The Radiation Balance

Readings

A&B: Ch. 3 (p. 60-69)

www: 4. Radiation

Lab: 5

Topics

1. Radiation Balance Equation
   a. Net Radiation
   b. Shortwave Radiation
   c. Longwave Radiation
2. Global Average
3. Spatial and Temporal Variations

Review

- Radiation = Mode of Energy transfer
  - Radiation is conserved: $\alpha_\lambda + a_\lambda + t_\lambda = 1$
  - Radiation emitted from Earth/atmosphere: terrestrial or longwave radiation
  - Radiation emitted from sun: solar or shortwave radiation
  - When solar radiation is absorbed in the Earth/atmosphere, part or most of it is re-emitted as longwave radiation
- "Balance" $\Rightarrow$ conservation of energy:
  - Storage change = Input – Output

Radiation Balance Equation

- The Radiation Balance can be expressed in a budget equation, composed of different terms that each represent a radiation transport or conversion process

  $Q^* = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow)$ [Units: W m^{-2}]

  $= K^* + L^*$

  - Q^* : net all wave radiation
  - K^* : net shortwave radiation
    - $K\downarrow$: incoming shortwave radiation.
    - $K\uparrow$: outgoing shortwave radiation
  - L^* - net longwave radiation
    - $L\downarrow$: incoming longwave radiation
    - $L\uparrow$: outgoing longwave radiation

Radiation Balance: Net Radiation (Q^*)

$$Q^* = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow)$$
$$= K^* + L^*$$

Q^* : net all-wave radiation ("net radiation")

- Summary effect of all radiation processes
- Net radiative energy that is absorbed and then transformed into a different form (non-radiative)

$\rightarrow$ Available to be partitioned in the Energy Balance* to

- Heat the air
- Heat the ground or
- Evaporate water

* Lecture Notes Section 5

Radiation Balance: Shortwave Radiation

$$Q^* = K^* + L^*$$

- **K* : net shortwave radiation**
  - **$K^* = (K\downarrow - K\uparrow)$**
- **K↓ : incoming shortwave radiation**
  - **Emitted by the sun, transmitted through atmosphere**
  - **Dependent on solar altitude, transmissivity of the atmosphere above**
  - ***Solar constant*: maximum K↓, occurs at the top of the earth's atmosphere at right angles = 1376 W m^{-2}**
- **K↑ : outgoing shortwave radiation (reflected!)**
  - **Depends on K↓ and the albedo (α)**
  - **$K\uparrow = \alpha K\downarrow$**
  - ***Albedo*: ratio of reflected to incoming shortwave radiation ($\alpha = K\uparrow / K\downarrow$)**

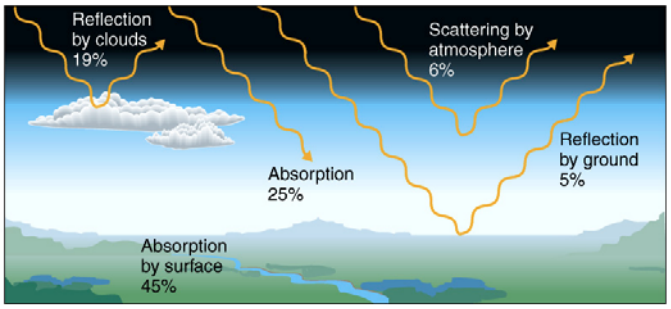
Radiation Balance: Longwave Radiation

$$Q^* = K^* + L^*$$

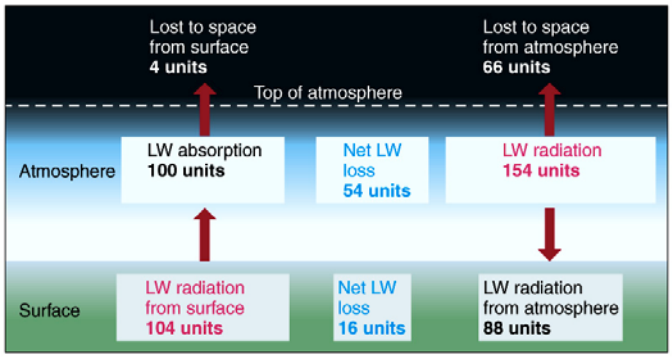
- **L* : net longwave radiation**
  - **$L^* = (L\downarrow - L\uparrow)$**
- **L↓ : incoming longwave radiation**
  - **Depends on apparent sky temperature (T_s) and sky emissivity (ε_s)**
  - **$L\downarrow = \varepsilon_s \sigma T_s^4$**
  - **T_s and ε_s: summary effect of all layers of the atmosphere; depend on cloud cover, humidity, temperature structure**
- **L↑ : outgoing longwave radiation**
  - **Depends on surface temperature (T_0) and surface emissivity (ε_0)**
  - **$L\uparrow = \varepsilon_0 \sigma T_0^4$**

Radiation Balance: Global Average

- **Shortwave Radiation**
  - Total reflected to space: 30% (= global albedo)
  - Total absorbed: 70%



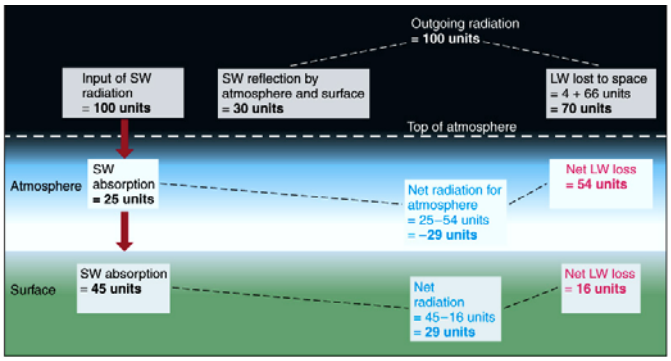
- **Longwave Radiation**
  - Total lost to space: 70%
  - L↓ at surface: from atmosphere = greenhouse effect



Radiation Balance: Global Average

- **Balance can be formed at any level**
  - Top of atmosphere
  - Atmosphere
  - Surface
- **At top of atmosphere**
  - Zero net radiation
- **In the atmosphere and at the surface:**
  - Non-zero net radiation

  → Other forms of energy transport must compensate



★**These numbers are long-term global averages (average cloud cover, temperature, etc.)**
- **Considerable spatial and temporal (weather, seasons, climate) variations exist**

Global Shortwave Radiation Balance

	Average Conditions	Clear-sky Conditions (No Clouds)	Cloudy Conditions (Overcast)
Reflected or Scattered By Surface or Atmosphere	30%	13%	51%
Absorbed by Atmosphere Clouds, Gases, and Aerosols	25%	17%	24%
Absorbed by Surface Oceans and Land	45%	70% (55% direct, 15% diffuse sky)	25% (4% direct 21% diffuse sky)

Radiation Balance: Temporal Variation

- Daily Variation – because of earth's rotation
  - Daytime:
    - Positive Q* (net radiation)
  - Nighttime:
    - No K↓, no K* (shortwave radiation)
    - Negative Q*
- Annual Variation – because of earth-sun geometry
  - Winter
    - Less K↓, less Q*
  - Summer
    - More K↓, more Q*
- Other Variations
  - Clouds, dust, pollution
    - Absorb incoming K↓ and outgoing L↑

    → Daytime Q* at surface is less positive than w/ clear skies

    → Nighttime Q* at surface is less negative " " " "

Radiation Balance: Spatial Variation

- Latitude
  - More K↓, more Q* near equator than near poles
- High elevation → Less atmospheric absorption
  - More K↓ and Less L↓
    - During day: More positive Q* (than at sea level)
    - During night: More negative Q* (than at sea level)
- Clouds and Humidity
  - Absorb incoming K↓ and outgoing L↑
    - During day: less positive Q* at surface (than clear skies)
    - During night: less negative Q* at surface " " "
- South vs. North Facing Hills
  - South facing slopes receive more K↓, thus have higher Q*
- Dark surface vs. White surface
  - E.g. trees vs. snow
  - Darker surface has lower albedo → lower K↑, higher Q*

Radiation Balance: Poleward Transport

- Q* surplus at low latitudes (< 40° N/S)
- Q* deficit at high latitudes (> 40° N/S)
- To prevent runaway heating at low lat. and runaway cooling at high lat., energy is transported from the surplus to the deficit regions (poleward transport) by:
  - Ocean currents (~1/3)
  - Warm/cold winds (sensible heat) (~1/3)
  - Moisture in air (latent heat) (~1/3)