UM6P SCIENCE WEEK

THEME:

COMPLEXITY

20 – 26 February 2023

UM6P Campus – Benguerir

ASARI – UM6P Lâayoune

Climate change :

transition
bifurcation
or catastrophe ?

Ivar Ekeland, CEREMADE,
Université Paris-Dauphine

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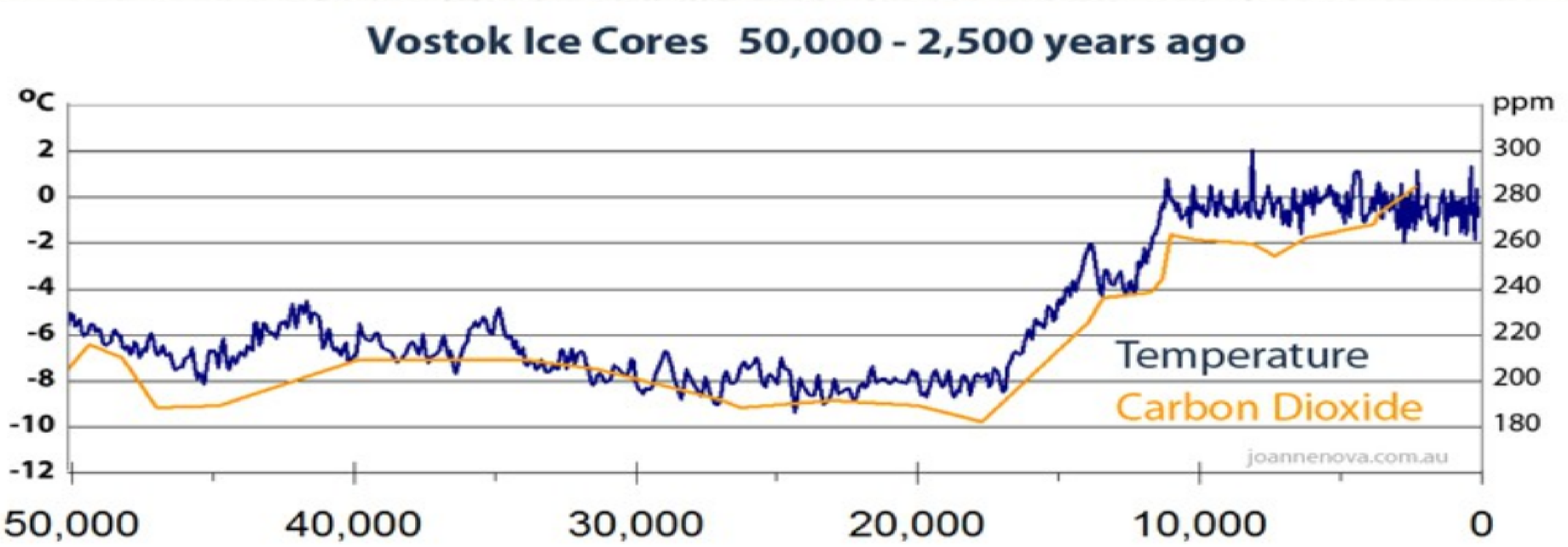
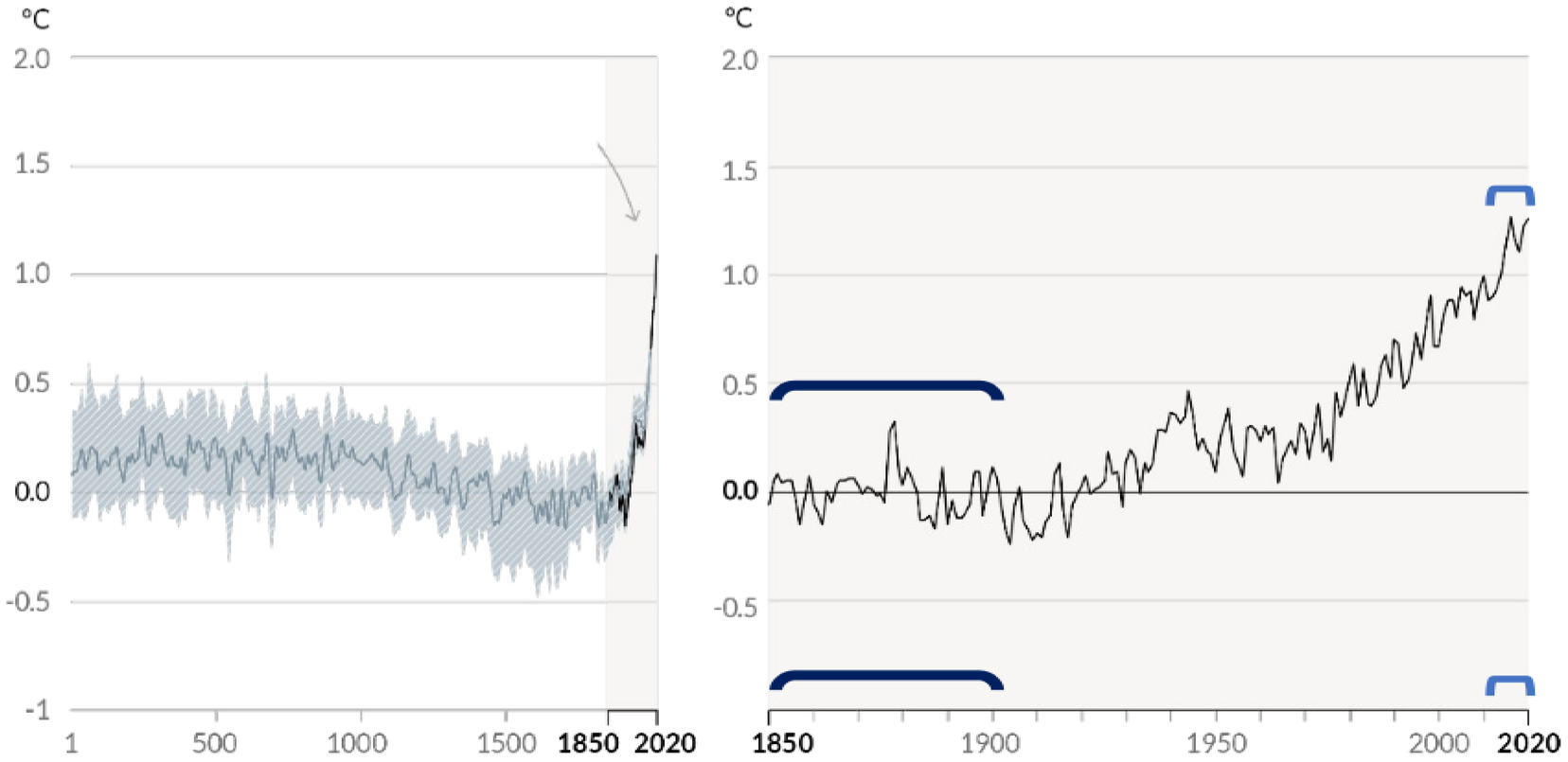
Temperatures of the past 50,000 ys

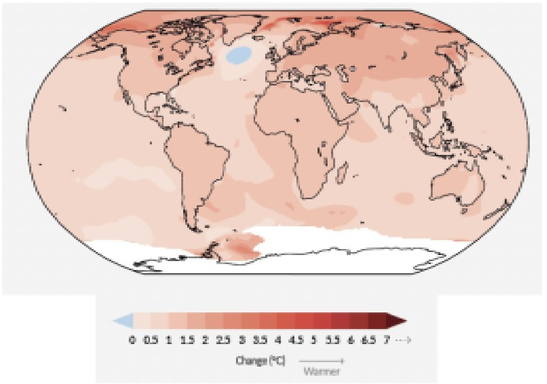


Temperatures of the past 2,000 or 200 ys

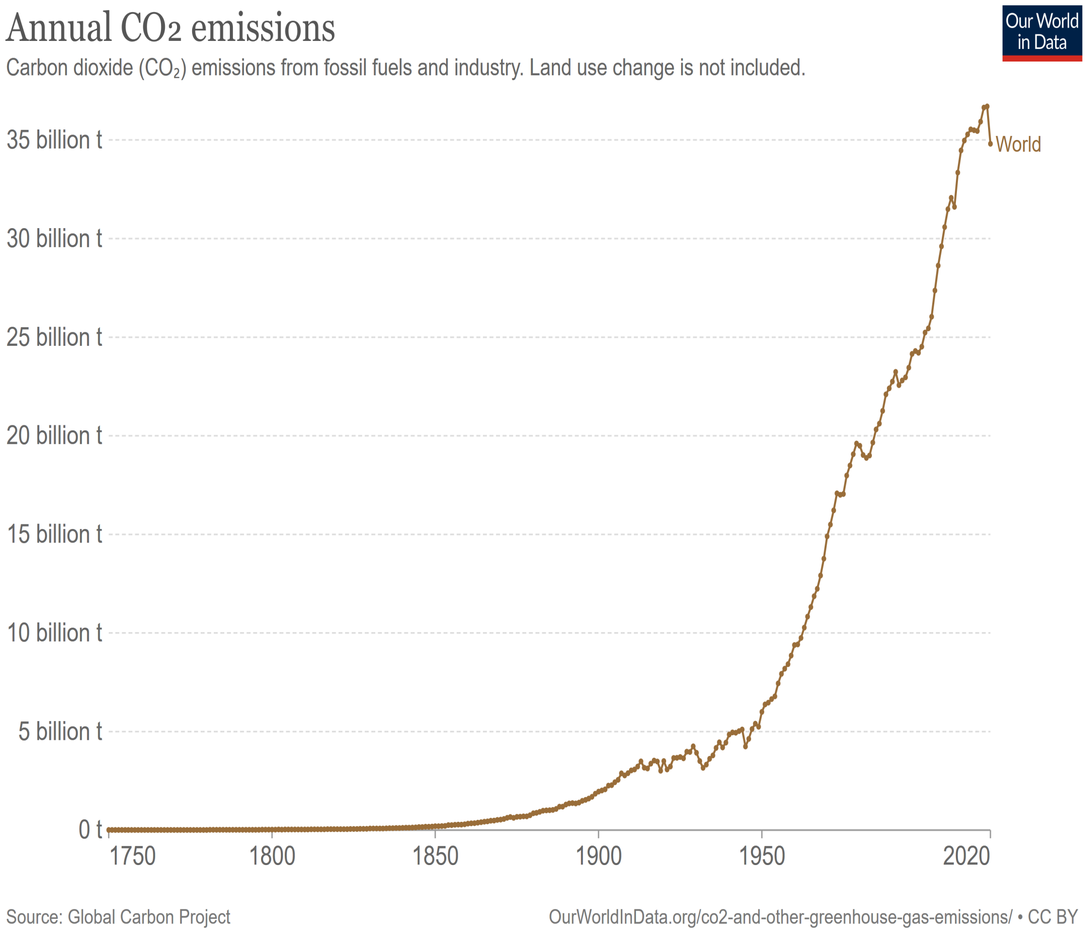
Changement **observé** de température de surface planétaire
depuis 1850-1900

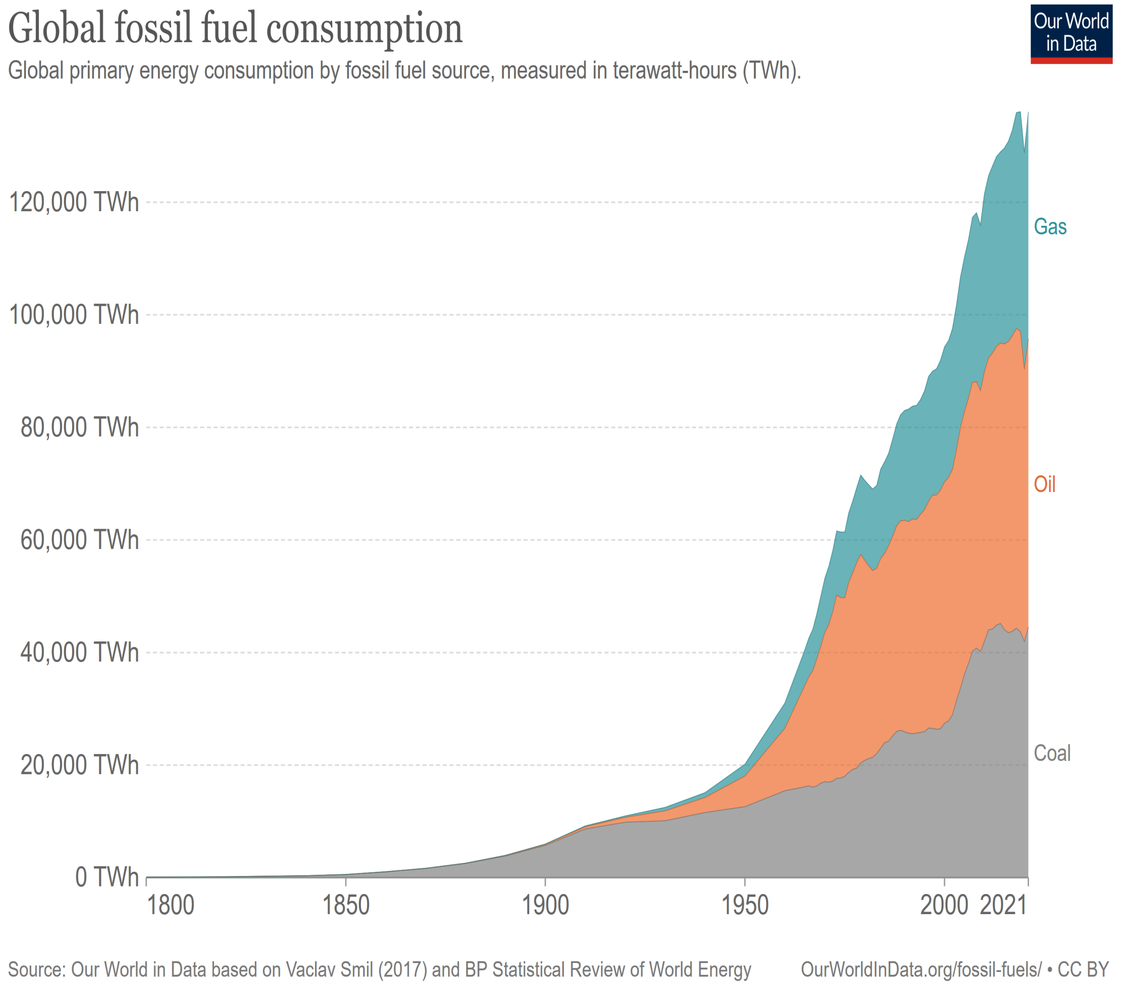


+ 1,7°C en France



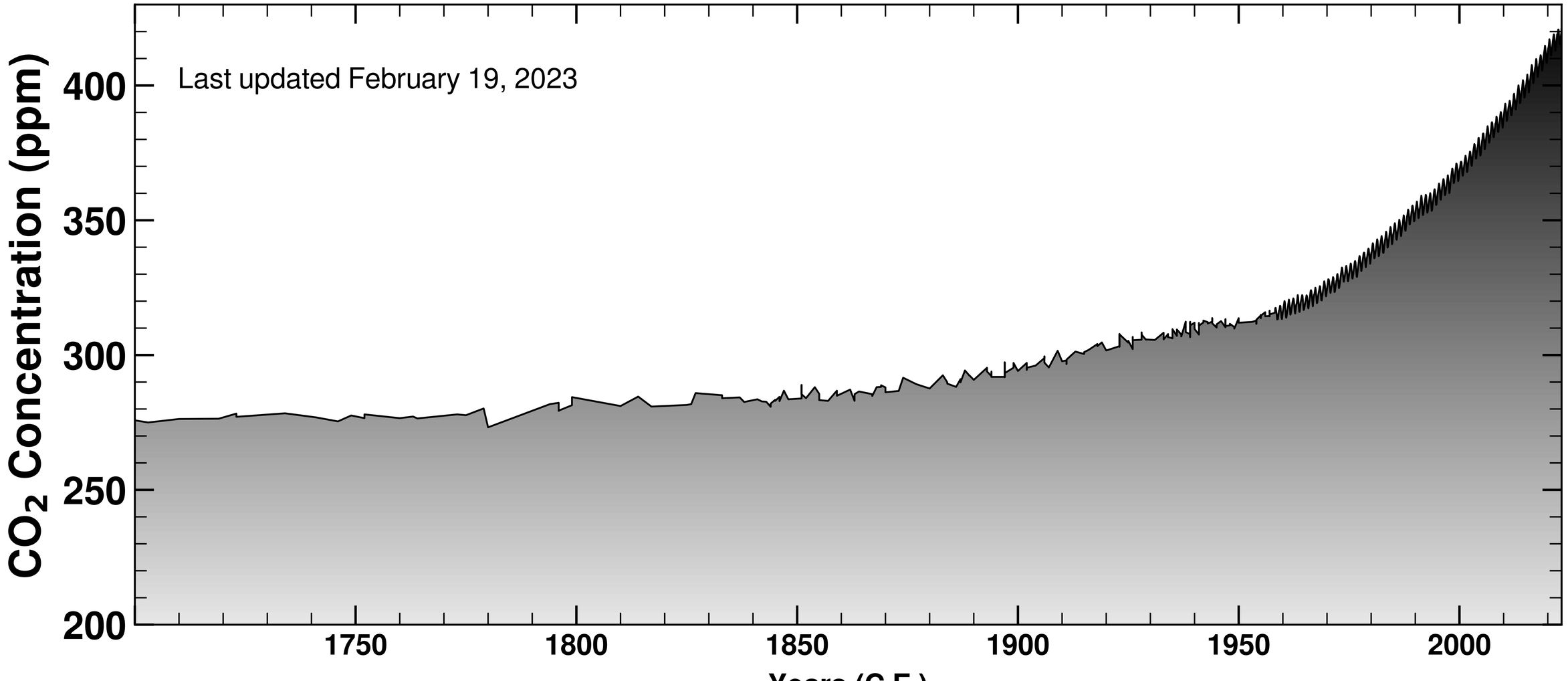
A nudge


Annual CO_2 emissions
Carbon dioxide (CO_2) 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
1750
1800
1850
1900
1950
2020
World
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
1800
1850
1900
1950
2000
2021
Gas
Oil
Coal
Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy
OurWorldInData.org/fossil-fuels/ • CC BY

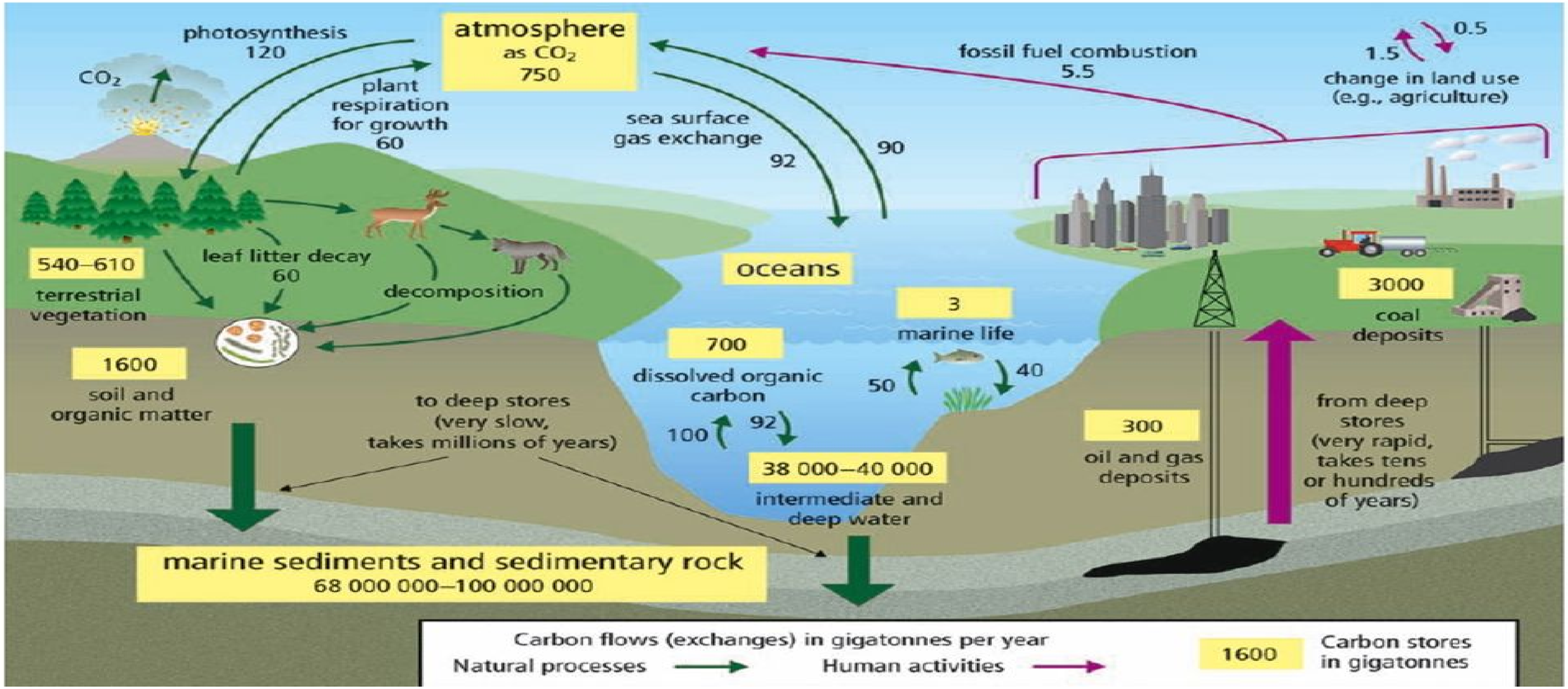
A small nudge

The Keeling curve : we have reached 420 ppm



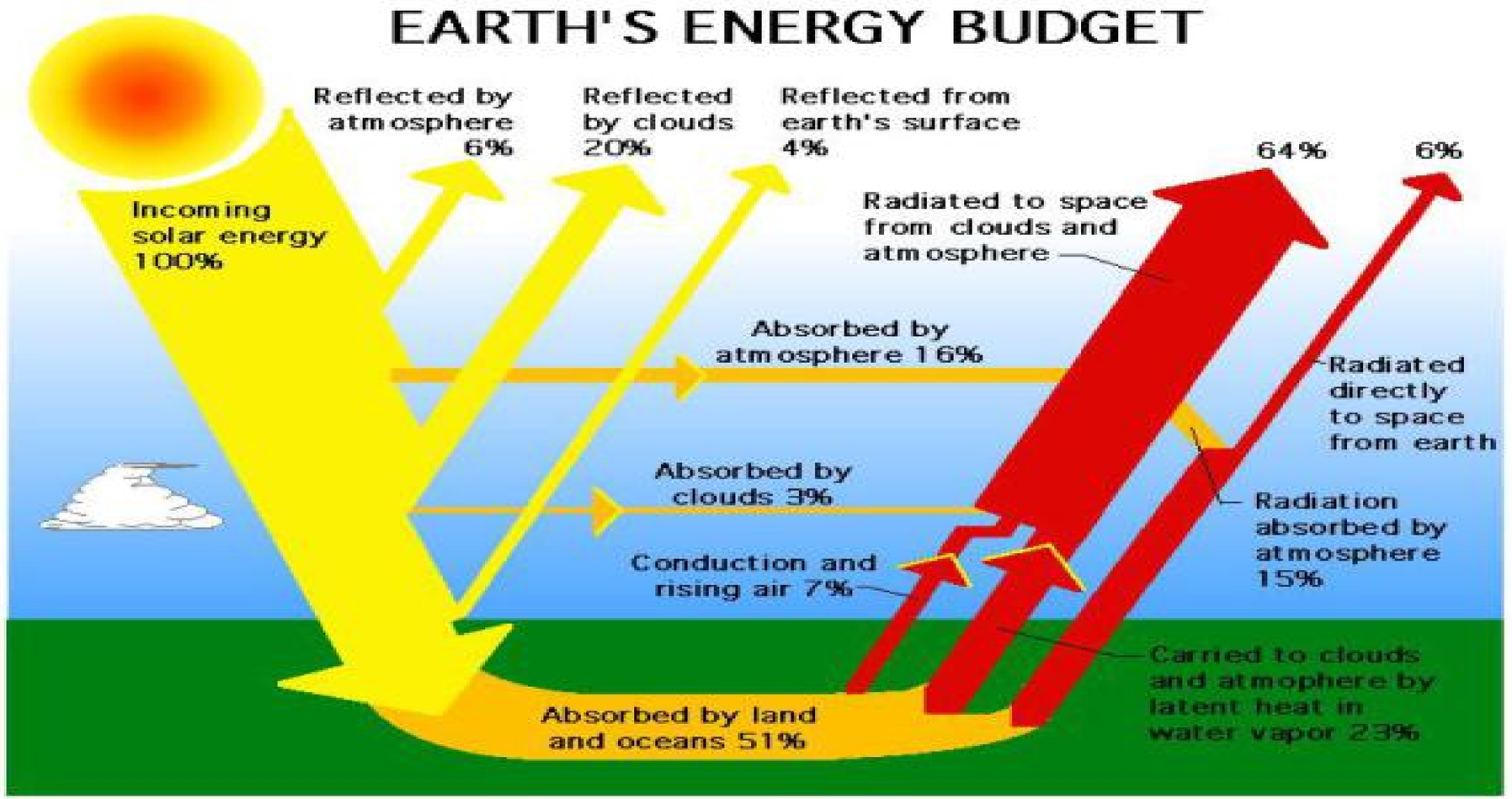
The Earth is a complex system

Nutrient Cycles: The Carbon Cycle



which is thrown out of equilibrium

It should send back as much energy as it receives



How does a complex system in equilibrium respond to a small nudge ?

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First answer : smooth transition

Small changes all over the place

- 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

- 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 can already have dire consequences : some combinations of heat and humidity are lethal (40°C and 100%). Such combination would become much more frequent and render some regions unhabitable (Costa Rica)

Assuming a smooth transition...

William Nordhaus, Nobel prize in economics (2018)

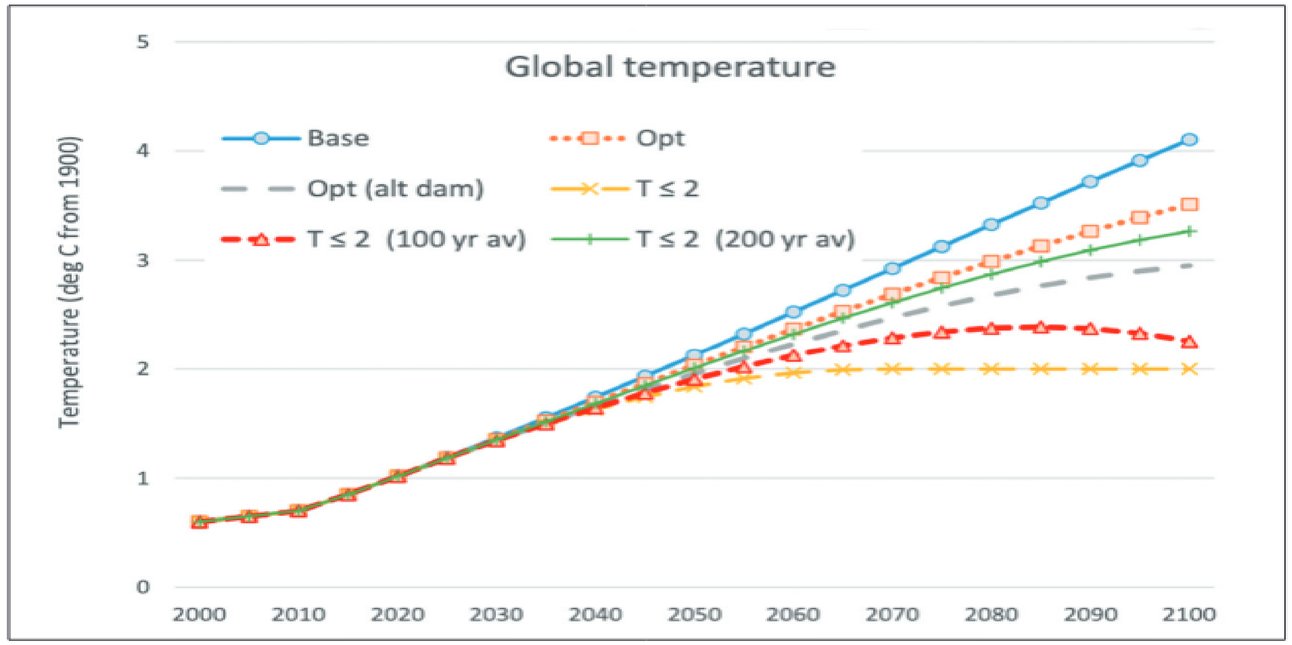


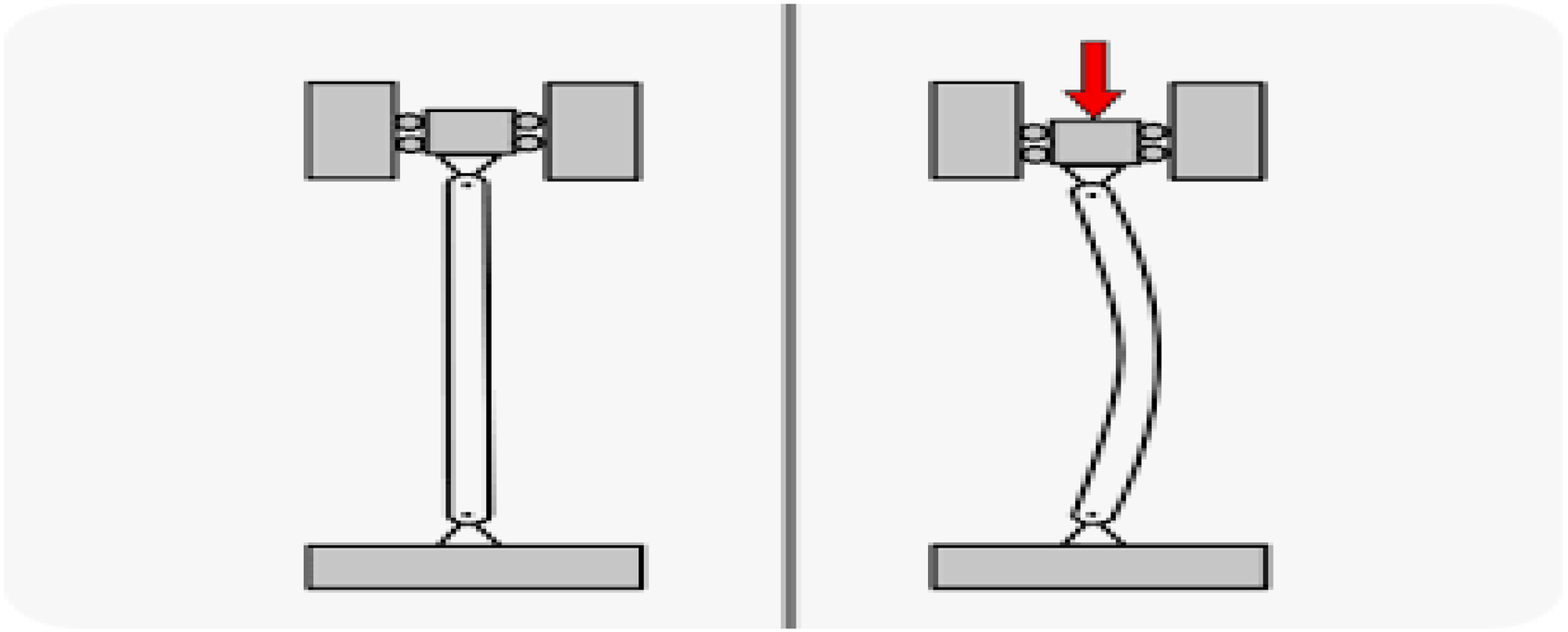
Figure 5. Temperature trajectories for different objectives.

3°5 warming is « optimal » ? Really ?

y

Second answer : bifurcation

- An example : buckling



Wikipédia

Flambage — Wikipédia

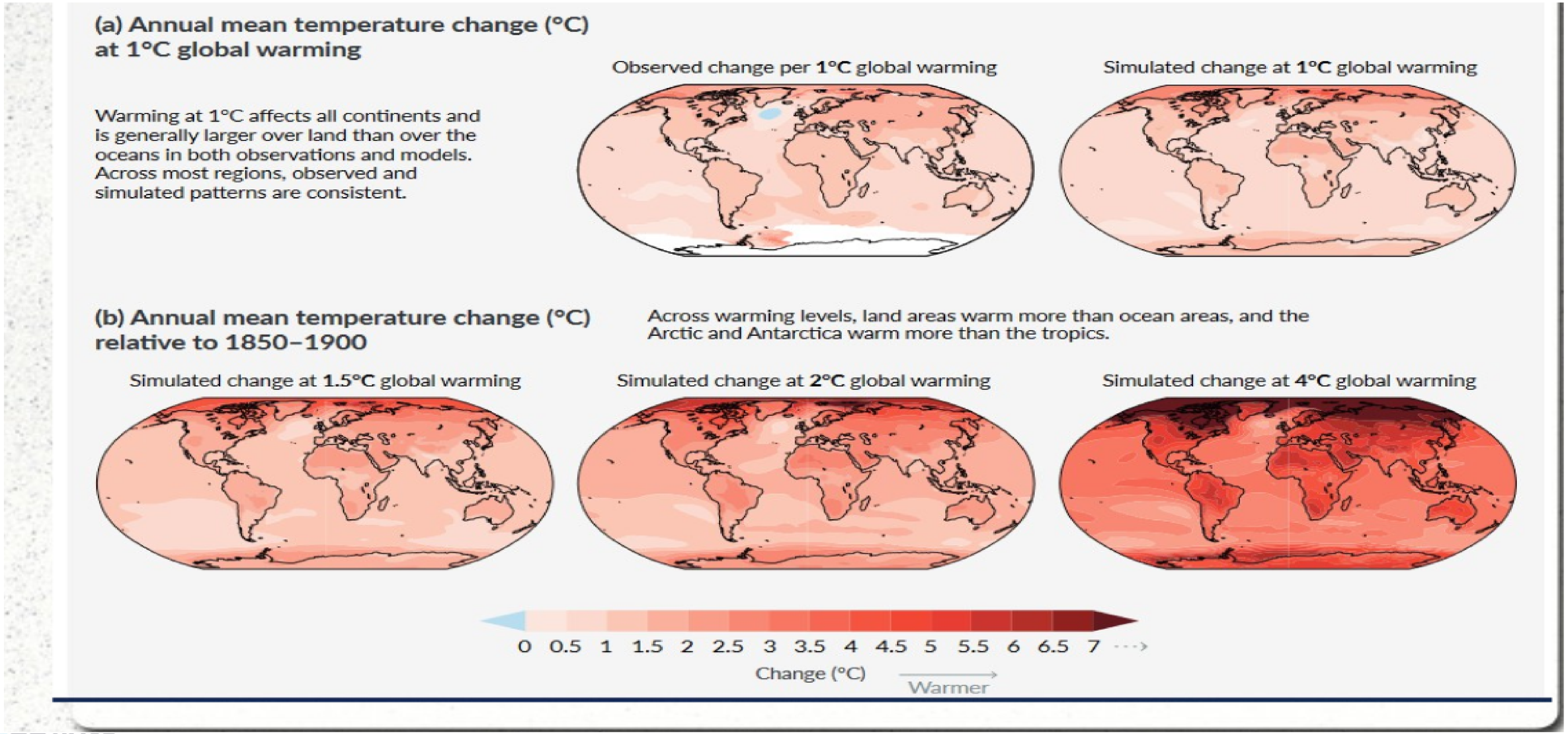
Second answer : bifurcation

- There is now a *qualitative* difference : if the force exceeds a certain threshold, the structure of the system changes

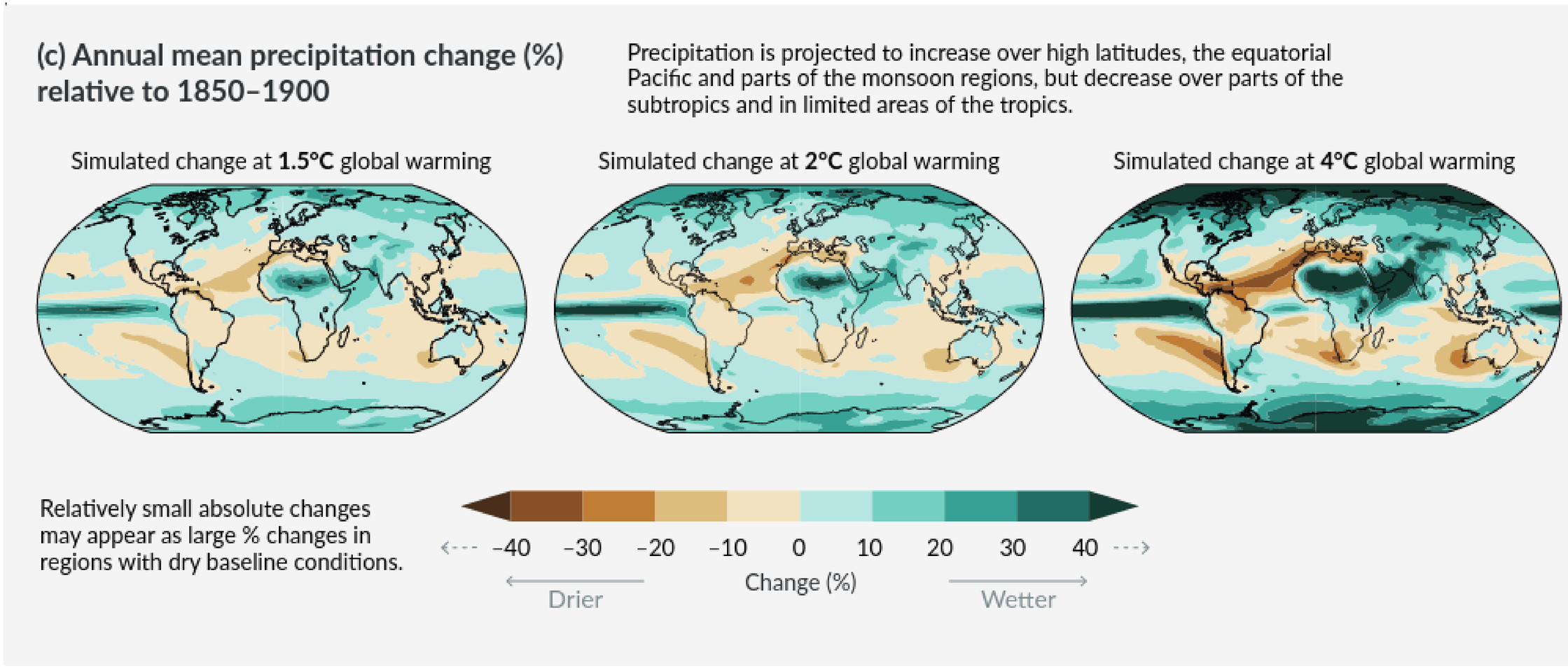
- This change is *continuous*, proportional to the distance from the threshold

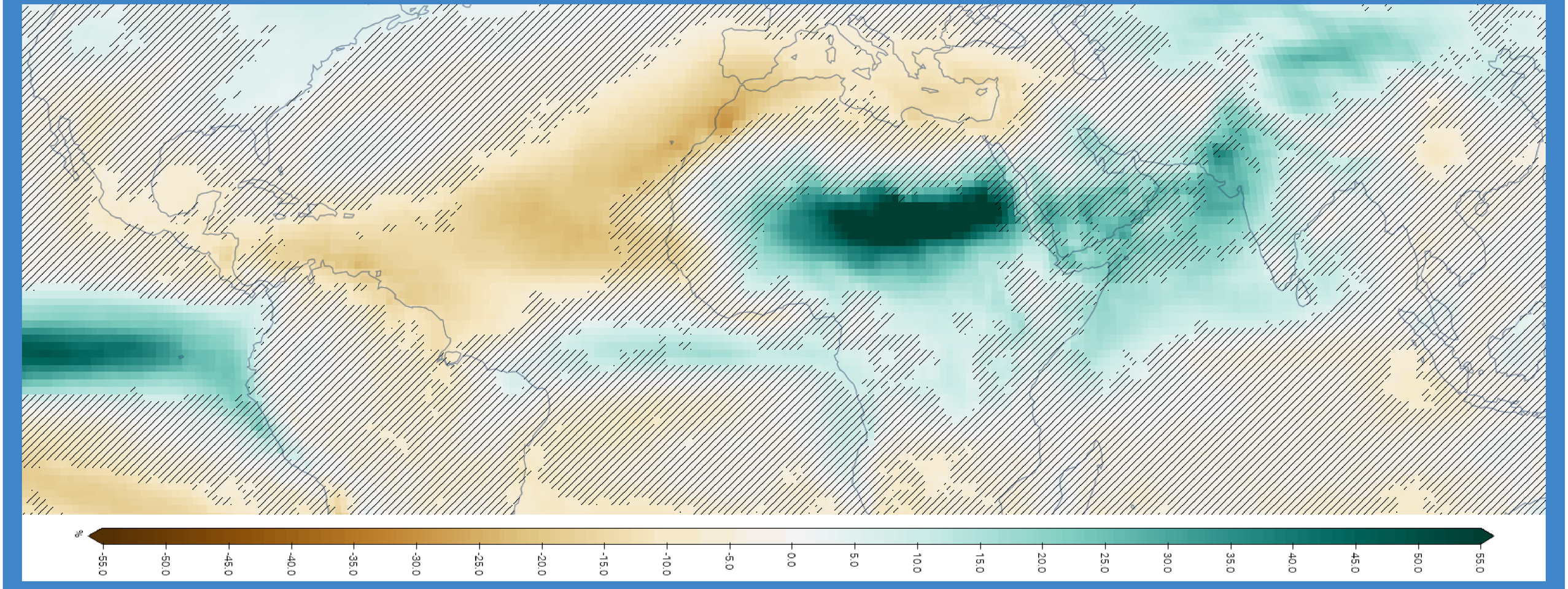
- The change is *reversible* : if we stop applying force, or if we decrease the force we apply, the beam recovers its original shape (the original equilibrium is restored)

Climate bifurcation



Climate bifurcation





Total precipitation (PR) - Change (%)
Warming 2°C (SSP5-8.5) (rel. to 1850-1900)
CMIP6 - Annual (33 models)

High agreement
Low agreement

ipcc
INTERGOVERNMENTAL PANEL ON climate change

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http://www.ipcc.ch/copyright

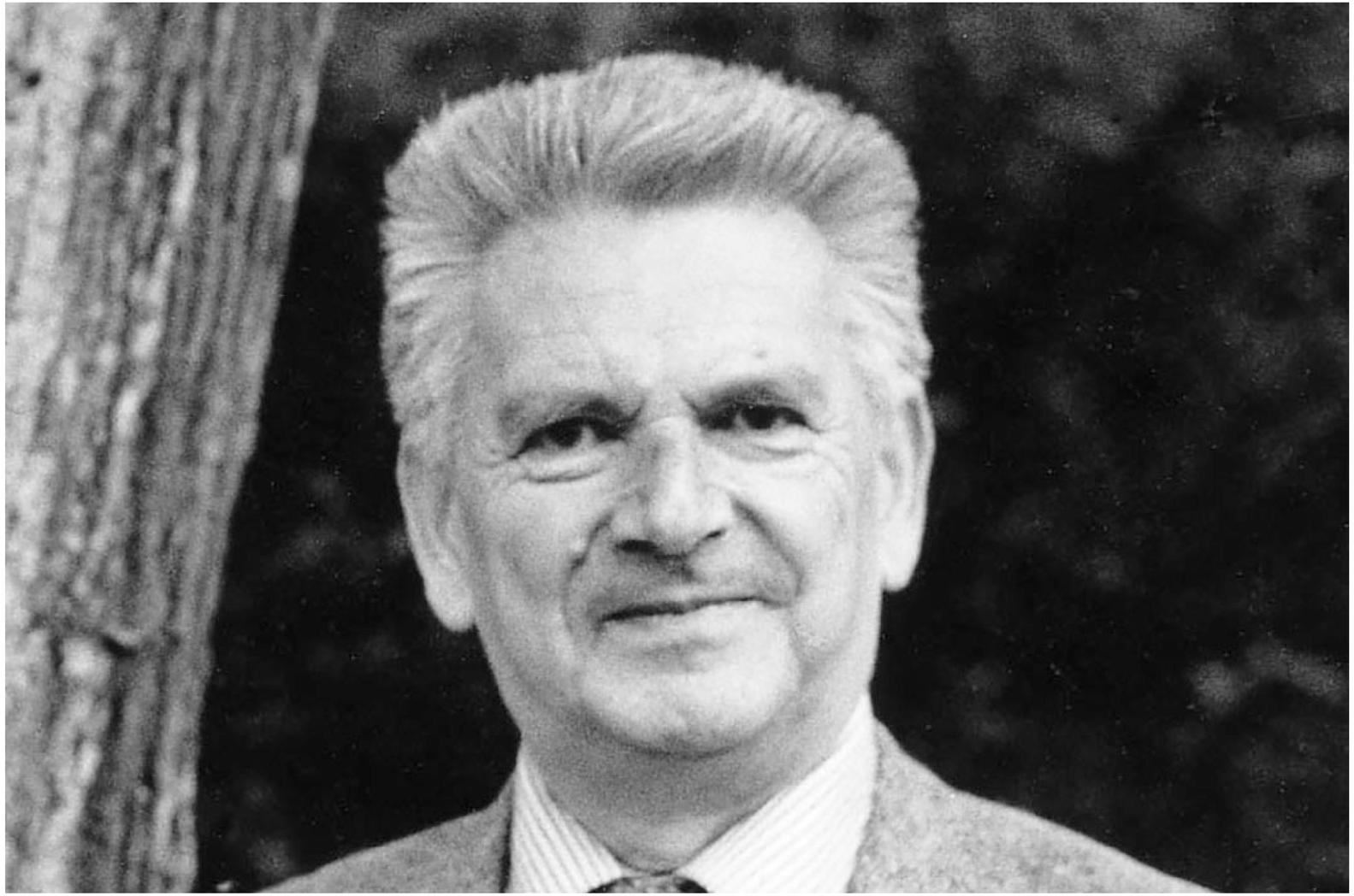
Find out what happens to your favorite region

- There is an interactive atlas on the IPCC website

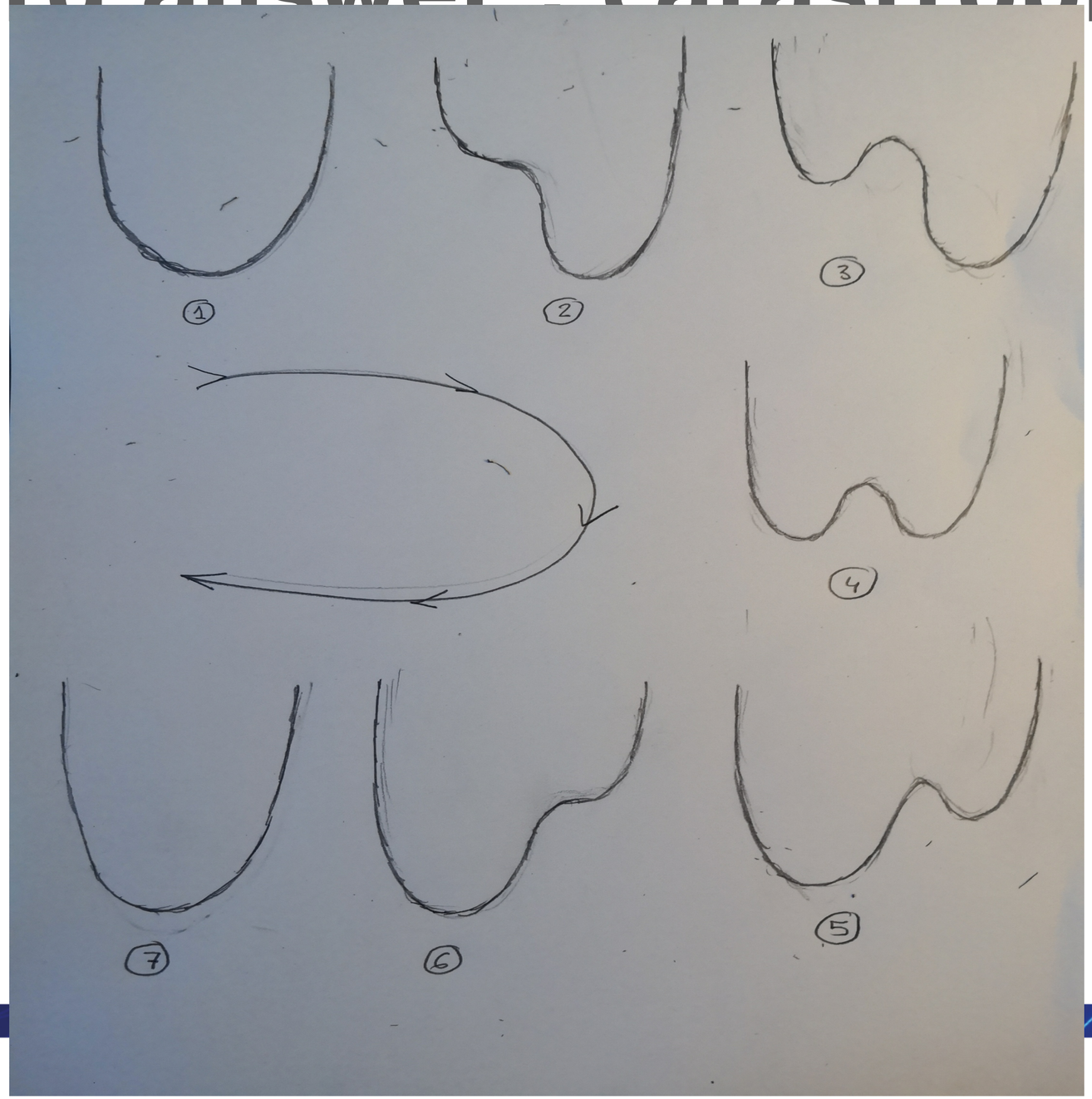
https://interactive-atlas.ipcc.ch/

Third answer : catastrophe

René Thom 1923-2002



Third answer : catastrophe



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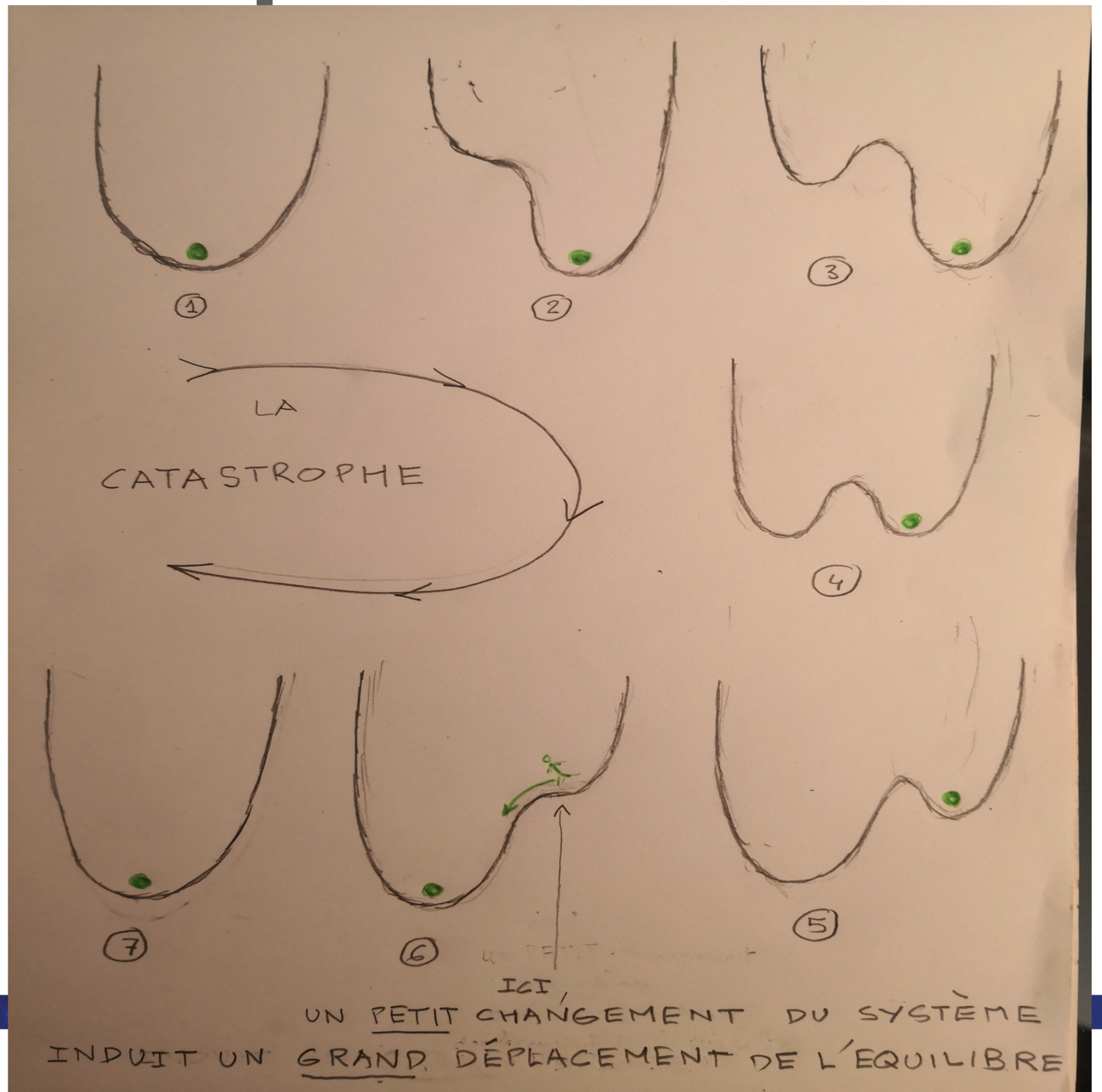
A large response to a small nudge



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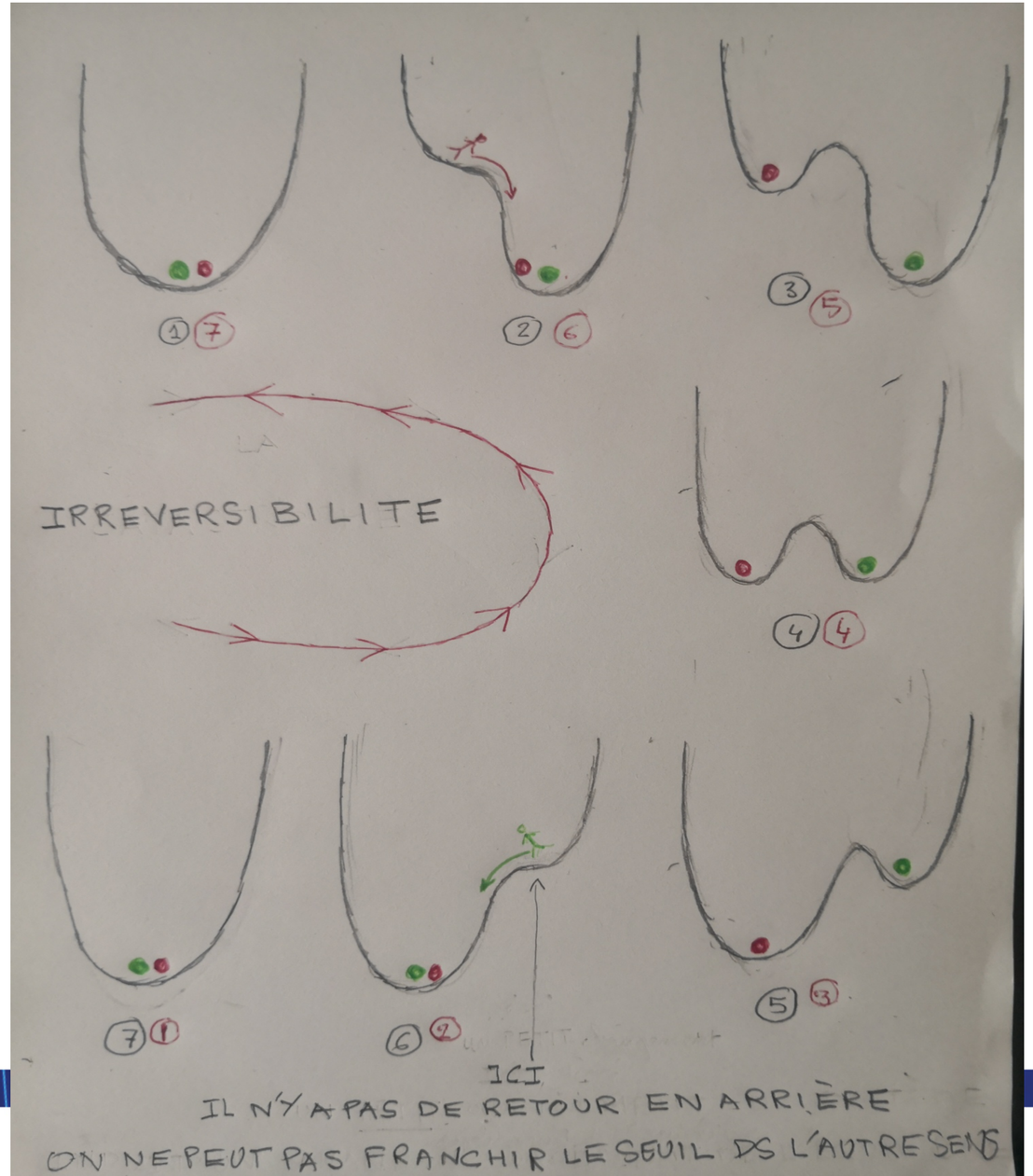
No turning back



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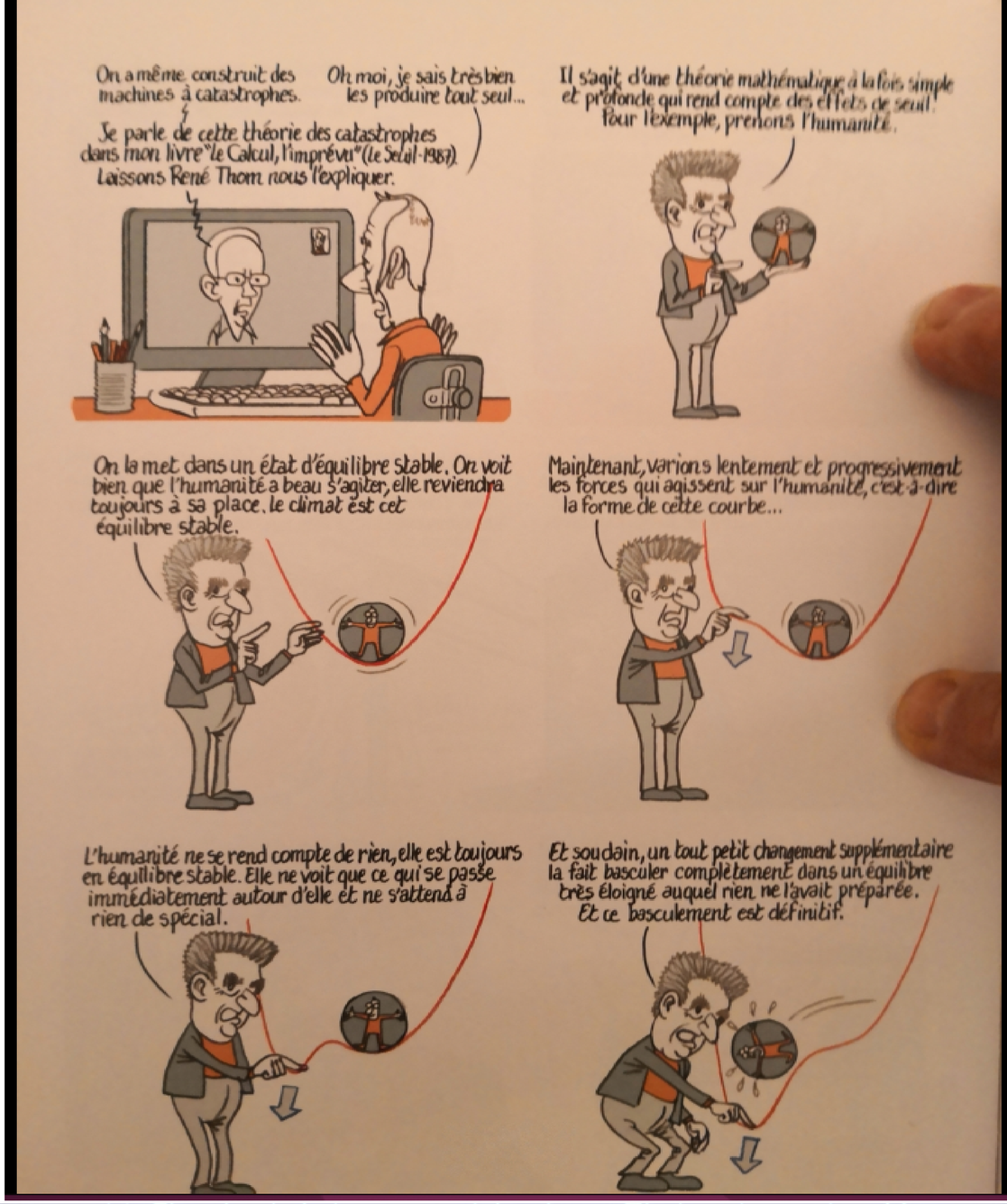
The master himself

Tiré de la BD
« *Urgence Climatique :*
il est encore temps ! »

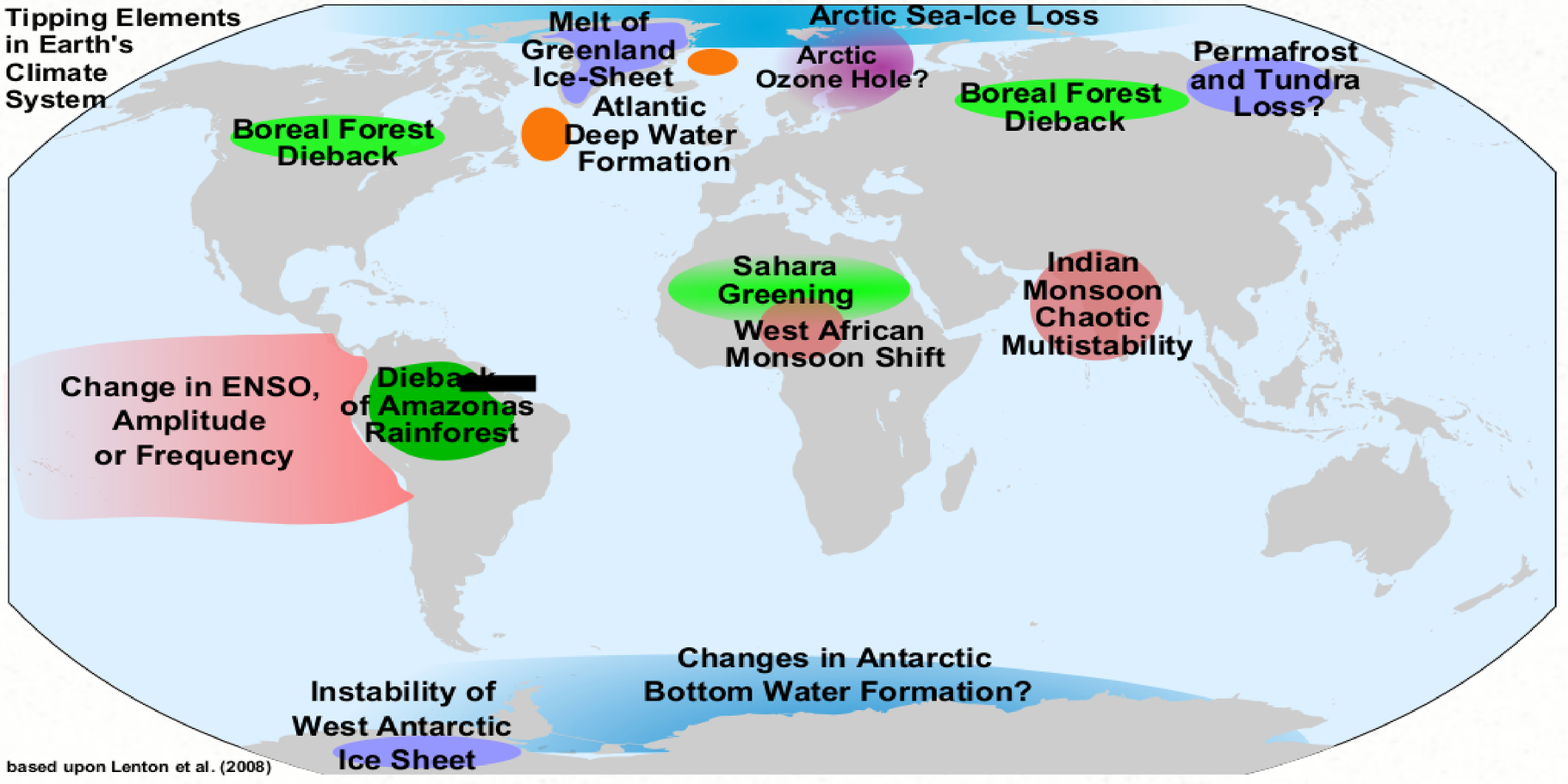
I. Ekeland et E. Lecroart



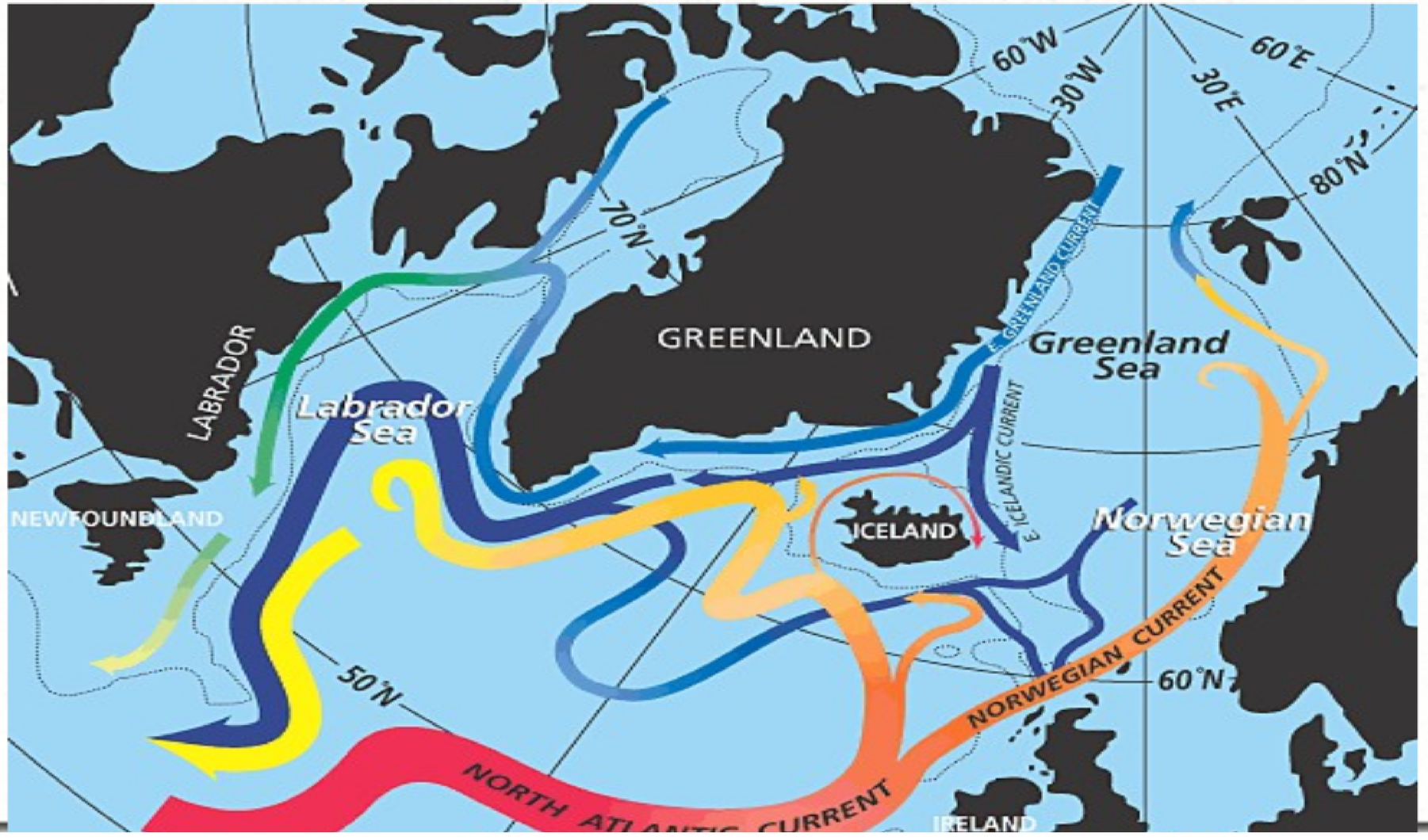
Third answer : catastrophe

- A small nudge may cause a catastrophic change : the system jumps from one equilibrium to another one far away
- The change is *irreversible* : crossing the threshold back in the other direction does not restore the former equilibrium
- There is *hysteresis* : for a given value of the input (CO2), there may be several possible equilibria. Which one prevails depends on the past history

Les seuils planétaires



Les courants Atlantique Nord



Fourth answer : the unexpected

- Throwing the dice
  - From Snorri Sturluson, The saga of Olav Haraldsson (1230)
  - Retold in Ekeland, « Au hasard » (2000)

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- The Rumsfeld classification
  - Known knowns
  - Known unknowns
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It is impossible to know all there is to know about a living being, and all the more about planet Earth l

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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

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Unpleasant surprises in the gre...
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What is to be done ?

- Fortunately, there is much to be done. This is also part of the problem, because :
- There is no simple answer to a complex problem. The answer has to be complex

The future

- Paris agreement (2015) : limit global warming to 2°C, and preferably 1,5°C by 2100
- This is 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
- So how to we do it ?

The future

- Paris agreement (2015) : limit global warming to 2°C, and preferably 1,5°C by 2100
- The economist wants a carbon tax, the engineer wants a carbon-free process of production, the agronomist wants customized fertilizers, municipalities want to restructure urban tranportation…
- But there is no simple answer to a complex problem. The answer itself has to be complex- !
- There is no silver bullet, we should do everything at once, and do it together

Prepare for the future

- This is exciting, because it is a common endeavour, with a rôle for everyone : for the economist, for the engineer, for the agronomist, for the politician, for the sociologist, for the modeller.

- Future education and research should take this new perspective into account : the future is collaborative. UM6P and Dauphine

Be humble

- However, since the system is complex, we cannot predict everything, especially in chaotic times such as these

- So we have to develop rules to act by when information fails :
  - Precautionary principle (when in doubt, abstain)
  - Personal ethics (Greta Thunberg and flyskam)

No man is an island,

Entire of itself;

Every man is a piece of the continent,

A part of the main.

If a clod be washed away by the sea,

Europe is the less,

As well as if a promontory were:

As well as if a manor of thy friend's

Or of thine own were.

Any man's death diminishes me,

Because I am involved in mankind.

And therefore never send to know for whom the bell tolls;

It tolls for thee.