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Projection of ocean acidification in the  
Australian region and its effect on the coral  
reefs and other marine organisms

Wealth from Oceans Flagship

Richard Matear  
September, 2008

National Research  
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# Projection of ocean acidification in the Australian region and its effect on the coral reefs and other marine organisms



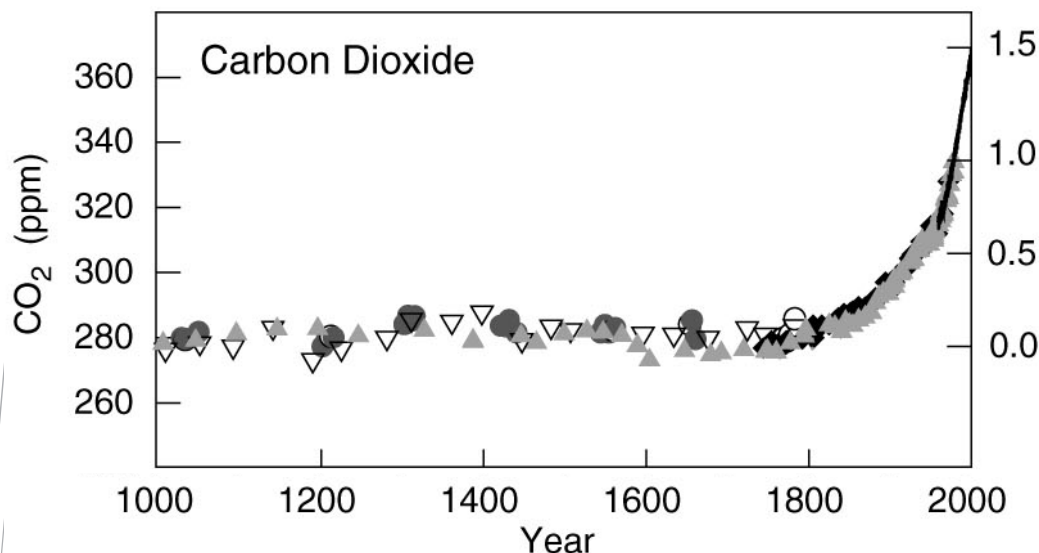
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## OUTLINE

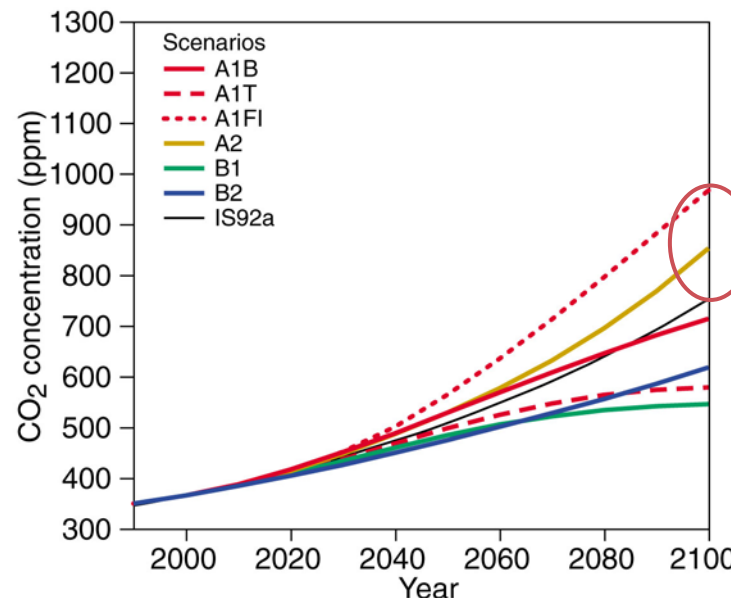
- Present how atmospheric CO<sub>2</sub> levels are increasing due to human activities
- Discuss the chemical response of the oceans to rising CO<sub>2</sub>
- Present how the ocean acidification is and will affect the Australian region
- Discuss the potential biological impacts of ocean acidification



# Past and Future Atmospheric Concentration of CO<sub>2</sub>



(b) CO<sub>2</sub> concentrations



- By 2100, atmospheric CO<sub>2</sub> will exceed the highest levels in the last 45 Million years

If reach 780ppm than the equilibrium atmospheric CO<sub>2</sub> will be about 380ppm (≈ the present day value)

## Emission Scenarios of the IPCC

A1: rapid growth, rapid technology introduction

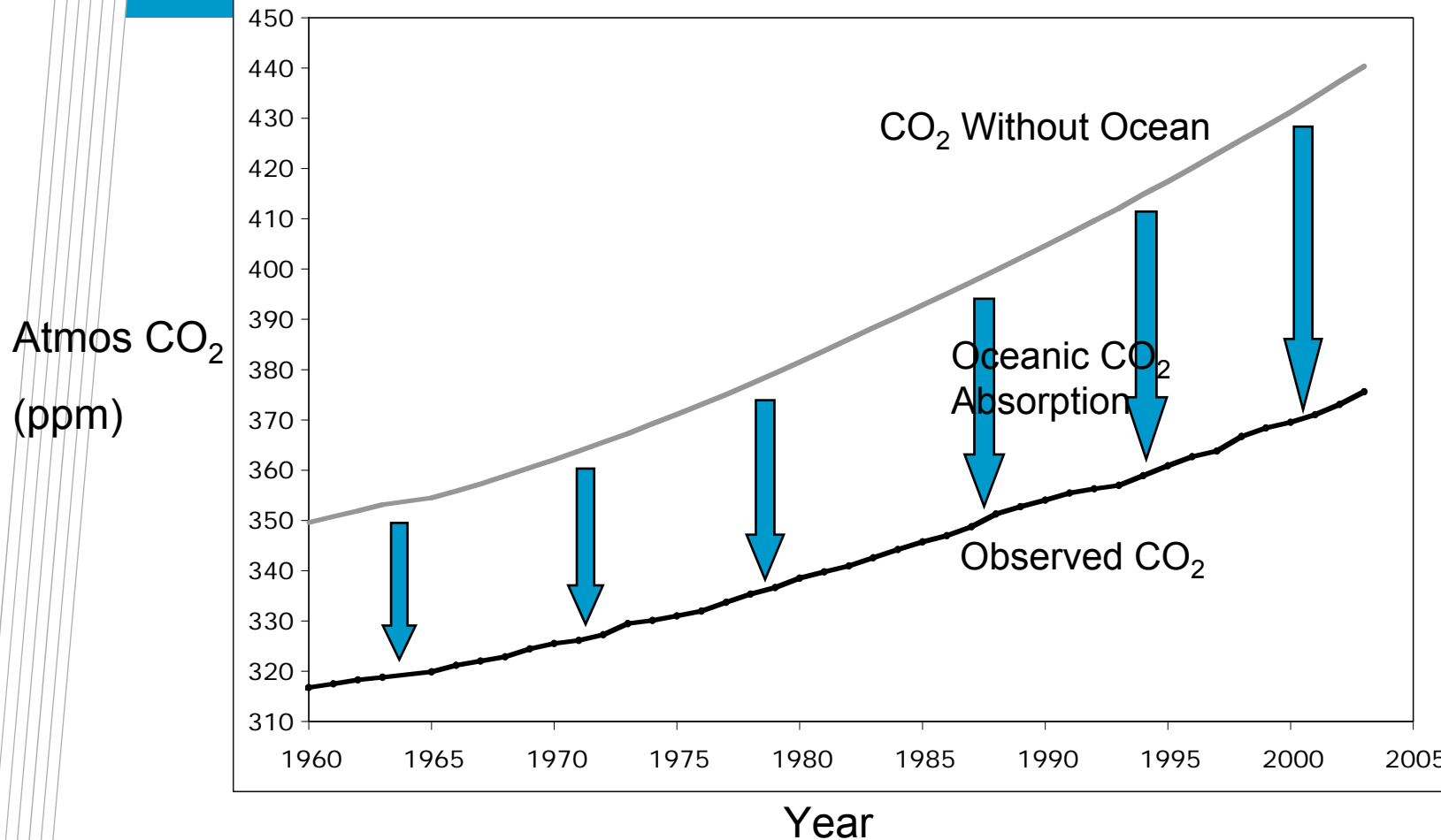
A2: self-reliance and local identity

B1: clean and resource efficient technology

B2: local, environmental, social equity diverse technology



# Importance of the Ocean for Atmospheric CO<sub>2</sub>



# Ocean Carbon Chemistry Primer



	280 $\mu\text{atm}$	560 $\mu\text{atm}$
$\text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3$ Carbonic acid	8 $\mu\text{mol kg}^{-1}$	15 $\mu\text{mol kg}^{-1}$
$\text{H}_2\text{CO}_2 \leftrightarrow \text{H}^+ + \text{HCO}_3^-$ Bicarbonate	1617 $\mu\text{mol kg}^{-1}$	1850 $\mu\text{mol kg}^{-1}$
$\text{HCO}_3^- \leftrightarrow \text{H}^+ + \text{CO}_3^{2-}$ Carbonate	268 $\mu\text{mol kg}^{-1}$	176 $\mu\text{mol kg}^{-1}$
<b>TCO<sub>2</sub> (DIC)</b>	<b>1893 <math>\mu\text{mol kg}^{-1}</math></b>	<b>2040 <math>\mu\text{mol kg}^{-1}</math></b>

**100% increase in pCO<sub>2</sub> ~ 8% increase in DIC**

**100% increase pCO<sub>2</sub> ~ 33% decrease in CO<sub>3</sub><sup>2-</sup>**

# Biological Impacts of Ocean Acidification

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1. Reduced stability of calcium carbonate shells impacts both the rate of calcification and the dissolution of calcium carbonate in the ocean
2. Elevated CO<sub>2</sub> may alter the growth rate of phytoplankton - e.g some coccolithophore show elevated growth with increased CO<sub>2</sub>
3. Acidification may alter the metabolic processes of marine organisms (acidosis)

# Biological Impacts of Ocean Acidification: Organisms that calcify



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## Coccolithophores

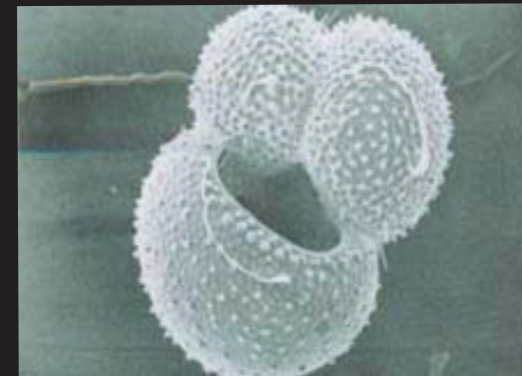
calcite



*T. Tyrrel*

## Forams

calcite



## Calcareous algae

High-Mg  
calcite



*Nancy Sefton*

## Corals

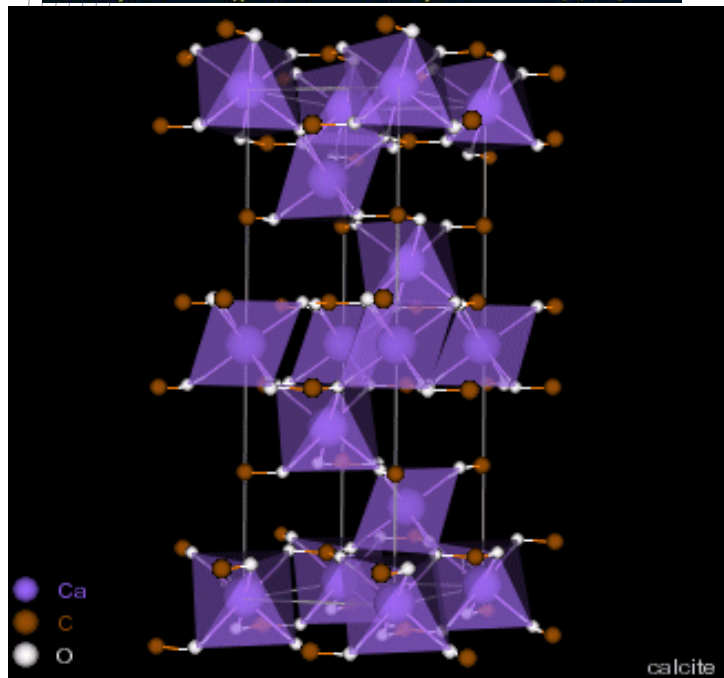
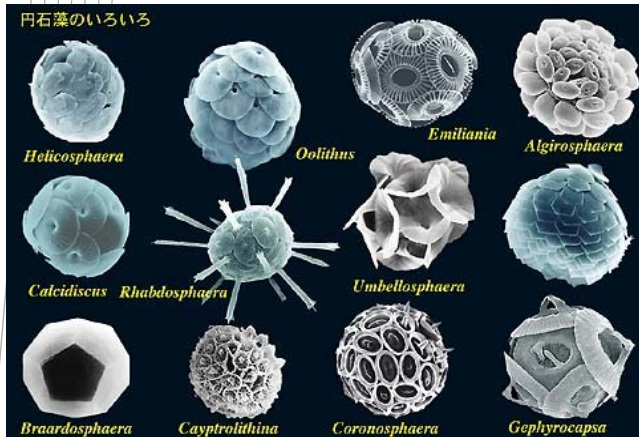
aragonite



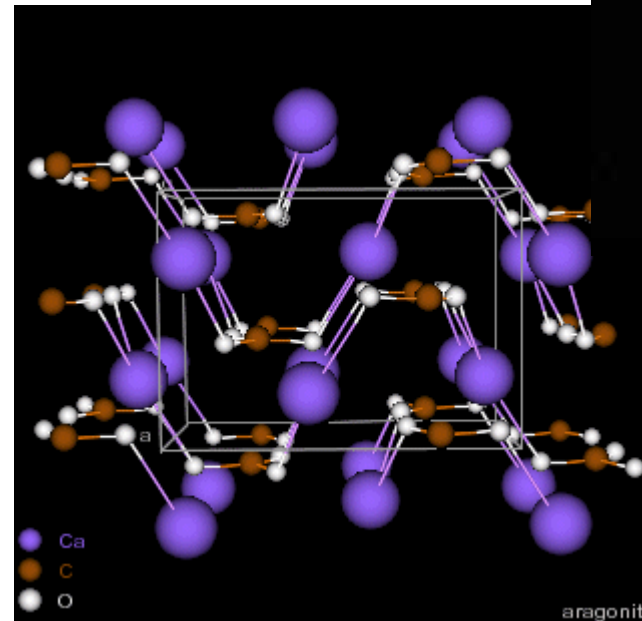
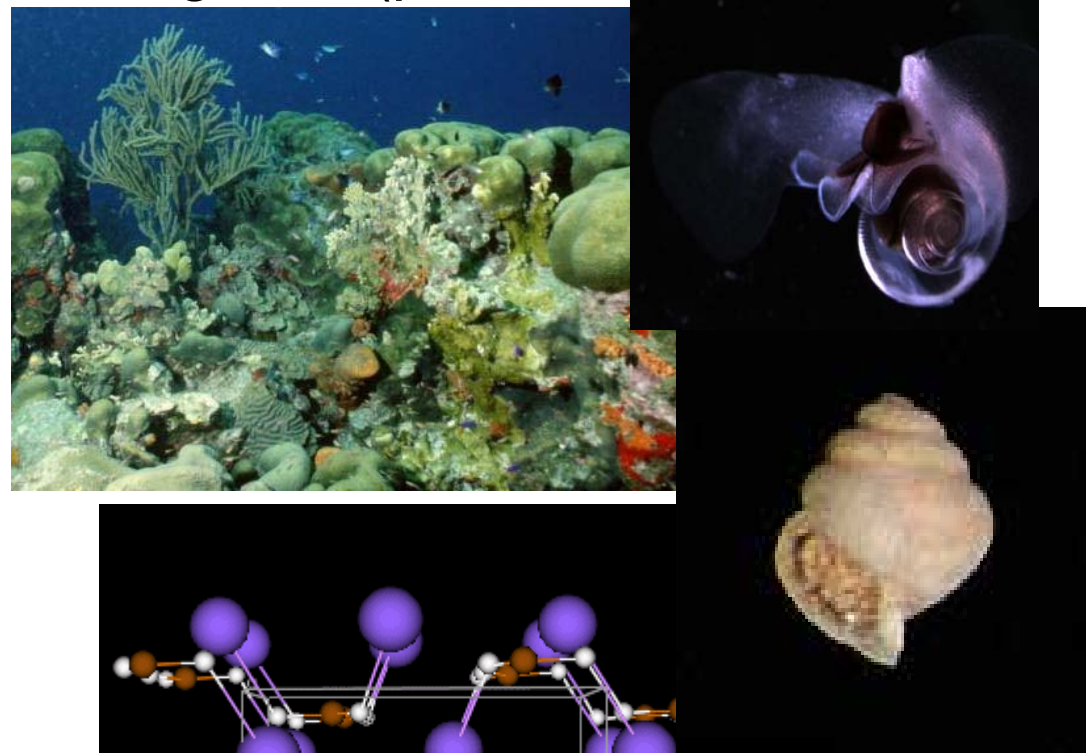
NOAA

# Two forms of calcium carbonate - different stability

## Calcite (plankton)



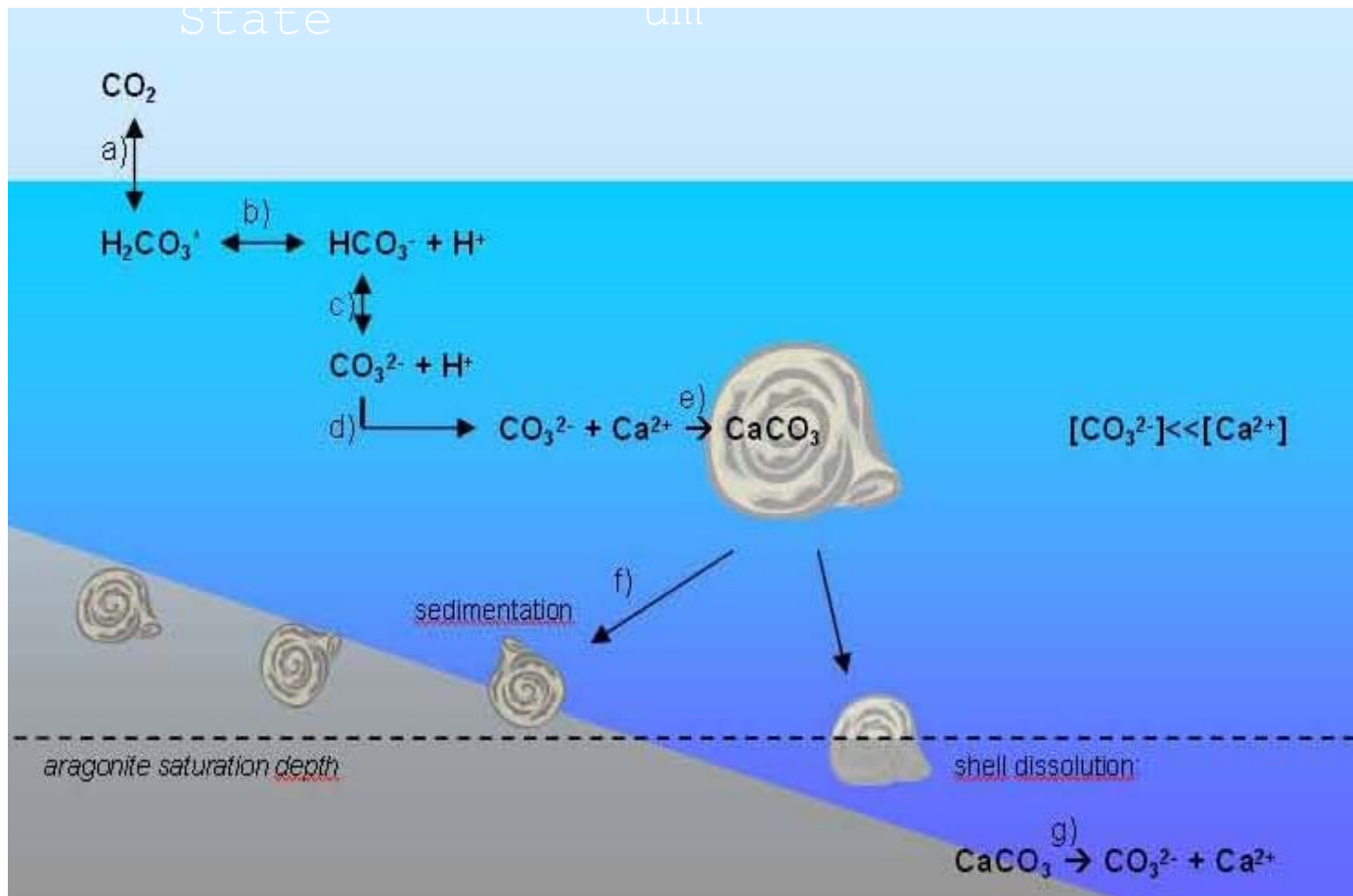
## Aragonite (plankton and corals)



# Calcium Carbonate (CaCO<sub>3</sub>) Cycle

$$\Omega = \frac{[\text{Ca}^{2+}][\text{CO}_3^{2-}]}{K_{sp}}$$

Aragonite Saturation State      Calcium Ion      Carbonate Ion      Aragonite Solubility Coeff



Stable CaCO<sub>3</sub>

$\Omega > 1$

Unstable CaCO<sub>3</sub>

$\Omega < 1$

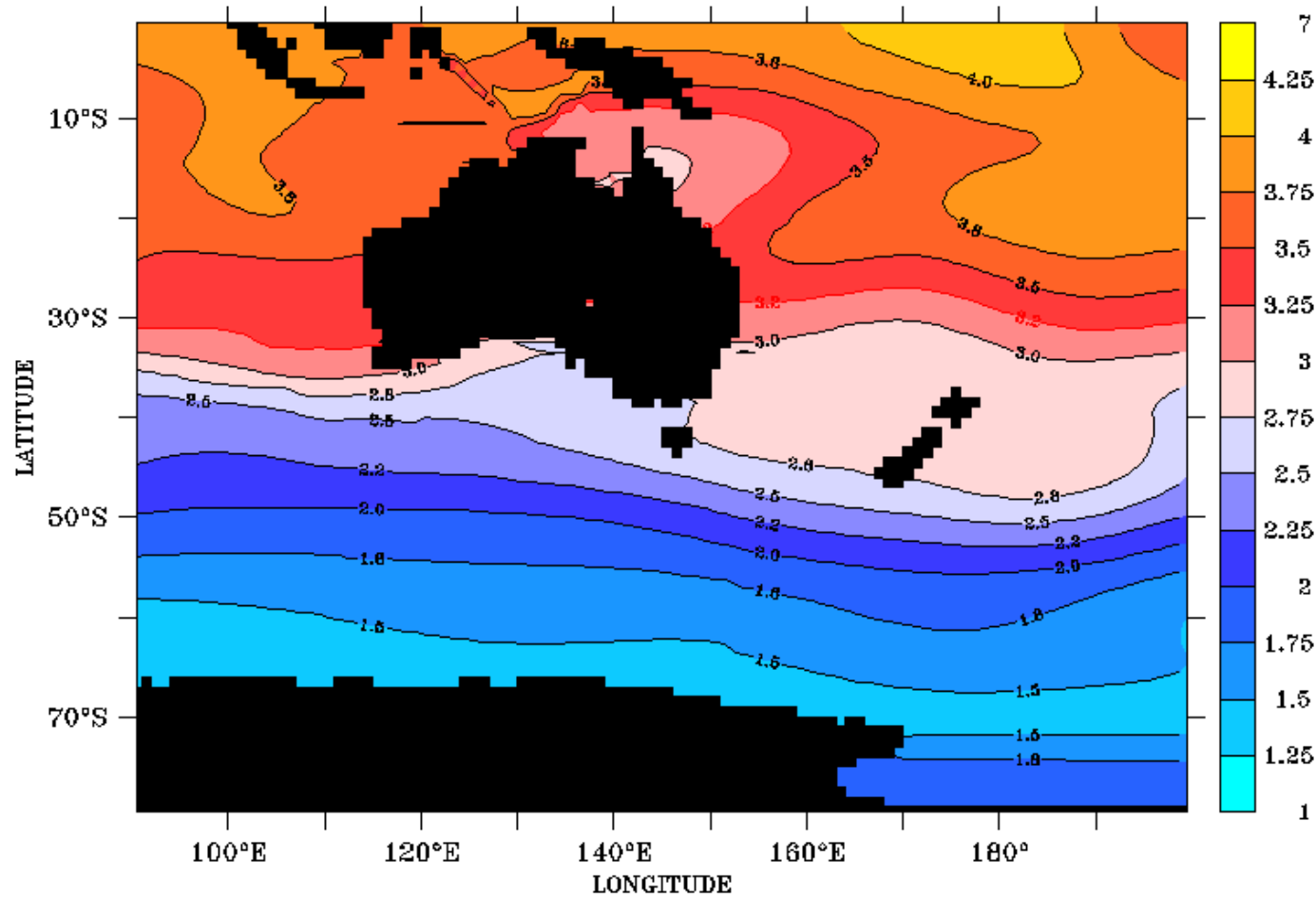
# For A2 scenario: Future Aragonite Saturation State



Z (calendar\_year as) : 2000  
T (YEAR) : 2000

FERRET (alpha) Ver. 3.70  
NOAA/PMEL TMAP  
Mar 22 2009 10:45:05

DATA SET: omega

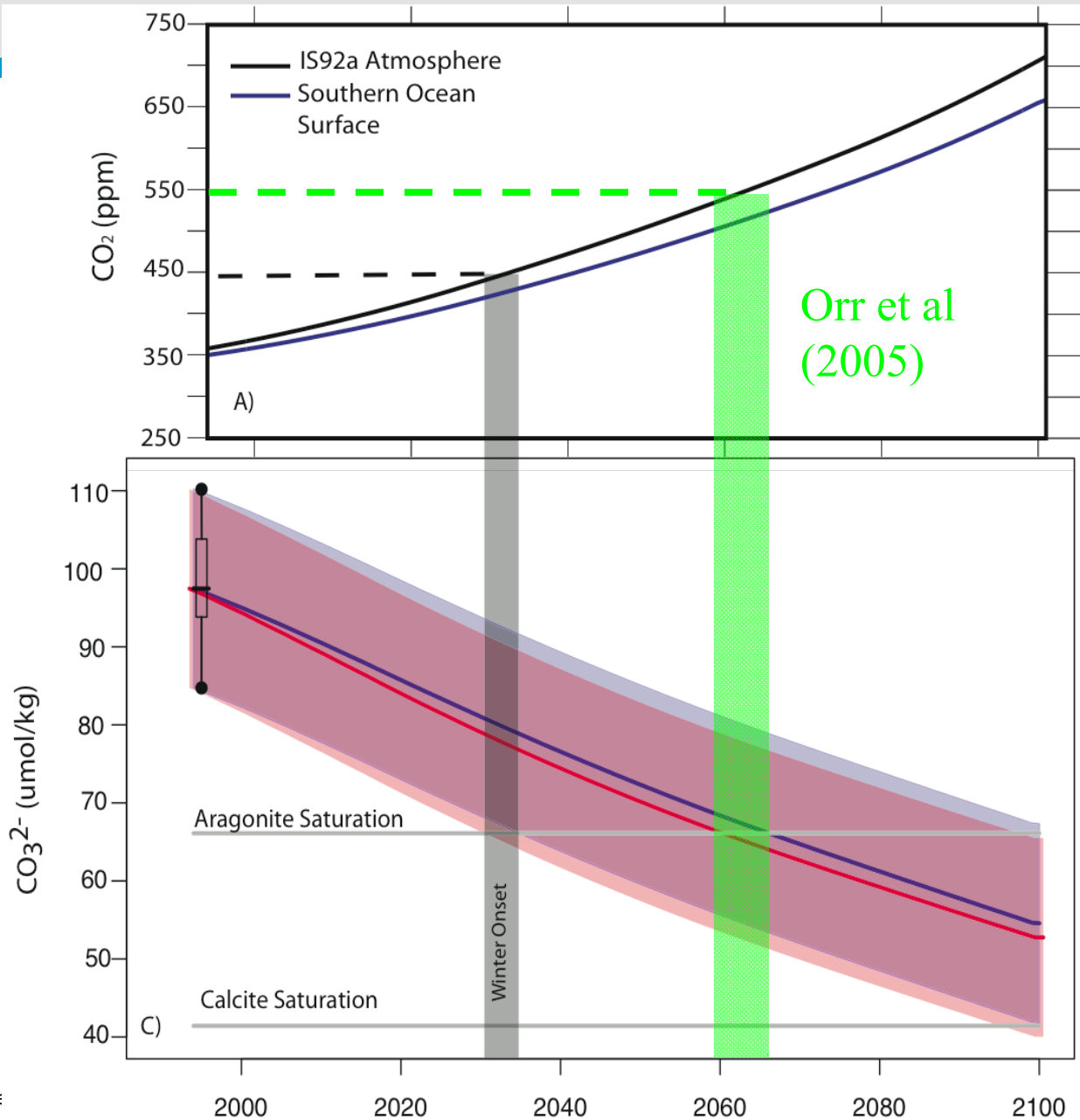


Saturation State

A value less than 1 equals corrosive conditions for aragonite

Aragonite

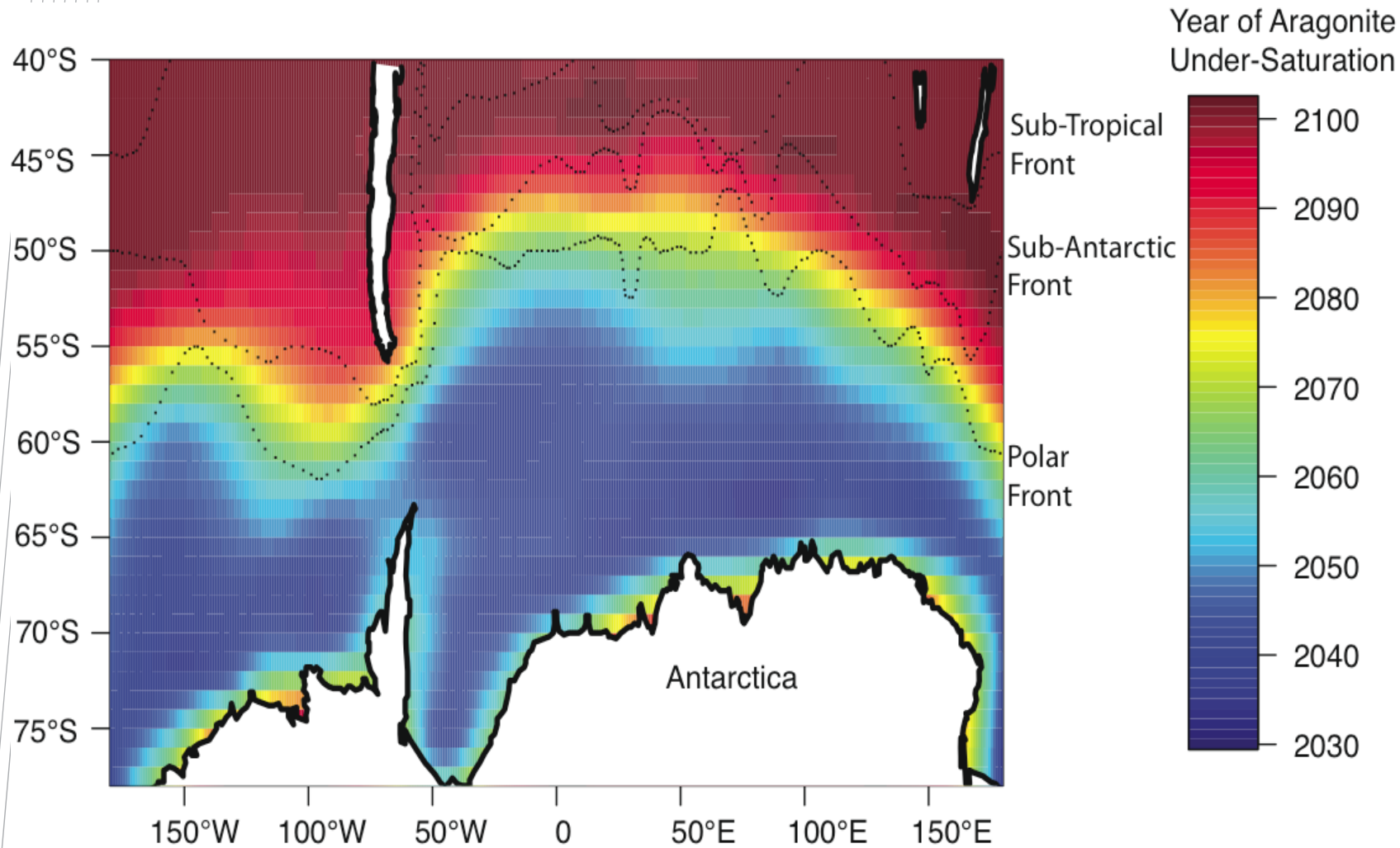
# 450ppm is the tipping point



# Southern Ocean Acidification Divide



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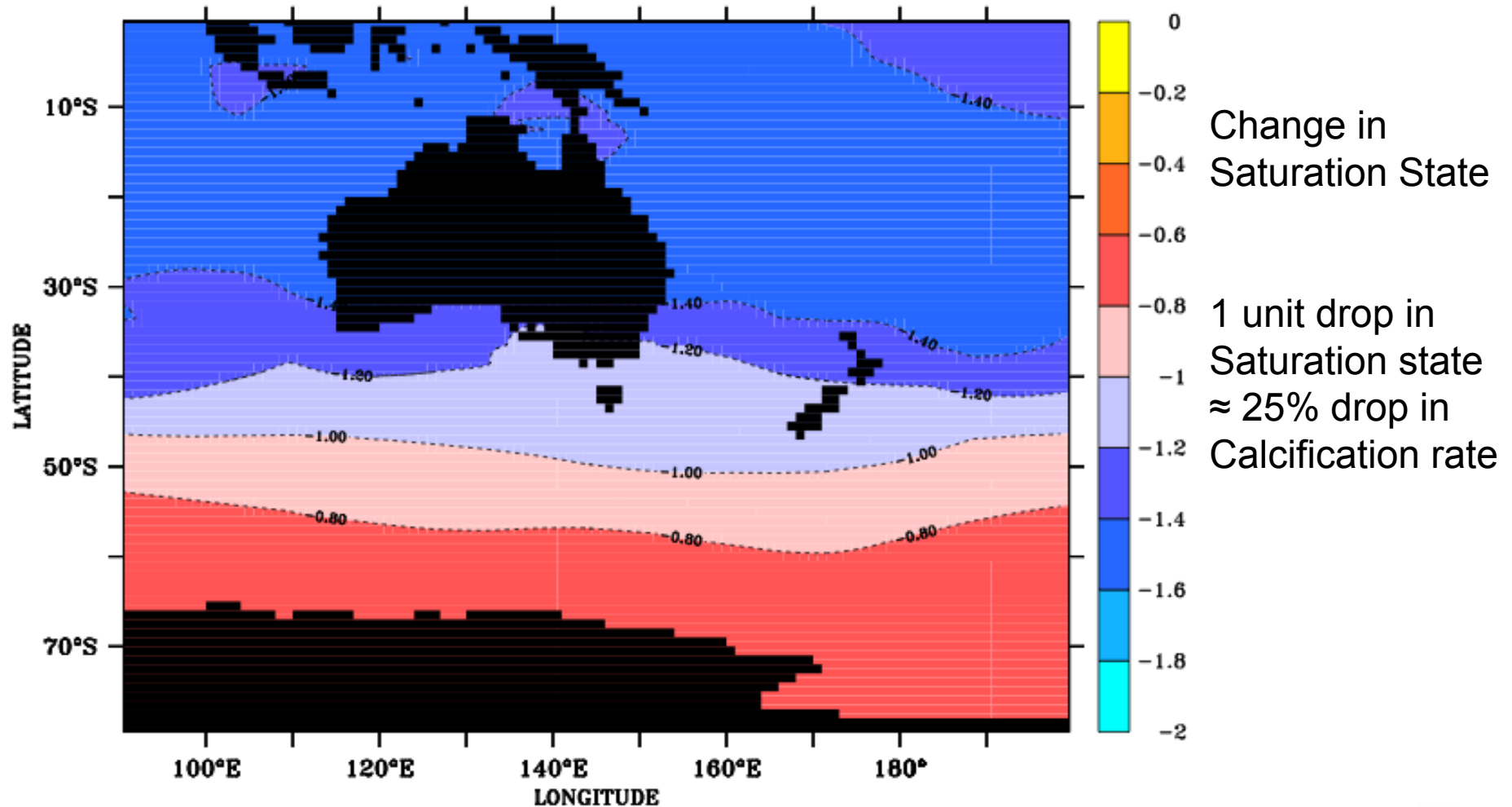


Acidification divide set-up by  
the Polar Front  
Ocean Acidification McNeil and Matear, PNAS, 2008

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# For A2 scenario: Change in Aragonite Saturation State



Aragonite

# Direct Impact of Elevated CO<sub>2</sub> on phytoplankton (coccolithophores)

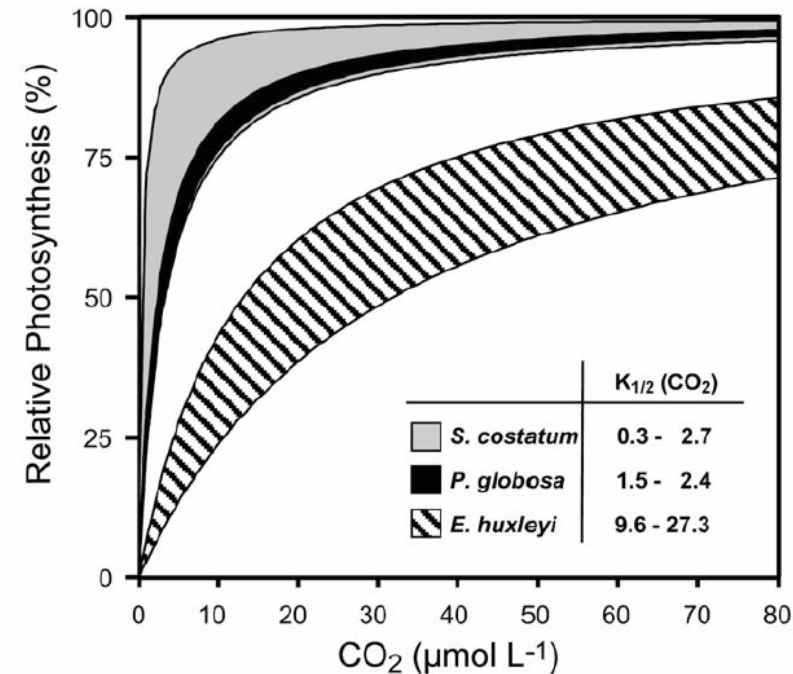
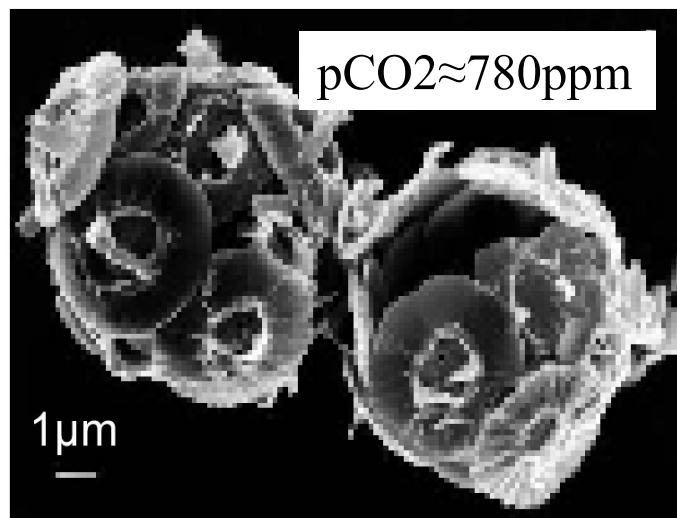
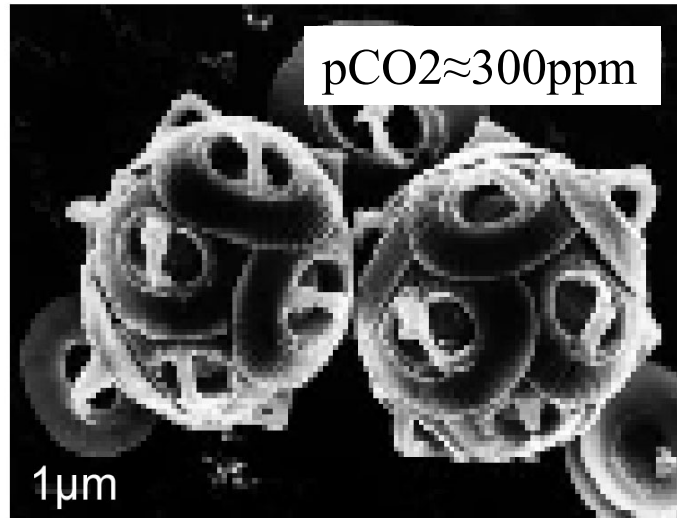
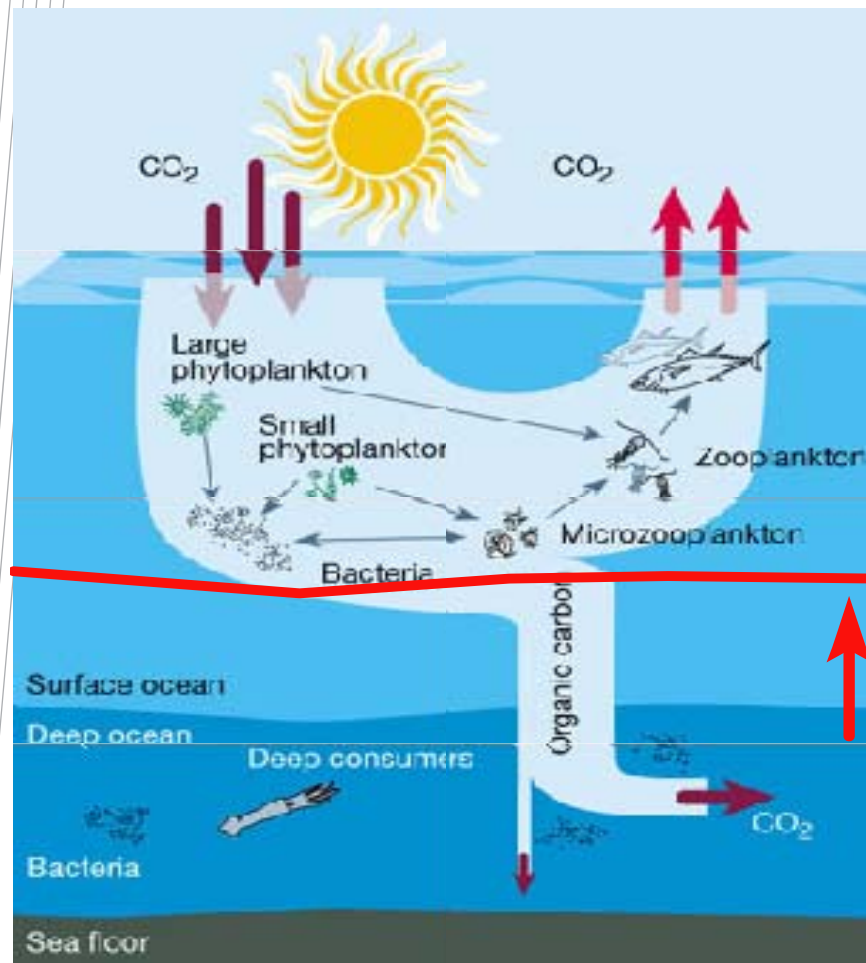


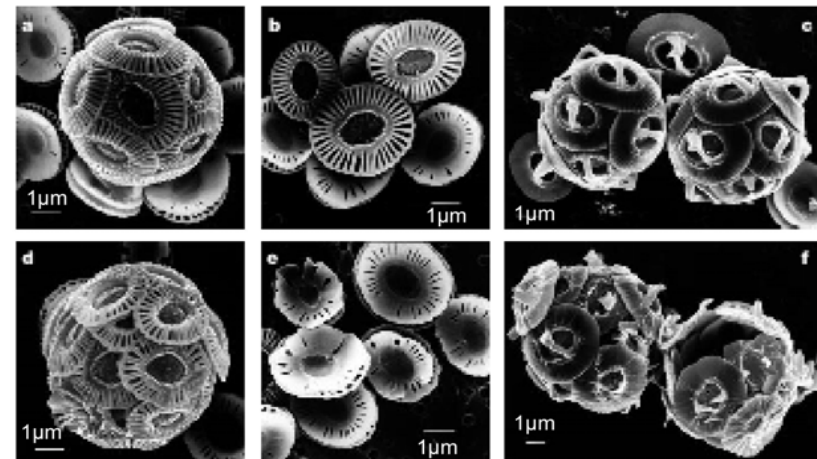
Fig. 2. Photosynthesis of phytoplankton species differs with respect to CO<sub>2</sub> sensitivity: While most species (here *Skeletonema costatum* and *Phaeocystis globosa*) are at or close to CO<sub>2</sub> saturation at present day CO<sub>2</sub> levels (8–20 μmol L<sup>-1</sup>), coccolithophores such as *Emiliana huxleyi* have comparatively low affinities for inorganic carbon and appear to be carbon-limited in today's ocean. This raises the

*Assessing the outcome of multiple forcings is complex*



Ocean Acidification

*Emiliana huxleyi* has **expanded** northward in the past 30 years into the Bering and Icelandic Seas



# Summary:

## Biological Impacts of Ocean Acidification

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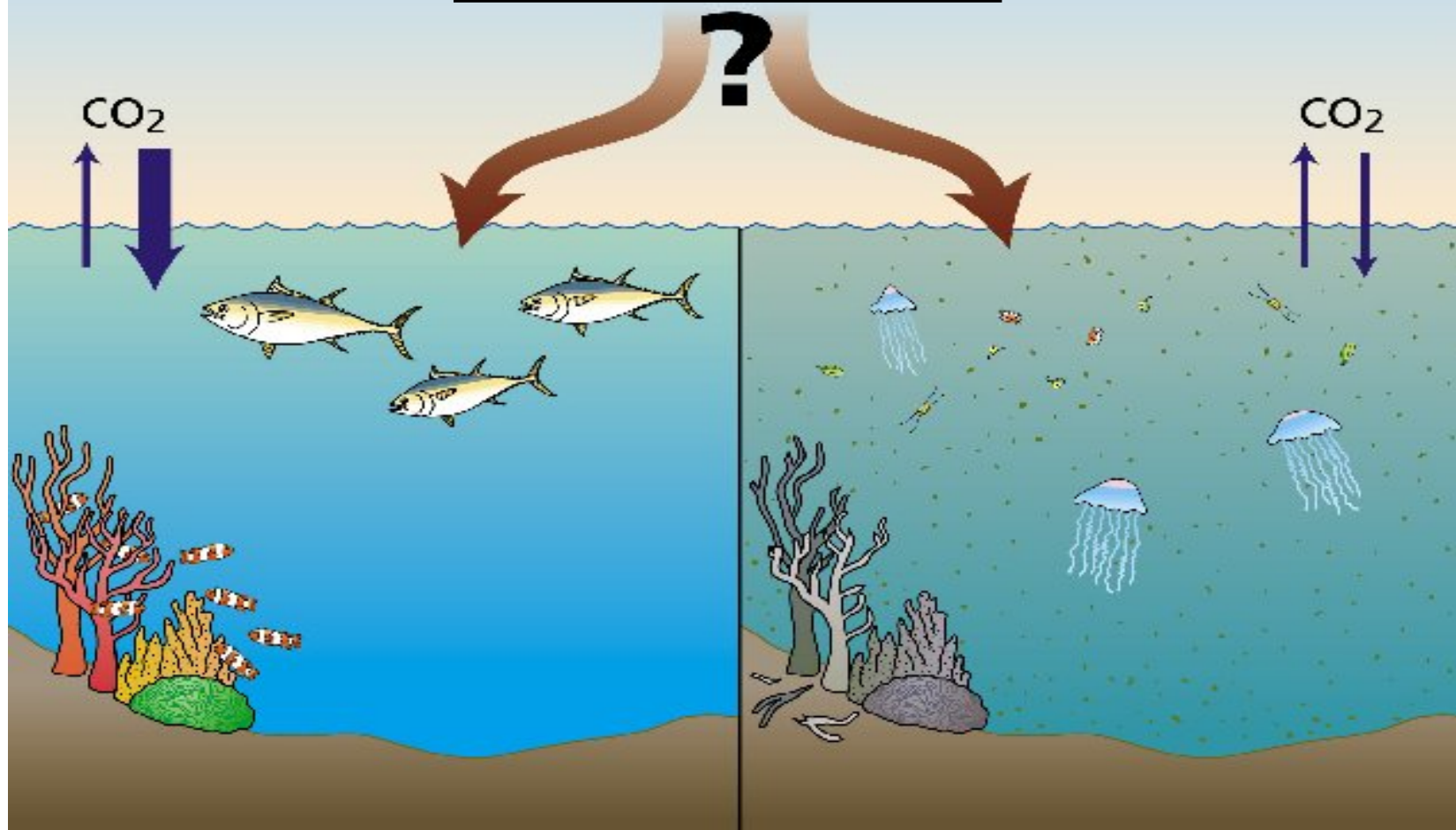
- Rising CO<sub>2</sub> levels in the atmosphere will reduce the ability of biological organisms to calcify and decrease the stability of calcium carbonate, BUT it is not clear what the wider ecosystem consequences of these changes will be!

### What we don't know

- Impacts on biogeochemical cycles
- Responses of other calcifying species:
  - Planktonic (other coccolithophorids, molluscs)
  - Benthic (bryozoans, corals, coralline algae)
- Impacts on food webs & ecosystems



# Ecosystem vulnerability to CO<sub>2</sub> exposure





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## Centre for Australian Weather and Climate Research

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# Summary Points



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# Biological Responses to ocean Acidification

# Summary



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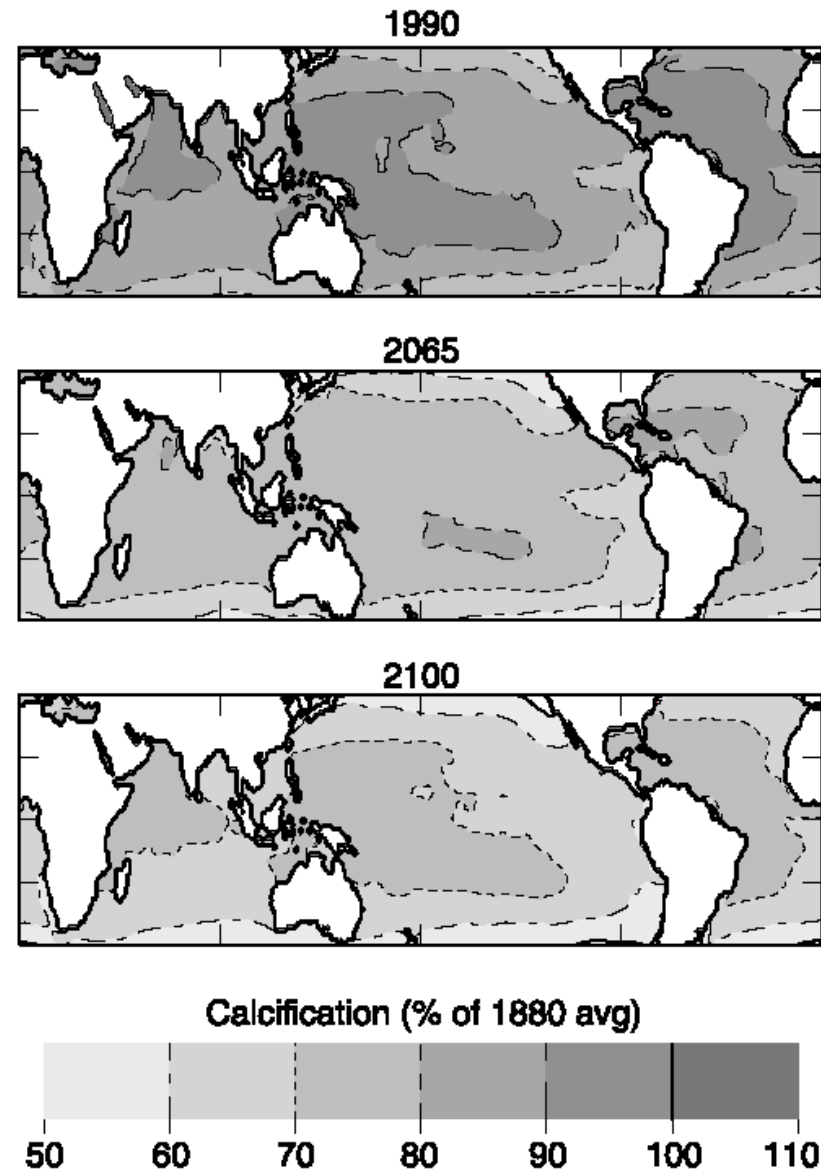
- **Rising CO<sub>2</sub> levels in the atmosphere will reduce the ability of biological organisms to calcify and decrease the stability of calcium carbonate, BUT it is not clear what the wider ecosystem consequences of these changes will be!**
- The impact of elevated CO<sub>2</sub> on marine phytoplankton growth is variable with laboratory experiments showing increase, decrease and no change. The wider ecosystem impacts of these potential changes are unknown, however, I speculate that the phytoplankton response to environmental change is more important to the functioning of a marine ecosystem than changes to higher trophic level organisms. Phytoplankton are more important than whales.
- pH does influence metabolic processes but it is not yet apparent whether the projected changes are large enough to have a significant impact. New laboratory experiments show elevated temperature and reduced pH do negatively impact the larval development of oysters.

## Changes to the calcification rate of corals

# Geochemical Consequences of Increased Atmospheric Carbon Dioxide on Coral Reefs

Joan A. Kleypas,<sup>1\*</sup> Robert W. Buddemeier,<sup>2</sup> David Archer,<sup>3</sup>  
Jean-Pierre Gattuso,<sup>4</sup> Chris Langdon,<sup>5</sup> Bradley N. Opdyke<sup>6</sup>

A coral reef represents the net accumulation of calcium carbonate ( $\text{CaCO}_3$ ) produced by corals and other calcifying organisms. If calcification declines, then reef-building capacity also declines. Coral reef calcification depends on the saturation state of the carbonate mineral aragonite of surface waters. By the middle of the next century, an increased concentration of carbon dioxide will decrease the aragonite saturation state in the tropics by 30 percent and biogenic aragonite precipitation by 14 to 30 percent. Coral reefs are particularly threatened, because reef-building organisms secrete metastable forms of  $\text{CaCO}_3$ , but the biogeochemical consequences on other calcifying marine ecosystems may be equally severe.



**Fig. 2.** Projected changes in reef calcification rate based on average calcification response of two species of tropical marine algae and one coral (12) and a marine mesocosm (13).

# The Big Picture



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QuickTime™ and a  
YUV420 codec decompressor  
are needed to see this picture.