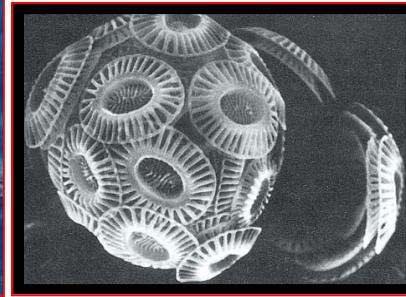
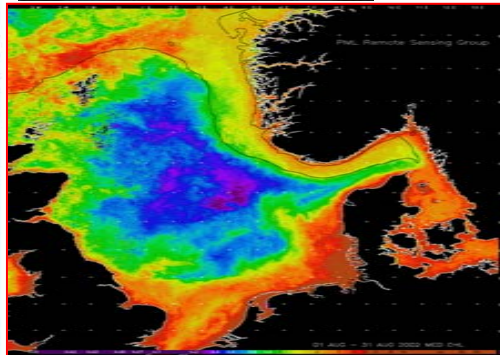


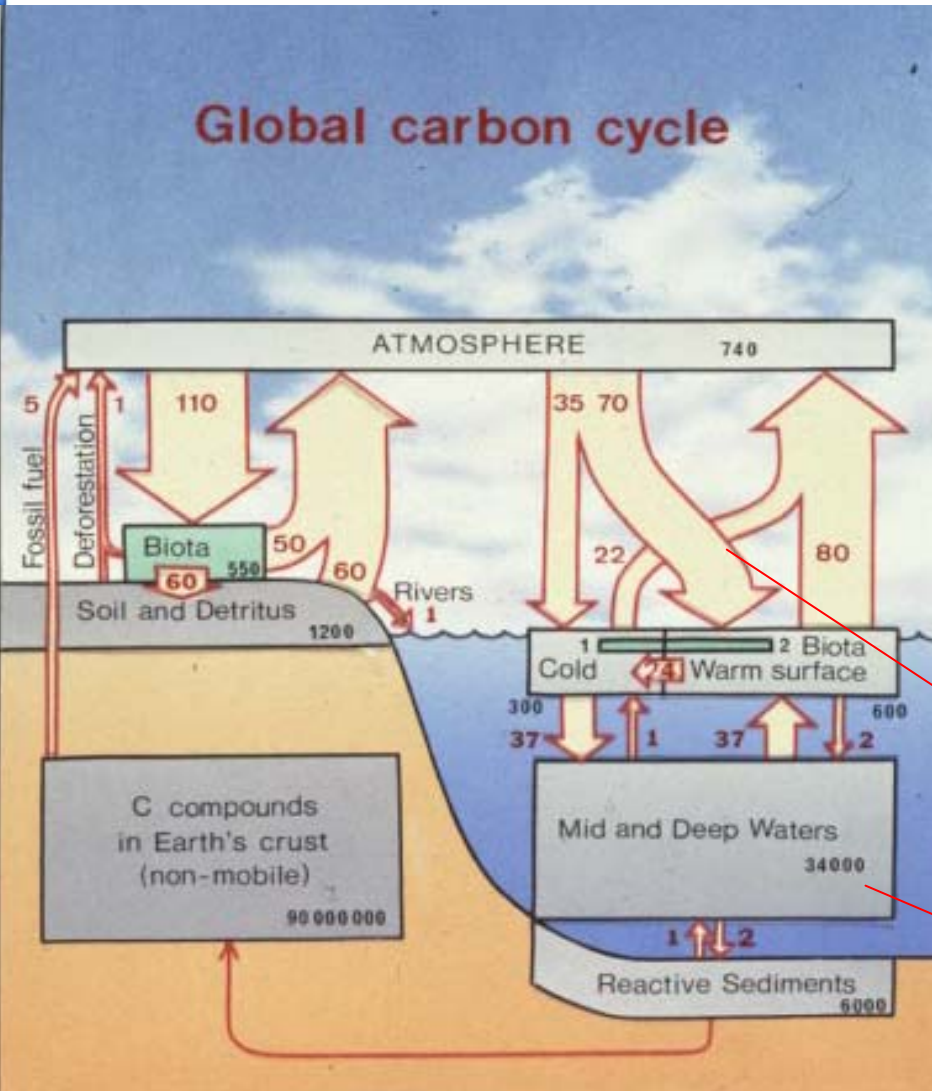
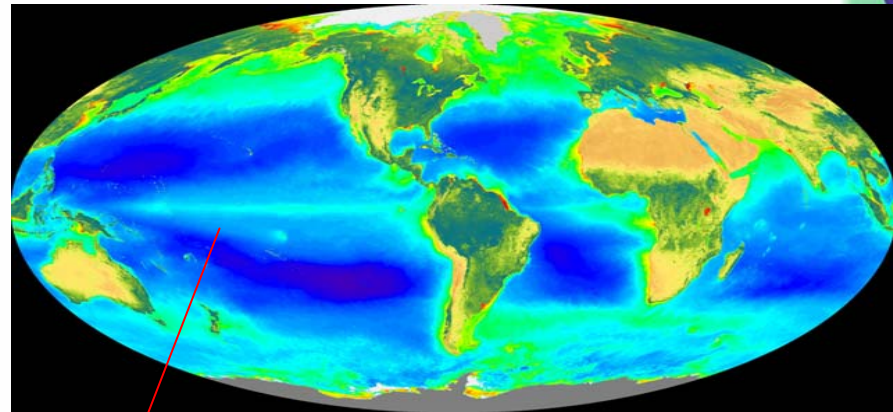
Reviewing the Impact of Increased Atmospheric CO₂ on Oceanic pH and the Marine Ecosystem

Carol Turley, Jerry Blackford, Steve Widdicombe
David Lowe, Francis Gilbert and Philip Nightingale

Plymouth Marine Laboratory, UK



Oceanic Role in the Global Carbon Cycle

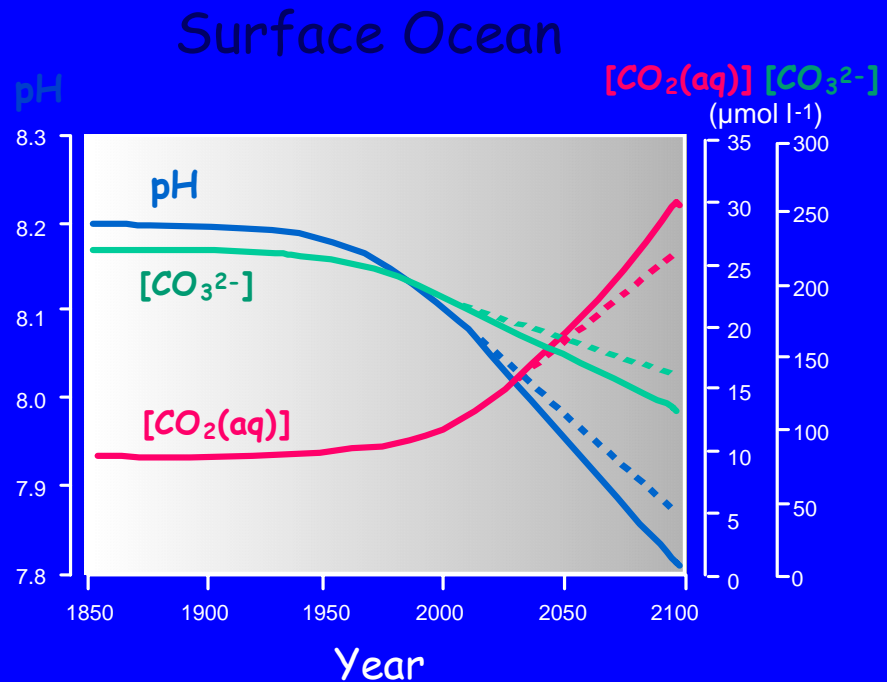
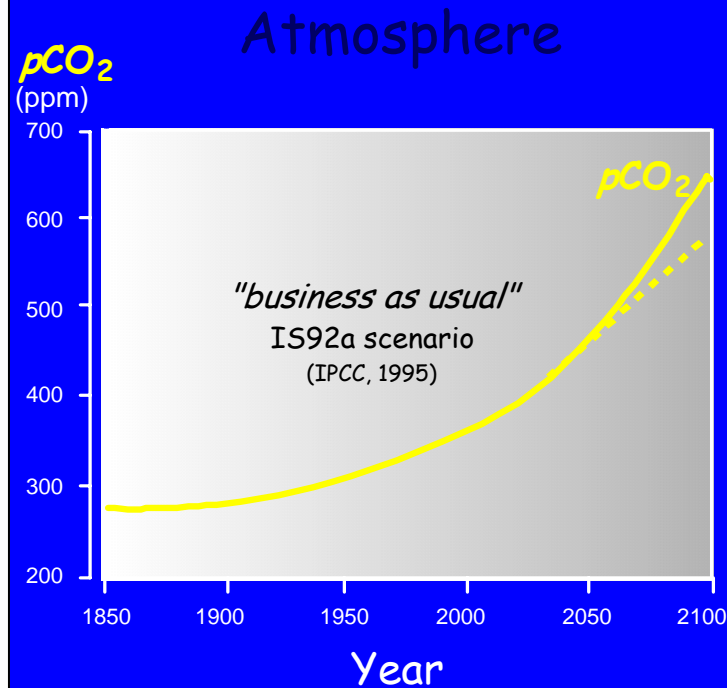
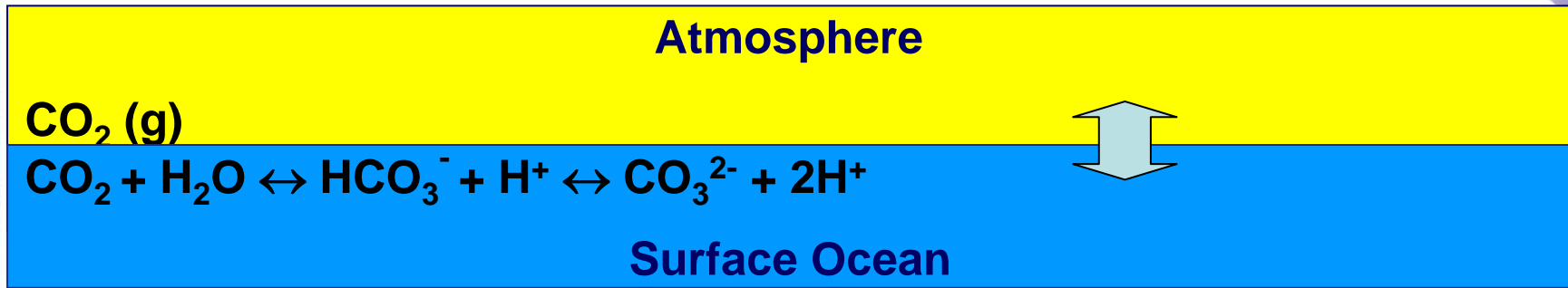


50% of global primary production is carried out in the oceans by plankton <math><10\mu\text{m}</math>

Fluxes of CO_2 in and out of the oceans are large

Oceans are an important reservoir for CO_2 with c. 50% of anthropogenic CO_2 taken up by oceans (Sabine et al. 2004 *Science*)

Oceanic Acidification

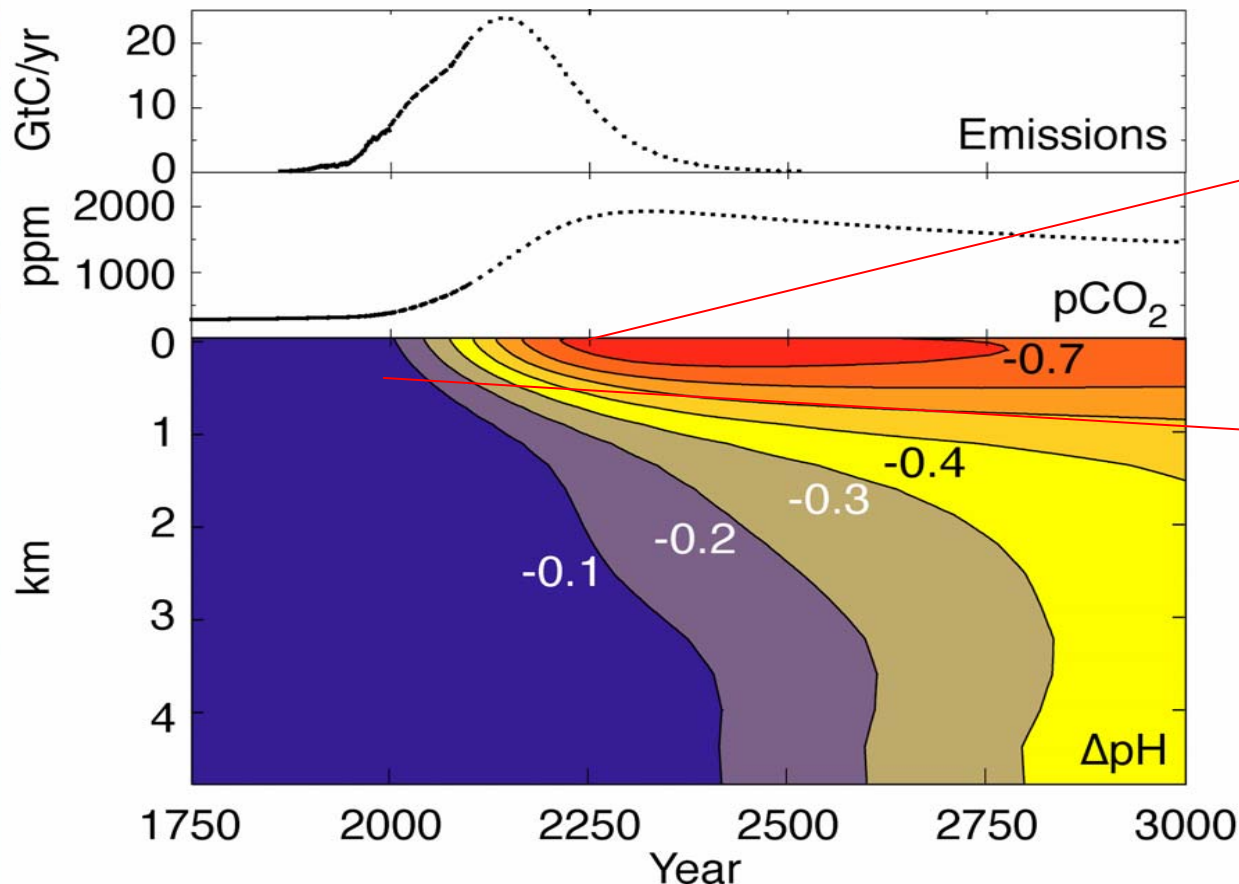


The Oceans are becoming more acid as they take up more CO₂

Wolf-Gladrow, Riebesell, Burkhardt, Bijma (1999) Tellus 51B, 461

Continued CO₂ Emissions and Ocean Acidification

While climate change has uncertainty, these geochemical changes are highly predictable. Only the time scale, and thus mixing scale length are really under debate.

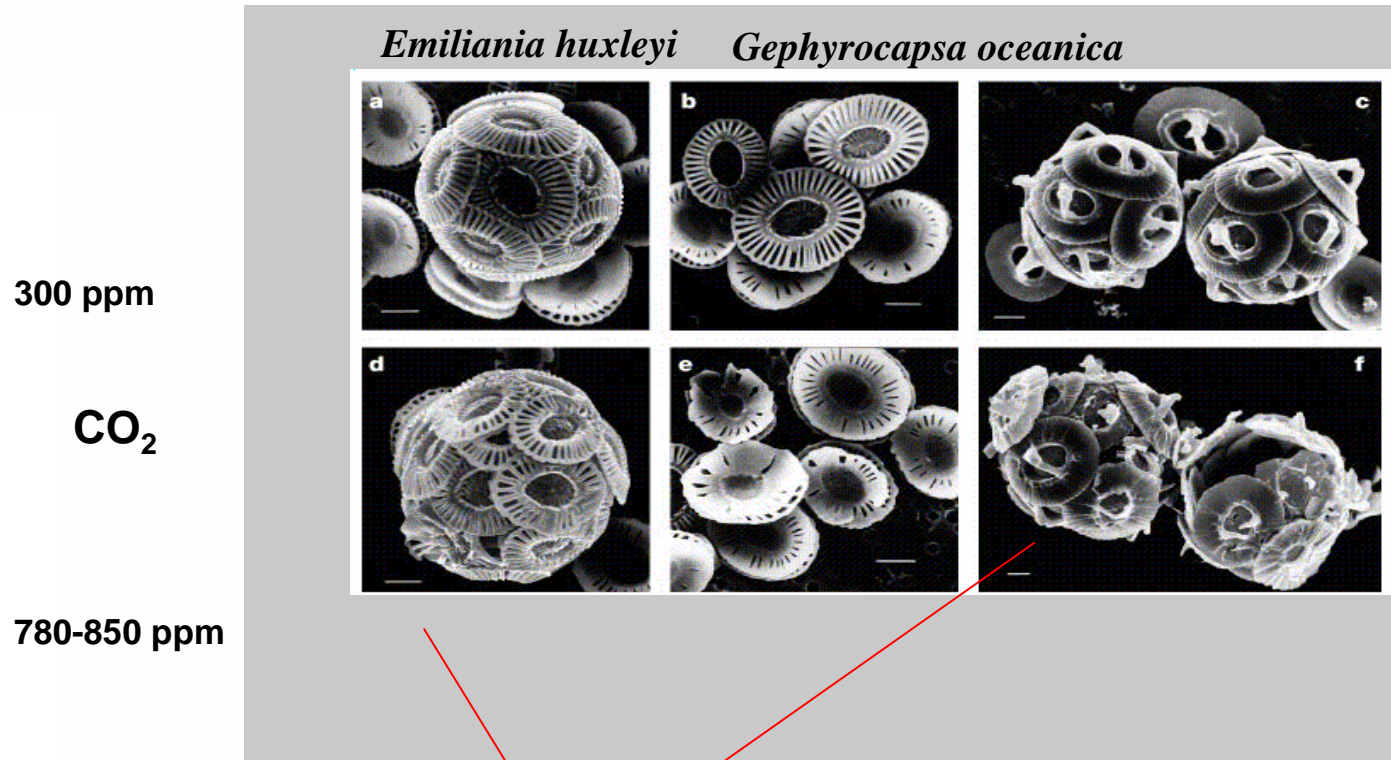


Anthropogenic CO₂ predicted to decrease surface ocean pH by 0.77
- Other models agree

pH has probably already changed by 0.1 in surface waters due to absorption of anthropogenic CO₂

Caldeira & Wickett 2003, Nature: A simulation of changes in ocean pH assuming continued usage of known fossil fuel reserves.

Effects of higher CO₂: Calcifying Phytoplankton - Coccolithophores



Reduced calcification

280 ppm Pre-industrial

370 ppm 2005

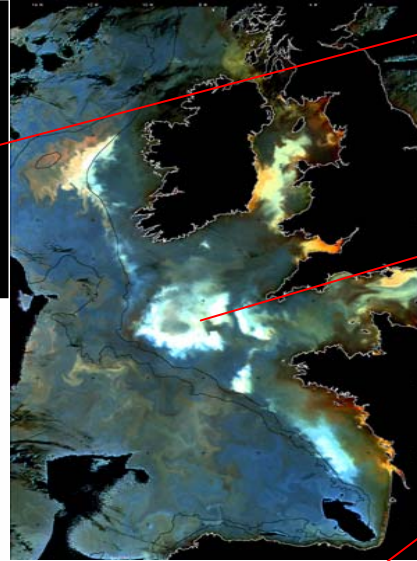
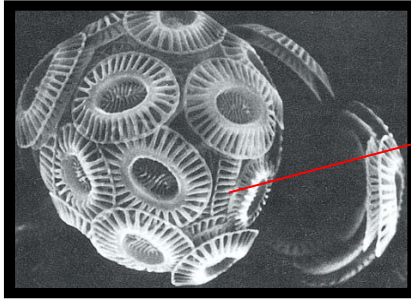
500 ppm 2050 median estimate

700 ppm 2100 median estimate

1000 ppm 2100 worst case

Riebesell et al. Nature (2000)

Coccolithophores: Important Primary Producers on European Shelf Seas



Largest current producer of **calcite** on Earth

Extensive blooms (often 100,000's km²) of these calcite forming phytoplankton occur on shelf seas

Important role in the global carbon cycle through the **transport of calcium carbonate** to deeper waters and sediments



Coccolithophores are major producers of dimethyl sulphide (**DMS**) to the atmosphere – thought to be important in cloud formation and hence a **negative feedback to climate**

Reduction in coccolithophores could change phytoplankton **biodiversity**

Change in biogeochemistry and ecosystem

Increased CO₂/Decreased pH: Effect on Corals



Increased CO₂ may have a direct effect on hard corals to build reefs

Corals cannot secrete stable forms of calcium carbonate (especially aragonite) at lower pH

BIOSPHERE-2: Coral calcification rates may be **reduced** by 21% - 40% during 1880 – 2065 due to changes in atmospheric CO₂



Knock on effect on whole coral ecosystem

Extensive cold water corals have recently been discovered on the European Shelf

Effects on Calcareous Invertebrates

Shelled animals may suffer from:

- reduced feeding
- reduced growth
- respiratory distress
- destruction of chemosensory systems
- increased susceptibility to infection
- decalcification of shell
- increased susceptibility to predation
- narcosis
- decrease in population size
- mortality

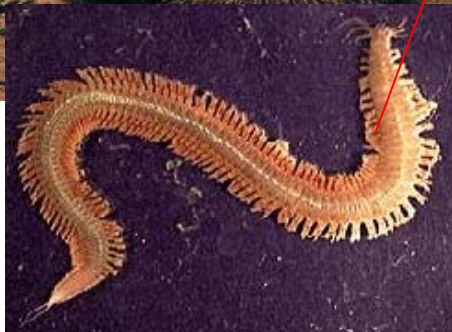
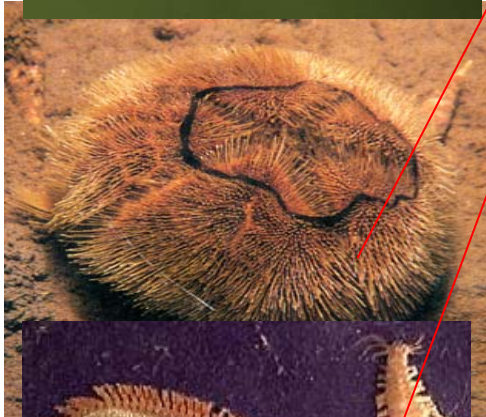
Measurable impacts on growth rates and survival of echinoderms and gastropods at 560ppm the 2050 projected levels



100% mortality of scallops at pH 7

Spat and juveniles **more sensitive**, recruitment may be effected

Effect of pH on Benthic Ecosystem Engineers

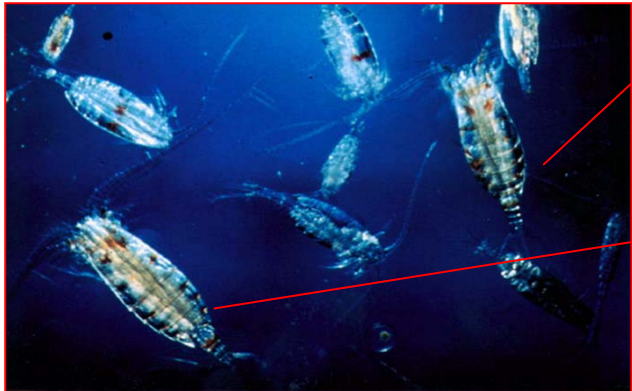


"Ecosystem engineers" important in:

- structuring habitats
- maintaining benthic diversity
- regulating biogeochemical processes

Unknown vulnerability to CO₂
induced pH change

Effects of Low pH on Zooplankton

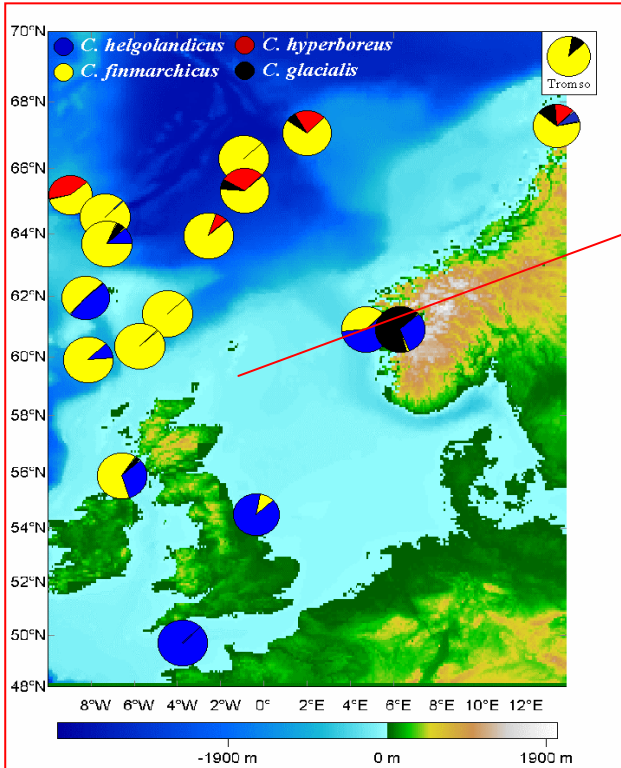


Evidence to indicate that marine zooplankton (crustacea) passing through plumes of CO₂ enriched seawater suffer high mortalities – but very little research

Some zooplankton have calcium carbonate shells (molluscs) or skeleton others are chitinous (crustacea), the latter may be less sensitive to pH

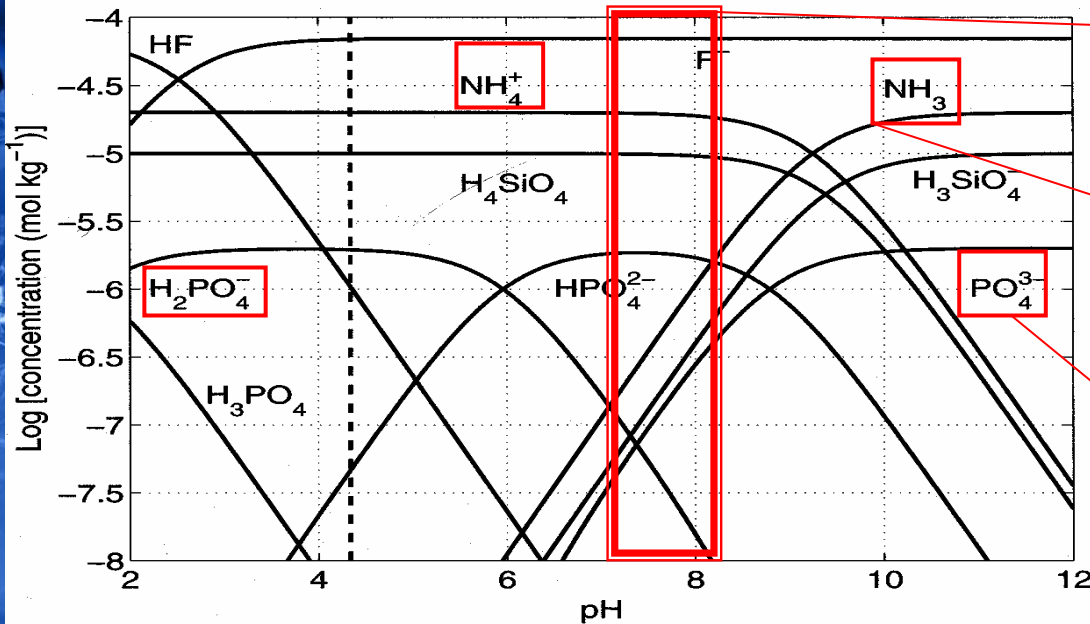
Reduced fertilization of copepod eggs at CO₂ levels beyond 1000 ppm (2100 worst case scenario)

Zooplankton are a key part of the food chain and species vary with water mass



A change in species diversity may change the size of faecal pellets and the biological pump

Effect of Reducing pH on Key Nutrients



Speciation: of key nutrients for phytoplankton and bacterial growth are pH dependent

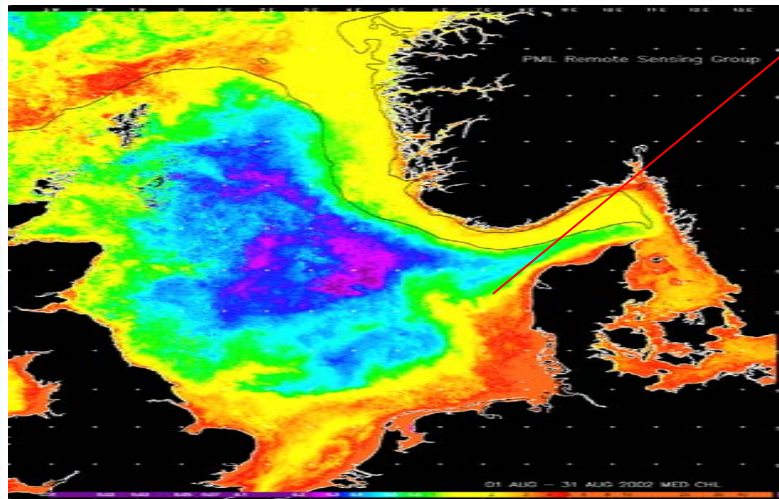
Nitrogen: in particular ammonia is pH dependent, with the concentration decreasing as pH declines

Inorganic phosphate: as pH falls the concentration of H₂PO₄⁻ rises as that of PO₄³⁻ decreases

Consequences: for nutrient availability to phytoplankton and bacteria is not clear

Changes in speciation of phosphate, silicate and ammonia with pH (from Reebe and Wolf-Gladrow 2001)

Effect of pH Induced Changes in Nutrient Speciation and Enzymes on Phytoplankton

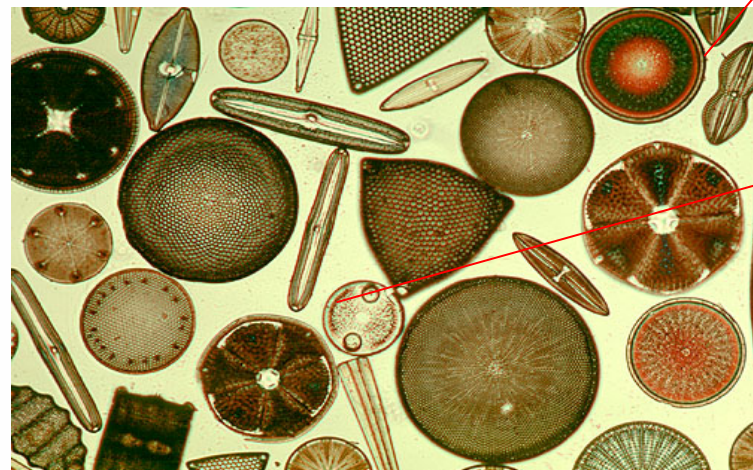


August 2002 mean chlorophyll concentration from SeaWiFS

Nutrients are an important control on the evolution of the spring phytoplankton bloom in surface waters of the shelf seas

- Phytoplankton use active transport mechanisms to acquire them i.e. use energy
- Will this impose an ecological deficit?

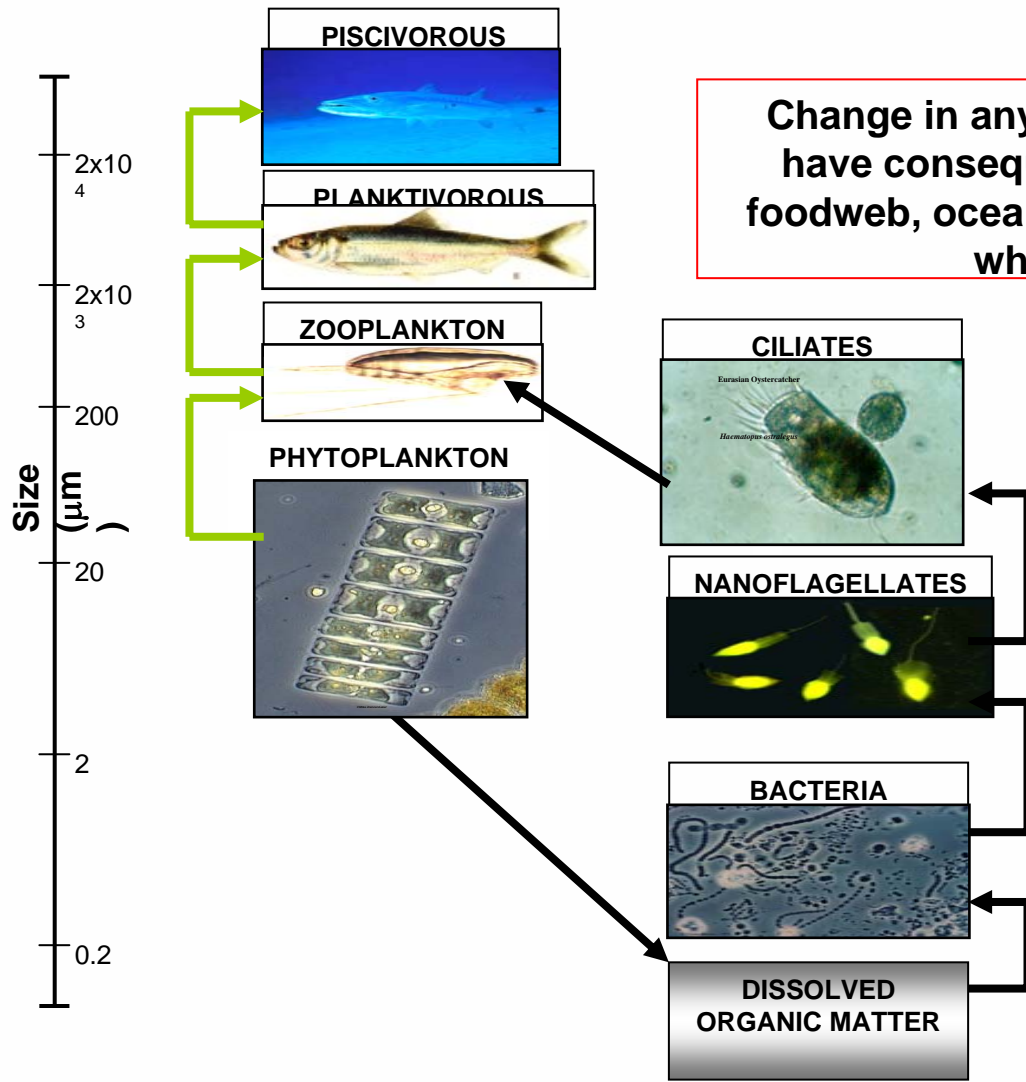
Efficiency of CO₂ uptake using the enzyme RUBISCO may be effected



Diatoms

Changes in the relative proportions of phosphorus, nitrogen and trace metal species may have an effect on plankton diversity

Whole Ecosystem Effects



Change in any part of the foodweb may have consequences on the rest of the foodweb, ocean biogeochemistry and the whole ecosystem

= microbial loop
 = classical food chain

Who is Paying Attention to Ocean Acidification?

International Panel on Climate Change (**IPCC**): formed a WG on ocean acidification

International Global Biosphere Programme (**IGBP**): reduced pH is a key issue in its new international programmes:

Integrated Marine Biogeochemistry and Ecosystem Research (**IMBER**) & the Surface Ocean-Lower Atmosphere Study (**SOLAS**)

International Council for Science (**ICS**), **IGBP** & **SCOR** funded an international conference at **UNESCO**, Paris 2004 The Ocean in a High- CO₂ World

The Royal Society Working Group on Ocean Acidification

OSPAR and **The London Convention** Environmental Impact of Placement of Carbon Dioxide in in the Maritime Area

Nature and **Science** – many articles over last 3 years

Media: TV, radio, newspapers – large interest in last 6mth

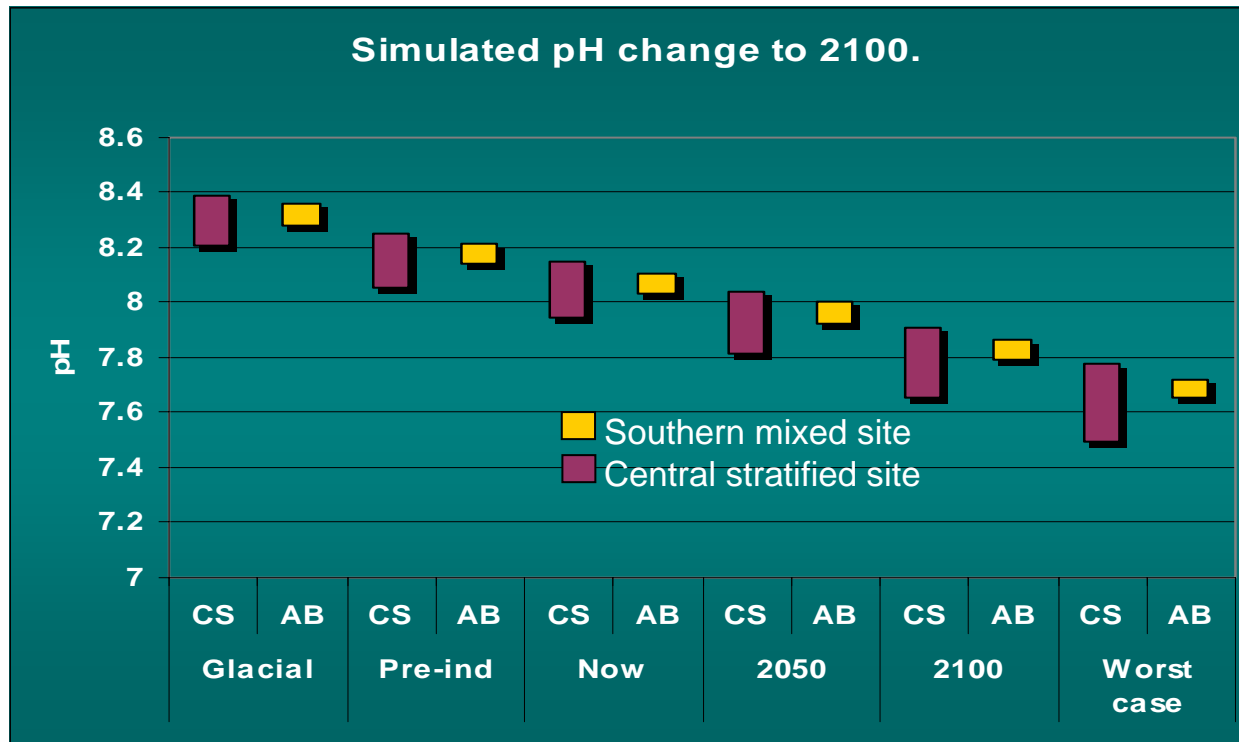
DEFRA, **DTI** and **NERC**

PML-IMCO₂ Objectives

- 1: To facilitate and promote **integration** of international and national R & D on ocean acidification through networking, collaboration and advice.
- 2: To create a UK **modelling** capacity for exploring the effects of high CO₂ (including lowered pH) on the marine ecosystem of UK shelf waters and to make an initial exploration of marine ecosystem response to elevated CO₂.
- 3: Develop a **UK facility** within the Plymouth Marine Laboratory to enable experiments examining the environmental impacts of CO₂ induced seawater acidification.
- 4: Determine the **impact** of pH change, as a result of CO₂ acidification, on:
 - a) the health and function of key benthic organisms.
 - b) the biodiversity and community structure of subtidal soft sediment communities.
 - c) nutrient cycling and the geochemical environment within the sediment.

Funded by DEFRA, DTI and NERC

Modelled pH change in the North Sea Glacial – 2100.



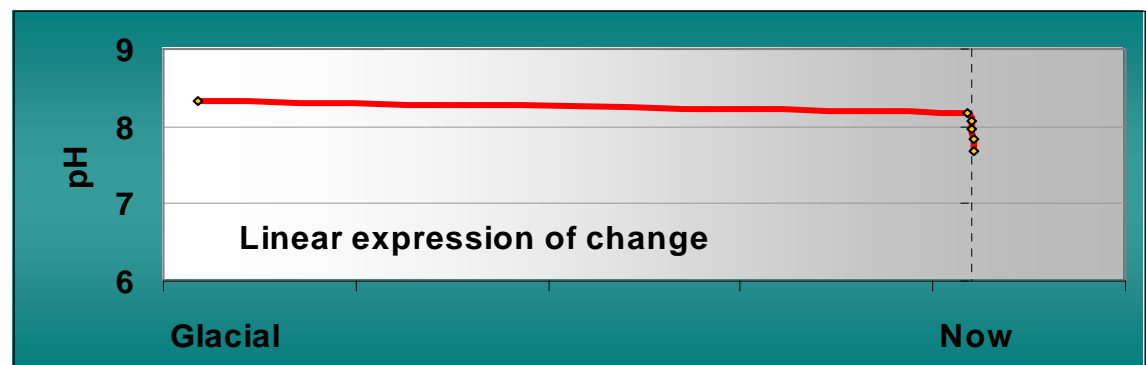
By 2050 the pH range will be discrete from the pre-industrial pH range. We will be in unknown territory.

Mesocosm experiments indicate that community structure and productivity are affected by pH.

Adaptation may mediate harmful effects

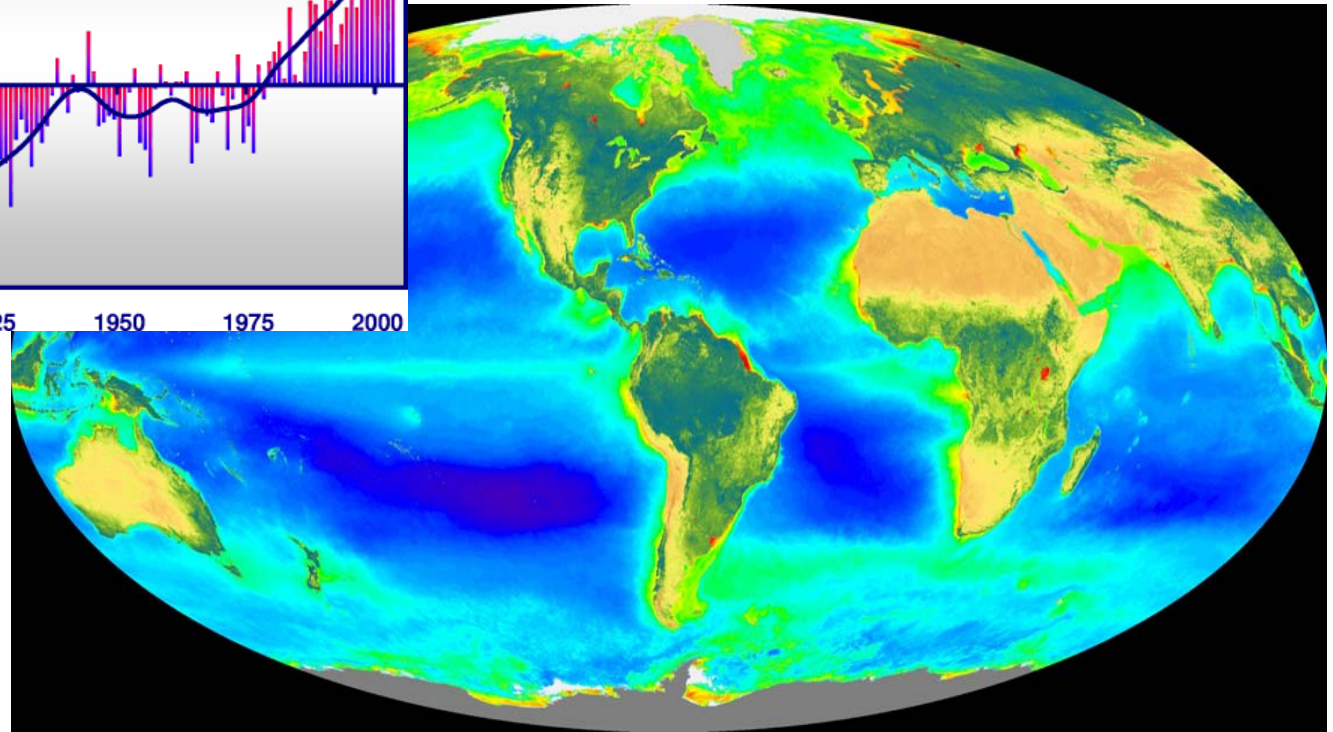
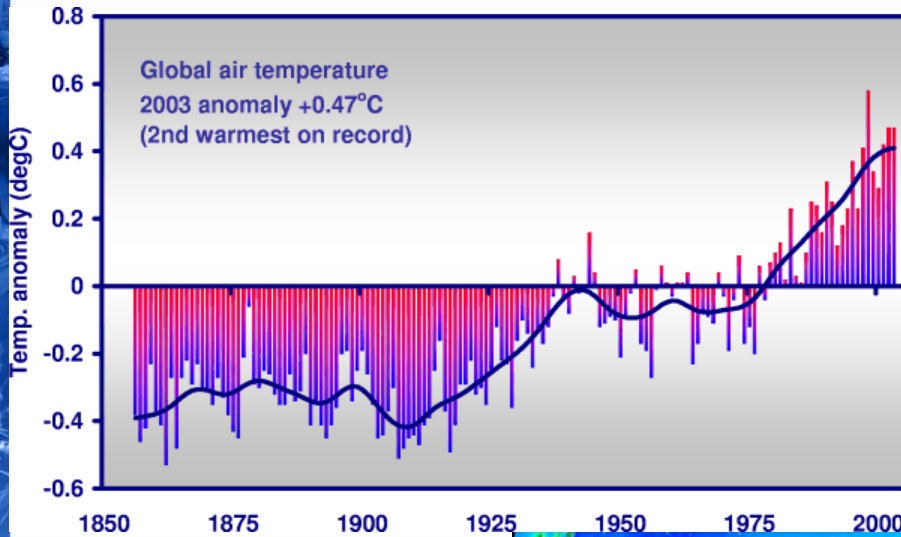
But we don't know how much change that physiological and community adaptation can buffer

Or if a modified system will be economically productive



Global Feedbacks and Synergistic Impacts

Changes that may accompany increased seawater CO₂ and reduced pH include increased temperature, changes in availability of nutrients, salinity, O₂, ocean mixing, circulation and wind



What are the combined effects on the oceans?

What are the feedbacks to the whole Earth system?

Sunset over a warming ocean now > 0.1 pH units lower than pre-industrial and which contains about 400 billion tons of fossil fuel CO₂

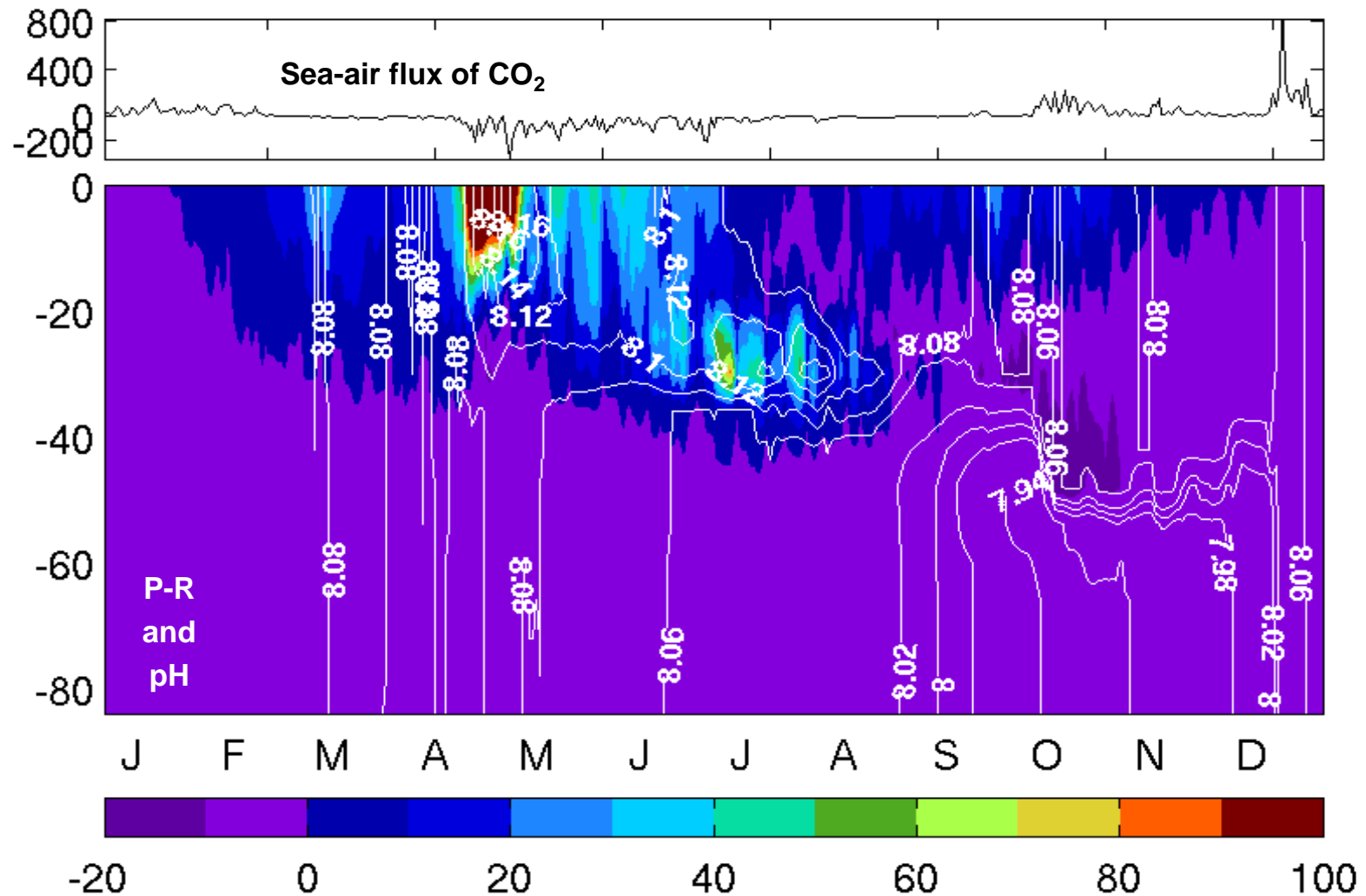


Ocean acidification: another argument for control of CO₂ emissions



Seasonal variability:

Modelling production, respiration, CO₂ and pH



Summary of Potential Biological Effects

- Significant shift in speciation of key **nutrients**
- Shift in **phytoplankton** diversity
- Reduced **calcification** rates
- Reduced behavioural capacity, **growth**, production and life span
- Reduced **tolerance** to other environmental fluctuations
- Reduced **distribution** ranges
- Changes to **community** structure and robustness

Potentially Important Factors for the Future Oceanic Uptake of CO₂

1. Reduced CO₂ buffering capacity of the oceans with increasing pH:

- reduced CO₂ uptake

2. Increased vertical stratification:

- reduced CO₂ uptake
- reduced nutrient supply to photic zone
- changes in rain ratio
- reduction in O₂

3. CO₂ is less soluble in warm water:

- increase sea to air flux as oceans warm, increasing atmospheric CO₂