

# **Ocean Acidification:**

## **Are we approaching dangerous greenhouse gas concentrations?**

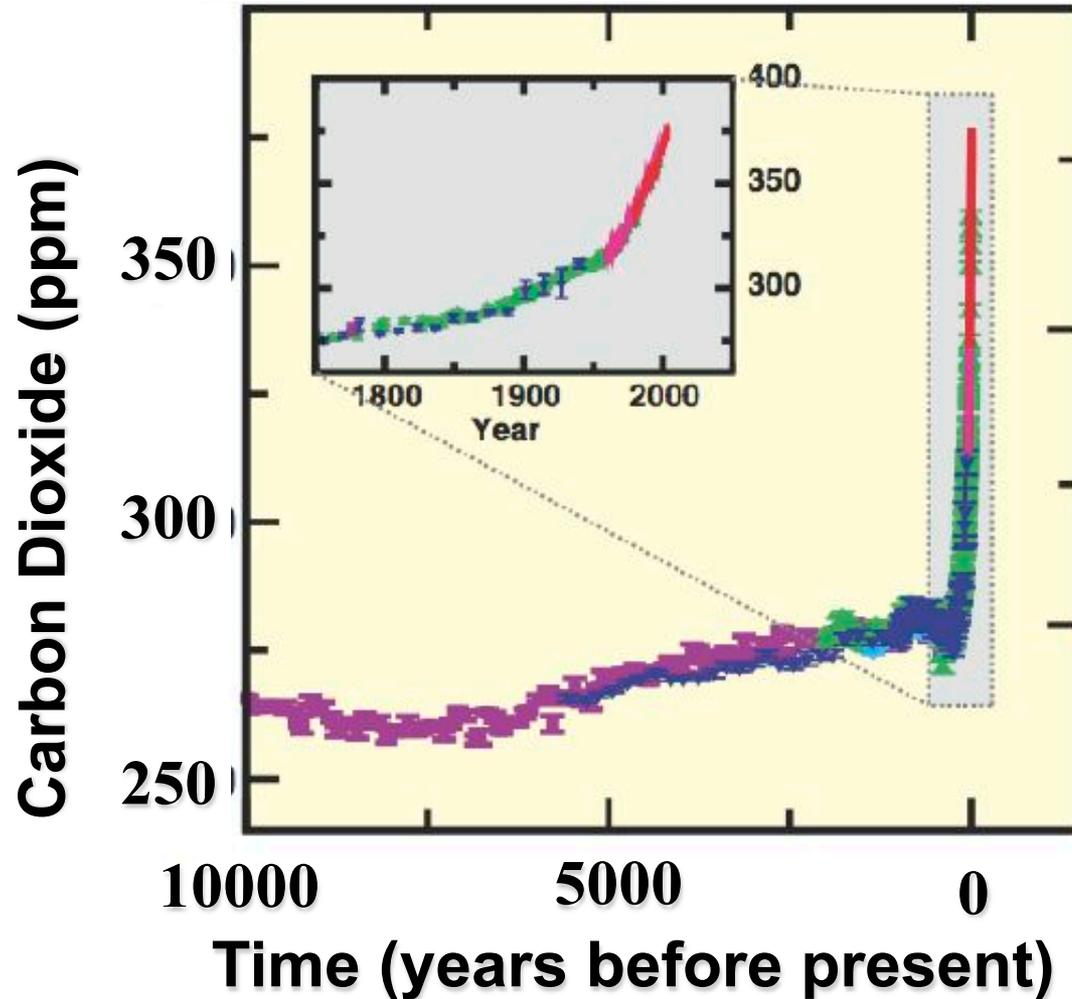
**Fortunat Joos**

Climate and Environmental Physics,  
Physics Institute, University of Bern  
[www.climate.unibe.ch/~joos](http://www.climate.unibe.ch/~joos)

**Thanks to T. Frölicher, G.-K. Plattner, R. Spahni, and  
M. Steinacher,**

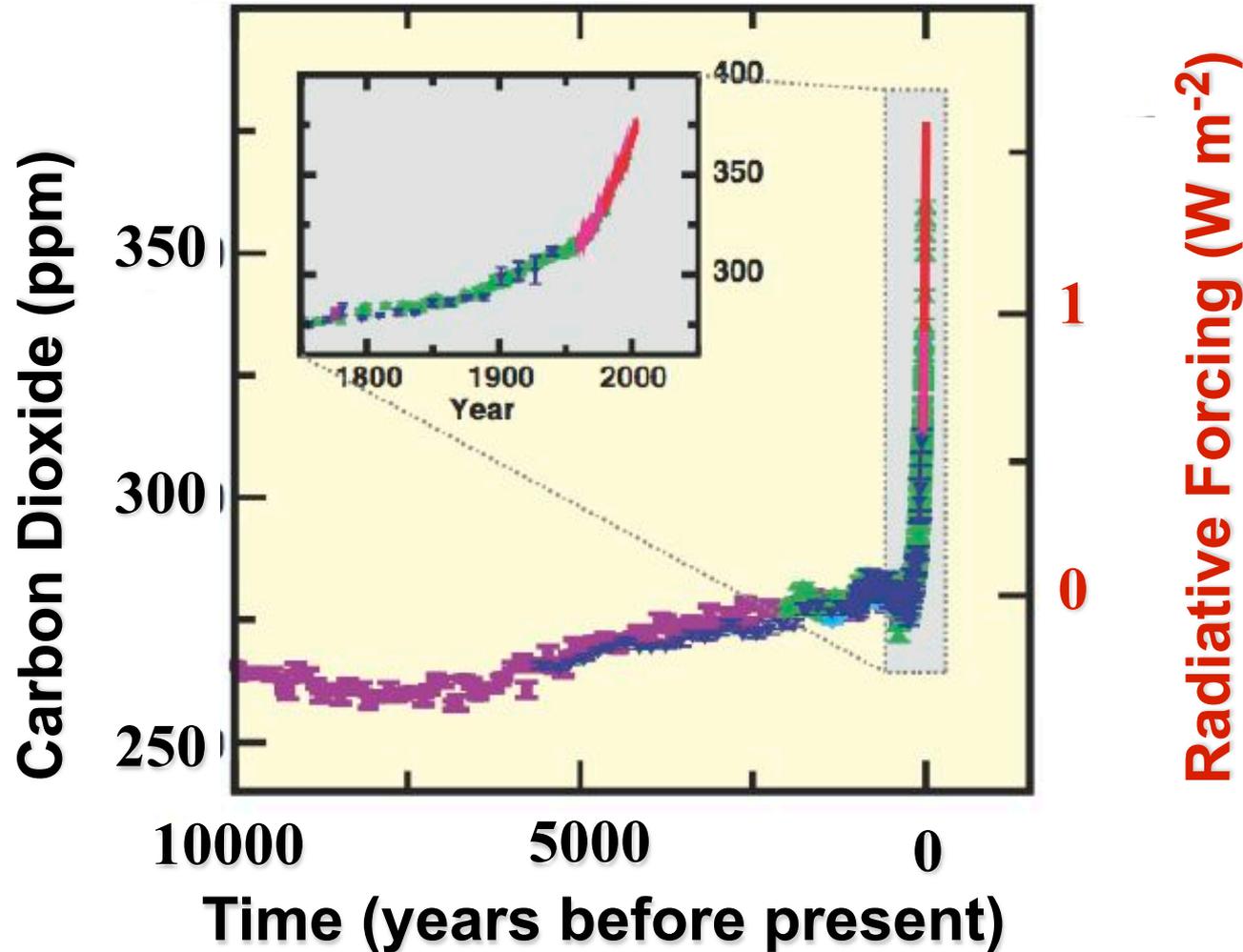
# Atmospheric CO<sub>2</sub> is rising and far above the preindustrial range

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(IPCC, 2007, Fig. SPM-1a)

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# Outline

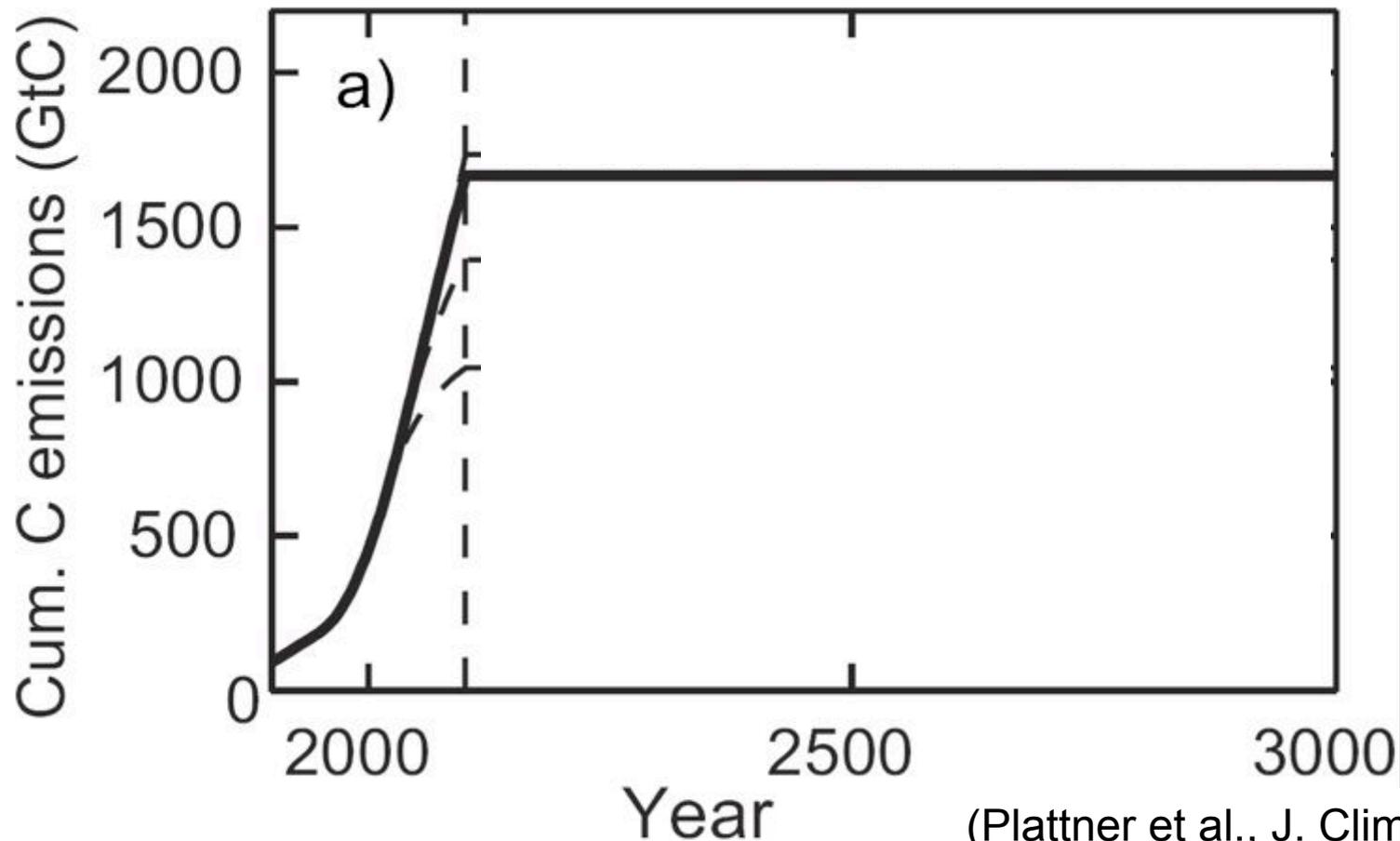
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- 1) The human climate perturbation persists for millennia**
- 2) Man-made change is progressing at high speed**
- 3) Ocean Acidification: A deterioration of living conditions for corals and marine organisms**
- 4) The way forward**

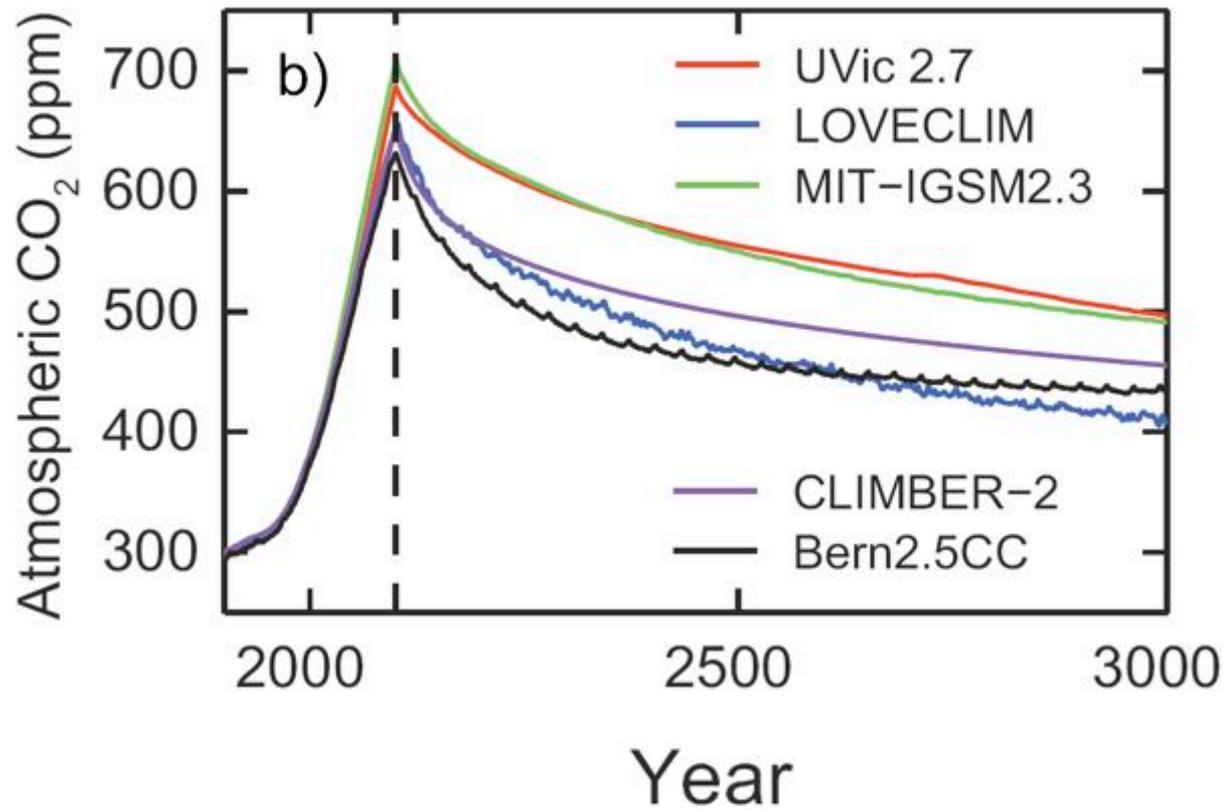
**1) Models and system understanding:  
current carbon emissions will affect the climate for many millennia**

# An illustrative climate model experiment:

- Business as Usual until 2100
- Stop all emissions in 2100

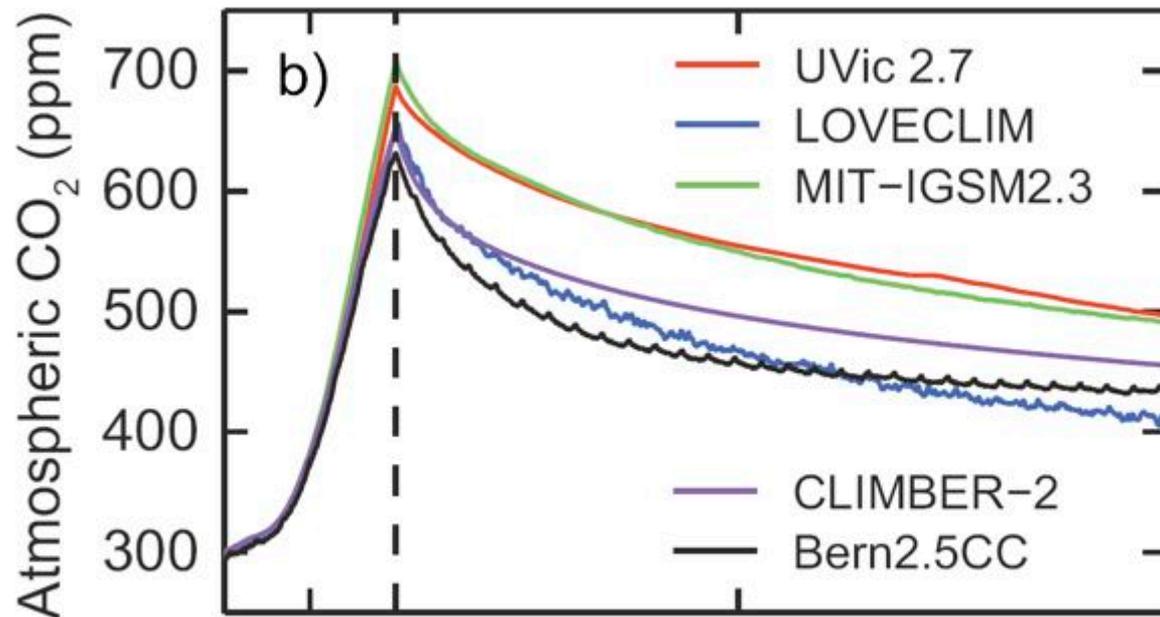


(Plattner et al., J. Clim, 2008)

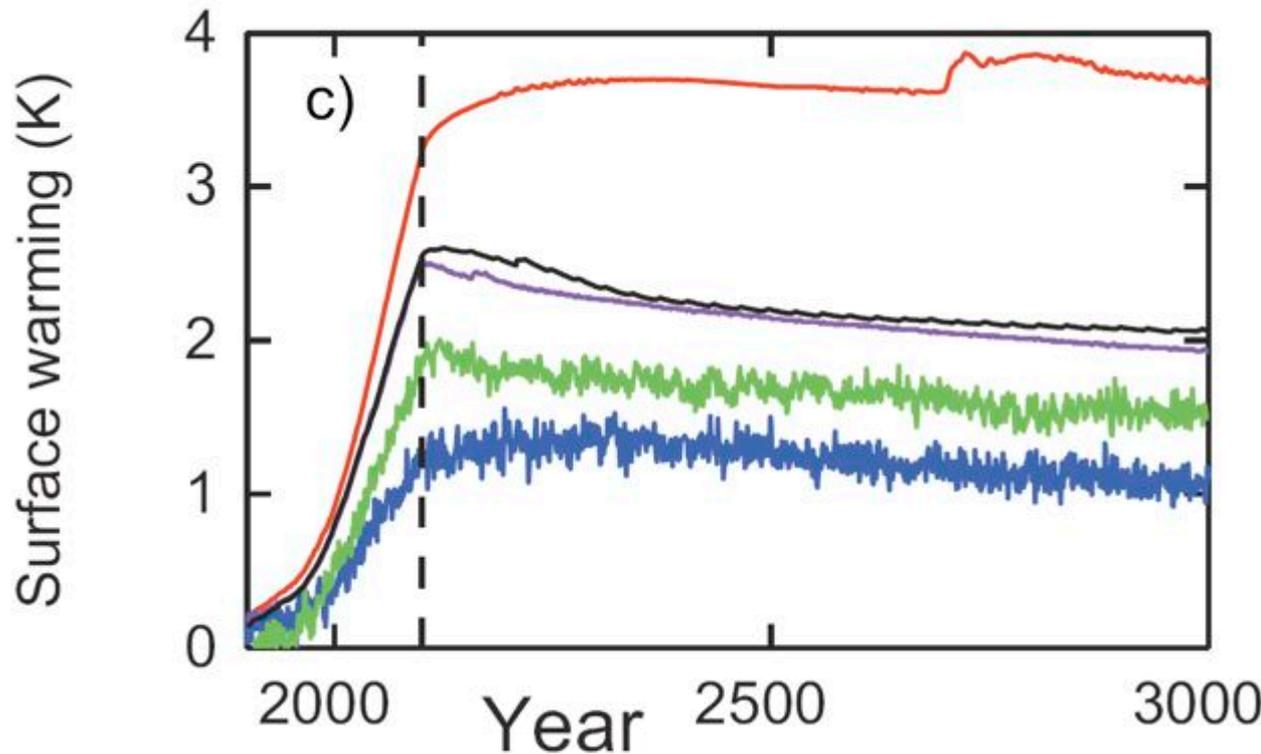


... and  
atmospheric CO<sub>2</sub>  
from a range of  
models

(Plattner et al., J. Clim, 2008,  
IPCC, WGI, Fig TS31)



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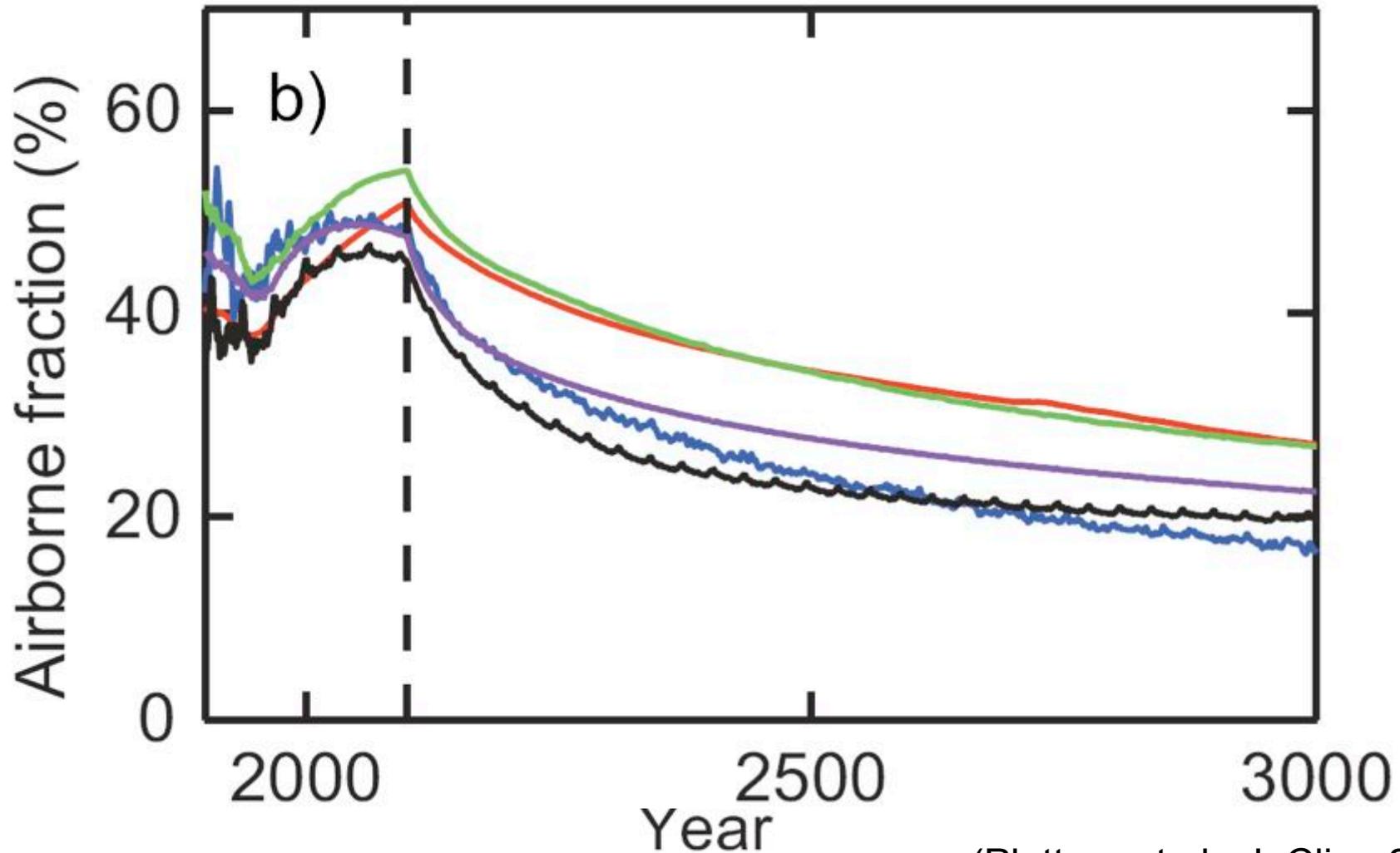


... and surface  
warming

(Plattner et al., J. Clim, 2008,  
IPCC, WGI, Fig TS31)

# A large fraction of carbon emissions remains in the atmosphere for millennia

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(Plattner et al., J. Clim, 2008)

**Today's and 21th century  
carbon emission will affect the  
climate system for many  
millenia**

## **2) What about rates of change?**

**Rates of climate change co-determine severity of impacts on socio-economic and natural systems**

**Proxy data of past temperature are uncertain  
and sparse**

**but**

**accurate records of past greenhouse gas  
concentrations, forcing climate to change,  
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**accurate records of past greenhouse gas concentrations, forcing climate to change, available**

**Ice core data:**

**-> Need to take into account smoothing of signals during enclosure process of air into firn and ice**

**Compare different gases and agents:**

**-> radiative forcing**

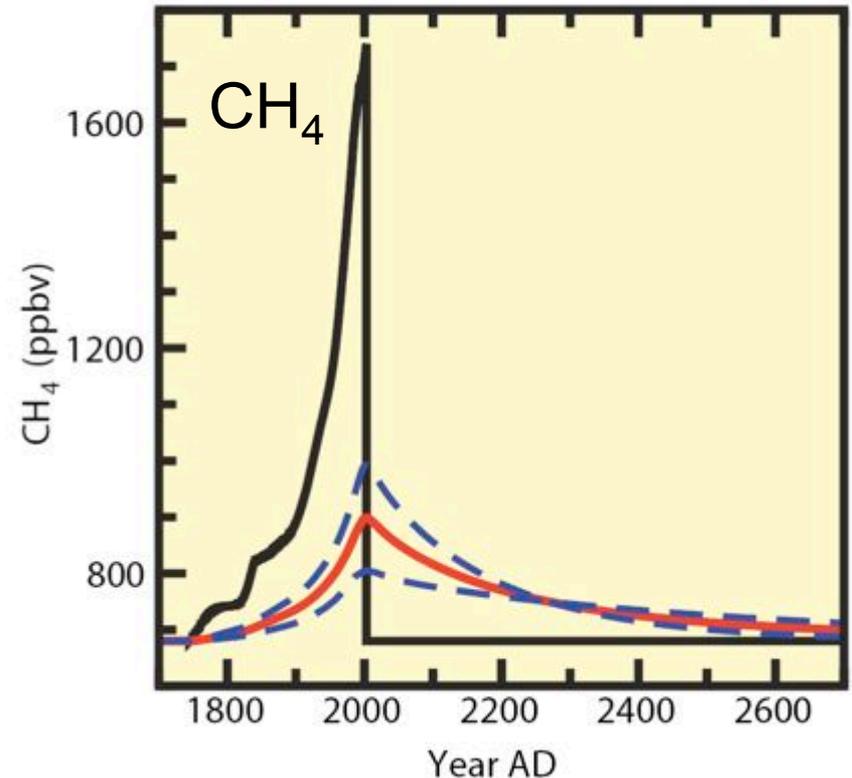
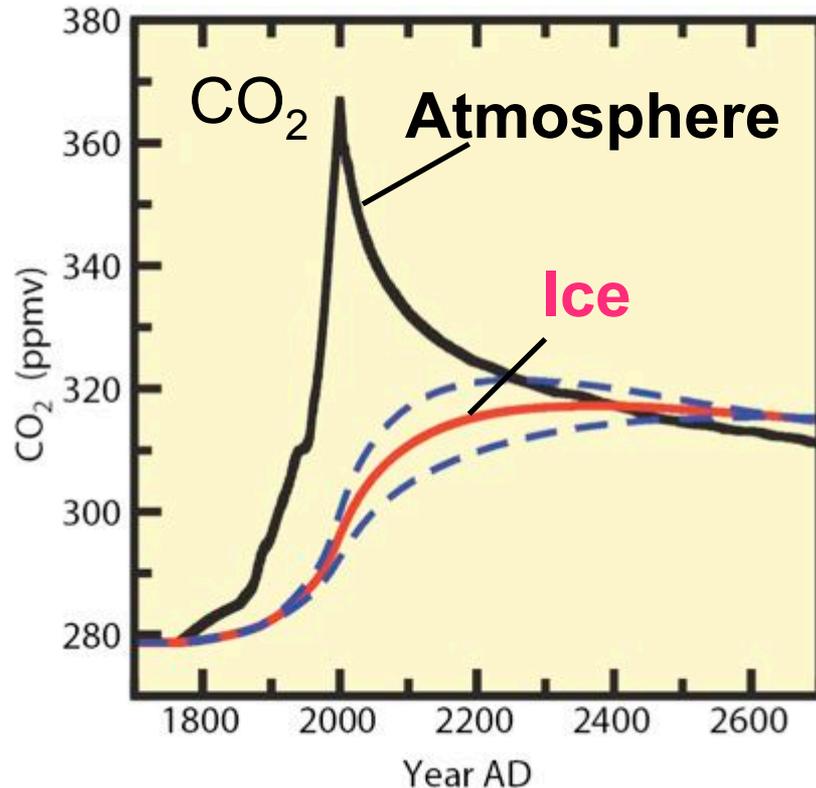
# How would the anthropogenic CO<sub>2</sub> and CH<sub>4</sub> peaks be recorded in Antarctic ice during the last transition?

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Results from a firn-diffusion and enclosure model

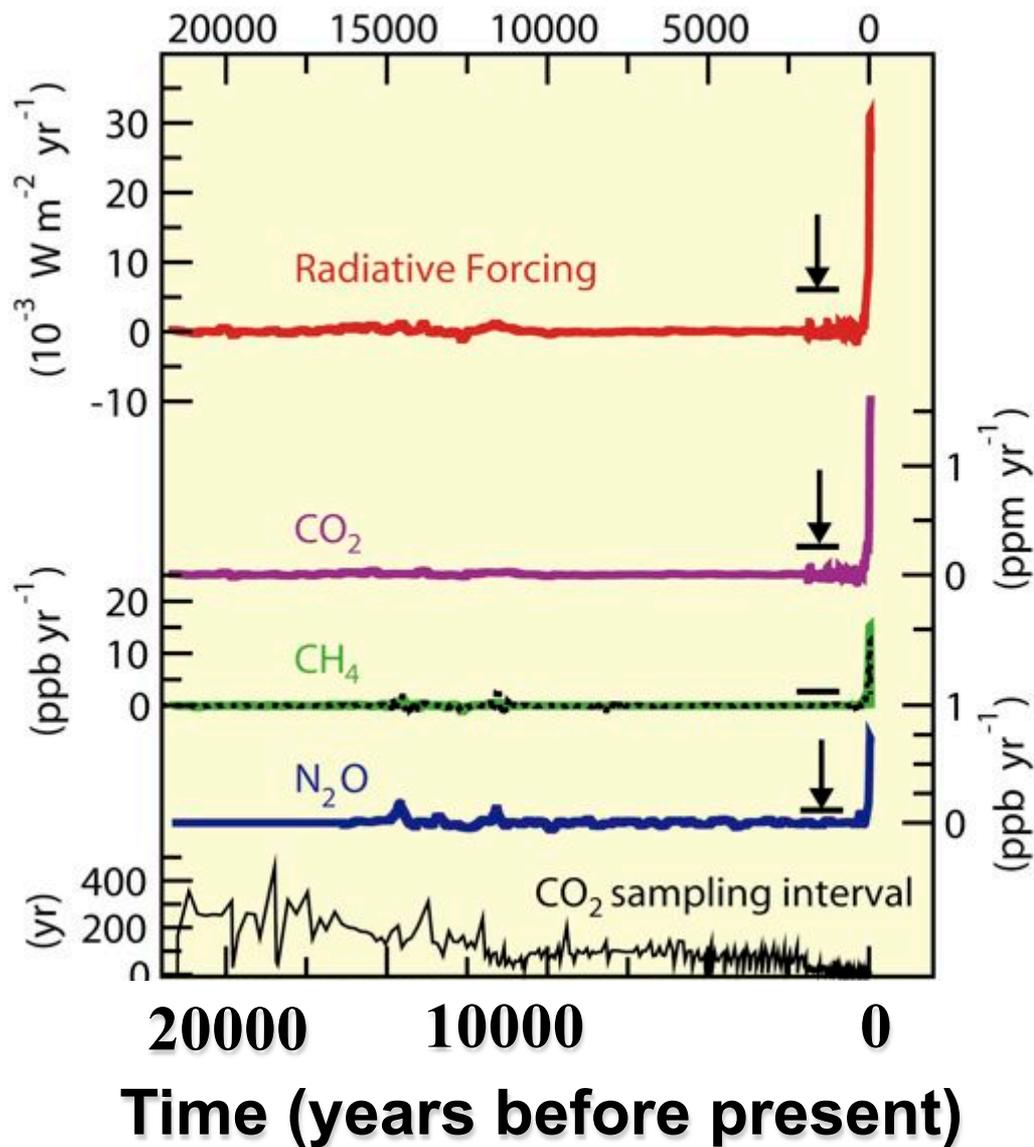
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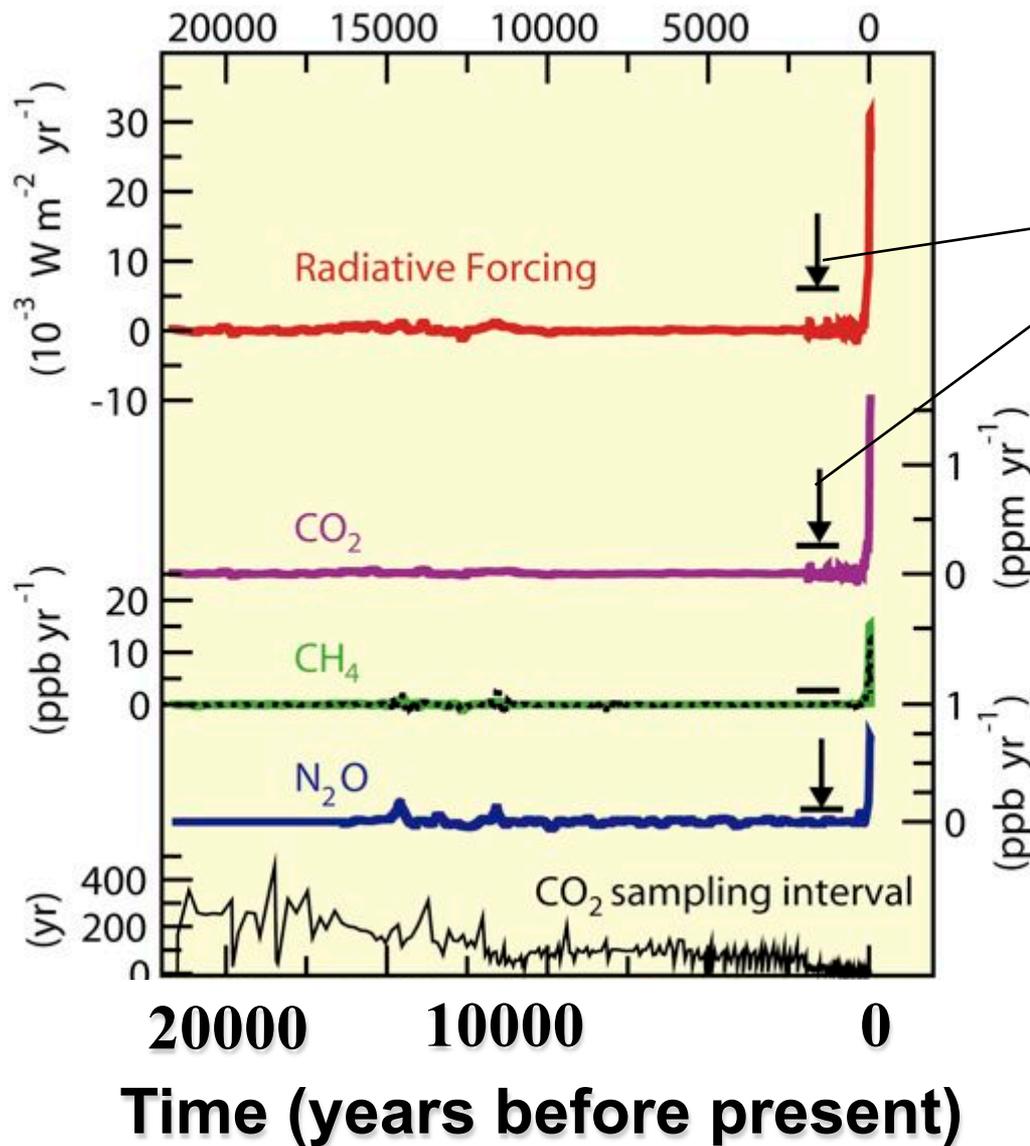
(Joos and Spahni, PNAS, 2008)

# Rates of change over the past 22,000 years inferred from ice core and atmospheric data



(Joos and Spahni, PNAS, 2008)

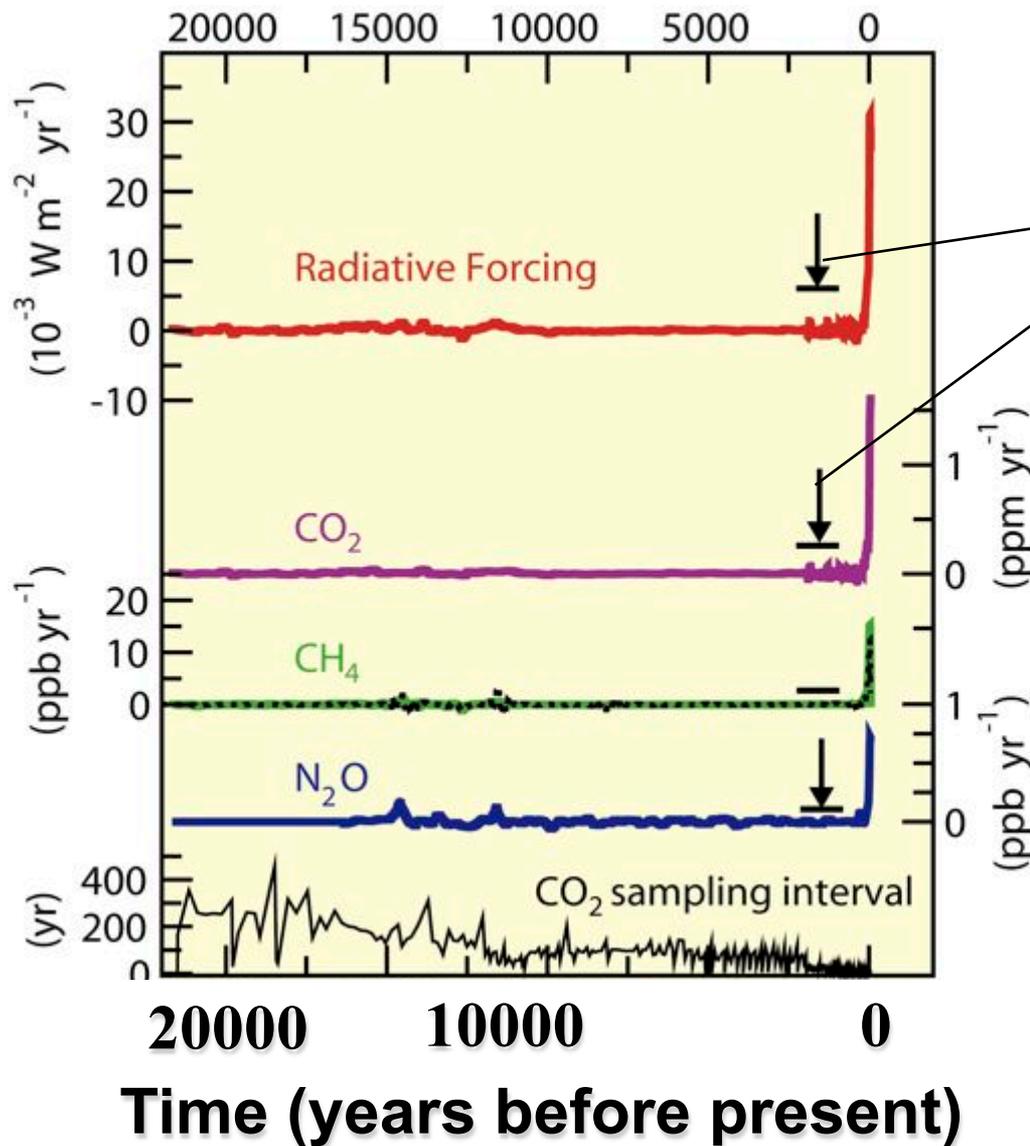
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Potential Smoothing of peak in ice

(Joos and Spahni, PNAS, 2008)

# Rates of change over the past 22,000 years inferred from ice core and atmospheric data

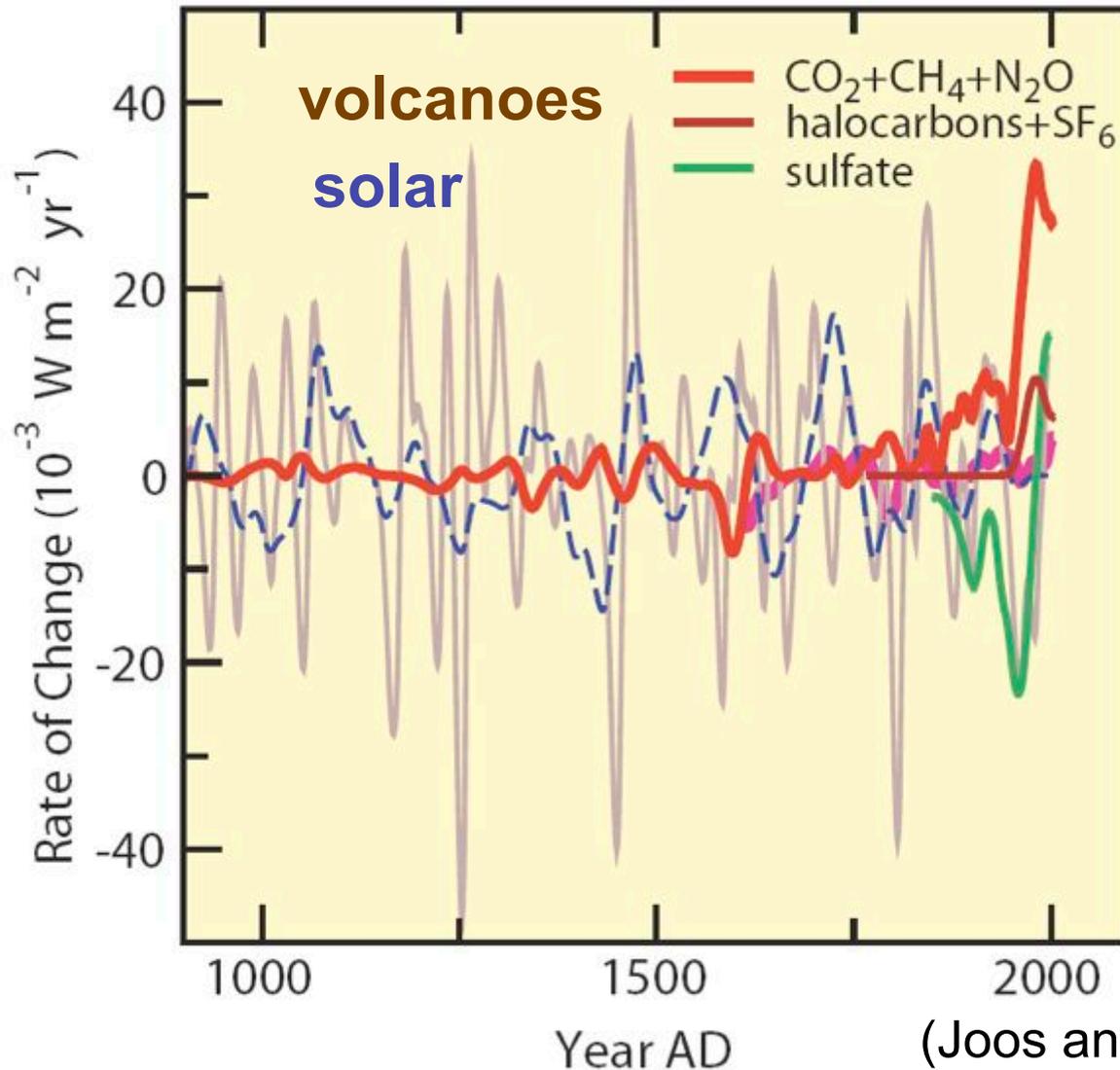


The rate of increase in the combined radiative forcing from  $\text{CO}_2$ ,  $\text{CH}_4$  and  $\text{N}_2\text{O}$  during the industrial era is *very likely* to have been unprecedented in more than 10,000 years (IPCC, SPM, 2007)

(Joos and Spahni, PNAS, 2008)

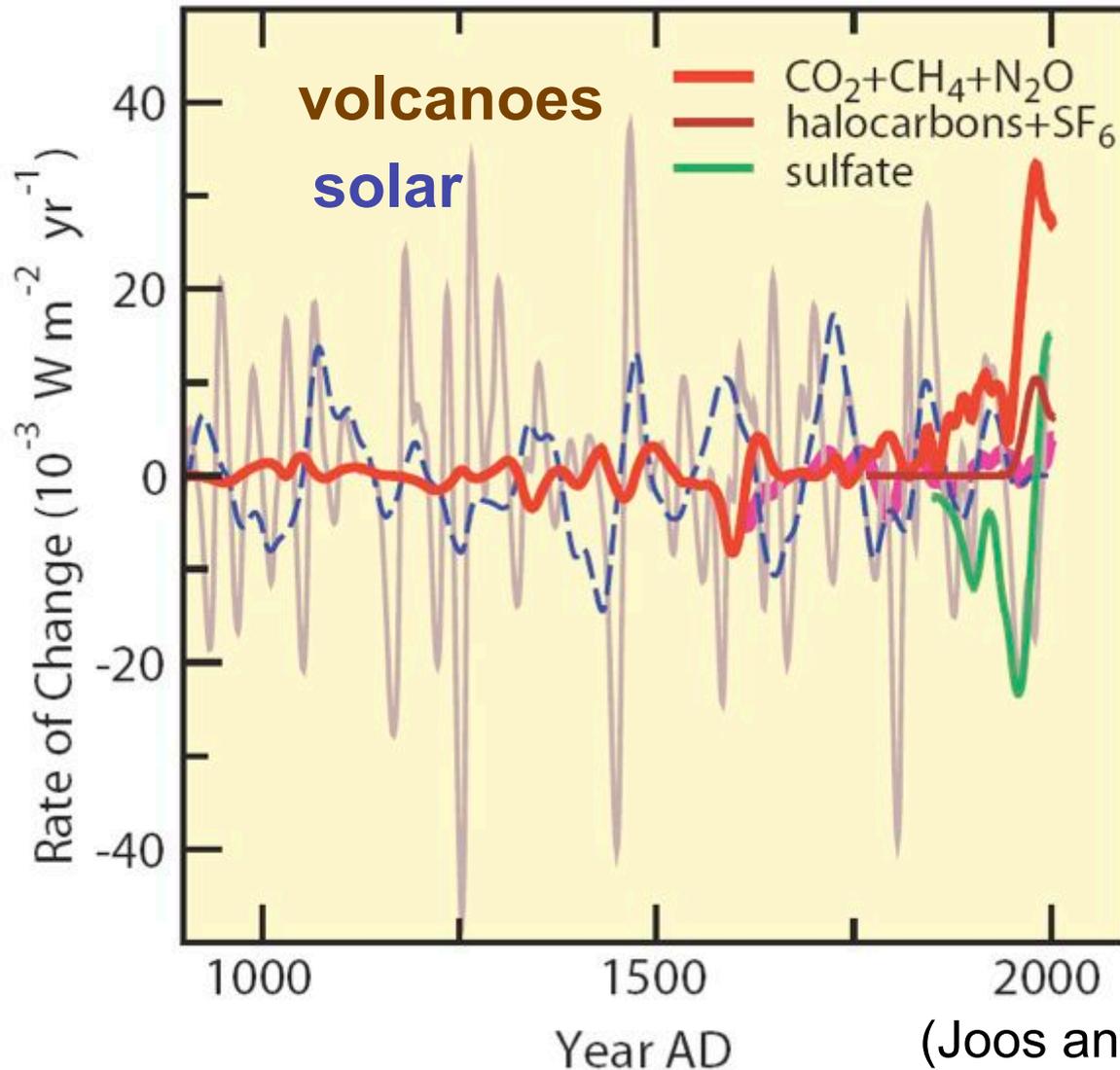
**Decadal-to-century scale rate of change in anthropogenic forcing is unusually high in the context of natural forcing variations (solar, volcanoes) of the last millennium**

# Rates of decadal-scale change: Natural (solar, volcanoes) versus human made



(Joos and Spahni, PNAS, 2008)

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**sum of current  
rates in  
anthropogenic  
forcings**

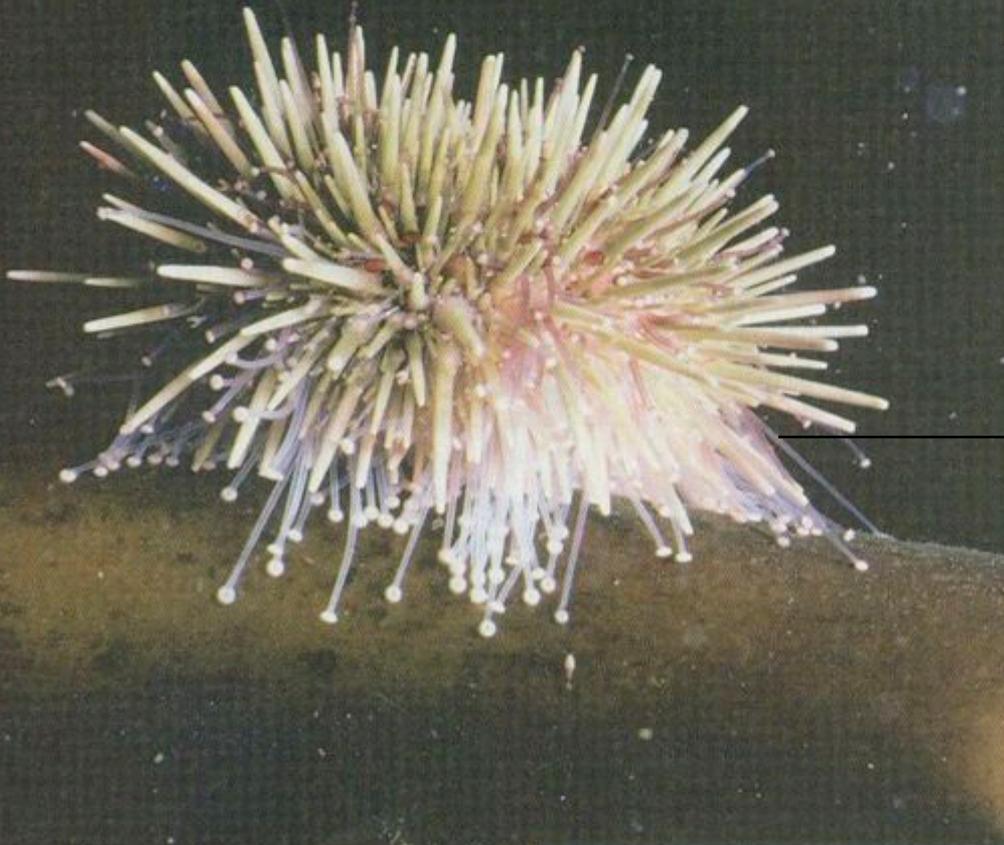
(Joos and Spahni, PNAS, 2008)

**The cause-effect chain implies that global, anthropogenic climate change is progressing at high speed compared to natural forcings of the last millennium and GHG forcing of the last 20,000 years**

## **3) Ocean Acidification**

**Water is becoming corrosive to calcium carbonate shells of organisms**

# Discover Magazine: The top 100 Science Stories



See them while you can: Organisms like this green sea urchin (*Strongylocentrotus droebachiensis*) may vanish if levels of atmospheric carbon dioxide keep rising.

## Greenhouse Gas Makes Oceans Acidic and Dissolves Marine Life

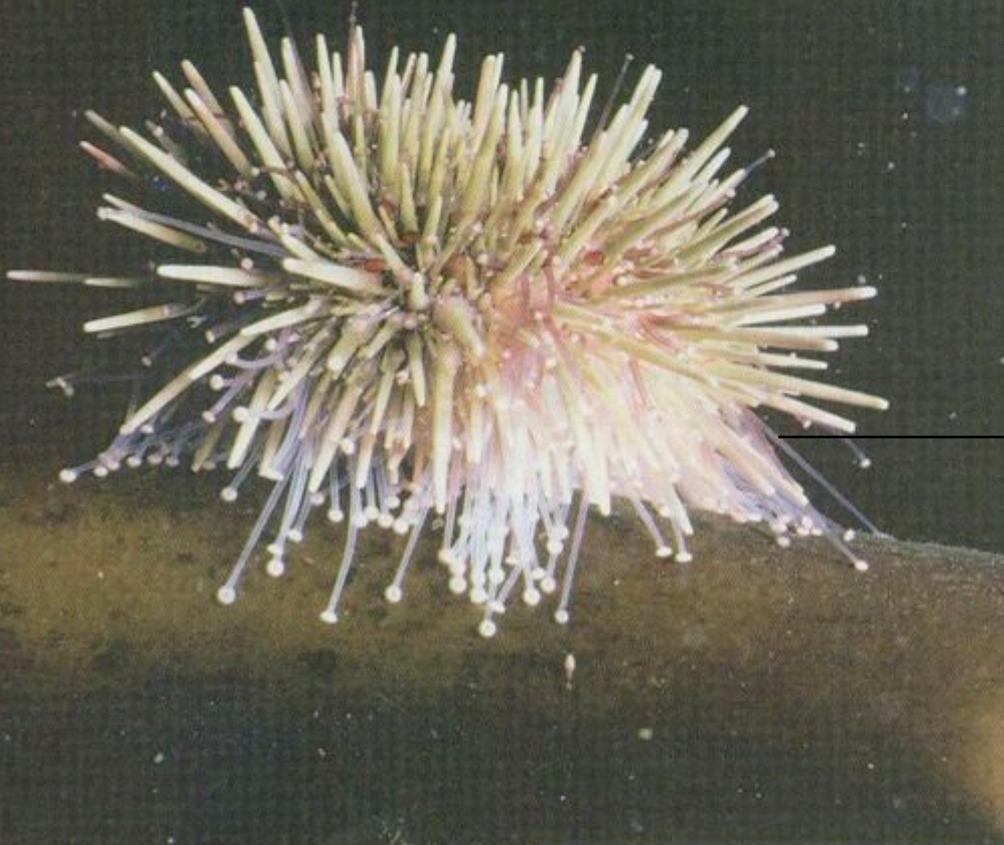
**OCEANOGRAPHY**—Increasing levels of carbon dioxide in the atmosphere are turning the oceans more

drop from an average of 8.1 today to 7.7 by the end of the century. That may doom small but essential

ern Ocean and part of the North Pacific will be so corrosive by the year 2100 that many calcifying

F  
c  
S  
M

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**Uptake of CO<sub>2</sub> (carbonic acid) by the ocean causes decrease in pH and in the concentration of carbonate ions (CO<sub>3</sub><sup>2-</sup>)**

**Uptake of  $\text{CO}_2$  (carbonic acid) by the ocean causes decrease in pH and in the concentration of carbonate ions ( $\text{CO}_3^{2-}$ )**

**The consequences:**

- Water becomes undersaturated with respect to  $\text{CaCO}_3$**
- Dissolution of aragonite and calcite**
- Problems for cold and warm water corals and calcifying organisms**

# Aragonite shells of Pteropods start to dissolve when water becomes undersaturated

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**Pteropod:**  
*Clio pyramidata*

**Orr et al.,  
Nature, 2005**

# Aragonite shells of Pteropods start to dissolve when water becomes undersaturated

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**Aragonite:  $\text{CaCO}_3 \rightarrow \text{Ca}^{2+} + \text{CO}_3^{2-}$**

**If aragonite saturation state of water < 100 %**



**Pteropod:**  
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**Orr et al.,  
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# Aragonite shells of Pteropods start to dissolve when water becomes undersaturated



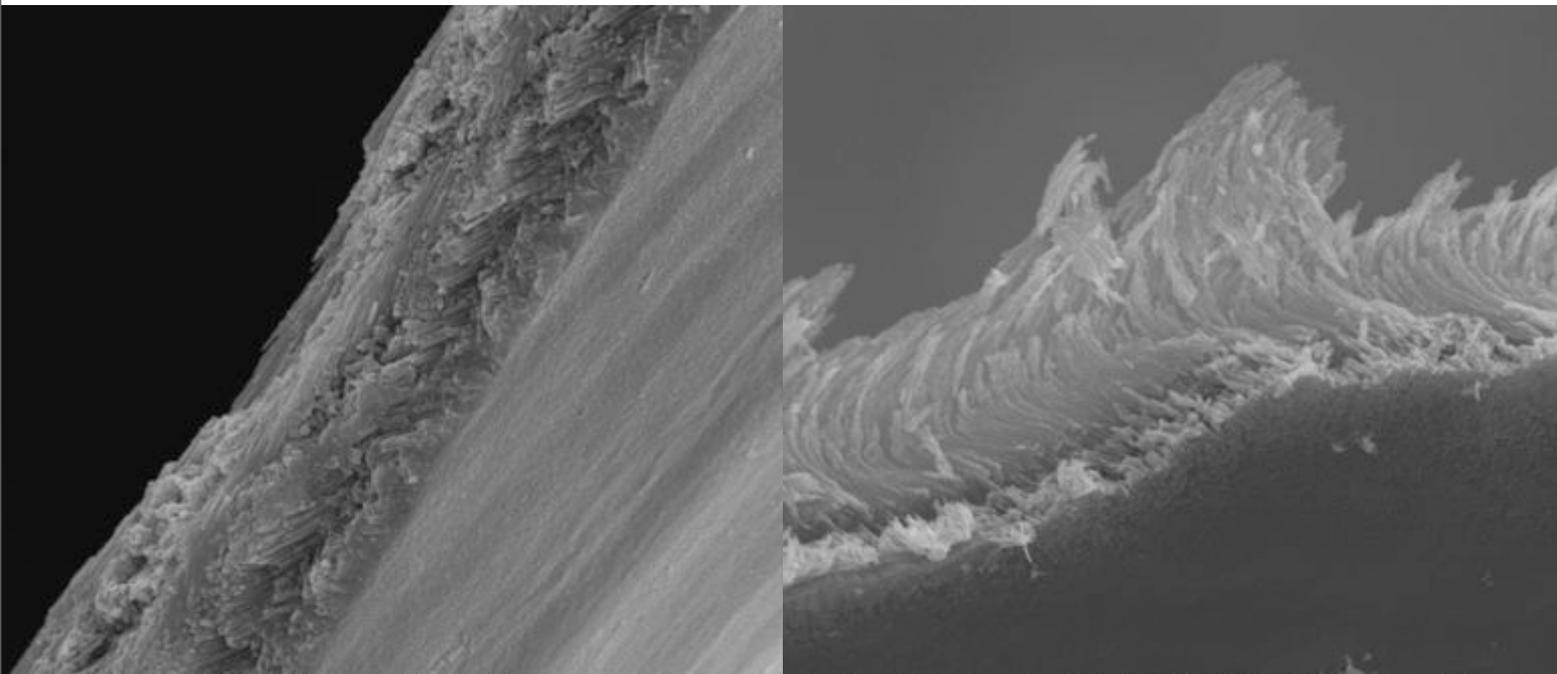
If aragonite saturation state of water < 100 %



Pteropod:  
*Clio pyramidata*

Normal Shell

Exposed Shell



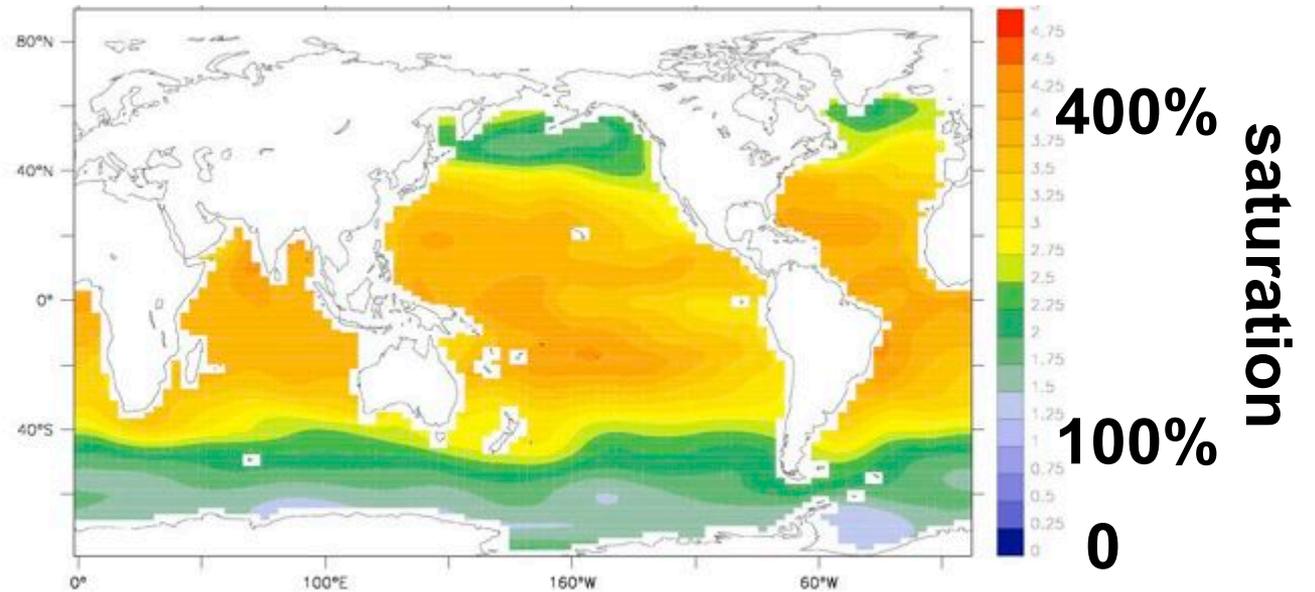
HV	WD	HFWD	Mag	Pressure	VacMode	—5 μm—
20.0 kV	42.25 mm	36.57 μm	7000x	---	Highvacuum	

HV	WD	HFWD	Mag	Pressure	VacMode	—5 μm—
20.0 kV	21.32 mm	32.00 μm	8000x	---	Highvacuum	

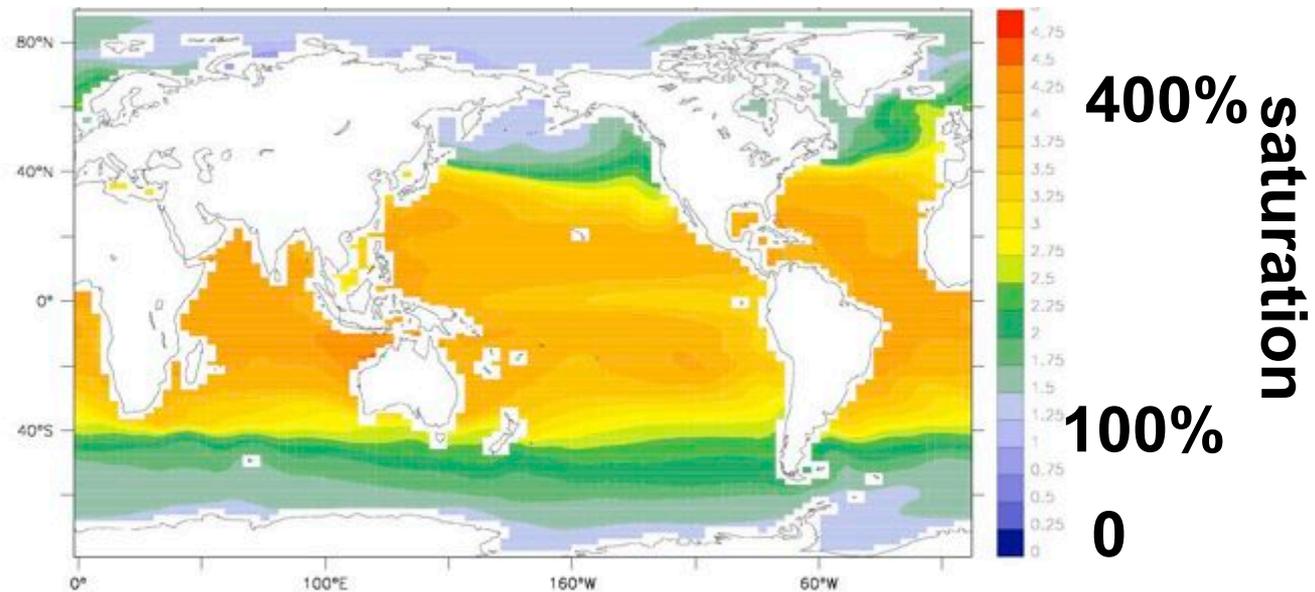
Orr et al.,  
Nature, 2005

# Ocean Acidification and Aragonite Saturation

**Observation-based**



**NCAR CSM1.4**



**Steinacher, 2007**

# Evolution of Aragonite Saturation in the Surface

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**90°N**

**Latitude**

**90°S**

**300**

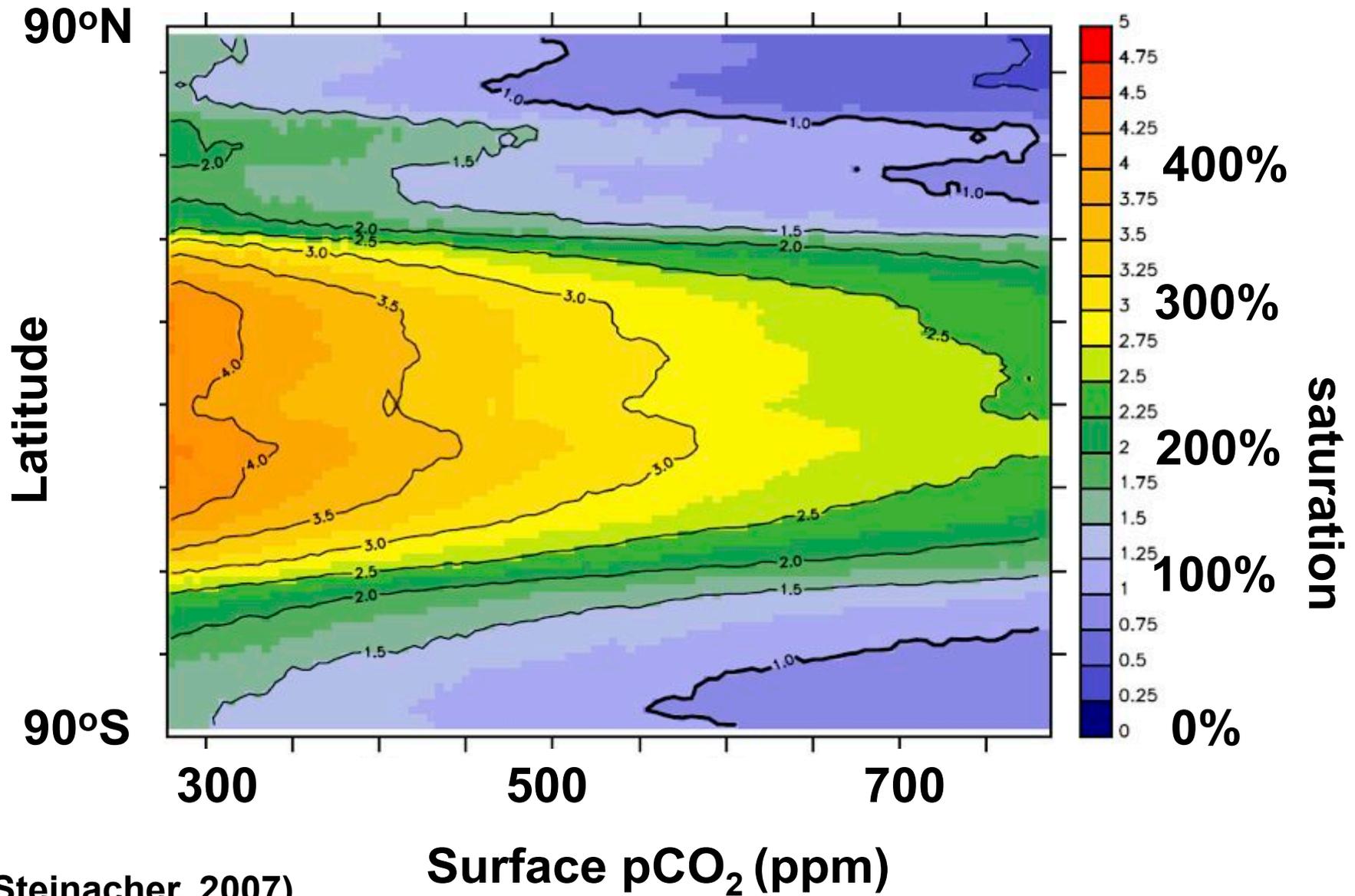
**500**

**700**

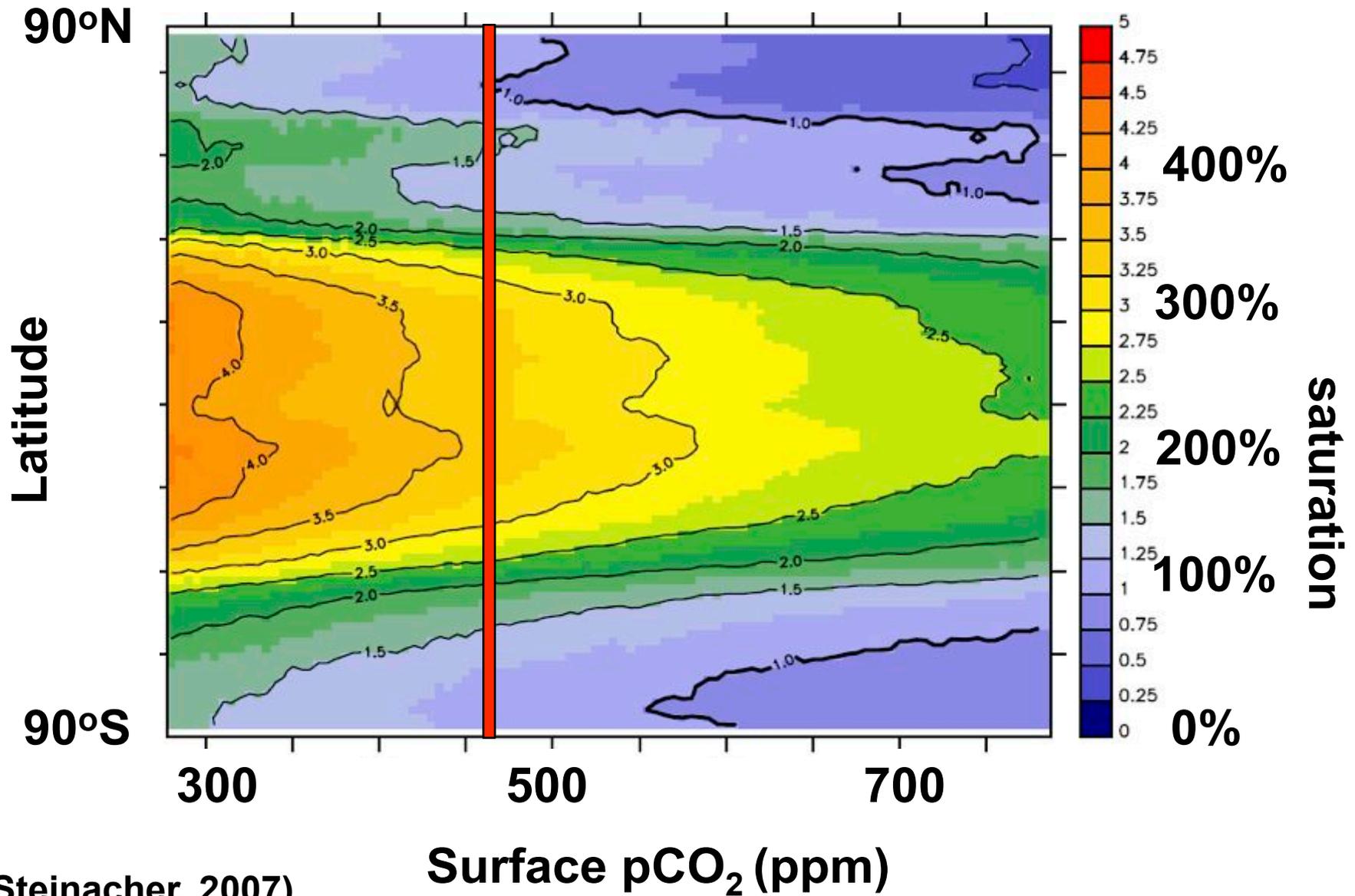
**Surface pCO<sub>2</sub> (ppm)**

**(Steinacher, 2007)**

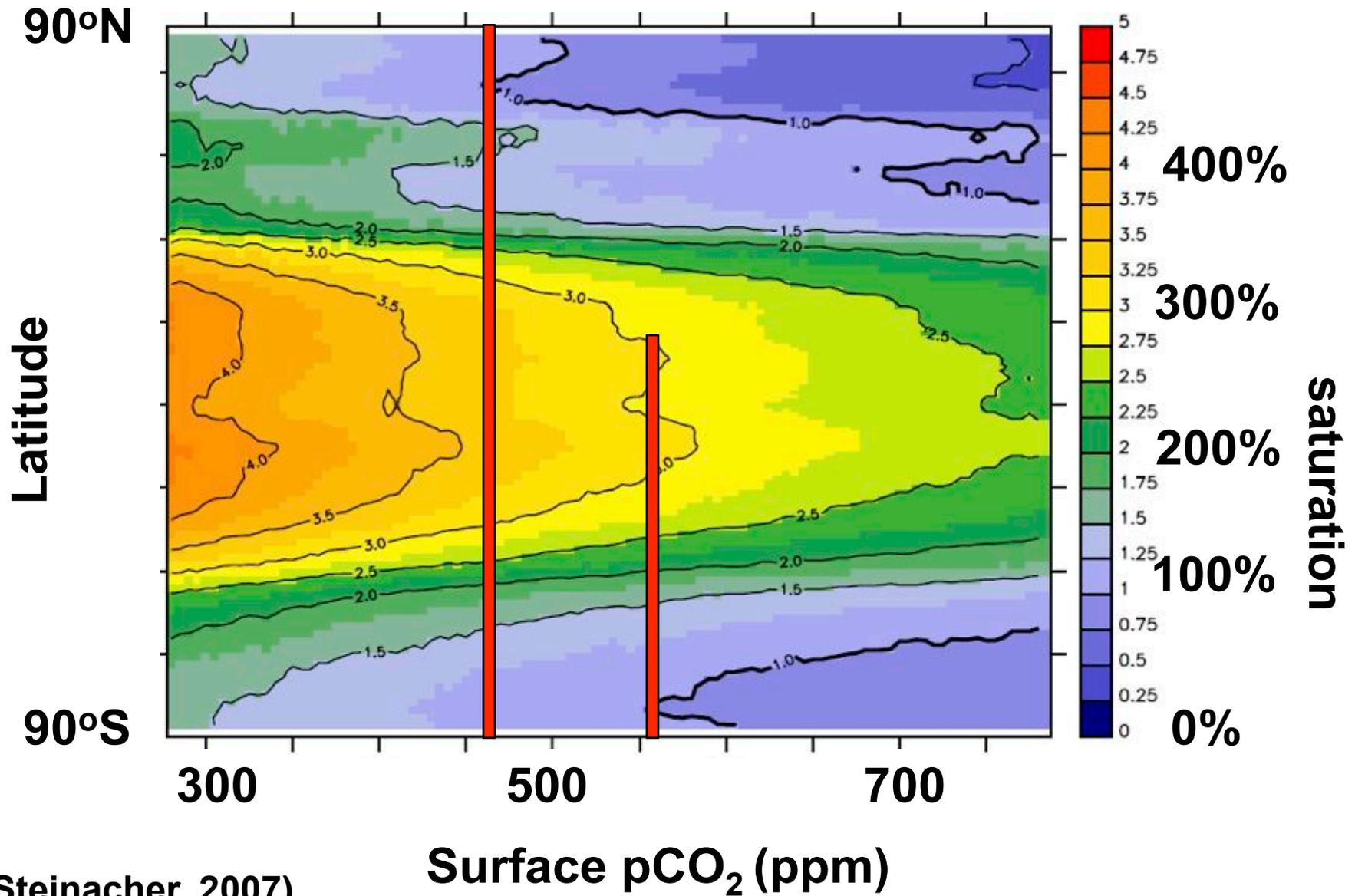
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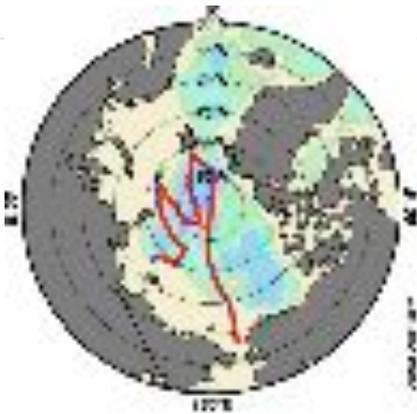
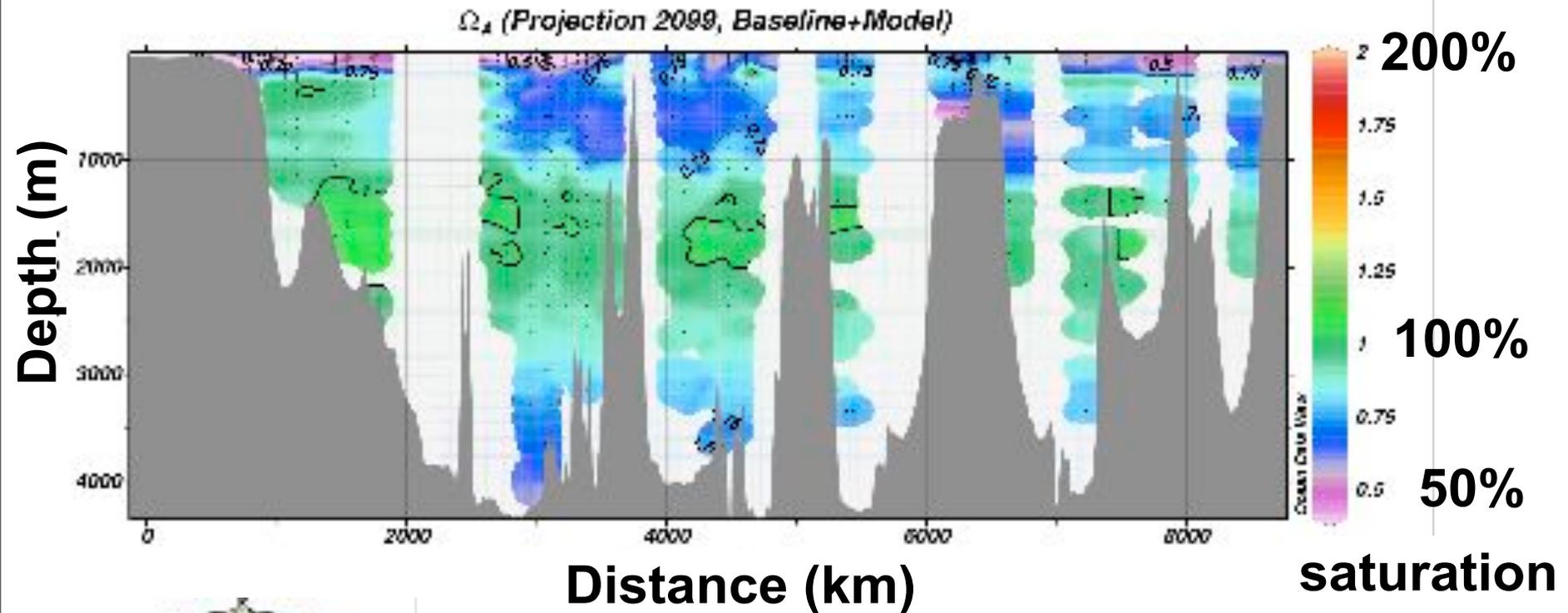
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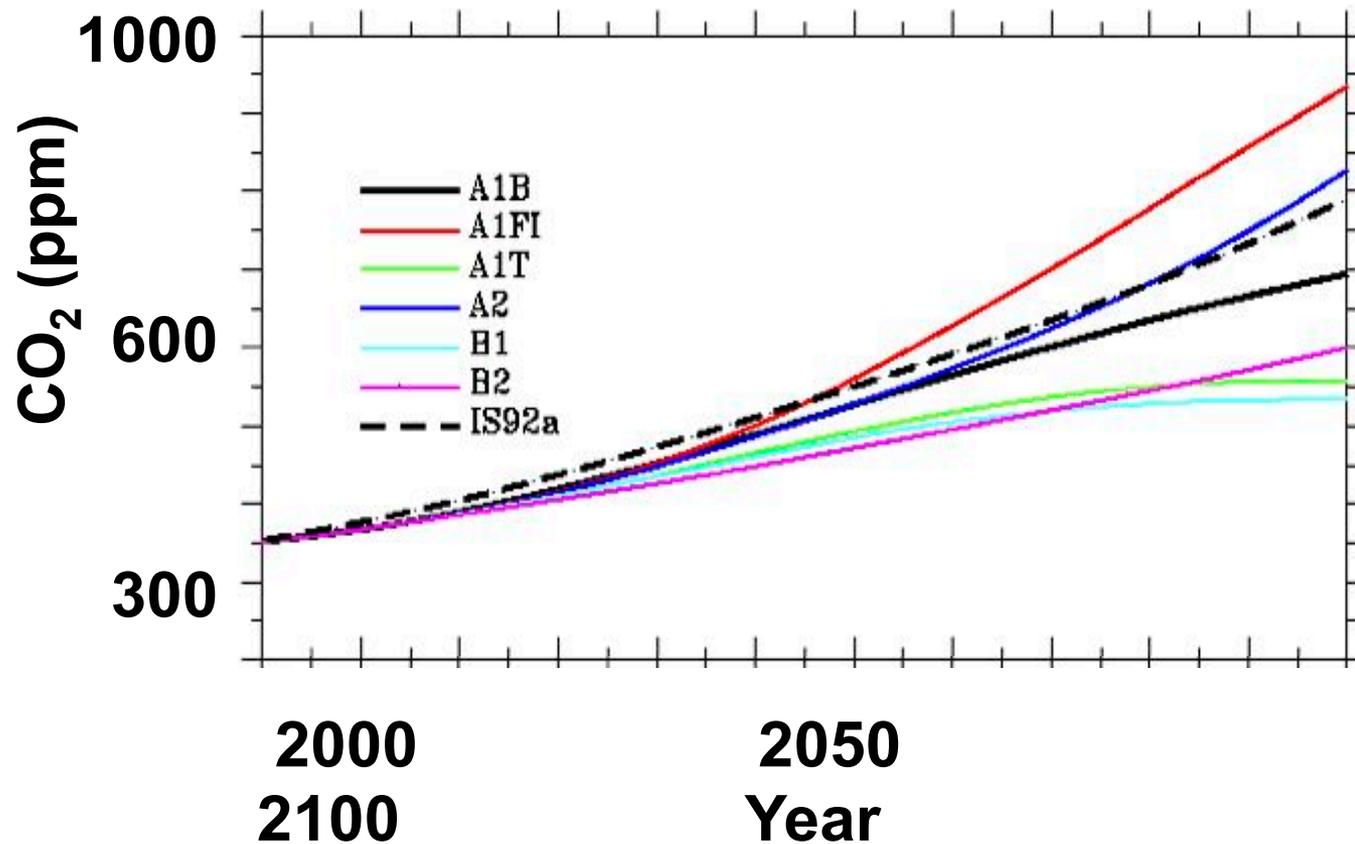
# Projected undersaturation in the Arctic extends to 4000 m depth in 2100 and SRES A2



Observation-based estimates from: ODEN-91, AOS-94, ARCSYS-96

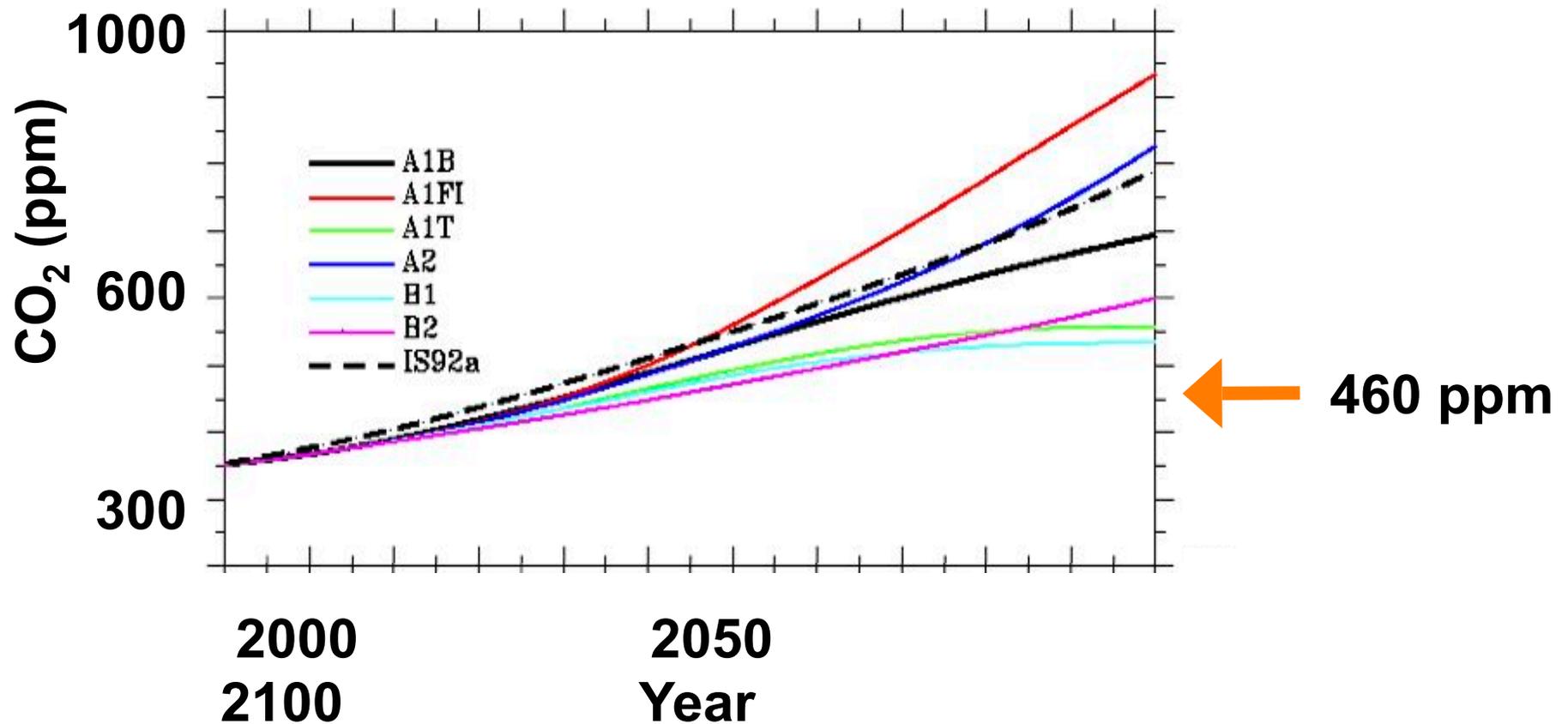
# Arctic and Southern Ocean surface Water becomes undersaturated for all/most IPCC SRES scenarios

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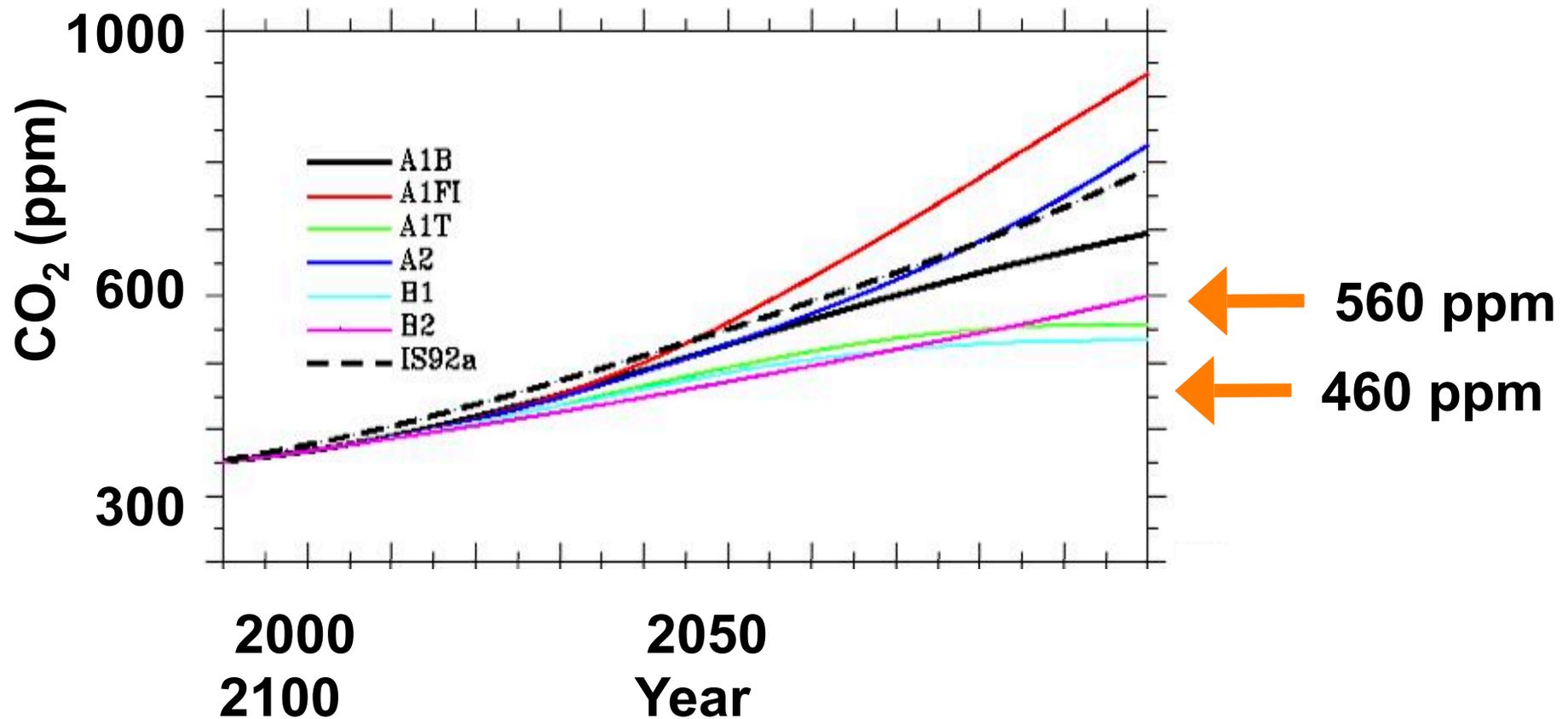
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**YES**

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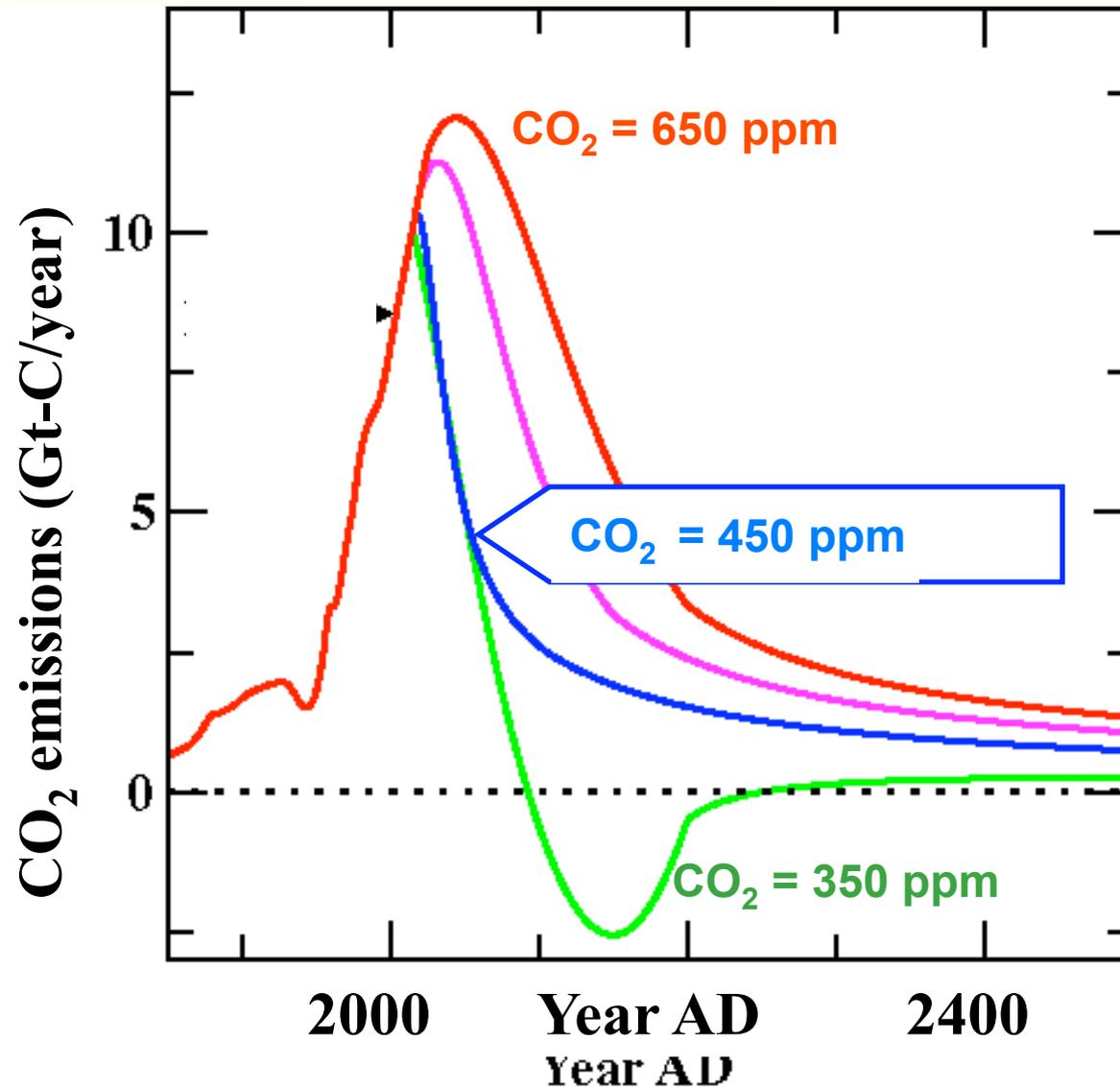
- **Changes appear irreversible on human time scales as carbon emissions from human activities perturb the atmosphere and climate for millennia**
- **A very high speed of the increase in greenhouse gases, causing Earth's surface to warm**
- **~ 460 ppm: Arctic Ocean becomes undersaturated with respect to Aragonite (reached within next 5 decades for BaU)**

## 4) The way forward

A stabilisation of the atmospheric CO<sub>2</sub> requires global carbon emissions to fall towards the emissions of Europe only.

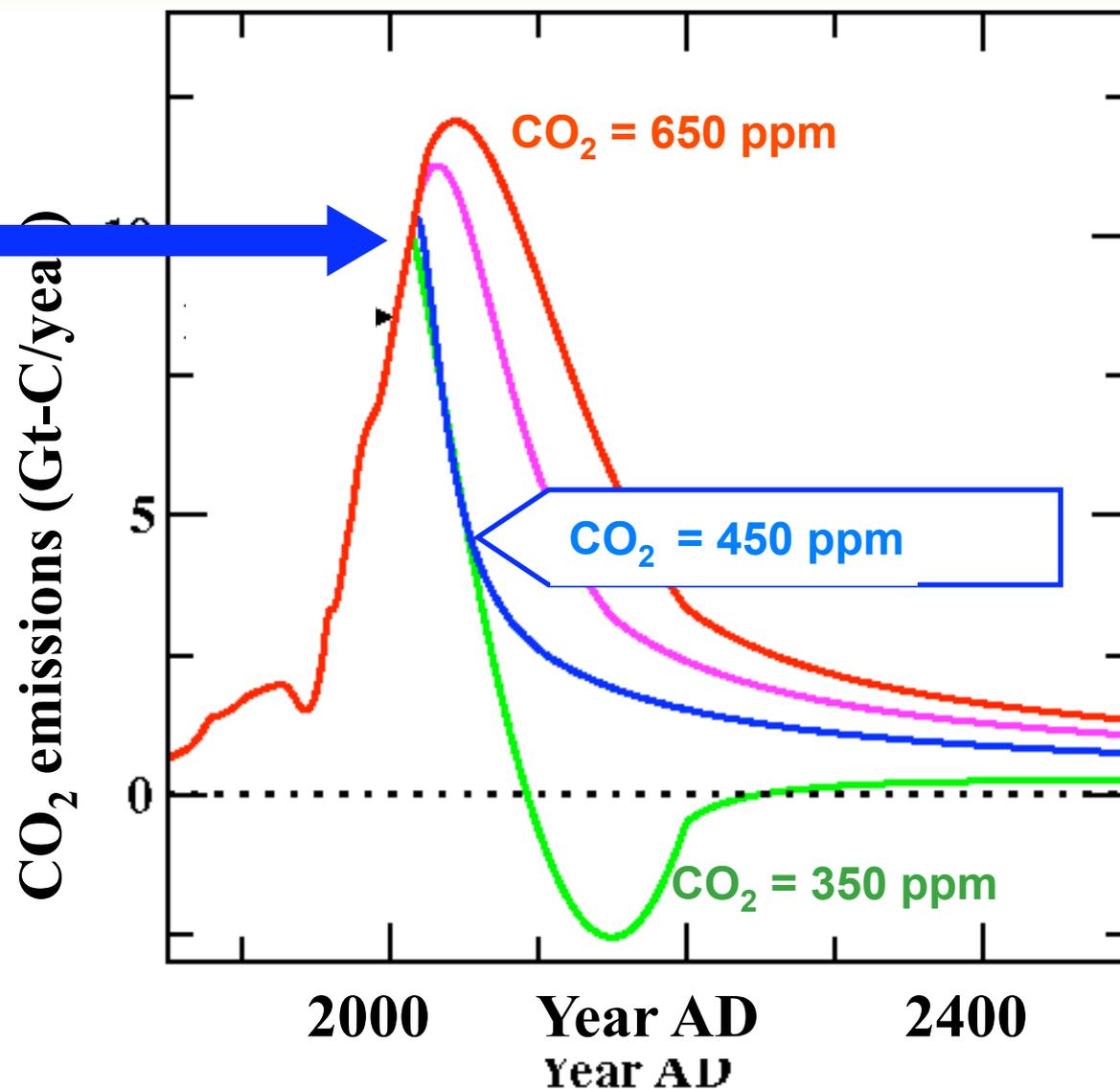
# Emission trajectories leading to CO<sub>2</sub>

stabilisation at different target concentrations



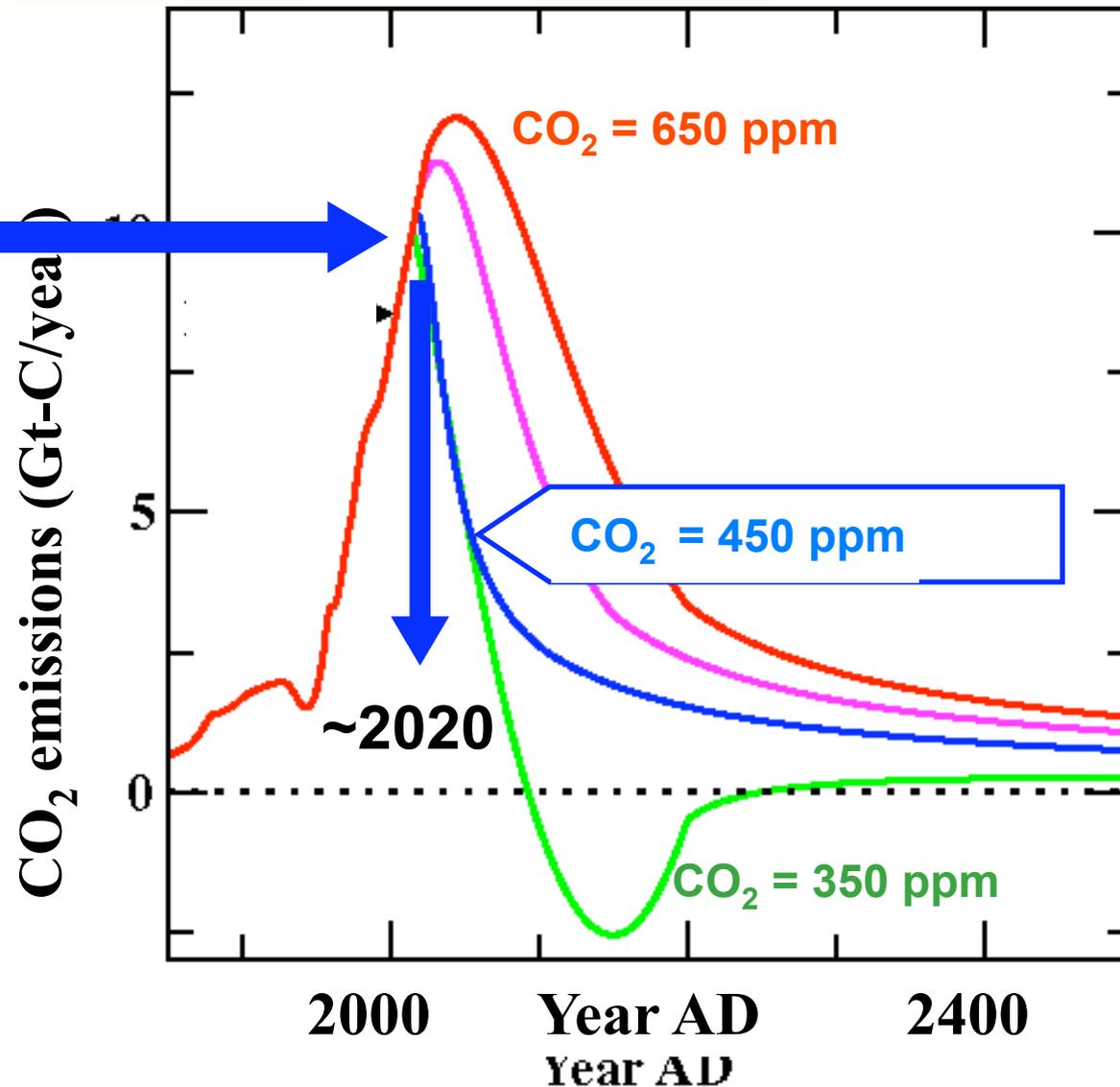
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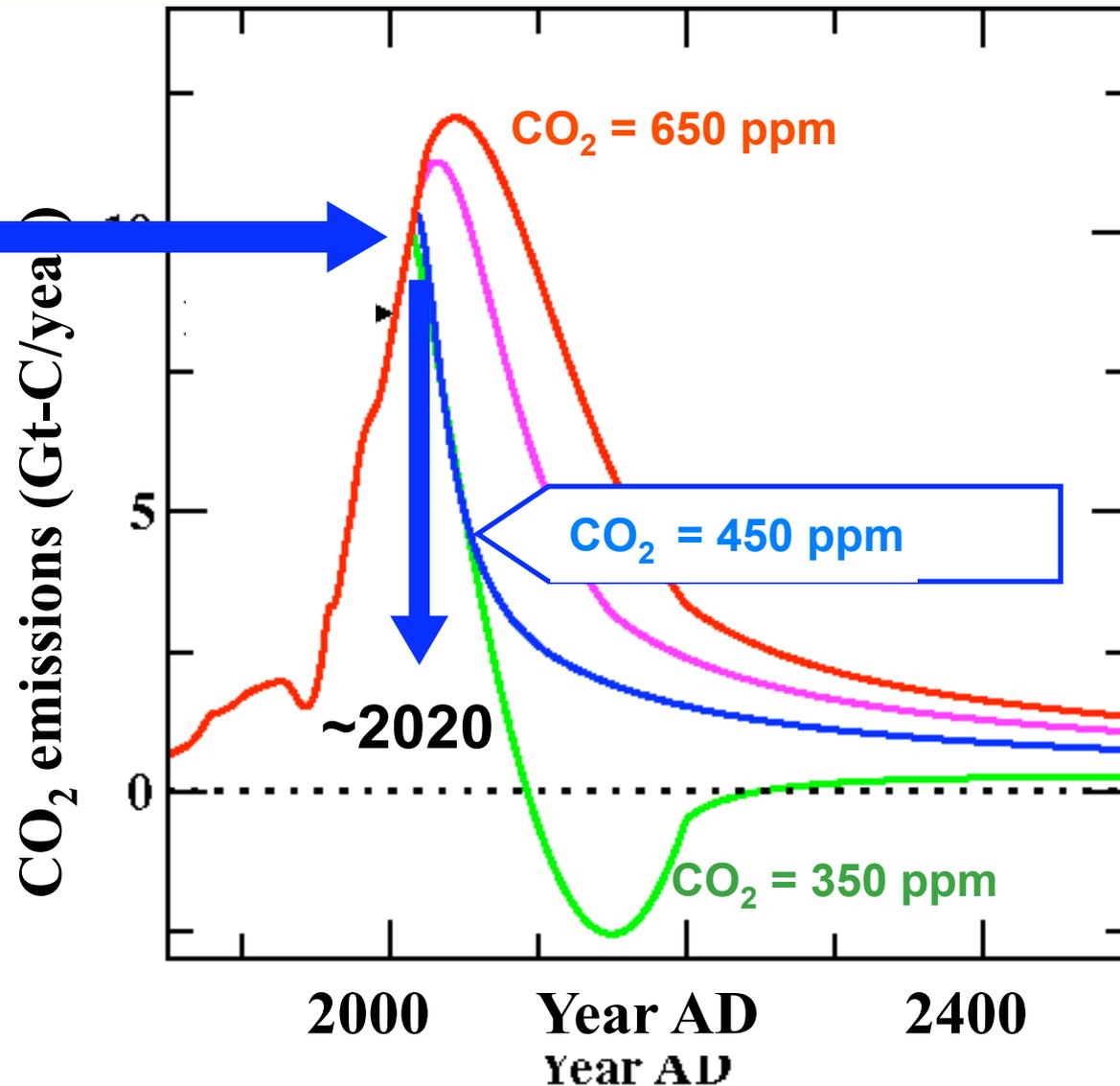
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## stabilisation at different target concentrations



Per Capita Emissions:  
CH: 1.6 t-C/y  
(3.3 t-C/y)

CH: 0.3 t-C/y?

## **..and in Switzerland**

**No investment in gas and coal fire plants without carbon capture and safe storage**

**Carbon emission reduction in Switzerland using available technology instead of buying „hot air“**