Global Climate Change in Industrial Time

Observations and Forcing

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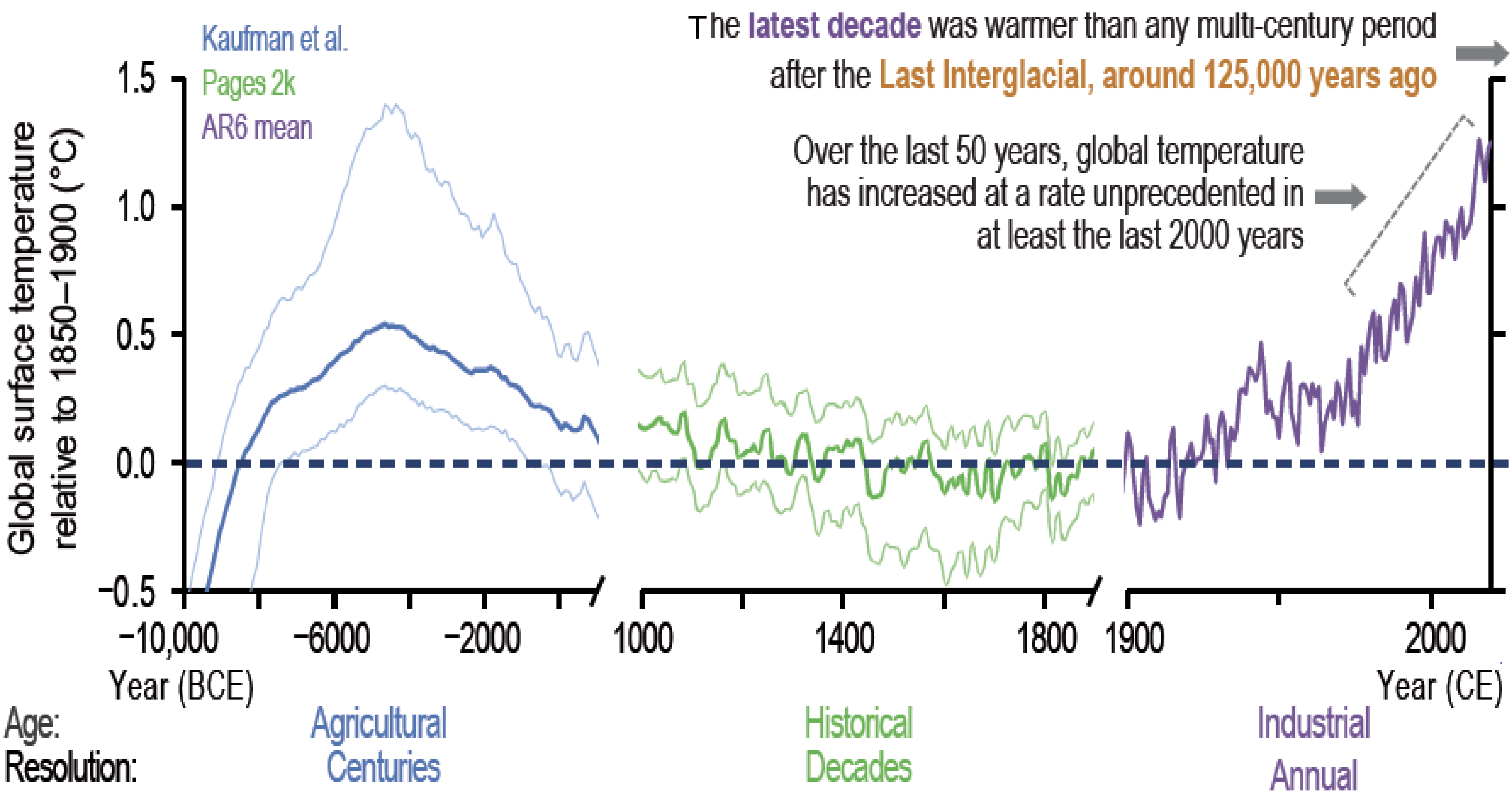
Introduction:
Some paleoclimatological remarks

- Age of Earth (and solar system): 4.6 bill. yr
- Paleoclim. Reconstructions: back to 3.8 bill. yr
- In this time very warm climate dominating (no ice on surface), interrupted by ice age eras
- Recent ice age era: since 2-3 mill. yr
- Fluctuations of cold/warm ages in ice age eras
- Recent cold (ice) age (Würm): $60\text{-}11 \cdot 10^3$ yr
- Recent warm age (Holocene): since $11 \cdot 10^3$ yr
- Industrial time: since c. 1800/1850 AD
- Direct climatological measurements (instead of indirect/uncertain reconstructions): since 1659 (Central England) or 1850/1880 (global), resp.



~11,000 yr bc: transition from last cold age (Würm) to recent warm age (Holocene), temperature increase c. 4 - 5 °C;

~5000 yr bc: Holocene maximum (c. 0.5 °C warmer than 1961-1990);

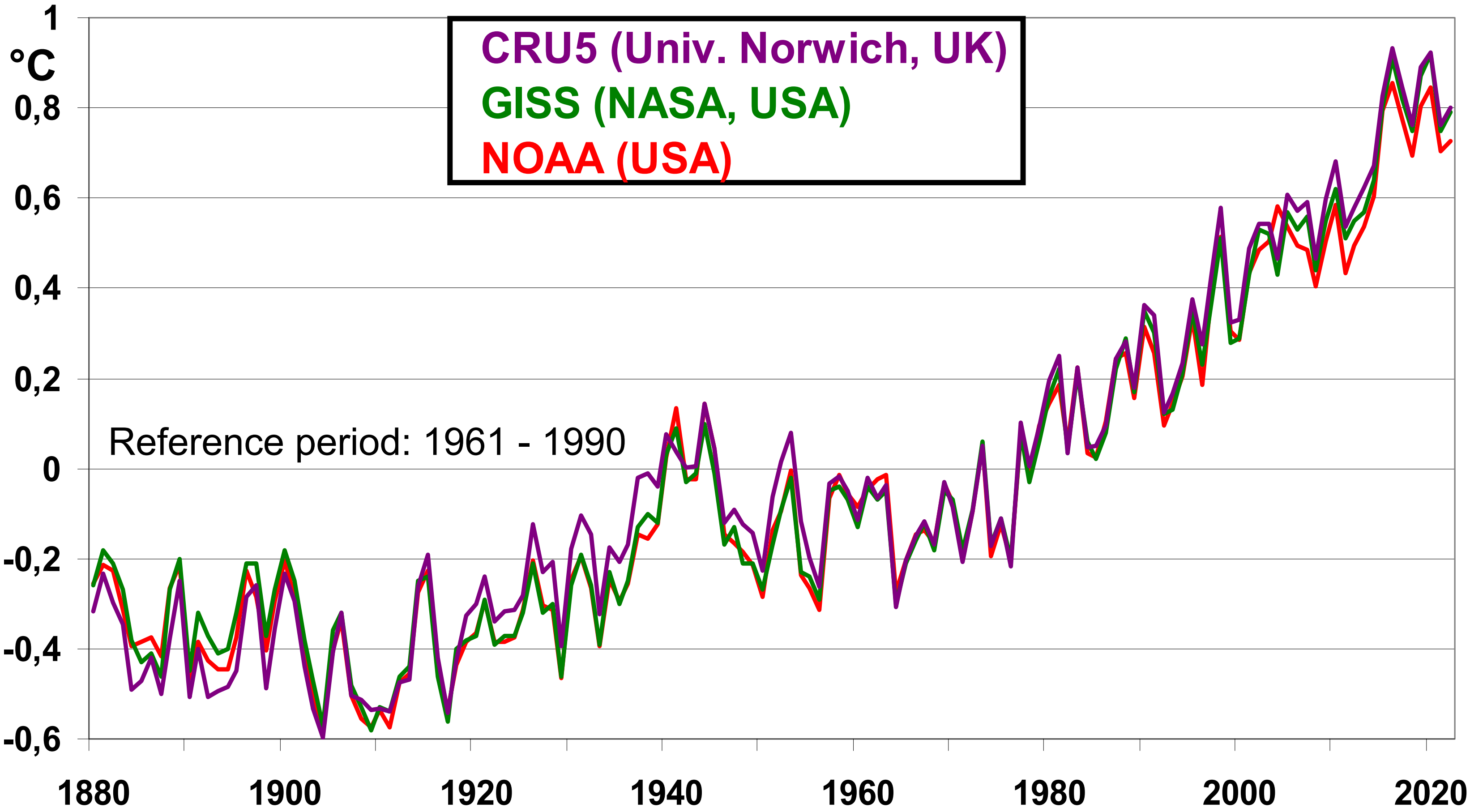
Until c. 1000 AD: Rapid cooling ► „Little Ice Age“ (c. 0.5 °C colder than 1961-1990);

Since c. 1850/1900: Industrial time, modern global warming *(details later).*

Global climate change in industrial time
Overview of presentation

- Global and regional temperature change
- Regional precipitation change
- Extreme events
- Ice sheets, glaciers, and sea level
- Climate system and processes (overview)
- Natural forcing (temperature)
- Anthropogenic forcing (temperature)
- Climate model assessments (temp., past)
- Climate model projections (temp., future)
- Some additional future projections
- Conclusions

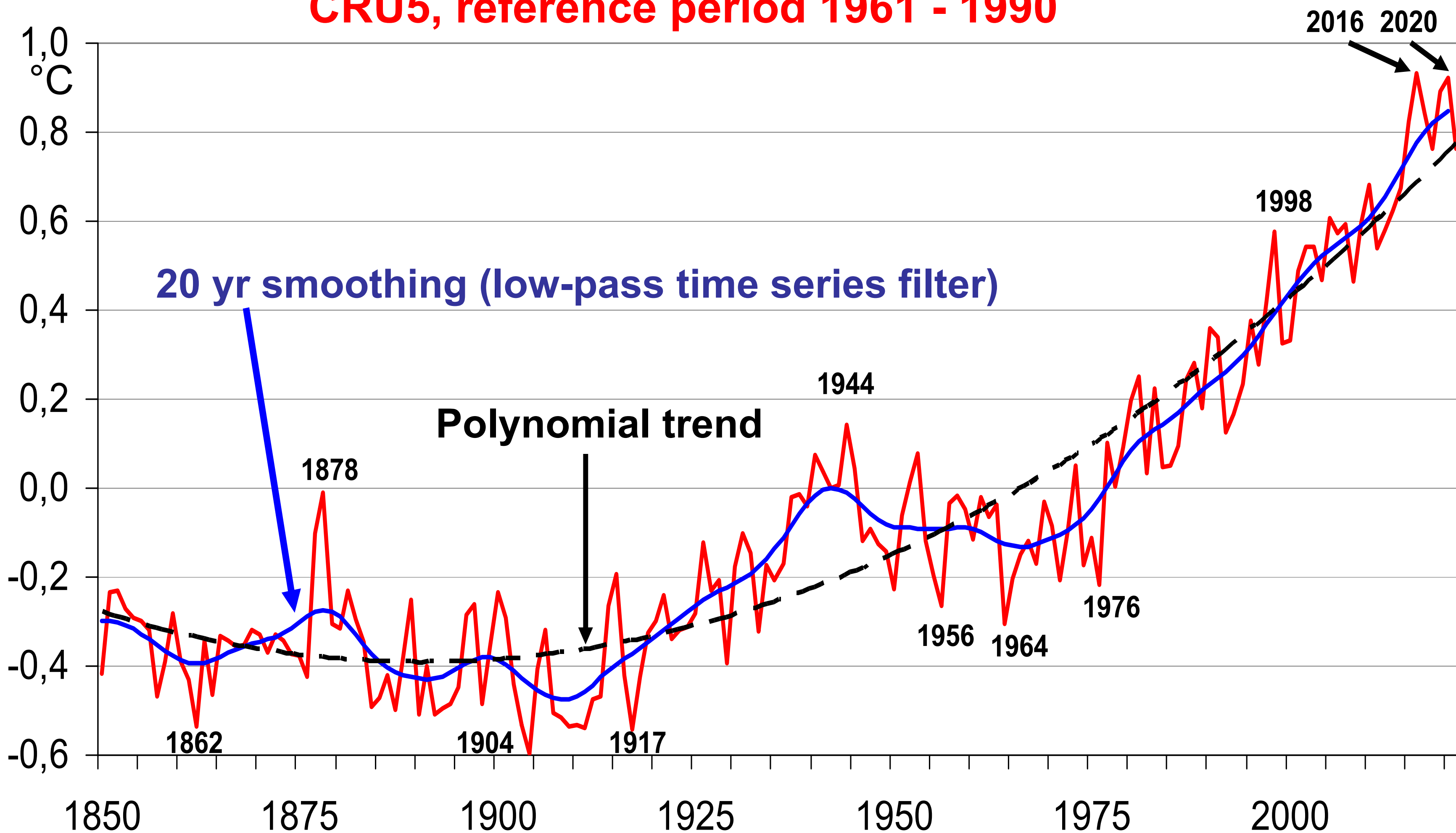
Global mean air temperature annual anomalies 1880 - 2022



CRU: Climatic Research Unit, Univ. Norwich, UK (recently 5583 stations); GISS: Goddard Institut for Space Studies, NASA, USA (rec. c. 6300 stations); NOAA: National Oceanic and Atmospheric Administration, USA (rec. 7280 stations; in 1880 roughly 300 stations); uncertainty c. < 0.1 °C.

Global mean air temperature annual anomalies 1850 - 2022

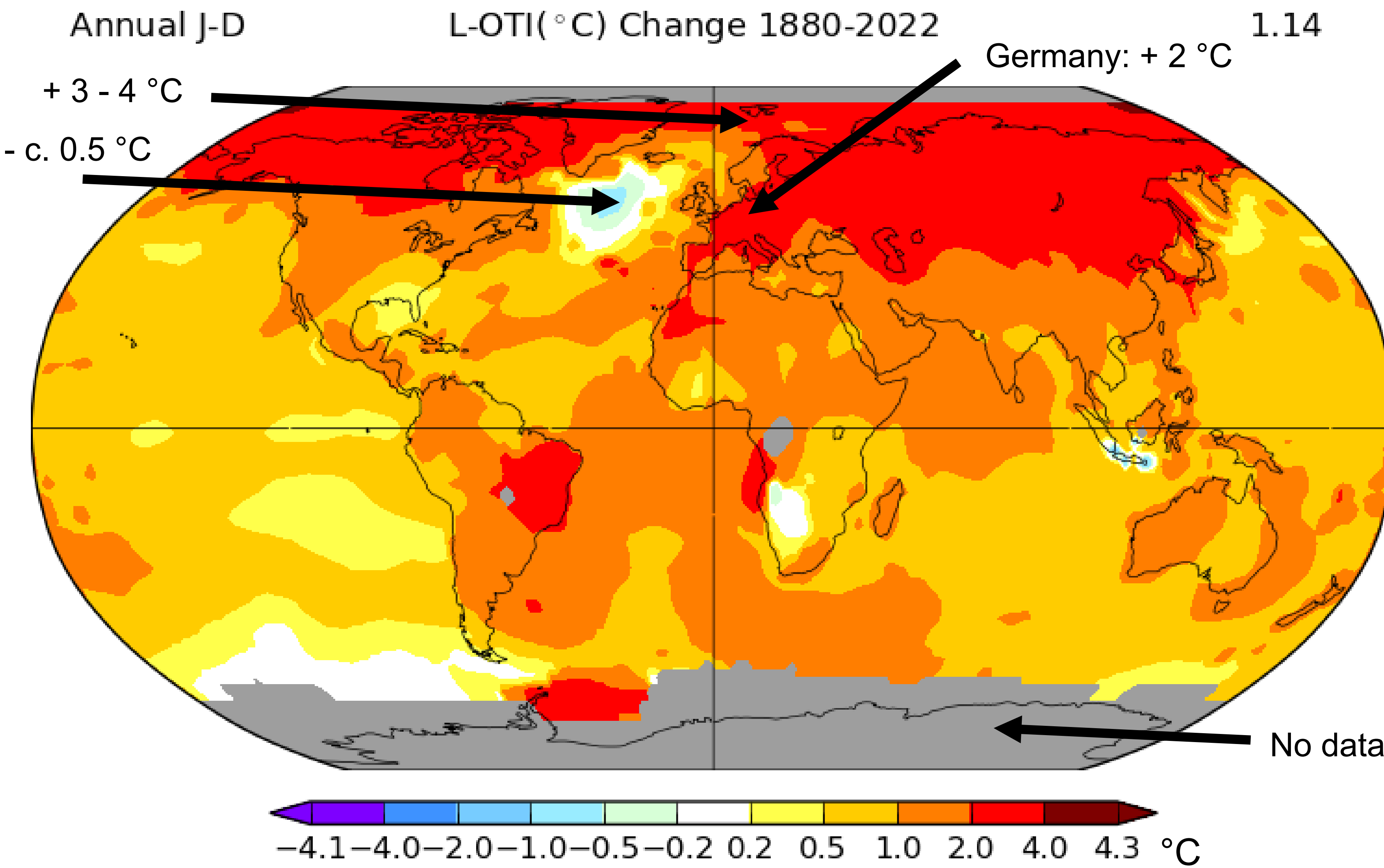
CRU5, reference period 1961 - 1990



1850-c.1905: Fluctuations; c.1905 -1944: Increase; 1944-c.1970: decrease; then increase;

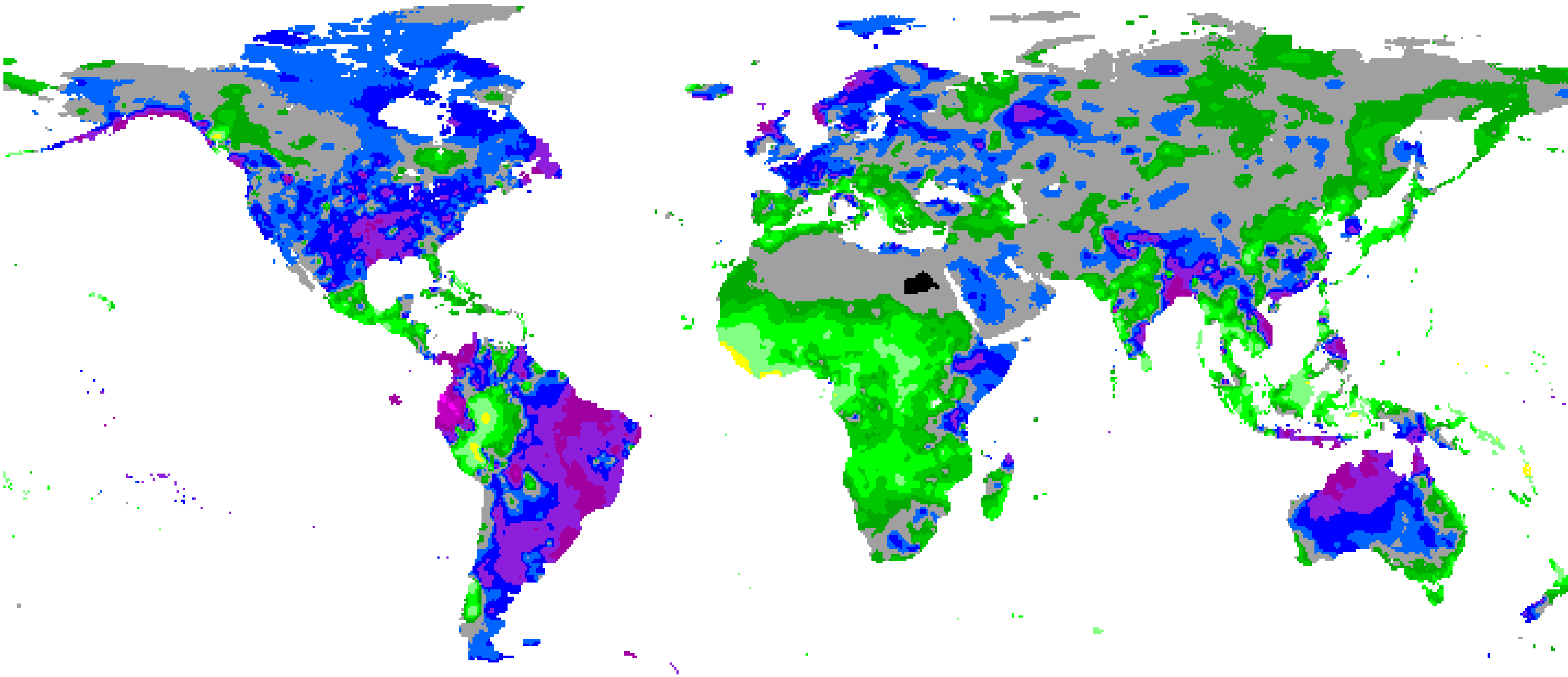
Polynomial (and linear) trend since 1880/1900: + 1,2 ± 0,1 °C

Regional patterns of temperature trends 1880 - 2022



GISS (NASA, USA) , Febr. 2023

Regional patterns of precipitation trends 1951-2000



Linear trends of annual means in mm

-100 -50 -20 -10 -5 -2 2 5 10 20 50 100

Year

Grid Resolution .5°x.5°

Beck, Rudolf, Schönwiese, Trömel und Staeger, 2007

Extreme events are becoming more frequent

Deaths: 1740; Damage: ~15 Mill. US$

Deaths: 70 000; Damage: 13 Bill. US$

Deaths: 6235; Damage: 10.5 Bill. US$

Deaths: 89; Damage: 5.2 Bill. US$

Fires: Forest and settlements

8.- 25 Nov. 2018: USA, California; deaths: 88, damage: 16,5 Bill. US$; 2019/2020 again severe bush fires in California, also in Australia, the Mediterranean area etc.

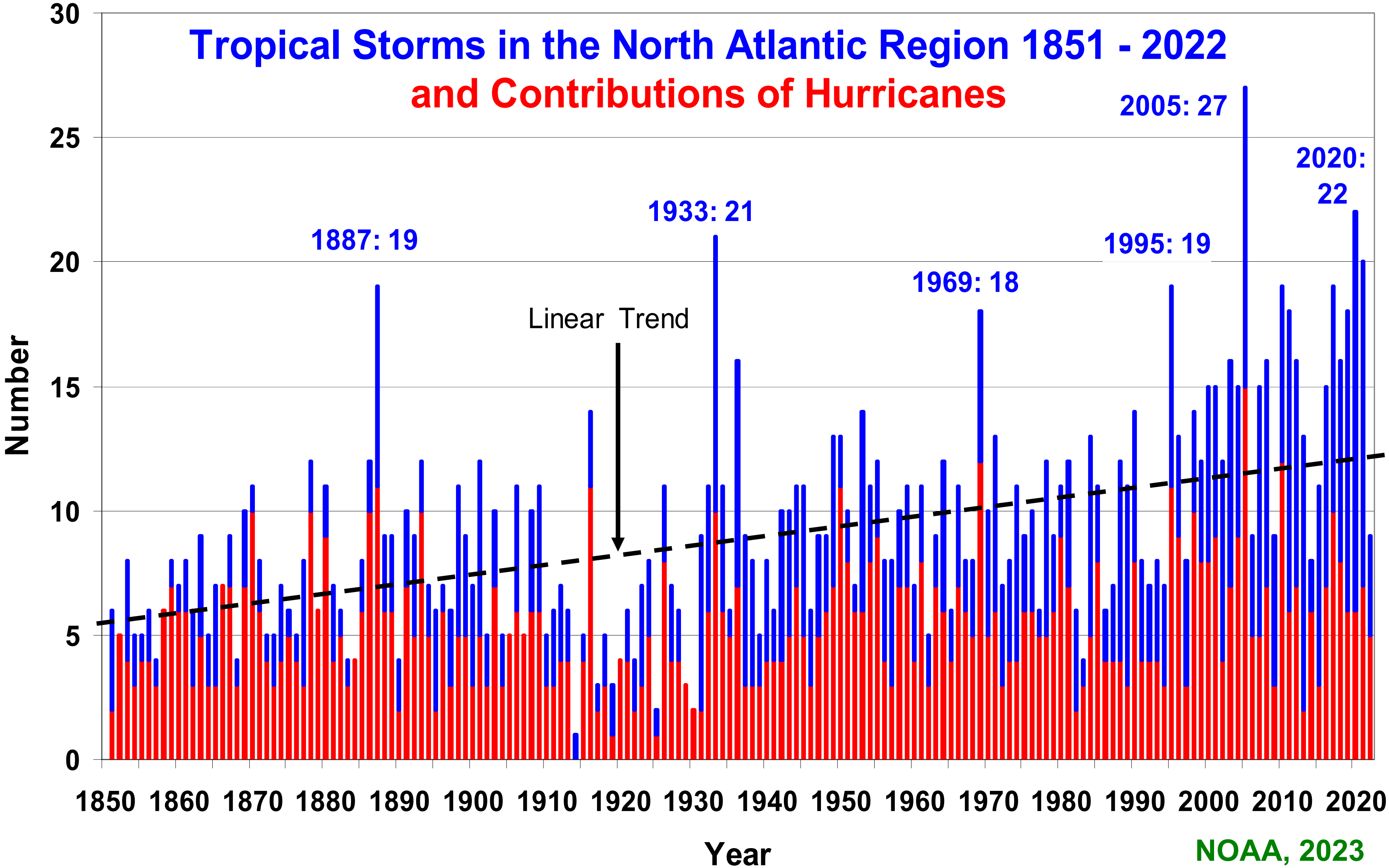
29. June 2021: temperature 49,6 °C in Lytton, Canada (record value so far), deaths: 486; 4. July 2021: temperature 54 °C, Death Valley, California, USA, again severe bush fires.

Temperature record so far, global:

58 °C, 13.9.1922, Al-Aziziyah, Libya;

Germany: 40,3 °C, 5.7./7.8. 2015, Kitzingen/Main.

Sources: MunichRe, 2018-2021; print media

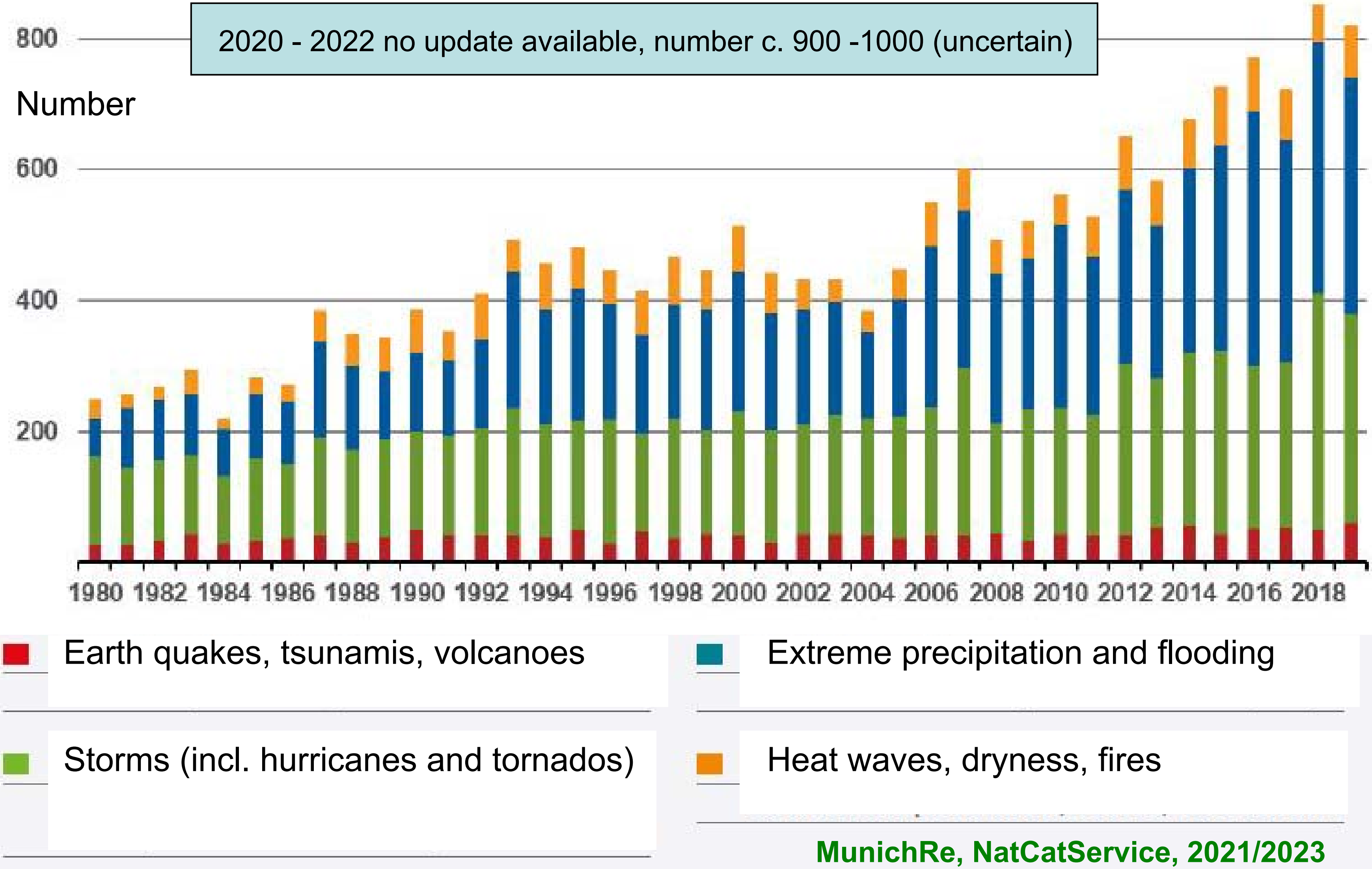


Within 1850 - 2022 the total number of tropical storms, including hurricanes, has increased from c. 5 to c. 12-20/yr

Global number of natural disasters 1980 - 2019

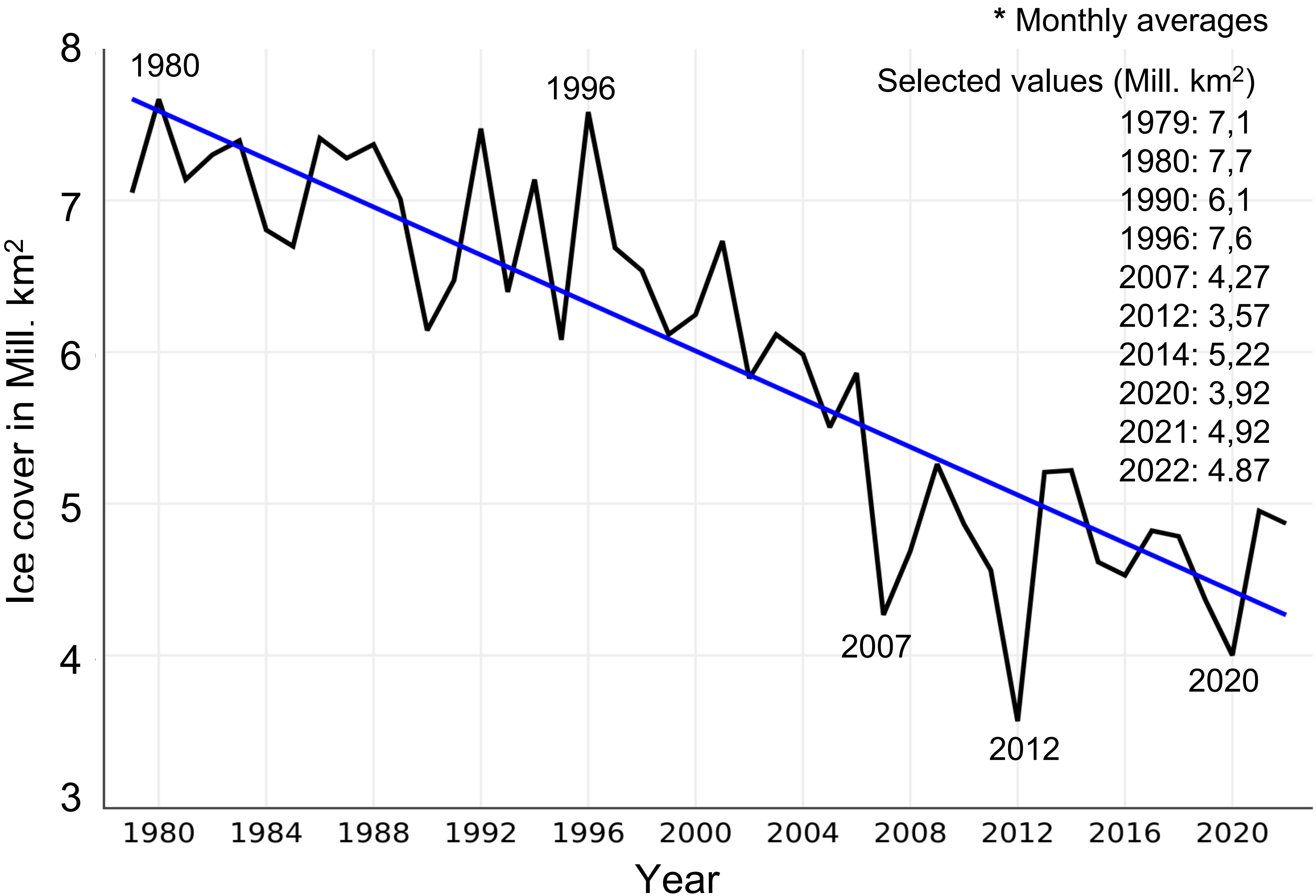
Increasse of economic damages from c. 50 to 250 bill. US$.
Maxima so far in *2011 und 2017, each c. 350 bill. US$.*

2020 - 2022 no update available, number c. 900 -1000 (uncertain)

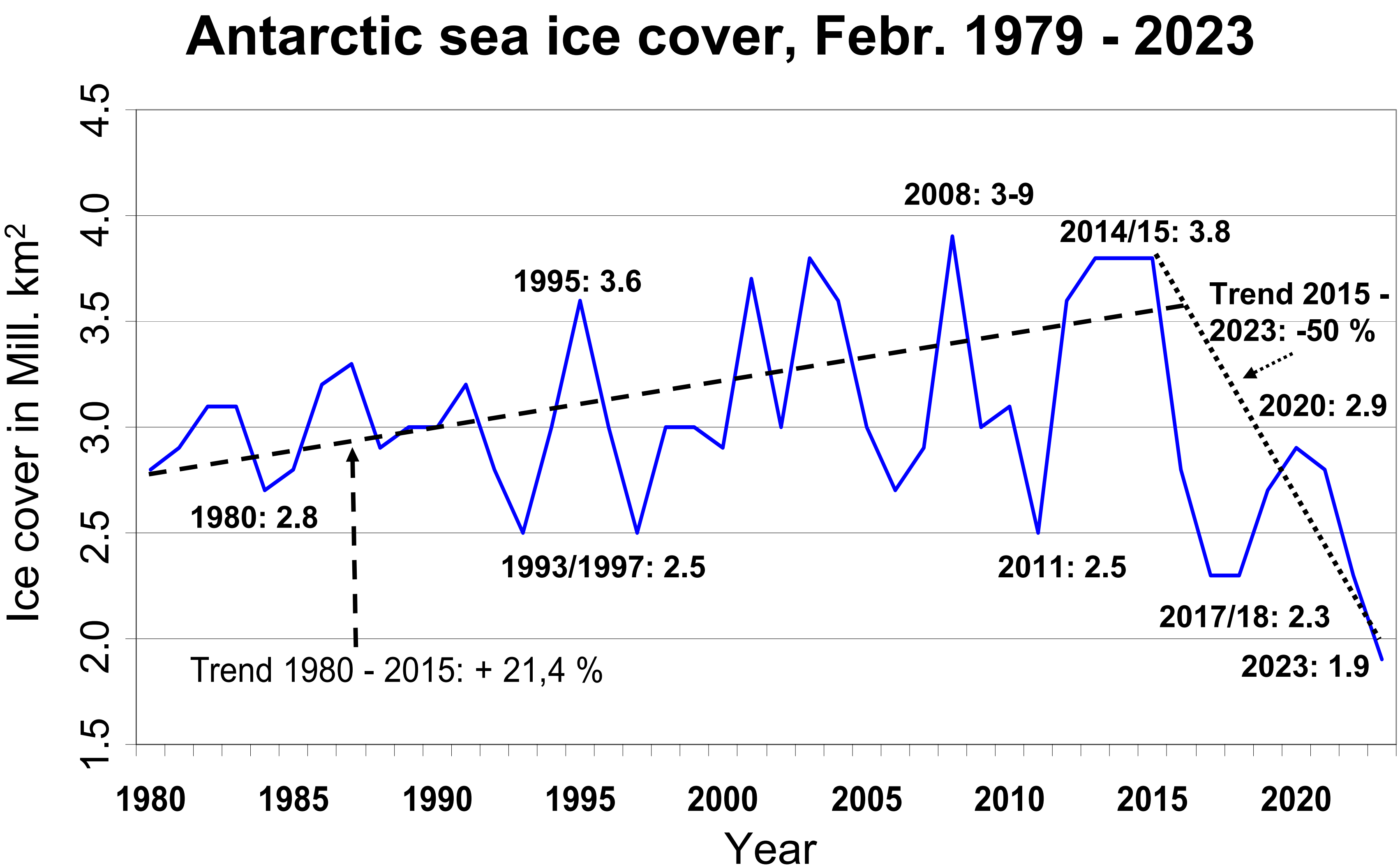


MunichRe, NatCatService, 2021/2023

Arctic sea ice cover, Sept. 1979 -2022

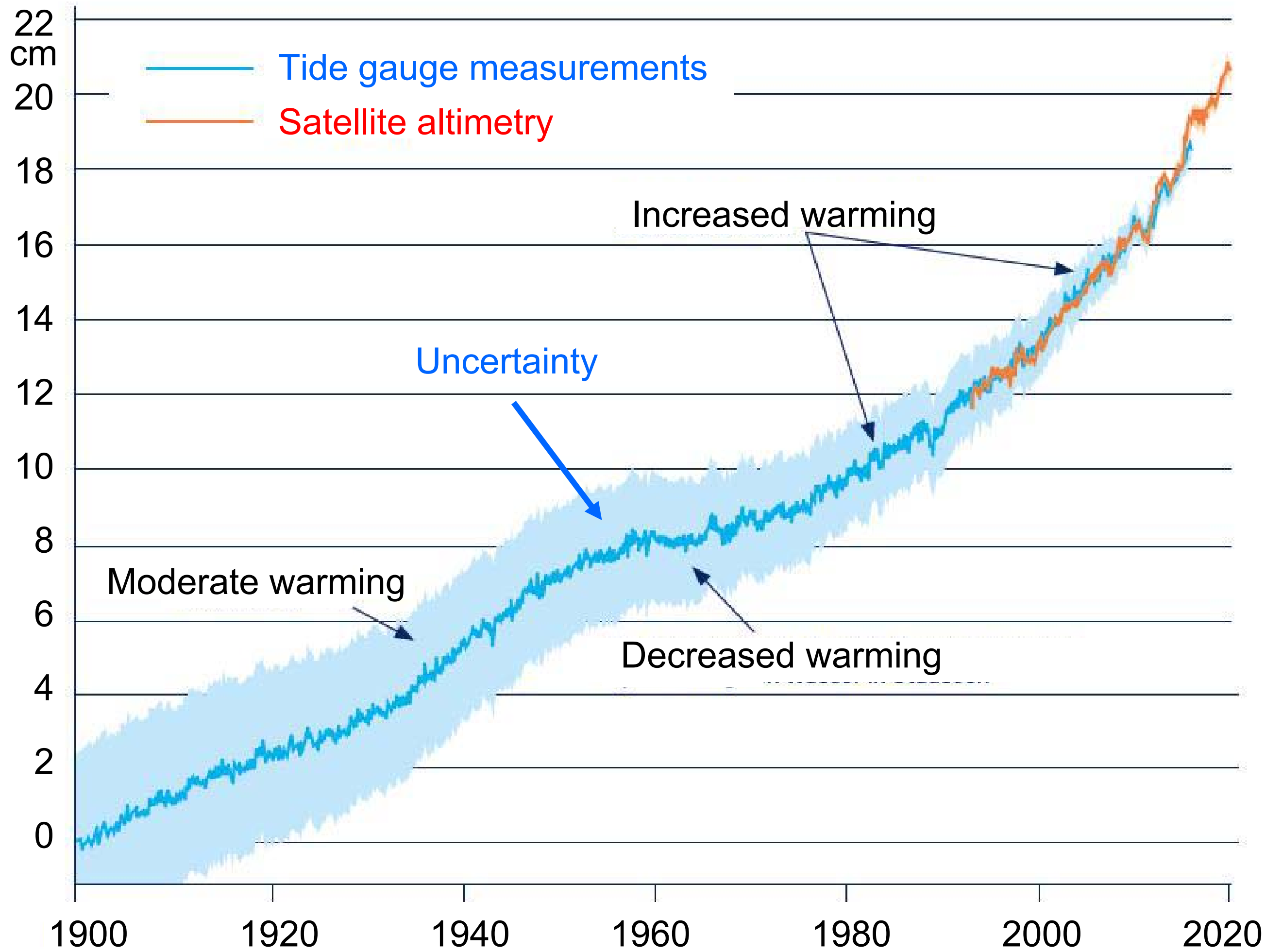


Source: National Snow and Ice Data Center (NSIDC), USA, Oct. 2022



After an increase until 2014/15 a pronounced decrease followed

Source: National Snow and Ice Data Center (NSIDC), USA, Oct. 2022



Global sea level rise 1900 - 2020: 21 cm

(Dengendorf, 2019; German Climate Consortium, 2022),

1880 - 2022: 21 - 24 cm

(NOAA, 2023)

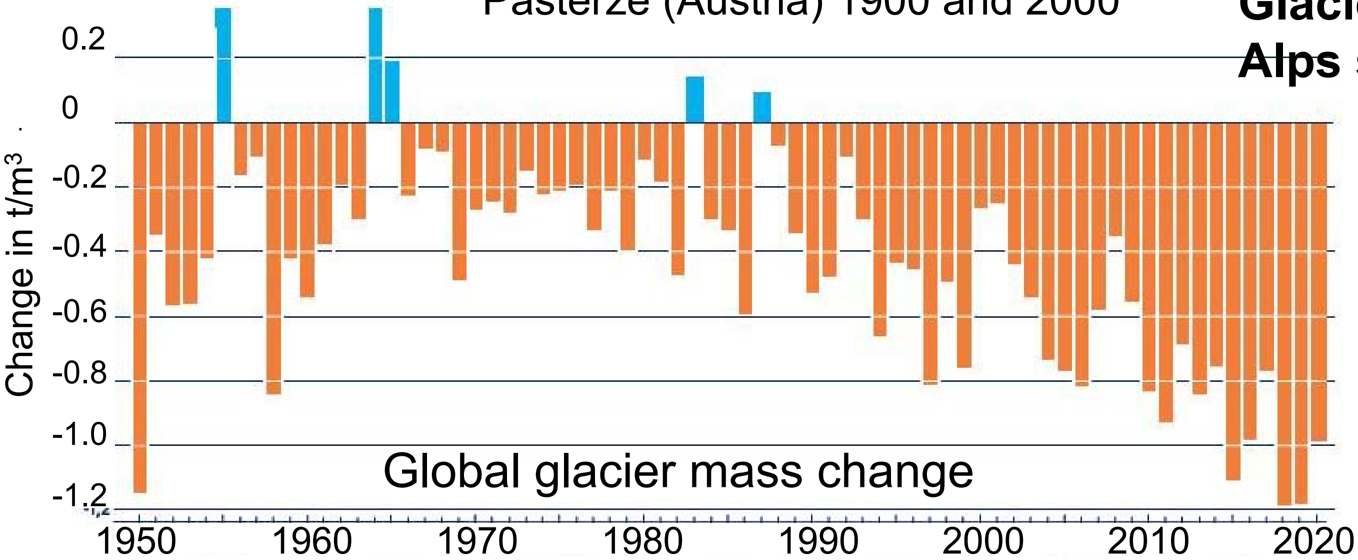
Recent IPCC Assessm. Report (2022), 1901-2018: 20,2 cm, where 16,5 cm can be simulated by models; see modelled components

Expansion of the upper (mixed layer) ocean:	**38.4 %**
Melt of mountain glaciers:	**40.8 %**
Melt of Greenland ice sheet:	**24.5 %**
Melt of Antarctica ice sheet:	**4.1 %**
Land water storage:	**- 7.8 %**

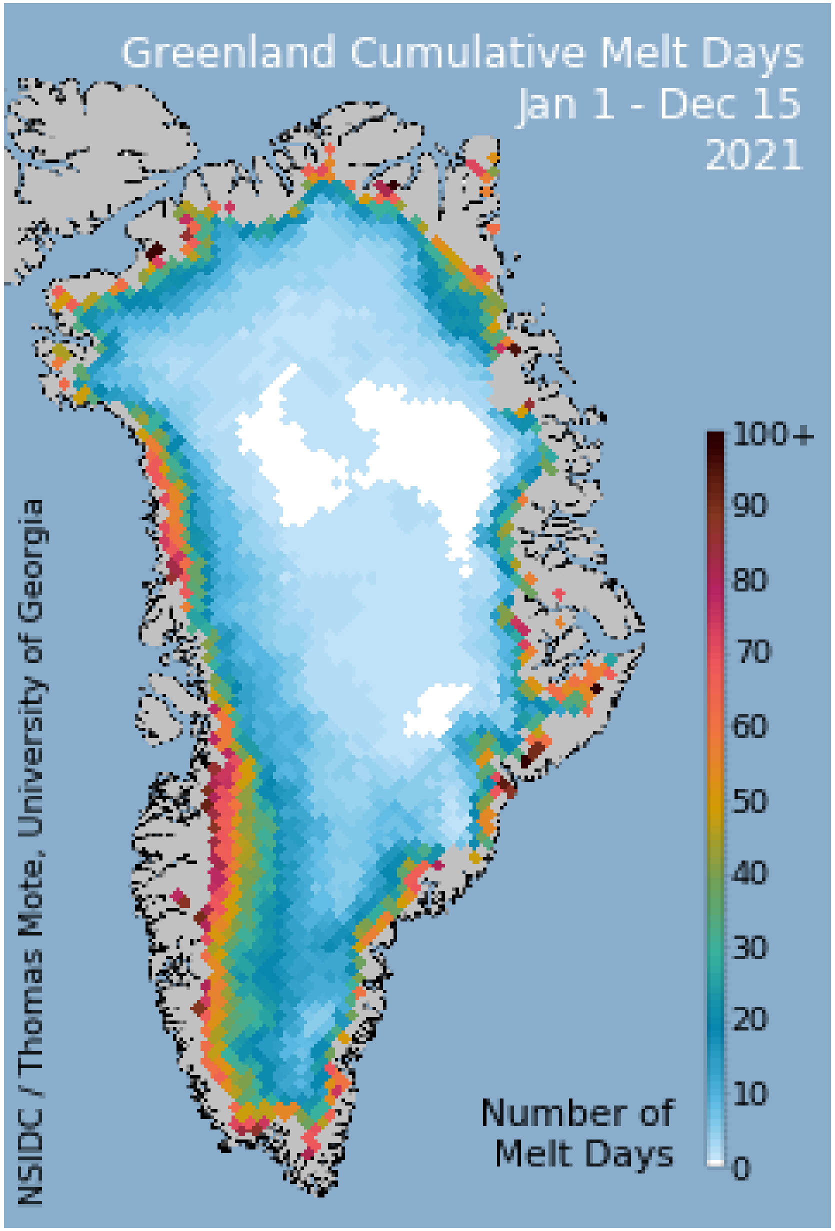
Melt of mountain glaciers

Pasterze (Austria) 1900 and 2000

Glacier ice area loss in the Alps since 1850: > 50 %



Actual annual loss: 220 ± 30 Gt/yr, total melt expected in the next c. 50 - 100 yr; sea level equivalent 40 cm (IPCC, 2019, 2022).



NSIDC, January 2022

Ice sheet melt

Greenland

Actual: 278 ± 11 Gt/yr (IPCC, 2019)
Earlier (~ 2000): ~ 100 Gt/yr

Remaining mass: 2,66 Mill. Gt
Maximum thickness: 3,5 km
Theoret. total melt time*: 9570 yr
Expected: n • 100 yr**
Sea level eqivalent: 7.3 m

Antarctica

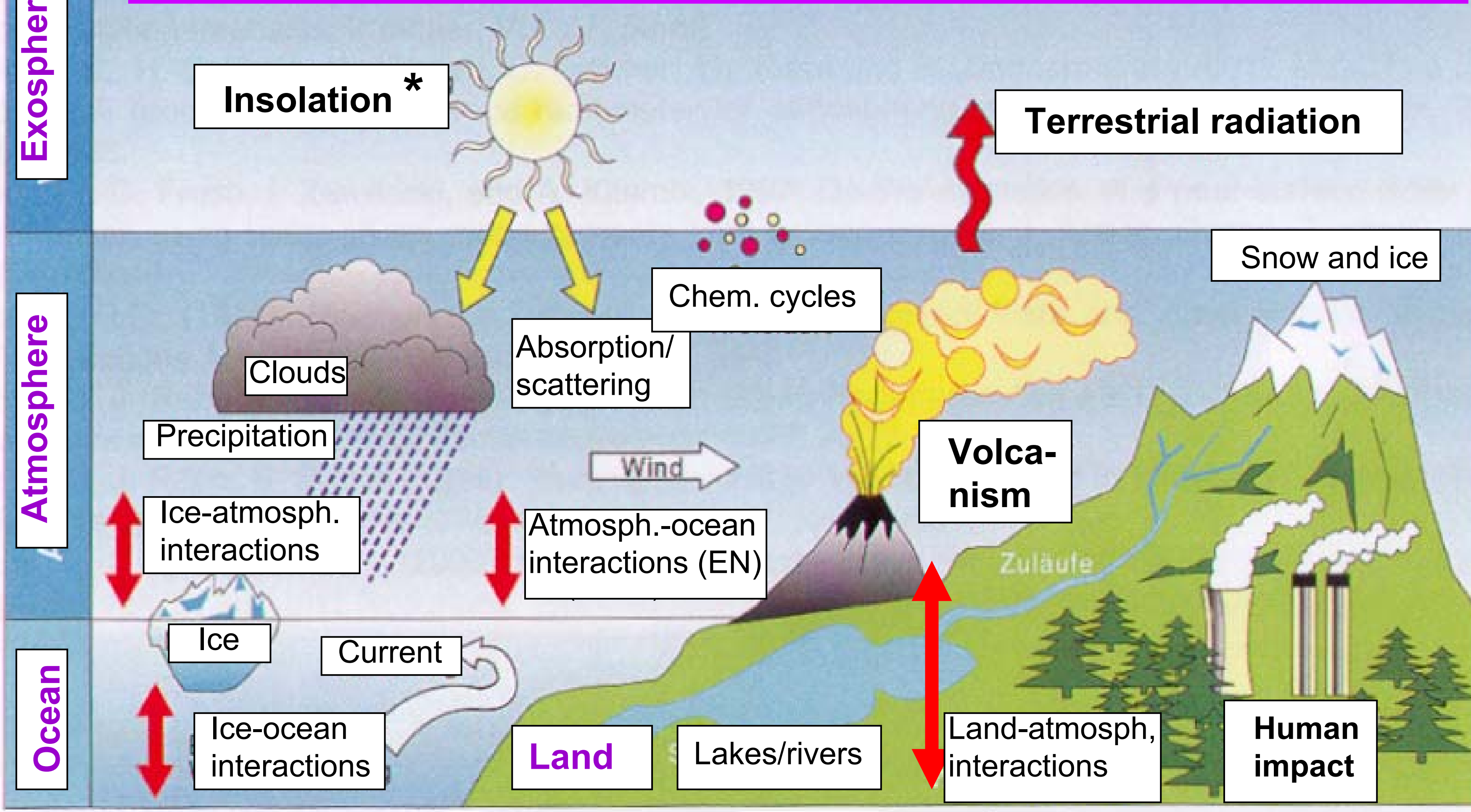
Actual: 155 ± 19 Gt/yr (IPCC, 2019)
Earlier (1979 - 1990): ~ 37 Gt/yr

Remaining mass: 22,67 Mill. Gt
Maximum thickness: 4,9 km
Theoret. total melt time*: 146 094 yr
Expected: n • 1000 yr**
Sea level equivalent: 58,3 m

* In case of constant actual conditions

** In case of major further accelleration

Climate forcing ►Climate system processes (CSP)



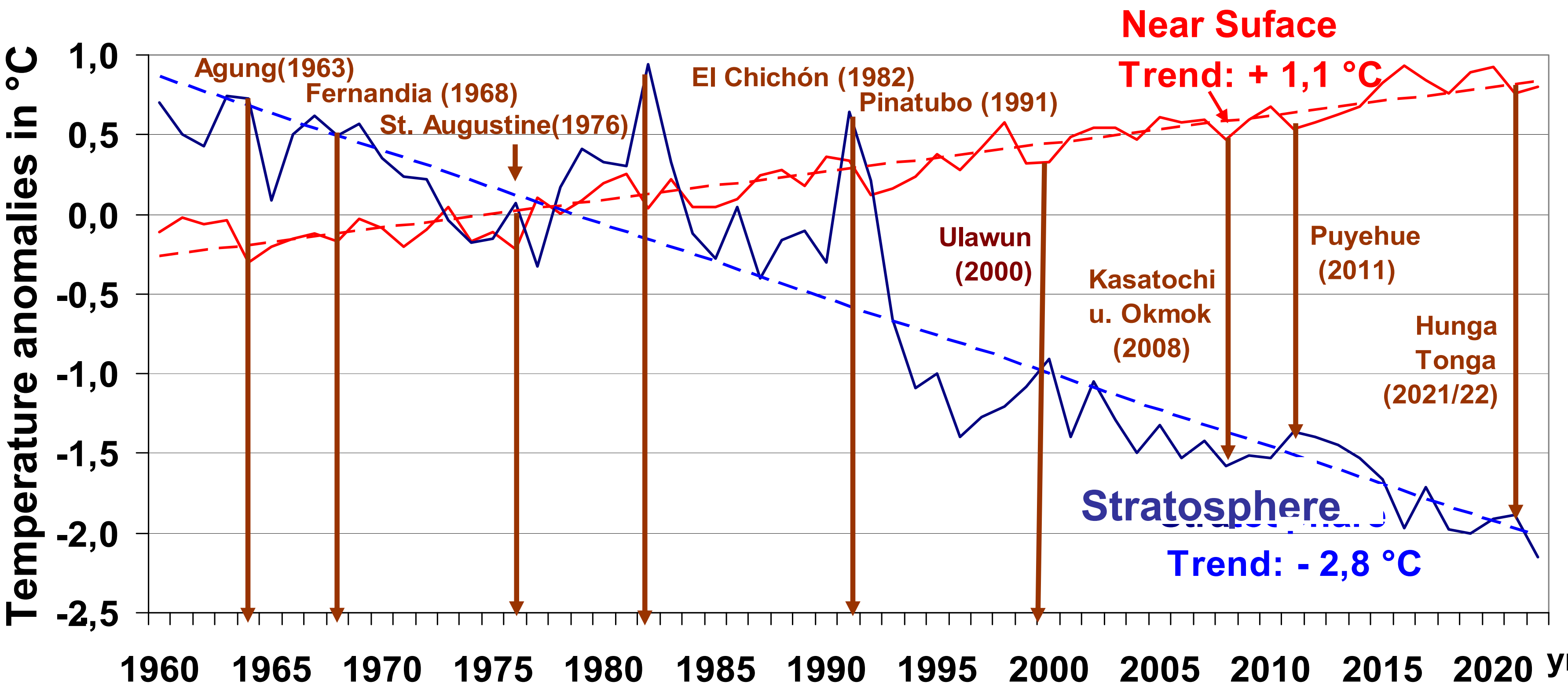
Incoming solar radiation (insolation) reachees the Earth‘s surface directly/scattered

CSP ► Internal climate system interactions: atm./ocean circulation, El Niño

► External forcing like volcanism, solar activity and human impact

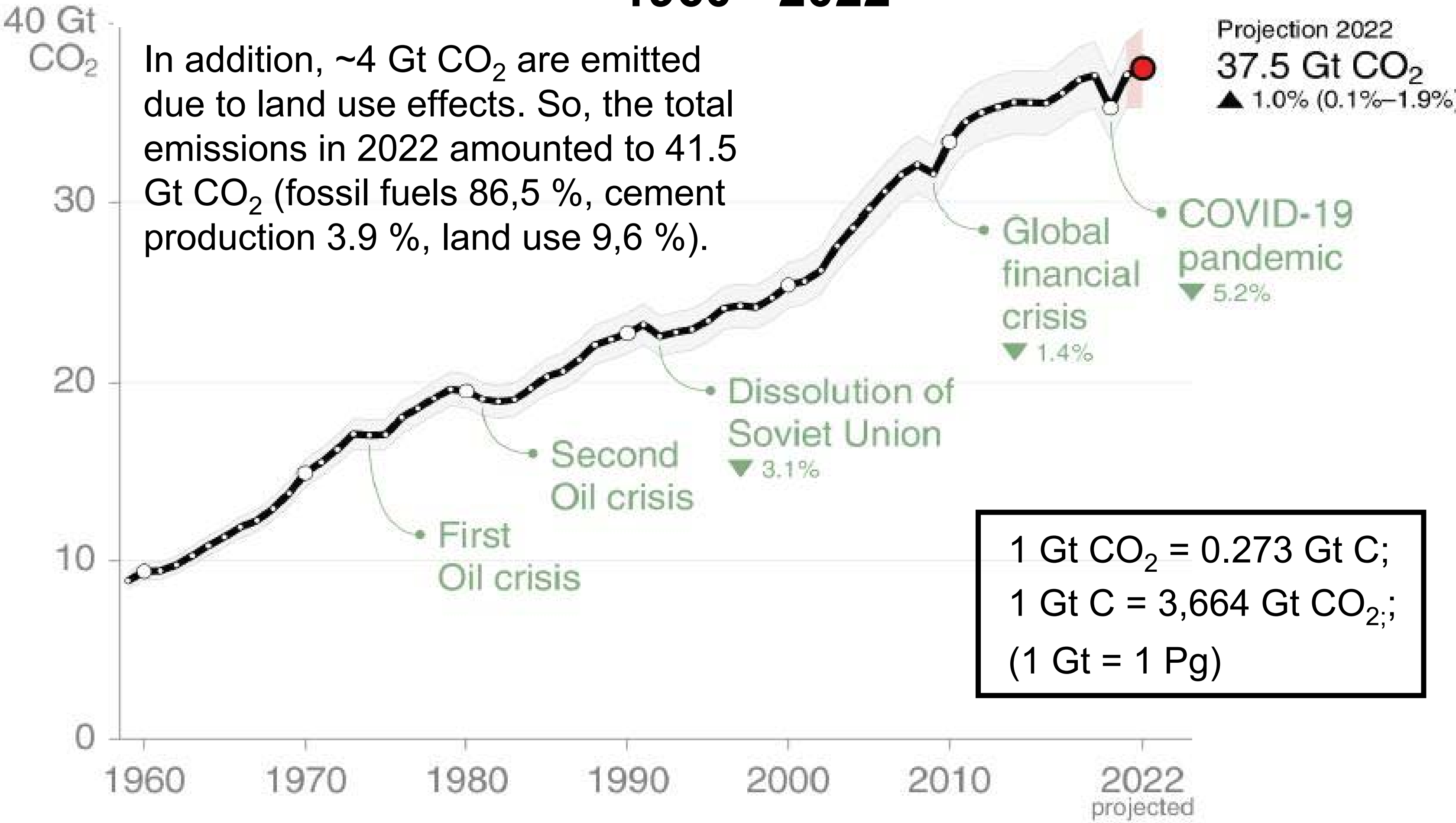
All external forcing is modified by internal interactions including feedbacks

Global mean temperature near surface (lower troposphere) and mid stratosphere (30 hPa, coresponding to 24 km of altitude), 1960 - 2022, and some important explosive volcanic eruptions



Note: Major explosive volcanic eruptions warm the stratosphere and cool the lower troposphere (near surface) for a few (1 - 3) years; in contrast, the (additional anthropogenic) „greenhouse effect“ cools the stratosphere and warms the lower troposphere in form of long-term trends. (Solar activity effects are not detectable in this context.)

Global CO_2 emissions due to fossil fuels and cement production 1960 - 2022



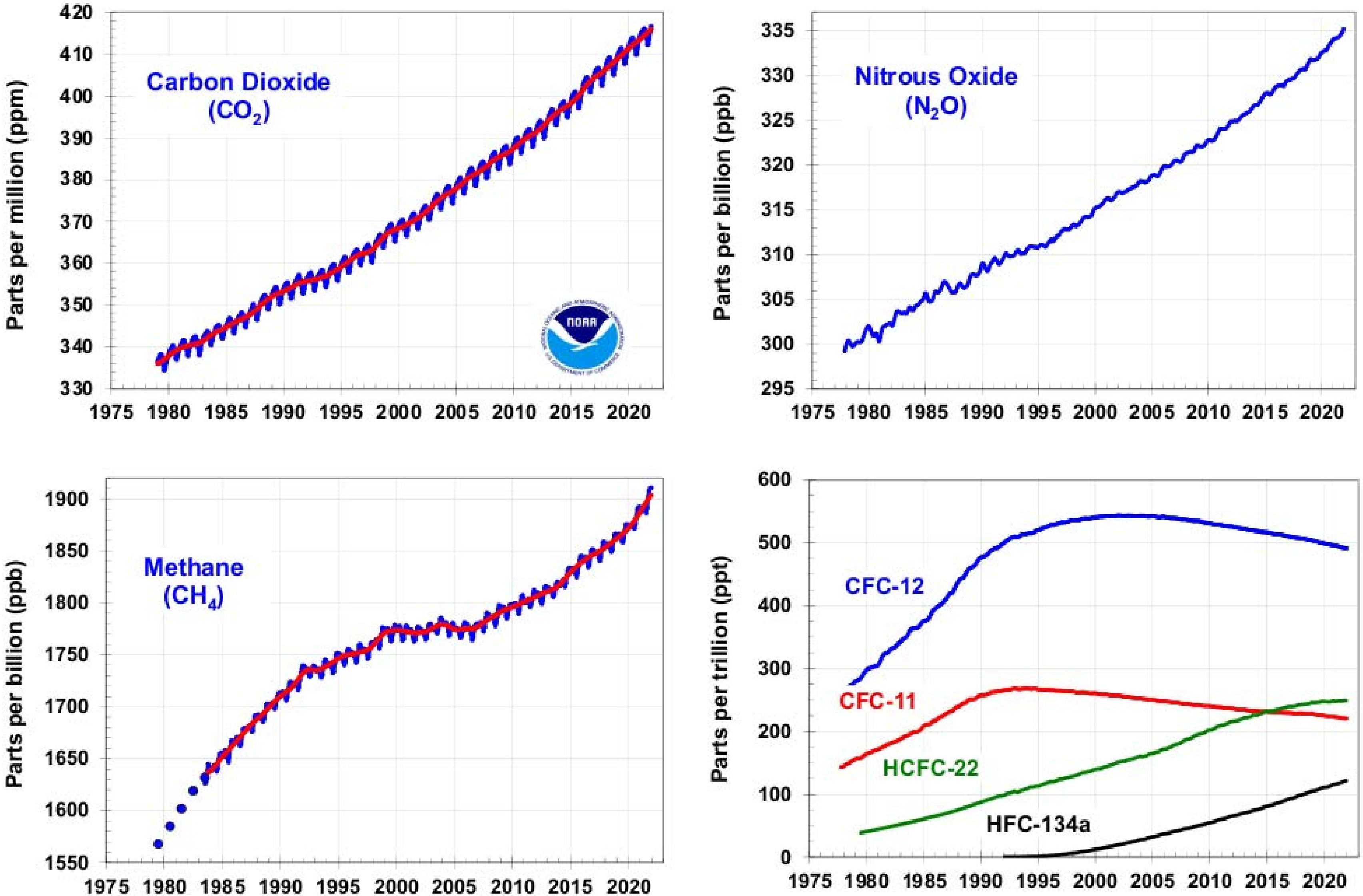
In addition, ~4 Gt CO_2 are emitted due to land use effects. So, the total emissions in 2022 amounted to 41.5 Gt CO_2 (fossil fuels 86,5 %, cement production 3.9 %, land use 9,6 %).

1 Gt CO_2 = 0.273 Gt C;
1 Gt C = 3,664 Gt $CO_{2;}$;
(1 Gt = 1 Pg)

Source: Global Carbon Project (GCP), 2022, 2023

For comparison (without land use): 1900 ►2.0, 1940 ►5.6, 1980 ►19,3 Gt CO_2

Atmospheric concentration increase 1979 - 2022 of some climate-active trace gases („greenhose gases“)



NOAA, 2023

Most important climate-active trace gases

Emissions (CO_2 2022, GCP; CH_4 and N_2O 2008 - 2017; IPCC, 2022), atmospheric concentrations (2022), preindustrial (~1750/1800) values in parantheses, and contributions to the natural and additional anthropogenic “greenhouse effect“

Trace gas	Anthrop. Emission	Atmospheric concentration	Greenh. natural	Greenh. anthrop.
Carbon dioxide, CO_2	41,5 Gt/yr	417,1*(280) ppm	26 %	55,3 %
Methane, CH_4	356 (225-283) Mt/yr[1]	1,912 (0,72) ppm	2 %	31,6 %
CFCs	small	F12: 0,49 (0) ppb	-	5,2 %
Nitrous oxide, N_2O	7.3 (4.2-11.4) Mt/yr	0,336 (0,27) ppm	4 %	7,9 %
Ozone, O_3	~0,5 Gt a^{-1} (?)	~ 34 (24) ppb **	8 %	?
Water vapour, H_2O	rel. small	2,6 (2,6) % **	60 %	(indirect)

* Mauna Loa 418,6 ppm; sources: NOAA, 2023, IPCC, 2022; natural greenhouse after Kiehl/Trenberth,1997; anthropogen based on radiative forcing 1750 - 2019 (IPCC, 2022) ** very variable in space and time

Global radiative forcing 1750-2019 (IPCC, 2022) and related temperature signals 1860-2008 (statistical assessments*)

Component	Radiative forcing	Signal	Time characteristic
Greenhouse Gases	+ 3,8 (3.2 ↔ 4.4) Wm^{-2}	0,9 - 1.3 °C	Progressive trend
Aerosols (esp. H_2SO_4)	– 0,9 (0,2 ↔ 1,6) Wm^{-2}	0,2 - 0,4 °C	Varying trends
Combined	(theor. + 2,9 Wm^{-2})	0,5 - 0,7 °C	Varying trend
Land use (albedo)	– 0,15 Wm^{-2}	< 0,1 °C	Long-term trend
Air traffic ***	+ 0,01 Wm^{-2}	Very small	Long-term trend
Volcanic eruptions	max. – (1 - 3) Wm^{-2} **	0,1 - 0,2 °C	Short-term (1- 3 years)
Solar activity	+ 0,05 (0 - 0,1) Wm^{-2}	0,1 - 0,2 °C	Fluktuations
ENSO (El Niño) ****	–	0,2 - 0,3 °C	Short-term (months)

* Global mean temperature response near surface, neural network analysis (Schönwiese et al., 2010) the combined signal 1850 - 2020 amounts actually to 1.2 °C (IPCC, 2021)

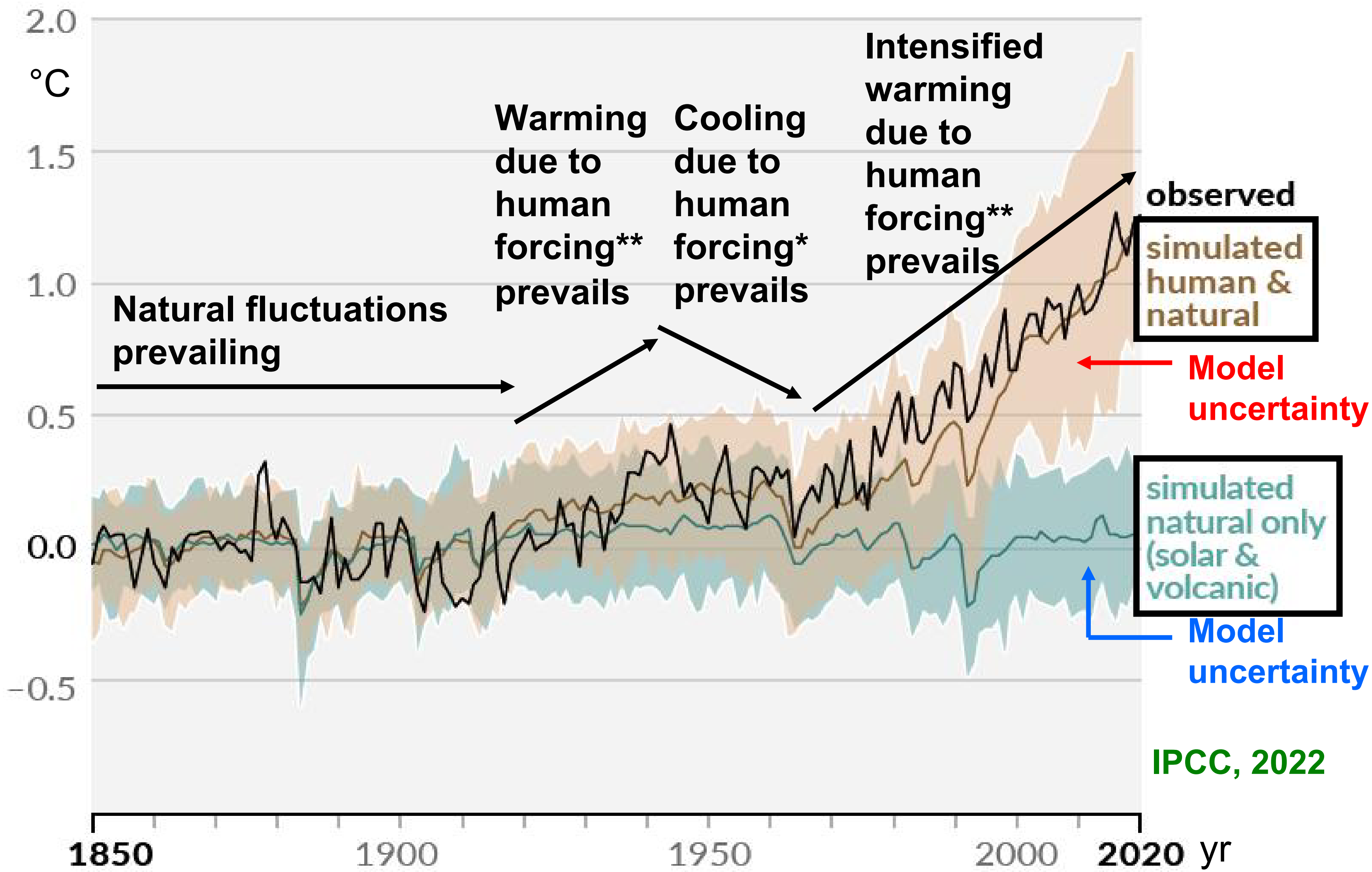
** Pinatubo eruption forcing: 1991: 2,4 Wm^{-2}, 1992: 3,2 Wm^{-2}, 1993: 0,9 Wm^{-2} (McCormick et al., 1995)

*** Due to contrails and a variety of emitted gases

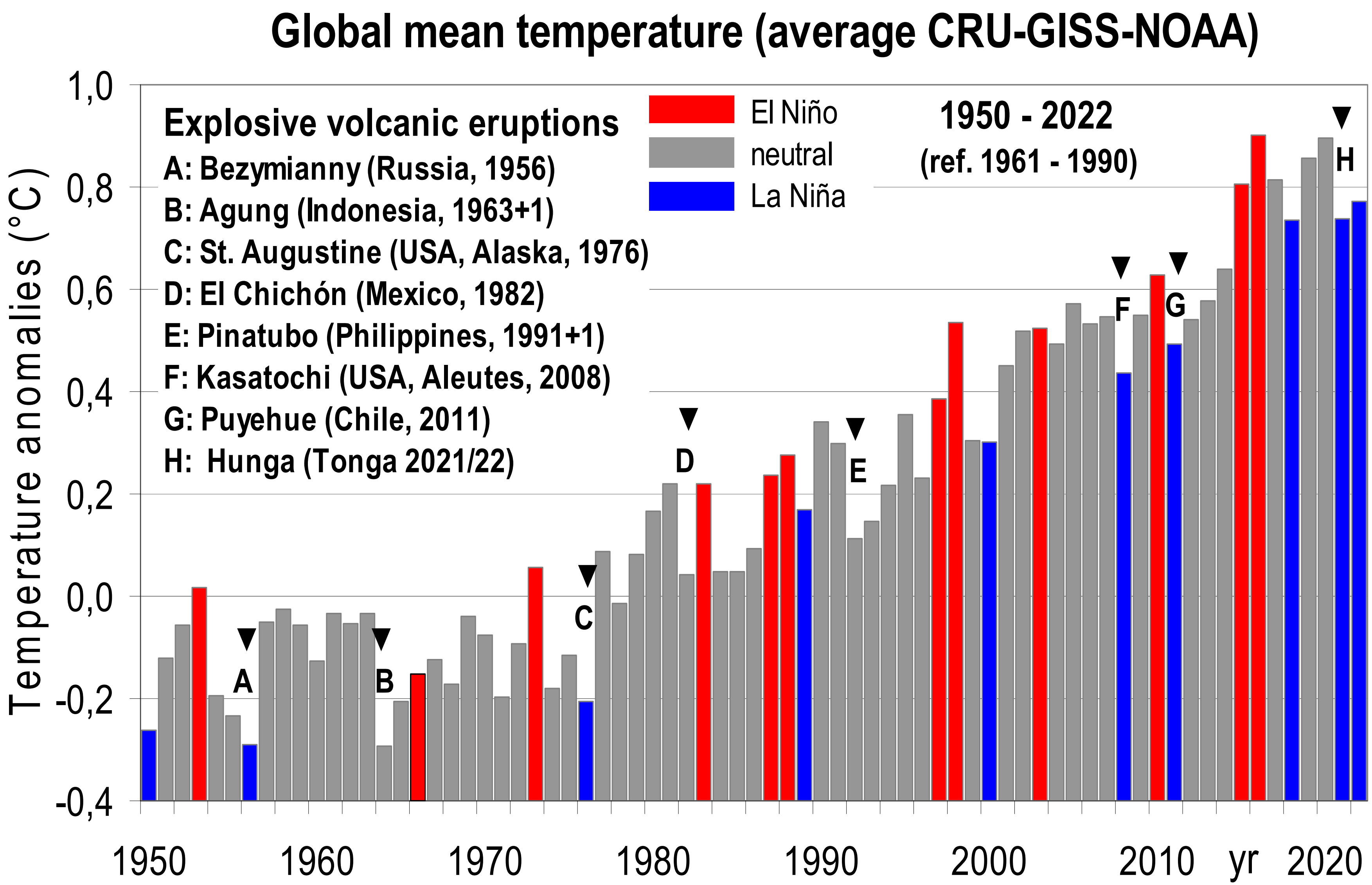
**** El Niño / La Niña oscillation, internal interaction, radiative forcing not attributable

Radiative forcing assessments do not include feedbacks. So, for realistic climate simulations, sophisticated (atmosphere-ocean) models are needed.

Global annual mean temperature (near surface) 1850 - 2020



* Aerosols, mainly H_2SO_4; ** Greenhouse gases etc.



WMO, 2015; supplemented and updated 2023

A Note on future projections (IPCC, 2022)

- Based on the new scenarios (shared socio-economic pathways, SSP) and the CMIP6 (Coupled model intercomparison project), on a global average a temperature rise of 2.7 - 4.4 °C (incl. uncertainties 2.1 - 5.7 °C, without GHG removal from the atmosphere) until 2100 is projected (rel. to 1850-1900). However, note that there are pronounced regional and seasonal peculiarities.
- Under the same conditions a global mean sea level rise of 56 - 77 cm (44 - 101 cm) is projected. However, in case of ice sheet instabilities (especially in Antarctica), 1.5 - 2 m are possible (until 2100).
- Precipitation rates will change significantly, decrease in subtropics and, increase in subpolar regions. In moderate latitudes a winter increase and a summer decrease are expected.
- More important: Similar as in the past, also in the future more frequent and probably also more intense extreme events may occur like heat waves (including forest and settlement fires), more flooding on the one hand and more dryness on the other, more tropical storms etc.
- **There is urgent need for action in order to avoid too heavy climate change which may be seriously adverse to human welfare.**


Thank you so much
for your attention