Atmosphere and Surface Energy Balances

Physical Geography Lecture - GEOG B1

Available on: www.cherylnail.com

Energy-Balance

Review:

>Earth’s energy budget: the balance between shortwave radiation coming into Earth, and shortwave/longwave radiation going back into space

Transmission: the uninterrupted passage of shortwave and longwave energy through either the atmosphere or water

Since insolation is distributed unevenly due to latitude and seasonal fluctuations, the energy budget is not the same at all locations.

See Fig. 4.1

Heat Energy

Heat: the flow of kinetic energy between molecules and from one body or substance to another resulting from a temperature difference between them.
Heat always moves from an area of higher temperature into an area of lower temperature.
Heat flow stops when the temperatures, or molecular kinetic energy, become equal.

Heat Transfer Methods (Fig. 4.2)

Radiation: the transfer of heat in electromagnetic waves - these waves do not need a medium, like air or water, to travel through

>>Examples - Sun to Earth, fire, burner on stove

Conduction: molecule-to-molecule transfer of heat energy as it diffuses through a substance - molecules vibrate faster as they warm, causing collisions and heat transfer with neighboring molecules (substances must be touching)

>>Examples - metal becomes hot to the touch as it heats

Convection: heat transfer by vertical mixing or circulation - warmer gases or liquids have less mass, so they rise - cooler masses are more dense, so they sink

>>Example - movement of boiling water in pot

Insolation at Earth's Surface

Incoming solar radiation (**insolation**) is the one energy input driving the Earth-atmosphere system.

Consistently higher insolation values along equatorial and tropical latitudes.

Insolation decreases toward the poles from about 25° north or south.

See Fig. 4.3 - isolines represent areas with same level of insolation

Greater insolation at the surface occurs in low-latitude deserts worldwide because of frequently cloudless skies.

Scattering and Diffuse Radiation

Scattering: when insolation is redirected by atmospheric gases, dust, cloud droplets, water vapor, and pollutants - the direction of the light is changed, but the wavelength is not altered.
Some insolation is reflected back to space without reaching the surface.
Diffuse radiation: insolation that reaches Earth's surface after scattering occurs - it is weaker and dispersed.
Direct radiation travels to the surface without being scattered.

Refraction

When insolation passes from one medium to another (*empty space into atmosphere*, or *air into water*), the insolation experiences a change of speed which also shifts its direction. This is the bending action of **refraction** (Fig. 4.4).

- *Prisms refract light*
- *Rainbows* are formed by refracted light
- **Mirage**: an image that appears near the horizon when light waves are refracted by layers of air at different temperatures/densities (Fig. 4.5)
- Because Earth has an atmosphere, we get 8 minutes of extra daylight each day.

Reflection and Albedo

Reflection: the arriving insolation that gets bounced directly back into space
Albedo: the reflective quality, or natural brightness, of a surface - controls the amount of insolation that reaches Earth

>>Albedo is measured by the percentage of insolations that is reflected >>>> 0% = total absorption; 100% = total reflectance (**Fig. 4.6**)

- Darker colored and rough surfaces have a lower albedo (asphalt, forests).
- Lighter colored and smooth surfaces have a higher albedo (snow, light roofs, grass, sand).
- Earth and its atmosphere on average reflect 31% of all insolation.

Absorption

Insolation not reflected by Earth's surface is absorbed, and either converted into longwave radiation or chemical energy (photosynthesis by plants).

Absorption: the assimilation of radiation by molecules of matter, converting the radiation from one form of energy to another

Atmospheric gases can only absorb certain wavelengths. For example:

>>oxygen & O_3 absorb incoming ultraviolet radiation in stratosphere

>>Water vapor & CO_2 absorb outgoing longwave radiation in lower troposphere - explains why our atmosphere is warmer at the surface

Clouds, Aerosols, and Atmospheric Albedo

Clouds and aerosols are unpredictable factors in the tropospheric energy budget.
Clouds reflect shortwave insolation - less insolation reaches Earth's surface
Clouds absorb longwave radiation leaving Earth. See Fig. 4.7
Air pollutants, both natural and anthropogenic, affect atmospheric albedo.

>>large volcanic eruptions → increased albedo → cooling trend

>>industrial pollutants → increased albedo → cooling trend

>>black carbon → absorb radiation & reradiate back to Earth → warming trend

Energy Balance in Troposphere

Earth-atmosphere energy system budget naturally balances itself in a steady-state equilibrium.

Insolation to Earth's atmosphere and surface are eventually balanced by outputs of reflected shortwave energy and longwave energy emitted from Earth's atmosphere and surface back out to space.

Certain atmospheric gases delay longwave energy loses to space, and they warm the lower atmosphere.

See Geosystems in Action: pp. 92-93, 4.1 and 4.2 - summarizes the Earth-atmosphere radiation balance

Greenhouse Effect and Atmospheric Warming

Earth emits longwave radiation from its surface and its atmosphere toward space. Certain gases in the lower atmosphere absorb that longwave radiation and reradiate, or emit, it toward Earth - increase heating.
Similarity between this process and the way a greenhouses works gives this process its name: the **greenhouse effect**
Those gases are called **greenhouse gases**
>> CO_2, water vapor, methane, nitrous oxide, CFCs

Clouds and Earth's "Greenhouse"

Clouds can cause cooling or heating depending on the percentage of cloud cover, cloud type, altitude, and thickness.
Cloud-albedo forcing: increased albedo due to low, thick stratus clouds with an albedo of 90% - increased albedo = cooling trend to climate (Fig. 4.8 **a**)
Cloud-greenhouse forcing: increased insulation due to high-altitude, ice-crystal clouds with an albedo of 50% - cirrus clouds allow more insolation in and trap longwave radiation = warming trend to climate (Fig. 4.8 **b)**

Latitudinal Energy Imbalances

See **Fig. 4.10**

At tropics: insolation high & daylight is consistent + very little seasonal variation (more energy gained than lost) = energy surplus

At polar regions: sun is at low angle + highly reflective surfaces + 6 months of no insolation (more energy lost than gained) = energy deficit

This energy imbalance drives a vast global circulation pattern in wind patterns and ocean currents, weather patterns, and other related phenomena

from the tropics to the poles

Daily Radiation Patterns

Final stage in the Sun-to-Earth energy system is the Earth's surface environment where solar energy is the main heat source.
See **Fig. 4.11** - Daily radiation and temperature curves graph: insolation and temperature increases do not coincide - there is a lag

Warmest time of day does NOT occur at the moment of maximum insolation
>>it occurs at the point when a maximum of insolation has been absorbed by the ground and emitted to the atmosphere

A Simplified Surface Energy Budget

Boundary layer: lower atmosphere at Earth's surface where energy and moisture are continually exchanged - energy balance here is affected by what is at the surface (vegetation, topography, etc.)

Microclimatology: the science of physical conditions, including radiation, heat, and moisture, in the boundary layer

>>Microclimates: local climate conditions over small areas (park, slope, backyard) (**Fig. 4.12**)

Net radiation (NET R): the sum of all radiation gains and losses at any defined location on Earth's surface (graph **Fig. 4.13**)

>>day = positive / night = negtive

Global and Seasonal NET R

Globally, the average annual NET R is positive over most of Earth’s surface.
See **Fig. 4.14** (*note the abrupt difference between ocean and land surfaces*)
NET R Expenditure: areas with positive NET R need to dissipate, or lose, heat to balance the energy budget

>>heat is used when water evaporates - biggest expenditure over water surfaces >>flow of energy (heat) into and out of the surface (land or water) by conduction

Urban Environment

Urban microclimates generally get warmer than the surrounding suburban and rural areas (as much as 6℃ / 10℉).

Urban heat island (UHI): urbanized regions that have average maximum and minimum temperatures higher than the non-urban surroundings (**Fig. 4.16**)

>>Main UHI causes: removal of vegetation / increase in human-made materials

>>UHI effects greater in bigger cities than smaller ones

Mitigation strategies for UHI effects: (**Fig. 4.17**)

>>more parks with vegetation, "green" roofs, "cool" roofs, and "cool" pavements (high-albedo materials)

Focus Study 4.1 - Solar Energy Applications

Earth receives enough solar energy in one hour to meet world power needs for a year.

In the U.S., the energy produced by fossil fuels in a year arrives in equivalent insolation every 35 minutes.

- Solar cooking solutions
- Solar thermal energy production
- Solar photovoltaic energy production
- **See pp. 98-99**