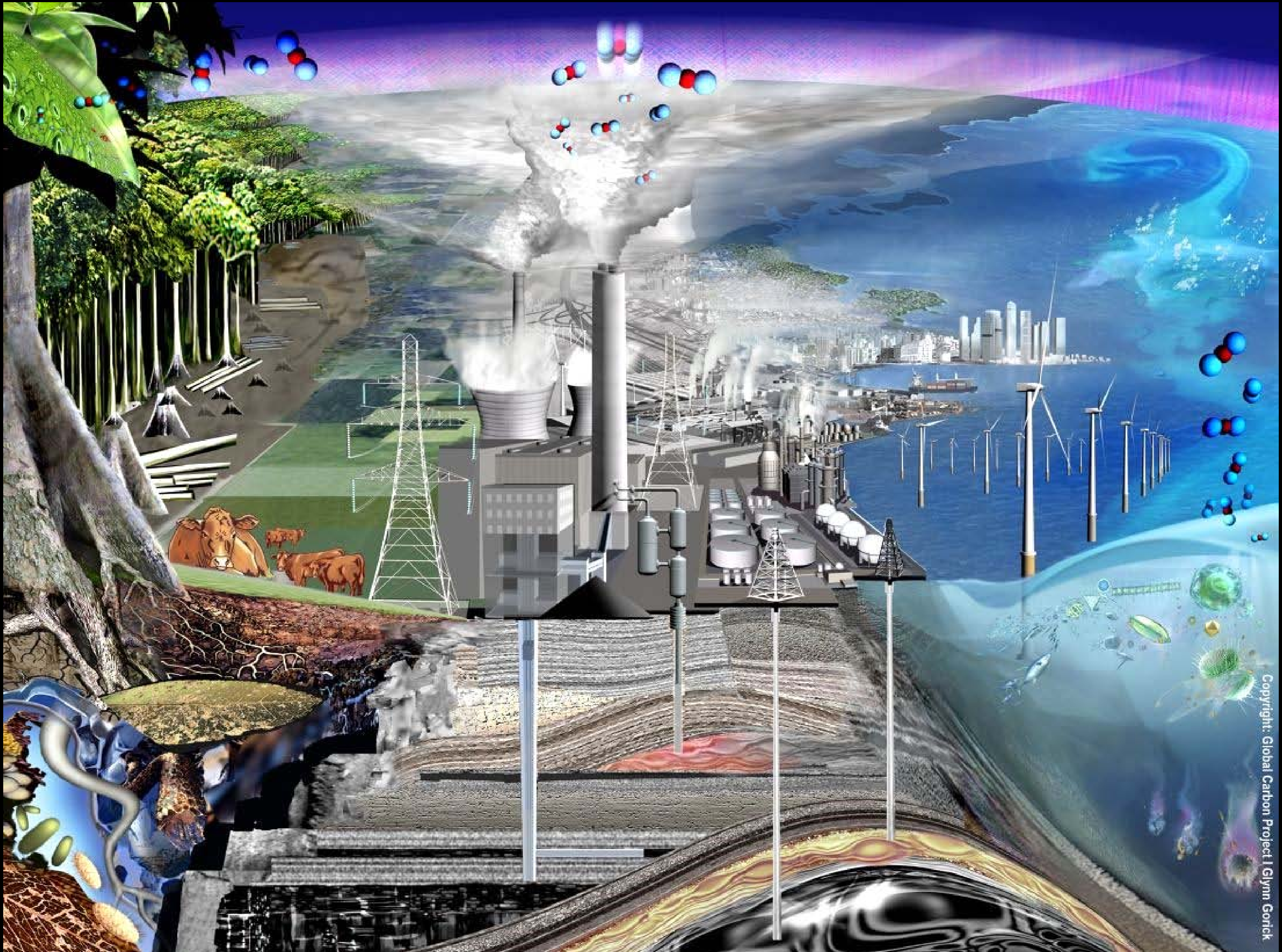
Ocean acidification: a biogeological perspective

Jelle Bijma (AWI, Bremerhaven, Germany)

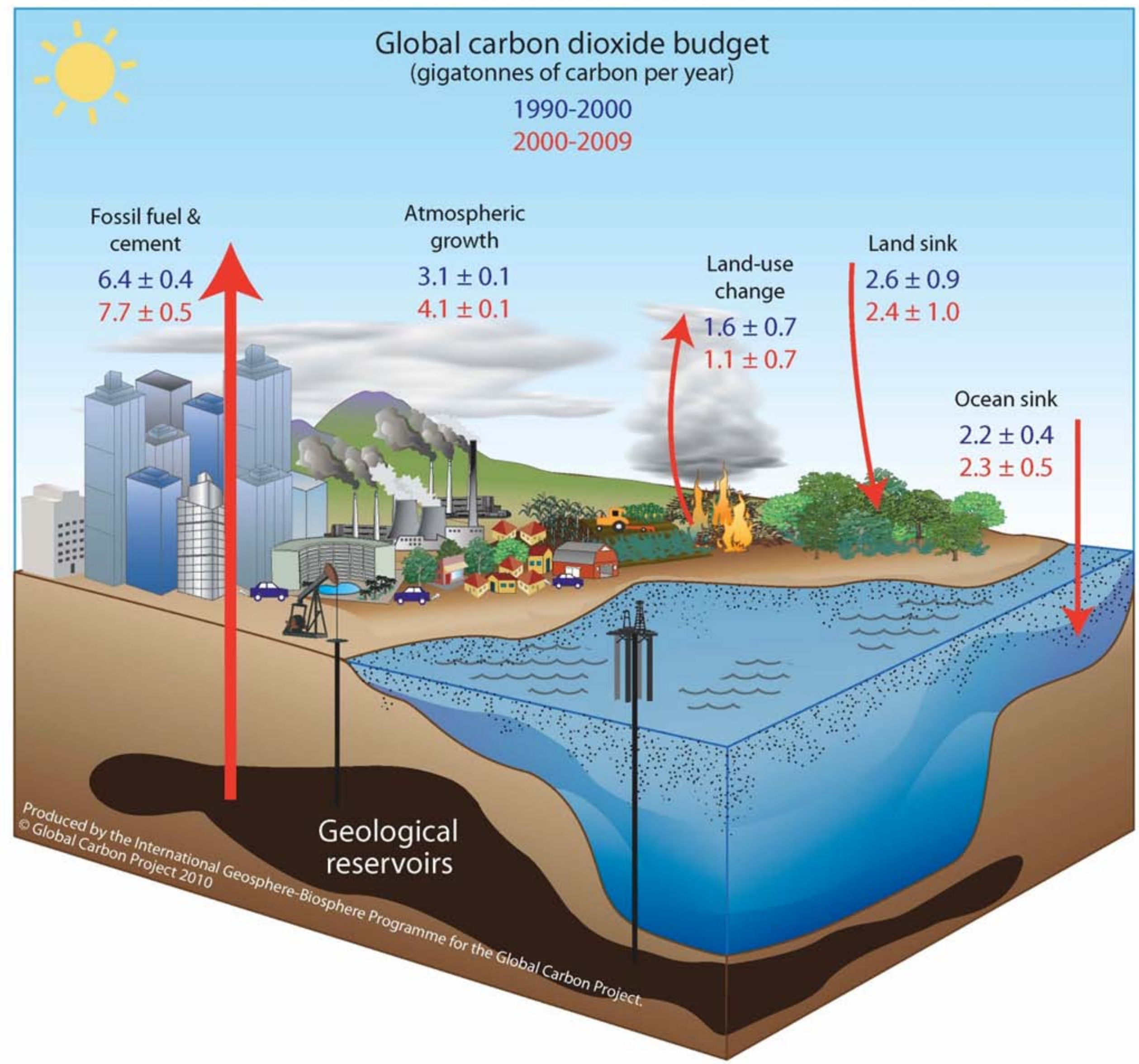
- Ocean acidification: present and future . . . . .
- Why a biogeological perspective?
- Ocean acidification in the past . . . . .
- Consequences for Biodiversity . . . . .

International Conference on Science and Technology for Sustainability
Climate Change and Biodiversity, Kanazawa, Dec. 17, 2010

Artist Impression of the Human Perturbation of the Carbon Cycle



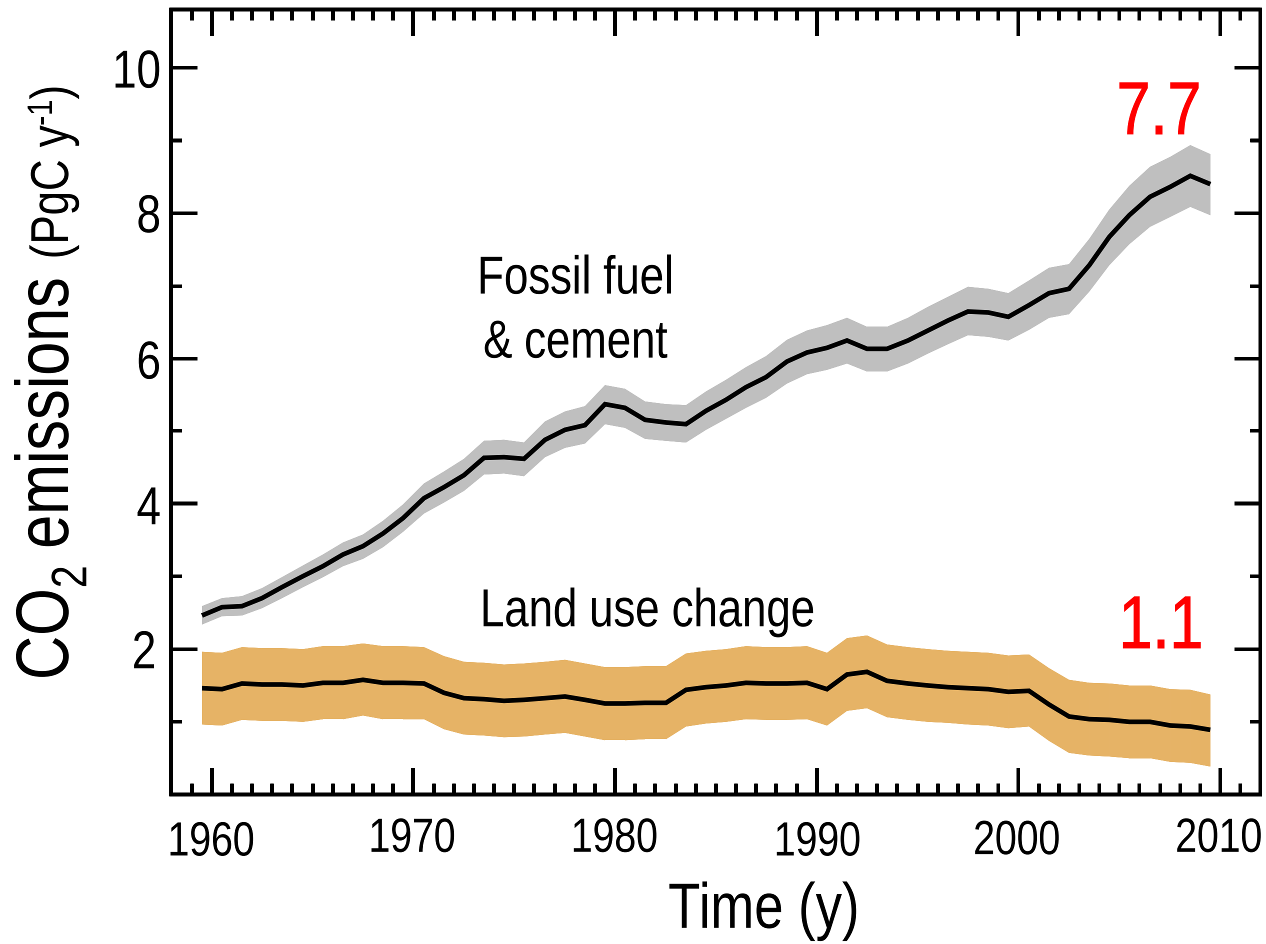
Anthropogenic Global Carbon Dioxide Budget



CO_2 Emissions from Land Use Change (1960-2009)

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = $1x10^{15}$g]

Average (2000-2009)



8.8 PgC

LUC emissions now
~10% of total CO_2 emissions

Updated from Le Quéré et al. 2009, Nature Geoscience

Fate of Anthropogenic CO_2 Emissions (20?0-2009)

Double trouble

1.1 0.7 PgC y^{-1}

7.7 0.5 PgC y^{-1}

4.1 0.1 PgC y^{-1}

47%

C y^{-1}

7%

Calcula… s the … dual of
all ot… lux co… onents

26%

2.3 0.4 PgC y^{-1}

Average of 5 models

Global Carbon Project

Global Carbon … 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

Earth System Science Partnership

DIVERSITAS

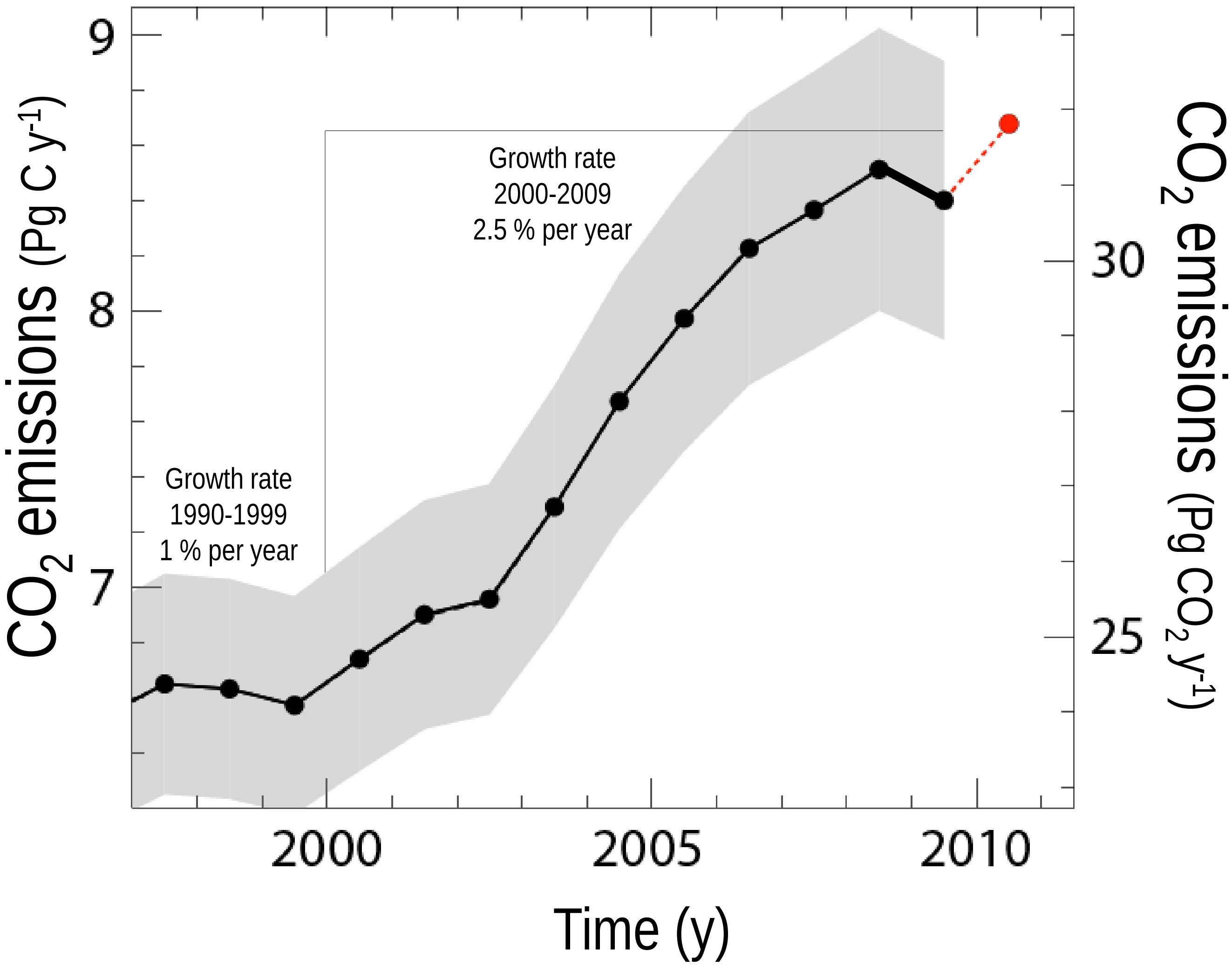
GLOBAL IGBP CHANGE

IHDP

WCRP World Climate Research Programme

Fossil Fuel CO_2 Emissions

[1 Pg = 1 Petagram = 1 Billion metric tonnes = 1 Gigatonne = 1×10^{15}g]



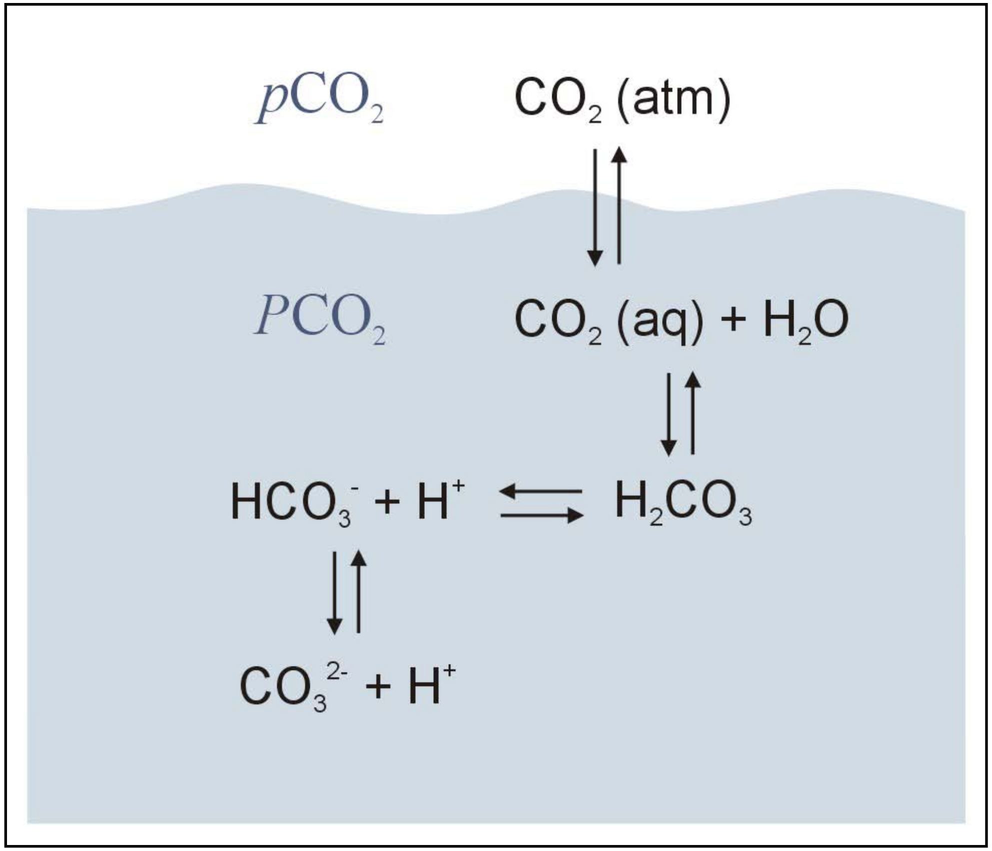
2009:
Emissions:8.4 0.5 PgC
Growth rate: -1.3%
1990 level: +37%

2000-2008
Growth rate: +3.2%

2010 (projected):
Growth rate: >3%

Friedlingstein et al. 2010, Nature Geoscience; Gregg Marland, Thomas Boden-CDIAC 2010

The marine carbonate system



CO_2 (aq): aqueous carbon dioxide

HCO_3^-: bicarbonate ion

CO_3^{2-}: carbonate ion

H_2CO_3: carbonic acid

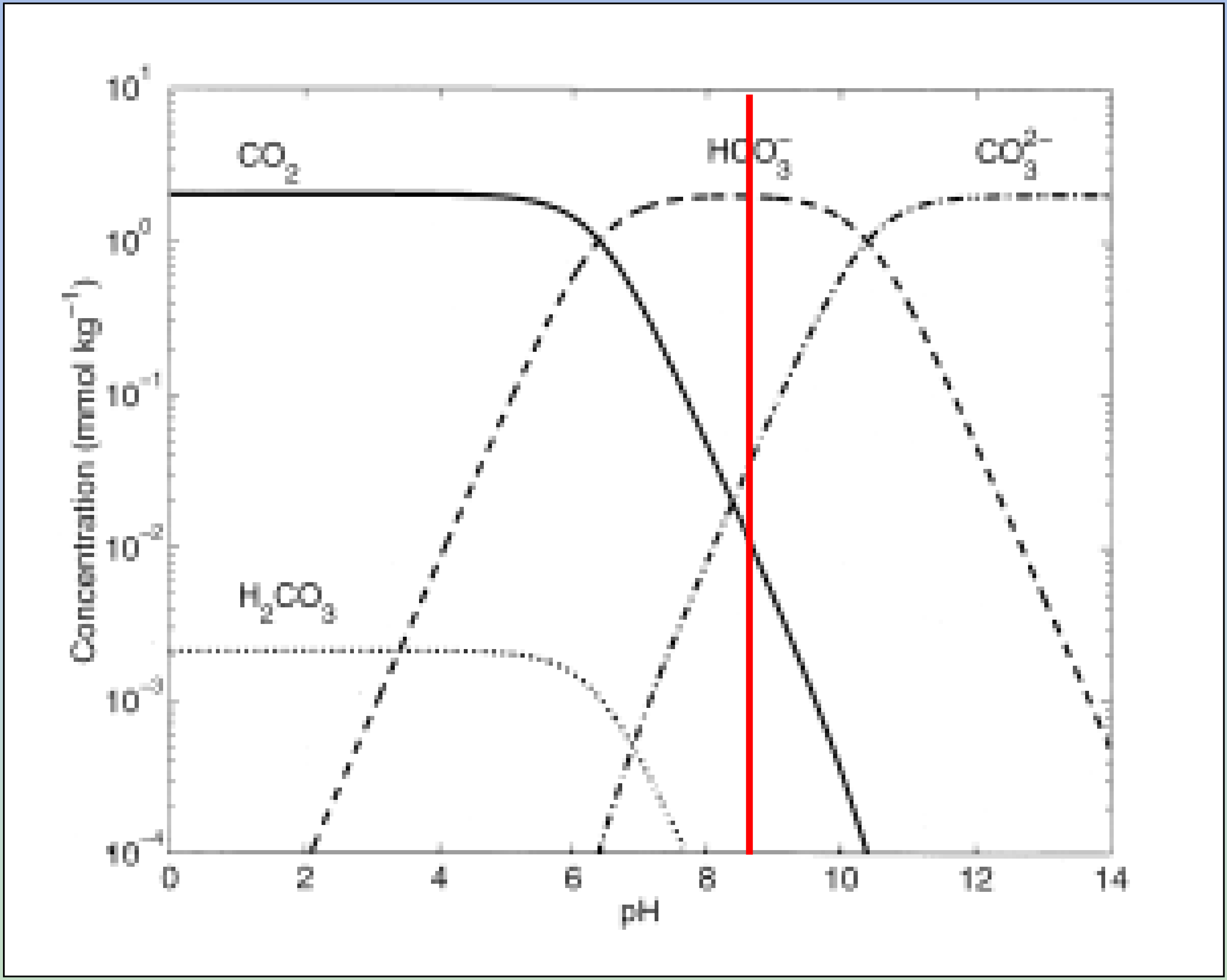
ΣCO_2 or DIC or TCO_2:

Total dissolved inorganic carbon

$$\Sigma CO_2 = [HCO_3^-] + [CO_3^{2-}] + [CO_2(aq)] + [H_2CO_3]$$

~90% ~10% <1%

„Bjerrum plot“



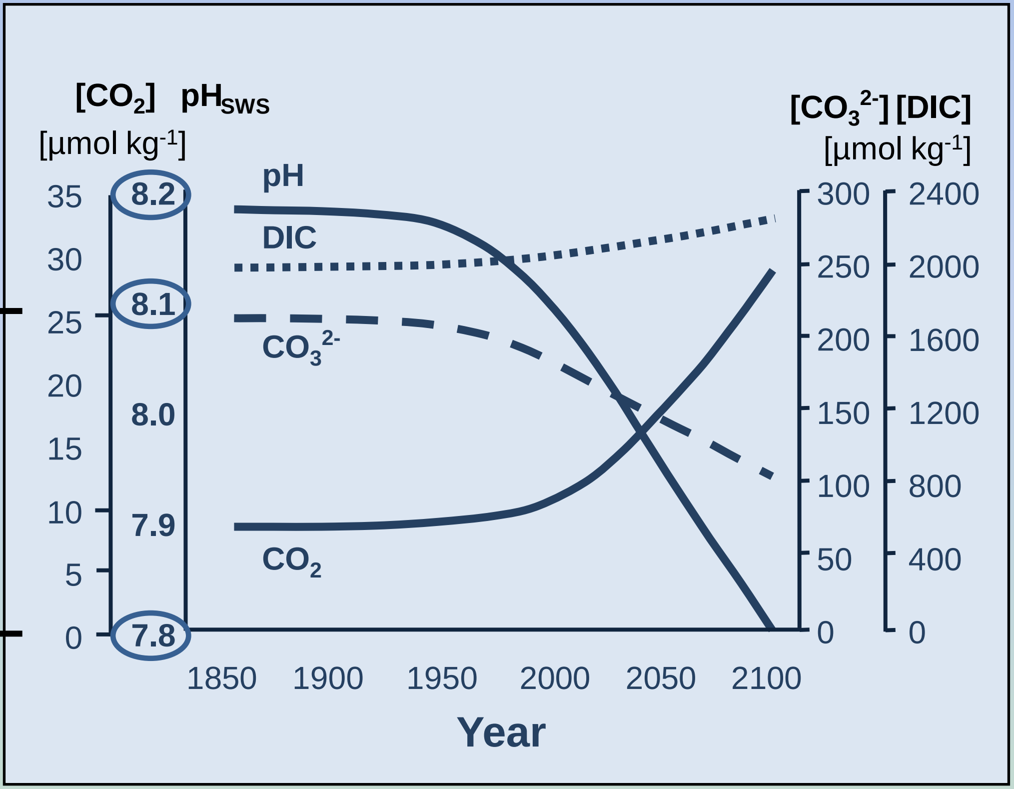
Ocean Acidification

Changes in surface ocean chemistry based on the IS92a scenario IPCC report 1995 (linear increase from 6.3 GtC yr^{-1} to 20 GtC yr^{-1} in the year 2100).

30%

more acidic!

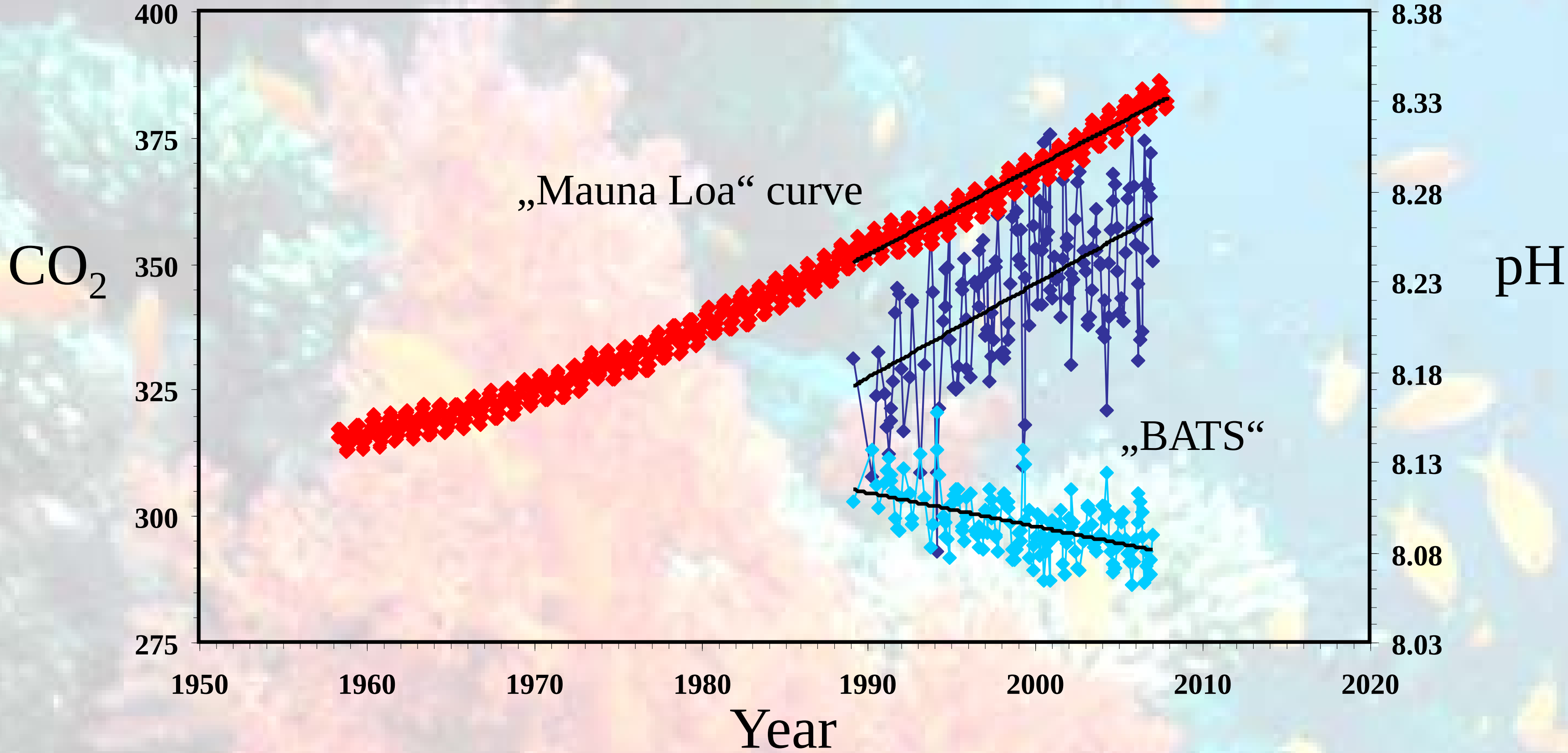
150%



Wolf-Gladrow et al., 1999

What we know about ocean CO_2 chemistry

…from time series stations

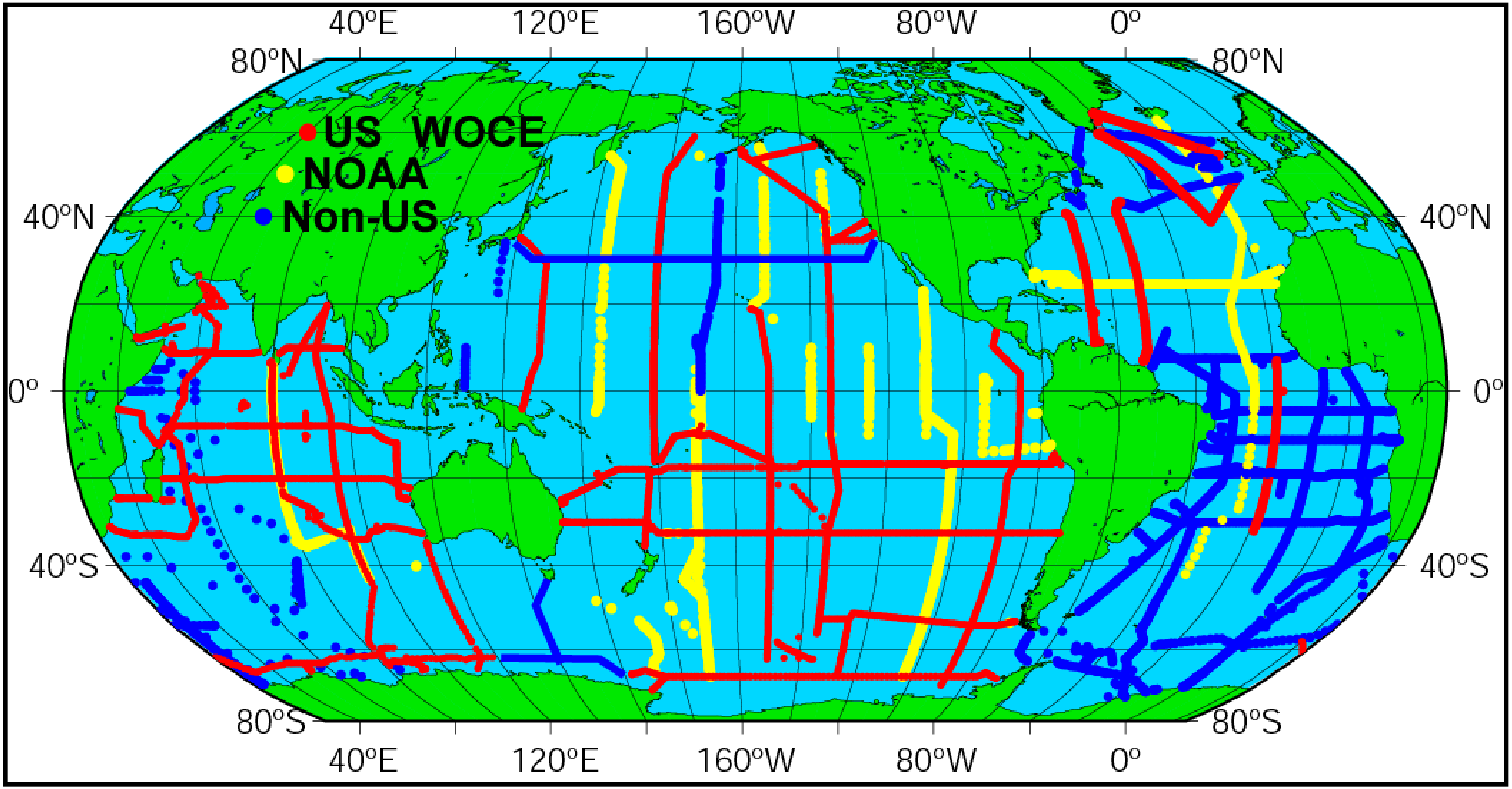


Courtesy: Richard A. Feely

NOAA/Pacific Marine Environmental Laboratory

What we know about ocean CO_2 chemistry

...from field observations



WOCE/JGOFS/OACES Global CO_2 Survey

~72,000 sample locations collected in the 1990s

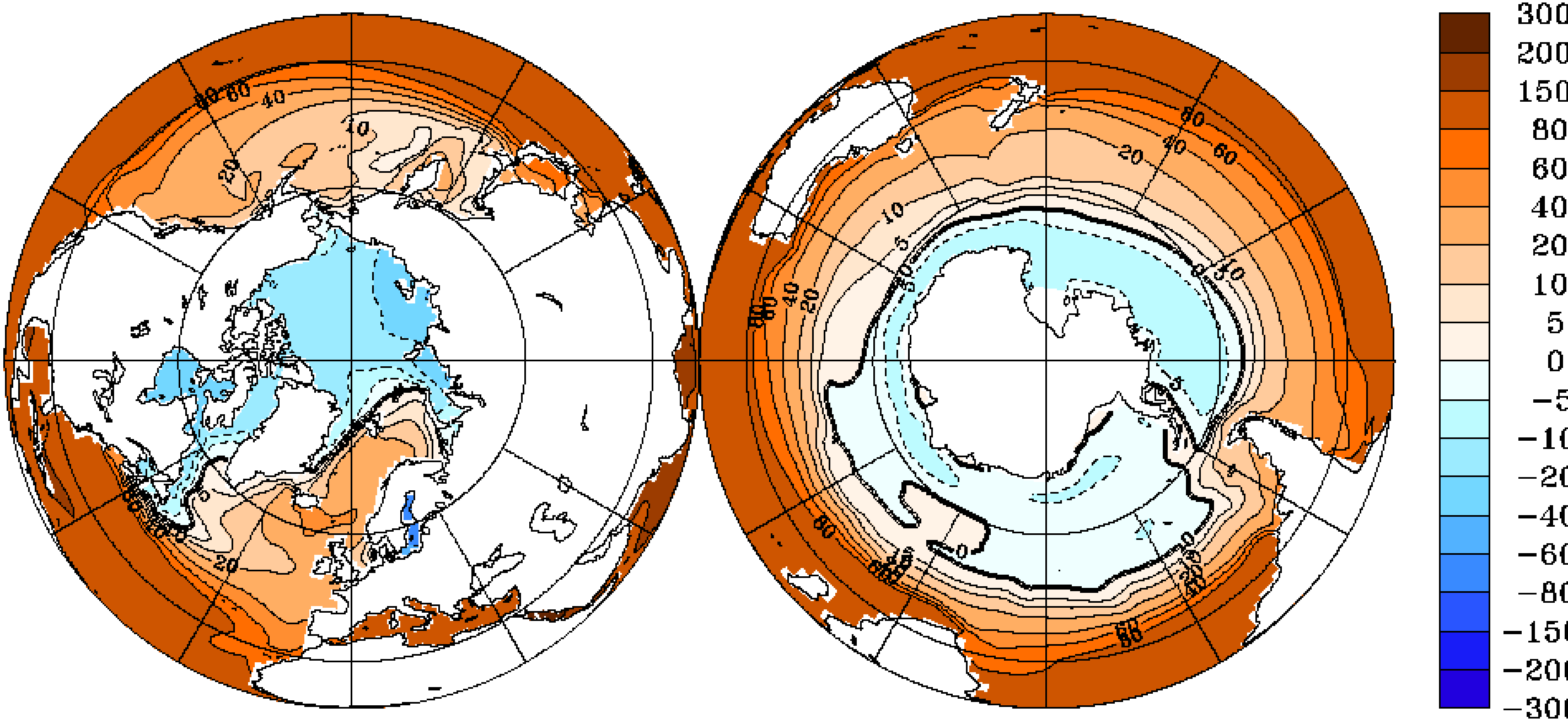
DIC 2 $\mu mol\ kg^{-1}$

TA 4 $\mu mol\ kg^{-1}$

Sabine et al (2004)

Undersaturation is strongest in the high latitudes

Aragonite undersaturation $\Delta[CO_3^{2-}]_{Arag}$ at $2xCO_2$



*Model approach assuming a simulation with +1% increase per year (model results only)

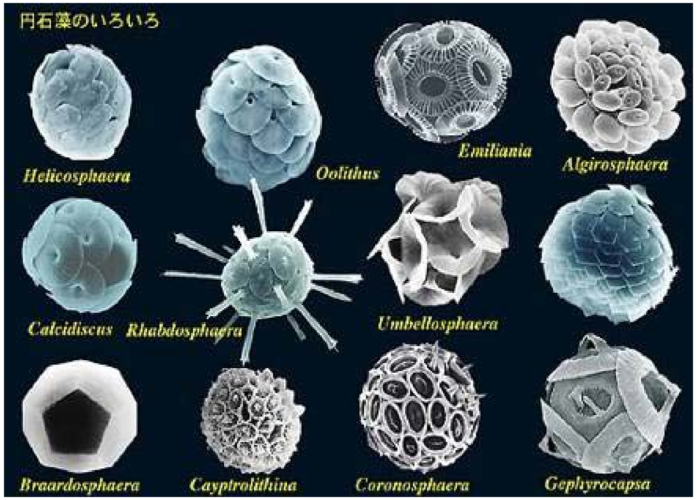
Jim Orr (CEA/IAEA)

Ocean Acidification

- Decrease in pH 0.1 over the last two centuries (30% increase in acidity; decrease in carbonate ion of about 16%)
- How will this impact marine organisms and ecosystems?

Photo: Missouri Botanical Gardens

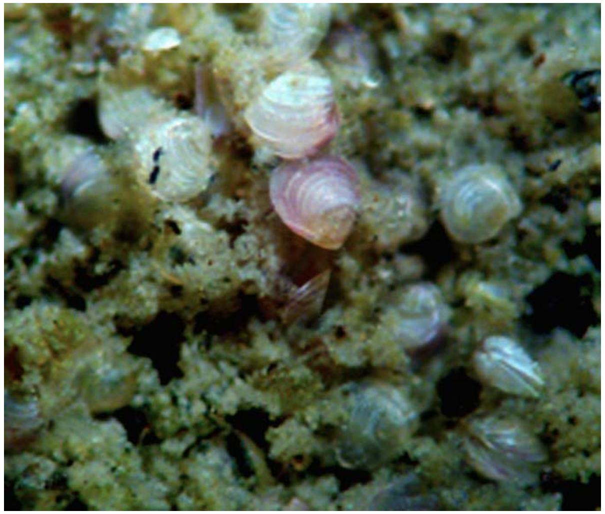
Corals



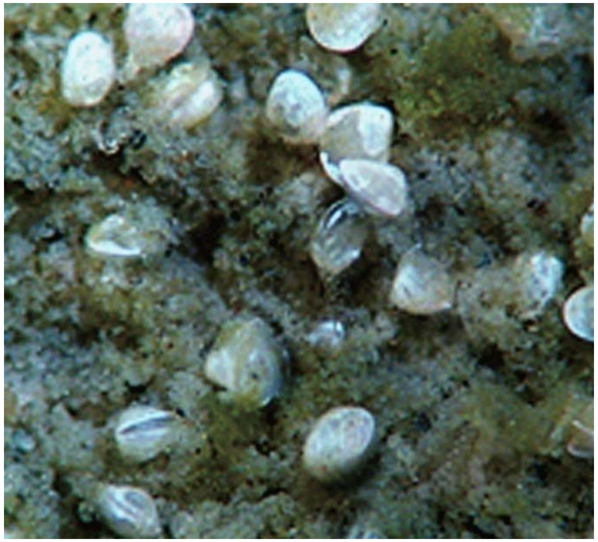
Calcareous Plankton

http://www.biol.tsukuba.ac.jp/~inouye

Bivalve juvenile stages can also be sensitive to carbonate chemistry



Control
$\Omega_A = 1.5$



$\Omega_A = 0.3$

Hard shell clam *Mercenaria*

- Common in soft bottom habitats

Used newly settled clams

- Size 0.3 mm
- Massive dissolution within 24 h in undersaturated water; shell gone w/in 2 wks
- Dissolution is source of mortality in estuaries & coastal habitats

Green et al., 2004

Potential impacts of high CO_2 on marine fauna

- Adverse effects on reproductive success
  - Decreased fertilization rates (sea urchins, bivalves)
  - Increased juvenile mortality (bivalves, sea urchins, copepods, fish larvae)

- Reduced growth in adults (sea urchins, bivalves)
- Impaired oxygen transport (squid)

- Reduced metabolism/scope for activity (squid)

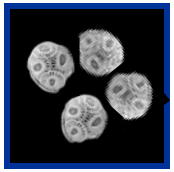
Potential Ecosystem Responses

Changes in relative abundance & distribution of calcifying species

- Non-calcifying species may outcompete calcifiers
- Geographical ranges of calcifying species may shift
- Vertical depth distributions of calcifying species may shoal with decreasing $CaCO_3$ saturation state

Changes in food webs and other species interactions

Potential Effects on Open Ocean Food Webs



Coccolithophores

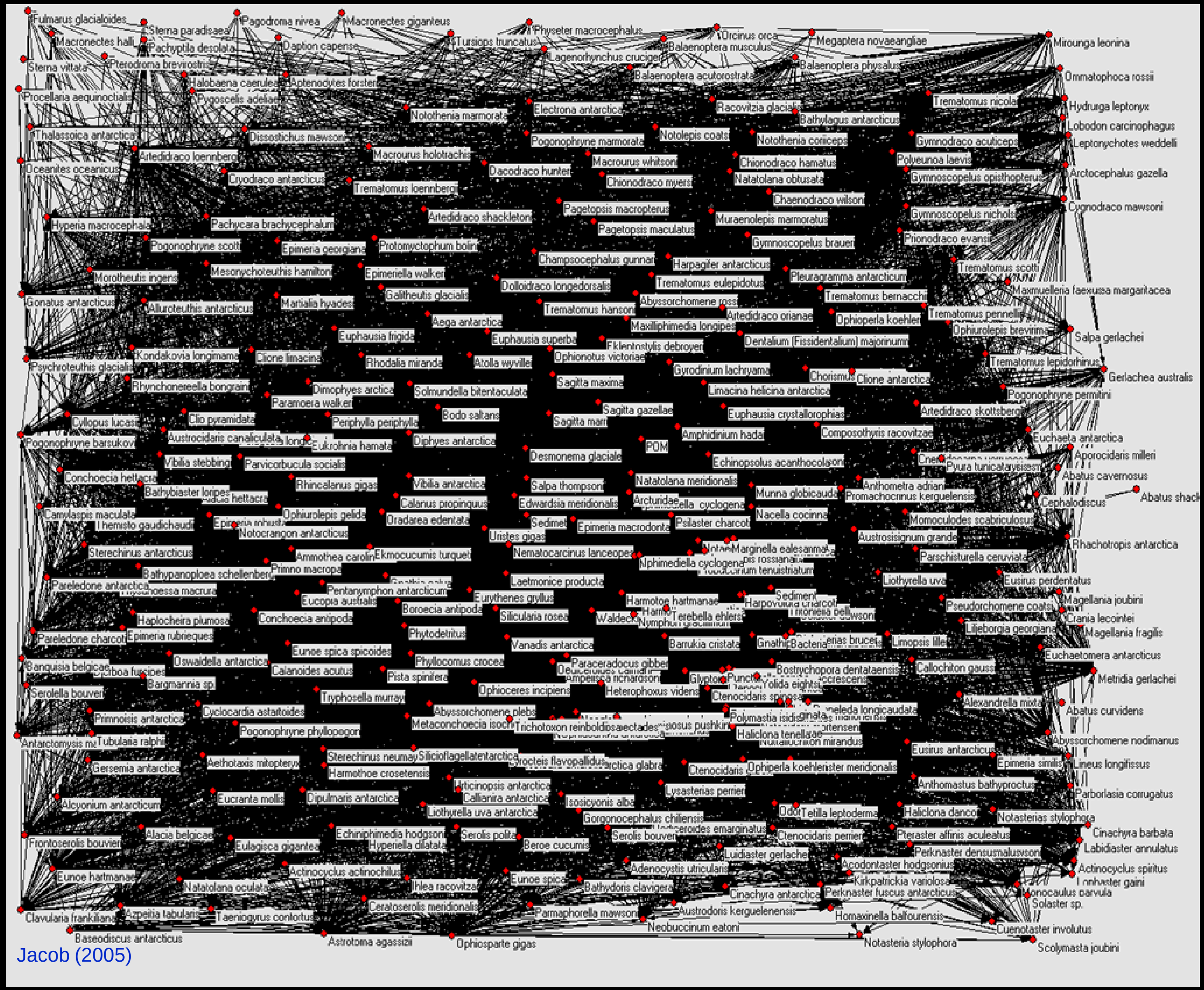
ARCOD@ims.uaf.edu

Copepods

Pacific Salmon

Vicki Fabry

Weddell Sea Food Web: 489 species (incl 62 autotrophs, >16000 trophic links (Jacob, 2005)



Potential Ecosystem Responses

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Changes in food webs and other species interactions

Impacts on biogeochemical cycles

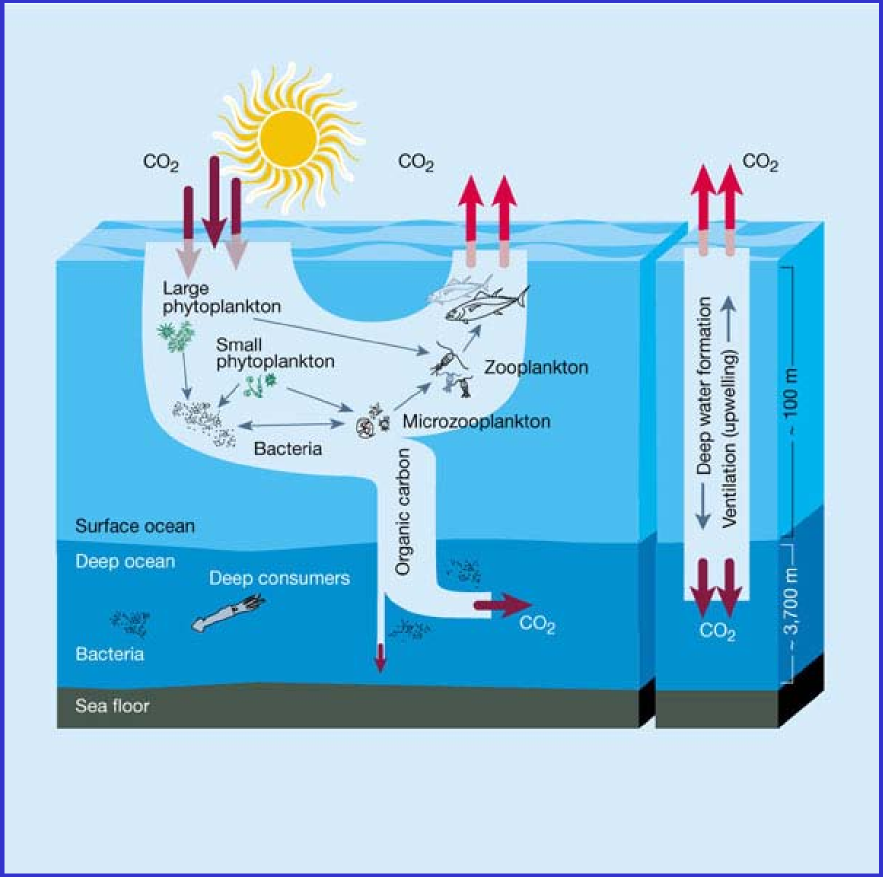
- Speciation of nutrients and trace metals
- Changes in cycling of carbon and $CaCO_3$ within oceans (e.g. "ballasting")
- Changes in the "microbial loop"
- Feedbacks to climate

The global carbon cycle is largely driven by biology: How will the „biological pump" respond to OA?

What happens if biology is turned of?

<u>**The „Strangelove ocean":**</u>

- **The biological pump stops**
- **The surface-deep CO_2 gradient disappears**
- **Within 250 yrs atmospheric CO_2 increases 2.4 times**



see: Maier-Reimer, Mikolajewicz and Winguth (1996); Zeebe and Westbroek (2003)

Wrap up ....

- Oceans are stabilising global warming (but very slowly) ....

- At the same time are oceans acidifying (very fast) ....

- Society is facing double trouble....

Ocean acidification: a biogeological perspective

Jelle Bijma (AWI, Bremerhaven, Germany)

- Ocean acidification: present and future . . . . .
- Why a biogeological perspective?
- Ocean acidification in the past . . . . .
- Consequences for Biodiversity . . . . .

Biological aspects

Real world

- comprises the actual complexity of the chemical, biological and ecological systems and interactions between them

Real time

- capture the time component inherent to carbonate perturbation and physiological and ecosystem response

Limitations

- gradual change makes it difficult to identify responses
- complexity of biology itself
- difficulty to capture longer term processes such as ecological adaptation, evolution and, biogeochemical cycles
- no information on recovery processes

Why paleo?

The farther backward you can look, the farther forward you are likely to see.” Winston Churchill

- What has happened *can* happen (e.g. perturbation of ocean chemistry)
- Long-term (natural) context for recent changes
- Investigate the impact on biogeochemical cycles
- Reduced complexity (integration of space and time)
- Different time scales (historical/sub-recent, G-IG, deep time,….)
- Process of recovery
- Different scenarios as case and sensitivity studies and testbeds for models

Limitations

- limited biological information (hard parts and biomarkers)
- limited by accuracy of proxy reconstructions
- restrictions on temporal and spatial resolution
- no perfect analogues

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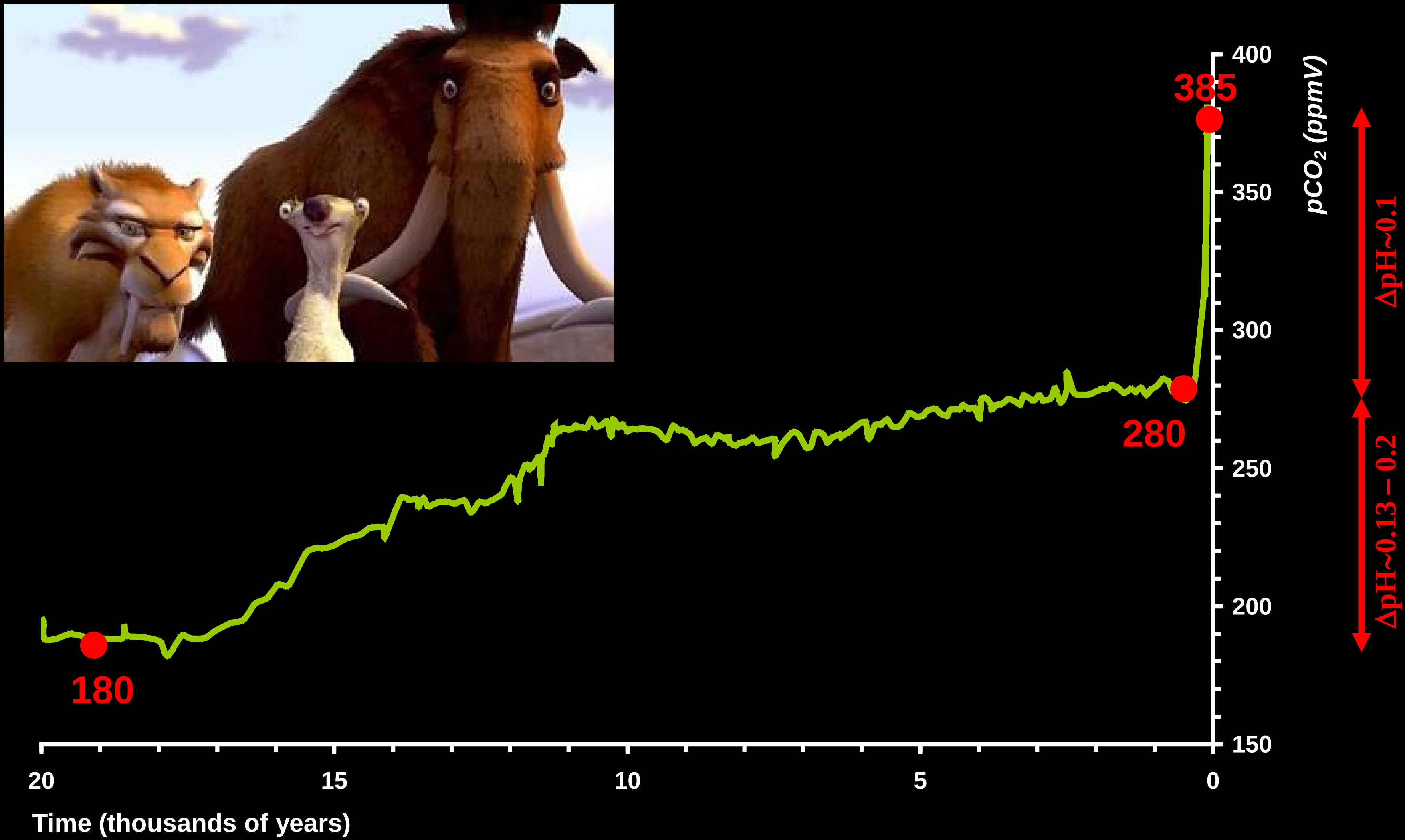
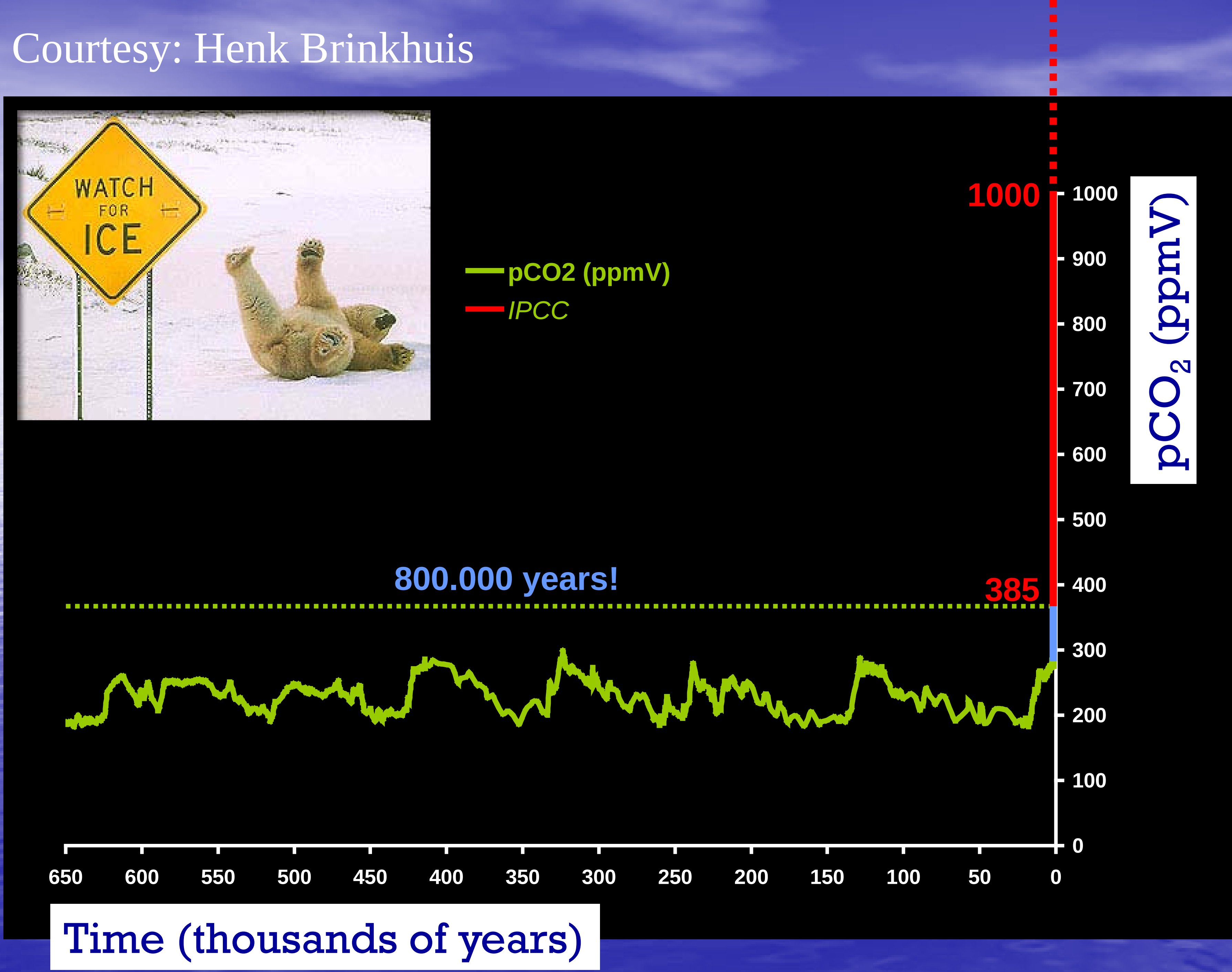
- Ocean acidification in the past . . . . .
- Consequences for Biodiversity . . . . .

Courtesy: Henk Brinkhuis

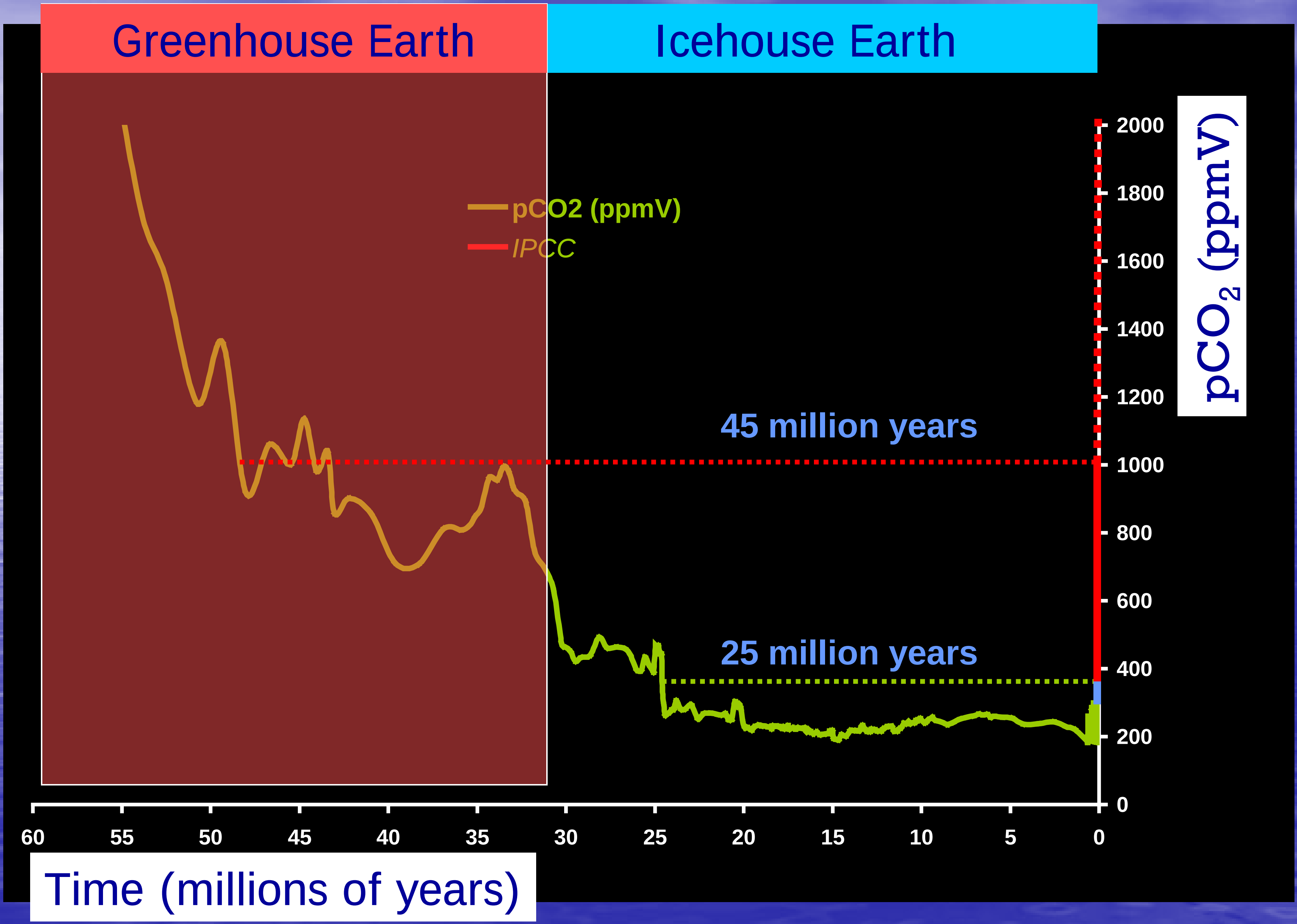
De Last Ice age



Courtesy: Henk Brinkhuis

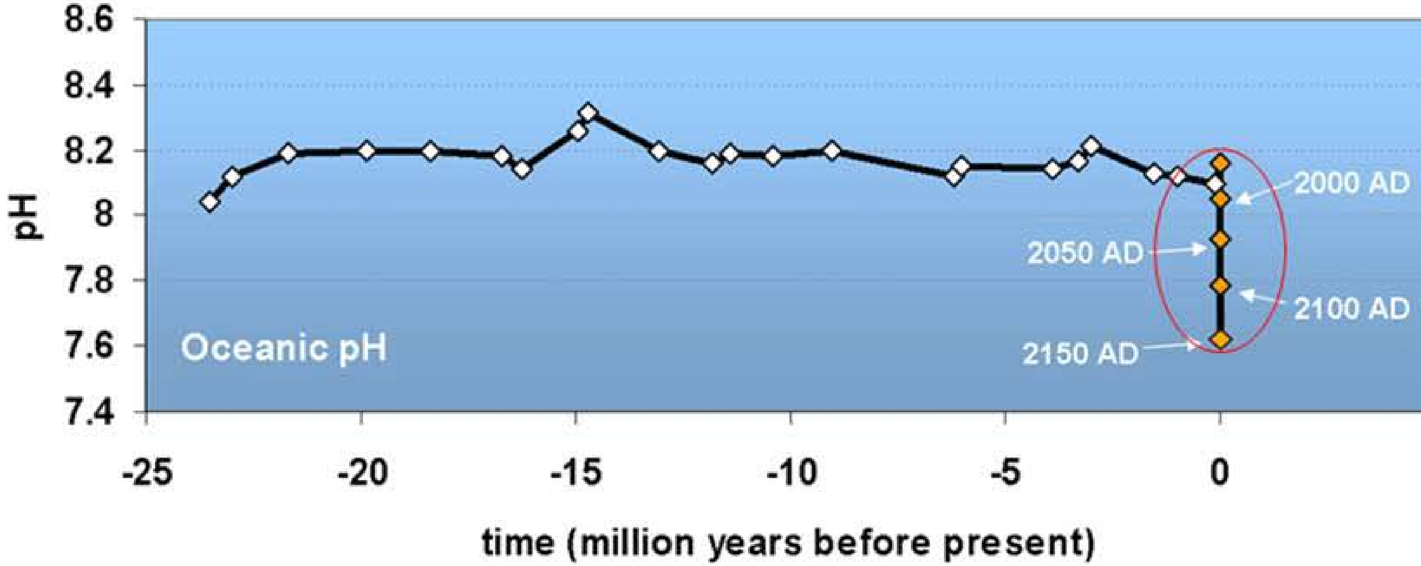


Courtesy: Henk Brinkhuis



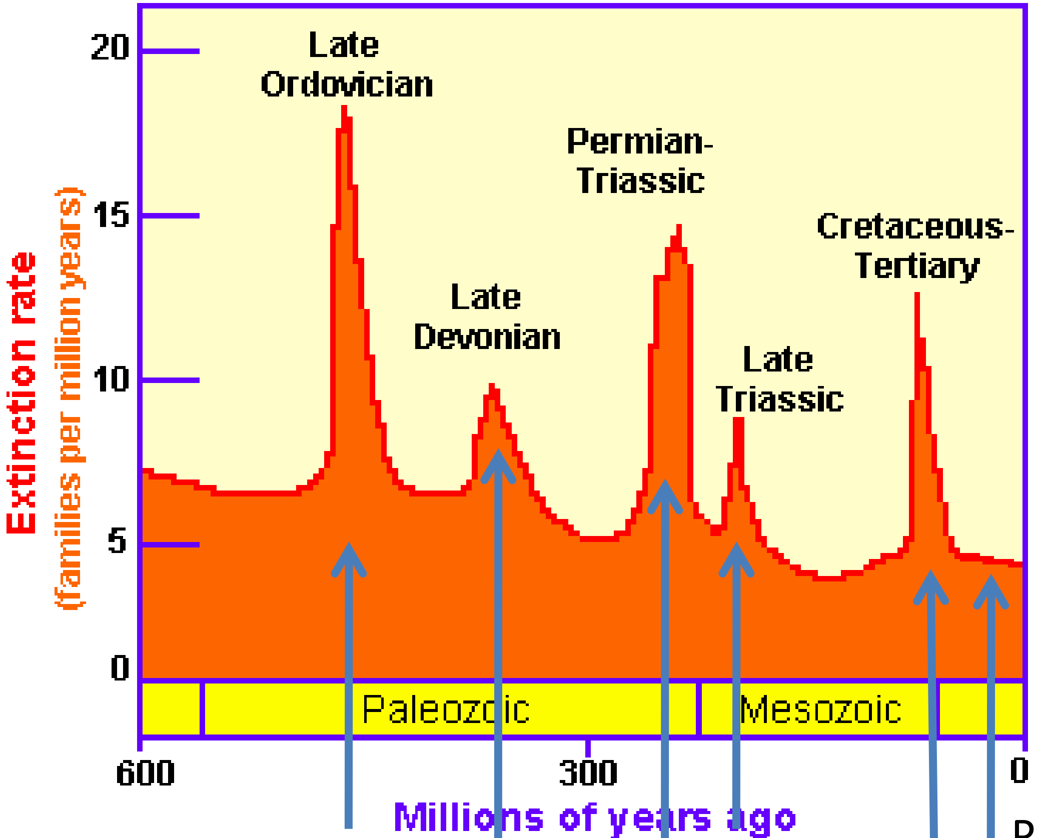
Oceans are Acidifying Fast ……….

Changes in pH over the last 25 million years



It is happening now, at a rate and to a level not experienced by marine organisms for ~ 20MY

Turley et al. 2006



Ord.-Silurian

Viluy traps (Eastern Siberia)

Siberian traps

Trias-Jurasic (CAMP)

Deccan traps; Asteroid impact

PETM; 55Myr

Carbon pertubation (symtoms):

- Global warming
- Ocean acidification
- Anoxia

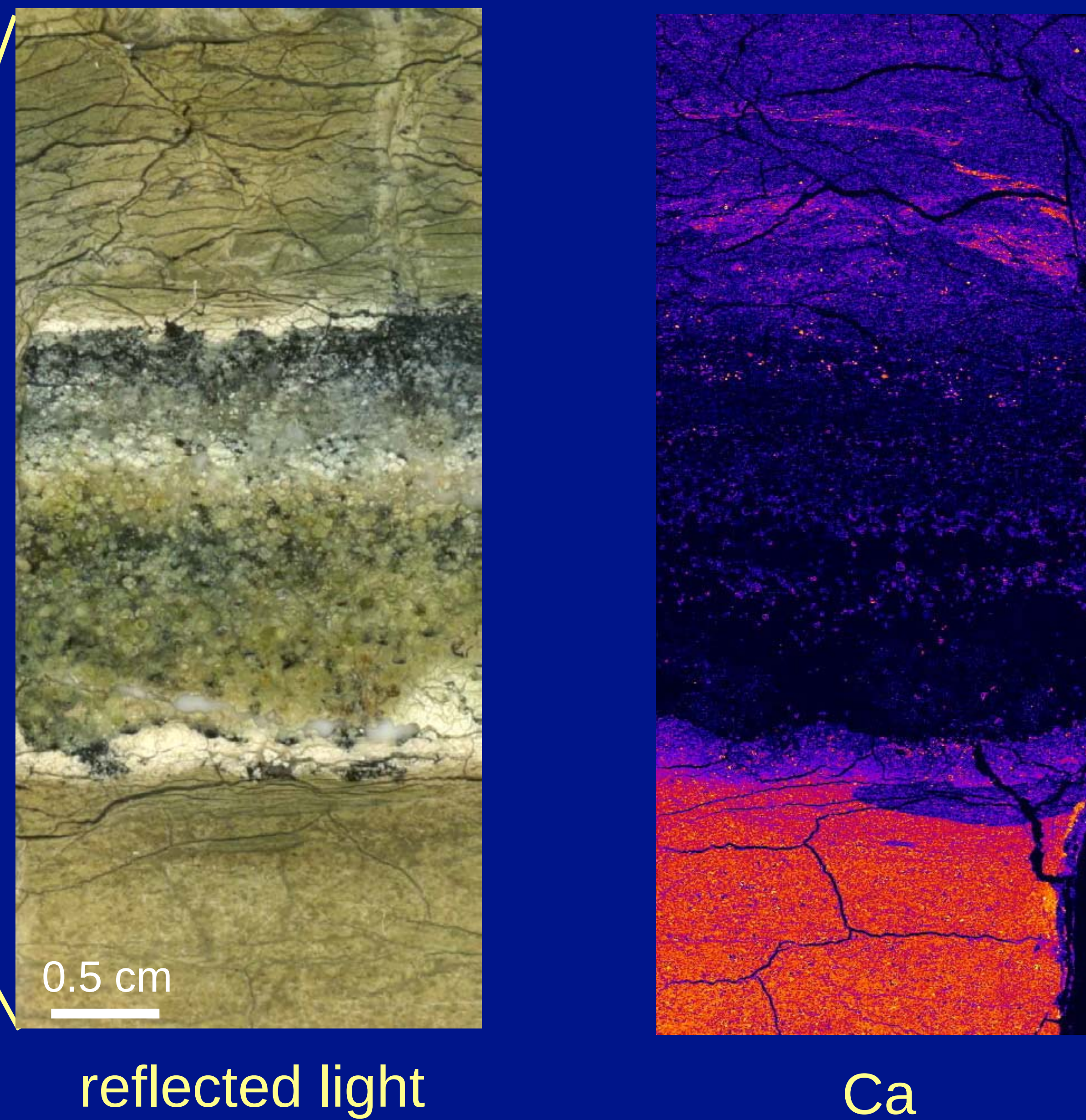
Evidence:

- Elevated pCO_2 (global warming)?
- Reduced pH?
- Reduced Ω?
- Anoxia?

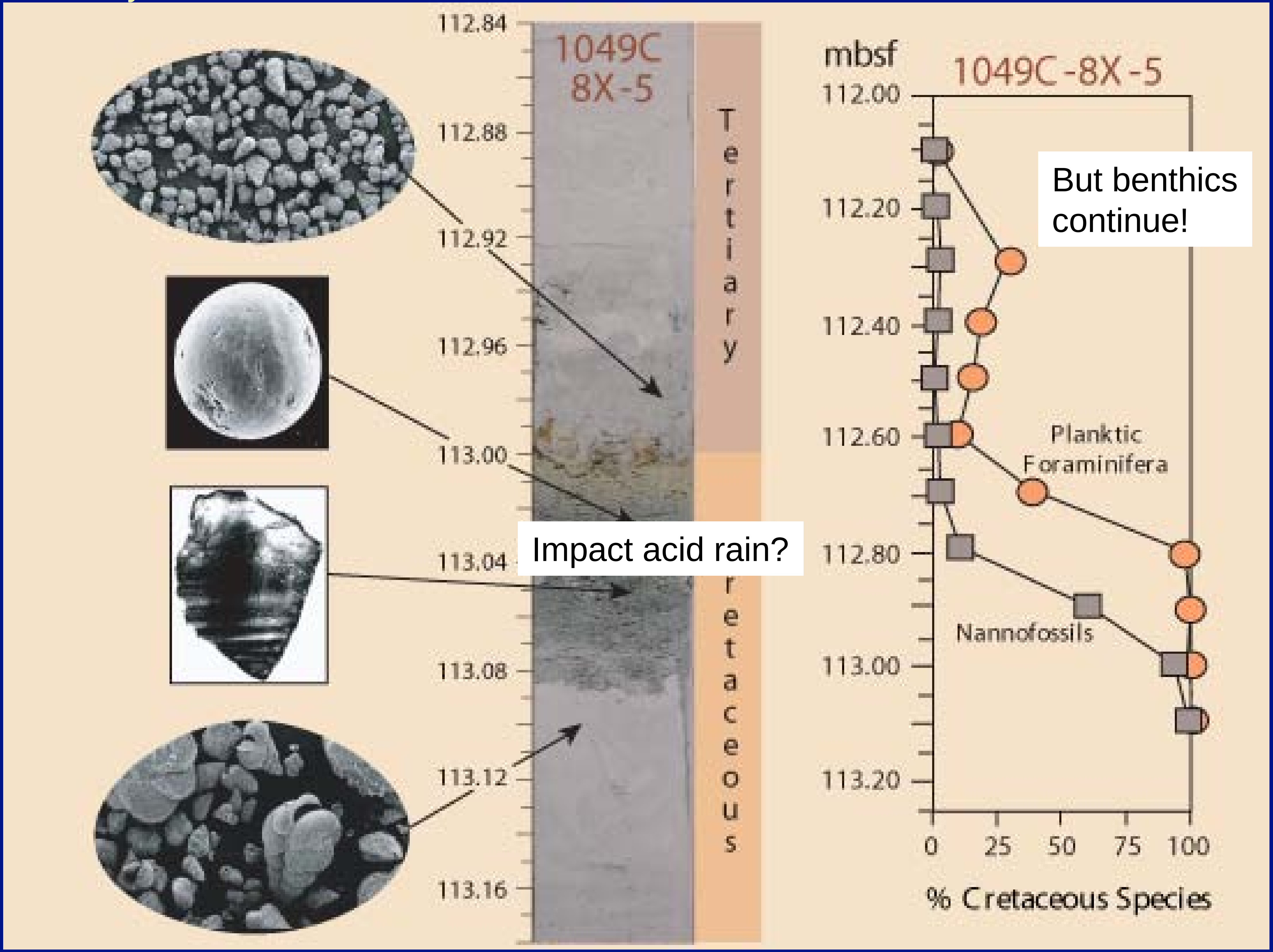
Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)

Hole 1259B 13R, 37-60 cm- boundary interval



Courtesy: Brian Huber



Response of marine biota to OA and climate change

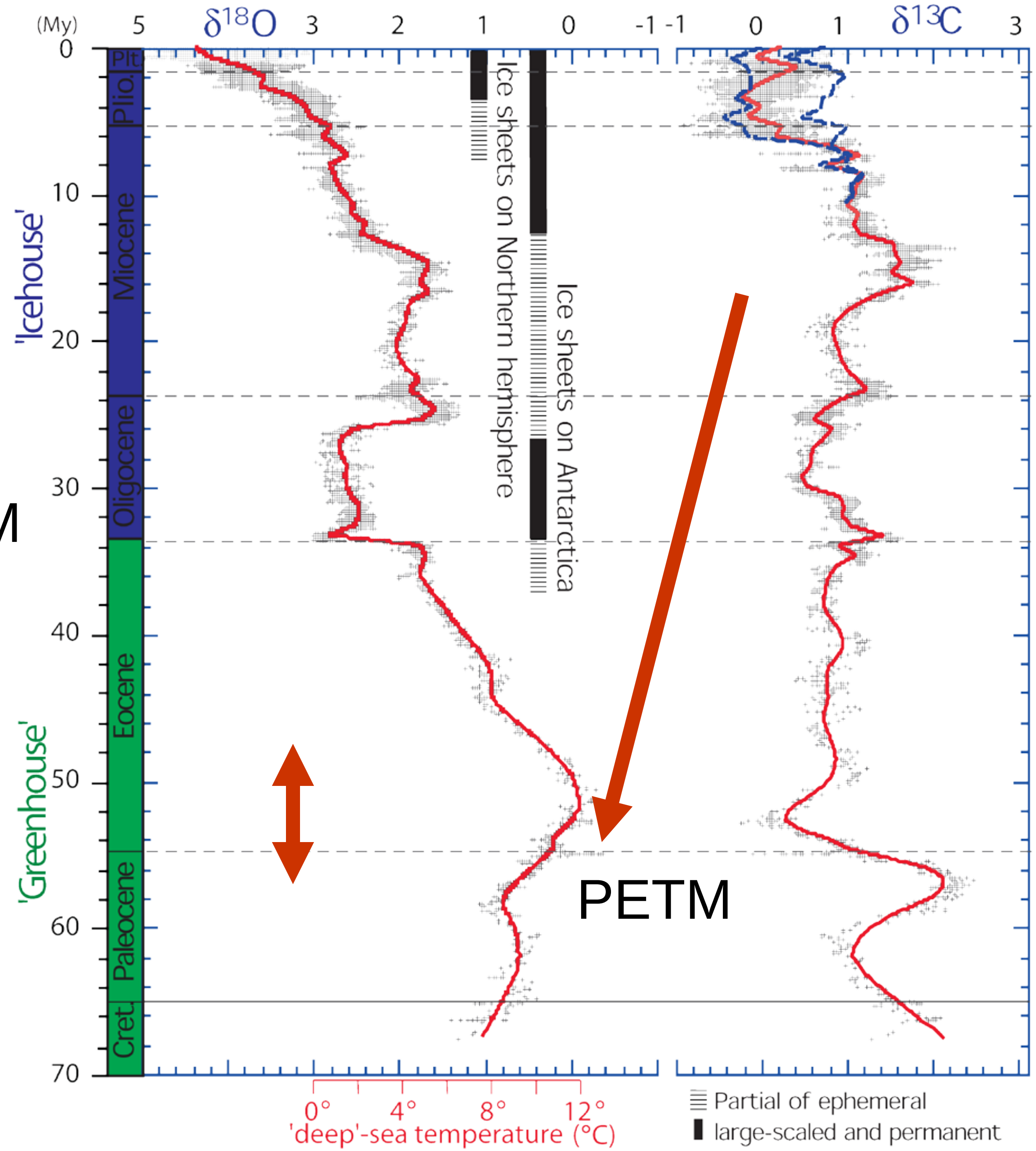
- Strong perturbation at a fast rate → K/T impact (major planktonic extinction)

- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)

Cenozoic
long-term trends

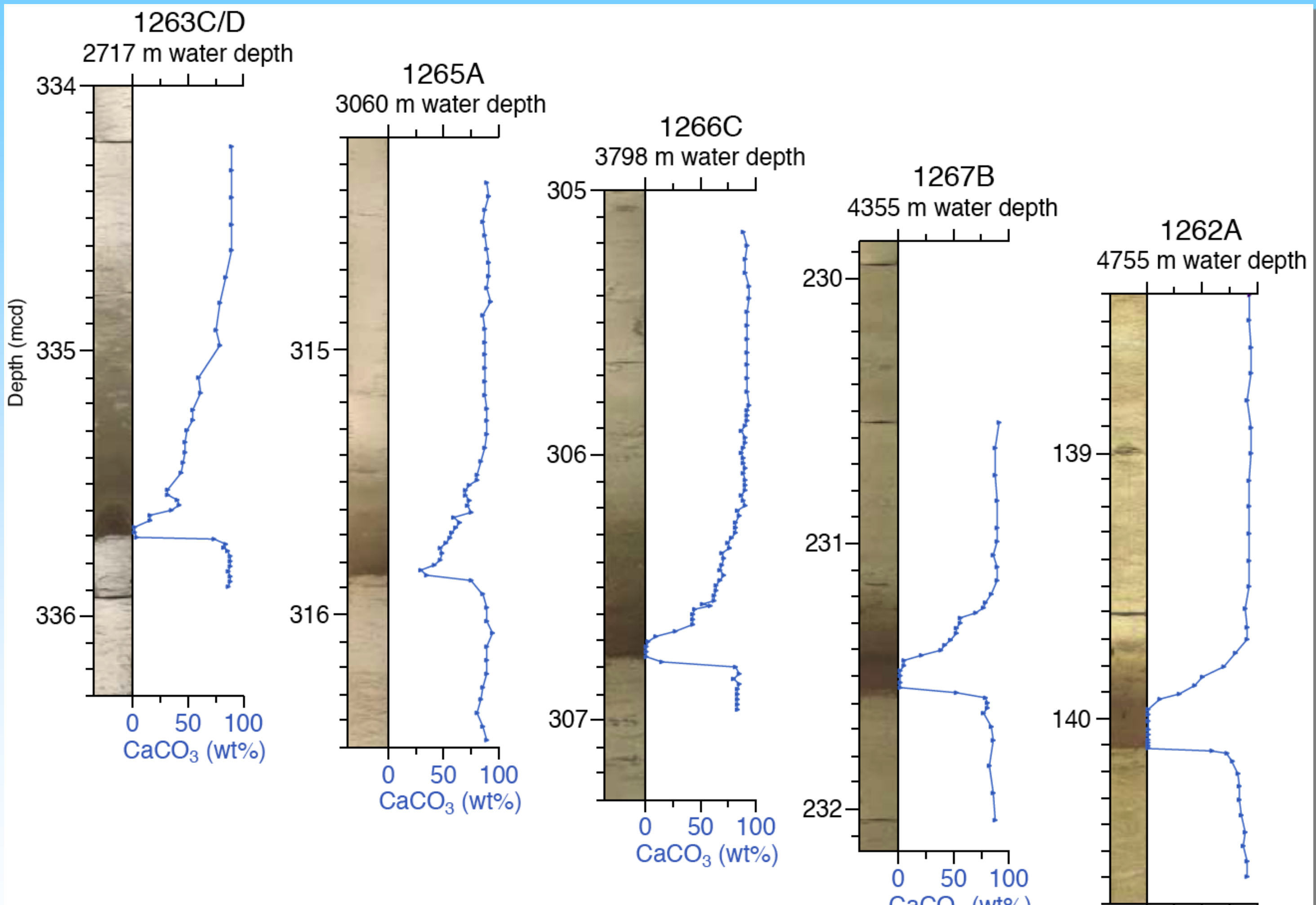
Early Eocene: warm
superimposed: PETM

One of the largest
benthic mass
Extinction in Earth
history



Zachos et al., 2001

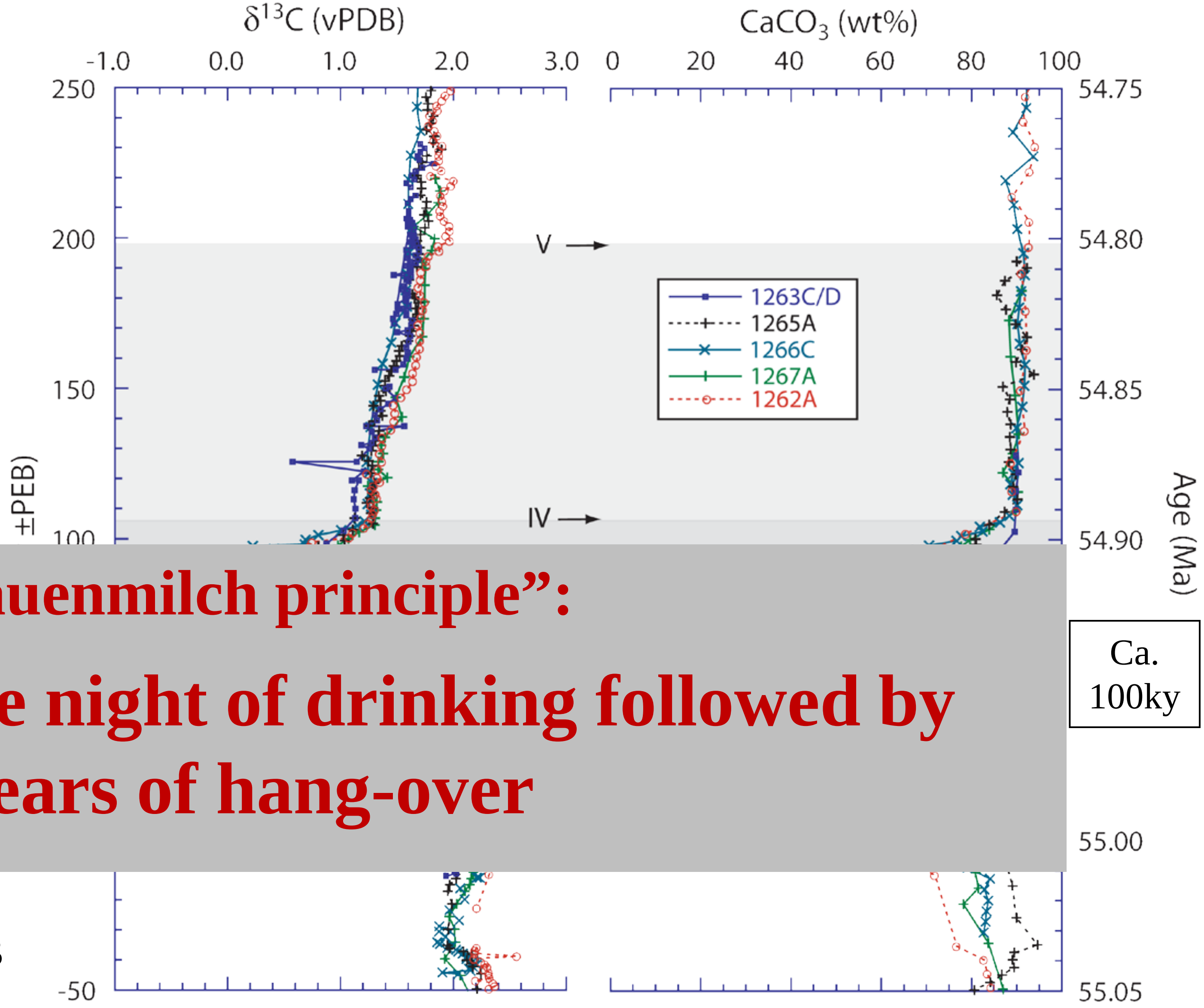
Ocean Carbonate; Walvis Ridge ODP Leg 208



ODP 208 Walvis Ridge, Zachos *et al.*, 2005

„Carbonate compensation“: as lysocline is rising it destroys benthic habitats

Oceanic recovery. Walvis Ridge ODP Leg 208



"Liebfrauenmilch principle":

One night of drinking followed by 2 years of hang-over

Ca. 100ky

Zachos et al., Science 2005

Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)
- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)
- Small perturbation at a slow rate → Neogene, G-IG (acclimation/adaptation)

Geochemistry Geophysics Geosystems G3
AN ELECTRONIC JOURNAL OF THE EARTH SCIENCES
Published by AGU and the Geochemical Society

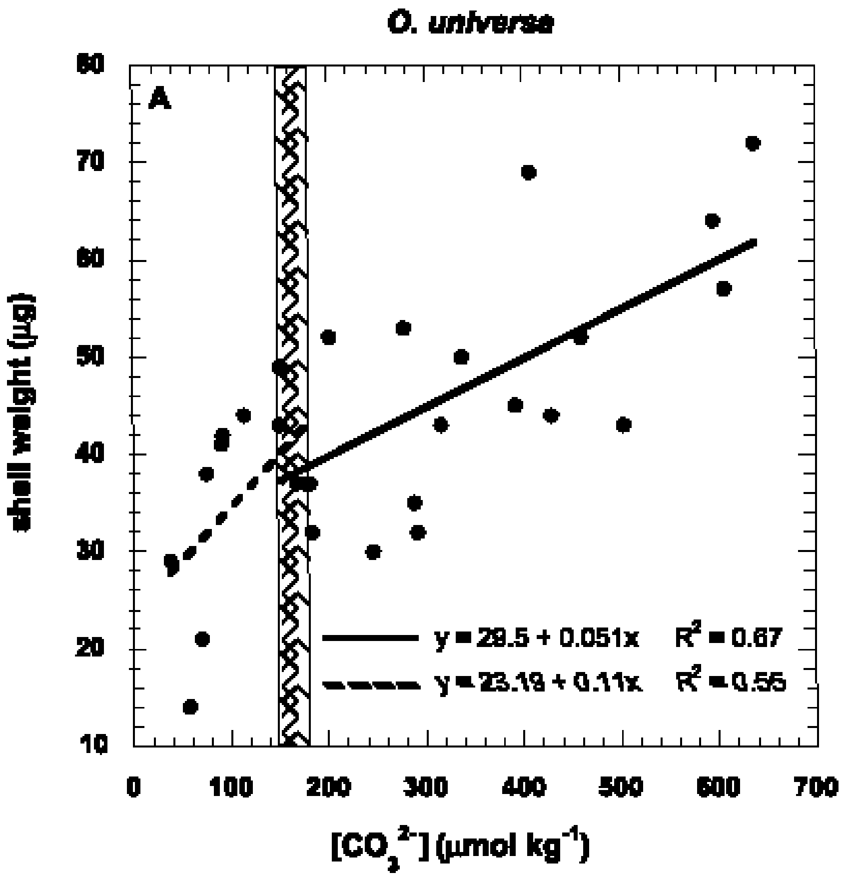
Comment
Volume 3, Number 11
8 November 2002
1064, doi:10.1029/2002GC000388
ISSN: 1525-2027

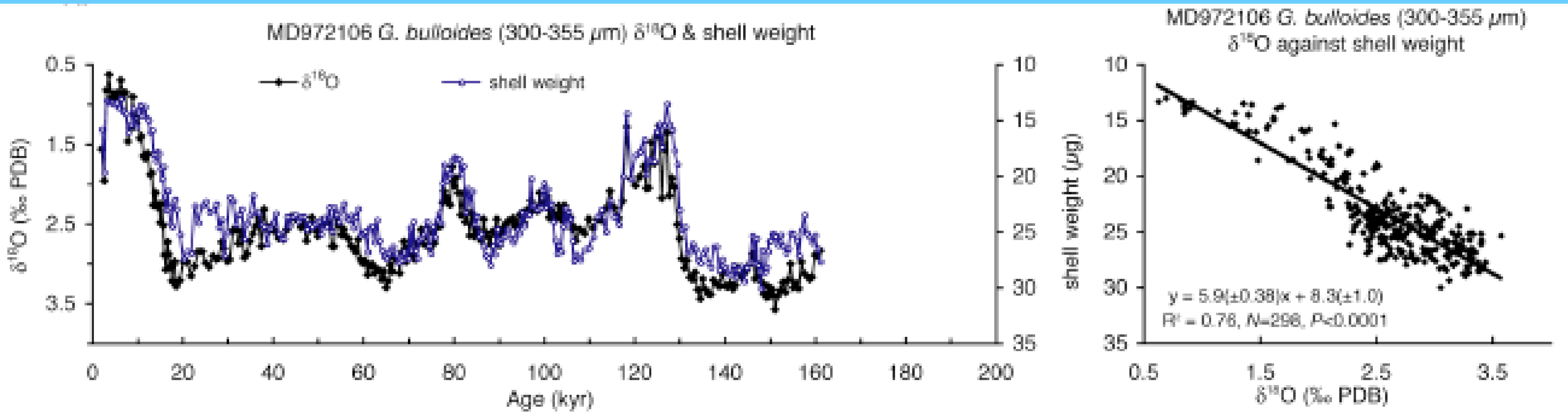
Impact of the ocean carbonate chemistry on living foraminiferal shell weight: Comment on "Carbonate ion concentration in glacial-age deep waters of the Caribbean Sea" by W. S. Broecker and E. Clark

Jelle Bijma, Bärbel Hönisch, and Richard E. Zeebe
Alfred Wegener Institute, Am Handelshafen 12, Bremerhaven, D-27570, Germany
(jbijma@awi-bremerhaven.de; bhoenisch@awi-bremerhaven.de; rzeebe@awi-bremerhaven.de)

$\Delta[CO_3^{2-}]_{G\text{-}IG} \rightarrow 100 \mu mol\ kg^{-1}$

ca. 15% shell weight change



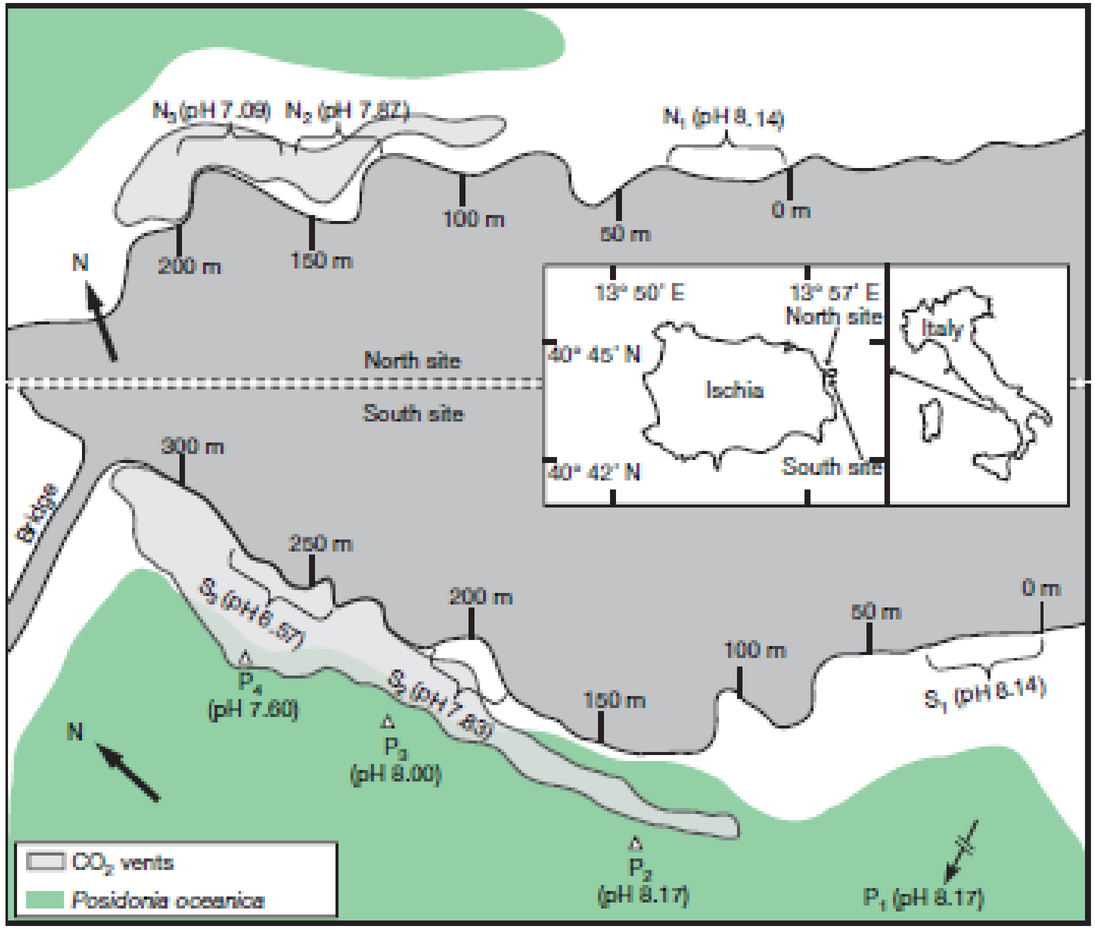


Moy, 2005

$\Delta[CO_3^{2-}]_{G\text{-}IG} \rightarrow 100\mu mol\ kg^{-1}$

ca. 50% shell weight change!

CO_2 Vents: "Windows" into High CO_2 Ocean to Assess Ecosystem Impacts



CO_2 Vents: "Windows" into High CO_2 Ocean to Assess Ecosystem Impacts

Hall-Spencer et al. Nature (2008)

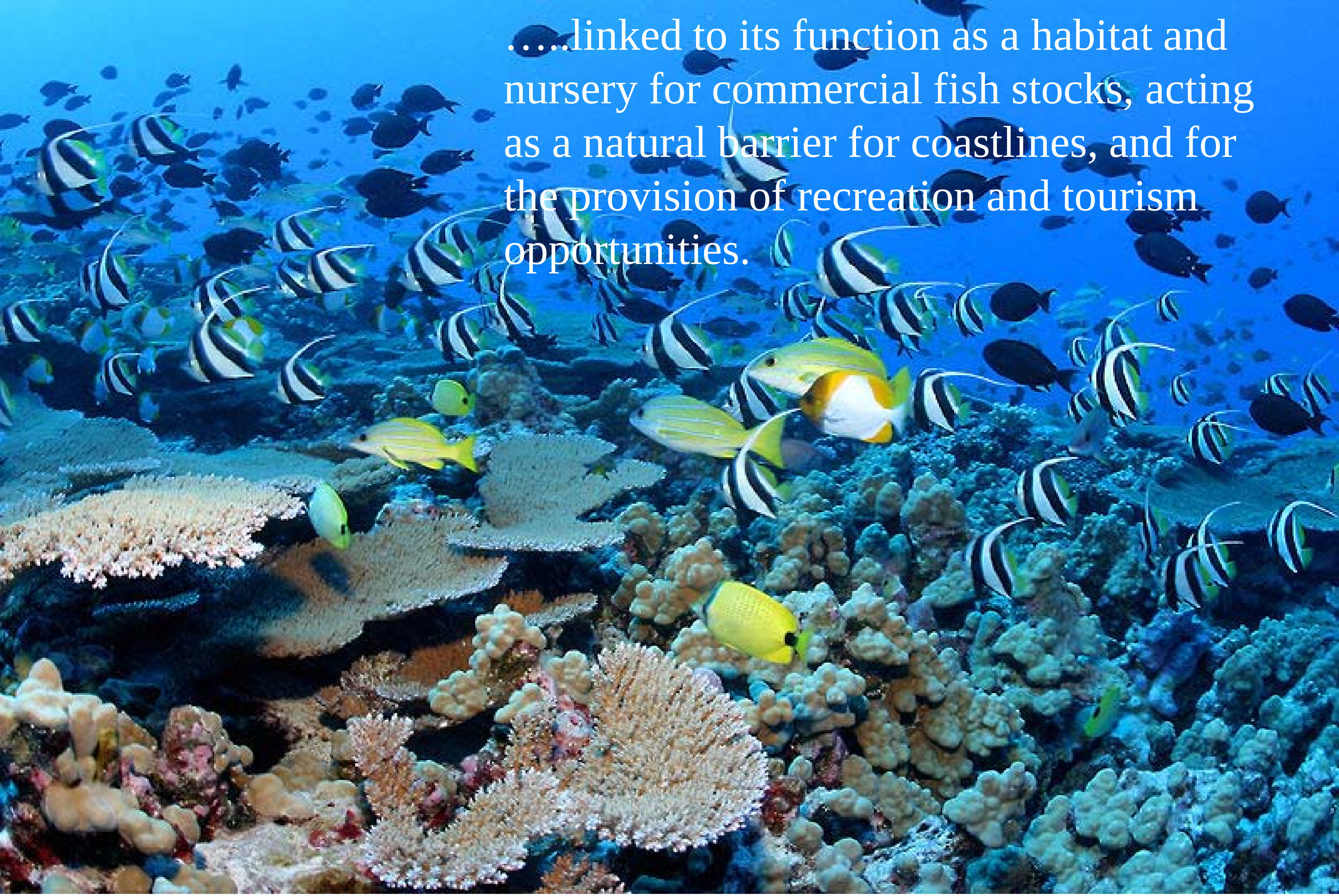
Studies in the shallow waters of the Mediterranean and deep-sea show:

- total loss of some calcareous species
- reduced biodiversity
- "regime shifts": totally different ecosystems

e.g. Sea grass benefit but so do invasive species

Response of marine biota to OA and climate change

- Strong perturbation at a very fast rate → K/T impact (major planktonic extinction)
- Strong perturbation at a „moderate“ rate → PETM (major benthic extinction)
- Small perturbation at a slow rate → Neogene, G-IG (acclimation/adaptation)
- Strong perturb. at a fast rate → Anthropocene: decrease in species richness → breakdown of ecosystems → extinction?



A conservative value of \$100,000 km^{-2} y^{-1} (Burke and Maidens, 2004), the global economic value associated with reefs is in the order of \$30 billion yr^{-1}.

Conclusions

- ocean acidification is ongoing and future changes are very well predictable
- organismal response – poor knowledge but growing (mostly calcifiers)
- ecosystem response – not known
- evolutionary capability – completely unknown
- no perfect analogue to the present – rate of change is unprecedented
- Earth history tells us that the combination of ocean acidification, global warming and anoxia is a deadly mix

PML | Plymouth Marine Laboratory

EPOCA European Project on OCean Acidification

UK Ocean Acidification Research Programme

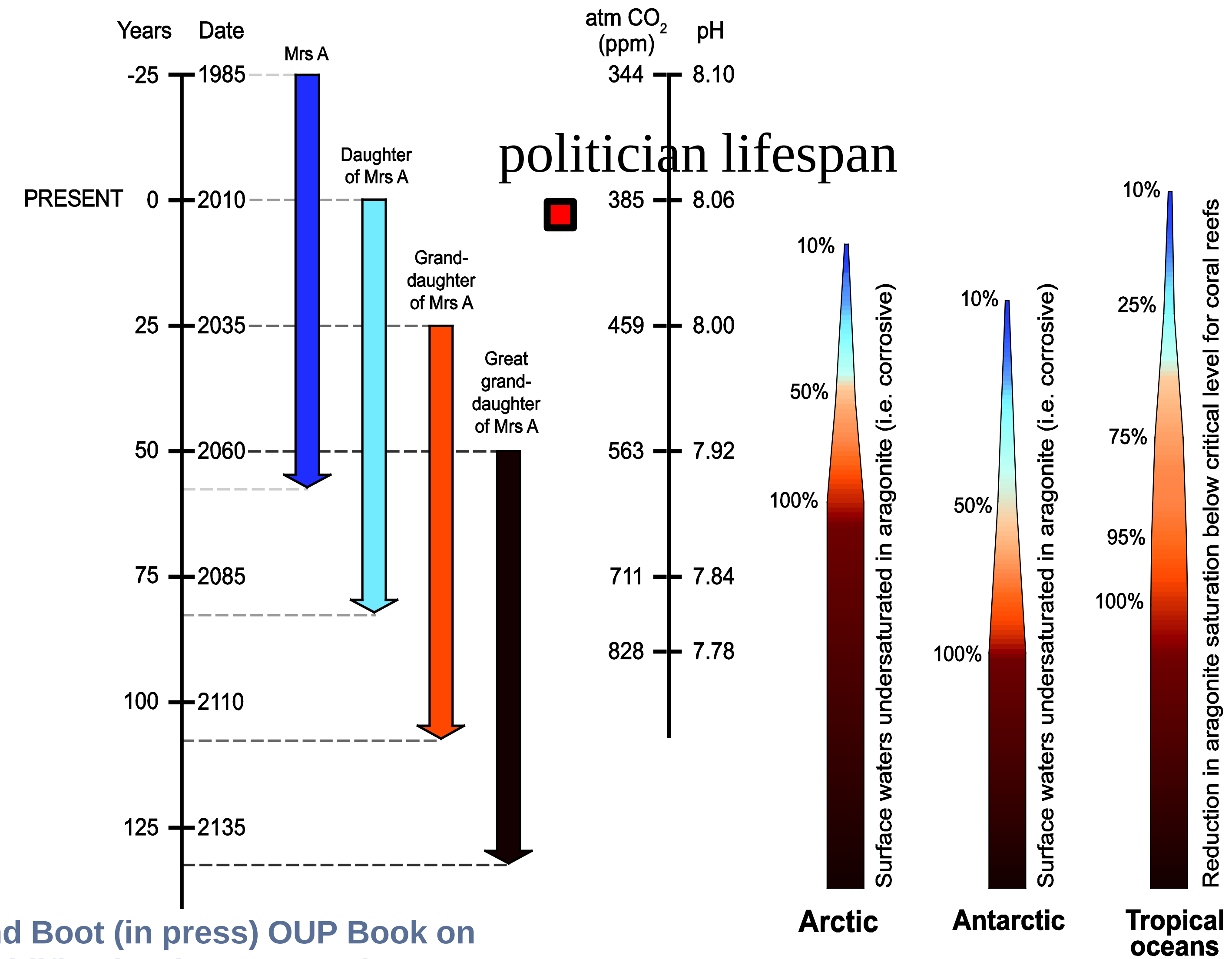
Marine Matters

Is there a tipping point in ocean acidification which should be avoided?

Carol Turley

Joint EPOCA, BIOACID UKOARP Workshop on Ocean Acidification

Potential Vulnerabilities in Relation to Human Life spans



Turley and Boot (in press) OUP Book on Ocean Acidification (Gattuso and Hansson