Global warming - physicist's perspective
02 – measurements and modelling

Szymon P. Malinowski

University of Warsaw, Faculty of Physics, Institute of Geophysics

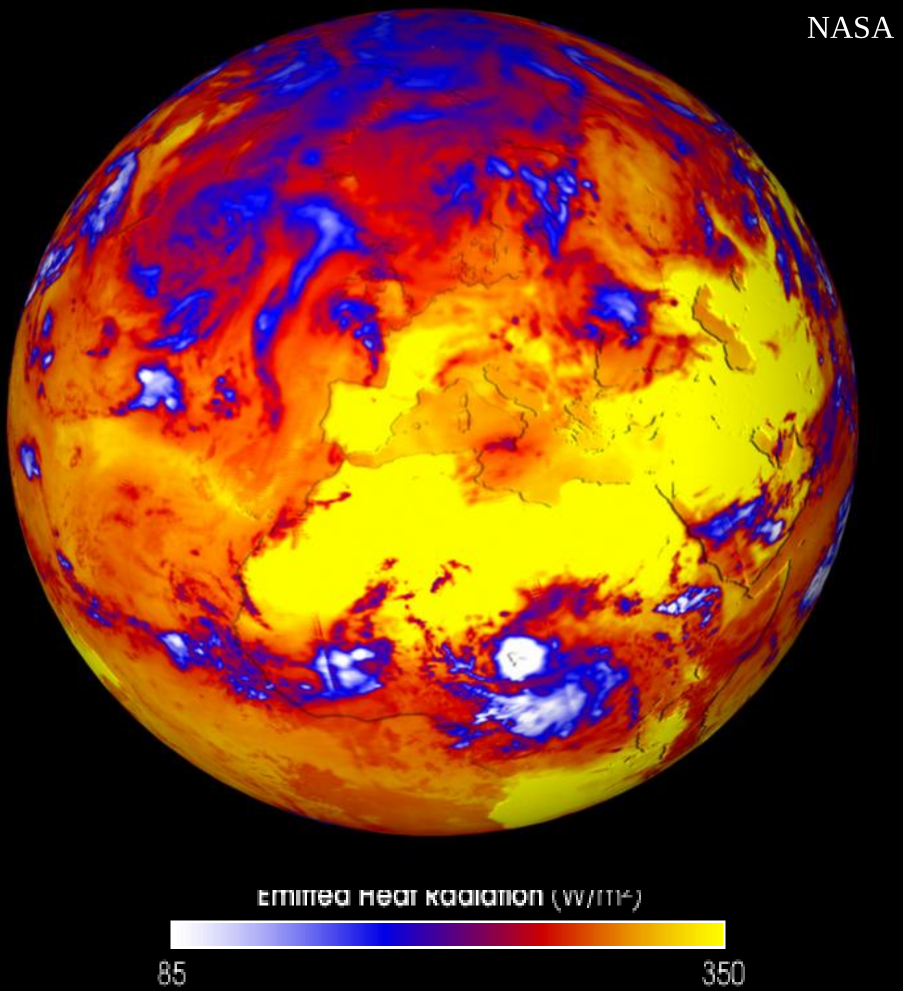
NAUKA O KLIMACIE
DLA SCEPTYCZNYCH

UNIVERSITY OF WARSAW

Outline:

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

Energy Balance



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.

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

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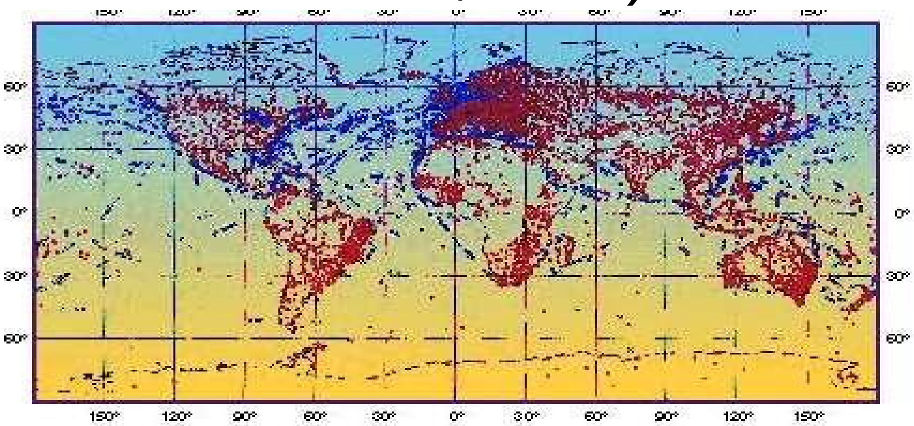
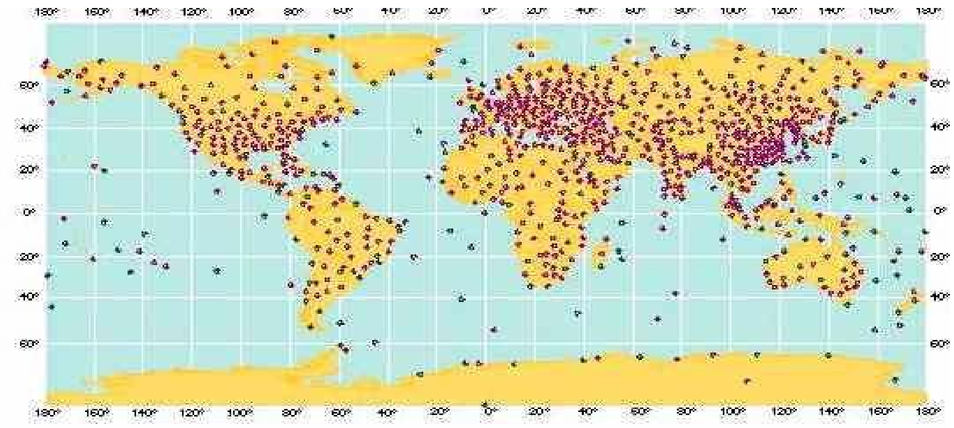
http://www.wmo.int/pages/themes/climate/climate_observation_networks_systems.php

World Meteorological Organization
Weather • Climate • Water

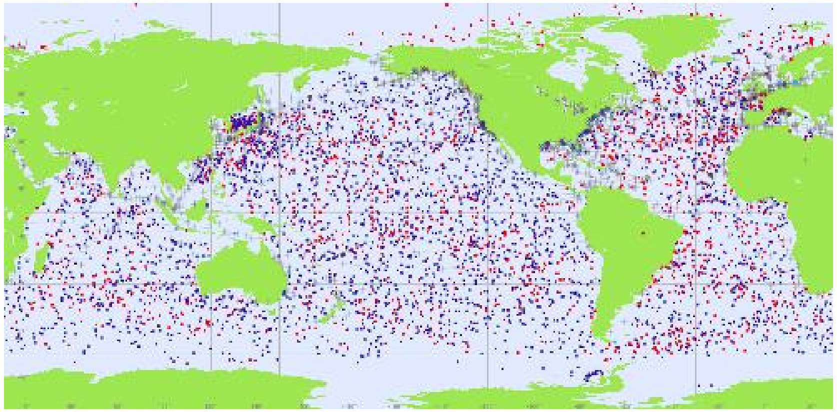
Atmosphere: Over 11,000 weather stations, as we
satellites, ships and aircraft take measurements.
1040 of stations are selected to provide high quality climate data.
There are special networks at national (e.g. Reference Climate Stations), regional (e.g. Regional Basic Climatological Network) and global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



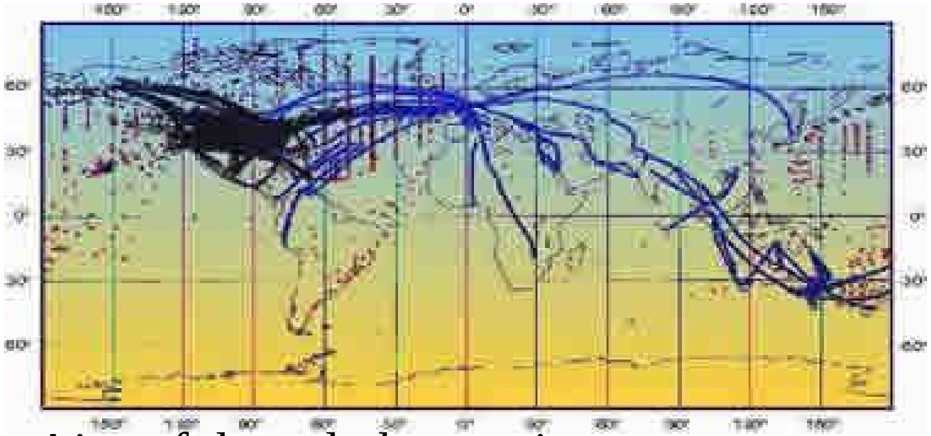
Weather stations and buoys



Upper air soundings



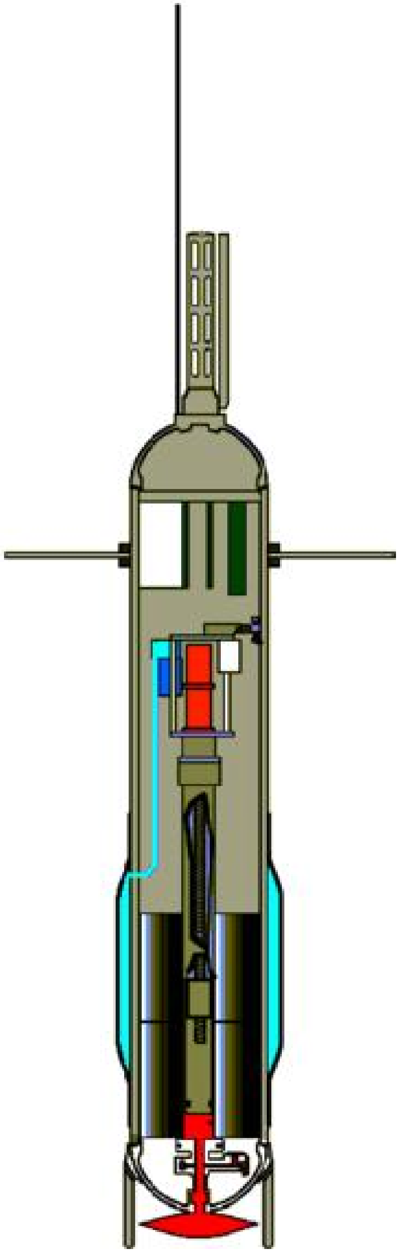
Voluntary ship observations

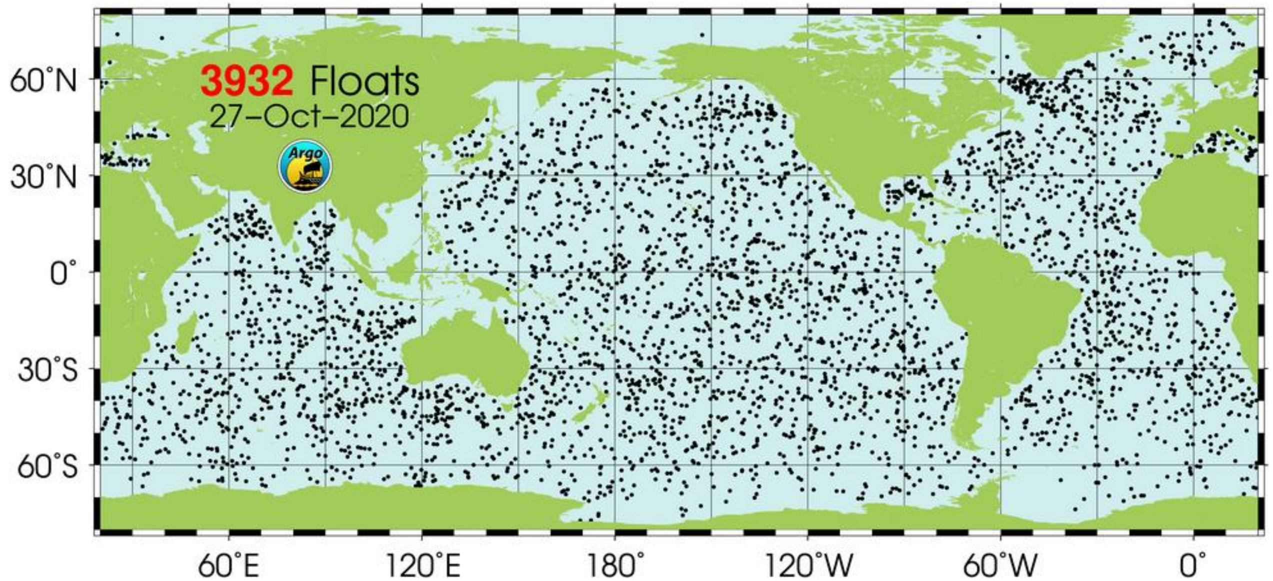


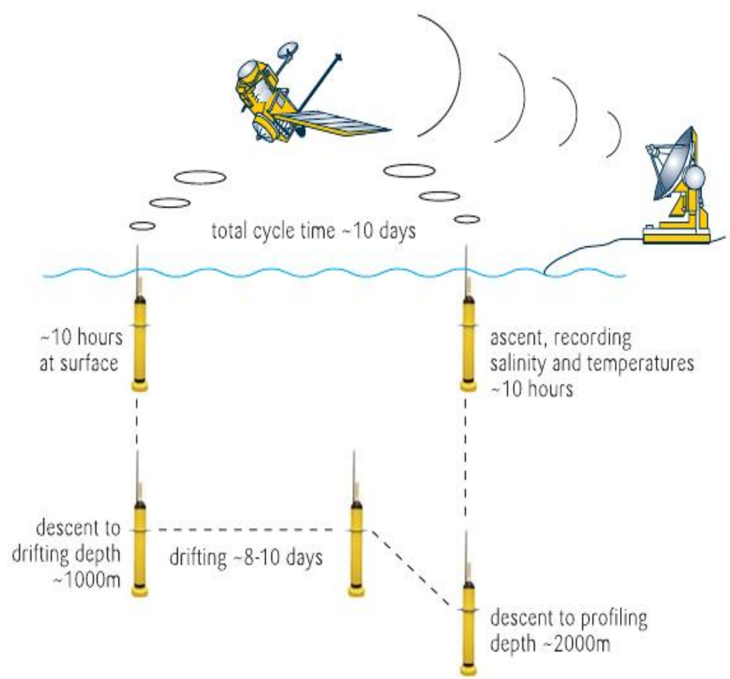
Aircraft based observations

OCEAN:

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

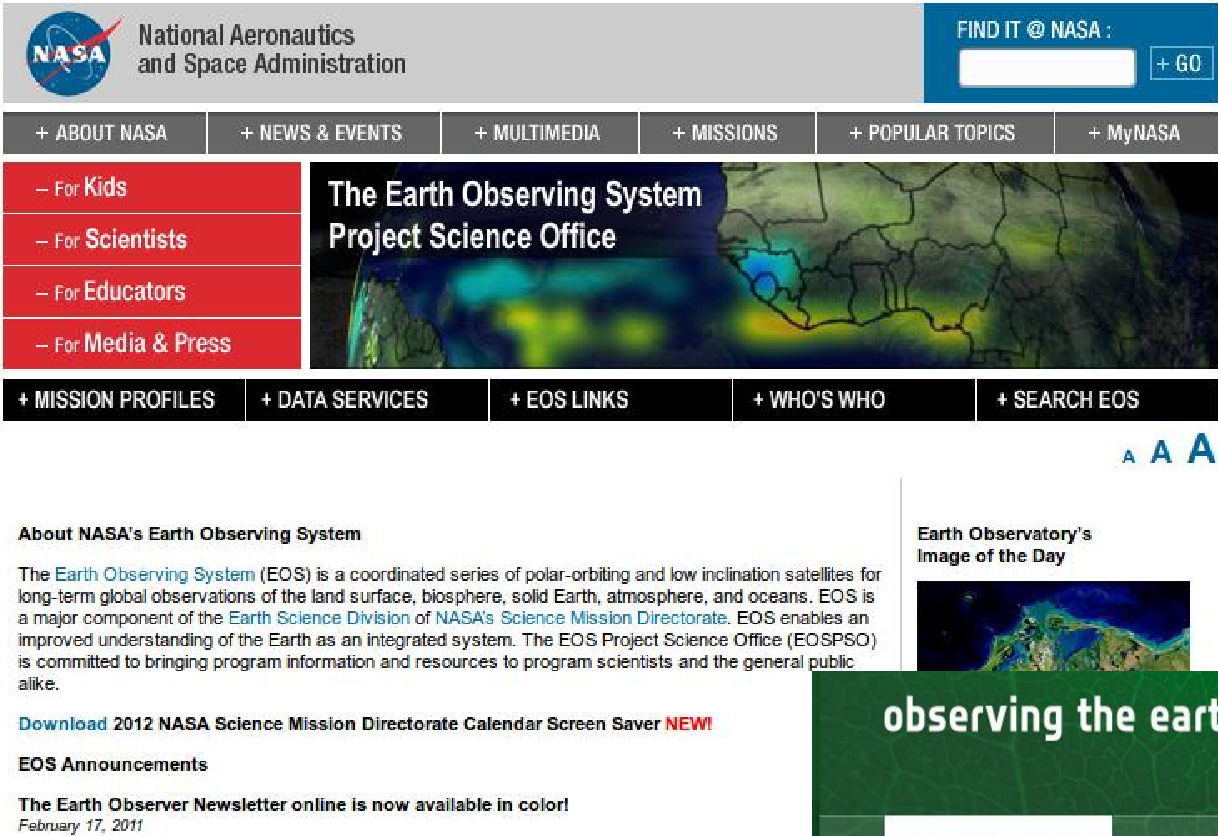


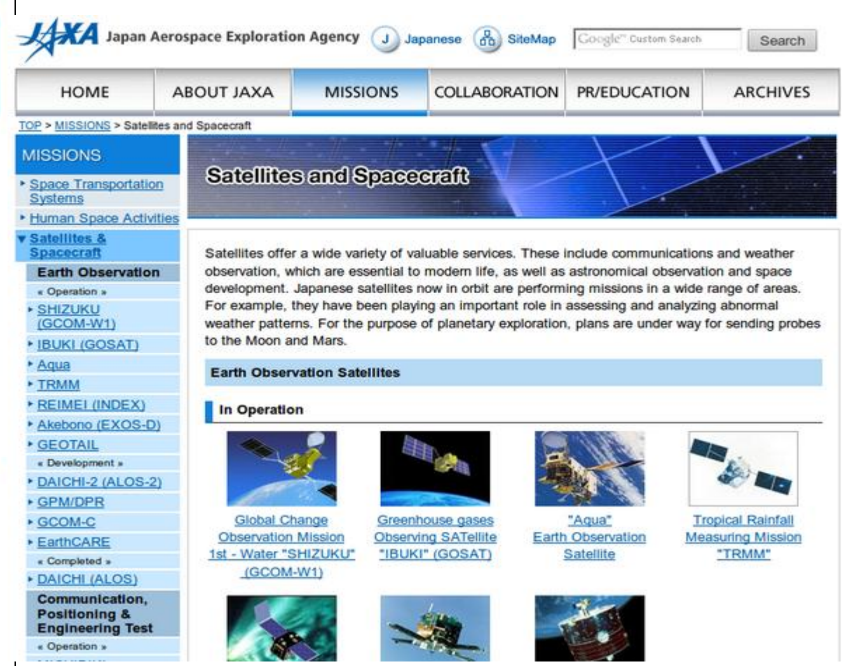




Thousands of automatic profilers provide actual data from the world ocean.

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

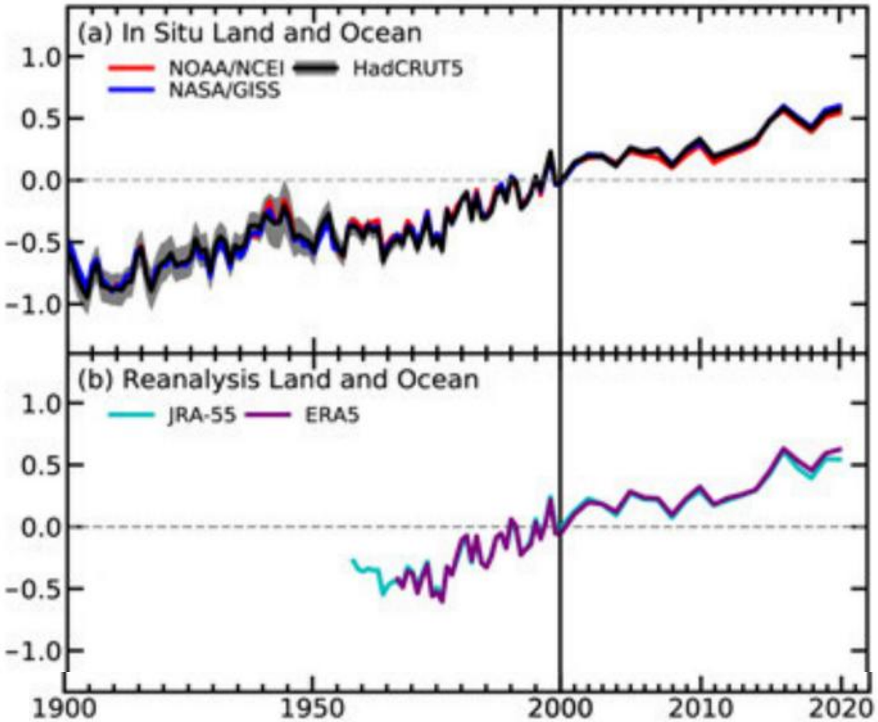




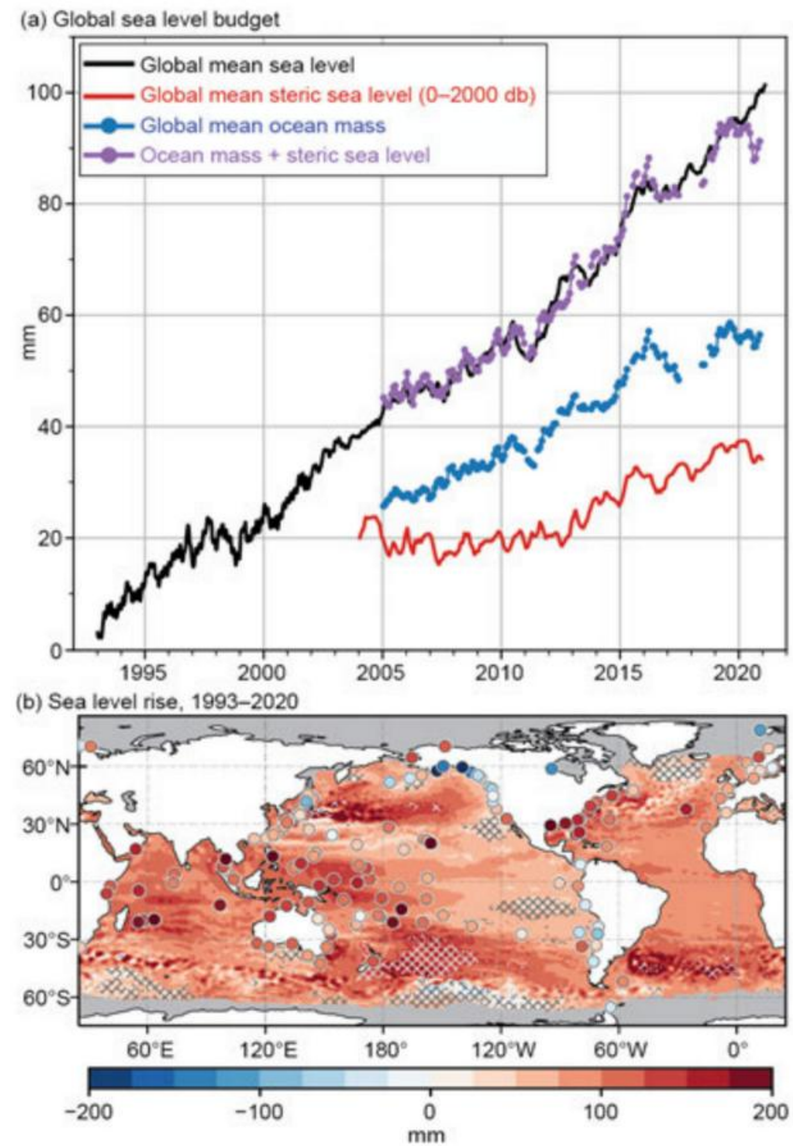
Satellite systems of NASA, ESA, JAXA and others.

Observations - summary

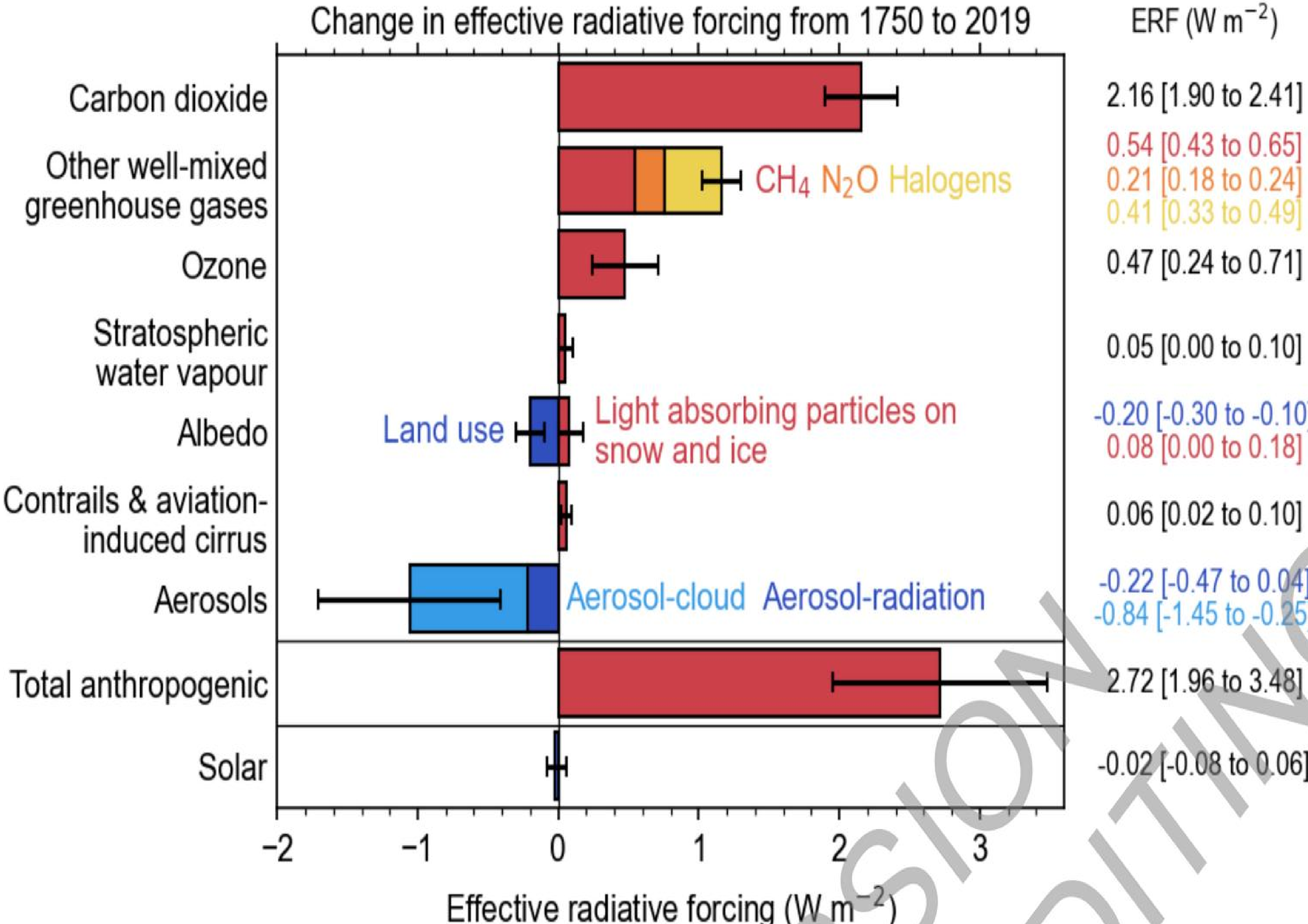
Temperature anomaly

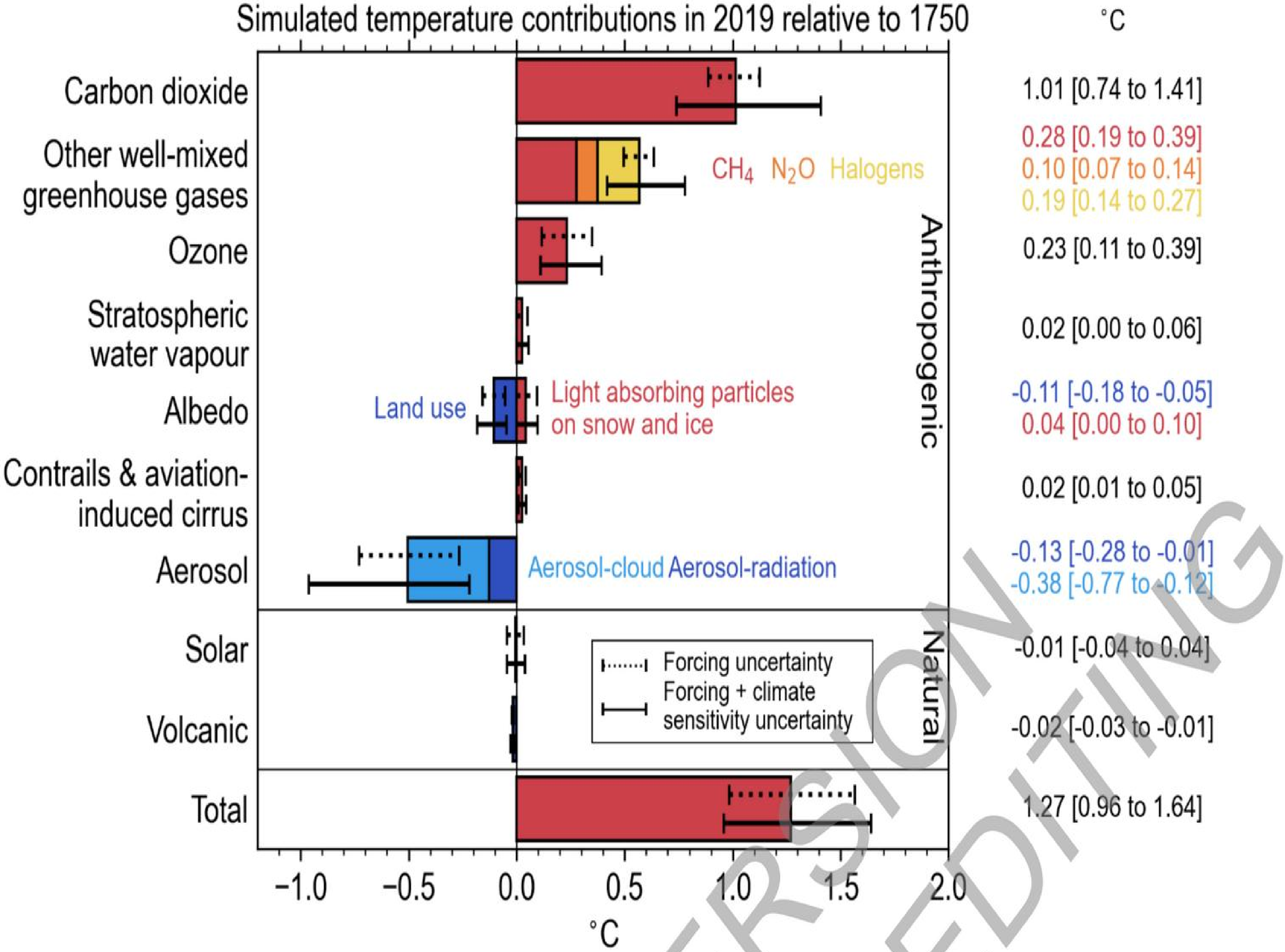


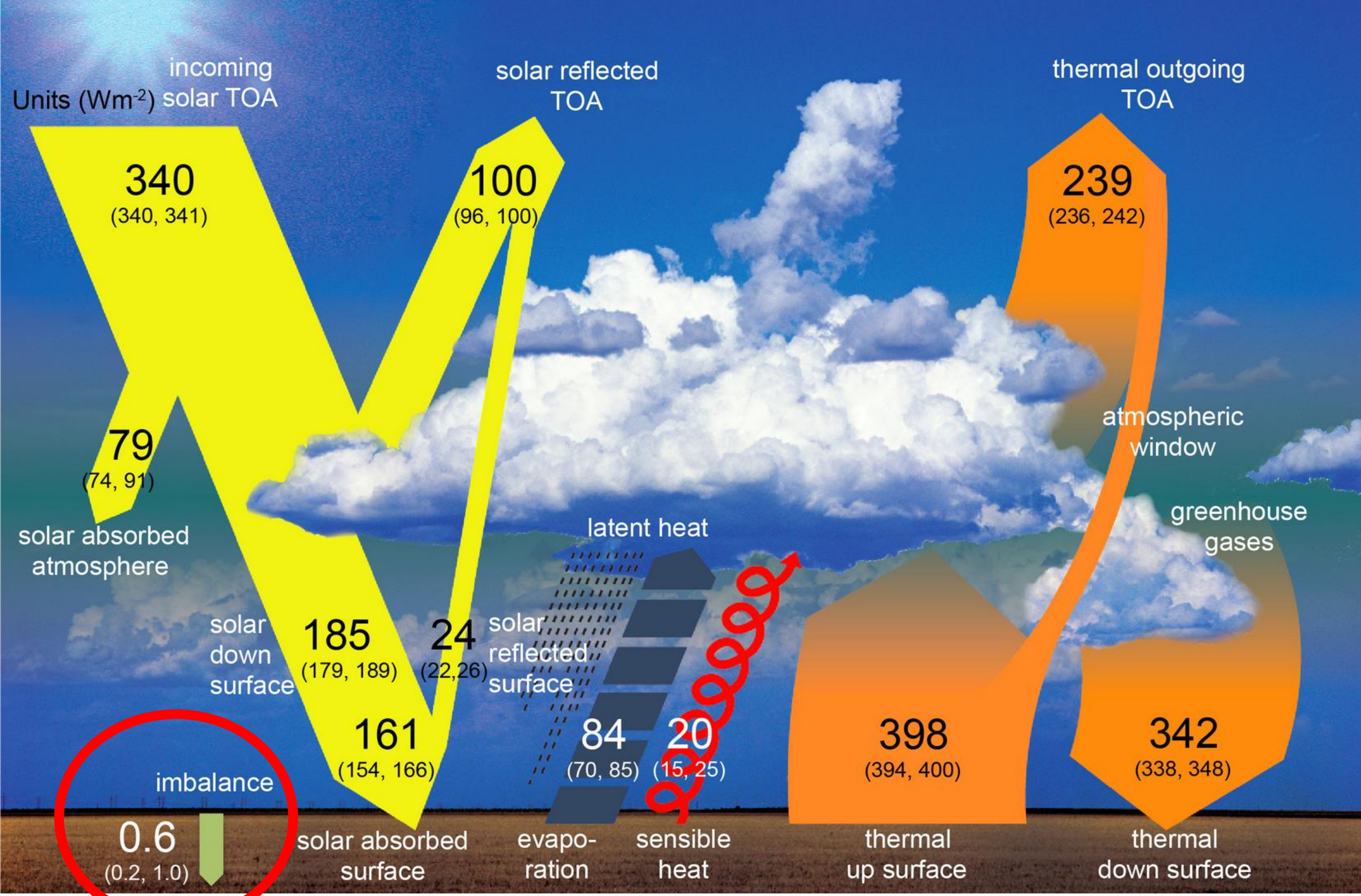
Sea level change



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

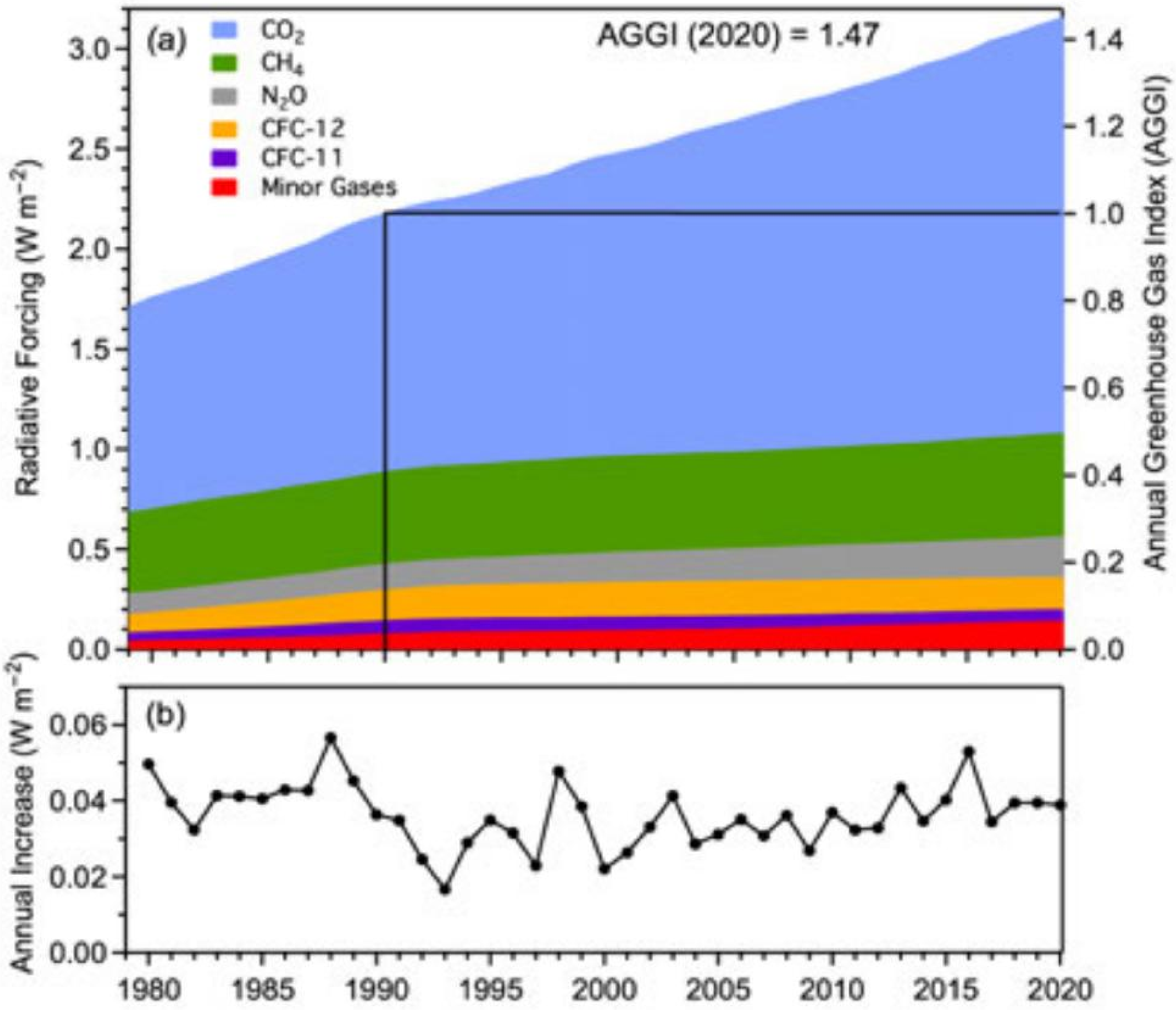

Change in effective radiative forcing from 1750 to 2019
ERF (W m−2)
Carbon dioxide
2.16 [1.90 to 2.41]
Other well-mixed greenhouse gases
CH4 N2O Halogens
0.54 [0.43 to 0.65]
0.21 [0.18 to 0.24]
0.41 [0.33 to 0.49]
Ozone
0.47 [0.24 to 0.71]
Stratospheric water vapour
0.05 [0.00 to 0.10]
Albedo
Land use
Light absorbing particles on snow and ice
-0.20 [-0.30 to -0.10]
0.08 [0.00 to 0.18]
Contrails & aviation-induced cirrus
0.06 [0.02 to 0.10]
Aerosols
Aerosol-cloud
Aerosol-radiation
-0.22 [-0.47 to 0.04]
-0.84 [-1.45 to -0.25]
Total anthropogenic
2.72 [1.96 to 3.48]
Solar
-0.02 [-0.08 to 0.06]
−2
−1
0
1
2
3
Effective radiative forcing (W m−2)


Simulated temperature contributions in 2019 relative to 1750
°C
Carbon dioxide
1.01 [0.74 to 1.41]
Other well-mixed greenhouse gases
CH4 N2O Halogens
0.28 [0.19 to 0.39]
0.10 [0.07 to 0.14]
0.19 [0.14 to 0.27]
Ozone
0.23 [0.11 to 0.39]
Stratospheric water vapour
0.02 [0.00 to 0.06]
Albedo
Land use
Light absorbing particles on snow and ice
-0.11 [-0.18 to -0.05]
0.04 [0.00 to 0.10]
Contrails & aviation-induced cirrus
0.02 [0.01 to 0.05]
Aerosol
Aerosol-cloud
Aerosol-radiation
-0.13 [-0.28 to -0.01]
-0.38 [-0.77 to -0.12]
Anthropogenic
Solar
-0.01 [-0.04 to 0.04]
Volcanic
-0.02 [-0.03 to -0.01]
Natural
Forcing uncertainty
Forcing + climate sensitivity uncertainty
Total
1.27 [0.96 to 1.64]
−1.0 −0.5 0.0 0.5 1.0 1.5 2.0
°C



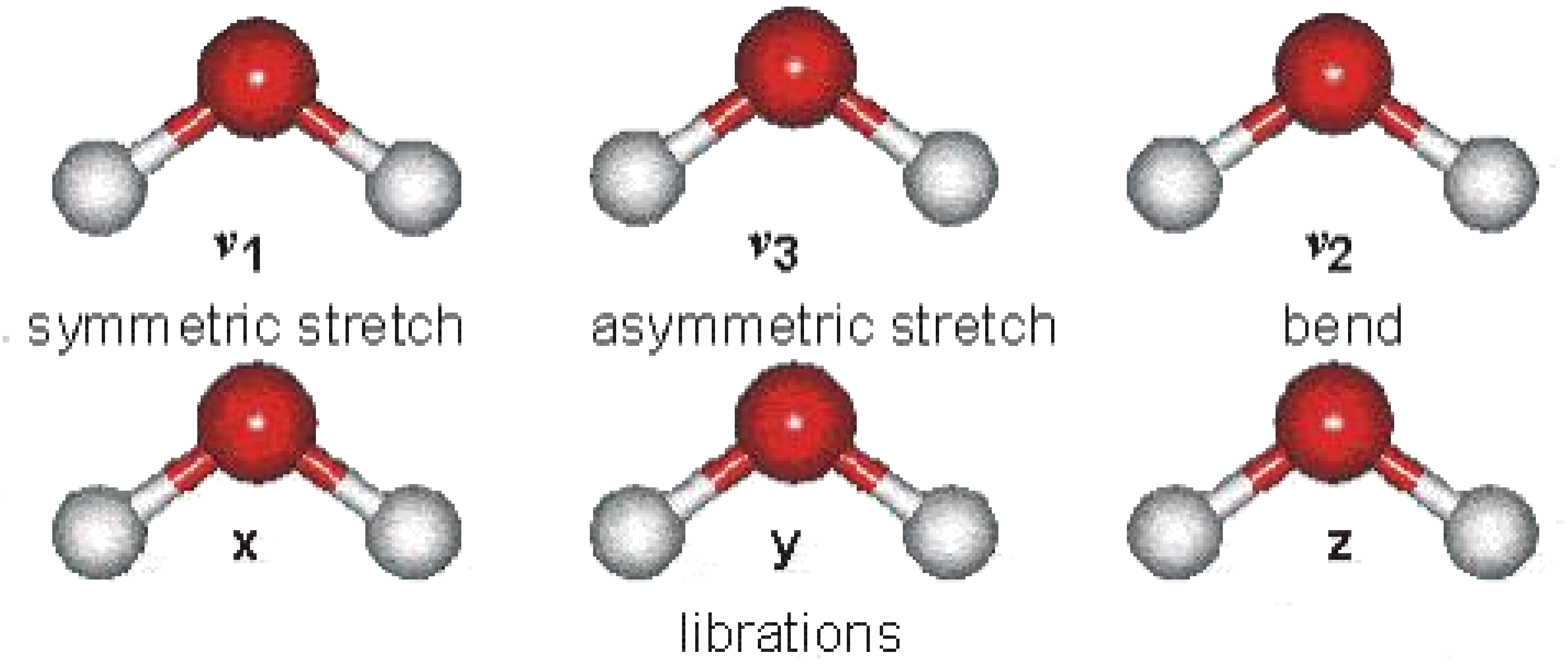
Energy balance of climate system. Units: W/m^2.

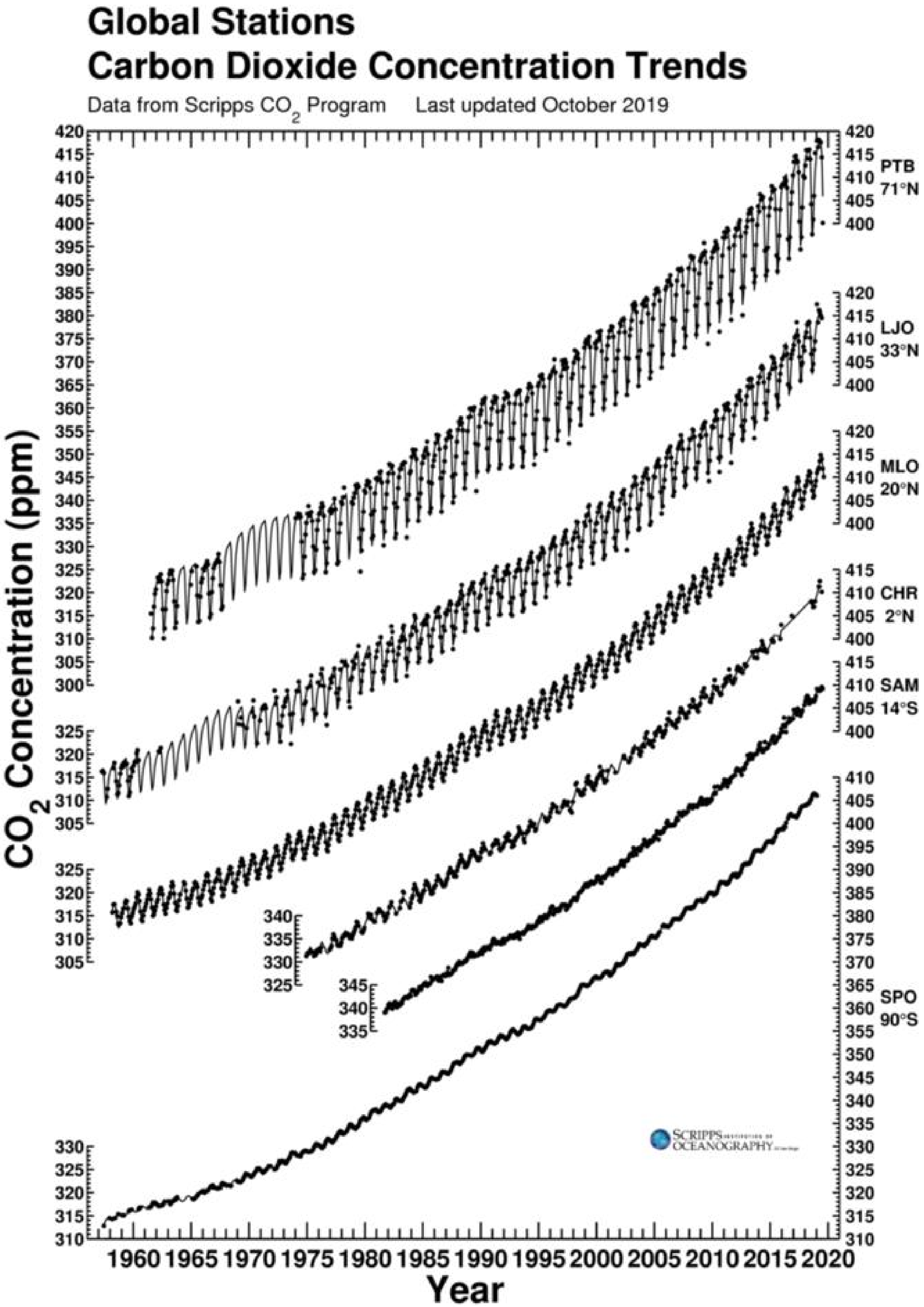
http://www.climatechange2013.org/report/



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

Why particles with 3 or more atoms absorb long-wave (low energy) radiation?

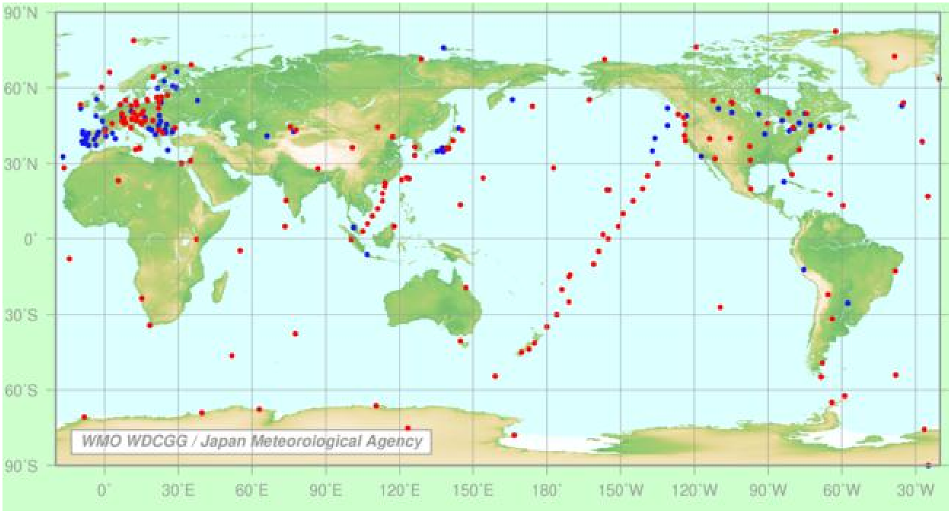




Regular observations of CO_2 and the other atmospheric gases are reported to WMO World Data Centre for Greenhouse Gases (WDCGG)

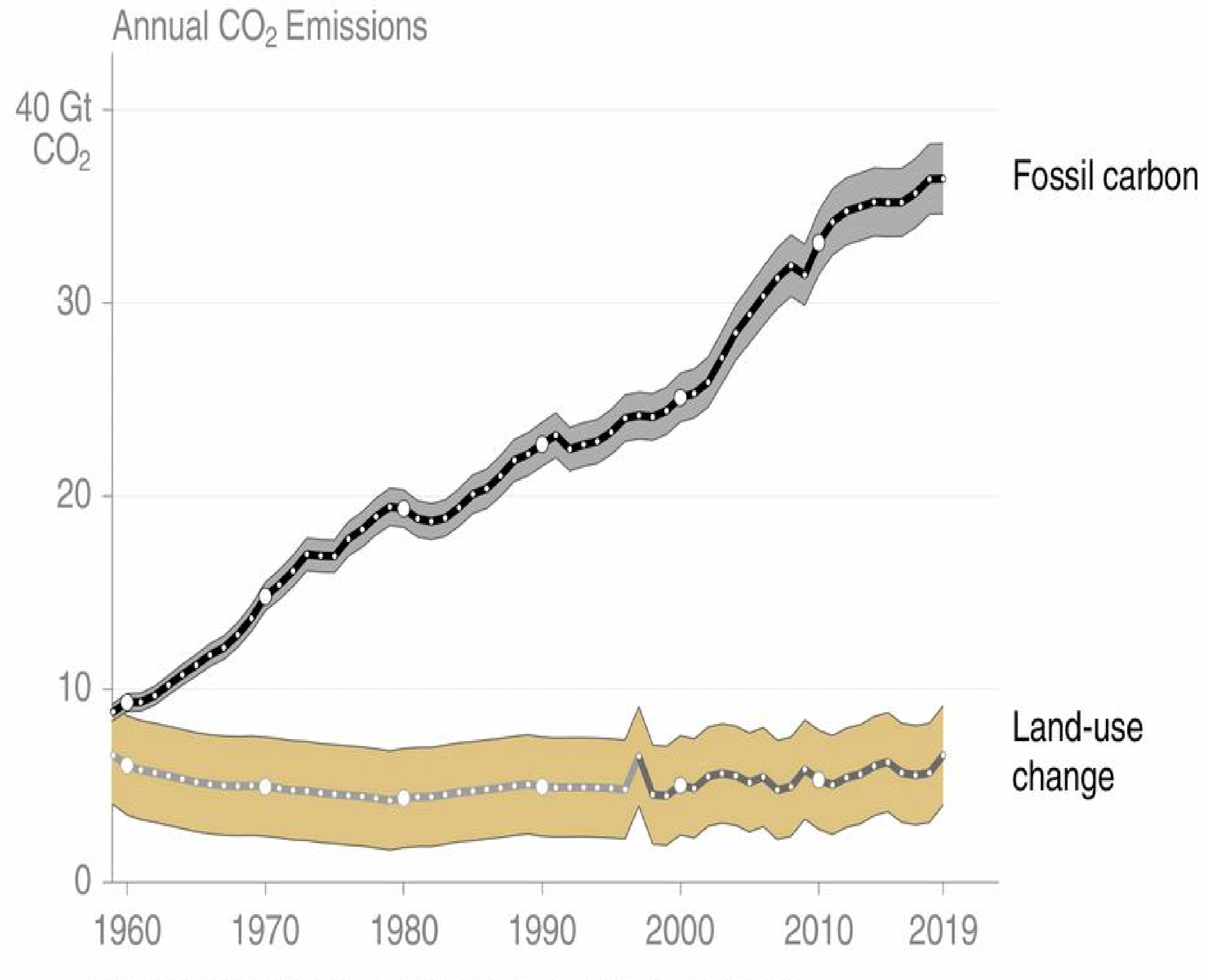
http://ds.data.jma.go.jp/gmd/wdcgg/

http://scrippsco2.ucsd.edu/

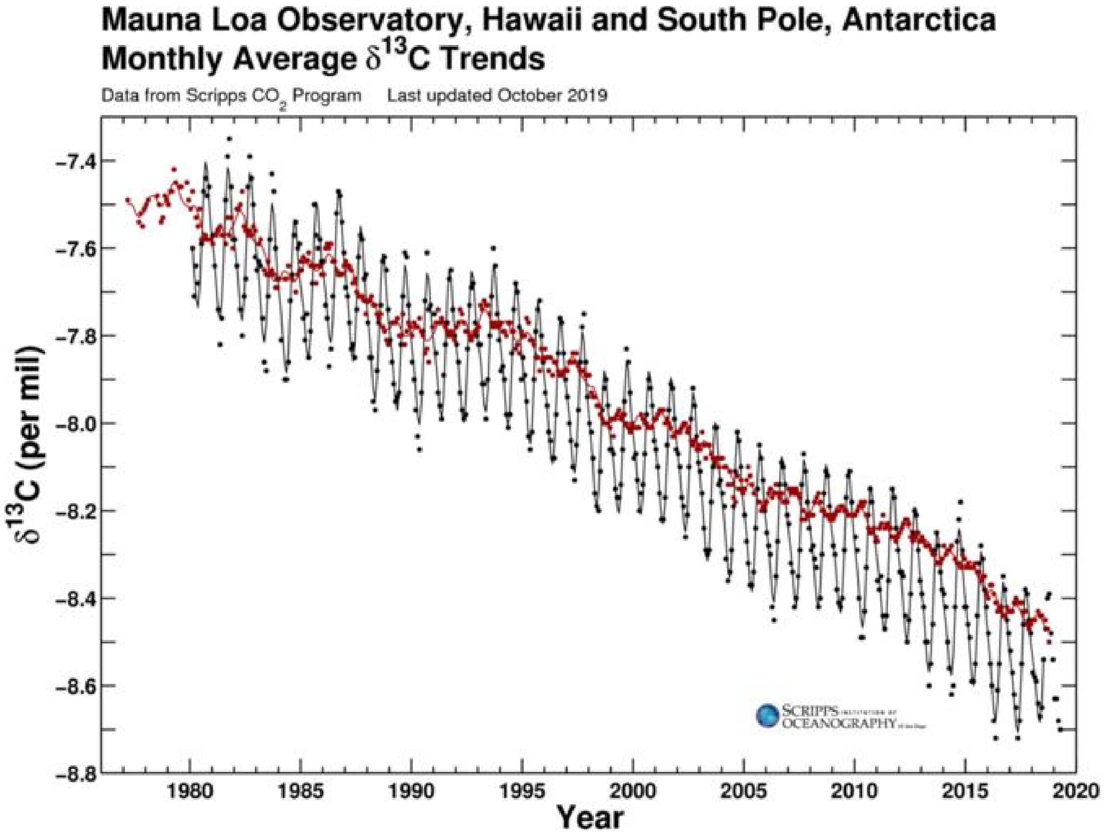


Total global emissions

Total global emissions: 43.0 ± 3.3 $GtCO_2$ in 2019, 56% over 1990
Percentage land-use change: 39% in 1960, 14% averaged 2010–2019



Land-use change estimates from three bookkeeping models, using fire-based variability from 1997
Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; Gasser et al 2020; van der Werf et al. 2017
;
Friedlingstein et al 2020; Global Carbon Budget 2020

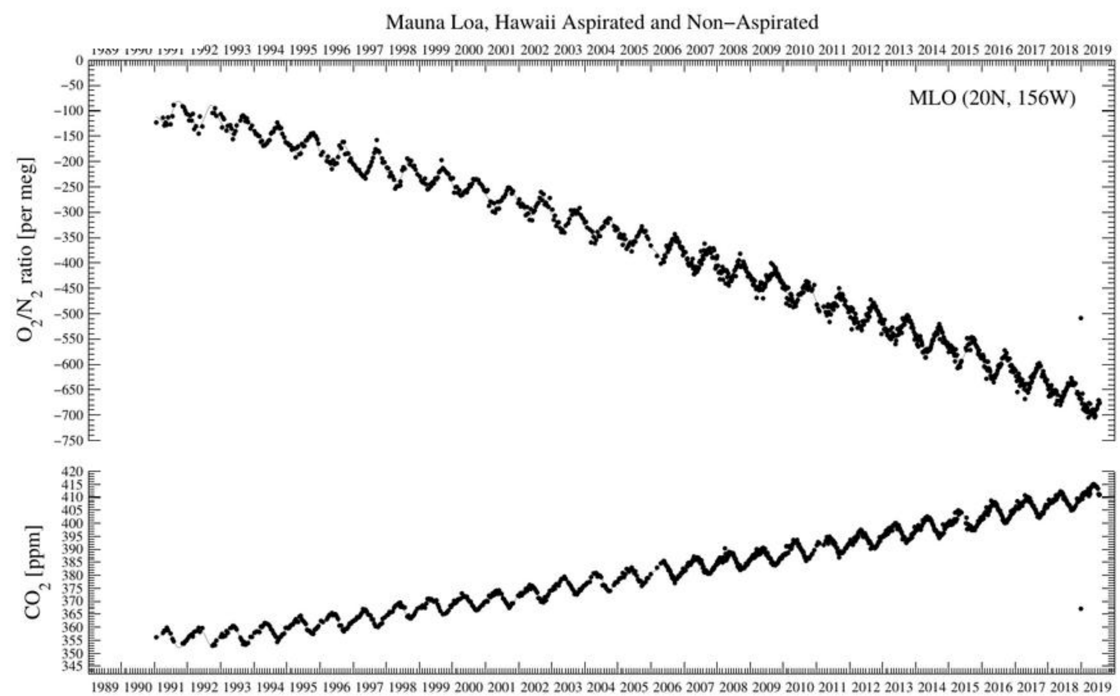


Carbon stable isotopes concentration ratio $^{13}C/^{12}C$ allows to determine the role of fossil fuel combustion in CO_2 concentration increase in the atmosphere and in the ocean.

Another signature of fossil fuel combustion

$$C+2O=CO_2$$

is the ratio of O_2/N_2 in air.



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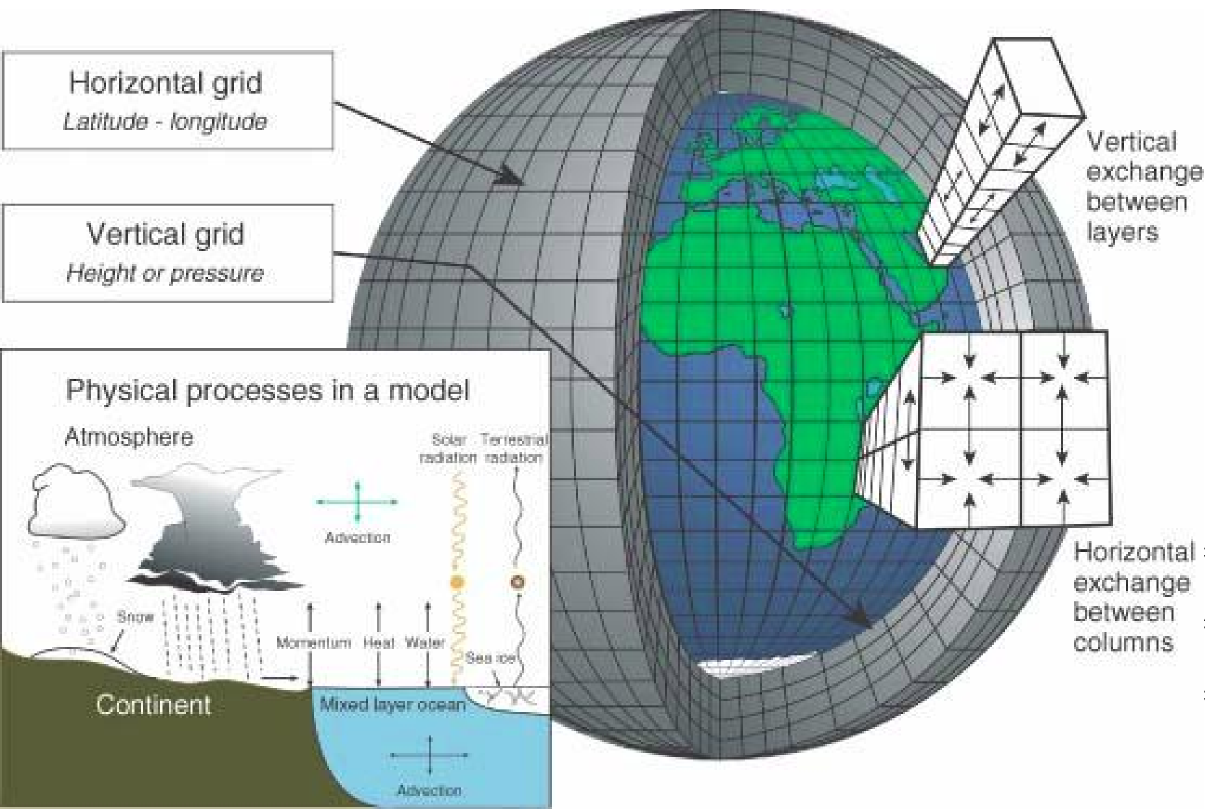
Climate modeling: a virtual planet



geophysical fluid dynamics
thermodynamics
radiative transfer
chemistry equations
boundary conditions

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model equations

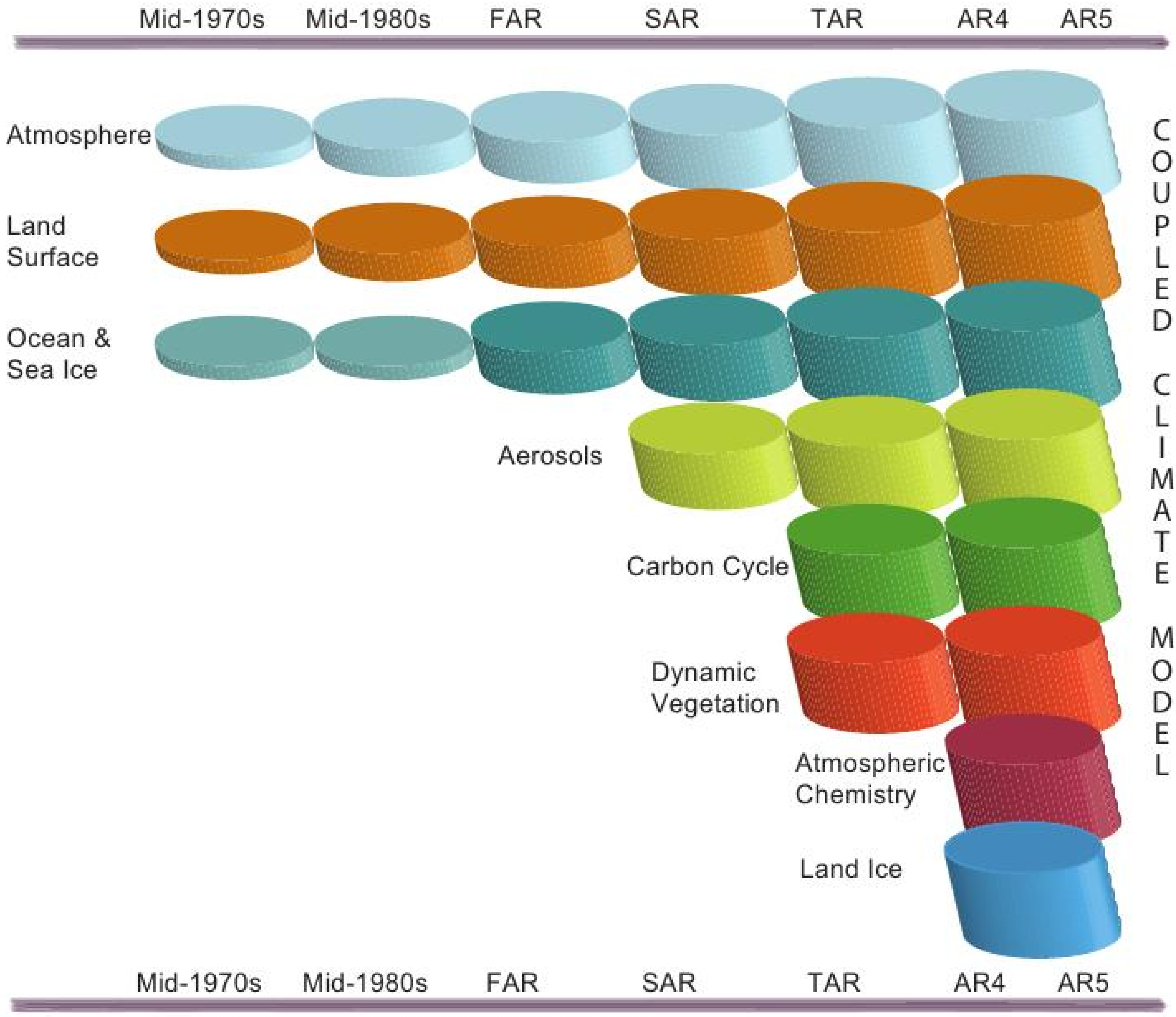
↓

numerical code
data and initial conditions
supercomputing facility

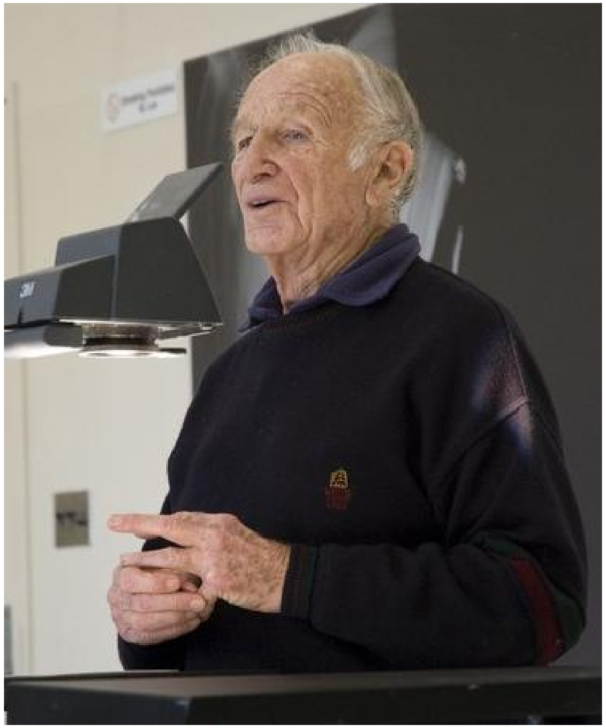
↓

virtual reality allowing for simulating climate

The development of climate models over the last 35 years



Predictability of weather and climate



Edward N. Lorenz (1917-2008):

Selected papers:

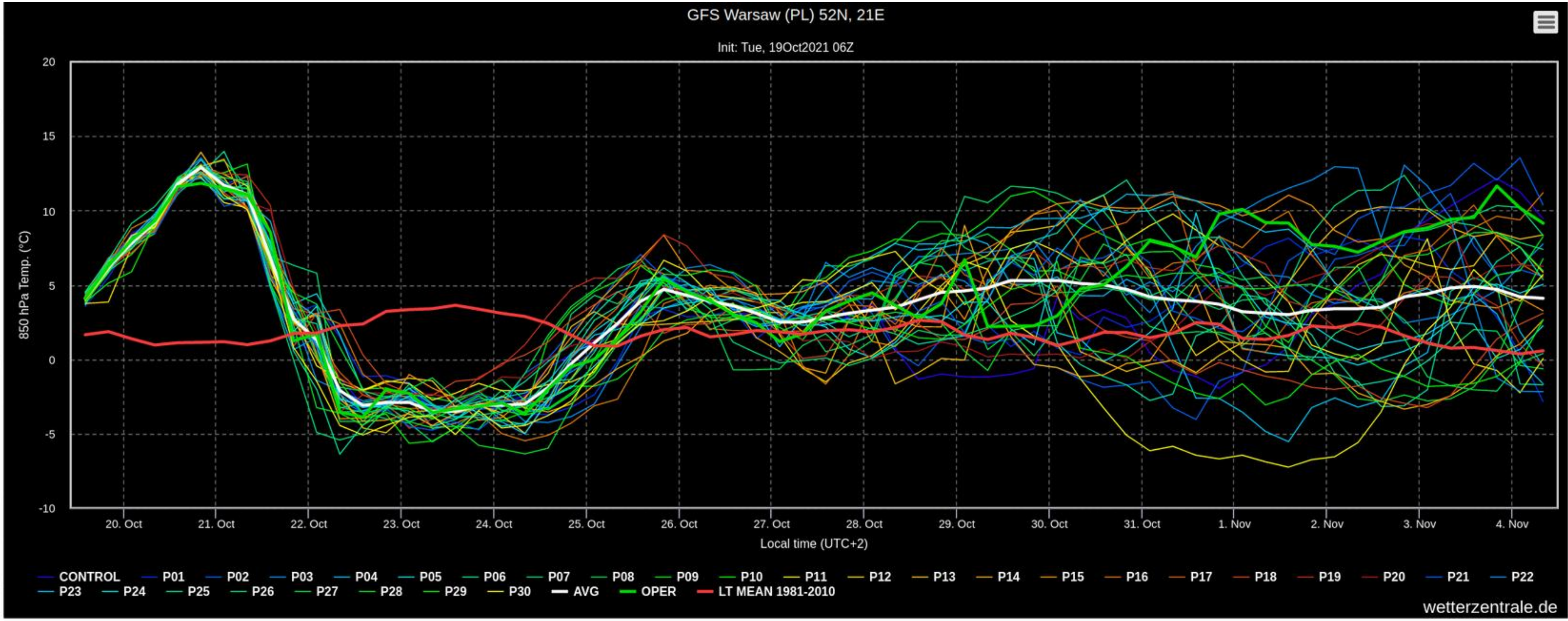
„Deterministic nonperiodic flow", 1963
(sensitivity of solutions to initial conditions: "butterfly effect", a well defined attractor)

„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)

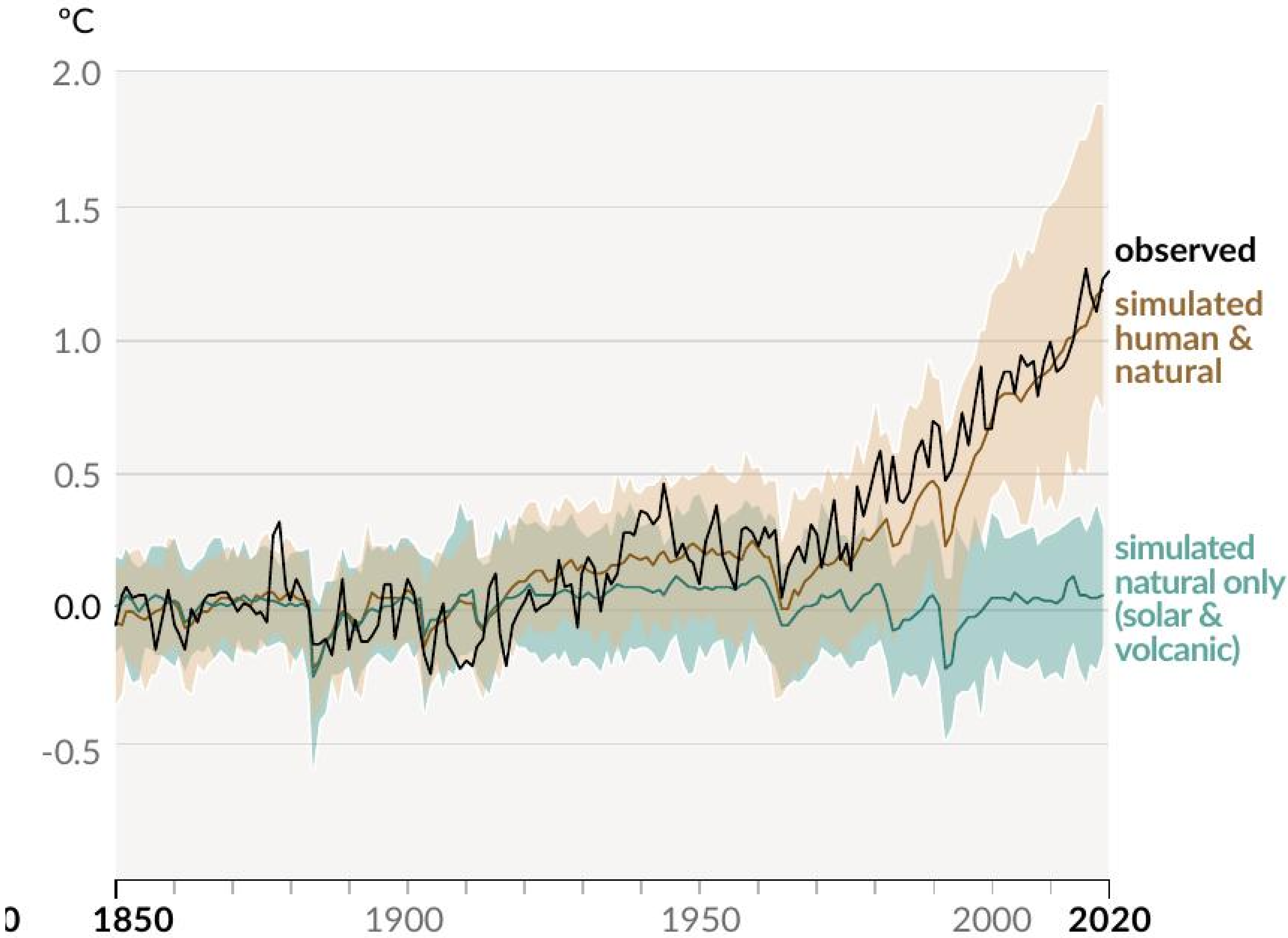
„Predictability – a problem partly solved", 2006

Predictability of weather and climate – illustration:



http://www.wetterzentrale.de/topkarten

b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850-2020)

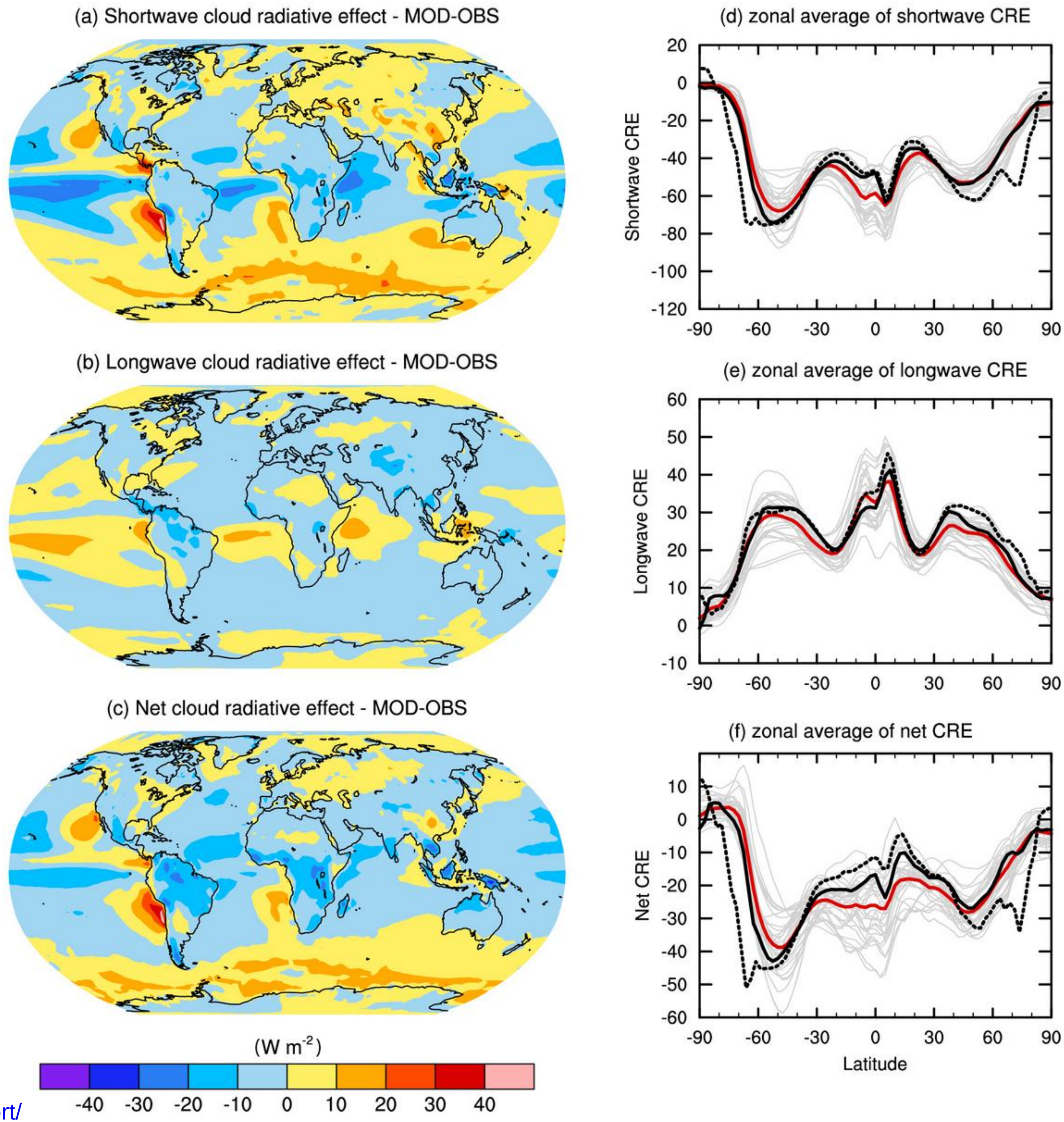


Model validations:

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).

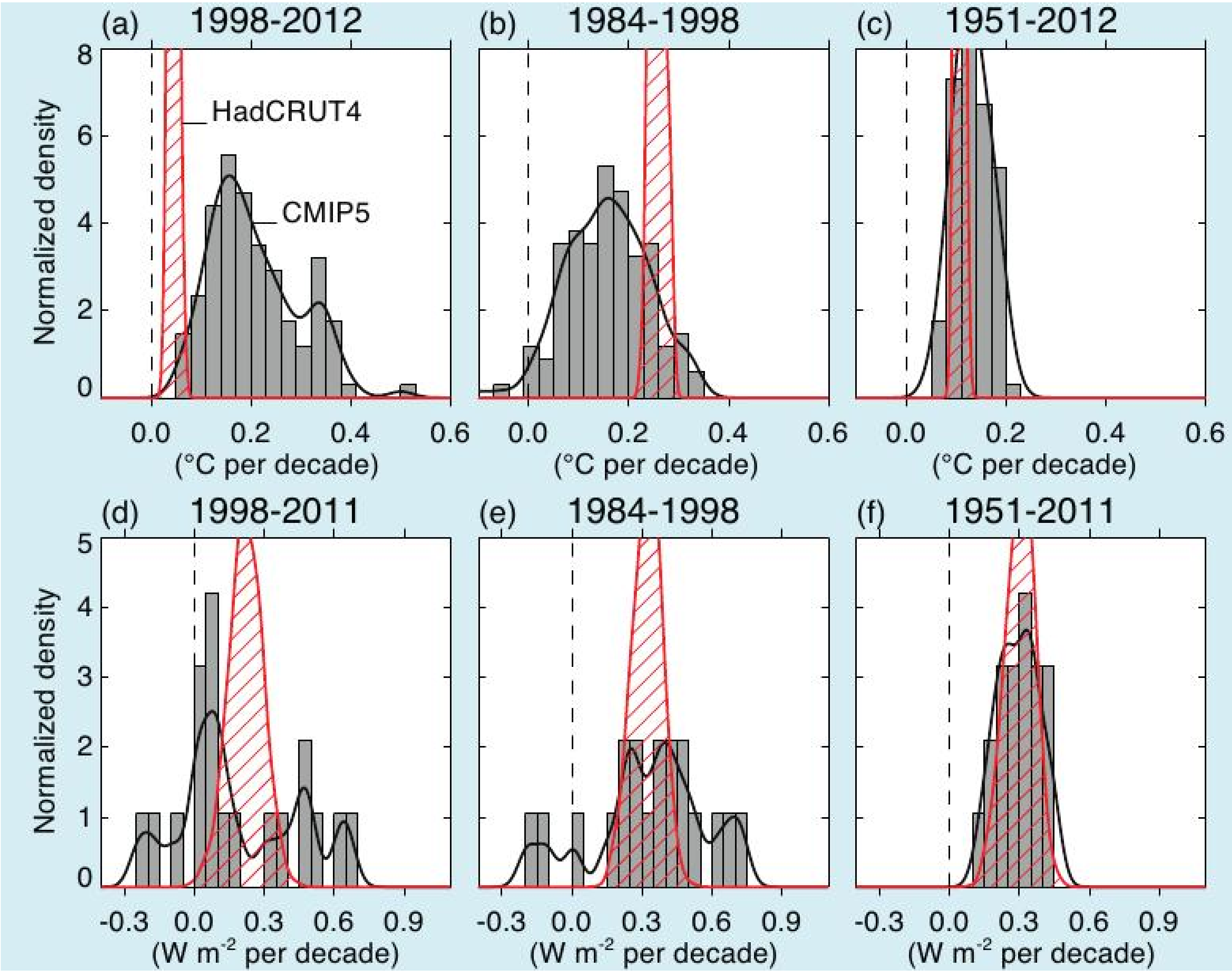
On the left are the global distributions of the multi-model-mean biases, and on the right are the zonal averages of the cloud radiative effects from observations.

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



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

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