Global warming - physicist's perspective - 02

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NAUKA O KLIMACIE
DLA SCEPTYCZNYCH

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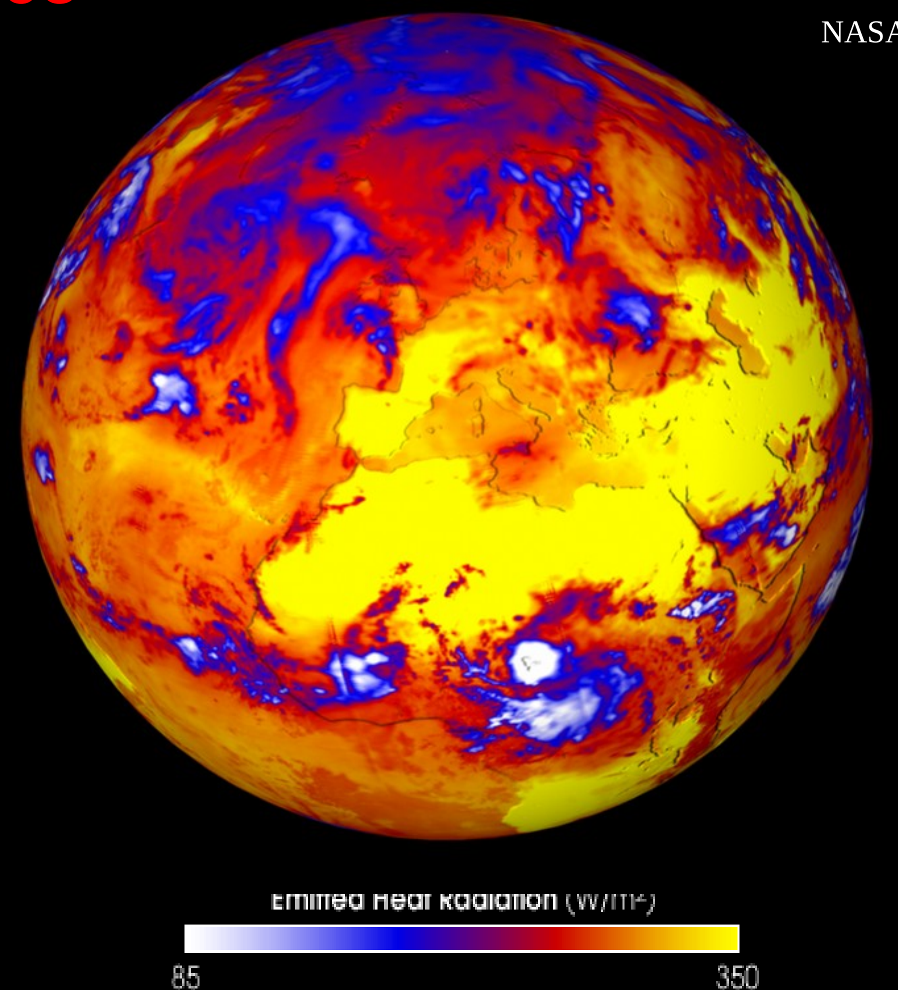
OF WARSAW

Outline:

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

Energy Balance

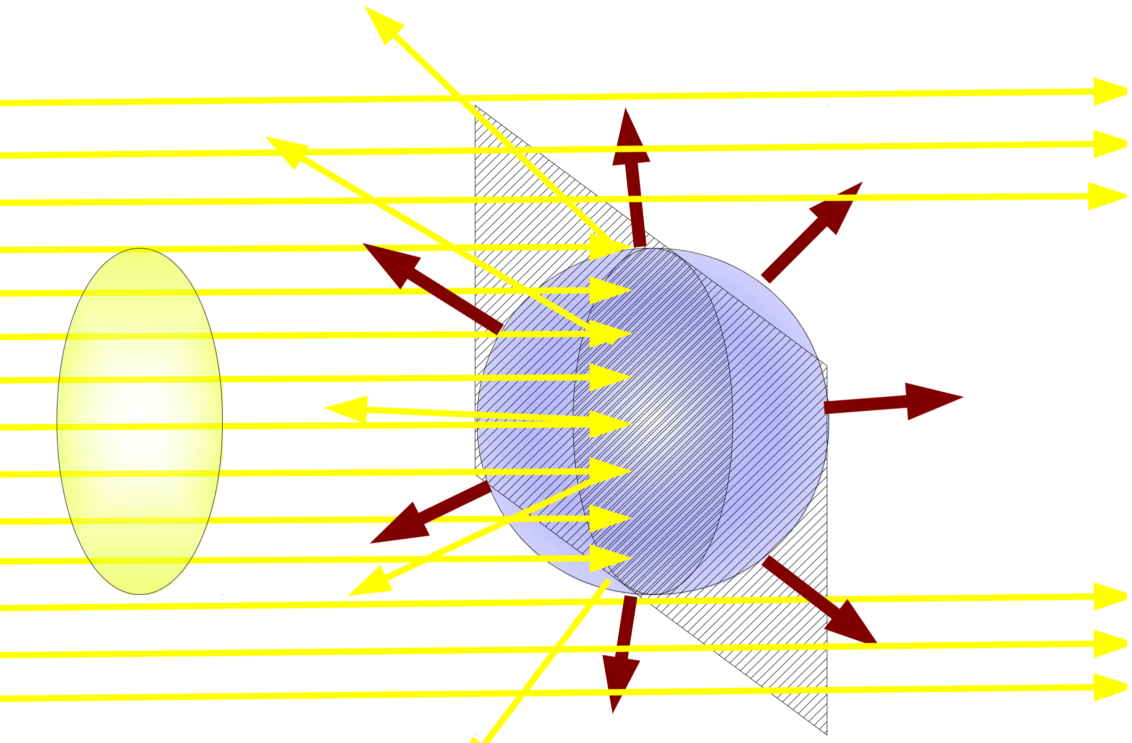


THE EARTH is illuminated by shortwave SOLAR radiation, which is partially absorbed and partially reflected.

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:

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

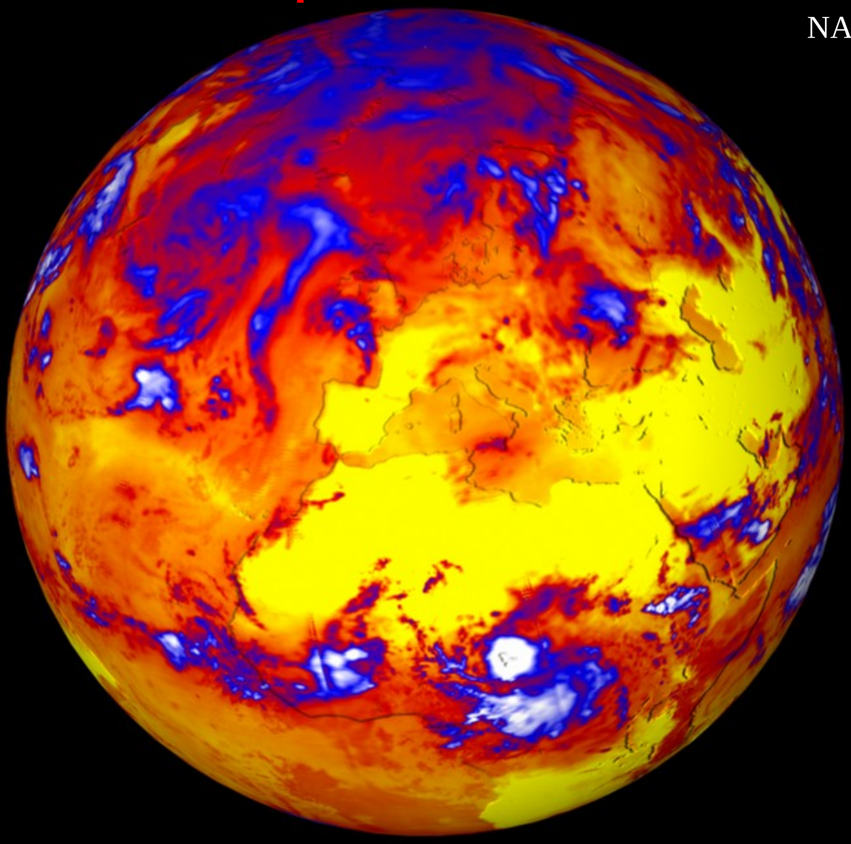
Assume energetic equlibrium $E_S = E_P$

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

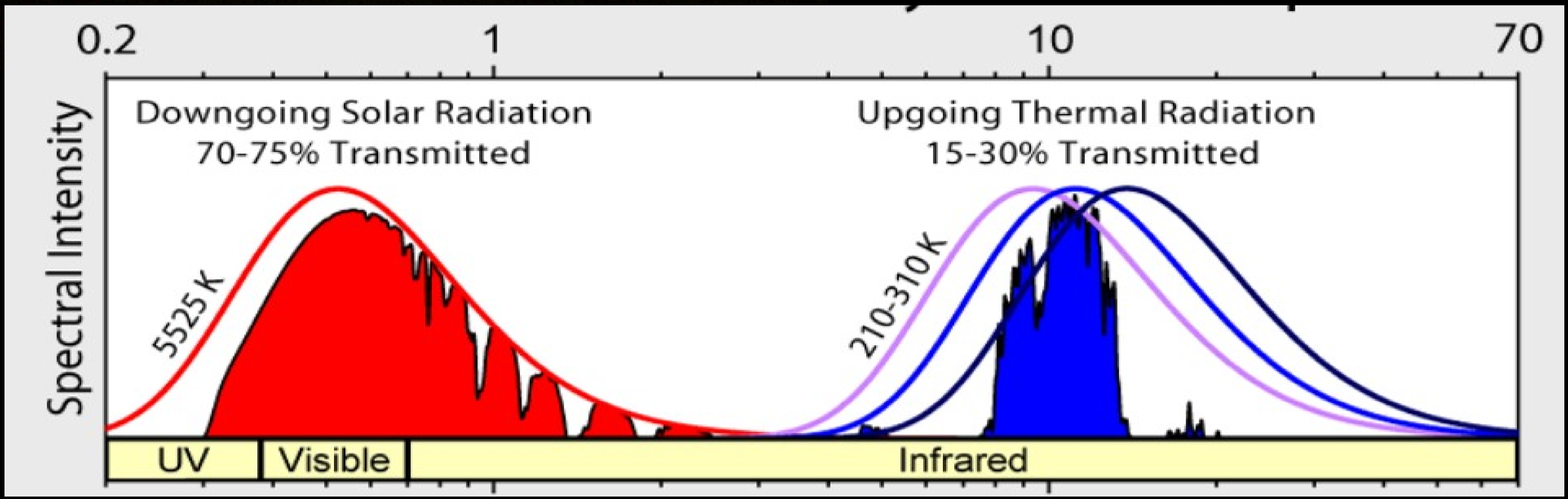
$$T_E = \sqrt[4]{\frac{(1-A)S}{4\sigma}}$$

For S=1362±1 W/m^2 and A=0.3 T_E=254.81±0.05K

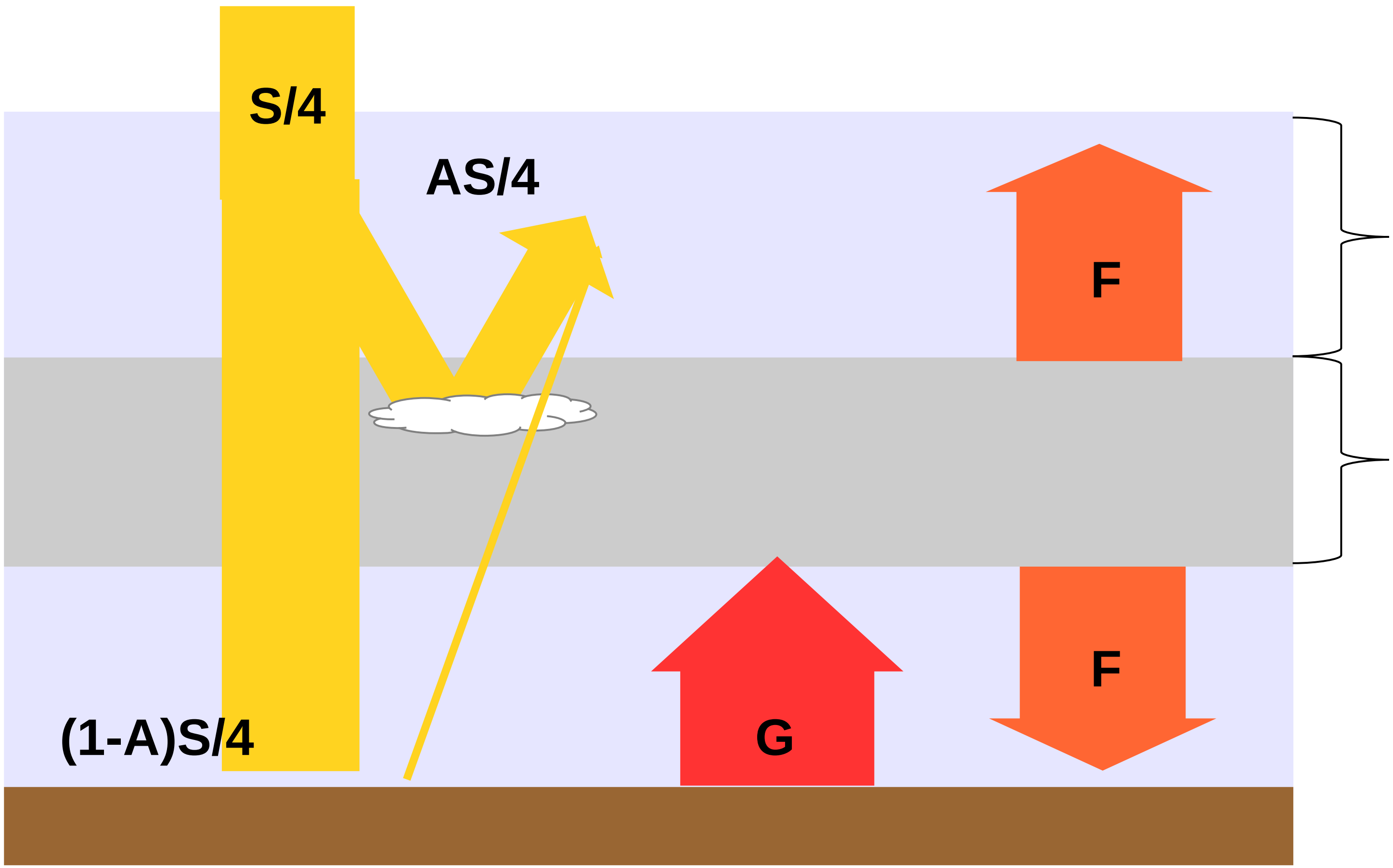
Transmission through the atmosphere



NASA



Greenhouse effect – single layer model



$$\frac{(1-A)S}{4} = F = \sigma T_E^4$$

$$G = 2F$$

$$G = \sigma T_G^4 = 2\sigma T_E^4$$

$$\Rightarrow T_G = \sqrt[4]{2}\,T_E$$

$T_E \approx 255K$ $\quad$ $T_G \approx 303K$

ENERGY IN CLIMATE SYSTEM

1. Solar energy flux = ¼ of Solar constant
   $1/4 * 1362 W/m^2 \approx 341 W/m^2$.
2. Earth's surface albedo, mean ≈0.3, highly variable, from 0.9 (fresh snow) to 0.07 (clean ocean).
3. Geothermal energy flux $\approx 0.092 W/m^2$.
4. Heat flux from fossil fuel combustion $\approx 0.026 W/m^2$.

BASIC PROPERTIES OF THE CLIMATE SYSTEM

1. Air: surface pressure ≈1000hPa (10m of water), $c_p = 1004 J/kg*K$.
2. Water: global average depth ≈ 3000m, $c_w = 4192 J/kg*K$.
3. Ground – only a shallow layer responding to radiative fluxes.
4. Greenhouse gases: H_2O, CO_2, CH_4, 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, CO2 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.

http://www.ncdc.noaa.gov/paleo/paleo.html

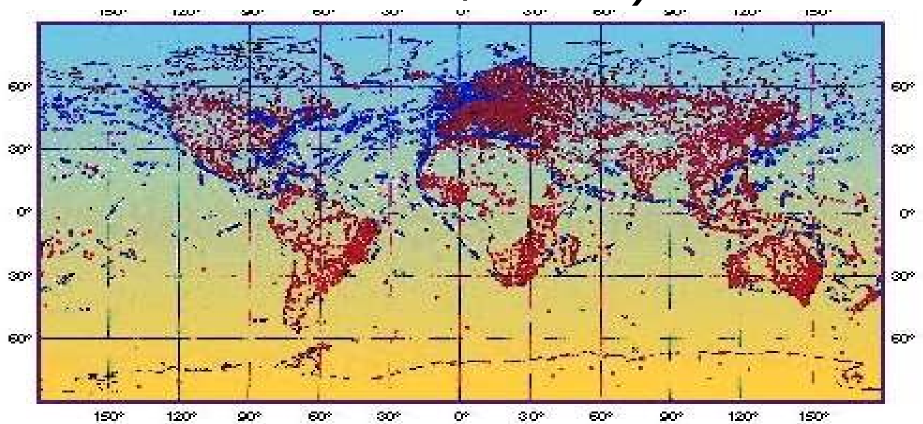
Outline:

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

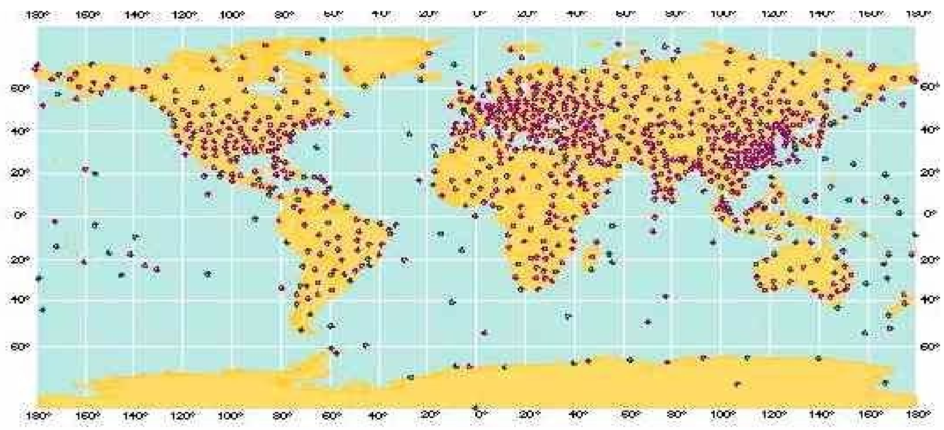
http://www.wmo.int/pages/themes/climate/climate_observation_networks_systems.php

World Meteorological Organization
Weather • Climate • Water

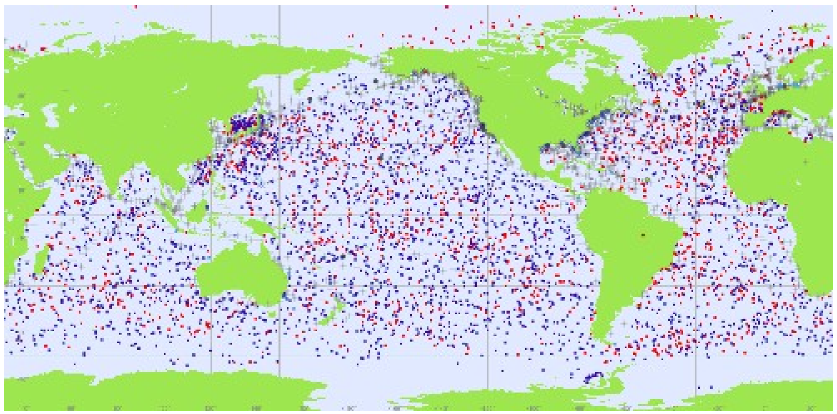
Atmosphere: Over 11,000 weather stations, as we
satellites, ships and aircraft take measurements.
1040 of stations are selected to provide high quality climate data.
There are special networks at national (e.g. Reference Climate Stations), regional (e.g. Regional Basic Climatological Network) and global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



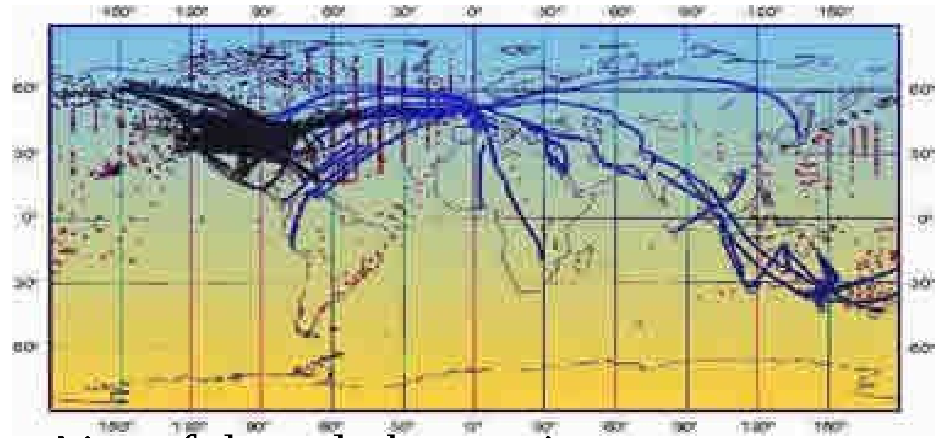
Weather stations and buoys



Upper air soundings



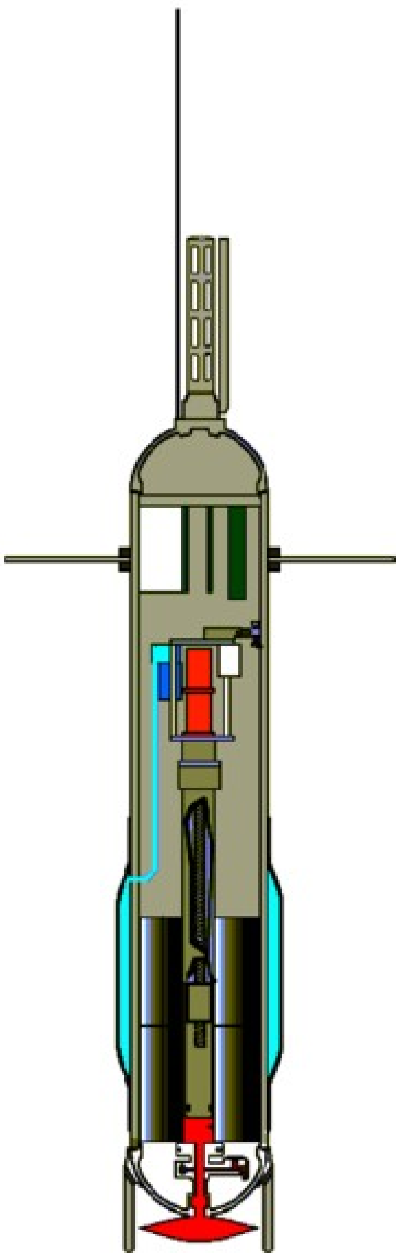
Voluntary ship observations

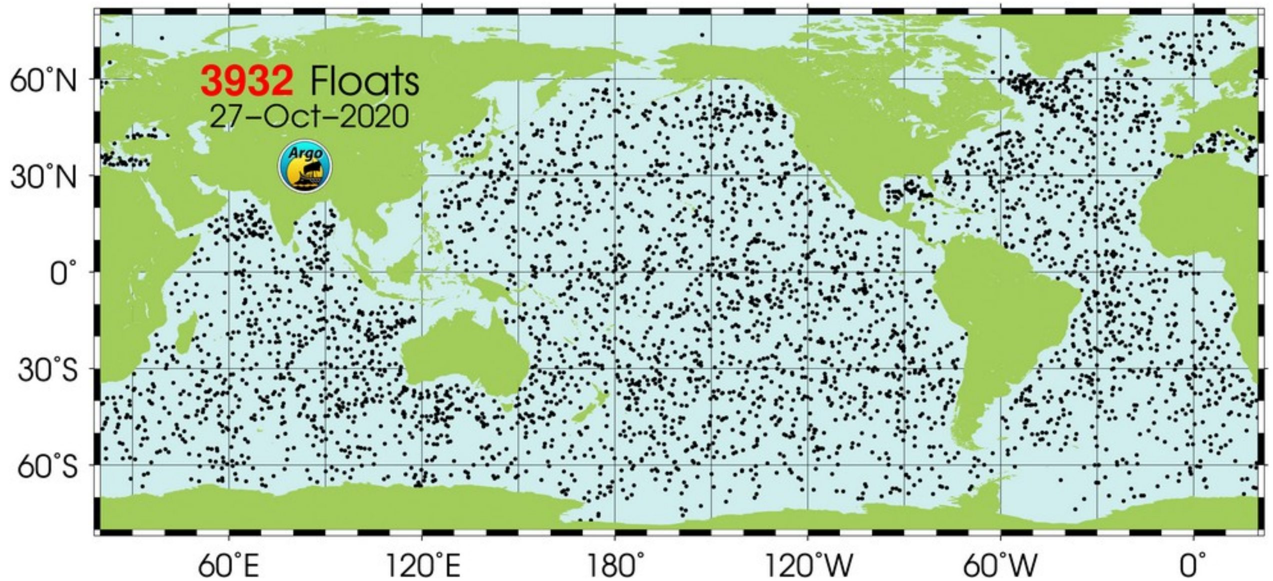


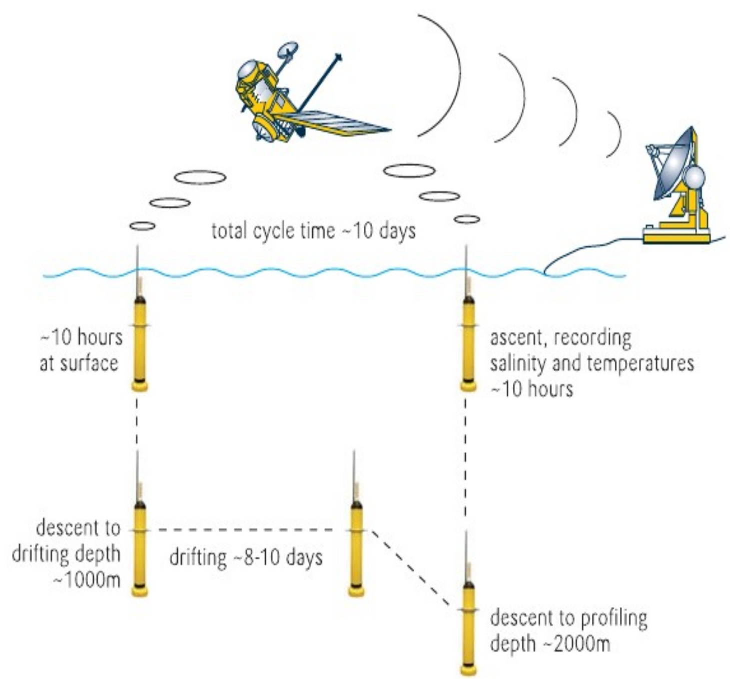
Aircraft based observations

OCEAN:

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

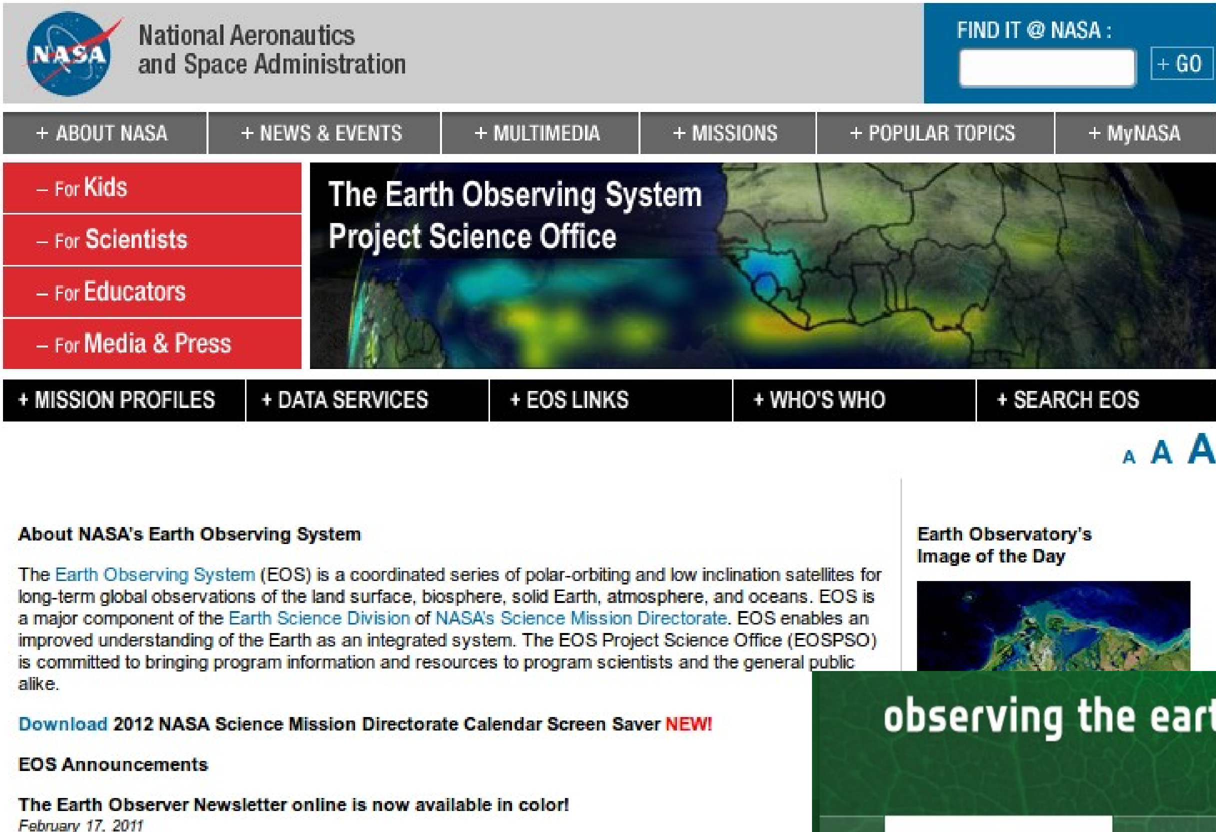


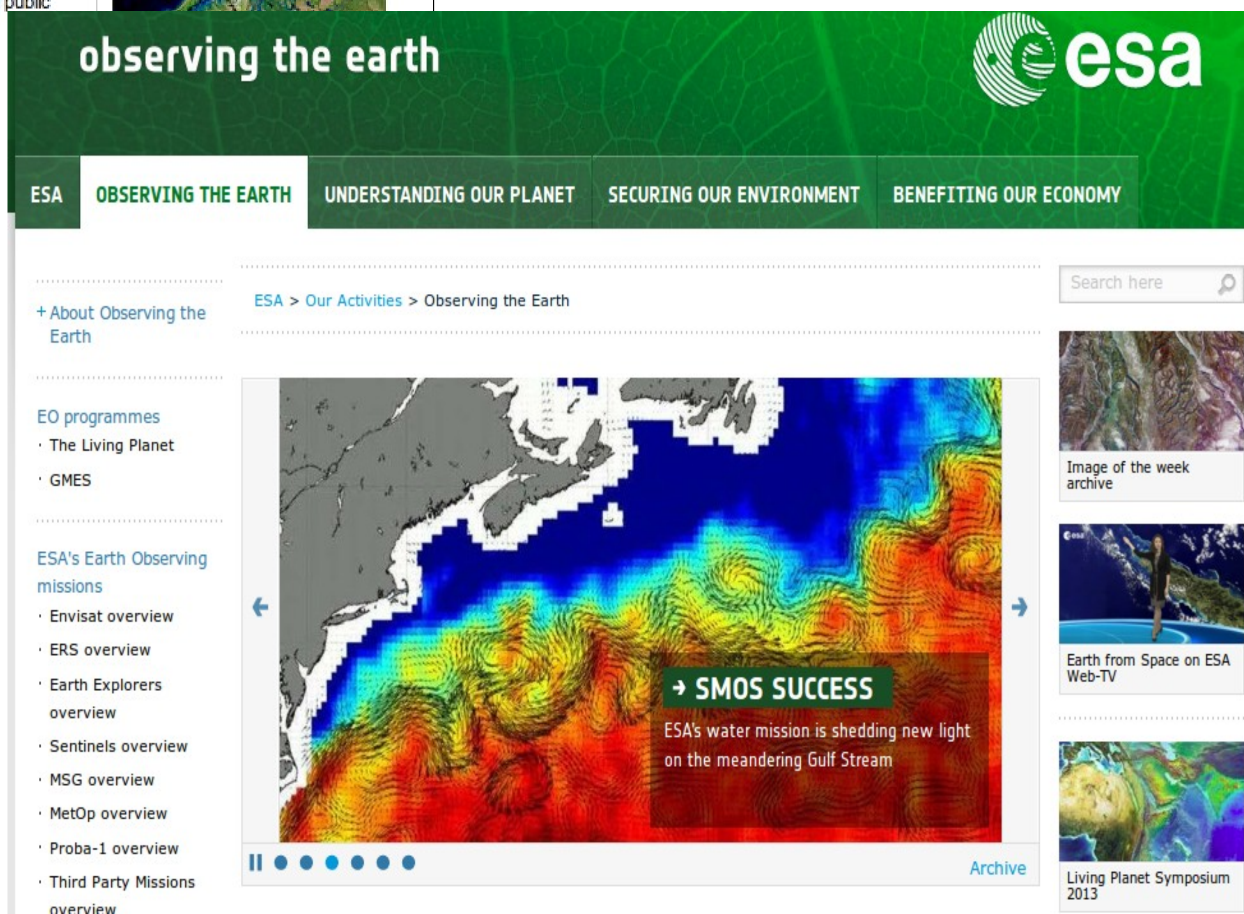




Thousands of automatic profilers provide actual data from the world ocean.

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

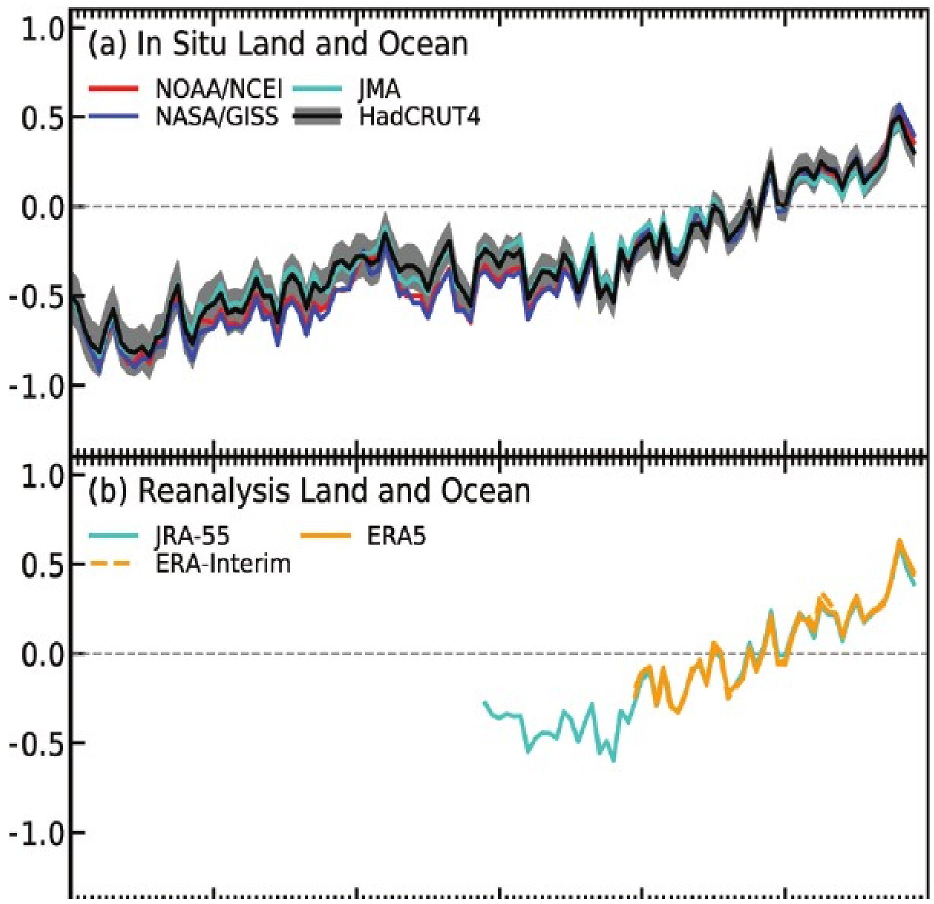




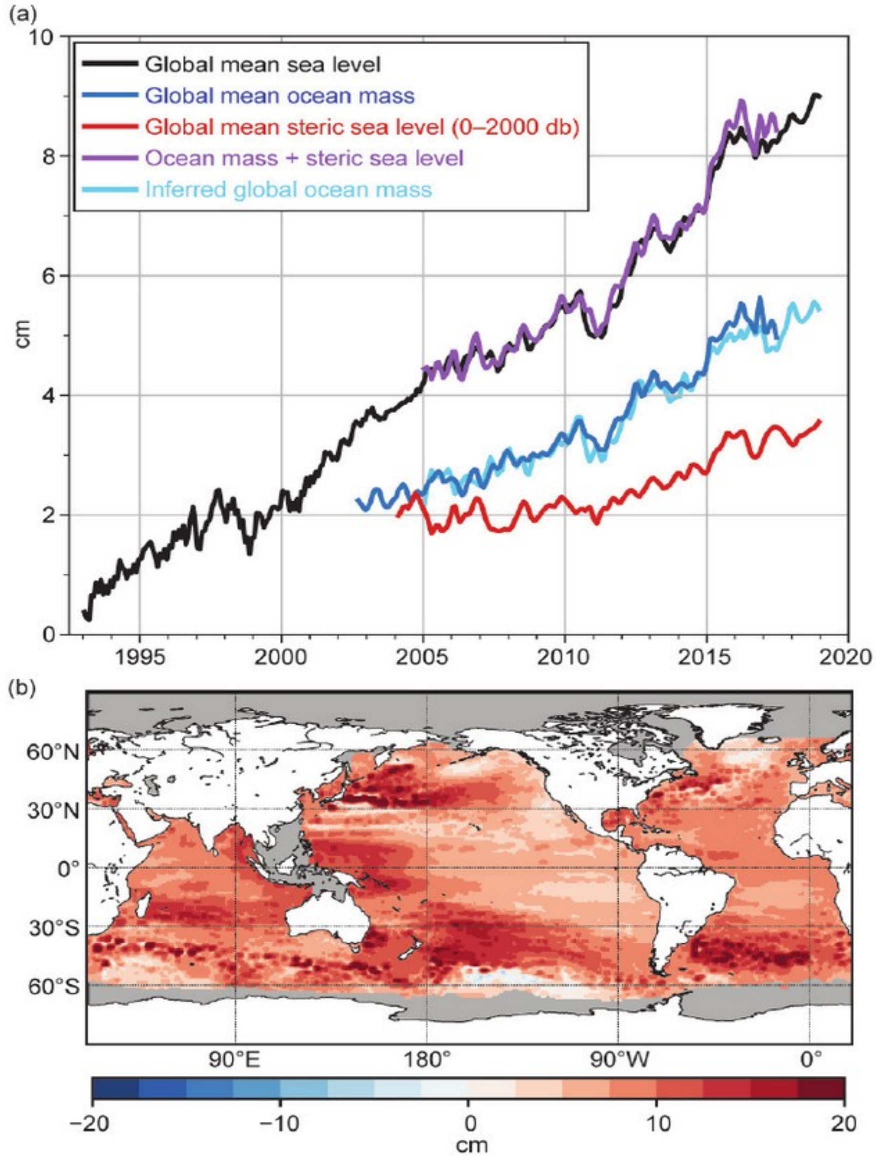
Satellite systems of NASA, ESA, JAXA and others.

Observations - summary

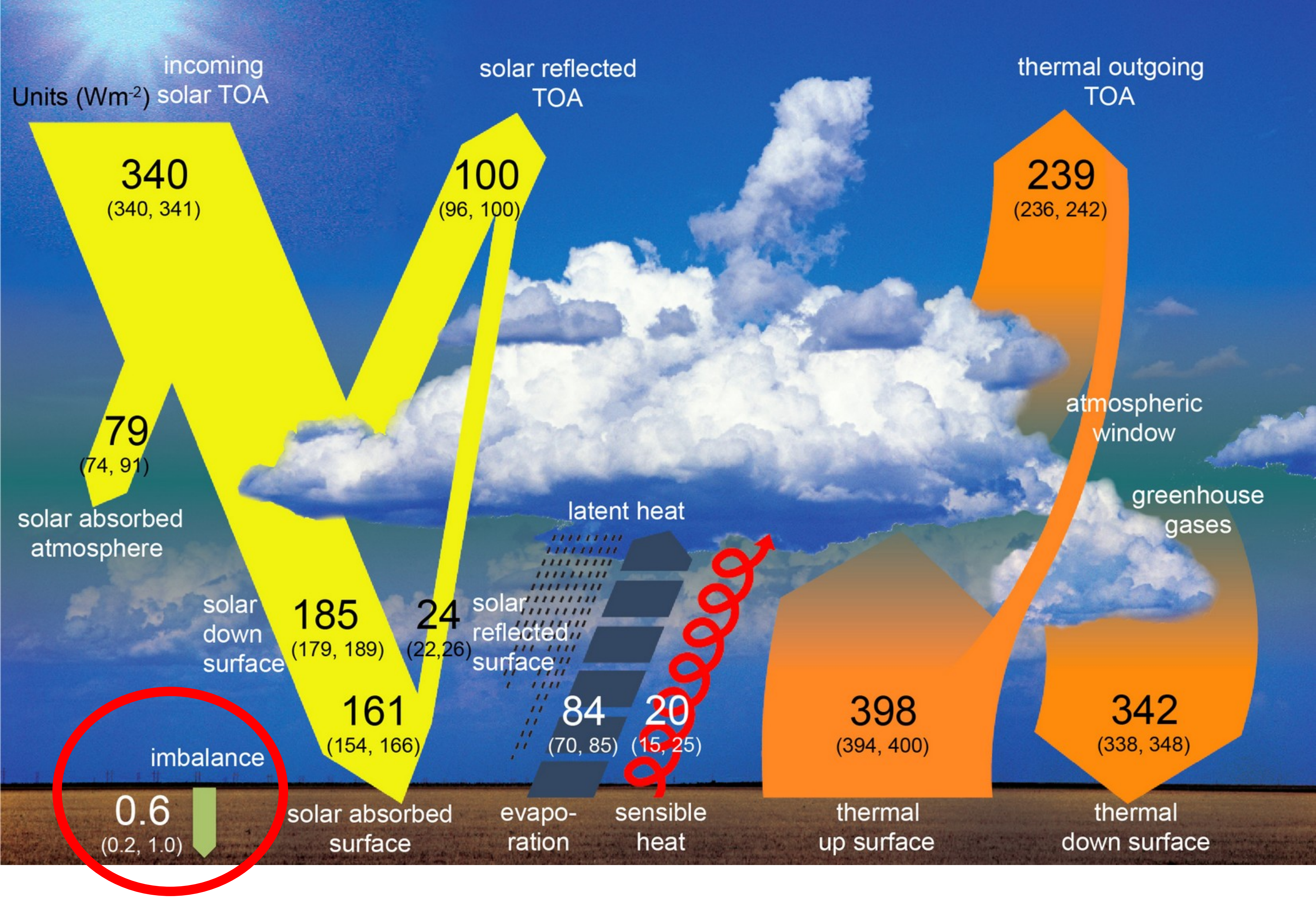
Temperature anomaly



Sea level change



https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/

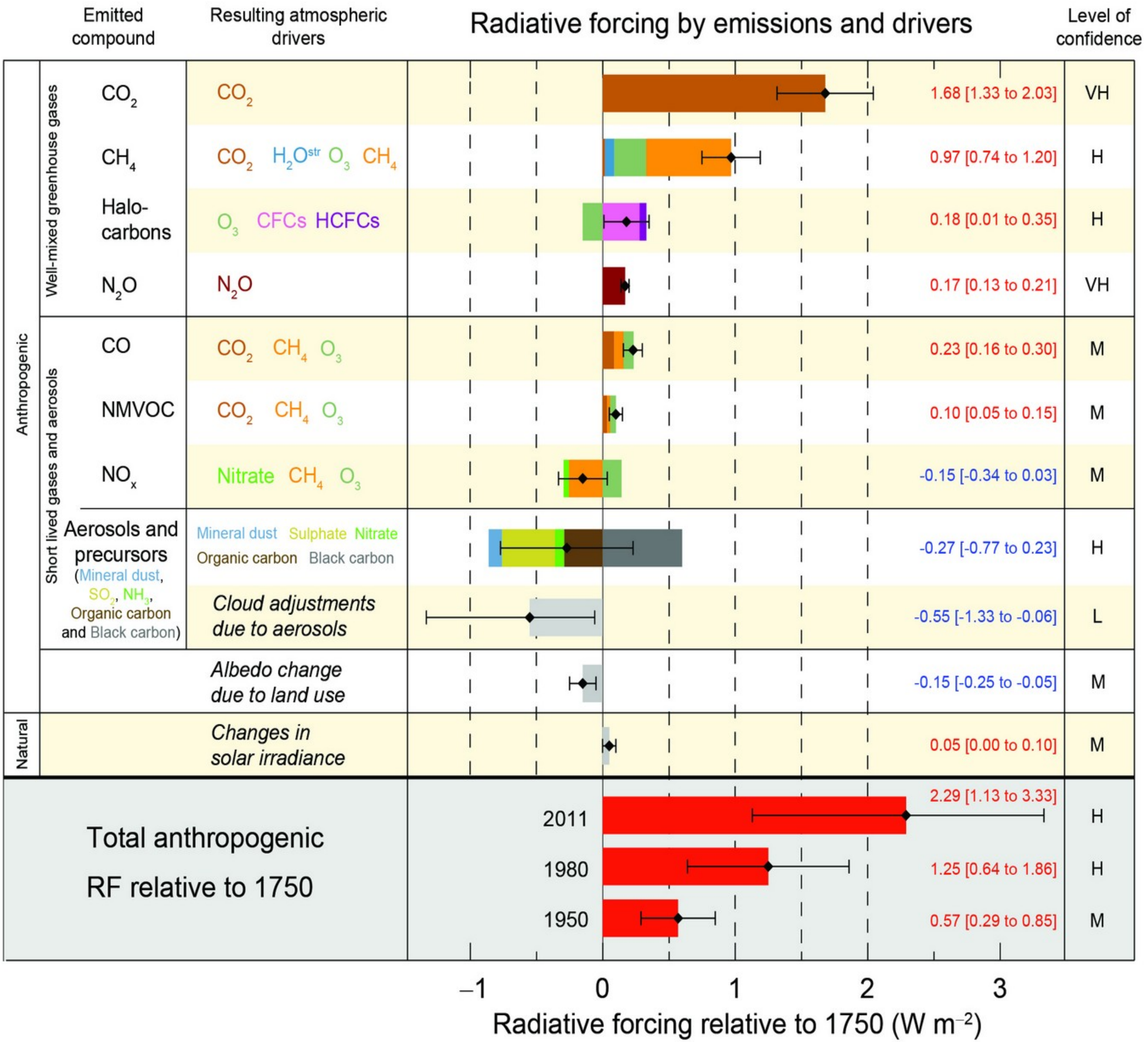


Energy balance of climate system. Units: W/m^2.

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

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

GHG
– positive,
aerosols
– negative
others
– minor.



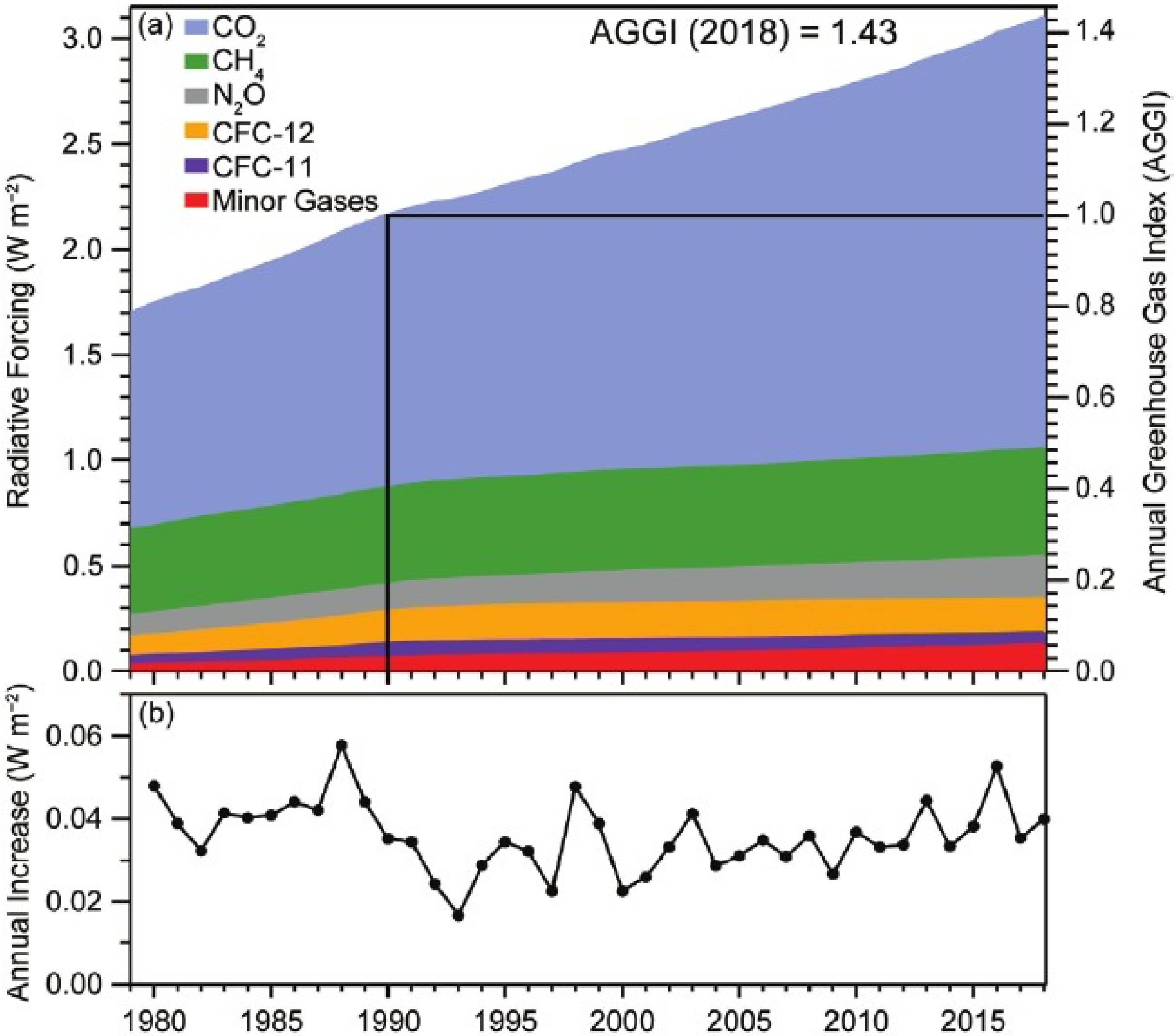
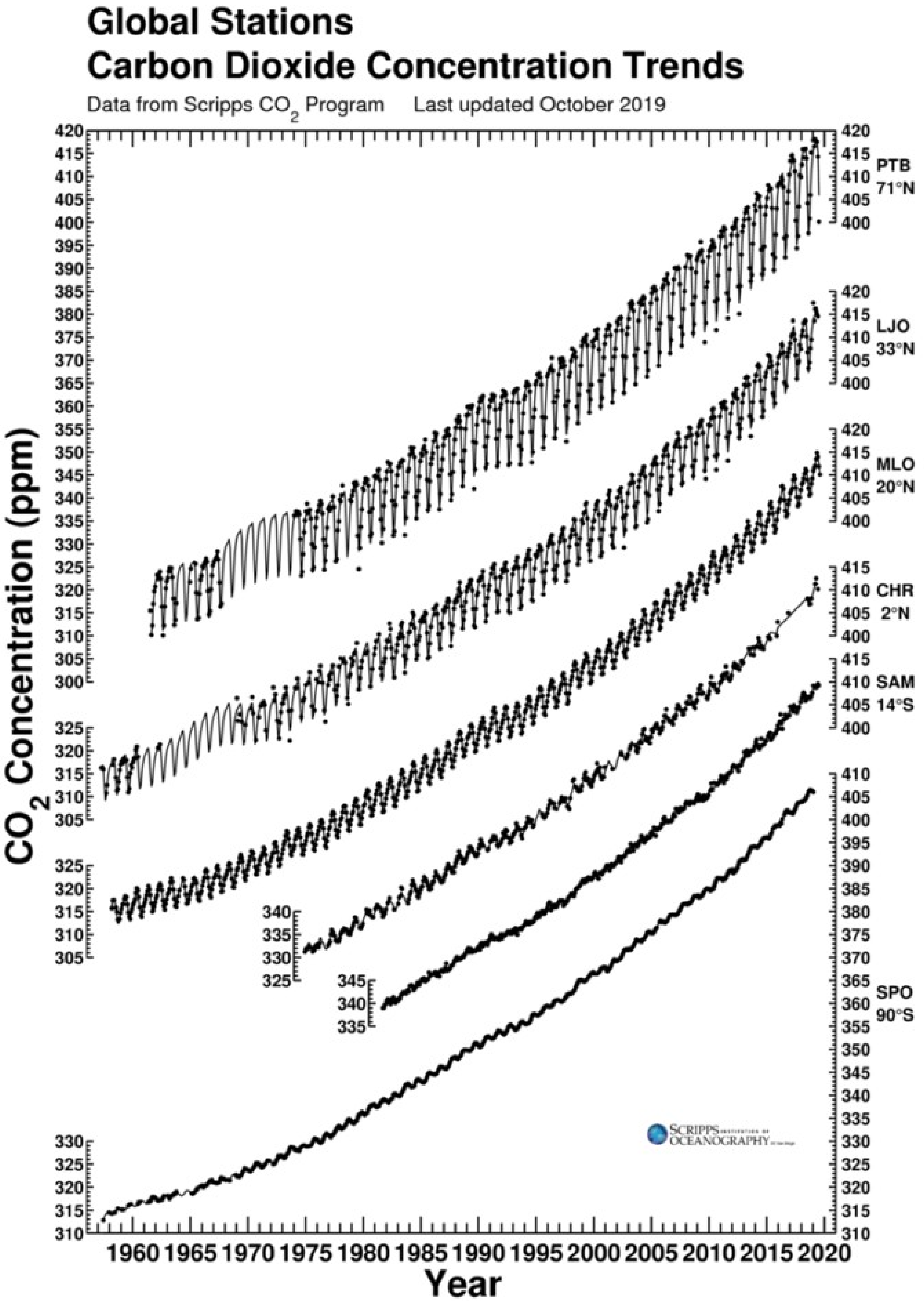


FIG. 2.46. (a) Direct radiative forcing (W m^{-2}) due to 5 major LLGHG and 15 minor gases (left axis) and the associated values of the NOAA AGGI (right axis), and (b) annual increase in direct radiative forcing (W m^{-2}). Solid black lines indicate that the AGGI had a value of 1.0 in 1990.

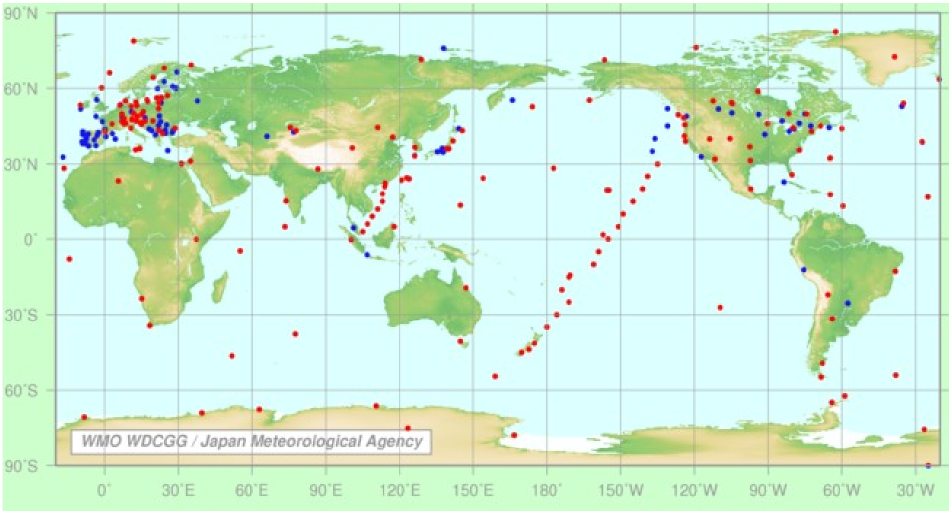
https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/

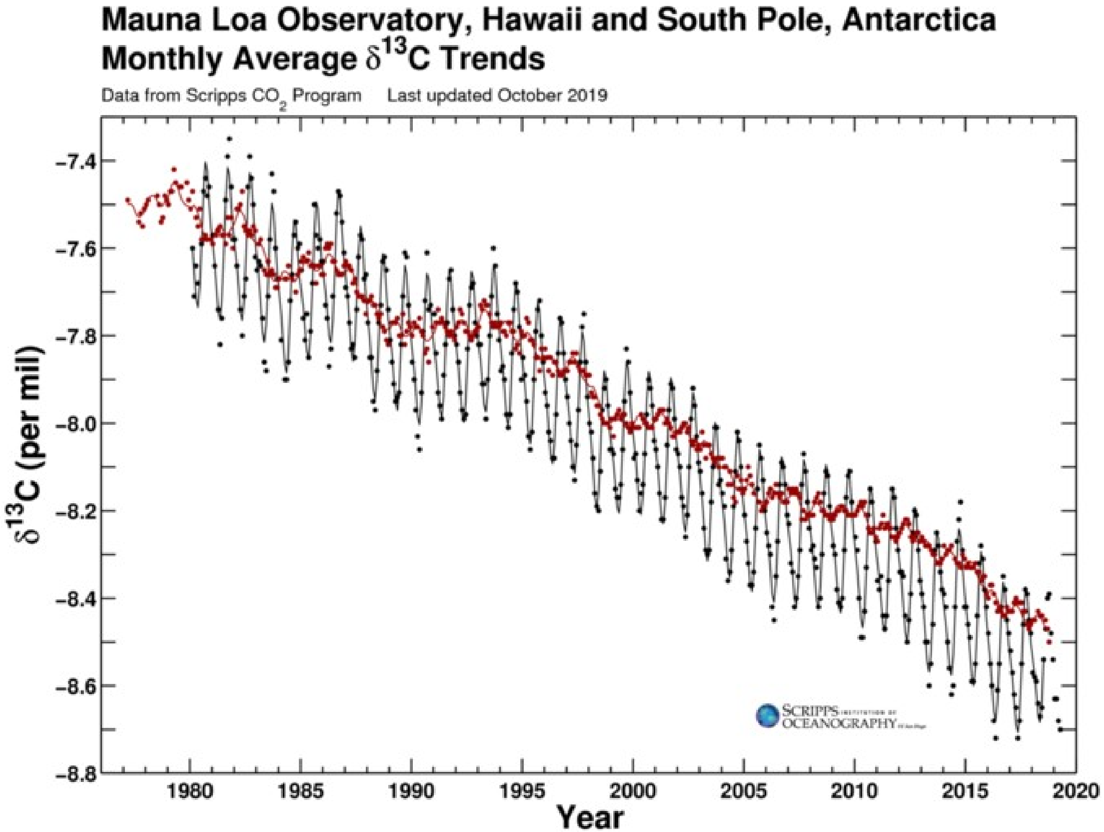


Regular observations of CO_2 and the other atmospheric gases are reported to WMO World Data Centre for Greenhouse Gases (WDCGG)

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

http://scrippsco2.ucsd.edu/



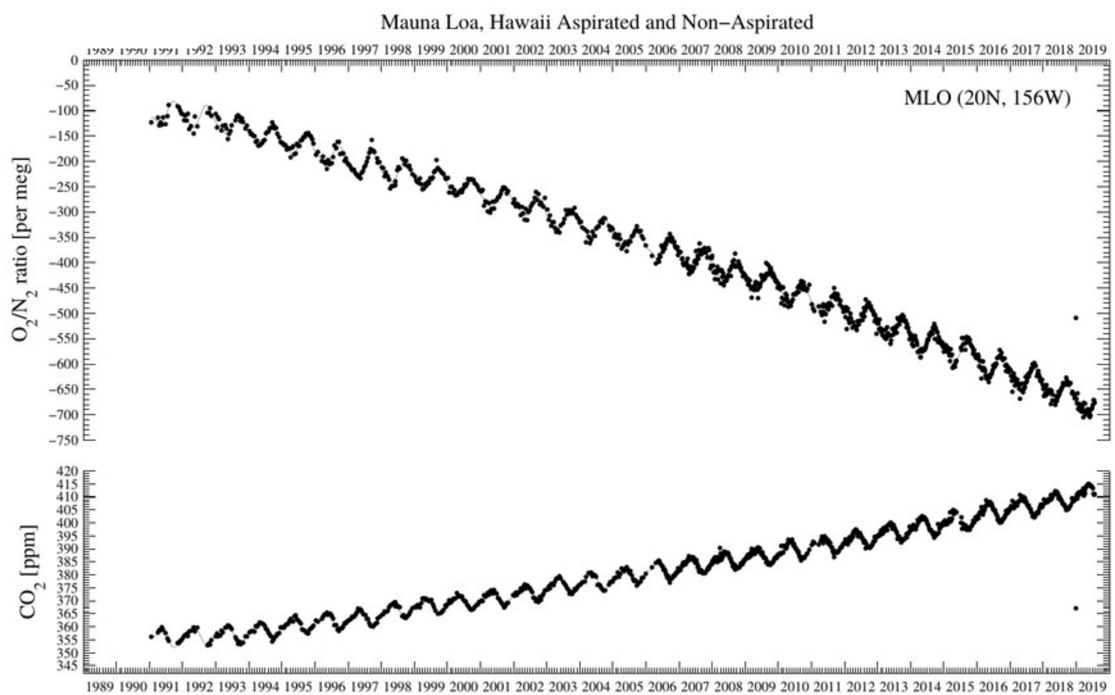


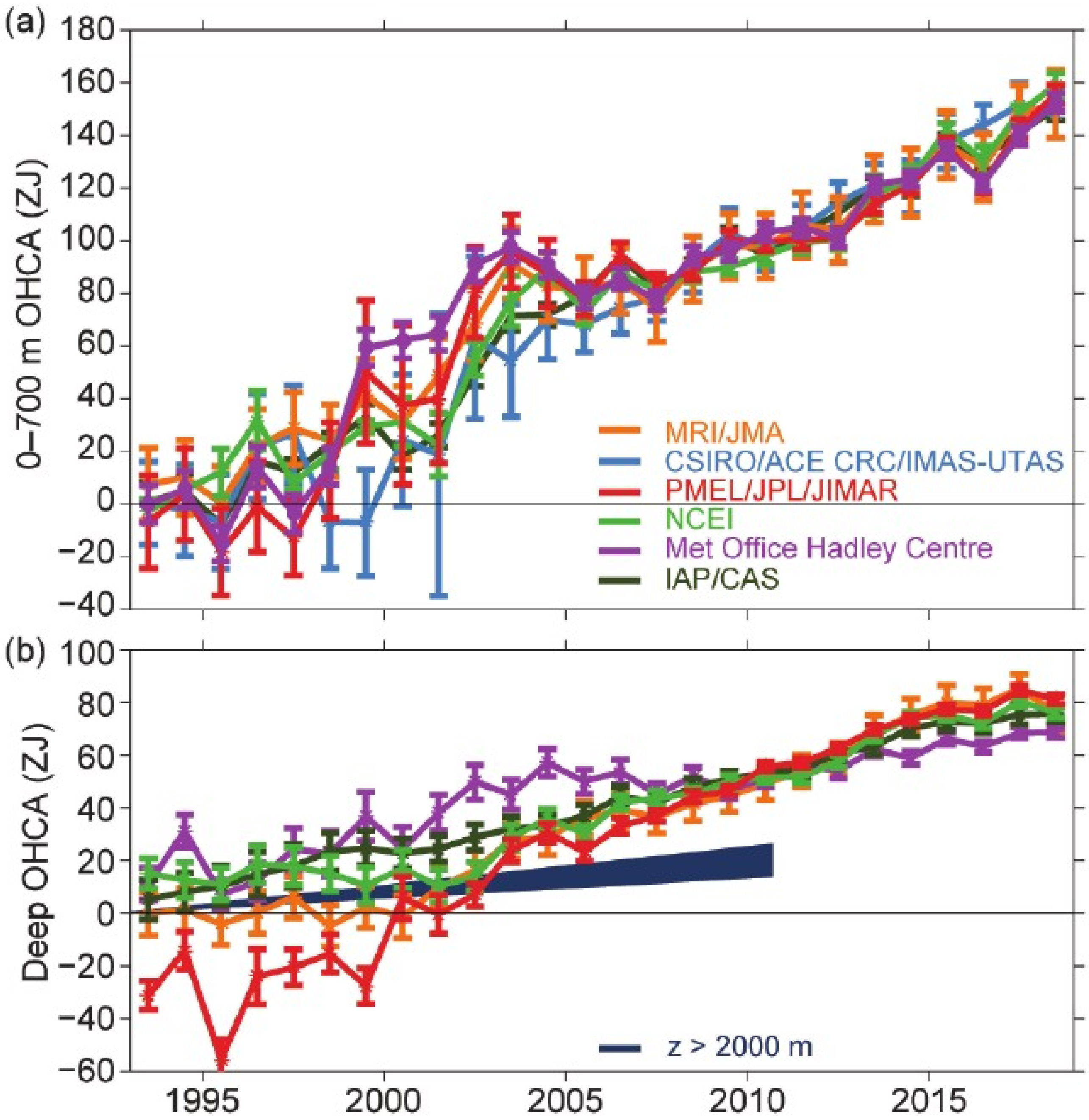
Carbon stable isotopes concentration ratio $^{13}C/^{12}C$ allows to determine the role of fossil fuel combustion in CO_2 concentration increase in the atmosphere and in the ocean.

Another signature of fossil fuel combustion

$$C+2O=CO_2$$

is the ratio of O_2/N_2 in air.





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.

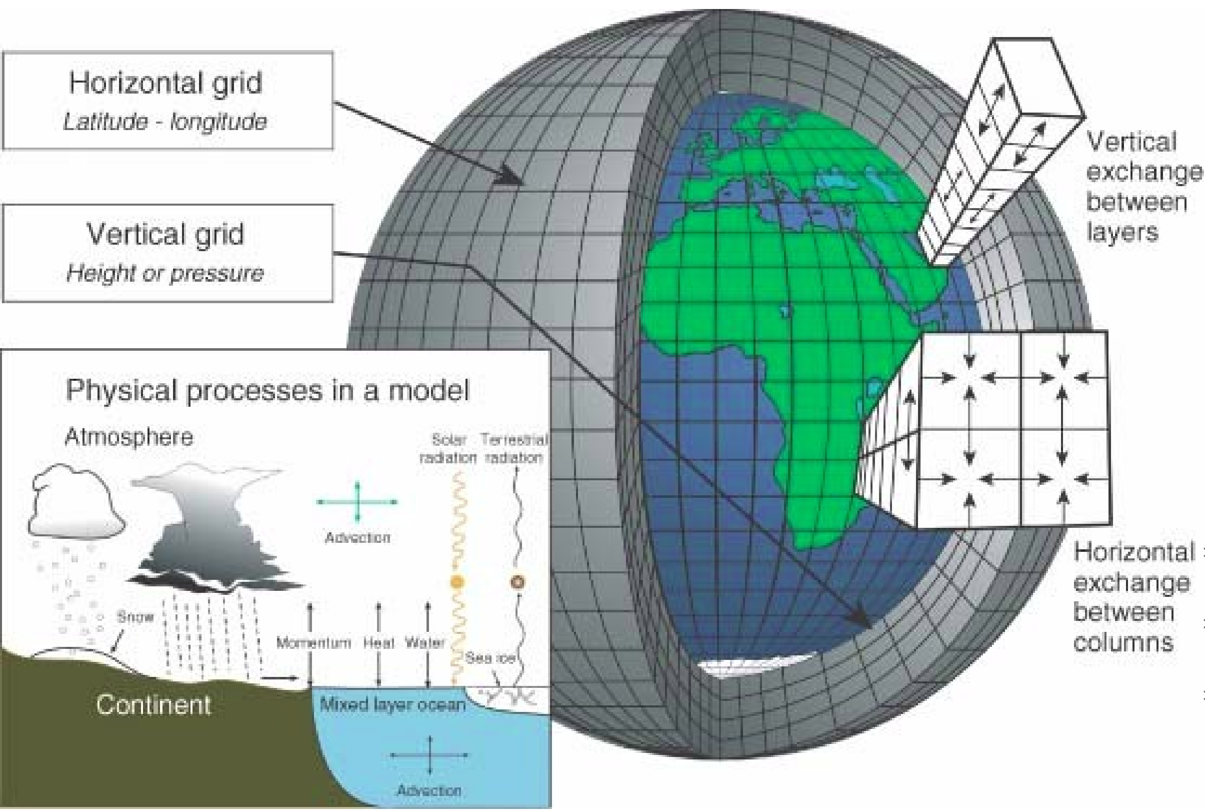
(b) Annual average global integrals of in situ estimates of intermediate (700–2000 m) OHCA for 1993–2018 with standard errors of the mean, and a long-term trend with one standard error uncertainty shown from 1992–2010 for deep and abys.

https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/

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

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model equations

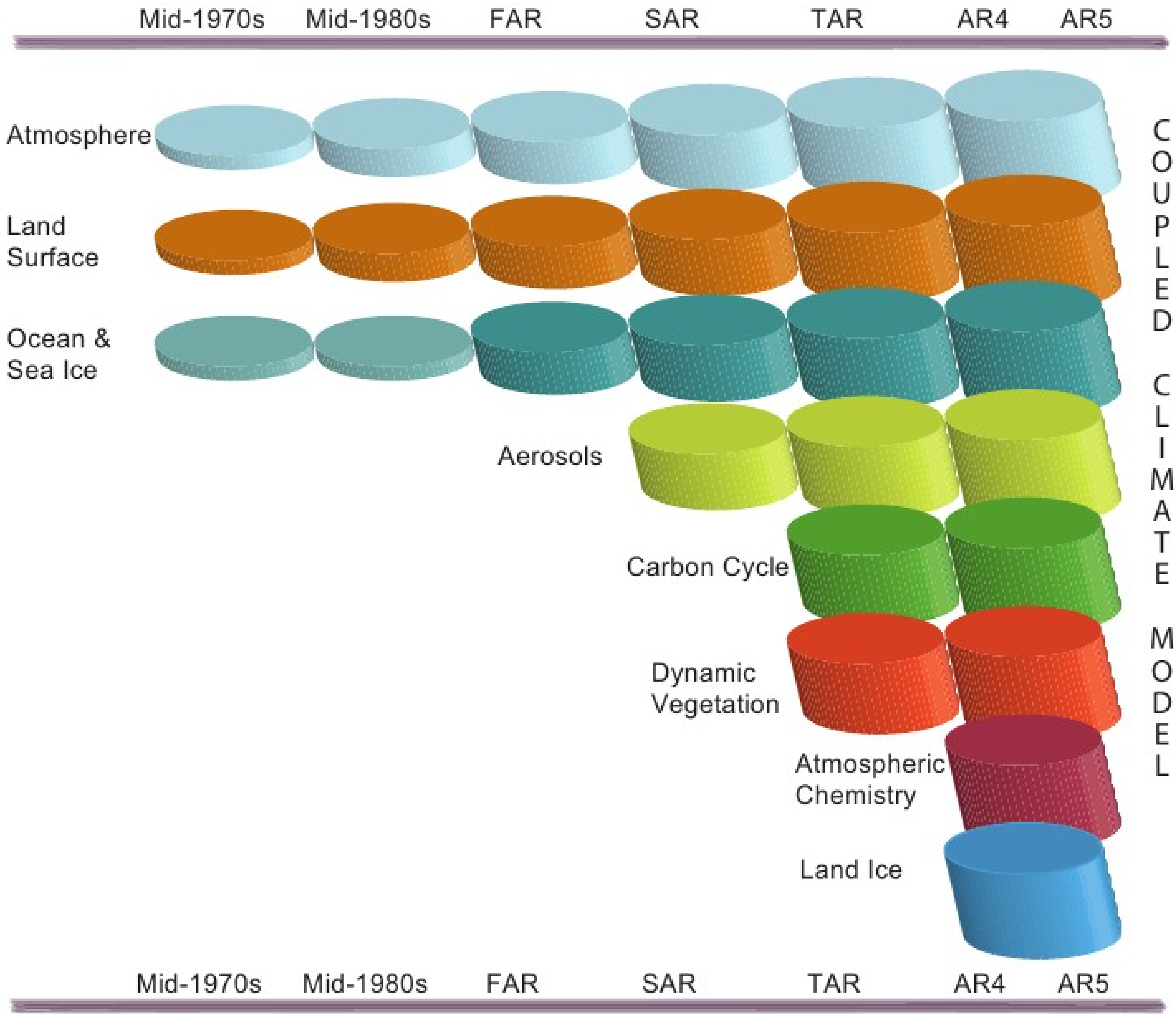
↓

numerical code
data and initial conditions
supercomputing facility

↓

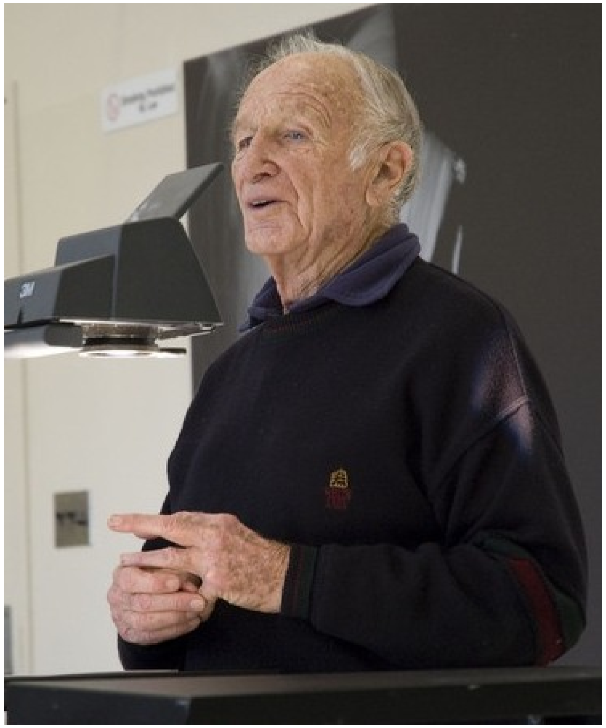
virtual reality allowing for simulating climate

The development of climate models over the last 35 years



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

Predictability of weather and climate



Edward N. Lorenz (1917-2008):

Selected papers:

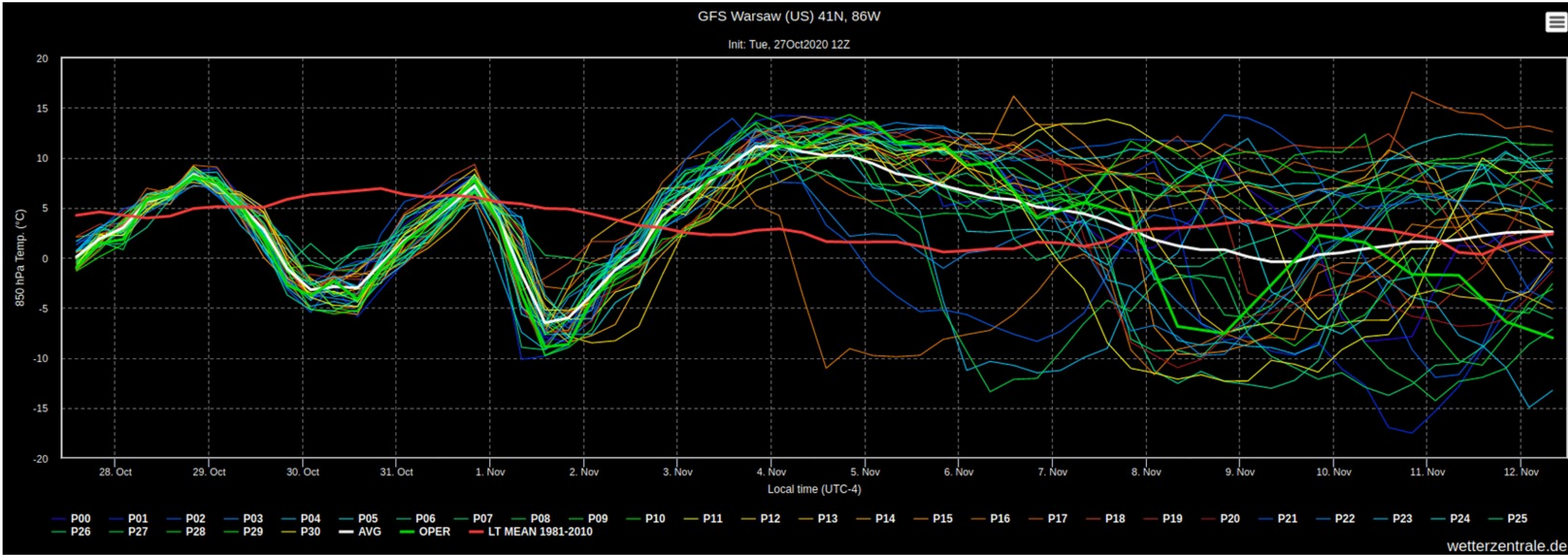
„Deterministic nonperiodic flow", 1963
(sensitivity of solutions to initial conditions: "butterfly effect", a well defined attractor)

„The problem of deducing the climate from the governing equations", 1964
(long term predictability – obcertainties 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:

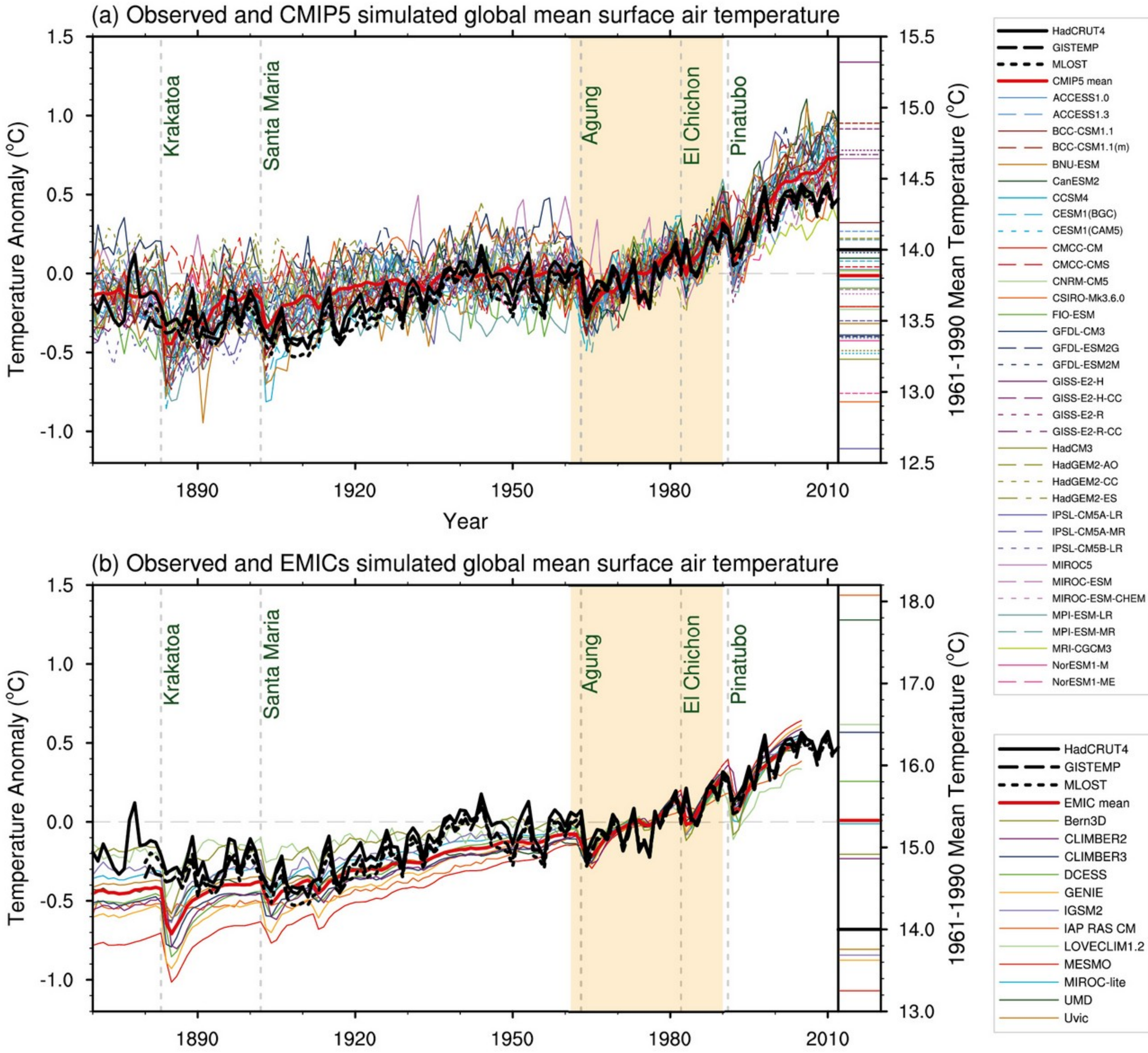


http://www.wetterzentrale.de/topkarten

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),



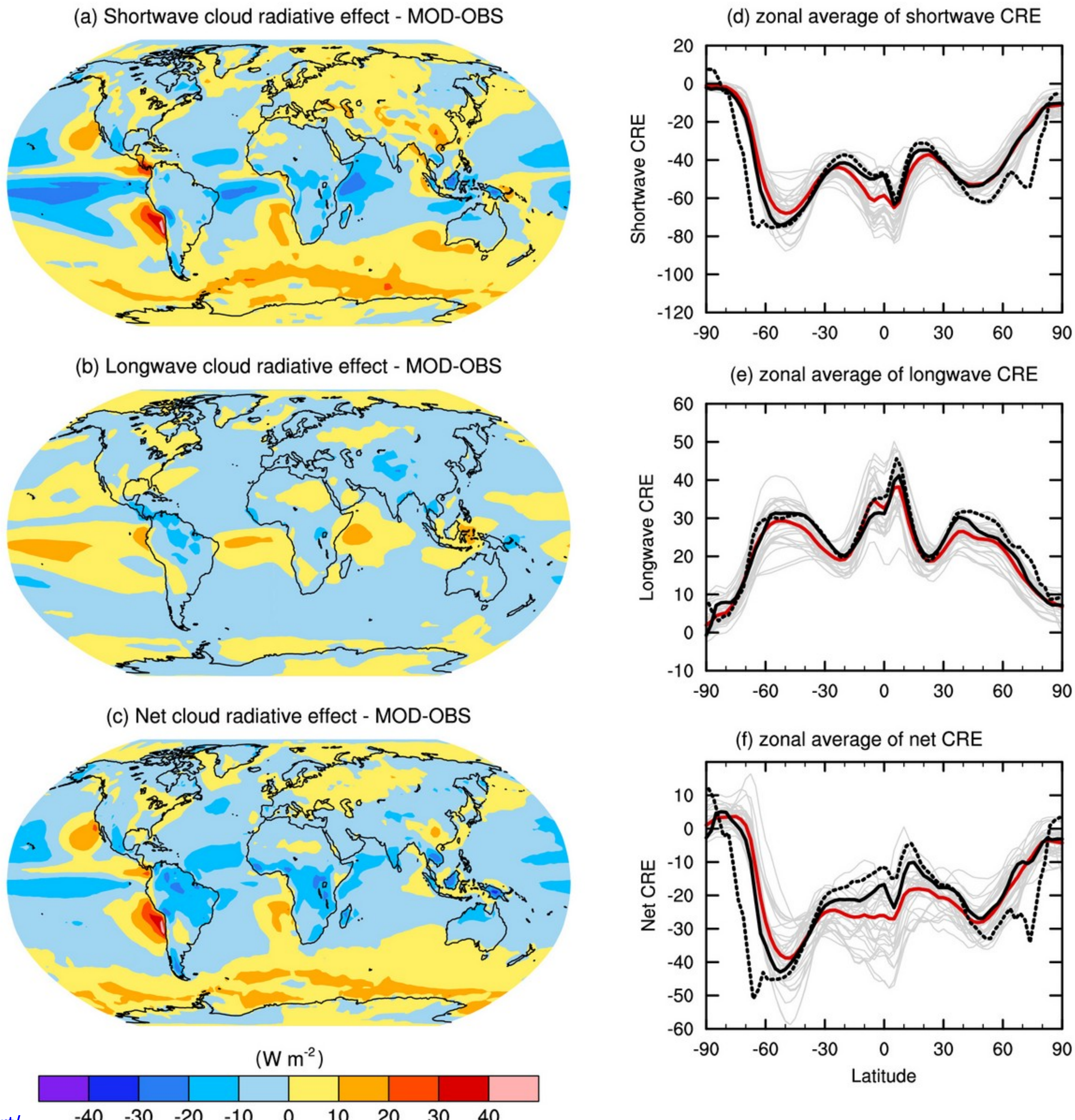
http://www.climatechange2013.org/report/

Model validations:

Annual-mean cloud radiative effects of the CMIP5 models compared against the measurements (CERES EBAF 2.6) data set (in 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.



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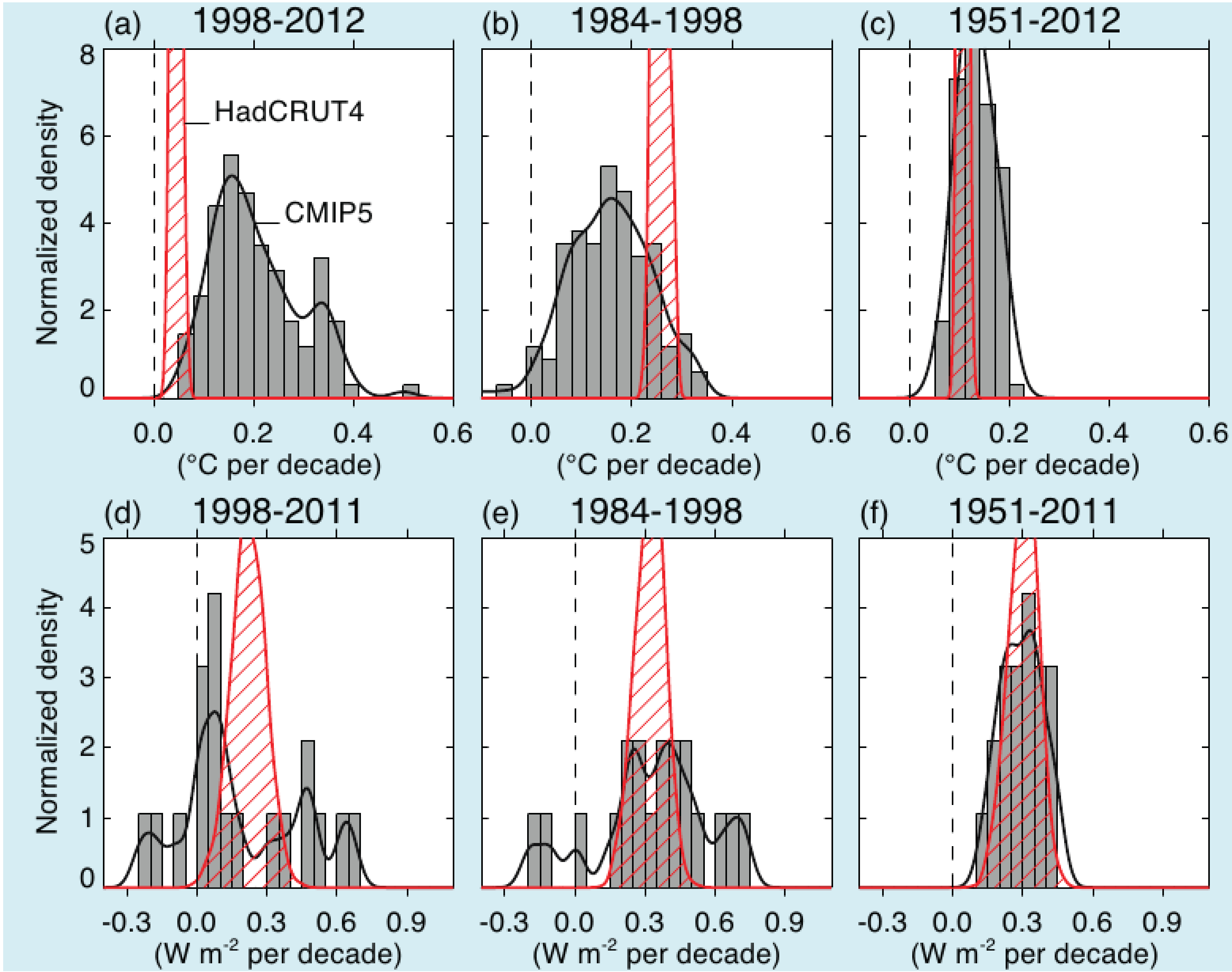
Model ensembles vs. observations.



(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.

Knutti, R., 2008: Should we believe model predictions of future climate change?doi: 10.1098/rsta.2008.0169

nature geoscience
LETTERS
PUBLISHED ONLINE: 4 DECEMBER 2011 | DOI: 10.1038/NGEO1327

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 ◦ C of warming (5–95% uncertainty: 0.6–1.1 ◦ 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 ◦ 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.

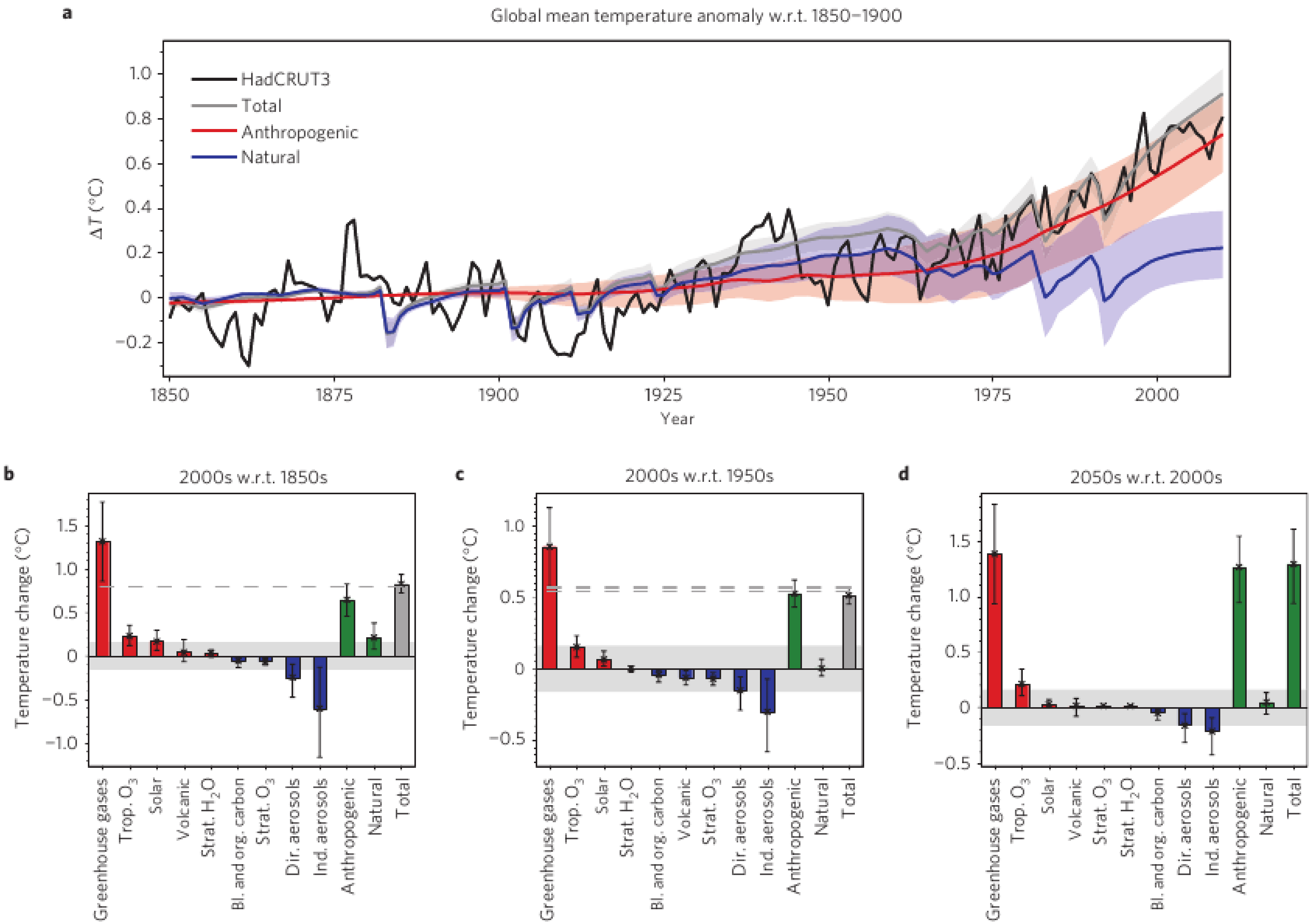


Figure 3 | Contributions of different forcing agents to the total observed temperature change. a, Time series of anthropogenic and natural forcings contributions to total simulated and observed global temperature change. The coloured shadings denote the 5-95% uncertainty range. **b-d**, Contributions 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.