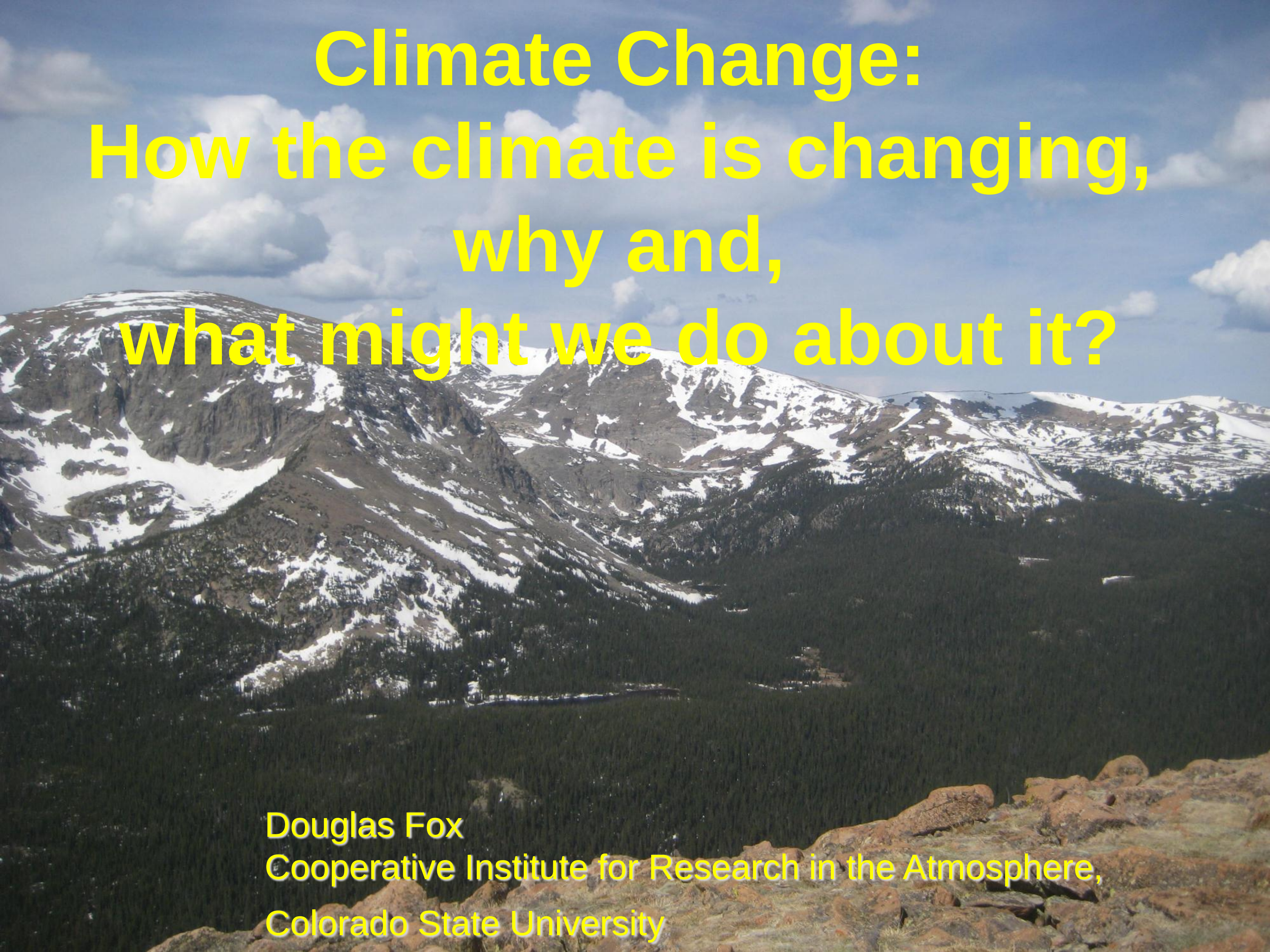


Climate Change:
How the climate is changing, why and, what might we do about it?

Douglas Fox
Cooperative Institute for Research in the Atmosphere,
Colorado State University

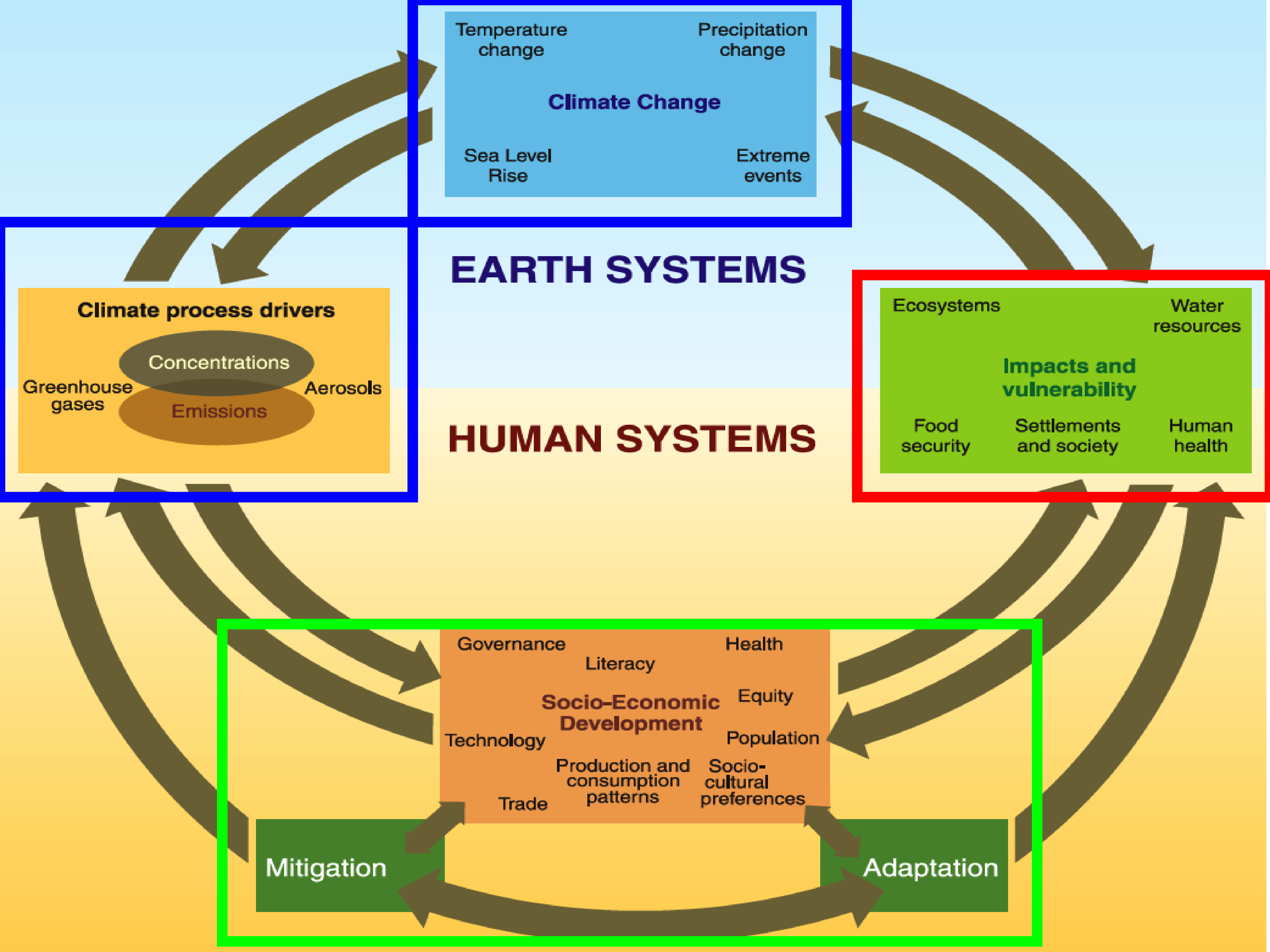
Climate Change Science

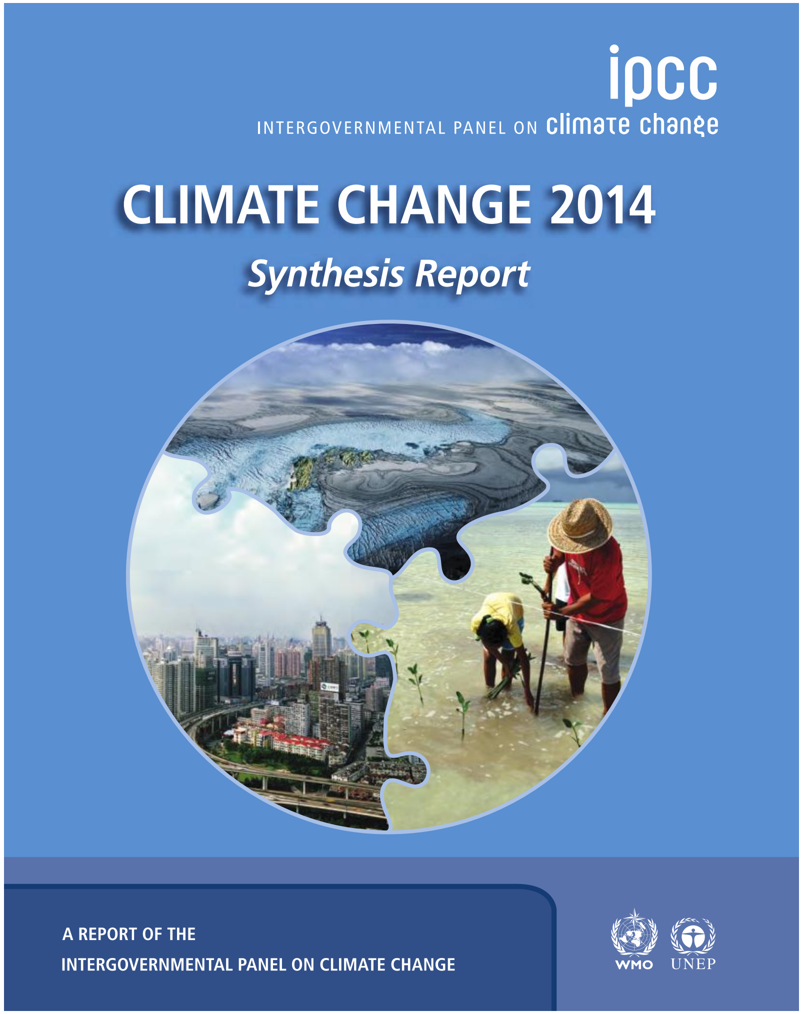
- Overview of climate and mountains
- Observations of climate change
- Latest scientific understanding of climate change (IPCC AR5)
- ESM abilities
- Regional climate projections, especially for mountains
- Regional impacts (geophysical, ecological, human systems)
- Food security Impacts

Adapting to Changing Climate

- Vulnerability, exposure & risk
- Adaptation programs

Participants Small Group Discussions


Temperature change
Precipitation change
Climate Change
Sea Level Rise
Extreme events
EARTH SYSTEMS
Climate process drivers
Concentrations
Greenhouse gases
Aerosols
Emissions
HUMAN SYSTEMS
Ecosystems
Water resources
Impacts and vulnerability
Food security
Settlements and society
Human health
Governance
Literacy
Health
Socio-Economic Development
Equity
Technology
Population
Production and consumption patterns
Socio-cultural preferences
Trade
Mitigation
Adaptation



Observed Changes and their Causes

Future Climate Changes, Risks and Impacts

Future Pathways for Adaptation, Mitigation and Sustainable Development.

Adaptation and Mitigation

Assessment Report 5, AR5, 2014

AR5 SPM Synthesis

- **Observed Changes and their Causes:**

Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

- **Future Climate Changes, Risks and Impacts:**

Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.

- **Future Pathways for Adaptation, Mitigation and Sustainable Development:**

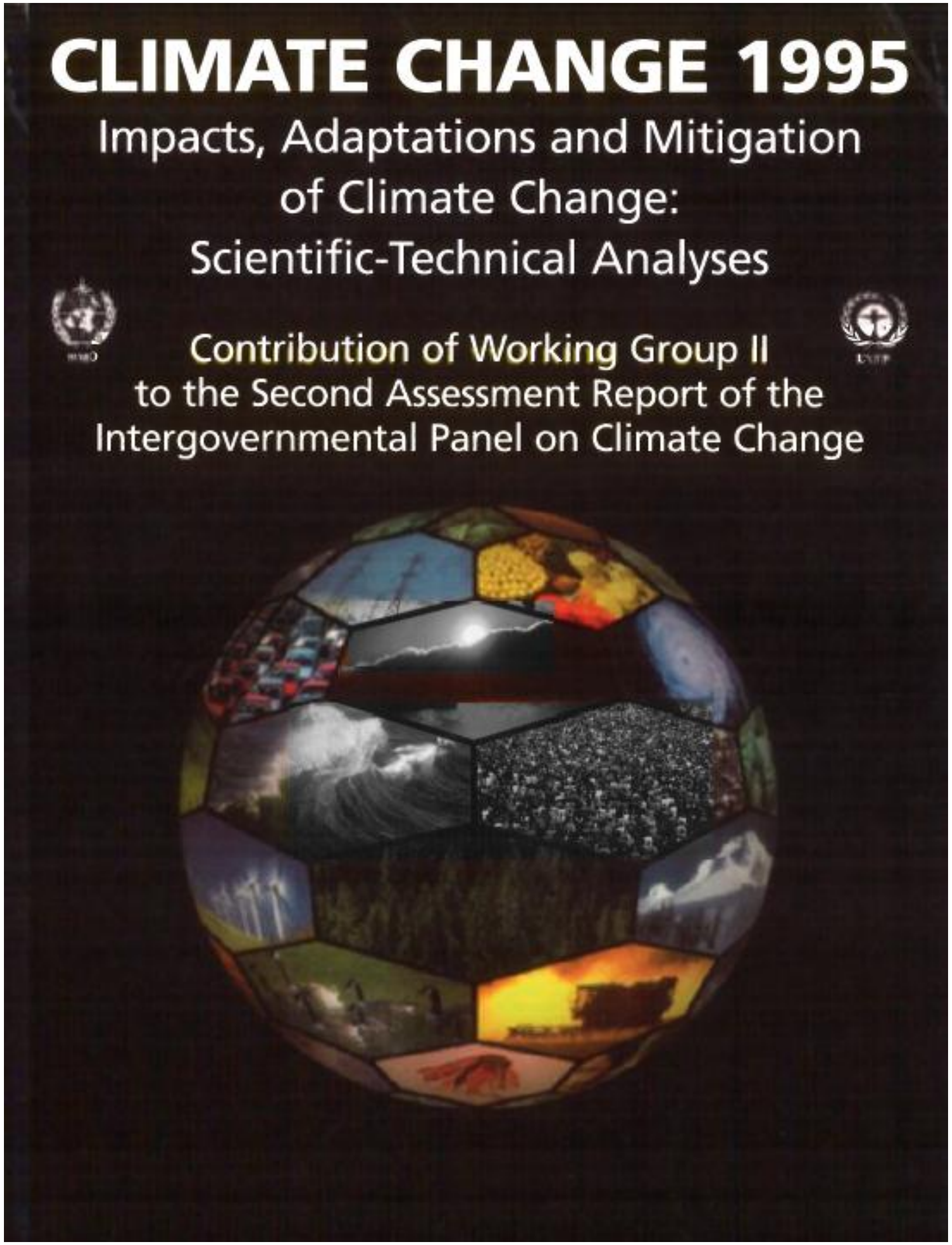
Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term, and contribute to climate-resilient pathways for sustainable development.

- **Adaptation and Mitigation:**

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales, and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

Climate Change Science: Take away concepts:

- **Humans influences on the climate system are clear.**
  - Human-caused emissions of greenhouse gases, especially CO_2 are the highest in history.
  - The result is a changing climate that impacts both natural and human systems.
- ***Earth System Models* present increasingly accurate simulation of current condition and future potential.**
  - Improving projections of climate features (Monsoons, ENSO) and Regional climates.
  - Changed regional climates impact water resources, ecosystems, agriculture, and human settlements among others.
- **Mountain climates are complex so projection of changes are more uncertain.**



5

Impacts of Climate Change on Mountain Regions

MARTIN BENISTON, SWITZERLAND; DOUGLAS G. FOX, USA

Principal Lead Authors:
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Second Assessment Report, SAR 1995

Mountain Characteristics

- 22% of the world's surface, all continents;
- Exhibit great biodiversity;
- Source of major river systems & provides 60-80% of available freshwater;
- Home to 800 Million people who are among the poorest but most resourceful in surviving harsh conditions;
- Ag dominated by small family farming;
- Integral part of climate system:
  - Physical barrier to flow
  - Perturb synoptic patterns
  - Alter mid-latitude cyclogenesis

Table 5-1: Climatic effects of the basic controls of mountain climate.

Factors	Primary Effects	Secondary Effects
Altitude	Reduced air density, vapor pressure; increased solar radiation receipts; lower temperatures	Increased wind velocity and precipitation (mid-latitudes); reduced evaporation; physiological stress
Continentality	Annual/diurnal temperature range increased; cloud and precipitation regimes modified	Snow line altitude increases
Latitude	Daylength and solar radiation totals vary seasonally	Snowfall proportion increases; annual temperatures decrease
Topography	Spatial contrasts in solar radiation and temperature regimes; precipitation as a result of slope and aspect	Diurnal wind regimes; snow cover related to topography

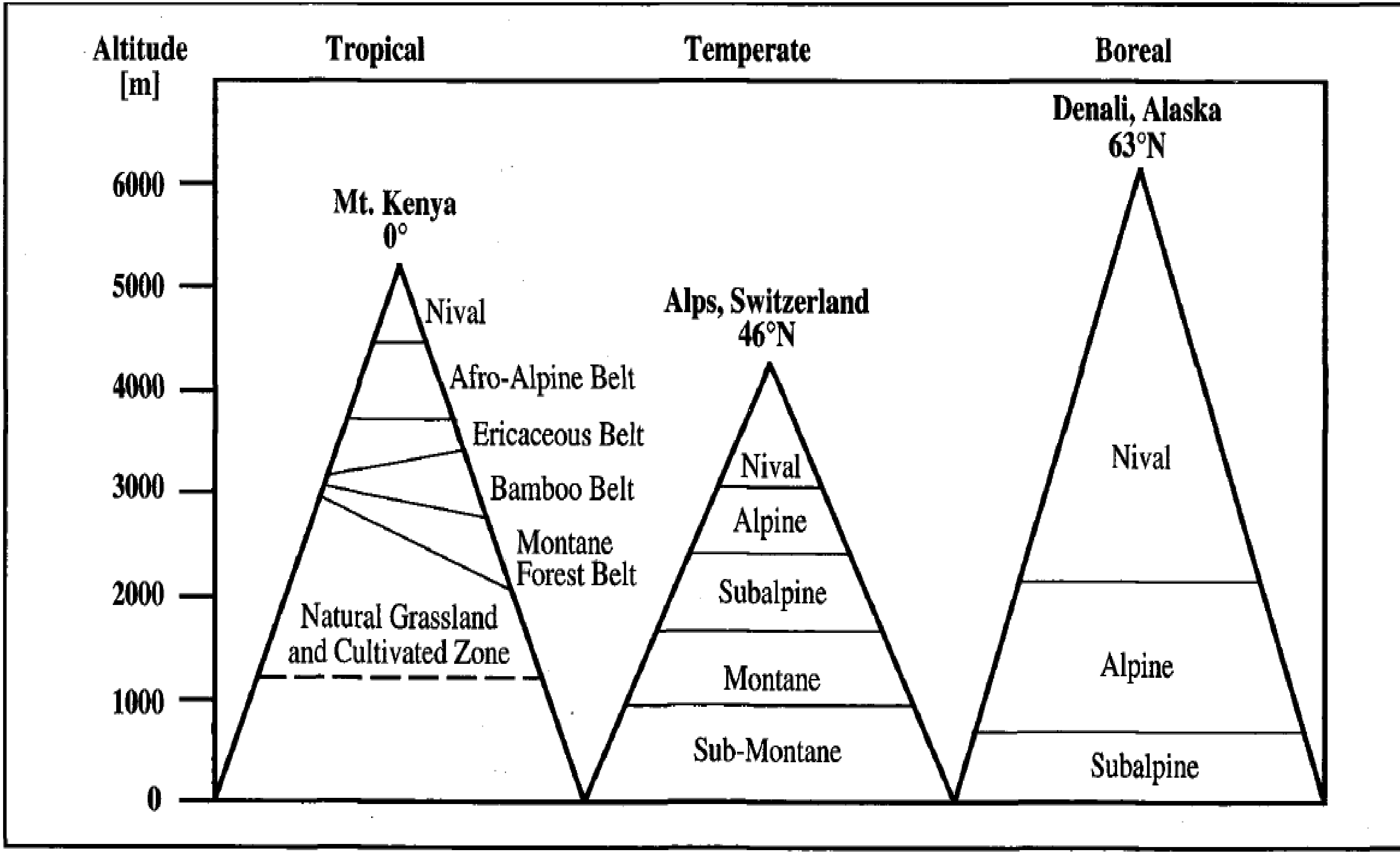


Figure 5-1: Schematic illustration of vegetation zonations in tropical, temperate, and boreal mountains.

Figure 1: **A representation of mountain stratification with respect to altitude, temperature, and vegetation for mountains located in humid climates**

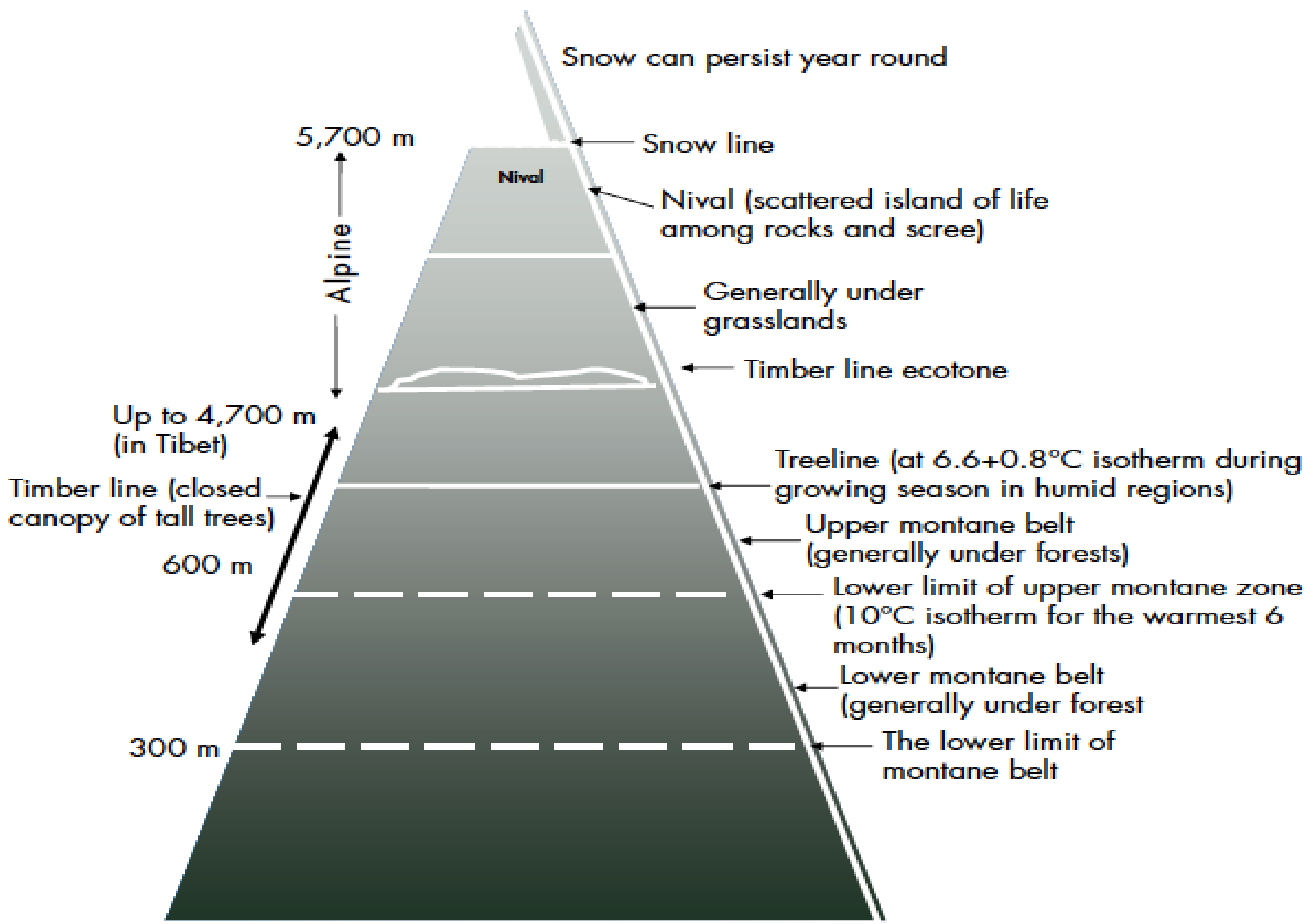
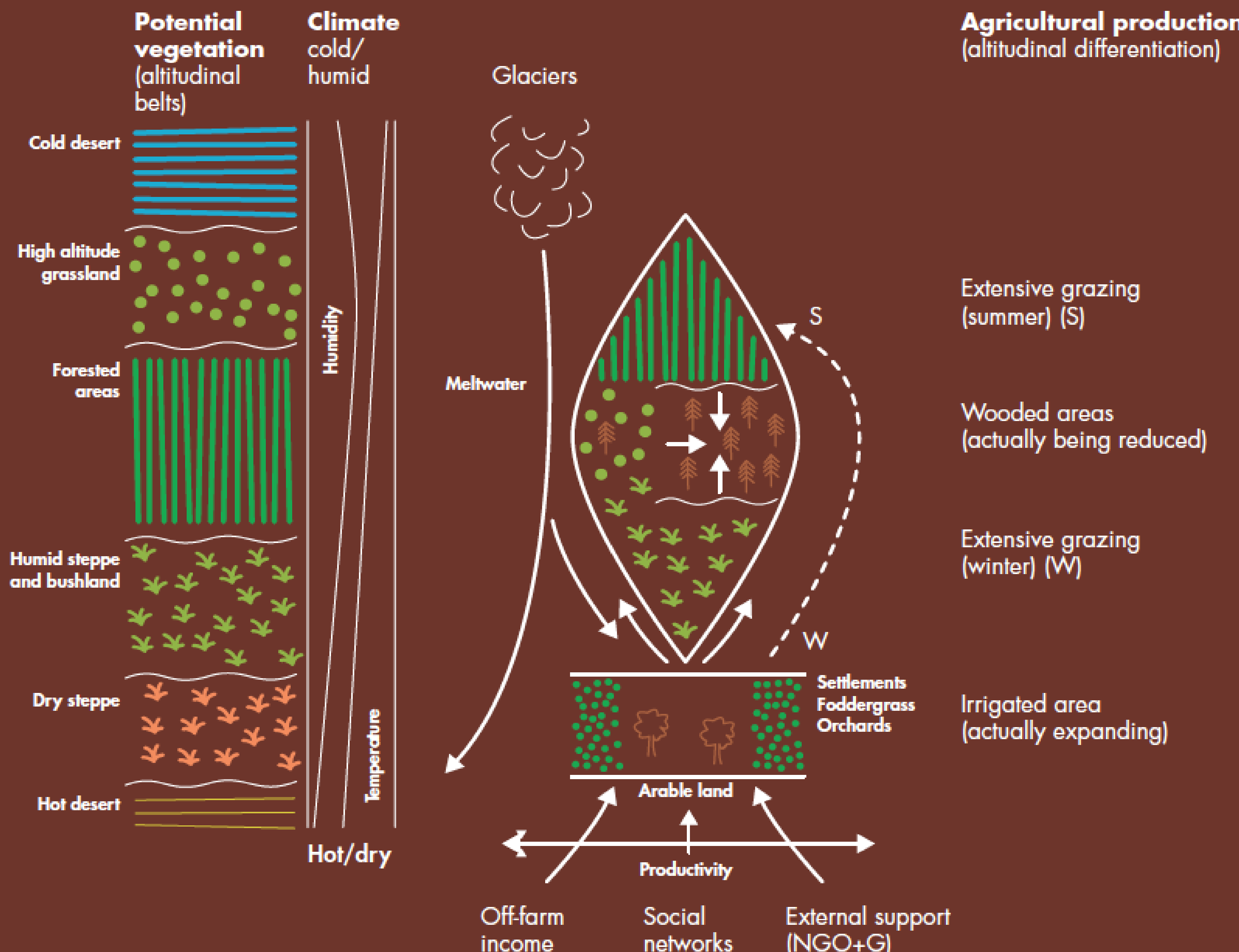
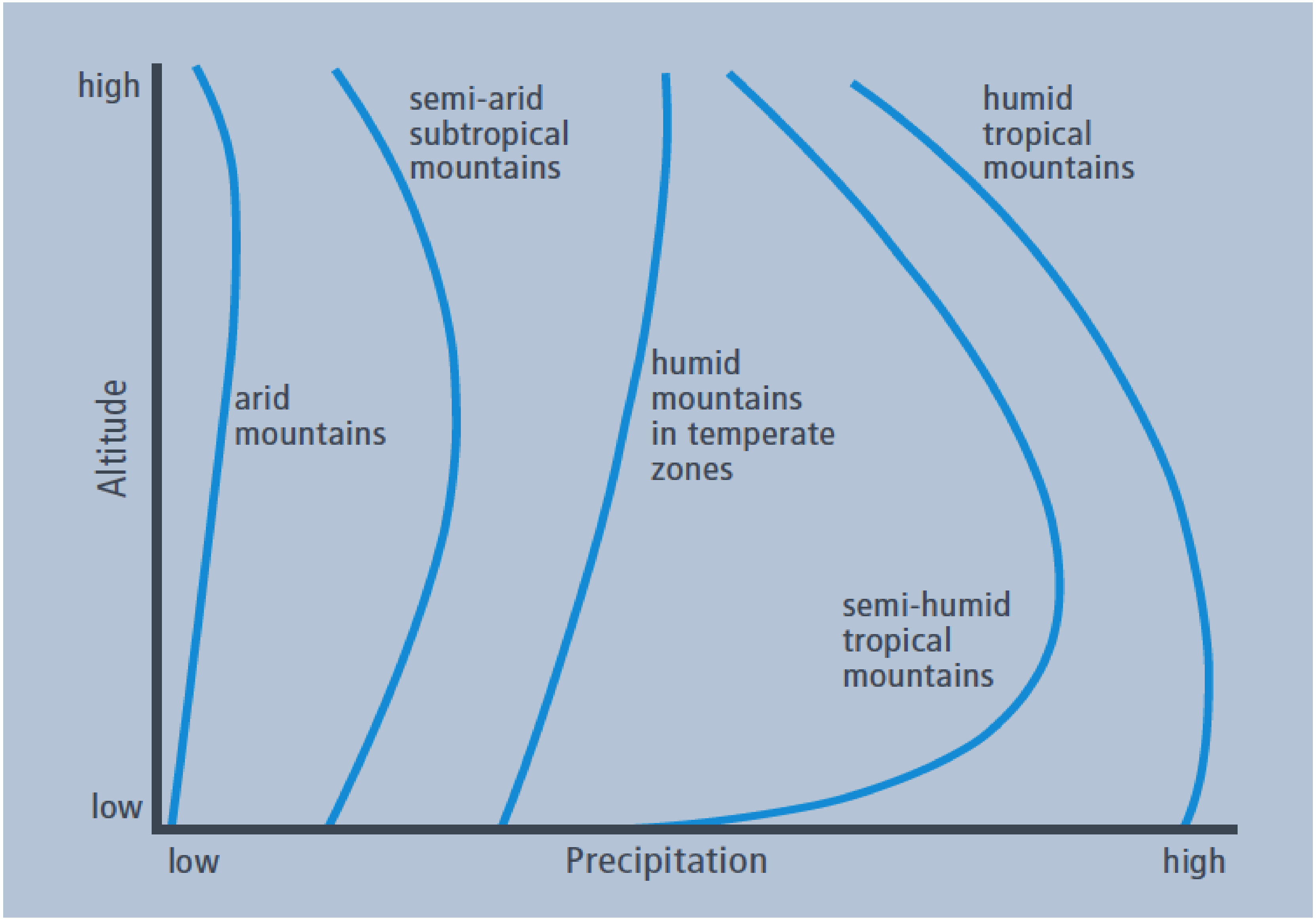


Figure 2: **Vertical arrangement of natural vegetation and agricultural productivity**





Precipitation increases with altitude due to uplift of air masses and condensation - the main reason for the role of mountains as water towers of the world (see Chapter 2). Precipitation maxima vary and occur at different altitudes in different mountain regions of the world (Richter 1996).

Thomas Kohler, Daniel Maselli 2009

We know with certainty…

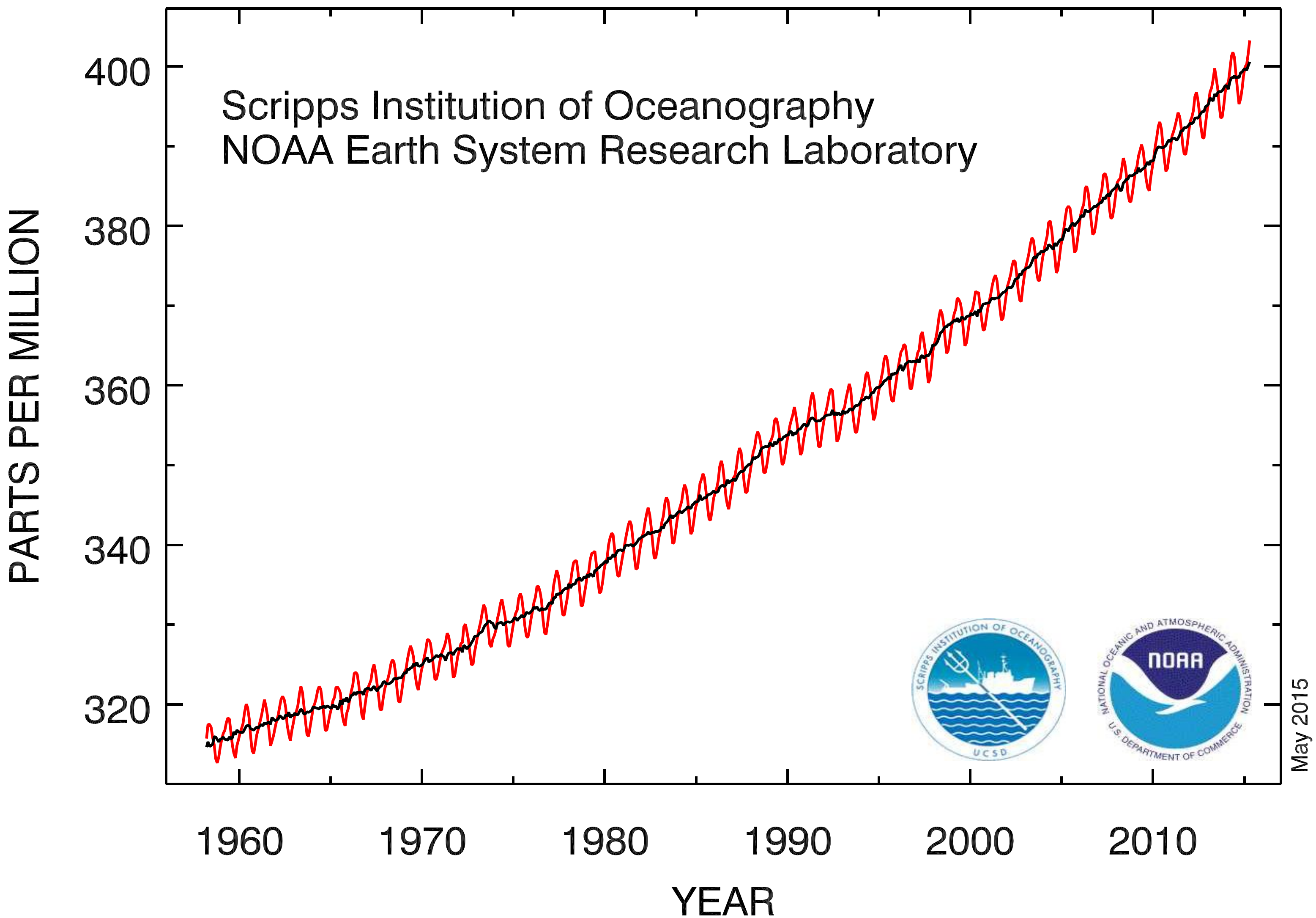
- The concentration of CO_2 in the atmosphere is higher than it has been for at least the last 800,000 years.

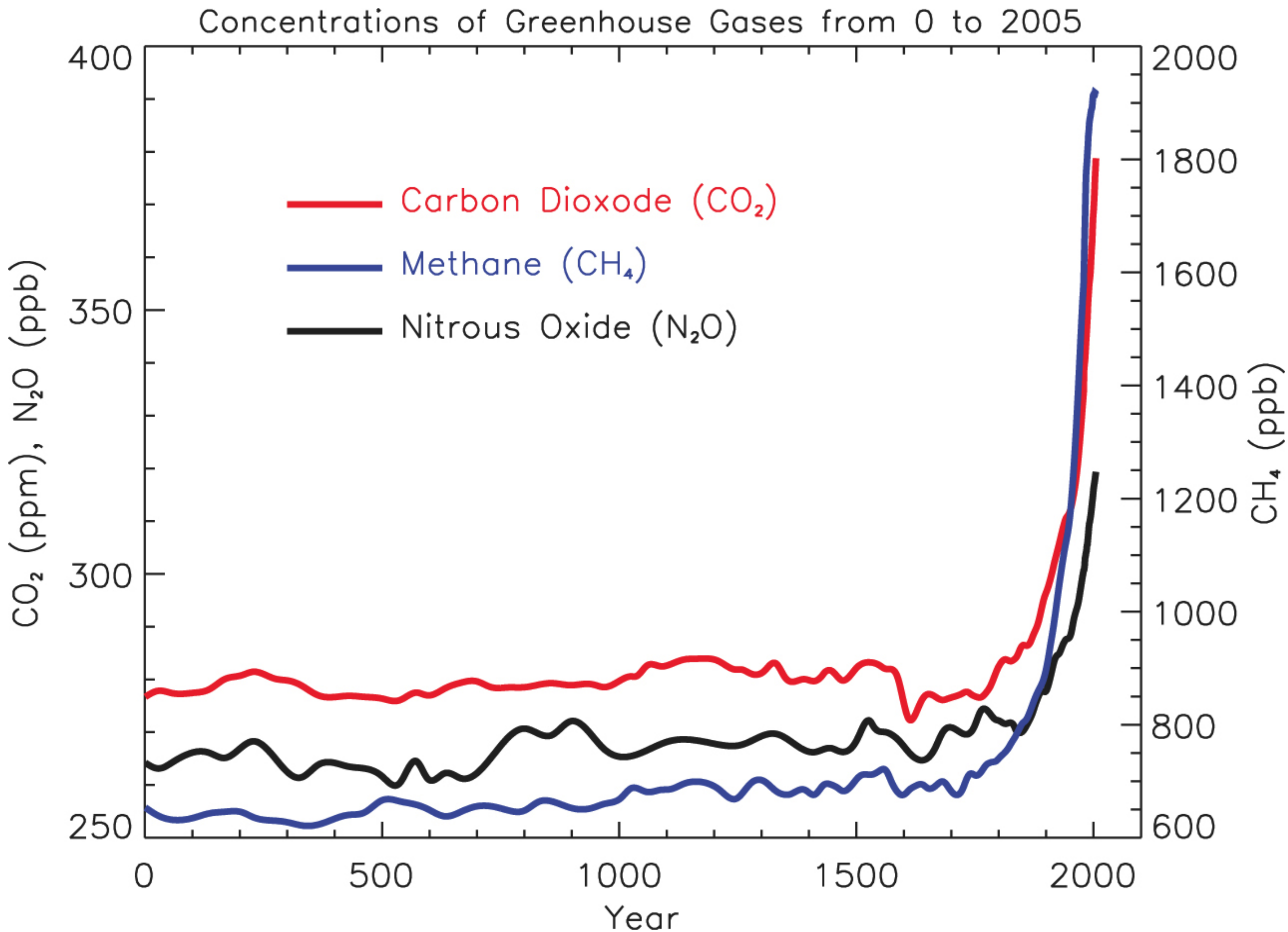
- All plausible causes for the size of CO_2 increase are human:
  - burning fossil fuels,
  - making cement &
  - manipulating land cover - deforestation, urbanization, etc.

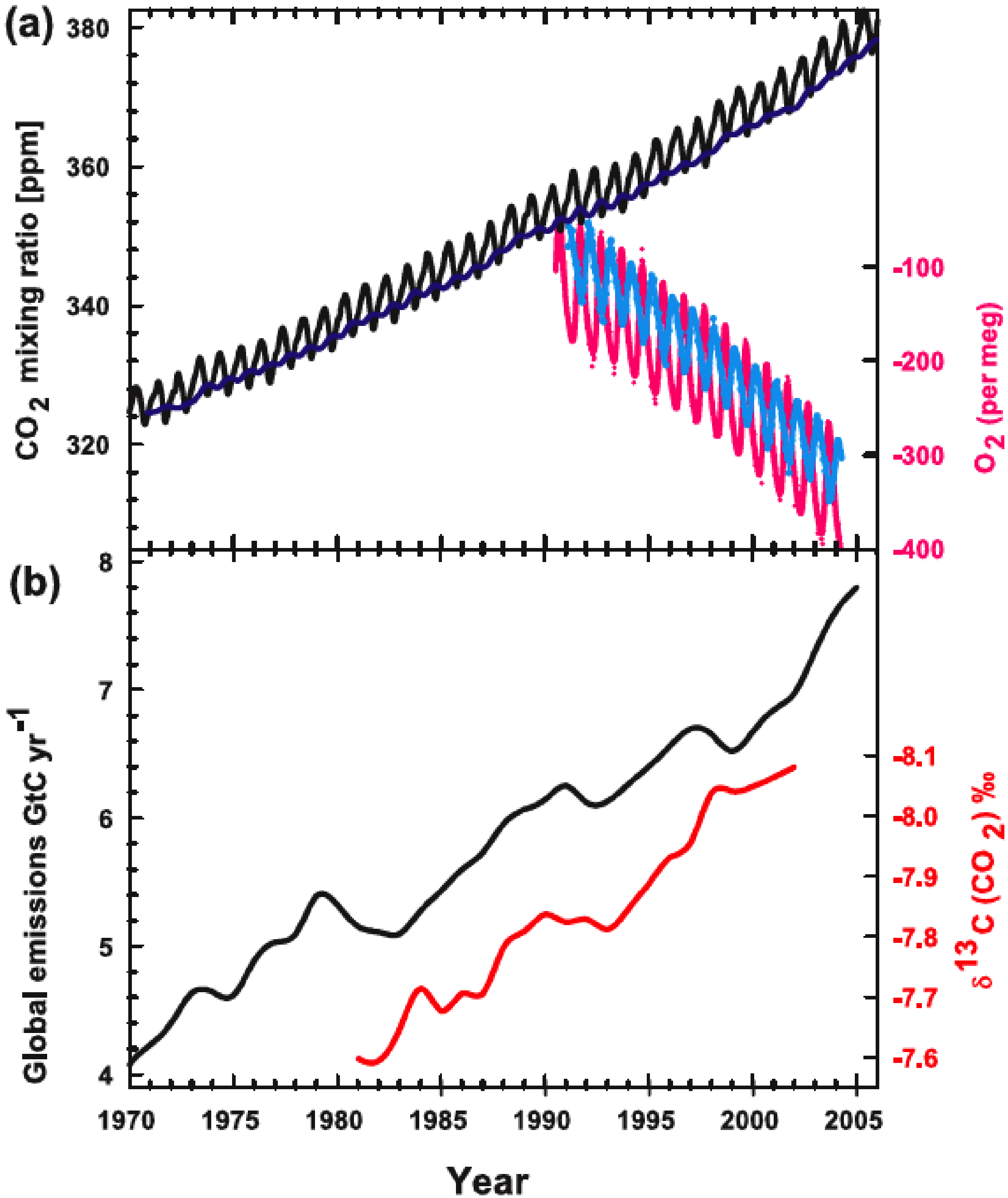
- Increased CO_2 captures more of the earth’s heat, in turn, forcing a new global energy balance and resulting in a warmer atmosphere, the greenhouse effect.

- A new global energy balance alters the “atmosphere ocean general circulation” (AOGC) system and, in turn, the whole Earth System

Atmospheric CO_2 at Mauna Loa Observatory

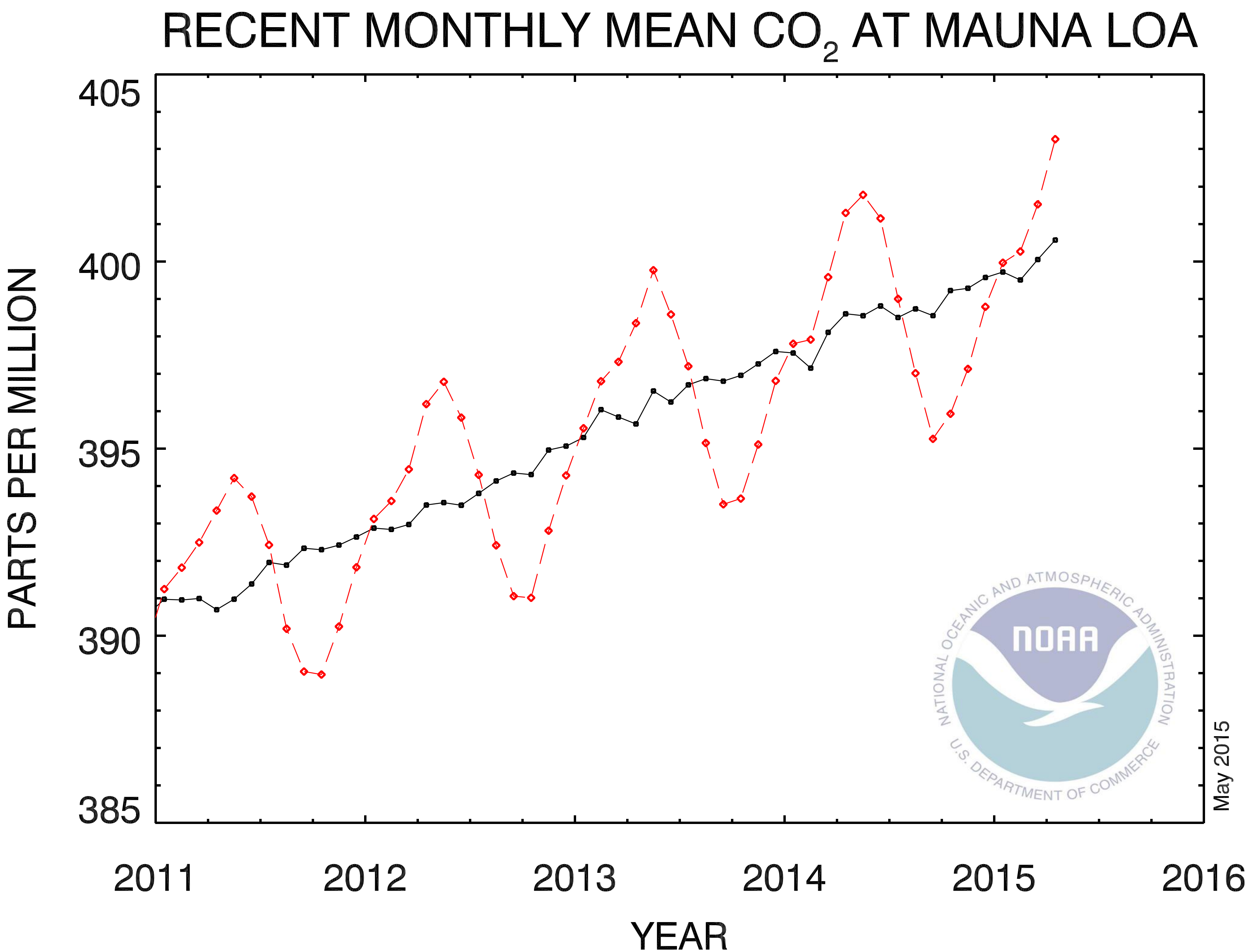



Concentrations of Greenhouse Gases from 0 to 2005
Carbon Dioxode (CO2)
Methane (CH4)
Nitrous Oxide (N2O)
CO2 (ppm), N2O (ppb)
CH4 (ppb)
Year
400
350
300
250
2000
1800
1600
1400
1200
1000
800
600
0
500
1000
1500
2000



Recent measurements in both hemispheres are shown to emphasize the strong linkages between atmospheric CO_2 increases, O_2 decreases, fossil fuel consumption and the $^{13}C/^{12}C$ ratio of atmospheric CO_2.

CO_2 concentrations and emissions:
(a) CO_2 concentrations (monthly averages) over the period 1970 to 2005 from Mauna Loa, Hawaii (19° N, black) and Baring Head, New Zealand. Also, atmospheric oxygen (O_2) measurements from Alert, Canada (82° N, pink) and Cape Grim, Australia (41° S, cyan).
(b) Annual global CO_2 emissions from fossil fuel burning and cement manufacture in GtC yr^{-1} (black). Land use emissions are not shown (~ 0.5 - 2.7 GtC yr^{-1}). Annual averages of the $^{13}C/^{12}C$ ratio measured in CO_2 at Mauna Loa from 1981 to 2002 (red).
Emissions of CO_2 from coal, gas and oil combustion and land clearing have $^{13}C/^{12}C$ isotopic ratios less than those in atmospheric CO_2, thus, when CO_2 from fossil fuel combustion enters the atmosphere, the $^{13}C/^{12}C$ ratio in atmospheric CO_2 decreases.


RECENT MONTHLY MEAN CO_2 AT MAUNA LOA
PARTS PER MILLION
405
400
395
390
385
2011
2012
2013
2014
2015
2016
YEAR
May 2015
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

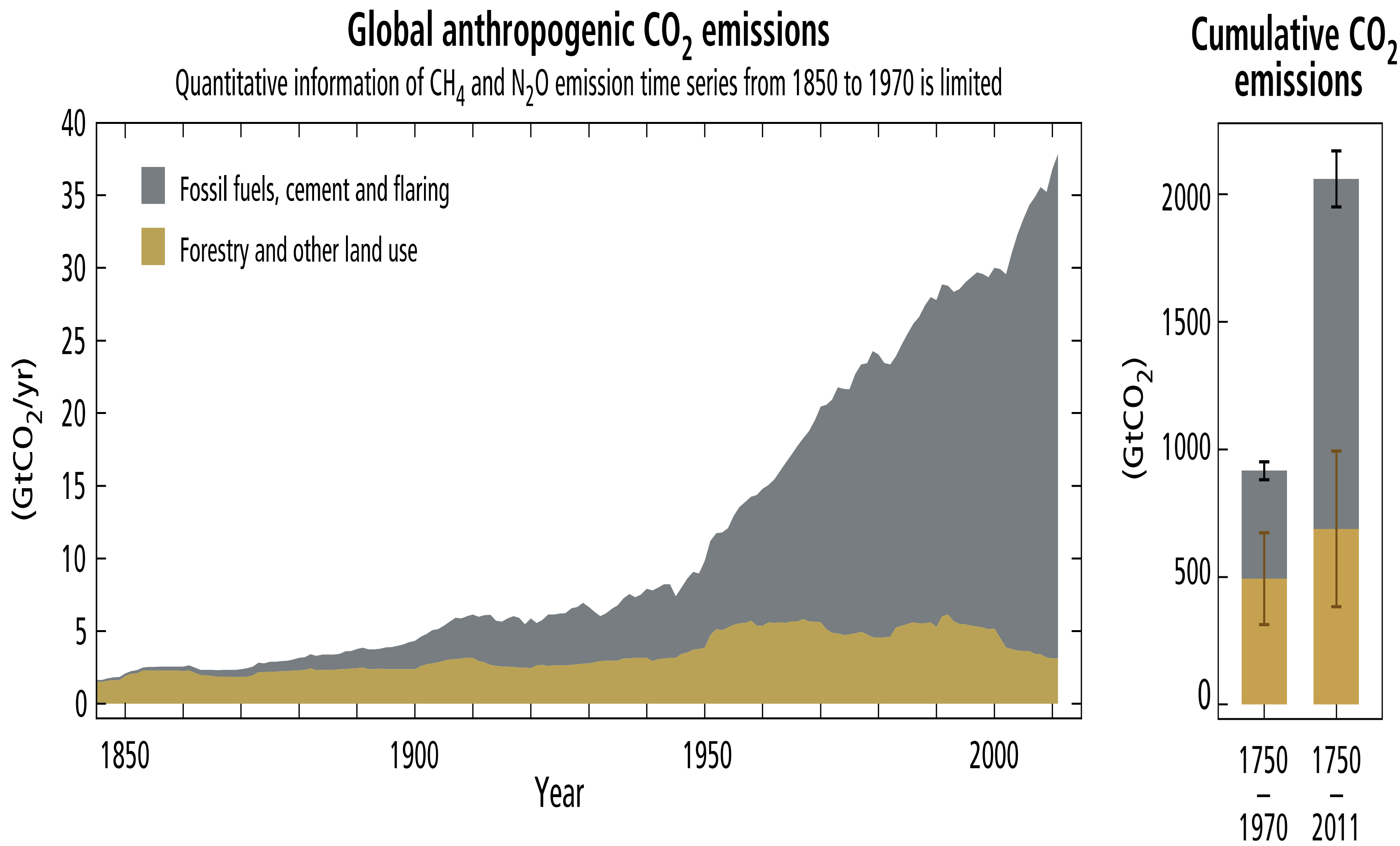
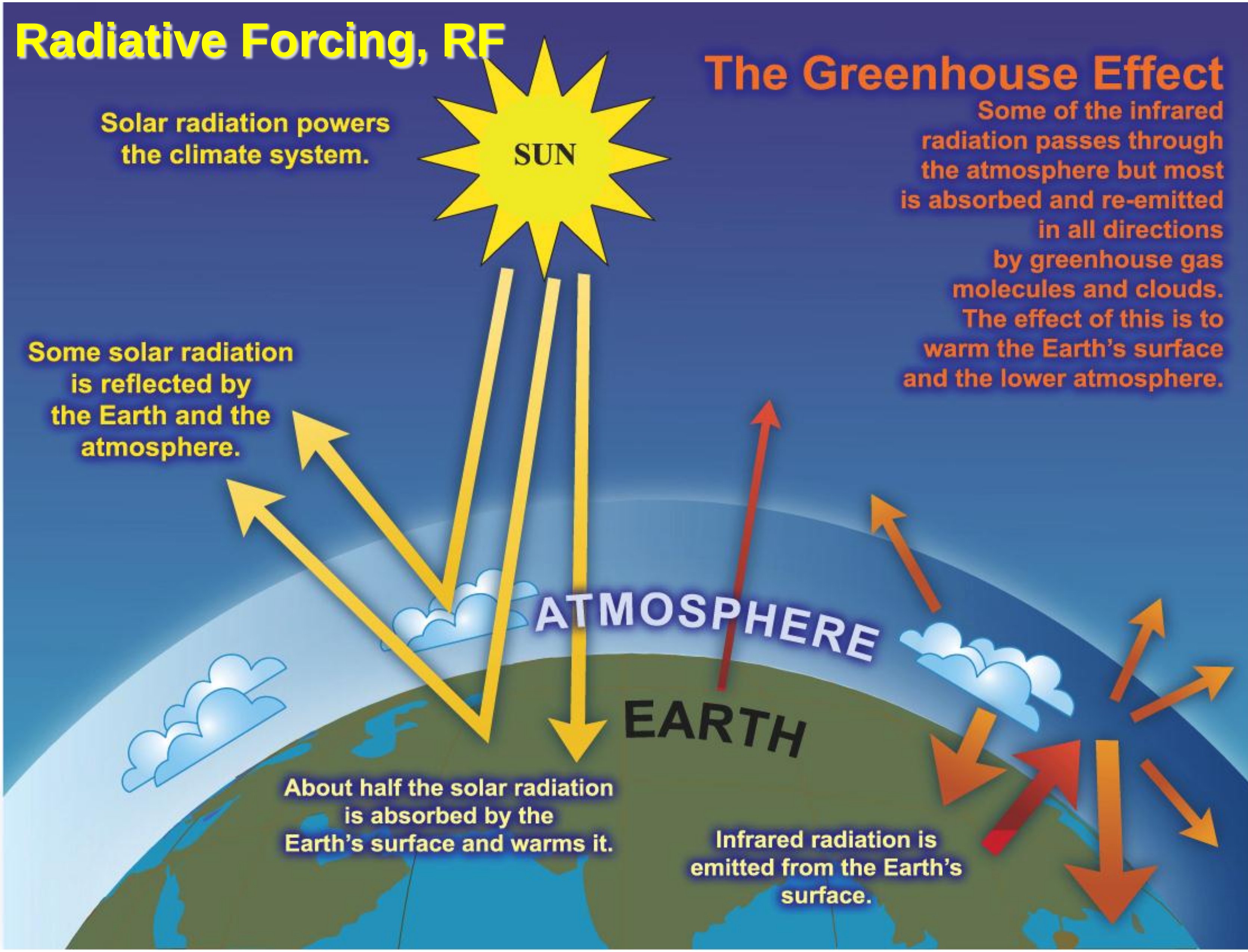
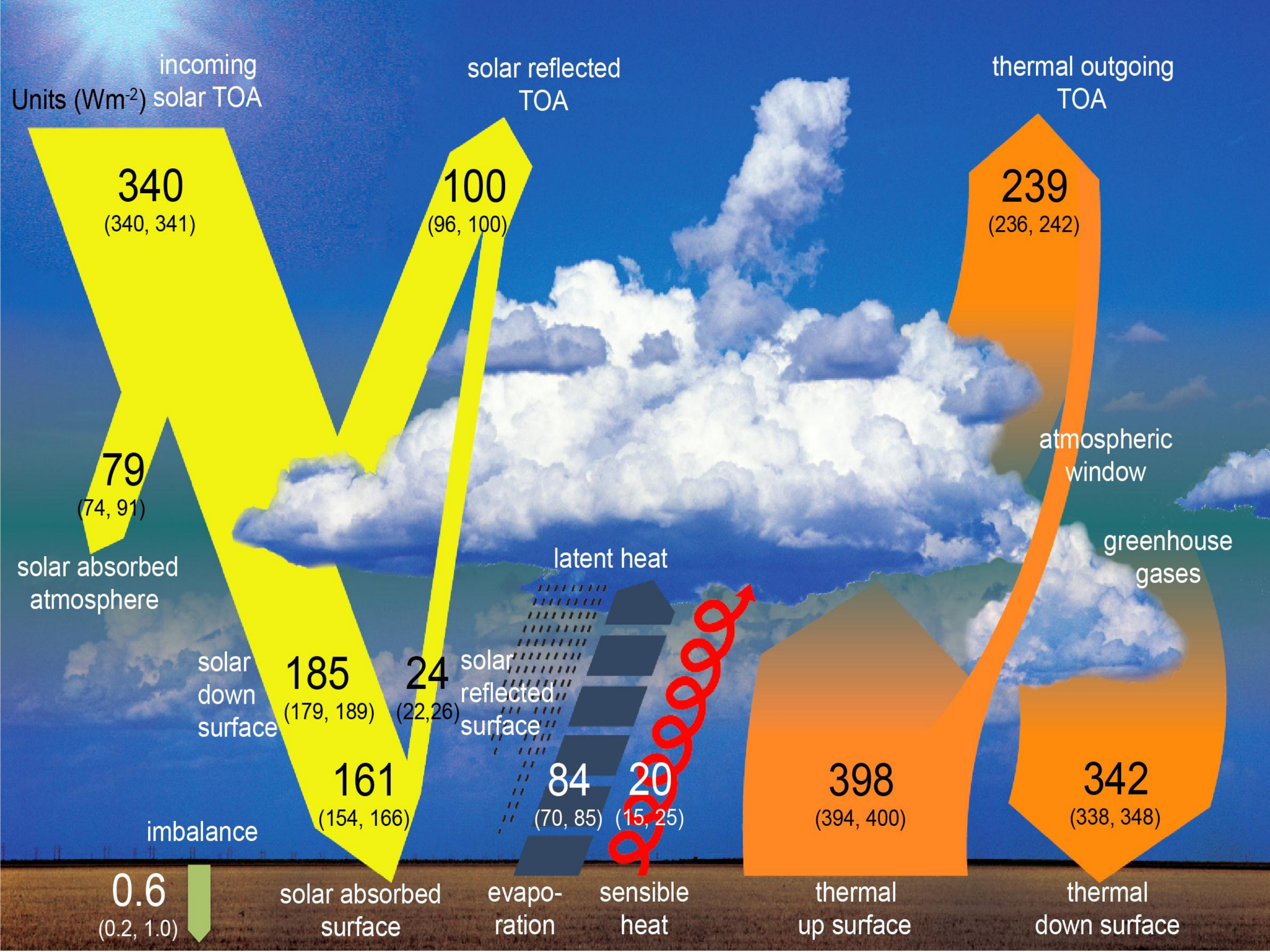


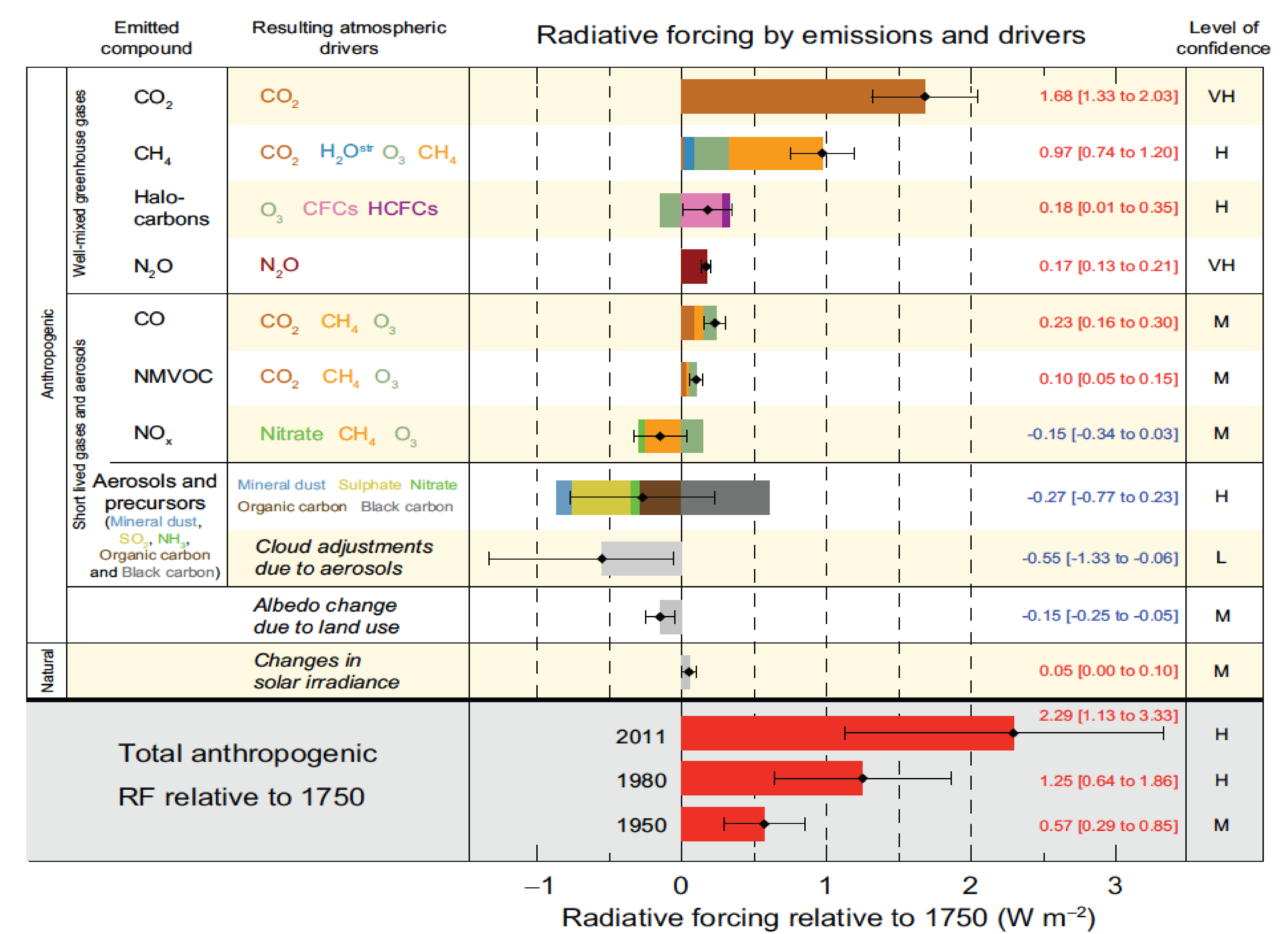
Figure 1.5 | Annual global anthropogenic carbon dioxide (CO_2) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$/yr) from fossil fuel combustion, cement production and flaring, and forestry and other land use (FOLU), 1750–2011. Cumulative emissions and their uncertainties are shown as bars and whiskers, respectively, on the right-hand side.

Radiative Forcing, RF

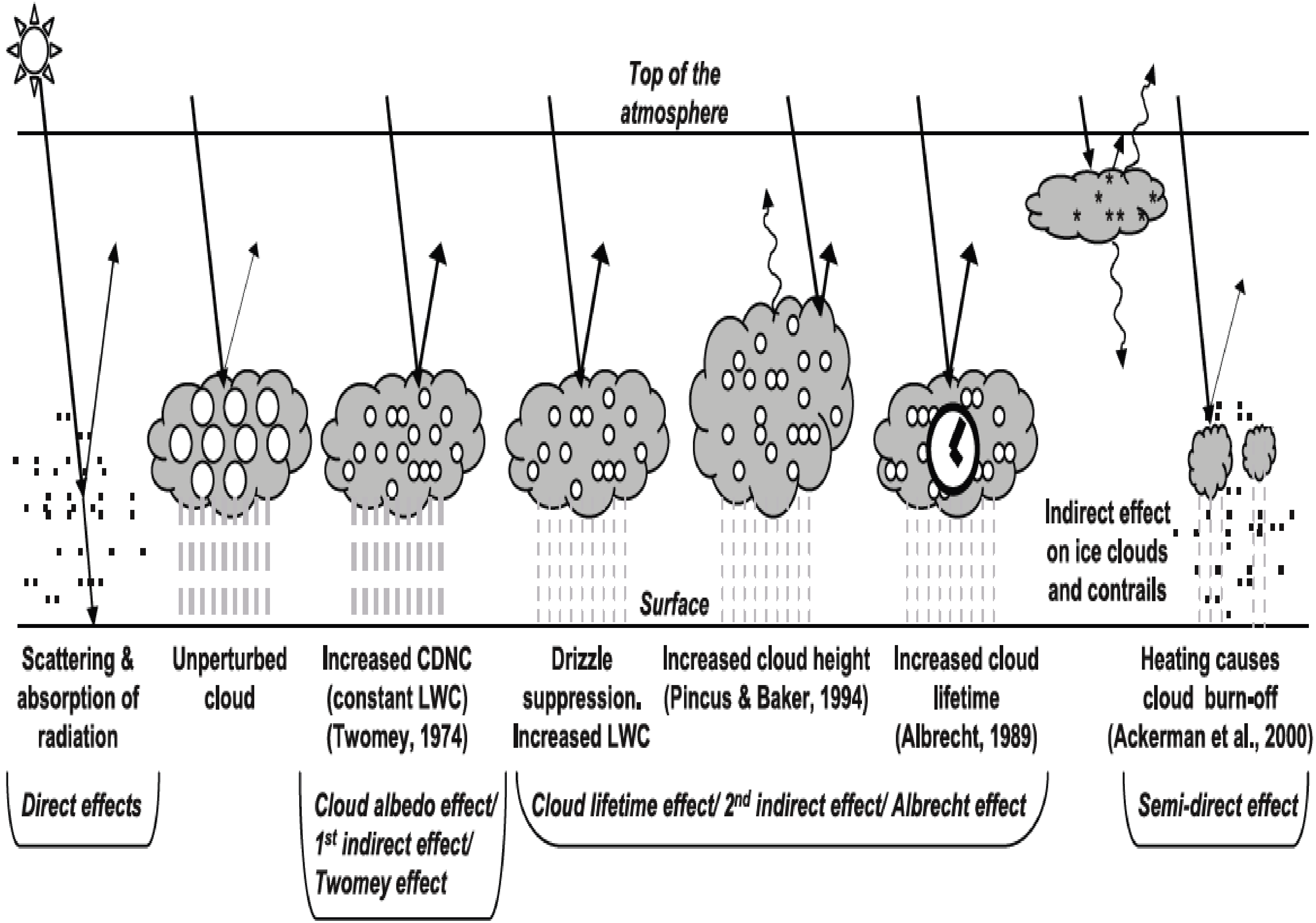




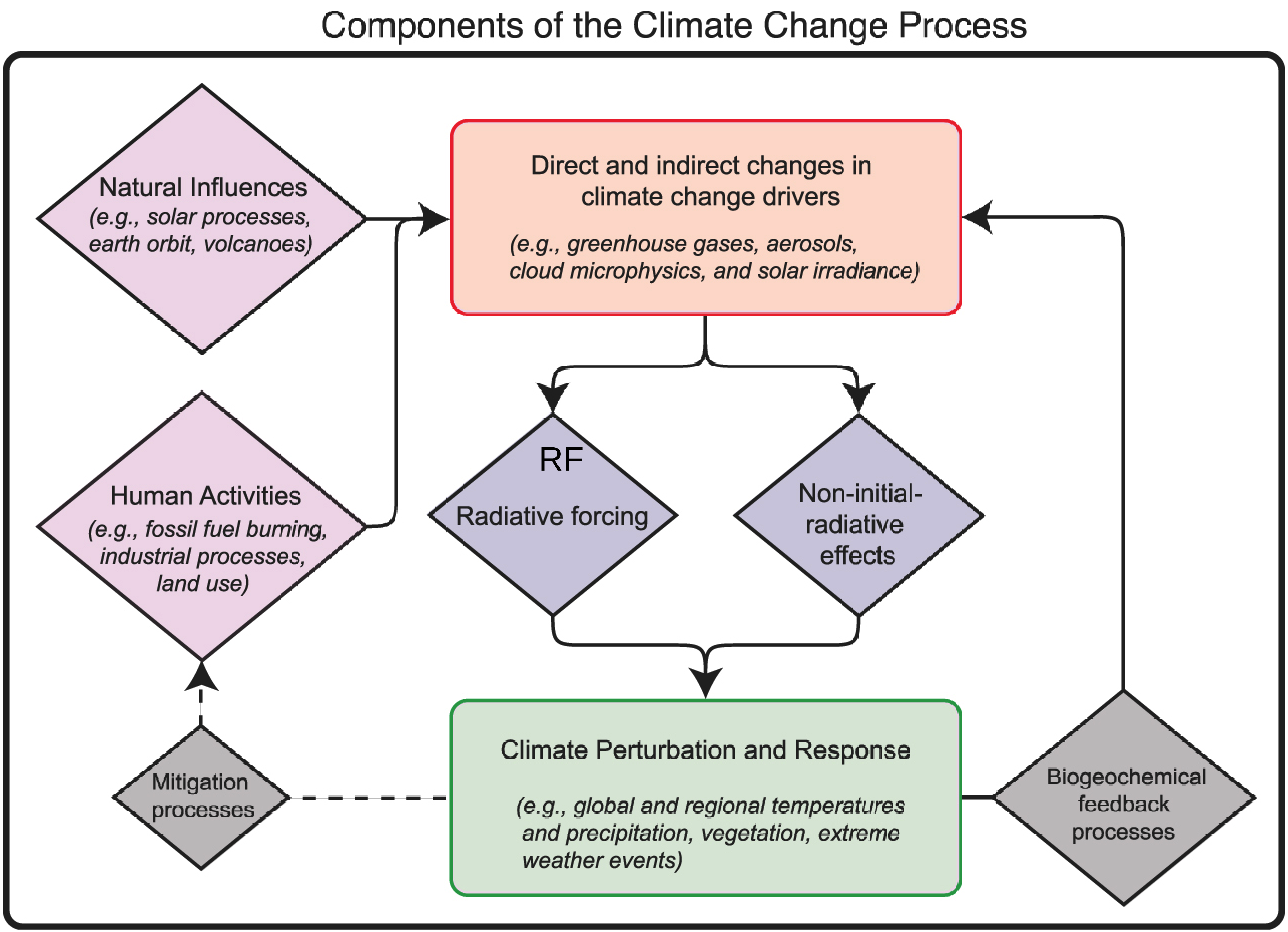
Units (Wm-2)
incoming solar TOA
340
(340, 341)
solar reflected TOA
100
(96, 100)
thermal outgoing TOA
239
(236, 242)
79
(74, 91)
solar absorbed atmosphere
atmospheric window
greenhouse gases
latent heat
solar down surface
185
(179, 189)
24
(22,26)
solar reflected surface
161
(154, 166)
84
(70, 85)
20
(15, 25)
398
(394, 400)
342
(338, 348)
imbalance
0.6
(0.2, 1.0)
solar absorbed surface
evapo-ration
sensible heat
thermal up surface
thermal down surface

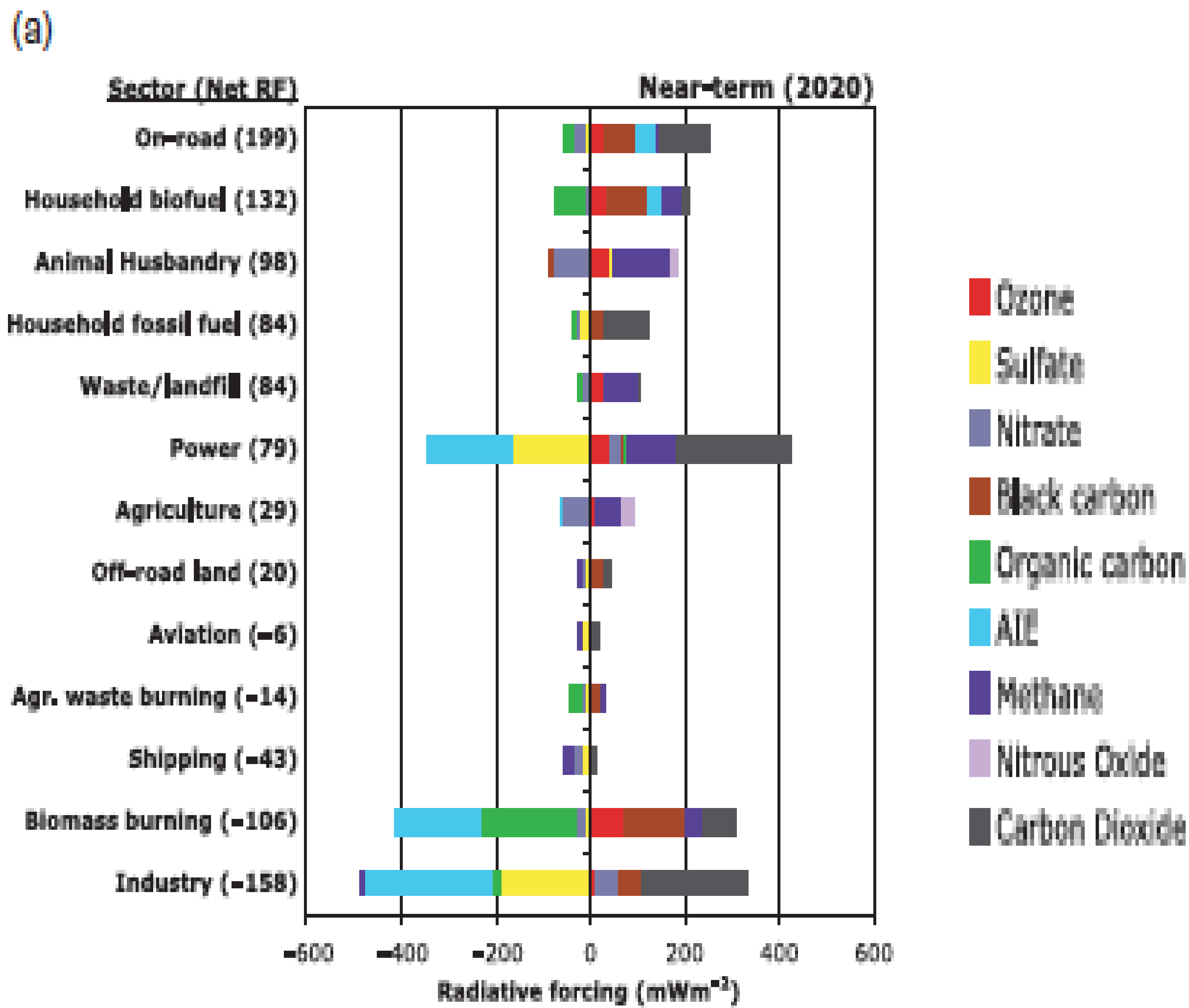


Emitted compound
Resulting atmospheric drivers
Radiative forcing by emissions and drivers
Level of confidence
Anthropogenic
Well-mixed greenhouse gases
CO2
CO2
1.68 [1.33 to 2.03]
VH
CH4
CO2 H2Ostr O3 CH4
0.97 [0.74 to 1.20]
H
Halo-carbons
O3 CFCs HCFCs
0.18 [0.01 to 0.35]
H
N2O
N2O
0.17 [0.13 to 0.21]
VH
Short lived gases and aerosols
CO
CO2 CH4 O3
0.23 [0.16 to 0.30]
M
NMVOC
CO2 CH4 O3
0.10 [0.05 to 0.15]
M
NOx
Nitrate CH4 O3
-0.15 [-0.34 to 0.03]
M
Aerosols and precursors (Mineral dust, SO2, NH3, Organic carbon and Black carbon)
Mineral dust Sulphate Nitrate Organic carbon Black carbon
-0.27 [-0.77 to 0.23]
H
Cloud adjustments due to aerosols
-0.55 [-1.33 to -0.06]
L
Albedo change due to land use
-0.15 [-0.25 to -0.05]
M
Natural
Changes in solar irradiance
0.05 [0.00 to 0.10]
M
Total anthropogenic RF relative to 1750
2011
2.29 [1.13 to 3.33]
H
1980
1.25 [0.64 to 1.86]
H
1950
0.57 [0.29 to 0.85]
M
–1 0 1 2 3
Radiative forcing relative to 1750 (W m–2)



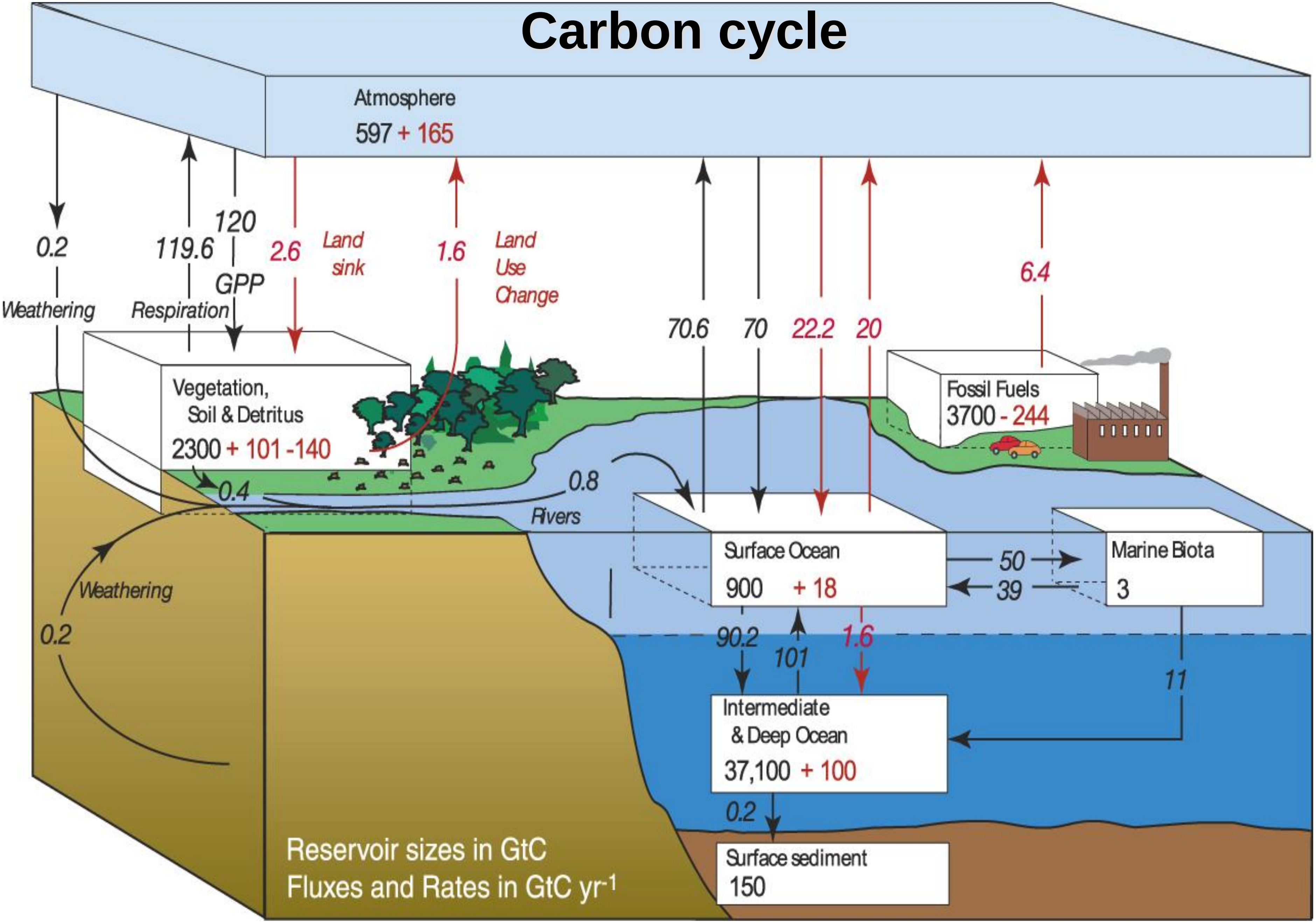
Top of the atmosphere
Surface
Indirect effect on ice clouds and contrails
Scattering & absorption of radiation
Unperturbed cloud
Increased CDNC (constant LWC) (Twomey, 1974)
Drizzle suppression. Increased LWC
Increased cloud height (Pincus & Baker, 1994)
Increased cloud lifetime (Albrecht, 1989)
Heating causes cloud burn-off (Ackerman et al., 2000)
Direct effects
Cloud albedo effect/ 1st indirect effect/ Twomey effect
Cloud lifetime effect/ 2nd indirect effect/ Albrecht effect
Semi-direct effect

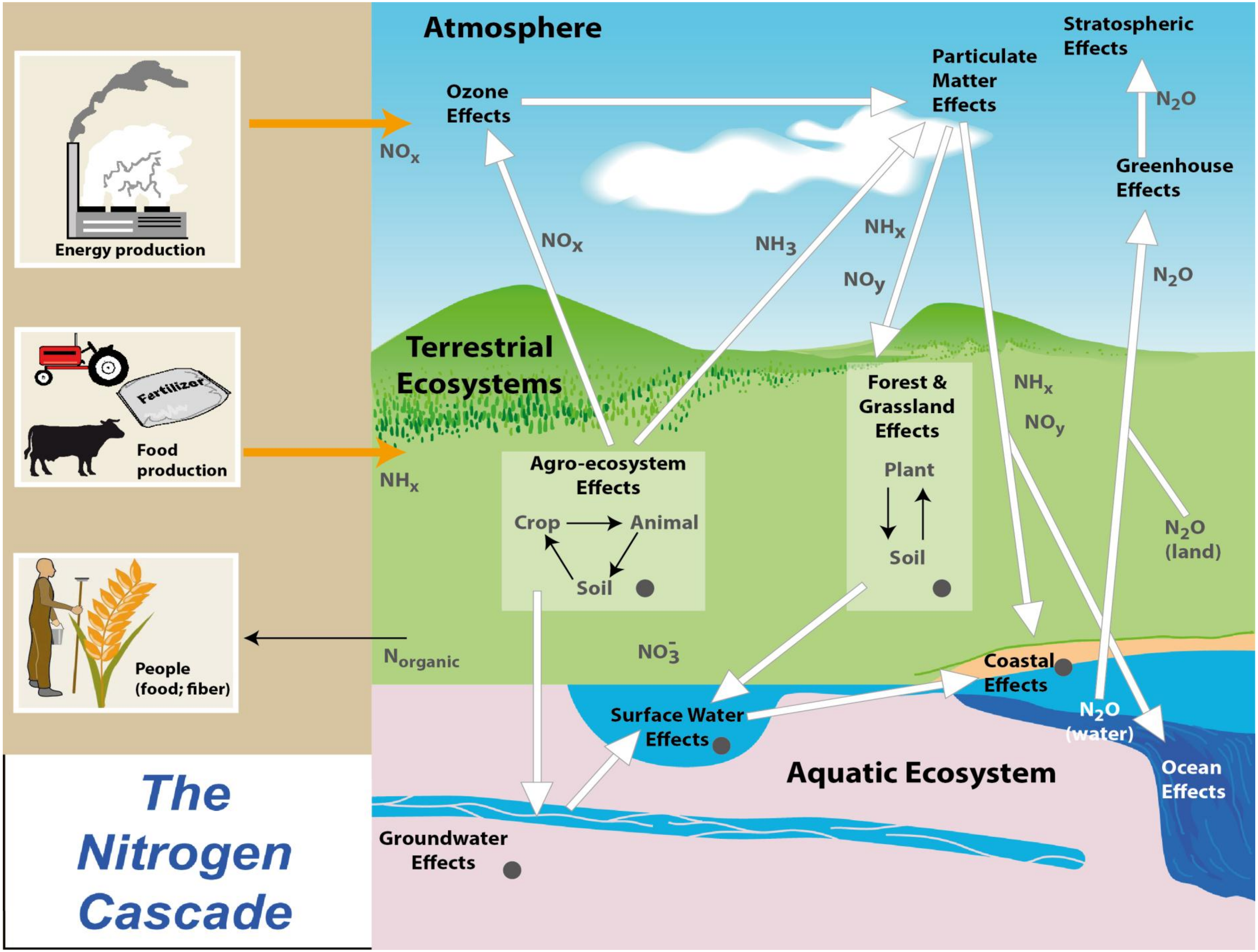

Components of the Climate Change Process
Natural Influences
(e.g., solar processes, earth orbit, volcanoes)
Direct and indirect changes in climate change drivers
(e.g., greenhouse gases, aerosols, cloud microphysics, and solar irradiance)
Human Activities
(e.g., fossil fuel burning, industrial processes, land use)
RF
Radiative forcing
Non-initial-radiative effects
Mitigation processes
Climate Perturbation and Response
(e.g., global and regional temperatures and precipitation, vegetation, extreme weather events)
Biogeochemical feedback processes



(a)
Sector (Net RF)
Near-term (2020)
On-road (199)
Household biofuel (132)
Animal Husbandry (98)
Household fossil fuel (84)
Waste/landfill (84)
Power (79)
Agriculture (29)
Off-road land (20)
Aviation (-6)
Agr. waste burning (-14)
Shipping (-43)
Biomass burning (-106)
Industry (-158)
-600
-400
-200
0
200
400
600
Radiative forcing (mWm-2)
Ozone
Sulfate
Nitrate
Black carbon
Organic carbon
AIE
Methane
Nitrous Oxide
Carbon Dioxide

Carbon cycle





Atmosphere
Stratospheric Effects
Particulate Matter Effects
Ozone Effects
N_2O
NO_x
Greenhouse Effects
Energy production
NO_x
NH_3
NH_x
NO_y
N_2O
Terrestrial Ecosystems
Fertilizer
Forest & Grassland Effects
NH_x
NO_y
Food production
Agro-ecosystem Effects
Plant
NH_x
Crop
Animal
Soil
N_2O (land)
Soil
$N_{organic}$
NO_3^-
Coastal Effects
People (food; fiber)
Surface Water Effects
N_2O (water)
Aquatic Ecosystem
Ocean Effects
The Nitrogen Cascade
Groundwater Effects

We know with certainty….

- The atmosphere and oceans circulate in response to known physics driven by global distribution solar energy, the earth's rotation and surface and atmospheric heating.

- The hydrological system is similarly driven by physical principles, especially the fact that water exists in gas, liquid and solid forms on earth and in the atmosphere.

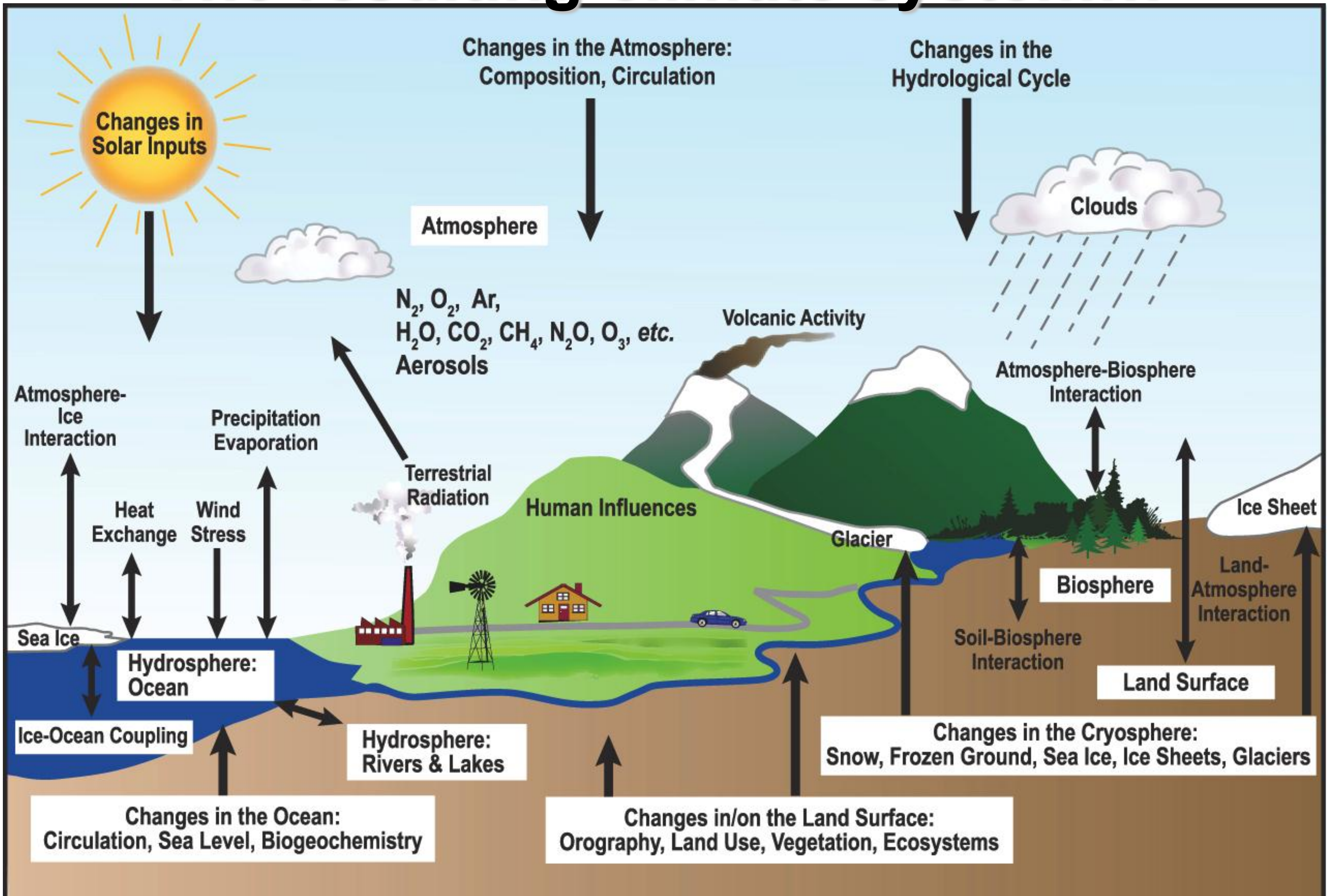
- Models have been constructed based on these physical principles which ultimately simulate the behavior of the atmosphere ocean general circulation (AOGCM). Most recently models have expended to include interactive biogeochemical cycles, Earth System Models, ESM

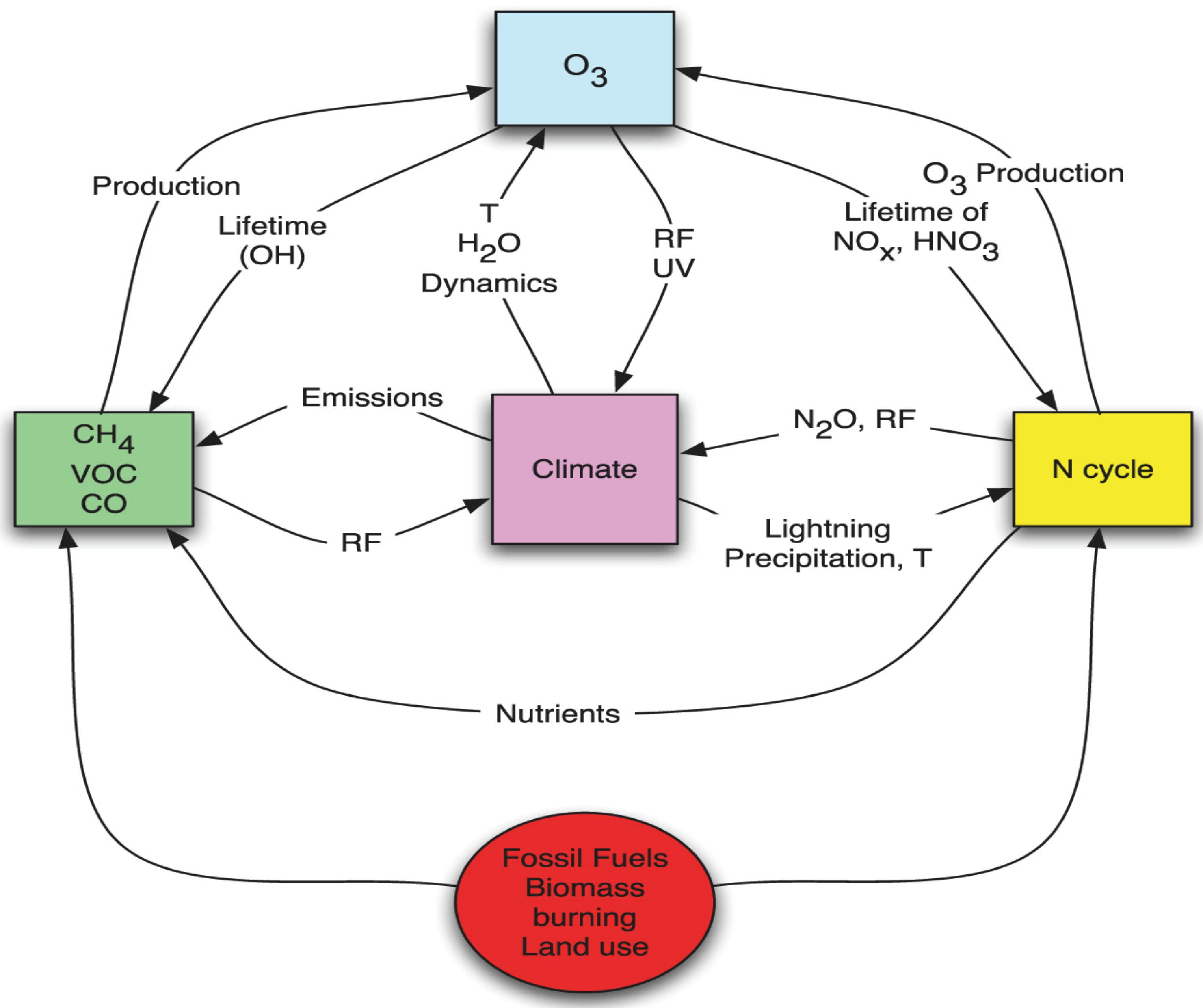
- Studying how the AOGCMs and ESMs respond to new changing forcings continues to provide insight on potential future climates.

Earth System Modeling: what it is & how it works

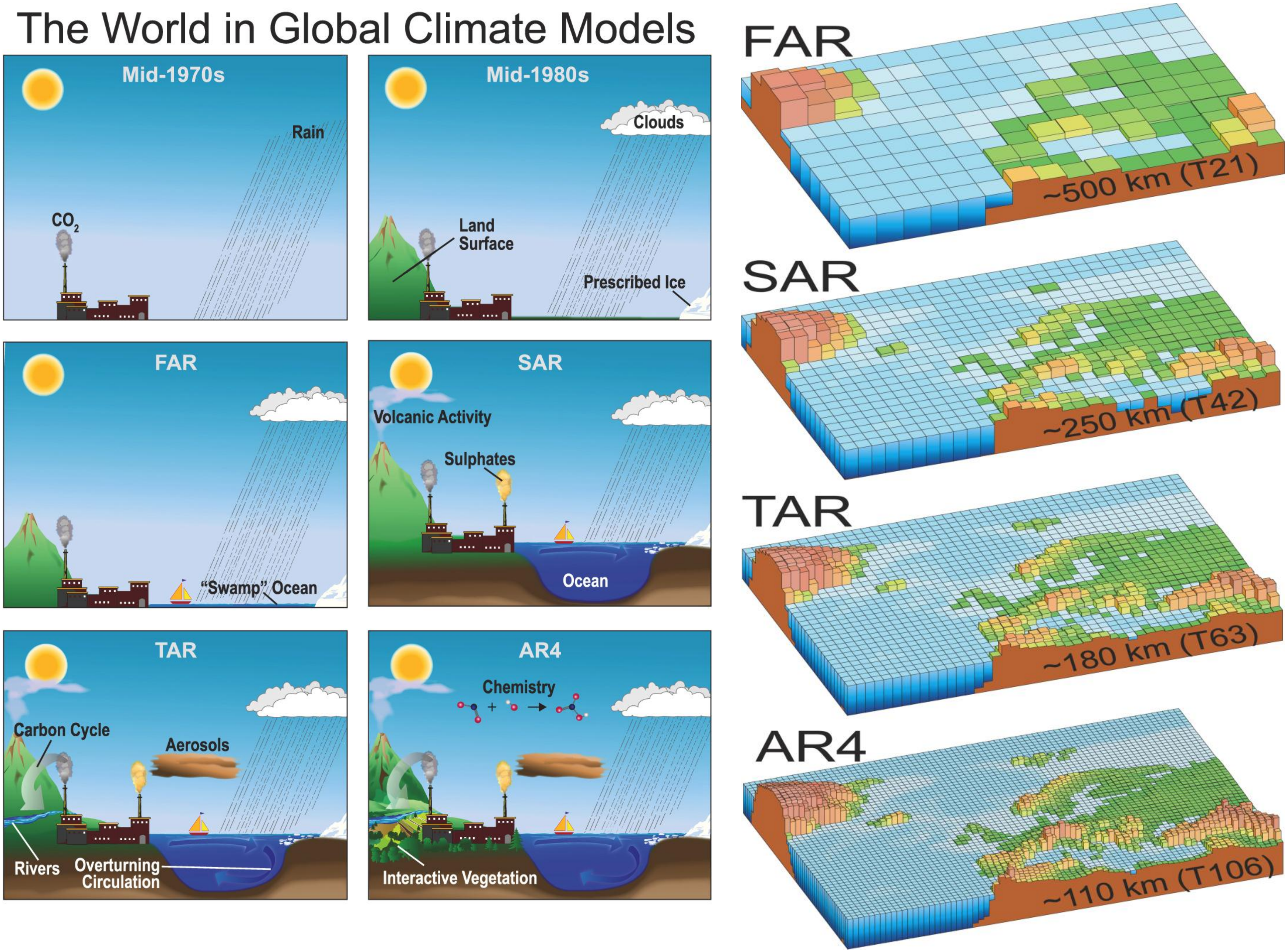
- Physical/Chemical Simulation of:
  - Atmosphere;
  - Ocean (including sea ice);
  - Land (including biosphere & cryosphere).
- Coupling between all three including:
  - Energy balance (radiation, sensible & latent heat);
  - Water & water vapor;
  - Chemical cycles and components, especially:
    - Carbon, CO_2 & other greenhouse gases,
    - Aerosols and Nitrogen.

The resulting climate system…





O_3
Production
Lifetime (OH)
T
H_2O
Dynamics
RF
UV
Lifetime of NO_x, HNO_3
O_3 Production
CH_4
VOC
CO
Emissions
Climate
N_2O, RF
N cycle
RF
Lightning
Precipitation, T
Nutrients
Fossil Fuels
Biomass burning
Land use


The World in Global Climate Models
Mid-1970s
Rain
CO_2
Mid-1980s
Clouds
Land Surface
Prescribed Ice
FAR
"Swamp" Ocean
SAR
Volcanic Activity
Sulphates
Ocean
TAR
Carbon Cycle
Aerosols
Rivers
Overturning Circulation
AR4
Chemistry
Interactive Vegetation
FAR
~500 km (T21)
SAR
~250 km (T42)
TAR
~180 km (T63)
AR4
~110 km (T106)

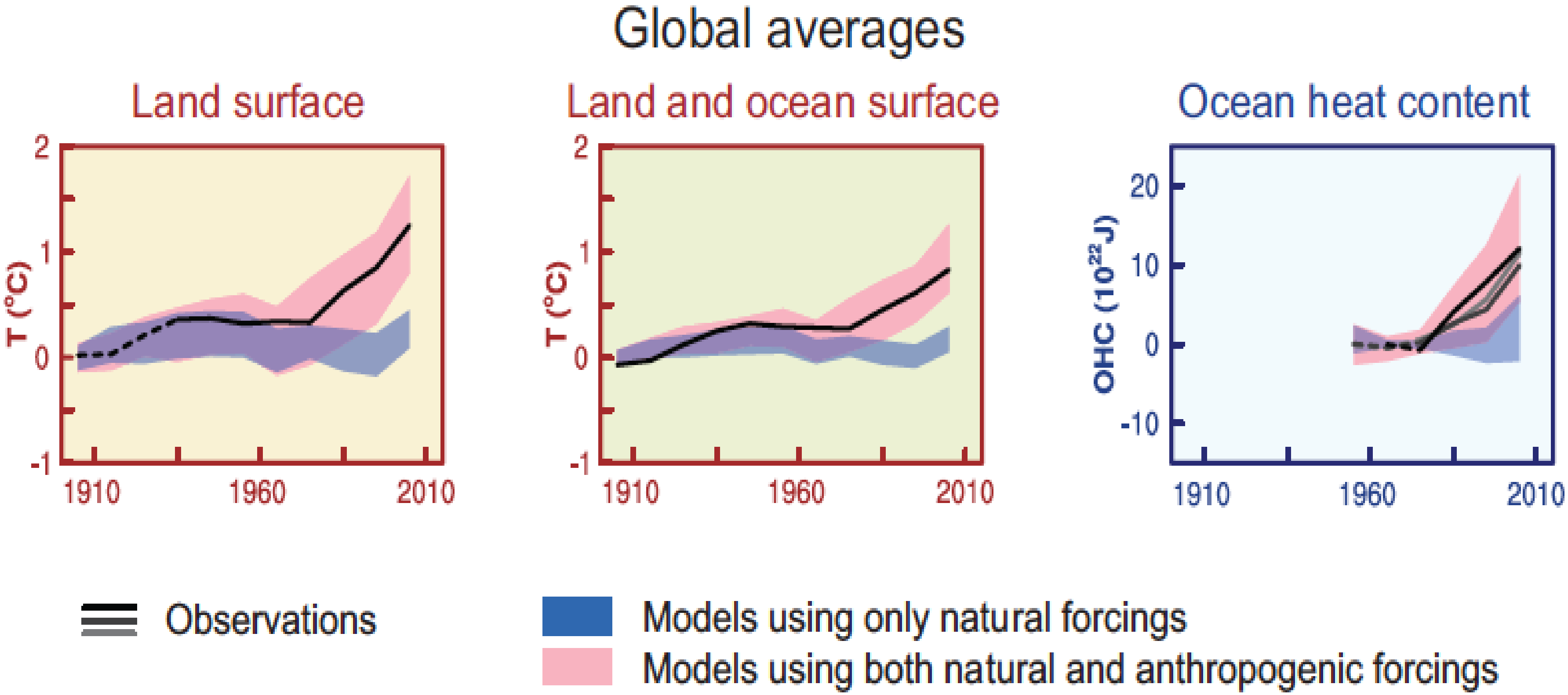
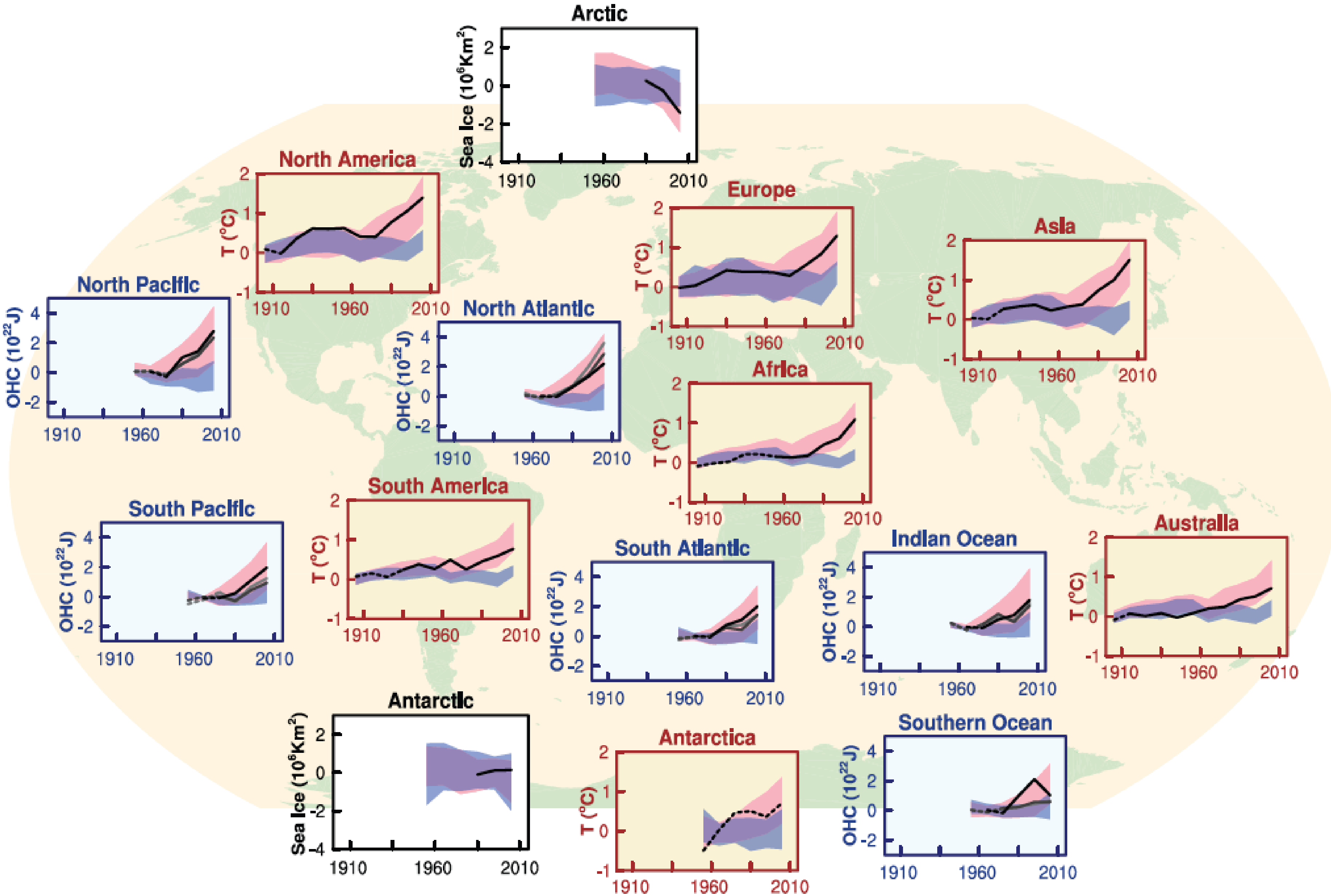


Figure SPM.6 | Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty is larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions see the Technical Summary Supplementary Material. {Figure 10.21; Figure TS.12}


Arctic
Sea Ice (10^6Km^2)
North America
Europe
Asia
North Pacific
North Atlantic
Africa
South America
South Pacific
South Atlantic
Indian Ocean
Australia
Antarctic
Antarctica
Southern Ocean
T (°C)
OHC (10^{22}J)
1910
1960
2010

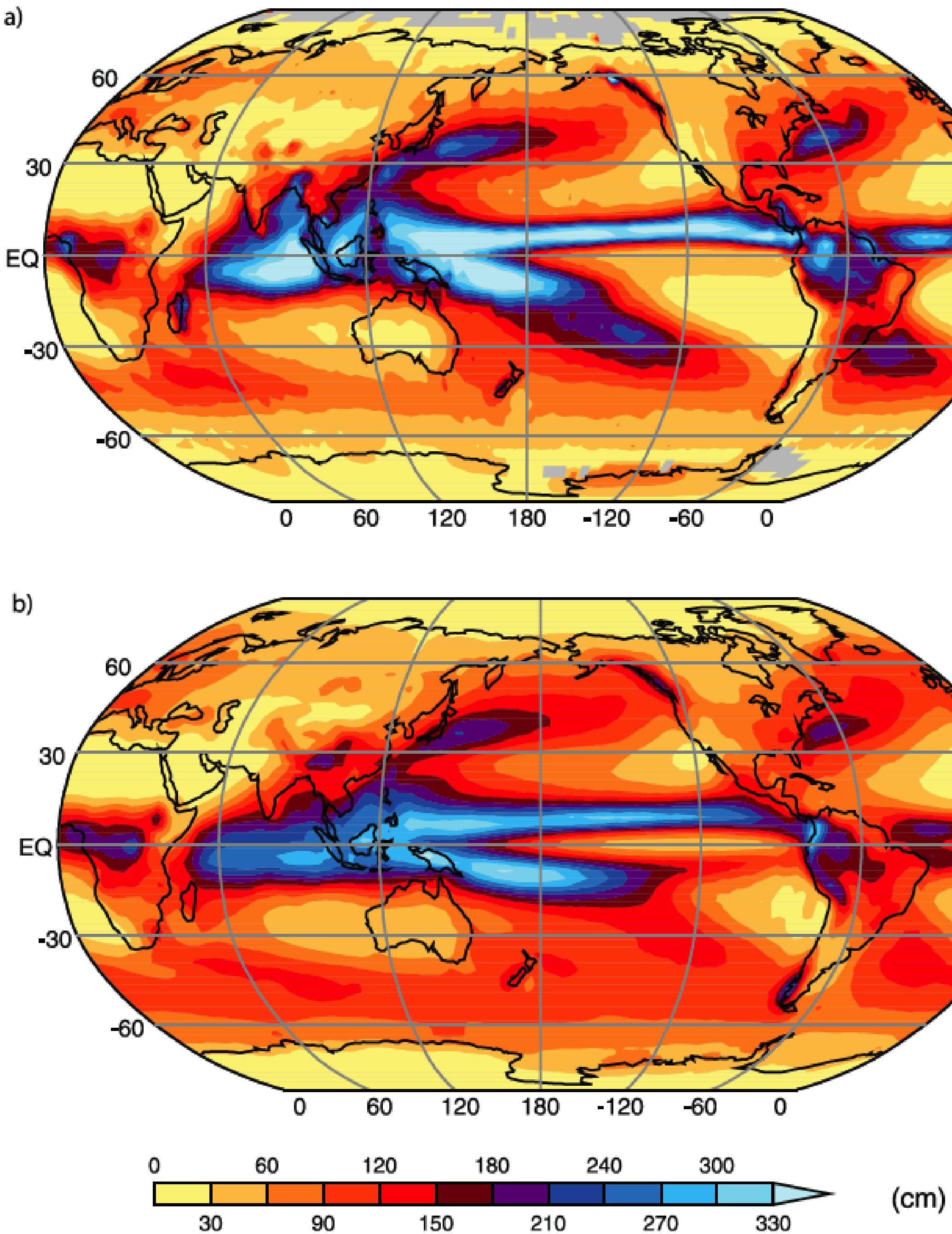
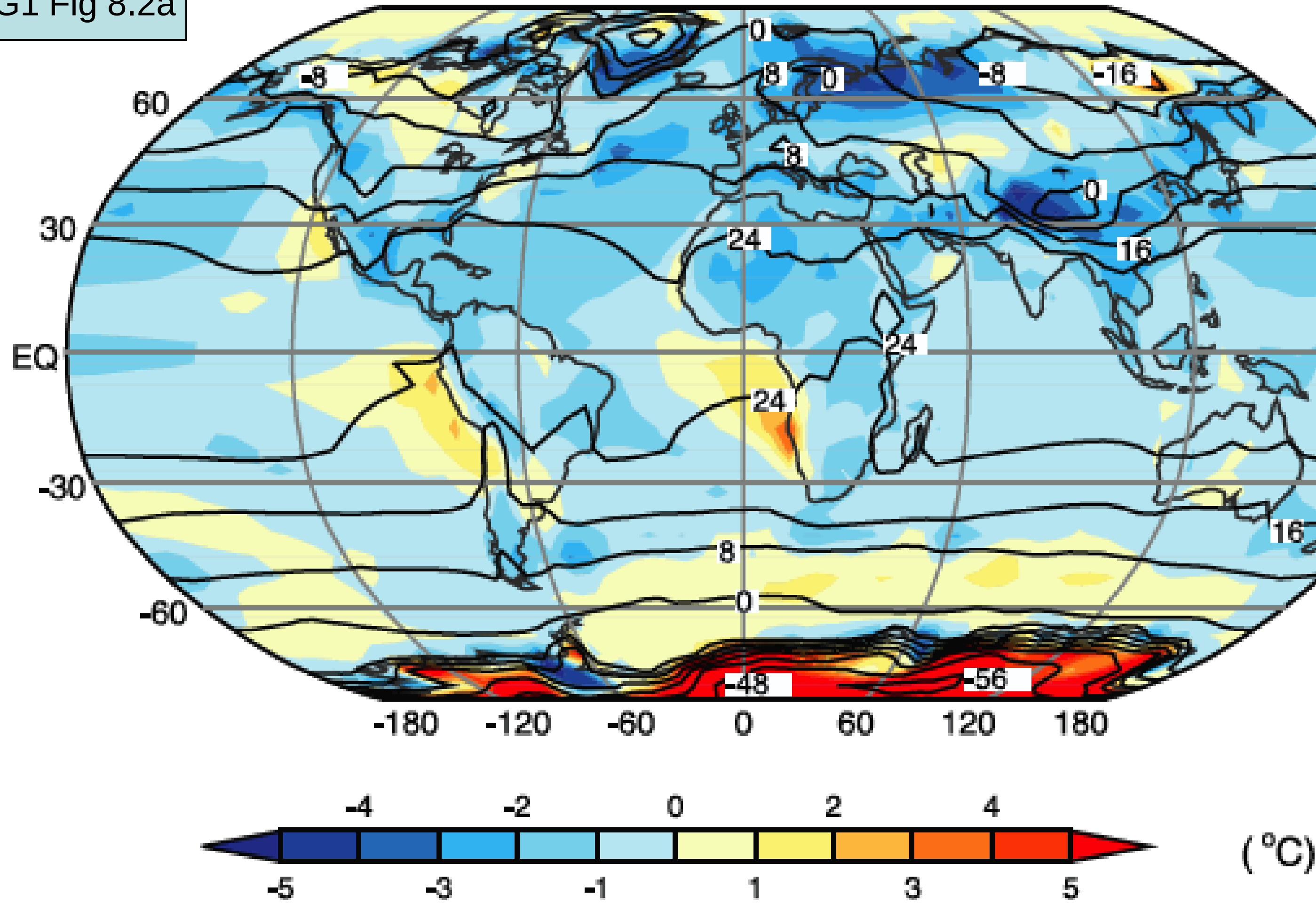
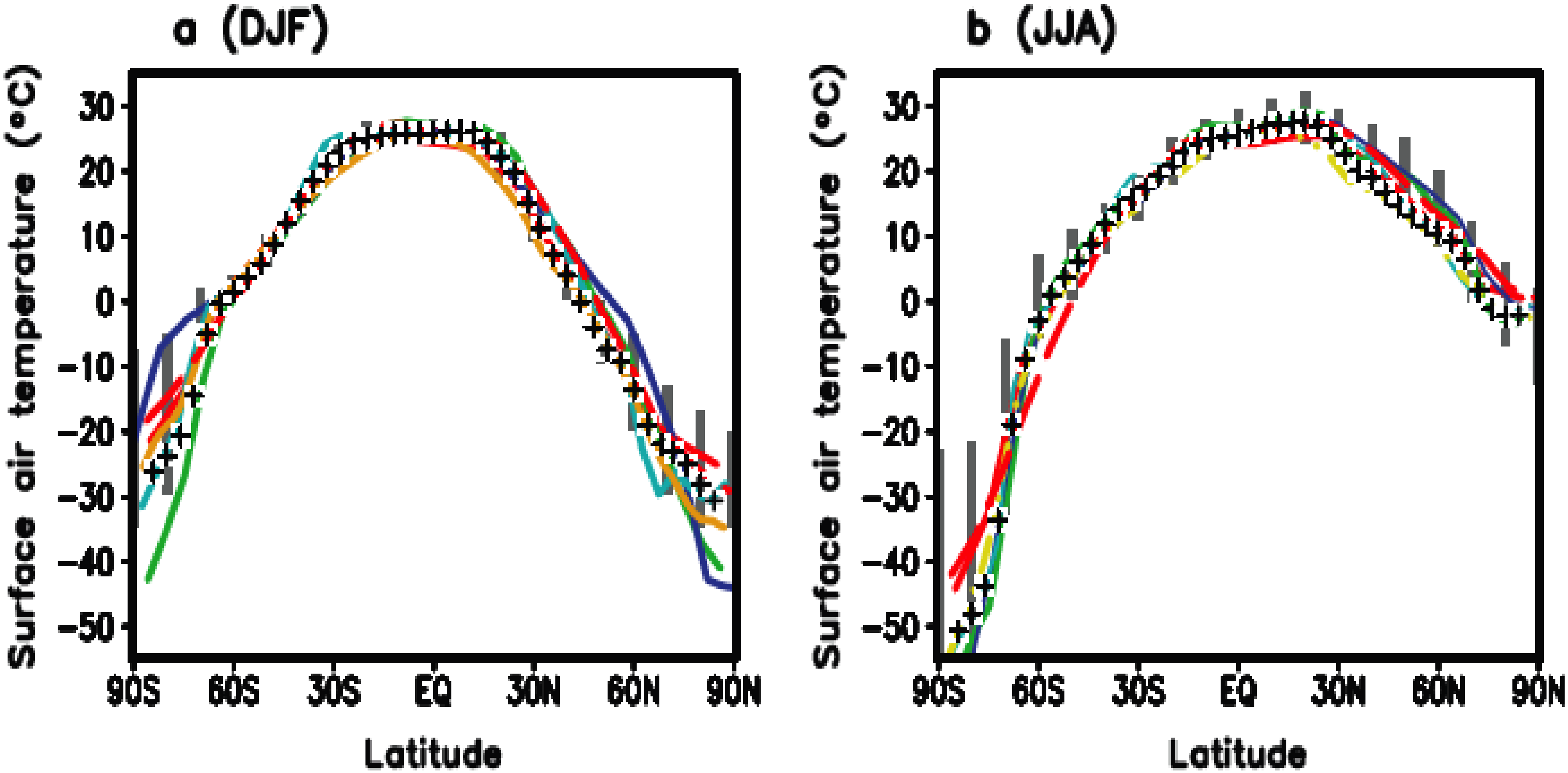


Figure 8.5. Annual mean precipitation (cm), observed (a) and simulated (b), based on a multimodel mean.

IPCC WG1 Fig 8.2a

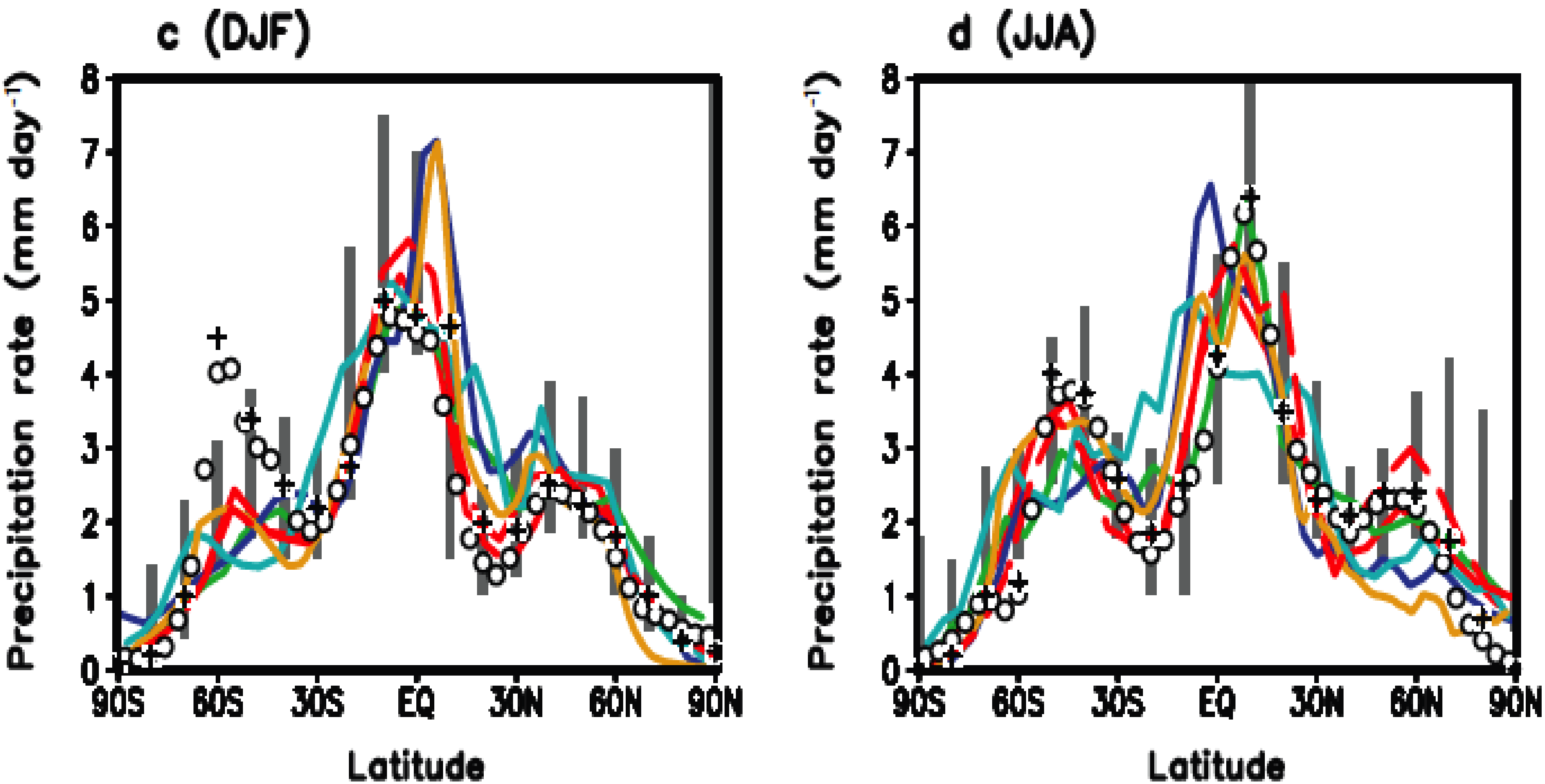


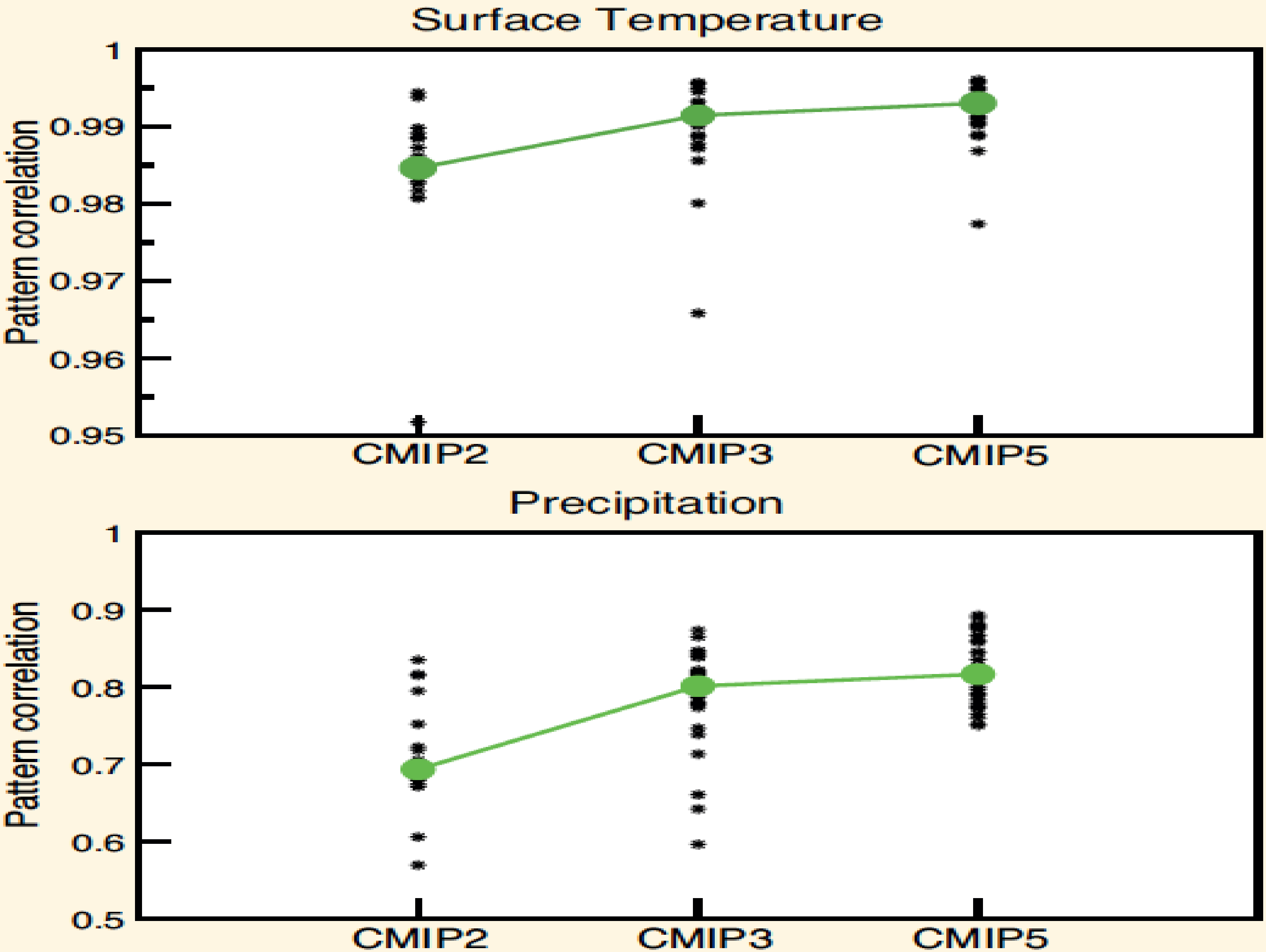
Observed climatological annual mean SST and, over land, surface air temperature (labelled contours) and the multi-model mean error in these temperatures, simulated minus observed (colour-shaded contours)



Latitudinal distributions of the **zonally averaged surface air temperature** for NH winter (DJF) (a) and NH summer (JJA) (b) as simulated at equilibrium by some of the EMICs (Simplified AOGCMs) for an atmospheric CO2 of 280 ppm. In (a) and (b), observational data are shown by crosses. The vertical grey bars indicate the range of GCM results from AMIP and CMIP1

Latitudinal distributions of the **zonally averaged precipitation rate** (c, d) for NH winter (DJF) (c) and NH summer (JJA) (d) as simulated at equilibrium by some of the EMICs (simplified AOGCMs) for an atmospheric CO2 concentration of 280 ppm. Observation-based estimates crosses and open circles are shown. The vertical grey bars indicate the range of GCM results from AMIP and CMIP1.





Surface Temperature
Pattern correlation
1
0.99
0.98
0.97
0.96
0.95
CMIP2
CMIP3
CMIP5
Precipitation
Pattern correlation
1
0.9
0.8
0.7
0.6
0.5
CMIP2
CMIP3
CMIP5

AR5 Model Improvements

1. There is considerable confidence that AOGCM/ESMs provide credible quantitative estimates of future climate change, particularly at continental scales and above. Confidence in these estimates is higher for temperature than for precipitation.

2. The ability of climate models to simulate surface temperature has improved in many, though not all, important aspects. Regional scale skill and ability to simulate historically different climates have increased.

3. Whilst simulation of large-scale precip patterns has improved some, models continue to perform less well for precipitation than for surface temperature including regionally.

4. The simulation of clouds in climate models remains challenging. Biases in cloud simulation lead to regional errors on cloud radiative effect of several tens of watts per square meter.

AR5 Model Improvements / 2

5. Ability to capture characteristics of storm tracks and extra-tropical cyclones improved but storm tracks are too zonal and cyclone intensity too low.

6. Simulation of tropical Pacific Ocean mean state has improved with a 30% reduction in the spurious westward extension of the cold tongue near the equator, a pervasive bias of coupled models. Tropical Atlantic is not as good.

7. There is *robust evidence* that the downward trend in Arctic summer sea ice extent is better simulated, with about 24% of the simulations showing a trend as strong or stronger, than observations over the satellite era (1979).

8. Models are able to reproduce features of the observed global and NH mean temperature variance on inter-annual to centennial time scales (*high confidence*), and most models are now able to reproduce the observed peak in variability associated with the El Niño (2- to 7-year period) in the Tropical Pacific.

–

AR5 Model Improvements / 3

9. Important modes of climate variability and intra-seasonal to seasonal phenomena show some improvements. There is *high confidence* that the multi-model statistics of monsoon and ENSO have improved in some models.

10. Statistics of the global monsoon, the North Atlantic Oscillation, ENSO, the Indian Ocean Dipole and the Quasi-Biennial Oscillation are simulated well by several models but not modes of Atlantic Ocean variability and ENSO teleconnections outside the tropical Pacific.

11. Modeling extreme events has improved. Changes in frequency of extreme warm and cold days and nights over the second half of the 20th century are consistent between models and observations. Models may underestimate the projected increase in extreme precip.

12. New Earth System models include an interactive carbon cycle. In most ESMs, simulated global land and ocean carbon sinks over the latter part of the 20th century fall within the range of observational estimates.

AR5 Model Improvements / 4

13. Most ESMs now include interactive aerosol, including anthropogenic SO_2 emissions. Uncertainties in S & N cycle processes, natural sources and sinks remain so, for example, simulated aerosol optical depth 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. Fires also remain uncertain.

14. <u>There is *high confidence* that regional downscaling adds value in regions with highly variable topography and for various small-scale phenomena</u>. Regional models necessarily inherit biases from the global models used to provide boundary conditions, however, studies demonstrate added value from higher resolution of stationary features like topography and coastlines, and from improved representation of small-scale processes like convective precipitation.

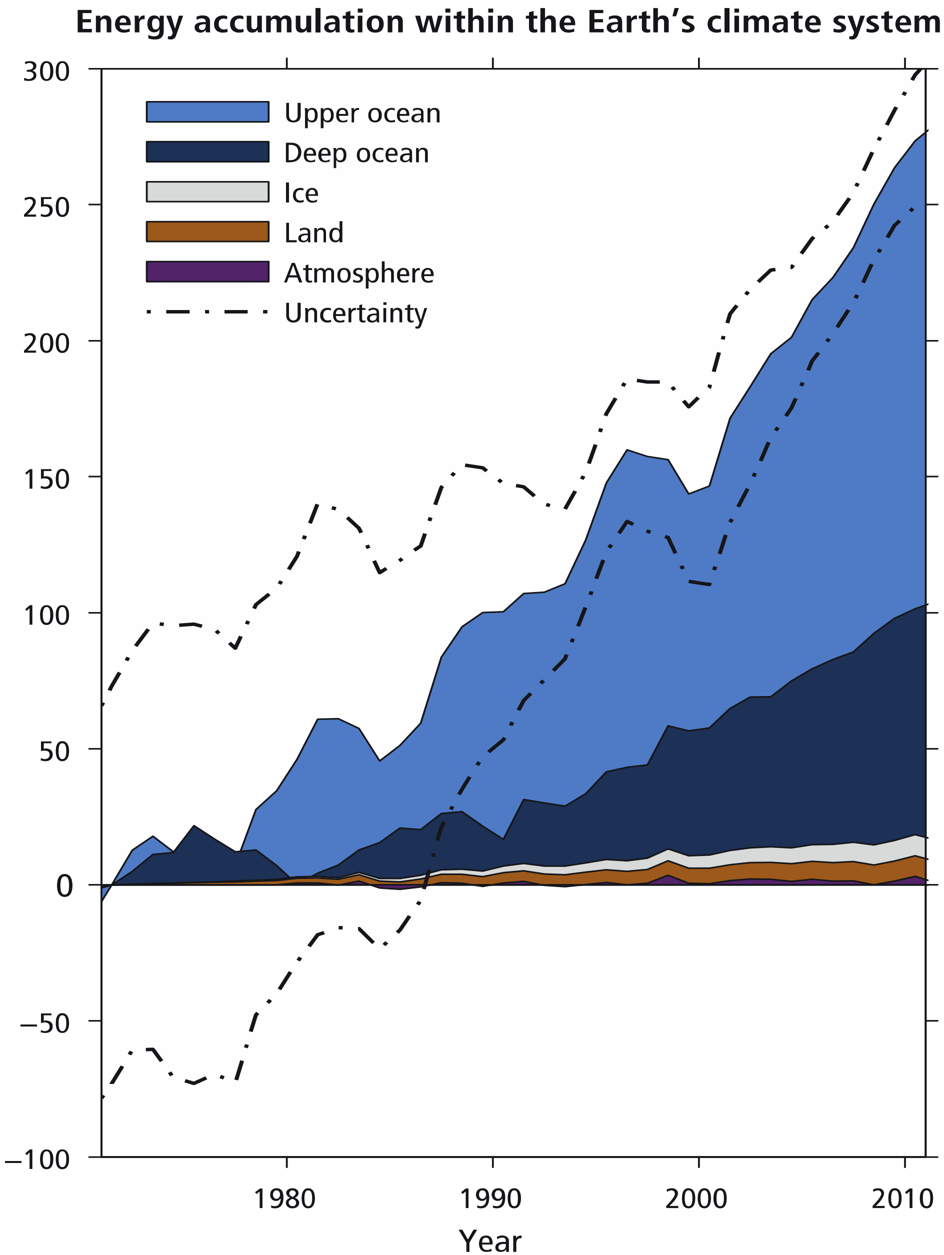
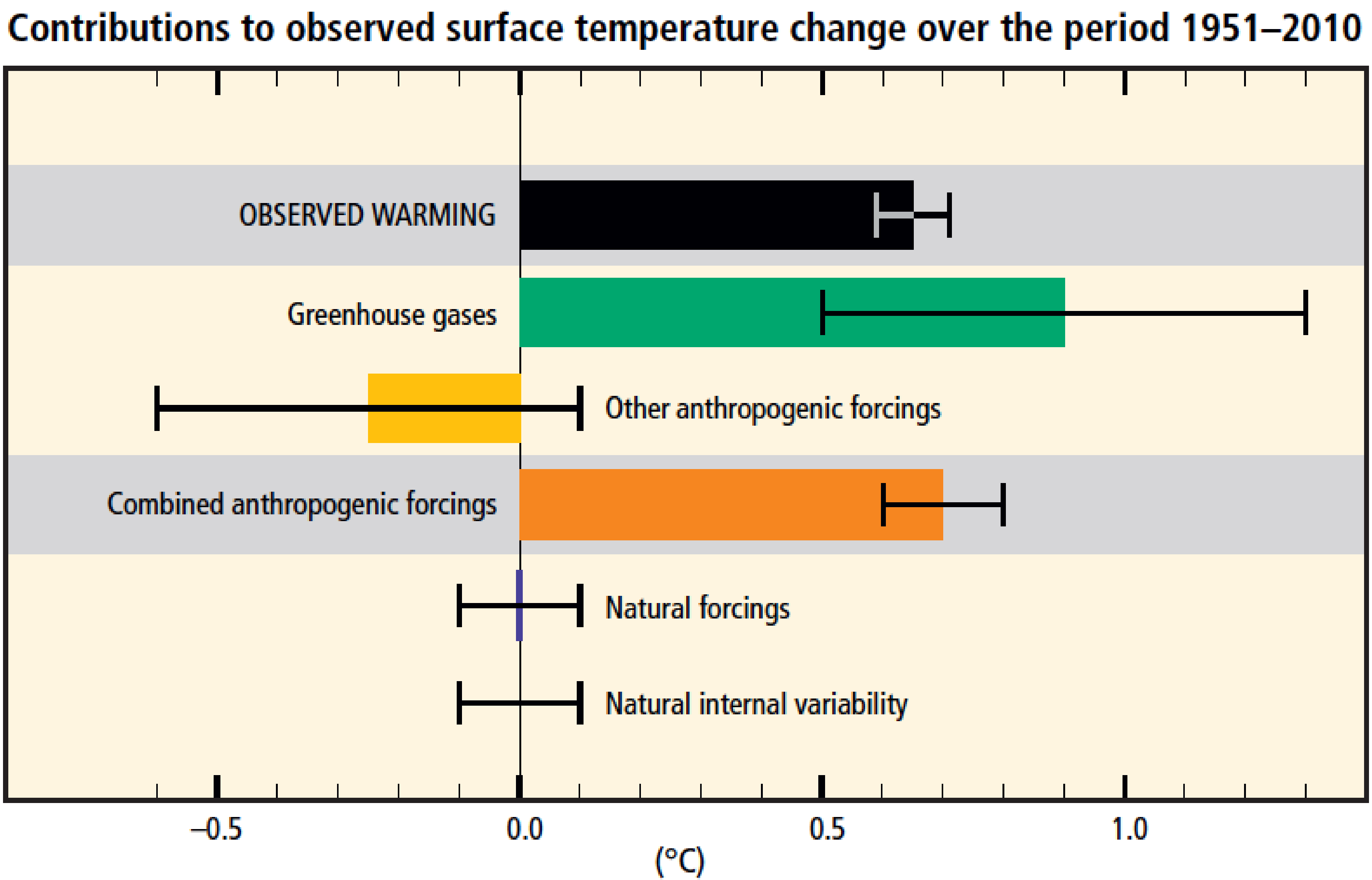
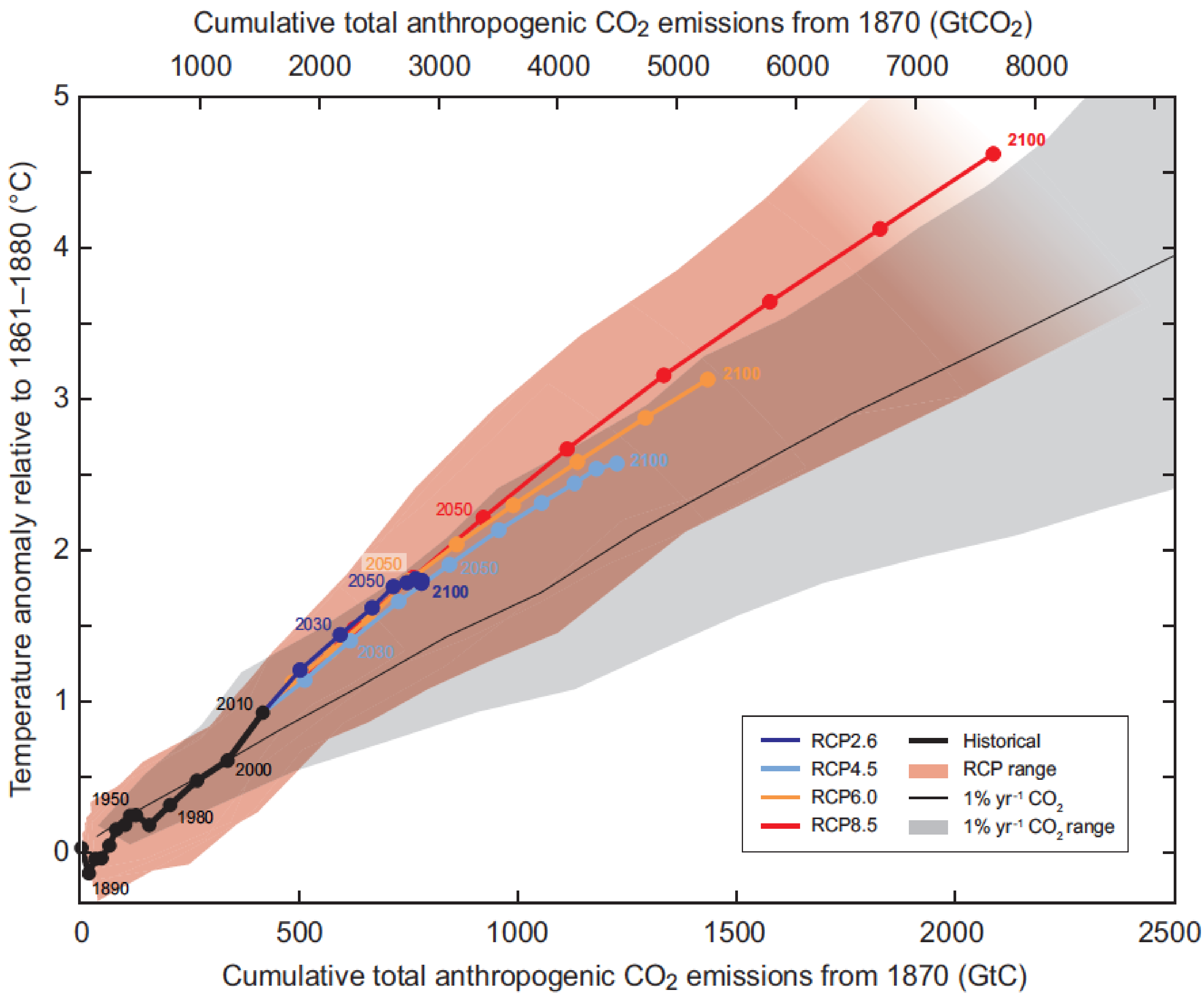


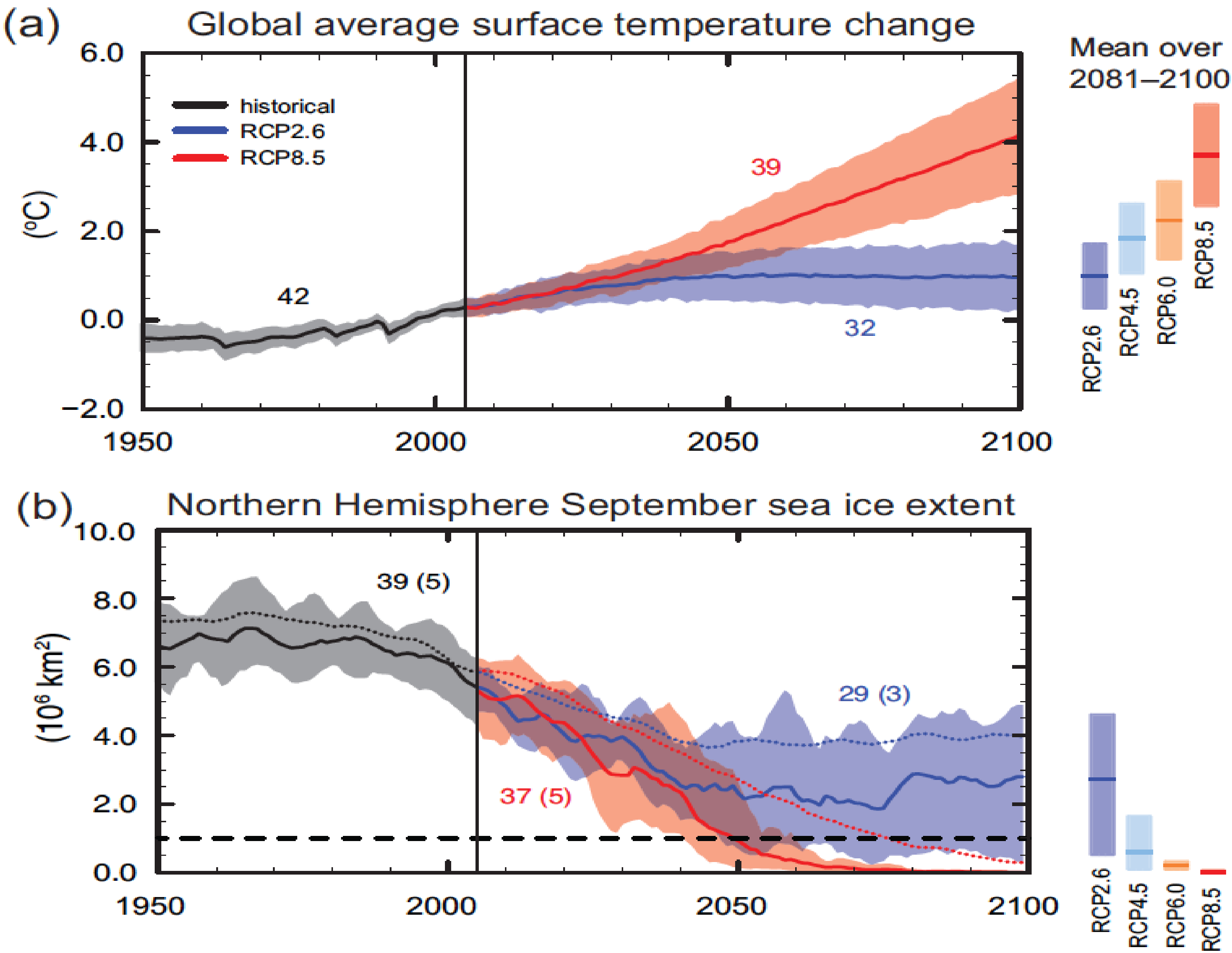
Figure 1.2 | Energy accumulation within the Earth's climate system. Estimates are in 10^21 J, and are given relative to 1971 and from 1971 to 2010, unless otherwise indicated. Components included are upper ocean (above 700 m), deep ocean (below 700 m; including below 2000 m estimates starting from 1992), ice melt (for glaciers and ice caps, Greenland and Antarctic ice sheet estimates starting from 1992, and Arctic sea ice estimate from 1979 to 2008), continental (land) warming, and atmospheric warming (estimate starting from 1979). Uncertainty is estimated as error from all five components at 90% confidence intervals. {WGI Box 3.1, Figure 1}



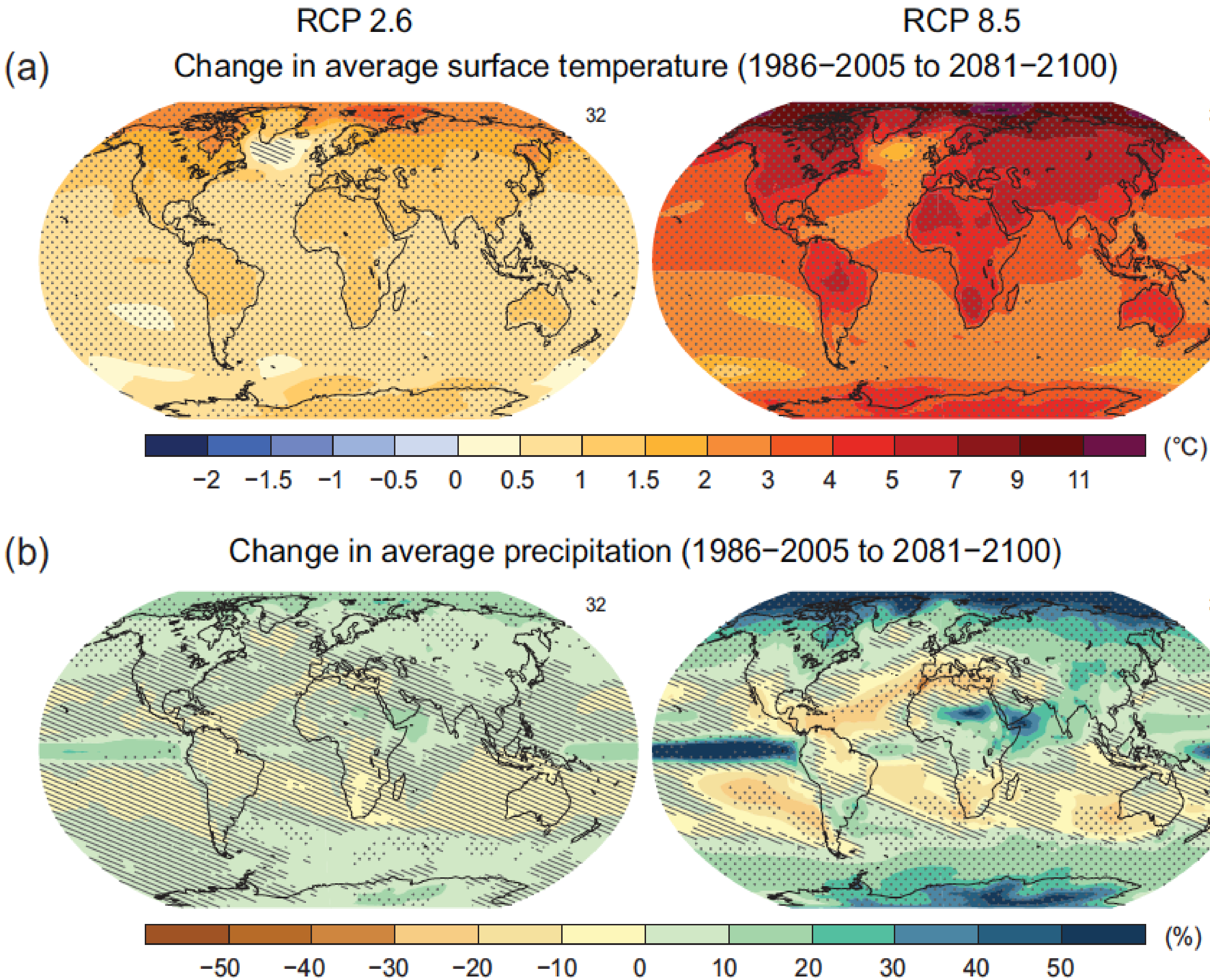
Contributions to observed surface temperature change over the period 1951–2010
OBSERVED WARMING
Greenhouse gases
Other anthropogenic forcings
Combined anthropogenic forcings
Natural forcings
Natural internal variability
–0.5
0.0
0.5
1.0
(°C)



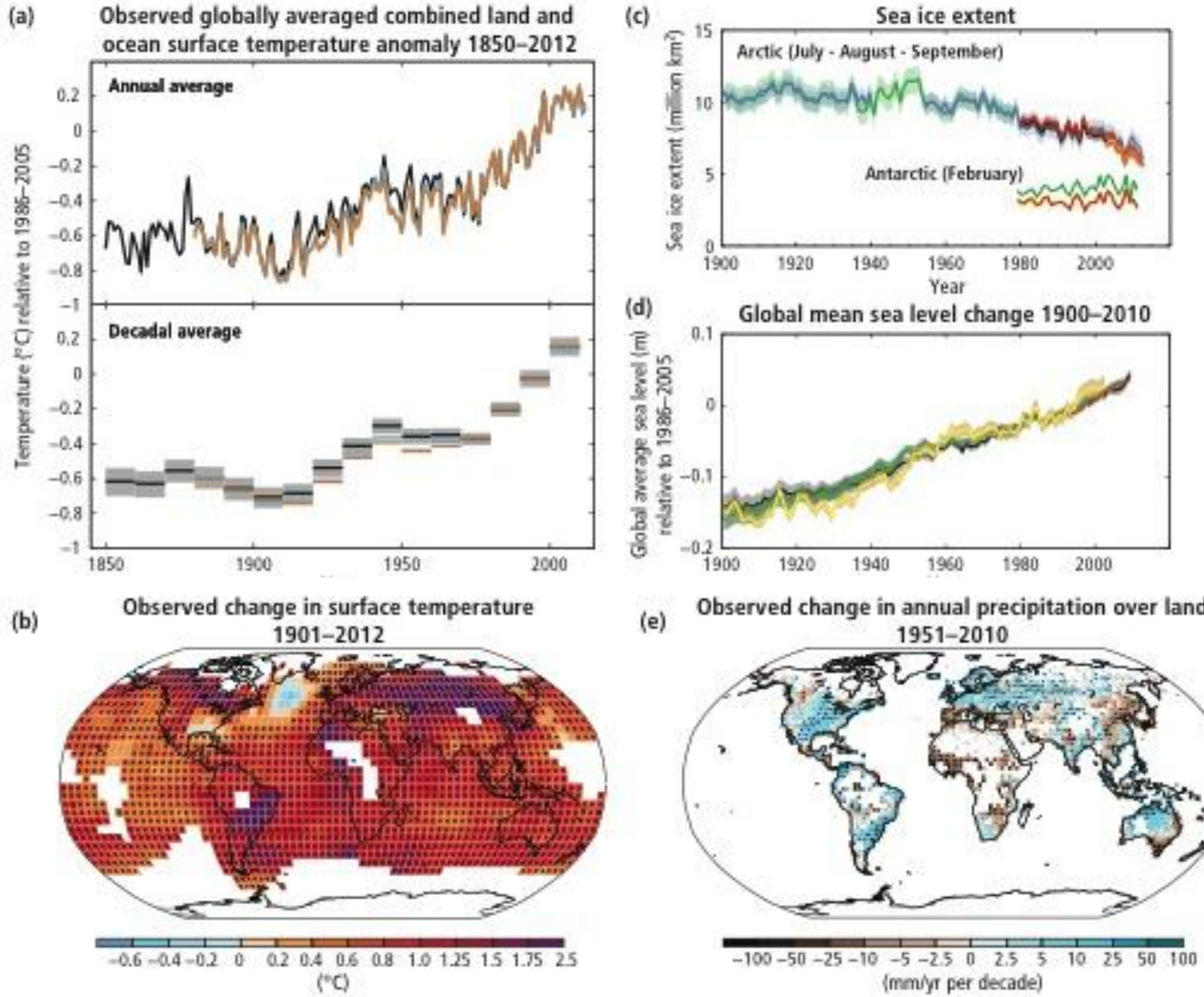
Cumulative total anthropogenic CO_2 emissions from 1870 ($GtCO_2$)
1000
2000
3000
4000
5000
6000
7000
8000
Temperature anomaly relative to 1861–1880 (°C)
5
4
3
2
1
0
2100
2100
2100
2050
2050
2050
2050
2100
2030
2030
2010
2000
1950
1980
1890
RCP2.6
RCP4.5
RCP6.0
RCP8.5
Historical
RCP range
1% yr^{-1} CO_2
1% yr^{-1} CO_2 range
0
500
1000
1500
2000
2500
Cumulative total anthropogenic CO_2 emissions from 1870 (GtC)



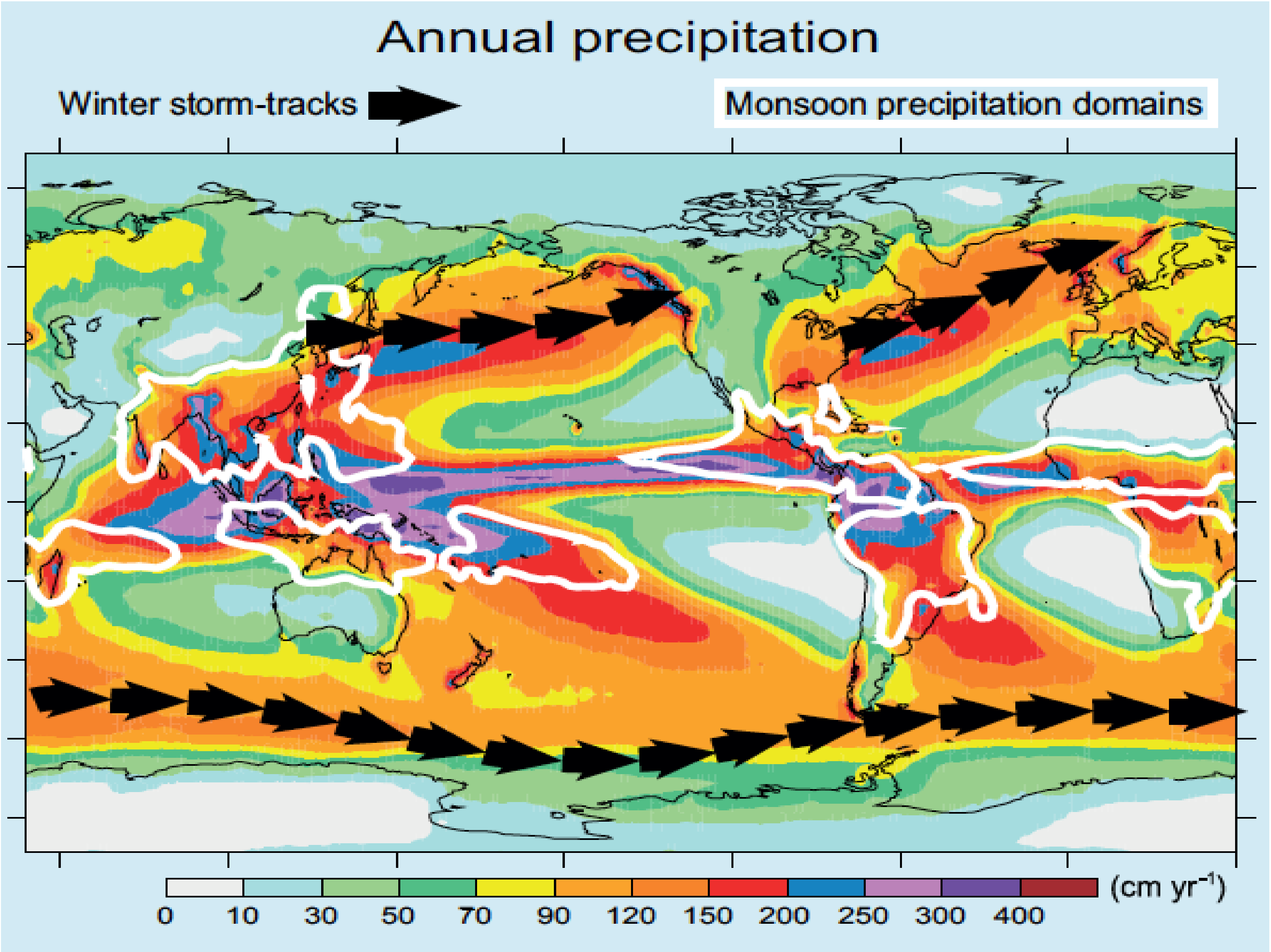
(a)
Global average surface temperature change
Mean over
2081–2100
6.0
4.0
2.0
0.0
−2.0
(°C)
historical
RCP2.6
RCP8.5
39
42
32
1950
2000
2050
2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5
(b)
Northern Hemisphere September sea ice extent
10.0
8.0
6.0
4.0
2.0
0.0
(10^6 km^2)
39 (5)
29 (3)
37 (5)
1950
2000
2050
2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5

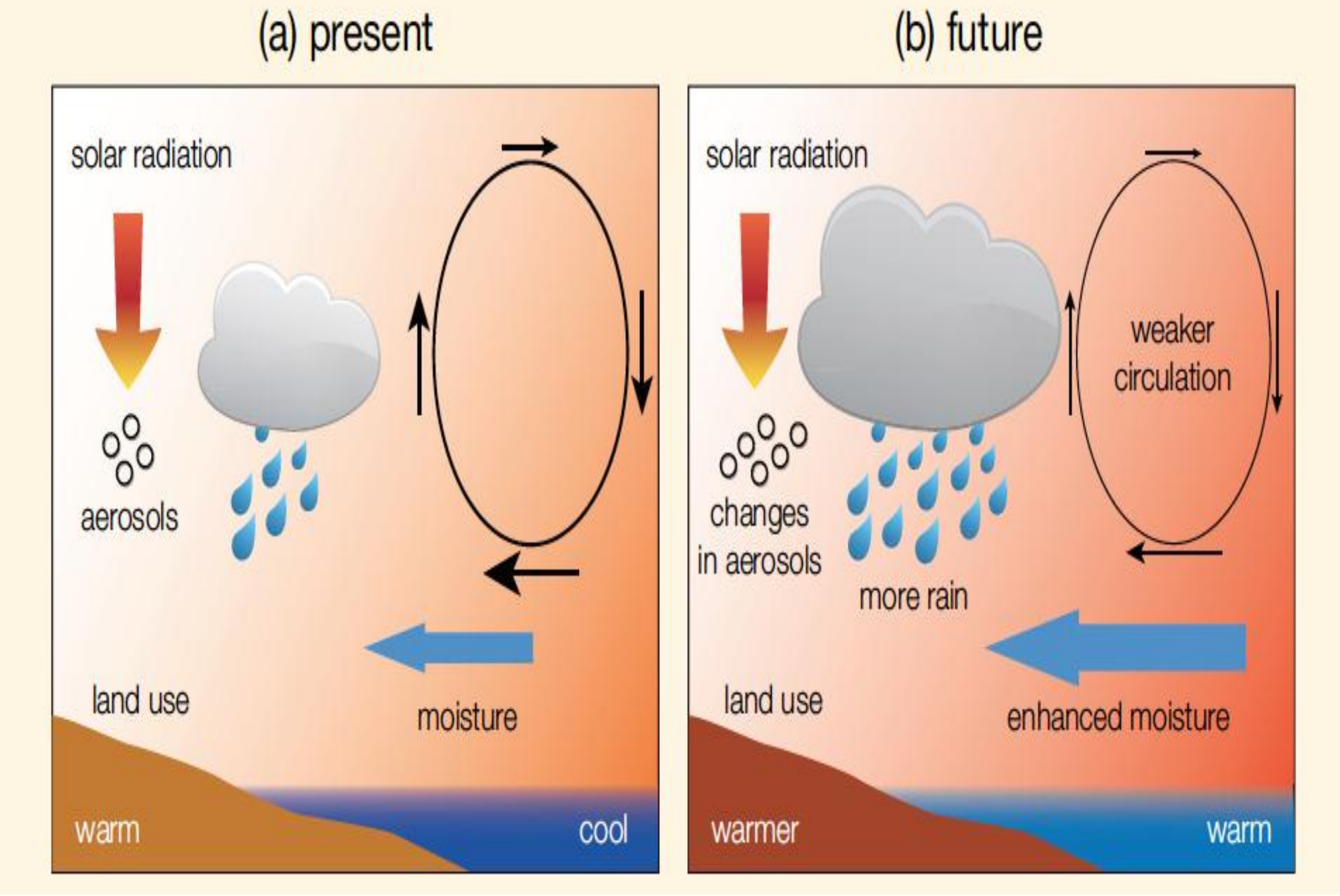


RCP 2.6
RCP 8.5
(a)
Change in average surface temperature (1986−2005 to 2081−2100)
32
39
(°C)
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(b)
Change in average precipitation (1986−2005 to 2081−2100)
32
39
(%)
−50 −40 −30 −20 −10 0 10 20 30 40 50



(a)
Observed globally averaged combined land and ocean surface temperature anomaly 1850–2012
Annual average
Decadal average
Temperature (°C) relative to 1986–2005
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1850
1900
1950
2000
(b)
Observed change in surface temperature 1901–2012
−0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1.0 1.25 1.5 1.75 2.5
(°C)
(c)
Sea ice extent
Arctic (July - August - September)
Antarctic (February)
Sea ice extent (million km²)
15
10
5
0
1900
1920
1940
1960
1980
2000
Year
(d)
Global mean sea level change 1900–2010
Global average sea level (m) relative to 1986–2005
0.1
0
−0.1
−0.2
1900
1920
1940
1960
1980
2000
(e)
Observed change in annual precipitation over land 1951–2010
−100 −50 −25 −10 −5 −2.5 0 2.5 5 10 25 50 100
(mm/yr per decade)


Annual precipitation
Winter storm-tracks
Monsoon precipitation domains
0
10
30
50
70
90
120
150
200
250
300
400
(cm yr⁻¹)



(a) present
(b) future
solar radiation
aerosols
land use
moisture
warm
cool
solar radiation
weaker circulation
changes in aerosols
more rain
land use
enhanced moisture
warmer
warm

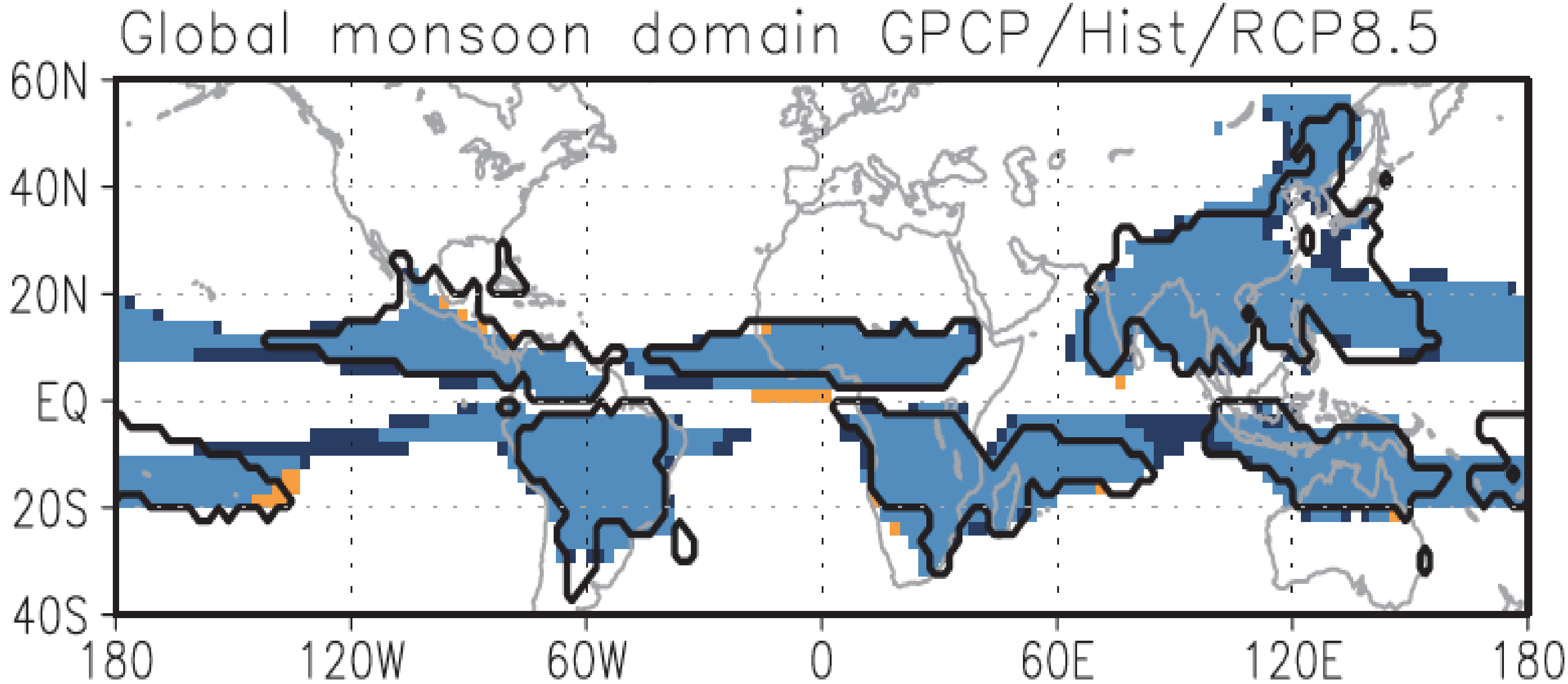


Figure 14.1 Observed (thick contour) and simulated (shading) global monsoon domain (Wang et al., 2011). The observations are based on GPCP v2.2 data (Huffman et al., 2009), and the simulations are based on 26 CMIP5 multi-model mean precipitation with a common 2.5 by 2.5 degree grid in the present day (1986–2005) and the future (2080–2099; RCP8.5 scenario). Orange (dark blue) shading shows monsoon domain only in the present day (future). Light blue shading shows monsoon domain in both periods.

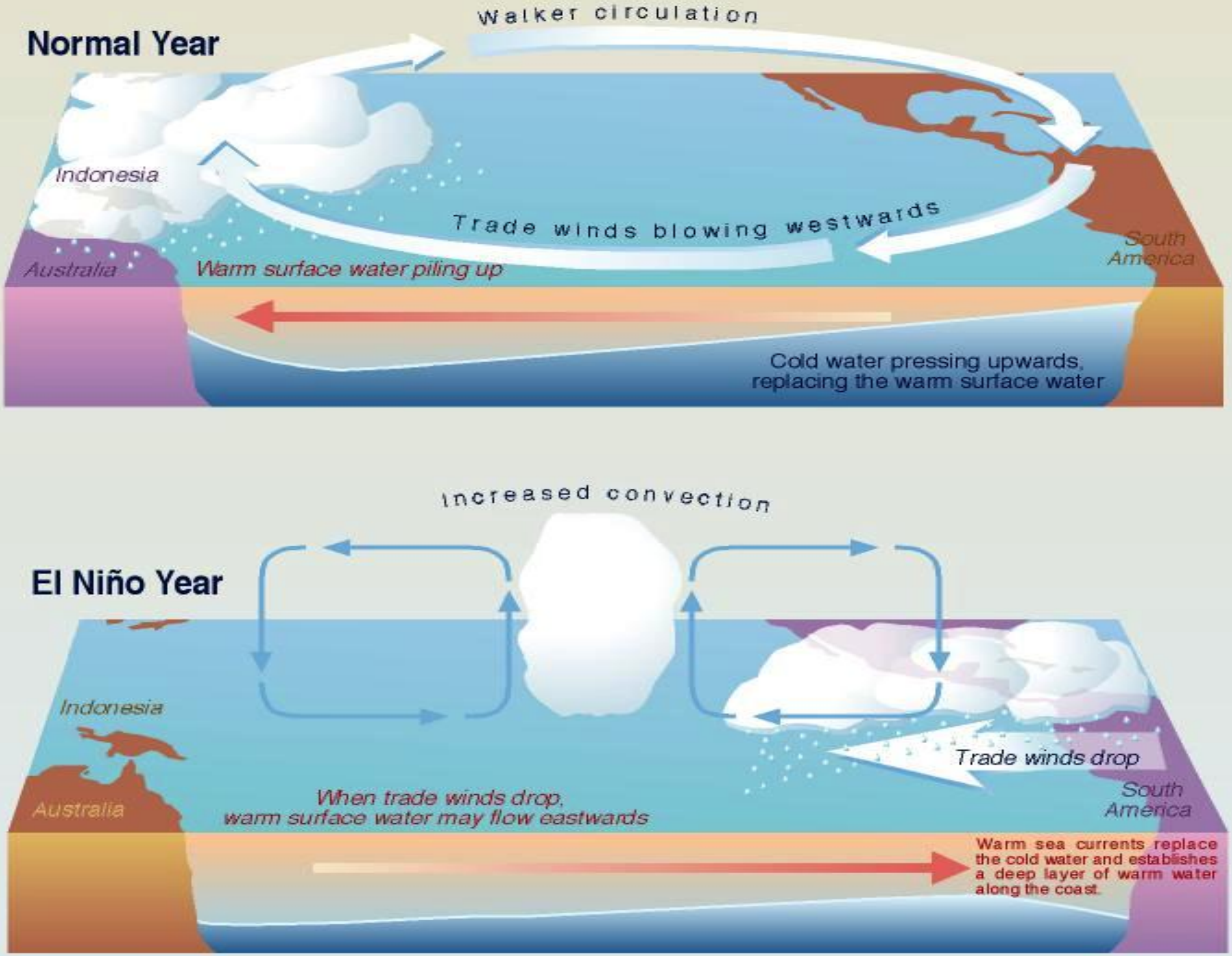
Monsoons, AR5

- There is growing evidence of improved skill of climate models in reproducing climatological features of the global monsoon. Taken together with identified model agreement on future changes, the global monsoon, aggregated over all monsoon systems, is *likely* to strengthen in the 21st century with increases in its area and intensity, while the monsoon circulation weakens. Monsoon onset dates are *likely* to become earlier or not to change much and monsoon retreat dates are *likely* to delay, resulting in lengthening of the monsoon season in many regions.

- Future increase in precipitation extremes related to the monsoon is very likely in South America, Africa, East Asia, South Asia, Southeast Asia and Australia. Lesser model agreement results in medium confidence that monsoon-related interannual precipitation variability will increase in the future.

- Model skill in representing regional monsoons is lower compared to the global monsoon and varies across different monsoon systems.

El Niño Phenomenon (ENSO)



UNEP GRID Arendal

DELPHINE DIGOUT
JUNE 2002

El Niño episodes

- -- ***increase rainfall*** across the tropical east-central and eastern Pacific and ***drier*** than normal for northern Australia, Indonesia and the Philippines. Elsewhere, ***wetter than normal*** conditions 1) during DJF along coastal Ecuador, northwestern Peru, southern Brazil, central Argentina, and equatorial eastern Africa & 2) during JJA in the intermountain regions of the US and over central Chile. ***Drier*** than normal conditions generally observed over northern South America, Central America and southern Africa during DJF, and over eastern Australia during JJA.

- -- large-scale ***temperature departures*** globally with ***abnormally warm*** DJF and 1) ***warmer than normal*** DJF across southeastern Asia, southeastern Africa, Japan, southern Alaska and western/central Canada, southeastern Brazil and southeastern Australia; 2) ***warmer than normal*** JJA along the west coast of South America and across southeastern Brazil; and 3) ***cooler than normal*** DJF along the Gulf coast of the United States.

Tropical Phenomena, AR5

- The tropical Indian Ocean is *likely* to feature a zonal (east–west) pattern of change in the future with reduced warming and decreased precipitation in the east, and increased warming and increased precipitation in the west, directly influencing East Africa and Southeast Asia precipitation.

- The realism of the representation of El Niño-Southern Oscillation (ENSO) in climate models is increasing and models simulate ongoing ENSO variability in the future. Therefore there is *high confidence* that ENSO *very likely* remains as the dominant mode of interannual variability in the future and due to increased moisture availability, the associated precipitation variability on regional scales *likely* intensifies.

- Natural modulations of the variance and spatial pattern of ENSO are so large in models that confidence in any specific projected change in its variability in the 21st century remains low.

We know with certainty, AR5

- **Observed Changes and their Causes:**

1. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen*.*

1. Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years**.** Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are *extremely likely* to have been the dominant cause of the observed warming since the mid-20th century.

1. In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate.

We know with certainty, AR5/2

- **Observed Changes and their Causes:**

5. Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions.

5. The character and severity of impacts from climate change and extreme events emerge from risk that depends not only on climate-related hazards but also on exposure (people and assets at risk) and vulnerability (susceptibility to harm) of human and natural systems.

5. Adaptation and mitigation experience is accumulating across regions and scales, even while global anthropogenic greenhouse gas emissions have continued to increase.

Climate Change Science: Take away concepts:

- **Humans influences on the climate system are clear.**
  - Human-caused emissions of greenhouse gases, especially CO_2 are the highest in history.
  - The result is a changing climate that impacts both natural and human systems.
- ***Earth System Models* present increasingly accurate simulation of current condition and future potential.**
  - Improving projections of climate features (Monsoons, ENSO) and Regional climates.
  - Changed regional climates impact water resources, ecosystems, agriculture, and human settlements among others.
- **Mountain climates are complex so projection of changes are more uncertain.**

Questions

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Regional results of IPCC climate modeling

- Regional climate change driven by larger scale processes may be simulated by ESM:
  - El Nino & La Nino cycles;
  - Monsoon patterns.
- Regional climate change driven by smaller scale processes is not well simulated:
  - Cloud processes;
  - Topographic patterns improve with resolution;
  - Land use driven patterns.

Patterns (Modes) of Climate Variability

- Analysis of atmospheric and climatic variability has shown that a significant component of it can be described in terms of fluctuations in the amplitude and sign of indices of a relatively small number of preferred patterns of variability.
- Some of the best known of these are:
  - El Niño-Southern Oscillation (ENSO), a coupled fluctuation in the atmosphere and the equatorial Pacific Ocean, with preferred time scales of two to about seven years. ENSO is often measured by the difference in surface pressure anomalies between Tahiti and Darwin and the SSTs in the central and eastern equatorial Pacific. ENSO has global teleconnections. Suggestion of recent increases.
  - North Atlantic Oscillation (NAO), a measure of the strength of the Icelandic Low and the Azores High, and of the westerly winds between them, mainly in winter. The NAO has associated fluctuations in the storm track, temperature and precipitation from the North Atlantic into Eurasia.
  - Northern Annular Mode (NAM), a winter fluctuation in the amplitude of a pattern characterised by low surface pressure in the Arctic and strong mid-latitude westerlies. The NAM has links with the northern polar vortex and hence the stratosphere

Patterns (Modes) of Climate Variability

- Southern Annular Mode (SAM), the fluctuation of a pattern with low antarctic surface pressure and strong mid-latitude westerlies, analogous to the NAM, but present year round.
- Pacific-North American (PNA) pattern, an atmospheric large-scale wave pattern featuring a sequence of tropospheric high- and low-pressure anomalies stretching from the subtropical west Pacific to the east coast of North America.
- Pacific Decadal Oscillation (PDO), a measure of the SSTs in the North Pacific that has a very strong correlation with the North Pacific Index (NPI) measure of the depth of the Aleutian Low. However, it has a signature throughout much of the Pacific.
- Monsoon

Atlantic Meridional Overturning Circulation (MOC

A feature common to all climate model projections is the increase in high-latitude temperature as well as an increase in high-latitude precipitation. This was reported in the TAR and is confirmed by the projections using the latest versions of comprehensive climate models. Both of these effects tend to make the high-latitude surface waters less dense and hence increase their stability, thereby inhibiting convective processes. As more coupled models have become available since the TAR, the evolution of the Atlantic Meridional Overturning Circulation (MOC) can be more thoroughly assessed. The MOC is influenced by the density structure of the Atlantic Ocean, small-scale mixing and the surface momentum and buoyancy fluxes. Some models simulate a MOC strength that is inconsistent with the range of present-day estimates. The MOC for these models is shown for completeness but is not used in assessing potential future changes in the MOC in response to various emissions scenarios.

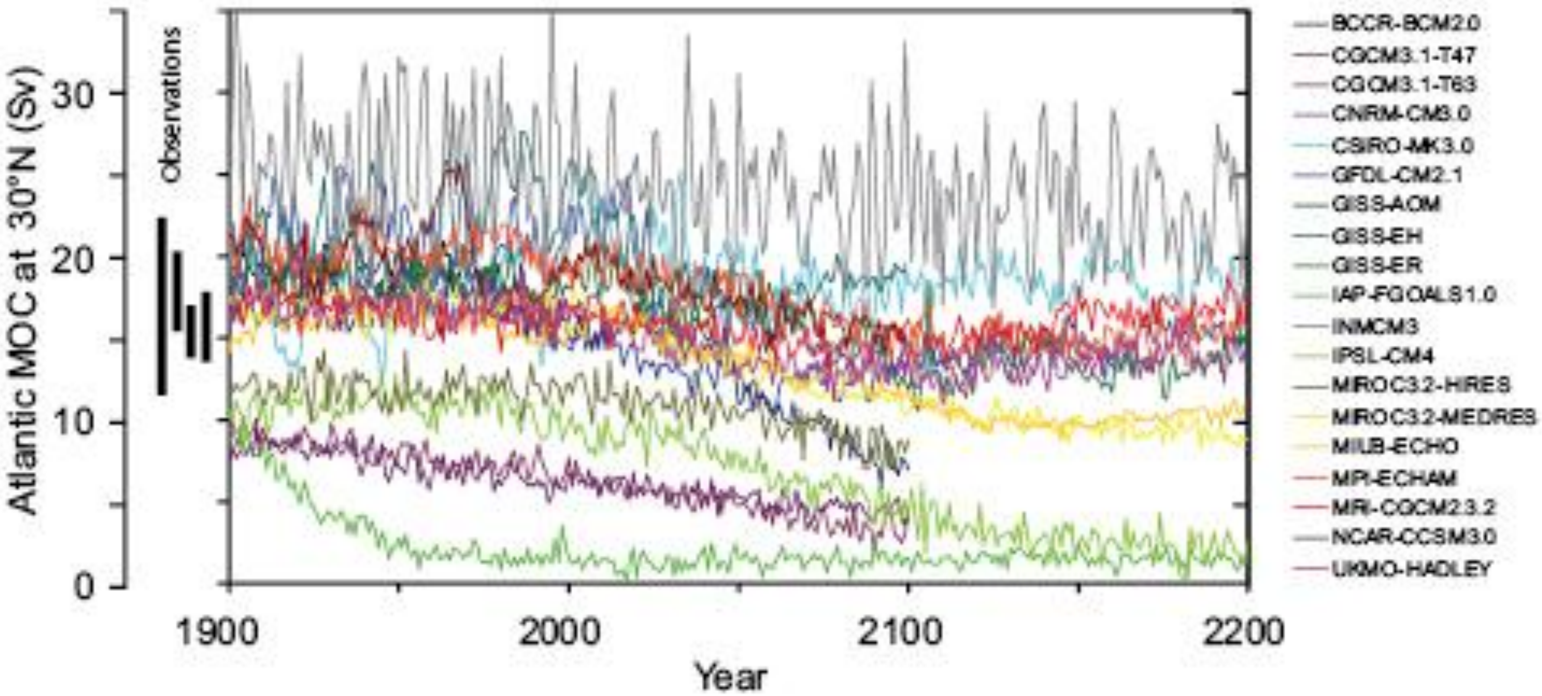
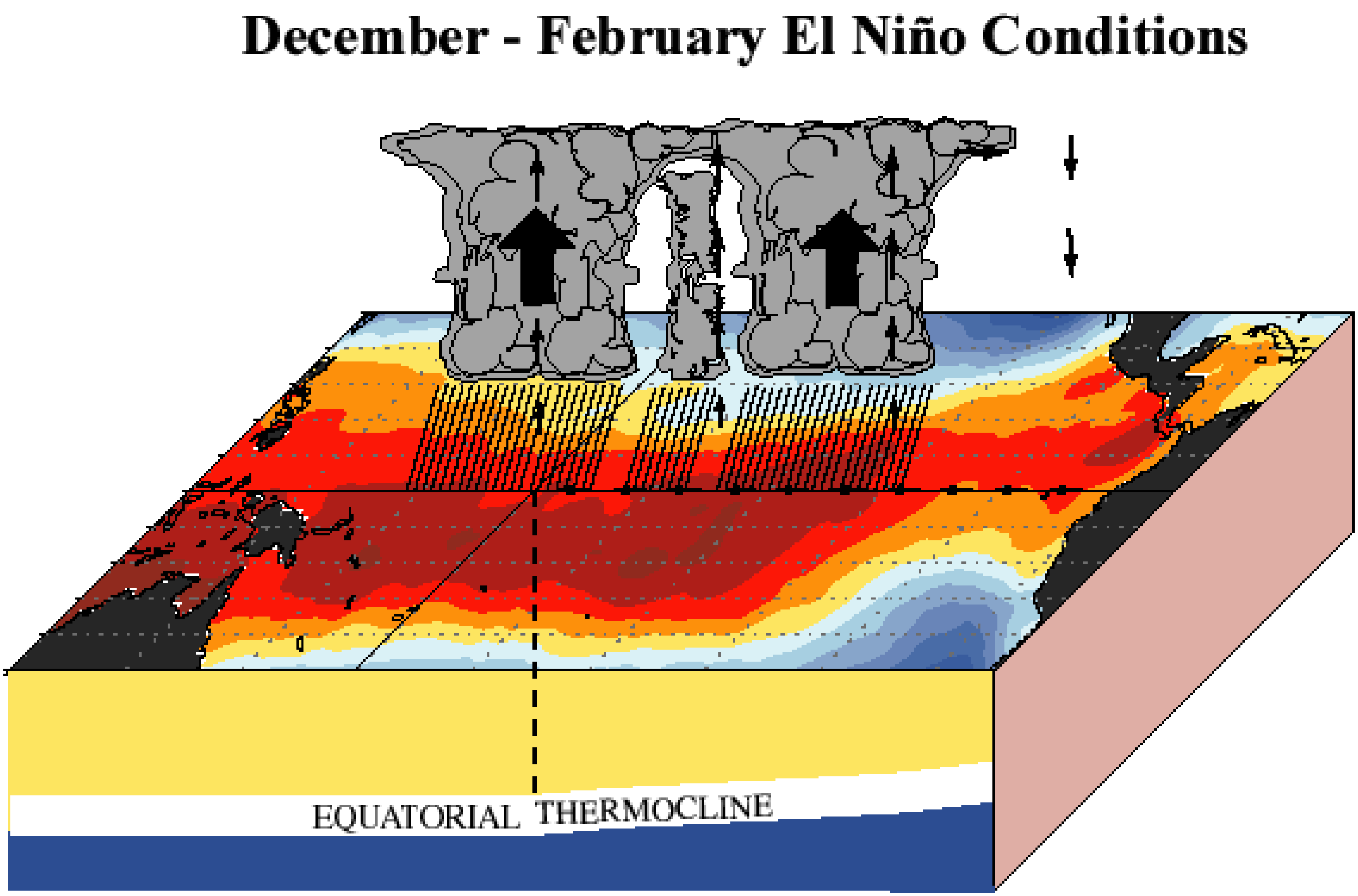


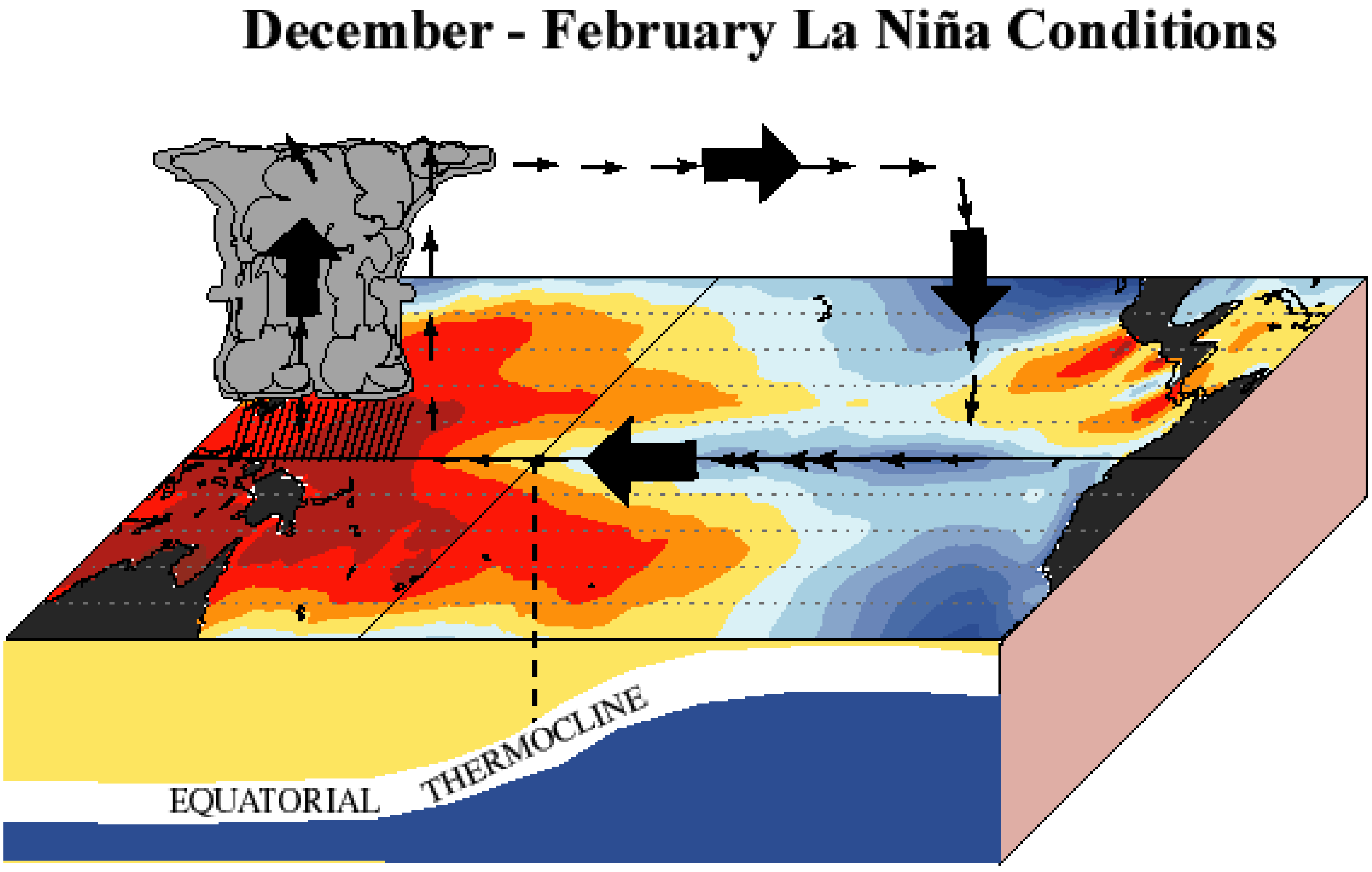
Figure 10.15. Evolution of the Atlantic meridional overturning circulation (MOC) at 30° N in simulations with the suite of comprehensive coupled climate models (see Table 8.1 for model details) from 1850 to 2100 using 20th Century Climate in Coupled Models (20C3M) simulations for 1850 to 1999 and the SRES A1B emissions scenario for 1999 to 2100. Some of the models continue the integration to year 2200 with the forcing held constant at the values of year 2100. Observationally based estimates of late-20th century MOC are shown as vertical bars on the left. Three simulations show a steady or rapid slow down of the MOC that is unrelated to the forcing; a few others have late-20th century simulated values that are inconsistent with observational estimates. Of the model simulations consistent with the late-20th century observational estimates, no simulation shows an increase in the MOC during the 21st century; reductions range from indistinguishable within the simulated natural variability to over 50% relative to the 1960 to 1990 mean; and none of the models projects an abrupt transition to an off state of the MOC. Adapted from Schmittner et al. (2005) with additions.

El Nino



In the tropics, there has been an overall improvement in the AOGCM simulation of the spatial pattern and frequency of ENSO, but problems remain in simulating its seasonal phase locking and the asymmetry between El Niño and La Niña episodes

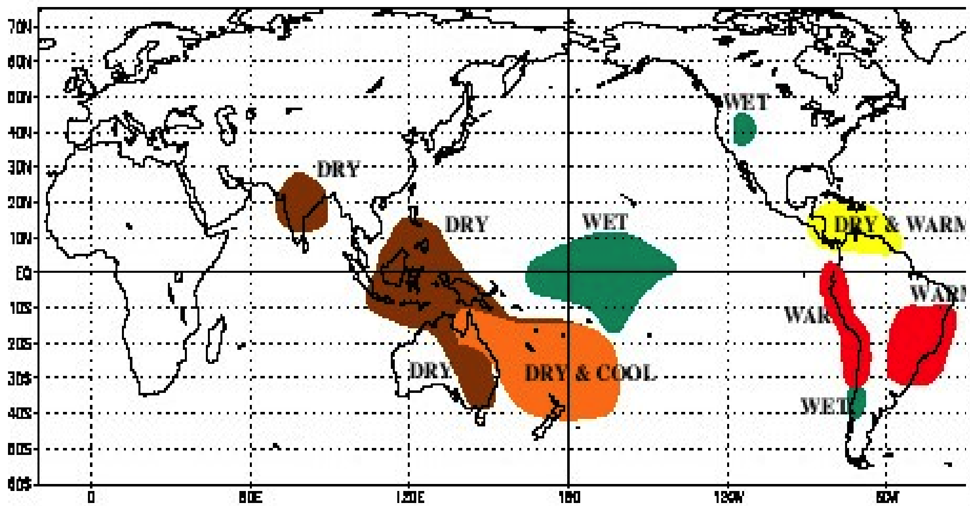
La nina


December - February La Niña Conditions
EQUATORIAL
THERMOCLINE

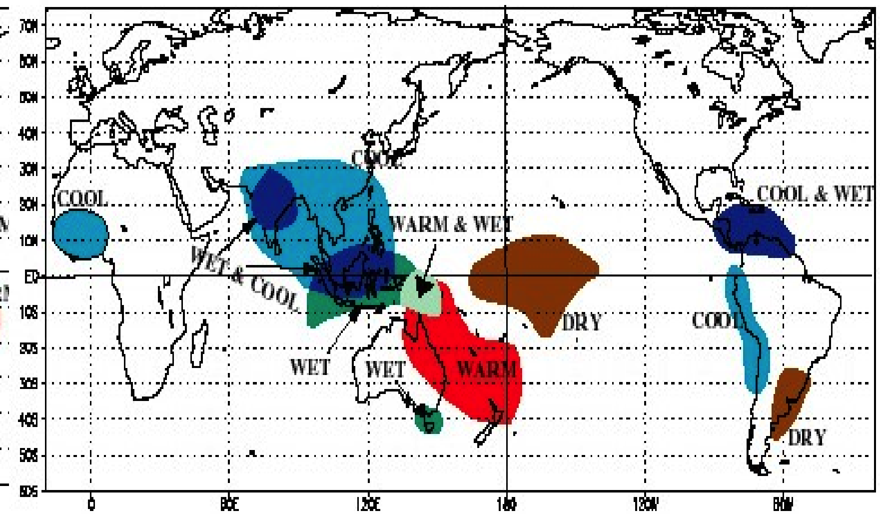
El Nino

La Nino

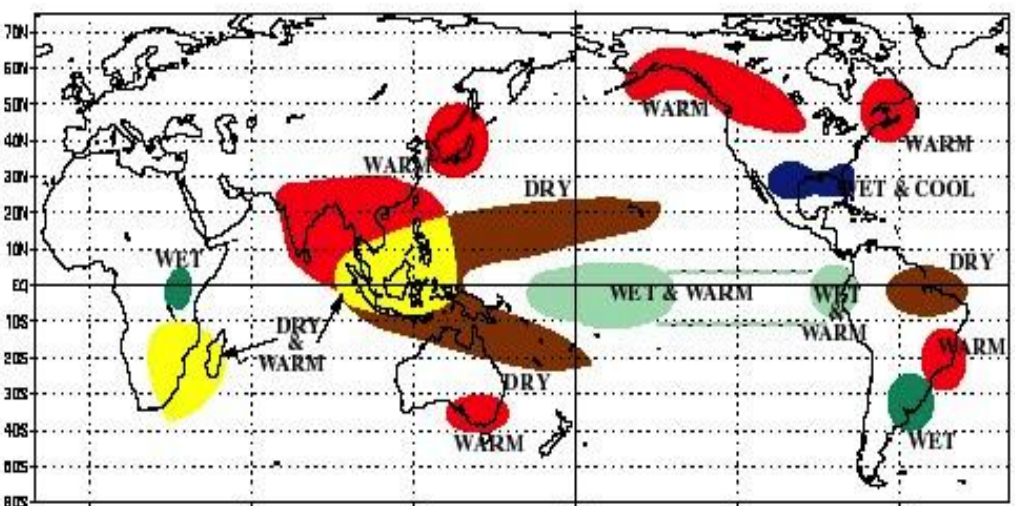
WARM EPISODE RELATIONSHIPS JUNE - AUGUST



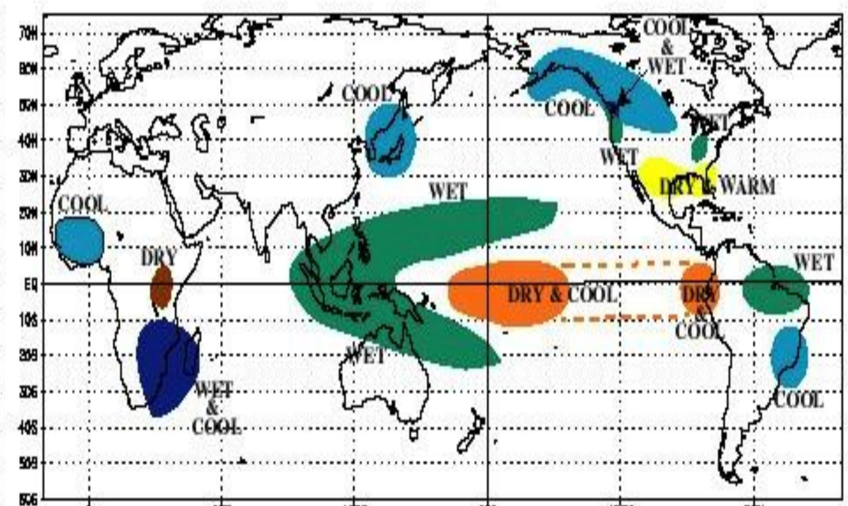
COLD EPISODE RELATIONSHIPS JUNE - AUGUST

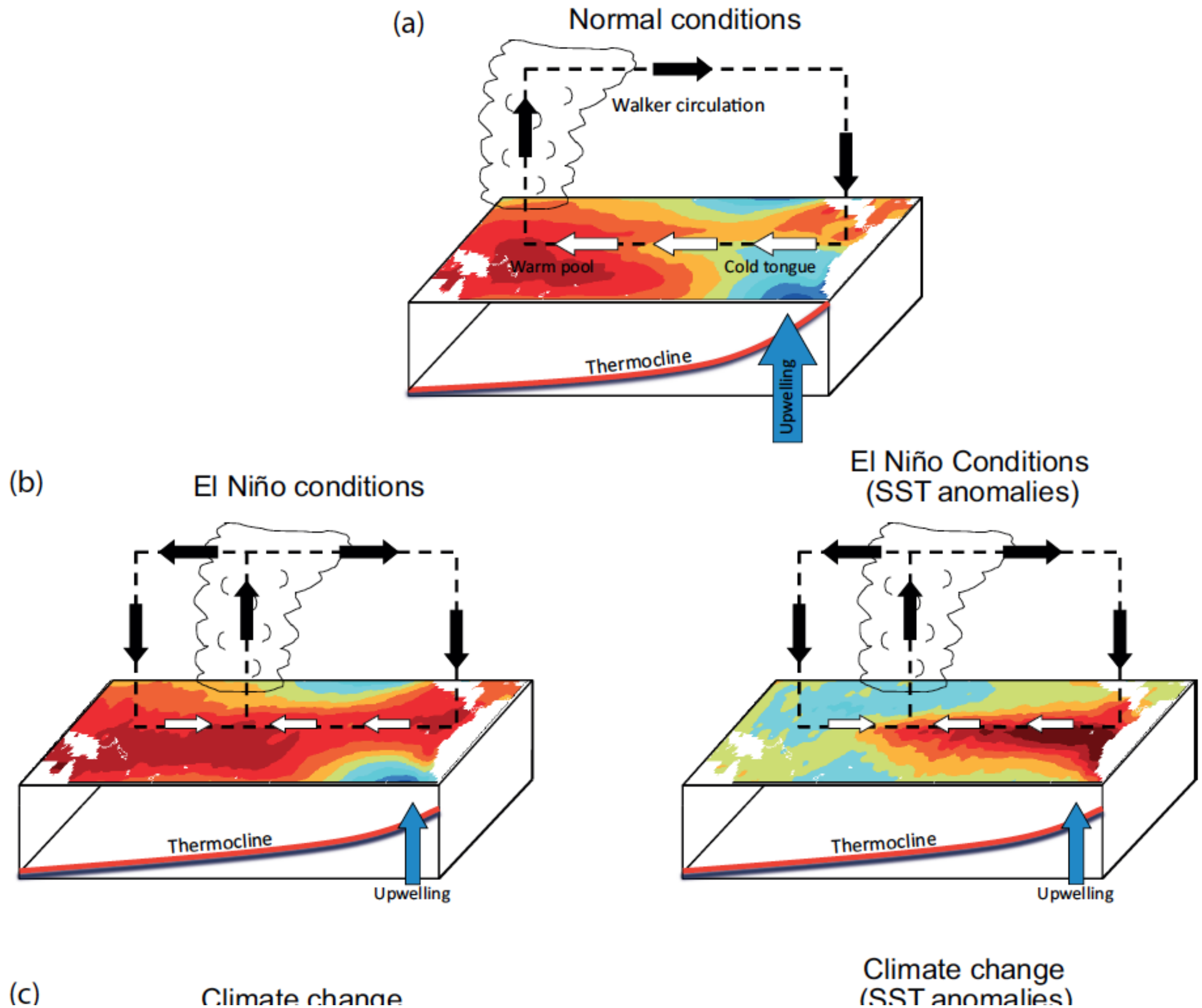


WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY




(a)
Normal conditions
Walker circulation
Warm pool
Cold tongue
Thermocline
Upwelling
(b)
El Niño conditions
Thermocline
Upwelling
El Niño Conditions
(SST anomalies)
Thermocline
Upwelling
(c)
Climate change
Climate change
(SST anomalies)

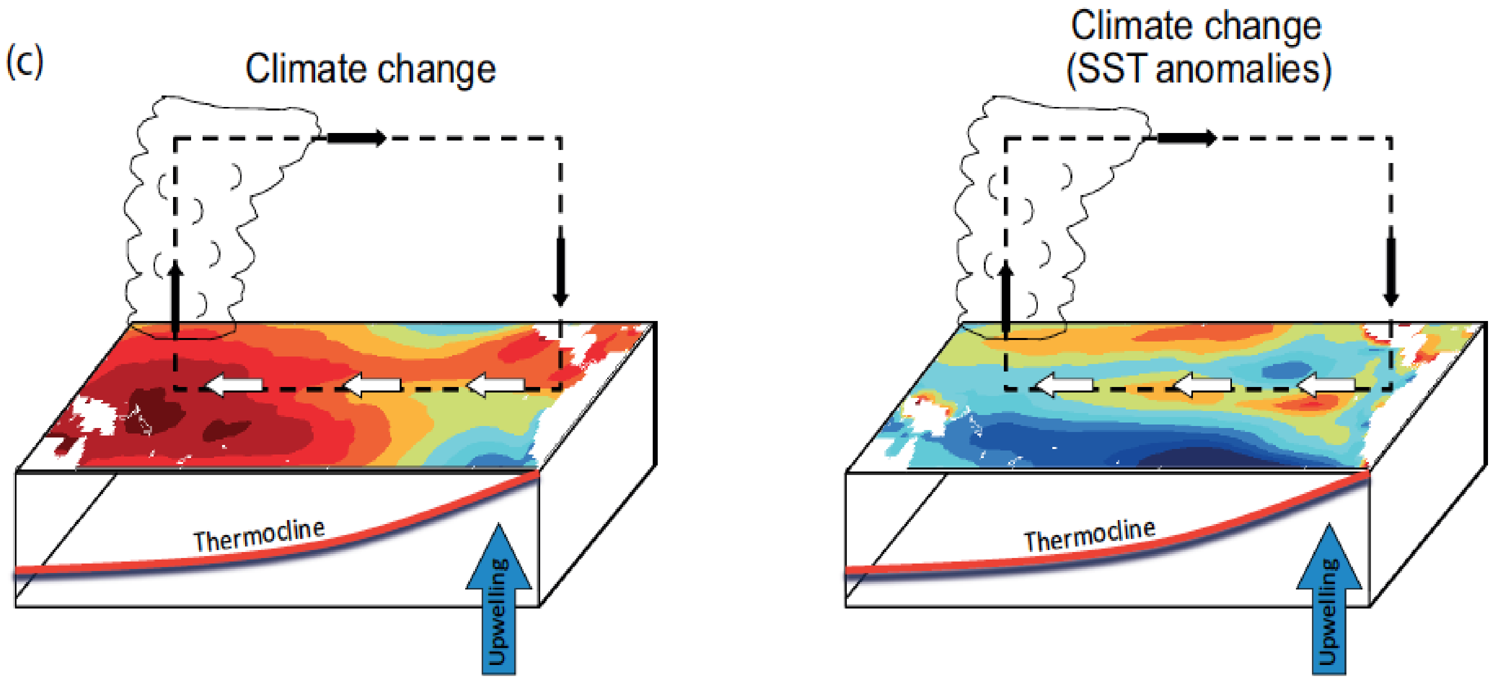


Figure 14.12 | Idealized schematic showing atmospheric and oceanic conditions of the tropical Pacific region and their interactions during normal conditions, El Niño conditions, and in a warmer world. (a) Mean climate conditions in the tropical Pacific, indicating sea surface temperatures (SSTs), surface wind stress and associated Walker Circulation, the mean position of convection and the mean upwelling and position of the thermocline. (b) Typical conditions during an El Niño event. SSTs are anomalously warm in the east; convection moves into the central Pacific; the trade winds weaken in the east and the Walker Circulation is disrupted; the thermocline flattens and the upwelling is reduced. (c) The likely mean conditions under climate change derived from observations, theory and coupled General Circulation Models (GCMs). The trade winds weaken; the thermocline flattens and shoals; the upwelling is reduced although the mean vertical temperature gradient is increased; and SSTs (shown as anomalies with respect to the mean tropical-wide warming) increase more on the equator than off. Diagrams with absolute SST fields are shown on the left, diagrams with SST anomalies are shown on the right. For the climate change fields, anomalies are expressed with respect to the basin average temperature change so that blue colours indicate a warming smaller than the basin mean, not a cooling (Collins et al., 2010).

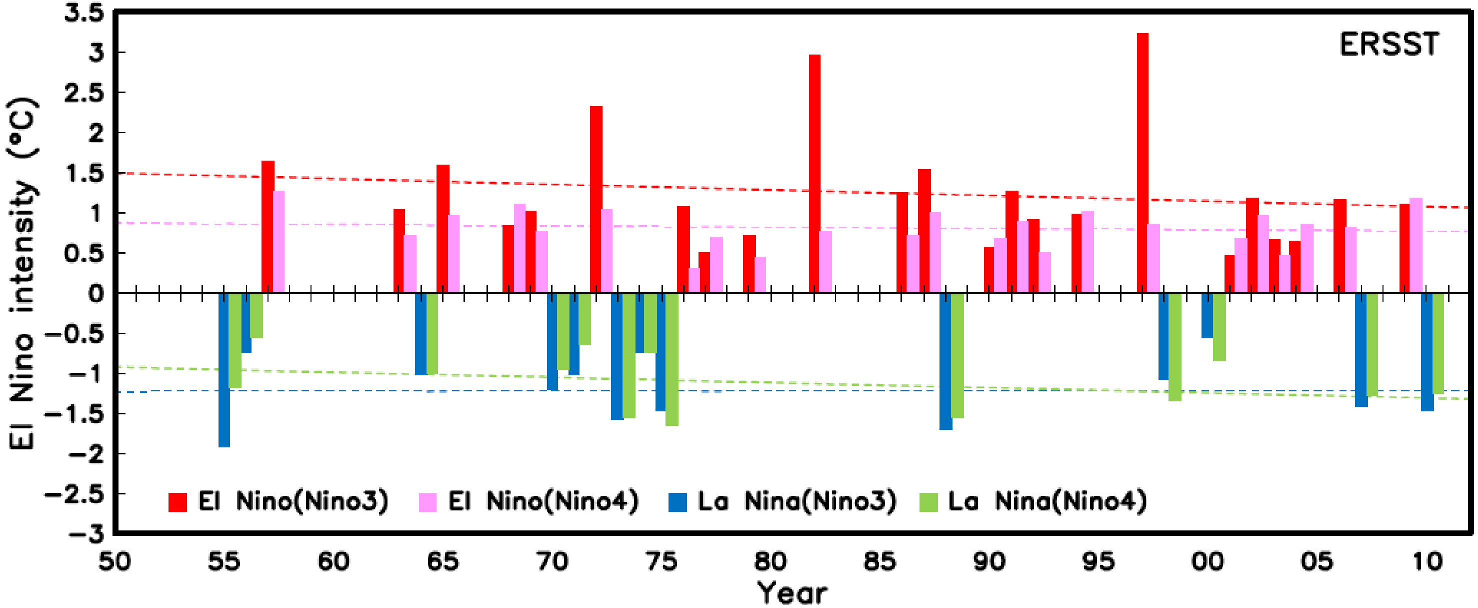


Figure 14.13 | Intensities of El Niño and La Niña events for the last 60 years in the eastern equatorial Pacific (Niño3 region) and in the central equatorial Pacific (Niño4 region), and the estimated linear trends, obtained from Extended Reconstructed Sea Surface Temperature v3 (ERSSTv3).

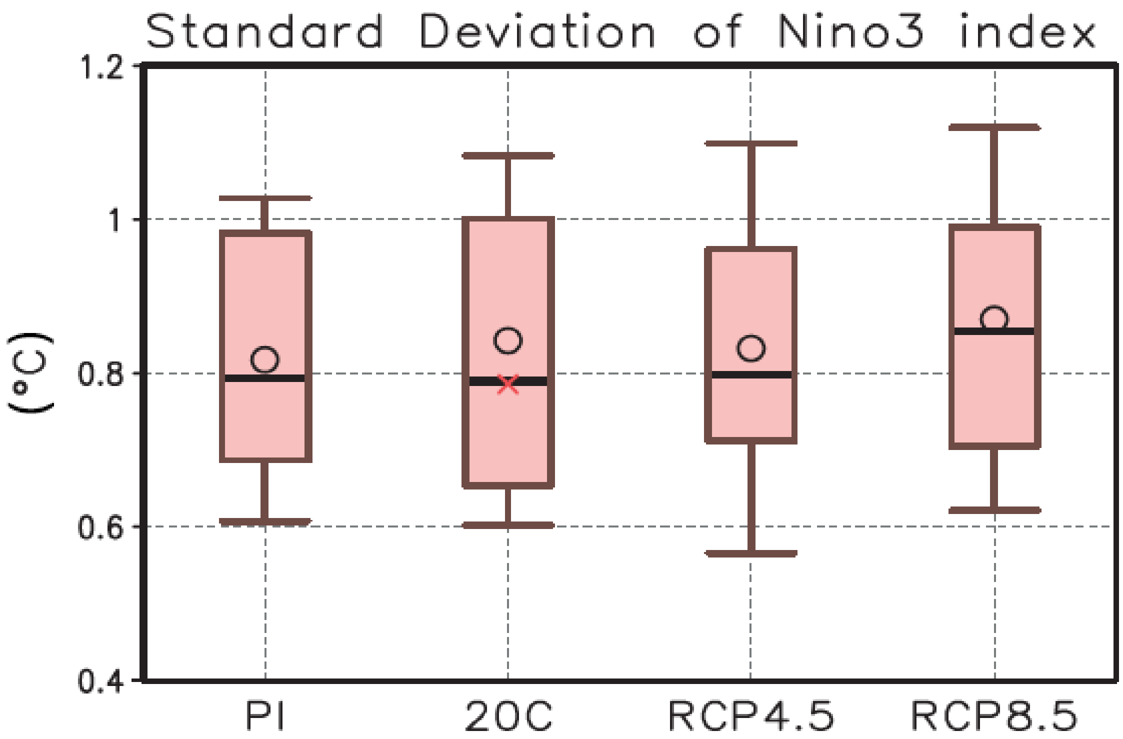
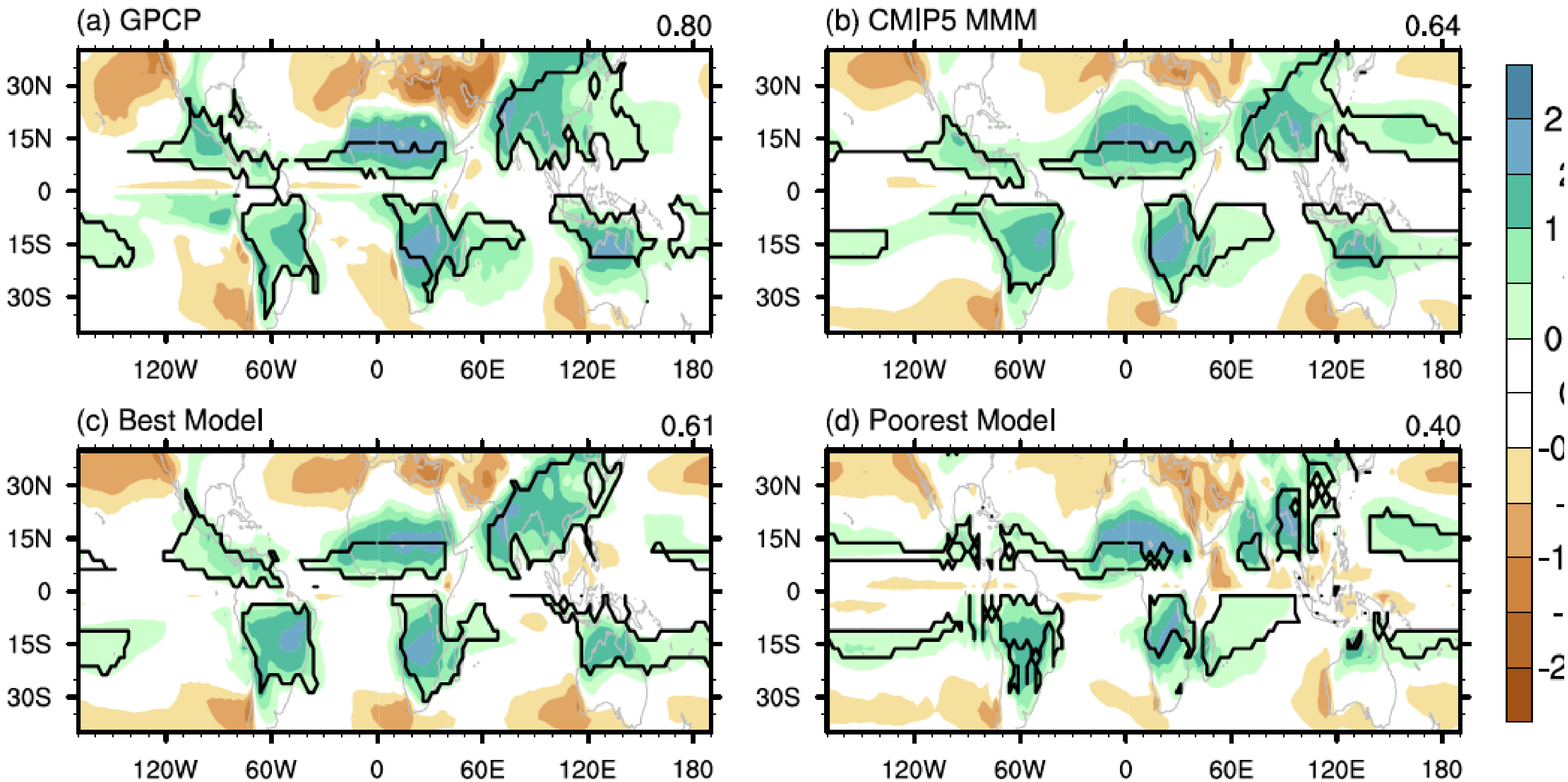
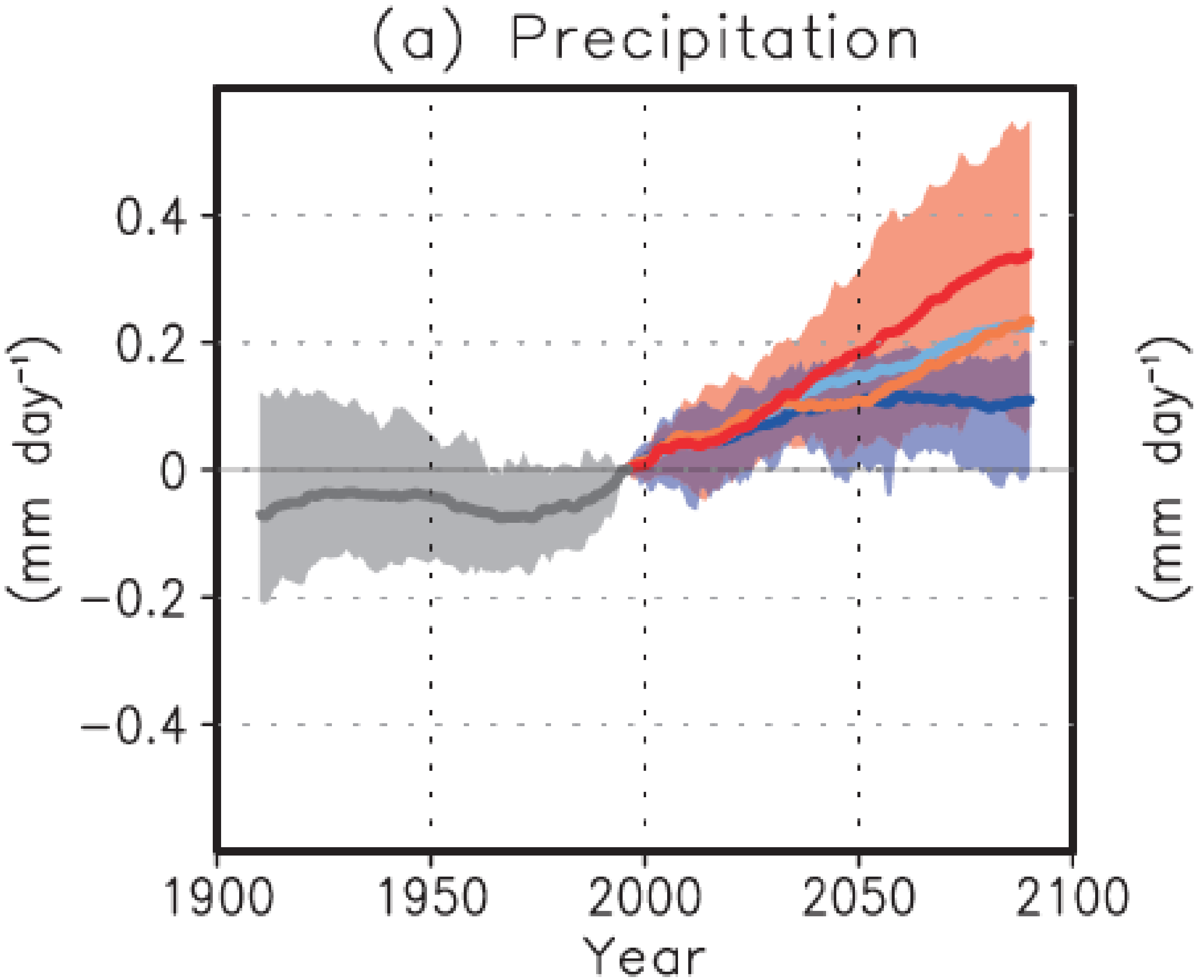


Figure 14.14 | Standard deviation in CMIP5 multi-model ensembles of sea surface temperature variability over the eastern equatorial Pacific Ocean (Nino3 region: 5°S-5°N, 150°W-90°W), a measure of El Nino amplitude, for the pre-industrial (PI) control and 20th century (20C) simulations, and 21st century projections using RCP4.5 and RCP8.5. Thirty-one models are used for the ensemble average. Open circles indicate multi-model ensemble means, and the red cross symbol is the observed standard deviation for January 1870 – December 2011 obtained from HadISSTv1. The linear trend and climatological mean of seasonal cycle have been removed. Box-whisker plots show the 16th, 25th, 50th, 75th, and 84th percentiles.



e 9.32 | Monsoon precipitation intensity (shading, dimensionless) and monsoon precipitation domain (lines) are shown for (a) observation-based estimates from
ion Climatology Project (GPCP), (b) the CMIP5 multi-model mean, (c) the best model and (d) the worst model in terms of the threat score for this diagnostic. These
sed on the seasonal range of precipitation using hemispheric summer (May through September in the Northern Hemisphere (NH)) minus winter (November throug
ł) values. The monsoon precipitation domain is defined where the annual range is >2.5 mm day^{-1}, and the monsoon precipitation intensity is the seasonal range
nual mean. The threat scores (Wilks, 1995) indicate how well the models represent the monsoon precipitation domain compared to the GPCP data. The threat sco
etween GPCP and CMAP rainfall to indicate observational uncertainty, whereas in the other panel it is between the simulations and the GPCP observational data s
of 1.0 would indicate perfect agreement between the two data sets. See Wang and Ding (2008), Wang et al. (2011a), and Kim et al. (2011) for details of the calcu



Simulated 20-year running mean over the global land monsoon domain for precipitation (mm day–1), relative to the present-day (1986–2005), based on CMIP5 multi-model monthly outputs. Historical (grey; 29 models), RCP2.6 (dark blue; 20 models), RCP4.5 (light blue; 24 models), RCP6.0 (orange; 16 models), and RCP8.5 (red; 24 models) simulations are shown in the 10th and 90th percentile (shading), and in all

Global Projections: Robust findings

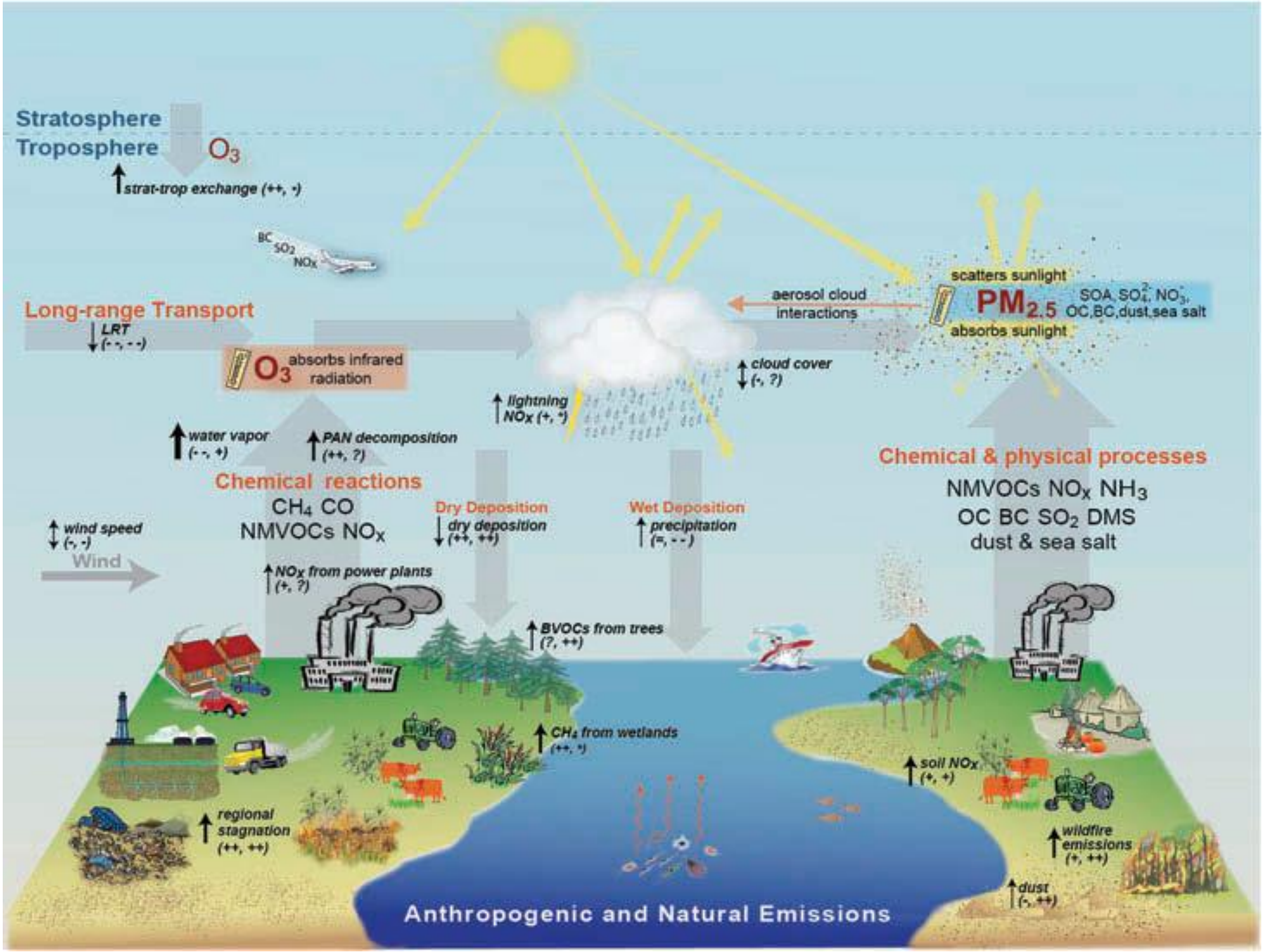
- As the climate warms, snow cover and sea ice extent decrease; glaciers and ice caps lose mass and contribute to sea level rise. Sea ice extent decreases in the 21st century in both the Arctic and Antarctic. Snow cover reduction is accelerated in the Arctic by positive feedbacks and widespread increases in thaw depth occur over much of the permafrost regions.
- Based on current simulations, it is very likely that the Atlantic Ocean MOC will slow down by 2100. However, it is very unlikely that the MOC will undergo a large abrupt transition during the course of the 21st century.
- Heat waves become more frequent and longer lasting in a future warmer climate. Decreases in frost days are projected to occur almost everywhere in the mid- and high latitudes, with an increase in growing season length. There is a tendency for summer drying of the mid-continental areas during summer, indicating a greater risk of droughts in those regions.
- Future warming would tend to reduce the capacity of the Earth system (land and ocean) to absorb anthropogenic CO2. As a result, an increasingly large fraction of anthropogenic CO2 would stay in the atmosphere under a warmer climate. This feedback requires reductions in the cumulative emissions consistent with stabilisation at a given atmospheric CO2 level compared to the hypothetical case of no such feedback. The higher the stabilisation scenario, the larger the amount of climate change and the larger the required reductions.

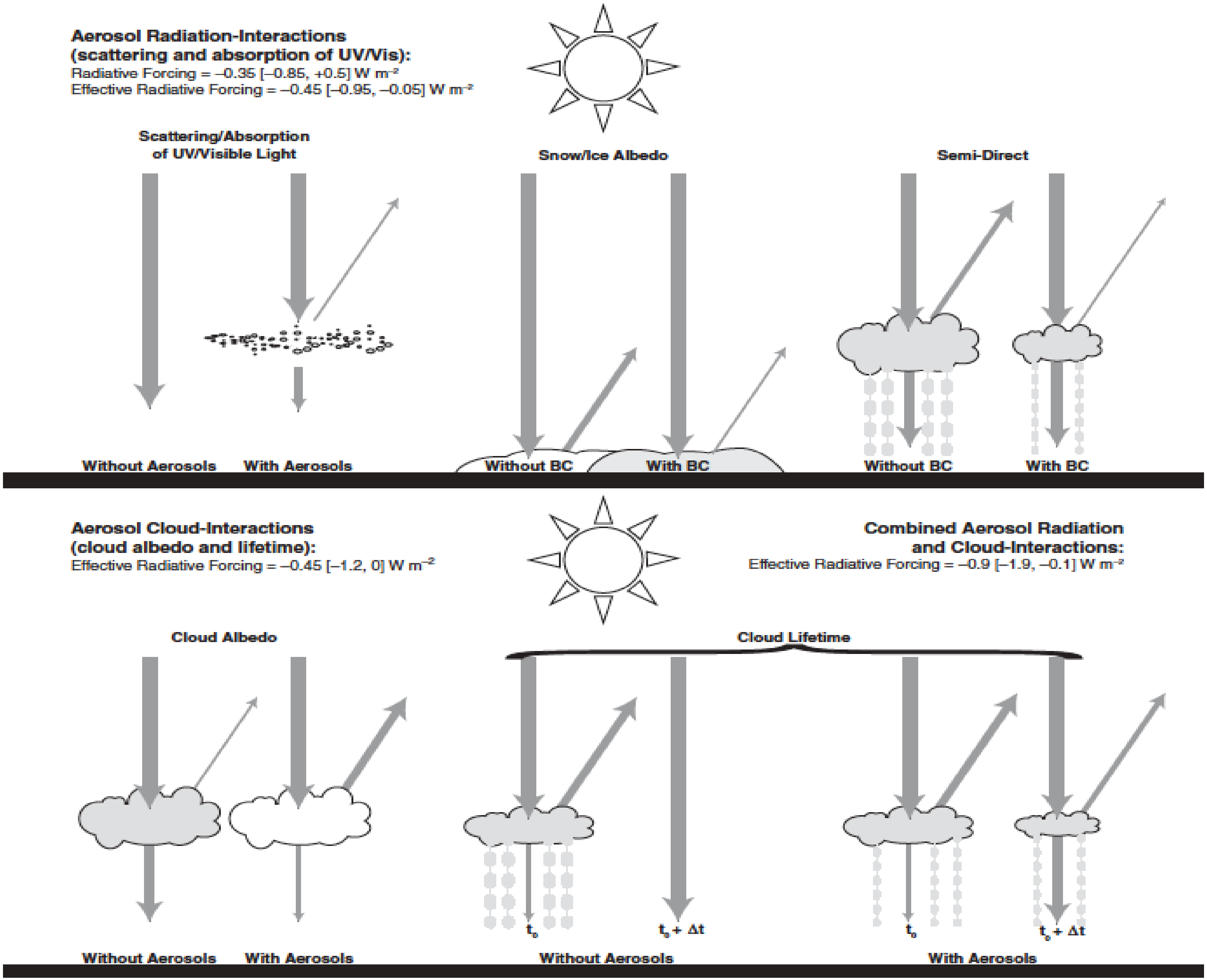
Global Projections: Robust findings

- Even if concentrations of radiative forcing agents were to be stabilised, further committed warming and related climate changes would be expected to occur, largely because of time lags associated with processes in the oceans.
- Near-term warming projections are little affected by different scenario assumptions or different model sensitivities, and are consistent with that observed for the past few decades. The multi-model mean warming, averaged over 2011 to 2030 relative to 1980 to 1999 for all AOGCMs considered here, lies in a narrow range of 0.64°C to 0.69°C for the three different SRES emission scenarios B1, A1B and A2.
- Geographic patterns of projected warming show the greatest temperature increases at high northern latitudes and over land, with less warming over the southern oceans and North Atlantic.
- Changes in precipitation show robust large-scale patterns: precipitation generally increases in the tropical precipitation maxima, decreases in the subtropics and increases at high latitudes as a consequence of a general intensification of the global hydrological cycle.

Global Projections: Key uncertainties

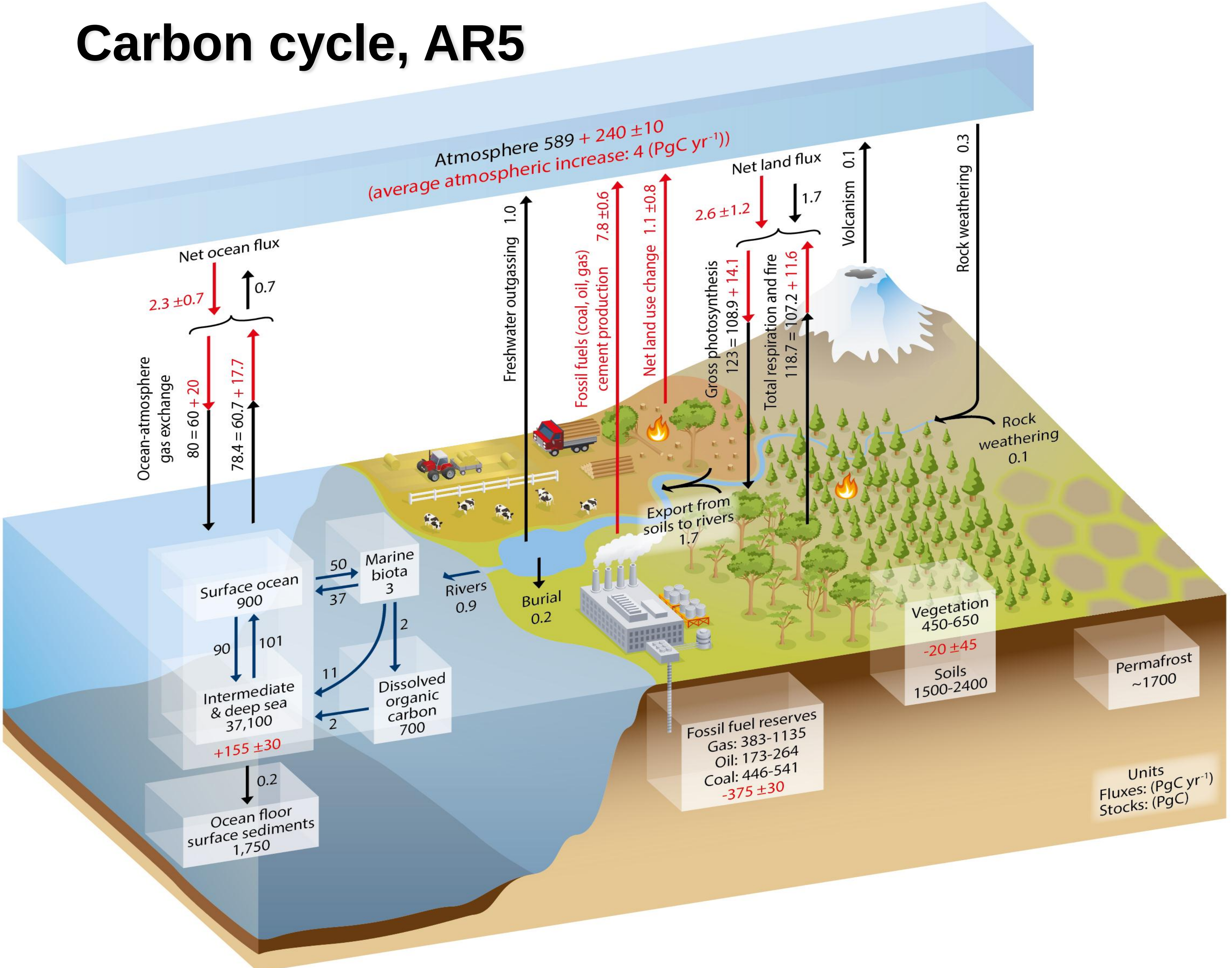
- The likelihood of a large abrupt change in the MOC beyond the end of the 21st century cannot yet be assessed reliably. For low and medium emission scenarios with atmospheric greenhouse gas concentrations stabilised beyond 2100, the MOC recovers from initial weakening within one to several centuries. A permanent reduction in the MOC cannot be excluded if the forcing is strong and long enough.
- The model projections for extremes of precipitation show larger ranges in amplitude and geographical locations than for temperature.
- The response of some major modes of climate variability such as ENSO still differs from model to model, which may be associated with differences in the spatial and temporal representation of present-day conditions.
- The robustness of many model responses of tropical cyclones to climate change is still limited by the resolution of typical climate models.
- Changes in key processes that drive some global and regional climate changes are poorly known (e.g., ENSO, NAO, blocking, MOC, land surface feedbacks, tropical cyclone distribution).
- The magnitude of future carbon cycle feedbacks is still poorly determined.

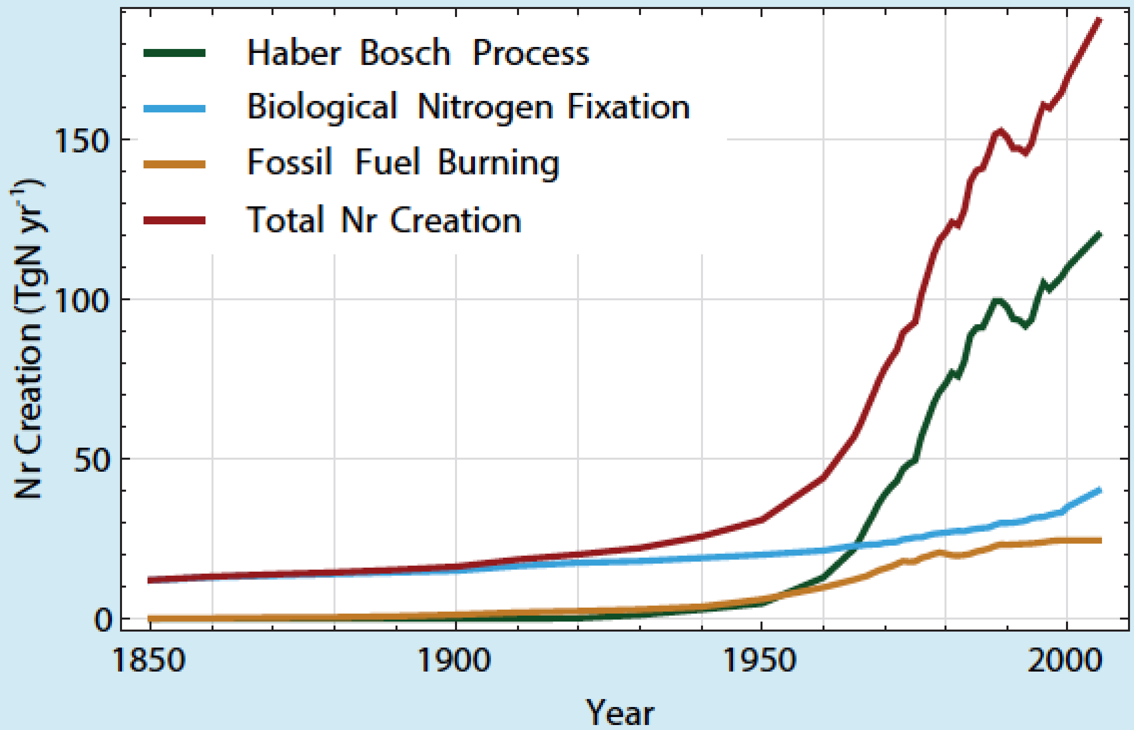

Stratosphere
Troposphere
O3
strat-trop exchange (++, -)
BC
SO2
NOx
Long-range Transport
LRT
(- -, - -)
O3 absorbs infrared radiation
aerosol cloud interactions
scatters sunlight
PM2.5
SOA, SO4 2-, NO3 -, OC,BC,dust,sea salt
absorbs sunlight
cloud cover
(-, ?)
lightning
NOx (+, -)
water vapor
(- -, +)
PAN decomposition
(++, ?)
Chemical reactions
CH4 CO
NMVOCs NOx
Dry Deposition
dry deposition
(++, ++)
Wet Deposition
precipitation
(=, - -)
Chemical & physical processes
NMVOCs NOx NH3
OC BC SO2 DMS
dust & sea salt
wind speed
(-, -)
Wind
NOx from power plants
(+, ?)
BVOCs from trees
(?, ++)
CH4 from wetlands
(++, -)
soil NOx
(+, +)
regional stagnation
(++, ++)
wildfire emissions
(+, ++)
dust
(-, ++)
Anthropogenic and Natural Emissions



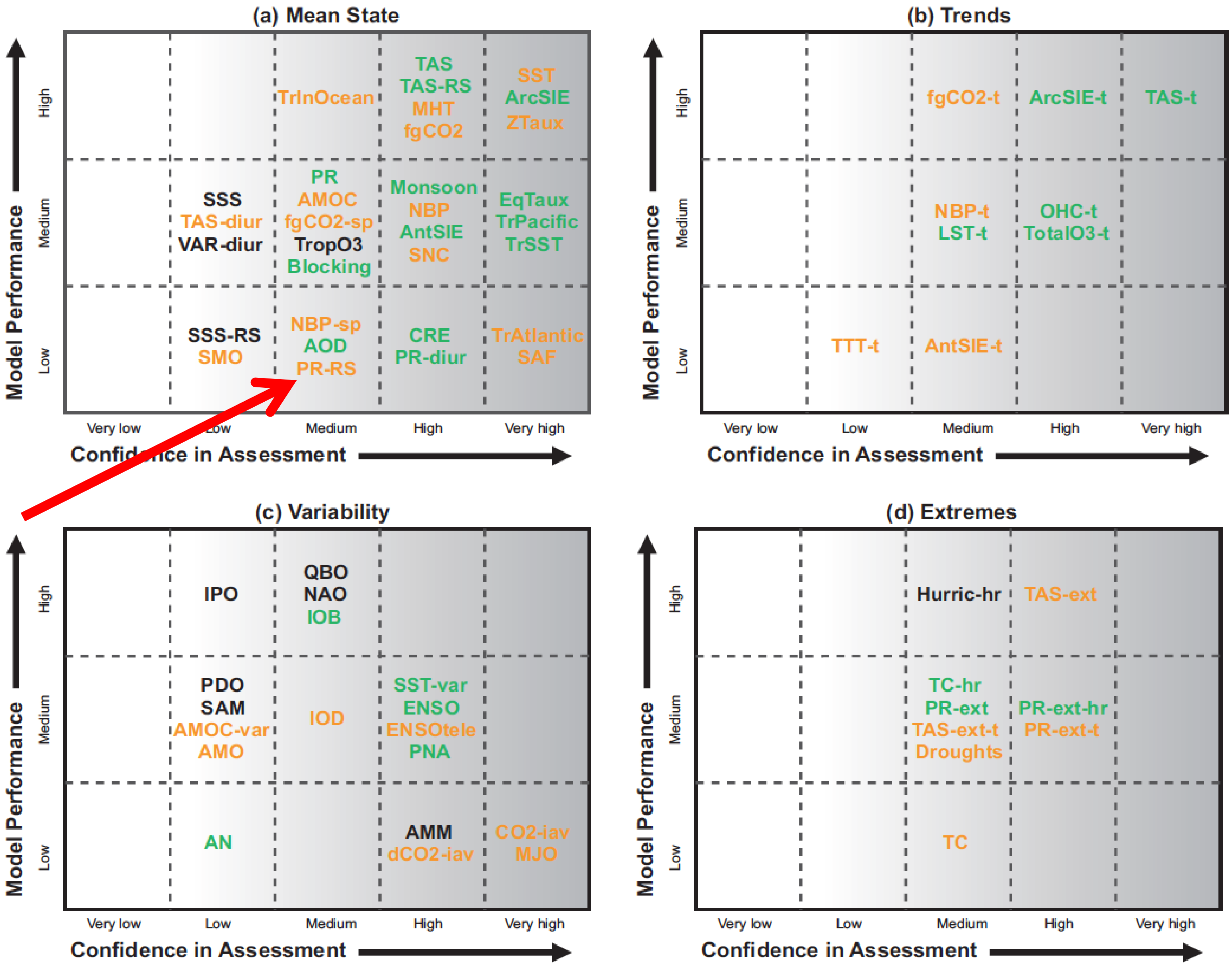
Aerosol Radiation-Interactions
(scattering and absorption of UV/Vis):
Radiative Forcing = –0.35 [–0.85, +0.5] W m⁻²
Effective Radiative Forcing = –0.45 [–0.95, –0.05] W m⁻²
Scattering/Absorption of UV/Visible Light
Snow/Ice Albedo
Semi-Direct
Without Aerosols
With Aerosols
Without BC
With BC
Without BC
With BC
Aerosol Cloud-Interactions
(cloud albedo and lifetime):
Effective Radiative Forcing = –0.45 [–1.2, 0] W m⁻²
Combined Aerosol Radiation and Cloud-Interactions:
Effective Radiative Forcing = –0.9 [–1.9, –0.1] W m⁻²
Cloud Albedo
Cloud Lifetime
t0
t0 + Δt
t0
t0 + Δt
Without Aerosols
With Aerosols
Without Aerosols
With Aerosols

Carbon cycle, AR5





Box 6.2, Figure 1 | Anthropogenic reactive nitrogen (Nr) creation rates (in TgN yr^{-1}) from fossil fuel burning (orange line), cultivation-induced biological nitrogen fixation (blue line), Haber–Bosch process (green line) and total creation (red line). Source: Galloway et al. (2003), Galloway et al. (2008). Note that updates are given in Table 6.9. The only one with significant changes in the more recent literature is cultivation-induced BNF) which Herridge et al. (2008) estimated to be 60 TgN yr^{-1}. The data are only reported since 1850, as no published estimate is available since 1750.



(a) Mean State
(b) Trends
(c) Variability
(d) Extremes
Model Performance
High
Medium
Low
Very low
Low
Medium
High
Very high
Confidence in Assessment
TrInOcean
TAS
TAS-RS
MHT
fgCO2
SST
ArcSIE
ZTaux
SSS
TAS-diur
VAR-diur
PR
AMOC
fgCO2-sp
TropO3
Blocking
Monsoon
NBP
AntSIE
SNC
EqTaux
TrPacific
TrSST
SSS-RS
SMO
NBP-sp
AOD
PR-RS
CRE
PR-diur
TrAtlantic
SAF
fgCO2-t
ArcSIE-t
TAS-t
NBP-t
LST-t
OHC-t
TotalO3-t
TTT-t
AntSIE-t
IPO
QBO
NAO
IOB
PDO
SAM
AMOC-var
AMO
IOD
SST-var
ENSO
ENSOtele
PNA
AN
AMM
dCO2-iav
CO2-iav
MJO
Hurric-hr
TAS-ext
TC-hr
PR-ext
TAS-ext-t
Droughts
PR-ext-hr
PR-ext-t
TC

Degradation since CMIP3
No changes since CMIP3
Improvements since CMIP3
No relative assessment CMIP3 vs. CMIP5

Figure 9.44 | Summary of the findings of Chapter 9 with respect to how well the CMIP5 models simulate important features of the climate of the 20th century. Confidence in the assessment increases towards the right as suggested by the increasing strength of shading. Model performance improves from bottom to top. The colour coding indicates changes since CMIP3 (or models of that generation) to CMIP5. The assessment of model performance is expert judgment based on the agreement with observations of the multi-model mean and distribution of individual models around the mean, taking into account internal climate variability. Note that assessed model performance is simplified for representation in the figure and it is referred to the text for details of each assessment. The figure highlights the following key features, with the sections that back up the assessment added in parentheses:

AntSIE	Seasonal cycle Antarctic sea ice extent (Section 9.4.3)
AOD	Aerosol Optical Depth (Section 9.4.6)
ArctSIE	Seasonal cycle Arctic sea ice extent (Section 9.4.3)
Blocking	Blocking events (Section 9.5.2.2)
CRE	Cloud radiative effects (Section 9.4.1.2)
EqTaux	Equatorial zonal wind stress (Section 9.4.2.4)
fgCO2	Global ocean carbon sink (Section 9.4.5)
fgCO2-sp	Spatial pattern of ocean–atmosphere CO_2 fluxes (Section 9.4.5)
MHT	Meridional heat transport (Section 9.4.2.4)
Monsoon	Global monsoon (Section 9.5.2.4)
NBP	Global land carbon sink (Section 9.4.5)
NBP-sp	Spatial pattern of land–atmosphere CO_2 fluxes (Section 9.4.5)
PR	Large scale precipitation (Sections 9.4.1.1, 9.4.1.3)
PR-diur	Diurnal cycle precipitation (Section 9.5.2.1)
PR-RS	Regional scale precipitation (Section 9.6.1.1)
SAF	Snow albedo feedbacks (Section 9.8.3)
SMO	Soil moisture (Section 9.4.4)
SNC	Snow cover (Section 9.4.4)
SSS	Sea surface salinity (Section 9.4.2.1)
SSS-RS	Regional Sea surface salinity (Section 9.4.2.1)
SST	Sea surface temperature (Section 9.4.2.1)
TAS	Large scale surface air temperature (Sections 9.4.1.1, 9.4.1.3)
TAS-diur	Diurnal cycle surface air temperature (Section 9.5.2.1)
TAS-RS	Regional scale surface air temperature (Section 9.6.1.1)
TrSST	Tropical sea surface temperature (Section 9.4.2.1)
TropO3	Tropospheric column ozone climatology (Section 9.4.1.4.5)
TrAtlantic	Tropical Atlantic mean state (Section 9.4.2.5)
TrInOcean	Tropical Indian Ocean mean state (Section 9.4.2.5)
TrPacific	Tropical Pacific mean state (Section 9.4.2.5)
VAR-diur	Diurnal cycle other variables (Section 9.5.2.1)
ZTaux	Zonal mean zonal wind stress (Section 9.4.2.4)

PANEL b (Trends)

AntSIE-t	Trend in Antarctic sea ice extent (Section 9.4.3)
ArctSIE-t	Trend in Arctic sea ice extent (Section 9.4.3)
fgCO2-t	Global ocean carbon sink trends (Section 9.4.5)
LST-t	Lower stratospheric temperature trends (Section 9.4.1.4.5)
NBP-t	Global land carbon sink trends (Section 9.4.5)
OHC-t	Global ocean heat content trends (Section 9.4.2.2)
TotalO3-t	Total column ozone trends (Section 9.4.1.4.5)
TAS-t	Surface air temperature trends (Section 9.4.1.4.1)

AMOC-var	Atlantic Meridional Overturning Circulation (Section 9.5.3.3)
AN	Atlantic Niño (Section 9.5.3.3)
CO2-iav	Interannual variability of atmospheric CO_2 (Section 9.8.3)
dCO2-iav	Sensitivity of CO_2 growth rate to tropical temperature (Section 9.8.3)
ENSO	El Niño Southern Oscillation (Section 9.5.3.4)
ENSOtele	Tropical ENSO teleconnections (Section 9.5.3.5)
IOB	Indian Ocean basin mode (Section 9.5.3.4)
IOD	Indian Ocean dipole (Section 9.5.3.4)
IPO	Interdecadal Pacific Oscillation (Section 9.5.3.6)
MJO	Madden-Julian Oscillation (Section 9.5.2.3)
NAO	North Atlantic Oscillation and Northern annular mode (Section 9.5.3.2)
PDO	Pacific Decadal Oscillation (Section 9.5.3.6)
PNA	Pacific North American (Section 9.5.3.5)
QBO	Quasi-Biennial Oscillation (Section 9.5.3.7)
SAM	Southern Annular Mode (Section 9.5.3.2)
SST-var	Global sea surface temperature variability (Section 9.5.3.1)

PANEL d (Extremes):

Hurric-hr	Year-to-year counts of Atlantic hurricanes in high-resolution AGCMs (Section 9.5.4.3)
PR-ext	Global distributions of precipitation extremes (Section 9.5.4.2)
PR-ext-hr	Global distribution of precipitation extremes in high-resolution AGCMs (Section 9.5.4.2)
PR-ext-t	Global trends in precipitation extremes (Section 9.5.4.2)
TAS-ext	Global distributions of surface air temperature extremes (Section 9.5.4.1)
TAS-ext-t	Global trends in surface air temperature extremes (Section 9.5.4.1)
TC	Tropical cyclone tracks and intensity (Section 9.5.4.3)
TC-hr	Tropical cyclone tracks and intensity in high-resolution AGCMs (Section 9.5.4.3)
Droughts	Droughts (Section 9.5.4.4)