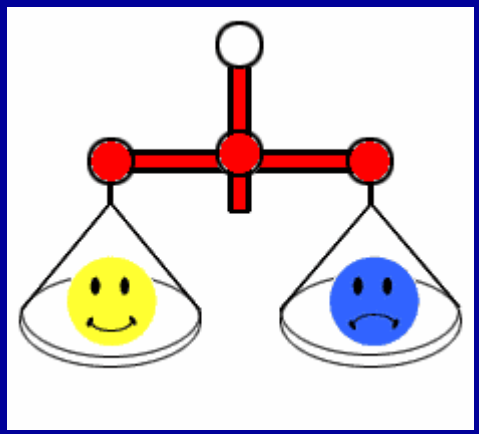
Topic # 10
THE EARTH'S GLOBAL ENERGY BALANCE

STARTING TO PAINT THE BIG PICTURE!

Tying together the Radiation Laws, Thermodynamics, and Atmospheric Structure & Composition to understand how they all work together to create global weather & climate!!

(pp 61-65 & 151-154 in Class Notes)

Today's Quote: A Different Sort of "ENERGY BALANCE":



Look at life as an energy economy game. Each day, ask yourself,

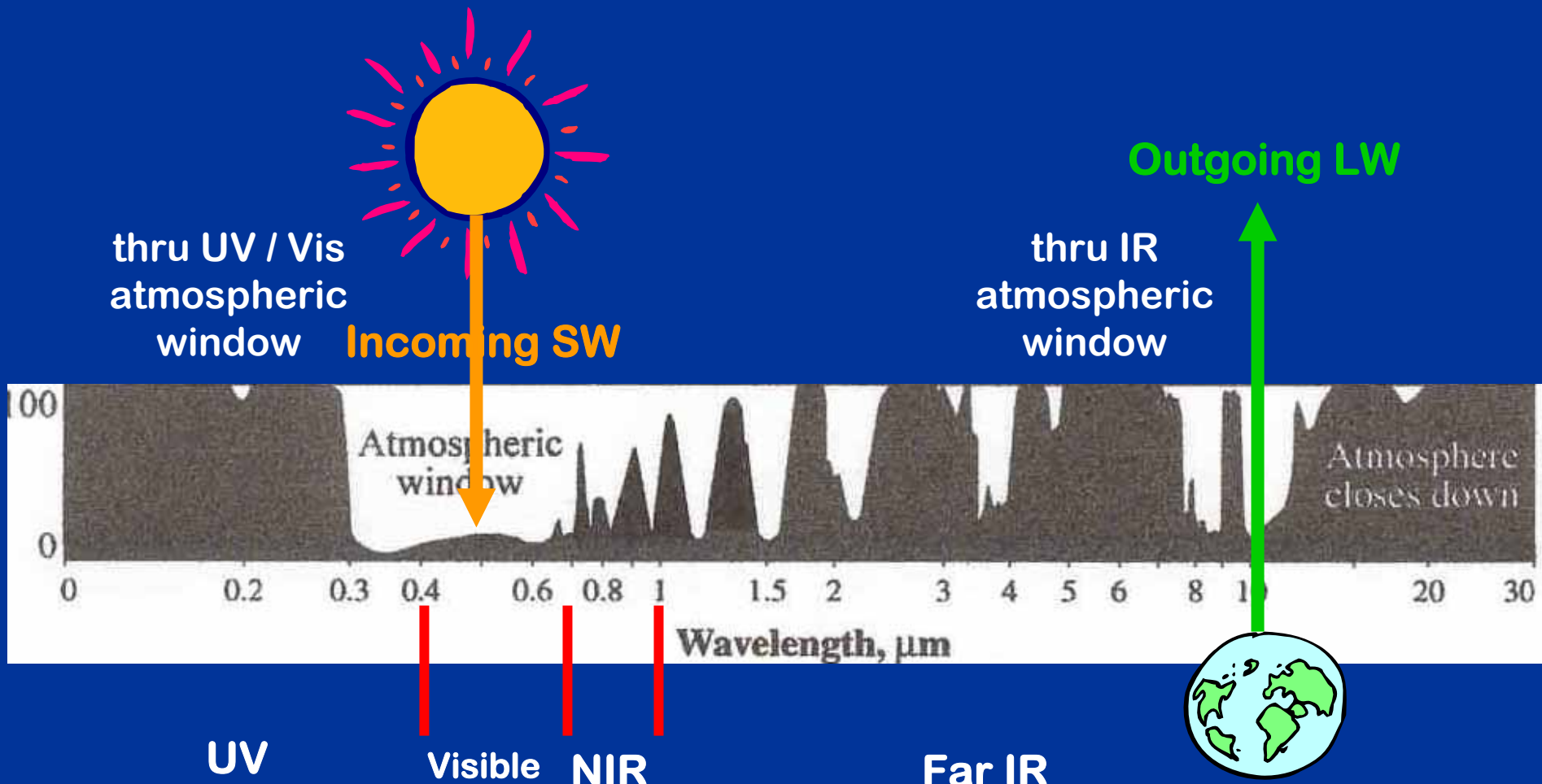
Are my energy expenditures (actions, reactions, thoughts, and feelings) productive or nonproductive?

During the course of my day, have I accumulated more stress or more peace?

~ Doc Childre and Howard Martin

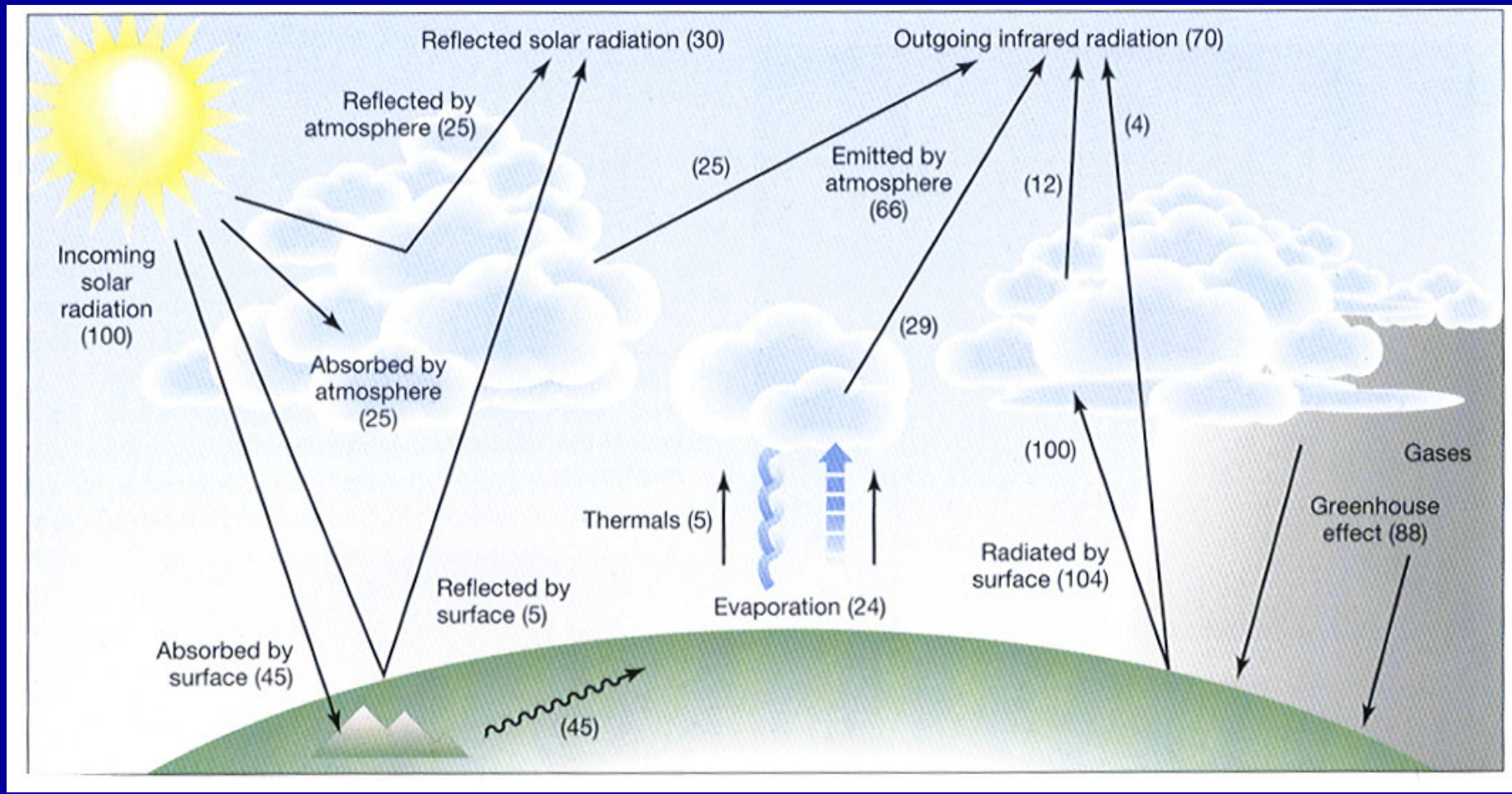
Review: Absorption curve for the "Whole Atmosphere"

OVERALL BALANCE: **Incoming = Outgoing**



Turn back to p 50

Typical Energy Balance Diagram



IGC p 50, Fig 3-19

Similar to p 61 in Class Notes

Energy Balance Equation:

$$R_{net} = (Q + q) - a - Lu + Ld = H + LE + G$$

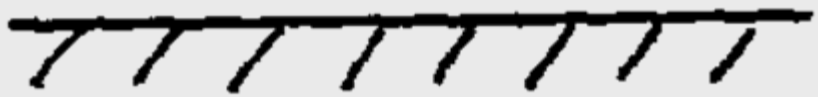
(one of several ways this equation can be written)

Let's try to find an easy way to understand and remember all the components of the Earth's Energy Balance

We'll use "cartoon symbols" . . .

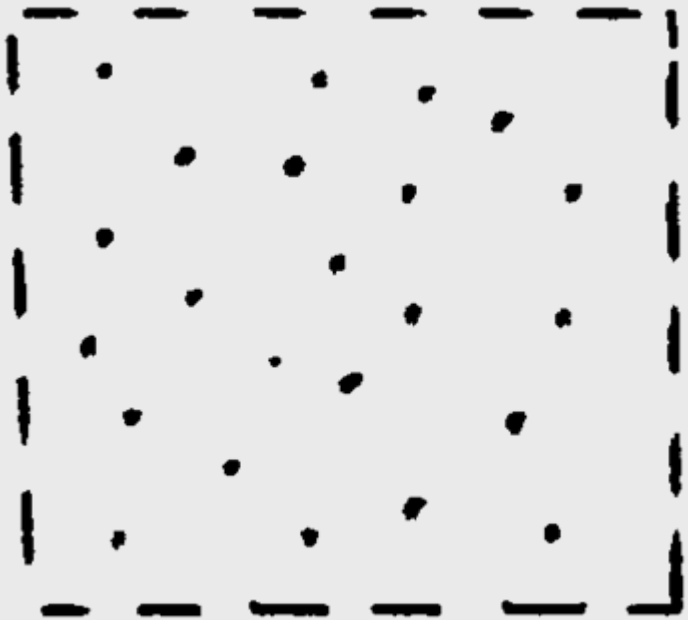
"CARTOON" SYMBOLS:

To represent the Earth's surface:



Take notes on p 60

“CARTOON” SYMBOLS:



To represent the atmosphere – composed of both invisible gases, aerosols, dust and other particulate matter:

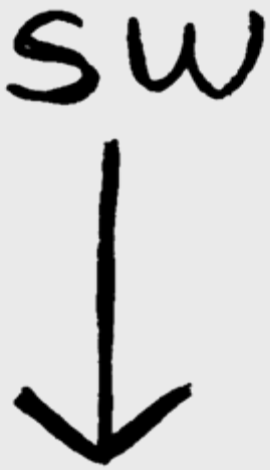
Take notes

“CARTOON” SYMBOLS:

To represent CLOUDS

Take notes

"CARTOON" SYMBOLS:

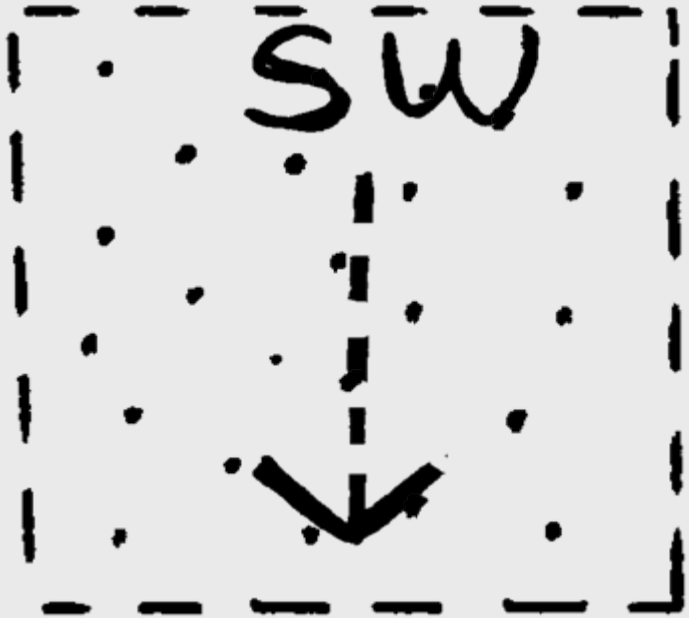


To represent SOLAR (shortwave) radiation coming in DIRECTLY.
(aka Direct shortwave radiation)

Take notes

Direct SW radiation easily casts well-defined shadows when blocked

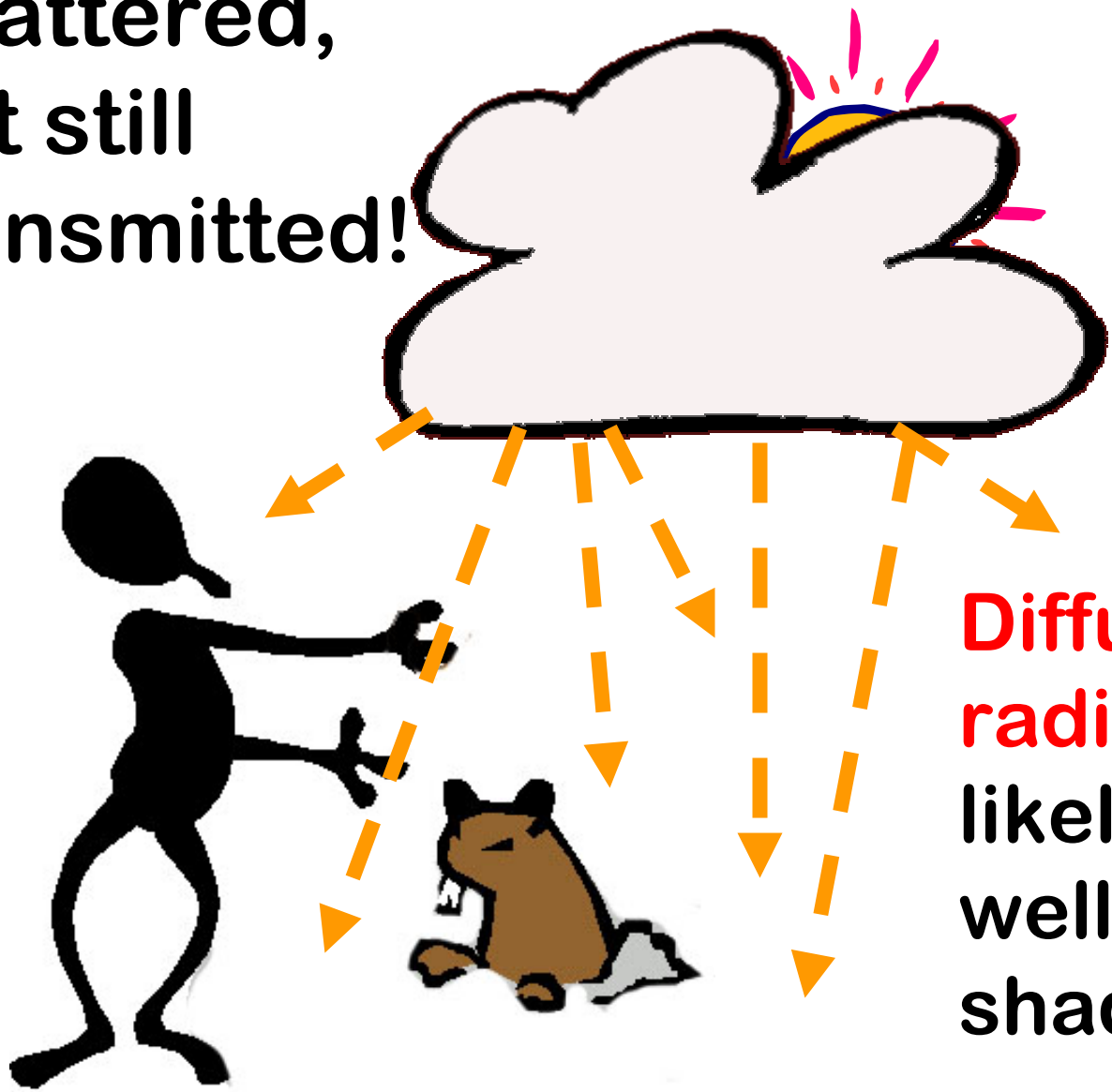
"CARTOON" SYMBOLS:



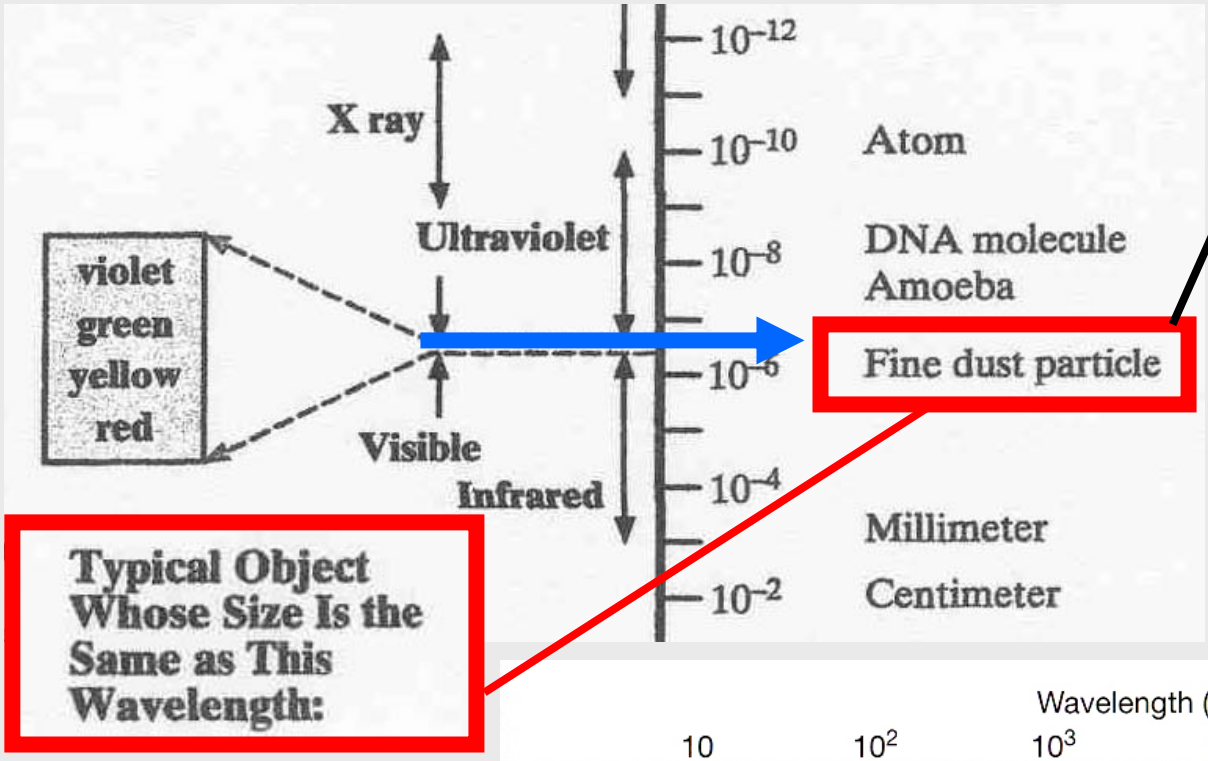
To represent SOLAR (shortwave) radiation coming in as DIFFUSE shortwave radiation, i.e. scattered by gases, clouds, and particles in the atmosphere.

Take notes

Scattered, but still transmitted!



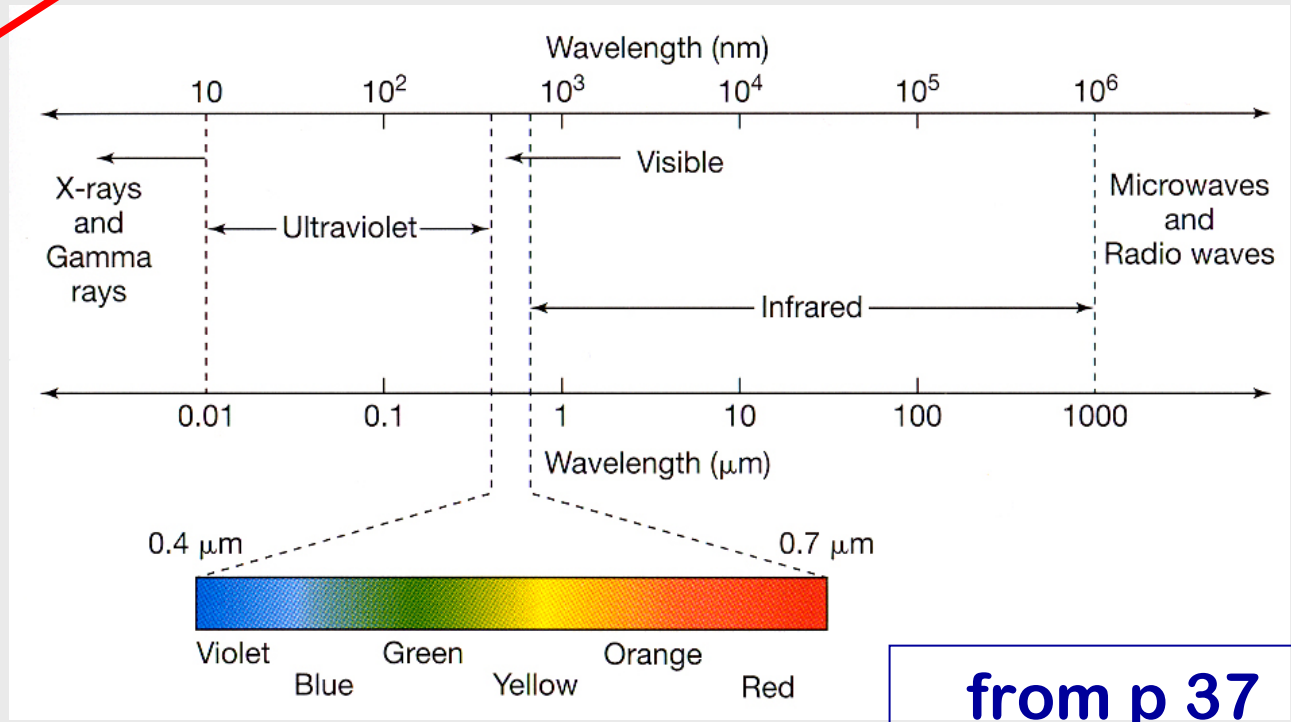
Diffuse SW radiation is less likely to cast a well-defined shadow!



Different sized dust particles, water droplets, aerosols,

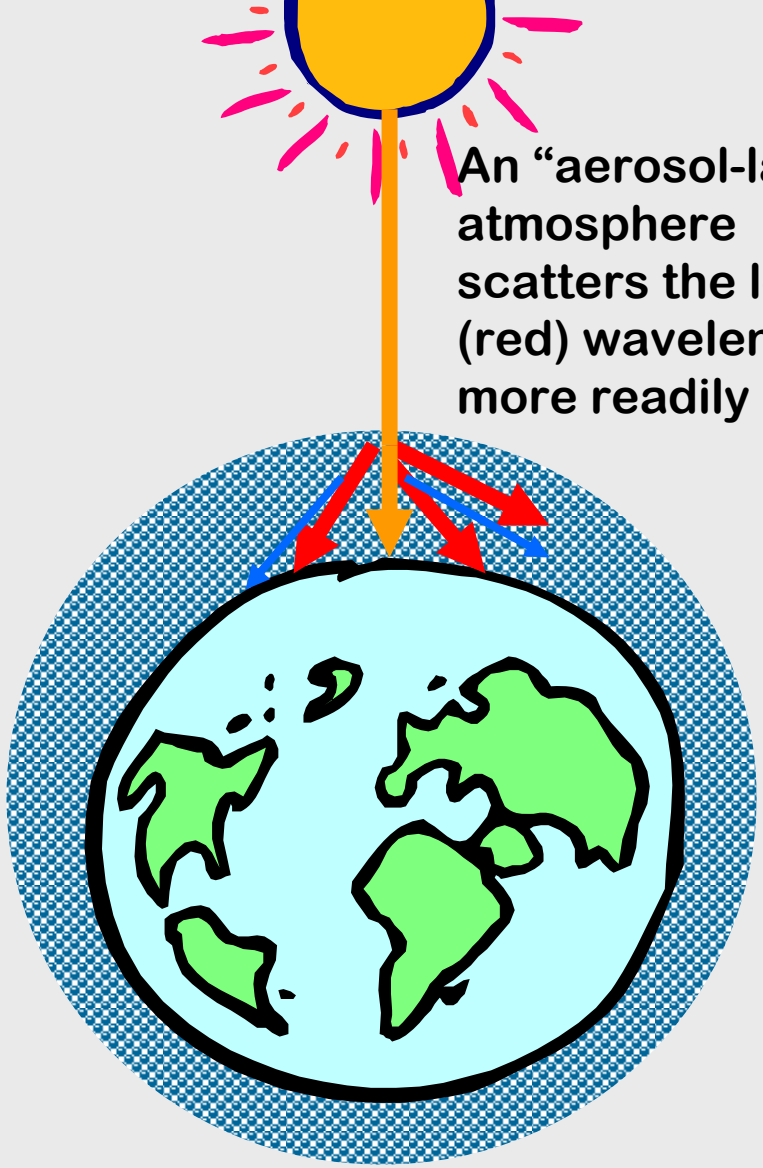
(even gas molecules themselves)

Scattering of visible light



from p 37

"Clear" atmosphere composed primarily of fine particles, water droplets, gas molecules



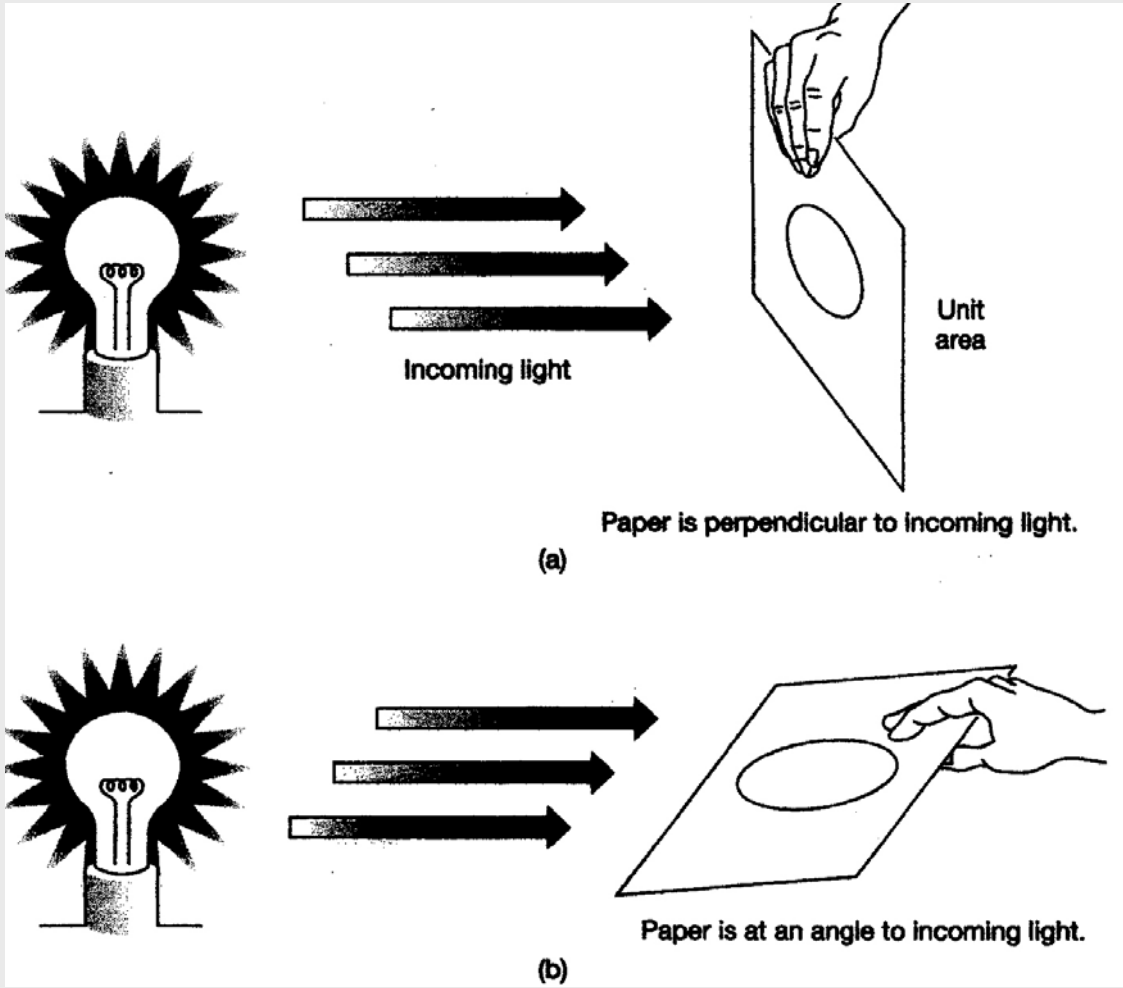
An "aerosol-laden" atmosphere scatters the longer (red) wavelengths more readily

"Dirty" (aerosol-laden) atmosphere composed of fine particles, gases, & H_2O -- PLUS larger dust particles, aerosols, pollution, etc. ☺

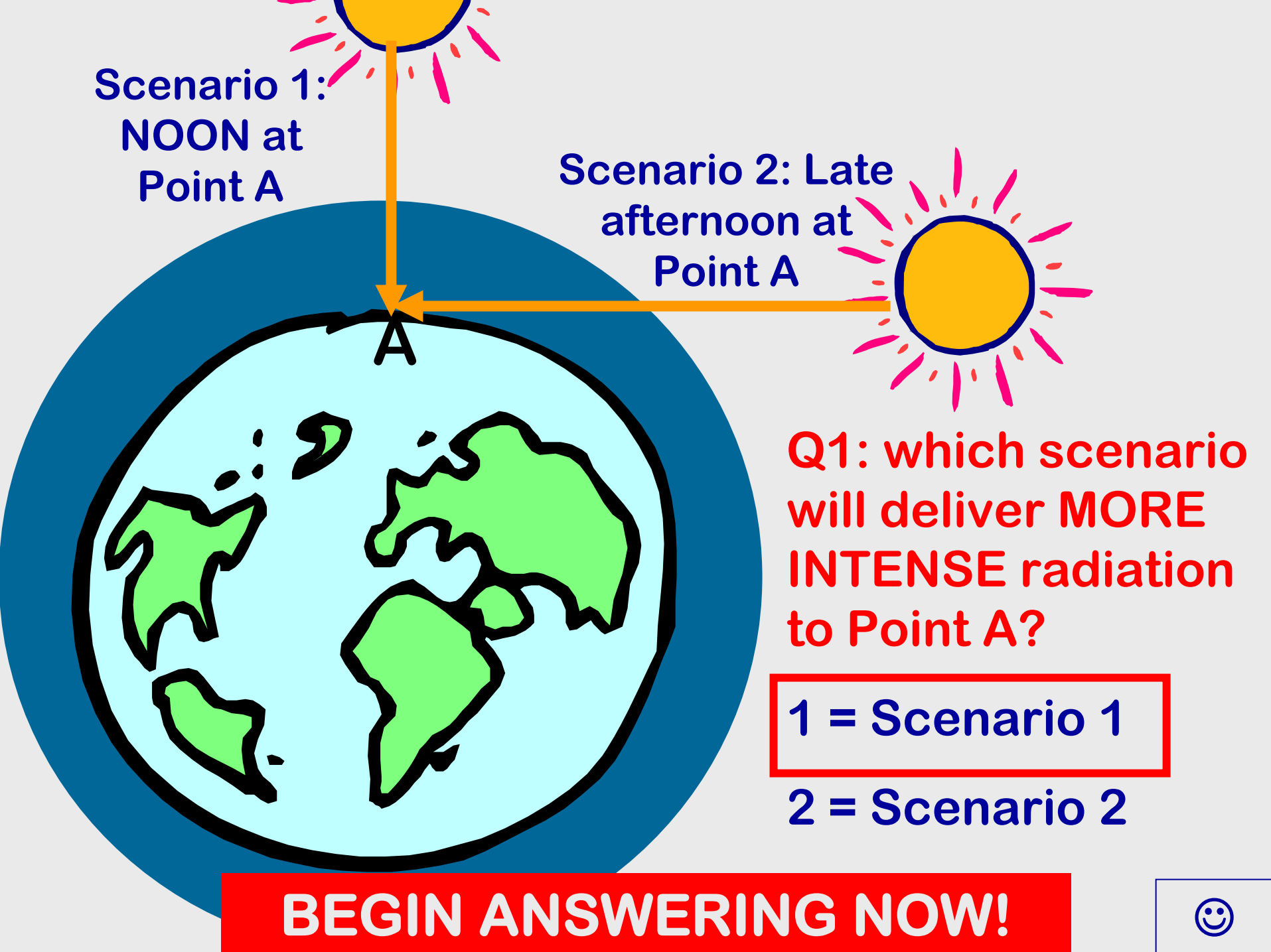
ALSO: The angle at which direct SW radiation is intercepted by a surface makes a difference!!

Radiation is concentrated over a small area & hence is more intense when it comes in perpendicular to the surface

Radiation is spread out over a larger area & hence is less intense per unit area when it comes in at an angle.



From Figure on p 37 in IGC, Ch 3



Q1: which scenario will deliver MORE INTENSE radiation to Point A?

1 = Scenario 1

2 = Scenario 2

BEGIN ANSWERING NOW!

☺

Q2 = WHY is the intensity of the SW radiation at Point A not as strong in the late afternoon as it is at noon?

1 = because as the Sun goes down close to sunset time, it gives off less radiation

2 = because the SW radiation is coming in at an angle in the late afternoon, and is not directly overhead (perpendicular) like it is at noon.

3 = because the SW radiation is being transmitted through a thicker atmosphere & hence scattered more BOTH #2 & #3 are applicable!

BEGIN ANSWERING NOW!

"CARTOON" SYMBOLS:

To represent SOLAR (shortwave) radiation that is REFLECTED (or scattered) BACK TO SPACE by: atmosphere, clouds, Earth's surface, etc.

Take notes

New term:

ALBEDO = reflectivity of a surface

"*symbol*" = a

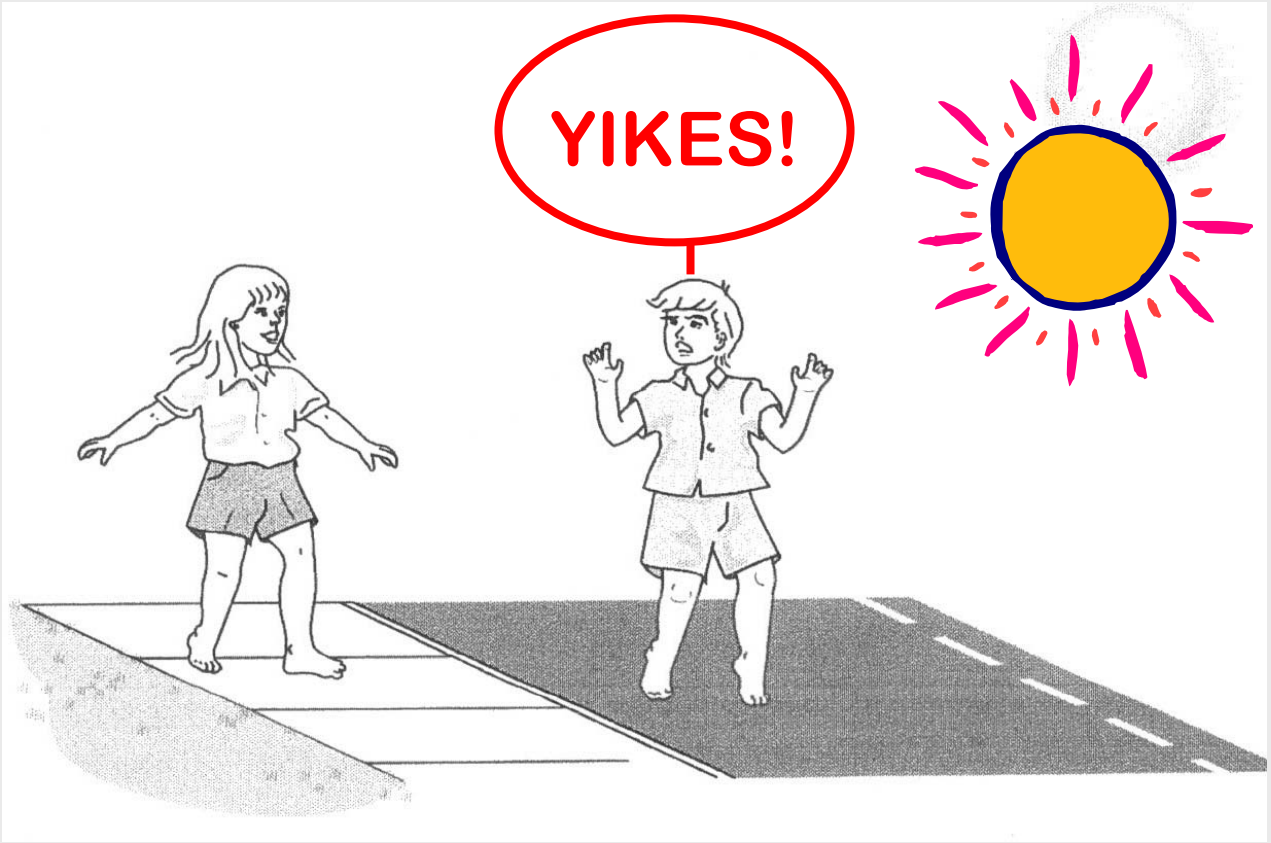
Represented as:

a decimal from 0 to 1.0 *or*

% from 0 – 100 % (perfect reflectivity)

Hence, amount ABSORBED = (1 – albedo)

Take notes



If a surface's albedo is HIGH, absorption by the surface is LOW ➔ COOLER surface

If a surface's albedo is LOW absorption by the surface is HIGH => HOTTER surface!

Albedos of Some Common Surfaces

Type of Surface	*Albedo*
Sand	0.20–0.30
Grass	0.20–0.25
Forest	0.05–0.10
Water (overhead Sun)	0.03–0.05
Water (Sun near horizon)	0.50–0.80
Fresh snow	0.80–0.85
Thick cloud	0.70–0.80

Low albedo

High albedo

➔ CLOUDS: 0.44 (high, thin clouds) - 0.90 (low, thick clouds)

AVERAGE PLANET EARTH = ~ 0.30

Take notes

Q3: What will happen to incoming SW over the Amazon Rain Forest if parts of it are deforested?

1 = more SW will be absorbed

2 = less SW will be absorbed

BEGIN ANSWERING NOW!

"CARTOON" SYMBOLS:

To represent TERRESTRIAL (longwave IR) radiation emitted upward by the Earth's surface or the atmosphere

Take notes

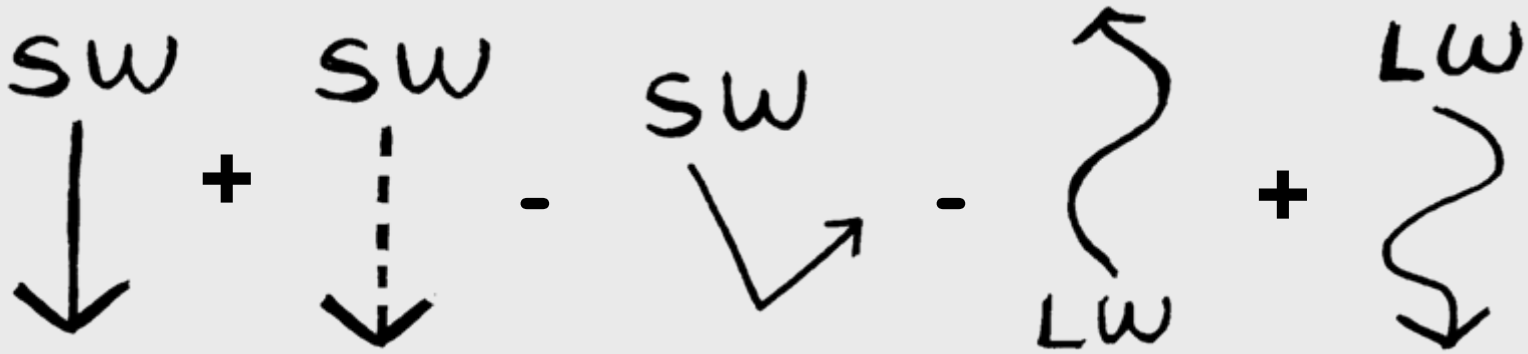
"CARTOON" SYMBOLS:

To represent TERRESTRIAL (longwave IR) re-radiation emitted downward by the Earth's ATMOSPHERE

Take notes

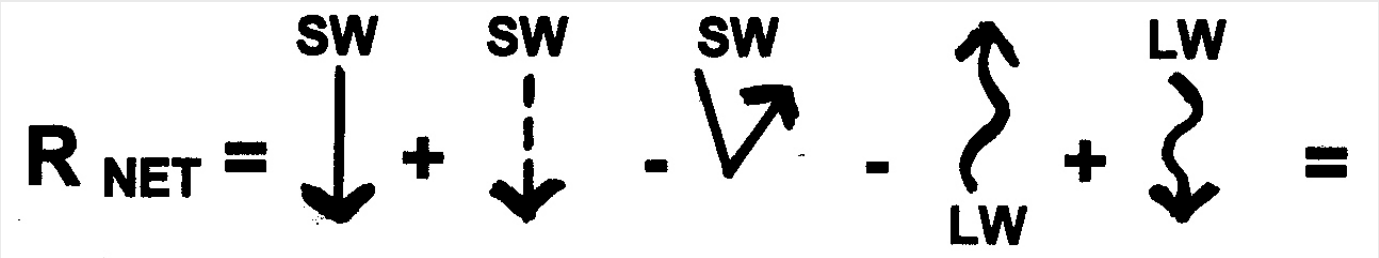
PUTTING IT TOGETHER:

Can you place + and – signs where they ought to go in the equation?

R_{NET} = 

$R_{NET} = (Q + q) - a - Lu + Ld$

See top p 61



Now we'll look at the energy pathways in a bit more detail by combining the cartoon symbols in various ways . . .

See top p 61

First, what if . . .

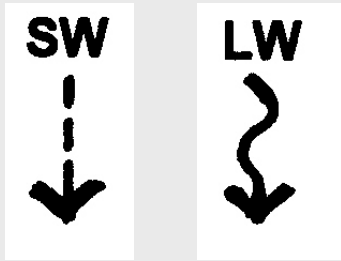
. . . The Earth didn't have an atmosphere, and therefore didn't have a greenhouse effect??

What would the energy pathways in the Earth-Sun system look like?

LW

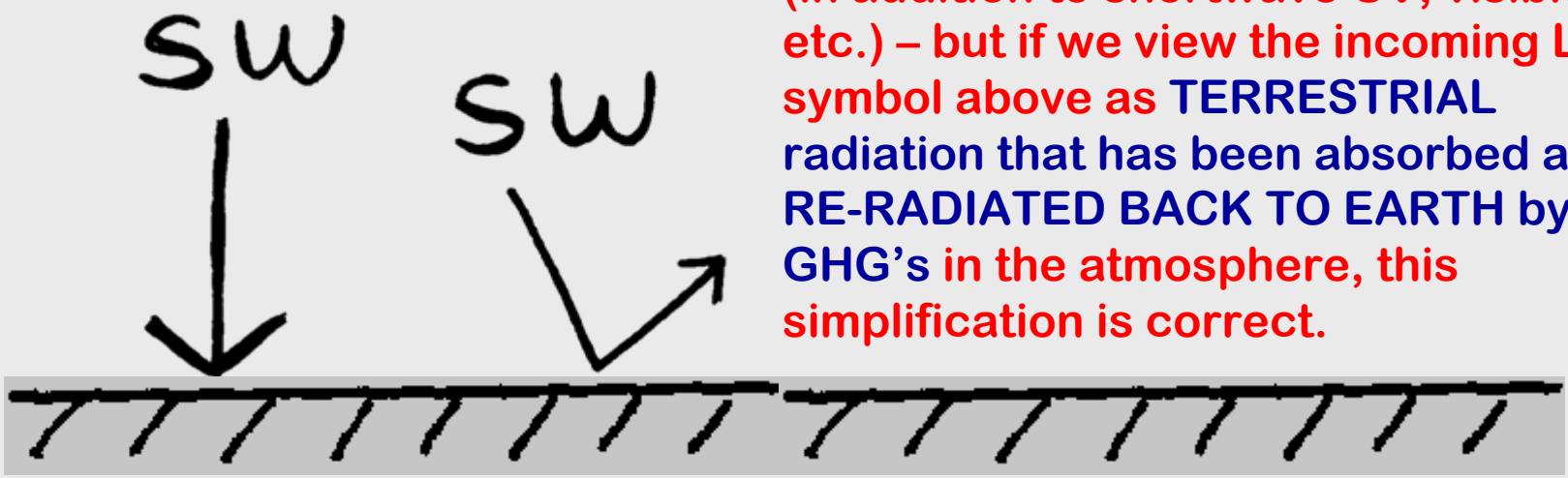
Which terms are not involved?

No scattering by atmosphere



No re-radiation of infrared by GHG's

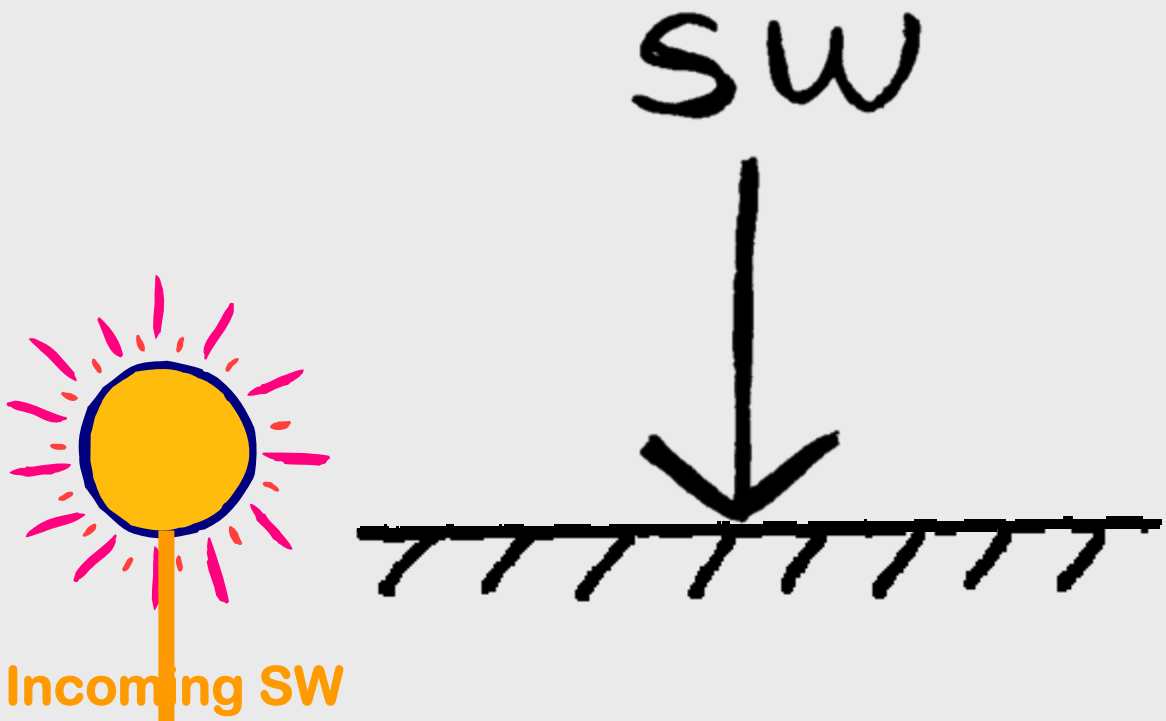
NOTE: Technically, the SUN does give off incoming longwave infrared radiation (in addition to shortwave UV, visible, etc.) – but if we view the incoming LW symbol above as TERRESTRIAL radiation that has been absorbed and RE-RADIATED BACK TO EARTH by the GHG's in the atmosphere, this simplification is correct.

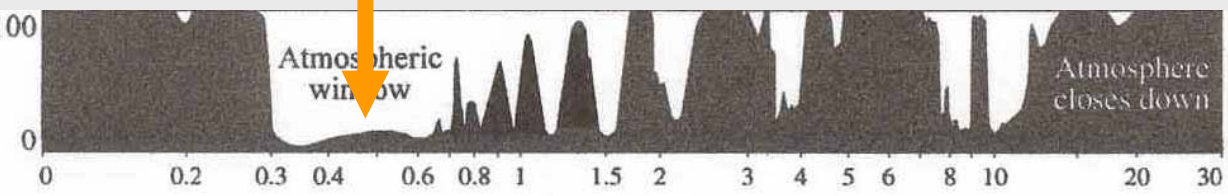


To describe the real Earth-Atmosphere system, more detail is needed in our simple representation . . . . .
We'll use our symbols to build an energy balance "model"

Flip to p 151

SW BEAMED DIRECTLY TO EARTH'S SURFACE WHERE IT IS ABSORBED:





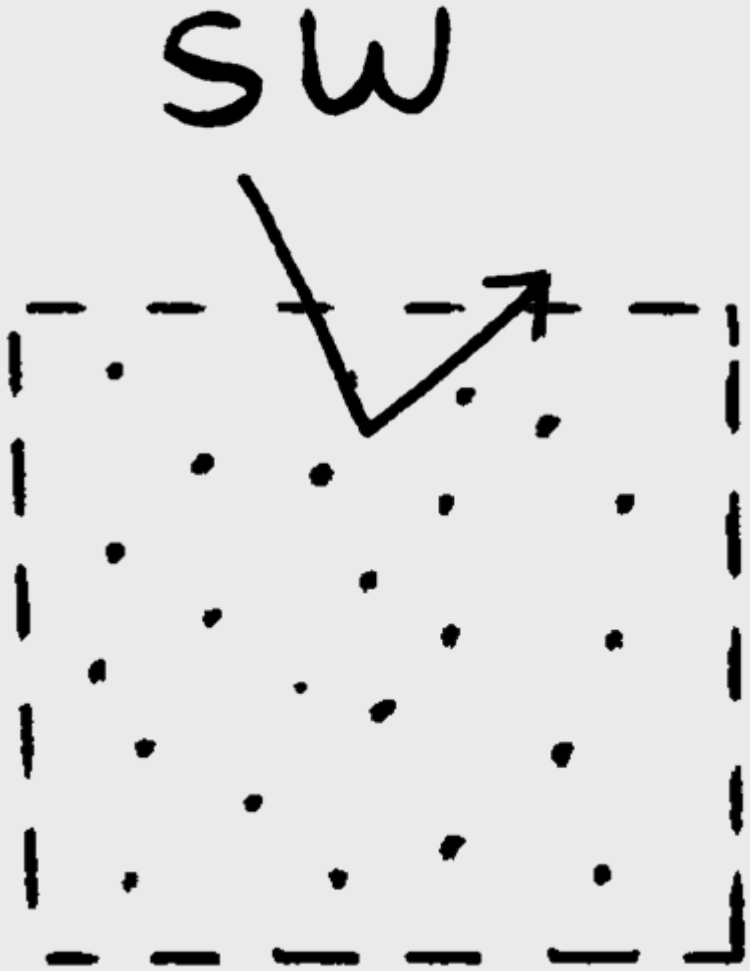
SW REFLECTED BACK TO SPACE:

By
clouds

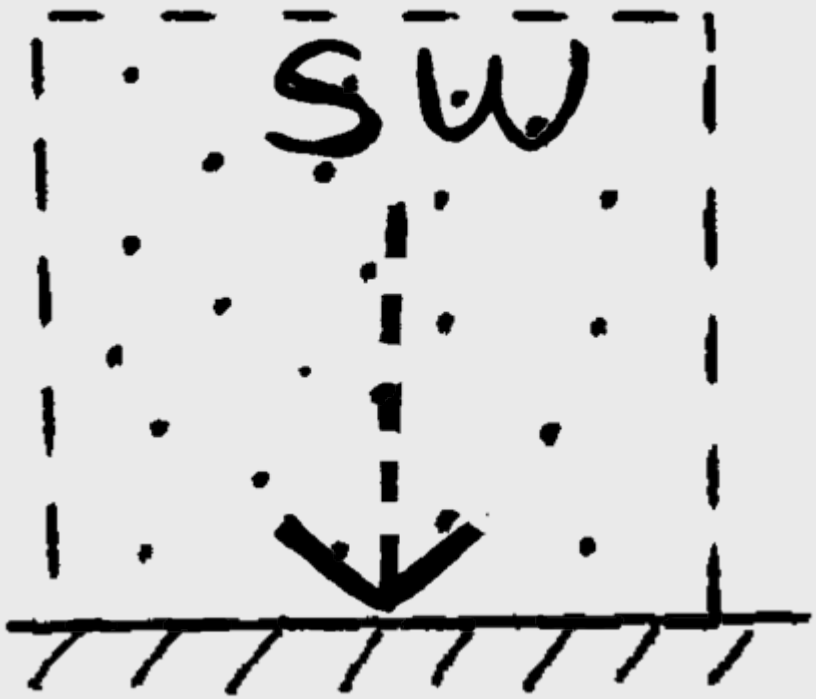
By
Earth's
surface

This is determined by the ALBEDO of the clouds or surface

SW SCATTERED BACK TO SPACE BY ATMOSPHERE:

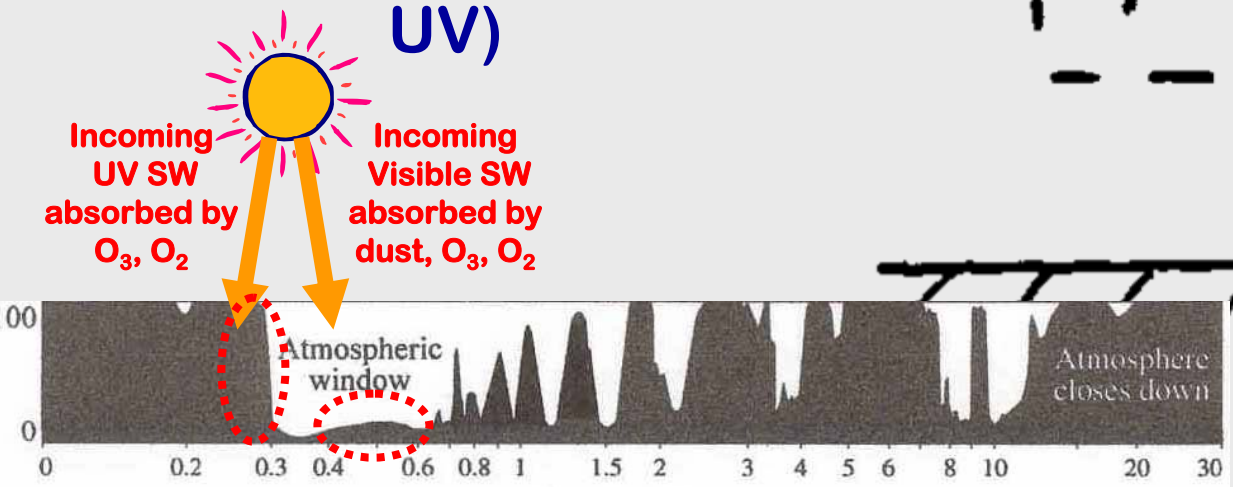


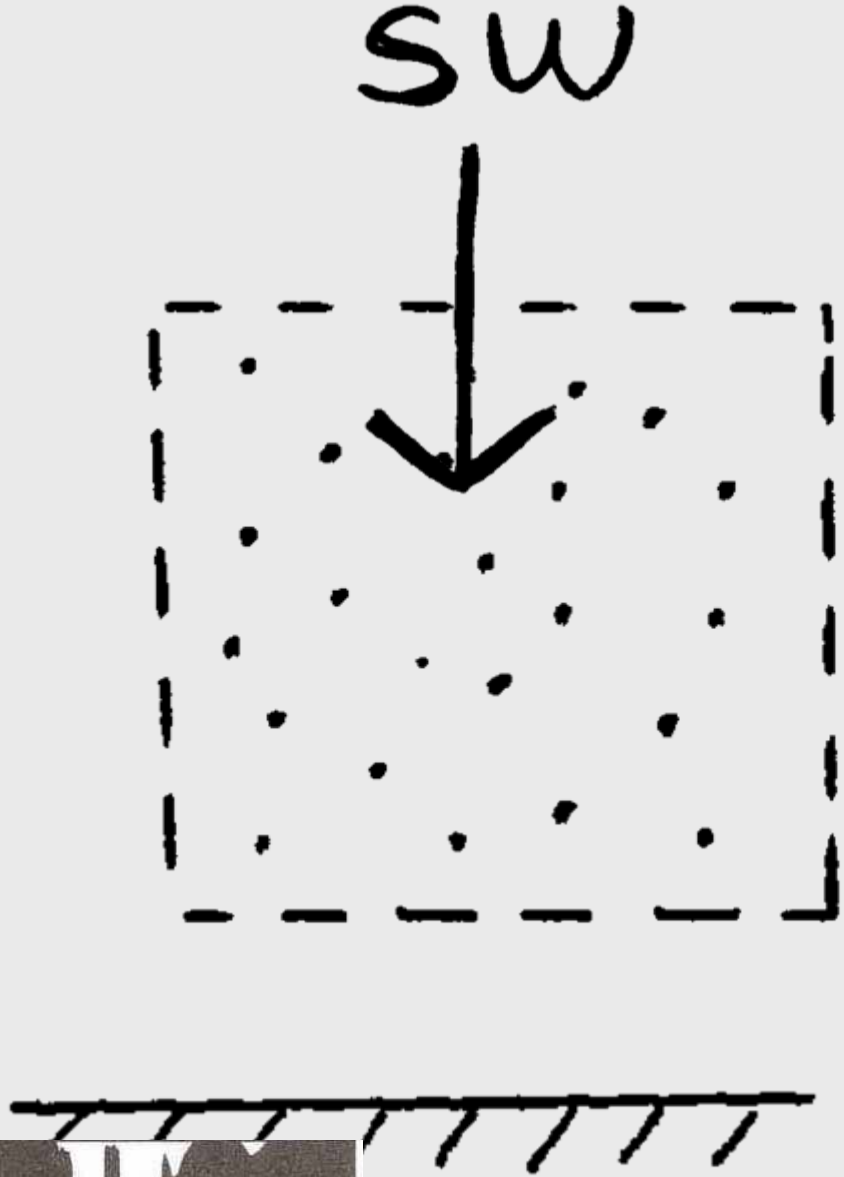
SW SCATTERED DOWN TO EARTH's SURFACE where it is absorbed



SW ABSORBED IN ATMOSPHERE BY GASES, DUST, etc.

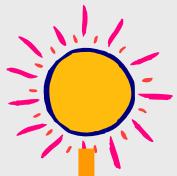
(including Ozone absorbing shortwave UV)



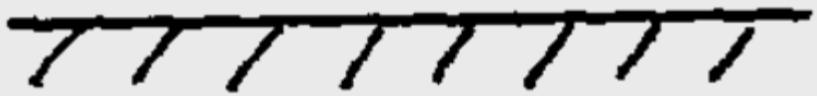


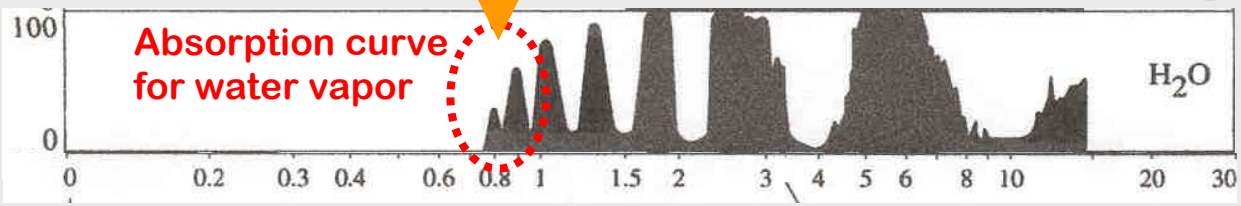
SW ABSORBED In ATMOSPHERE BY CLOUDS & H2O vapor:

(NOTE: clouds are made up of tiny droplets of water surrounded by lots of water vapor)



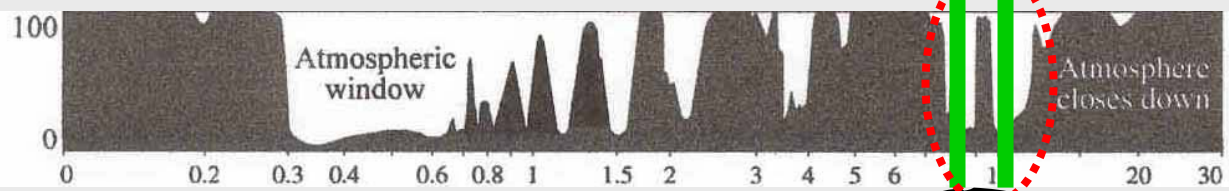
Incoming Visible & Near IR SW absorbed by water vapor & clouds

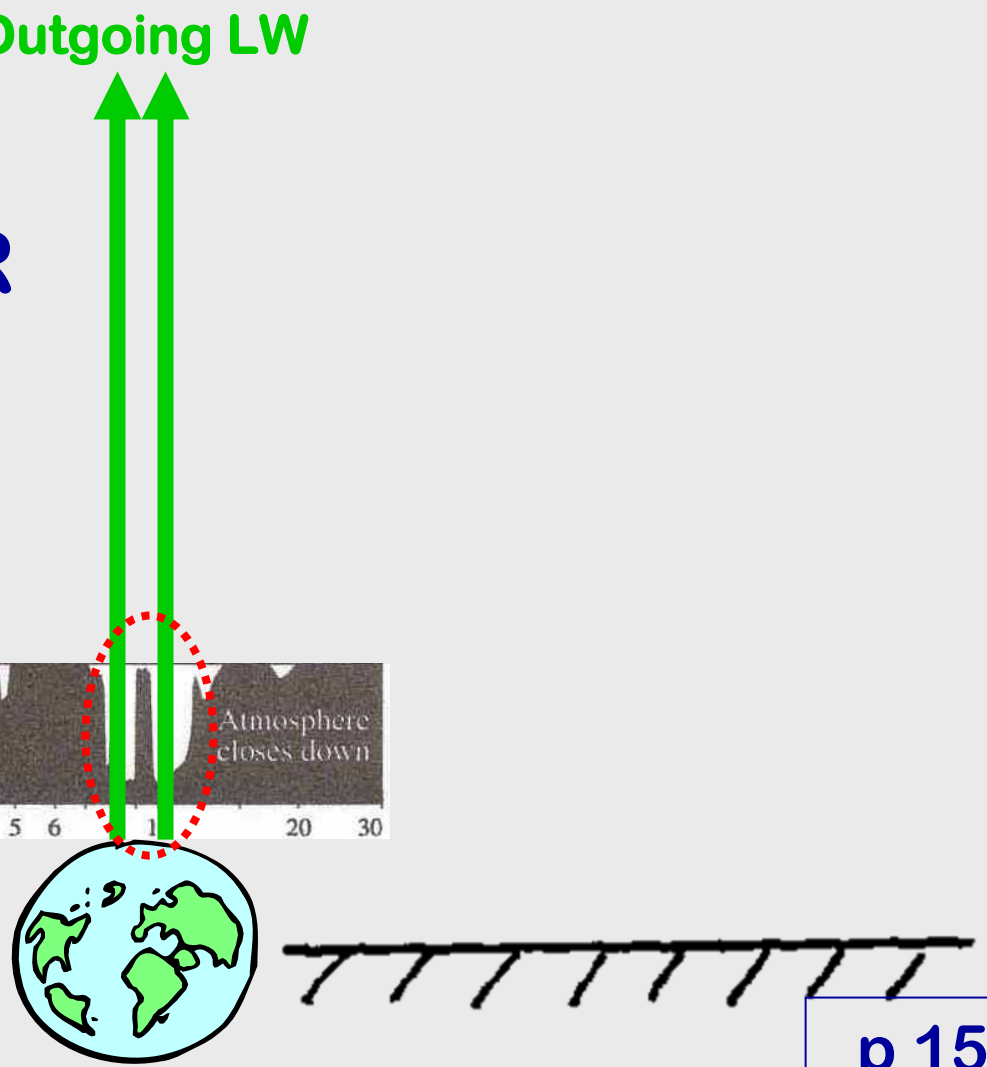




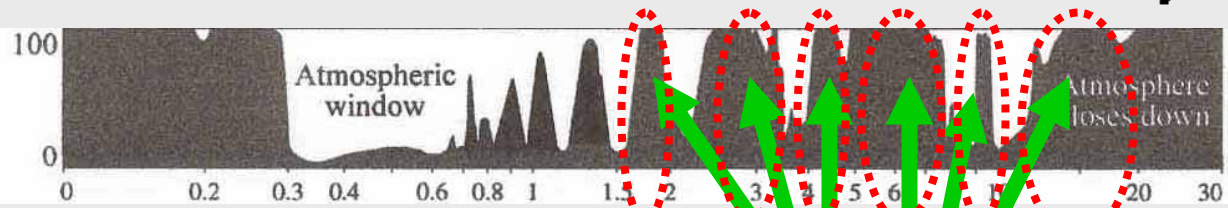
LW (IR) EMITTED FROM EARTH'S SURFACE ESCAPING TO SPACE THROUGH THE "OUTGOING IR ATMOSPHERIC WINDOW"

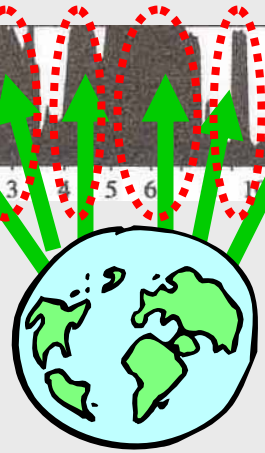
LW

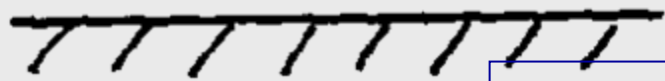




IR EMITTED FROM EARTH'S SURFACE BUT ABSORBED IN THE ATMOSPHERE BY GREENHOUSE GASES (H_2O,CO_2, CH_4, ETC.)

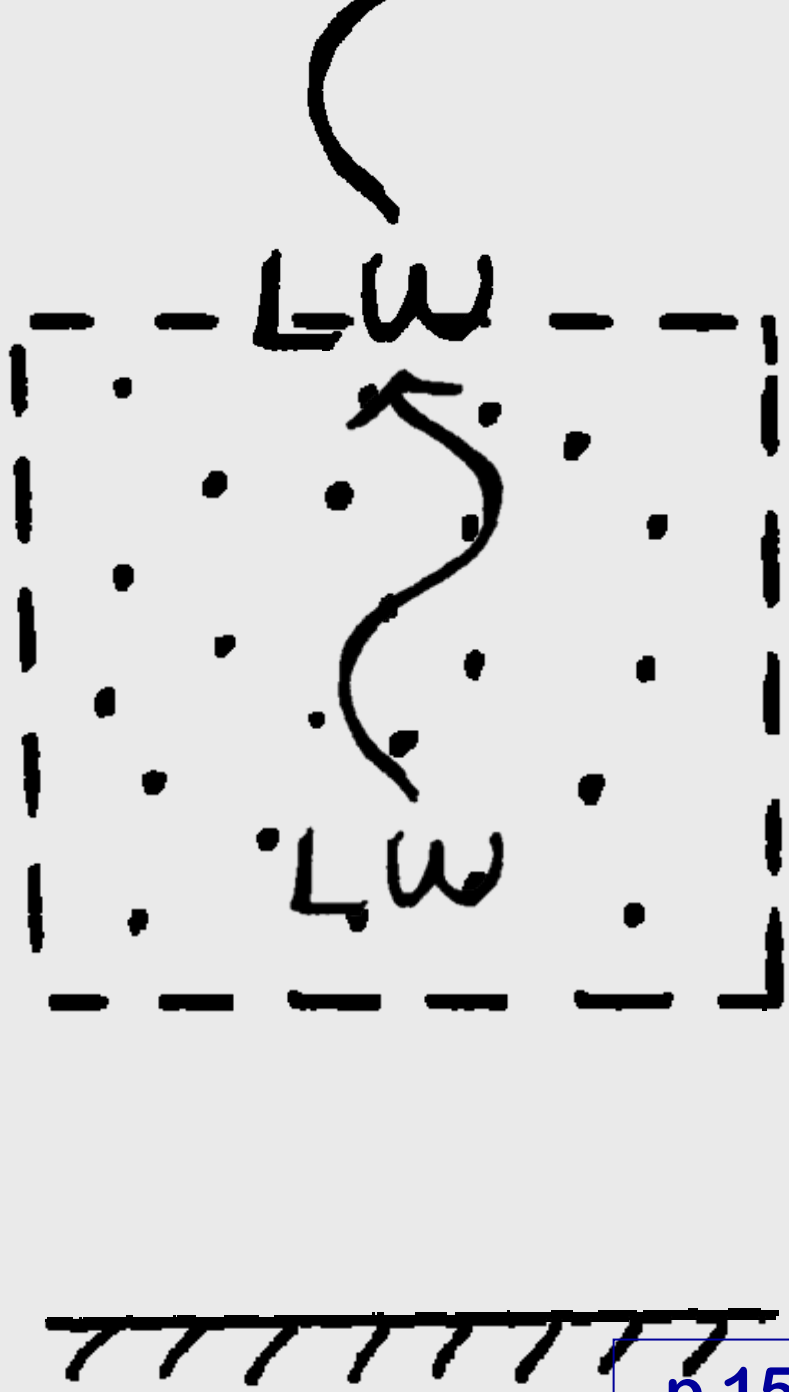






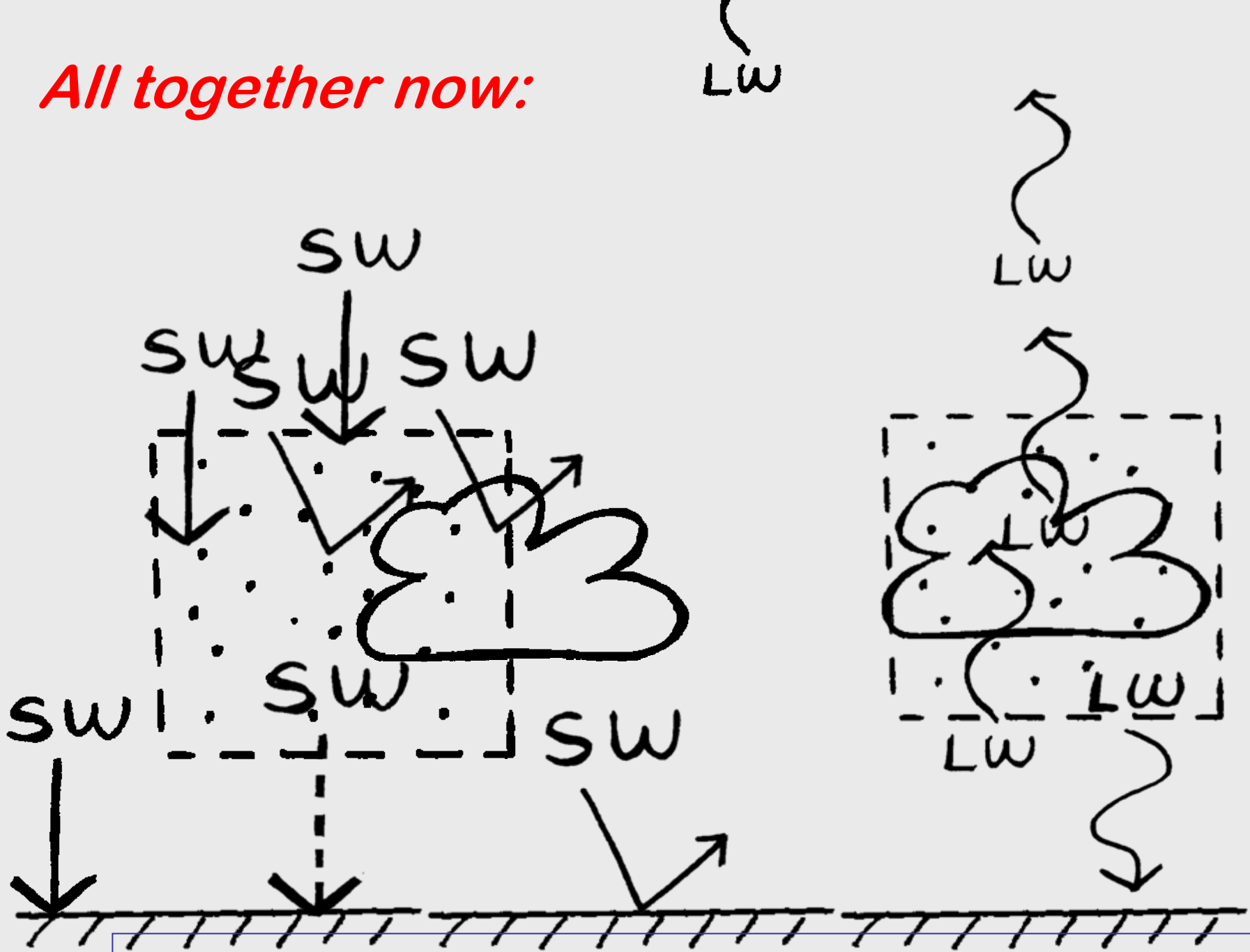
IR EMITTED FROM ATMOSPHERE

ESCAPING TO SPACE



IR EMITTED FROM ATMOSPHERE AND RADIATED BACK TO SURFACE WHERE IT IS ABSORBED

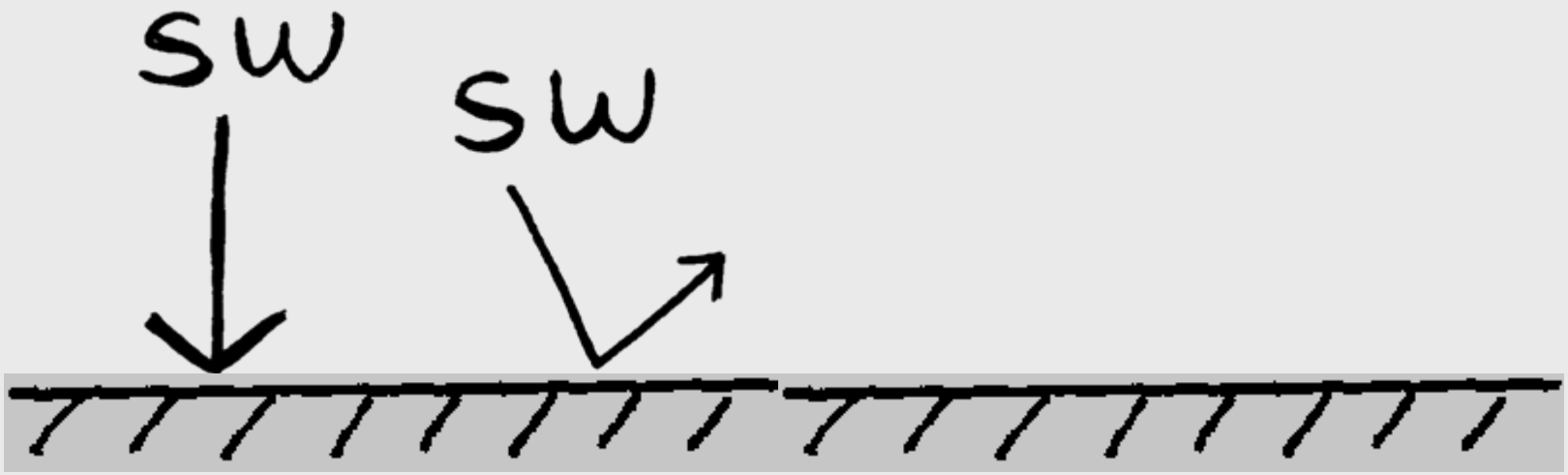
All together now:



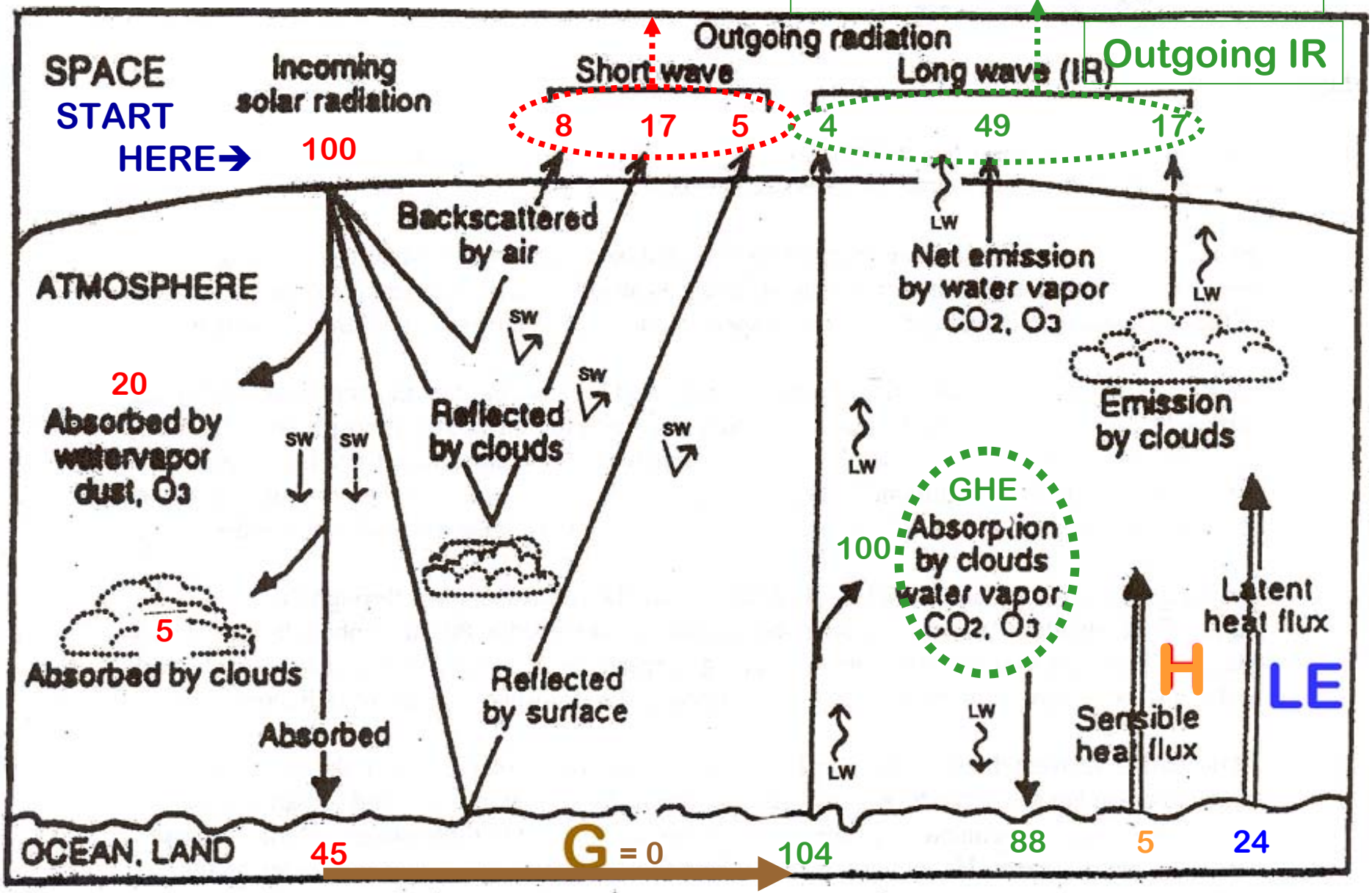
Can you sketch all the pathways in yourself? p 152

LW

Compare with simpler model of energy balance with NO atmosphere:



Earth's average albedo: 8 + 17 + 5 = 30 4 + 49 + 17 = 70



G + H + LE

45 ↓ - 104 ↑ + 88 ↓ = 29 → 0 + 5 + 24 = 29 = R_{net}

Back to p 61

Two Energy Balance Animations

showing energy flow pathways & "units" of energy that eventually balance out:

GLOBAL ENERGY BALANCE & PATHWAYS:

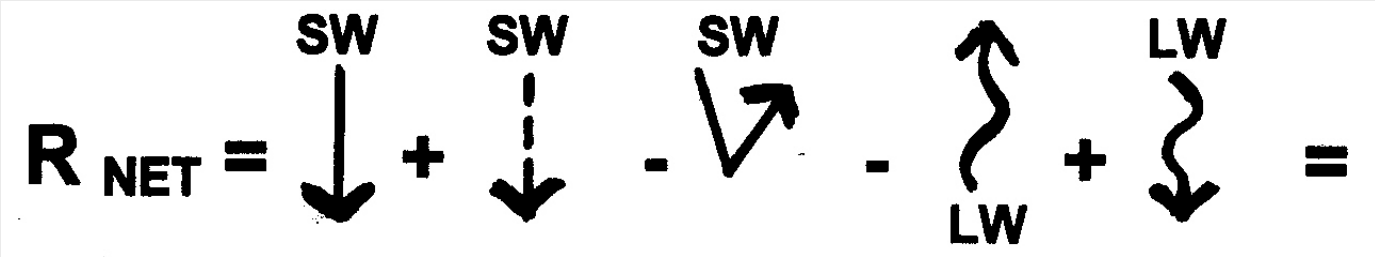
http://earthguide.ucsd.edu/earthguide/diagrams/energybalance/index.html

SHORTWAVE & LONGWAVE ENERGY FLOW & BUDGET:
http://mesoscale.agron.iastate.edu/agron206/animations/10_AtmoEbal.html

BREAK TIME!!!

BACK TO THE BALANCE!

NET RADIATION = In – Out = Whatever is left over



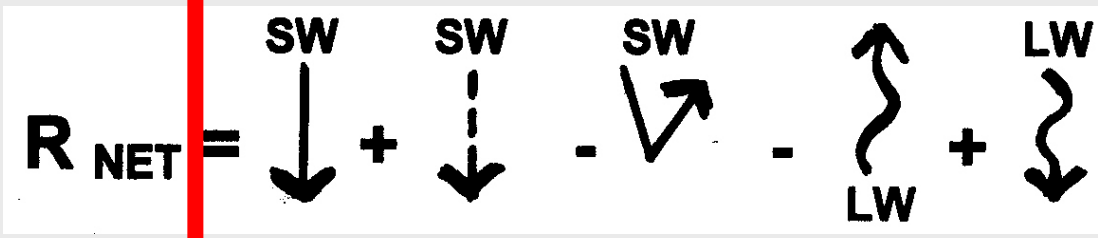
If some energy is "left over," it can be used to DRIVE WEATHER & CLIMATE through HEAT TRANSFER processes or it can STORED by the Earth (in the ground or ocean).

p 61 top

FINAL PART OF TOPIC #10:

The RIGHT side of the ENERGY BALANCE EQUATION . . .

Left side of equation



= H + LE + G

Right side of equation

R net = “net” left over energy can be used to DRIVE WEATHER & CLIMATE through HEAT TRANSFER processes or it can STORED by the Earth (in the ground or ocean).

$$R_{NET} = H + LE + G$$

Review of: THERMODYNAMICS & HEAT TRANSFER

Conduction = passage of thermal energy through a body **without large-scale movement** of matter within the body. Most effective in SOLIDS.

Convection = passage of thermal energy through a fluid (liquid or gas) **by means of large-scale movements** of material within the fluid, as in a convection cell. Most effective in GASES & LIQUIDS.

Radiation = the transfer of thermal energy by ***electromagnetic radiation.*** The only one of the three mechanisms of heat transfer that does not require atoms or molecules to facilitate the transfer process, i.e., **does not even need MATTER as a medium to transfer energy!**

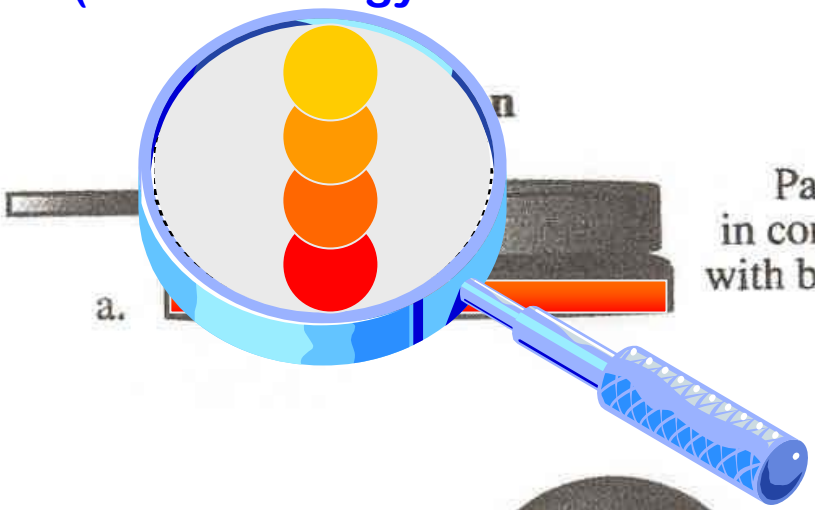
See bottom of p 61

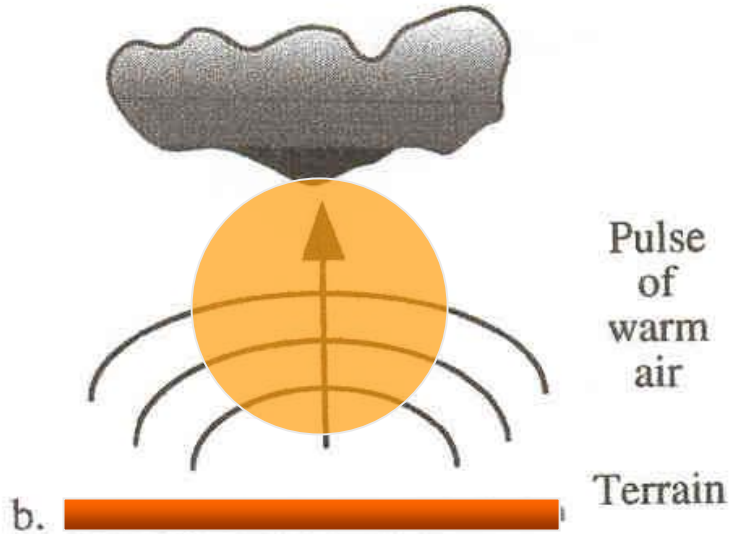
CONVECTION

Mass of warm air or liquid heats, expands, rises

CONDUCTION

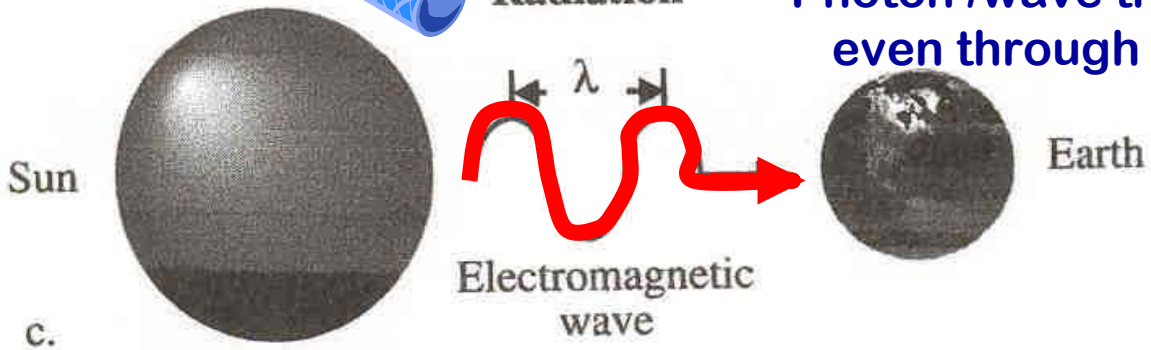
Jiggling molecule ➔ jiggling molecule
transfer of heat
(kinetic energy at molecular scale)





RADIATION

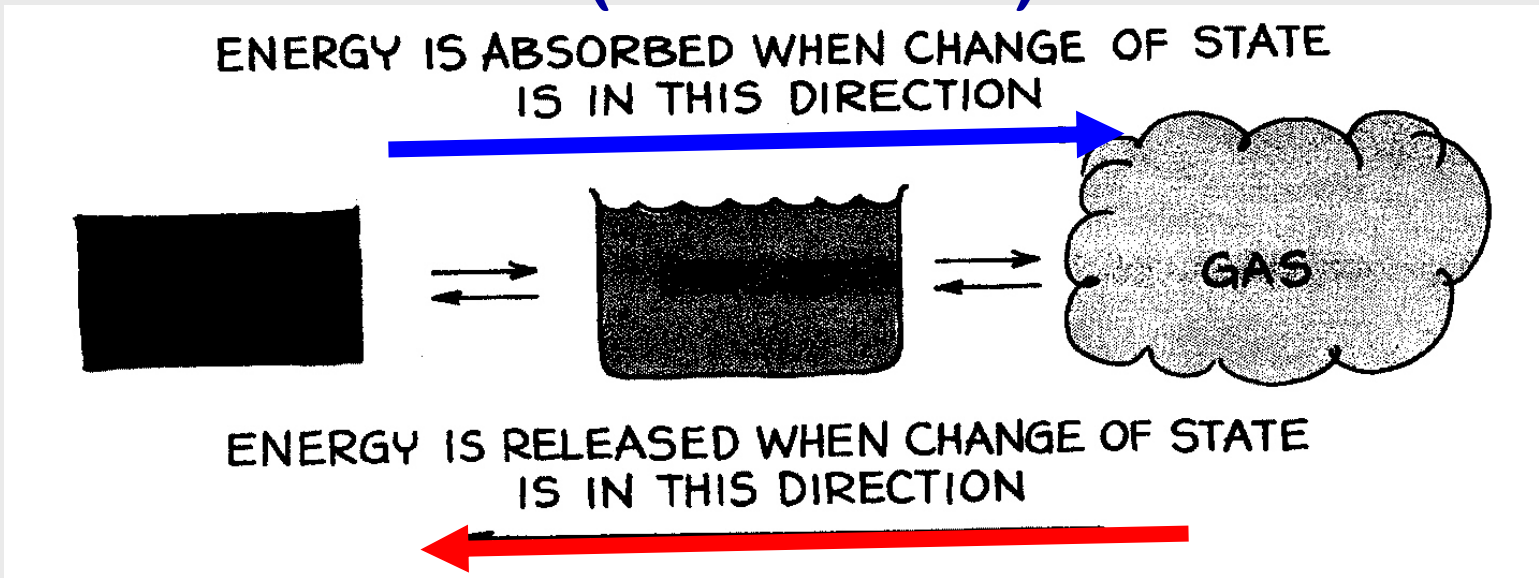
Photon /wave transport:
even through a void!



Review p 61

HEAT TRANSFER & STORAGE DURING PHASE CHANGES: LE & H

LE = LATENT (hidden) ENERGY (LE stored)



(LE released, hence it can be sensed as H)

H = SENSED (via thermometer) ENERGY

H = sensible heat transfer

Sensible heat is the energy or heat of molecular motion. It can be "sensed" with a thermometer, and we "feel" it as heat, unlike LE.

- It is transferred by ***conduction*** from warmer to cooler objects (most common in solids);
- and by ***convection*** (large scale, mostly vertical, motion of gases or liquids)

Bottom p 73

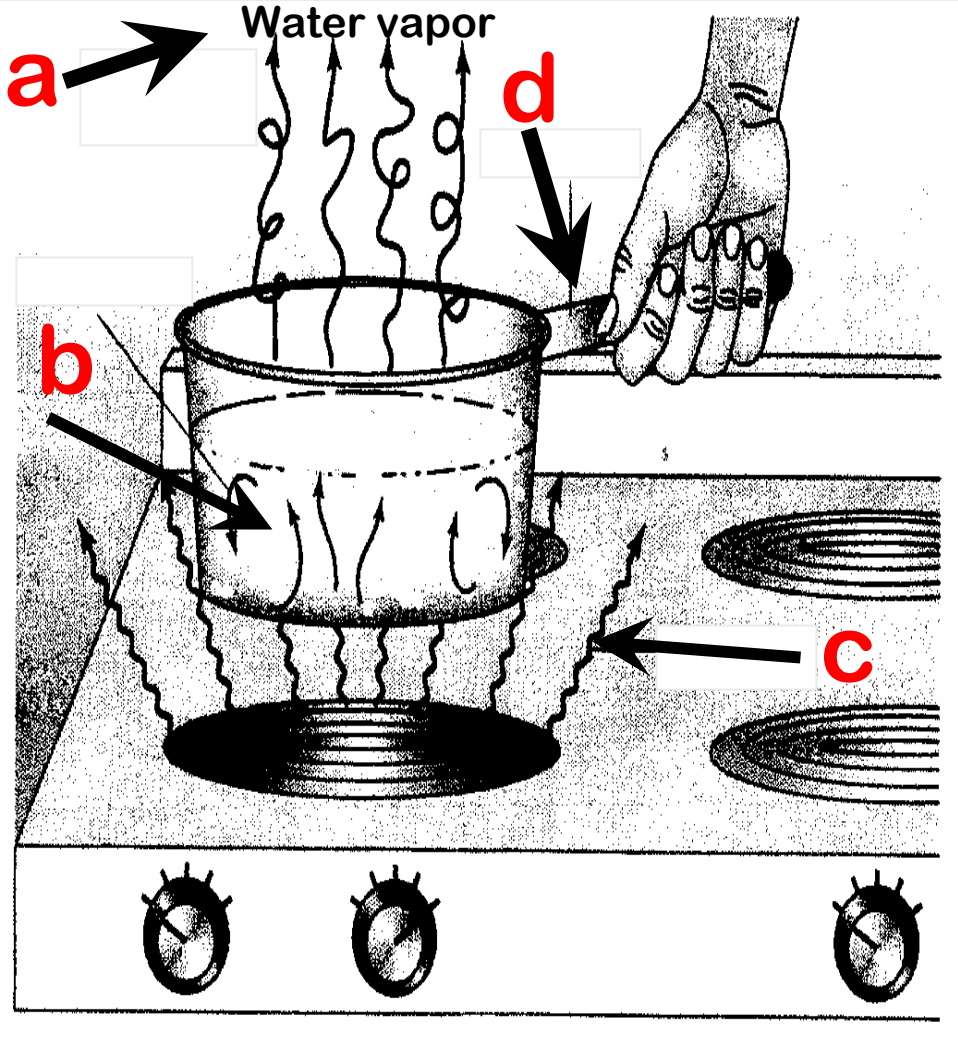
LE = latent energy (latent heat) transfer

Latent energy is energy needed for ***phase changes*** in H_2O:

- LE is removed from the environment and "hidden" in H_2O during the evaporation of water and melting of ice => environment cools.
- LE is released to the environment from H_2O during condensation of water vapor and freezing of ice => environment warms.

Bottom p 73

Review of
HEAT TRANSFER PROCESSES (THERMODYNAMICS)



← Consider this diagram

Q4 - Which heat transfer processes are shown by a, b, c, & d?

__Latent heat

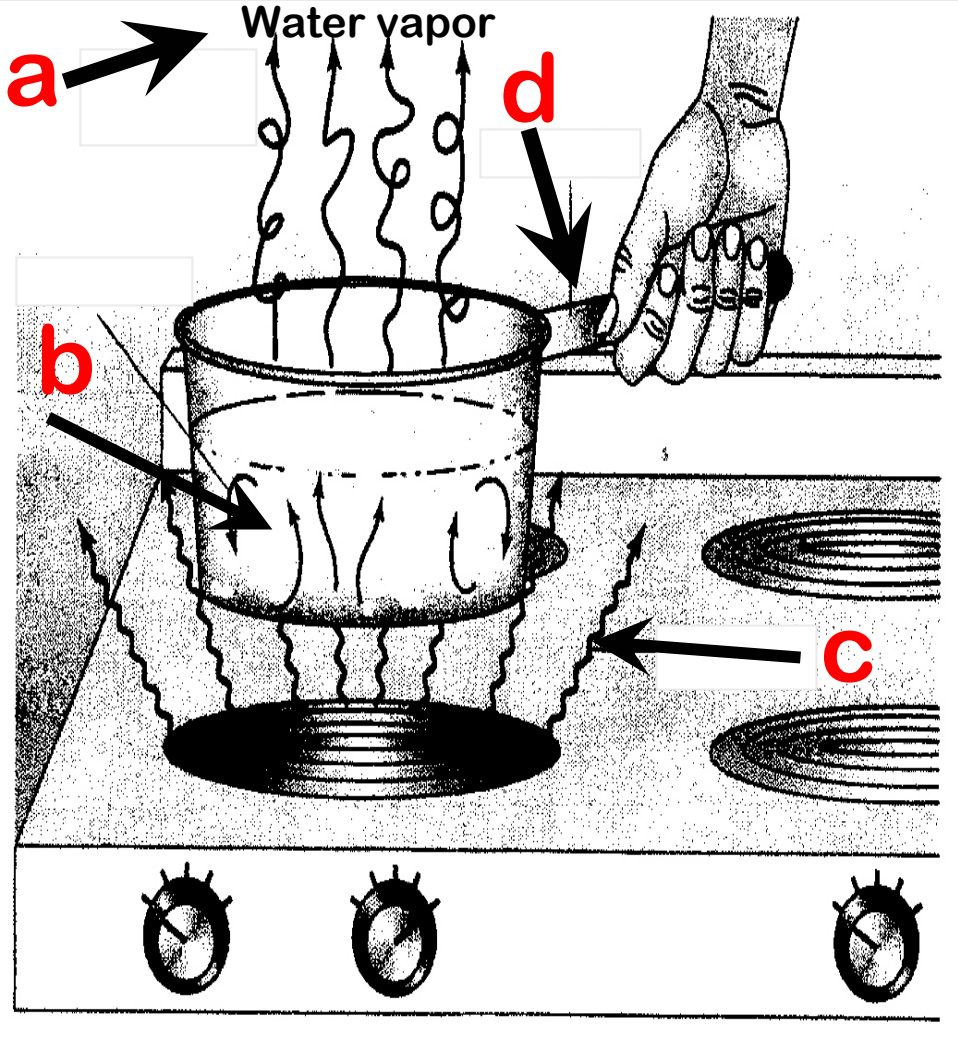
__Conduction

__Convection

__Radiation

BEGIN ANSWERING NOW!

Review of
HEAT TRANSFER PROCESSES (THERMODYNAMICS)



← Consider this diagram

Q4 - Which heat transfer processes are shown by a, b, c, & d?

a. Latent heat

d. Conduction

b. Convection

c. Radiation

HEAT TRANSFER SUMMARY:

Conduction:

molecule–to-molecule transfer

Most effective in SOLIDS

(earth's surface; soil; the ground)

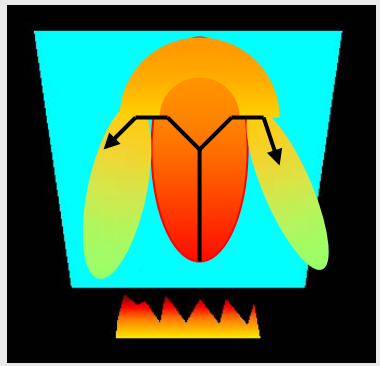
Molecule ➔ molecule vibrations

Convection:

transfer by large-scale movements

Most effective in GASES & LIQUIDS

(atmosphere & oceans)



Radiation:

transfer by ***electromagnetic radiation***

doesn't need MATTER to transfer energy!

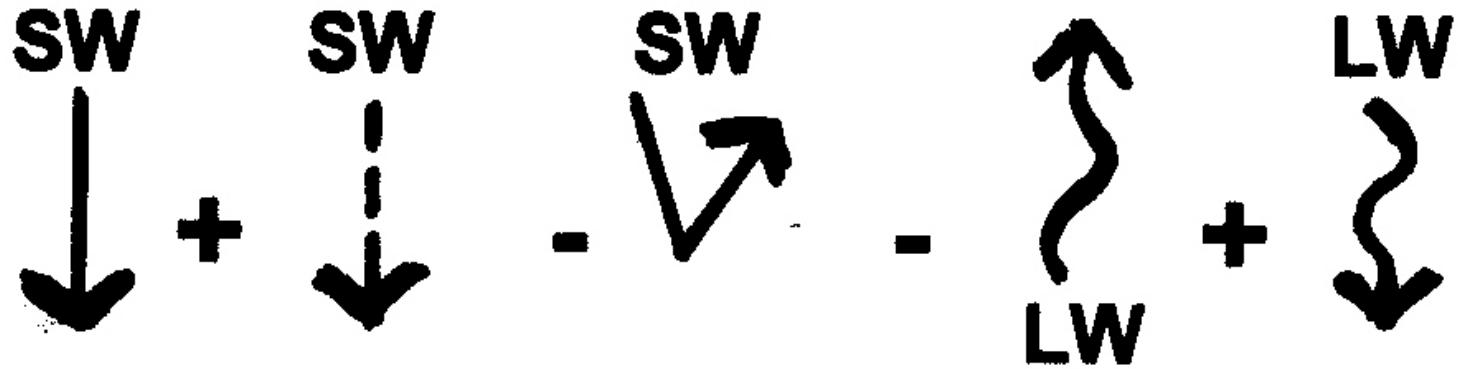
(sun ➔ earth, earth ➔ atmosphere,

atmosphere ➔earth, earth ➔ space)

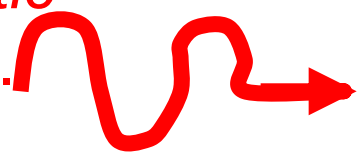
PLUS: LE ➔ H and H ➔ LE

during PHASE CHANGES

Link to the Left Side of Equation:



Radiation = the transfer of heat by *electromagnetic radiation*.

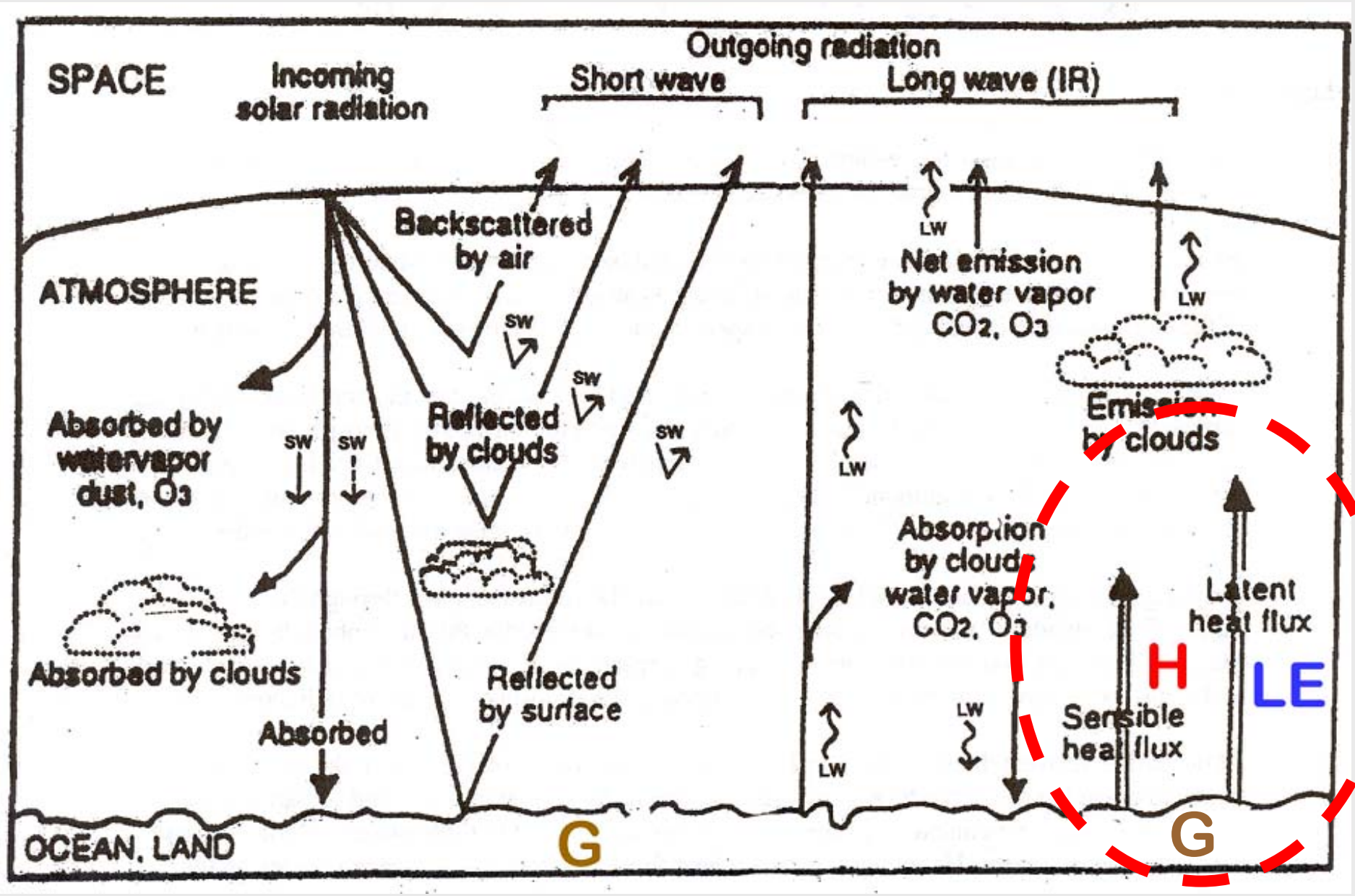


It doesn't need MATTER to transfer energy!
(sun ➔ earth, earth ➔ atmosphere, atmosphere ➔earth, earth ➔ space)

Link to the Right Side of Equation:

$$H + LE + G$$

Conduction & convection
plus energy stored & released during phase changes (latent energy => sensible heat, etc.)


SPACE
Incoming solar radiation
Outgoing radiation
Short wave
Long wave (IR)
ATMOSPHERE
Backscattered by air
SW
Absorbed by watervapor dust, O3
SW
SW
Reflected by clouds
SW
SW
Absorbed by clouds
Absorbed
Reflected by surface
OCEAN, LAND
G
LW
Net emission by water vapor CO2, O3
LW
Emission by clouds
LW
Absorption by clouds water vapor, CO2, O3
LW
LW
Latent heat flux
H
LE
Sensible heat flux
G

Back to p 61

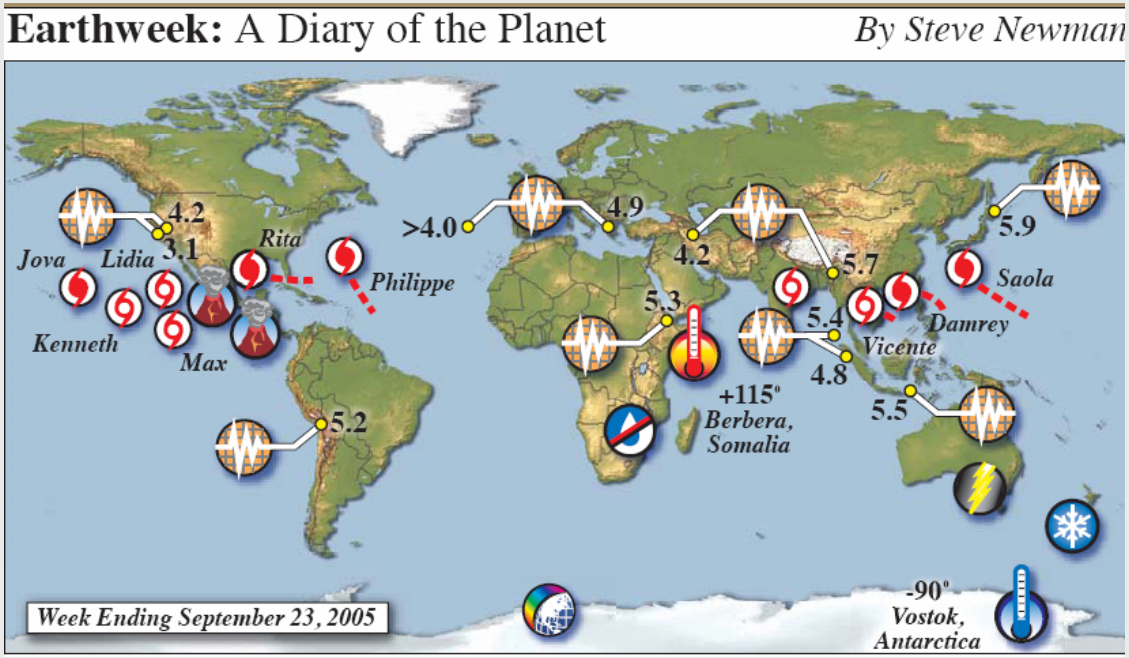
Encore: Energy Balance Animation

showing energy flow pathways
& "units" of energy that
eventually balance out:

SHORTWAVE & LONGWAVE ENERGY FLOW & BUDGET:

http://mesoscale.agron.iastate.edu/agron206/animations/10_AtmoEbal.html

SOME APPLICATIONS OF THE ENERGY BALANCE IN DIFFERENT PARTS OF THE GLOBE:

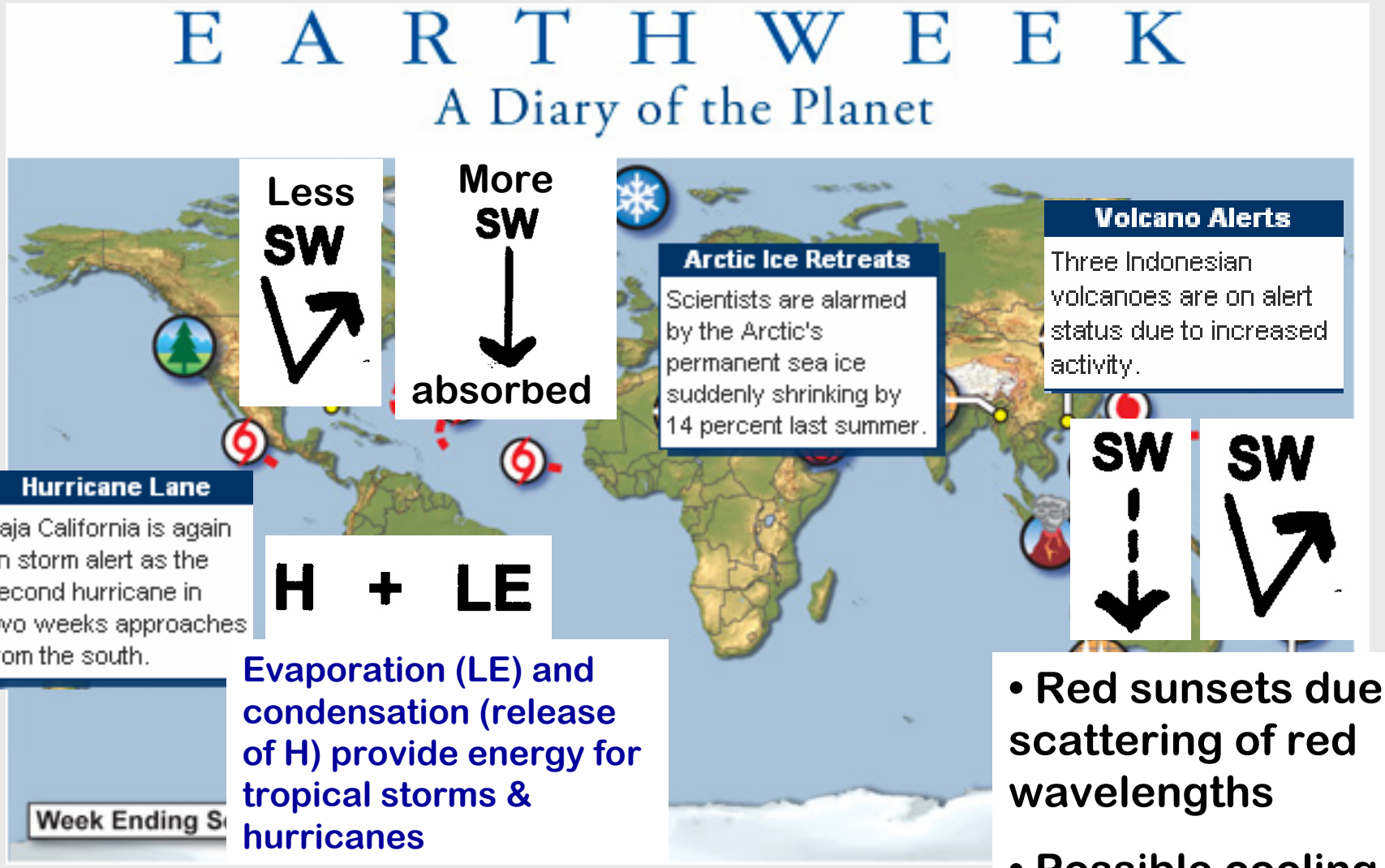


SOME APPLICATIONS OF THE ENERGY BALANCE IN DIFFERENT PARTS OF THE GLOBE:

EARTHWEEK

A Diary of the Planet

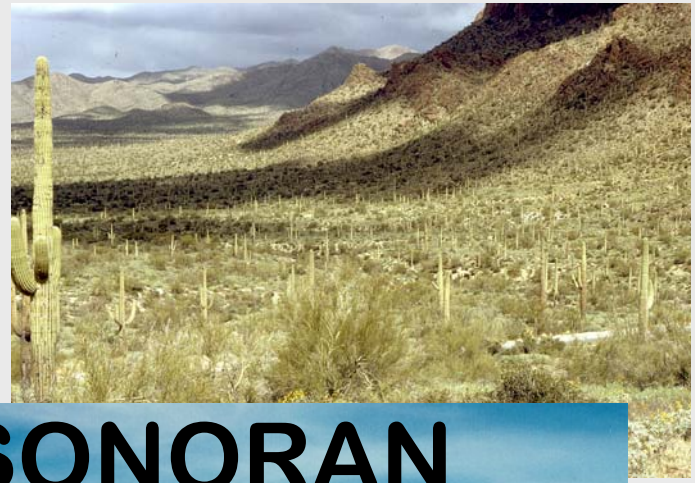
http://www.earthweek.com/

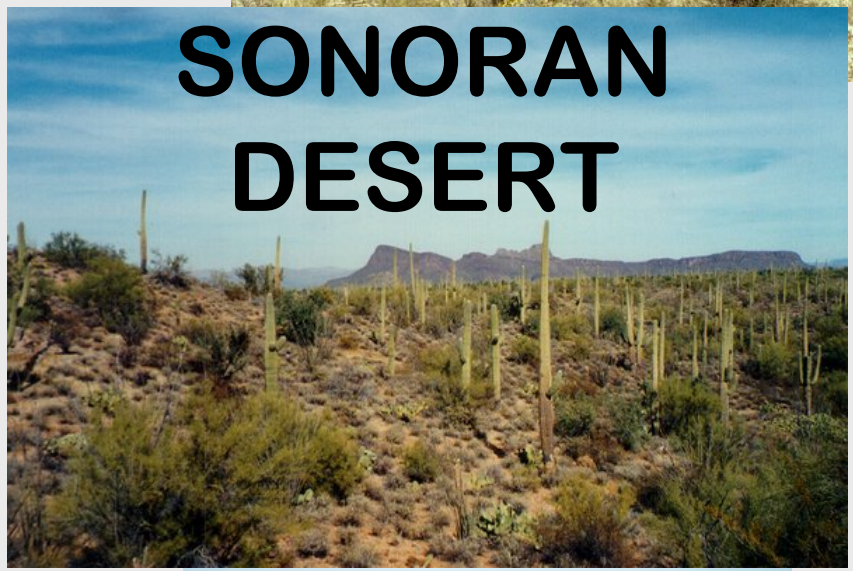


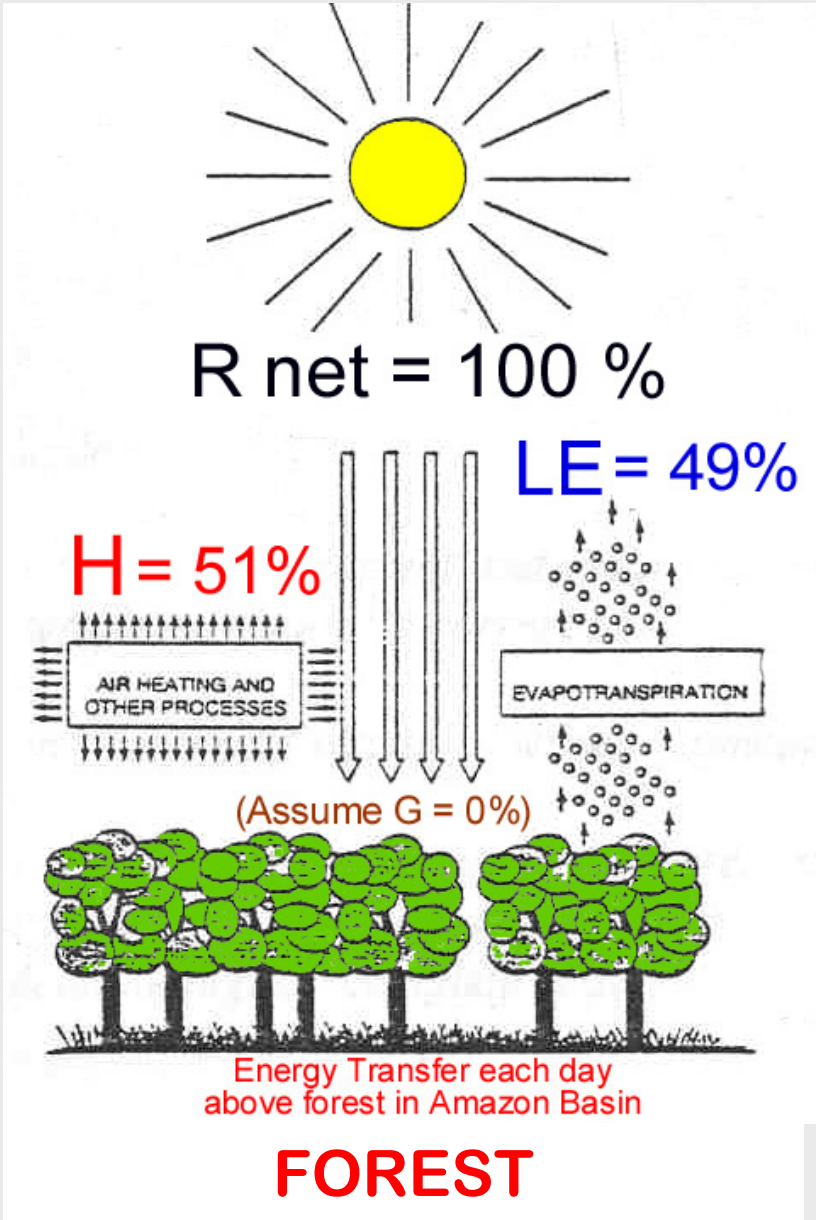
Evaporation (LE) and condensation (release of H) provide energy for tropical storms & hurricanes

- Red sunsets due to scattering of red wavelengths
- Possible cooling due to reflection of incoming SW

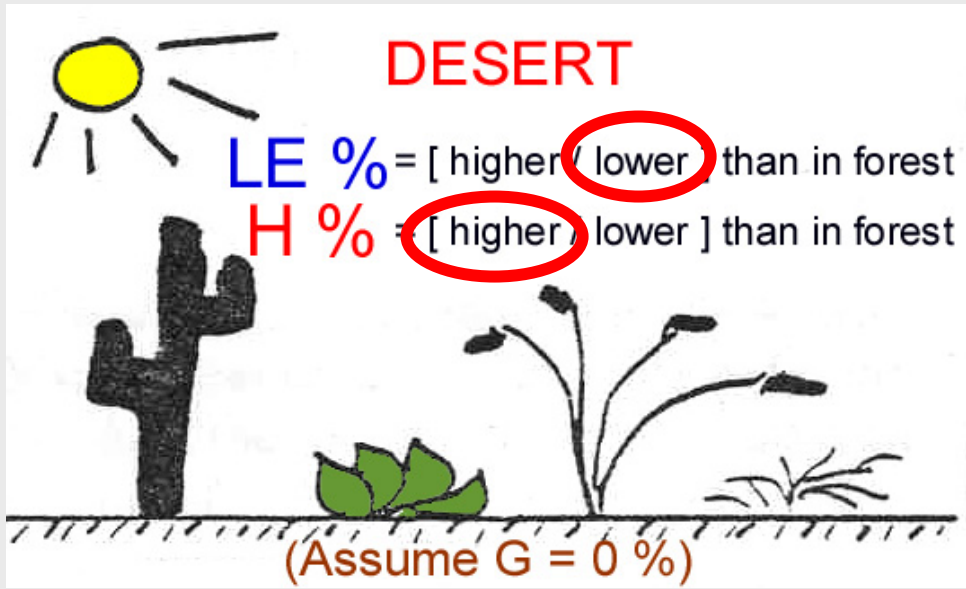

AMAZON RAIN
FOREST




SONORAN
DESERT

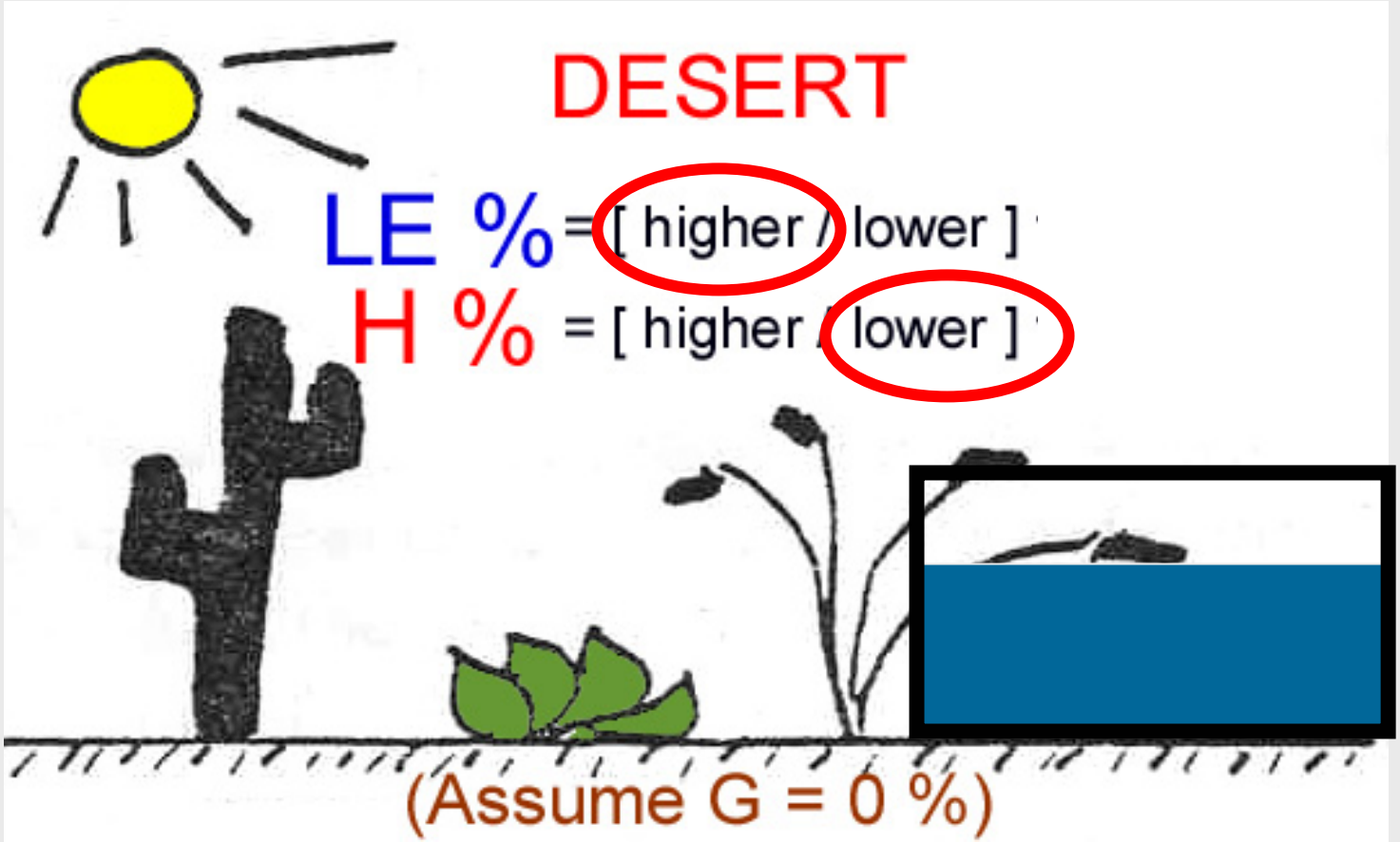


Will the % of net radiation in LE form be HIGHER or LOWER in the Desert, when compared to a Rainforest?



What if humans put in canals (CAP), lakes, & artificial water bodies in a desert?

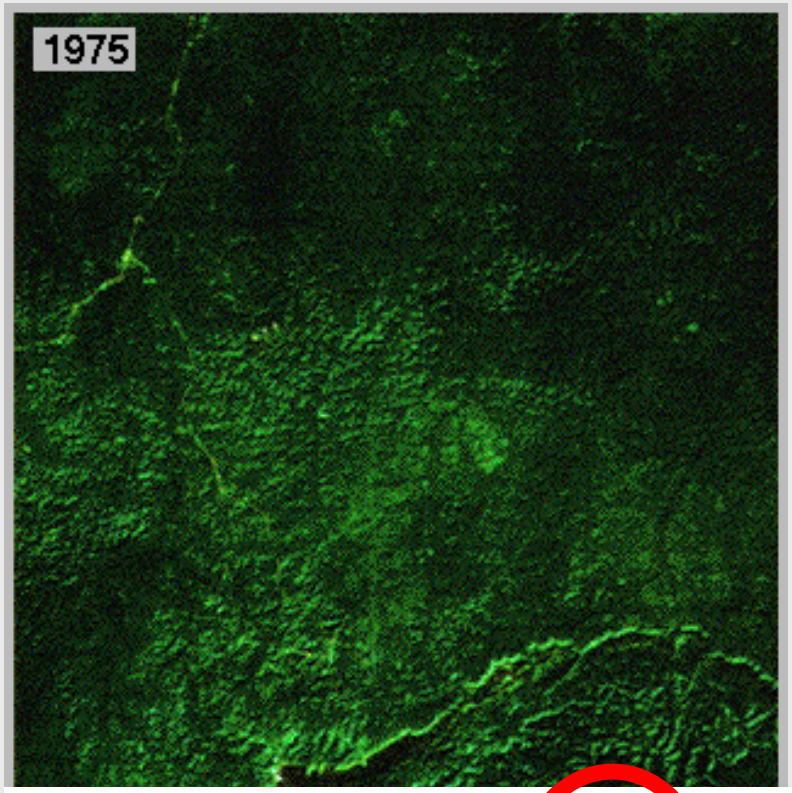
Central Arizona Project (CAP) Canal

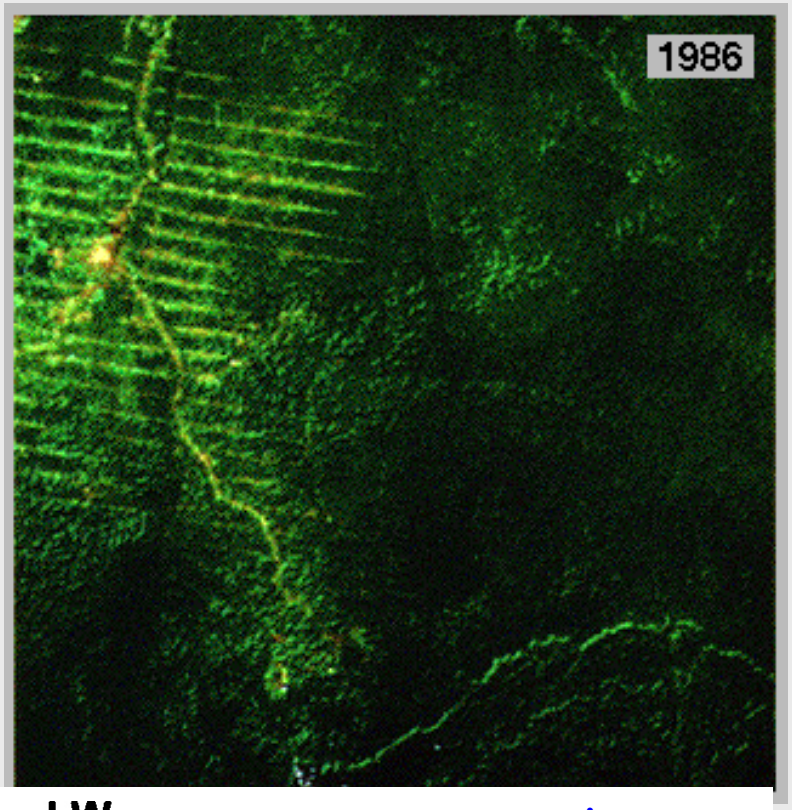


What if humans put in canals (CAP), lakes, & artificial water bodies in a desert?

How would the % of LE in the Desert change?

How does DEFORESTATION change the local energy balance???





$$R_{NET} = \downarrow_{SW} + \downarrow_{SW} - \nearrow_{SW} - \leftrightarrow_{LW} + \sim_{LW} = H + LE + G$$

Less

More → cooler temperatures?

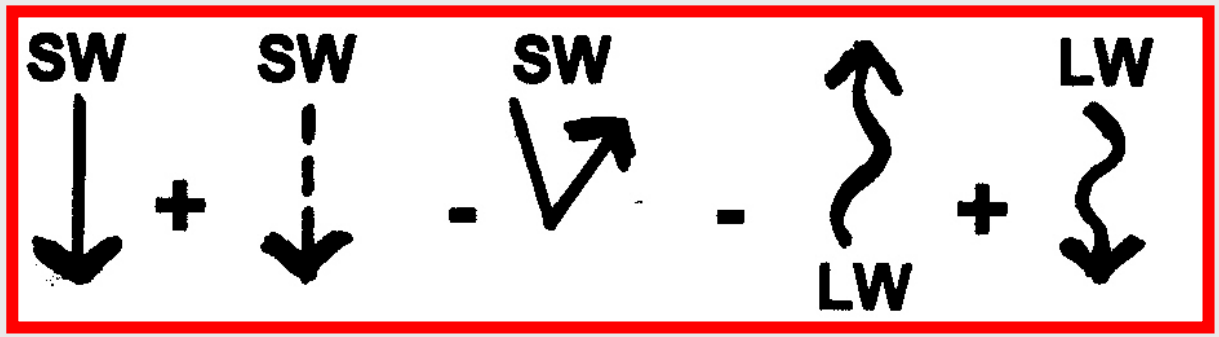
More → warmer temperatures?

G-4 ASSIGNMENT (10 pts)

Applying the Energy Balance Terms

Your task is to decide which **component** or **components working together** ***are most directly related to*** or ***responsible for*** the observed phenomenon.

 # 1 – #12 : Left side of equation



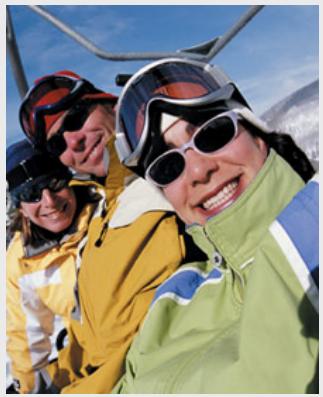
 # 13 - #15: Right side of equation

H + LE + G

p 65

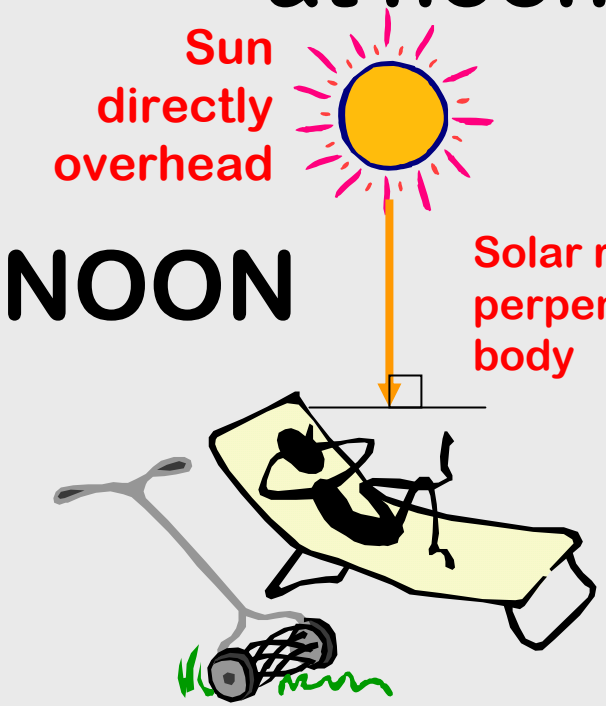
1. blue skies

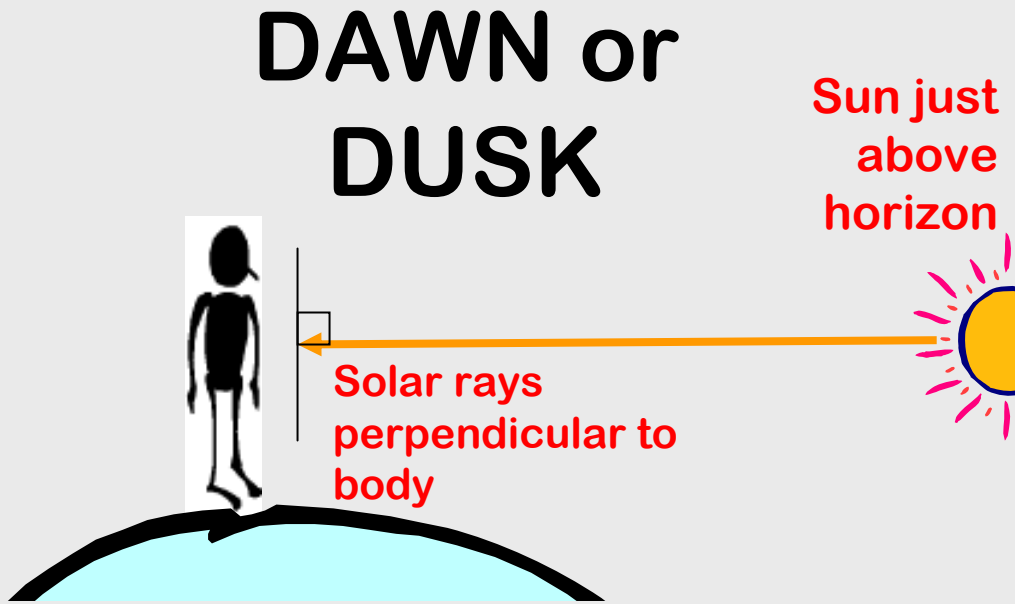
2. Sunglasses while skiing



3. Bright even though cloudy

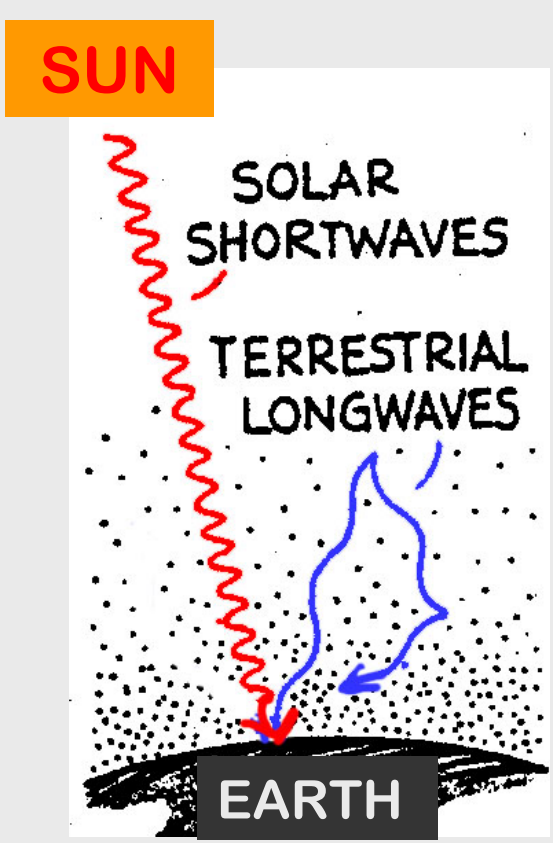
4. More intense solar radiation (tan /skin damage, etc.) at noon vs. dawn or dusk

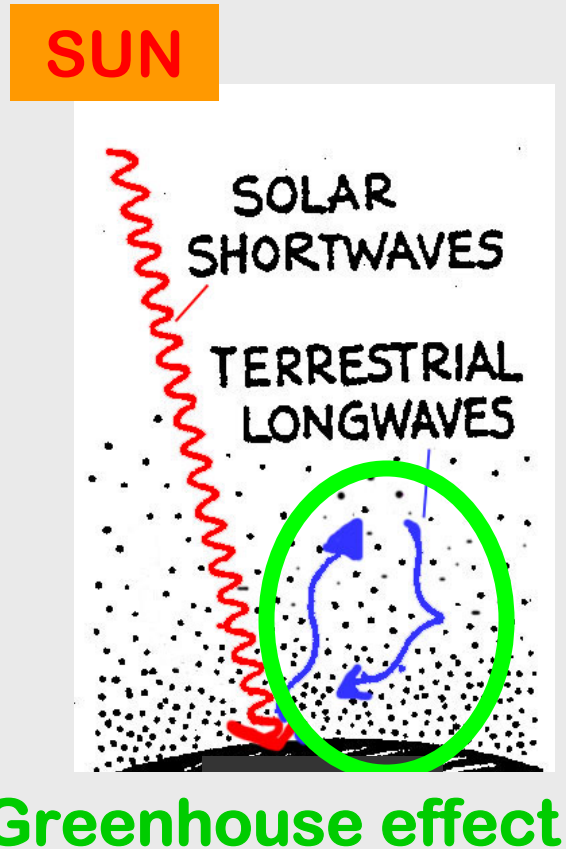




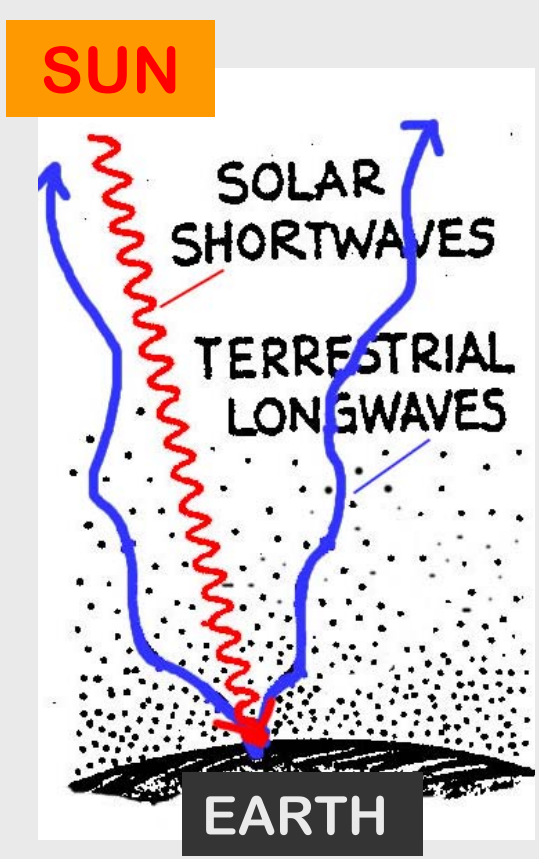
5. The Greenhouse Effect ➔

To illustrate the GREENHOUSE EFFECT:





Greenhouse effect

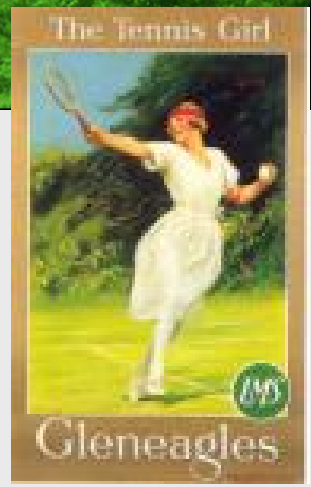


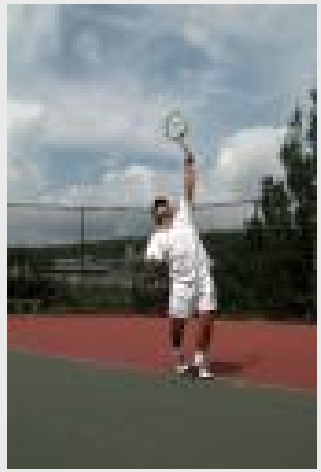
B is better than the others . . . But only the circled part represents the GH Effect!! . . .

6. Red sunsets

7. Infrared cameras / "night vision"

8. "Tennis whites" tradition





9. Shadow on sunny day

10. Rainbow

11. Black streaks

12. Parking on blacktop

13. Hot air balloon

14. Pigs cooling off in the mud

15. Evaporative coolers work best in the desert

TIME TO FINISH UP

G-4 ASSIGNMENT (10 pts) (cont.)

Applying the Energy Balance Terms

Your task is to decide which component or components working together *are most directly related to* or *responsible for* the observed phenomenon.

Each member of the group must take the lead in answering at least TWO of the items below *without* asterisks ** in his or her own handwriting. Members present should sign below and indicate which 2 or 3 items they filled in, e.g.: Katherine K. Hirschbeck (#2, #10, & #12)

_____ _____

Don't forget to SIGN IN with the #'s you wrote up!

Time to finish up G-4 and the G-4 answers will be given on Thursday . . .

. . . after the Group Test.

See you on Thursday for Test #2!