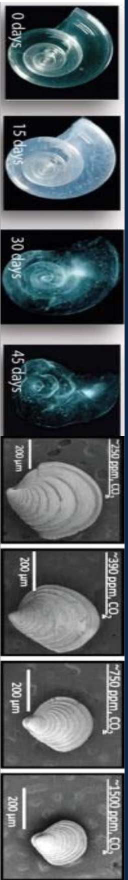
Ocean Warming and Acidification: Present Conditions and Future Projections

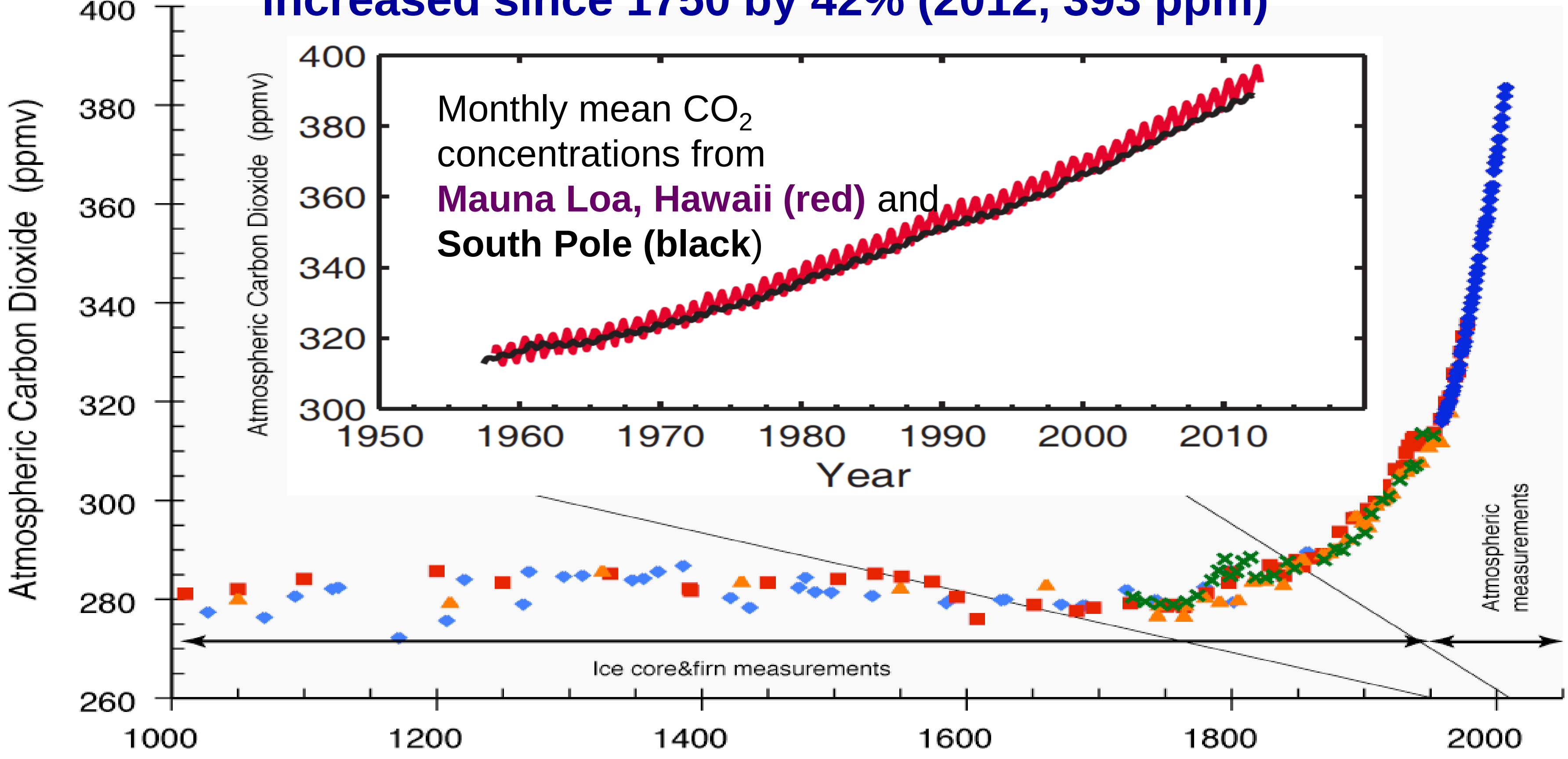


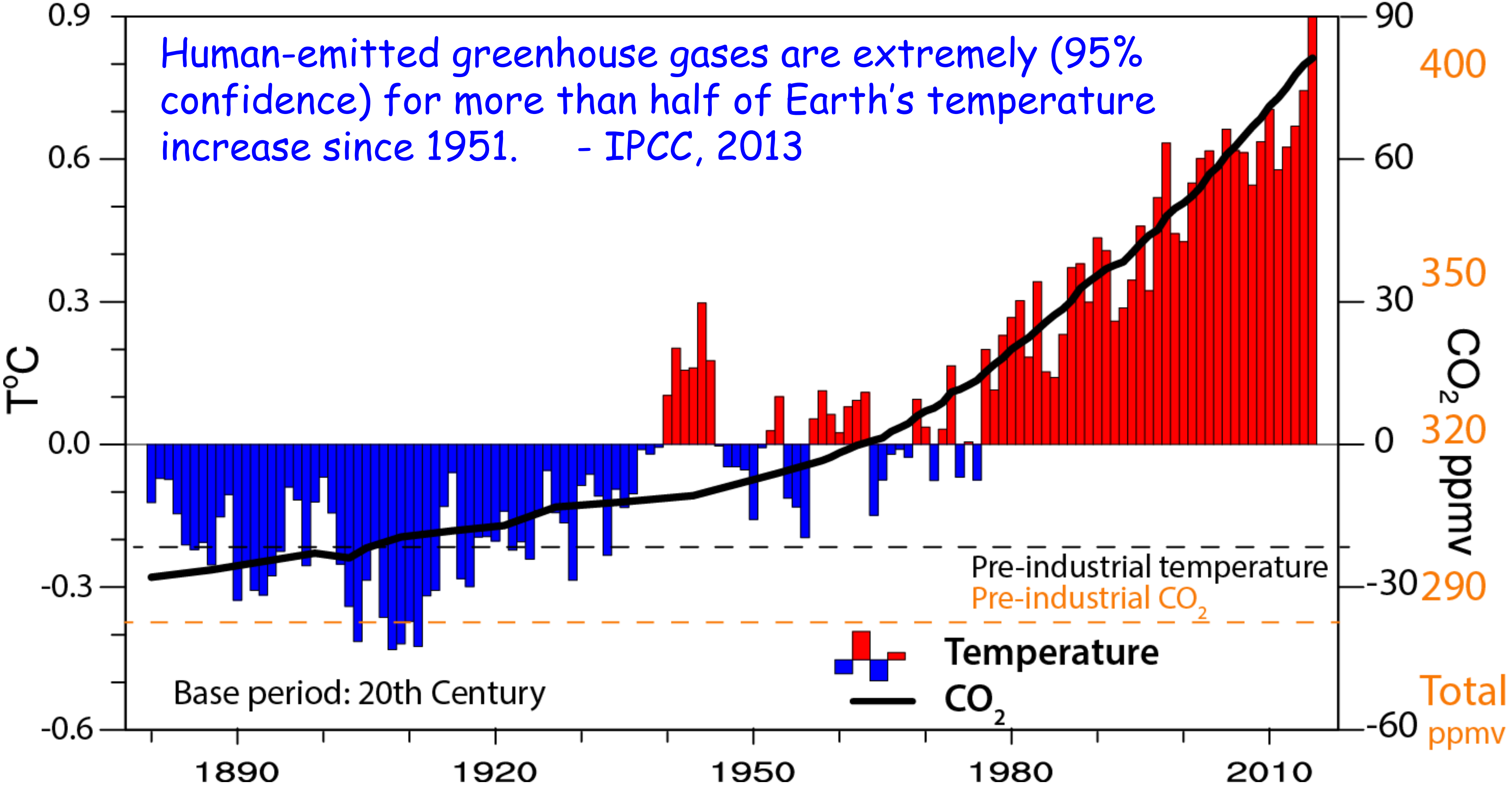
Dr. Richard A. Feely
Senior Scientist
Pacific Marine Environmental Laboratory/NOAA, Seattle, WA

Photo credit: Nina Bednarsek

Blue Planet Oceans and Society
a GEO Initiative

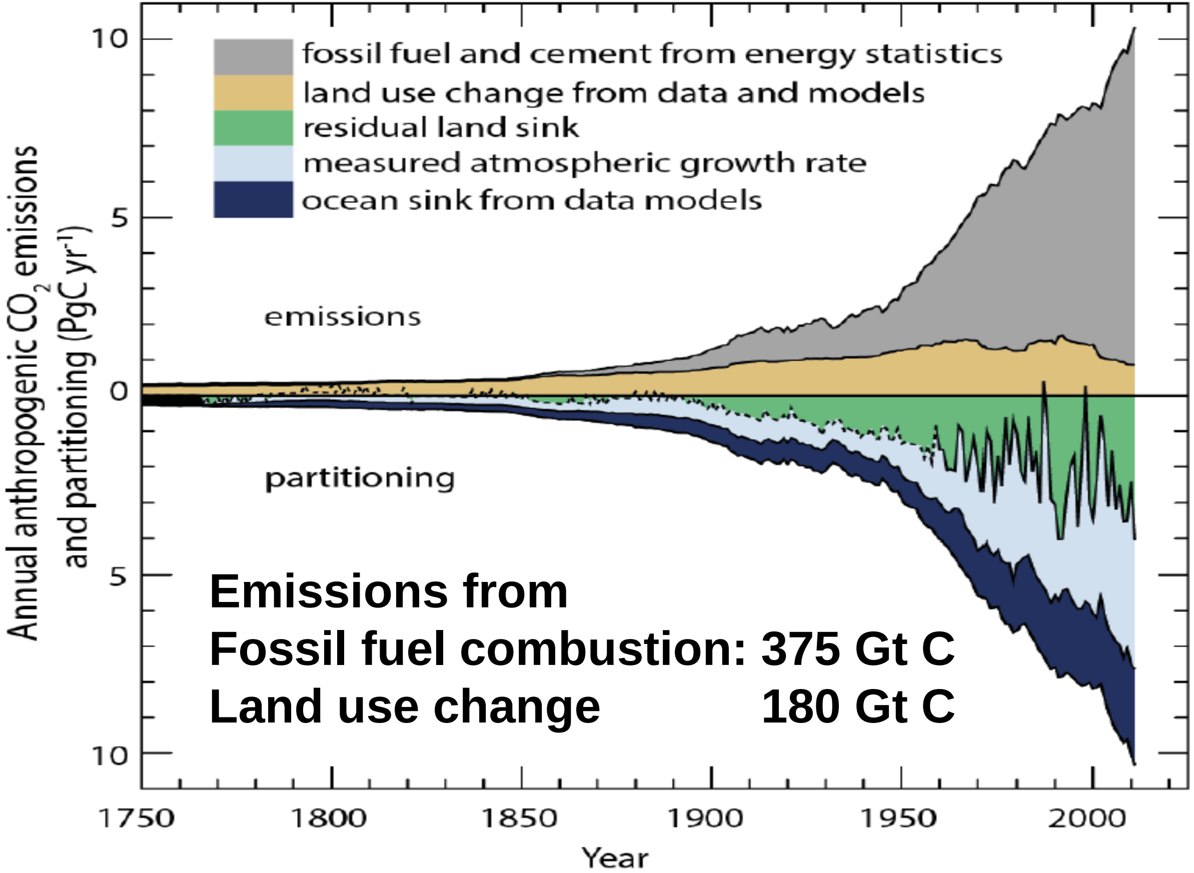
The main driver for recent climate change: Atmospheric CO_2 increased since 1750 by 42% (2012, 393 ppm)




Human-emitted greenhouse gases are extremely (95% confidence) for more than half of Earth's temperature increase since 1951. - IPCC, 2013
0.9
0.6
0.3
0.0
-0.3
-0.6
T°C
90
60
30
0
-30
-60
400
350
320
290
CO_2 ppmv
Total ppmv
Pre-industrial temperature
Pre-industrial CO_2
Temperature
CO_2
Base period: 20th Century
1890
1920
1950
1980
2010

Source: NOAA

Total anthropogenic CO_2 emissions and partitioning (1Pg C = 1Gt C = 3.65 Gt CO_2)



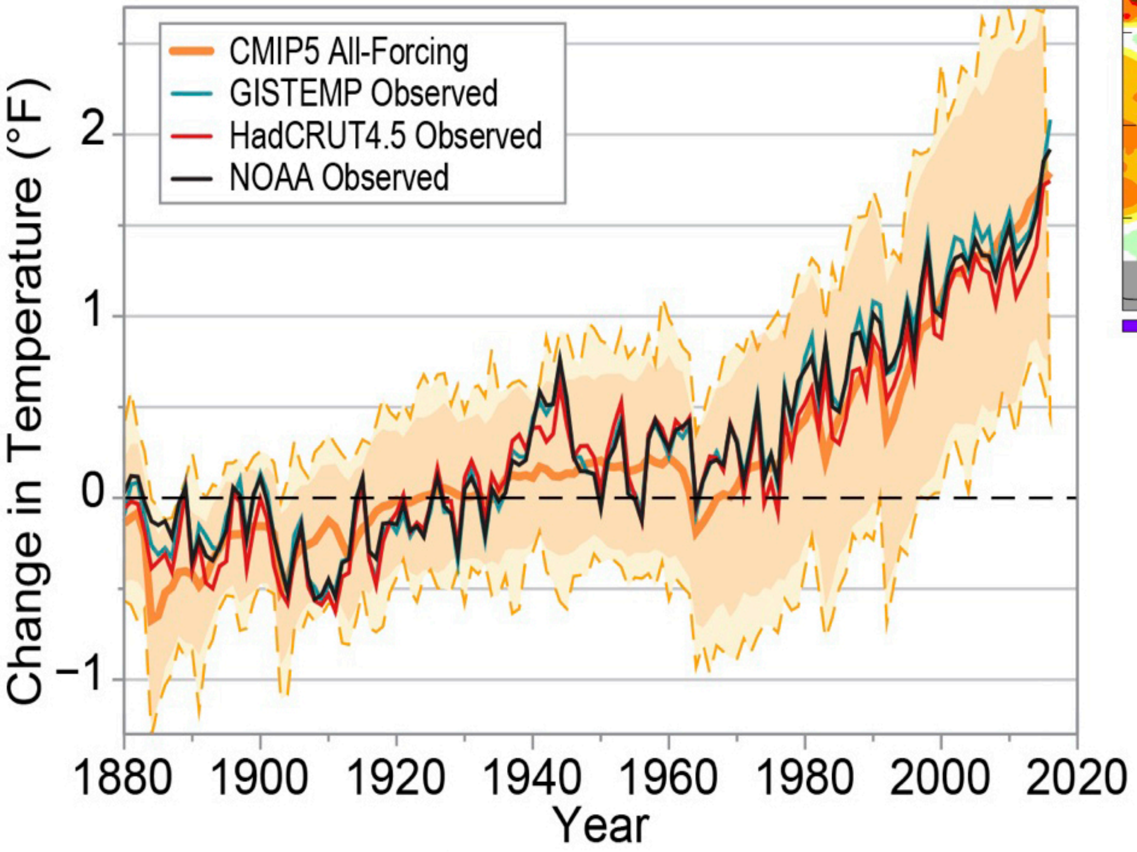
40% remain in atmosphere

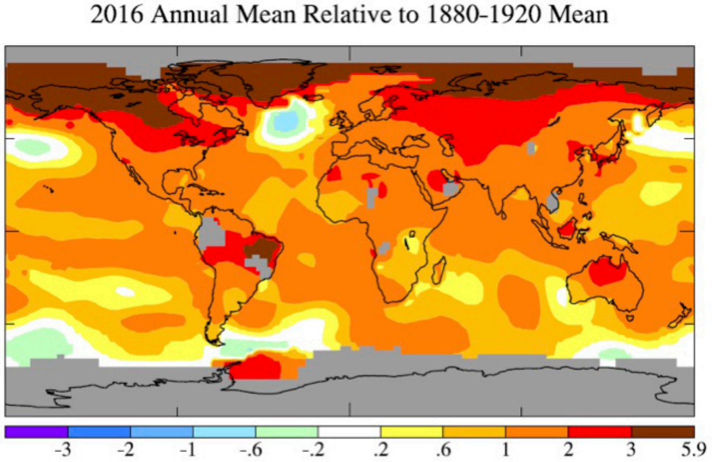
30% stored in biosphere

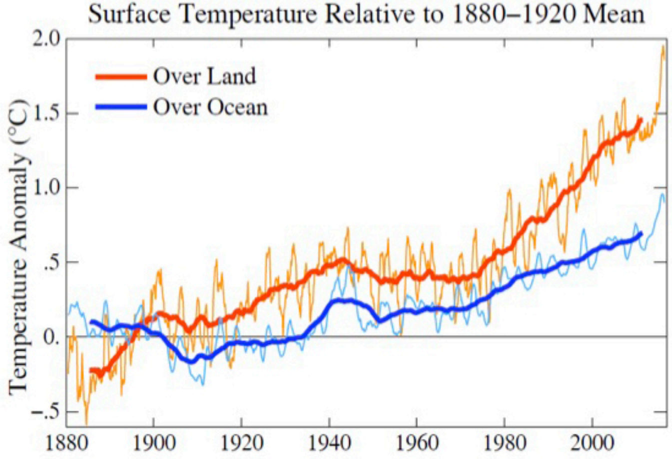
30% stored in ocean

IPCC AR5 2013

Global Mean Temperature Change







Hansen et al., 2017

Changes in Sea Surface Temperature Anomaly

Climate modes and natural variability

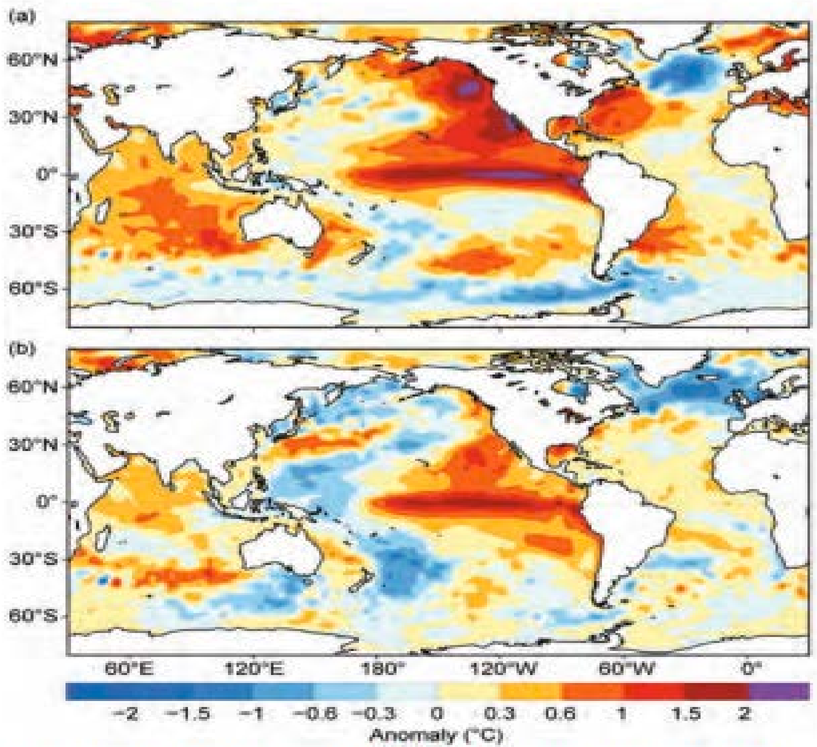


FIG. 3.1. (a) Yearly mean OISST anomaly in 2015 (°C, relative to the 1981–2010 average) and (b) 2015–2014 OISST difference.

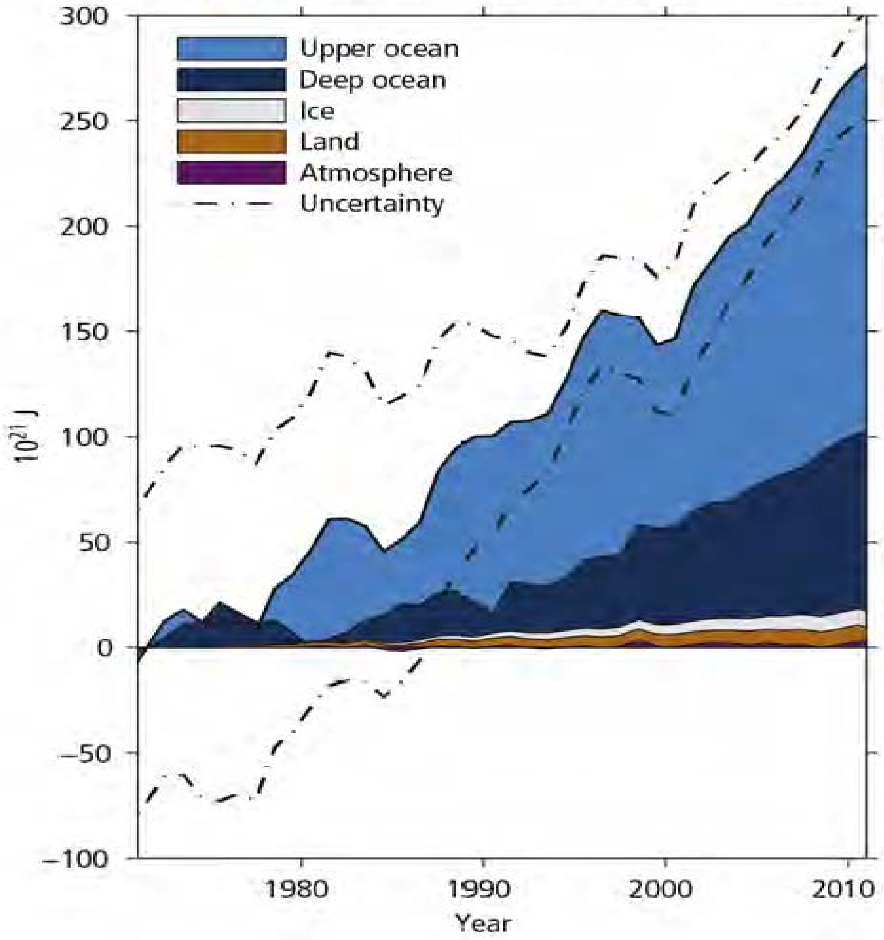
2015 – (1981-2010)

2015-2014

Anthropogenic warming ≈0.1 ˚C/decade

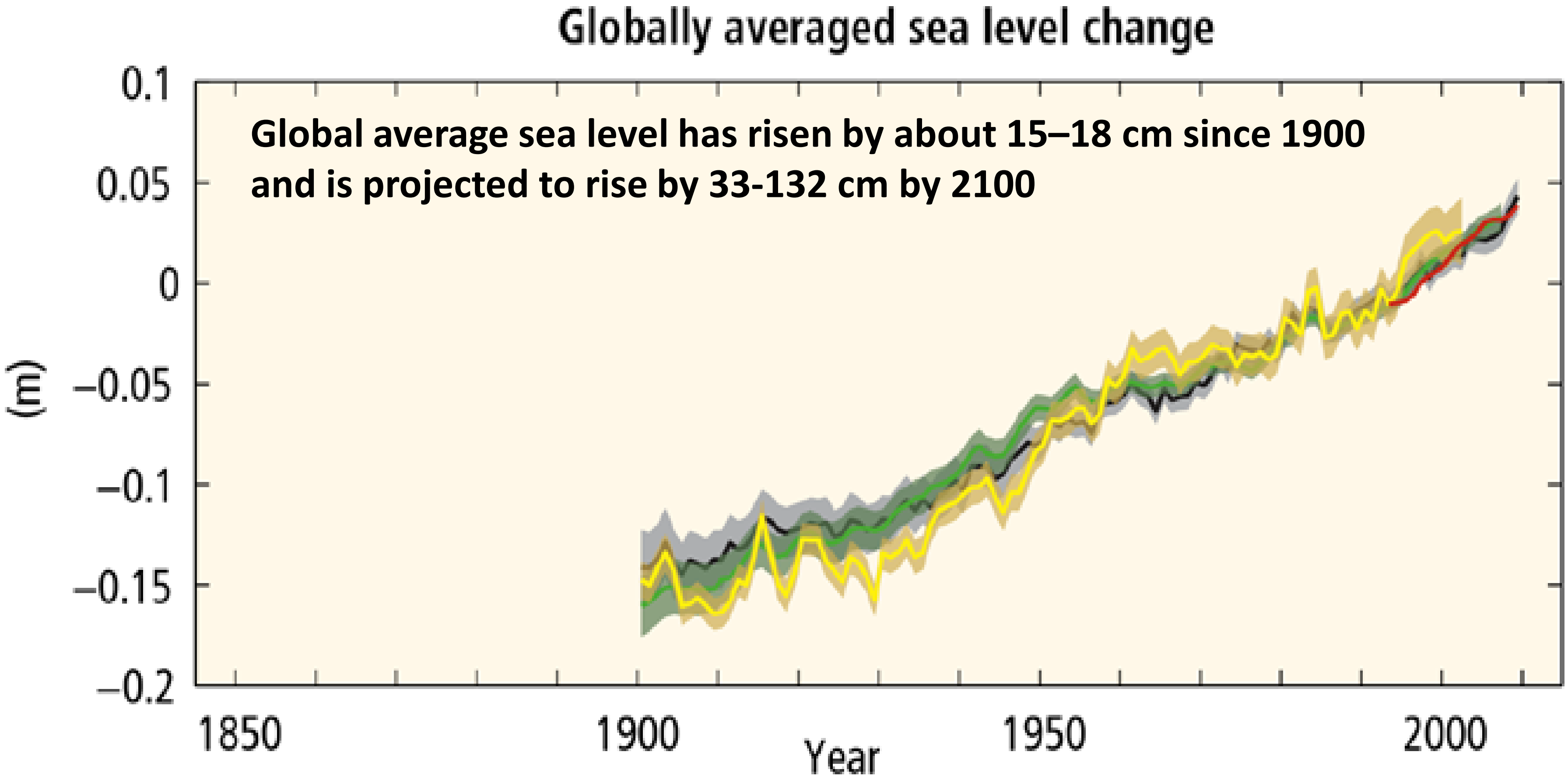
Sea surface temperatures—B. Huang, J. Kennedy, Y. Xue, and H.-M. Zhang

Changes over time: Ocean heat content



- More than 90% of the energy accumulating in the climate system between 1971 and 2010 has accumulated in the ocean.
- Land temperatures remain at historic highs while ocean temperatures continue to climb.

IPCC AR5 Report



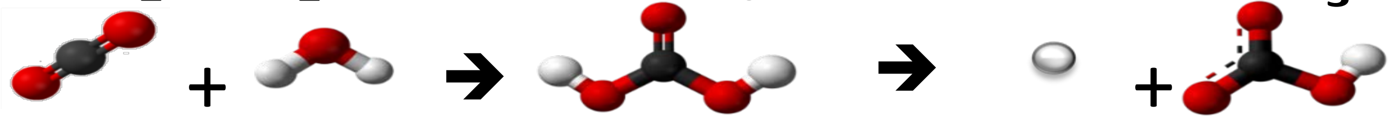
IPCC AR5 Report

Key Findings

- Global annually averaged surface-air temperature has increased by about 1.6°F (0.9°C) over the last 135 years (1880–2015).
- Human-emitted greenhouse gases are responsible for most of Earth's temperature increase since 1951.
- Land temperatures remain at historic highs while ocean temperatures continue to climb.
- More than 90% of the energy accumulating in the climate system between 1971 and 2010 has accumulated in the ocean.

Ocean Acidification: the other CO_2 problem

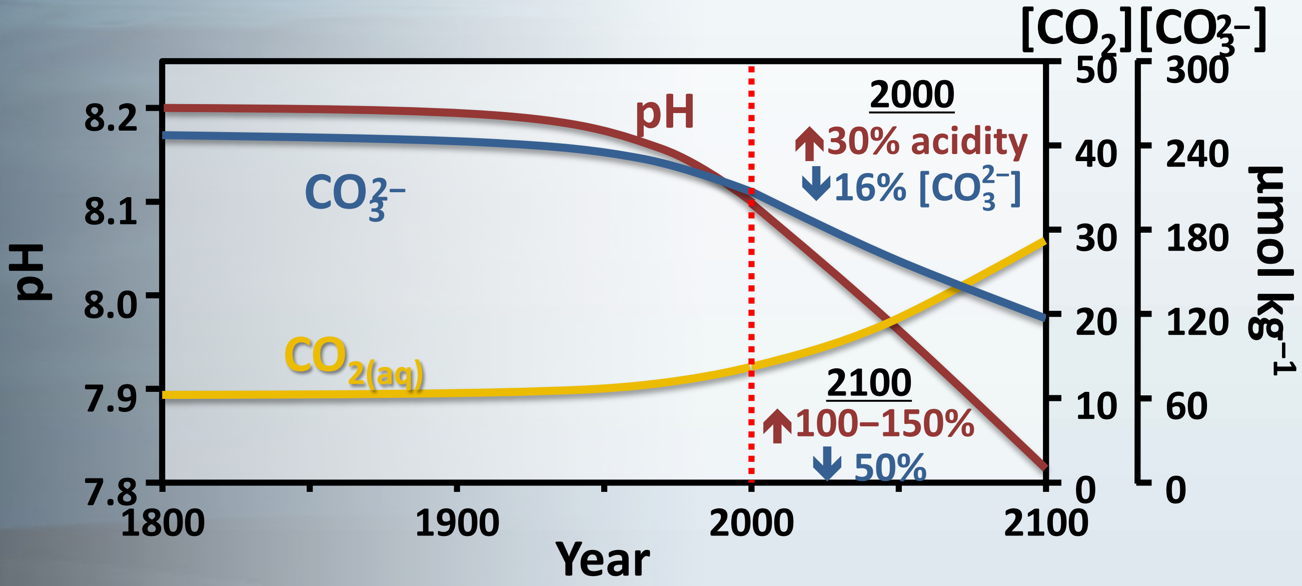
$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$



carbon dioxide + water → carbonic acid → hydrogen ion + bicarbonate ion

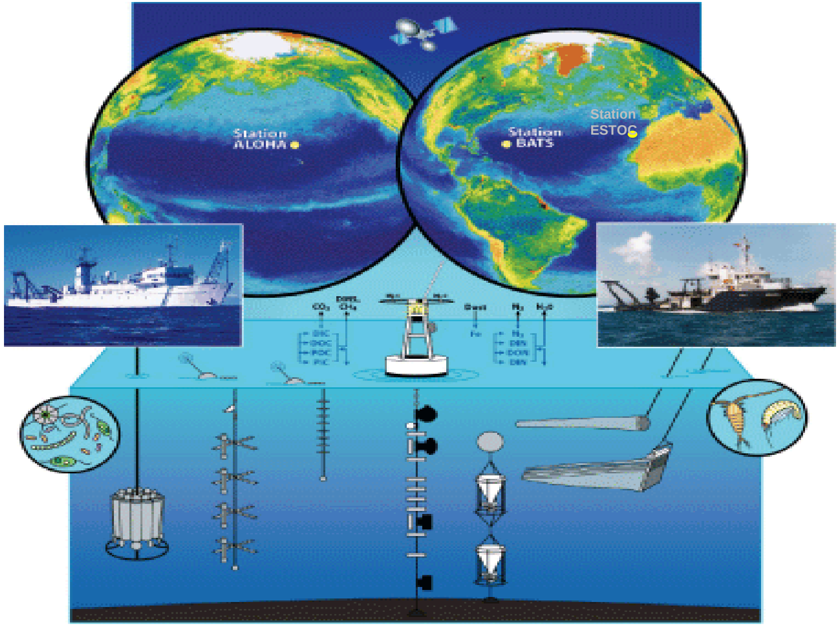
Ocean Acidification

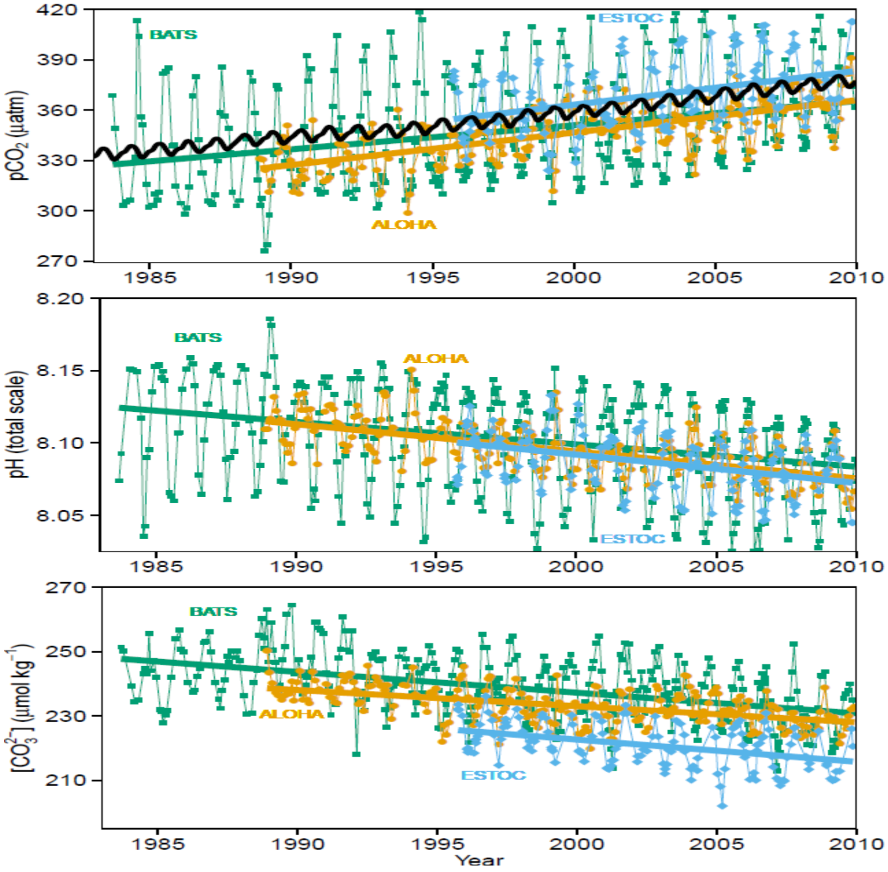
$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$; $H^+ + CO_3^{2-} \rightarrow HCO_3^-$; $CO_3^{2-} + H_2O \Leftrightarrow 2HCO_3^-$



Wolf-Gladrow et al. (1999)

Change in pH from ocean acidification already measurable



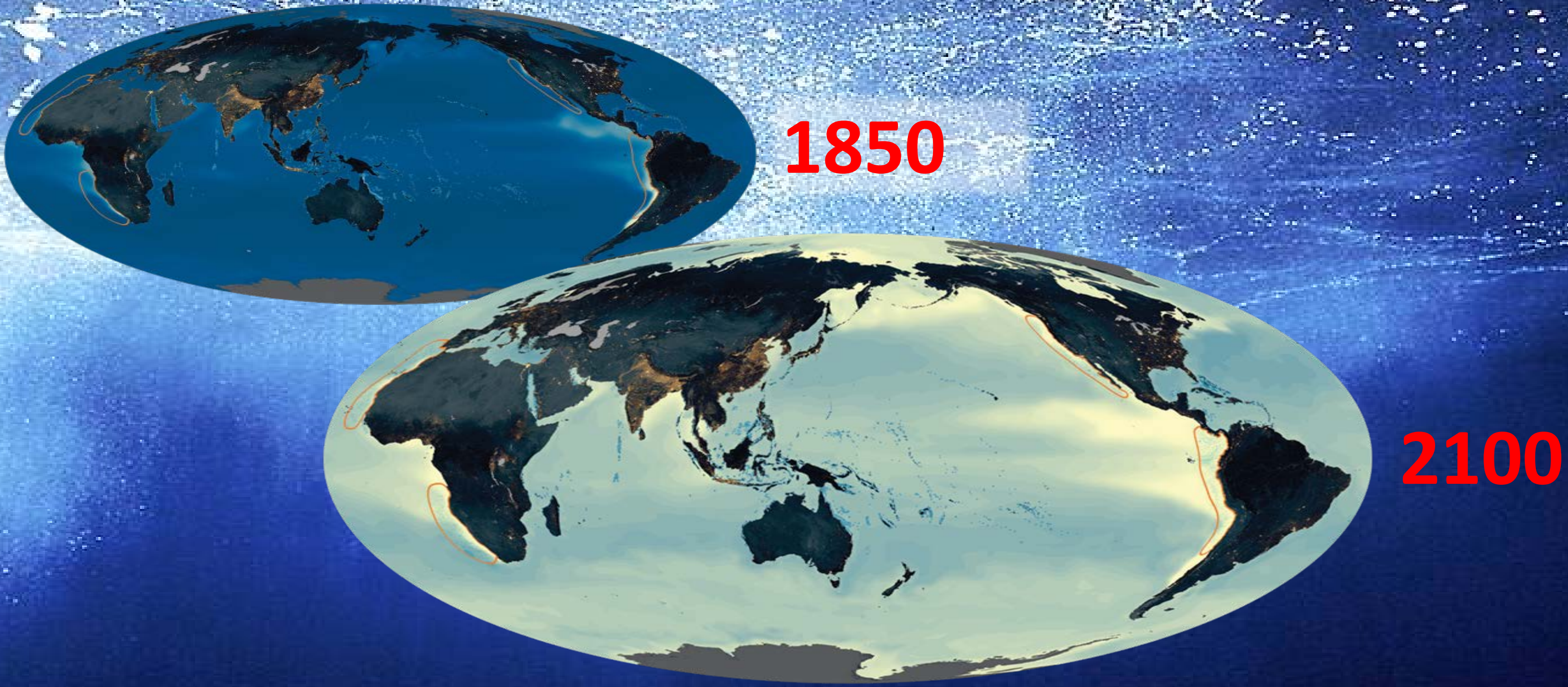


Data:
Bates (2007)
Dore et al. (2009)
Santana-Casiano et al. (2007)
Gonzàles-Dàvila et al. (2010)

In-situ pH change = -0.0019 ± 0.0002 yr^{-1}

IPCC AR5 WG1 Report, Chap. 3 (2013)

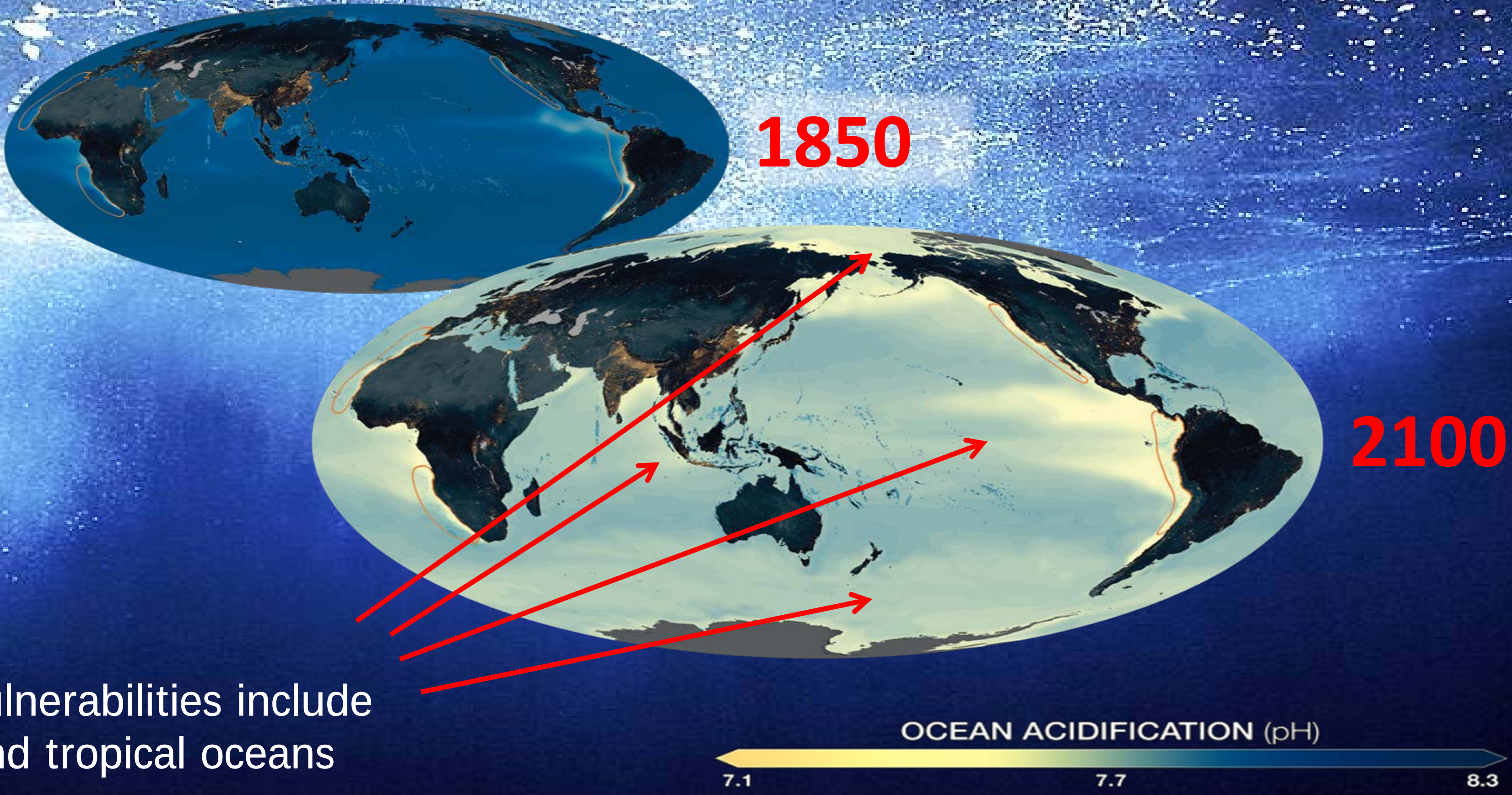
Surface ocean pH change since the industrial revolution



Rapid change in pH across the whole global ocean

IGBP, IOC, SCOR (2013) Ocean Acidification Summary for Policy Makers

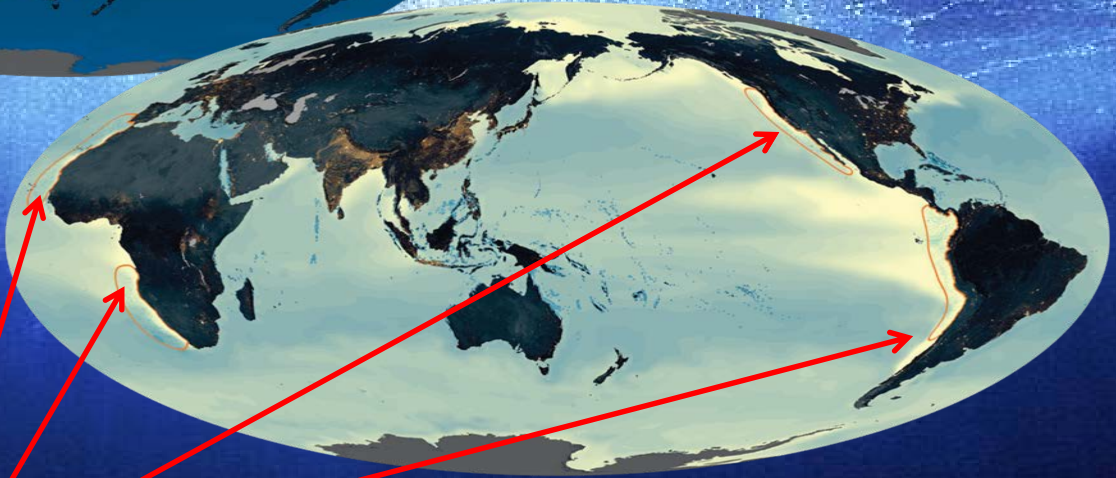
Surface ocean pH change since the industrial revolution

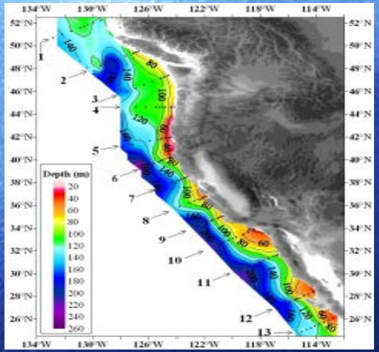


Early vulnerabilities include polar and tropical oceans

IGBP, IOC, SCOR (2013) Ocean Acidification Summary for Policy Makers

Surface ocean pH change since the industrial revolution



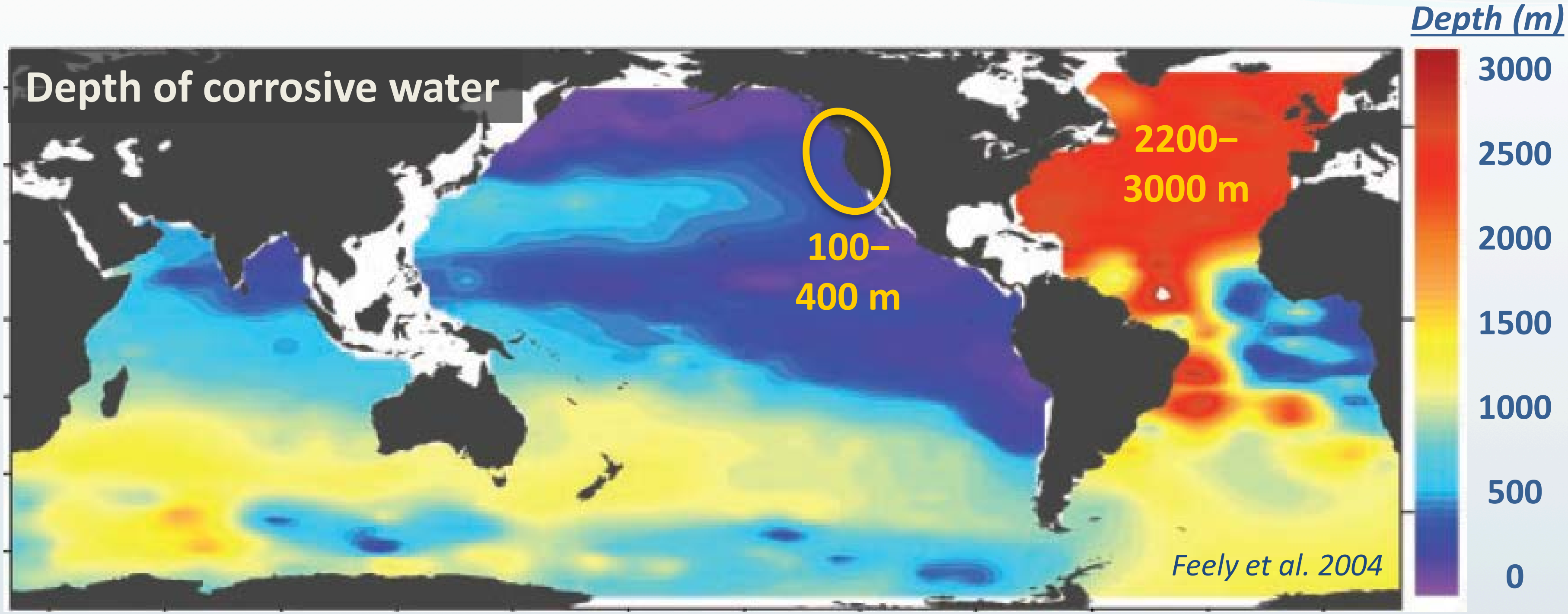


Feely et al. (2008)

Early vulnerabilities
include upwelling regions

IGBP, IOC, SCOR (2013) Ocean Acidification Summary for Policy Makers

Global context for West Coast ocean acidification

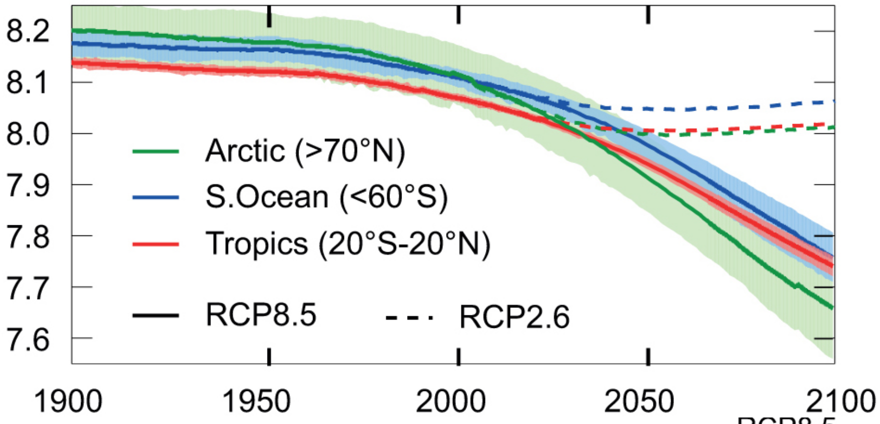


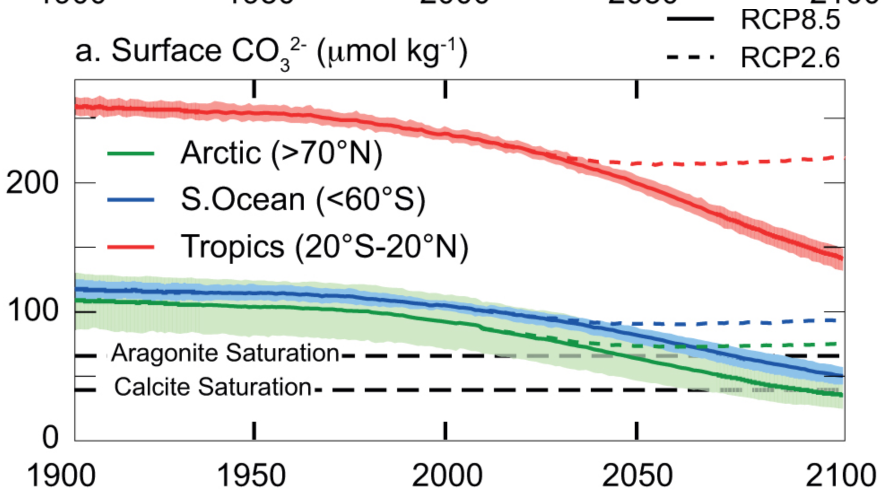
- The ocean absorbs 30% of CO_2 emitted to the atmosphere by human activities.
- CO_2-driven acidification brings corrosive water closer to the surface by 1–3 m/yr (3–10 ft/yr).

Long-term Impacts of Acidification (IPCC AR5 Chapter 6)

Projections

Surface pH





- pH decrease as much 0.4- 0.5 from 1900
- Surface waters of the Arctic Ocean are undersaturated with respect to aragonite by 2040 and by 2060 in the Southern Ocean

Key Findings

- Approximately 28% of the CO_2 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.

How CO_2 in seawater affects marine life

Changes in chemistry

$CO_{2(aq)}$ ↑

HCO_3^- ↑

CO_3^{2-} ↓

pH ↓

Biological effects

Increase in photosynthesis

Decrease in shellfish calcification

Changes in physiology

Global

Temp ↑

Oxygen ↓

Regional

Overfishing

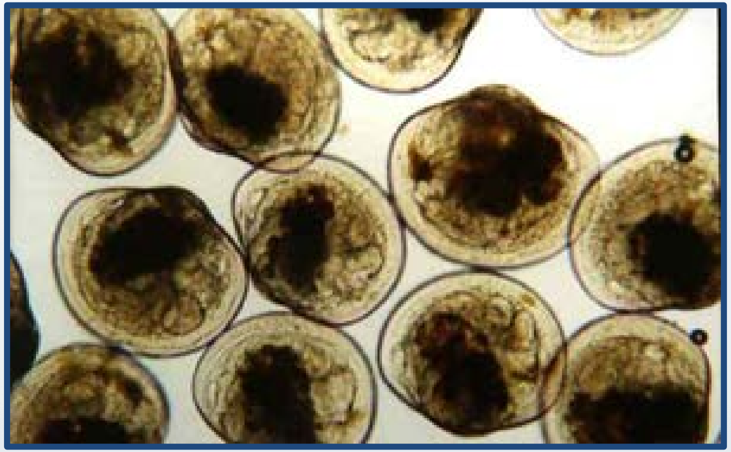
Pollution

Oil spills

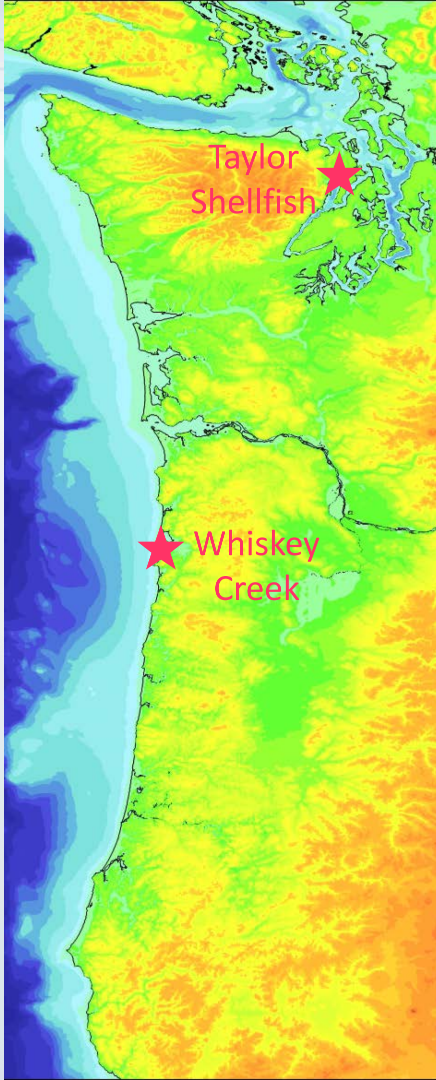
Saturation State

$$\Omega_{phase} = \frac{[Ca^{2+}][CO_3^{2-}]}{K^*_{sp,phase}}$$

Pacific Northwest hatchery failures



Photos: Taylor Shellfish



"Between 2005 and 2009, disastrous production failures at Pacific Northwest oyster hatcheries signaled a shift in ocean chemistry that has profound implications for Washington's marine environment."

Washington Blue Ribbon Panel on Ocean Acidification 2012

Dissolution as an indicator of past, present and future impacts

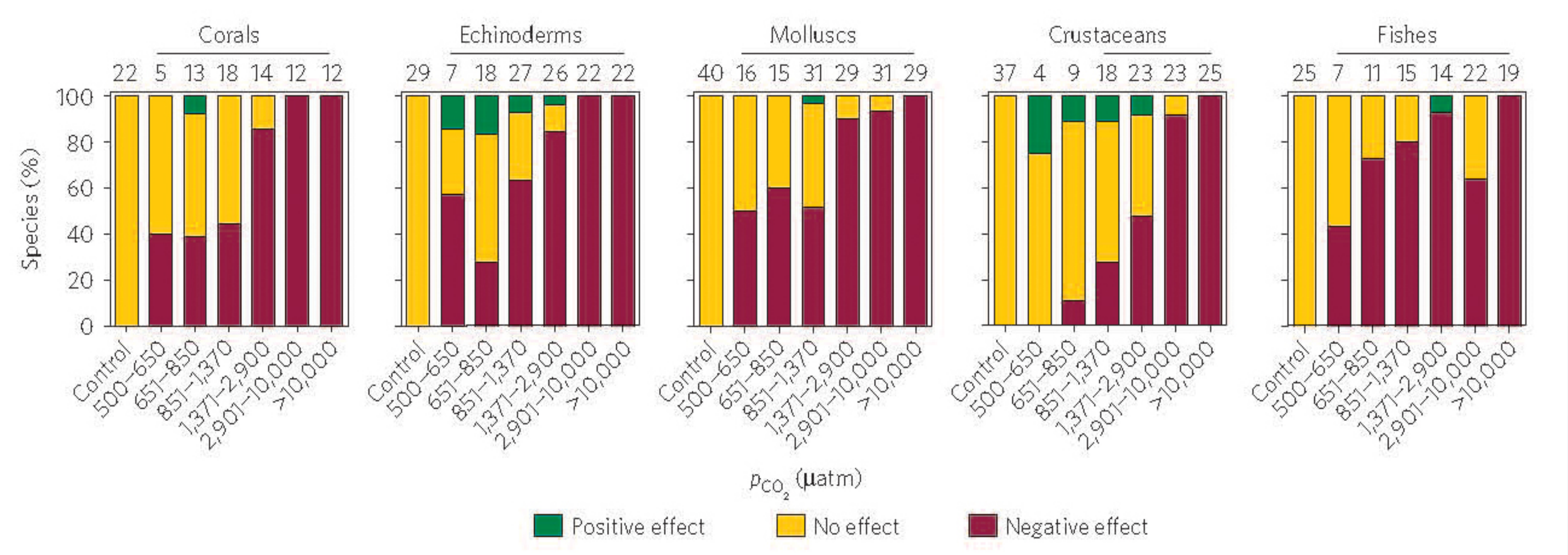
Pre-industrial level of dissolution due only to upwelling: naturally occurring dissolution (~18%)

*S*ignificant increase in the current level of dissolution → 53% in the coastal regions with anthropogenic CO_2 contribution in addition to upwelling.

By 2050: ~70% of water column will be undersaturated →70% of pteropods affected by severe dissolution in the coastal regions.

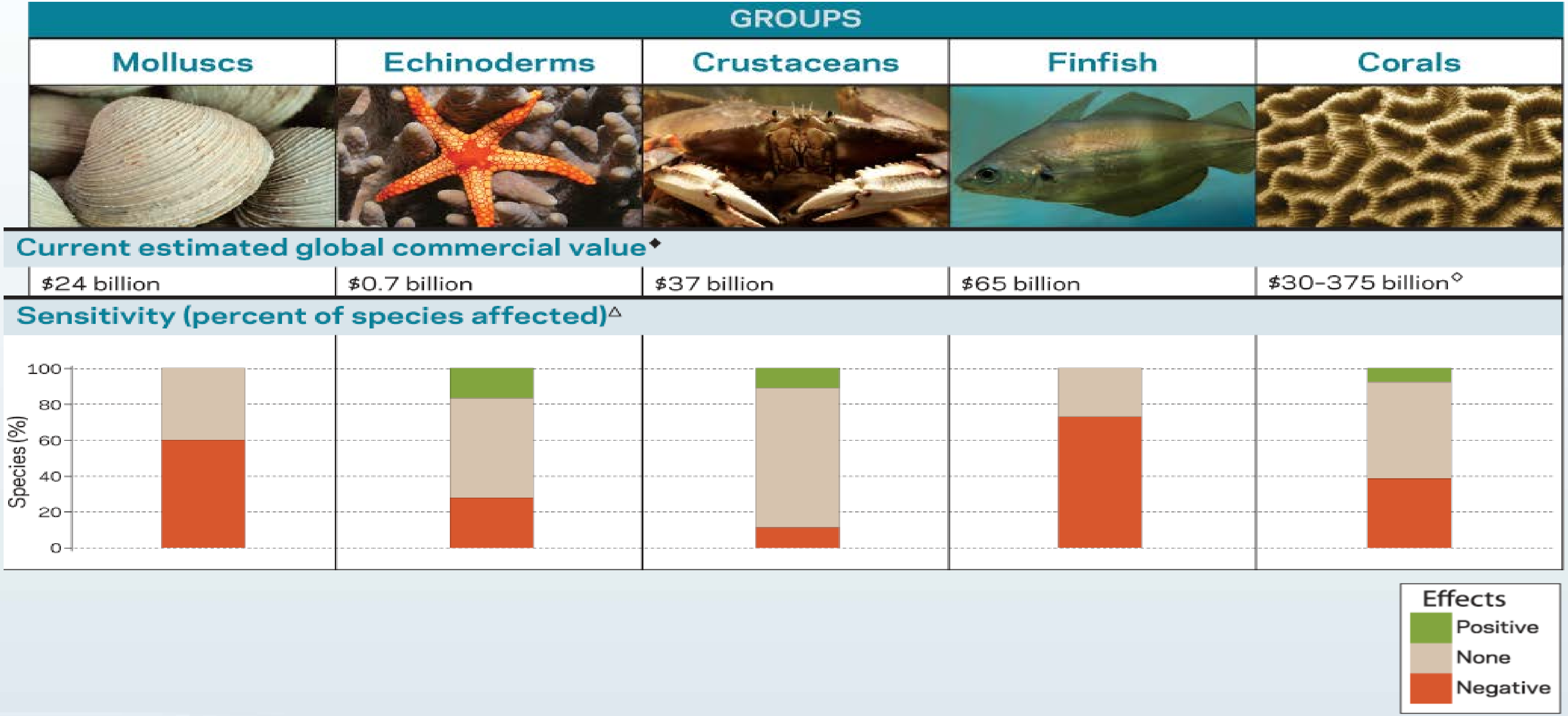
Bednarsek et al 2014

Impacts of Acidification (after Wittmann and Pörtner, 2013)



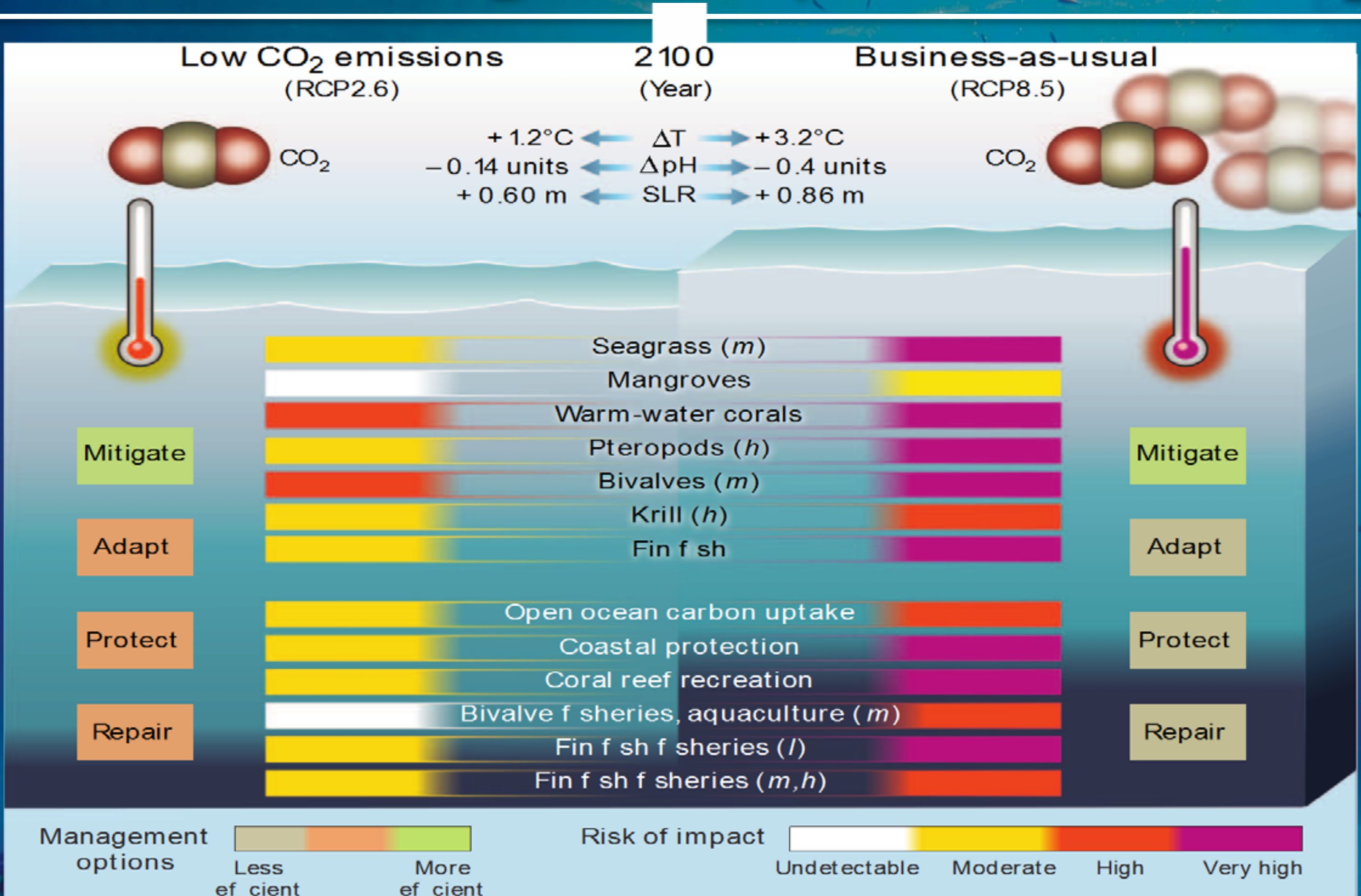
Corals, echinoderms and molluscs are more sensitive to 936 ppm pCO_2 than are crustaceans. Larval fishes may be even more sensitive than the lower invertebrates, but taxon sensitivity on evolutionary timescales remains obscure. The variety of responses within and between taxa, together with observations in mesocosms and palaeo-analogues, suggest that ocean acidification is a driver for substantial change in ocean ecosystems this century, potentially leading to long-term shifts in species composition.

Commercially Important Organisms



SCOR UNESCO GLOBAL IGBP CHANGE International Geosphere-Biosphere Programme

Future Biological Impacts from CO_2 Emissions



Gattuso et al., Science 2015

Changes in impacts on organisms and ecosystems according to stringent (RCO2.6) and high (RCP8.5) CO_2 emission scenarios.

Major Conclusions

Source: L. Whitely Binder, CIG

- The ocean is warming and acidifying rapidly
- Many species will be sensitive to warming and acidification
- Impacts of warming and acidification can transfer through food webs
- Other stressors can exacerbate response to warming and acidification
- Economic consequences of warming and acidfication are significant