Disposition of Solar Radiation at Earth’s Surface

- Reflection: Albedo is a key property of surfaces controlling the surface energy balance
- Absorbed radiation: used to
  - Heat the soil: soil heat flux (G)
  - Heat the air: sensible heat flux (H)
  - Evaporation water: latent heat flux (LE)

**ALBEDO**

\[
\alpha = \frac{K_{\downarrow}}{K_{\uparrow}}
\]

where:
\[\alpha = \text{albedo}\]
\[K_{\downarrow} = \text{reflected shortwave radiation}\]
\[K_{\uparrow} = \text{downward shortwave radiation}\]

**Typical Albedo**

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>0.12 - 0.14</td>
</tr>
<tr>
<td>Grassland</td>
<td>0.16 - 0.25</td>
</tr>
<tr>
<td>Crops</td>
<td>0.16 - 0.22</td>
</tr>
<tr>
<td>Bare soil (wet)</td>
<td>0.08 - 0.10</td>
</tr>
<tr>
<td>Bare soil (dry)</td>
<td>0.15 - 0.25</td>
</tr>
<tr>
<td>Burned vegetation</td>
<td>0.06 - 0.10</td>
</tr>
<tr>
<td>Snow</td>
<td>0.80 - 0.90</td>
</tr>
<tr>
<td>Ocean (calm; high zenith angle)</td>
<td>0.08</td>
</tr>
<tr>
<td>Planet Earth</td>
<td>0.30</td>
</tr>
</tbody>
</table>

Energy Balance and Temperature
GLOBAL ALBEDO PATTERN

Influences on Albedo

• Density, LAI, and height of vegetation
• Soil color and moisture content
• Sun angle and slope/aspect of land surface
• Relative amount of direct and diffuse light

Albedo vs. LAI

Longwave Radiation

• Surface emits longwave radiation as a function of its temperature and emissivity
• Atmosphere absorbs most longwave radiation from the surface: Greenhouse Effect
• Surface also receives longwave radiation from the atmosphere
Greenhouse Effect

Exchange of Radiation Between the Surface and the Atmosphere

- Of the shortwave radiation reaching the surface, a certain amount is reflected, depending on the albedo of the surface, the rest is absorbed. Once absorbed, that energy is converted to other forms.
- One result of absorbing solar radiation is that the surface becomes warmer. This increases the emission of longwave radiation by the surface (Stefan-Boltzmann Eq.).

LONGWAVE EXCHANGE

- Longwave radiation by the surface is strongly absorbed by greenhouse gases in the atmosphere.
- The atmosphere is warmed as a result of absorbing longwave radiation, and hence emits more radiation. Atmospheric radiation goes in all directions, some warming the layers of air above, and some warming the surface. This re-radiation by the atmosphere to the surface is responsible for the greenhouse effect.

Radiation Balance

- Radiation balance is achieved when the total radiation received at the surface is equal to the total radiation emitted by the atmosphere. The diagram shows the balance of incoming and outgoing radiation, with net radiation and radiation absorbed or lost at different levels of the atmosphere.
SURFACE NET RADIATION

\[ R_{\text{net}} = K \downarrow - K \uparrow + A \downarrow - L \uparrow \]

where:
- \( R_{\text{net}} \) = net radiation
- \( A \downarrow = \) downward longwave radiation absorbed by the surface
- \( L \uparrow = \) upward longwave radiation emitted by the surface

SURFACE NET RADIATION

\[ R_{\text{net}} = (1 - \alpha)K \downarrow + A \downarrow - \epsilon_s \sigma T_s^4 \]

where
- \( \alpha \) = albedo
- \( \epsilon_s \) = surface emissivity
- \( T_s \) = surface temperature
- \( L \downarrow = \) downward longwave radiation from atmosphere

Radiation Measurement

- Shortwave radiation
  - Eppley 8-48 “black & white”
  - Eppley PSP: precision spectral pyranometer
  - Kipp & Zonen CM11

Radiation Measurement

- Direct shortwave radiation
  - NIP: Normal incidence pyrhiometer

- Diffuse
  - shade band
  - shade disk
Radiation Measurement

• Surface temperature (upward LW): *infrared thermometer*
  – Apogee IRTS-P

Radiation Measurement

• Net radiation: *net radiometer*
  – REBS Q*7.1

Energy Balance of Earth

Radiation Measurement

• Net radiation: *net radiometer*
  – Kipp & Zonen CNR1
Energy Balance of Earth

Solar constant: 1367 W m\(^{-2}\)
Area intercepting radiation (disk area): \(\pi r^2\)
Surface area of earth (surface of sphere): \(4\pi r^2\)
Solar constant per unit surface area of earth
= \(1367 \times \pi r^2 / 4\pi r^2 = 1367/4\)
= 341.75 W m\(^{-2}\)

Energy Balance of Earth

Assume earth maintains energy equilibrium
Assume exchanges of energy into and out of the earth’s planetary system are only in the form of radiation
Earth receives 341.75 W m\(^{-2}\) of solar energy
To maintain energy equilibrium, Earth must give up 341.75 W m\(^{-2}\)
Planetary albedo: 30%
Therefore, the earth absorbs 70% of 341.75 W m\(^{-2}\) = 239.23 W m\(^{-2}\)
To maintain balance earth must emit 239.23 W m\(^{-2}\)

Energy Balance of Earth

What is the radiative equilibrium temperature of earth (temp. necessary to emit 239.23 W m\(^{-2}\))? Use the Stefan-Boltzmann equation:
Rearranging \(I = \sigma T^4\) we get:
\[ T = \left( \frac{I}{\sigma} \right)^{0.25} \]
\[ T = \left( \frac{239.23}{5.67 \times 10^{-8}} \right)^{0.25} \]
= 254.86 K
= -18.3°C \(\Rightarrow\) Radiative Equilibrium Temperature of Earth

Energy Balance of Earth

Radiative Equilibrium Temperature of Earth = -18.3°C
Actual mean surface temperature of earth:
20th Century Mean: 13.9°C (57.0°F)
2010 Mean: 14.5°C (58.12°F)

Question 1: Why is the actual surface temperature 32.8°C higher than the radiative equilibrium temperature?

Question 2: Is the radiative equilibrium temperature of the earth changing due to increasing greenhouse gases?

Question 3: Why is the surface temperature of the earth increasing?
Energy Balance of Earth System Components

Planetary System: $R_{\text{net}}$ for planetary system = 0
Atmosphere: $R_{\text{net}}$ for planetary system < 0
Surface: $R_{\text{net}}$ for planetary system > 0

Why no radiative equilibrium for atmosphere or surface?

• Because of other (non-radiation) energy exchanges between surface and atmosphere
• Sensible and latent energy flux moves energy derived from radiation surplus at surface to make up the radiation deficit in the atmosphere

Surface Energy Balance

• Energy balance equation:
  
  $R_{\text{net}} = \text{LE} + \text{H} + \text{G} + \text{P}$

  where: \( \text{LE} \) = latent energy flux to the atmosphere, \( \text{H} \) = sensible energy flux to the atmosphere, \( \text{G} \) = sensible energy conduction into the soil, and \( \text{P} \) = photosynthesis

• \( \text{G} \) is positive during the day and negative at night; on a 24-hour basis \( \text{G} \) can be ignored
• \( \text{P} \) is small relative to other energy balance terms and can also be ignored
• Simplified Energy Balance Equation
  
  $R_{\text{net}} = \text{LE} + \text{H}$

  This says that the energy derived from net radiation at the surface goes primarily into two things: energy for evaporation of water and energy for heating the air.
• Surface characteristics control the partitioning of net radiation into \( \text{LE} \) and \( \text{H} \).

Temperature

Fundamental Influences on Air Temperature

• net radiation: latitude, time of year, time of day, cloudiness, surface characteristics
Temperature
Fundamental Influences on Air Temperature
• net radiation: latitude, time of year, time of day, cloudiness, surface characteristics
• partitioning of net radiation: surface characteristics (vegetation cover, moisture availability) $R_{\text{net}} = L_{\text{E}} + H$

• energy advection: horizontal transfer of energy via ocean currents and atmospheric circulation
• land or ocean: specific heat, evaporation, mixing, transparency

• altitude-elevation: air is primarily heated by the surface—distance from the source; reduced downward longwave radiation with elevation; rising air cools by expansion.