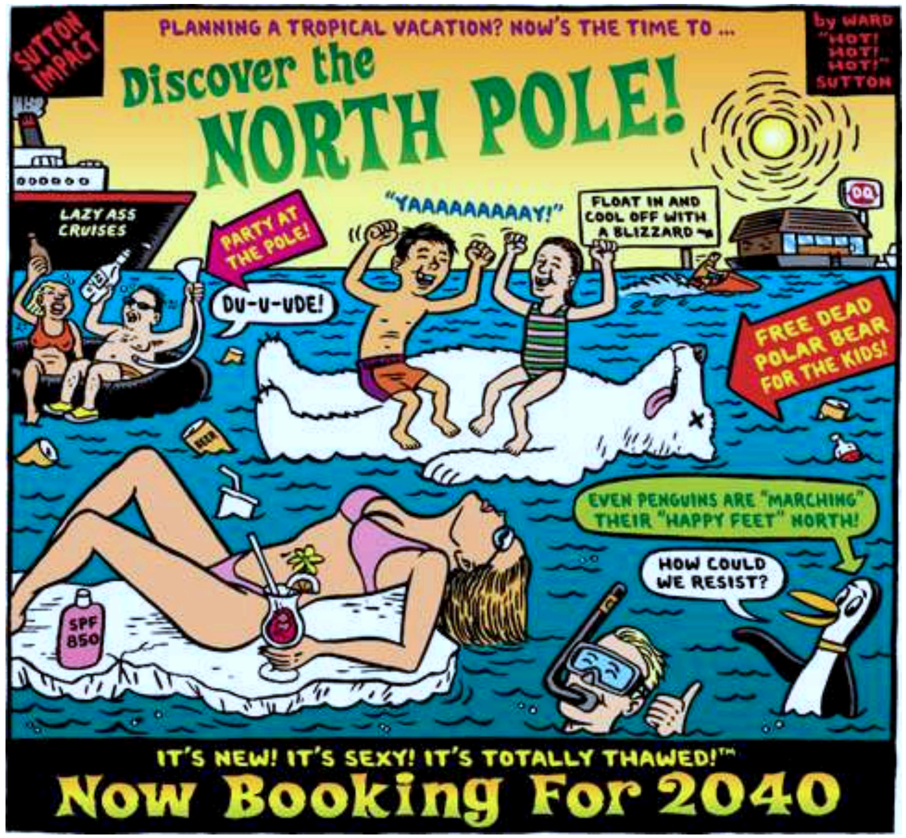
Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111



By Ward Sutton
Village Voice, December 2006

Quiz #2 next Tuesday on material through Thursday

Reading Assignment Revisions

Carbon Cycle required supplemental reading posted on moodle and noted on schedule (see class web site) by Turco
read **p307-308 FOR THURSDAY (for quiz #2)**, skim 309, read p 310-313 up to the integrated carbon cycle For Tuesday (so not on quiz #2)

New Extra Credit Opportunity Posted

Review a news article FROM OUR LIST

See course homepage

The Oceans (*RG p. 106-127*)

Finish up on Sea Level Rise

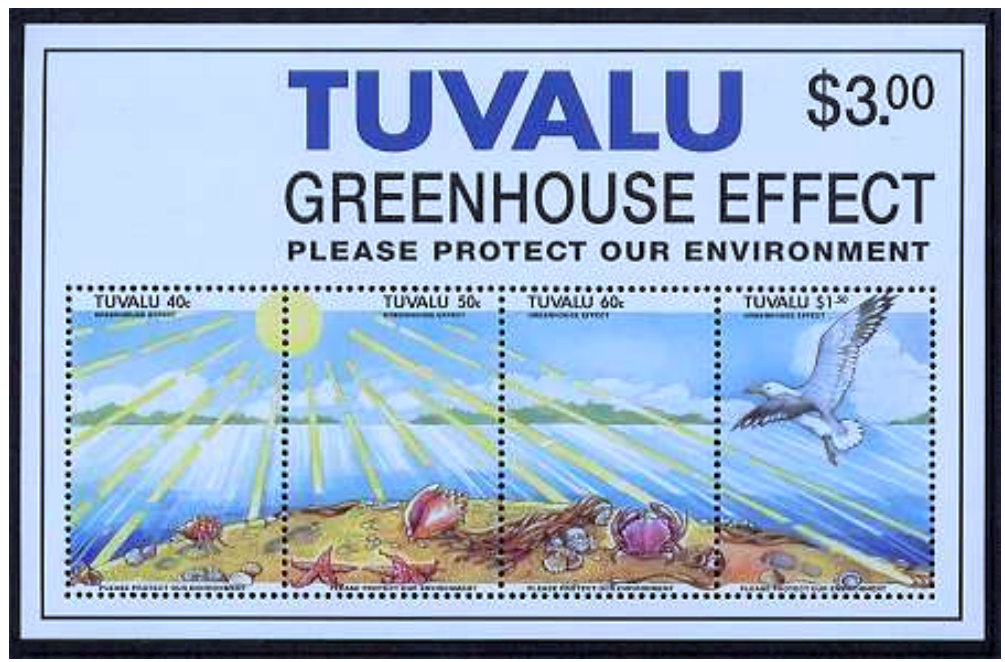
Climate change and El Niño

Will the Atlantic turn cold on Britain

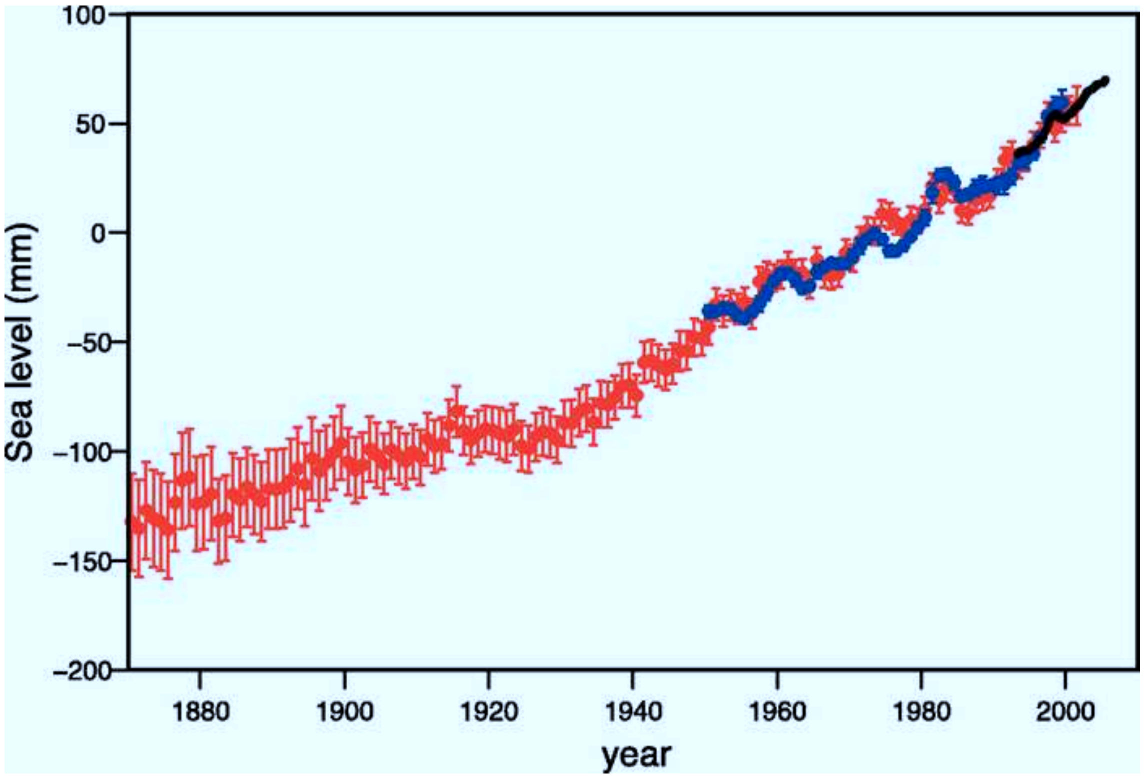
Living in a changing sea

Coral reefs at risk

ocean acidification



20th century rise was 1.2-2.2 mm/yr on average



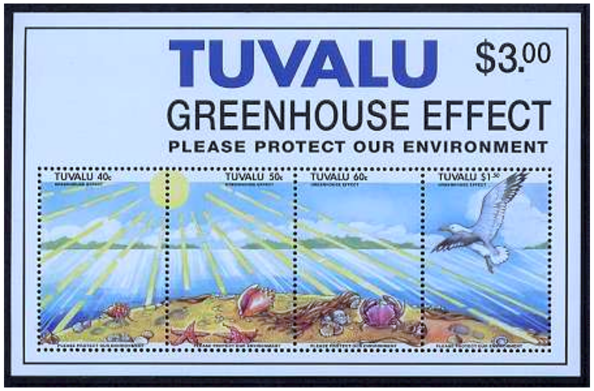
IPCC 2007 Figure 5.13
red = “reconstructed” from tide gauges and other
blue = tide gauges
black = satellite altimetry

Seattle sea level rise science/art project in 2009

Rough Guess of 2100 Storm Surge height

Costs of sea level rise

1) Wetland loss
2) Salinization of crops and aquifers
3) Constructing barriers
4) Relocation
5) Increased storm surge risk



Sugiyama et al 2008 MIT science policy group

Population Distribution

11 of the 15 largest cities in the world are along coasts or estuaries

"It was estimated that in 2003, approximately 153 million people (53 percent of the nation's population) lived in the 673 U.S. coastal counties, an increase of 33 million people since 1980."

The population living within 1 m of sea level is unknown

More than 1 trillion cost globally, mostly from wetland loss

EPPA regions	Present values of cost and loss: Total	Protection	Capital	Net wetland	% of wetland	Protection fraction [%]
Global	1182.21	126.35	37.94	1017.93	86.10	29.86
United States	317.72	10.31	3.32	304.09	95.71	40.14

Costs in billions of US dollars in 1995
For raising sea level 1m in one century

Sugiyama et al 2008 MIT science policy group

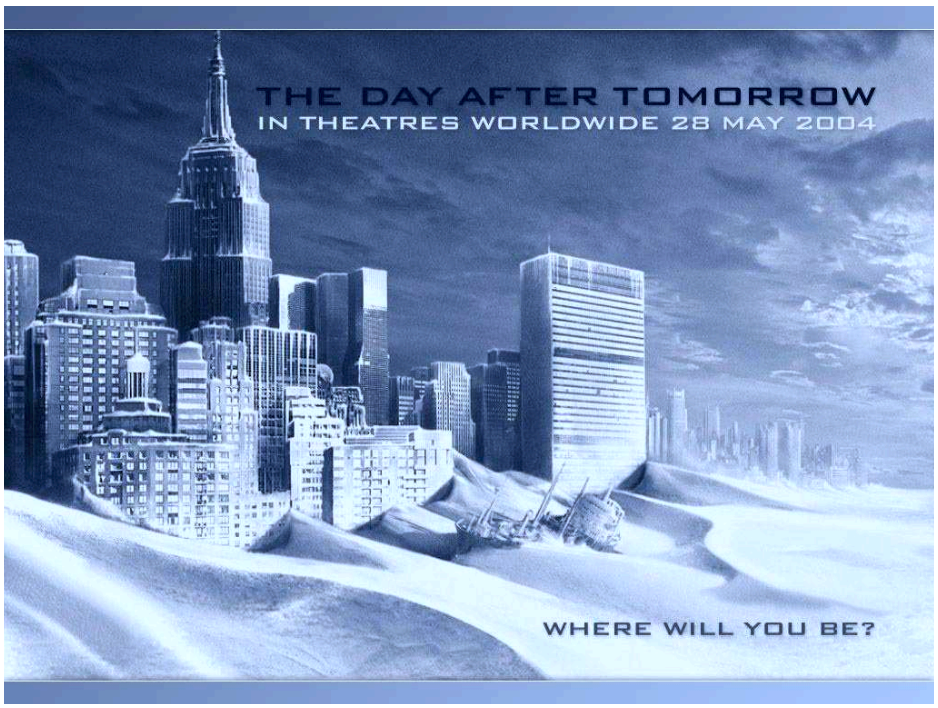
Value of Wetlands

"Wetlands are considered valuable because they clean the water, recharge water supplies, reduce flood risks, and provide fish and wildlife habitat. In addition, wetlands provide recreational opportunities..."

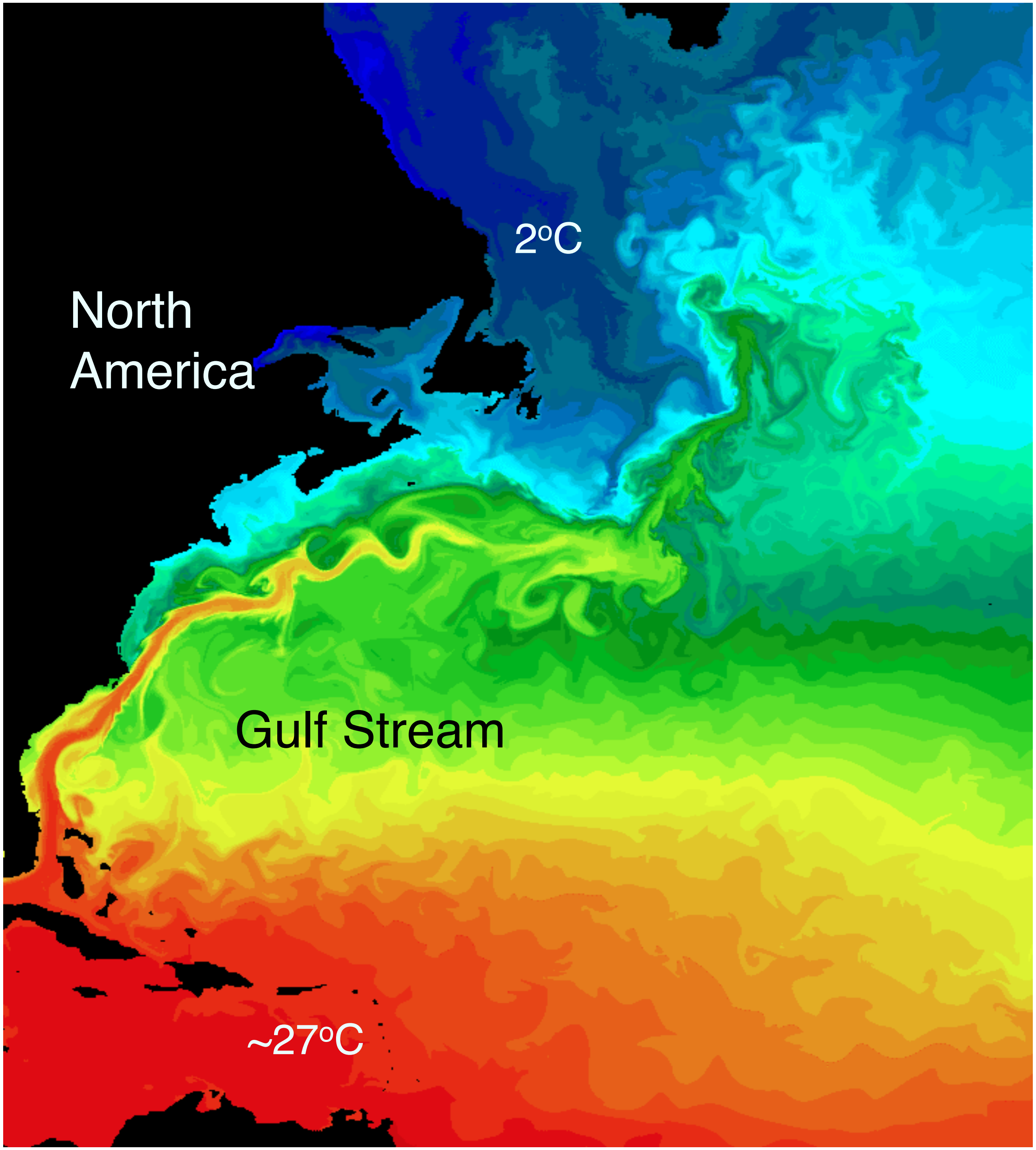
EPA Wetlands fact sheet

"The Day After Tomorrow" had it wrong: a disintegrating floating ice shelf is sea level neutral. The cooling that ensued should have caused sea level to drop! It wouldn't cause hurricanes over land either.

(All this is forgivable for making science cool.)



What is wrong with this picture?



Gulf Stream transports heat

it is mostly wind driven (not subject to stopping)

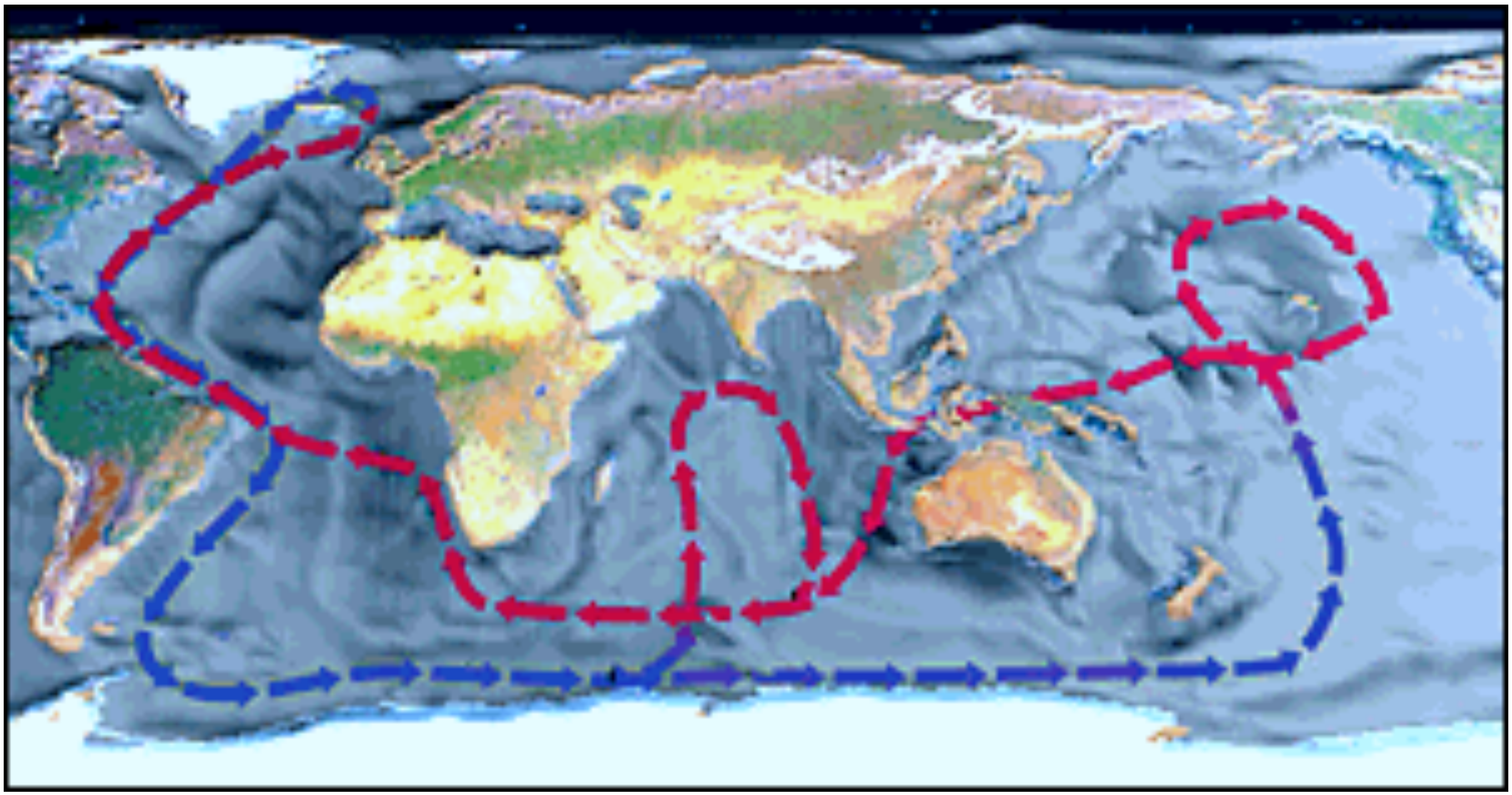
Colors show Temperature

AVHRR satellite

Thermohaline circulation sinking driven by production of heavy water near poles “deep water production”

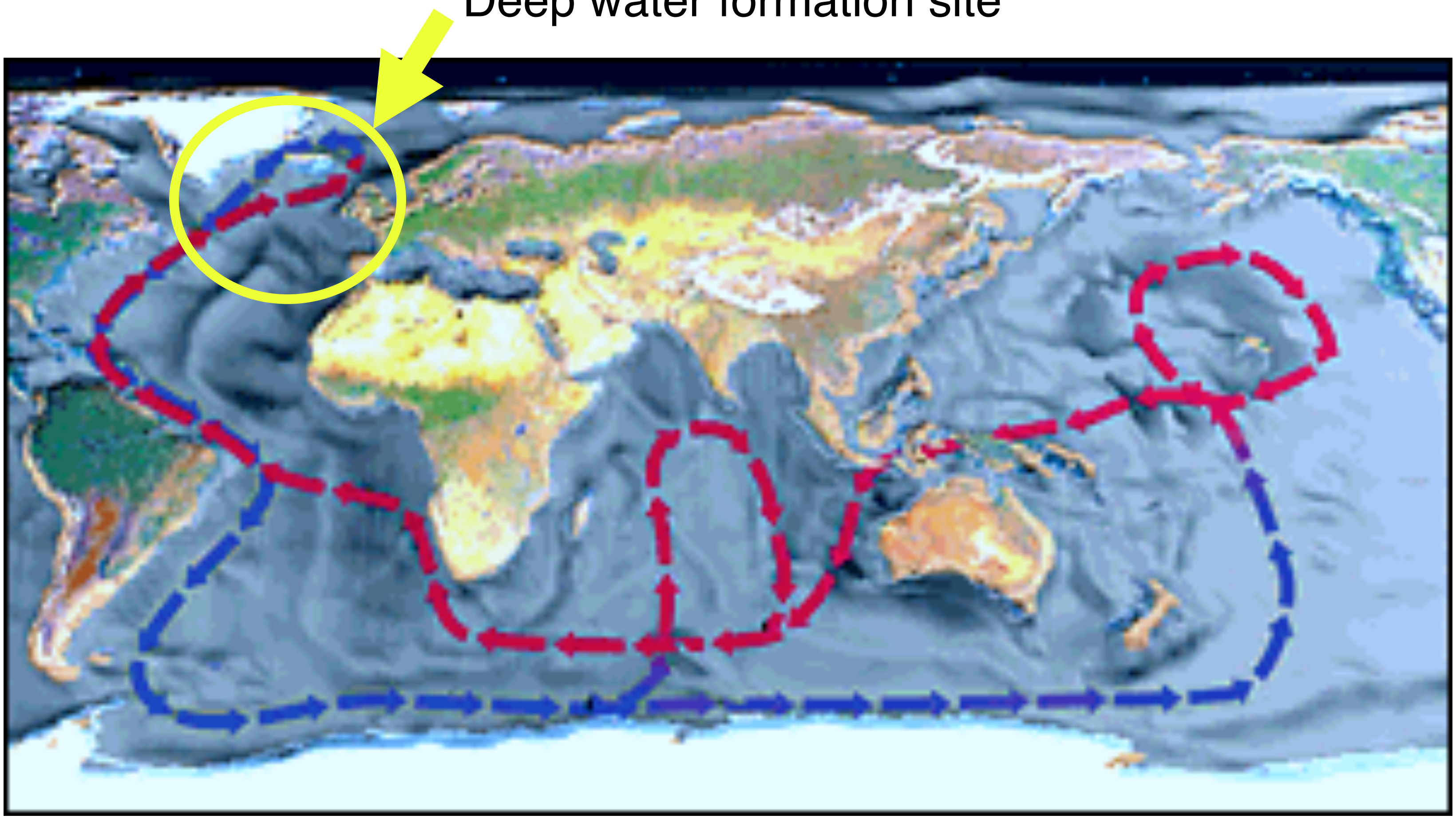
Upwelling is widespread and driver is still debated

Moves heat especially from tropical Atlantic to subpolar Atlantic.

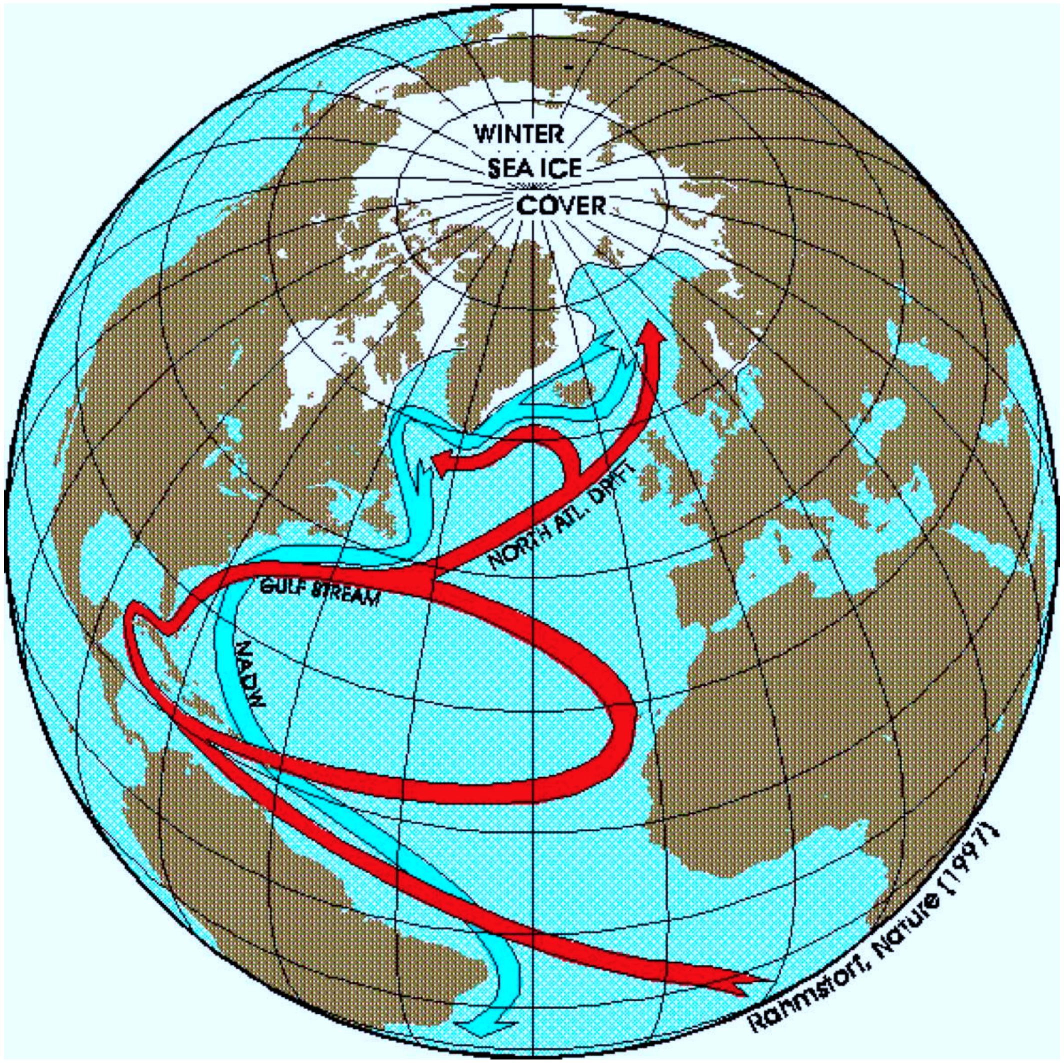


Sometimes called a conveyer but keep in mind that it takes ~1,000 years for a drop of water to make the circuit

Deep water formation site



Atlantic circulation



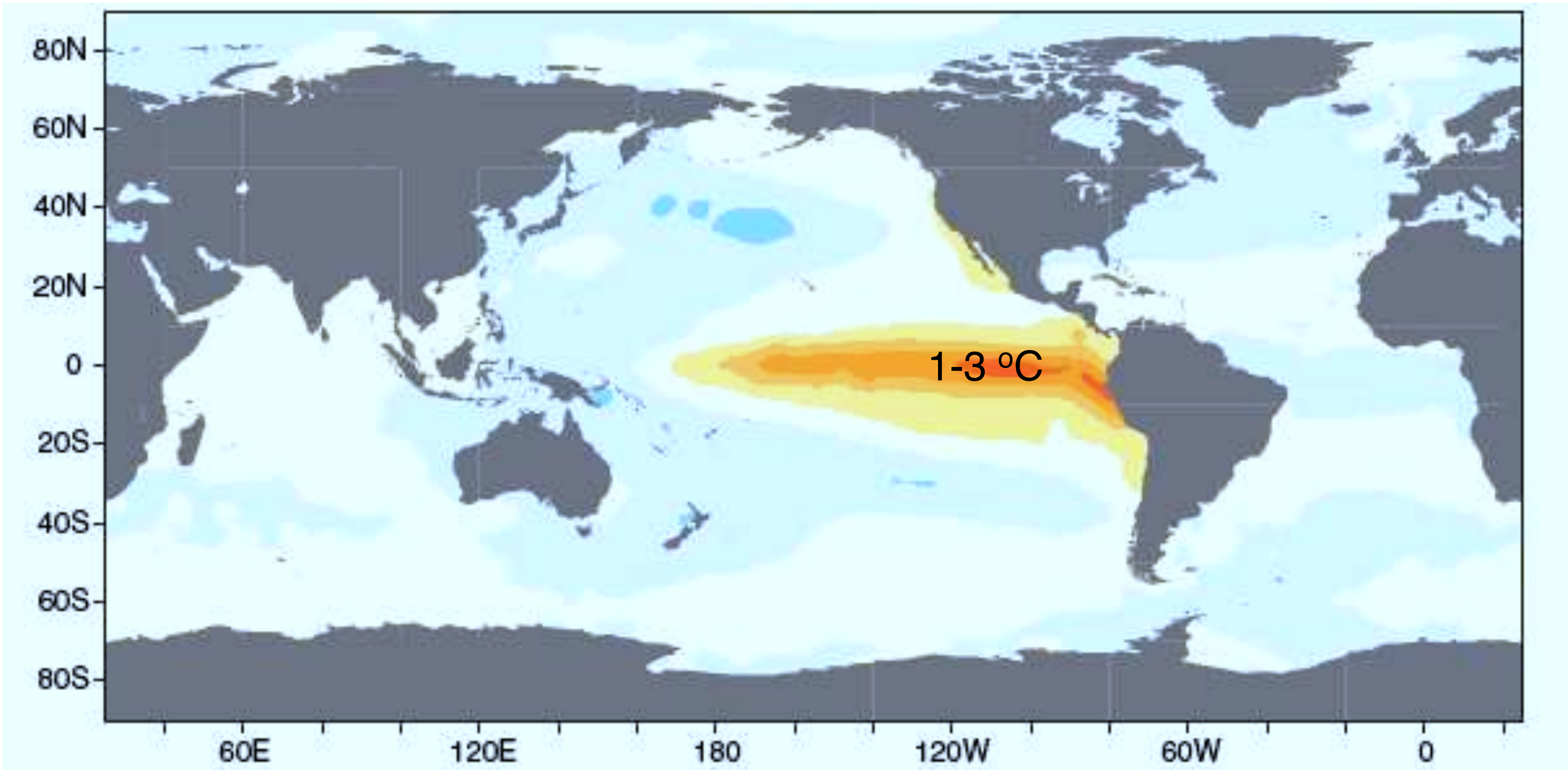
Red branches carry heat northward

When water loses enough heat it tends to sink

Weaken this circulation would cool England and Norway

Global warming is expected to enhances buoyancy, as the water would not lose as much heat.

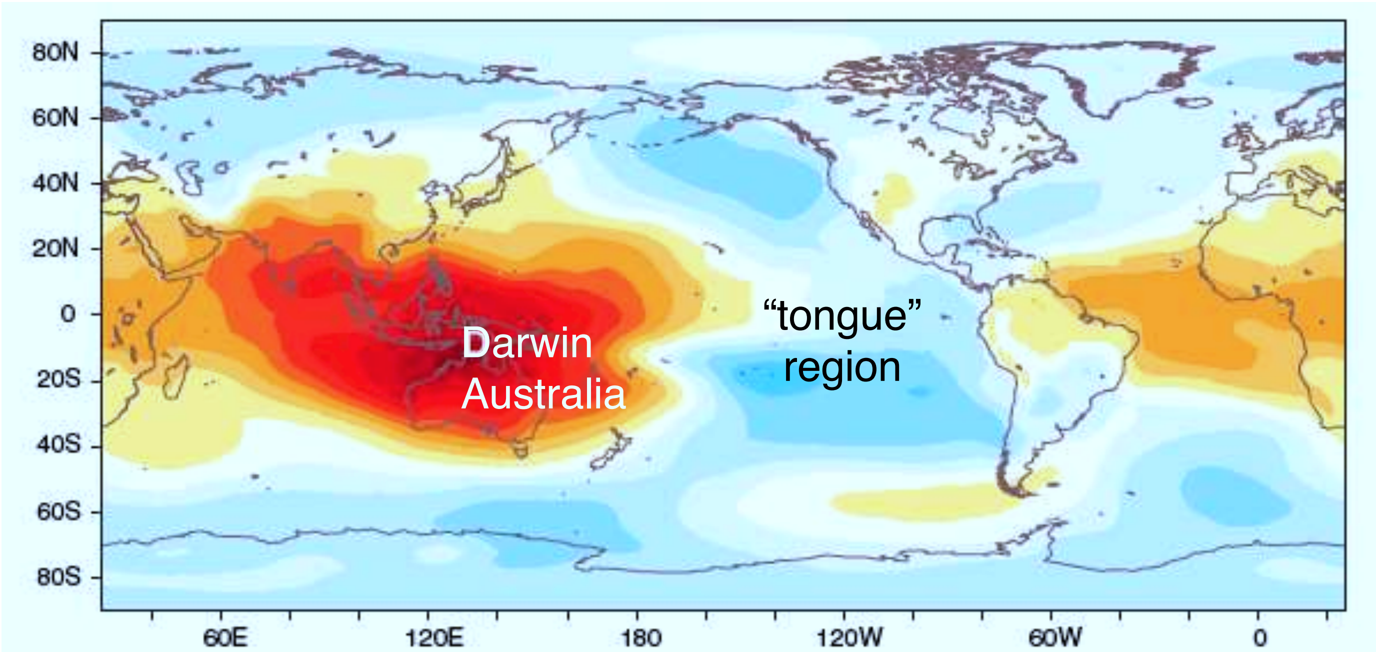
Climate change and El Niño or ENSO



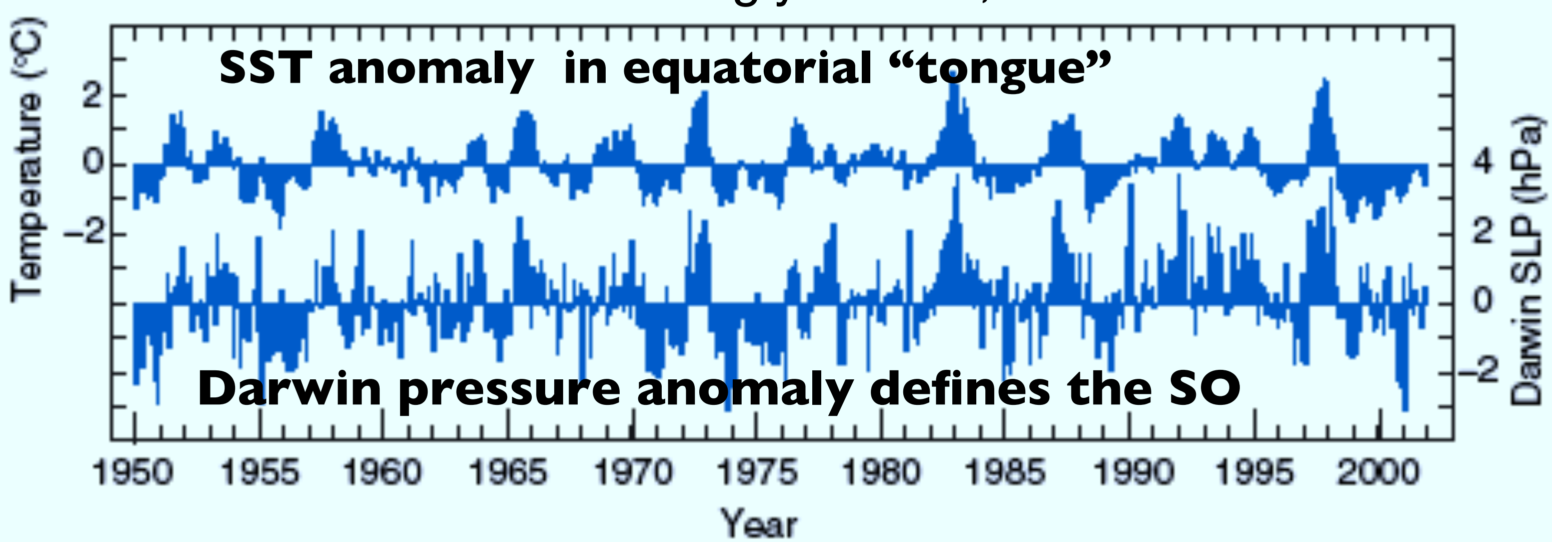
The sea surface temperature SST *anomaly* of El Nino

ENSO = El Nino/Southern Oscillation, where the SO part describes the associated variations in atmospheric circulation.

This is the Southern Oscillation pattern of ENSO



SO and SST are strongly related, thus the "ENSO"



Coral reefs at risk

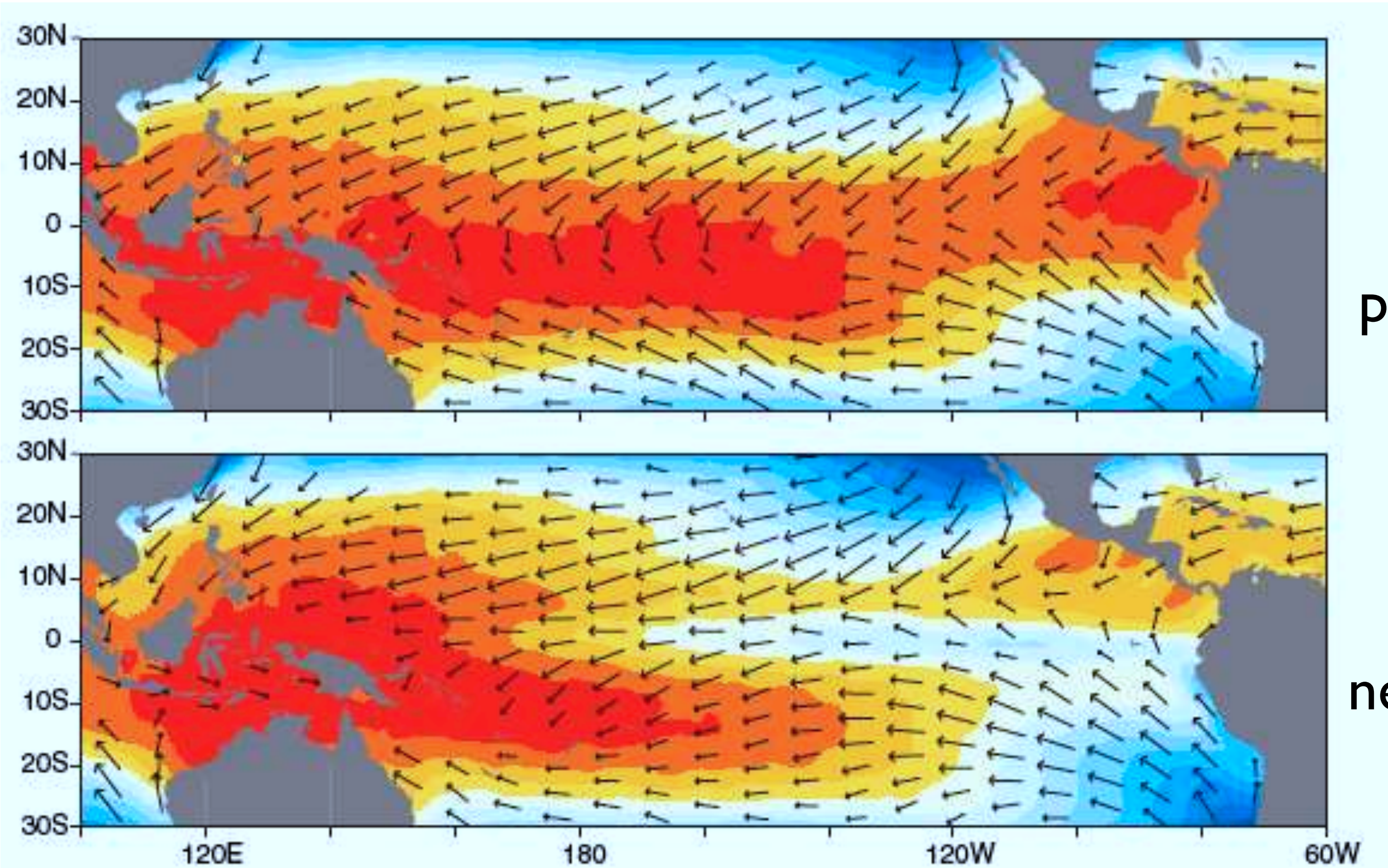
Why is El Ninõ of interest in a global warming course?

It provides an example of widespread climate impacts and how ecosystems and society adapt to them

Climate models indicate a shift in the mean climate toward a more “El Niño-like” state as the Earth warms. Hence “El Nino” is an analog for global warming.

SST and wind patterns with El Nino and La Nina

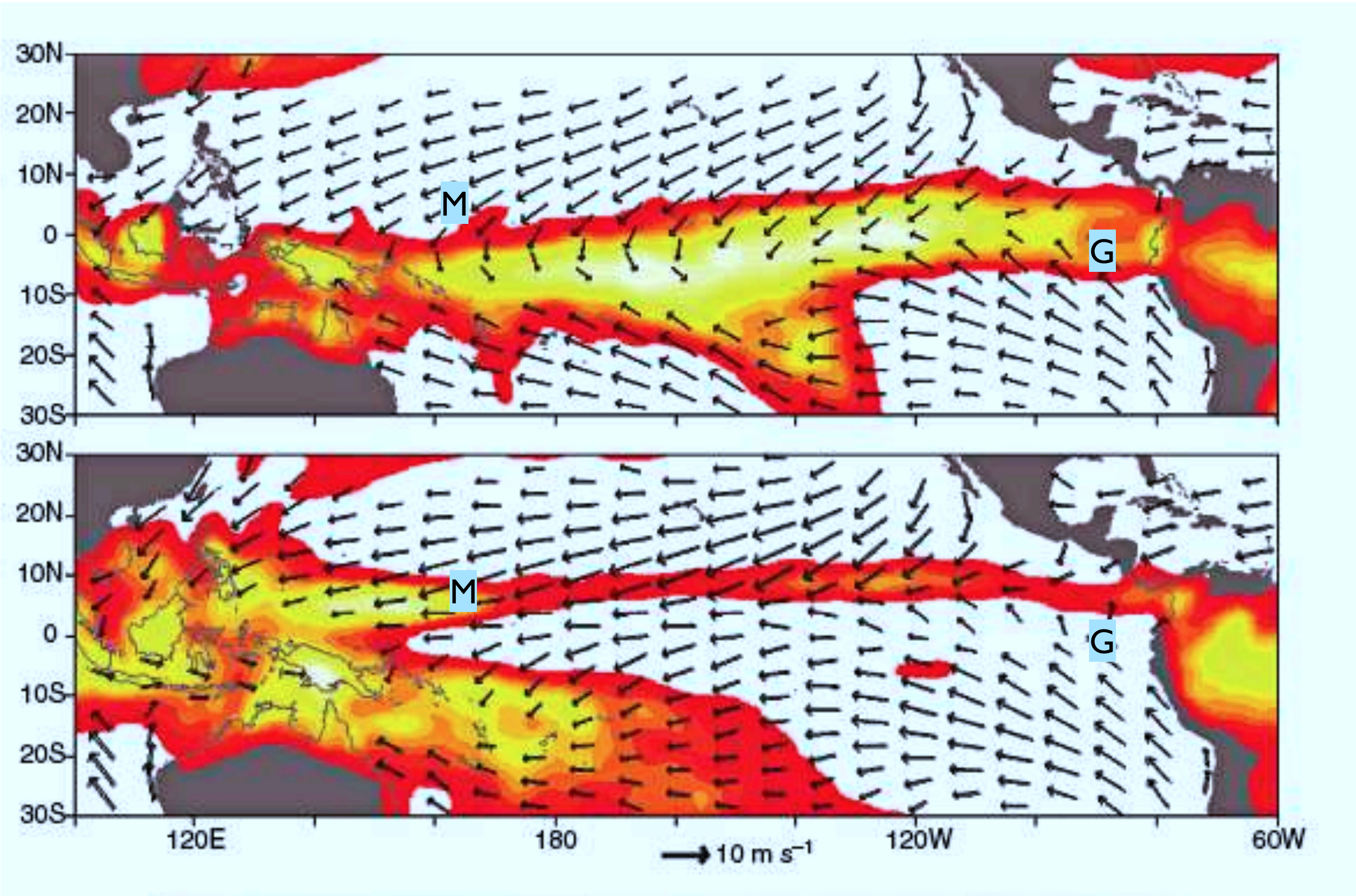
pressure gradients make winds, more about this in a few weeks



El Niño
or
positive ENSO

La Niña
or
negative ENSO

During El Nino, winds on the equator relax (or turn around a bit)
During La Nina, winds on the equator strengthen

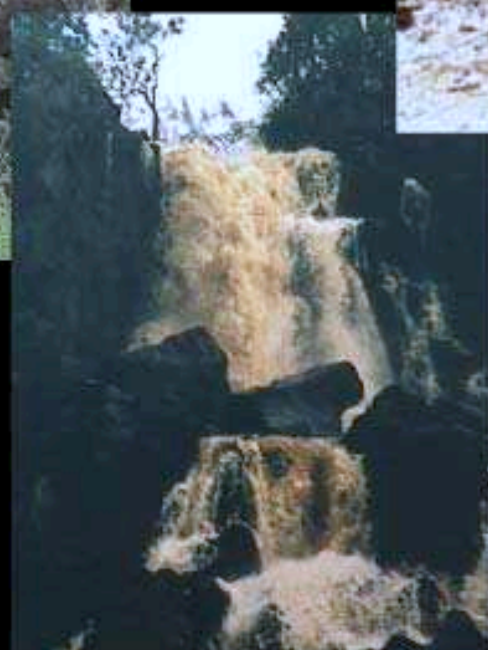


El Niño

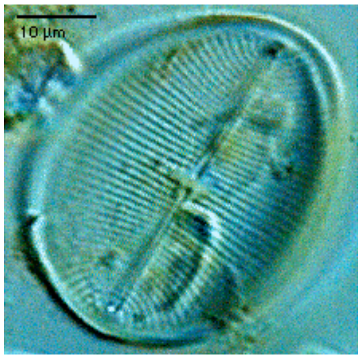
La Niña

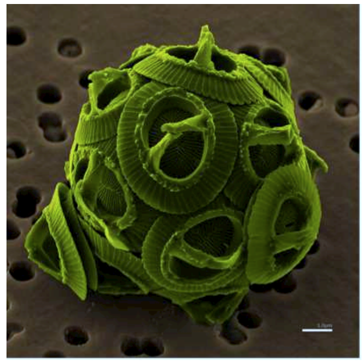
Yellow represents the regions of highest rainfall and arrows denote surface winds. M denotes Marshall Islands, G the Galapagos Islands

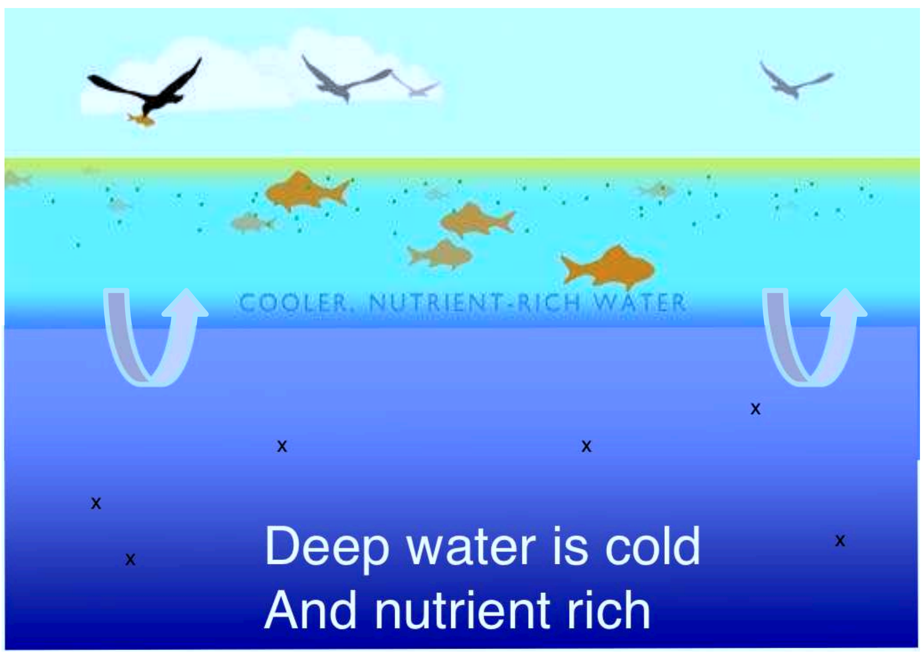
Impacts of El Niño on the Galapagos



Phytoplankton and Ocean nutrient cycle
“Biological Pump”



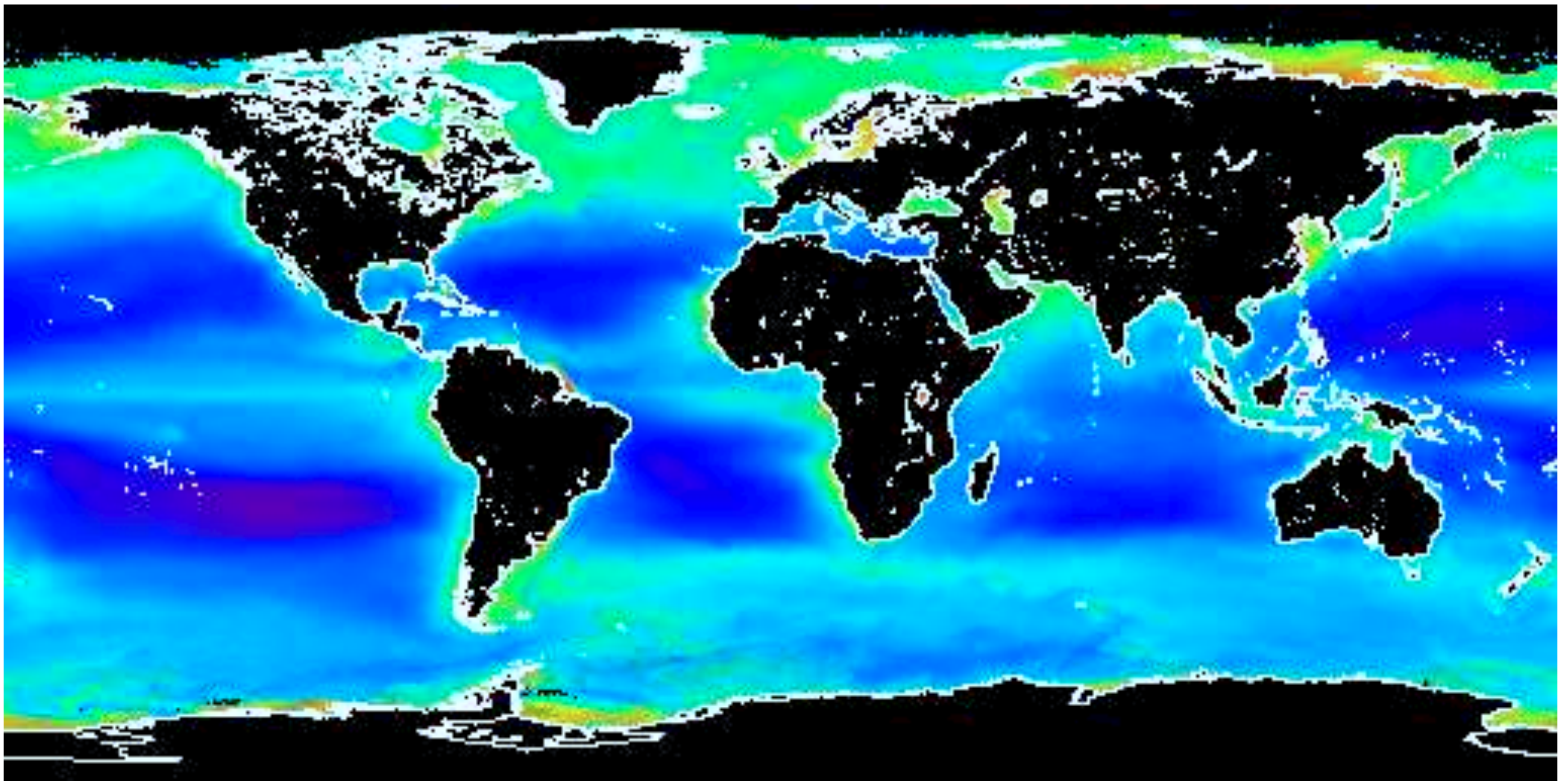


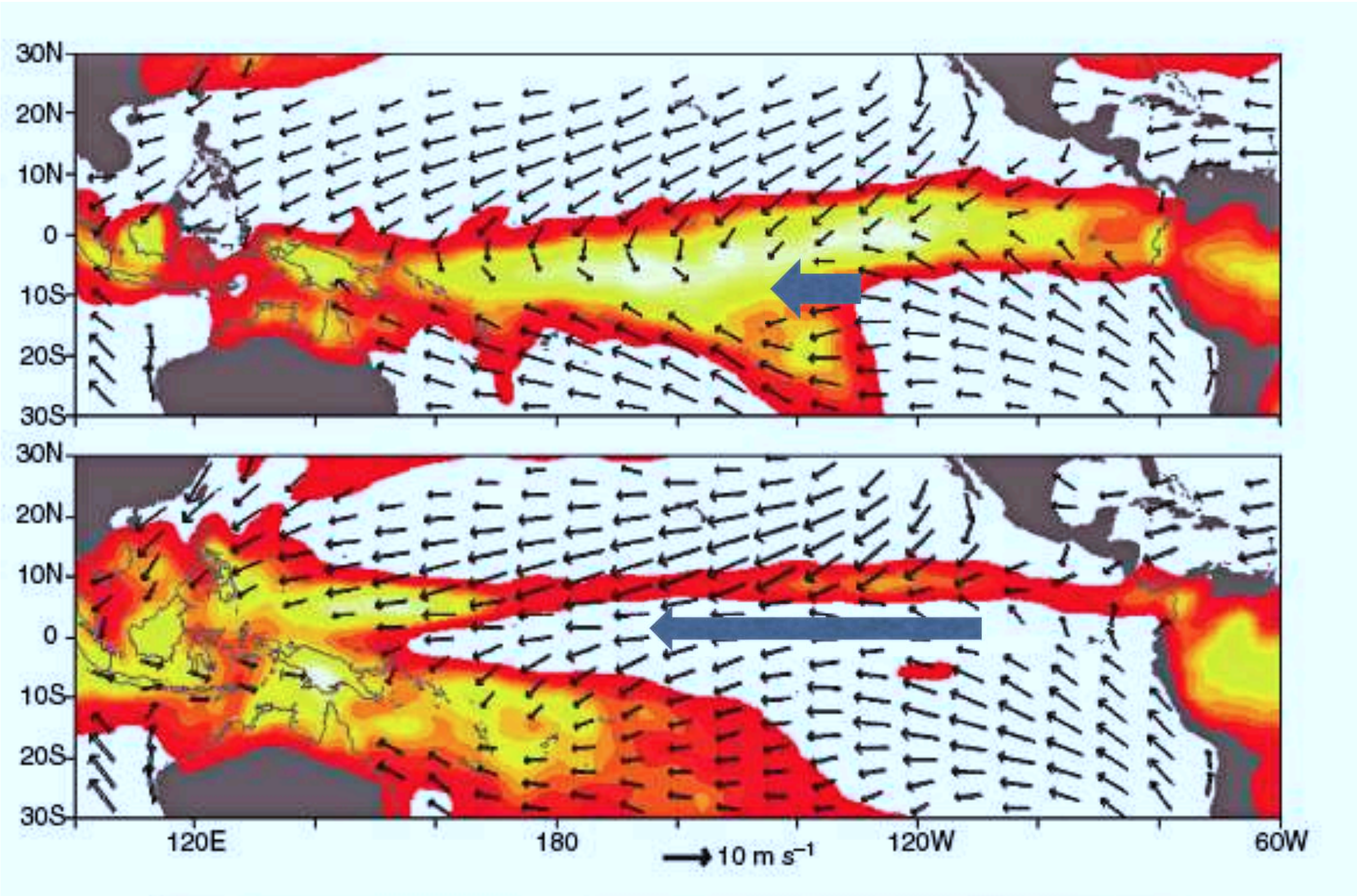


- •Photosynthesize (like plants they have chlorophyll) utilize sunlight and uptakes CO2
- •Deplete surface nutrients
- •Rain nutrients at depth when they die and sink (x’s at left)
- •Decomposition makes deep water CO2 and nutrient rich
- •Need recirculation with deep to replenish surface nutrients (grey arrows at left)

Ocean color from Seawifs satellite

"lighter colors" are high in phytoplankton chlorophyll indicating mixing with deep ocean

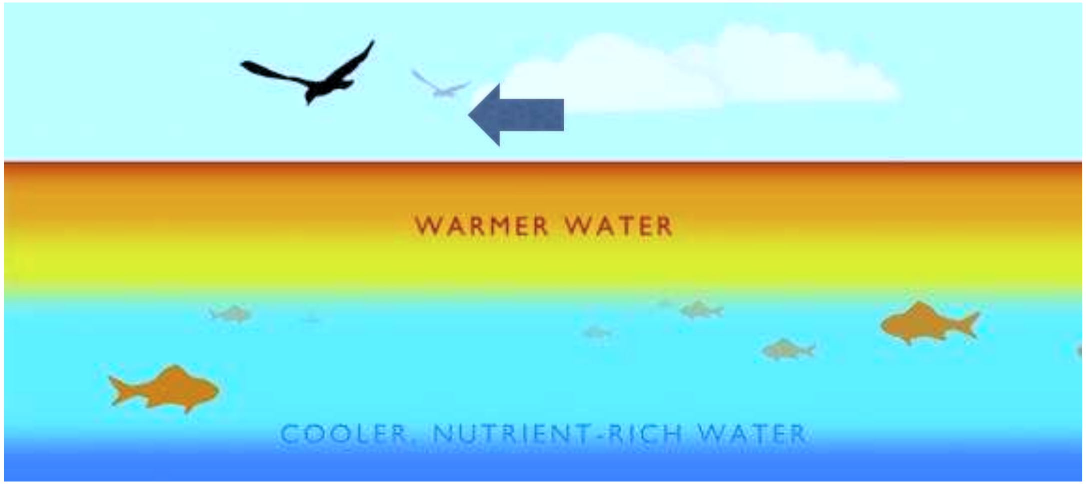




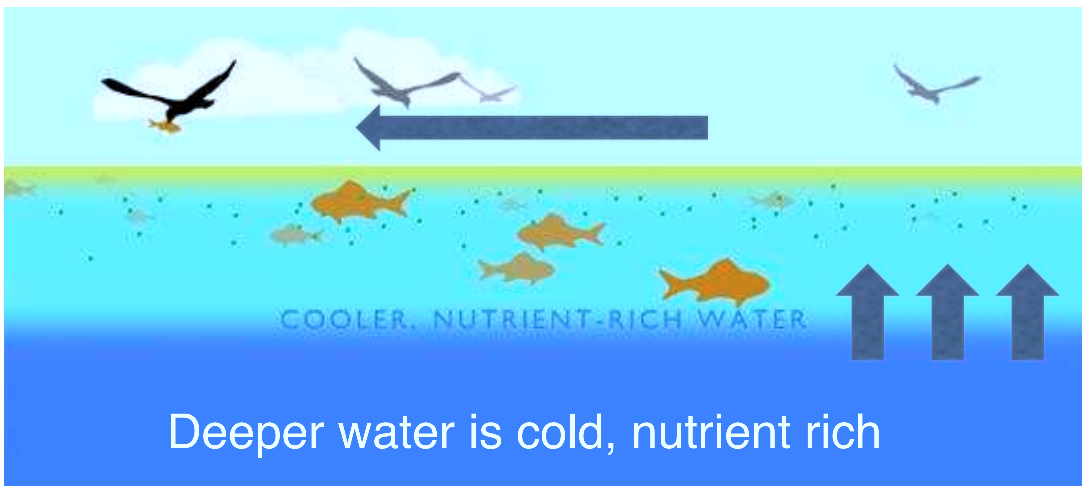
El Niño

La Niña

Weaker easterly wind during El Nino pulls less water away from S. America and inhibits coastal upwelling.
Reduces nutrients for fish, so fish and sea birds die. Big $ impacts

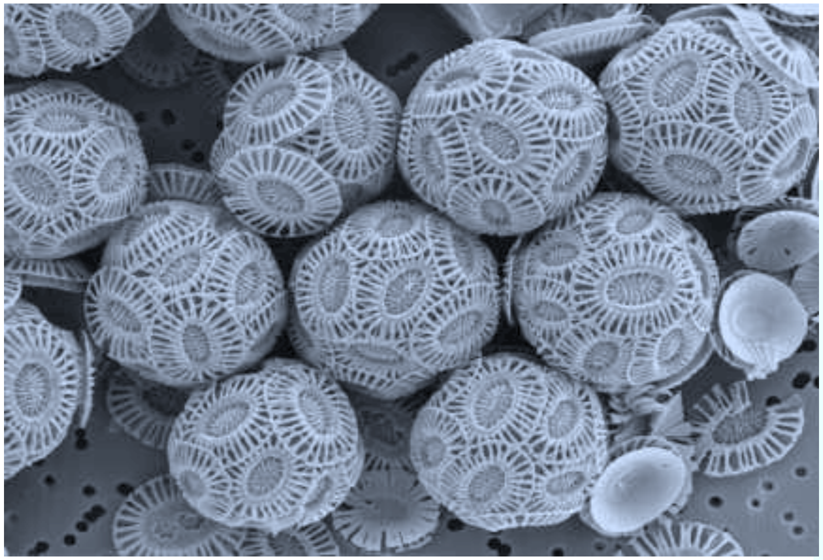


Eastern Pacific
El Niño



Eastern Pacific
La Niña

In La Nina, the water is upwelling so it is cold and nutrient rich. In contrast, water long present at the surface is depleted by creatures who then sink and deposit their nutrients below the surface.



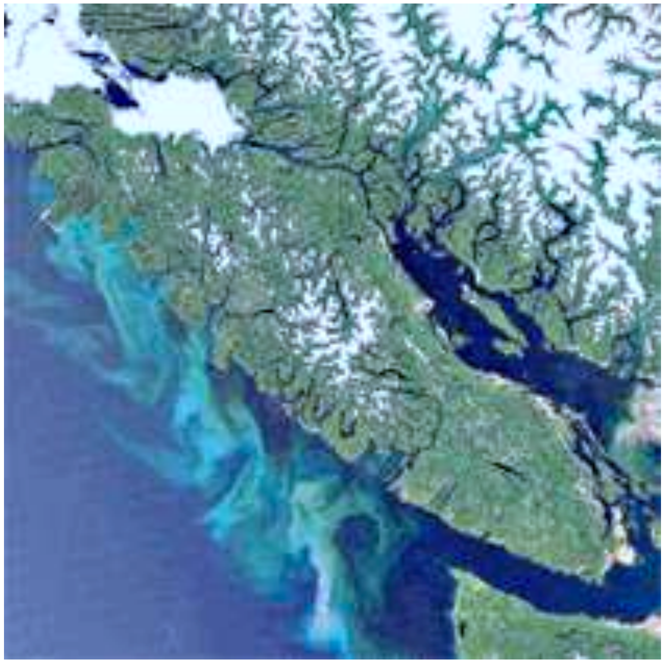
Emiliania huxleyi

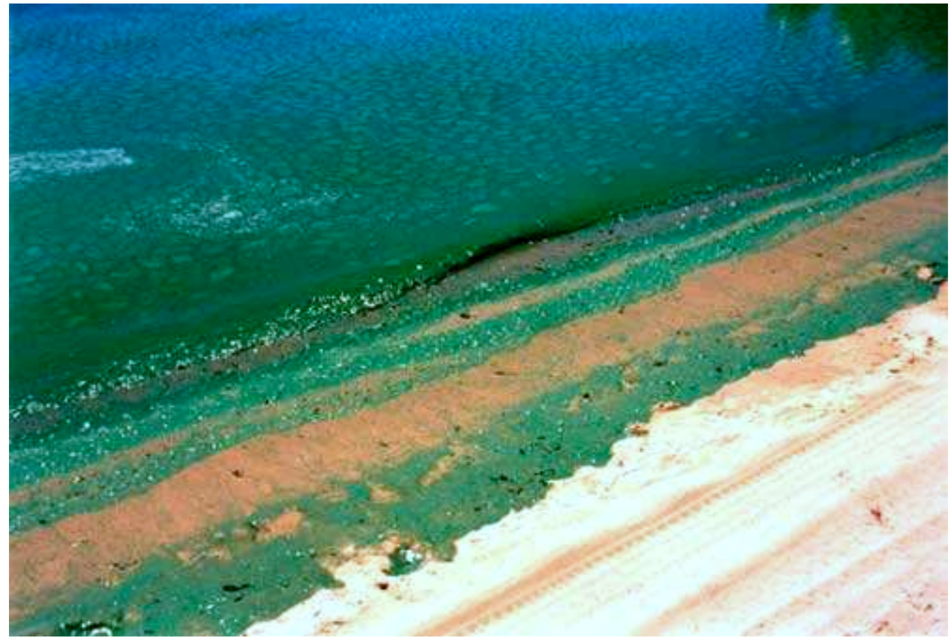
planktonic coccolithophorids
covered with scales of
calcium carbonate

abundant in ocean
can form large blooms

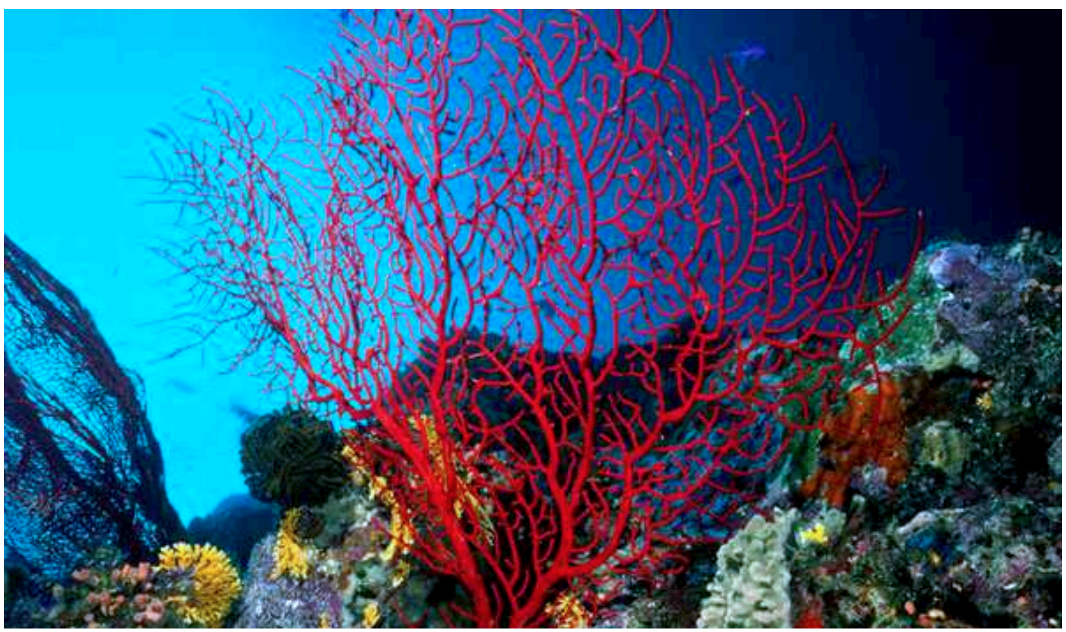
www.co2.ulg.ac.be/peace/intro.htm

Harmful algal (a plankton) blooms (HABs)



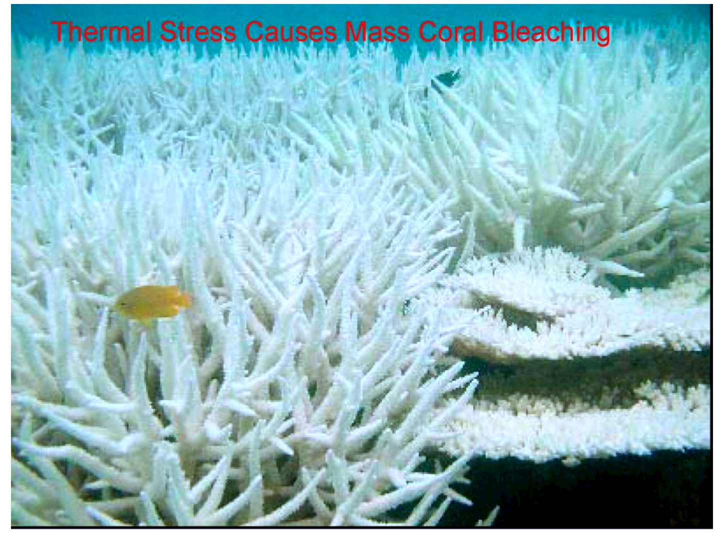


Coral reefs at risk


Projected changes due to temperature

Coral Bleaches in high temperature

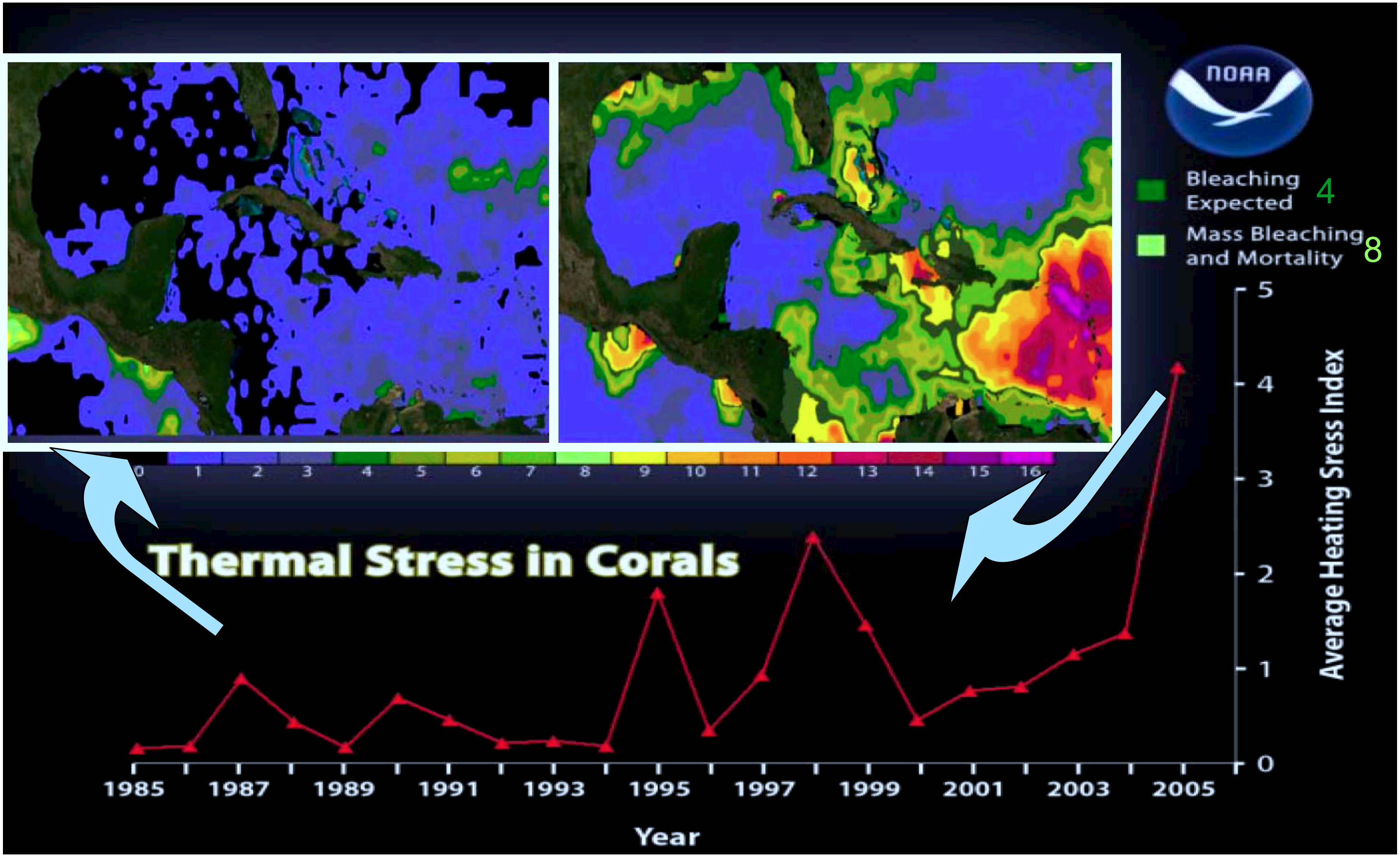


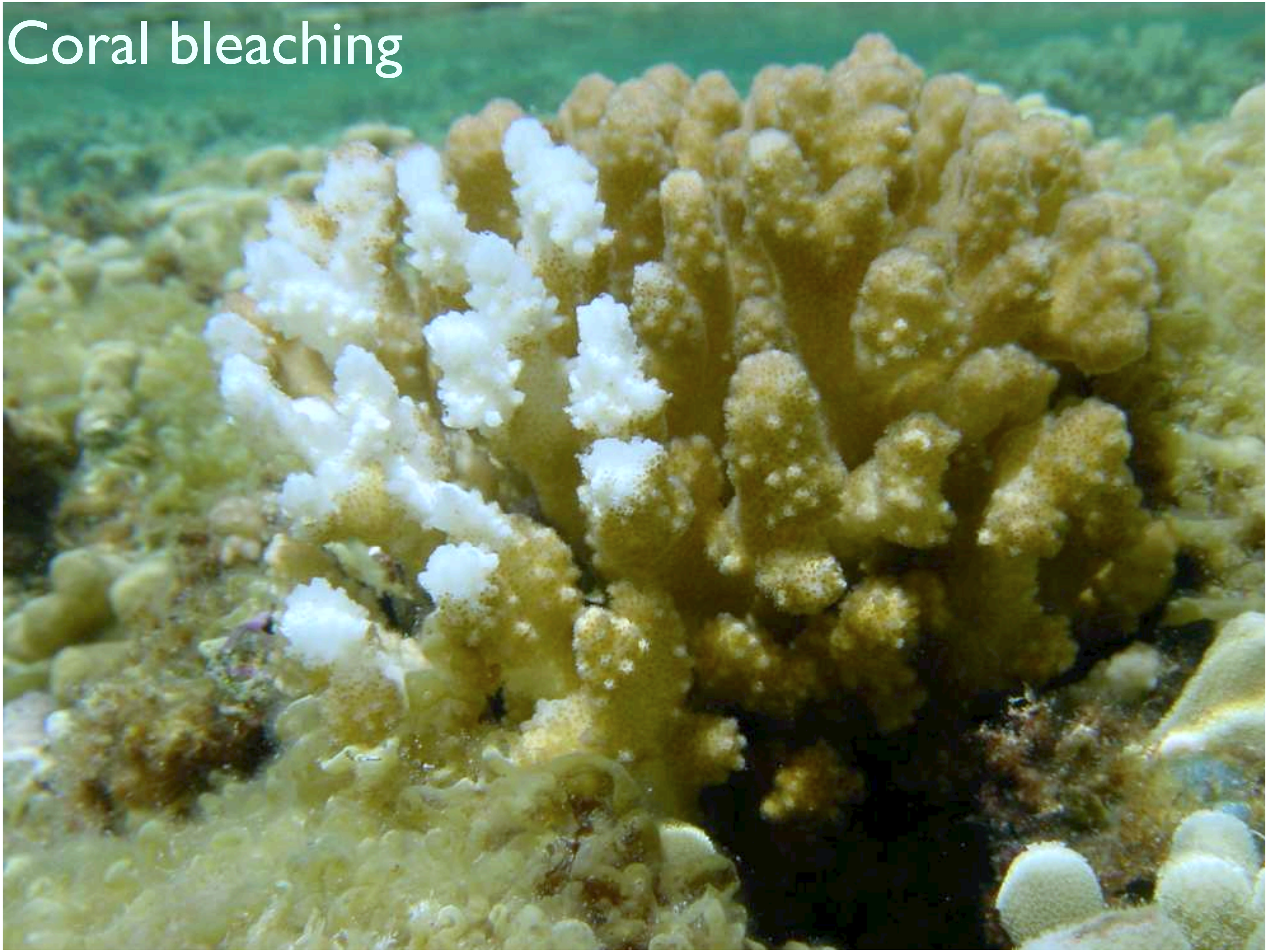
Coral health is highly dependent on a symbiont phytoplankton algae that provides nutrients for slow growing coral
Algae dies/leaves when the temperature exceeds about ~24°C, so color of reef reflects color of underlying coral (white).

Coral is then vulnerable to harmful UV radiation
impact is greater at higher temperature and lower pH

Projected changes due to temperature

Coral Bleaches in high ENSO years and with global warming




Coral bleaching

Projected changes due to temperature

Severe coral bleaching (1979-2008)

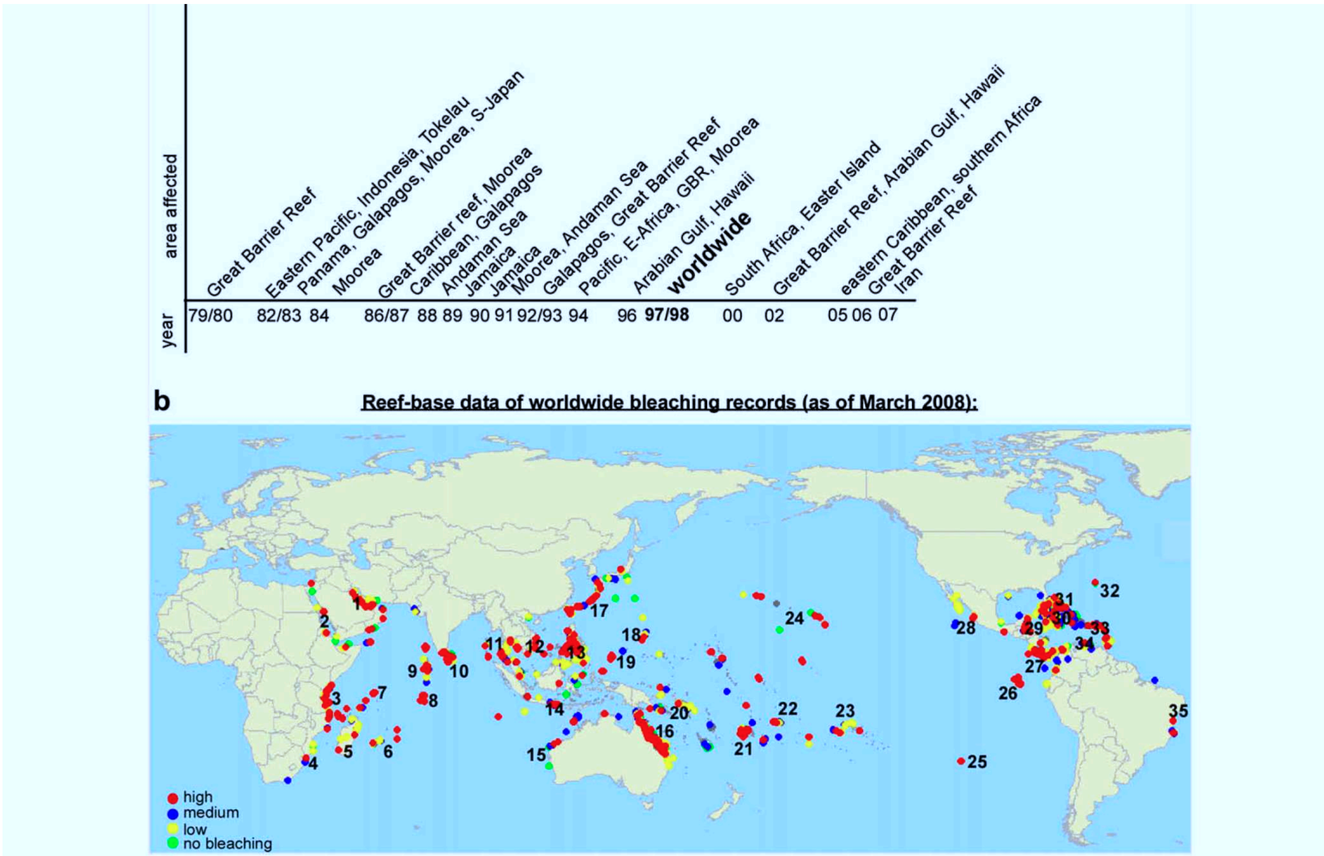


Fig. 3. Incidence of coral reef bleaching on a worldwide scale. (a) Selected bleaching years and locations (from various sources; Brown, 1987; Glynn, 1993, 1996; Coles and Brown,

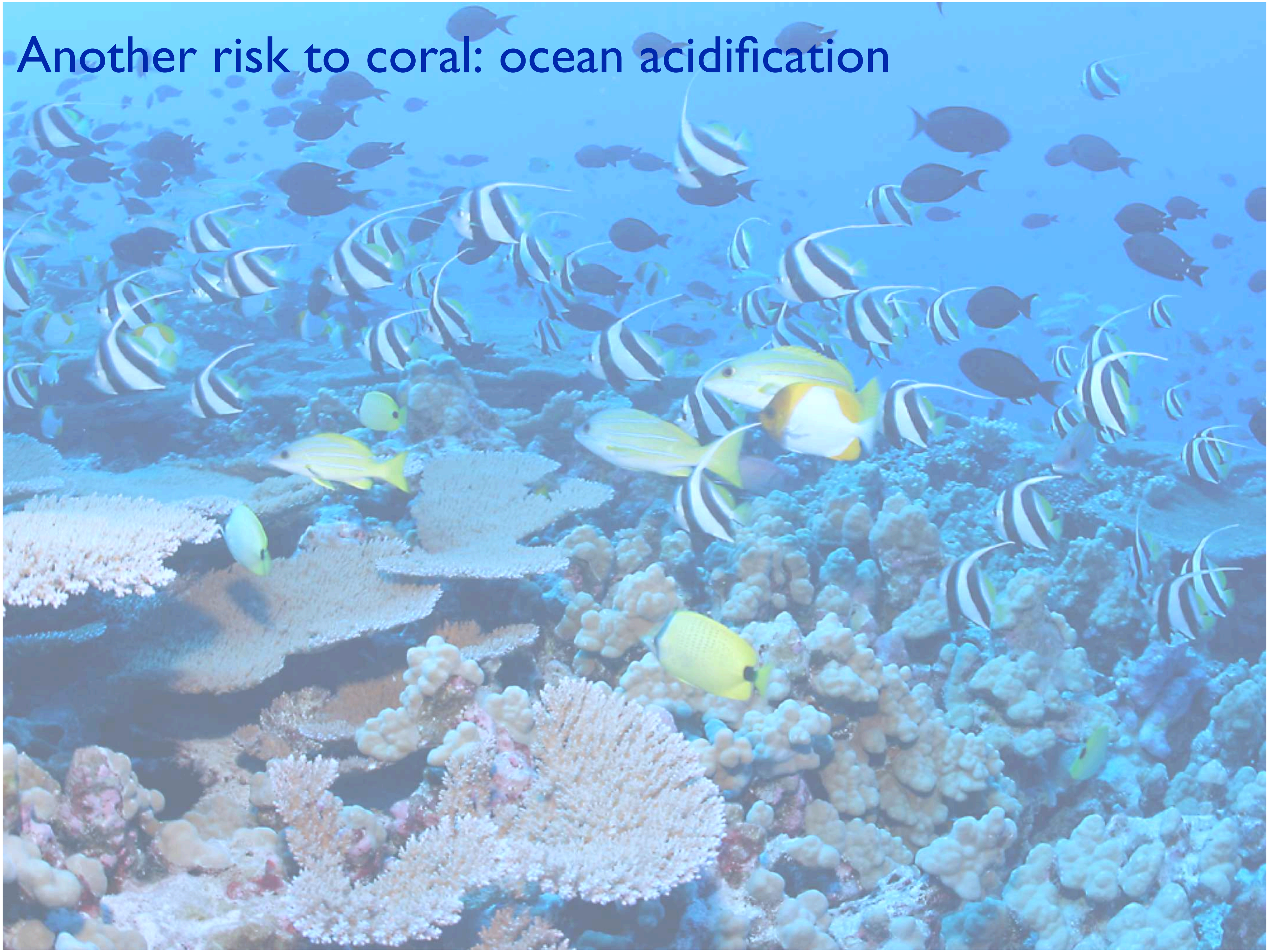
“By 2030 or 2050, bleaching thresholds will be exceeded annually or bi-annually at the majority of reefs worldwide”

Projected changes due to temperature (more)

Increased disease in fish
Poleward movement of some species
Tuna, marlin, cod, …
Increased mortality of winter flounder eggs and larvae
Marine mammals, birds, cetaceans and pinnipeds (seals, sea lions and walruses), which feed mainly on plankton, fish and squid, are vulnerable to climate change-driven changes in prey distribution, abundance and community composition in response to climatic factors
Nesting biology of sea turtles is strongly affected by temperature, both in timing and in the determination of the sex ratio of hatchlings

Source: IPCC 2007 WG2

Another risk to coral: ocean acidification



Chemistry of ocean acidification

What happens when you open a can of sparkling water?

CO2 comes out of the water.

The opposite is happening on Earth today. So CO_2 is going into the ocean. *And this acidifies the ocean…*

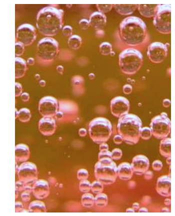
When CO_2 dissolves in water, carbonic acid is produced via the reaction:

$$\mathbf{CO_2\ (aq) + H_2O <-> H_2CO_3}$$

This carbonic acid is like sparkling water.

Chemistry of ocean acidification

When CO2 dissolves in water, carbonic acid is produced via the reaction:



$$CO_2\ (aq) + H_2O \leftrightarrow H_2CO_3$$

Acid dissociate into ions, including hydrogen ion

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

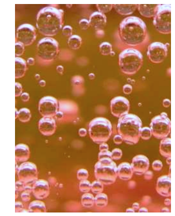
The increase in the hydrogen ion concentration causes an increase in acidity, since acidity is defined by the pH scale, where pH = -log [H+] (so as hydrogen increases, the pH decreases).

This log scale means that for every unit decrease on the pH scale, the hydrogen ion concentration has increased 10-fold.

so far the hydrogen ion concentration has increased by 30%

Chemistry of ocean acidification

When CO2 dissolves in water, carbonic acid is produced via the reaction:



$$CO_2\ (aq) + H_2O \leftrightarrow H_2CO_3$$

Acid dissociate into ions, including hydrogen ion

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

H^+ reacts with carbonate ion as in

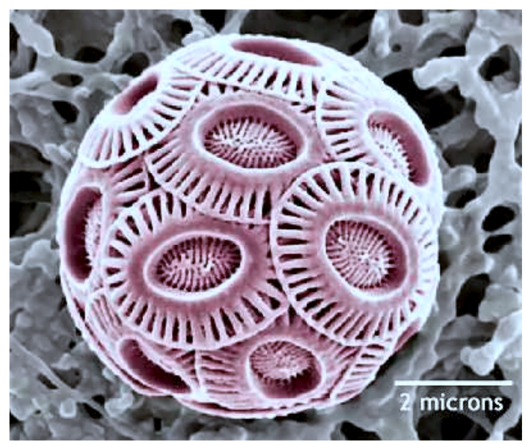
$$H^+ + CO_3^{2-} \leftrightarrow HCO_3^-$$

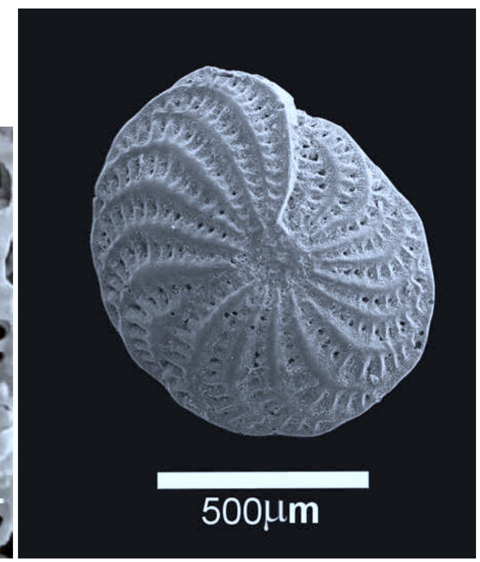
In your stomach or in the ocean, the chemistry is the same

The source of the carbonate ions CO_3^{2-} is calcium carbonate $CaCO_3$

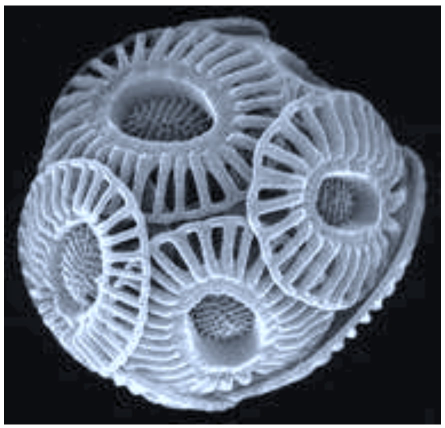
Just as the Tums react with acid, creatures with shells (same material as Tums) also react

Such as phytoplankton, which is responsible for 1/3 of all photosynthesis on the planet and feeds the marine food web.



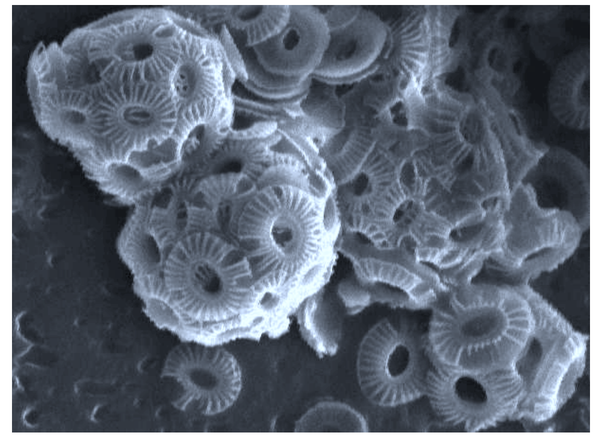


normal coccolithophorid



10-30 microns

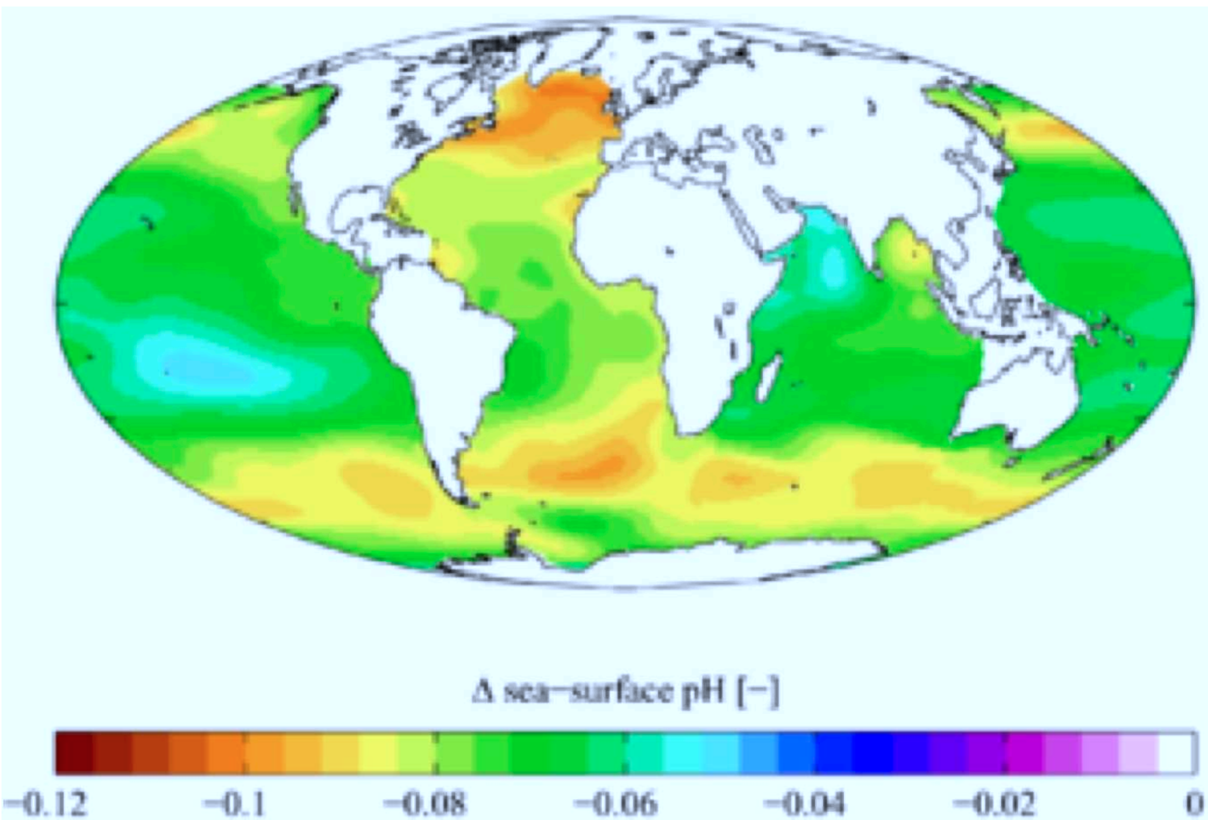
coccolithophorids in acidified conditions

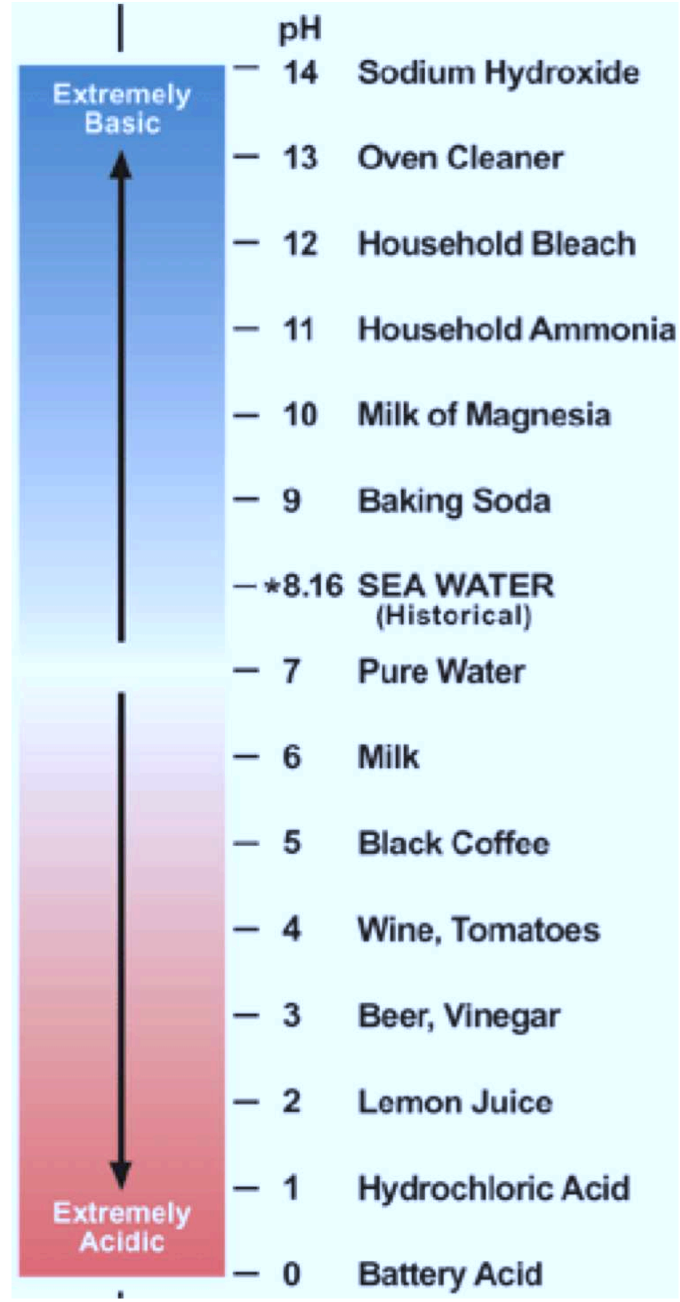


Ocean acidification is likely to impair shell formation in plankton and corals

Ocean Acidification

	pH
Pre-industrial (1700s)	8.18
Recent past (1990s)	8.10
2050 ($2\times CO_2$ = 560 ppm)	7.95
2100 (IS92a)	7.82

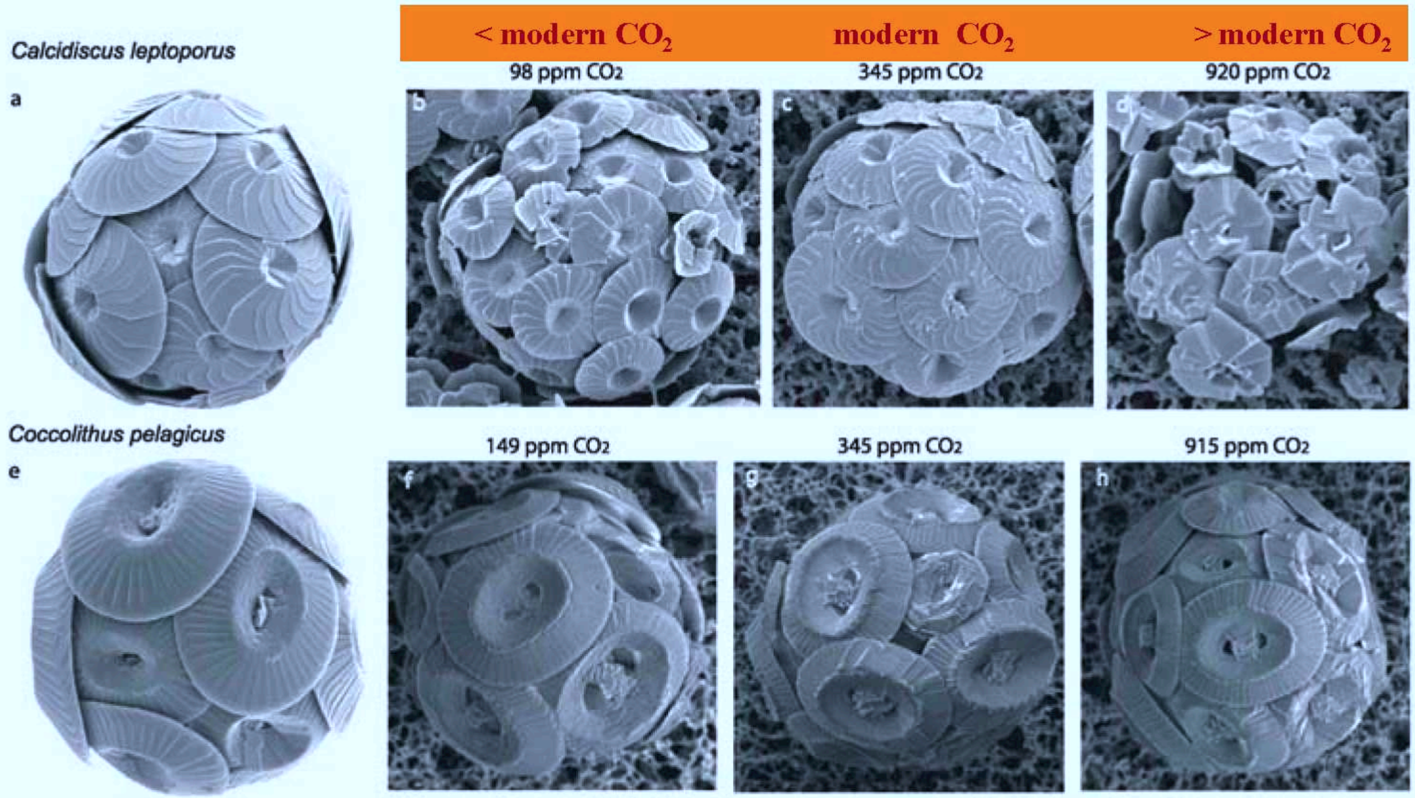




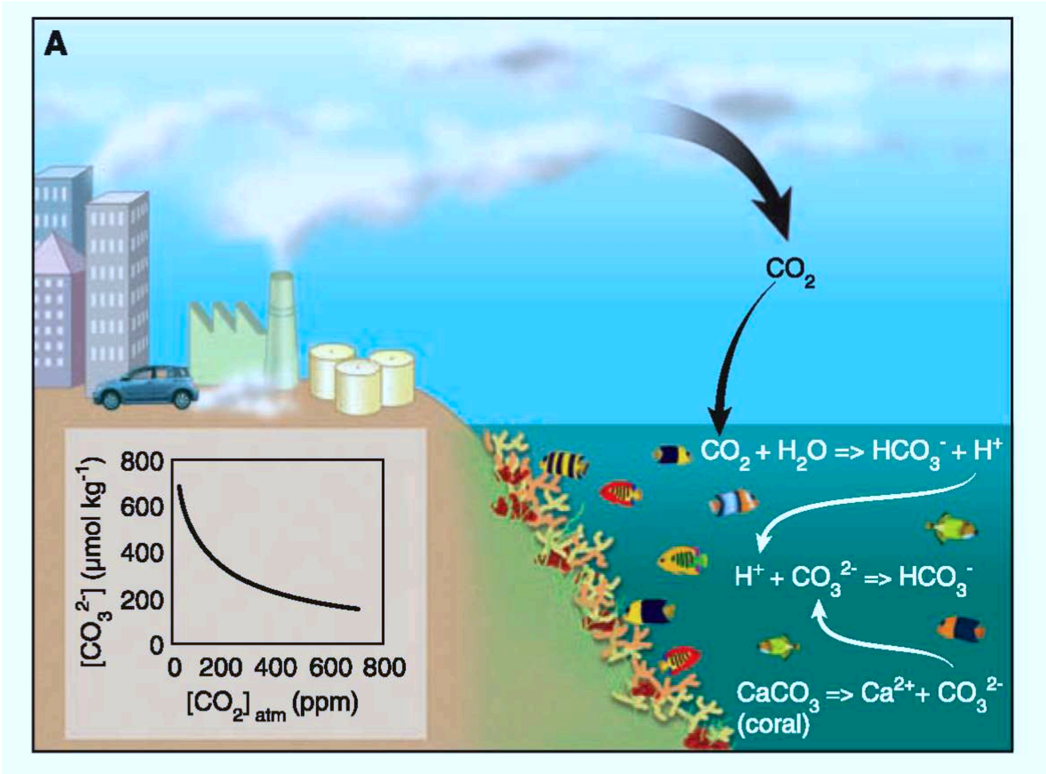
Experiment - Coccolithophorid Calcification

Upper *vs.* Lower = Species Differences

Left to Right = Increasing CO_2 concentration



Langer et al. (2006)



Increased ocean CO_2 causes hydrogen ions H^+ conc. to increase

In the net, increases in have caused the ocean to become more acidic

pH of upper ocean in 1700 and 2007 was ~ 8.15 and 8.05 (~25% more acidic)

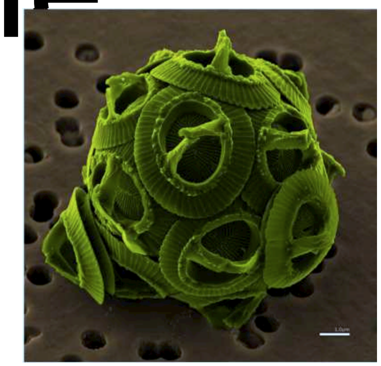
Some H^+ combines with carbonate ions to form bicarbonate HCO^-_3

The removal of carbonate ions causes further dissociation of $CaCO_3$, which destroys shells

Increasing the acidity of the ocean has a negative impact on many types of biology

Pteropods (small molusks)

Coral



Coccolithophore

(single-celled algae, protists and phytoplankton)

Shellfish

Coralline (red) algae

Dissociation of

$$CaCO_3 <-> Ca^{2+} + CO_3^{2-}$$

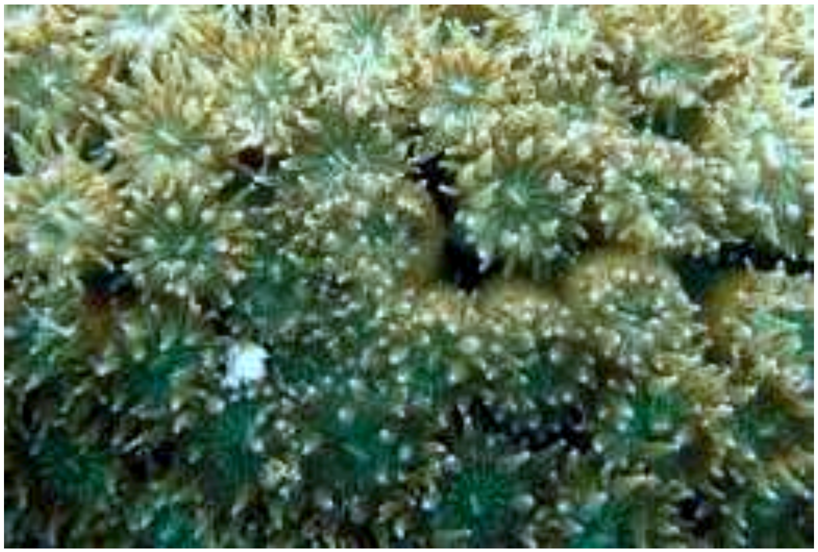
and the subsequent combination of Ca^2 with hydrogen ions lowers the saturation value of $CaCO_3$

With CO_2 at 550ppm, coral habitat shrinks somewhat owing to warming. But more critical is that this habitat will be in water where the saturation value of $CaCO_3$ is lower than where any corals lived prior to the industrial revolution

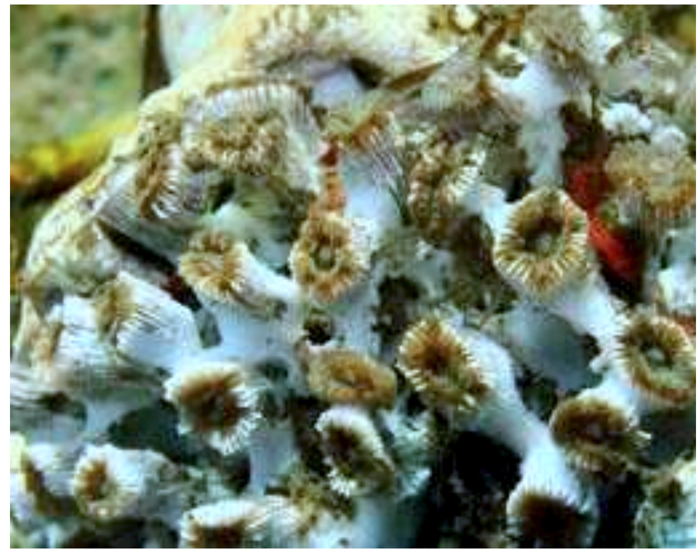
Particularly vulnerable: Central Pacific and the Great Barrier Reef

The Record 1997-8 El Nino

Coral in normal conditions



Coral in acidified conditions



16% of all coral were damaged in 1997-9 El Nino alone. Some bounced back.

"Corals could become rare on tropical and subtropical reefs by 2050 due to the combined effects of increasing CO_2 and increasing frequency of bleaching events"

Source: IPCC 2007 WG2

Value of Coral Reefs in the US

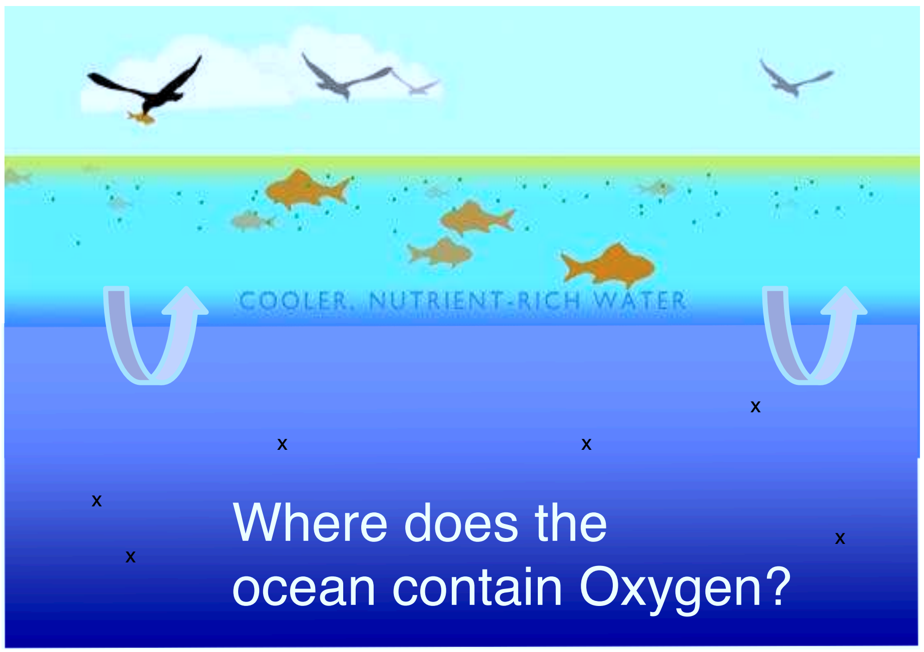
NOAA estimates the commercial value of U.S. fisheries from coral reefs is over $100 million.

Revenues from diving tours, recreational fishing trips, and other businesses based near reef ecosystems are in the billions.

For example, In the 1990s, over four million tourists visited the Florida Keys each year, contributing $1.2 billion annually to tourism-related services.

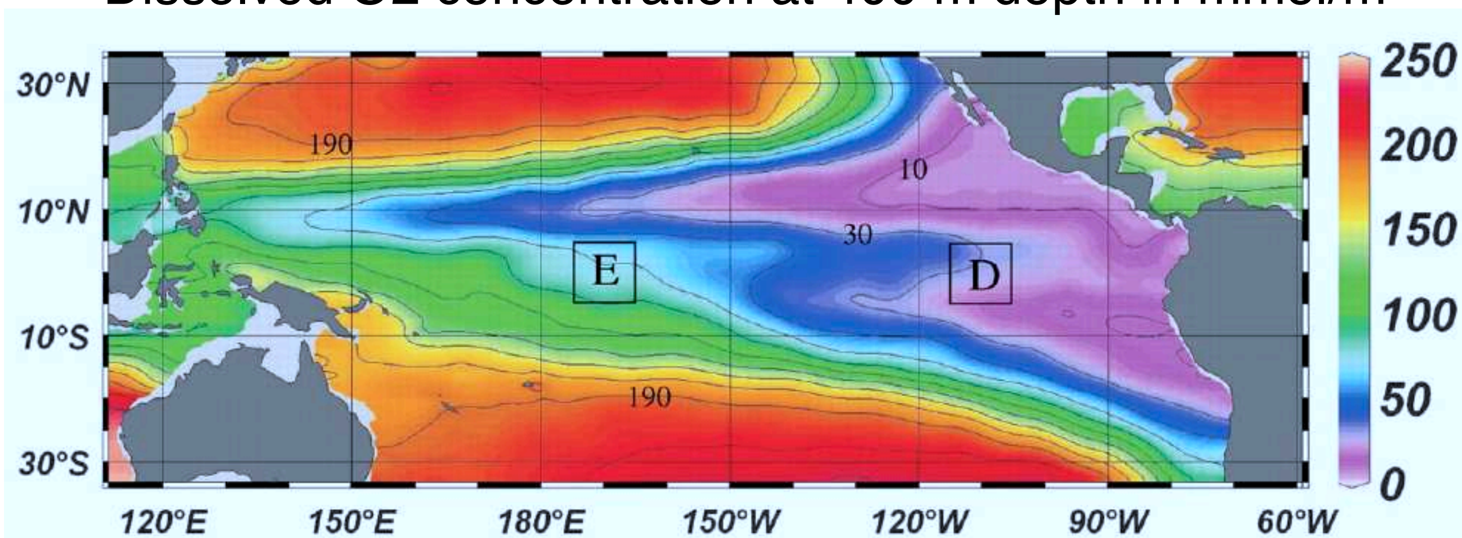
Sources of medicines.

Phytoplankton and Ocean Oxygen cycle



- **Water contains O_2 from contact with the atmosphere**
- **Found at depth as a result of deep water formation**
- **Rotting dead organic material uses O_2**
- **Hence O_2 is low underlying surface ocean that is very productive.**

Dissolved O2 concentration at 400 m depth in mmol/m³



Stramma et al 2008

O2 is low in the upwelling region of the eastern Pacific as easterly winds blow waters away from the shore

Dead Zones are regions of the ocean where the dissolved oxygen is too low to support marine life

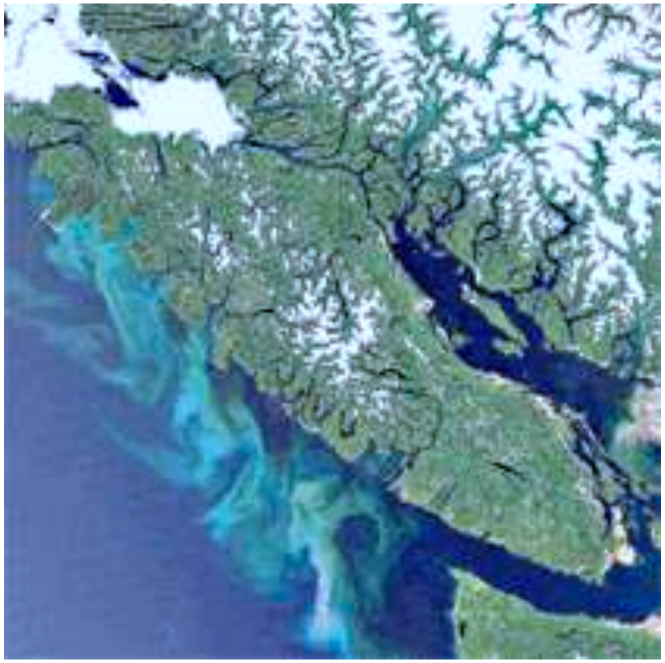
Example: off the coast of Chile where easterly trade winds drives strong upwelling. Nothing lives at depth. If this water comes to the surface, it can kill all organisms quickly

"Carbon dioxide fertilizes biological production," says Oschlies. "It's really like junk food for plants. When the carbon-fattened excess biomass sinks it gets decomposed by bacteria which first consume the oxygen, and then the nutrients."

Reported by Schiermeier 2008

Note: Carbon-fattening as higher CO2 drives photosynthesis. Opposing shell damage. Different chemistry

In regions where there is river runoff that brings a lot of nutrients (N) with it (fertilizer from agriculture). This causes large phytoplankton blooms that eventually die, fall below the surface, decay, and may create a dead zone



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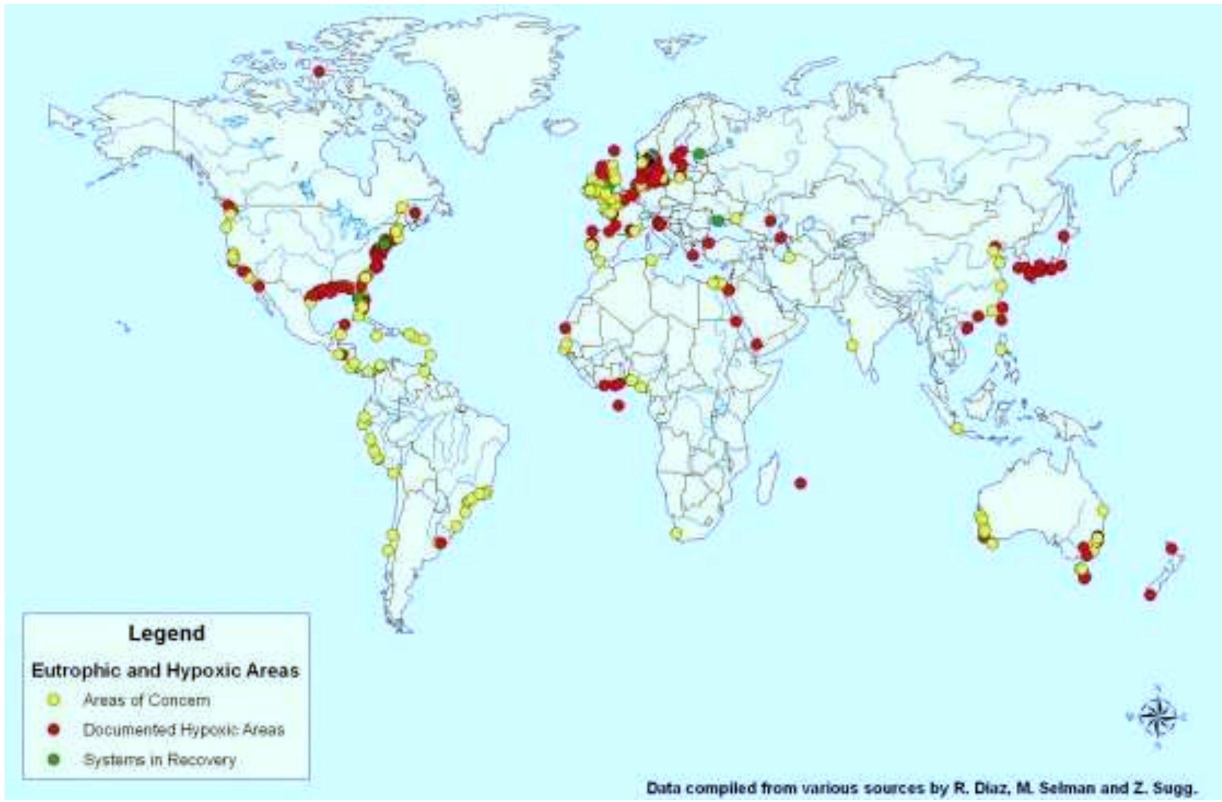
Summary of Ocean Ecosystem Changes

Ocean warming bleaches corals

Increased CO_2 is taken up by ocean

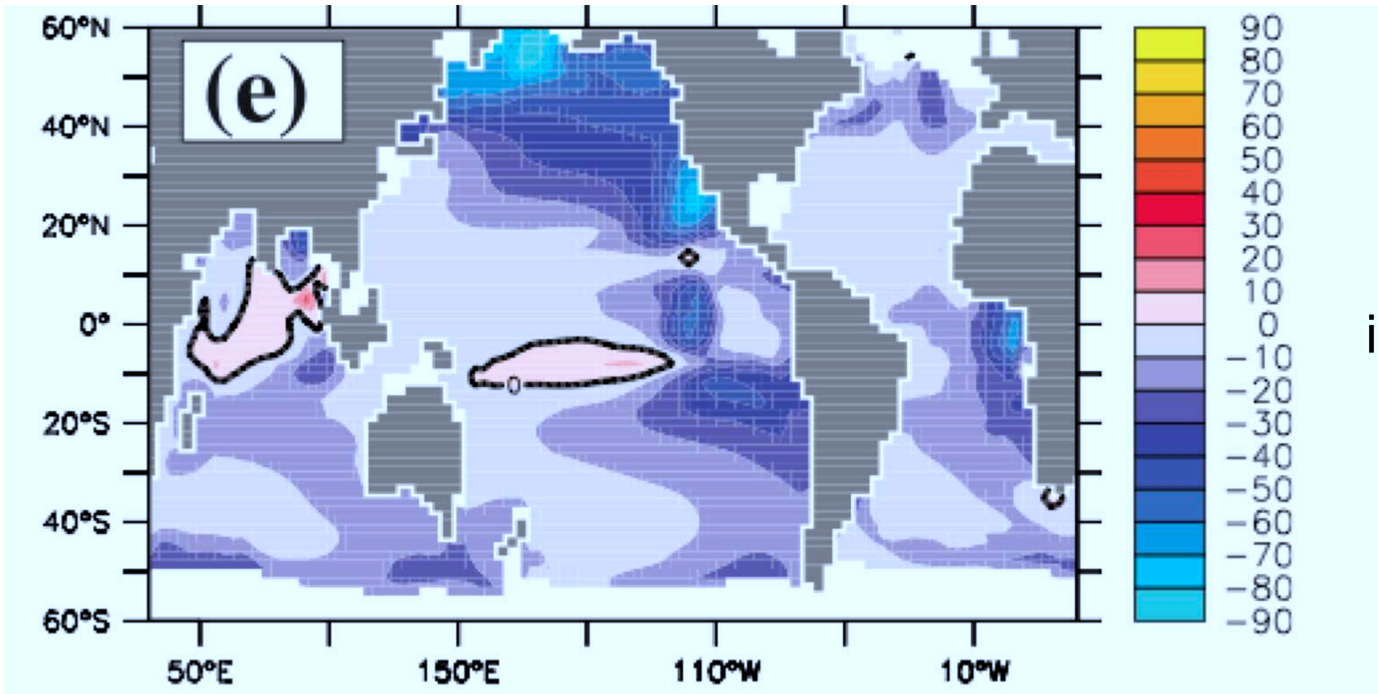
- Increases Ocean acidity, shells/corals damages
- Stimulates photosynthesis ($CO_2 \rightarrow O_2$)
  - Algal blooms are harmful at the surface
  - Greater raining of dead organic material, the decay of which depletes O_2 at depth ($O_2 \rightarrow CO_2$) causing dead zones

Regions of the world with Dead Zones today



Most are due to human activity. For example, off Oregon, scientists believe a stronger sea breeze is causing prolonged upwelling, producing a surplus of phytoplankton that isn't consumed and ultimately dies, drifts down to the seafloor and rots.

Global Warming and Dead Zones



in mmol/m^3

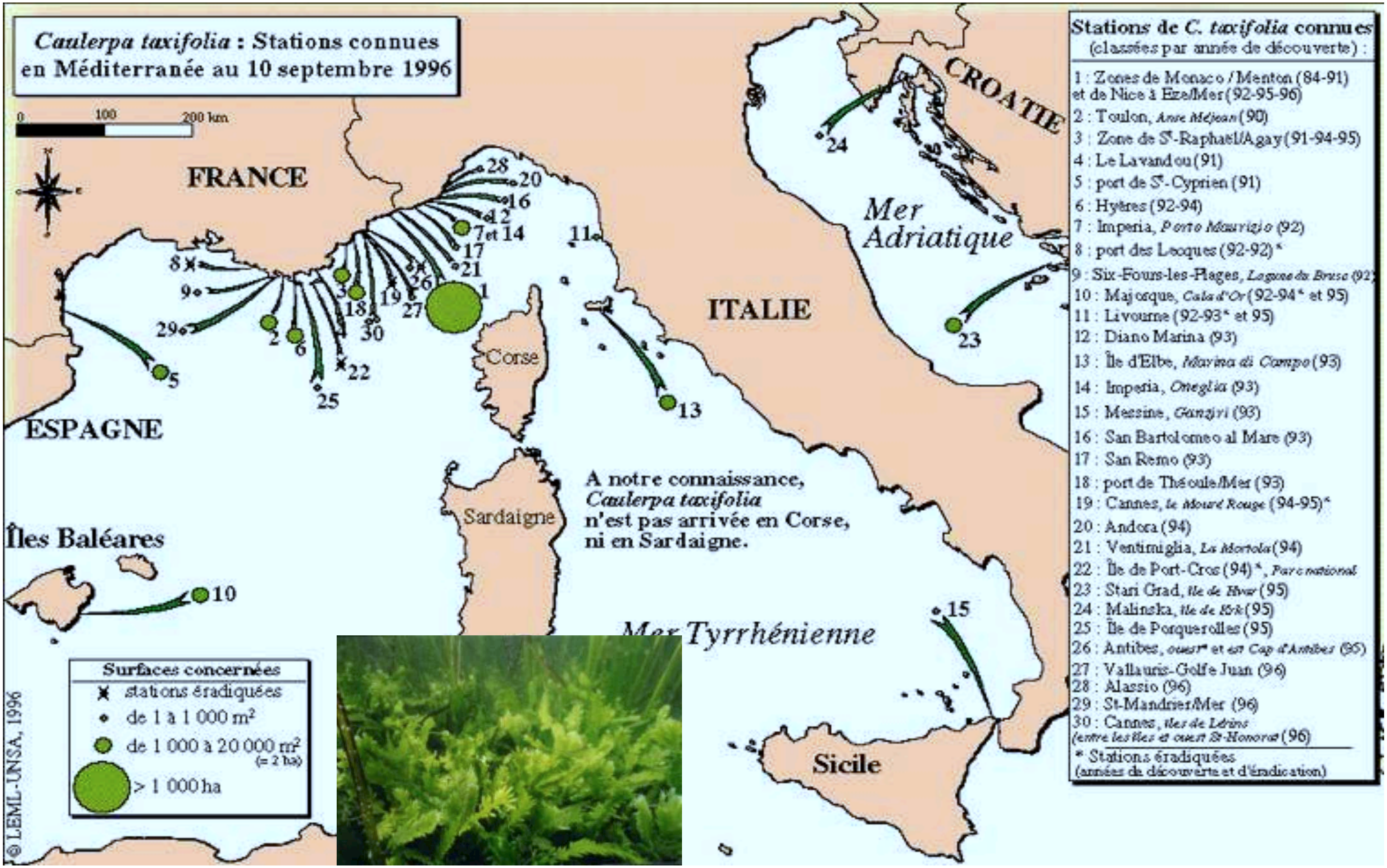
Oschlies et al 2007

Currently 2% of ocean is classified as a dead zone. Projections of Global Warming increase this volume of water to ~ 50% by 2100; largest impacts off the west coast of the Americas.

Climate Change will cause species movements

Biological invasions result when environmental conditions change to be more favorable to non-native species and/or less favorable to the native species

A non-native species of seaweed released from an aquarium in Germany in 1980 into the Mediterranean Sea



Summary of ways global warming impacts marine biology

Increasing GG concentrations

↓

Climate Change

Raising Temperature,
Acidifying Ocean

→

Effects on a species

→

Physiology

Phenology

Distributions

Habitat

Evolution

Disease