Climate Science 102

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MIT IAP 2017

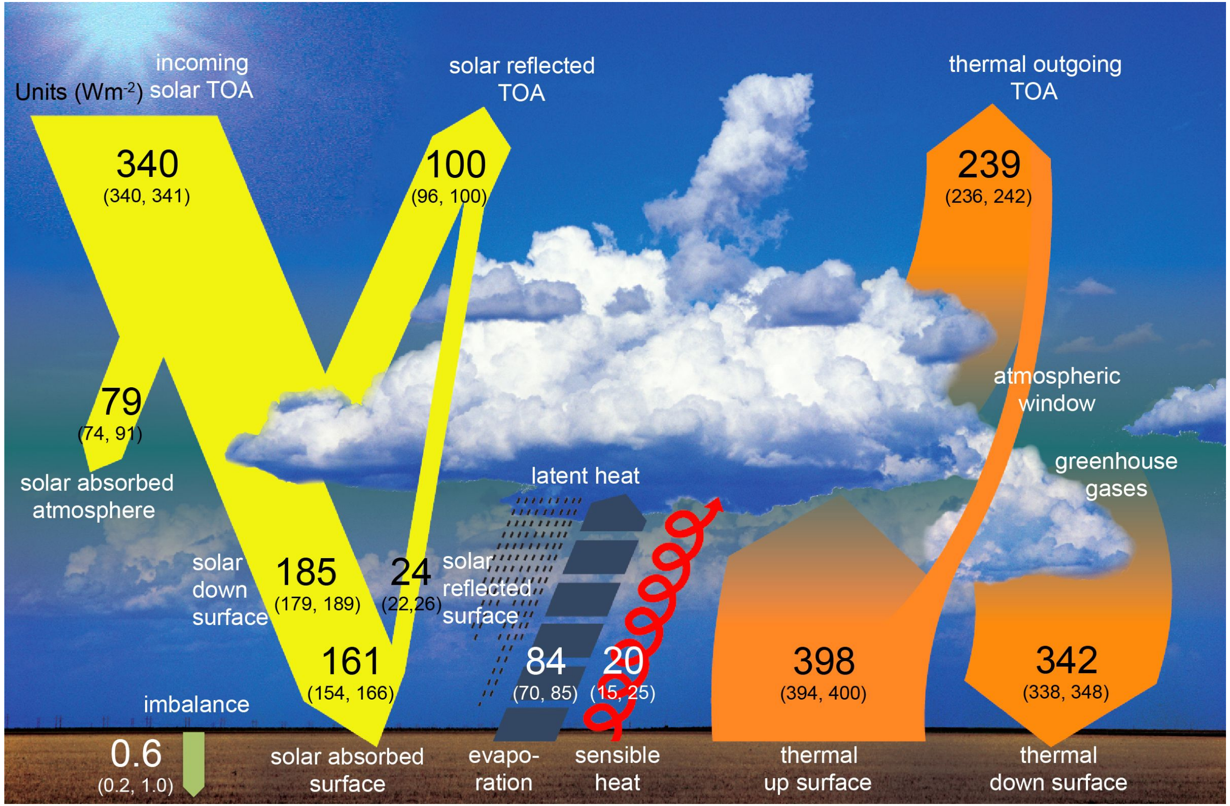
Today's topics

- Understanding climate forcings and feedbacks
- Global climate models as a valuable tool for experimentation in climate science
    - Parametrization
    - Uncertainty
- Detection and attribution of human-caused climate change

Quick recap from yesterday

Earth's radiative fluxes:

What factors can disrupt the balance of incoming and outgoing energy from the system?



IPCC AR5, Chapter 2, p.181

Forcings and feedbacks in the climate system

What are **climate forcings**?

- Changes in the amount of energy that enters or leaves the system, alters Earth's radiative equilibrium and can force temperatures to rise or fall

- Natural or man-made

- Solar cycle, changes in Earth's orbit, volcanic eruptions, pollution (aerosols), greenhouse gases, land-use changes/deforestation

Forcings and feedbacks in the climate system



What are **climate forcings**?

- A positive radiative forcing (more incoming energy) warms the system, while a negative radiative forcing (more outgoing energy) cools it
- Quantitatively given as the change in energy flux at the top of the atmosphere
- Does not entirely predict climate response!

Forcings and feedbacks in the climate system

Climate forcing analogy:

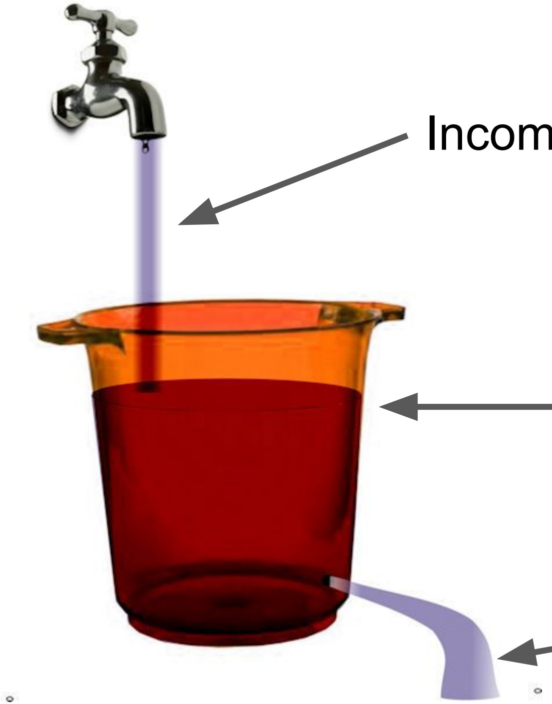
Imagine water flowing into the bucket at a fixed rate, the rate of water exiting through the bottom hole is dependent on the size of the hole and depth of water.

Water in the bucket will reach a fixed level once the amount of water entering the bucket equals that which is leaving.

Forcings and feedbacks in the climate system

Climate forcing analogy:

A steady state climate exists when the energy entering the system equals that leaving.



Incoming solar energy

Level is analogous to Earth’s global heat content

Earth’s outgoing longwave energy

Forcings and feedbacks in the climate system

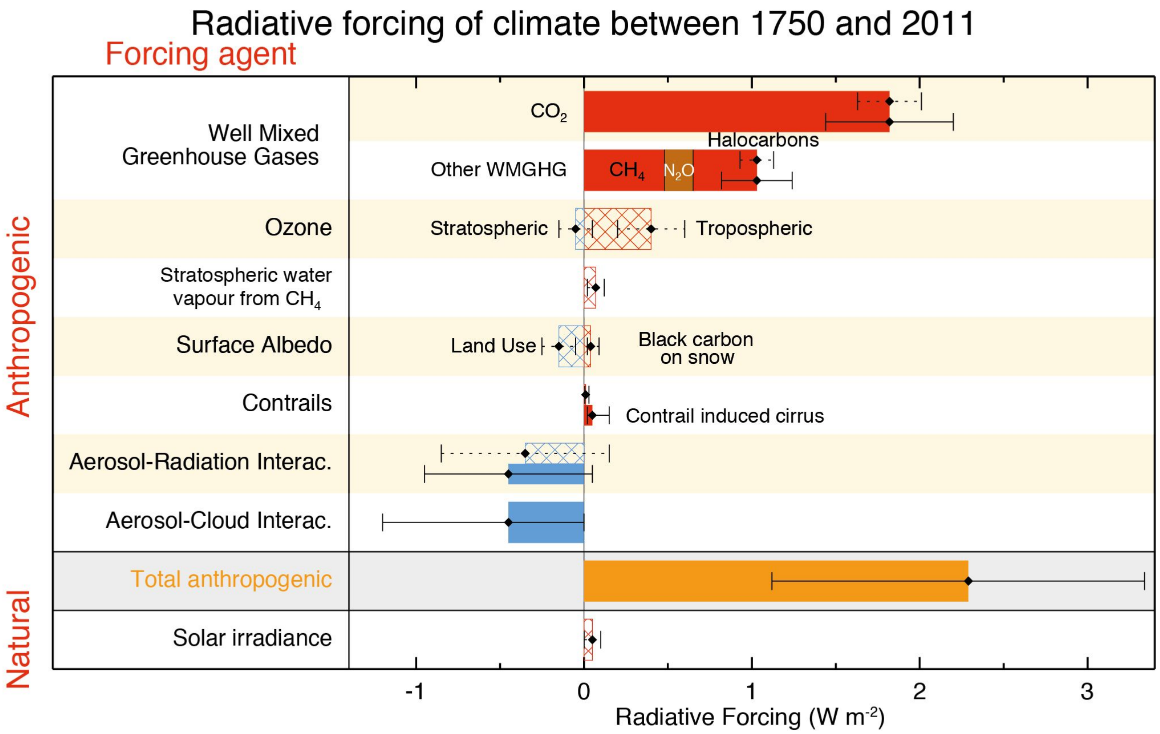
Climate forcing analogy:

Radiative forcing is analogous to changing the amount of water either entering or leaving the bucket.

For example if we made the hole smaller, the water level in the bucket would rise.

The same as increasing the amount of greenhouse gases in the atmosphere, impeding escape of IR to space, the surface temperature will rise!

Forcings and feedbacks in the climate system



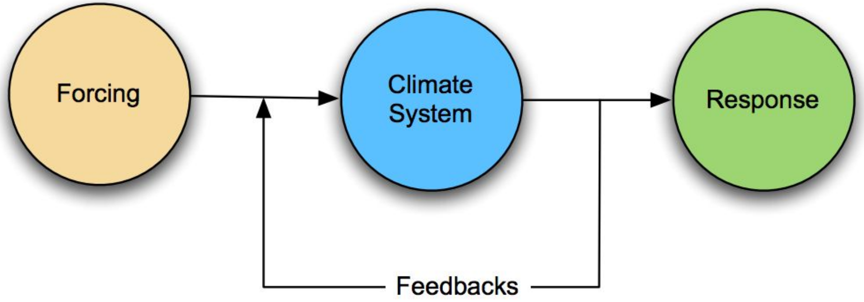
Quantitative estimates of anthropogenic (man-made) and natural radiative forcing relative to 1750.

IPCC AR5, Fig 8.15

Forcings and feedbacks in the climate system

What are **forcing feedbacks**?

- Climate feedbacks are internal climate processes that can amplify or weaken the climate response to an initial forcing
- Positive feedback increases initial warming
- Negative feedback reduces initial warming

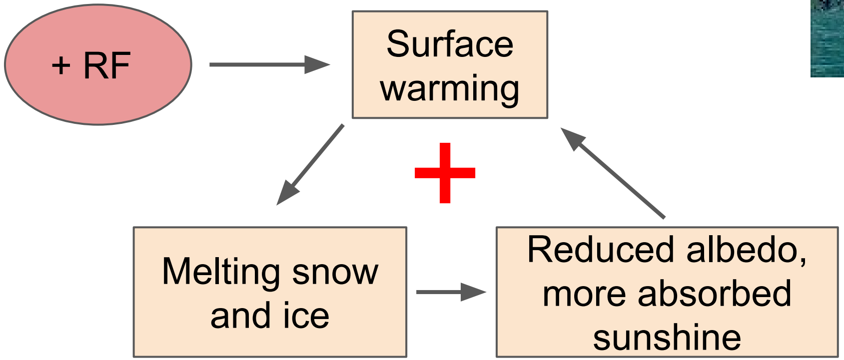


Forcings and feedbacks in the climate system

What are **forcing feedbacks**?

Examples:

<u>Positive</u>: Ice-albedo effect

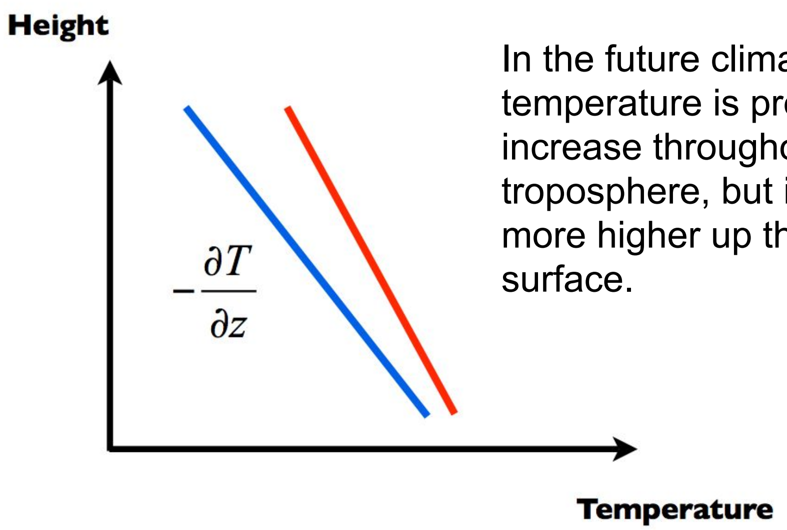


Forcings and feedbacks in the climate system

What are **forcing feedbacks**?

Examples:

<u>Negative</u>: Temperature lapse rate feedback



In the future climate, the temperature is predicted to increase throughout the troposphere, but it increases more higher up than near the surface.

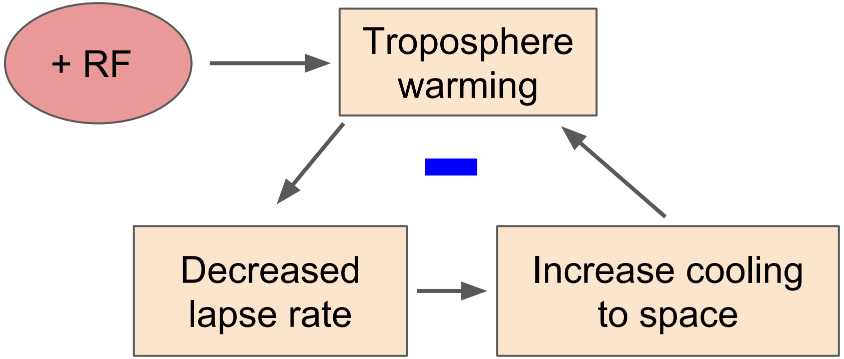
The lapse rate is the rate at which temperature decreases upward.

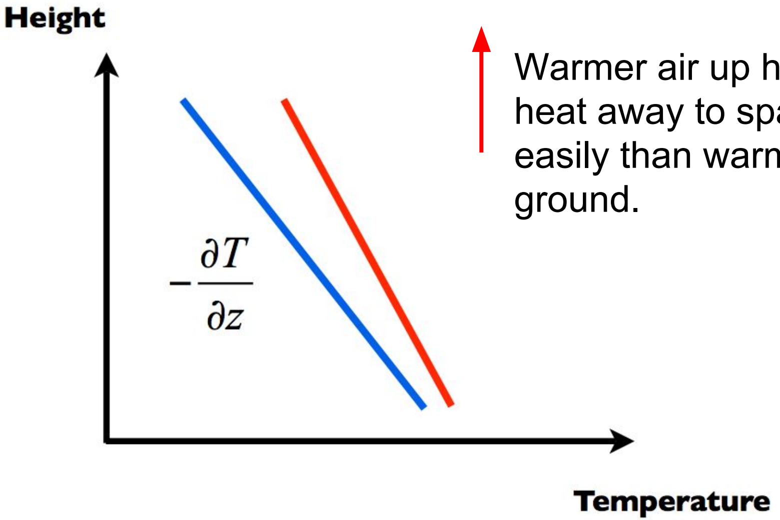
Forcings and feedbacks in the climate system

What are **forcing feedbacks**?

Examples:

Negative: Temperature lapse rate feedback



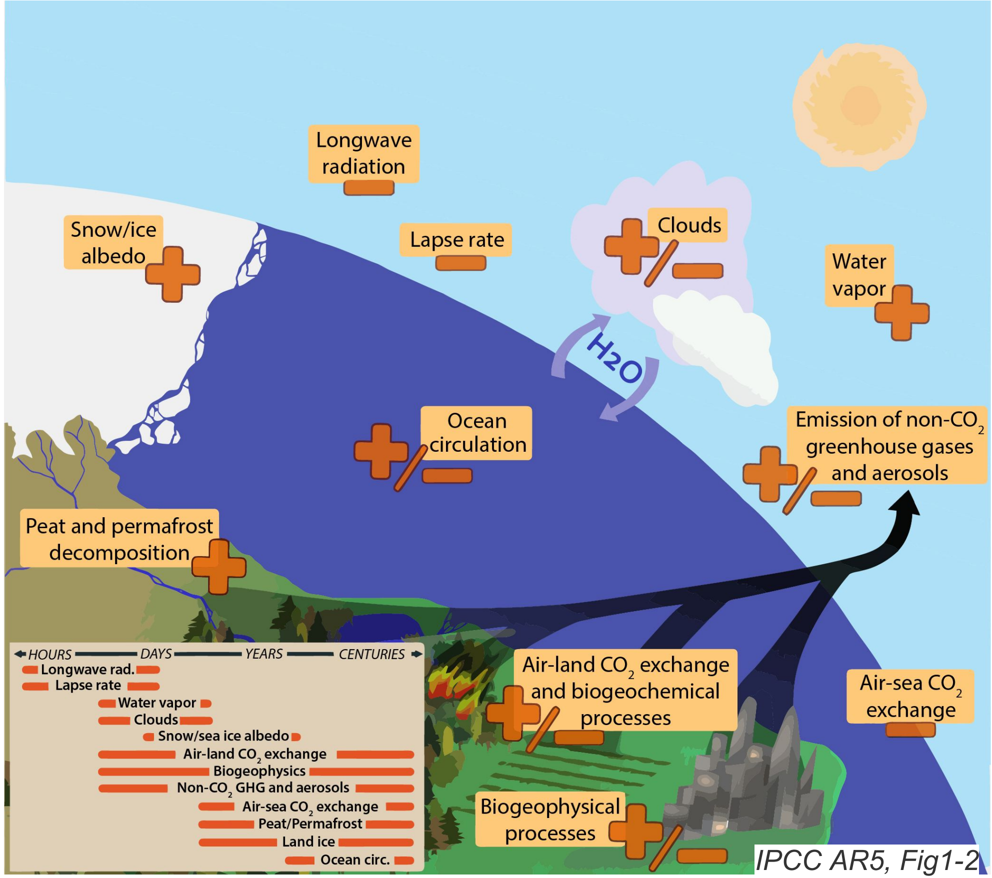


Warmer air up high can radiate heat away to space more easily than warmer air near the ground.

Forcings and feedbacks in the climate system

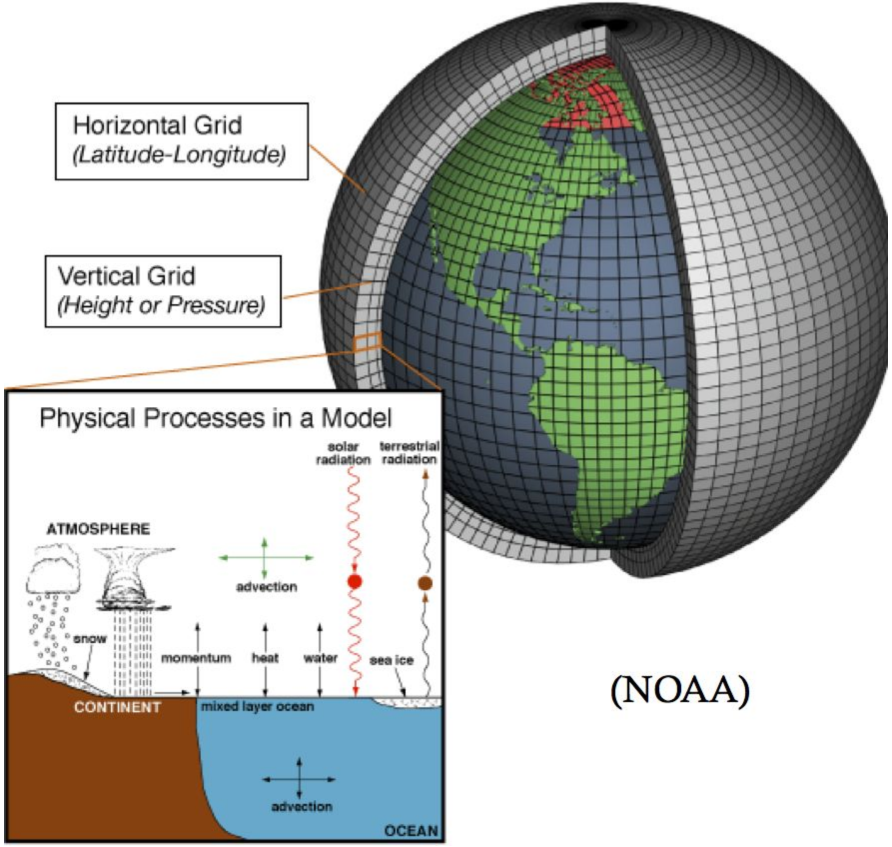
What are **forcing feedbacks**?

- The response of the climate system to specified forcings that can intensify (+) or weaken (-) the original forcing
- Many more climate feedbacks with large differences in timescales!
- How can we estimate Earth's response with all these feedbacks?



IPCC AR5, Fig1-2

Global climate models



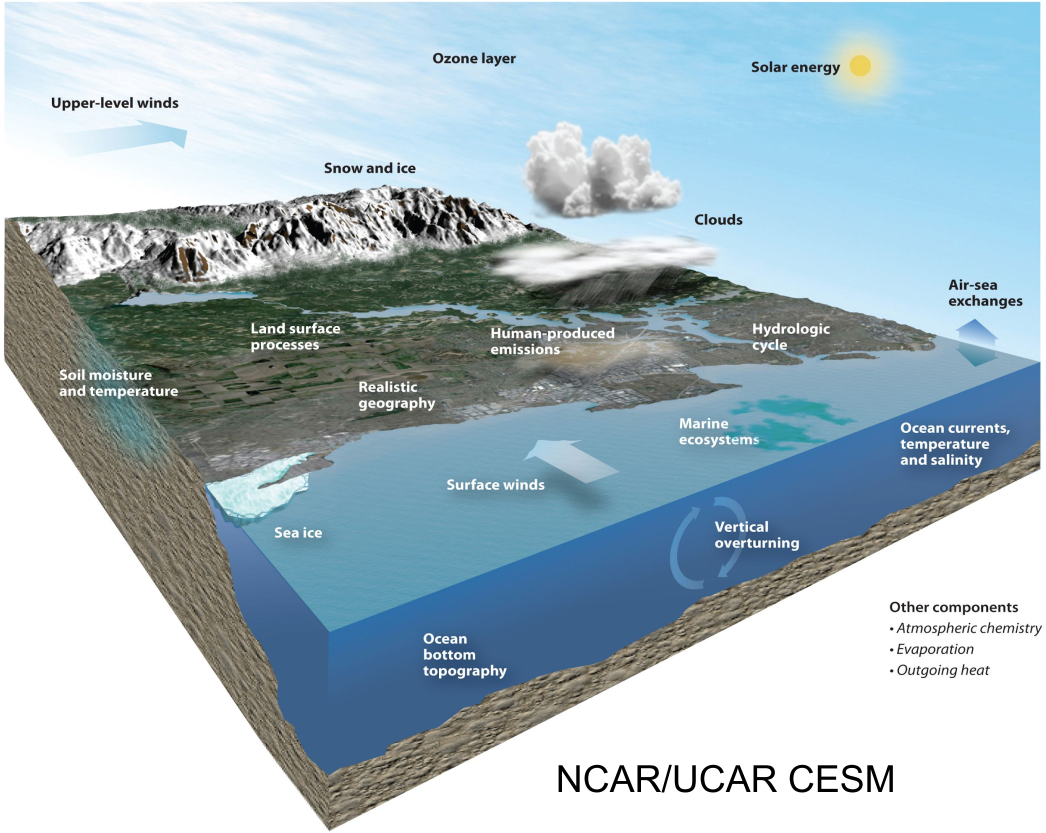
(NOAA)

Given the number and diversity of elements in the climate system, we need models to make a quantitative assessment about climate change.

What is a global climate model?

- Numerical representation of the Earth system
- System of of differential equations that describe fluid motion, radiative transfer, chemical composition, etc.
- Planet divided into 3-dimensional grid to solve the equations
- Sub-gridscale processes are parametrized

Global climate models

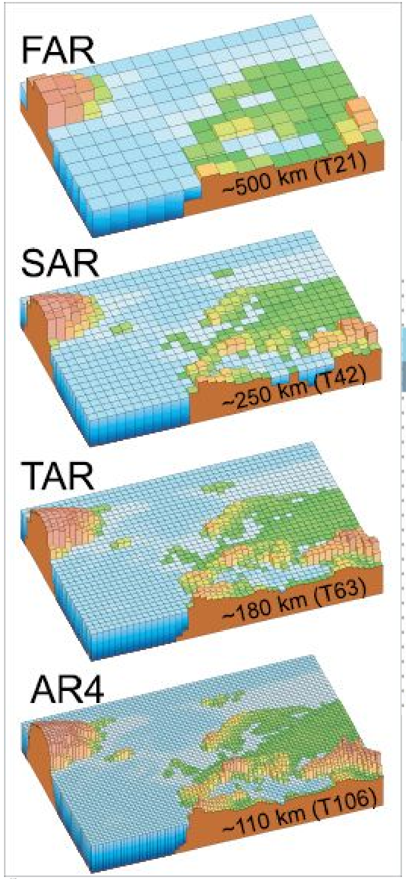


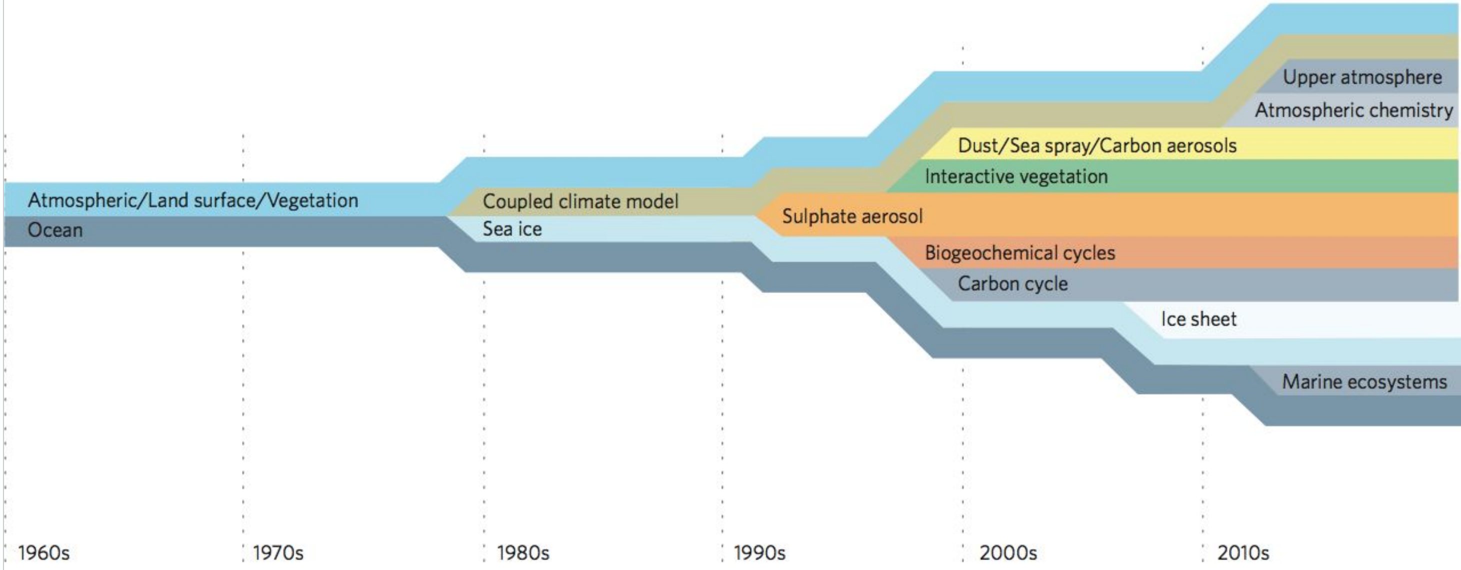
NCAR/UCAR CESM

Coupled climate model:

- Different components of the climate system working together
- The atmosphere, ocean, land, and sea-ice components ‘talk’ to each other (coupling)
- Can apply changes in external forcings - solar input, greenhouse-gases, volcanic eruptions
- Provide a virtual laboratory for experimentation

Global climate models





NCAR/UCAR CESM

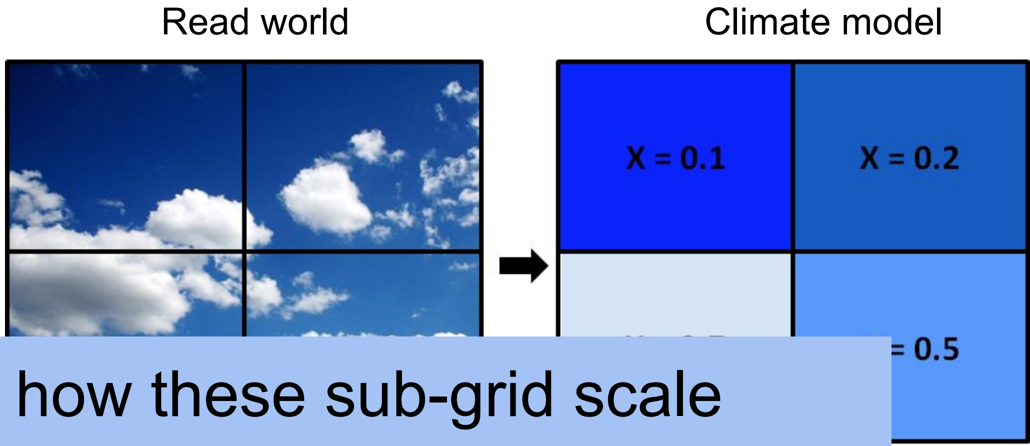
Global climate models

Parametrization:

- Many physical processes occur at small spatial scales that the GCM cannot
large)

- The ph
repres
within
empirically supported

- Examples include: cloud processes, radiative transfer, boundary-layer processes



The difference in how these sub-grid scale processes are parametrized, is an important reason why climate models differ from each other.

Average relative humidity in grid cell

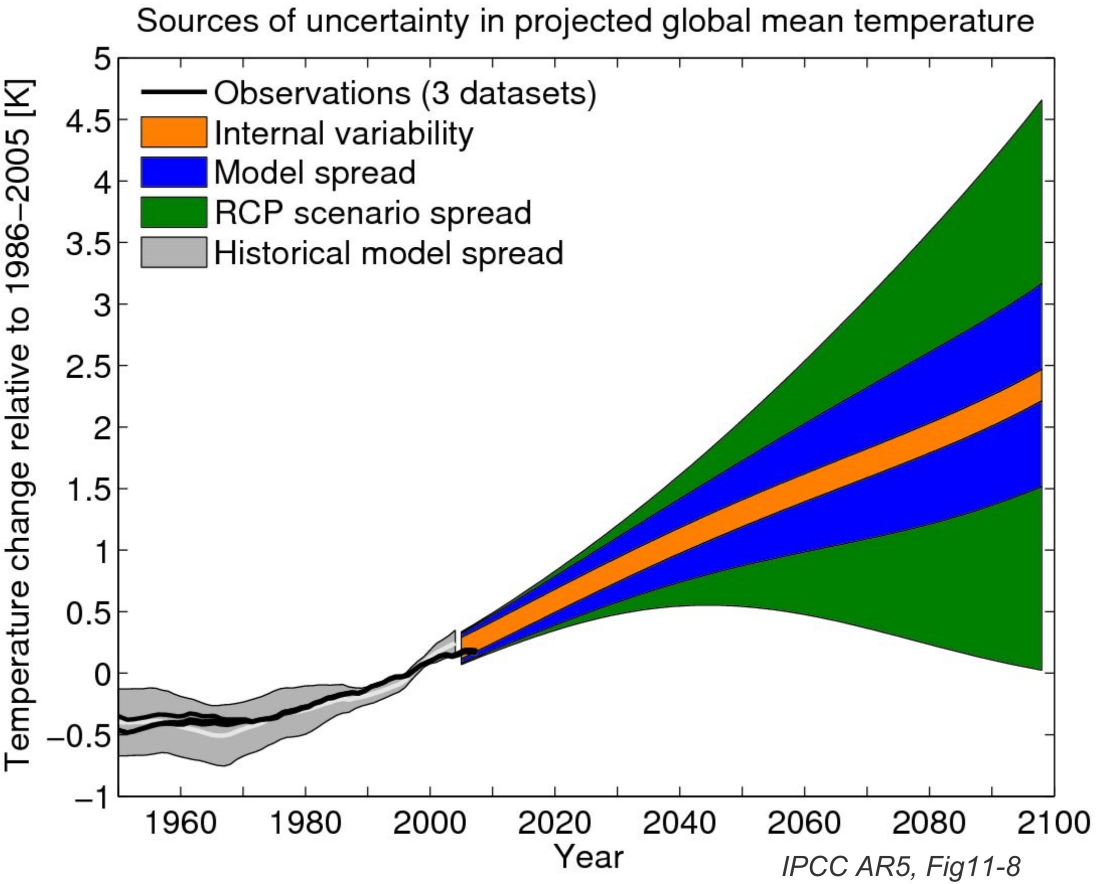
Land/ocean?

Use observations to derive statistical relationship between relative humidity and cloud formation conditions

Cloud fraction in grid cell

Global climate models

Why is there uncertainty in future predicted temperatures?



IPCC AR5, Fig11-8

Detection and attribution of climate change

- **Climate change**: change in the state of the climate that can be identified (e.g. by statistical tests) by changes in the mean or variability of its properties that persists for an extended period, decades or longer

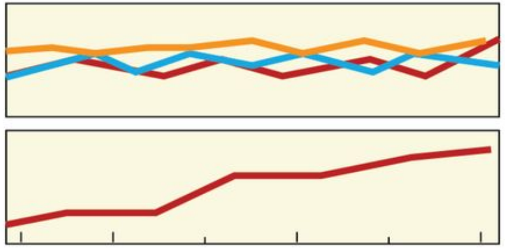
- **Climate variability**: variations beyond individual weather events in the mean state and other statistics of the climate (e.g. standard deviations, occurrence of extremes) on all spatial and temporal scales

Detection and attribution of climate change

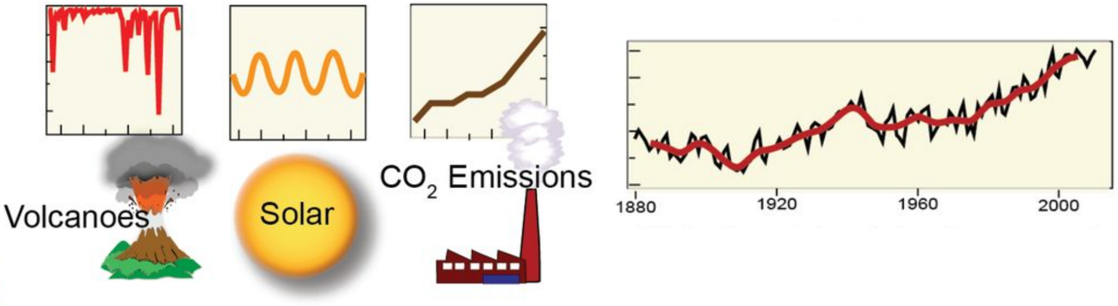
- **Detection**: demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change

- **Attribution**: establishing the most likely causes for the detected change with some defined level of confidence. Are observed changes consistent with expected forced response.

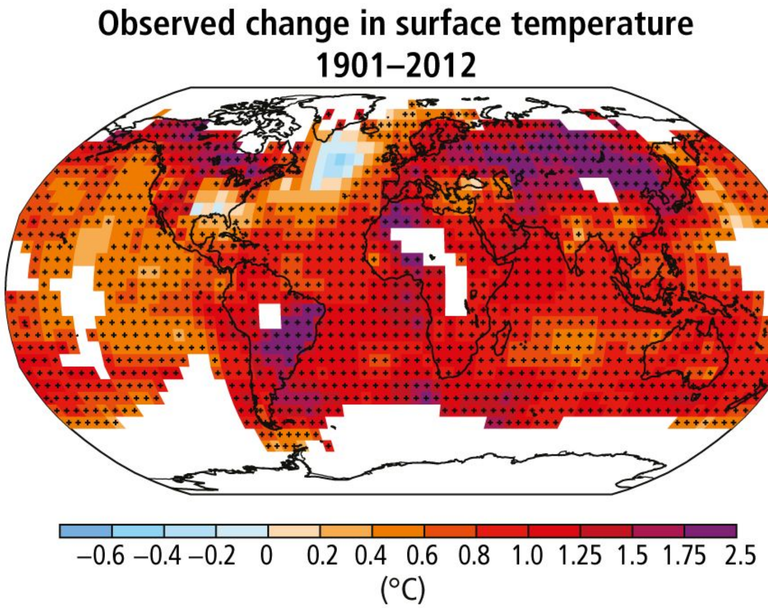
Observations

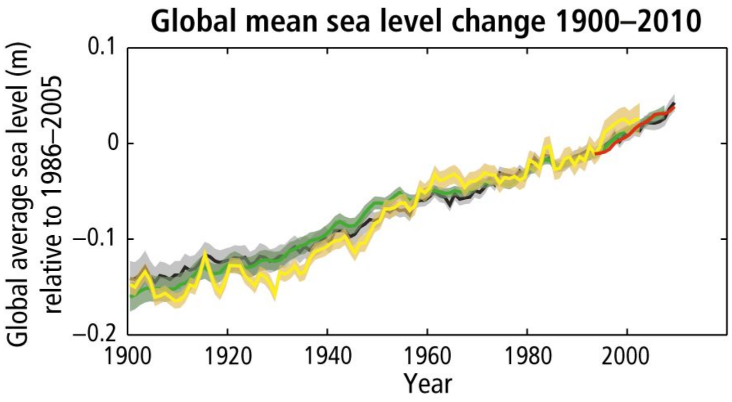


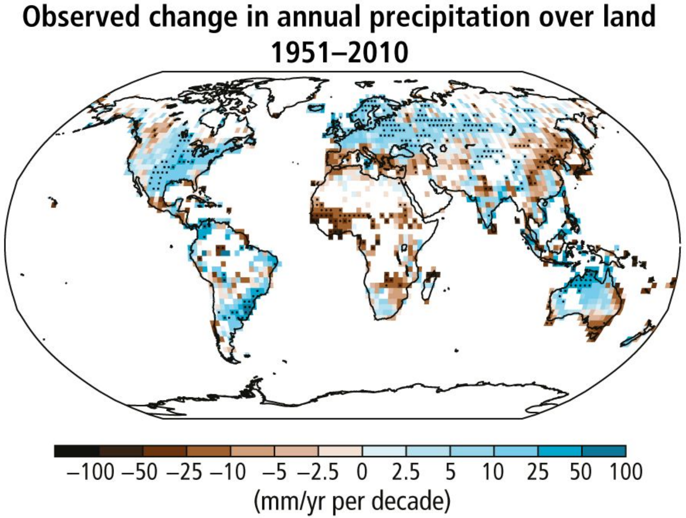
Climate models



Detection of climate change:







IPCC AR5 - WGI Fig 1.1

Attribution of climate change:

What do we need:

Observations of climate indicators: Space and time measurements

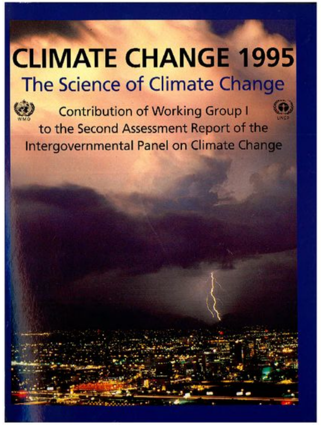
An estimate of external forcing: How external drivers of climate change have evolved before and during period of investigation, e.g. GHG and solar

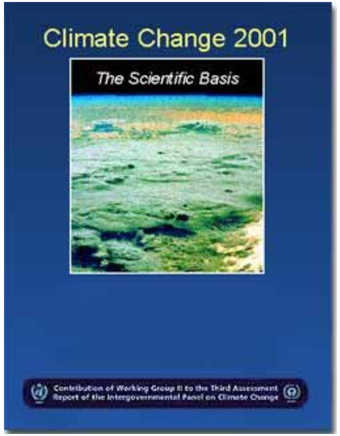
A quantitative physically-based understanding: How external forcing might affect the climate indicators - normally with physically-based model

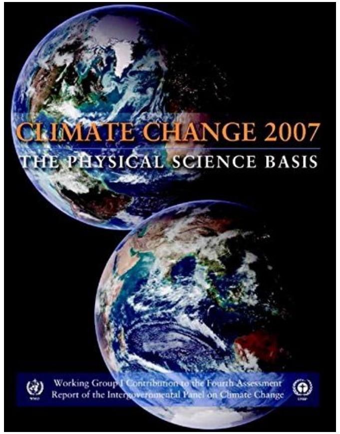
Estimate of climate internal variability: Frequently derived from a physically-based model

Attribution of climate change:

The scientific evidence for a human “fingerprint” on global climate as strengthened over time:







“The balance of evidence suggests a discernible human influence on global climate”

Attribution of climate change:

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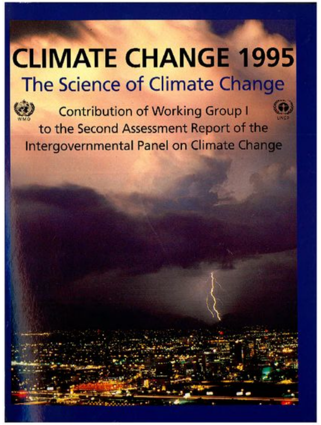

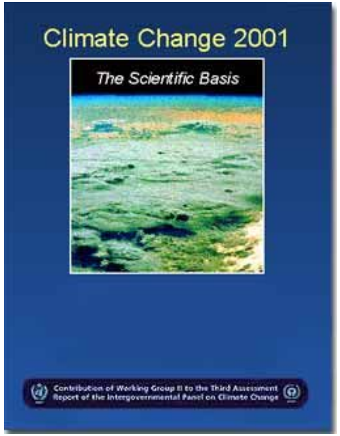

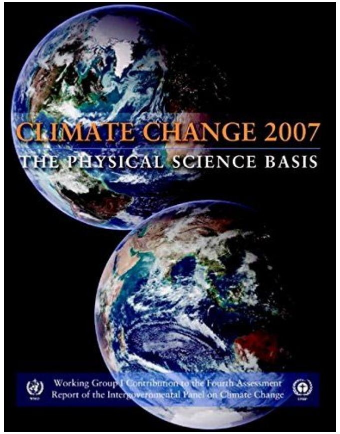

"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities"

Attribution of climate change:

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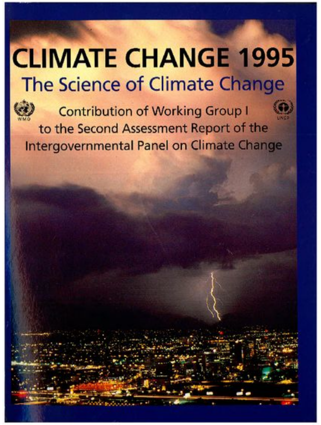
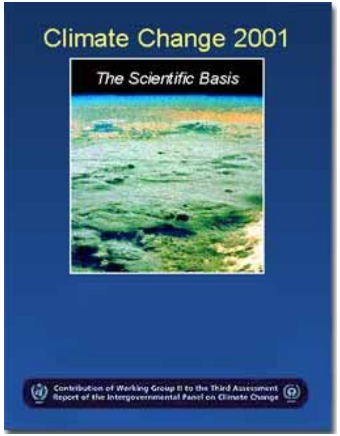
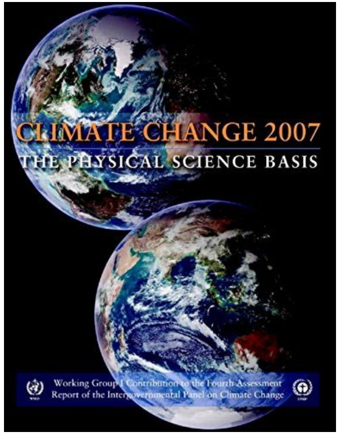


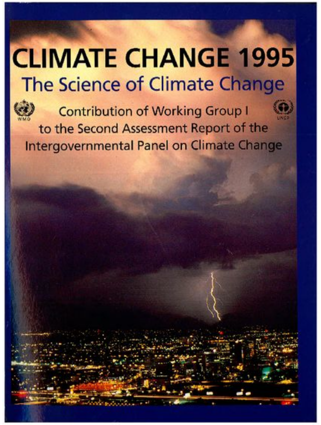


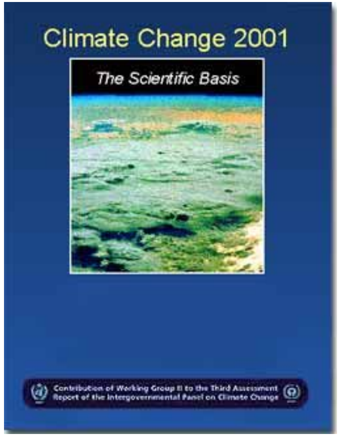


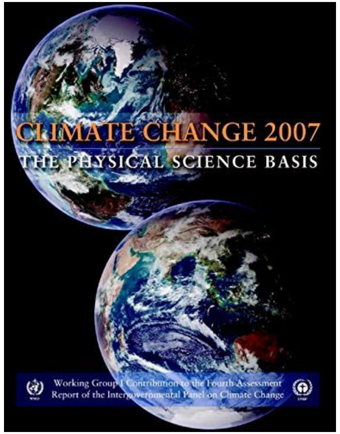
"Most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations"

Attribution of climate change:

The scientific evidence for a human "fingerprint" on global climate as strengthened over time:







"Anthropogenic greenhouse gas emissions have increased since the pre-industrial era...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"

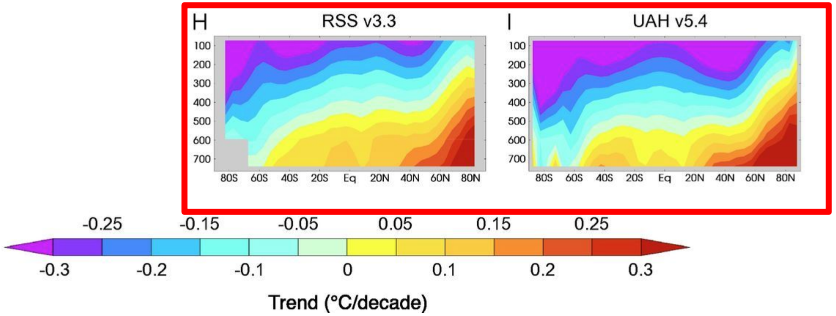
Attribution of climate change:

Example: Searching for ‘fingerprints’ of human-caused climate change in observational records of atmospheric temperature

Example of attribution:

1979-2012 Atmospheric Temperature Trends

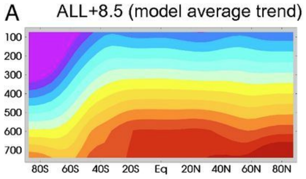
Observations



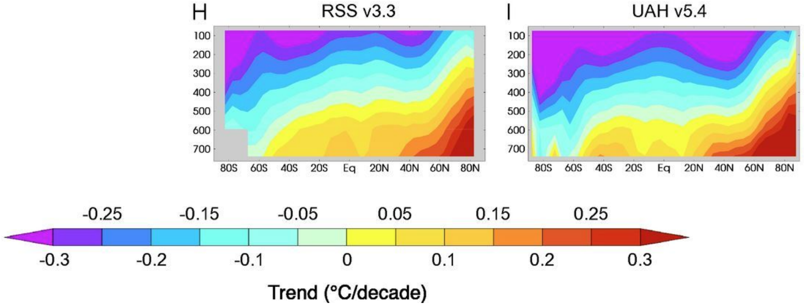
Santer et al., 2013, PNAS.

Example of attribution:

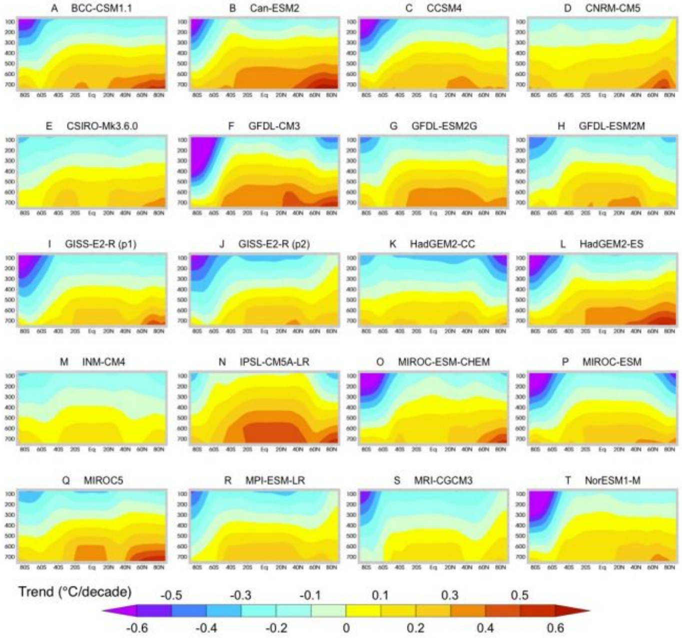
1979-2012 Atmospheric Temperature Trends



Multi-model mean historical simulation

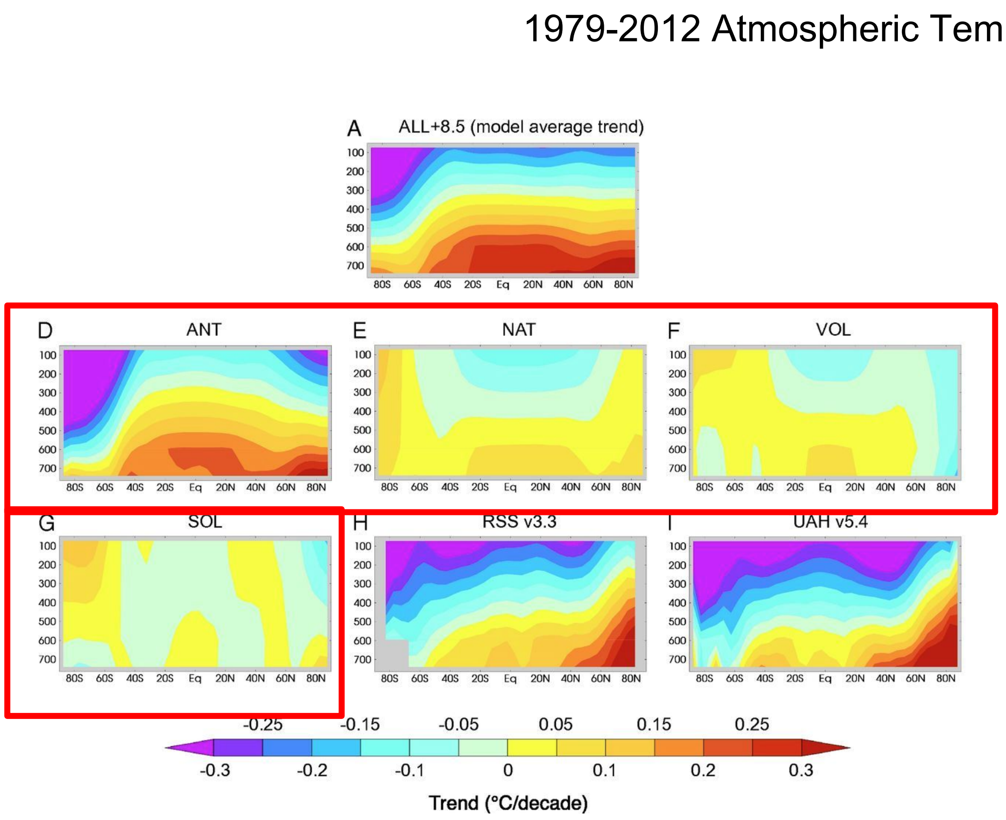


All 20 historical CMIP-5 models:



Santer et al., 2013, PNAS.

Example of attribution:

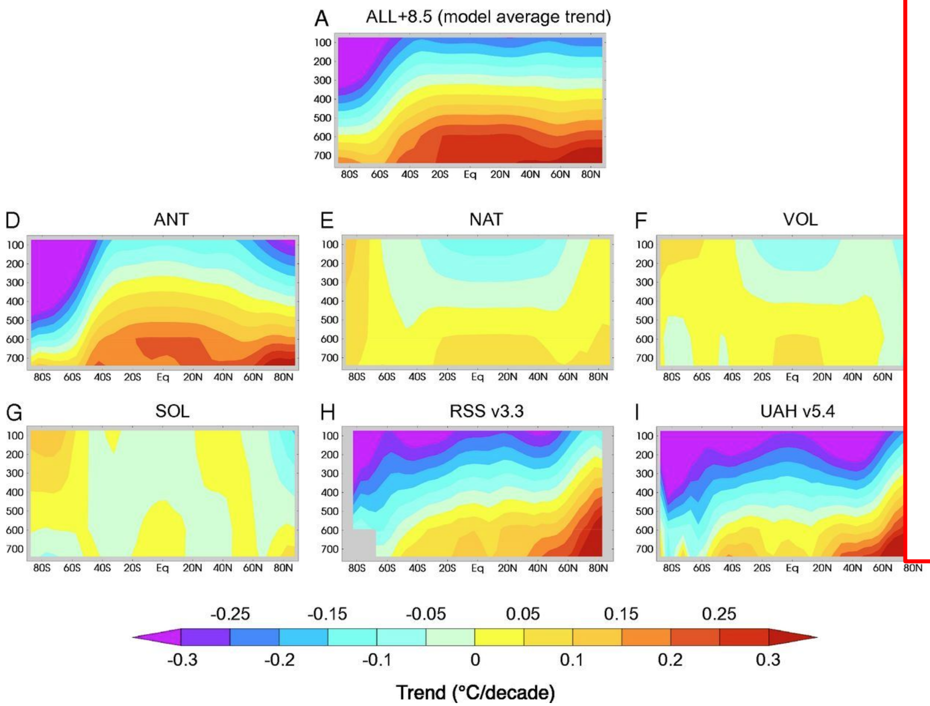


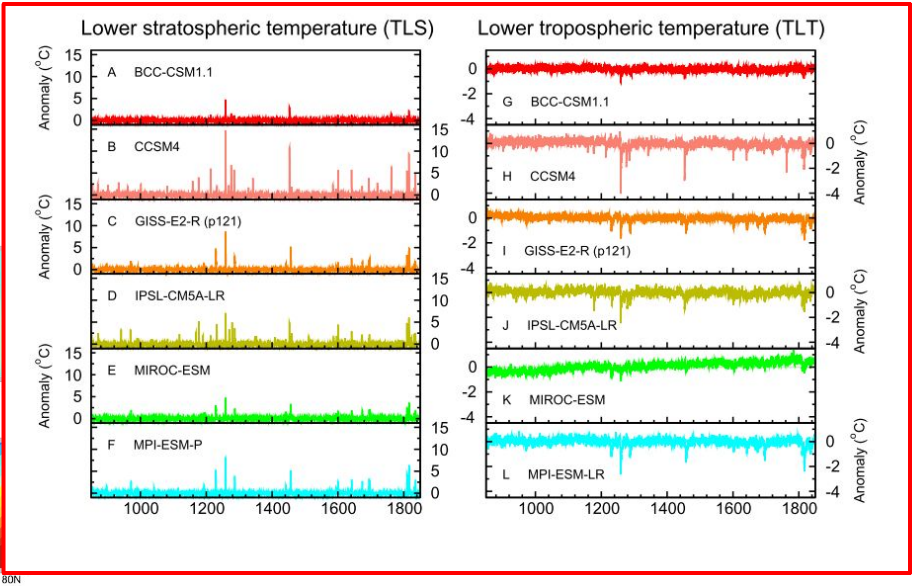
Multi-model simulations with specified external forcings

Santer et al., 2013, PNAS.

Example of attribution:

1979-2012 Atmospheric Temperature Trends





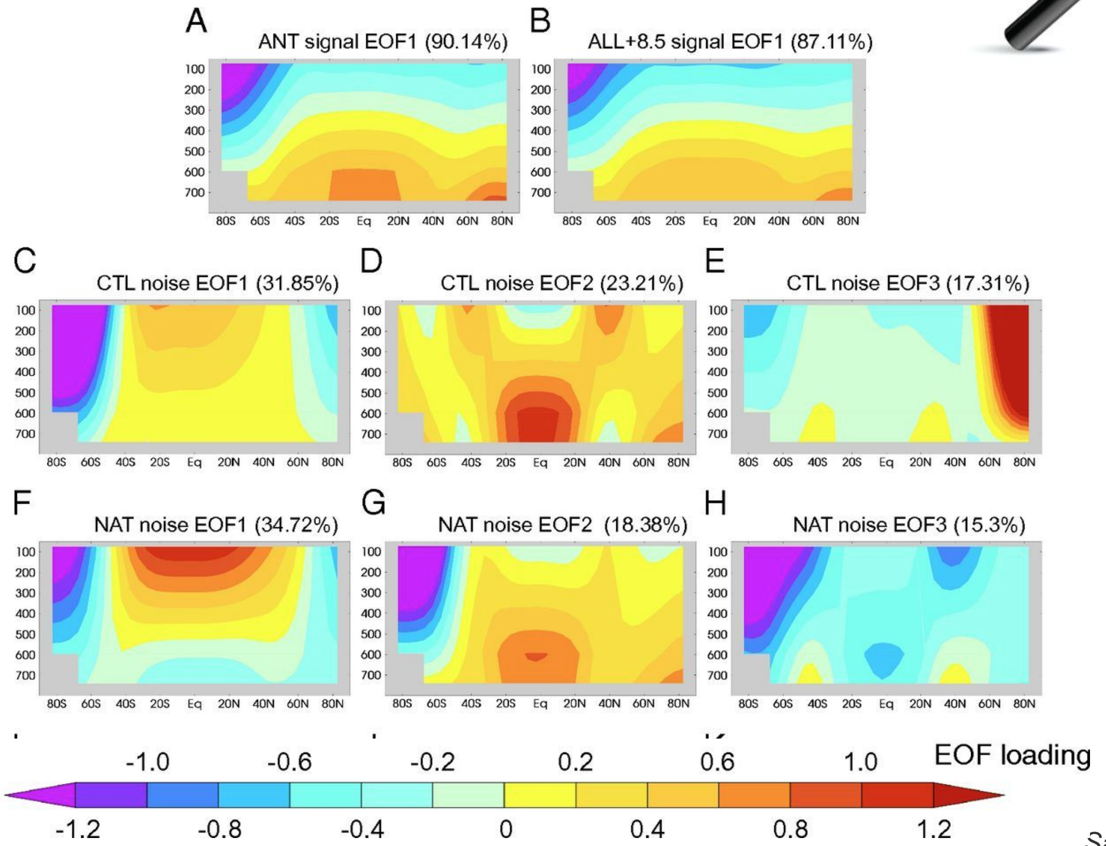
‘Unforced’ pre-industrial control simulations

Santer et al., 2013, PNAS.

Example of attribution:

Identifying forcing **fingerprints**:

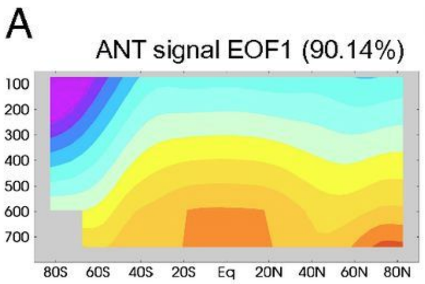
The dominant modes of forced response and internal/natural variability

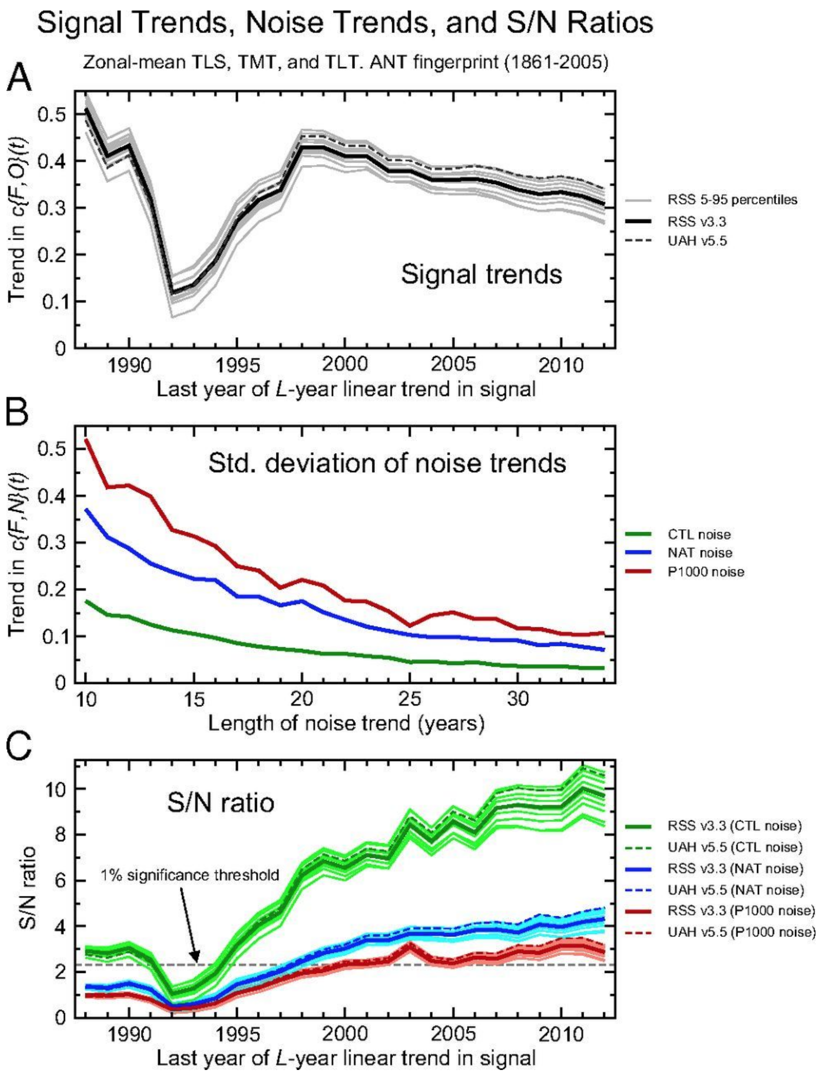


Santer et al., 2013, PNAS.

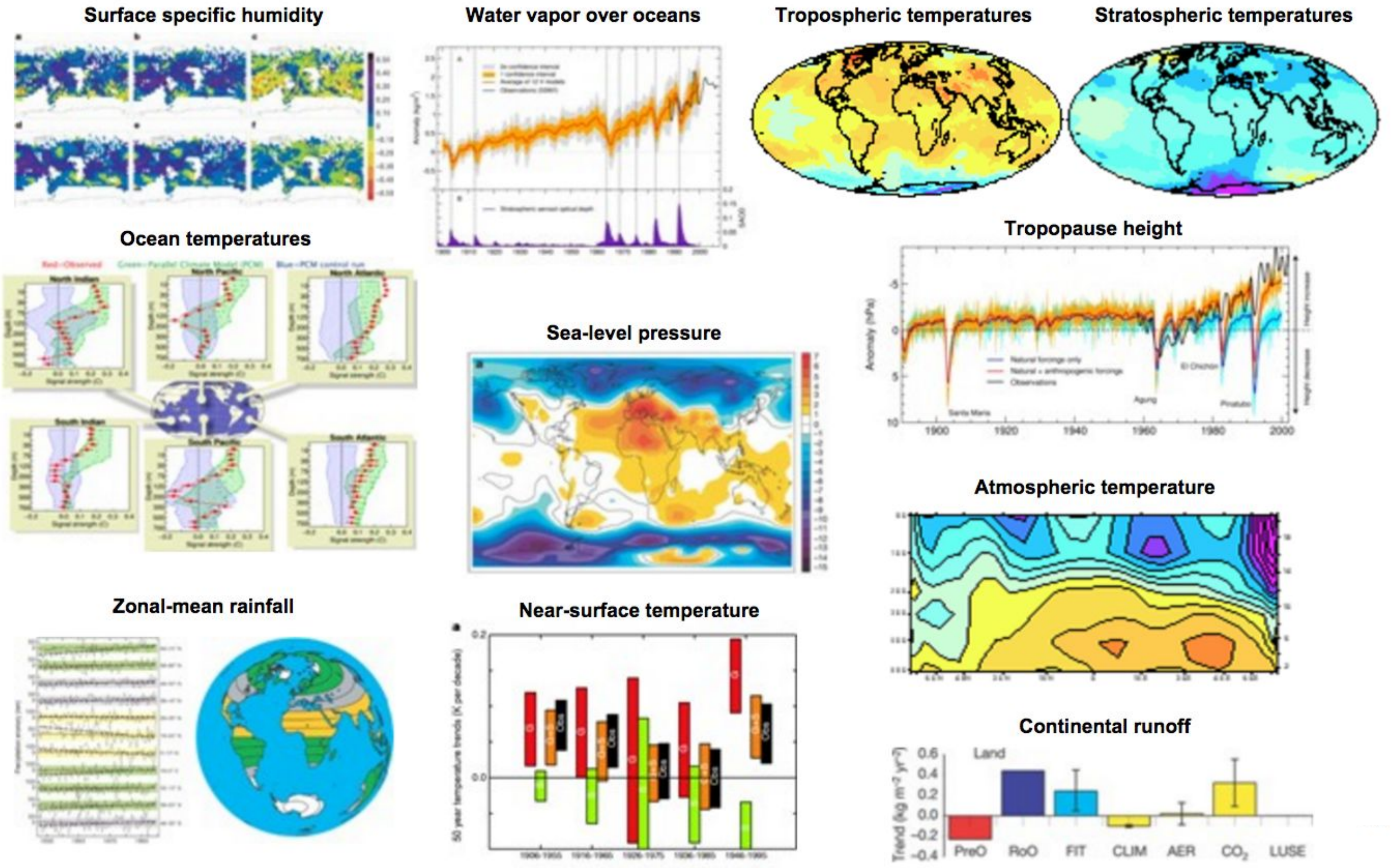
Example of attribution:

Use the ANT (anthropogenic only) fingerprint, and a pattern-correlation analysis to look at how the amplitude of the pattern is changing over time in observations (**signal**), and compare to the control/natural runs (**noise**).





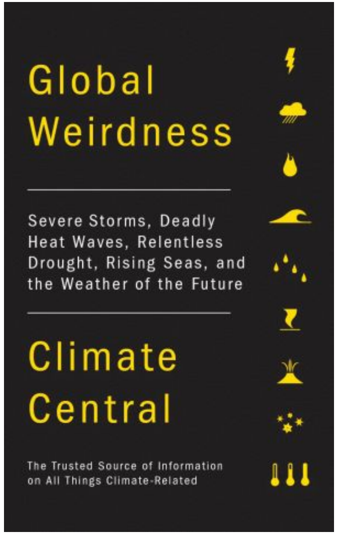
Fingerprints of human-caused climate change

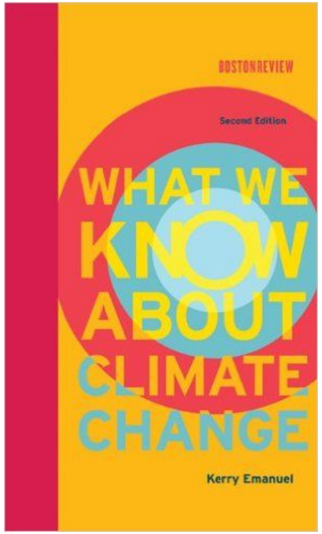


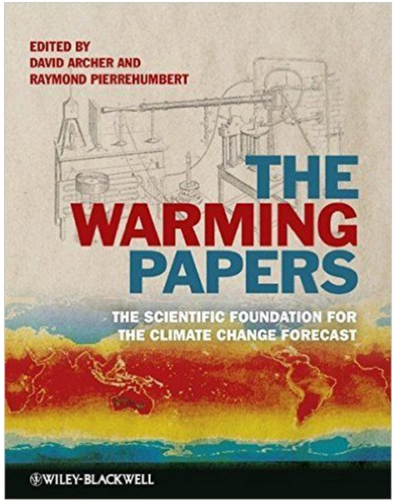
Summary:

- Large radiative forcings from greenhouse-gas emissions have contributed to positive imbalance in the climate system, though there is uncertainty to the magnitude of which aerosols and clouds have offset this forcing
- Climate feedbacks control the magnitude of response to positive radiative forcing, complex system with uncertainty in certain feedbacks (eg. cloud response)
- Global climate models are an invaluable tool for investigating how the climate system responds to external forcings, differences in parametrization and coupling are responsible for model spread
- Human-caused effects on the climate system can be identified through detection and attribution studies

Resources:







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