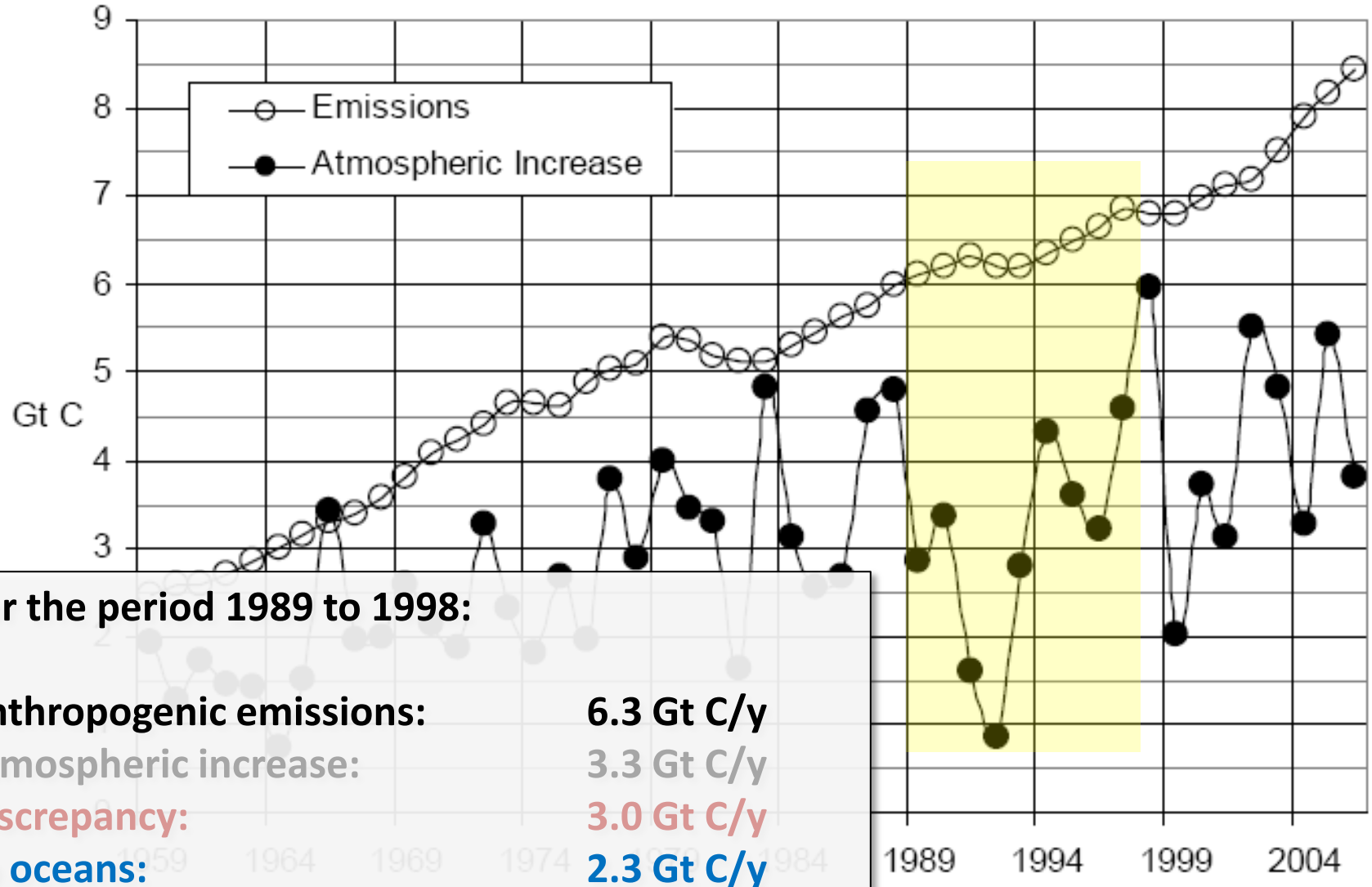

Ocean Acidification

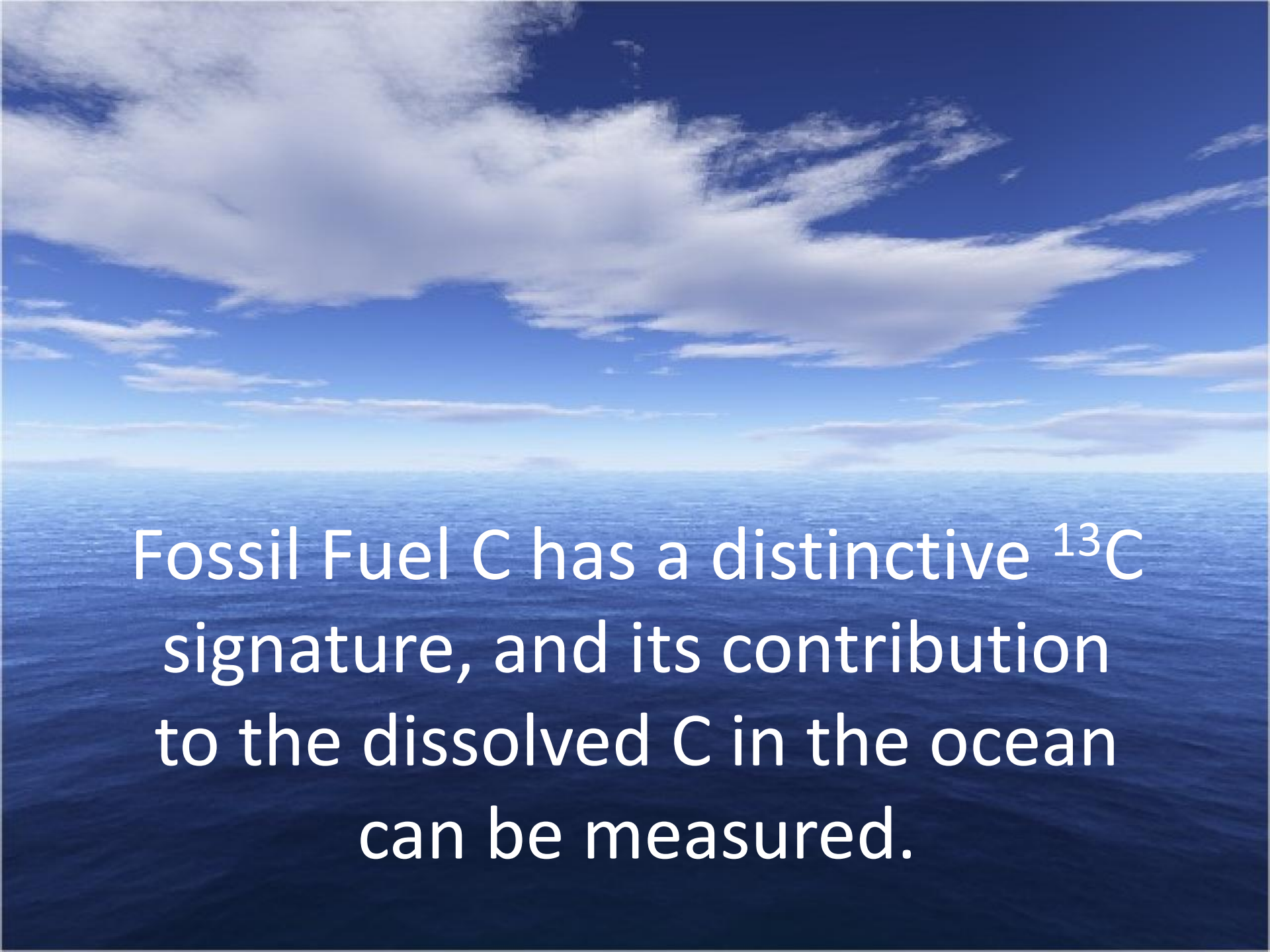
A The fate of CO_2 emissions



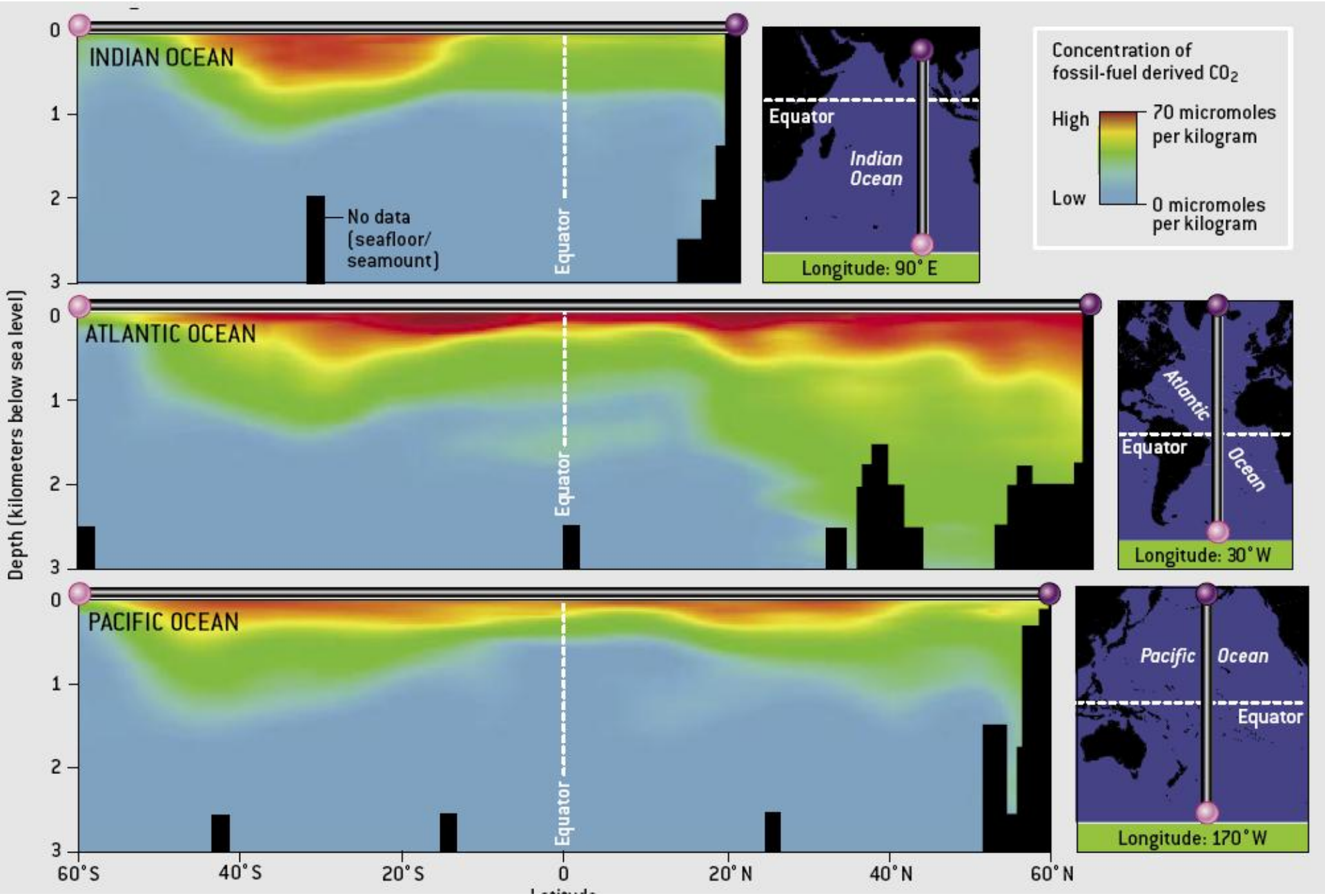
For the period 1989 to 1998:

Anthropogenic emissions:	**6.3 Gt C/y**
Atmospheric increase:	**3.3 Gt C/y**
Discrepancy:	**3.0 Gt C/y**
To oceans:	**2.3 Gt C/y**
To land:	**0.7 Gt C/y**

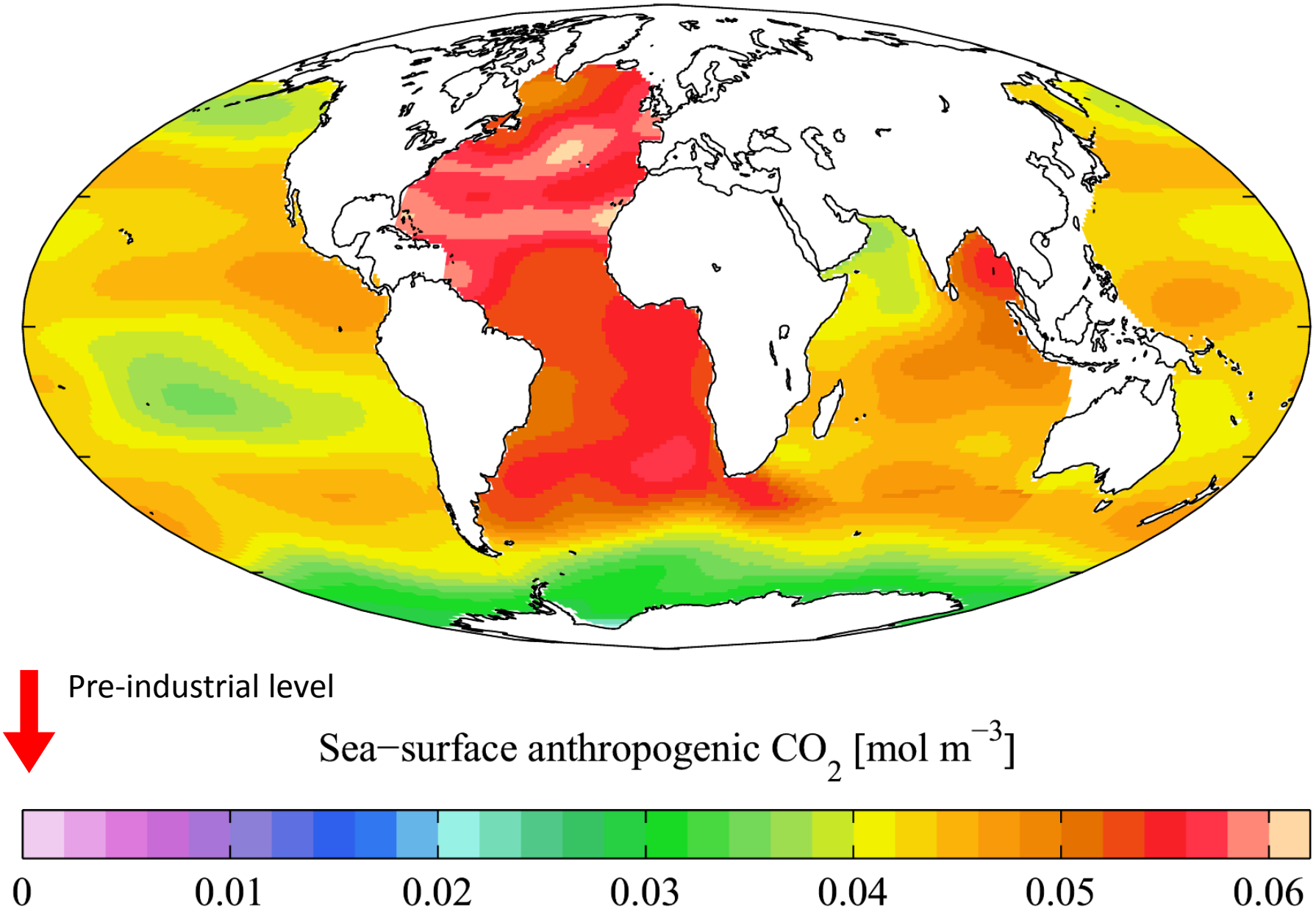
Source: IPCC


Fossil Fuel C has a distinctive ^{13}C signature, and its contribution to the dissolved C in the ocean can be measured.

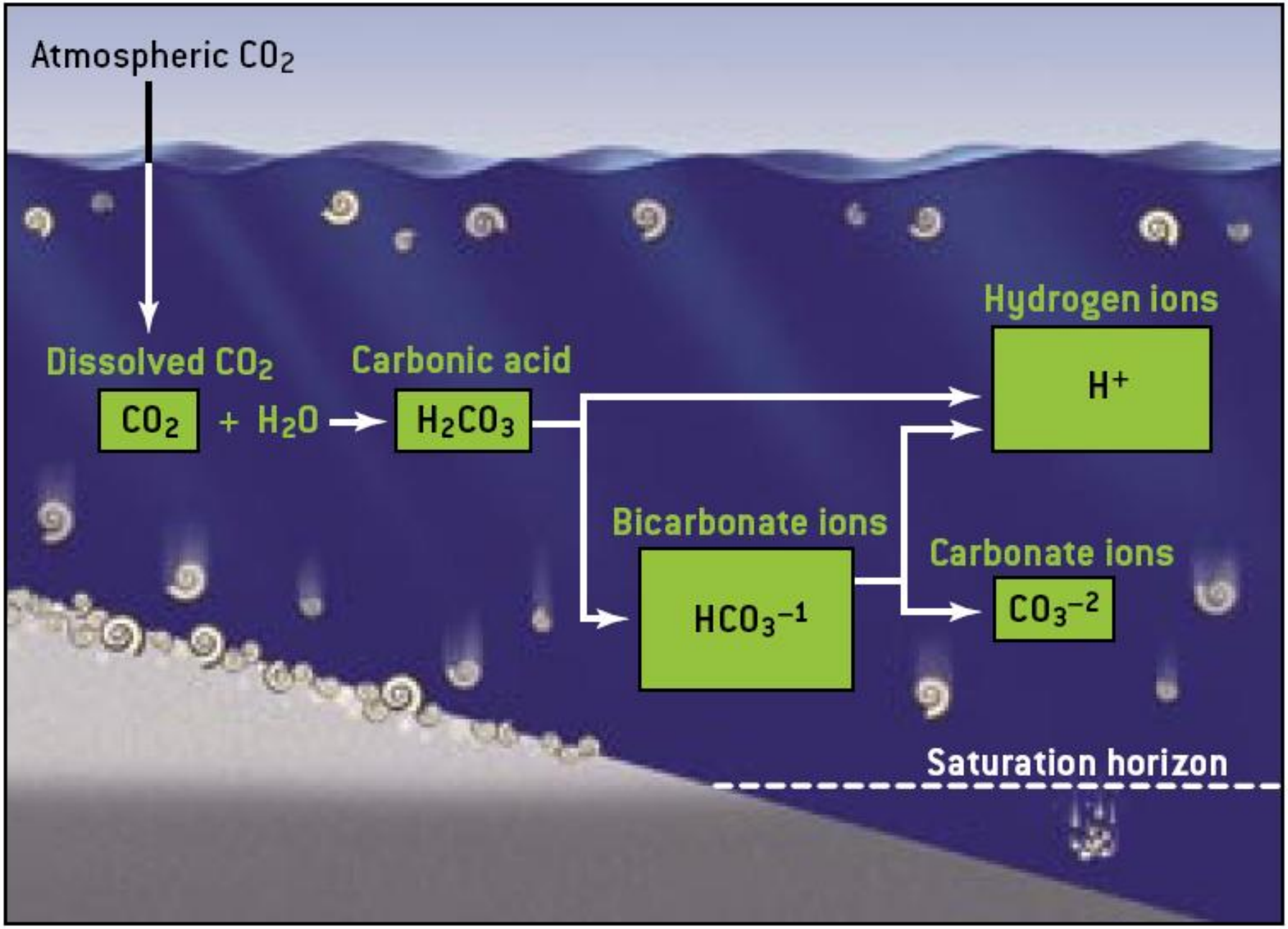
Global Ocean Data Analysis Project (GLODAP)



From Doney, 2006



Data from the Global Ocean Data Analysis Project, map by Plumbago



From Doney, 2006

Carbonate Geochemistry Reactions

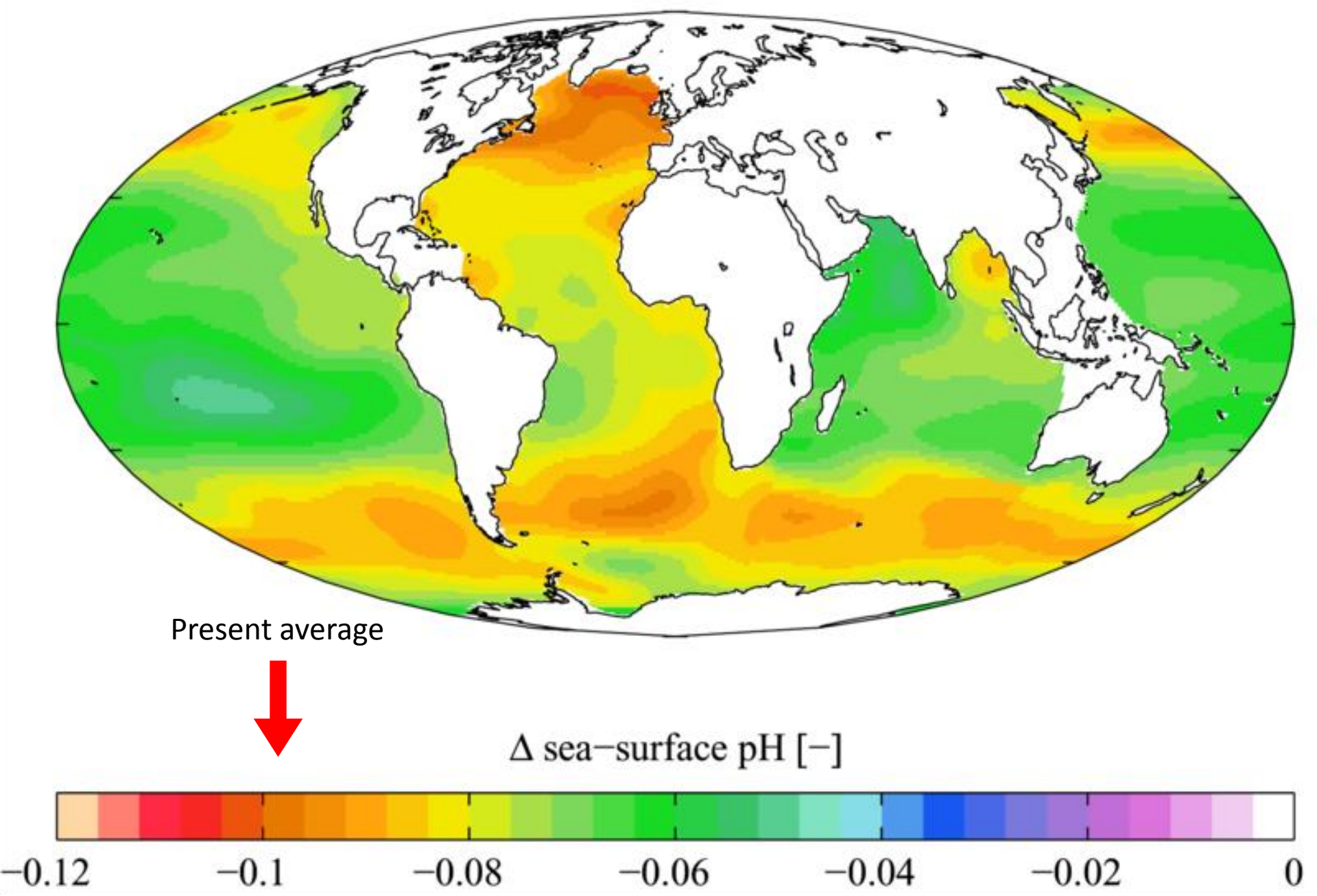
$$CO_2\ (gas) + H_2O \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$

$$HCO_3\text{-} \rightarrow H^+ + CO_3^{2-}$$

$$Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3\ (calcite, aragonite)$$

Typically is mediated by organisms,
but it does happen inorganically



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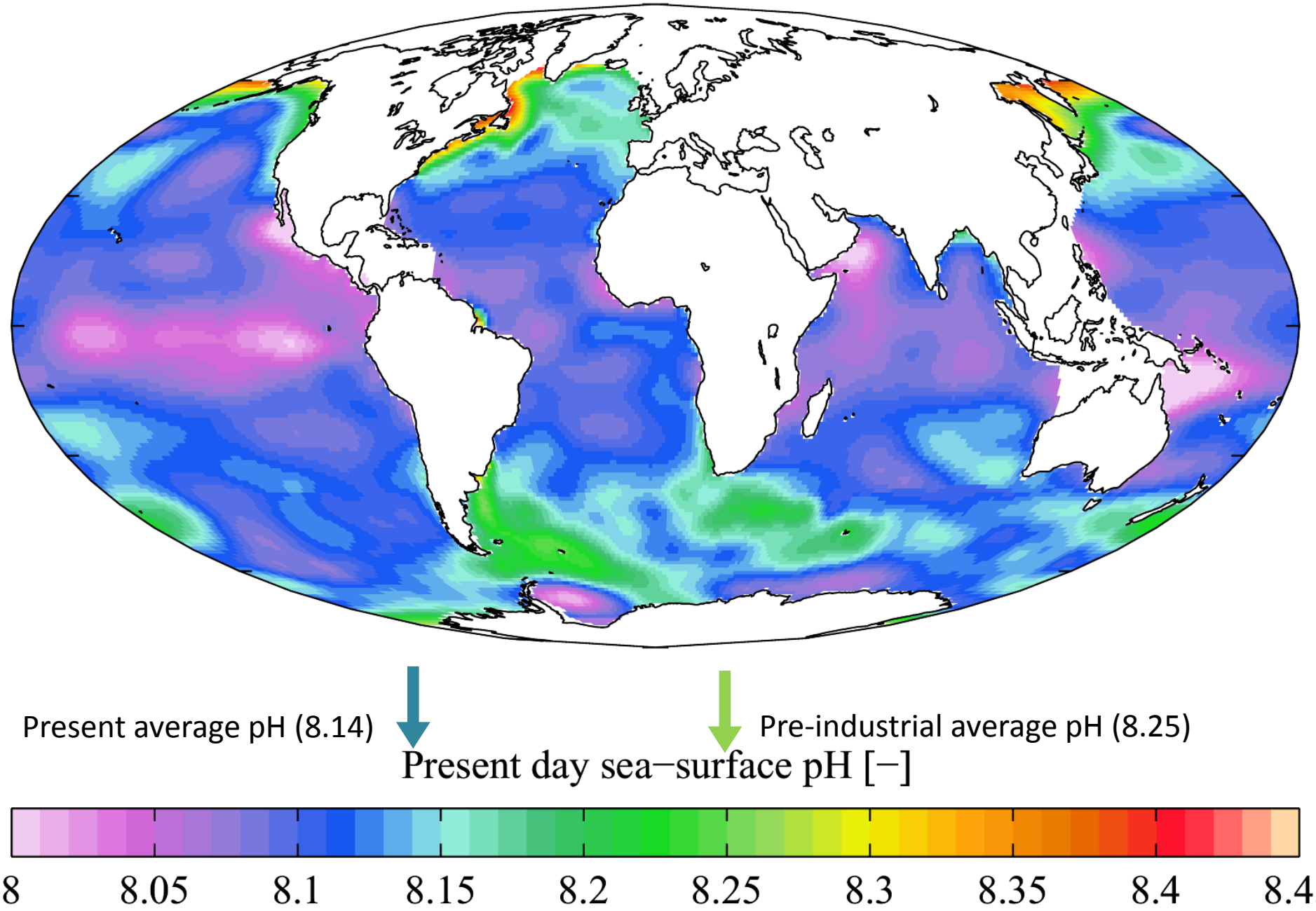
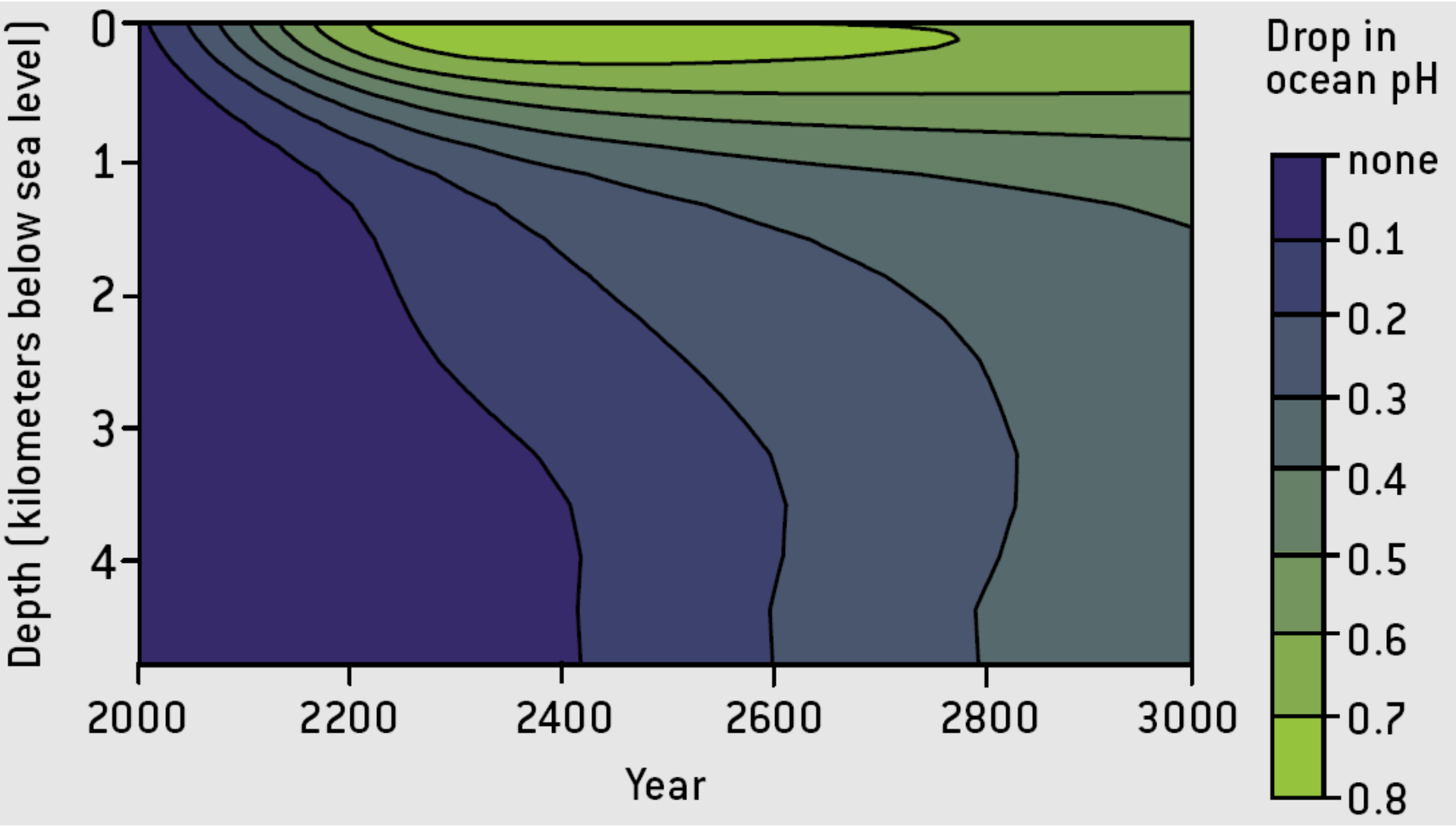
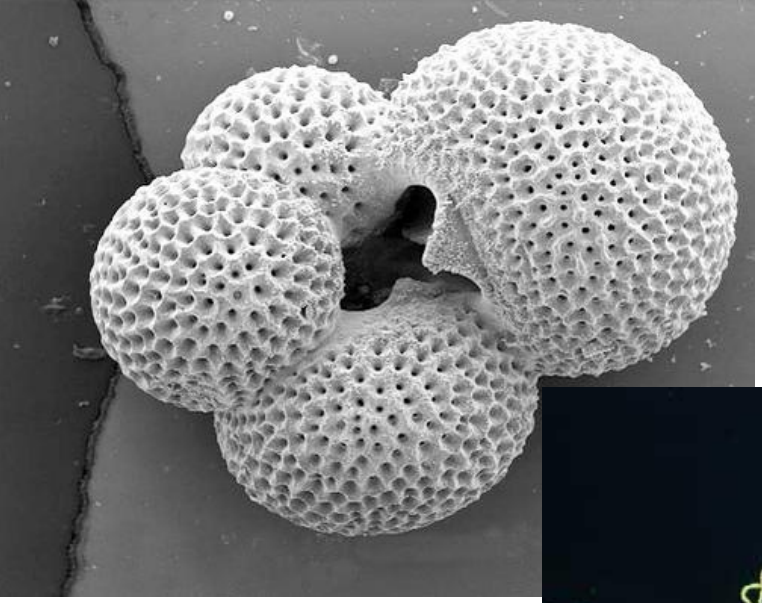


Data from the Global Ocean Data Analysis Project, map by Plumbago

pH changes versus depth and time



From Doney, 2006



How does this acidity affect carbonate secreting marine organisms?

Carbonate minerals of marine organisms

Calcite:

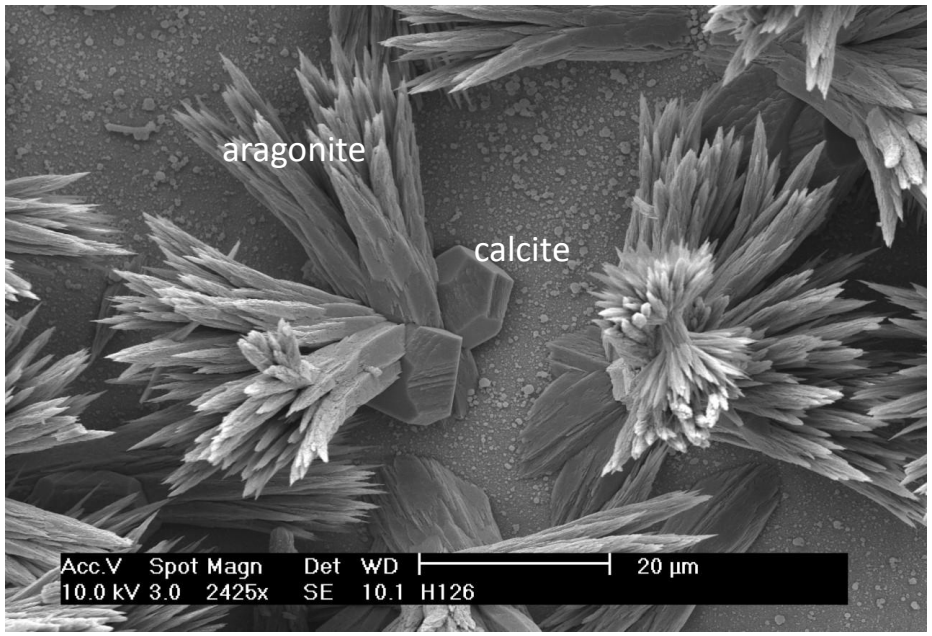
rhombohedral $CaCO_3$

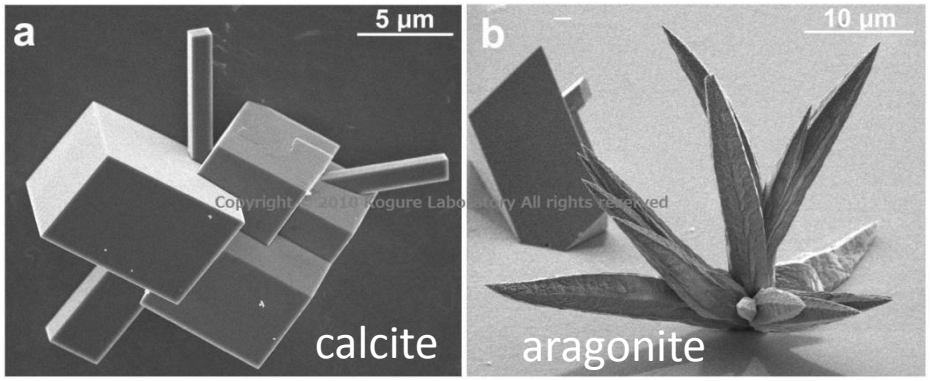
High-magnesian calcite:

rhombohedral $CaCO_3$ with
5-25% Mg substituting for Ca

Aragonite:

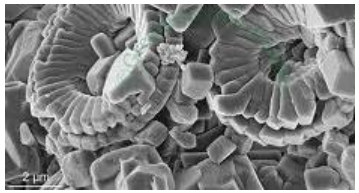
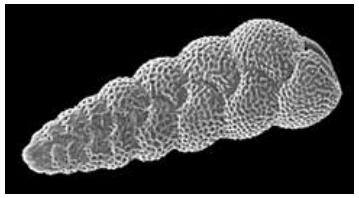
Orthorhombic $CaCO_3$





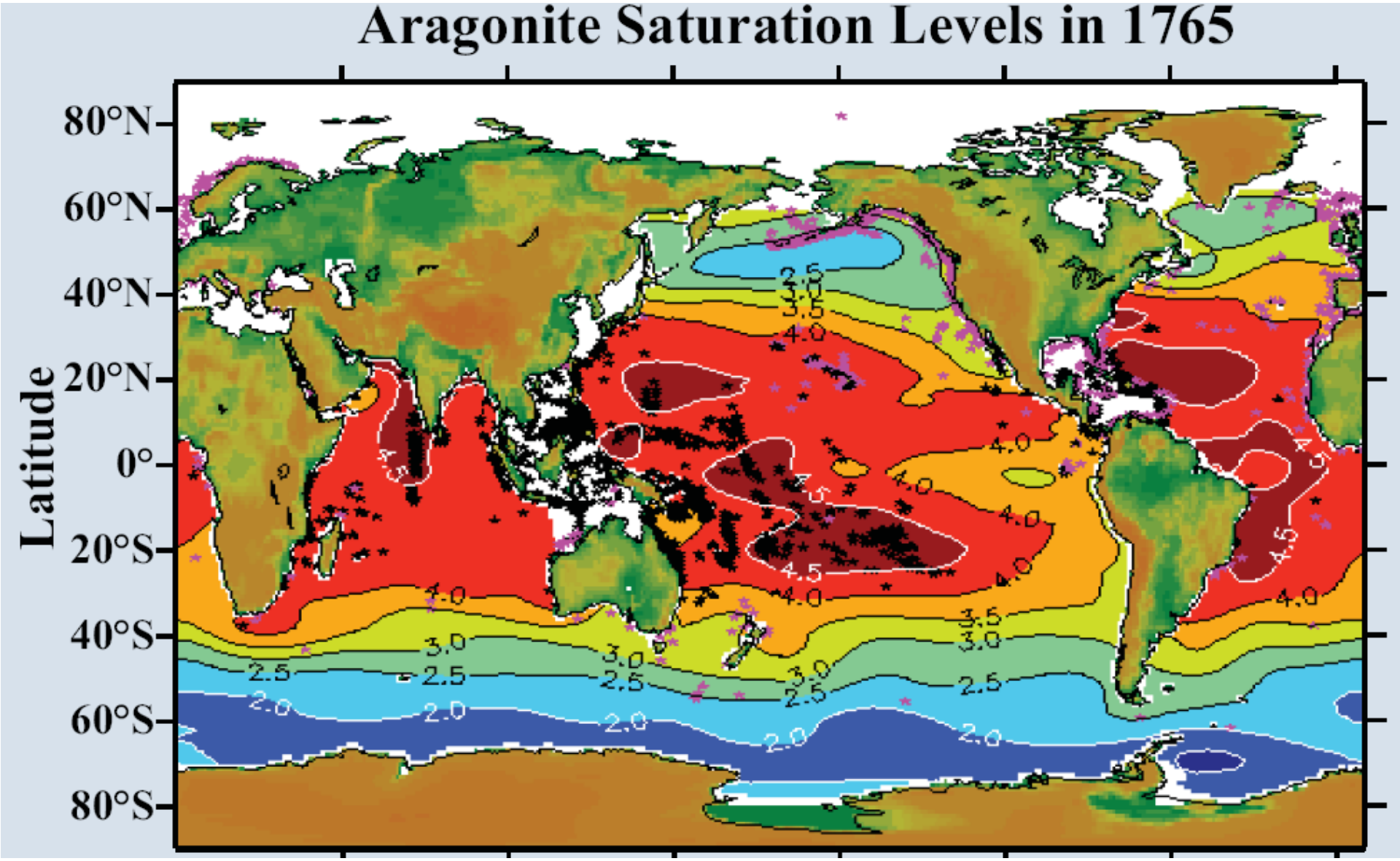
Dolomite: rhombohedral $CaMg(CO_3)_2$ (not made by organisms)

Skeletal carbonate mineralogy of some common marine organisms

Coralline algae		High-magnesian calcite
Calcareous green algae		Aragonite
Coccoliths (calcareous algae)		Calcite
Foraminifers		High-magnesian calcite
Most corals		Aragonite
Pteropods		Aragonite

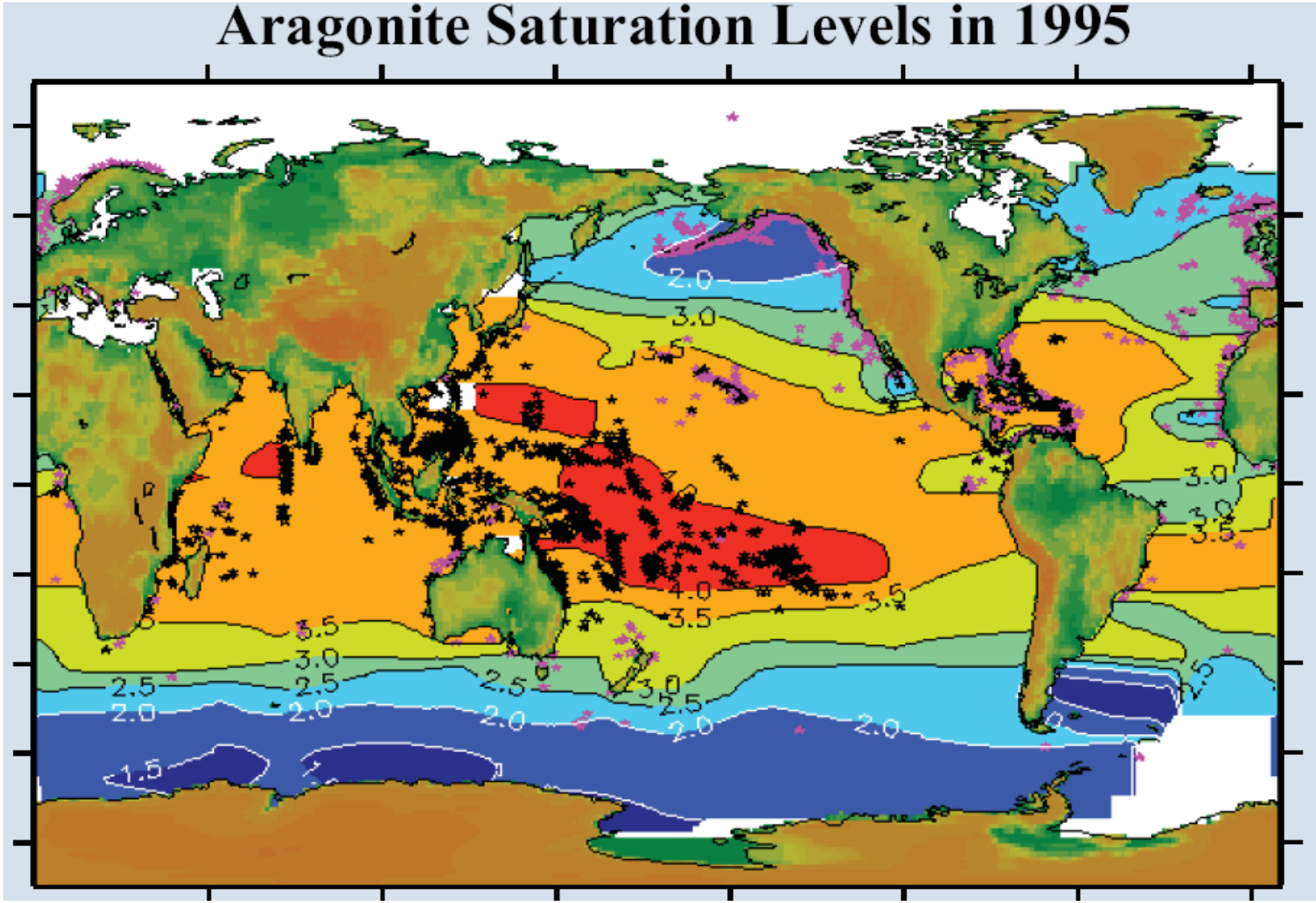
Aragonite is especially susceptible to dissolution at reduced pH levels.

Magnesian calcite is more susceptible than regular calcite.



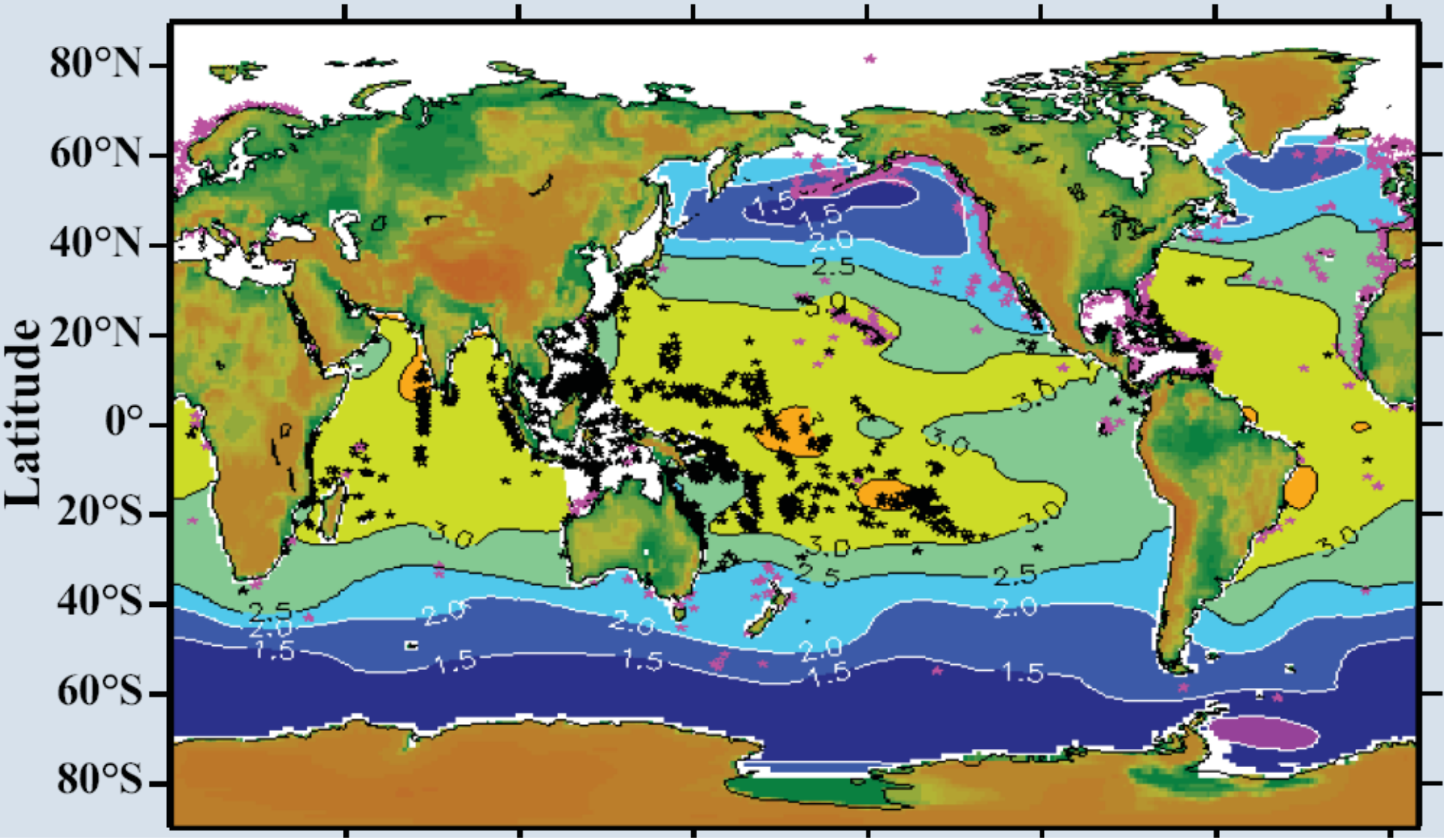
Most of the ocean is 2 to 4 times supersaturated with respect to aragonite, and even more with respect to calcite.

From Kleypas, et al., 1995



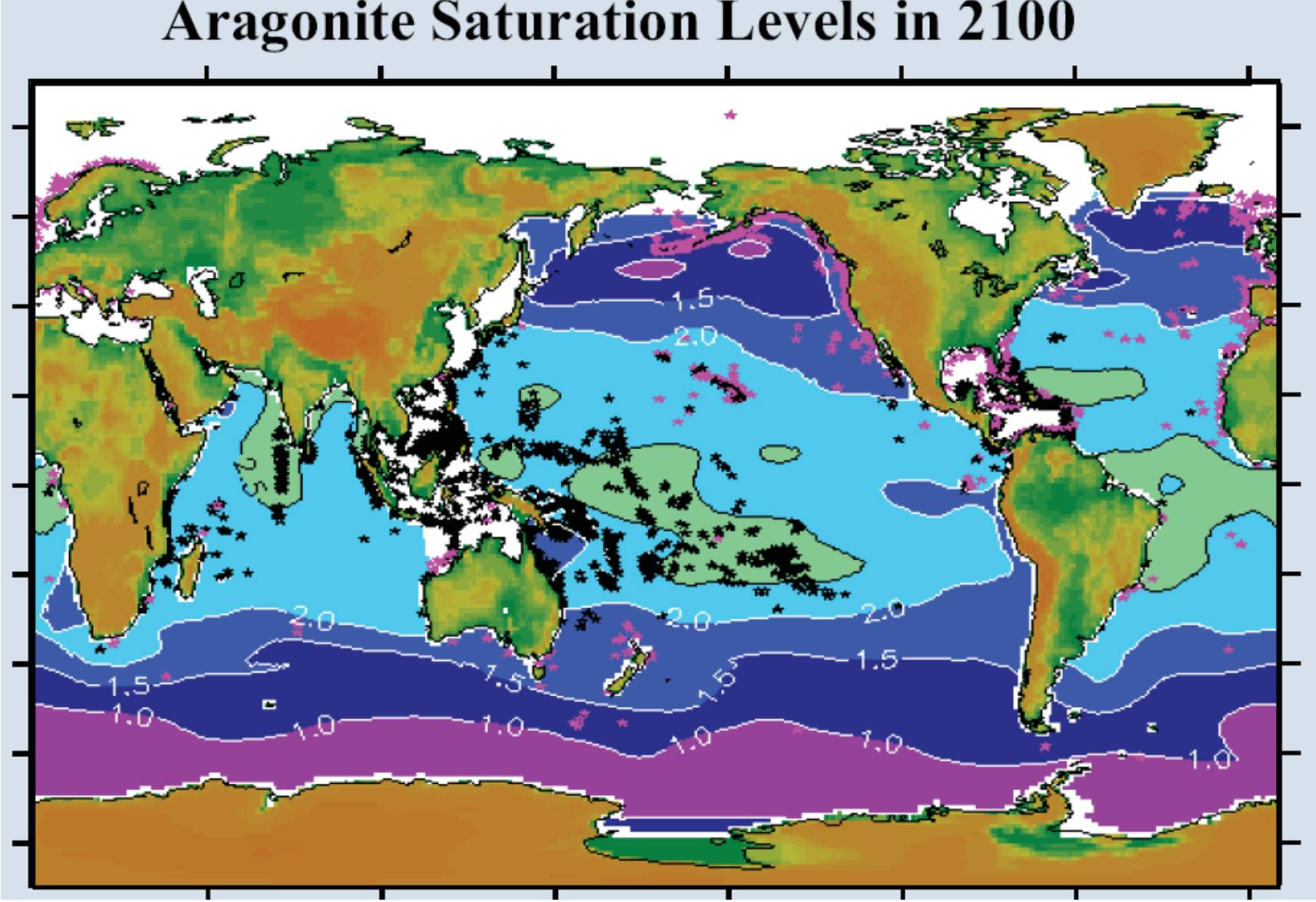
From Kleypas, et al., 1995

Aragonite Saturation Levels in 2040



Within 30 years it is expected that some parts of the ocean surface will be undersaturated with respect to aragonite. Aragonite shells and skeletons will start to dissolve.

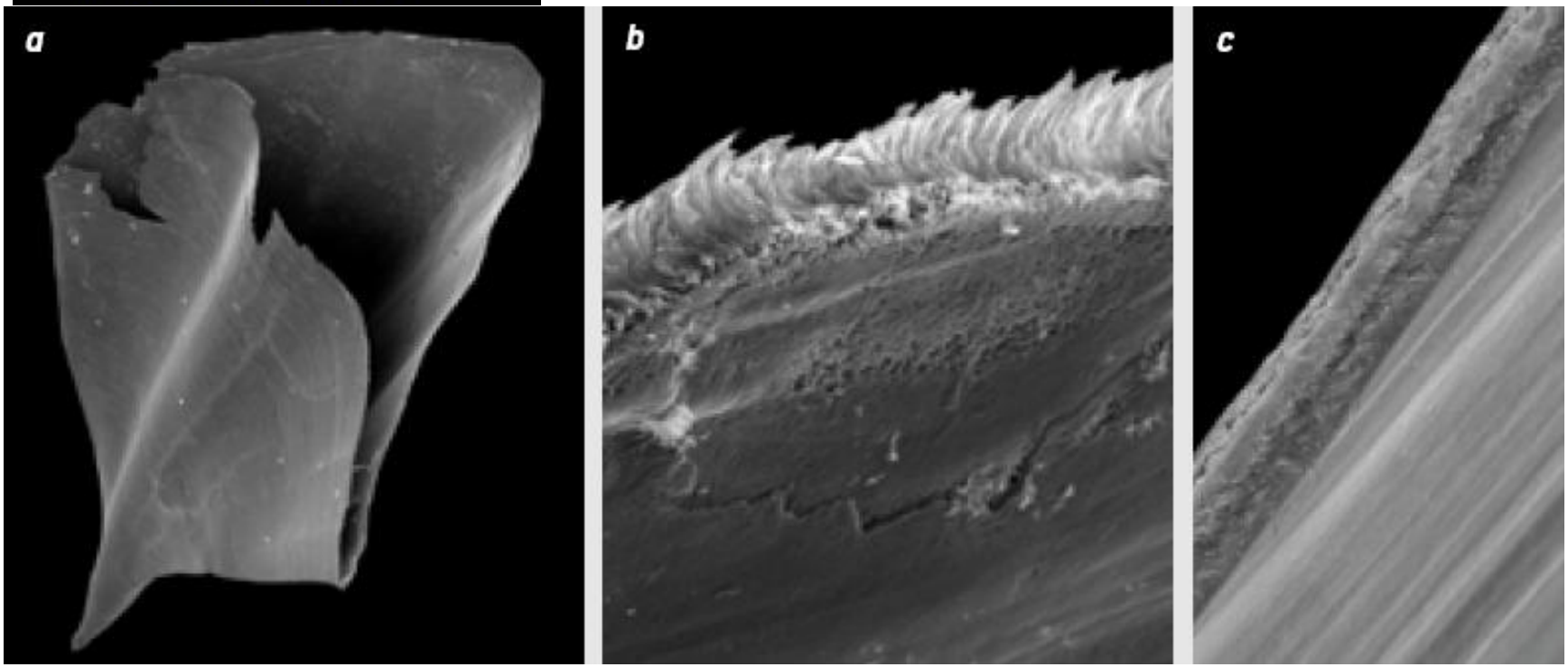
From Kleypas, et al., 1995



By the end of this century very large parts of the ocean surface will be undersaturated with respect to aragonite.

From Kleypas, et al., 1995

Pteropods, which make aragonite shells and are common in high-latitude surface waters may be the most significantly affected



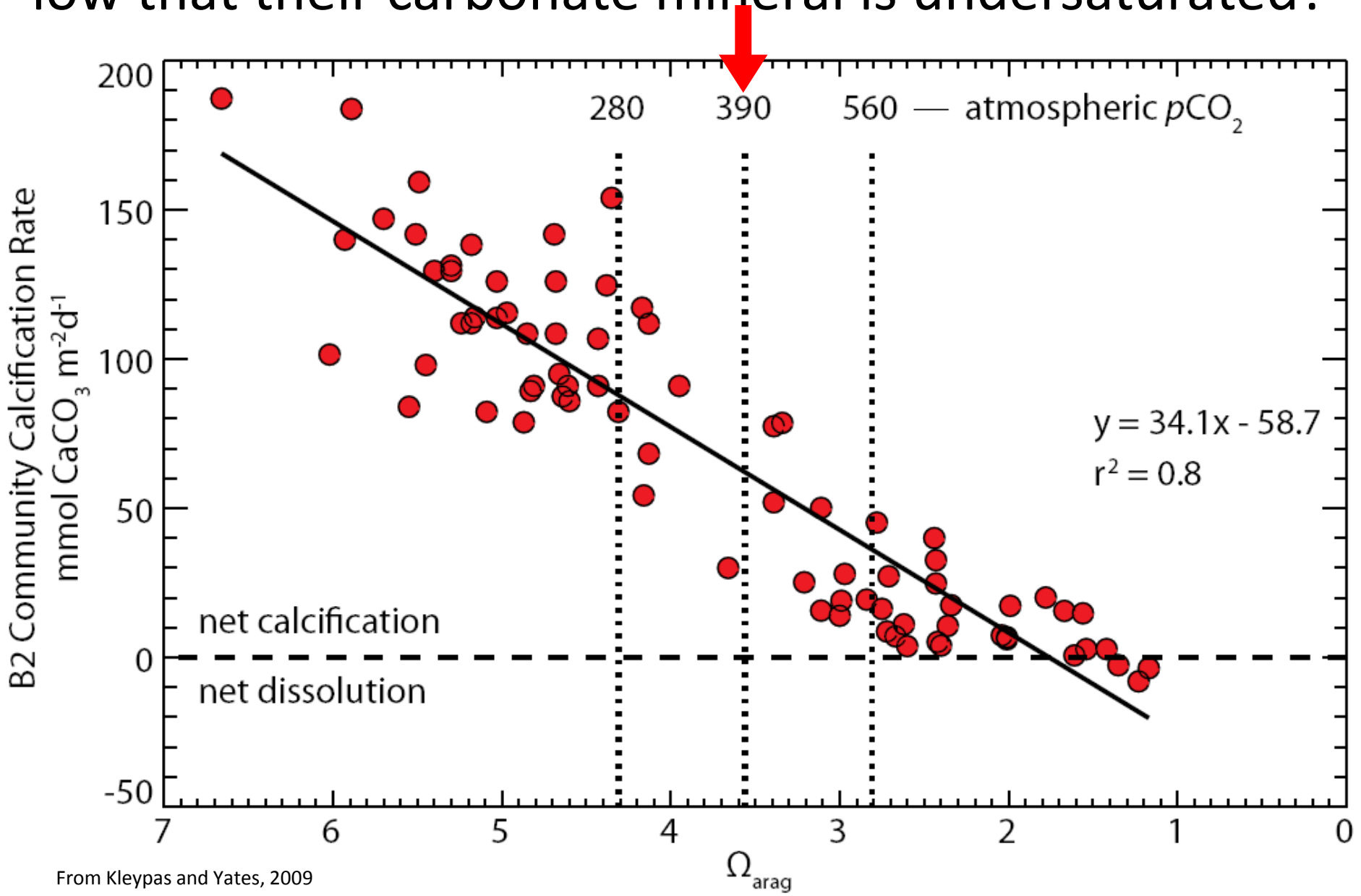
From Doney, 2006

The impact on coral reefs

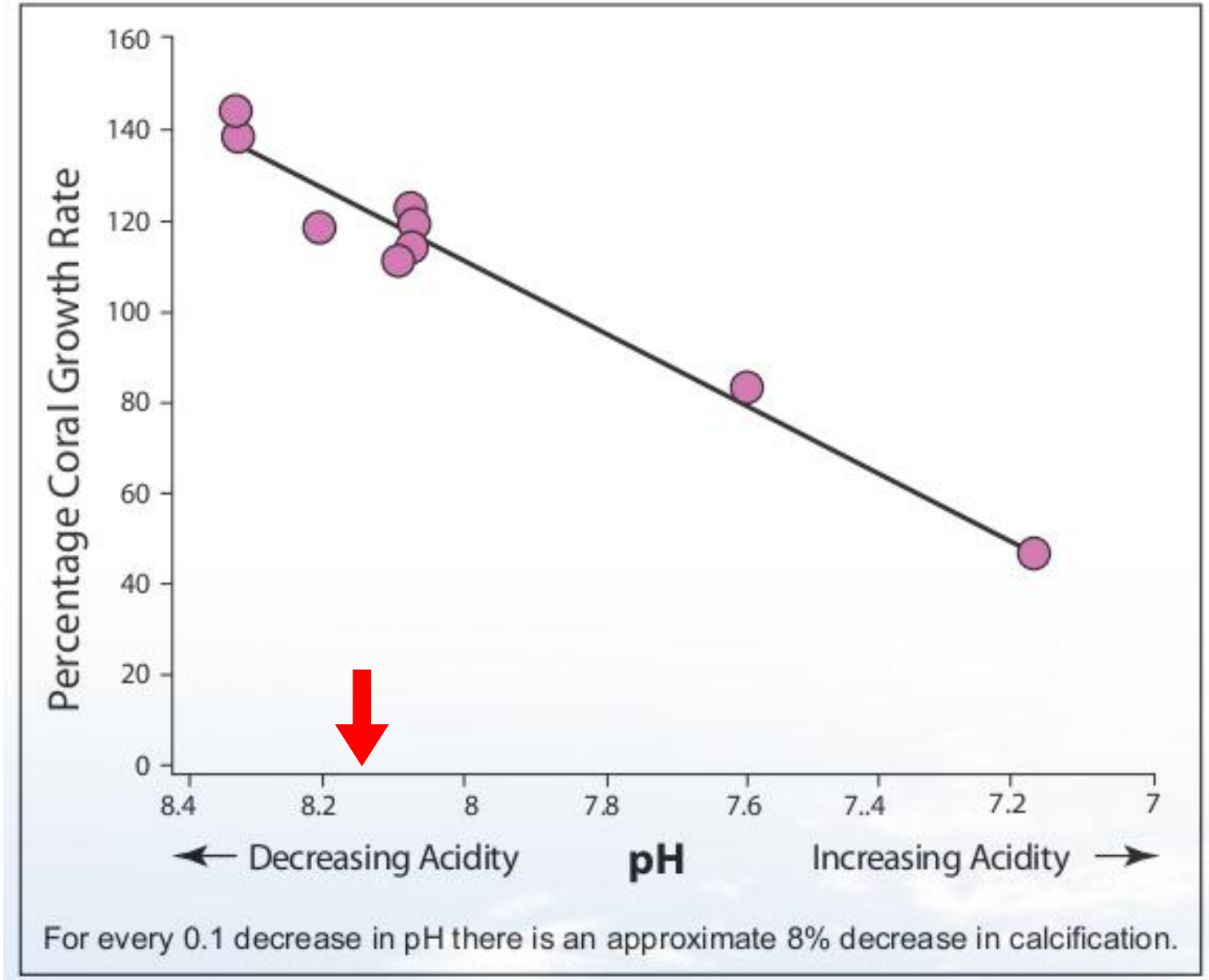
CO_2 CONCENTRATION (ppm)	CONDITION OF CORAL REEFS
380	Reefs will change due to ocean acidification, however they will remain coral dominated.
450	Density and diversity of corals on reefs will decline, including the loss of coral associated fish and invertebrates.
450-500	Reefs will likely become "rapidly eroding rubble banks". This may be seen as the tipping point for corals, beyond which reefs as we know them would be extremely rare, if not non-existent. It would be millions of years before coral reefs returned to their former diversity and density.

From Harrould-Kolieb & Savitz (2009)

Are marine organisms only affected when pH is so low that their carbonate mineral is undersaturated?

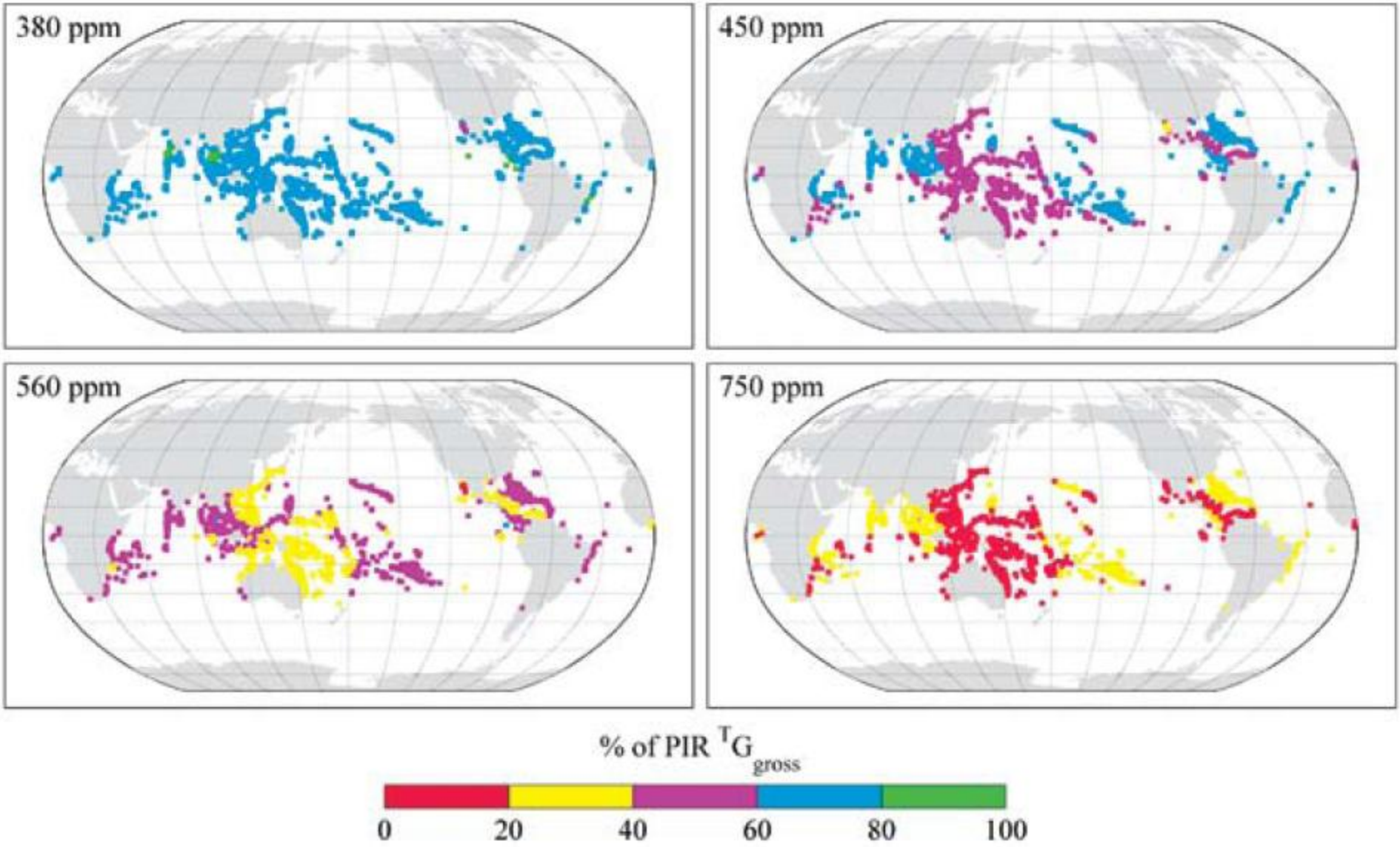


From Kleypas and Yates, 2009



Source: Fernand, L. and Brewer, P. (Eds) (2007) Report of the Workshop on the Significance of Changing Ocean CO2 and pH in Shelf Sea Ecosystems, defra and ICES CIEM, with changes made with permission from author, F.Marubini

From Harrould-Kolieb & Savitz (2009)



Calculated changes in reef building for coral reefs worldwide at four different atmospheric *pCO2 stabilization levels, based on the* combined effects of predicted changes in saturation state and temperature on coral community calcification. The values are expressed as a percentage of pre-industrial calcification rates.

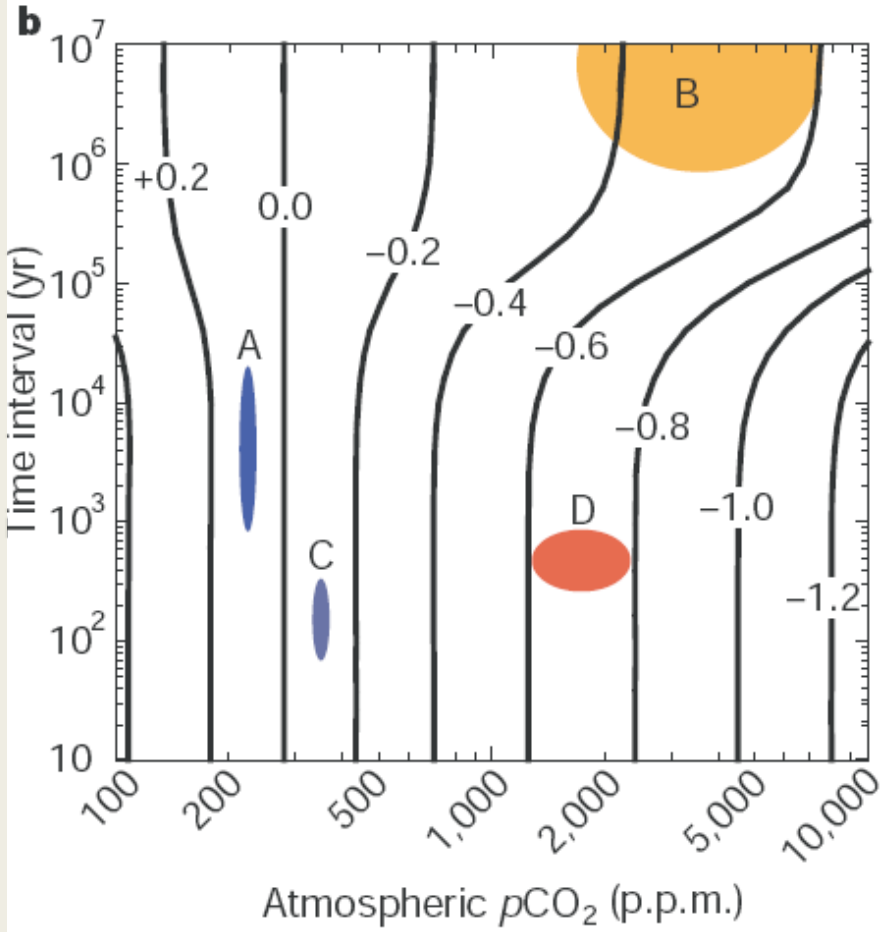
Figure and caption from Kleypas and Yates, 2009

But CO_2 levels have been much higher in the distant past, does that mean that the oceans have been even more acidic?

"Based on the record of atmospheric CO2 levels over the past 300 Myr and our geochemical model, there is no evidence that ocean pH was more than 0.6 units lower than today. Our general circulation model results indicate that continued release of fossil-fuel CO2 into the atmosphere could lead to a pH reduction of 0.7 units.

We conclude that unabated CO2 emissions over the coming centuries may produce changes in ocean pH that are greater than any experienced in the past 300 Myr, with the possible exception of those resulting from rare, catastrophic events in Earth's history."

Caldeira and Wickett, 2003



From Caldeira and Wickett, 2003