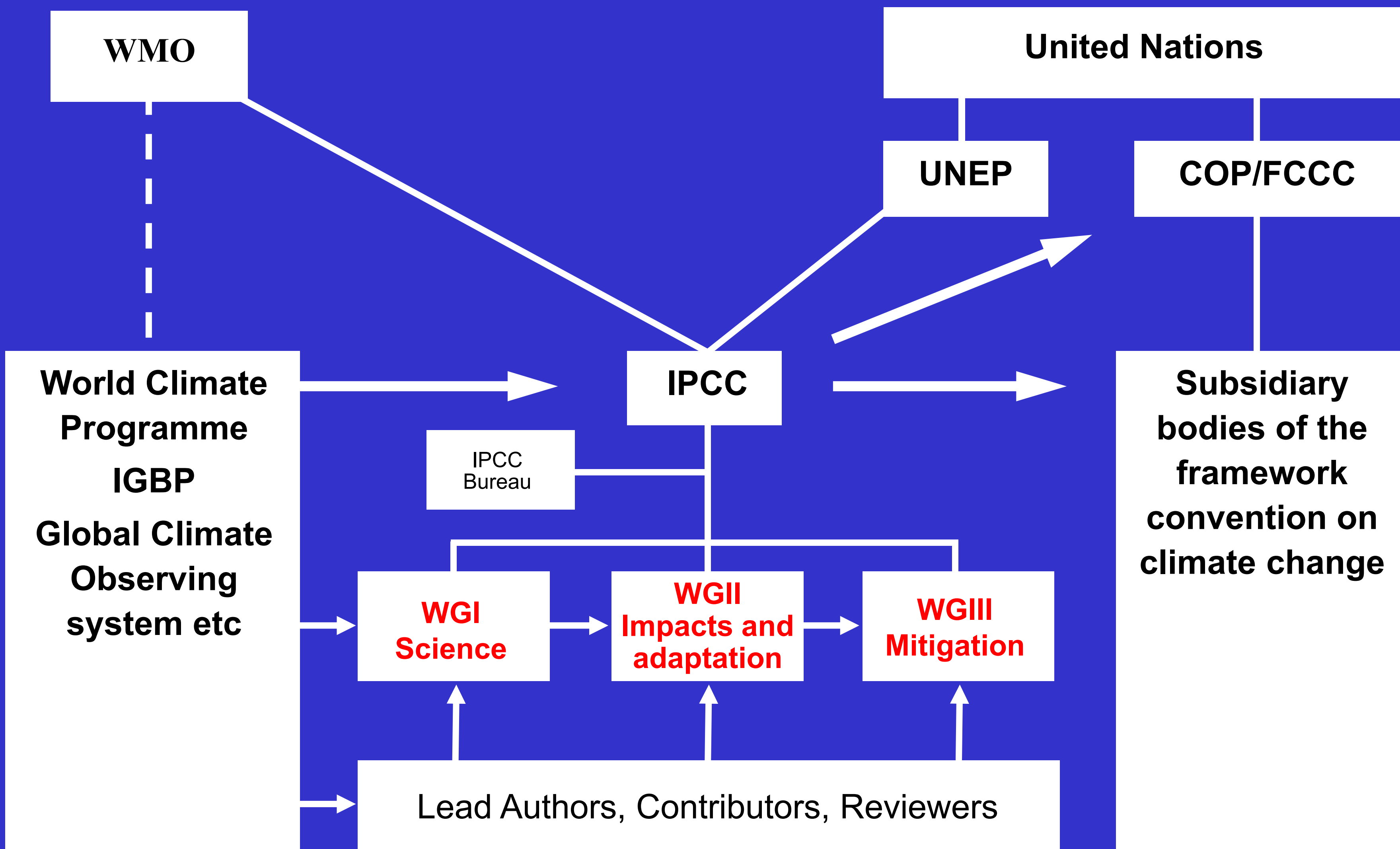
Lecture 12: Future Climate Changes

- ***I***ntergovernmental ***P***anel on ***C***limate ***C***hange
- Main Conclusions of the SPM (Summary For Policy Makers)

IPCC Web Site

http://www.ipcc.ch

Structure of IPCC 1997 – 2001



(adapted from IPCC website; presented by John Houghton)

History of IPCC

1988 - The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) establish the Intergovernmental Panel on Climate Change.
- The United Nations General Assembly endorses the action of UNEP and the WMO in setting up the IPCC.

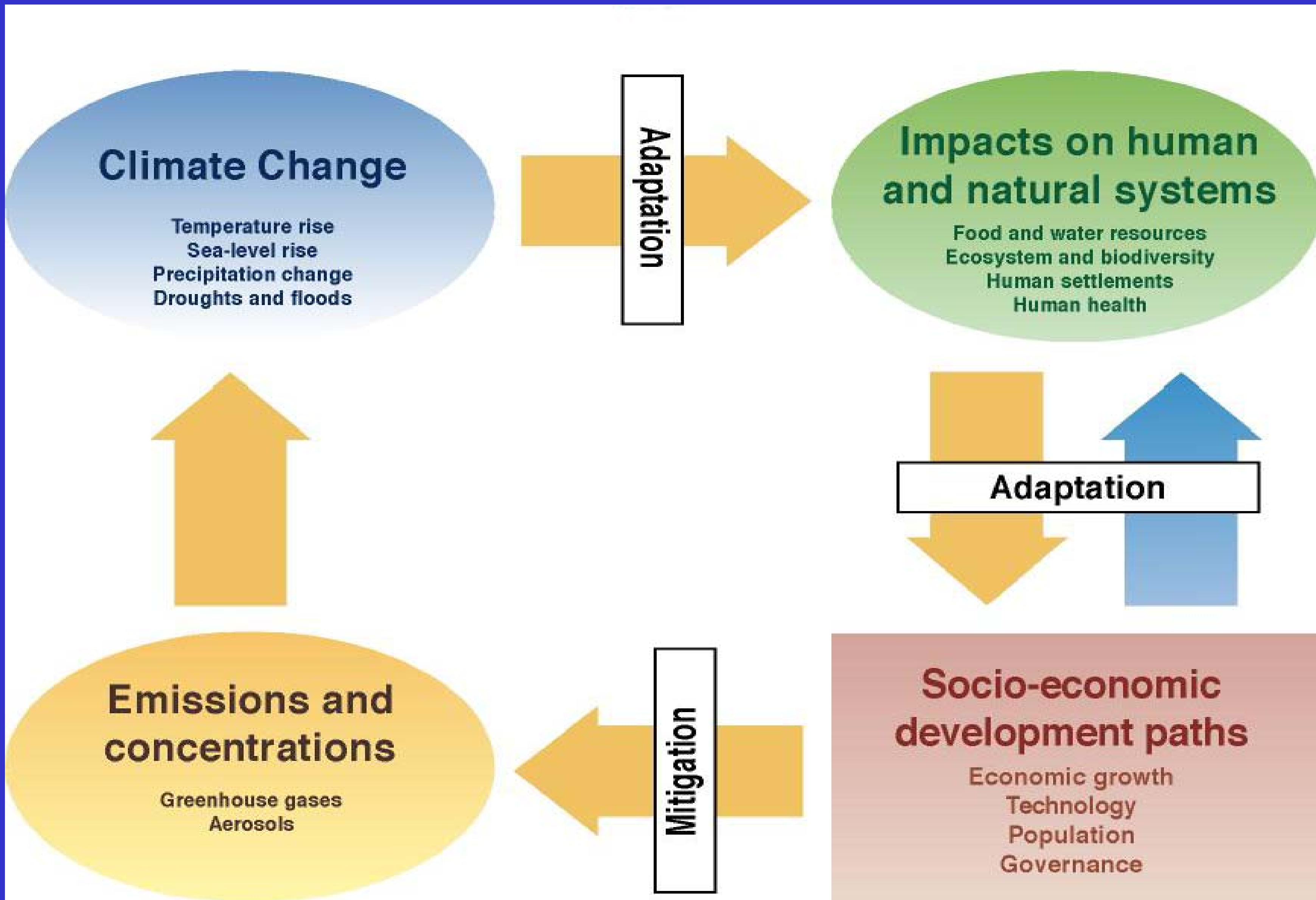
1990 - The IPCC publishes its First Assessment Report (Working Group I – *Climate Change: The IPCC Scientific Assessment*; Working Group II – *Climate Change: The IPCC Impacts Assessment*; Working Group III – *Climate Change: The IPCC Response Strategies*).
- The UN General Assembly notes the report findings and decides to initiate negotiations for a framework convention on climate change.

1995 - The IPCC publishes its Second Assessment Report (Working Group I – *Climate Change 1995: The Science of Climate Change*; Working Group II – *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses*; Working Group III – *Climate Change 1995: Economic and Social Dimensions of Climate Change; IPCC Second Assessment: Climate Change 1995* (includes Synthesis Report)).

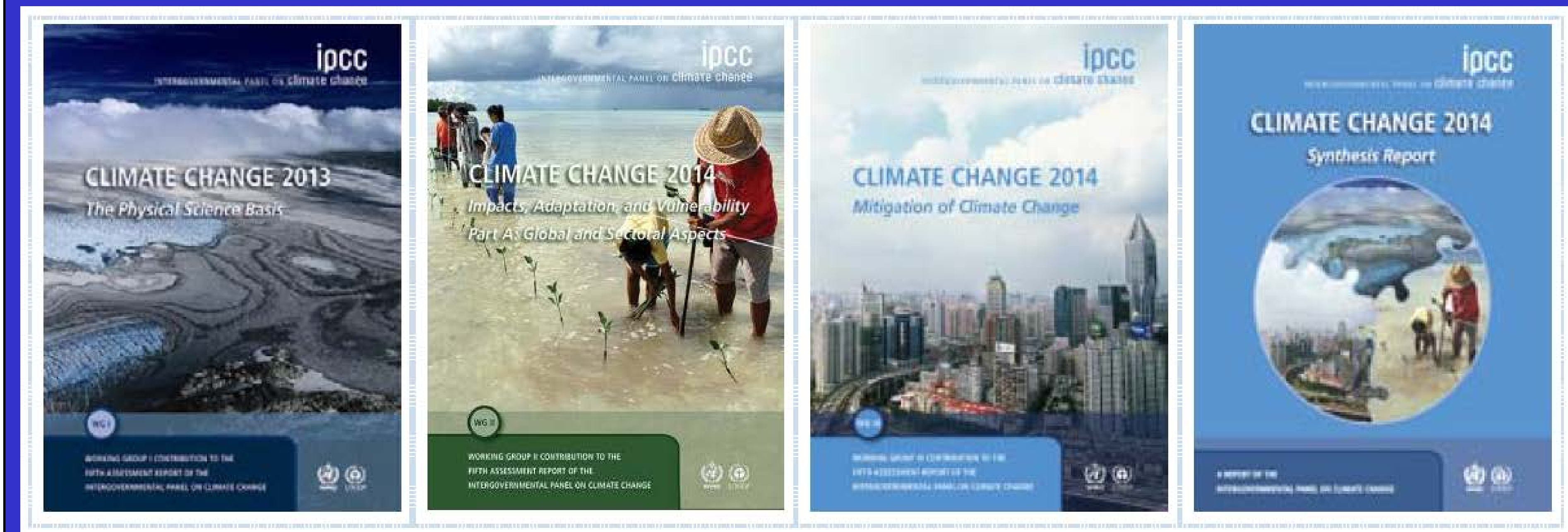
2001 - The IPCC publishes its Third Assessment Report (Working Group I – *Climate Change 2001: The Scientific Basis*; Working Group II – *Climate Change 2001: Impacts, Adaptation, and Vulnerability*; Working Group III – *Climate Change 2001: Mitigation*; *Climate Change 2001: Synthesis Report*).

2007 - The IPCC publishes its Fourth Assessment Report (AR4) (Working Group I – *Climate Change 2007: The Physical Science Basis*; Working Group II – *Climate Change 2007: Impacts, Adaptation and Vulnerability*; Working Group III – *Climate Change 2007: Mitigation of Climate Change*; *Climate Change 2007: Synthesis Report*)

2013 - The IPCC approves *Climate Change 2013: The Physical Science Basis*, the Working Group I contribution to AR5.


Climate Change
Temperature rise
Sea-level rise
Precipitation change
Droughts and floods
Adaptation
Impacts on human and natural systems
Food and water resources
Ecosystem and biodiversity
Human settlements
Human health
Adaptation
Socio-economic development paths
Economic growth
Technology
Population
Governance
Mitigation
Emissions and concentrations
Greenhouse gases
Aerosols

IPCC AR5 (Fifth Assessment Report)



WGI
(Sciences)

WGII
(Impacts and Adaptation)

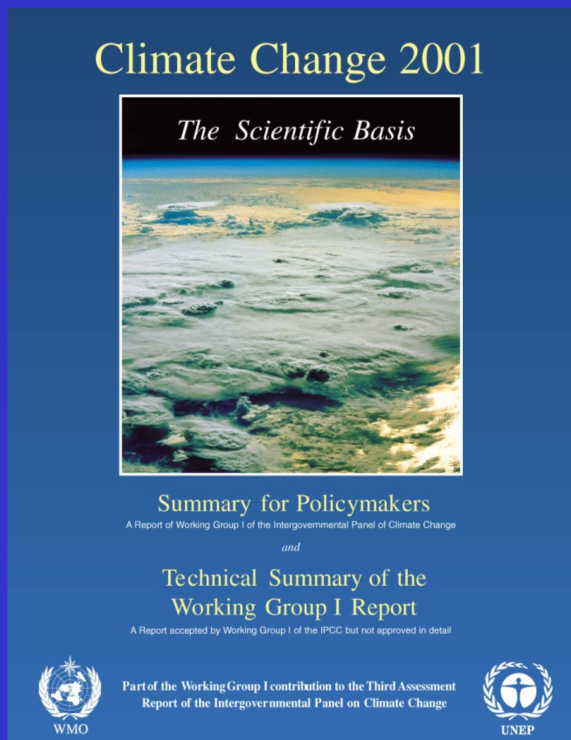
WGIII
(Mitigation)

Synthesis Report

Climate Change 2001: The Scientific Basis

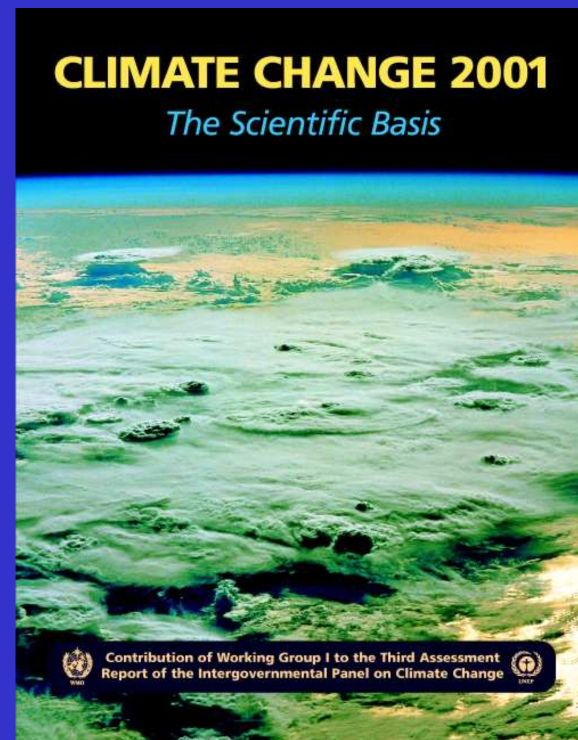
WGI contribution to IPCC Third Assessment Report

Summary for Policymakers (SPM)



Approved 'sentence by sentence' by WGI plenary
(99 Governments and 45 scientists)

The Scientific Basis (Technical Summary)



14 chapters; 120 Lead Authors
515 Contributing Authors
4621 References quoted

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The IPCC Working Group ___________ aims at assessing the physical scientific basis of the climate system and climate change.

(A) I

(B) II

(C) III

Understand and Project Our Climate System

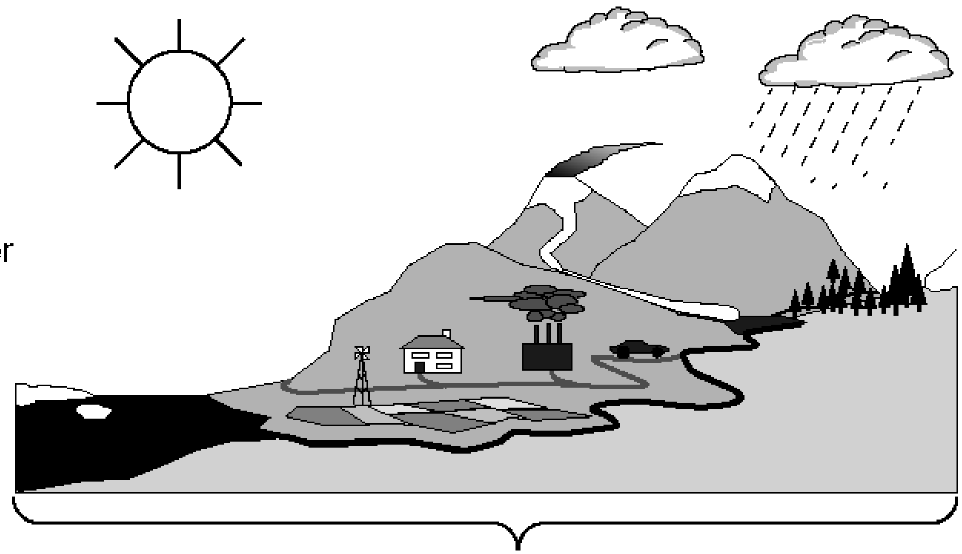
What changes have occurred?

How well are the past and present climates understood?

What changes could lie ahead?

Observations:

- temperatures
- precipitation
- snow / ice cover
- sea level
- circulation
- extremes



Simulations:

- natural variation
- forcing agents
- global climate
- regional climate
- high impact events
- stabilisation

Observations vis-à-vis Simulations

Timeline:	Palaeo & Instrumental Periods	The Present	The Future

Major Conclusions in SPM (TAR)

1. An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
2. Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.
3. Confidence in the ability of models to project future climate has increased.
4. There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.
5. Human influences will continue to change atmospheric composition throughout the 21st century.
6. Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.
7. Anthropogenic climate change will persist for many centuries.
8. Further action is required to address remaining gaps in information and understanding.

IPCC's Probability Phrases

Table 1 | IPCC guidelines for translation of probability phrases.

Phrase	Likelihood
Virtually certain	>99%
Very likely	>90%
Likely	>66%
About as likely as not	33%–66%
Unlikely	<33%
Very unlikely	<10%
Exceptionally unlikely	<1%

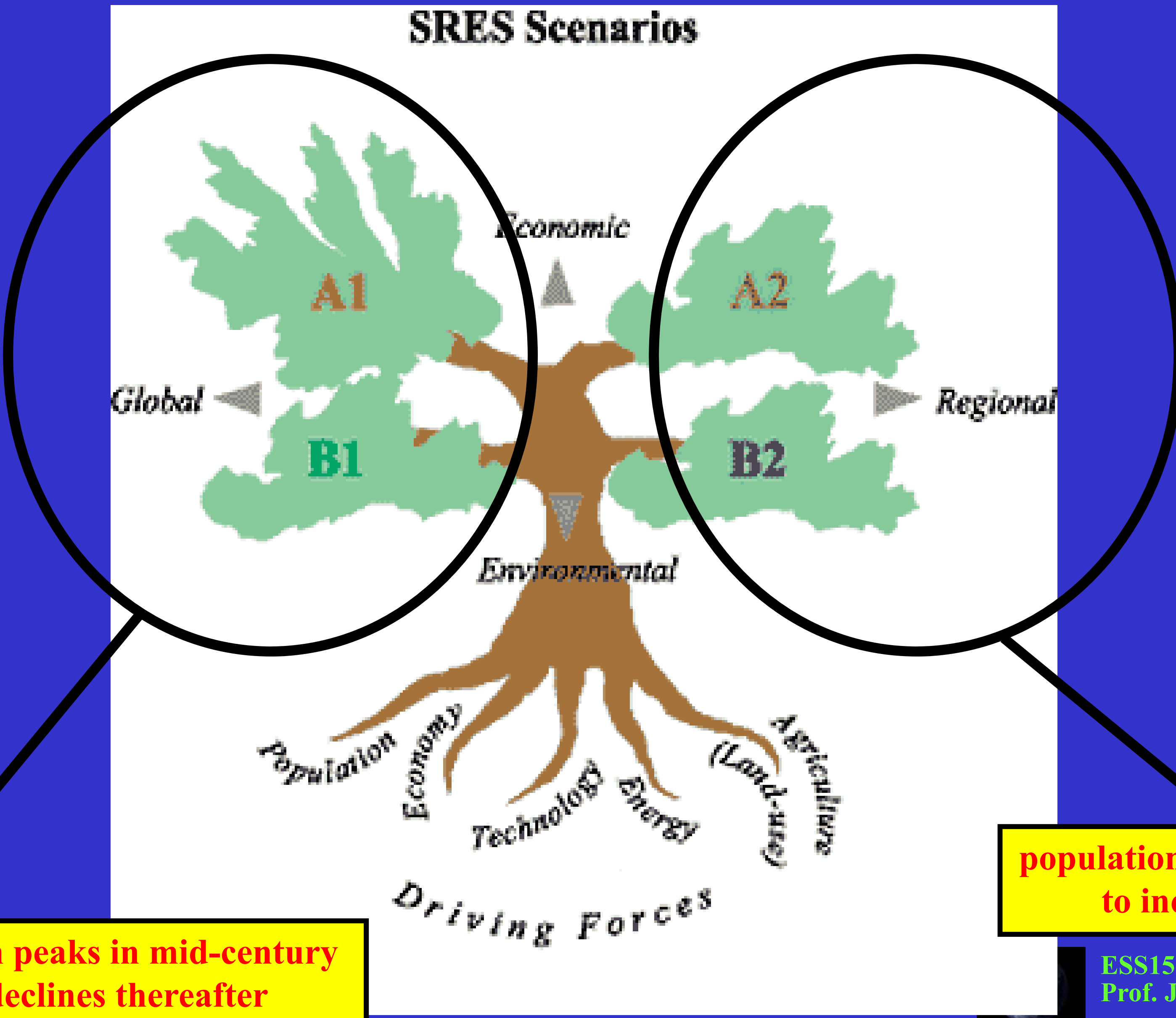
Note: In some IPCC reports authors have used the phrases 'More likely than not' for probabilities > 50%, 'Extremely likely' for probabilities above 95% and 'Extremely unlikely' for probabilities below 5%.

How Future CO2 Emission Calculated?

$$\begin{array}{c}\text{\% increase}\\\text{in carbon}\\\text{emissions}\end{array} = \begin{array}{c}\text{\% increase}\\\text{in population}\end{array} \times \begin{array}{c}\text{\% change in}\\\text{emissions}\\\text{per person}\end{array} \times \begin{array}{c}\text{Changes in}\\\text{efficiency of}\\\text{carbon use}\end{array}$$

- ***Global Population***: is expected to increase to 11 billion between 2075 and 2100 (100% increase).
- ***Emission Per Person***: is linked to averaged standard of living (such as car and home heating or cooling).
- ***Efficiency of Use***: The hardest factor to project. The efficiency depends on technologies. This is also the factor that may keep carbon emissions from increasing in the future.

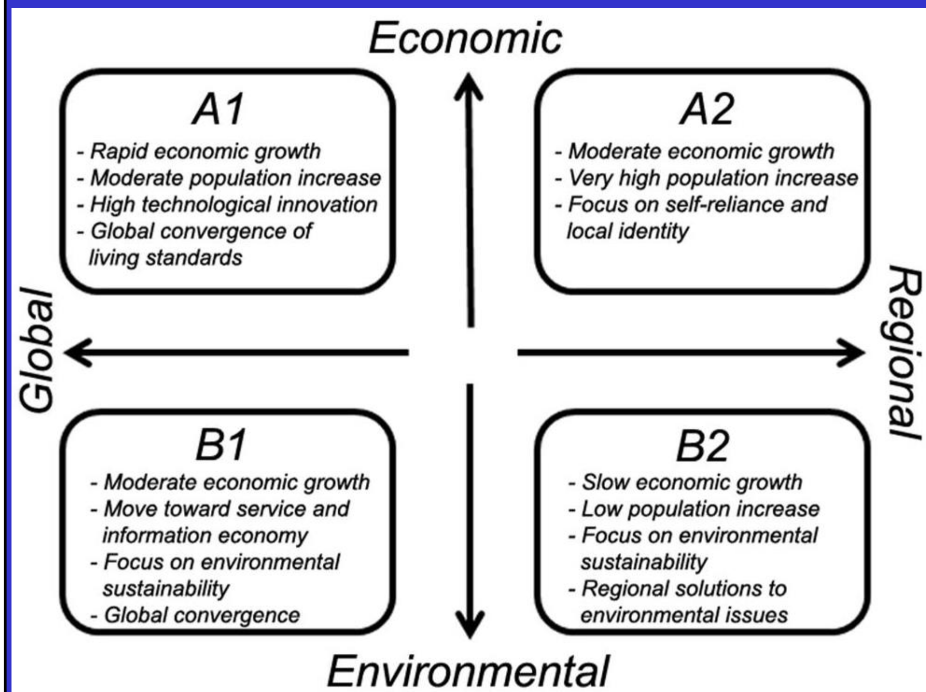
IPCC Special Report on Emission Scenarios (SRES)



population peaks in mid-century and declines thereafter

population continues to increase

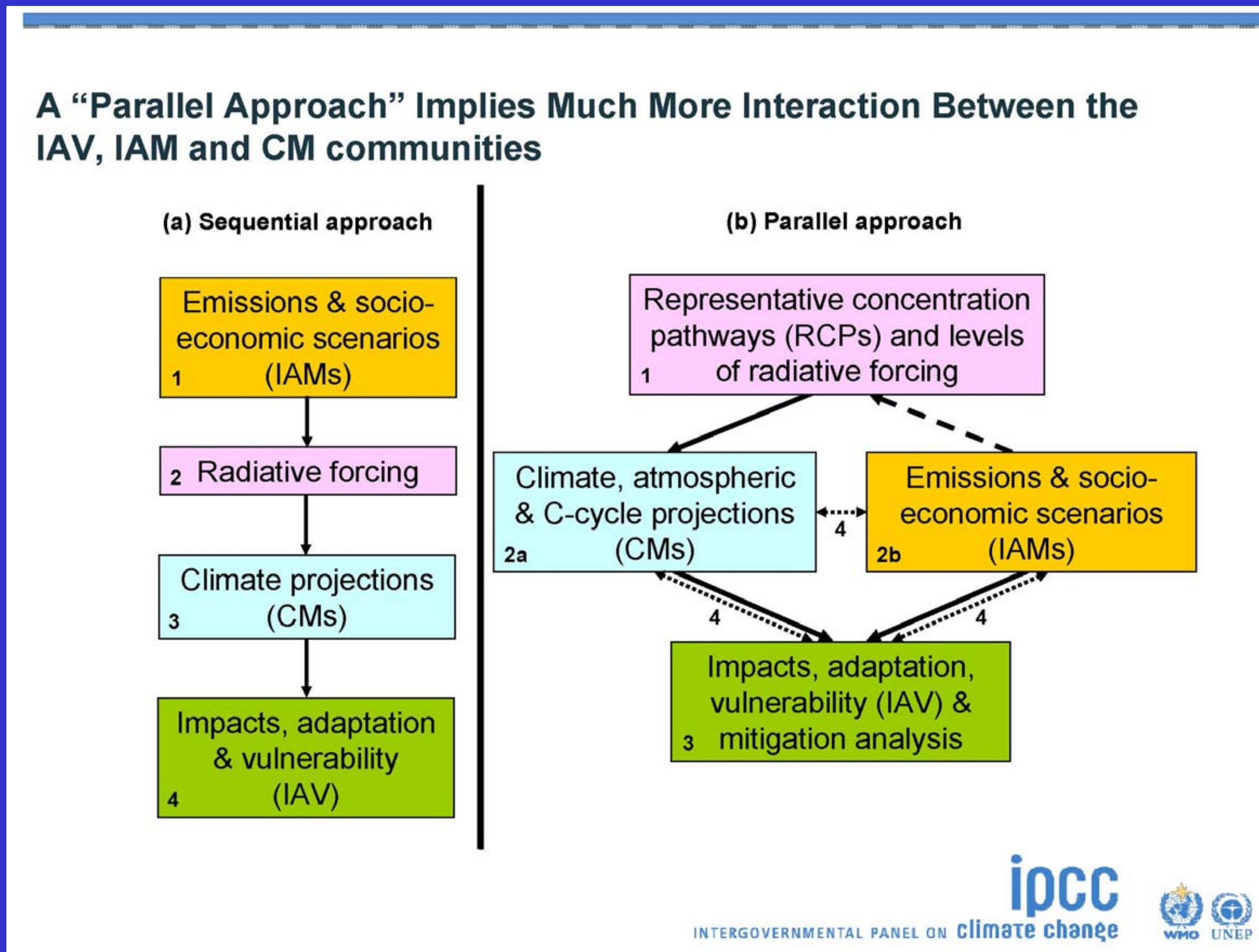
IPCC Special Report on Emission Scenarios (SRES)



The four *SRES* scenario families[5][6][7] of the *Fourth Assessment Report* vs. projected global average surface warming until 2100

AR4 (Summary; PDF) (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf)	More economic focus	More environmental focus
Globalisation (homogeneous world)	**A1** rapid economic growth (groups: A1T; A1B; A1FI) **1.4 - 6.4 °C**	**B1** global environmental sustainability **1.1 - 2.9 °C**
Regionalisation (heterogeneous world)	**A2** regionally oriented economic development **2.0 - 5.4 °C**	**B2** local environmental sustainability **1.4 - 3.8 °C**

RCP vs. SRES


A "Parallel Approach" Implies Much More Interaction Between the IAV, IAM and CM communities
(a) Sequential approach
Emissions & socio-economic scenarios (IAMs) 1
2 Radiative forcing
Climate projections (CMs) 3
Impacts, adaptation & vulnerability (IAV) 4
(b) Parallel approach
Representative concentration pathways (RCPs) and levels of radiative forcing 1
Climate, atmospheric & C-cycle projections (CMs) 2a
Emissions & socio-economic scenarios (IAMs) 2b
Impacts, adaptation, vulnerability (IAV) & mitigation analysis 3
4
4
4
ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO
UNEP

Representative Concentration Pathway (RCP)

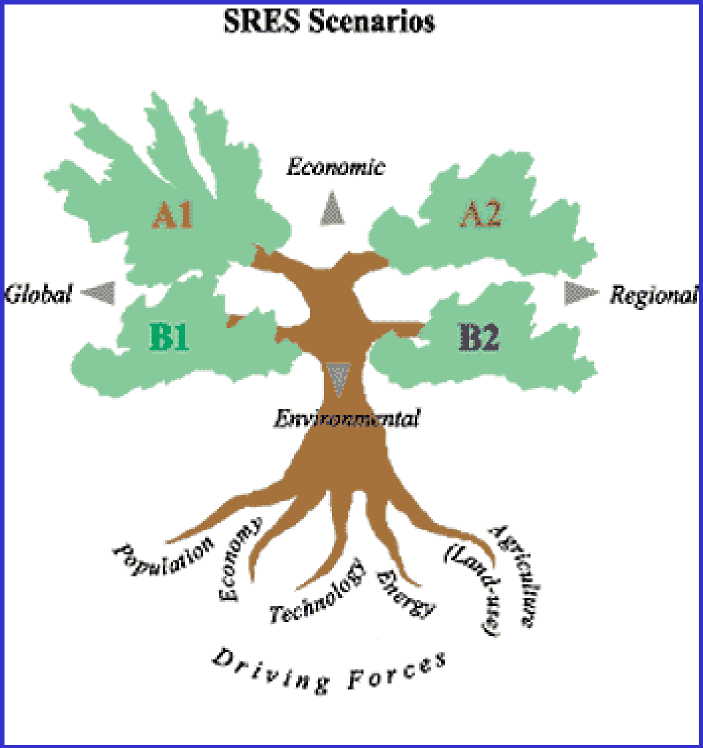
Name	Radiative forcing	CO_2 equiv (p.p.m.)	Temp anomaly (°C)	Pathway	SRES temp anomaly equiv
RCP8.5	8.5 Wm^2 in 2100	1370	4.9	Rising	SRES A1F1
RCP6.0	6 Wm^2 post 2100	850	3.0	Stabilization without overshoot	SRES B2
RCP4.5	4.5 Wm^2 post 2100	650	2.4	Stabilization without overshoot	SRES B1
RCP2.6 (RCP3PD)	3Wm^2 before 2100, declining to 2.6 Wm^2 by 2100	490	1.5	Peak and decline	None

Table 4: from Moss et.al. 2010. *Median temperature anomaly over pre-industrial levels and SRES comparisons based on nearest temperature anomaly, from Rogelj et.al. 2012*

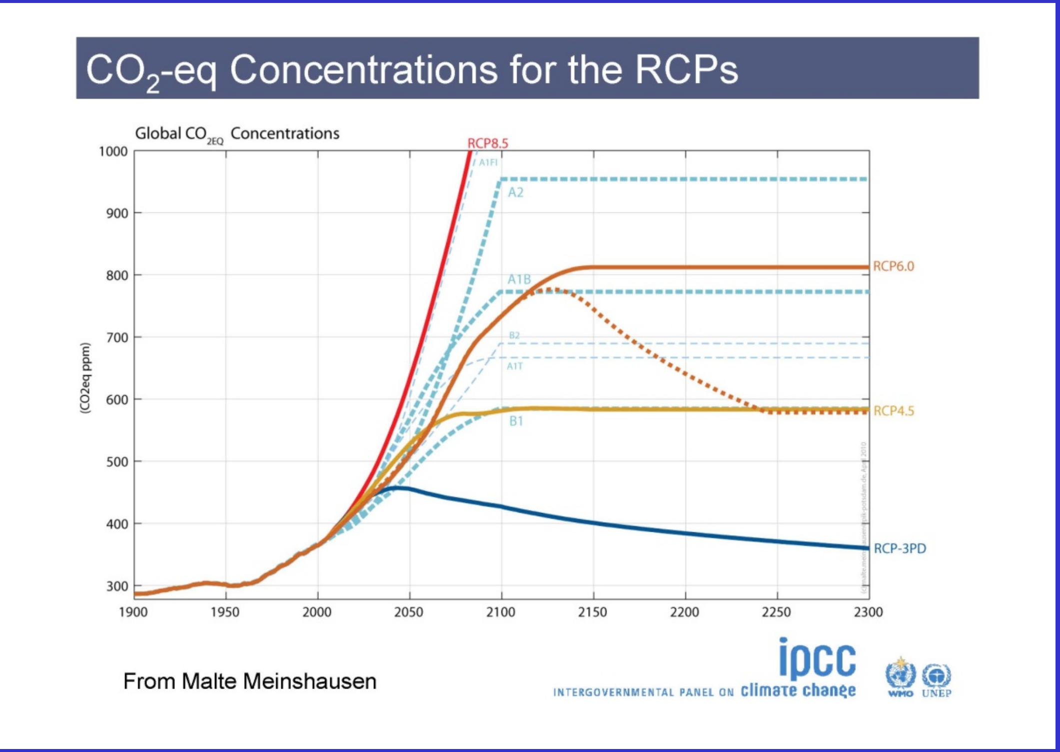
- RCPs are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its AR5 in 2014.
- It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000.
- RCP 4.5 is a scenario that stabilizes radiative forcing at 4.5 Watts per meter squared in the year 2100 without ever exceeding that value.

RCP vs. SRES

Emission Scenarios



Concentration Scenarios



ESS15
Prof. Jin-Yi Yu

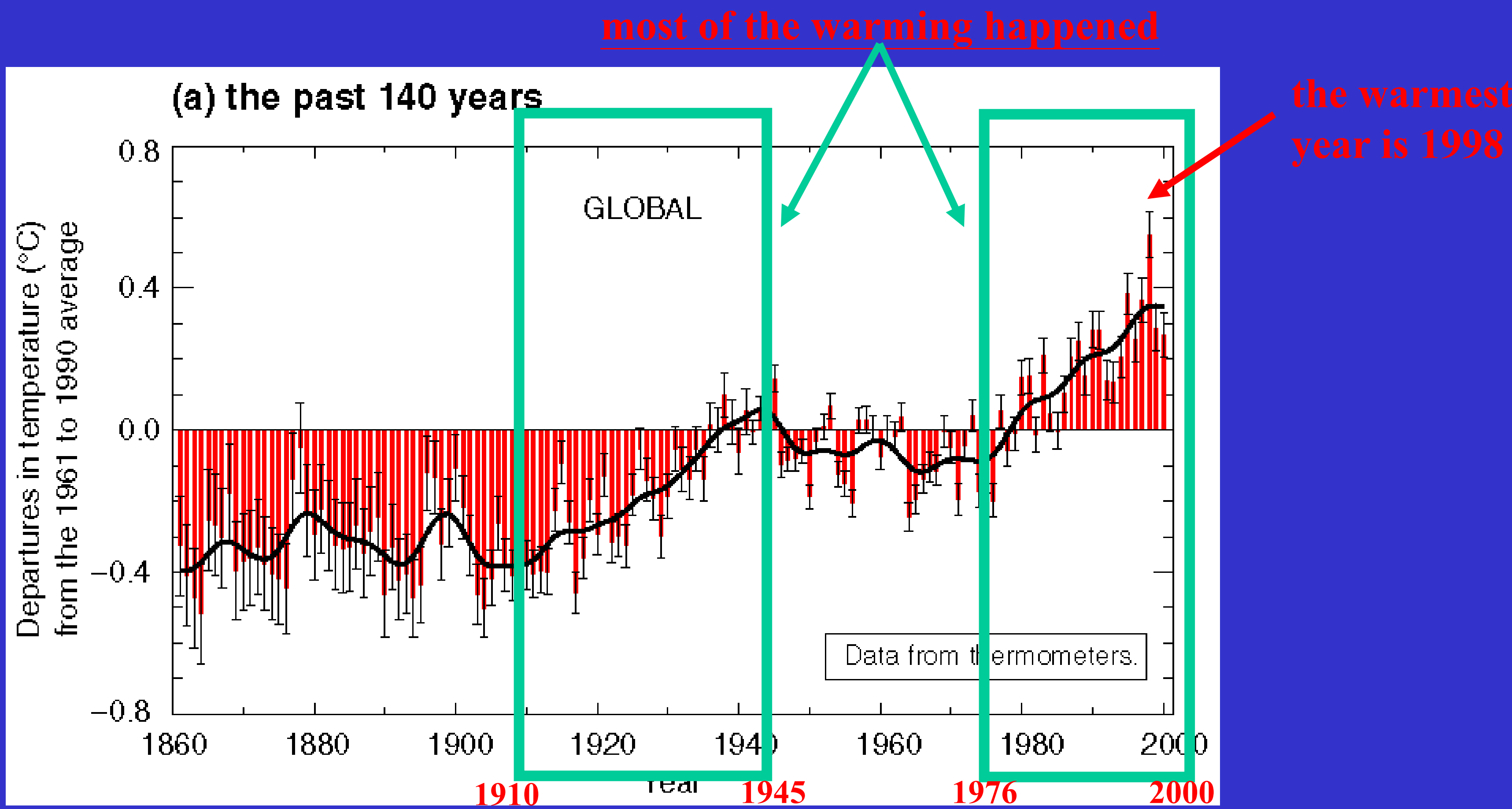
Major Conclusions in SPM (TAR)

1. **An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.**
2. **Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.**
3. **Confidence in the ability of models to project future climate has increased.**
4. **There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.**
5. **Human influences will continue to change atmospheric composition throughout the 21st century.**
6. **Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.**
7. **Anthropogenic climate change will persist for many centuries.**
8. **Further action is required to address remaining gaps in information and understanding.**

Evidences of Global Warming and Other Changes

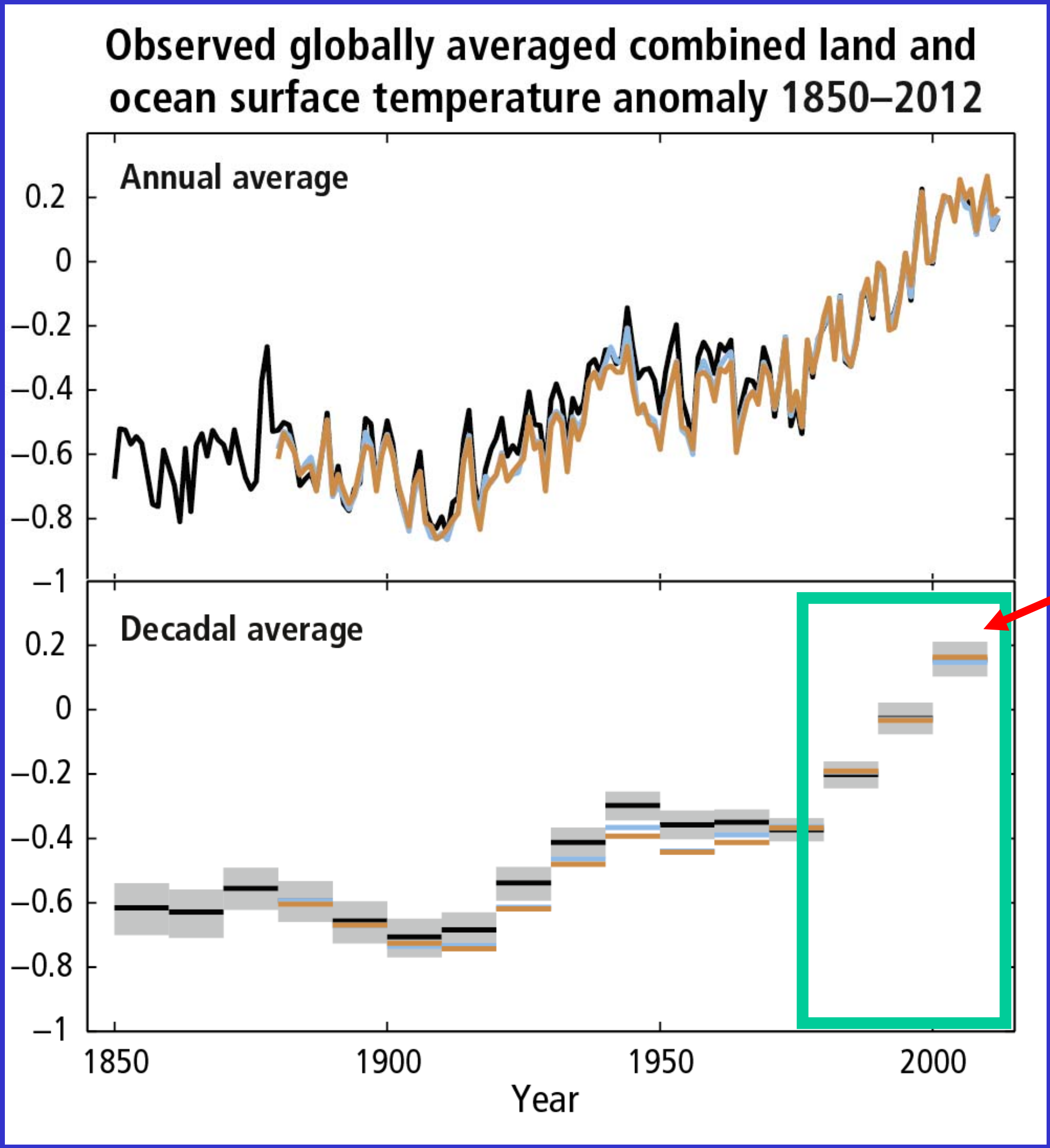
- ❑ Temperature
- ❑ Precipitation
- ❑ Snow / Ice Cover
- ❑ Sea Level
- ❑ Circulation
- ❑ Extremes

Global Surface Temperature (TAR)



The global average surface temperature has increased over the 20th century by about 0.6°C.

Global Surface Temperature (AR5)



Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

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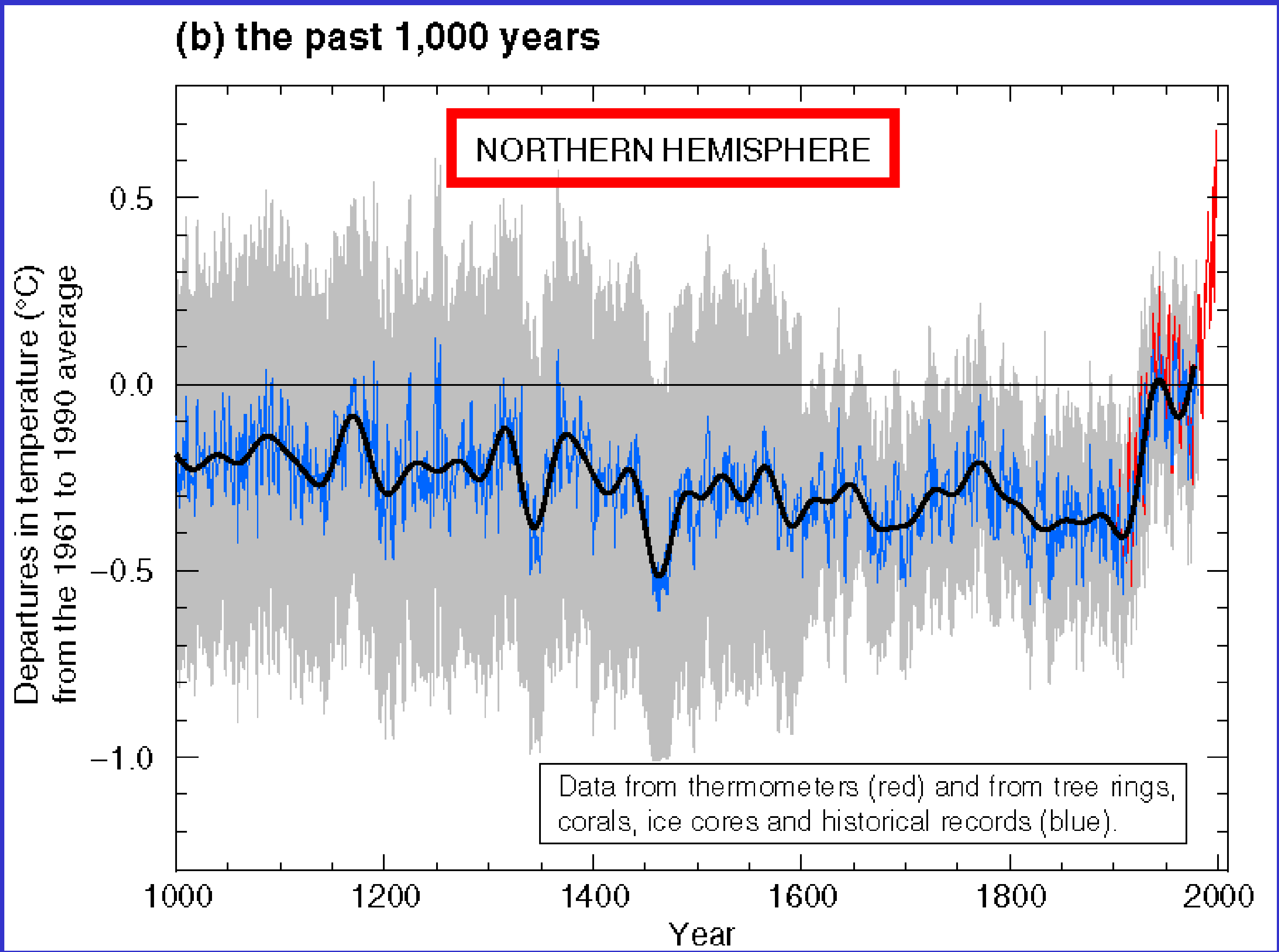
Compared to the Past 1000 Years



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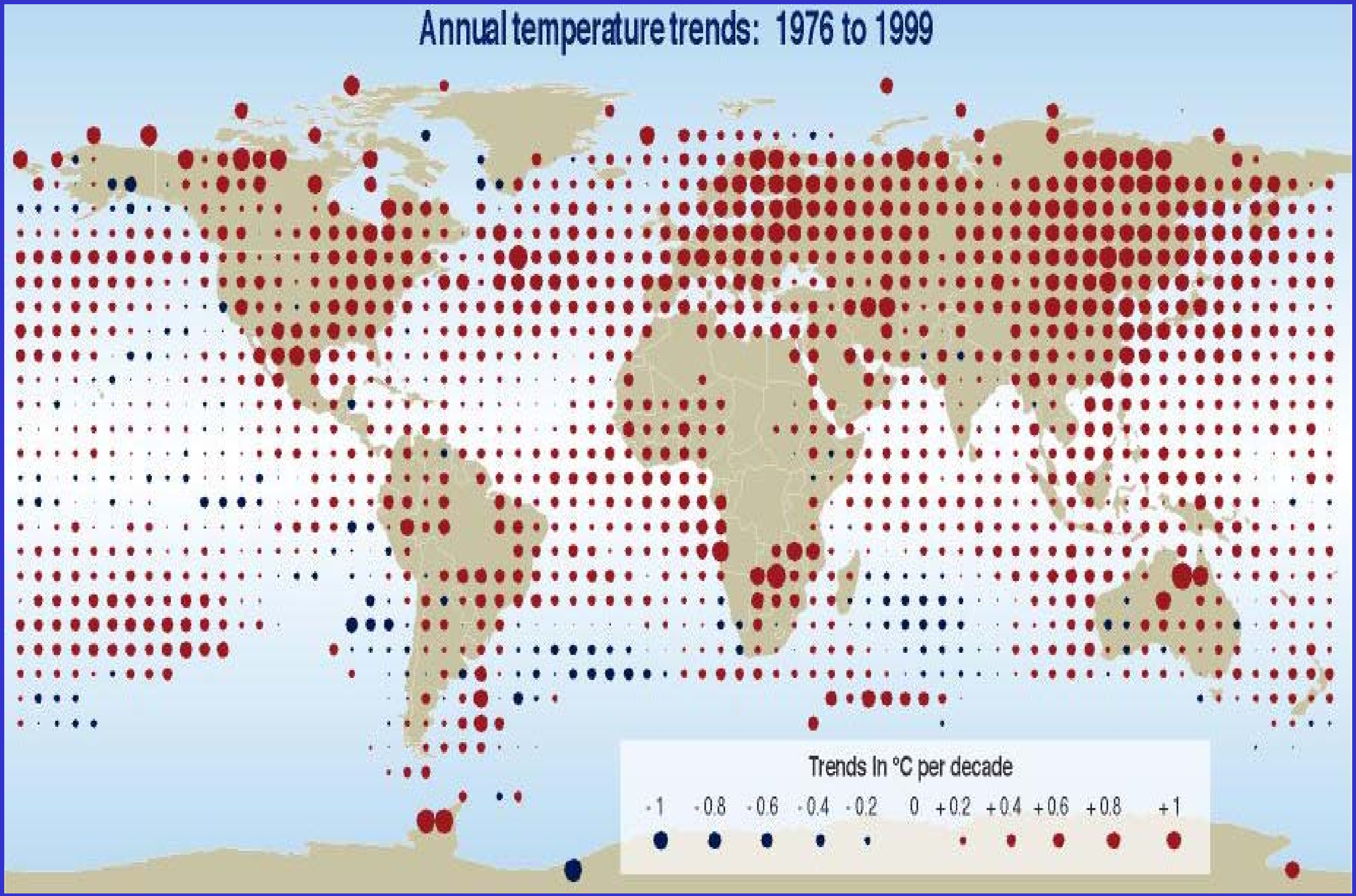
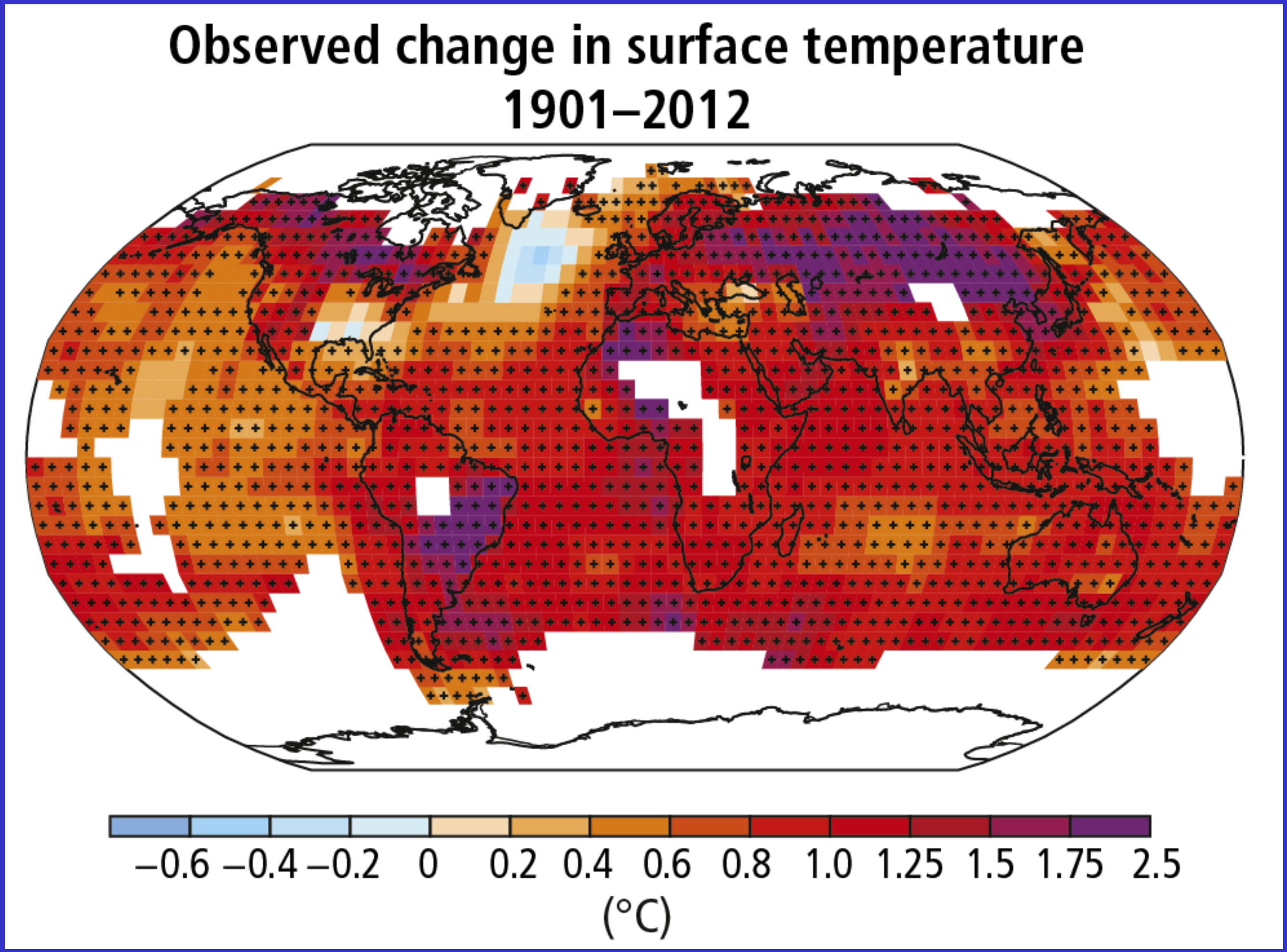
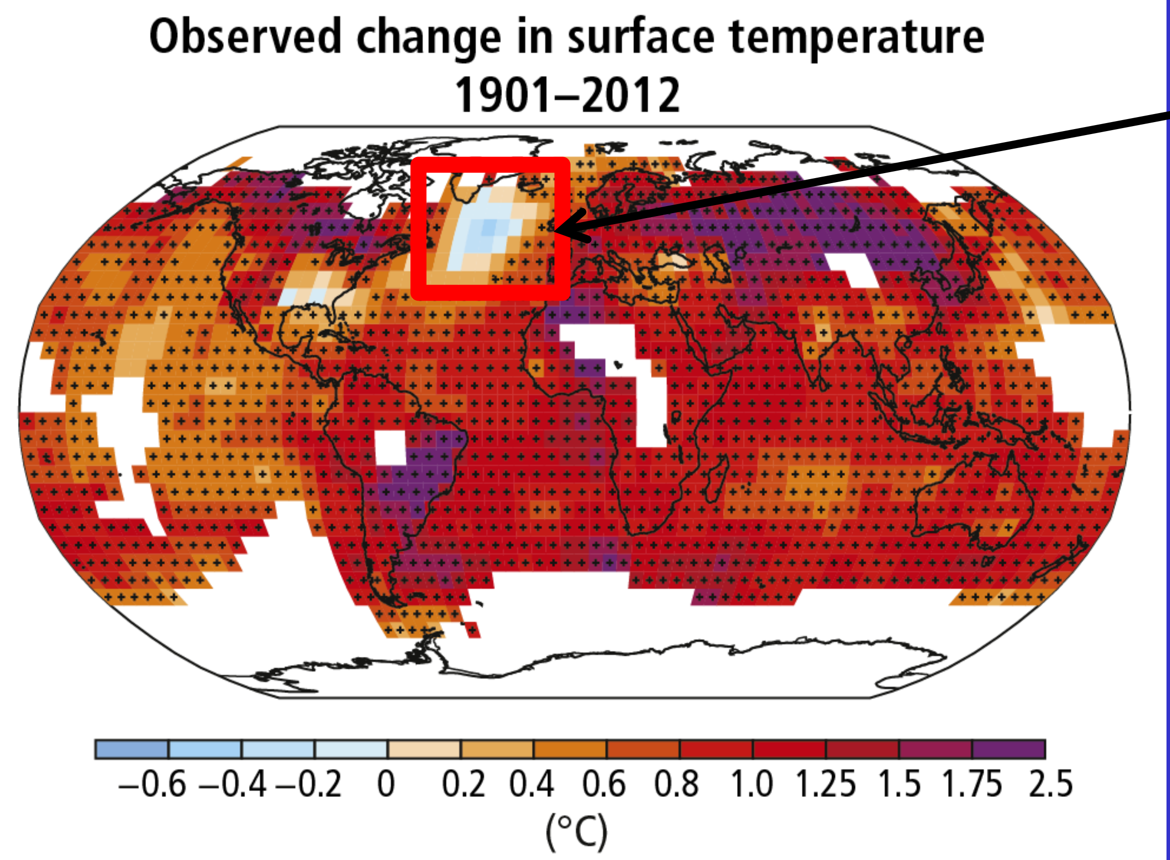
The Land and Oceans Have Warmed



The Land Have Warmed (AR5)

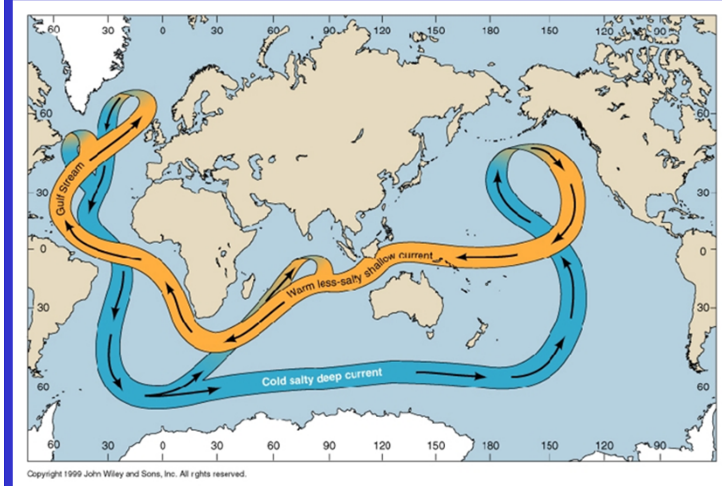


Oceans Have Warmed (AR5)



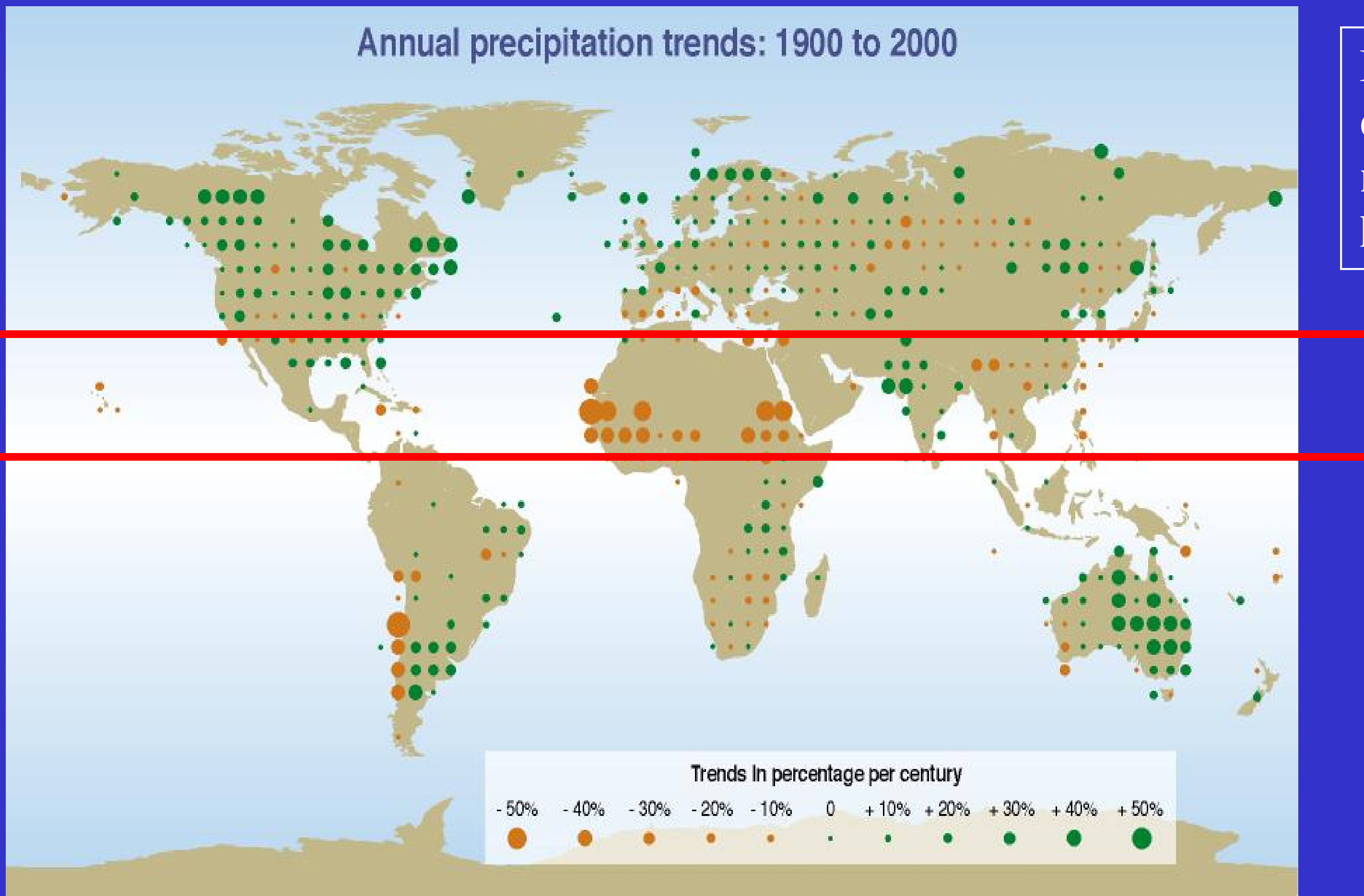
North Atlantic "Warming Hole"

➔ may be due to the slow down of the AMOC.



- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence).
- More than 60% of the net energy increase in the climate system is stored in the upper ocean (0–700 m) during the relatively well-sampled 40-year period from 1971 to 2010, and about 30% is stored in the ocean below 700 m.
- It is virtually certain that the upper ocean (0−700 m) warmed from 1971 to 2010.

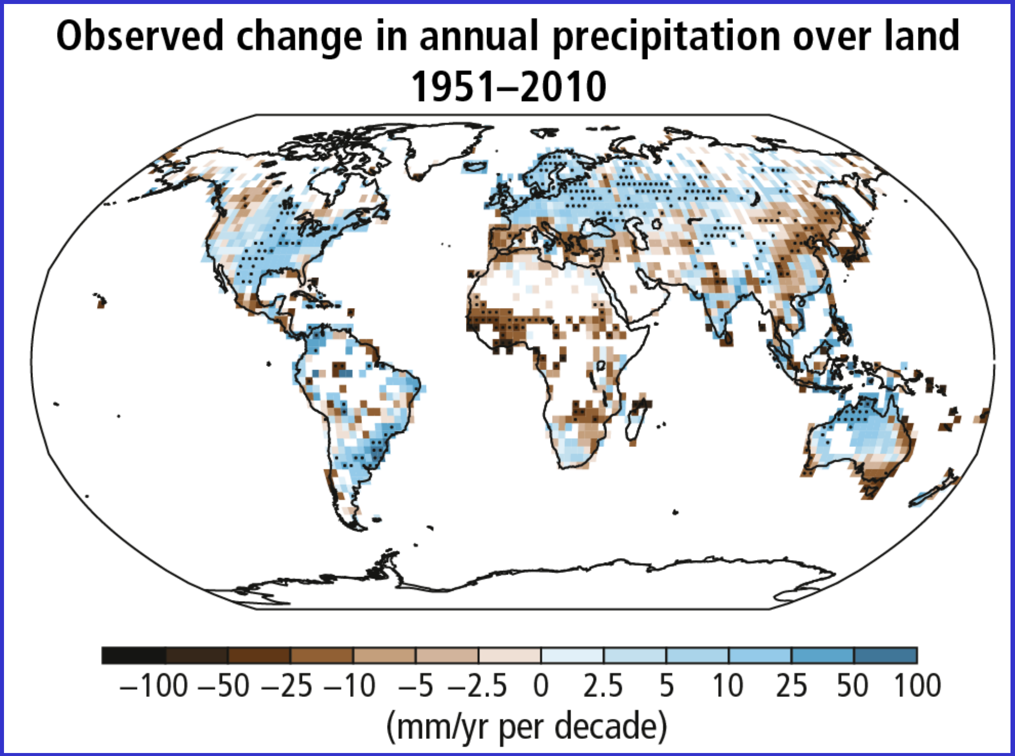
Precipitation Patterns Have Changed



Rainfall maybe decreased over much subtropical lands.

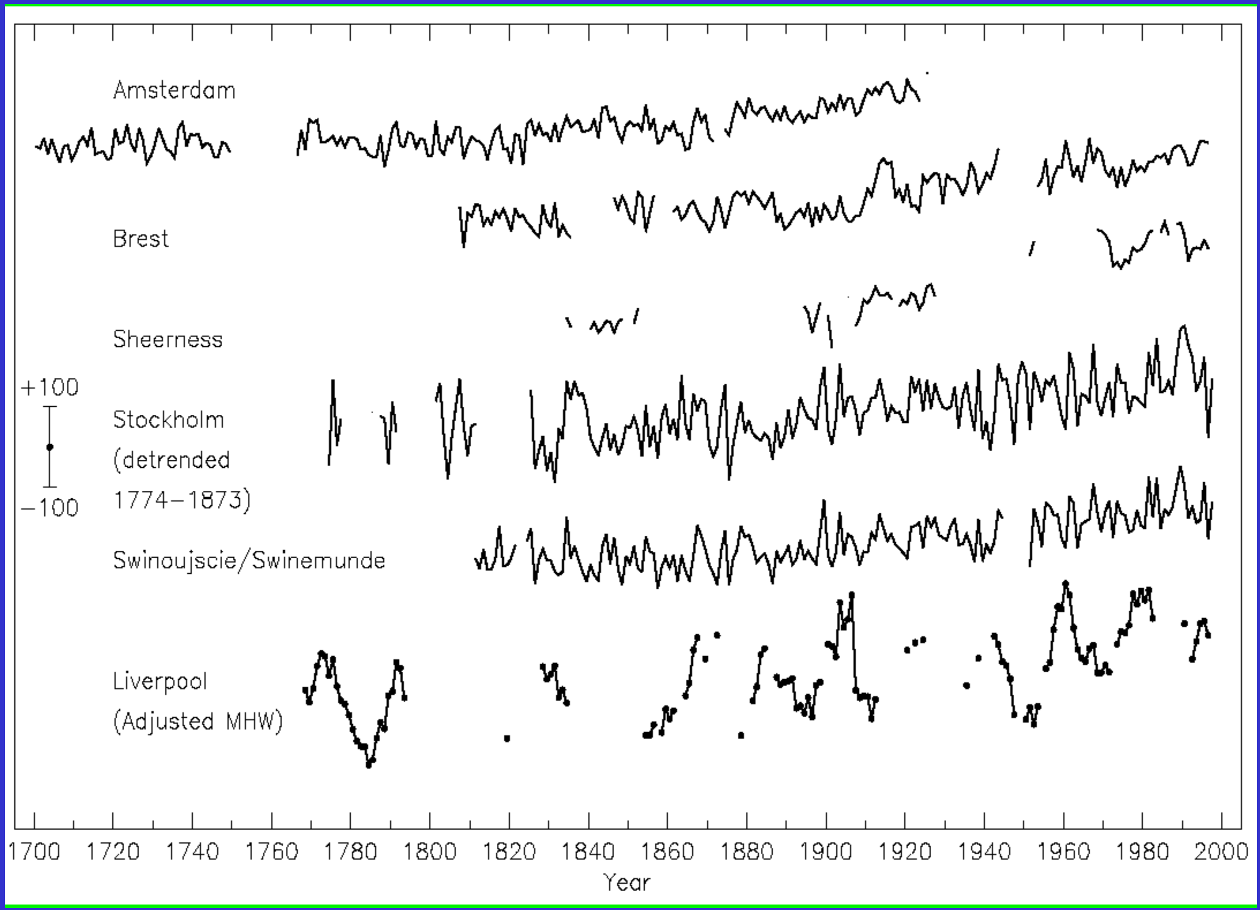
It is likely that precipitation has increased by 0.5 to 1% per decade in the 20th century over most mid- and high latitudes of the N.H. continents.

Precipitation Changes (AR5)



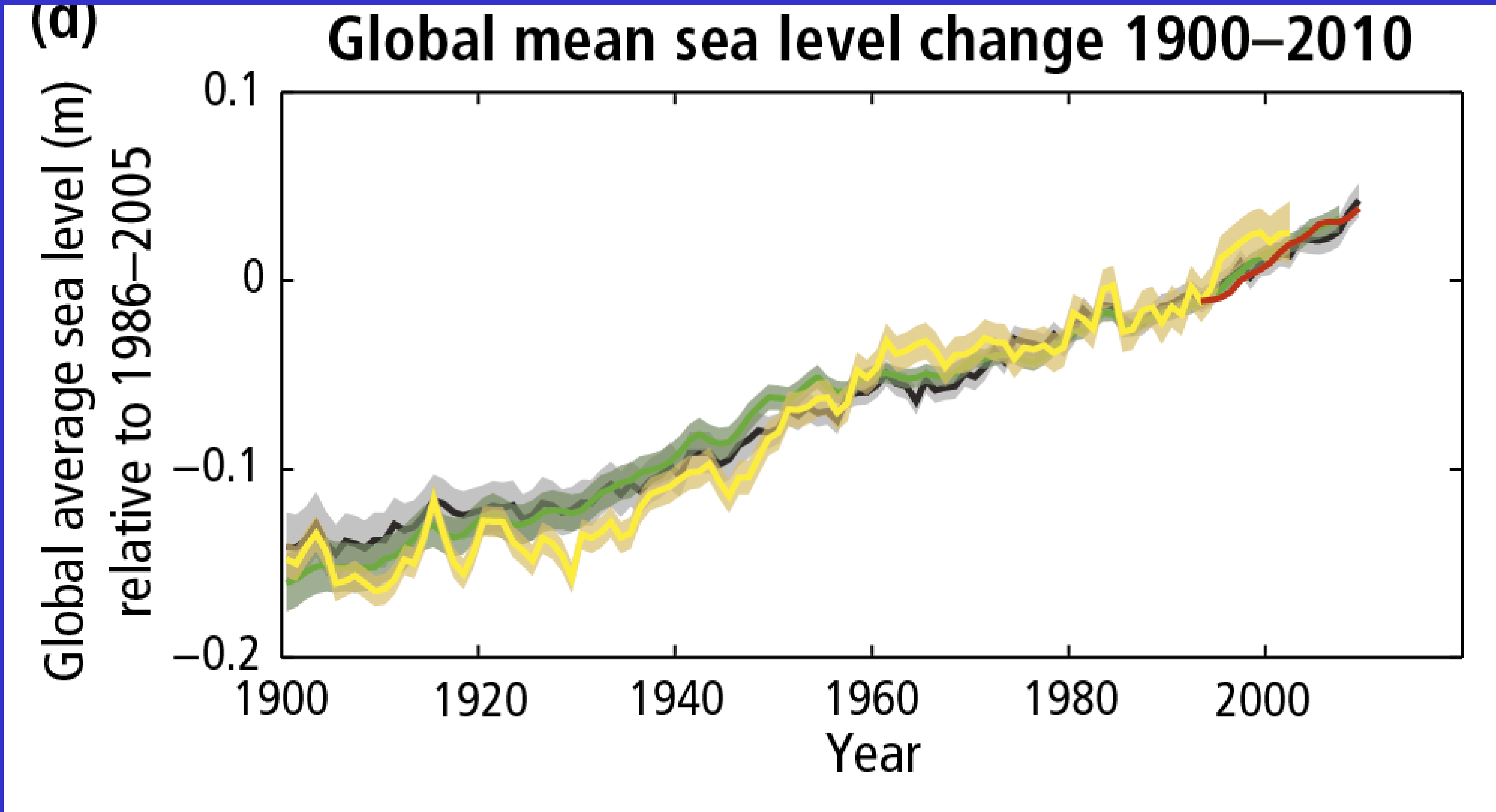
- Confidence in precipitation change averaged over global land areas since 1901 is low prior to 1951 and medium afterwards.
- Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has likely increased since 1901 (medium confidence before and high confidence after 1951).
- For other latitudes area-averaged long-term positive or negative trends have low confidence

Global Sea Level Has Risen



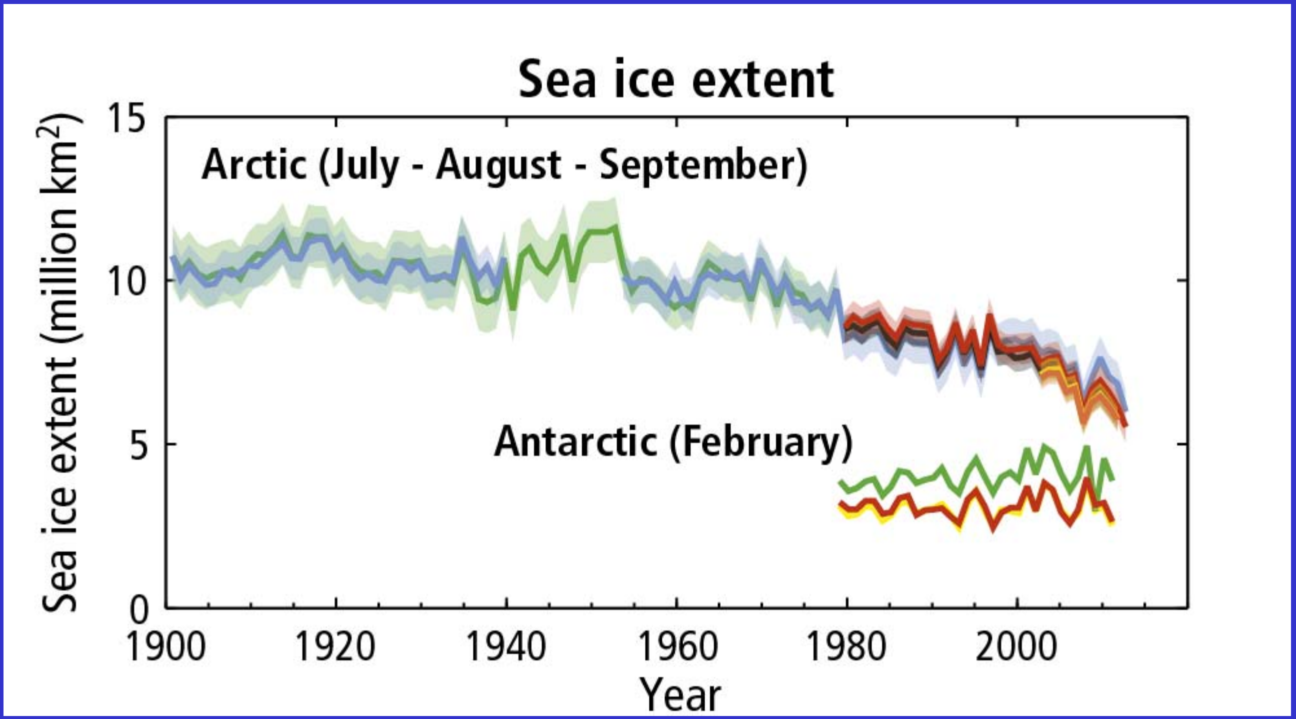
Tidal gauge data show that global average sea level rose between 10 and 20 cm during the 20th.

Global Sea Level Change (AR5)



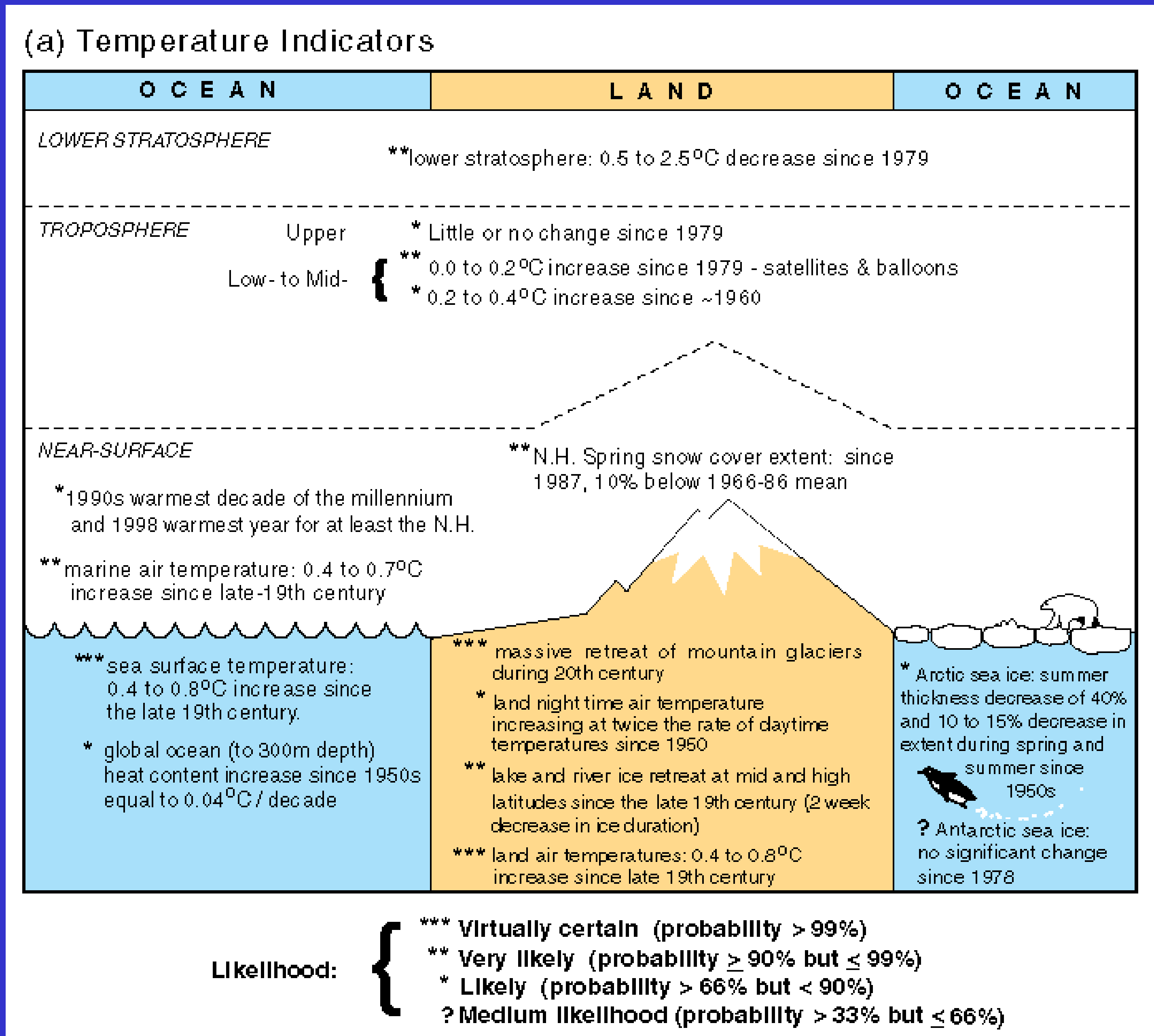
- Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.
- The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (high confidence).

Changes in Cryosphere (AR5)



- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass (high confidence).
- Glaciers have continued to shrink almost worldwide (high confidence).
- Northern Hemisphere spring snow cover has continued to decrease in extent (high confidence).
- There is high confidence that there are strong regional differences in the trend in Antarctic sea ice extent, with a very likely increase in total extent.

Summary from TAR



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Changes in Extreme Weather/Climate Events (AR5)

Table SPM.1 | Extreme weather and climate events: Global-scale assessment of recent observed changes, human contribution to the changes, and projected further changes for the early (2016–2035) and late (2081–2100) 21st century. Bold indicates where the AR5 (black) provides a revised* global-scale assessment from the SREX (blue) or AR4 (red). Projections for early 21st century were not provided in previous assessment reports. Projections in the AR5 are relative to the reference period of 1986–2005, and use the new Representative Concentration Pathway (RCP) scenarios (see Box SPM.1) unless otherwise specified. See the Glossary for definitions of extreme weather and climate events.

Phenomenon and direction of trend	Assessment that changes occurred (typically since 1950 unless otherwise indicated)	Assessment of a human contribution to observed changes	Likelihood of further changes	
			Early 21st century	Late 21st century
Warmer and/or fewer cold days and nights over most land areas	*Very likely* {2.6} *Very likely* *Very likely*	***Very likely*** {10.6} *Likely* *Likely*	*Likely* {11.3}	*Virtually certain* {12.4} *Virtually certain* *Virtually certain*
Warmer and/or more frequent hot days and nights over most land areas	*Very likely* {2.6} *Very likely* *Very likely*	***Very likely*** {10.6} *Likely* *Likely* (nights only)	*Likely* {11.3}	*Virtually certain* {12.4} *Virtually certain* *Virtually certain*
Warm spells/heat waves. Frequency and/or duration increases over most land areas	***Medium confidence*** on a global scale *Likely* in large parts of Europe, Asia and Australia {2.6} *Medium confidence* in many (but not all) regions *Likely*	***Likely***[a] {10.6} Not formally assessed *More likely than not*	Not formally assessed[b] {11.3}	*Very likely* {12.4} *Very likely* *Very likely*
Heavy precipitation events. Increase in the frequency, intensity, and/or amount of heavy precipitation	*Likely* more land areas with increases than decreases[c] {2.6} *Likely* more land areas with increases than decreases *Likely* over most land areas	***Medium confidence*** {7.6, 10.6} *Medium confidence* *More likely than not*	*Likely* over many land areas {11.3}	***Very likely*** over most of the mid-latitude land masses and over wet tropical regions {12.4} *Likely* over many areas *Very likely* over most land areas
Increases in intensity and/or duration of drought	***Low confidence*** on a global scale *Likely* changes in some regions[d] {2.6} *Medium confidence* in some regions *Likely* in many regions, since 1970[e]	***Low confidence*** {10.6} *Medium confidence*[f] *More likely than not*	*Low confidence*[g] {11.3}	***Likely*** *(medium confidence)* on a regional to global scale[h] {12.4} *Medium confidence* in some regions *Likely*[e]
Increases in intense tropical cyclone activity	***Low confidence*** in long term (centennial) changes *Virtually certain* in North Atlantic since 1970 {2.6} *Low confidence* *Likely* in some regions, since 1970	***Low confidence***[i] {10.6} *Low confidence* *More likely than not*	*Low confidence* {11.3}	***More likely than not*** in the Western North Pacific and North Atlantic[j] {14.6} *More likely than not* in some basins *Likely*
Increased incidence and/or magnitude of extreme high sea level	*Likely* (since 1970) {3.7} *Likely* (late 20th century) *Likely*	***Likely***[k] {3.7} *Likely*[k] *More likely than not*[k]	*Likely*[l] {13.7}	***Very likely***[l] {13.7} *Very likely*[m] *Likely*

* The direct comparison of assessment findings between reports is difficult. For some climate variables, different aspects have been assessed, and the revised guidance note on uncertainties has been used for the SREX and AR5. The availability of new information, improved scientific understanding, continued analyses of data and models, and specific differences in methodologies applied in the assessed studies, all contribute to revised assessment findings.

Notes:

[a] Attribution is based on available case studies. It is *likely* that human influence has more than doubled the probability of occurrence of some observed heat waves in some locations.

[b] Models project near-term increases in the duration, intensity and spatial extent of heat waves and warm spells.

[c] In most continents, *confidence* in trends is not higher than *medium* except in North America and Europe where there have been *likely* increases in either the frequency or intensity of heavy precipitation with some seasonal and/or regional variation. It is *very likely* that there have been increases in central North America.

[d] The frequency and intensity of drought has *likely* increased in the Mediterranean and West Africa, and *likely* decreased in central North America and north-west Australia.

[e] AR4 assessed the area affected by drought.

[f] SREX assessed *medium confidence* that anthropogenic influence had contributed to some changes in the drought patterns observed in the second half of the 20th century, based on its attributed impact on precipitation and temperature changes. SREX assessed *low confidence* in the attribution of changes in droughts at the level of single regions.

[g] There is *low confidence* in projected changes in soil moisture.

[h] Regional to global-scale projected decreases in soil moisture and increased agricultural drought are *likely (medium confidence)* in presently dry regions by the end of this century under the RCP8.5 scenario. Soil moisture drying in the Mediterranean, Southwest US and southern African regions is consistent with projected changes in Hadley circulation and increased surface temperatures, so there is *high confidence* in *likely* surface drying in these regions by the end of this century under the RCP8.5 scenario.

[i] There is *medium confidence* that a reduction in aerosol forcing over the North Atlantic has contributed at least in part to the observed increase in tropical cyclone activity since the 1970s in this region.

[j] Based on expert judgment and assessment of projections which use an SRES A1B (or similar) scenario.

[k] Attribution is based on the close relationship between observed changes in extreme and mean sea level.

[l] There is *high confidence* that this increase in extreme high sea level will primarily be the result of an increase in mean sea level. There is *low confidence* in region-specific projections of storminess and associated storm surges.

[m] SREX assessed it to be *very likely* that mean sea level rise will contribute to future upward trends in extreme coastal high water levels.

Major Conclusions in SPM

1. An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
2. Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.
3. Confidence in the ability of models to project future climate has increased.
4. There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.
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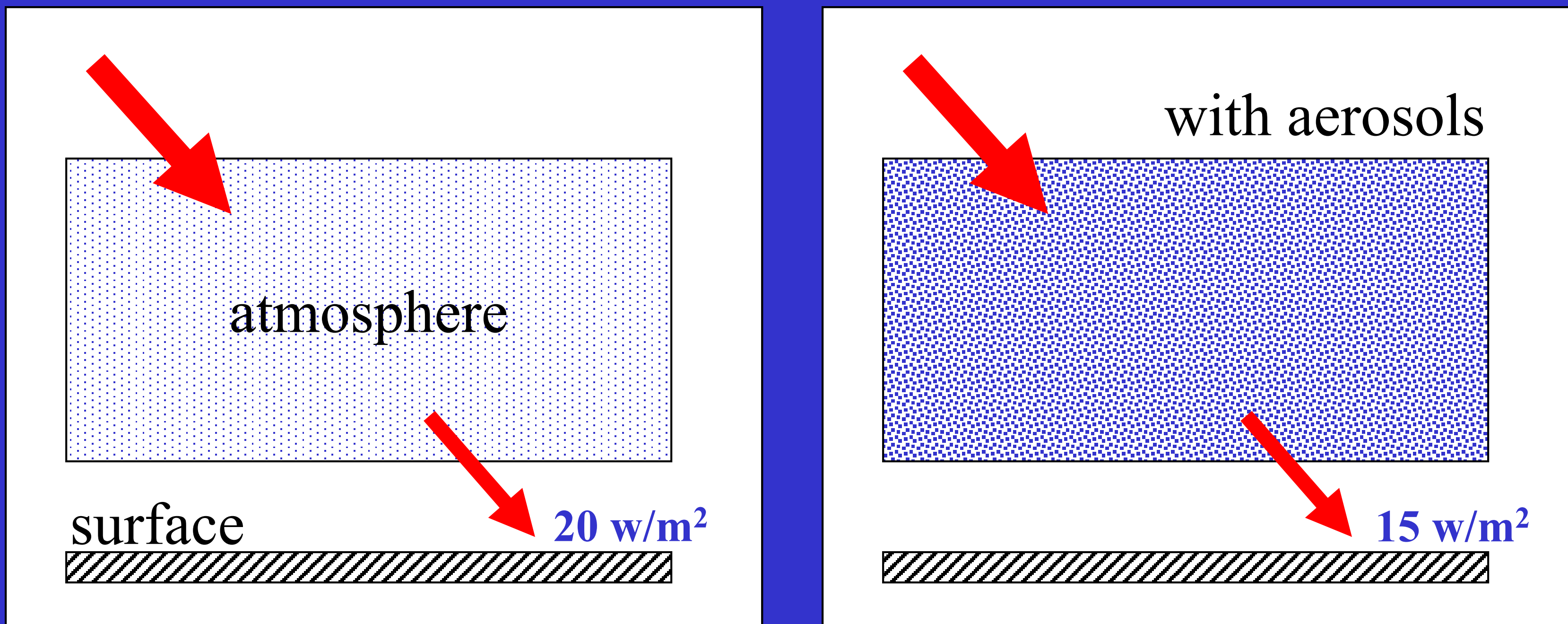
Emissions of Greenhouse Gases and Aerosols

- Concentrations of atmospheric greenhouse gases and their radiative forcing have continued to increase as a result of human activities.
- Anthropogenic aerosols are short-lived and mostly produce negative radiative forcing.

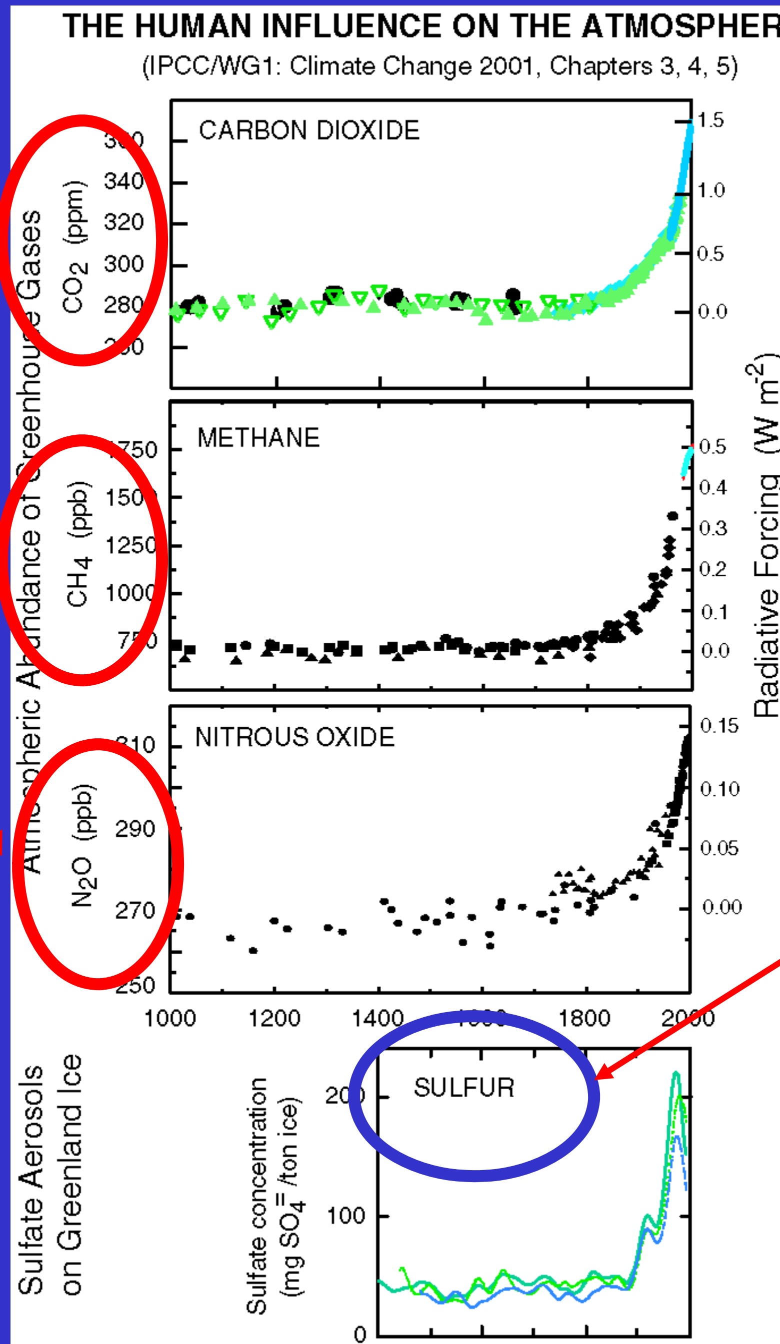
Radiative Forcing



radiative forcing of the aerosols = 15-20 = -5 w/m^2

- *Radiative forcing* is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, and is an index of the importance of the factor as a potential climate change mechanism. It is expressed in Watts per square meter (Wm^{-2}).

Produce Positive Radiative Forcing



Produce Negative Radiative Forcing

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Increase of CO_2 Concentration

- The atmospheric concentration of carbon dioxide (CO2) has increased by 31% since 1750. The present CO2 concentration has not been exceeded during the past 420,000 years and likely not during the past 20 million years. The current rate of increase is unprecedented during at least the past 20,000 years.
- About three-quarters of the anthropogenic emissions of CO2 to the atmosphere during the past 20 years is due to fossil fuel burning. The rest is predominantly due to land-use change, especially deforestation.
- Currently the ocean and the land together are taking up about half of the anthropogenic CO2 emissions. On land, the uptake of anthropogenic CO2 very likely exceeded the release of CO2 by deforestation during the 1990s.

The Missing Carbon Sink

Human Inject 6 Gigaton of Carbon Into the Atmosphere (per year)

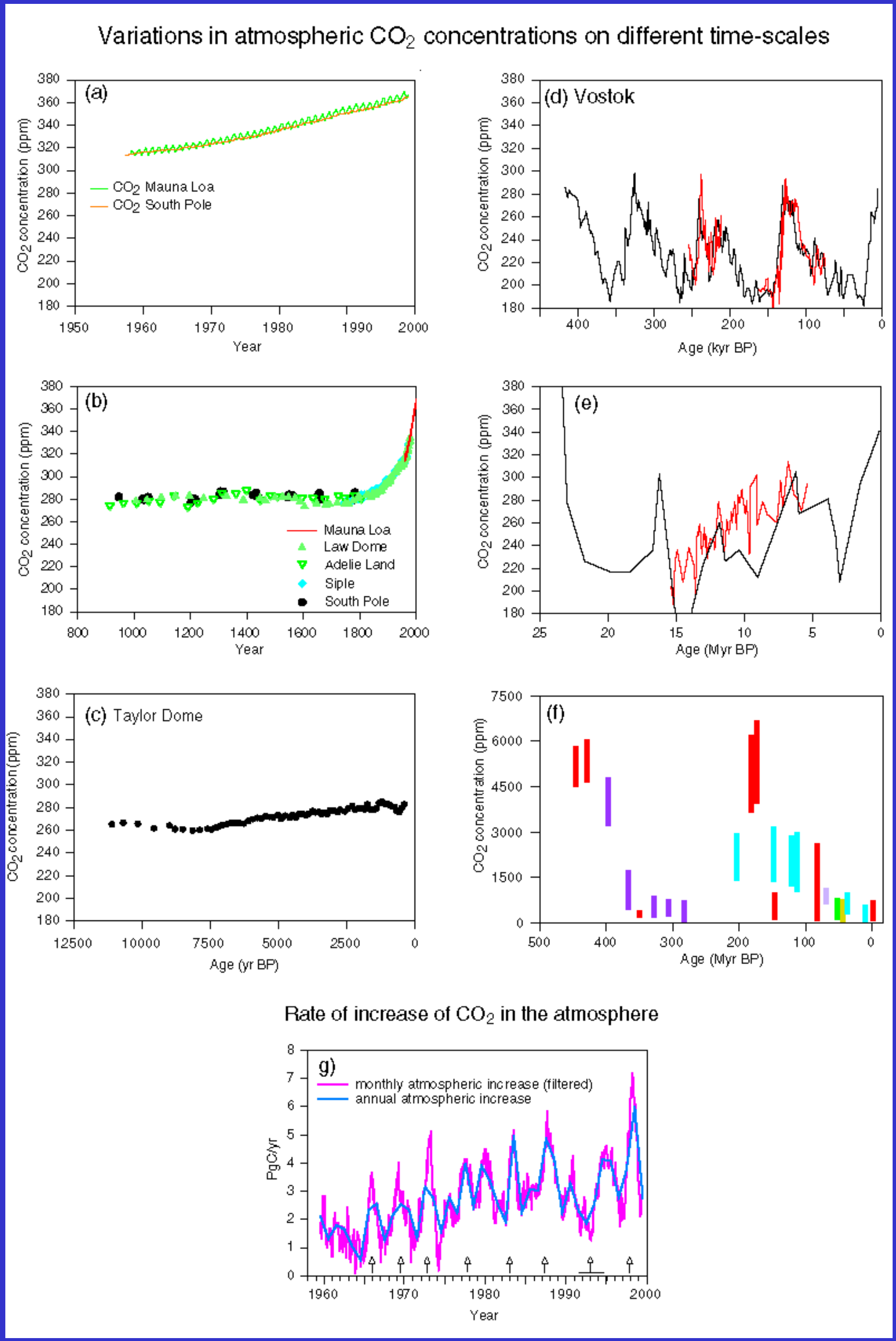
3 Gigaton Remains in the Atmosphere

1.5 Gigaton Is Absorbed By the Ocean

?

Where Is he Missing 1.5 Gigaton (Sink)?

(Is this missing sink going to be saturated soon?)



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Ocean Acidification

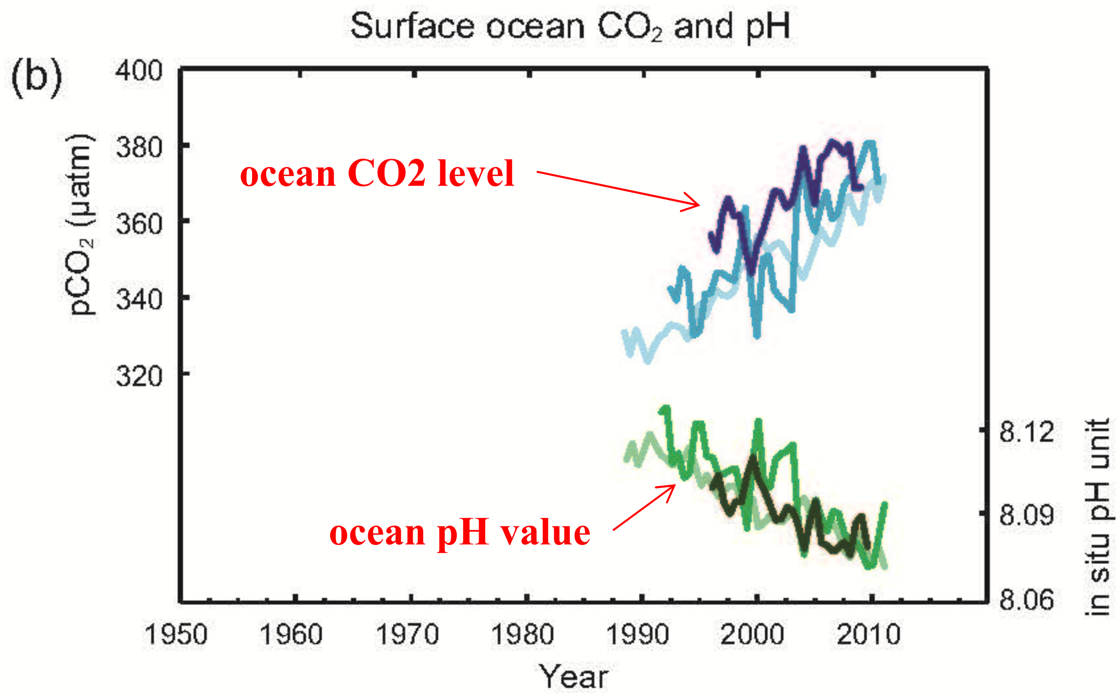


Figure SPM.4 | Multiple observed indicators of a changing global carbon cycle: (a) atmospheric concentrations of carbon dioxide (CO_2) from Mauna Loa (19°32'N, 155°34'W – red) and South Pole (89°59'S, 24°48'W – black) since 1958; (b) partial pressure of dissolved CO_2 at the ocean surface (blue curves) and in situ pH (green curves), a measure of the acidity of ocean water. Measurements are from three stations from the Atlantic (29°10'N, 15°30'W – dark blue/dark green; 31°40'N, 64°10'W – blue/green) and the Pacific Oceans (22°45'N, 158°00'W – light blue/light green). Full details of the datasets shown here are provided in the underlying report and the Technical Summary Supplementary Material. {Figures 2.1 and 3.18; Figure TS.5}

- The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.
- Ocean acidification is quantified by decreases in pH. The pH of ocean surface water has decreased by 0.1 since the beginning of the industrial era (high confidence).

Increase of N_2O Concentration

- The atmospheric concentration of nitrous oxide (N2O) has increased by 46 ppb (17%) since 1750 and continues to increase. The present N2O concentration has not been exceeded during at least the past thousand years.
- About a third of current N2O emissions are anthropogenic (e.g., agricultural soils, cattle feed lots and chemical industry).

Increase of Methane Concentration

- The atmospheric concentration of methane (CH4) has increased by 151% (1060 ppb9) since 1750 and continues to increase.
- The present CH4 concentration has not been exceeded during the past 420,000 years.
- Slightly more than half of current CH4 emissions are anthropogenic (e.g., use of fossil fuels, cattle, rice agriculture and landfills).

Halocarbon Concentration

- Since 1995, the atmospheric concentrations of many of those halocarbon gases that are both ozone-depleting and greenhouse gases (e.g., $CFCl_3$ and CF_2Cl_2), are either increasing more slowly or decreasing, both in response to reduced emissions under the regulations of the Montreal Protocol and its Amendments.

- Their substitute compounds (e.g., CHF_2Cl and CF_3CH_2F) and some other synthetic compounds (e.g., perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) are also greenhouse gases, and their concentrations are currently increasing.

Ozone Concentration

- The observed depletion of the stratospheric ozone ($O3$) layer from 1979 to 2000 is estimated to have caused a negative radiative forcing (–0.15 Wm^{-2}).

- The total amount of $O3$ in the troposphere is estimated to have increased by 36% since 1750, due primarily to anthropogenic emissions of several $O3$-forming gases. This corresponds to a positive radiative forcing of 0.35 Wm^{-2}.

Anthropogenic Aerosols

- The major sources of anthropogenic aerosols are fossil fuel and biomass burning. These sources are also linked to degradation of air quality and acid deposition.
- In general, the direct radiative forcing of aerosols is negative (except for black carbon fossil).
- There is much less confidence in the ability to quantify the total aerosol direct effect, and its evolution over time.
- Aerosols also vary considerably by region and respond quickly to changes in emissions.
- In addition to their direct radiative forcing, aerosols have an indirect radiative forcing through their effects on clouds.
- There is now more evidence for this indirect effect, which is negative, although of very uncertain magnitude.

Precipitations

"Precipitation is any liquid or solid water particle that falls from the atmosphere and reaches the ground."

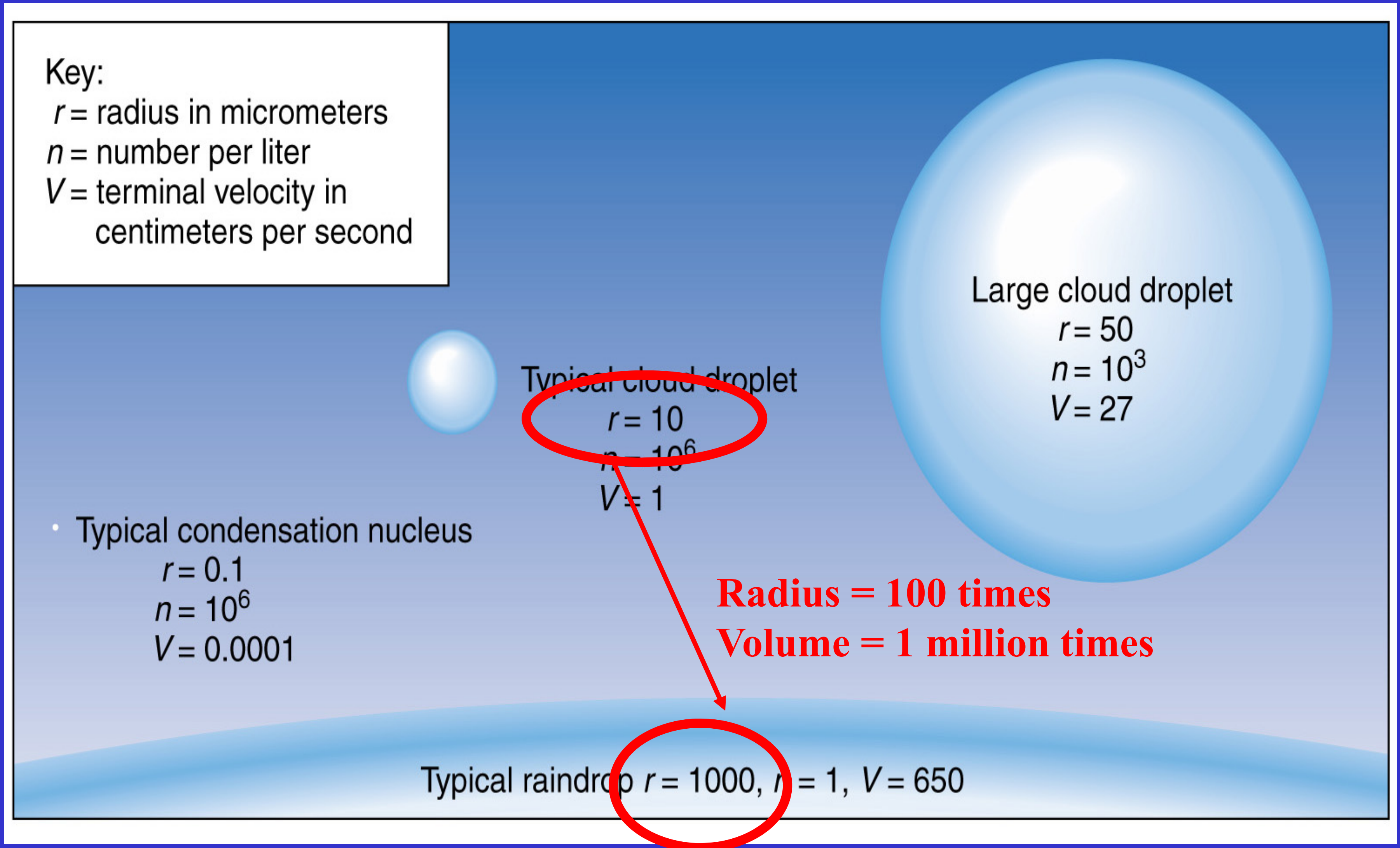
Water Vapor Saturated

↓ Need cloud nuclei

Cloud Droplet formed around Cloud Nuclei

↓ Need to fall down

Precipitation


Key:
r = radius in micrometers
n = number per liter
V = terminal velocity in centimeters per second
Large cloud droplet
r = 50
n = 10^3
V = 27
Typical cloud droplet
r = 10
n = 10^6
V = 1
Typical condensation nucleus
r = 0.1
n = 10^6
V = 0.0001
Radius = 100 times
Volume = 1 million times
Typical raindrop r = 1000, n = 1, V = 650

Cloud Seeding

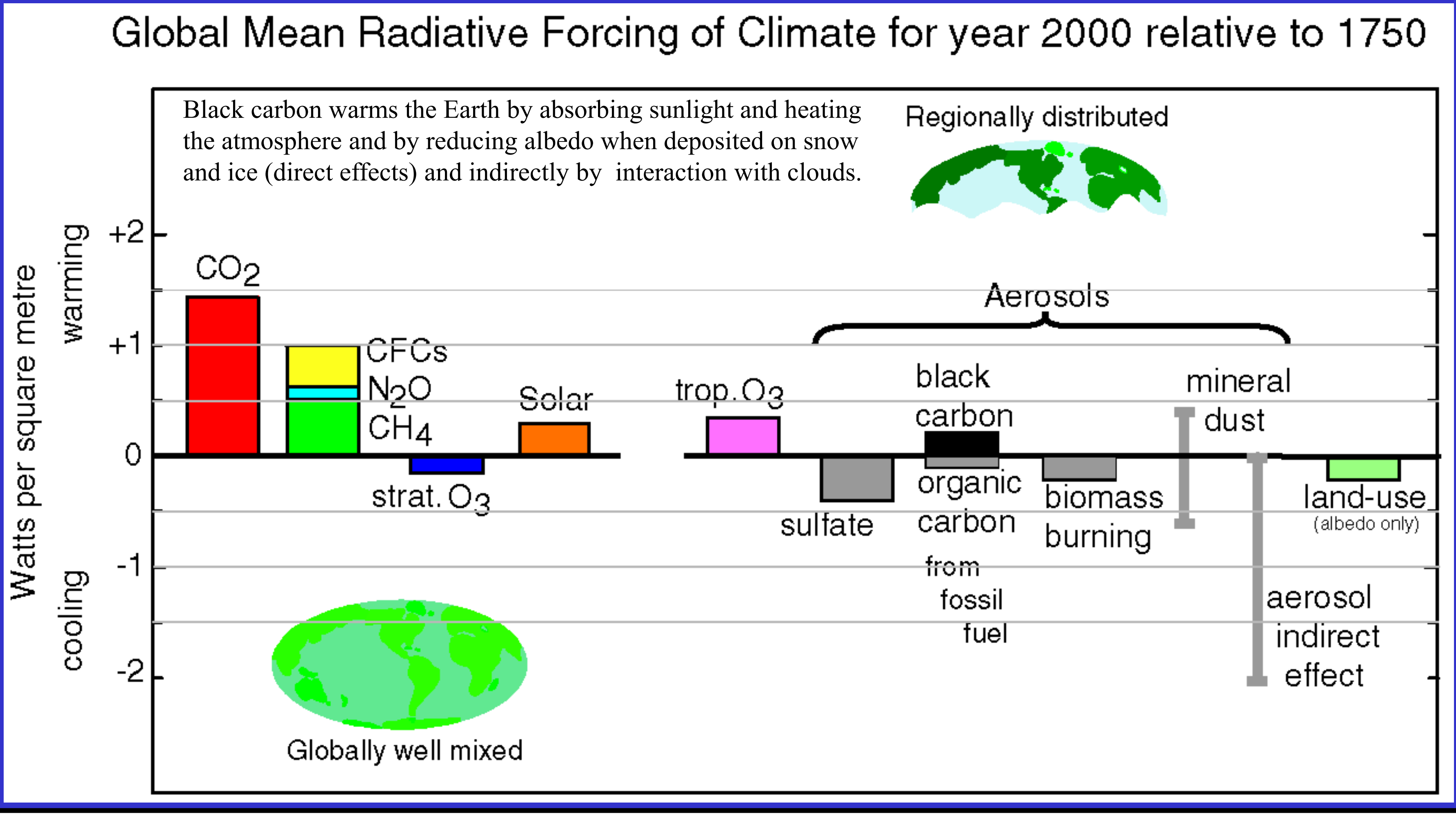
- The objective is to convert some of the supercooled droplets in a cool clouds to ice and cause precipitation by the Bergeron process.
- Two primary methods are used to trigger the precipitation process.
- Dry ice is used to lower cloud temperature to a freezing point in order to stimulate ice crystal production leading to the Bergeron process.
- Silver iodide initiates the Bergeron process by directly acting as freezing nuclei.
- Under ideal conditions, seeding may enhance precipitation by about 10%.

Indirect Effects of Anthropogenic Aerosols

Effect	Cloud Types Affected	Process	Sign of Change in TOA Radiation	Potential Magnitude	Scientific Understanding
Cloud albedo effect	All clouds	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Negative	Medium	Low
Cloud lifetime effect	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby presumably prolonging cloud lifetime	Negative	Medium	Very low
Semi-direct effect	All clouds	Absorption of solar radiation by absorbing aerosols affects static stability and the surface energy budget, and may lead to an evaporation of cloud particles	Positive or negative	Small	Very low
Glaciation indirect effect	Mixed-phase clouds	An increase in IN increases the precipitation efficiency	Positive	Medium	Very low
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets delay freezing causing super-cooled clouds to extend to colder temperatures	Positive or negative	Medium	Very low

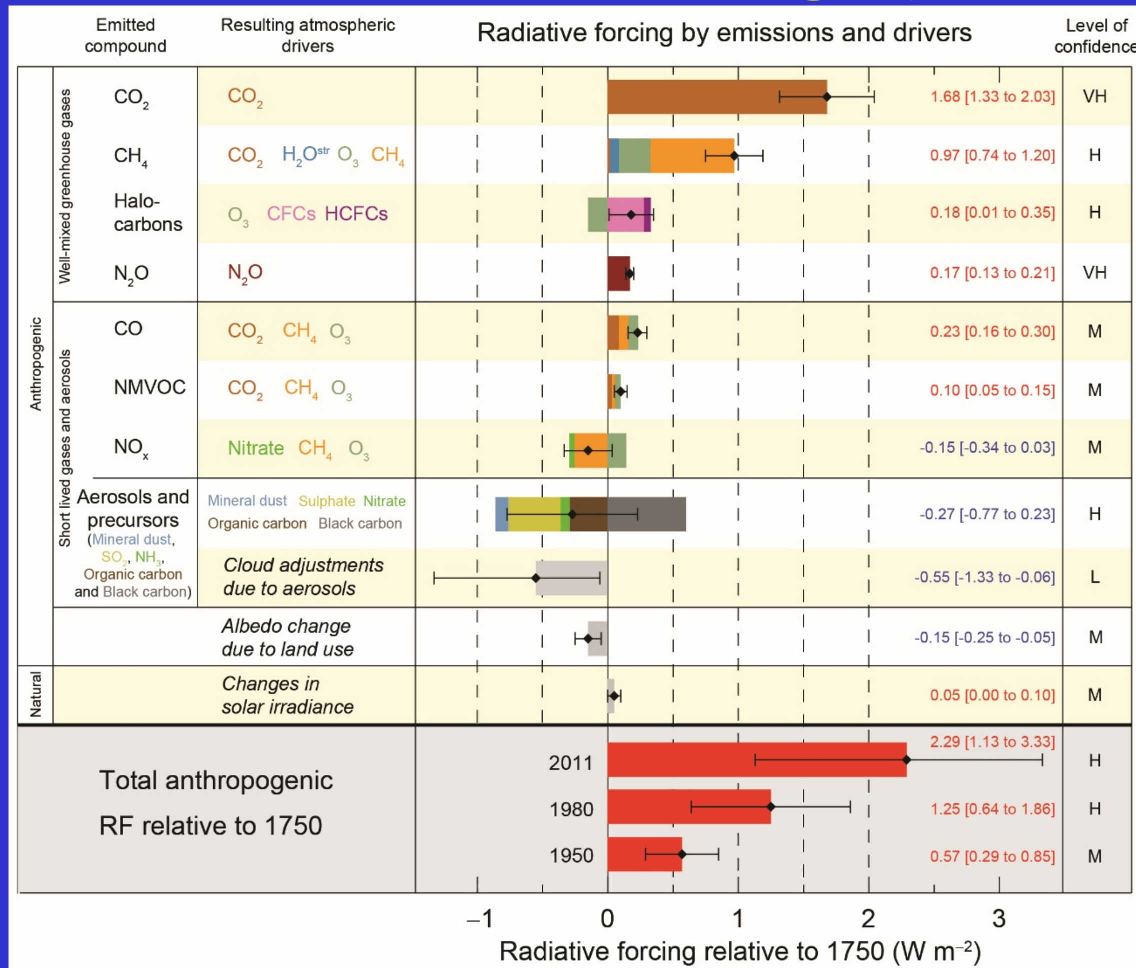
- The indirect effect of anthropogenic aerosols is probably negative, although of very uncertain magnitude.

Radiative Forcing (TAR)



- Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change.
- Radiative forcing (RF) quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750.
- Positive RF leads to surface warming, negative RF leads to surface cooling.

Radiative Forcing (AR5)



- The total anthropogenic RF for 2011 relative to 1750 is 2.29 W m^{-2}, and it has increased more rapidly since 1970 than during prior decades.
- The total natural RF from solar irradiance changes and stratospheric volcanic aerosols made only a small contribution to the net radiative forcing throughout the last century, except for brief periods after large volcanic eruptions.

Natural Factors of Radiative Forcing

- Since the late 1970s, satellite instruments have observed small oscillations due to the 11-year solar cycle. Mechanisms for the amplification of solar effects on climate have been proposed, but currently lack a rigorous theoretical or observational basis.

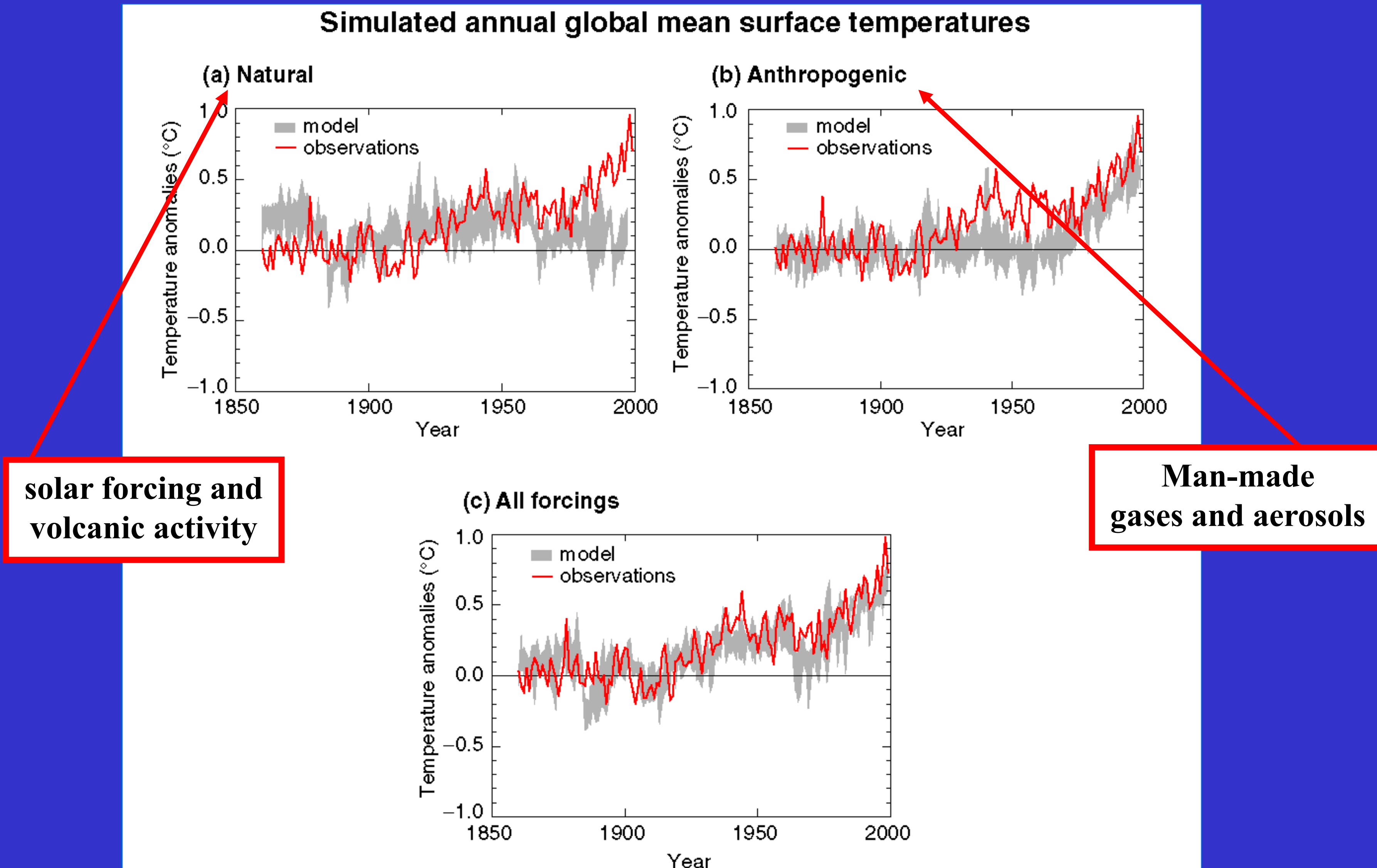
- Stratospheric aerosols from explosive volcanic eruptions lead to negative forcing, which lasts a few years. Several major eruptions occurred in the periods 1880 to 1920 and 1960 to 1991.

- The combined change in radiative forcing of the two major natural factors (solar variation and volcanic aerosols) is estimated to be negative for the past two, and possibly the past four, decades.

Major Conclusions in SPM

1. An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
2. Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.
3. Confidence in the ability of models to project future climate has increased.
4. There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities.
5. Human influences will continue to change atmospheric composition throughout the 21st century.
6. Global average temperature and sea level are projected to rise under all IPCC SRES scenarios.
7. Anthropogenic climate change will persist for many centuries.
8. Further action is required to address remaining gaps in information and understanding.

More Confidence in Climate Models



Evidence of Global Warming

- Detection and attribution studies consistently find evidence for an anthropogenic signal in the climate record of the last 35 to 50 years.
- Simulations of the response to natural forcings alone (i.e., the response to variability in solar irradiance and volcanic eruptions) do not explain the warming in the second half of the 20th century.
- However, they indicate that natural forcings may have contributed to the observed warming in the first half of the 20th century.
- Most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations.

Major Conclusions in SPM

1. An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.
2. Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.
3. Confidence in the ability of models to project future climate has increased.
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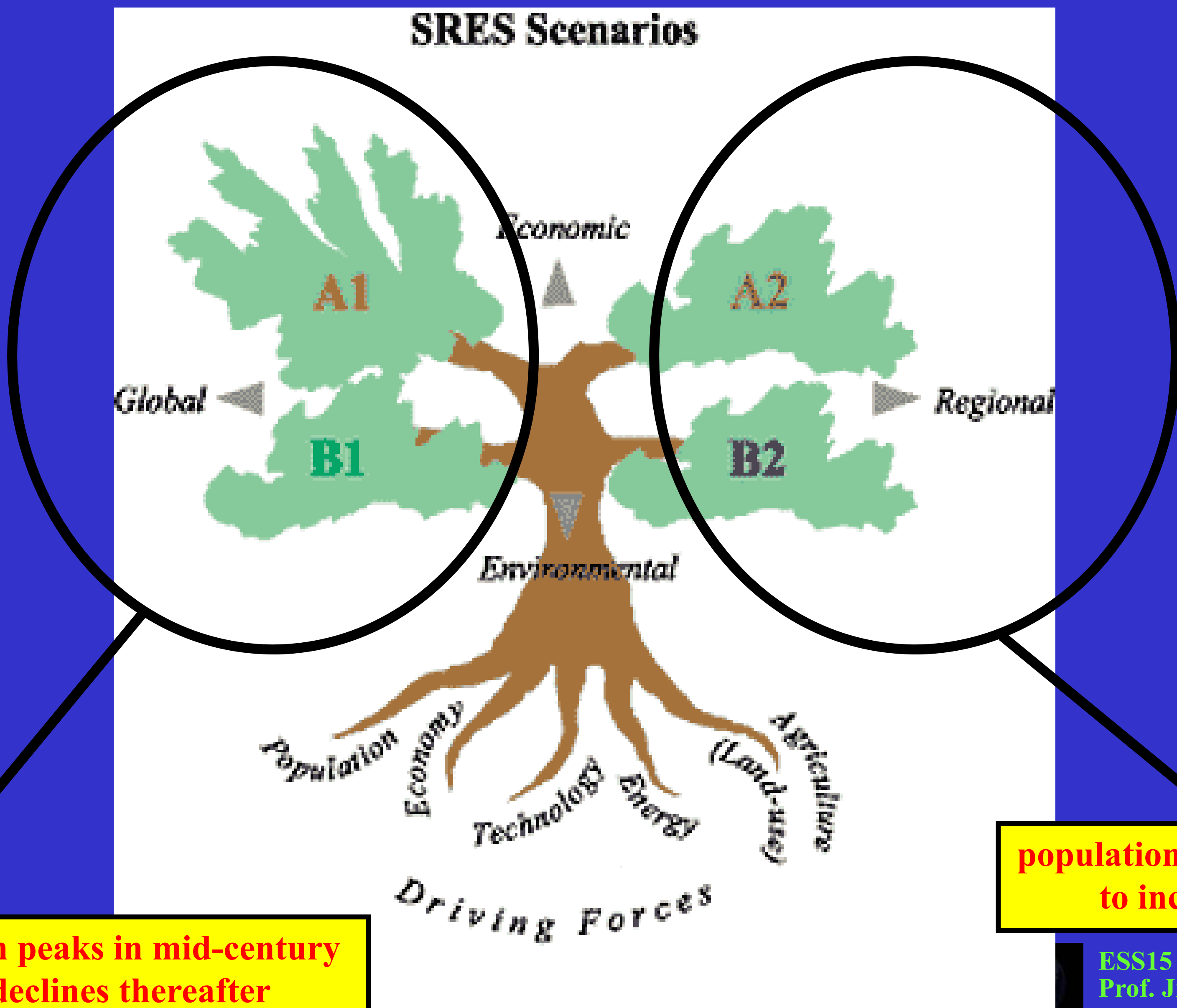
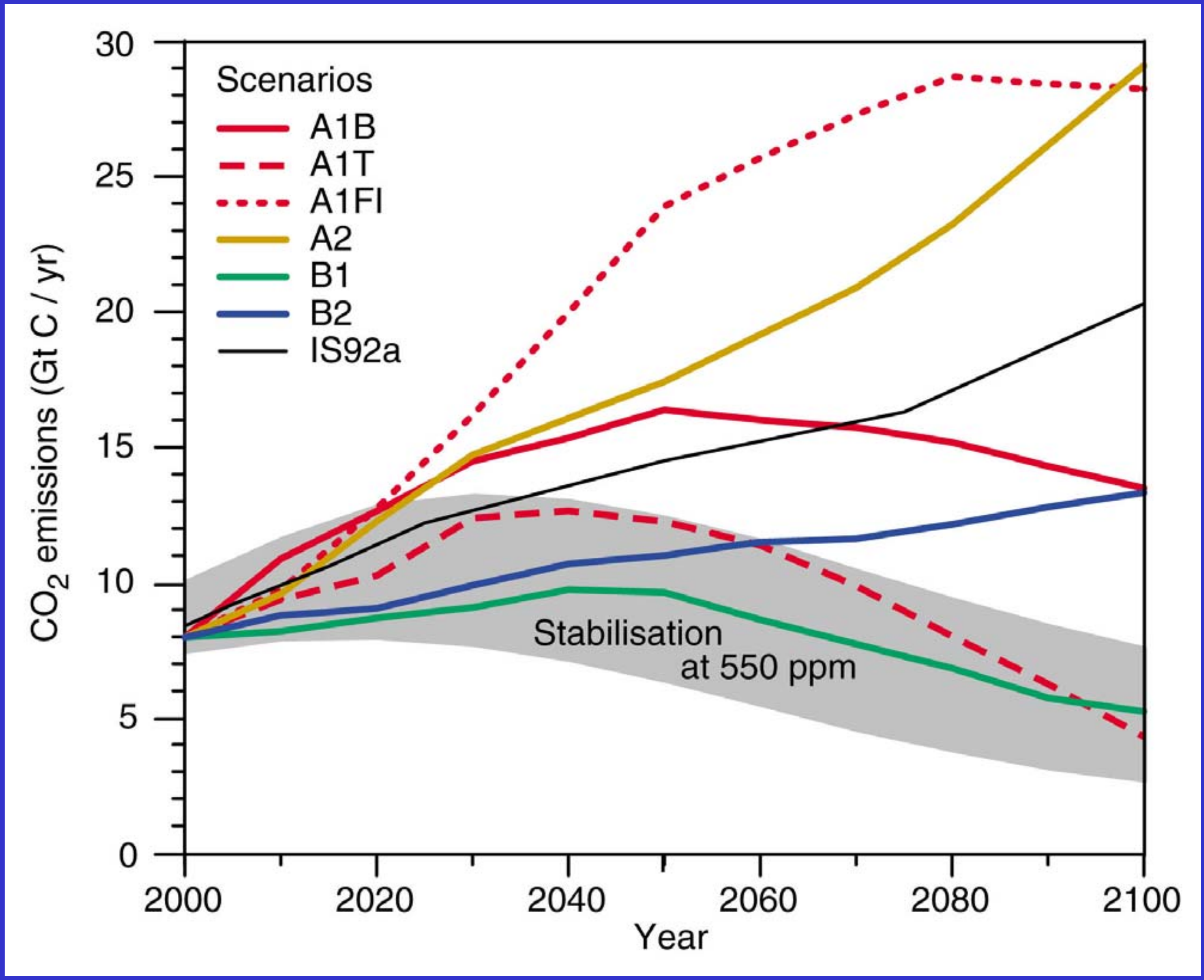
IPCC Special Report on Emission Scenarios (SRES)



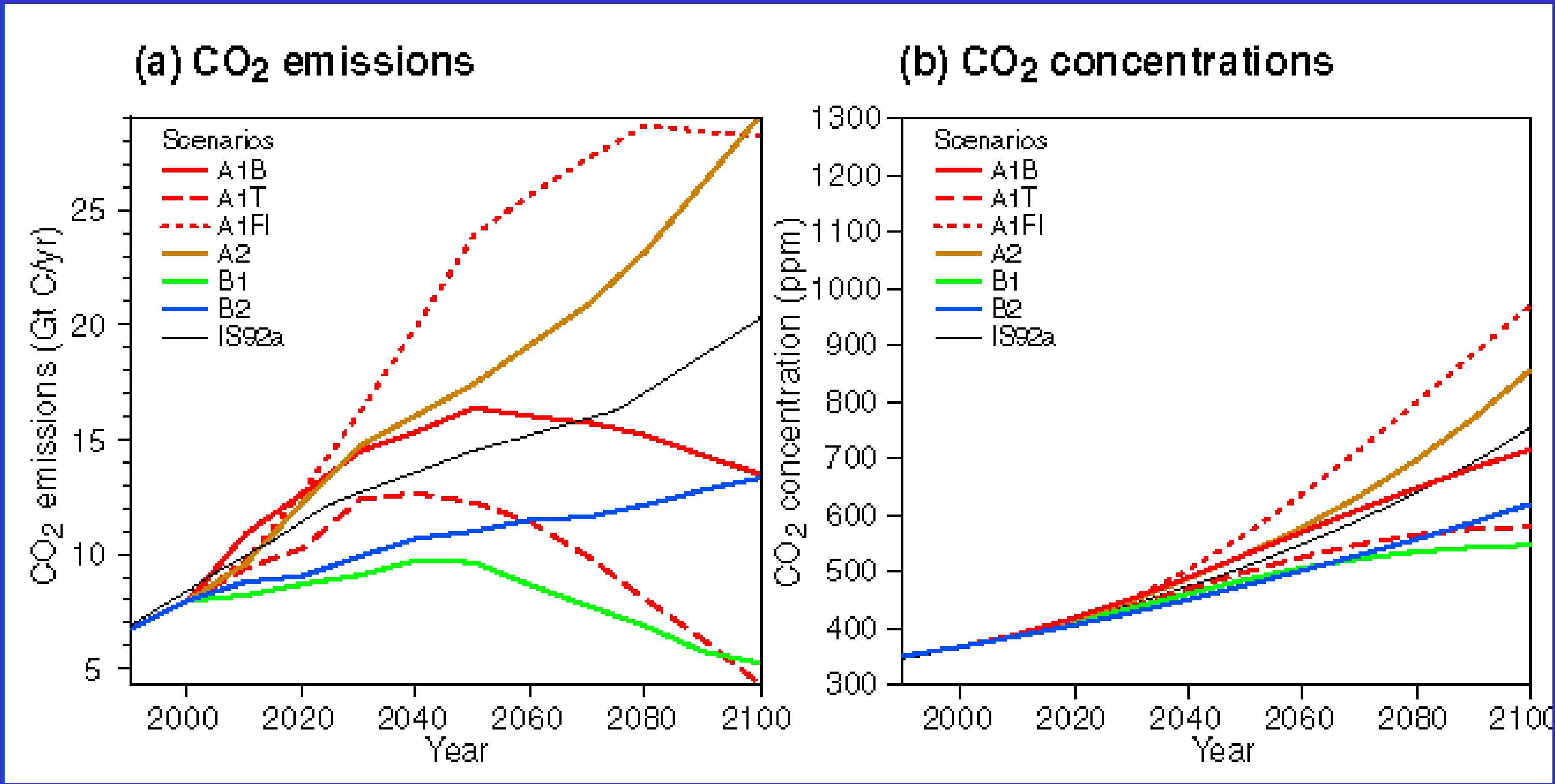
population peaks in mid-century and declines thereafter

population continues to increase

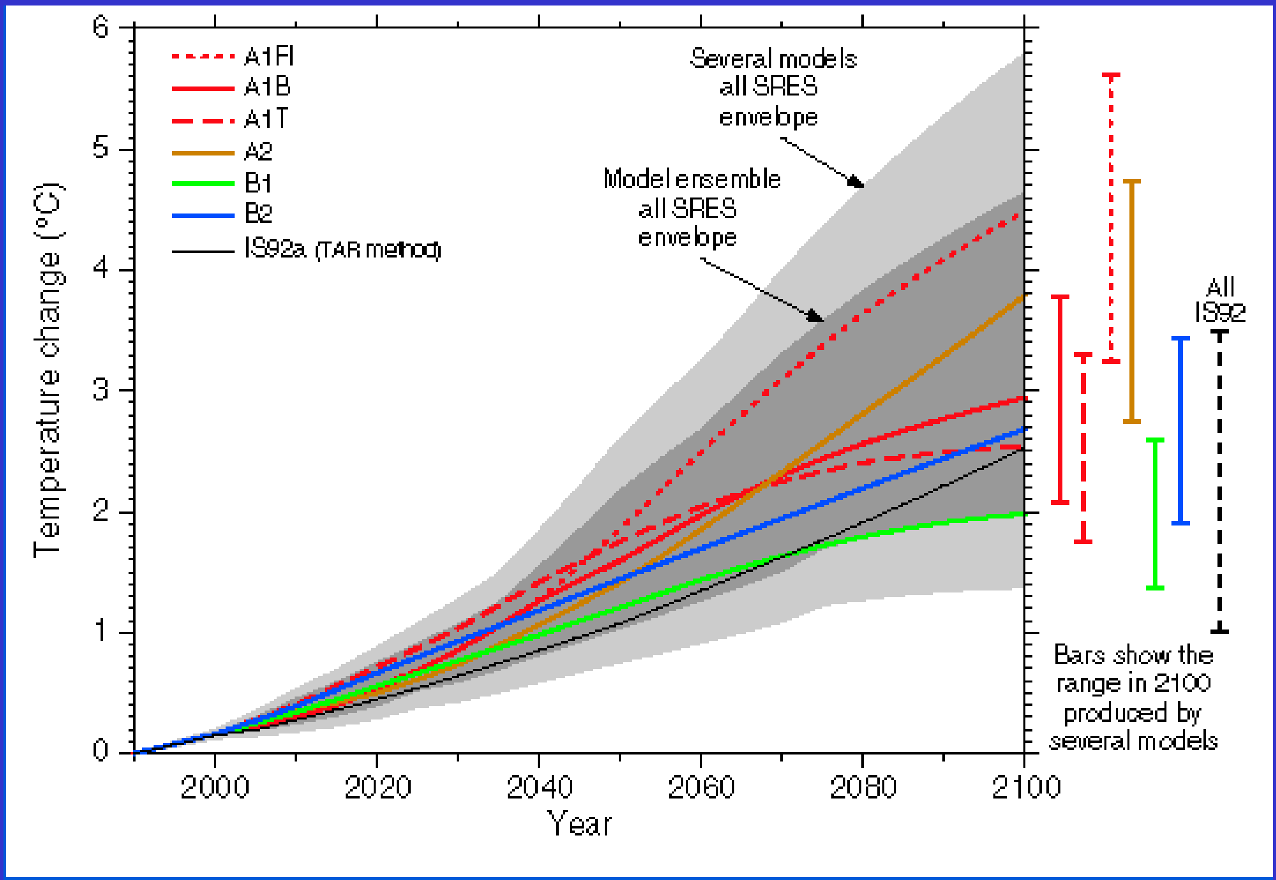
Projected CO2 Emissions



Projected CO2 Concentration



Projected Global Temperature (TAR)



- The globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100.

Global Distribution of The Warming

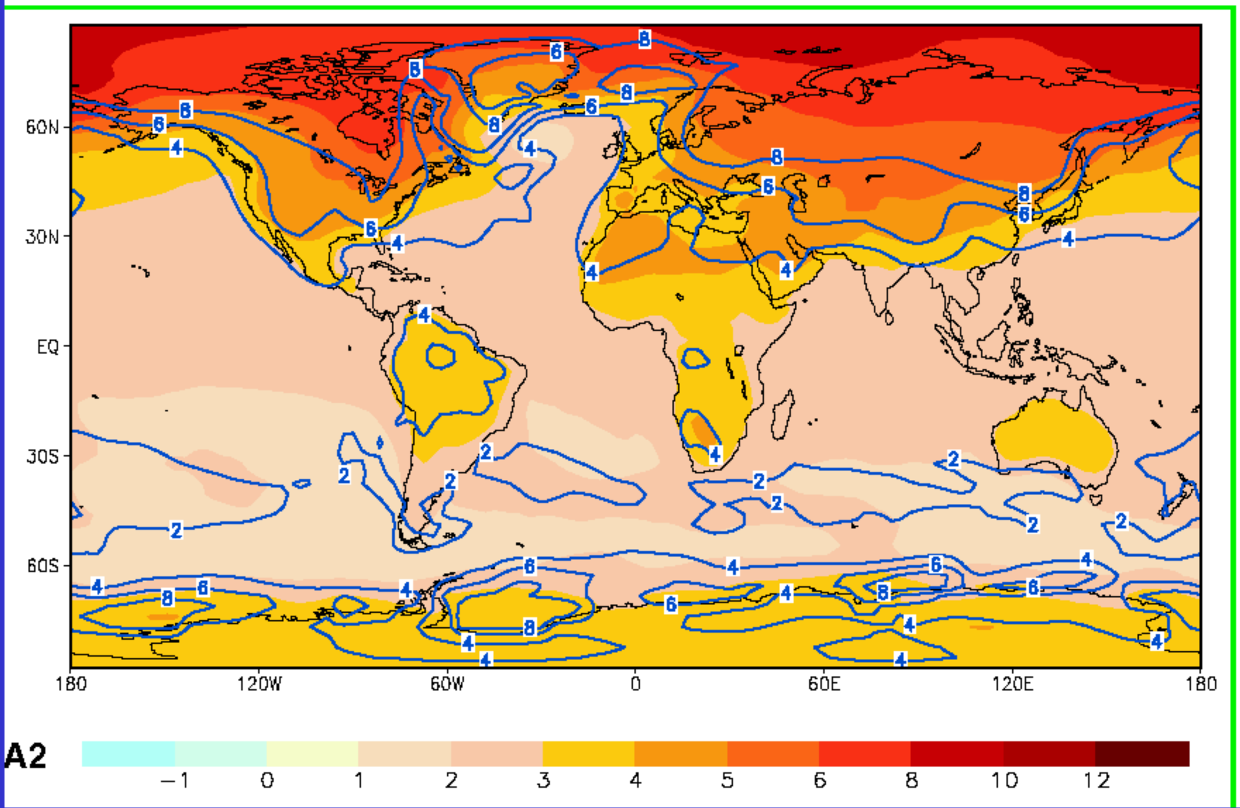
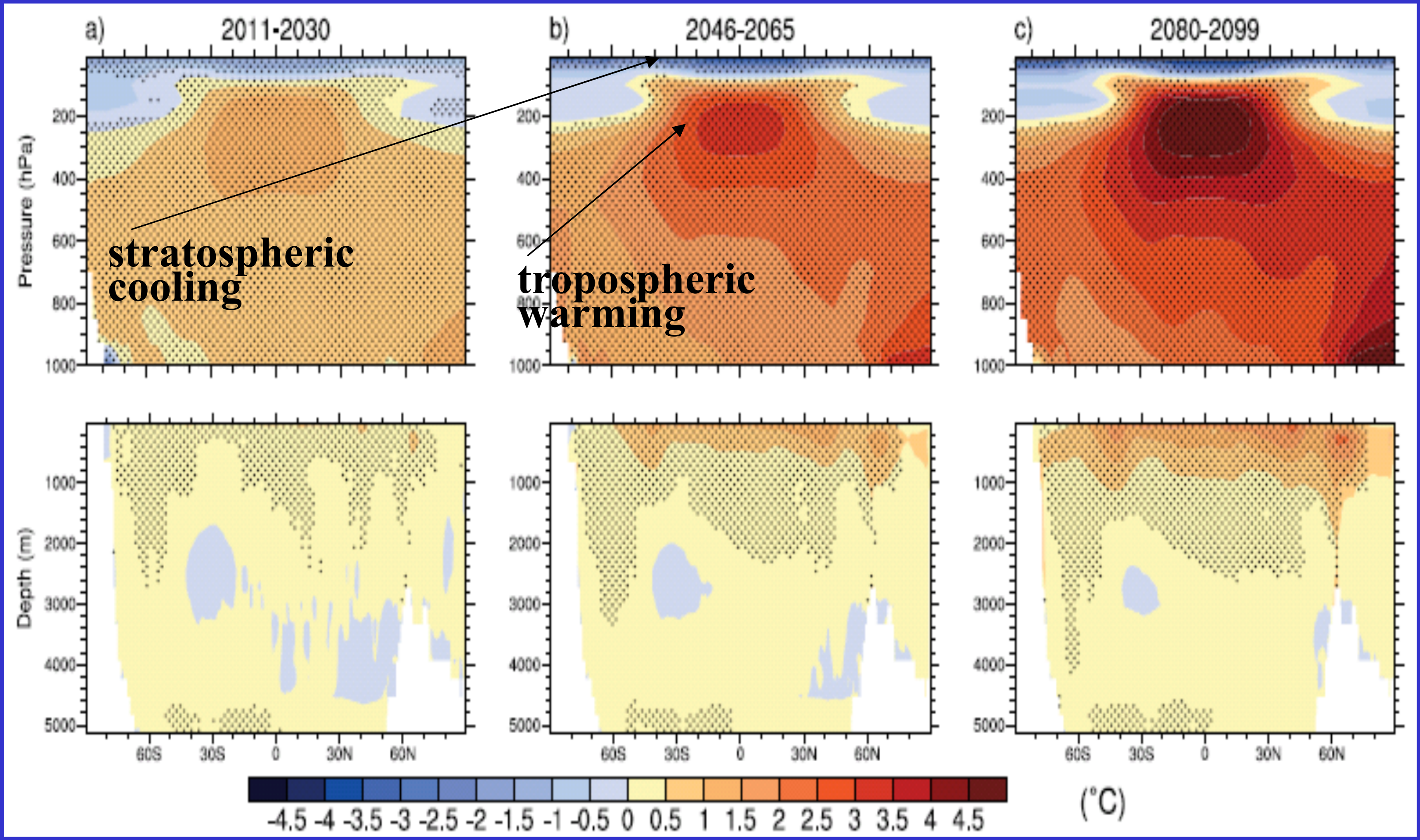


Figure 20: The annual mean change of the temperature (colour shading) and its range (isolines) (Unit: °C) for the SRES scenario A2 (upper panel) and the SRES scenario B2 (lower panel). Both SRES scenarios show the period 2071 to 2100 relative to the period 1961 to 1990 and were performed by OAGCMs. [Based on Figures 9.10d and 9.10e]

It is very likely that nearly all land areas will warm more rapidly than the global average, particularly those at northern high latitudes in the cold season.

Vertical Distribution of Warming (AR4)



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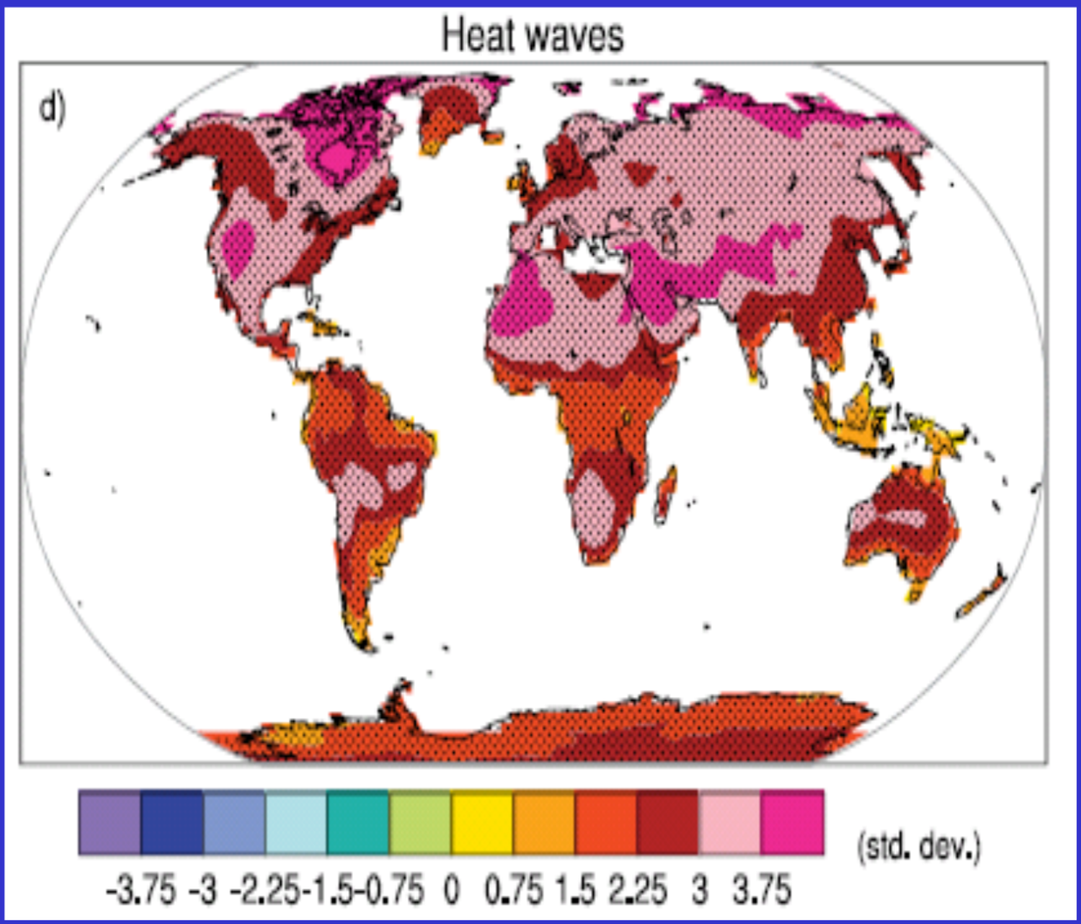
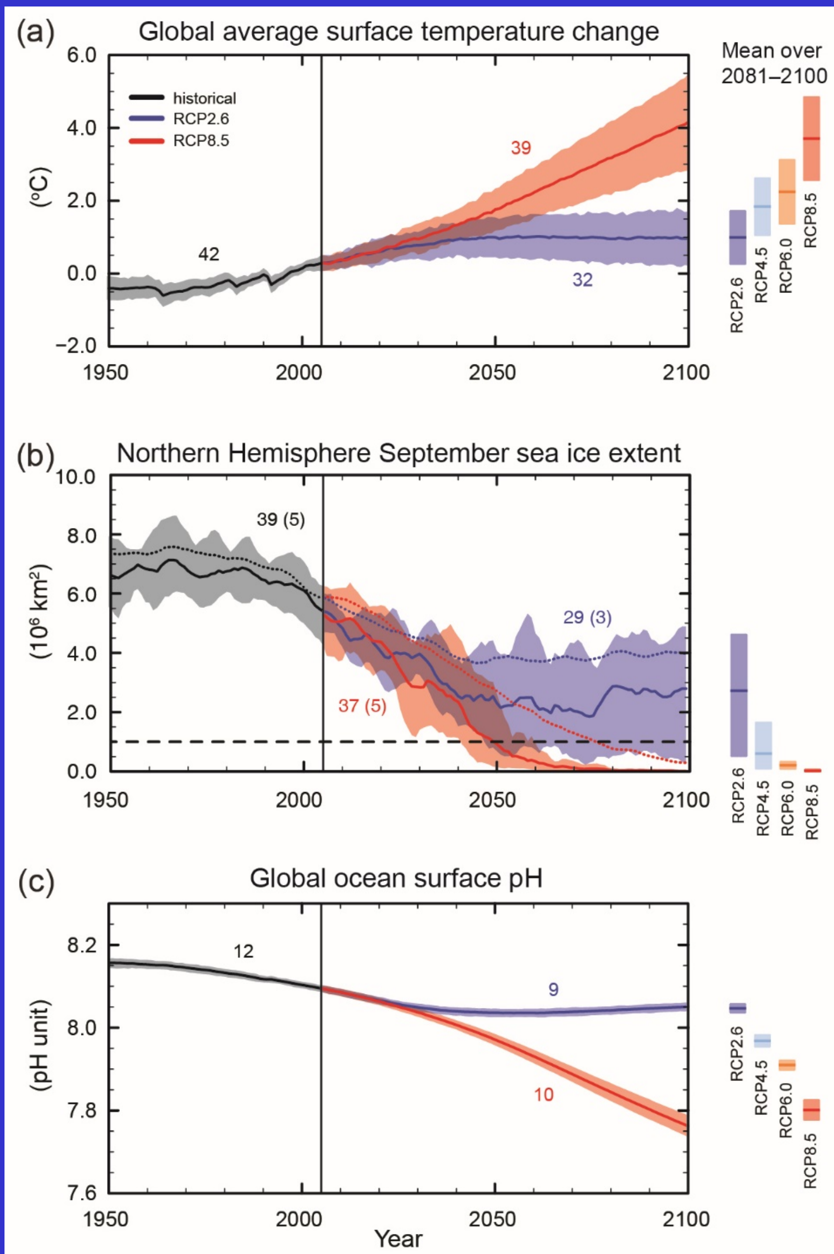
Projected Temperature Extreme (AR4)



- It is *very likely* that heat waves will be more intense, more frequent and longer lasting in a future warmer climate. Cold episodes are projected to decrease significantly.
- Almost everywhere, daily minimum temperatures are projected to increase faster than daily maximum temperatures, leading to a decrease in diurnal temperature range.

Future Projections (AR5)

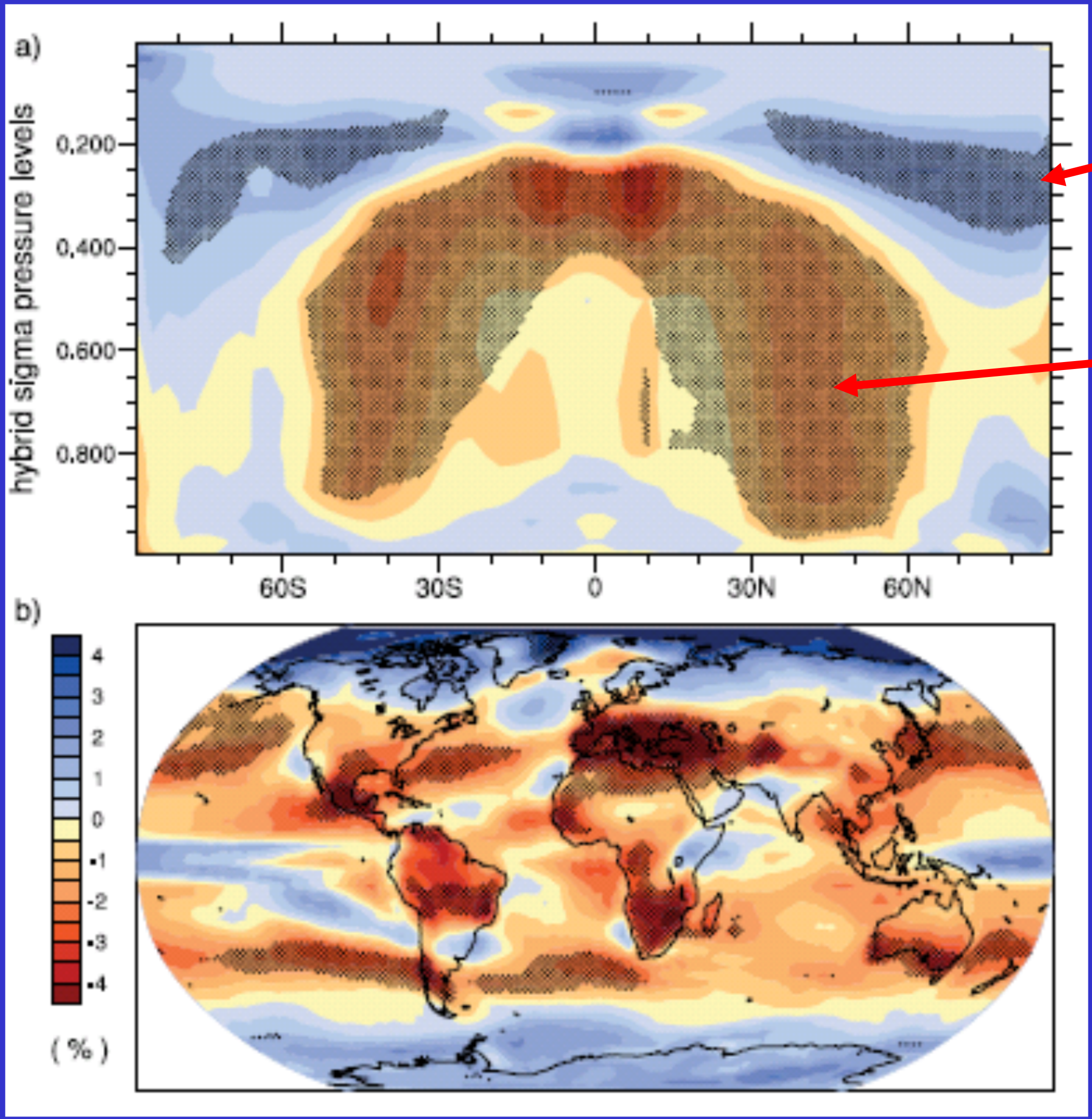


- ❑ Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6.
- ❑ It is very likely that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease.
- ❑ Earth System Models project a global increase in ocean acidification for all RCP scenarios.
- ❑ Most aspects of climate change will persist for many centuries even if emissions of CO2 are stopped.

Projected Precipitation (TAR)

- Based on global model simulations and for a wide range of scenarios, global average water vapor concentration and precipitation are projected to increase during the 21^{st} century.
- By the second half of the 21st century, it is likely that precipitation will have increased over northern mid- to high latitudes and Antarctica in winter.
- At low latitudes there are both regional increases and decreases over land areas.
- Larger year to year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected.

Projected Changes in Cloud Cover (AR4)



more high clouds

less middle clouds

decease cloud cover

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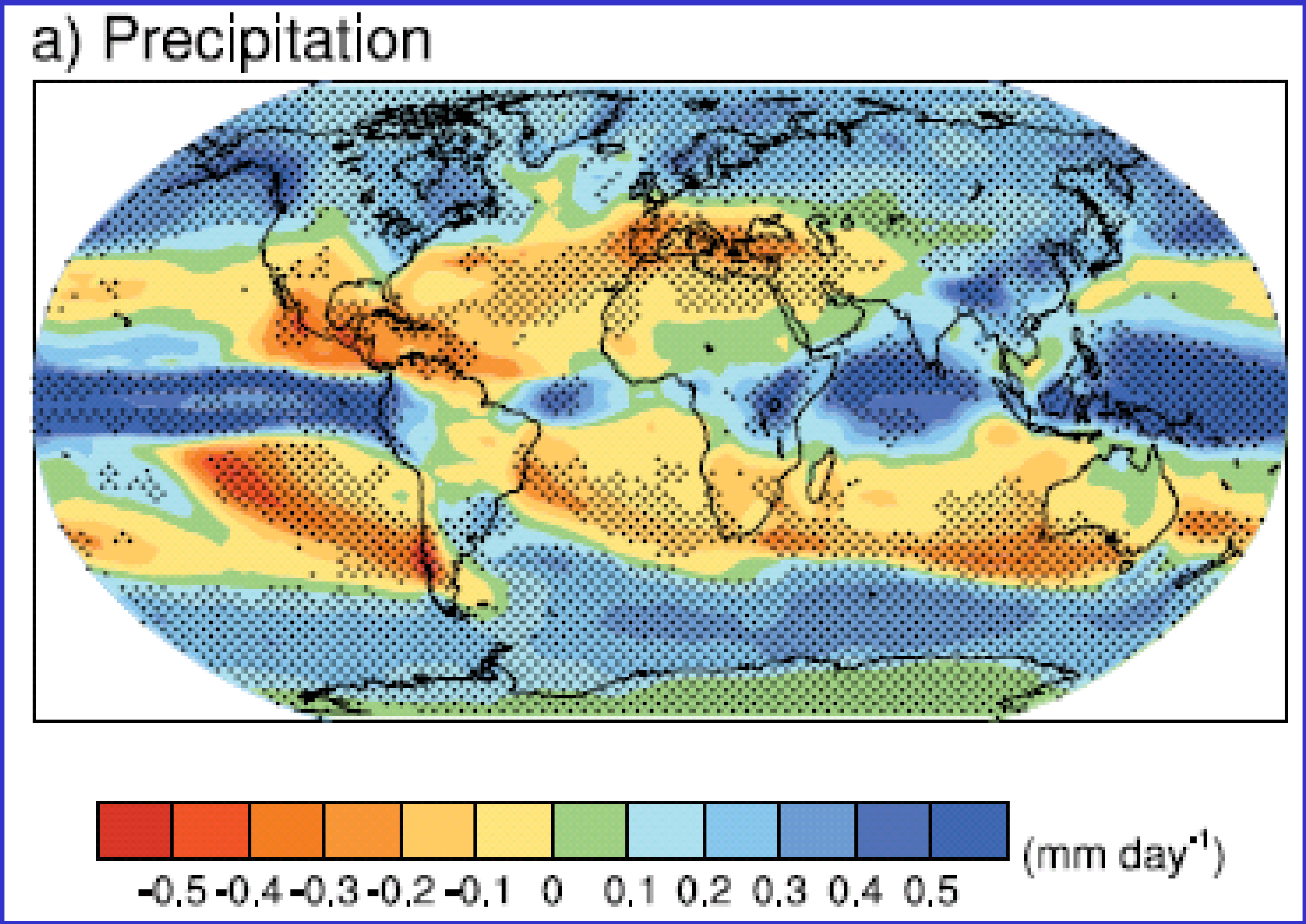
Projected Precipitation Changes (AR4)



- Precipitation generally increases in the areas of regional tropical precipitation maxima (such as the monsoon regimes) and over the tropical Pacific.
- Precipitation generally decreases in the subtropics and increases at high latitudes ➔ due to the poleward shift of the storm track ➔ due to the expansion of the Hadley circulation.

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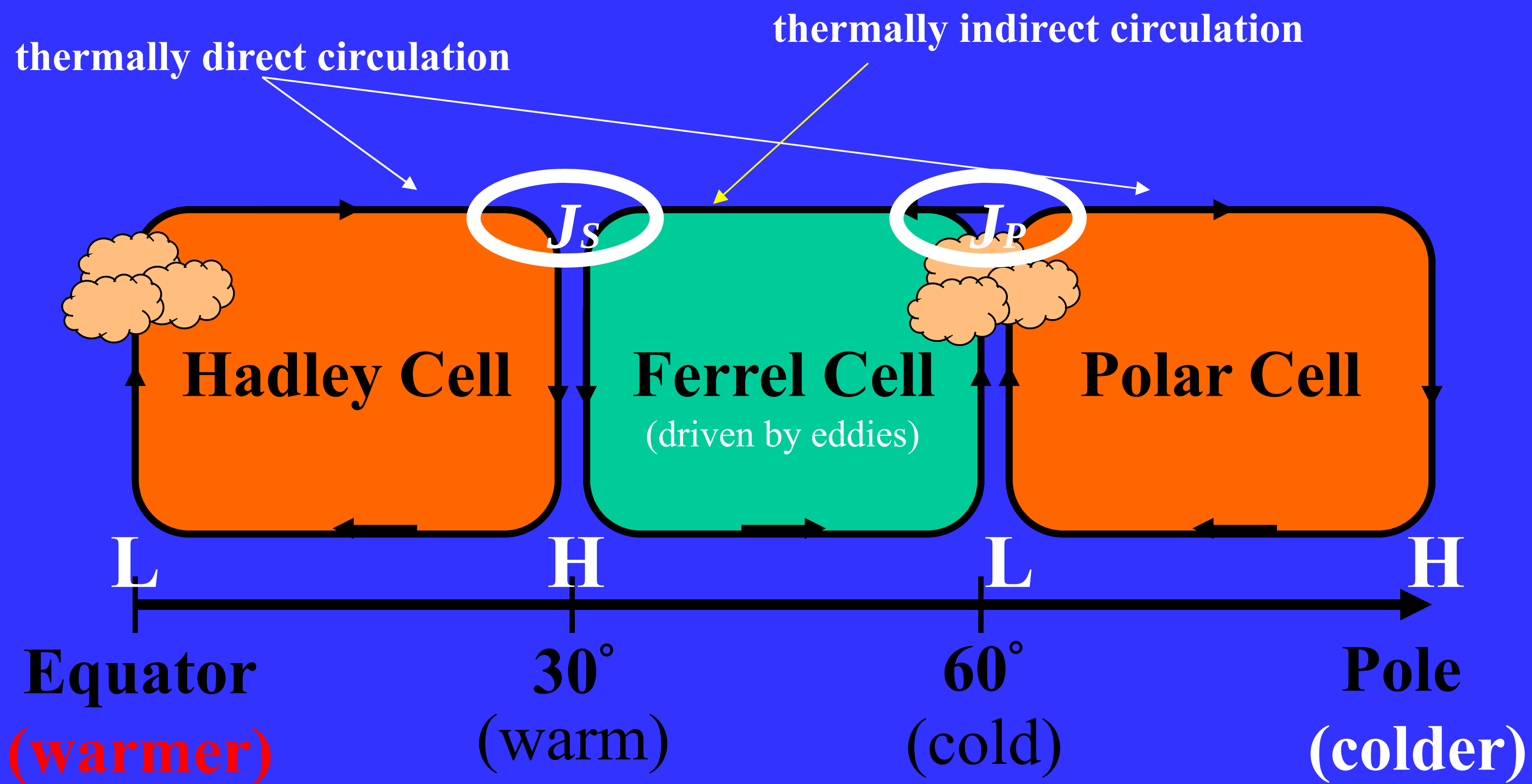
Properties of the Three Cells



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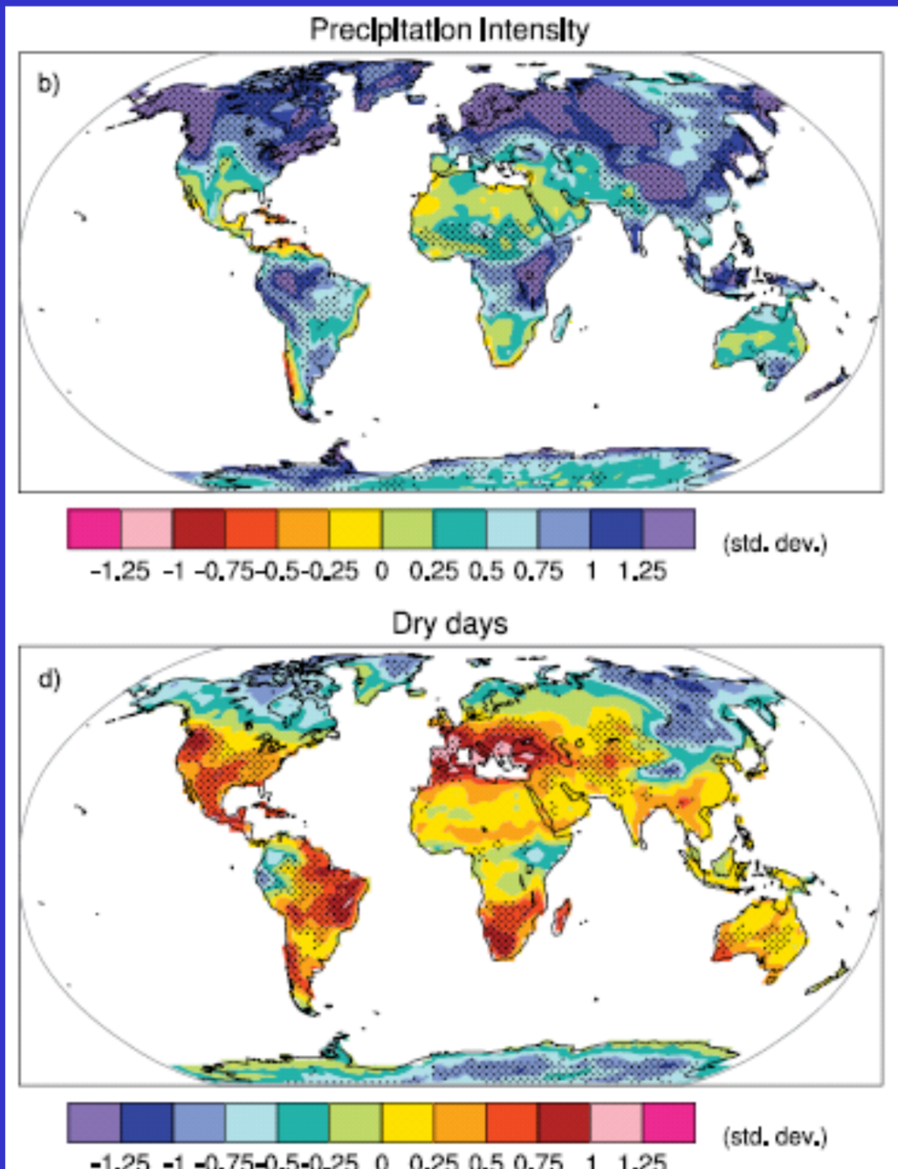
Projected Precipitation Extreme (AR4)



- Intensity of precipitation events is projected to increase, particularly in tropical and high latitude areas that experience increases in mean precipitation.

- The number of dry days increases between precipitation events in the subtropics and lower mid-latitudes

- There is a tendency for drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions.

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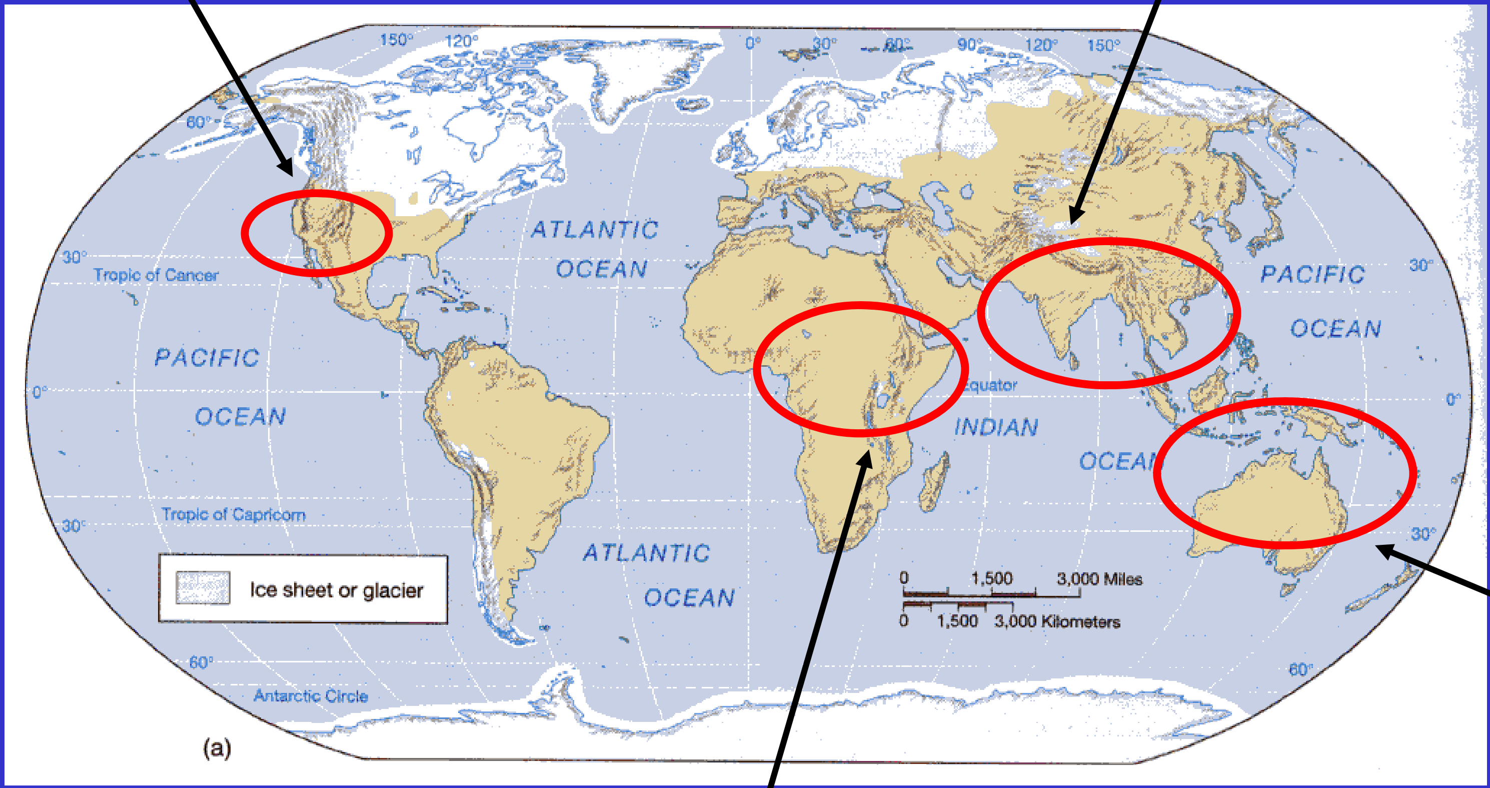
Projected Monsoon Variability (TAR)

- It is likely that warming associated with increasing greenhouse gas concentrations will cause an increase of Asian summer monsoon precipitation variability.
- Changes in monsoon mean duration and strength depend on the details of emission scenario.

Projected Monsoon Precipitation Changes (AR4)

North America Monsoon **(decrease)**

Asian Monsoon **(increase)**



Australian Monsoon **(increase)**

West Africa Monsoon **(increase)**

Weaker monsoon circulation
+ more water vapor available
= increase monsoon rainfalls

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Projected Hurricane Activities (AR4)

- Most recent published modelling studies projected a decrease in the overall number of storms.
- Although less confidence, studies projected decrease of relatively weak storms in most basins, with an increase in the numbers of the most intense tropical cyclones.

Projected Extratropical Storms (AR4)

- For a future warmer climate, a poleward shift of storm tracks in both hemispheres that is particularly evident in the SH, with greater storm activity at higher latitudes.
- A future tendency for more intense extratropical storms, although the number of storms could be less.

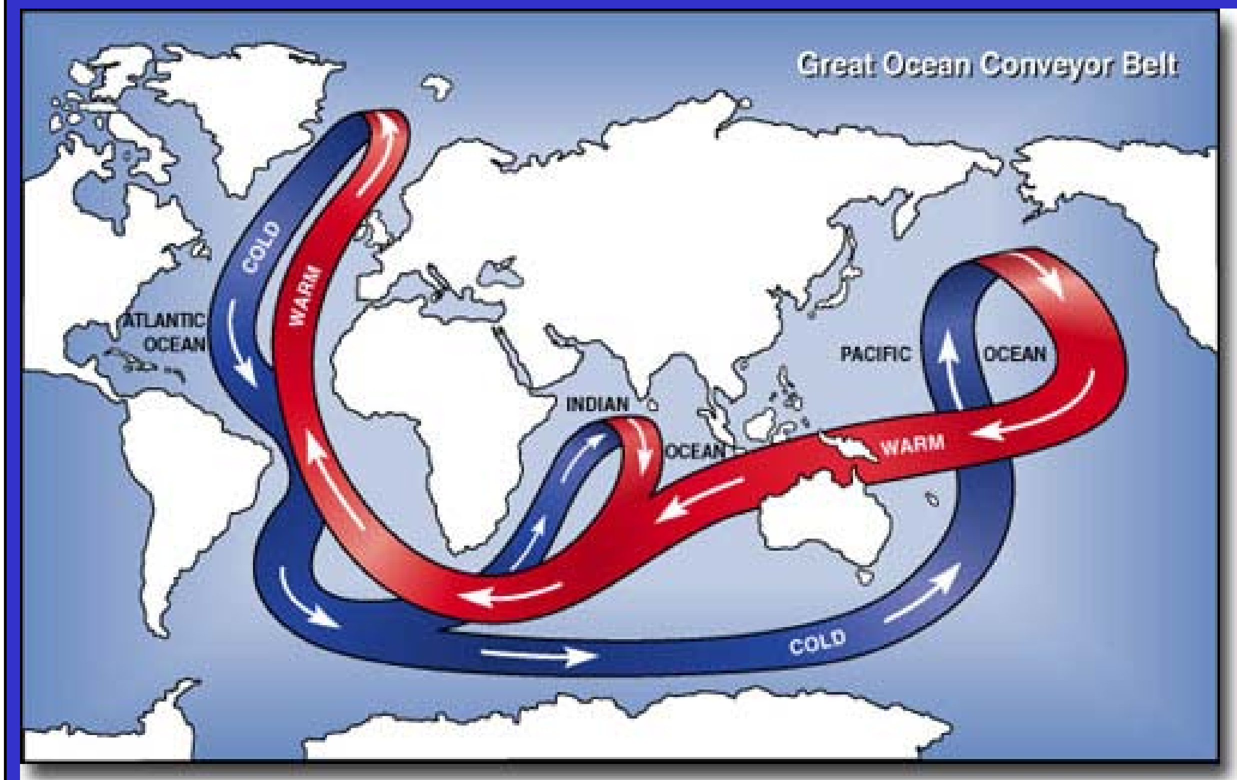
Projected Thermohaline Circulation (TAR)

- Most models show weakening of the ocean thermohaline circulation which leads to a reduction of the heat transport into high latitudes of the Northern Hemisphere.

- The current projections using climate models do not exhibit a complete shut-down of the thermohaline circulation by 2100.

- Beyond 2100, the thermohaline circulation could completely, and possibly irreversibly, shut-down in either hemisphere if the change in radiative forcing is large enough and applied long enough. scenarios.

Projected Change in Atlantic Meridional Overturning Circulation (MOC) / AR4



- The MOC is an indicator of ocean circulation changes in response to global warming.
- The MOC is projected to slow down in the future.
- It is due to the warming and increased precipitation at higher latitudes.
- The weakened MOC will help to reduce global warming at higher latitude, because less heat will be transported there.

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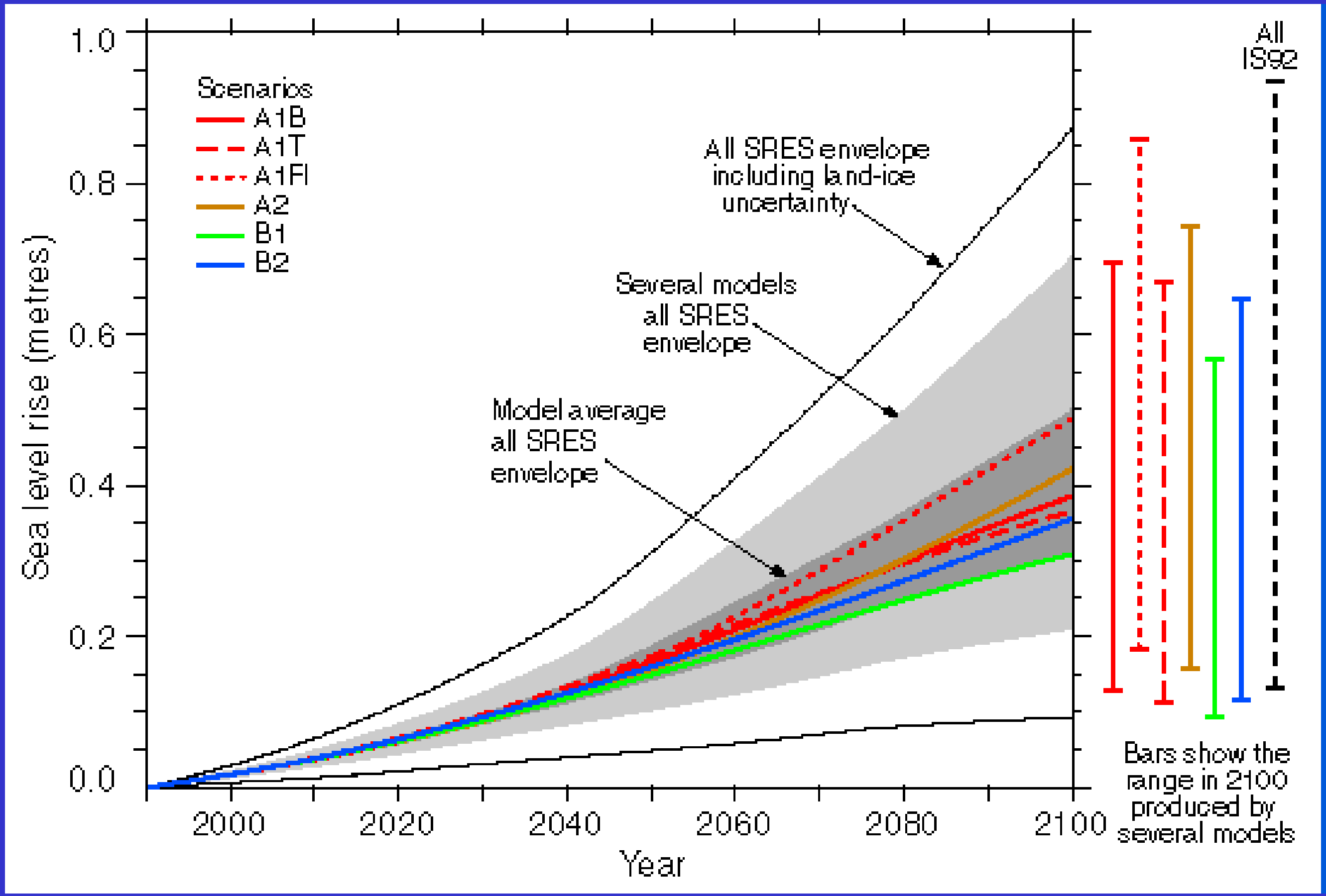
Projected Snow/Ice Cover (TAR)

- Northern Hemisphere snow cover and sea-ice extent are projected to decrease further.
- Glaciers and ice caps are projected to continue their widespread retreat during the 21st century.
- The Antarctic ice sheet is likely to gain mass because of greater precipitation, while the Greenland ice sheet is likely to lose mass because the increase in runoff will exceed the precipitation increase.

Projected Sea-Level Change (TAR)



- Global mean sea level is projected to rise by 0.09 to 0.88 metres between 1990 and 2100, for the full range of SRES scenarios.

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Global Warming and Sea-Level Change

Global Warming
(2.5°C by 2100)

Thermal Expansion
(11 inches)

Glacier and Ice Caps
(6.3 inches)

Greenland Ice Sheet
(2.4 inches)

Antarctic Ice Sheet
(-0.4 inches)

Sea Level Rise
(19.3 inches by 2100)

Positive Climate-Carbon Cycle Feedback

- Future climate change would reduce the efficiency of the Earth system (land and ocean) to absorb anthropogenic CO_2.
- As a result, an increasingly large fraction of anthropogenic CO_2 would stay airborne in the atmosphere under a warmer climate.

Global mean sea level is projected to rise in the future warming world. The rise is contributed the most by this factor:

a. Antarctic ice sheet melting

b. Greenland ice sheet melting

c. Glacier and ice cap melting

d. thermal expansion