Heat (Q)

• 1 calorie = 4.18 Joule
• Heat : Total Kinetic Energy
• Temperature: Average Kinetic Energy
• Heat that causes a change in temperature: Sensible Heat

Temperature Change

\[ \Delta Q = m \cdot c_{\text{water}} \cdot \Delta T \]

• \( Q \) in Joules
• \( c_{\text{water}} = 4186 \text{ J/kg}^\circ\text{C} \)
• \( m \) = mass. Per unit volume: \( m/v ol = \text{density of the water} \)

• \[ \frac{\Delta Q}{\text{vol}} = \rho \cdot c_{\text{water}} \cdot \Delta T \]

Heat Capacity

<table>
<thead>
<tr>
<th>Substance</th>
<th>Sp. Heat (cal per gm per °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.000</td>
</tr>
<tr>
<td>Ice</td>
<td>0.48</td>
</tr>
<tr>
<td>Wood</td>
<td>0.42</td>
</tr>
<tr>
<td>Brick</td>
<td>0.21</td>
</tr>
<tr>
<td>Sand</td>
<td>0.20</td>
</tr>
<tr>
<td>Air</td>
<td>0.17</td>
</tr>
<tr>
<td>Copper</td>
<td>0.09</td>
</tr>
<tr>
<td>Gold</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Latent Heat

• The heat absorbed or released in the change of phase of water.
• Latent heat of fusion = 80 cal/gm
• Latent heat of evaporation = 540 cal/gm
• The 1 gm ice cube is 0°C.
• What happens if it absorbs 5 cal of heat?
Heat Fluxes
Transfer of heat in/out of the ocean

• Flux = Quantity/(Area • Time)

• Heat Flux = Joule /(m²•s)

• 1 Watt = 1 Joule/s

• Heat Flux = W/m²

Transfer of heat in/out of the ocean surface

• Heat In - One Heat Flux
  – Shortwave Radiation or Insolation (Qs)

• Heat Out - Three Heat Fluxes
  – Longwave or Back Radiation (Qb)

These are the 2 heat fluxes involving Radiation

Heat Fluxes
Transfer of heat in/out of the ocean surface

• Shortwave Radiation or Insolation (Qs)
• Longwave or Back Radiation (Qb)
• Latent Heat Flux (Qe)
• Sensible Heat Flux (Qh)

Heat In = Heat Out

Heat In = Heat Out is not true for the short-term

Smaller Region of Ocean

• Sept: Measurements show Qs = Qb + Qe +Qh. What happens to the Bay’s temperature?

• June: Measurements show Qs > Qb + Qe +Qh. What happens to the Bay’s temperature?

• June: Measurements show the Bay’s temperature was constant. How??

Advective Heat Flux

• Qv
  • Qv is the only heat flux that does not transfer heat in and out of the ocean (through the surface)
  • Qv transfers heat in and out of a region
Heat Fluxes

\[ Q_s - Q_b - Q_e - Q_h = 0 \]

List of Symbols

- \( Q_s \): solar radiation
- \( Q_b \): longwave radiation
- \( Q_e \): sensible heat flux
- \( Q_h \): latent heat flux

Total Air-Sea flux = Adveotive flux

\[ Q_s - Q_b - Q_e - Q_h \]

Bay

Net Surface Heat Flux (W/m²)

Unequal Surface Heating/Cooling Produces:

- Wind Driven Circulation (surface currents)
  - Pump heat poleward
- Thermohaline Circulation (deep currents)
  - Pump cold water equatorward
- Oceans circulate to redistribute heat, caused by the unequal heating/cooling at the surface.

Stefan-Boltzmann Law

\[ Q (W/m²) = cT^4 (°K) \]

\[ c = 5.67 \times 10^{-8} W/m² K^4 \]
Wien’s Law

\[ \lambda(\mu m) = \frac{2897.8\mu m}{T(°K)} \]

What gives off longer wavelength energy, the Earth (10°C) or the Sun (6000°C)?

Shortwave Radiation

- Once the Sun's radiation reaches Earth:
- A certain % is reflected away
- A certain % is absorbed in the atmosphere and is converted to heat
- The remainder is absorbed by the land/ocean (Qs)

Shortwave Budget

\[ \text{Albedo} + \text{Absorptivity} + \text{Transmissivity} = 100\% \]

Annual Global Average

Annual Qs in W/m²
Latent Heat

Latent Heat Flux (W/m²)

\[ Q_e = E \cdot L \cdot \rho \]
- \( E \) - evaporation rate
- \( L \) - latent heat of evaporation (540 cal/gm)
- \( \rho \) - density

\[ Q_e = c_e (q_s - q_a)W \]
- \( c_e = 1.5 \times 10^{-3} \)
- \( q_s \) - saturation vapor pressure (mb)
- \( q_a \) - actual vapor pressure (mb)
- \( W \) - wind speed (m/s)

Vapor Pressure

- **Vapor Pressure** - the air pressure produced by all the water vapor in the air (a portion of the total air pressure). It is a measure of how much water is in the air. Unit is millibar.
- **Saturation Vapor Pressure** - the maximum amount of water vapor that can be in the air (i.e., when humidity is 100%). Its value depends on the air temperature.
- **Actual Vapor Pressure** - the actual amount of water vapor in the air.

Sat. Vapor Pressure

When humidity = 90% is \((q_s - q_a)\) a large or small value?

Qe and Temperature

- Late at night the temperature in Conway suddenly plummets. What happens to the latent heat flux? Why?
- \( T \) down, \( q_s - q_a \) down, humidity up, \( Q_e \) down

\( Q_e = c(q_s - q_a)W \)

- When \((q_s - q_a)\) is small, air is close to saturation, humidity is high, evaporation is small.
- When \((q_s - q_a)\) is large, air is dry, humidity is low, easy to evaporate

- \((q_s - q_a)\) is the opposite of humidity
Temp and Humidity

Sensible Heat Flux

(Conduction/convection)

- \( Q_h = c_h (T_s - T_a)W \)
  - \( c_h = 1.2 \times 10^{-3} \)
  - \( T_s \) = sea temperature
  - \( T_a \) = air temperature
  - \( W \) = wind speed
  - When \( T_s > T_a \), the sensible heat flux represents cooling

- Bowen’s Ratio \( B = Q_h/Q_e \)
For every 100 units of Energy that reach Earth:
(Global Annual Averages)

- 22 units leave the oceans as Qe
- 7 units leave the oceans as Qh (smallest of the 3 cooling terms)
- These fluxes do not transfer energy in/out of Earth system, but transfer energy from the oceans to the atmosphere.

Calculating Back Radiation (Qb)

- Radiation leaving ocean (W/m²) = $c_s \cdot b \cdot T(°K)^4$
- °K = °C + 273
- Need to know the % that returns to Earth (or escapes & becomes heat) to estimate Qb
- $Q_b = \text{Radiation leaving ocean} - \text{radiation returned to ocean}$