
NPS Photo by Jeff Henry


SPEED
LIMIT
20


http://www.euronews.com/2014/01/07/polar-blast-grips-the-us-as-bitterly-cold-temperatures-spread-south/

Climate Change:

Fitting the pieces together

Presented by:

Barbara Scarnato

Acknowledge contributions from

Scarrnato, UiO

Myhre, CICERO

Stordal, UiO

Outline

- Observations
- What changes climate?
- How do we know?
- Why should we care?
  - a look on **projected future climate changes**

INTERGOVERNAL PANEL ON CLIMATE CHANGE (IPCC) is a scientific body, which looks on **Interactive processes** in the Earth system that govern climate and climate change.
(http://www.ipcc.ch/)

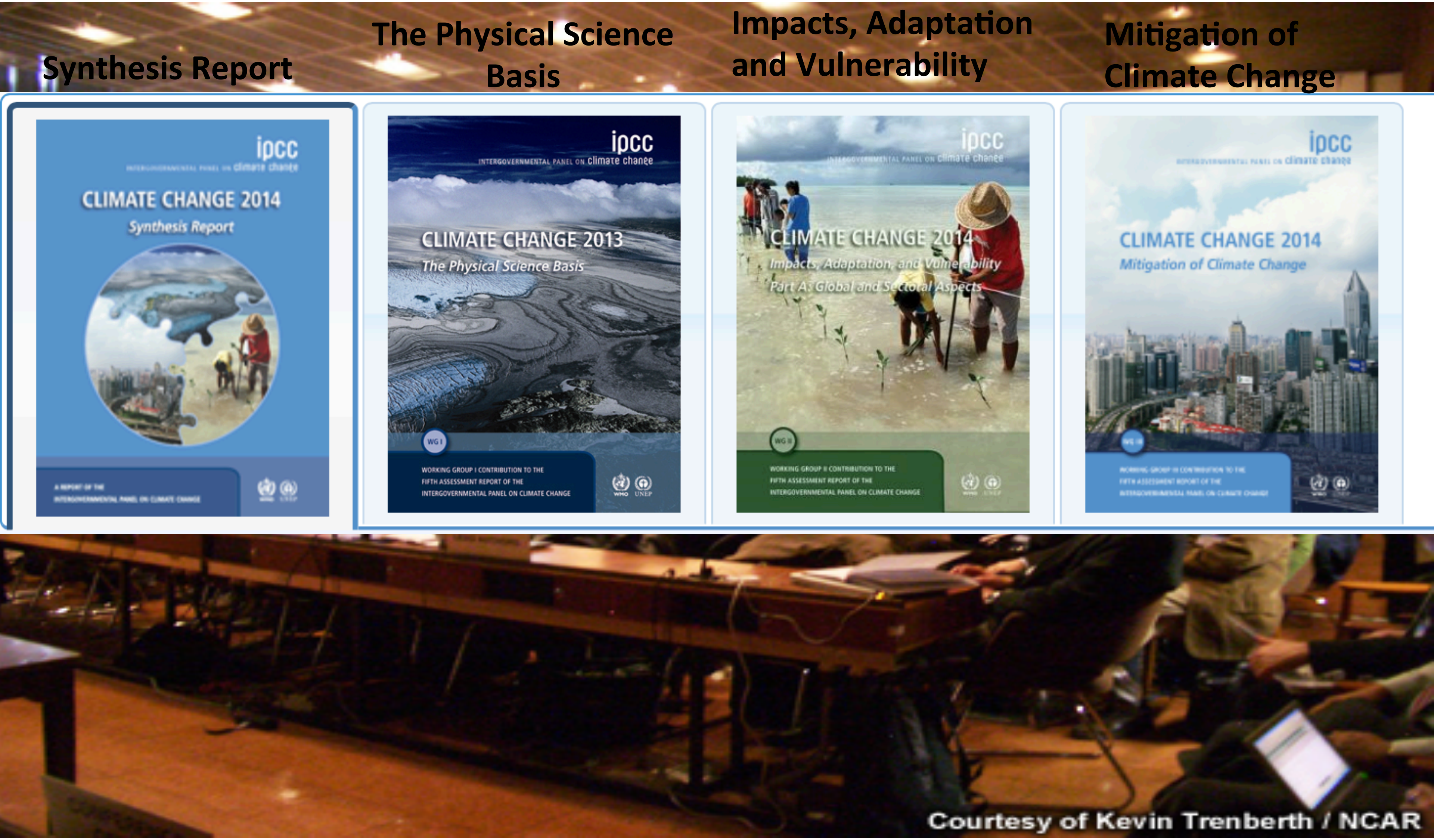
Since the IPCC First Assessment Report in 1990
we have a deeper understanding and quantification
of these processes and their incorporation in climate models.

WHY THE WORLD IS WARMER?

An increasing evidence of anthropogenic influences on climate change has been found.

The IPCC scientific intergovernmental body set up by WMO and UNEP 1988

http://www.ipcc.ch/index.htm



IPCC's Fifth Assessment Report (AR5) provides 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.

  – Evaluate the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)

    - an important basis for information on changing weather and climate extremes.

- **Observations** of the climate system are **based on direct measurements** and **remote sensing** from satellites and other platforms.
    - ***Global-scale observations*** *from the instrumental era began in the* ***mid-19th century for temperature*** *and other variables.*
        - *More comprehensive and diverse sets of observations available for the period 1950 onwards.*
        - ***Paleoclimate reconstructions*** *extend some records* ***back hundreds to millions of years.***

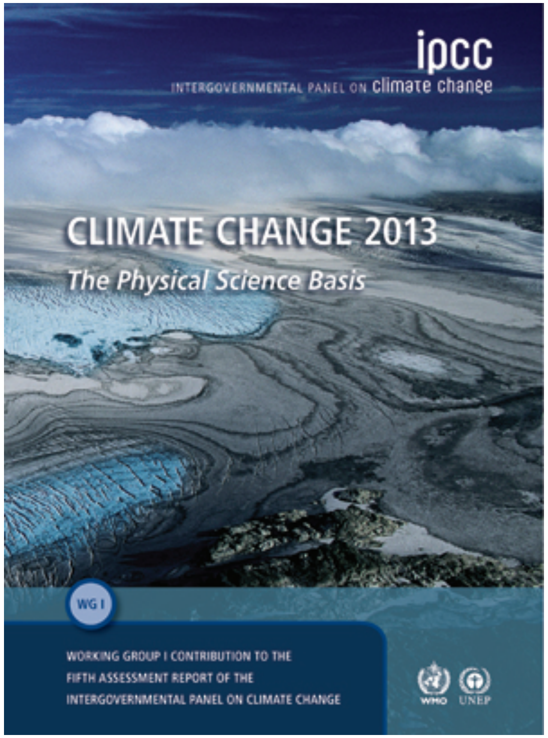
Together, they provide a comprehensive view *of the variability and long-term changes in the atmosphere, the ocean, the cryosphere, and the land surface.*

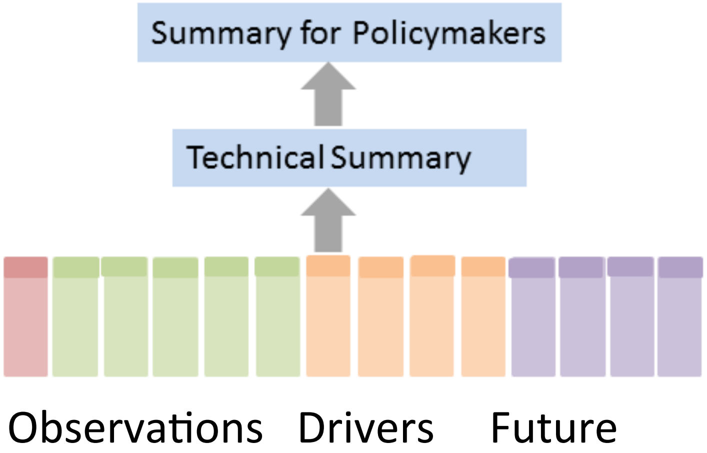
SOURCE IPCC 2013

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, sea level has risen, and the concentrations of greenhouse gases have increased (see Figures SPM.1, SPM.2, SPM.3 and SPM.4). {2.2, 2.4, 3.2, 3.7, 4.2–4.7, 5.2, 5.3, 5.5–5.6, 6.2, 13.2}

Facts About the WGI Contribution to IPCC AR5

- **209 Lead Authors** and 50 Review Editors from 39 countries
- Over **600 Contributing Authors**
- More than **2 million gigabytes** of numerical data from climate models
- Over **9200 scientific publications** cited
- **1089 expert reviewers** from 55 countries and 38 governments
- **54,677 review comments**





14 chapters

Outline

- Observations
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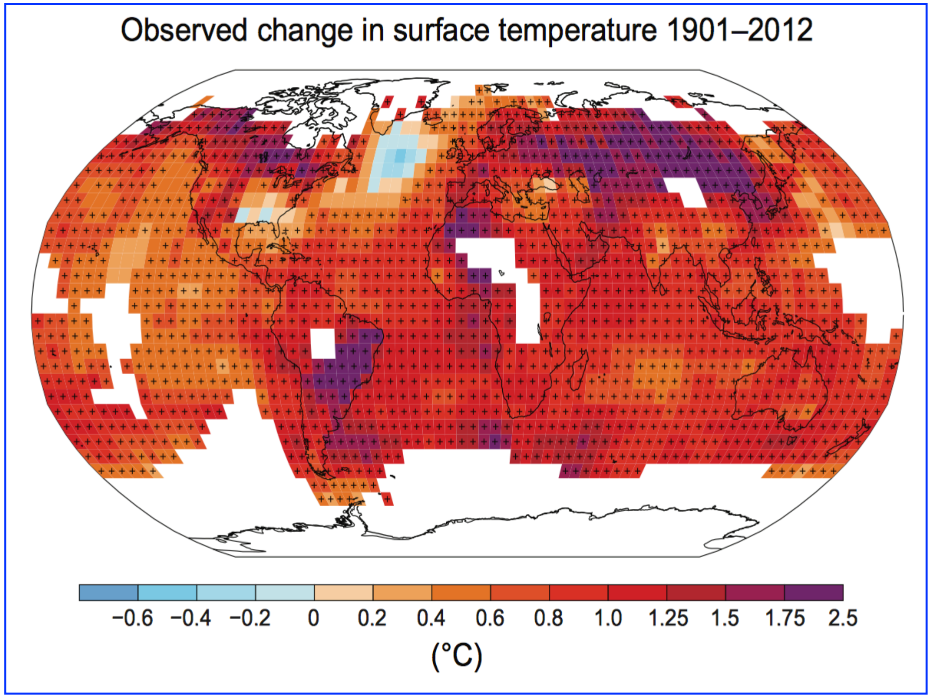
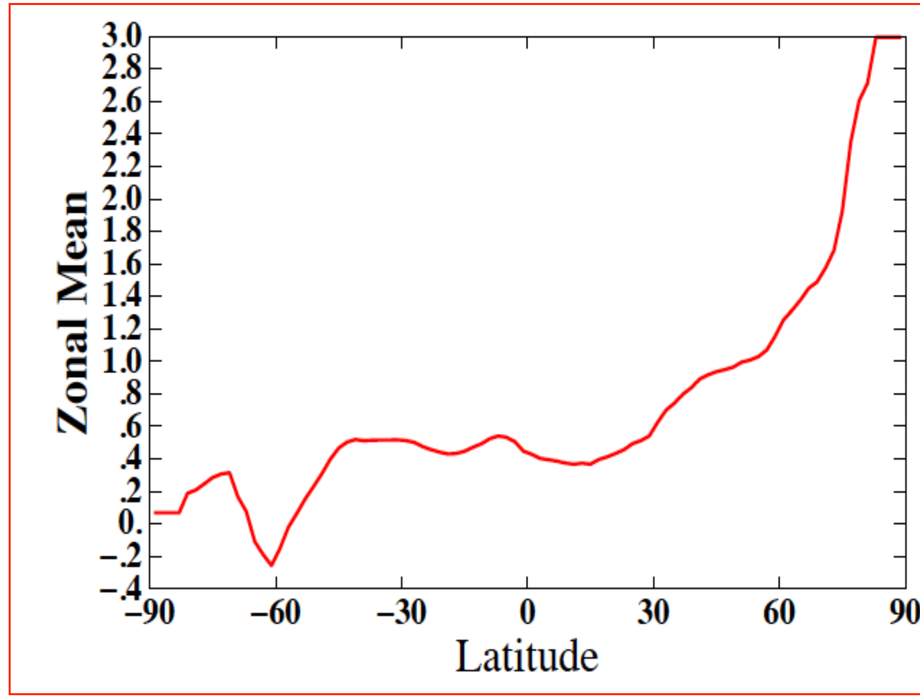
  - a look on projected **future climate changes**

EARTH HAS BEEN WARMING

"Temperature anomaly": departure from a reference value or long-term average





Yearly global average surface temperature trends since 1901. IPCC, WGI AR5 (2013)

Temperature anomaly in 2012 relative to mean global temperatures from 1951-1980 as a function of latitude.

http://www.climatechange2013.org/images/uploads/WGI_AR5_SPM_brochure.pdf

http://data.giss.nasa.gov/gistemp/maps/

Outline

- Observations
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- Why should we care?
  - ‘a look on future changes ‘forecast’

What changes climate?

Changes in:

– SUN’S OUTPUT
  - Its energy output increased about 0.1% from 1750 to 1950, increasing temperatures by 0.1°C in the first part of the 20th century.
  - But since 1979, when we began taking measurements from space, the **data show no long-term change in total solar energy, even though Earth has been warming**.

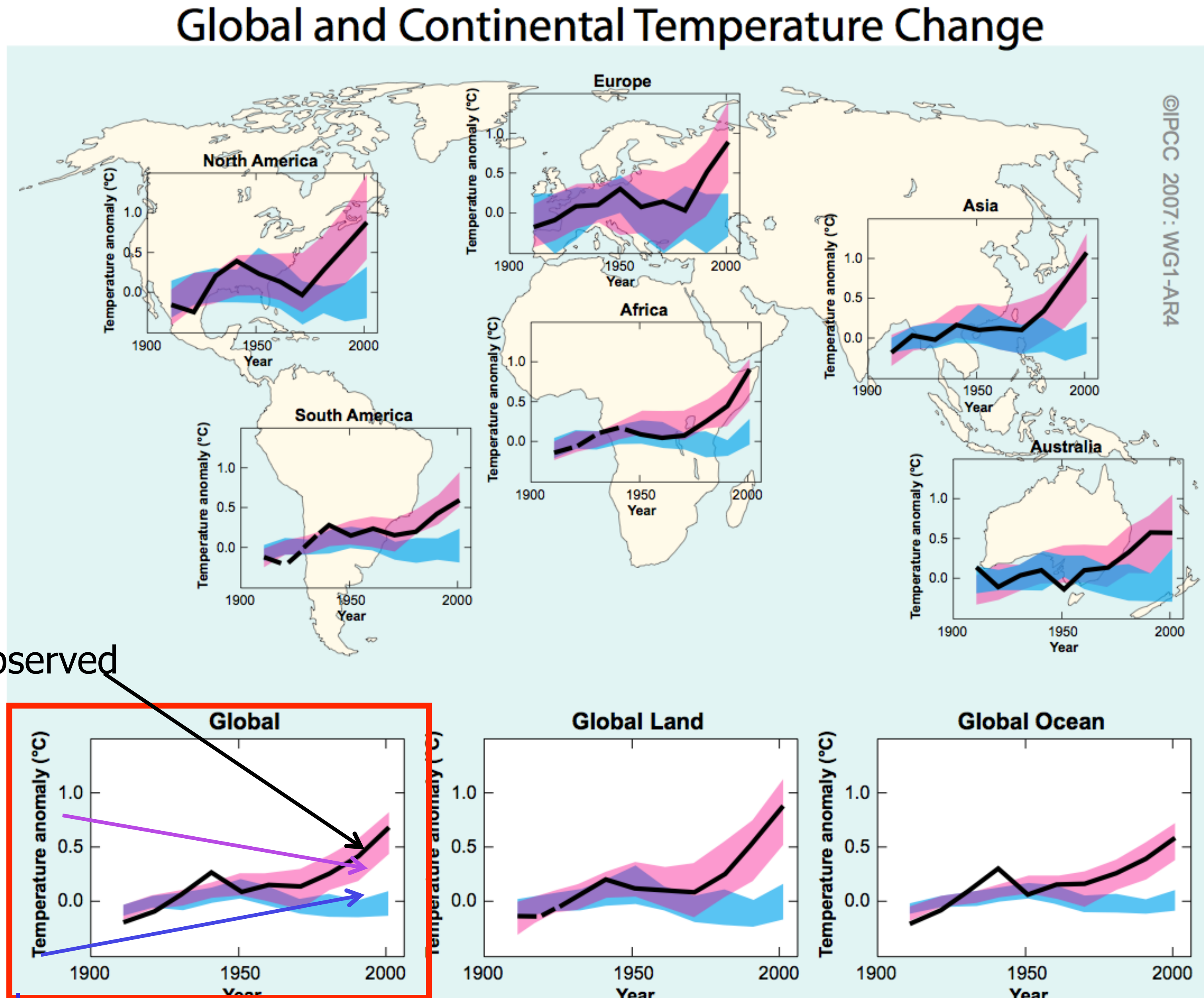
– EARTH’S ORBIT
  - Repetitive cycles in Earth’s orbit **that OCCUR OVER TENS OF THOUSANDS OF YEARS can influence the angle and timing of sunlight.**

– DRIFTING CONTINENTS
  - **by changing ice caps at the poles and by altering ocean currents, which transport heat and cold throughout the ocean depths.**

– VOLCANIC ERUPTIONS
  - Huge volcanic eruptions can cool Earth by injecting ash and tiny particles into the stratosphere.

– GREENHOUSE GASES and AEROSOLS
  - Changes in the concentration of greenhouse gases and aerosols, which occur both naturally and as a result of human activities, also influence Earth’s climate.

UNDERSTANDING AND ATTRIBUTING CLIMATE CHANGE



Observed

Expected for all forcing (Anthropogenic + Natural)

Natural forcing only

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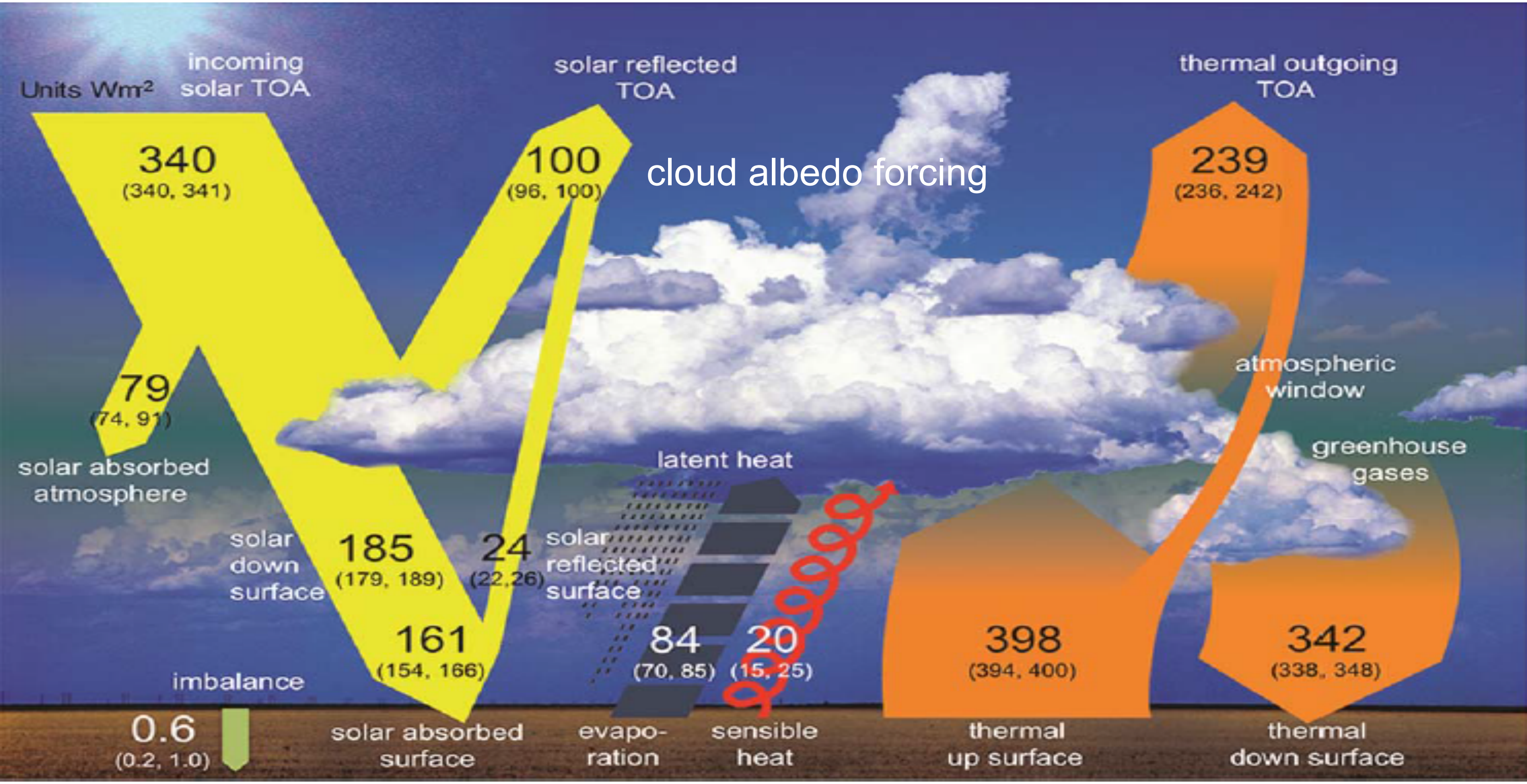
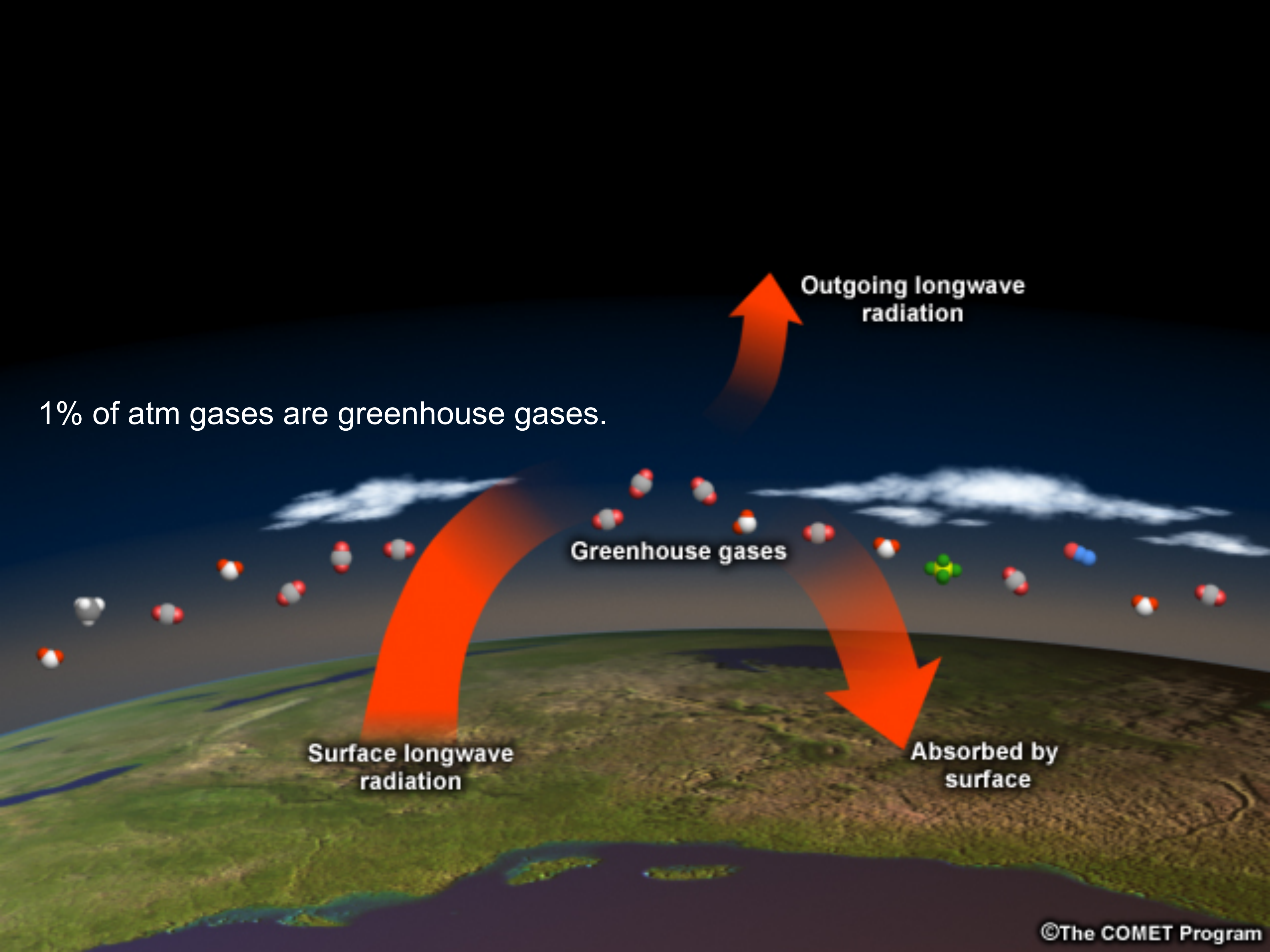
Energy balance and greenhouse effect

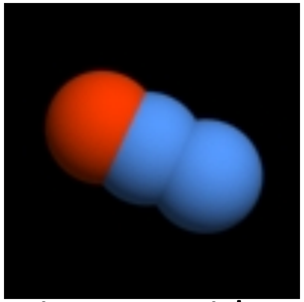


http://www.meted.ucar.edu/nwp/climate_models/print.htm

1% of atm gases are greenhouse gases.

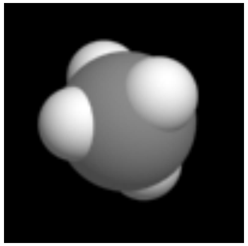


Greenhouse gases



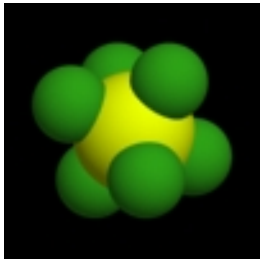
Nitrous oxide
N_2O^{O}

Carbon dioxide



Methane

Water



Sulfur hexafluoride

HOW TO COMPARE IMPACTS OF DIFFERENT GASES?

- The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases.

- Specifically, it is a measure of

how much energy the emissions of one ton of a gas will absorb over a given period of time, relative to the emissions of one ton of carbon dioxide

Examples of Human-Produced Greenhouse Gases

Species	Lifetime (years)	Global Warming Potential (Relative to CO_2)		
		20 years	100 years	500 years
Methane	12 +/- 3	56	21	6.5
Nitrous oxide	120	280	310	170
Sulfur hexafluoride	3,200	16,300	23,900	34,900
Carbon tetrafluoride	50,000	4,400	6,500	10,000

carbon dioxide that will last thousands of year

http://www3.epa.gov/climatechange/ghgemissions/gwps.html

The Global Warming Potential (GWP): allow comparisons of the global warming impacts of different gases.

The larger the GWP, the more that a given gas warms the Earth compared to carbon dioxide over that time period.

The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP.

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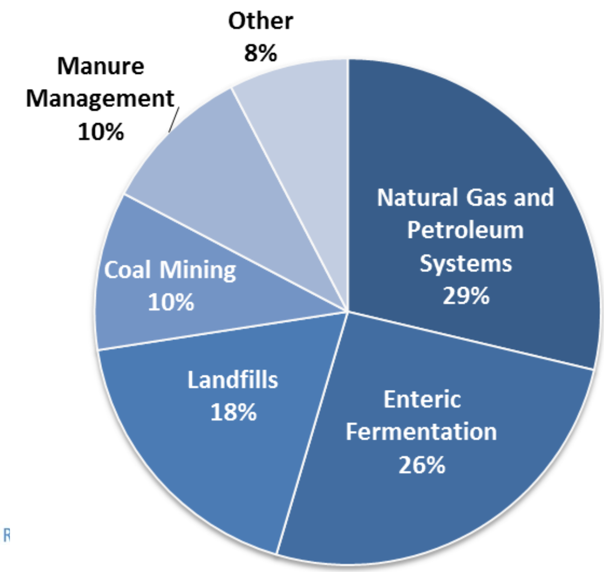
INTERGOVER

METHANE SOURCES



CO2 account for largest GHG emissions

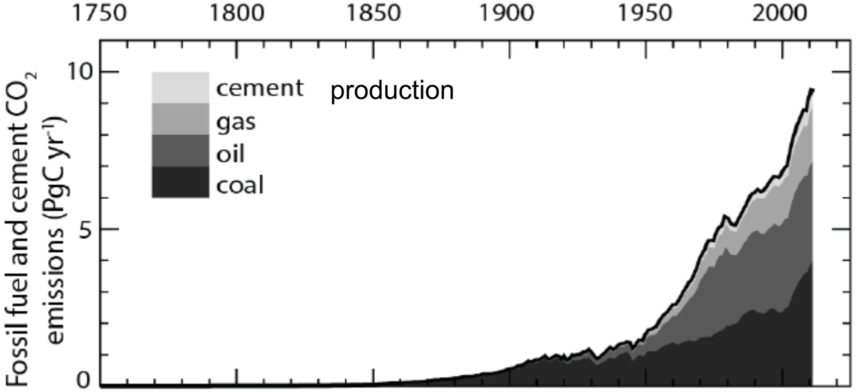
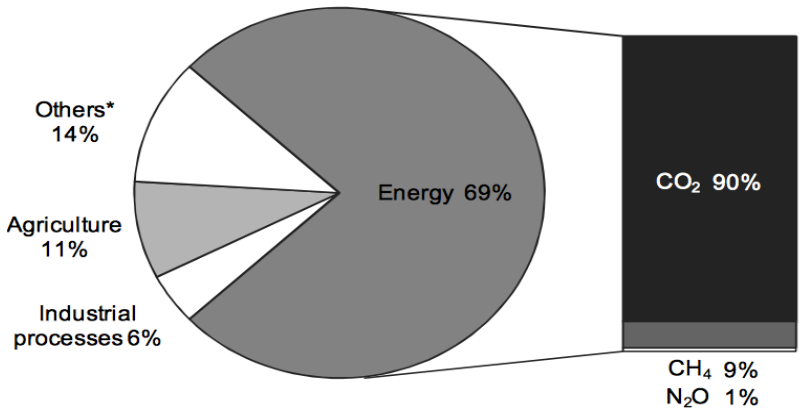


Figure 1. Shares of global anthropogenic GHG, 2010*



* Others include large-scale biomass burning, post-burn decay, peat decay, indirect N_2O emissions from non-agricultural emissions of NO_x and NH_3, Waste, and Solvent Use.

Source: IEA estimates for CO_2 from fuel combustion and EDGAR 4.2 FT2010 estimates for all other sources.

Key point: Energy emissions, mostly CO_2, account for the largest share of global GHG emissions.

Fossil fuel CO_2 emissions have increased by more than 50% since 1990

Emissions from coal have increased significantly over the last few years

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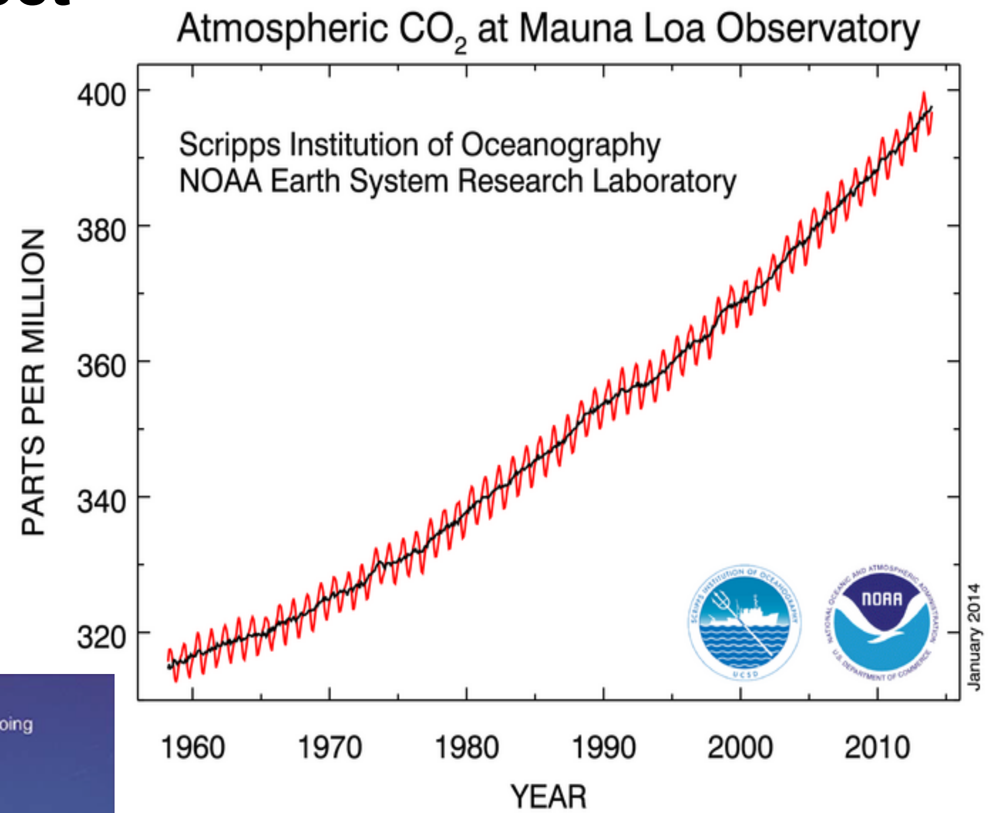
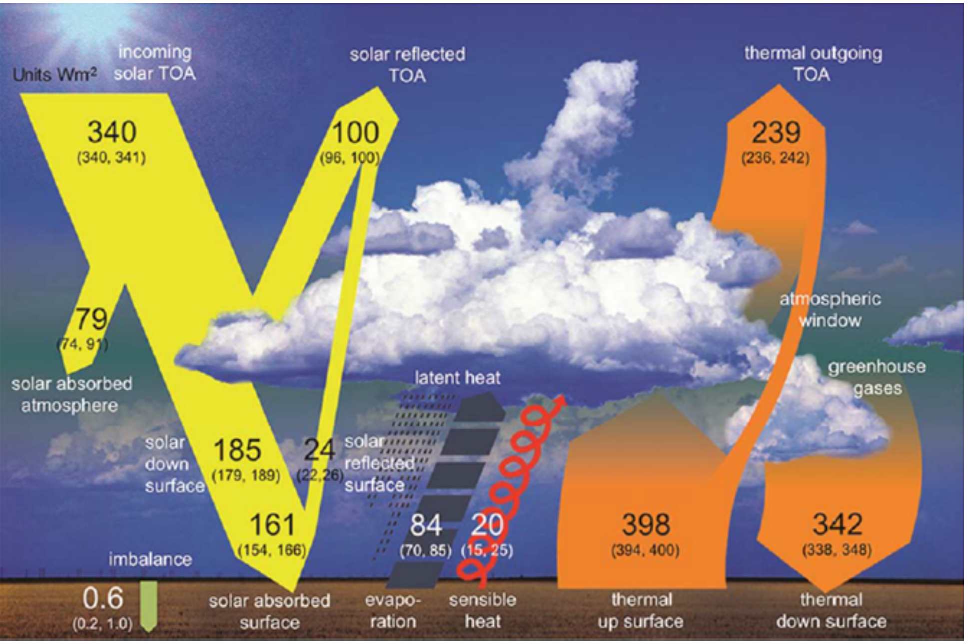
Increased greenhouse effect





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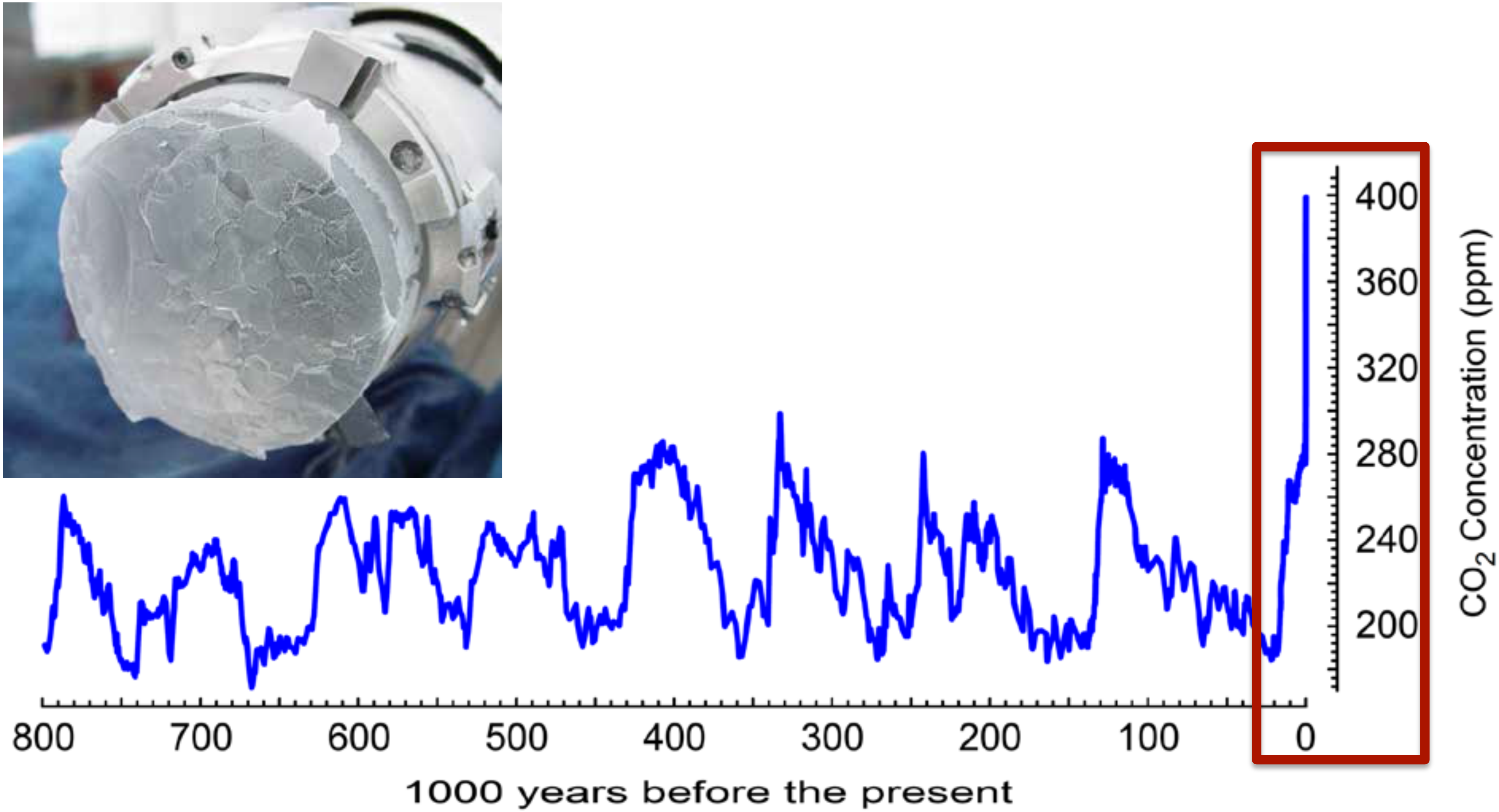
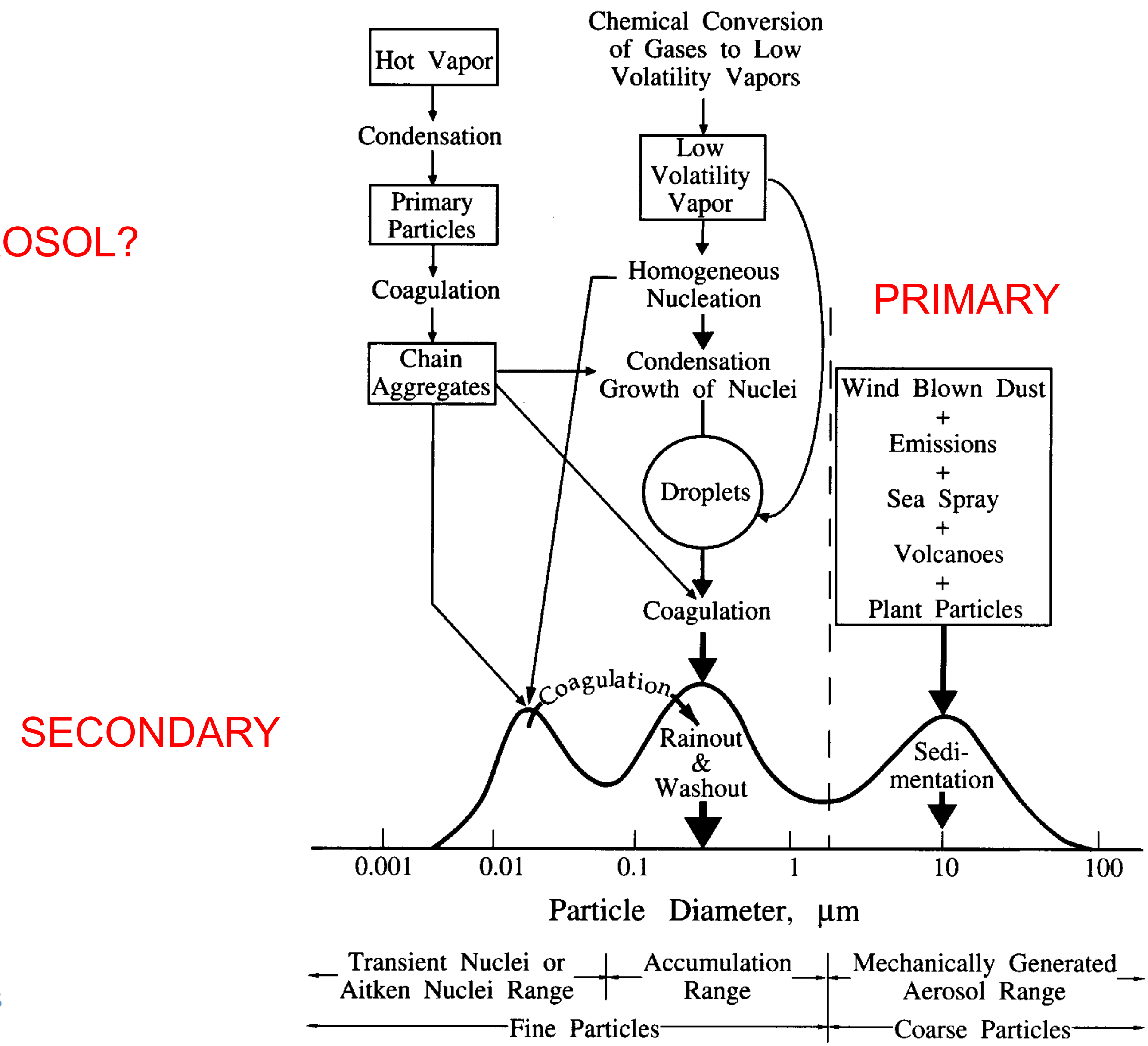


The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years.

AEROSOLS CAN IMPACT CLIMATE IN DIFFERENT WAYS

WHAT IS AN AEROSOL?



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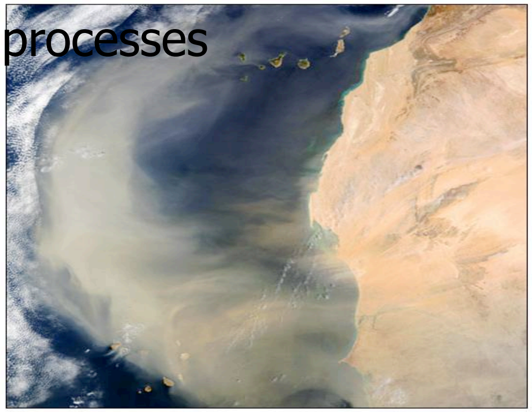
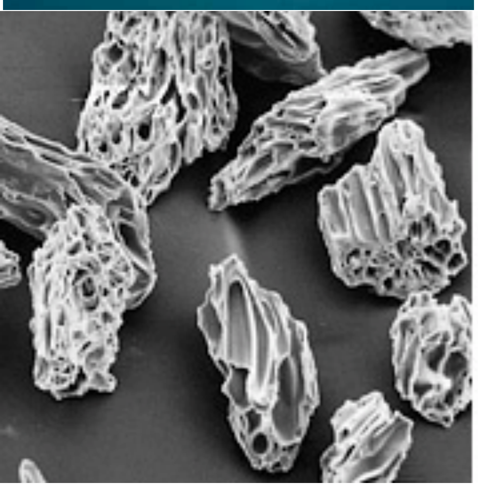
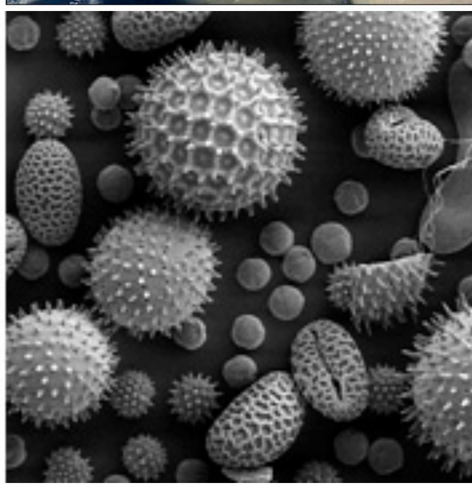
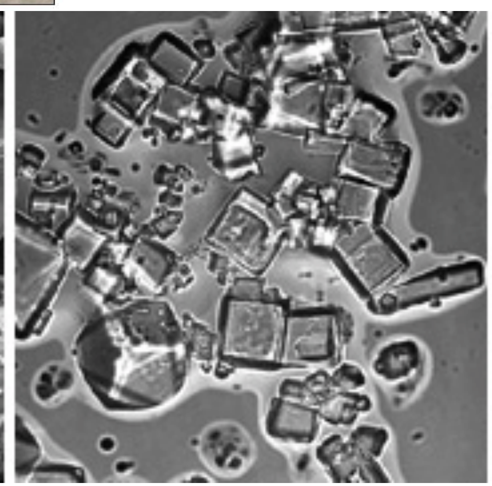
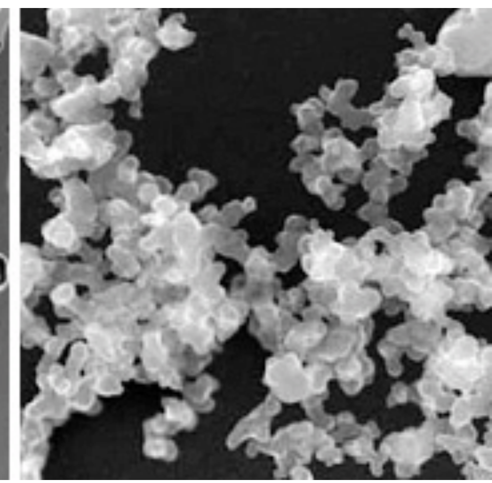
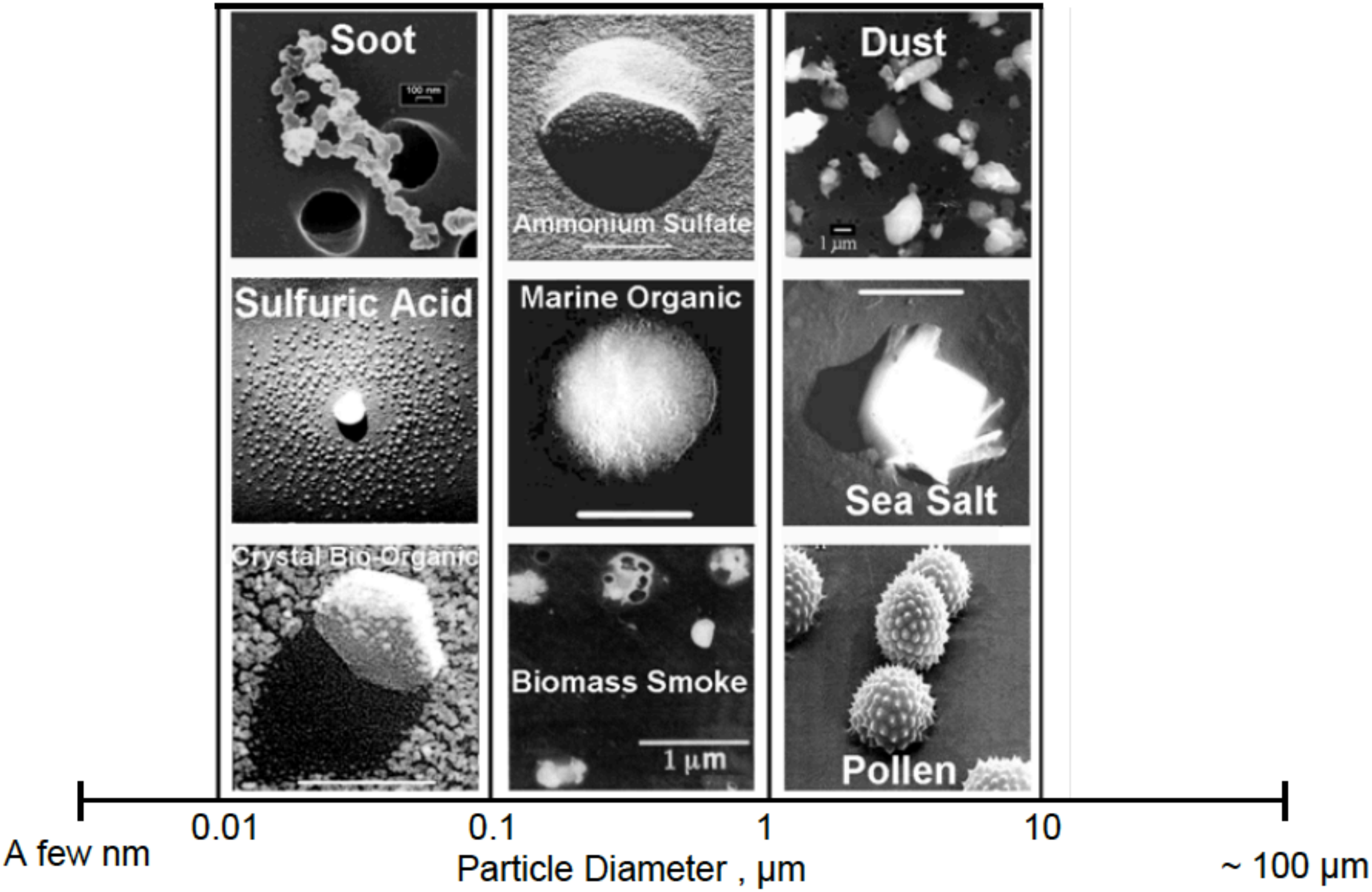
Anthropogenic processes

Natural processes

Aerosols come in all shapes and sizes

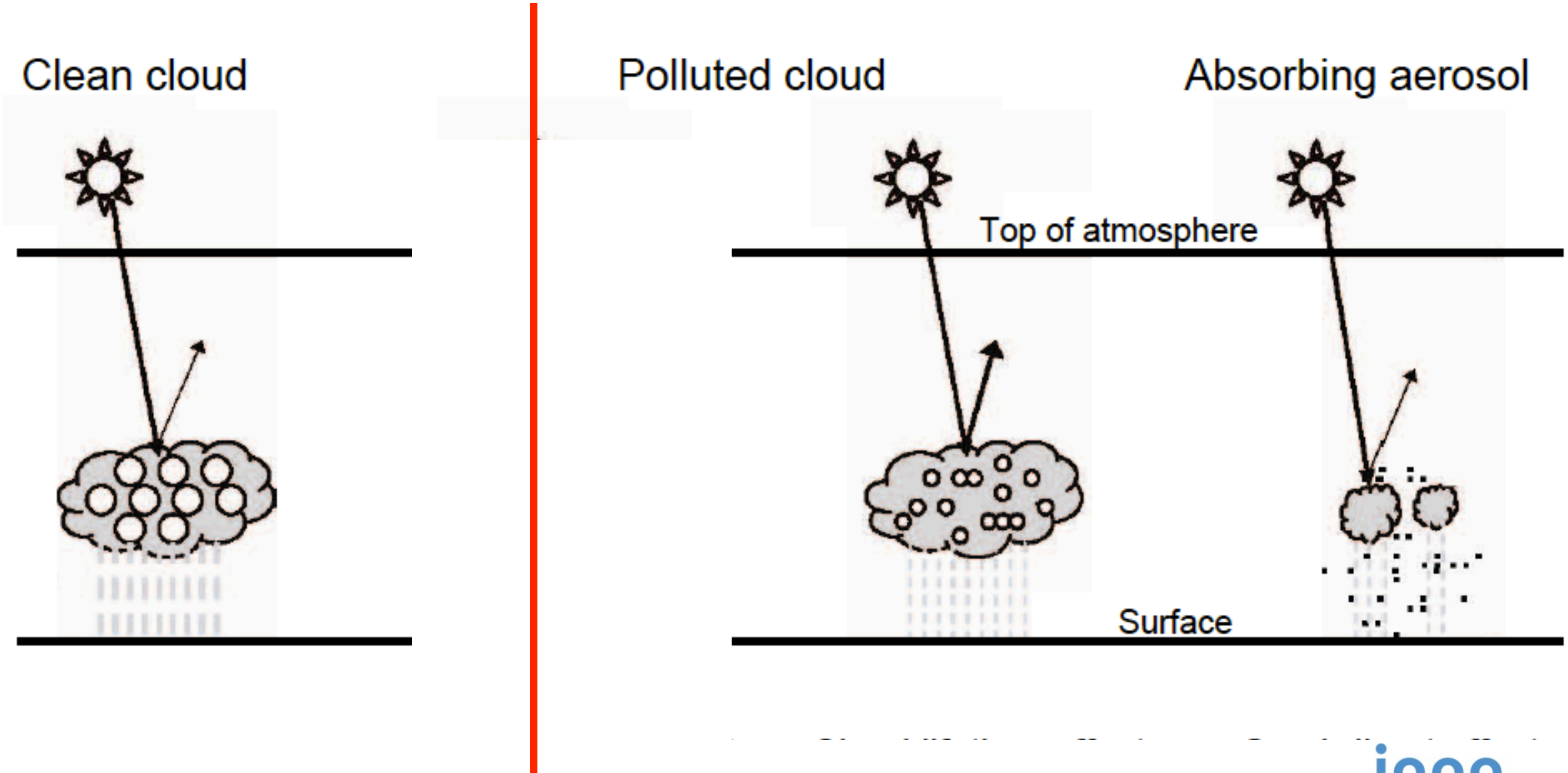


WHY DO WE CARE ABOUT AEROSOLS?

- Aerosols affect planetary energy balance in two ways:
  - **Directly**: aerosols scatter and absorb solar energy both in cloud-free and cloudy conditions;
  - **Indirectly**: via their role as cloud condensation nuclei (CCN), aerosols modify the optical properties and lifetimes of clouds playing an important role in the process of cloud formation and precipitation.

AEROSOLS CAN MODIFY CLOUD MICROPHYSICS AND THEN OPTICAL PROPERTIES

Modification of the microphysical and hence the radiative properties, lifetime, amount, and morphology of clouds.



From emissions to climate change

Climate changes

⬆

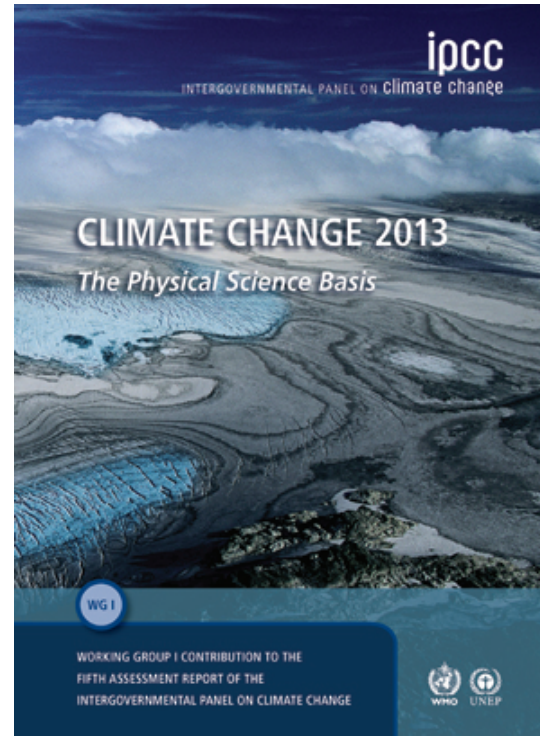
Climate (radiative) forcing/
change in energy fluxes

⬆

Atmospheric concentration changes

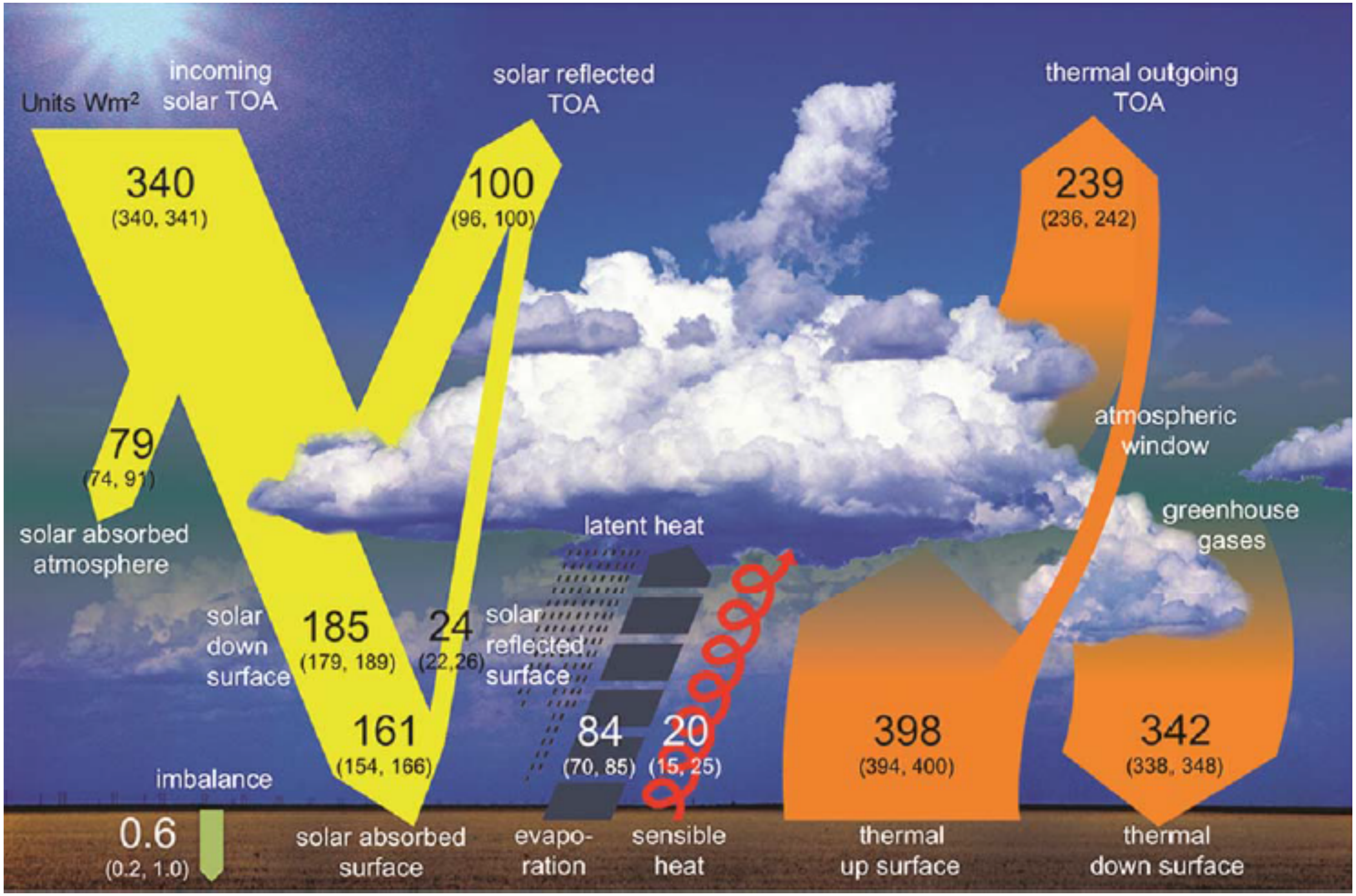
⬆

Emissions



Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change.

Energy balance and greenhouse effect



Radiative forcing (RF) quantifies the change in energy fluxes caused by changes in these drivers

Outline

- Observations
- What changes climate?
- How do we know?
  - Indicators and effects
- Why should we care?
  - a look on future changes ‘forecast’

Effects: Global temperature change

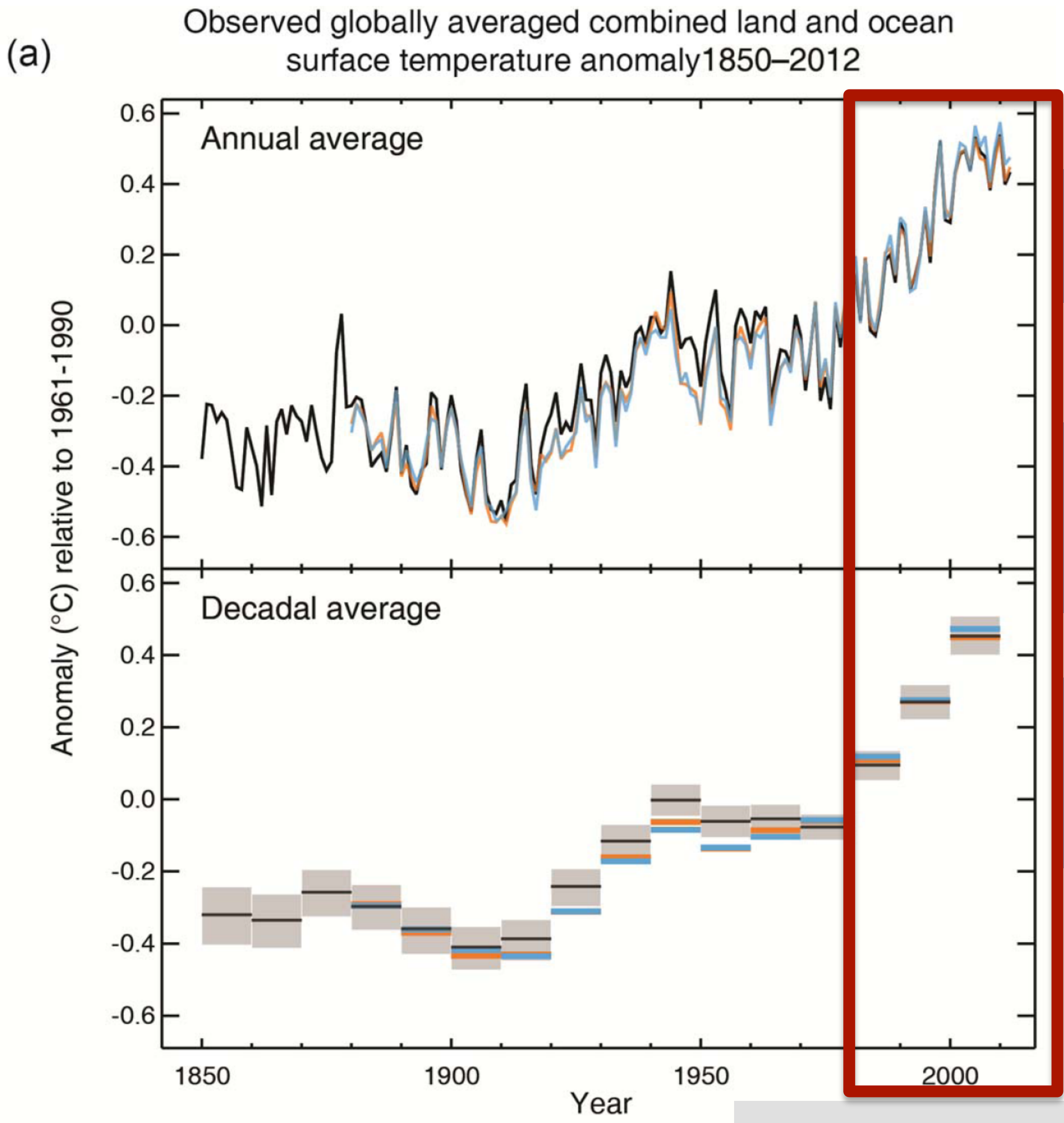


Figure SPM.1

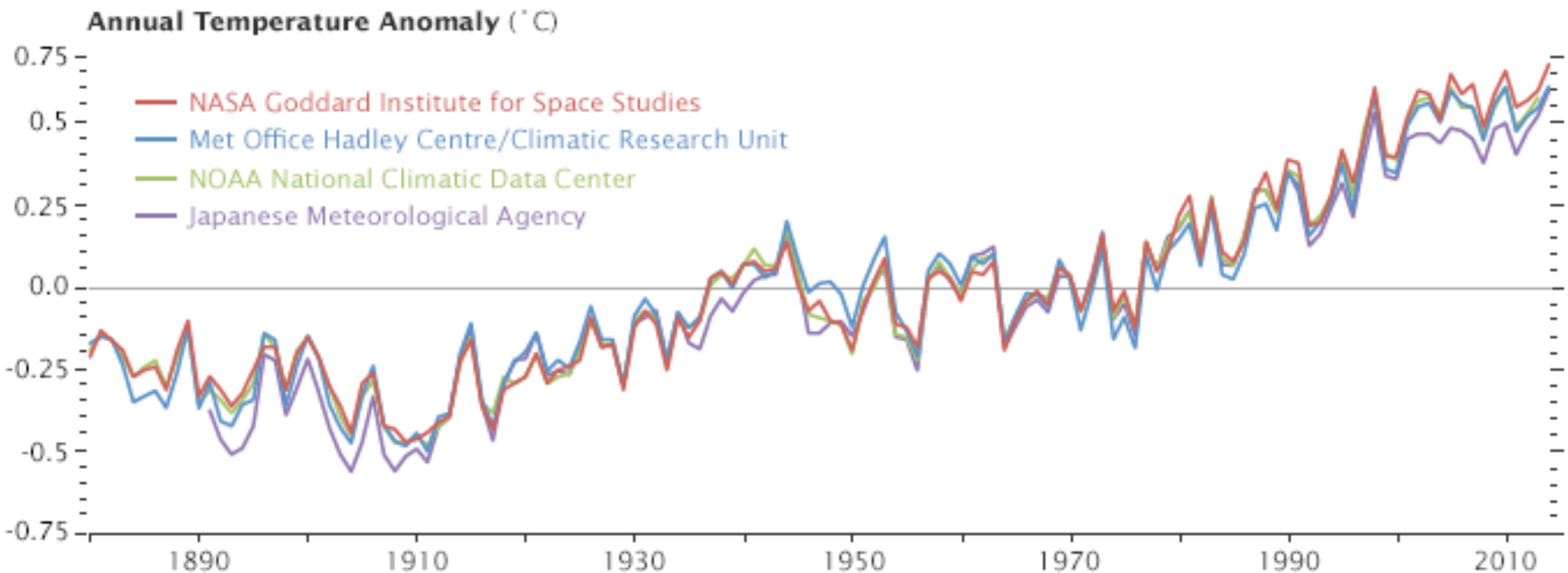
Warming during the period 1850-2012 is 0.85 °C

The first decade this century is the warmest in the period of instrumental record

The last 30 year period is *likely* the warmest 30 year period in 1400 years

NASA, Goddard Institute for Space Studies (GISS)

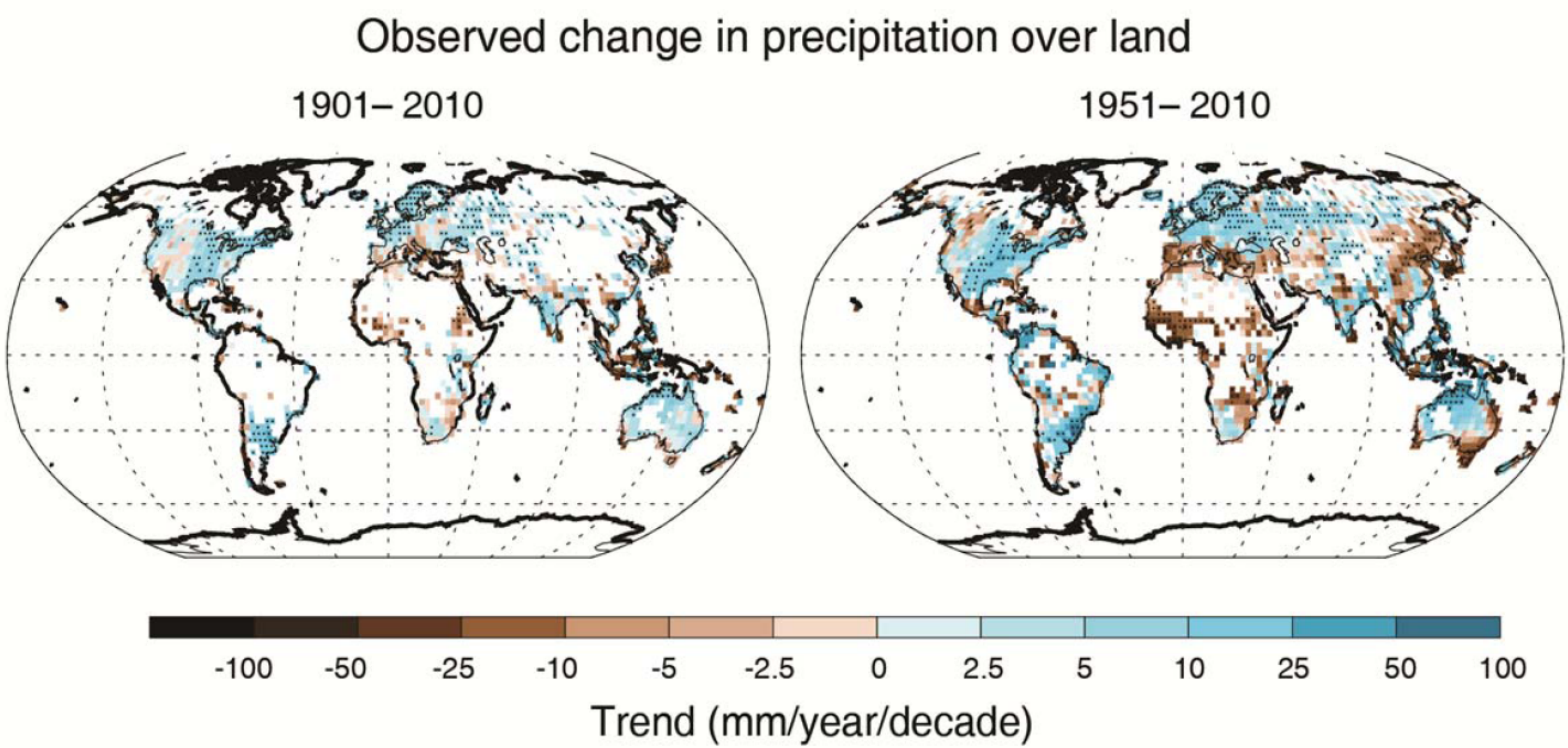
http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php



According to an ongoing temperature analysis conducted by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by about 0.8° Celsius since 1880.

Two-thirds of the warming has occurred since 1975, at a rate of roughly 0.15-0.20°C per decade.

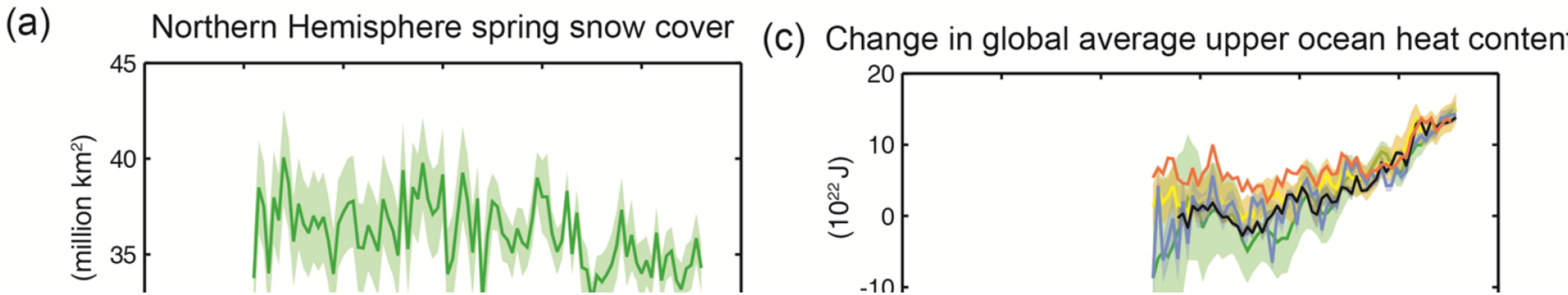
Effects: Global distribution of precipitation changes



White areas lack long time observations

Figure SPM.2

Effects: Warming of the entire climate system



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, sea level has risen, and the concentrations of greenhouse gases have increased (see Figures SPM.1, SPM.2, SPM.3 and SPM.4). {2.2, 2.4, 3.2, 3.7, 4.2–4.7, 5.2, 5.3, 5.5–5.6, 6.2, 13.2}

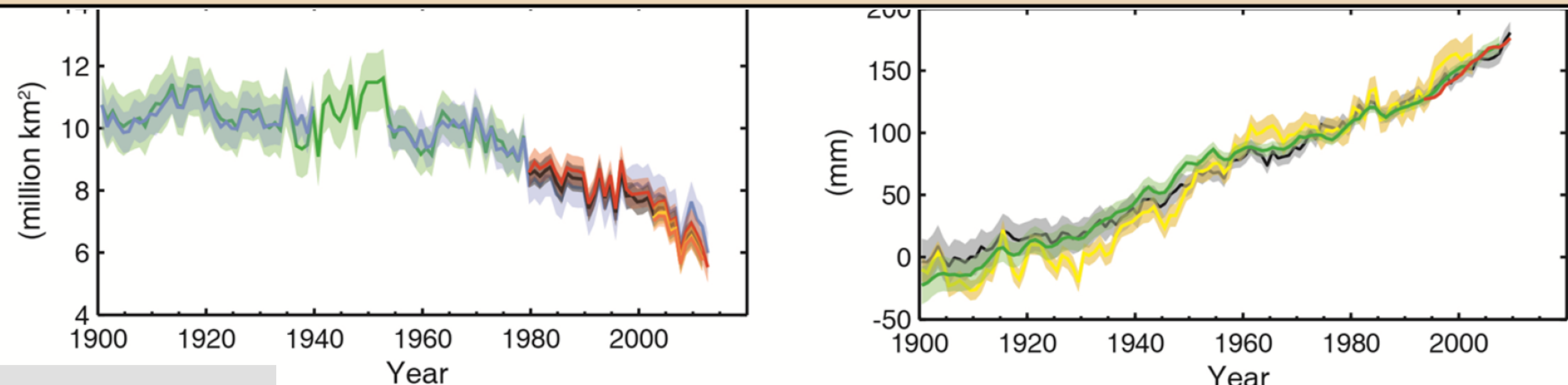


Figure SPM.3

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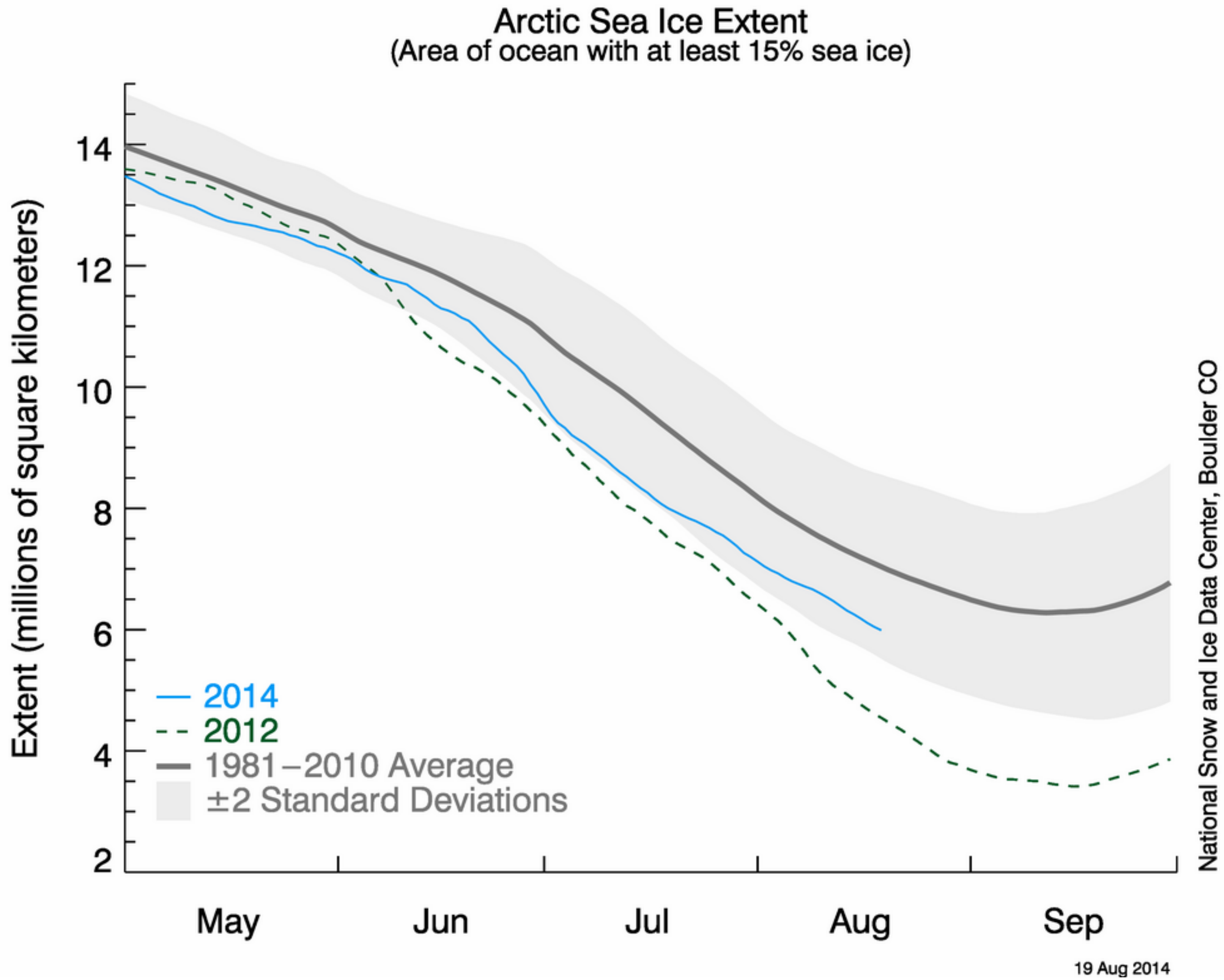
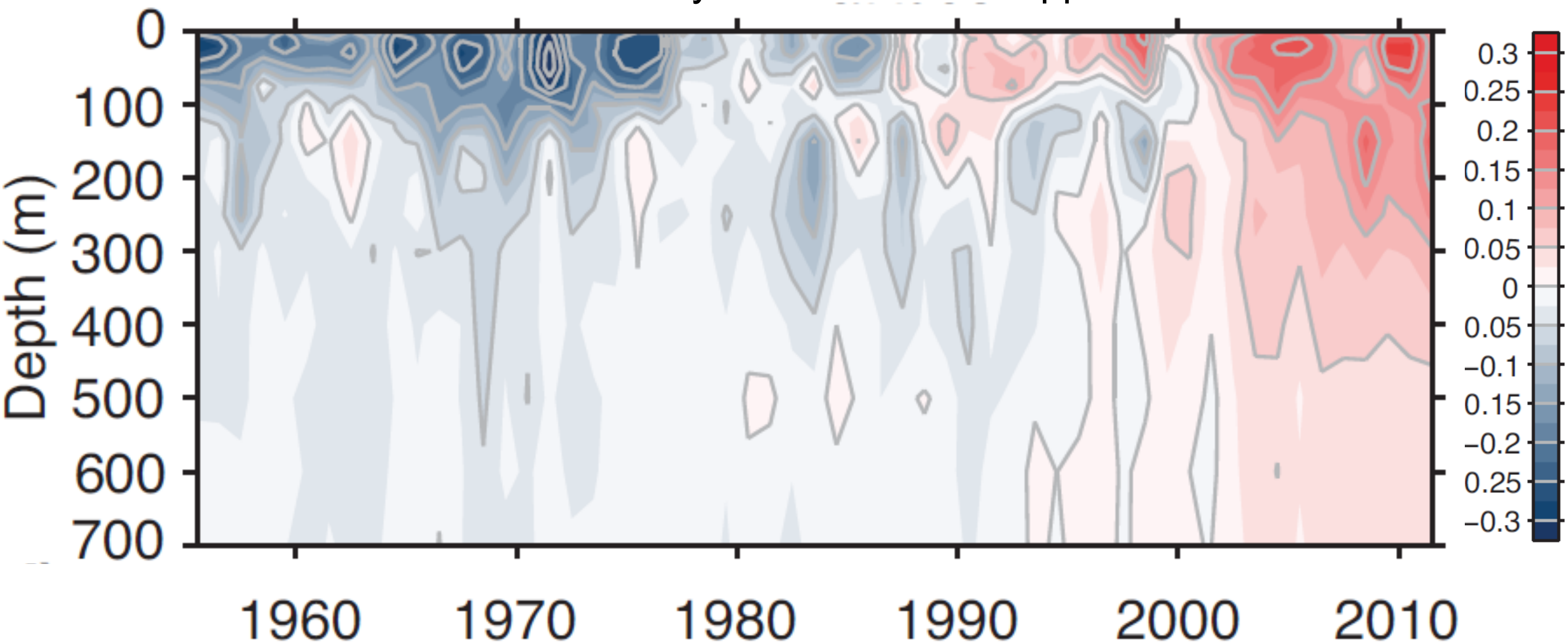


http://nsidc.org/arcticseaicenews/

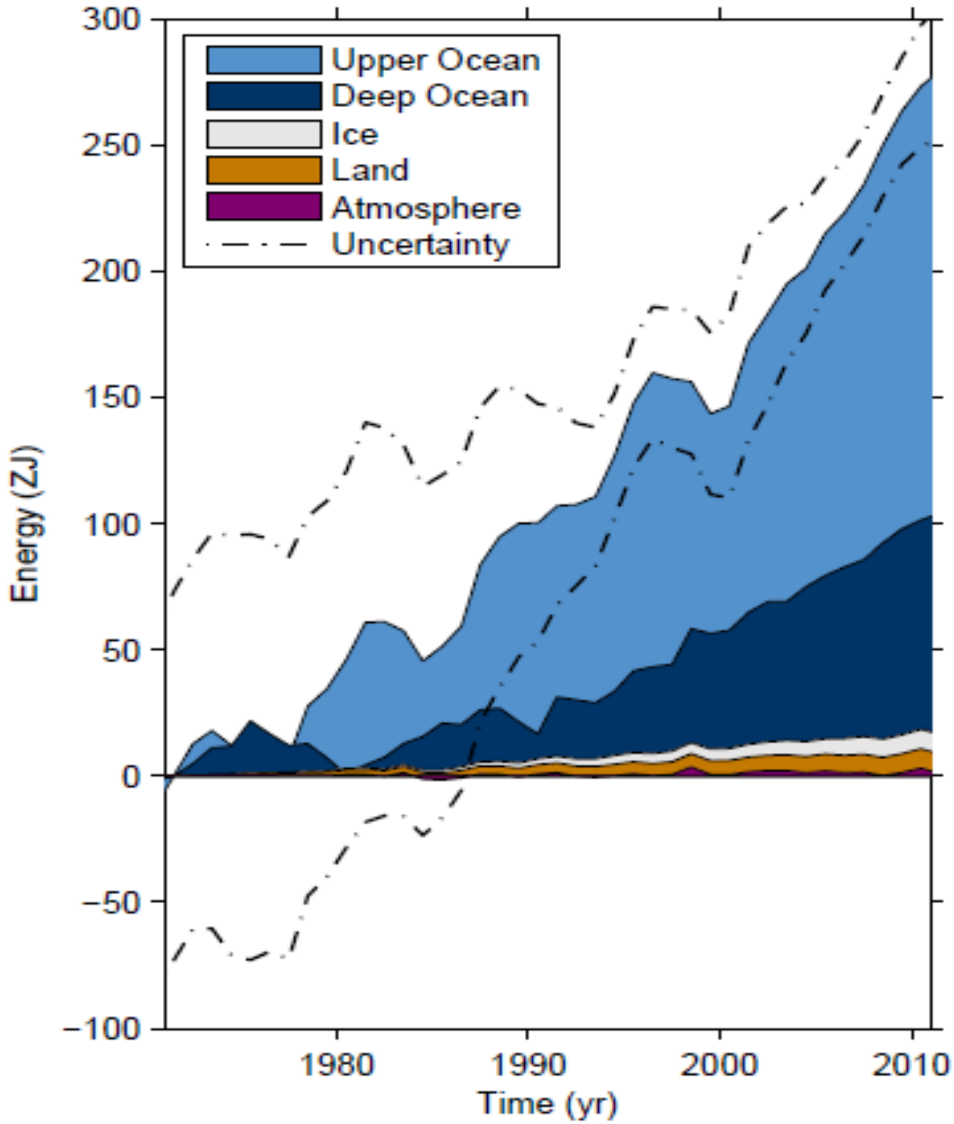
Warming of the ocean

Note well: ~60% of the net energy increase in the climate system is stored In upper ocean



The warming of the oceans goes deeper during the last decade

The oceans absorb most of the energy



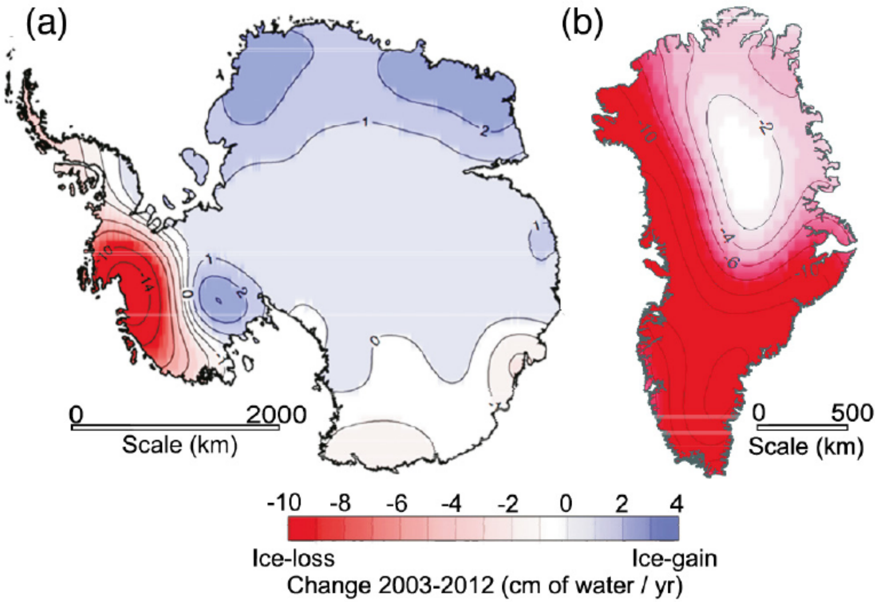
The warming of the oceans amounts to 93% of the energy accumulated in the climate system between 1970 and 2010

3% has heated land surfaces, 1% the atmosphere and 3% has melted glaciers

Warming of the ocean has contributed to a significant part of the sea level rise

The zettajoule (ZJ) is equal to one sextillion (10^{21}) joules

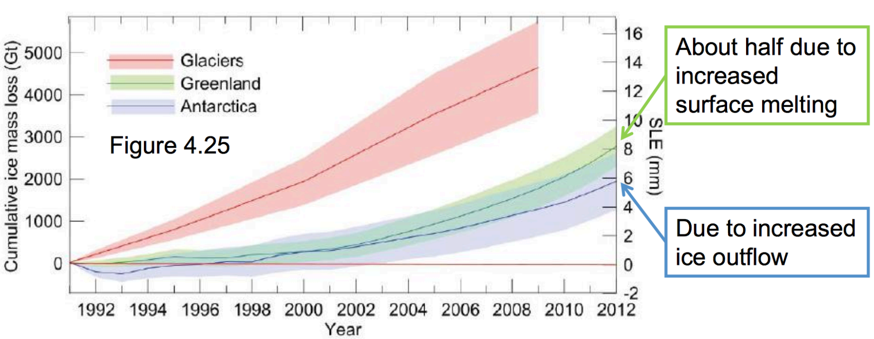
Greenland and Antarctica melting yields sea level rise



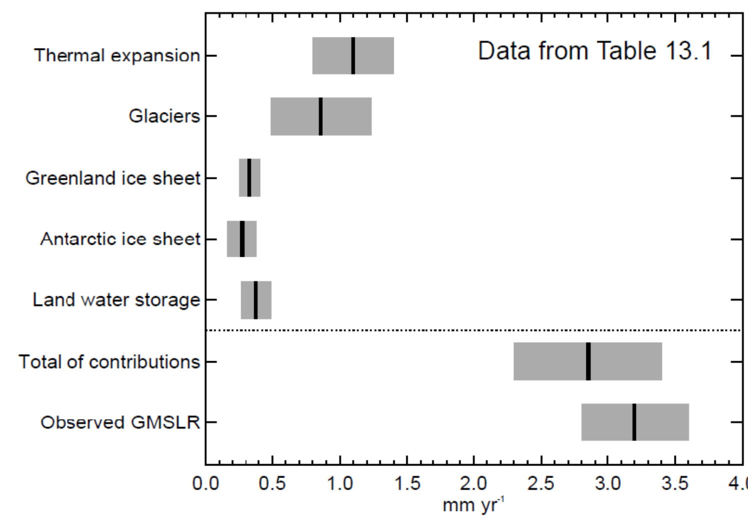
(a) Plots of decadal averages of daily sea ice extent in the Arctic.

GMSLR = global mean sea level rise
GMSLR during 1901–2010 can be accounted for by ocean thermal expansion, ice loss by glaciers and ice sheets, and change in liquid water storage on land.

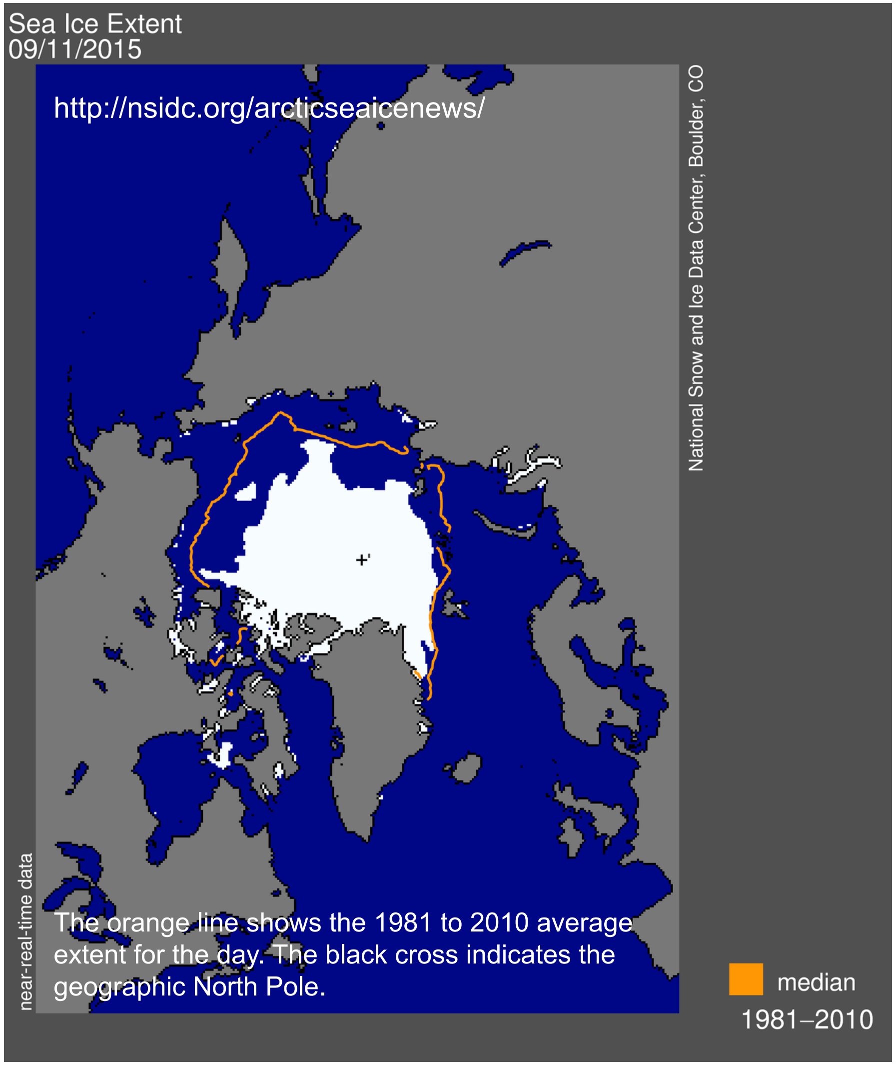
Recent and projected mass loss from the ice sheets



Observed contributions explain observed GMSLR 1993-2010



At present .. Ice melting

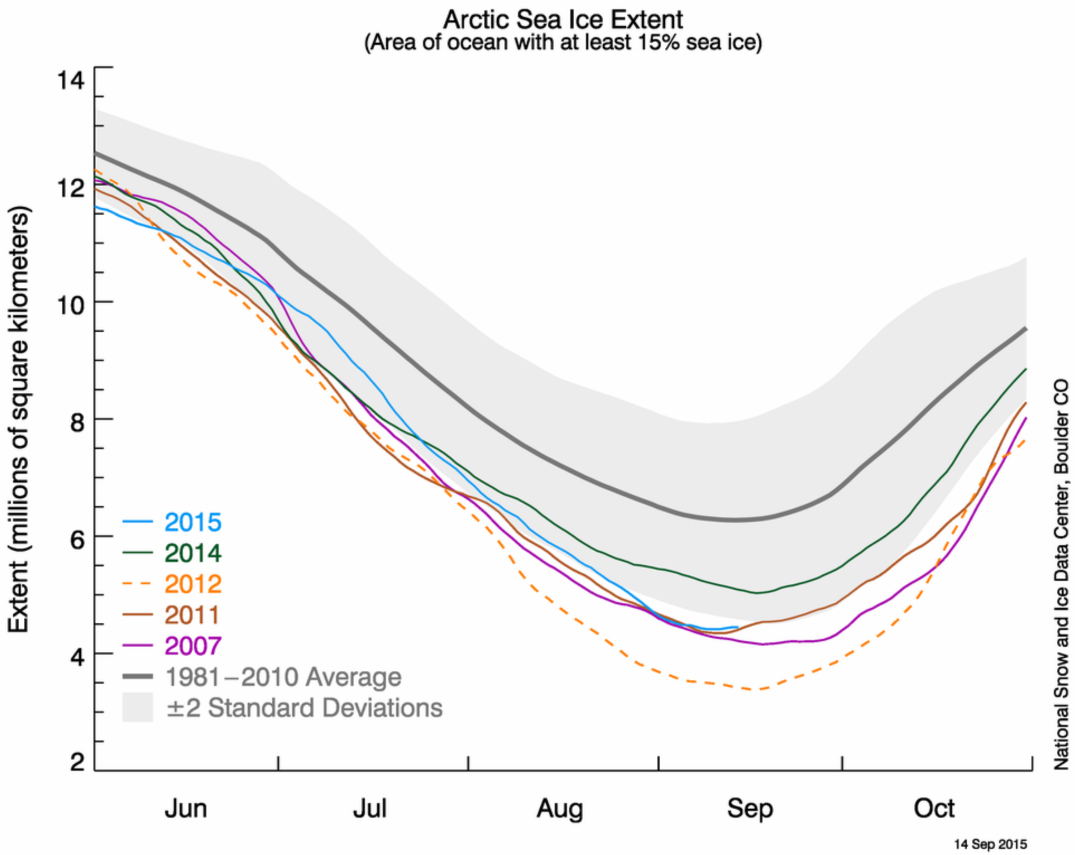


On September 11, 2015, sea ice extent dropped to 4.41 million square kilometers, **the fourth lowest minimum in the satellite record.**

In response to the setting sun and falling temperatures, ice extent will now climb through autumn and winter. However, a shift in wind patterns or a period of late season melt could still push the ice extent lower.

Both the **Northern Sea Route**, along the coast of Russia, and Roald Amundsen's route through the Northwest Passage **are open**

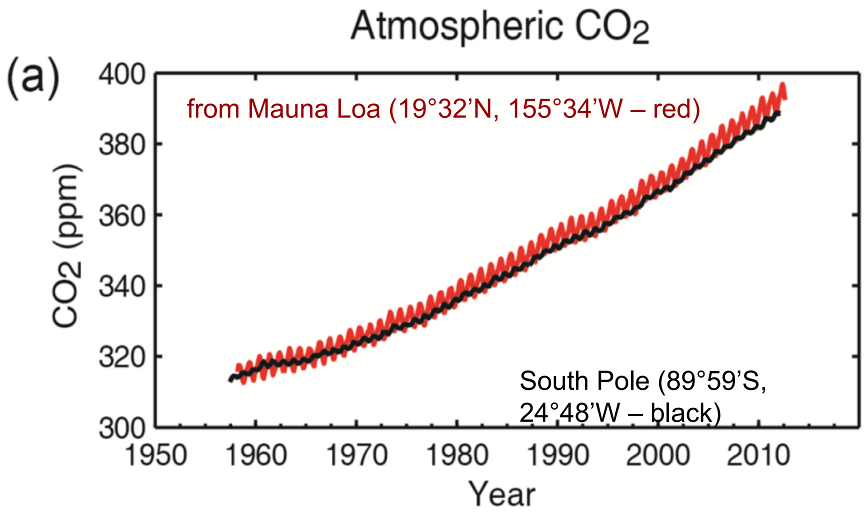
At present .. Ice melting

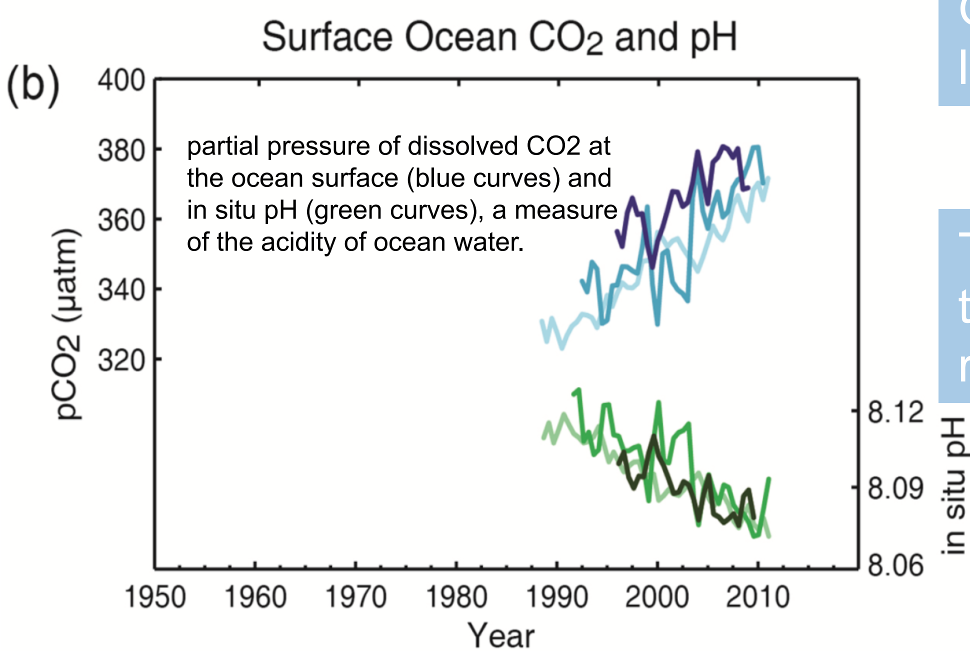


http://nsidc.org/arcticseaicenews/

The graph above shows Arctic sea ice extent as of September 14, 2015, along with daily ice extent data for last year and the three lowest ice extent years (2012, 2007, and 2011). 2015 is shown in blue, 2014 in green, 2012 in orange, 2011 in brown, and 2007 in purple. The 1981 to 2010 average is in dark gray. The gray area around the average line shows the two standard deviation range of the data

MULTIPLE OBSERVED INDICATORS OF A CHANGING GLOBAL CARBON CYCLE:





CO_2 has increased by 40% since pre-industrial time to a concentration of 391 ppm in 2011 **(primarily from fossil fuel emissions and secondarily from net land use change emissions)**

Fossil fuel emissions in 2011 were 9.5 GtC/yr which is 54% above the 1990 level

The oceans have absorbed ca 30% of the anthropogenic CO_2 emissions resulting in acidification of the oceans

Figure SPM.4

From emissions to climate change

Climate changes

⬆

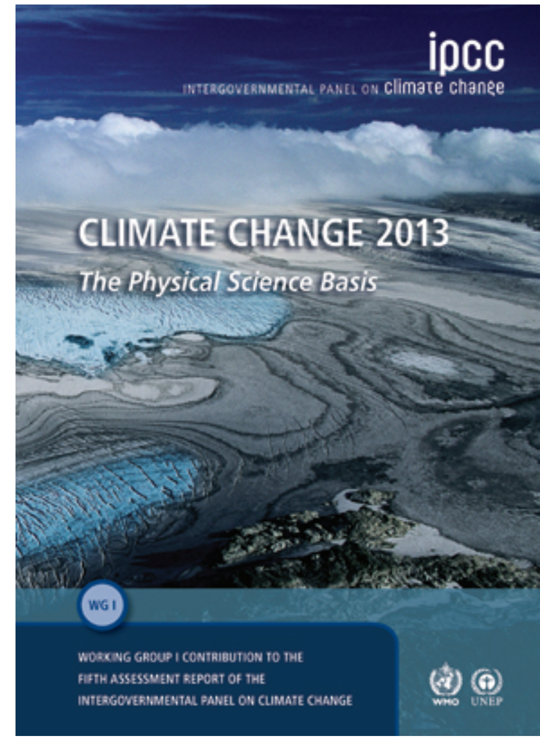
Climate (radiative) forcing

⬆

Atmospheric concentration changes

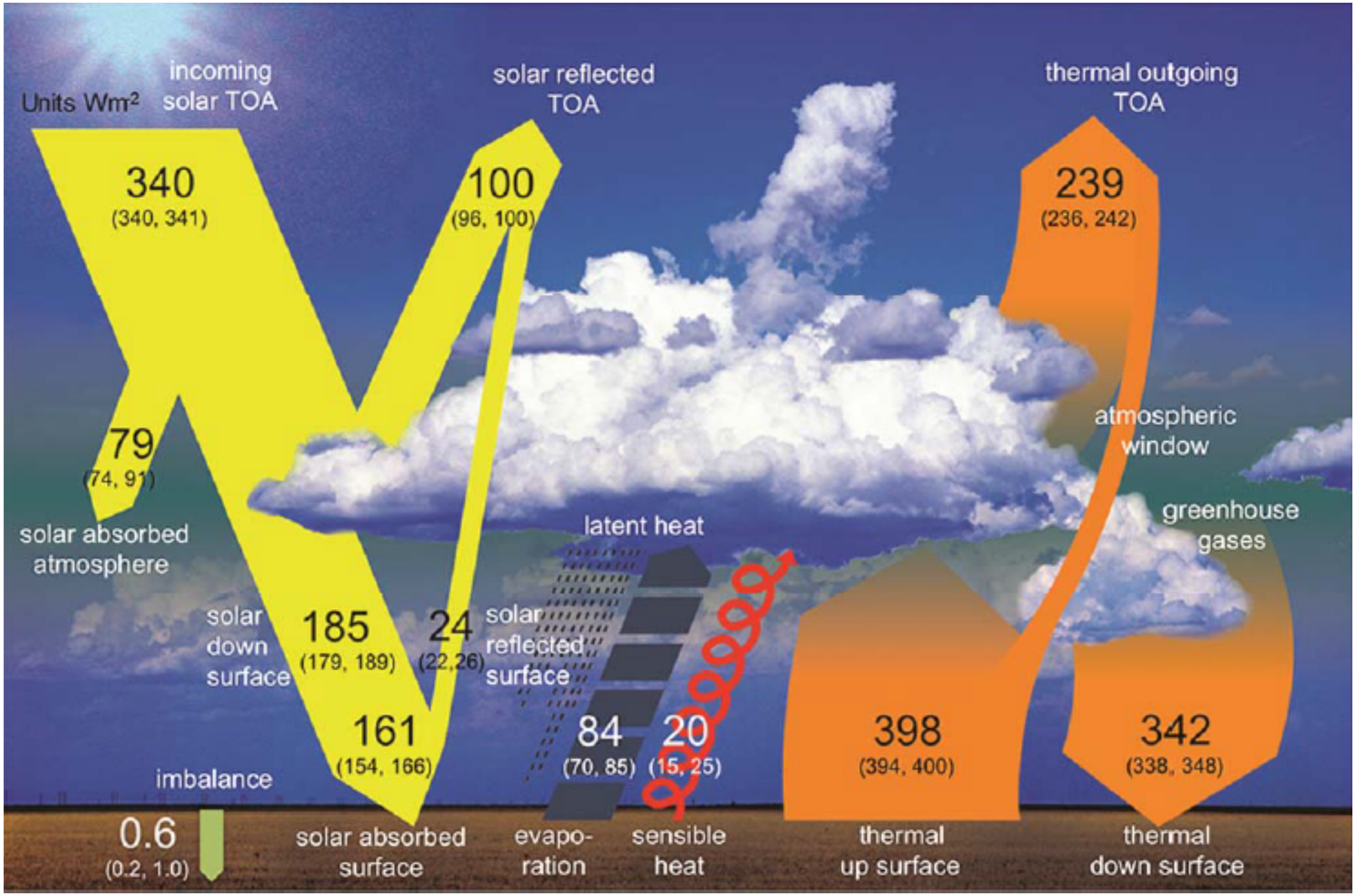
⬆

Emissions



We talked about the indicators, now an outlook on the drivers

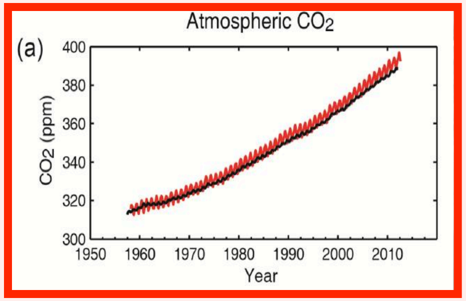
Energy balance and greenhouse effect



GHGs AND AEROSOLS CAN ALTER THE CLIMATE

WARMING:

1. GHGs



2. Black Carbon aerosols

COOLING:

1. **Most of aerosols** reflect some of the incoming solar radiation!

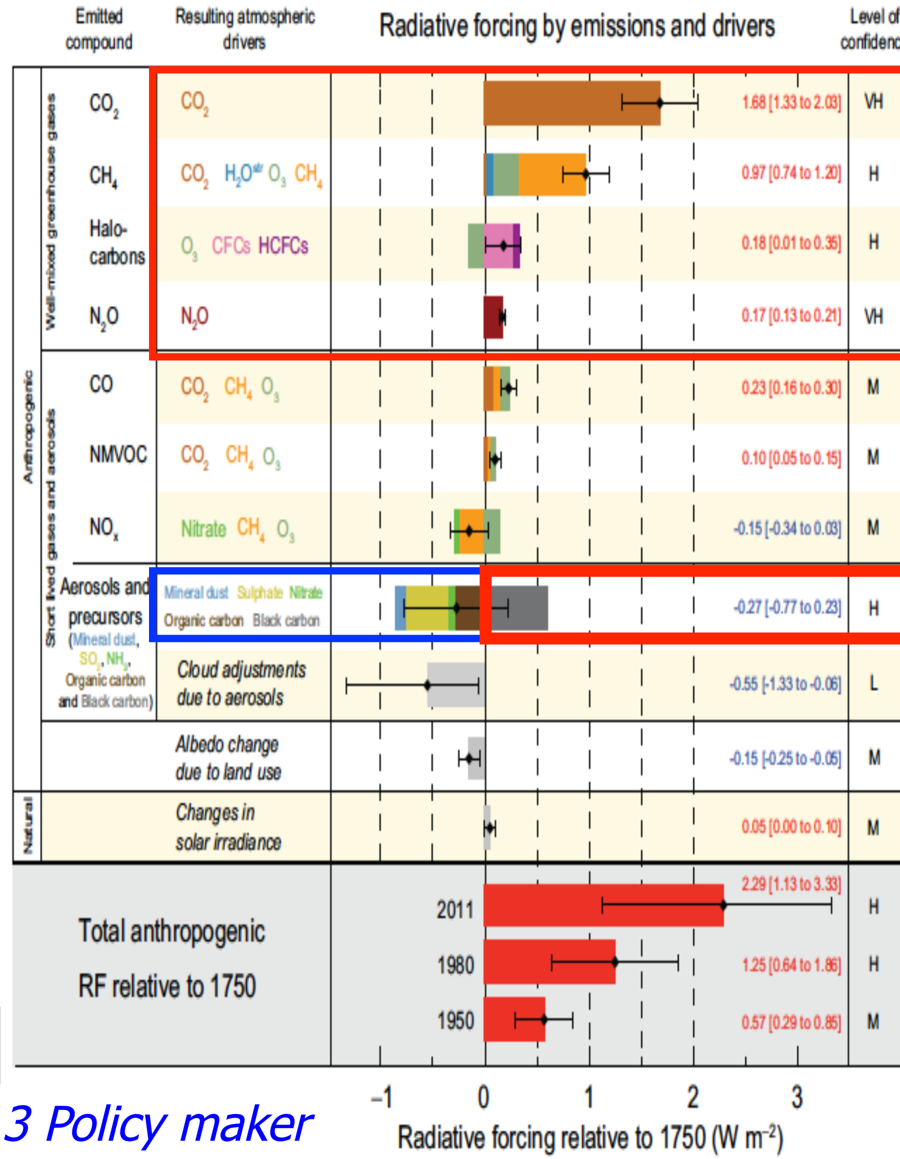
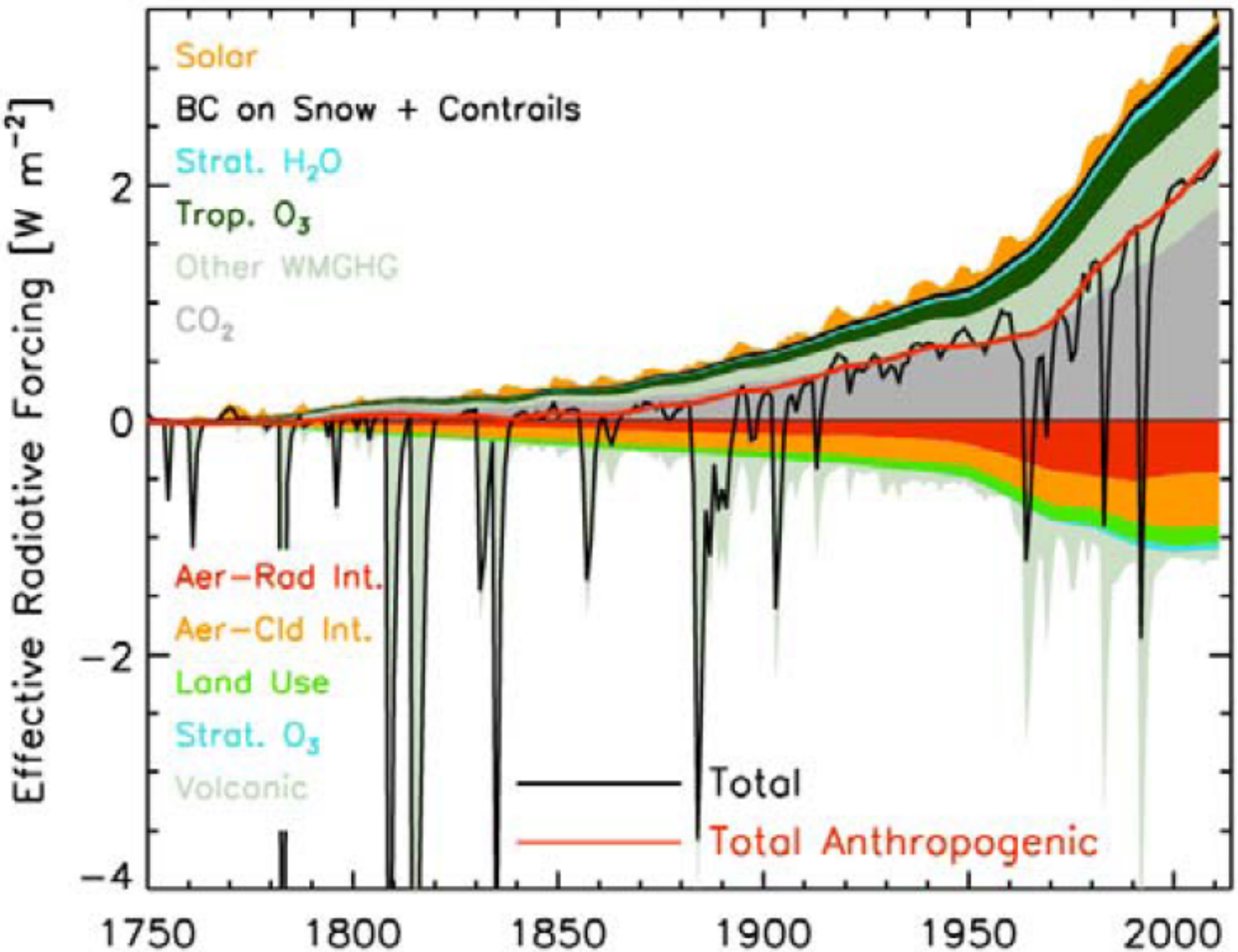


Figure SPM.5

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

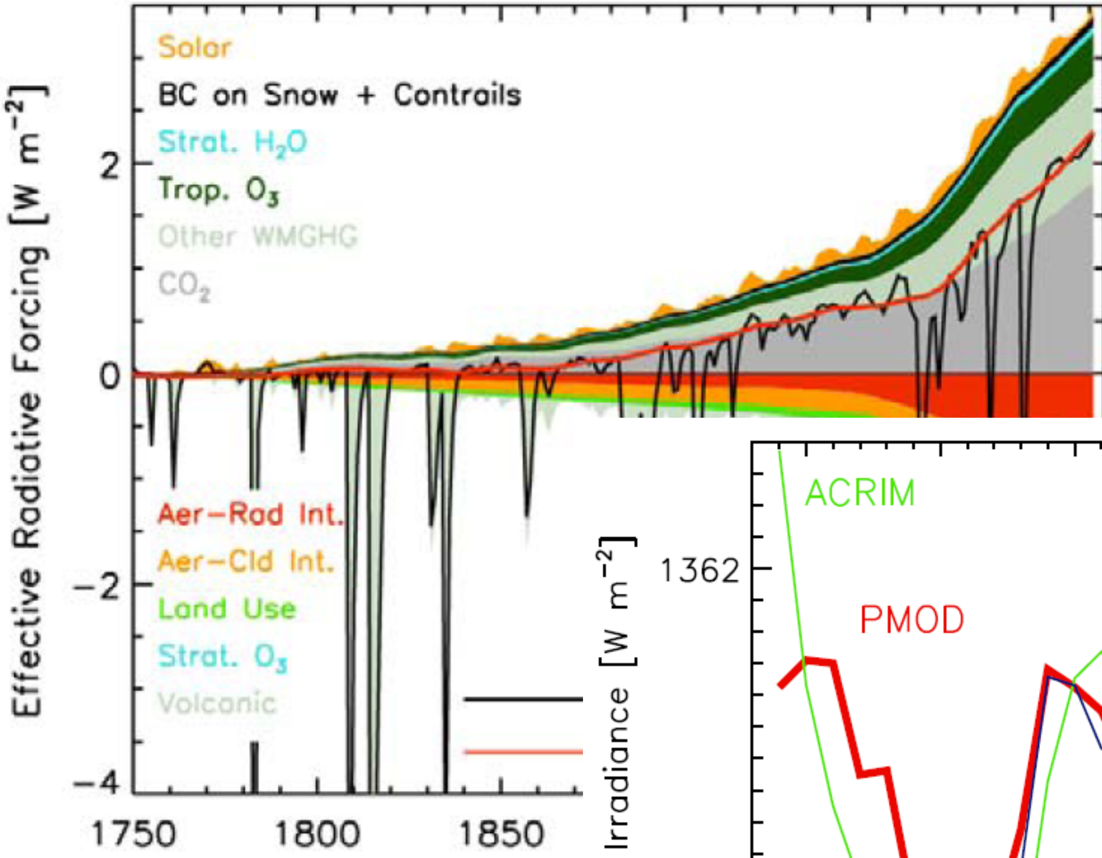
IPCC, WGI AR5, 2013 Policy maker

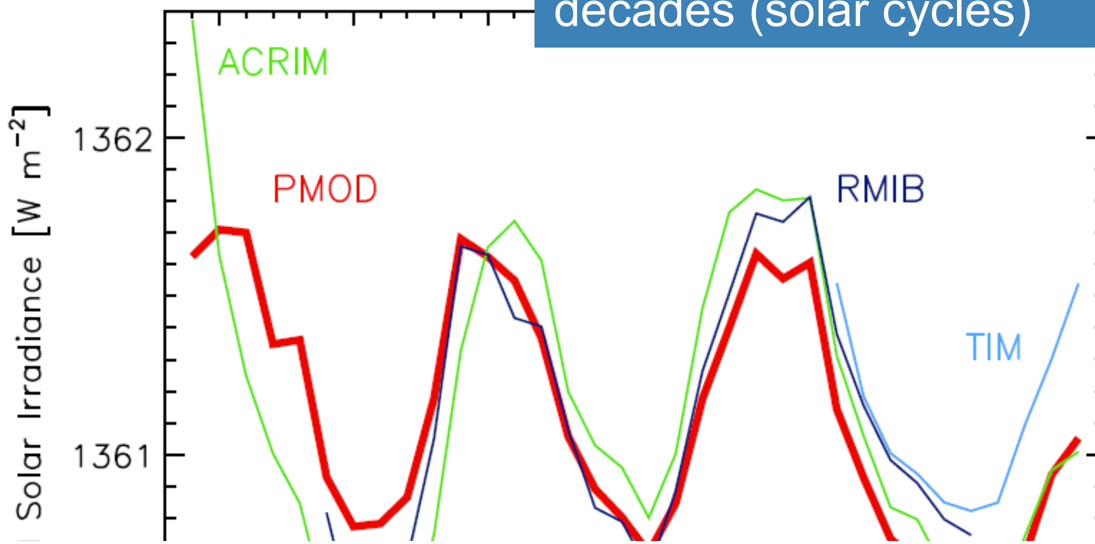


Steady increase for all drivers except volcanos

Strong increase in total anthropogenic forcing since 1970

CO_2 and other GHG clearly most important, but other contributions are significant





Solar radiation slightly weaker over the last few decades (solar cycles)

Total radiative forcing 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 (see Figure SPM.5). {3.2, Box 3.1, 8.3, 8.5}

From emissions to climate change

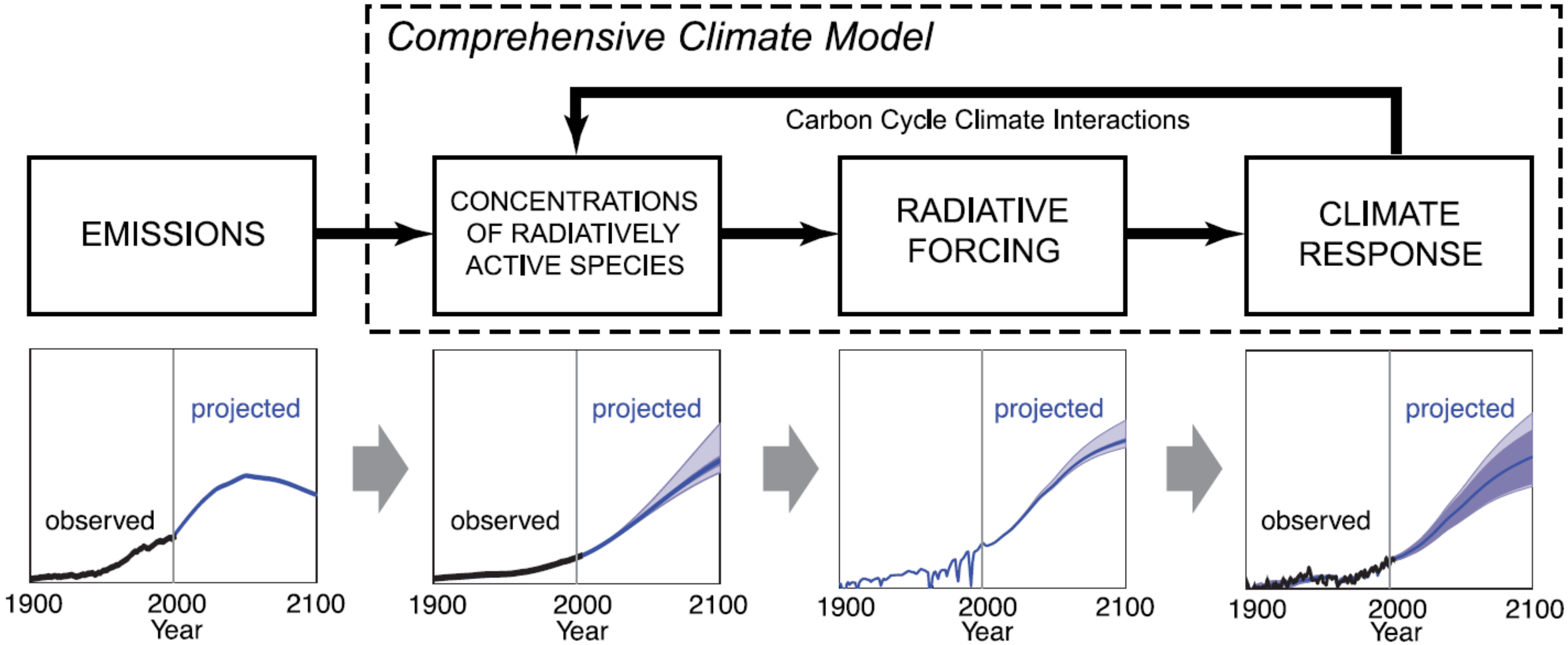
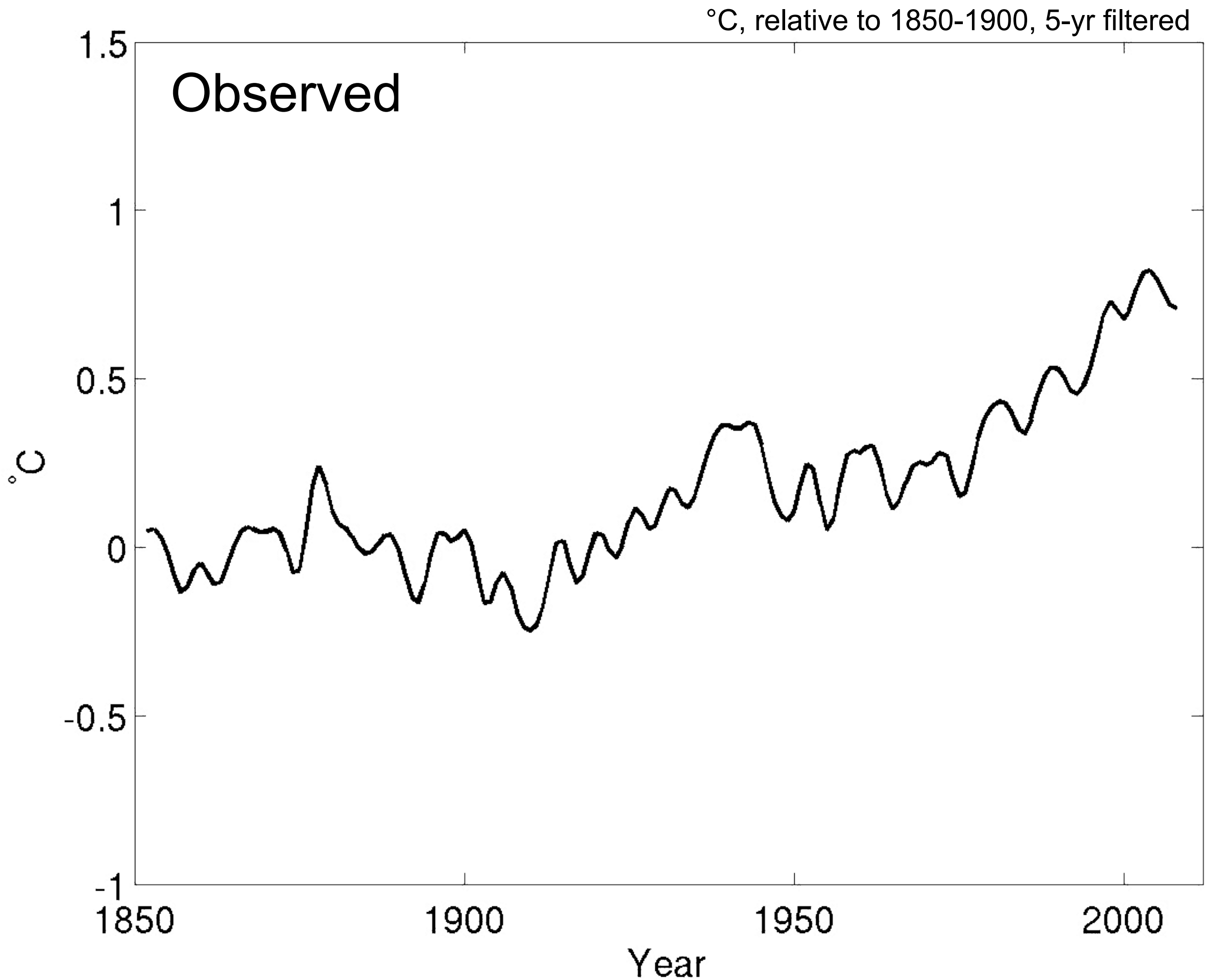


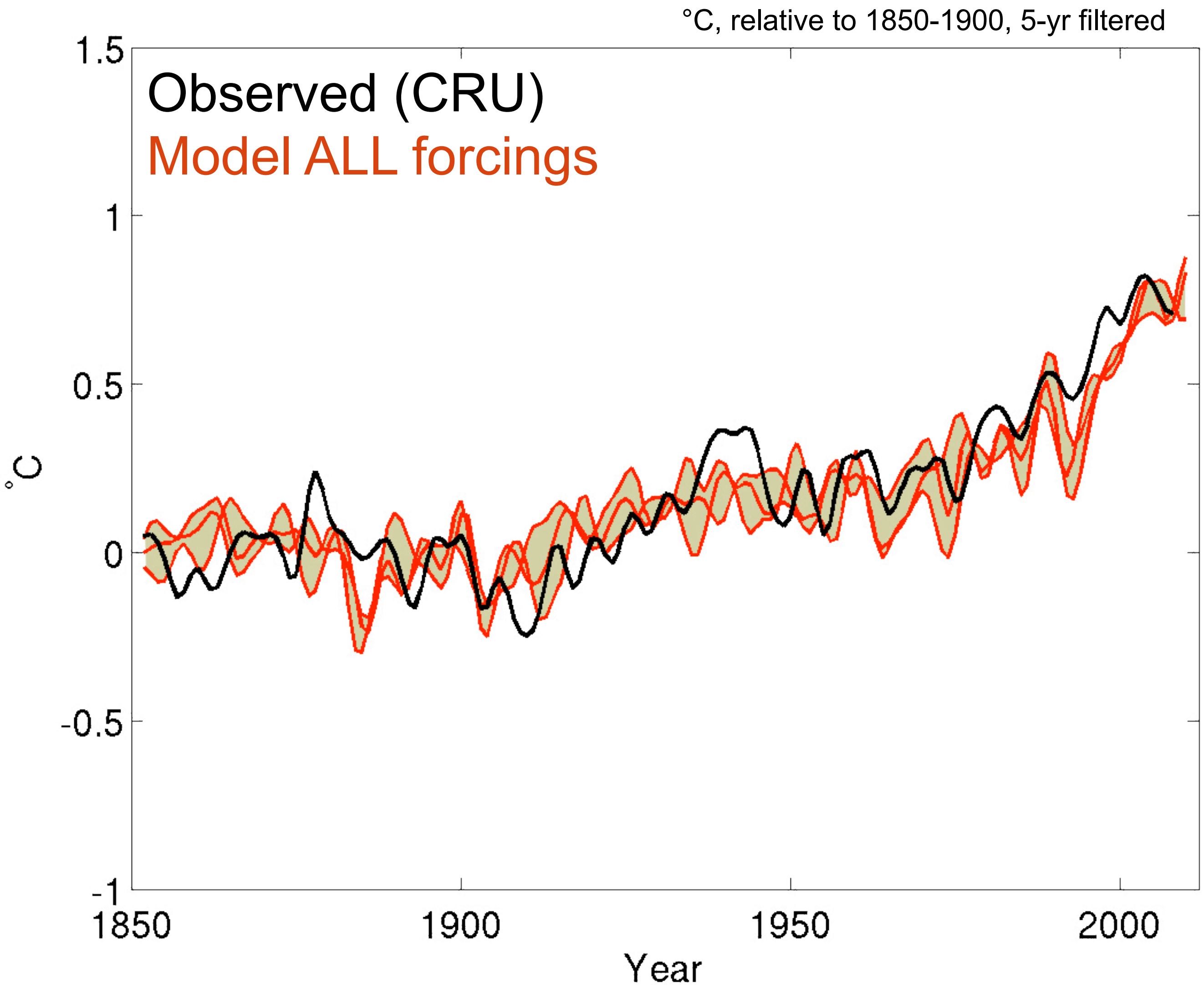
Figure 10.1. *Several steps from emissions to climate response contribute to the overall uncertainty of a climate model projection. These uncertainties can be quantified through a combined effort of observation, process understanding, a hierarchy of climate models, and ensemble simulations. In a comprehensive climate model, physical and chemical representations of processes permit a consistent quantification of uncertainty. Note that the uncertainty associated with the future emission path is of an entirely different nature and not addressed in Chapter 10. Bottom row adapted from Figure 10.26, A1B scenario, for illustration only.*

IPCC, 2007

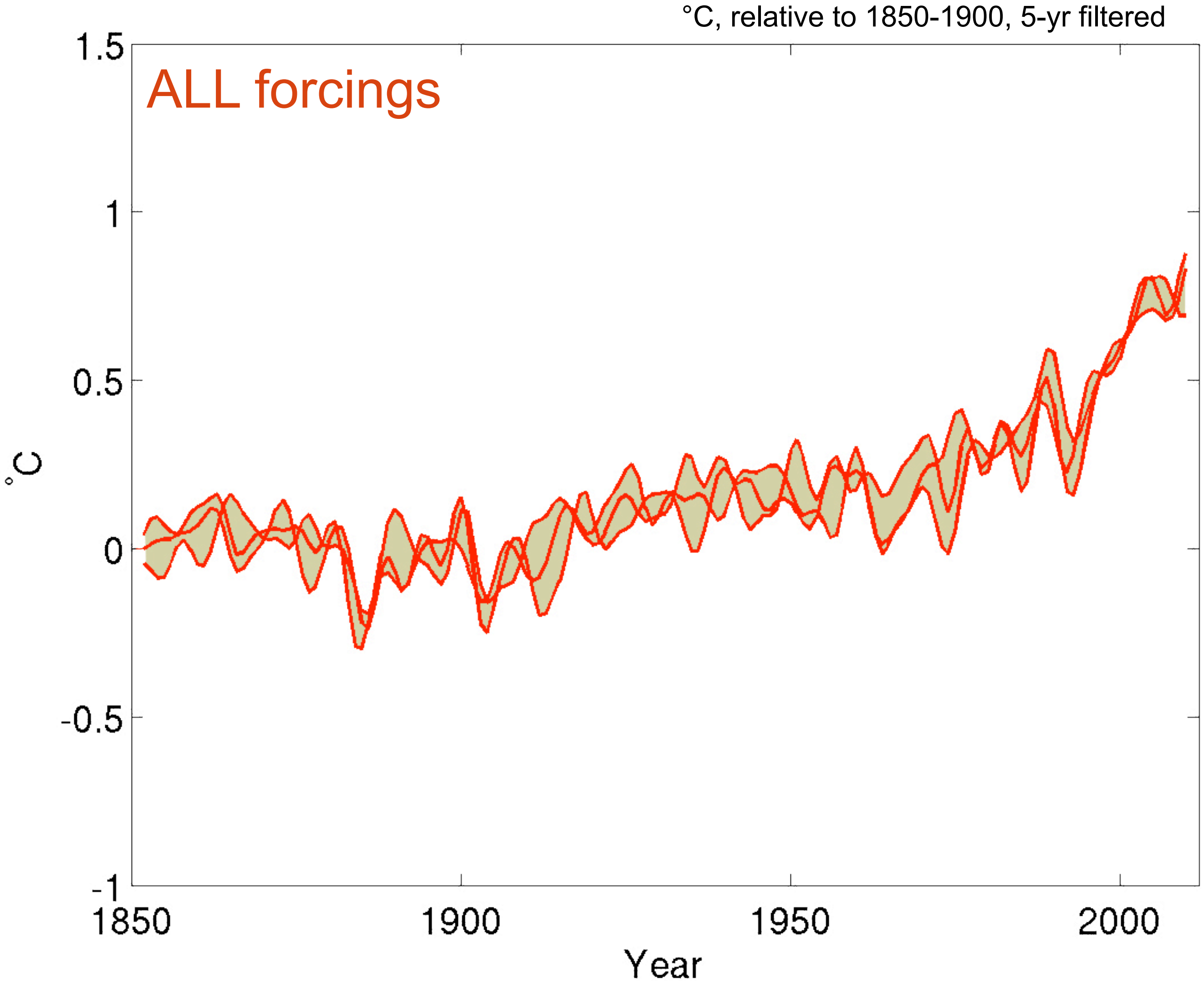
Simulated vs observed global temperature



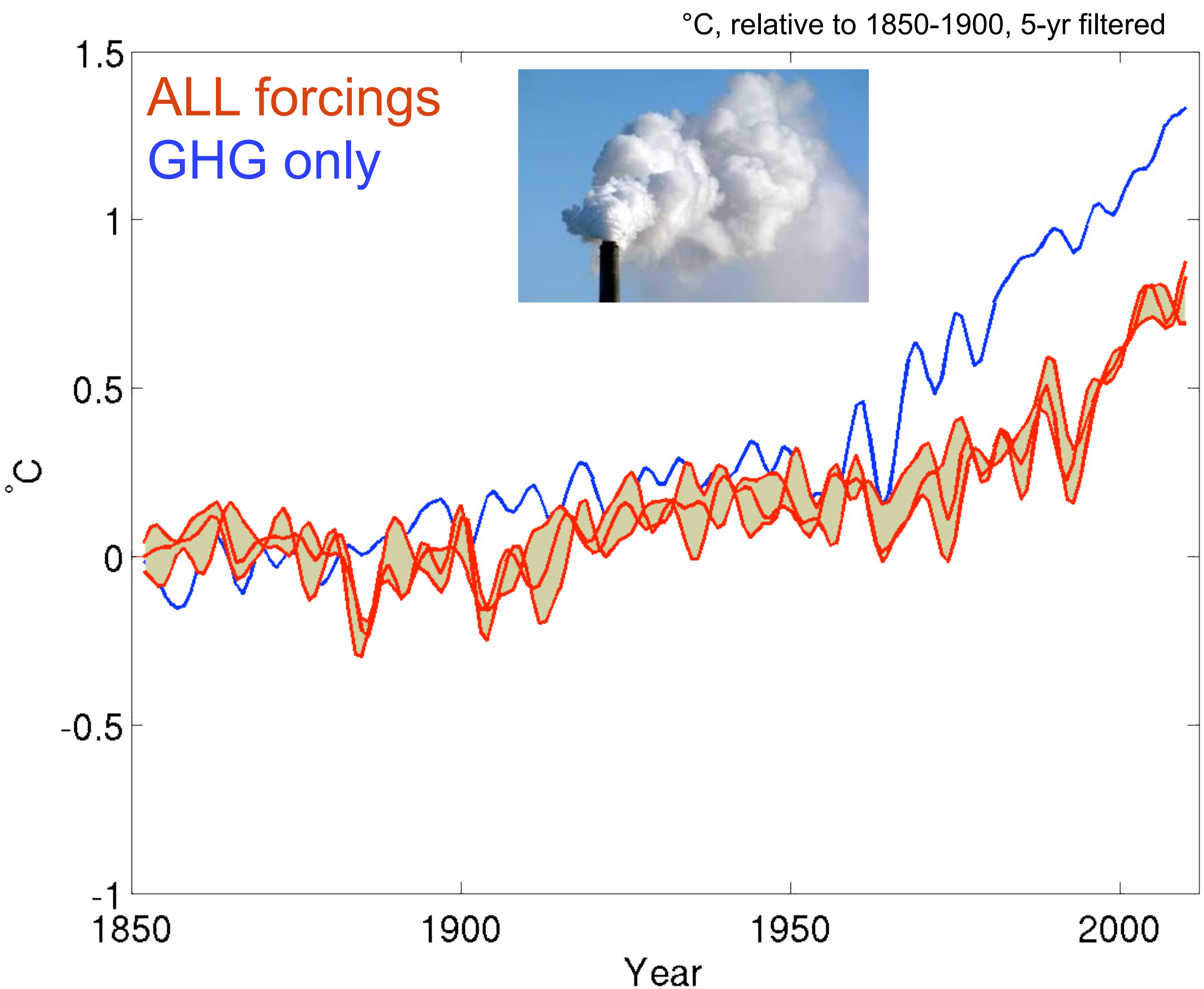
Simulated vs observed global temperature



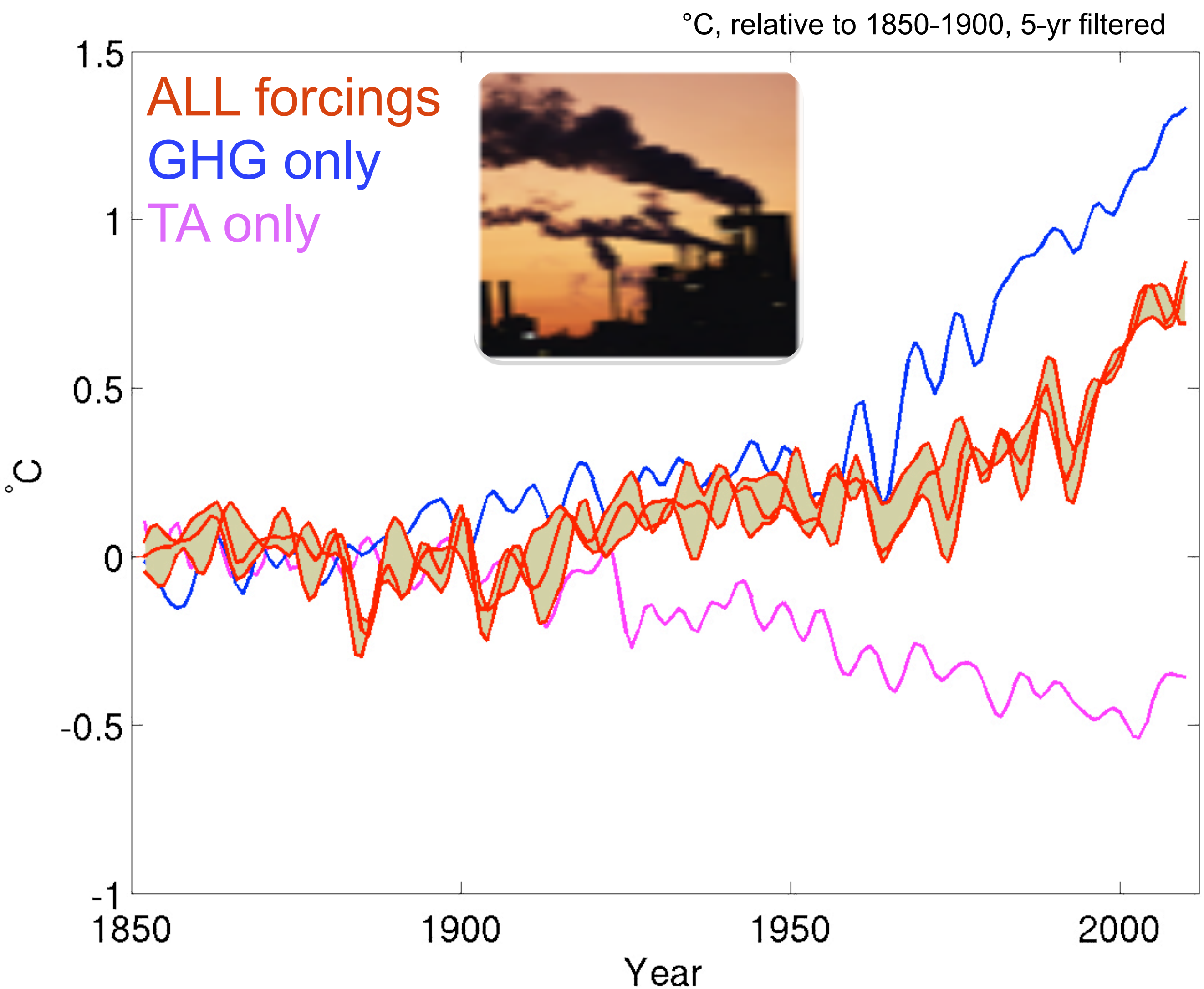
Natural vs. human-induced forcings



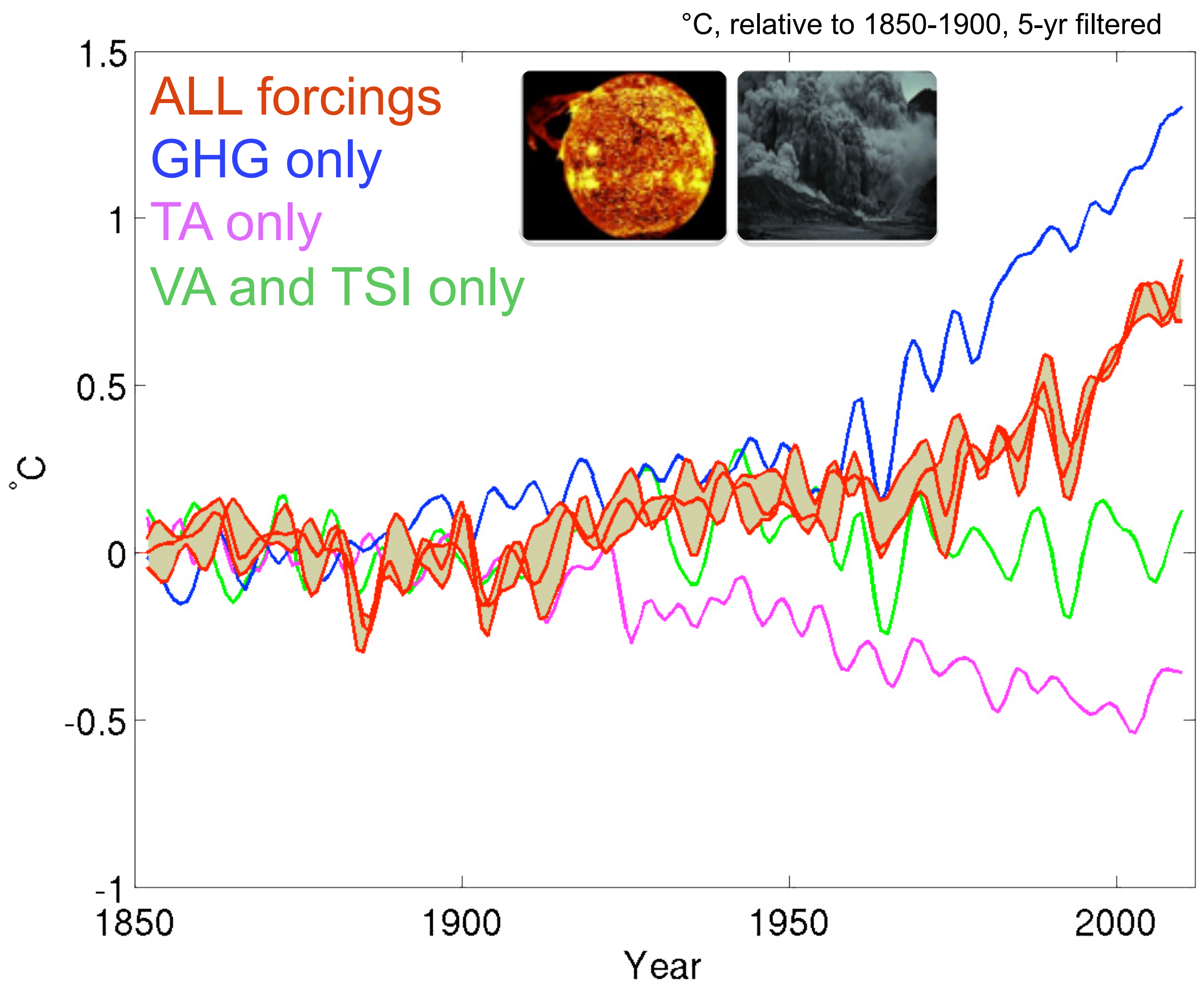
Natural vs human-induced forcings



Natural vs human-induced forcings



Natural vs human-induced forcings



Outline

- Observations
- What changes climate?
- How do we know?
- Why should we care?
  - a look on **projected future climate changes**

FUTURE CHANGES WILL DEPEND ON MANY FACTORS

The magnitude and rate of future climate change will primarily depend on the following factors:

1. The rate at which levels of greenhouse gas concentrations in our atmosphere continue to increase

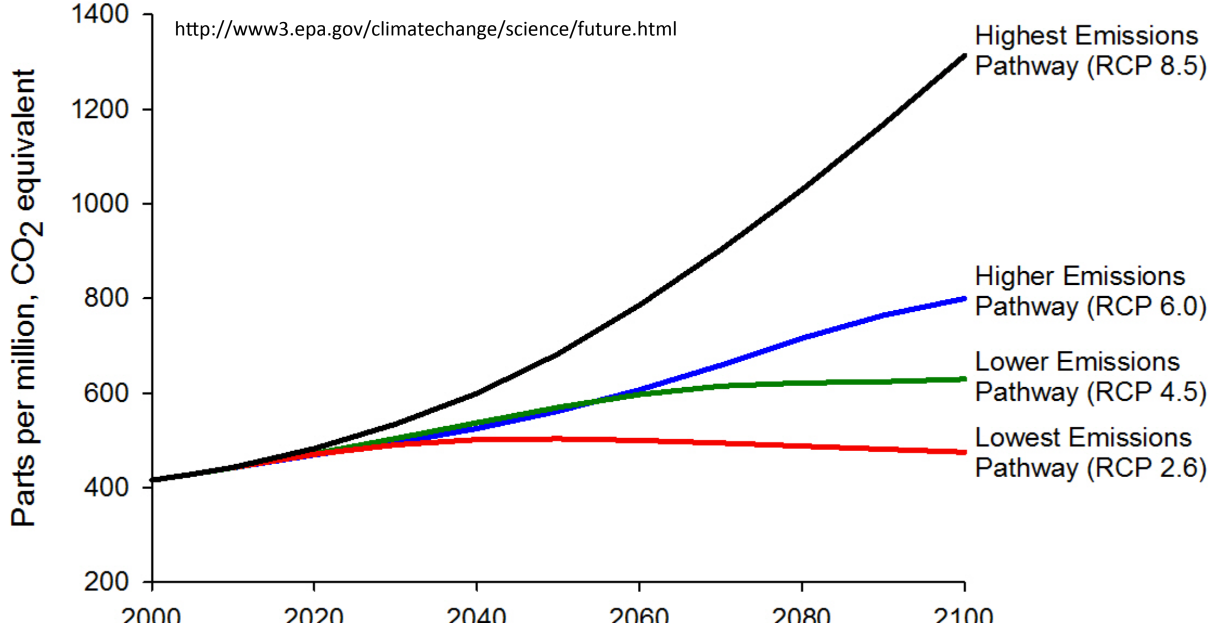
2. How strongly features of the climate (e.g., temperature, precipitation, and sea level**) respond to the expected increase** in greenhouse gas concentrations

3. Natural influences on climate (e.g., from volcanic activity and changes in the sun's intensity) and natural processes within the climate system (e.g., changes in ocean circulation patterns)

Scientists use computer models of the climate system to better understand these issues and **project future climate changes**.

EMISSIONS PATHWAYS

Source: Graph created from data in the Representative Concentration Pathways Database (Version 2.0.5)



projected greenhouse gas concentrations for four different emissions pathways (RCP).

TOP: pathway assumes that greenhouse gas emissions will **continue to rise** throughout the current century.

BOTTOM: pathway assumes that emissions reach a peak between 2010 and 2020, **declining** thereafter.

SETTING TEMPERATURE RISE GOALS

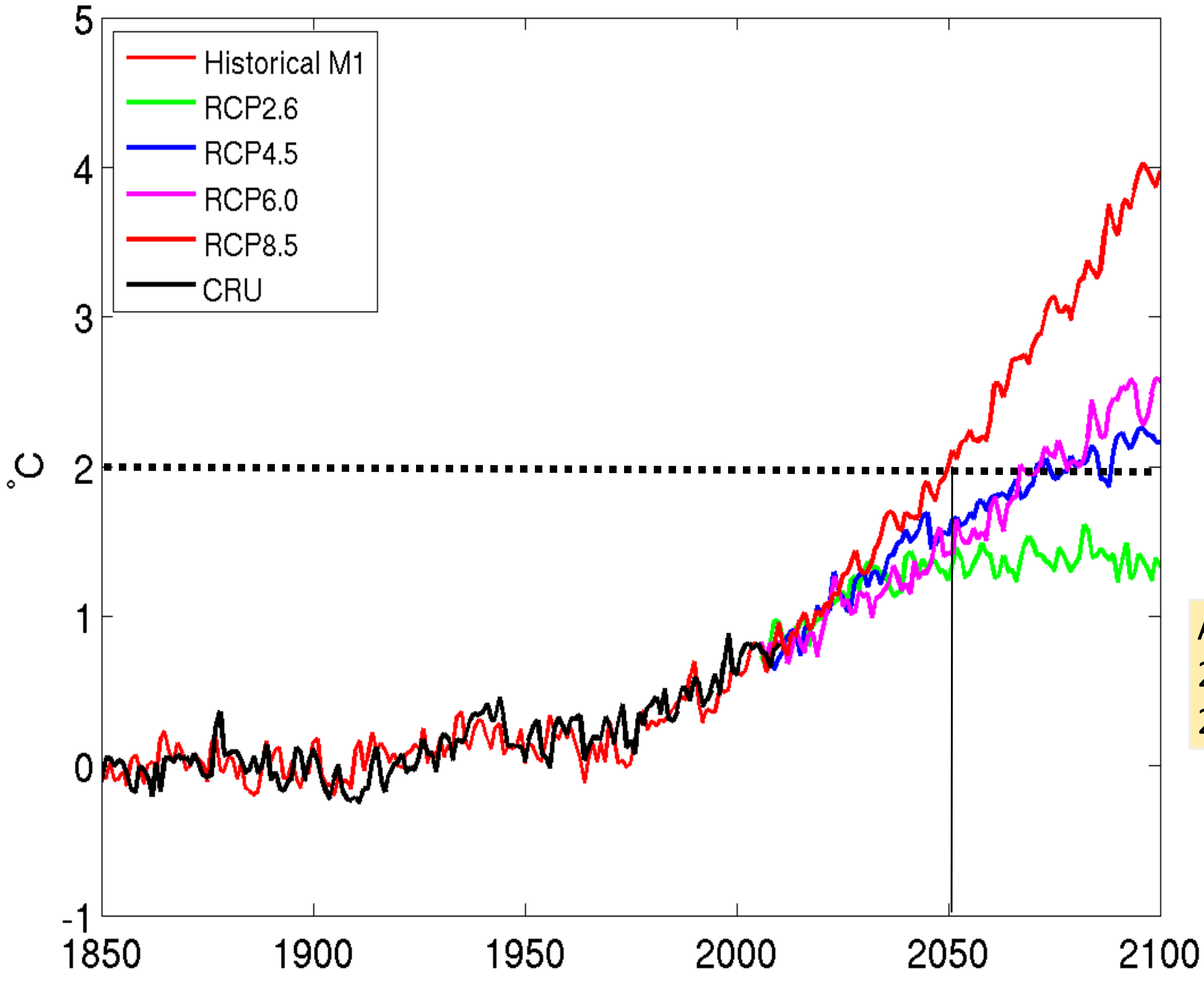
- Limiting the average global surface temperature increase of 2°C over the pre-industrial average has, since the 1990s, been commonly regarded as an adequate means of avoiding dangerous climate change, in science and policy making.

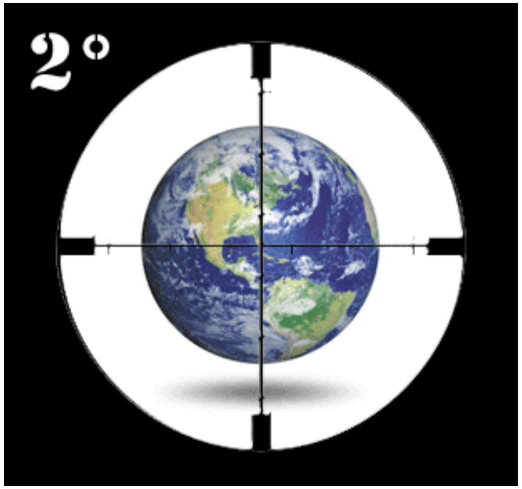
dried-up bed of a reservoir in Sanyuan county, Shaanxi province July 30, 2014

Limiting global warming to 2 degrees 'inadequate', scientists say

http://www.unep.org/publications/ebooks/emissionsgapreport/chapter1.asp

Simulated future global temperature change

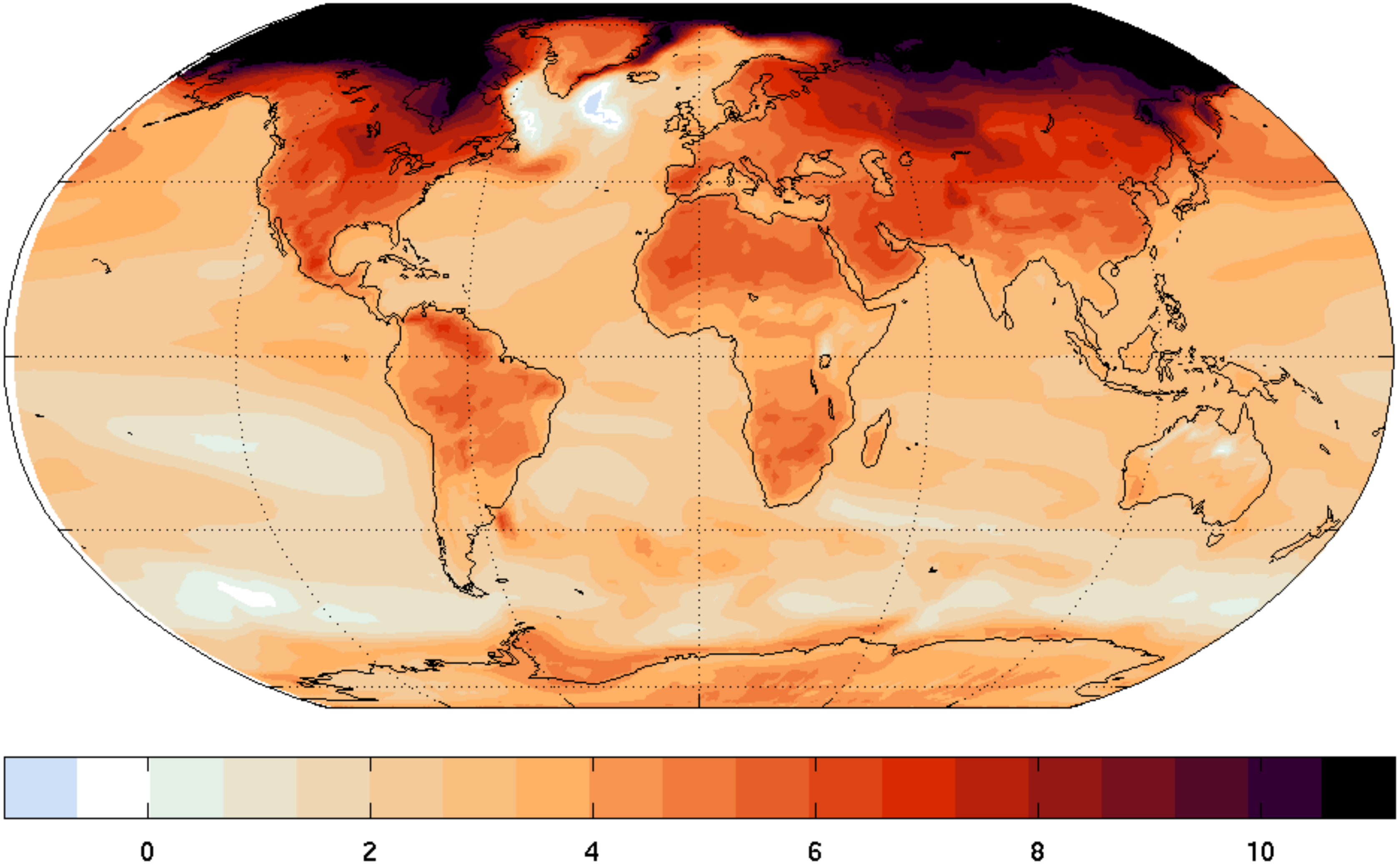




According to NorESM only RCP 2.6 pathway keeps us below 2°C global warming

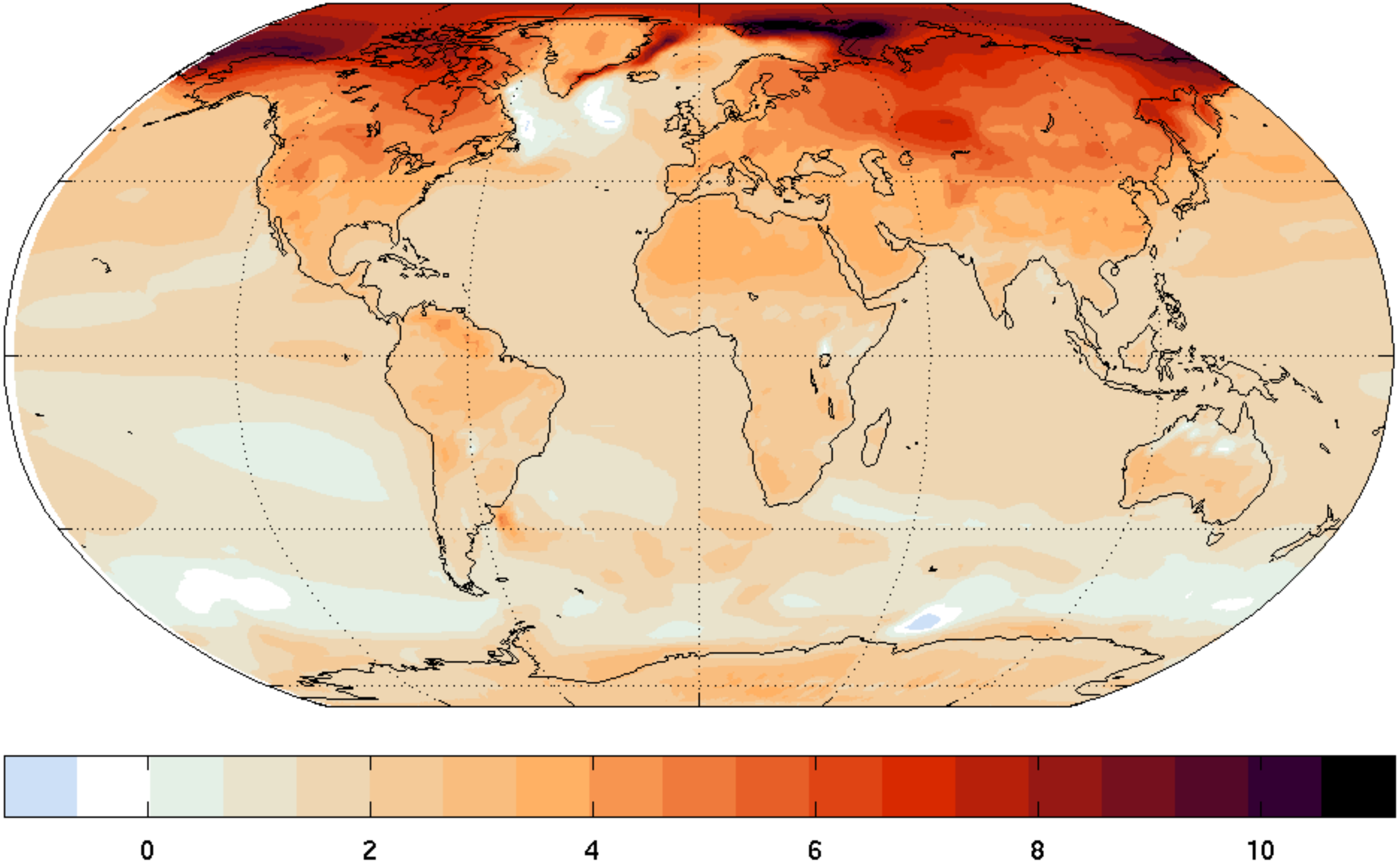
Simulated change in surface temperature, RCP8.5
RCP: representative concentrations pathaways

°C, 2090-2099 vs 1961-1990



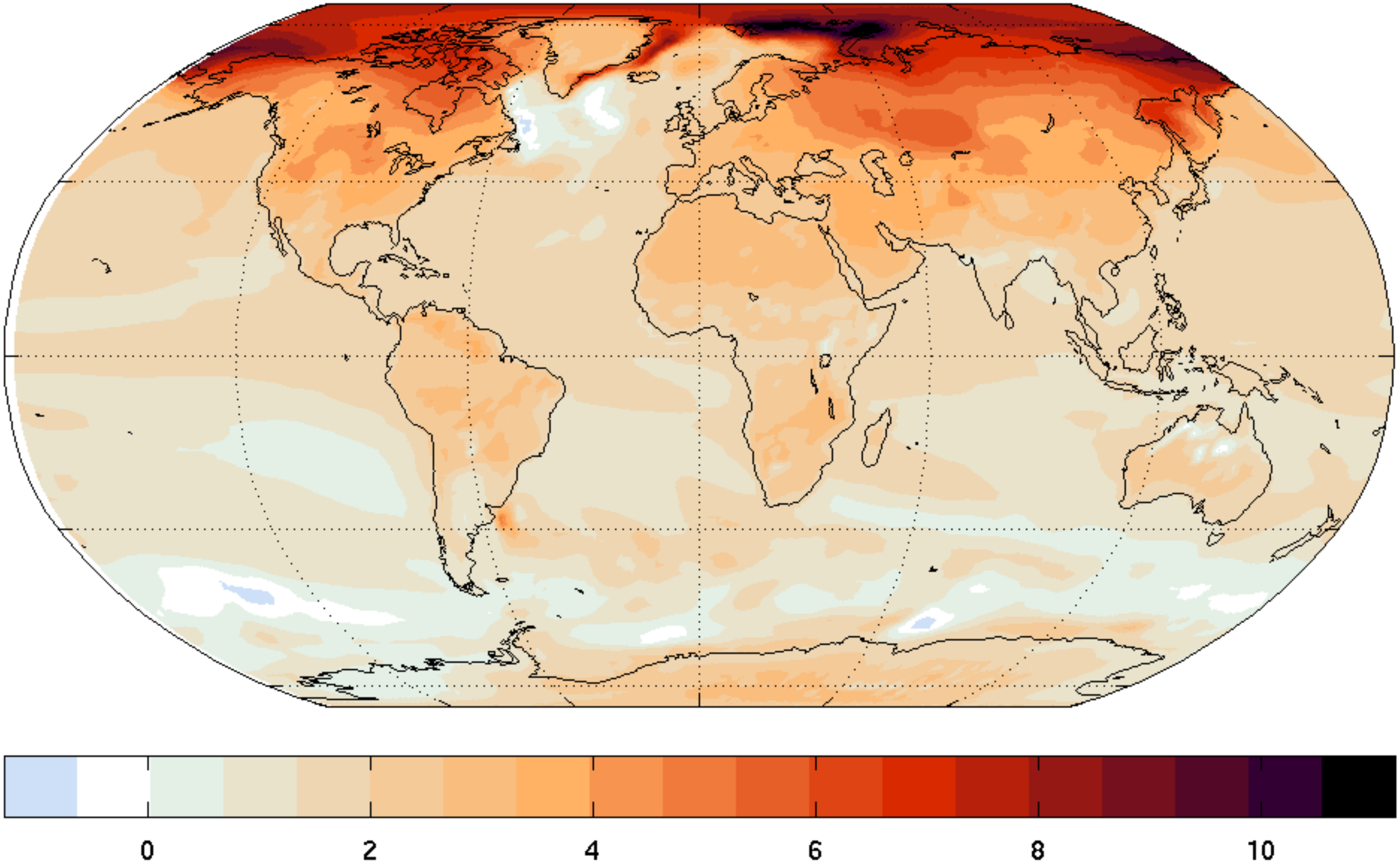
Simulated change in surface temperature, RCP6.0

°C, 2090-2099 vs 1961-1990



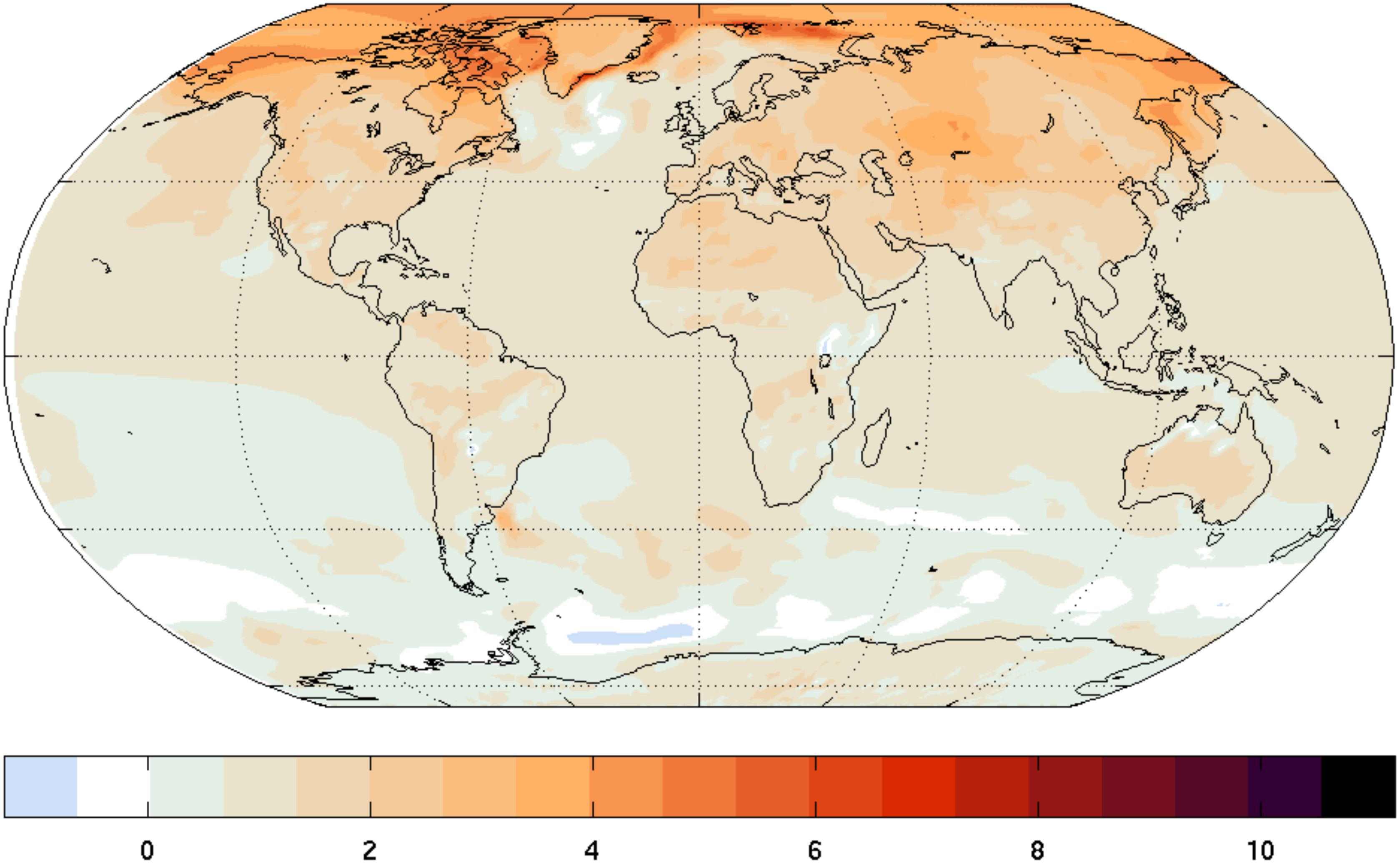
Simulated change in surface temperature, RCP4.5

°C, 2090-2099 vs 1961-1990



Simulated change in surface temperature, RCP2.6

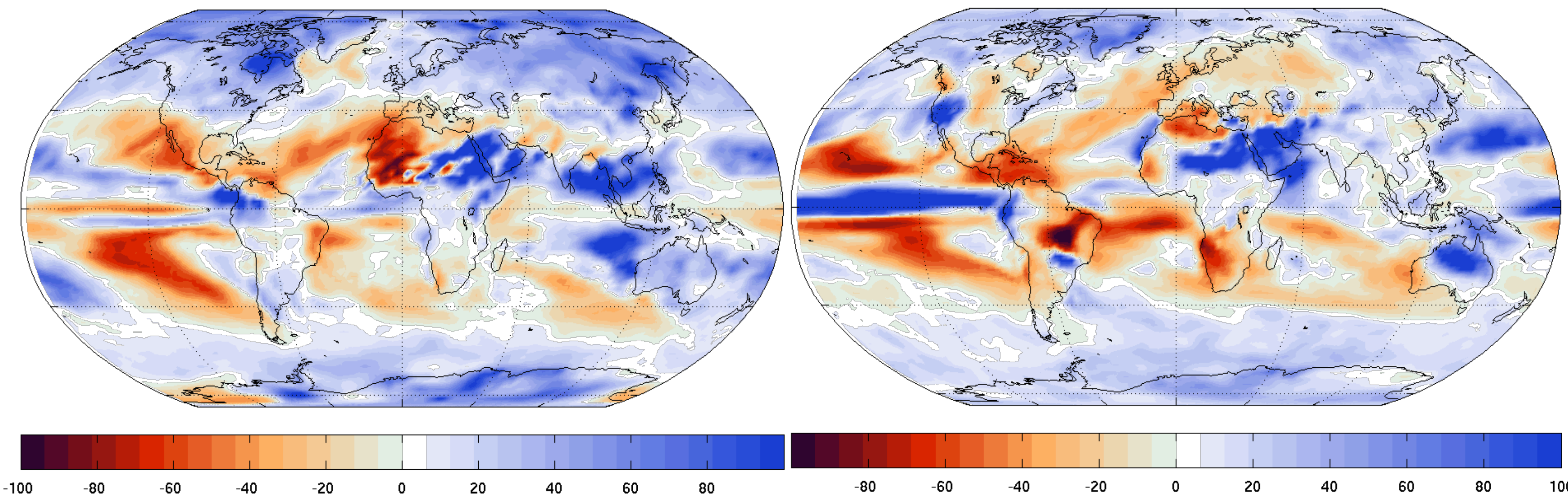
°C, 2090-2099 vs 1961-1990



Simulated change in precipitation, RCP8.5

%, 2080-99 vs 1961-1990

DJF **JJA**



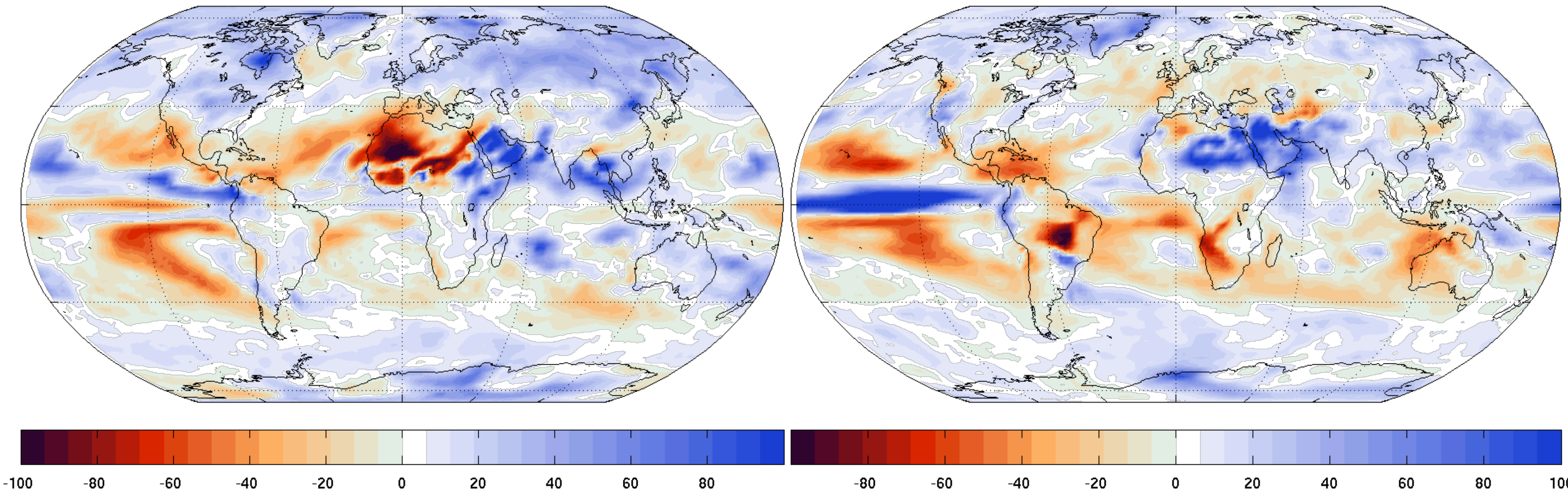
Increase: Mostly in the tropics and at mid/high latitudes

Decrease: Mostly in the sub-tropics (pushing sub-tropics towards mid latitides

Simulated change in precipitation, RCP6.0

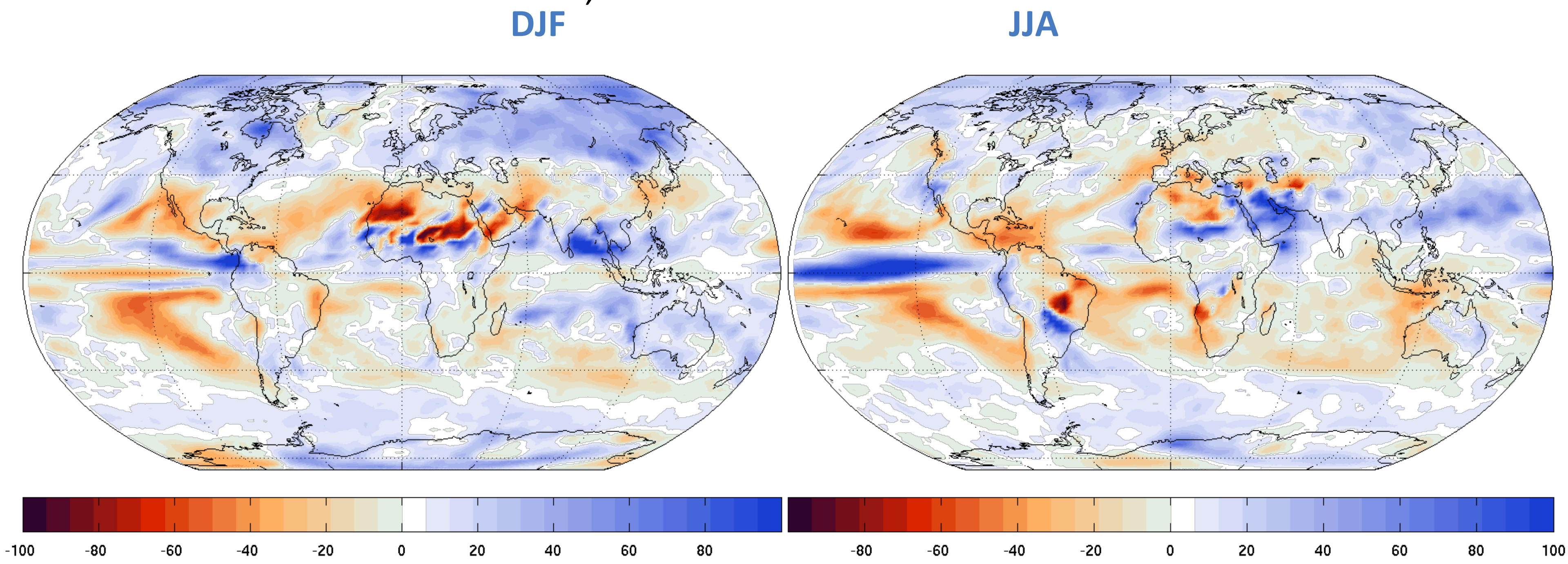
%, 2080-99 vs 1961-1990

DJF **JJA**



Simulated change in precipitation, RCP4.5

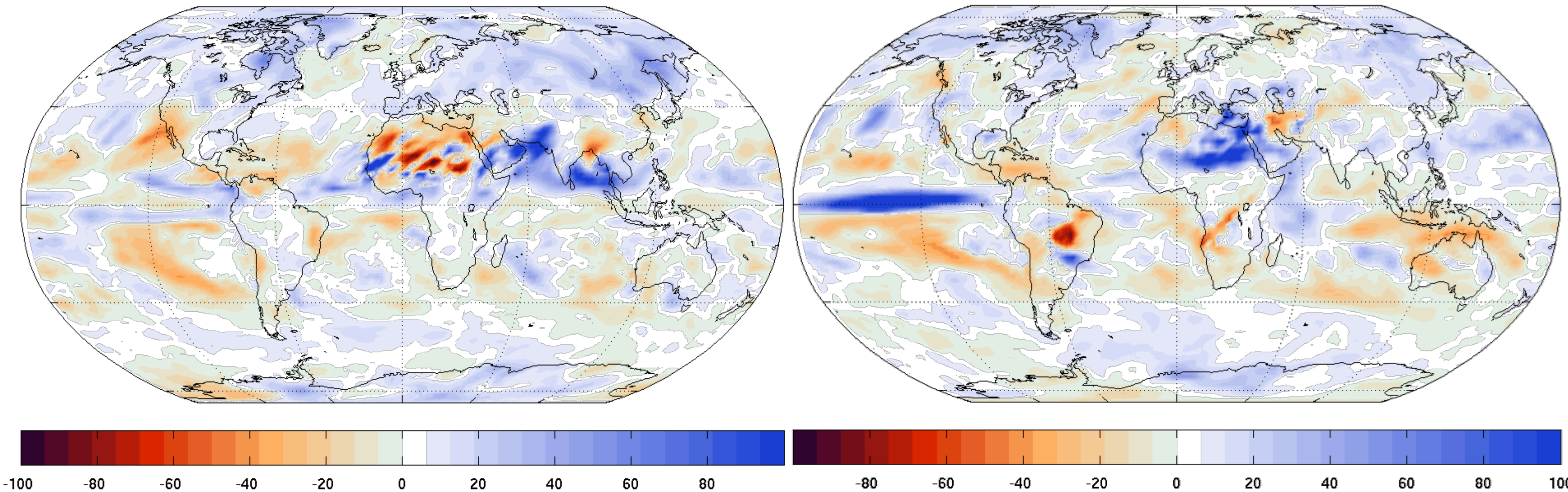
%, 2080-99 vs 1961-1990



Simulated change in precipitation, RCP2.6

%, 2080-99 vs 1961-1990

DJF **JJA**



Climate models with anthropogenic and natural climate forcings

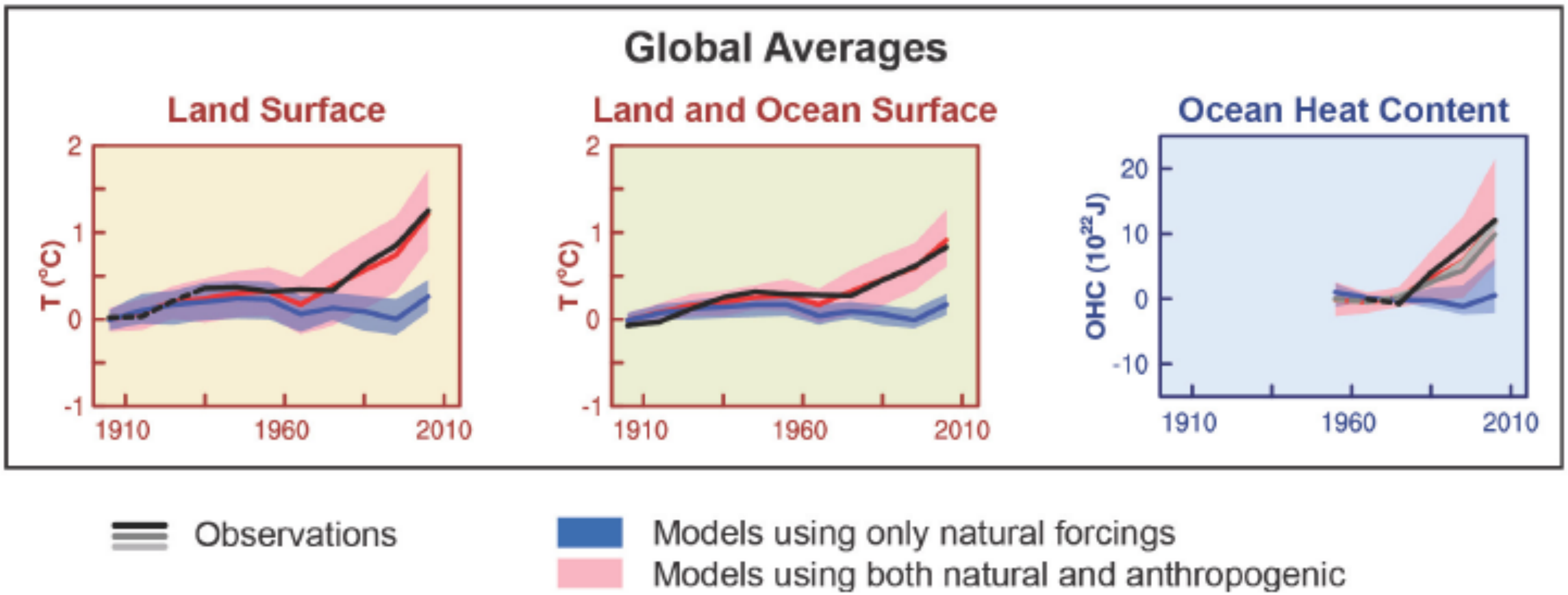


Figure SPM.6

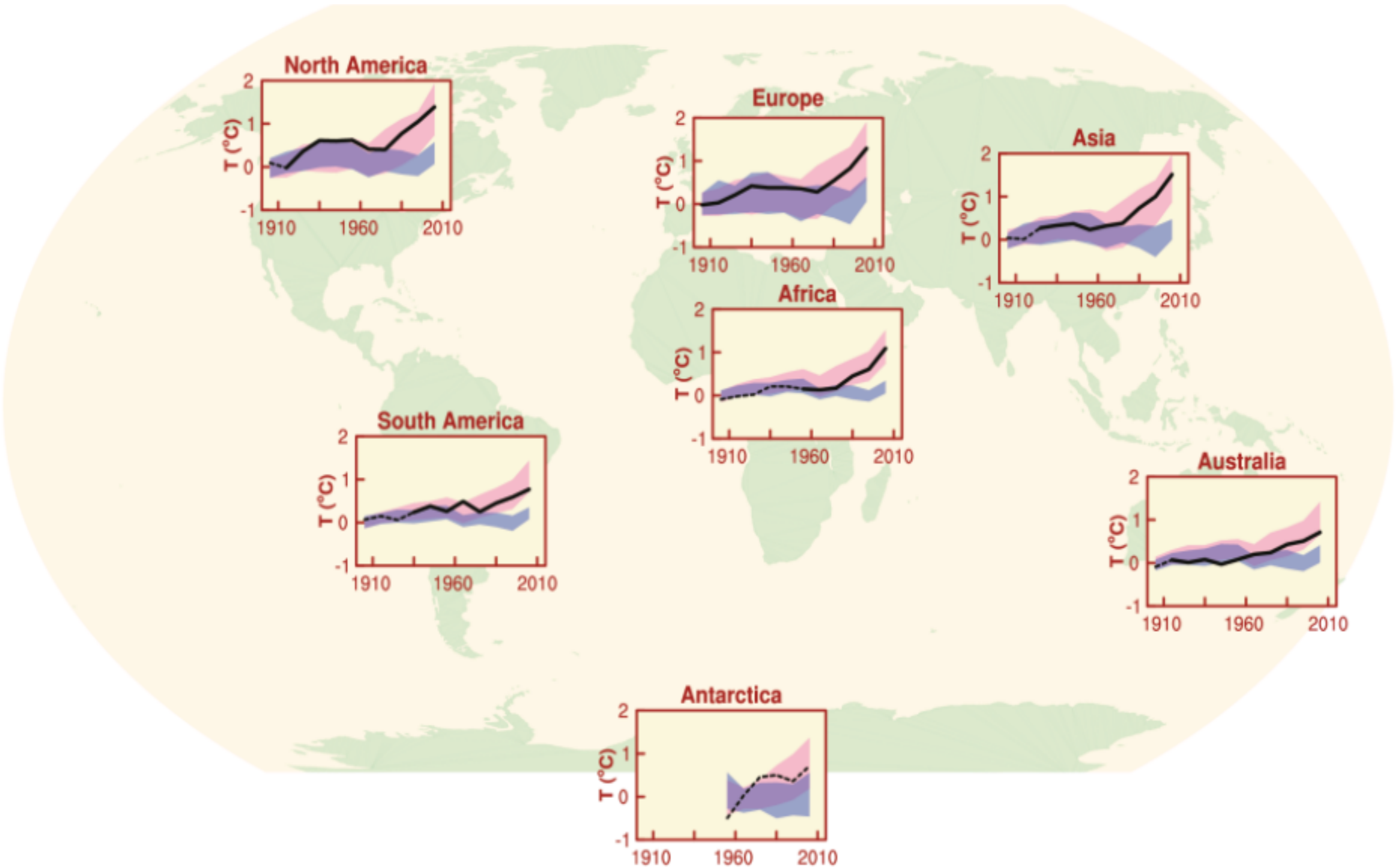
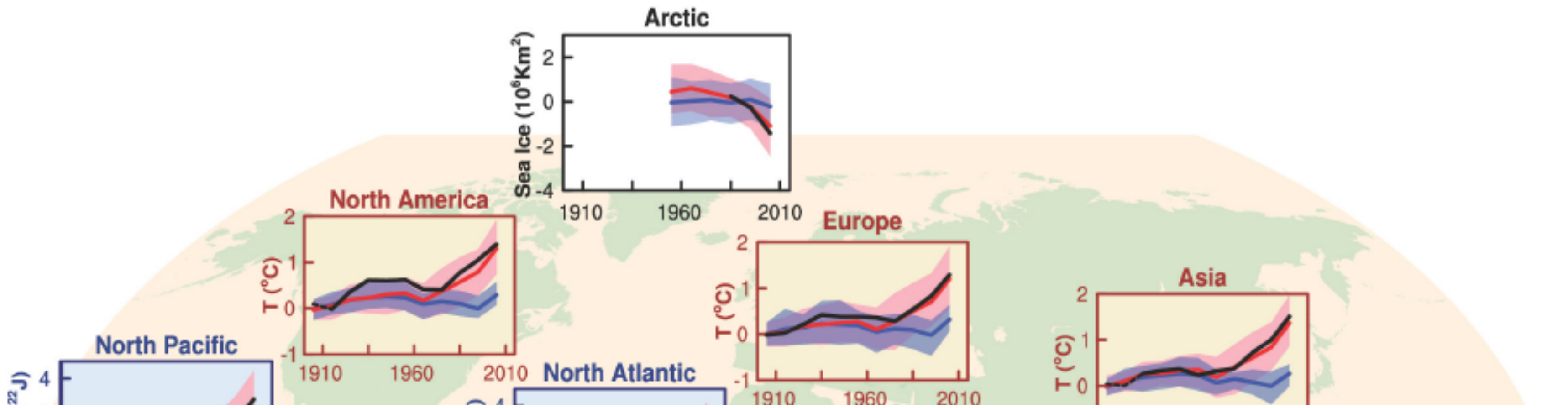

North America
Europe
Asia
Africa
South America
Australia
Antarctica
T (°C)
2
1
0
-1
1910
1960
2010
Observations
Models using only natural forcings
Models using both natural and anthropogenic

Figure SPM.6



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 (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}

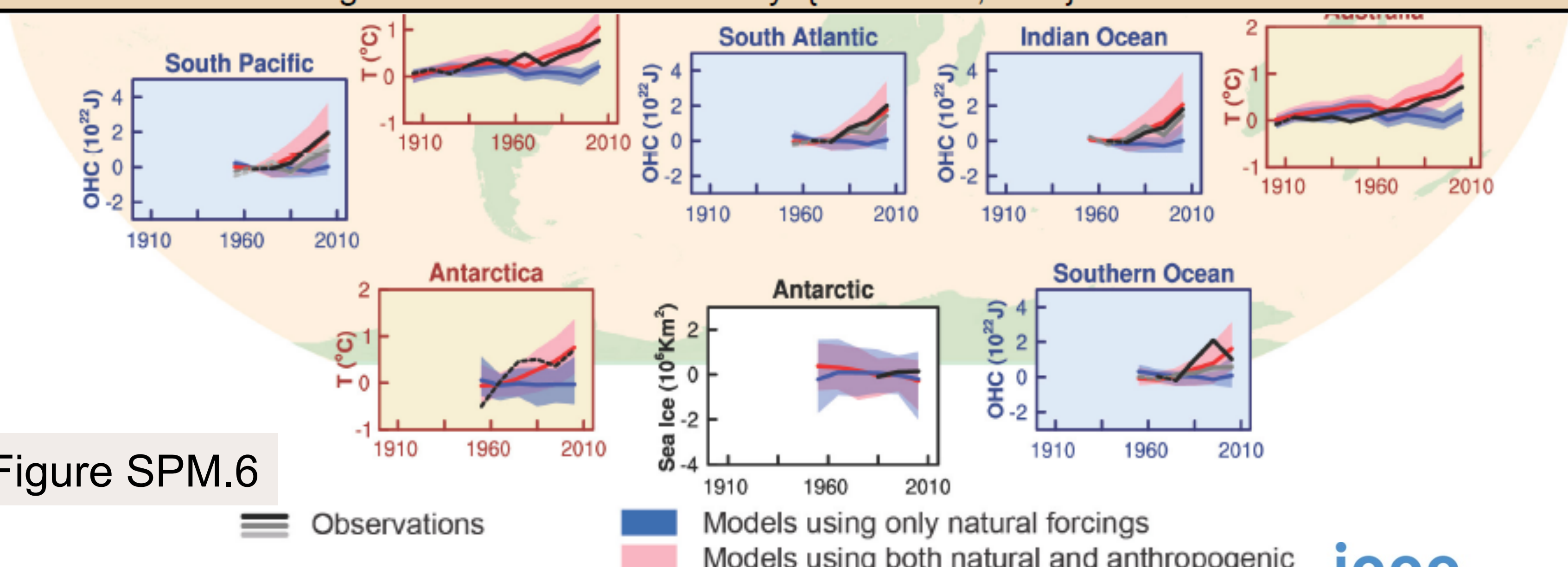
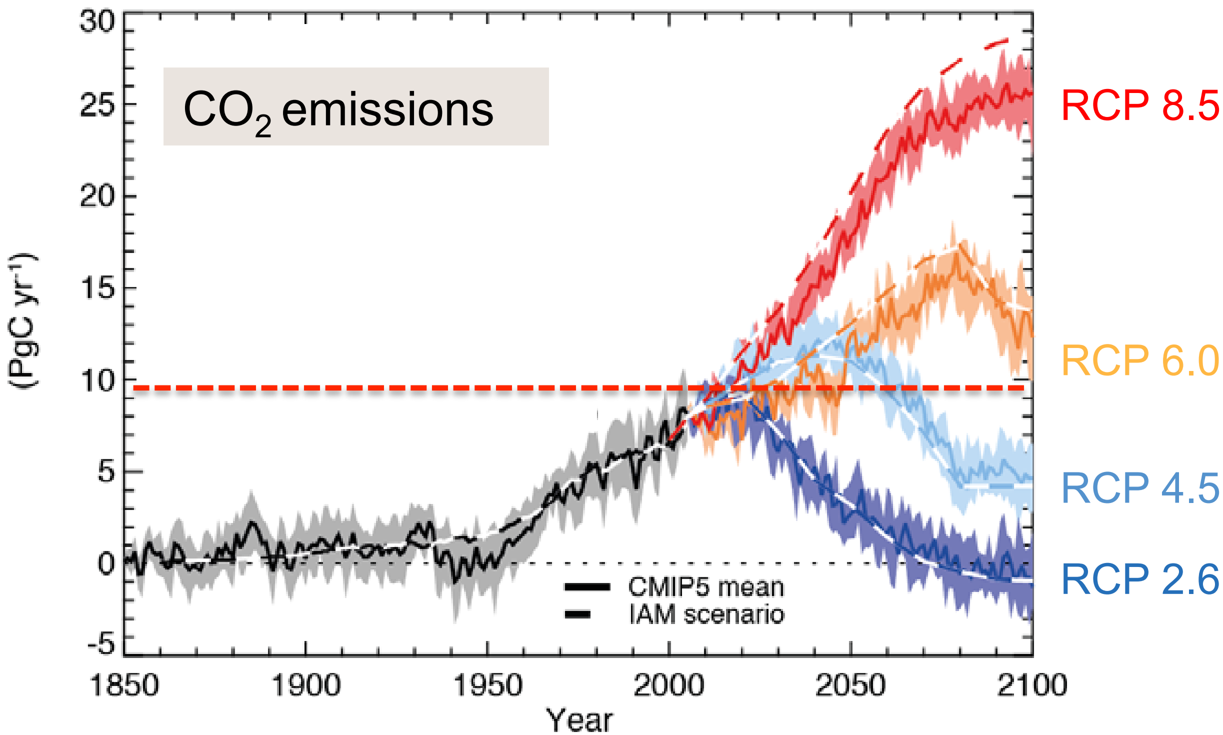


Figure SPM.6

Future changes



Future estimates based on 4 Representative Concentration Pathways (RCPs)

Likelihood are not given for any RCP

The development of CO_2 over the last decade is closest to RCP8.5

RCP2.6 particularly useful related to the 2 degree target

Future changes

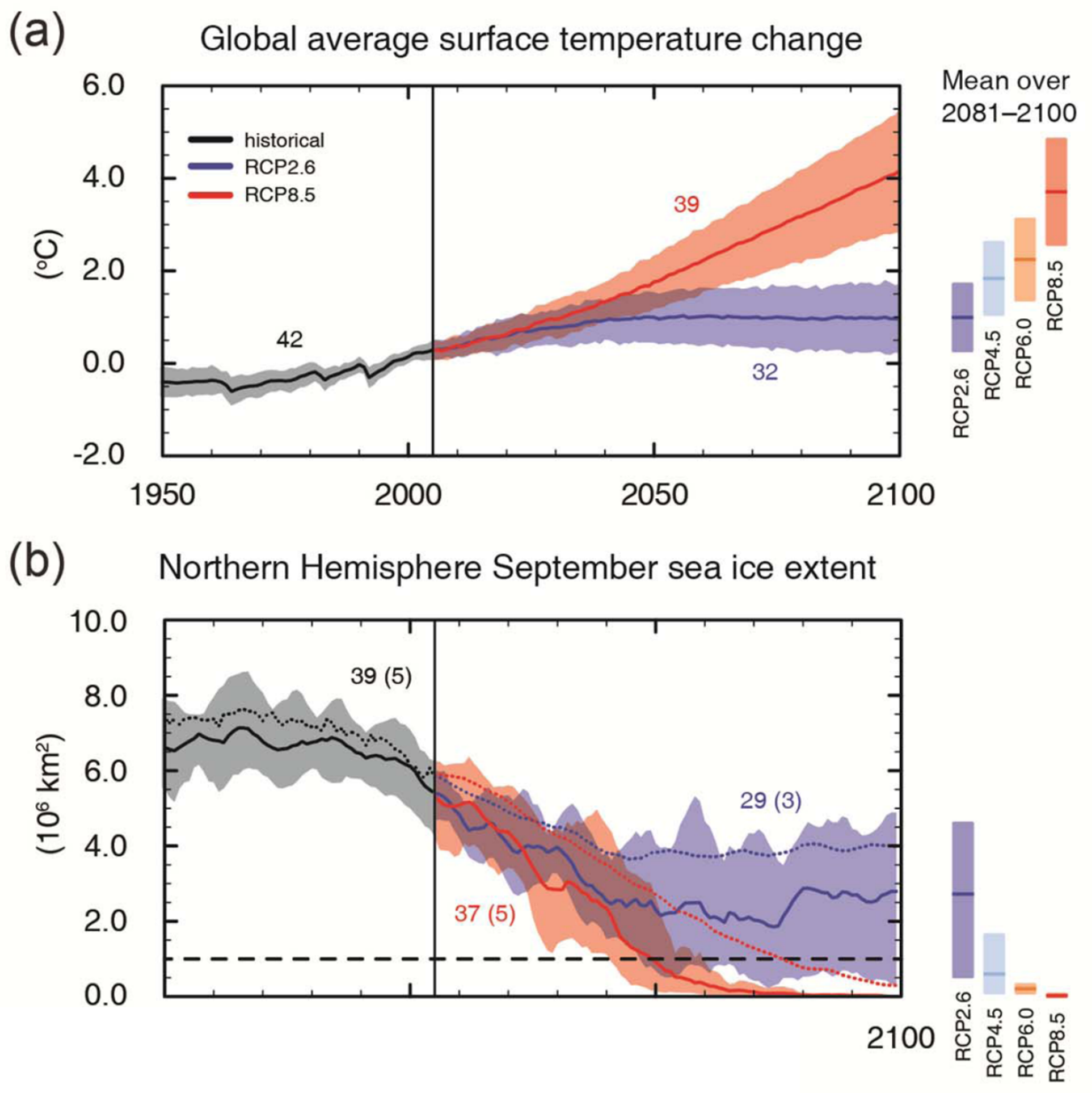


Figure SPM7

RCP 8.5 warming 2081-2100: 3.7 (2.6 to 4.8) °C relative to 1986-2005

RCP 2.6 warming 2081-2100: 1.0 (0.3 to 1.7) °C relative to 1986-2005

Observed warming 1986-2005: 0.61 (0.55 to 0.67) °C

Models that best reproduce trend 1979-2012 imply a near ice free Arctic ocean during summer is *likely* by middle of this century

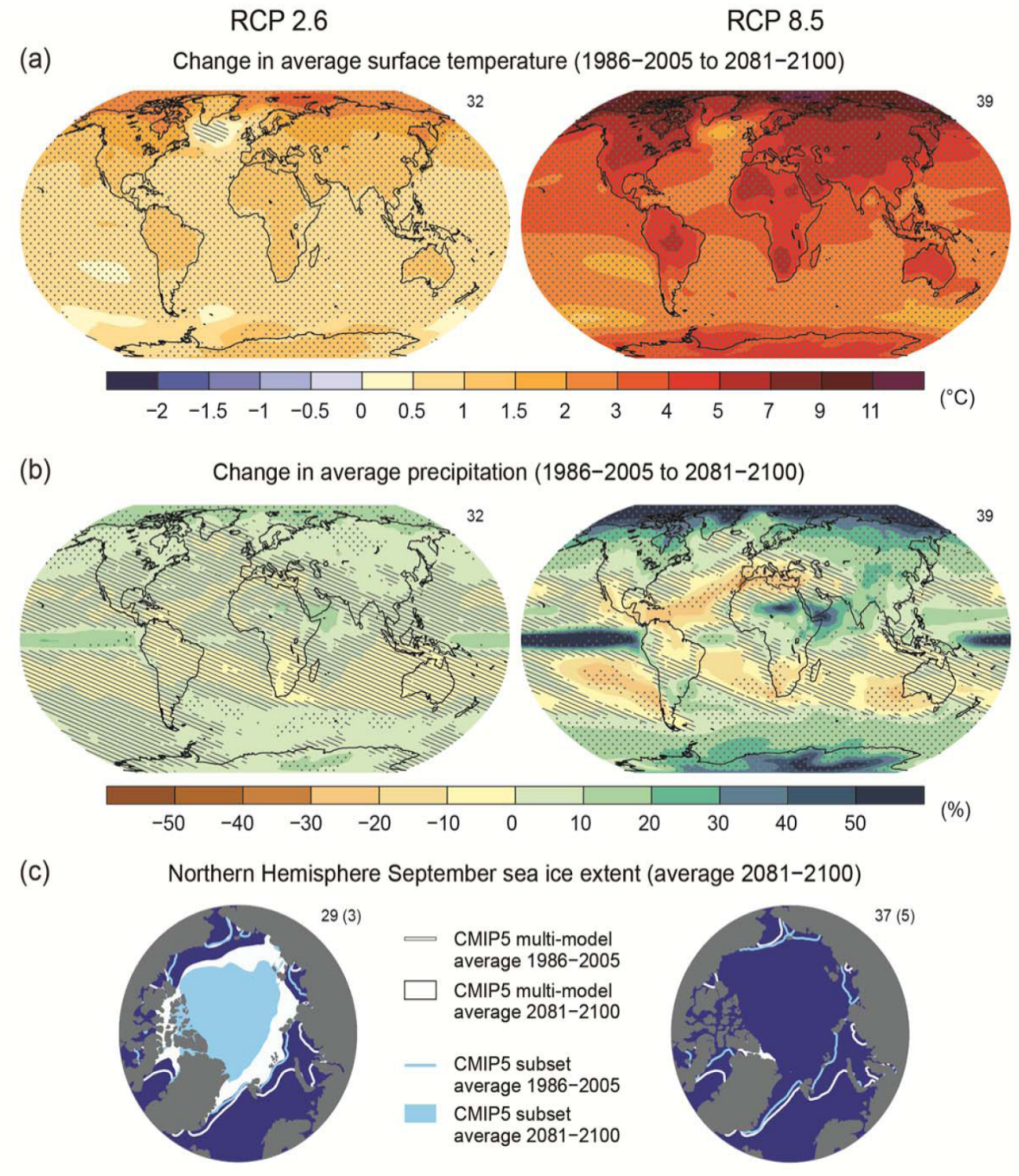


Figure SPM8

Temperature

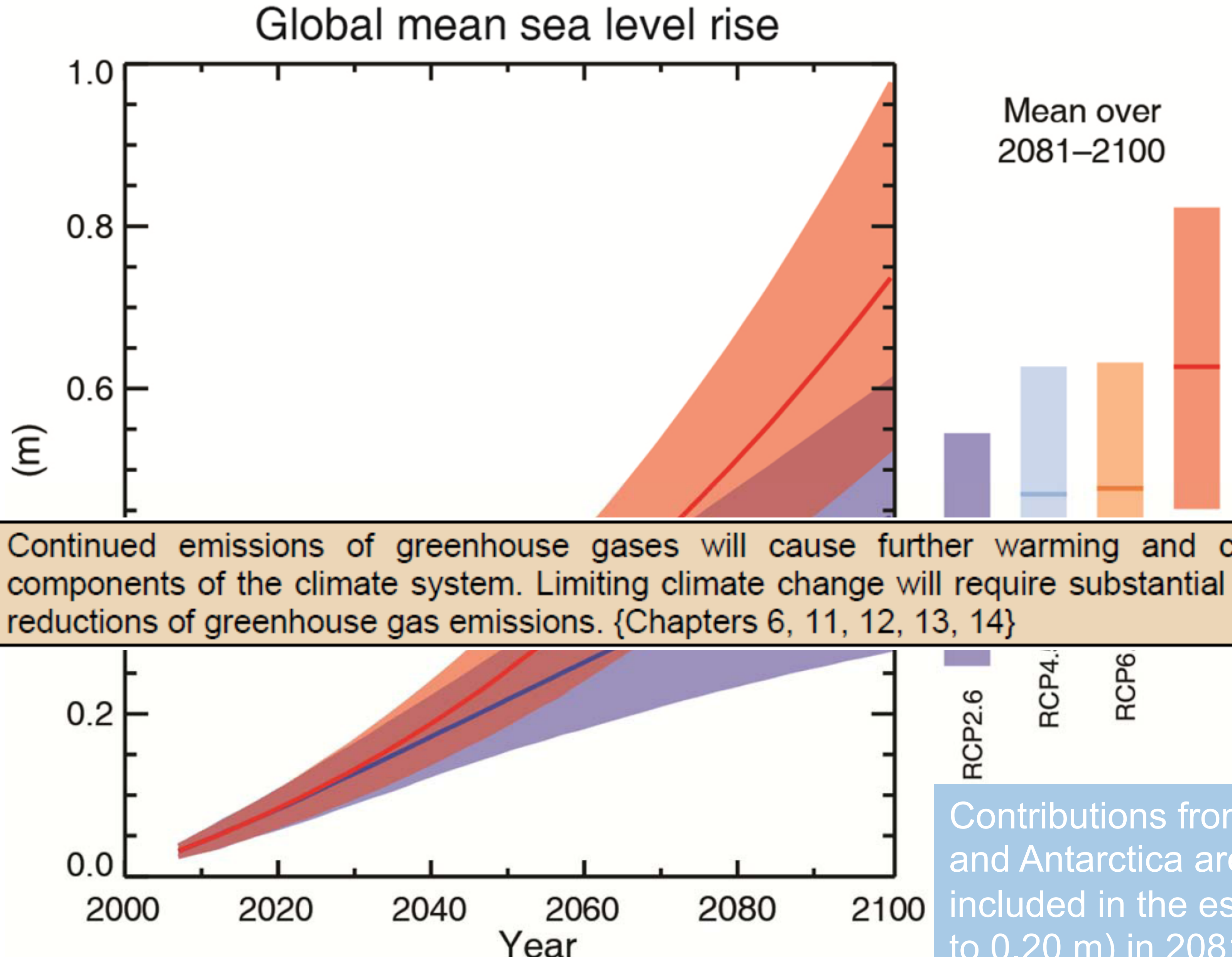
Larger warming over land and in the Arctic than globally

Precipitation

Strengthening of patterns observed until now

Arctic Sea ice

Blue ocean in RCP8.5 in September

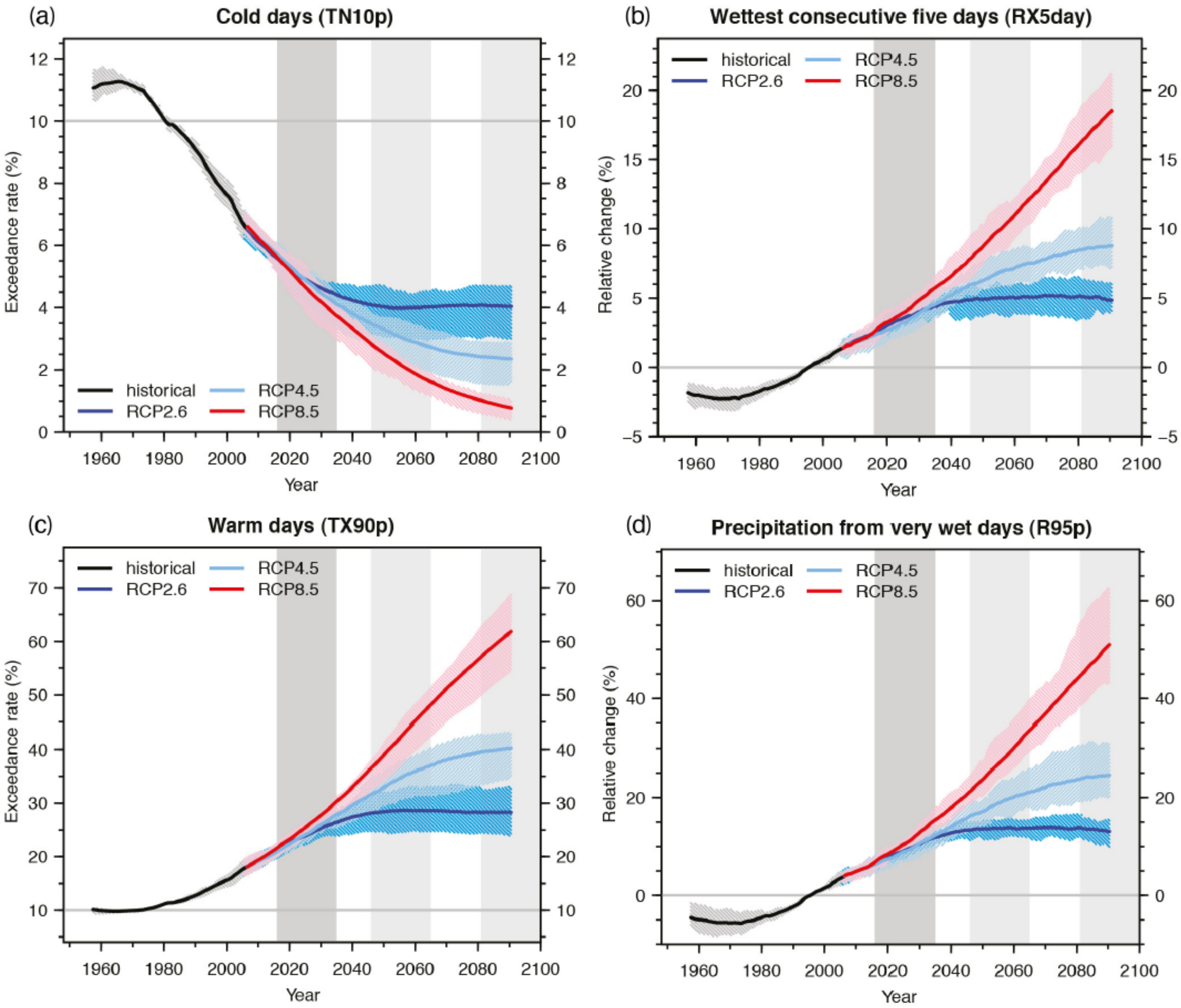


Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. {Chapters 6, 11, 12, 13, 14}

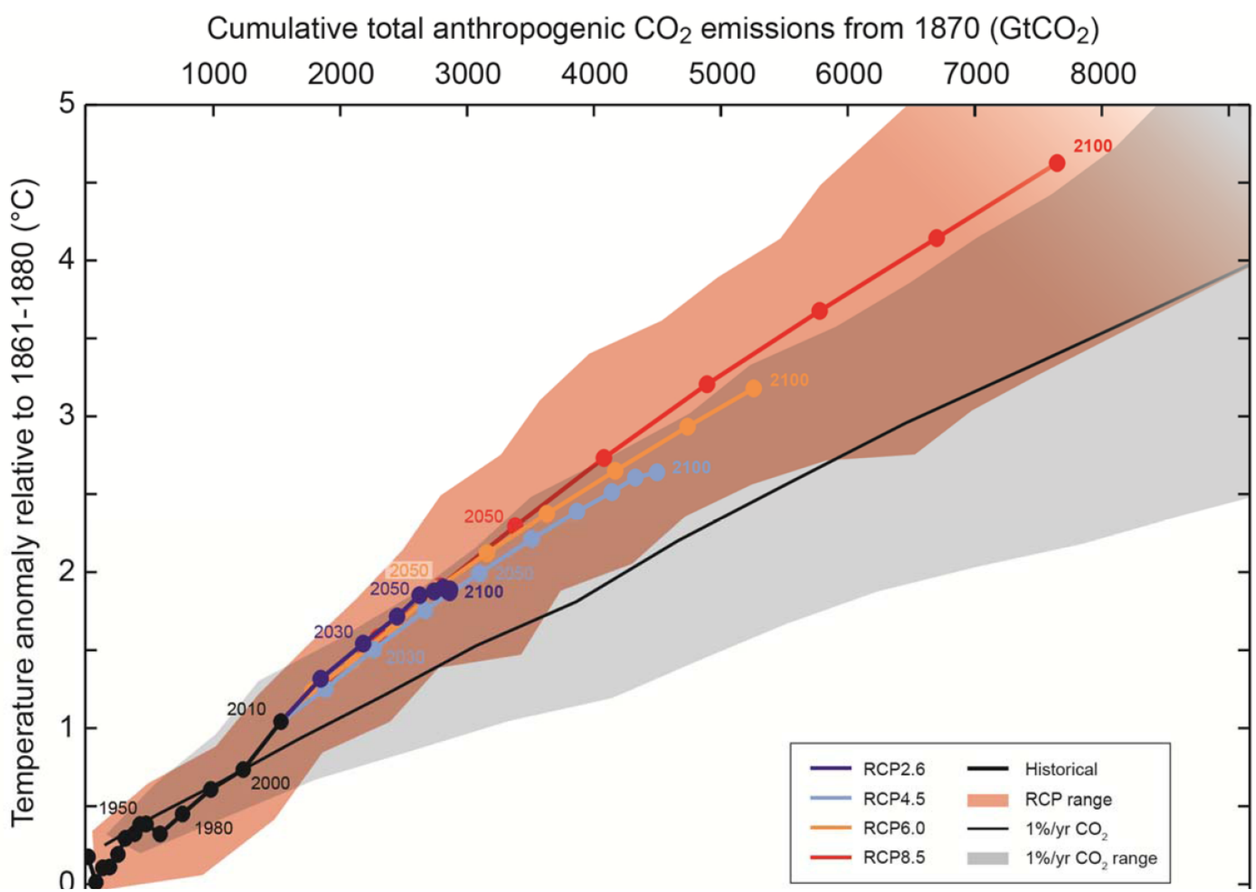
Contributions from Greenland and Antarctica are now included in the estimate (0.03 to 0.20 m) in 2081-2100

Figure SPM9

Extreme temperatures and precipitation



Historical changes are from models, but they are in generally good agreement with observations



Taking into account also non-CO_2 climate gases we have only 250 - 300 GtC to *likely* stay below 2 °C warming relative to pre-industrial time

That is 25-30 years with present day emissions and 20 years assuming current growth rate

Cumulative emissions of CO_2 largely determine global mean surface warming by the late 21st century and beyond (see Figure SPM.10). Most aspects of climate change will persist for many centuries even if emissions of CO_2 are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO_2. {12.5}

Figure SPM10

CONCLUSIONS

- Warming of the climate system is **unequivocal**

- **Very high confidence** that global average net effect of human activities since 1750 one of warming

- Human-caused warming over last 30 years has **likely** had a visible influence on many physical and biological systems

- Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would **very likely** be larger than those observed during the 20th century."

Be an educated consumer

- IPCC AR5 Synthesis Report

https://www.ipcc.ch/report/ar5/

- Other organizations:
  - NAS http://dels.nas.edu/climatechange/
  - US CCSP http://www.climatescience.gov/


NASA / The Visible Earth / The COMET Program