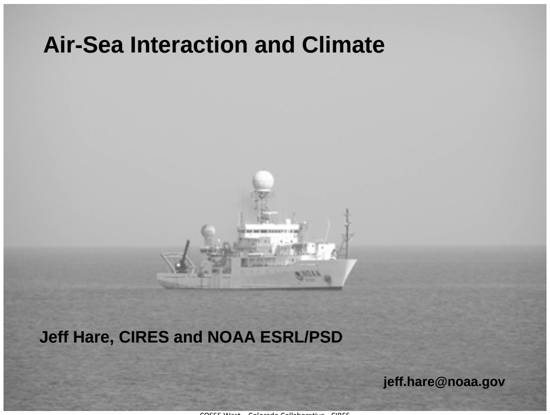
Air-Sea Interaction and Climate



Jeff Hare, CIRES and NOAA ESRL/PSD

jeff.hare@noaa.gov

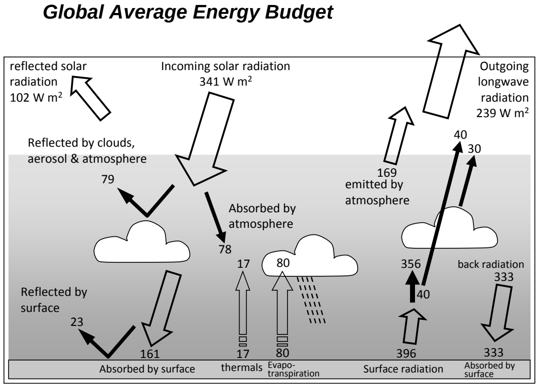
The Ocean Difference
- Energy budget, albedo, heat capacity, circulation, transport of heat

Tropical Ocean (example that affects CO climate)
- El Nino, observations across the Pacific Ocean,

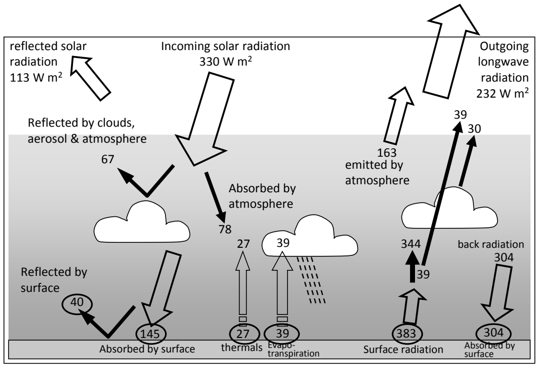
Air-Sea Biogeochemical Interactions
- Carbon pump, nutrients, iron

Possible Implications of Climate Change

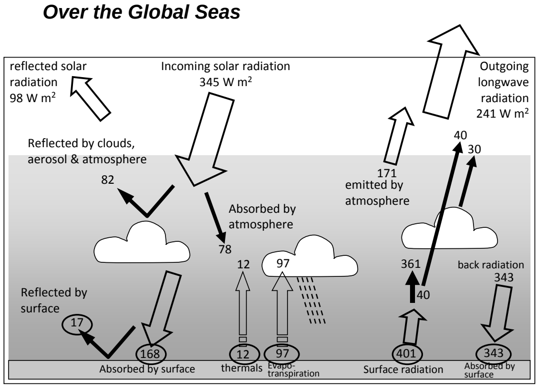
Global Average Energy Budget



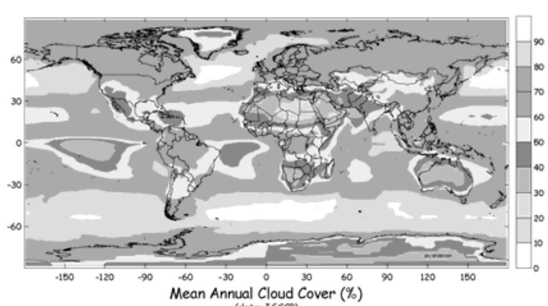
Over Global Land Areas



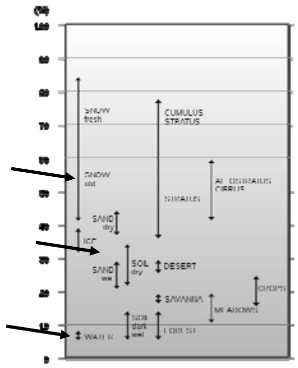
Over the Global Seas



Annual Global Cloud Fraction



Albedo (% solar energy reflected)

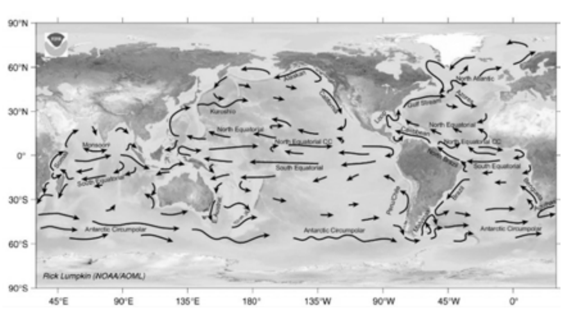


Water has a high specific heat

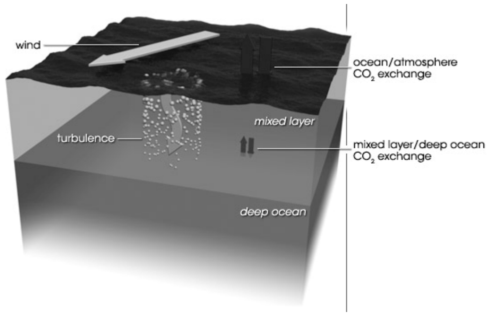
Specific Heats of Some Common Substances

Substance	Specific Heat [cal/(g · °C)]	
Water (liquid)	1.00	
Water (solid)	0.50	
Water (gas)	0.47	
Ethyl alcohol	0.54	
Wood	0.42	
Aluminum	0.21	Sand
Glass	0.12	Dry air
Iron	0.11	
Copper	0.09	
Silver	0.06	
Gold	0.03	

Winds drive surface currents and mixing



Wind stress drives turbulent mixing (top 100m)



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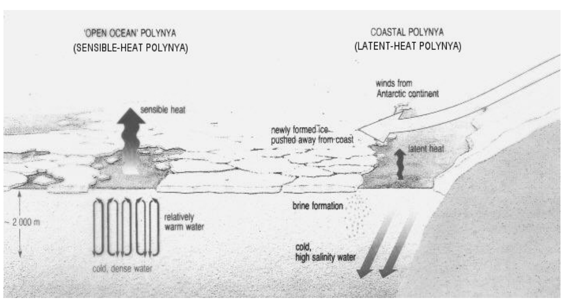
Winds, ice formation and heat/moisture transfer drive slow vertical mixing



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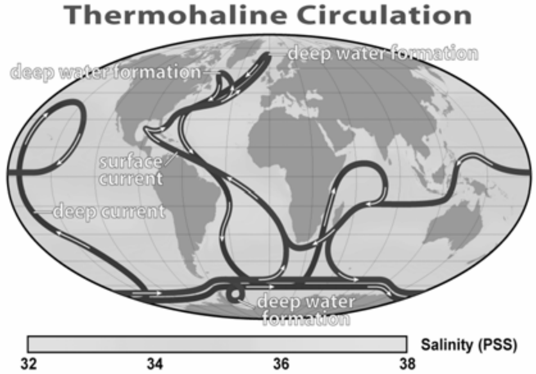
Thermohaline Circulation



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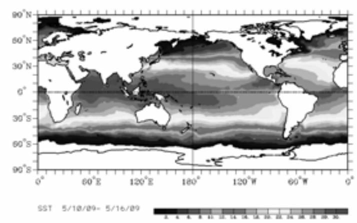
The Tropical Oceans



El Nino – La Nina

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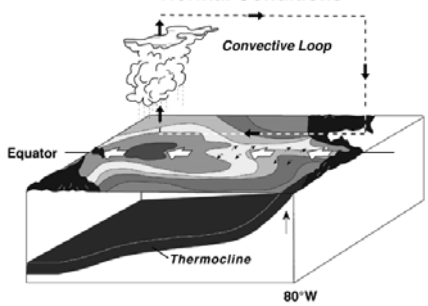
Normal Conditions



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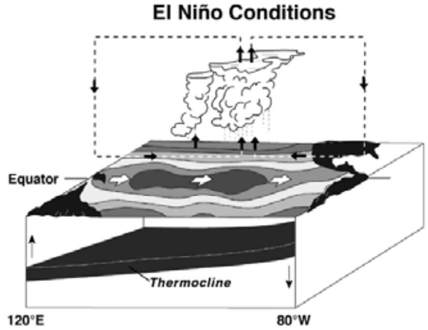
El Niño Conditions



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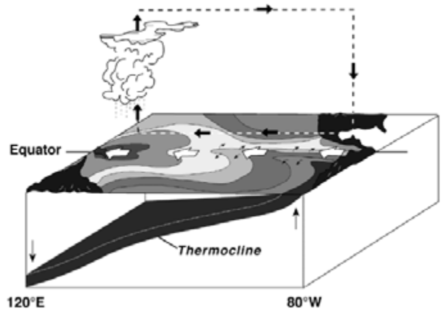
La Niña Conditions



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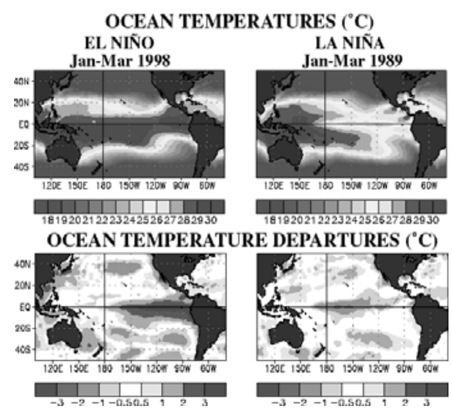

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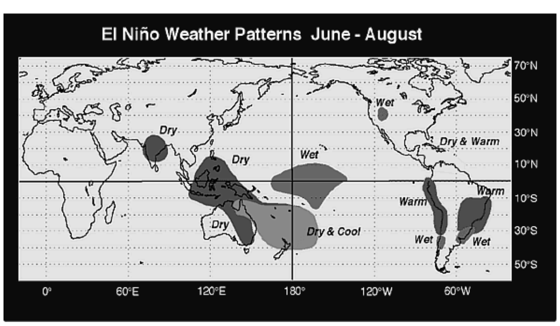

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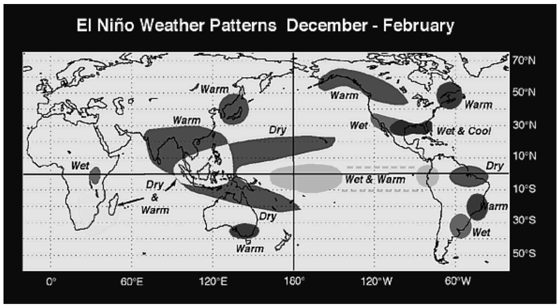
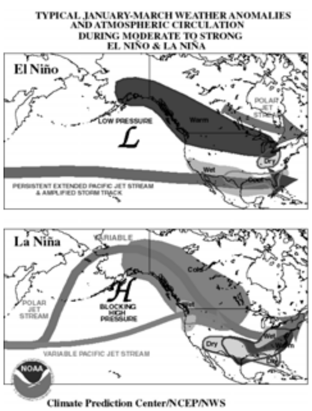
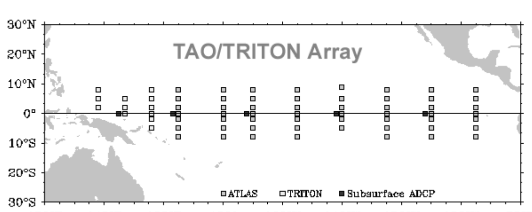


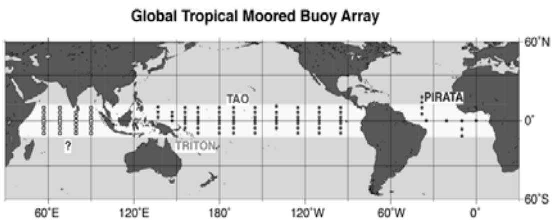


Tropical Atmosphere Ocean (TAO)

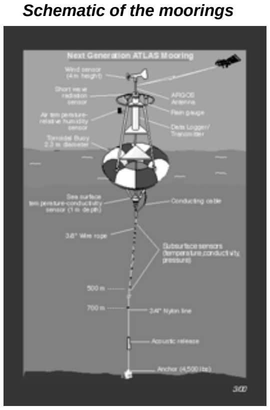


Started in 1985, completed in 1994

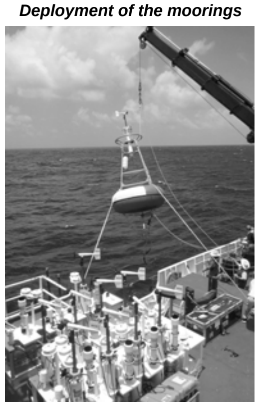
The Tropical Observation System



Schematic of the moorings



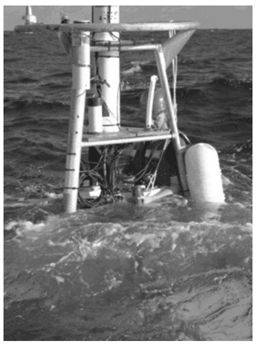
Deployment of the moorings



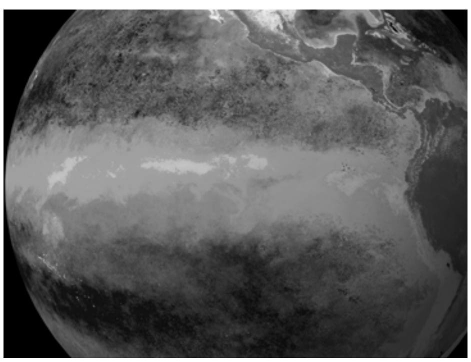
Servicing the buoys

Barnacles accumulated on the buoy within 12 months

Whatever it takes ...

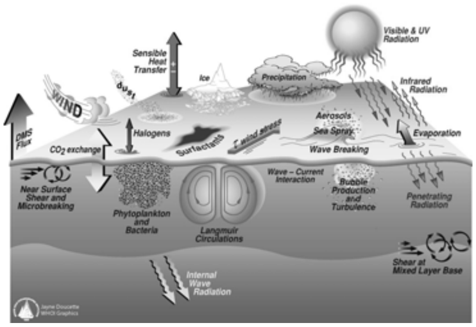


The Marine Biosphere – SeaWiFS during El Nino



Air-Sea Biogeochemical Exchange

Surface Ocean Lower Atmosphere Study (SOLAS)



Ocean Biogeochemistry

50% of Earth's total photosynthetic production is from phytoplankton

Each day, 100 million tons of CO_2 are fixed into organic material by plankton

Termed 'primary production', as these organisms provide the fundamental energy to system

Each day, 100 million tons of CO2 are exported to deep sea or transferred in marine ecosystems by grazing

Ocean Biogeochemistry

Photosynthesis – sunlight energy removes oxygen from carbon dioxide

Carbon atom attaches to water molecules, forming carbohydrates, oxygen is released

$$\text{Energy} + CO_2 + H_2O \longrightarrow C(H_2O) + O_2$$

Carbohydrates are stored until needed (respiration)

$$C(H_2O) + O_2 \longrightarrow CO_2 + H_2O + \text{Energy}$$

Ocean Biogeochemistry

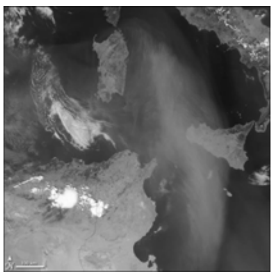
Requirements for production:

1. Water

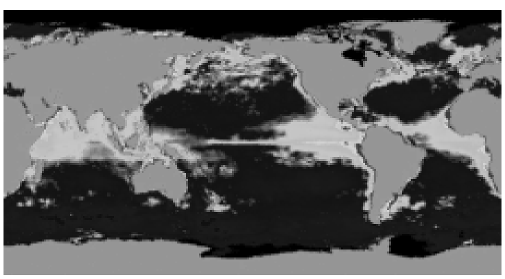
2. Sunlight

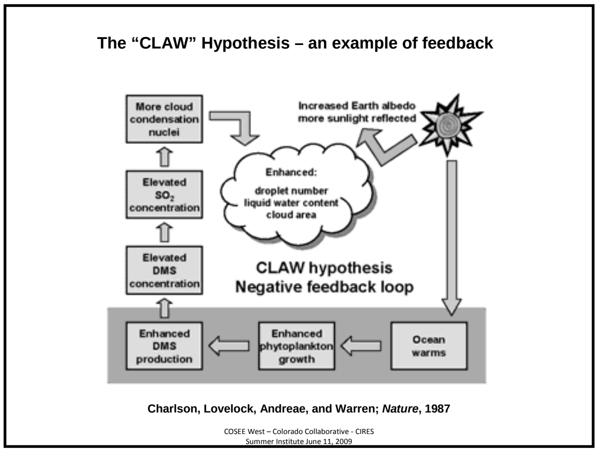
3. Nutrients (nitrates, phosphates, silica, iron)
These compounds typically limit production
Too much leads to 'red tides', 'algal blooms'

Wind-borne dust -
An important component of ocean productivity



Annual Net Primary Production 2003




The "CLAW" Hypothesis – an example of feedback
More cloud condensation nuclei
Increased Earth albedo more sunlight reflected
Elevated SO2 concentration
Enhanced:
droplet number
liquid water content
cloud area
Elevated DMS concentration
CLAW hypothesis
Negative feedback loop
Enhanced DMS production
Enhanced phytoplankton growth
Ocean warms
Charlson, Lovelock, Andreae, and Warren; Nature, 1987
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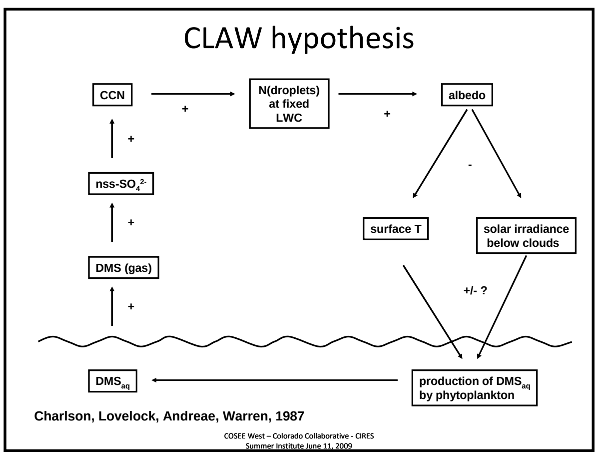
CLAW hypothesis
CCN
+
N(droplets) at fixed LWC
+
albedo
+
-
nss-SO4 2-
+
surface T
solar irradiance below clouds
DMS (gas)
+/- ?
+
DMSaq
production of DMSaq by phytoplankton
Charlson, Lovelock, Andreae, Warren, 1987
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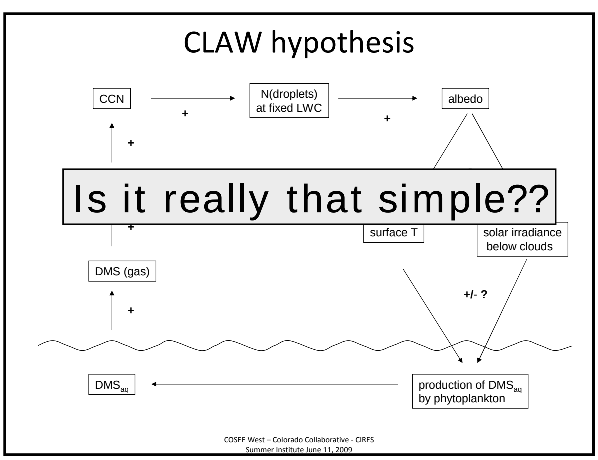
CLAW hypothesis
CCN
+
N(droplets) at fixed LWC
+
albedo
+
Is it really that simple??
+
surface T
solar irradiance below clouds
DMS (gas)
+/- ?
+
DMSaq
production of DMSaq by phytoplankton
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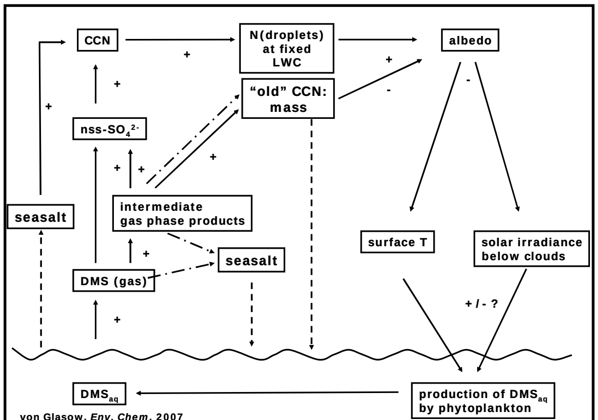
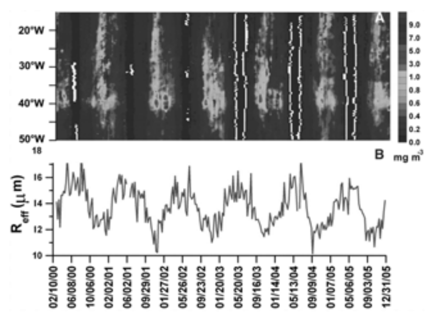


von Glasow, *Env. Chem*, 2007

SeaWiFS chl-a and MODIS cloud particle radius

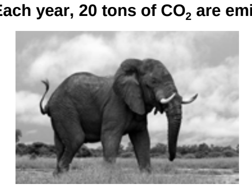
Near South Georgia Island (54°S South Atlantic)



Meskhidze and Nenes, *Science*, 2006

Number of cloud drops ~ $1/R_{eff}^3$

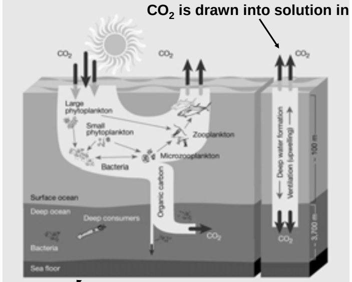
Each year, 20 tons of CO_2 are emitted per person in the USA




The Carbon Pump

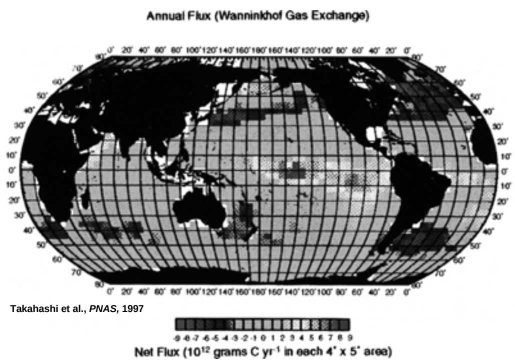
Physical Pump
CO_2 is drawn into solution in the cold water

(turbulence, breaking, bubbles, etc)



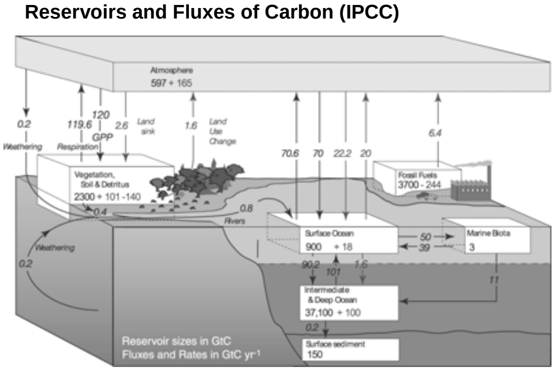
CO_2 is incorporated into living matter (and to the sea floor)
Biological Pump

Annual Air-Sea Flux of CO_2



Takahashi et al., *PNAS*, 1997

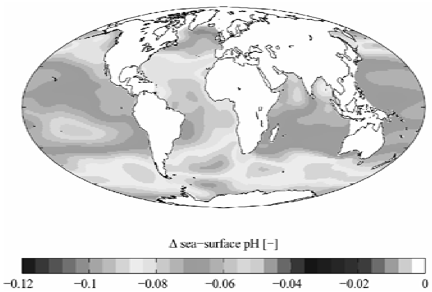
Reservoirs and Fluxes of Carbon (IPCC)

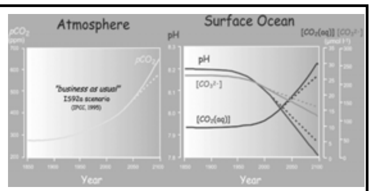


Natural, Anthropogenic

Ocean Acidification

Change in sea surface pH 1700 - 1995





Ocean Acidification

Carbonic acid is produced:
$CO_2 + H_2O \longleftrightarrow H_2CO_3$

Hydrogen ions are formed:
$H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$

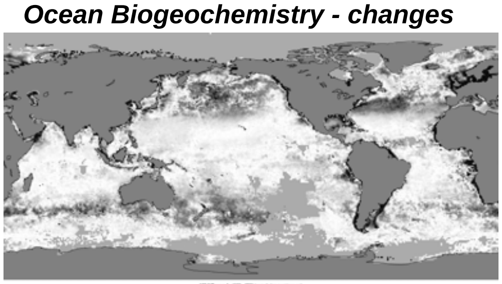
Combine with carbonate ions to form bicarbonate:
$H^+ + CO_3^{2-} \longleftrightarrow HCO_3^-$

Change over industrial age pH has dropped ~0.1 units (~ 25% increase in H^+)

Studies suggest pH may change an additional 0.3 by year 2100 due to uptake of anthropogenic CO2

Negative consequences for calcifying organisms; carbonate is removed (coccolithophores, corals, crustaceans, etc)

Ocean Biogeochemistry - changes

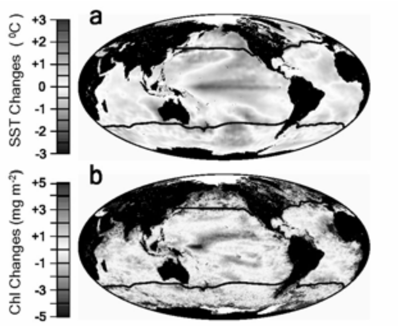


Net Primary Production has decreased by ~5% globally between 1980-2000

Potentially due to warming seas (lower solubility for CO2), and increased stratification (blocking of nutrients).

From NASA satellite analysis - Behrenfeld, et al 2006, *Nature*

Correlation between sea surface temperature change and drop in production



Possible (and competing) oceanic implications of climate change

Higher sea surface temperature (SST) results in lower solubility for CO_2

Higher SST results in increased stratification at low latitudes

Increased rainfall at high latitudes (increased stratification)

Stratification results in less nutrient supply from below, decreasing surface production

Stratification has implications to nitrogen fixation, oxygen supply

Possibilities…..

Stratification reduces export of CO2 to deep ocean

Less mixing could actually increase production at high latitudes

Higher SST may lead to increased productivity in highly productive areas, less productivity in low producing regions

Higher SST could increase decomposition, releasing CO_2

Biological pump efficiency may increase, atmospheric CO_2 taken up

Possibilities…..

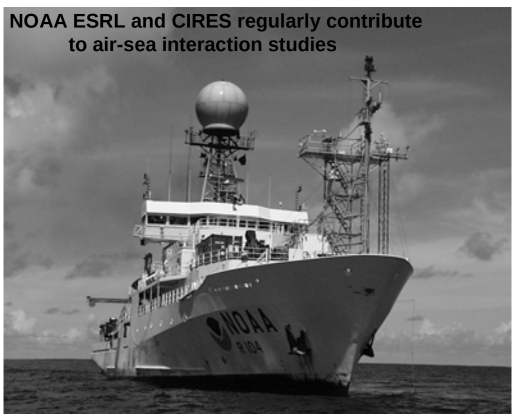
Increased CO_2 acidifies the ocean, reducing calcification

Changes in biogeography of plankton functional groups – shifts away from coccolithophores (calcifyers) to diatoms (silicate)

Trade winds may slow, upwelling could be reduced, lower dust deposition, productivity declines

CO_2 reacts with water to make carbonic acid which inhibits further uptake (Revelle buffer factor)

NOAA ESRL and CIRES regularly contribute to air-sea interaction studies



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