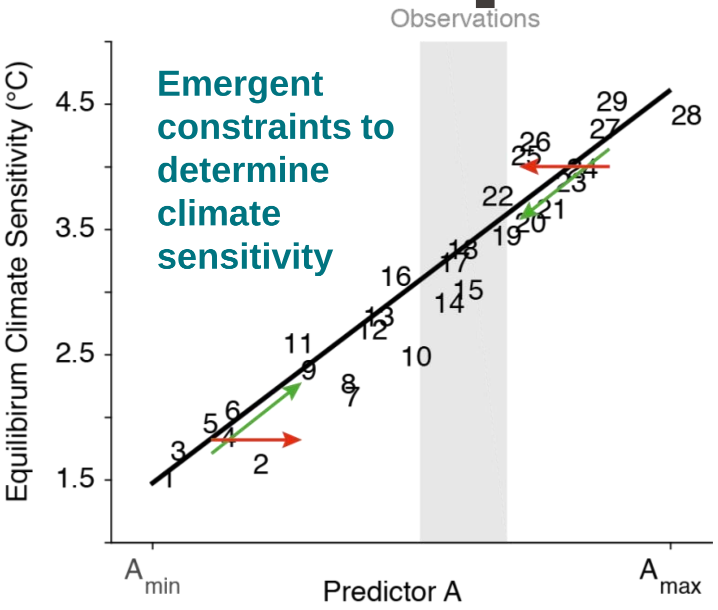
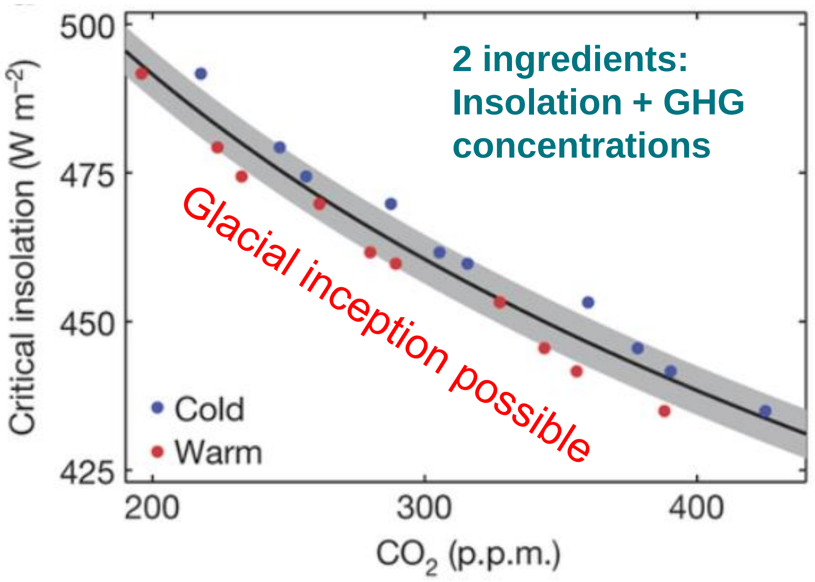
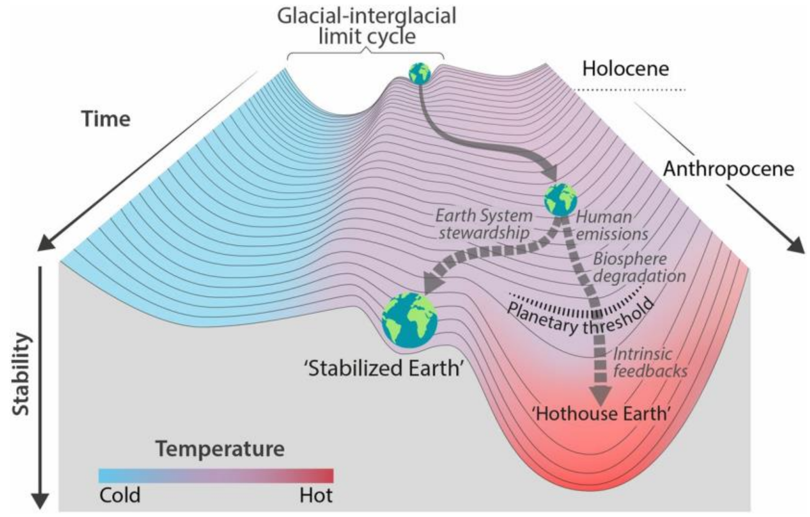
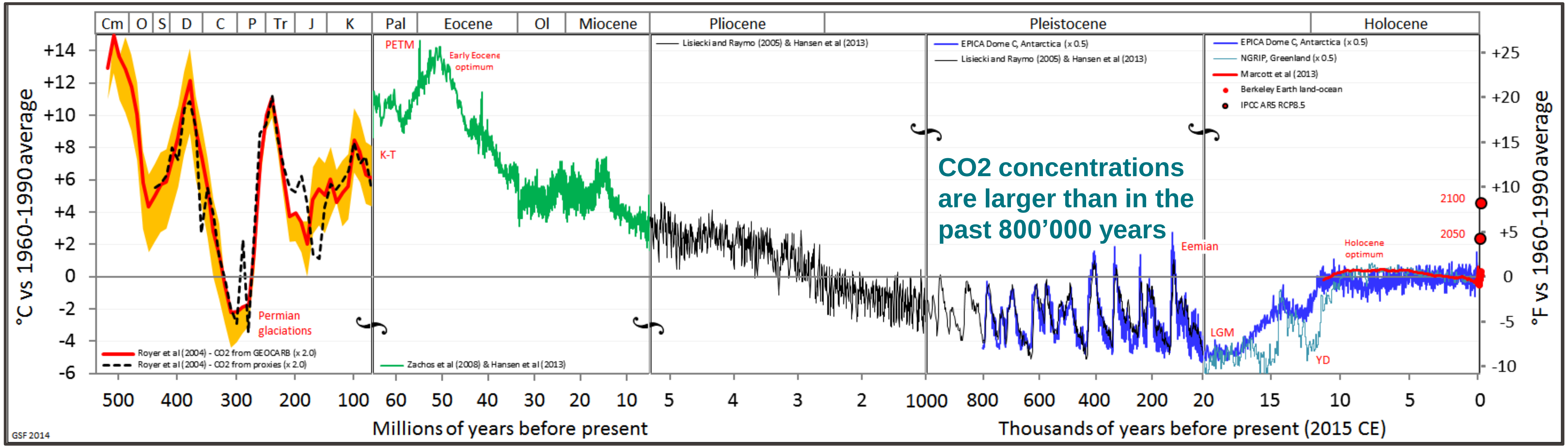
Recap from last lecture









General outline

Basics

Present and future Climate change

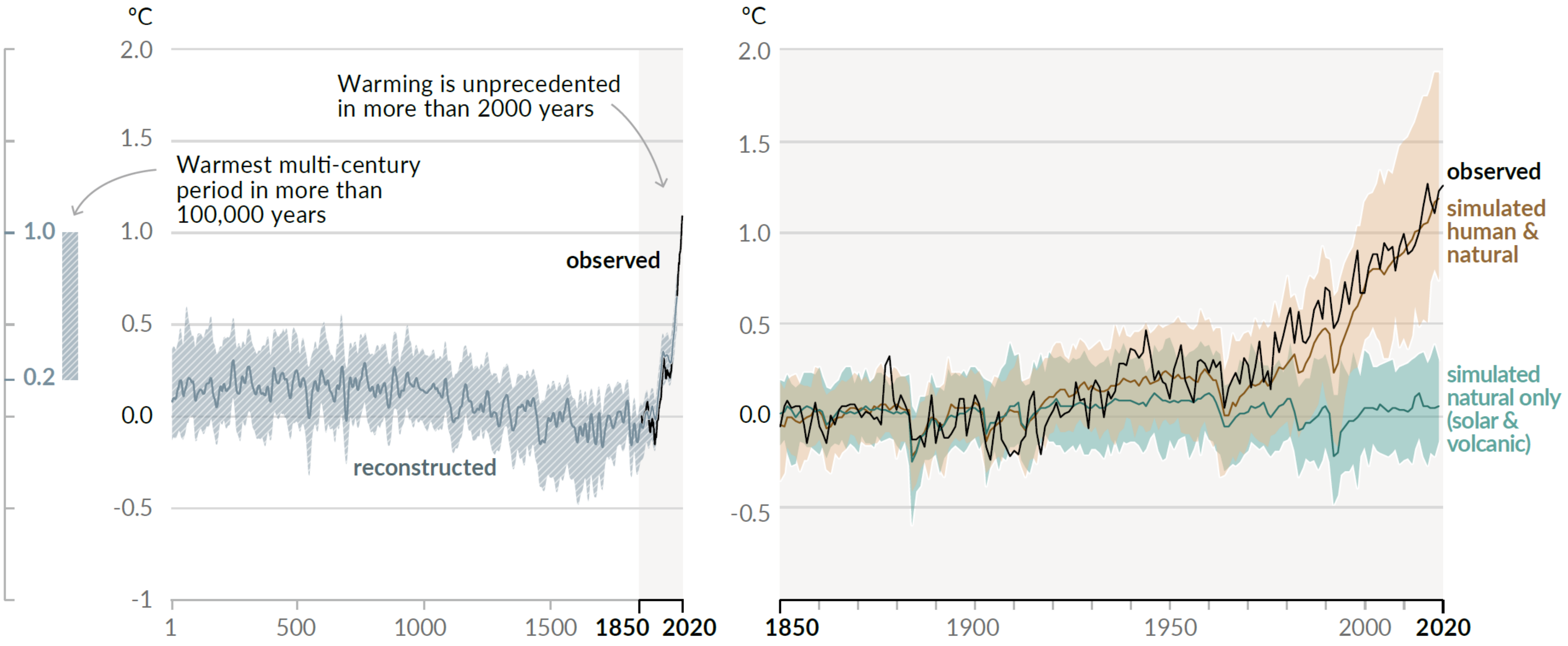
Actions

No.	Date	Topics	Deadlines
1.	12.09.2024	Introduction	fill in Questionnaire in exercises (not graded)
2.	19.09.2024	Climate System, Radiation, Greenhouse effect	
3.	26.09.2024	Earth's energy balance, Radiative transfer,	
4.	03.10.2024	Aerosols & clouds, Radiative Forcing	Launch of poster assignment
5.	10.10.2024	Feedback mechanisms, Climate Sensitivity	
6.	17.10.2024	Emergent Constraints, Paleoclimate	submission of Poster proposal (01.11.2024)
7.	31.10.2024	**Climate variability**	
8.	07.11.2024	Paris Agreement, Emission Gap, IPCC – present day climate change	
9.	14.11.2024	Extreme Events	
10.	21.11.2024	Climate scenarios (RCPs, SSPs), Tipping elements, 1.5 vs 2.0°C	submission of Poster draft
11.	28.11.2024	Carbon budget, carbon offsets, metrics	submission of assignment (graded)
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)

Today's temperature change

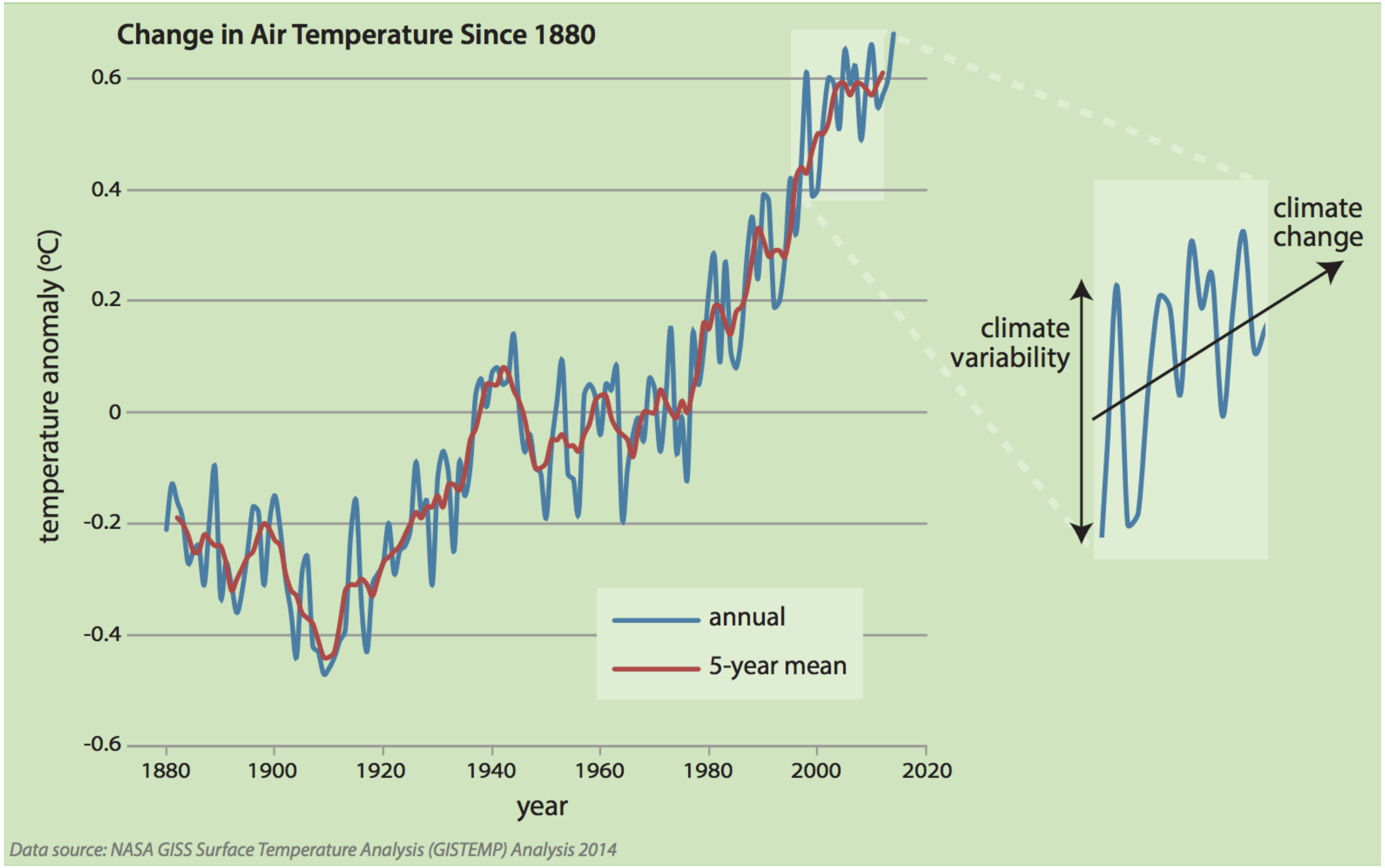
a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and observed (1850-2020)

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



- IPCC, AR6, Figure SPM.1 (2021)

Anthropogenic climate change vs natural climate variability



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

Natural Climate Variability – Why do we care?

- Climate change since the preindustrial time is a combination of long-term anthropogenic change and natural variations.
- The relative importance (anthropogenic vs natural) depends on the climate variable (e.g., temperature, precipitation) and location (e.g., Arctic, Europe). Natural variations tend to have stronger impact on more local or regional and short-term changes.
- Climate models need to be able to represent natural climate variability in order to distinguish the anthropogenic signal.

Natural Climate Variability

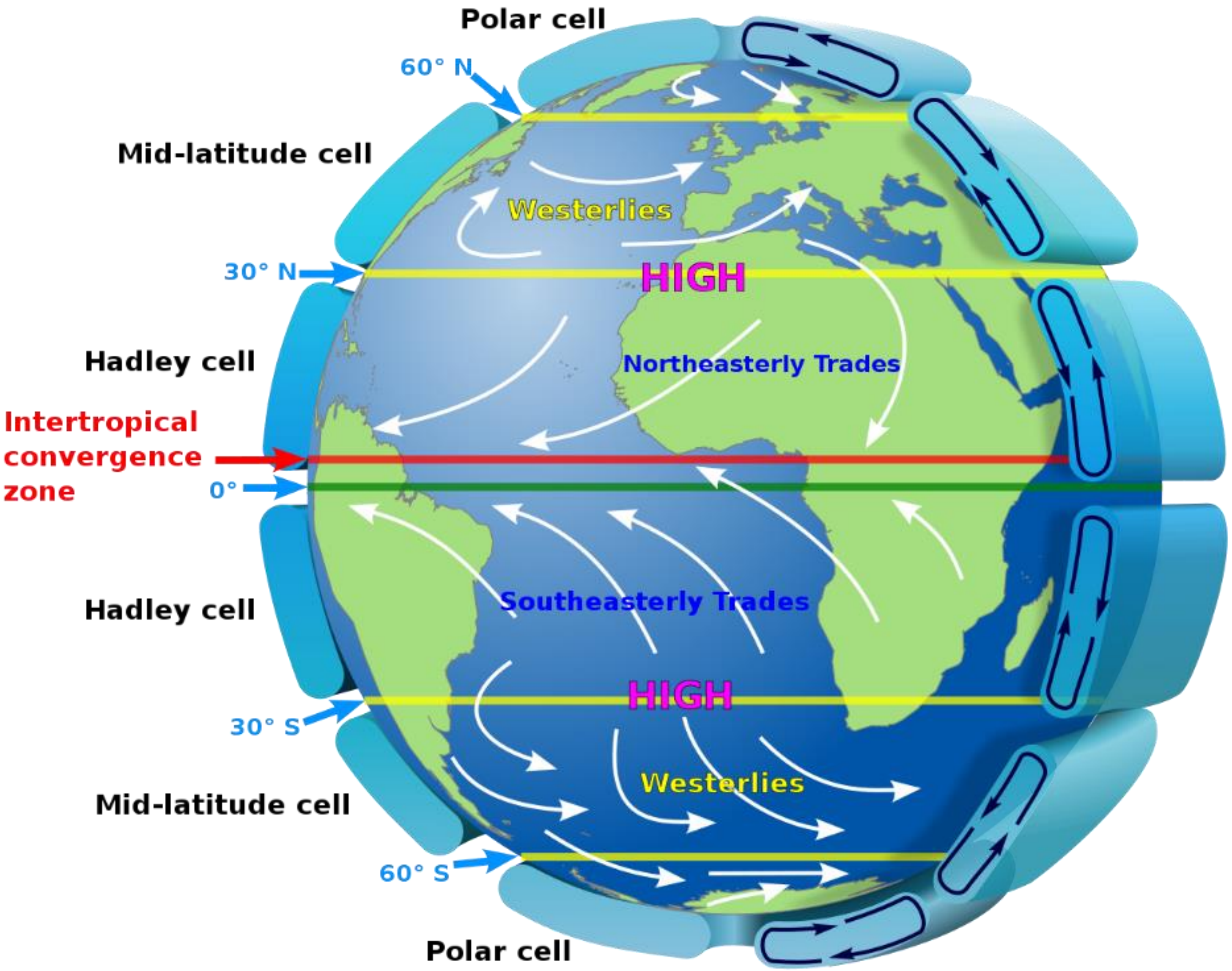
- External forcing
  - Solar forcing: day / night, seasons → periodic
  - Astronomical forcing: position of Earth relative to the sun → periodic
  - Volcanic eruptions → aperiodic/random
- Internal (intrinsic) variablility
  - Recurring modes (this lecture)

Natural Climate Variability

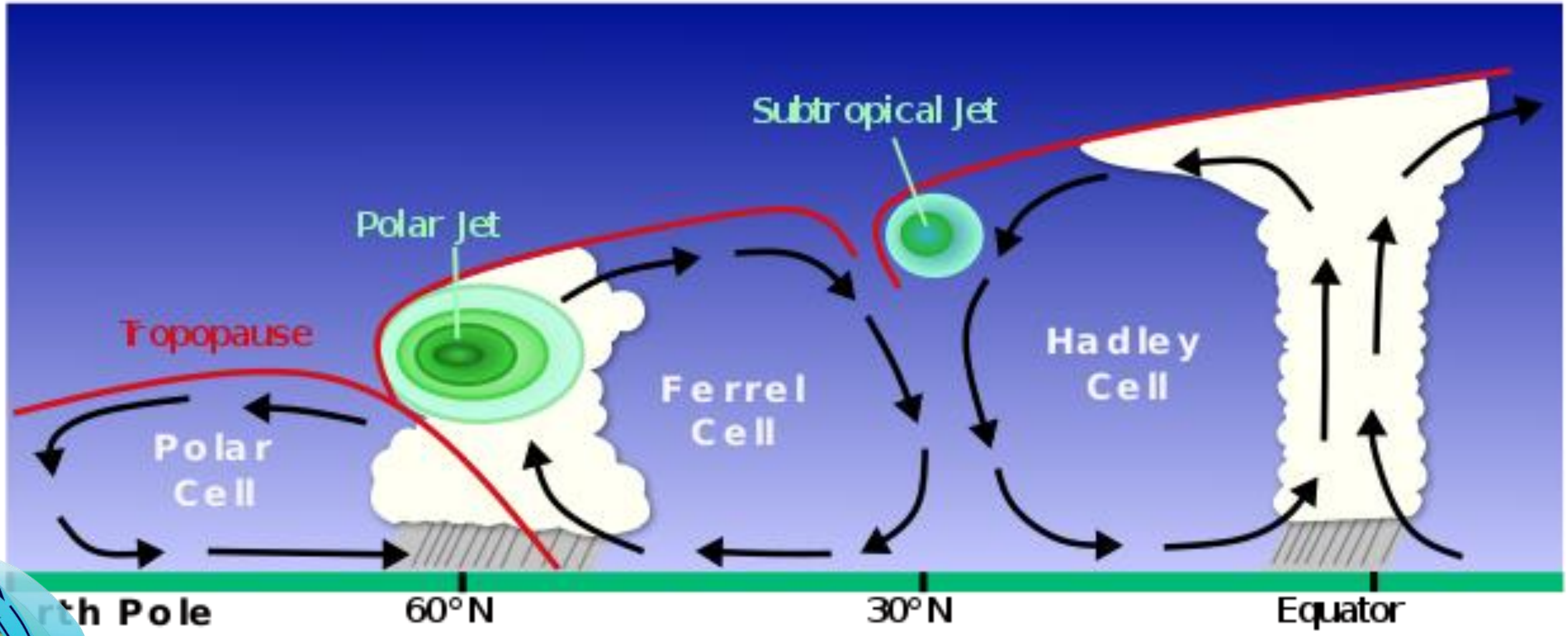
- Modes of **climate variability** are defined as **recurrent space-time structures** of variability of the climate system with intrinsic **spatial patterns, seasonality** and **timescales**.
- They can arise through the dynamical characteristics of the **atmospheric circulation** but also through **coupling between the ocean and the atmosphere**.
- The variability of the climate system at ocean- or continental-basin scales, and in particular on **seasonal-to-multidecadal timescales**, can be described to a large extent by the **occurrence and often combination of several modes of climate variability** which lead to local impacts and remote responses through teleconnection processes on top of externally forced trends.
- The concept of "**teleconnection**" refers to the ability of modes of variability to relate climate in remote regions through **associated atmospheric or oceanic pathways**.

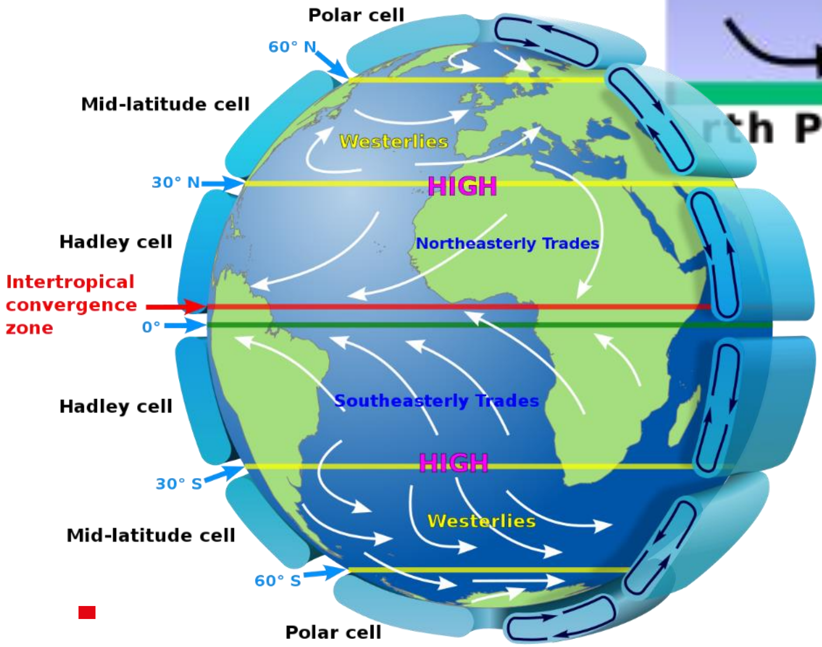
- IPCC, AR6, Annex IV

Global circulation patterns

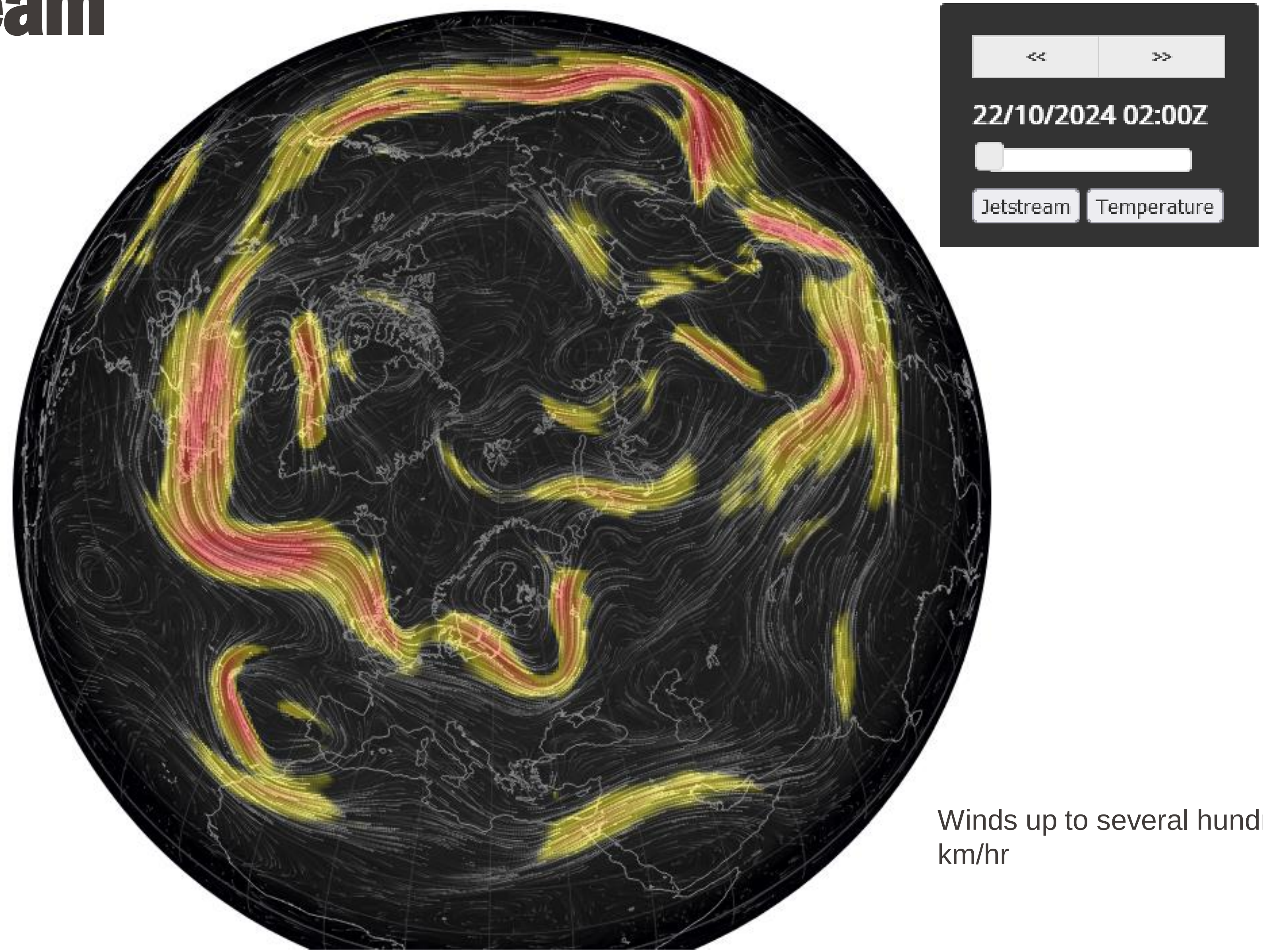


Global circulation patterns





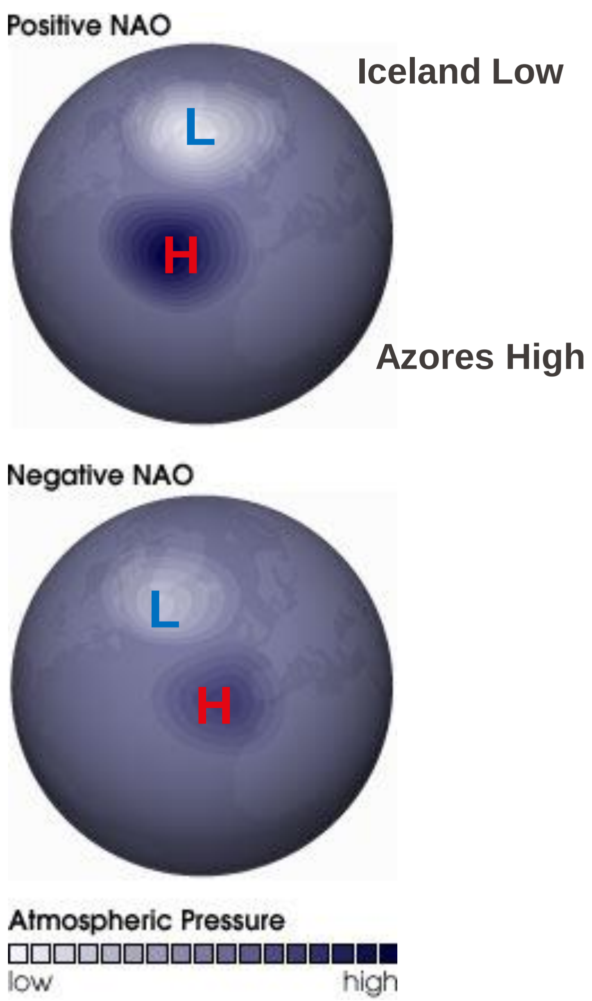
Polar jetstream



Winds up to several hundred km/hr

- https://www.netweather.tv/charts-and-data/global-jetstream#current/wind/surface/level/orthographic=-338.50,73.33,234

North Atlantic Oscilliation (NAO)

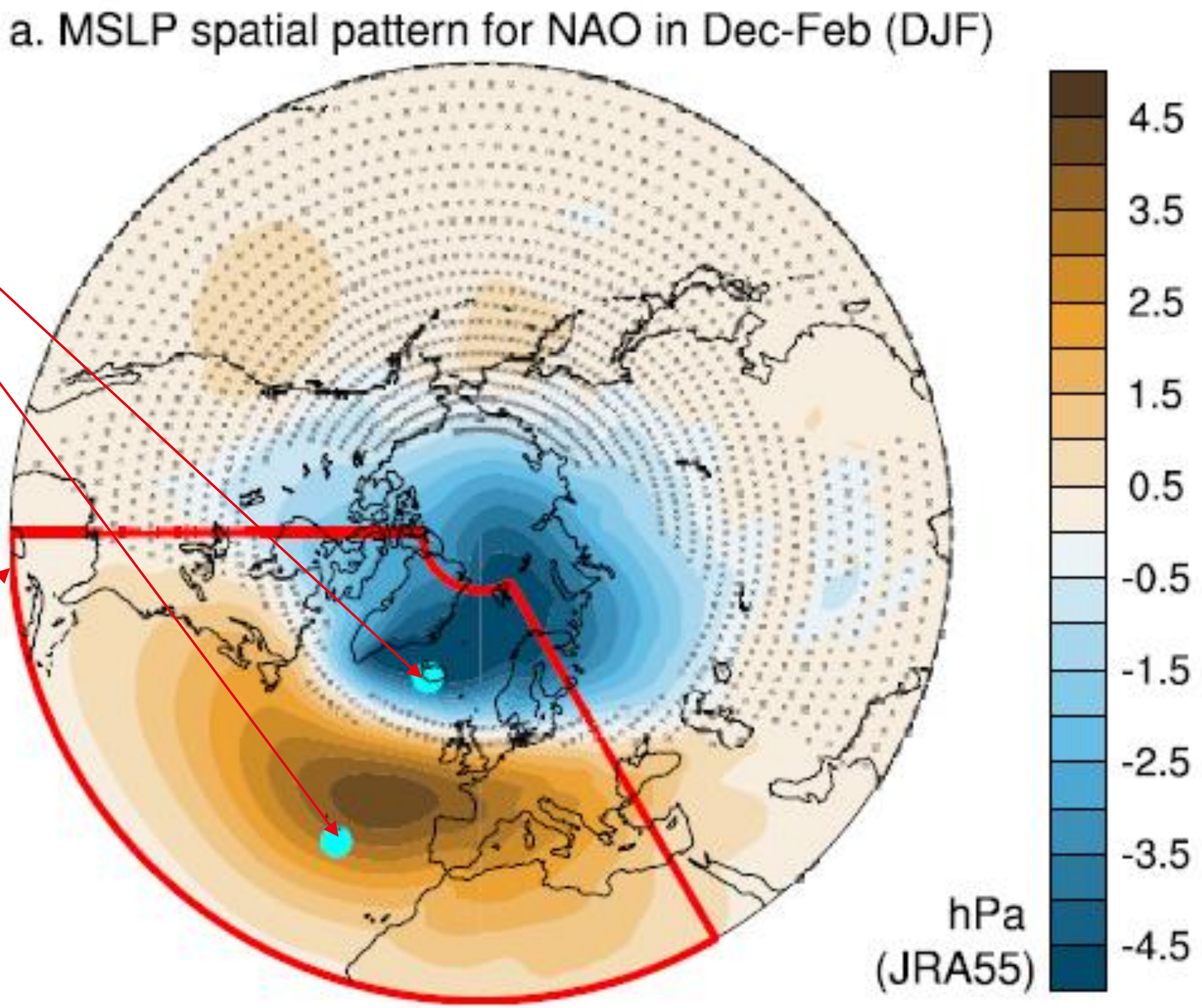


- The NAO is the main mode of climate variability over a broad North Atlantic-Europe region in all seasons for **intra-seasonal to multidecadal timescales**
- Influences the **weather** over Europe and North America: temperature, precipitation, wind
- Oscillation between pressure states of the Icelandic Low and Azores High. **Atmospheric variability.**
- **Positive** mode: **strong** high and **strong** low
- **Negative** mode: **slackened** high and **slackened** low
- Controls **extremes** over Europe and Eastern North America: cold waves, very strong wind episodes related to explosive storminess, heavy precipitation events...

North Atlantic Oscilliation (NAO)

These two observatories on Iceland and the Azores are often used to calculate the **weather station-based NAO index**: i.e. the difference of the normalized sea level pressures (SLP) anomalies at the Azores minus those on Iceland

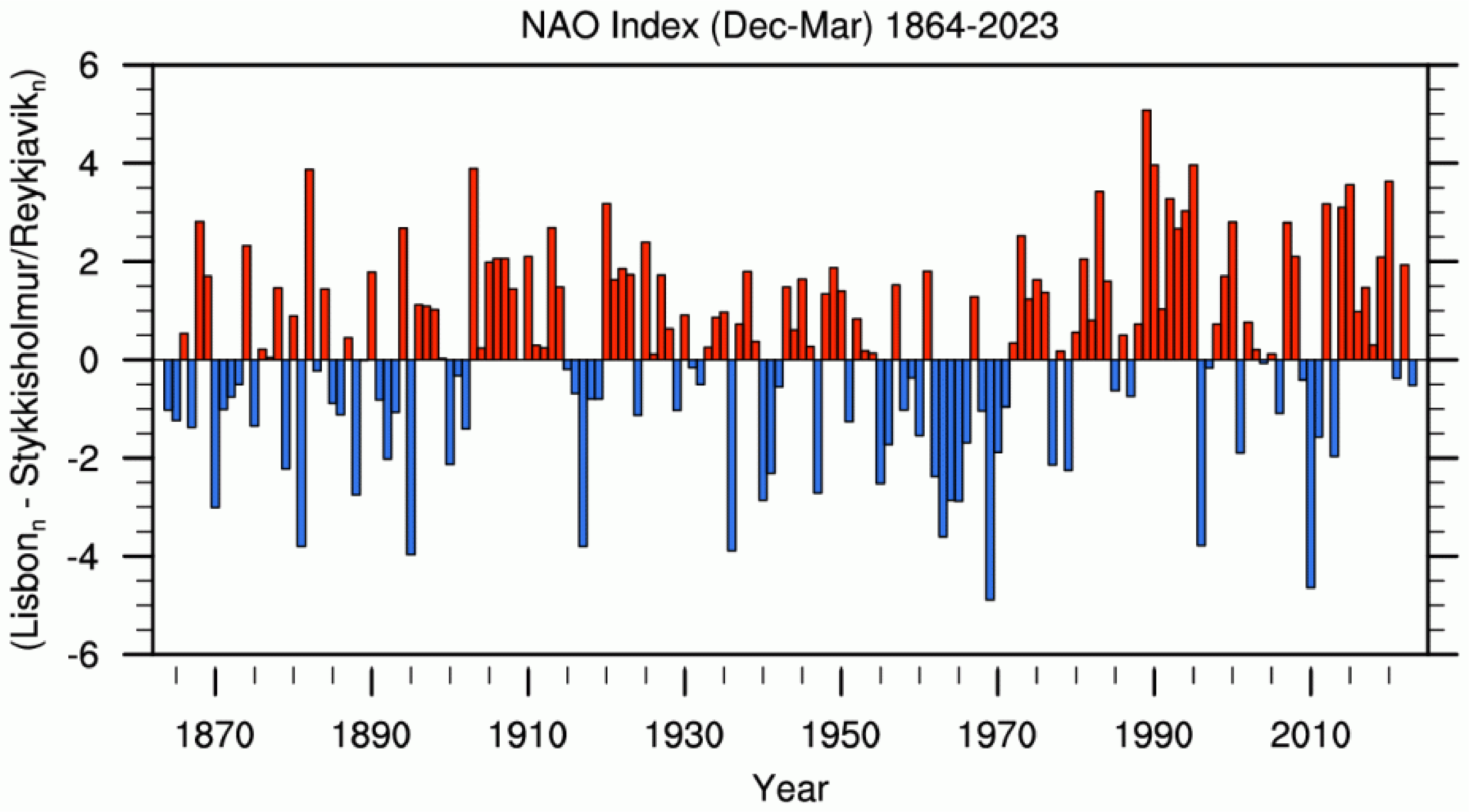
Caveat: does not capture the latitudinal spread.
→ Calculate the index from the normalized average across longitudes at 35 °N and 65°N (zonal average).



IPCC, AR6, Annex IV, Fig. AIV1

MSLP mean sea level pressure

NAO Index



Winter (December through March) index of the NAO based on the difference of normalized sea level pressure (SLP) between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland since 1864.

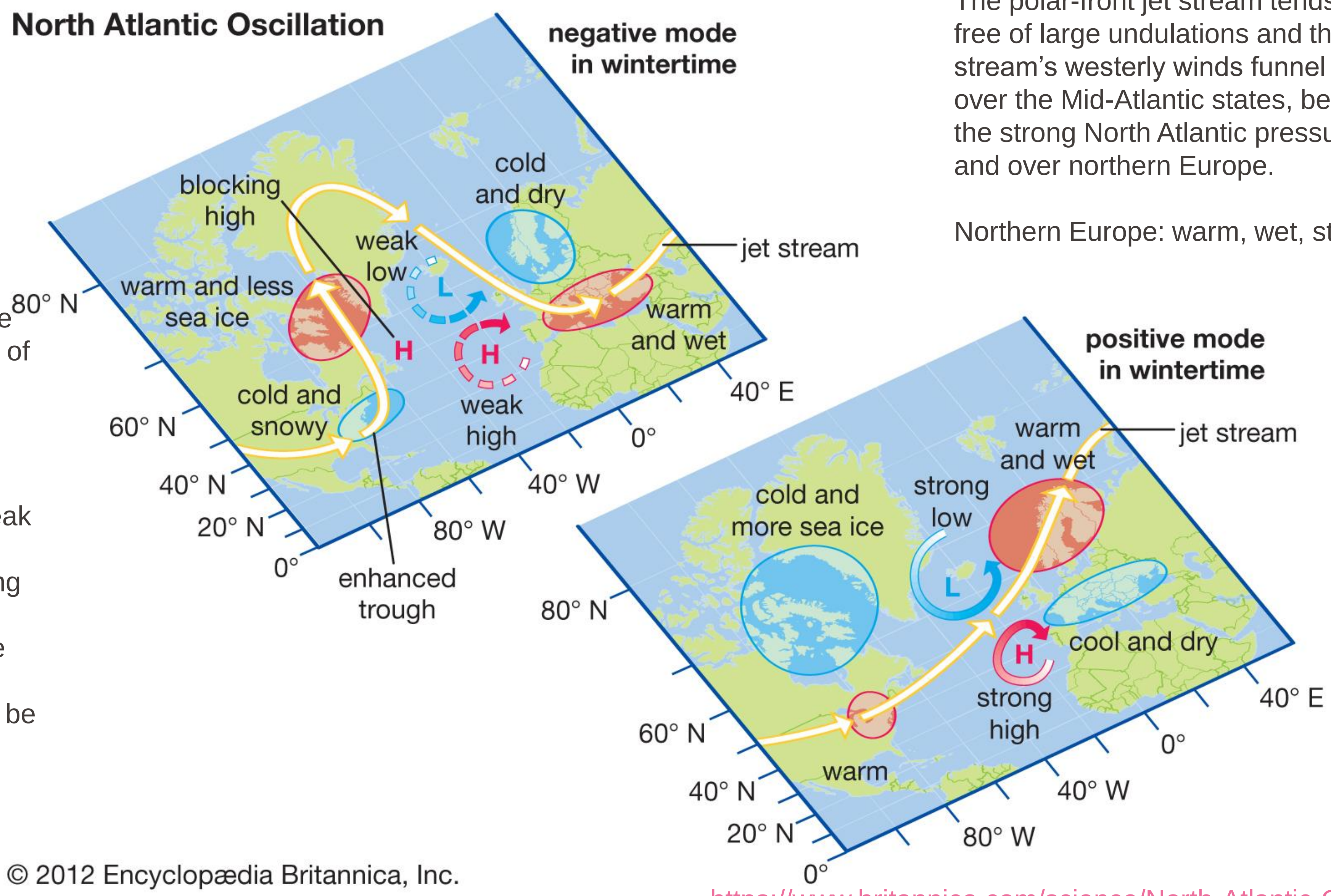
The SLP values at each station were normalized by removing the long-term mean and by dividing by the long-term standard deviation. Both the long-term means and standard deviations are based on the period 1864-1983.

Normalization is used to avoid the series being dominated by the greater variability of the northern station.

- https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based

North Atlantic Oscilliation (NAO)

Negative mode:
During winters governed by the negative mode of the NAO, colder conditions are brought to eastern North America and northern Europe mainly by more-frequent intrusions of Arctic air. North America receives additional snow, while Europe receives less precipitation than normal. The drier conditions over northern Europe result from the weak state of the pressure cells over Iceland and the North Atlantic during the NAO's negative mode; the reduced pressure gradient over the region slows the pace of westerly winds, which allows cold, dry air to be drawn into northern Europe from northern Russia and the Arctic.



Positive mode:
The polar-front jet stream tends to be free of large undulations and the jet stream's westerly winds funnel storms over the Mid-Atlantic states, between the strong North Atlantic pressure cells, and over northern Europe.

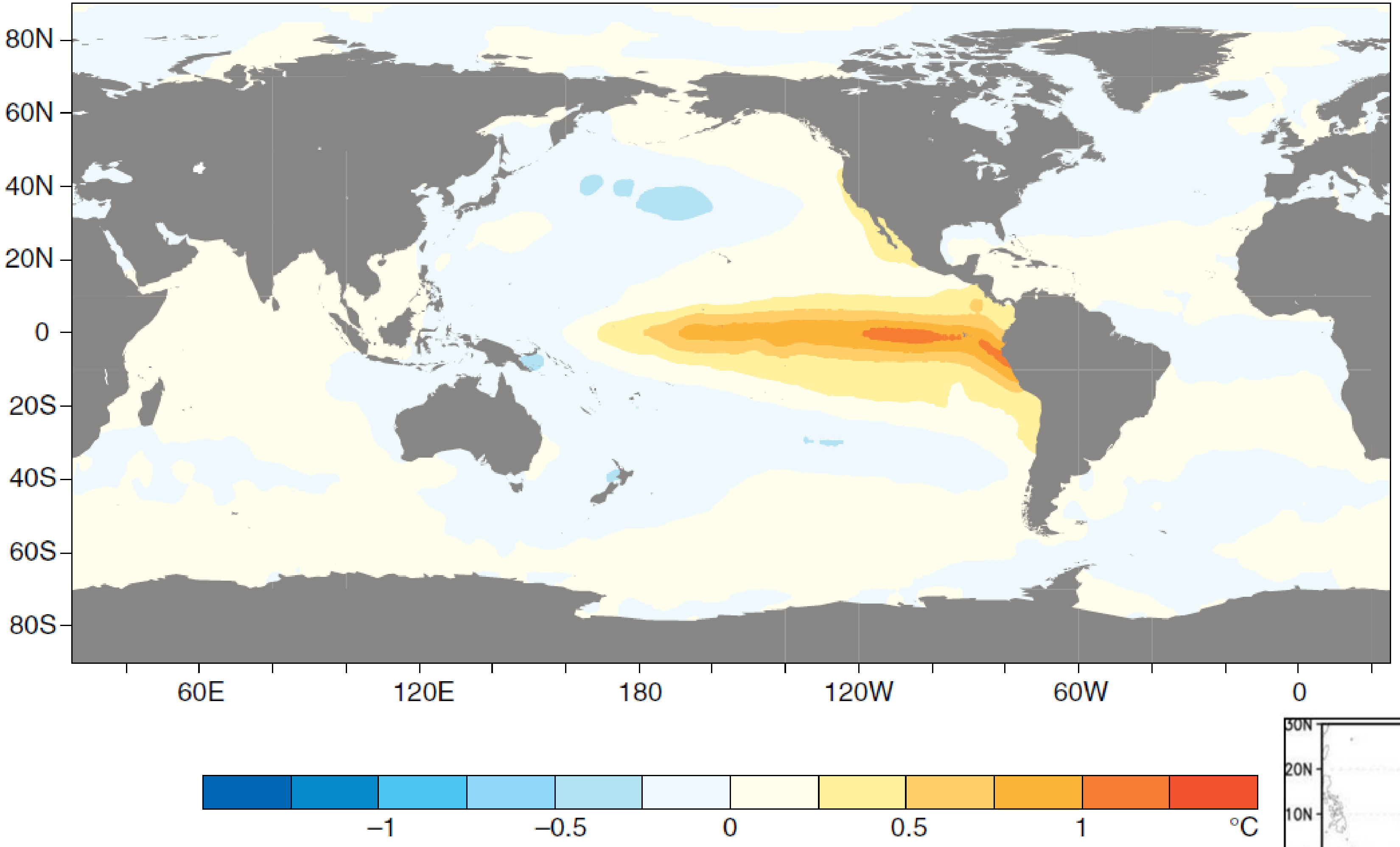
Northern Europe: warm, wet, stormy

https://www.britannica.com/science/North-Atlantic-Oscillation

El Niño Southern Oscillation (ENSO)

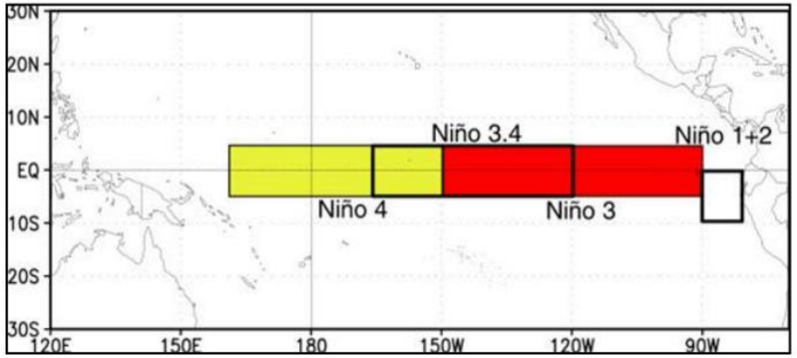
- **Coupled ocean-atmosphere** climate variability mode.
- The El Niño Southern Oscillation (ENSO) refers to the **large-scale** alternation between anomalous warming (El Niño) and cooling (La Niña) of central/eastern equatorial Pacific sea surface temperature (SST) that coincide with changes in winds and precipitation.
- ENSO is the **primary mode of tropical variability on interannual timescales**. It also triggers climate teleconnections in many other parts of the world.
- **ENSO is consistently the main modulator of the global surface temperature at interannual timescales. It is the main predictor of climate on seasonal to interannual timescales.**

El Niño sea surface temperature anomaly (El Niño)



Unusally warm water off the western coast of South America.
Normally there is the northward flowing and cold Humboldt current.

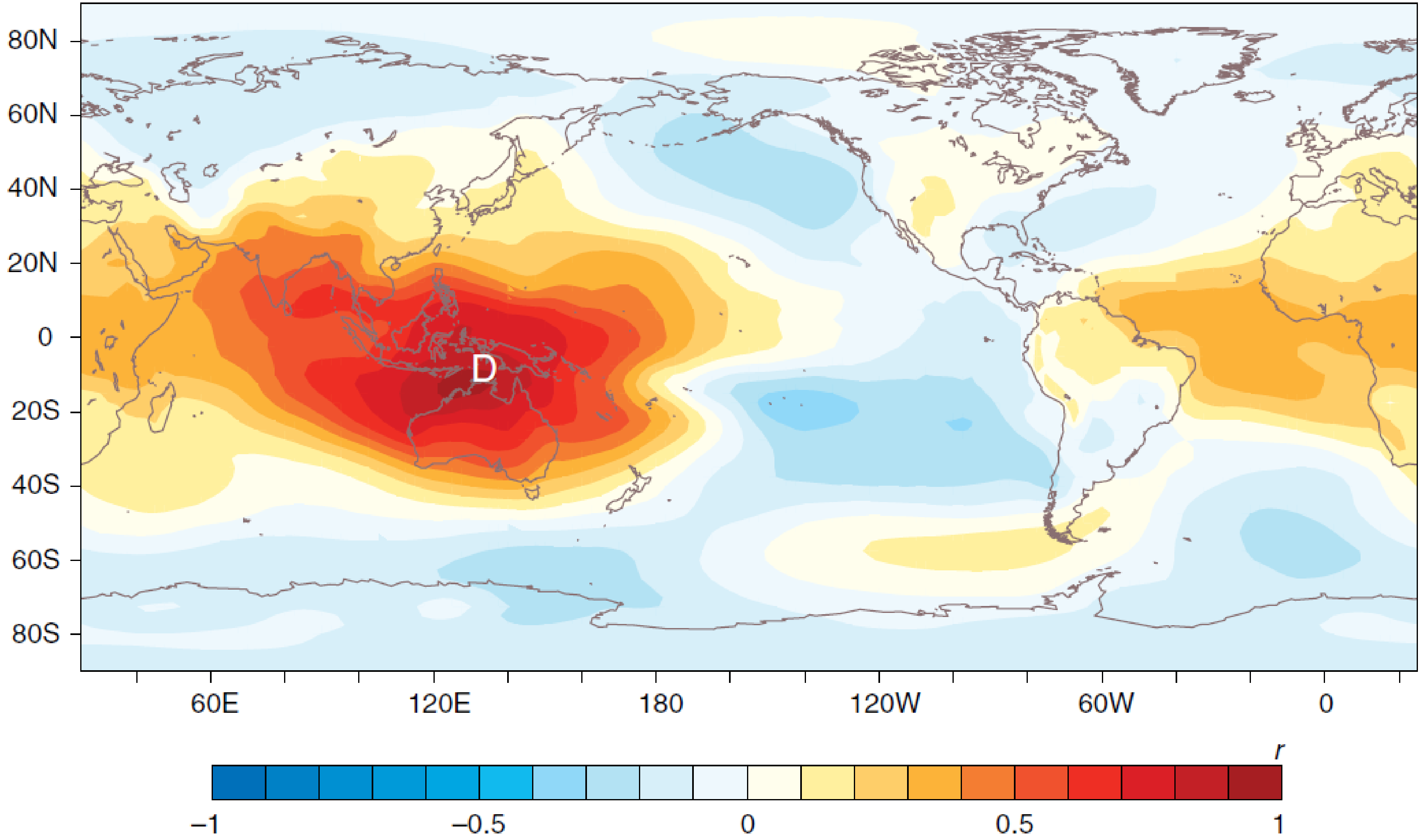
Regions where sea surface temperatures are monitored.



- Wallace and Hobbs, 2006, Fig. 10.18

https://en.wikipedia.org/wiki/El_Ni%C3%B1o%E2%80%93Southern_Oscillation

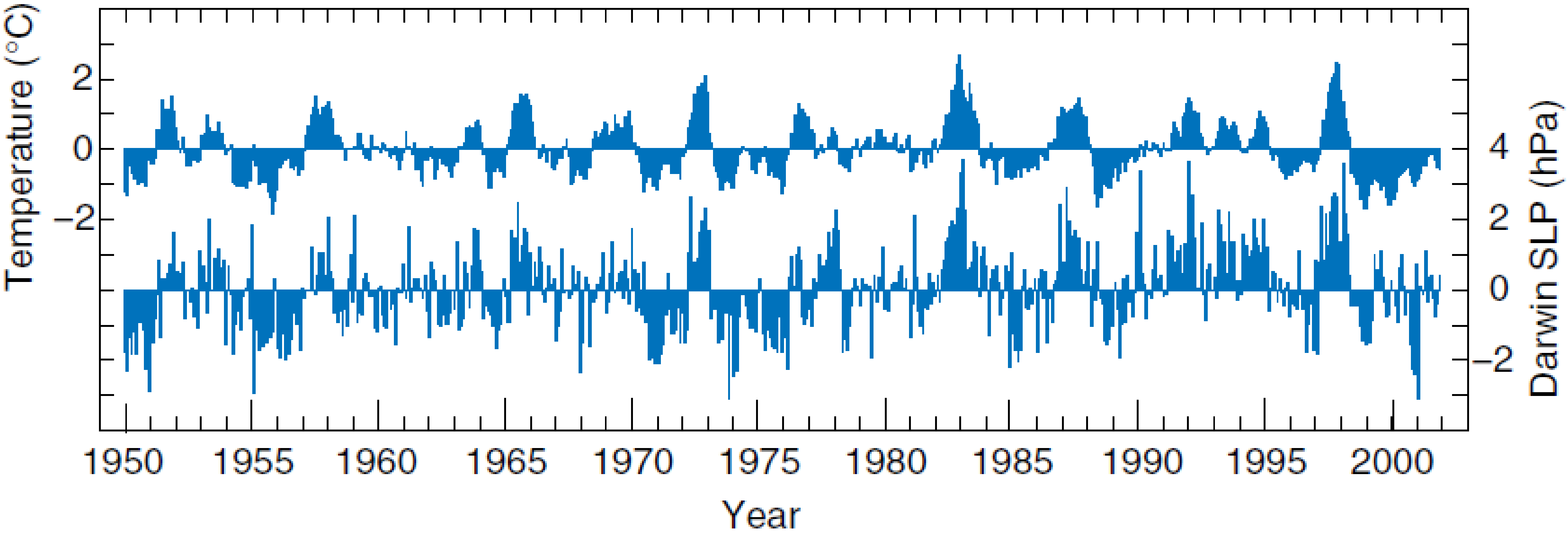
El Niño sea level pressure anomaly (Southern Oscillation)



- Wallace and Hobbs, 2006, Fig. 10.19

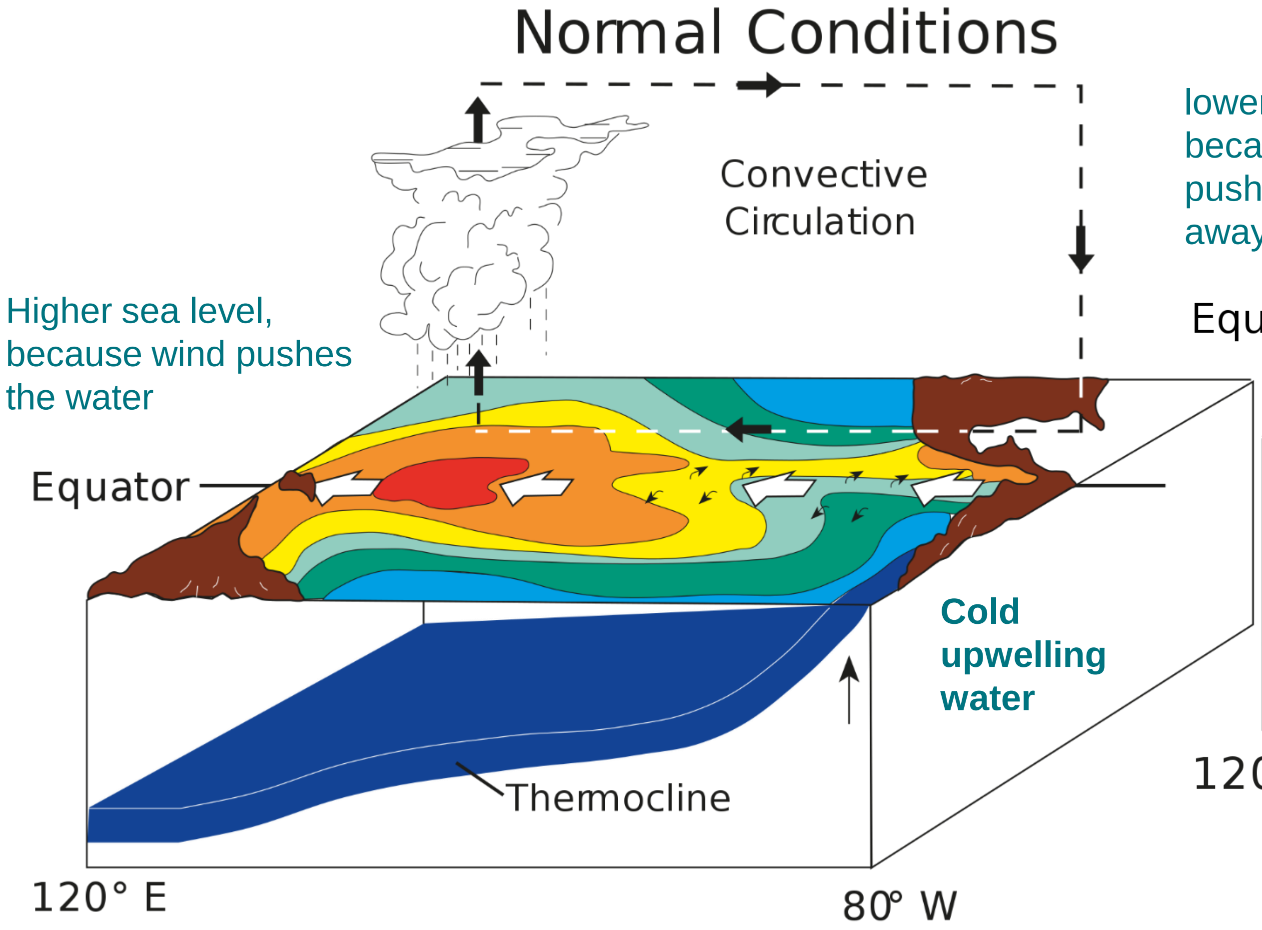
D = Darwin, Australia

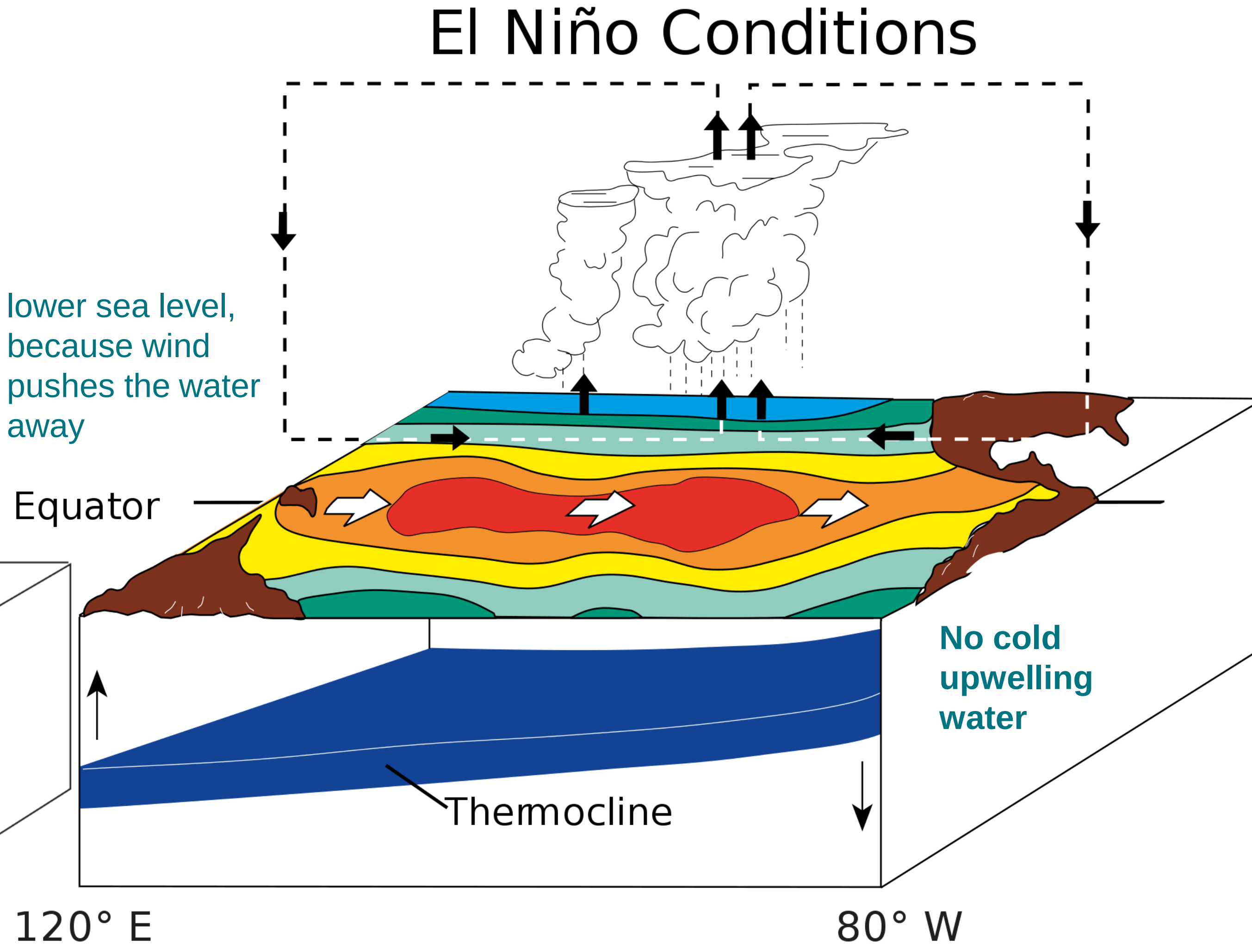
Strong coupling between atmosphere and ocean



- Wallace and Hobbs, 2006, Fig. 10.20

The mechanism





- https://en.wikipedia.org/wiki/El_Ni%C3%B1o%E2%80%93Southern_Oscillation

El Niño 2023

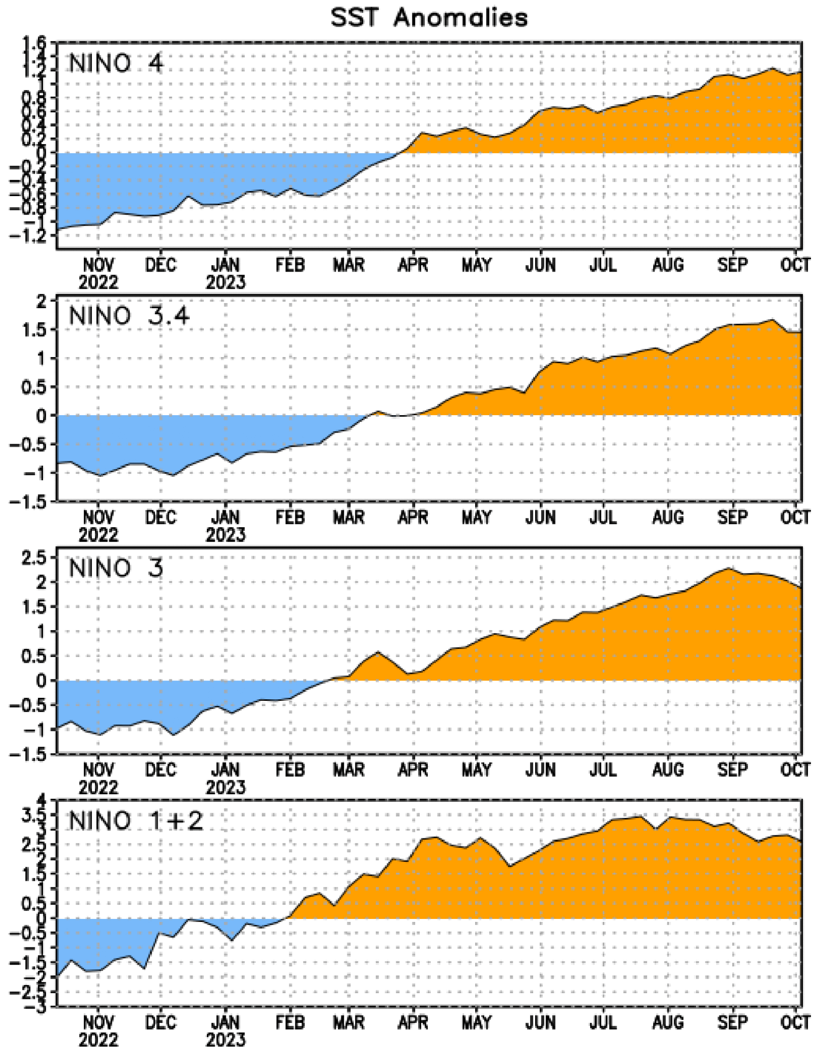


Figure 2. Time series of area-averaged sea surface temperature (SST) anomalies (°C) in the Niño regions [Niño-1+2 (0°-10°S, 90°W-80°W), Niño-3 (5°N-5°S, 150°W-90°W), Niño-3.4 (5°N-5°S, 170°W-120°W), Niño-4 (5ºN-5ºS, 150ºW-160ºE)]. SST anomalies are departures from the 1991-2020 base period weekly means.

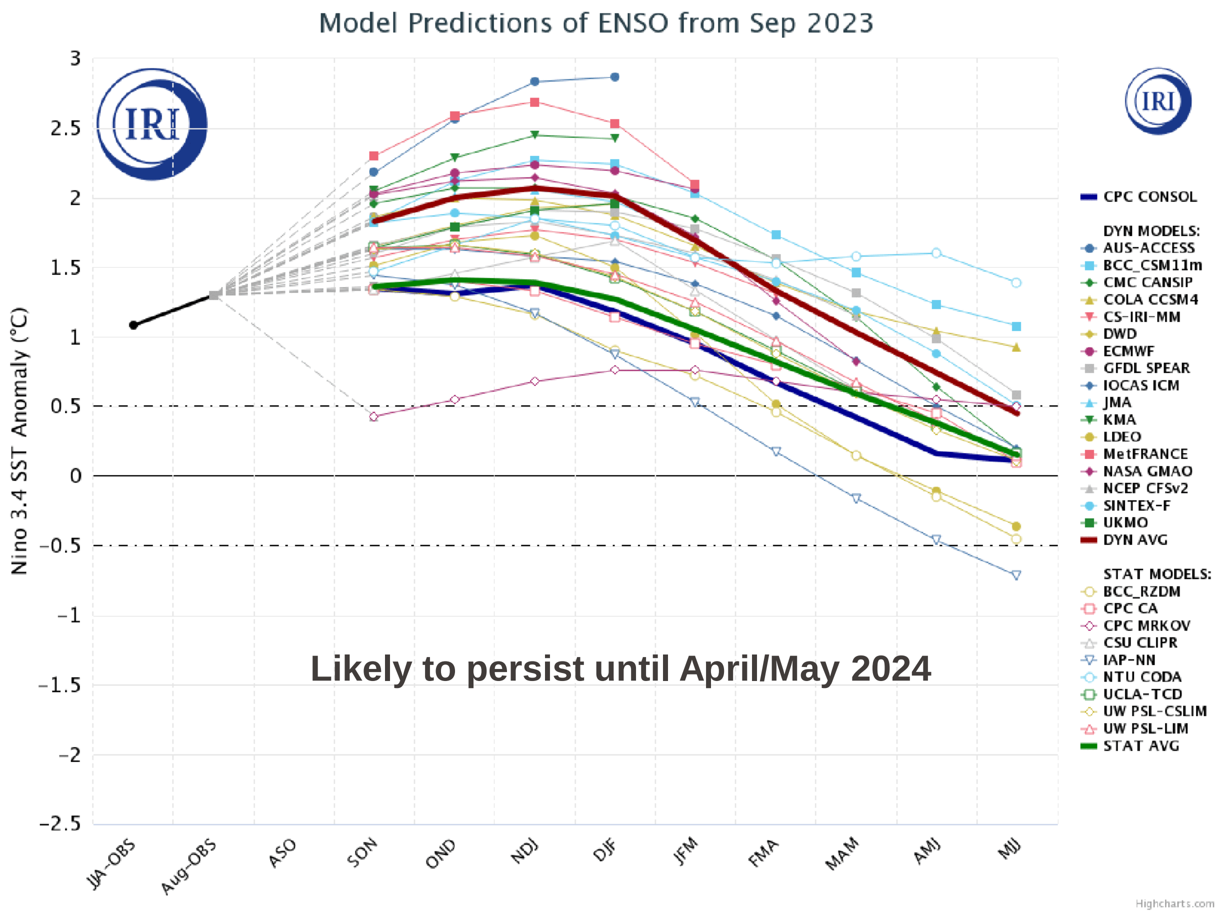
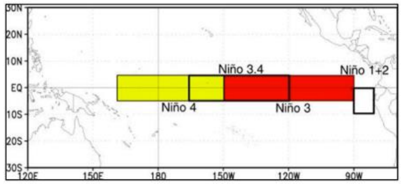


Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure updated 20 September 2023 by the International Research Institute (IRI) for Climate and Society.



https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.shtml

El Niño 2024

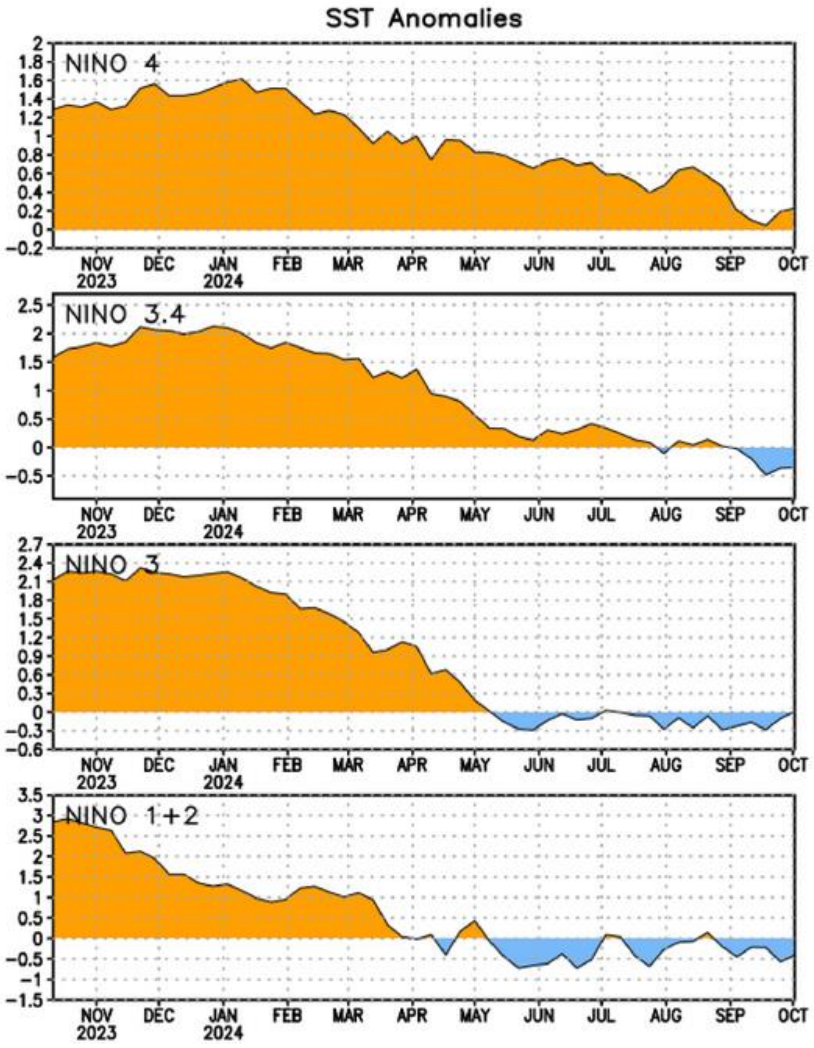


Figure 2. Time series of area-averaged sea surface temperature (SST) anomalies (°C) in the Niño regions [Niño-1+2 (0°-10°S, 90°W-80°W), Niño-3 (5°N-5°S, 150°W-90°W), Niño-3.4 (5°N-5°S, 170°W-120°W), Niño-4 (5°N-5°S, 150°W-160°E)]. SST anomalies are departures from the 1991-2020 base period weekly means. Data credit: UKMet OSTIA.

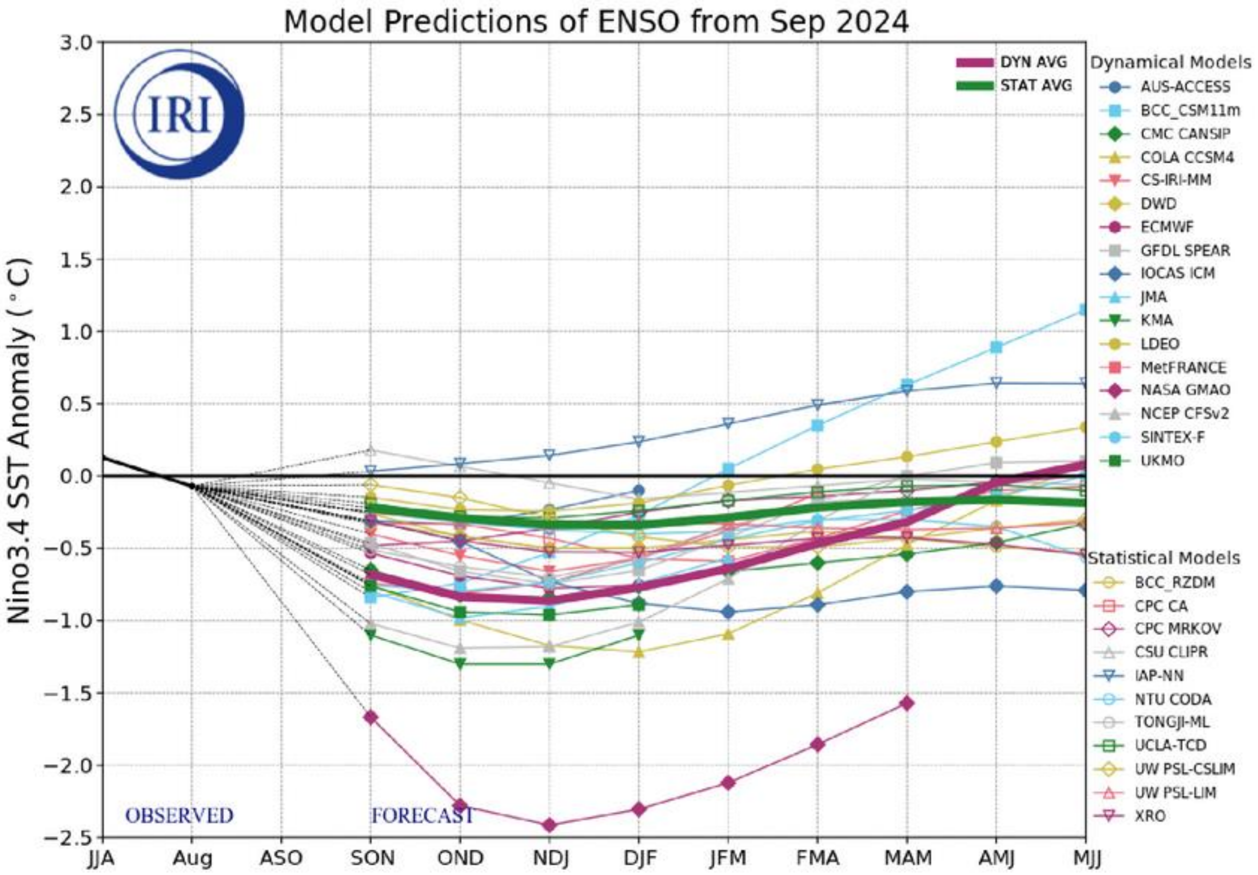
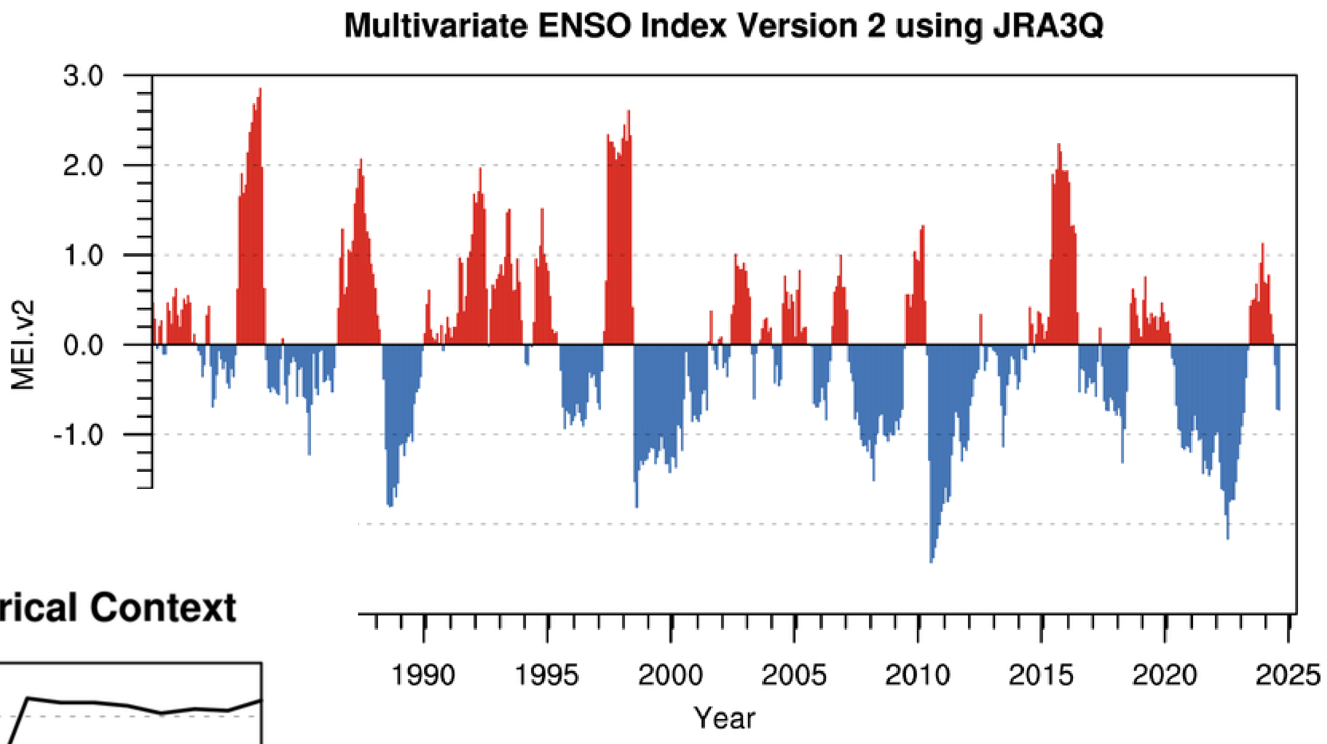
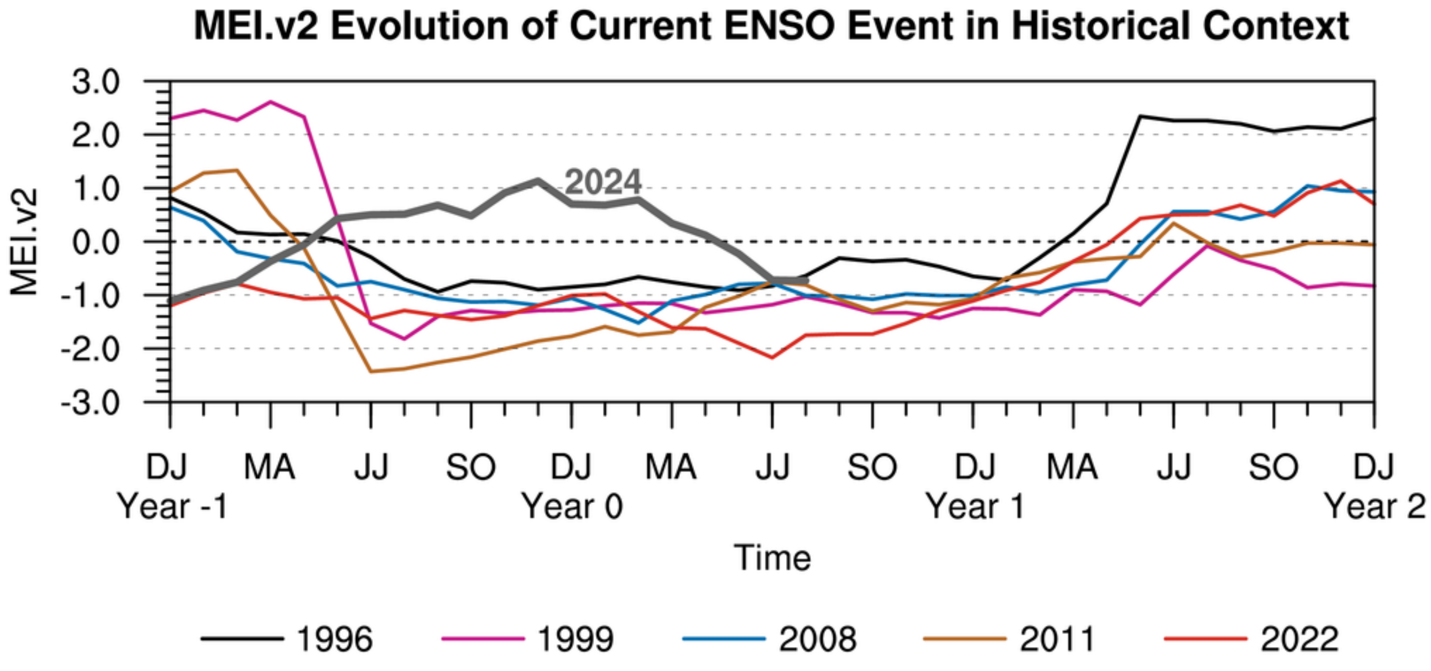


Figure 6. Forecasts of sea surface temperature (SST) anomalies for the Niño 3.4 region (5°N-5°S, 120°W-170°W). Figure updated 19 September 2024 by the International Research Institute (IRI) for Climate and Society.

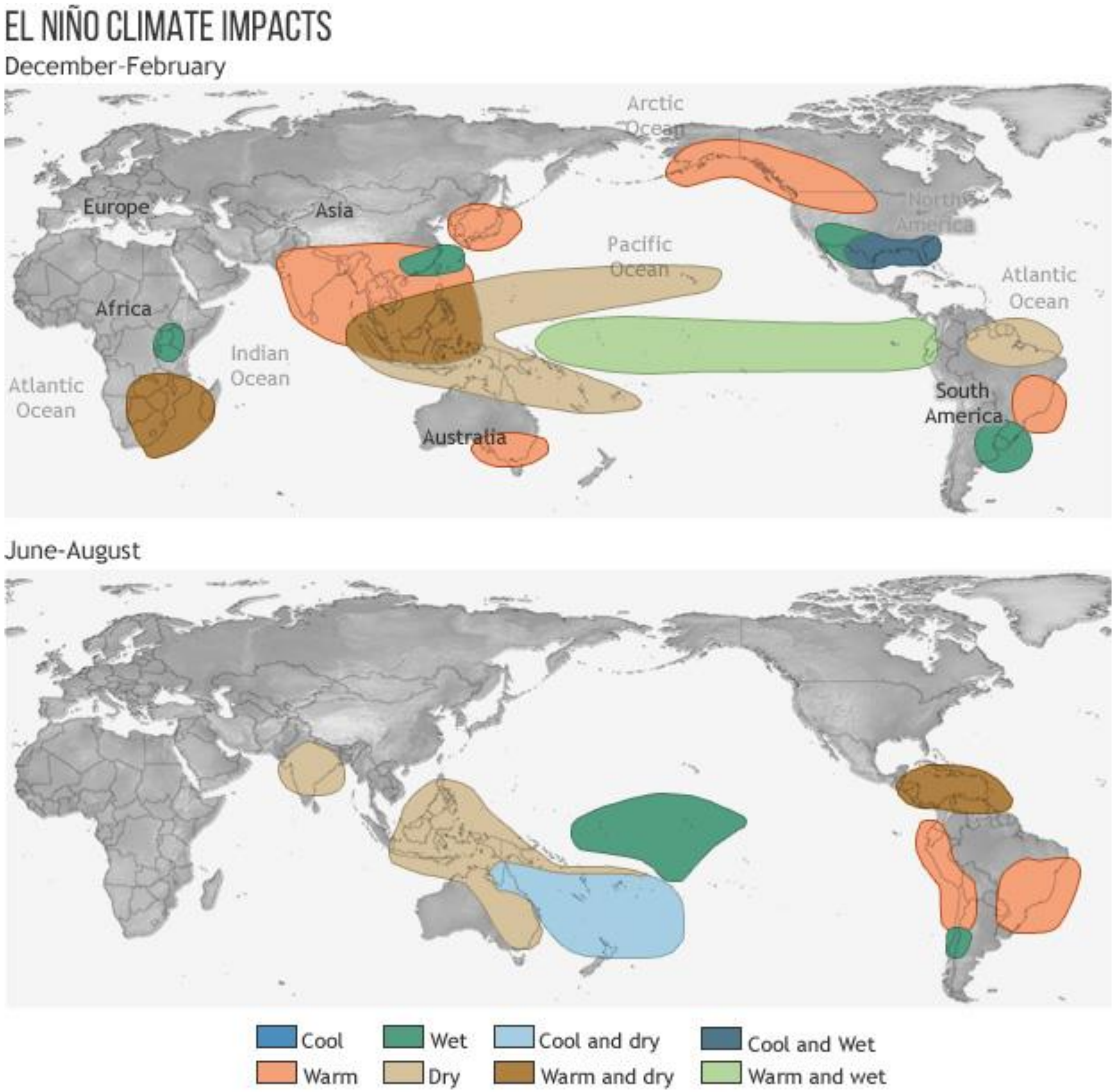
ENSO status and forecast

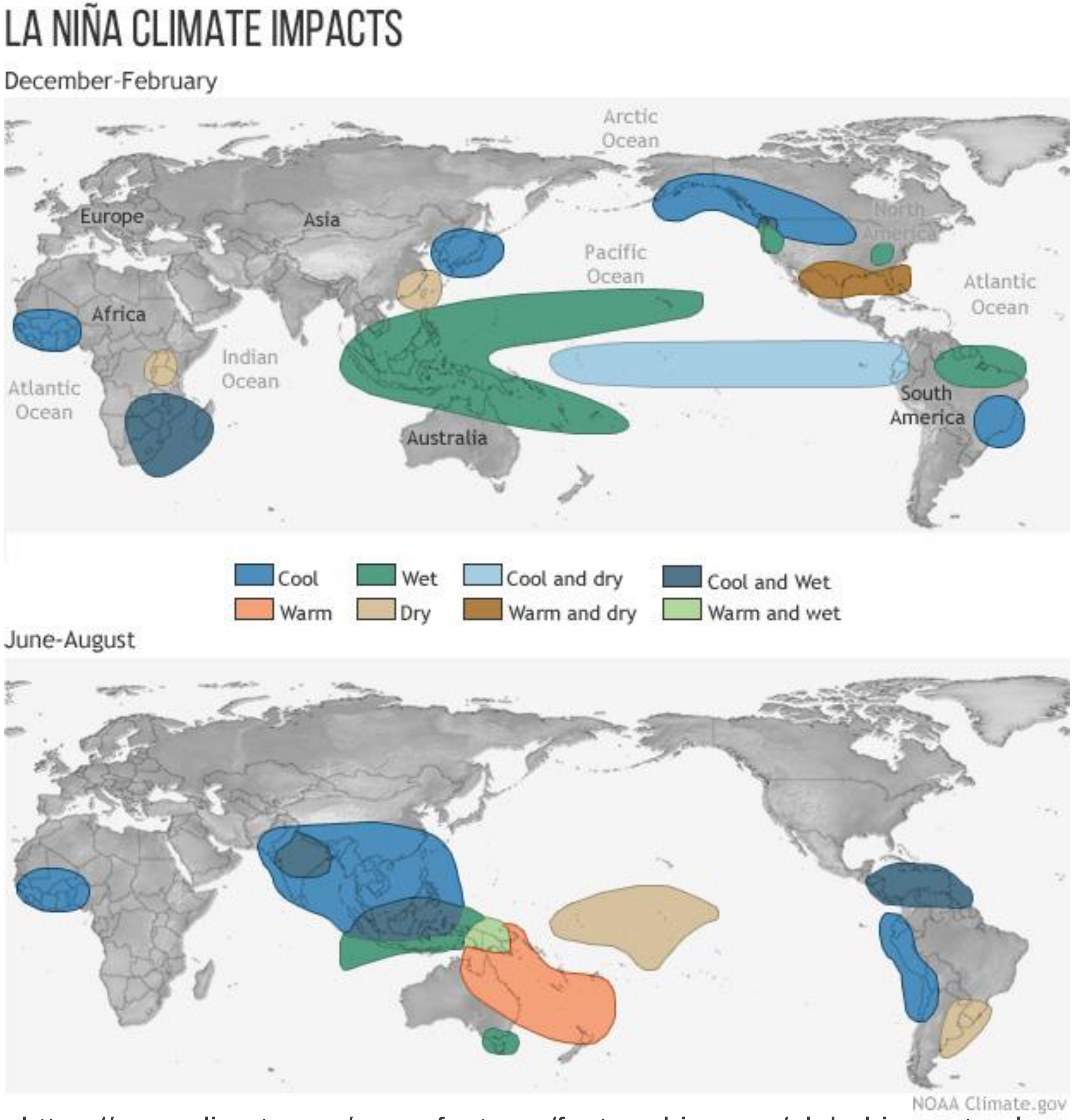




https://psl.noaa.gov/enso/mei/

Impacts

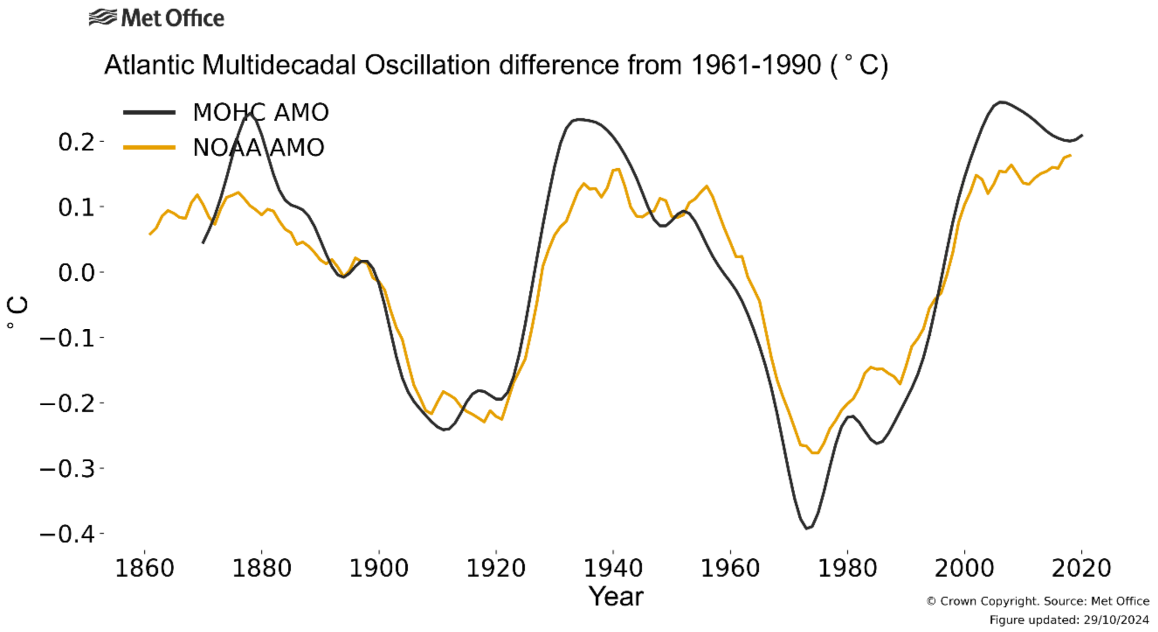




https://www.climate.gov/news-features/featured-images/global-impacts-el-ni%C3%B1o-and-la-ni%C3%B1a

AMO - Atlantic Multidecadal Oscillation

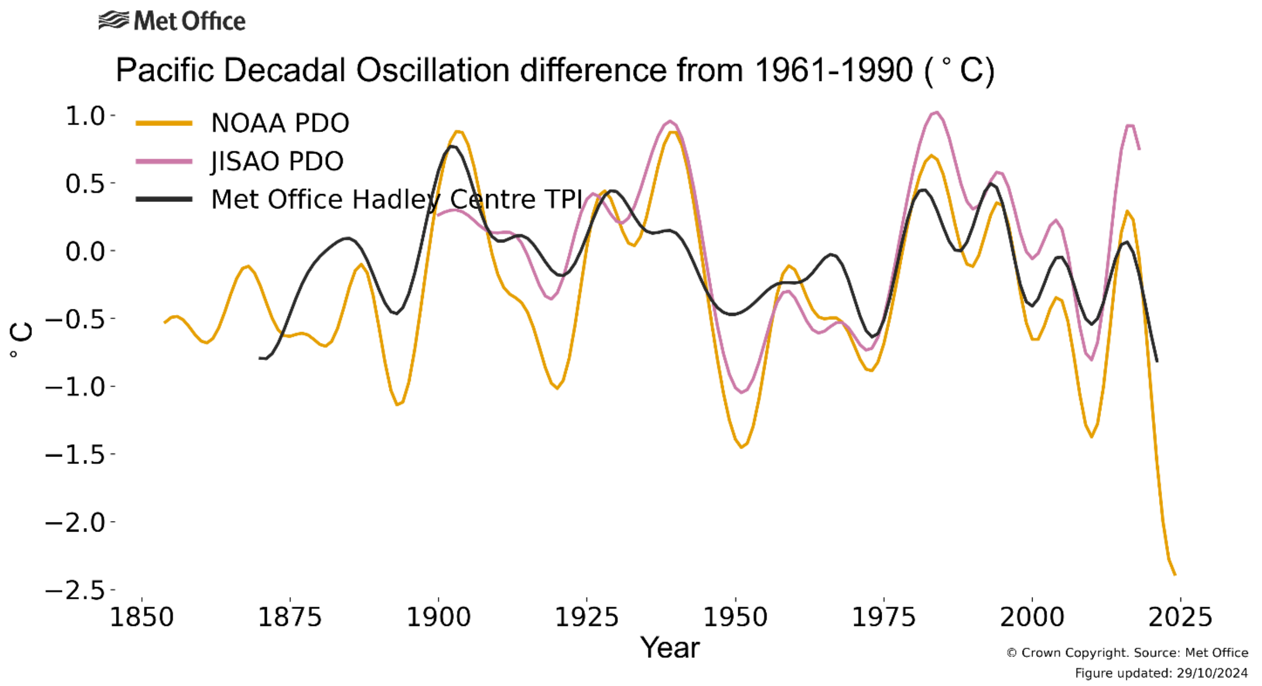
- The Atlantic Multidecadal Oscillation (or AMO for short) has two phases, a **positive phase** where **sea-surface waters** in the North Atlantic are **warmer than average** and a **negative phase** when they are **colder than average**.
- It is not entirely clear what **causes** changes in the AMO. Long records suggest that it is a long-lived natural fluctuation generated spontaneously within the ocean-atmosphere system. There is also evidence that switches in phase can be driven by changes in the output of anthropogenic pollution.
- The different phases of the AMO have been associated with a variety of **impacts**.
  - positive phase: associated with reduced Arctic sea ice, melting of the Greenland ice sheet, increased hurricane activity in the North Atlantic and increased rainfall over the Sahel region of sub-Saharan Africa.
  - negative phase: cooling at high latitudes, reduced hurricane activity and a drier Sahel.

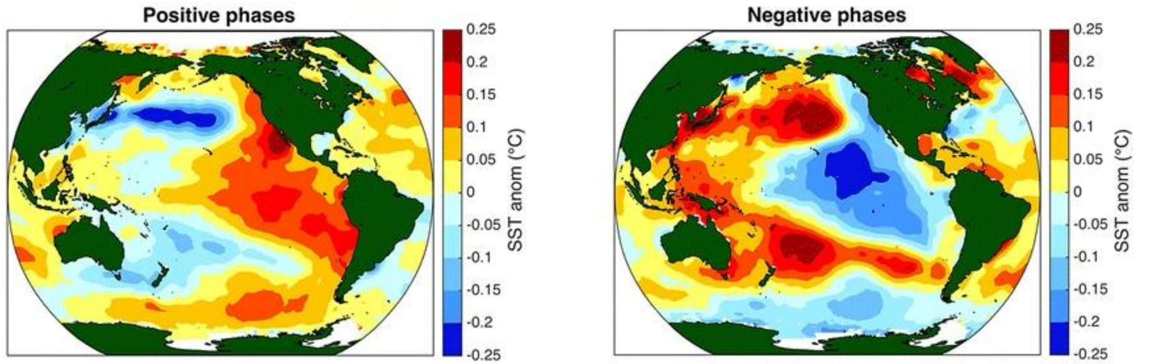


https://climate.metoffice.cloud/climate_modes.html

PDO - Pacific Decadal Oscillation

- The Pacific Decadal Oscillation describes climatic variations over vast areas of the Pacific Ocean over periods of 20 to 30 years. At shorter time scales, there is some overlap between the PDO and other high-frequency variability such as ENSO. Therefore, the PDO series is typically smoothed to remove high-frequency variability and emphasise the slower changes.
- PDO has positive and negative phases.
- There are a number of apparent "shifts" in the PDO between the two phases, which occur around 1925, 1945, 1976 and 2000. The shift from the positive to negative phase around 2000 has been associated with a recent slowdown in the rate of global temperature change. The exact causes of the "shifts" are unknown and may be due to a combination of different mechanisms acting at different time scales.





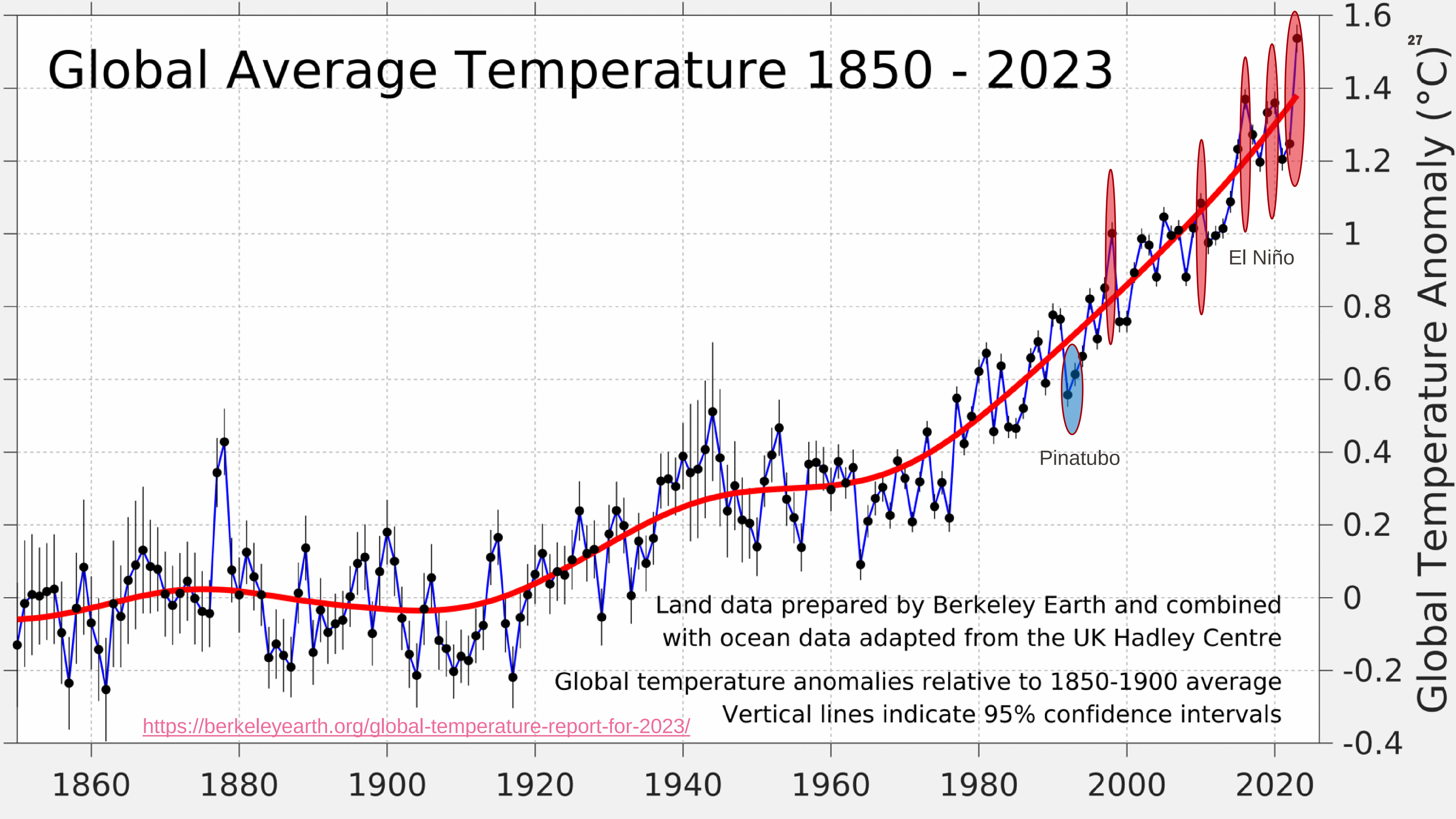
- https://climate.metoffice.cloud/climate_modes.html, https://link.springer.com/article/10.1007/s00382-015-2525-1/figures/6

Further modes of Climate Variability

- There are several more modes.

Mode	Name
AMV	Atlantic Multidecadal Variability
AMO	Atlantic Multidecadal Oscillation
DO	Dansgaard Oeschger Event
ENSO	El Niño-Southern Oscillation
HE	Heinrich Event
MJO	Madden Julian Oscillation
NAO	North Atlantic Oscillation
PDO	Pacific Decadal Oscillation
IPO	Interdecadal Pacific Oscillation
QBO	Quasi-biennial Oscillation
SOVC	Southern Ocean Centennial Variability

- Von der Heydt et al. (2021), 10.1016/j.gloplacha.2020.103399


Global Average Temperature 1850 - 2023
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
Global Temperature Anomaly (°C)
1860
1880
1900
1920
1940
1960
1980
2000
2020
El Niño
Pinatubo
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/

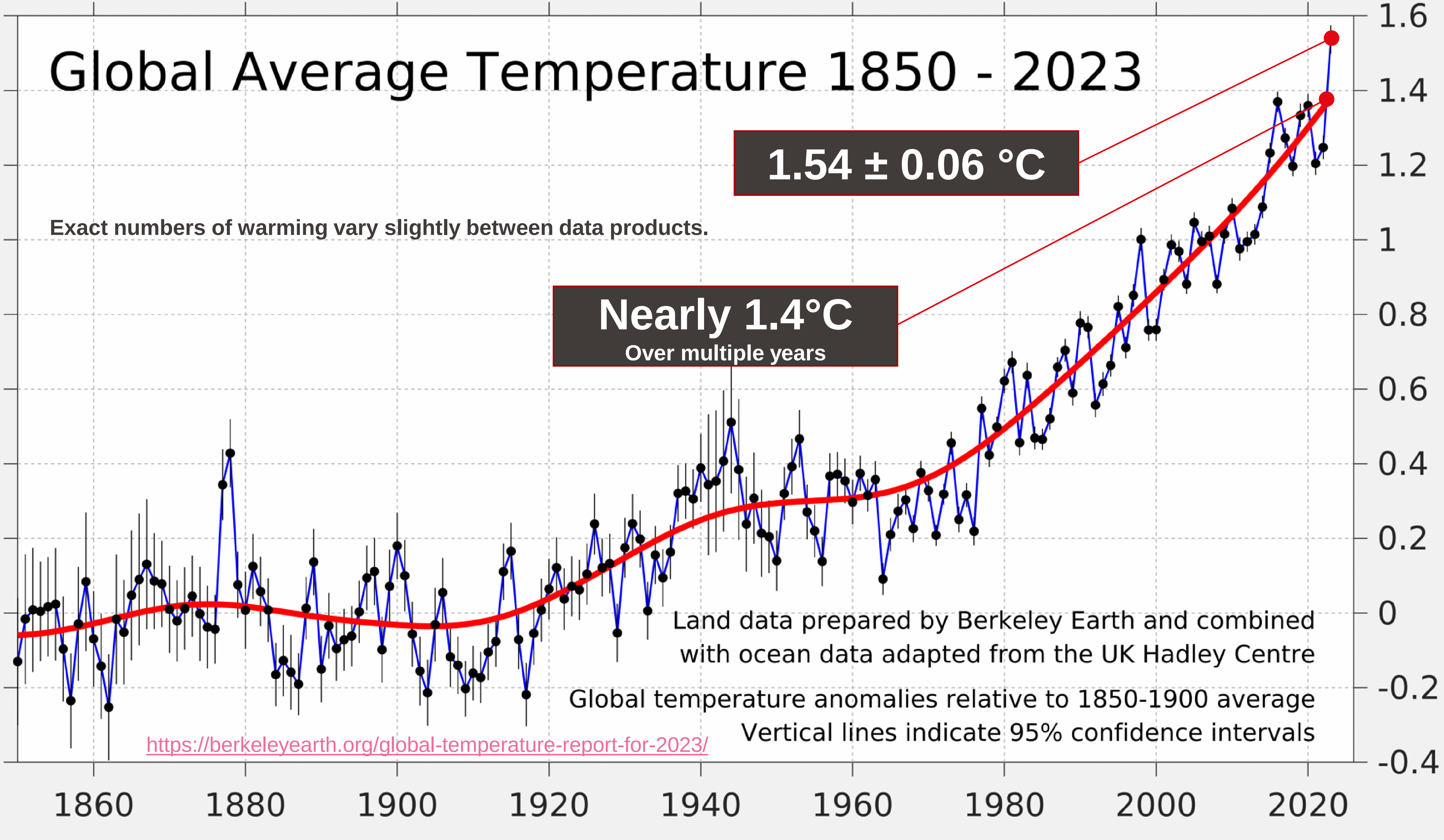
Why do we need to understand climate variability?

- Many modes of variability are **driven by internal climate processes** and are a **critical potential source of climate predictability** on sub-seasonal to decadal timescales.
- It is essential to understand the physical processes behind the past evolution of the modes of climate variability in order to **assess, with confidence**, their future changes.
- External forcing may affect their temporal (occurrence, variance, seasonality, persistence etc.) or spatial properties and associated teleconnections.
  - → meaning anthropogenic climate change can change natural climate variability.
  - → key research area for extremes

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


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)
1.6
1.4
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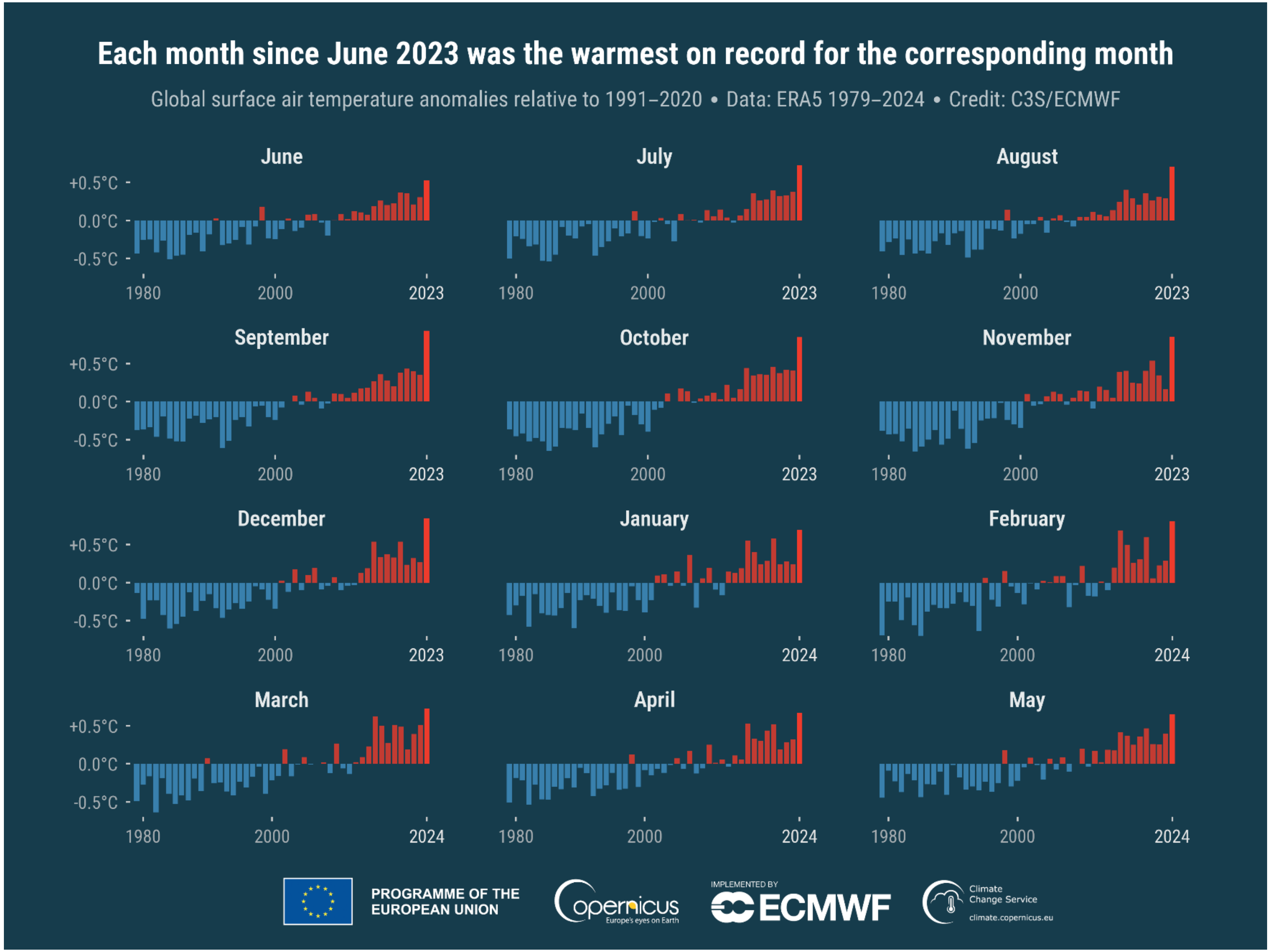
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1860
1880
1900
1920
1940
1960
1980
2000
2020

Record temperatures since June 2023



- The record series continued through July 2024.

Breaching 1.5°C much faster than expected?

- 66% chance that at least one full year between 2023 and 2027 will be above 1.5°C above preindustrial temperatures (WMO). → 2023 was > 1.5°C
- 2024 will be hottest year on record, very likely, and that in La Niña conditions
- Not the same consideration: one year vs. long-term average
- BUT
  we are extremely close to the 1.5°C target and heading towards 2-3°C warming by 2100 with 2 main implications:
  - More vigorous emissions reduction needed.
  - The most climate sensitive regions and related tipping points might cause drastic impacts sooner than anticipated.

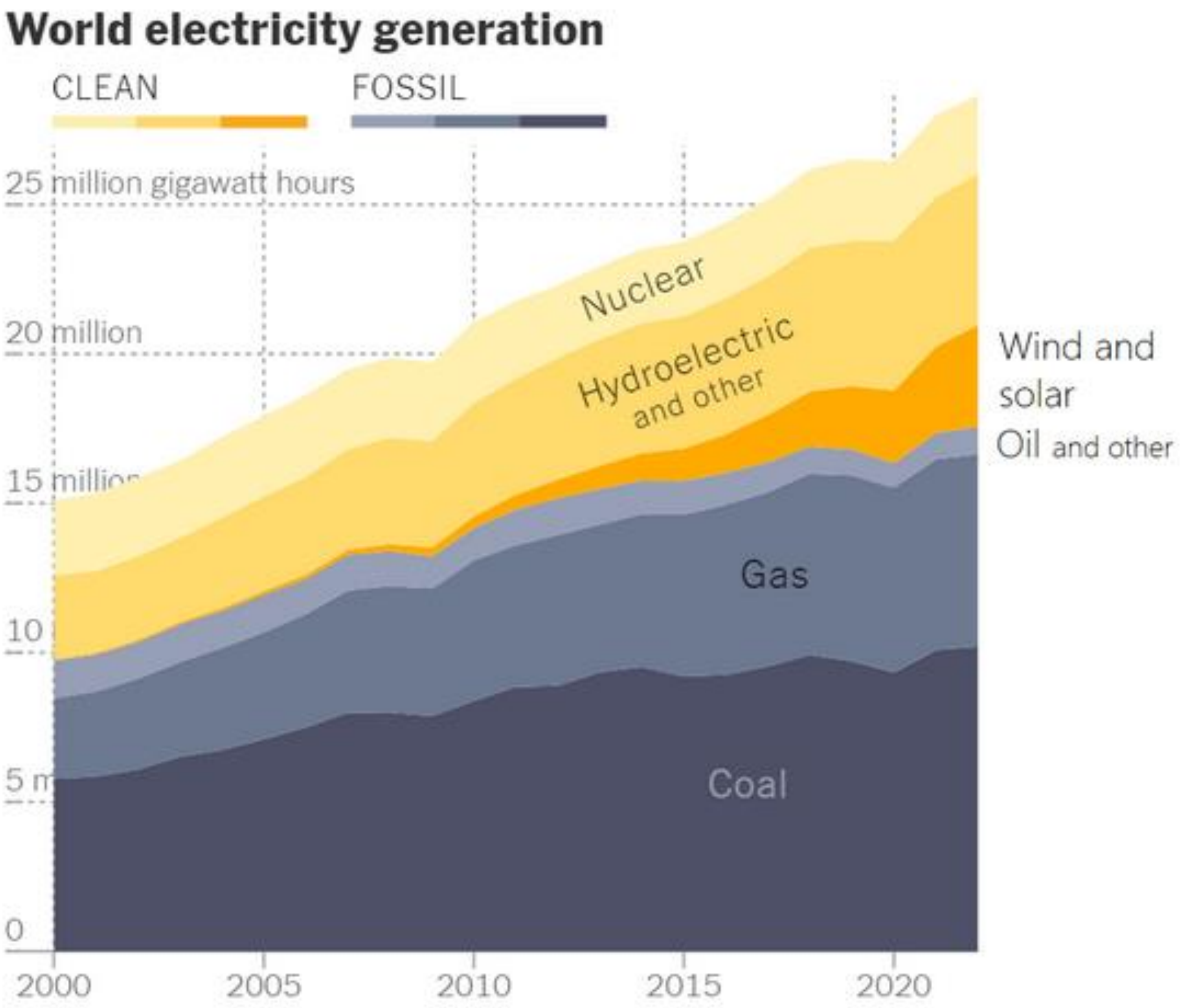
Reading Task – «Energy transition»

1. Trajectory of renewables: «Renewable energy passes 30% of world's electricity supply"
   - See moodle file: Reading_1_Guardian, or
   - https://www.theguardian.com/environment/article/2024/may/08/renewable-energy-passes-30-of-worlds-electricity-supply?CMP=Share_AndroidApp_Other
2. Trajectory of electricity consumption: Global Electricity Sources
   - See moodle file: Reading_1_NYT
3. Kerry gives scathing rating on climate action: 'Is there a letter underneath Z?'
   - See moodle file: Reading_1_Guardian**b**
   - https://www.theguardian.com/us-news/2024/sep/23/new-york-climate-week-al-gore-john-kerry-condemn-fossil-fuels?CMP=Share_AndroidApp_Other

- For the discussion on 31.10.2024, think about:
  - What are the good news?
  - What are the bad news?
  - What action is needed?

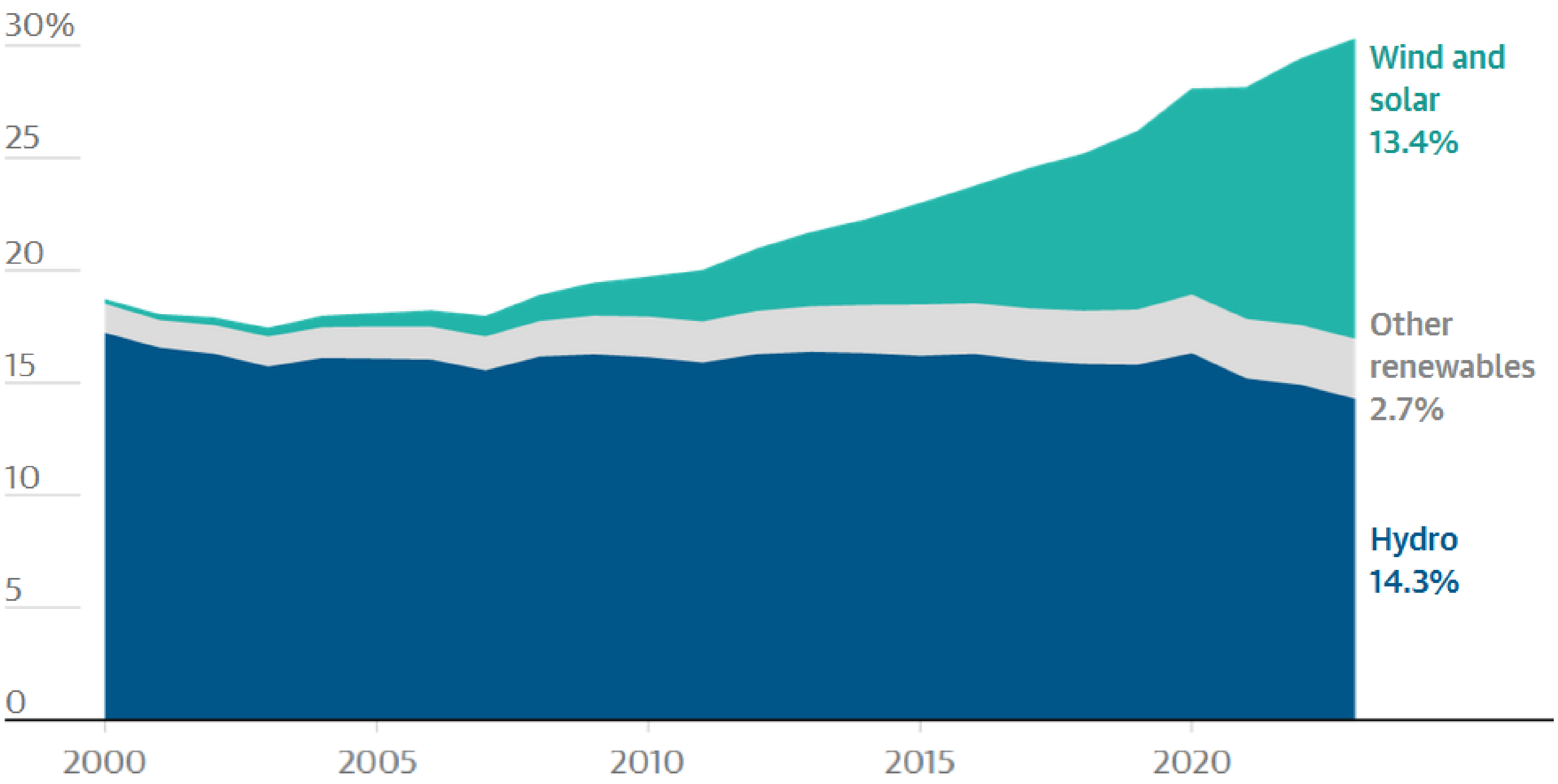
Discussion

- Good news: Renewable energy passes 30% of world's electricity supply
- Bad news: overall electricity need is on the rise
  - Electricity generation from coal, gas and oil is not declining
- Renewables have slowed the rate of increase in the use of fossils
- Major growth is observed in the renewable sector
- World leaders are aiming to grow renewables to 60% of global electricity by 2030 under an agreement struck at the UN's Cop28 climate change conference in December.



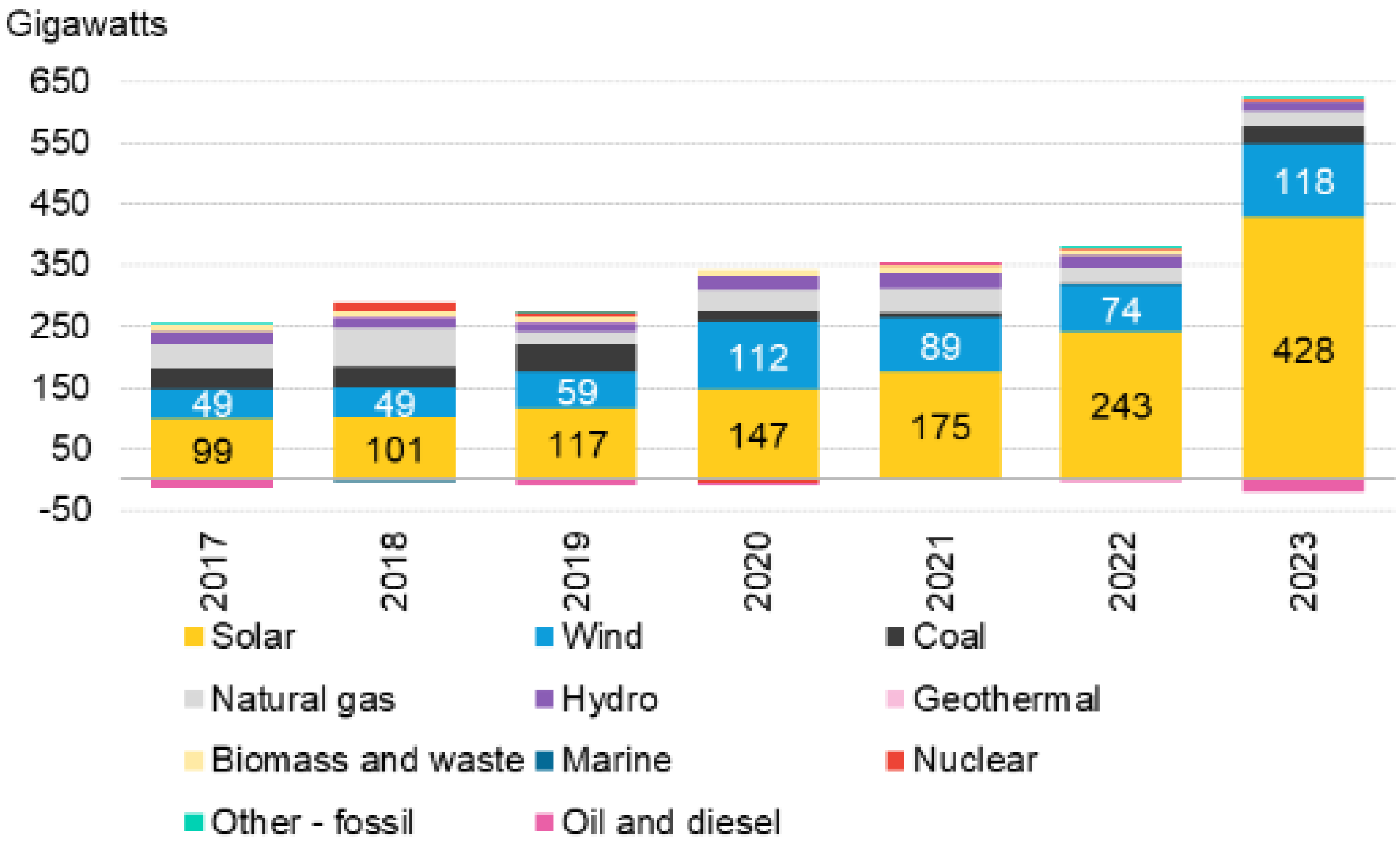
Renewables made up 30% of the global electricity mix in 2023

Share of global electricity generation from renewable sources



Guardian graphic. Source: Ember, annual electricity data

Fig 1: Global net power capacity additions by technology



Source: BloombergNEF. Note: Total net additions to global capacity. 'Other - fossil' accounts for plants that use more than one fuel or fuels other than coal, oil, gas, hydro and nuclear. Net capacity additions based on the change in the installed base year-on-year by technology, inclusive of retirements and gross additions.

- https://www.weforum.org/agenda/2024/09/global-renewables-generation-top-energy-stories/

Where do we stand with fossil vs renewables?

- UN pact signed in Dubai by nearly 200 countries in December to “transition away” from oil, coal and gas.
- World leaders are aiming to grow renewables to 60% of global electricity by 2030 under an agreement struck at the UN’s Cop28 climate change conference in December.
- This would require countries to triple their current renewable electricity capacity in the next six years, which would almost halve power sector emissions.
- US has become largest oil and gas exporter under Biden.
- Wealthy countries have been handing out new oil and gas exploration leases at record levels
- “In signing such a surge of new oil and gas licenses, they are signing away our future,” António Guterres, secretary general of the UN, said of the highest emitters in July.
- Gore said there were some optimistic signs ahead of the upcoming Cop29, to be held in Azerbaijan in November, such as the “incredible” levels of investment flowing into renewable energy like solar and wind, primarily in China, but that the pace of the transition must accelerate drastically if the world was to avoid disastrous climate impacts.