Air-Sea Interaction and Climate

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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
Albedo (% solar energy reflected)

Water has a high specific heat

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific Heat [cal/g \cdot °C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water (liquid)</td>
<td>1.00</td>
</tr>
<tr>
<td>Water (solid)</td>
<td>0.50</td>
</tr>
<tr>
<td>Water (gas)</td>
<td>0.47</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.54</td>
</tr>
<tr>
<td>Wood</td>
<td>0.42</td>
</tr>
<tr>
<td>Aluminum</td>
<td>0.21</td>
</tr>
<tr>
<td>Glass</td>
<td>0.12</td>
</tr>
<tr>
<td>Iron</td>
<td>0.11</td>
</tr>
<tr>
<td>Copper</td>
<td>0.09</td>
</tr>
<tr>
<td>Silver</td>
<td>0.06</td>
</tr>
<tr>
<td>Gold</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Winds drive surface currents and mixing
Wind stress drives turbulent mixing (top 100m)

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

Thermohaline Circulation

Salinity (PSU)

32 34 36 38
The Tropical Oceans

El Niño – La Niña

Normal Conditions

Convective Loop

Equator

Thermocline

80°W

El Niño Conditions

Equator

Thermocline

120°E

80°W
Started in 1985, completed in 1994

Tropical Atmosphere Ocean (TAO)
The Tropical Observation System

Global Tropical Moored Buoy Array

Deployment of the moorings

Schematic of the moorings

Servicing the buoys
Barnacles accumulated on the buoy within 12 months

Whatever it takes ...

The Marine Biosphere – SeaWiFS during El Nino
50% of Earth’s total photosynthetic production is from phytoplankton. Each day, 100 million tons of CO₂ 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.

Photosynthesis – sunlight energy removes oxygen from carbon dioxide. Carbon atom attaches to water molecules, forming carbohydrates, oxygen is released.

\[
\text{Energy} + \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{C(H}_2\text{O)} + \text{O}_2
\]

Carbohydrates are stored until needed (respiration).

\[
\text{C(H}_2\text{O)} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{Energy}
\]
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


CLAW hypothesis

Charlson, Lovelock, Andreae, Warren, 1987

Is it really that simple??

Charlson, Lovelock, Andreae, Warren, 1987
DMS (gas) + nss-SO$_4^{2-}$ + CCN + N(droplets) at fixed LWC + albedo

\[ \text{seasalt} \rightarrow \text{intermediate gas phase products} \]

seasalt + DMS (gas) + seasalt + production of DMS$_aq$ by phytoplankton

DMS$_{aq}$ production of DMS$_aq$ by phytoplankton

von Glasow, Env. Chem., 2007

Meskhidze and Nenes, Science, 2006

SeaWiFS chl-a and MODIS cloud particle radius
Near South Georgia Island (54oS South Atlantic)

Meskhidze and Nenes, Science, 2006

Each year, 20 tons of CO$_2$ are emitted per person in the USA
The Carbon Pump

**Physical Pump**
CO₂ is drawn into solution in the cold water (turbulence, breaking, bubbles, etc)

**Biological Pump**
CO₂ is incorporated into living matter (and to the sea floor)

Annual Air-Sea Flux of CO₂

Takahashi et al., PNAS, 1997

Reservoirs and Fluxes of Carbon (IPCC)

Natural, Anthropogenic
Ocean Acidification

Carbonic acid is produced:
\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \]

Hydrogen ions are formed:
\[ \text{H}_2\text{CO}_3 \rightarrow \text{H}^+ + \text{HCO}_3^- \]

Combine with carbonate ions to form bicarbonate:
\[ \text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^- \]

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

Higher sea surface temperature (SST) results in lower solubility for CO₂.

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.

Possible (and competing) oceanic implications of climate change

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 CO₂.

Biological pump efficiency may increase, atmospheric CO₂ taken up.
**Possibilities.....**

Increased CO₂ acidifies the ocean, reducing calcification

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

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

CO₂ reacts with water to make carbonic acid which inhibits further uptake (Revelle buffer factor)

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

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**Thanks!**

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