Science of Climate Change

ENV-410, Julia Schmale

Who are we?

eerl.epfl.ch

Teaching assistants

Mihnea Surdu

Joanna Dyson

Radiance Calmer

Associate Campus Sion
Alpine and Polar Environmental Research Center (ALPOLE)

Interactive sequences

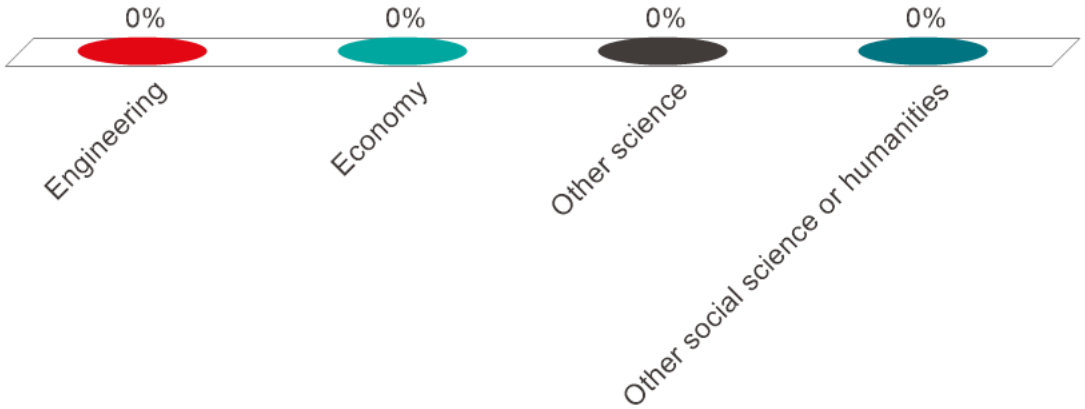
- Type 1
  - Discussion of media articles on climate change at the beginning of class. Short reading tasks!

- Type 2
  - We will use Point Solutions in class for polls and short exercises.
  - All answers are **anonymous**.
  - Please go to: responseware.eu
  - Enter as guest, do not provide any name or contact information.
  - Be aware, the data will go outside of Switzerland, but will be erased when the session is closed.
  - Let’s try. Session ID is: **env410**

What is your background?

Go to: **responseware.eu**
Login: **enter as guest**
Session-ID: **env410**

A. Engineering
B. Economy
C. Other science
D. Other social science or humanities



General Outline

Conference of the Parties (COP) 29
Baku, Azerbaijan
11 – 22 Nov 2024

For all assignments:
Work in teams of 4 with mixed backgrounds.
Teach colleagues, ask colleagues, challenge colleagues!

	No.	Date	Topics	
Basics	1.	12.09.2024	Introduction	exercises (not graded)
	2.	19.09.2024	Radiation, Earth's energy balance	
	3.	26.09.2024	Greenhouse effect, Radiative transfer, aerosols & clouds	
	4.	03.10.2024	Radiative Forcing, Feedback mechanisms	Launch of poster assignment
	5.	10.10.2024	Climate Sensitivity	
	6.	17.10.2024	Paleoclimate	submission of Poster proposal (28.10.2024)
Present and future Climate change	7.	31.10.2024	Climate variability	
	8.	07.11.2024	Paris Agreement, Emission Gap, IPCC – present day climate change	
	9.	14.11.2024	Climate scenarios (RCPs, SSPs), Tipping elements, 1.5 vs 2.0°C	
	10.	21.11.2024	Carbon budget, carbon offsets, metrics	submission of Poster draft
	11.	28.11.2024	Extreme Events	submission of assignment (graded)
Actions	12.	05.12.2024	Regional climate change	
	13.	12.12.2024	Mitigation and adaptation, Climate Engineering	**Poster Conference** (graded)
	14.	19.12.2024	Recapitulation of key points, questions and answers session	fill in Questionnaire in exercises (not graded)

Some details

- Lectures give you the general introduction to the topic
- Exercises will discuss content more in detail and partly quantitatively
- Grading (see also moodle):
  - 1 graded assignment: 25 %
  - Conference poster project: 25 %
  - Final written exam: 50 %
- The conference: 12 December in the afternoon
  - **Please make room in your schedules for the conference 3 – 5 pm (plus aperitif) → If you cannot make it, I will need a formal excuse by email until 28 November.**
- Online discussion forum Ed Discussions for yourselves (students).

Assignment and poster groups

- Groups of 4 student
- Same group for both assignment and poster
- Rules:
  - Minimum 3 different educational backgrounds (e.g., economy, life sciences, natural sciences)
- You organize yourselves
- Deadline: 25 September

- Enter your groups in this spreadsheet: https://docs.google.com/spreadsheets/d/12ciRsNRLwzOoqhVXWVJ32Xbm4dC3B1oPta-1aHIde0I/edit?gid=0#gid=0
  - You'll also find the link on moodle

ENV-410 learning outcomes

- Express the **basic physics and chemistry** of climate change
- Discuss the concepts of **climate variability** and **climate sensitivity**
- Reason why present day climate change is **different** from historical climate change
- Contrast climate change **scenarios**
- Apply simple **climate metrics**
- Interpret basic **climate data** and model output
- Critique mitigation, adaptation and climate engineering **options**

Lectures will provide the concepts.
Exercises will help you deepen your knowledge and apply it.

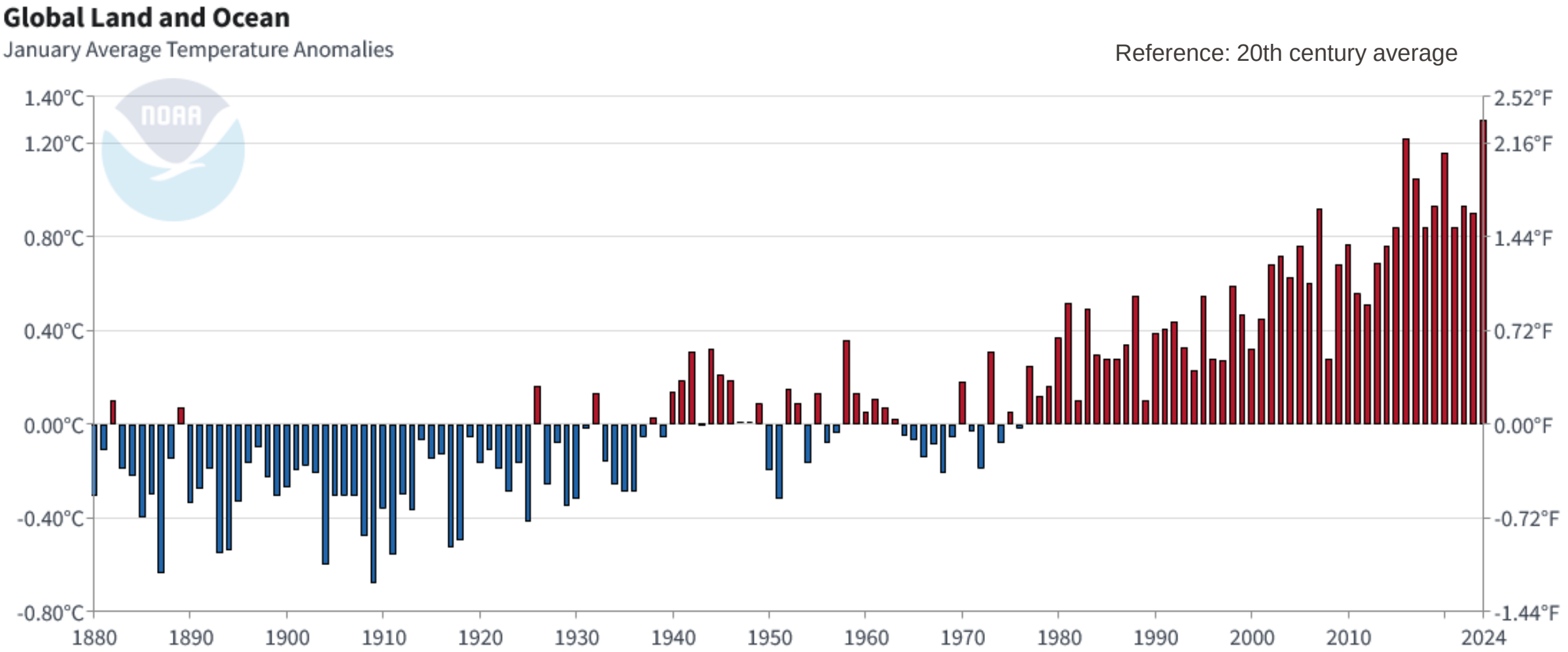
ENV-410 transversal skills

- Assess one's own level of skill acquisition, and plan their on-going learning goals.
  - → interactive sequences in lectures and exercises
- Plan and carry out activities in a way which makes optimal use of available time and other resources.
  - → see the schedule of deadlines and plan accordingly
- Communicate effectively with professionals from other disciplines.
  - → groups of four from various disciplines
  - → poster conference
- Give feedback (critique) in an appropriate fashion.
  - → groups of four from various disciplines
  - → poster conference
- Summarize an article or a technical report.
  - → assignments and poster conference
- Access and evaluate appropriate sources of information.
  - → assignments and poster conference

More general questions?

Ready for the class?

Temperature anomalies



- https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/global/time-series/globe/land_ocean/1/1/1880-2024

How many hottest years were there in your lifetime?

A. All were hottest years.
B. More than 7.
C. More than 10.
D. More than 15.

Why Climate Emergency?

CLIMATE

The countries that could go extinc change may surprise you

Eur

Climate crisis made deac floods 'up to nine times r

Study reinforces the hard evidence that carbo main cause of worsening extreme weather

r the flooding of the River Ahr in Rech in the Ahrweiler district of ann Vogel/EPA

ugust 2021

Press release

One billion children at 'extremely high risk' of the impacts of the climate crisis - UNICEF

Children in the Central African Republic, Chad, and Nigeria are among the most at risk of climate change, according to UNICEF's first child-focused climate risk index.

19 August 2021

UNICEF, 19 August, 2021

The cost of the climate crisis? 20 million homeless every year

Over the past decade, extreme weather has displaced 20 million people a year Image: REUTERS/Marco Bello

WEF, 6 December 2019

Deforestation in Brazilian Amazon hits highest annual level in a decade

Rainforest lost 10,476 sq km between August 2020 and July 2021, report says, despite increasing global concern

▲ 'Deforestation is still out of control,' Carlos Souza, a researcher at Imazon said. Photograph: Mayke Toscano/Mato Grosso State Communication/AFP/Getty Images

The Guardian, 20 August 2021

Short summary
2021 – Floods
2022 – Heat waves
2023 – Cyclones, Heat waves/fires
2024 – Floods, heat waves

Cyclones – February 2023

- Southern Africa hit by stronges Southern Hemisphere cyclone so far
- 400 death
- > 80’000 displaced

Heavy precipitation in California - March

- Hurricane force winds affect 35 Million people
- 120’000 people without electricity
- Several deaths

Heat Waves – April through August 2023

- > 60’000 people died in Europe due to heat stress
- Spain experienced 40°C in April

All time heat records in 2023: many weather stations in China reached record heat levels and the all-China heat record was broken, hottest night recorded for Toksun, China, national heat record for all Albania broken, heat record broken for Catalunya, many parts of France, parts of Japan, many parts of Canada have seen their hottest ever day and night, Russia with also many record warm nights, Kazakhstan, high elevation parts of Iran are seeing the world’s worst high elevation heatwave, many all time records broken in Algeria and Tunisia, including hottest ever night in Africa, the Canaries had their hottest ever night which was the tied second hottest in Africa, highest ever records of daily minimum temperature in parts of Spain, highest ever max temps in parts of Spain, highest minimum temperatures in Marathon, Florida three days in a row and then beat it again, seawater temperatures in Florida smashed local record and now have possibly broken the global record, parts of Cuba, parts of Nevada, Colorado and New Mexico tied their all time high, parts of Arizona, Cayman Islands, highest ever night time temperatures in Phoenix Arizona which also had its record for longest time without falling below 90F/32.2C AND record number of days above 110F/43.3C, parts of Austria, First time ever stations at 1000m asl in Andorra recorded a ‘tropical night’, over 20C, Rome and many other parts of Italy, parts of Albania, all time record tied in part of Greece, new records set in parts of Turkiye,….AND COUNTING!!!

Fires – April through August 2023

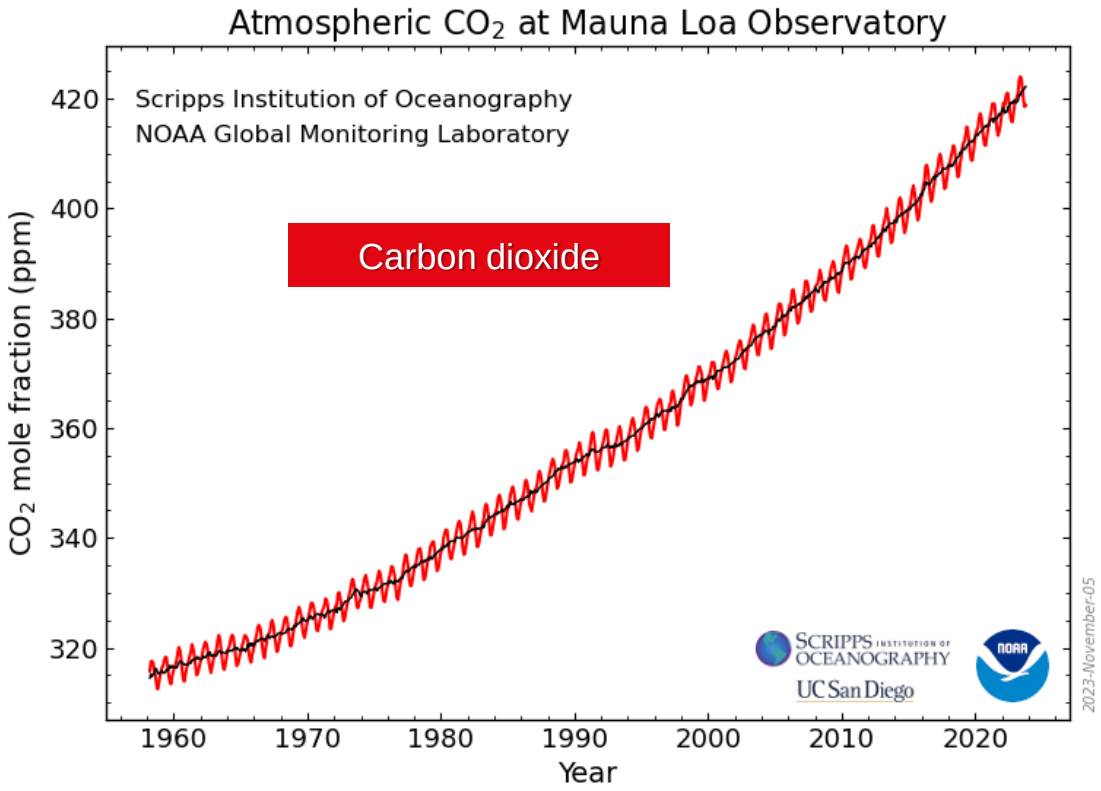
Fires – April through August 2023

- Worst season on record in Canada
- More than 1000 active fires
- 15.3 million hectares burnt (Switzerland is 4.1 million hectares)
- 350 megatonnes of carbon (Switzerland emits 10 megatonnes / year)
- Also: Greece, Hawai…

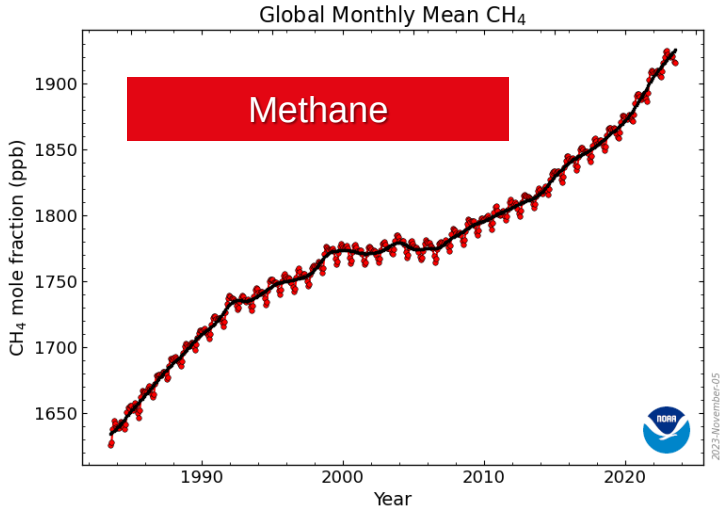
All these events have become more likely because of climate change.

Impacts are current reality.
Not a problem of the future. They come thicker and faster than anticpated.

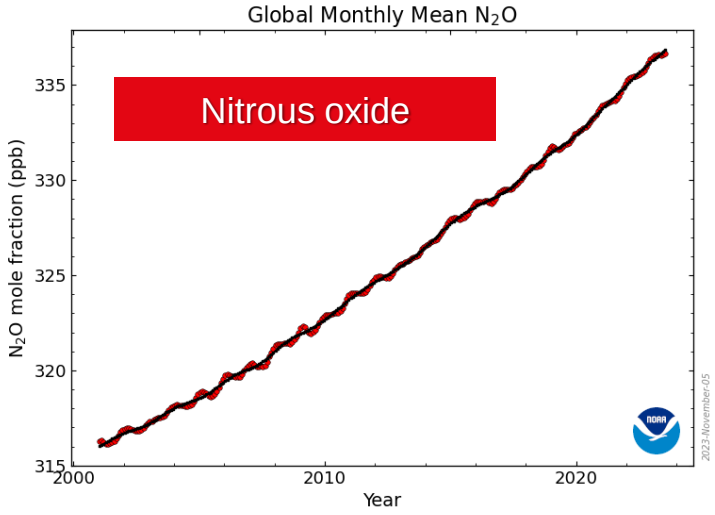
Trends of greenhouse gases in the atmosphere



October 2023: 418.82 ppm
October 2022: 415.74 ppm
Last updated: Nov 05, 2023

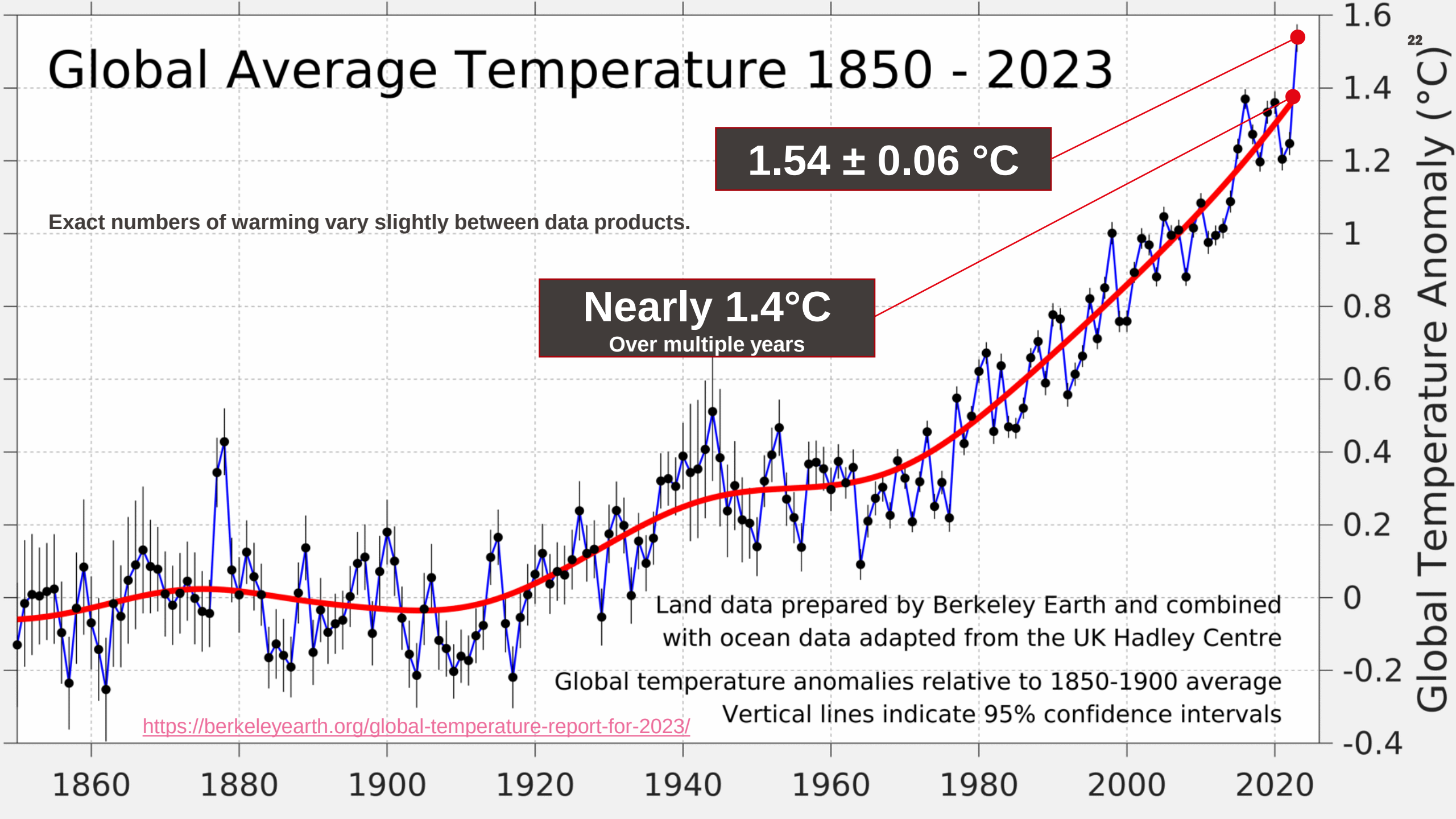


July 2023: 1915.25 ppb
July 2022: 1904.42 ppb
Last updated: Nov 05, 2023

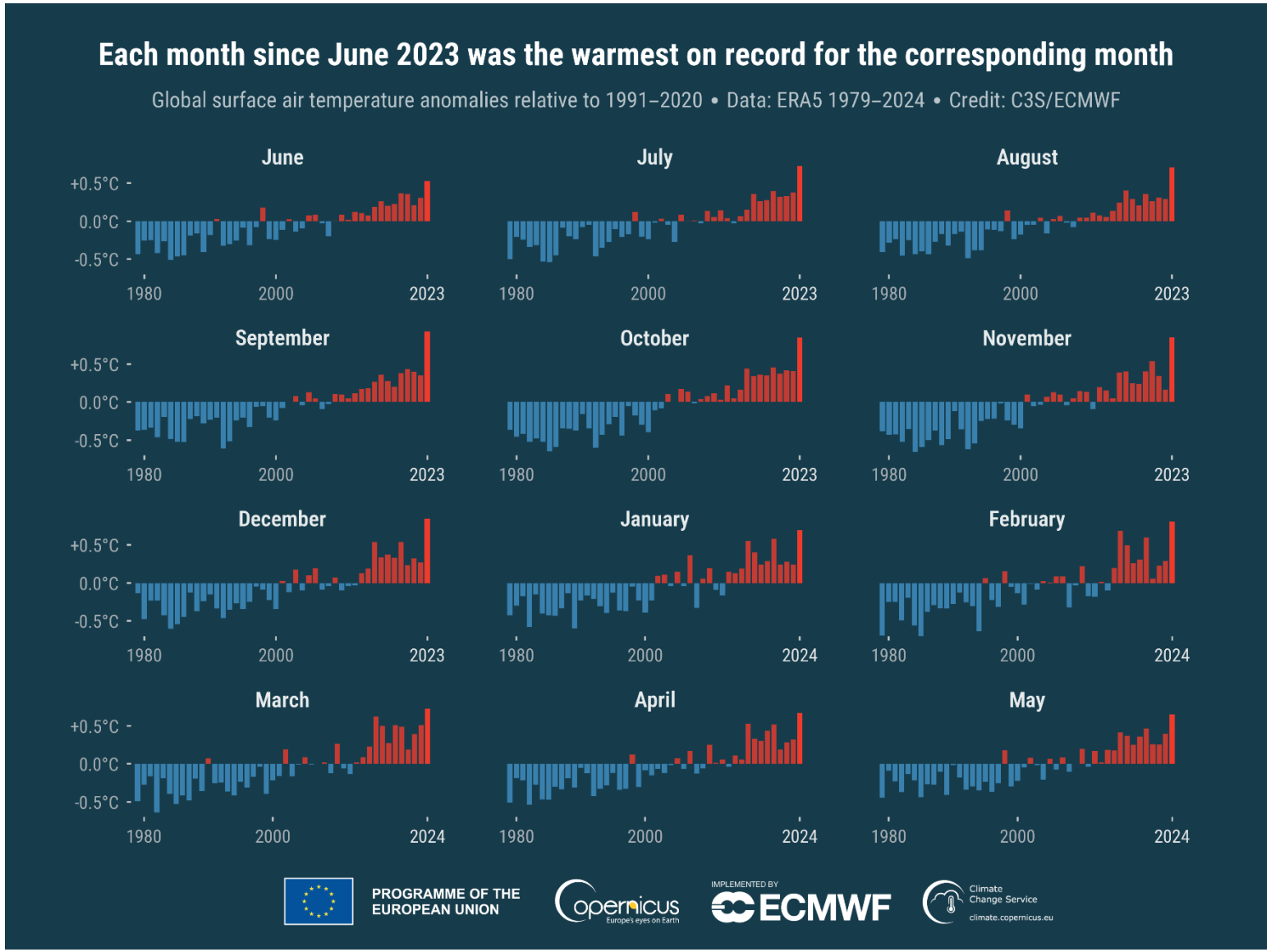


July 2023: 336.66 ppb
July 2022: 335.56 ppb
Last updated: Nov 05, 2023

- https://gml.noaa.gov/ccgg/trends/


Global Average Temperature 1850 - 2023
1.54 ± 0.06 °C
Exact numbers of warming vary slightly between data products.
Nearly 1.4°C
Over multiple years
Land data prepared by Berkeley Earth and combined
with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals
https://berkeleyearth.org/global-temperature-report-for-2023/
Global Temperature Anomaly (°C)
22
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1860
1880
1900
1920
1940
1960
1980
2000
2020

Record temperatures since June 2023



Paris Agreement 2015

*"The **Paris Agreement** central aim is to [...]*
keep global temperature rise [...] well below 2°C above pre-industrial levels
and to pursue efforts to limit the [...] increase [...] to 1.5 °C."

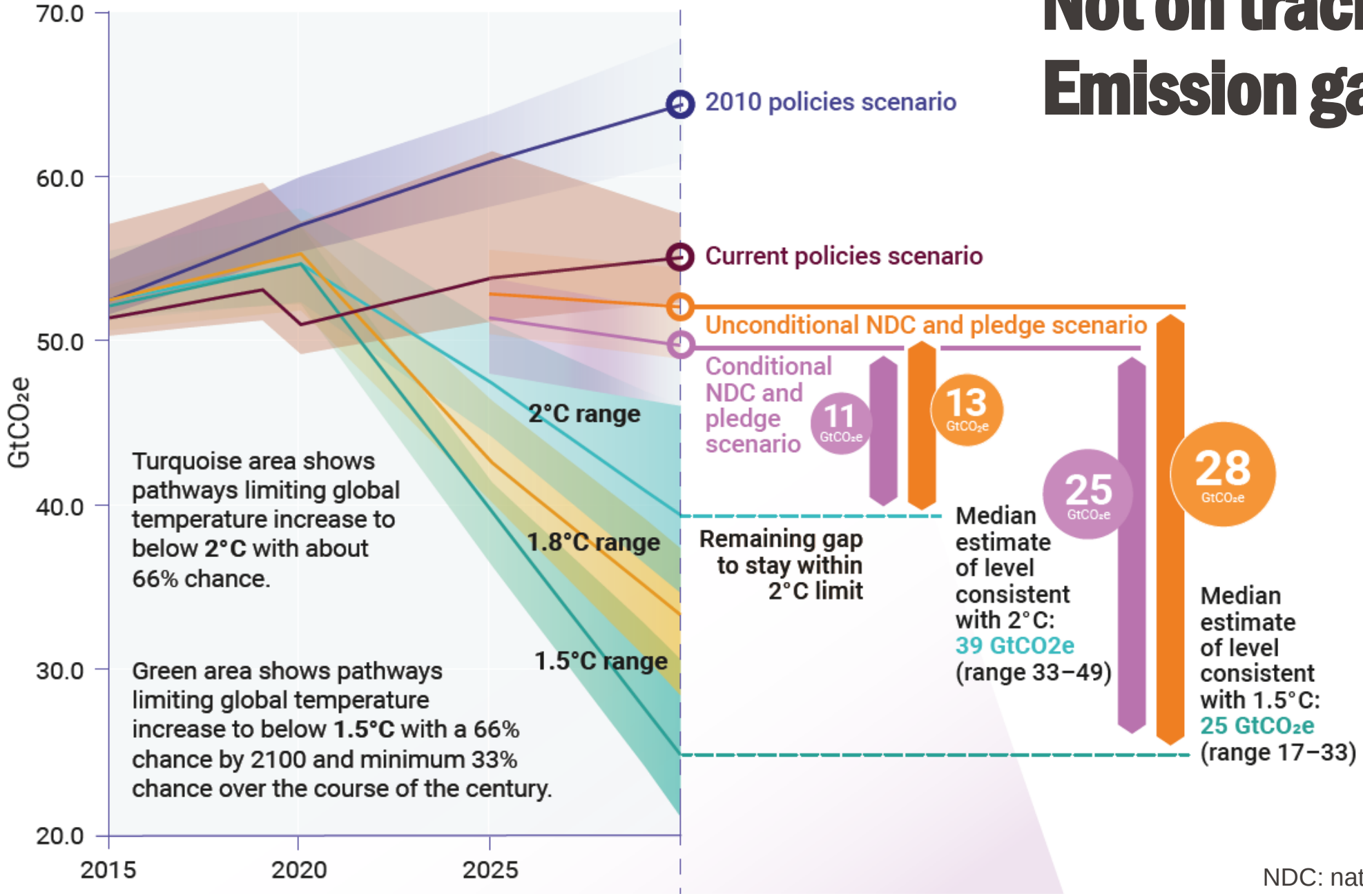
https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

«1.5°C vs warmer»

- Limitation of global warming to 1.5°C compared to 2°C allows to avoid substantial additional changes in **extremes** and their impacts:
  - Increase in **hot extremes** in most inhabited regions of the world
  - Heavier **precipitation** in several regions
  - Increased **drying** in some regions
- **Tipping points and irreversible impacts**
  - sea level rise,
  - extinction of animals, plants, coral
  - Loss of the cryosphere
  - …

- IPCC SR1.5, Ch.3, AR6 SPM

Not on track: Emission gap

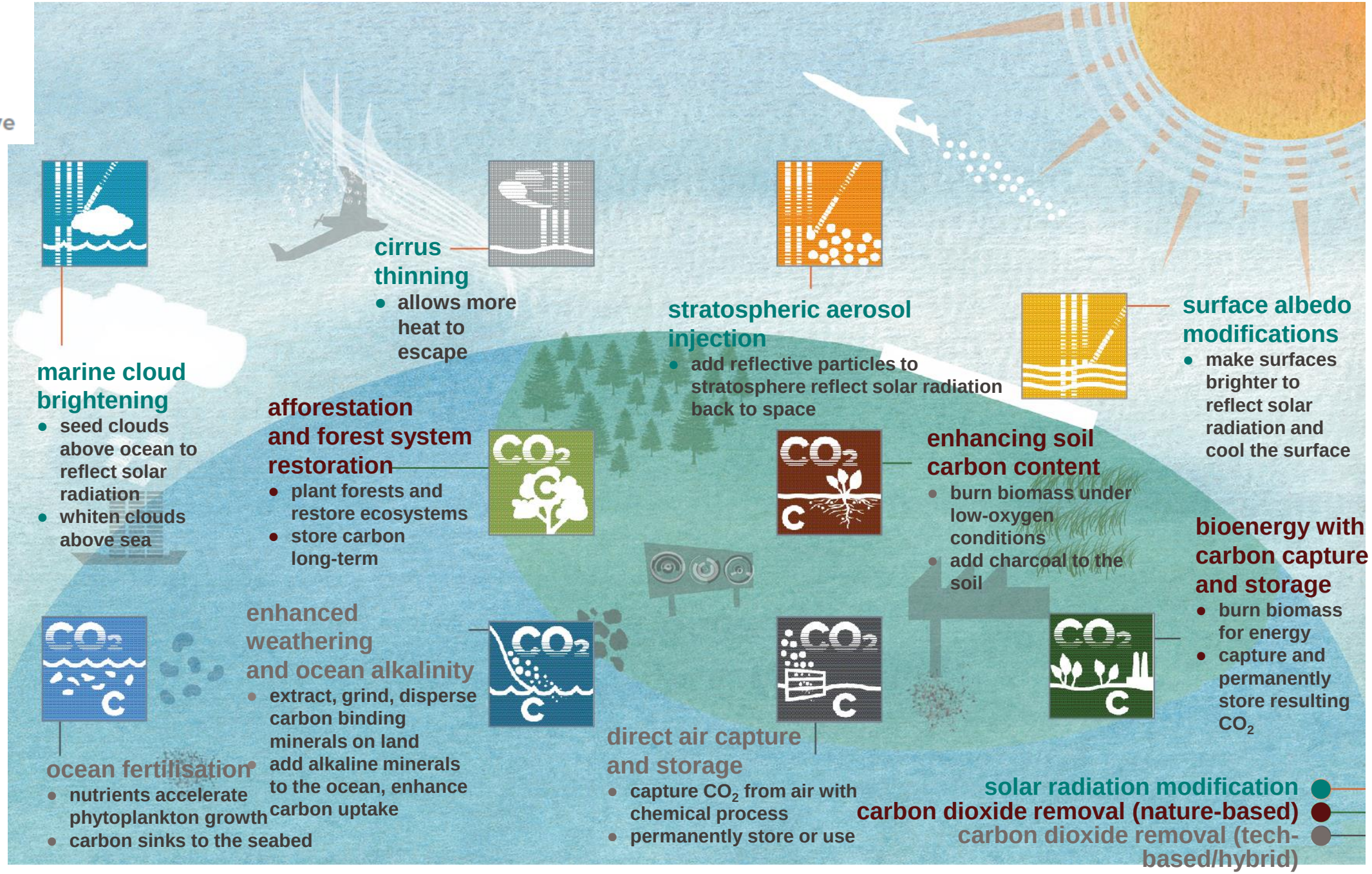


https://www.unep.org/resources/emissions-gap-report-2021, Fig. 6 from Executive Summary

NDC: nationally determined contribution

C2G
Carnegie Climate Governance Initiative

Climate-altering approaches as solution??



Climate Emergency in a nutshell

1. We are extremely close to our global temperature target of 1.5/2.0°C for 2100.

2. Drastic emission reductions are needed now and net-zero needs to be achieved by 2050.

3. Humanity is faced with a technological, political and behavioral challenge never encountered before.

The climate system

Definition of «climate» and «climate change»

- Climate is the **average weather** in a given area over a longer period of time. A description of a climate includes information on, e.g. the average temperature in different seasons, rainfall, and sunshine. Also a description of the **(chance of) extremes** is often included.
- The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization (WMO).
- Climate change is any **systematic change in the long-term statistics** of climate variables such as temperature, precipitation, pressure, or wind sustained over several decades or longer. Climate change can be due to natural external forcings (changes in solar emission or changes in the Earth's orbit, natural internal processes of the climate system) or it can be human induced.

- https://www.climateurope.eu/what-is-climate-and-climate-change/

The climate system

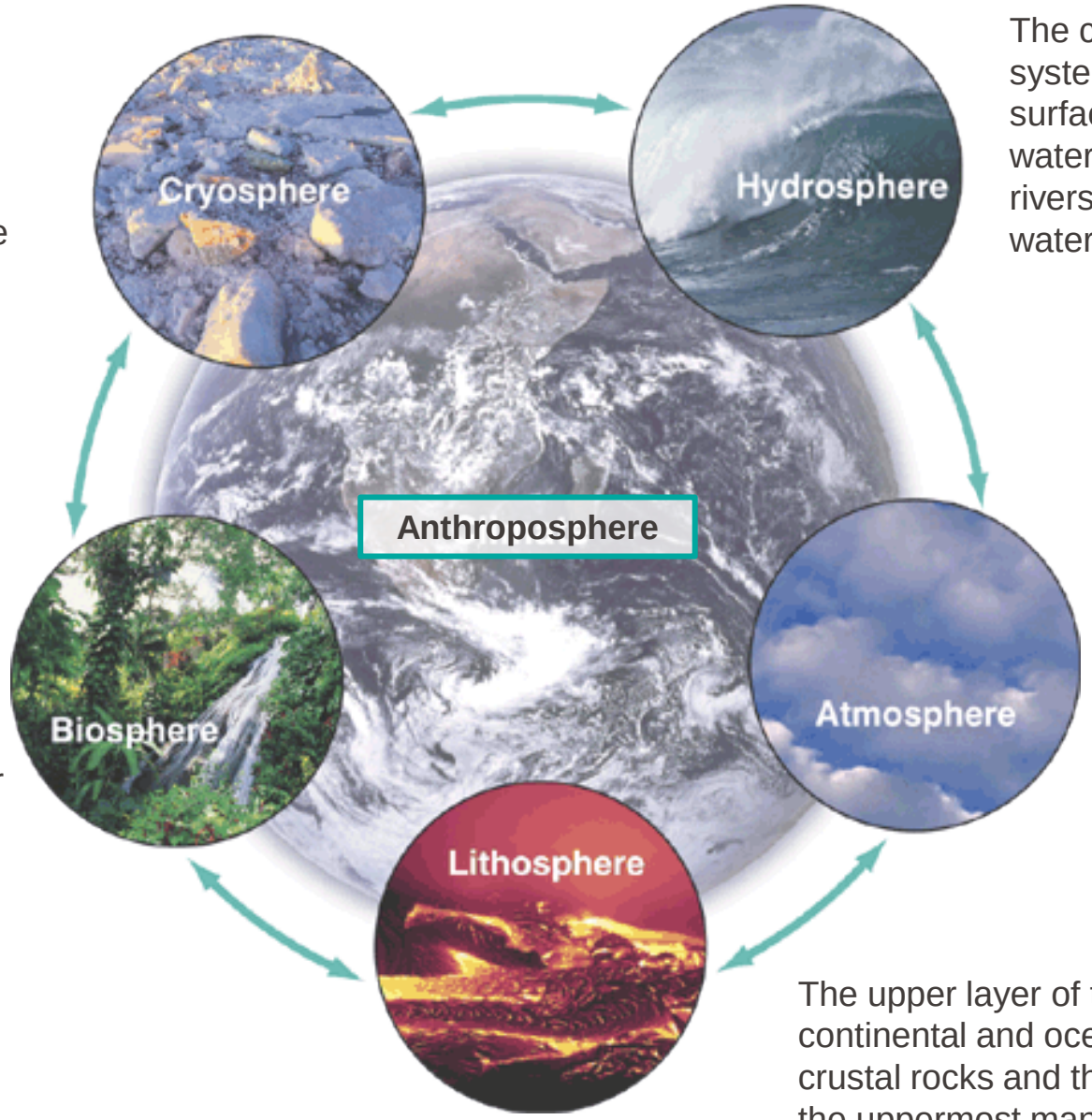
From the IPCC AR5 report:

"The climate system is the highly complex system consisting of five major **components**: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the **interactions** between them. The climate system **evolves in time** under the **influence** of its own **internal** dynamics and because of **external** forcings such as volcanic eruptions, solar variations and **anthropogenic forcings** such as the changing composition of the atmosphere and land use change."

IPCC – Intergovernmental Panel on Climate Change, AR – Assessment Report, AR5 is from 2013.

Earth System Components

All regions on and beneath the surface of the Earth and ocean where water is in solid form, including sea ice, lake ice, river ice, snow cover, glaciers and ice sheets, and frozen ground (which includes permafrost).



The component of the climate system comprising liquid surface and subterranean water, such as oceans, seas, rivers, lakes, underground water, etc.

Anthroposphere represents activities of the **Anthropocene** epoch, the periods in which human activity has significantly affected Earth's biogeochemistry and climate.

The part of the Earth system comprising all ecosystems and living organisms, including derived dead organic matter, such as litter, soil organic matter and oceanic detritus.

The gaseous envelope surrounding the Earth.

Recommended reading:
Wallace and Hobbs, chapter 2.1

The upper layer of the solid Earth, both continental and oceanic, which comprises all crustal rocks and the cold, mainly elastic part of the uppermost mantle.

- Adapted from DOI: 10.1126/science.1070629

Atmosphere

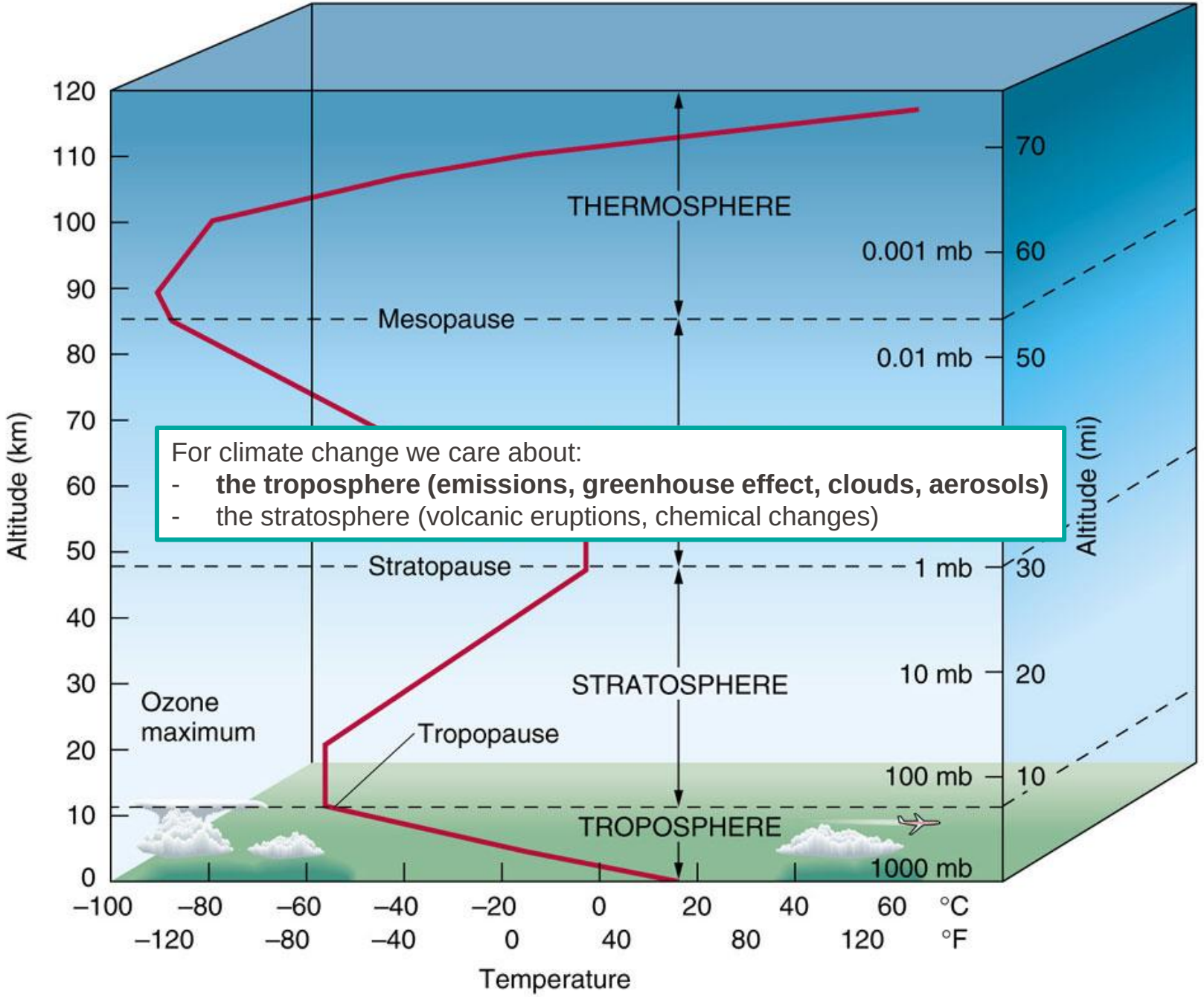
The vertical temperature profile provides basis for dividing the atmosphere into four layers:

• *Troposphere*: sun warms the surface, because atmosphere is mostly transparent to visible solar radiation, warm and moist air rises, cools and forms clouds, average **lapse rate** of -6.5 °C km^{-1}.

• *Stratosphere*: dry and ozone-rich; ozone absorbs UV radiation, critical for life on Earth, receives warmth from solar radiation, inversion.

• *Mesosphere*: temperature decreases to a minimum at top, because much of the high energetic radiation is already absorbed by the thermosphere.

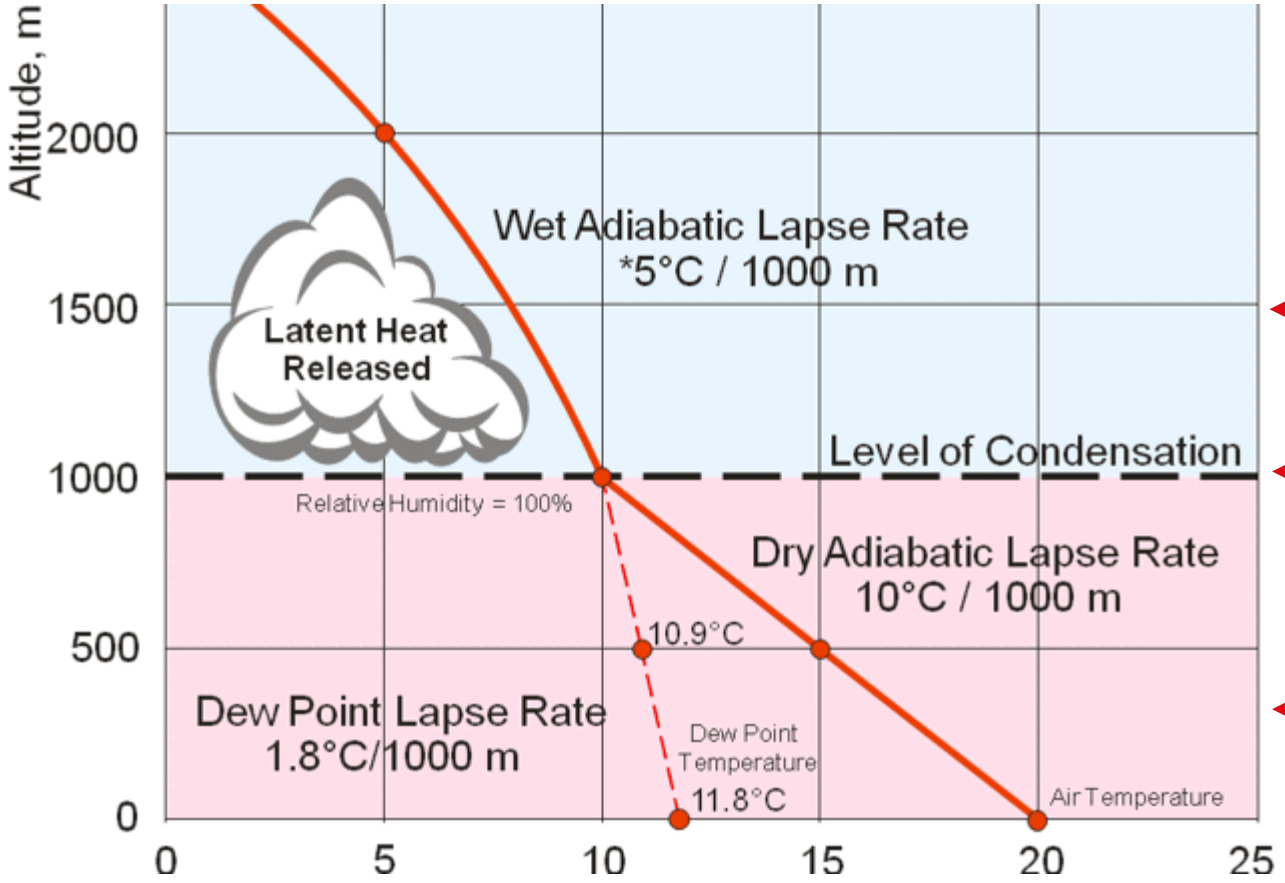
• *Thermosphere*: increase in temperature due to absorption of solar radiation and photodissociation of nitrogen and oxygen molecules.



Lapse Rate

A critical climate feedback

Dew point temperature: temperature of air at which it will become saturated with water vapor (RH = 100%)



Environmental lapse rate Γ is the rate at which temperature (T) decreases with height (z), it is roughly 6.5 degrees per 1000 m.

$$\Gamma = -\frac{dT}{dz} \qquad \text{(K/m)}$$

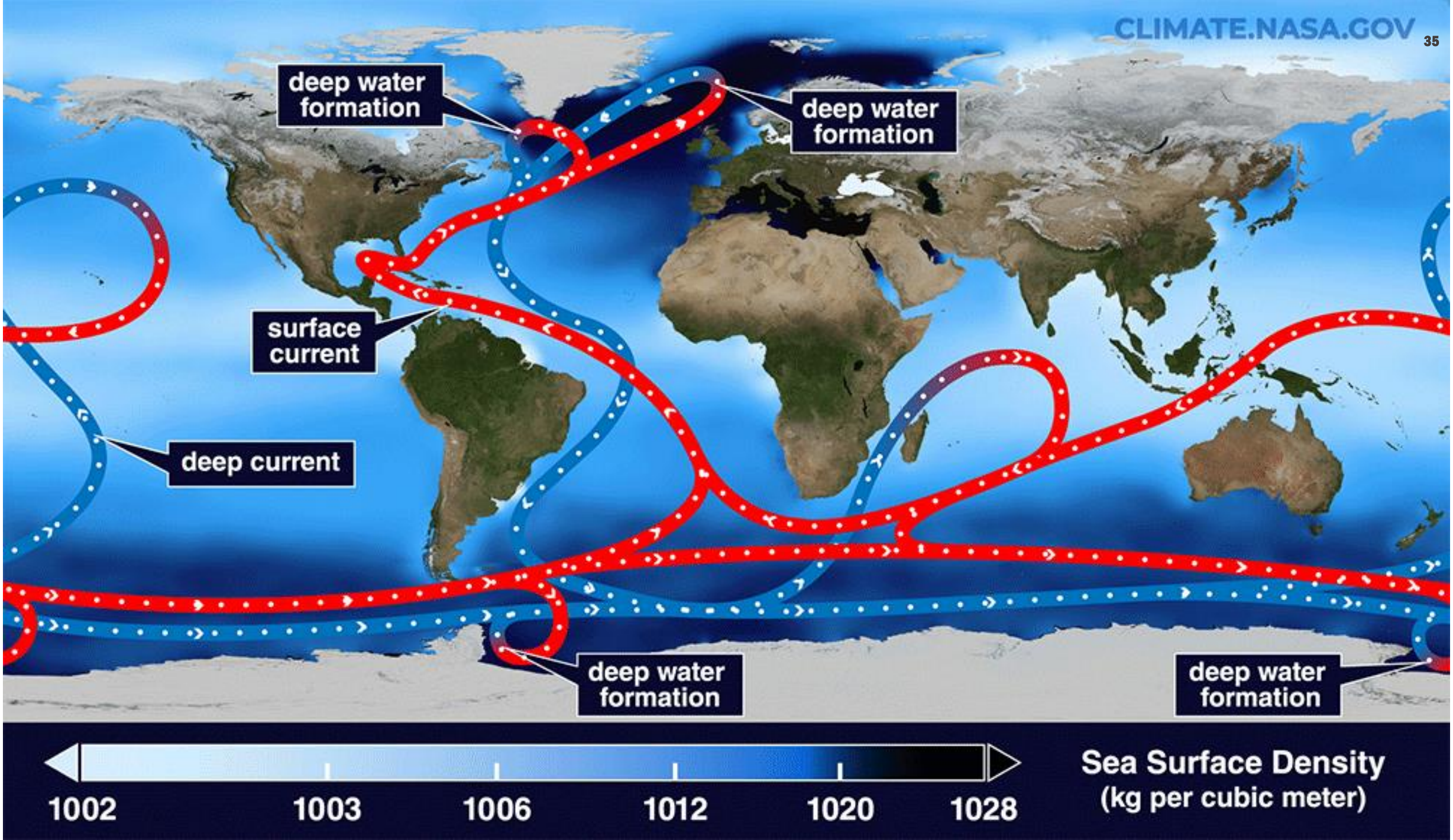
Because condensation is involved, we speak of the *wet* (moist) adiabitic lapse rate. Air parcels cool because heat is released as condensation heat.

Air becomes saturated with water vapor and clouds can form through condensation (a process of latent heat release).

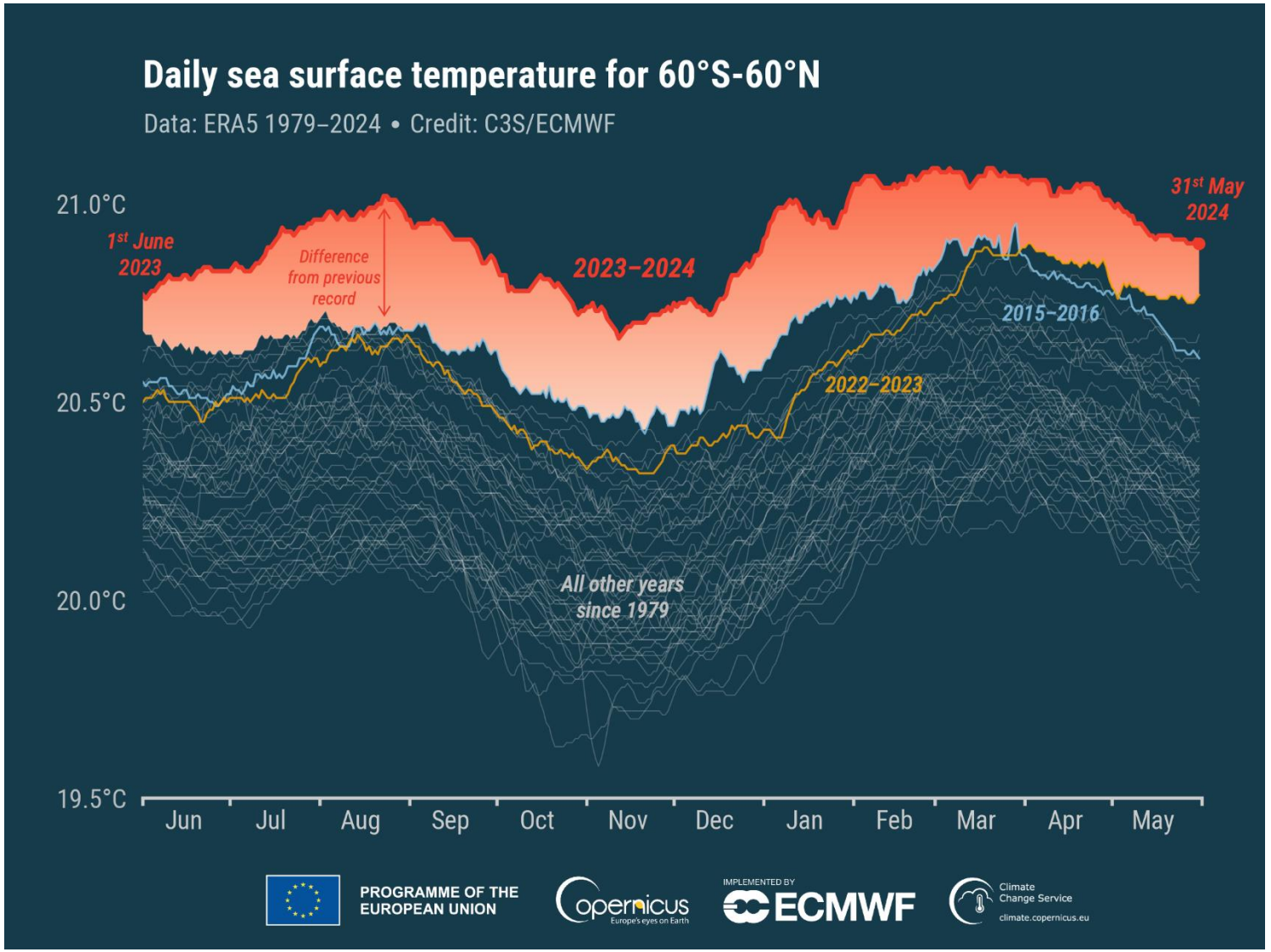
Pockets of warmer air rise, expand and cool and the cooler air compresses and falls until it is in equilibrium with the surrounding air. There is no condensation involved, hence *dry* adiabatic lapse rate.

- https://weatherworkedout.weebly.com/air-masses-and-weather-systems.html

Adiabatic means, there is no heat or mass transfer between the air parcel and environment, only work is done (expansion).


deep water formation
deep water formation
surface current
deep current
deep water formation
deep water formation
1002
1003
1006
1012
1020
1028
Sea Surface Density
(kg per cubic meter)

Global Ocean Temperature Records in 2023

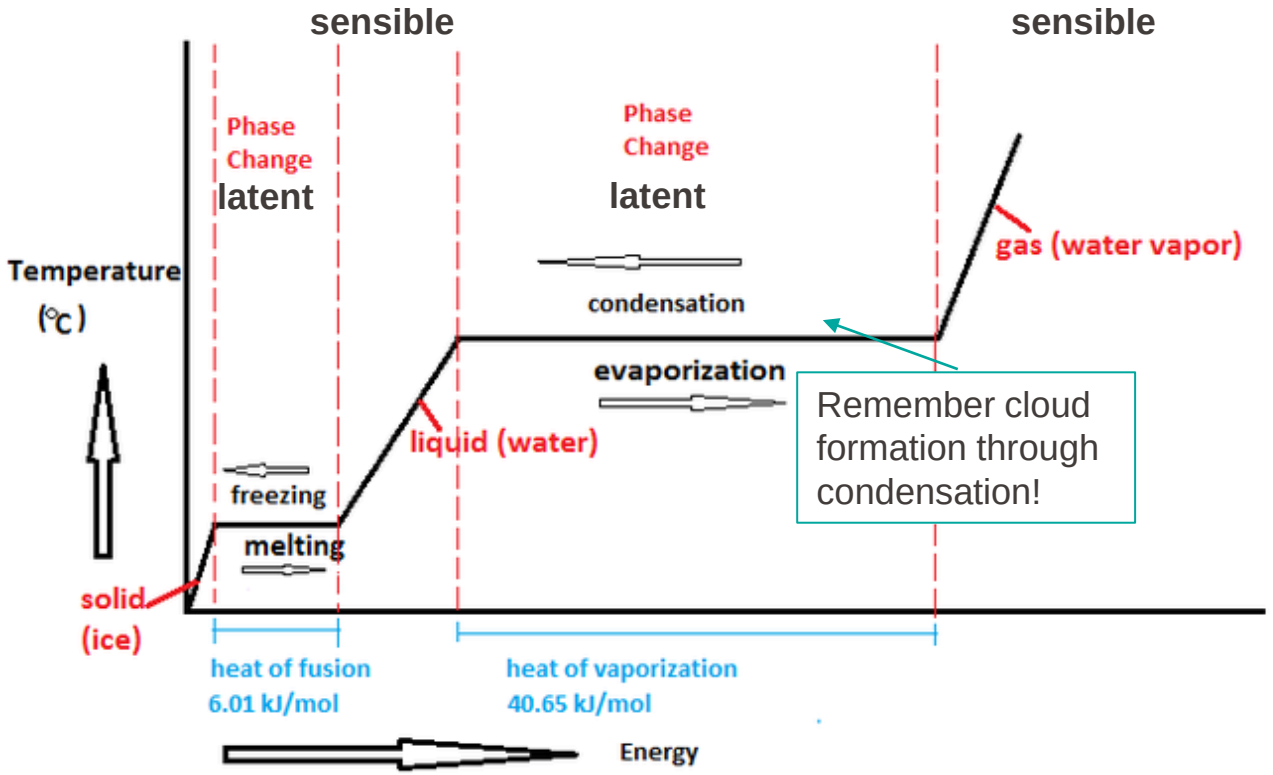


Latent and sensible heat

Both processes **transfer energy** in the climate system.

Latent heat: energy transferred in a process without change of the body's temperature, it is associated with the change of phase of atmospheric or ocean water: vaporization, condensation, freezing or melting.

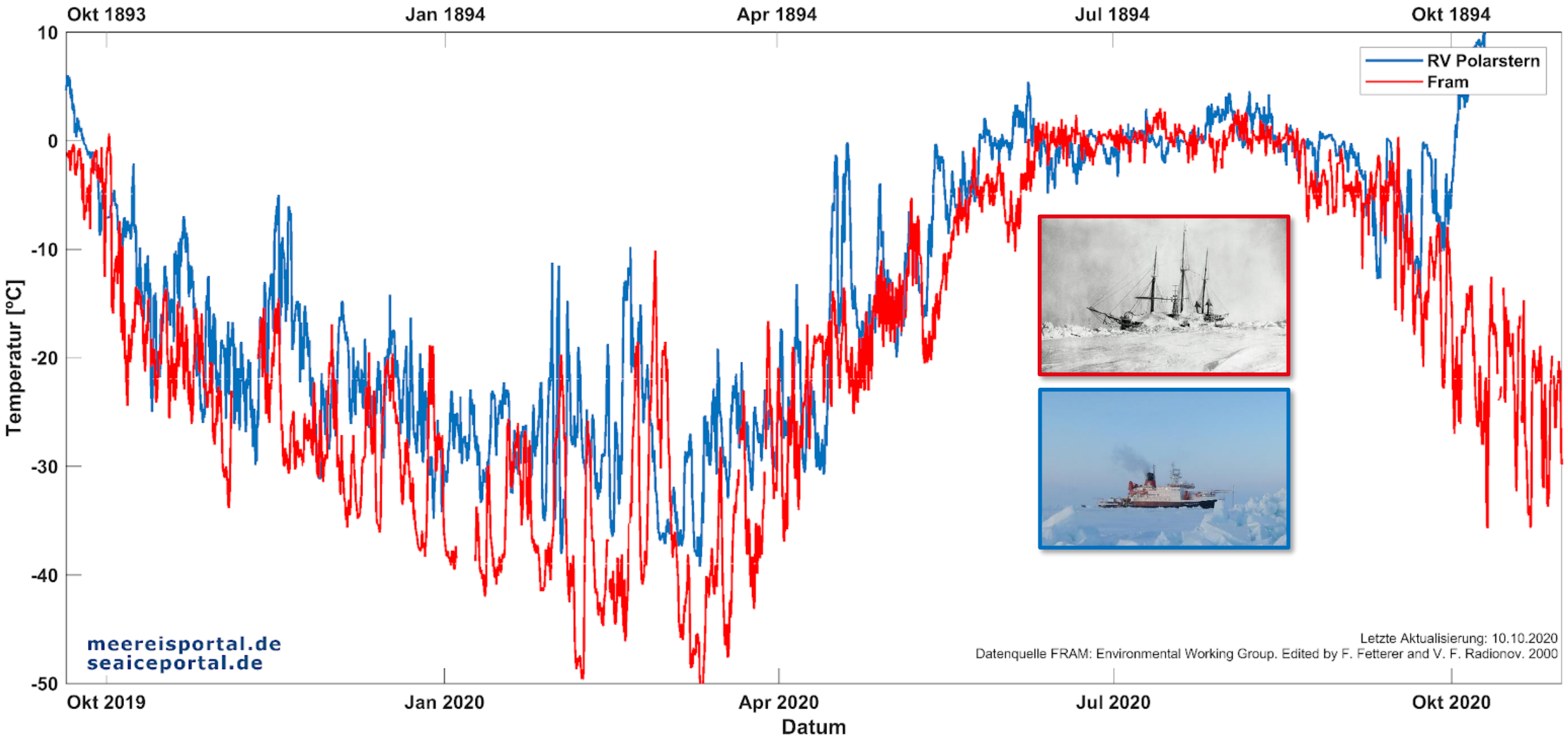
Sensible heat: "sensed" or felt in a process as a change in the body's temperature, e.g., as increasing or decreasing air or water temperature.



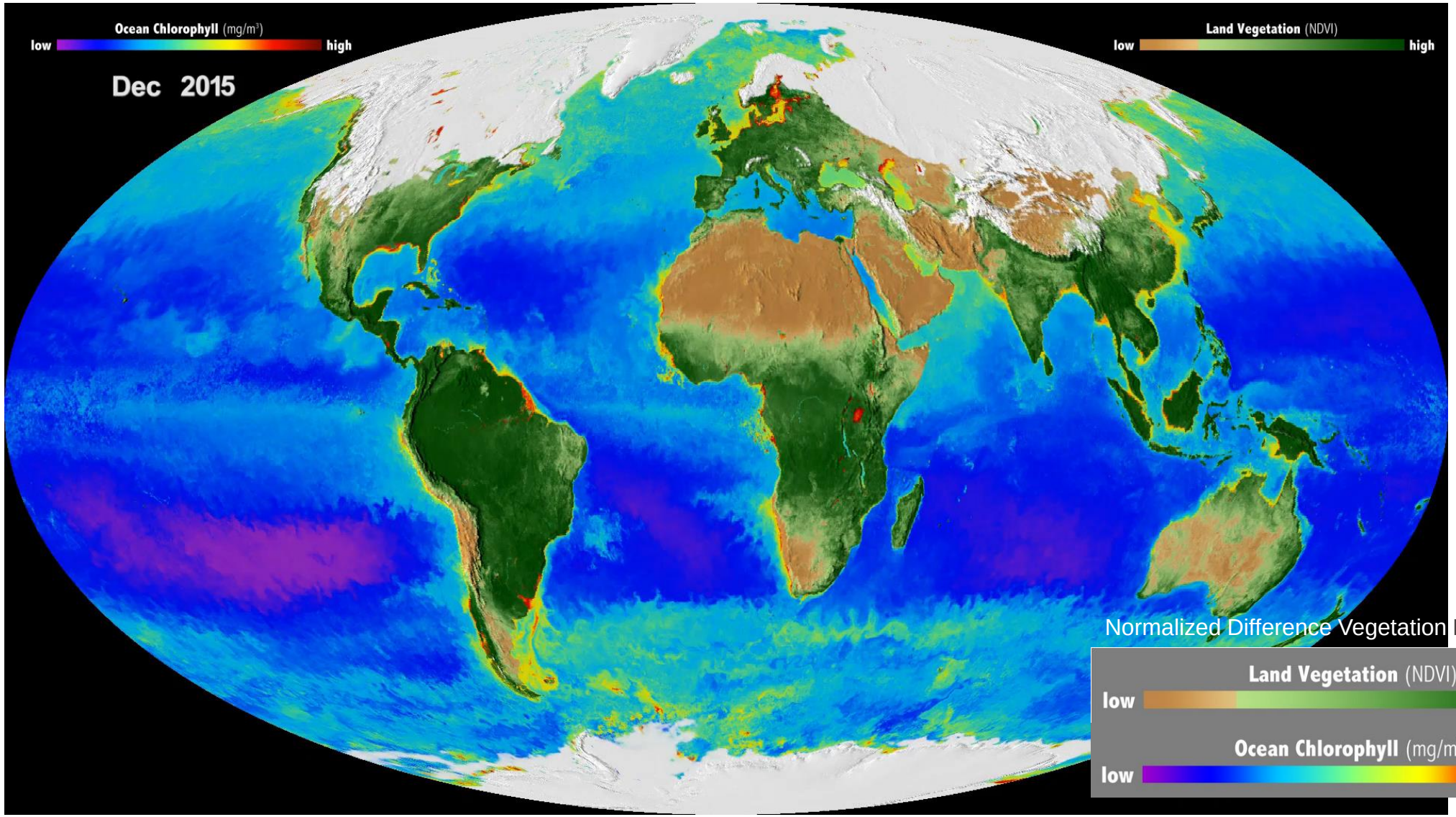
https://commons.wikimedia.org/wiki/File:Water_Phase_Change_Diagram.png

Also applies to fluxes from land!

Arctic temperature change: 1893/94 vs 2019/20



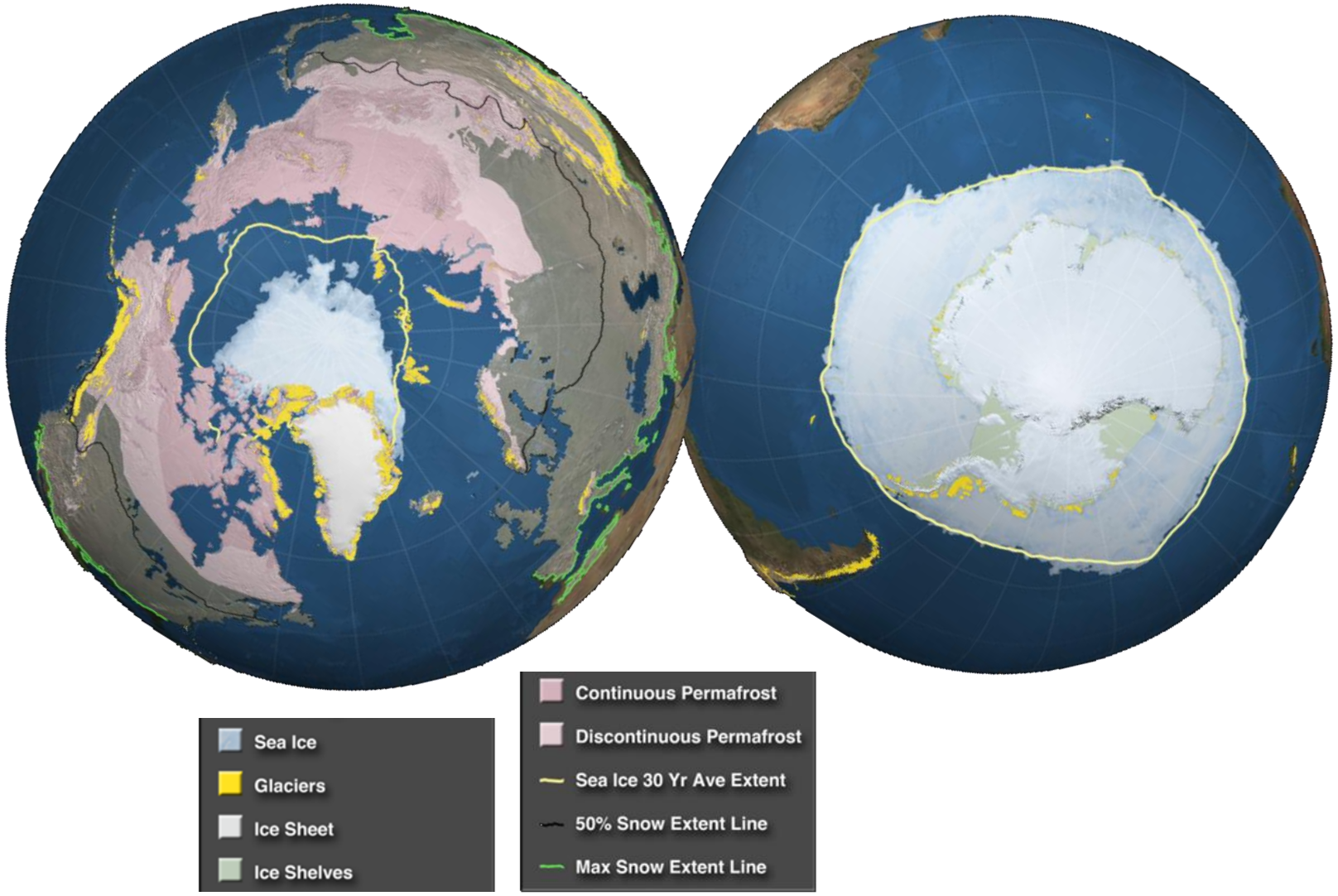
Biosphere (terrestrial and marine)



Normalized Difference Vegetation Index (NDVI)

- https://svs.gsfc.nasa.gov/4596

Cryosphere (terrestrial and marine)



Ice and seasonal snow strongly influence the **surface albedo** (reflectivity) and therefore the **radiation** budget, as well as the water cycle and the biosphere.

It is a key component of the **water cycle**.

99 % of the fresh water on Earth is in ice sheets. Greenland holds enough frozen water to raise the **sea level** by 6 m and Antarctica by 60 m.

Changes in sea ice extent, seasonality and thickness have potential impacts for **hemispheric-scale circulation**.

Changes in glacier mass balance contribute to changes in **sea level** but also have substantial implications for water supply for a substantial proportion of the global population.

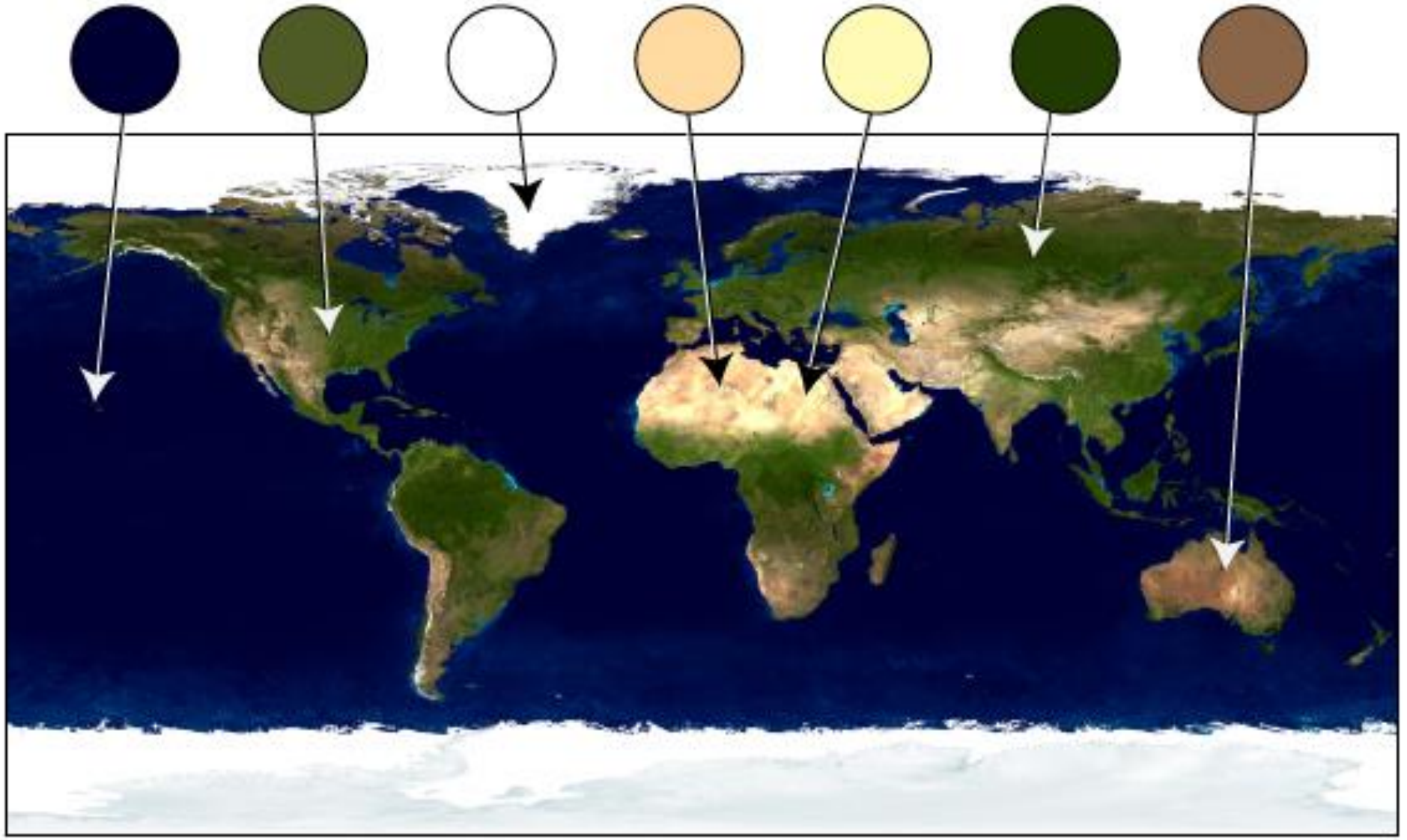
Changes in permafrost and the seasonally thawed active layer have substantial implications in mid- to high latitudes (soil stability, natural hazards) and store large amounts of **carbon**

- https://www.wikiwand.com/en/Cryosphere

Albedo

A critical climate feedback

Reflectivity of a surface
1: fully reflective
0: complete absorption



- https://scied.ucar.edu/learning-zone/how-climate-works/albedo-and-climate

Earth's albedo

Water (ocean), zenith angle: 45, 60, 70, 80°	0.05, 0.08, 0.12, 0.22
Fresh/worn asphalt	0.04/0.12
Conifer forest (summer)	0.08–0.15
Deciduous trees	0.15–0.20
Savanna	0.20–0.25
Green grass	0.25
Desert sand	0.30–0.40
New concrete	0.55
Ocean Ice	0.50–0.70
Old snow	0.45–0.80
Clouds	0.60–0.90
Fresh snow	0.80–0.90

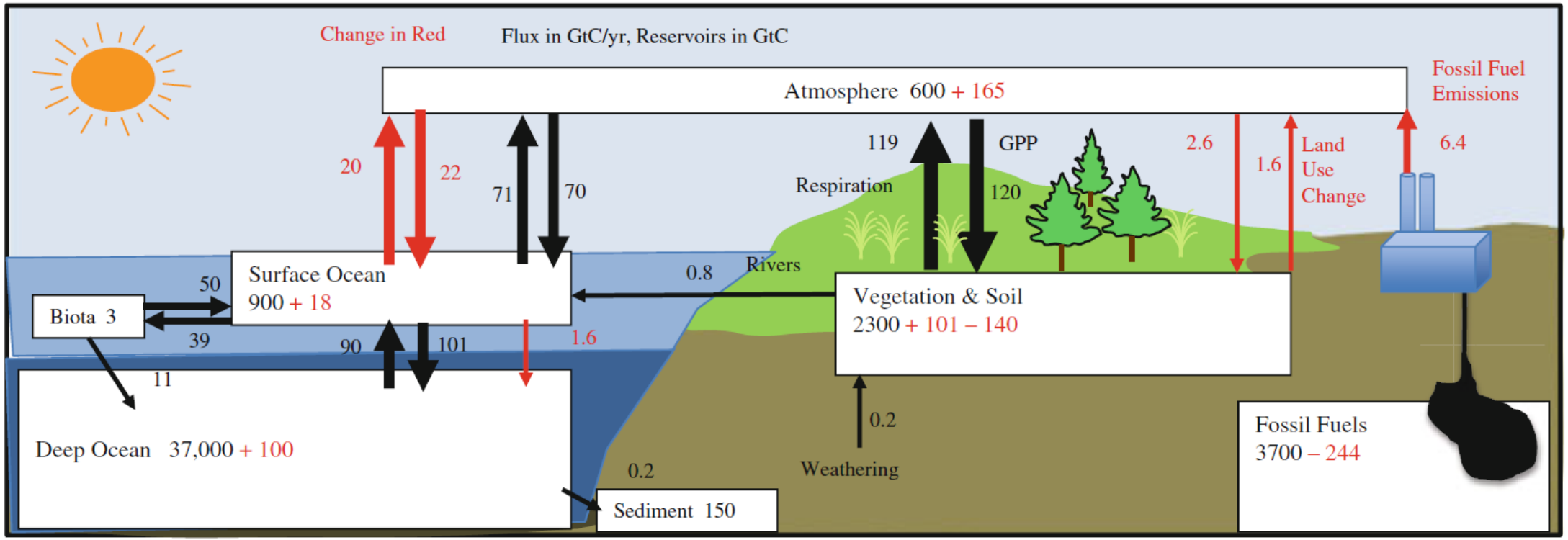
Planetary albedo, incl. atmosphere and clouds:

$\alpha \sim 0.3$

Anthroposphere

- Narsaq, Southern Greenland 2022 (picture credit J. Schmale)

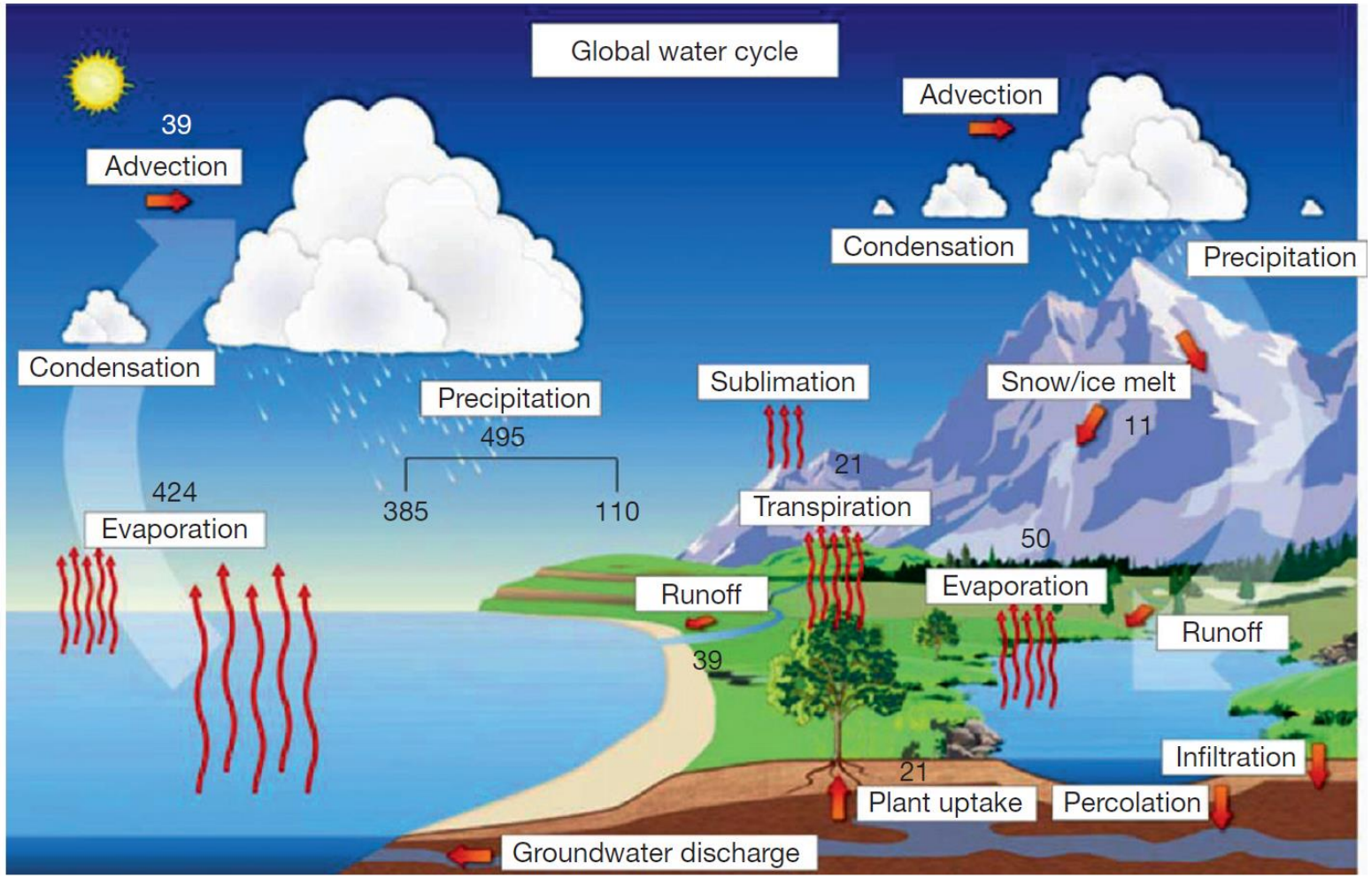
Carbon Cycle



The largest climate system reservoirs for carbon include the deep ocean, soil and vegetation, surface ocean, and atmosphere.
The approximate size of annual carbon fluxes is given by the width of the arrows; red arrows indicate perturbations by humans. Black arrows are natural exchanges. Quantities are in gigatons (10^9 tons) of carbon (GtC) for reservoirs and gigatons of carbon per year (GtC/yr) for fluxes.

- Fig. 7.6 in Demystifying Climate Models

Water Cycle



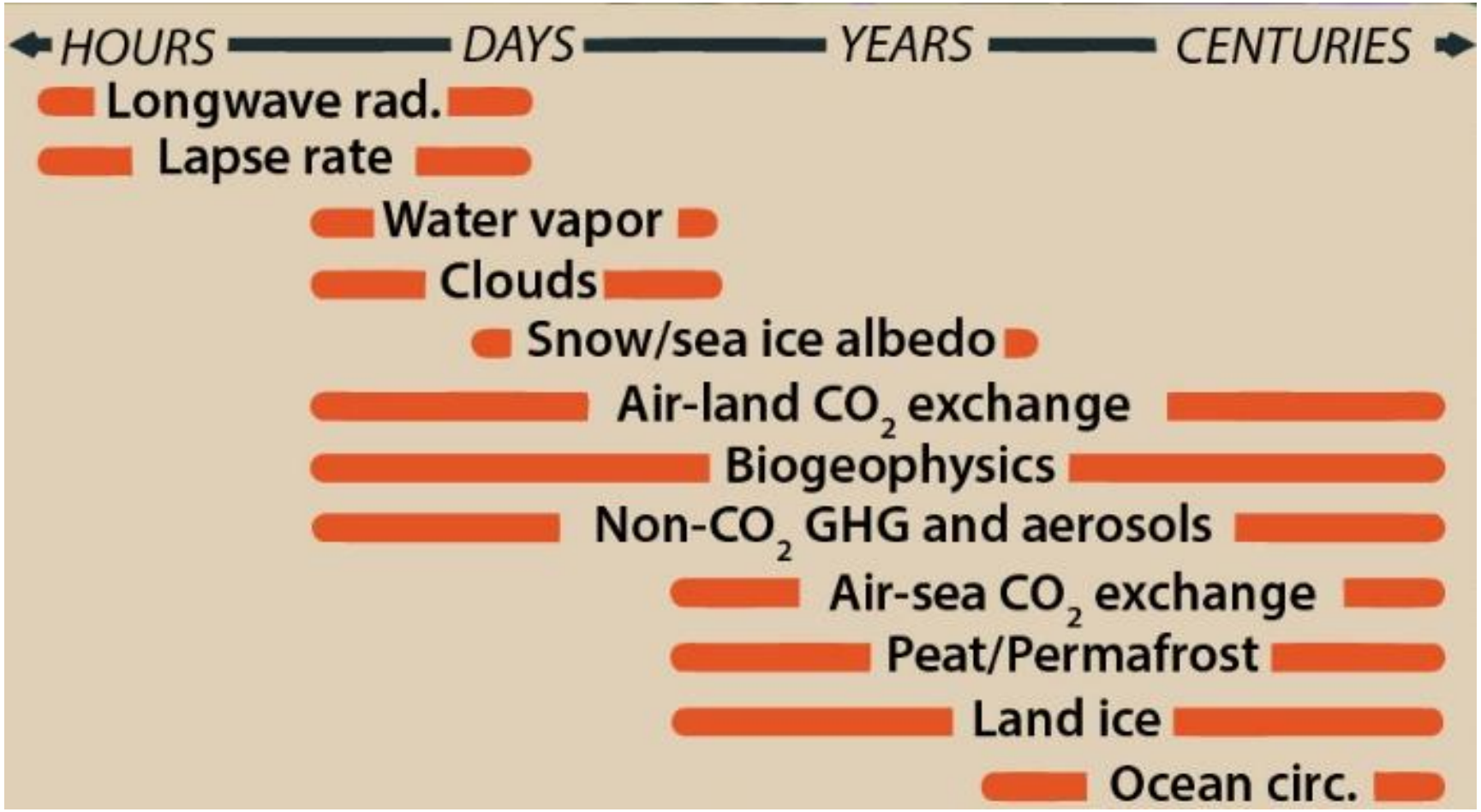
fluxes in (tera) 10^{12} m^2 yr^{-1}

Advection: movement of solid, liquid, and gaseous water through the atmosphere.
Condensation: water vapor changes into water droplets (clouds).
Evaporation: water changes state from a liquid to vapor.
Infiltration: movement of water into the ground from the surface.
Percolation: movement of water past the soil and going deep into the groundwater.
Sublimation: ice and snow change into vapor without going through the liquid phase.
Transpiration: moisture from plants and trees evaporates into the atmosphere.

Water vapor is the most abundant greenhouse gas on Earth.

- https://www.sciencedirect.com/topics/earth-and-planetary-sciences/hydrological-cycle

Timescales



Biogeophysics: how plants, microbial activity and other organisms alter geologic materials and affect geophysical signatures

Climate relevant processes occurring within and between «spheres» have different time scales. There are processes which occur on even longer time scales than shown here (e.g., continental movement).

- http://www.climatechange2013.org/images/figures/WGI_AR5_Fig1-2.jpg

Summary: Climate system

- Earth's climate system is driven by the **sun**.
- The **atmosphere mediates the flow of energy** between the sun and the Earth, through the action of clouds and greenhouse gases.
- There are several different components of the Earth's climate system, "**spheres**": atmosphere, terrestrial surface, ocean, cryosphere, biosphere and anthroposphere (the sphere of human effects).
- In addition to energy, several **critical substances flow through the Earth system**. Two of the most important are **water and carbon**. They are important for climate, and they are important for life.
- In the atmosphere water vapor and carbon dioxide are **greenhouse gases**.
  Exact discussion of mechanism follows.
- **Transformation of water** is a mechanism for **moving heat** from where it evaporates and releasing it on condensation. Exact discussion of mechanism follows.
- Climate relevant processes occur on different **time scales**.
- There are **climate feedback mechanisms** which slow or accelerate change.
  Exact discussion of mechanism follows.