

# Global warming - physicist's perspective - 02

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**NAUKA O KLIMACIE**  
DLA SCEPTYCZNYCH



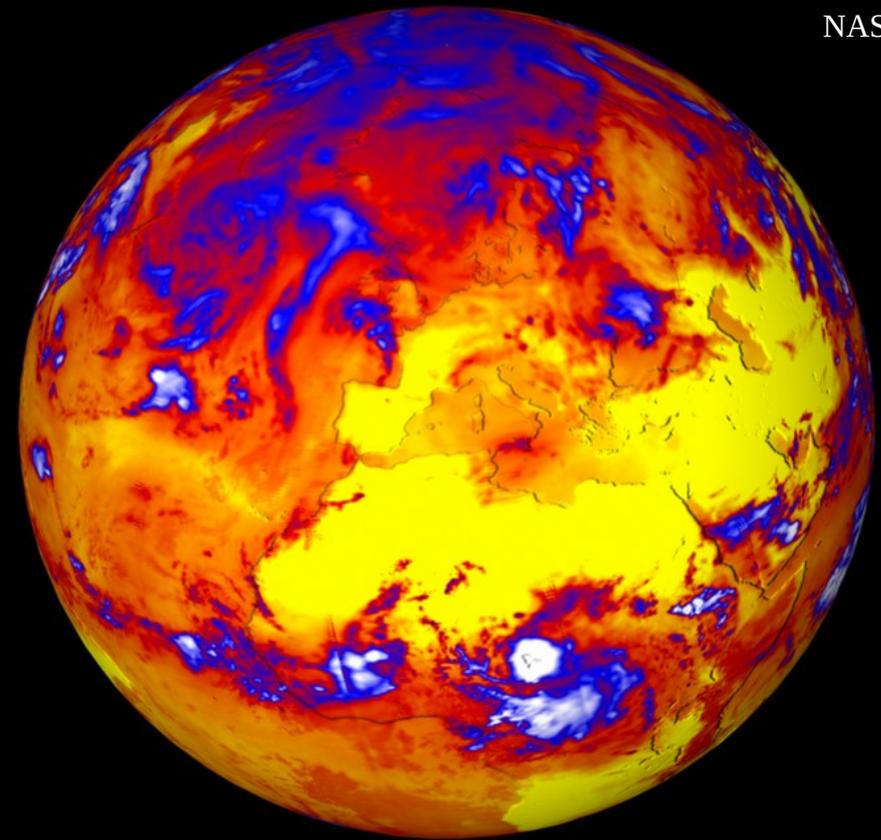
UNIVERSITY  
OF WARSAW

## Outline:

1. Physical properties and principles of climate system
2. Contemporary climate
3. Climate modeling

# Energy Balance

NASA



emitted heat radiation ( $\text{W/m}^2$ )

85

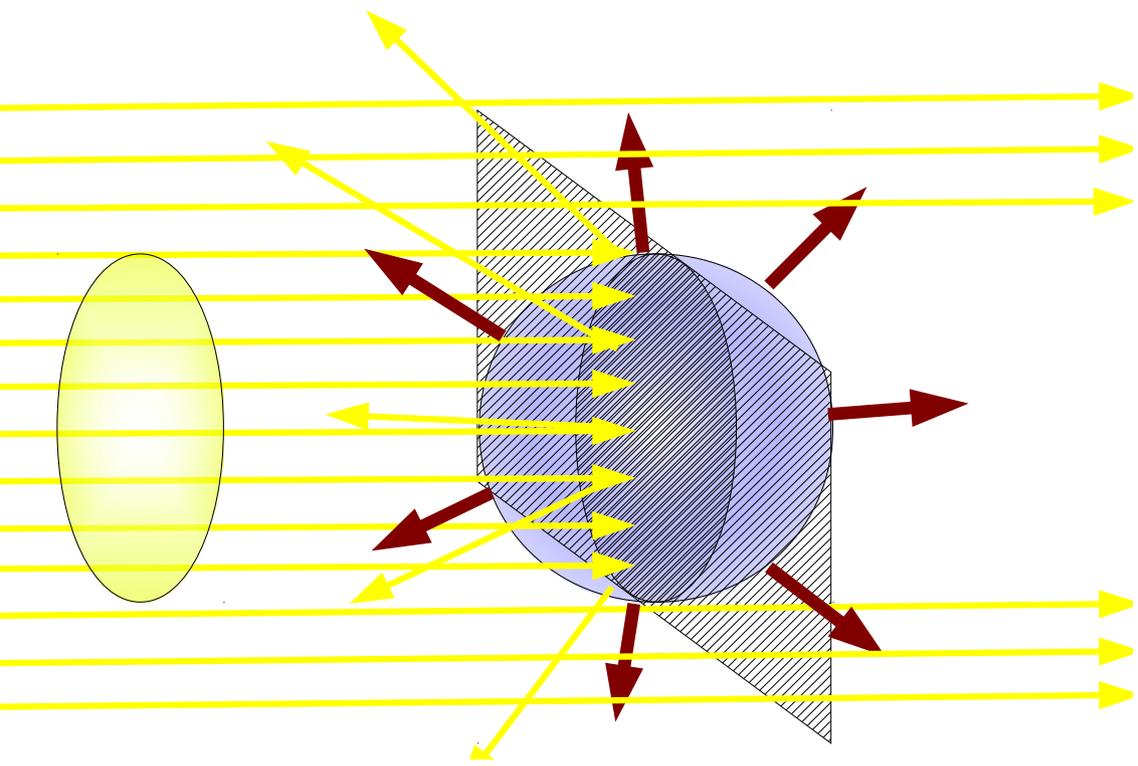
350

**THE EARTH** is illuminated by shortwave **SOLAR** radiation, which is partially absorbed and partially reflected.

In (quasi) equilibrium energy of absorbed radiation is balanced by emission in thermal infrared.

Deflections from the equilibrium result in climate system heating/cooling.

# Effective temperature of the Earth



R- radius,

S- solar constant,

A- albedo,

$E_S$  - absorbed solar energy:

$$E_S = (1-A)S\pi R^2.$$

Assume blackbody.

$T_E$  - emission temperature

$E_P$  - emitted energy:

$$E_P = 4\pi R^2\sigma T_E^4.$$

Assume energetic equilibrium  $E_S = E_P$

$$(1-A)S/4 = \sigma T_E^4.$$

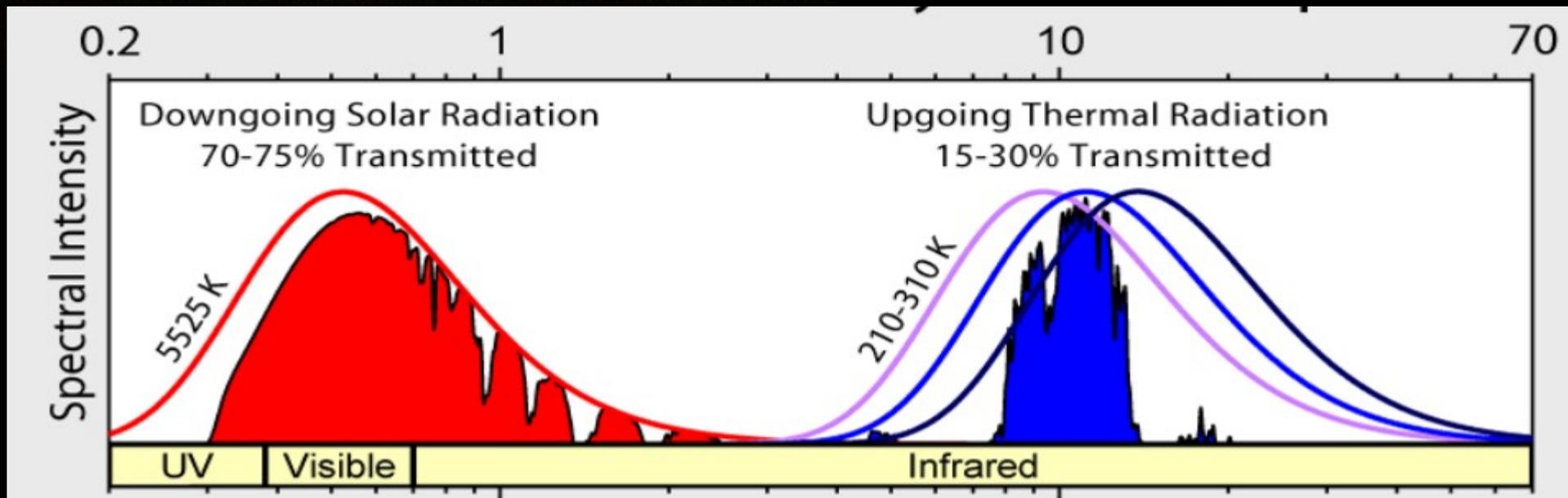
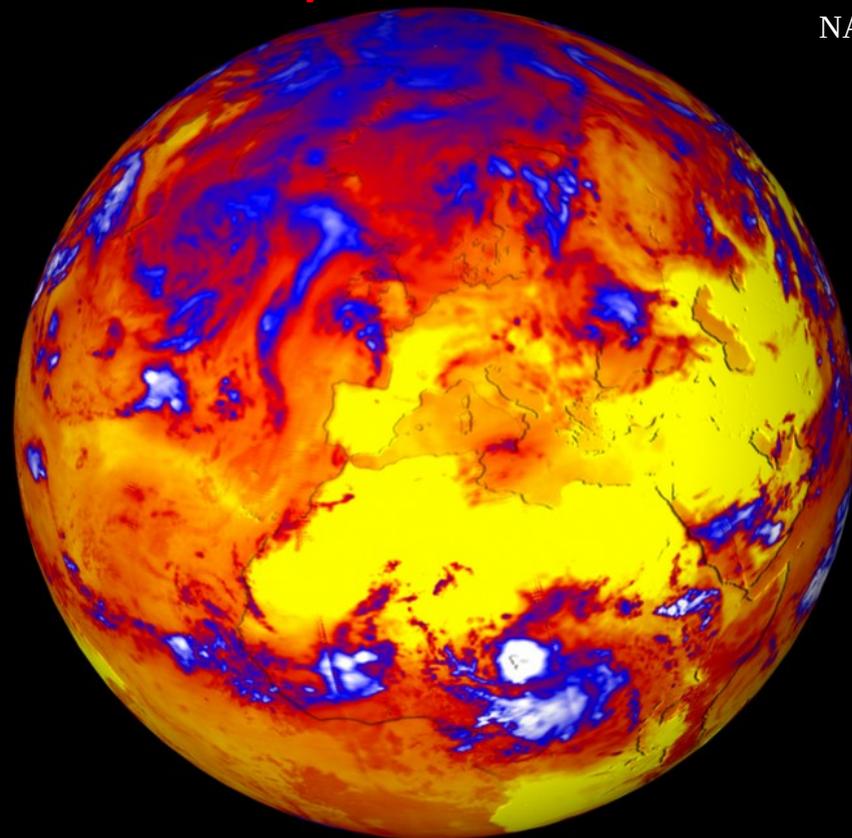
$$T_E = \sqrt[4]{\frac{(1-A)S}{4\sigma}}$$

For  $S=1362\pm 1 \text{ W/m}^2$  and  $A=0.3$

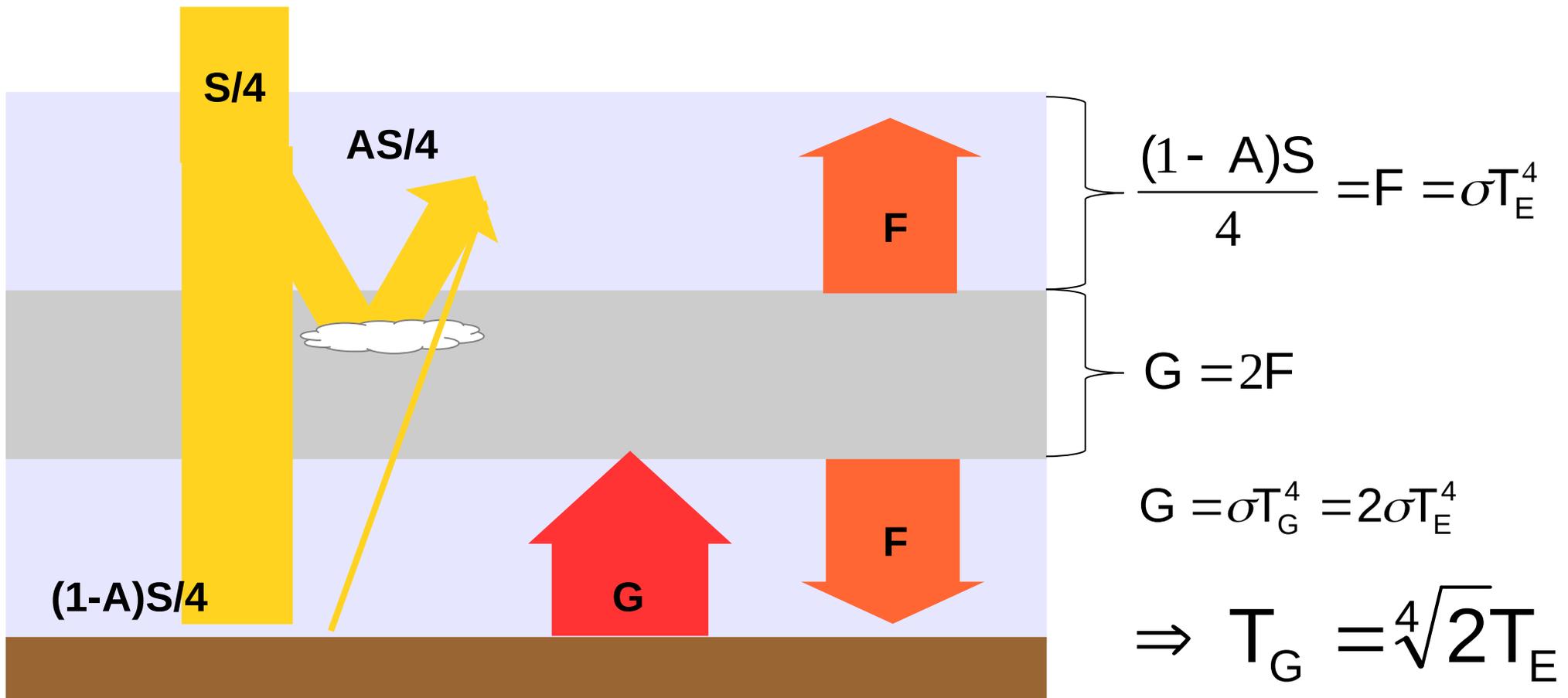
$T_E=254.81\pm 0.05\text{K}$

# Transmission through the atmosphere

NASA



# Greenhouse effect – single layer model



$$T_E \approx 255\text{K}$$

$$T_G \approx 303\text{K}$$

## ENERGY IN CLIMATE SYSTEM

1. Solar energy flux =  $\frac{1}{4}$  of Solar constant  
 $\frac{1}{4} * 1362 \text{W/m}^2 \approx 341 \text{W/m}^2$ .
2. Earth's surface albedo, mean  $\approx 0.3$ , highly variable, from 0.9 (fresh snow) to 0.07 (clean ocean).
3. Geothermal energy flux  $\approx 0.092 \text{W/m}^2$ .
4. Heat flux from fossil fuel combustion  $\approx 0.026 \text{W/m}^2$ .

## BASIC PROPERTIES OF THE CLIMATE SYSTEM

1. Air: surface pressure  $\approx 1000 \text{hPa}$  (10m of water),  
 $c_p = 1004 \text{J/kg} \cdot \text{K}$ .
2. Water: global average depth  $\approx 3000 \text{m}$ ,  $c_w = 4192 \text{J/kg} \cdot \text{K}$ .
3. Ground – only a shallow layer responding to radiative fluxes.
4. Greenhouse gases:  $\text{H}_2\text{O}$ ,  $\text{CO}_2$ ,  $\text{CH}_4$ ,  $\text{O}_3$ , many others.

## **Forcings and feedbacks in climate system.**

Climate **forcings** are the **initial drivers** of a climate shift.  
Examples: solar irradiance, changes in the planetary orbit, anthropogenic or volcanic emissions of greenhouse gases.

Climate **feedbacks** are processes that **change as a result of a change in forcing**, and **cause additional climate change**.  
Examples : ice-albedo feedback, CO<sub>2</sub> solubility.

## **Feedbacks can be positive or negative.**

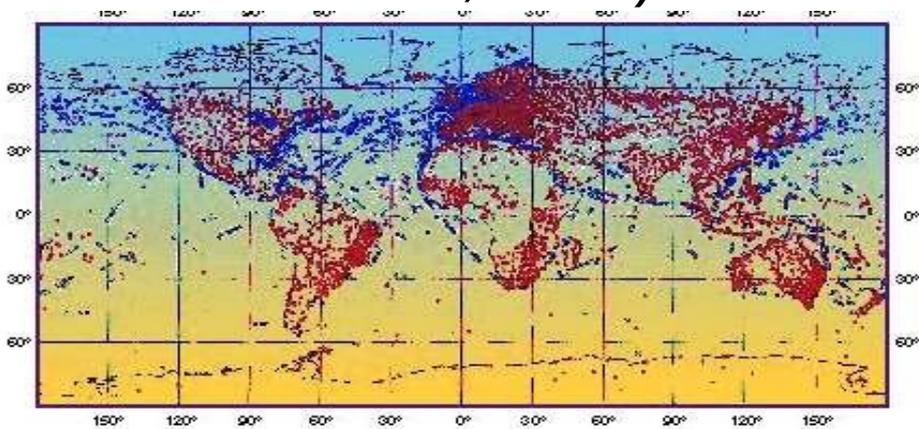
Positive feedbacks, when exceeding thresholds, may lead to rapid climate changes.

There are indications in paleoclimatological data that such changes occurred in geological history of the planet.

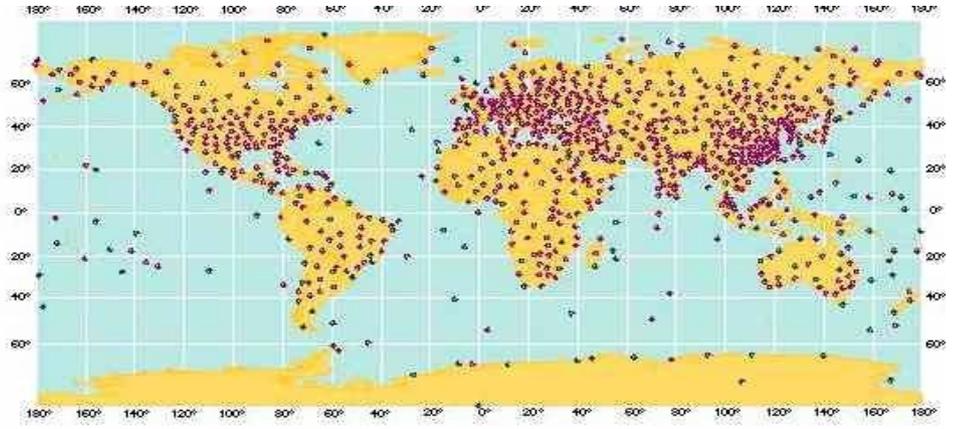
## Outline:

1. Physical properties and principles of climate system
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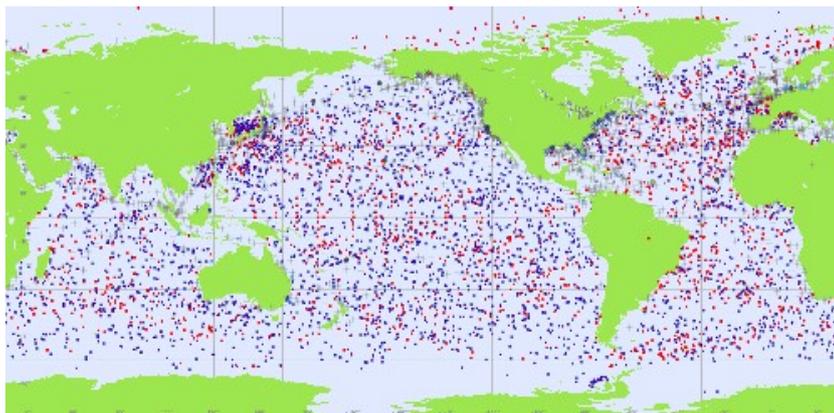
**Atmosphere:** Over 11,000 weather stations, as well as satellites, ships and aircraft take measurements. 1040 of stations are selected to provide high quality climate data. There are special networks at national (e.g. Reference Climate Stations), regional (e.g. Regional Basic Climatological Network) and global scales. (e.g. the Global Climate Observing System - GCOS - Surface Network, GSN).



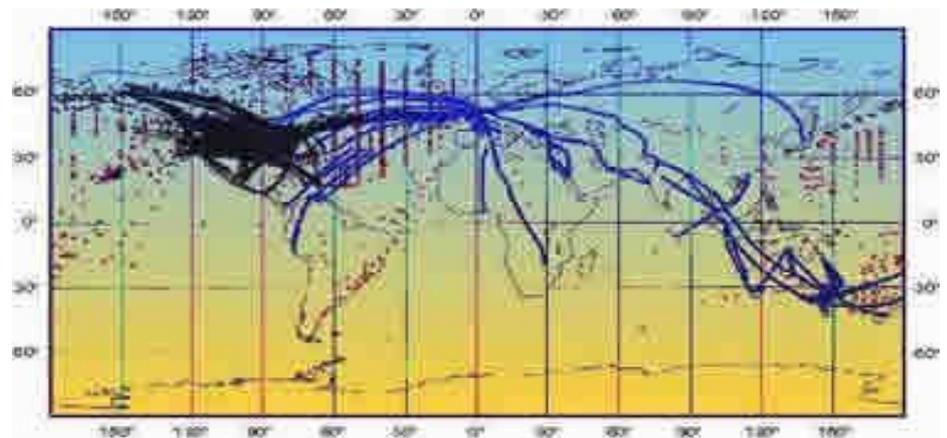
Weather stations and buoys



Upper air soundings



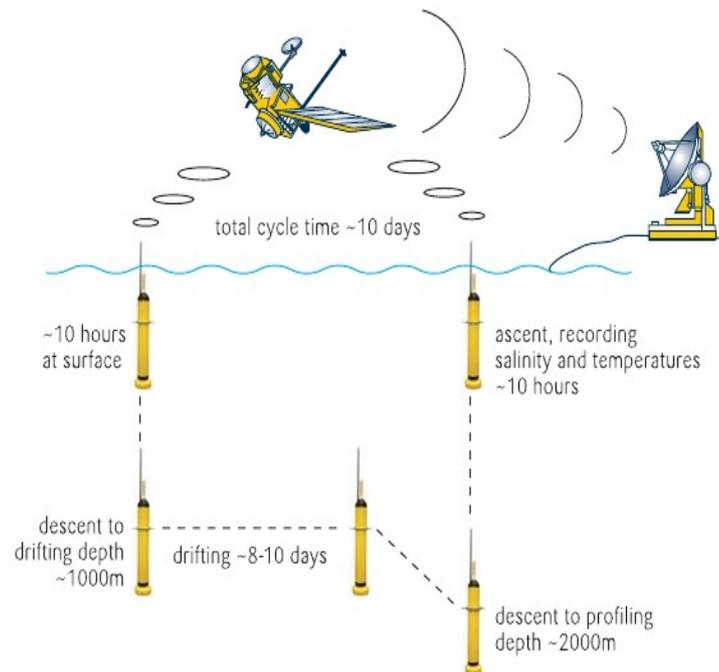
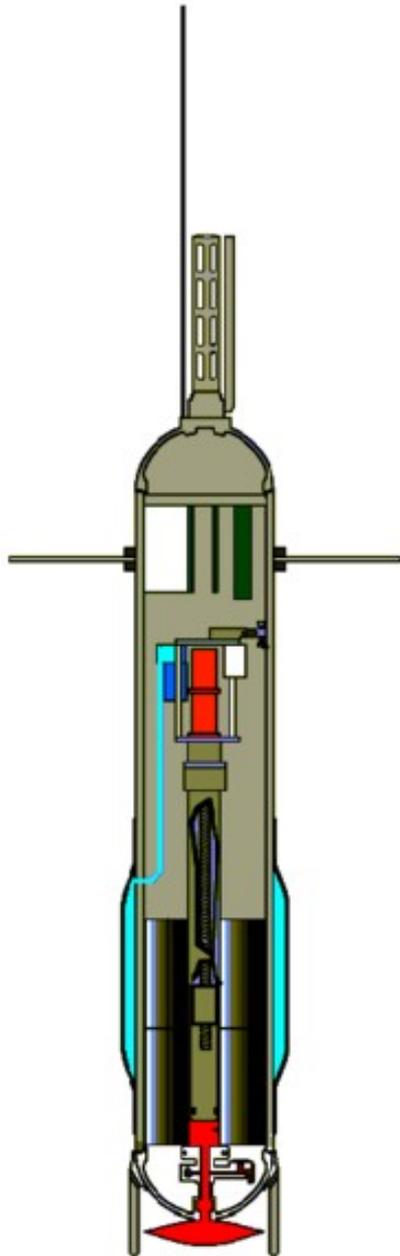
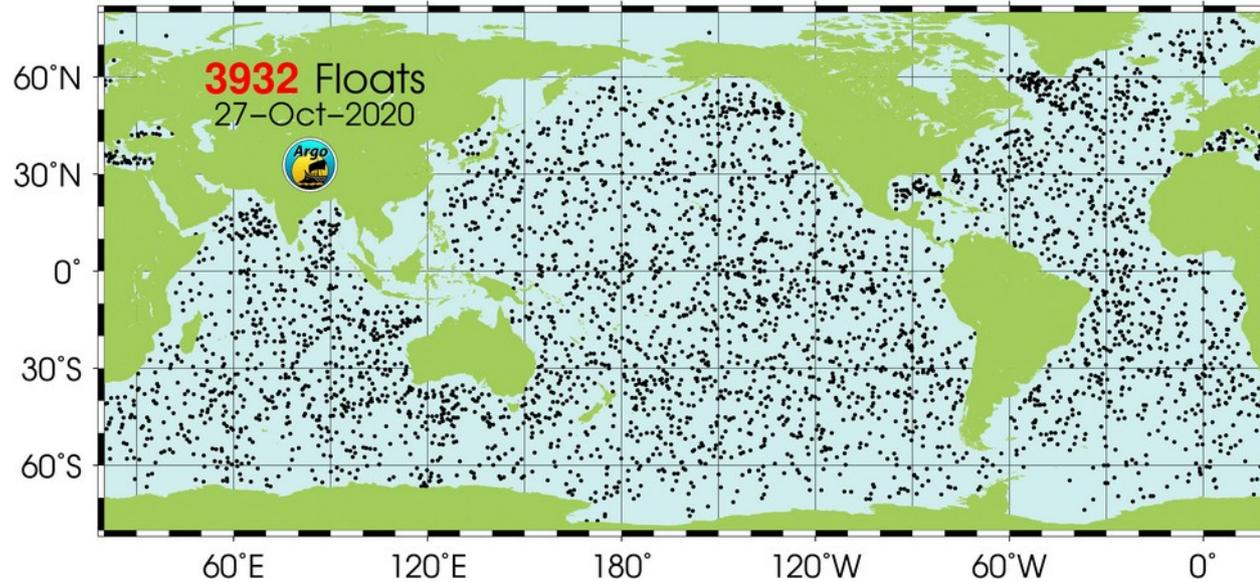
Voluntary ship observations



Aircraft based observations

# OCEAN:

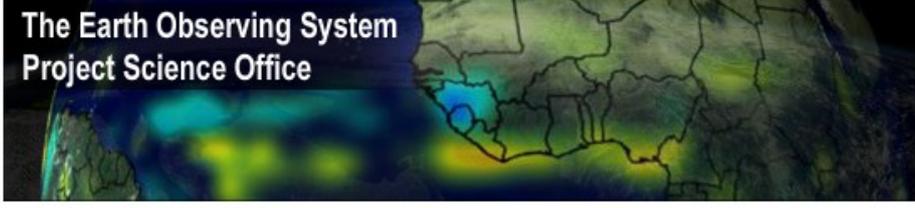
ARGO project: temperature and salinity profiling, deep sea currents.



Thousands of automatic profilers provide actual data from the world ocean.

<http://www.argo.ucsd.edu/>

- For Kids
- For Scientists
- For Educators
- For Media & Press



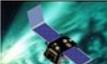
- TOP > MISSIONS > Satellites and Spacecraft
- MISSIONS**
- ▶ Space Transportation Systems
  - ▶ Human Space Activities
  - ▼ **Satellites & Spacecraft**
    - ▶ **Earth Observation**
      - ◀ Operation ▶
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        - ▶ IBUKI (GOSAT)
        - ▶ Aqua
        - ▶ TRMM
        - ▶ REIMEL (INDEX)
        - ▶ Akabono (EXOS-D)
        - ▶ GEOTAIL
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          - ▶ GPM/DPR
          - ▶ GCOM-C
          - ▶ EarthCARE
          - ◀ Completed ▶
            - ▶ DAICHI (ALOS)
      - ▶ Communication, Positioning & Engineering Test
        - ◀ Operation ▶

## Satellites and Spacecraft

Satellites offer a wide variety of valuable services. These include communications and weather observation, which are essential to modern life, as well as astronomical observation and space development. Japanese satellites now in orbit are performing missions in a wide range of areas. For example, they have been playing an important role in assessing and analyzing abnormal weather patterns. For the purpose of planetary exploration, plans are under way for sending probes to the Moon and Mars.

### Earth Observation Satellites

**In Operation**

 Global Change Observation Mission 1st - Water "SHIZUKU" (GCOM-W1)	 Greenhouse gases Observing SATellite "IBUKI" (GOSAT)	 "Aqua" Earth Observation Satellite	 Tropical Rainfall Measuring Mission "TRMM"
			

### About NASA's Earth Observing System

The **Earth Observing System** (EOS) is a coordinated series of polar-orbiting and low inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans. EOS is a major component of the **Earth Science Division** of NASA's **Science Mission Directorate**. EOS enables an improved understanding of the Earth as an integrated system. The EOS Project Science Office (EOSPSO) is committed to bringing program information and resources to program scientists and the general public alike.

Download 2012 NASA Science Mission Directorate Calendar Screen Saver **NEW!**

### EOS Announcements

The Earth Observer Newsletter online is now available in color!  
February 17, 2011

### Earth Observatory's Image of the Day



## observing the earth

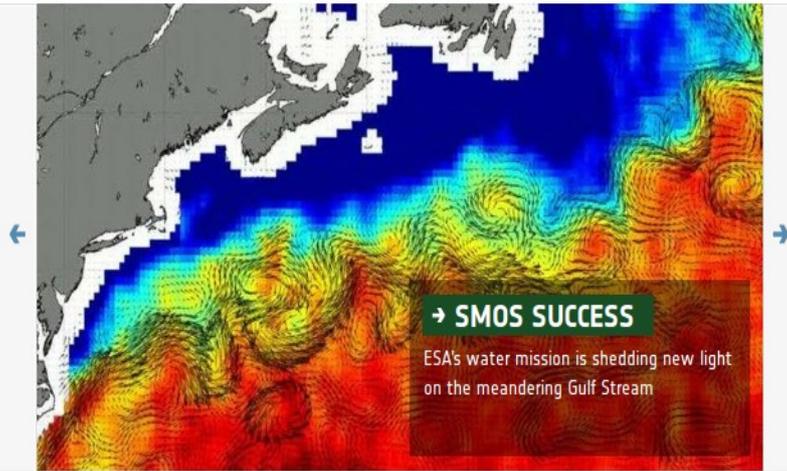


ESA OBSERVING THE EARTH UNDERSTANDING OUR PLANET SECURING OUR ENVIRONMENT BENEFITING OUR ECONOMY

- + About Observing the Earth
- EO programmes
  - The Living Planet
  - GMES
- ESA's Earth Observing missions
  - Envisat overview
  - ERS overview
  - Earth Explorers overview
  - Sentinels overview
  - MSG overview
  - MetOp overview
  - Proba-1 overview
  - Third Party Missions overview

ESA > Our Activities > Observing the Earth





→ SMOS SUCCESS

ESA's water mission is shedding new light on the meandering Gulf Stream

Image of the week archive

Earth from Space on ESA Web-TV

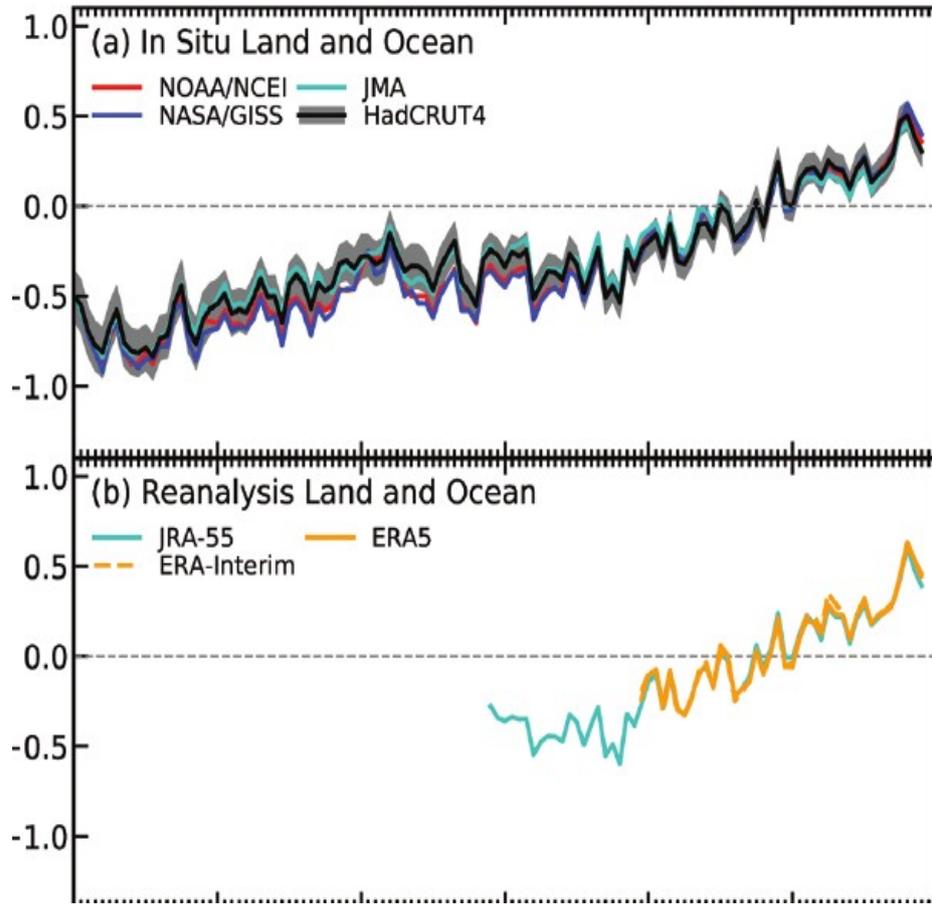
Living Planet Symposium 2013

Archive

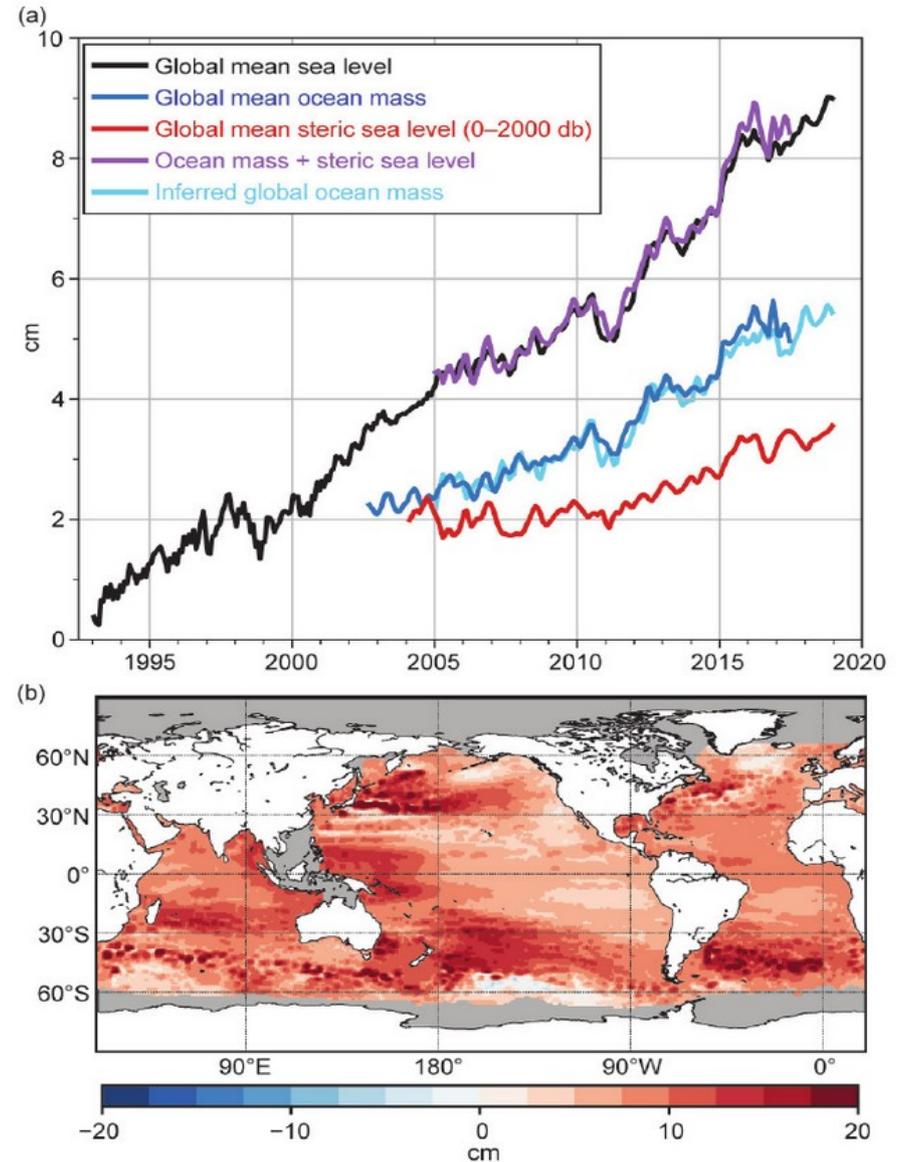
Satellite systems of NASA, ESA, JAXA and others.

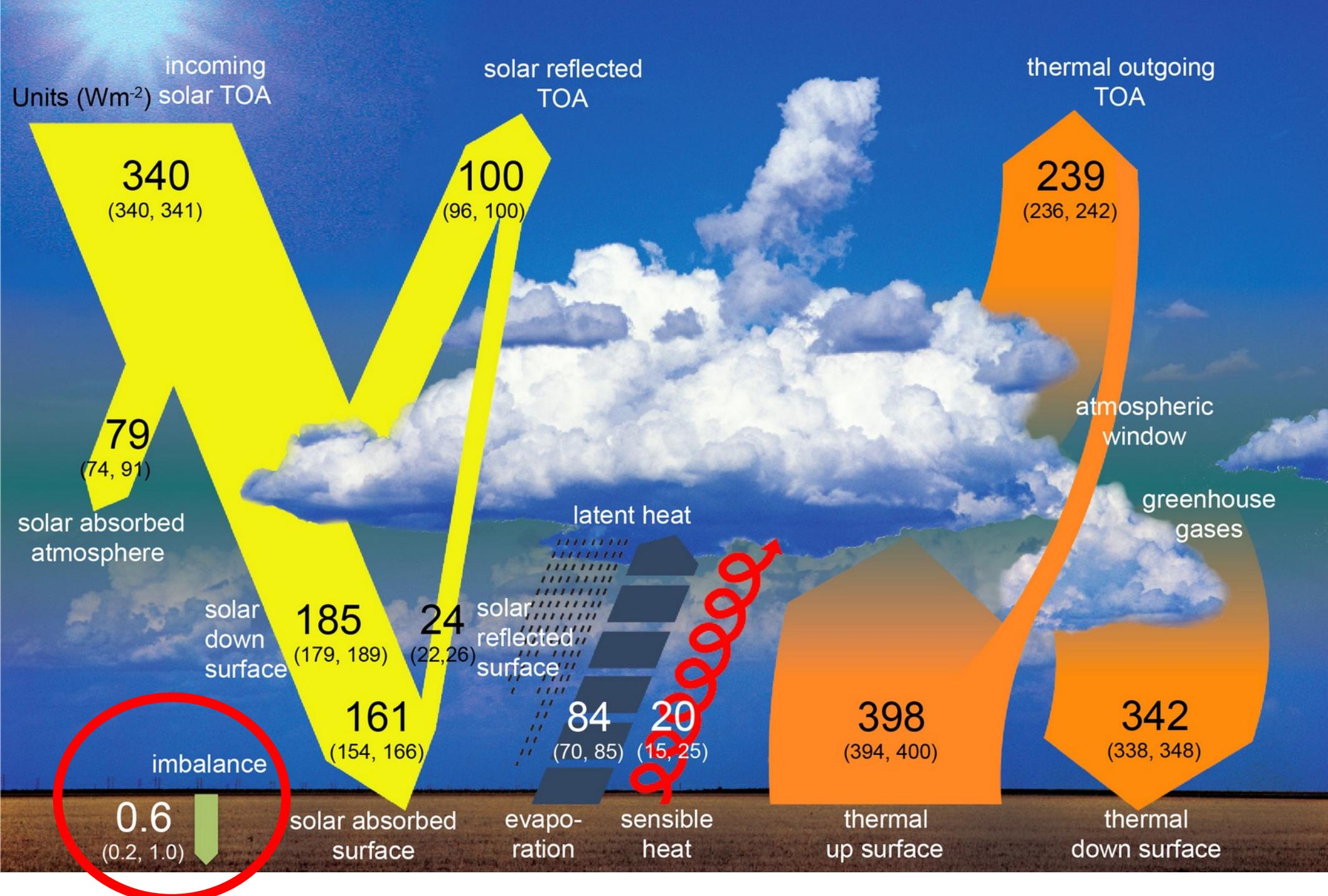
# Observations - summary

## Temperature anomaly



## Sea level change

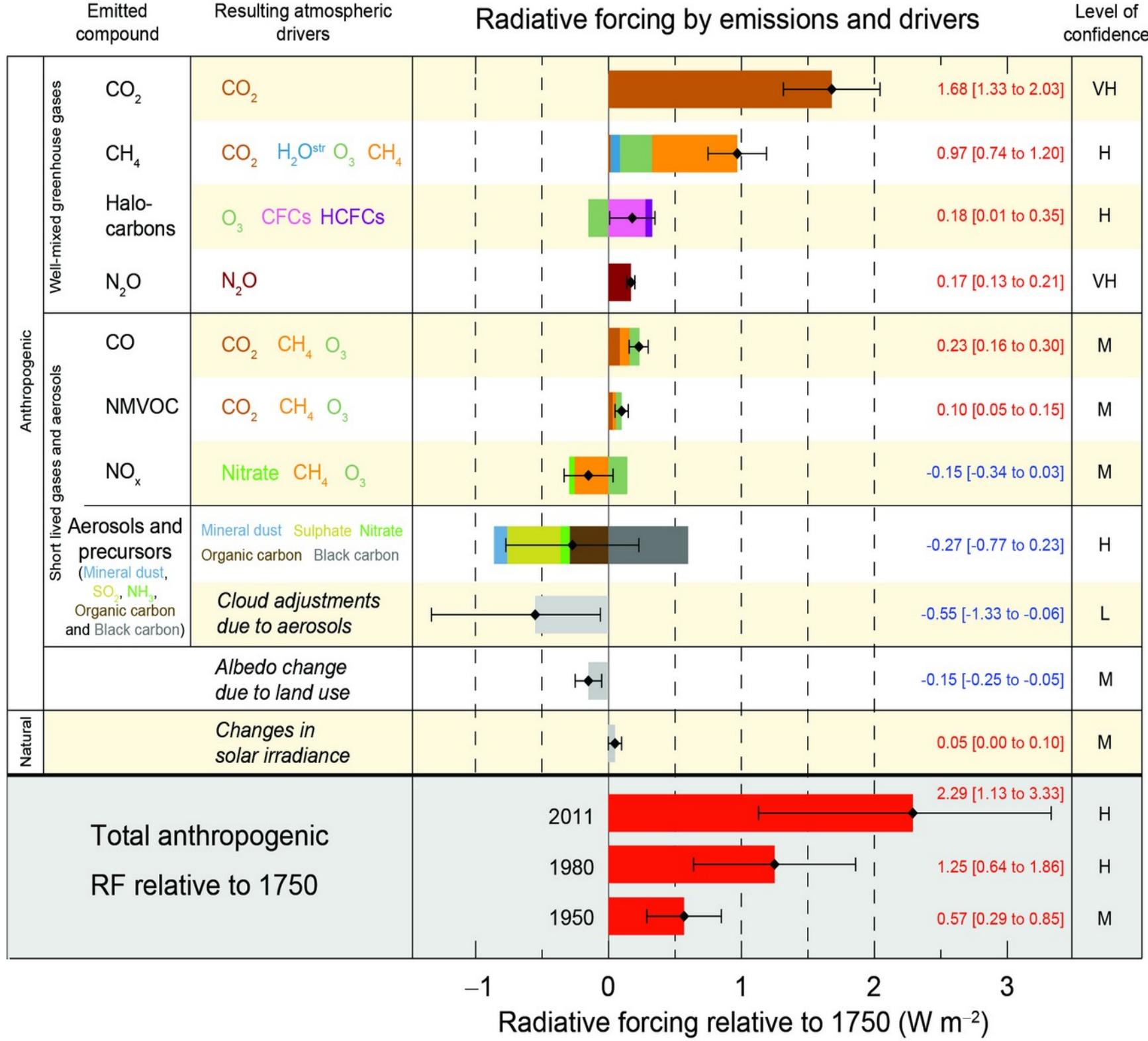




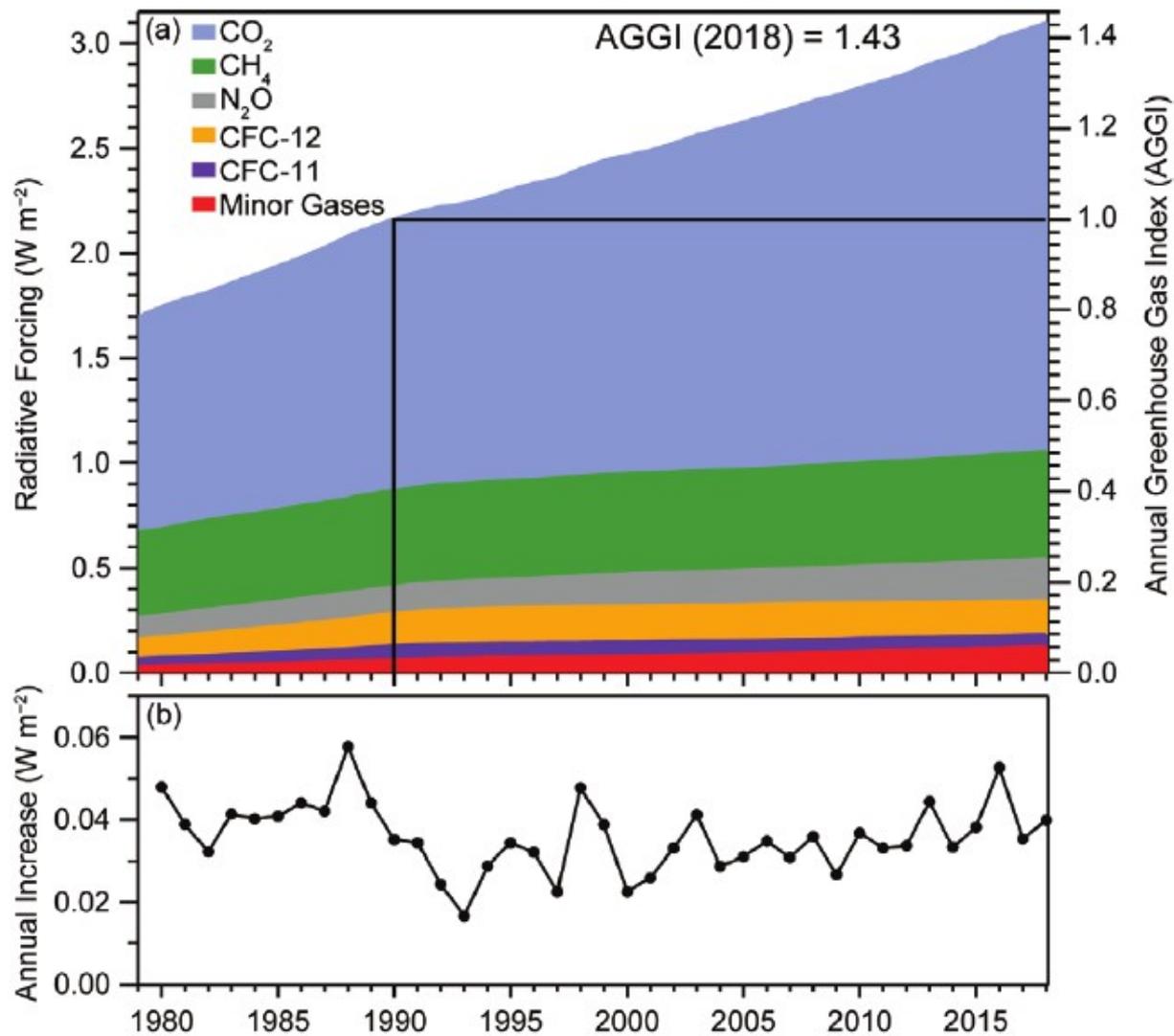
Energy balance of climate system. Units:  $W/m^2$ .

“Radiative forcing” i.e. changes in radiative fluxes since 1750:

GHG  
 – positive,  
 aerosols  
 – negative  
 others  
 – minor.



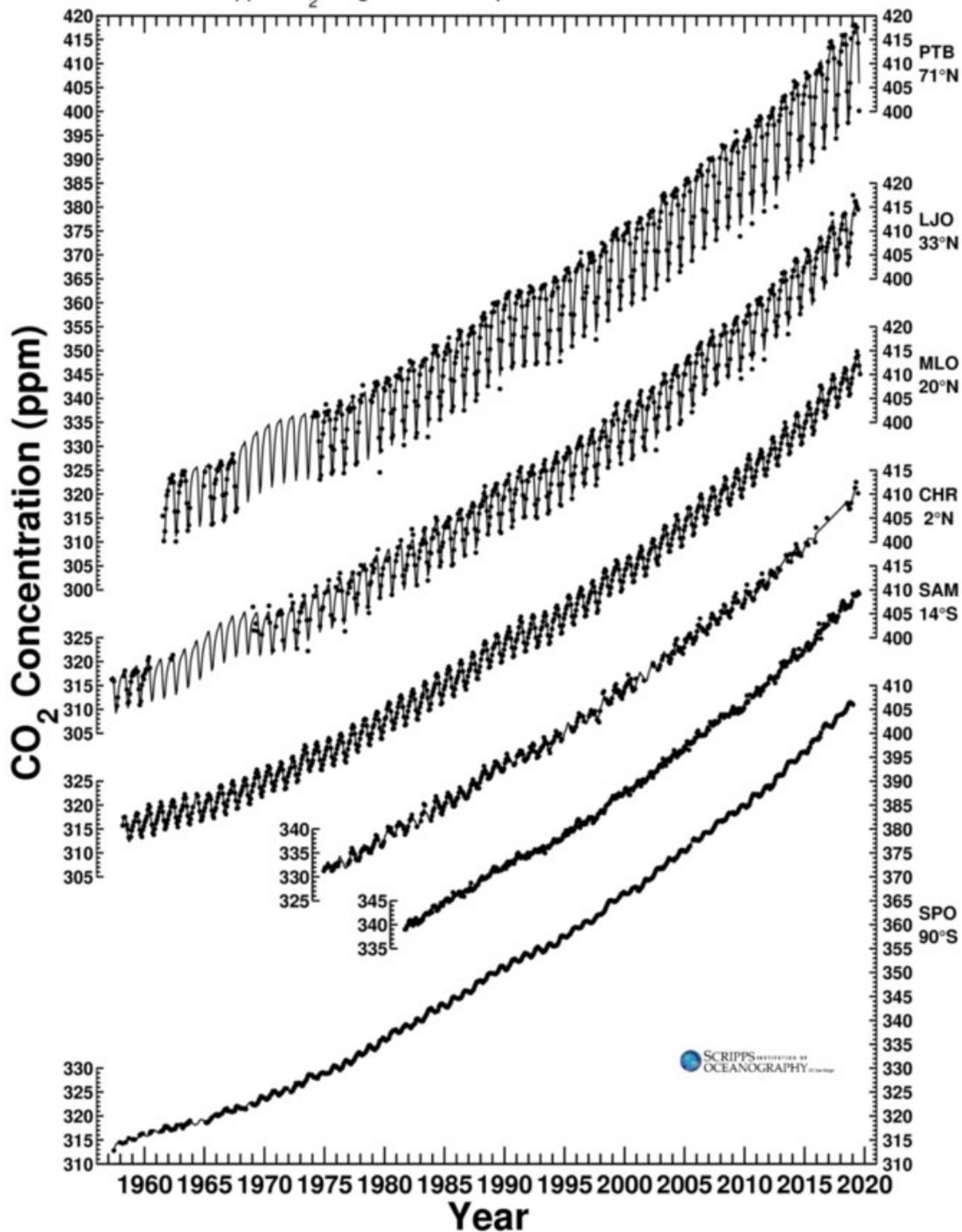
Radiative forcing relative to 1750 (W m<sup>-2</sup>)



**FIG. 2.46. (a) Direct radiative forcing ( $\text{W m}^{-2}$ ) due to 5 major LLGHG and 15 minor gases (left axis) and the associated values of the NOAA AGGI (right axis), and (b) annual increase in direct radiative forcing ( $\text{W m}^{-2}$ ). Solid black lines indicate that the AGGI had a value of 1.0 in 1990.**

# Global Stations Carbon Dioxide Concentration Trends

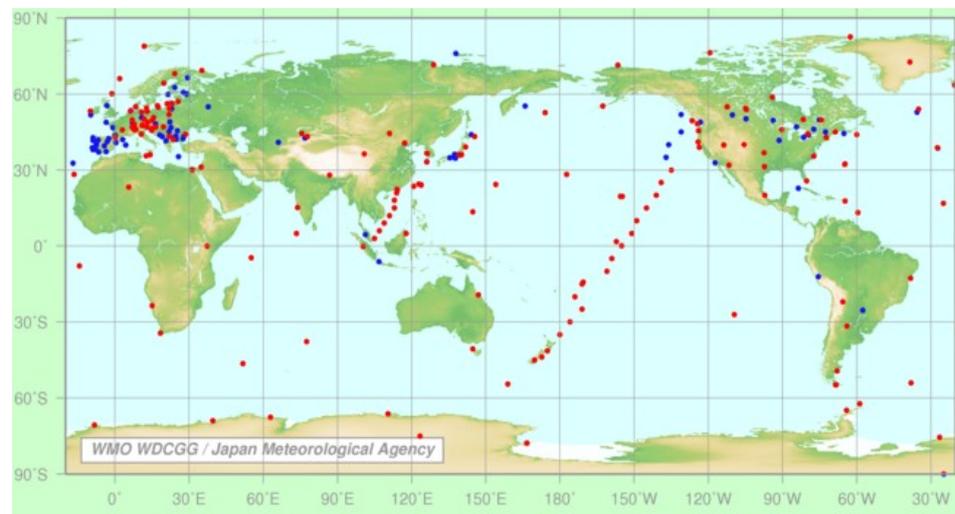
Data from Scripps CO<sub>2</sub> Program Last updated October 2019



Regular observations of CO<sub>2</sub> and the other atmospheric gases are reported to WMO World Data Centre for Greenhouse Gases (WDCGG)

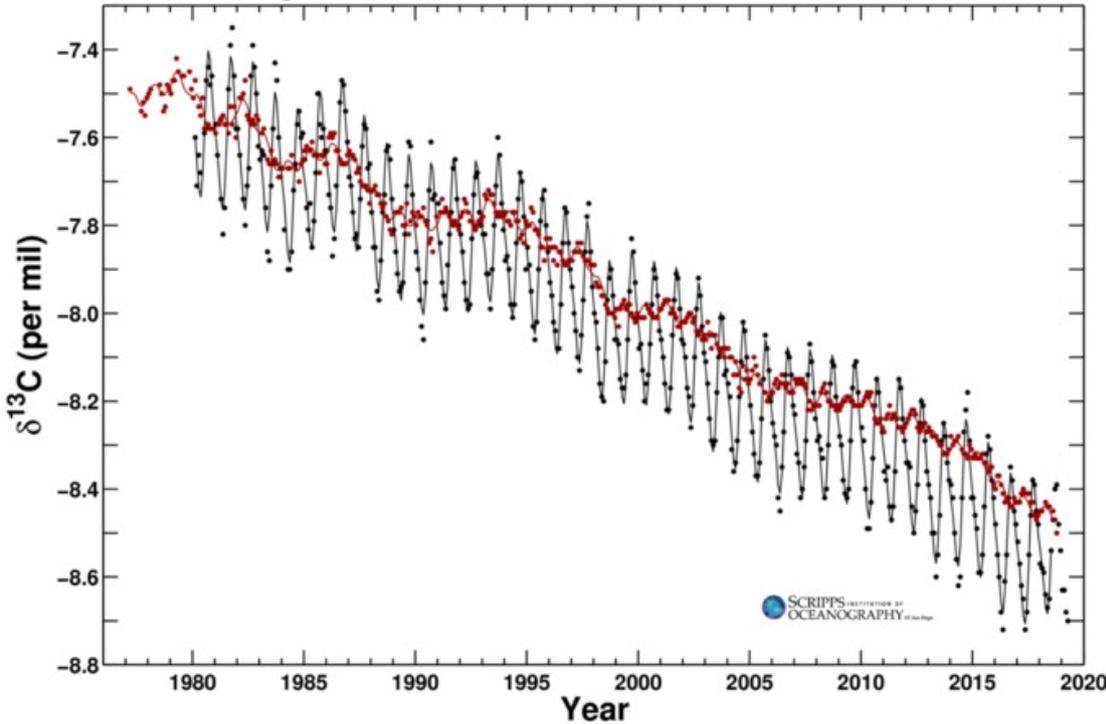
<http://ds.data.jma.go.jp/gmd/wdcgg/>

<http://scrippsco2.ucsd.edu/>



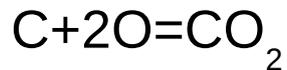
# Mauna Loa Observatory, Hawaii and South Pole, Antarctica Monthly Average $\delta^{13}\text{C}$ Trends

Data from Scripps CO<sub>2</sub> Program Last updated October 2019



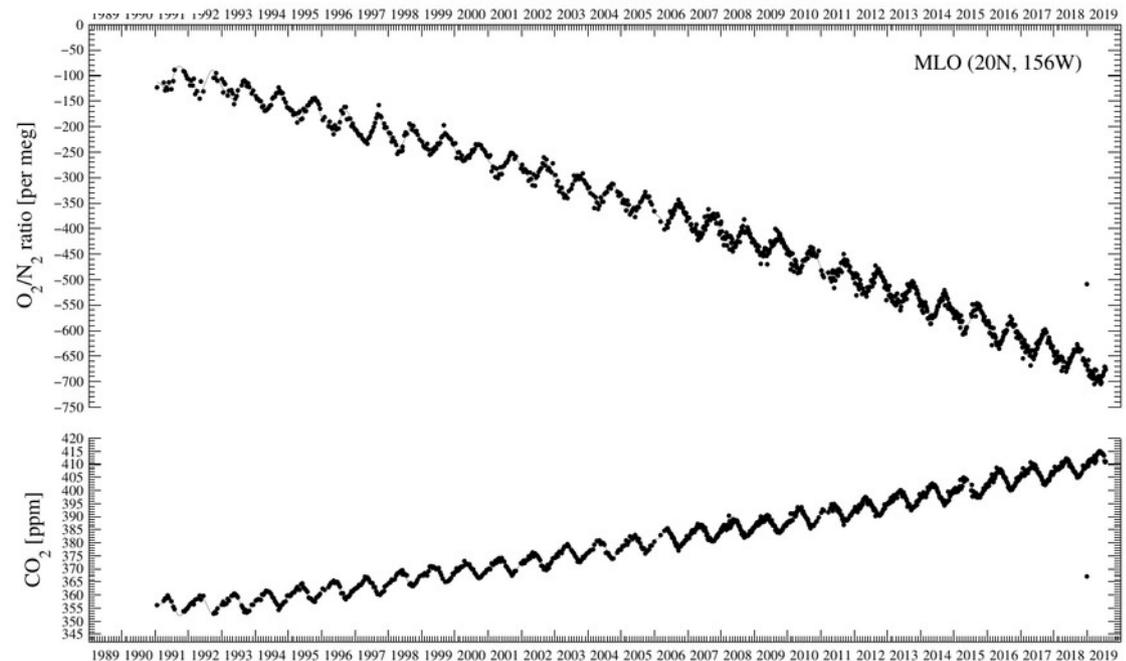
Carbon stable isotopes concentration ratio  $^{13}\text{C}/^{12}\text{C}$  allows to determine the role of fossil fuel combustion in CO<sub>2</sub> concentration increase in the atmosphere and in the ocean.

Another signature of fossil fuel combustion

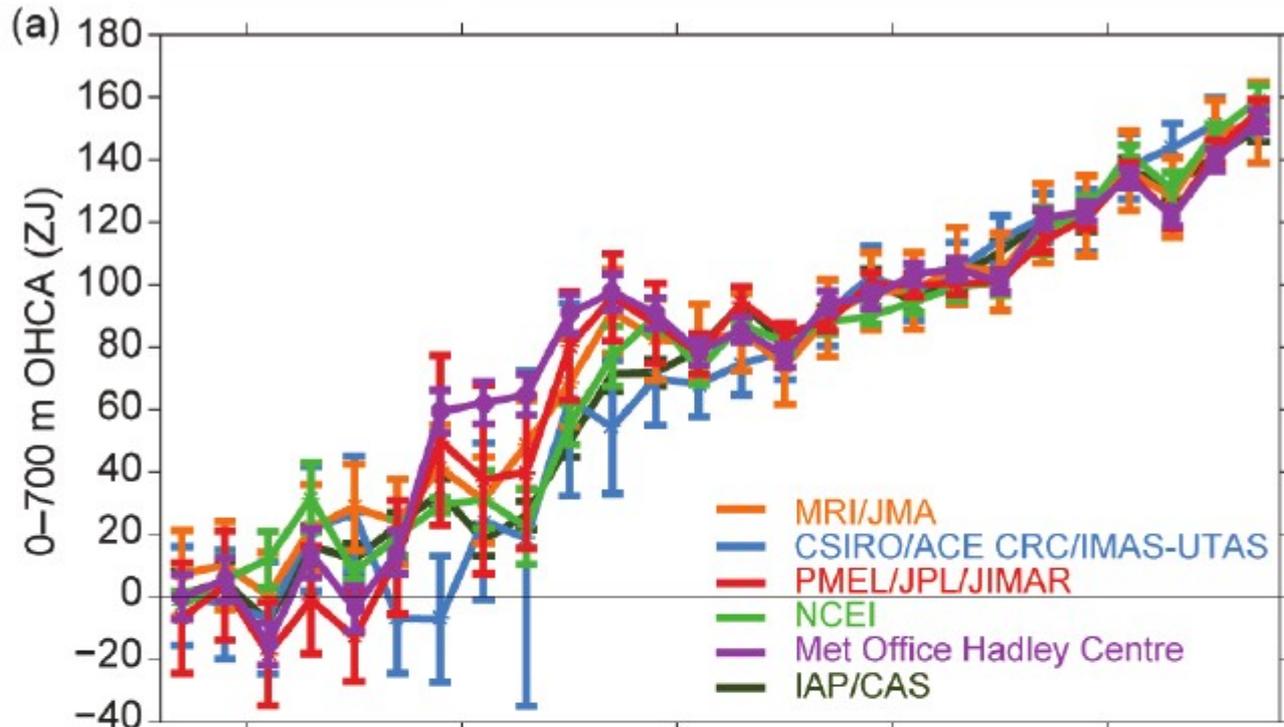


is the ratio of O<sub>2</sub>/N<sub>2</sub> in air.

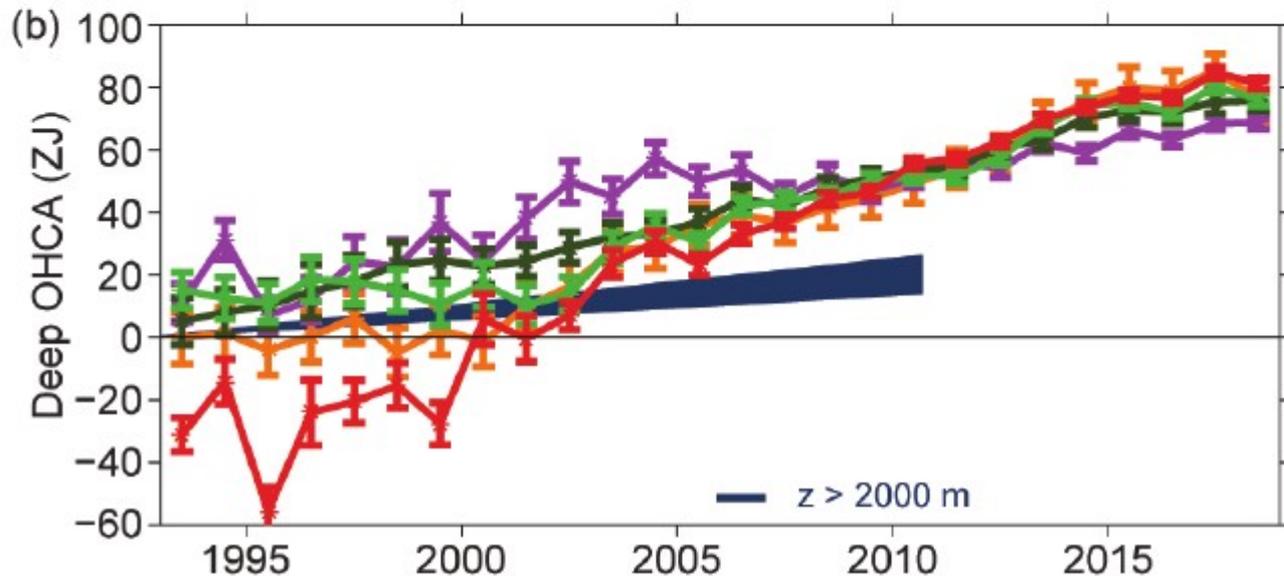
Mauna Loa, Hawaii Aspirated and Non-Aspirated



# Ocean heat content



(a) Annual average global integrals of in situ estimates of upper (0–700 m) OHCA (ZJ; 1 ZJ = 1021 J) for 1993–2018 with standard errors of the mean.

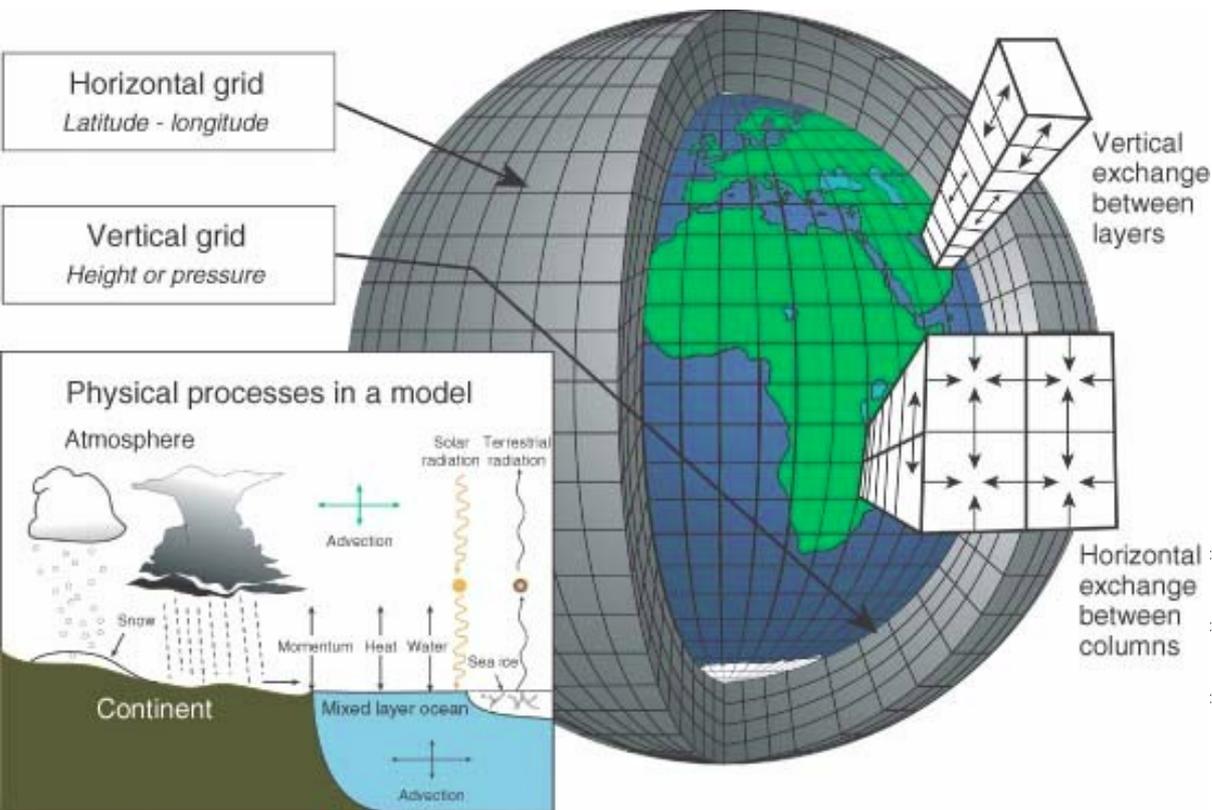


(b) Annual average global integrals of in situ estimates of intermediate (700–2000 m) OHCA for 1993–2018 with standard errors of the mean, and a long-term trend with one standard error uncertainty shown from 1992–2010 for deep and abys.

## Outline:

1. Physical properties and principles of climate system
2. A short history of climate science
3. Contemporary climate
4. Climate modeling
5. Conclusions

# Climate modeling: a virtual planet



geophysical fluid dynamics  
thermodynamics  
radiative transfer  
chemistry equations  
boundary conditions

model equations

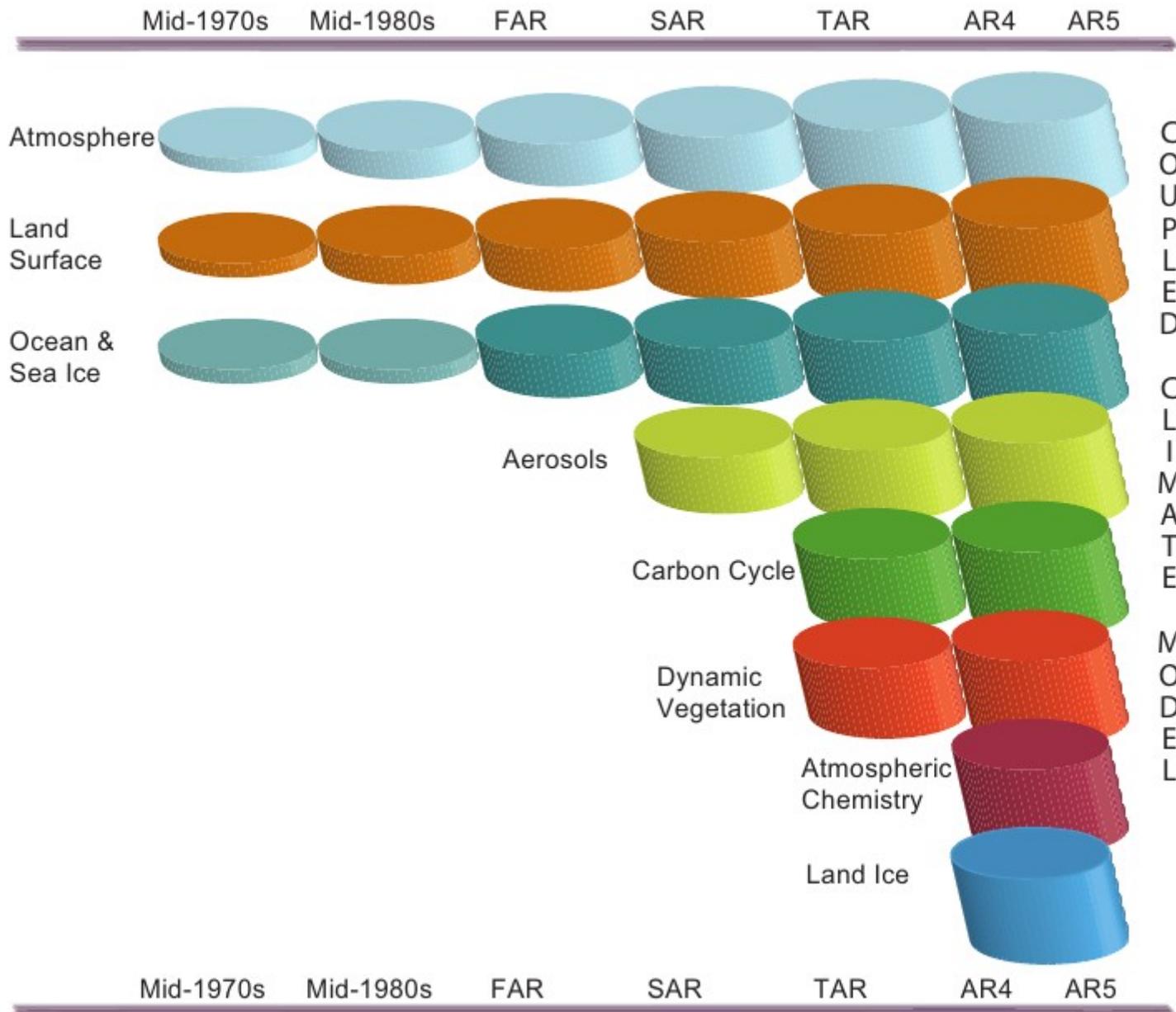


numerical code  
data and initial conditions  
supercomputing facility



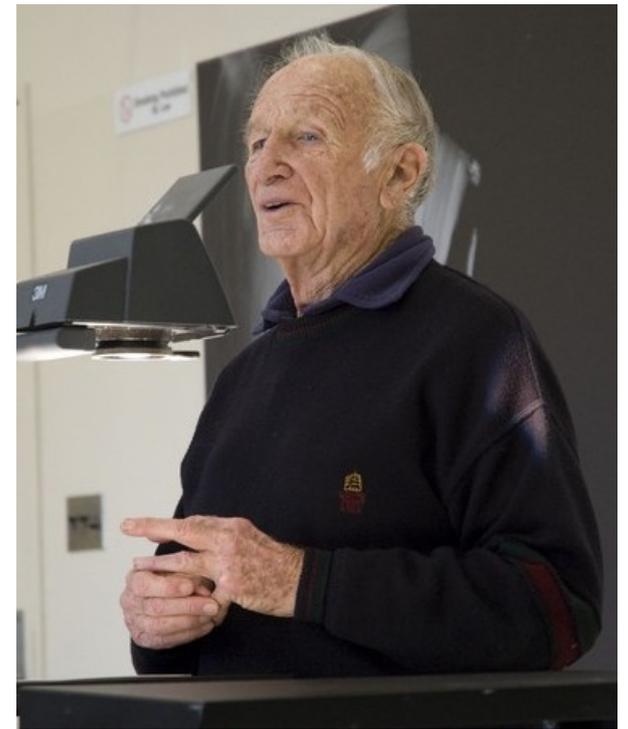
virtual reality allowing for  
simulating climate

# The development of climate models over the last 35 years



# Predictability of weather and climate

Edward N. Lorenz (1917-2008):



Selected papers:

„Deterministic nonperiodic flow”, 1963

(sensitivity of solutions to initial conditions: “butterfly effect”, a well defined attractor)

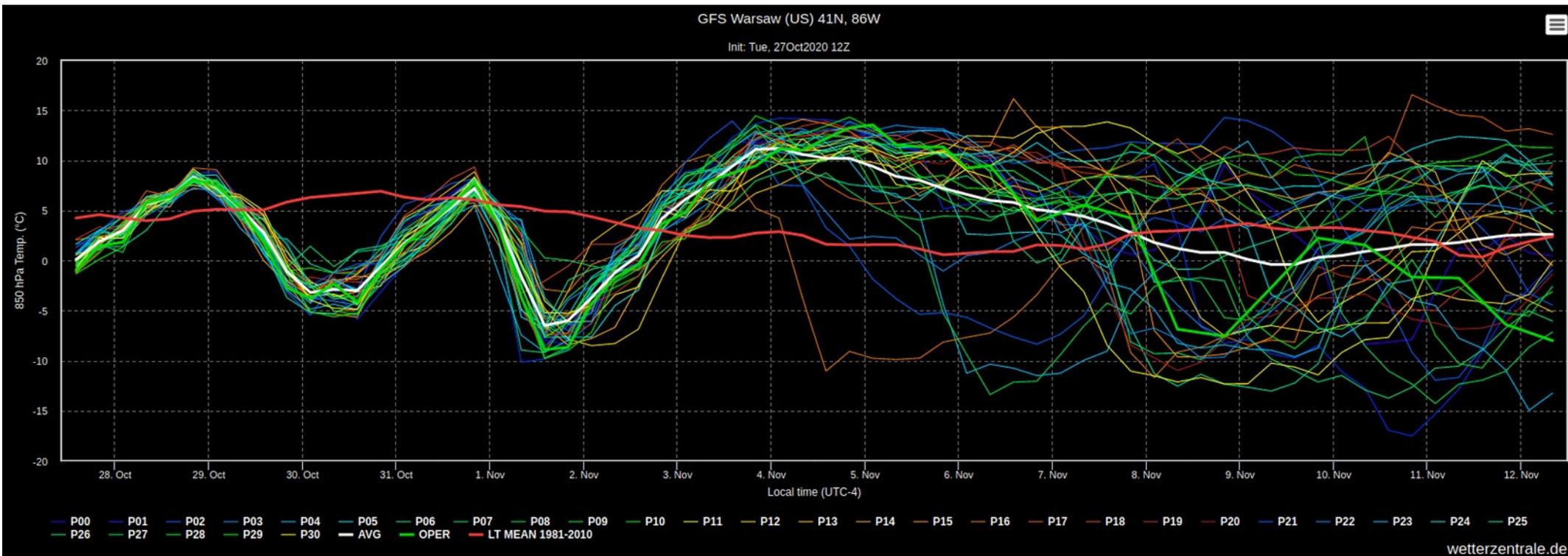
„The problem of deducing the climate from the governing equations”, 1964  
(long term predictability – uncertainties in the governing equations)

„Climatic change as a mathematical problem”, 1970

(unpredictable weather does not mean that climate is not predictable)

„Predictability – a problem partly solved”, 2006

# Predictability of weather and climate – illustration:

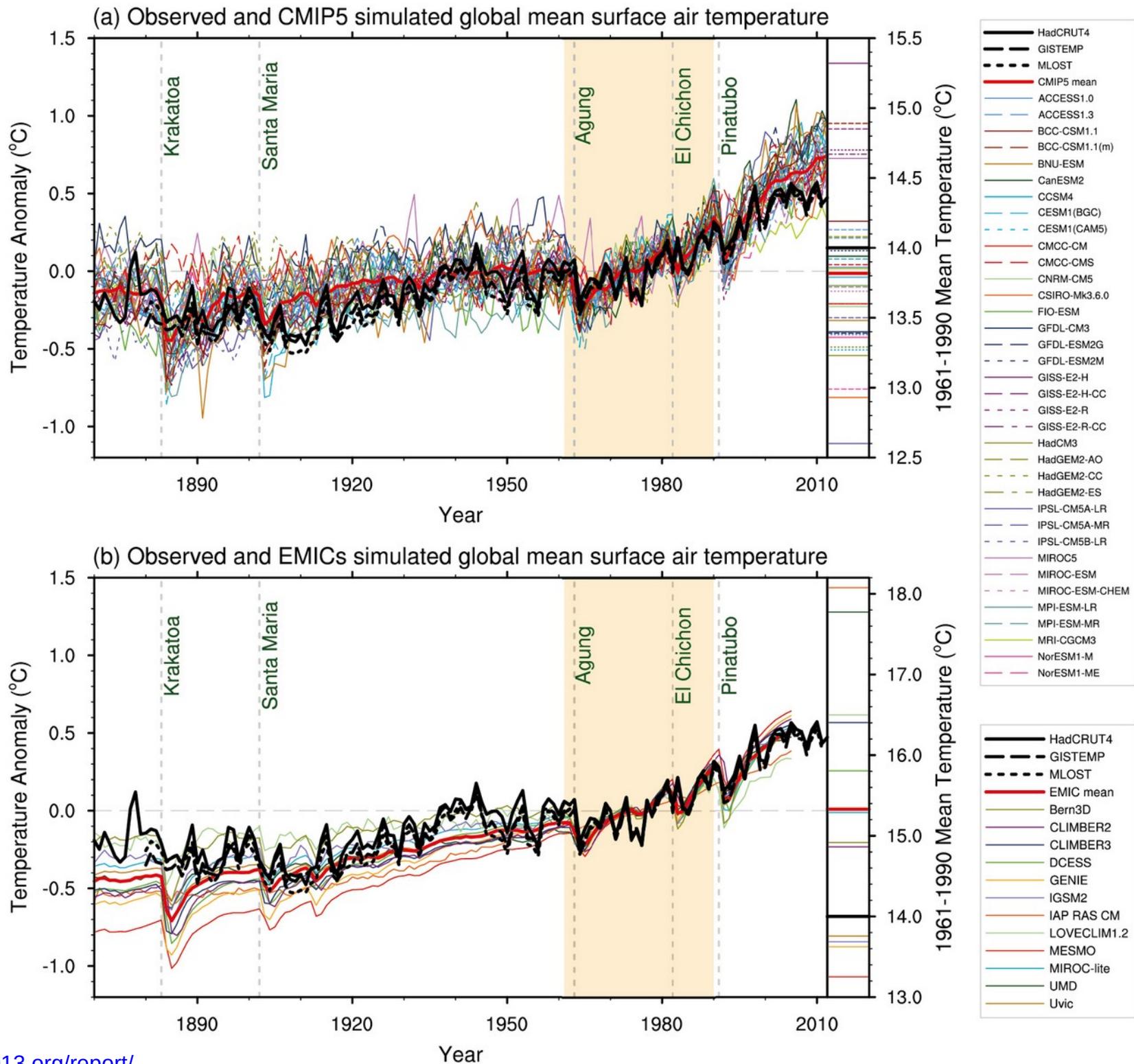


**Multimodel ensemble validations:**

Observed and simulated time series of the anomalies in annual and global mean surface temperature. All anomalies are differences from the 1961–1990 time-mean of each individual time series.

(a) the global mean surface temperature for the reference period 1961–1990, for each individual model (colours), the CMIP5 multi-model mean (thick red), and the observations (thick black).  
 (b) available EMIC simulations (thin lines),

<http://www.climatechange2013.org/report/>



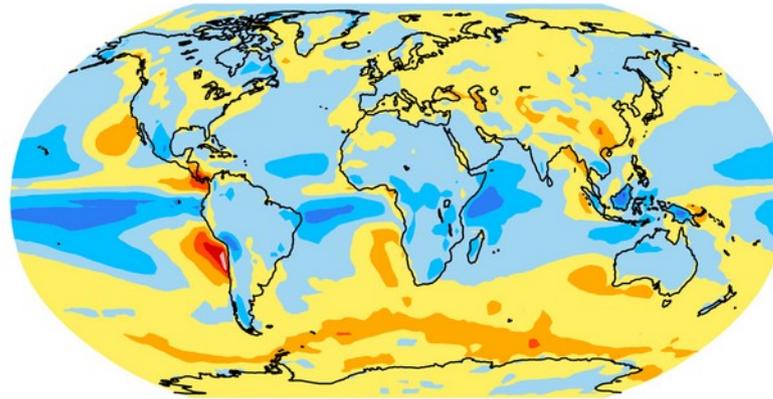
## Model validations:

Annual-mean cloud radiative effects of the CMIP5 models compared against the measurements (CERES EBAF 2.6) data set (in  $\text{W m}^{-2}$ ; top row: shortwave effect; middle row: longwave effect; bottom row: net effect).

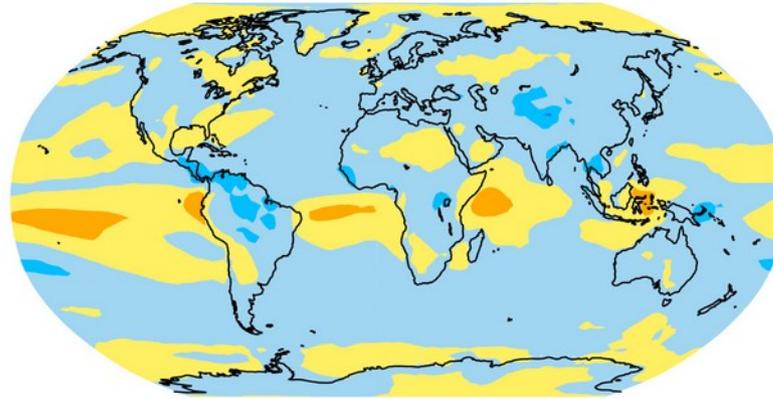
On the left are the global distributions of the multi-model-mean biases, and on the right are the zonal averages of the cloud radiative effects from observations.

Model results are for the period 1985–2005, while the available CERES data are for 2001–2011.

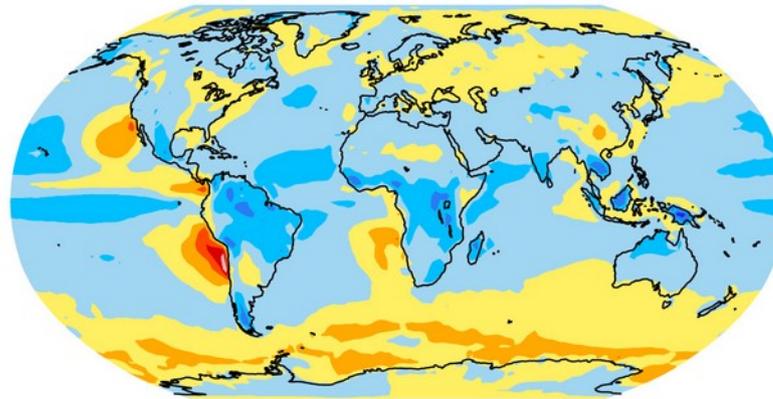
(a) Shortwave cloud radiative effect - MOD-OBS



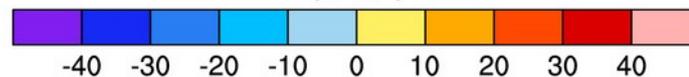
(b) Longwave cloud radiative effect - MOD-OBS



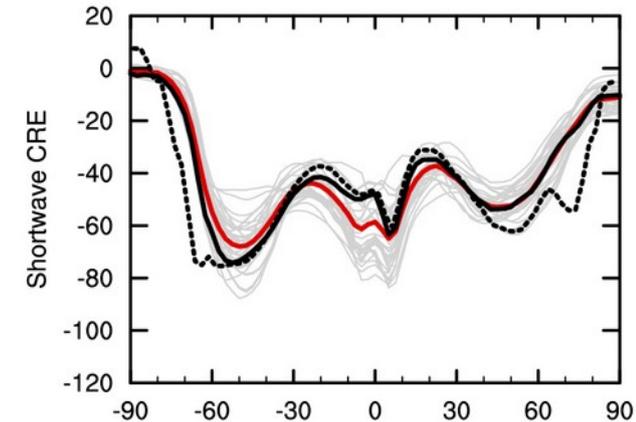
(c) Net cloud radiative effect - MOD-OBS



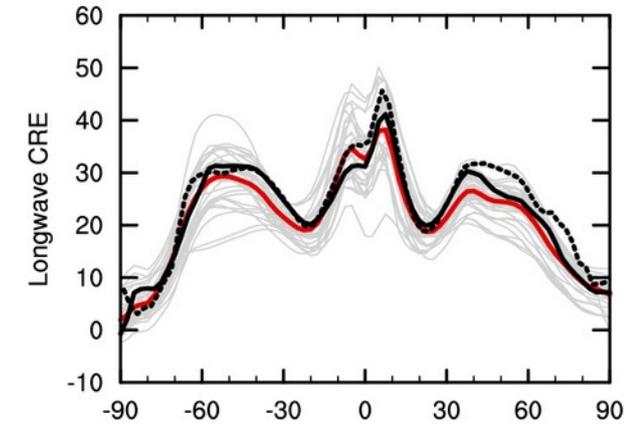
( $\text{W m}^{-2}$ )



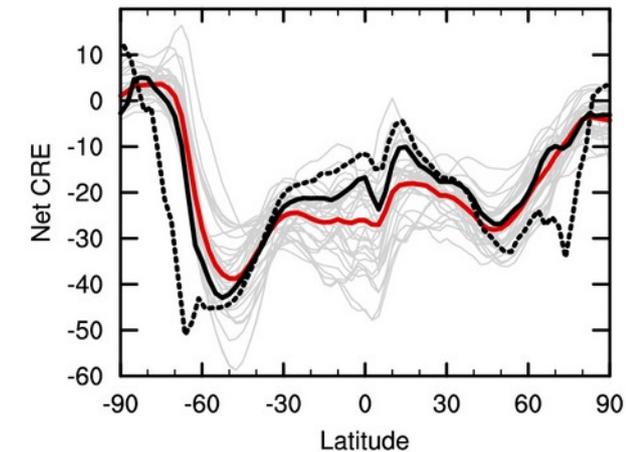
(d) zonal average of shortwave CRE



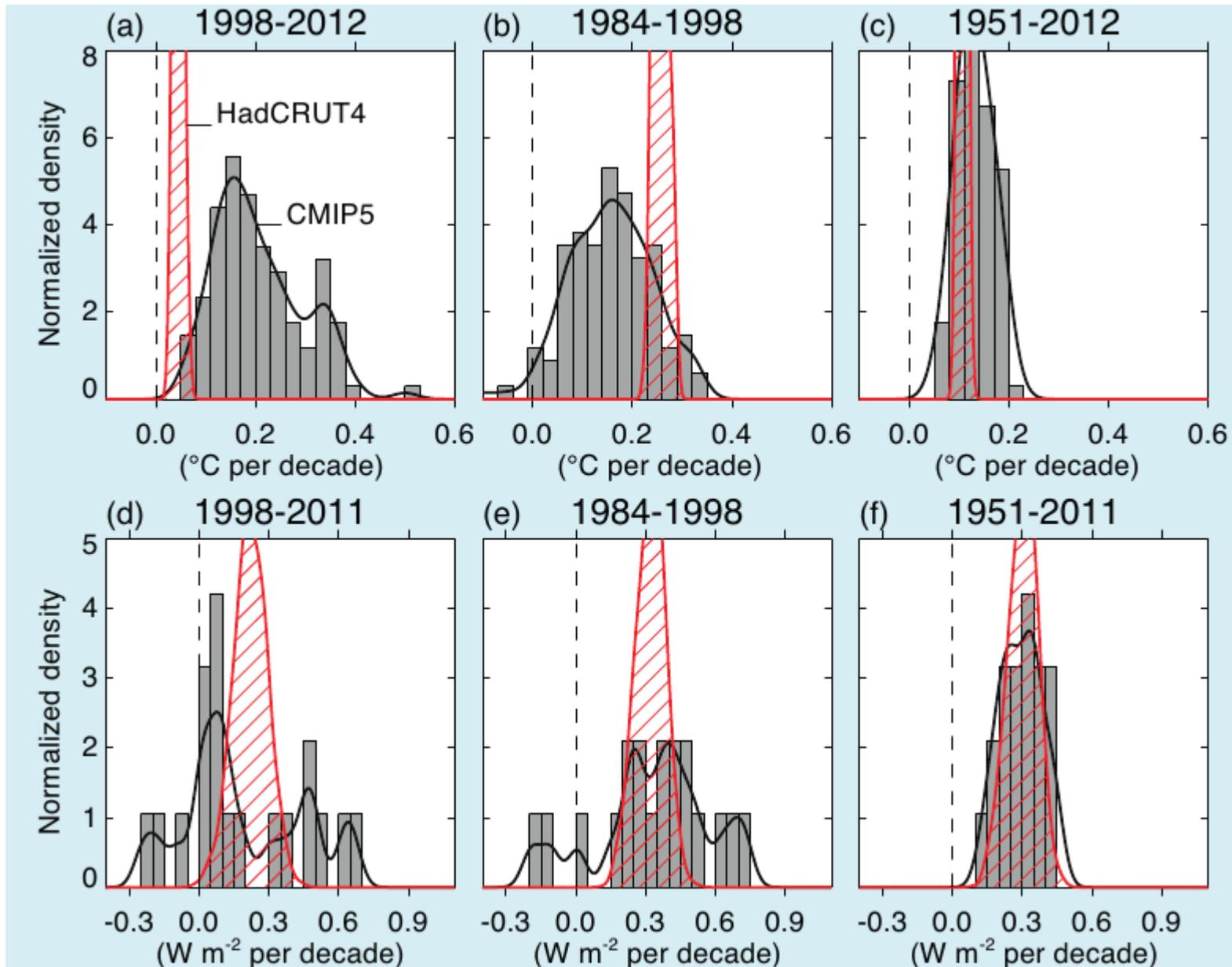
(e) zonal average of longwave CRE



(f) zonal average of net CRE



# Model ensembles vs. observations.



(Top) Observed and simulated global mean surface temperature (GMST) trends in degrees Celsius per decade, over the periods 1998–2012 (a), 1984–1998 (b), and 1951–2012 (c). For the observations, 100 realizations of the Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4) ensemble are shown (red, hatched).

Arguments, that climate model provide valuable information:

- 1) the models can reproduce the current climate;
- 2) the models can reproduce the recent observed trends as well as the more distant past;
- 3) the models are based on physical principles;
- 4) there is a hierarchy of the models from the simplest ones to most complicated, which allows for understanding and interpretation many of the results;
- 5) the value of simulations is increased where multiple models are available, since they indicate which changes are more certain than others.

# Anthropogenic and natural warming inferred from changes in Earth's energy balance

Markus Huber and Reto Knutti\*

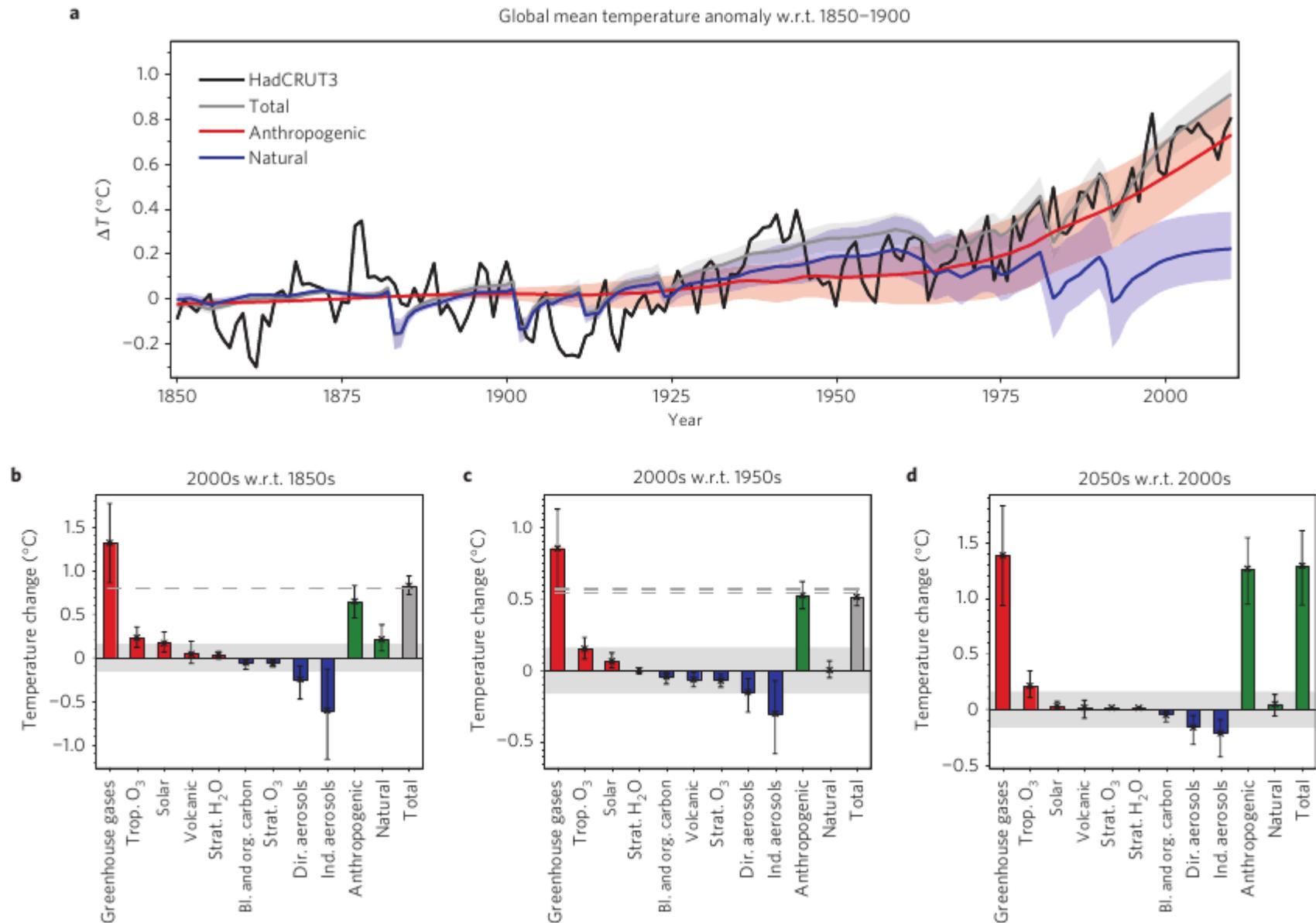
Here we present an alternative attribution method that relies on the principle of conservation of energy, without assumptions about spatial warming patterns.

Based on a massive ensemble of simulations with an intermediate-complexity climate model we demonstrate that known changes in the global energy balance and in radiative forcing tightly constrain the magnitude of anthropogenic warming.

We find that since the mid-twentieth century, greenhouse gases contributed  $0.85 \text{ }^\circ\text{C}$  of warming (5–95% uncertainty:  $0.6\text{--}1.1 \text{ }^\circ\text{C}$ ), about half of which was offset by the cooling effects of aerosols, with a total observed change in global temperature of about  $0.56 \text{ }^\circ\text{C}$ .

The observed trends are extremely unlikely (<5%) to be caused by internal variability, even if current models were found to strongly underestimate it.

Our method is complementary to optimal fingerprinting attribution and produces fully consistent results, thus suggesting an even higher confidence that human-induced causes dominate the observed warming.



**Figure 3 | Contributions of different forcing agents to the total observed temperature change. a**, Time series of anthropogenic and natural forcings contributions to total simulated and observed global temperature change. The coloured shadings denote the 5–95% uncertainty range. **b–d**, Contributions of individual forcing agents to the total decadal temperature change for three time periods. Error bars denote the 5–95% uncertainty range. The grey shading shows the estimated 5–95% range for internal variability based on the CMIP3 climate models. Observations are shown as dashed lines.