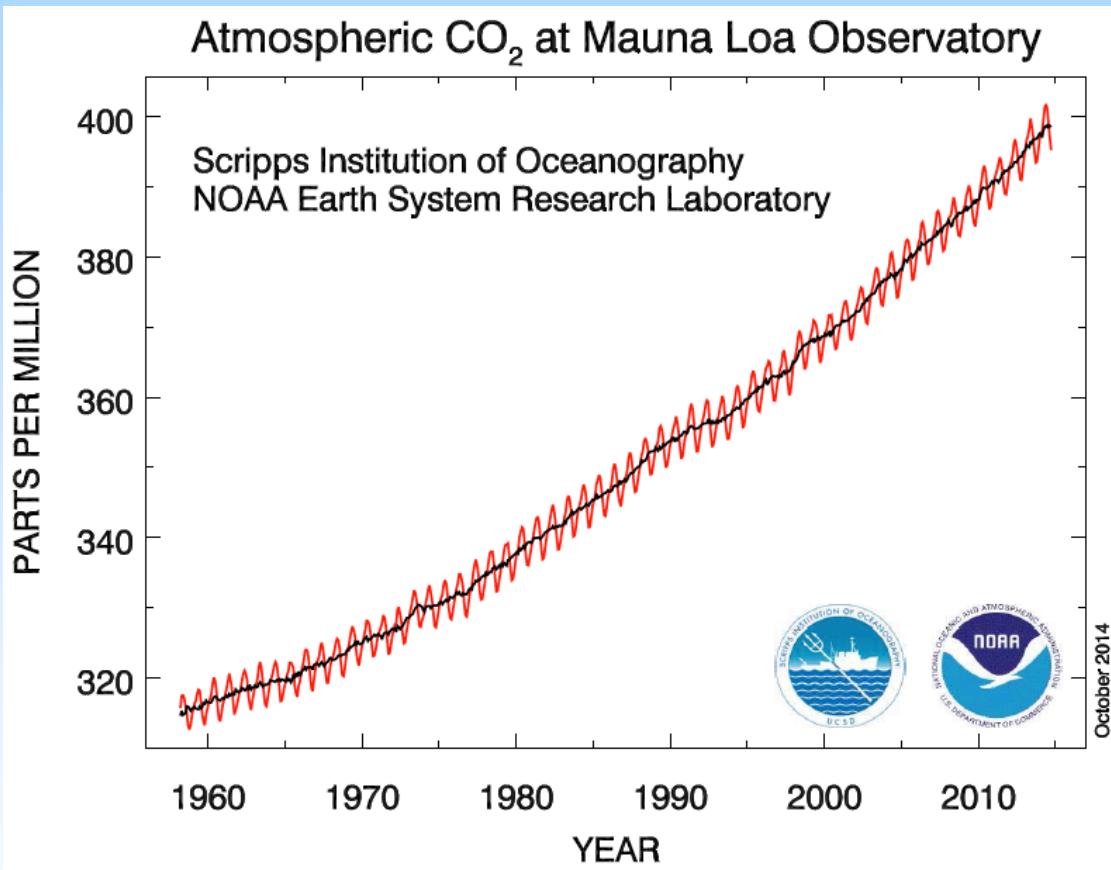


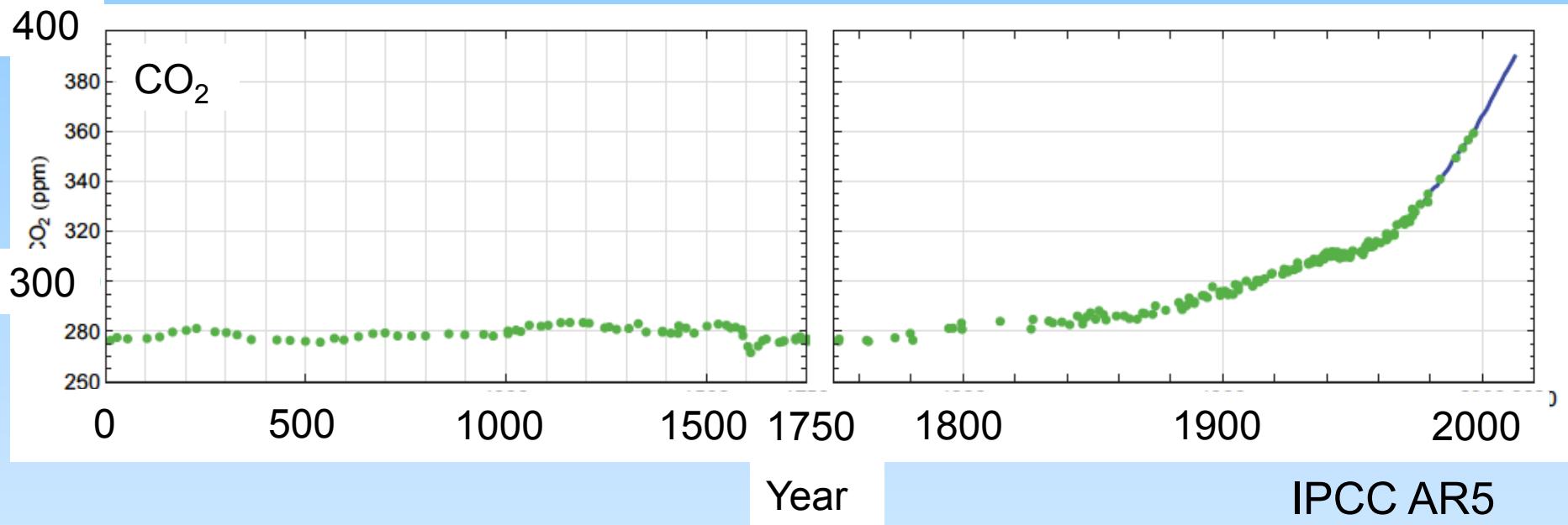
Coastal Ocean Acidification

Scott Doney

Woods Hole Oceanographic
Institution



Rising Atmospheric CO₂



IPCC AR5
WG1 Chap. 6

Present-day CO₂ level highest in past several million years

Rate of increase 50-100 times larger than natural rates of change



Fate of Human-Driven CO₂ Emissions (2003-2012)



+ ~9.5 billion tons
carbon per year



Atmosphere

45%



Land
29%



Oceans

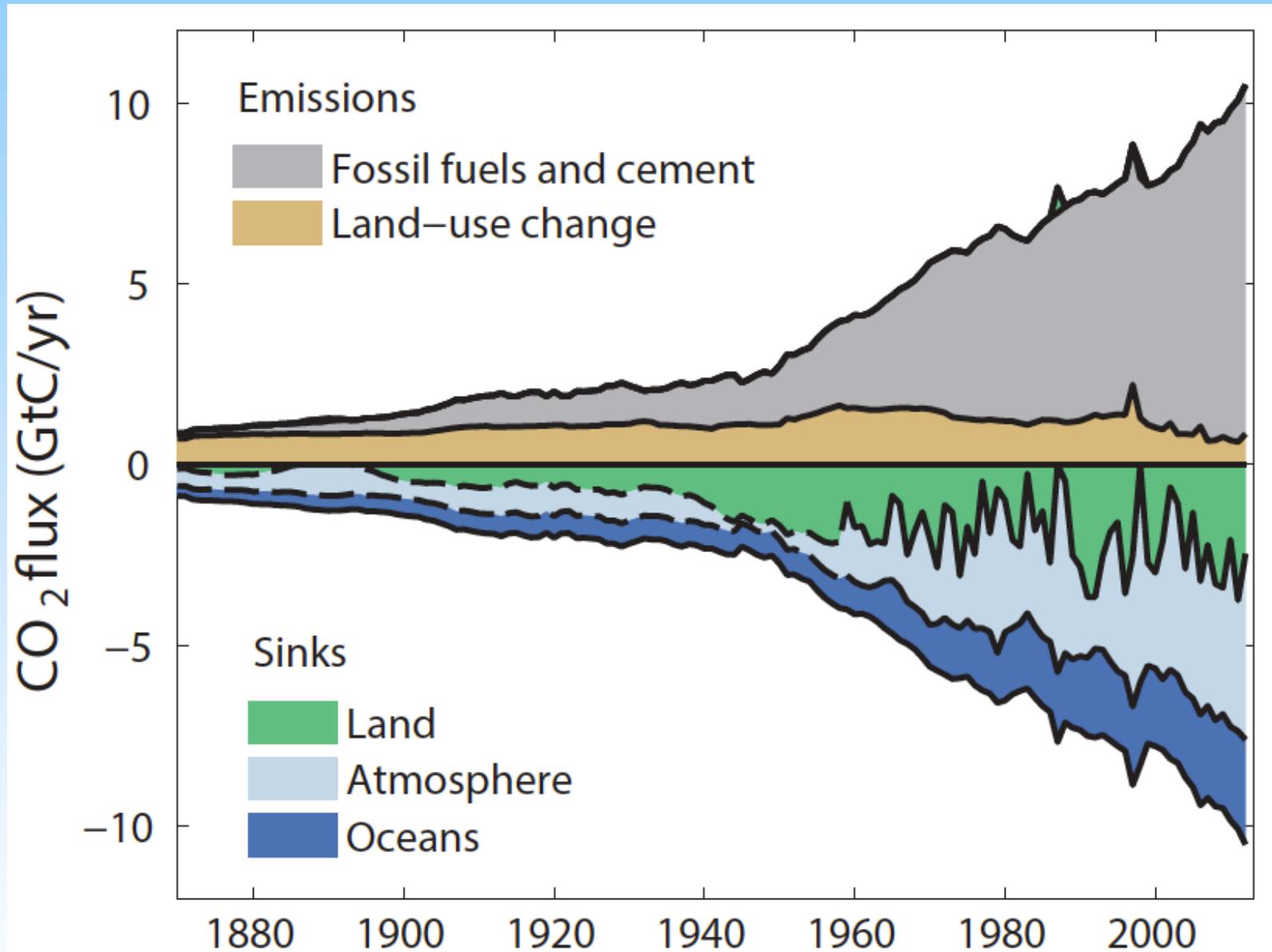
26%

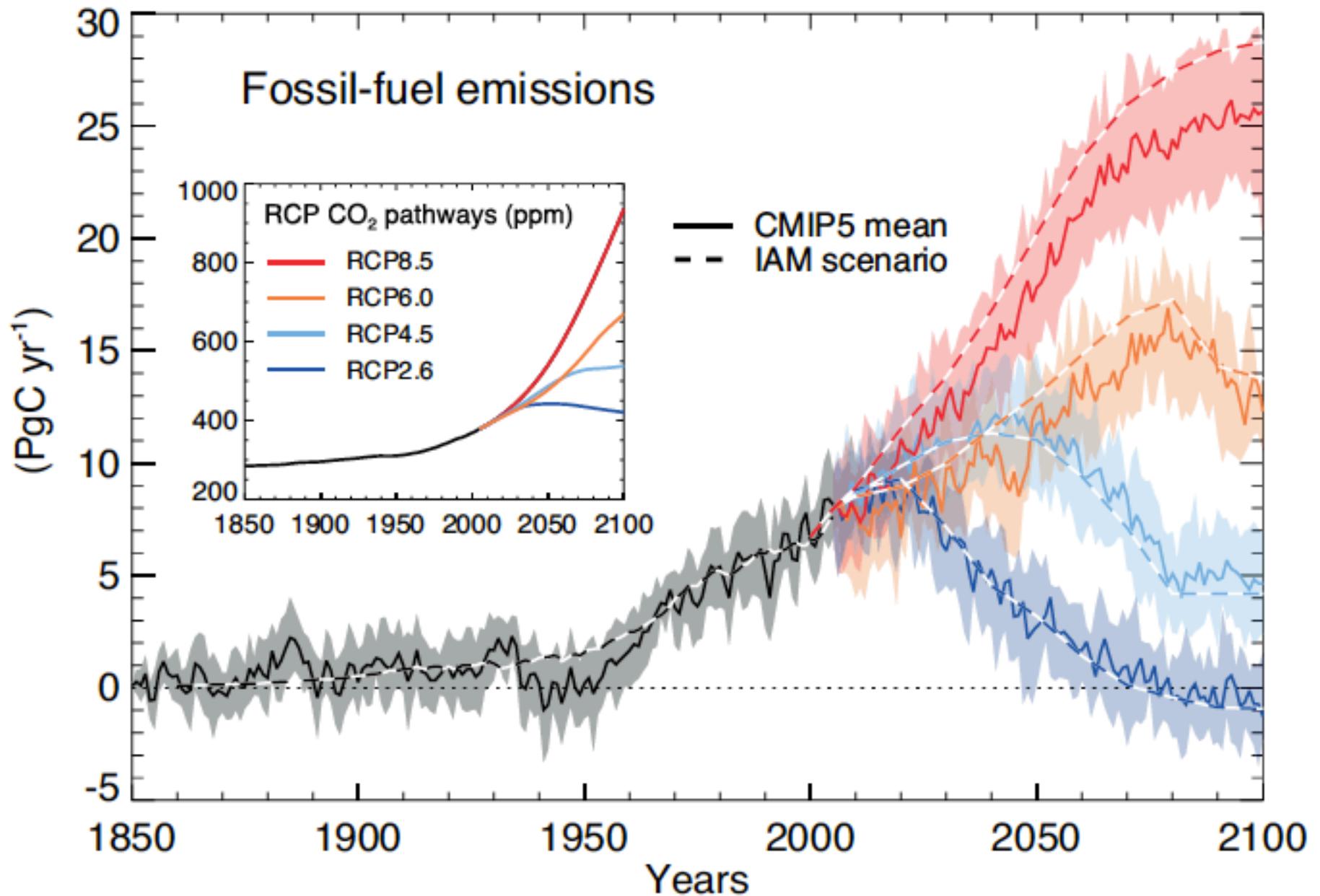


LeQuere et al. Earth System Sci. Data 2014 ; Global Carbon Project 2014



Human-Driven Carbon Sources & Sinks

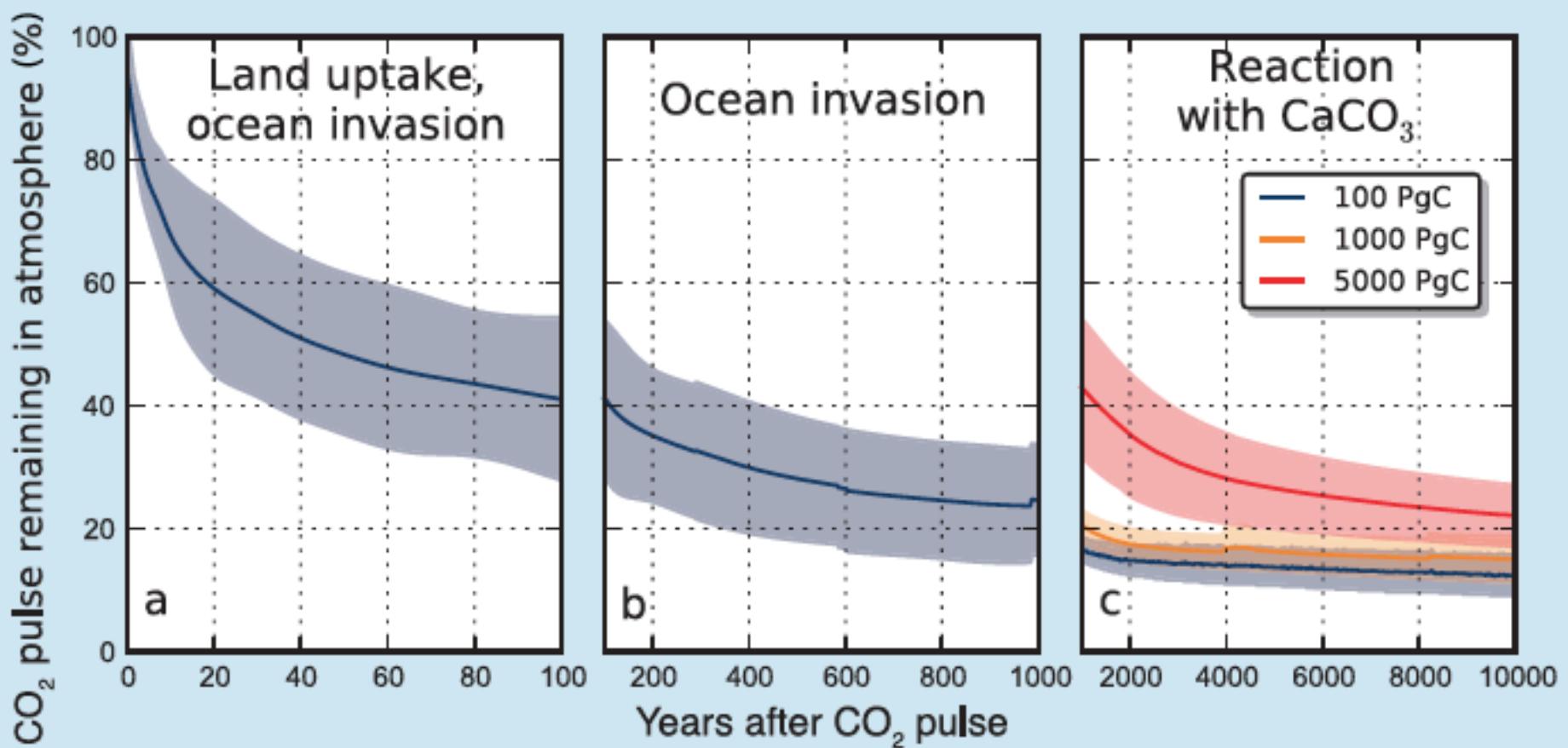




IPCC AR5
WG1 Chap. 6



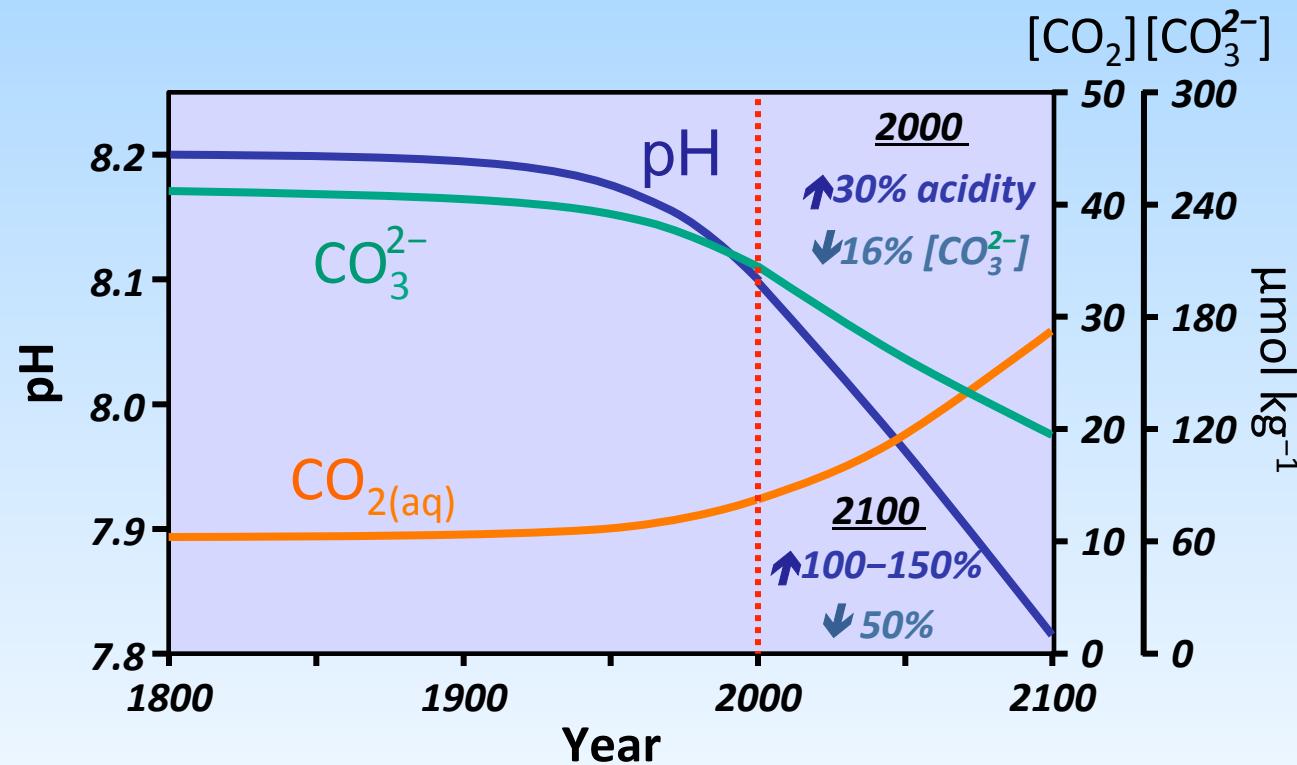
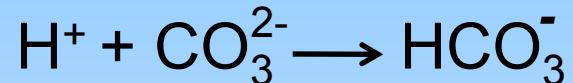
How Long Will Anthropogenic Carbon Dioxide and Its Climate Impacts Persist?



IPCC AR5
WG1 Chap. 6

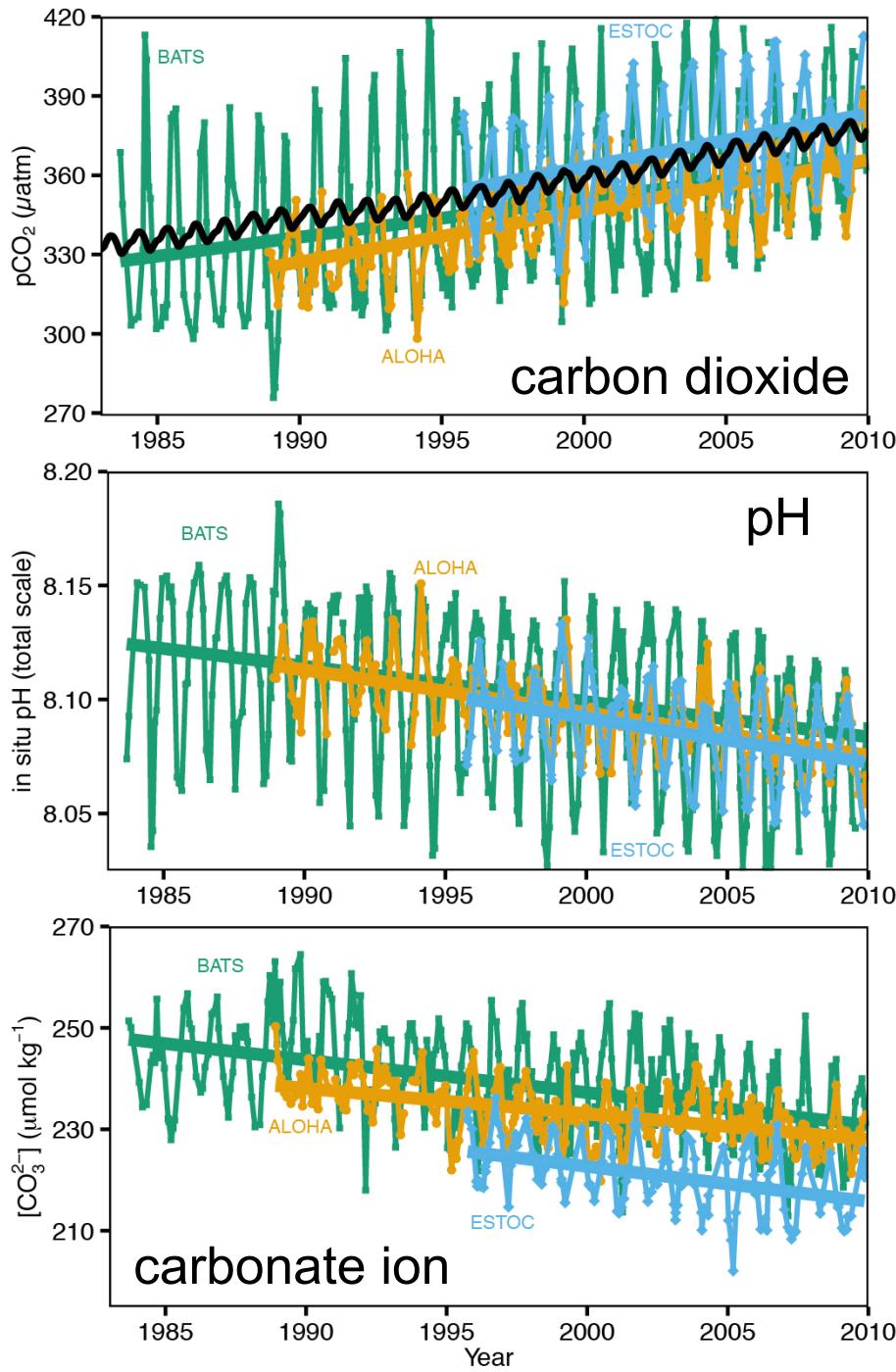


Ocean Acidification



Wolf-Gladrow et al. (1999)





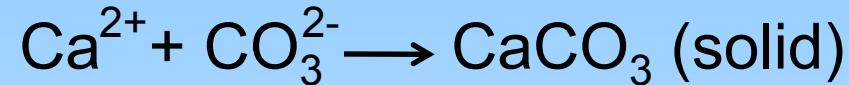
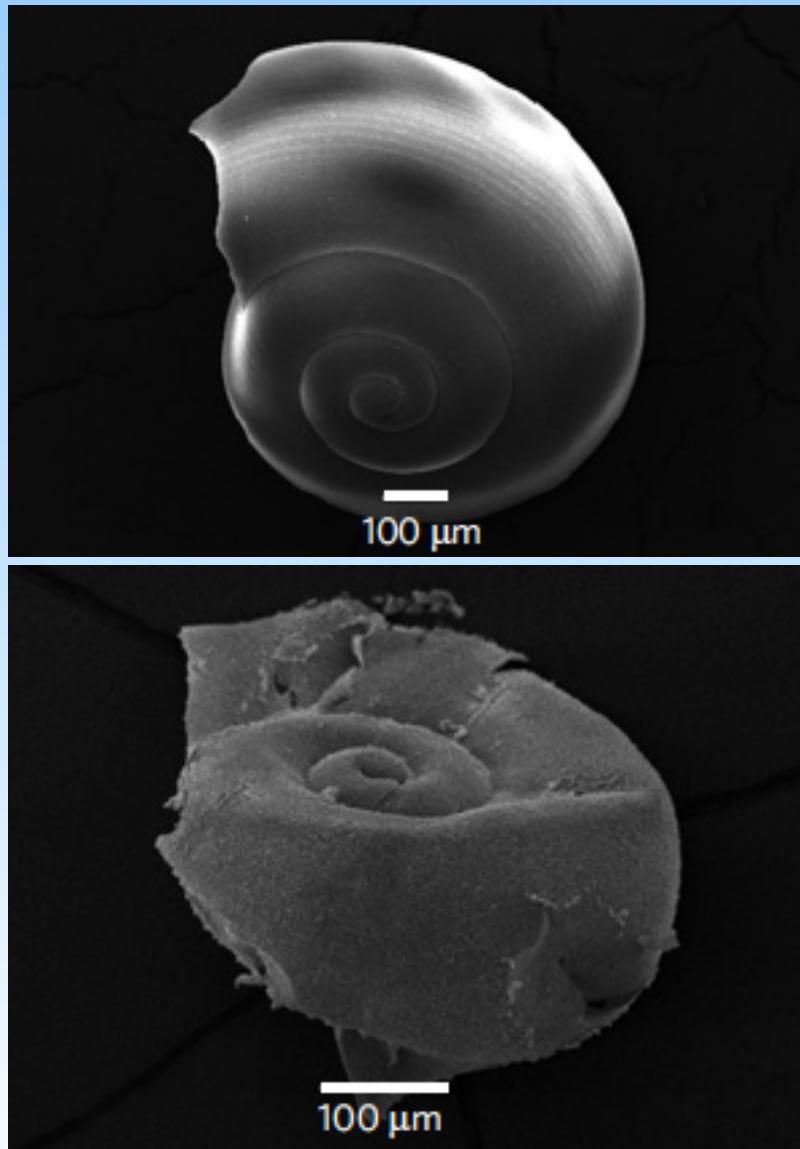
Changing Seawater Chemistry

Open-ocean sites exhibit seasonal cycle & clear long-term trend

IPCC 2014
WG1, Chapter 3
Doney et al. Ann. Rev.
Mar. Sci. 2009
Dore et al. PNAS 2009



Calcium Carbonate Saturation State



More difficult to form shells at lower carbonate ion levels

Saturation State

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

$\Omega > 1$ saturated

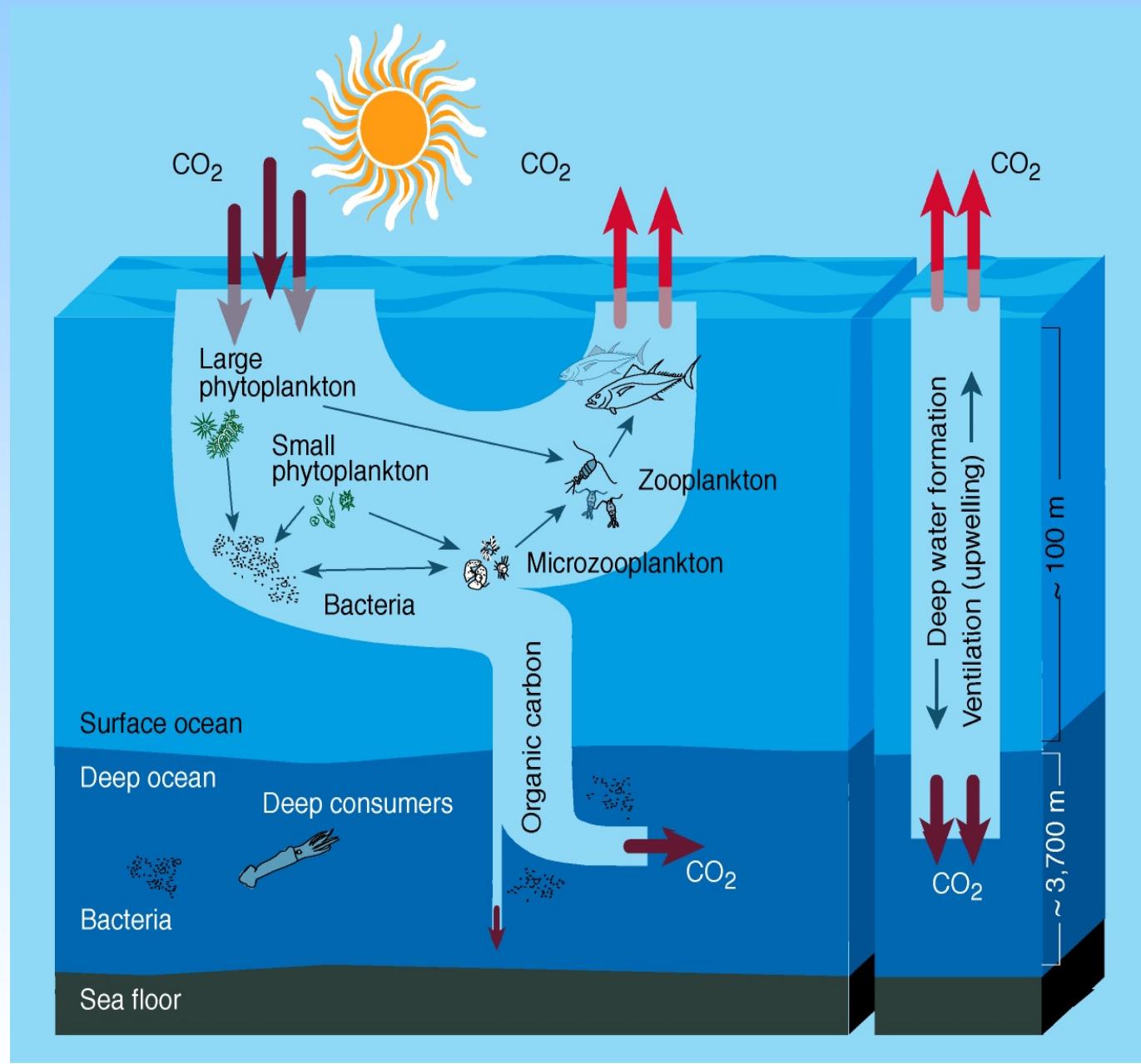
$\Omega < 1$ undersaturated

depends on mineral form

Feely et al. Nature 2005; Bednaršek Nature Geosci. 2012



Ocean Solubility and Biological Carbon Pumps



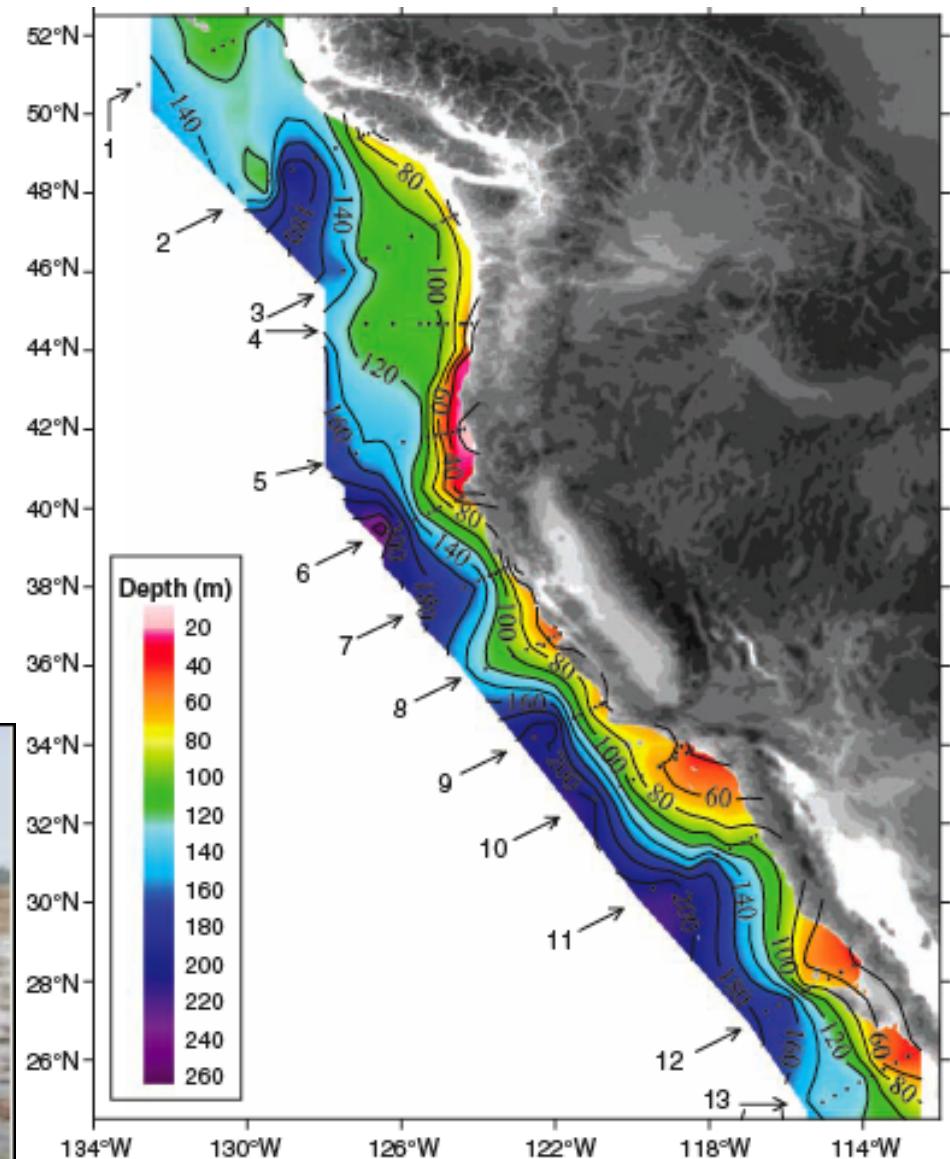
Collapse of Pacific NW Oyster Hatcheries

The Seattle Times

Oysters in deep trouble: Is Pacific Ocean's chemistry killing sea life?

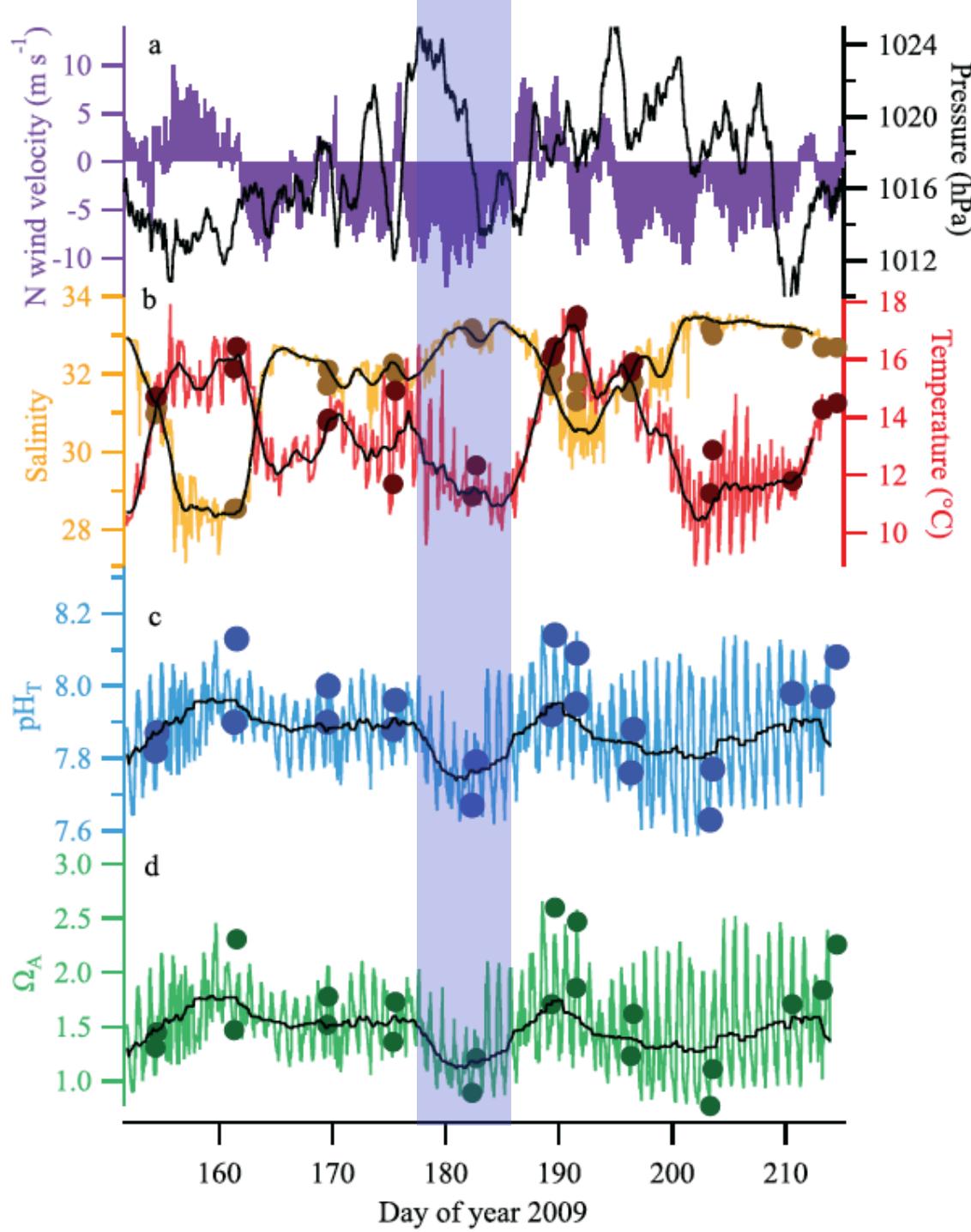


STEVE RINGMAN / THE SEATTLE TIMES



Upwelling of water with elevated CO₂ due to natural & anthropogenic sources

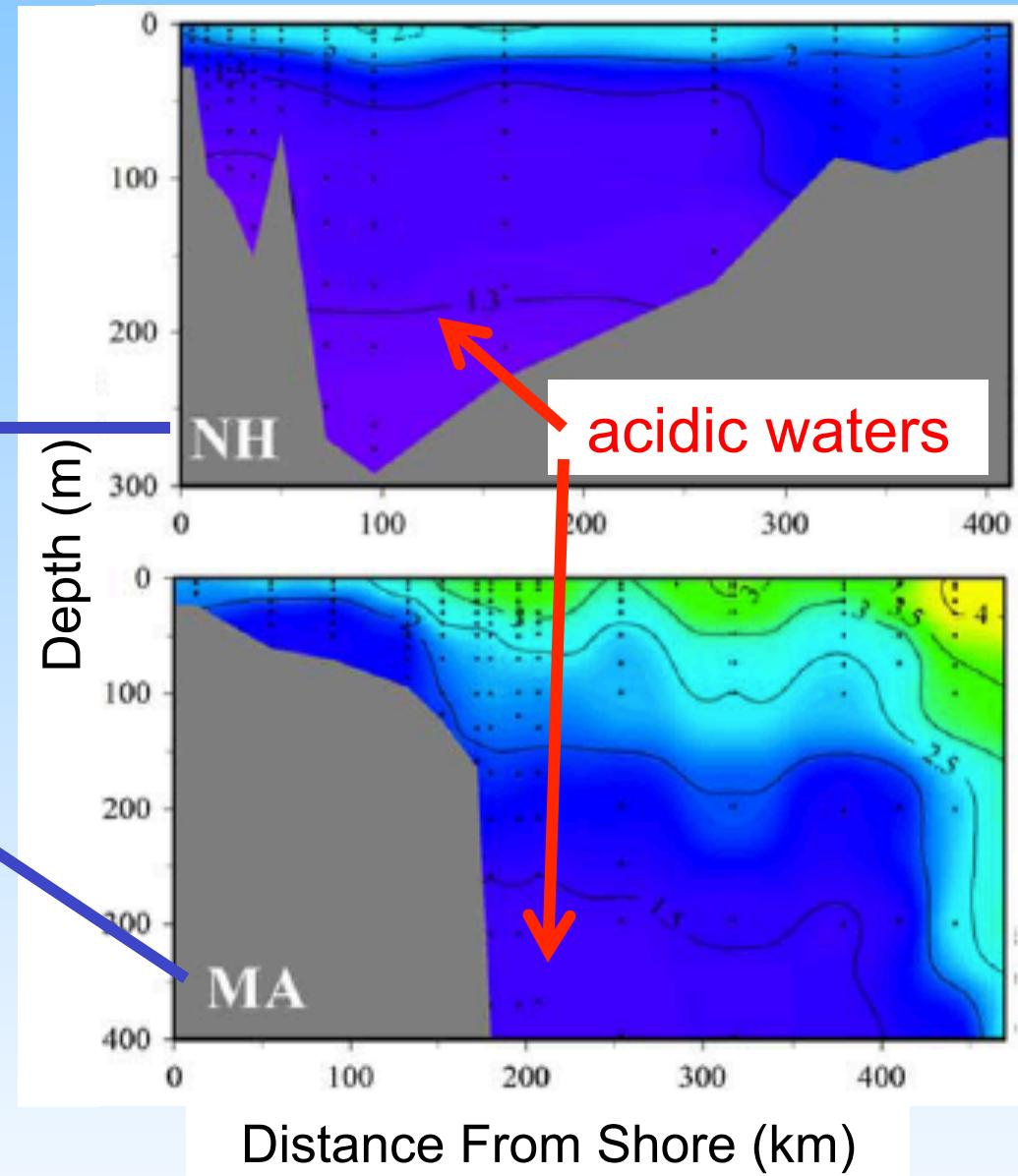
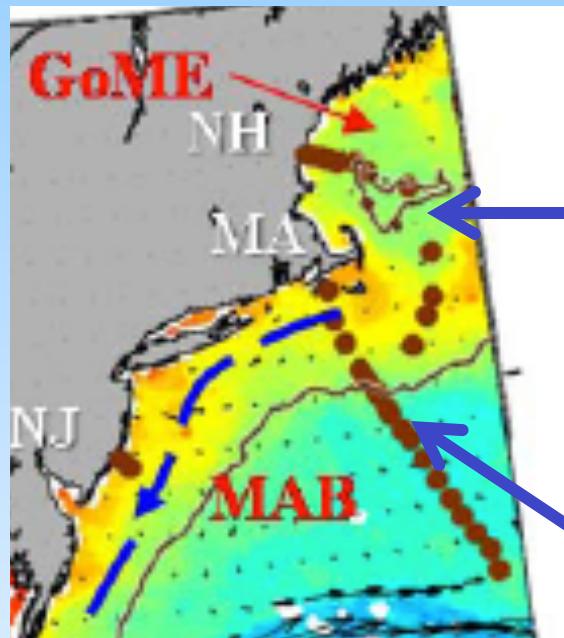
Coastal Upwelling



Barton et al.
Limnol. Oceanogr.
2012



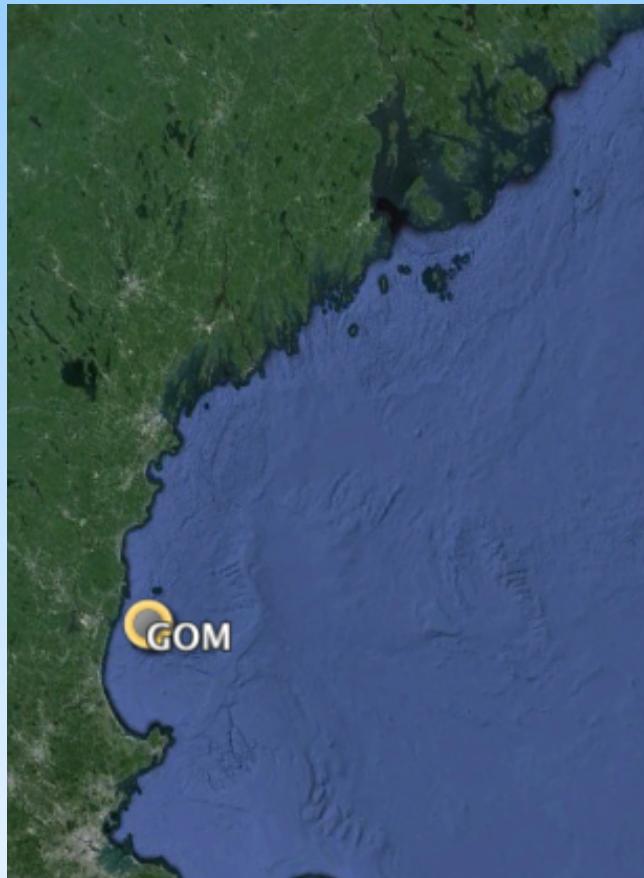
Acidification along U.S. East Coast



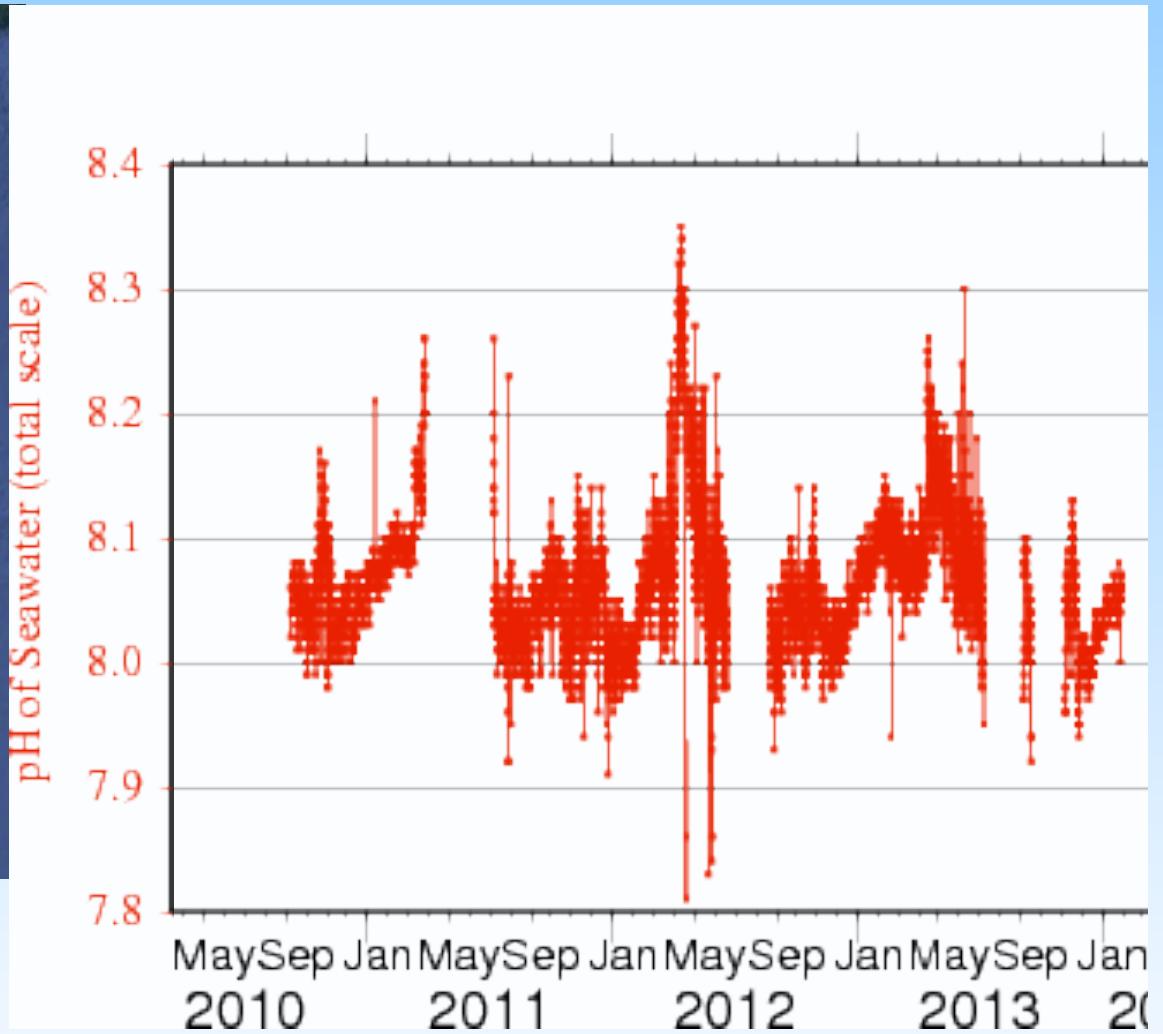
Wang et al. Limnology & Oceanography 2013



Large pH & CO₂ Variability in Coastal Waters



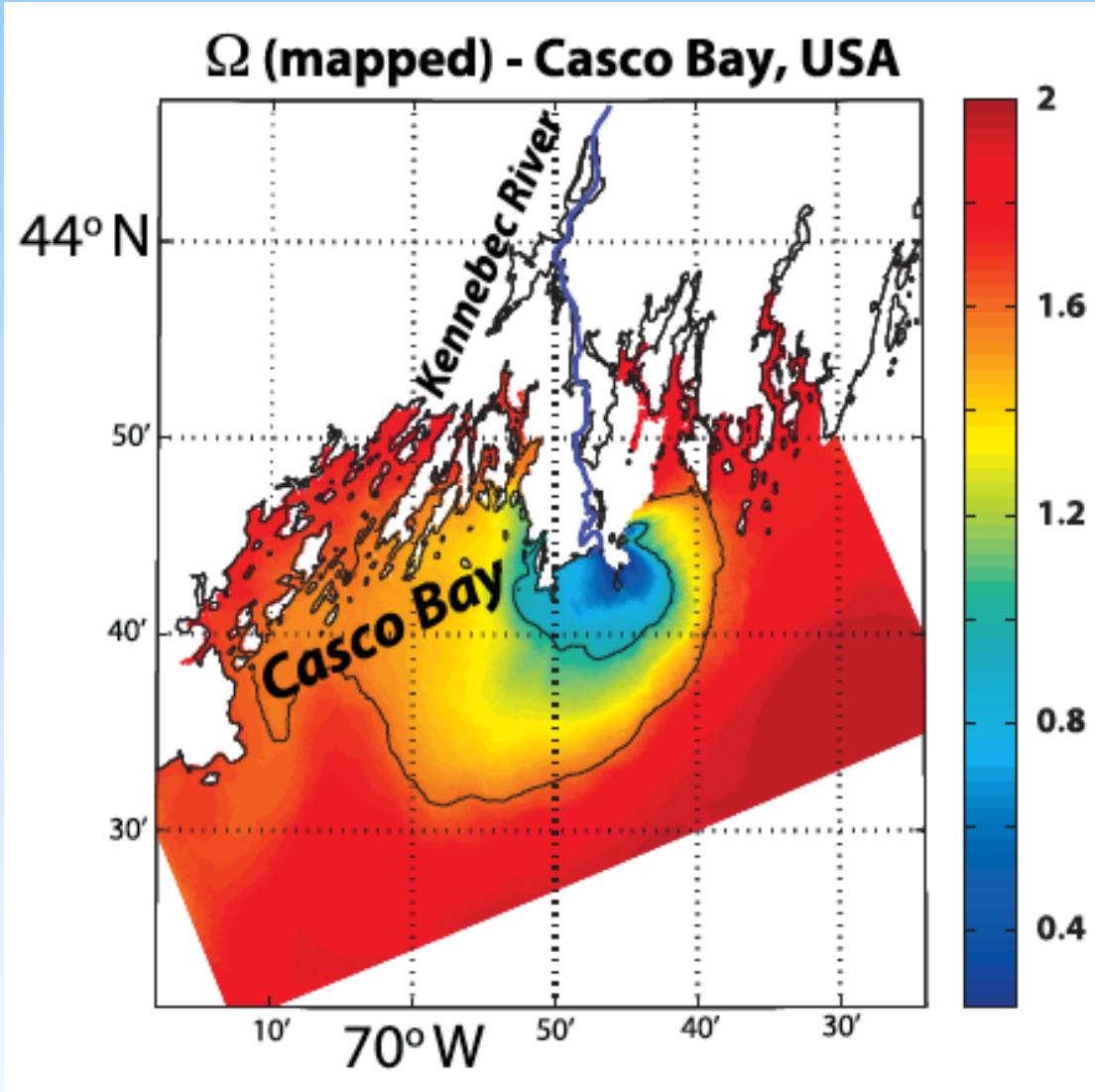
NOAA Coastal Gulf of
Maine Ocean
Acidification Mooring



<http://www.pmel.noaa.gov/co2/story/GOM>



River Flow Affects Estuaries & Coastal Waters



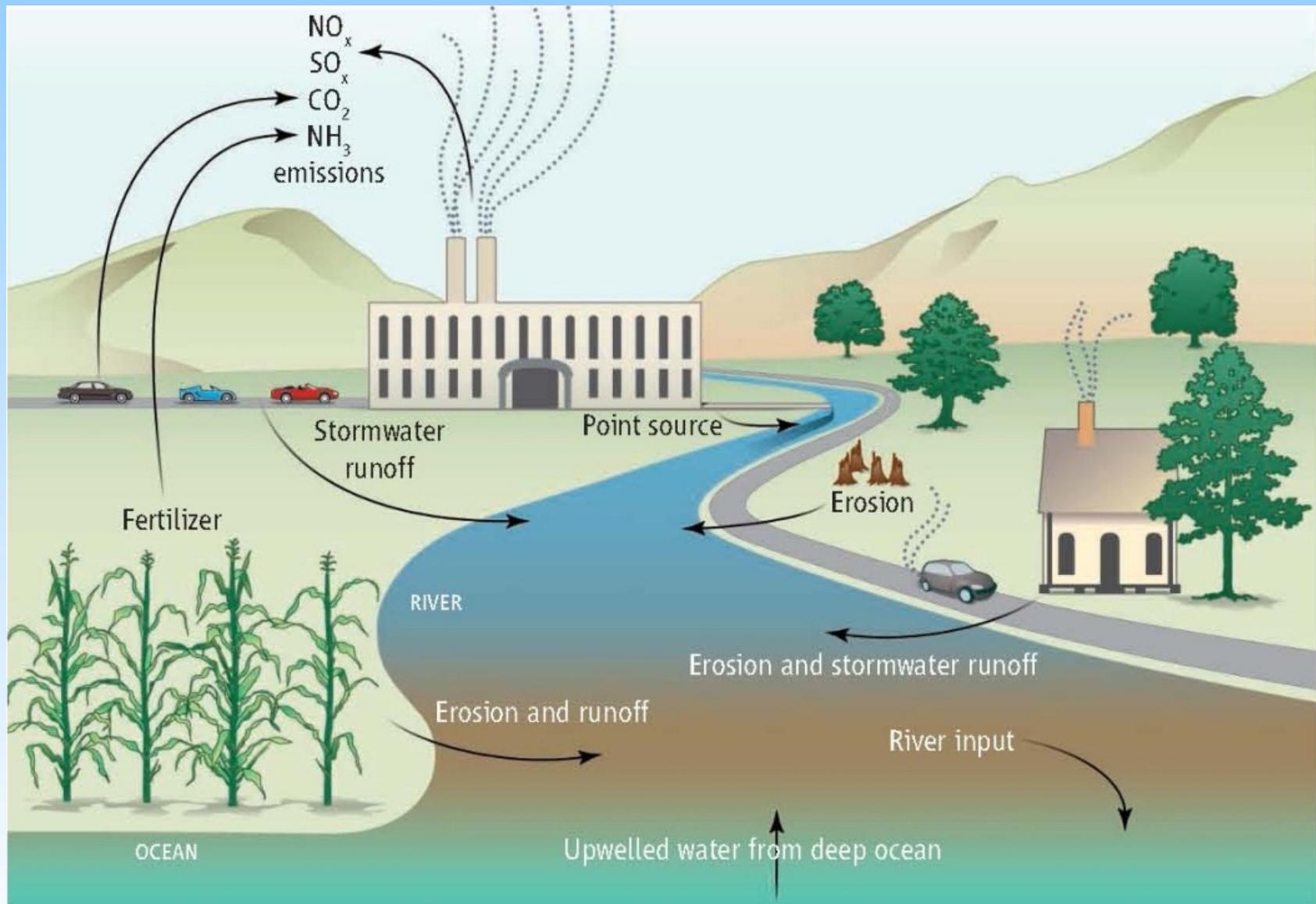
Varies with river chemistry (natural & pollution)

Salsbury et al. EOS 2008

Aufdenkampe et al. Frontiers in Ecology & Environment 2011

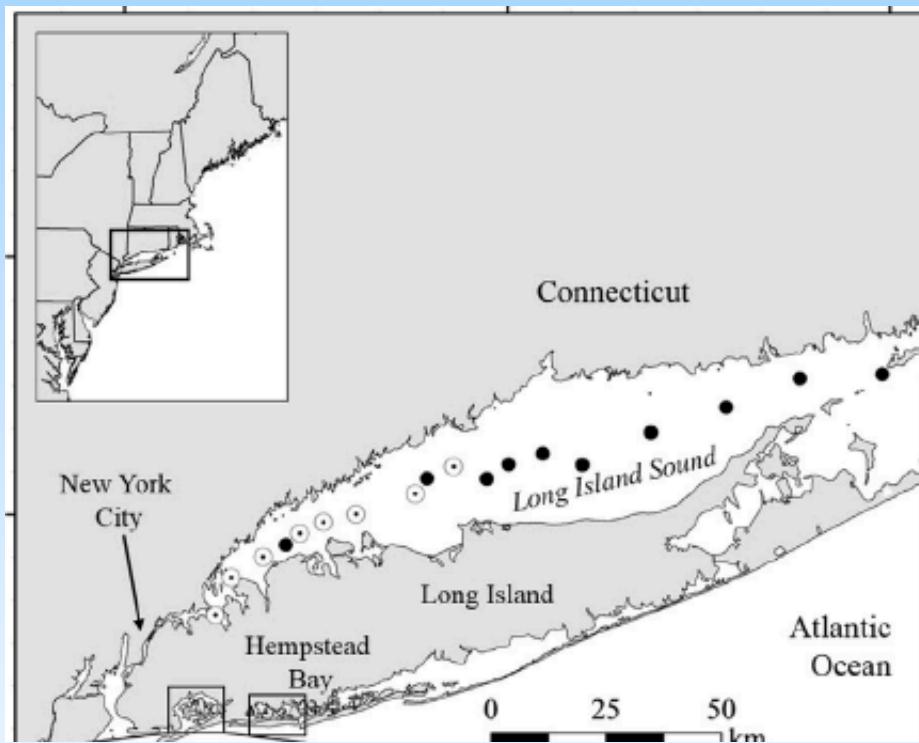


Other Local Sources of Acidification

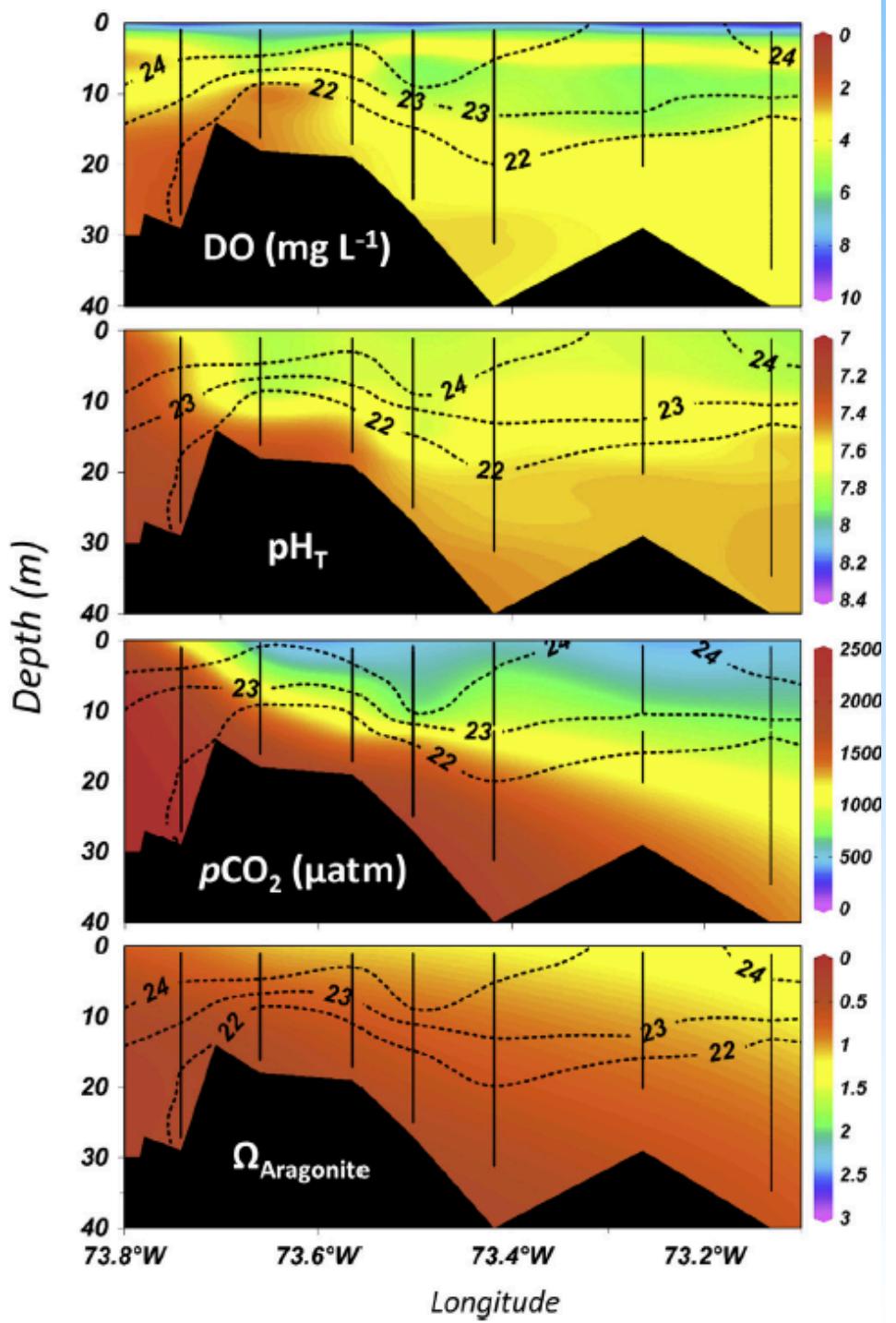


Doney et al. PNAS 2007; Doney Science 2010; Kelly et al. Science 2011

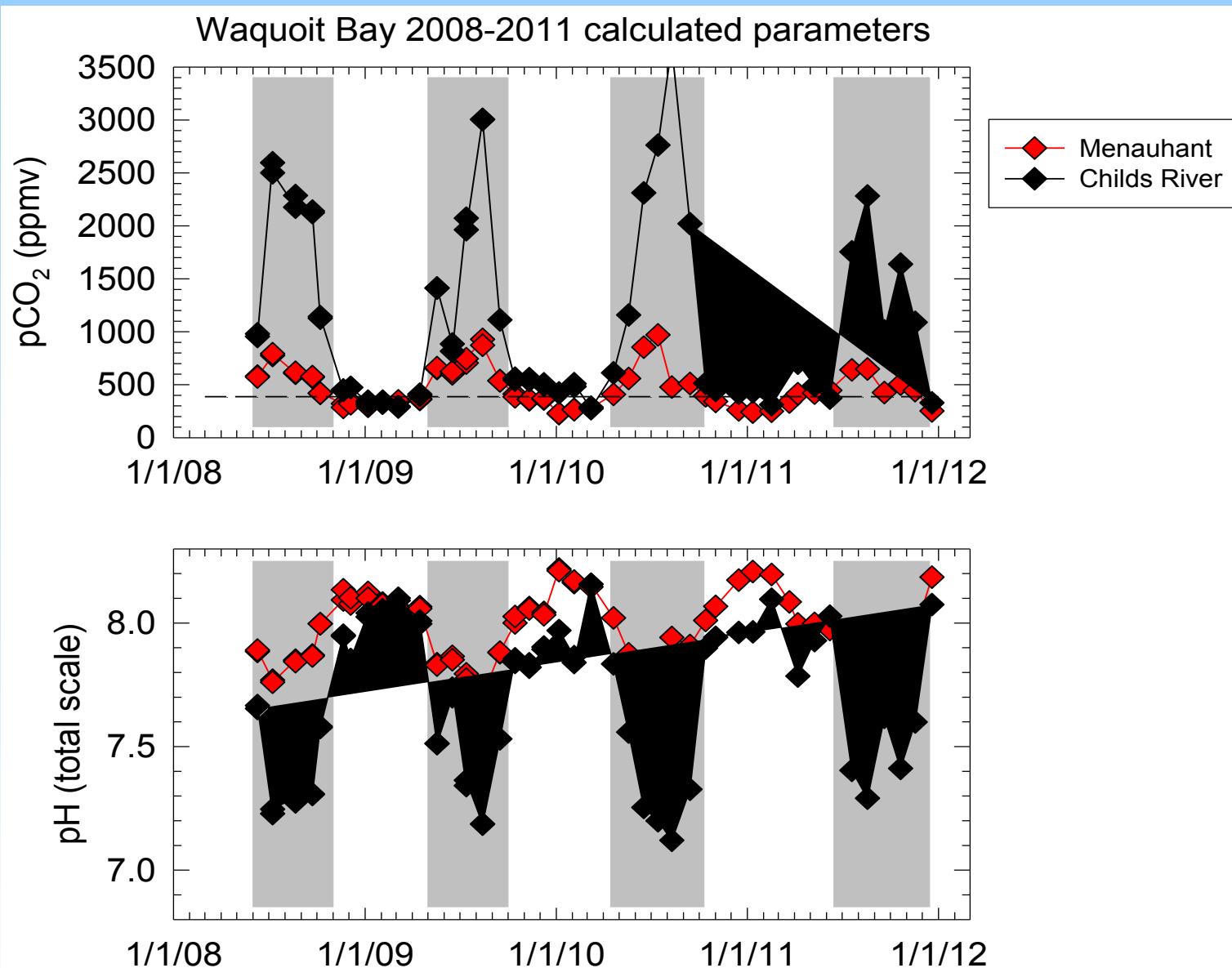
Excess Nutrients, Low Oxygen & Coastal Acidification



Wallace et al., Estuarine, Coastal & Shelf Science, 2014



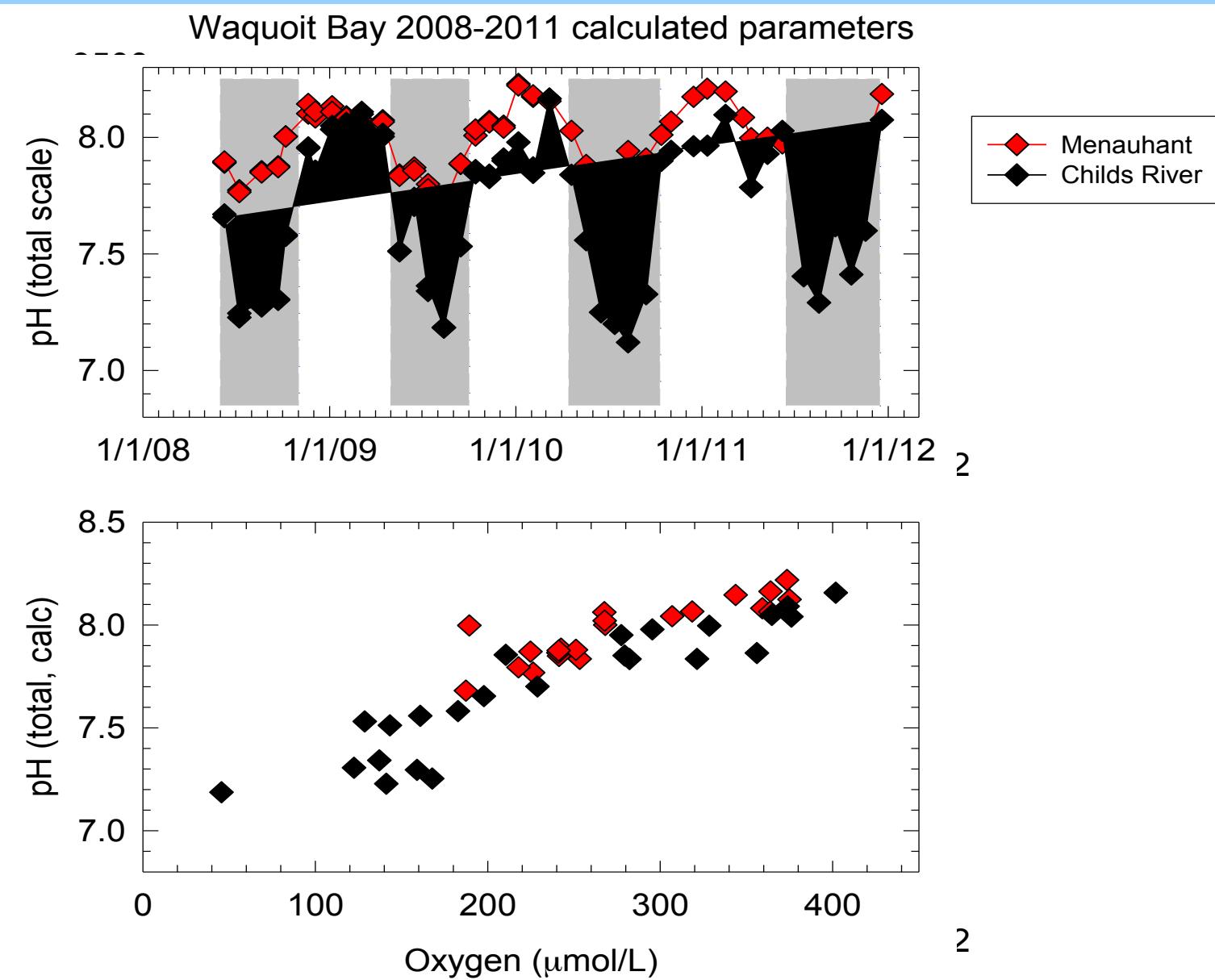
Elevated CO₂ & Acidification in Estuaries



McCorkle et al., in prep.



Acidification & Low Oxygen (Hypoxia)



McCorkle et al., in prep.



Summary Points

- Atmospheric carbon dioxide (CO_2) rising because of human emissions (mostly fossil fuel burning)
- About 25% of human CO_2 emissions enter the ocean, changing seawater chemistry
 - more acidic (lower pH)
 - calcium carbonate shells more soluble
- Coastal acidification can occur because of excess nutrients (and other processes)

