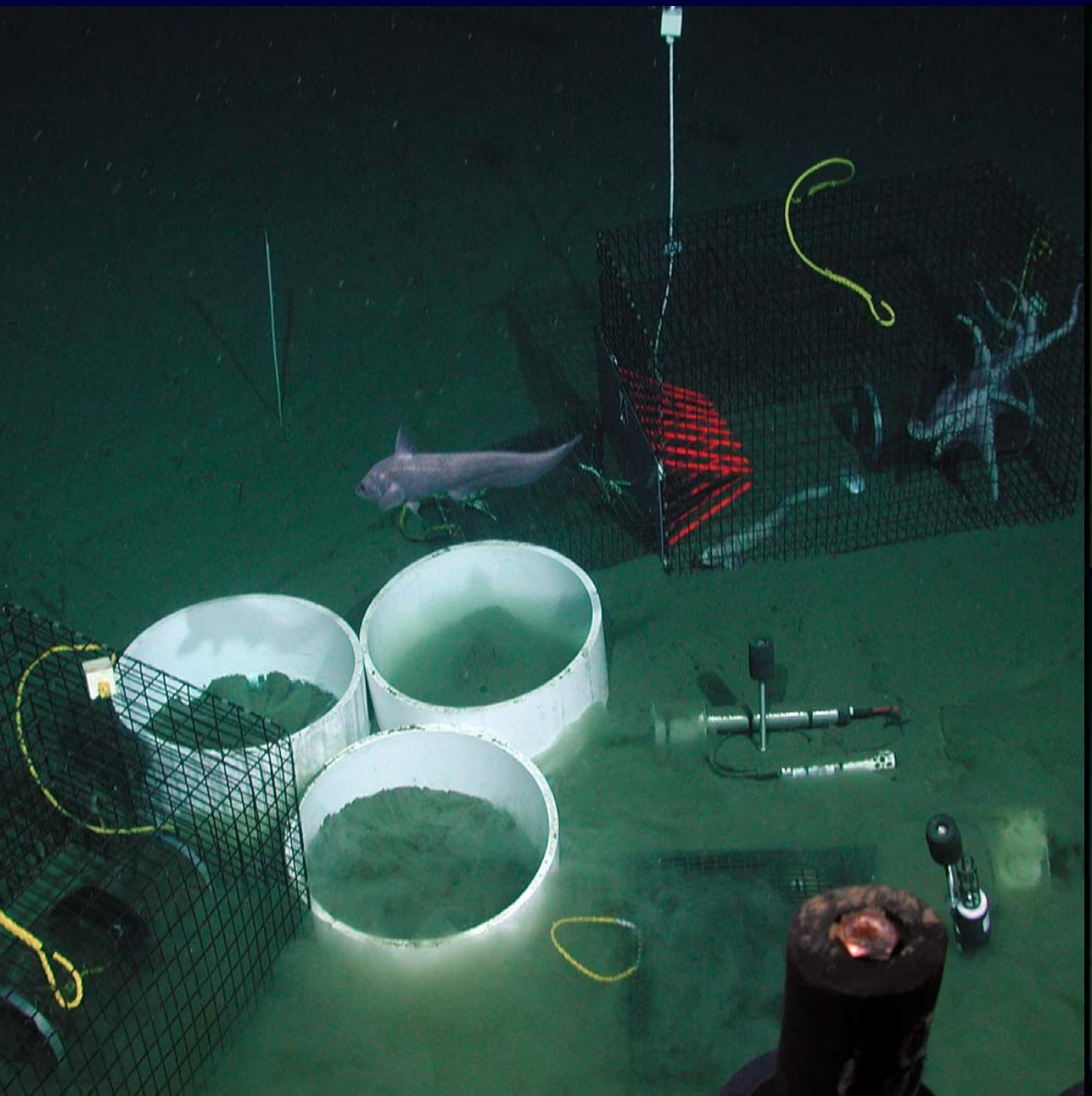
Global Climate Change and the Ocean

James Barry - *Monterey Bay Aquarium Research Institute*



Global Climate Change and the Ocean

Road Map for Talk

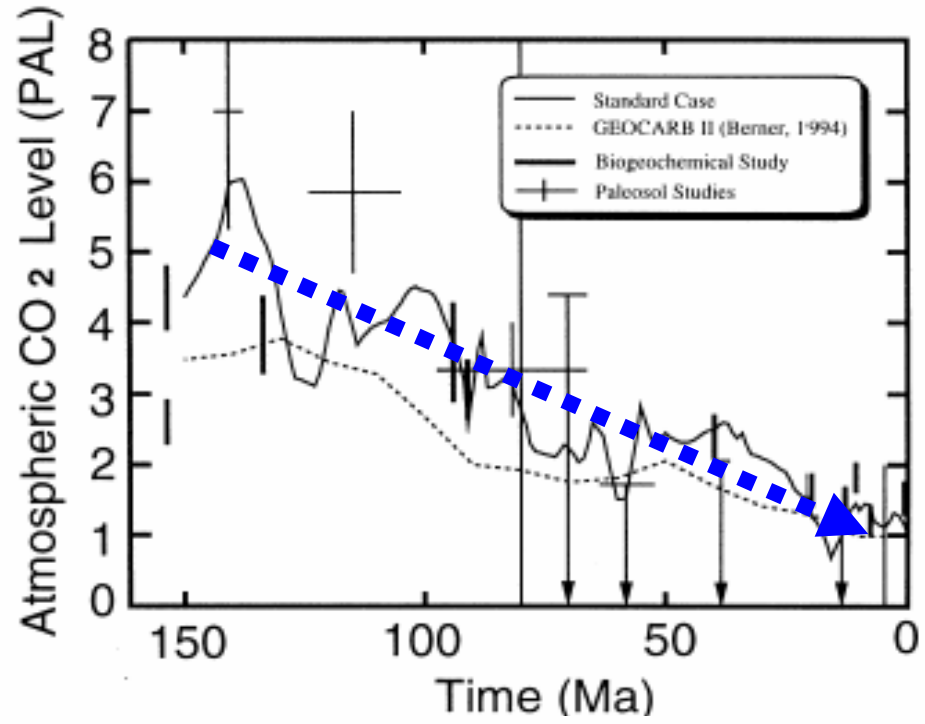
- **A short climate change introduction**
  - Carbon dioxide on Earth – the long and short of it
- **Global warming and the oceans**
  - Sea level rise
  - Effects of climate warming on ocean ecosystems
- **The high-CO2 ocean and ocean acidification**
  - How does increased ocean carbon affect ocean ecosystems?
  - A glimpse of our research at MBARI on ocean acidification
- **Summary**

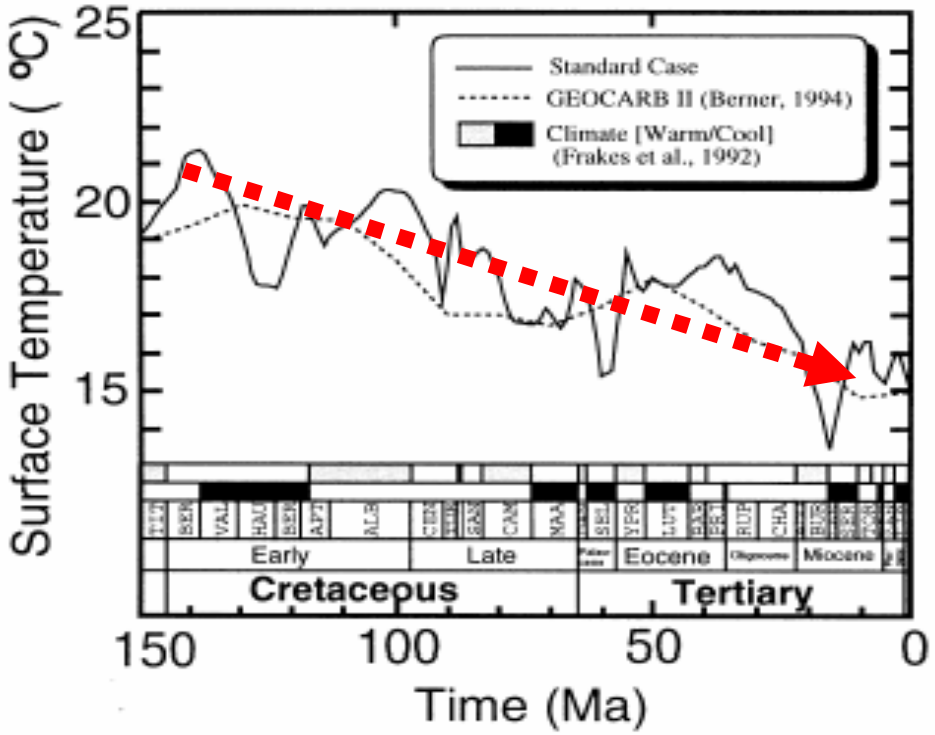
Climate Change during the last 150 million years

(Reconstruction from a carbon cycle model)

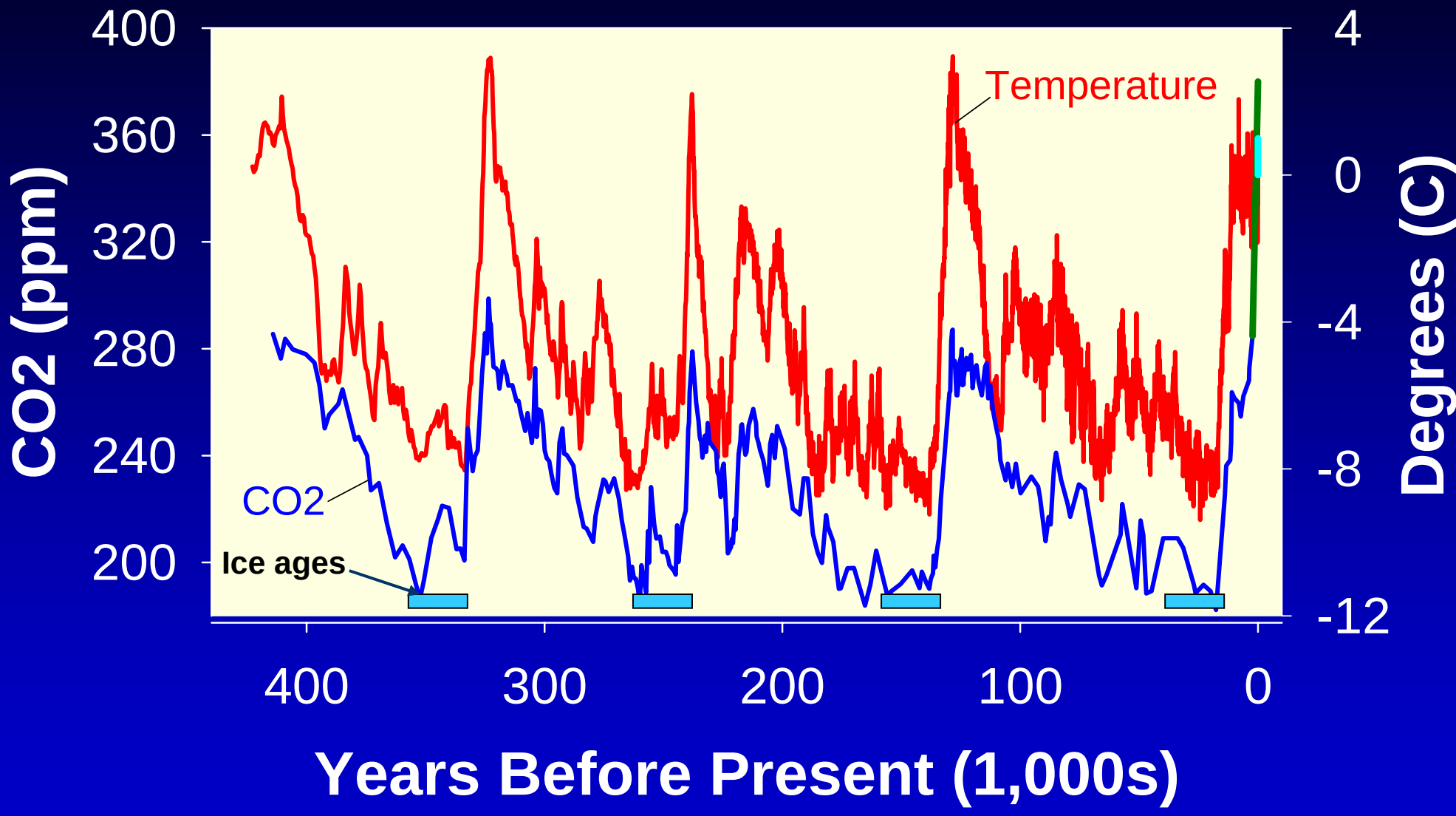
Tajika, E. (1998) Earth & Planet. Sci. Lett. 160

- CO2 has declined over the past 150 million years
- Up to ~6 x present atmospheric level (PAL) in the past
- ~1 C change in surface T per PAL

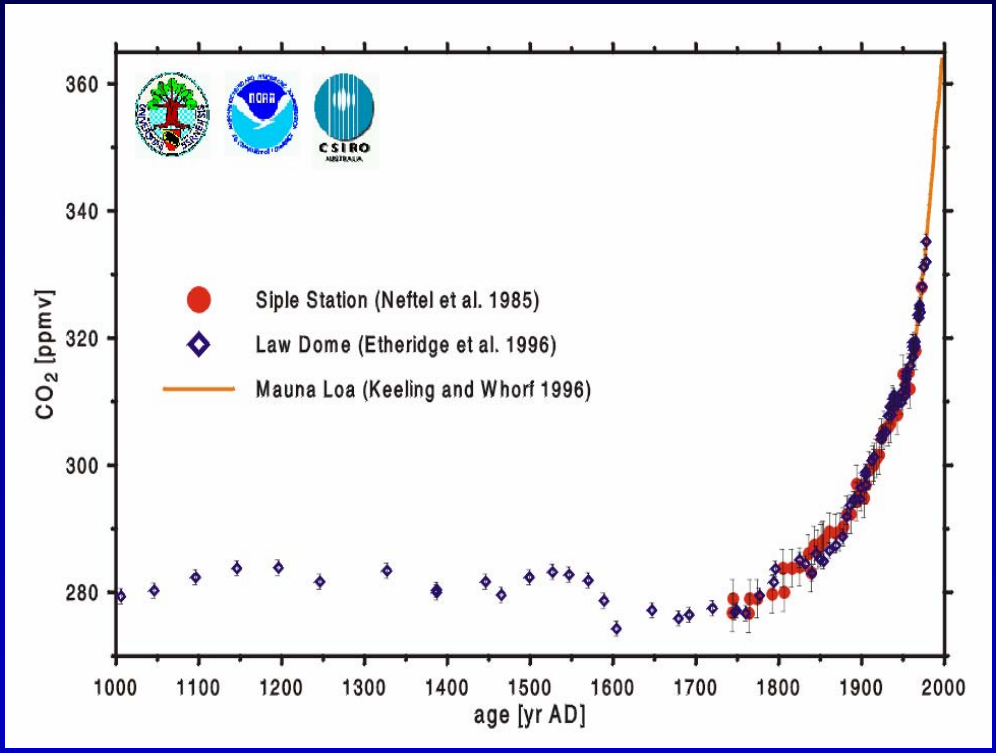


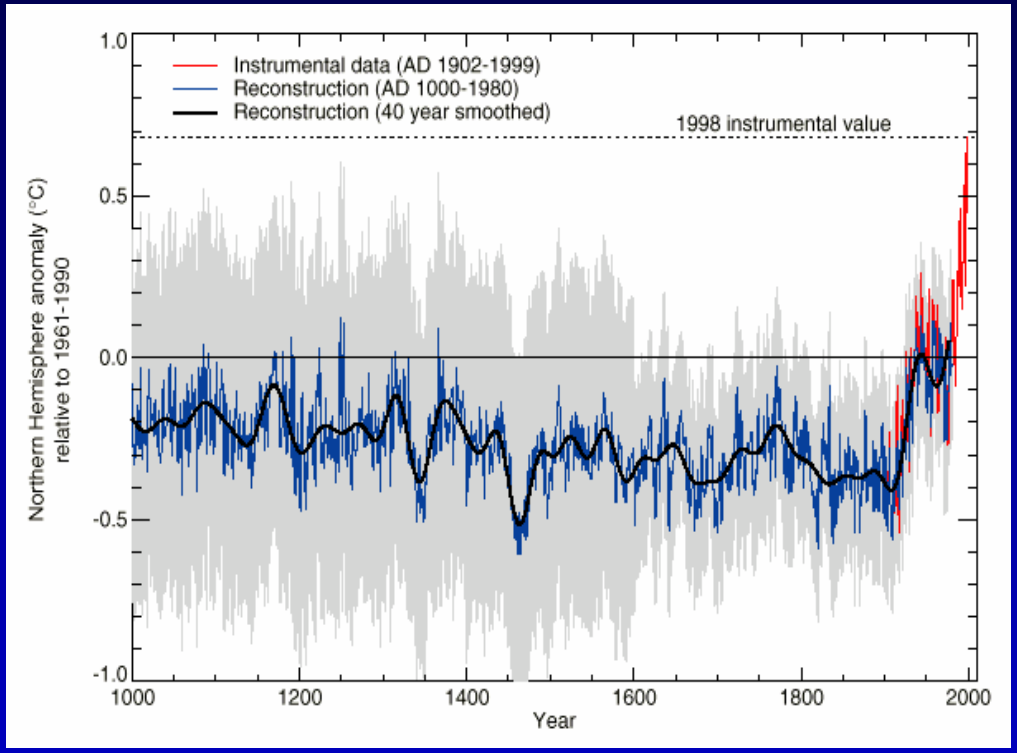


What is the link between CO2 and Climate?



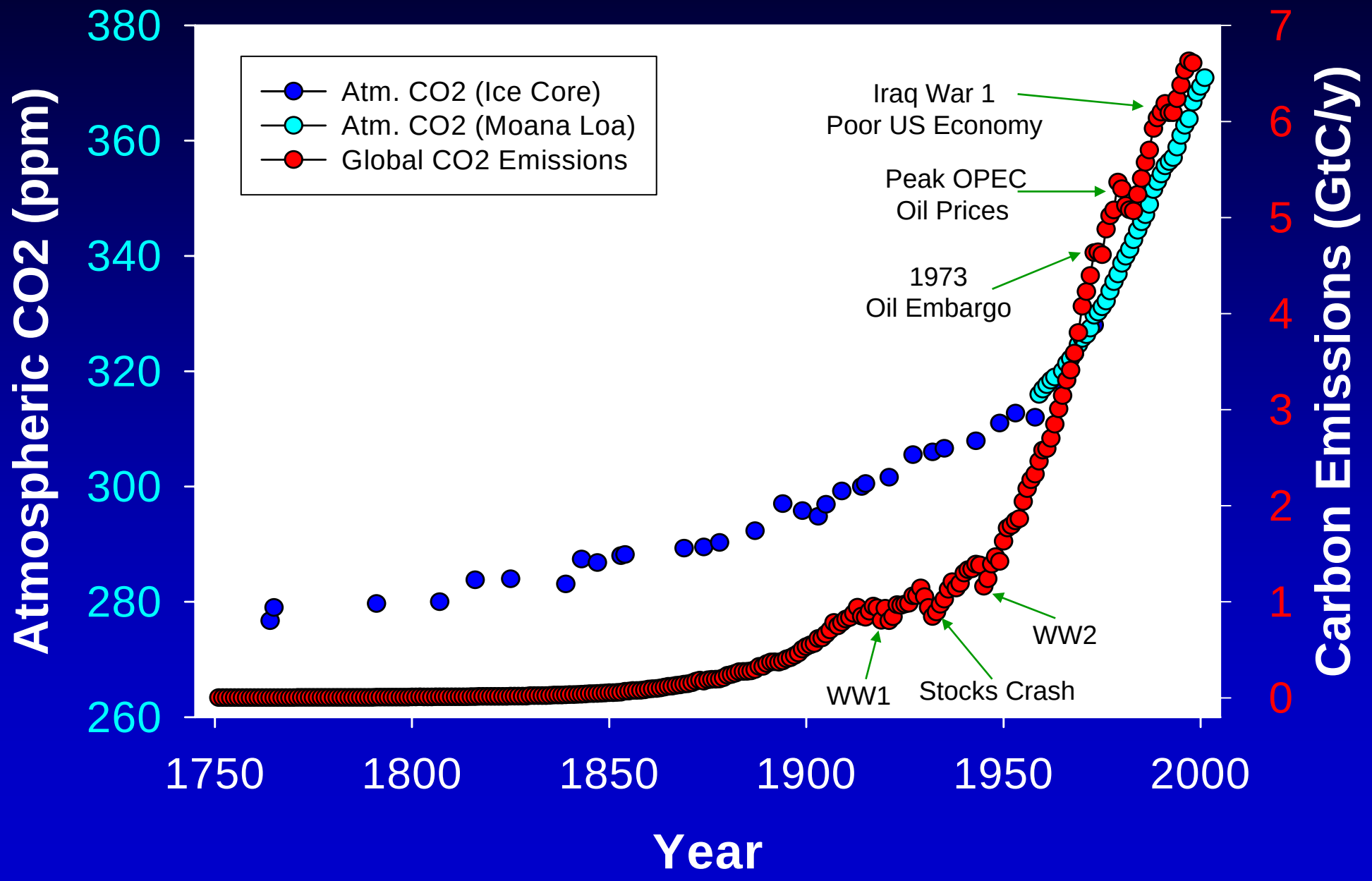
Millennial Northern Hemisphere CO_2 & Temperature

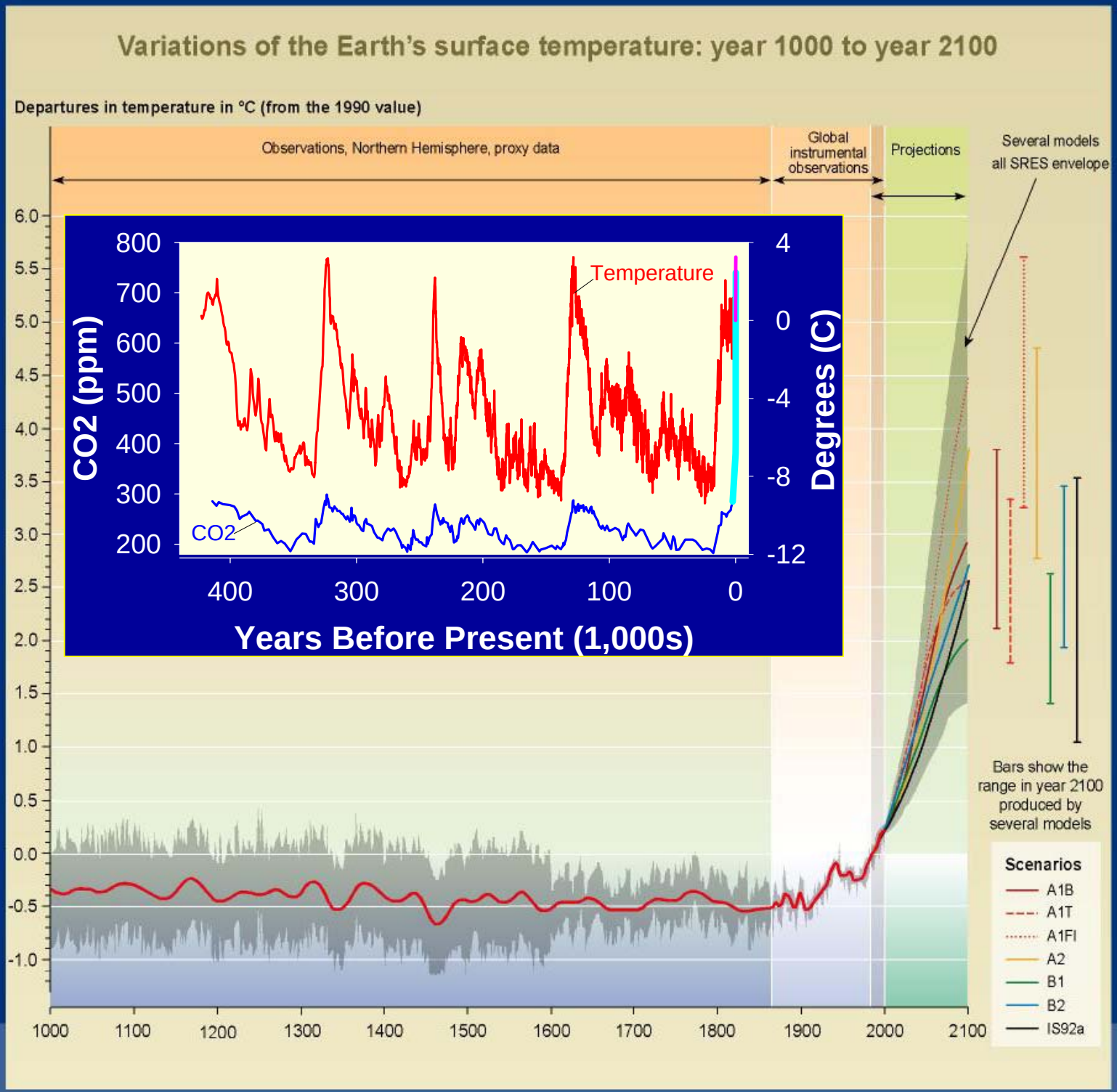




Source: Mann et al. 1999.

History of CO_2 Emissions & Atmospheric CO_2 Levels



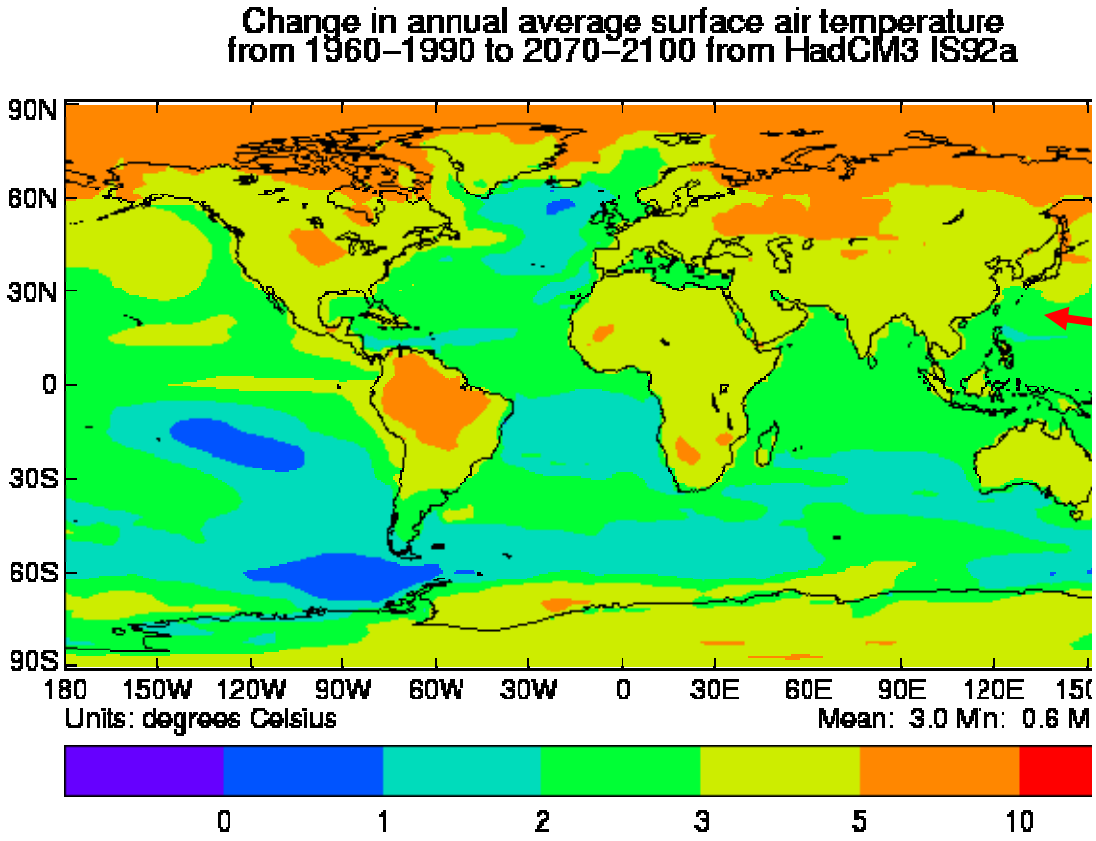


Climate Response = 1.0 - 4.5 °C per PAL CO_2

PAL = Present Atmospheric Level

SYR - FIGURE 9-1b

Warming by ~2090



Hadley Centre for Climate Prediction and Research, The Met. Office

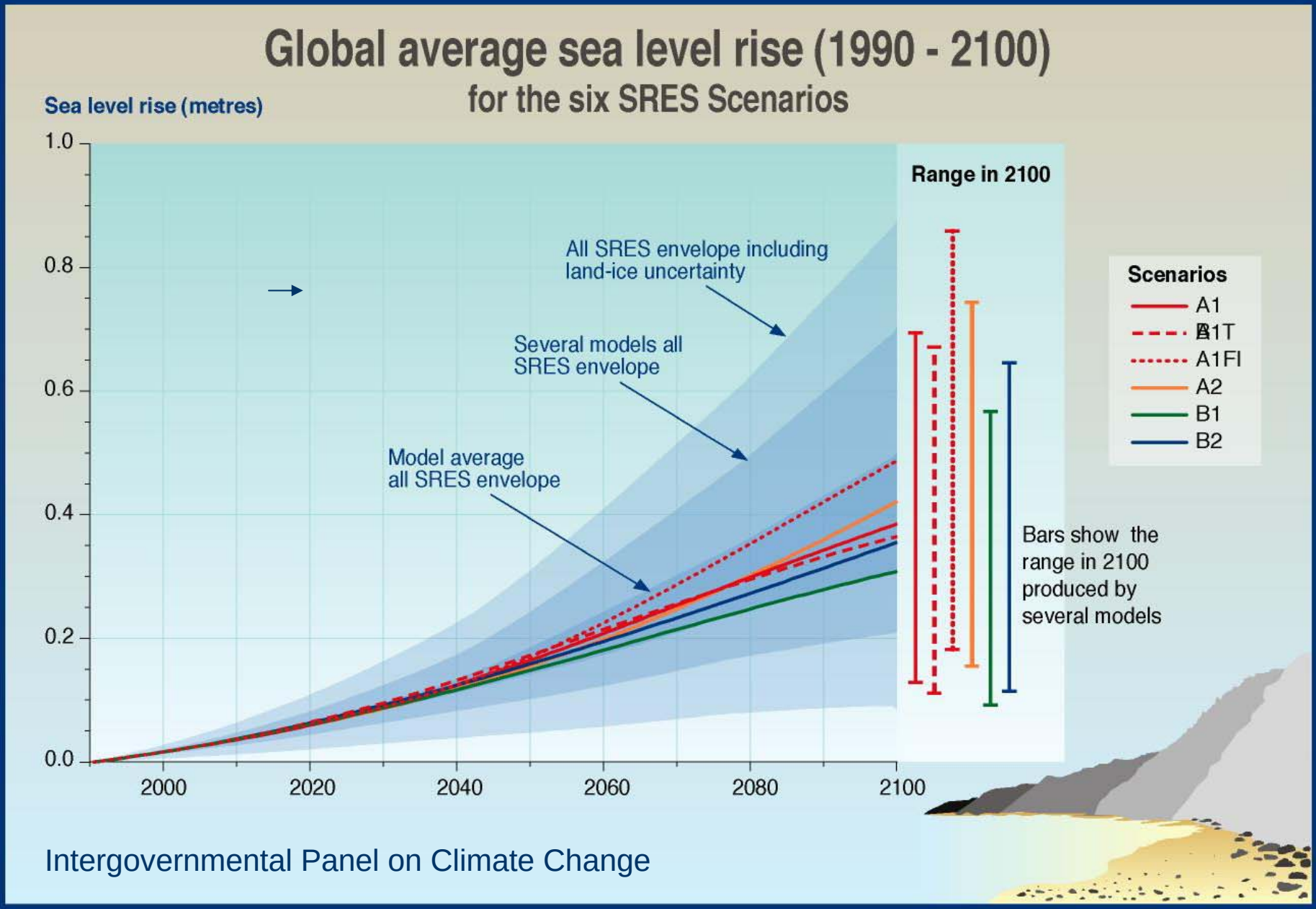
Precipitation

Arctic Ice Cover Sept. 1979

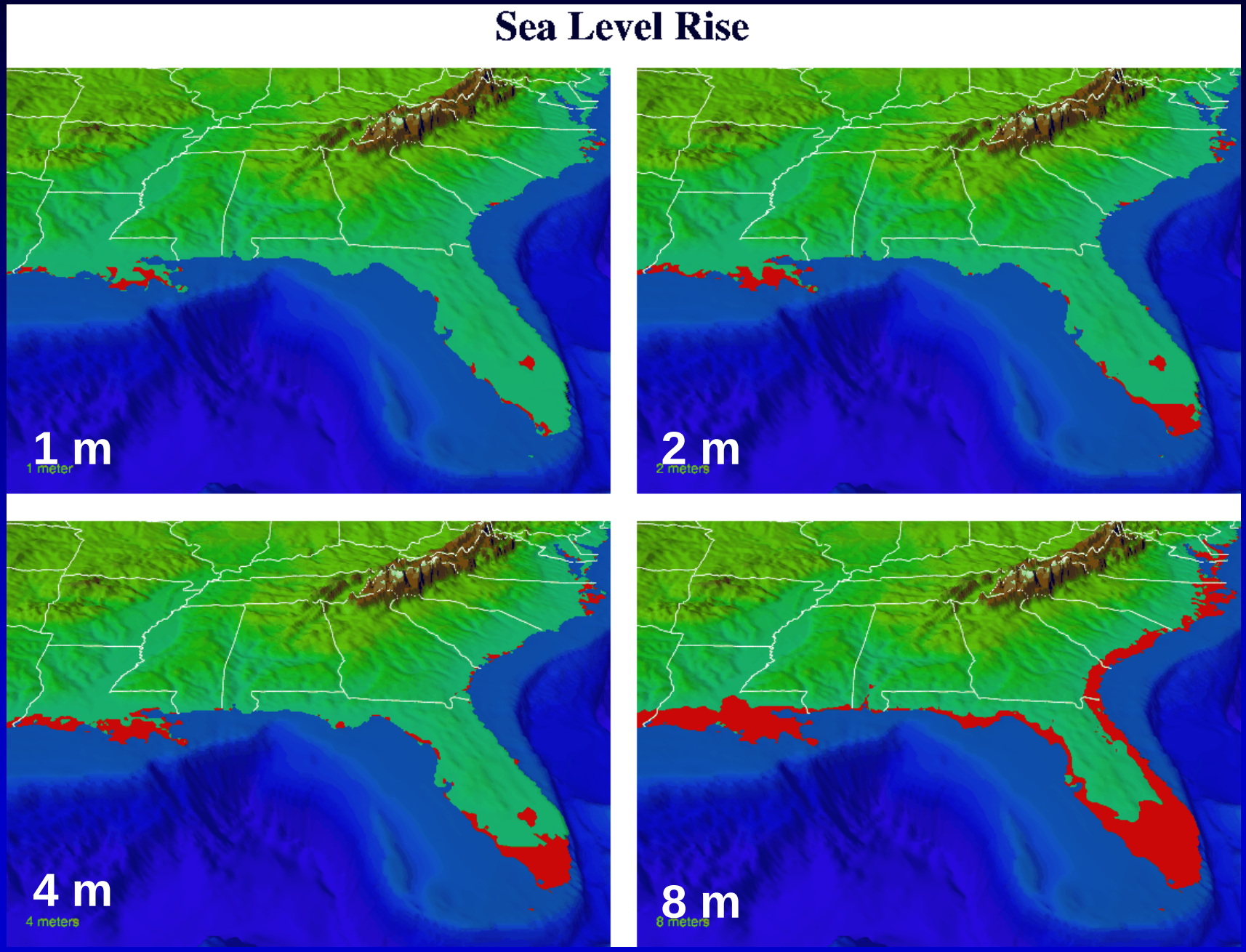
Arctic Ice Cover Sept. 2003

Source:
Arctic Climate Impact Assessment (ACIA), 2004.
Impacts of a Warming Arctic

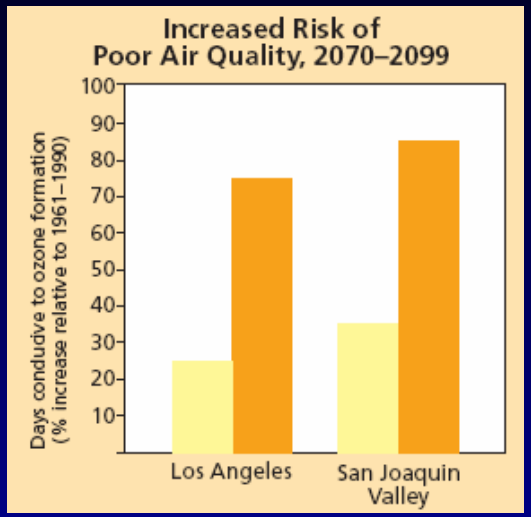
Sea Level Rise and Coastal Flooding

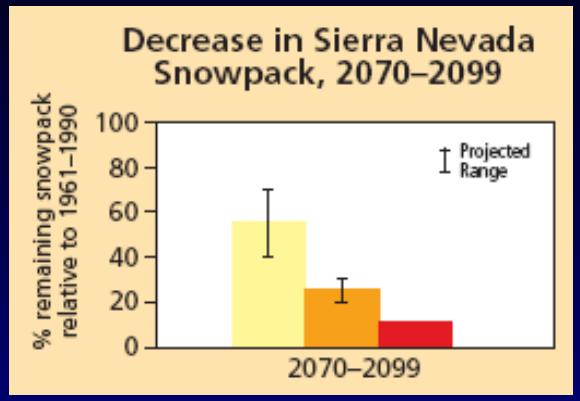


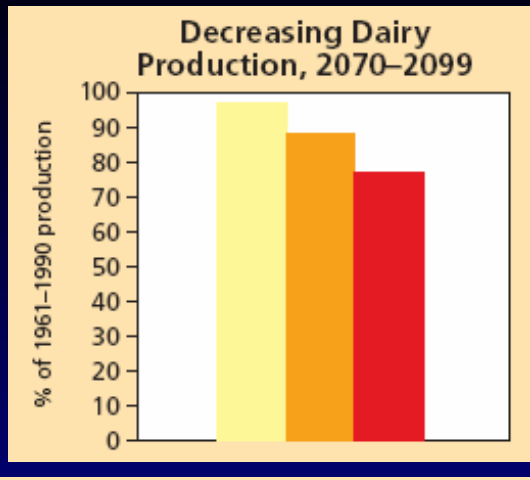
Sea Level Rise and Coastal Flooding

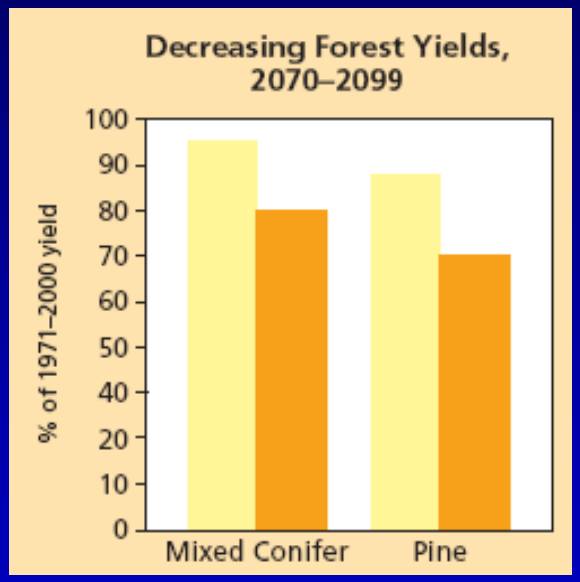


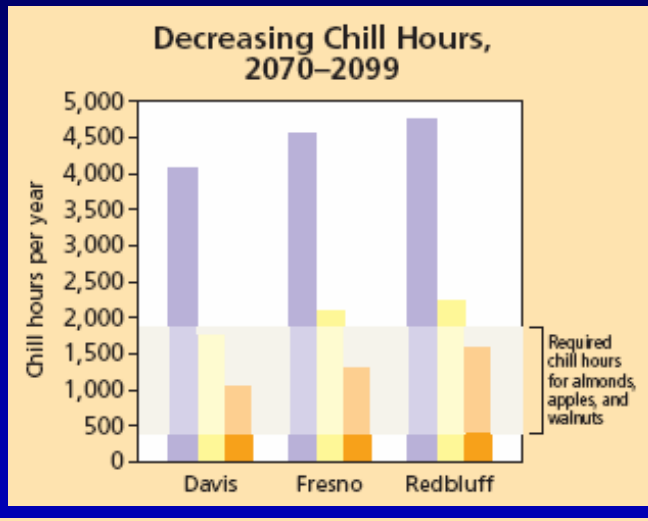
Societal Impacts: Effects on California

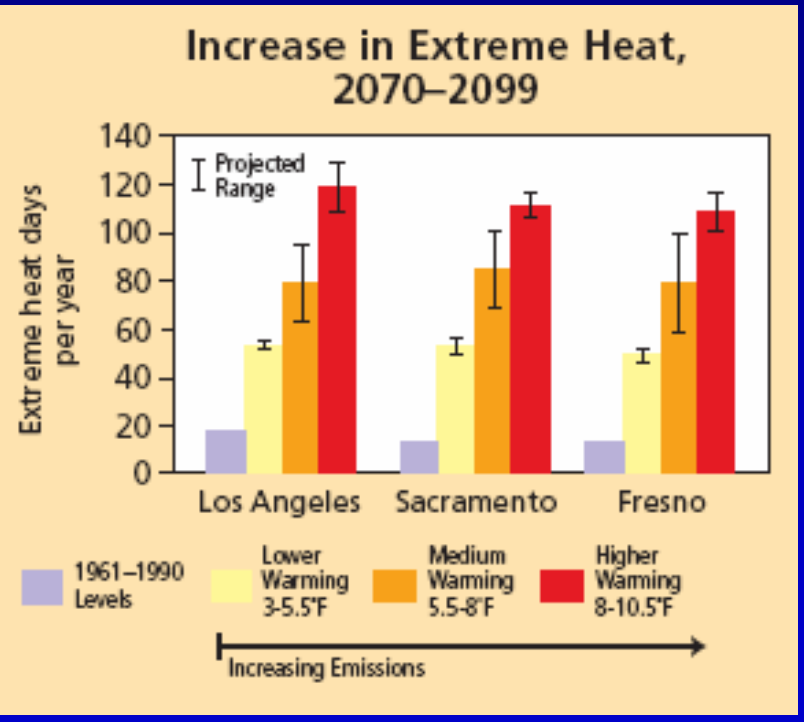


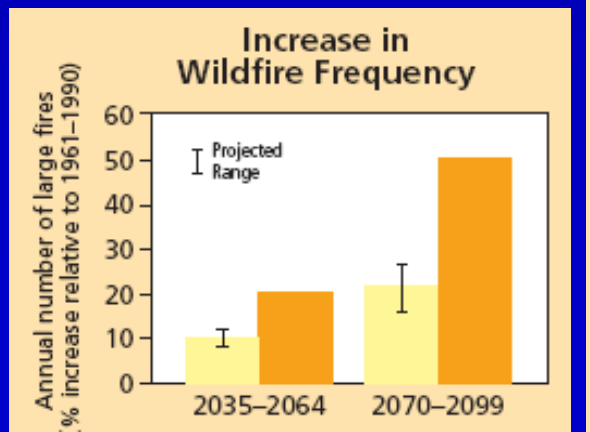


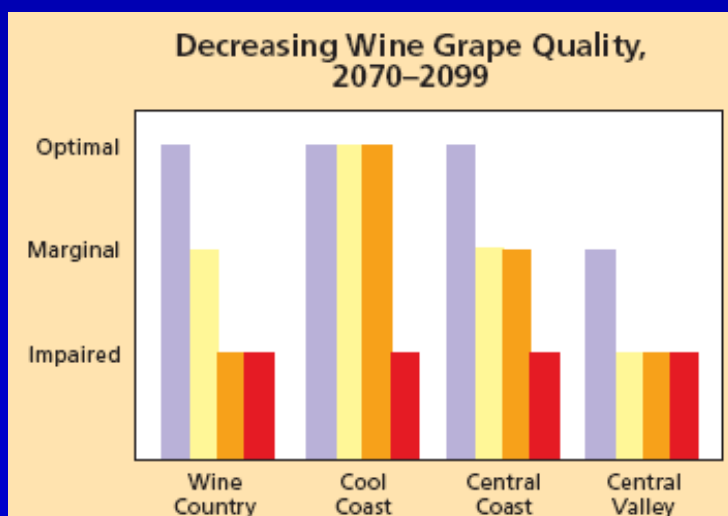










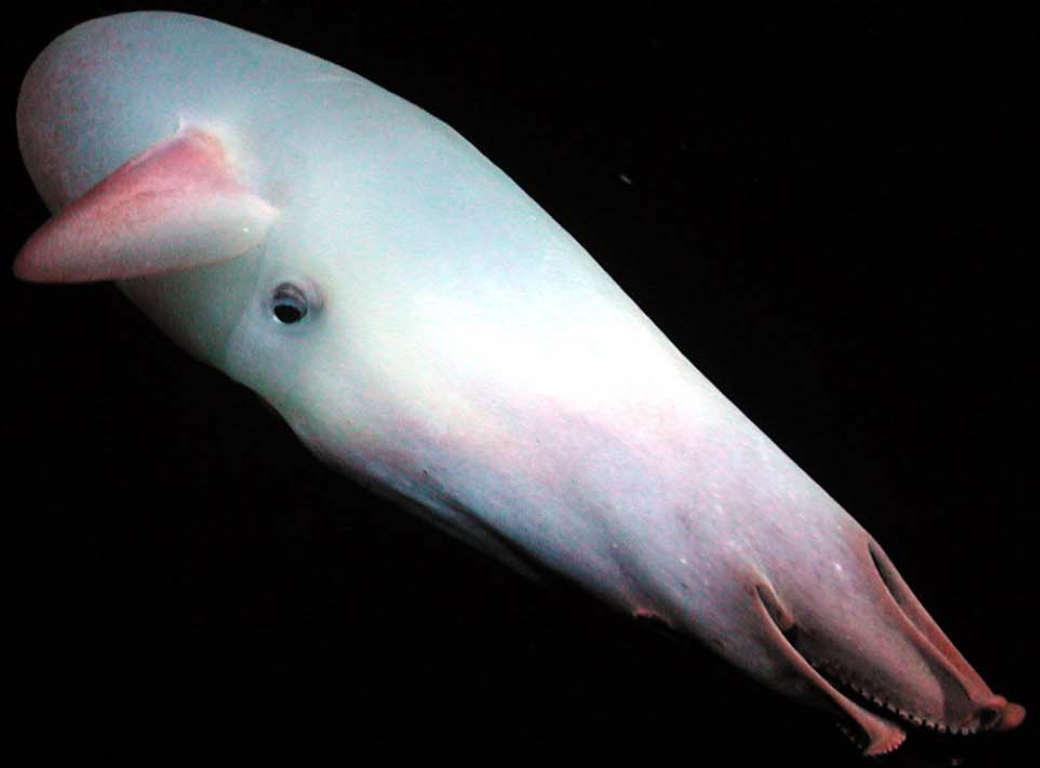


Source: Union of Concerned Scientists - uscusa.org

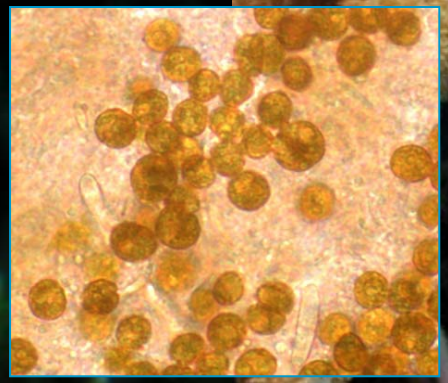
Global Warming & Ocean Ecosystems

Warming
1900 to 2075

HADLEY CENTRE
FOR CLIMATE PREDICTION+RESEARCH

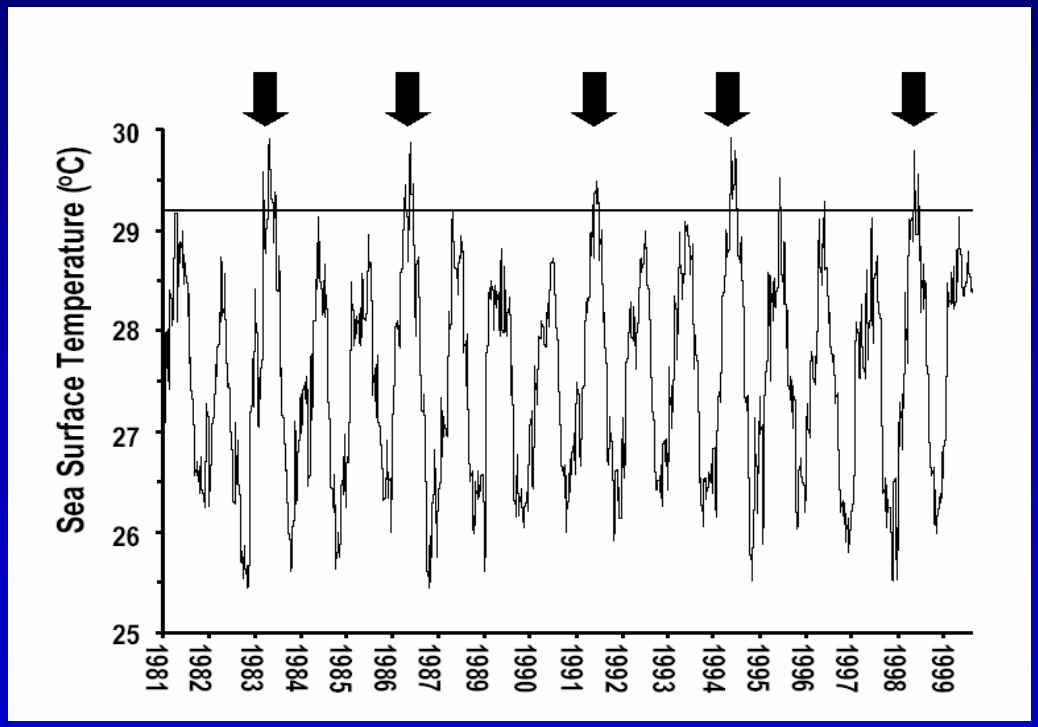


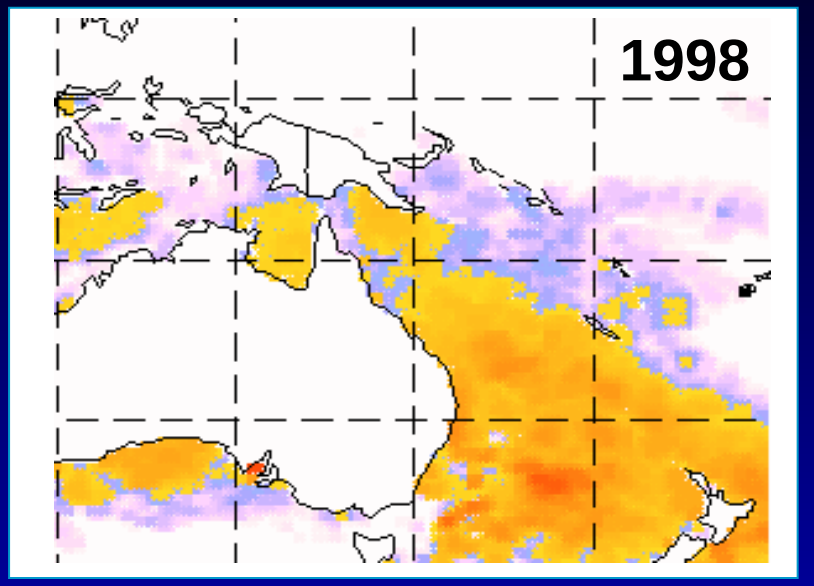
Ecosystem Impacts:
Coral Reefs

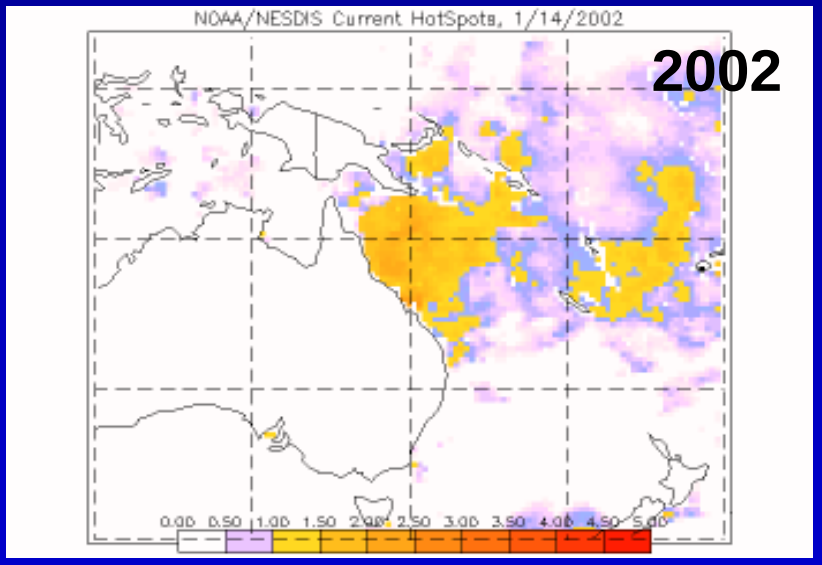


Mass coral bleaching caused by thermal stress

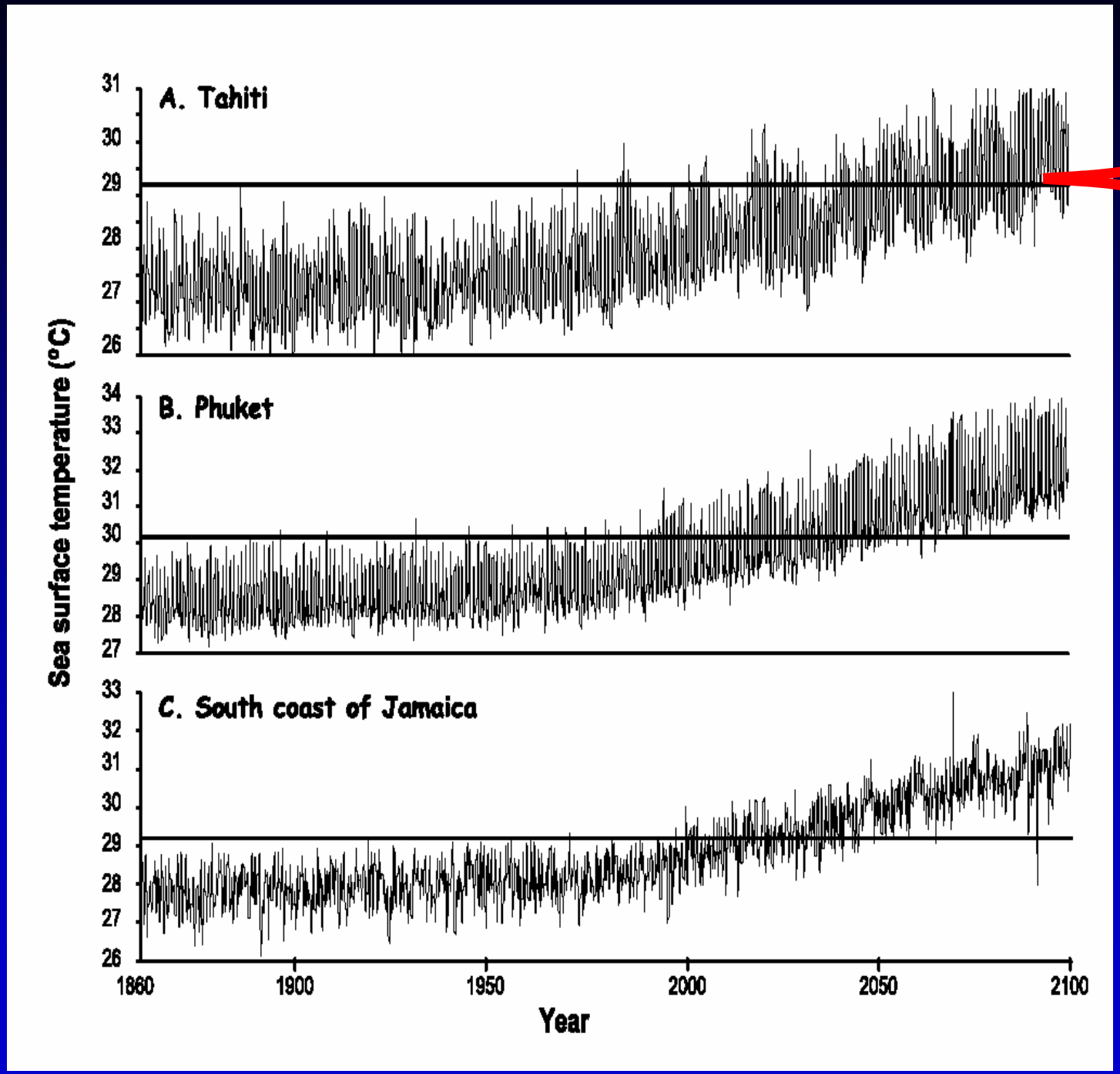
1. 95% correlation with increases in sea temperature (1-2°C above long-term summer sea temperature maxima) and bleaching.
2. Backed up experimentally
3. Basis for a highly predictive SST program at NOAA (HotSpots):







Strong, Hayes, Goreau, Causey and others



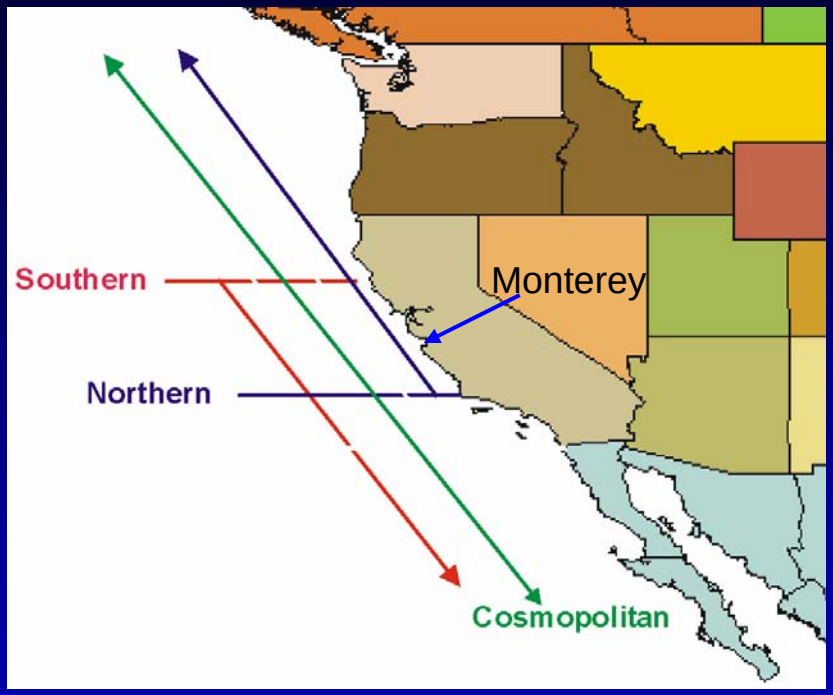
Threshold temperature – above which bleaching manifests itself (1-2oC above the long-term summer maximum temperatures

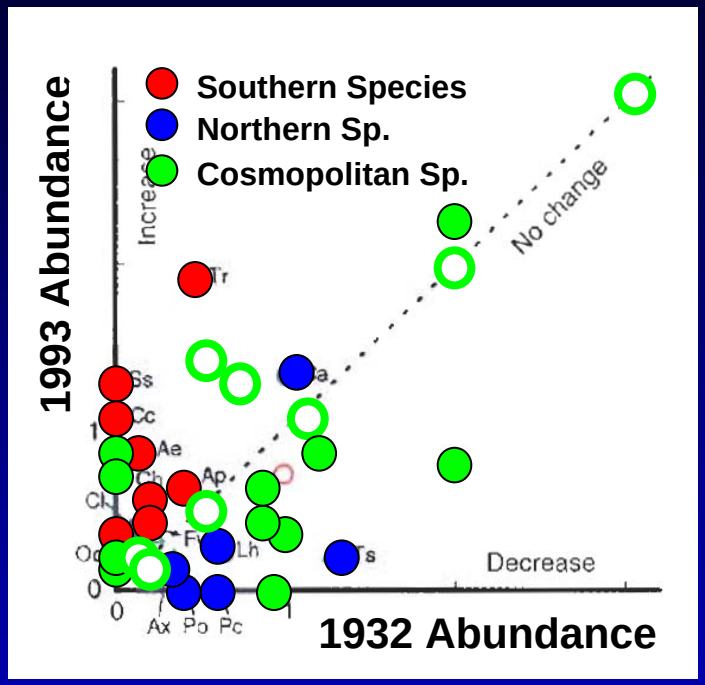
WHAT DOES THE FUTURE HOLD?

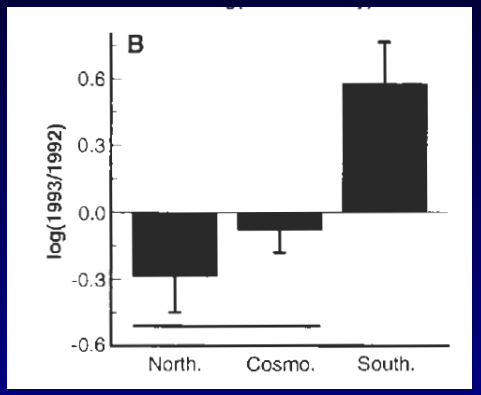
Hoegh-Guldberg (1999)

Climate-related shifts in rocky intertidal animals (1932-19

Warming of water temperatures over 60 years has been accompanied by a shift in the geographic ranges of species







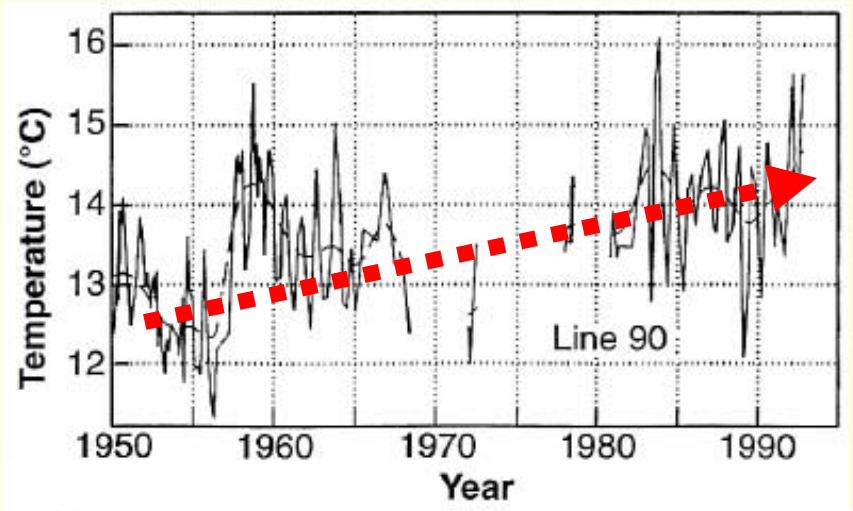
Warming prediction: Species ranges should migrate poleward with warming temperatures

Southern Species Increased

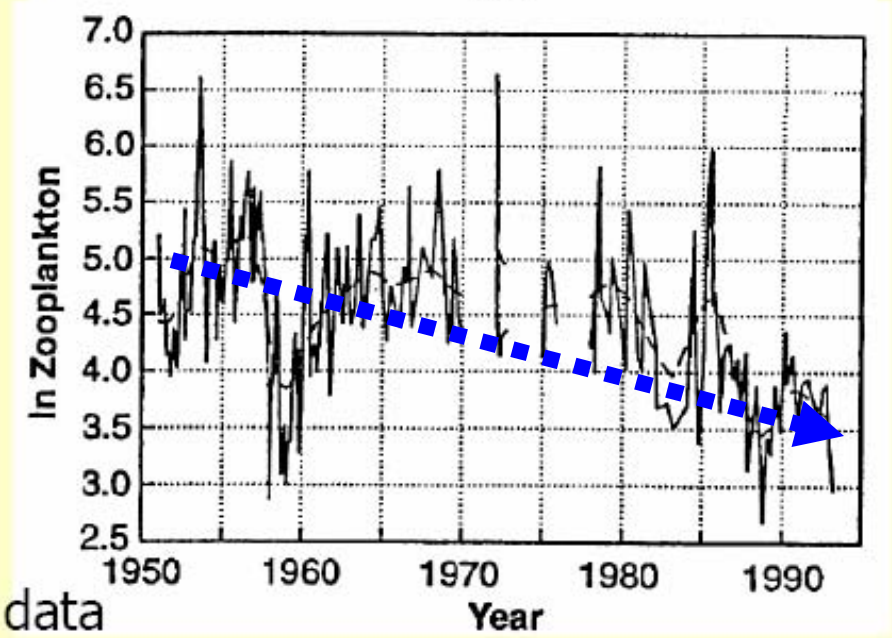
Northern Species Declined

Barry et al. 1995

Long-term Ocean Warming
and effects on Zooplankton Biomass



Warming of 1.2-1.4º C



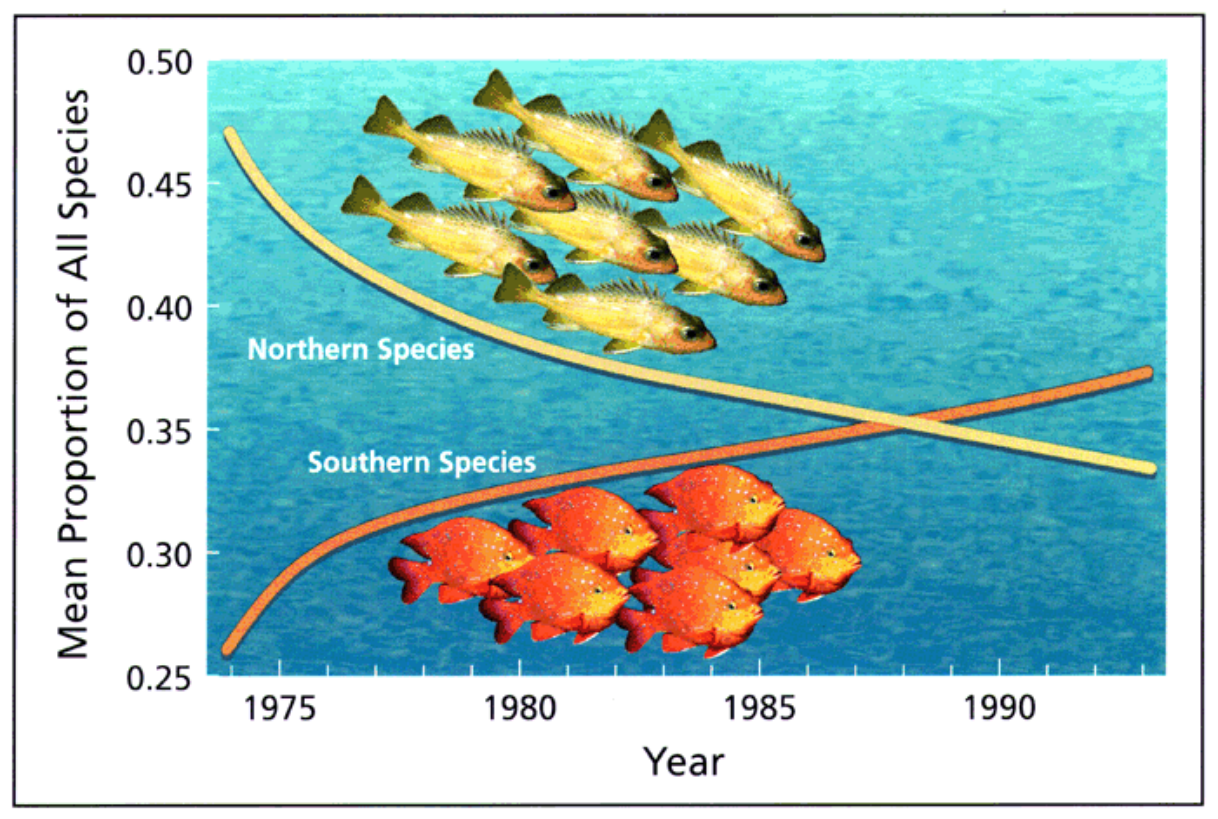
70% decline in zooplankton biomass

N.B. This warming and decline may have partially reversed after 1999

CalCOFI data

Roemmich and McGowan 1995 a,b

Changes in Fish Communities in the Channel Islands, California



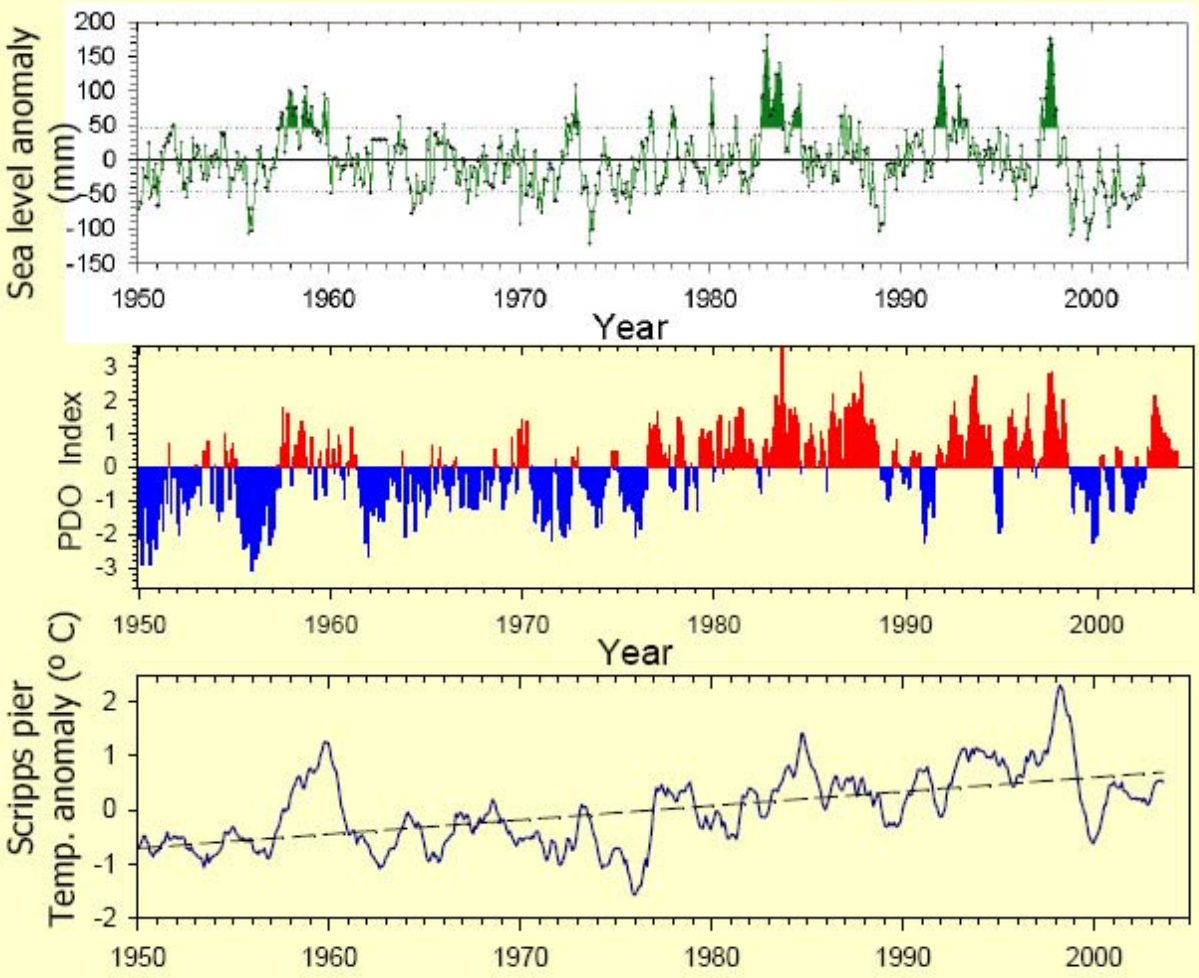
Holbrook et al. 2002

Conclusions:
Northern Species decreased
Southern Species increased

Are observed changes a response to short-term climate variation or long-term climate warming?

Scale of Oceanographic Variability

How will these different processes interact to affect living components of marine ecosystems ?



El Niño

3-12 years

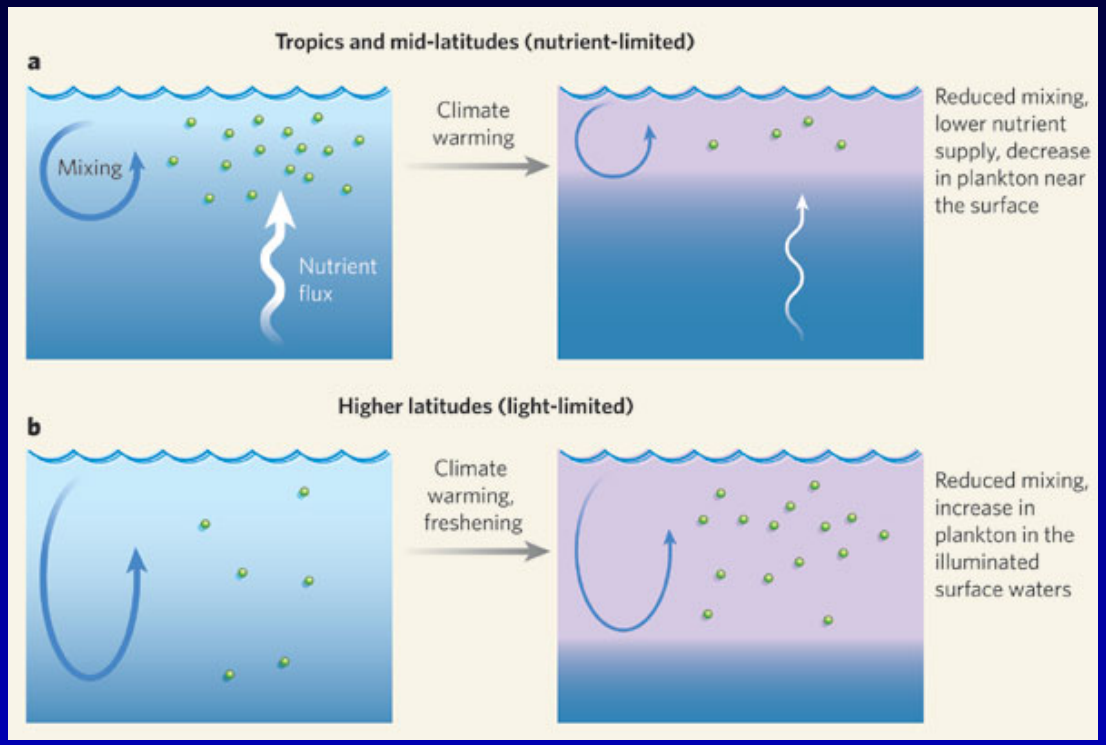
PDO

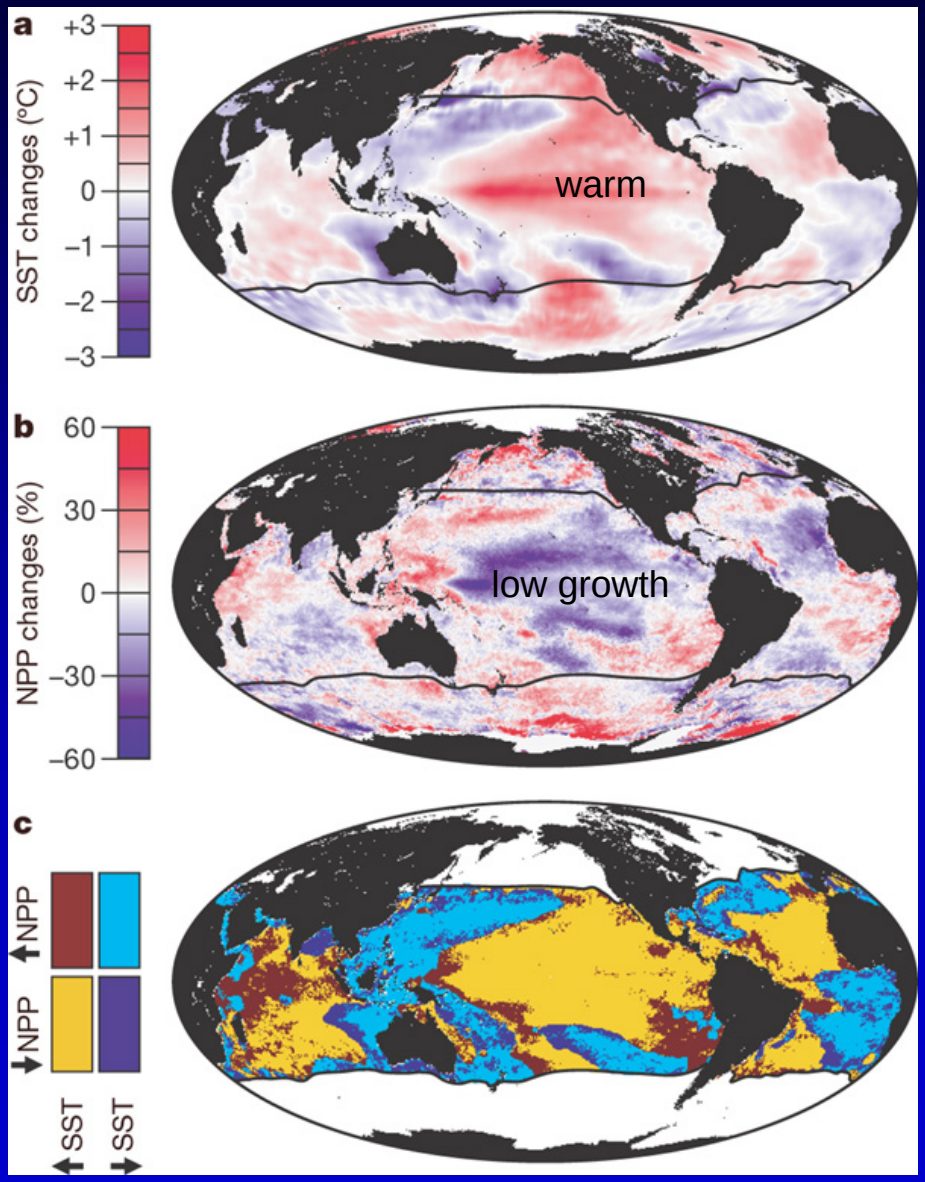
~25 years

Warming Trend

Centuries+?

Effects of Ocean Warming on Productivity





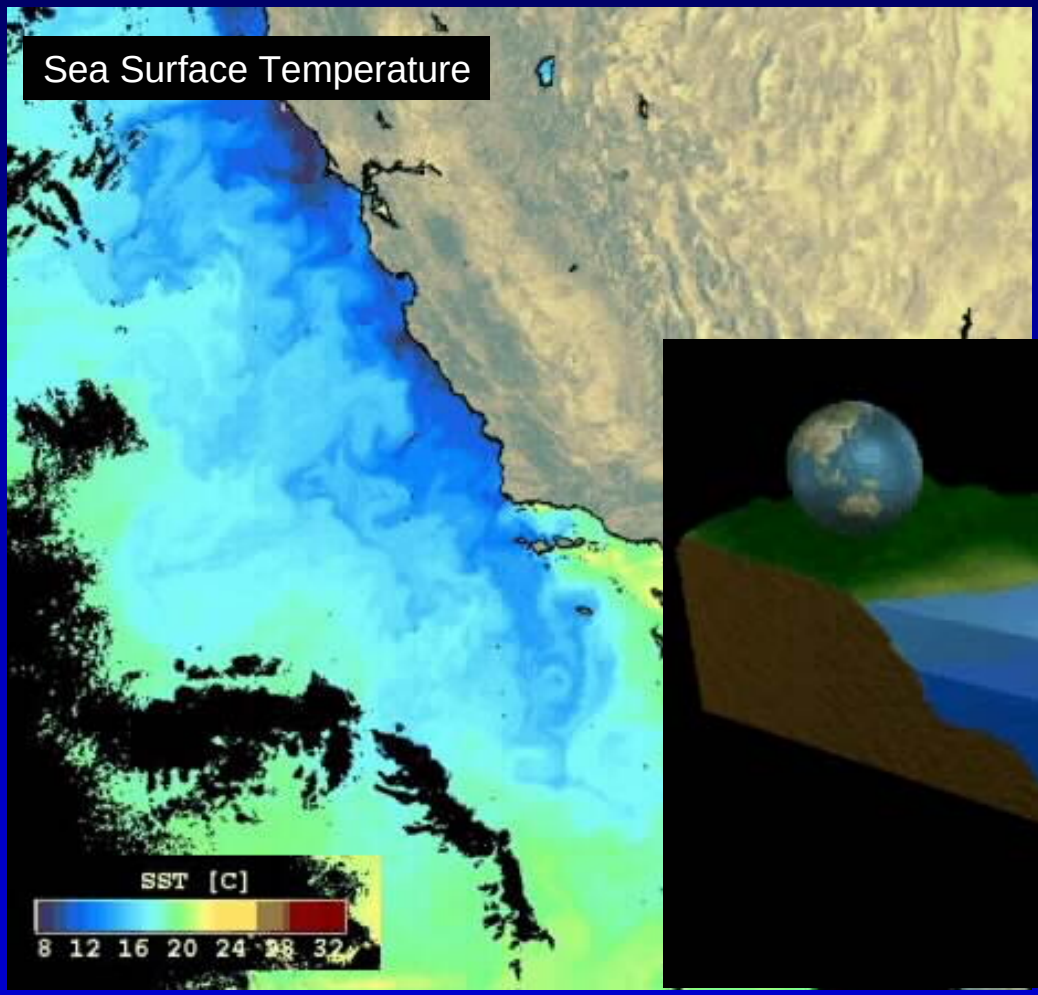
Warming increases stratification of the upper ocean, leading to reduced mixing.

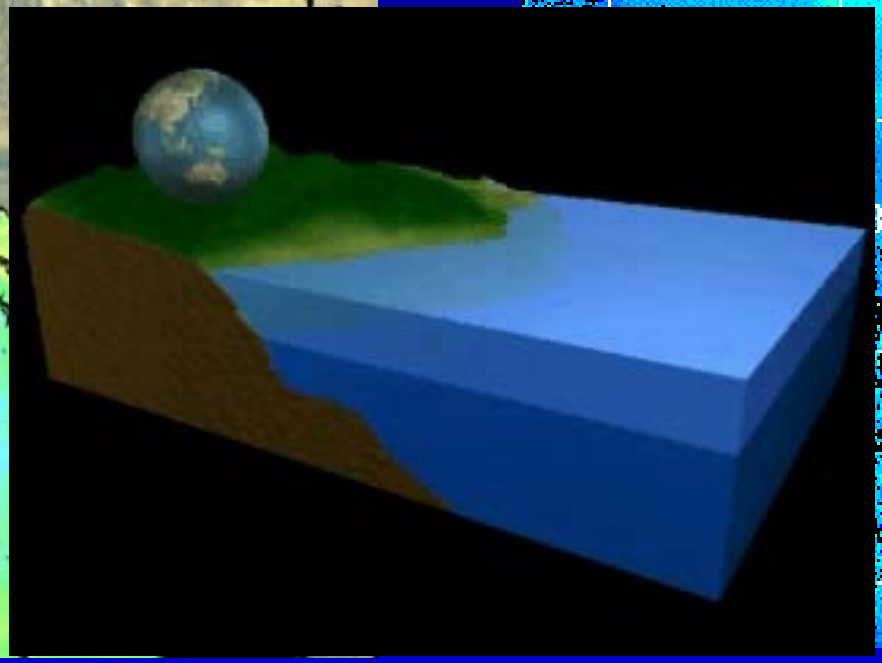
In low latitudes, this reduces growth of phytoplankton, which are the base of the food chain

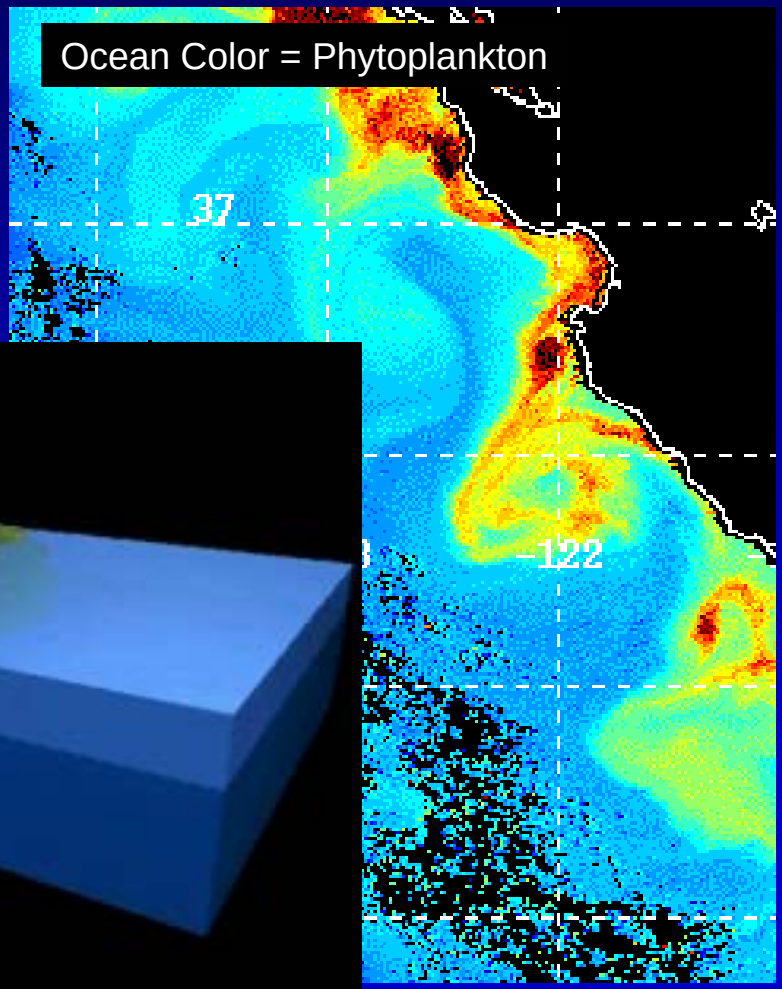
Behrenfeld et al. 2006

Will global warming affect coastal upwelling ecosystems?

- Spring and summer NW winds (alongshore) move water offshore rather than alongshore
- Deeper, cooler, nutrient-rich waters ‘up-well’ to the surface
- Phytoplankton communities flourish in these high nutrient waters: = high primary production
- The food web (zooplankton to whales) benefits from upwelling



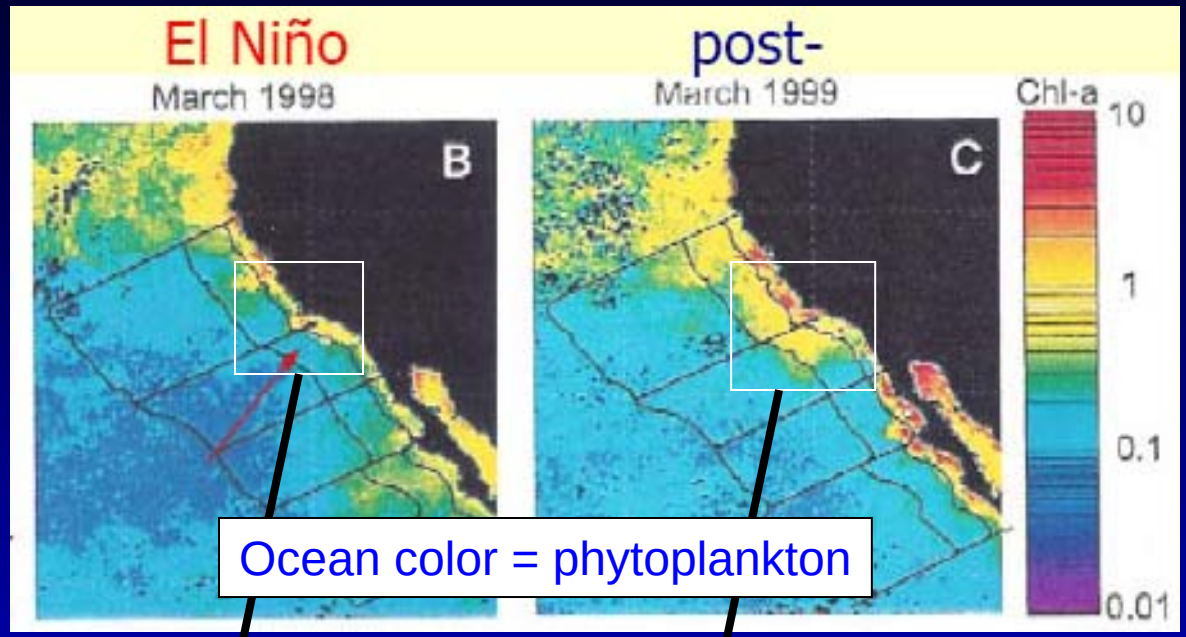


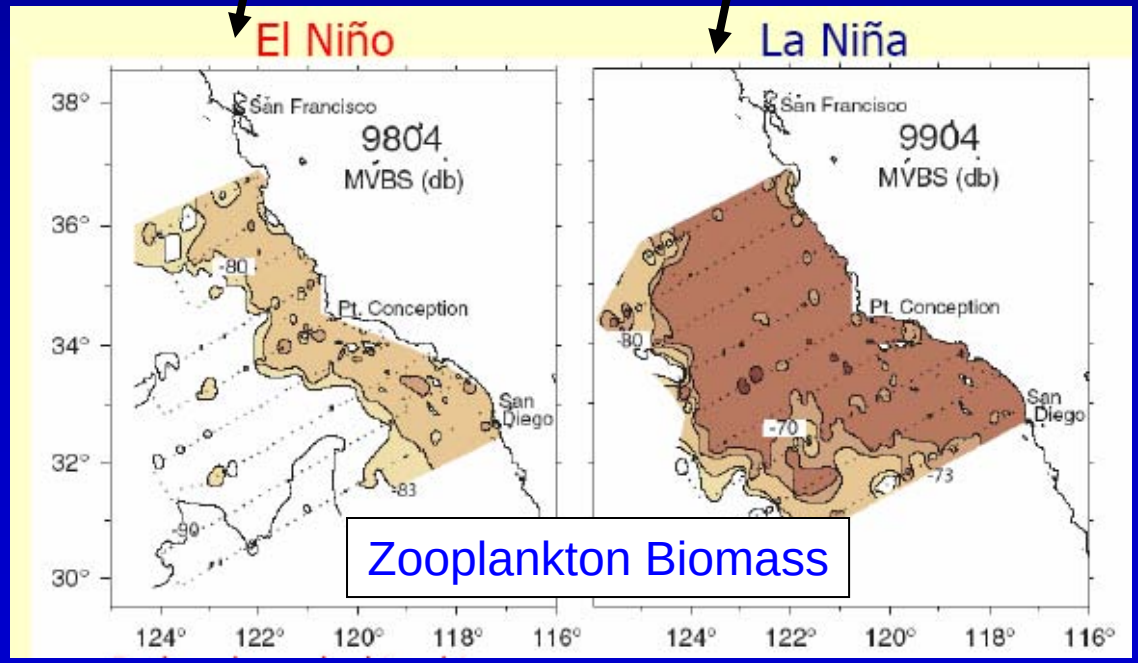


El Nino and Ocean Productivity

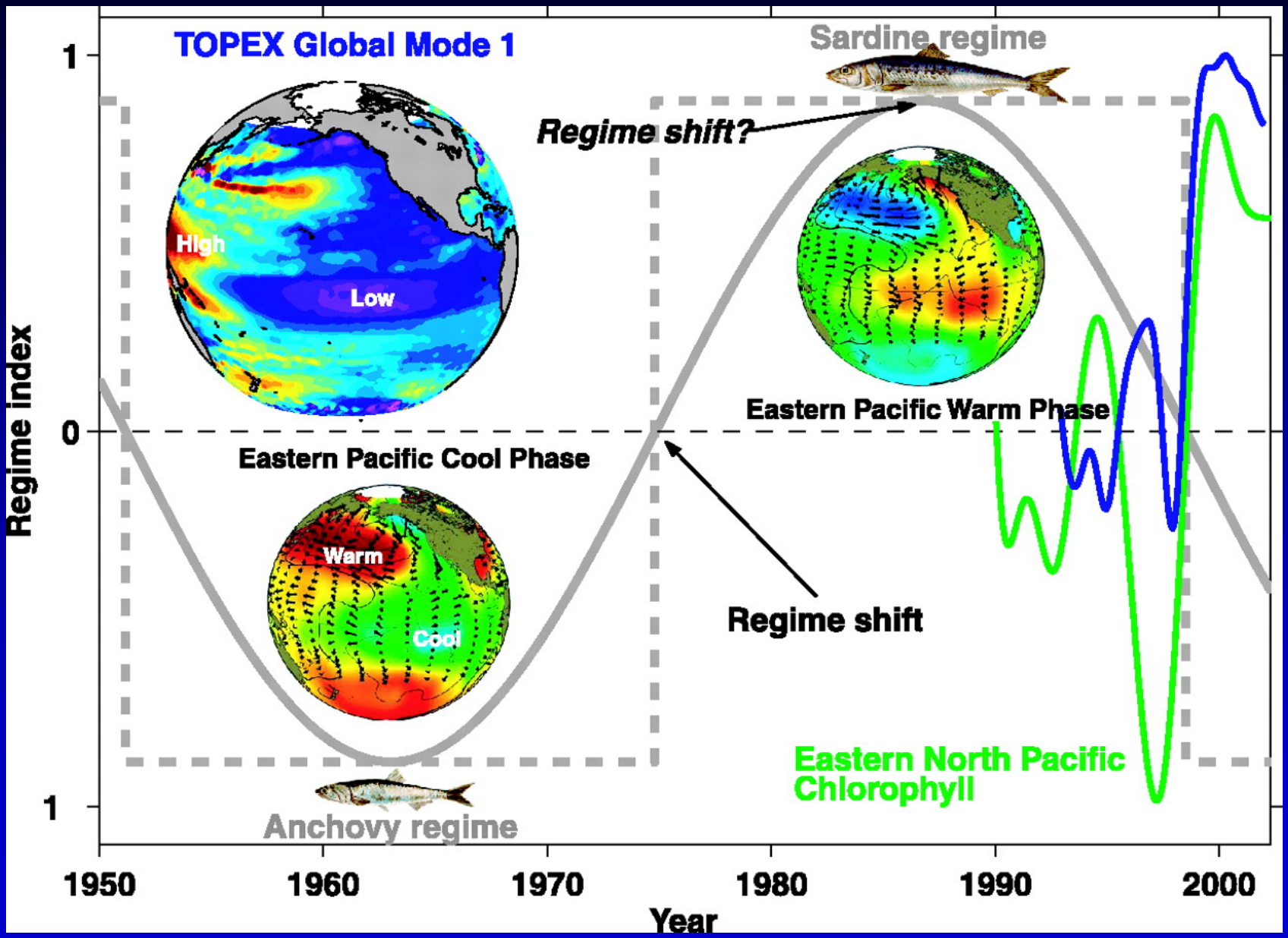
El Nino
- Low upwelling
- Warm, unmixed waters
- Low ocean productivity
- Low zooplankton biomass and growth

La Nina
- More wind, greater upwelling
- Cool, mixed, nutrient-rich waters
- Low ocean productivity
- Low zooplankton biomass and growth



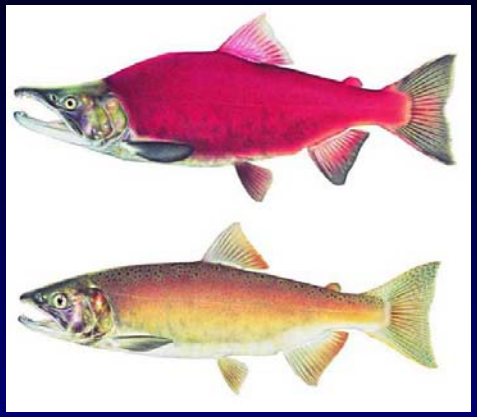


Pacific Decadal Variation in Ocean "Climate"



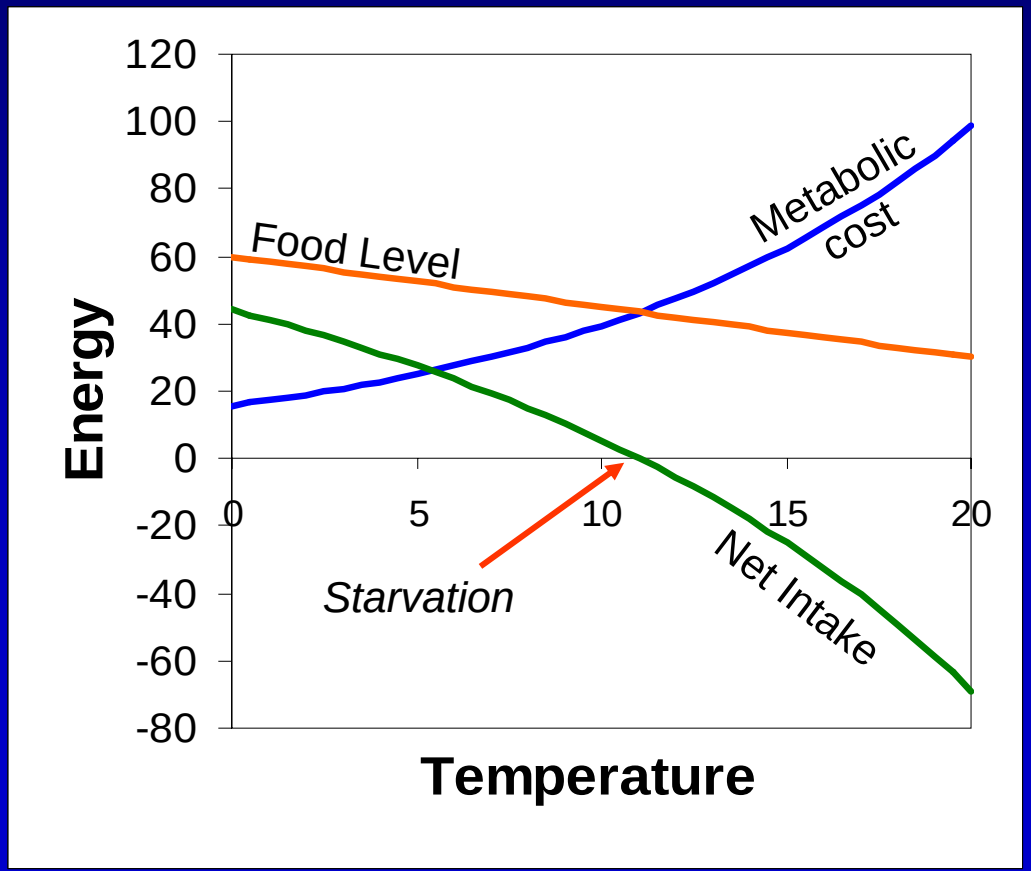
Chavez et al. 2004

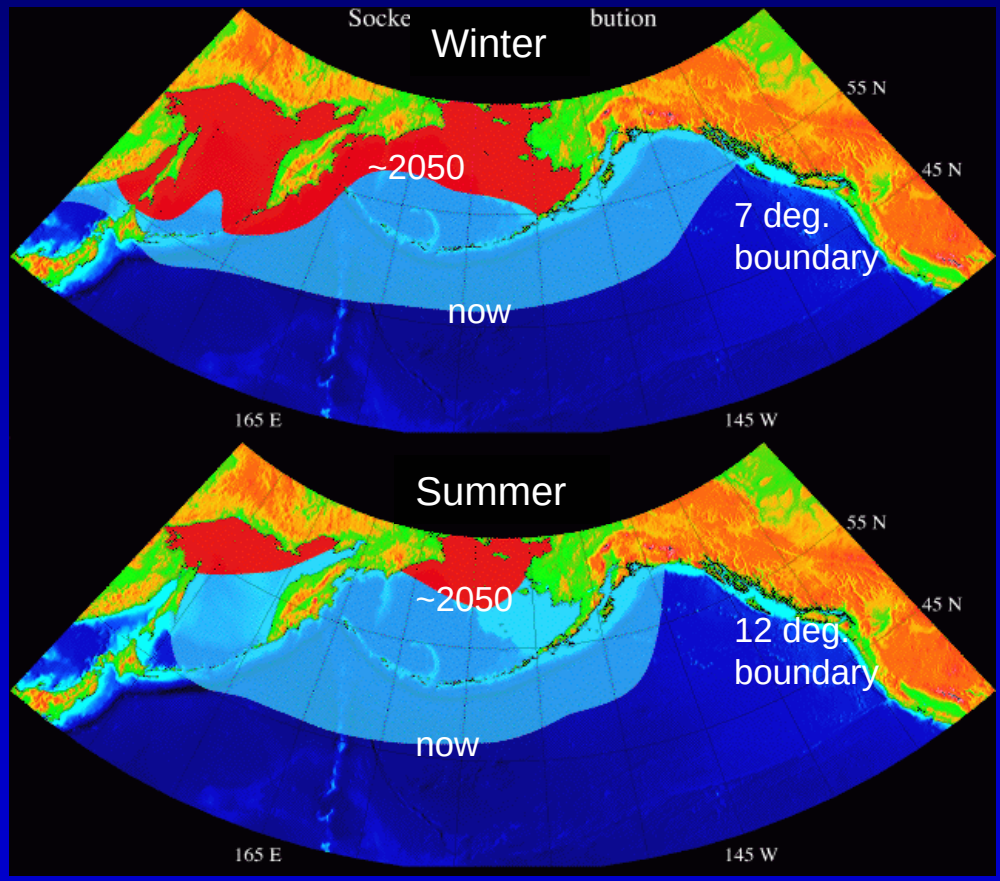
Potential Changes in Sockeye Salmon Distribution from a Doubling of CO2



Sockeye Salmon spend ~2-3 y in the NE Pacific and Bering Sea

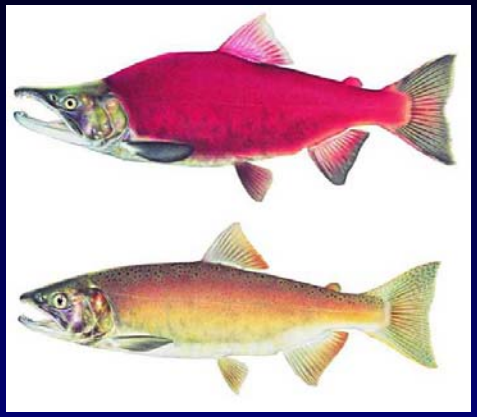
- Migrate northward in summer, southward in winter
- Food availability greatest in summer, but decreases with warmer temperature
- Metabolic costs increase exponentially with temperature.
- Net intake drops to <0 (beginning starvation) at warmer temperatures





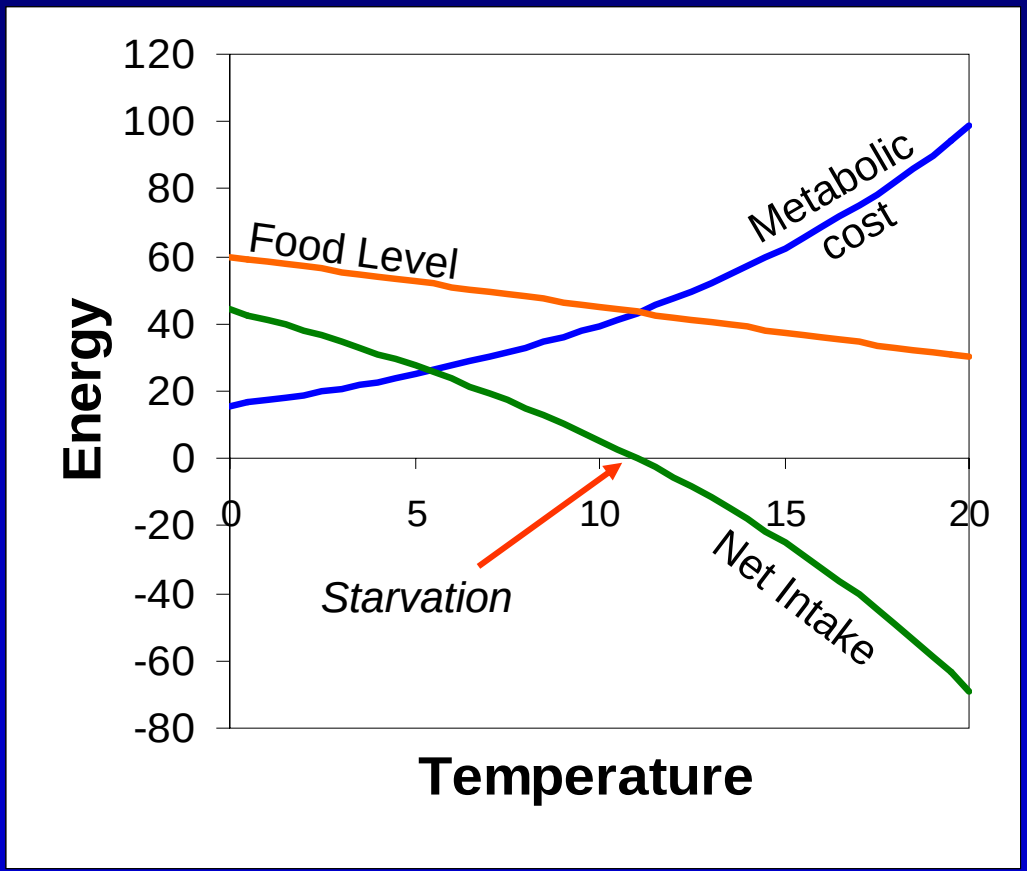
Welch et al. 1998

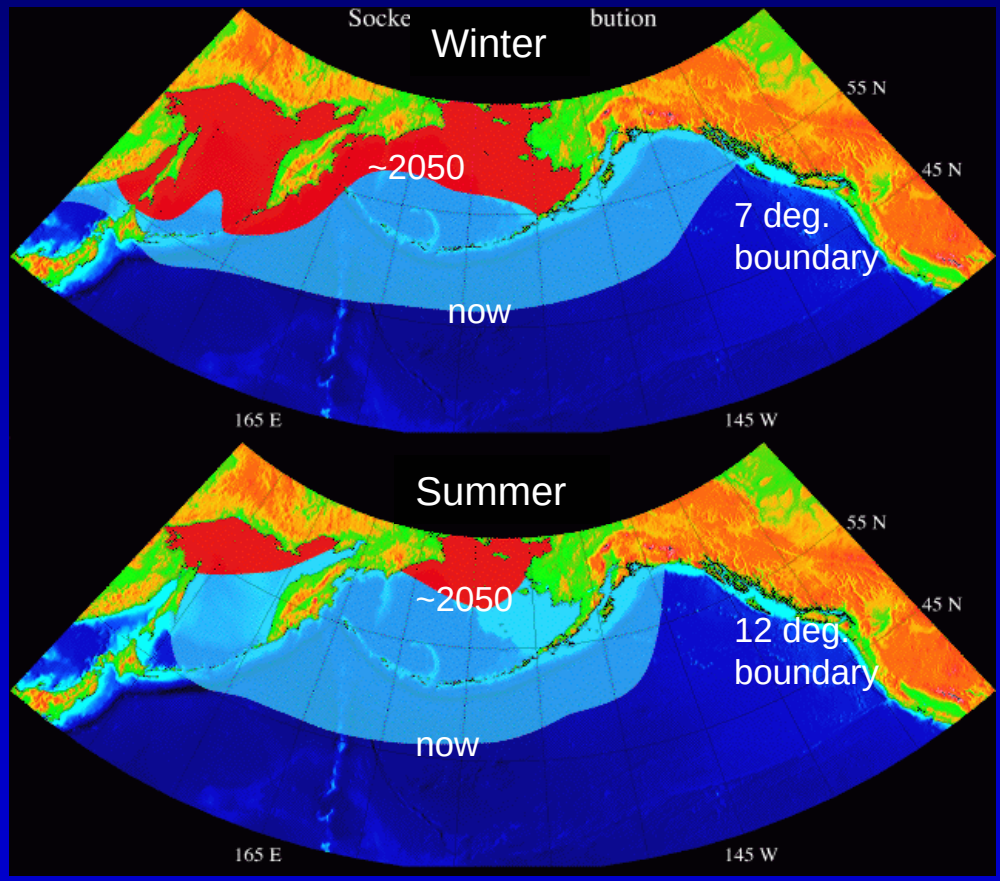
Potential Changes in Sockeye Salmon Distribution from a Doubling of CO2



Warming of ocean waters will:

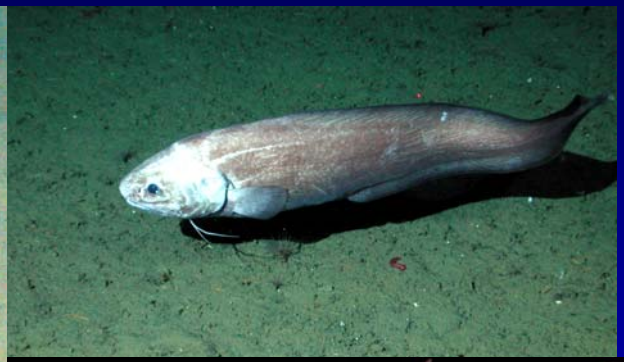
- Increase metabolic costs
- Decrease food levels
- Shift optimal feeding areas northward
- Increase starvation rates, thereby reducing both individual size and catch
- These effects cascade through the entire food chain (i.e. birds & mammals)



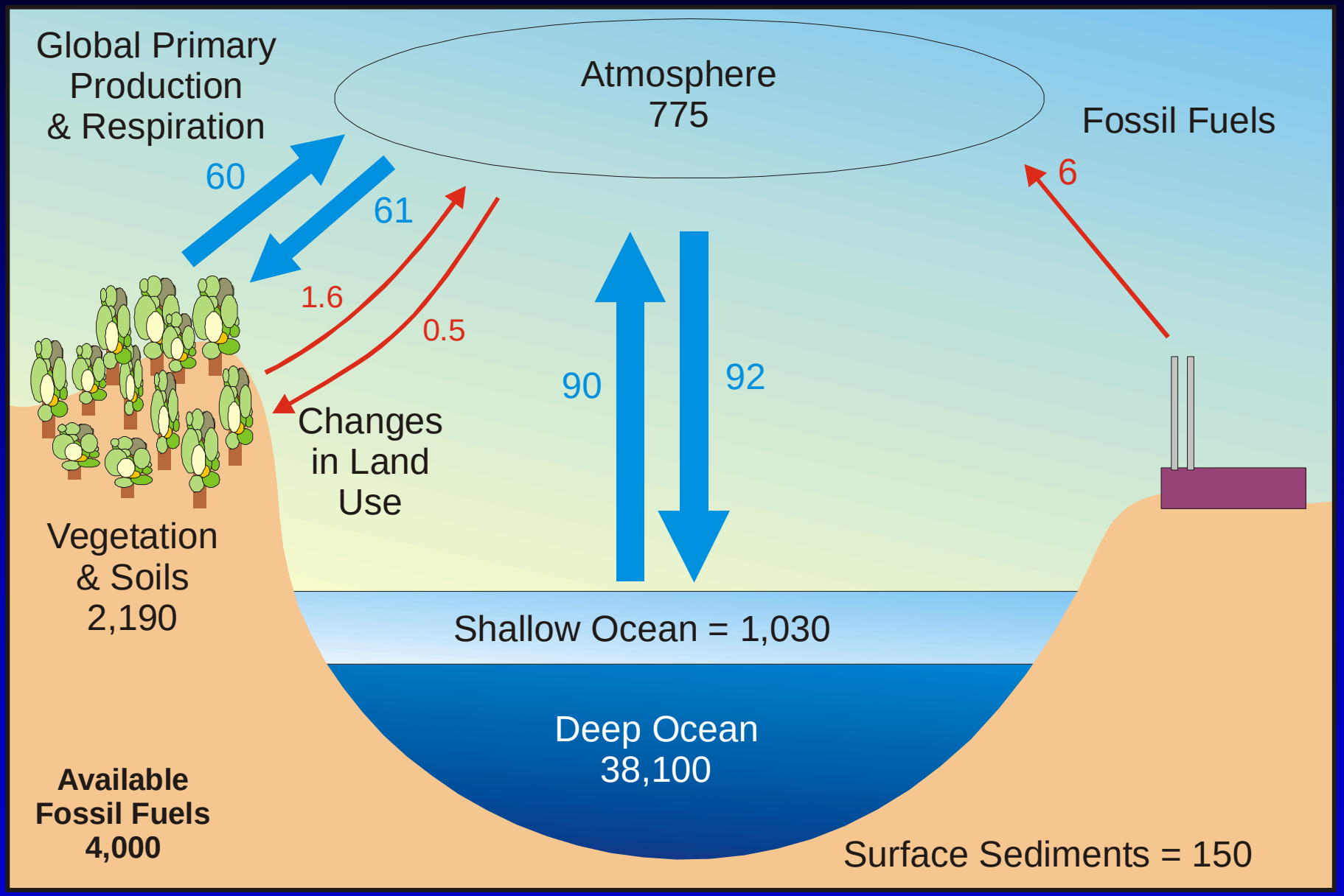


Welch et al. 1998

The High CO_2 Ocean

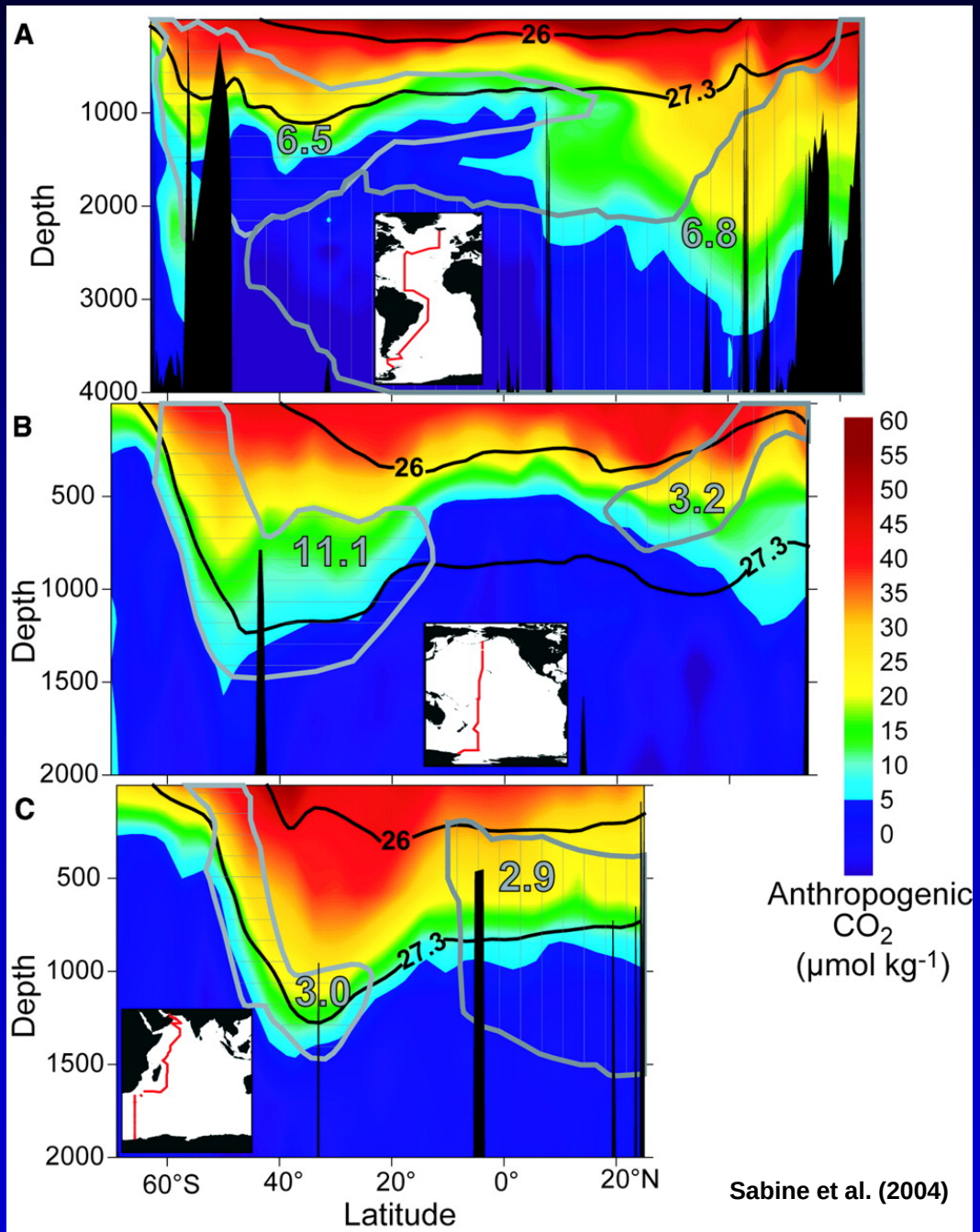


Global Carbon Pools & Fluxes



Values in billions of metric tonnes (Gt C/y)

Ocean CO_2 "Disposal" Today

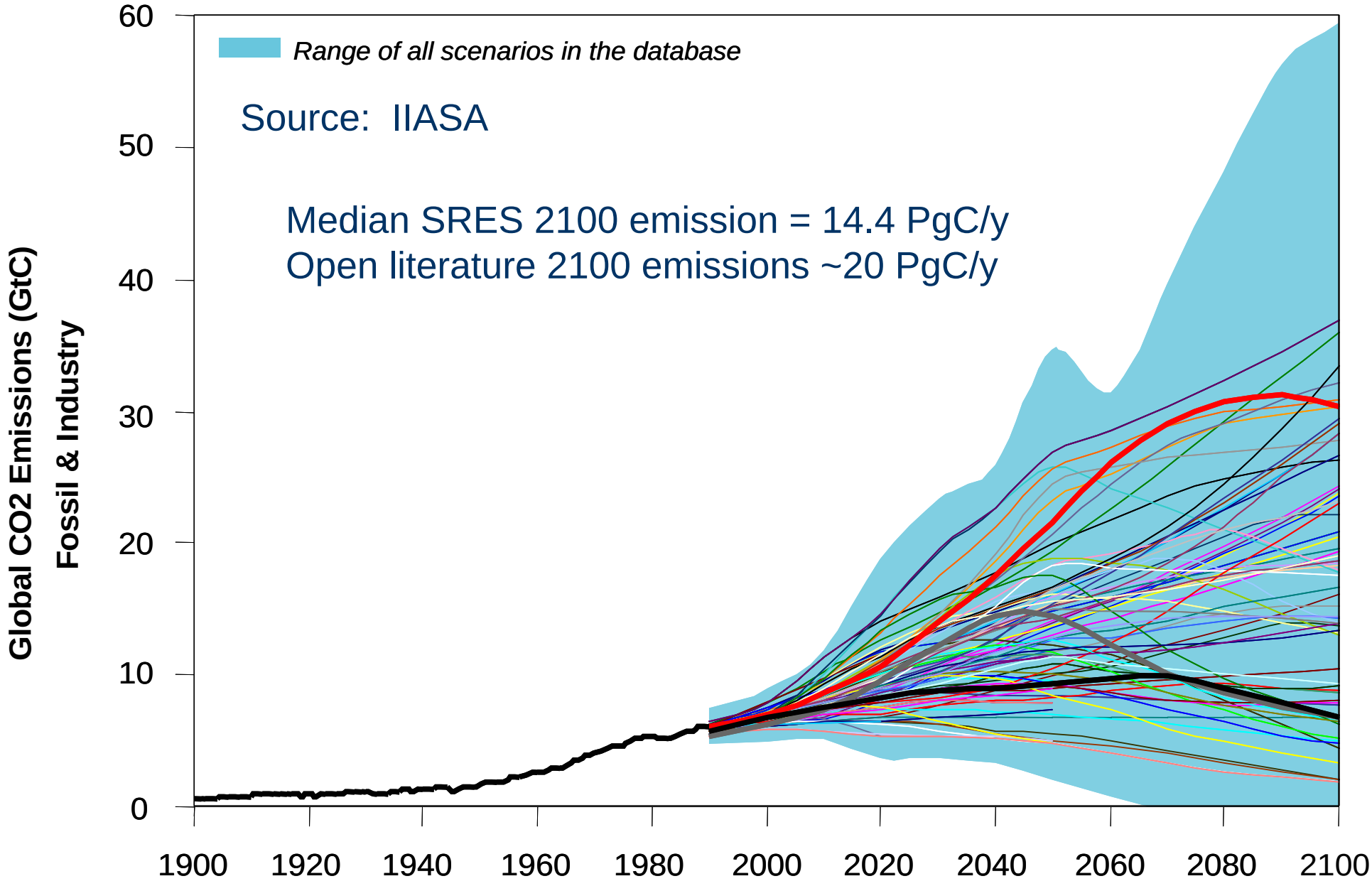


Sabine et al. (2004)

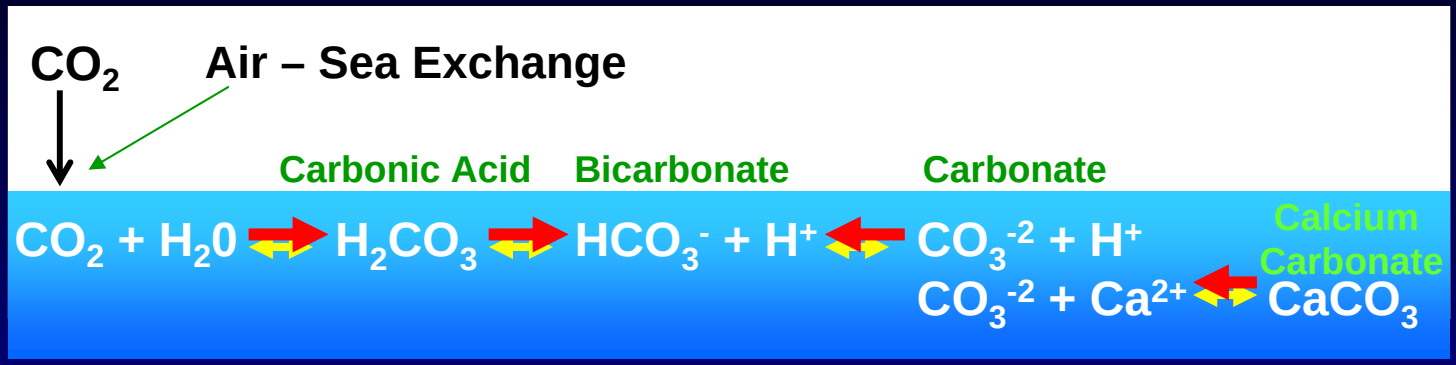
Fossil fuel signal has penetrated to >1000 - 2000m.

- The inventory was 48 Pg C in 1994.
- We have disposed of 118 PgC in the world ocean.
- Global surface ocean CO_2 disposal is now about 20-25 million tons per day (61 kg/km^2)

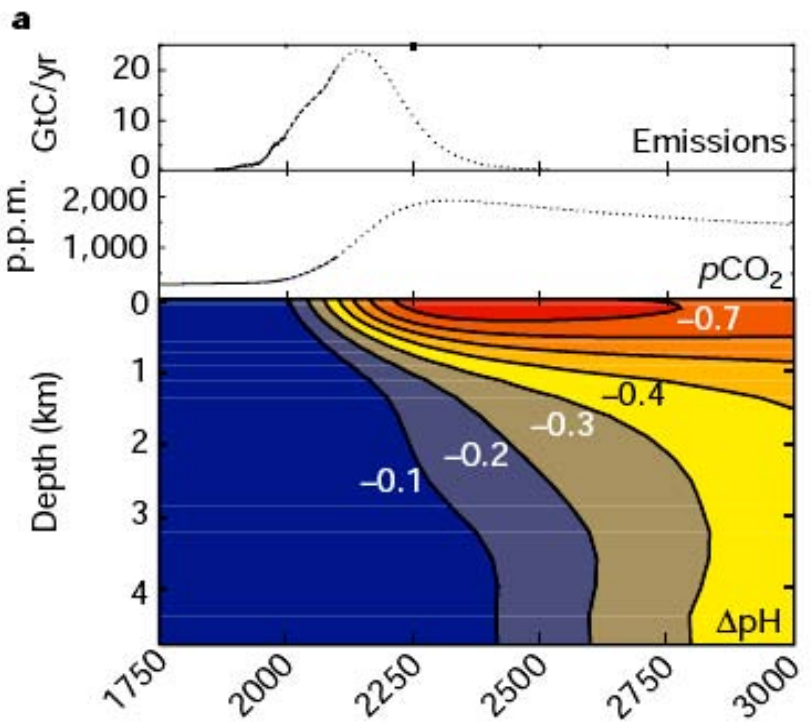
Range of Reference Case Fossil Fuel Carbon Emissions



Ocean Carbonate Chemistry



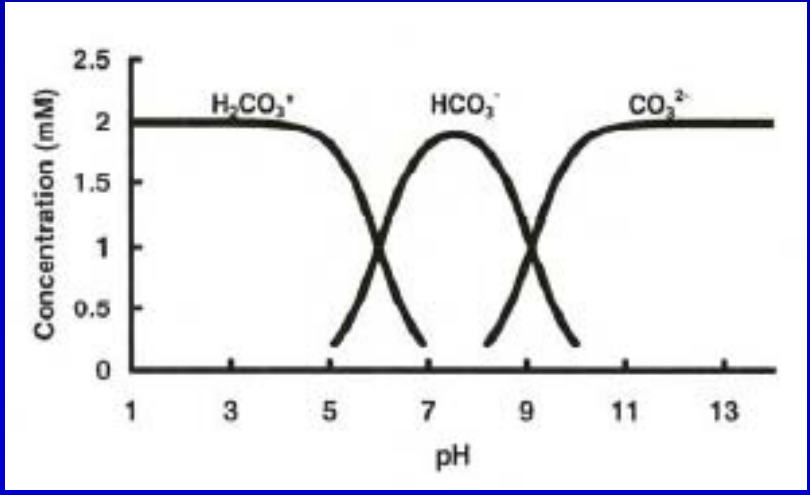
Future Decrease in Ocean pH



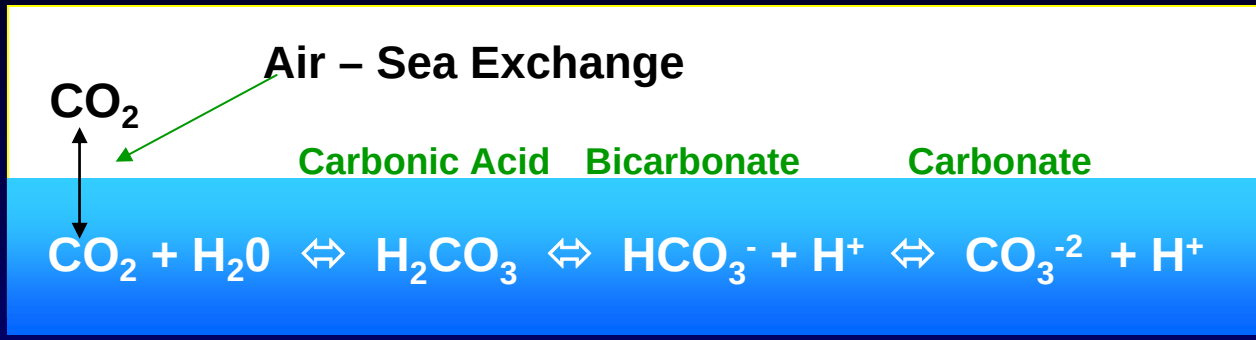
Caldeira and Wickett (2005)

Addition of CO_2

- Increases acidity
- Decreases carbonate ions
- Decreases carbonate saturation
- Decreases calcification



Physiological Stresses Associated with High CO_2



Physiological Challenges

Respiratory Stress

Reduced pH limits oxygen-binding and transport by respiratory proteins, leading to reduced aerobic capacity.

Acidosis (reduced internal pH)

Disruption of acid/base balance impairs function and requires energy to restore or maintain optimal internal pH levels.

Reduced Calcification

Depression in carbonate saturation state increases the difficulty of carbonate deposition, with unknown metabolic consequences

Metabolic Depression (Torpor)

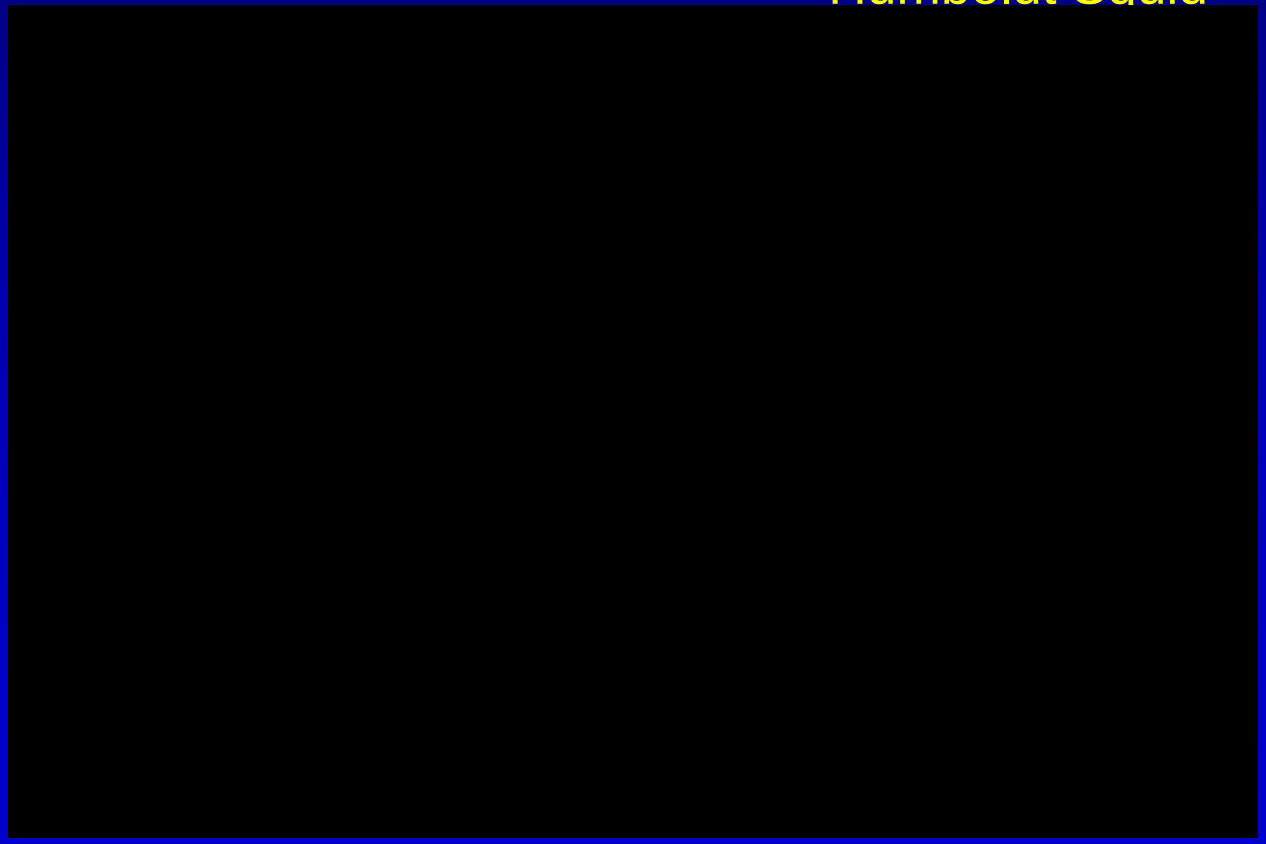
Elevated CO_2, reduced pH, or both can cause some animals to enter a state of reduced metabolic rate and semi-hibernation

Are CO_2-related stresses severe for deep-sea animals?

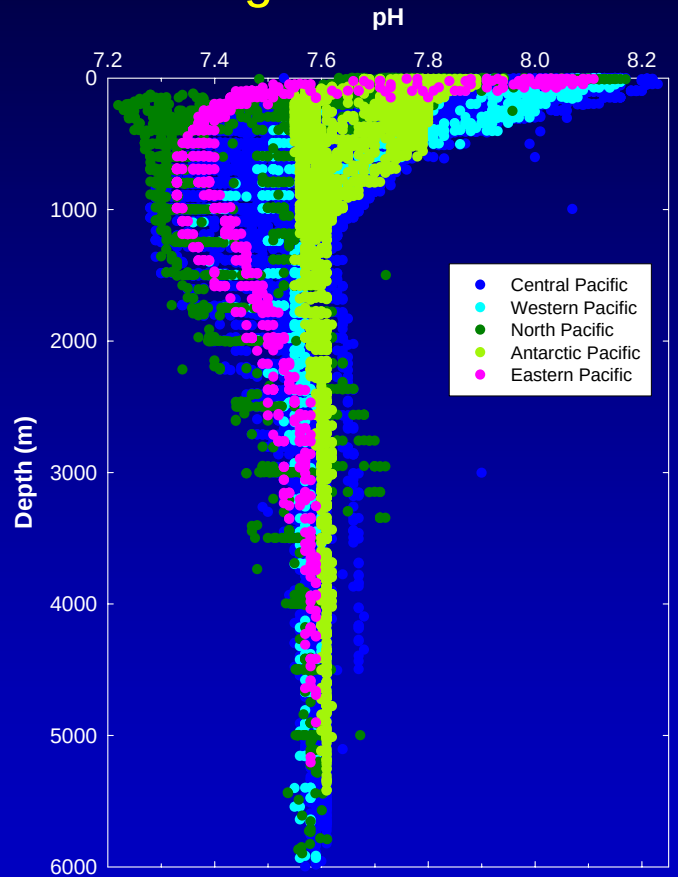
Deep-Sea Animals

1. Reduced metabolic rates
2. Reduced enzyme function
3. Evolved in highly stable deep-sea environment
4. Food-limited –
   "Living on the edge"

Humboldt Squid



pH Variation
Among Ocean Basins



Expected Reduction in Coral Reef Calcification due to Reduced Ocean pH

Kleypas et al 1999

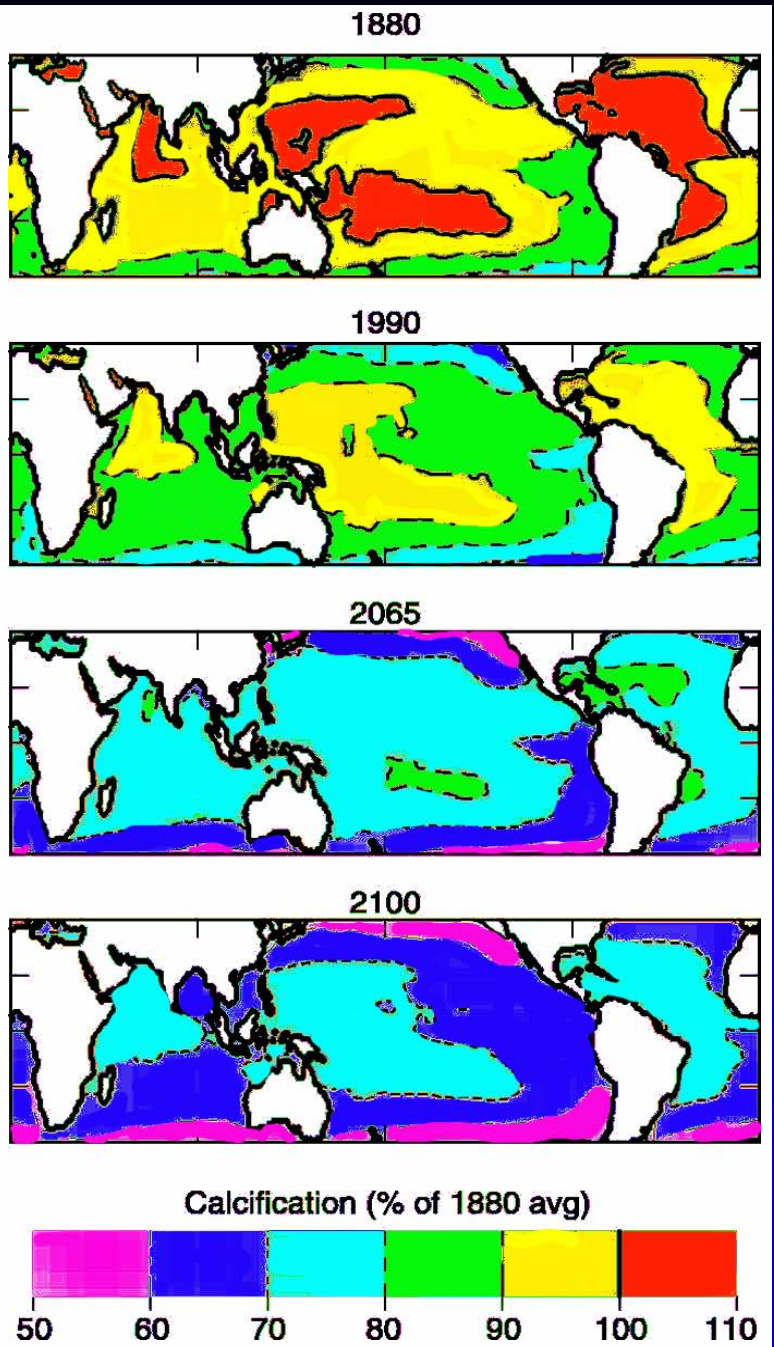
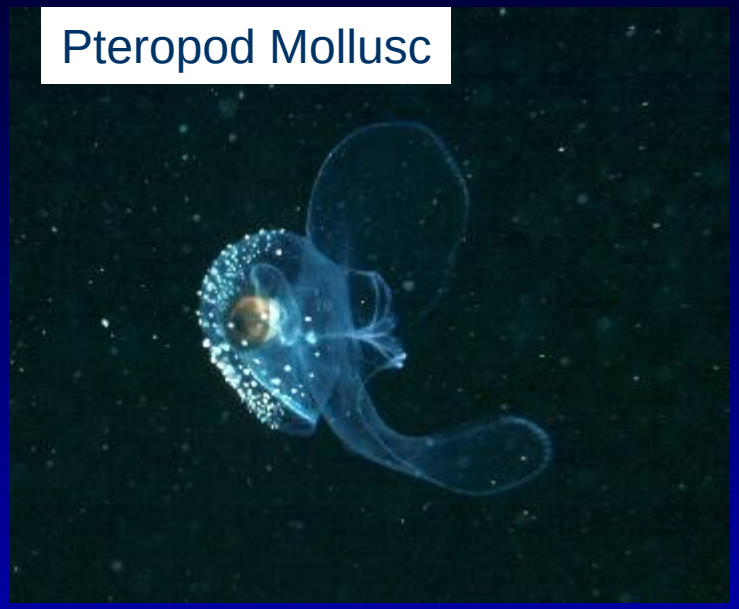
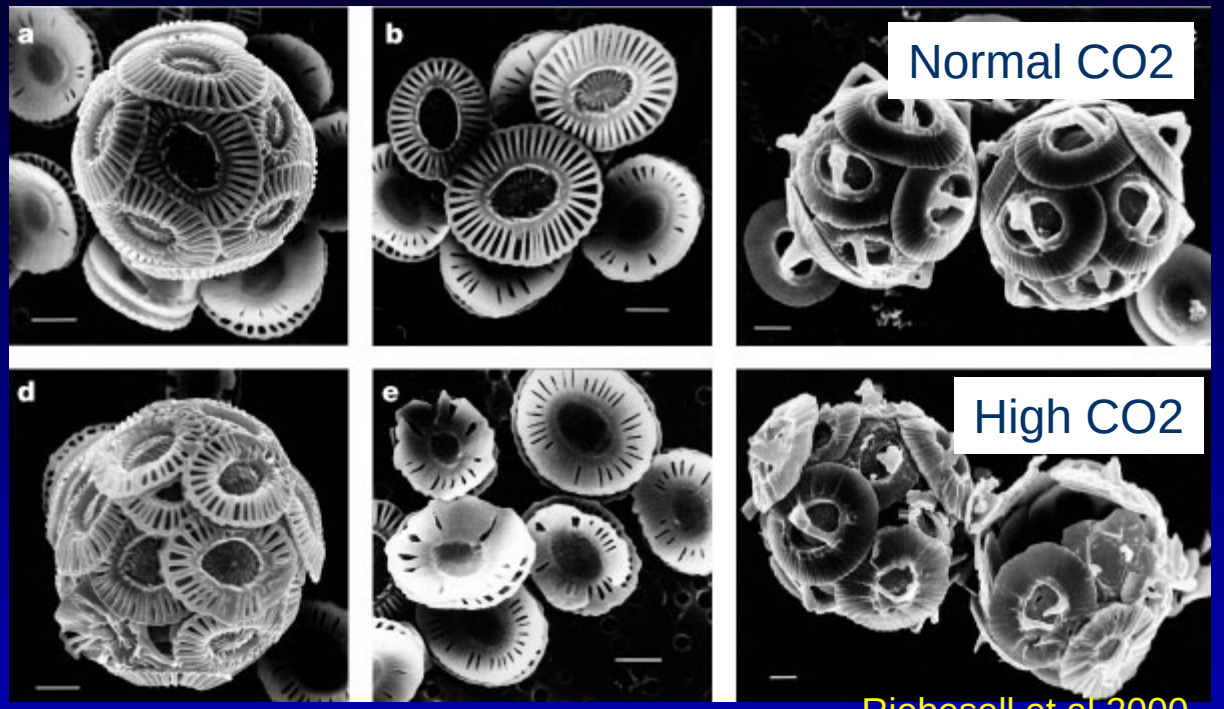


Fig. 2. Projected changes in reef calcification rate based on average calcification response of two species of tropical marine algae and one coral (*12*) and a marine mesocosm (*13*).

Reduced Calcification





Riebesell et al 2000

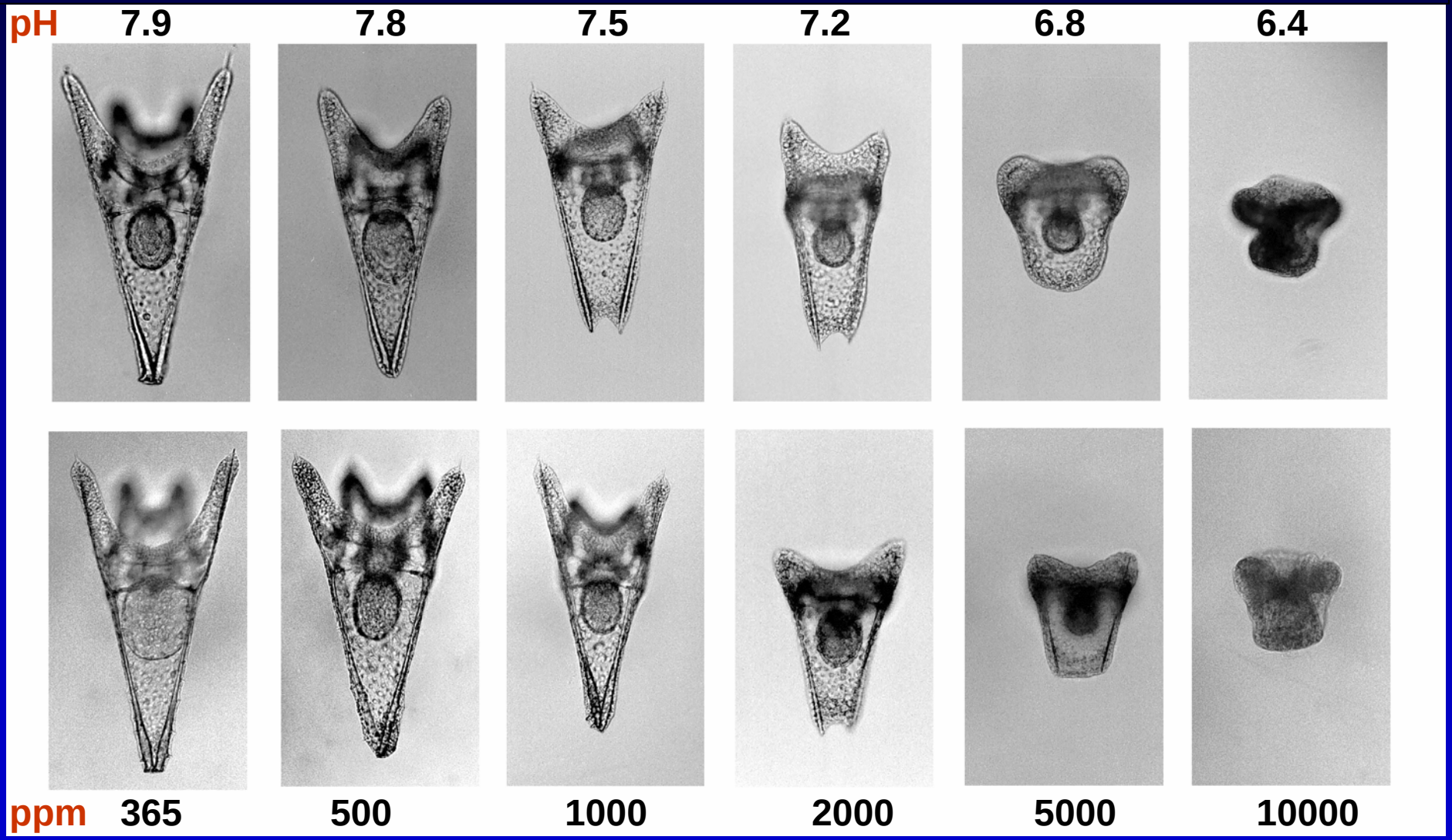
Ocean acidification will effect calcification for may species

Clams, Snails, Sea Stars, Urchins, Crabs, Shrimp, Others

The consequences of reduced calcification are not known.

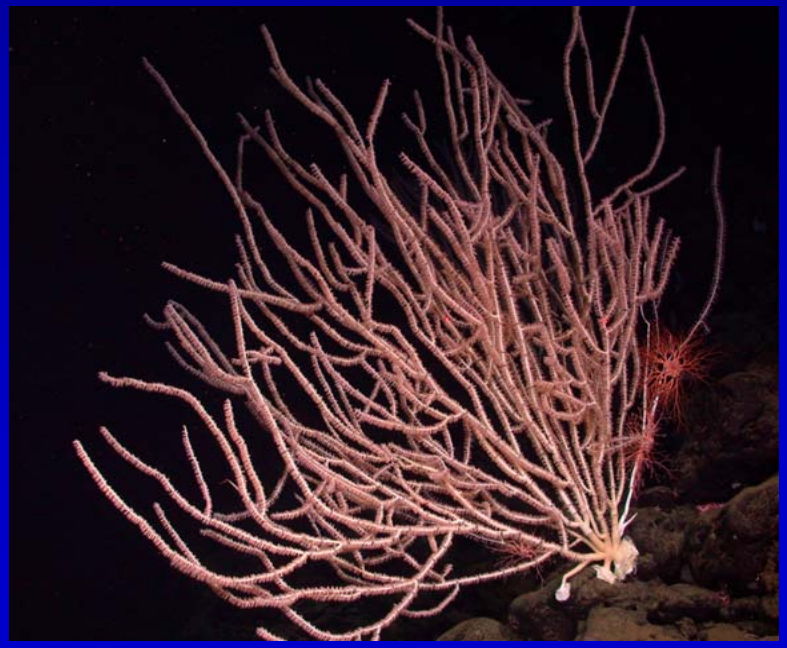
Ocean acidification may affect early life stages more than adults

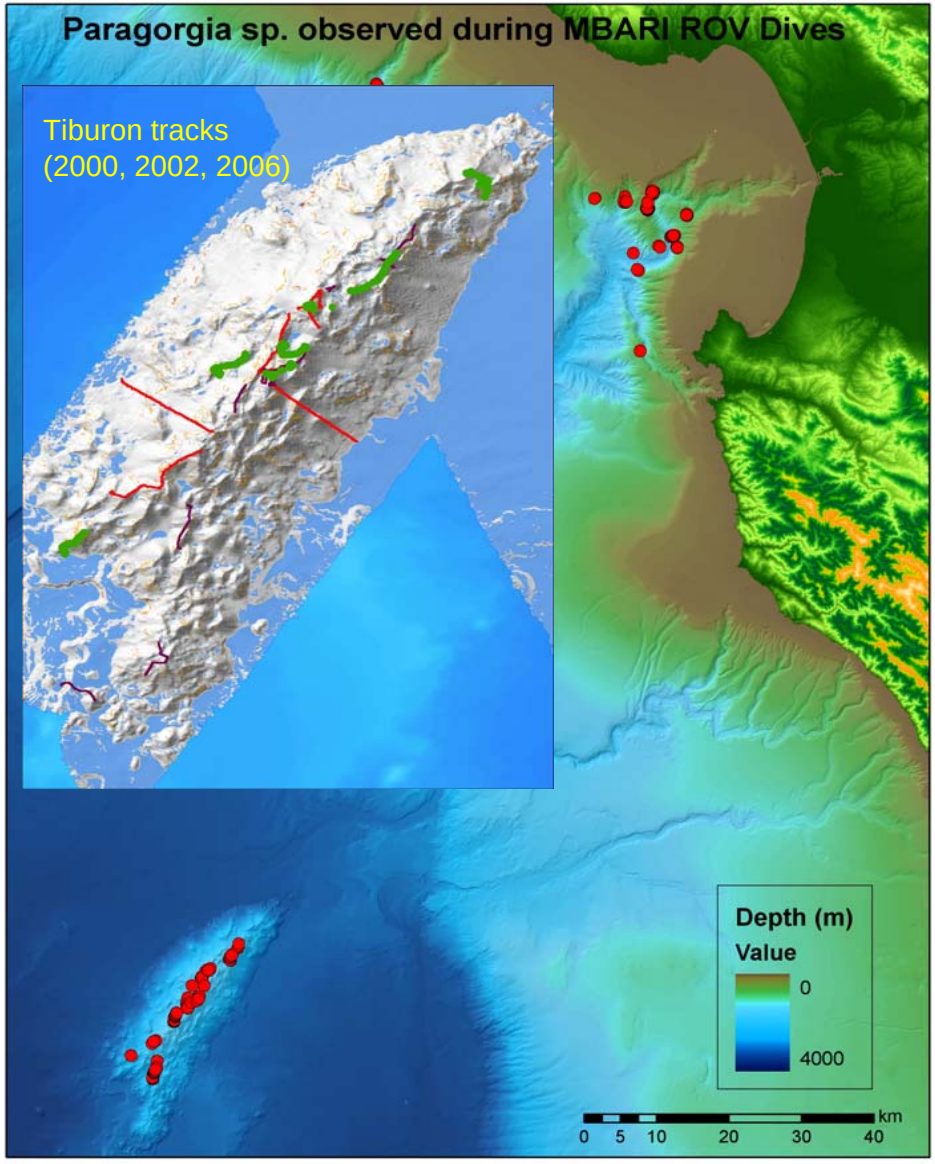
Impaired development of sea urchin larvae in high CO2 sea water



Kurihara et al. 2004

Deep-sea Corals – Vulnerable to CO2?





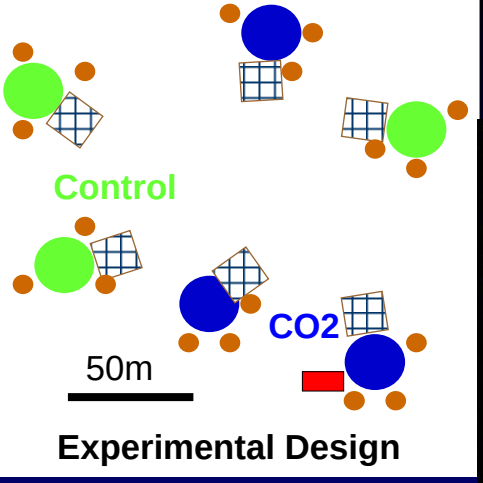
MBARI small scale CO_2 experiments

ROV Tiburon

RV Western Flyer

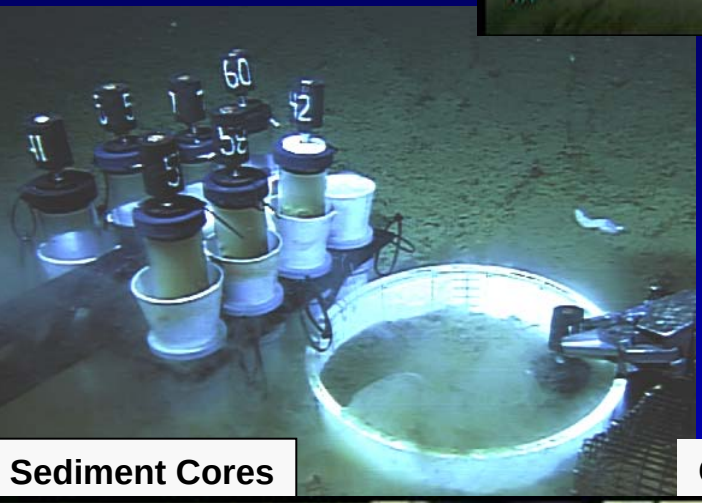
20 liter CO2 pool

Deep-Sea CO_2 Experiments



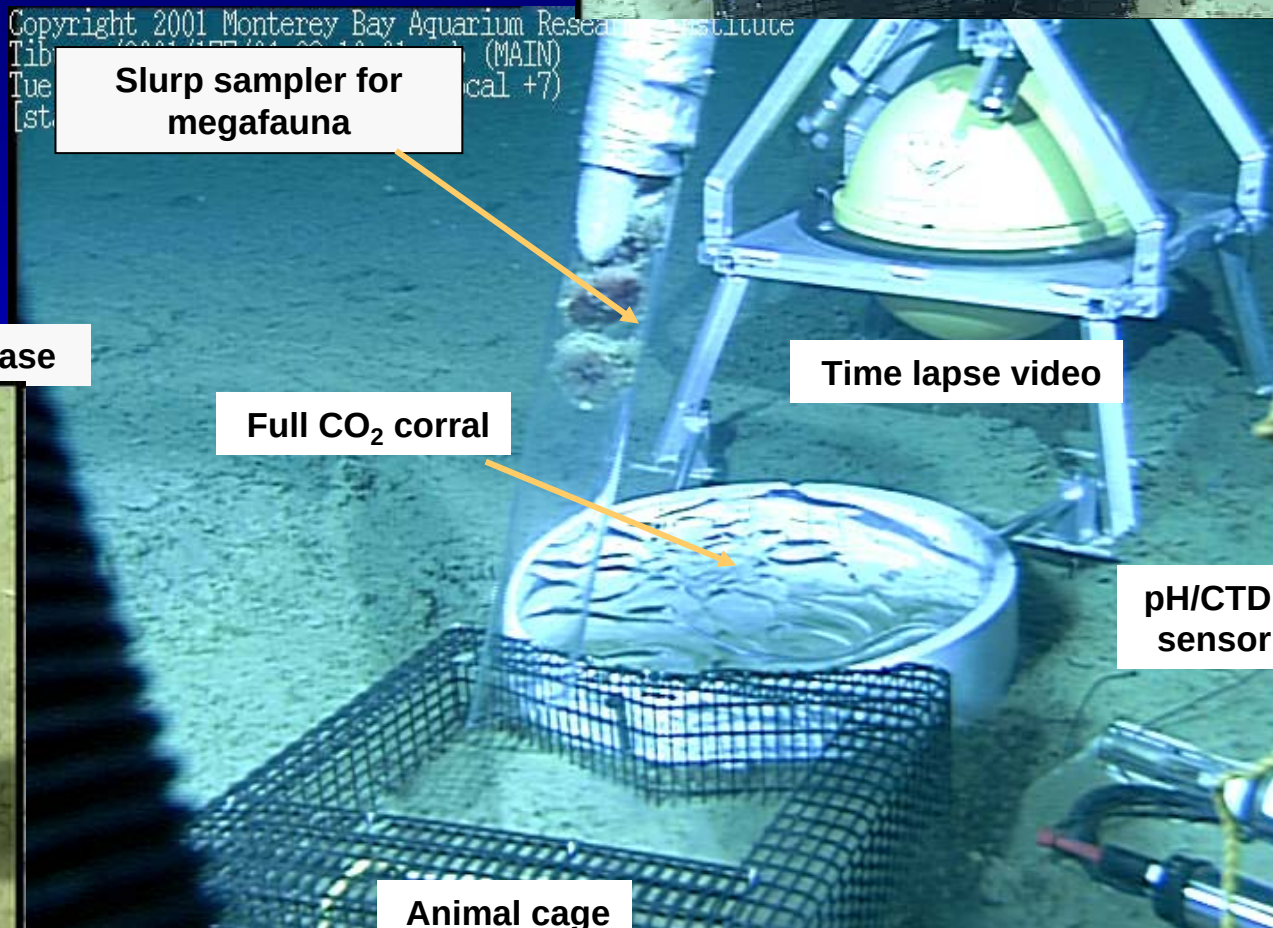
Experimental Design

Collecting Megafauna



Sediment Cores

CO_2 release



Slurp sampler for megafauna

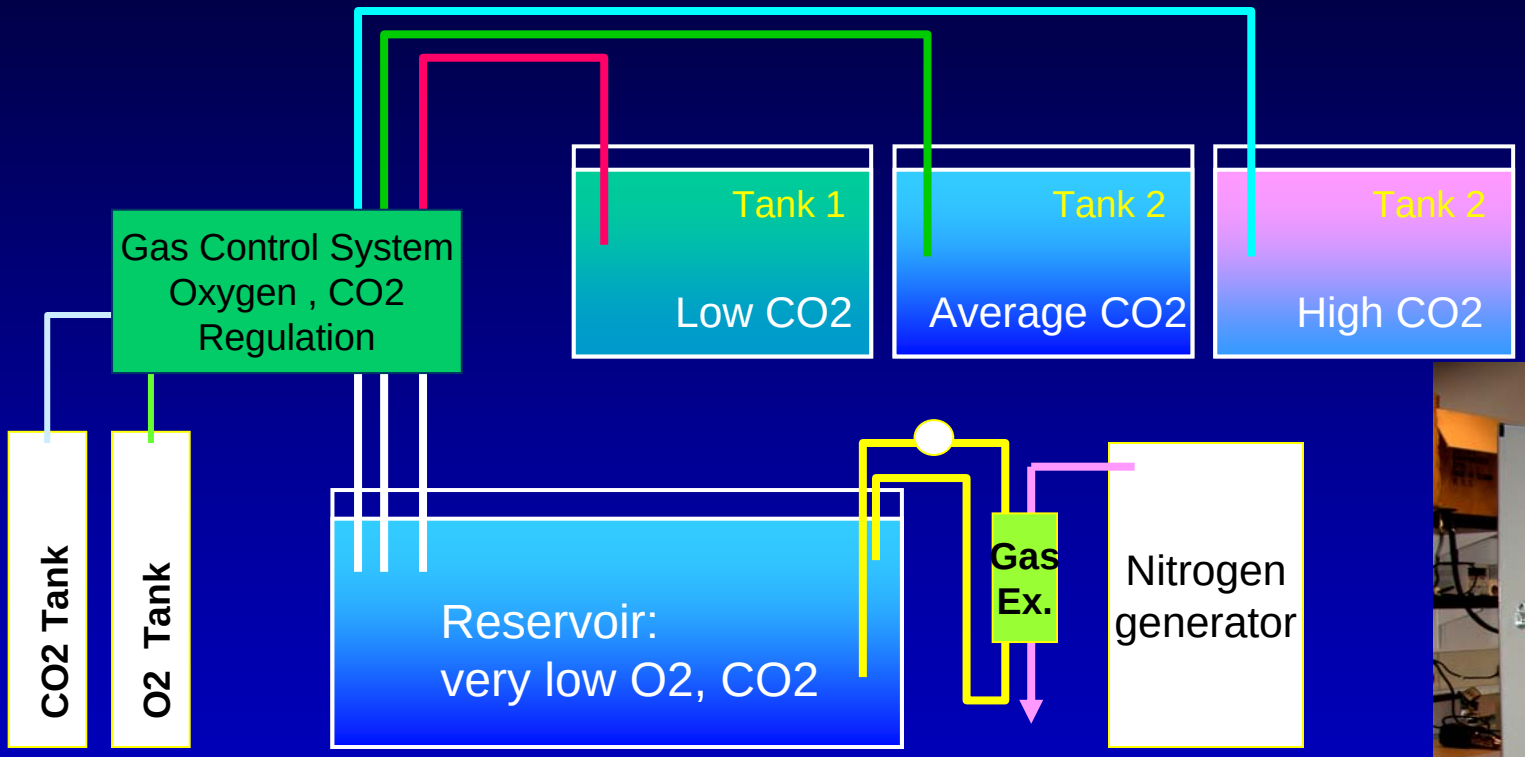
Time lapse video

Full CO_2 corral

pH/CTD sensor

Animal cage

Controlled-gas Aquarium System for lab-based studies of CO2 tolerance



- Control of temperature, oxygen, carbon dioxide
- Use:
  - Studies of chronic hypercapnia on marine animals
  - Growth rates, respiration, physiology

Summary of Expected Effects of Ocean Warming

Ocean Warming

- Increased stratification of surface waters, reduced primary productivity, cascading effects throughout the food chain.
  - Reduced catch for important fishery species
  - Reduced abundance of marine mammals and birds These phenomena are known best for short-term events (e.g. El Nino)
- Changes in species distributions, perhaps a disconnect between feeding and breeding grounds
- Warming-related mortality for coral reefs is expected to be severe
- Ocean communities will change with ongoing climate warming, perhaps drastically, but the nature of future ocean ecosystems remains unclear

Summary of Expected Effects of Ocean Warming

- Ocean acidification
  - Metabolic Stress (respiratory stress, acidosis, reduced calcification)
  - Marine calcifiers (from phytoplankton to corals) will be impaired, with as yet unknown consequences.
  - Plankton communities will likely change
  - Water-breathing animals will have higher costs for coping with CO2-related stress, resulting in lower growth, survival and reproduction
    - Unclear effects on food webs, but may include a loss of biodiversity, simplified food webs
  - Deep-sea organisms are the most sensitive to CO2-related stress (respiratory stress, acidosis)

- **Mitigation of climate warming and ocean acidification is essential**