Lecture 14: Wind

Winds at ~jet plane altitude

200 hPa wind

Tue Aug 31 12:15:00 2004

Introduction to Oceanography

Pacific surface wind forecast-hindcast, National Weather Service Environmental Modeling Center/NOAA. Public Domain, GIF by E. Schauble using EZGif
Dissolved Gases in the Ocean

<table>
<thead>
<tr>
<th>Gas</th>
<th>Atmosphere (Volume %)</th>
<th>Dissolved in Ocean (Volume %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (N₂)</td>
<td>78.08%</td>
<td>48%</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>20.95%</td>
<td>36%</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂)</td>
<td>0.039%</td>
<td>15%</td>
</tr>
</tbody>
</table>

Oxygen (O₂)

- Produced in the photic zone (top 200 m) where photosynthesis occurs
  - Also dissolves from atmosphere
- Consumed below photic zone by
  - Animal respiration
  - Bacterial oxidation of organic detrital matter
    - Mainly at sea floor
- Oxygen minimum in region below photic zone (200 - 1000 m)
  - Also depleted bottom water zone

Plot from Station ALOHA, N. of Hawaii, from Dore et al. (2009) PNAS doi: 10.1073/pnas.0906044106
Carbon Dioxide

- Like N$_2$ and O$_2$, dissolves from the atmosphere at the ocean surface
- Also produced by respiration (digestion) of organic matter
- Consumed by photosynthesis
- CO$_2$ combines chemically with H$_2$O
  - VERY soluble in seawater—1000x solubility of nitrogen or oxygen

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-}
\]

- > 90% stored in bicarbonate ions, HCO$_3^-$
  - At 10$^\circ$ C, Salinity = 3.43% and pH = 8.0:

<table>
<thead>
<tr>
<th>CO$_2$</th>
<th>(HCO$_3^-$)</th>
<th>(CO$_3^{2-}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1%</td>
<td>94%</td>
<td>5%</td>
</tr>
</tbody>
</table>

- Consumed in photic zone (photosynthesis)
- Produced by respiration, decomposition of organic matter
Photosynthesis

- Plants and phytoplankton make simple organic compounds (sugars) from H₂O, CO₂ and light energy
  - Energy stored in compounds
  - O₂ formed as byproduct
  - Occurs in the photic zone

\[
6\text{H}_2\text{O} + 6\text{CO}_2 + \text{sunlight} \rightleftharpoons \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2
\]

Photo by Wikiwatcher1, Wikimedia Commons, Creative Commons A S-A 3.0, http://commons.wikimedia.org/wiki/File:Seaweed_Rocks2_wiki.jpg

Respiration

- Plants and animals oxidize sugars to release energy
  - Water and carbon dioxide are by products
  - Occurs throughout the water column

\[
6\text{H}_2\text{O} + 6\text{CO}_2 + \text{sunlight} \rightleftharpoons \text{C}_6\text{H}_12\text{O}_6 + 6\text{O}_2
\]
**Acid-Base Balance**

- \( \text{H}_2\text{O} \) occasionally splits into \( \text{H}^+ \) and \( \text{OH}^- \)
  - 1 molecule in \( 5.5 \times 10^8 \) dissociates at \( 25^\circ \text{C} \)

\[
\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-
\]
pH Scale

- pH scale = Logarithmic scale
  \[ \text{pH} = -\log_{10}(H^+) \]
- Neutral (pure) water:
  - \(1/(5.5 \times 10^8)\) water molecules is disassociated
  - there are about 55 moles of water per liter

Concentration of \(H^+\):
\[ \frac{55}{(5.5 \times 10^8)} = 10^{-7} \text{ moles/liter} \]
- Neutral water pH = 7
  - lower pH = acid, higher pH = base
The Carbonate Buffer System

• Seawater pH = ~8.0 (slightly basic)
• Maintained by carbonate buffer system:

\[
\text{CO}_2 + \text{H}_2\text{O} \rightleftharpoons \text{H}_2\text{CO}_3 \rightleftharpoons \text{H}^+ + \text{HCO}_3^- \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-}
\]

• Increase CO₂ in water, acidity increases
  What happens to pH?
• Add acid and CO₂ is produced

The CO₂ system and carbonate

• Deep waters form at the poles: High CO₂ and therefore acidic
• Acidity interacts to dissolve calcium carbonate (CaCO₃) deposits on the deep sea floor
  – Acidity and temperature control carbonate compensation depth (CCD)
Questions


Wind

Atmosphere-Ocean Coupling

• Why study atmospheric circulation?
  – Atmosphere & ocean processes are intertwined
  – Atmosphere-ocean interaction moderates surface temperatures, weather & climate
    • Weather: local atmospheric conditions
    • Climate: regional long-term weather
  – Atmosphere drives most ocean surface waves and currents (our next topic)

Composition of the Atmosphere

• Dry Air: 78% Nitrogen, 21% Oxygen
• BUT it is never completely dry
  – Typically contains about 1% water vapor
  Chemical residence time of water vapor in the air is about 10 days
    (liquid water residence time in ocean: 3x10^3 years!)
    – Liquid evaporates into the air, then is removed as dew, rain, or snow
  – Warm air holds much more water vapor than cold air
    
Figure by Greg Benson, Wikimedia Commons
Density of Air

- Typical air density ~ 1 mg/cm³
  - About 1/1000th the density of water
- Temperature and pressure affect the density of air
- Temperature: Hot air is less dense than cold air
- Pressure: Air expands with elevation above sea level
  - Air is much easier to compress than water

![Density of Air](image)

Density & temperature of Air

- Rising air expands & cools
  - Vapor condenses into clouds, precipitation
- Sinking air is compressed and warms
  - Clear air

![Density & temperature of Air](image)
Expanding Air Cools and Condenses

- Like opening a pressurized bottle of soda
- Air expands and cools
- Water vapor condenses -- cloud formation

Movies by J. Aurnou, E. Schauble, UCLA

Solar Heating of the Earth

- Solar energy absorbed unevenly over Earth’s surface
- Energy absorbed / unit surface area varies with:
  - Angle of the sun
  - Reflectivity of the surface (i.e., ice v. ocean)
  - Transparency of the atmosphere (i.e., clouds)


Solar Heating of the Earth

Sunlight heats the ground more intensely in the tropics than near poles

Figure by William M. Connolley using HadCM3 data, Wikimedia Commons, Creative Commons A-SA 3.0, http://commons.wikimedia.org/wiki/File:Insolation.png
• Seasons are caused by Earth’s 23.5° tilt
• Northern summer: north hemisphere points at sun
Redistribution of Solar Heat Energy

- Equator absorbs more heat from the sun than it radiates away (net > 0).
- Polar regions radiate much more heat than they absorb from the sun(!)
- E.g., Equator isn’t that Hot; Poles aren’t that Cold
- Evidence that the atmosphere (~2/3) & oceans (~1/3) redistribute heat
- Result: convective heat transfer moderates climate

CERES/NASA animation, Public Domain,
Redistribution of Solar Heat Energy

- Convective heat transfer moderates Earth climate
- Heated air expands & rises, then cools & sinks


Atmospheric Circulation **Without Rotation**

- Warm, less dense air rises near the Equator
- Cold, more dense air sinks near the Poles


- Warm, less dense air rises near the Equator
- Cold, more dense air sinks near the Poles