The consequences of an increase of atmospheric CO_2 concentration, a global survey of our current state of knowledge

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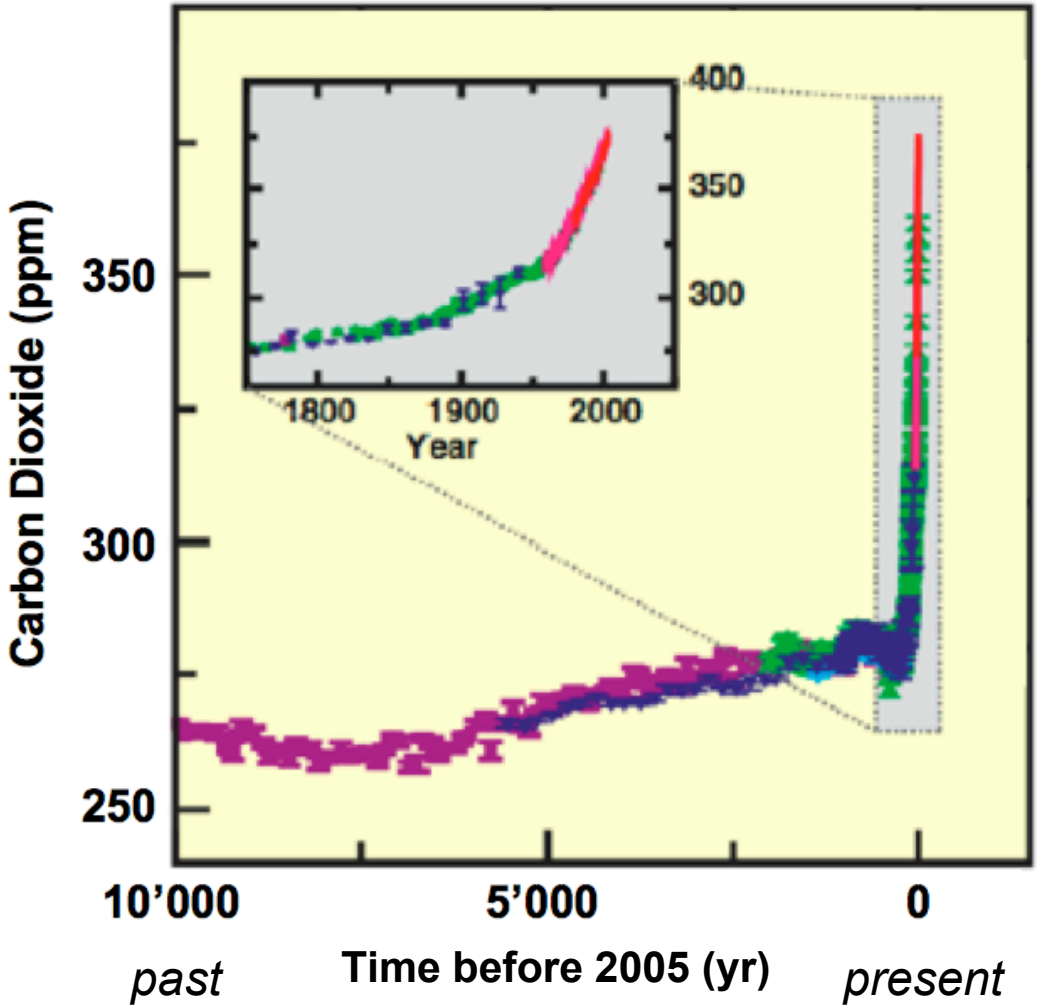
A fact : the increase of atmospheric CO_2 concentration …

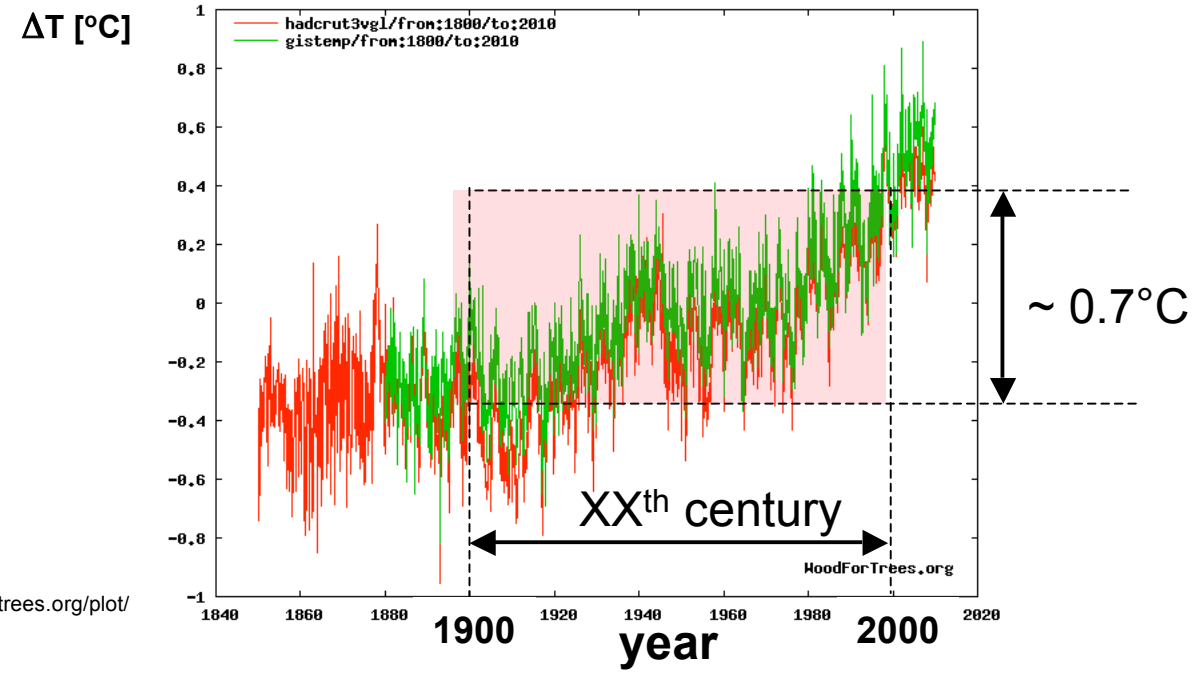
IPCC, Working Group I: The Physical Science Basis, Summary for Policymakers



http://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-1.html

… with two main consequences …

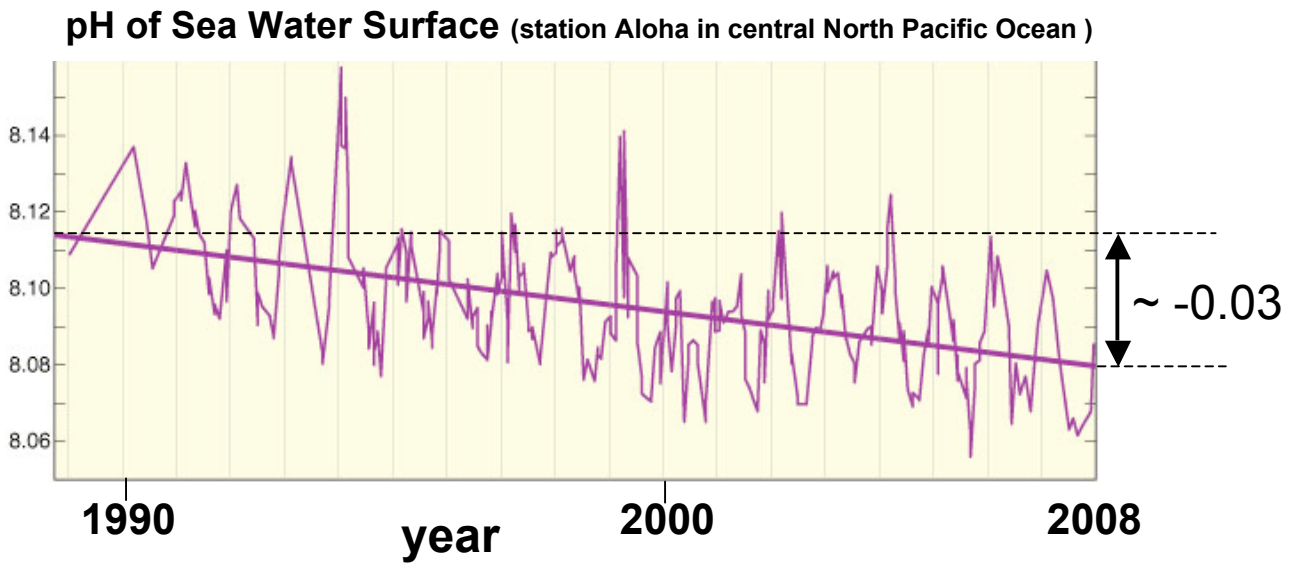
1. Temperature has increased because of greenhouse effect



http://www.woodfortrees.org/plot/

2. Ocean acidification has increased because dissolution of CO_2 in water !

   (if pH decreases, water acidity increases)

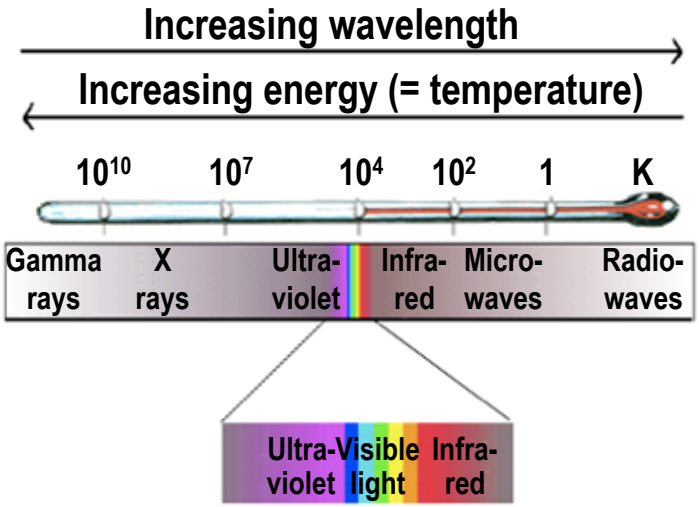


http://www.ocean-acidification.net/
http://scentofpine.org/gw101-4/

Mechanism of Greenhouse Effect ?

Electromagnetic waves and matter interact in various ways

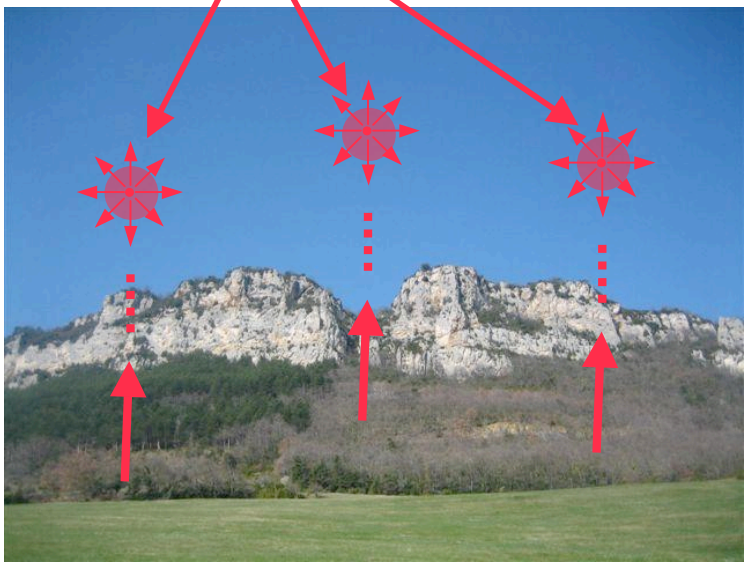
An usual example :
skin is transparent to the X-rays, but not to visible light



The atmosphere is transparent to the visible light, but only partially transparent to the infrared light

greenhouse gas molecules can absorb infrared photons

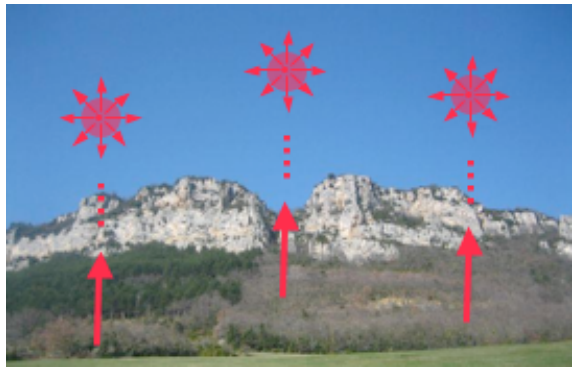
The question is :
« What happens with the energy that is absorbed ? »



What happens with the energy absorbed by CO_2 molecules ?

Usually the proposed explanation is the following :

« *This energy is reemitted by the molecules of greenhouse gas as infrared rays* ».

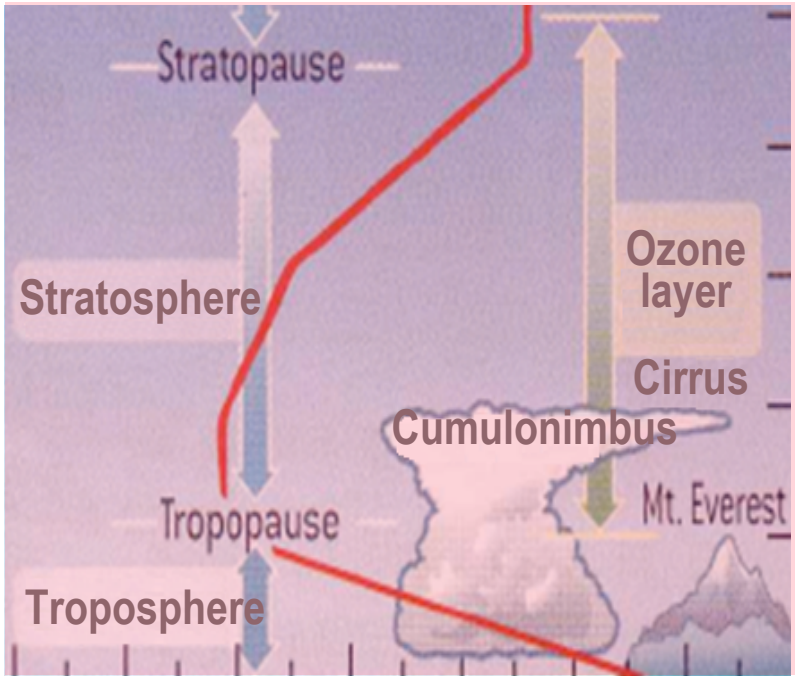


But this is not always true !

The real process depends

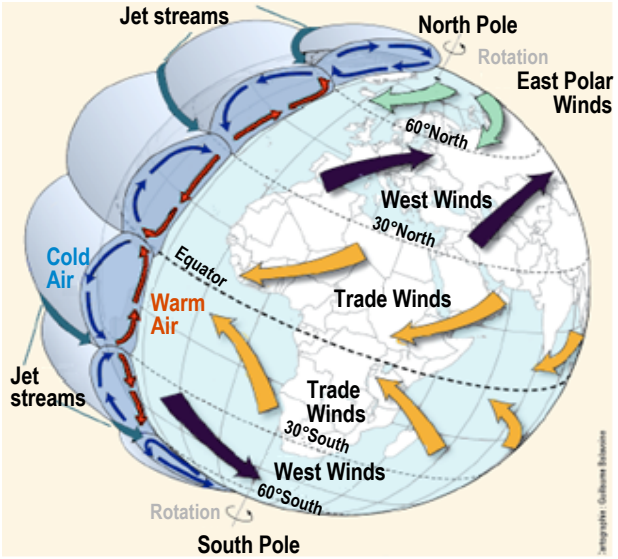
on the Local Thermodynamic Equilibrium (LTE).

Greenhouse effect : summary



In the higher atmosphere, where the air density is low, LTE does not exist :
IR absorption by greenhouse gas molecules
IR reemission of the absorbed energy
reemission of IR downwards and upwards

LTE is good : IR absorption, direct energy transformation **into heat** (with limited IR emission), collisions arise before the IR reemission



http://www.sauvonsleclimat.org/new/spip/spip.php?auteur32

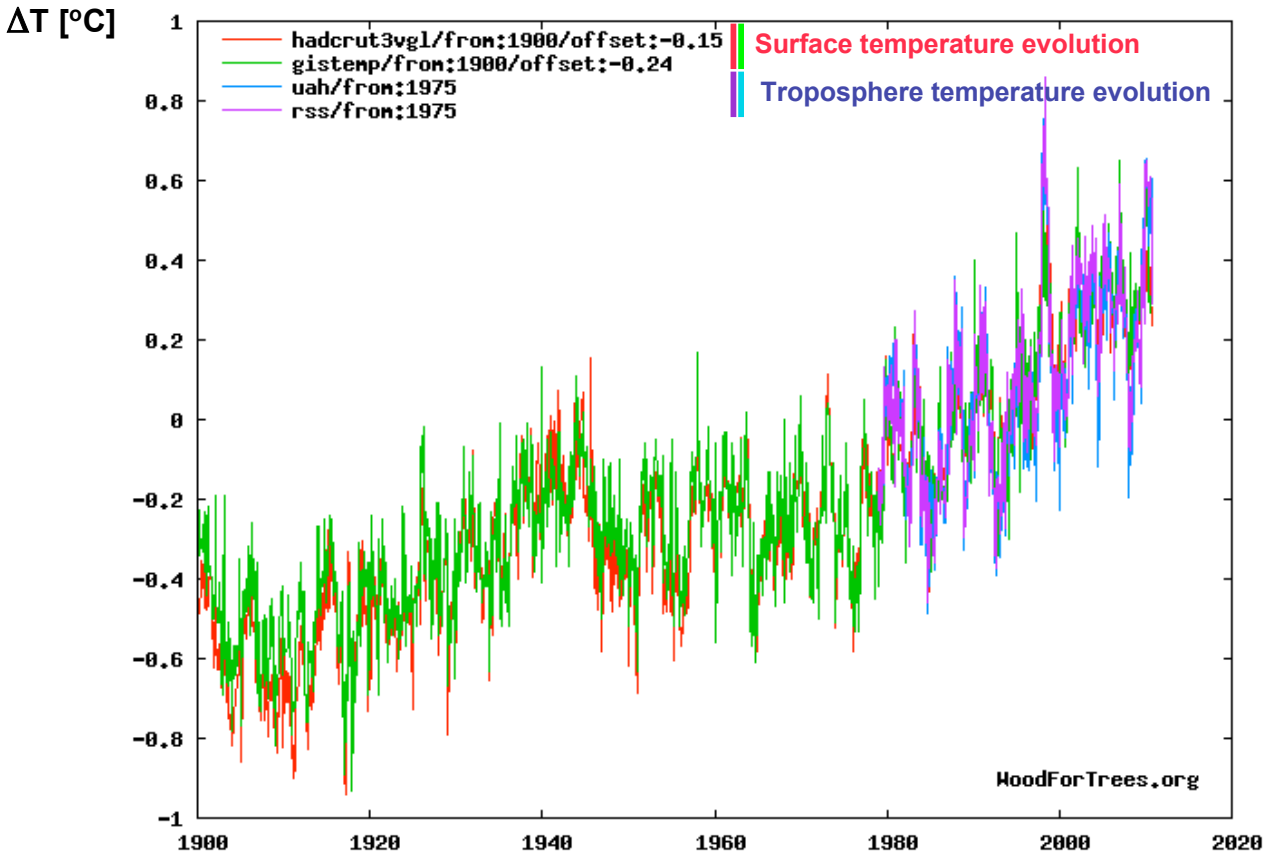
What happens with this heat ?

In the troposphere, the strong convective atmospheric circulations transfer part of the thermal energy downwards to the surface of the Earth,

- with adiabatic compression that increases the temperature of the downward air,
- and with transfer of energy to the higher latitude.

Consequence of greenhouse effect : increase of the troposphere and surface temperatures

- Temperature increase from 1900 to 2010 :



http://www.woodfortrees.org/plot/

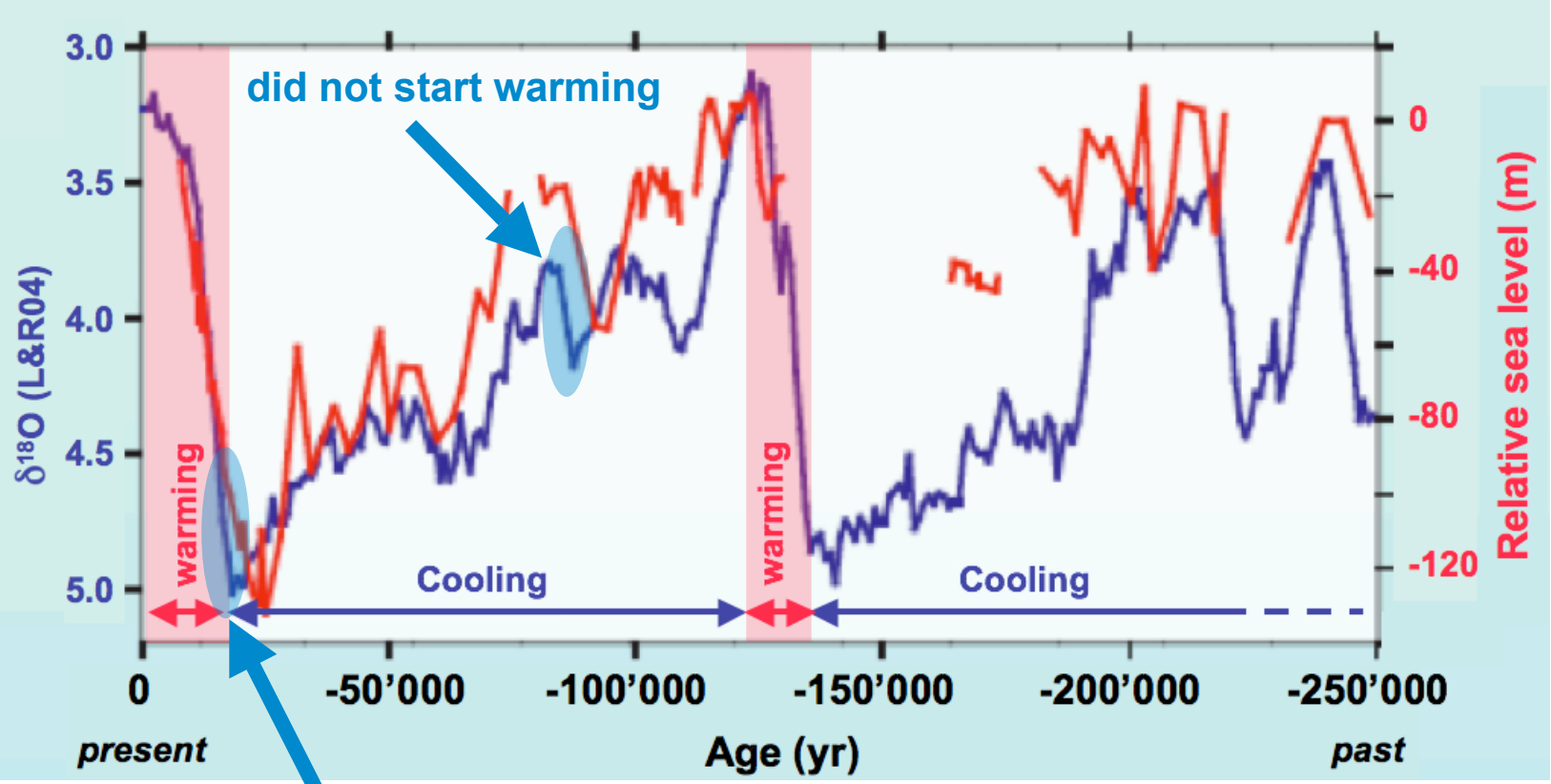
Is this increase of temperature a serious problem ?

- The increase of temperature entails a rise of the ocean level !

Things that can be learnt from the past

- The greenhouse effect played a major role in the past !

Blue curve is an indicator of temperature **Red curve is the level of ocean**

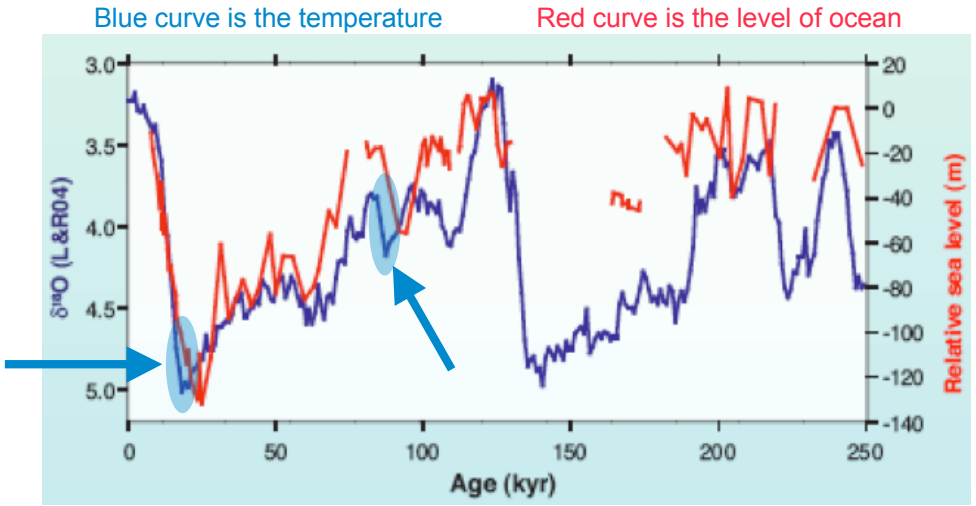


Why ?

Reference: **The Last Glaciation Termination**
G.H. Denton, and al.
Science 328, 1652 (2010)

Things that can be learnt from the past

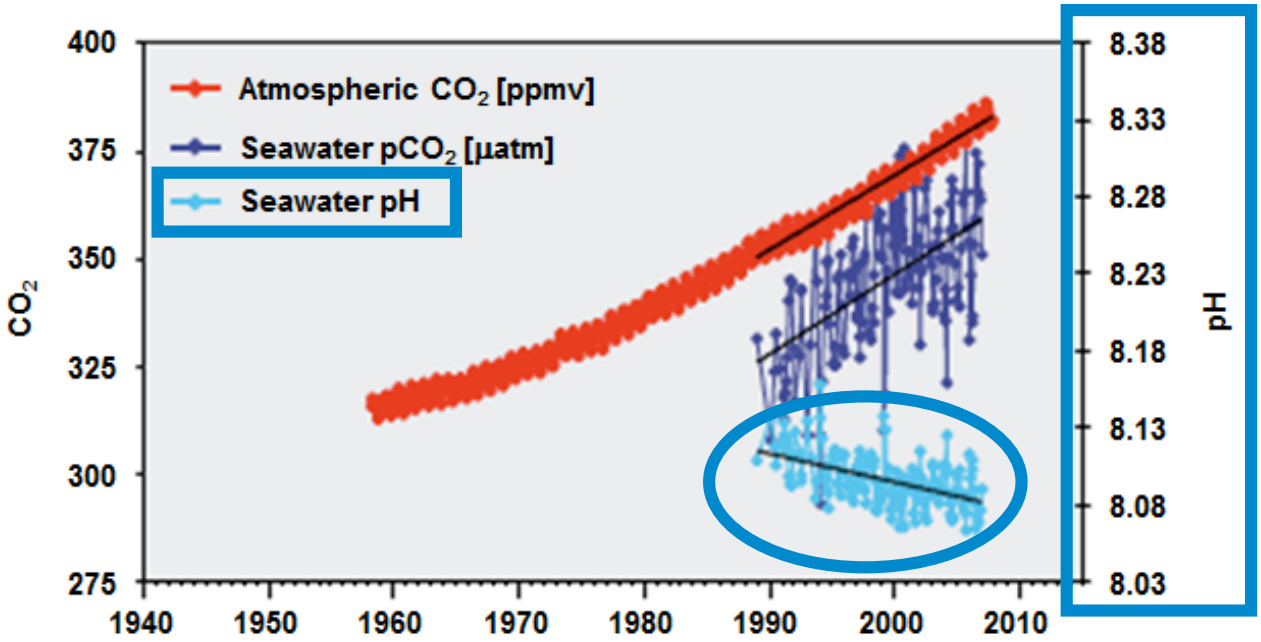
- The increase of solar radiation is not sufficient to trigger an interglacial period; the northern hemisphere must in addition be covered with a significant thickness of ice.
- With the increase of solar energy, this ice melts.
- This melting is significant enough to disrupt ocean currents.
- This induces a mixing of the waters and in the southern hemisphere there is water that goes up and that releases large amounts of CO_2 in the atmosphere.
- **The greenhouse effect (because CO_2 released) amplifies the initial warming due to the solar radiation increase !**



Reference :
The Last Glaciation Termination
G.H. Denton, and al.
Science 328, 1652 (2010);
DOI: 10.1126/Science.1184119

Acidification of the oceans

- The average pH of surface water is currently about 8.05.
- It has decreased by 0.1 since the beginning of the industrial era.
- This decline is 100 times faster than any change that the marine organisms had to withstand for at least 20 million years.



A Summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World
www.ocean-acidification.net

Dissolved CO_2 is responsable of ocean acidification

- The CO_2 dissolves in the water (with pH decrease) :

  $CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^-$

  H^+ ↗ acidity ↗

- the bicarbonate ion HCO_3^- decomposes in the water :

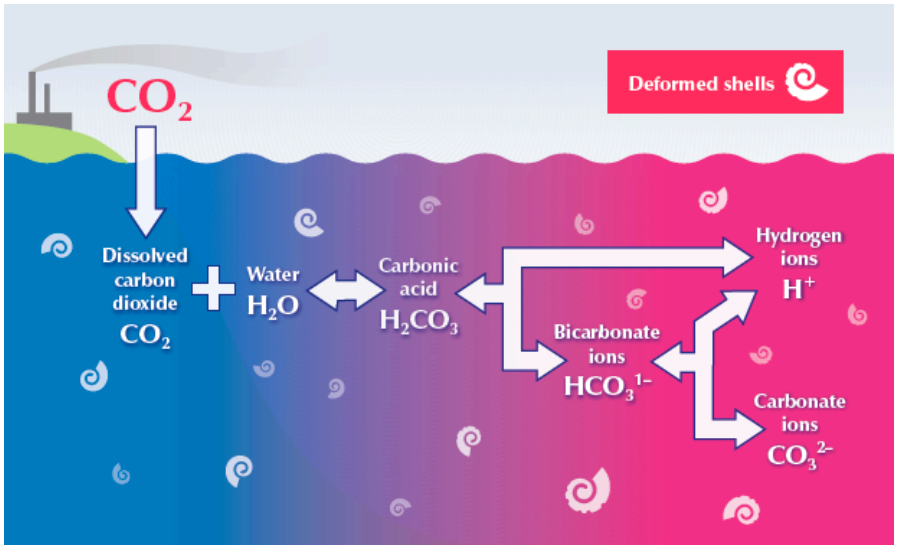
  $HCO_3^- \Leftrightarrow H^+ + CO_3^{2-}$

  if H^+ ↗ then HCO_3^- ↗ and CO_3^{2-} ↘

- $CaCO_3$ dissolves in the water and react with H^+ :

  $CaCO_3 \Leftrightarrow Ca^{2+} + CO_3^{2-}$ if CO_3^{2-} ↘ then $CaCO_3$ dissolves !

  $CaCO_3 + H^+ \Leftrightarrow Ca^{2+} + HCO_3^-$ if H^+ ↗ then $CaCO_3$ decomposes into ions !



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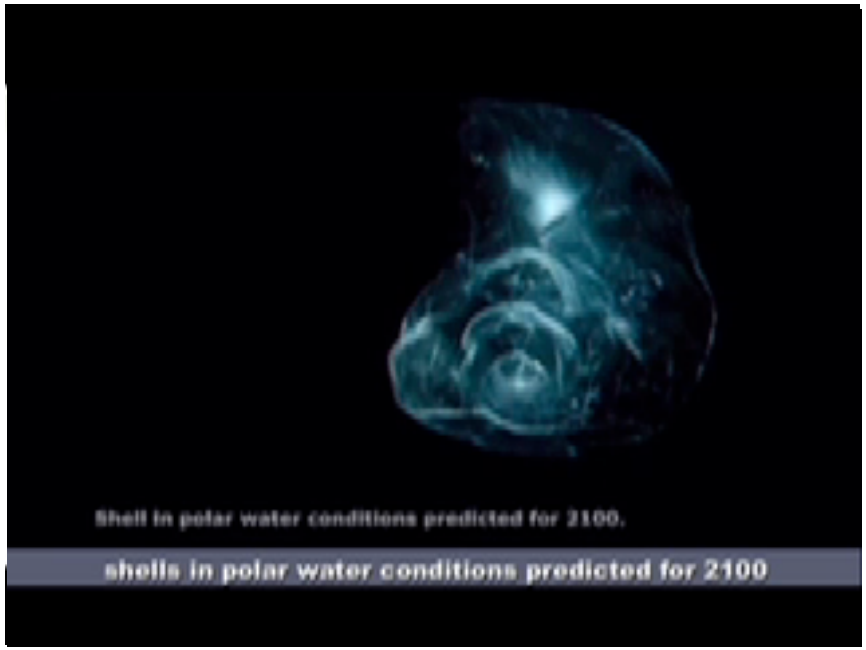
Is this increase of ocean acidification a serious problem ?

- It could have important consequences on shells !
- If the concentration of CO_3^{2-} decreases below 66 µmoles per kg, water is no more saturated in aragonite that, thus, becomes soluble in water (limestone has 2 differents crystalline forms : aragonite and calcite).
- Aragonite is found in the shells of most molluscs and free-swimming pteropods (small planktonic snails).

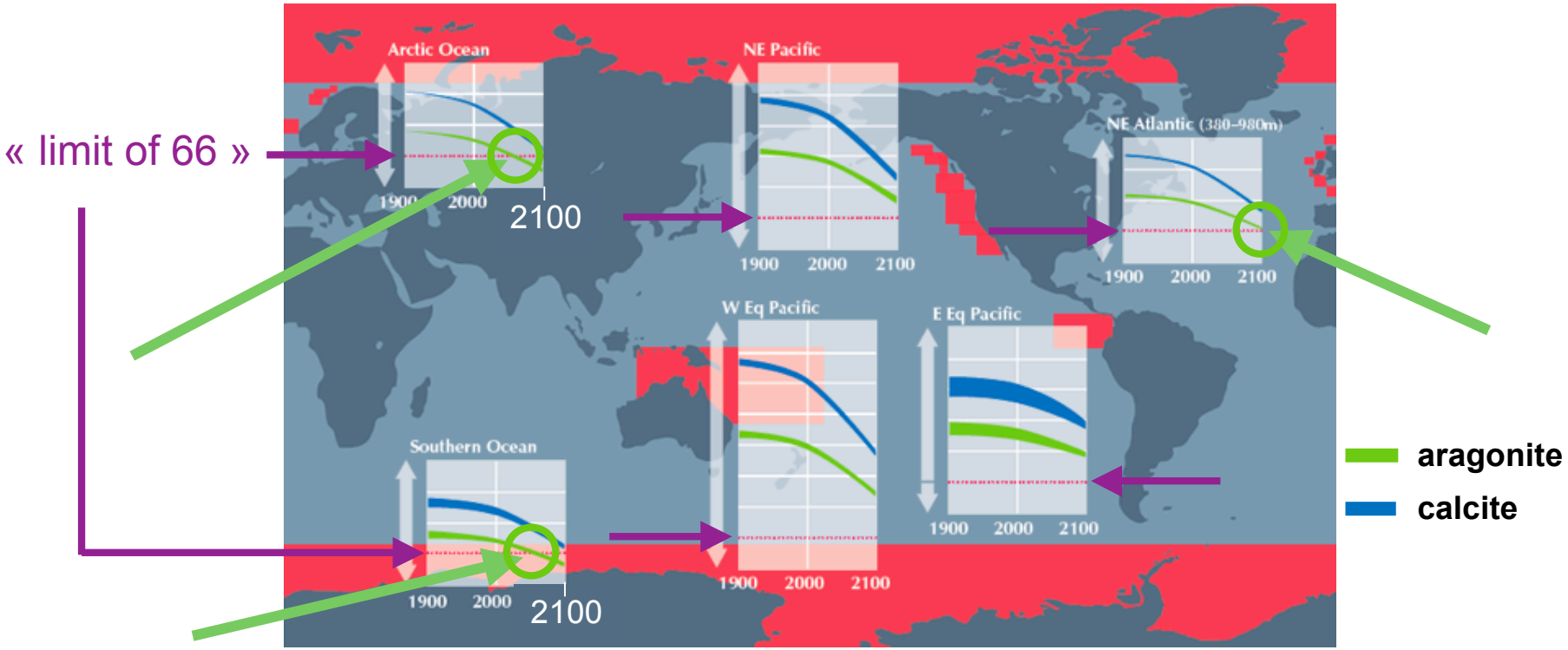
Example : Pteropod artic *Limacina helicina* - food for whale (size about 1 cm)



Source: ACID TEST, the global challenge of ocean acidification
A Naturel Resources Defence Council Production

Predictions for the 21st century

- If the acidity level continues to increase with the same rate, this limit of 66 µmoles/kg may well be reached before the end of the 21st century.
- And thus could cause the disappearance of the pteropods.
- This disappearance could have dramatic consequences for all animals that feed on these micro-organisms (some species of zooplankton, salmon, herring, mackerel, whales, etc.).

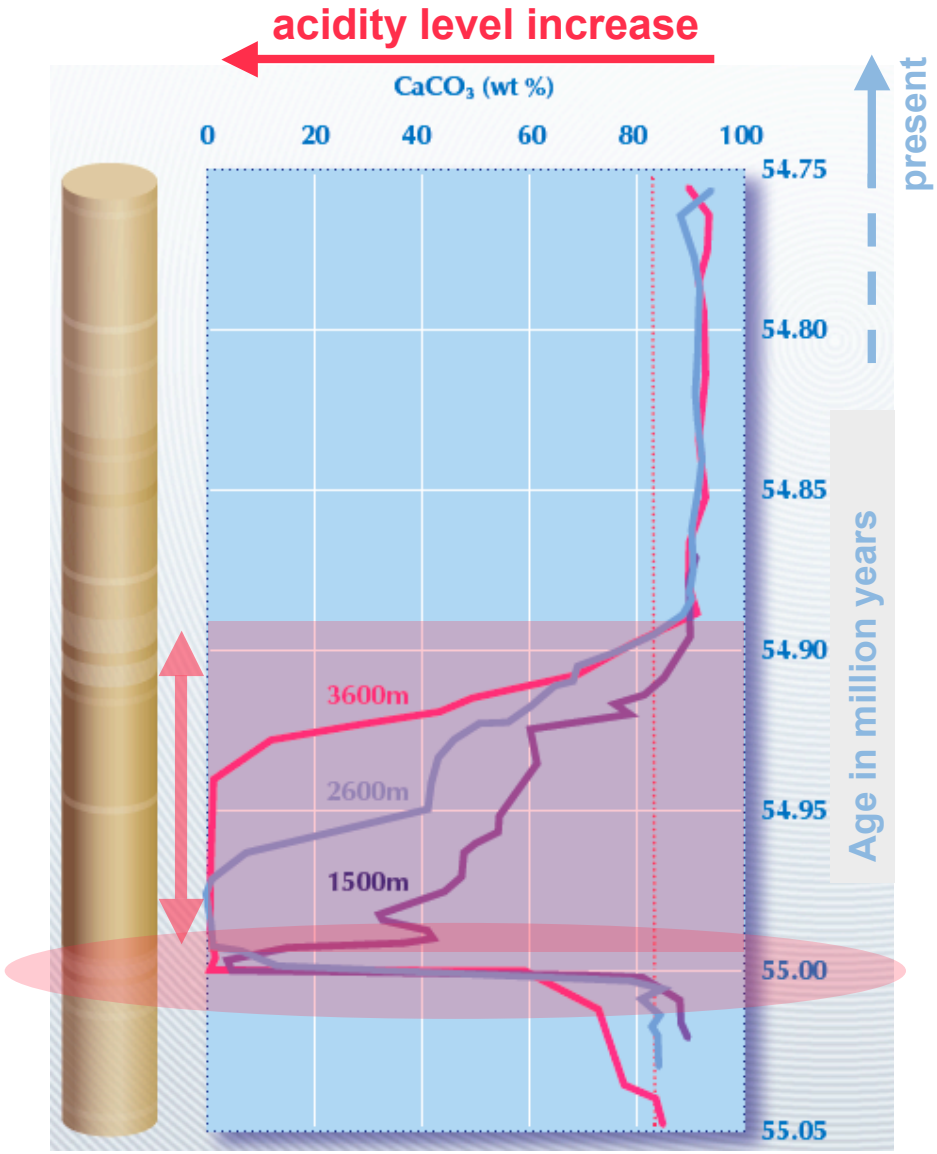


A Summary for Policymakers from the Second Symposium on the Ocean in a High-CO_2 World
www.ocean-acidification.net

Things that can be learnt from the past

- Fifty-five million years ago, the acidity level increased very quickly (in a few hundreds of years only).
- The oceans required then approximately 100'000 years to come back to the previous conditions :

resulting in a major extinction of living species !



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www.ocean-acidification.net

What can we do and how ?

- To comply with the **precautionary principle**, if nothing else, we have to decrease our CO_2 emissions ! … But how ? …

We want to decrease this value !

This requires to decrease this product

$$CO_2 = \frac{CO_2}{energy} \cdot \frac{energy}{GDP} \cdot \frac{GDP}{population} \cdot population$$

CO_2 content of the consumed energy; it can be decreased by - fuel switching - renewable energy - sequestration of carbon - rational use of energy - …	Indicator of the energy intensity of economy; it decreased of ~30% during the last 35 years	Indicator of the economic growth (production per person); it should grow, at least in developing countries	The world population will continue to increase, at least during a few decades

Engineers have a fundamental role to play in these 2 fields !

http://fr.wikipedia.org/wiki/Équation_de_Kaya

« We live in an extraordinarily challenging time – a time when we have learned to walk on the moon, but not yet how to walk on the earth »

William S. Becker, Colorado Energy Research Institute at the Colorado School of Mines

(Presentation to the 2nd Annual Intelligent Green & Energy Efficient Buildings Conference & Expo, March 29, 2006, Beijing, China)

Thank’s for you attention !

« Earthrise», 29/12/68, Apollo 8, NASA