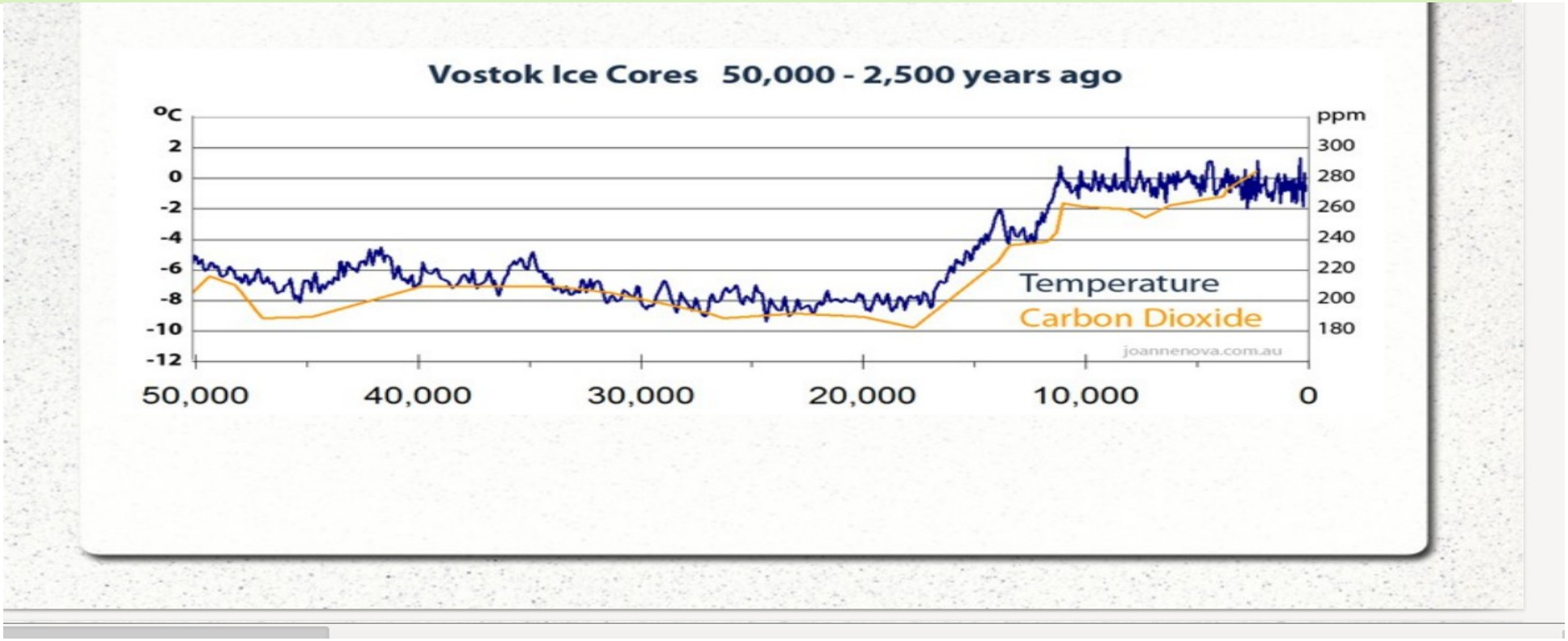
What is climate change ?

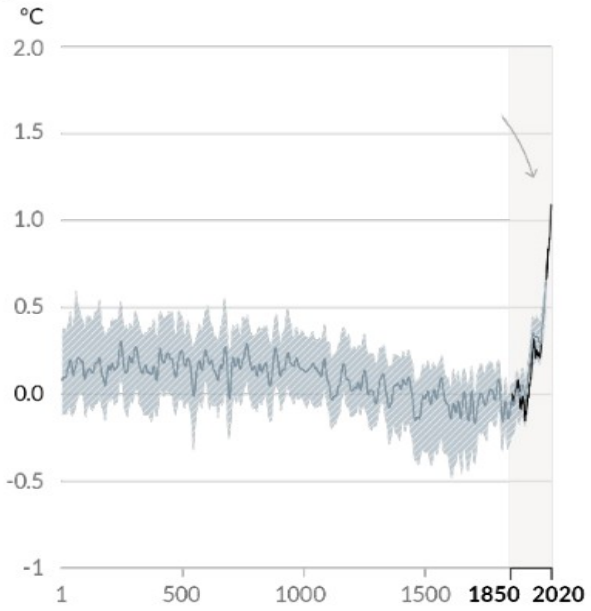
Temperatures of the past 50,000 years

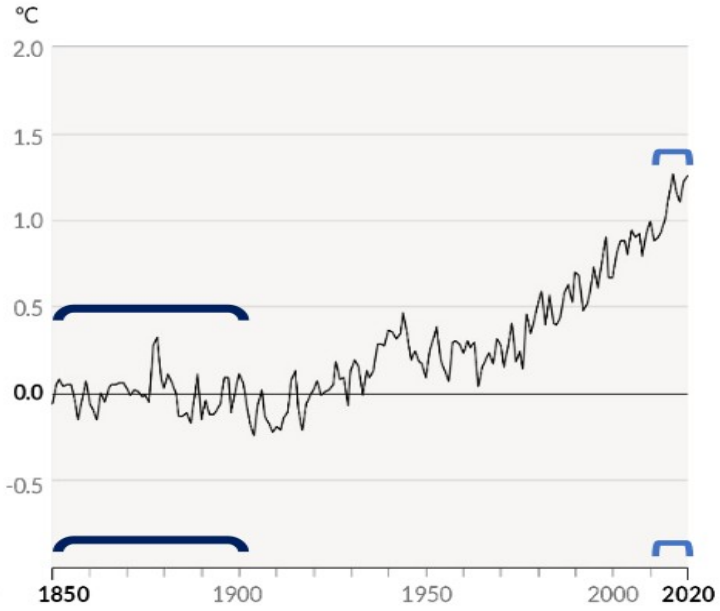


An equilibrium has prevailed for the past 10,000 Years

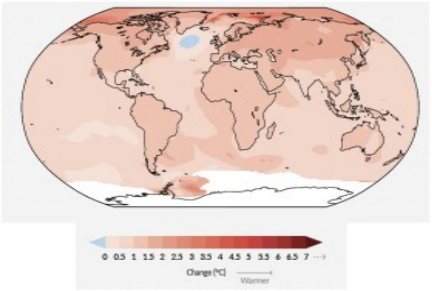
Temperatures of the past 200 Years

Changement **observé** de température de surface planétaire
depuis 1850-1900



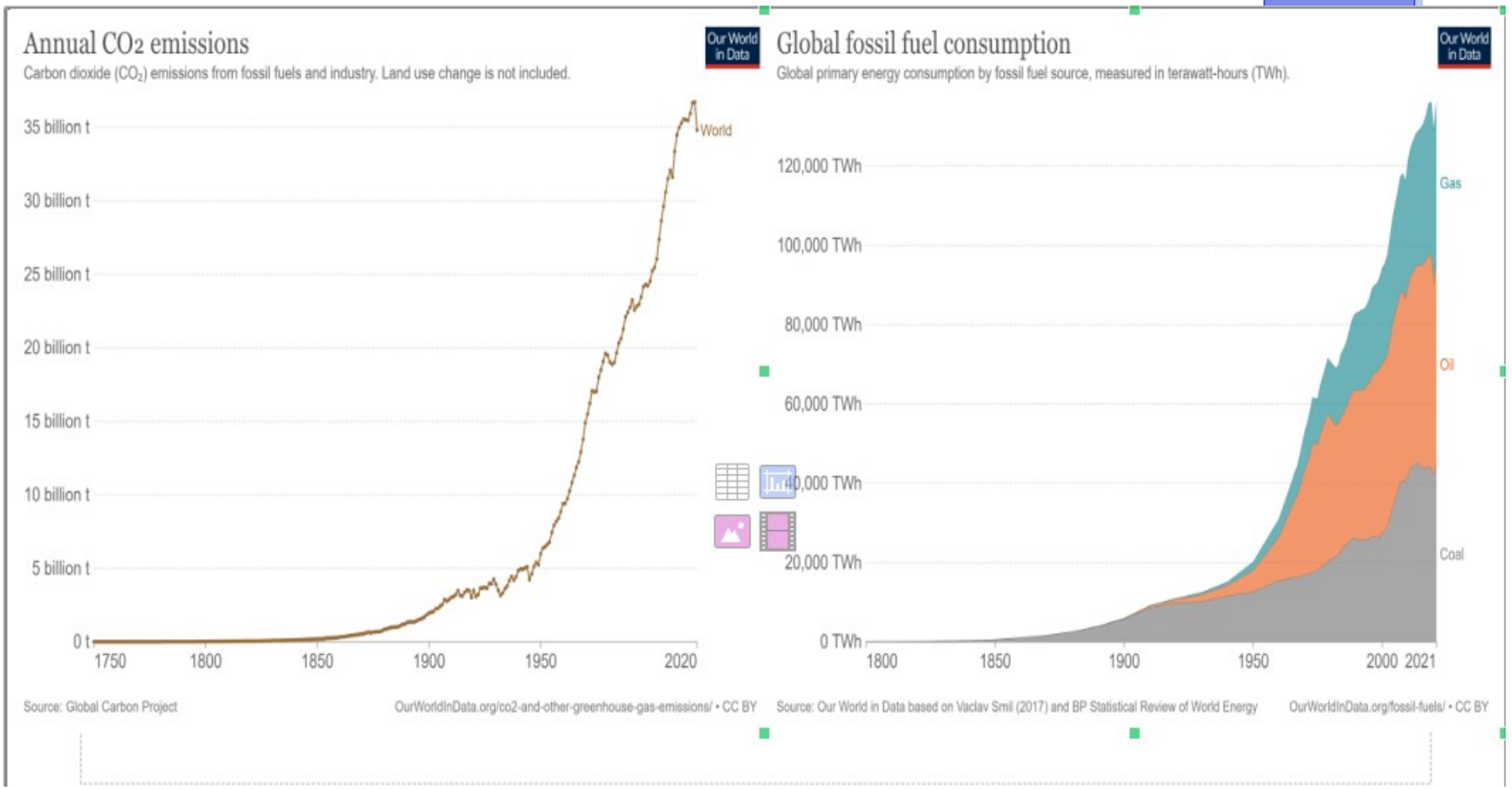


+ 1,7°C en France

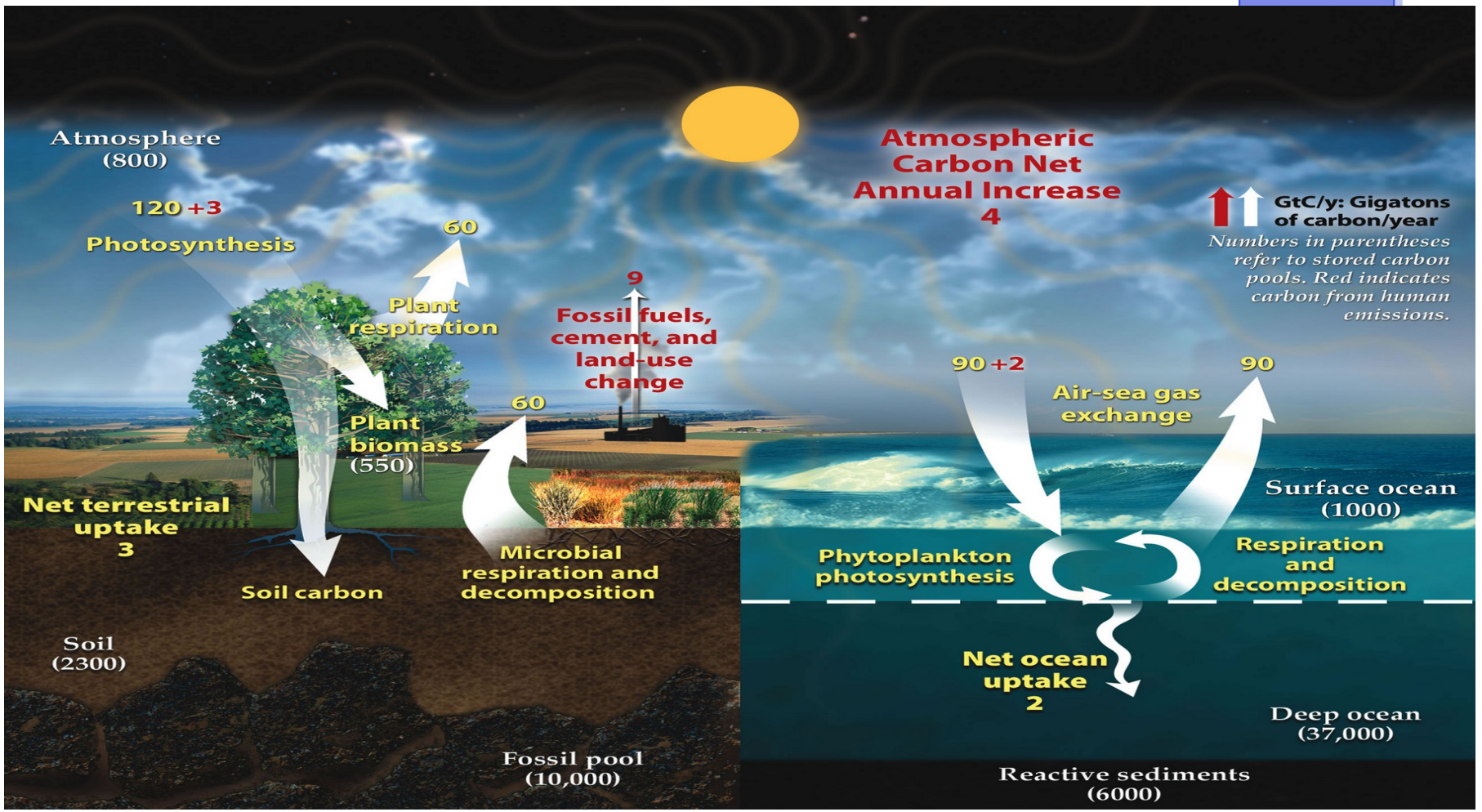


We are rapidly moving away from the past equilibrium

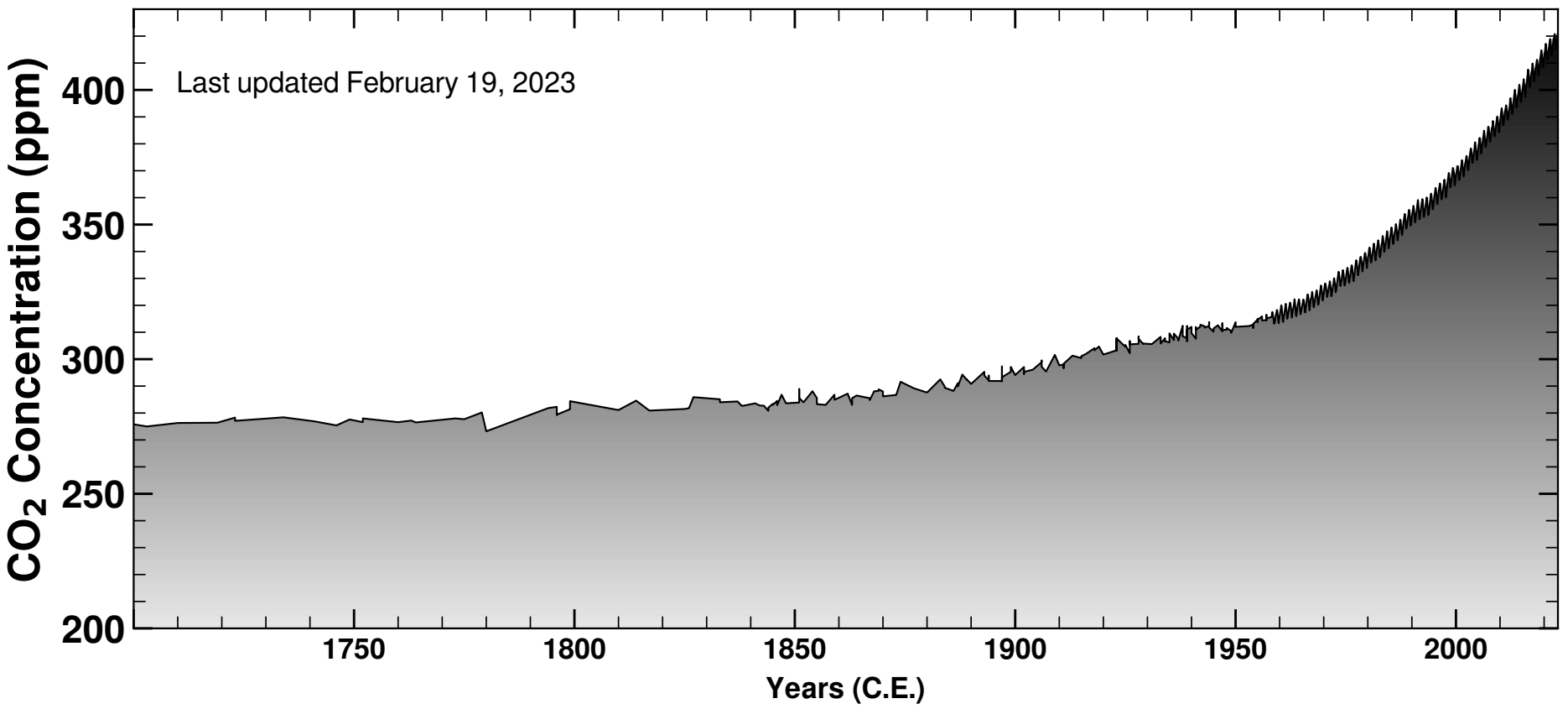
The push


Annual CO2 emissions
Carbon dioxide (CO2) emissions from fossil fuels and industry. Land use change is not included.
Our World in Data
35 billion t
30 billion t
25 billion t
20 billion t
15 billion t
10 billion t
5 billion t
0 t
World
1750
1800
1850
1900
1950
2020
Source: Global Carbon Project
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY
Global fossil fuel consumption
Global primary energy consumption by fossil fuel source, measured in terawatt-hours (TWh).
Our World in Data
120,000 TWh
100,000 TWh
80,000 TWh
60,000 TWh
40,000 TWh
20,000 TWh
0 TWh
Gas
Oil
Coal
1800
1850
1900
1950
2000
2021
Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy
OurWorldInData.org/fossil-fuels/ • CC BY

In fact, a nudge : the carbon cycle



The Keeling curve



Summary

- Earth is a complex system which is in thermal equilibrium
  - It sends back as low-frequency (infrared) radiation the high-frequency radiation it receives from the sun
- Human emissions of CO^2 and other greenhouse gases (GGs) perturb the equilibrium
  - GGs absorb part of the infrared radiations emitted by the ground. As a result, Earth is no longer sending back as much energy as it receives from the sun (the surplus retained is 4Watt/m^2)
- This is a small shock (a nudge)
  - A shock because of the time scale : 1 century vs 10,000 ys
  - Small because of the magnitude : from 250 ppm to 420 ppm

How does a complex system in equilibrium react to a nudge ?

- It will move to another equilibrium, but how ?
  - First answer : smooth transition
  - Second answer : bifurcation
  - Third answer : catastrophe
  - Fourth answer

First answer :

Smooth transition

Smooth transition

- It is estimated that if the CO^2 level from 250 (preindustrial) doubles to 500 ppm, mean temperatures will increase between 3 and 6°C
  - It is now at 420 ppm
- The smooth transition scenario would be that there is a *quantitative* change : the climate we know would be about the same, with warmer summers and winters
  - This is what mainstream economists assume

Nordhaus, Nobel prize in economics 2018

- His models show that 3°5 in 2100 is optimal. Really ?

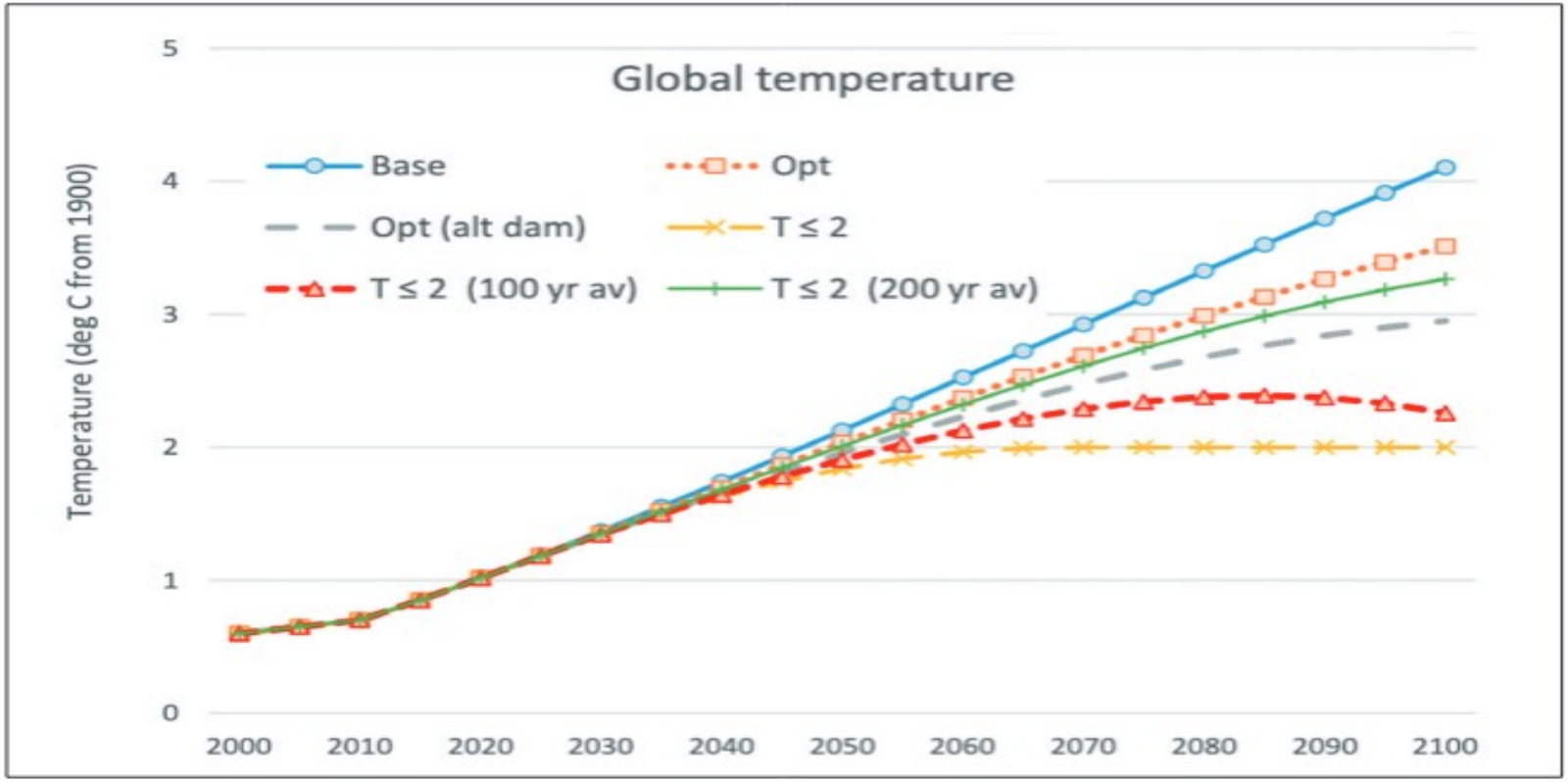
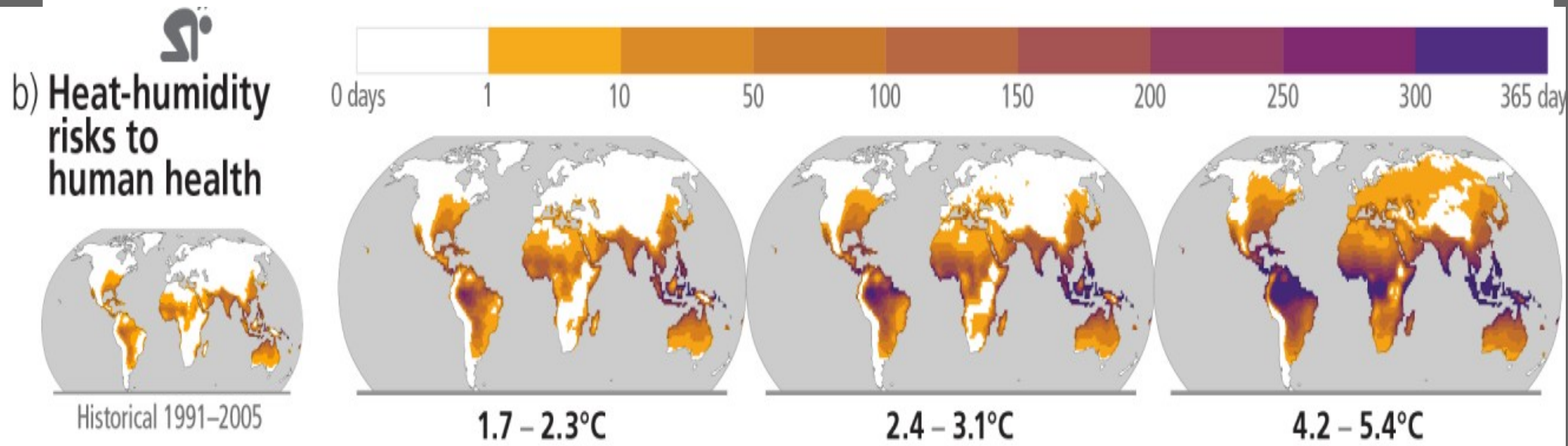


Figure 5. Temperature trajectories for different objectives.

Smooth transition

- The smooth transition scenario would be that there is a *quantitative* change : the climate we know would be about the same, with warmer summers and winters
  - This is what Nordhaus assumes
- Even a smooth transition may have dire consequences

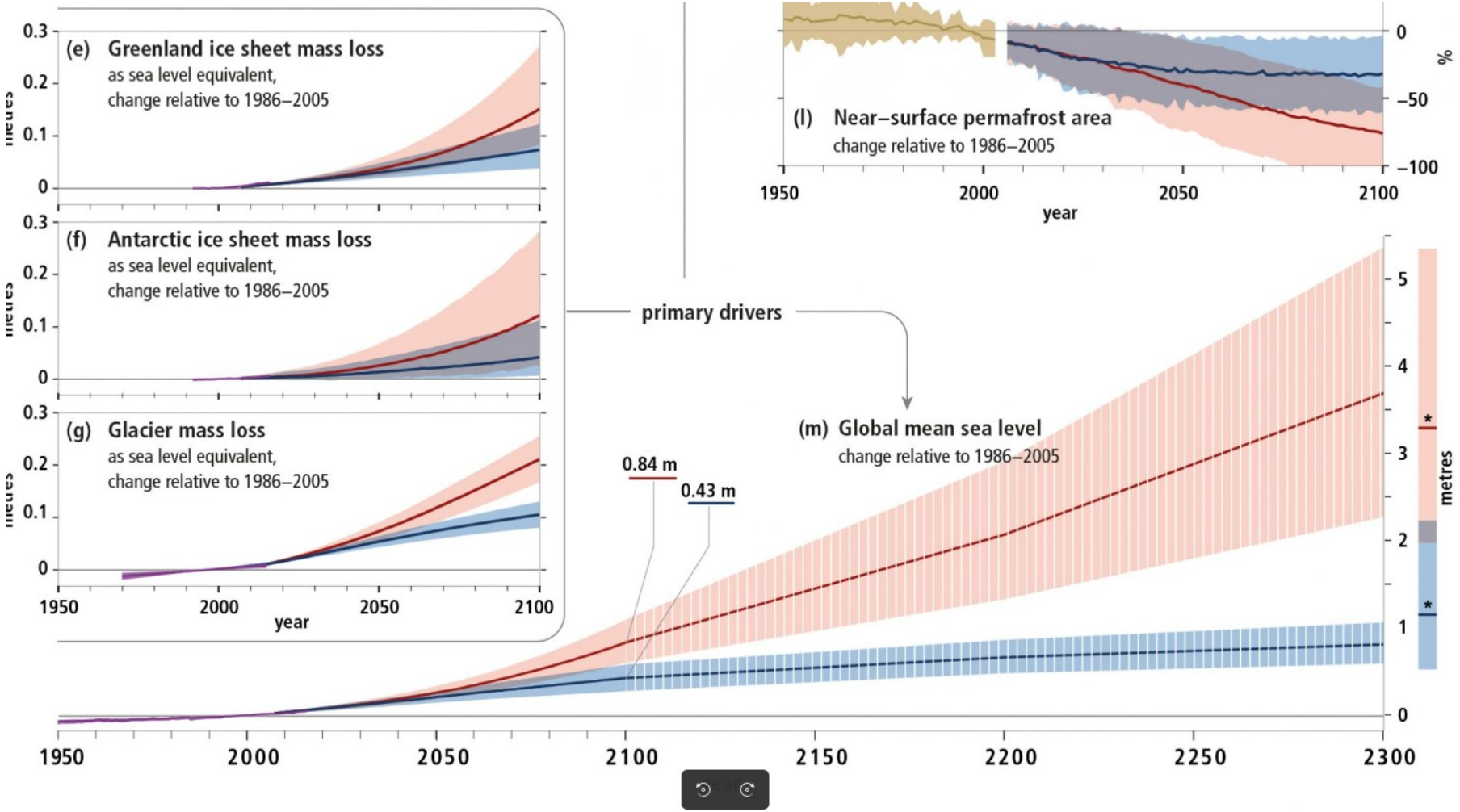
In the optimal world : killer days



Days per year where combined temperature and humidity conditions pose a risk of mortality to individuals[3]

[3]Projected regional impacts utilize a global threshold beyond which daily mean surface air temperature and relative humidity may induce hyperthermia that poses a risk of mortality. The duration and intensity of heatwaves are not presented here. Heat-related health outcomes vary by location and are highly moderated by socio-economic, occupational and other non-climatic determinants of individual health and socio-economic vulnerability. The threshold used in these maps is based on a single study that synthesized data from 783 cases to determine the relationship between heat-humidity conditions and mortality drawn largely from observations in temperate climates.

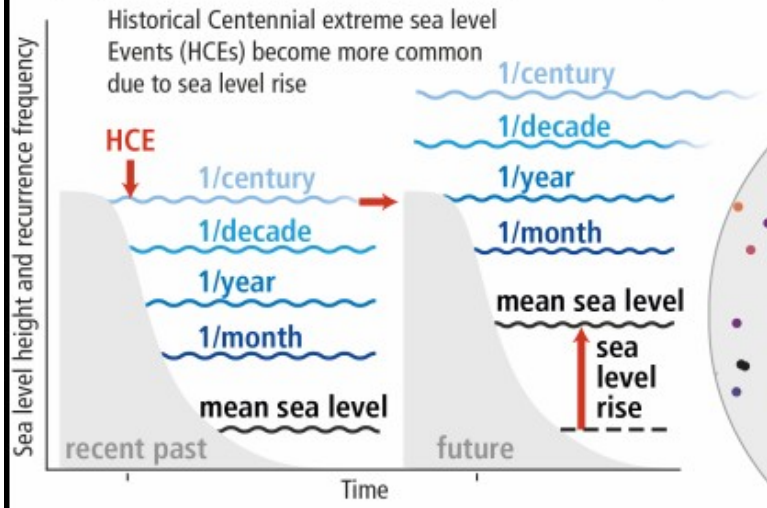
In the optimal world : sea level rise



In the optimal world : extreme sea events

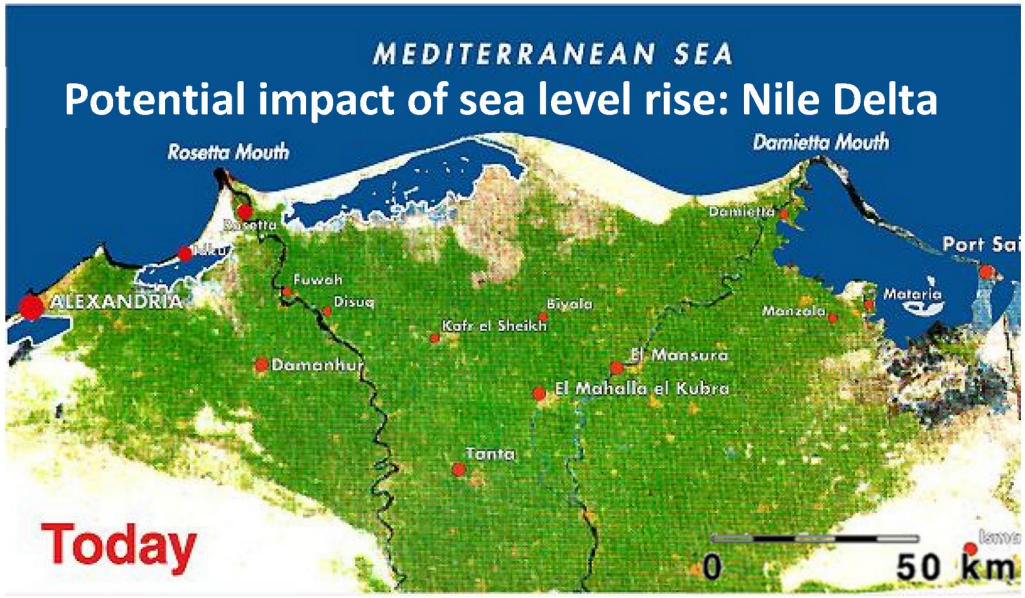
Due to projected global mean sea level (GMSL) rise, local sea levels that historically occurred once per century (historical centennial events, HCEs) are projected to become at least annual events at most locations during the 21st century. The height of a HCE varies widely, and depending on the level of exposure can already cause severe impacts. Impacts can continue to increase with rising frequency of HCEs.

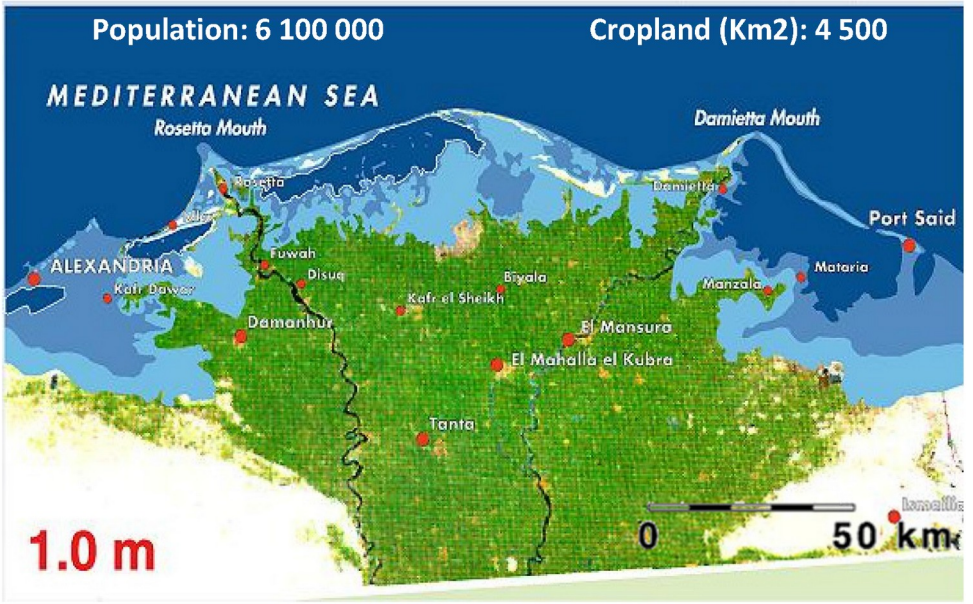
(a) Schematic effect of regional sea level rise on projected extreme sea level events (not to scale)



(b) Year when HCEs are projected to recur once per year on average

Impact on coastal communities





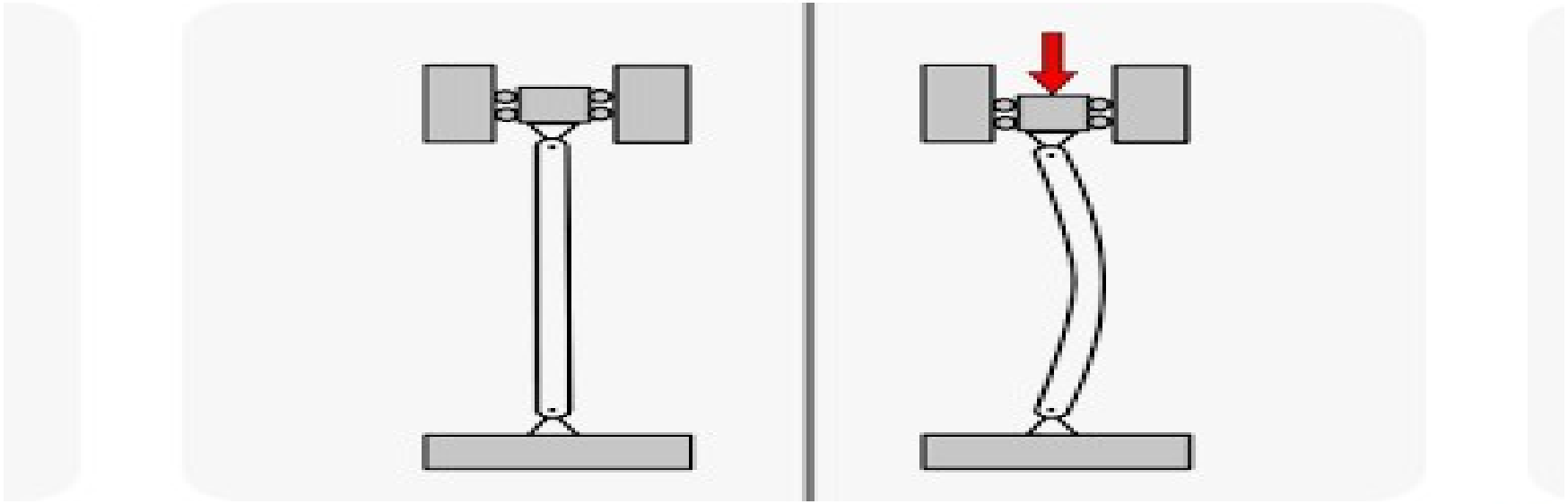
- 600 Million people live less than 10m above sea level
- 2.4 Billion people live less than 100 km from the sea

Second answer :

Bifurcation

Bifurcation

An example : buckling (Leonard Euler, 1677)



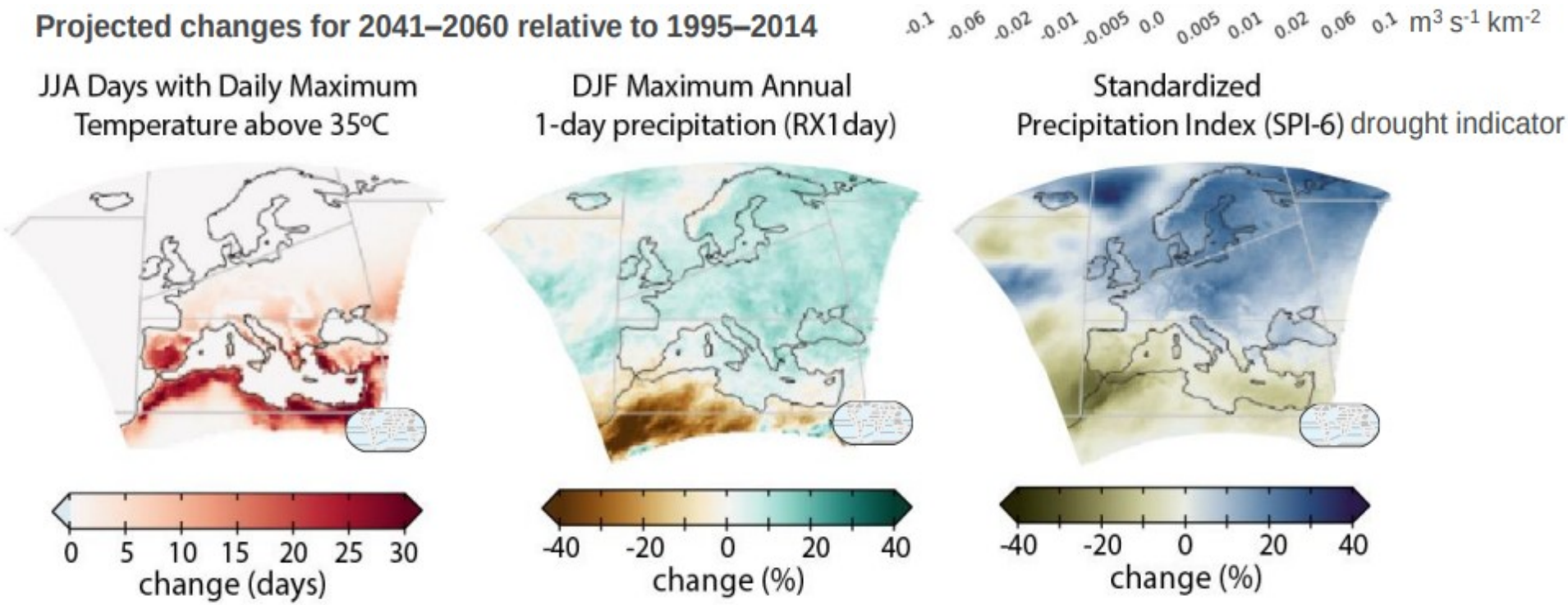
Wikipédia

Flambage — Wikipédia

Bifurcation

- There is now a *qualitative* difference : if the force exceeds a certain threshold, the structure of the system changes
- This change is *continuous*, proportional to the distance from the threshold
- The change is *reversible* : if we stop applying force, or if we decrease the force we apply, the beam recovers its original shape (the original equilibrium is restored

Qualitative changes : the Mediterranean



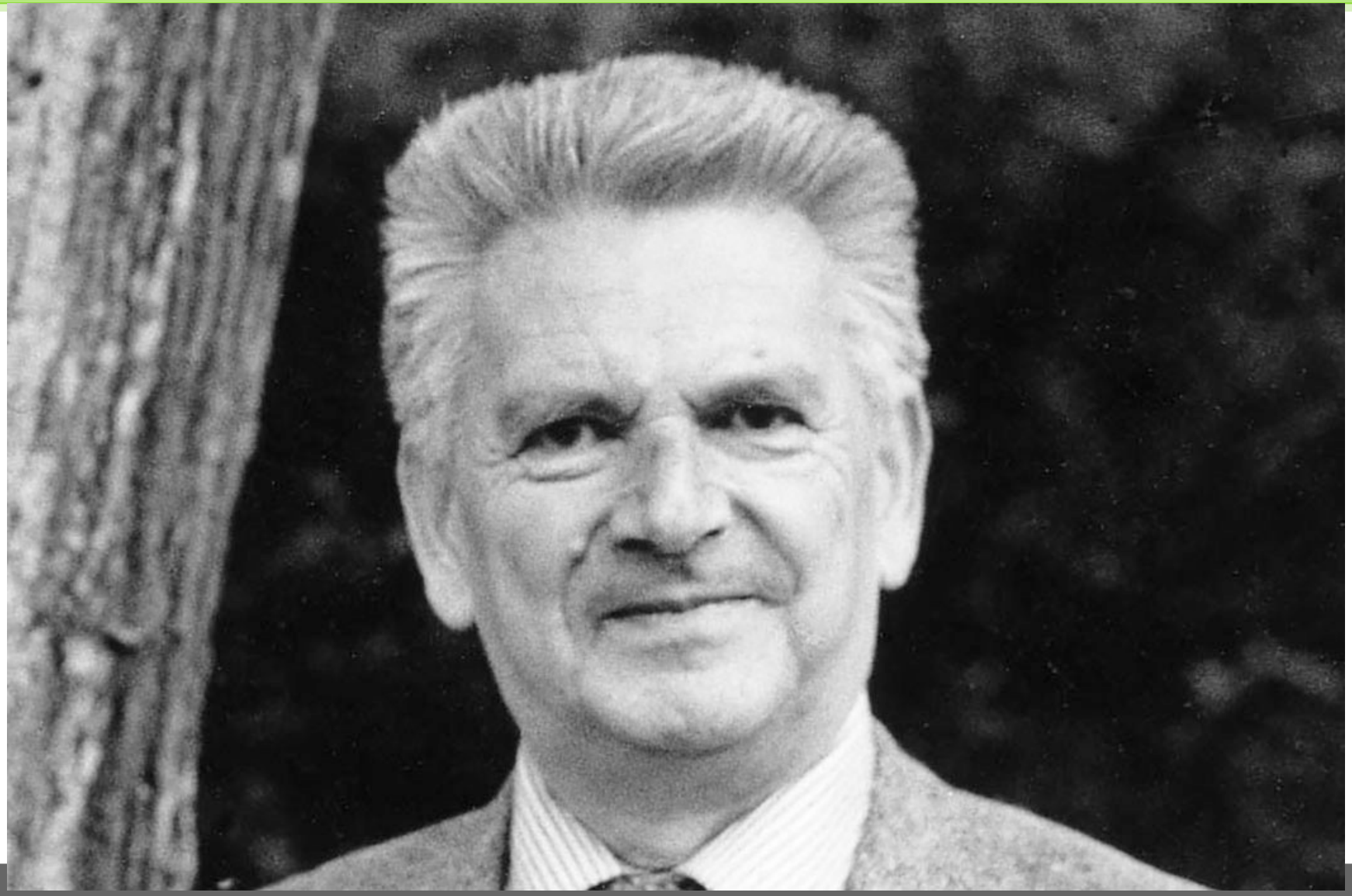
To learn more about your region: see the IPCC Interactive Atlas
https://interactive-atlas.ipcc.ch/

Third answer :

Catastrophes

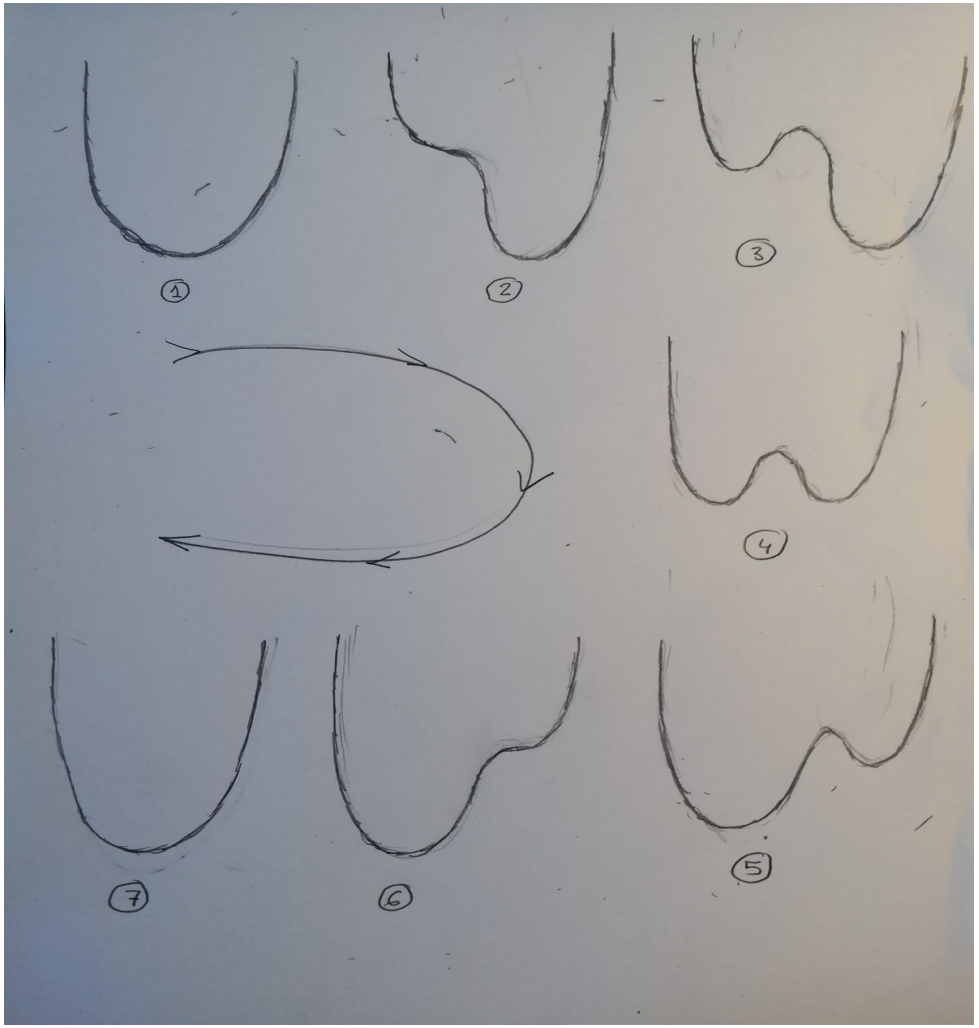
(in the sense of René Thom)

René Thom (1923-2002)



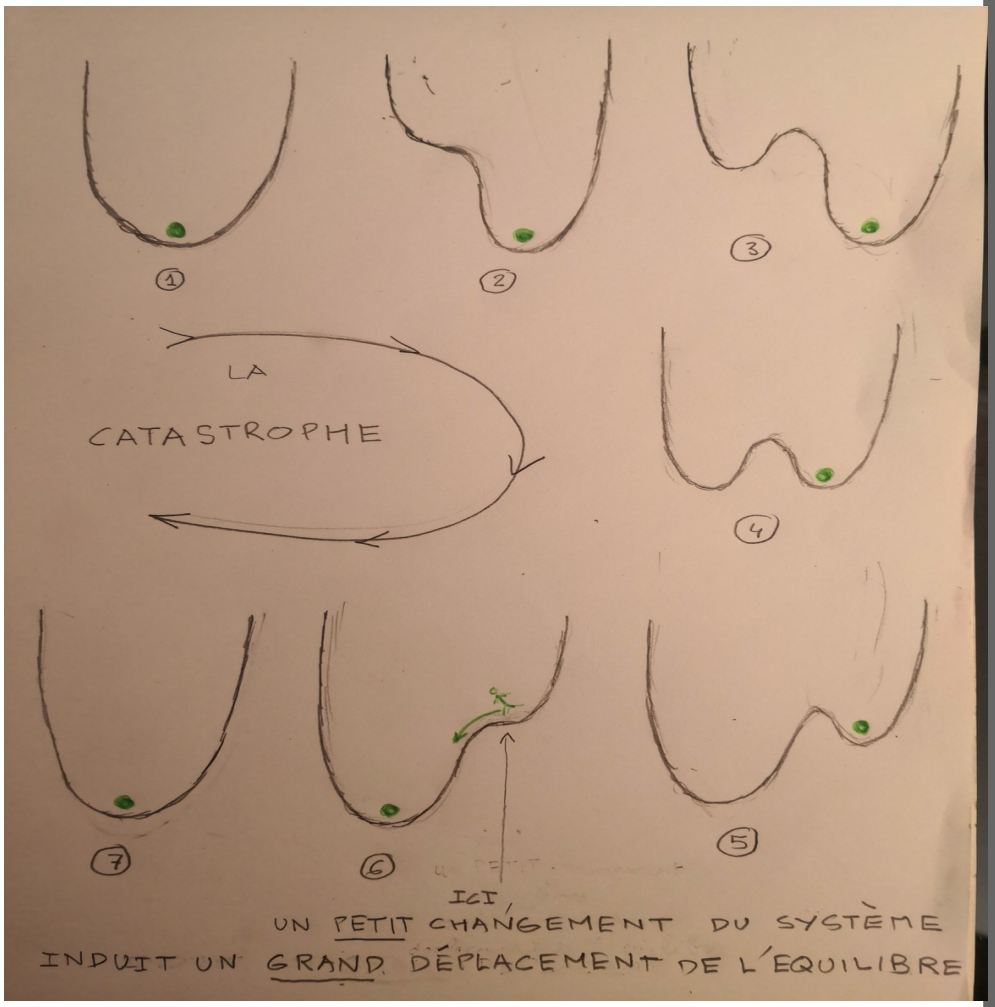
Smooth changes

- The curve deforms as we move from position 1 to position 7
- We can also move back from position 7 to 1
- The point to note is that the changes are continuous and reversible



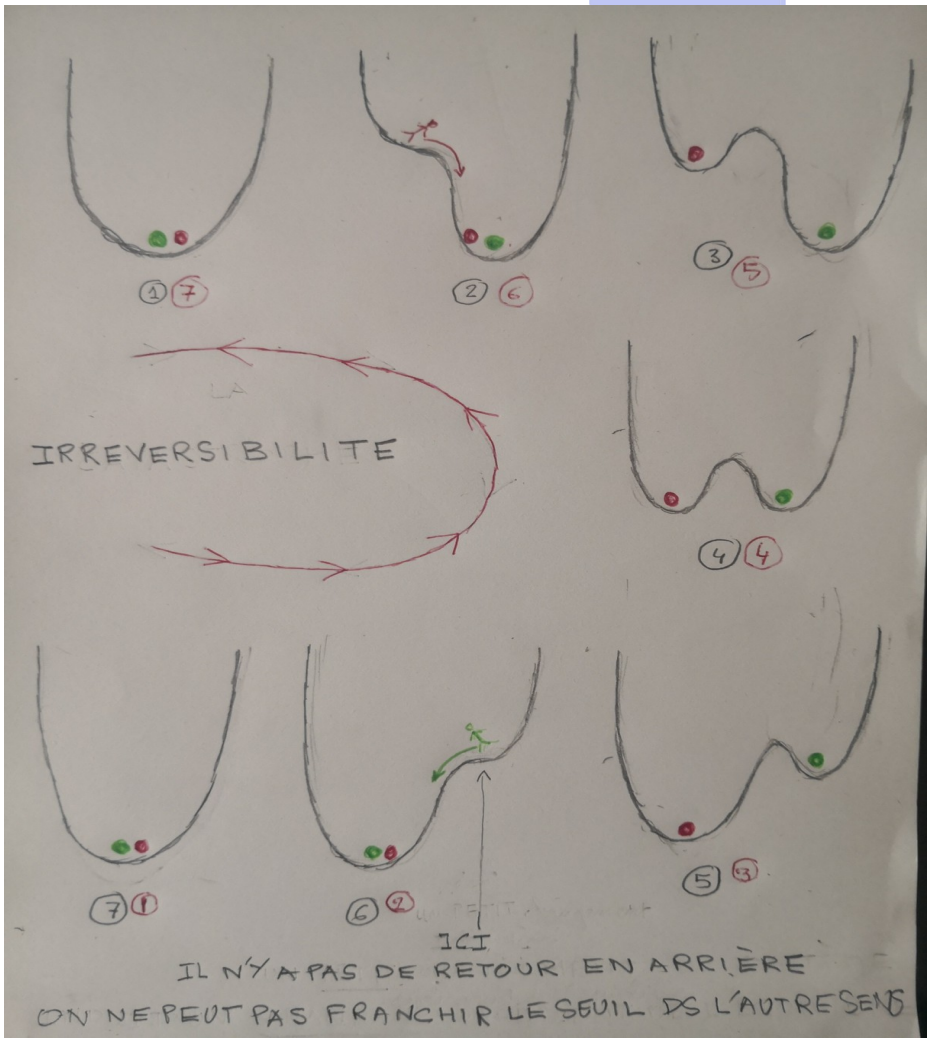
Abrupt response

- We now put a green marble a the bottom
- It is in equilibrium
- As we move from 1 to 7 the equilibrium persists until position 6
- The marble then drops precipiteously into another equilibrium far away



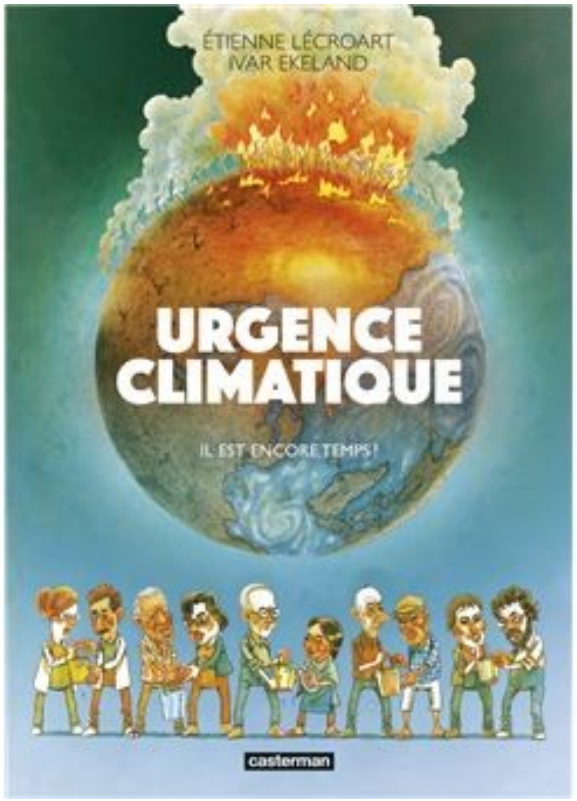
No turning back

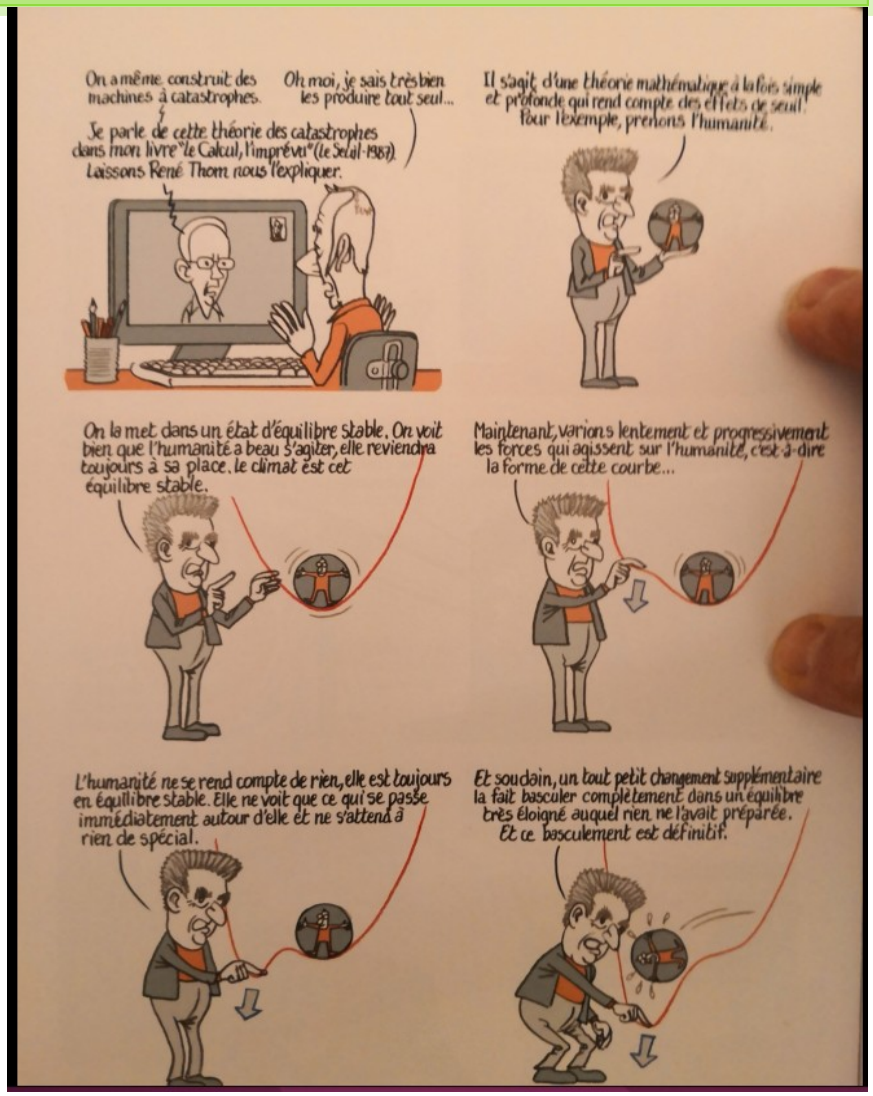
- We now want to turn the clock back : we put a red ball down in position 7 and we move back to 1
- The red ball does NOT jump at position 6 where the green ball dropped
- It drops only in position 6



The master himself

- Look up my graphic course
-





Thom’s catastrophe theory

- The change is discontinuous : if the threshold is crossed, the system jumps to another equilibrium far away
- The change is irreversible : crossing the threshold in the other direction does not restore the previous equilibrium
- There is hysteresis : for a given value of the input (CO2) there may be several possible equilibria. Which one prevails depends on past history

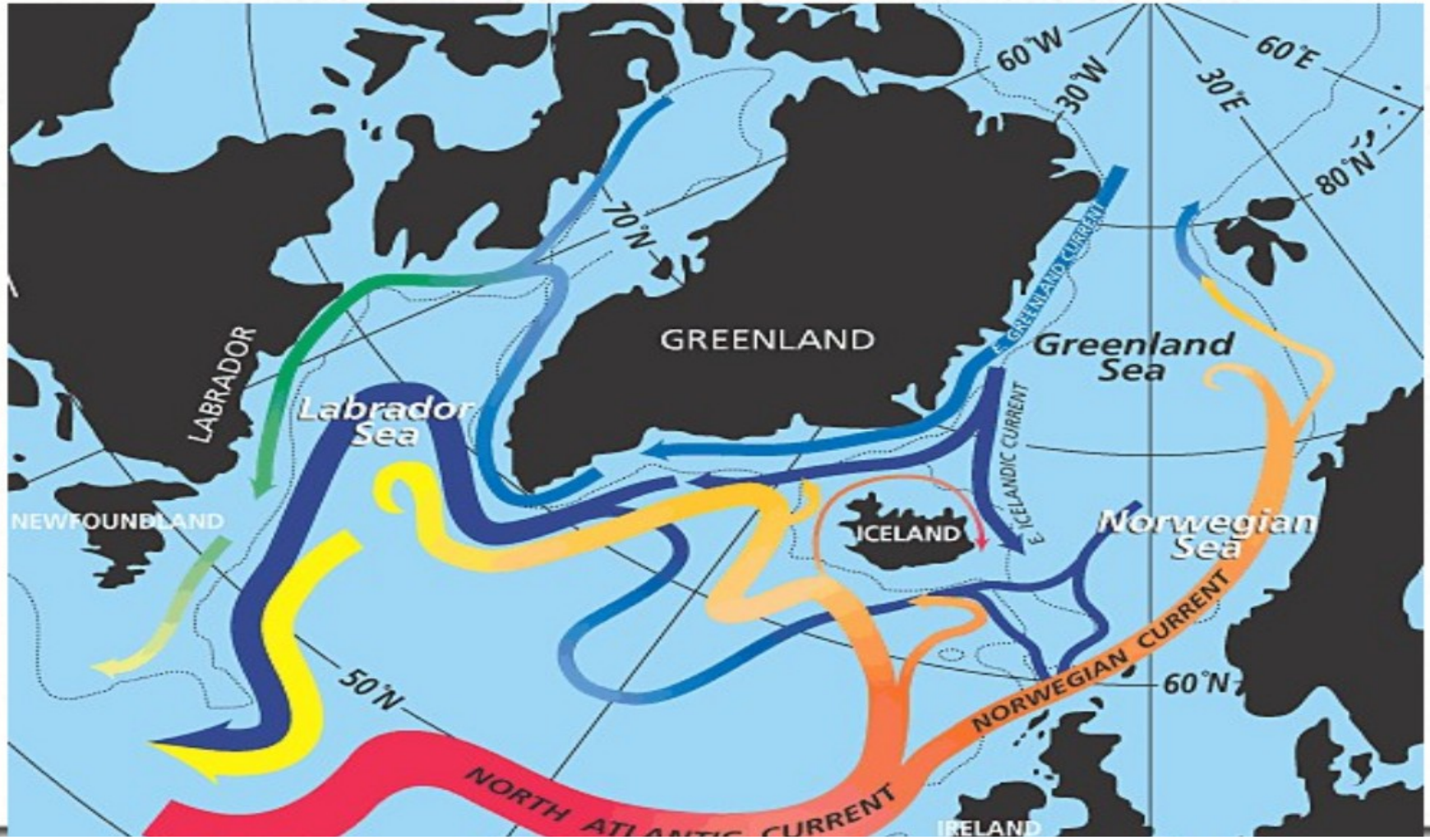
These three properties characterize a catastrophe. The basic intuition is due to René Thom and there is a beautiful mathematical theory

Catastrophes in the climate system

- Climatologists call them tipping points : these are thresholds,
  - which are known to exist
  - which will lead to abrupt, irreversible and major changes if crossed
  - but which cannot be located precisely : we do not know when we will cross them, and when we cross them we may not even know it
  - latest study in Science, 2022 *« Exceeding 1.5°C global warming could trigger multiple climate tipping points »*


ARCTIC WINTER SEA ICE
COLLAPSE
BOREAL FOREST
NORTHERN EXPANSION
GREENLAND ICE SHEET
COLLAPSE
BARENTS SEA ICE
ABRUPT LOSS
BOREAL PERMAFROST
COLLAPSE
BOREAL PERMAFROST
ABRUPT THAW
LABRADOR SEA/ SUBPOLAR GYRE
COLLAPSE
BOREAL FOREST
SOUTHERN DIEBACK
ATLANTIC MERIDIONAL OVERTURNING CIRCULATION
COLLAPSE
SAHEL / WEST AFRICAN MONSOON
GREENING
LOW-LATITUDE CORAL REEFS
DIE-OFF
AMAZON RAINFOREST
DIEBACK
MOUNTAIN GLACIERS
LOSS
WEST ANTARCTIC ICE SHEET
COLLAPSE
EAST ANTARCTIC ICE SHEET
COLLAPSE
EAST ANTARCTIC SUBGLACIAL BASINS
COLLAPSE
GLOBAL WARMING THRESHOLDS
<2°C
2–4°C
≥4°C

Les courants Atlantique Nord



Consequences for policy

- The « optimal » strategy of Nordhaus put us close to triggering all the tipping points
- The consequences cannot be forecast based on past data, since the system moves to a very different equilibrium
- The precautionary principle : stay away from the tipping points

Fourth answer

Knowing and not knowing

- When you know, you know that you know,

Knowing and not knowing

- When you know, you know that you know,
- and you know that you know that you know,

Knowing and not knowing

- When you know, you know that you know,
- and you know that you know that you know,
- and so on to infinity
  - *Spinoza, Ethica, 2, XXI, Scholium*
  - died in 1677

Knowing and not knowing

- When you know, you know that you know
- But when you don’t know, you may not know that you don’t know.

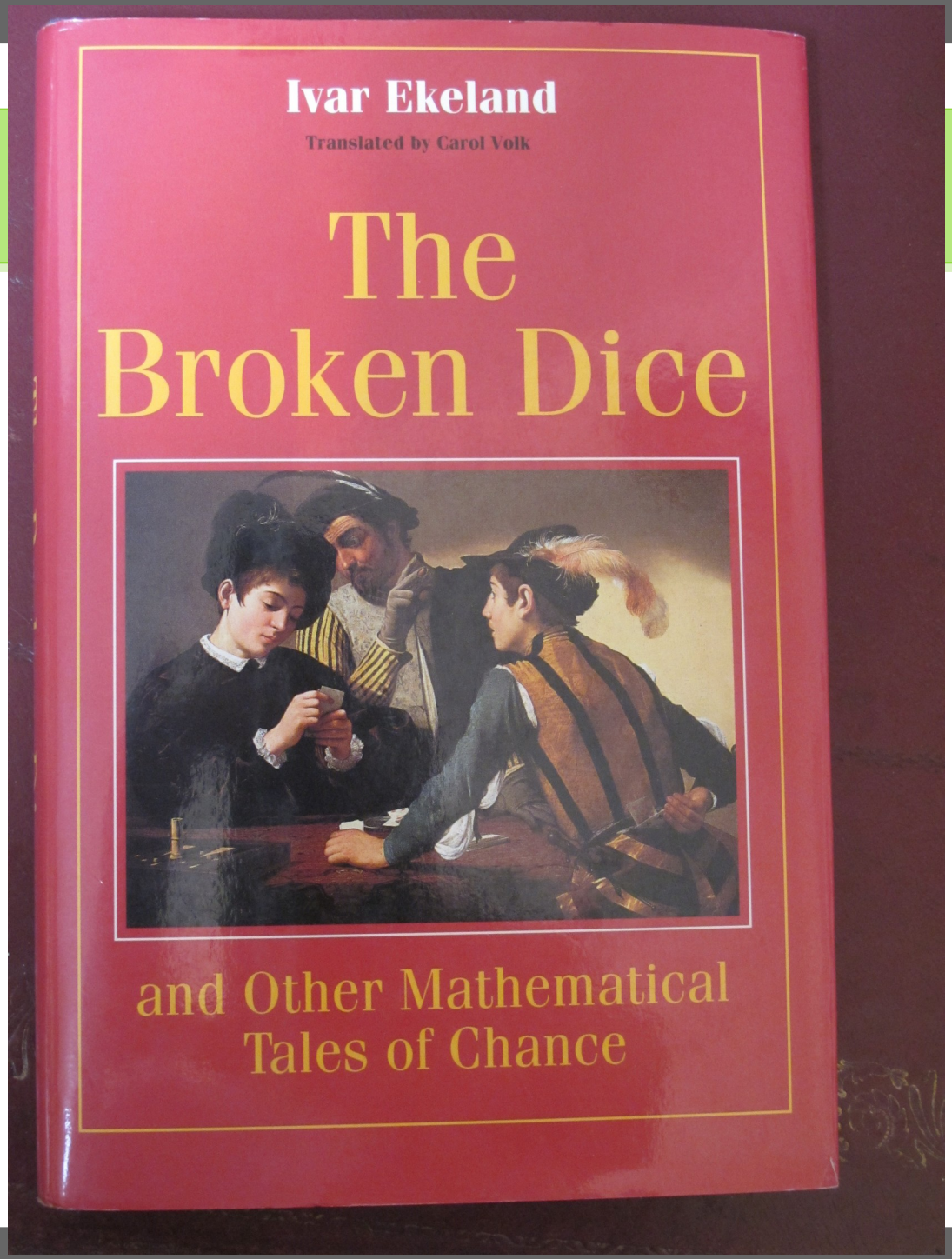
A tale from Norway

- Snorri Sturluson, *The saga of Olav Haraldsson,* 1230

Olav med de Erender, at han skulde fare i Stævne-le
Sveakongen, og det tillige, at Sveakongen vilde, at de
da Kong Olav hørte denne Ordsending, da var han fr

Kongerne kaste Terninger om en Bygd paa Hisingen.

for Gud min Herre er det en let Sag at lade dem
Sexere kom op. Da kastede Olav Sveakonge, og a
Olav, Norges Konge


Ivar Ekeland
Translated by Carol Volk
The Broken Dice
and Other Mathematical Tales of Chance

Knowing and not knowing

- When you know, you know that you know
- But when you don’t know, you may not know that you don’t know. Hence the classification of unknowns :
  - Known unknowns (probability theory)
  - Unknown unknowns (precautionary principle)

Knowing and not knowing

- When you know, you know that you know
- But when you don’t know, you may not know that you don’t know. Hence the classification of unknowns :
  - Known unknowns (probability theory)
  - Unknown unknowns (precautionary principle)
- It is impossible to know all there is to know about a living being, or about the planet Earth
- Expect many unknown unknowns !

Unpleasant surprises in the greenhouse?

Wallace S. Broecker

There is now clear evidence that changes in the Earth's climate may be sudden rather than gradual. It is time to put research into the build-up of carbon dioxide in the atmosphere on a better footing.

THE inhabitants of planet Earth are quietly conducting a gigantic environmental experiment. So vast and so sweeping will be the consequences that, were it brought before any responsible council for approval, it would be firmly rejected. Yet it goes on with little interference from any jurisdiction or nation. The experiment in question is the release of CO_2 and other so-called 'greenhouse gases' to the atmosphere. Because these releases are largely by-products of energy and food production, we have little choice but to let the experiment continue. We can perhaps slow its pace by eliminating frivolous production and by making more efficient use of energy from fossil fuels. But beyond this we can only prepare ourselves to cope with its effects.

The task of scientists is to predict the consequences of the build-up of CO_2 and other gases. To be useful these predictions must be reasonably detailed, but we are in

hunches. They come from viewing the results of experiments nature has conducted on her own. The results of the most recent of them are well portrayed in polar ice, in ocean sediment and in bog mucks. What these records indicate is that Earth's climate does not respond to forcing in a smooth and gradual way. Rather, it responds in sharp jumps which involve large-scale reorganization of Earth's system. If this reading of the natural record is correct, then we must consider the possi-

"We play Russian roulette with climate [and] no one knows what lies in the active chamber of the gun . . ."

bility that the main responses of the system to our provocation of the atmosphere will come in jumps whose timing and magnitude are unpredictable. Coping with this

This record does not show the gradual change scientists had become accustomed to. Instead it shows an abrupt end to glacial time and, even more interesting, a brief period of intense cold interrupting the warm period that followed (Fig. 1). Although the two records shown in Fig. 1 are quite different, they are not incompatible. Changes in $^{18}O/^{16}O$ in the shells of marine sediments are largely the result of the waxing and waning of the ^{18}O-deficient continental ice caps. As the response time of global ice caps is thousands of years, the ^{18}O record smooths out the rapid changes in climate.

It took more than this, however, to make us take these abrupt changes seriously. The evidence that turned our heads came from holes drilled through the Greenland ice cap. As a foot or so of ice forms from each year's snowfall, the record captures changes in the ice-cap environment no matter how rapid they h

Climate policies

The scope of the problem

- This is an oil barrel. It contains 160 liters. How many are burned in a day ?

1 colonne
2 colonne
3 colonne

The scope of the problem

- This is an oil barrel. It contains 160 liters. How many are burned in a day ?
- 100 Million
- About the same in gas and in coal
- 80 % of all energy used by humans

1 colonne
2 colonne
3 colonne

Climate policies : statements

- Paris agreement (2015) : limit global warming to 2°C, and preferably 1,5°C by 2100
- This is a political agreement, as close to a consensus as we will ever come in such a divided world
- Supported by growing anxiety in the developed world, especially among the younger generation

Climate policies : facts

- Since 2000, annual emissions of CO2 have increased 60 %. More carbon has been put into the atmosphere than in the 75 preceding years. Carbon concentration has gone from 373 ppm to 420 ppm
- Shell and Exxon Mobil plan to increase their production 35 to 38 % from now to 2030. As for coal, existing mines would be enough to break the 1°5 C barrier.
- In France, the government has given up pretending :
  - The National Council for Ecological Transition has just issued a statement whereby France should operate on the assumption of 3°C global warming in 2100.

The poverty of ethics

- A compelling ethical case :
  - We are all in the same boat
  - The stakes could hardly be higher
  - *Any man's death diminishes me/ Because I am a involved in mankind / Therefore never send to know for whom the bell tolls/ It tolls for thee* (John Donne, 1600)
  - The case has been made over and over again (the first IPCC report is in 1988)
- So why is nothing happening ?
  -

The poverty of ethics

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  - The case has been made over and over again (the first IPCC report is in 1988)
- So why is nothing happening ?
- But we are used to that, aren't we ?
  -

The true situation

- We are NOT all in the same boat. The 50/10 rule :
  - 10 % of the population is responsible for 50 % of the emissions
  - 50 % of the population is responsible for 10 % of the emissions
  - This holds on the world level as within nations
- People responsible for climate change knew perfectly well what they were doing
  - In the 80's all major oil companies had internal reports warning that pouring CO2 into the atmosphere would have catastrophic effects in the 21st century

Climate change is the modern version of colonialism : a small minority uses violence to appropriate common resources causing immense suffering to the rest

What is to be done ?

- Fighting climate change is a political struggle, at par with the other struggles for liberation.
- Resort to the usual tools of political activism
  - Spread the information
  - Educate, teach the science,
  - Fight the ideology of markets will not solve the problem
  - Vote, organise and demonstrate
- State violence is already present, but has not as yet been answered
  - « *It is strange and striking that climate activists have not committed any acts of terrorism* » John Lanchester, LRB, 2007

Bibliography

- On climate change :
  - course by IE at Paris-Dauphine
    - https://www.ceremade.dauphine.fr/~ekeland/lectures/Climate%20course%20_compressed.pdf
  - Naomi Klein, 2014
    - *This changes everything : capitalism vs. the climate*
- Projections :
  - IPCC projections : the interactive atlas
    - https://interactive-atlas.ipcc.ch/
  - Tipping points
    - *Exceeding 1.5°C global warming could trigger multiple climate tipping points,* Science (Sept 9, 2022) https://doi.org/10.1126/science.abn7950
- What big oil knew
  - https://phys.org/news/2021-10-big-oil-knew-climate-words.html

Bibliography

- On violence
  - John Lanchester, *Warmer, Warmer,* London Review of Books, February 2007
  - Kim Stanley Robinson, *The ministry for the future,* Orbit Books, 2020
  - Andreas Malm, *How to blow up a pipeline : learning to fight in a world on fire,* Verso Books, 2021
  - *Outcry as scientists sanctioned for climate protests,* Nature, Feb. 15, 2023

The end

Thank you for your attention