Climate and Climate Changes : The physical basis

Dr. Jessica Vial

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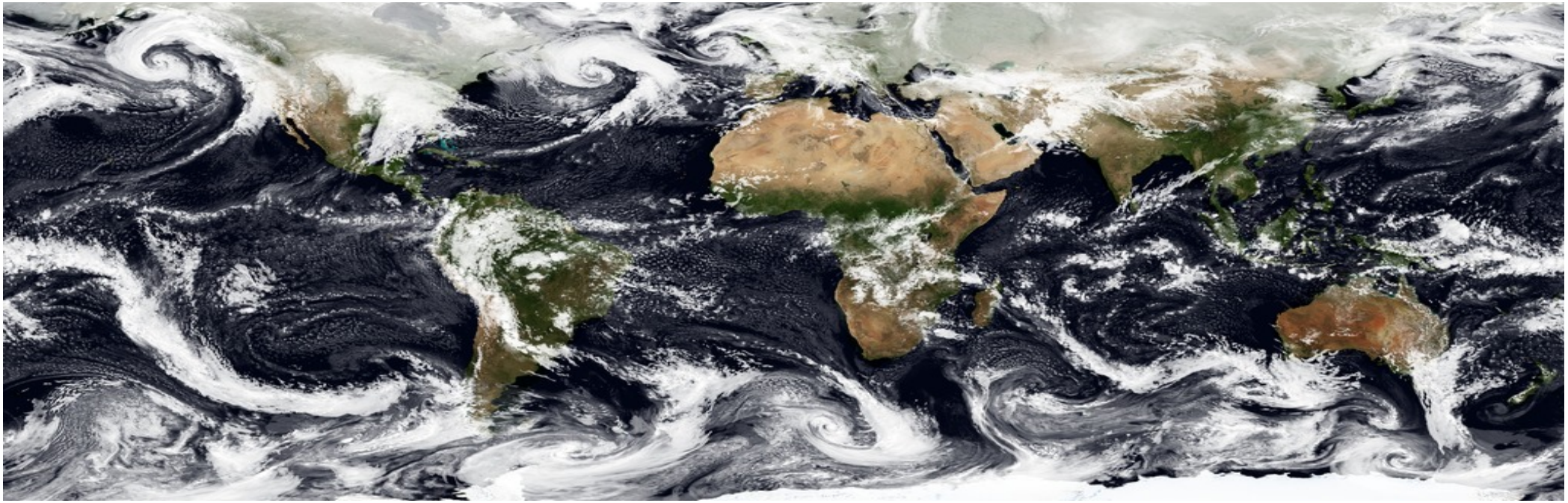

AXA Climate
Paris, January 16th 2020

Plan

Climate and weather: The basis

Understanding climate change

Recent changes: What has been measured

Brief history of climate science

The future: Modeling, scenarios and projections

What is climate ?

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What is climate ?

A Simple definition

Ensemble of weather parameters or phenomena measured over large geographical regions and a long period of time

What is climate ?

A Simple definition

Ensemble of weather parameters or phenomena measured over large geographical regions and a long period of time

Climate ≠ Weather

Weather forecasts are only valid locally and over short time periods !

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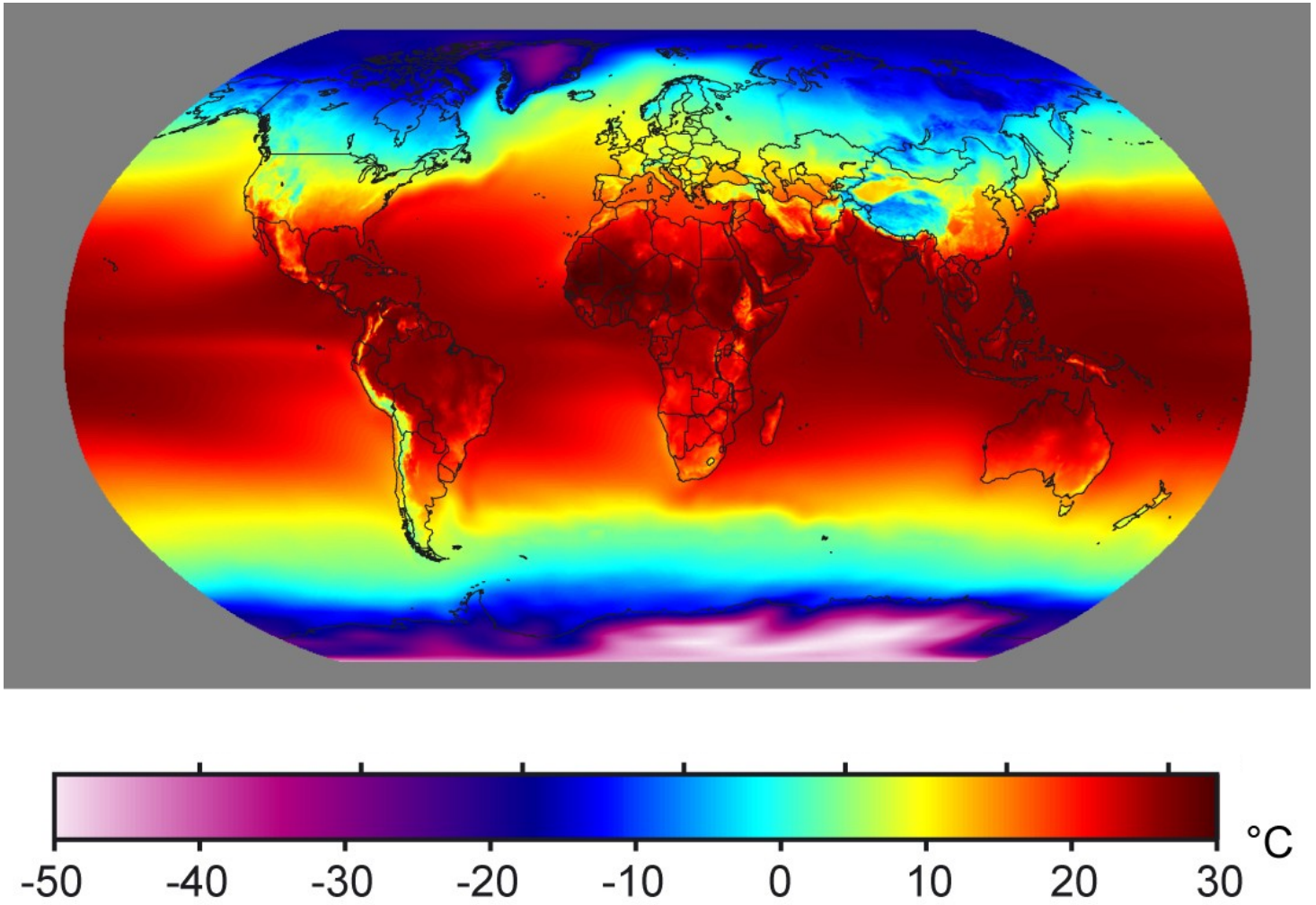
What is climate ?

Temperature climatology at the Earth surface:
Average annual temperature from 1961 to 1990



Data sources: CRU land surface temperature (New et al. 2002) ; NOAA OISST sea surface temperature (Reynolds et al. 2002) ; NCEP/NCAR Reanalysis (Kalnay et al. 1996)

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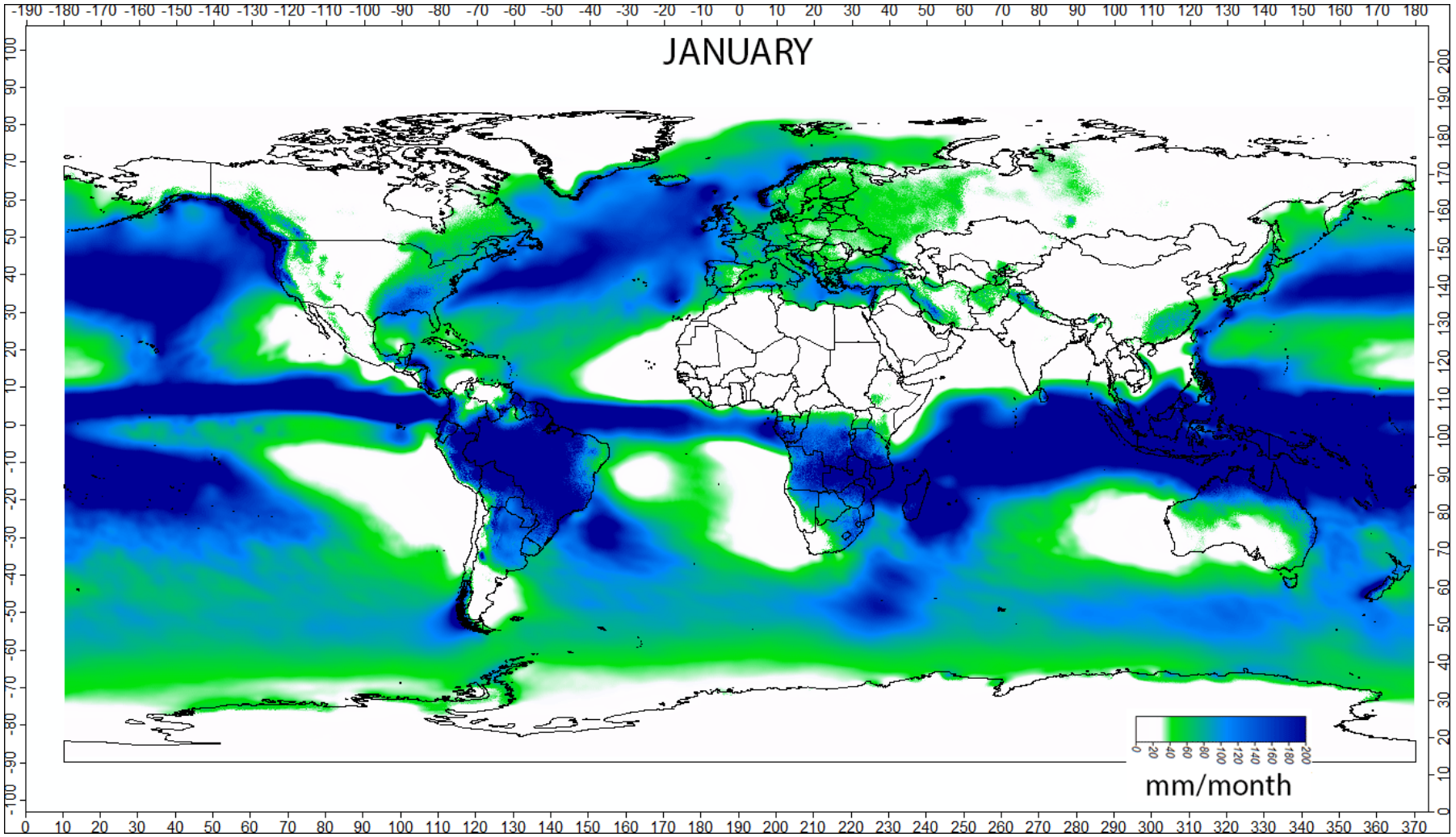
What is climate ?

Precipitation climatology:

Over the month of January averaged from 1979 to 2013



Data : ERA-Interim (Dee et al. 2011)

Source : Karger DN et al., Scientific Data 2017

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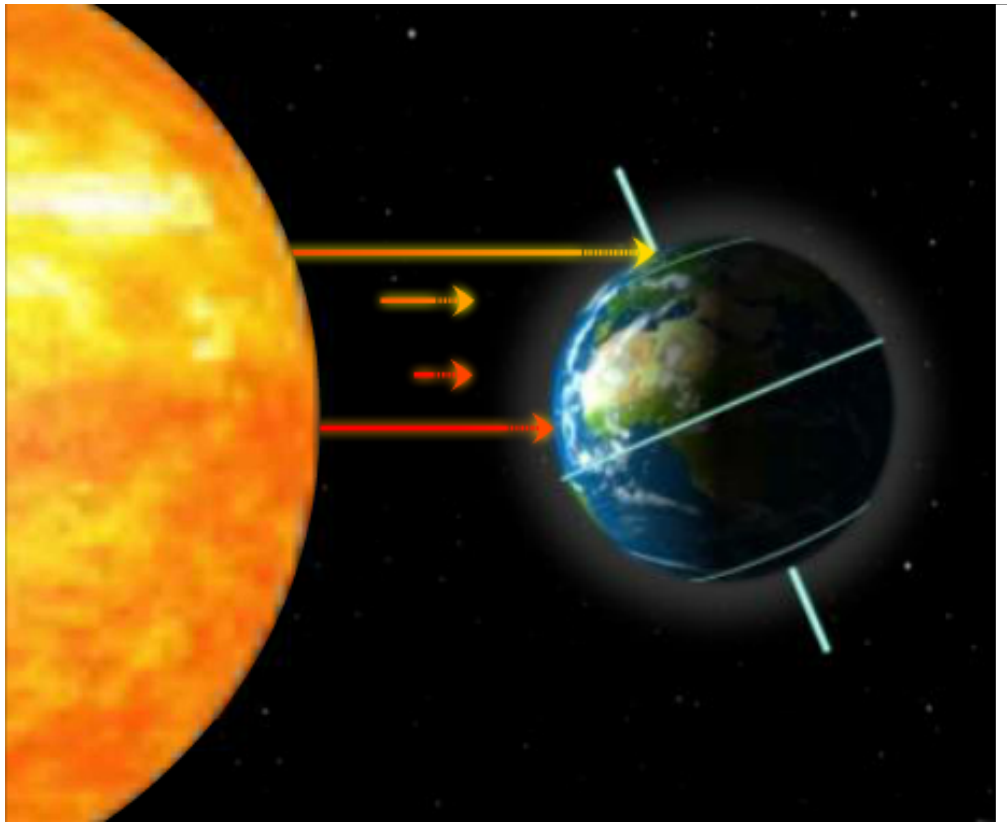
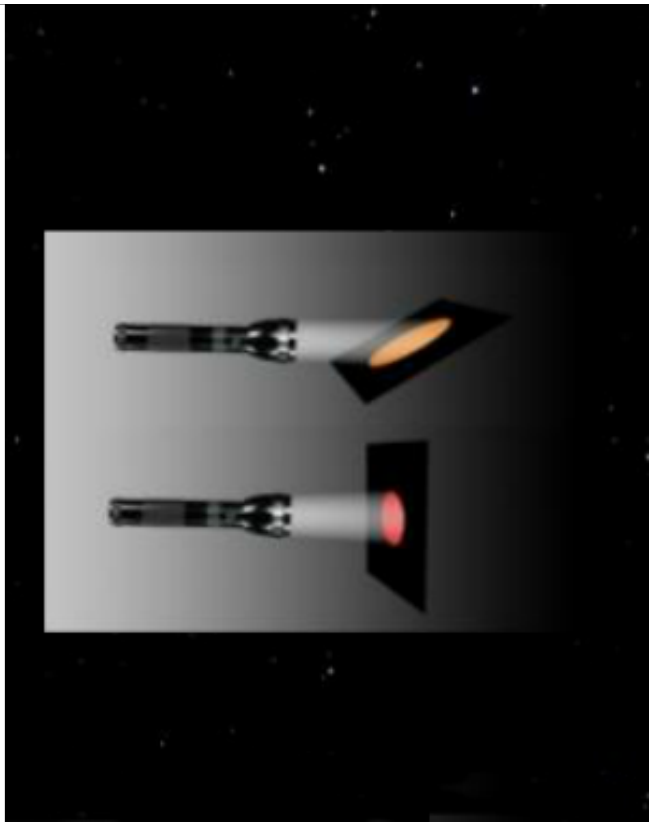
The sun, our climate driver !





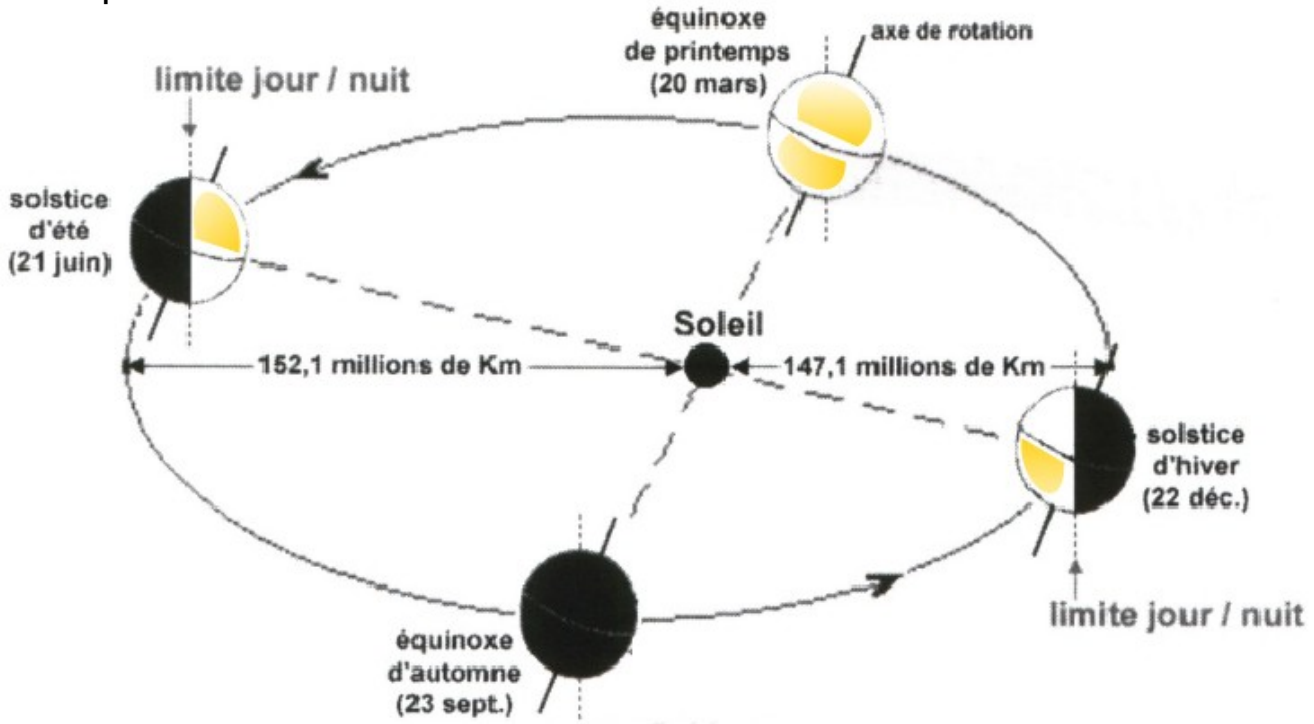
- Solar radiation warms up the Earth. It's the **solar energy** (in Watt/m^2)
- The incoming solar energy is unevenly distributed over the Earth surface: **warming is larger over the tropics than the poles** (by unit of surface).

« Climate » comes from the Greek « klima » that means « tilt »

→ The tilt of the Earth with respect to the sun (~ 23.5°)

The tilt of the Earth axis : at the origin of the seasons

For the Northern hemisphere:



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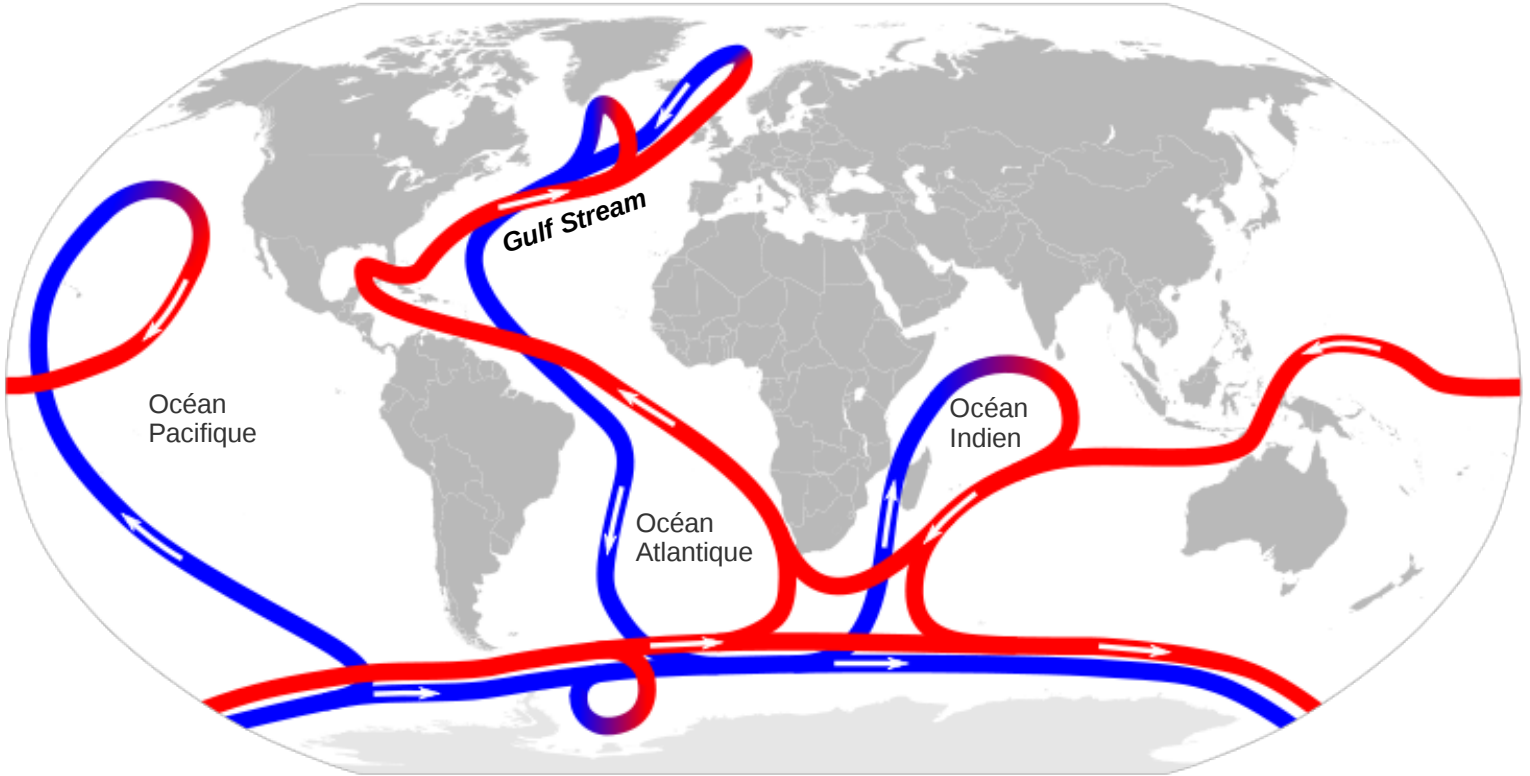
The circulation: winds and ocean currents

They redistribute heat accross the globe,

… from the warmest regions to the coldest

The Oceans

93% of the heat is stored in the ocean



« Thermohaline circulation » or *« overturning meridional circulation »*

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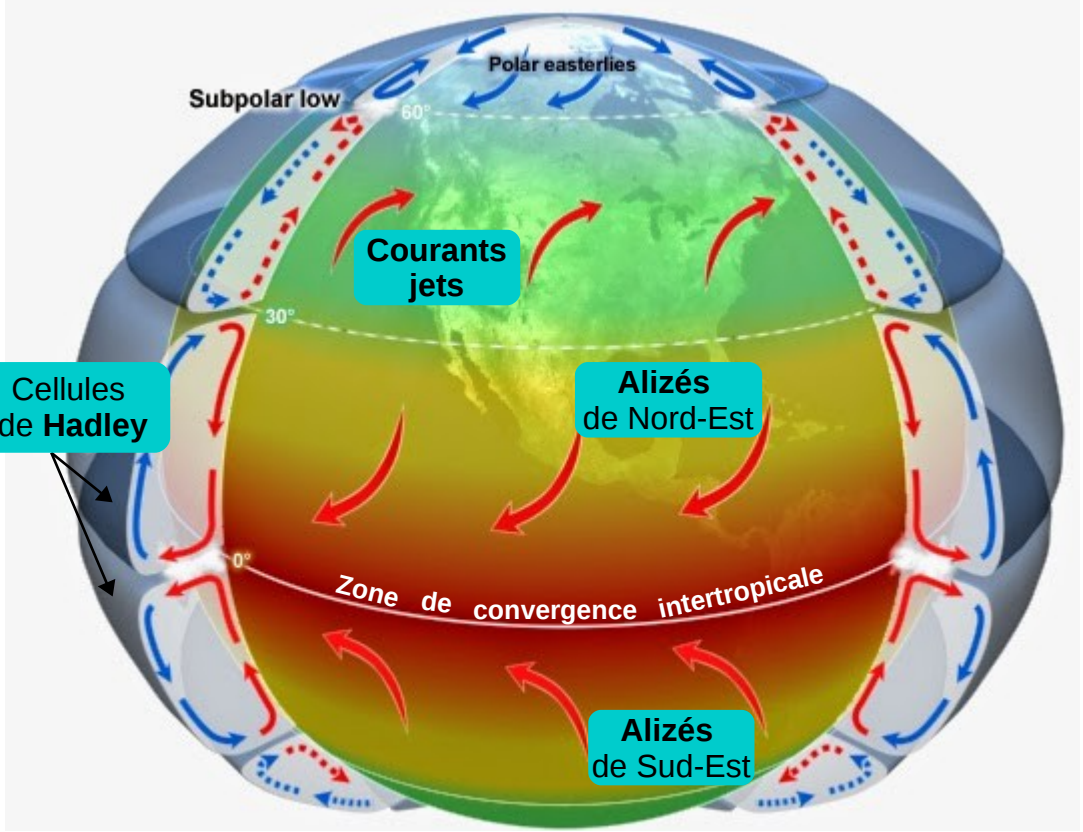
The circulation: winds and ocean currents

They redistribute heat accross the globe,

… from the warmest regions to the coldest

The atmosphere



General circulation of the atmosphere

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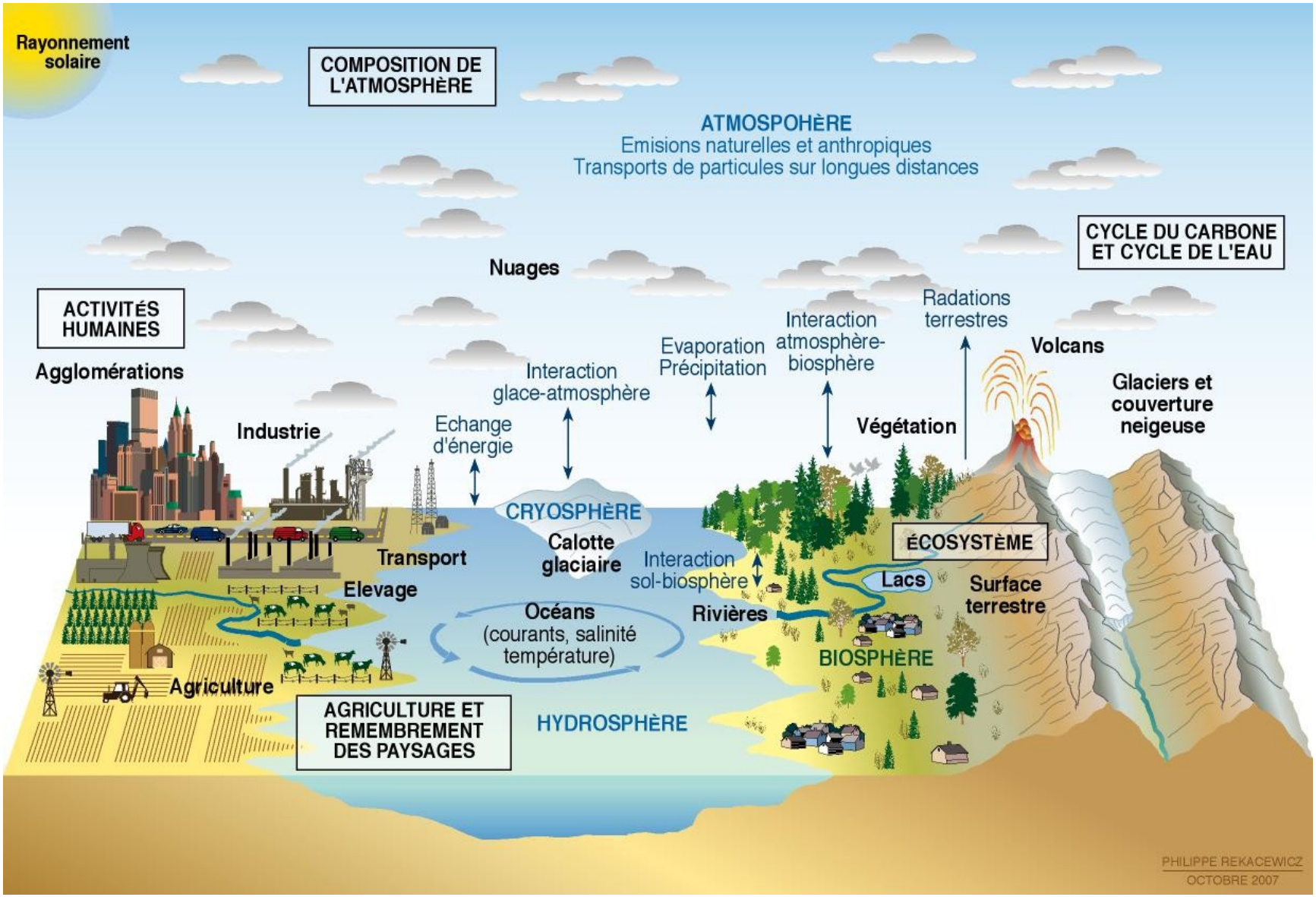
A myriad of factors influence the Climate system



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Understanding climate change...

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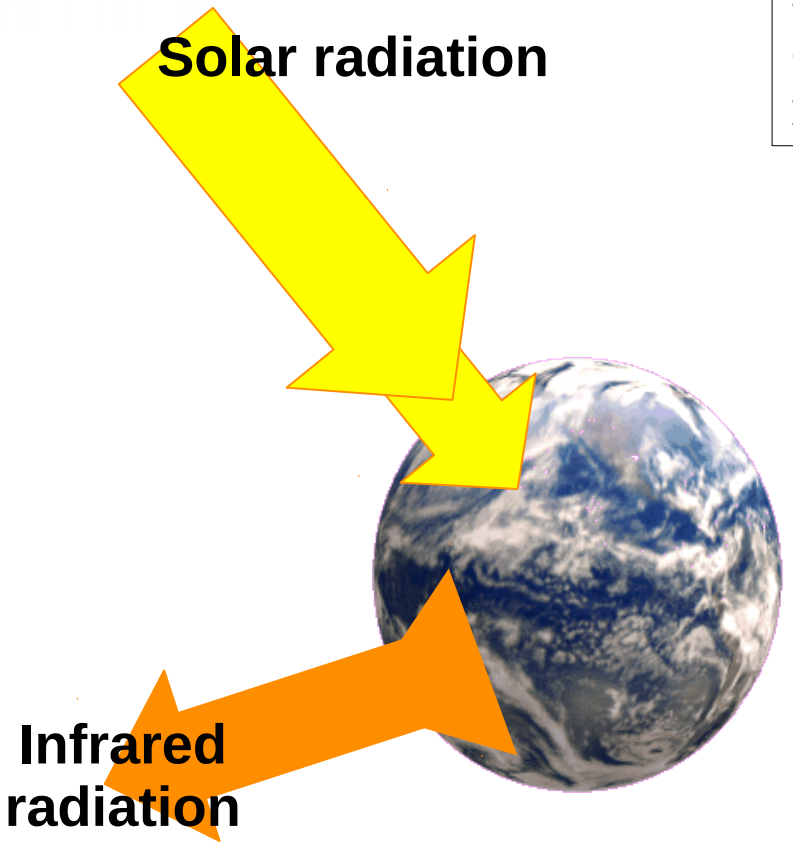
… means understanding what controls the Earth temperature



Energy exchange between the Earth and space:

- The Earth absorbs solar radiation ; it warms up
- The Earth emits infrared radiation ; it cools down

… until an equilibrium is reached:

Solar radiation absorbed by the Earth = Infrared radiation Emitted back to space

What is the Earth temperature under this « radiative equilibrium » ?

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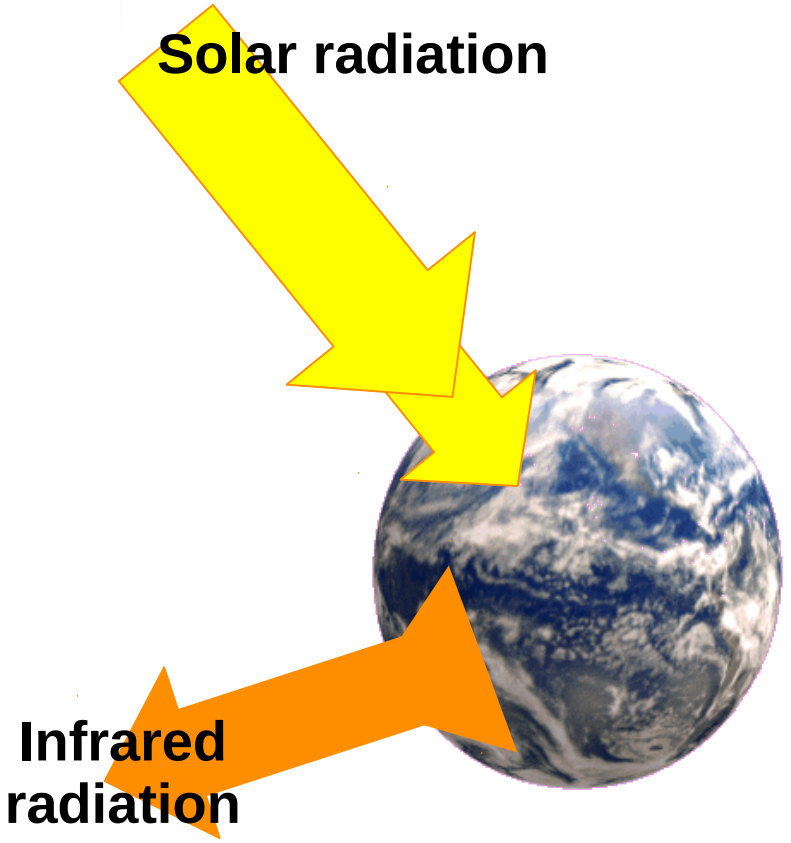
… means understanding what controls the Earth temperature

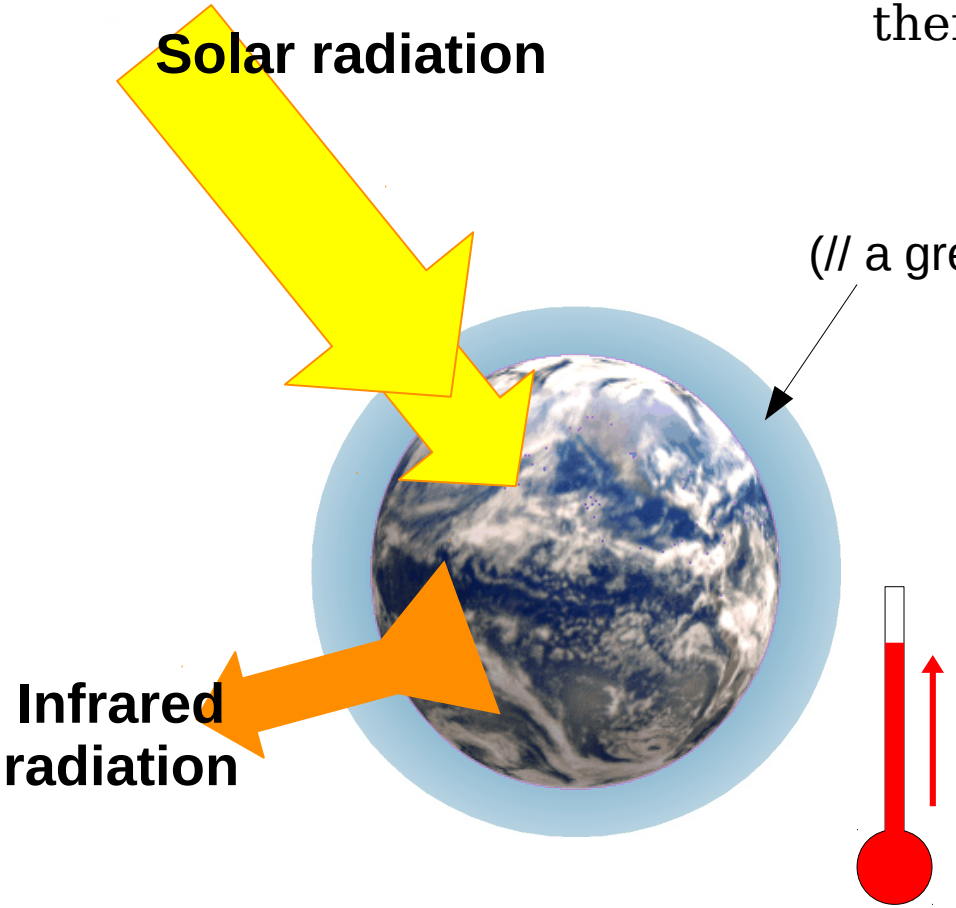


- **Radiative Equilibrium temperature** at the Earth surface: **-18°C**
- **Measured** température: **+15°C**
- The difference comes from **the greenhouse effect**

Greenhouse effect on Earth

The Earth artmosphere absorbs infrared radiations.

The Earth looses less energy than it would without the atmosphere, and therefore warms up.



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Greenhouse effect on Earth

A natural phenomenon

The atmosphere is composed of a mix of gases that absorb infrared radiations

What is the main greenhouse gas ?

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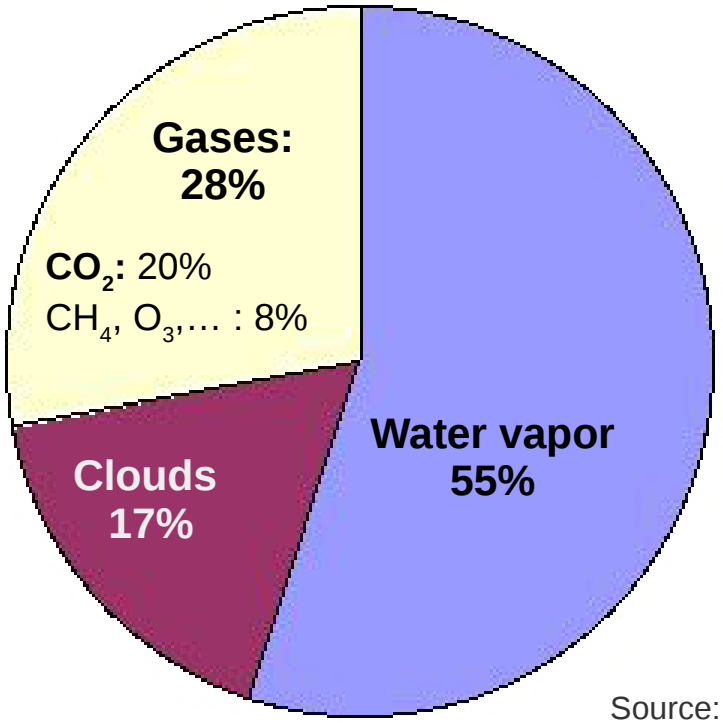
Greenhouse effect on Earth

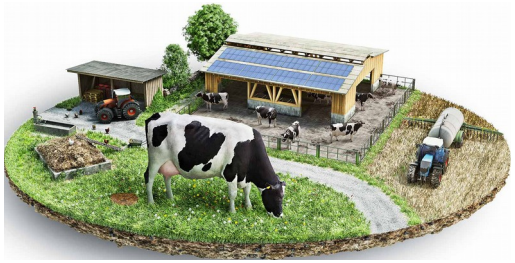
A natural phenomenon

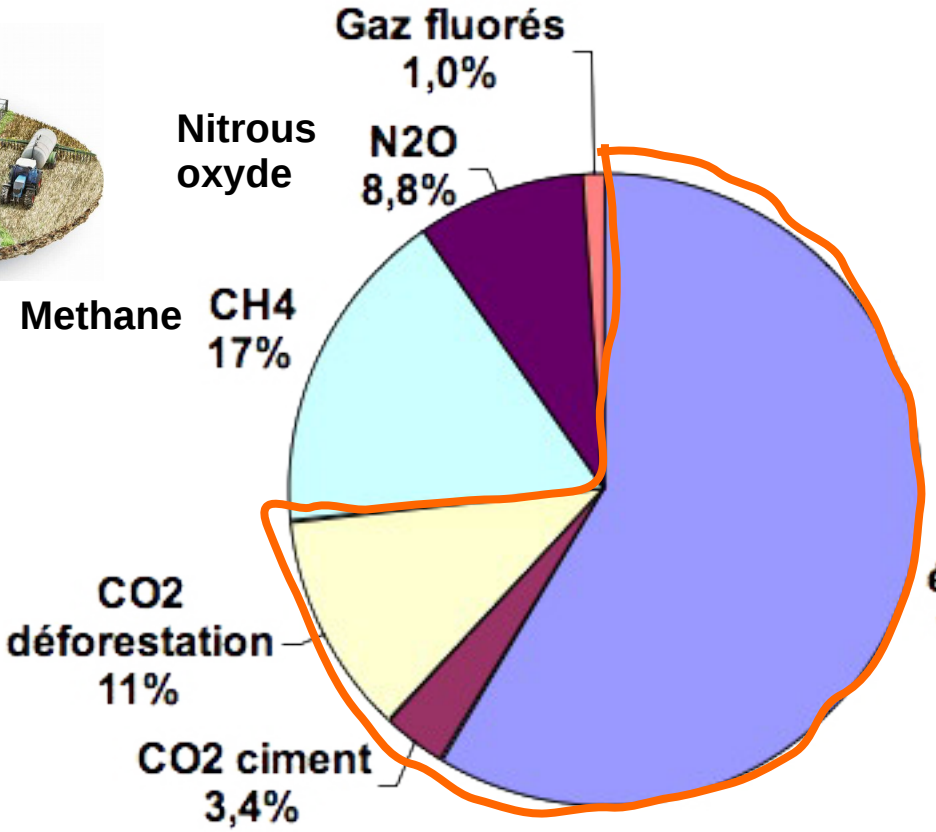
The atmosphere is composed of a mix of gases that absorb infrared radiations



Source: GIEC

Human emissions of greenhouse gases





Carbon dioxyde (CO_2):

¾ of the total emissions

Sources: BP statistical Review 2009 pour les consommations de combustibles fossiles ; IPCC AR4 WG 3 (2007) pour la production de ciment et les gaz hors CO_2; Houghton, The Woods Hole Research Center pour le CO_2 du à la déforestation.

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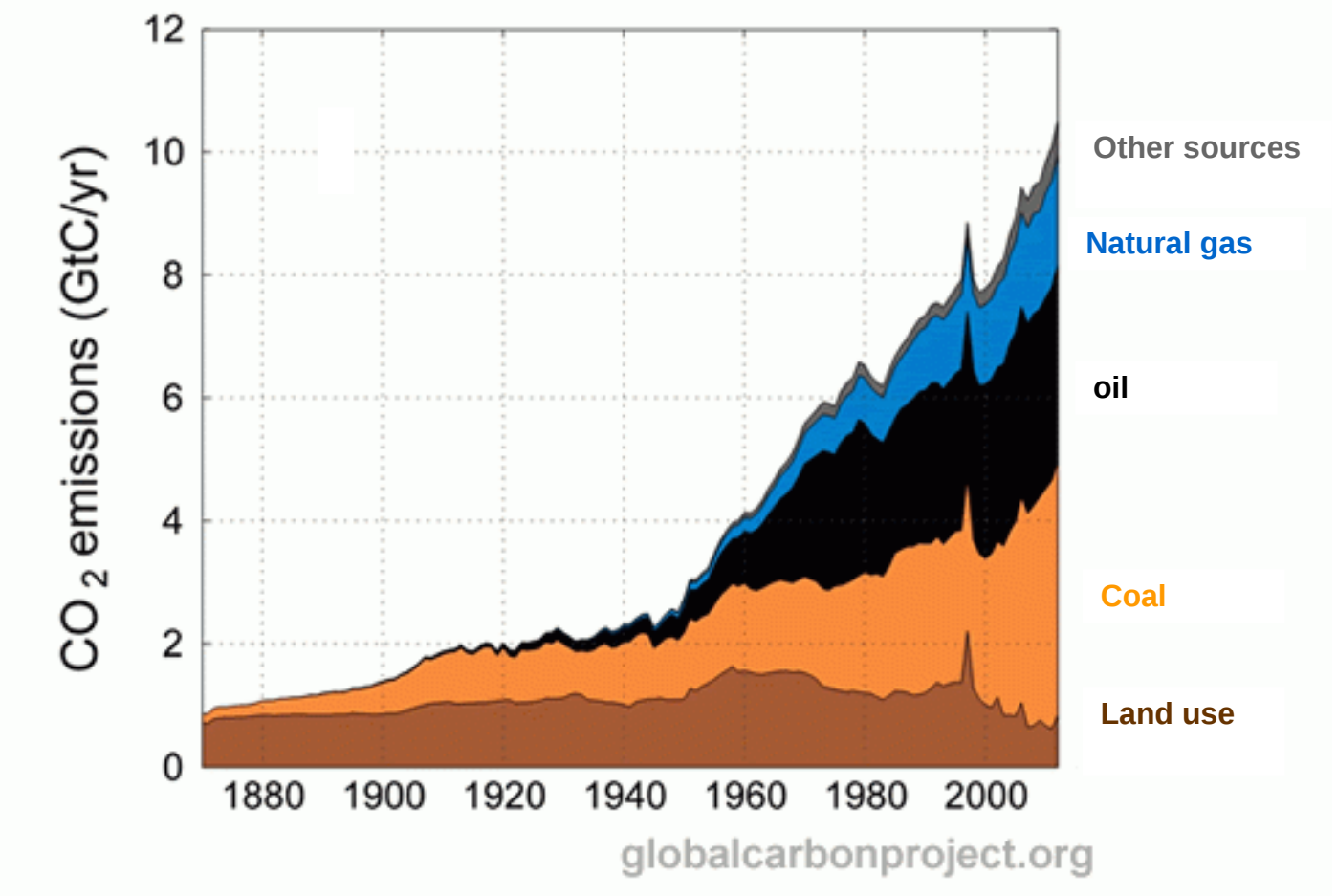
Evolution of CO_2 emissions by source



Half of the CO_2 emissions is absorbed by vegetation and oceans. The other half builds up in the atmosphere.

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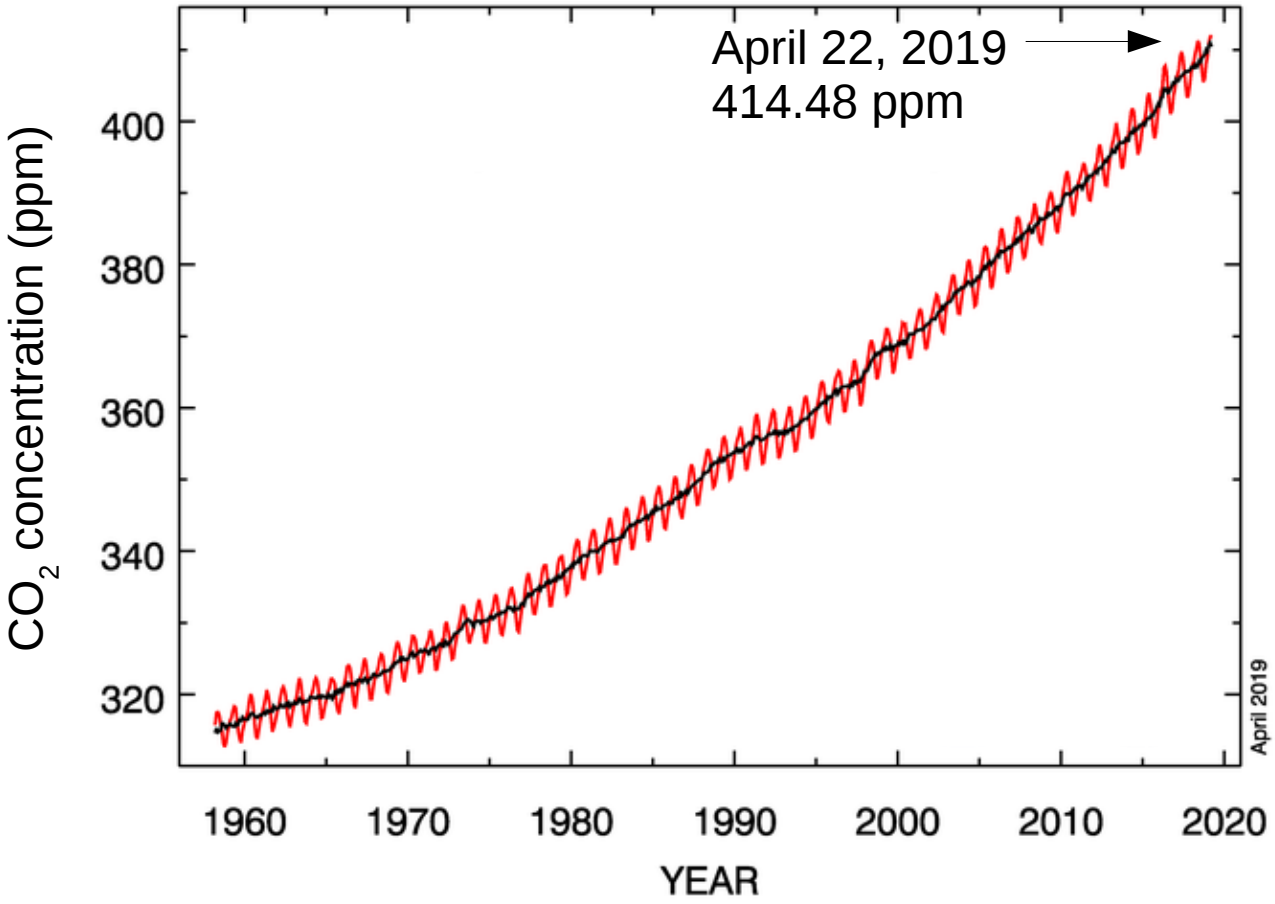
Evolution of CO_2 concentration in the atmosphere

Measurements at the Mauna Loa observatory (Hawaii)



An increase of 50 % compared to the pre-industrial era
(277 ppm en 1750)

Source: NOAA-ESRL ; Scripps Institution of Oceanography

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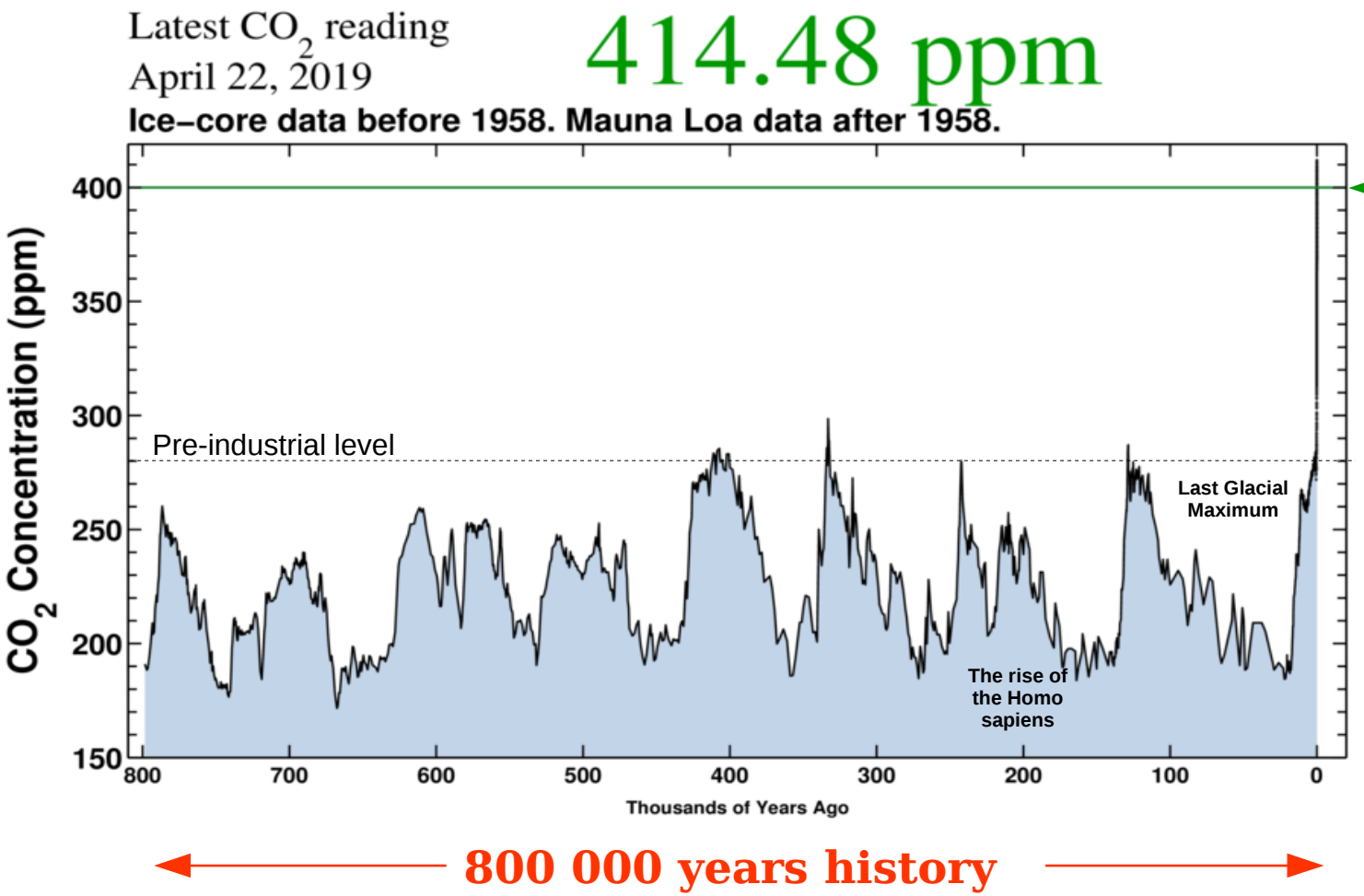
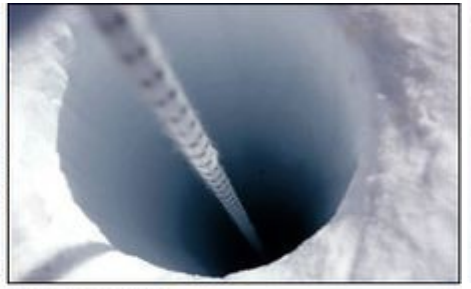
Evolution of CO_2 concentration in the atmosphere



CO_2 concentration has never been so high in nearly 1 million years !

800 000 years history



Source : NOAA-ESRL ; Scripps Institution of Oceanography

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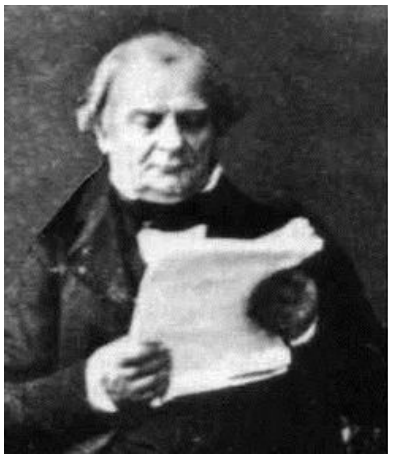
Evolution of water vapor concentration

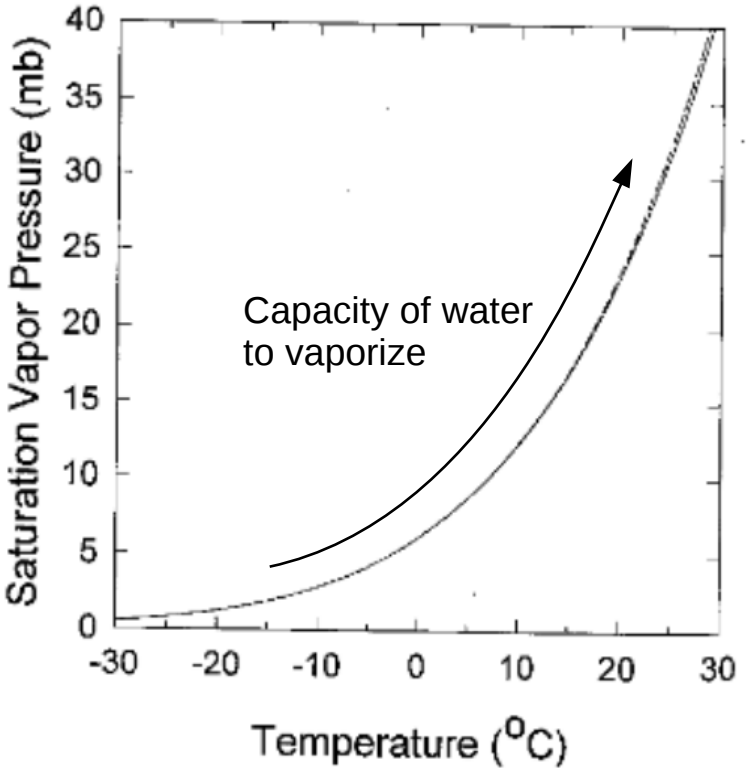
Water vapor is not the driver of climate change,
… but it certainly has an **amplifying effect**

→ Clausius-Clapeyron's law

Rudolf Clausius



Benoît Clapeyron



A warmer atmopshere can hold more water vapor

Figure: Bohren & Albrecht

Evolution of water vapor concentration

Water vapor is not the driver of climate change,
… but it certainly has an **amplifying effect**

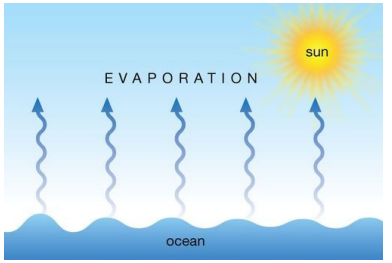
The Earth warms

Human activities
(CO_2, CH_4,… ↗)

Greenhouse effect ↗

Positive feedback loop

Water vapor ↗



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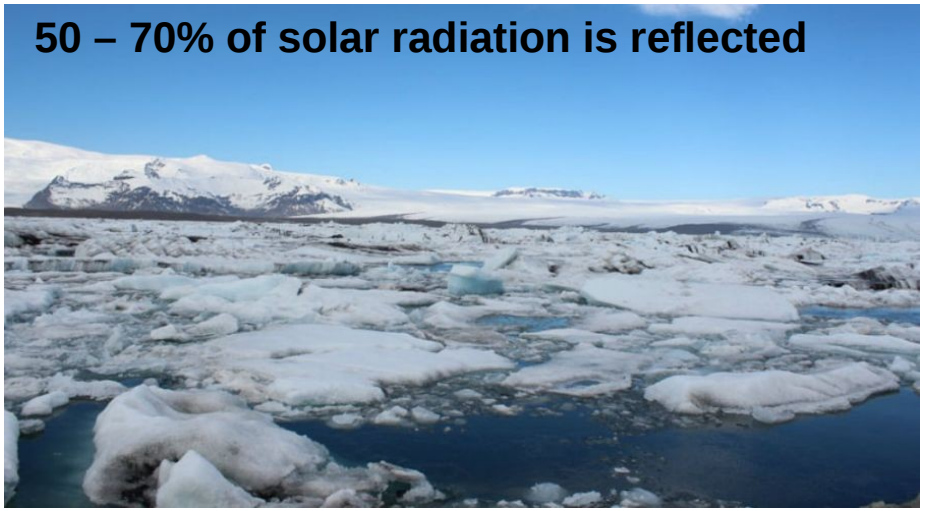
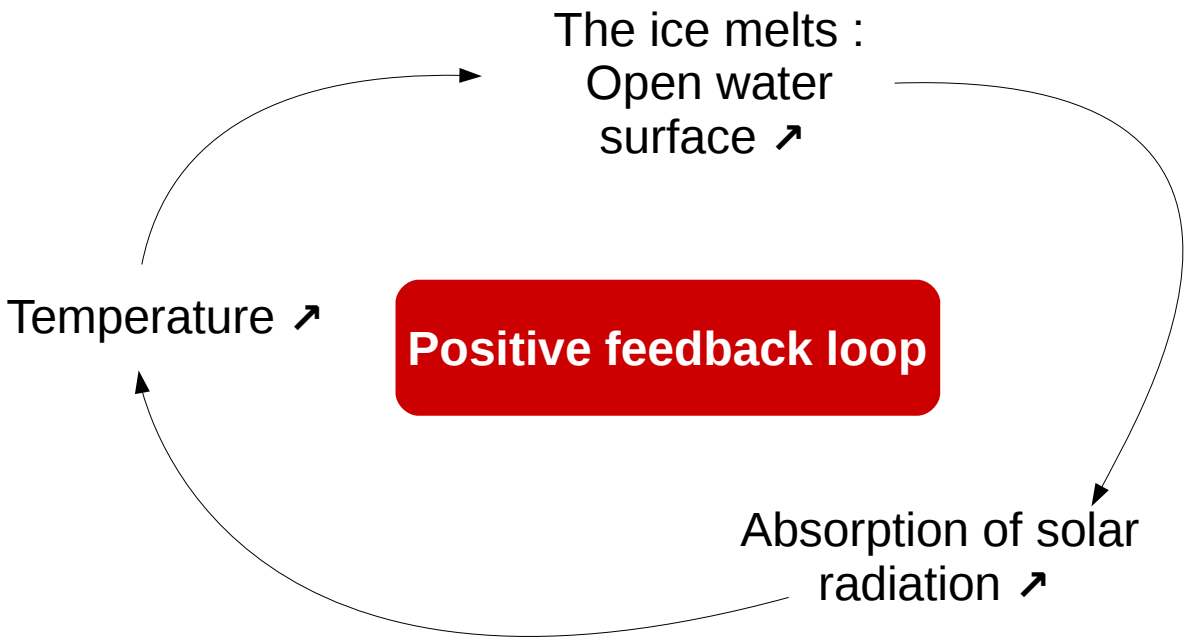
Ice albedo feedback





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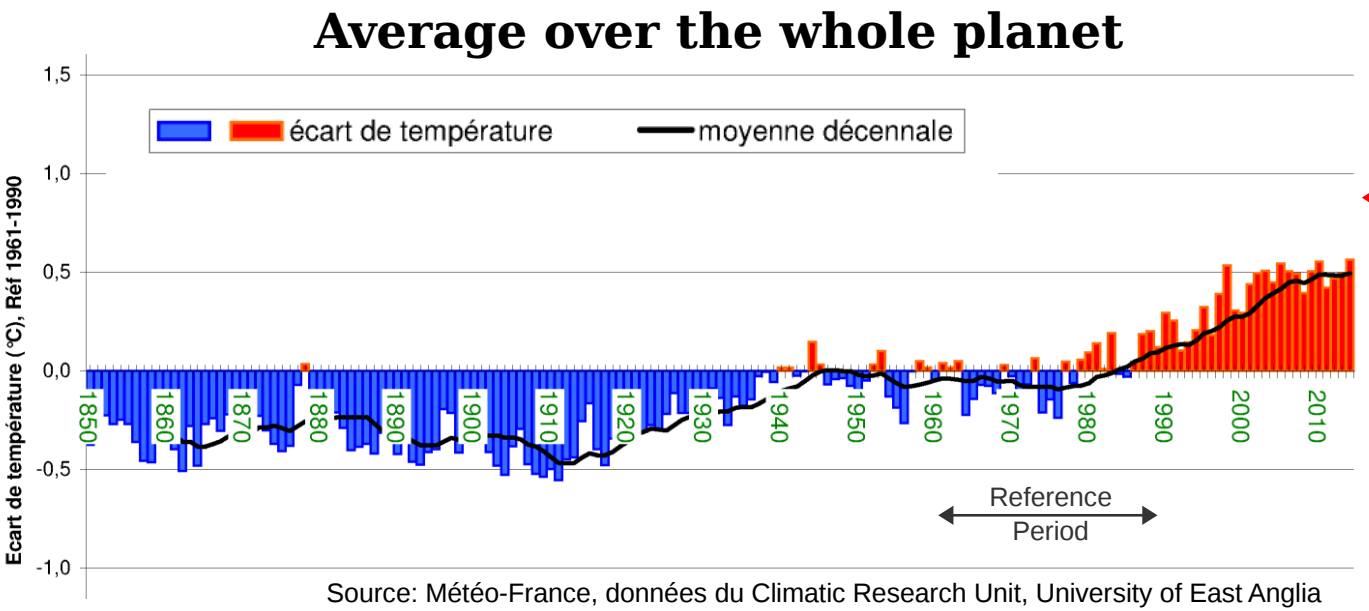
Recent changes

What has been measured

Temperature changes at the Earth surface



0.82°C in 2018

Source: Météo-France, données du Climatic Research Unit, University of East Anglia

- **Planetary warming**

  → 1,1°C since 1850 (industrial revolution)

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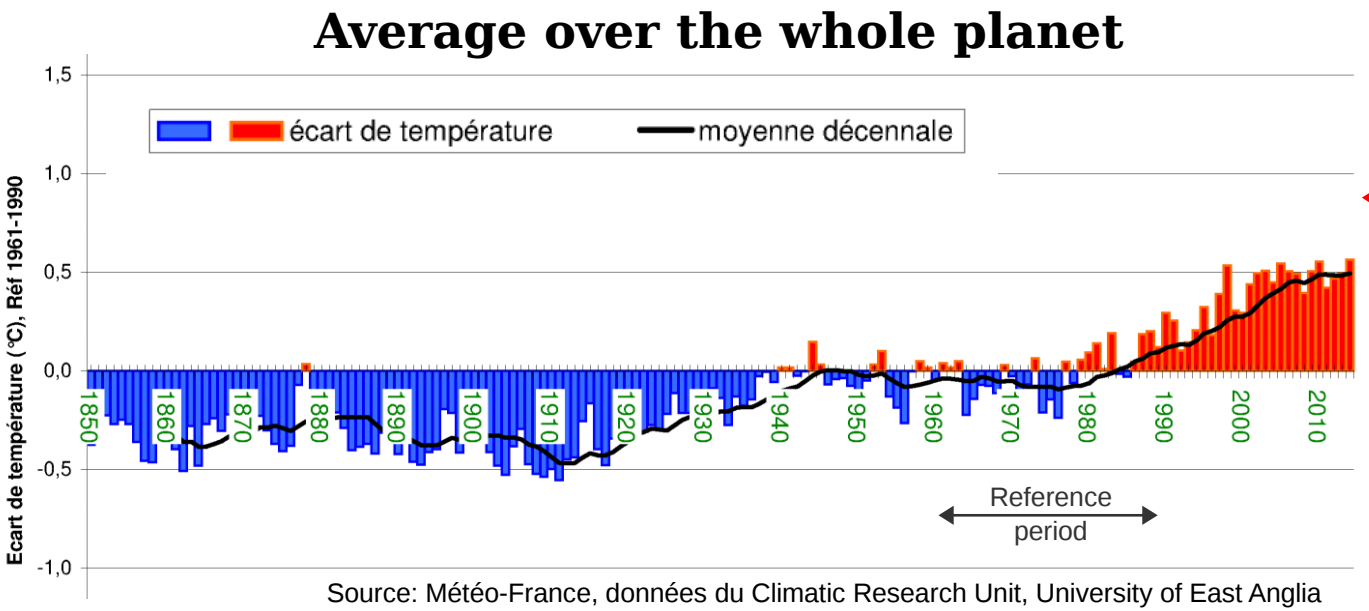
Temperature changes at the Earth surface



0.82°C in 2018

Source: Météo-France, données du Climatic Research Unit, University of East Anglia

- **Planetary warming**

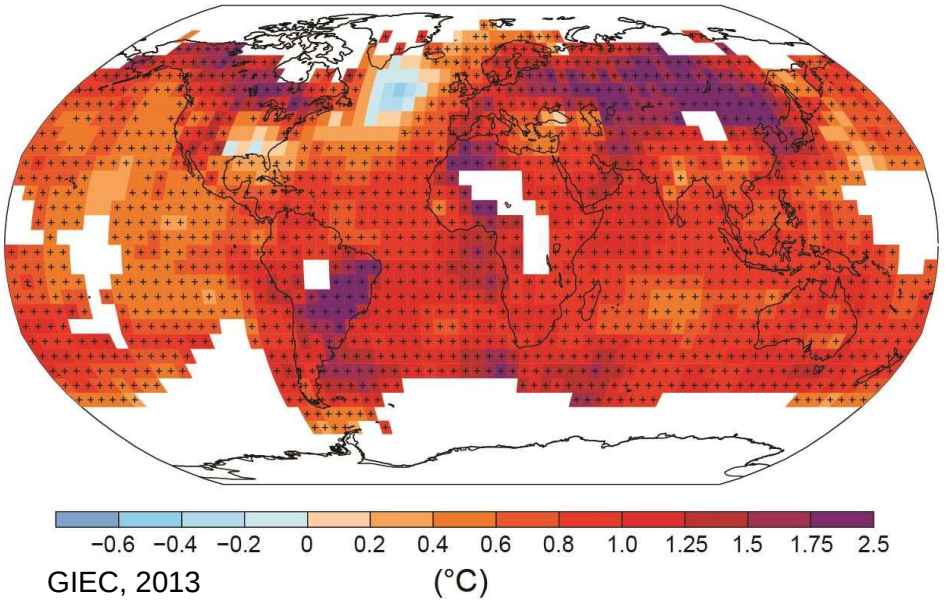
  → 1,1°C since 1850 (industrial revolution)

- **« *Internal variability* » of climate**

  → Geographic disparity

  → One single year can be locally colder !

Changes between 2012 and 1901



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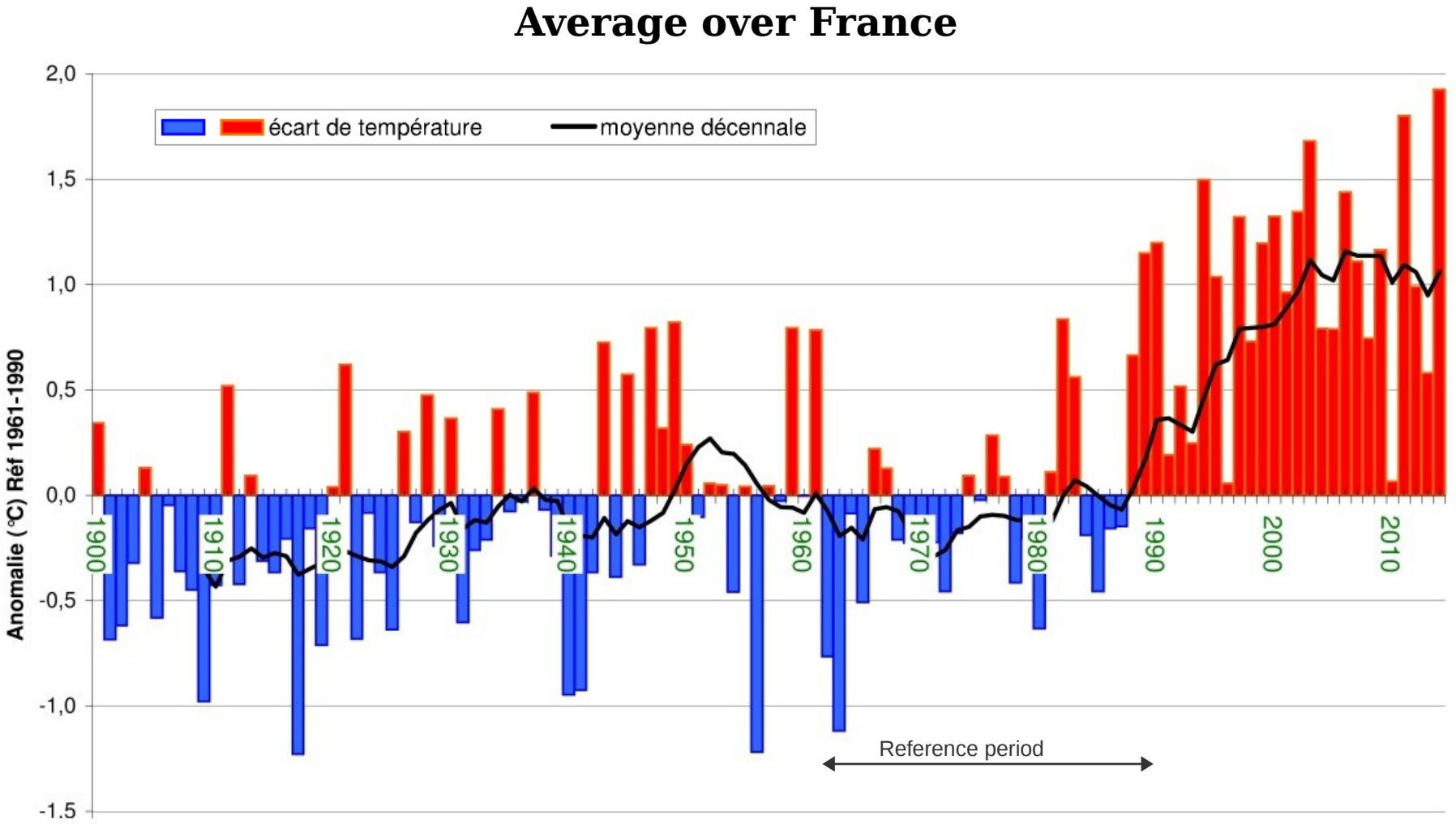
Temperature changes at the Earth surface



- 2002-2011 has been the warmest decade: **warming over 1°C!**
- 2010: relatively cold year, while at planetary scale, it was one of the warmest of the past 130 years! It's the internal variability.

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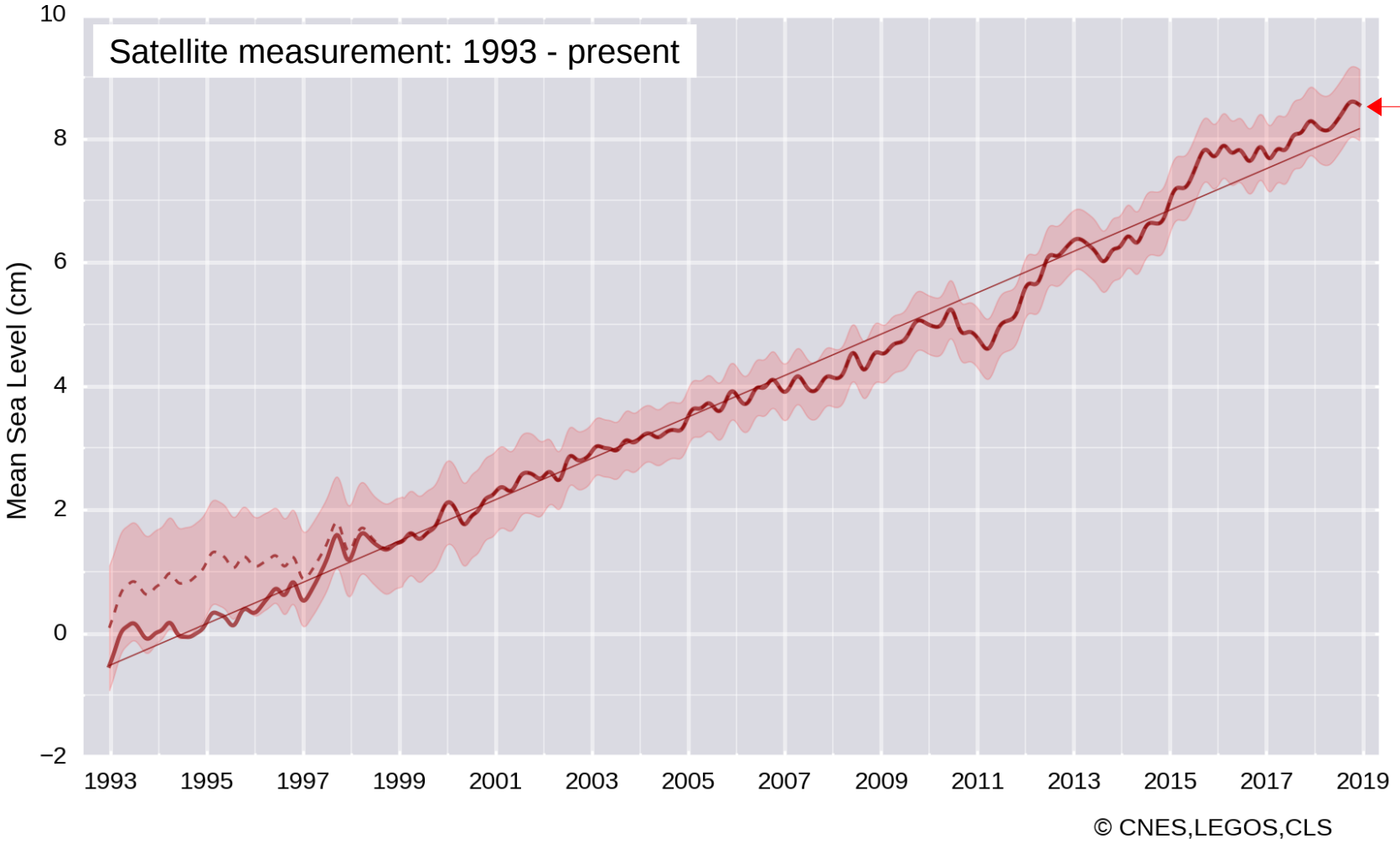
Evolution of sea level rise



+ 9 (± 0,1) cm
in 25 years

- Stable level until the 1900, then +1-3 mm / year
- Mean increase of 3,34 mm / year since 1992

What are the causes?

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Causes of sea level rise

Thermal expansion:

→ When temperature increases,
water expands (dilatation): 1,1 (± 0,3) mm / year

Continental ice sheet:

→ Mountain glaciers melting: 0,8 (± 0,4) mm / year

→ Polar ice caps loosing mass:

Greenland: 0,33 (± 0,08) mm/year

West Antarctica: 0,27 (± 0,11) mm/year

The melting of icebergs do not lead to sea level rise!

Other factors: ground subsidence, groundwater pumping, dams, coastal urbanism, ocean currents,...

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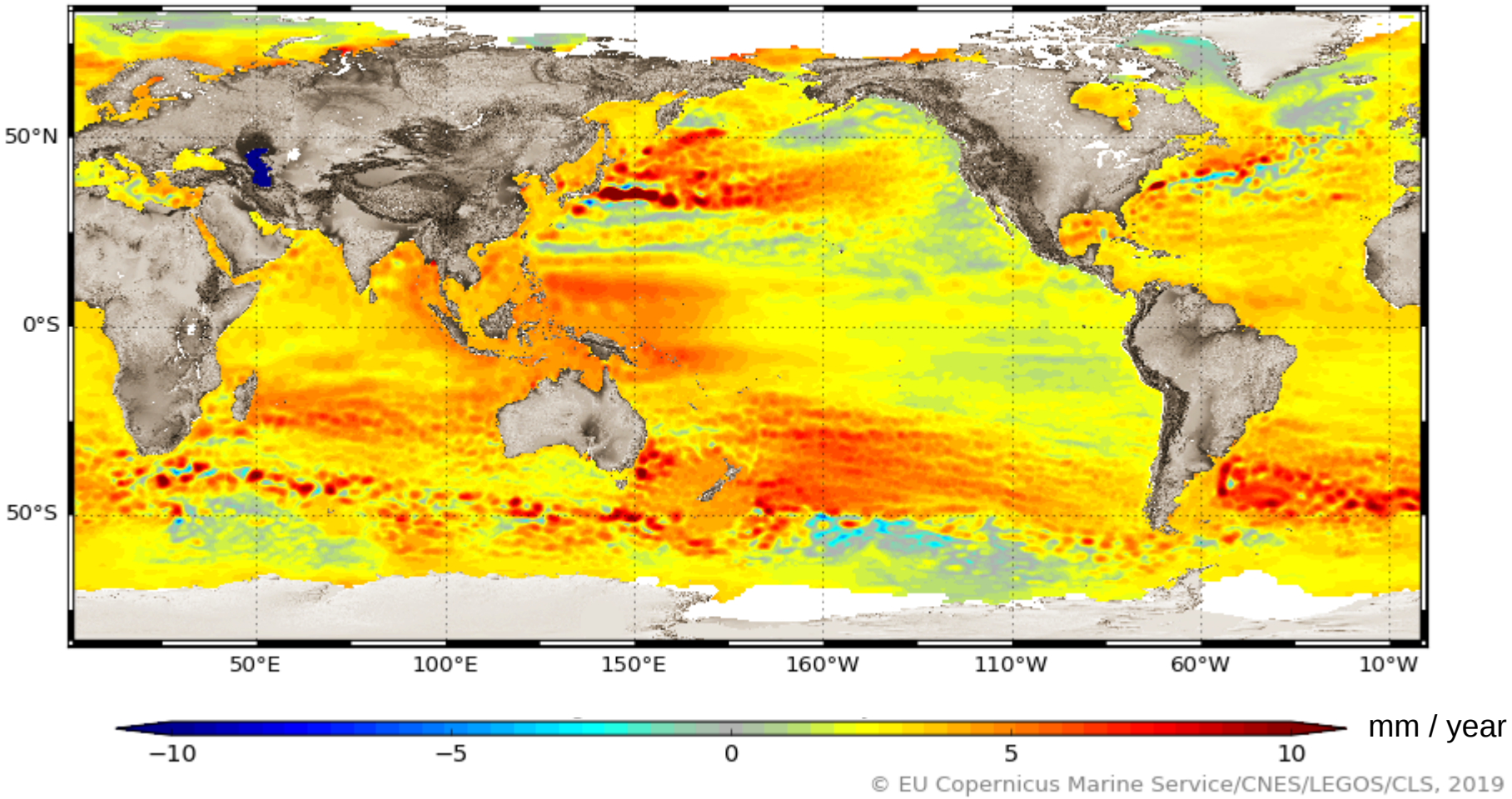
Evolution of sea level rise

Average evolution from 1992 to 2018



Heat is not spread uniformly over the ocean

→ Water level is rising faster in some regions than others

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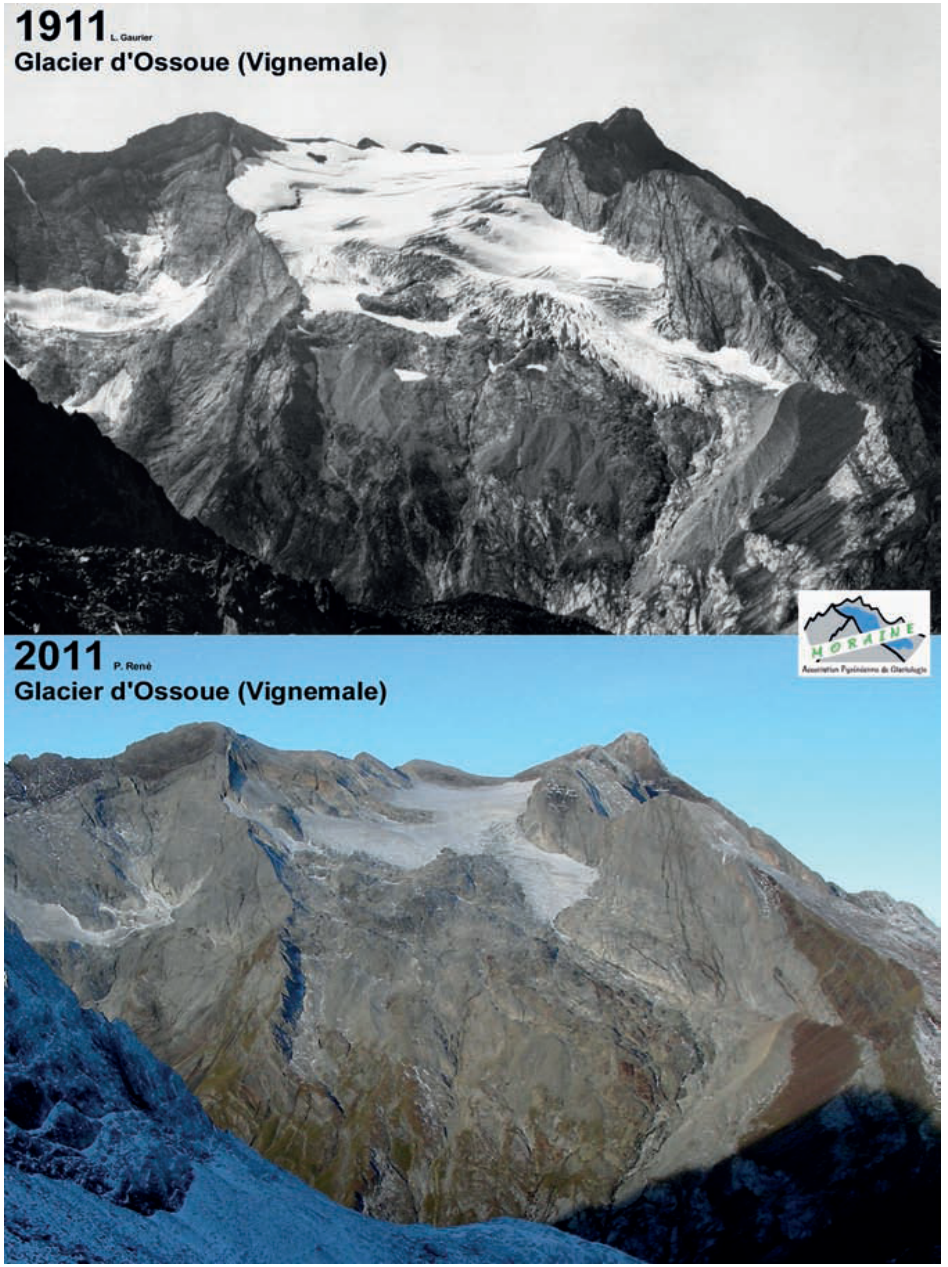
Evolution of continental ice sheet

Glacier of Ossoue (Pyrénées)

-59% of it's surface in 100 years
-1,80 m / year thickness since 2001



Source: Observatoire National sur les Effets du Réchauffement Climatique (ONERC)

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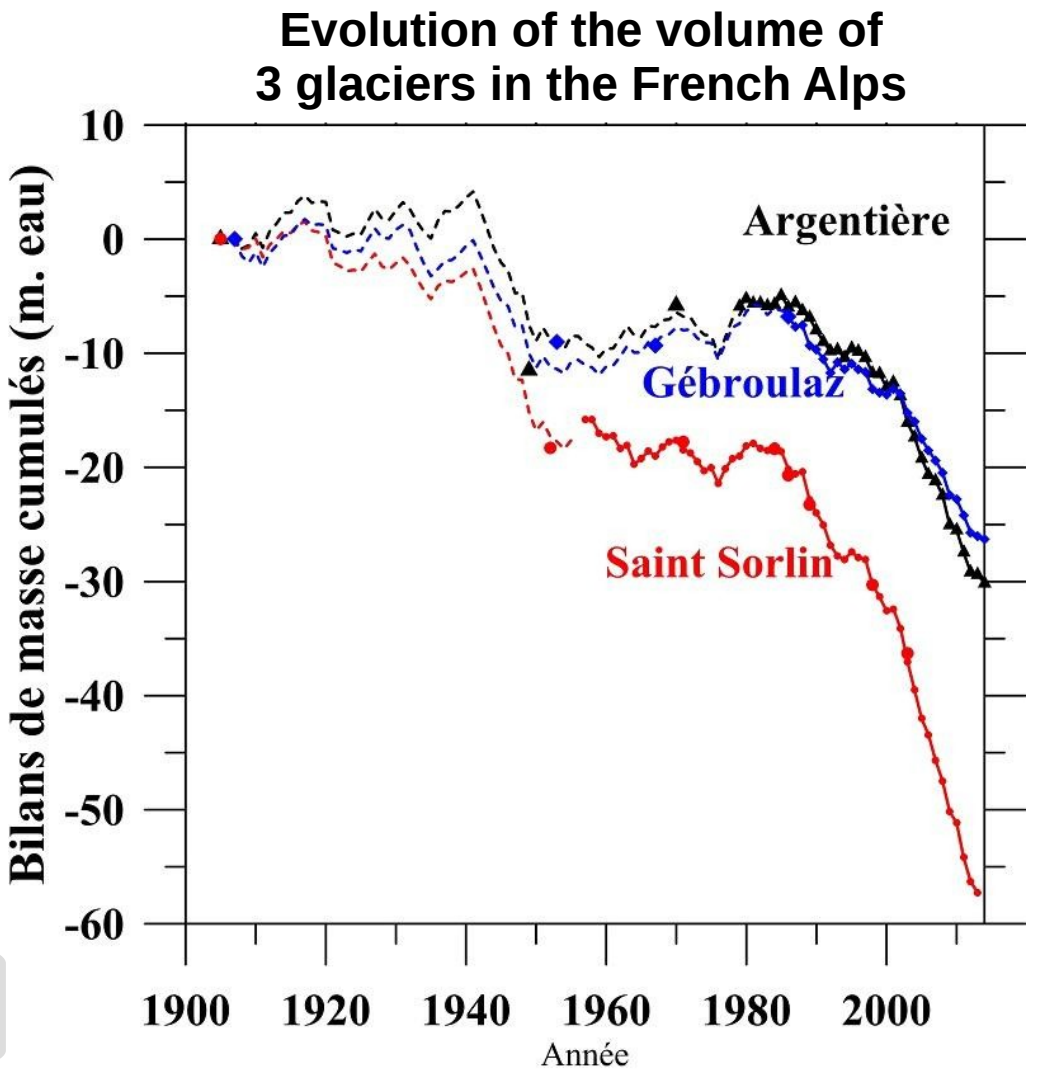
Evolution of continental ice sheet



Difference between winter accumulation and summer melting

Source: Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE)

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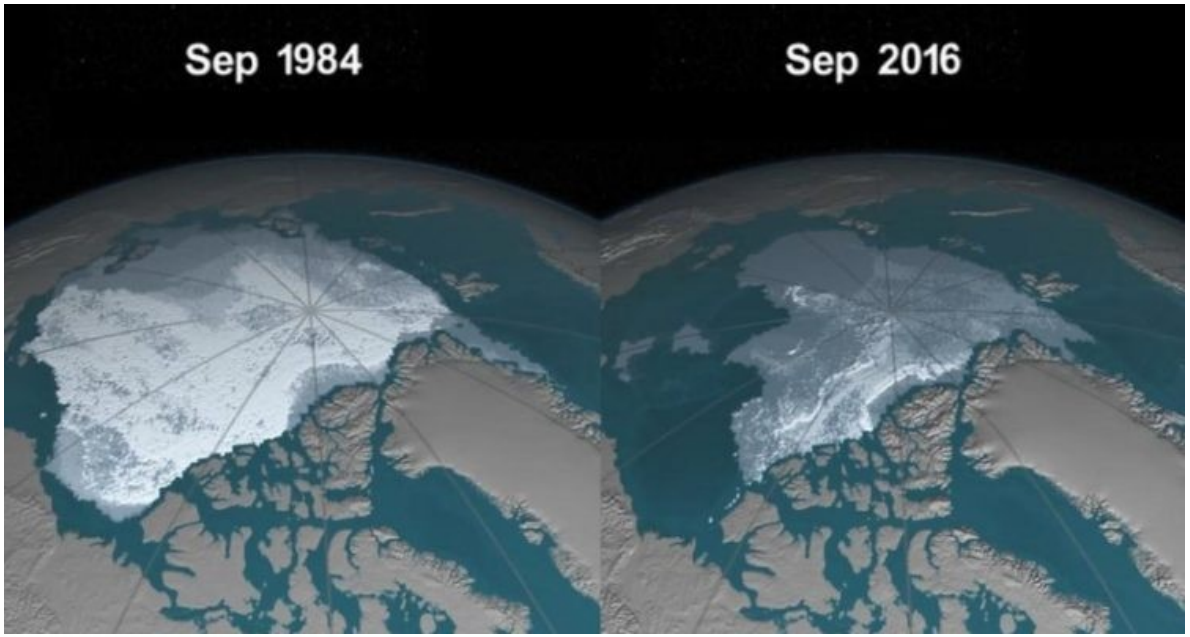
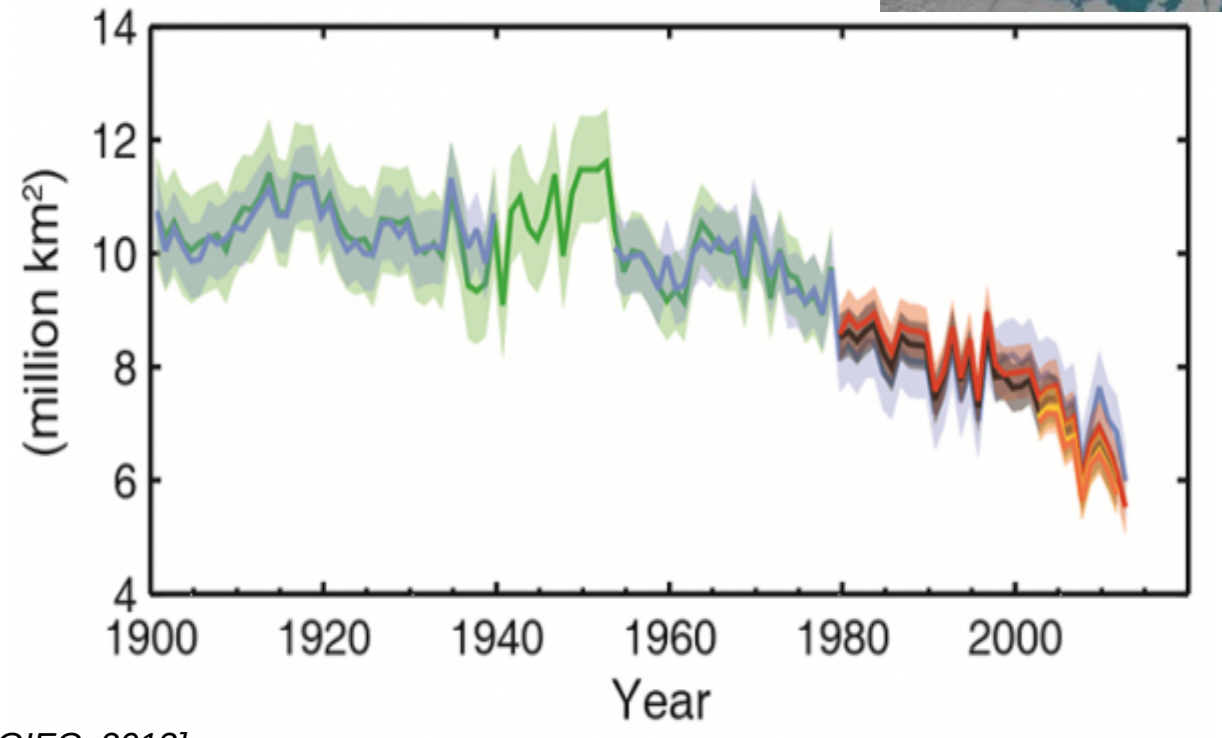
Sea ice melting in the Arctic

Evolution of sea ice extent in summer





-12.8% per decade

[GIEC, 2013]

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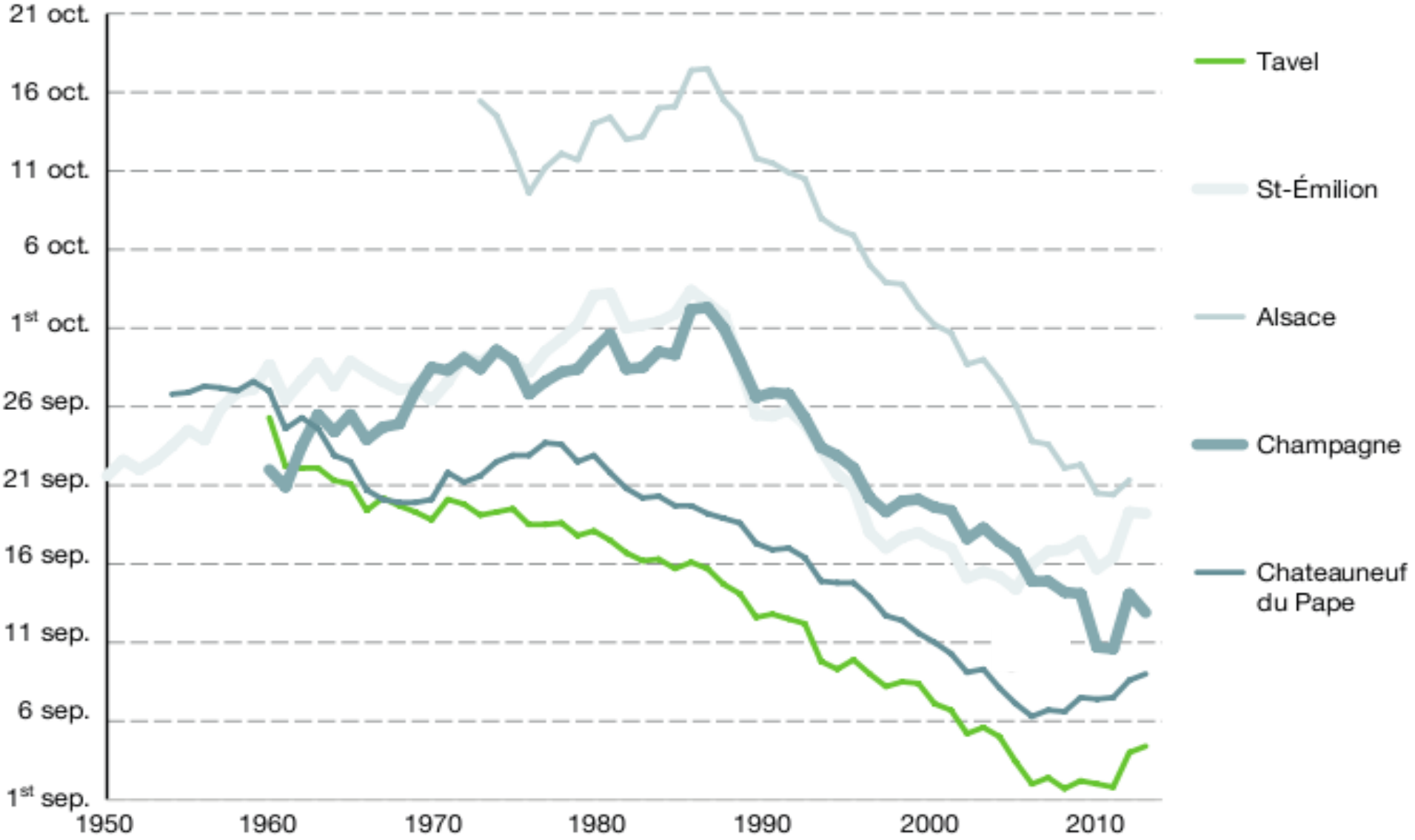
ÉVOLUTION DES DATES DE VENDANGES

Evolution of grape harvesting date



Sources : *Inter-Rhône, ENITA Bordeaux, Inra, CICV, Inter-Rhône*

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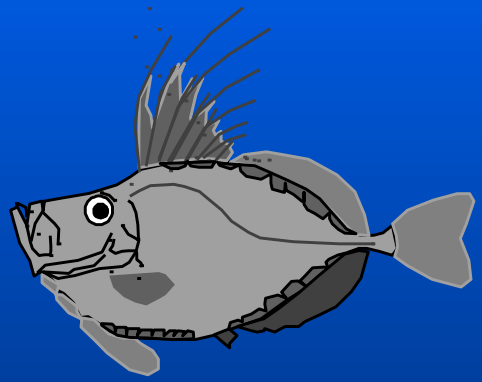
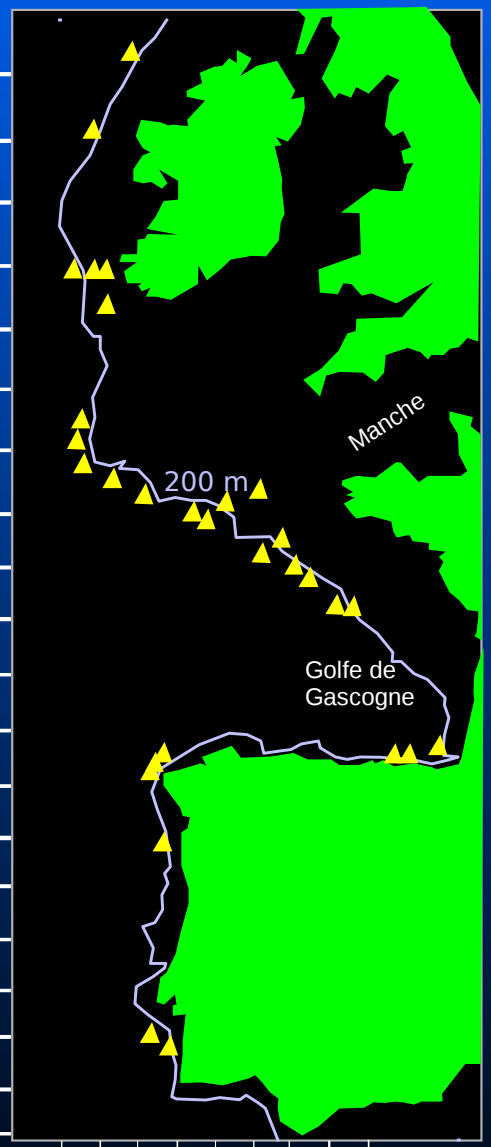
Distribution changes of Zenopsis conchifer

Progression de la distribution de *Zenopsis conchifer*



55 °
50 °
45 °
40 °N

1960 1965 1970 1975 1980 1985 1990 1995



55 °
50 °
45 °
40 °N

10° 5°W

Source : Quero,

Climate science:

from the XIX century to the present day

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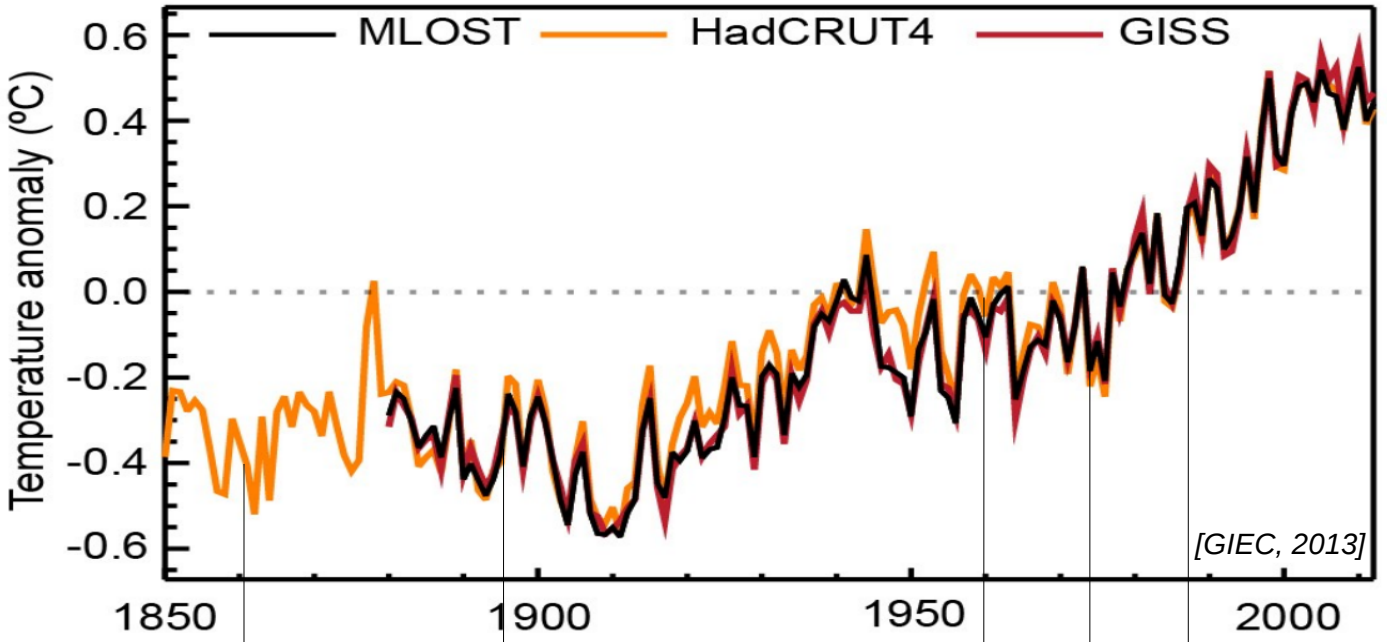
Questions around climate sciences and climate change have been tackled before changes started occuring



1824: J. B. Fourrier

- Radiative equilibrium temperature calculation
- Greenhouse effect hypothesis

1861: J. Tyndall

Greenhouse effect measures for H_2O and CO_2

1896: S. Arrhénius

Estimation of warming in response to CO_2

1960: C. Keeling

First direct measures of CO_2 (Mauna Loa)

1970-1980: first climate models & climate projections

1988: IPCC creation

S. Manabe

J. Charney

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The 1980's decade: when we almost stopped climate change

Nathanael Rich, New York Times:
"Losing Earth: The decade we almost stopped climate change"

A very interesting article!

- **In the US, in 79-89, climate change due to human activities was taken very seriously by:**
  - Scientists
  - Politicians
  - Activists
  - Major oil companies

An unprecedented union!

- **A real awakening to this imminent danger:**
  - Effort to quantify climate risk
  - Production of assessment reports (*"The Charney report"* en 1979, amazingly prescient!)
  - Meetings: alternative energy planning projects (renewable energies)

- **George Bush's election as president (1989-1993) marks the end of that period:**
  - Gulf war: oil energy supply is number one concern of the government
  - Oil companies launch a "doubt propaganda" that has a major impact on public opinion

1988 → today: IPCC (GIEC in French)

- IPCC: Intergovernmental panel on climate change, **created in 1988** by the **World Meteorological Organization** (WMO) and the **United Nation Environmental Programme** (UNEP). Has currently **195 member countries**.
- Its **mission**: Evaluate the **state of the art of scientific, technical and socio-economic knowledge** around climate change
  - Does not perform research; summarizes the work of worldwide scientific community
  - Does not prescribe political recommendations: *"policy relevant, not policy prescriptive"*
- Three working groups:
  I- **Physical science basis** of climate change
  II- **Impacts, adaptation and vulnerability** to climate change
  III- **Attenuation** of climate change

<u>2013 report:</u>
1500 pages
14 chapters
259 authors and 600 contributors
9200 cited publications
54,677 comments from 1089 experts

… next report in 2021

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COP, What is it ?

- The **United Nations Framework Convention on Climate Change** (UNNFCC); adopted during the Earth Summit in Rio de Janeiro in 1992 (ratified by 189 countries)

- Its mission: setting climate commitments, relying on the IPCC conclusions

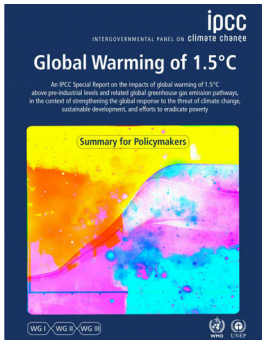
→ **Conference of parties** (COP). Composed of member states, it meets every year.

1997: COP 3. Signature of the **Kyoto protocol**. Limit the increase in greenhouse gas emissions by industrialized countries for the period 2005-2012.

2009: Failure of the Copenhagen conference (COP 15) goal to reach a global agreement

2015: COP 21 Paris climate conference; reach an agreement to limit global warming to 2 degrees and, if possible, to 1.5°C

IPCC special report, published in 2018



The 1.5° report: this target requires -7% emissions of greenhouse gases every year to reach:
-45 % emissions in 2030 and **0 net emissions en 2050**

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The future :

Modeling, scenarios and projections

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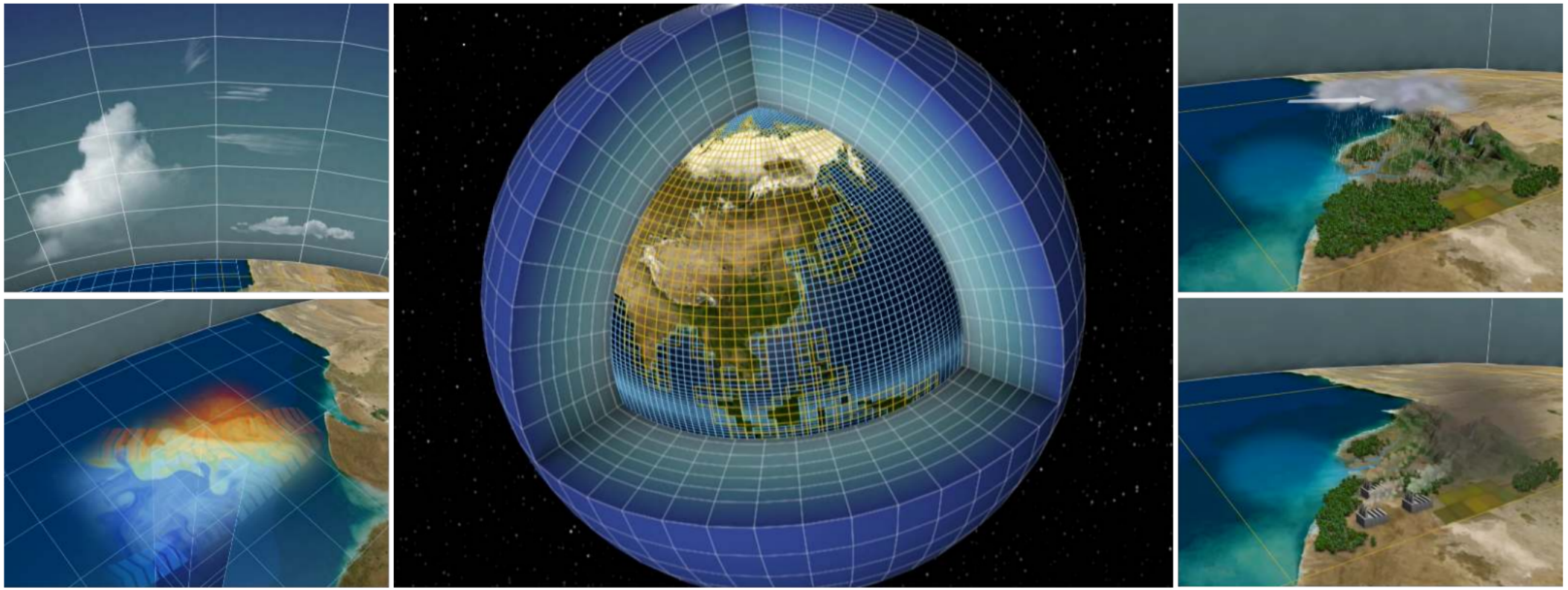
Climate modeling



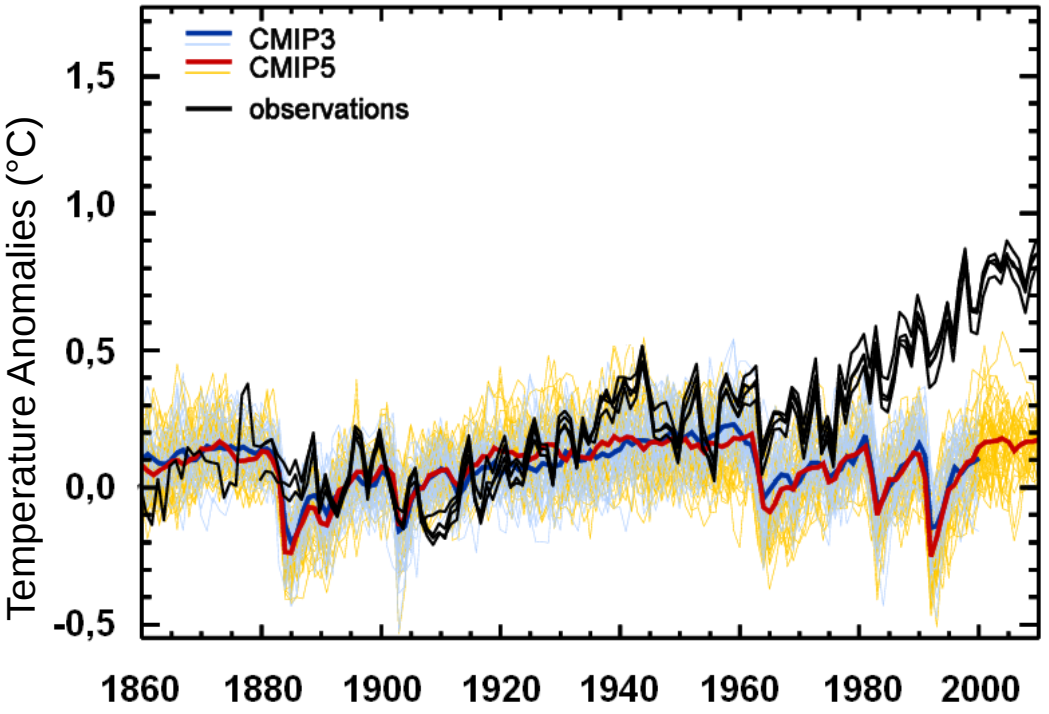
Images from a movie describing climate modeling. Copyright CEA
https://www.youtube.com/watch?v=S5f5dJyvezY

- 3D representation of the atmosphere, ocean, sea ice and continental surface (coupling between the different modules)
- Based on physics laws and equations (radiative transfer, fluid dynamics, …)
- Climate model: a **tool** to **understand** and **“predict”** climate

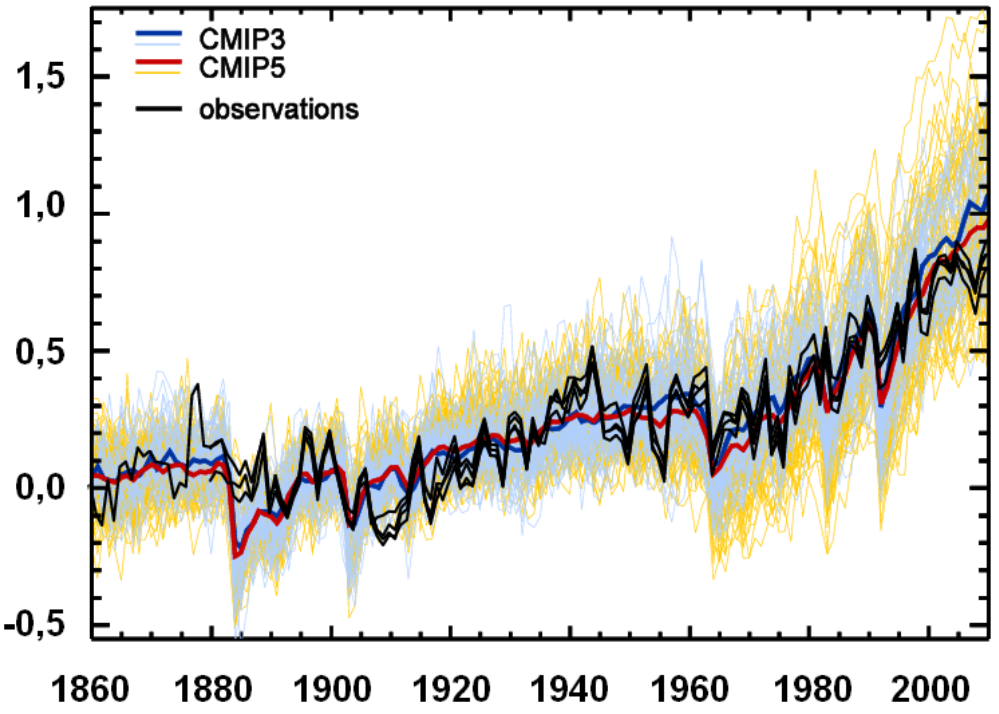
Using climate models to understand :

Are climate variations linked to human activities or to natural climate variability ?

Simulations with **only natural factors** (internal variability, volcanic erruptions, solar variations)



Simulations with **natural factors and anthropogenic factors** (… + greenhouse gases and aerosols)



[GIEC, 2013]

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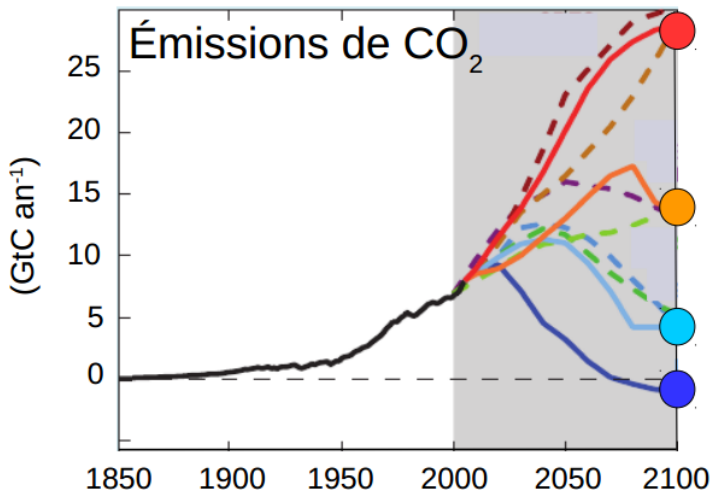
Using climate models for projections:

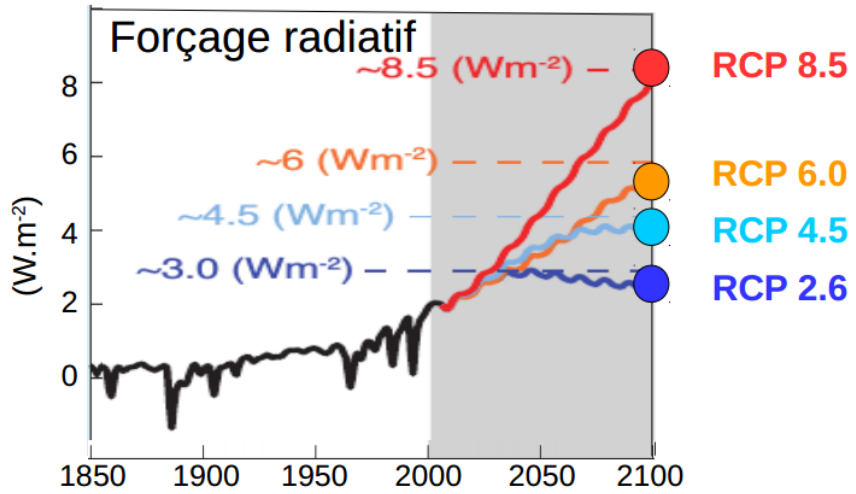
IPCC greenhouse gas emission scenarios

→ Hypotheses on the evolution of demography and economic growth worldwide



Strong emissions
"Business as usual"

Control of the emissions
Limit warming to 2°C



RCP 8.5

RCP 6.0

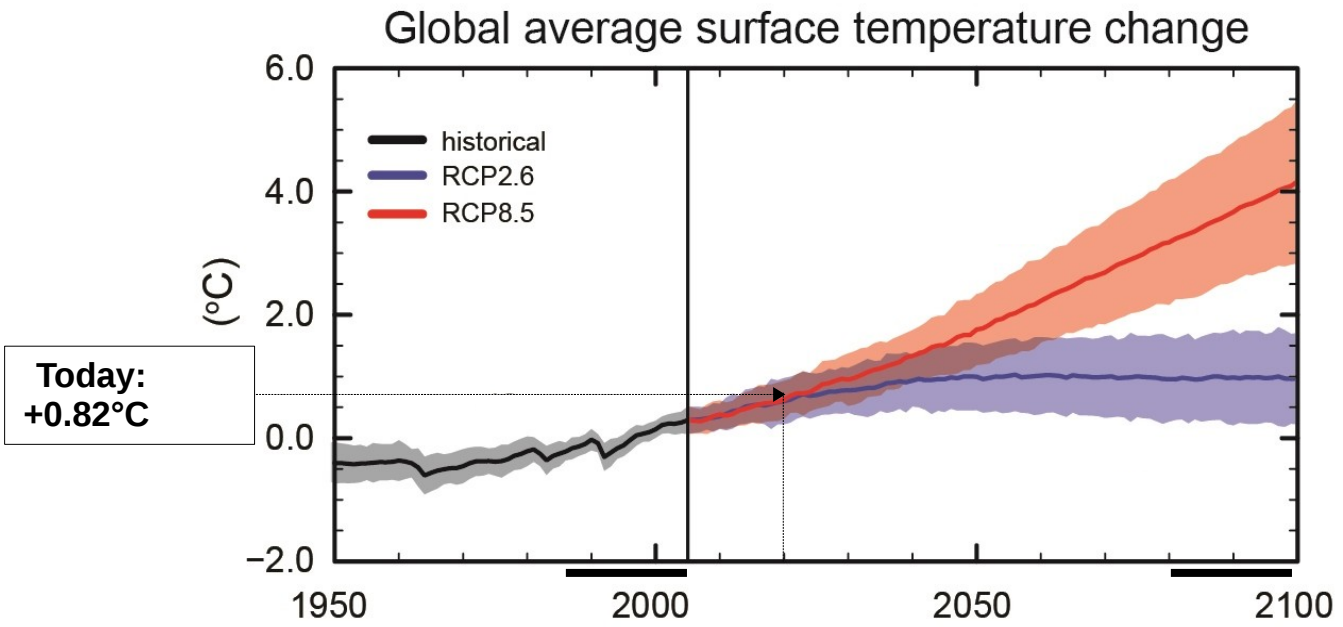
RCP 4.5

RCP 2.6

RCP: representative pathways of the evolution of greenhouse gas concentration

[GIEC, 2013]

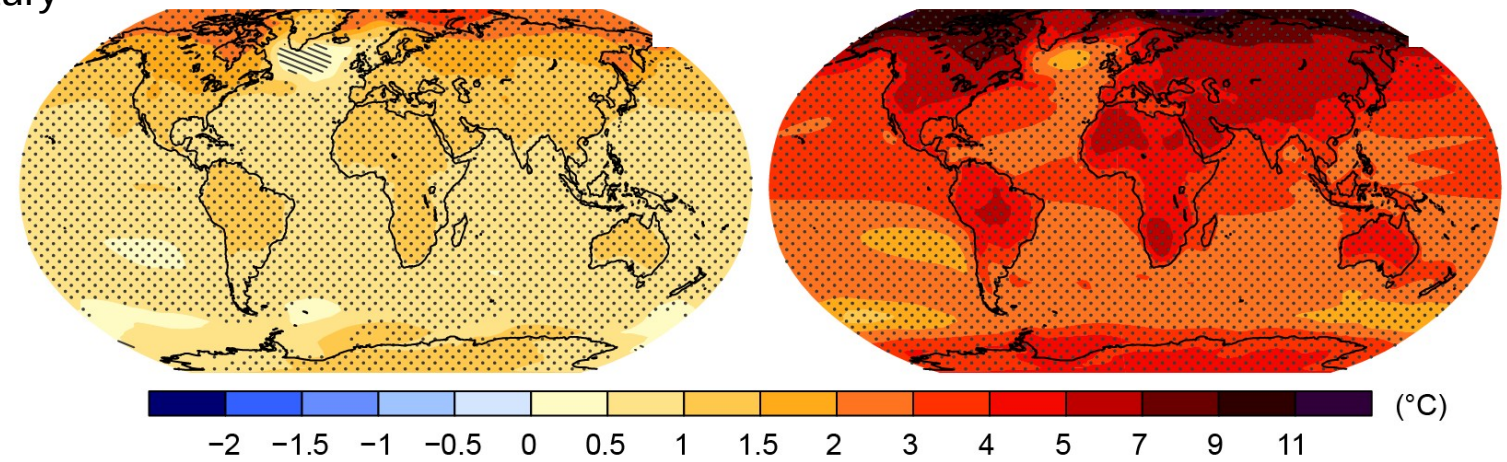
Temperature change projections



Changes at the end of the century

RCP2.6

RCP8.5



[GIEC, 2013]

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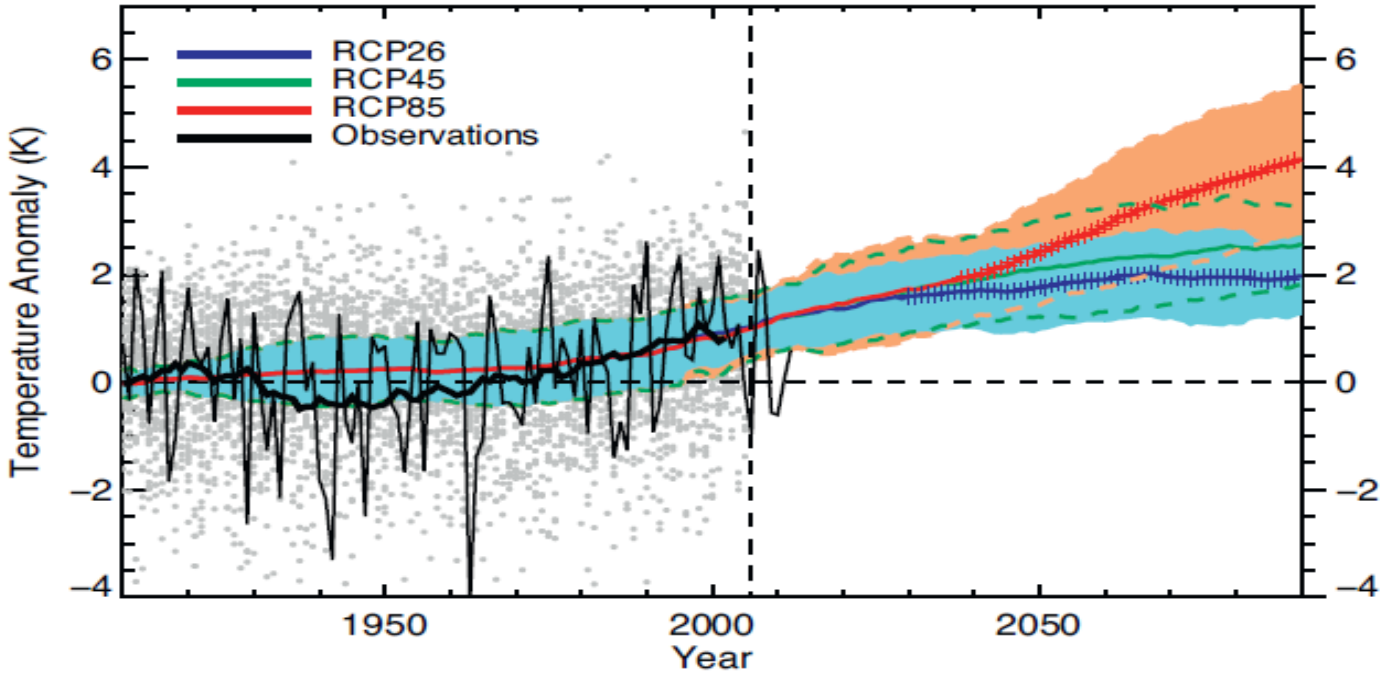
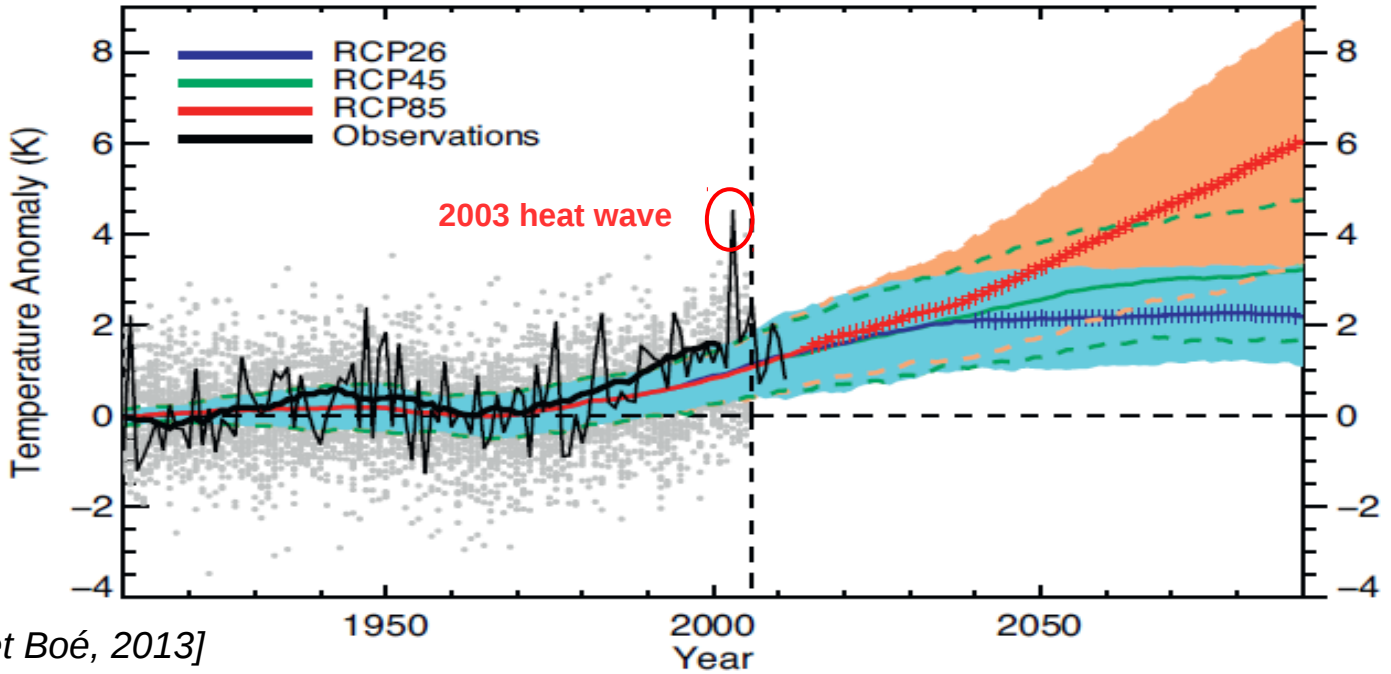
Temperature change projections over France



winter



summer

[Terray et Boé, 2013]

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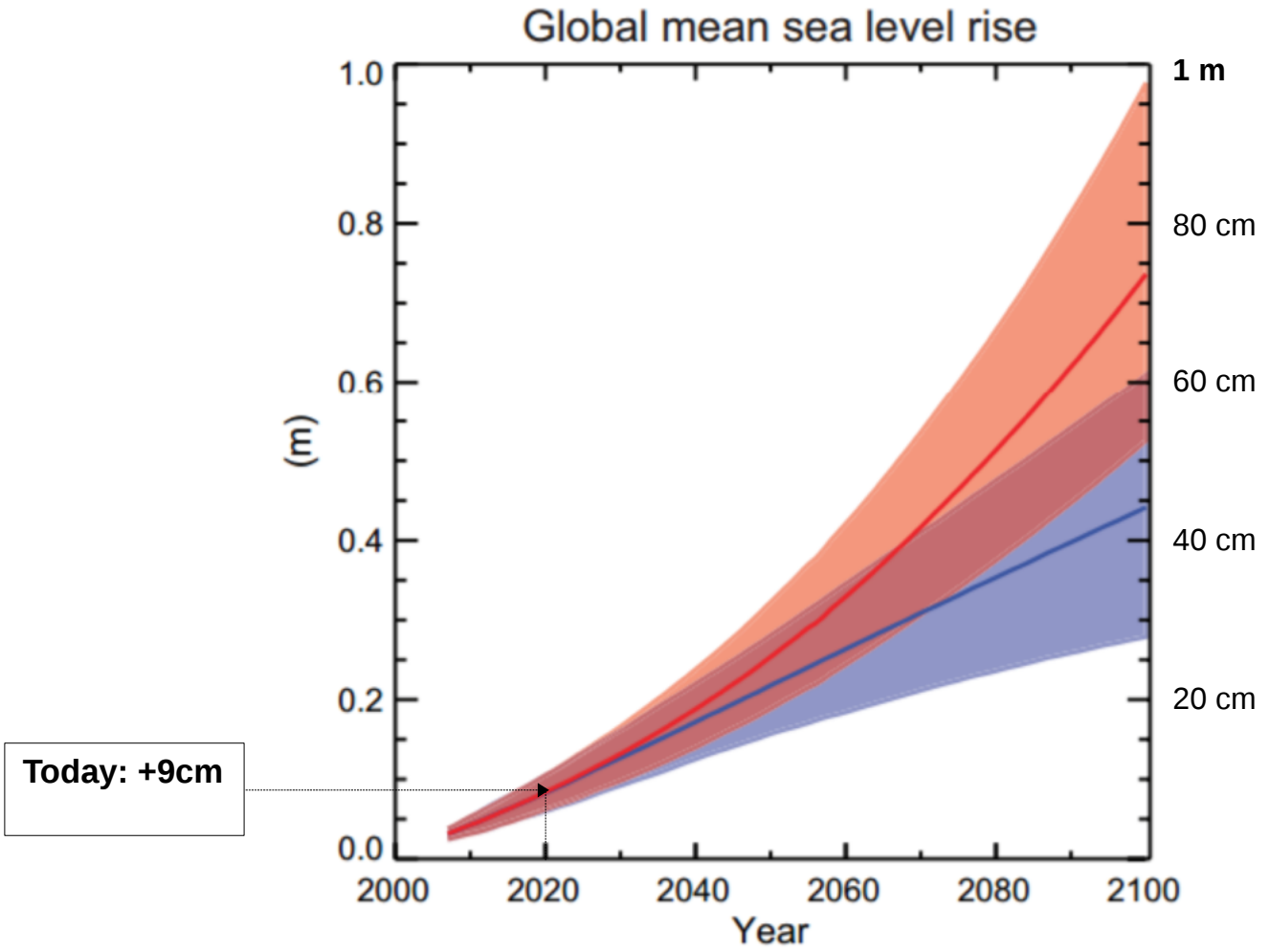
Sea level rise projections



GIEC, 2013

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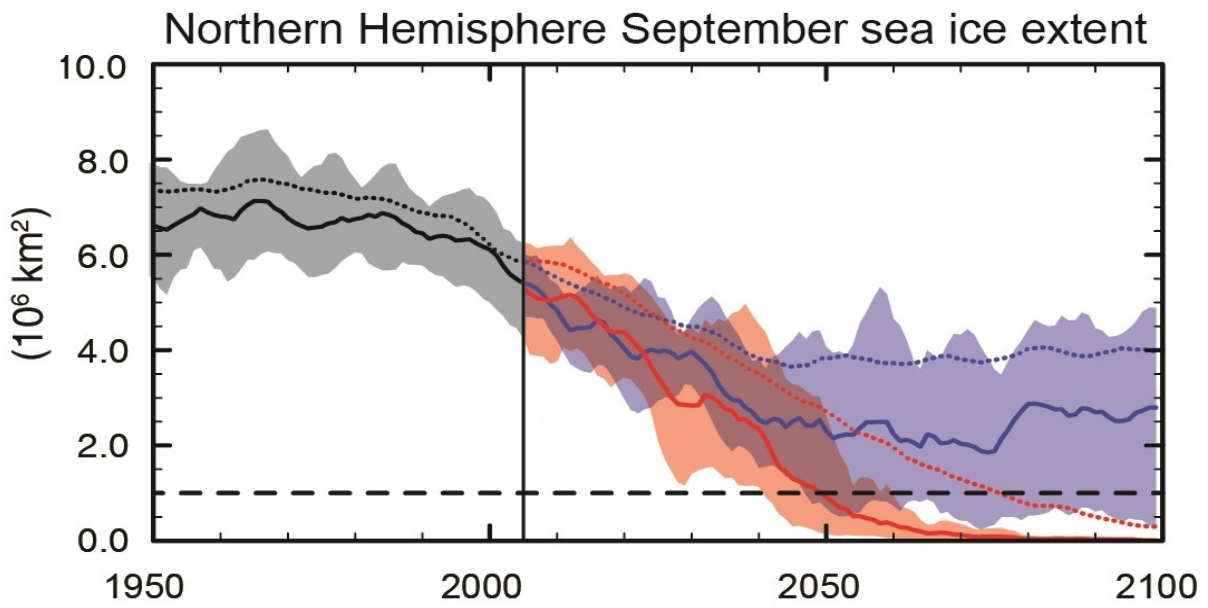
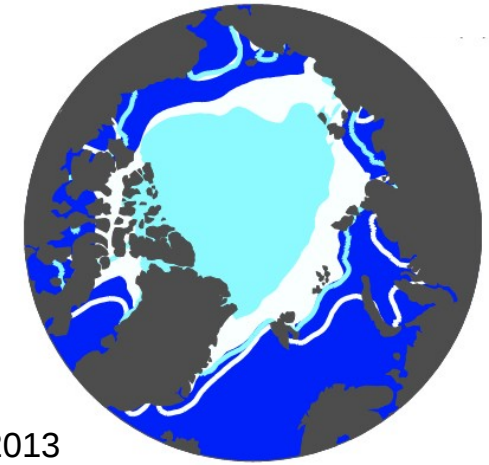
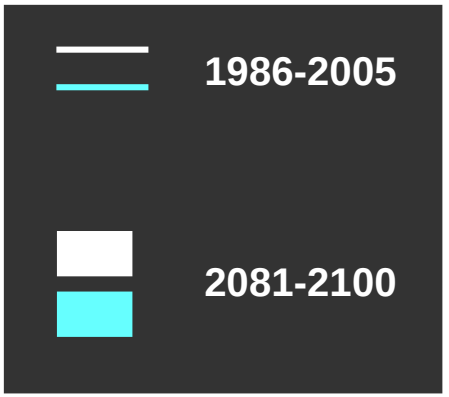
Projections de l'extension de la glace de mer

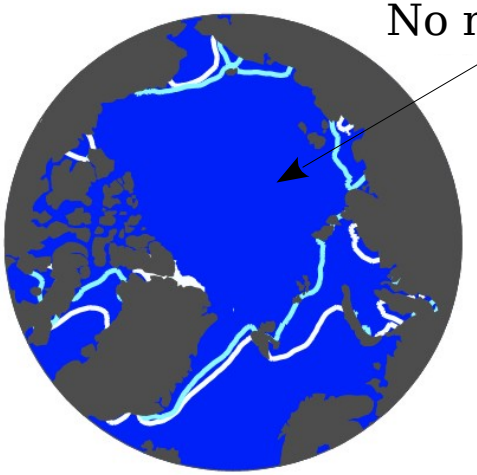


RCP2.6





RCP8.5



GIEC, 2013

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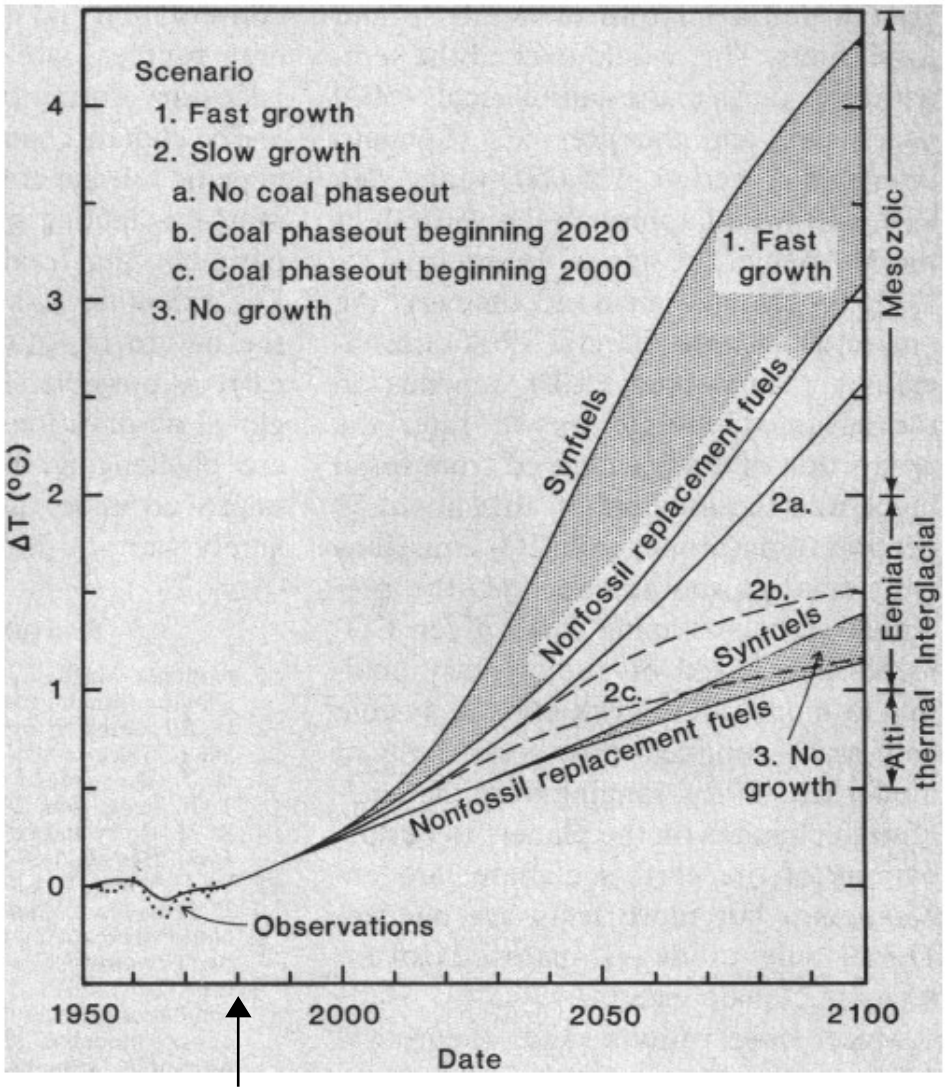
Projections haven't changed over the past 40 years !

Surface warming projections
performed in 1980



Hansen et al., 1981

Use of a **very simple climate model**:

- no ocean circulation
- no biogeochimical cycle
- partial representation of processes (nuages, précipitations,…)
- etc…

Warming range between 3 and 4.5°C until 2100 for the worse case scenario (*"fast growth"*).

In comparison, IPCC estimations in 2013 range between 3 and 5.5°C for the worse case scenario (RCP 8.5)

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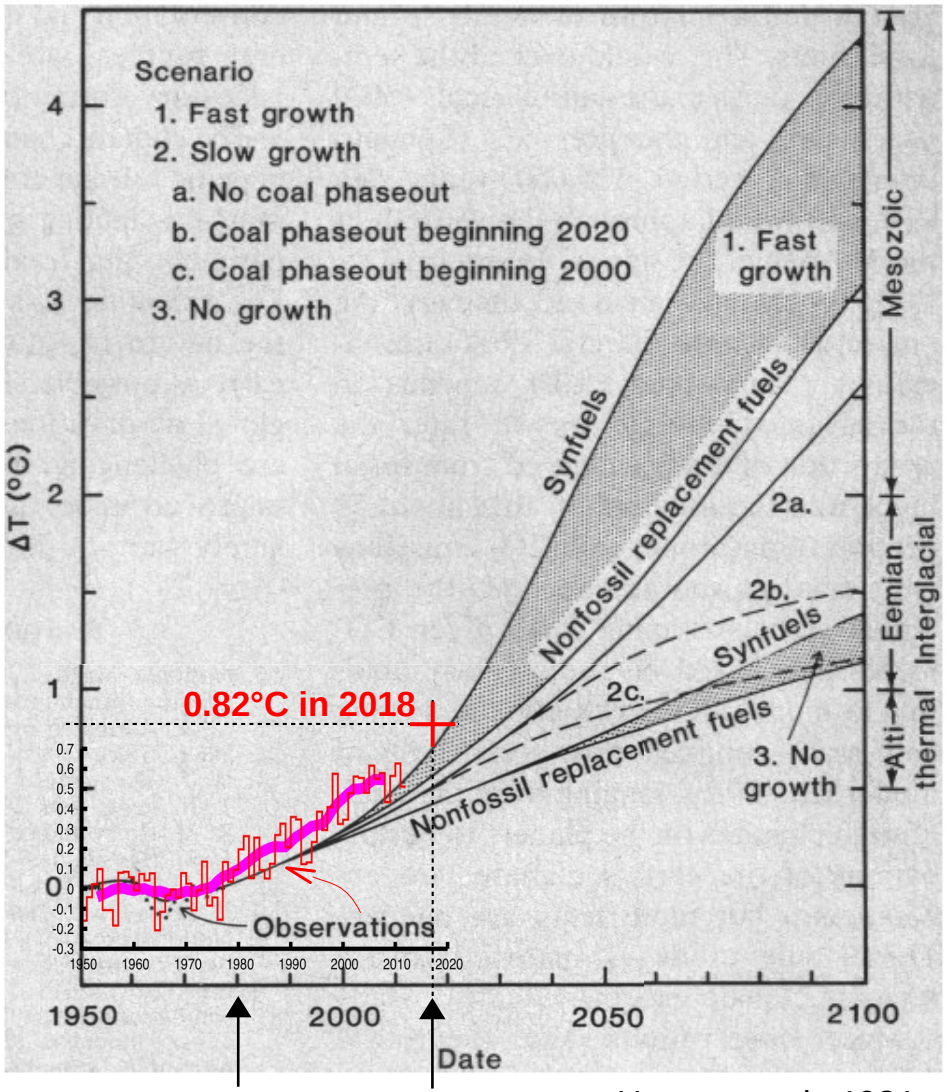

Hansen et al., 1981
RealClimate, 2012

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Warming projections until 2018 are very close to the observed tendencies (in red)

Jessica Vial, Jan. 2020

Conclusions

Global warming is **unequivocal**, and **human influence** is **clearly established.**

Since the **1950s**, a lot of **observed changes** are **unprecedented** since centuries, even milleniums.

Climate projections show that these **changes** could **continue** and sometimes **amplify** by **the end of the century**.

Limiting warming to 1,5 or 2°C requires **a radical reduction** in the **emissions of CO_2**.

Jessica Vial, Jan. 2020