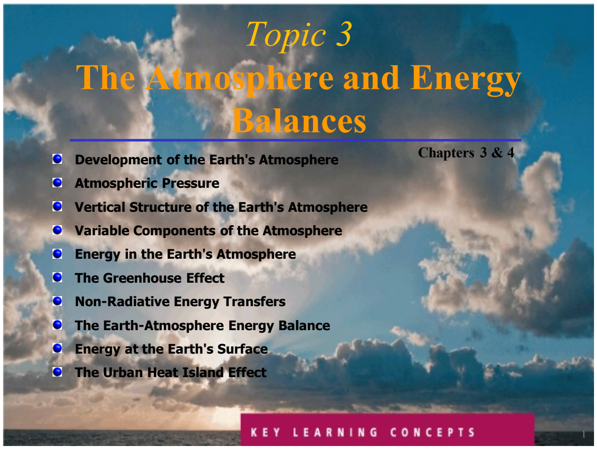
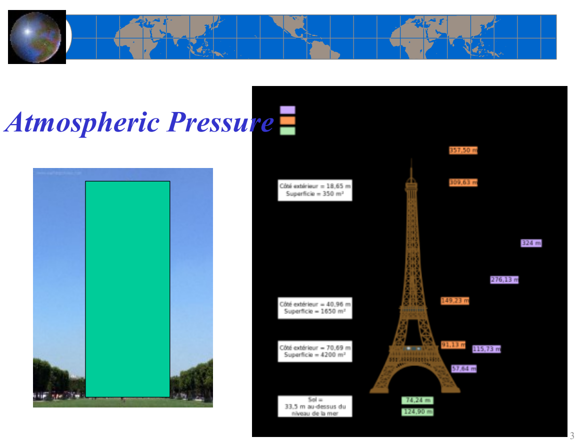
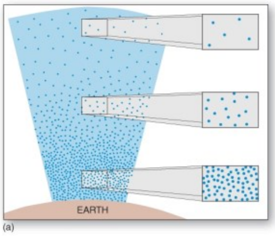

Topic 3
The Atmosphere and Energy Balances
Chapters 3 & 4
Development of the Earth's Atmosphere
Atmospheric Pressure
Vertical Structure of the Earth's Atmosphere
Variable Components of the Atmosphere
Energy in the Earth's Atmosphere
The Greenhouse Effect
Non-Radiative Energy Transfers
The Earth-Atmosphere Energy Balance
Energy at the Earth's Surface
The Urban Heat Island Effect
KEY LEARNING CONCEPTS

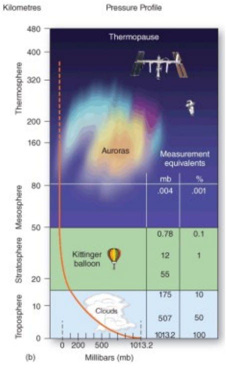

Development of Atmosphere
Primordial Atmosphere
Evolutionary Atmosphere
Living Atmosphere
Modern Atmosphere
Anthroposphere?
2


Atmospheric Pressure
3

Atmospheric Pressure



Result of gravity
Pressure decreases with altitude:
decreasing thickness
decreasing density



4

Atmospheric Pressure

- Also varies with temperature

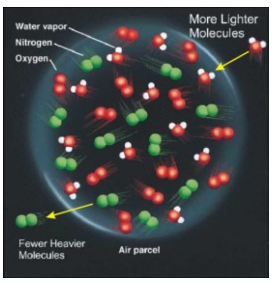
Air Density Table

Temperature °C	Air Density kg/m³
-20	1.395
-10	1.342
0	1.293
10	1.247
20	1.204
30	1.165
40	1.128
50	1.093
60	1.060
70	1.029
80	1.000
90	0.972
100	0.946

5

Atmospheric Pressure

- and moisture content (i.e. humidity)



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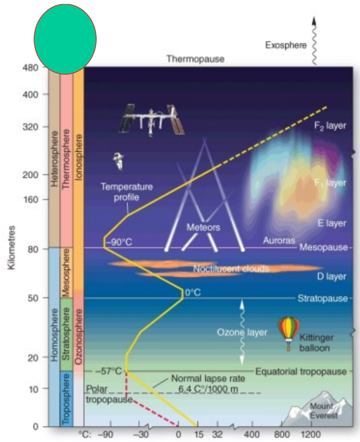
Atmospheric Profile



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Based on Composition

Figure 3.2a

- Heterosphere
  - Not uniform
  - Layers sorted by gravity, based on wgt
- Homosphere
  - Uniform
  - Evenly blended, single gas
  - Exceptions?

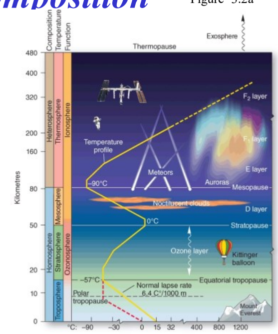

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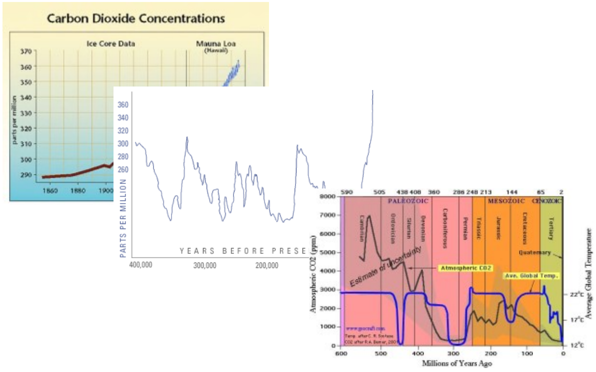
TABLE 3.1 Stable Components of the Modern Homosphere

Gas (Symbol)	Percentage by Volume	Parts per Million (ppm)
Nitrogen (N_2)	78.084	780 840
Oxygen (O_2)	20.946	209 460
Argon (Ar)	0.934	9340
Carbon dioxide (CO_2)*	0.0394	394
Neon (Ne)	0.001818	18
Helium (He)	0.000525	5
Methane (CH_4)	0.00014	1.4
Krypton (Kr)	0.00010	1.0
Ozone (O_3)	Variable	
Nitrous oxide (N_2O)	Trace	
Hydrogen (H)	Trace	
Xenon (Xe)	Trace	

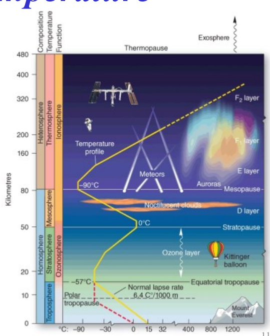
*May 2011 average CO_2 measured at Mauna Loa, Hawai'i (see http://www.esrl.noaa.gov/gmd/ccgg/trends/.)

9



Based on Temperature

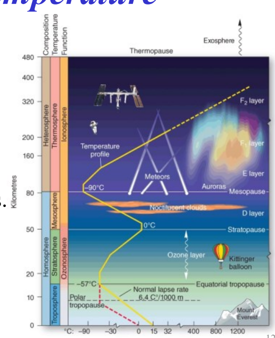
- Thermosphere
  - Bounded by:
    - thermopause above
    - mesopause below
  - Temperature ↑ with elev.
  - Absorption of SW
  - But is kinetic not sensible heat energy
  - So not "hot"



11

Based on Temperature

- Mesosphere
  - Bounded by:
    - mesopause above
    - stratopause below
  - Temp ↓ with elev.
  - Coldest layer, no SW abs.
  - Space dust
    - noctilucent clouds



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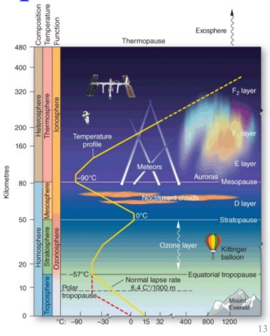
Based on Temperature

- Stratosphere
  - Bounded by:
    - stratorpause above
    - tropopause below
  - Temperatures ↑ with elev.
  - Ozone absorbs SW
  - Reradiates LW (heat) nrg.



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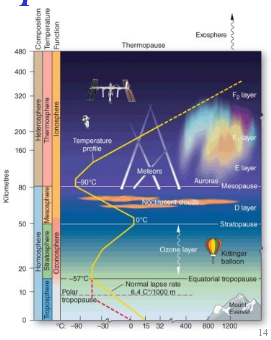
Based on Temperature

- Troposphere
  - Upper boundary defined by temp.
  - Temp. ↓ with elev.
  - 90% mass of atm.
  - All pollutants
  - Meteorological activity
  - Tropopause acts like a "ceiling"



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Temperature Profile of the Troposphere

Fcn of ↑ distance from radiant heat source

Normal rate is an avg.

Env. rate varies with pressure and moisture

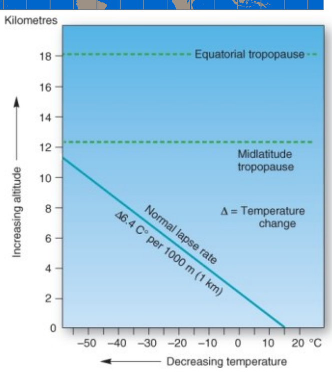

Figure 3.5

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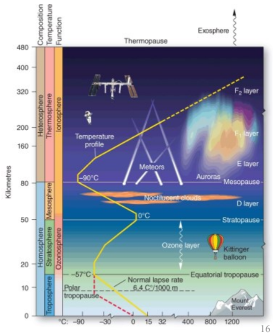
Based on Function

- Ionosphere
  - Absorbs gamma rays, xrays, UV
  - 4 sub-layers
  - Expands and contacts
- Ozonosphere
  - Increased O3 (ozone)
  - Absorbs UV
  - Reradiates LW



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Variable Transmission

Shorter, harmful wavelengths absorbed

Most visible light transmitted

Most infrared transmitted but often delayed

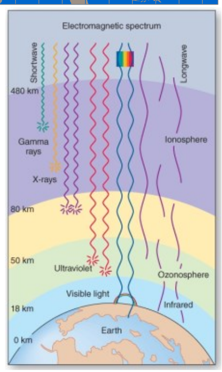

Figure 3.6

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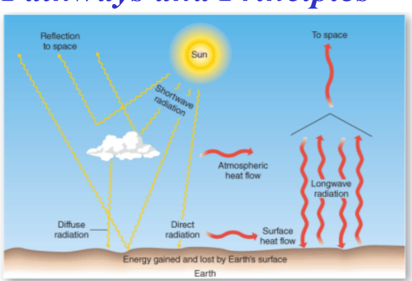
Energy Pathways and Principles

<u>Transmission</u>

Refraction

Reflection

Absorption



Chapter 4

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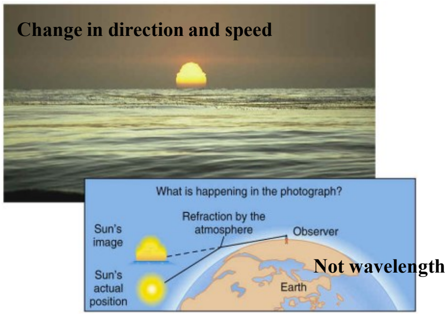
Refraction



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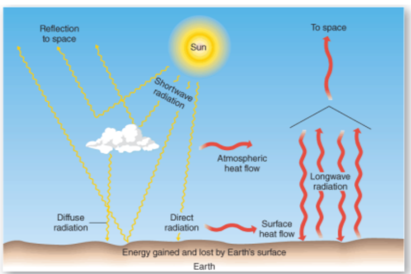
Reflection and Absorption



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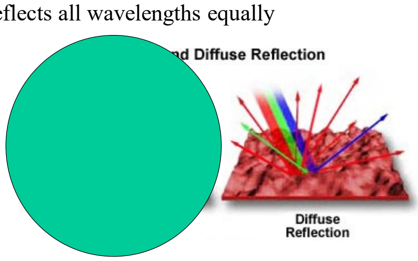
Specular Reflection

Reflects all wavelengths equally

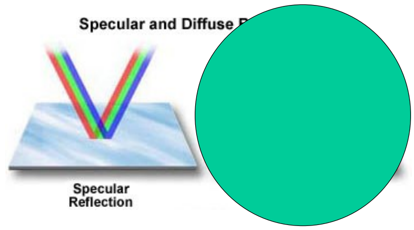


Does not change wavelength: SW ↓, SW↑

21

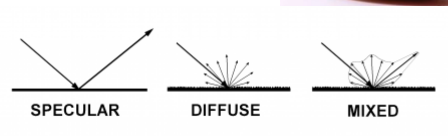
Diffuse Reflection

Wavelength dependent



Does not change wavelength: SW ↓, SW↑;
but does change amount in particular wavelengths

22



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Reflection and Albedo

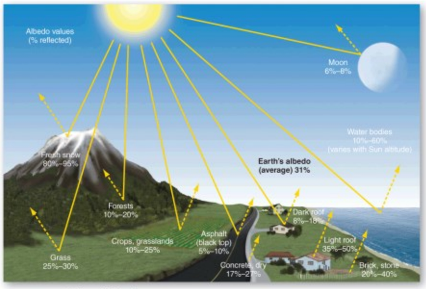

FIGURE 4.5 Various albedo values.
In general, light-coloured surfaces are more reflective than dark surfaces and thus have higher albedo values.

Global Albedo Values, Global Shortwave Radiation

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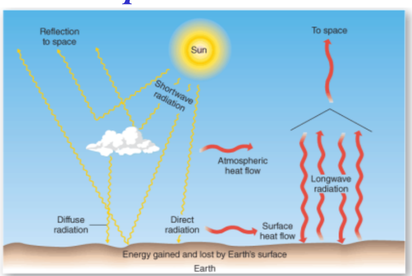
Absorption

EMR not reflected is absorbed

So also wavelength dependent and determined by "colour", texture, angle of incidence

SW absorbed and <u>converted</u> to heat is reradiated as LW



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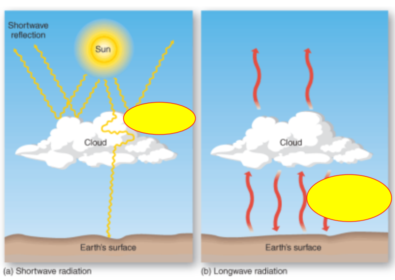
Clouds and SW vs. LW Radiation

FIGURE 4.6 The effects of clouds on shortwave and longwave radiation.
(a) Clouds reflect and scatter shortwave radiation; a high percentage is returned to space. (b) Clouds absorb and radiate longwave radiation emitted by Earth; some longwave energy returns to space and some toward the surface.



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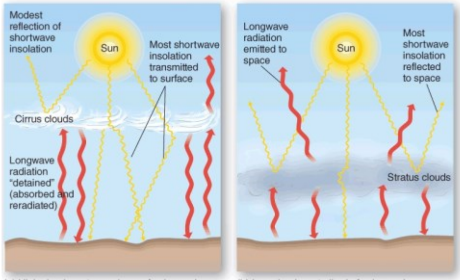
Clouds and Earth's "Greenhouse"



(a) High clouds: net greenhouse forcing and atmospheric warming

(b) Low clouds: net albedo forcing and atmospheric cooling

Figure 4.9

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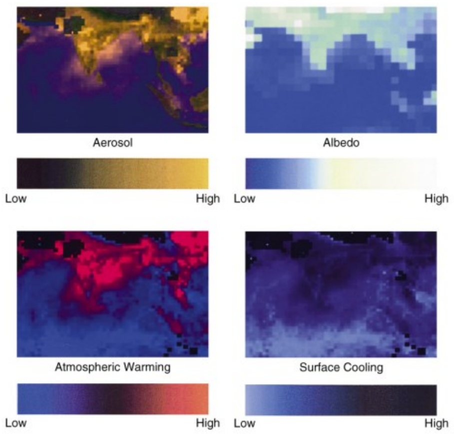

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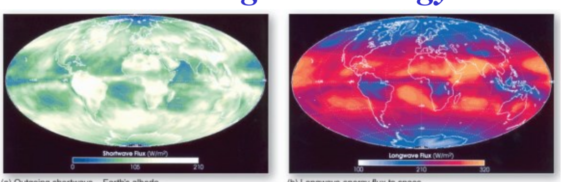
Short and Longwave Energy Flux



(a) Outgoing shortwave – Earth's albedo.

(b) Longwave energy flux to space.

FIGURE 4.11 Shortwave and longwave images show Earth's radiation budget components. The CERES sensors aboard *Terra* made these portraits, capturing (a) outgoing shortwave energy flux reflected from clouds, land, and water—corresponding to Earth's albedo; and (b) longwave energy flux emitted by these surfaces back to space. The scale beneath each image displays values in $W \cdot m^{-2}$. [CERES, Langley Research Center, NASA.]

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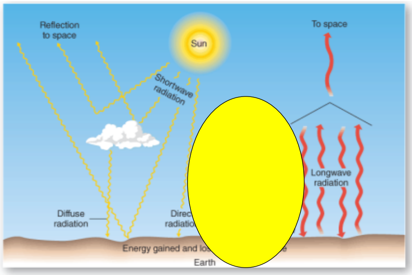
Heat Transfers



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Heat Transfer Processes

Convection – vertical movement

Advection – horizontal movement

Conduction – physical contact

Radiation – transmitted LW EMR

Latent Heat – stored energy

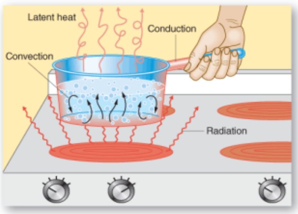

FIGURE 4.8 A pan of water on the stove illustrates heat transfer processes.
Infrared energy *radiates* from the burner to the saucepan and the air. Energy *conducts* through the molecules of the pan and the handle. The water mixes physically, carrying heat energy by *convection*.

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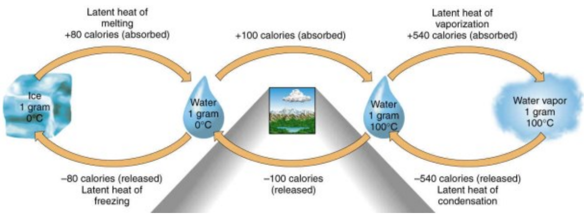
Latent Heat

Energy stored or released when water changes state



V. important for transferring heat energy in the atmosphere 33

Earth-Atmosphere Energy Balance

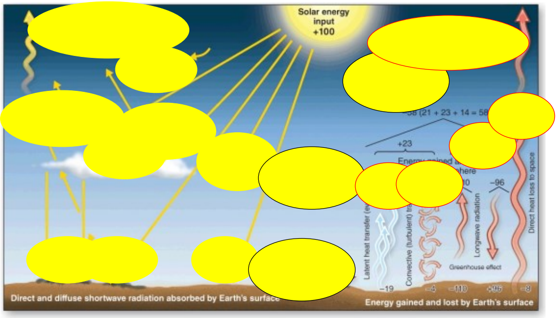


Figure 4.10

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Actual Energy Imbalance

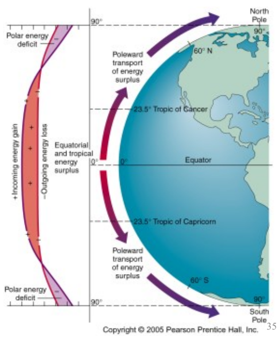
Due to variations in:

Sun angle, Daylength, Albedo

Net surplus in tropics

Net deficit nearer poles

Drives global circulation and redistribution of nrg and mass



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Daily Radiation Patterns

Lag between peak SW and highest air temp

Coolest after maximum period of reradiation

What is the longest day of the year in Brandon?

What are typically the hottest months/weeks?

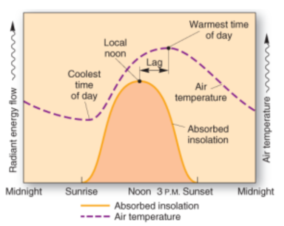

FIGURE 4.13 Daily radiation curves. Sample radiation plot for a typical day shows the changes in insolation (solid line) and air temperature (dashed line). Comparing the curves demonstrates a lag between local noon (the insolation peak for the day) and the warmest time of day.

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Simplified Surface Energy Balance

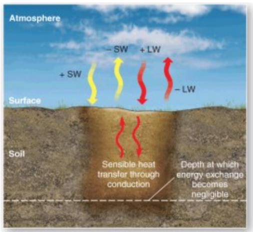

FIGURE 4.15 Surface energy budget.
Idealised input and output energy budget components for surface and a soil column. Sensible heat transfer in the soil is through conduction, predominantly downward during the day or in summer and toward the surface at night or in winter (SW = shortwave, LW = longwave).

Simplified Surface Energy Balance

- NET R (Net radiation) =
  +SW↓ (insolation)
  - SW↑ (reflection)
  + LW↓ (infrared)
  - LW↑ (infrared)

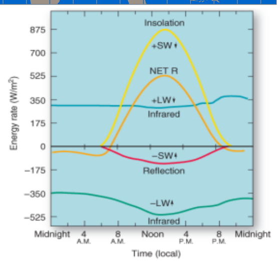

FIGURE 4.16 A day's radiation budget.
Radiation budget on a typical July summer day at a midlatitude location (Matador in southern Saskatchewan, about 51° N). [After T. R. Oke, *Boundary Layer Climates* (New York: Methuen & Co., 1978), p. 21.]

Function of SW & LW inputs - outputs **and global redistribution of energy**

Net Radiation

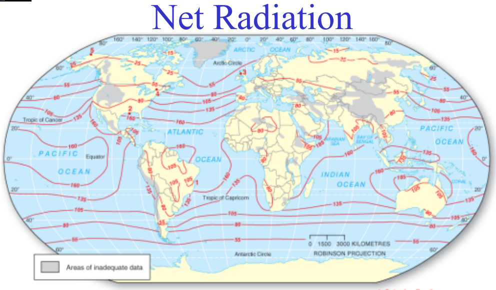

FIGURE 4.17 Global net radiation.
Distribution of mean annual net radiation (NET R) at surface level in watts per square metre ($100\ W \cdot m^{-2} = 75\ kcal \cdot cm^{-2} \cdot year^{-1}$). Temperature graphs for the five cities noted on the map, and in Figures 4.19 and 4.20, are graphed in Figure 5.4. [After M. I. Budyko, *The Heat Balance of the Earth's Surface* (Washington, D.C.: U.S. Department of Commerce, 1958), p. 106.]

1. Salvador, Brazil
2. New Orleans, Louisiana
3. Edinburgh, Scotland
4. Montreal, Canada
5. Barrow, Alaska

(see Figure 5.4)

Satellite Global Net Radiation

Net Radiation Expenditures

- Net radiation (Q) utilized for:
  1.
  2.
  3.
  4.

- Ratio of H to LE is called the Bowen Ratio; and determines ____________________?

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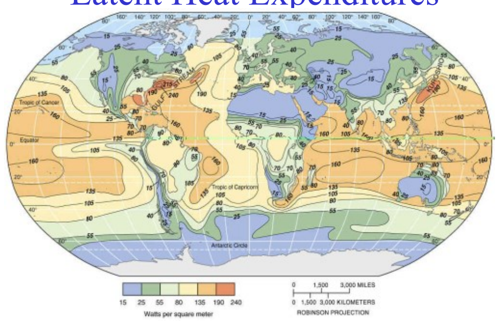
Latent Heat Expenditures



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Sensible Heat Expenditures

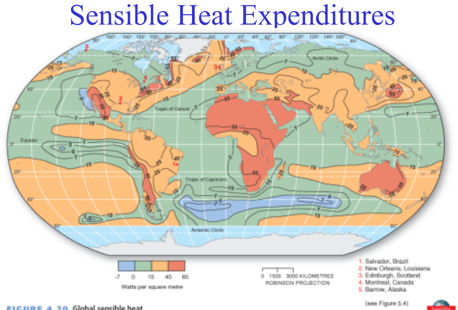

FIGURE 4.20 **Global sensible heat.**
Annual energy expenditure as sensible heat (*H*) at surface level in watts per square metre (100 W · m² · year⁻¹ = 75 kcal · cm⁻² · year⁻¹). [Adapted by permission from M. I. Budyko, *The Earth's Climate, Past and Future* (New York: Academic Press, 1982), p. 59.]

Global Sensible Heat

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Contrasting Radiation Budgets

- El Mirage, CA:
  - 35º N Lat.
  - hot, dry
- Pitt Meadows, BC:
  - 49 º N Lat.
  - warm, moist

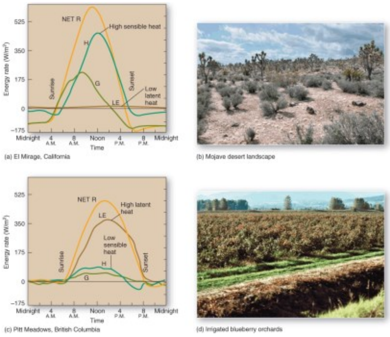

Figure 4.21

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The Urban Environment

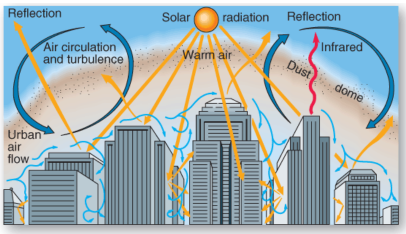

FIGURE 4.22 The urban environment.
Insolation, wind movements, and a dust dome in a city environment.

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Urban Heat Islands

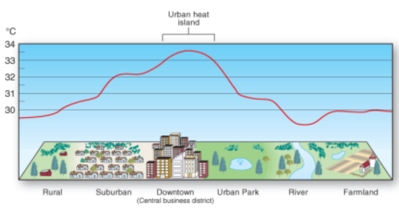

FIGURE 4.23 Typical urban heat island profile.
Cross section of a typical urban heat island from rural to downtown. Temperatures steeply rise in urban settings, plateau over the suburban built-up area, and peak where temperature is highest at the urban core. Note the cooling over the park area and river.

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