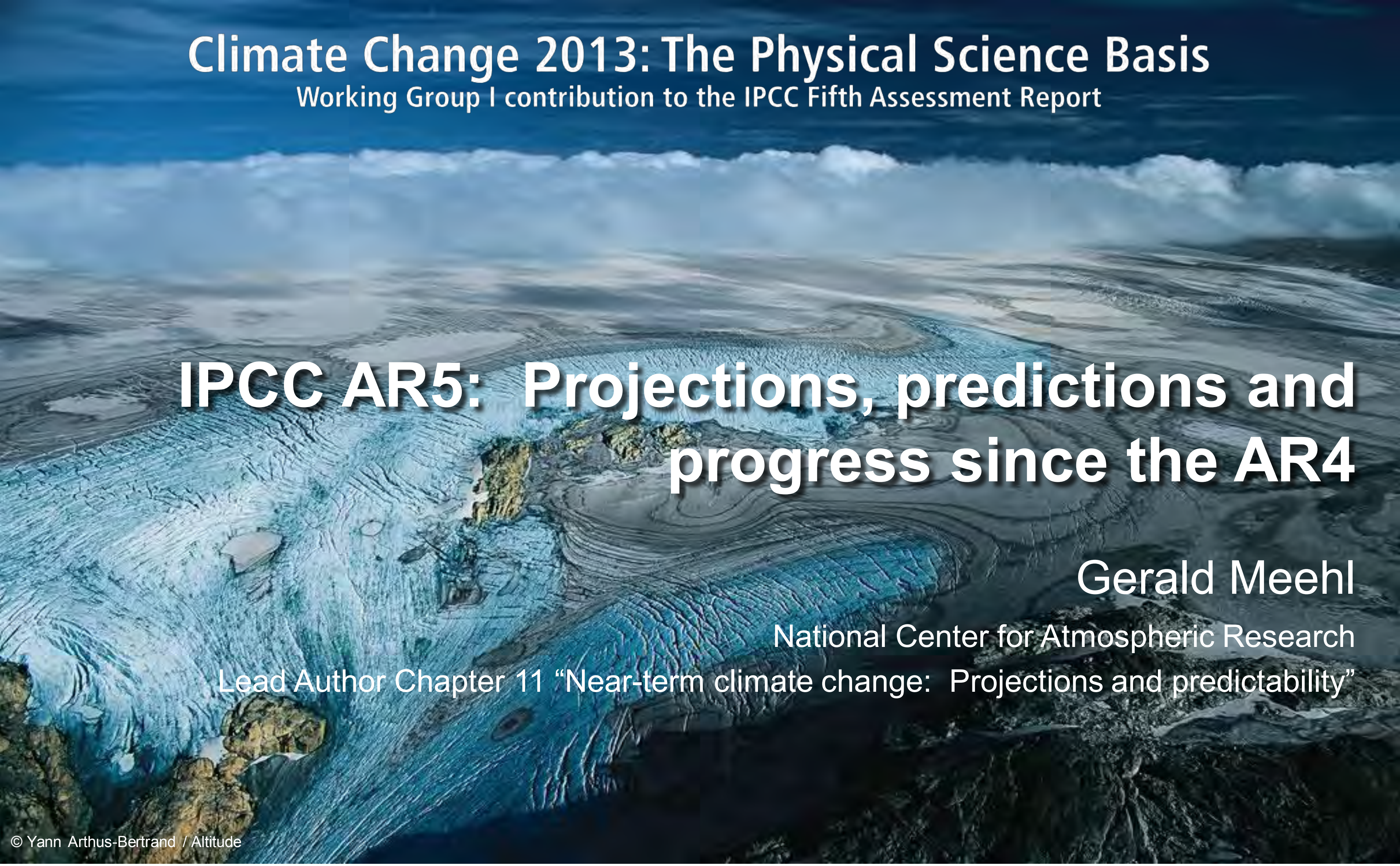


Climate Change 2013: The Physical Science Basis

Working Group I contribution to the IPCC Fifth Assessment Report

IPCC AR5: Projections, predictions and progress since the AR4

Gerald Meehl

National Center for Atmospheric Research

Lead Author Chapter 11 “Near-term climate change: Projections and predictability”

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

Overview

I. Introduction

- Overview IPCC
- Structure and Timeline IPCC 5th Assessment WG I Report

II. What is new compared to AR4?

- Observational Evidence for Climate Change
- Understanding and Attributing Climate Change

III. Projections and predictions

IV. Outlook

Introduction

Key SPM Messages

19 Headlines

on less than 2 Pages

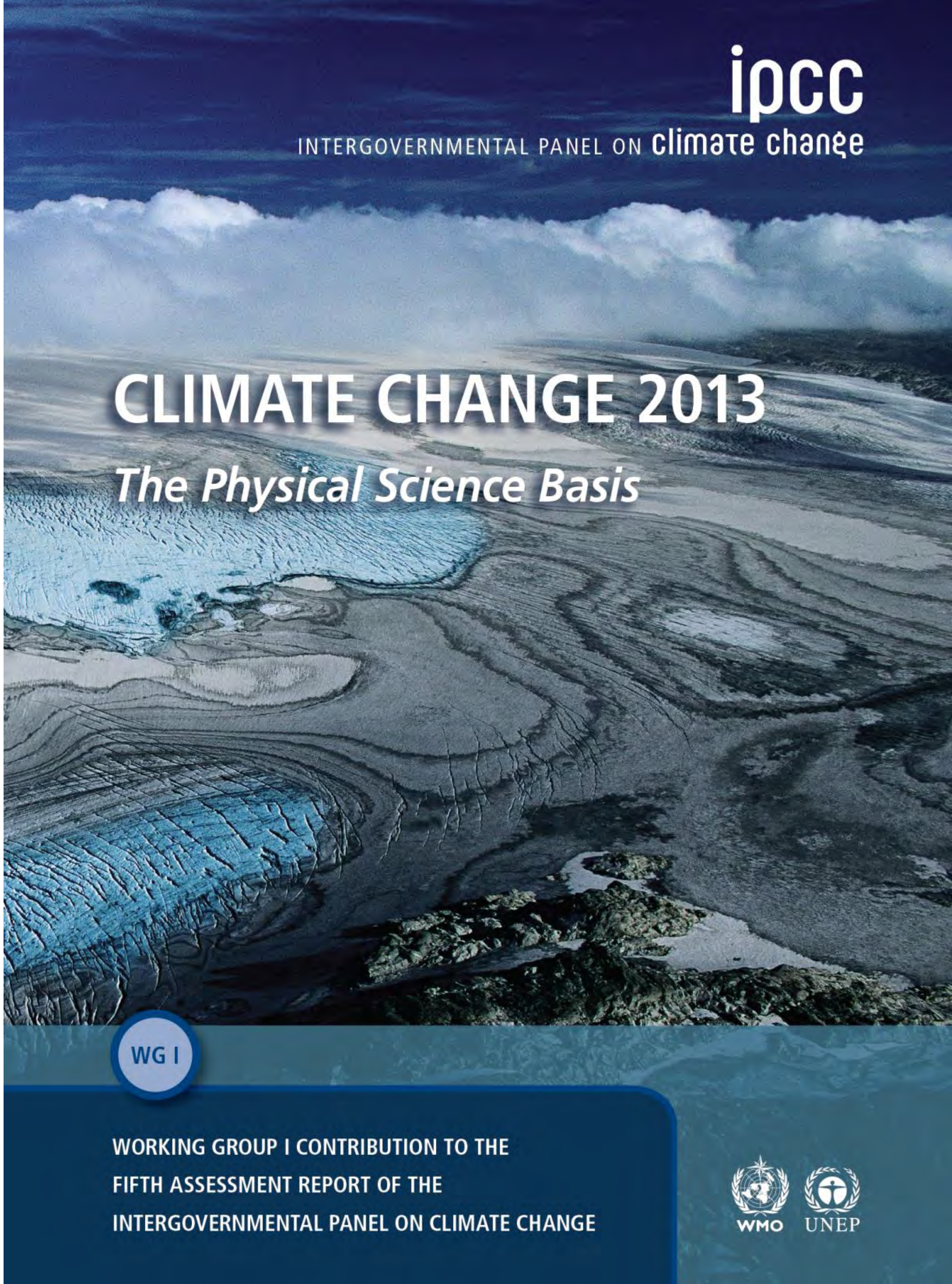
Summary for Policymakers
27 pp, Took 4 days to approve
line by line, word for word

14 Chapters
Atlas of Regional Projections

2 rounds of international review
54,677 Review Comments
by 1089 Experts

255 authors from 39 countries
18% female; 24% DC/EIT;
~50% new to IPCC

2009: WGI Outline Approved
4 Lead author meetings over 4 years



Structure of the IPCC WG I AR5 Report

IPCC Plenary for approval of the Summary for Policymakers, Stockholm
Sept. 23-26, 2013

Roughly 110 governments and about 300 delegate
Simultaneous translation into the six UN languages

Four full days and two nights (until 2:20AM Thursday morning, and 5:20AM Friday morning) to approve 27 page document

The first sentence of the Summary for Policymakers:

started with (edits added to government version in response to comments from governments):

The Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) considers new evidence of past and ~~projected~~ future climate change based on many independent scientific analyses ~~ranging~~ from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models.

The first sentence of the Summary for Policymakers:

started with:

The Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) considers new evidence of past and ~~projected~~ future climate change based on many independent scientific analyses ~~ranging~~ from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models.

40 minutes of discussion later…

Final approved version:

The Working Group I contribution to the IPCC's Fifth Assessment Report (AR5) considers new evidence of climate change based on many independent scientific analyses from observations of the climate system, paleoclimate archives, theoretical studies of climate processes and simulations using climate models.

Final sentence gaveled down at 5:20AM Friday morning (press conference started at 10AM)

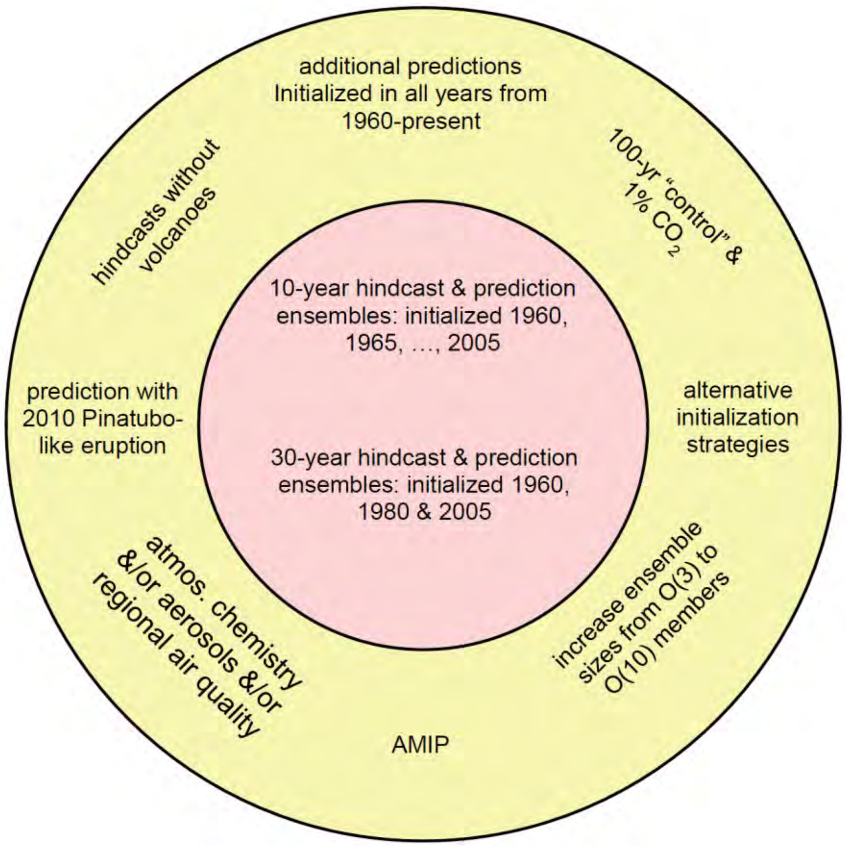
What is new compared to AR4

What is New?

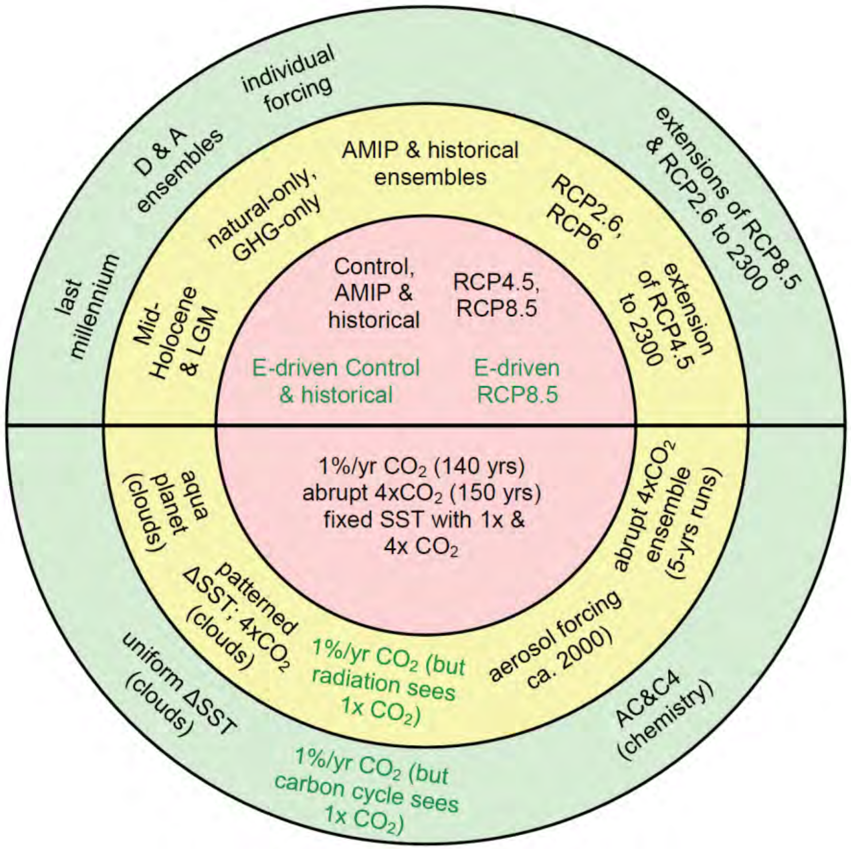
- **Improved treatment of regional information**
  - by specifically assessing key climate phenomena (monsoon, El Niño, etc.)
  - Atlas of Global and Regional Climate Projections to enhance accessibility for users and stakeholders and ease the hand-over of relevant information from WG I to WG II.
- Assessment of the science of **clouds and aerosols (incl. Geoengineering)**
- An end-to-end assessment of **sea level change**
- An end-to-end assessment of the **carbon cycle (e.g. ocean acidification, feedbacks)**
- Future climate change broken down into **near- and long-term projections**

(1) Coupled Model Intercomparison Project Phase 5 (CMIP5) experimental design

Near-term (next decades)



Long-term (2100 and beyond)



Taylor et al., BAMS, 2012
Figure 9.1

Models have improved in terms of simulation capability

Of the roughly 45 “standard” models in the CMIP5 database:

14 are “high top” with a resolved stratosphere (only 1 in CMIP3)

19 are “Earth System Models” with at least interactive ocean biogeochemistry (none in CMIP3)

Most have some kind of prognostic aerosol formulation and can resolve direct and indirect effect (very few included prognostic indirect effect in CMIP3)

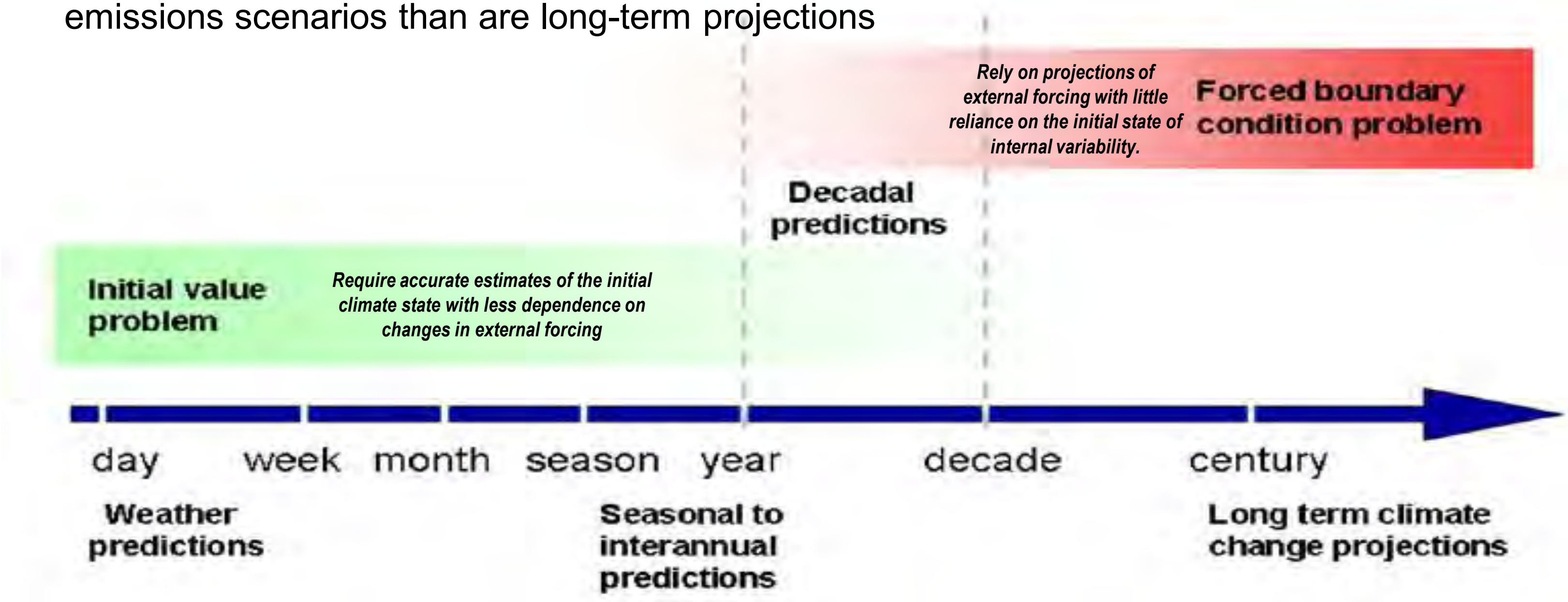
None use flux correction (about a third of the models in CMIP3 used flux correction)

(1) CMIP 5 experimental design: Decadal Predictions

(observationally-based information used to initialize the models)

Why an emphasis on decadal predictions?

i. a recognition of its importance to decision makers in government and industry;
ii. new international research effort to improve understanding of interaction of internally generated variability and externally forced response in near-term climate;
iii. a recognition that near-term projections are generally less sensitive to differences between future emissions scenarios than are long-term projections

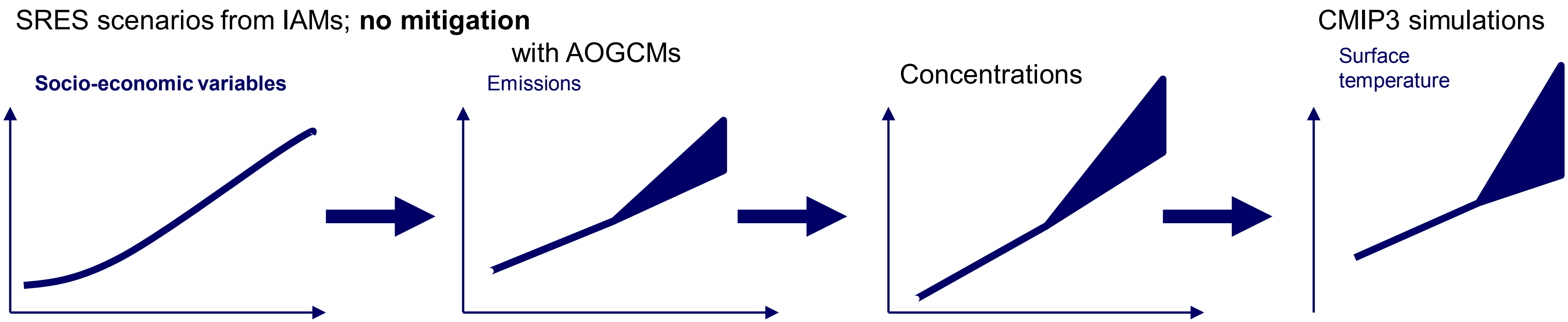


Estimates of near-term climate depend partly on

i. committed change (caused by the inertia of the oceans as they respond to historical external forcing),
ii. the time evolution of internally-generated climate variability, and
iii. the time evolution of external forcing.

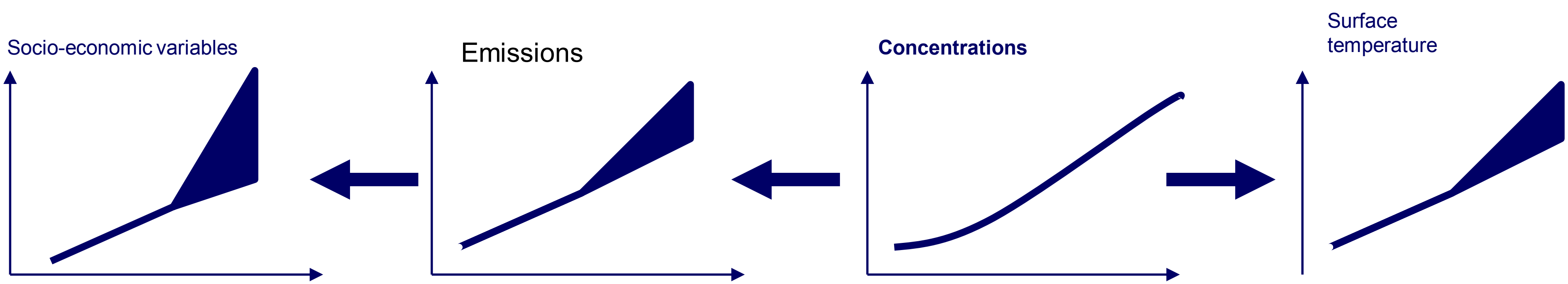
(2) Representative Concentration Pathways (RCPs)

Forward approach: start with socio-economic variables



Reverse approach: start with stabilization scenario concentrations

Community "parallel process" for CMIP5 with RCPs and SSPs, assessed in IPCC AR5



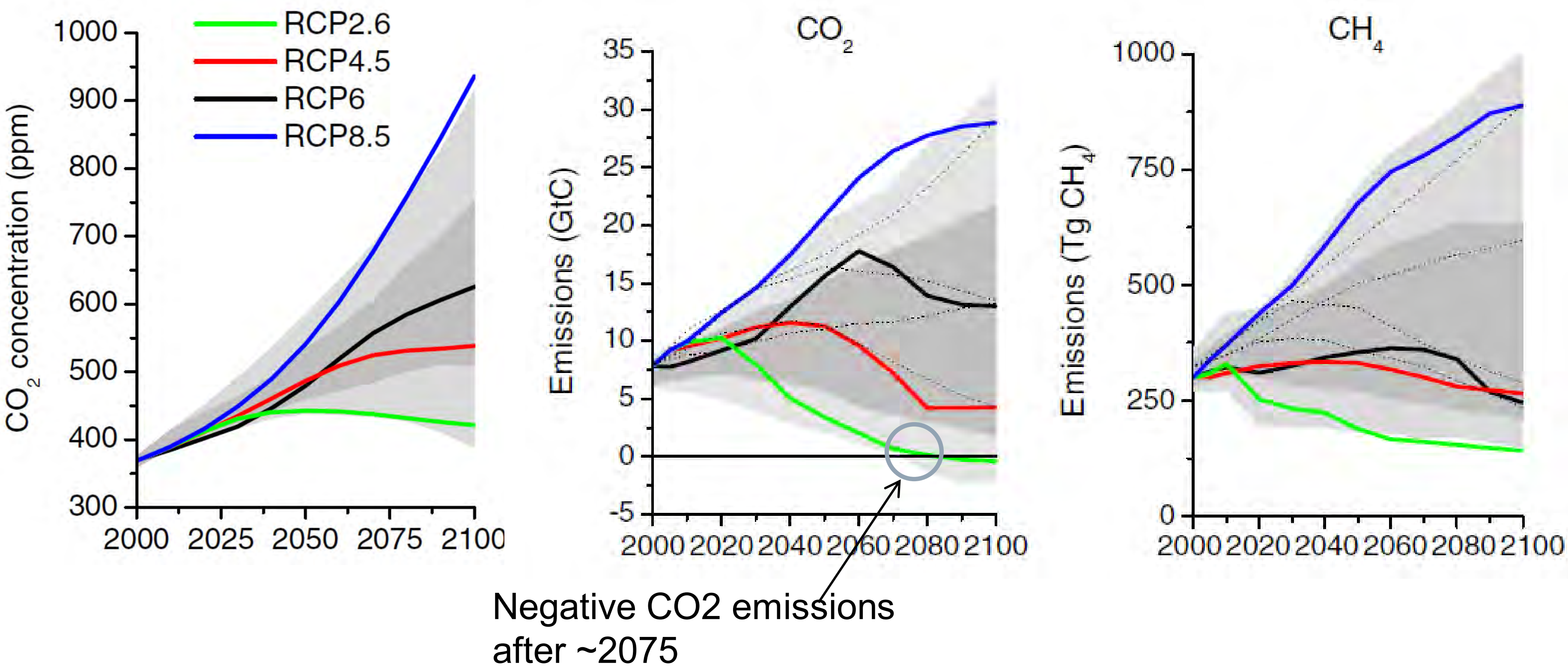
Shared socio-economic pathways (SSPs) from IAMs
No mitigation

Representative concentration pathways (RCPs) from IAMs; **mitigation**

CMIP5 simulations with AOGCMs and ESMs

(figure from Meehl and Hibbard, 2007, WCRP; and Hibbard et al., 2007, EOS)

(2) Representative Concentration Pathways (RCPs) cont'd …



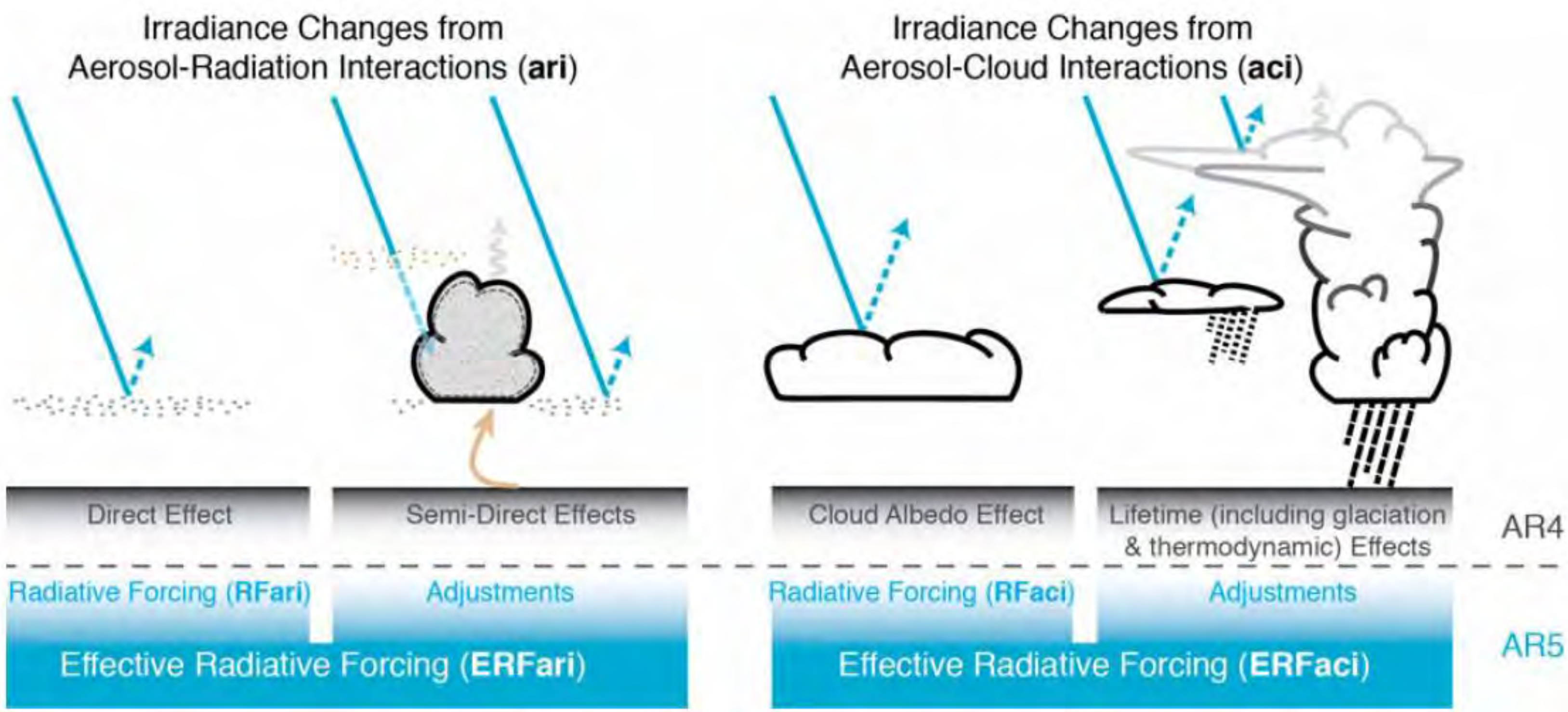
- IPCC 5th Assessment made extensive use of model projections based on four representative concentration pathways (RCPs) intended to span a broad range of plausible future greenhouse gas scenarios; RCP2.6 designed to meet goal of less than 2°C warming from pre-industrial by 2100.

van Vuuren et al., 2011

(4) Radiative Forcing & Effective Radiative Forcing

RF (as in AR4 stratospherically-adjusted RF): change in net downward radiative flux at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, while holding surface and tropospheric temperatures and state variables fixed at the unperturbed values.

ERF (accounts for rapid adjustments): change in net top-of-the-atmosphere downward radiative flux after allowing for atmospheric temperatures, water vapor, and clouds to adjust, but with surface temperature or a portion of surface conditions such as water vapor and cloud cover unchanged = **makes ERF a better indicator of the eventual global mean temperature response**



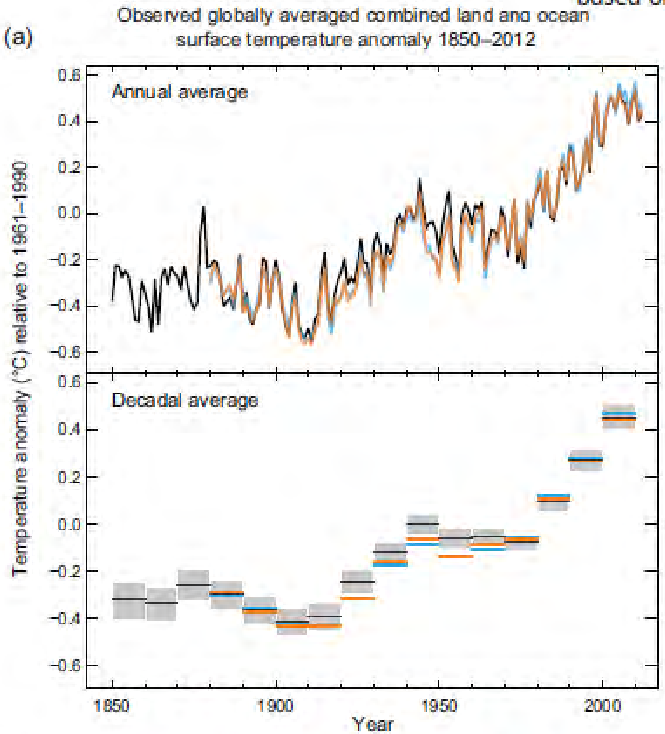
Chapter 7, Fig. 7.3

A summary assessment of the effects of solar forcing on climate was included for the first time in the SPM:

There is *high confidence* that changes in total solar irradiance have not contributed to the increase in global mean surface temperature over the period 1986 to 2008, based on direct satellite measurements of total solar irradiance. There is *medium confidence* that the 11-year cycle of solar variability influences decadal climate fluctuations in some regions. No robust association between changes in cosmic rays and cloudiness has been identified. {7.4, 10.3, Box 10.2}

Observed Global Mean Surface Temperature Time Series

- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65 to 1.06] °C[3], over the period 1880 to 2012, when multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72 to 0.85] °C, based on the single longest dataset available[4] (see Figure SPM.1). {2.4}

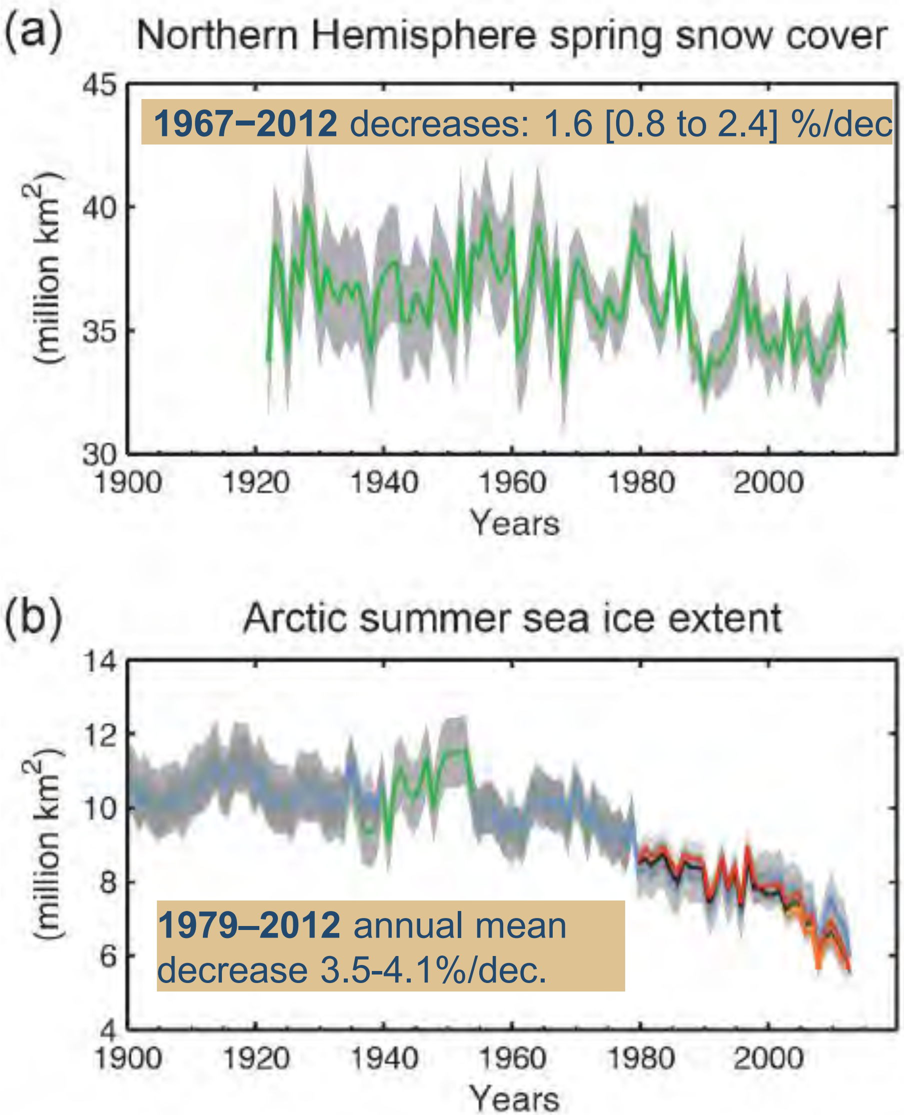


- Warming of the climate system is **unequivocal**, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.
- Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

- In addition to robust multi-decadal warming, global mean surface temperature exhibits substantial decadal and interannual variability (see Figure SPM.1). Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends. As one example, the rate of warming over the past 15 years (1998–2012; 0.05 [–0.05 to 0.15] °C per decade), which begins with a strong El Niño, is smaller than the rate calculated since 1951 (1951–2012; 0.12 [0.08 to 0.14] °C per decade)[5]. {2.4}

Figure SPM.1

Multiple complementary indicators of a changing climate

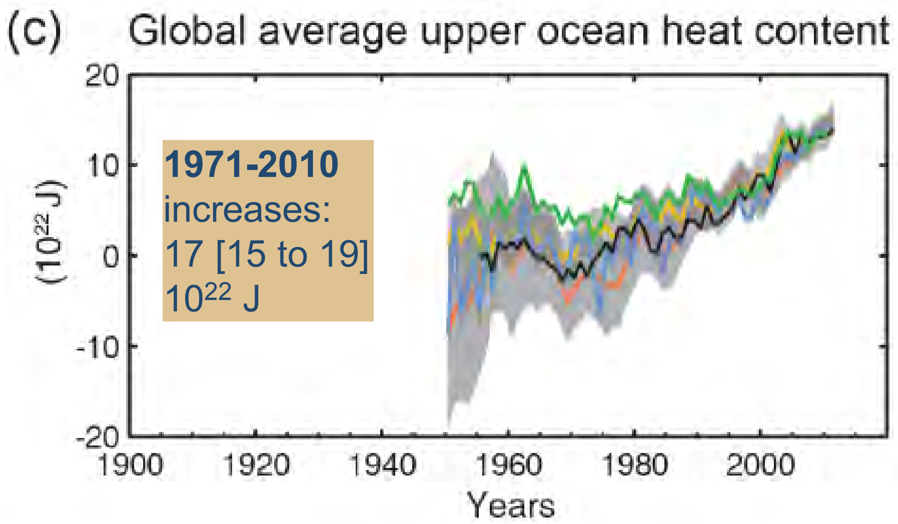


- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent *(high confidence).*

Figure SPM.3

Multiple complementary indicators of a changing climate

- 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).*
- It is virtually certain that the upper ocean (0−700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.



- 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).*
- Over the period 1901–2010, global mean sea level rose by 0.19 [0.17 to 0.21] m.

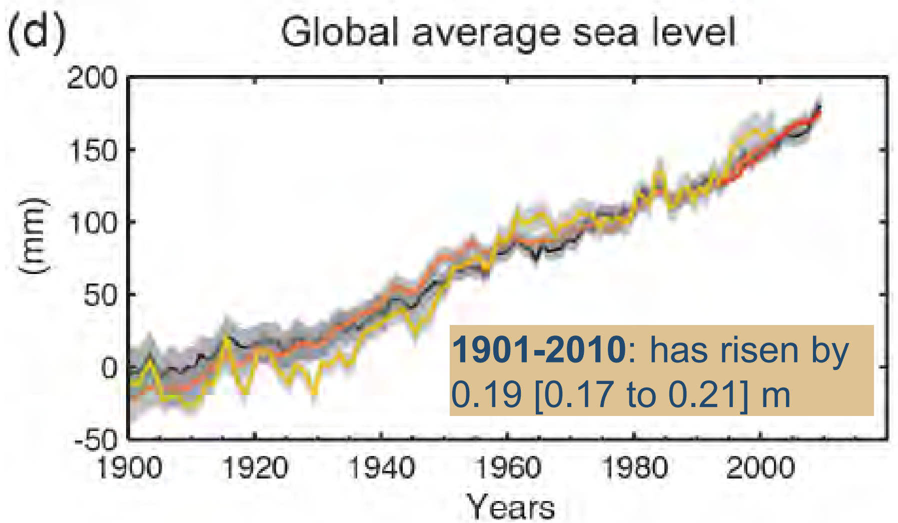
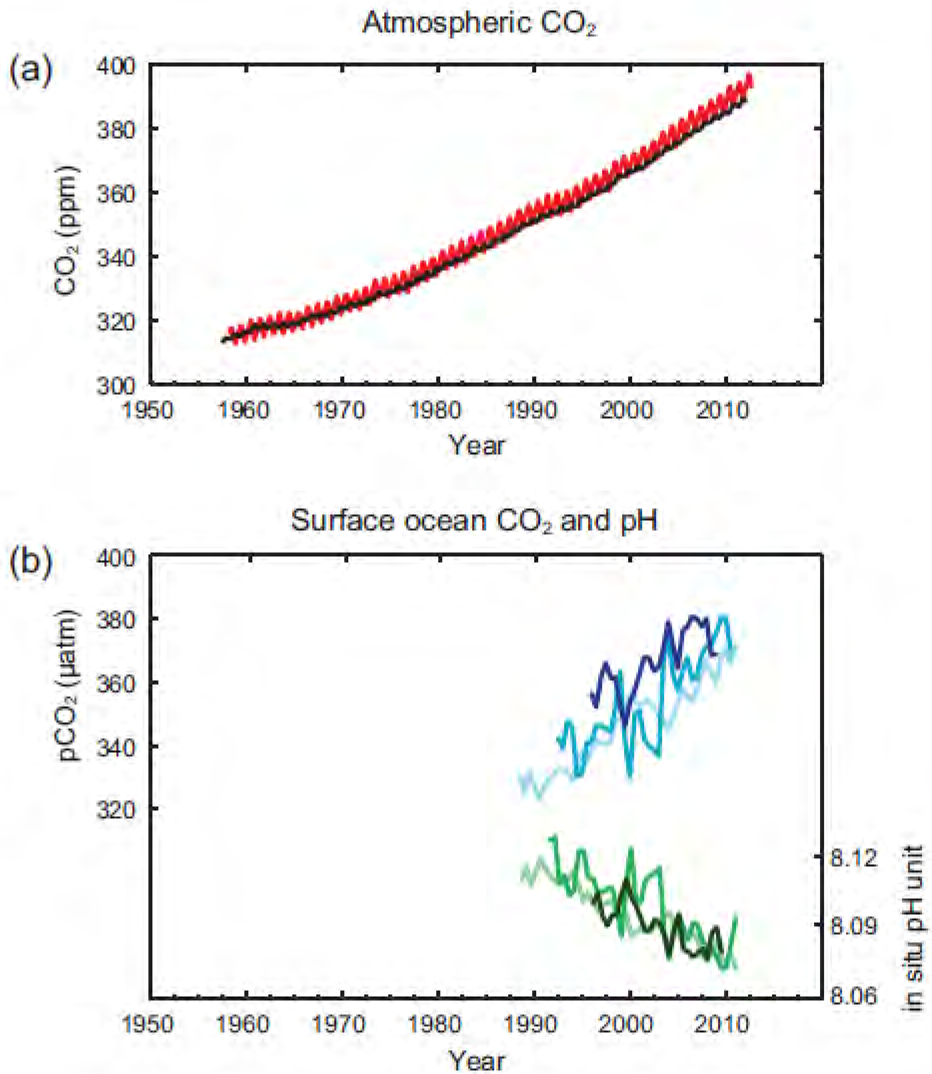


Figure SPM.3

Carbon and Other Biogeochemical Cycles

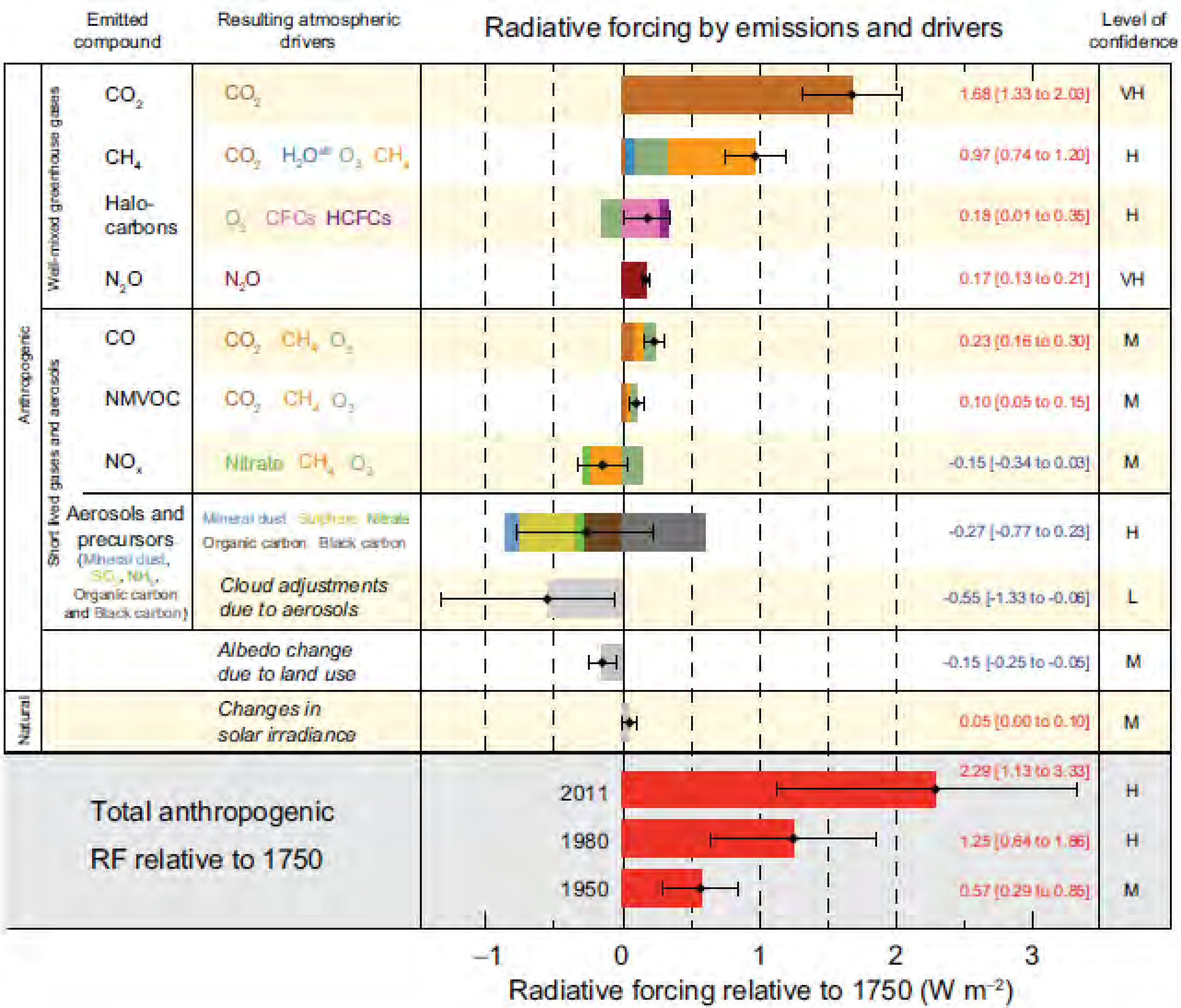


- The atmospheric concentrations of carbon dioxide (CO_2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years.
- CO_2 concentrations have increased by **40% since pre-industrial times**, primarily from fossil fuel emissions and secondarily from net land use change emissions.
- The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification

Figure SPM.4

Radiative Forcing in 2011 since 1750 ($W\ m^{-2}$)

- grouped by *emissions*, rather than by *concentrations* to allow the indirect effects to be seen clearly -



- Total RF is positive, and has led to an uptake of energy by the climate system.
- The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750.

WGI AR5 Final Draft 07 June

Figure SPM.5

INTERGOVERNMENTAL PANEL ON climate change

Human influence on the climate system is clear

Evidence of human influence has grown since the AR4.

It is *extremely likely* that human influence has been the **dominant cause of the observed warming since the mid-20th century**.

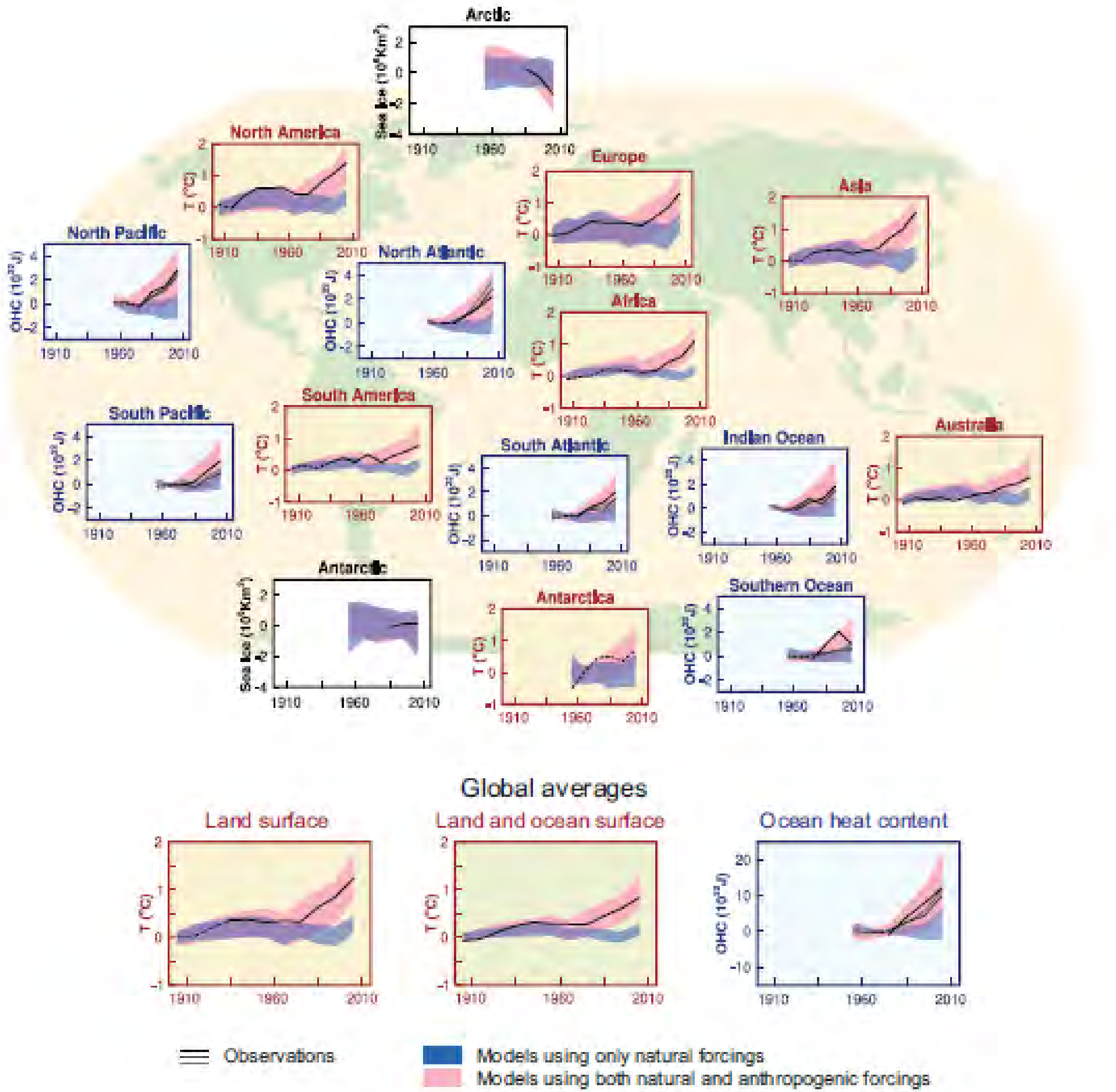
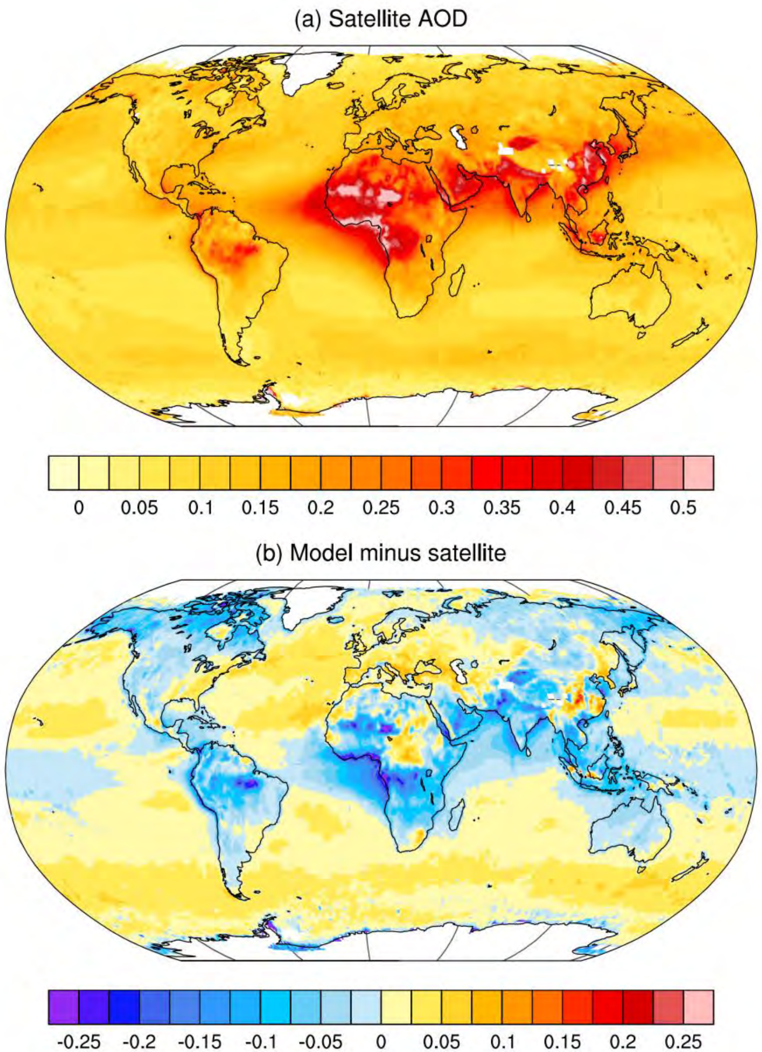


Figure SPM.6

WGI AR5 Final Draft 07 June

Evaluation of Climate Models: Aerosol Optical Depths (AOD)

Annual-mean visible AOD 2001-2005

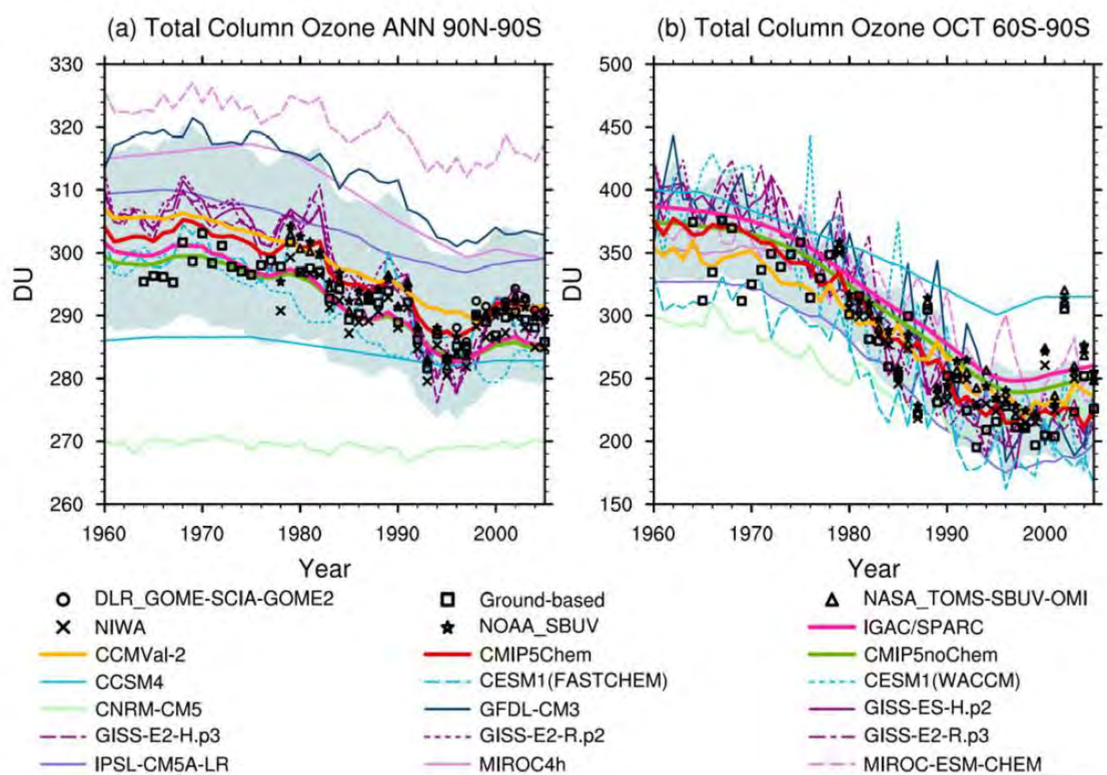


- **The majority of Earth System models now include an interactive representation of aerosols**, and make use of a consistent specification of anthropogenic sulphur dioxide emissions.
- Simulated **AOD** over oceans ranges from **0.08 to 0.22** with roughly equal numbers of models over- and under-estimating the satellite-estimated value of **0.12**.
- CMIP5 models **underestimate the mean AOD** at 550 nm relative to satellite-retrieved AOD **by at least 20% over virtually all land surfaces.**

  ⇒ **Improvement:** **Yes**
  ⇒ **Confidence:** **Medium**
  ⇒ **Performance:** **Low**

Chapter 9, Fig. 9.28

Evaluation of Climate Models: Total Column Ozone

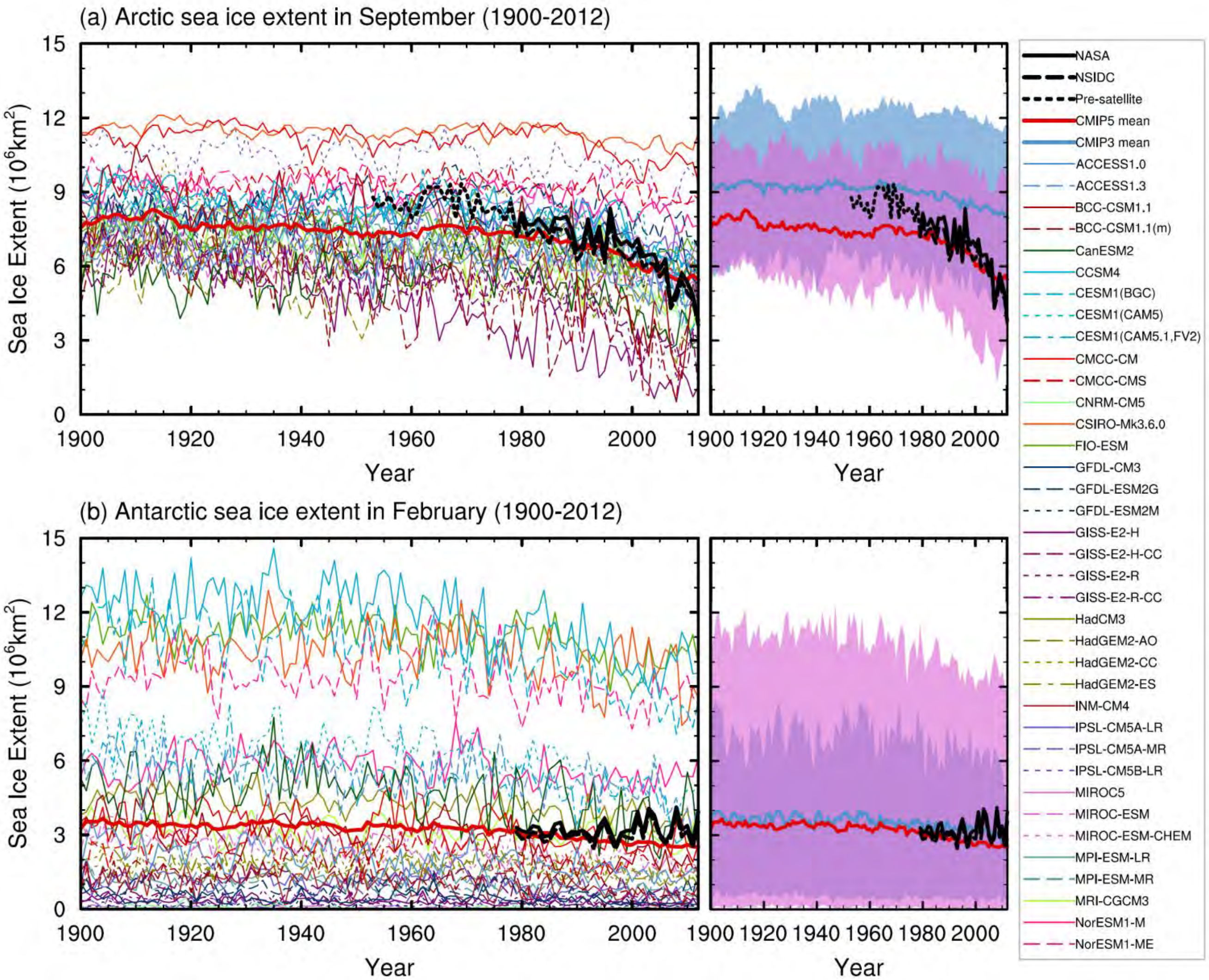


TotalO3-t	
Improvement:	**Yes**
Confidence:	**High**
Performance:	**Medium**

- **Time-varying ozone** is now included in the latest suite of models, either prescribed or calculated interactively.
- Although in some models there is only **medium agreement with observed changes** in total column ozone, the inclusion of time-varying stratospheric ozone constitutes a substantial improvement since the AR4 where half of the models prescribed a constant climatology.
- As a result, there is robust evidence that the representation of climate forcing by stratospheric ozone has improved since the AR4.

Figure 9.10
Adapted from Eyring et al., 2013

Evaluation of Climate Models: Sea-Ice



Robust evidence that the **downward trend in Arctic summer sea-ice extent** is better simulated than at the time of the AR4, with about one-quarter of the simulations showing a trend as strong as, or stronger, than in observations over the satellite era (since 1979).

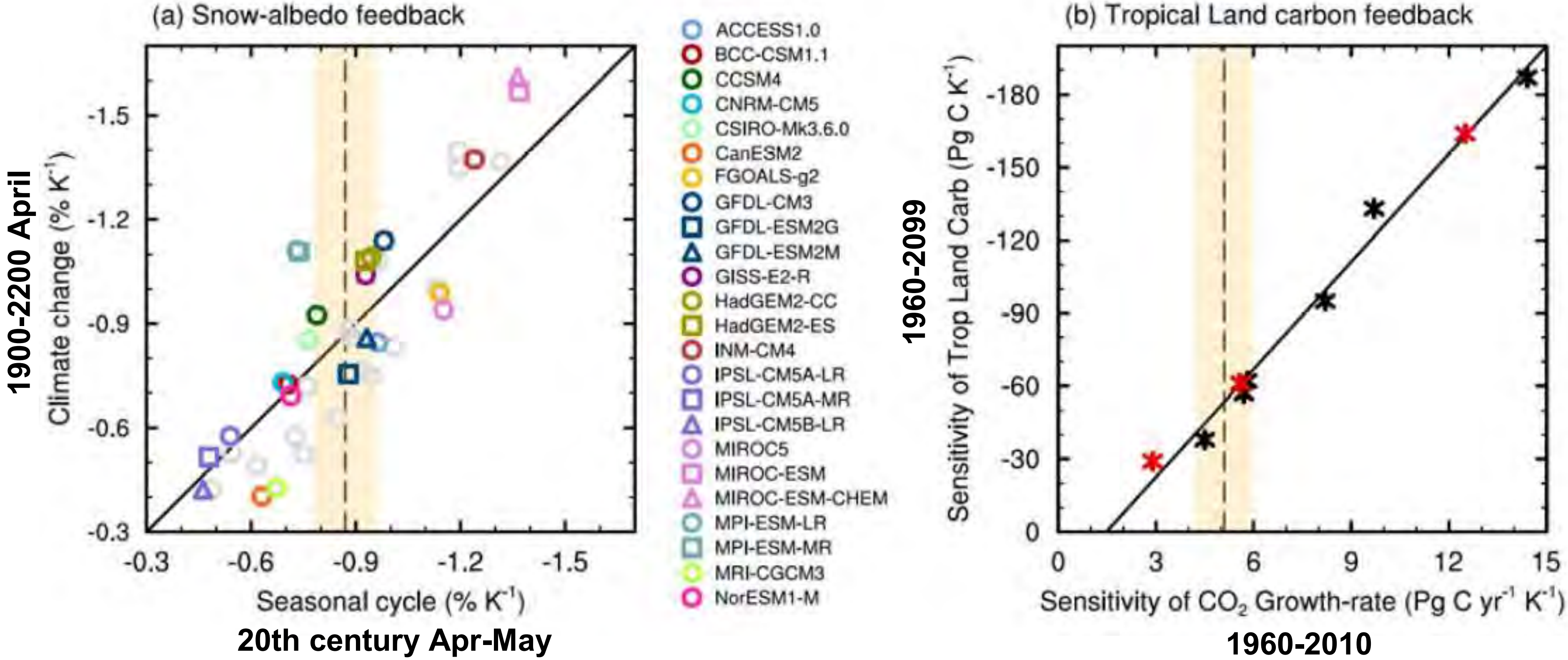
Most models simulate a **small decreasing trend in Antarctic sea-ice extent**, albeit with large inter-model spread, in contrast to the **small increasing trend in observations**

Chapter 9, Fig. 9.24

Evaluation of Climate Models: Emergent Constraints

Emergent constraints: relationships across an ensemble of models between some aspect of Earth System sensitivity and an observable trend or variation in the contemporary climate.

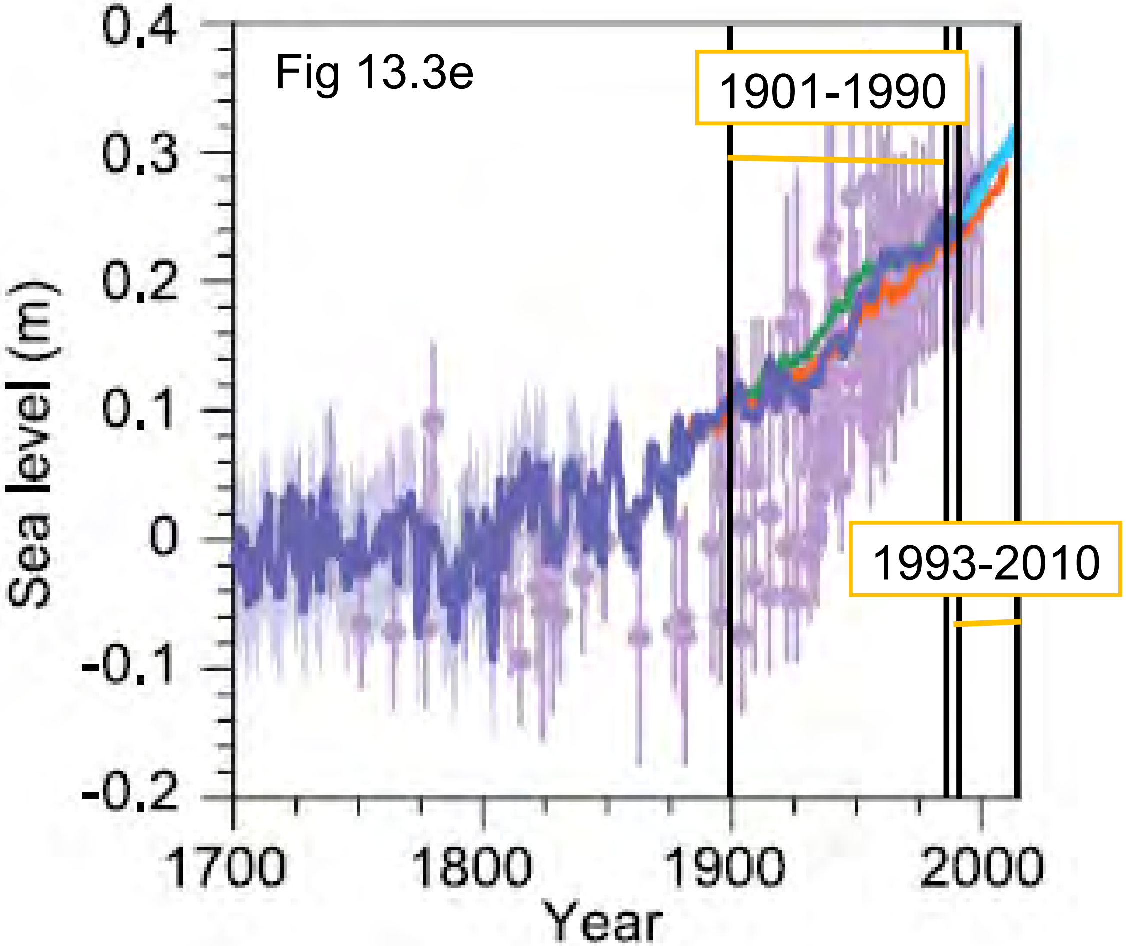
*There is increasing evidence that some elements of observed variability or trends are well correlated with inter-model differences in model projections for quantities such as **Arctic summer sea-ice trends**, the **snow–albedo feedback**, and the **carbon loss from tropical land**.*



Chapter 9, Fig. 9.45

Updated estimates of Global Mean Sea Level Rise (GMSLR)

The rate of GMSLR since the mid-19th century has been larger than the mean rate during the previous two millennia



Rate during 1901-1990 was 1.5 [1.3 to 1.7] mm yr^{-1}.

Rate during 1993-2010 was 3.2 [2.8 to 3.6] mm yr^{-1}.

Causes of global mean sea level rise (GMSLR)

Global mean sea level rise is caused by an increase in the volume of the global ocean.

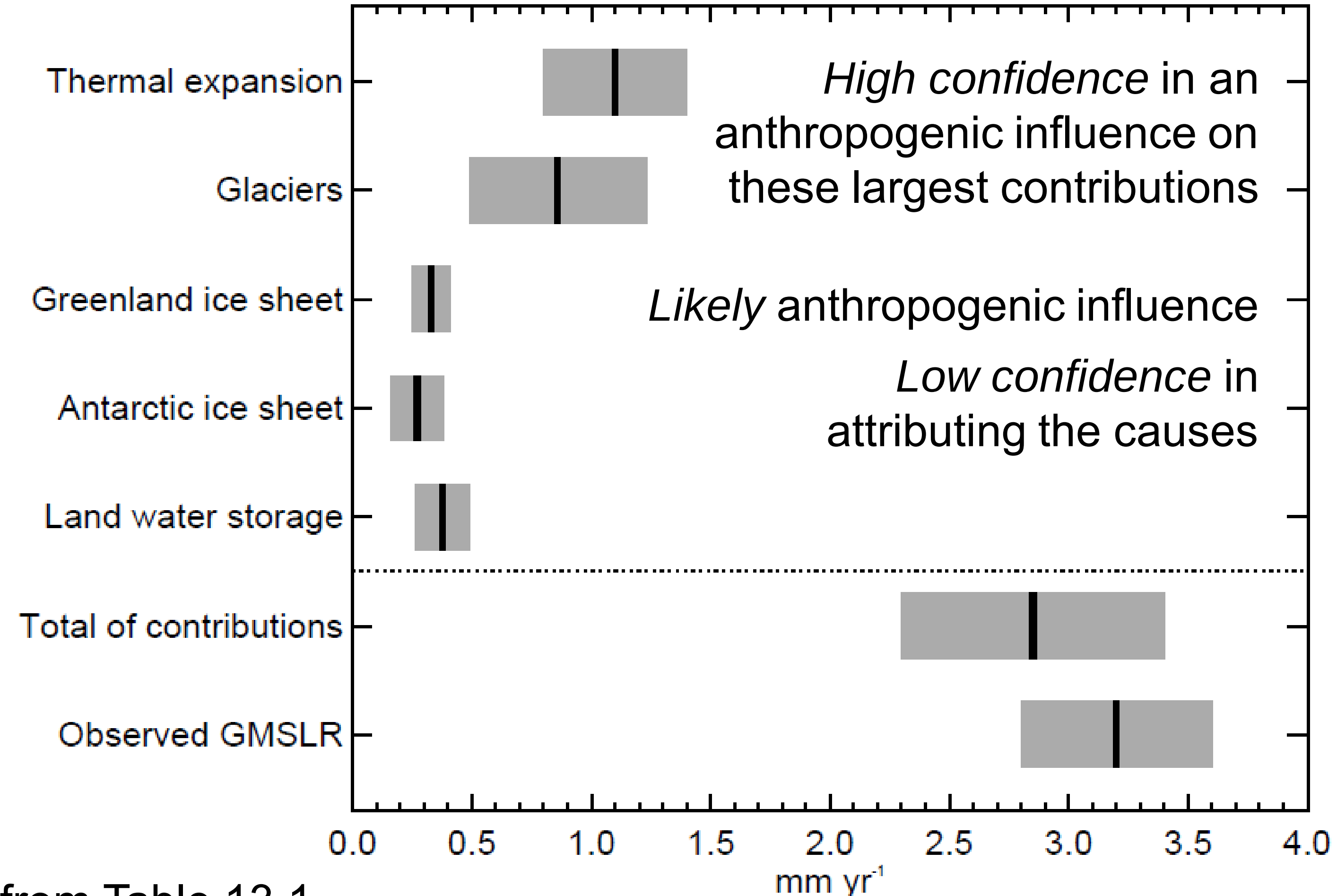
This in turn is caused by:

Warming the ocean (thermal expansion, global thermosteric sea level rise).

Adding mass to the ocean (**barystatic** sea level rise, not ~~eustatic~~), due to:

- Loss of ice by glaciers.
- Loss of ice by ice sheets.
- Reduction of liquid water storage on land.

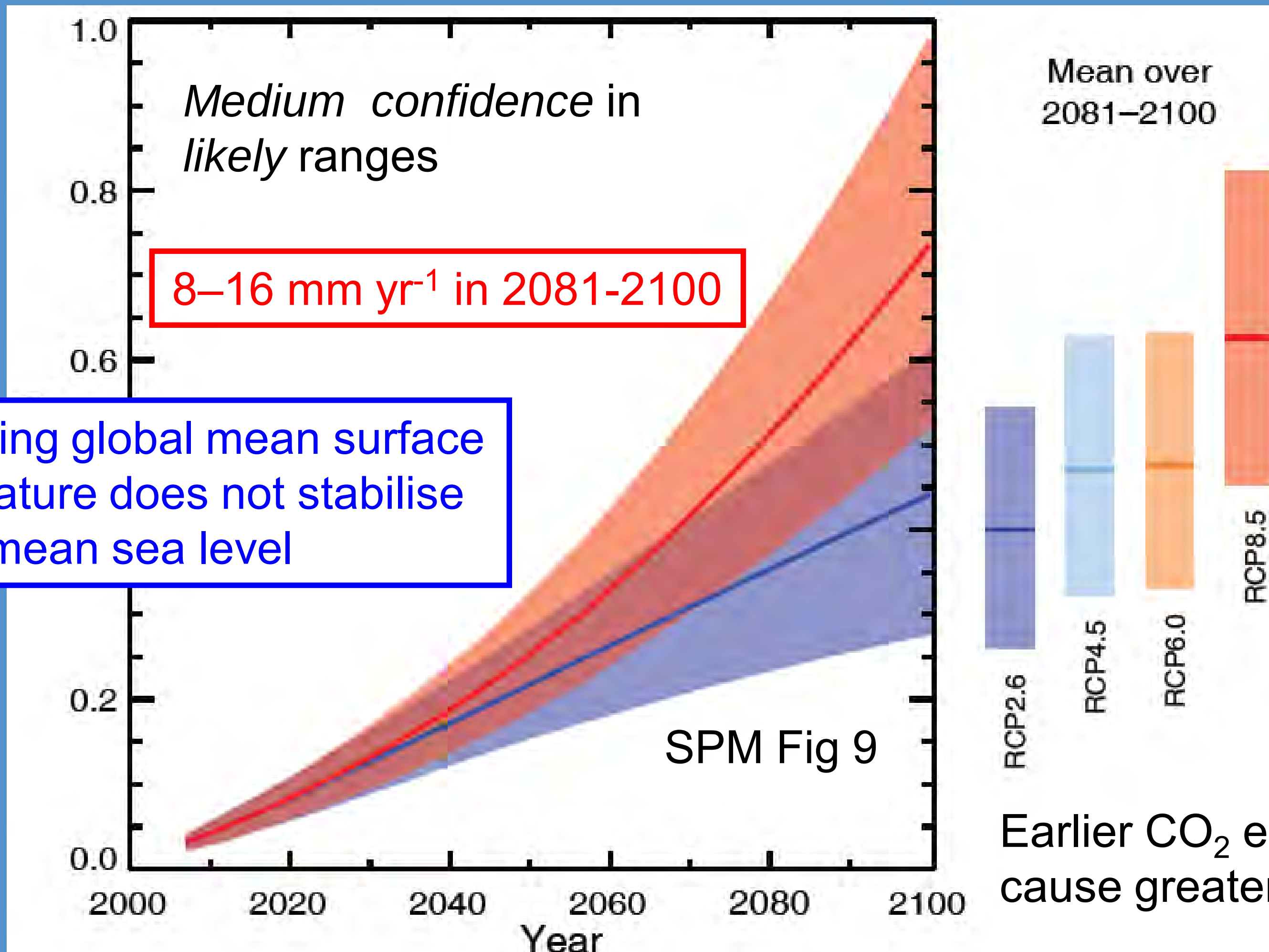
Observed GMSLR 1993-2010 is consistent with the sum of observed contributions (*high confidence*)



Data from Table 13.1

Projections and predictions

Under all RCPs the rate of GMSLR will *very likely* exceed that observed during 1971–2010



8–16 mm yr^{-1} in 2081-2100

Stabilising global mean surface temperature does not stabilise global mean sea level

Earlier CO_2 emissions cause greater GMSLR

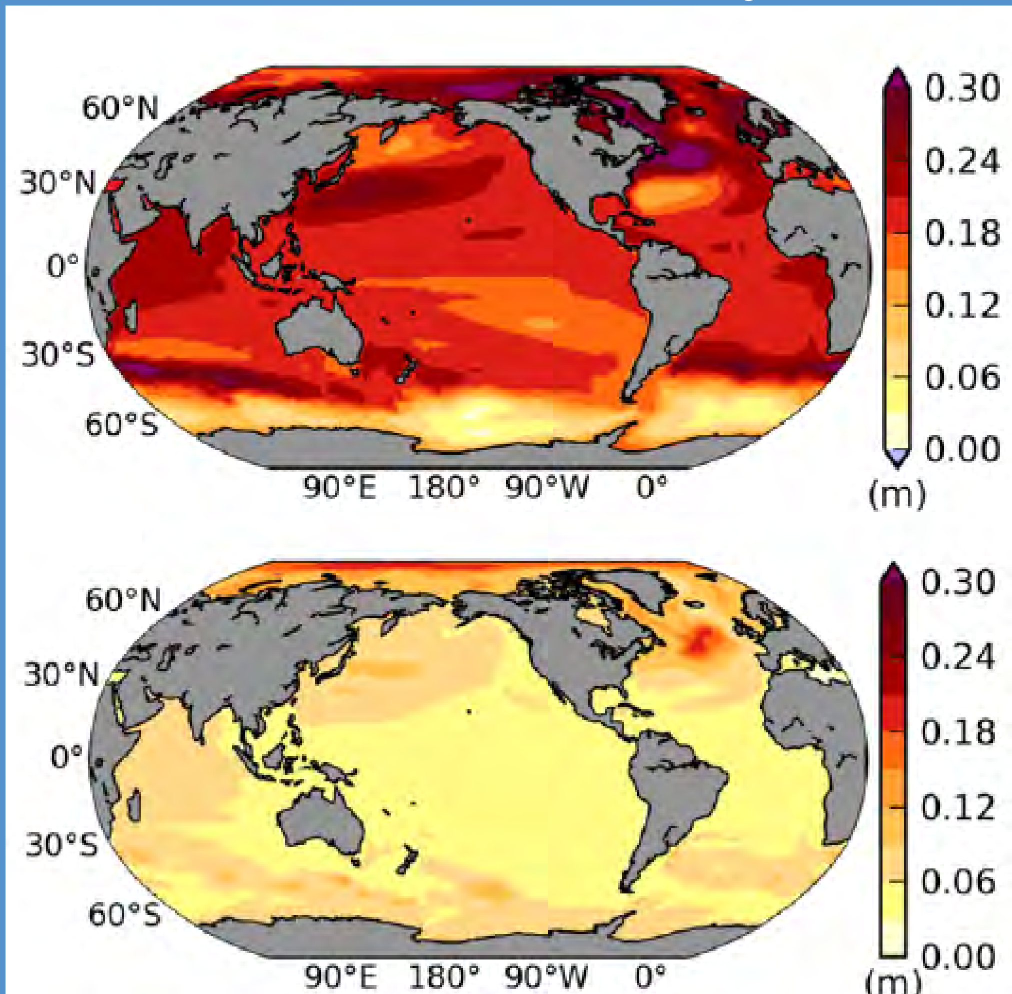
Collapse of marine-based sectors of the Antarctic ice sheet

Only this effect, if initiated, could cause GMSL to rise substantially above the *likely* range during the 21st century.

Medium confidence that this additional contribution would not exceed several tenths of a metre.

Current evidence and understanding do not allow a quantification of either the timing of its onset or of the magnitude of its multi-century contribution.

Regional sea level rise by the end of the 21st century due to ocean density and circulation change



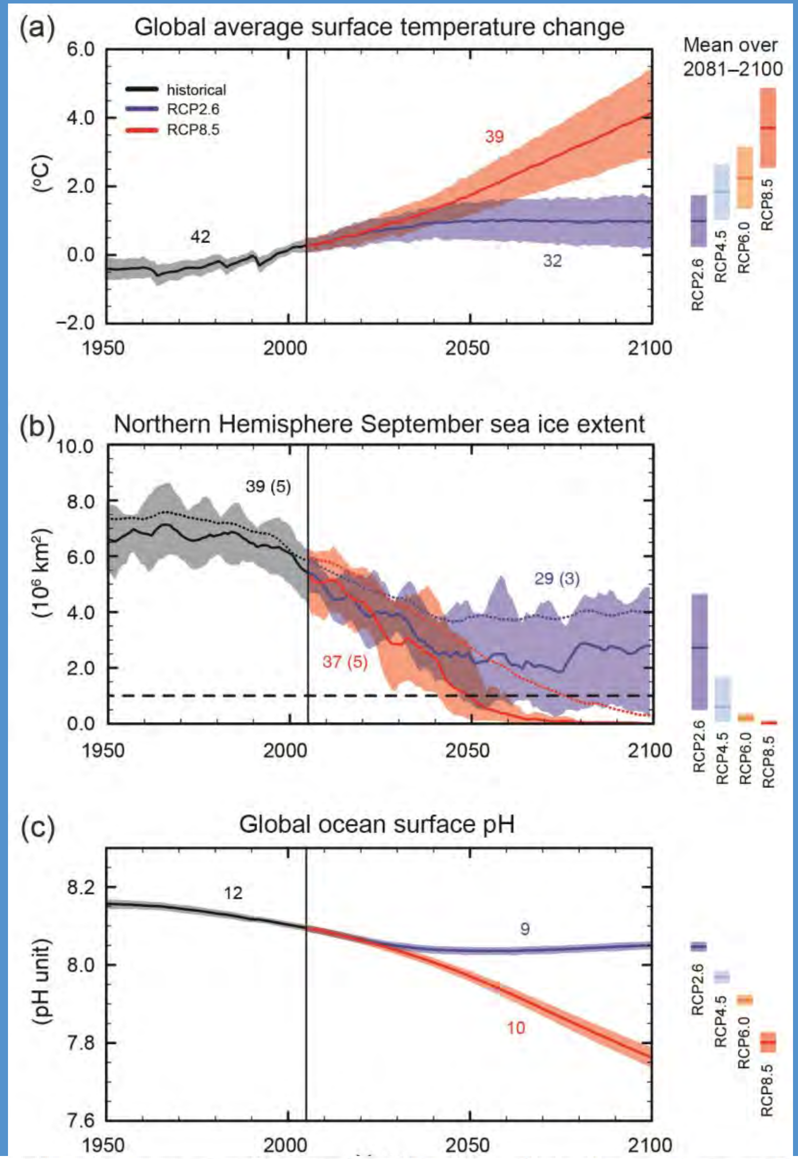
CMIP5 ensemble mean

Includes GSMLR due to thermal expansion of 0.18 m

Ensemble standard deviation

Fig 13.16

Projections



- Based on an assessment of the subset of models that most closely reproduce the climatological mean state and 1979 to 2012 trend of the Arctic sea ice extent, a nearly ice-free Arctic Ocean[19] in September before mid-century is *likely* for RCP8.5 (*medium confidence*) (see Figures SPM.7 and SPM.8). A projection of when the Arctic might become nearly ice-free in September in the 21st century cannot be made with confidence for the other scenarios. {11.3, 12.4, 12.5}

Fig. SPM.7

Projections

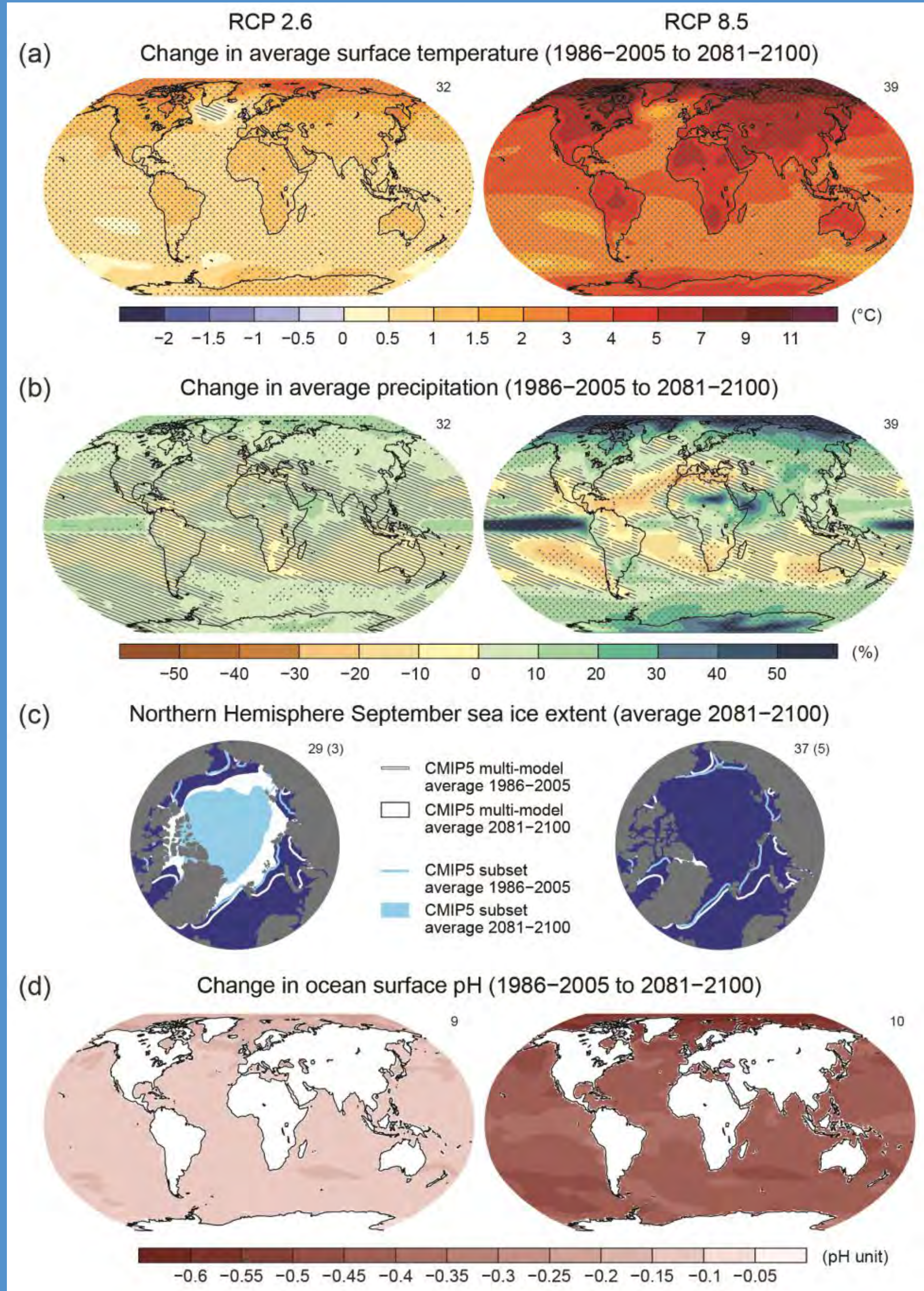
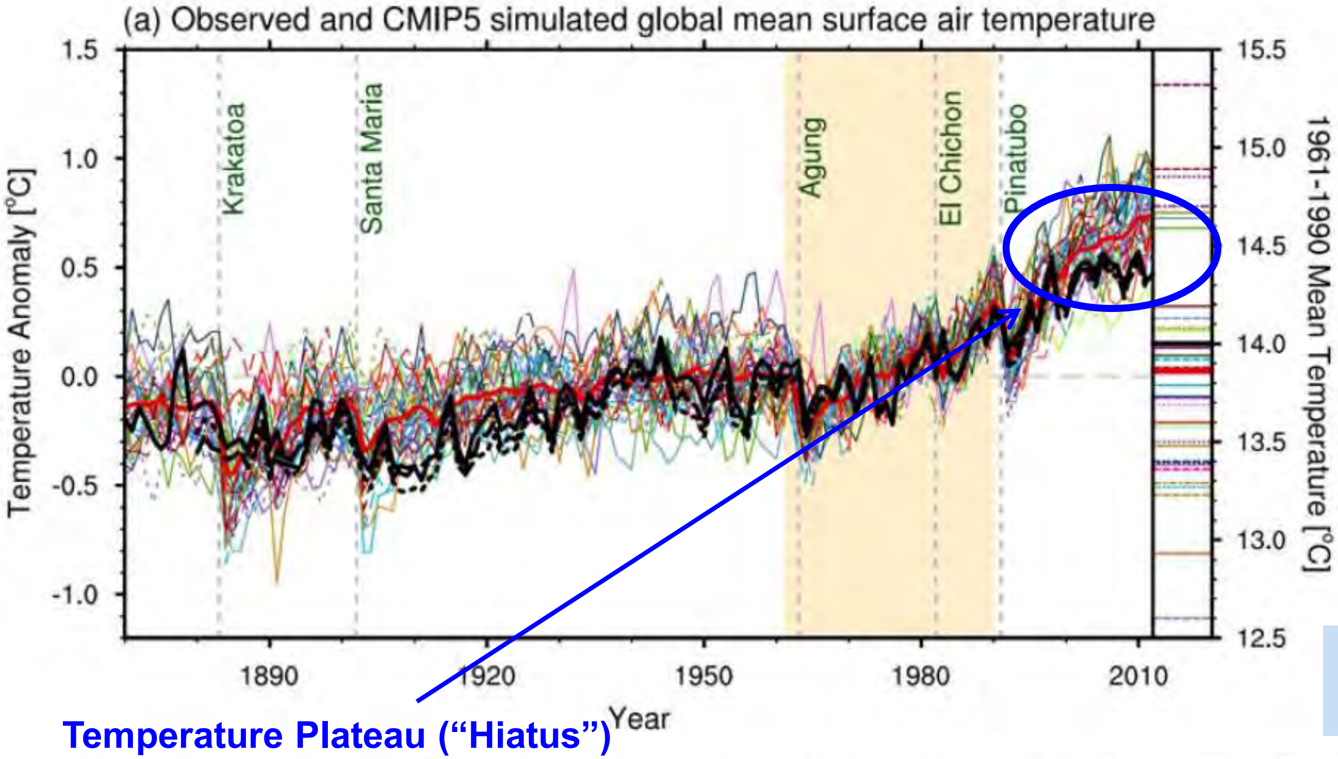


Fig. SPM.8

What about the early-2000s hiatus?



Climate models have improved since the AR4.

Models reproduce observed temperature trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*).

1998–2012: 0.04 ºC/decade
1951–2012: 0.11 ºC/decade

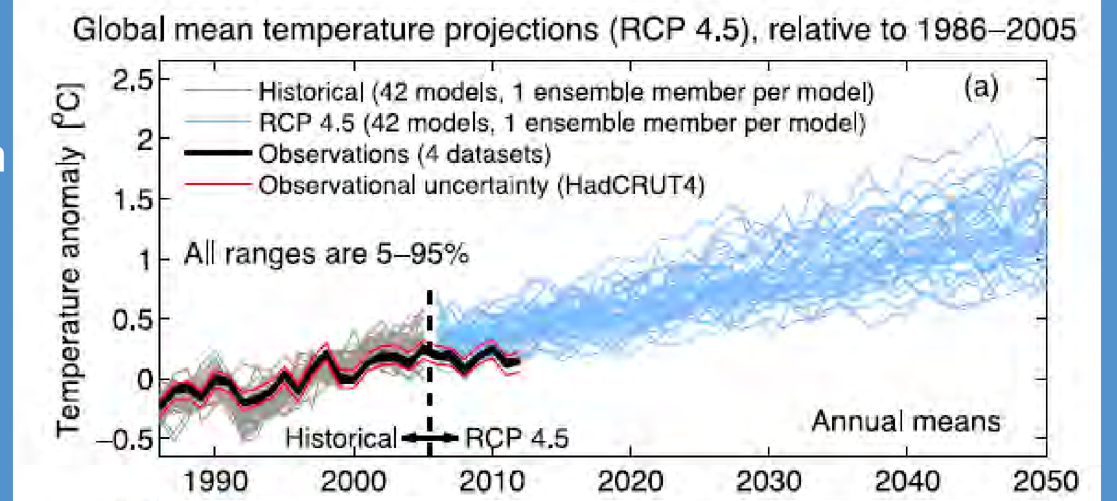
- The observed reduction in surface warming trend over the period 1998 to 2012 as compared to the period 1951 to 2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from natural internal variability, which includes a possible redistribution of heat within the ocean (*medium confidence*). The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle. However, there is *low confidence* in quantifying the role of changes in radiative forcing in causing the reduced warming trend. There is *medium confidence* that natural internal decadal variability causes to a substantial degree the difference between observations and the simulations; the latter are not expected to reproduce the timing of natural internal variability. There may also be a contribution from forcing inadequacies and, in some models, an overestimate of the response to increasing greenhouse gas and other anthropogenic forcing (dominated by the effects of aerosols). {9.4, Box 9.2, 10.3, Box 10.2, 11.3}

Chapter 9, Fig. 9.8

2016-2035 assessed temperature range is less than from uninitialized projections in part due to results from initialized decadal predictions

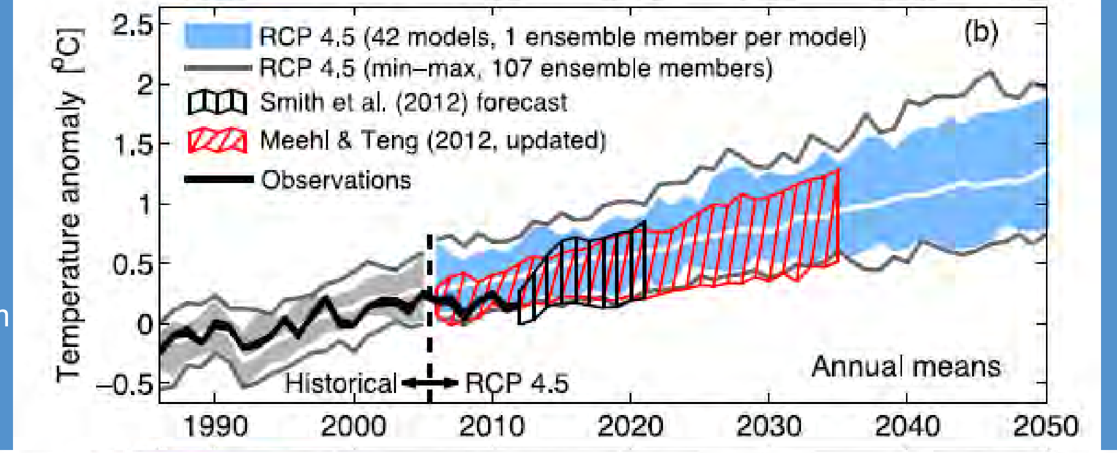
Uninitialized

Figure 11.9a from IPCC AR5, ch 11



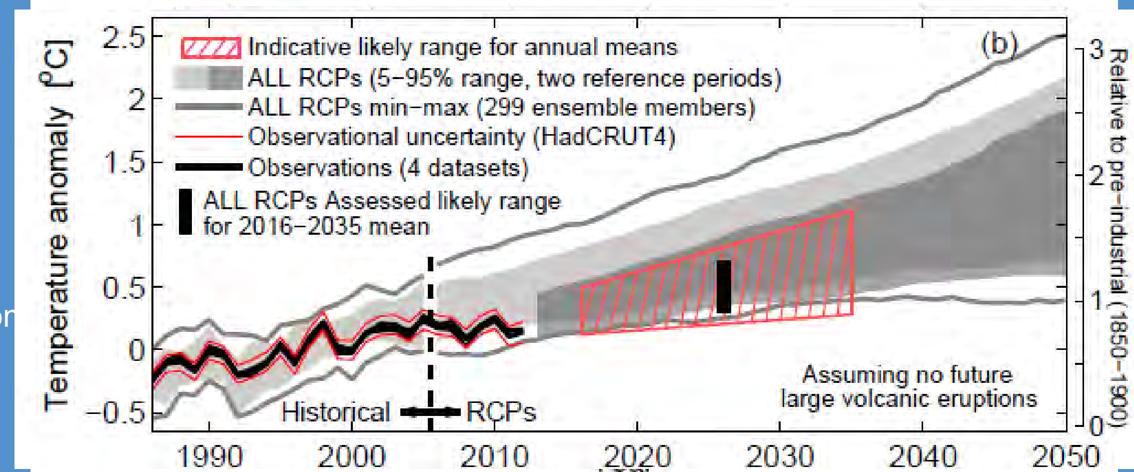
Initialized

Figure 11.9b from IPCC AR5, ch 11



Assessed Temperature change

Figure 11.25b from IPCC AR5, ch 11



IPCC AR5 Working Group I
Climate Change 2013: The Physical Science Basis

Chemistry and Aerosols in AR5

Spread over the report, in particular part of

Chapter 2: Observations: Atmosphere and Surface
Chapter 7: Clouds and Aerosols
Chapter 6: Carbon and Other Biogeochemical Cycles
Chapter 8: Anthropogenic and Natural Radiative Forcing
Chapter 9: Evaluation of Climate Models
Chapter 10: Detection and Attribution of Climate Change: from Global to Regional
Chapter 11: Near-term Climate Change: Projections and Predictability
Annex II: Climate System Scenario Tables

Example Chapter 11

- Projected changes in surface ozone
- Based on multi-model simulations from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP)
- Also used in Chapter 8 on RF
- Includes EMAC simulations (so far 7 ACCMIP publications)

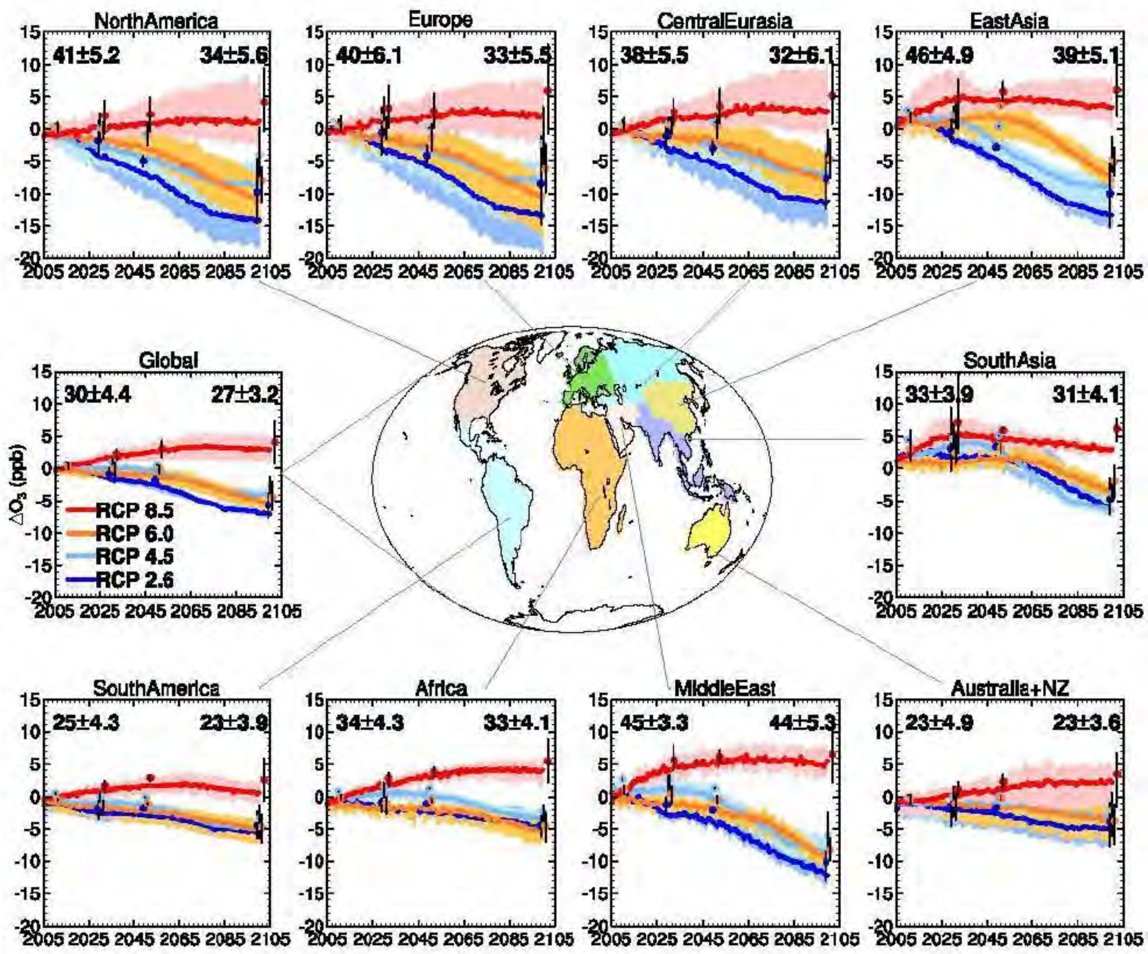
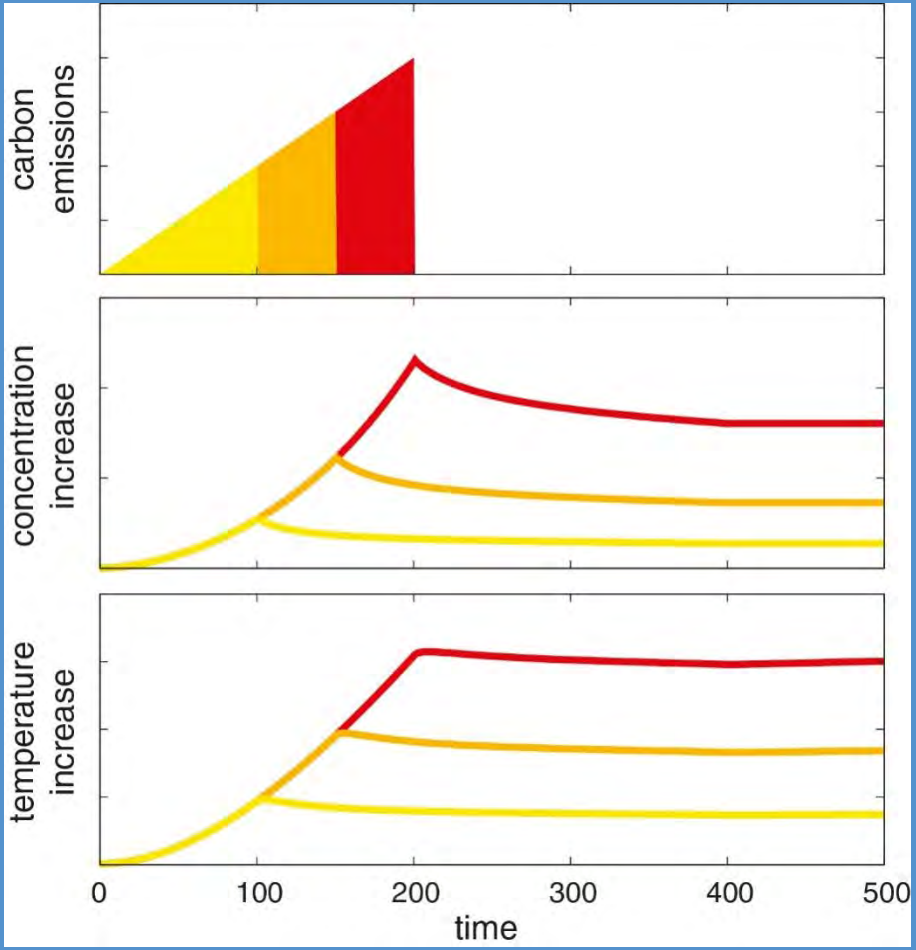


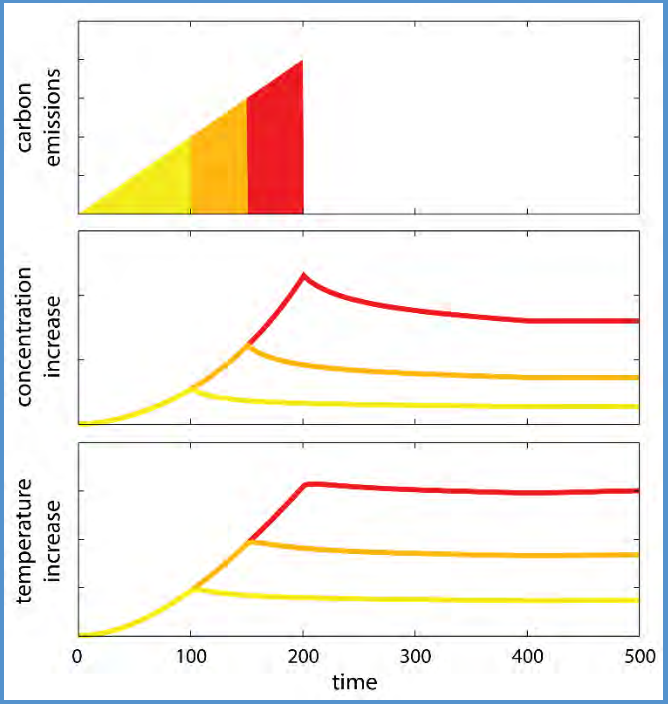
Figure 11.23a
Adapted from Fiore et al., 2012

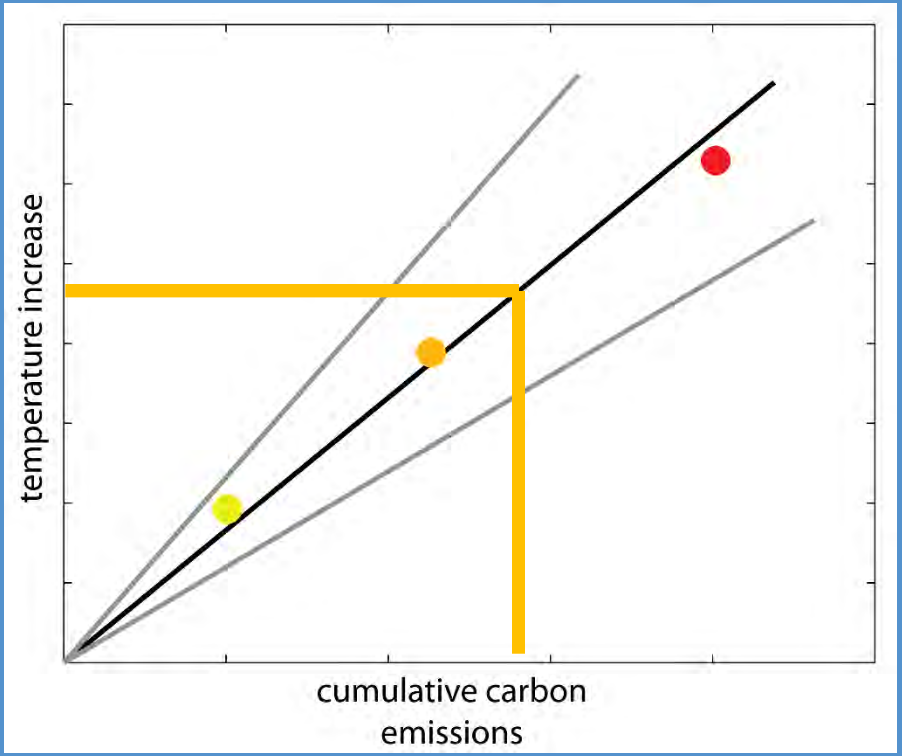
Warming will persist for centuries



- Zero CO_2 emissions lead to near constant surface temperature.
- A large fraction of climate change persists for many centuries.
- Depending on the scenario, about 15-40% of the emitted carbon remains in the atmosphere for 1000 yrs.

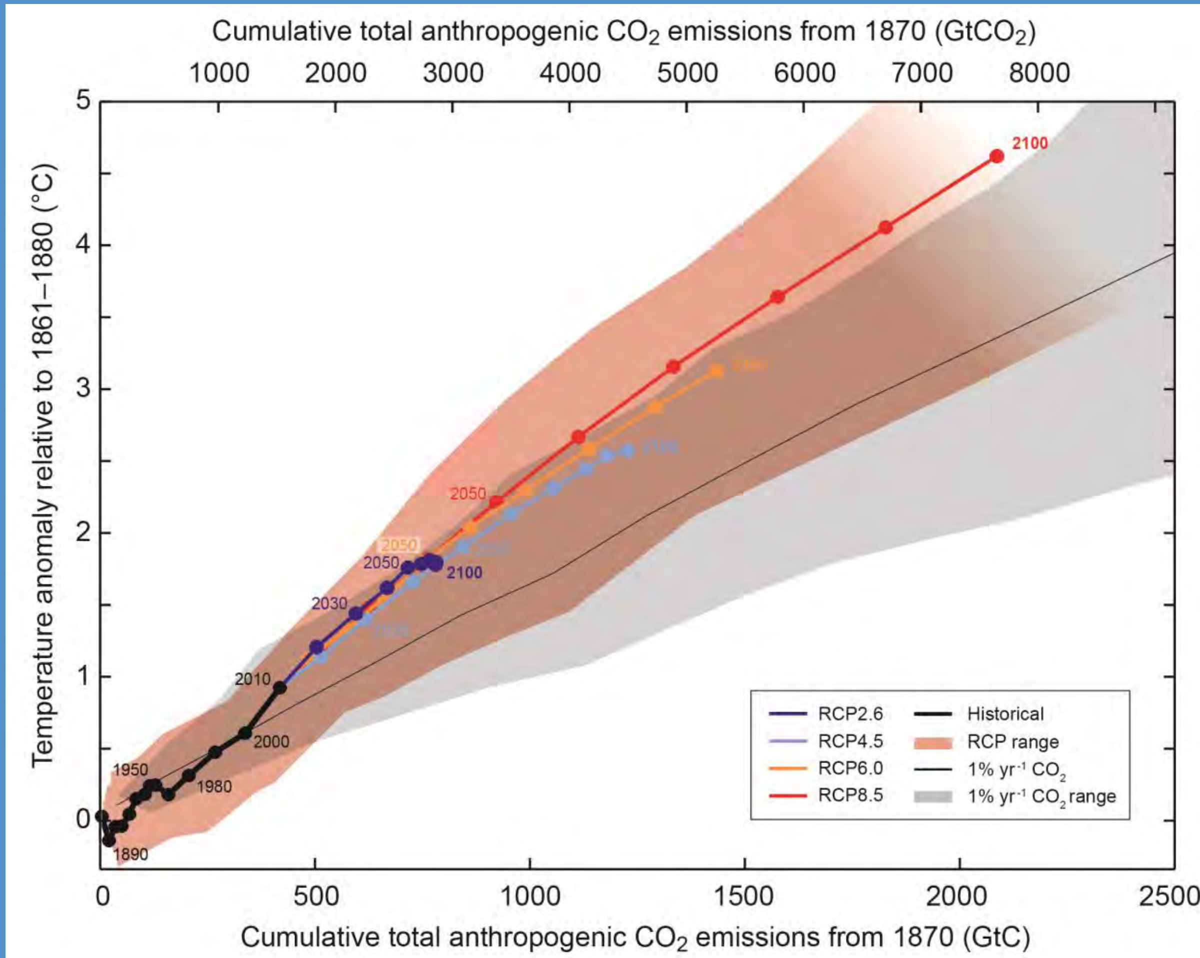
Cumulative carbon determines warming





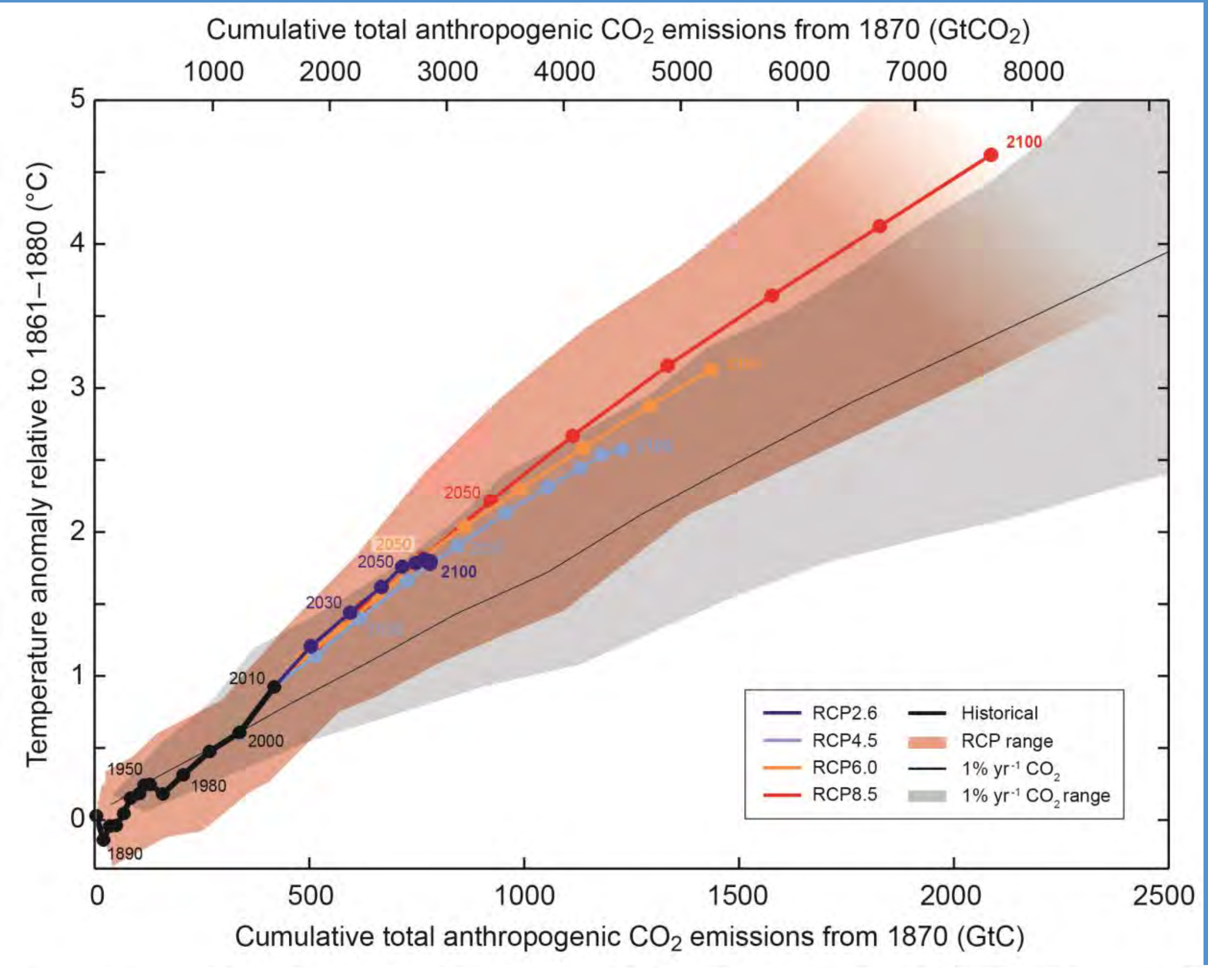
- Peak warming is approximately proportional to cumulative (total) emissions.
- Transient climate response to cumulative carbon emissions TCRE = Warming per 1000 PgC

Cumulative carbon determines warming



SPM.10

Cumulative carbon determines warming



Limiting the warming caused by anthropogenic CO_2 emissions alone with a probability of >33%, >50%, and >66% to less than 2°C since the period 1861–1880[22], will require cumulative CO_2 emissions from all anthropogenic sources to stay between 0 and about 1570 GtC (5760 $GtCO_2$), 0 and about 1210 GtC (4440 $GtCO_2$), and 0 and about 1000 GtC (3670 $GtCO_2$) since that period, respectively[23]. These upper amounts are reduced to about 900 GtC (3300 $GtCO_2$), 820 GtC (3010 $GtCO_2$), and 790 GtC (2900 $GtCO_2$), respectively, when accounting for non-CO_2 forcings as in RCP2.6. An amount of 515 [445 to 585] GtC (1890 [1630 to 2150] $GtCO_2$), was already emitted by 2011. {12.5}

SPM.10

Outlook

WGI AR5 Production and Publication

- Publication in **early 2014**

The Working Group (WG) Reports and Synthesis Report will be completed in 2013/2014:

- WG I: The Physical Science Basis 23-26 September 2013, Stockholm, Sweden
- WG II: Impacts, Adaptation and Vulnerability 25-29 March 2014, Yokohama, Japan
- WG III: Mitigation of Climate Change 7-11 April 2014, Berlin, Germany
- AR5 Synthesis Report (SYR) 27-31 October 2014, Copenhagen, Denmark
- More than 830 authors are involved in writing the reports.

Will there be an AR6?

The governments, not the scientific community, make this decision

IPCC is a group of over 150 governments, and they will have a plenary some time in 2015 to address future assessments

Whether or not there is an AR6, the international climate science community has begun preparing for the Coupled Model Intercomparison Project Phase 6 (CMIP6)

Coordinated by CMIP Panel http://www.wcrp-climate.org/wgcm/cmip.shtml, not IPCC

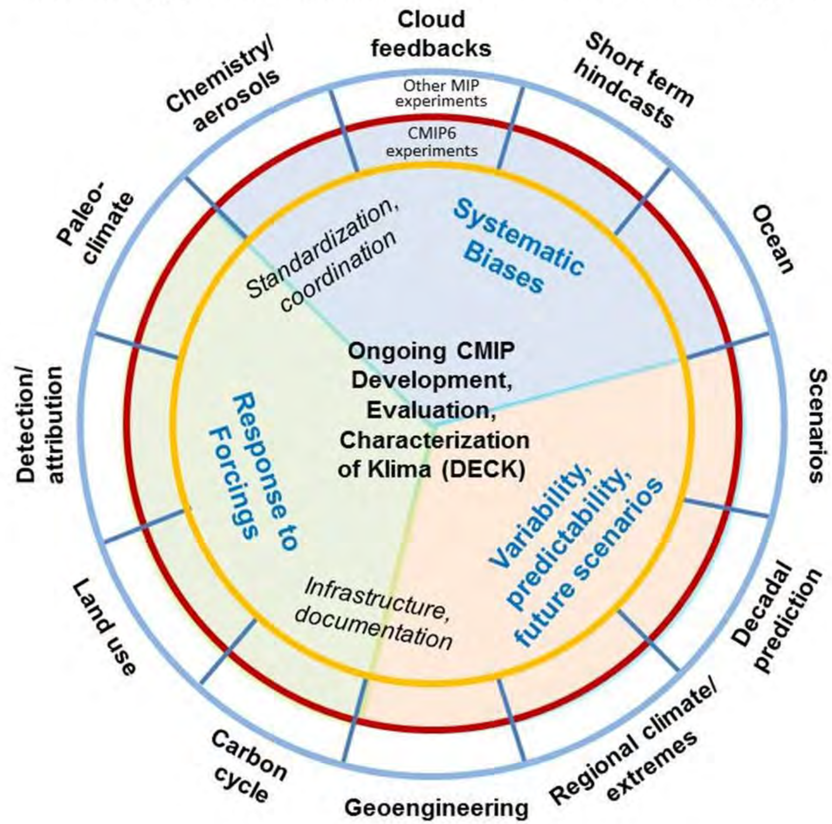
(CMIP Panel part of WCRP Working Group on Coupled Models, WGCM)

1. Establish a set of CMIP **ongoing model development evaluation and characterization (DECK)** experiments to gain basic information about model performance and sensitivity (CMIP)

2. Organize sets of experiments to **address science questions** within the context of the **WCRP Grand Challenges** and **AIMES input** specific to CMIP6
   - Systematic biases,
   - Response to forcings,
   - Variability, predictability and future scenarios

3. Around these experiments build CMIP6 with additional, **specialized intercomparisons ("MIPs")** that would make use of the same standards and infrastructure.

WCRP Grand Challenges: (1) Clouds, circulation and climate sensitivity, (2) Changes in cryosphere, (3) Climate extremes, (4) Regional climate information, (5) Regional sea-level rise, and (6) Water availability, plus an additional theme on "biospheric forcings and feedbacks"



Meehl et al., EOS, subm., 2014

WCRP World Climate Research Programme

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INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP