Environmental Physics: The study of energy and mass exchange between living organisms or living systems (ecosystems, agricultural systems) and the environment. Of primary concern is the movement and storage of heat, water, and carbon in the soil-plant-atmosphere continuum.

Microenvironments: The environmental conditions immediately adjacent to the surface of an organelle, cluster of organelles, organism, or physical and functional zones of interest. When considering microenvironments, the spatial and temporal scales are an important aspect of the analysis.

Environmental Variables of Interest:

<table>
<thead>
<tr>
<th>Above Ground</th>
<th>Below Ground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Temperature</td>
</tr>
<tr>
<td>Humidity</td>
<td>Soil Water Content or Water Potential</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>Atmospheric Pressure</td>
</tr>
<tr>
<td>$\text{CO}_2$</td>
<td>$\text{CO}_2$</td>
</tr>
<tr>
<td>$\text{O}_2$</td>
<td>$\text{O}_2$</td>
</tr>
<tr>
<td>Radiation</td>
<td>Others</td>
</tr>
<tr>
<td>Short-wave</td>
<td></td>
</tr>
<tr>
<td>Long-wave</td>
<td></td>
</tr>
<tr>
<td>Photosynthetically active</td>
<td></td>
</tr>
<tr>
<td>Wind Speed</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
</tbody>
</table>

Note: Most of these variables are scalar variables. Direction in space is not specified or not relevant (as opposed to vectors, which are variables that have a direction). Wind speed is treated as a scalar when direction does not matter, but is a vector when both the magnitude and direction of the wind are relevant.

Transport Processes:
Characterizing microenvironments requires the study of energy, mass, and momentum exchange between the surface or object and its surroundings.
Campbell and Norman Equation 1.1:

$$\text{Flux} = g (C_s - C_a)$$

Energy Exchange:
In micrometeorology, we are concerned primarily with heat and radiation

First and Second Laws of Thermodynamics (dictate the specifics for the movement of heat and work)
First law: Conservation of energy (energy balance, inputs – outputs = change in storage)
Second law: laws of entropy (direction of energy flow)
Heat Transport (3 modes)
1. Conduction: heat movement in solids (i.e., soils)
   Flux = thermal conductivity * temperature gradient (Fourier’s Law)
2. Convection: heat transport in moving fluids (Newtons law of cooling)
   Boundary layer processes affected by wind (e.g., evaporation)
3. Radiation: transfer of electromagnetic radiation (no transfer media required)
   Solar radiation
   Long wave radiation

Conduction
Transmission of heat through a substance from a region of high temperature to a region of low temperature (in a stationary media).

Fourier’s Law: (one dimensional steady-state)
\[ G = -k \frac{\partial T}{\partial z} \]
\( k = \) thermal conductivity, \( \text{W m}^{-1} \text{K}^{-1} \)
\( \frac{\partial T}{\partial z} = \) temperature gradient, \( \text{K m}^{-1} \)
\( G = \) heat flux density, \( \text{W m}^{-2} \)

Typical k values:
   Aluminum: 237 \( \text{W m}^{-1} \text{K}^{-1} \)
   Soil: 0.2 –1.4
   Air at 300K: 0.026
   Water at 300K: 0.613

For example, soil heat flux:
Given: \( T_s \) at the surface: 60 C
\( T_s \) at 1 cm: 55 C
\[ G = -0.5 \left( \frac{60 - 55}{0 - 0.01} \right) = 250Wm^{-2} \]
**Convection**

Heat transfer between a fluid in motion and a bounding surface. Convection includes the effect of random molecular motion (diffusion) and bulk fluid flow (macroscopic motion). Convection can be laminar or turbulent.

Newton’s “Law” of Cooling: (engineering approach)

\[ q' = h (T_\infty - T_s) \]  
\( q' \) = heat flux density, \( W \cdot m^{-2} \)  
\( h \) = heat transfer coefficient, \( W \cdot m^{-2} \cdot K^{-1} \)

(Independent on wind speed, aerodynamic properties of the surface)

\( T_\infty - T_s \) = temperature difference between air and surface

**Example: heat transfer between leaf and air:**

Given: \( u = 3 \, m \cdot s^{-1} \)

\( T_\infty = 30 \, C \)

\( T_{leaf} = 28 \, C \)

1. Calculate \( h \) from \( \mu \) and size and properties of the leaf.
2. Assuming \( h = 40 \, W \cdot m^{-2} \cdot K^{-1} \)

\[ q' = 40(30-28) = 80 \, W \cdot m^{-2} \]

The leaf is absorbing convective heat from the air.

**Mass and Momentum Transport:**

We are most interested in the movement of water, water vapor, \( CO_2 \). The study of momentum transport is required to study the variation in wind speed with height above a surface.

**Diffusion**

Mixing of substances due to random molecular motion (atom, ions, molecules). Typically, substances move from a higher concentration to a lower concentration along a gradient. The term “diffusion” usually refers to mass transport by molecular agitation, but it is sometimes applied to heat and momentum.
Fick’s Law

\[ q_j = -D_j \frac{\partial c_j}{\partial z} \]

- \( q_j \): flux density of compound j, g m\(^{-2}\) s\(^{-1}\)
- \( c_j \): concentration of j, g m\(^{-3}\)
- \( D_j \): diffusion coefficient, m\(^2\) s\(^{-1}\)

Molecular diffusivity:

\[ D_{H_2O} = 21.2 \times 10^{-6} \text{ m}^2 \text{ s}^{-1} \]
\[ D_{CO_2} = 12.9 \times 10^{-6} \text{ m}^2 \text{ s}^{-1} \]

These are temperature dependent.

Flux density = diffusion coefficient * concentration gradient

Remember, a gradient has both magnitude and direction (results in a vector).

**Momentum Transport: Shearing stress**

Windspeed decreases adjacent to the roughness elements on the surface. Shearing stress can be defined as

\[ \tau = \mu \frac{\partial u}{\partial z} \]

- \( u \): velocity (wind speed)
- \( z \): height
- \( \mu \): dynamic viscosity of fluid

Note: like the diffusion and heat flow equations, momentum transport towards the surface is dependent on a gradient and a proportionality factor.

**Conservation of Energy and Mass: (Energy and mass Balance, Continuity)**

Rate form:

- Energy in – Energy out = Change in storage
- Heat flux in – Heat flux out = Rate change in storage

\[ J/s \quad J/s \quad J/s \]
Classic surface energy balance of a vegetated surface:

\[
\text{Net radiation} - \text{Soil heat flux} = \text{Latent heat flux} + \text{Sensible heat flux}
\]

\[
\text{RN} - G = \lambda E + H
\]

Radiation – Conduction = Mass transport + Convection

An example energy balance for a vegetated surface in Manhattan, KS at 1100 h in June is:

\[
\text{RN} = 500 \text{ W m}^{-2}
\]

\[
G = 100 \text{ W m}^{-2}
\]

\[
H = 150 \text{ W m}^{-2}
\]

\[
\lambda E = 250 \text{ W m}^{-2}
\]

Recall, it takes approximately 2450 J of energy to evaporate 1 g of water (i.e., latent heat of vaporization, \(\lambda\)). Thus, if we know the rate of mass flow of water in g m\(^{-2}\) s\(^{-1}\) we can multiply by \(\lambda\) to get the energy flow (e.g., if \(E = 0.102\) g m\(^{-2}\) s\(^{-1}\); then \(\lambda E\) is \(0.102\) g m\(^{-2}\) s\(^{-1}\) * 2450 J g\(^{-1}\) = 250 J s\(^{-1}\) m\(^{-2}\) or W m\(^{-2}\) ).

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**Figure 1.1.** Schematic representation of the inter-connectedness of water (in *italics*), carbon (underlined), radiation (normal font) and energy (**bold**) budgets in a biosphere.
Concept of a Continuum

Soil – Plant – Atmosphere Continuum (SPAC)

In the SPAC, the value of any environmental variable, and the movement of energy and matter (e.g. flux, magnitude and direction, kg H\textsubscript{2}O m\textsuperscript{-2} s\textsuperscript{-1}) is governed by complex interactions between the microenvironment and the biological system.

Spatial and Temporal Scales:

<table>
<thead>
<tr>
<th>Spatial Scale</th>
<th>Horizontal Extent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microscale</td>
<td>(10^{-2} - 10^{3}) m</td>
</tr>
<tr>
<td>Local scale</td>
<td>(10^{2} - 5 \times 10^{4}) m</td>
</tr>
<tr>
<td>Mesoscale</td>
<td>(10^{4} - 2 \times 10^{5}) m</td>
</tr>
<tr>
<td>Macroscale</td>
<td>(10^{5} - 10^{8}) m</td>
</tr>
</tbody>
</table>

Vertical Scale

We must consider the “boundary layer” of the surface on the object in question.

Boundary Layer:

This is the layer of fluid (liquid or gas) in the immediate vicinity of a surface in which exchange of heat, momentum, or mass is occurring. It is the transition between free, unobstructed flow and a solid boundary.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Boundary Layer Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roughness layer</td>
<td>0.0 – 0.1 m</td>
</tr>
<tr>
<td>Turbulent surface layer</td>
<td>0 – 10 m</td>
</tr>
<tr>
<td>Planetary boundary layer</td>
<td>0 – 1000 m</td>
</tr>
<tr>
<td>Troposphere</td>
<td>0 – 1 \times 10^{4} m</td>
</tr>
<tr>
<td>Stratosphere</td>
<td>&gt; 1 \times 10^{4} m</td>
</tr>
</tbody>
</table>

Note: The roughness sublayer is part of the surface layer. (Arya, Fig. 1.1).
Laminar Boundary Layer:

At very small scales (mm) the streamlines of flow become almost parallel to the object. Flow is not turbulent, and transport through the boundary layer (BL) is by molecular diffusion.

**Belowground Scale**

<table>
<thead>
<tr>
<th>Surface</th>
<th>0-1 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root zone (rhizosphere)</td>
<td>0-3 m (vegetation)</td>
</tr>
<tr>
<td>Vadose zone</td>
<td>Soil above the water table</td>
</tr>
</tbody>
</table>

**Time, Temporal Scale**

The time scale of interest is dependent on the process under investigation.

Examples:

- Turbulence         0.1 s (10 Hz)
- Radiation          hourly, diurnal
- Drought            monthly
- Climate change     yearly

**Weather vs. Climate?**

**Weather** is the condition of the atmosphere at a particular time.

**Climate** is the average weather in a location or region over a relatively long time (e.g., 15 yr).
Avg. Daily Air Temperature: Manhattan, KS

Annual Avg.: Long-term = 19.3°C; 2004 = 18.8°C
Historical Average: 1986-2004

Precipitation: Manhattan, KS

Annual Total
1986-2004: 769.1mm (30.3")
2004: 801.9 mm (31.5")

North Agronomy Farm Weather Station, Manhattan, KS