Summary of Waters Properties

• H-bonding accounts for high heat capacity, latent heats of fusion and evaporation. Important for heat transport, heat transfer to the atmosphere (weather), and thermal buffering

• Temperature and salinity determine density of seawater. Differences in density determines water column stratification (layering) and stability (resistance to mixing)
### Major Constituents of Seawater

- **water** (96.5%)

- **dissolved salts** (35% or 3.5%)
  - $\text{Cl}^-$ (chloride) 56%
  - $\text{Na}^+$ (sodium) 28%
  - $\text{SO}_4^{2-}$ (sulfate) 8%
  - $\text{Mg}^{2+}$ (magnesium) 4%
  - $\text{Ca}^{2+}$ (calcium) 1.5%
  - $\text{K}^+$ (potassium) 1%
  - $\text{HCO}_3^-$ (bicarbonate) 0.5%
  - all other ions 1%

- **dissolved gases**
  - $\text{N}_2$, $\text{O}_2$, $\text{CO}_2$, $\text{He}$, $\text{Ar}$
Other Constituents of Seawater

• dissolved organic carbon (DOC) compounds
  sugars, proteins, amino acids, nucleic acids

• suspended particulate materials
  inorganic compounds
    fragmented products of rocks
    weathering
  organic compounds
    living - phytoplankton, bacteria, larger organisms
    dead - detrital materials
Processes Controlling Seawater Composition

- the compounds that make up seawater are dynamic, not static
- there is a continuous input and loss of seawater components
The “Steady-State Approximation”

if rate of input = rate of losses
composition of seawater remains constant with time

good evidence that over the last 100 M years, the composition of seawater has remained ~ constant
The Water Cycle

Inputs
- precipitation
- melting
- river input

Losses
- evaporation
- freezing

Steady State
inputs = loses
Residence Time

\[
\text{residence time of water} = \frac{\text{total amount of compound}}{\text{rate of input or loss of compound}}
\]

- residence time of water in seawater
  average depth of the ocean = 4000 m
  average rate of evaporation = 0.01 m/year
  \[\text{residence time of water} = \frac{4000}{0.01} = 400,000 \text{ years}\]

- residence time of major ions in seawater
  residence time of Cl\(^-\) = 68,000,000 years
  residence time of Na\(^+\) = 260,000,000 years

- residence time of water is >100X shorter than for ions
  salinity of seawater is controlled by addition and removal of water
Conservative and Nonconservative Properties

**Conservative properties** of seawater are those that are only altered by physical processes at the sea surface. Once the water leaves the surface, these properties are conserved.

- salinity (‰)
- temperature
- inert gas concentration

**Nonconservative properties** of seawater are those that are altered by processes that occur anywhere in the water column.

- biological processes
- geochemical processes
Conservative Properties - Temperature

Heat loss at the North Pole, heat input at the Equator, and heat loss at the South Pole lead to ice formation and the formation of dense water. This dense water joins the thermohaline circulation, which is the global oceanic circulation driven by density differences due to temperature and salinity variations.
Conservative Properties - Inert Gas Content

Helium - He

solubility of gases decreases with increasing temperature

the ocean is a giant (but very slow) He pump
Nonconservative Properties - Dissolved $O_2$

**Biological processes:**

$CO_2 + H_2O$

inorganic $N$ ($NO_3^-$, $NH_4^+$)

inorganic $P$ ($PO_4^{3-}$)

photosynthesis

(light)

organic materials + $O_2$

respiration

**Physical processes:**

$O_2$ atmosphere

$O_2$ dissolved
Nonconservative Properties - Dissolved $O_2$

- Mixed layer:
  - Rapid:
    - Net photosynthesis
    - $O_2$
  - Slow:
    - Net respiration

- Deep water:
  - $O_2$
  - Sinking
  - Organics
  - Burial
  - Sediments

- Atmosphere
- Sea surface
- Oxygen minimum
- Rising water
- Wind mixing

[O$_2$] →
Nonconservative Properties - Nutrients

Nutrients - elements or compounds required by phytoplankton to grow and reproduce

- nitrogen\(\text{NO}_3^-\) (nitrate), \(\text{NH}_4^+\) (ammonium)
- phosphorus\(\text{PO}_4^{3-}\) (phosphate)
- silicon\(\text{SiO}_4^{2-}\) (silicate)
- trace metals Fe, Zn, Mo, Cu, Co, etc
Nonconservative Properties - Nutrients

- River input
- Mixed layer
- Deep water
- Sea surface
- Pycnocline
- Sediments
- Net photosynthesis
- Net respiration
- Slow
- Rising water
- Sinking
- Burial
- Wind mixing

Chemical Oceanography II
Spring 2002 Slide 15
Nonconservative Properties - CO$_2$

**Biological processes:**

\[
\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \quad \text{carbonic acid}
\]

**Chemical processes:**

\[
\begin{align*}
\text{H}_2\text{CO}_3 & \leftrightarrow \text{H}^+ + \text{HCO}_3^- \quad \text{bicarbonate} \\
\text{HCO}_3^- & \leftrightarrow \text{H}^+ + \text{CO}_3^- \quad \text{carbonate}
\end{align*}
\]
Nonconservative Properties - CO$_2$

\[ \text{CO}_2^{\text{gas}} \overset{(1.0)}{\rightleftharpoons} \text{CO}_2^{\text{dissolved}} + \text{H}_2\text{O} \overset{(0.3)}{\rightleftharpoons} \text{H}_2\text{CO}_3 \]

\[ \text{HCO}_3^- + \text{H}^+ \overset{(50)}{\rightleftharpoons} \text{CO}_3^{2-} + \text{H}^+ \]

\[ (0.01) \quad \text{organic C} \]

\[ \text{respiration} \quad \text{photosynthesis} \]

\[ (0.1) \quad \text{CO}_2^{\text{dissolved}} \]

\[ \text{biogenic precipitation} \]

\[ (0.01) \quad \text{organic C} \]

\[ \text{mineral precipitation} \]

\[ (10000) \quad \text{organic C} \]

\[ (30000) \quad \text{carbonate sediments} \]
CO$_2$ and Global Warming

- Atmospheric CO$_2$ has increased by 25% over the past 150 years due primarily to combustion of fossil fuels.

- There is some evidence to support the hypothesis that higher CO$_2$ is causing global warming through the greenhouse effect.

- A third of the CO$_2$ that has been produced from fossil fuels is not in the atmosphere (missing CO$_2$).
The “Missing CO₂”
Biogenic Precipitation and the Missing CO$_2$

\[
\text{CO}_2^{\text{gas}} \quad (1.0) \quad \text{atmosphere} \\
\text{CO}_2^{\text{dissolved}} \quad (0.1) \quad \text{ocean} \\
\text{respiration} \\
\text{photosynthesis} \\
\text{organic C} \quad (0.01) \\
\text{biogenic precipitation} \\
\text{organic C} \quad (10000) \\
\text{carbonate sediments} \quad (30000) \\
\text{mineral precipitation} \\
\text{sediments}
\]

\[
\begin{align*}
\text{CO}_2^{\text{gas}} & \quad \text{CO}_2^{\text{dissolved}} \quad + \text{H}_2\text{O} \quad \text{H}_2\text{CO}_3 \quad (0.3) \quad \text{ocean} \\
\text{respiration} & \quad \text{photosynthesis} \\
\text{organic C} & \quad (0.01) \\
\text{biogenic precipitation} \\
\text{organic C} & \quad (10000) \\
\text{carbonate sediments} & \quad (30000) \\
\text{mineral precipitation} \\
\text{sediments}
\end{align*}
\]

\[
\begin{align*}
\text{CO}_3^{2-} + \text{H}^+ & = \text{HCO}_3^- \quad (50) \\
\text{CO}_3^{2-} + \text{H}^+ & = \text{CO}_2^{\text{gas}} \quad (1.0) \\
\text{organic C} & \quad \text{respiration} \\
\text{biogenic precipitation}
\end{align*}
\]
Global Nutrient Distributions

Nitrate $\text{NO}_3^-$ (µM)

Phosphate $\text{PO}_4^{3-}$ (µM)

Depth (m)
Exchange between Pacific and Atlantic Oceans

- Bering Straight
- Low nutrient surface water
- High nutrient deep water

Ocean currents flow from the Pacific Ocean to the Atlantic Ocean, exchanging low nutrient surface water and high nutrient deep water.
Exchange between Pacific and Atlantic Oceans

• Pacific Ocean loses *low nutrient surface waters* to the Atlantic Ocean via the Bering Straights

• Atlantic Ocean loses *high nutrient deep waters* to the Pacific Ocean through the Southern Ocean

• back calculate rate of fractionation between the two oceans to time when the concentrations were equal in the two oceans = 5000 years ago

• this is the time that the Bering Straight land bridge was submerged at end of last Ice Age
Global Primary Production
What Limits Primary Production?

- **temperature**: highest in cold waters
- **light**: highest in polar regions (low light)
- **nutrients**: most important worldwide
  - surface waters depleted of nutrients
What Limits Primary Production?

Primary production is limited by nutrient availability - mixing of deeper, high nutrient water into the nutrient poor surface waters.
Thanks and have a great weekend !!