

Ocean Acidification: The Other CO₂ Problem

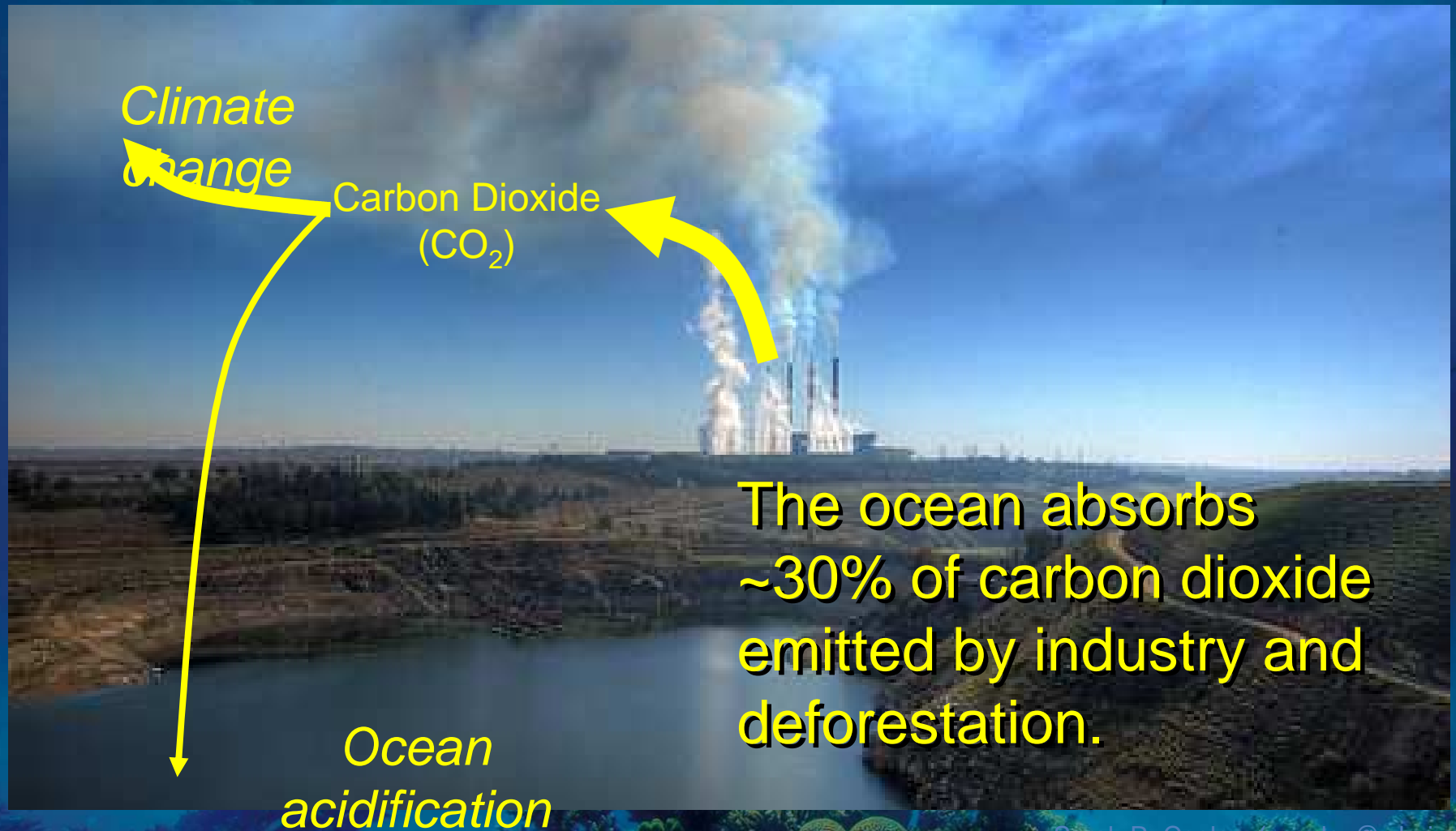
Outline

- Introduction to ocean acidification (OA)
- Why our coastal oceans are especially vulnerable
- Present and future OA Impacts

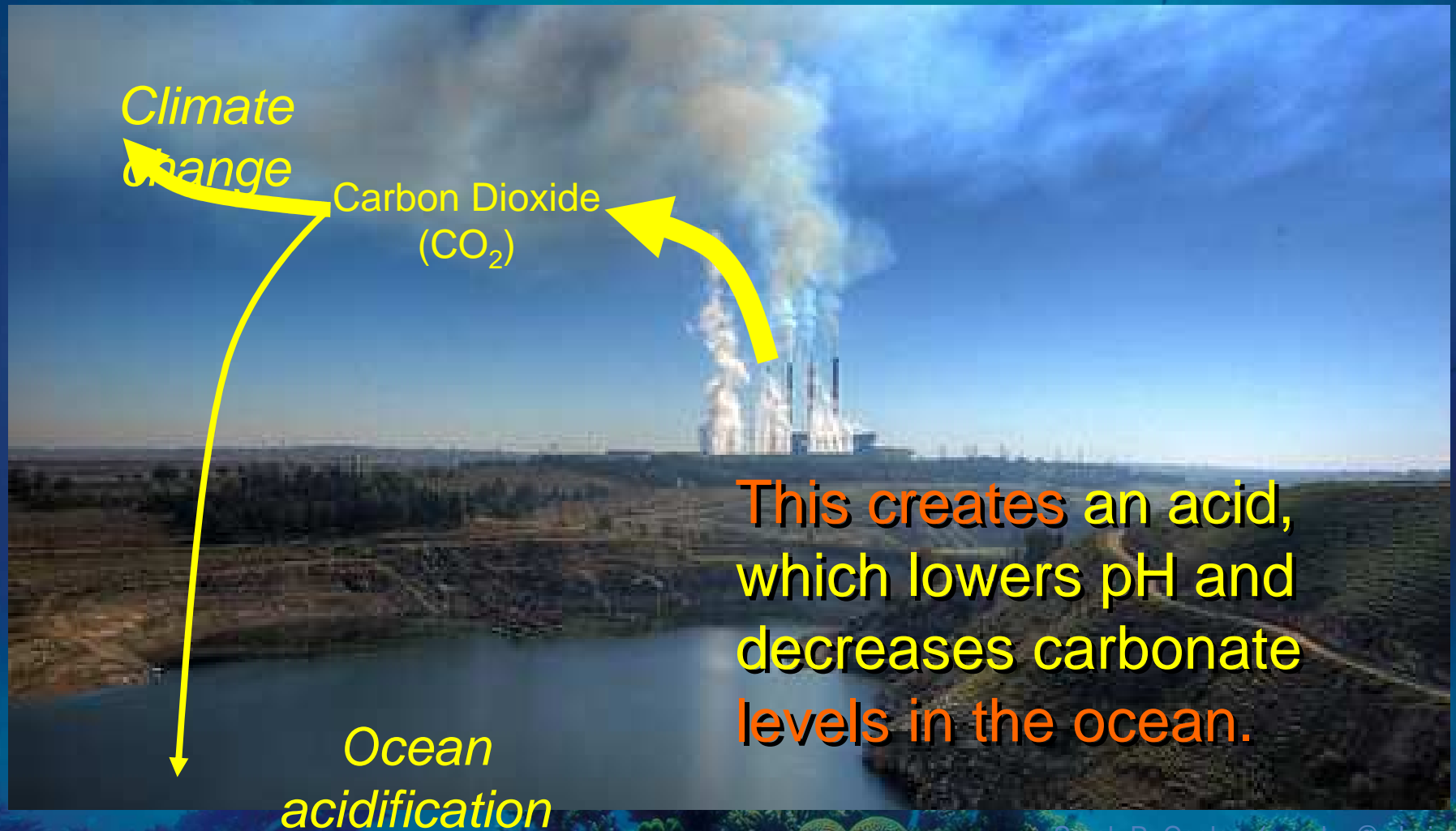
Dr. Richard A. Feely
Pacific Marine Environmental Laboratory
Seattle, Washington USA
United Nations Informal Consultative Process
On Oceans and Law of the Sea
17 June 2013



What is ocean acidification?

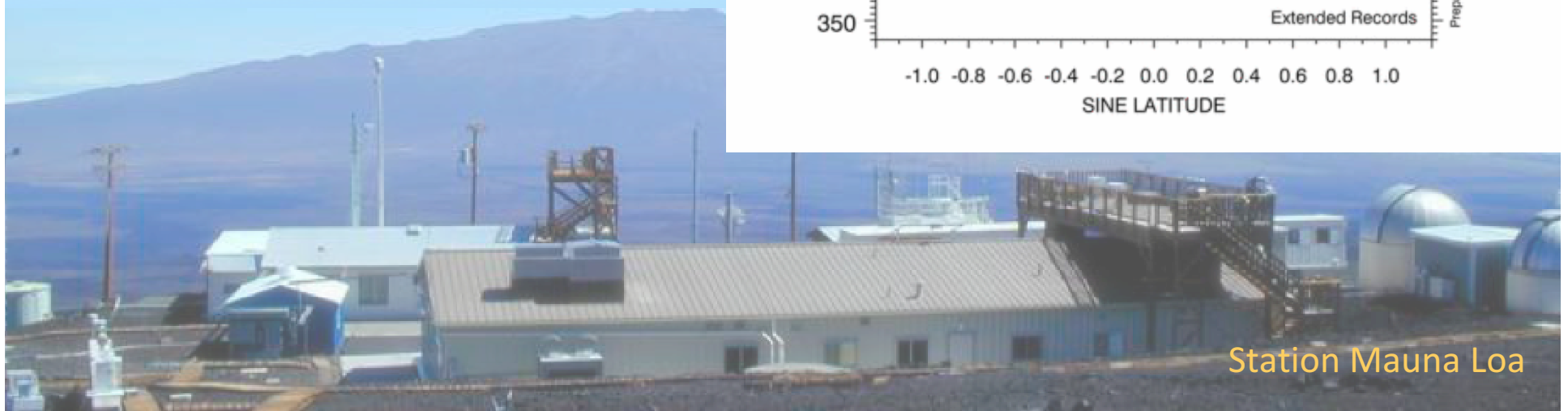
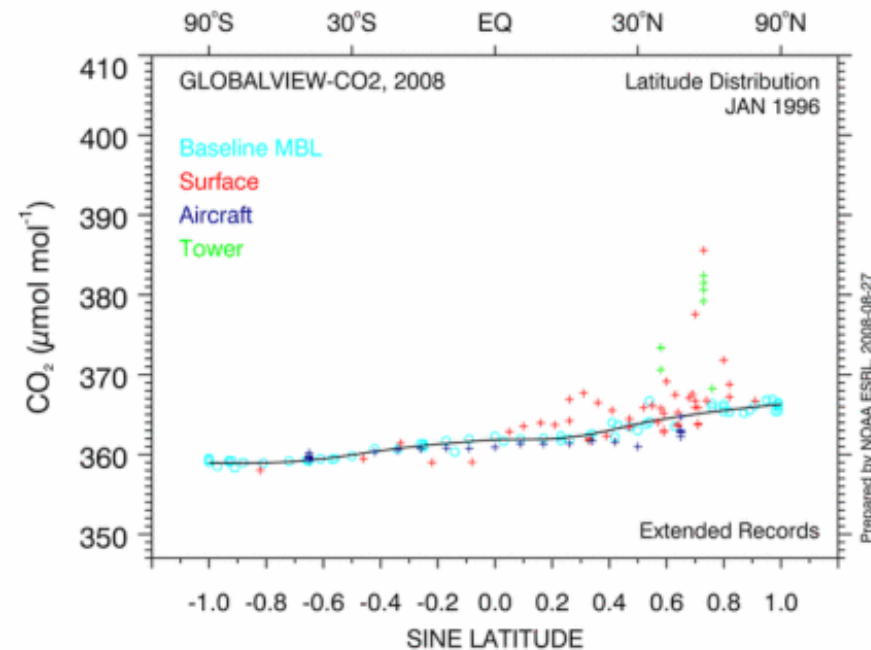
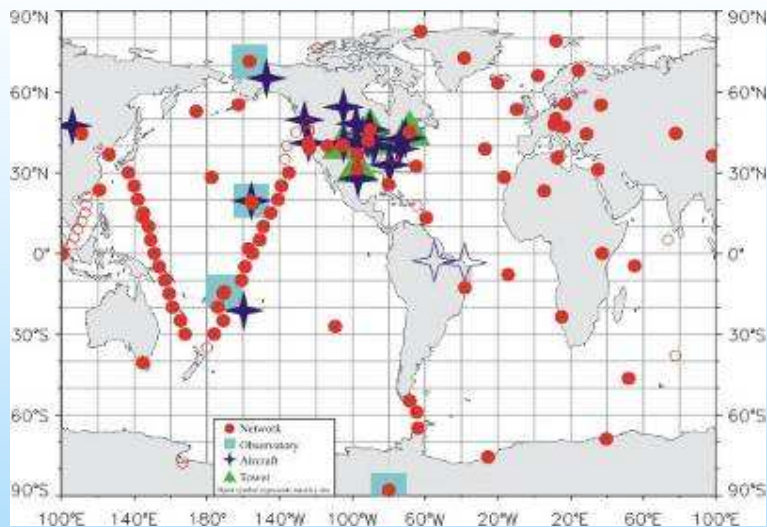


What is ocean acidification?



Atmospheric CO₂ Record

NOAA Earth Systems Research Laboratory, Global Monitoring Division Global CO₂ Monitoring Network



Fate of Anthropogenic CO₂ Emissions

$1.0 \pm 0.5 \text{ Pg C y}^{-1}$

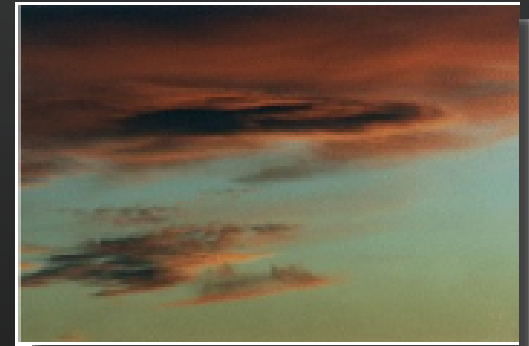


$8.3 \pm 0.4 \text{ Pg C y}^{-1}$



$4.3 \pm 0.1 \text{ Pg C y}^{-1}$
Atmosphere

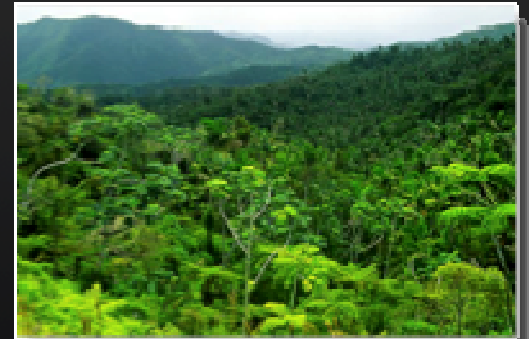
46%



$2.3 \pm 0.4 \text{ Pg C y}^{-1}$

Land

28%



$1.6 \pm 0.2 \text{ Pg C y}^{-1}$

Oceans

26%

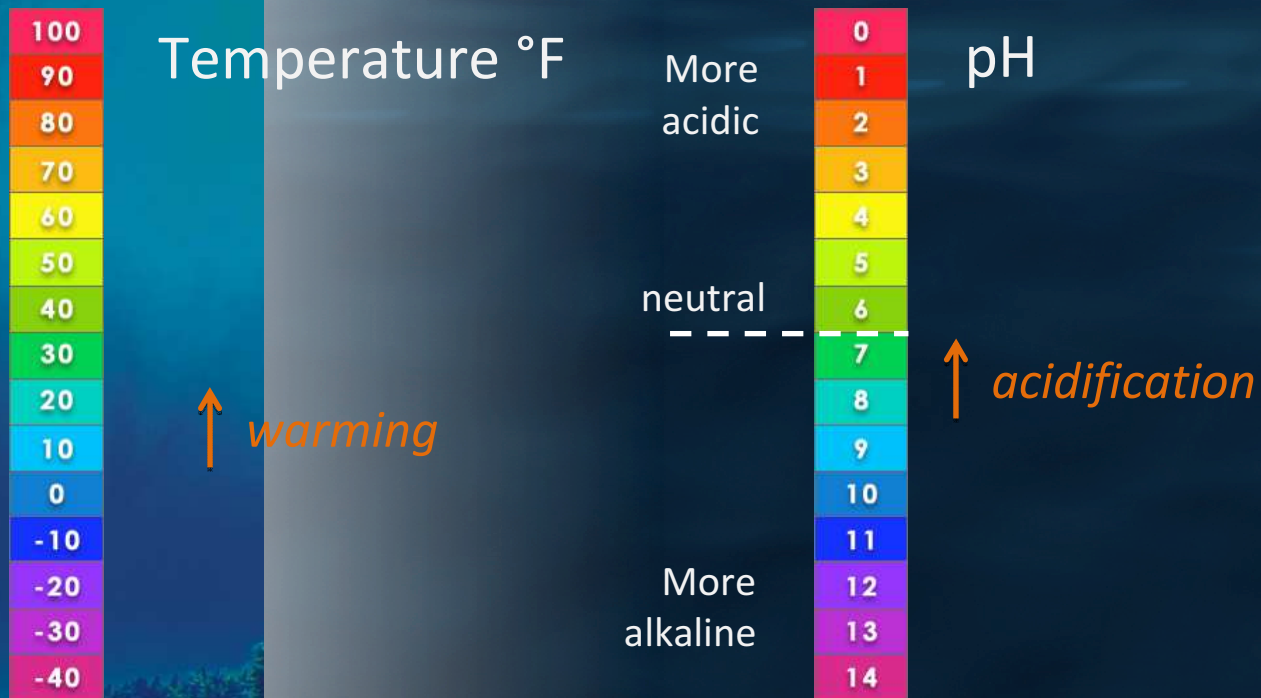


Ocean Acidification Statement #1

The oceans will never become acidic, so calling this “ocean acidification” is alarmist.

FALSE.

Acidification is the process of lowering pH, not the end state.



An underwater scene with a blue gradient background. At the bottom, there is a coral reef with various types of coral. Small fish are scattered throughout the water. The text is overlaid on this scene.

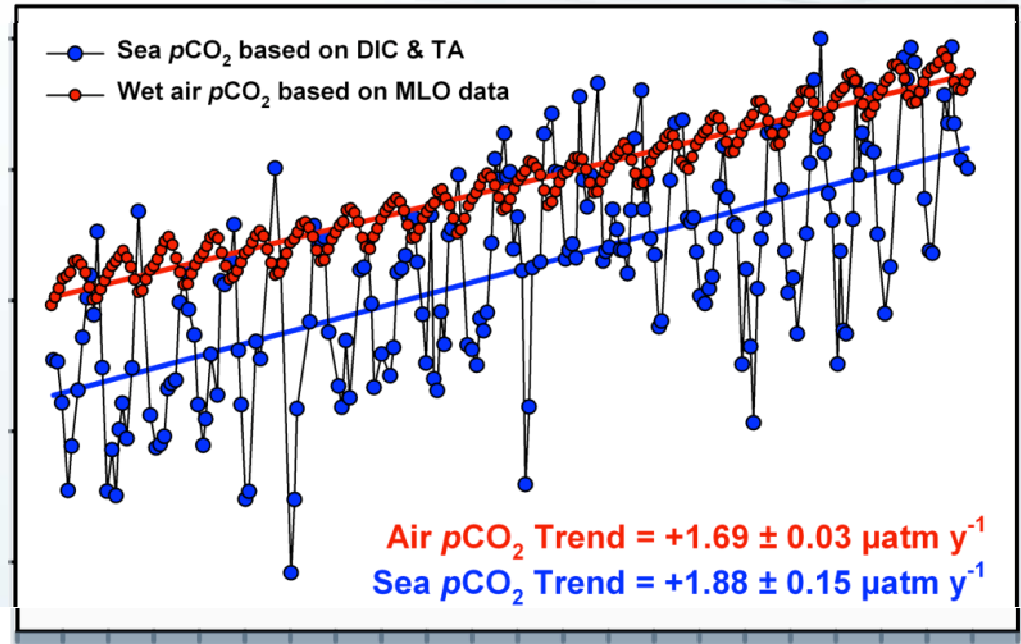
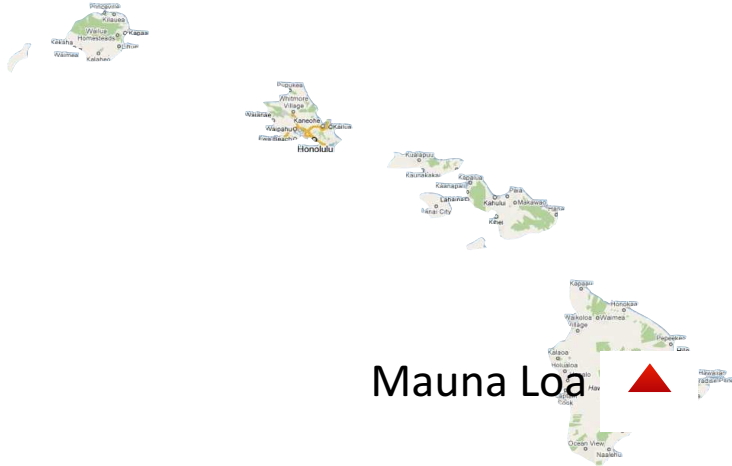
The Ocean is Acidifying Rapidly

“The outcome is very clear that we are in uncharted territory in the entire span of Earth history. The primary cause of this is simply the rate of CO₂ change; we are changing Earth far, far faster than any recorded geologic shift ever.”

-Peter Brewer, MBARI

Carbon Changes at the Hawaii Ocean Time-series (HOT) site

● Station Aloha



Surface water pCO₂ is increasing at about the same rate as atmosphere

We see a commensurate decrease in pH with the rise in surface water pCO₂

Doney, Science 2010
Dore et al., PNAS 2009

Rates of increase are important

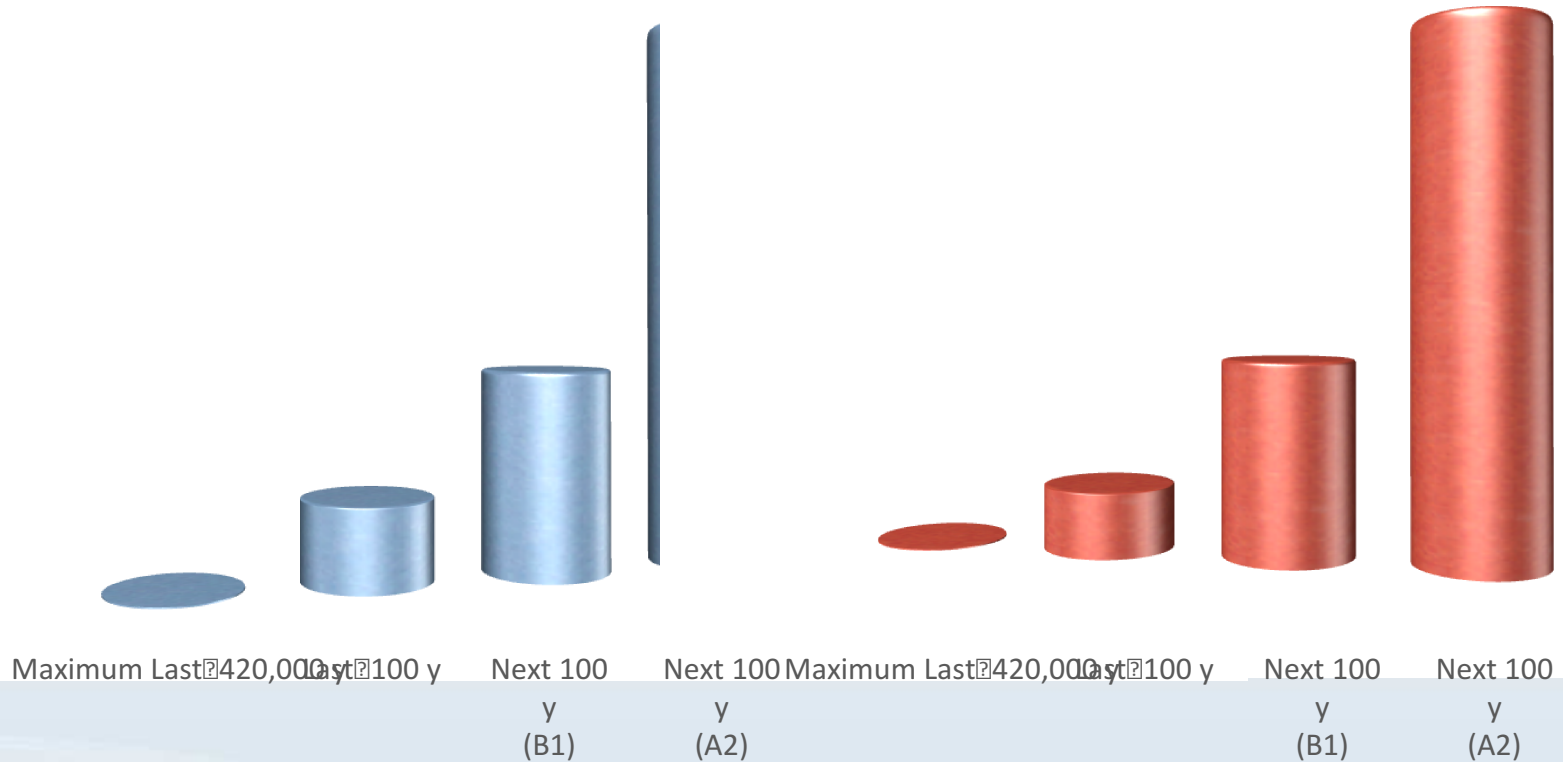
Atmospheric CO₂

Rate of rise in CO₂
(ppm/100y)

Global Temperature

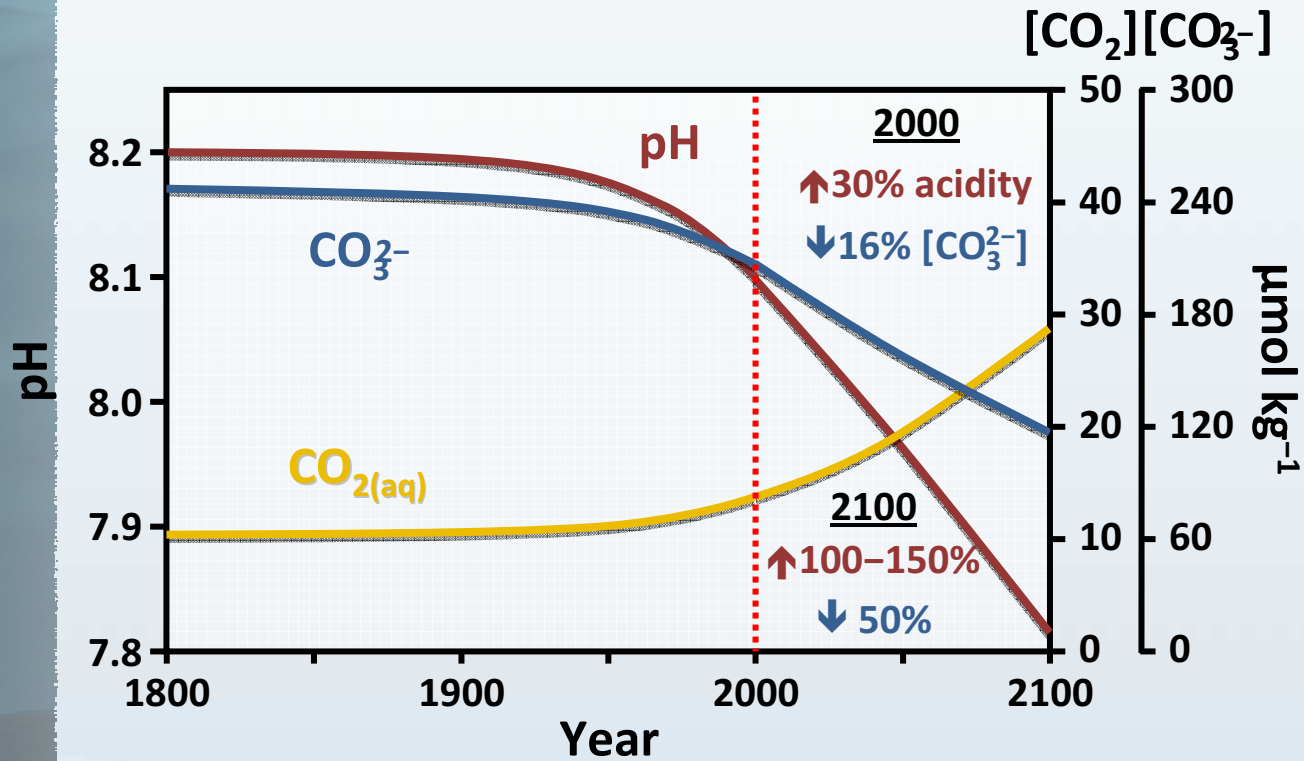
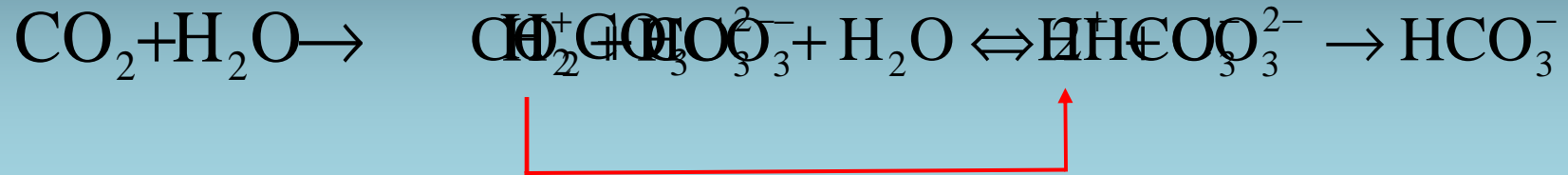
Rate of rise in global
temperature (°C/100)

Ocean CO₂ Chemistry



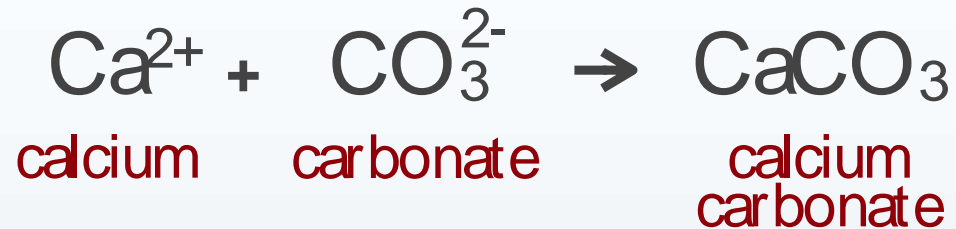
Hoegh-Guldberg et al. 2007, Science

Ocean Acidification



Wolf-Gladrow et al. (1999)

Saturation State



Saturation State

$$\Omega_{\text{phase}} = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_{\text{sp,phase}}^*}$$

$\Omega > 1$ CaCO_3 precipitates

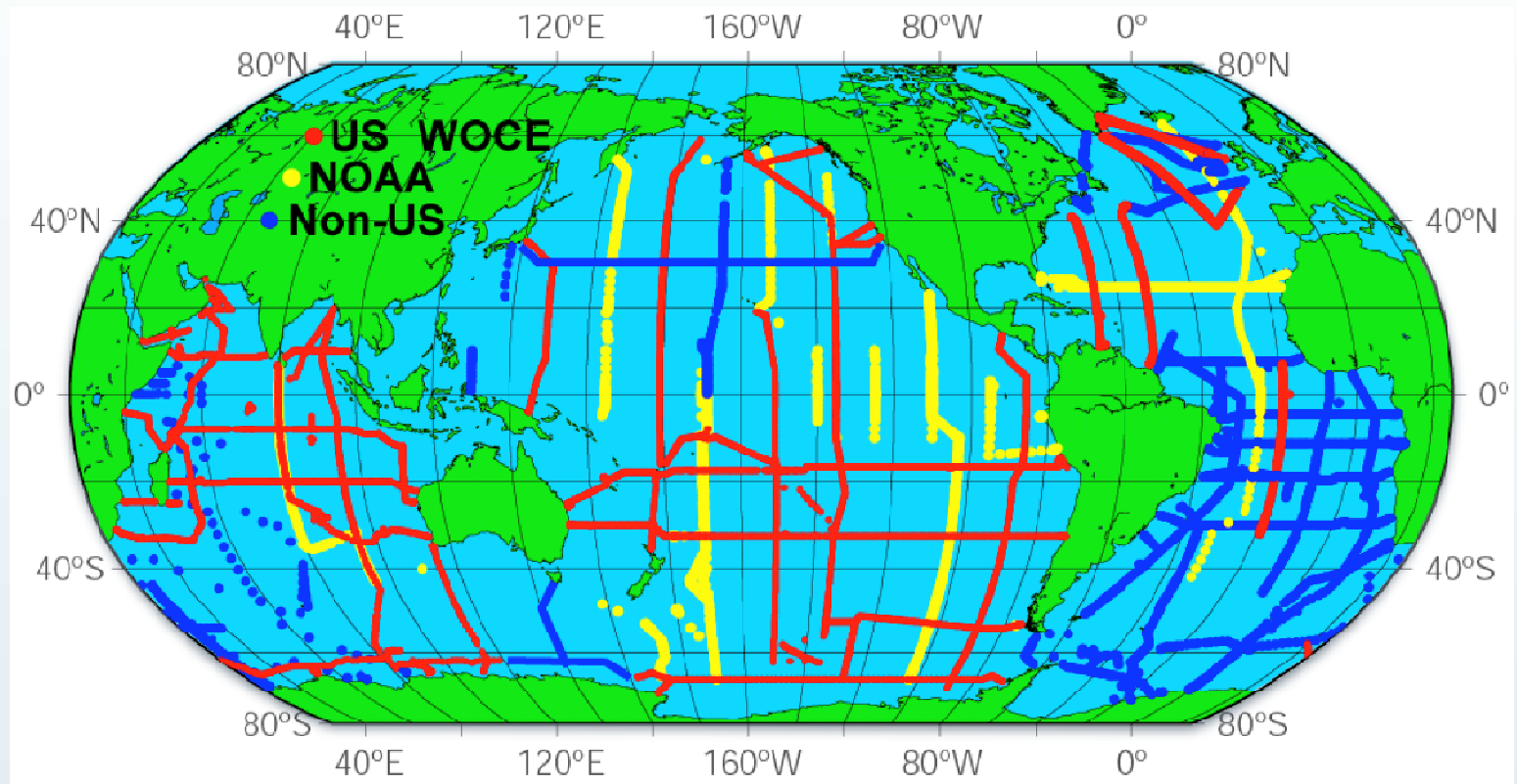
$\Omega = 1$ equilibrium

$\Omega < 1$ CaCO_3 dissolves

Common carbonate minerals:

aragonite (more soluble) and calcite (less soluble)

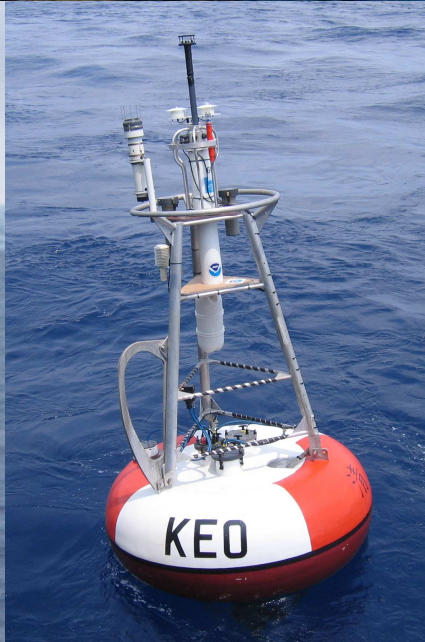
Field Observations



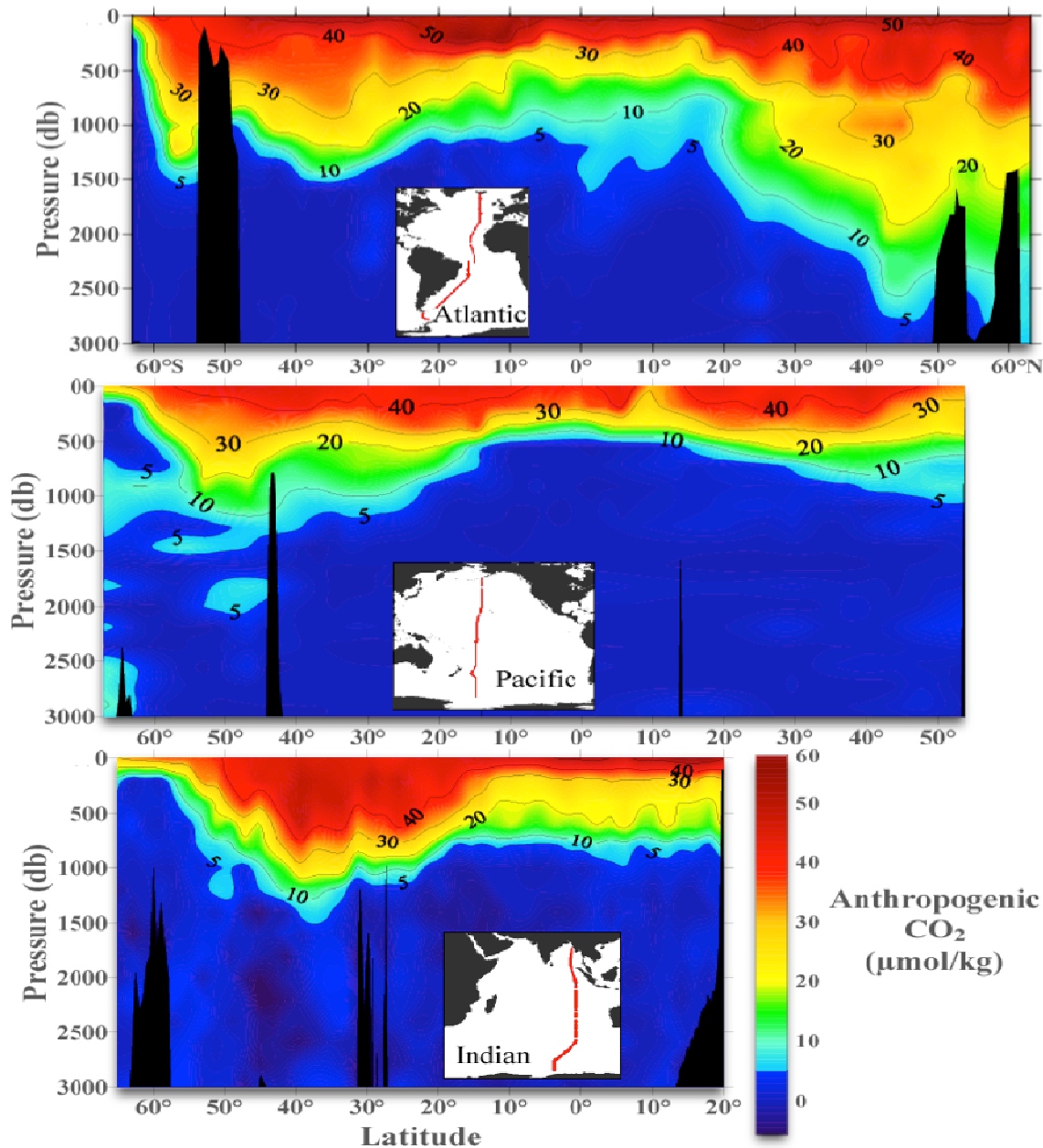
WOCE/JGOFS/OACES
Global CO₂ Survey

- ~72,000 sample locations
- collected in 1990s
- DIC $\pm 2 \mu\text{mol kg}^{-1}$
- TA $\pm 4 \mu\text{mol kg}^{-1}$

Monitoring Ocean Chemistry



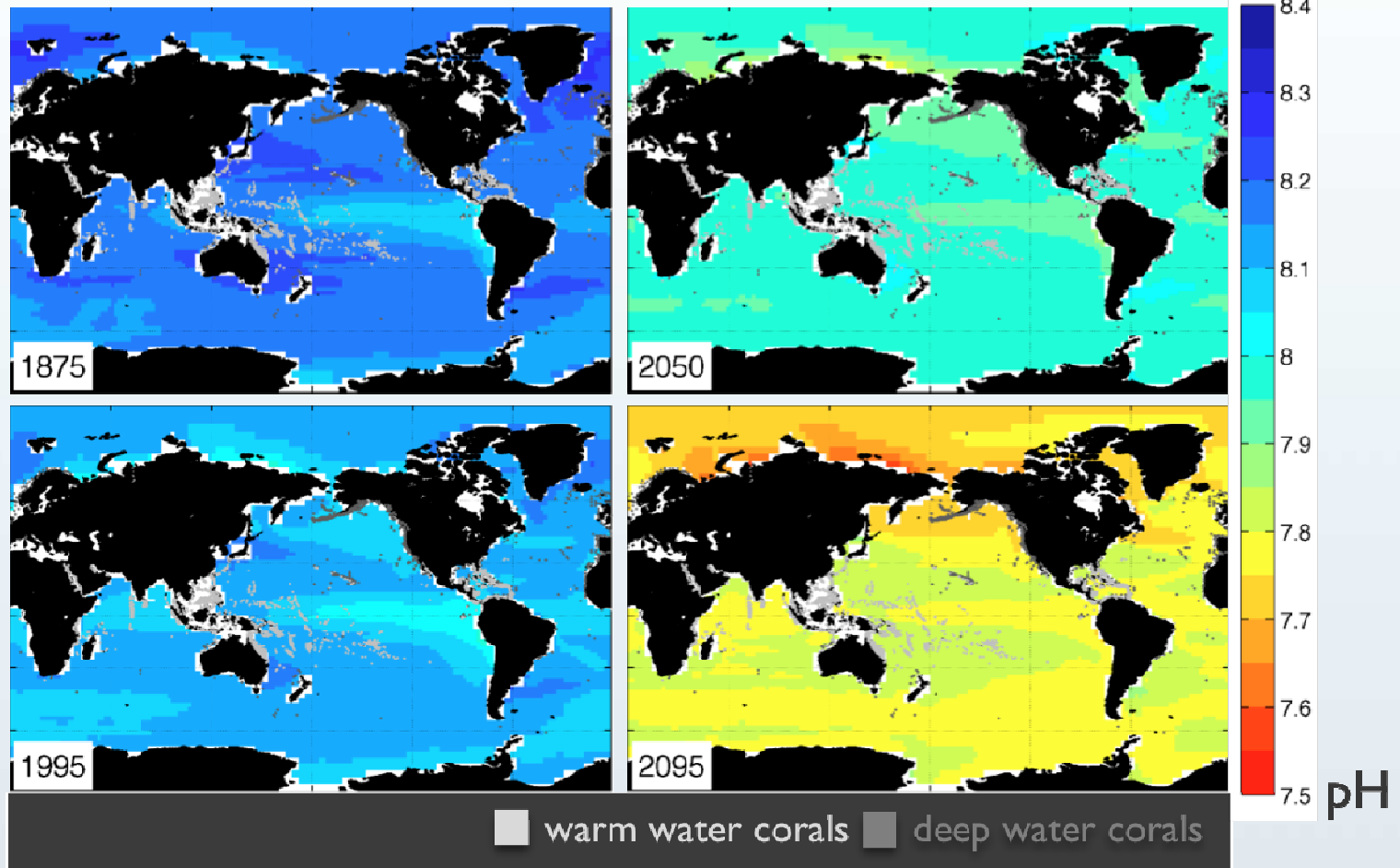
Penetration of Anthropogenic CO₂ into Ocean



- Difference of present-day levels minus pre-industrial (year 1800)
- Half trapped in upper 400 m
- Equivalent to about a third of all historical carbon emissions
- 150 Pg C since the beginning of the industrial era have accumulated in the oceans

Sabine et al. Science 2004

pH Distribution in Surface Waters

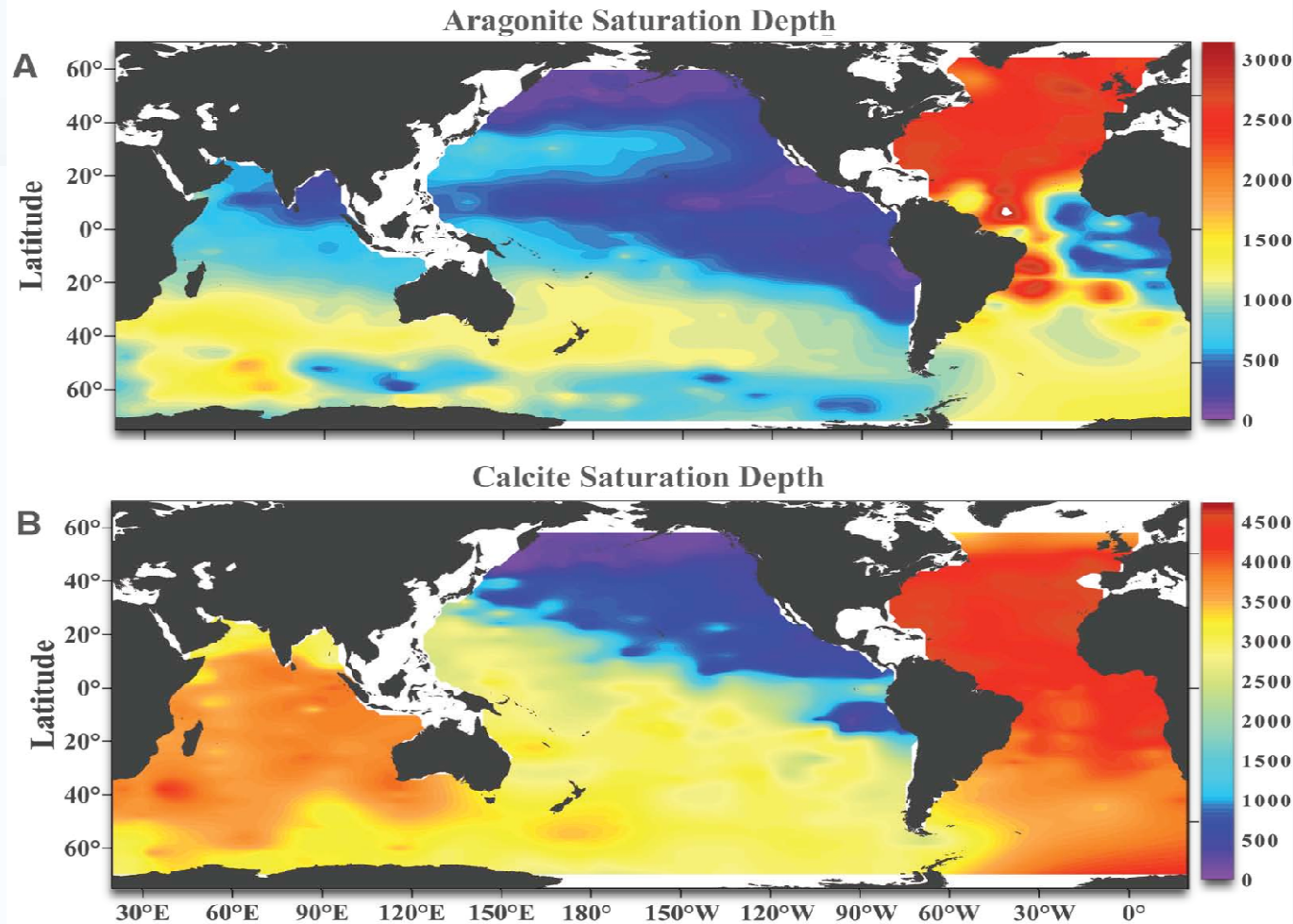


Projections

from the NCAR CCSM3 model projections using the IPCC A2 CO₂ Emission Scenarios

Feely, Doney and Cooley,
Oceanography (2009)

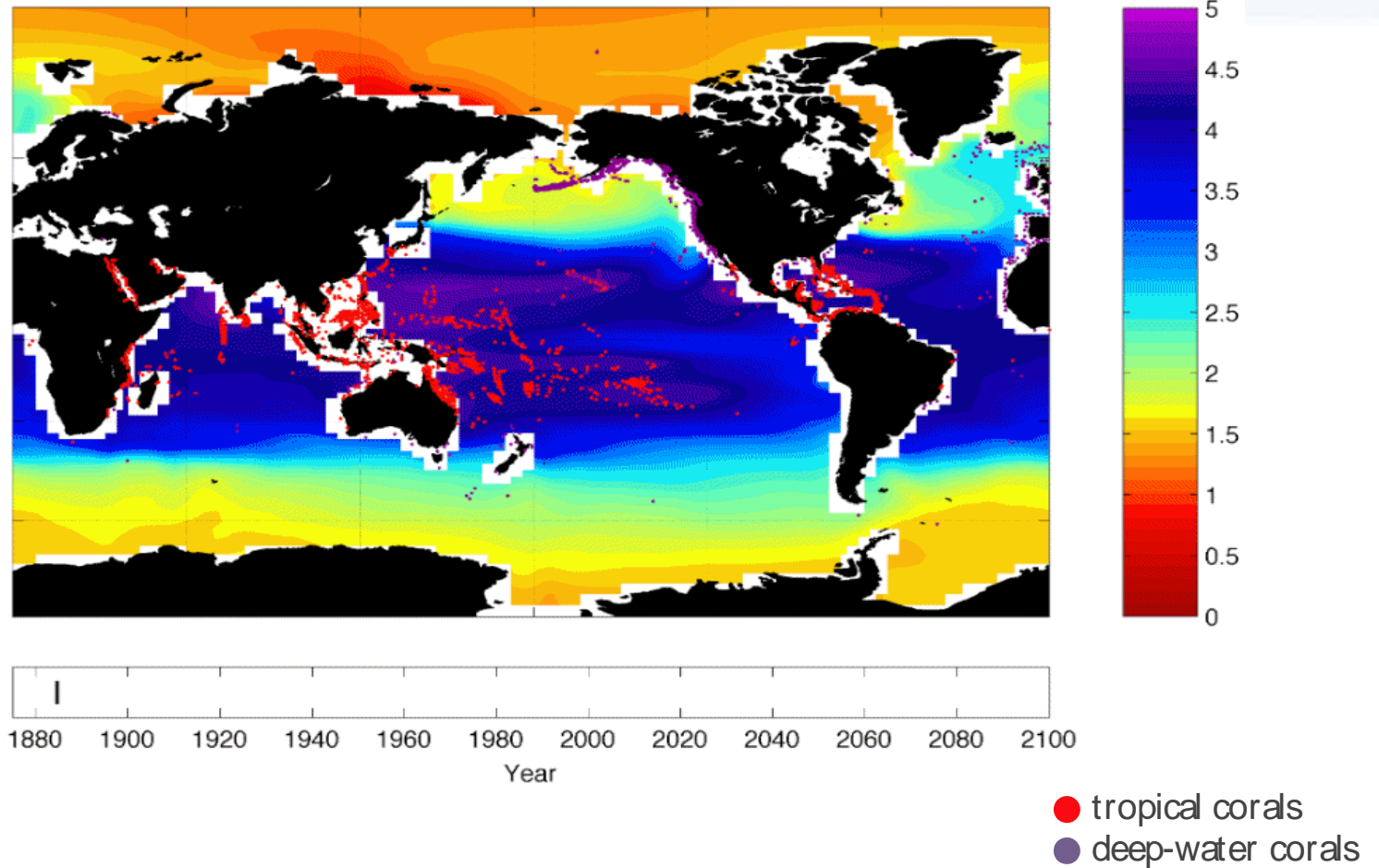
Observed aragonite & calcite saturation depths



Feely *et al.* (2004)

The **aragonite saturation state** migrates towards the surface at the rate of 1-2 m yr⁻¹, depending on location.

Predictions of Ocean Acidification in the Global Oceans



Aragonite Saturation State
blue = good for calcification
red = bad

after Feely et al (2009) with Modeled Saturation Levels using NCAR CCSM3 model

Calcification rates in the tropics may decrease by 30% over the next century

Long-term Impacts of Acidification (after Joos et al., 2011)

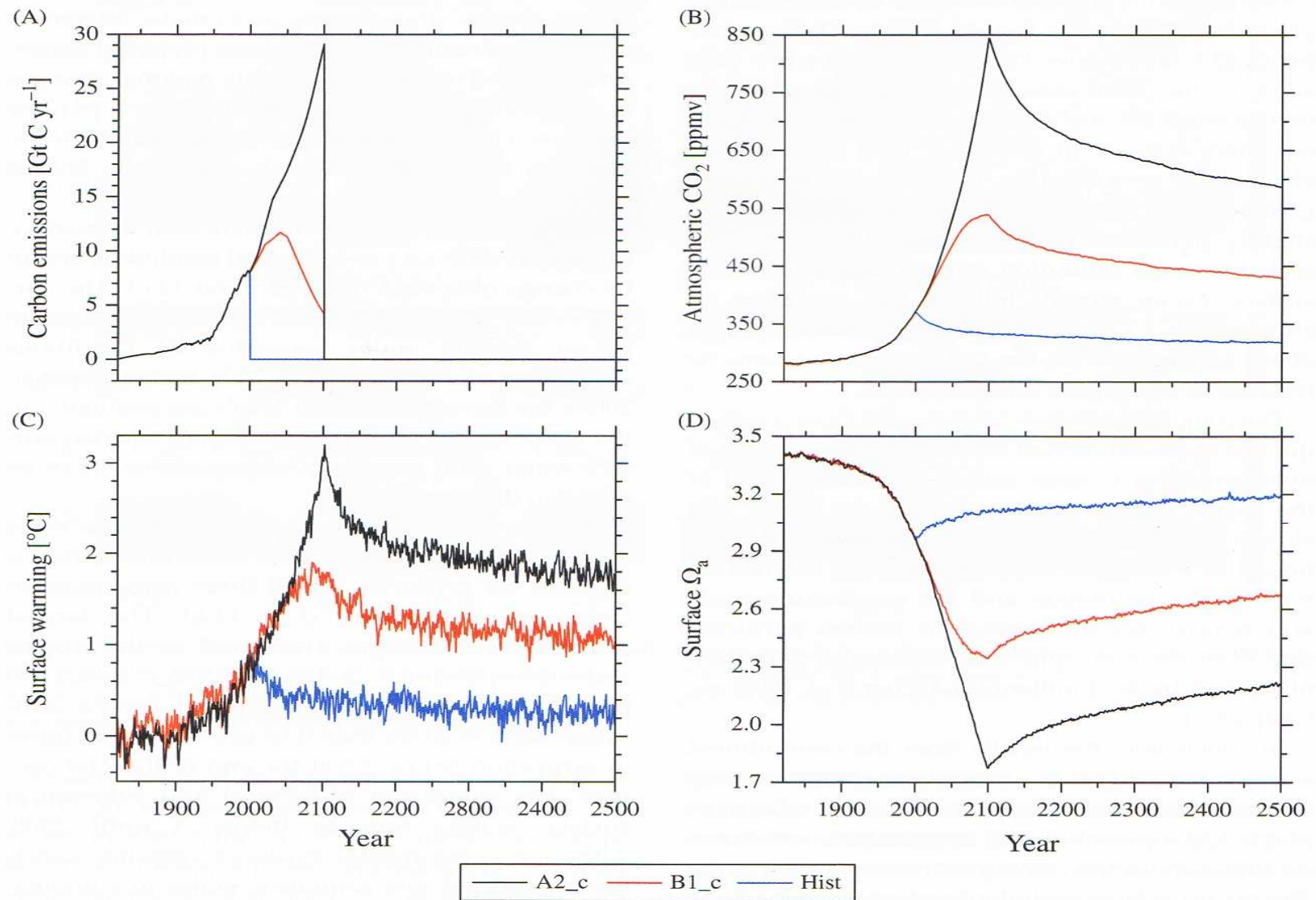
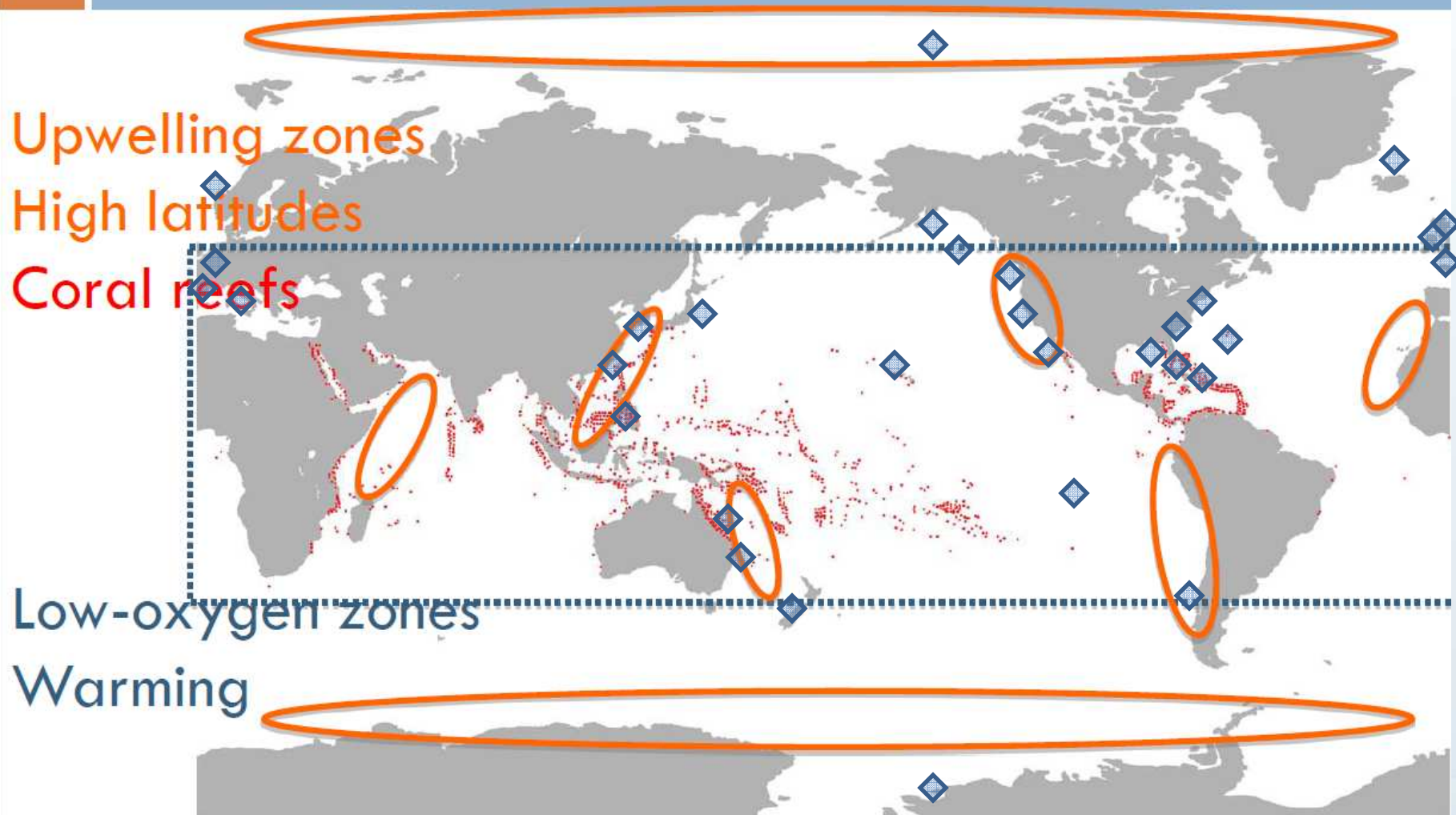


Figure 14.4 Long-term impact of 21st century carbon emissions. (A) Carbon emissions, (B) atmospheric CO₂, (C) global-mean surface air-temperature change, and (D) global average saturation state of surface waters with respect to aragonite (Ω_a) for three illustrative emissions commitment scenarios evaluated with the NCAR CSM1.4-carbon model (Frölicher and Joos 2010). In the high 'A2_c' case and the low 'B1_c' case, 21st century emissions follow the SRES A2 and SRES B1 business-as-usual scenario, respectively. Emissions are set to zero in both cases after 2100. In the 'Hist' case, emissions are stopped in the year 2000.

“Hot spots” for ocean acidification?



Upwelling zones

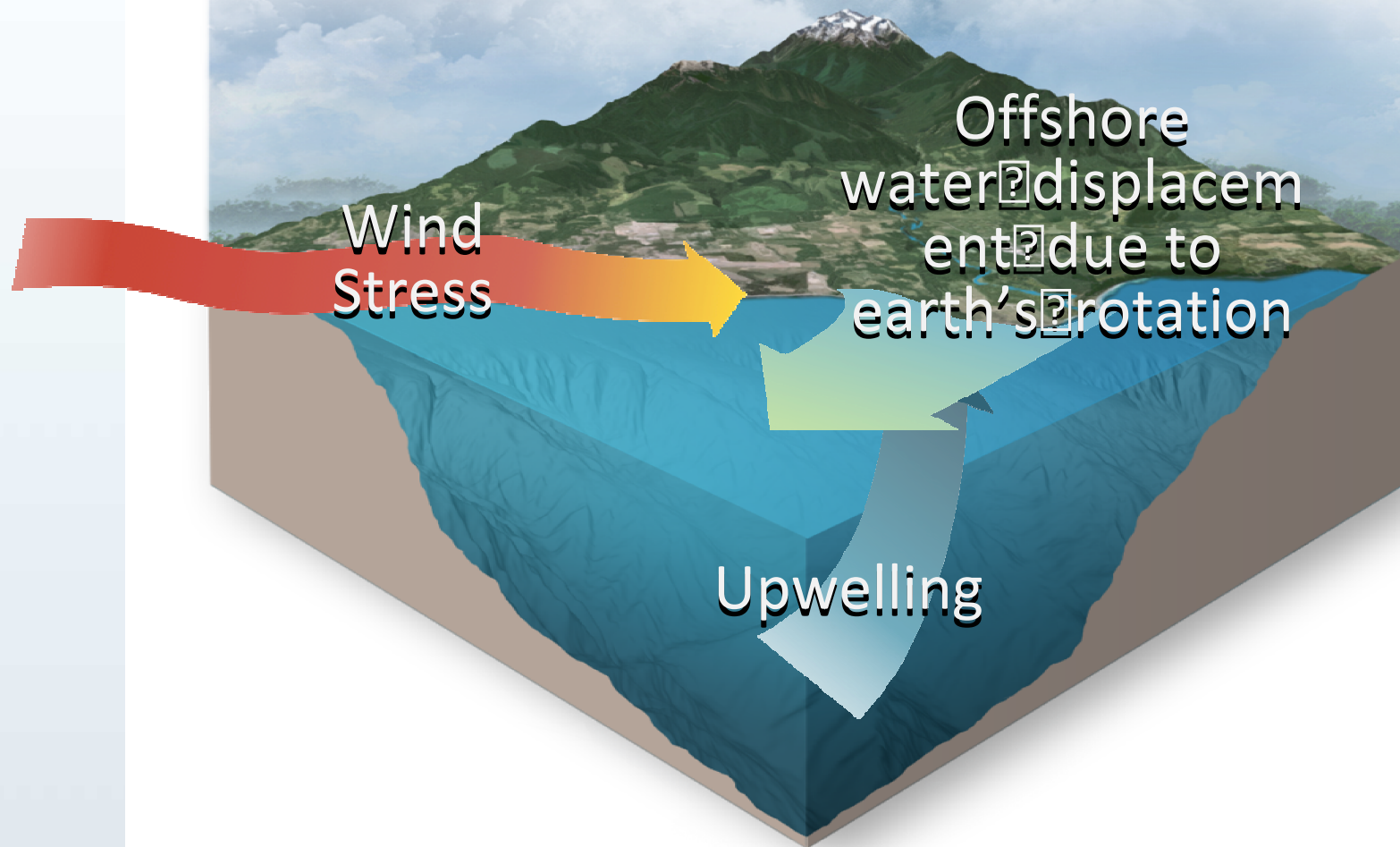
High latitudes

Coral reefs

Low-oxygen zones

Warming

Natural processes that could accelerate ocean acidification in coastal waters

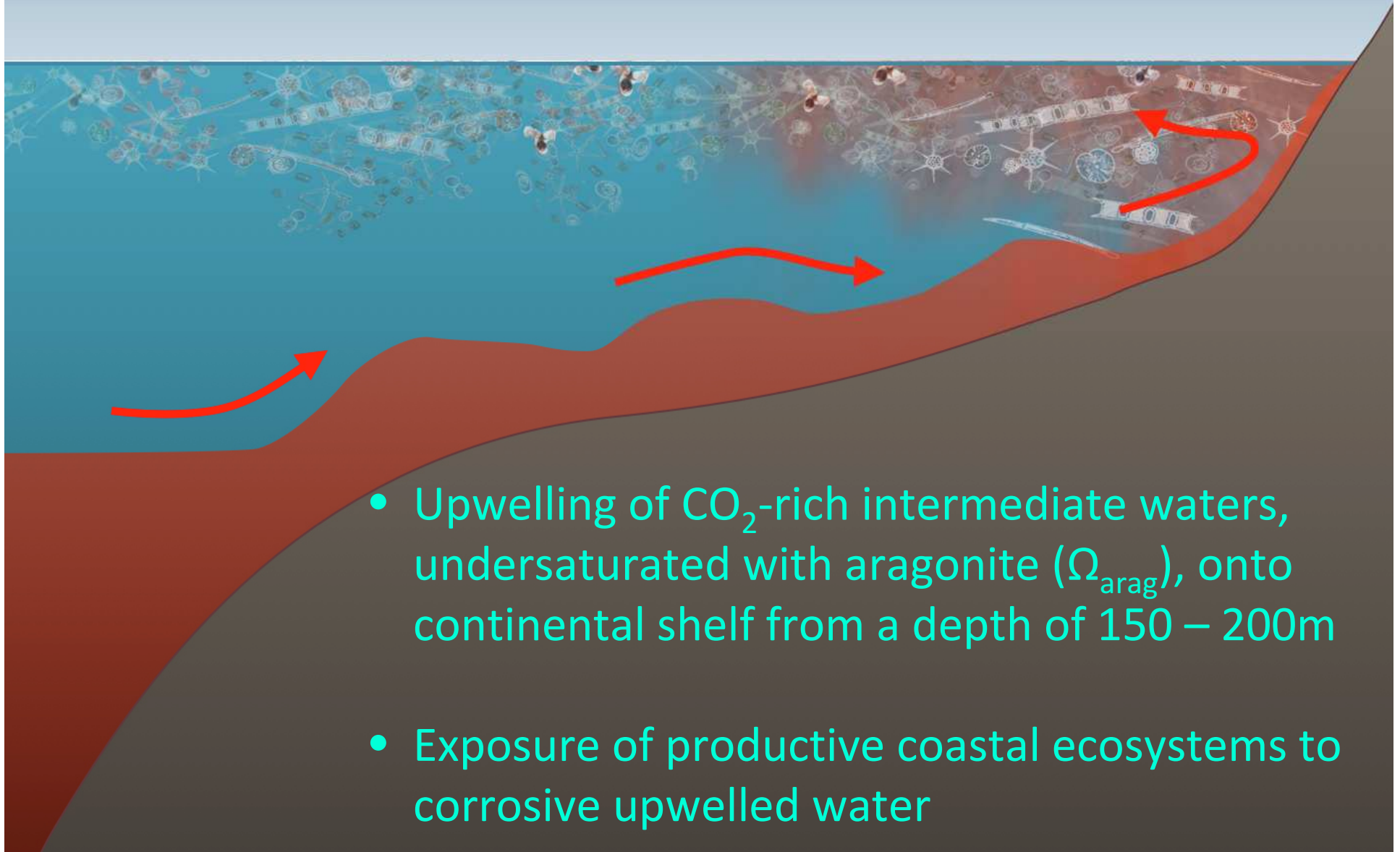


Projections

brings high CO₂, low pH, low Ω, low O₂ water to surface

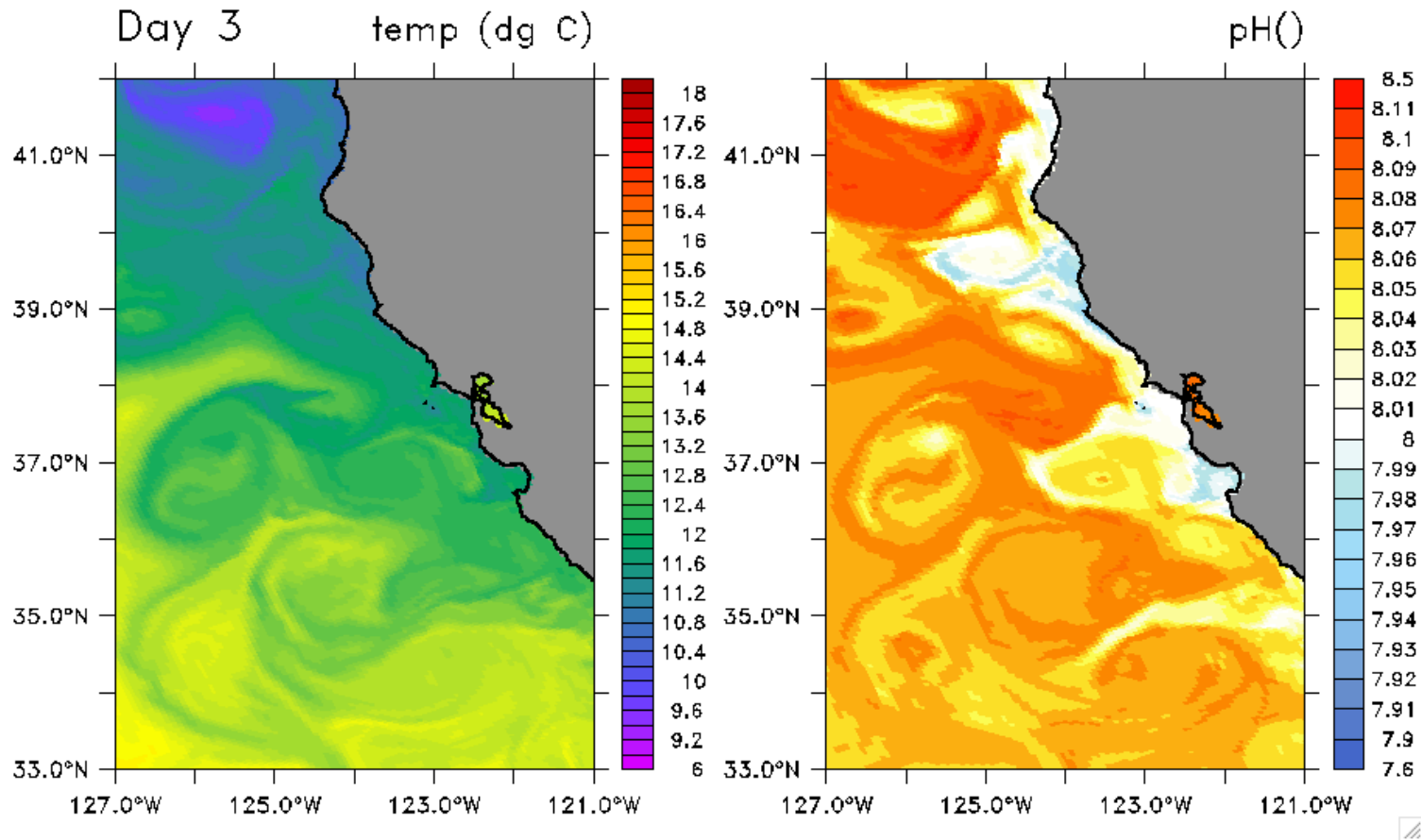
Coastal Upwelling

Seasonal invasion of corrosive upwelled water on the west coast of North America



Temperature & pH

California Current System in the Year 2000



Model results provided by Gruber and colleagues, 2008

ROMS (5km)

How CO₂ in seawater affects marine life

Changes in CO₂-system

CO_{2(aq)} ↑

HCO₃⁻ ↑

CO₃²⁻ ↓

pH ↓

Effects

Increase in photosynthesis

Decrease in calcification

Changes in physiology

Other changes

Temp ↑

Oxygen ↓

Global

Overfishing

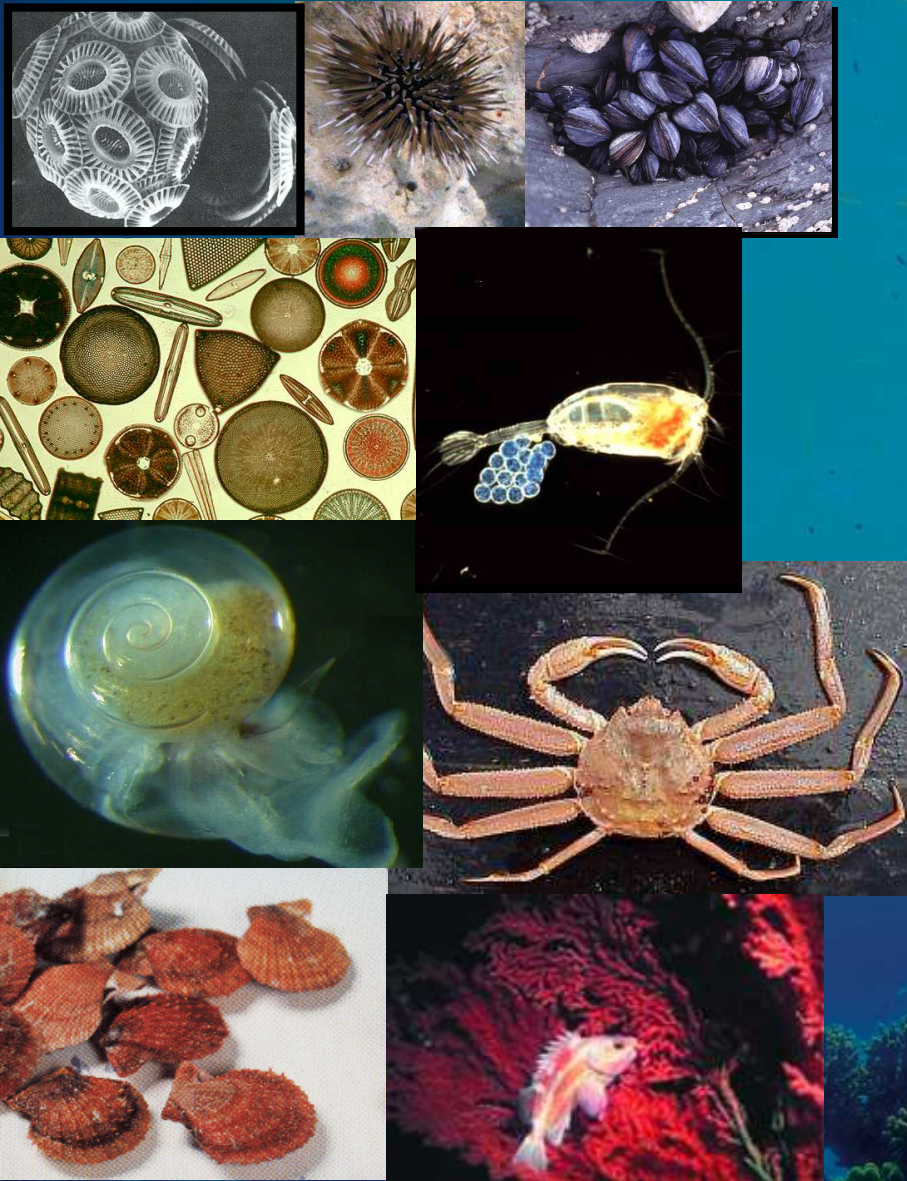
Pollution

Oil spills

Regional

The Challenge of Multiple Stressors

Concern for Marine Organisms and Ecosystems



- Reduced calcification rates
- Significant shift in key nutrient and trace element speciation
- Shift in phytoplankton diversity
- Reduced growth, production and life span of adults, juveniles & larvae
- Reduced tolerance to other environmental fluctuations
- Changes to fitness and survival
- Changes to species biogeography
- Changes to key biogeochemical cycles
- Changes to food webs
- Reduced sound absorption
- Reduced homing ability
- Reduced recruitment and settlement
- Changes to ecosystem goods & services
- Changes to behavior responses

Ocean Acidification is Occurring Rapidly

- Approximately 25% of the CO₂ generated by human activities since the mid-1700s has been absorbed by the oceans.
- Ocean acidity has increased 30% since the start of the industrial age.
- Ocean acidity is projected to increase 100-150% percent by 2100.
- Current rate of acidification is nearly 10x faster than any period over the past 50 million years.



Humankind's footprint in the oceans is now clearly detectable.

It is warmer, more acidic, and less diverse.

Thank you

www.tos.org/oceanography/issues/issue_archive/22_4.html

www.pmel.noaa.gov/co2/OA

www.epoca-project.eu

www.whoi.edu/OCB-OA

For More Information...

Washington Department of Ecology :
<http://www.ecy.wa.gov/water/marine/oceanacidification.html>

NOAA Pacific Marine Environmental Laboratory:
<http://www.pmel.noaa.gov/co2/story/Ocean+Acidification>