Transport In The Hydrologic Cycle

• Energy enters hydrologic cycle through solar radiation

• Energy, momentum and mass transport in the atmosphere and oceans

• Energy redistribution occurs by conduction and convection it the atmosphere and oceans
### Transport Phenomena

<table>
<thead>
<tr>
<th>Flux</th>
<th>Mass</th>
<th>Momentum</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laminar Flux</strong></td>
<td>$f_m = -D \frac{dC}{dz}$</td>
<td>$\tau = \mu \frac{du}{dz}$</td>
<td>$f_h = -k \frac{dT}{dz}$</td>
</tr>
<tr>
<td><strong>Turbulent Flux</strong></td>
<td>$f_m = -\rho K_w \frac{dC}{dz}$</td>
<td>$\tau = \rho K_m \frac{du}{dz}$</td>
<td>$f_h = -\rho C_p K_h \frac{dT}{dz}$</td>
</tr>
</tbody>
</table>

Shear stress = Momentum Flux = lateral movement of momentum between fluid elements with different velocities

Turbulent momentum flux – dominant mechanism in hydrology

Flux = Flow Rate/Area
Conduction and Convection

- **Conduction**
  - Molecular exchange between different layers due to differences in
    - temperature (transporting heat),
    - velocity (transporting momentum),
    - concentration (transporting mass)

- **Convection**
  - Turbulent exchange of mass, energy, and momentum
  - Much greater than molecular exchange (conduction)

In a wide stream:

\[
\mathcal{R} = \frac{V D \rho}{\mu} \geq 500 \quad (\text{turbulent})
\]

\[V = \text{mean velocity}
\]
\[D = \text{depth of flowing stream}
\]

Turbulence occurs:

\[VD \geq 7 \times 10^{-3} \quad (\text{air})
\]
\[VD \geq 6 \times 10^{-6} \quad (\text{water})
\]
Velocity Profile

- Determining momentum transfer requires knowing velocity profile
- Flow of air over land or water – log velocity profile

$$u(z) = \frac{u^*}{k} \ln\left(\frac{z}{z_0}\right)$$

- $k$ Von Karman constant
- $z_0$ Roughness height

$$u^* = \sqrt{\tau_0 / \rho}$$ Shear velocity

- $\tau_0$ Wall shear stress

$$\frac{du}{dz} = \frac{u^*}{k} \frac{1}{z}$$ Velocity profile

![Graph showing velocity profile](image-url)
Radiation

- **Low** temperatures
  - Conduction and convection dominate
- **High** temperatures
  - Radiation dominates
- **Earth’s** temperature (185 K to 311 K)
  - Balance between them
- **Solar constant** – radiation received on a plane at outer limit of atmosphere (1366 W/m²)
Radiation

- Radiation loss in the atmosphere
  - **Reflection** (clouds, snow, ice, water, surfaces)
    - Albedo, makes clouds appear white
  - **Scattering** (molecules, particles), and
  - **Absorption** (molecules) –
    Atmosphere is transparent to shortwave, but H2O and CO2 absorb longwave reradiation
  - **Greenhouse effect**, warms earth and provides energy for circulation of oceans and atmosphere

\[
0 \leq \alpha = \frac{\text{Reflected}}{\text{Incident}} \leq 1
\]
Radiation

- Albedo

- Net radiation at surface (main source of energy for evaporation)

\[
\begin{align*}
R_i & \quad \text{Incoming Radiation} \\
\alpha R_i & \quad \text{Reflected} \\
R_n & = (1-\alpha)R_i - R_e \\
(1-\alpha)R_i & \quad \text{Absorbed} \\
R_e & \quad \text{Emitted} \\
\end{align*}
\]

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>0.03 – 0.4</td>
</tr>
<tr>
<td>White sand</td>
<td>0.34 – 0.4</td>
</tr>
<tr>
<td>Snow</td>
<td>0.4 – 0.85</td>
</tr>
<tr>
<td>Green grass</td>
<td>0.26</td>
</tr>
<tr>
<td>Top of Pine</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Atmospheric Heat Balance

- **Space**
  - Incoming Radiation: 100
  - Shortwave: 6, 20, 4
  - Longwave: 6, 38, 26

- **Atmosphere**
  - Absorbed by H2O: 16
  - Absorbed: 3
  - Backscatter
  - Reflected
  - Emitted H2O, CO2
  - Absorbed H2O, CO2: 15
  - Latent: 21
  - Sensible: 7
  - Emitted: 23

- **Ocean, Land**
  - 51