GEF4400 “The Earth System”

Prof. Dr. Jon Egill Kristjansson,

Prof. Dr. Kirstin Krüger (UiO)

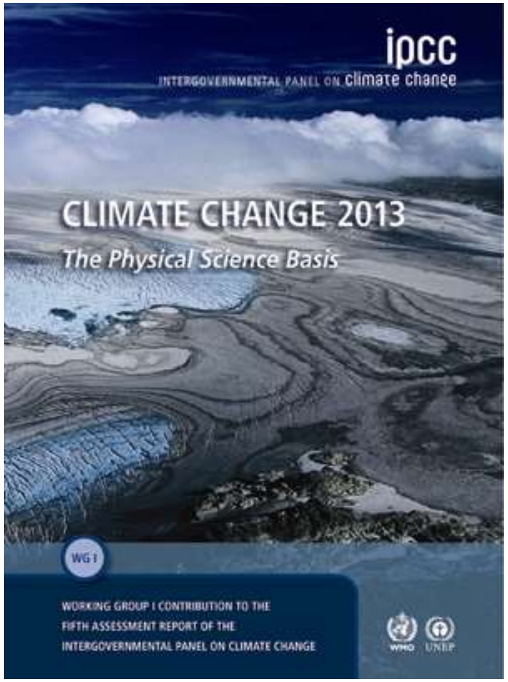
Email: kkruegergeo.uio.no

Repetition for final exams

The Earth System – exam preparation

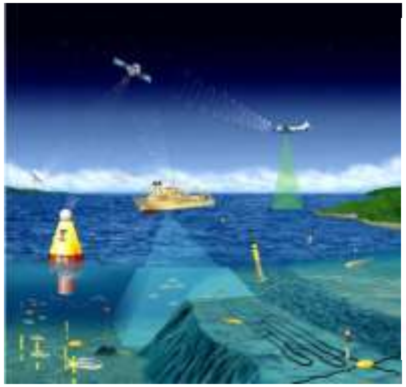
- The big picture: The Earth System
- Cross links between the IPCC chapters
- Interactions between the Earth System
- Physical understanding
- Feedback loops
- Limitations and uncertainties

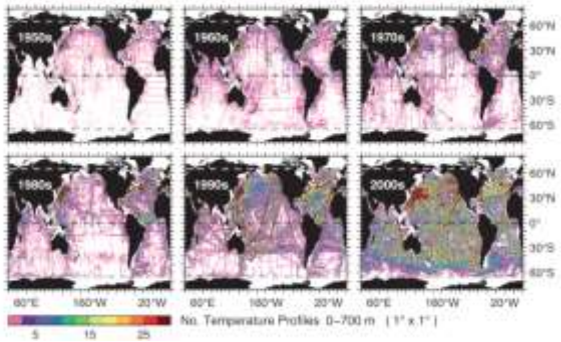
IPCC Chapter 3: **Observations: Ocean**



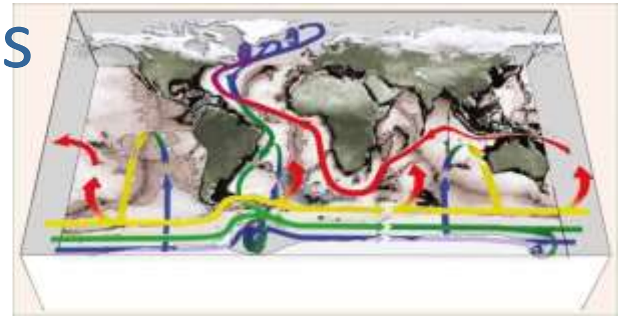
- Background
- Introduction *(Appendix 3A)*
- Ocean temperature and heat content *(Section 3.2)*
- Salinity and fresh water content *(Section 3.3)*
- Ocean surface fluxes *(Section 3.4)*
- Ocean circulation *(Section 3.6)*
- Sea level change *(Section 3.7)*
- Executive Summary *(Ch. 3)*

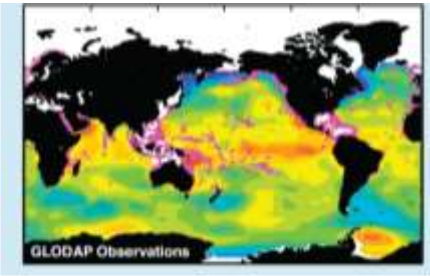
Rhein, M., et al., 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

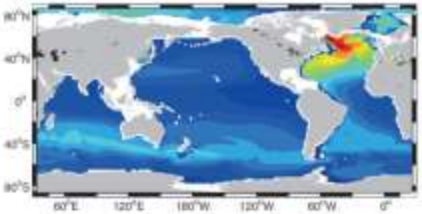




- Ocean observations
- Atmosphere–ocean interaction
- Ocean temperature/heat content
- Salinity – water cycle
- Ocean surface fluxes
- Ocean circulation
- Sea level
- Ocean acidification
- Anthropogenic carbon storage







Ocean changes since 1950s – Summary

Increase of anthropogenic CO_2, global mean sea level, upper ocean heat content, and high-low salinity regions.

→high confidence.

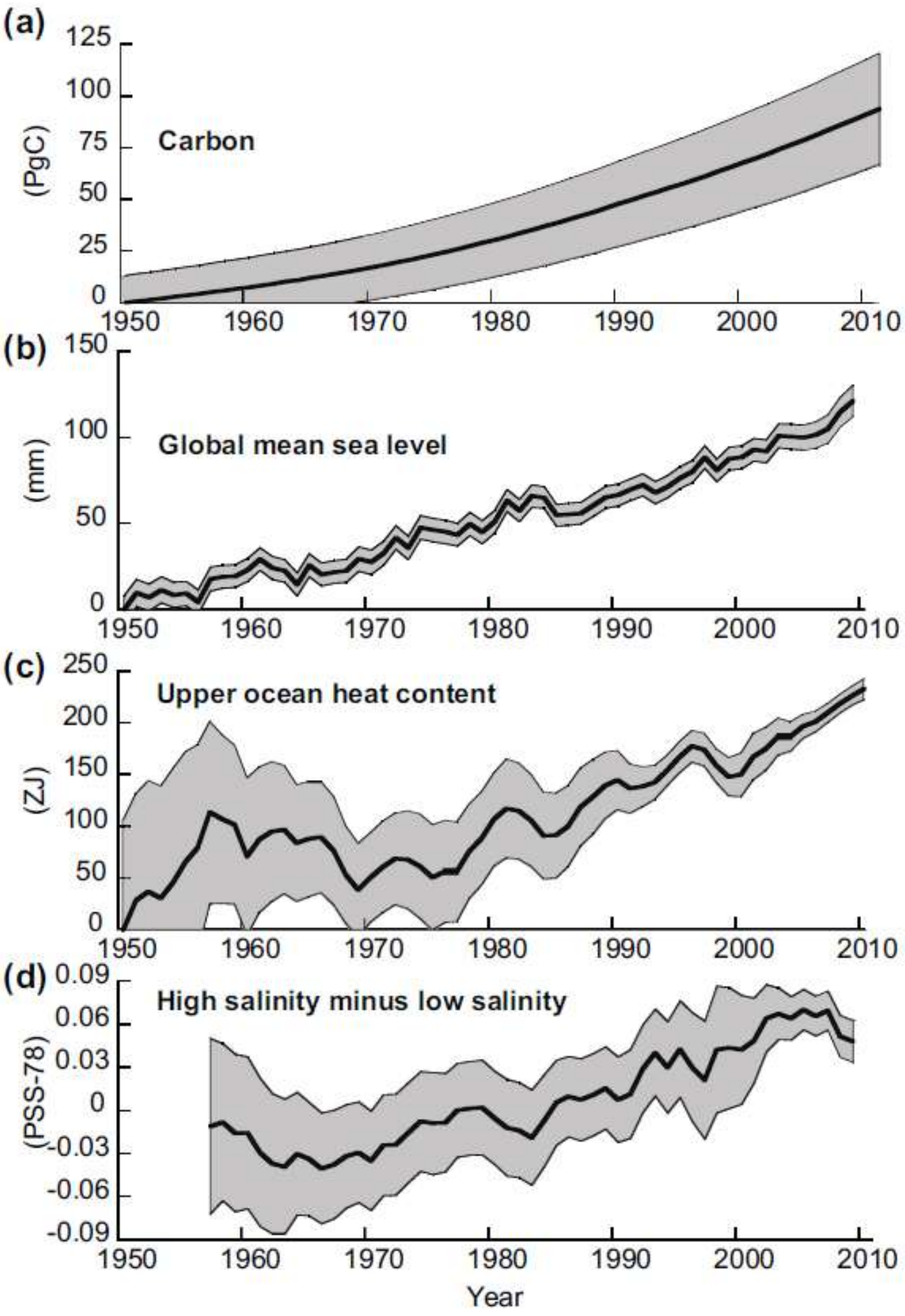
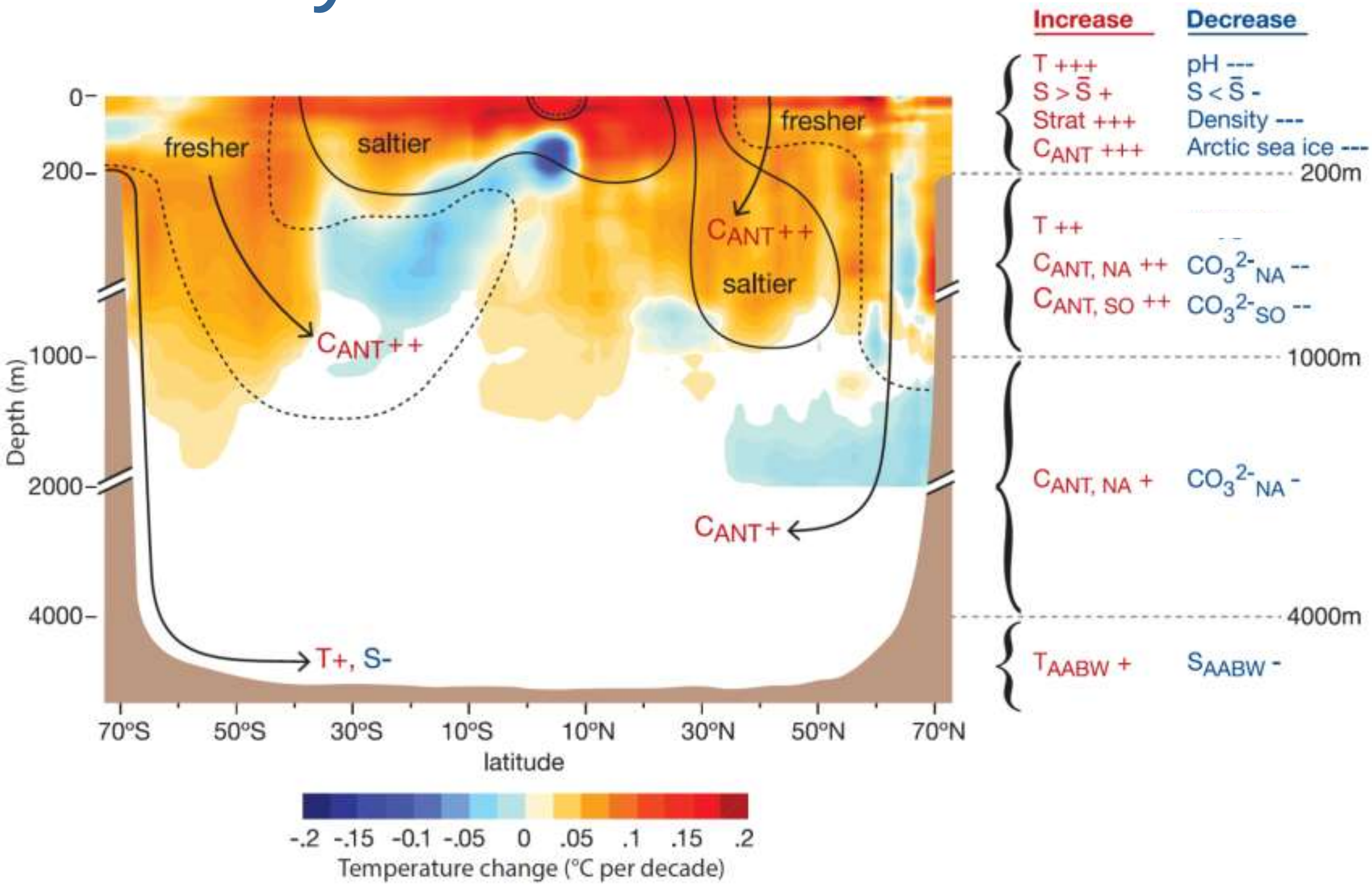


Figure 3.21 | Time series of changes in large-scale ocean climate properties. From top to bottom: global ocean inventory of anthropogenic carbon dioxide, updated from Khatiwala et al. (2009); global mean sea level (GMSL), from Church and White (2011); global upper ocean heat content anomaly, updated from Domingues et al. (2008); the difference between salinity averaged over regions where the sea surface salinity is greater than the global mean sea surface salinity ("High Salinity") and salinity averaged over regions values below the global mean ("Low Salinity"), from Boyer et al. (2009).

Summary



+++: *high confidence*; ++: *medium confidence*; +: *low confidence*

C_{ANT}: Anthropogenic Carbon, NA: North Atlantic, SO: Southern Ocean AABW: Antarctic Bottom Water

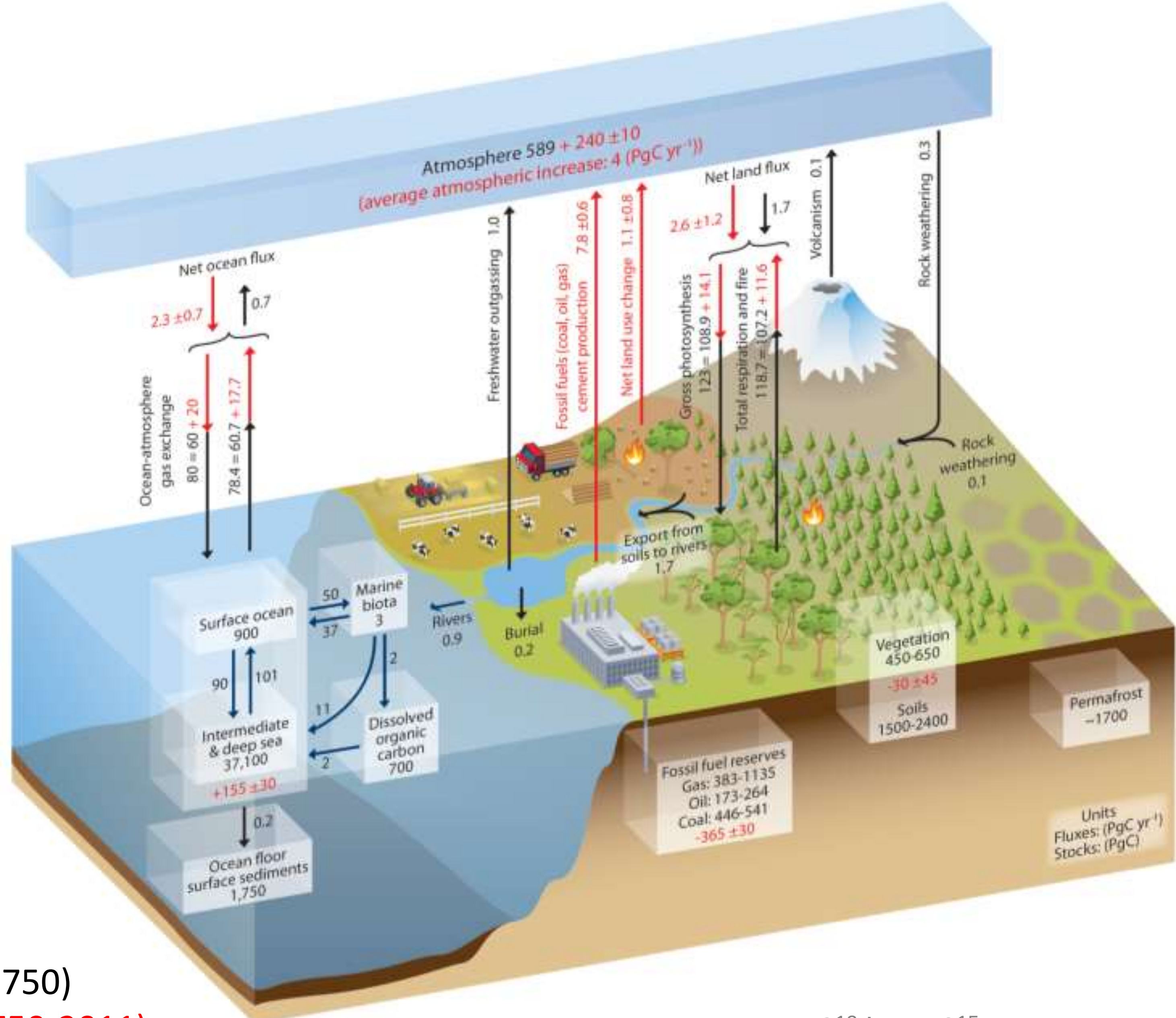
Carbonate ion: CO_3^{2-}

IPCC Chapter 6: **Carbon and other biogeochemical cycles**

- Background
- Introduction: Global Carbon Cycle *(Section 6.1)*
- Evolution of biogeochemical cycles since industrial era *(Section 6.3)*
- Variations in Carbon cycle before the fossil fuel era *(Section 6.2)*
- Projections of future carbon cycles *(Section 6.4)*
- Global Carbon Budget in 2014
- Executive Summary *(Ch. 6)*

Ciais, P., Cet al., 2013: Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Global Carbon Cycle



→ Fluxes: PgC yr^{-1}

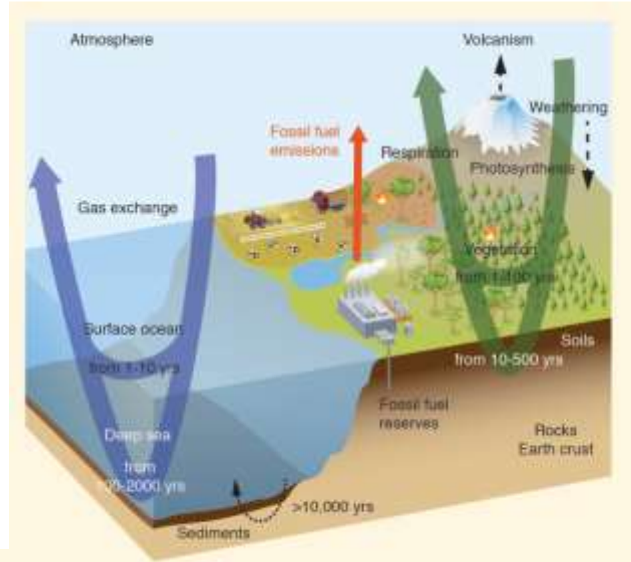
Stocks: Pg C

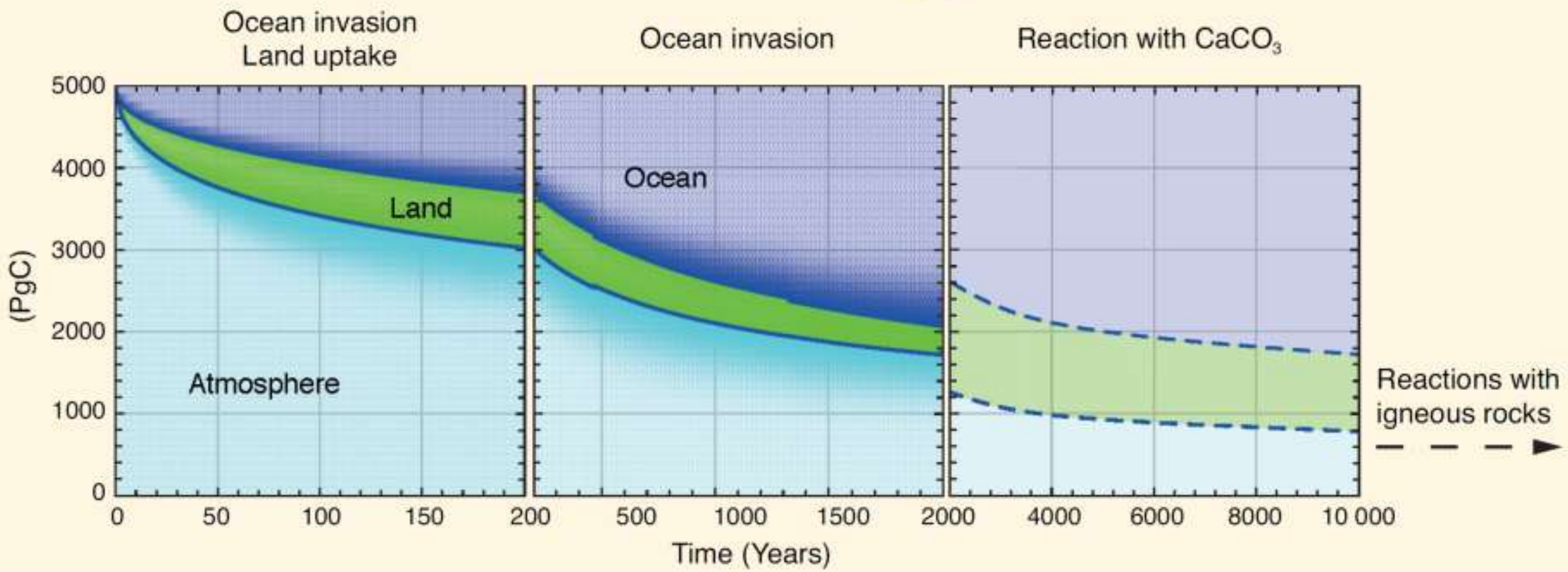
--pre-industrial (pre 1750)

--industrial period (1750-2011)

1 Petagram: 1Pg= 10^{12} kg= 10^{15} g

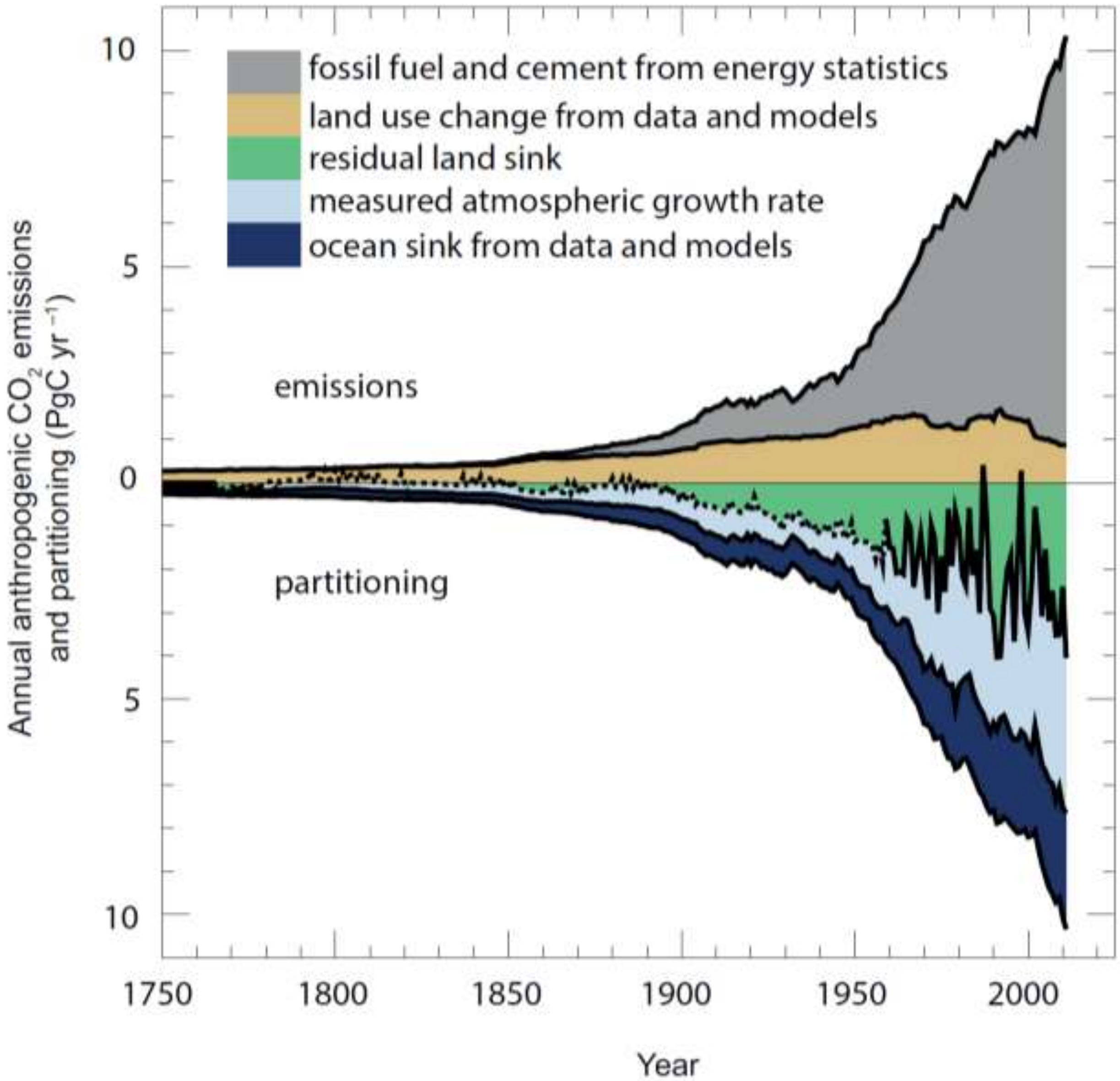
Decay of CO_2 excess – turn over time scales





FAQ 6.2, Figure 2 | Decay of a CO_2 excess amount of 5000 PgC emitted at time zero into the atmosphere, and its subsequent redistribution into land and ocean as a function of time, computed by coupled carbon-cycle climate models. The sizes of the colour bands indicate the carbon uptake by the respective reservoir. The first two panels show the multi-model mean from a model intercomparison project (Joos et al., 2013). The last panel shows the longer term redistribution including ocean dissolution of carbonaceous sediments as computed with an Earth System Model of Intermediate Complexity (after Archer et al., 2009b).

Anthropogenic CO_2 emissions and partitioning

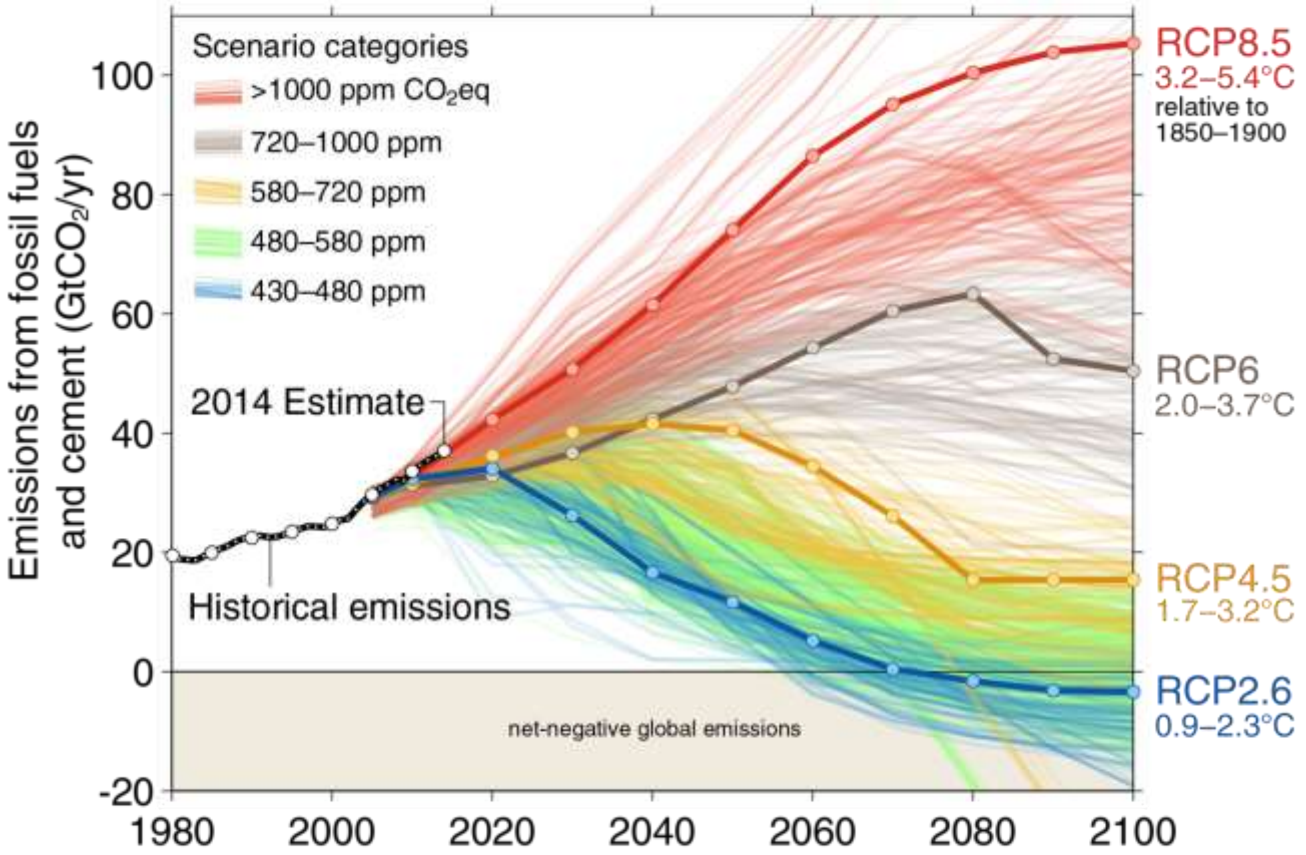


Observed Emissions and Emissions Scenarios

Emissions are on track for 3.2–5.4ºC "likely" increase in temperature above pre-industrial

Large and sustained mitigation is required to keep below 2ºC

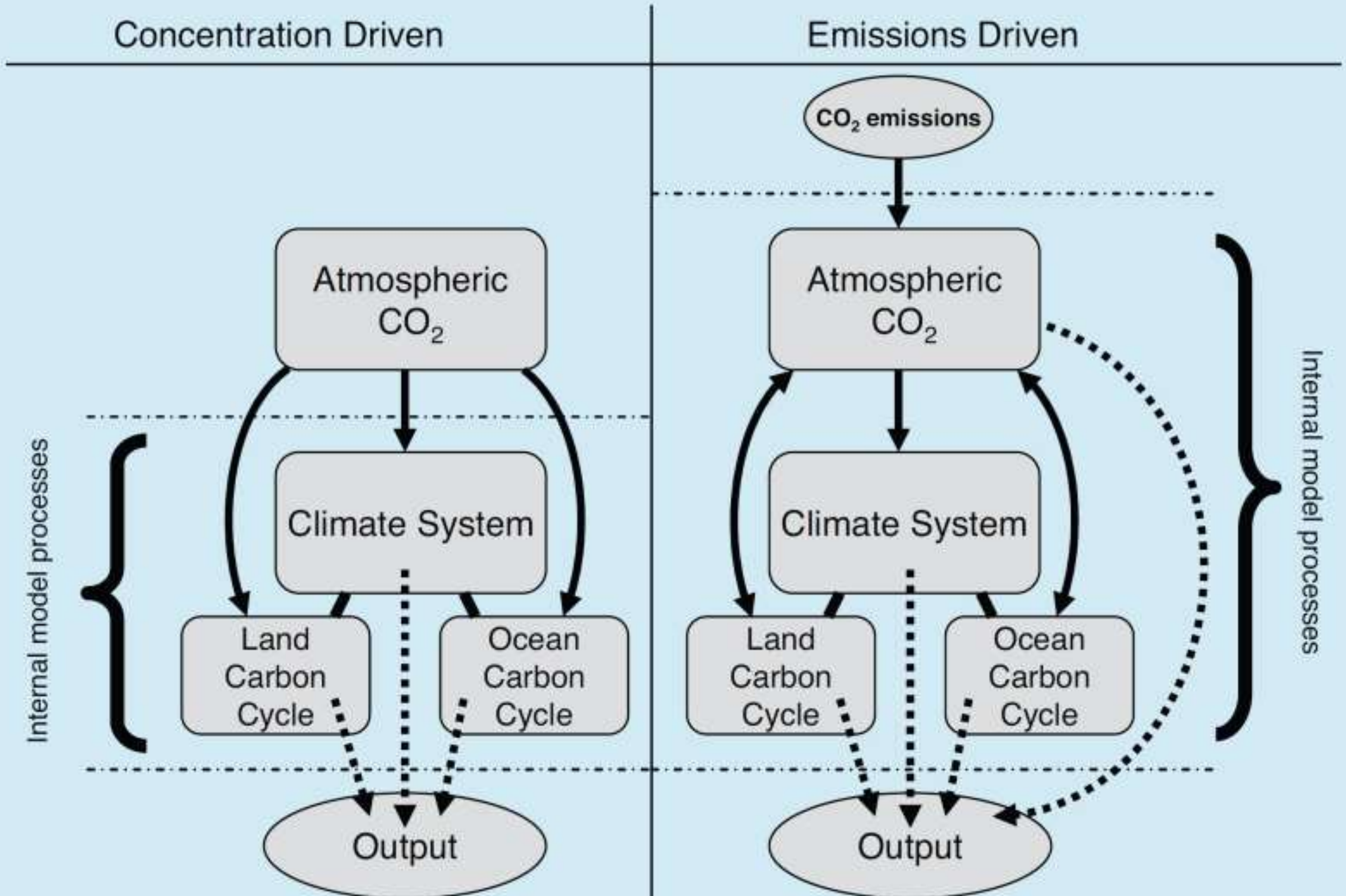
Data: CDIAC/GCP/IPCC/Fuss et al 2014



Over 1000 scenarios from the IPCC Fifth Assessment Report are shown

Source: Fuss et al 2014; CDIAC; Global Carbon Budget 2014

Box 6.4 | Climate–Carbon Cycle Models and Experimental Design



$$E = \left.\frac{dCO_2}{dt}\right|_{prescribed} + (\text{land\_carbon\_uptake} + \text{ocean\_carbon\_uptake})$$

$$\left.\frac{dCO_2}{dt}\right|_{simulated} = E - (\text{land\_carbon\_uptake} + \text{ocean\_carbon\_uptake})$$

E: «compatible fossil fuel» emissions

E: «anthropgenic» emissions

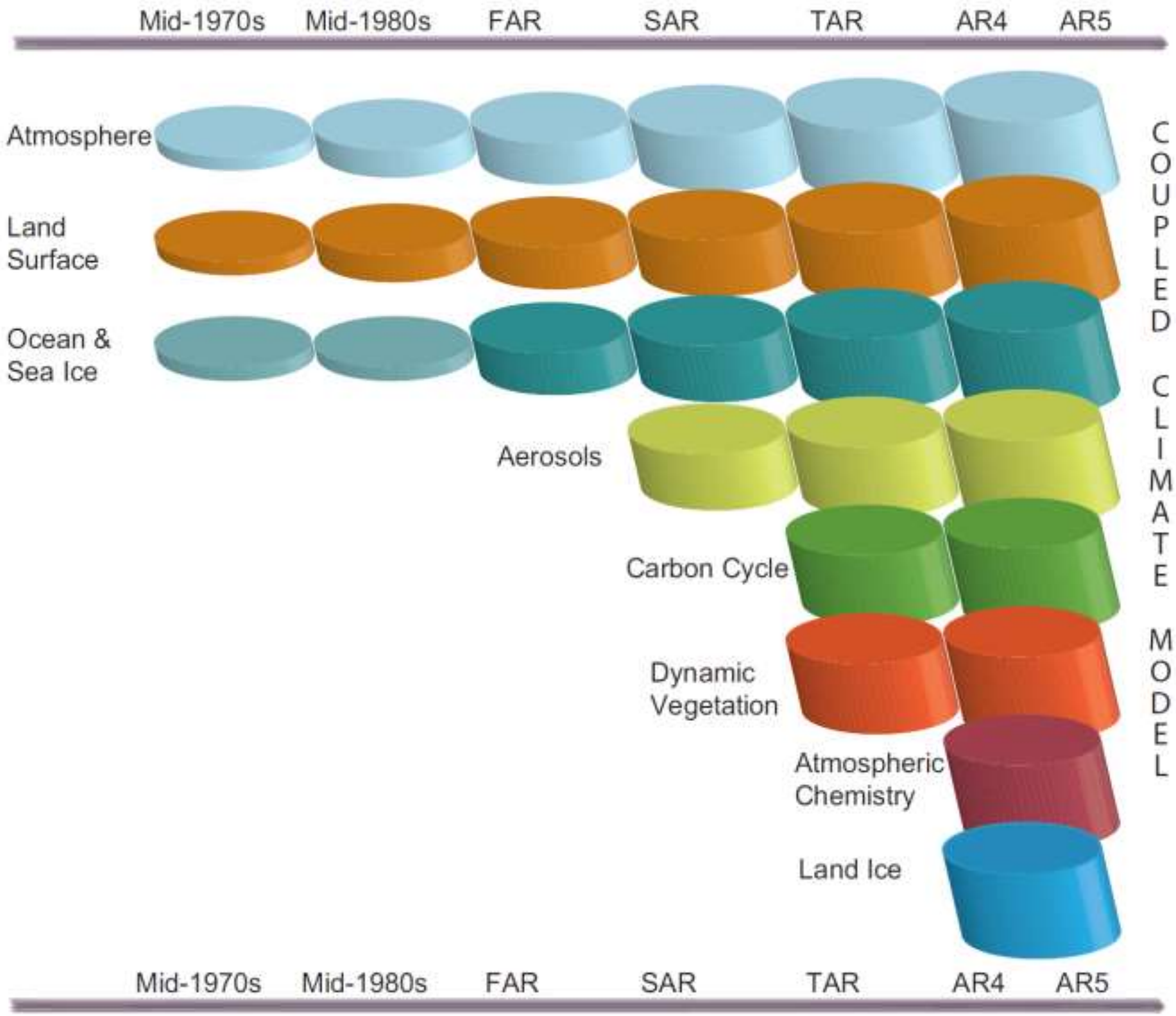
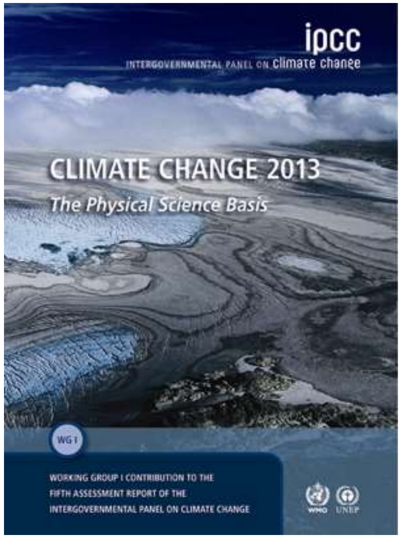


Figure 1.13 | The development of climate models over the last 35 years showing how the different components were coupled into comprehensive climate models over time. In each aspect (e.g., the atmosphere, which comprises a wide range of atmospheric processes) the complexity and range of processes has increased over time (illustrated by growing cylinders). Note that during the same time the horizontal and vertical resolution has increased considerably e.g., for spectral models from T21L9 (roughly 500 km horizontal resolution and 9 vertical levels) in the 1970s to T95L95 (roughly 100 km horizontal resolution and 95 vertical levels) at present, and that now ensembles with at least three independent experiments can be considered as standard.

Ch. 1 IPCC, 2013

IPCC Chapter 5: **Informations from paleoclimate archives**



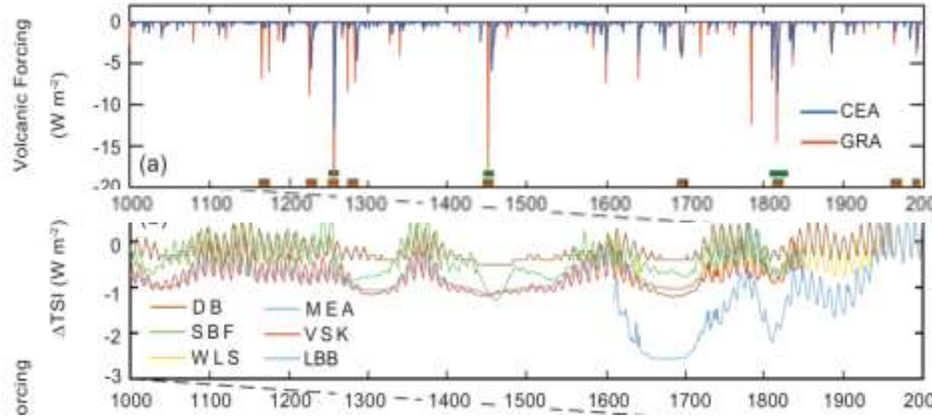
- Introduction *(Section 5.1)*
- Pre-industrial perspective on radiative forcing factors *(Section 5.2)*
- Earth System Responses and Feedbacks *(Section 5.3)*
- Executive summary *(Ch. 5)*

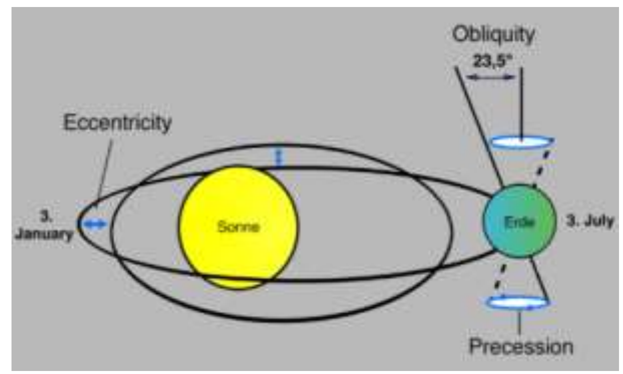
Masson-Delmotte, V., et al., 2013: Information from Paleoclimate Archives. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Radiative forcing factors

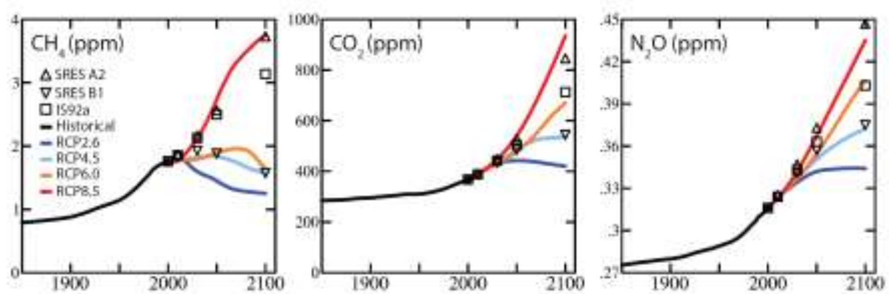
External forcing:

- Volcanic Forcing
- Solar Forcing
- Orbital Forcing





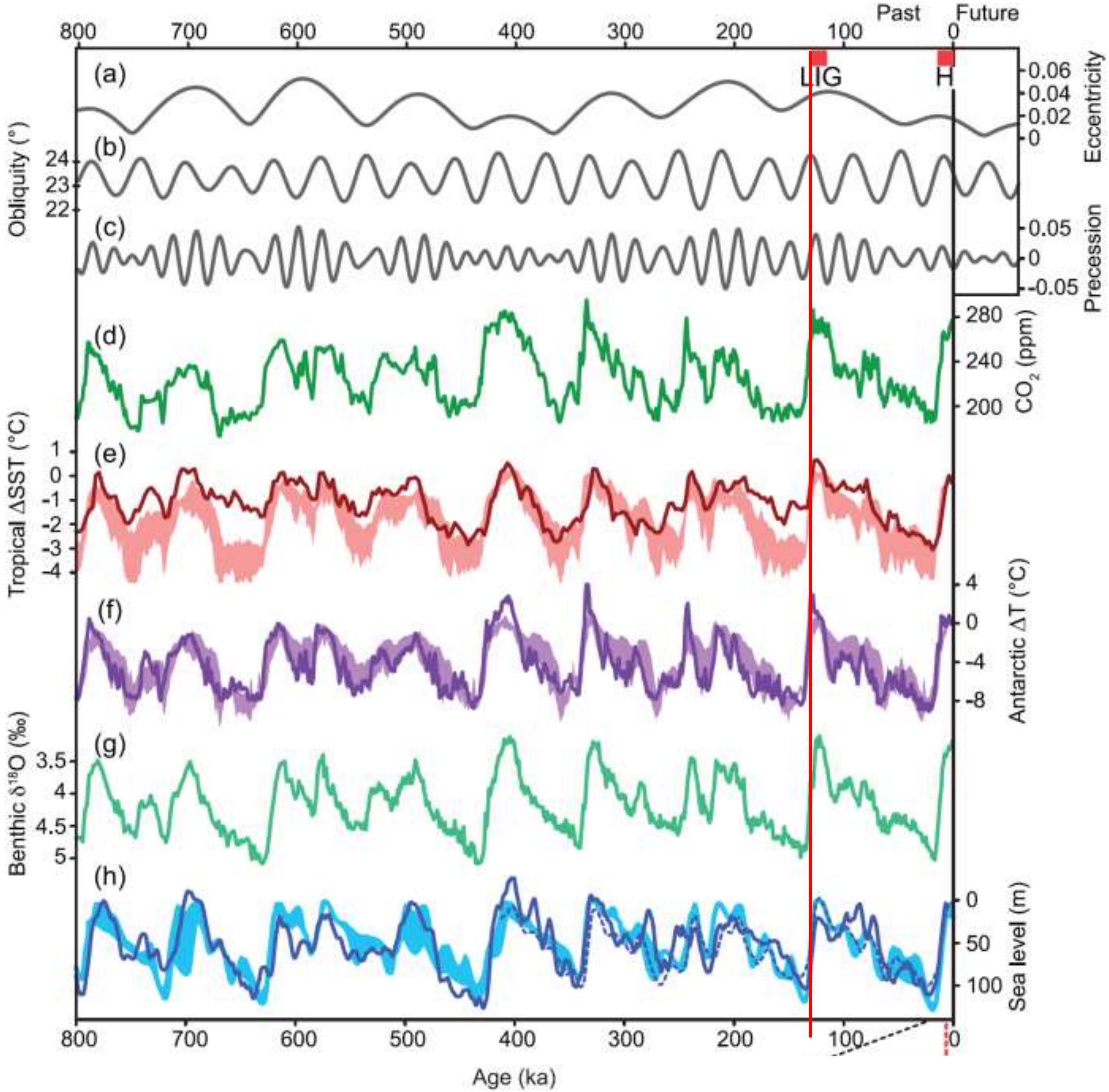
Greenhouse gases, aerosols, dust: CO_2, CH_4, N_2O, dust and aerosols



Climate archives

Source	Time (years)	Climate variable
1. Instruments	250	temperature, pressure, wind, precipitation
2. Historical documents	1000	temperature, precipitation
floods, strong winters, crop failure, wine quality, corn prices, coastal ice, etc.		
3. Paleoclimate data		
tree rings	10000	temperature, precipitation
varves	10000	temperature, precipitation
ice cores (d^{18}O)	100000	temperature
pollen	100000	temperature, precipitation
marine sediments	1000000	
fauna		temperature, sea-ice coverage
d^{18}O		continental ice volume
dust (grain size)		wind speed and direction

Past 800 ka



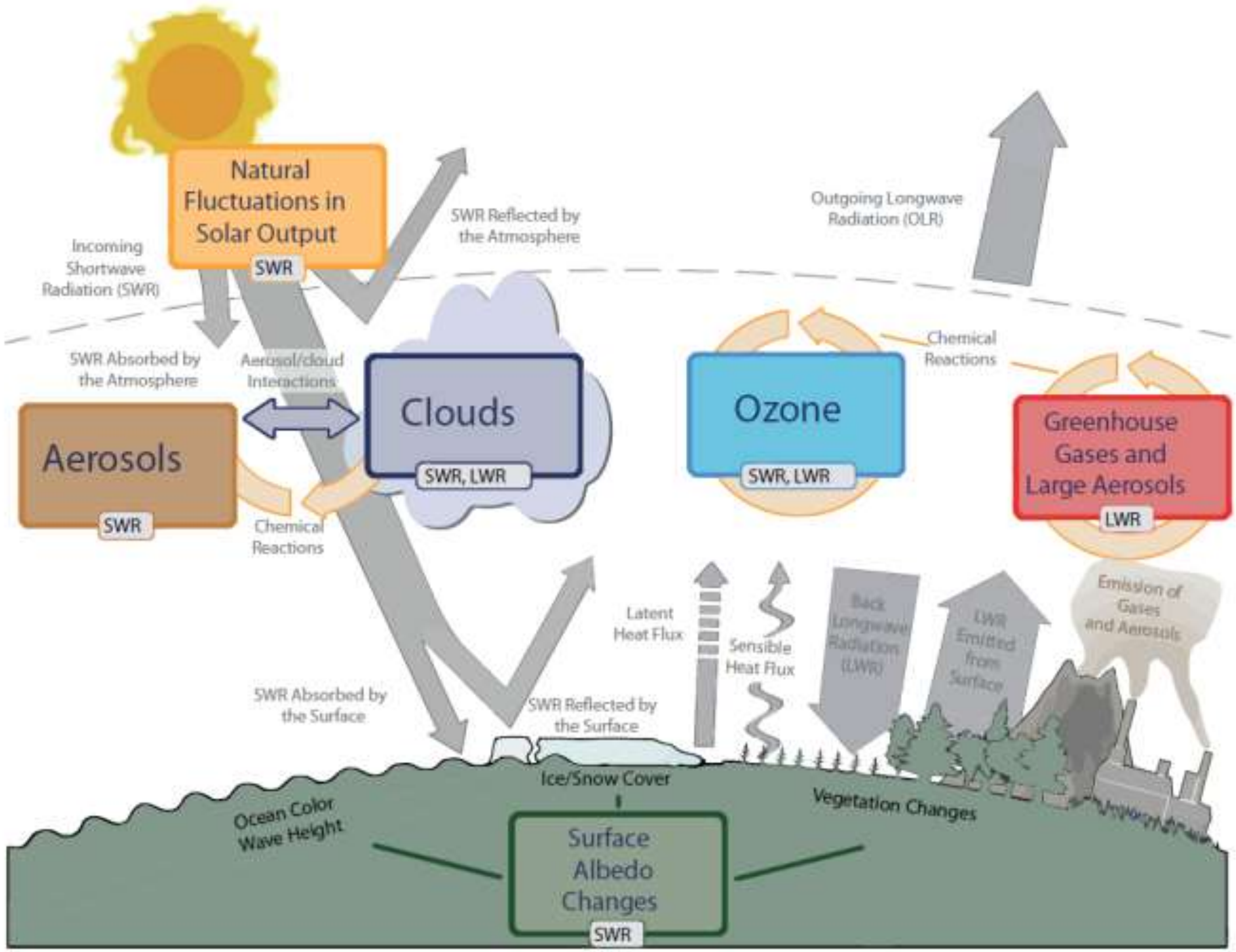
LIG: Last Interglacial
H: Holocene

IPCC Chapter 12: **Long-term climate change**: projections, commitments and irreversibility

- Introduction and Background *(from Chapter 10 and 11)*
- Climate Model Ensembles and Uncertainties *(Section 12.2)*
- Projected Climate Change over the 21st Century *(Section 12.4)*
- Executice Summary *(Ch. 12)*

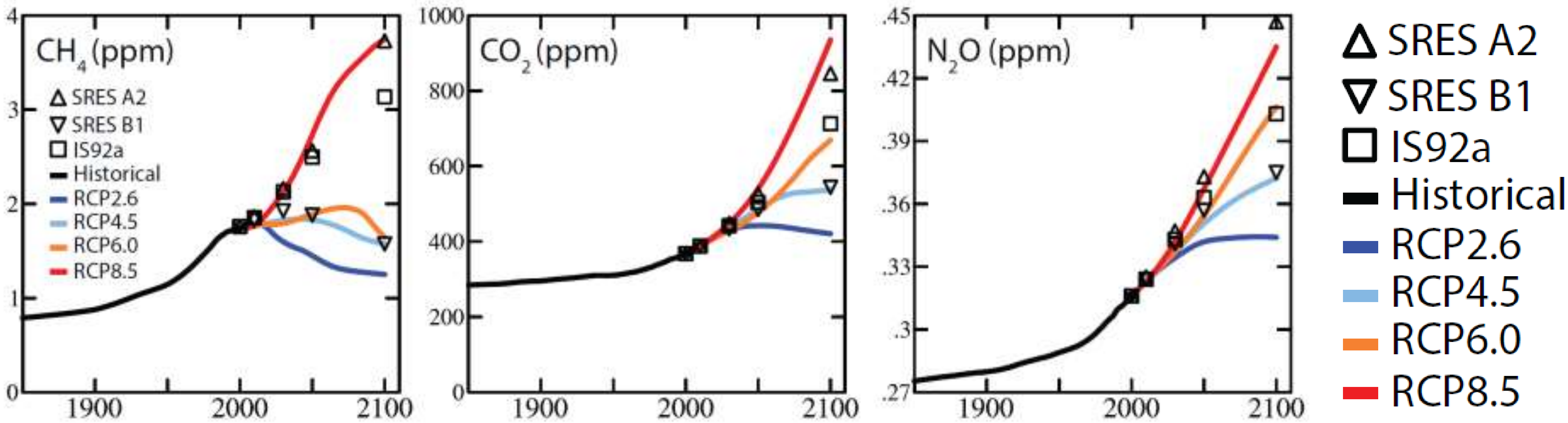
Collins, M.,et al., 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press,.

Main drivers of climate change



Chapter 1 IPCC (2013)

IPCC forcings for GHG

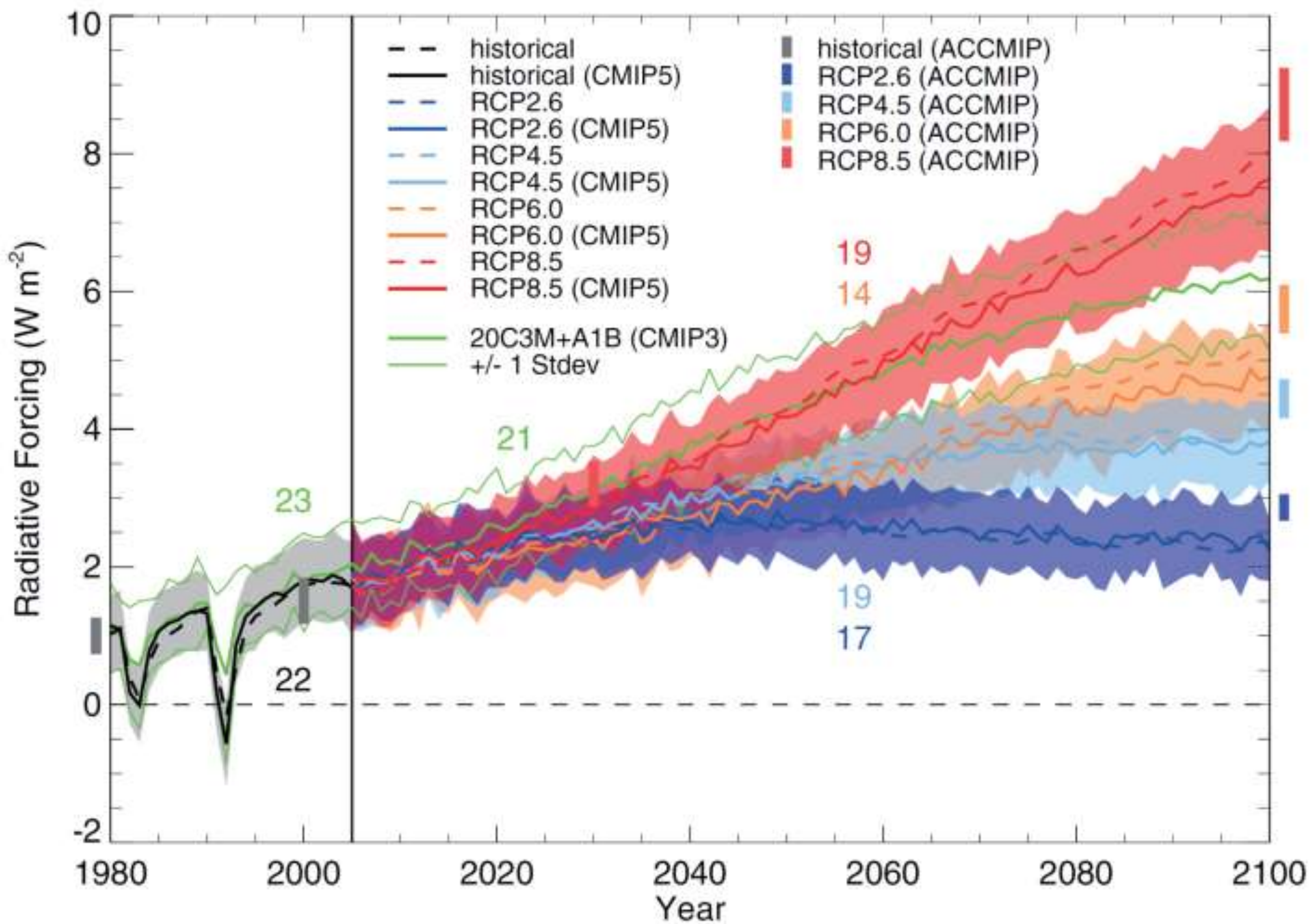


Meinshausen et al., 2011

Chapter 8 IPCC 2013 (www.climatechange2013.org)

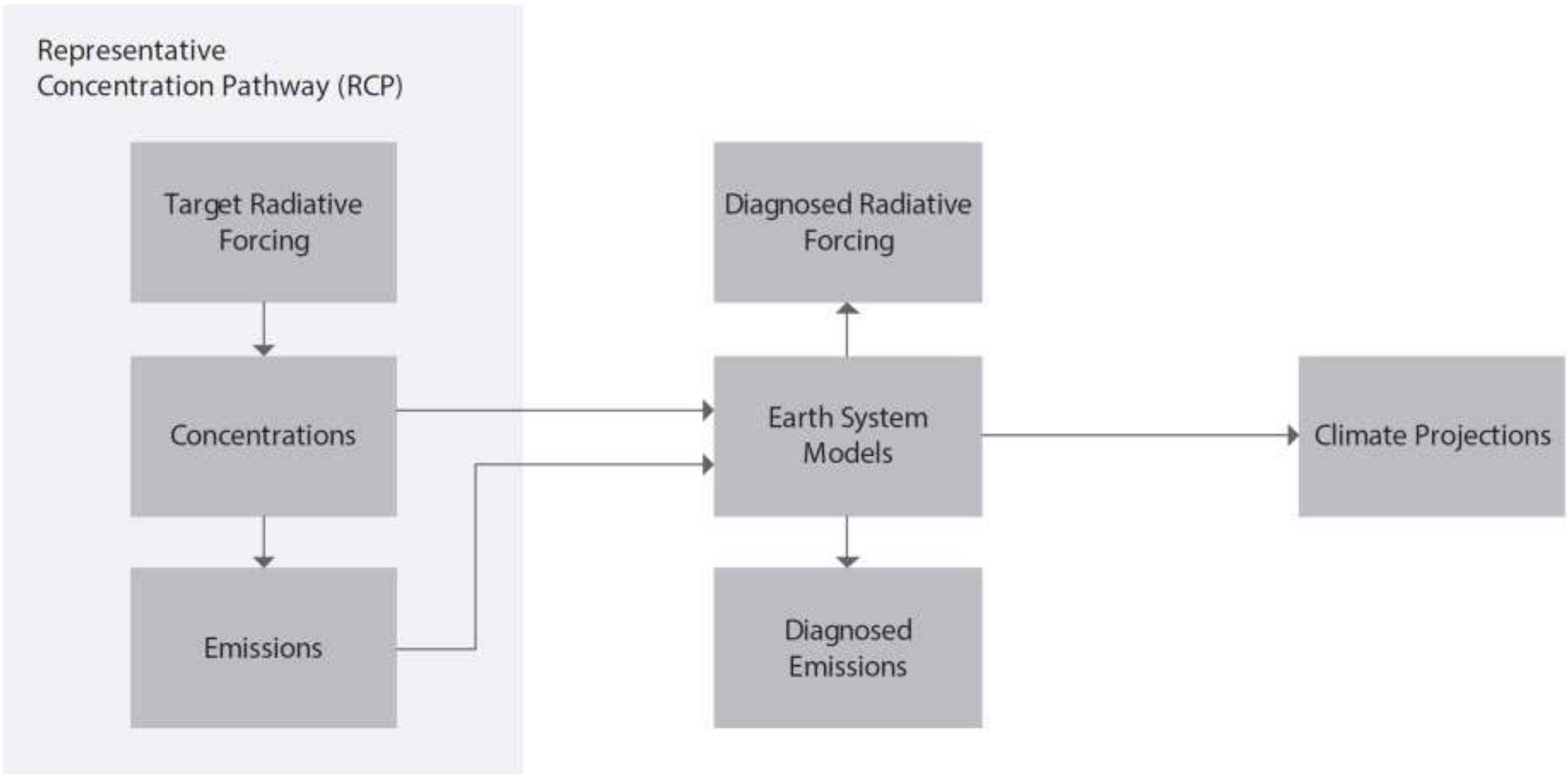
SRES: Special Report on Emissions Scenarios (TAR, IPCC 2000)
RCP: Representative Concentration Pathway

Global Mean Radiative Forcing
between 1980 and 2100



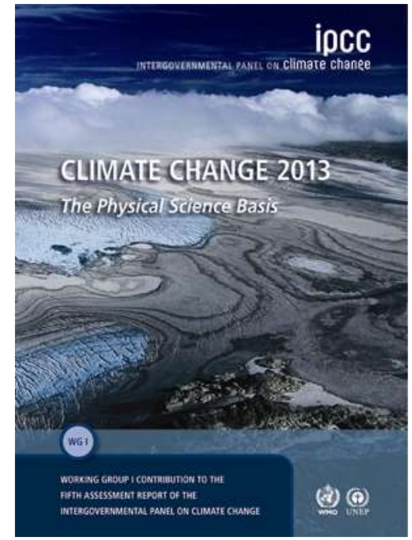
RCP: Representive Concentration Pathway, ACCMIP: Atmospheric Chemistry Climate Model Intercomparison Project

Scenario-Model-Climate Projection Chain



Uncertainty propagates through the chain and results in a spread of ESM projections →spread is assessing projection uncertainty.

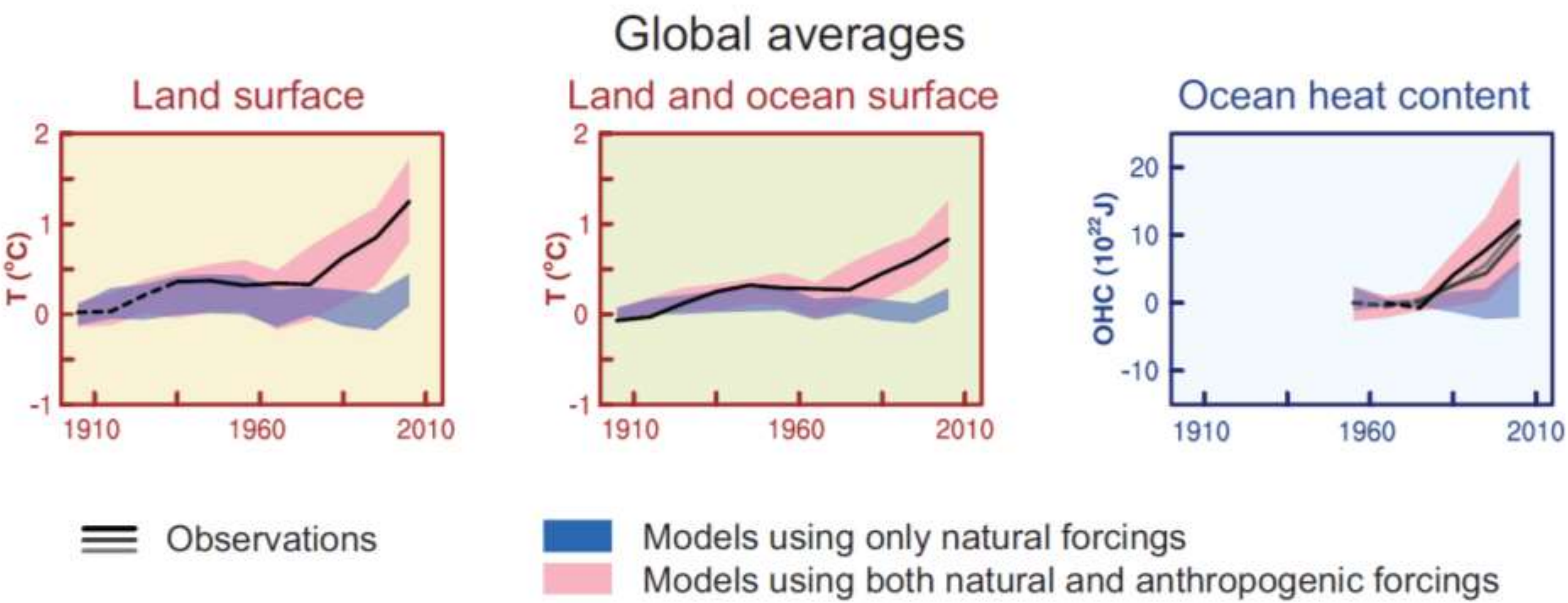
IPCC SPM: Summary for Policy Makers

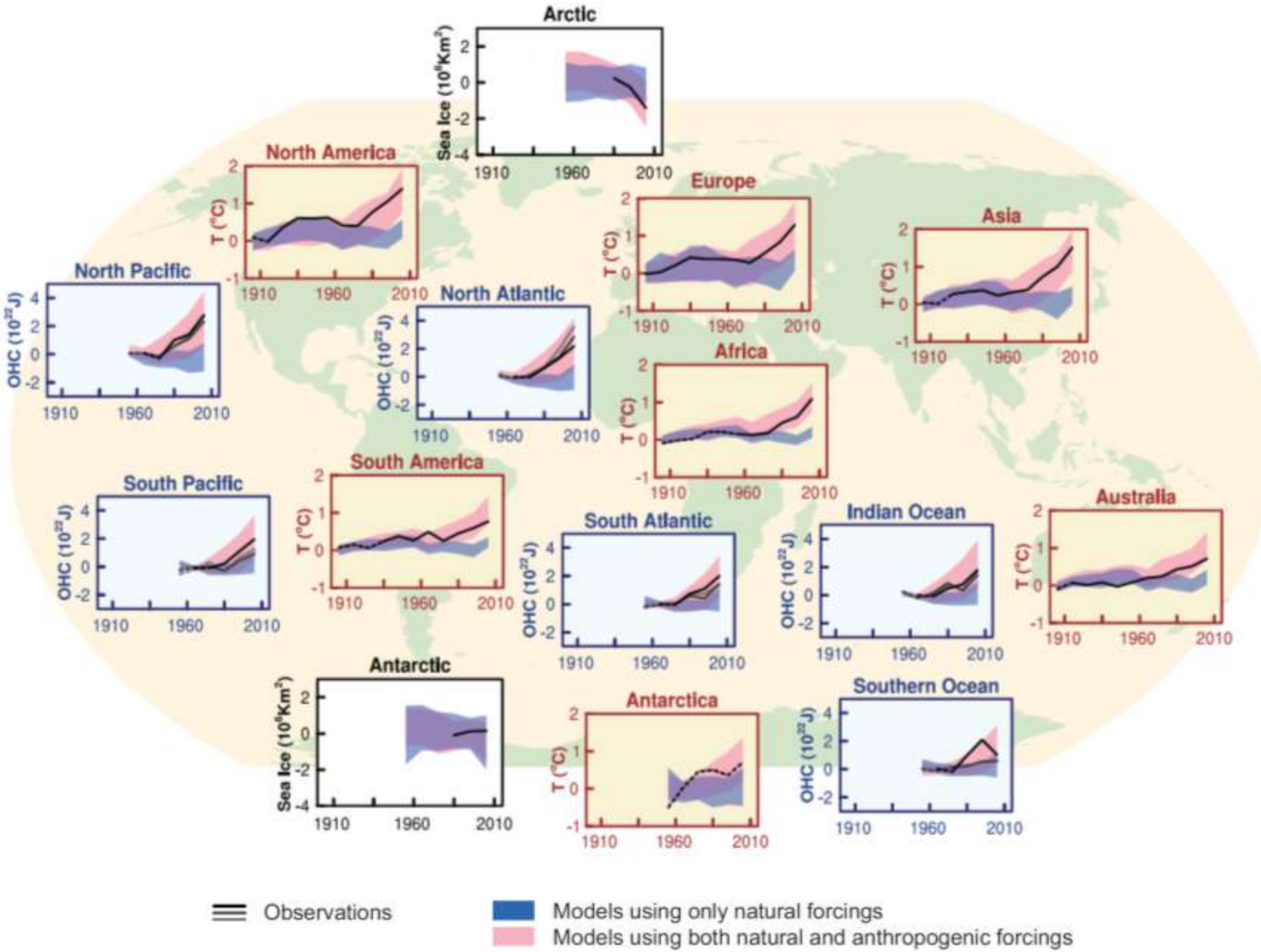


IPCC, 2013: Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

D.3 Detection and Attribution of Climate Change

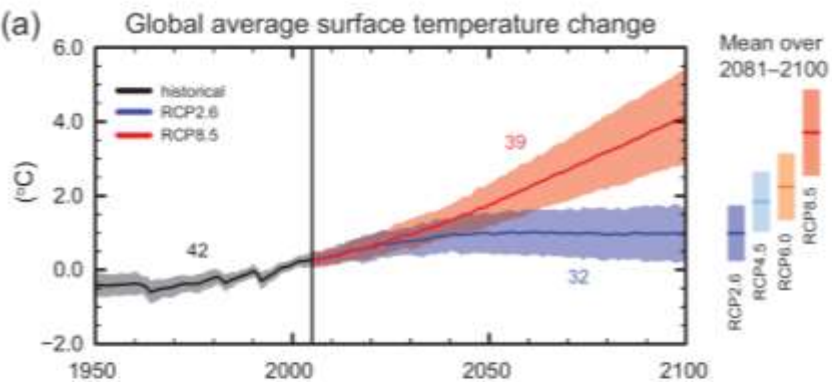
Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. {10.3–10.6, 10.9}

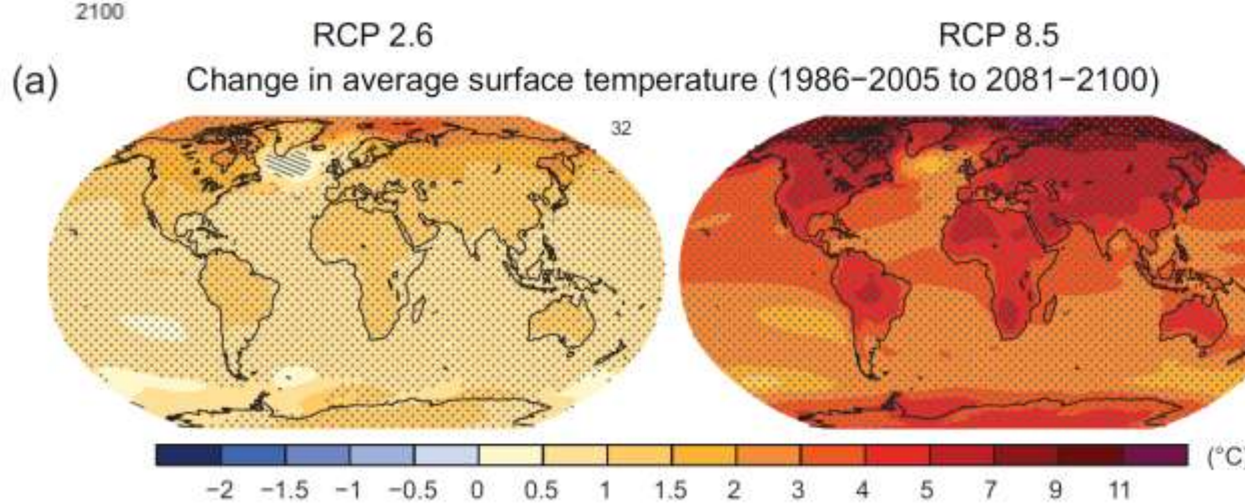



Arctic
North America
Europe
Asia
North Pacific
North Atlantic
Africa
South America
South Pacific
South Atlantic
Indian Ocean
Australia
Antarctic
Antarctica
Southern Ocean
Sea Ice ($10^6 Km^2$)
T (°C)
OHC (10^{22} J)
1910
1960
2010
Observations
Models using only natural forcings
Models using both natural and anthropogenic forcings

E.1 Atmosphere: Temperature

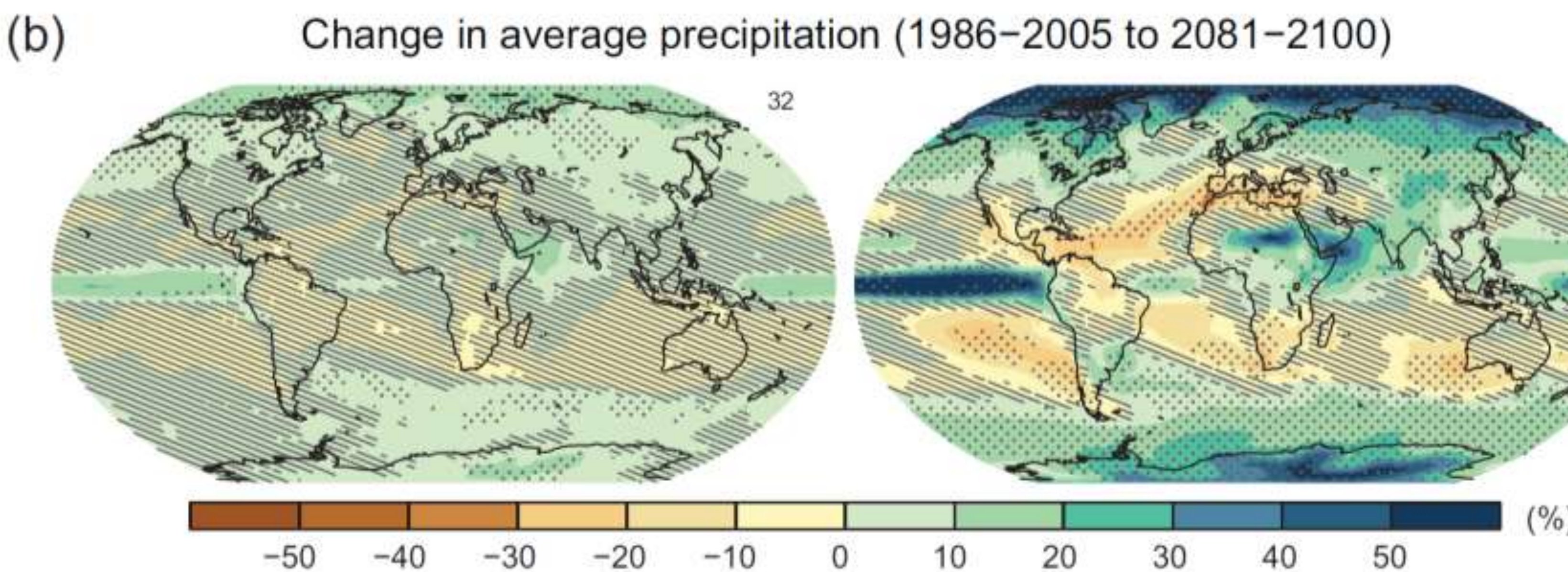
Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform (see Figures SPM.7 and SPM.8). {11.3, 12.3, 12.4, 14.8}





E.2 Atmosphere: Water Cycle

Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions (see Figure SPM.8). {12.4, 14.3}



E.4 Ocean

The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation. {11.3, 12.4}

E.5 Cryosphere

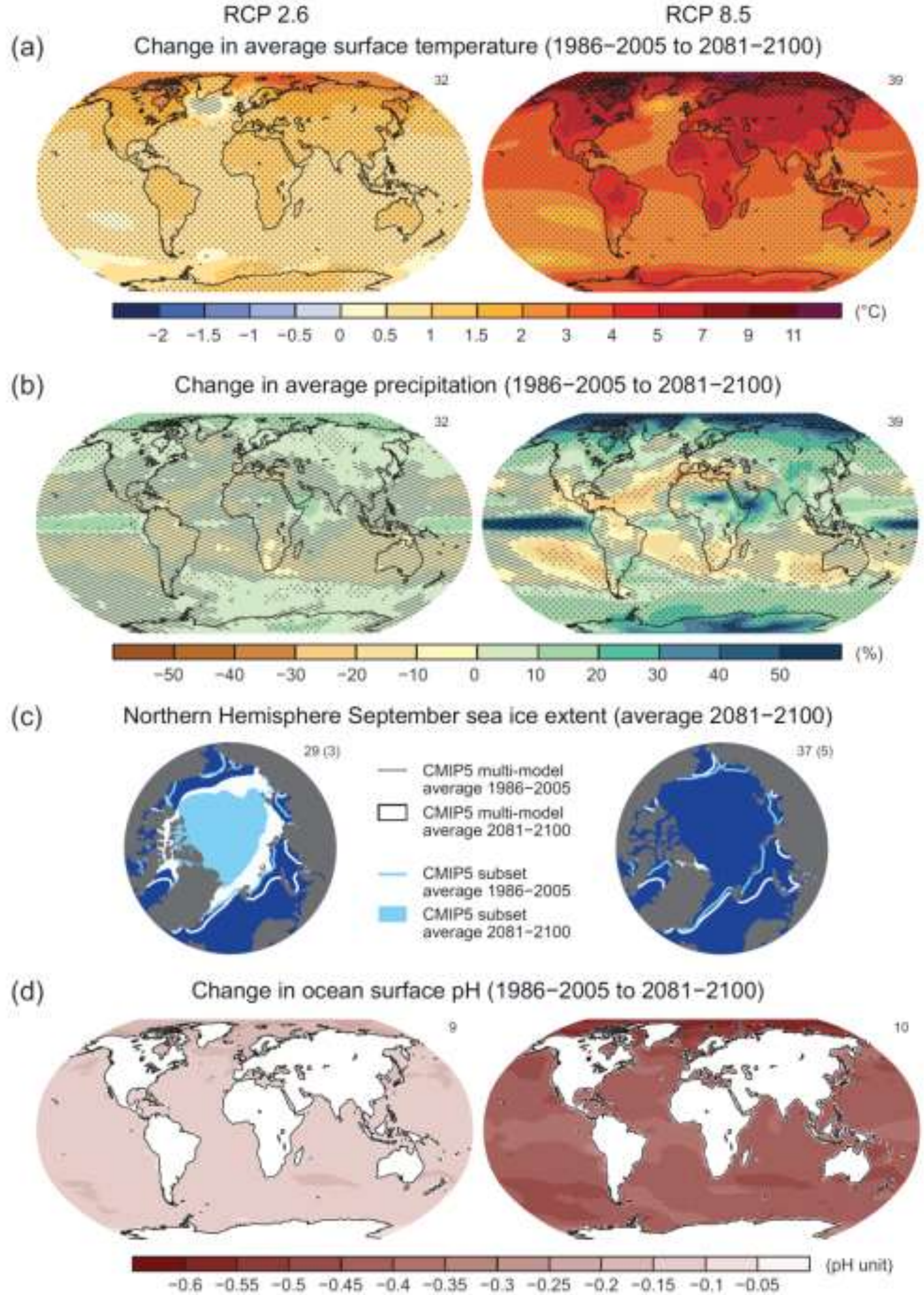
It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease. {12.4, 13.4}

E.6 Sea Level

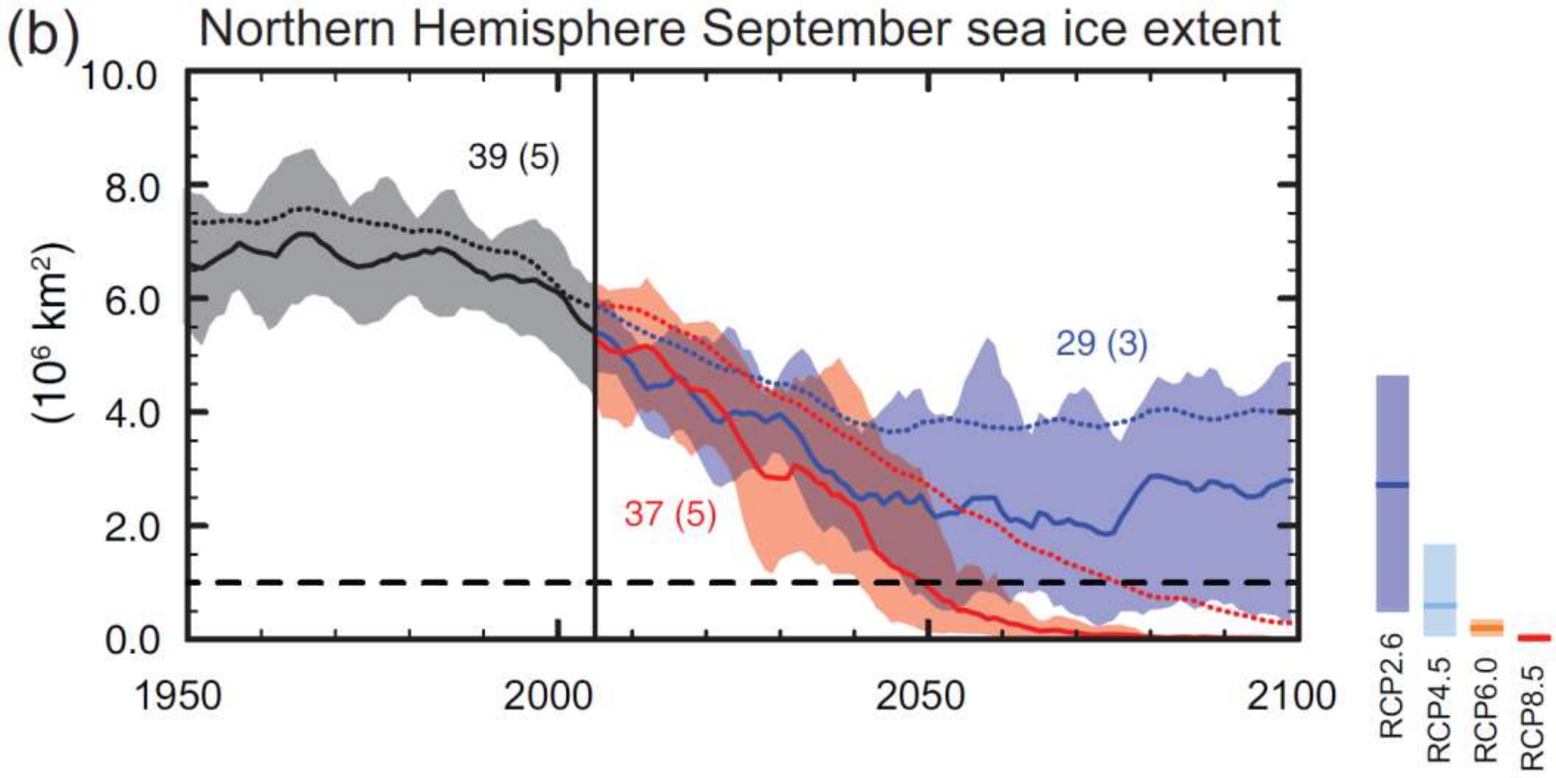
Global mean sea level will continue to rise during the 21st century (see Figure SPM.9). Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets. {13.3–13.5}

E.7 Carbon and Other Biogeochemical Cycles

Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere (*high confidence*). Further uptake of carbon by the ocean will increase ocean acidification. {6.4}


RCP 2.6
RCP 8.5
(a)
Change in average surface temperature (1986−2005 to 2081−2100)
32
39
(°C)
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(b)
Change in average precipitation (1986−2005 to 2081−2100)
32
39
(%)
−50 −40 −30 −20 −10 0 10 20 30 40 50
(c)
Northern Hemisphere September sea ice extent (average 2081−2100)
29 (3)
37 (5)
CMIP5 multi-model average 1986−2005
CMIP5 multi-model average 2081−2100
CMIP5 subset average 1986−2005
CMIP5 subset average 2081−2100
(d)
Change in ocean surface pH (1986−2005 to 2081−2100)
9
10
(pH unit)
−0.6 −0.55 −0.5 −0.45 −0.4 −0.35 −0.3 −0.25 −0.2 −0.15 −0.1 −0.05

NH September sea ice extent



E. Future Global and Regional Climate Change

Projections of changes in the climate system are made using a hierarchy of climate models ranging from simple climate models, to models of intermediate complexity, to comprehensive climate models, and Earth System Models. These models simulate changes based on a set of scenarios of anthropogenic forcings. A new set of scenarios, the Representative Concentration Pathways (RCPs), was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. In all RCPs, atmospheric CO_2 concentrations are higher in 2100 relative to present day as a result of a further increase of cumulative emissions of CO_2 to the atmosphere during the 21st century (see Box SPM.1). Projections in this Summary for Policymakers are for the end of the 21st century (2081–2100) given relative to 1986–2005, unless otherwise stated. To place such projections in historical context, it is necessary to consider observed changes between different periods. Based on the longest global surface temperature dataset available, the observed change between the average of the period 1850–1900 and of the AR5 reference period is 0.61 [0.55 to 0.67] °C. However, warming has occurred beyond the average of the AR5 reference period. Hence this is not an estimate of historical warming to present (see Chapter 2) .

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. {6, 11–14}

GEF4400/9400 exam schedule

Wednesday 02.12.2015, 9:00-11:30 hr, CIENS, Glashallen 4

- 09:00-9:30: Susanne Foldvik
- 09:30-10:00: Charalampos Sarchosidis
- 10:00-10:30: Malte Ziemek
- 10:30-11:00: Hans Brenna
- 11:00-11:30: Christine Smith-Johnsen