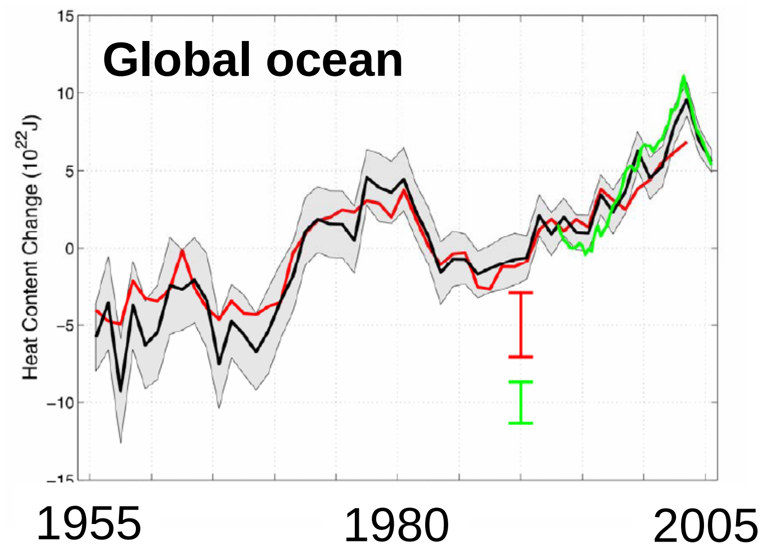
Observed widespread warming



Ch 3



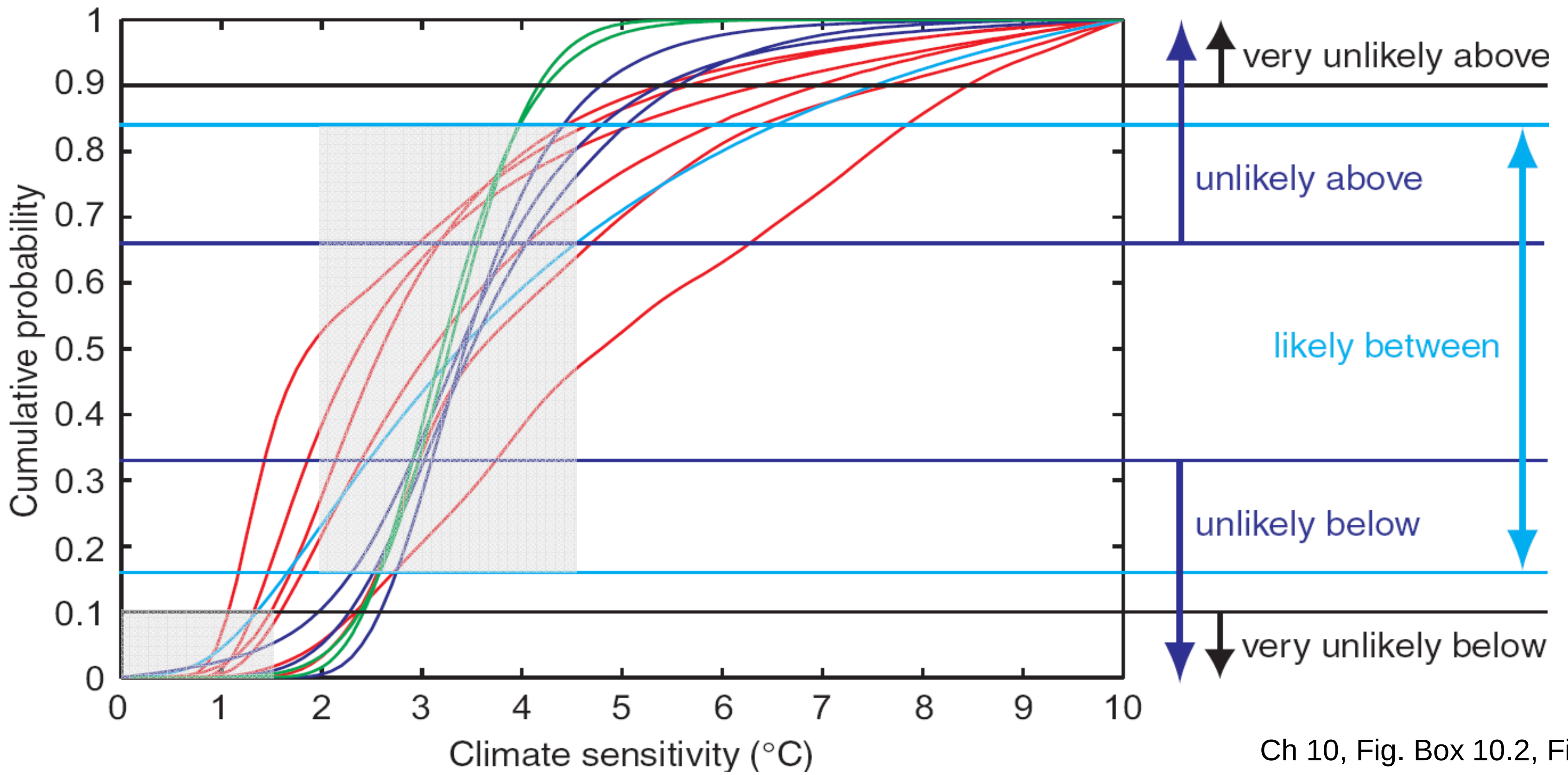
TS-6



TS-16

- extremely unlikely without external forcing
- very unlikely due to known natural causes alone

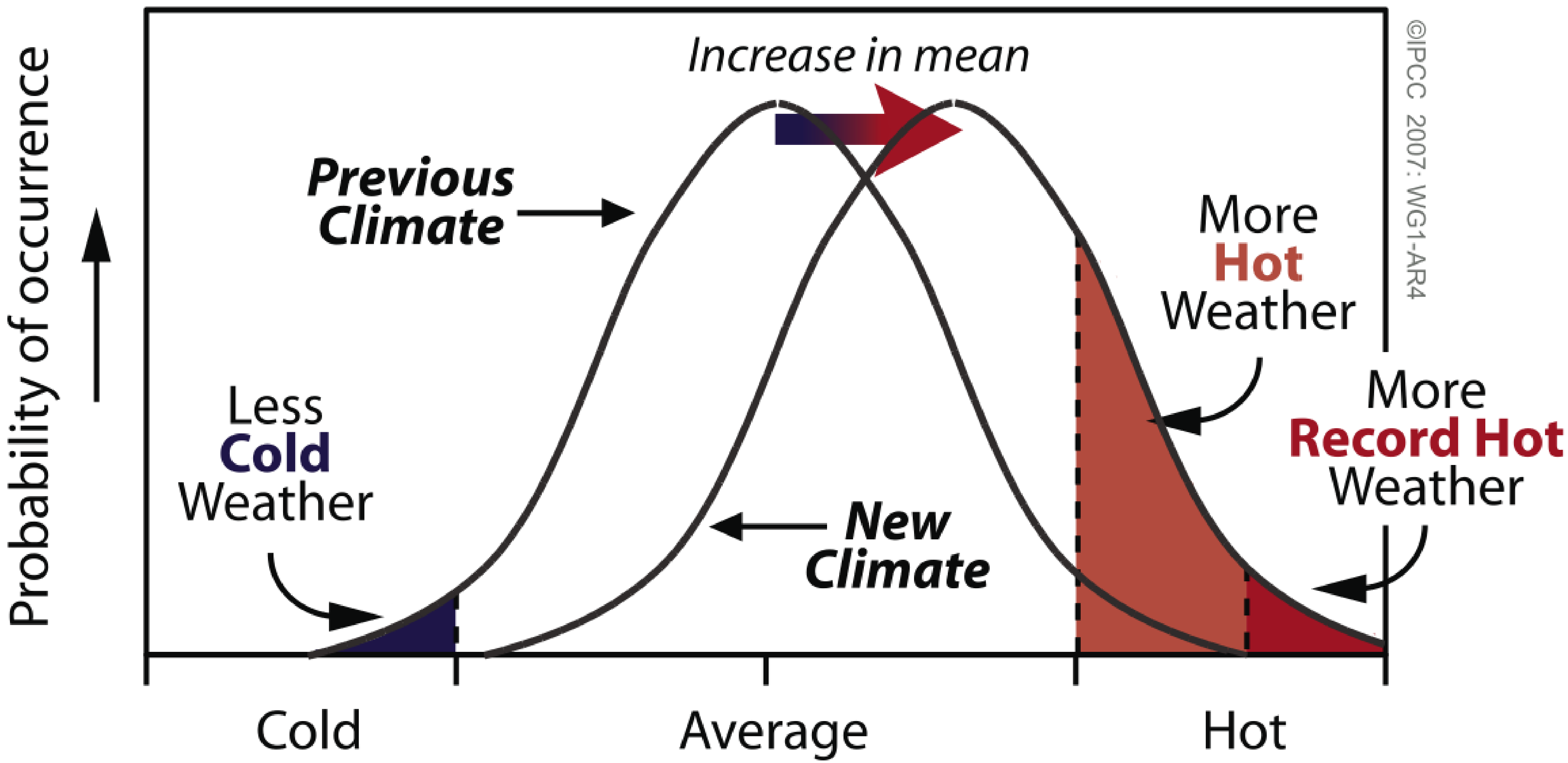
- Observed warming **extremely unlikely** due to unforced variability alone
- GHG's **very likely** caused most of the observed warming since mid-century; alone would **likely** have caused more warming than observed
- Human influence has **likely** caused significant warming on each continent (except Antarctic)
- Human influence has **likely** contributed to circulation change
- Role of external forcing over 20th century **consistent** with understanding of causes of change over past millennium
- Attribution remains difficult at smaller scales



Ch 10, Fig. Box 10.2, Fig. 2

ECS *very unlikely* below 1.5°C

ECS *likely* range is 2°C to 4.5°C

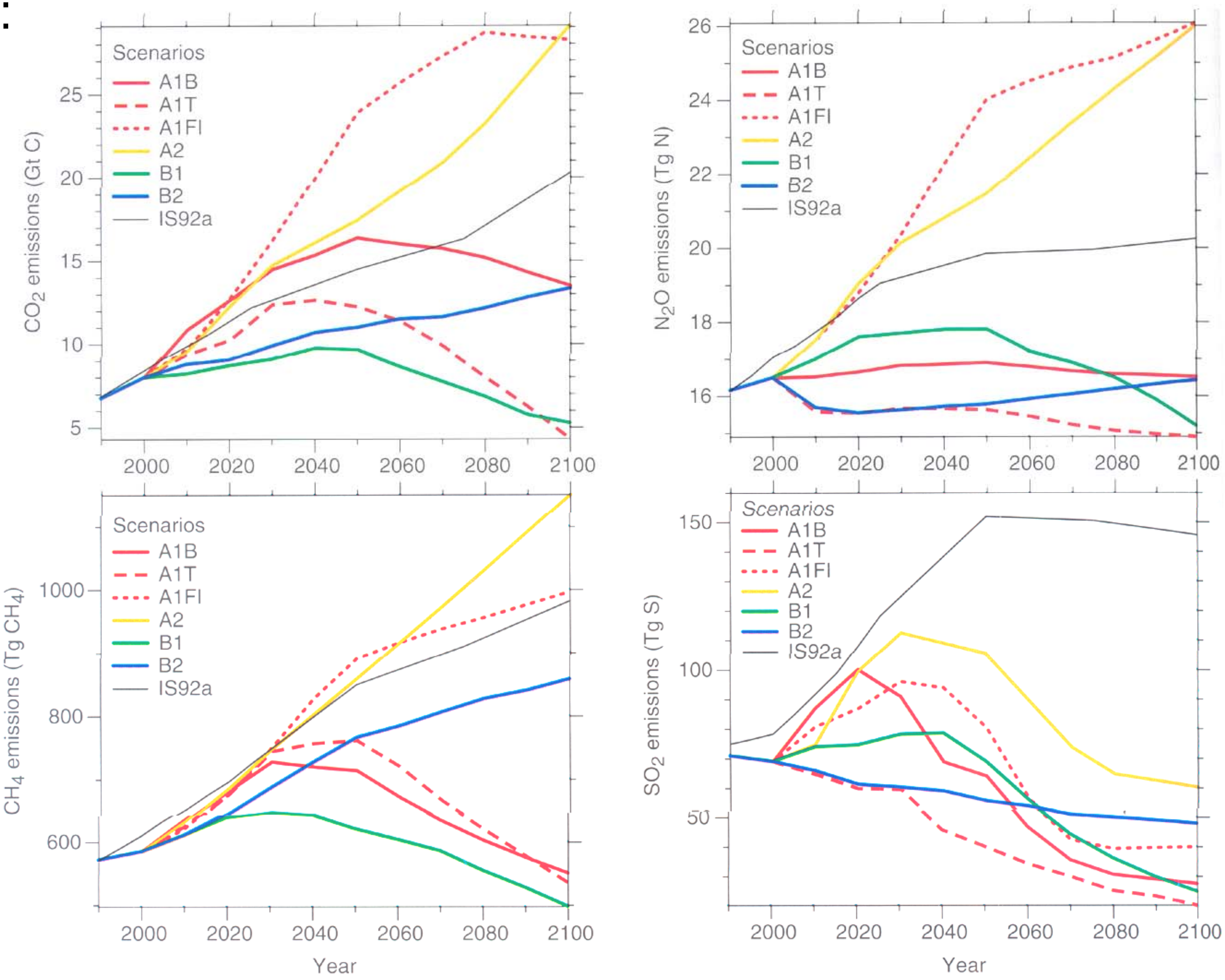

Increase in mean
Previous Climate
New Climate
Less Cold Weather
More Hot Weather
More Record Hot Weather
Probability of occurrence
Cold
Average
Hot
©IPCC 2007: WG1-AR4

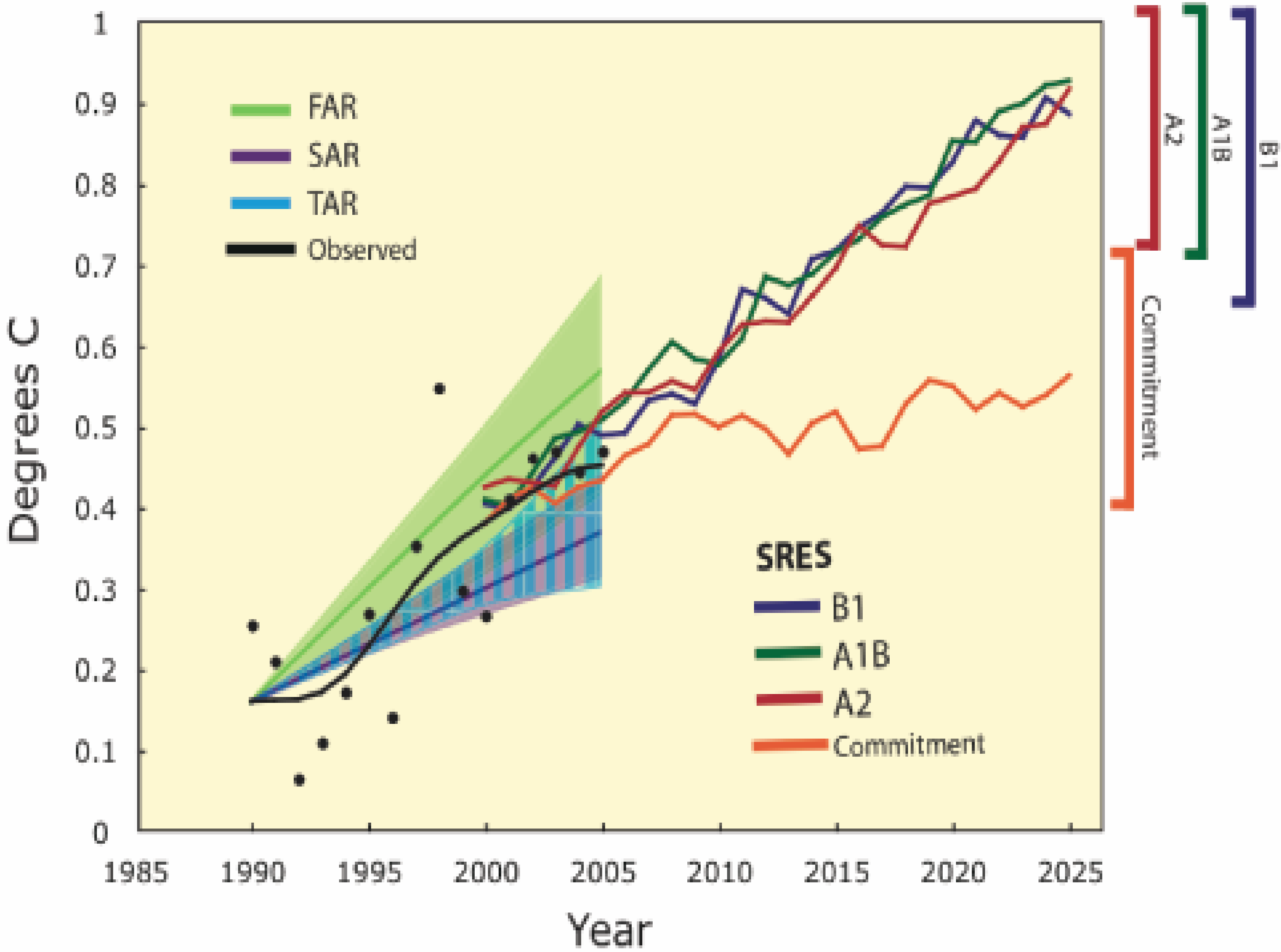
Climate projections

Key Points:

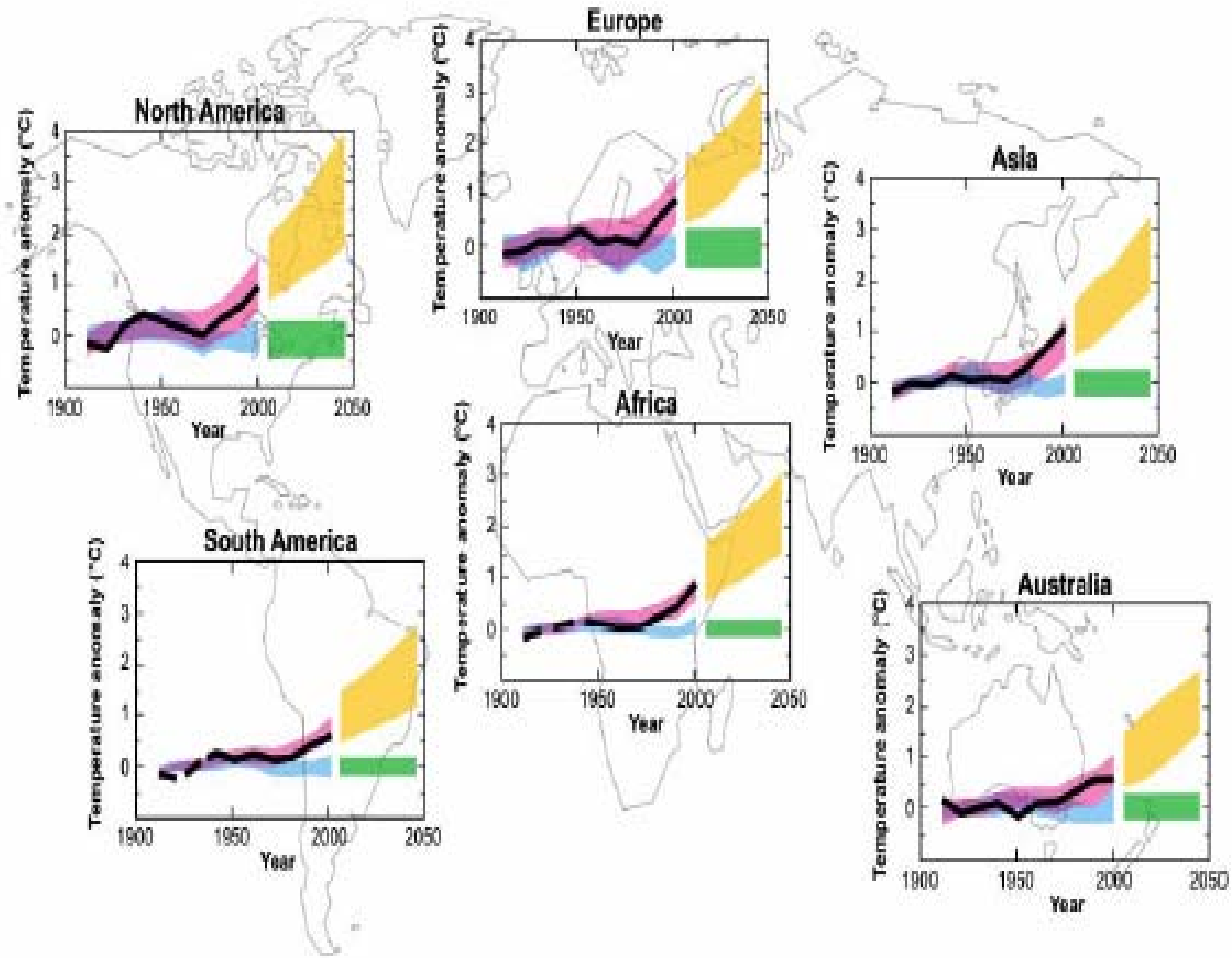
Most CO2 emission scenarios level off or decrease by 2100

Most sulfate emissions decrease by 2030

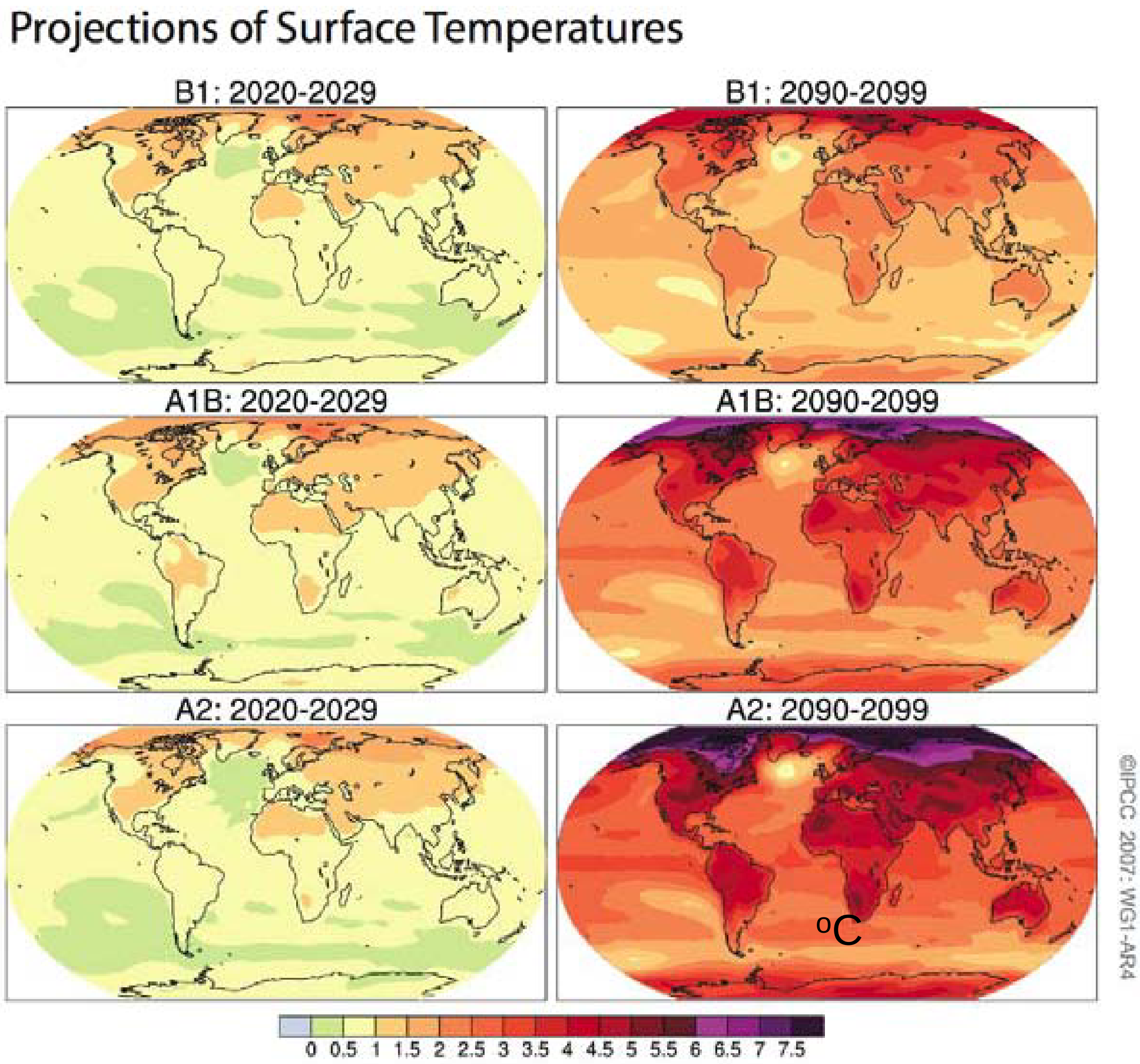




FAR
SAR
TAR
Observed
SRES
B1
A1B
A2
Commitment
Degrees C
Year
A2
A1B
B1
Commitment

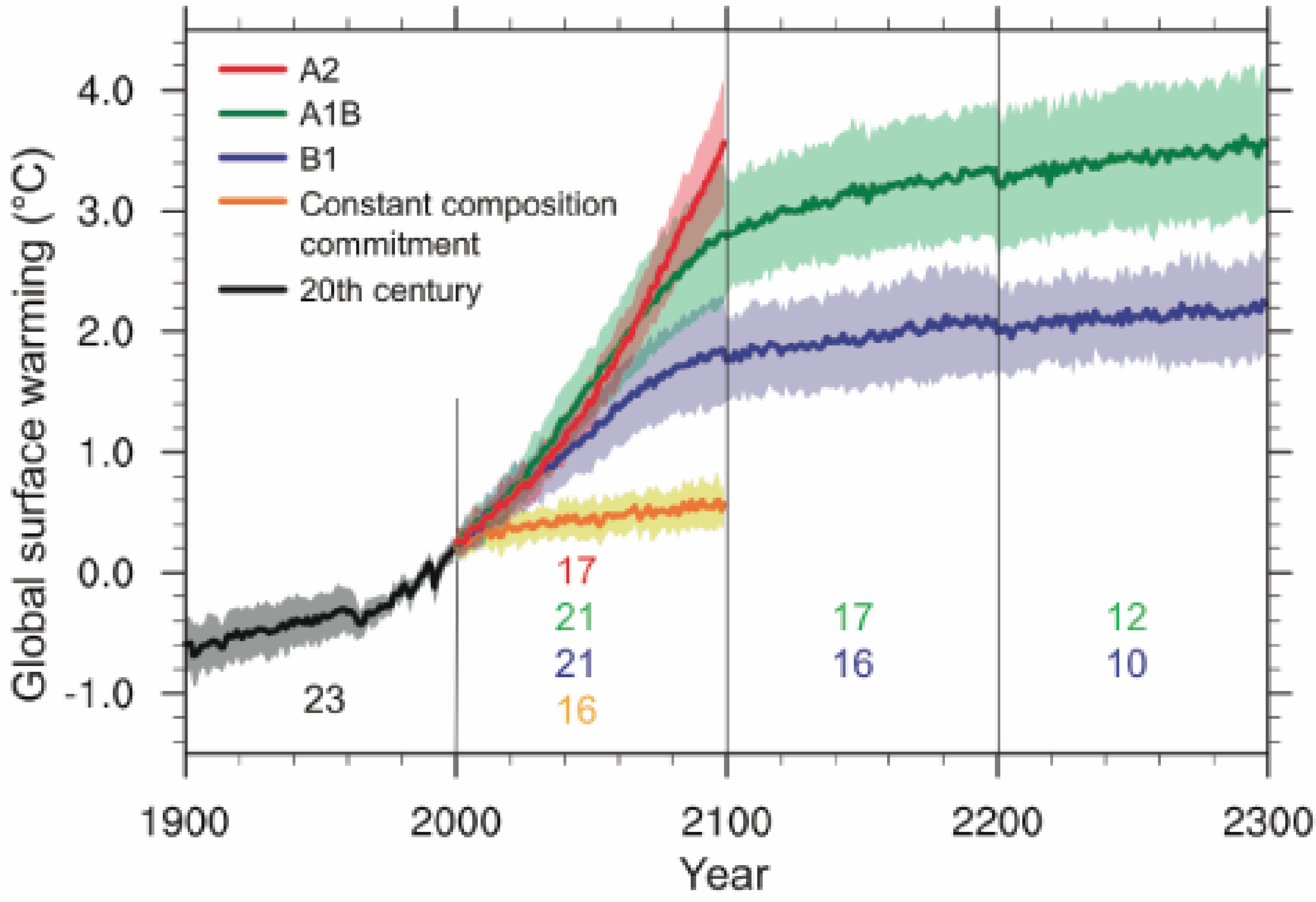


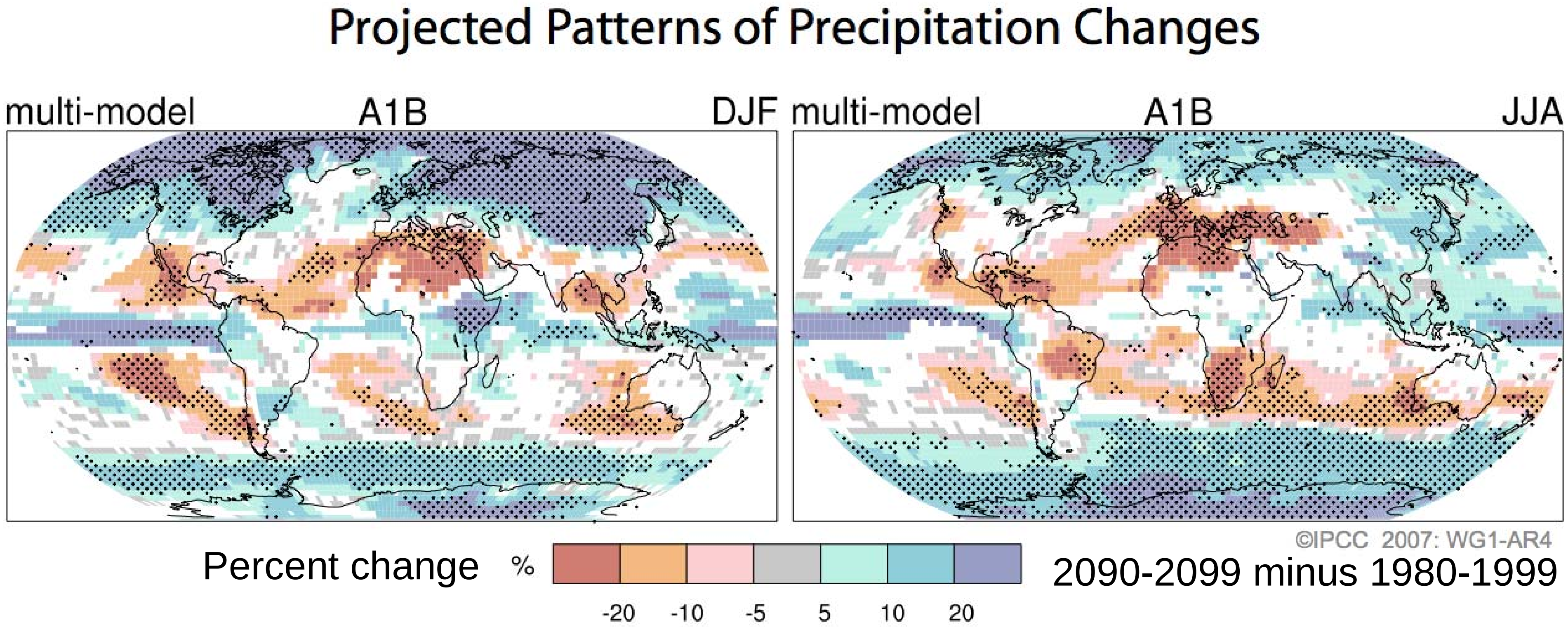
North America
Europe
Asia
Africa
South America
Australia
Temperature anomaly (°C)
Year
1900
1950
2000
2050
0
1
2
3
4



Key Points:

- Warming pattern similar in all panels, magnitude different.
- This pattern will be overlaid with natural variability.
- A1B warming middle of the road.
- Land areas tend to warm more than adjacent oceans.
- High latitudes tend to warm more than low latitudes.


A2
A1B
B1
Constant composition commitment
20th century
Global surface warming (°C)
4.0
3.0
2.0
1.0
0.0
-1.0
23
17
21
21
16
17
16
12
10
1900
2000
2100
2200
2300
Year



Key Points:

- Precipitation changes more uncertain than temperature changes.
- Models do not agree on *sign* of the change in many areas.
- High latitudes tend to receive more precipitation, especially in winter.
- The Mediterranean region tends to dry.

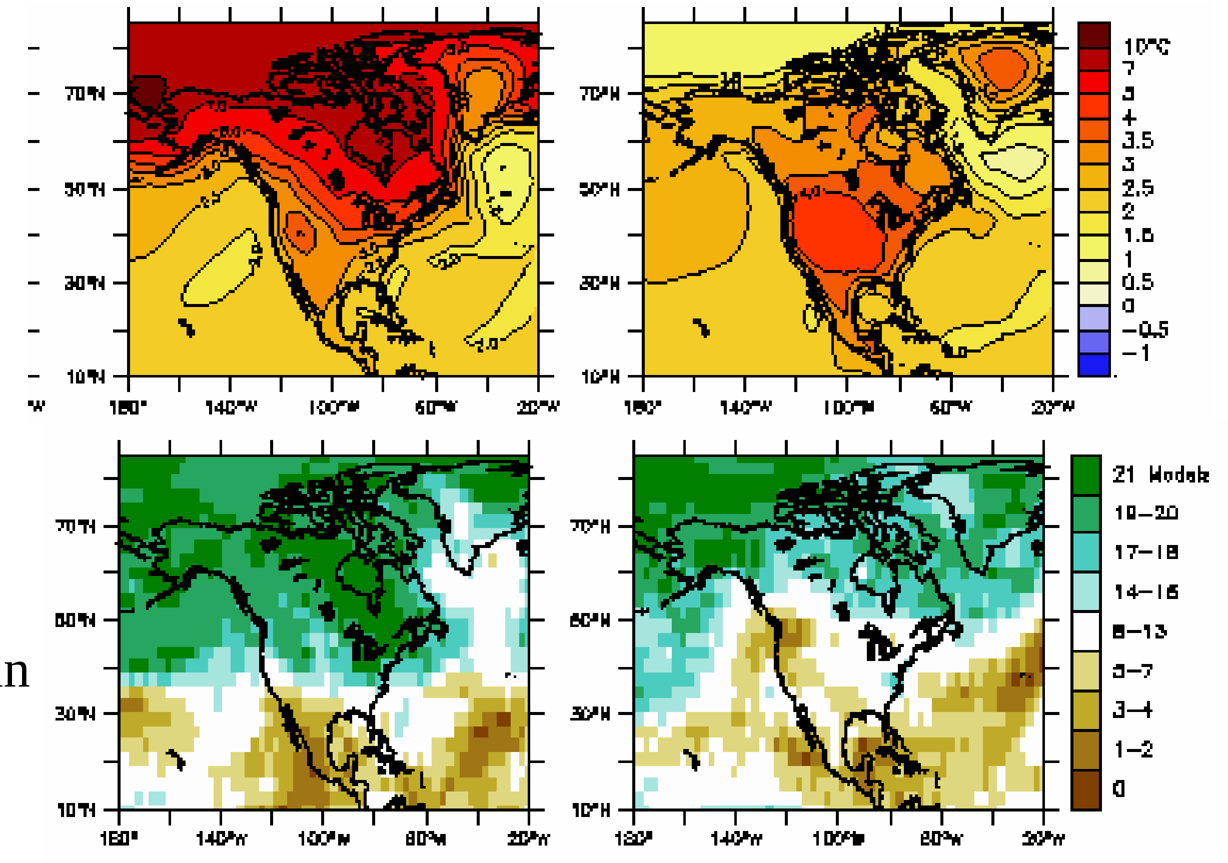
Projected changes in temperature and precipitation in 21st century

A1B emission scenario; averaged over ~20 models with spatial resolutions of ~ 200km

Winter Summer

Warming everywhere

Green => wetter
Brown=> drier
White => uncertain



Winter: wetter in Northeast – drier in Southwest –
Summer: Drying extends northward, with larger uncertainty

<u>Key summary points</u>

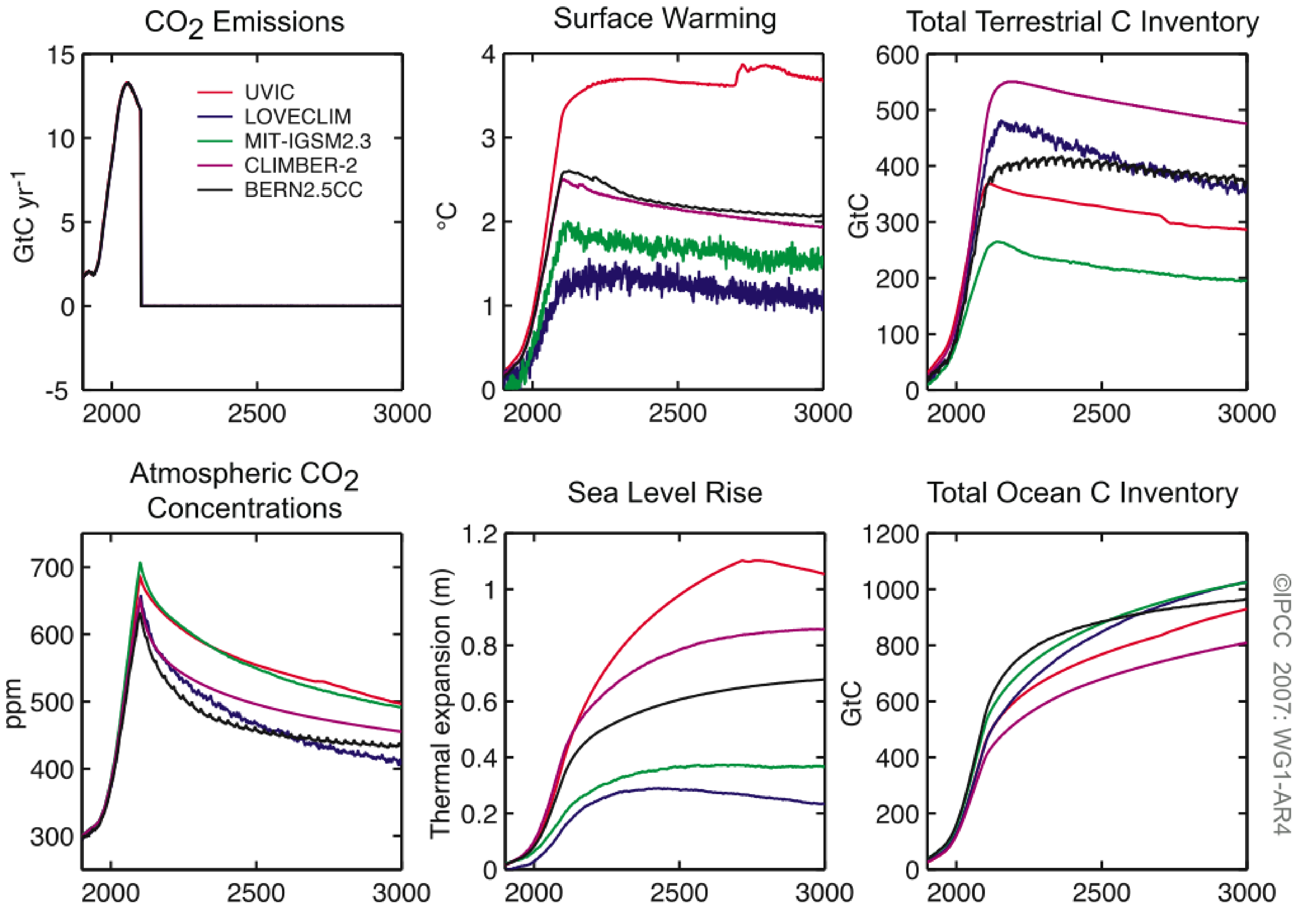
Unprecedented rise in long-lived anthropogenic greenhouse gases ➔ ***<u>“driver”</u>*** of climate change.

Warming of the climate system is ***<u>unequivocal</u>***. Warming unusual in at least the last 1300 years.

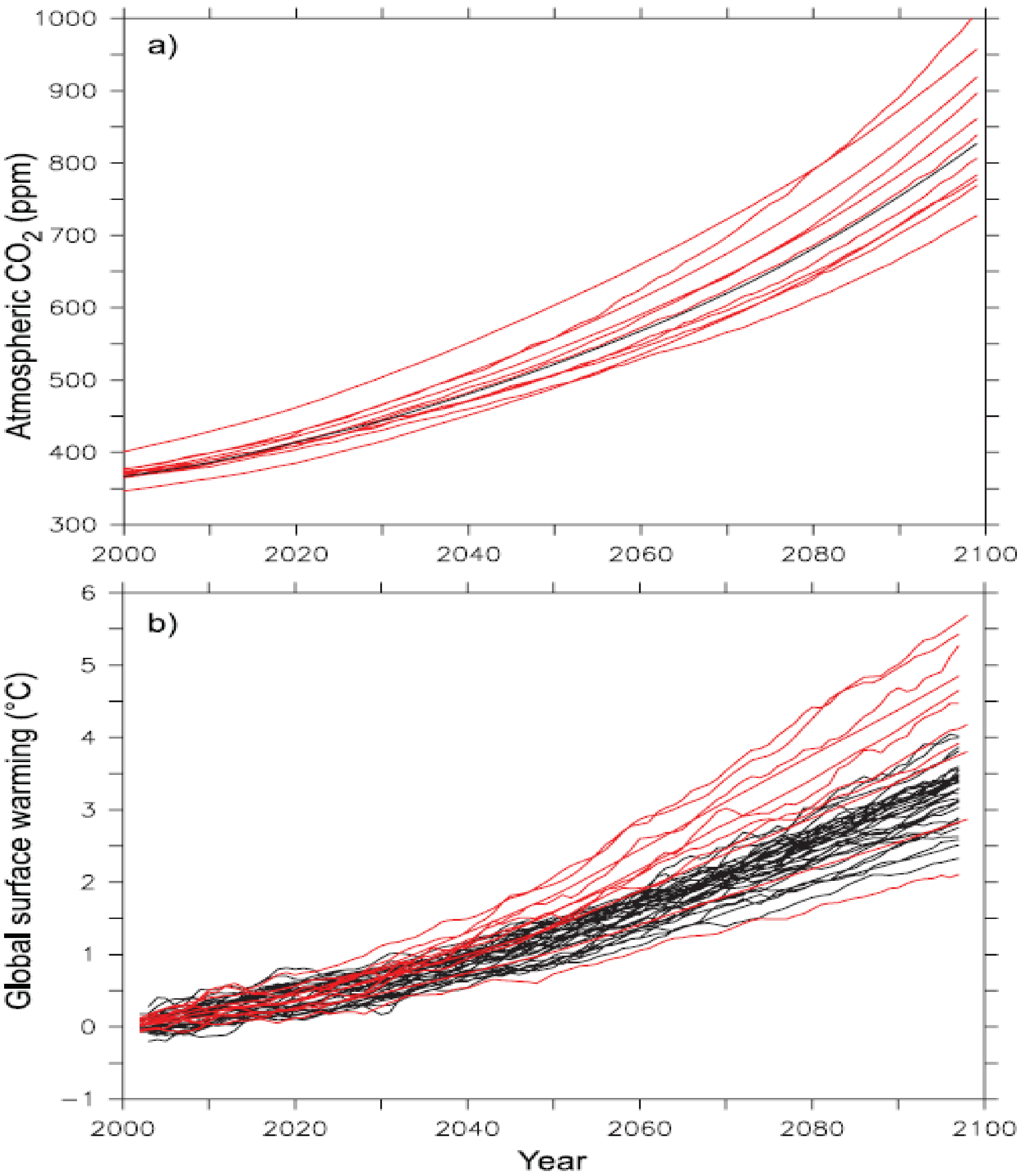
Most of the observed increase in global-mean temperatures since mid-20th century is ***<u>very likely</u>*** due to the anthropogenic greenhouse gas increases

Climate projected to warm further;
increased greenhouse gases ➔ ***<u>very likely</u>*** larger changes than observed in 20th century.

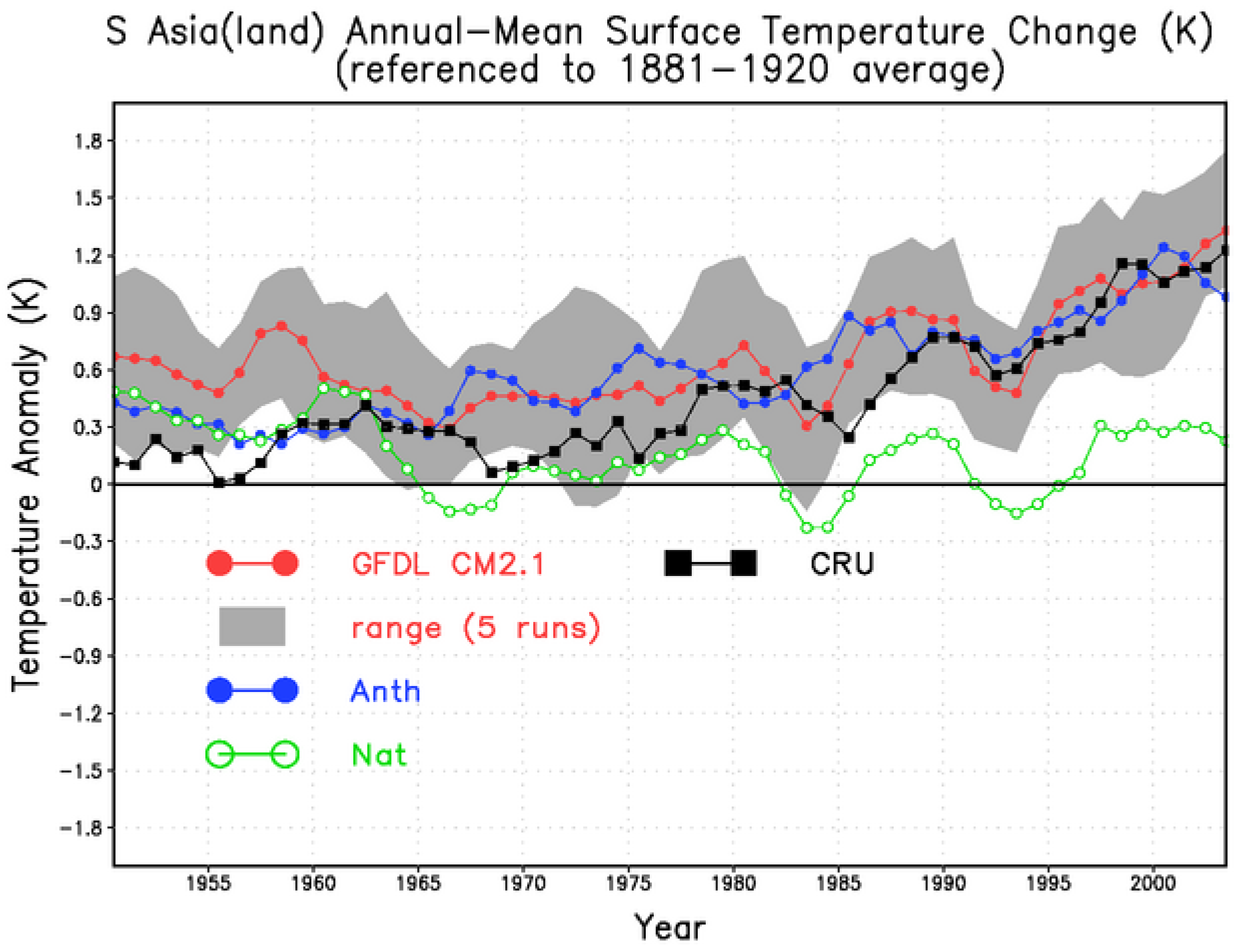
Figure TS.31



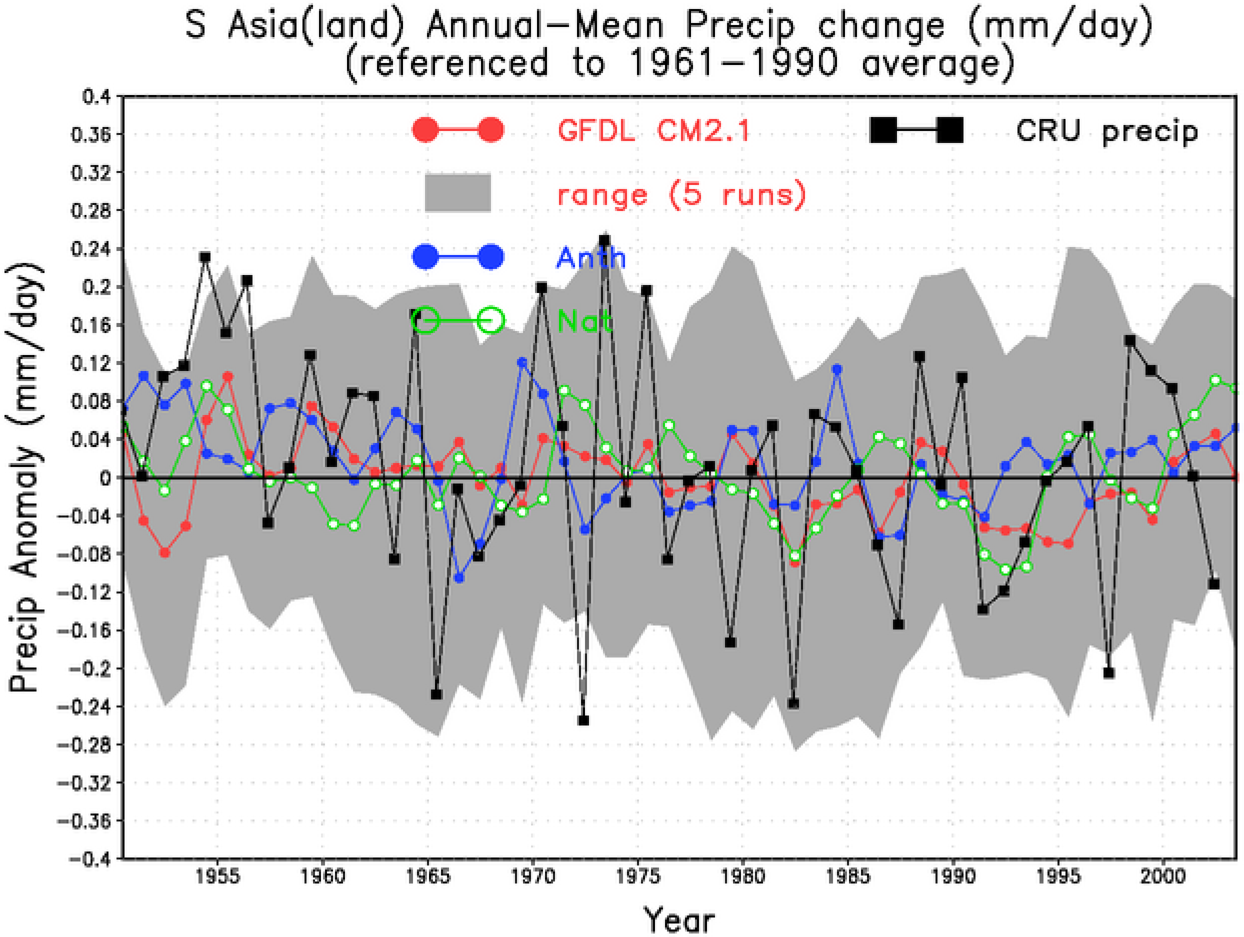
CO_2 Emissions
GtC yr^{-1}
15
10
5
0
-5
2000
2500
3000
UVIC
LOVECLIM
MIT-IGSM2.3
CLIMBER-2
BERN2.5CC
Surface Warming
°C
4
3
2
1
0
Total Terrestrial C Inventory
GtC
600
500
400
300
200
100
Atmospheric CO_2 Concentrations
ppm
700
600
500
400
300
Sea Level Rise
Thermal expansion (m)
1.2
1
0.8
0.6
0.4
0.2
Total Ocean C Inventory
1200
1000
800
©IPCC 2007: WG1-AR4



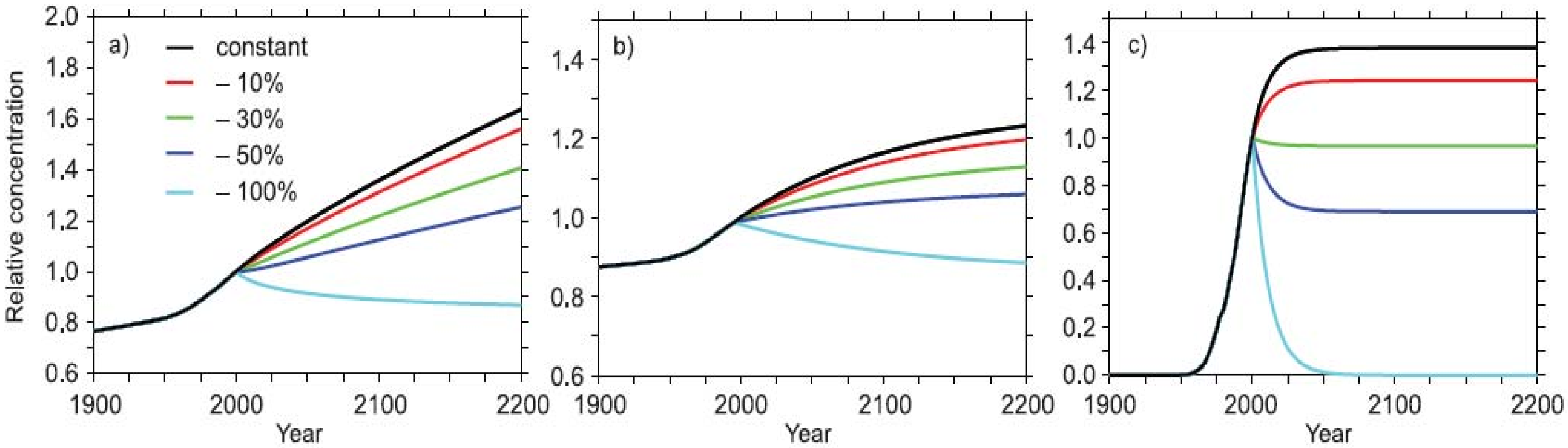
IPCC AR4 Chapter 10



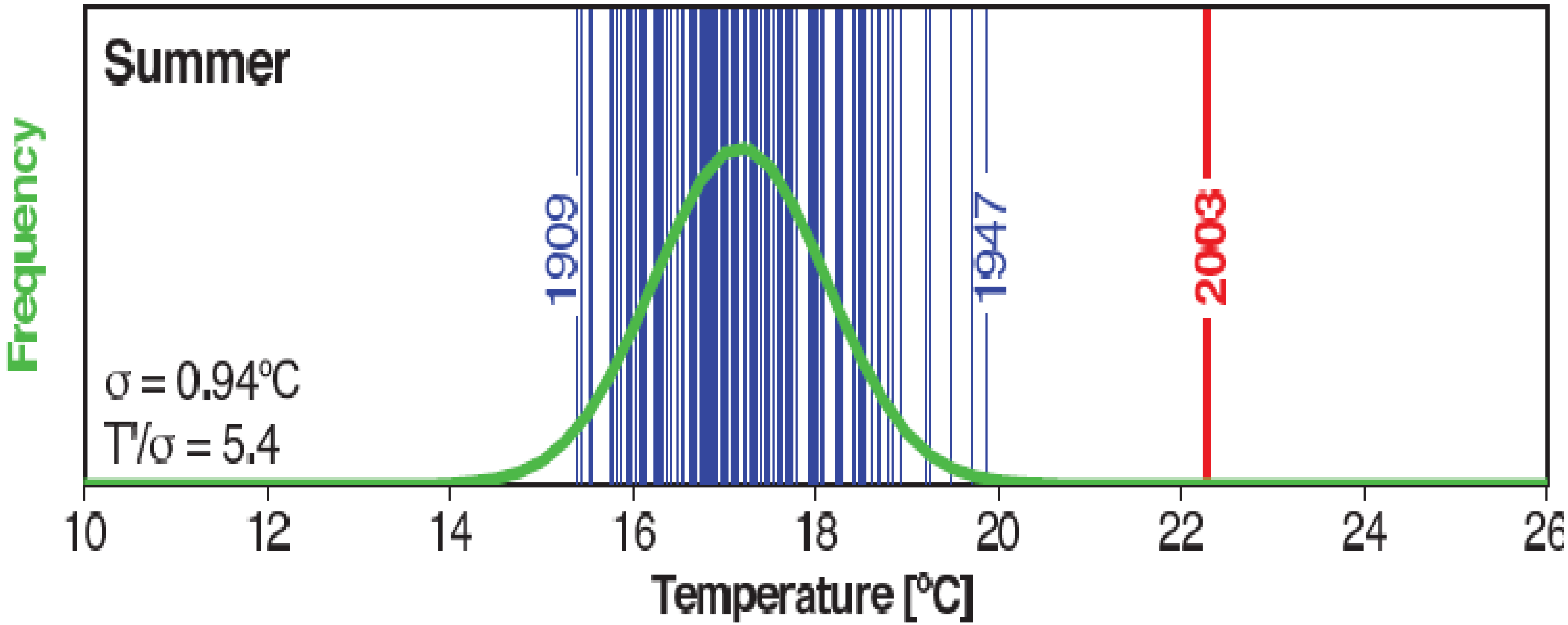
S Asia(land) Annual-Mean Surface Temperature Change (K)
(referenced to 1881-1920 average)
Temperature Anomaly (K)
1.8
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year
GFDL CM2.1
CRU
range (5 runs)
Anth
Nat



S Asia(land) Annual-Mean Precip change (mm/day)
(referenced to 1961-1990 average)
GFDL CM2.1
CRU precip
range (5 runs)
Anth
Nat
Precip Anomaly (mm/day)
0.4
0.36
0.32
0.28
0.24
0.2
0.16
0.12
0.08
0.04
0
-0.04
-0.08
-0.12
-0.16
-0.2
-0.24
-0.28
-0.32
-0.36
-0.4
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Year

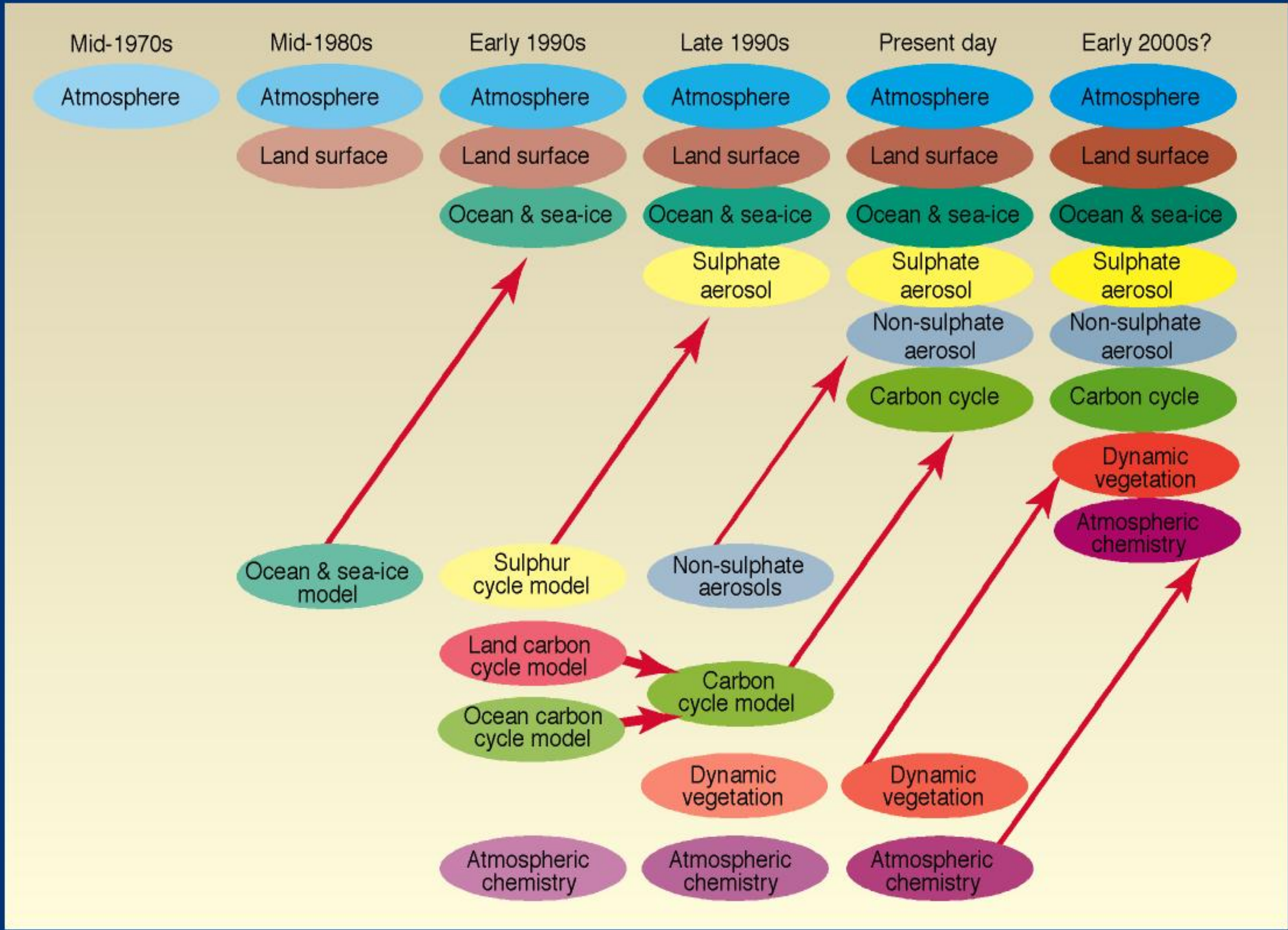


a)
b)
c)
constant
– 10%
– 30%
– 50%
– 100%
Relative concentration
Year
Year
Year
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.0
0.2
0.4
1900
2000
2100
2200



Summer
Frequency
σ = 0.94°C
T'/σ = 5.4
1909
1947
2003
10
12
14
16
18
20
22
24
26
Temperature [°C]

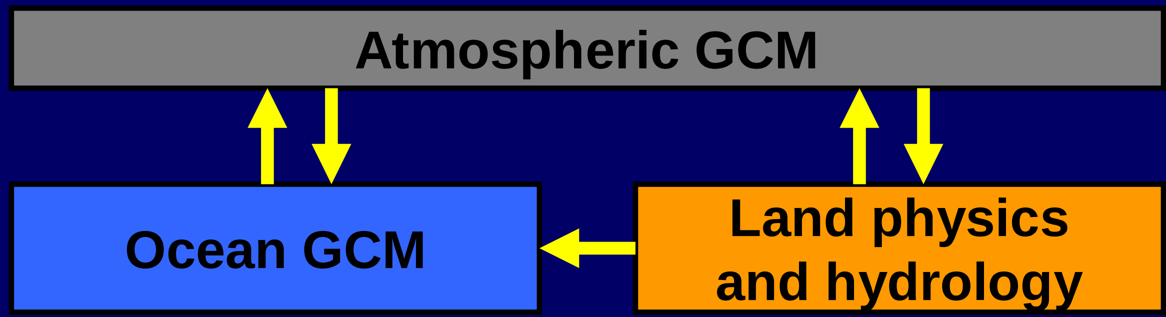
The development of climate models, past, present and future



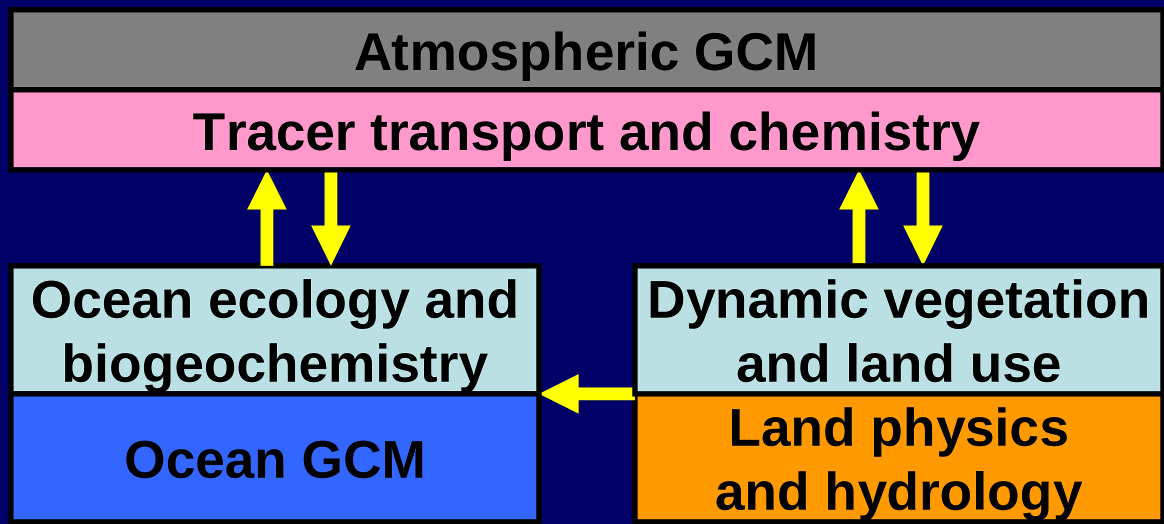
WG1 - TS BOX 3
FIGURE 1

What is an Earth System Model?

Climate Model



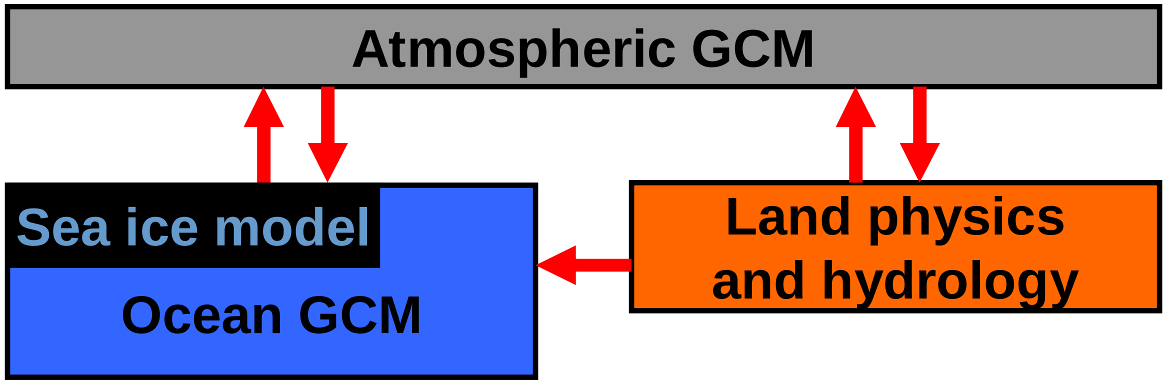
Earth System Model



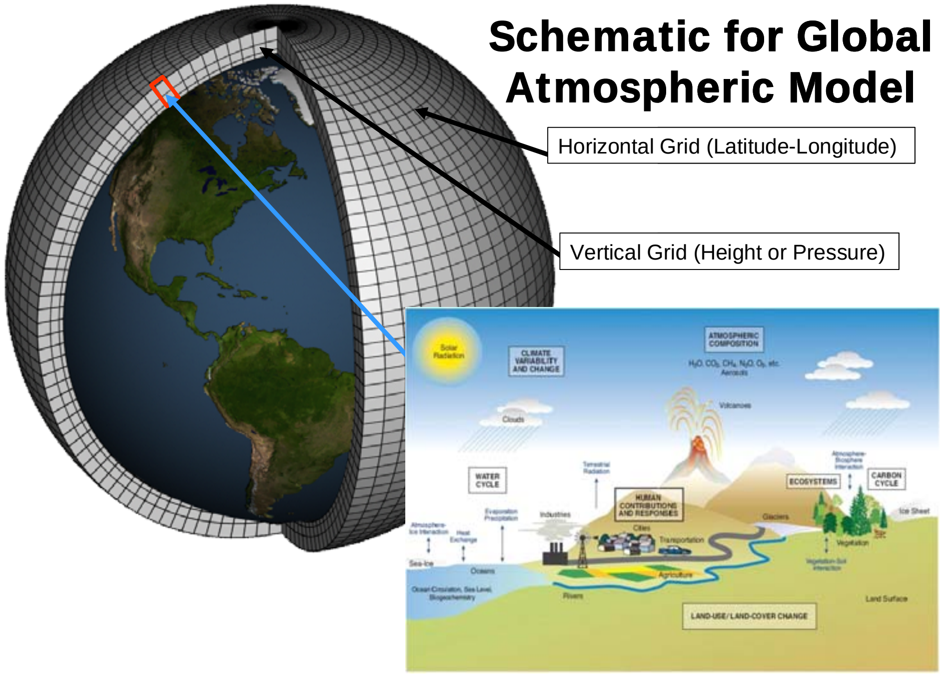
from John Dunne, GFDL

Use of State-of-the-Art Global Climate Models

The four physical climate components



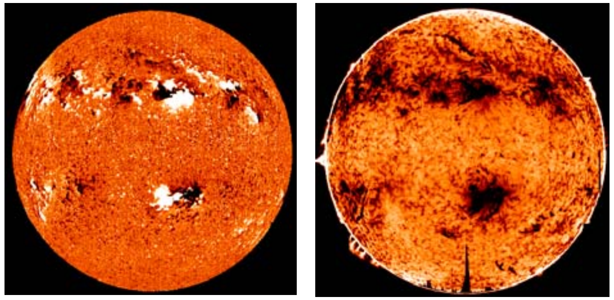
Current models have more than 300,000 atmospheric grid cells and a couple million ocean grids cells. And there’s thousands more for the land and sea ice model components.



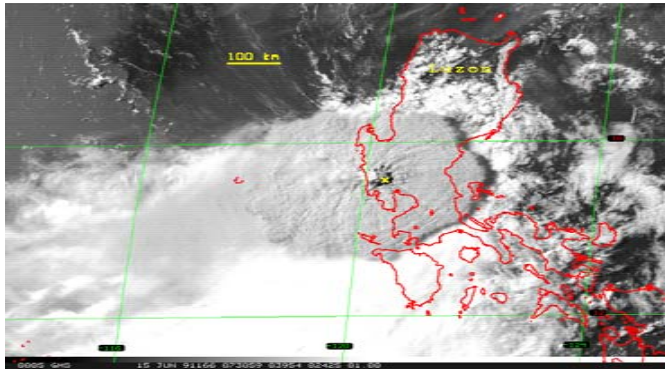
Climate Change 101: What factors can influence climate?

Natural mechanisms

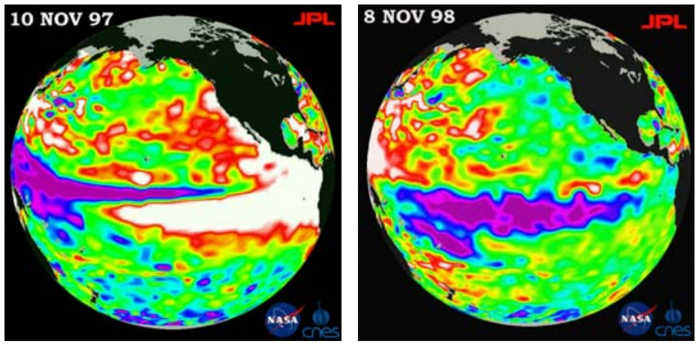
- **Changes in the Sun**



- **Changes in the amount of volcanic dust in the atmosphere**



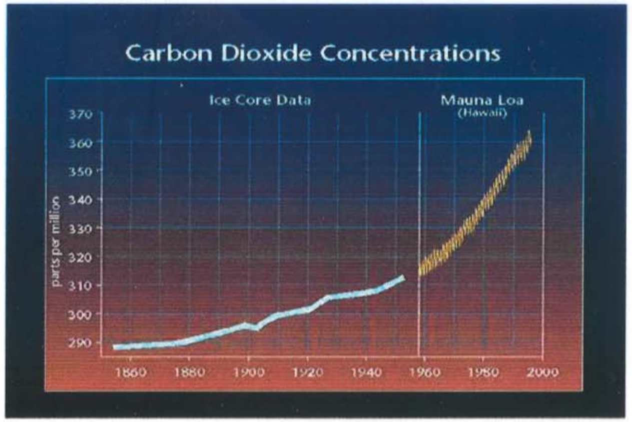
- **Internal variability of the coupled atmosphere–ocean system**



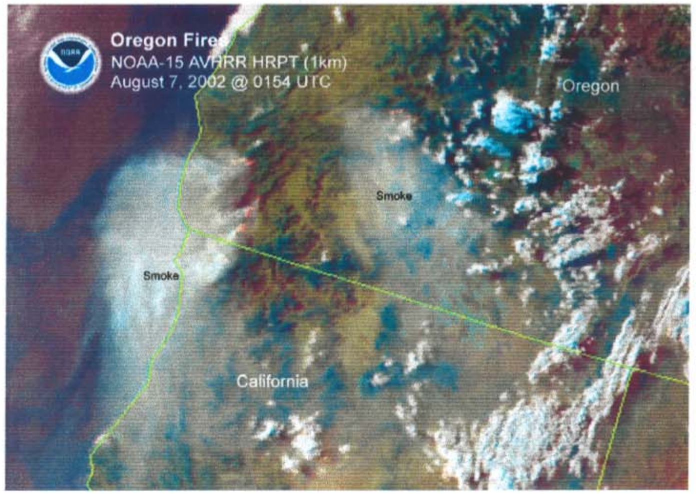
Climate Change 101: What factors can influence climate?

Non-natural mechanisms

- Changes in atmospheric concentrations of greenhouse gases

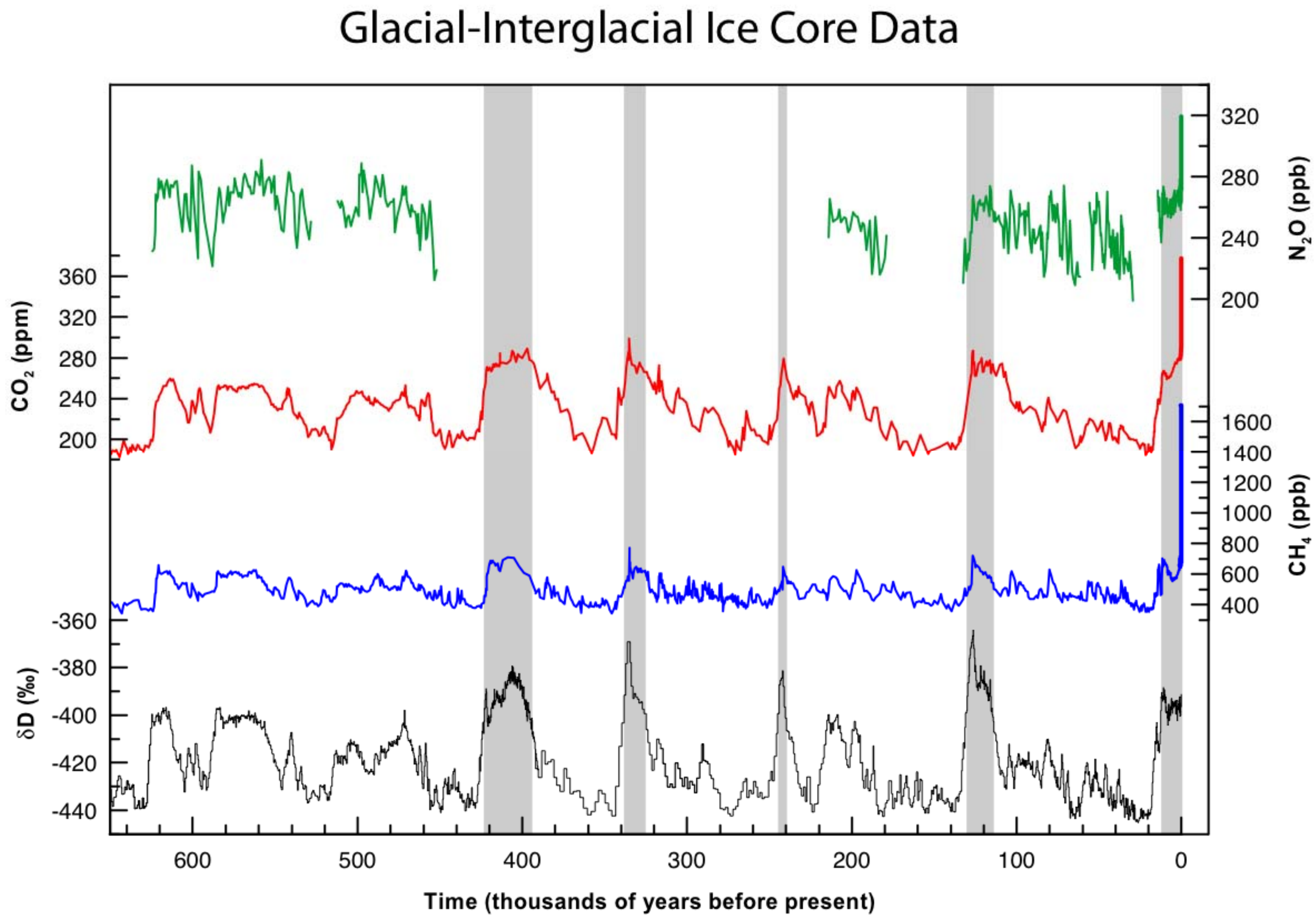


- Changes in aerosol particles from burning fossil fuels and biomass



- Changes in the reflectivity (albedo) of the Earth's surface

PCMDI



Change in carbon dioxide, methane and nitrous oxide concentrations over last 650,000 years, from Antarctic ice cores, and recent atmospheric measurements. Two temperature proxy timeseries are also shown.
[Figure 6.3]

Points

Long-term record, esp. CO_2, CH_4

N_2O record not as continuous

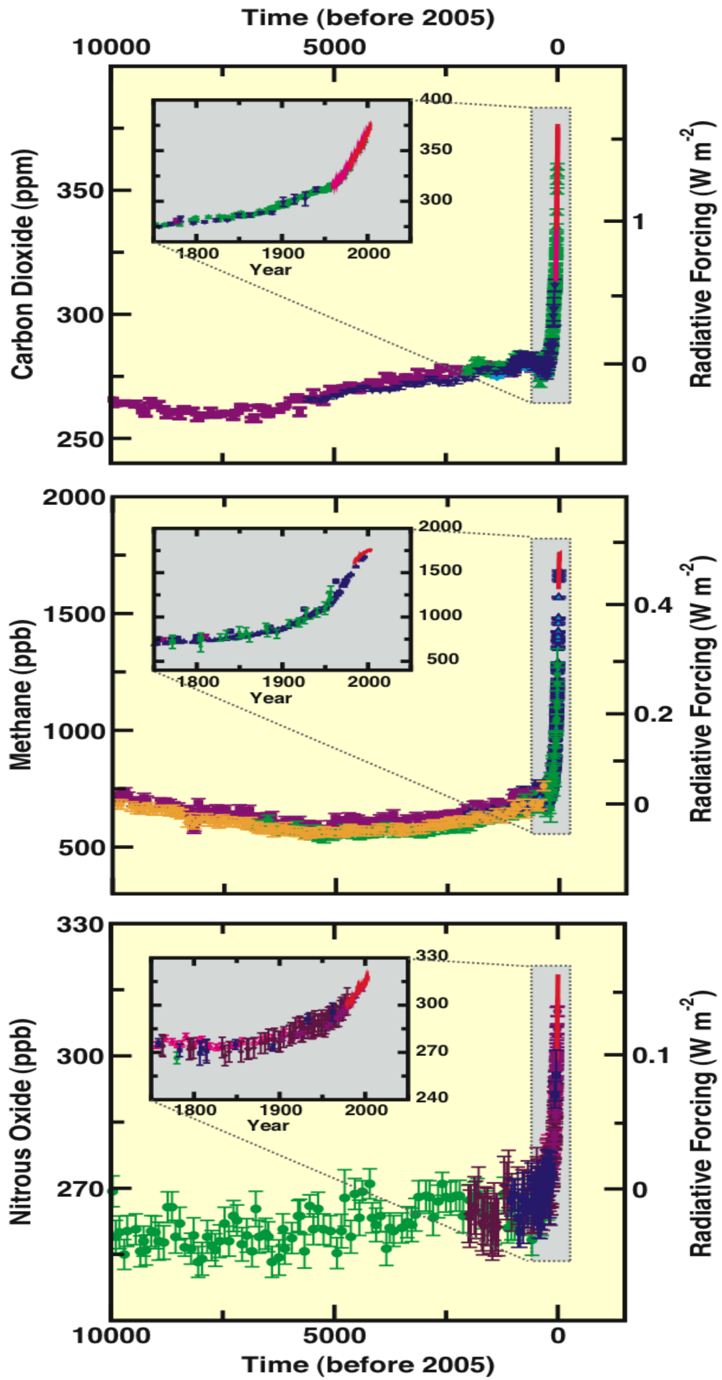
Long-lived greenhouse gas records approximately equivalent to global mixing ratio values

Temperature record is more local to Antarctica

CO_2

CH_4

N_2O



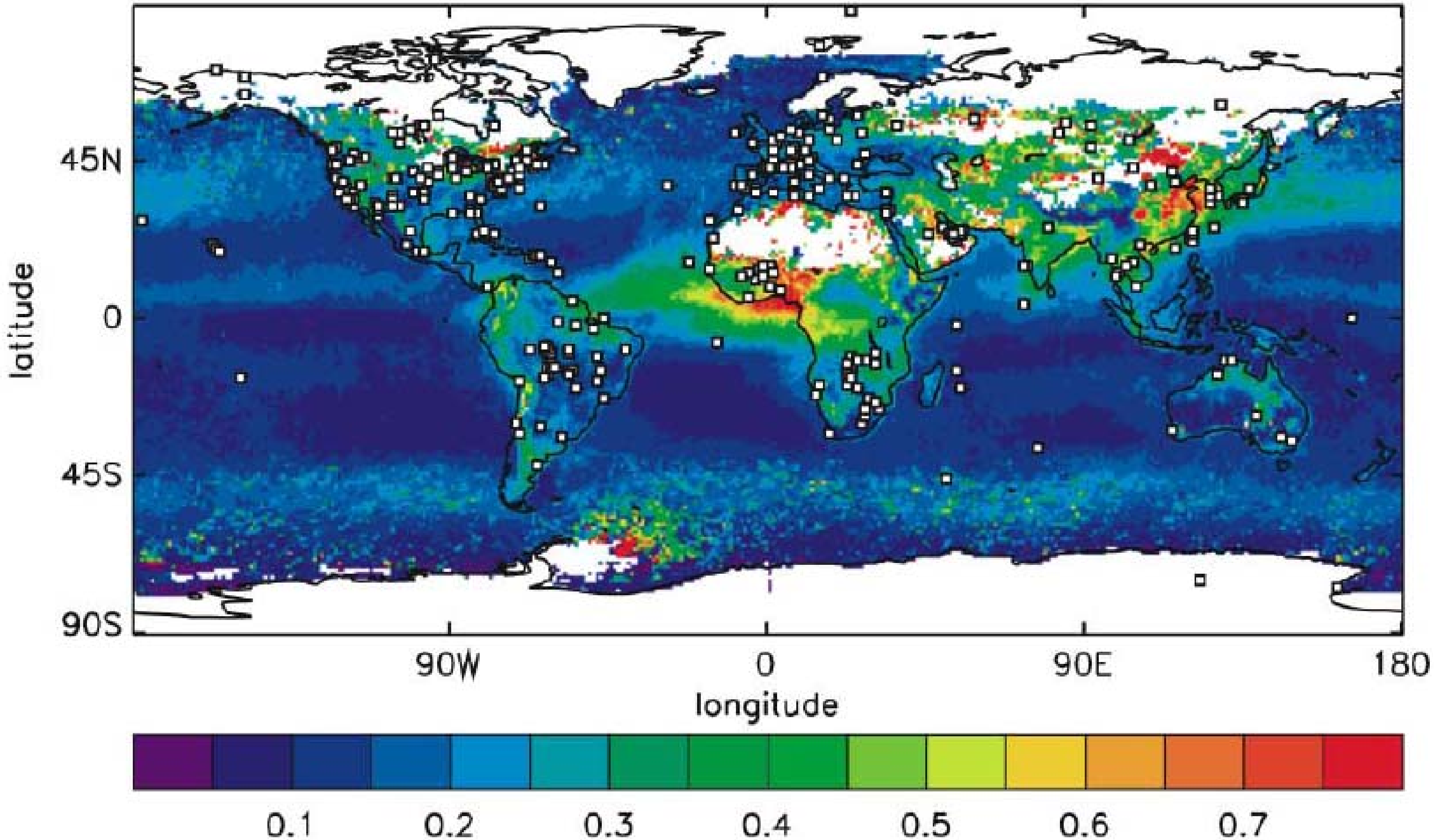
Change in carbon dioxide, methane and nitrous oxide concentrations and radiative forcing over last 10,000 years, and (inset) from 1750-2005 [Figure SPM-1].

Increase since 1750 is unprecedented in record

CO_2 radiative forcing has increased by 20% in last 10 years

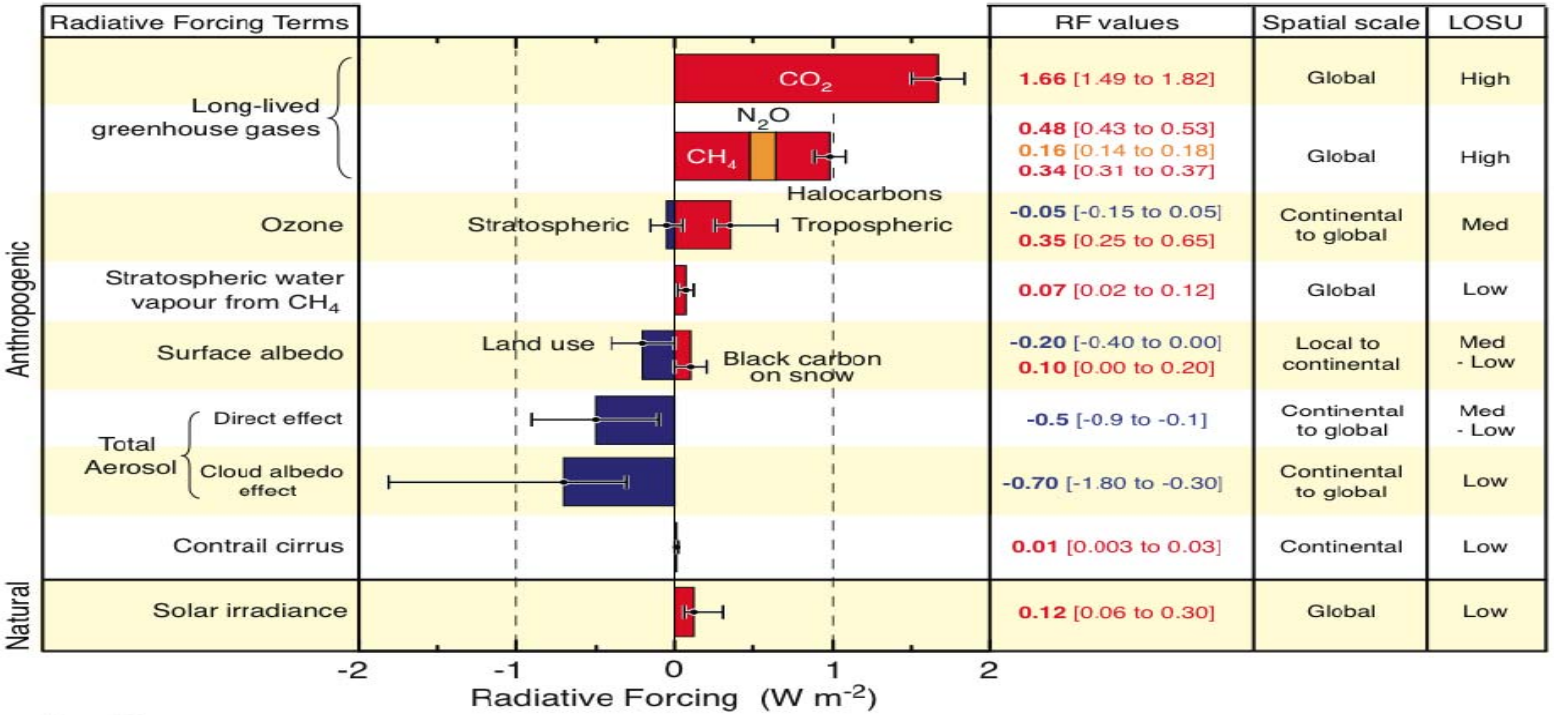
Total aerosol optical depth (natural+anthropogenic components) at mid-visible wavelength, from satellite instruments, and complemented by two different kinds of ground-based measurements [Figure TS-4 (top)]

January to March, 2001

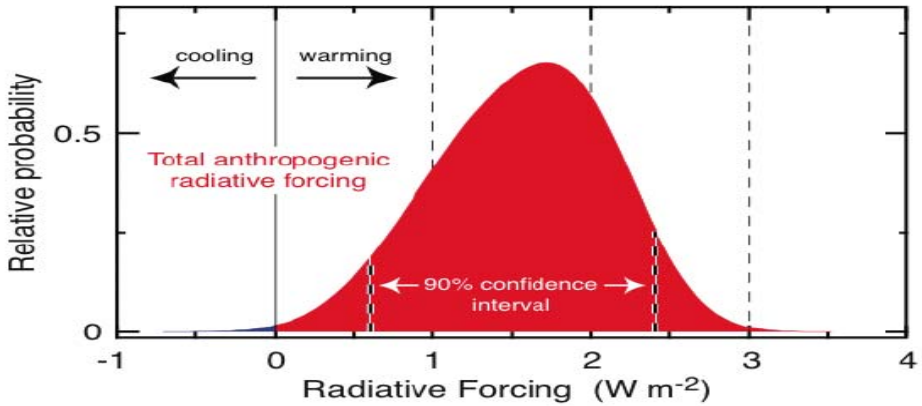


- **Observations reveal the presence and provide quantitative aspects.**
- **Aerosol transport-forcing models better tested and constrained.**

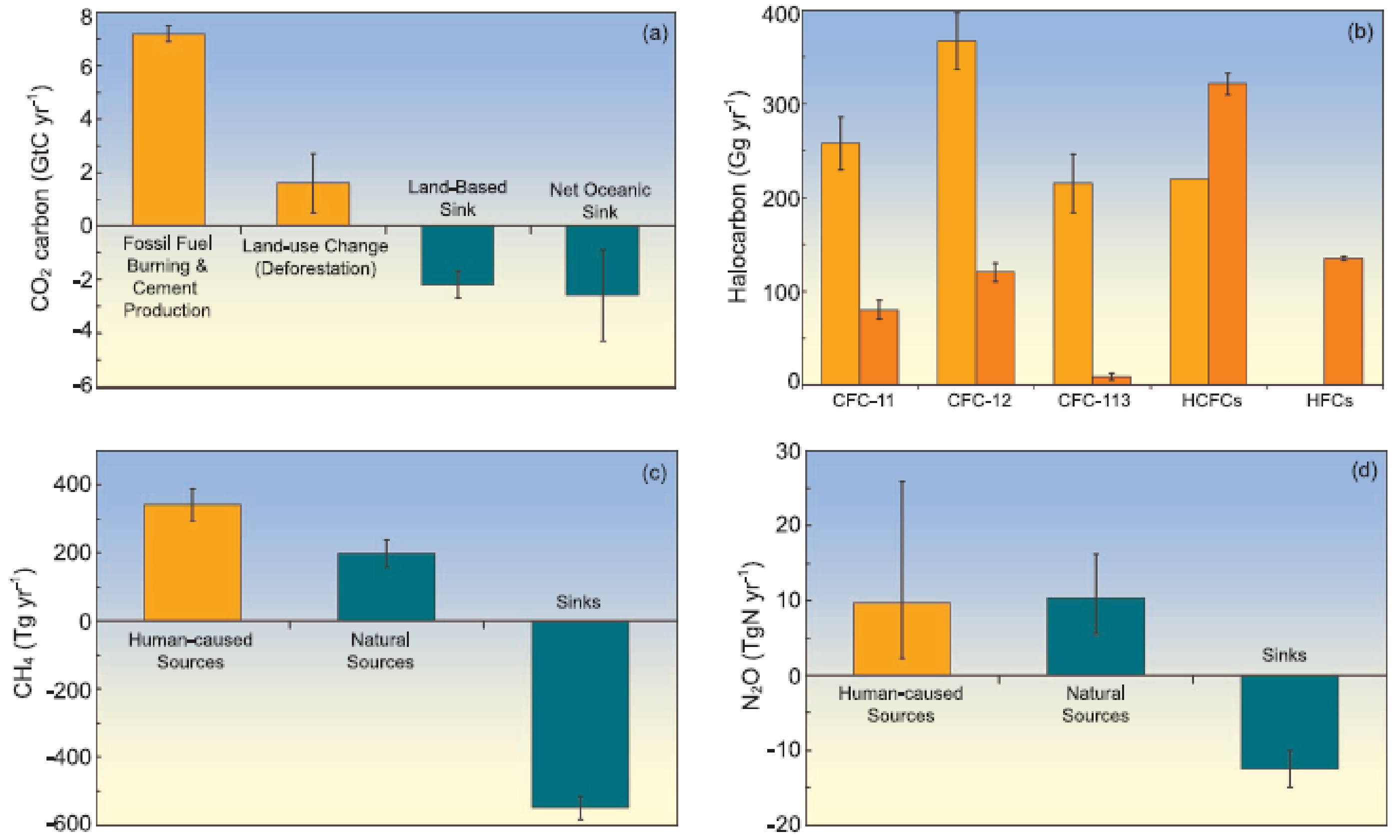
➔ More improved estimate of the Aerosol Direct Radiative Forcing.

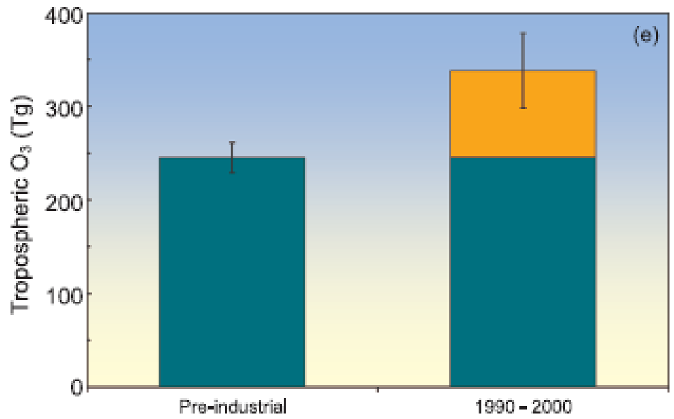


Panel A.

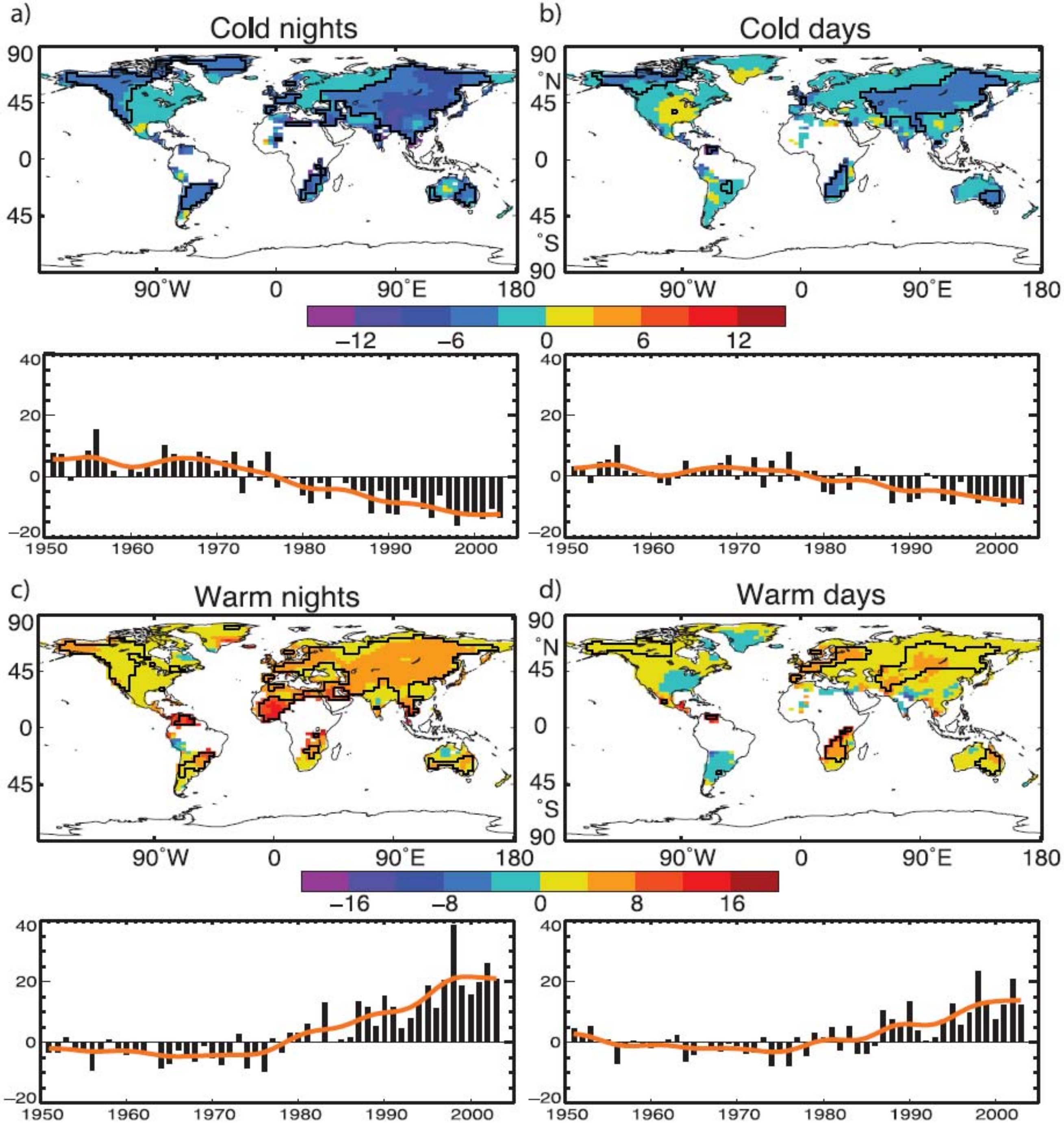


Agents of Climate Forcing

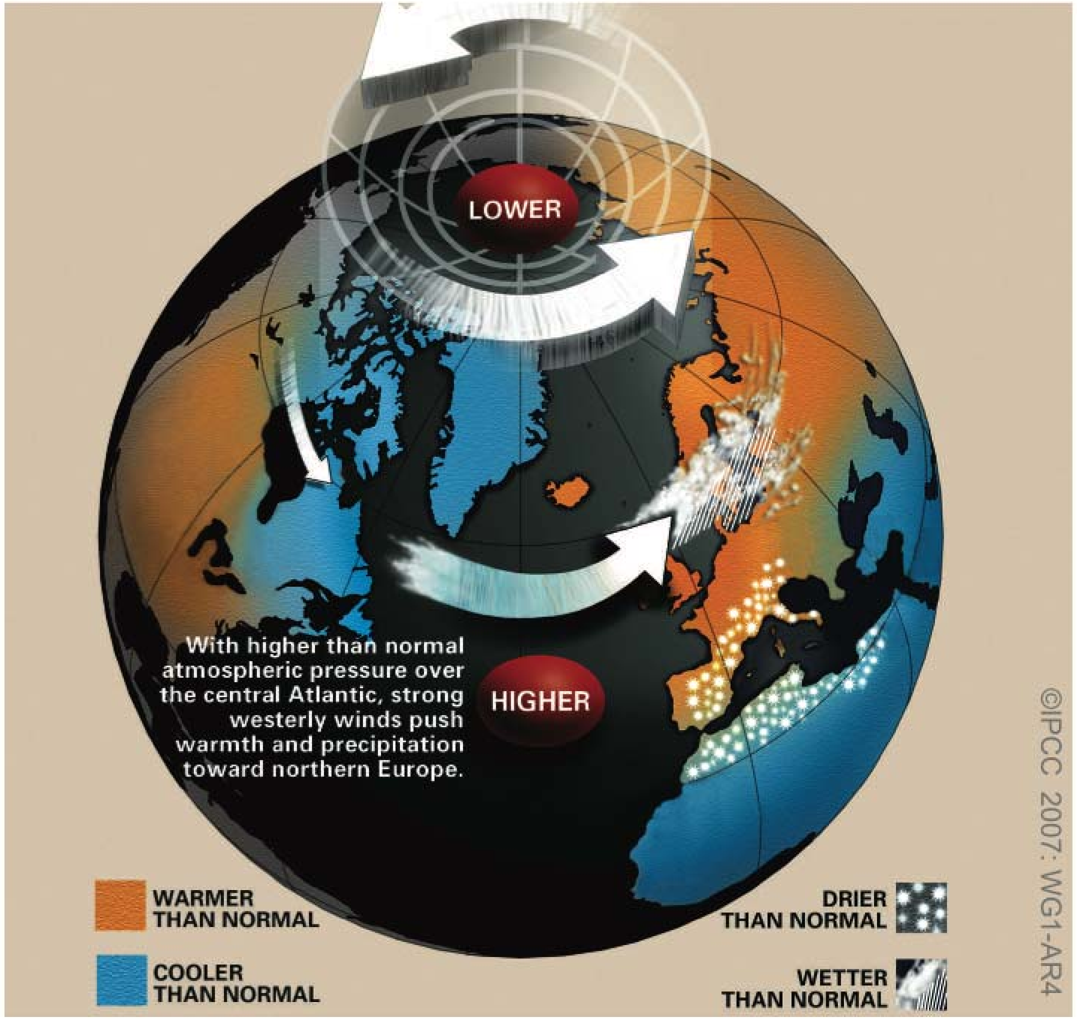




FAQ 7.1, Figure 1. *Breakdown of contributions to the changes in atmospheric greenhouse gas concentrations, based on information detailed in Chapters 4 and 7. In (a) through (d), human-caused sources are shown in orange, while natural sources and sinks are shown in teal. In (e), human-caused tropospheric ozone amounts are in orange while natural ozone amounts are in green. (a) Sources and sinks of CO_2 (GtC). Each year CO_2 is released to the atmosphere from human activities including fossil fuel combustion and land use change. Only 57 to 60% of the CO_2 emitted from human activity remains in the atmosphere. Some is dissolved into the oceans and some is incorporated into plants as they*



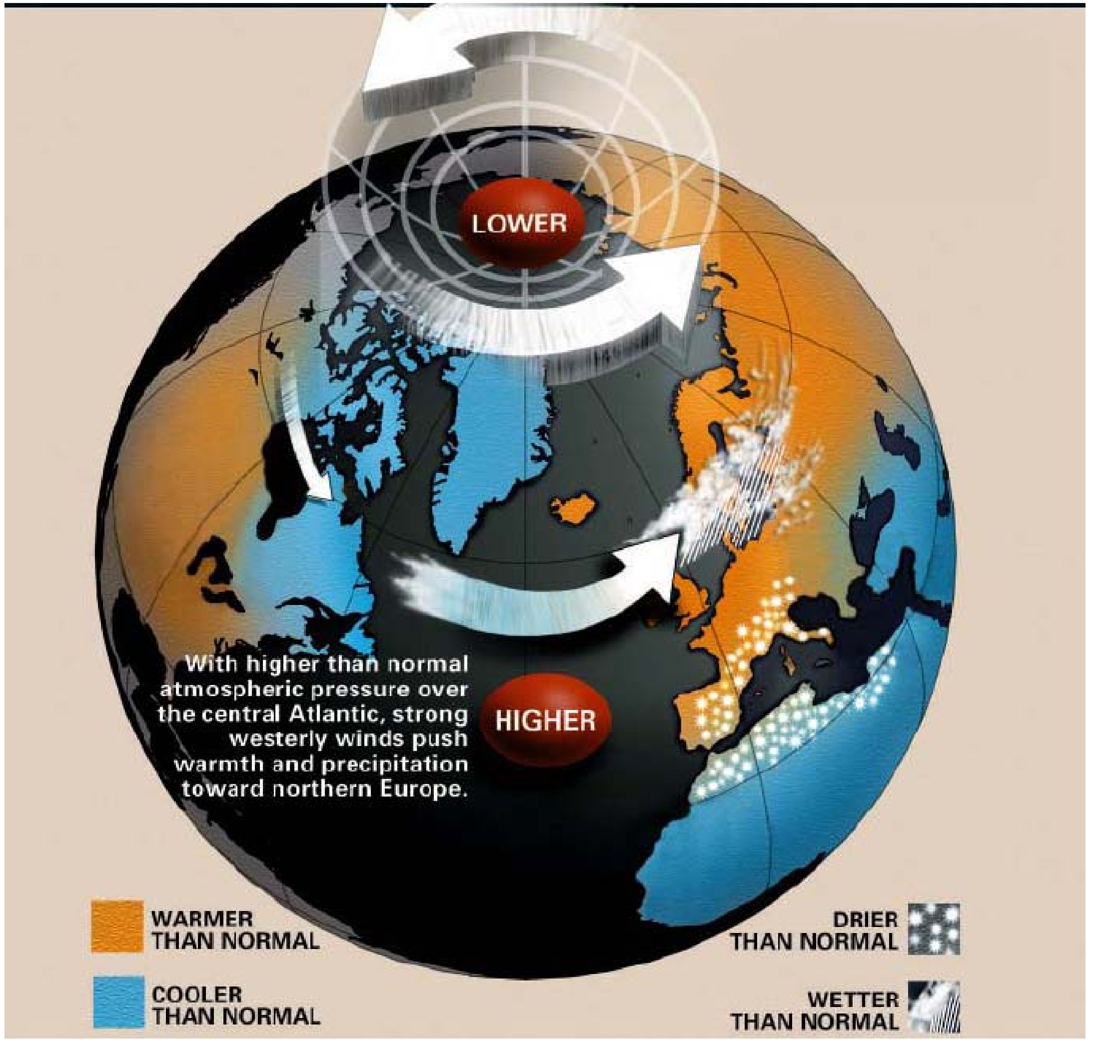
a)
Cold nights
b)
Cold days
90
45
0
45
90
°N
°S
90°W
0
90°E
180
–12
–6
0
6
12
40
20
0
–20
1950
1960
1970
1980
1990
2000
c)
Warm nights
d)
Warm days
–16
–8
0
8
16



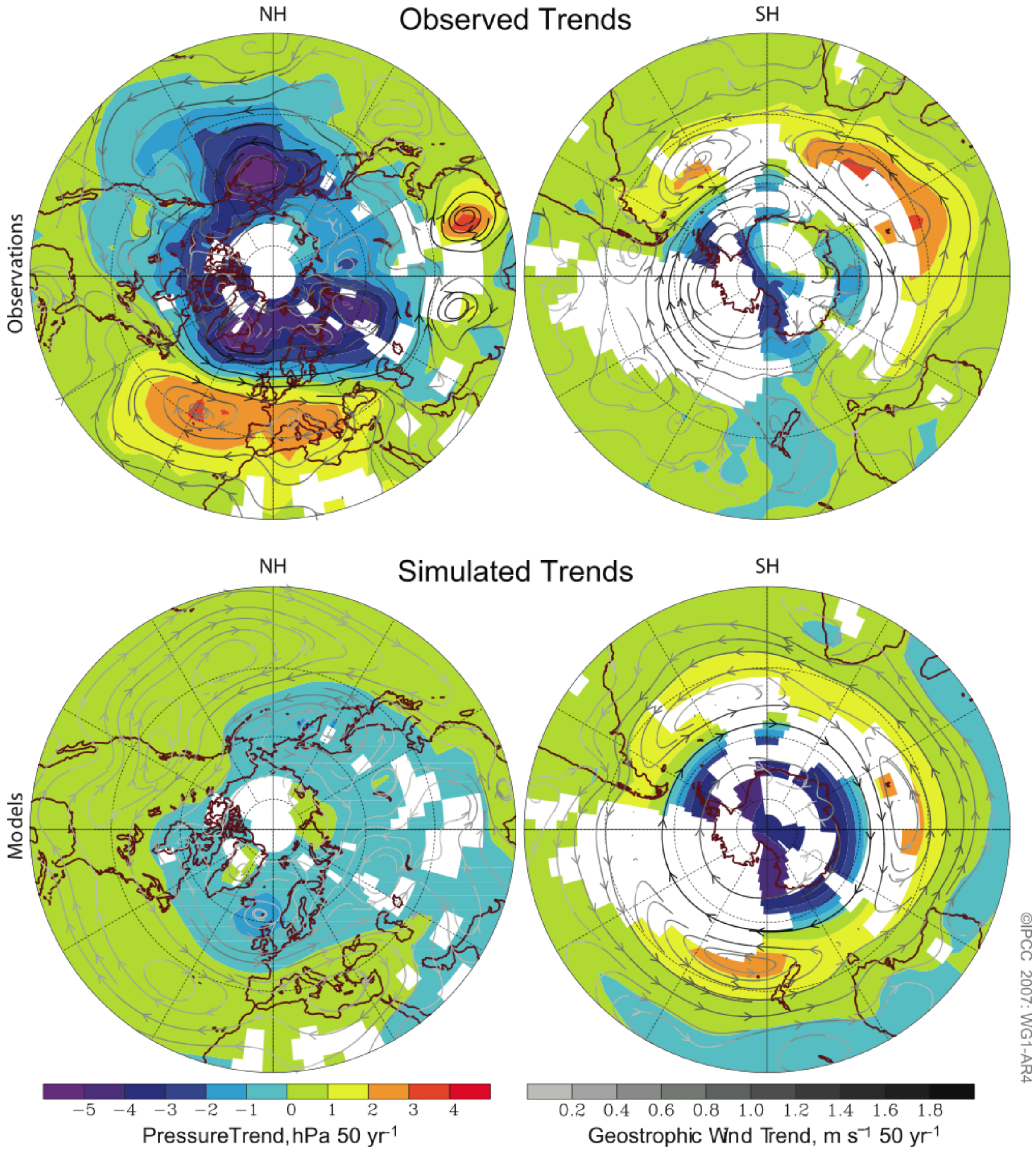
LOWER
HIGHER
With higher than normal atmospheric pressure over the central Atlantic, strong westerly winds push warmth and precipitation toward northern Europe.
WARMER THAN NORMAL
COOLER THAN NORMAL
DRIER THAN NORMAL
WETTER THAN NORMAL
©IPCC 2007: WG1-AR4

Additional Evidence

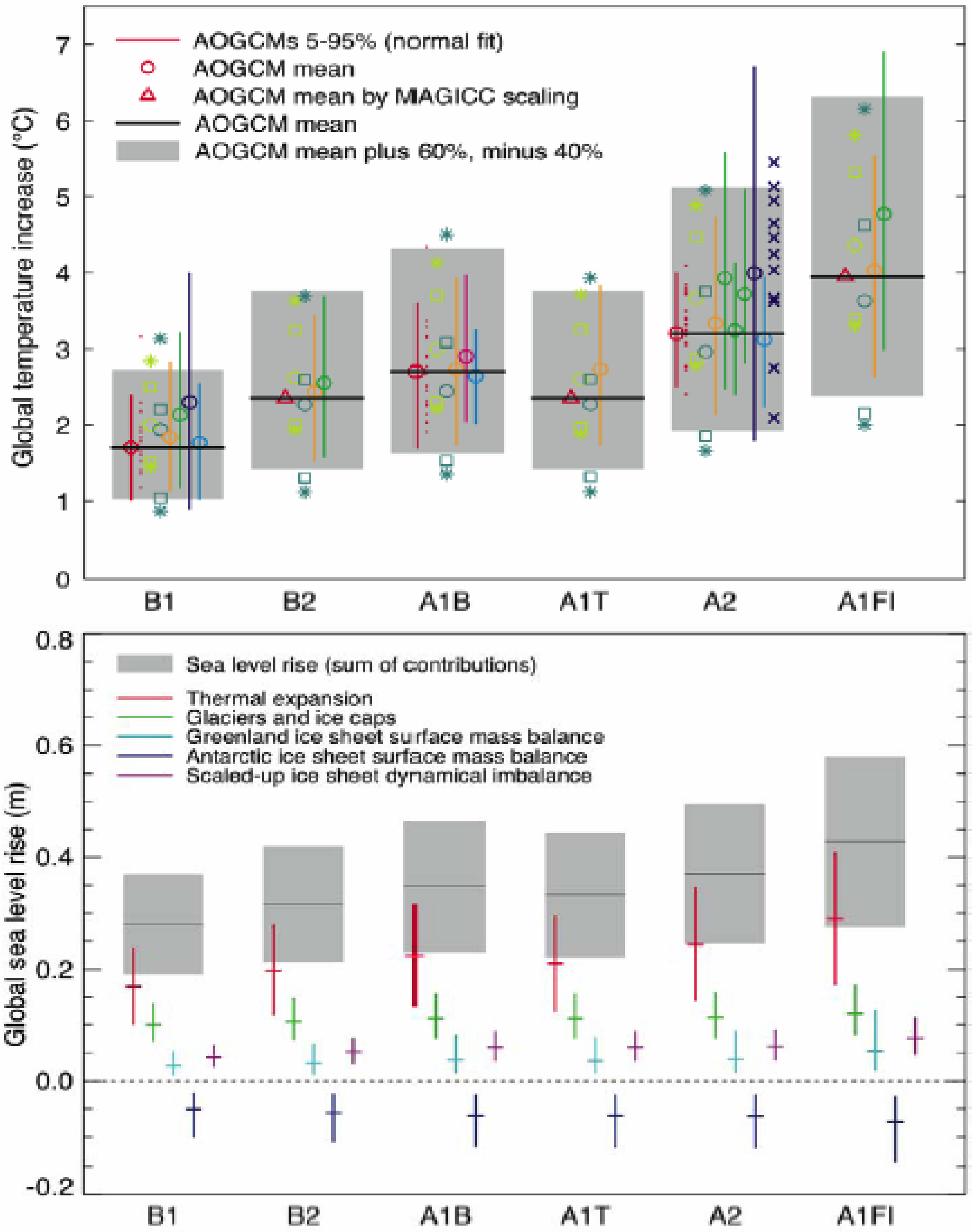
- Warming is widespread
  - Surface, atmosphere, ocean, cryosphere
  - Temperature extremes
- Anthropogenic forcing has **likely** contributed to circulation change
  - storm tracks, winds and temperature patterns
- External influence on rainfall, droughts, stream flow



TS, Box 3.1, Fig 1



Observed Trends
NH
SH
Observations
Simulated Trends
NH
SH
Models
−5 −4 −3 −2 −1 0 1 2 3 4
PressureTrend, hPa 50 yr-1
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
Geostrophic Wind Trend, m s-1 50 yr-1
©IPCC 2007: WG1-AR4



AOGCMs 5-95% (normal fit)
AOGCM mean
AOGCM mean by MAGICC scaling
AOGCM mean
AOGCM mean plus 60%, minus 40%
Global temperature increase (°C)
0
1
2
3
4
5
6
7
B1
B2
A1B
A1T
A2
A1FI
Sea level rise (sum of contributions)
Thermal expansion
Glaciers and ice caps
Greenland ice sheet surface mass balance
Antarctic ice sheet surface mass balance
Scaled-up ice sheet dynamical imbalance
Global sea level rise (m)
0.8
0.6
0.4
0.2
0.0
-0.2
B1
B2
A1B
A1T
A2
A1FI