Climate Physics and Chemistry

Role of the Atmosphere in Climate

(Read Hartmann, Chapters 1 and 2)
Ways by which the atmosphere influences climate:

• Strong effects on radiative transfer, including filtering of ultraviolet radiation
• Large advective and convective heat transfer
• Main driver of ocean circulation
• Important role in biogeochemical cycles
## Atmospheric Composition

<table>
<thead>
<tr>
<th>Gas Name</th>
<th>Chemical Formula</th>
<th>Percent Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>78.08%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>20.95%</td>
</tr>
<tr>
<td><em>Water</em></td>
<td>H₂O</td>
<td>0 to 4%</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>0.93%</td>
</tr>
<tr>
<td><em>Carbon Dioxide</em></td>
<td>CO₂</td>
<td>0.0360%</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>0.0018%</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>0.0005%</td>
</tr>
<tr>
<td><em>Methane</em></td>
<td>CH₄</td>
<td>0.00017%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>0.00005%</td>
</tr>
<tr>
<td><em>Nitrous Oxide</em></td>
<td>N₂O</td>
<td>0.00003%</td>
</tr>
<tr>
<td><em>Ozone</em></td>
<td>O₃</td>
<td>0.000004%</td>
</tr>
</tbody>
</table>

* variable gases
Top: Global average atmospheric carbon dioxide mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend.
Methane Measurements
NOAA CMDL Carbon Cycle Greenhouse Gases

Top: Global average atmospheric methane mixing ratios (blue line) determined using measurements from the NOAA CMDL cooperative air sampling network. The red line represents the long-term trend.

Image courtesy of NOAA.
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See Figure 1.6 and Figure 1.7 in Hartmann, Dennis L. *Global Physical Climatology*. Reading, MA: Academic Press, p.411. ISBN: 0123285305.
Elements of Thermal Balance: Solar Radiation

- Luminosity: $3.9 \times 10^{26} \text{ J s}^{-1} = 6.4 \times 10^7 \text{ Wm}^{-2}$ at top of photosphere
- Mean distance from earth: $1.5 \times 10^{11} \text{ m}$
- Flux density at mean radius of earth

$$S_0 \equiv \frac{L_0}{4\pi d^2} = 1370 \text{ Wm}^{-2}$$
Stefan-Boltzmann Equation: \[ F = \sigma T^4 \]
\[ \sigma = 5.67 \times 10^{-8} \text{ Wm}^{-2} \text{K}^{-4} \]

Sun: \[ \sigma T^4 = 6.4 \times 10^7 \text{ Wm}^{-2} \]
\[ \rightarrow T \approx 6,000 \text{ K} \]
Disposition of Solar Radiation:

Total absorbed solar radiation = \( S_0 \left( 1 - a_p \right) \pi r_p^2 \)

\( a_p \equiv \) planetary albedo \((\approx 30\%)\)

Total surface area = \( 4\pi r_p^2 \)

Absorption per unit area = \( \frac{S_0}{4} \left( 1 - a_p \right) \)

Absorption by clouds, atmosphere, and surface
Terrestrial Radiation:

Effective emission temperature:

\[ \sigma T_e^4 \equiv \frac{S_0}{4} \left(1 - a_p\right) \]

Earth: \( T_e = 255K = -18^\circ C \)

Observed average surface temperature = 288K = 15°C
Highly Reduced Model

- Transparent to solar radiation
- Opaque to infrared radiation
- Blackbody emission from surface and each layer
Radiative Equilibrium:

Top of Atmosphere:

\[
\sigma T_A^4 = \frac{S_0}{4} \left( 1 - a_p \right) = \sigma T_e^4
\]

\[\rightarrow T_A = T_e\]

Surface:

\[
\sigma T_s^4 = \sigma T_A^4 + \frac{S_0}{4} \left( 1 - a_p \right) = 2\sigma T_e^4
\]

\[\rightarrow T_s = 2^{\frac{1}{4}} T_e = 303 K\]
Surface temperature too large because:

- Real atmosphere is not opaque
- Heat transported by convection as well as by radiation
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Heat Transport by Oceans and Atmosphere

Figure by MIT OpenCourseWare.