Climate & Earth System Science

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Introduction to Meteorology & Climate

MAPH 10050

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Chapter 02

The Energy Cycle

LECTURE 3

Force, Work and Heat

FORCE AND MOTION

- The FORCE acting on a body is the product of the mass of the body and the acceleration caused by the force:

$$F = m\,a$$

- ACCELERATION is the change in speed. If there is no force, there is no acceleration – the velocity is constant.

WORK AND ENERGY

- Work is force times distance moved.
- Energy is the capacity to do work.
- Potential and kinetic energy. Heat.

HEAT AND TEMPERATURE

- **Heat** is the energy produced by the random motions of molecules and atoms.
- **Specific heat** - amount of heat required to raise the temperature of one gram of a substance by one degree centigrade.
- **Temperature** - Celsius, Fahrenheit and Kelvin scales.

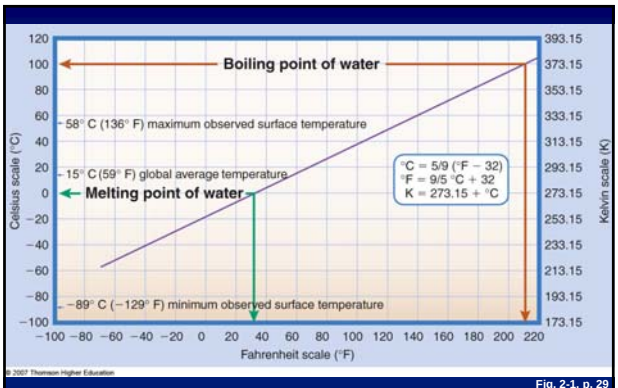


Fig. 2-1, p. 29

ENERGY and POWER

- Energy is measured in **Joules** or **calories**

  1 Joule = 0.24 calories

  1 calorie = 4.18 Joules

- **Power** is the rate at which work is done. It is measured in Watts

  1 Watt = 1 Joule per second.

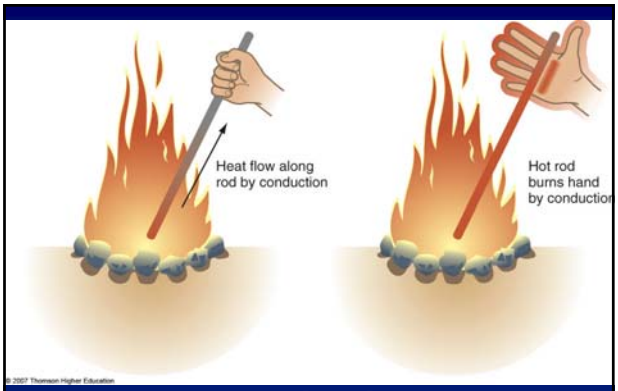
TABLE 2.1 The specific heat of a substance is the amount of heat required to increase the temperature of 1 gram of the substance 1° C

Substance	Specific Heat (cal/g/°C)	Specific Heat (J/kg/°C)
Water	1.0	4186
Ice	0.50	2093
Air	0.24	1005
Sand	0.19	795

Table 2-1, p. 30

TRANSFER OF ENERGY

- **CONDUCTION**
  - Transfer of energy through matter
  - Air is a poor conductor
  - Only important at the Earth's surface
- **CONVECTION**
  - Transfer of energy by movement of mass
  - Can only take place in fluids - e.g. Air
  - Energy transported upward by convective flow
  - Convection on a global scale creates worldwide atmospheric circulation
- **ADVECTION**
  - Horizontal movement of air
- **RADIATION**

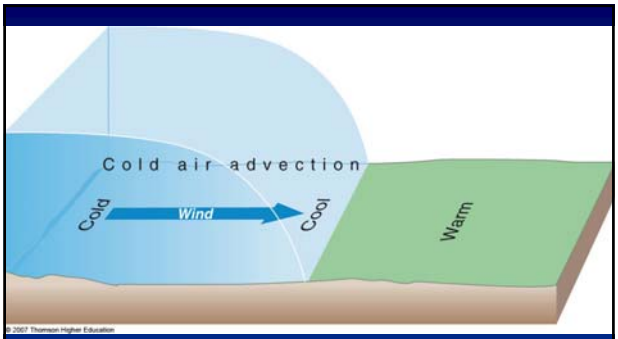


Conduction

Fig. 2-2, p. 30

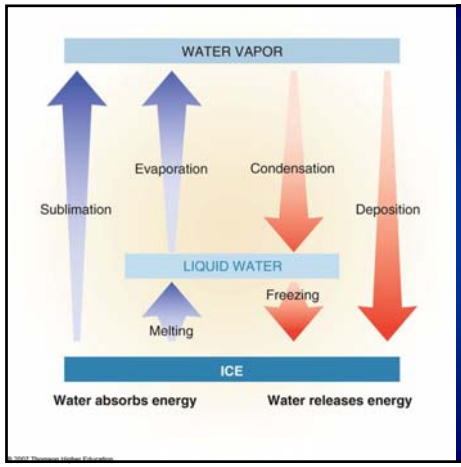
Convection

Fig. 2-3, p. 31



Advection

Fig. 2-4, p. 31



Phase Changes

Fig. 2-5, p. 33

LATENT HEAT – CHANGING THE PHASE OF WATER

- Latent heat is the heat absorbed or released by unit mass of water when it changes phase.
- Latent heat of melting / fusion
- Latent of vaporization / condensation
- Latent heat of sublimation / deposition

Radiation

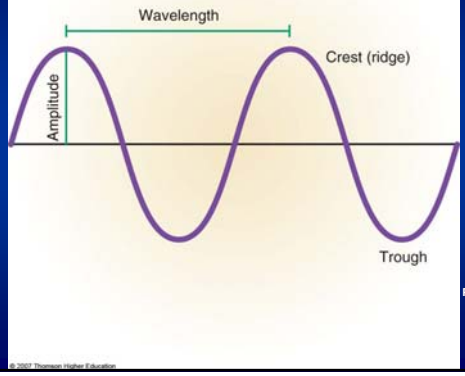


Fig. 2-6, p. 34

Everything radiates energy, even you and me.

Fig. 2.11

The EM Spectrum

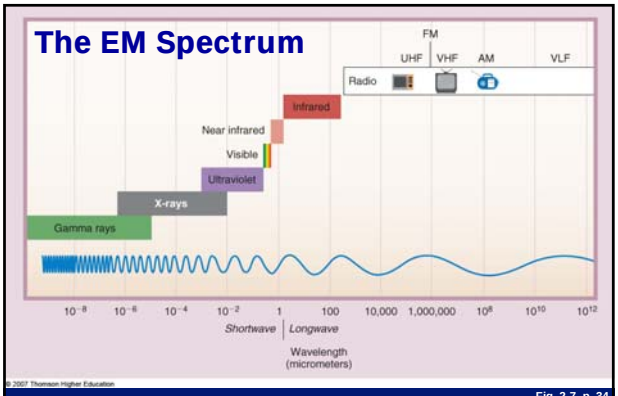


Fig. 2-7, p. 34

PLANCK'S LAW FOR BLACK BODY RADIATION

$$u(\lambda) = \frac{8\pi hc}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}(\mathrm{J/m^3/m})$$

Energy emitted, as a function of wavelength

WIEN'S DISPLACEMENT LAW

$$\lambda_m = \frac{2.9\times10^{-3}\,\mathrm{m\ K^{-1}}}{T}(\mathrm{m})$$

Wavelength of maximum energy radiated

STEFAN-BOLTZMANN LAW

$$R = \sigma T^4(\mathrm{W/m^2})$$

Energy radiated, as a function of temperature

Planck's Law for blackbody radiation:

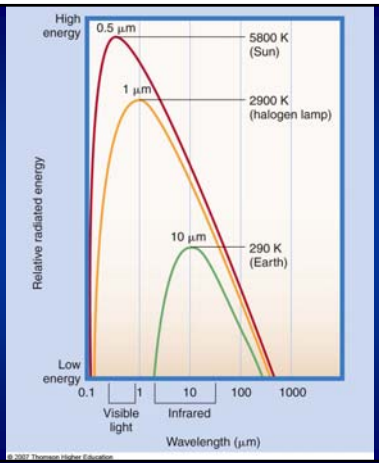
$$u(\lambda) = \frac{8\pi hc}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}(\mathrm{J/m^3/m})$$

Wien's Law:

$$\lambda_m = \frac{2.9\times10^{-3}\,\mathrm{m\ K^{-1}}}{T}(\mathrm{m})$$

Stephan-Boltzmann Law:

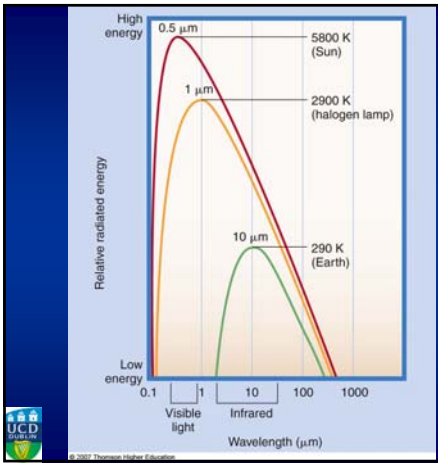
$$R = \sigma T^4(\mathrm{W/m^2})$$



The hotter the object, the higher the curve:

Stephan-Boltzmann Law

Fig. 2-8, p. 36



The hotter the object, the shorter the wavelength:

Wien's displacement law

Fig. 2-8, p. 36

Reading Exercise

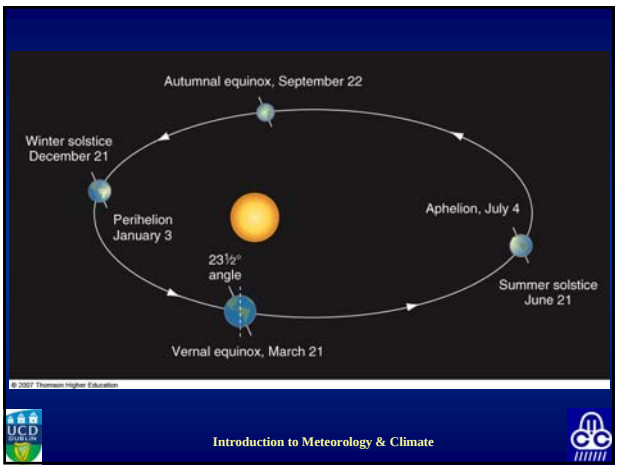
Study Ackerman and Knox

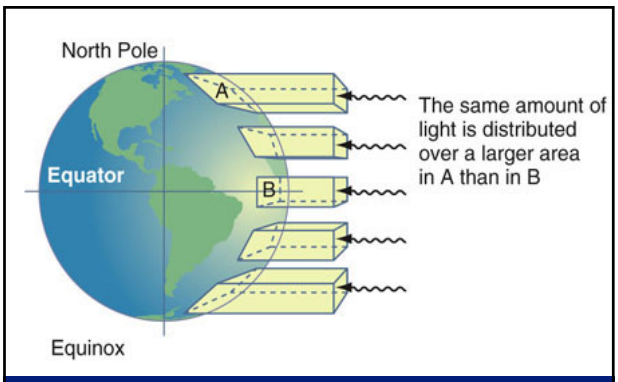
Chapter 2
Pages 26-40

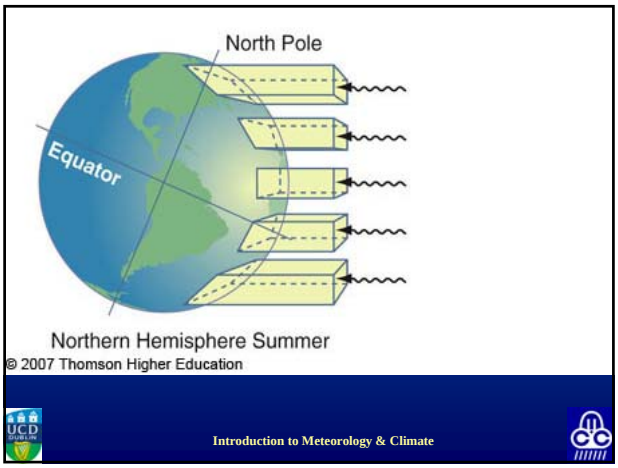
Preview reminder of chapter.

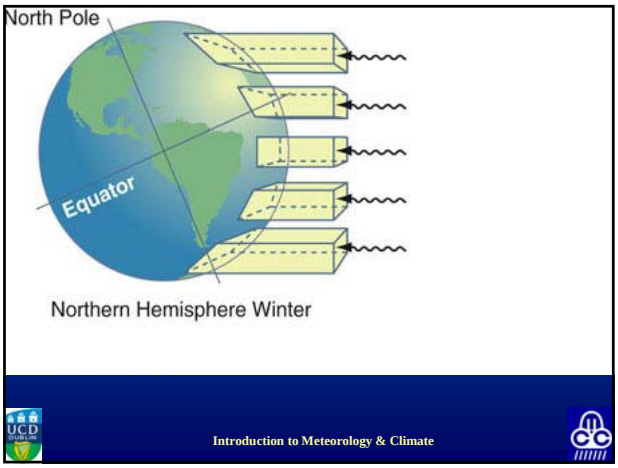
LECTURE 4

Energy Transfer in the Atmosphere









Zenith Angle

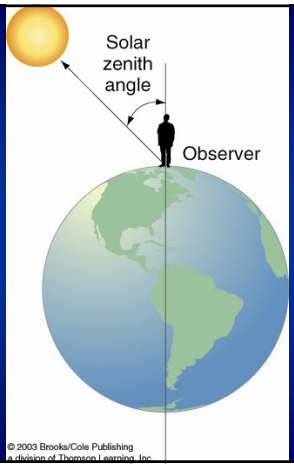


Fig. 2.15

The Solar Constant

- The average amount of solar energy reaching the outer limits of the atmosphere.
- This "constant" actually varies slightly.
- Changes by about 0.1% over the eleven year solar cycle.
- Mean value: 1368 W/m².

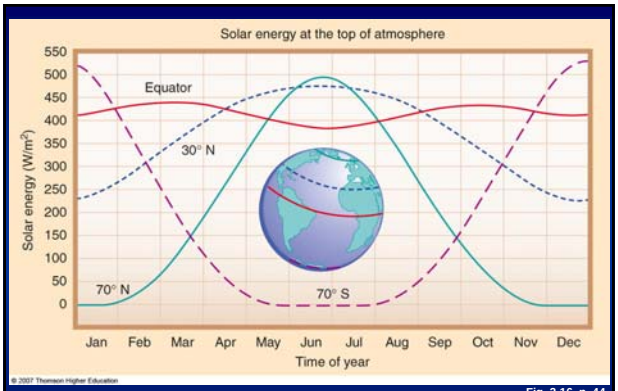


Fig. 2-16, p. 44

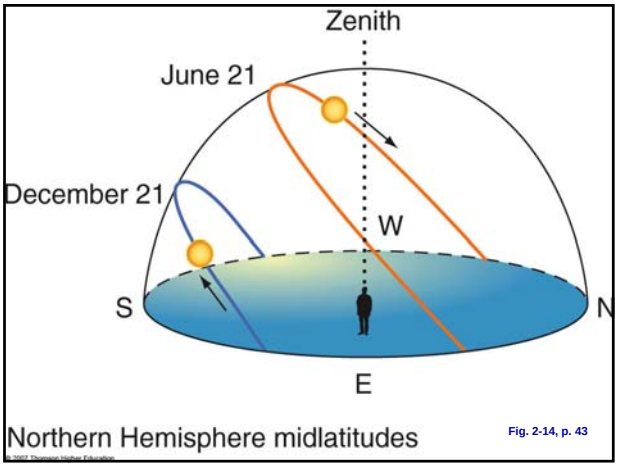


Fig. 2-14, p. 43

TABLE 2.2 The solar zenith angle at local noon, the number of daylight hours and the average incoming solar energy for four different latitudes on different days of the year

Latitude/date	Solar zenith at local noon (degrees)	Daylight hours (hours and minutes)	Average incoming solar radiation (W/m^2)
70°			
March 21	70	12 hr	150
June 21	46.5	24 hr	494
December 21	—	0 hr	0
42°			
March 21	42	12 hr	326
June 21	18.6	15 h 18 m	485
December 21	65.4	8 h 57 m	143
30°			
March 21	30	12 hr	380
June 21	6.6	13 h 54 m	476
December 21	53.4	10 h 4 m	229
Equator			
March 21	0	12 hr	438
June 21	23.5	12 hr	387
December 21	23.5	12 hr	413

Table 2-2, p. 44

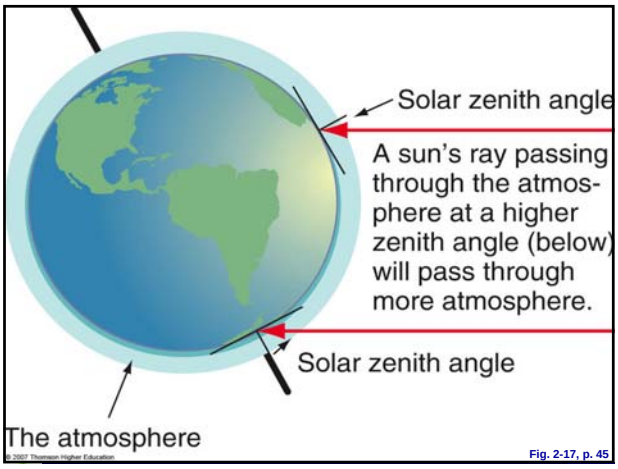


Fig. 2-17, p. 45

THE EARTH'S ORIENTATION

- Earth's axis is not perpendicular to the plane of its orbit around the sun.
- It is tilted 23.5° from the perpendicular: Inclination of the axis.
- Without this inclination we would have no seasons.
- This changes the solar zenith angle of the sun, and the area covered by a beam of sunlight.

THE EARTH'S ORIENTATION

- Area covered by beam of sunlight is proportional to 1/cos of the solar zenith angle
- In Belfield, solar zenith angle of the sun is 75° in December and 30° degrees in June.
- Ratio of 1/cos of the angles is about 3.3.
- Three times as much energy falls on unit area at the ground in Summer as in Winter.

INCOMING SOLAR RADIATION

- 25% penetrates directly to earth's surface.
- 26% scattered by atmosphere but then reaches the surface.
- Total of 51% reaches surface.
- 31% reflected back to space by clouds, atmospheric scattering, and reflective surfaces, e.g. snow and ice.
- 19% absorbed by clouds and atmosphere

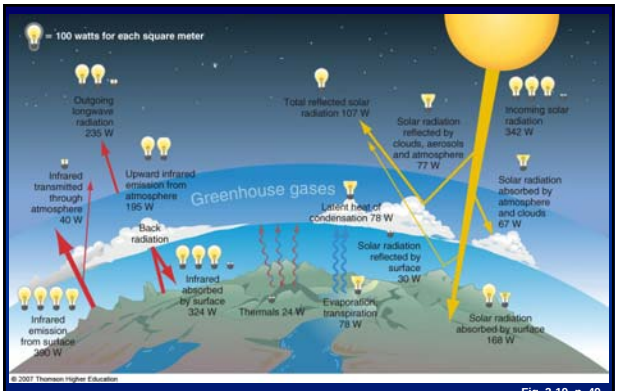


Fig. 2-19, p. 49

Energy and Matter

- Emission
- Absorption
- Reflection
- Scattering

ABSORPTION

- Gases are excellent absorbers.
  - When radiation is absorbed, energy is converted into internal molecular motion – temperature rises.
  - Significant absorbers are:
    - Oxygen and ozone
    - Water vapour
    - Carbon dioxide

REFLECTION - ALBEDO

- The fraction of energy that is reflected by a surface is called its albedo.
- Albedo of the earth as a whole is ~30%.
- Albedo of fresh snow is 80-85%.
- Thick cloud - 70 to 80%.
- Water - depends on elevation of the Sun, from 50 to 80% near horizon, 3-5% at 90°.
- Soil - 10%

SCATTERING

- Produces diffuse light.
- Shorter wavelengths (blue and violet) are scattered more effectively than longer wavelengths (red and orange).
- Sky appears blue when viewed at noon.
- At sunset, scattering depletes amount of blue light - sky appears reddish.
- Scattering more efficient as particle gets larger - aerosols or dust.

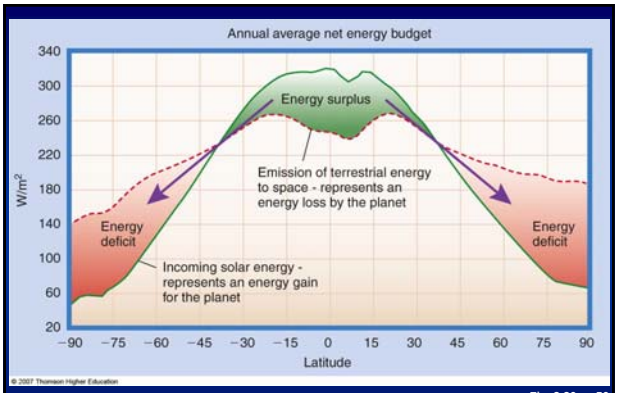


Fig. 2-20, p. 50

LATITUDINAL HEAT BALANCE

- The global amount of incoming solar radiation is nearly equal to the outgoing terrestrial radiation.
- However is not true at any given latitude.
- In general there is a surplus of energy at the equator - i.e. More radiation comes in than goes out.
- There is also a deficit of energy at the poles.
- Why then do the poles not get colder and the equator hotter?
- Because heat is transported from the equator to the poles by ocean currents and by the atmosphere.

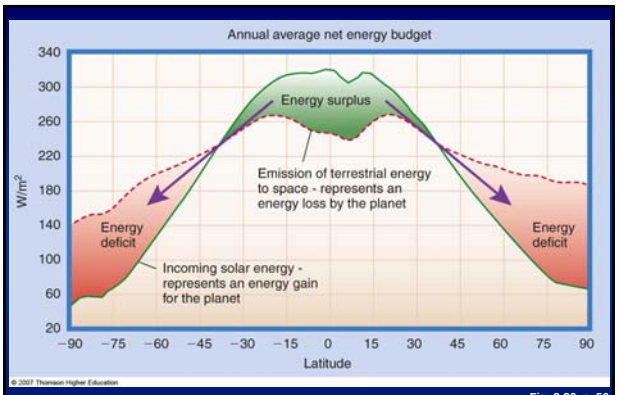


Fig. 2-20, p. 50

Reading Exercise

Study Ackerman and Knox

Chapter 2
Pages 44-53

Answer Review Questions.

NEXT LECTURE

Short movie from
Weatherbytes
DVD:
"Weather Fronts"

Class discussion on
"Weather Fronts
and the Weather in Ireland"

End of Chapter 2