Modern Climate Change and potential implications for river cruises and inland water transportation

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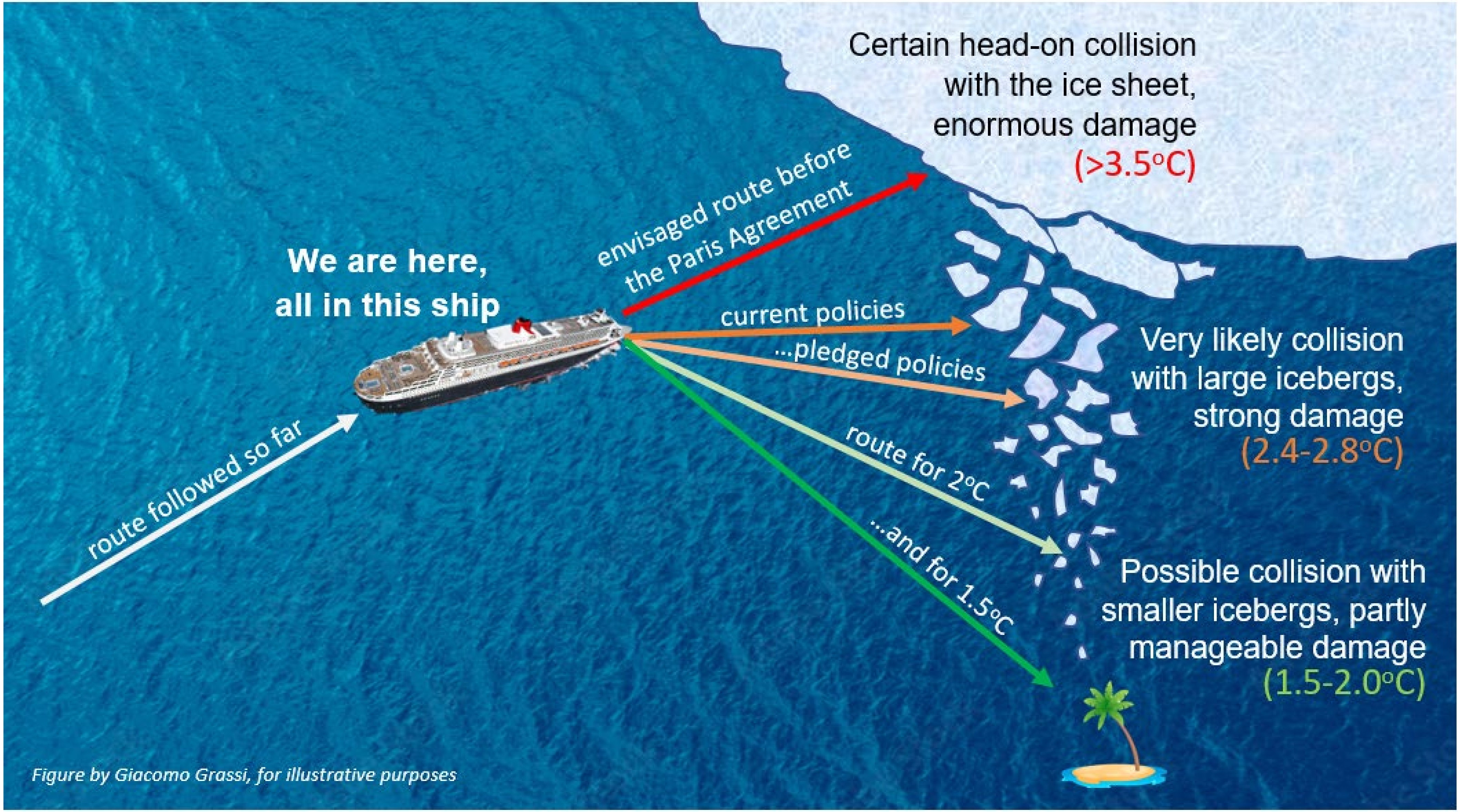
26. Internationale Donauschifffahrts- & Tourismuskonferenz| Melk/Donau, 29 Nov 2022

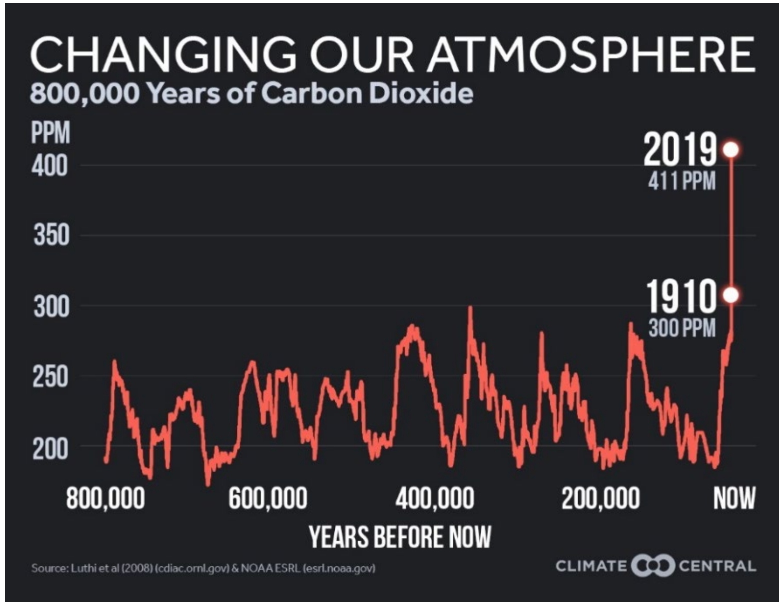
Where do we stand today and where should we head?



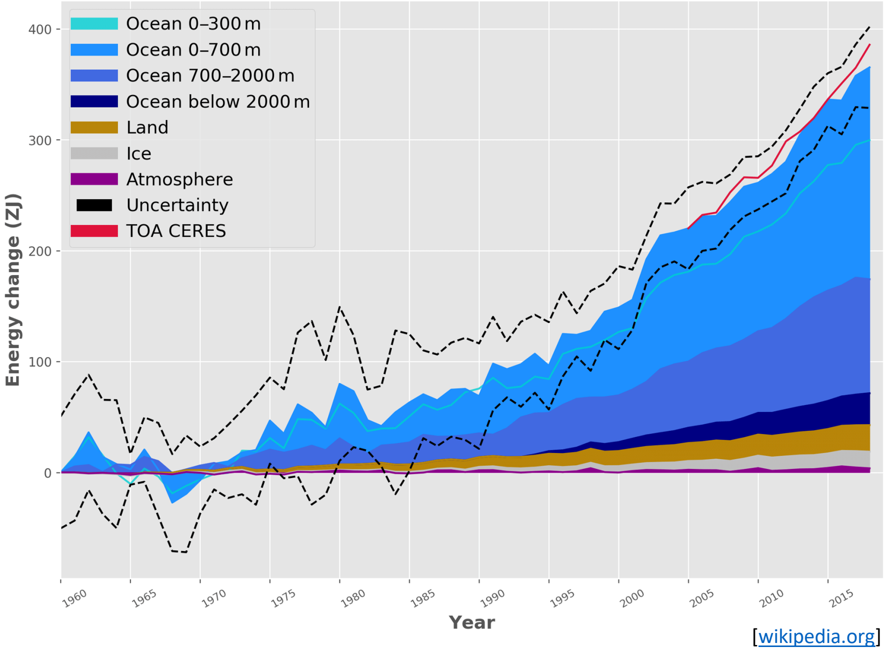
numbers indicate end of 21st century global warming above pre-industrial level; uncertainties are not shown [© Giacomo Grassi]

Welcome to the Anthropocene

Atmospheric CO_2 concentration



The Earth heat inventory: where does the extra energy go?



[wikipedia.org]

90% Oceans

10% land, atmosphere, ice melt

- The burning of fossil fuels (human activities) leads to enormous greenhouse gas emissions (carbon dioxide (CO_2), methane, nitrous oxide) of **59 $GtCO_2e$** * (64% of it CO_2) in 2022, increasing atmospheric concentrations
- CO_2 concentrations rose by 50% since 1750 and are now at the highest level since at least 2 million of years
- This enhances the natural greenhouse effect and traps heat at a rate of $0.47\ W/m^2$ in the earth system (1971-2018)

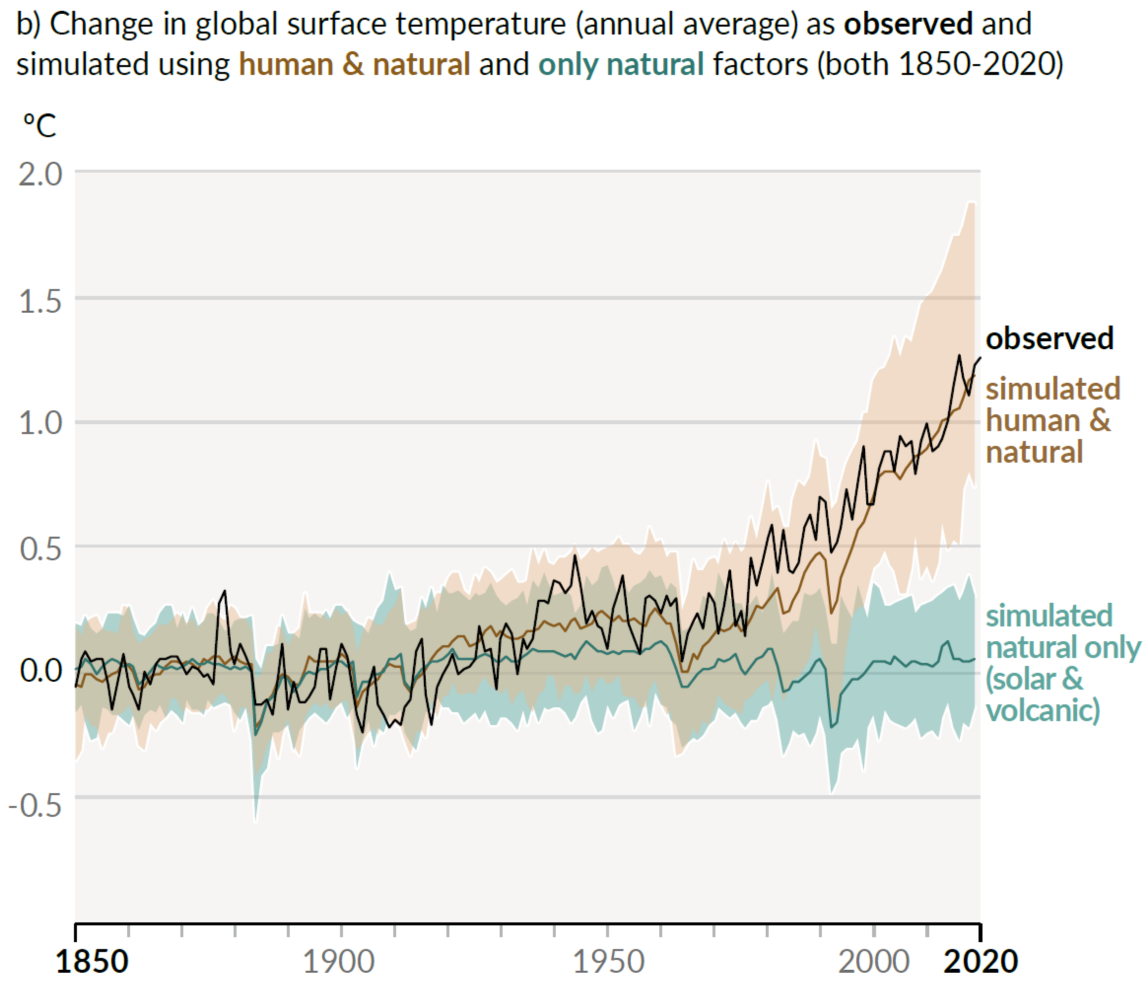
The heat absorbed by the oceans in **2021** due to human activities was equivalent to **seven Hiroshima atomic bombs** detonating each second (14 zettajoules (14×10^{21}J)).
Since 1960: **5.5 billion hiroshima atomic bombs of extra heat** (approx. 350 zettajoules)

Dr. Marc Olefs

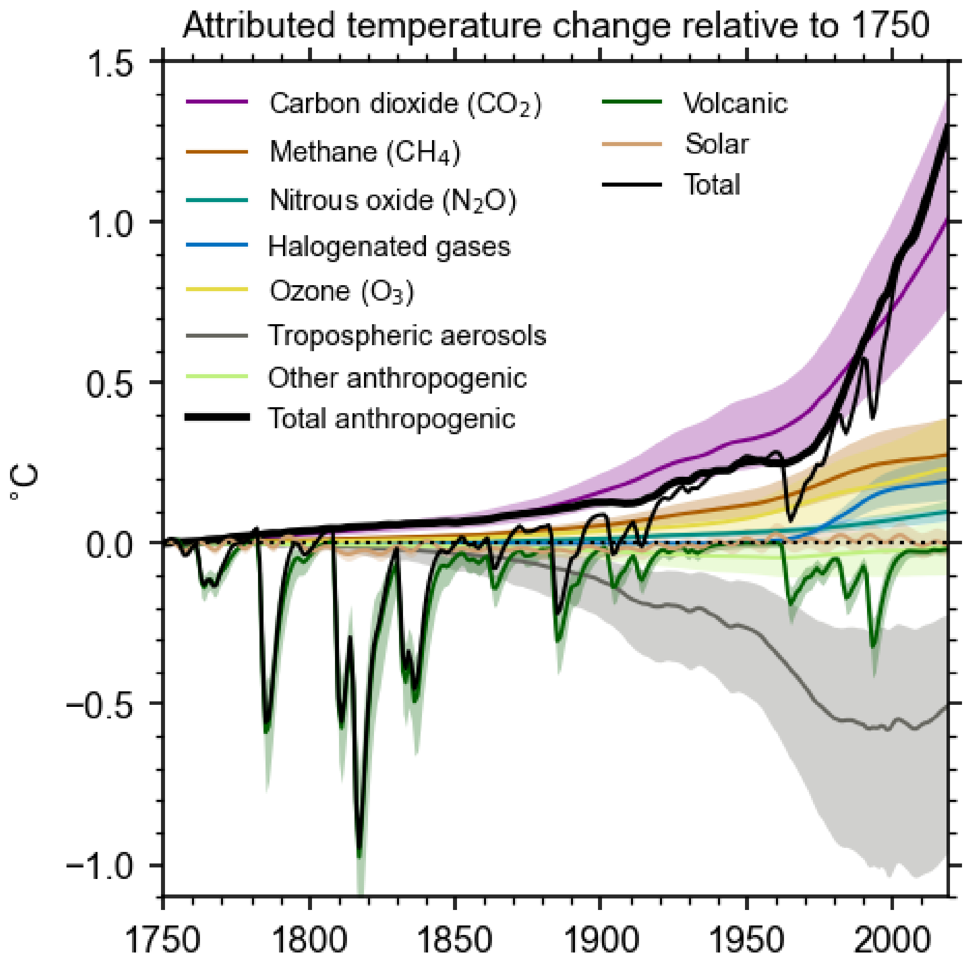
*gigatons (10^9 *tons*) of CO_2 equivalent

13.12.2022

Humans are causing 100% of the modern warming!



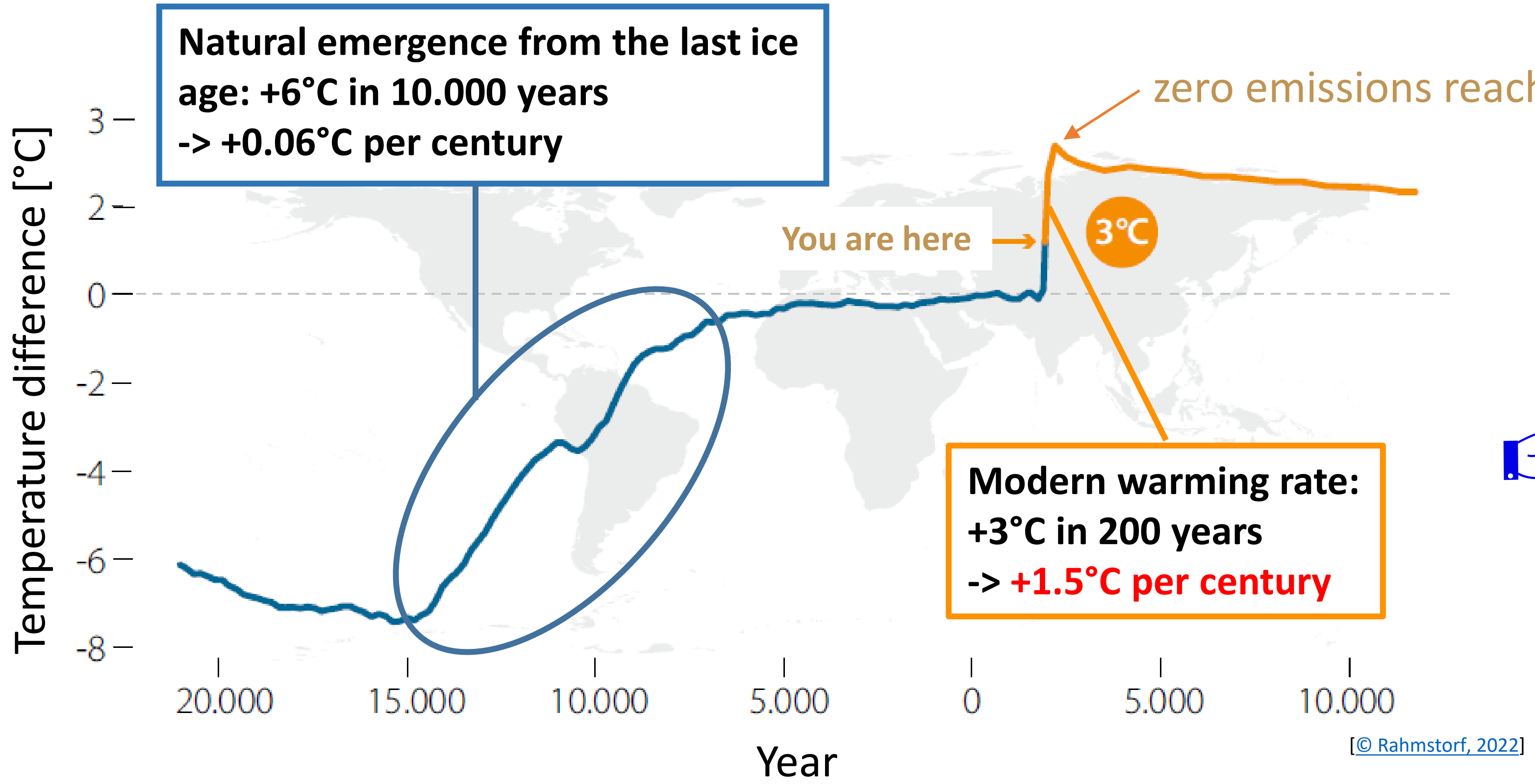
[IPCC AR6, SPM]



[IPCC AR6, Ch.7]

☞ **Observed global temperature evolution since pre-industrial times can only be explained by including anthropogenic greenhouse gas emissions as climate drivers.**

Why should I care and the legacy for the next generations

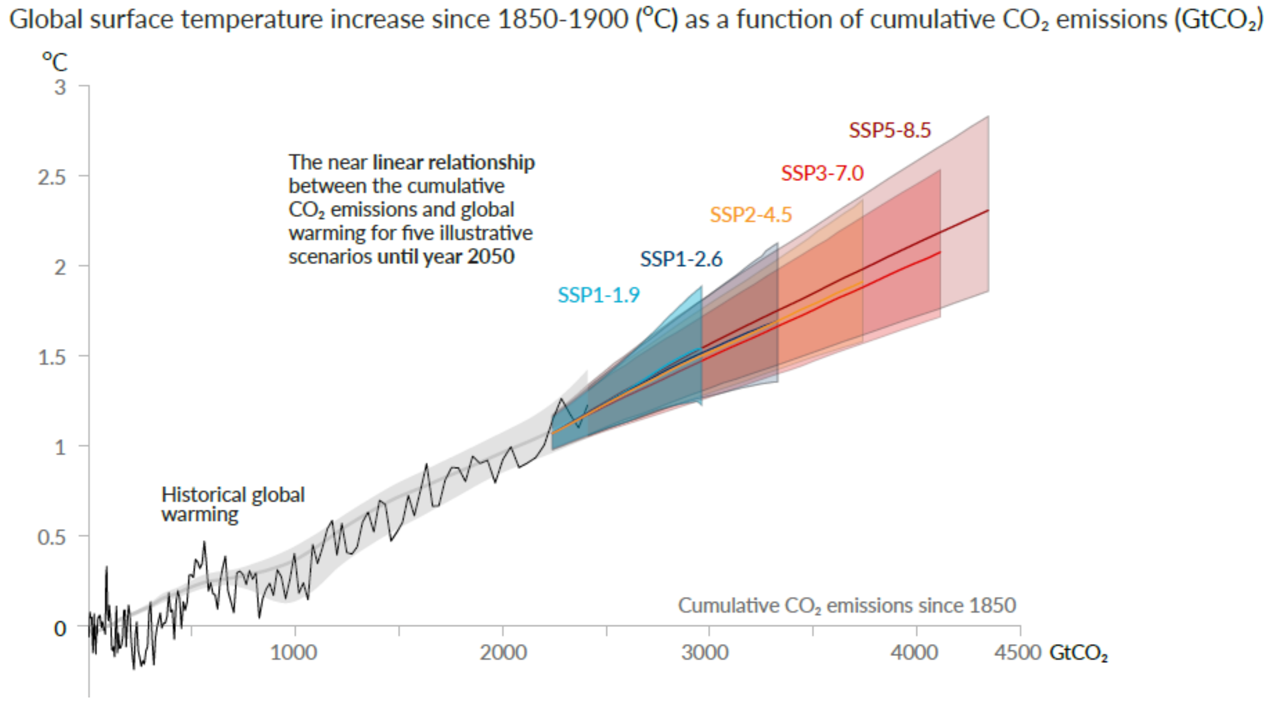


Policy decisions made in the next few years to decades will have profound impacts on global climate, ecosystems and human societies — not just for this century, but for the next ten millennia and beyond.

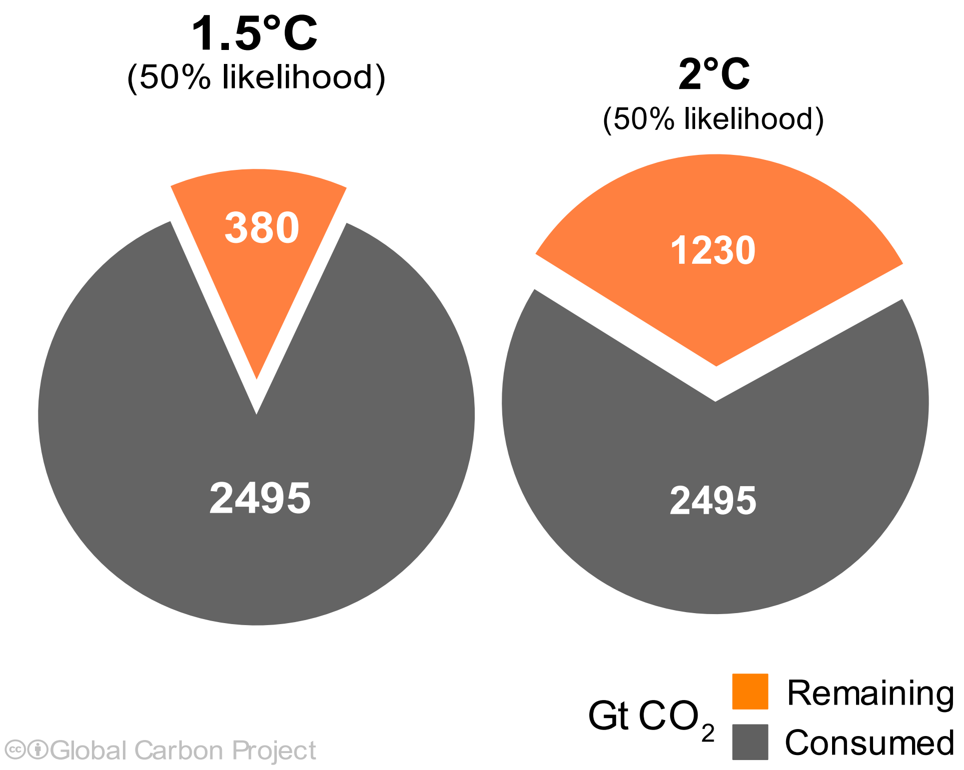
- Current global climate mitigation measures (end of 2022) lead to a global warming of +3°C until 2100
- Modern anthropogenic warming is 25 times faster than natural warming rates in the past (no time to adapt)
- Returning to a pre-industrial temperature level will take around 100.000 years (long lifetime CO_2, heat storage oceans)
- Human-induced climate change is irreversible (except we achieve to remove giant amounts of CO_2 from atmosphere)
- **The severity of all impacts (e.g. extreme weather events) stay at a level once reached even if emissions cease!**

Every ton of CO2 counts

The **cumulative sum of CO2** emissions defines the warming. Therefore, only a **restricted CO2 budget** can still be emitted to limit warming and thus the severity of the impacts on human and natural systems.

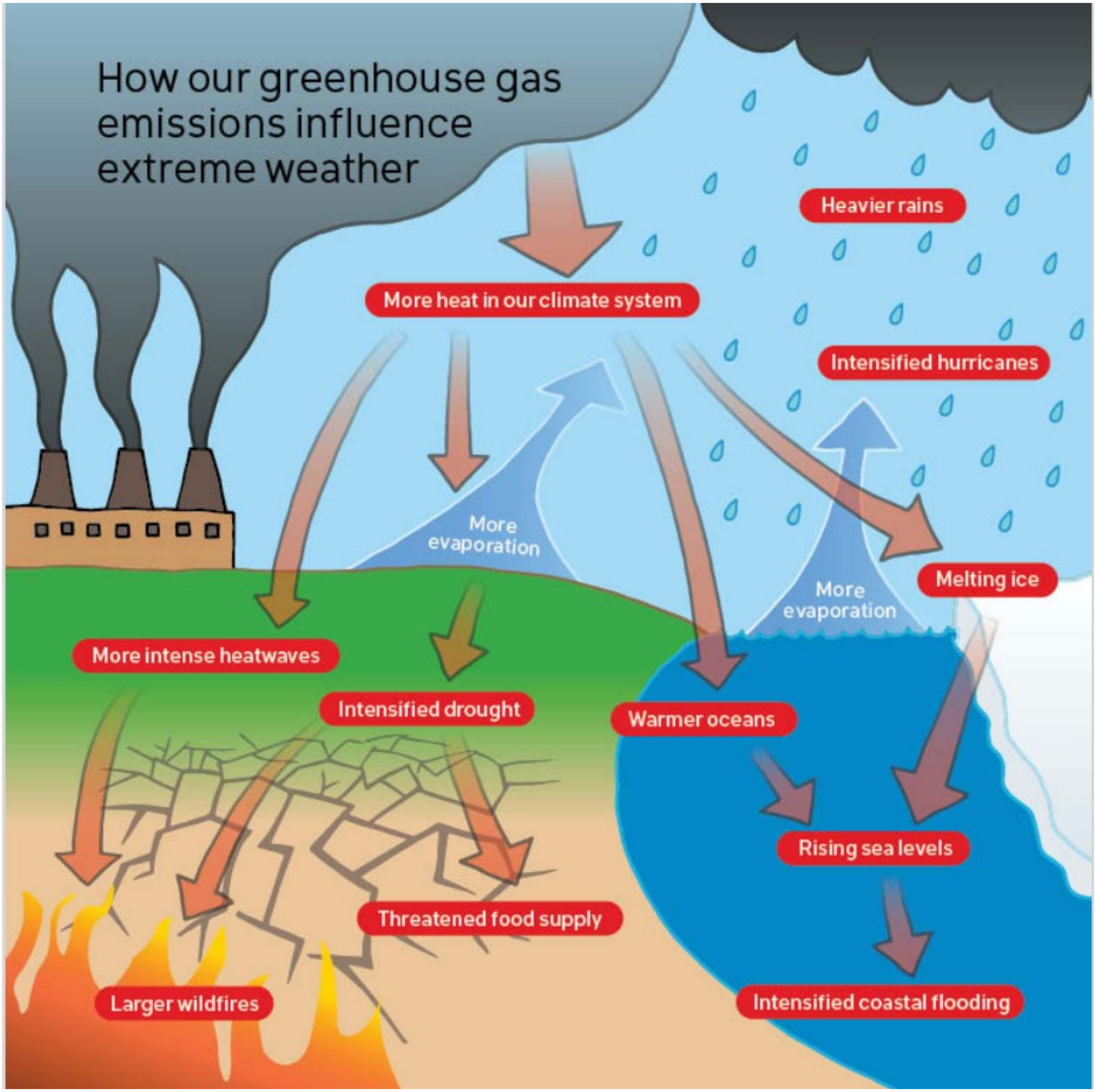


[IPCC AR6 SPM]



👉 **The remaining carbon budget to limit global warming to 1.5°C and 2°C is 380 GtCO2 and 1230 GtCO2, respectively, equivalent to 9 and 30 years from 2023.**
Net-zero CO2 emissions are required to stabilize temperatures and related impacts.

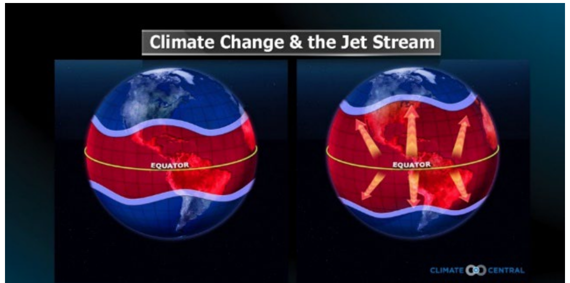
Global impacts of climate change



[crankyuncle.com]

More heat in the climate systems means…

- **increasing weather extremes**: intensified droughts and heatwaves, heavier rains, more intense thunderstorms and hurricanes
- melting ice and warming oceans lead to **sea level rise**
- **Intensified water cycle** leads to **changes in river flow**
- **atmospheric circulation** is changing too (amplifies effects)
- compound risks (examples):
    - sea level rise and more intense hurricanes increase the **storm surge hazard**
    - more intense heatwaves and droughts increase **fire weather conditions**
    - drought and heat increases **forest disturbances** (e.g. bark beetle)

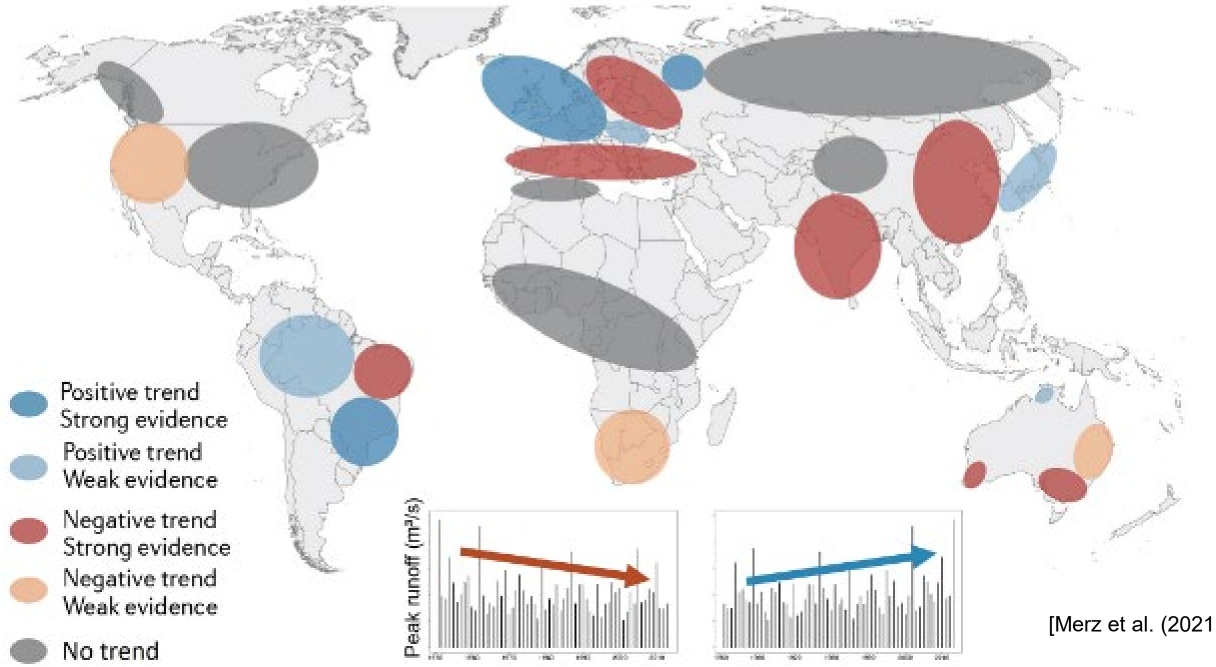


poleward shift due to Hadley cell expansion

Climate change and river flows: floodings

Is the hazard of river floods increasing with climate change?

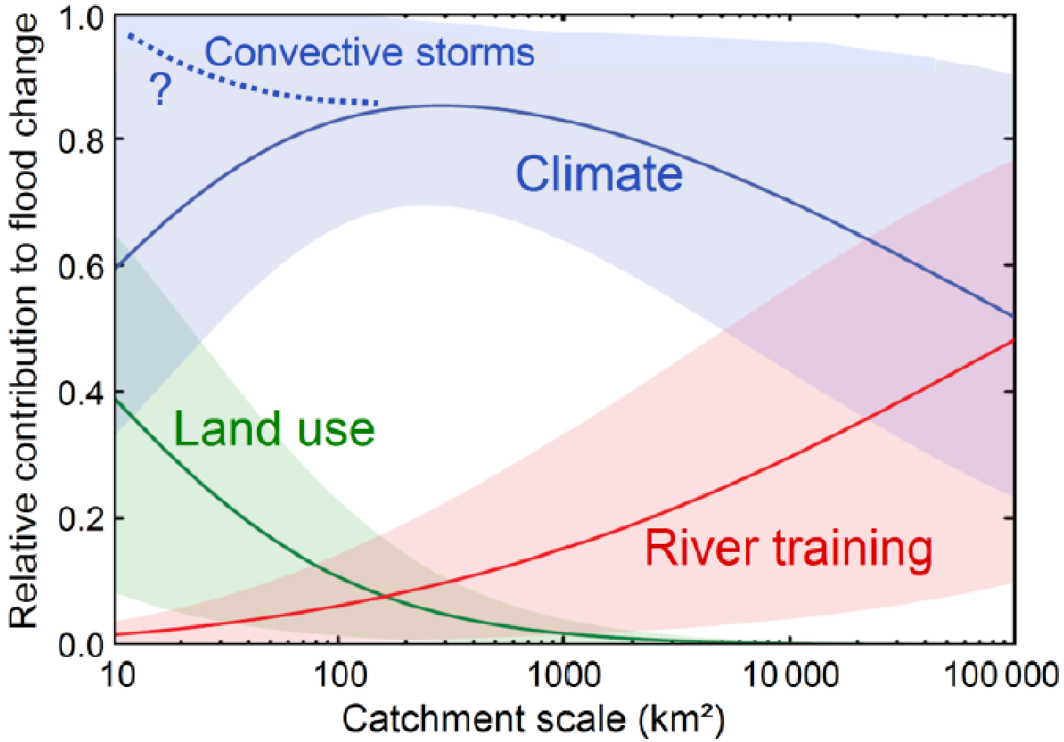
Observed flood trends 1960–2010



[Merz et al. (2021)]

Globally, there are both increasing and decreasing trends of flood hazards.

Contributions to river flood hazards



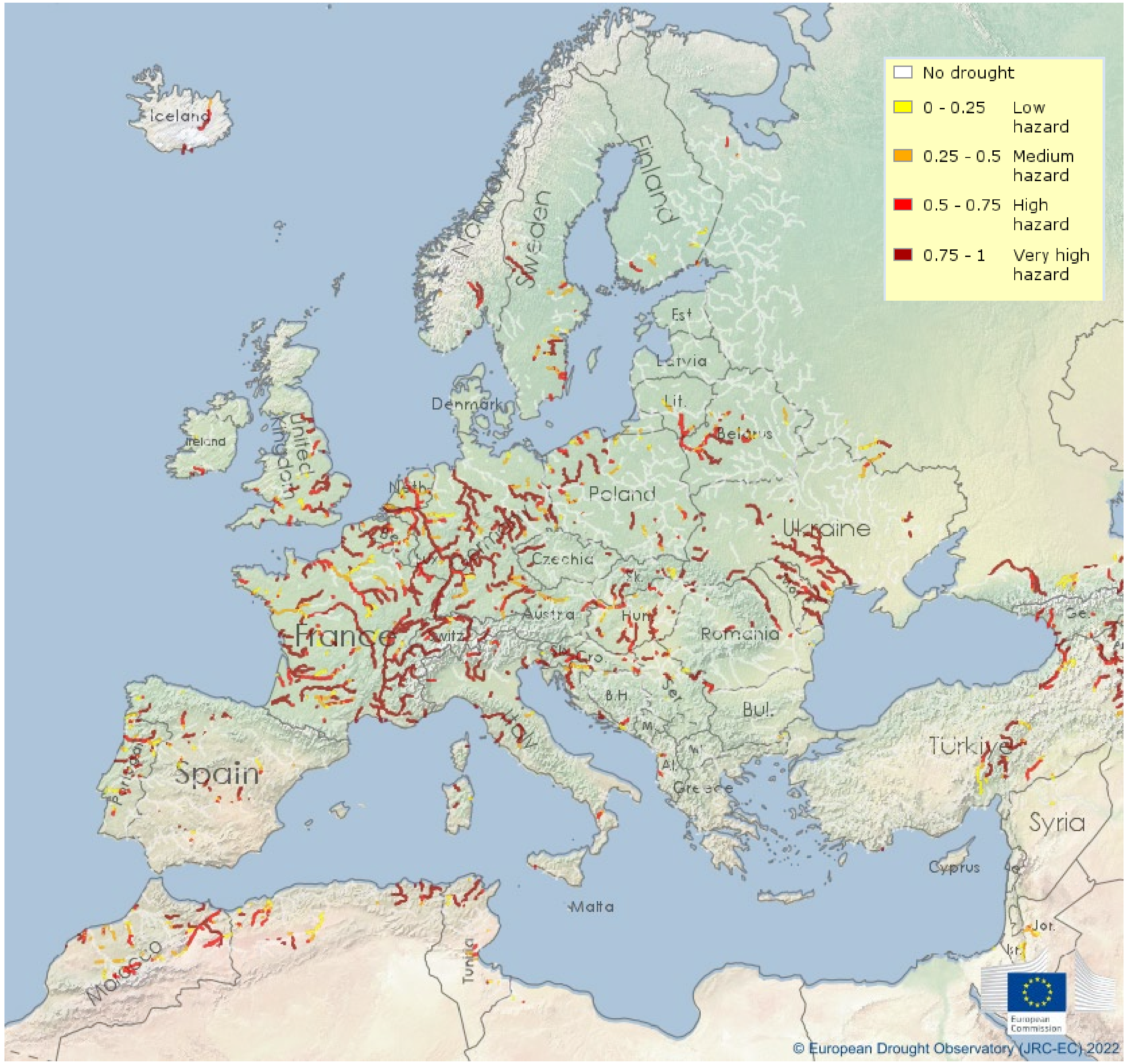
Synthesis of the relative contributions of land use change, river training and climate change to flood hazard changes as a function of catchment scale in Europe [Blöschl, 2022].

☞ Climate change is relevant at all catchment scales but never as the only factor!

Land-use changes: e.g. deforestation, urbanization, soil compaction by agriculture
River training: levees, dams, hydraulic interventions and structures

European drought 2022 – a singular event?

Low flow index 10-20 Aug 2022 (European drought observatory)



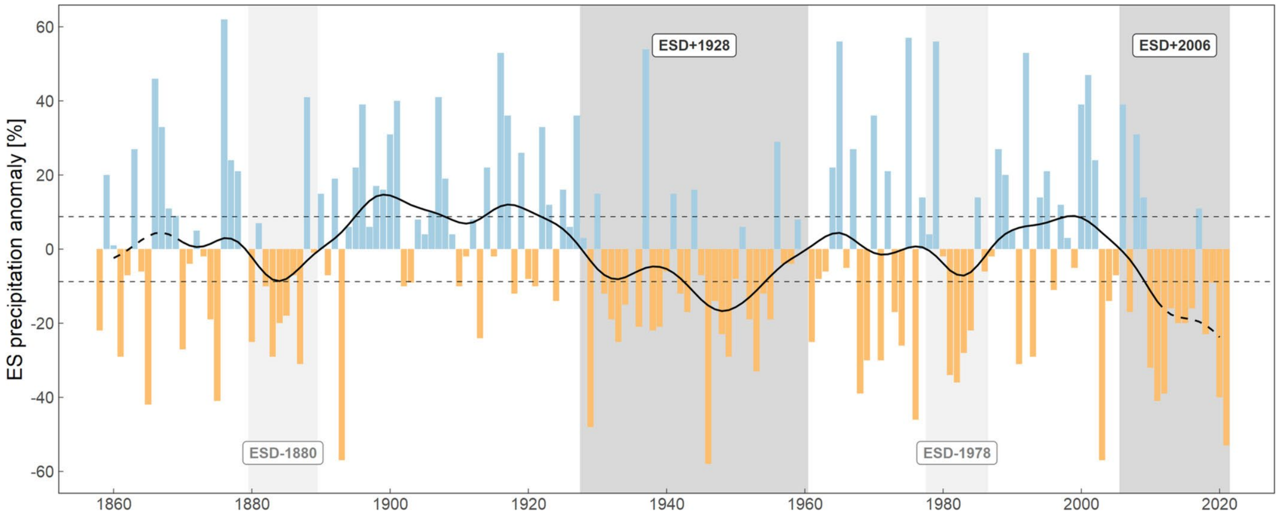
Reason for low river flows:
wide and persistent **lack of precipitation since early spring** combined with a sequence of **heatwaves** from May 2022 on. Dry winter conditions with scarce snow accumulation in the Alps aggravated the situation in some river basins (e.g. Rhine)

[twitter.com @histories_arch]

A warning signal: "hunger stone" from before 1616 at the Elbe river, used to mark desperately low river levels that would forecast famines. This stone became visible in 2022 due to low water levels.

Early spring droughts in Europe and its causes

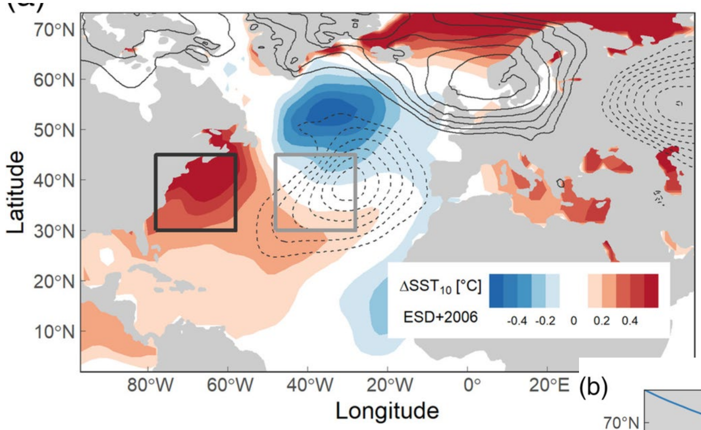
Early spring precipitation anomaly (Greater Alpine Region) 1860-2020



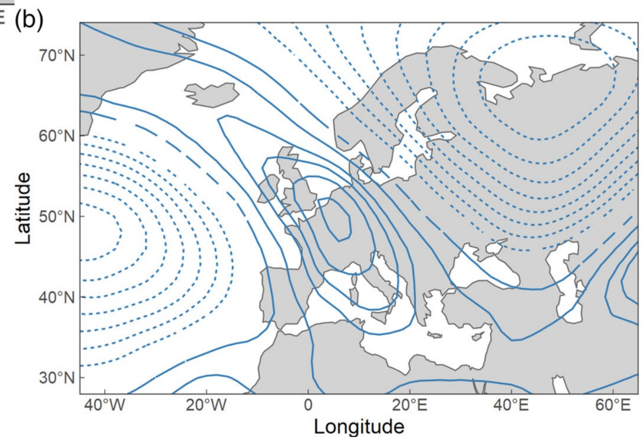
[Haslinger and Mayer, 2022]

In Europe, early springs (March, April) were particularly dry during 1926–1950 and most recently, from 2005–2022

Sea surface temperature anomalies



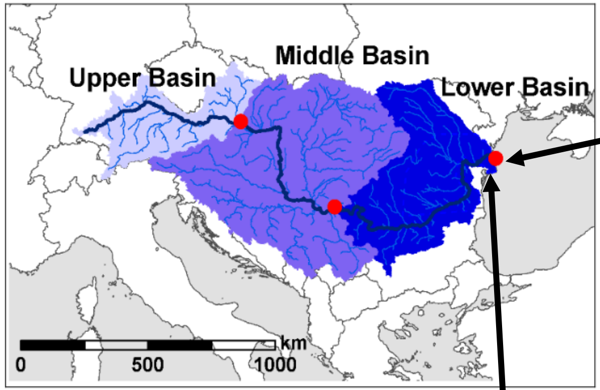
High-pressure over NW Europe

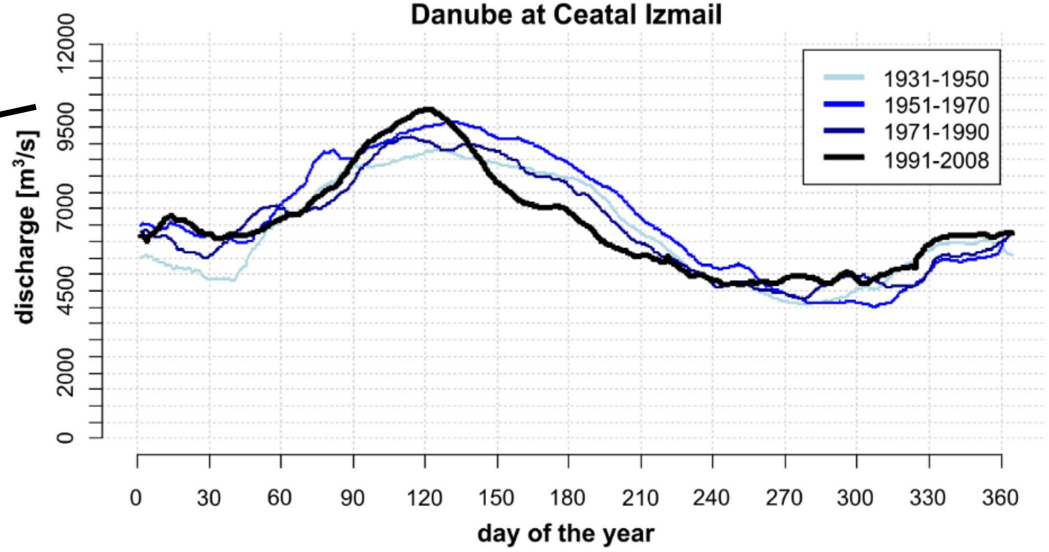


Natural variability in the North Atlantic ocean amplified by man-made warming (slowdown of the gulf stream) induces a distinct sea surface temperature pattern over the North Atlantic leading to persistent high-pressure over NW Europe, blocking the moisture supply from the Atlantic.
Actual climate models are still not able to reproduce this process very well.

Changes of runoff at the Danube

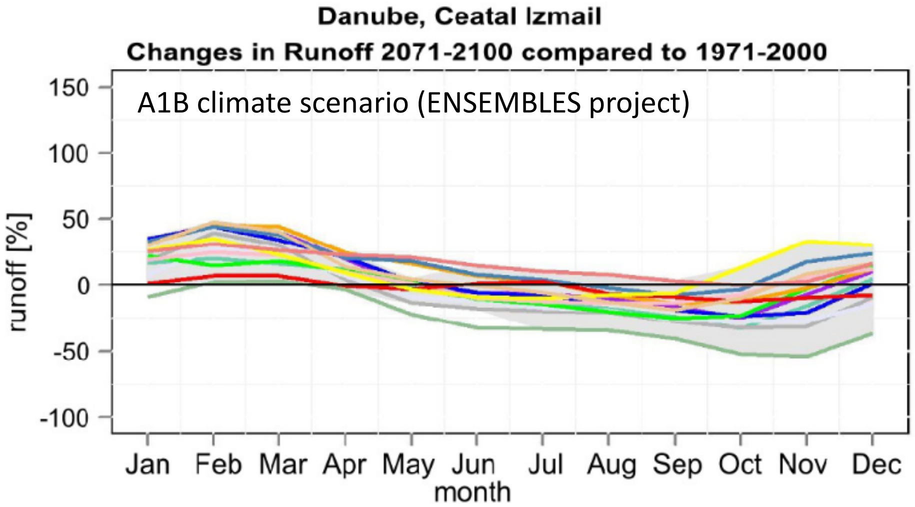
The Danube River catchment





- spring floods tend to come earlier and more distinctly
- summer runoff is reduced and the low flows in autumn are less distinct

Future changes in the long-term seasonal runoff

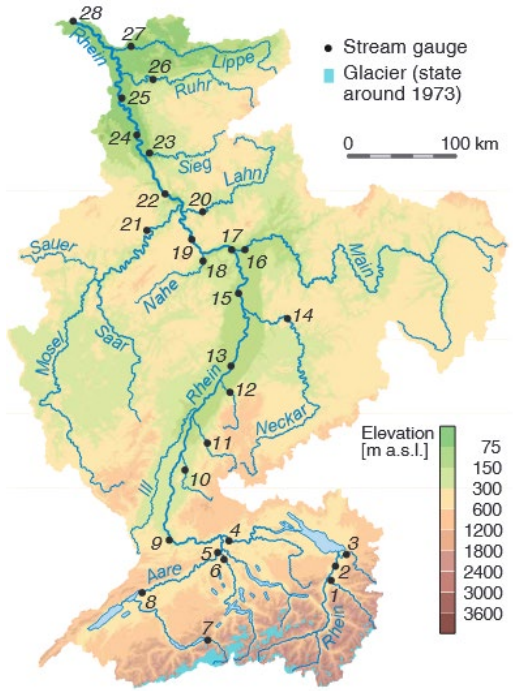


Runoff change (%)	Near Future (2050)	Far Future (2085)
Winter	9	24
Spring	4	12
Summer	-9	-11
Autumn	-10	-12

[Stagl and Hattermann, 2015]

- further decrease in summer
- decrease in autumn (middle, lower basin)
- increase in winter and early spring

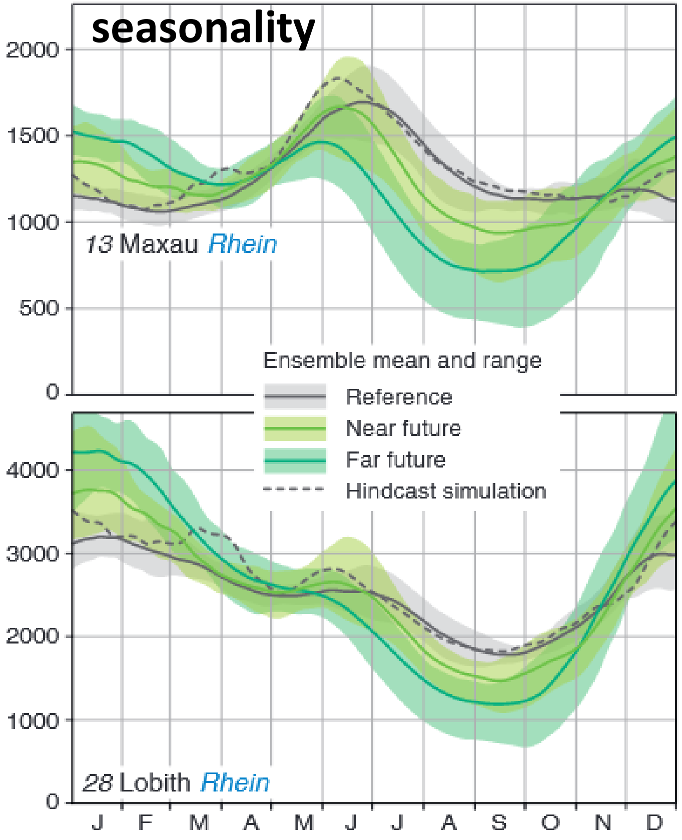
Future changes of runoff at the river Rhine



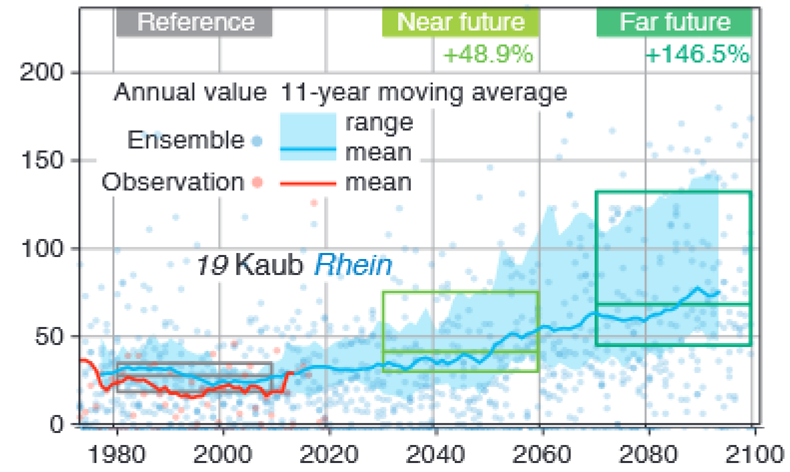
Rhine river basin

[Stahl et al., 2022]

Future changes in runoff
(worst-case climate scenario - RCP8.5)



[Stahl et al., 2022]



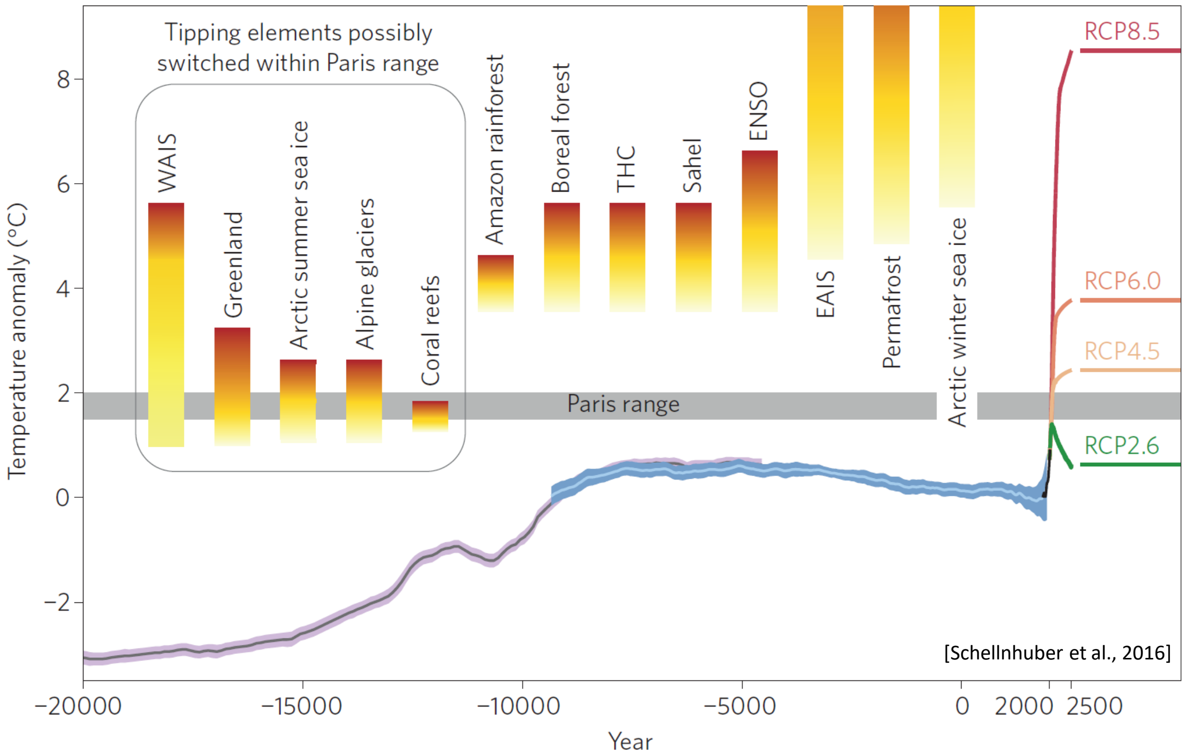
Based on the currently applicable thresholds, restrictions to navigation could prevail, on average, for more than two months per year at the end of the century

streamflow variability and low flow extremes will increase:
no more buffering ice melt at the end of century and less summer precipitation

Mean annual flow: -10% (Basel) to +1% (Lobith)
Low flows (annual 7-day minima): -10% to -20% in the near/far future
High Flows (annual 1-day maxima): +10% to +25% in the near/far future

Why +1.5°C? (and tipping points)

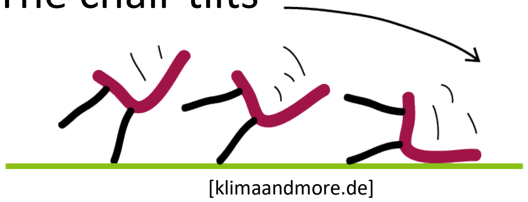
Tipping points - The *vital parts* of the climate system



☞ The Paris Climate Agreement as a „fire protecting wall" to avoid non tolerable risks for humanity. Well below 2°C of warming most tipping points will not be triggered.

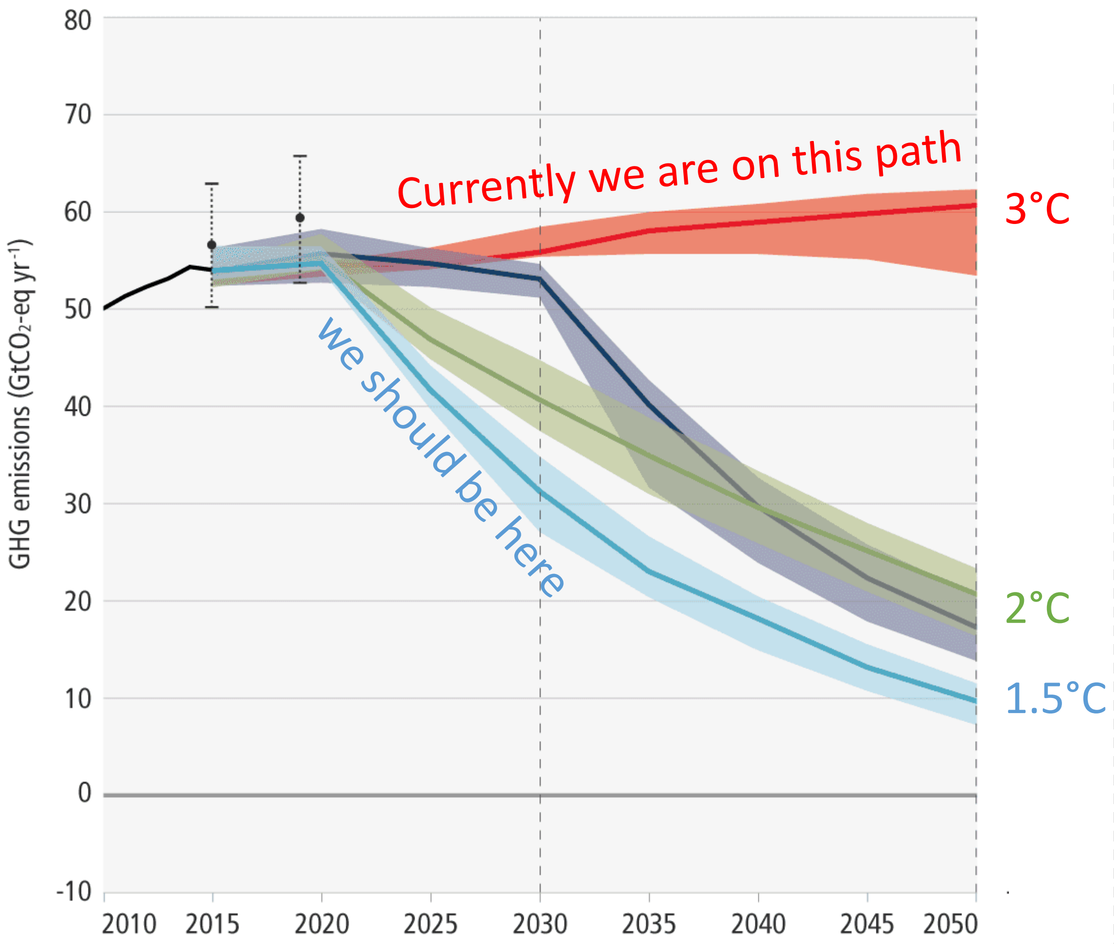
Tipping points are…
…abrupt…
…rapid…
…not stoppable…
…mostly irreversible…
…strong…
…changes in the climate system

The chair tilts



Where do we stand today and where should we head?

Global greenhouse gas (GHG) emissions (2010-2050)



[IPCC AR6 WGIII, Fig. SPM.4]

end of 21st century warming
Compared to 1850-1900
(pre-industrial)

- Global annual anthropogenic GHG emissions in 2022 (projected): **59 $GtCO_2e$** * (64% of it CO_2)
- GHG emissions **need to peak between 2020 and latest 2025** to limit warming to 1.5°C and 2°C
- **deep emissions cuts needed** thereafter (-30% to -45% until 2030 and 65-85% until 2050)
- **Net-zero global CO2 emissions** are needed **until 2050** (1.5°C) and 2070 (2°C), respectively
- **emissions gap**: planned national contributions to global emissions reductions until 2030 are still 12 to 20 $GtCo_2e$* too low (1.5°C and 2°C, repectively)

*gigatons of CO_2 equivalent; [UN emissions gap report 2022]

Take home points

- **Catastrophe is closer than you think:** Impacts in a +3°C world (current path) would be considerably more dramatic than just three times the current ones (already now +1.1°C) (many processes in the climate system are non-linear, remember exponential growth from COVID-19!)

- **Immediate and drastic fossil fuel emission cuts** are needed in order to avoid really dangerous climate change

- **River flow regimes will change considerably** in future, with high uncertainty in spring (early spring droughts)

- Tourism (including river cruising industry)…

    - …is both **affected by** the impacts of climate change **and contributes** substantially to it by greenhouse gas emissions (burning of fossil fuels)

    - …has a **vested interest to proactively support sustainability and climate mitigation** in order to preserve its treasure – the natural environment – for future tourism generations

    - …**needs to adapt** in various ways **to minimize risks** from already happening climate change impacts and those from fixed additional impacts in the next few decades (unavoidable climate change)

- **What can YOU do as an individual?** Spread the word: talk about the climate crisis, why it matters and how we can fix it and use your voice to **advocate for change within your sphere of influence**: as a parent, child, family member, or friend; student, employee, or boss; shareholder, stakeholder, member, or citizen: **connecting with one another is how we change ourselves**, how we **change others**, and ultimately, how we **change the world**. **It's contagious**.

Thank you for your attention!

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Together, let‘s...

[John Cook – The cranky uncle]

Some references

Haslinger, K., & Mayer, K. (2022). Early spring droughts in Central Europe: Indications for atmospheric and oceanic drivers. *Atmospheric Science Letters*, e1136. https://doi.org/10.1002/asl.1136

Stagl, J.C.; Hattermann, F.F. Impacts of Climate Change on the Hydrological Regime of the Danube River and Its Tributaries Using an Ensemble of Climate Scenarios. *Water* **2015**, *7*, 6139-6172. https://doi.org/10.3390/w7116139

Stahl, K., Weiler, M., van Tiel, M., Kohn, I., Hänsler, A., Freudiger, D., Seibert, J., Gerlinger, K., Moretti, G. (2022): Impact of climate change on the rain, snow and glacier melt components of streamflow of the river Rhine and ist tributaries. CHR report no. I 28. International Commission for the Hydrology of the Rhine basin (CHR), Lelystad.