「温暖化予測の鍵、海のCO_2」

大気CO_2の海洋吸収と生態系への影響（通訳付）

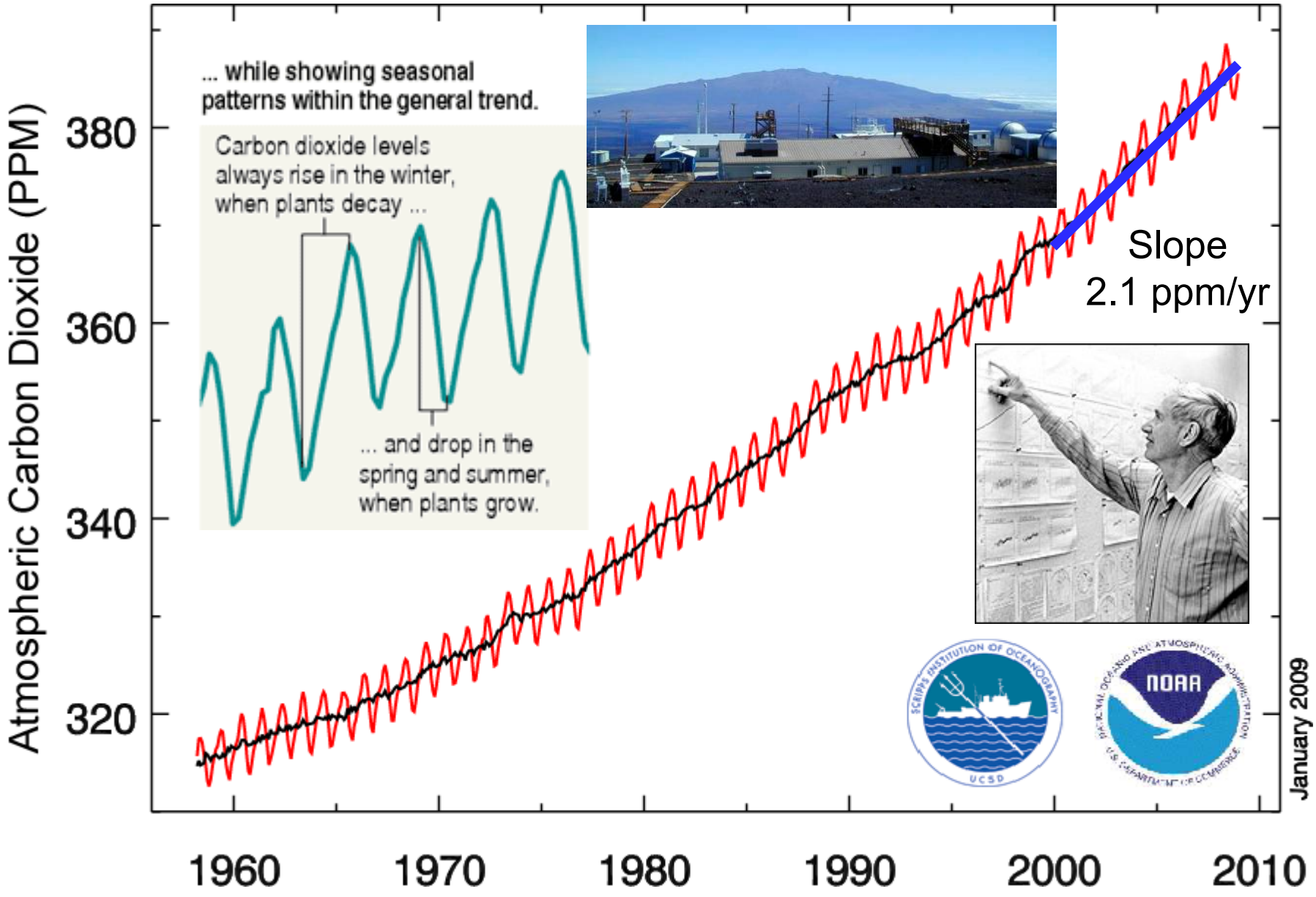
米国海洋大気庁　Christopher Sabine

Ocean Uptake of Atmospheric CO_2 and its Impact on Marine Ecosystems

Dr. Christopher L. Sabine, oceanographer at
NOAA's Pacific Marine Environmental Laboratory

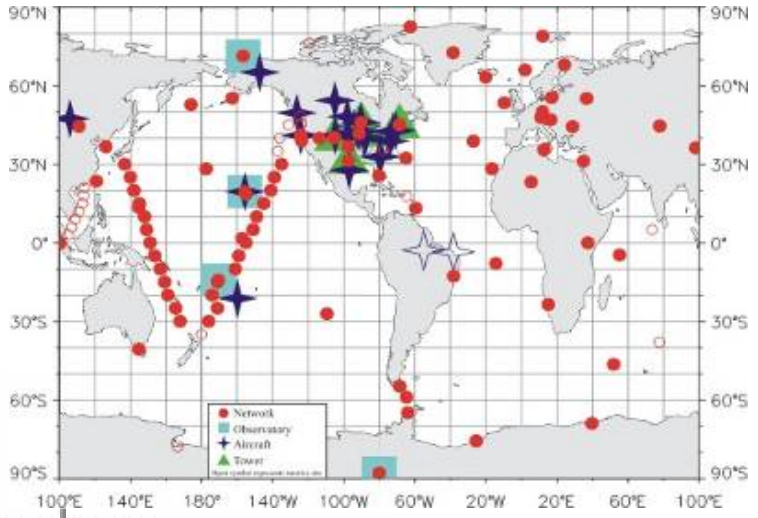
NOAA

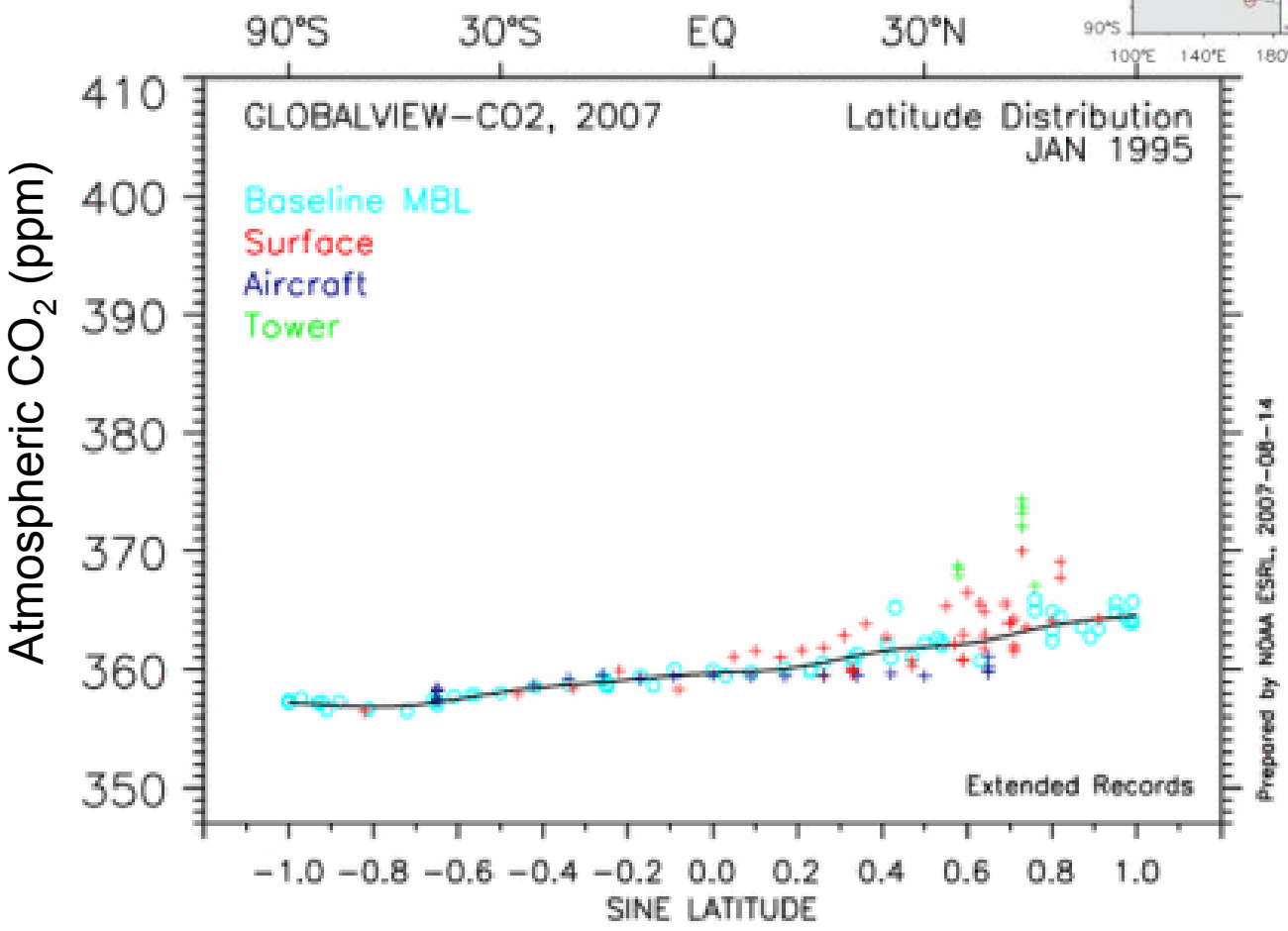
Rising Atmospheric CO_2 was first documented by Dr. David Keeling in the mid 1900s.



Atmospheric CO_2 Record

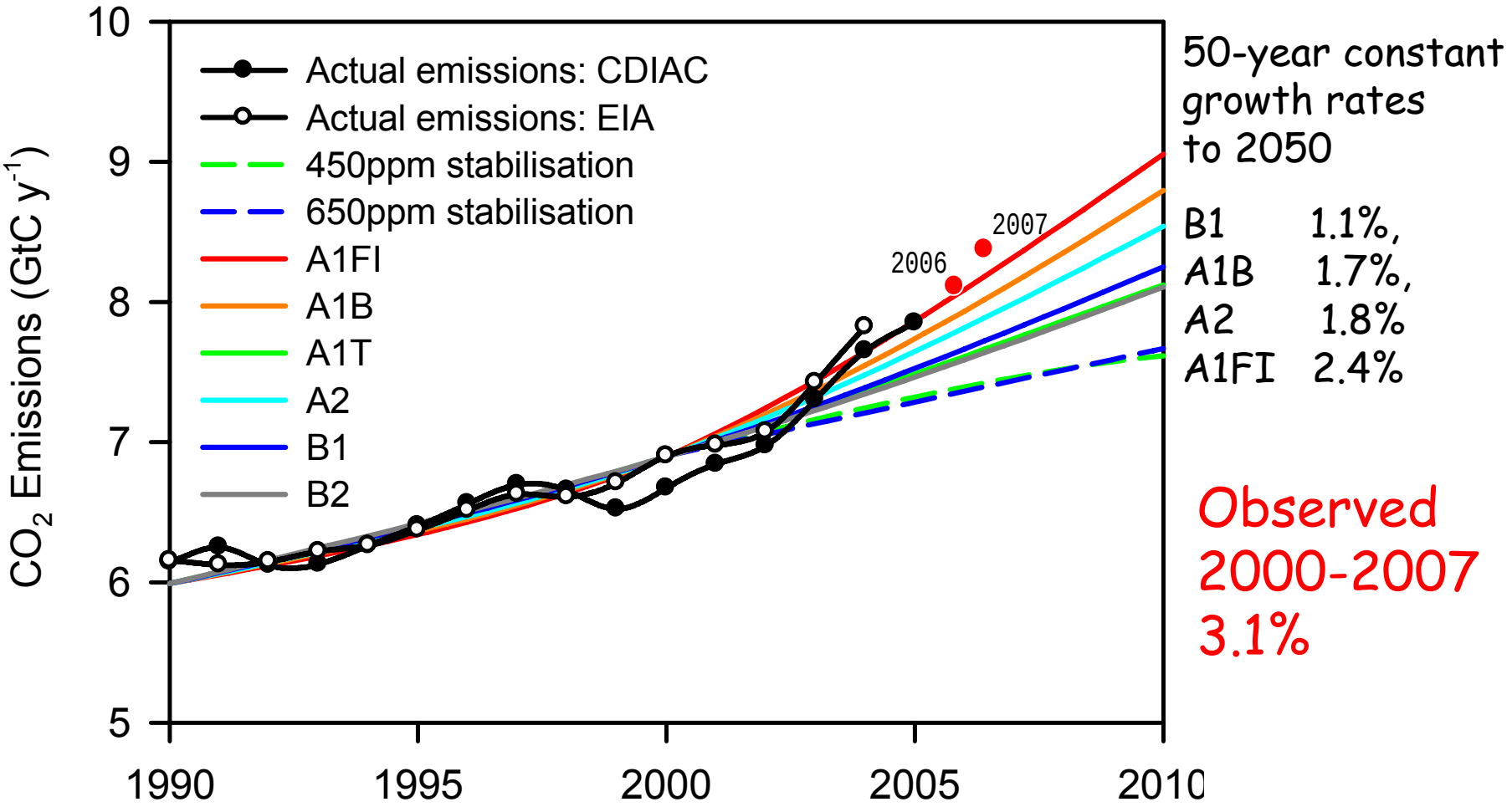
Atmospheric CO_2 levels are rising everywhere in the world. This can easily be seen even with the natural variability.



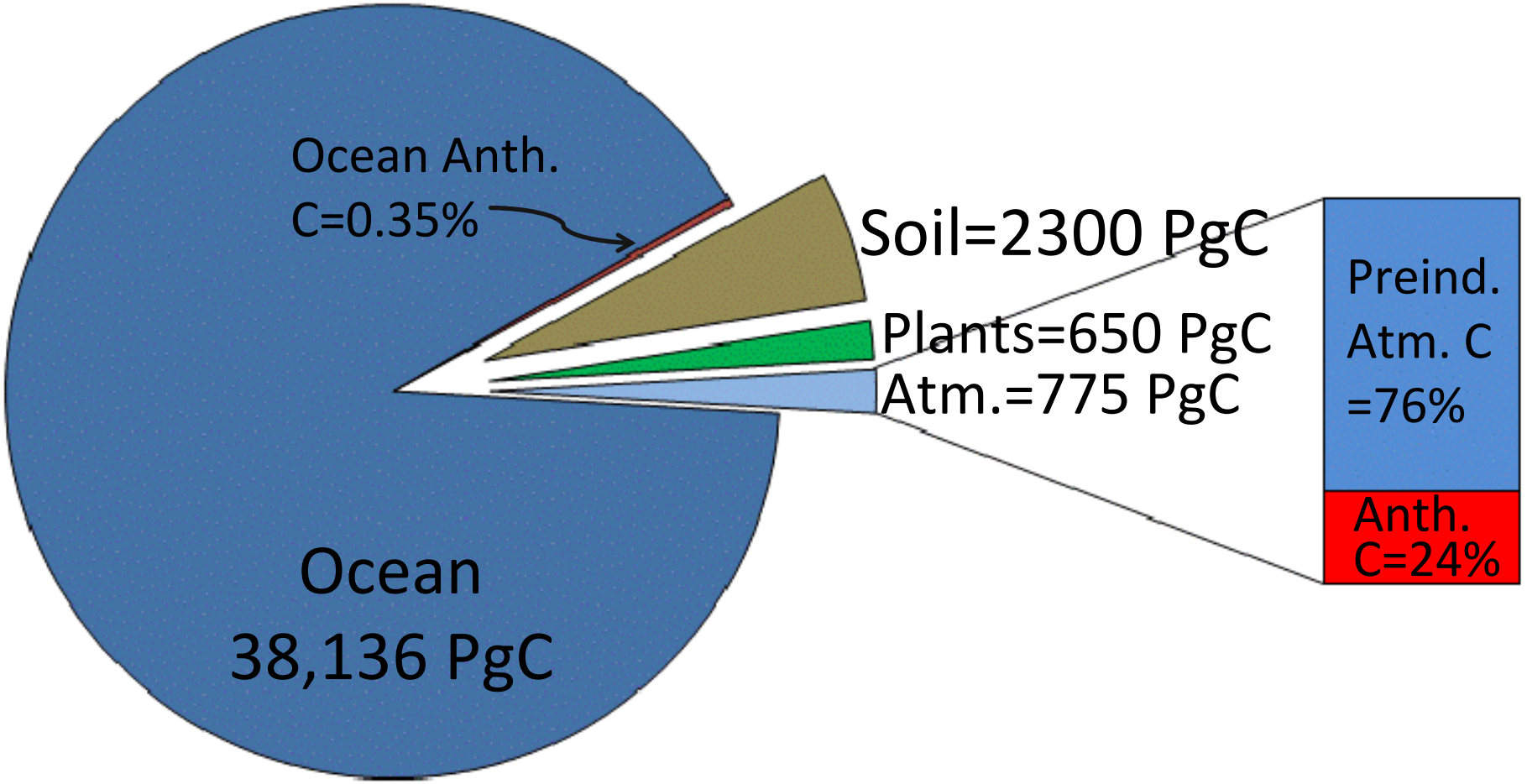


Northern Hemisphere has larger seasonal variability than southern hemisphere

Recent emissions have been higher than the worst of the IPCC projected scenarios



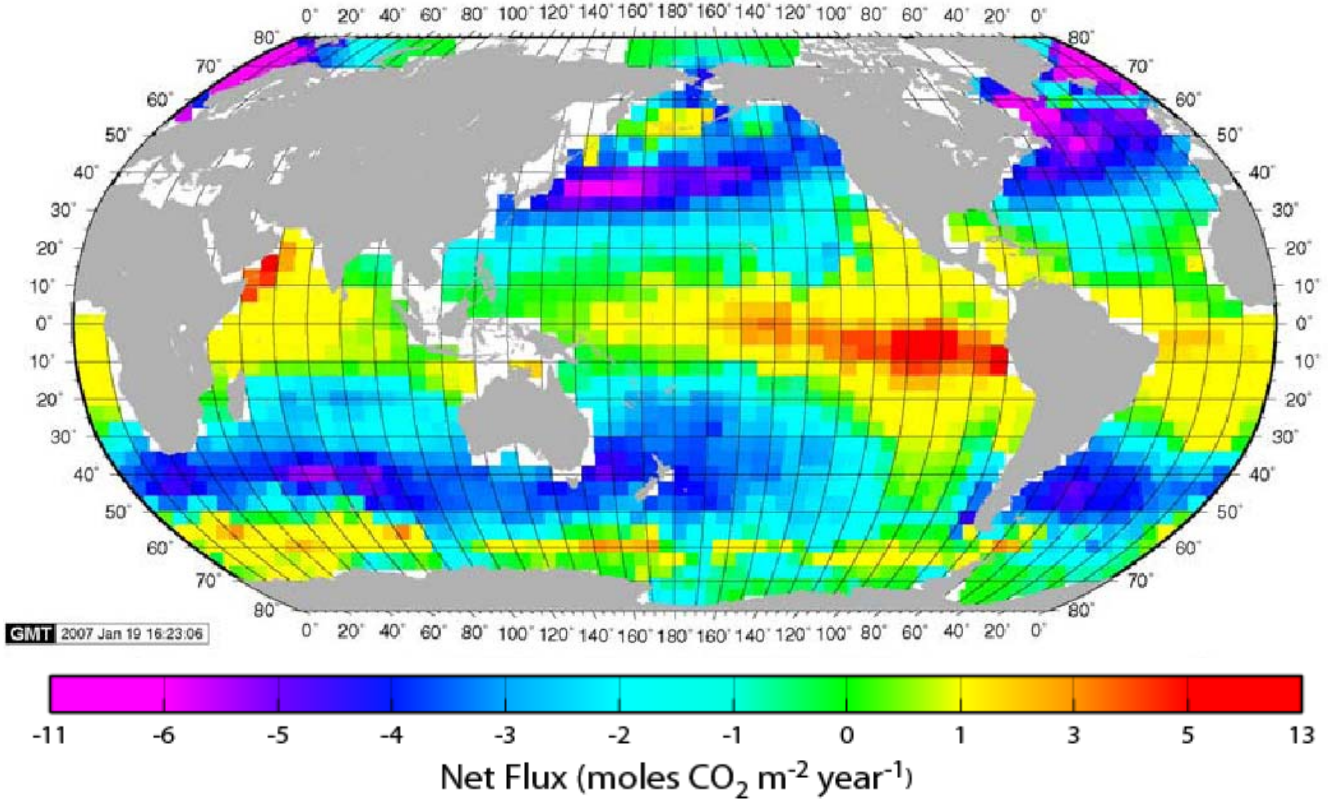
Carbon Inventories of Reservoirs that Naturally Exchange Carbon on Time Scales of Decades to Centuries



- Oceans contain ~90% of carbon in this 4 component system
- anthropogenic component is difficult to detect

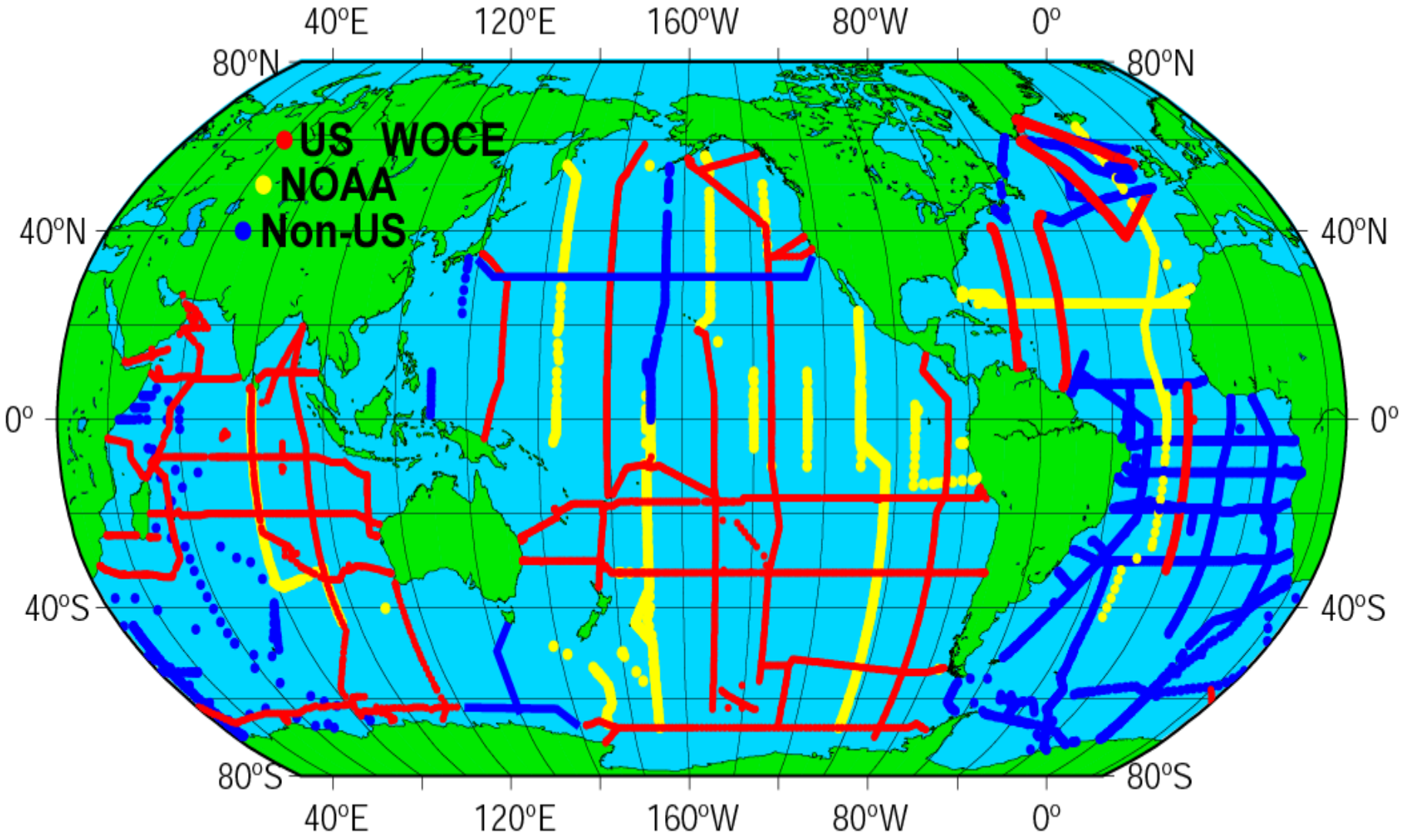
annual mean air-sea CO_2 flux for 2000

Based on 3 million measurements since 1970
Global flux is 1.4 Pg C/yr



Takahashi et al., Deep Sea Res. II, 2009

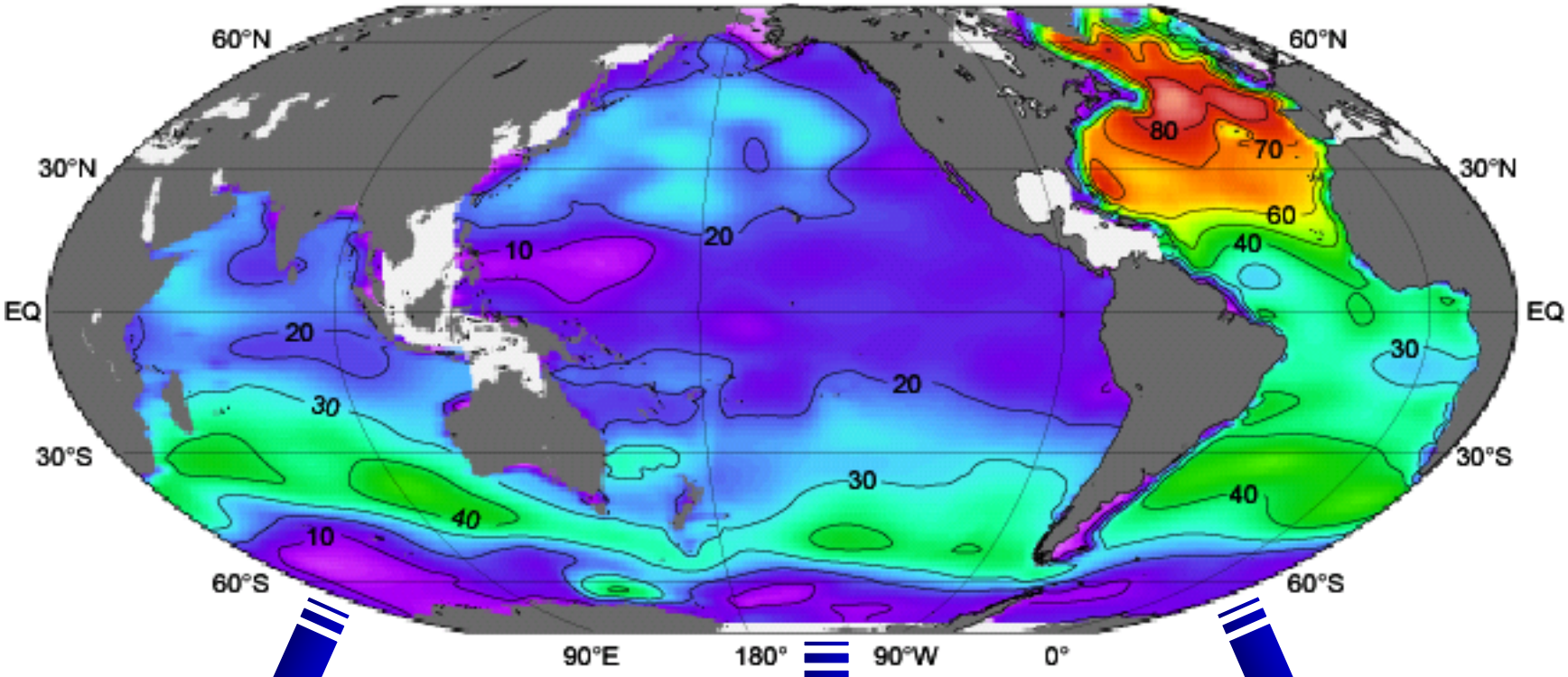
In the early 1990s we conducted a global survey of CO_2 in the oceans to determine how much fossil fuel is stored in the ocean.



~72,000 sample locations collected in the 1990s

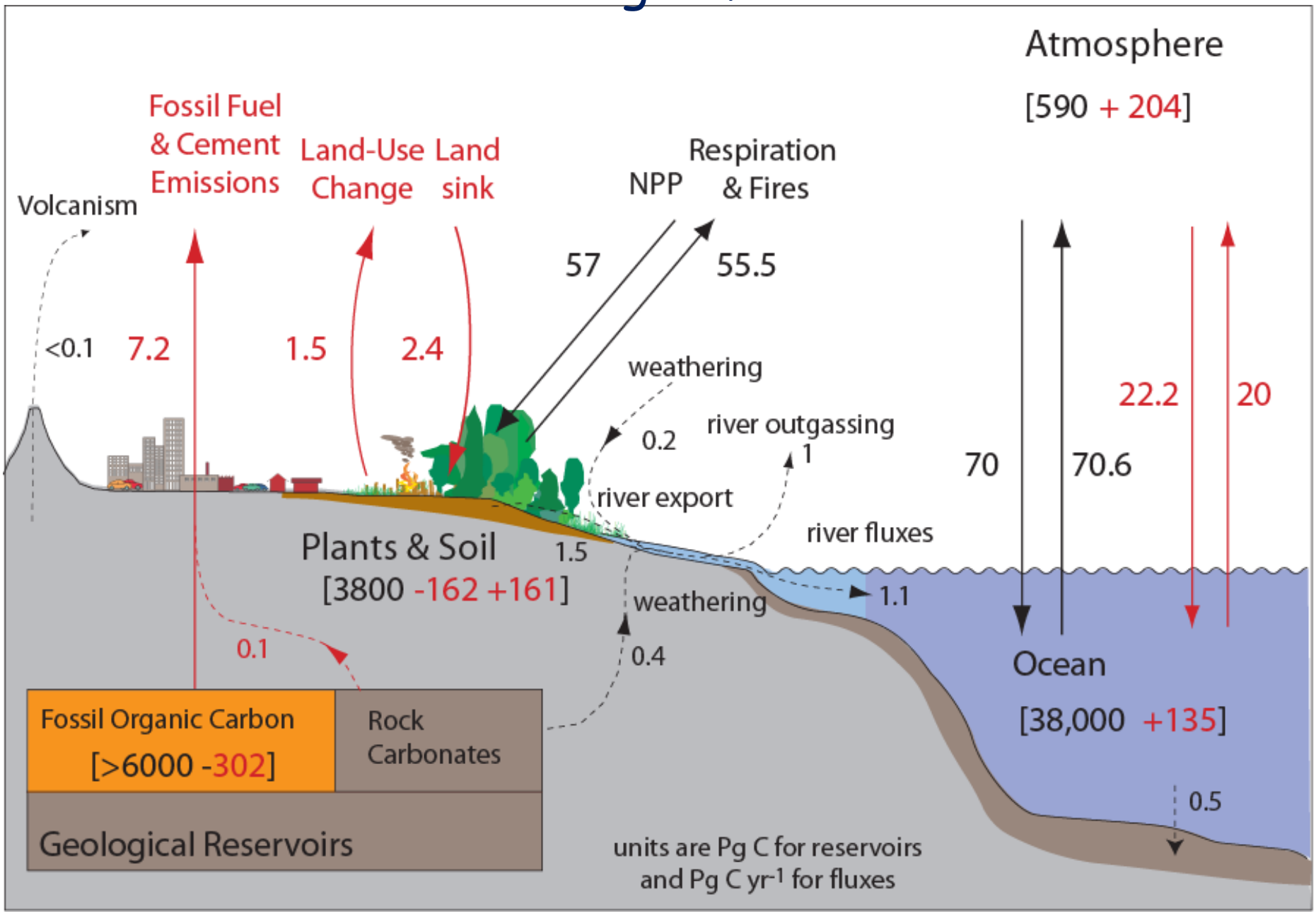
DIC ± 2 μmol kg^{-1}
TA ± 4 μmol kg^{-1}

Column inventory of anthropogenic CO_2 that has accumulated in the ocean between 1800 and 1994 (mol m^{-2})



Global Inventory =118±19 Pg C

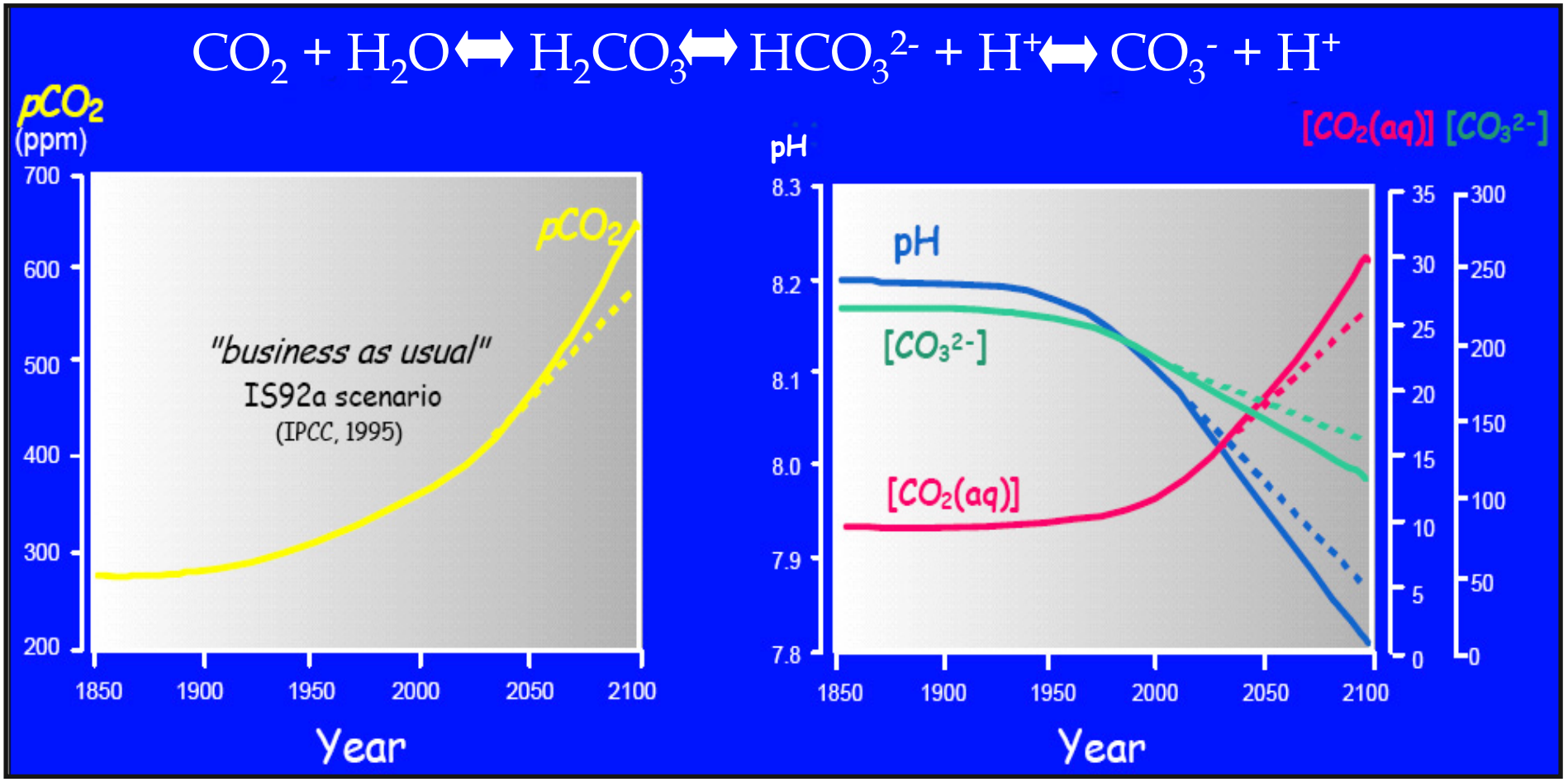
Global Carbon Budget for 2000-2005



adapted from Sabine et al., 2004

Rising atmospheric CO_2 is changing the chemistry of the ocean

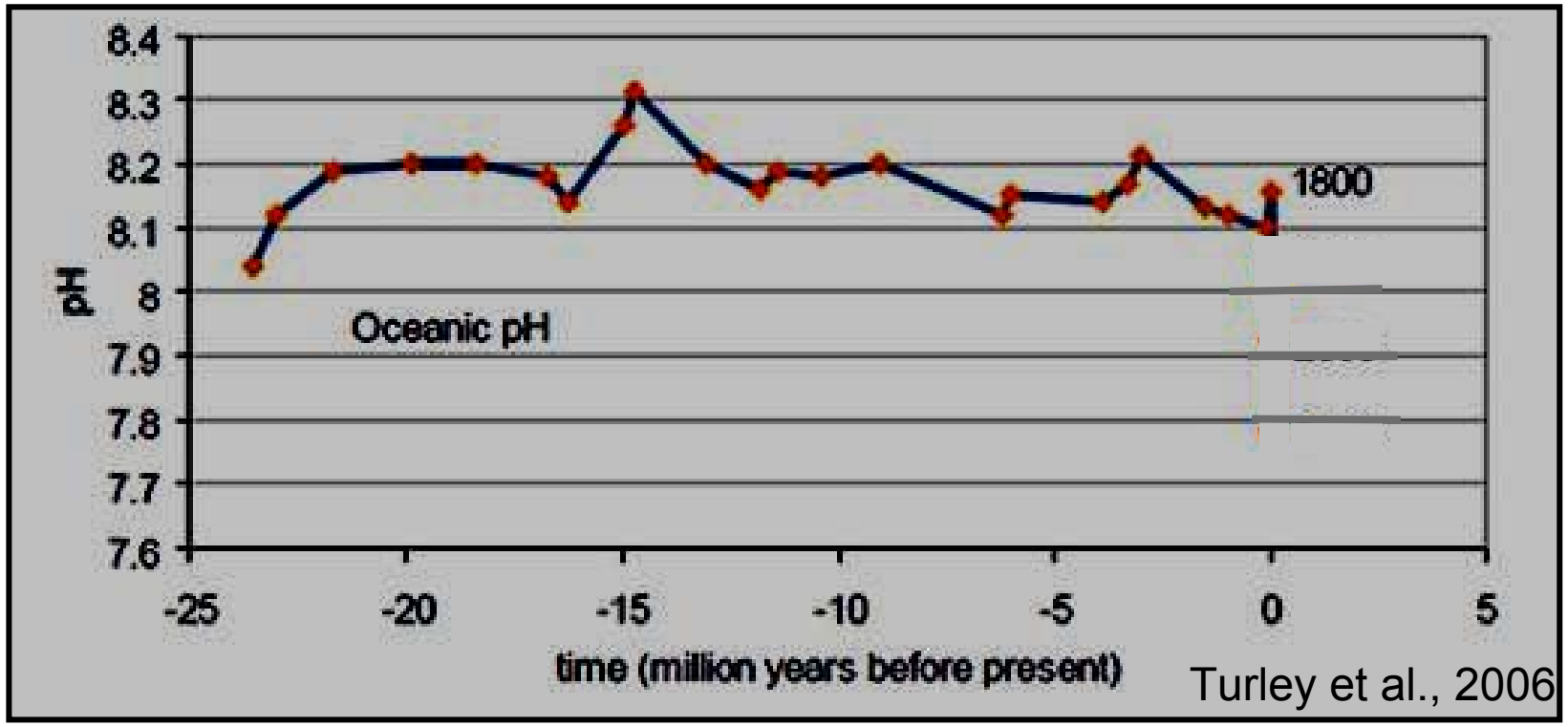
CO_2 is an acid gas so the addition of 22 million tons of carbon dioxide to the ocean every day is acidifying the seawater…we call this process "ocean acidification"



After Turley et al., 2005

Emerging Topic: Ocean Acidification

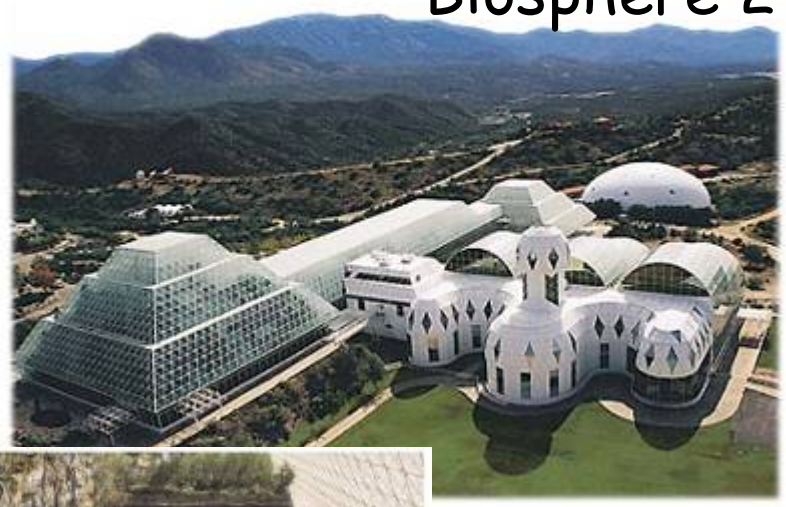
- For the last 20 Million years the pH of the ocean has remained relatively stable between approximately 8.1 and 8.2
- The uptake of anthropogenic CO_2 has lowered ocean pH by 0.1, representing a 30% increase in acidity over the last 200 years.
- The estimated drop in pH by the end of the century is not only larger than seen over the last 20 million years, but is also at least 100 times faster than in the past.

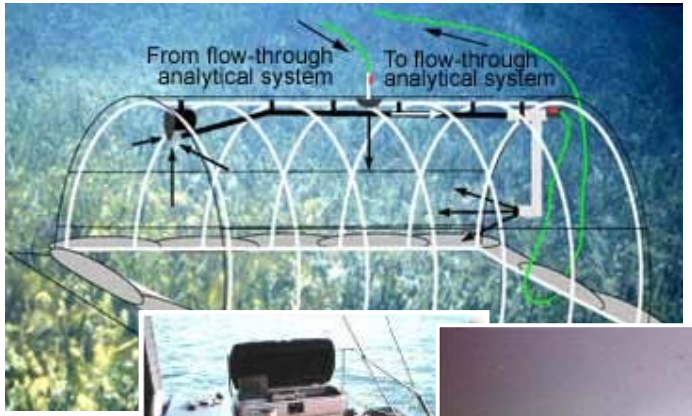


Turley et al., 2006

Experiments on Many Scales

Biosphere 2





SHARQ

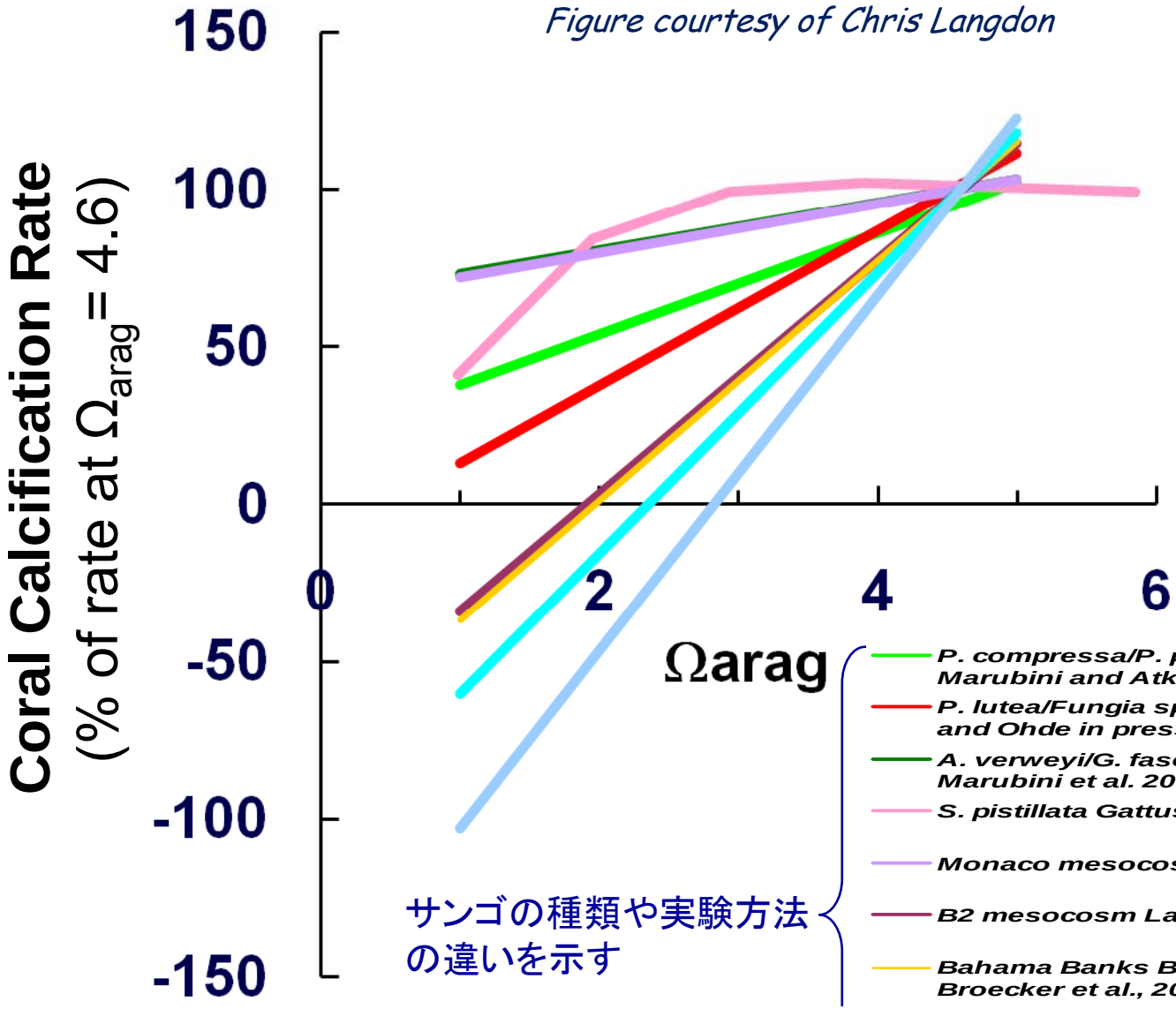
Submersible Habitat for Analyzing Reef Quality

Provided by Mark Eakin

Aquaria and Small Mesocosms

Corals
(warm water)

Figure courtesy of Chris Langdon



Saturation State

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

$\Omega > 1 =$ *precipitation*

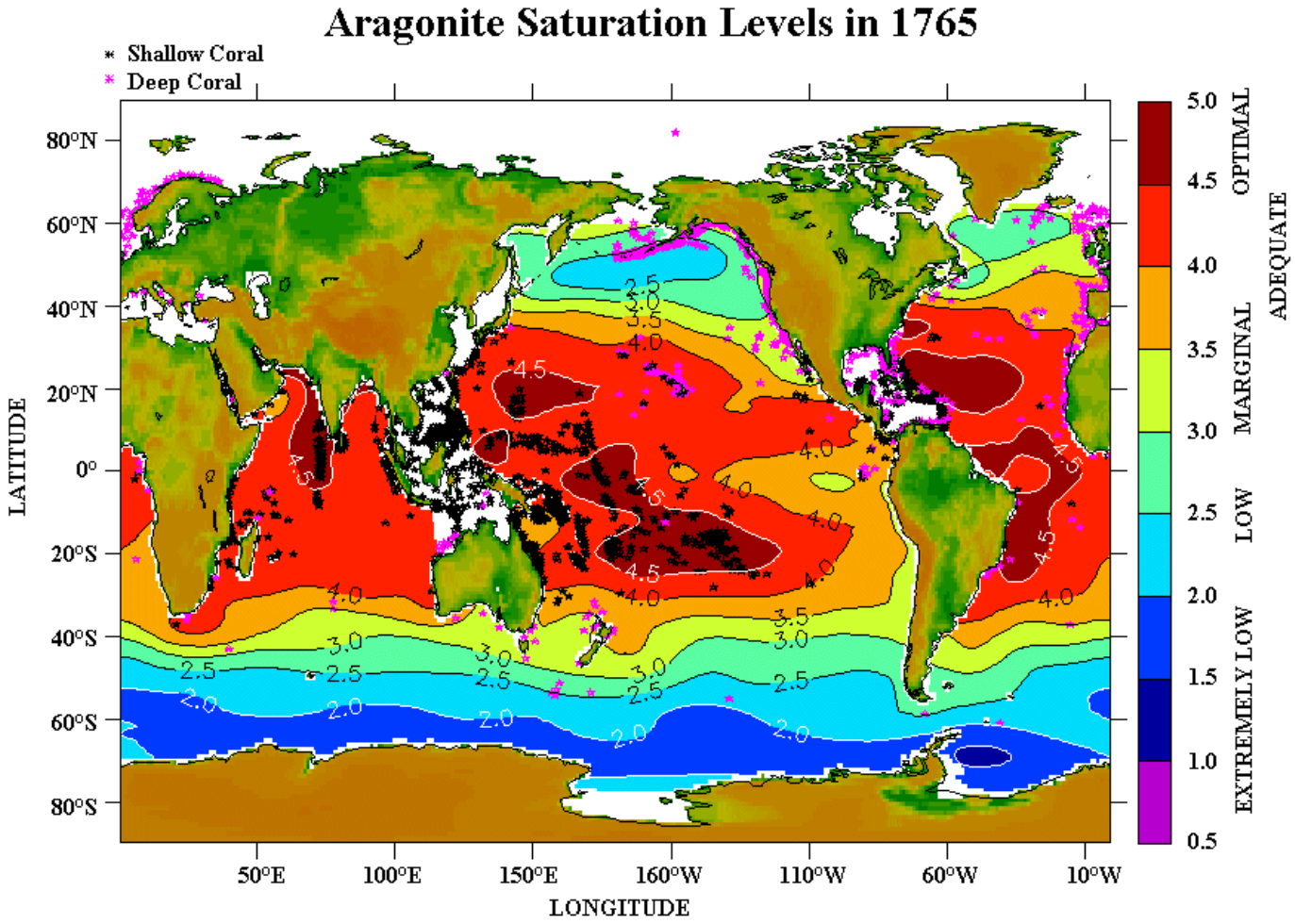
$\Omega = 1 =$ *equilibrium*

$\Omega < 1 =$ *dissolution*

Predictions of Ocean Acidification and the effects on coral reef calcification

Coral Reef calcification

- 1765 **Adequate**
- 2000 **Marginal**
- 2100 **Low**



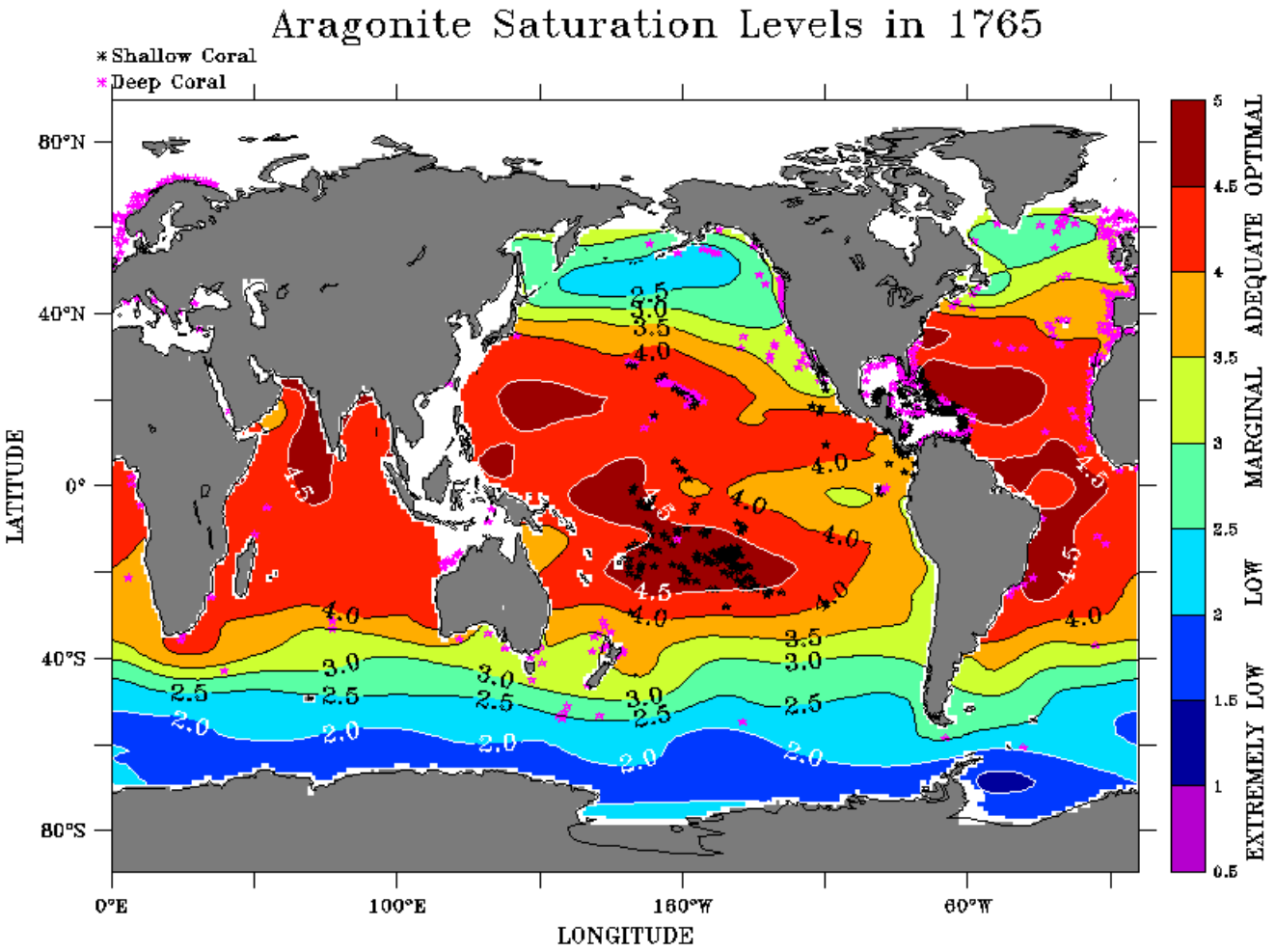
After Feely et al (in press) with Modeled Saturation Levels from Orr et al (2005)

Predictions of Ocean Acidification and the effects on coral reef calcification

Coral Reef calcification

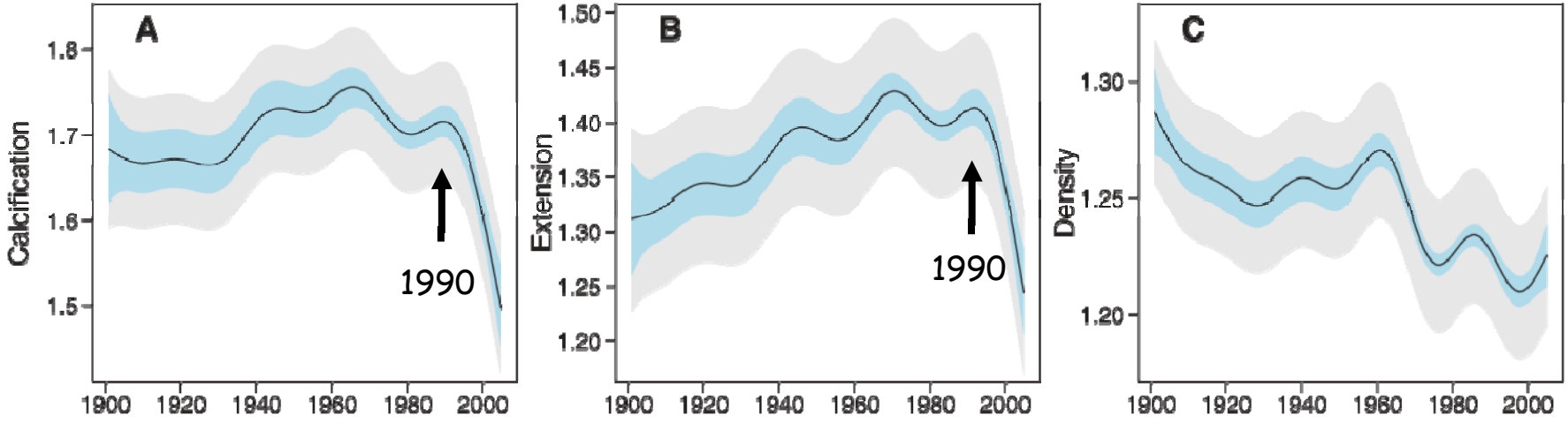
- 1765 **Adequate**
- 2000 **Marginal**
- 2100 **Low**

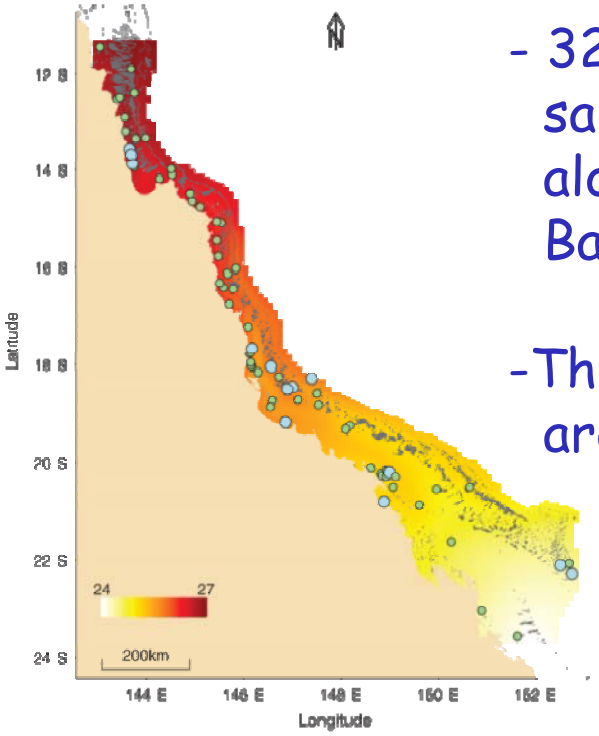
Coral calcification rates are likely to drop dramatically over the next century



After Feely et al (2008) with Modeled Saturation Levels from Orr et al (2005)

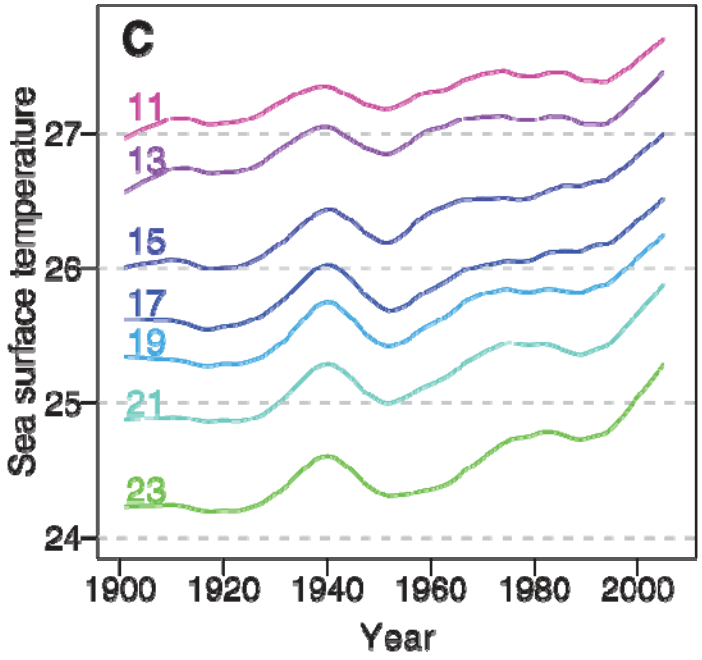
Climate Change and Ocean Acidification Impacts in the Field





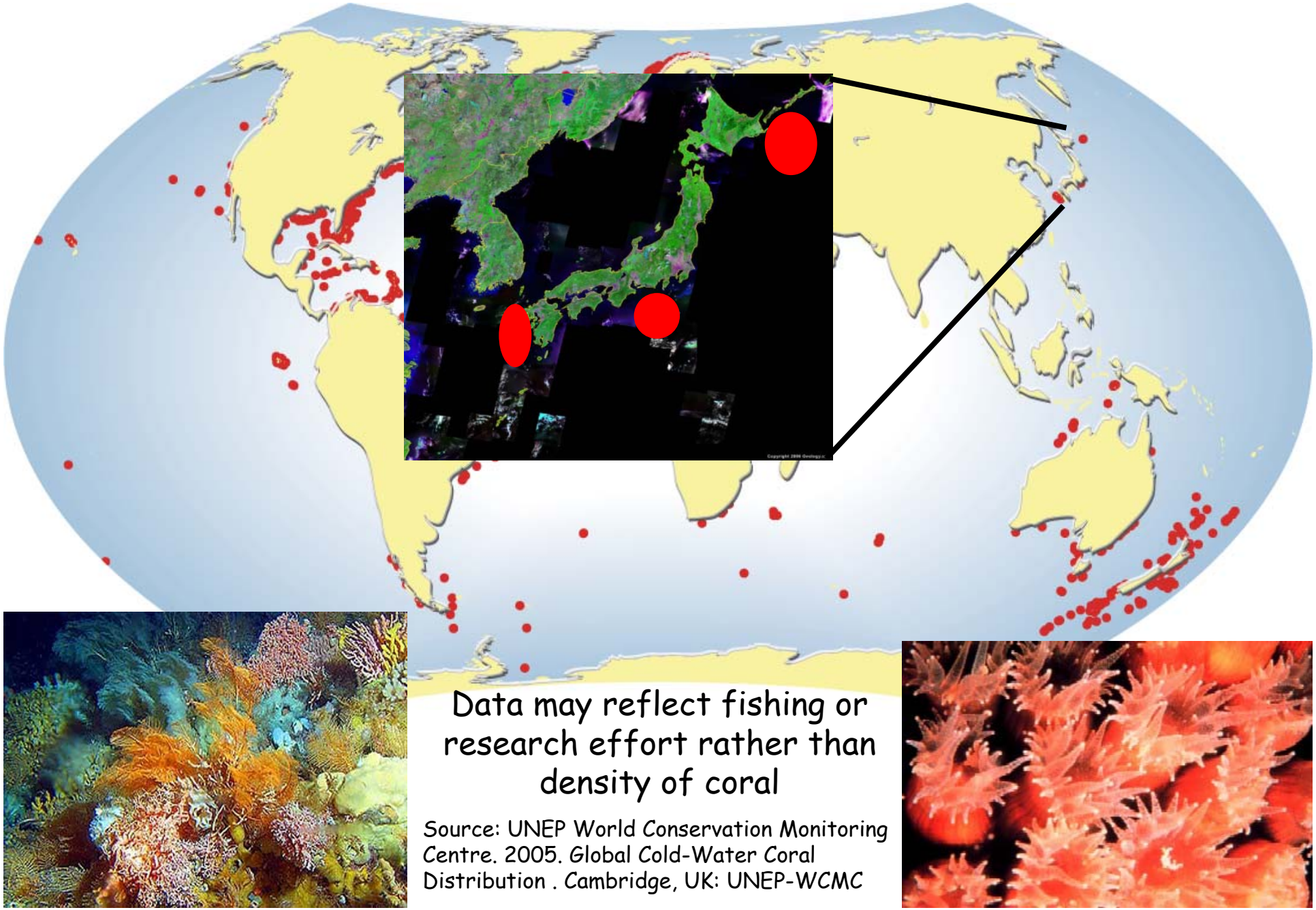
- 328 Porites（ハマサンゴ属）samples from 69 Sites along the Great Barrier Reef

-Threshold passed around 1990



De'ath, Lough and Fabricius Science, 2009

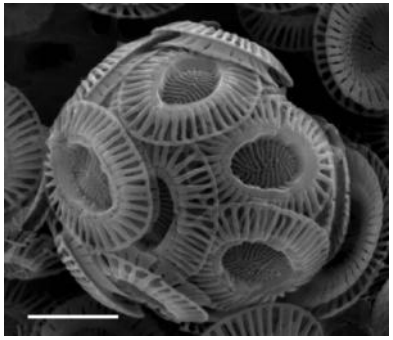
Known Locations of Deep-sea Corals



Data may reflect fishing or research effort rather than density of coral

Source: UNEP World Conservation Monitoring Centre. 2005. Global Cold-Water Coral Distribution . Cambridge, UK: UNEP-WCMC

Few planktonic calcifiers have been closely studied

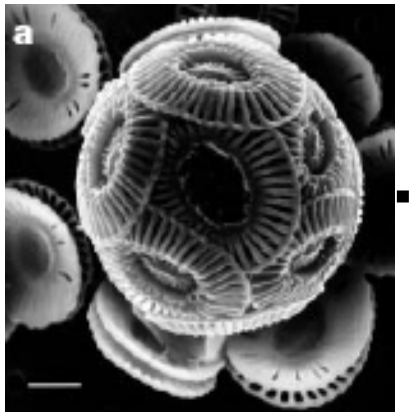


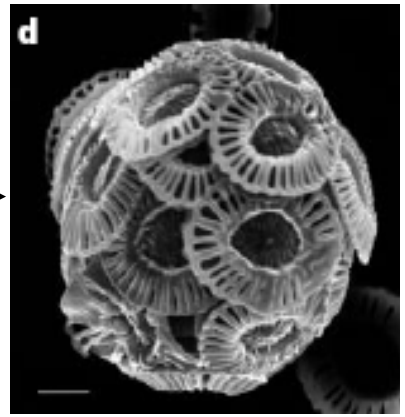
	# Extant species	Mineral form	Generation time
Coccolithophores (autotrophs) 円石藻:独立栄養生物	~ 200	calcite*	days
Foraminifera (heterotrophs) 有孔虫:従属栄養生物	~ 30	calcite	weeks
Pteropods (heterotrophs) 翼足類:従属栄養生物	~ 32	aragonite	months to year?

Coccolithophores（円石藻）

pCO_2 280-380 ppmv

pCO_2 780-850 ppmv

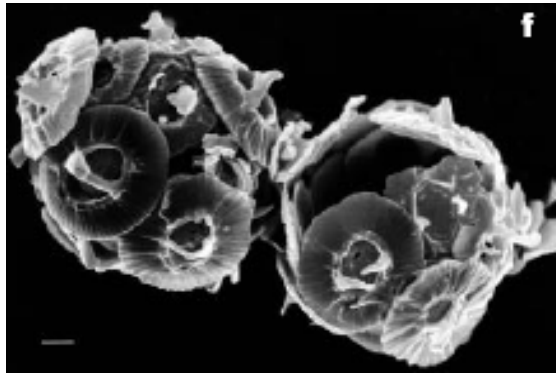




Calcification decreased

- 9 to 18%

Emiliania huxleyi



- 45%

Gephyrocapsa oceanica

Manipulation of CO_2 system by addition of HCl or NaOH

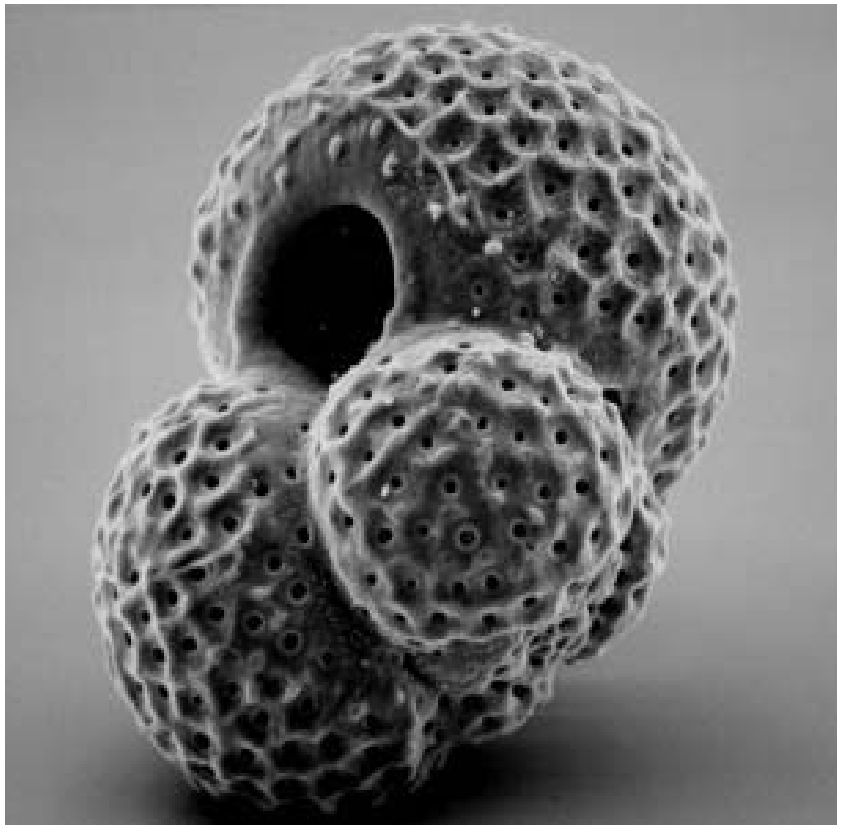
Riebesell et al.(2000); Zondervan et al.(2001)

Foraminifera（有孔虫）

(single-celled protists)（単細胞の原生動物）

Orbulina universa

Globigerinoides sacculifer



- at pCO_2 = 560 ppm, calcification declined by 4 to 8%
- at pCO_2 = 780 ppm, calcification declined by 6 to 14%

Bijma et al. (2002)

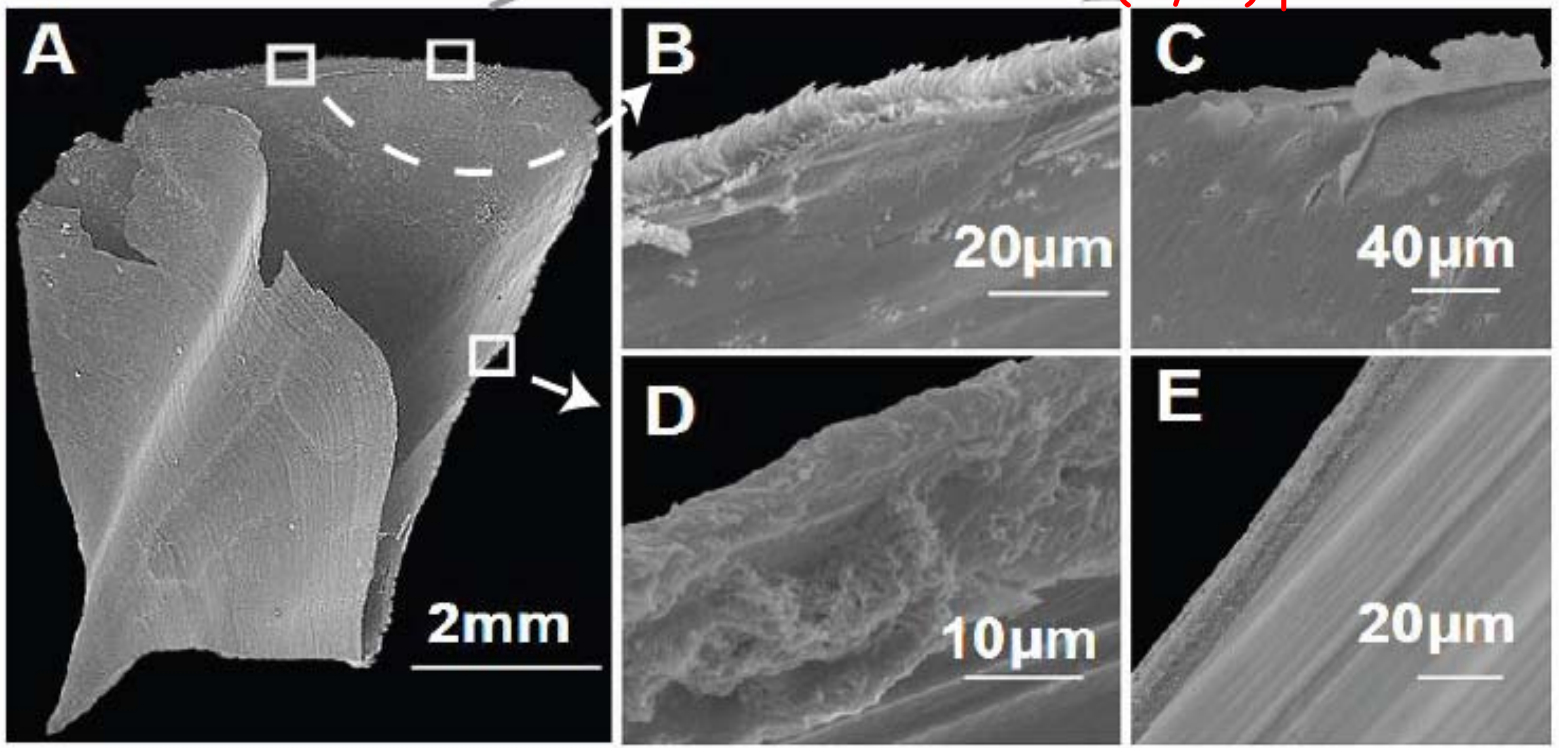
Shelled Pteropods（翼足類）
(planktonic snails)（浮遊性の貝類）

Respiratory CO_2 forced Ω_{arag} <1
Shells of live animals start to dissolve within 48 hours

Whole shell:
Clio pyramidata

Arag. rods exposed

Prismatic layer
(1 μm) peels back

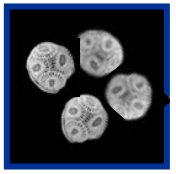


Aperture (~7 μm):
advanced dissolution

Normal shell: no
dissolution

Orr et al. (2005)

Potential Effects on Open Ocean Food Webs



Coccolithophores

ARCOD@ims.uaf.edu

Copepods

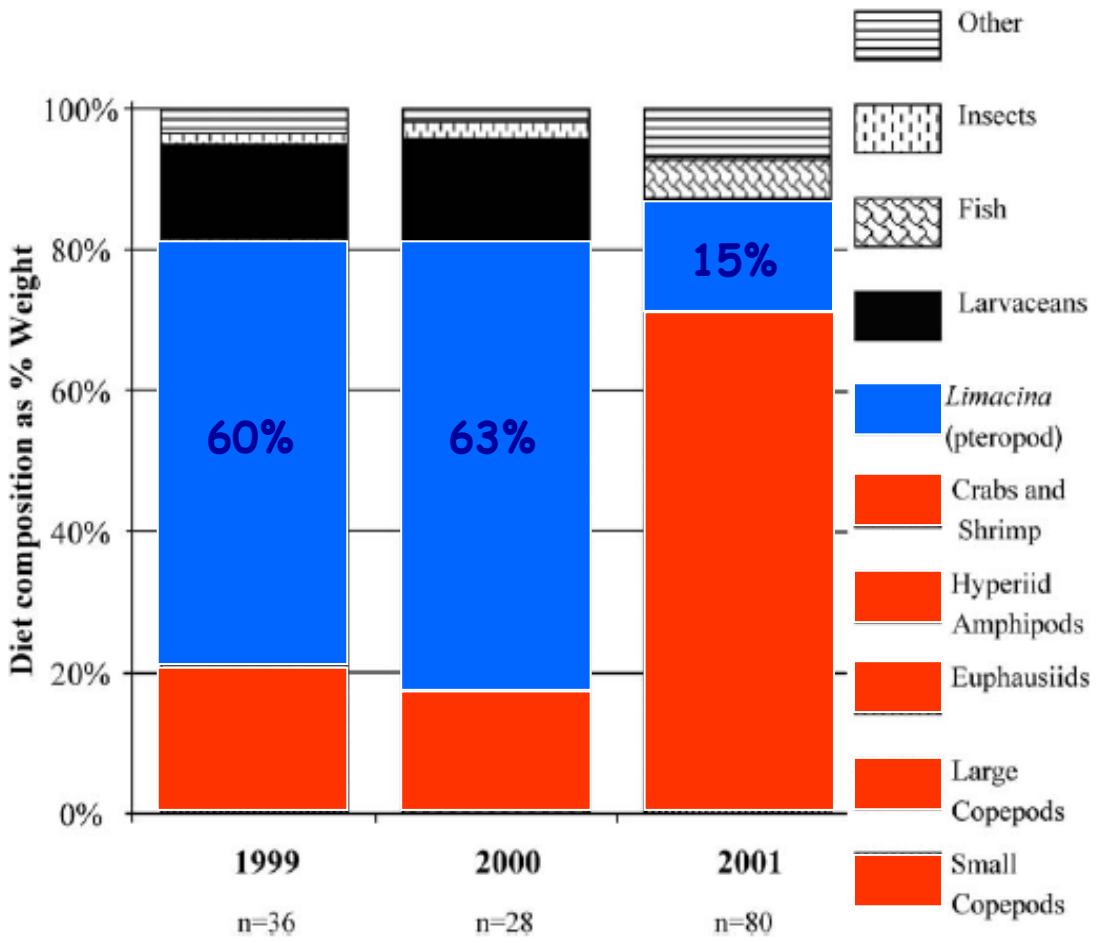
Vicki Fabry

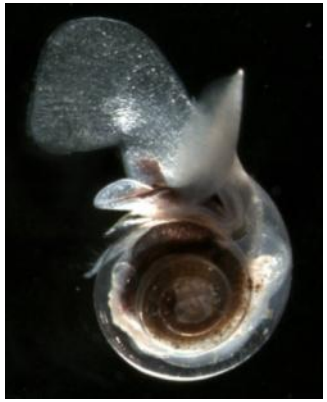
Pteropods

Barrie Kovish

Pacific Salmon

Food Web Impacts: Diet of Juvenile Pink Salmon

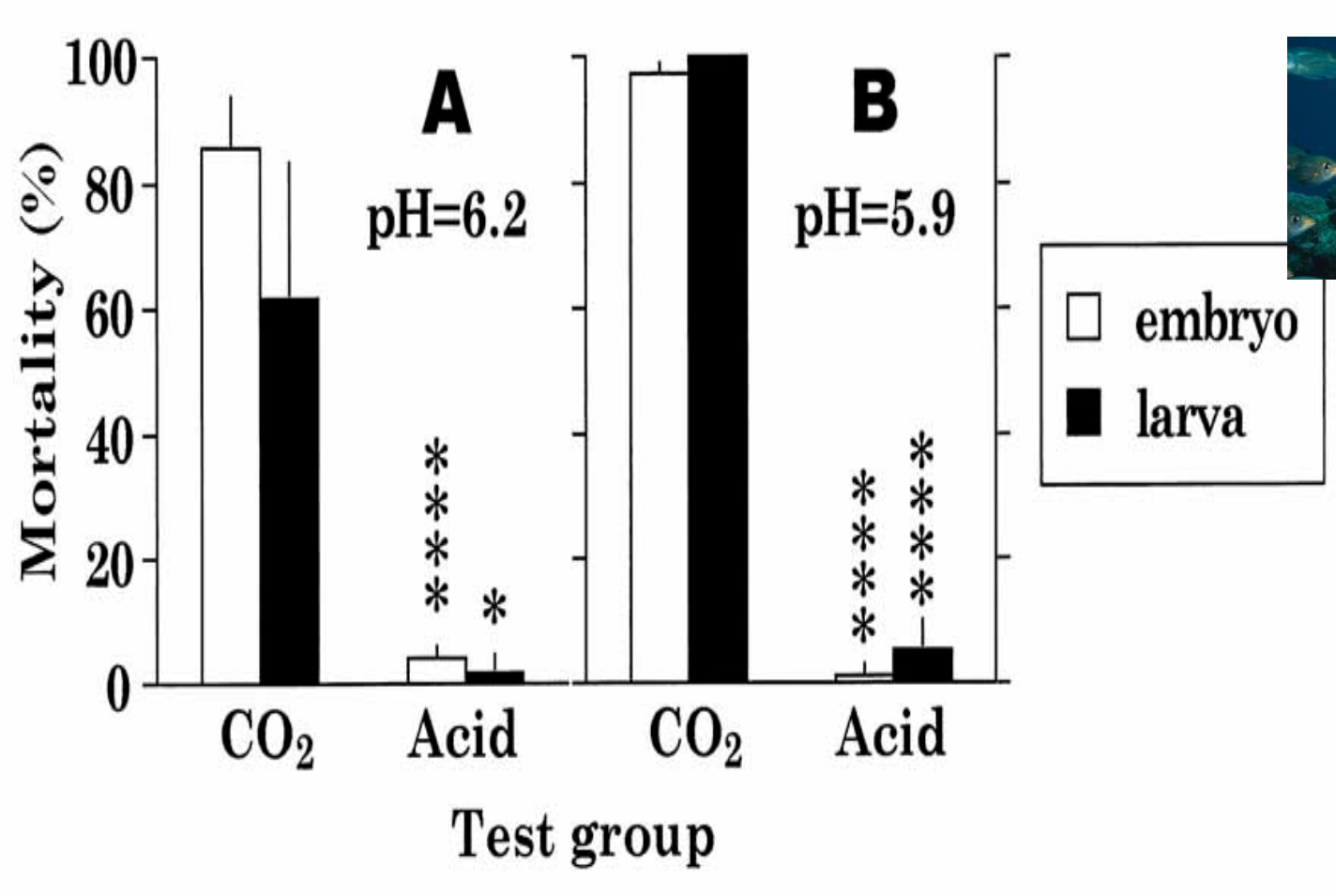




Impacts of increasing pCO_2 on nearly 100% of prey types are unknown

Armstrong et al., 2005

Increased fish larvae mortality



Ishimatsu et al. (2004)

Potential Ocean Acidification Impacts on Crustaceans, Cephalopods and Bivalves

Alaskan King Crab

~15% reduction in growth and
~67% reduction in survival when pH was reduced 0.5 units

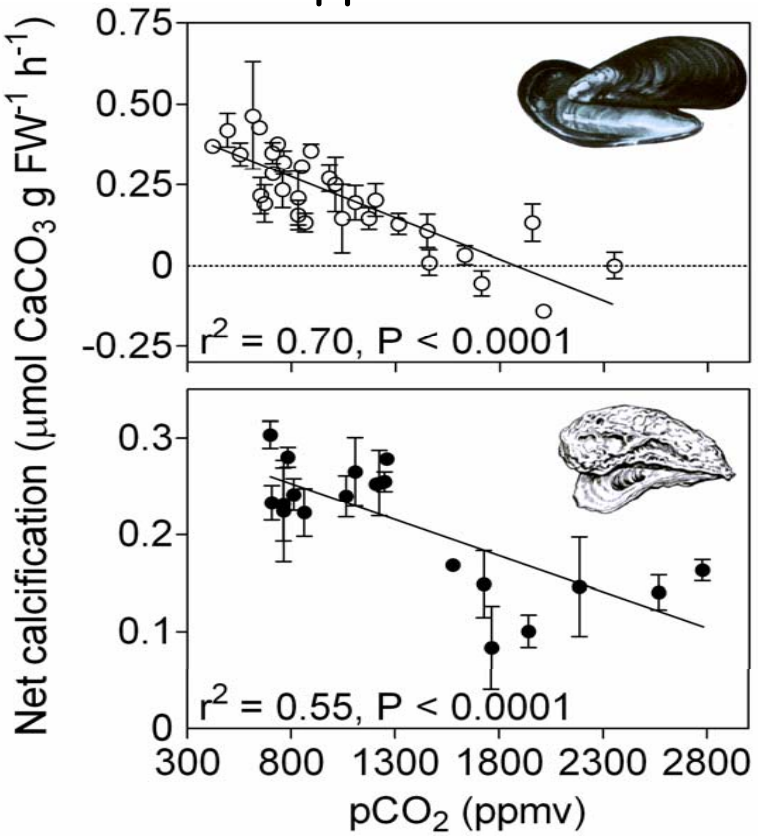
Squid

Impaired oxygen transport
Reduced metabolism/scope for activity

Mussels and Oysters

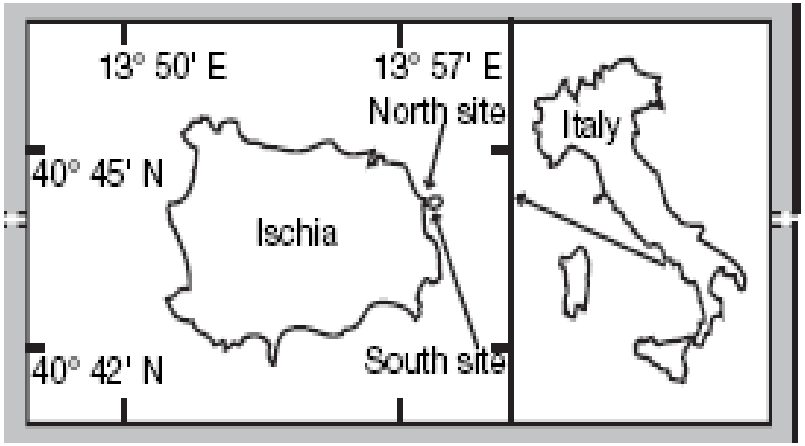
25% decrease in calcification for mussels at 740 ppm

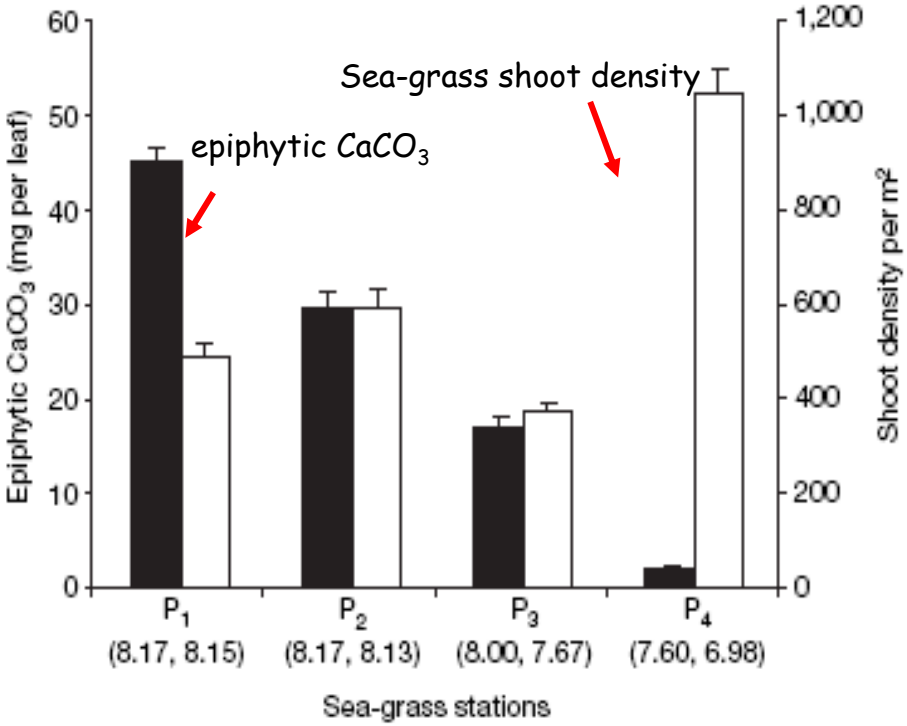
10% decrease in calcification for oysters at 740 ppm



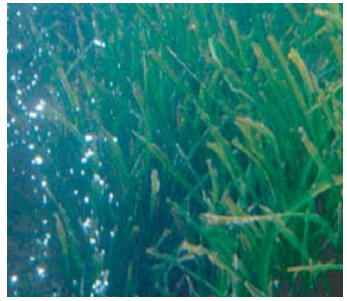
Winners and Losers

pH levels vary in Mediterranean CO_2 vents off Ischia Island (pH 8.17 to 6.57)





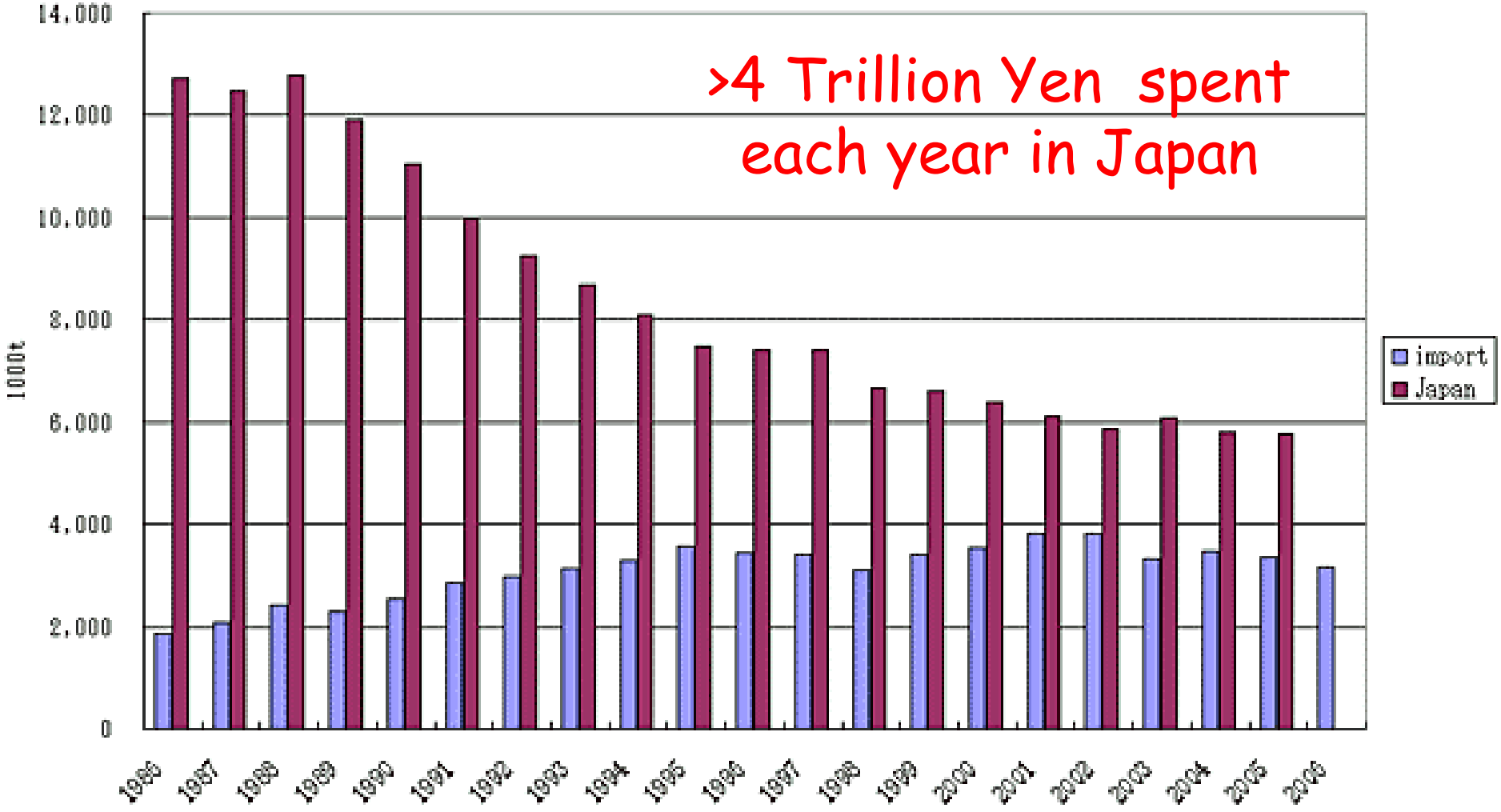
Live *Patella caerulea* and *Hexaplex trunculus* (gastropods) showing severely eroded, pitted shells in areas of minimum pH7.4



Hall-Spencer et al. Nature (2008)

Ecologically and economically important organisms likely to be impacted by ocean acidification

Domestic production of seawater fishery and culture in Japan has been decreasing every year and it was 5.6 million metric tons in 2006, down 1.5% or 83 mmt from the previous year. **Japan Fishery Products Annual Report 2007**



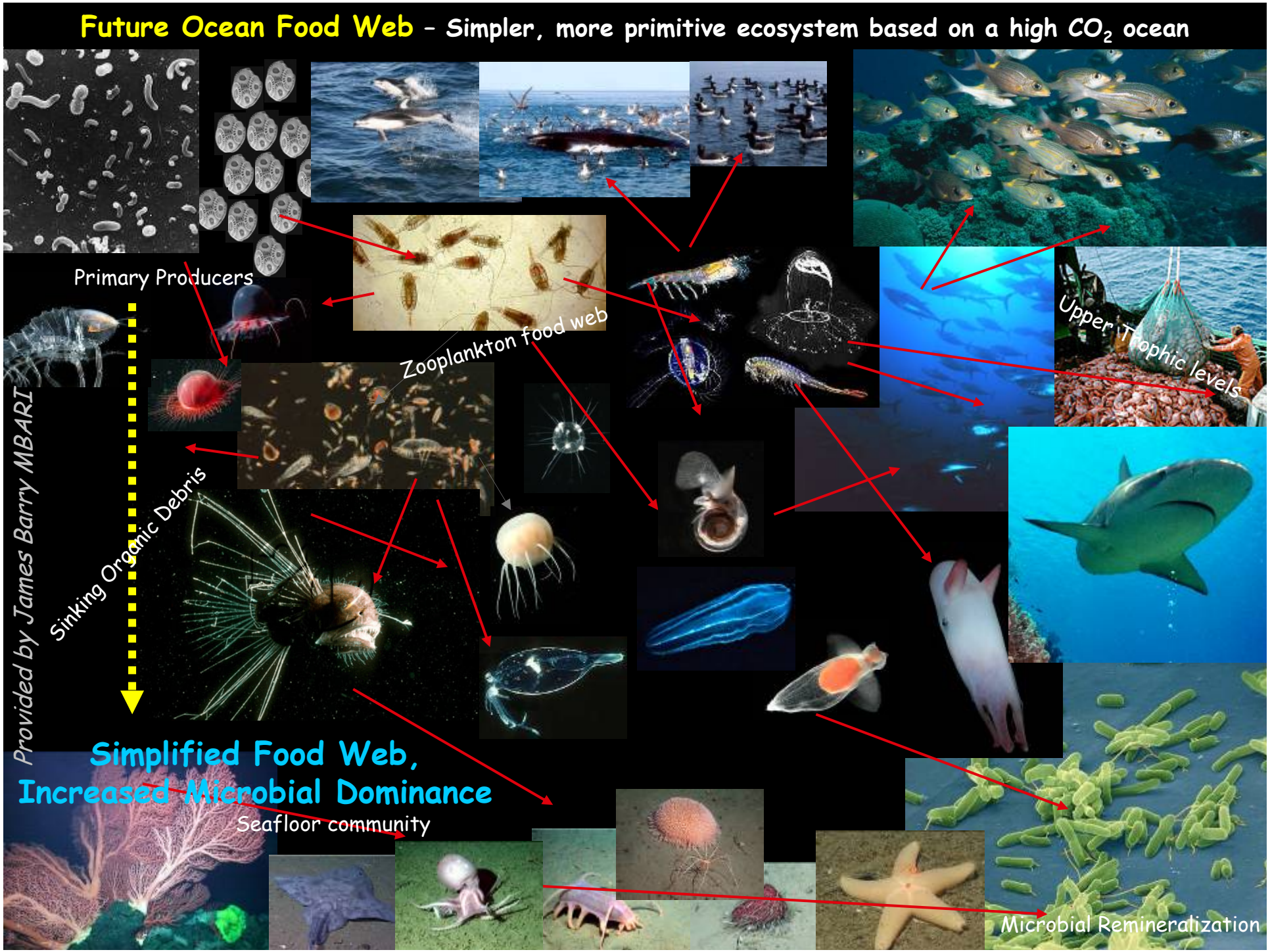
What we know…

Much of our present knowledge stems from

- abrupt CO_2/pH perturbation experiments
- with single species/strains
- under short-term incubations
- with often extreme pH changes

Hence, we know little about

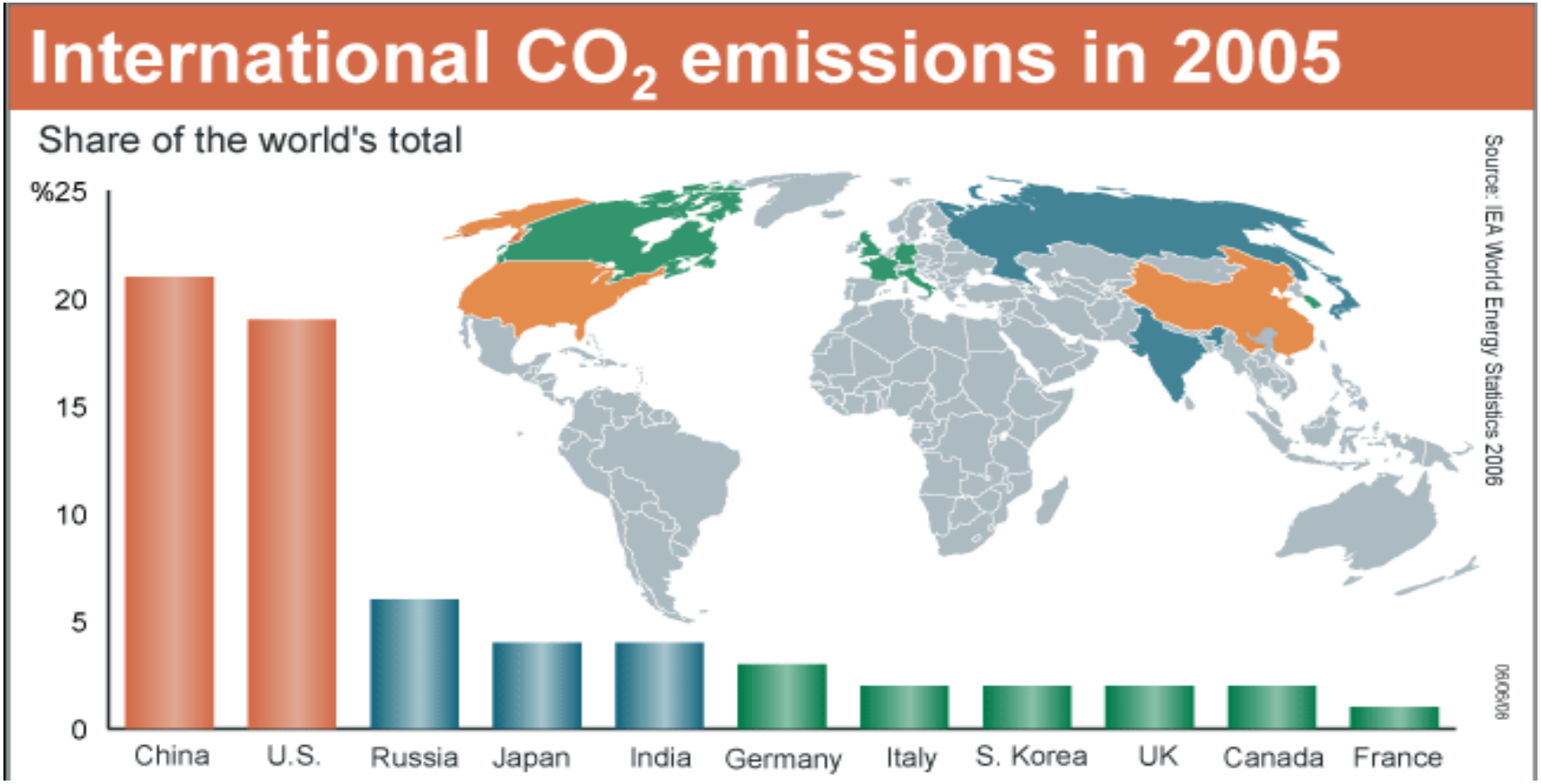
- responses of genetically diverse populations
- synergistic effects with other stress factors
- physiological and micro-evolutionary adaptations
- species replacements
- community to ecosystem responses
- impacts on global climate change


Future Ocean Food Web – Simpler, more primitive ecosystem based on a high CO_2 ocean
Primary Producers
Zooplankton food web
Upper Trophic levels
Sinking Organic Debris
Provided by James Barry MBARI
Simplified Food Web,
Increased Microbial Dominance
Seafloor community
Microbial Remineralization

Where do we go from here?

Initial research suggests that impacts are based not only on the ultimate amount of CO_2 released but also on the rate that we release it.

We must promote international agreements to substantially reduce or eliminate CO_2 emissions!



Conclusions

1. Atmospheric CO_2 is growing at an exponential rate
2. The ocean has provided a great service to society by helping to slow the rate of atmospheric increase.
3. The addition of ~150 billion metric tonnes of carbon to the ocean over the last 200 years has lowered ocean pH by 0.1 unit (30% increase in acidity).
4. By the end of this century pH may drop by another 0.3 units and will likely have dramatic consequences on the ocean ecosystems.
5. The rate of CO_2 growth may impact the ability of the ocean to adapt to climate change…slowing the rate of growth could determine the structure of the future oceans.

結　　論

1．大気の二酸化炭素濃度は、指数関数的に増加している

2．海洋は、大気の二酸化炭素濃度の上昇を抑えることにより社会に大きく貢献している。

3．過去200年で、海洋に炭素量にして1500億トンぶんの二酸化炭素が吸収され、海洋のpHが約0.1低くなった(30％酸性化した)

4．今世紀末までに、pHはさらに0.3低くなり、海洋生態系に多大な影響を与える可能性がある。

5．二酸化炭素の増加率が、海洋の気候変化に対する適応能力に影響を与えるかもしれない・・・
　つまり二酸化炭素の増加率を抑えることで、将来の海洋構造を決めることが出来るかもしれない。