Investigating two major unknowns in the climate equation

S. Speich (LMD-IPSL) for the EUREC⁴A-OA Pis – http://eurec4a-oa.eu

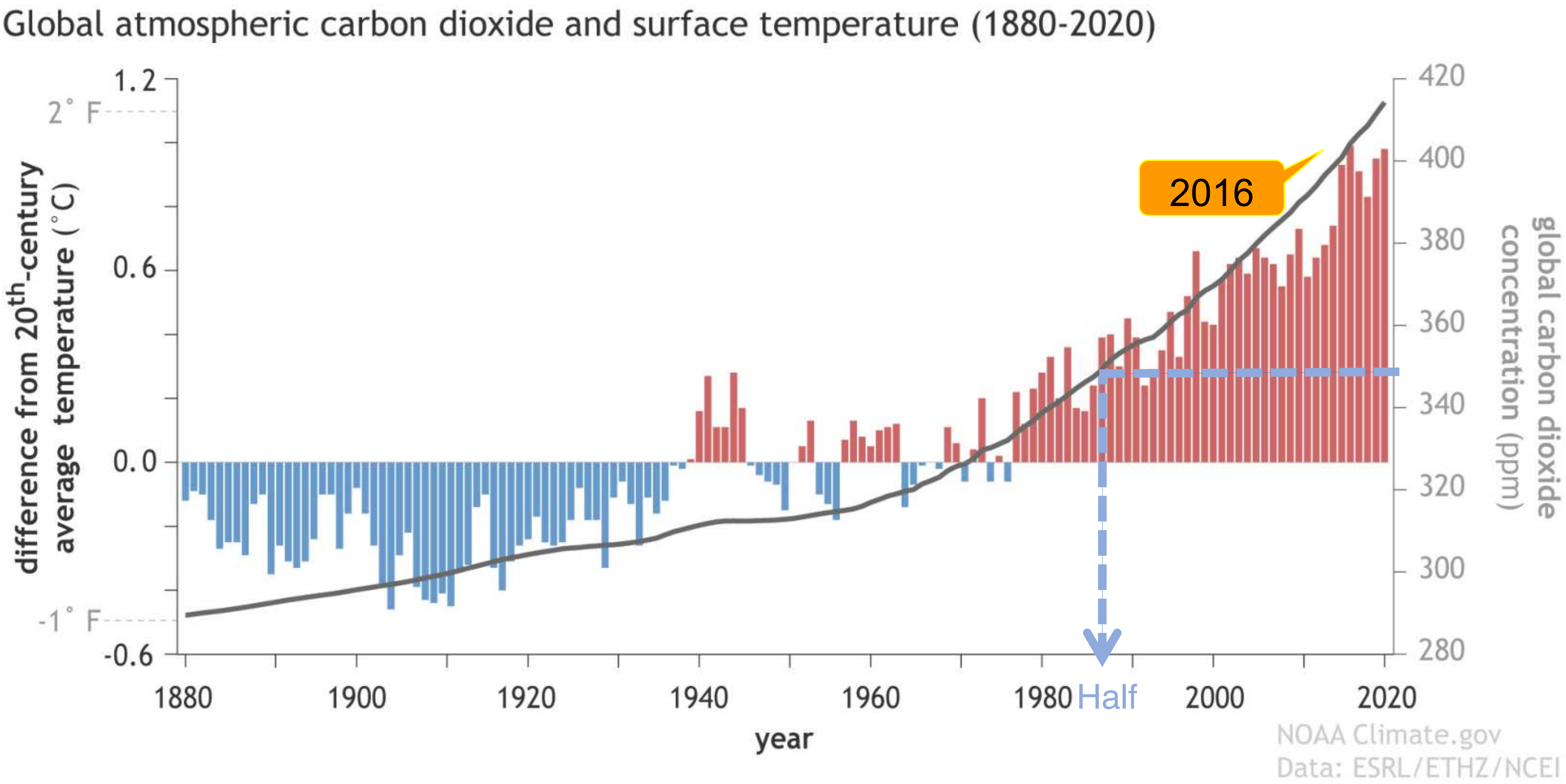
Among many others, 2 factors are major in regulating the warming of our climate linked with the increase of GHGs in the atmosphere:

- The reaction of clouds to warming
- The absorption of heat and CO_2 by the ocean and how they are transferred back to the atmosphere

The Earth climate is changing as never before: What do we observe and know ?

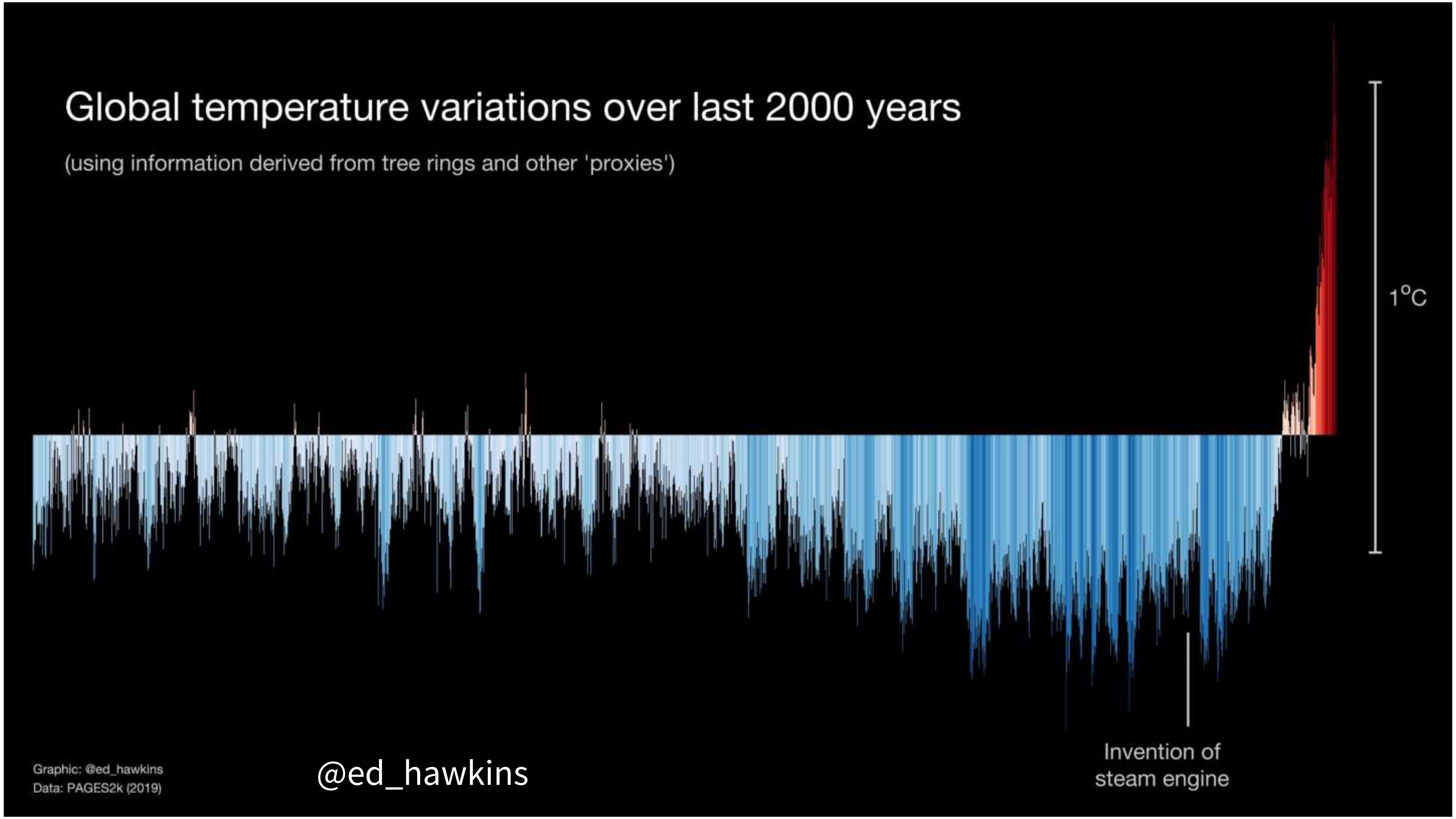
Cloud cover during the EUREC4A campaign

Earth's surface Temperature Anomalies & CO_2



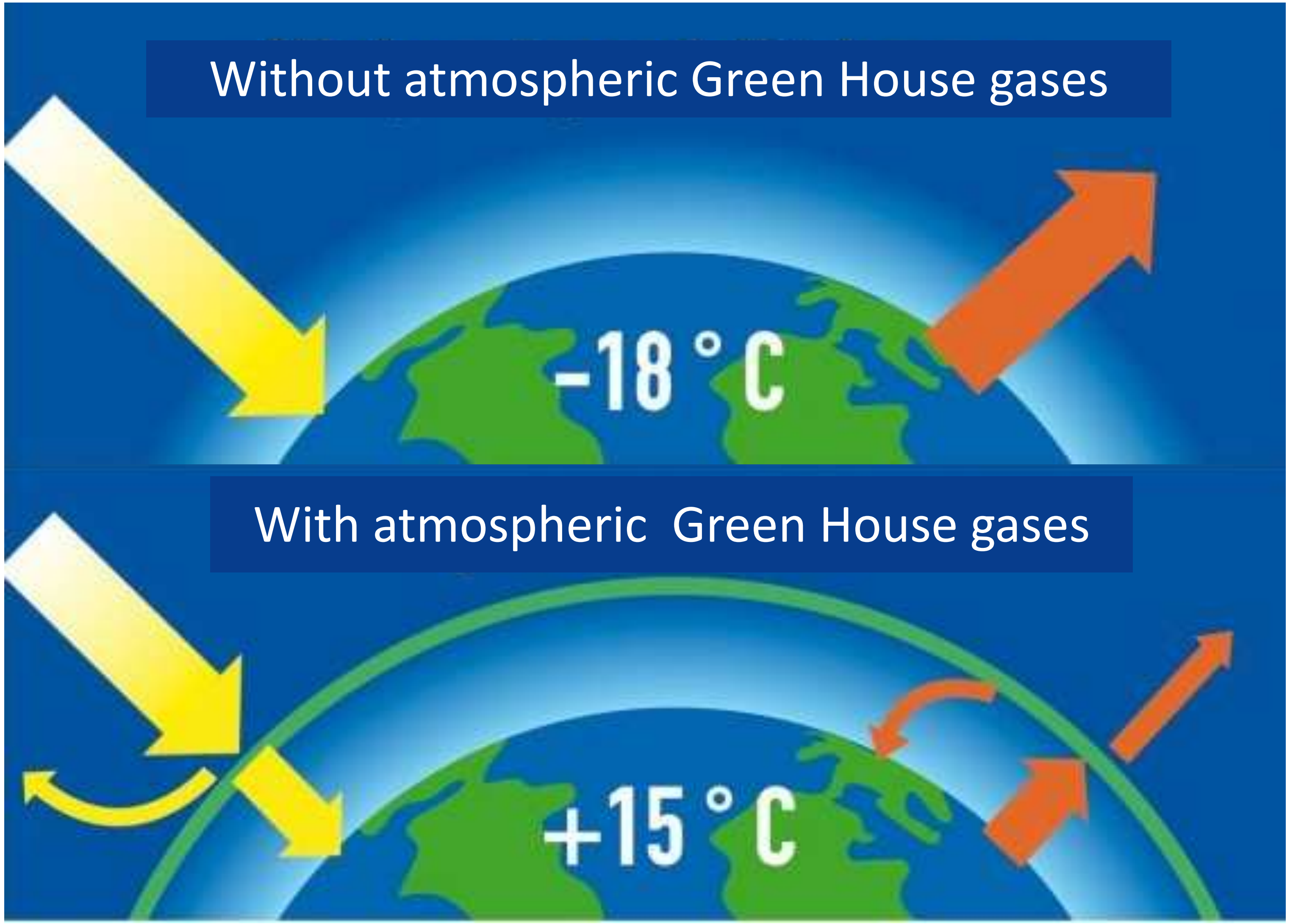
Base period 1900-99; data from NOAA

Earth’s surface Temperature Anomalies & CO2



https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

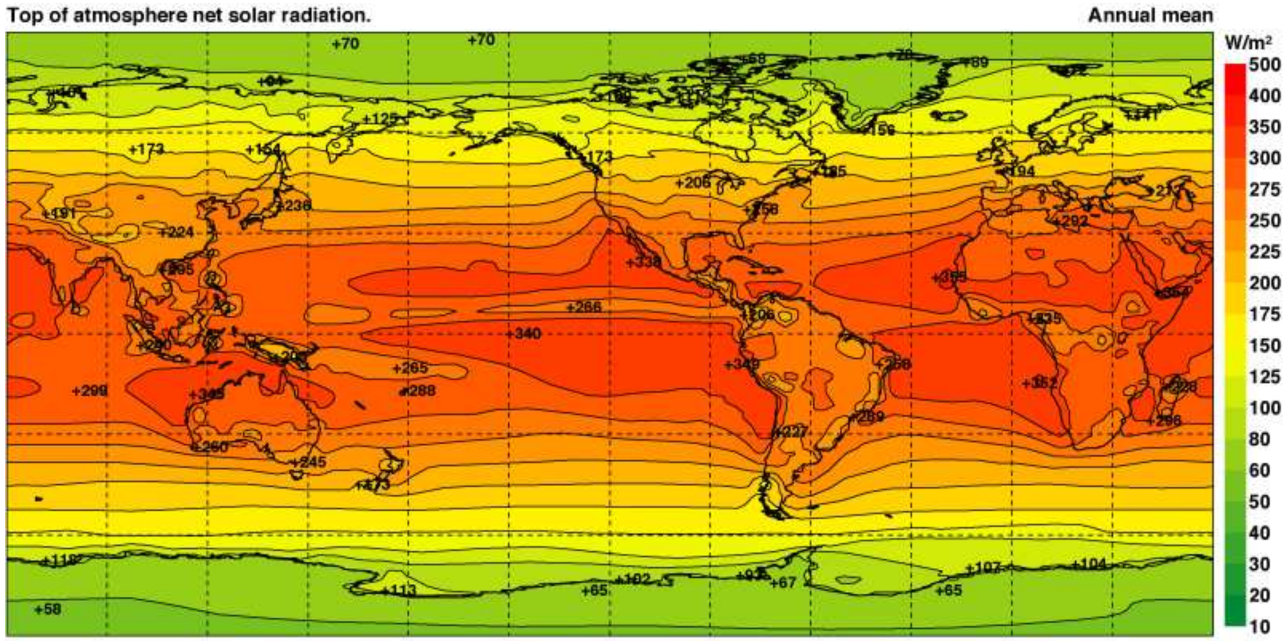
The Solar Radiation is transformed at the Earth surface in infrared radiation (heat)



All is about **ENERGY**

- The Sun provides the ENERGY to the Earth Climate System
- The Sun energy is mostly in the VISIBLE part of the radiation spectrum
- The Atmosphere is mostly TRANSPARENT to solar radiation
- The Sun energy that reaches the Earth is transformed at the surface of the planet in “HEAT” (that is INFRARED radiation)
- Such HEAT is radiated back to the atmosphere
- The Greenhouse gases retain part of the HEAT (infrared radiation). They absorb it and radiate it back to the Earth’ surface and to space
- This explains why the Earth surface temperature is about 15°C

Uneven solar radiation distribution on Earth



https://sites.ecmwf.int/era/40-atlas/docs/section_B/parameter_ntotafosrpd.html#

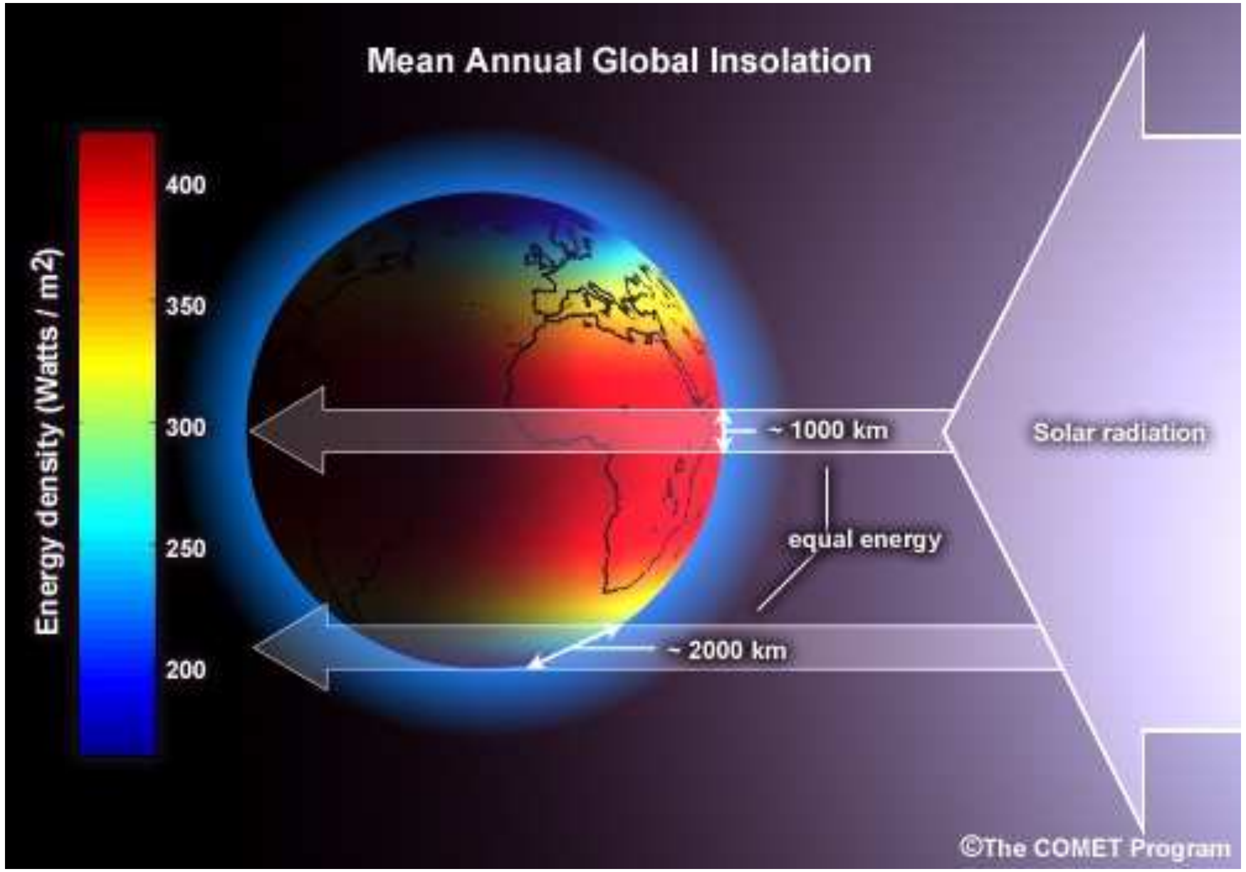


Image courtesy of MetEd, UCAR Community Programs

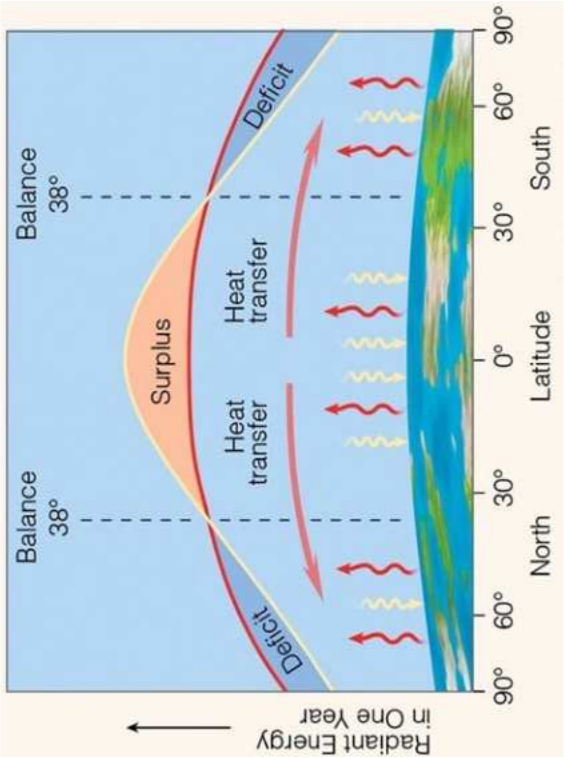
ENERGY ON EARTH & ATMOSPHERIC CIRCULATION

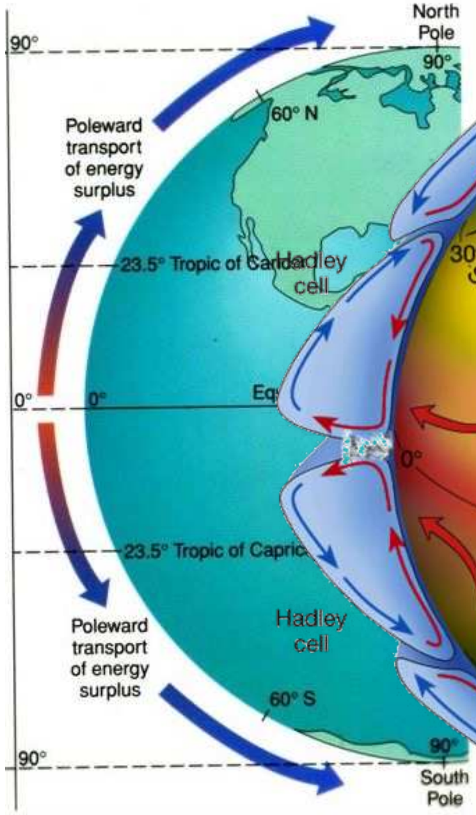
Radiative Earth Energy Budget (sum of components)

The latitudinal Energy imbalance induces a transport of energy from the Equator towards the Poles in the lower atmosphere

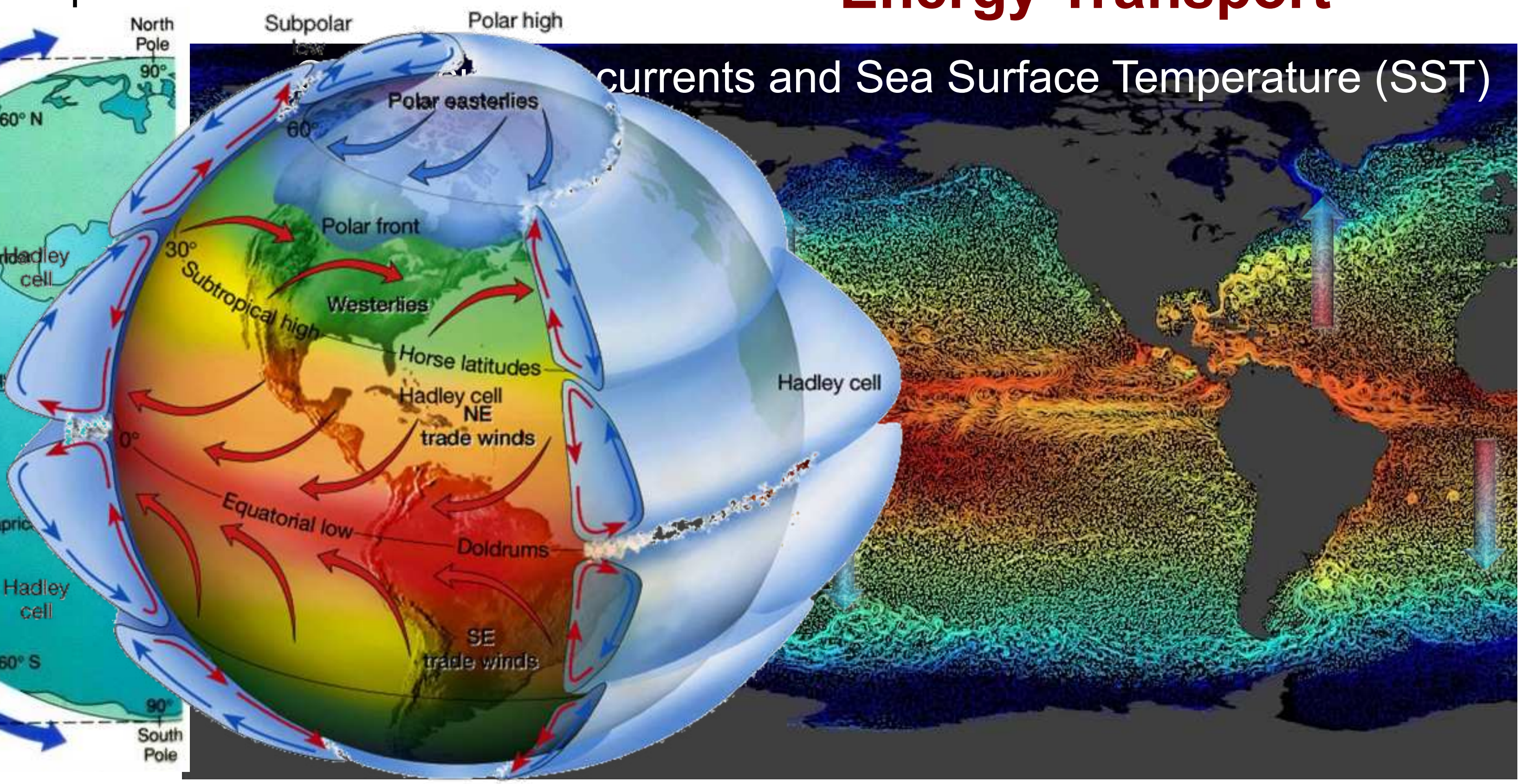
This is the driver of the general circulation of the atmosphere and the ocean

Energy Budget

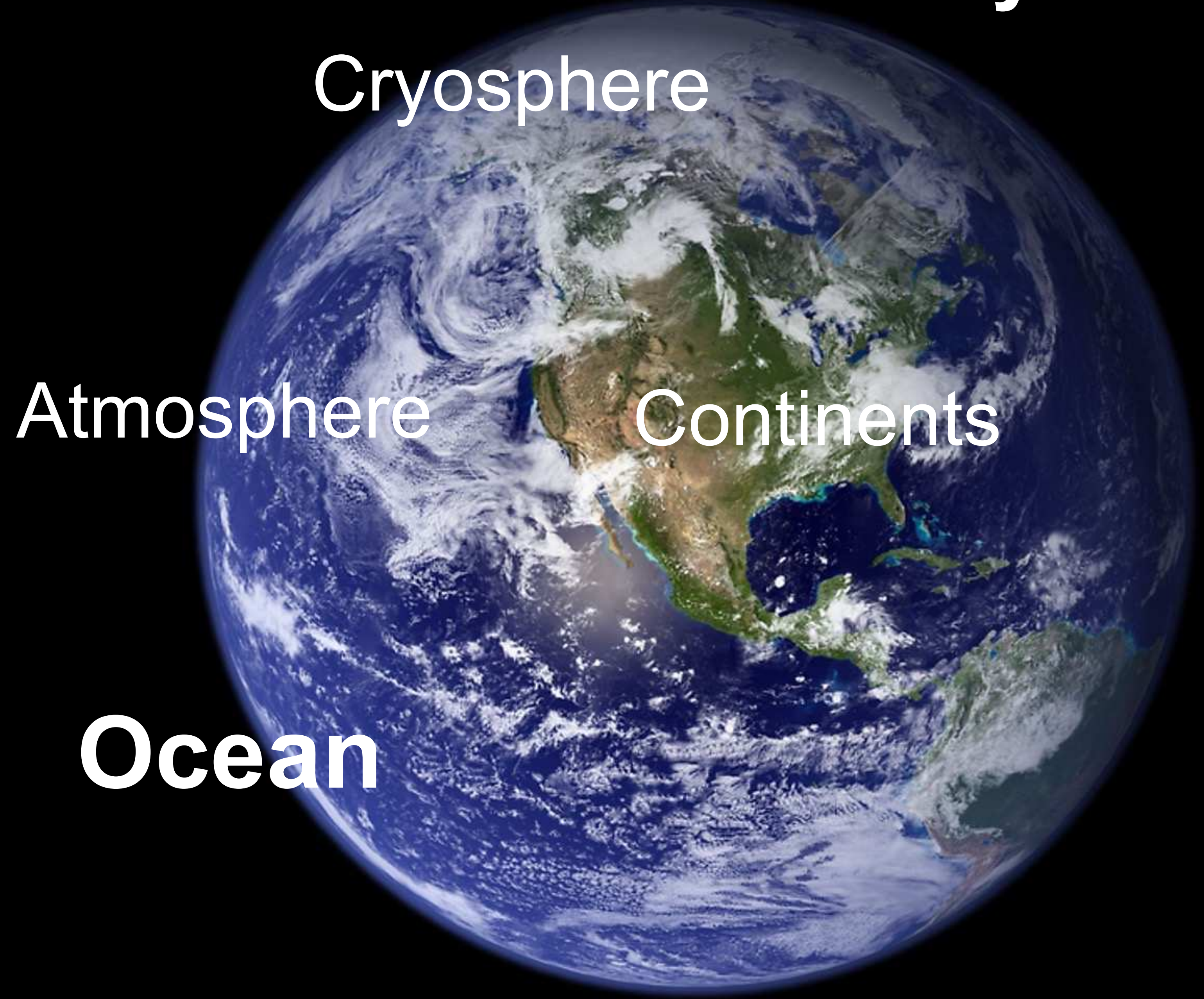


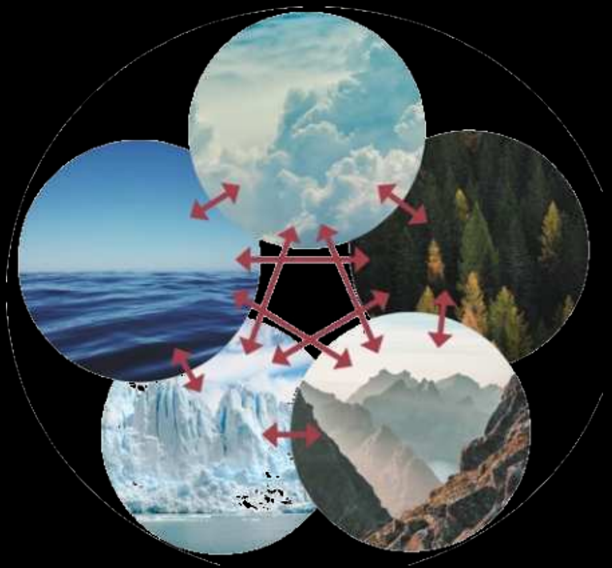


Energy Transport



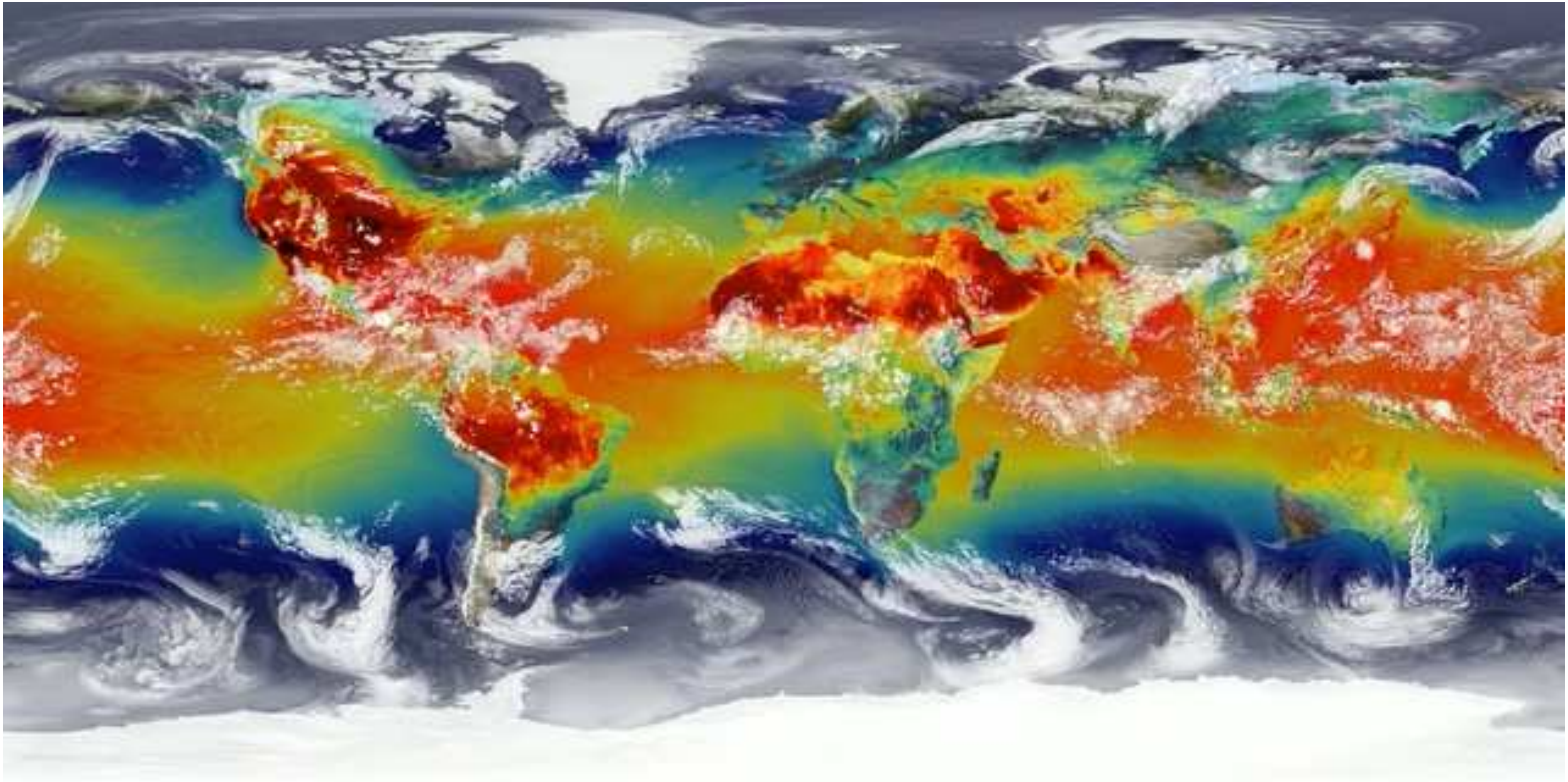
The Earth Climate System



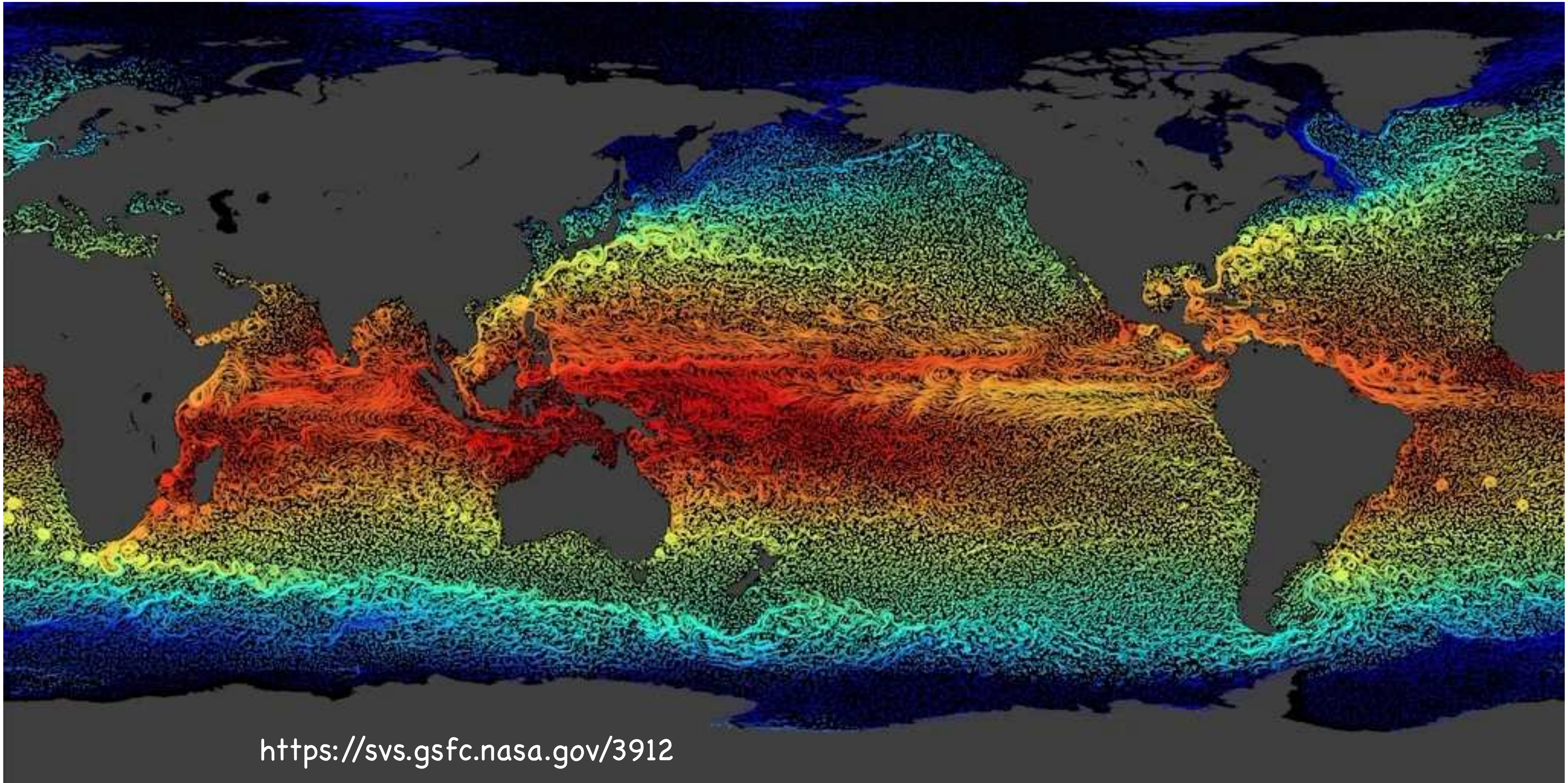


- A complex system
- Continuous interactions across subsystems

The atmospheric circulation

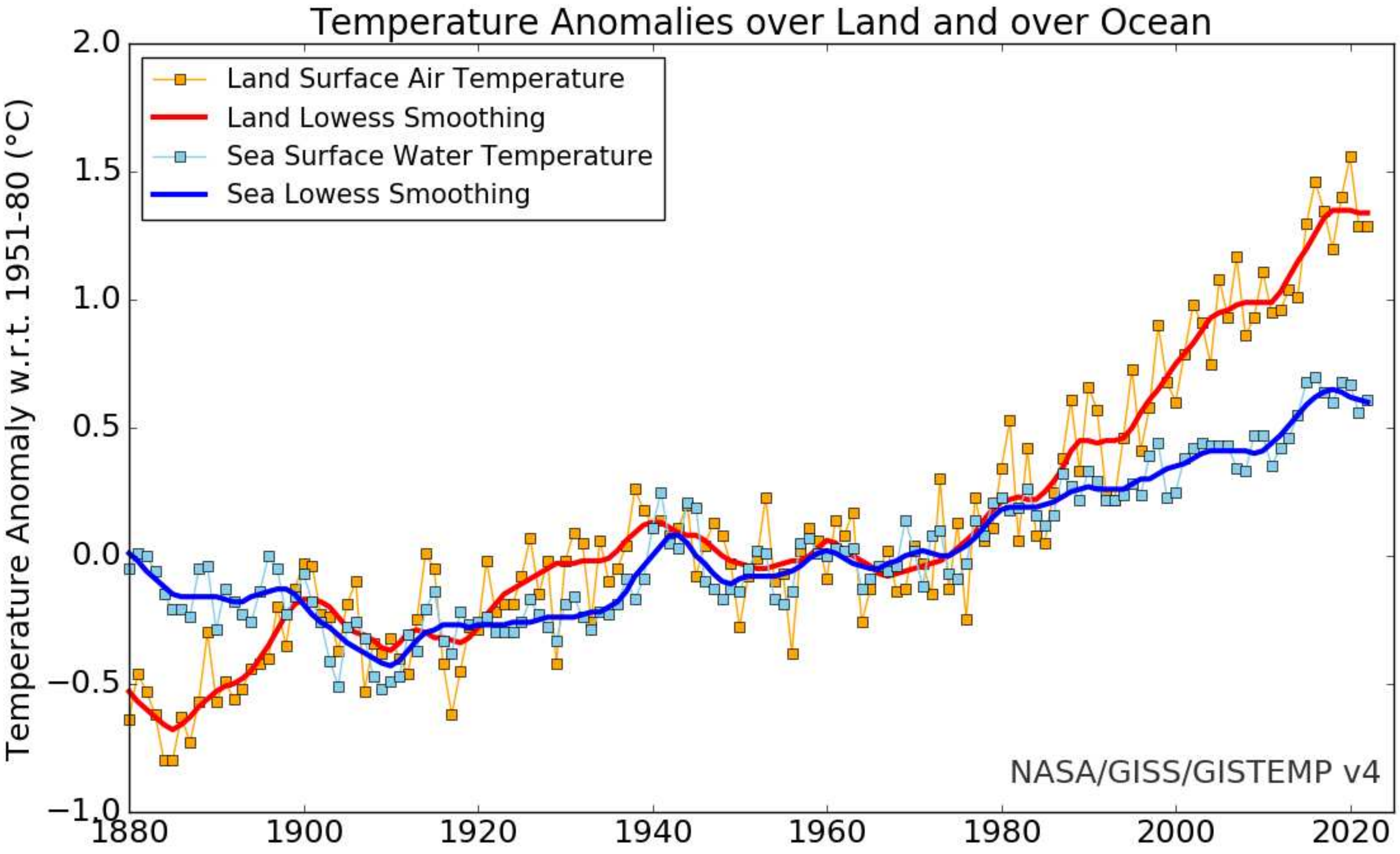


Ocean surface currents and Sea Surface Temperature (SST)
Merging satellite data and numerical models



https://svs.gsfc.nasa.gov/3912

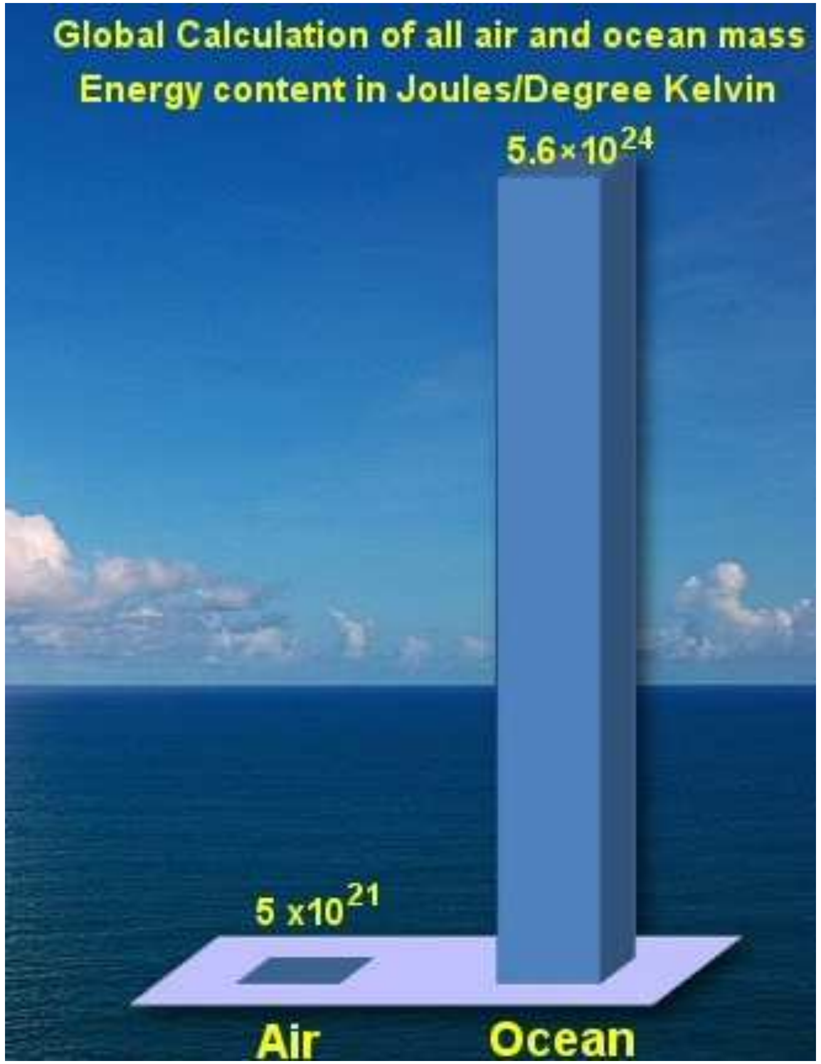
Surface Temperature : Land air vs Sea surface



https://data.giss.nasa.gov/gistemp/graphs_v4/

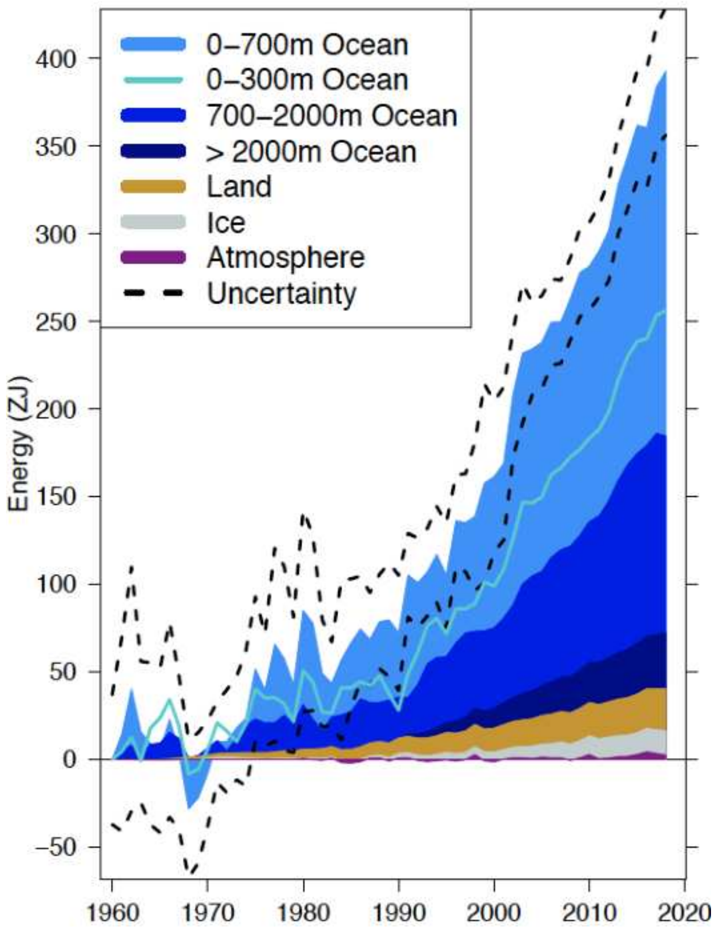
Thermal capacity of water

Substance	Phase	Specific Heat $J \cdot kg^{-1} \cdot K^{-1}$
Air (dry)	gas	1005
Air(satured in water vapor)	gas	≈ 1030
Nitrogen	solid	897
Nitrogen	gas	1042
Copper	solid	385
Diamond	solid	502
WATER	gas	1850
	liquid	**4185**
	solid (0 ° C)	2060
Wet mud	solid+liquide	2512
Iron	solid	444
Graphite	solid	720



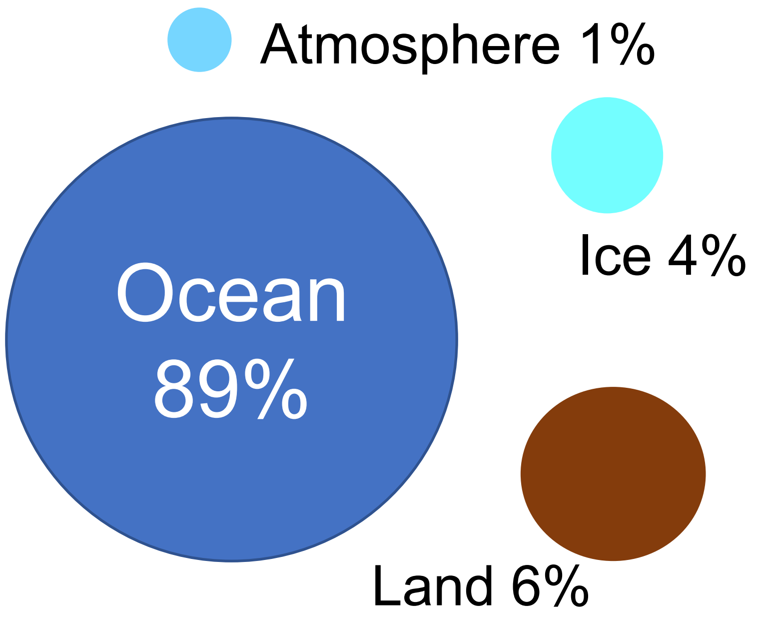
The Ocean : The anthropogenic heat repository

Changes in the ocean thermal energy (Heat Content)



VonSchuckmann et al 2020

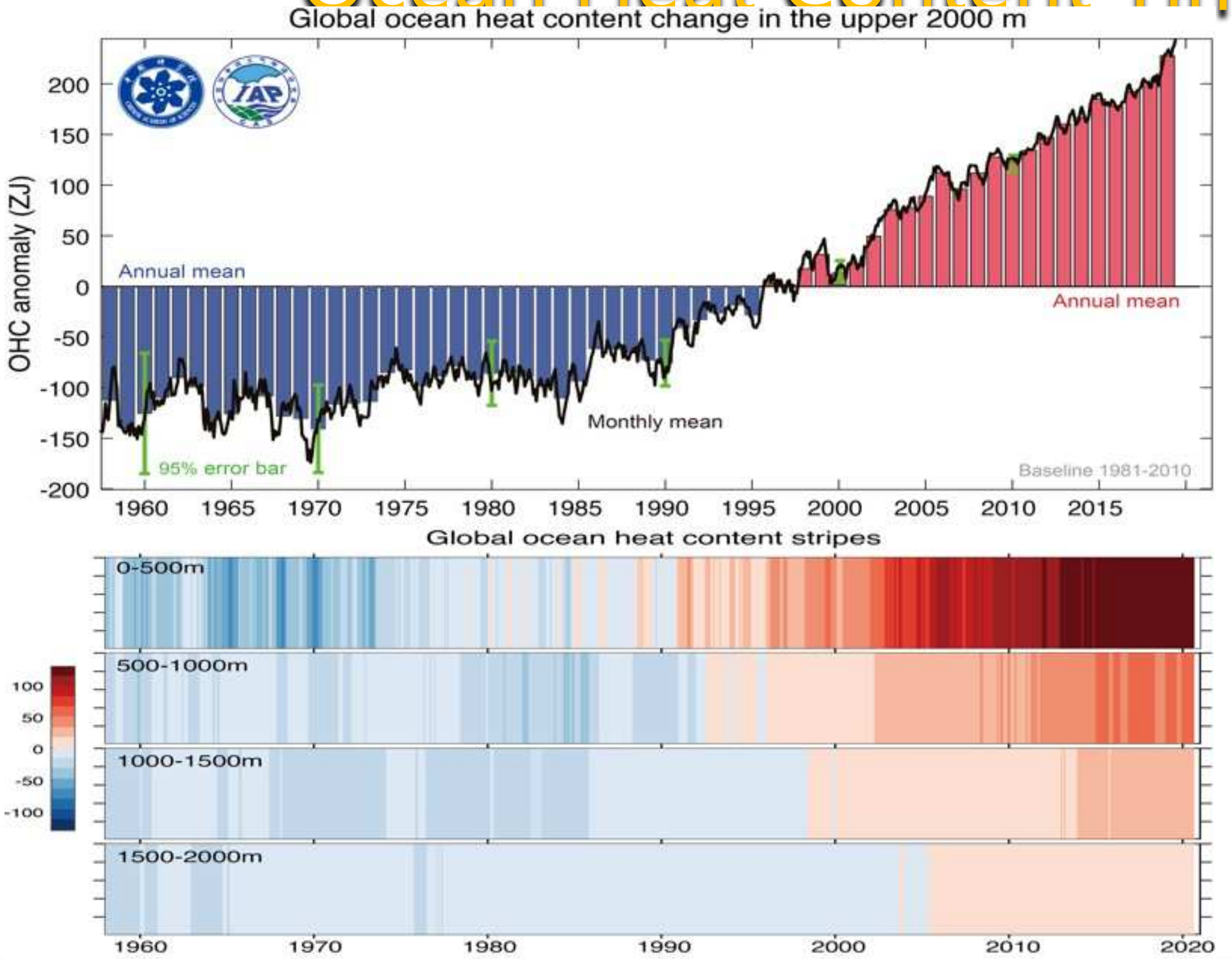
Earth climate energy surplus sinks



For comparison (1ZJ = 10^{21}J):

6.9×10^{21} J	Estimated energy contained in the world's natural gas reserves as of 2010
7.9×10^{21} J	Estimated energy contained in the world's petroleum reserves as of 2010

Ocean Heat Content Time Series:



This energy (heat) increase impacts the whole water column of the ocean

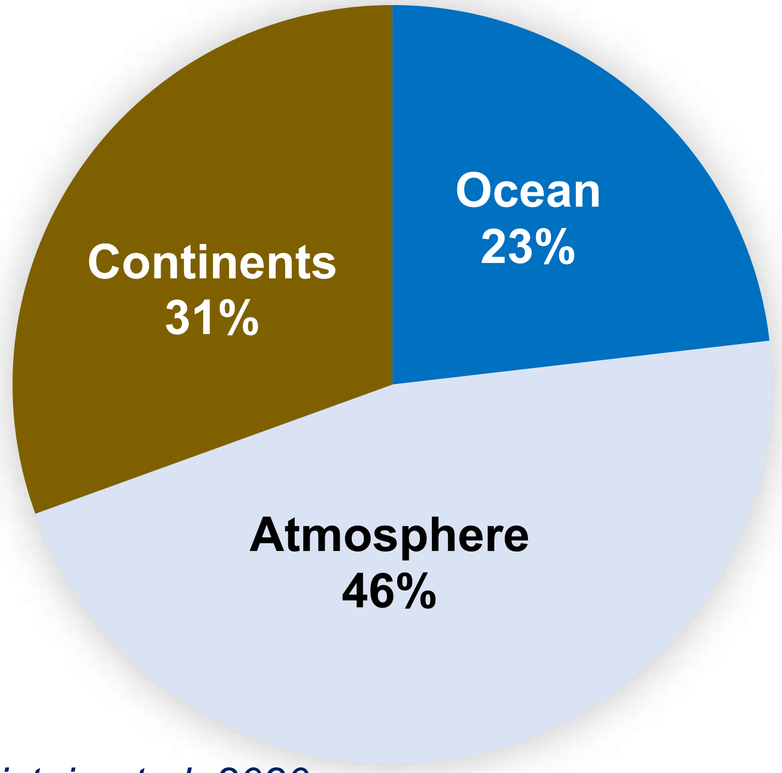
Cheng et al. 2021

Océan et CO2

Sep 05, 2022

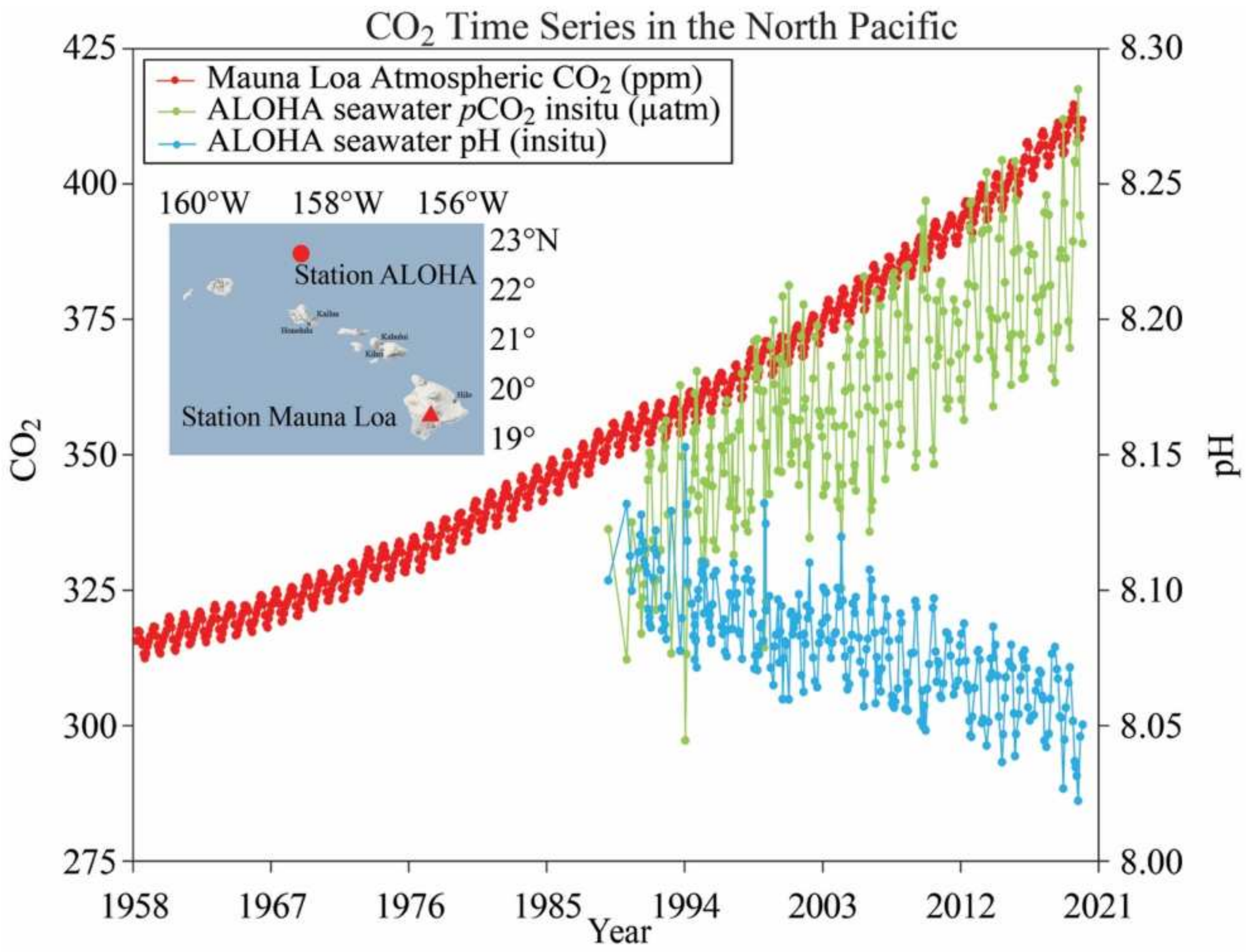
August 2022:	417.19 ppm
August 2021:	414.47 ppm

Augmentation de CO2:



Friedglistein et al. 2020

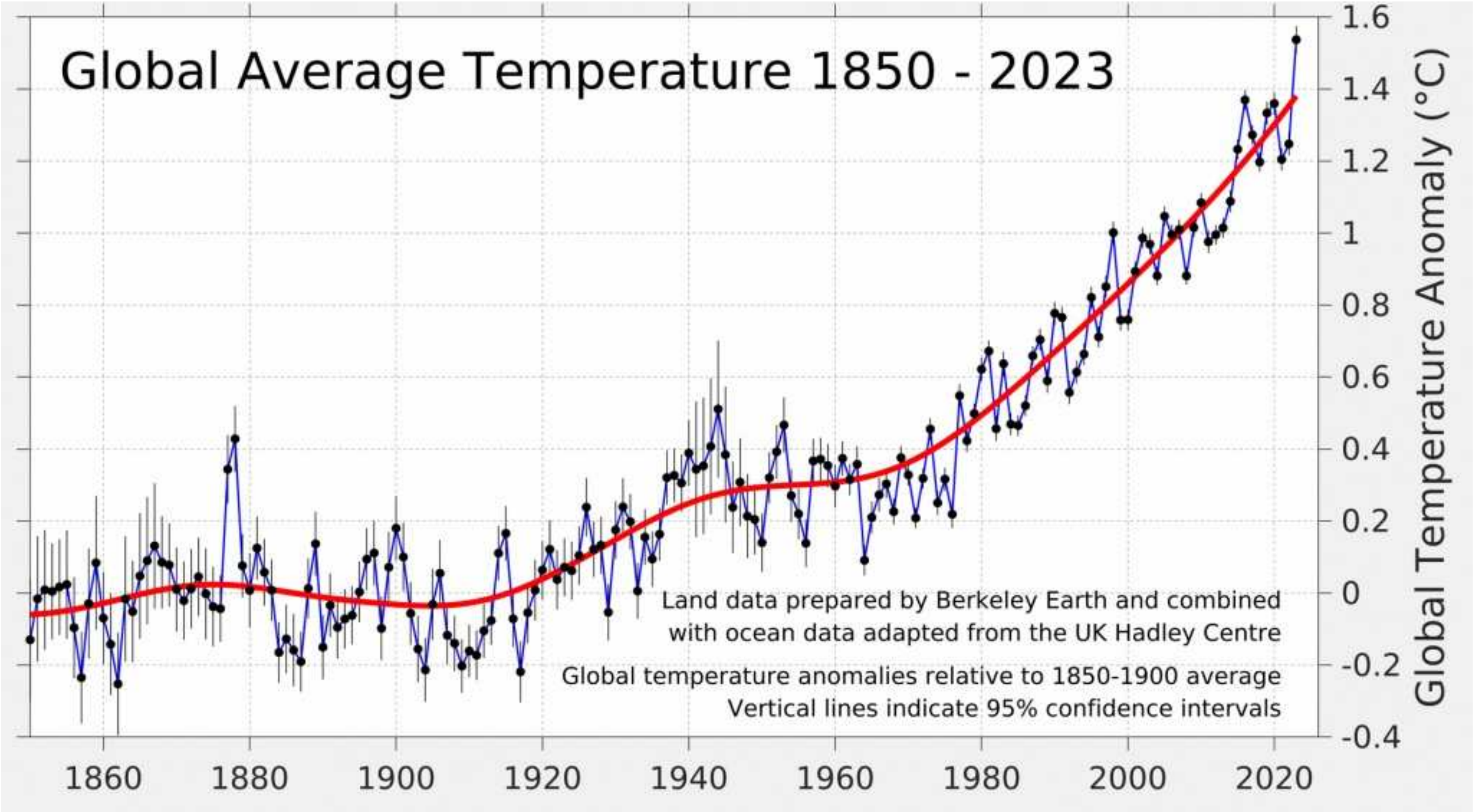
Acidification de l'Océan



Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/hot-dogs/bextraction.html) ALOHA pH & pCO_2 are calculated at in-situ temperature from DIC & TA (measured from samples collected on Hawaii Ocean Times-series (HOT) cruises) using co2sys (Pelletier, v25b06) with constants: Lueker et al. 2000, KSO4: Dickson, Total boron: Lee et al. 2010, & KF: seacarb

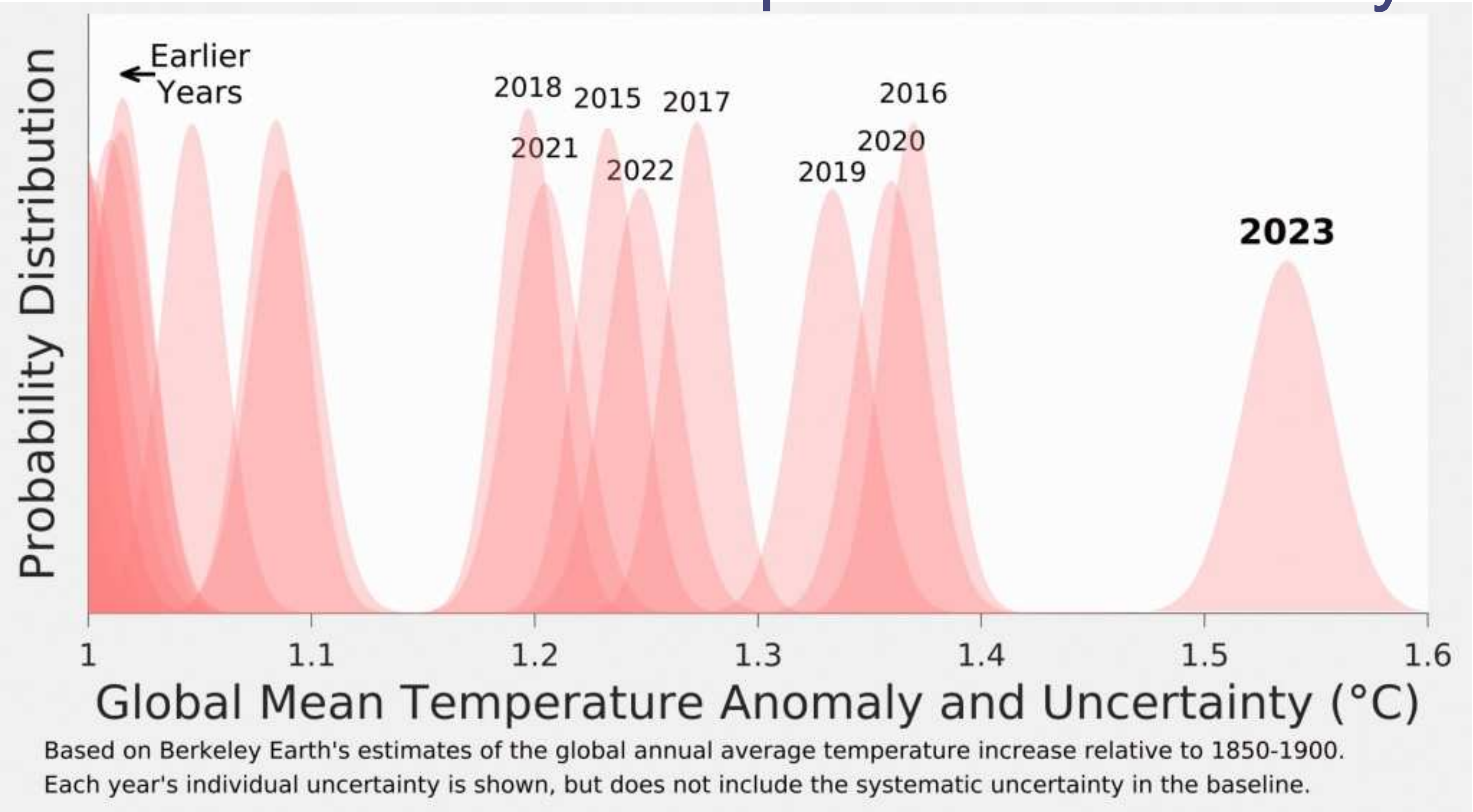
Changement du Climat & Evénements extrêmes

Earth surface temperature anomaly



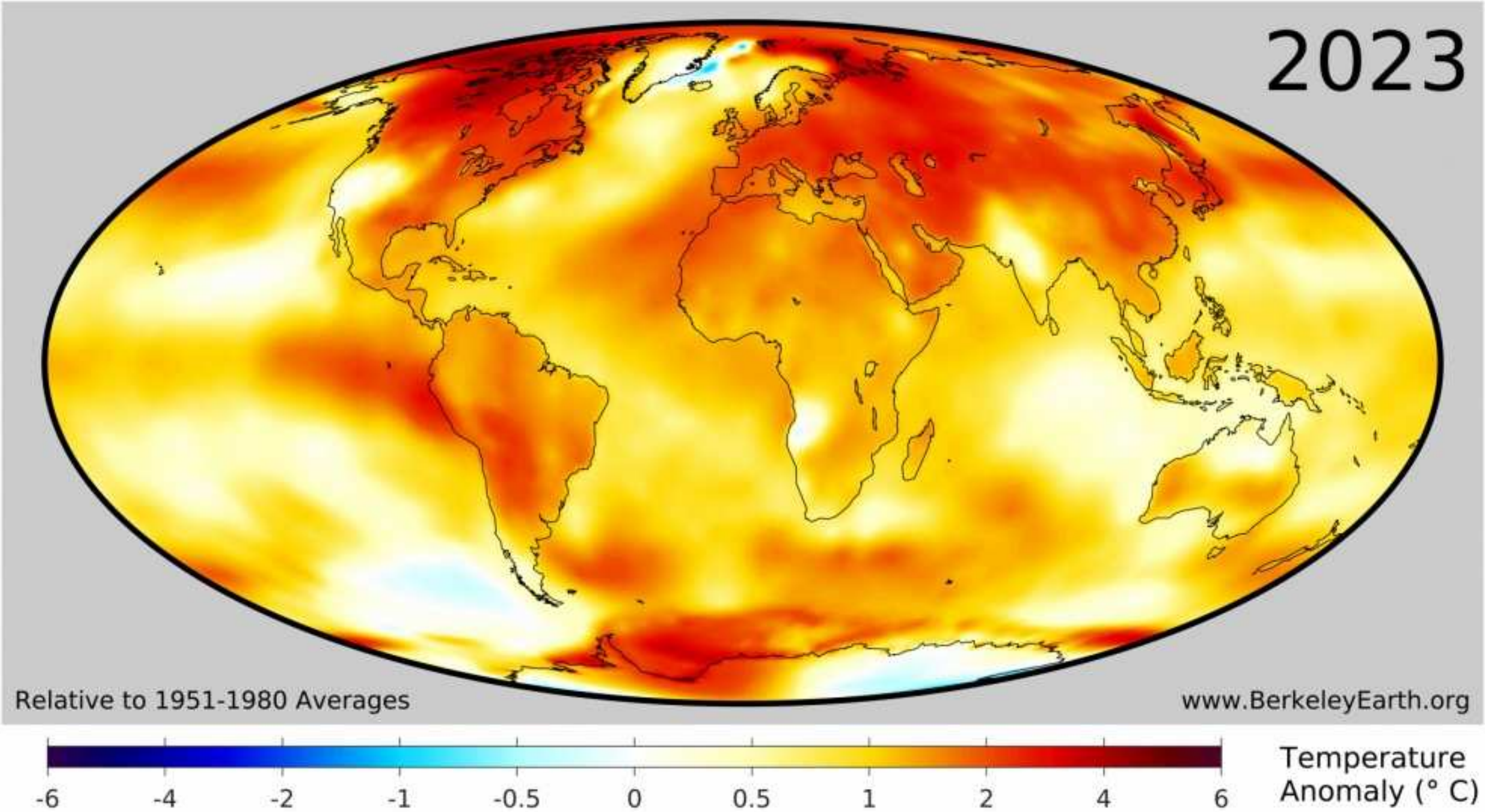
http://berkeleyearth.org

Earth surface temperature anomaly



http://berkeleyearth.org

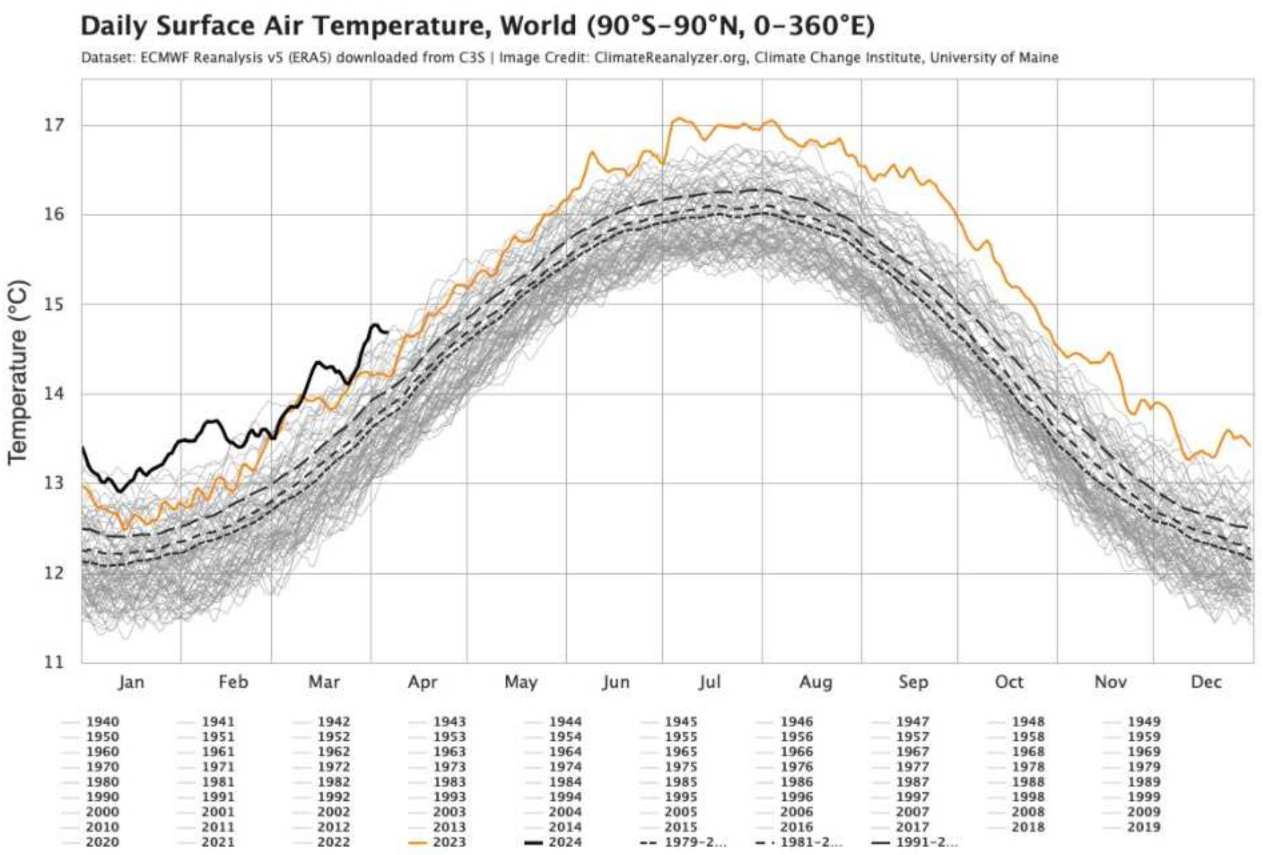
Earth surface temperature anomaly



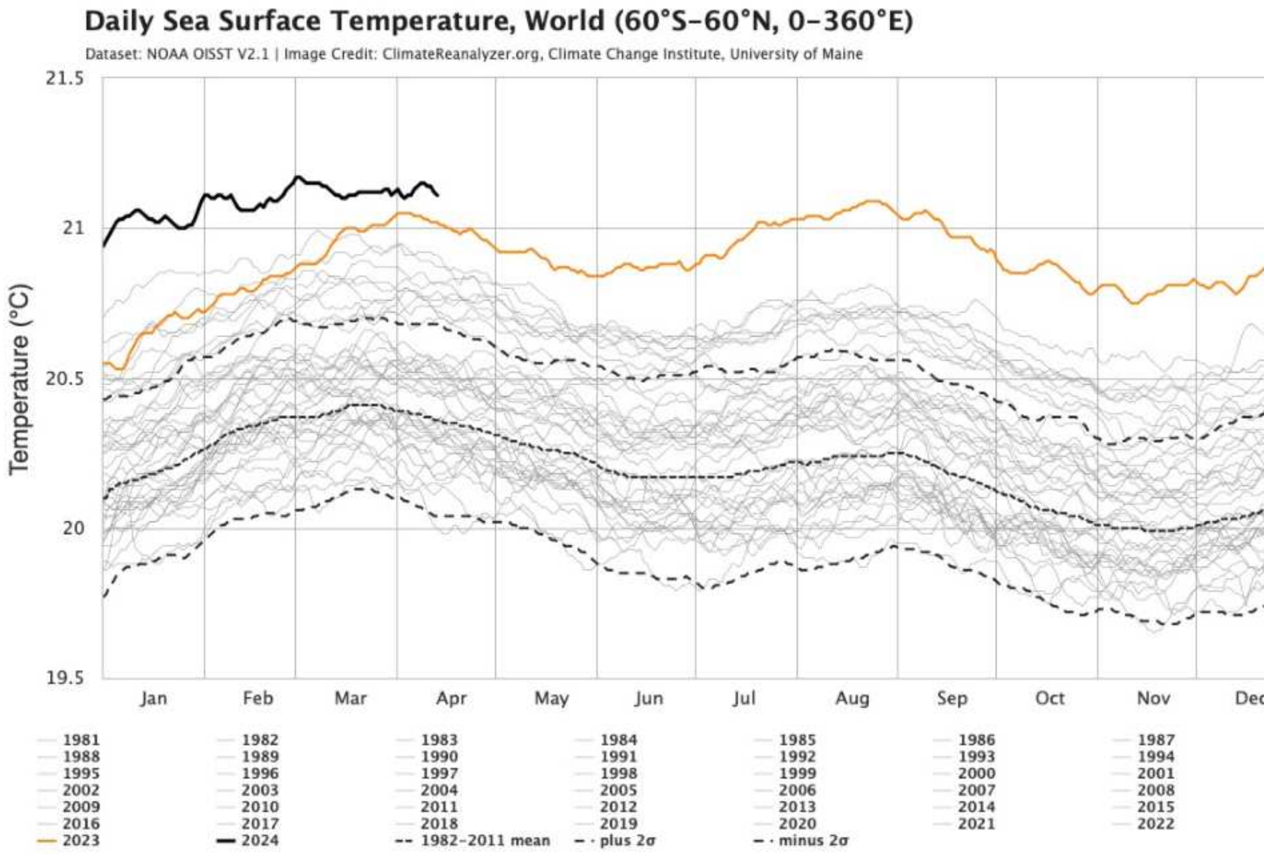
http://berkeleyearth.org

Daily Surface Temperature (seasonal cycle) : Land air vs Sea surface

Land Surface temperature, Daily data, seasonal cycle

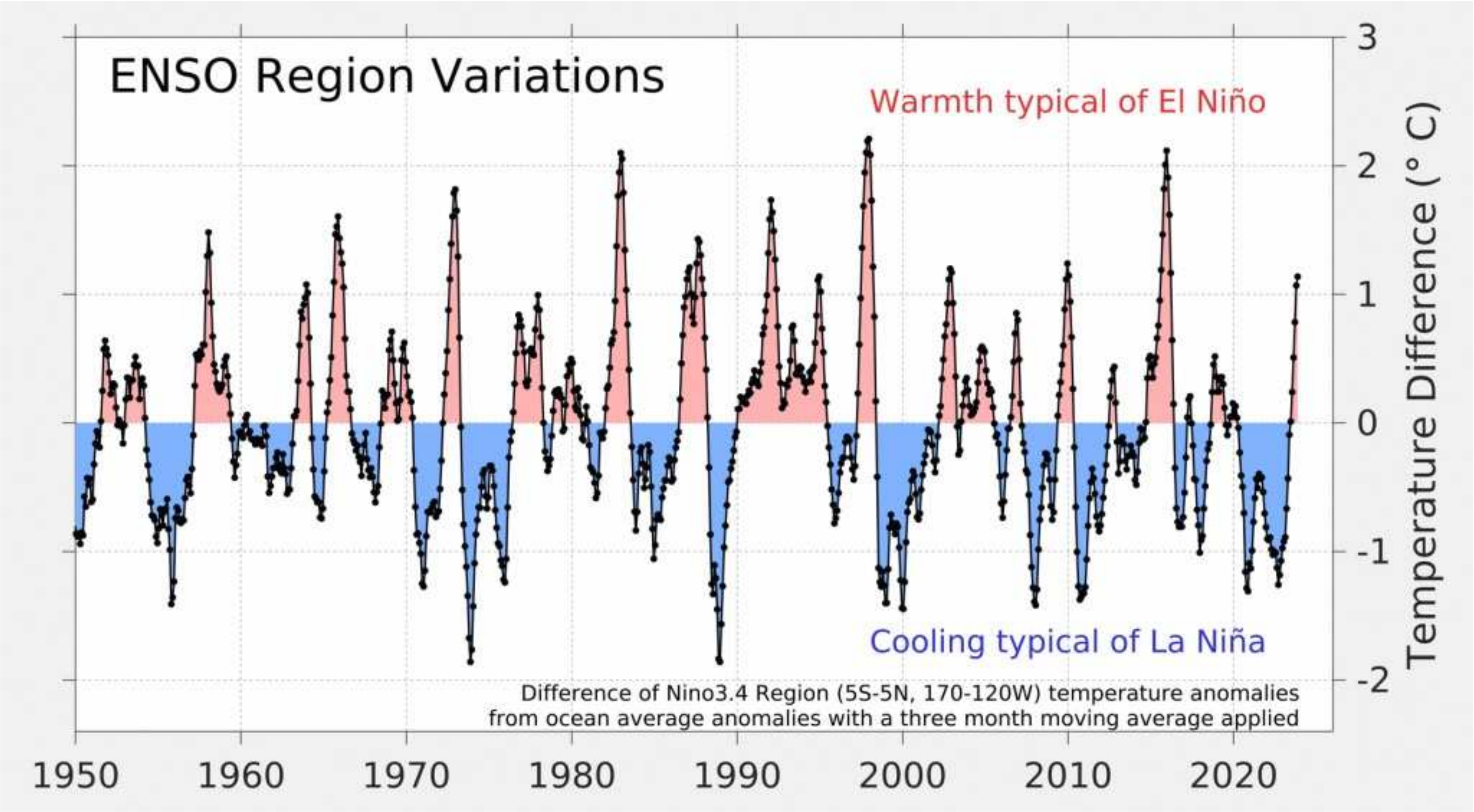


Sea Surface temperature, Daily data, seasonal cycle



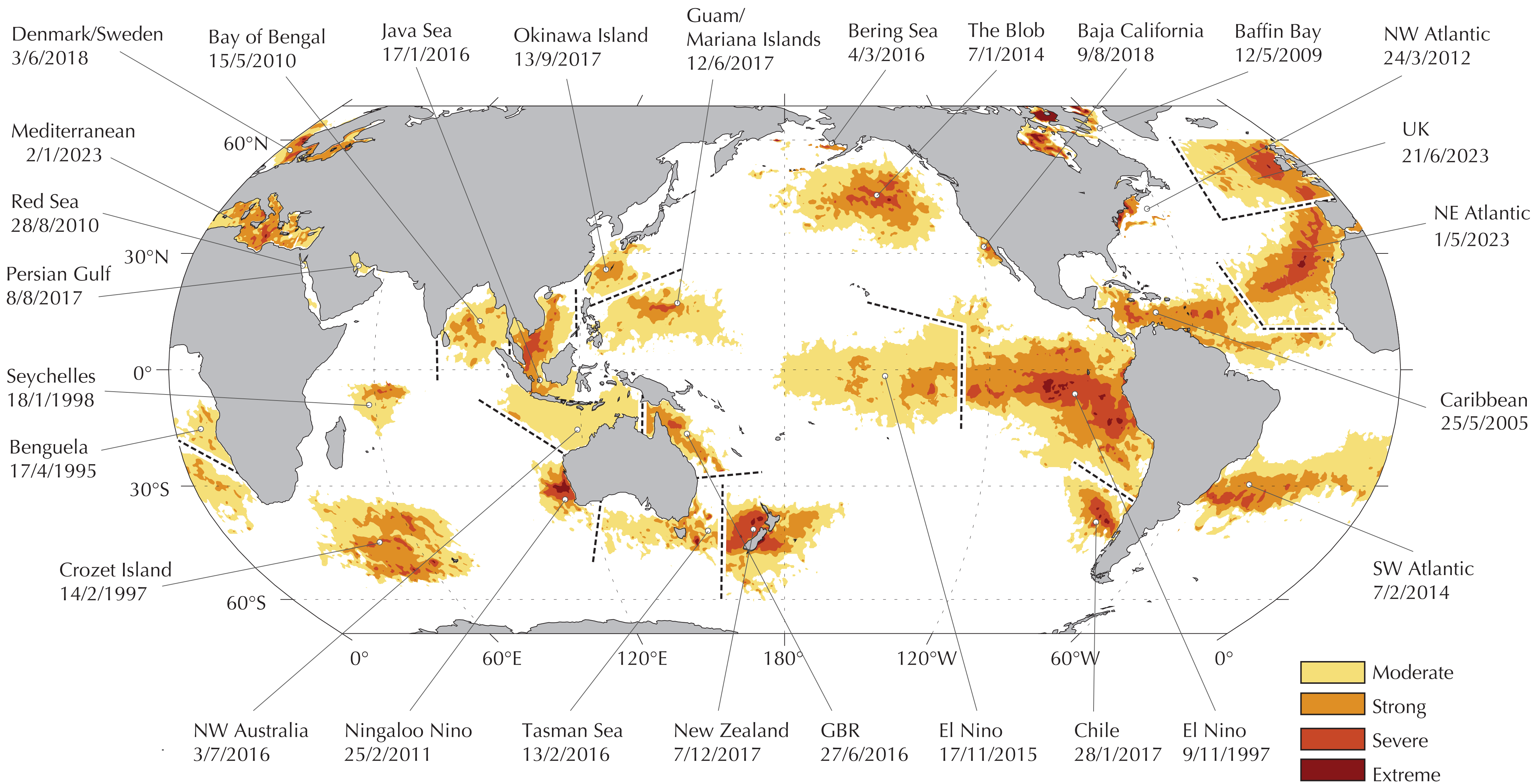
https://climatereanalyzer.org

El Niño – La Niña



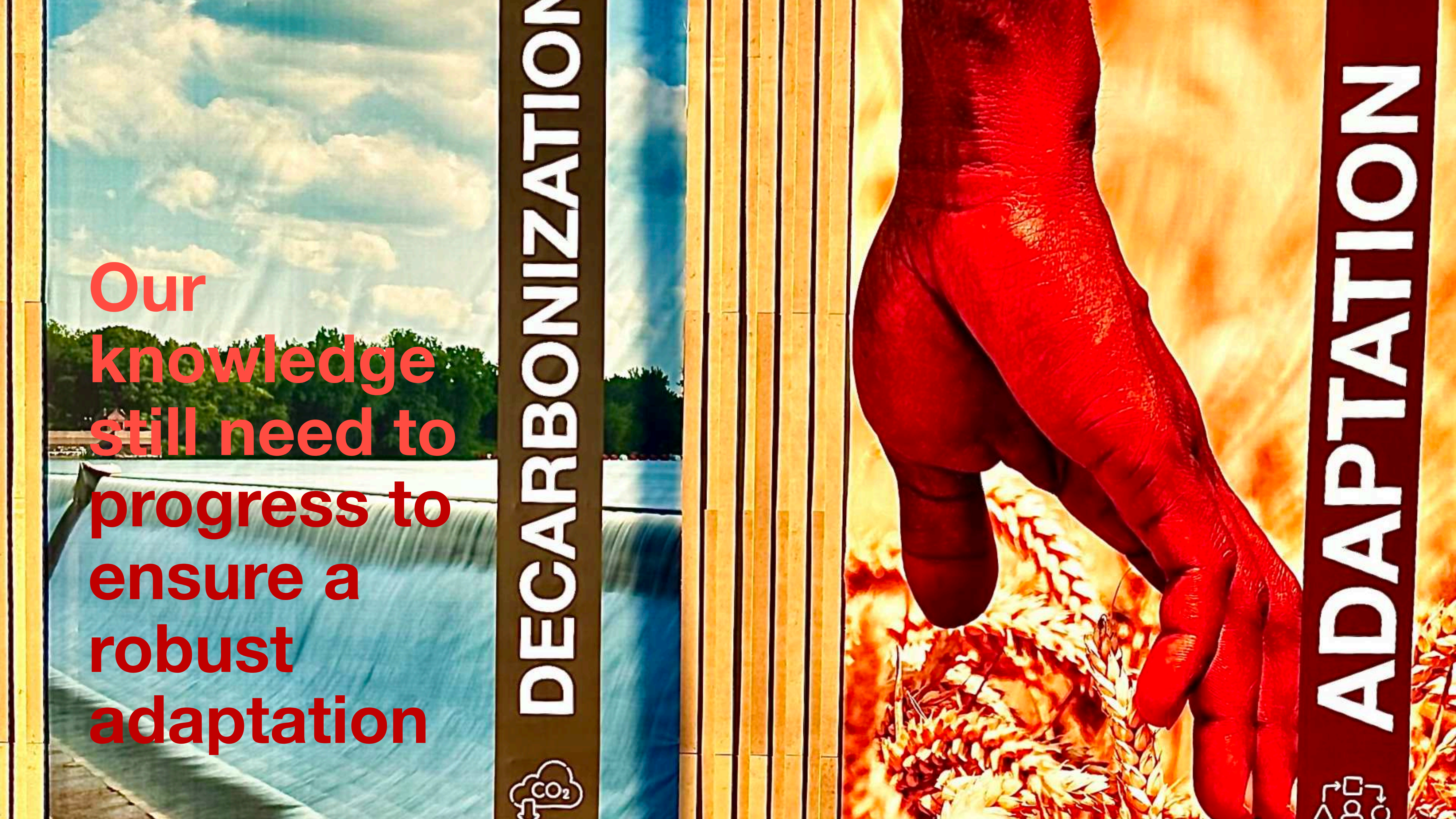
http://berkeleyearth.org

The Marine Heat Waves

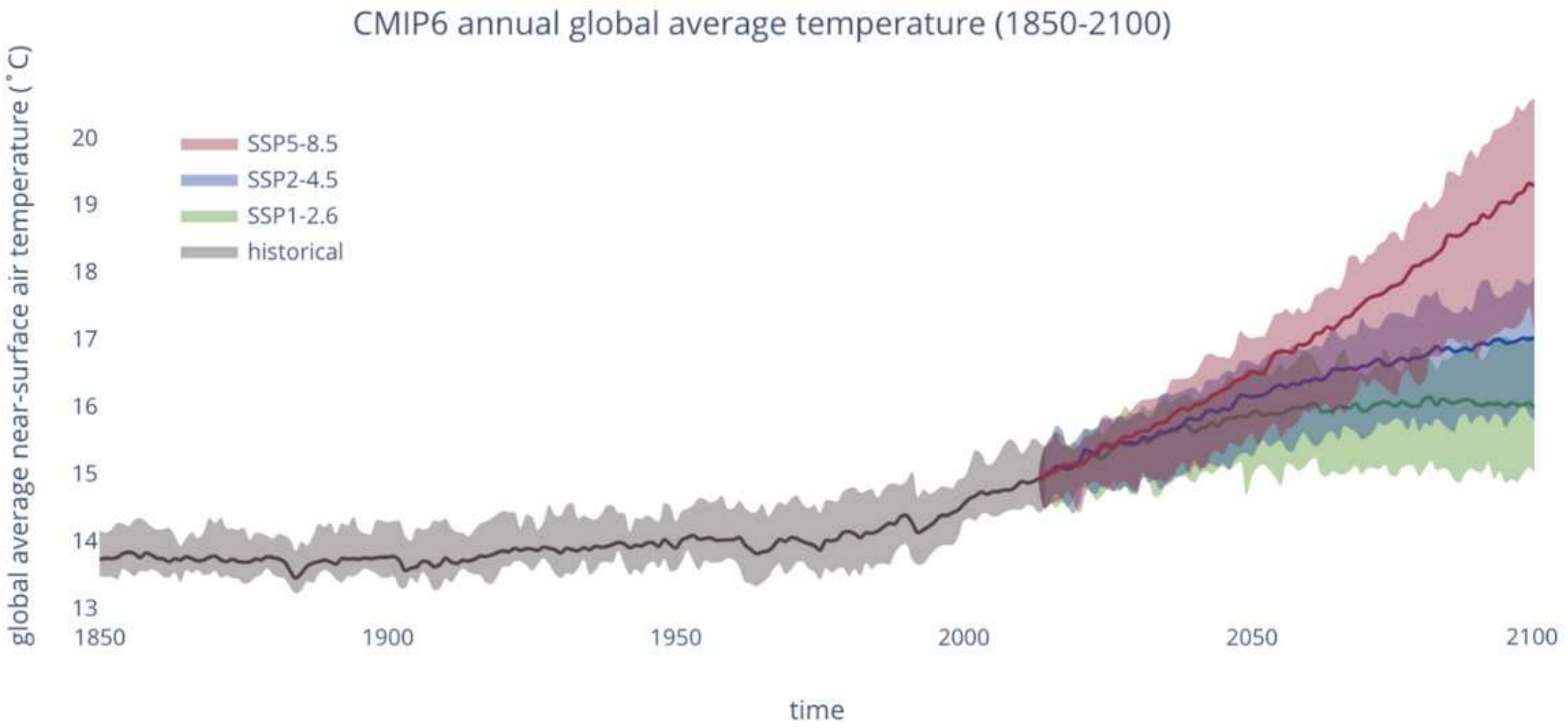


Global Ocean Observing Report Card 2022 , GOOS

Our knowledge still need to progress to ensure a robust adaptation

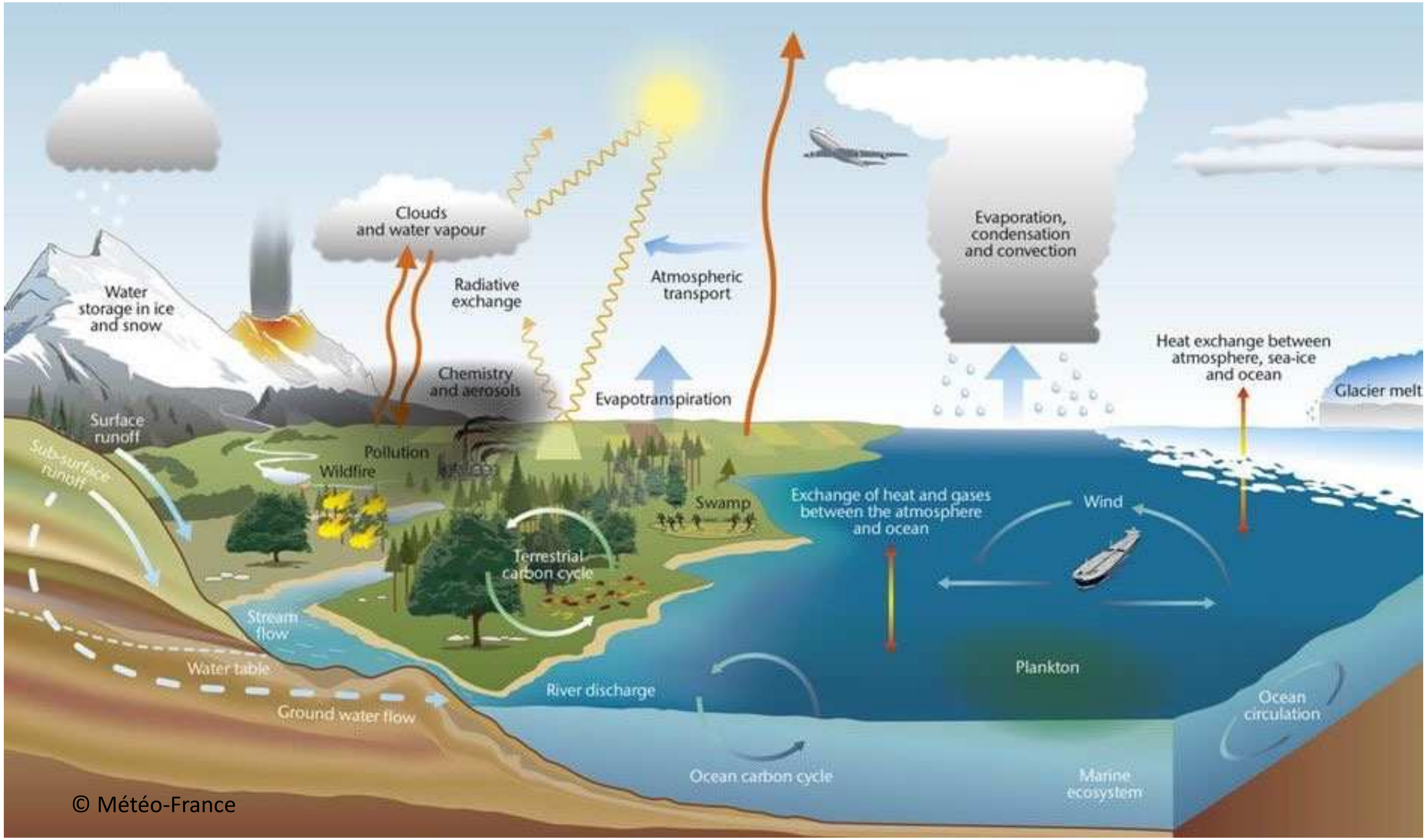


The latest climate projections (CMIP6, AR6 IPCC)

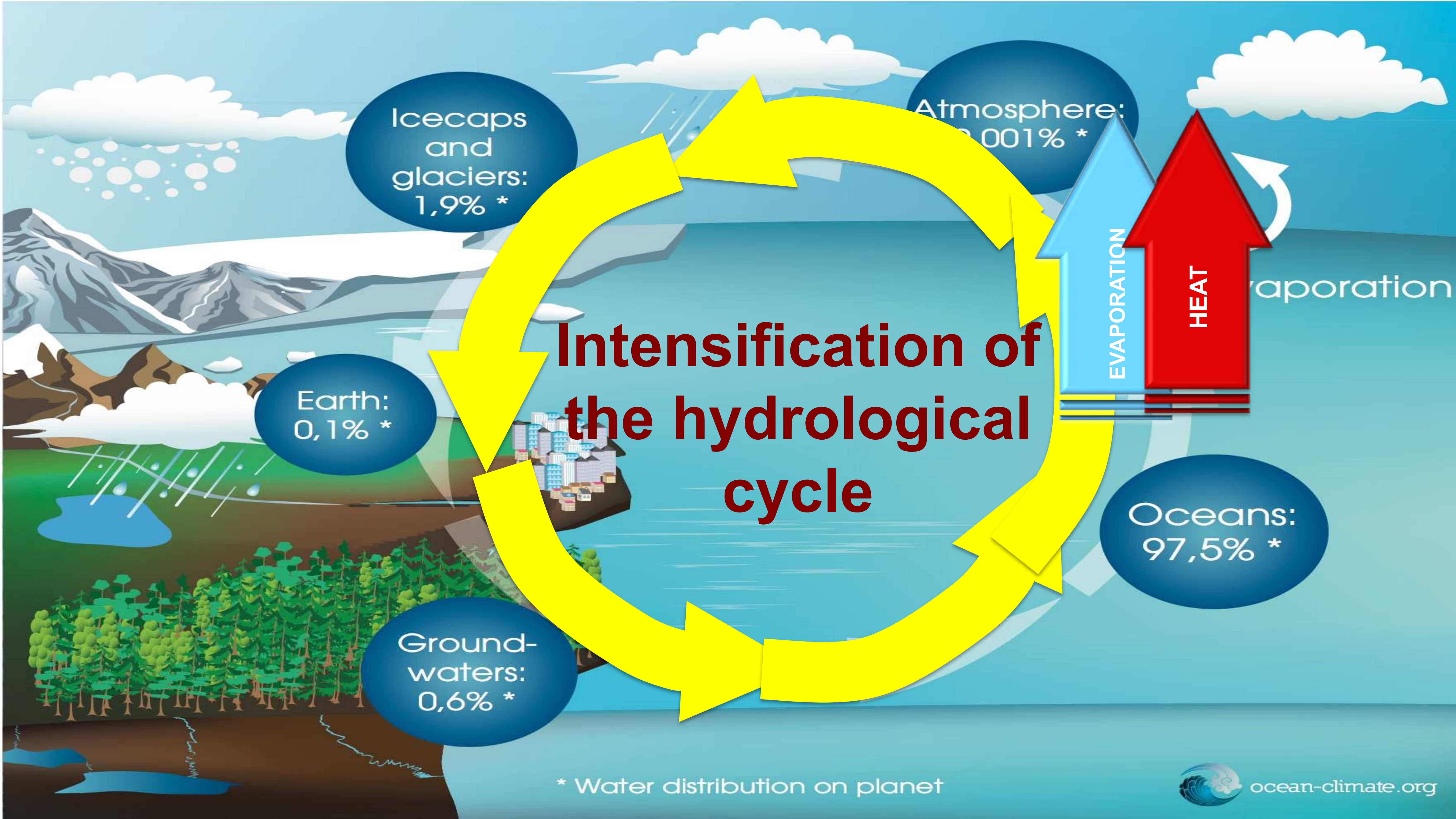


https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

The **Earth Climate System is an extremely complex system** with **energy exchanges** implying **physical, chemical, and biological processes** evolving continuously over a very wide spatio-temporal spectrum

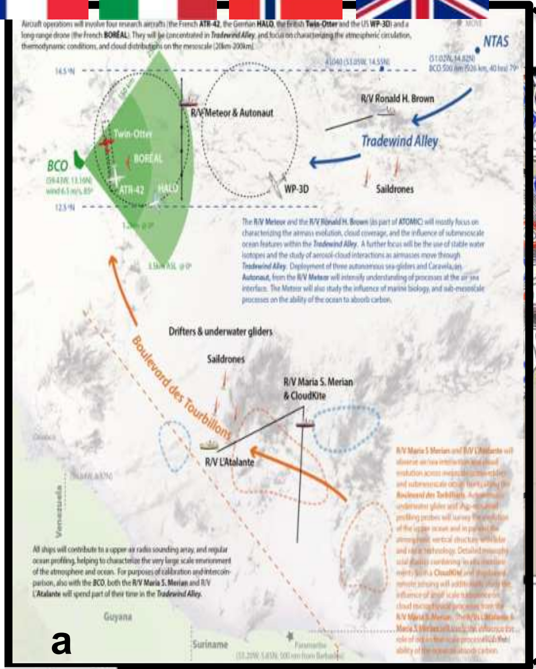


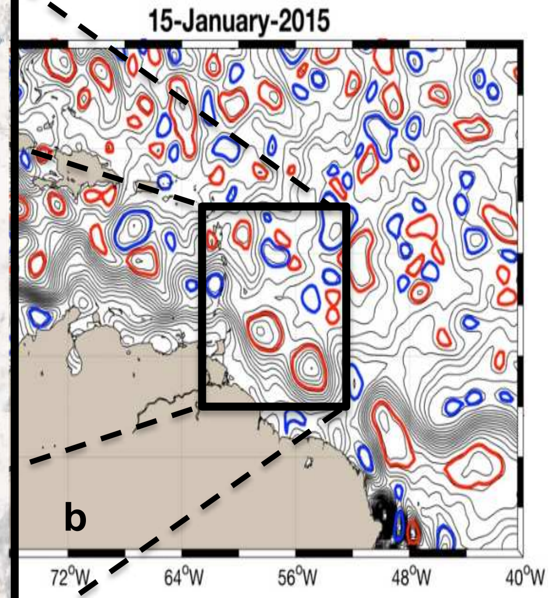
https://wmo.int/

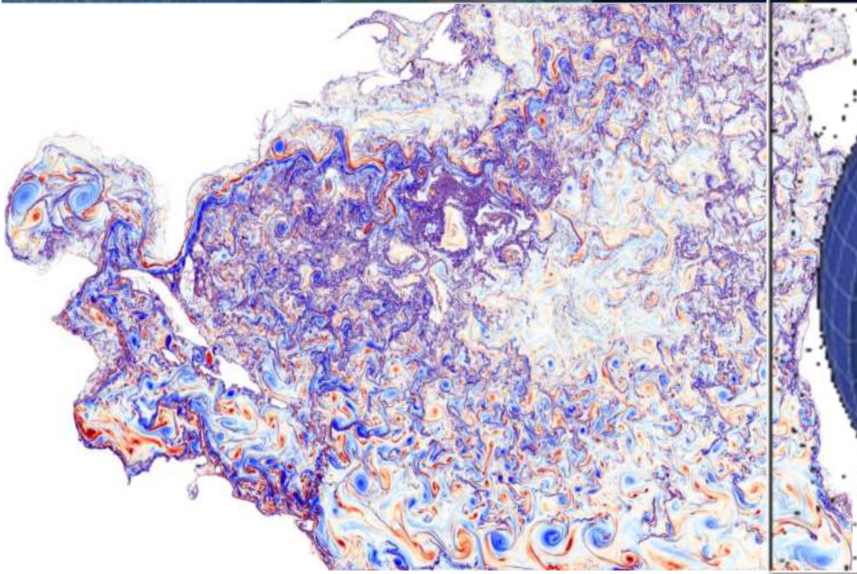

Intensification of the hydrological cycle
Icecaps and glaciers: 1,9% *
Atmosphere:
001% *
EVAPORATION
HEAT
vaporation
Earth: 0,1% *
Oceans: 97,5% *
Ground-waters: 0,6% *
* Water distribution on planet
ocean-climate.org

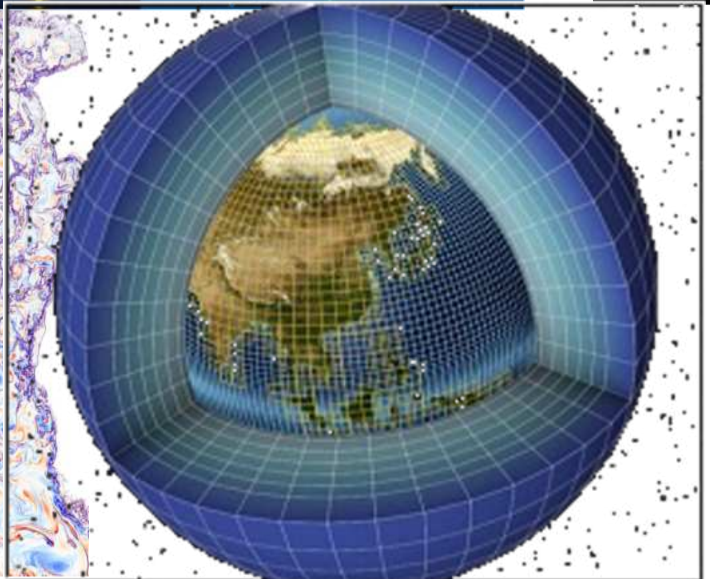
How do we, climate scientists, progress ?

An ambitious project: EUREC^{4}A-ATOMIC

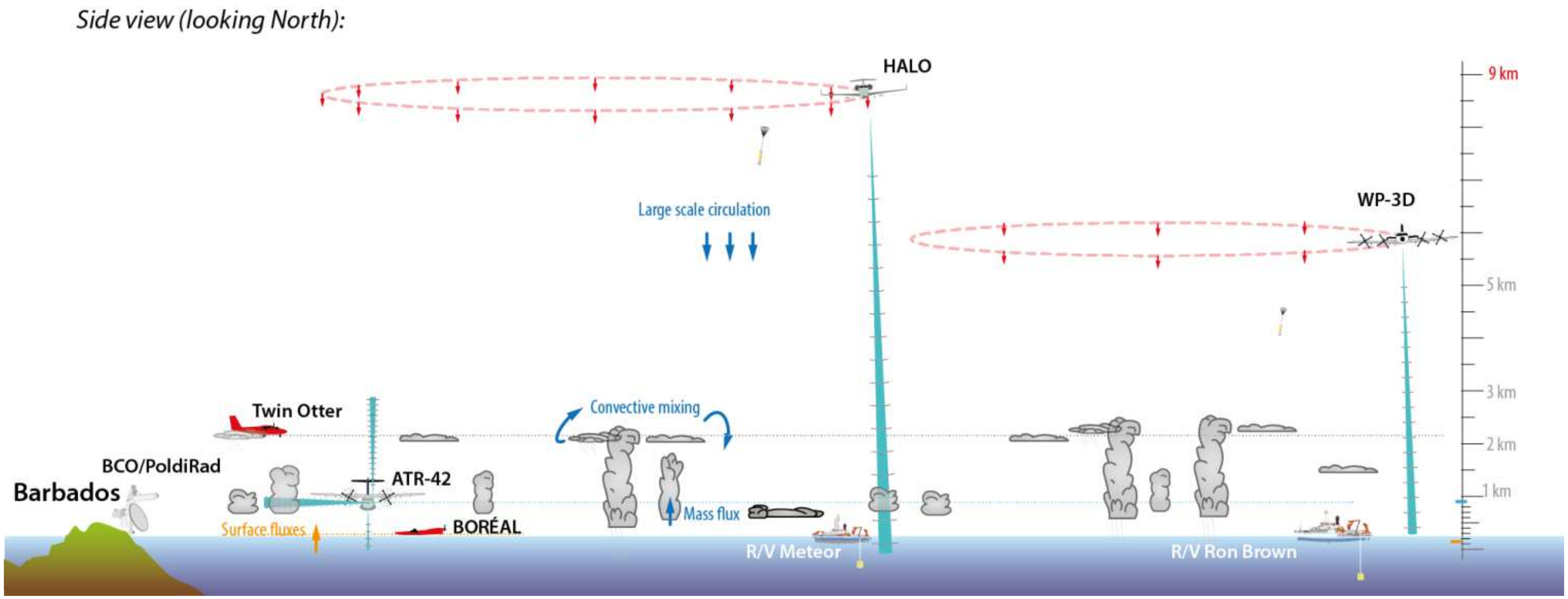






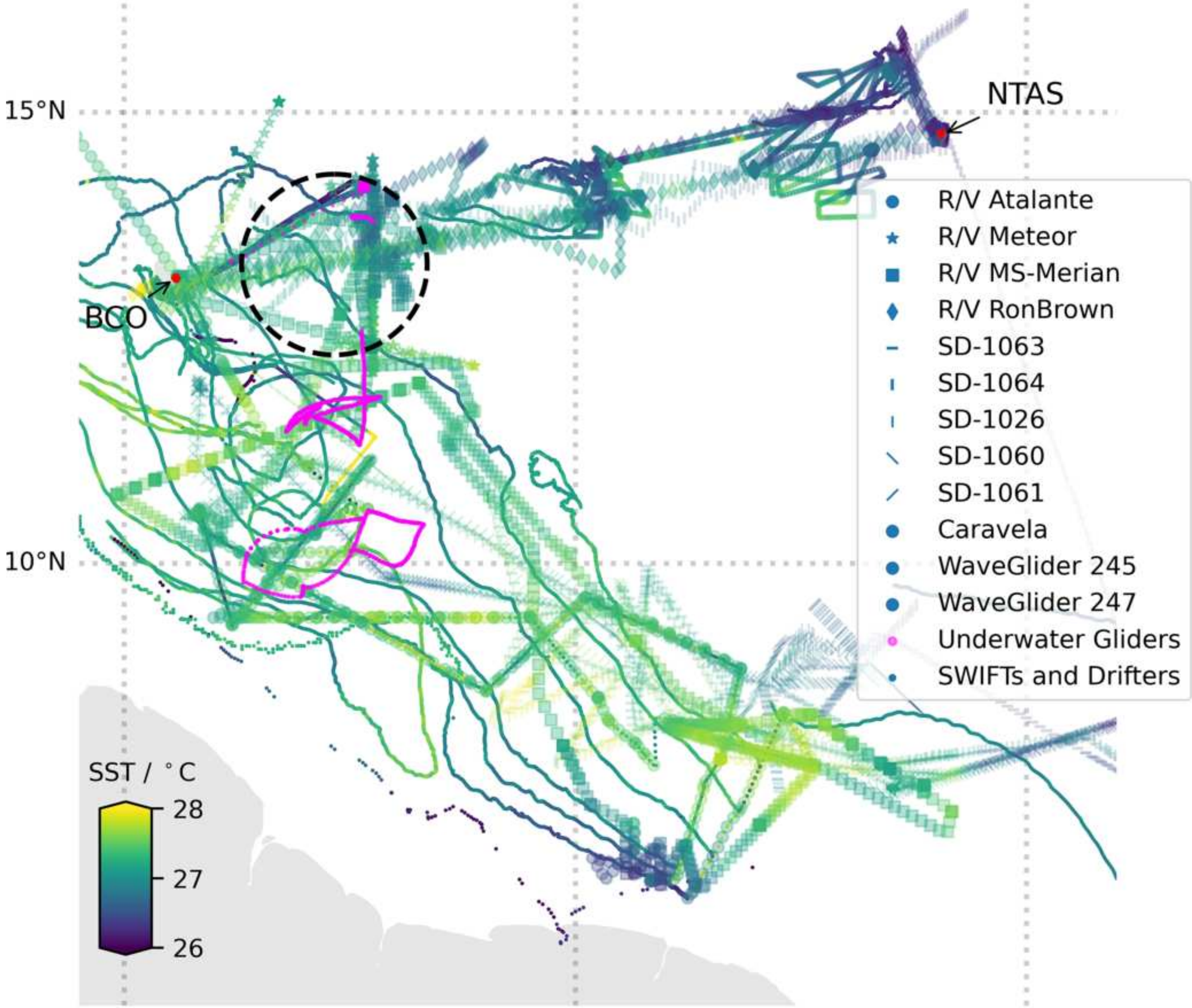


Improving the understanding of cloud cycles

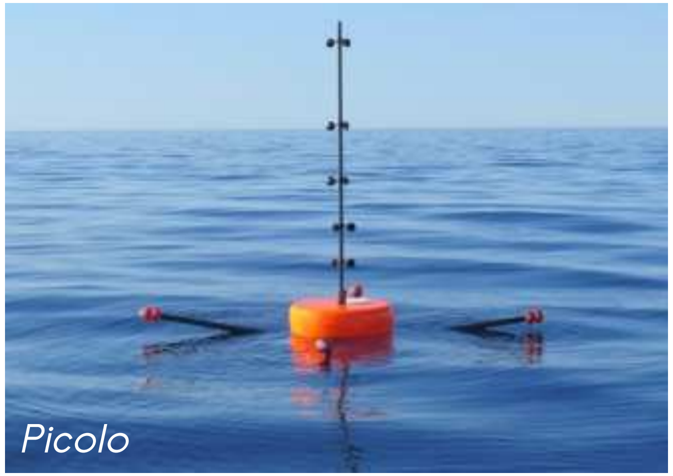


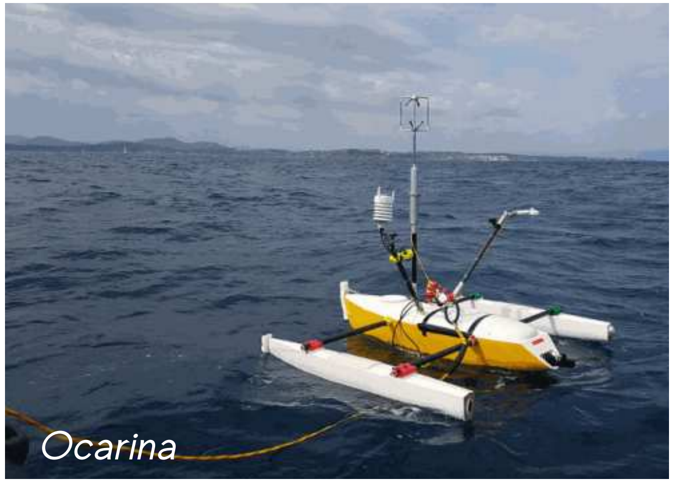
Sand rine BONY (LMD/IPSL, CNRS, Sorbonne Université)

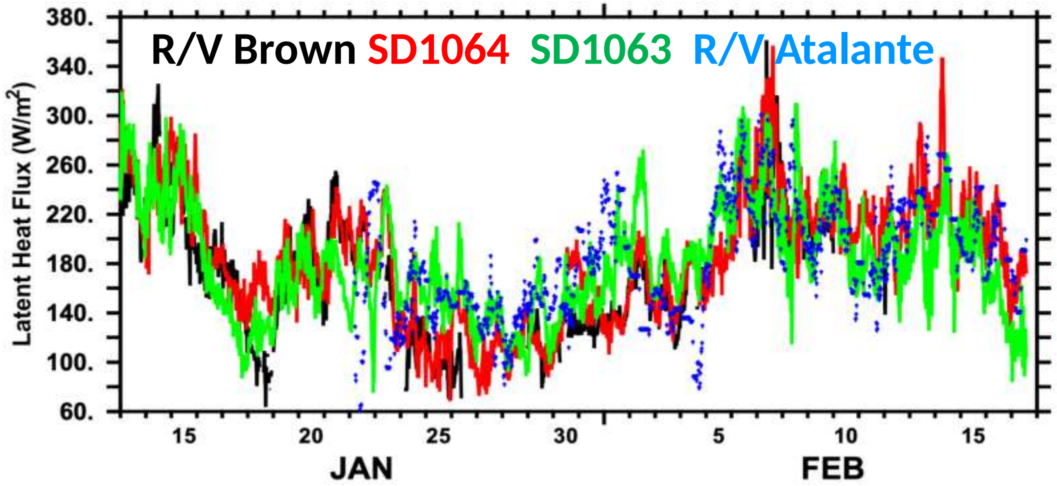
Surface and subsurface platforms



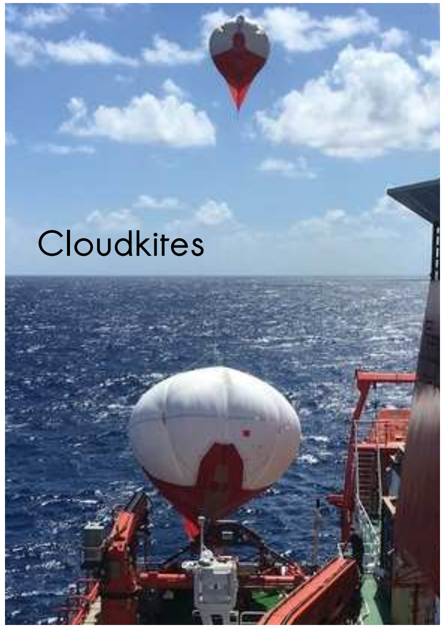
Turbulent fluxes at the ocean surface



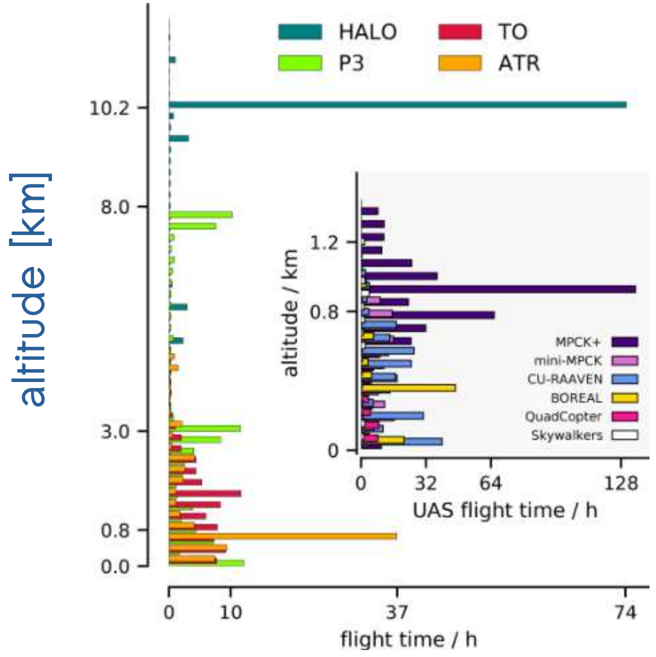


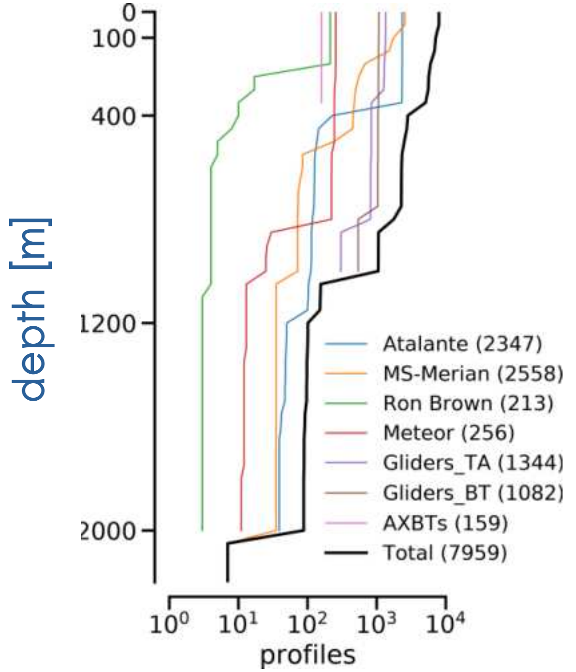


Ocean and atmospheric boundary layers



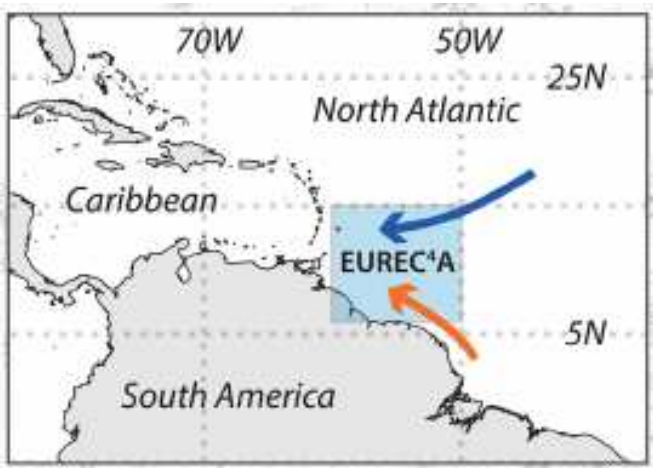
& much more (dropsondes, radiosondes, Raman lidars, CTDs, uCTDs, MVP, VMP, etc)





Cloud cover during the EUREC4A campaign

EUREC⁴A



Barbados
in winter (Jan-Feb)

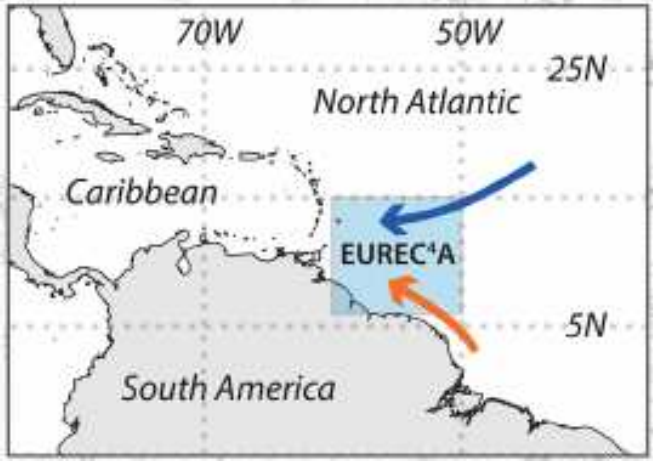
WCRP Grand Challenge on
Clouds, Circulation and Climate Sensitivity

WCRP
World Climate Research Programme

(Bony et al., 2015)

EUREC^{4}A

Barbados
in winter (Jan-Feb)



Marine boundary layer clouds at the heart of tropical cloud feedback uncertainties in climate models

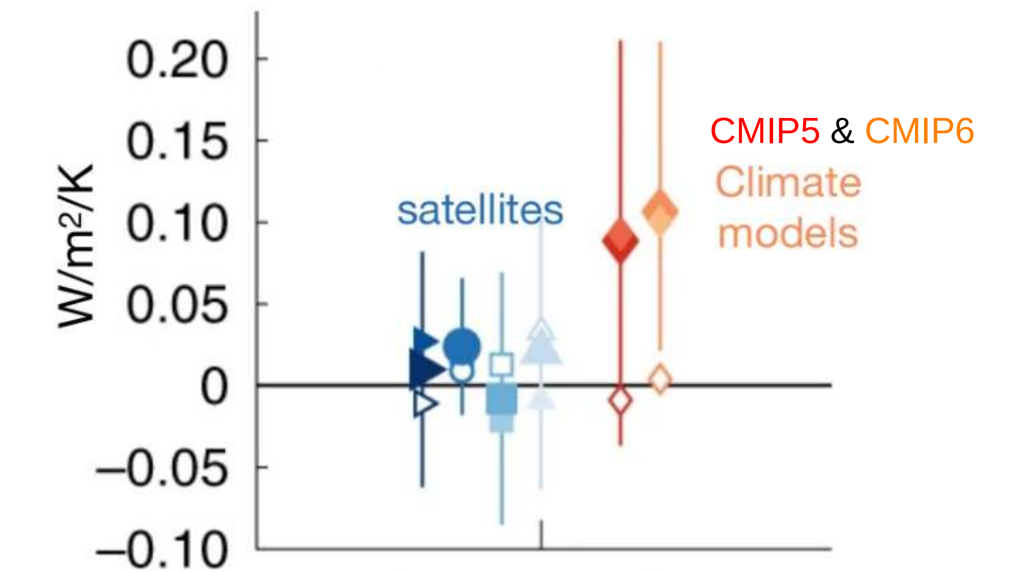
Sandrine Bony, Jean-Louis Dufresne,

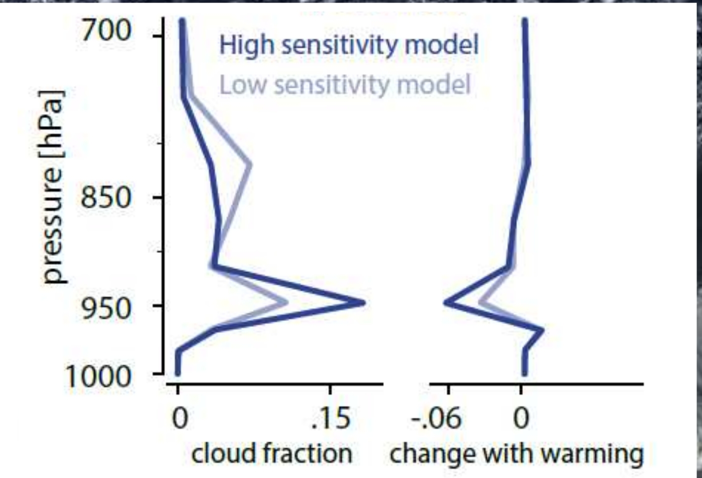
First published: 26 October 2005 | https://doi.org/10.1029/2005GL023851 | Citations: 852

ARTICLE
2 JANUARY 2014 | VOL 505 | NATURE | 37
doi:10.1038/nature12829

Spread in model climate sensitivity traced to atmospheric convective mixing

Steven C. Sherwood[1], Sandrine Bony[2] & Jean-Louis Dufresne[2]



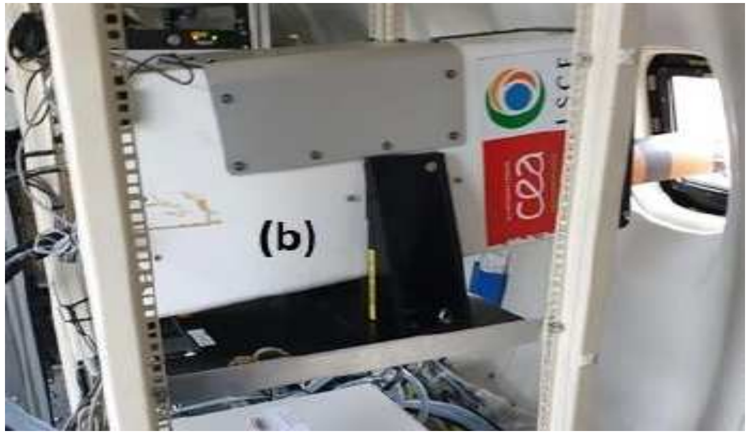


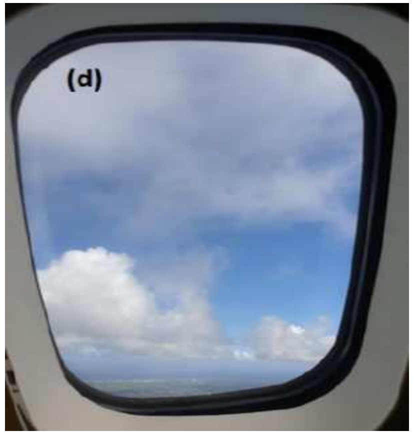
High climate sensitivity models predict a dessication of clouds at their base, that depends on the strength of vertical mixing in the lower troposphere (e.g. Vial et al. 2016)

Results obtained from EUREC4A

Cloud fraction near the cloud-base level

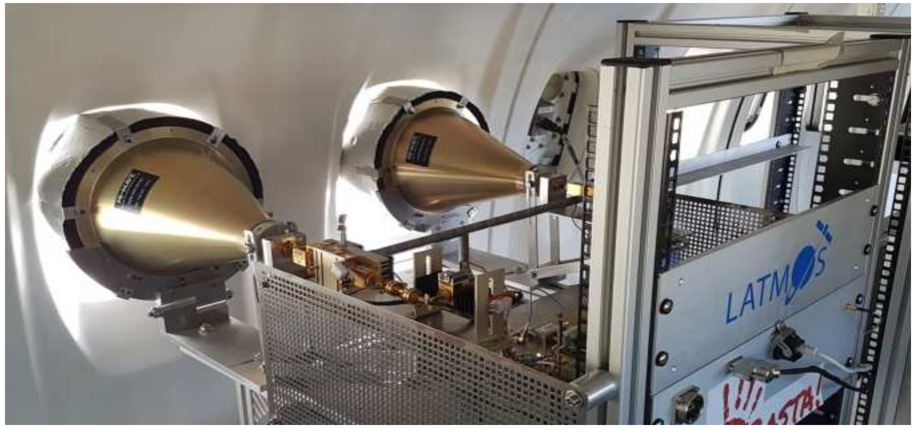
Horizontally-pointing lidar



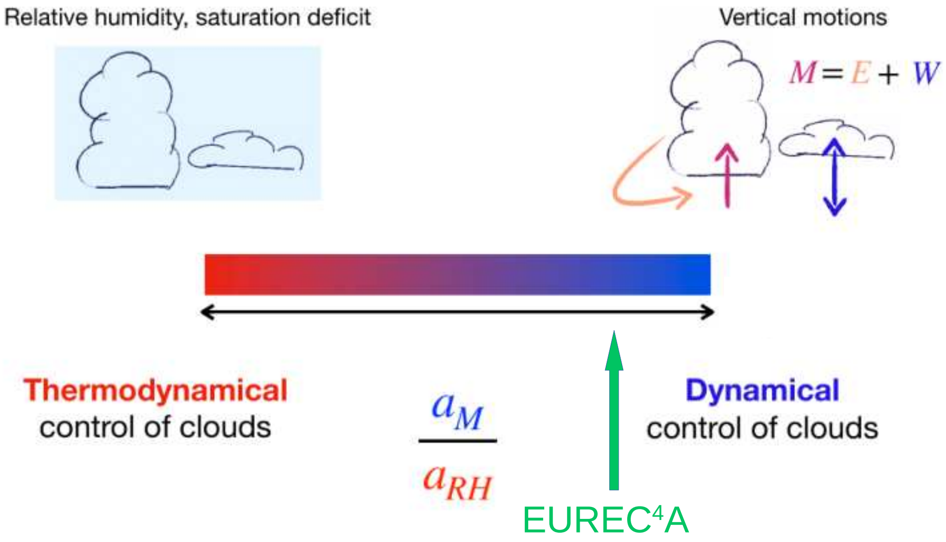


ALIAS 355 nm lidar (Chazette et al., 2020)

Horizontally-pointing radar



BASTA 94GHz Doppler cloud radar (Delanoë et al., 2016)



EUREC4A observations do not support the mixing-dessication mechanism at work in a number of models

EUREC4A observations suggest that trade-wind clouds are more dynamically controlled by convective and mesoscale motions than thermodynamically controlled by humidity variations

Very high-resolution sampling led to new insights on the mesoscale

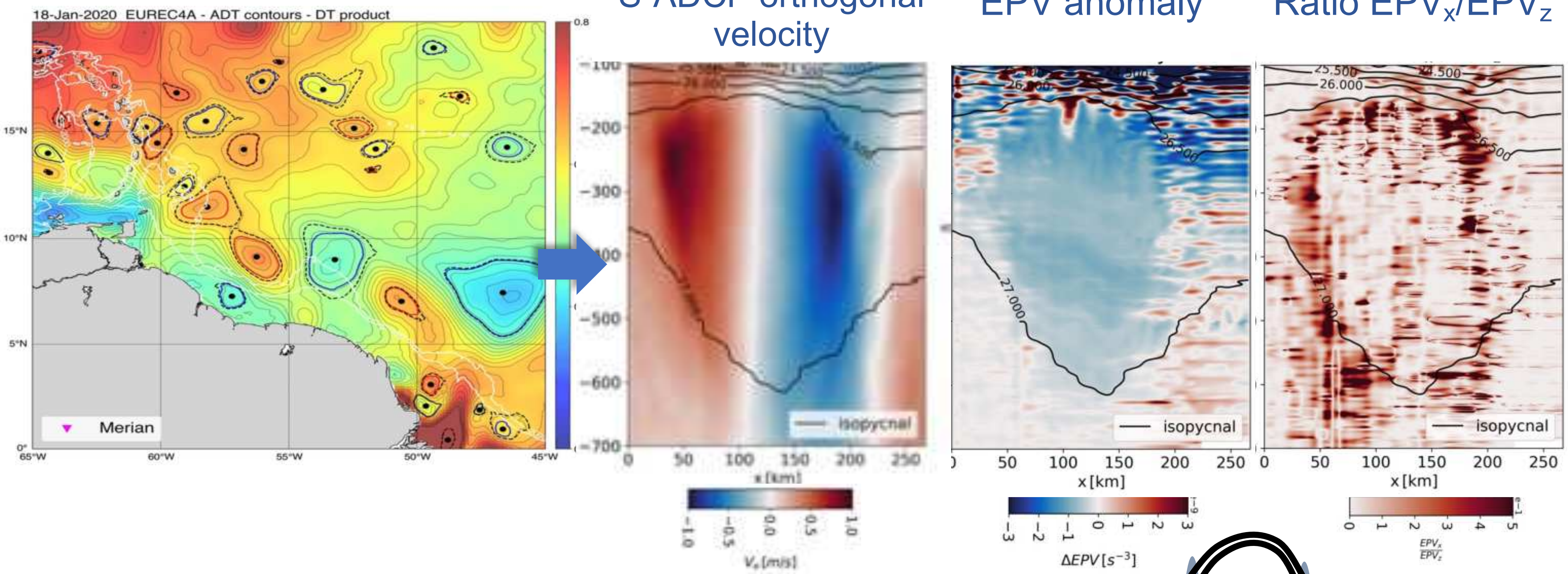
- **Ertel PV** (1942) on a 2D vertical section : $EPV = EPV_x + EPV_z = -\frac{\partial b}{\partial x}\frac{\partial V_o}{\partial z} + \left(\frac{\partial V_o}{\partial x} + f_0\right)\frac{\partial b}{\partial z}$

Synoptical situation

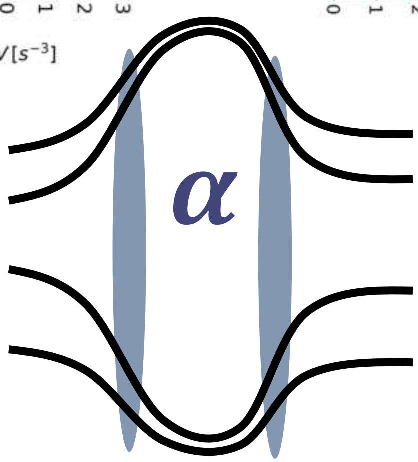
S-ADCP orthogonal velocity

EPV anomaly

Ratio EPV_x/EPV_z



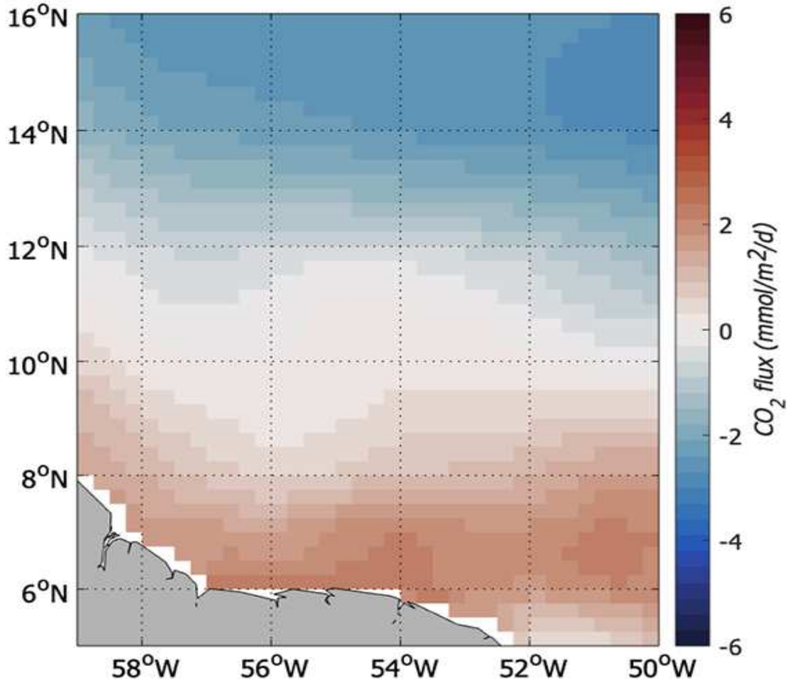
We were able to explain what makes ocean eddy long-lived coherent structure



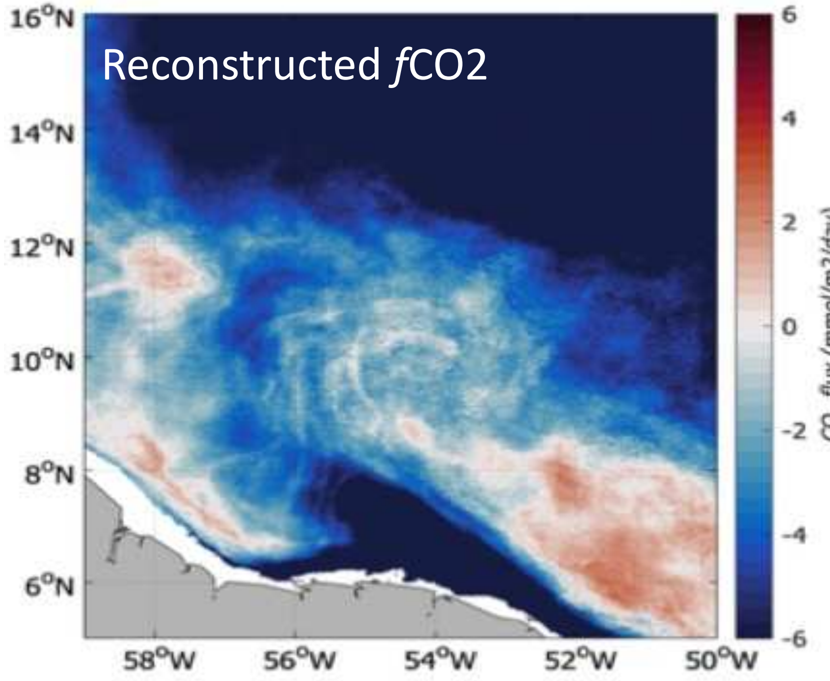
Barabinot et al., 2024

Ocean small-scale matters & fluxes are intenser than climatology

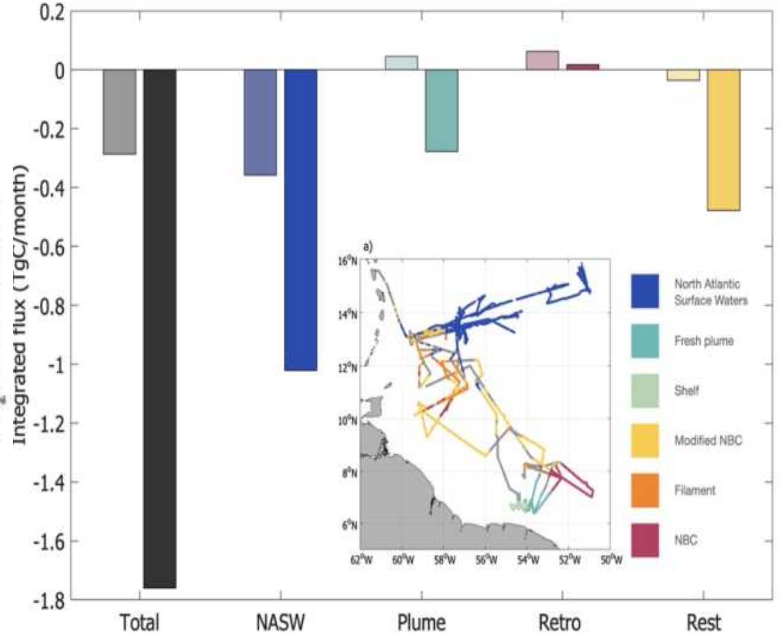
February air-sea CO_2 flux climatology
(Landschützer et al., 2020)



Reconstruction from R/V Atalante, Merian and Ron Brown & Satellite data
(EUREC4A-OA/ATOMIC, Jan-Feb 2020)

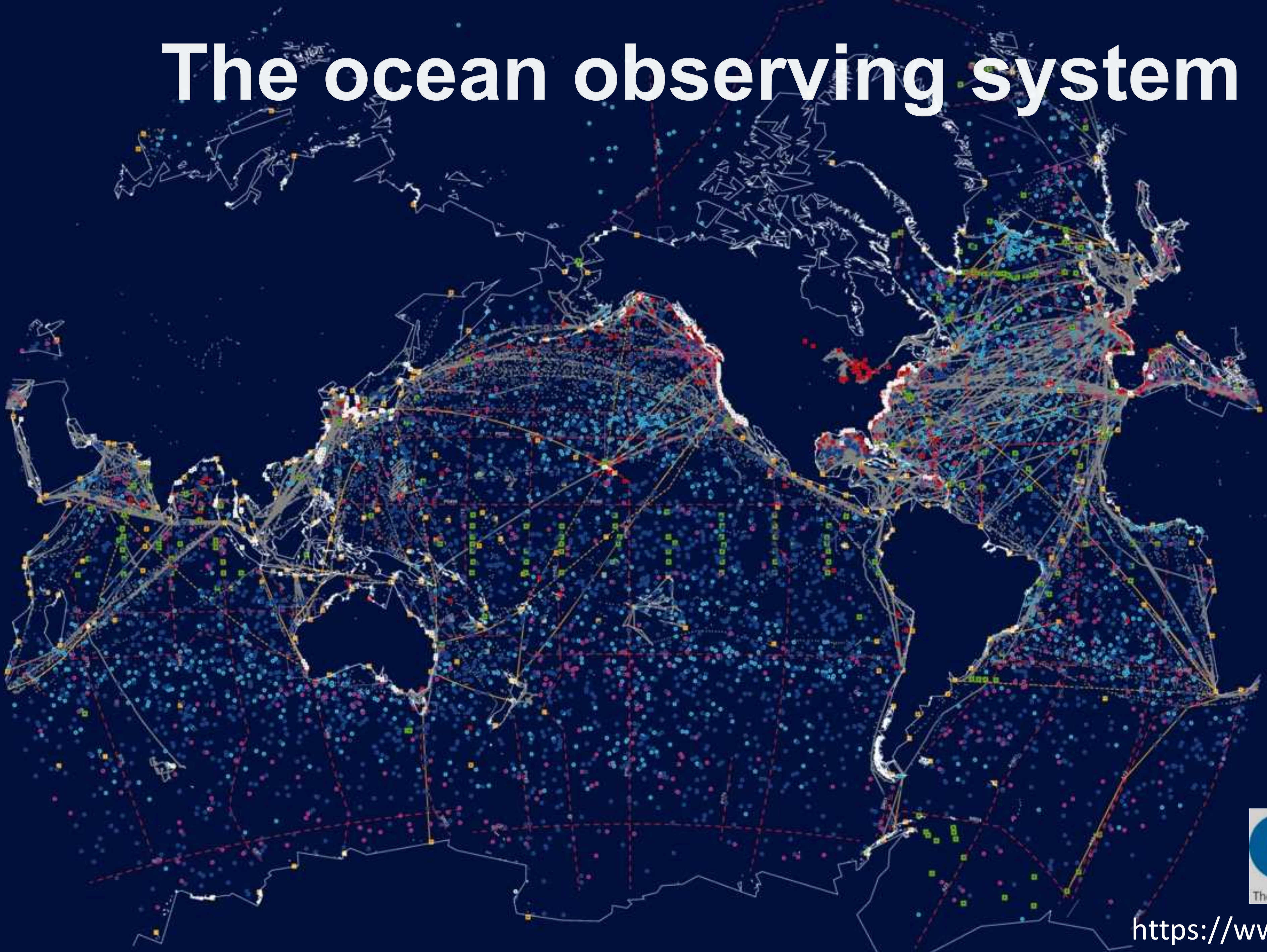


CO2 AIR-SEA FLUX BUDGET
EUREC4A-OA/ATOMIC vs CLIMATOLOGY



Olivier et al., 2022

The ocean observing system

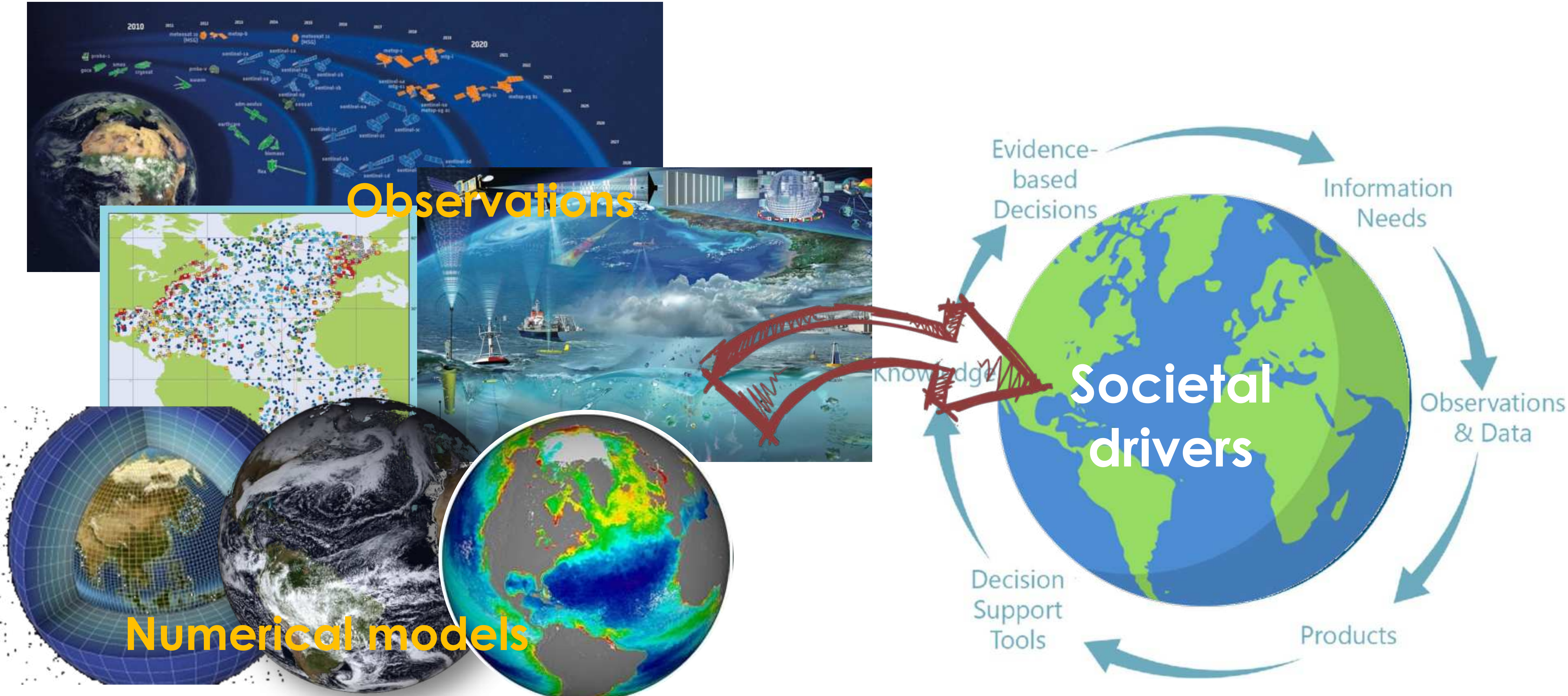


The Global Ocean Observing System

https://www.goosocean.org

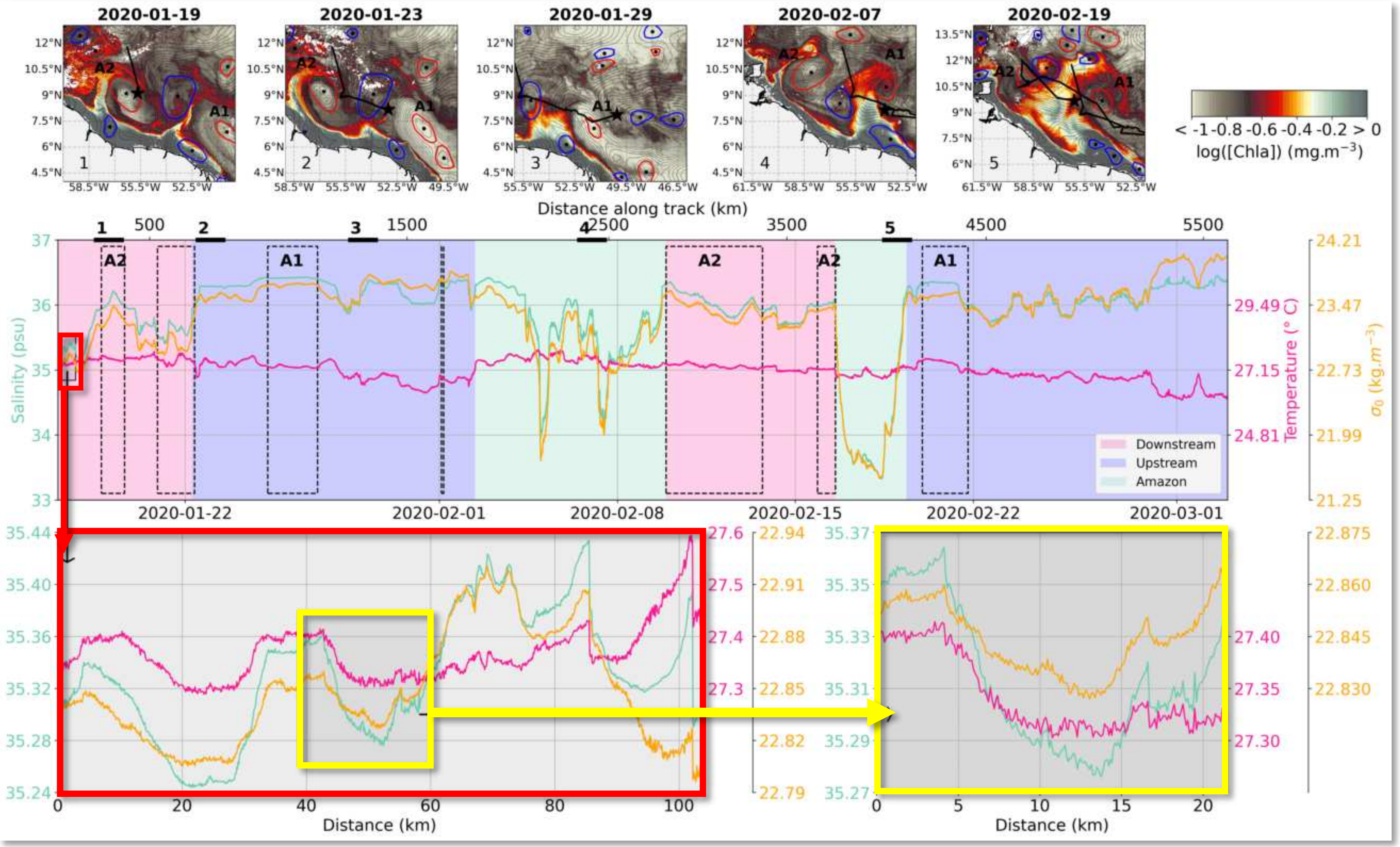
Integrated operational approaches based on science

Develop fit-for-purpose integrated ocean systems delivering the needed information



Cloud cover during the EUREC4A campaign

A highly dynamic region with contrasting surface properties



SSS (green), SST (pink) and DO (yellow) from SD1026 (center). Snapshots of Chla (top) computed from satellite data

Freshwater plume :

~ 120-km wide

MLD ~ 20 m, SSS down to 30 pss

After 14 days : an extent of 100,000 km^2

Reverdin et al. 2021

NBC rings :

A1 shed in late December, rather old

A2 shed during the cruise (early February)

Filaments :

Shelf waters & freshwater plume stirred by mesoscale eddies

O(1-10 km)

Strong surface thermohaline gradients occur at all scales, in particular close to the freshwater plume

Coadou et al., in review

Ocean surface currents and Sea Surface Temperature (SST)
Zoom on the GULF STREAM

https://svs.gsfc.nasa.gov/3912