

Topic # 10

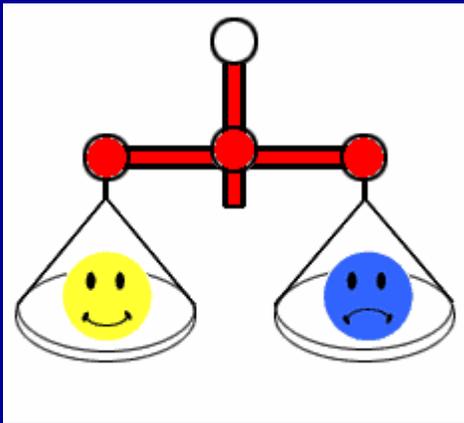
THE EARTH'S GLOBAL ENERGY BALANCE

Applying the laws, etc. to understand how processes all work together to create global weather & climate!!

→ **BOOKMARK pp 51 & 115**
in Class Notes now for lecture today

Today's Quote:

A Different Sort of "ENERGY BALANCE":



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

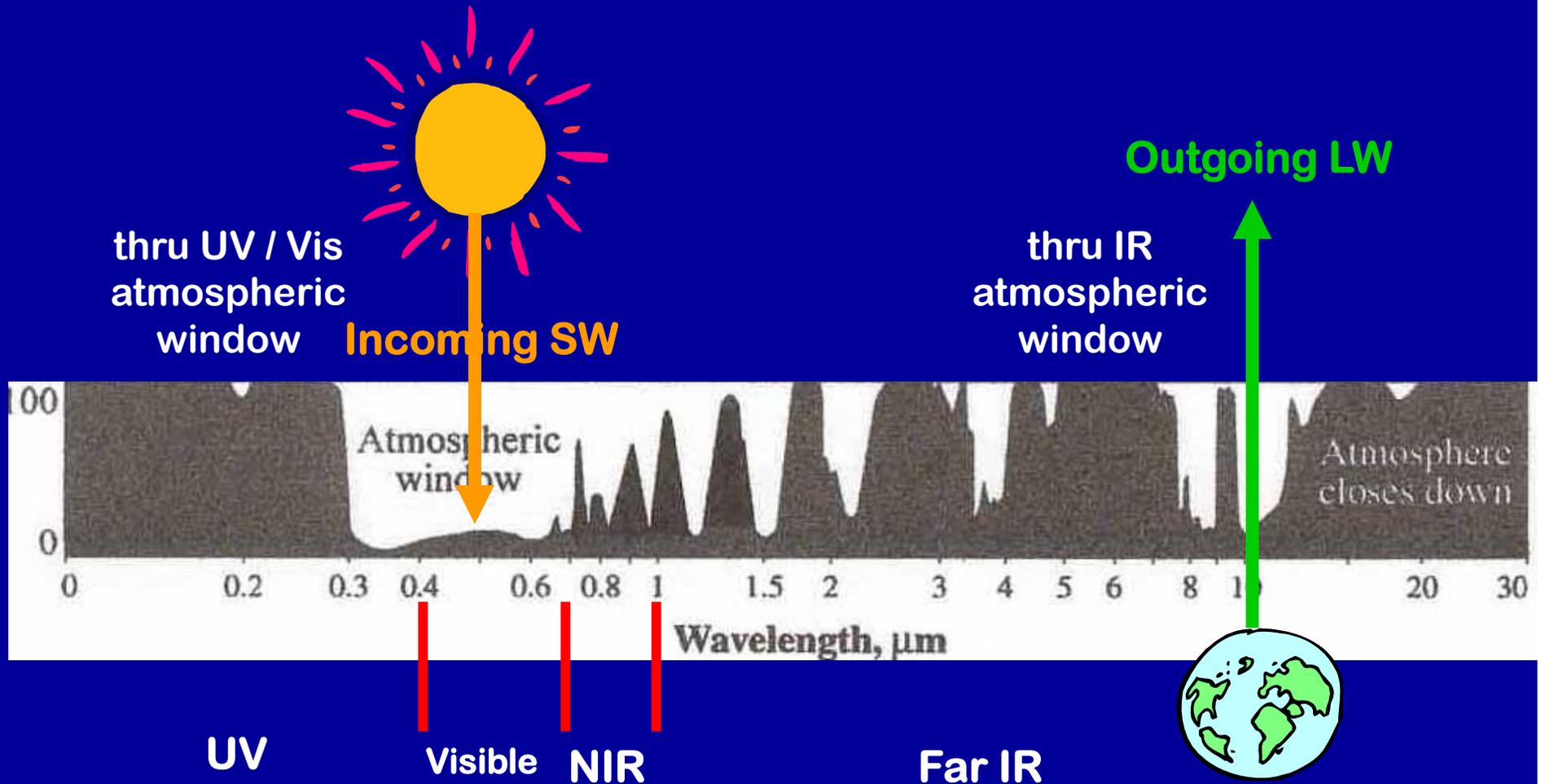
Are my energy expenditures (actions, reactions, thoughts, and feelings) productive or nonproductive?

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

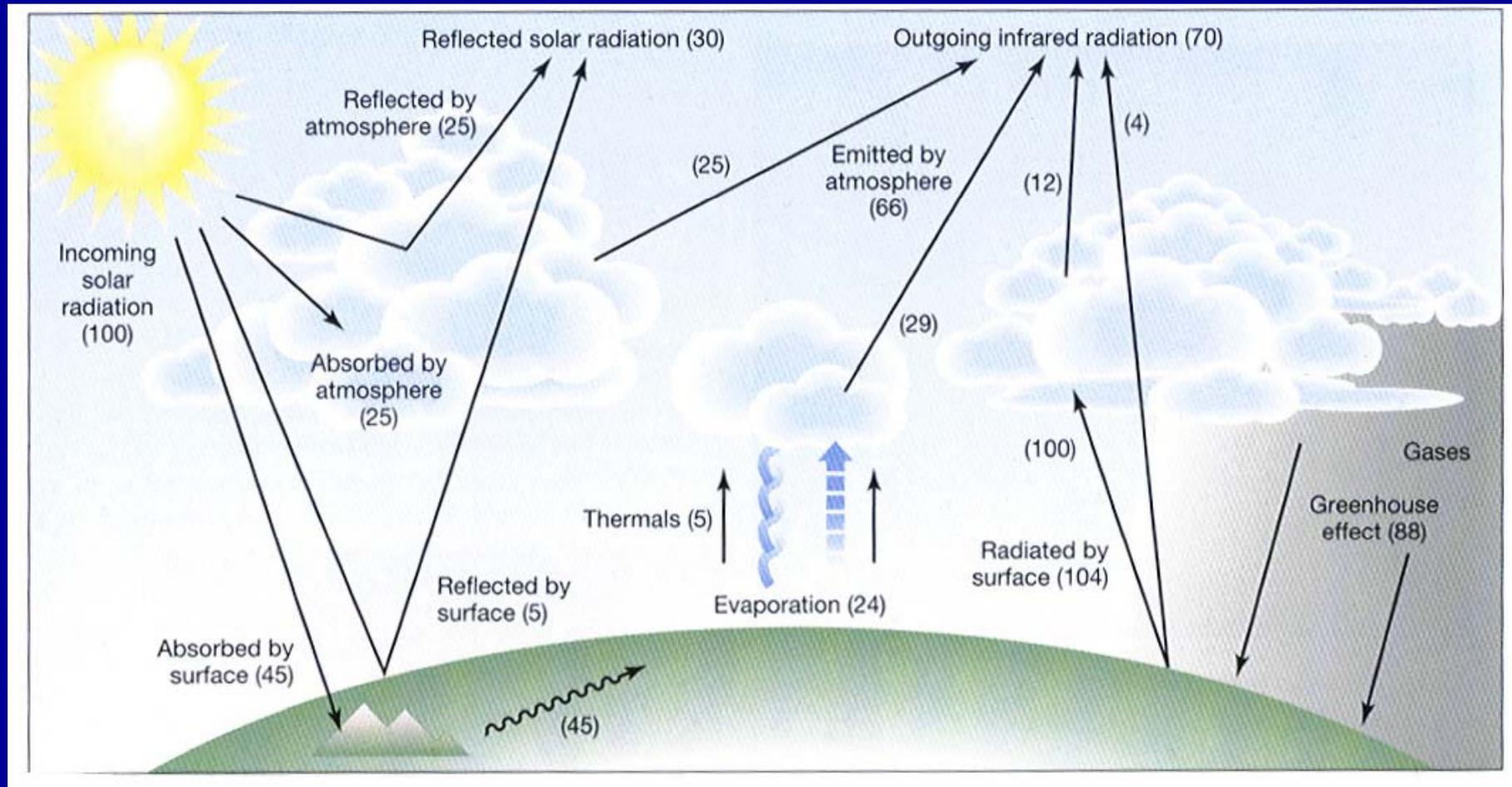
~ Doc Childre and Howard Martin

Review: Absorption curve for the "Whole Atmosphere"

OVERALL BALANCE: **Incoming = Outgoing**



Typical Energy Balance Diagram



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

From SGC-I Chapter 3, p 50, Fig 3-19

Similar to p 51
in Class Notes

Energy Balance Equation:

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

(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" . . .



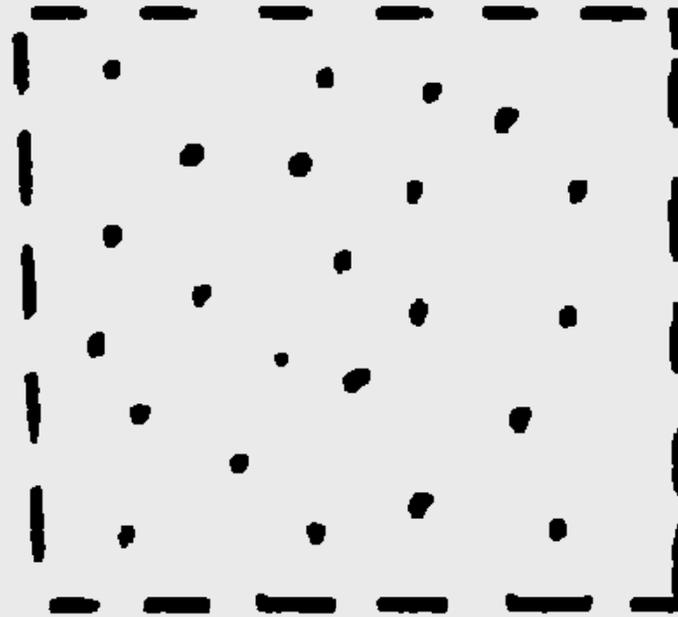
“CARTOON” SYMBOLS:

**To represent
the Earth’s surface:**



Go to p 115

“CARTOON” SYMBOLS:



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



“CARTOON” SYMBOLS:

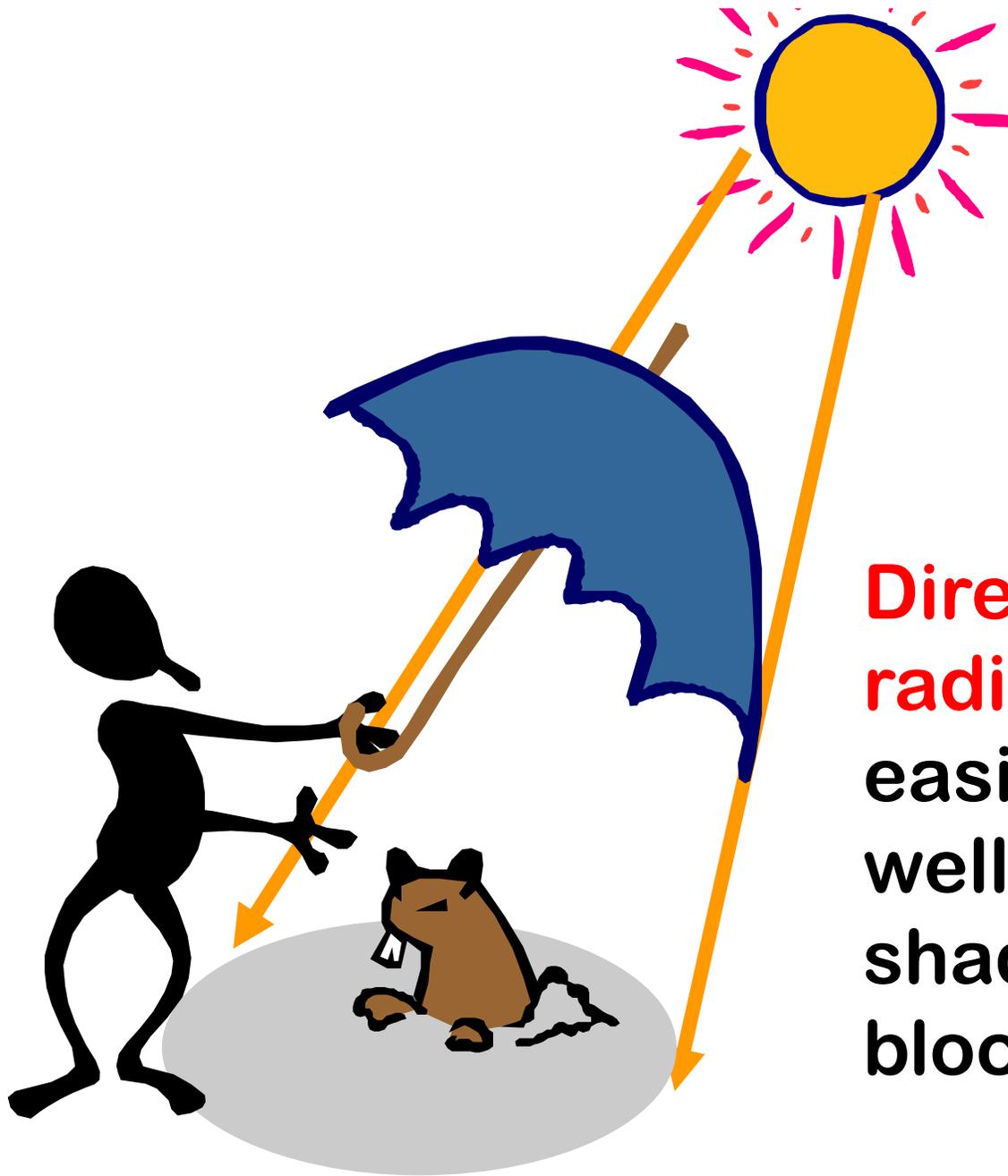


To represent CLOUDS

“CARTOON” SYMBOLS:



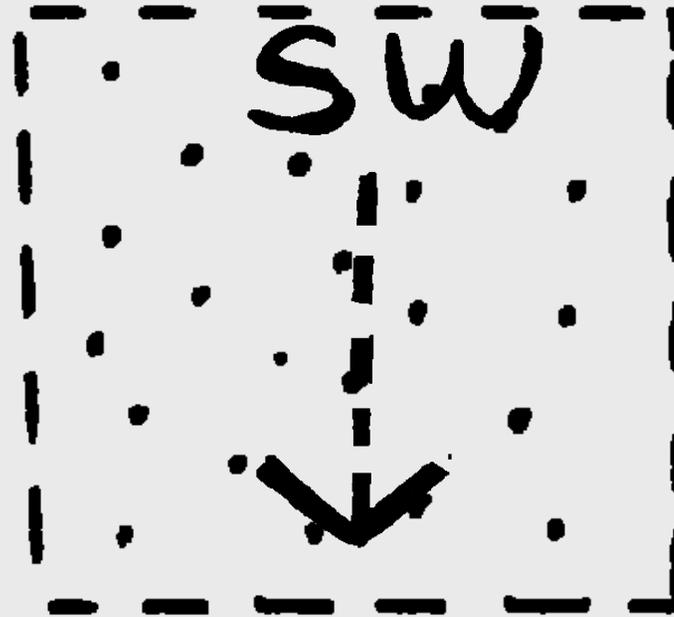
To represent SOLAR (shortwave) radiation coming in **DIRECTLY**.
(aka **Direct shortwave radiation**)



**Direct SW
radiation**
easily casts
well-defined
shadows when
blocked

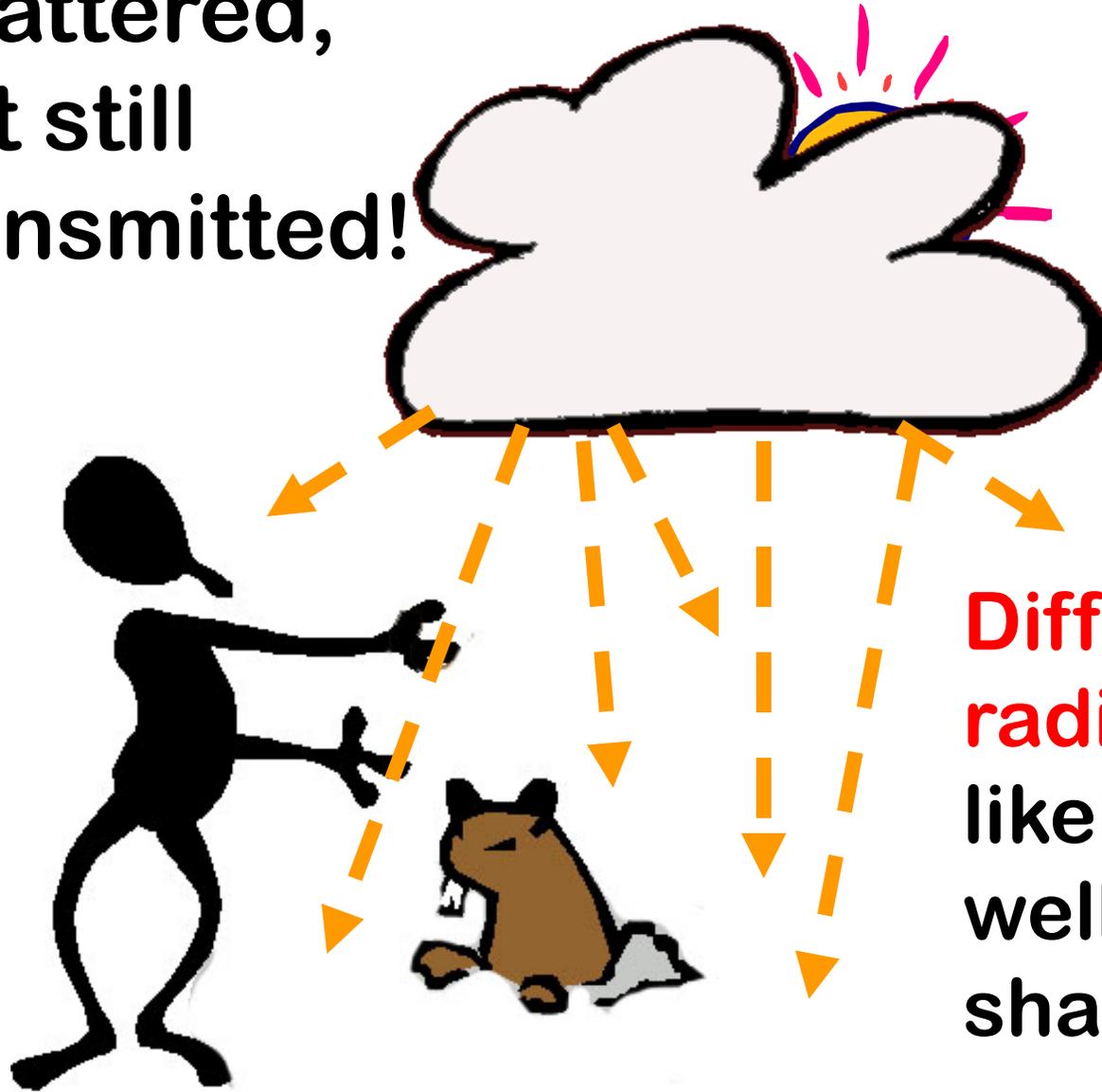
Take notes

“CARTOON” SYMBOLS:



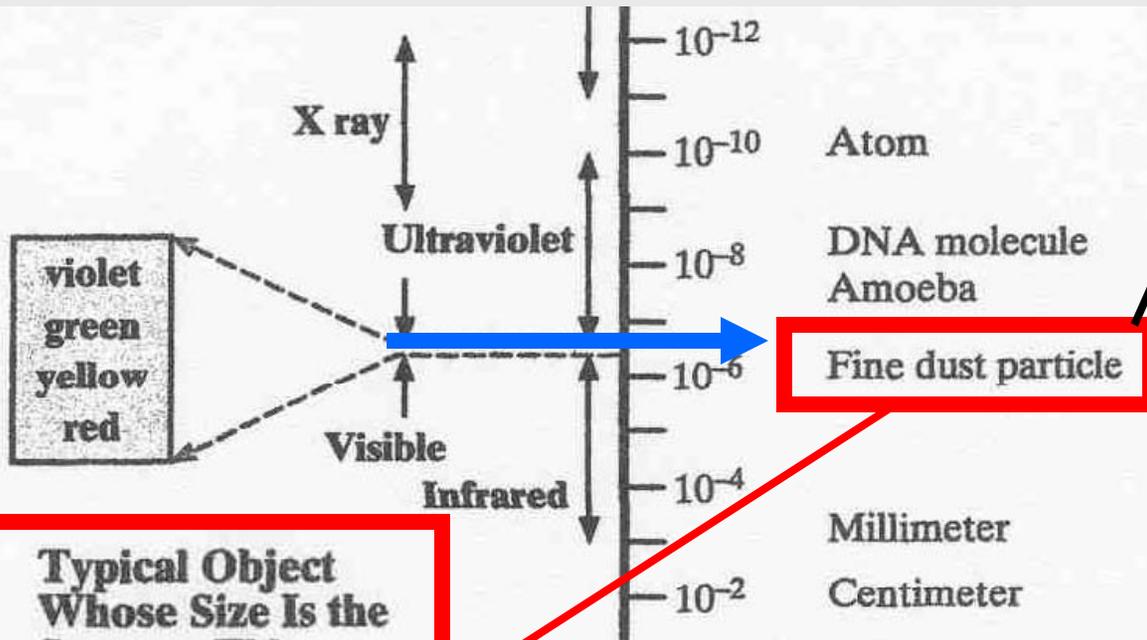
To represent SOLAR (shortwave) radiation coming in as **DIFFUSE shortwave radiation**, i.e. scattered by gases, clouds, and particles in the atmosphere.

Scattered,
but still
transmitted!



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

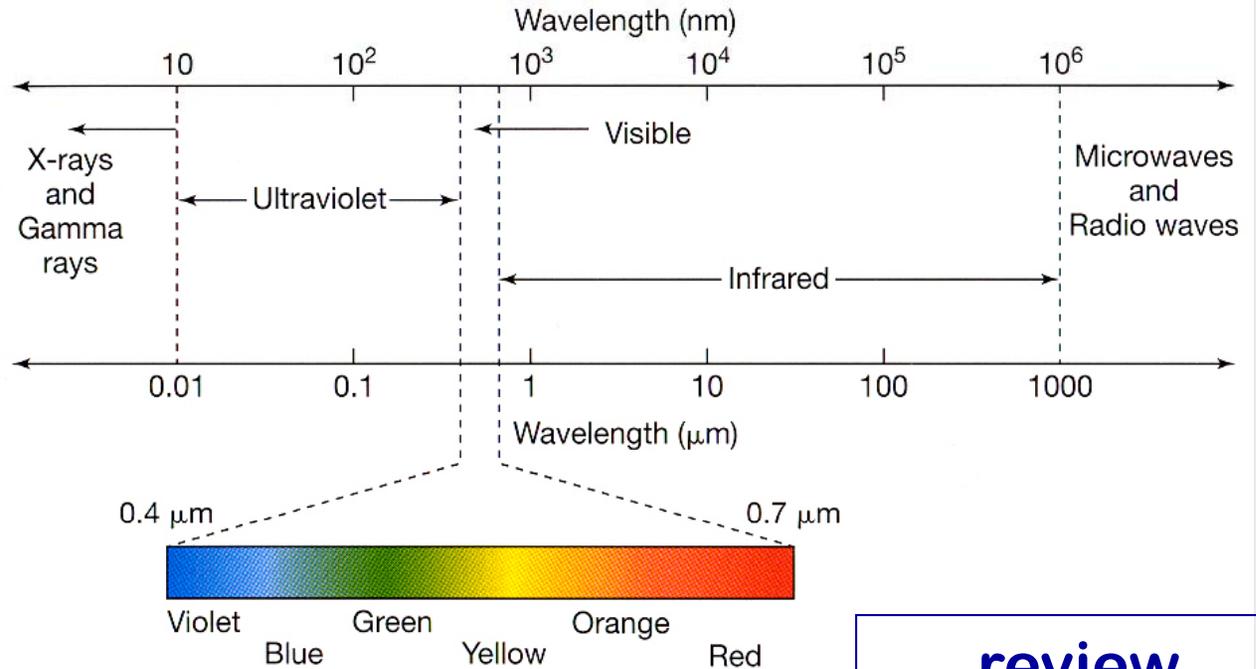
Take notes



Different sized dust particles, water droplets, aerosols, (even gas molecules themselves)

Typical Object Whose Size Is the Same as This Wavelength:

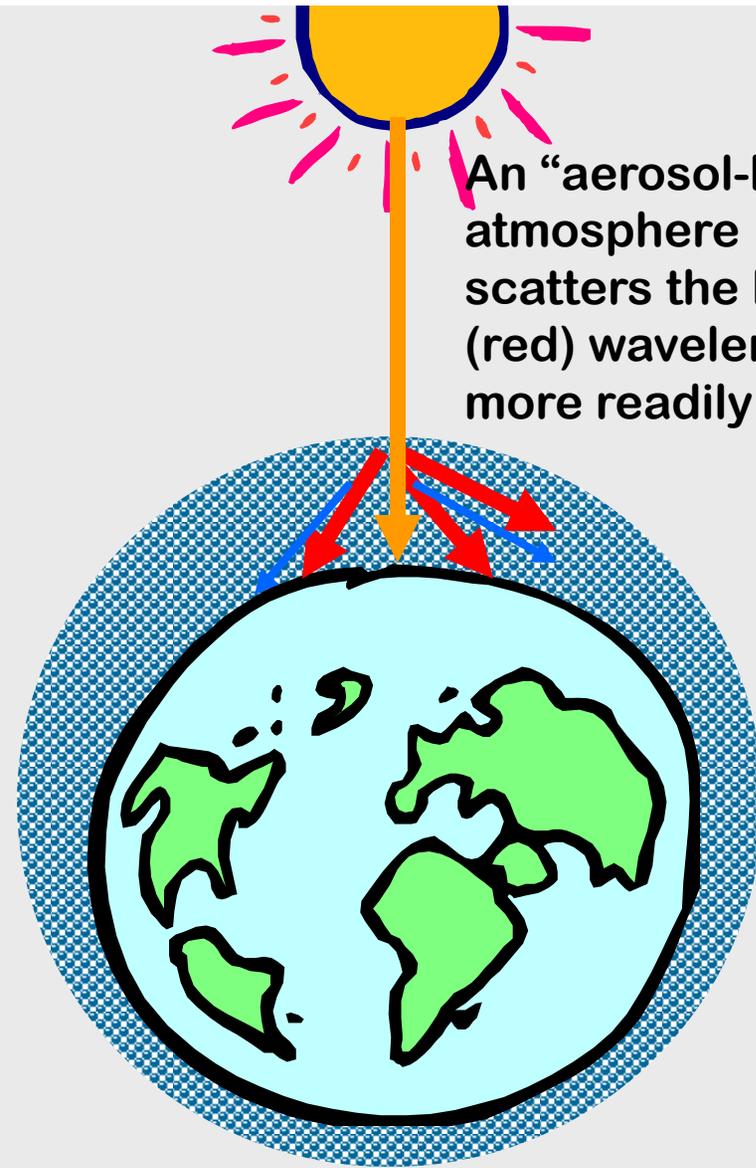
Scattering of visible light



review



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



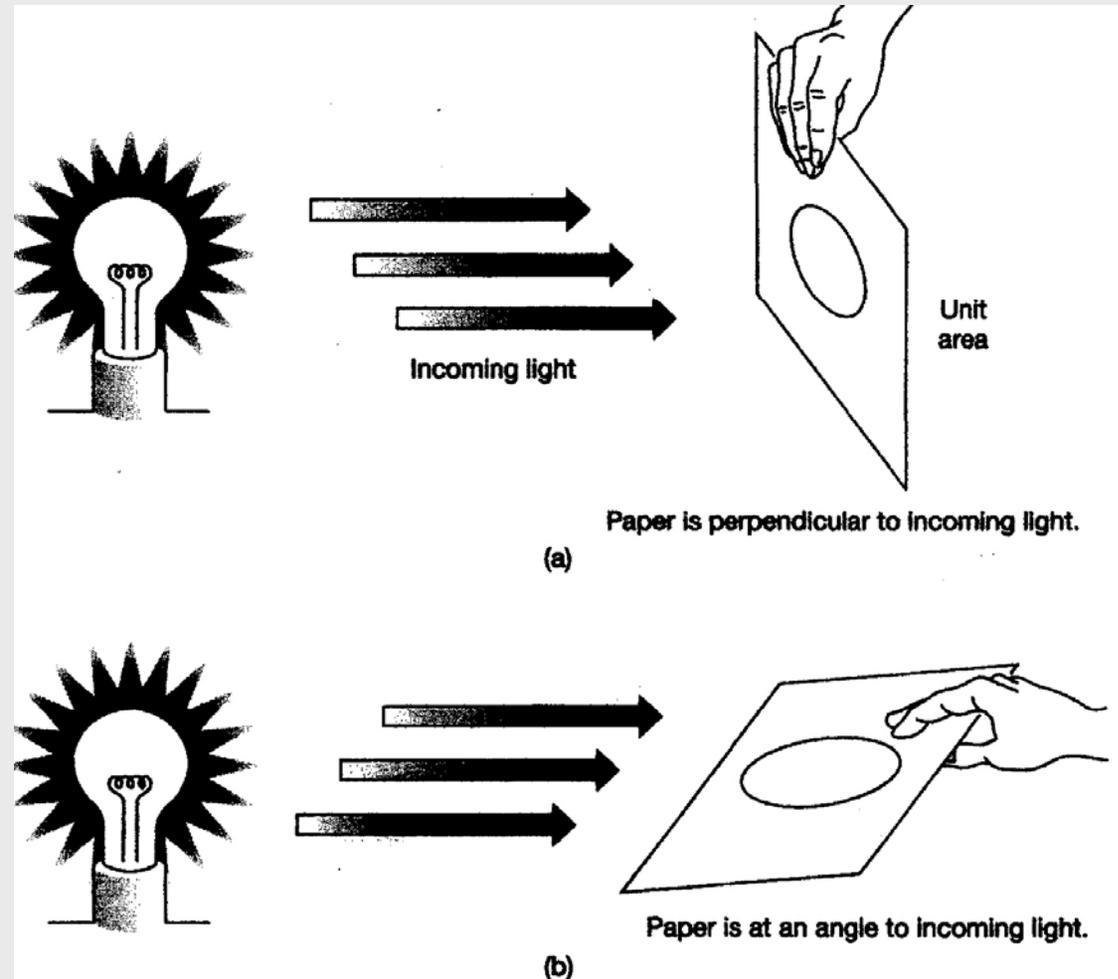
An “aerosol-laden” atmosphere scatters the longer (red) wavelengths more readily

“Dirty” (aerosol-laden) atmosphere composed of fine particles, gases, & H₂O -- **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 SGC-I, Ch 3

Scenario 1:
NOON at
Point A

Scenario 2: Late
afternoon at
Point A



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

1 = Scenario 1

2 = Scenario 2



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!**



“CARTOON” SYMBOLS:



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



New term:

ALBEDO = reflectivity of a surface
“symbol” = **a**

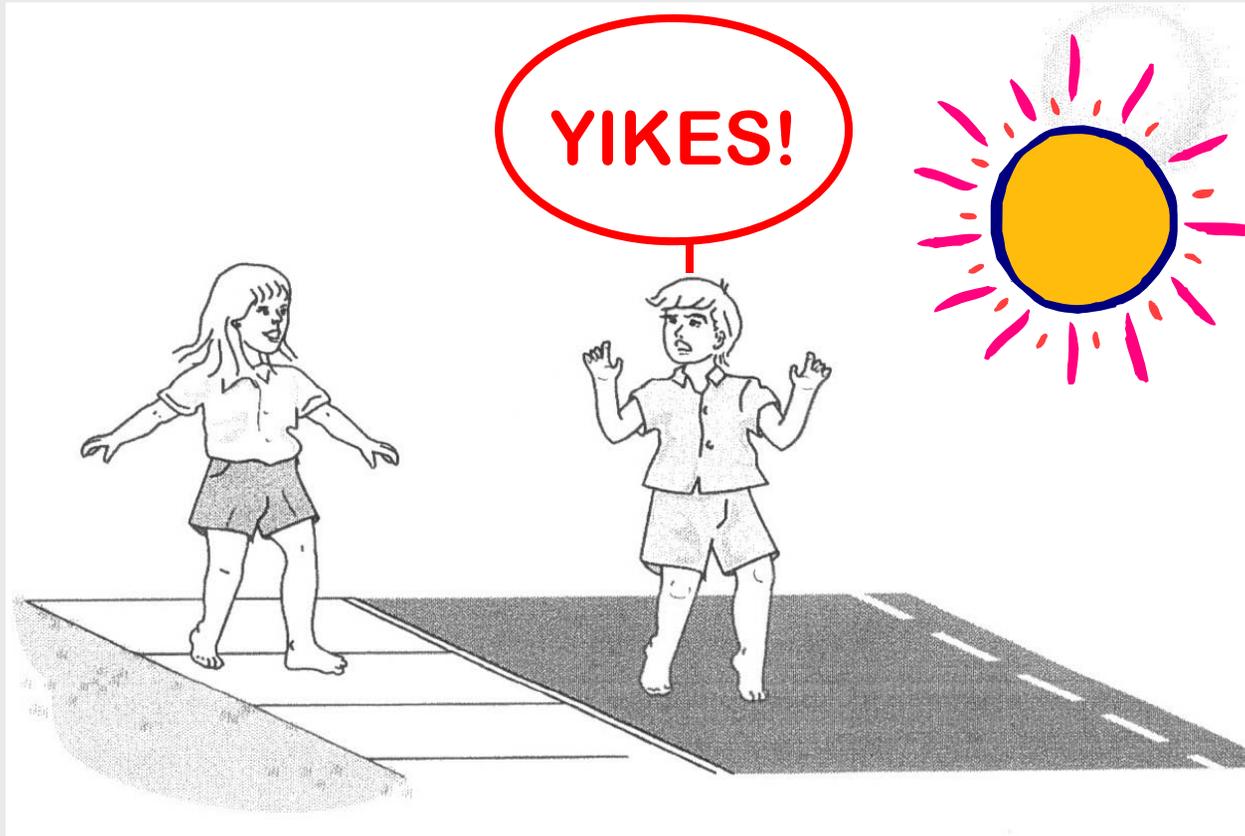
Represented as:

a decimal from 0 to 1.0 *or*

% from 0 – 100 % (perfect reflectivity)

Hence, amount **ABSORBED** = $(1 - \text{albedo})$

← Flip back to p 51



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

<i>Type of Surface</i>		<i>Albedo</i>
Sand		0.20–0.30
Grass		0.20–0.25
Forest	Low albedo	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	High albedo	0.70–0.80

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

AVERAGE PLANET EARTH = ~ 0.30

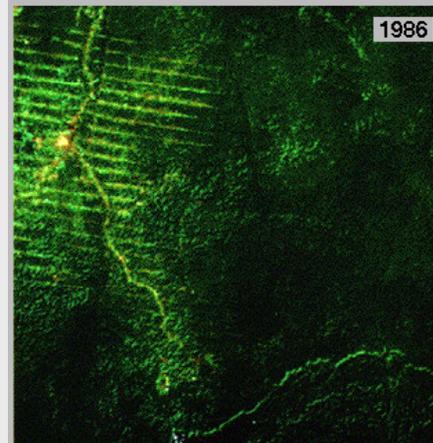
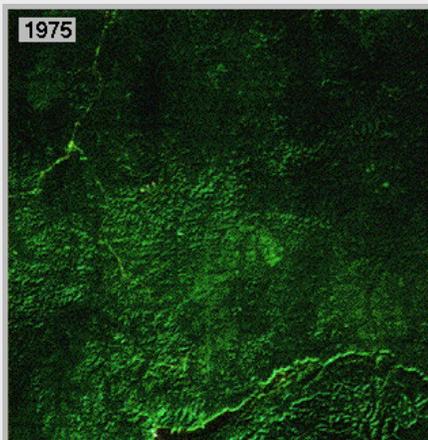
Q3: What will happen to incoming SW over the Amazon Rain Forest if parts of it are deforested?

1 = more SW will be absorbed

2 = less SW will be absorbed

SW
↘

Before



After



“CARTOON” SYMBOLS:

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



[Return to p 115](#)

“CARTOON” SYMBOLS:

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



PUTTING IT TOGETHER:

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

$$R_{NET} = \begin{array}{ccccccc} SW & & SW & & SW & & LW \\ \downarrow & + & \downarrow & - & \swarrow & - & \downarrow \\ R_{NET} = & & & & & & \\ (Q & + & q) & - & a & - & Lu & + & Ld \end{array}$$

$$R_{\text{NET}} = \begin{array}{c} \text{SW} \\ \downarrow \\ \text{SW} \\ \downarrow \\ \text{SW} \\ \swarrow \end{array} + \begin{array}{c} \text{SW} \\ \downarrow \\ \text{SW} \\ \downarrow \\ \text{SW} \\ \swarrow \end{array} - \begin{array}{c} \text{SW} \\ \swarrow \\ \text{SW} \\ \swarrow \\ \text{SW} \\ \swarrow \end{array} - \begin{array}{c} \uparrow \\ \text{LW} \\ \uparrow \\ \text{LW} \\ \uparrow \\ \text{LW} \end{array} + \begin{array}{c} \text{LW} \\ \downarrow \\ \text{LW} \\ \downarrow \\ \text{LW} \\ \downarrow \end{array} =$$

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

See top p 51

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

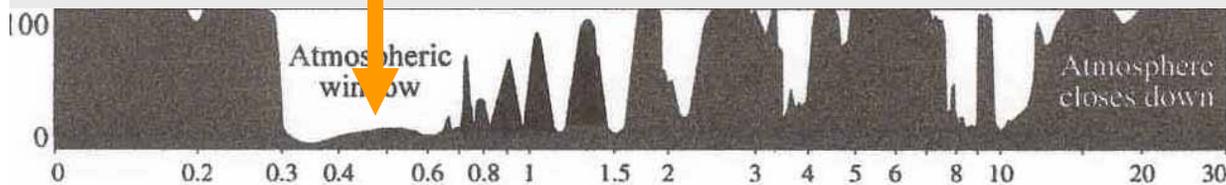
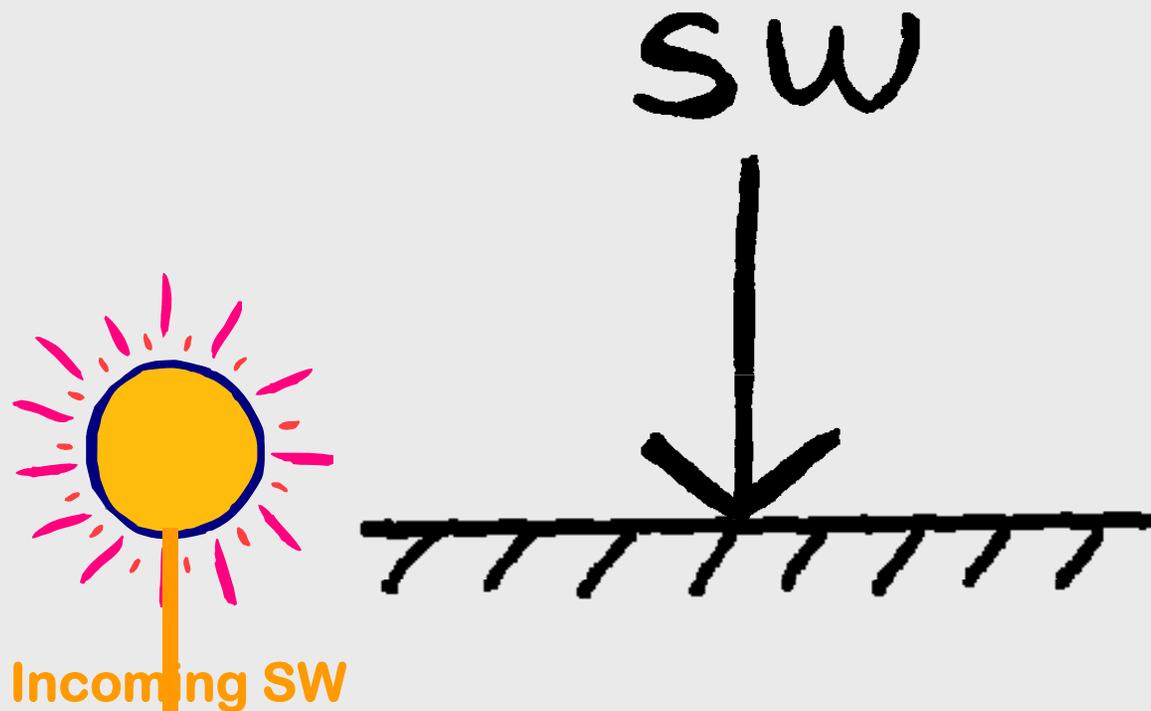


No re-radiation of infrared by GHG's



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”

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



SW REFLECTED BACK TO SPACE:

By
clouds



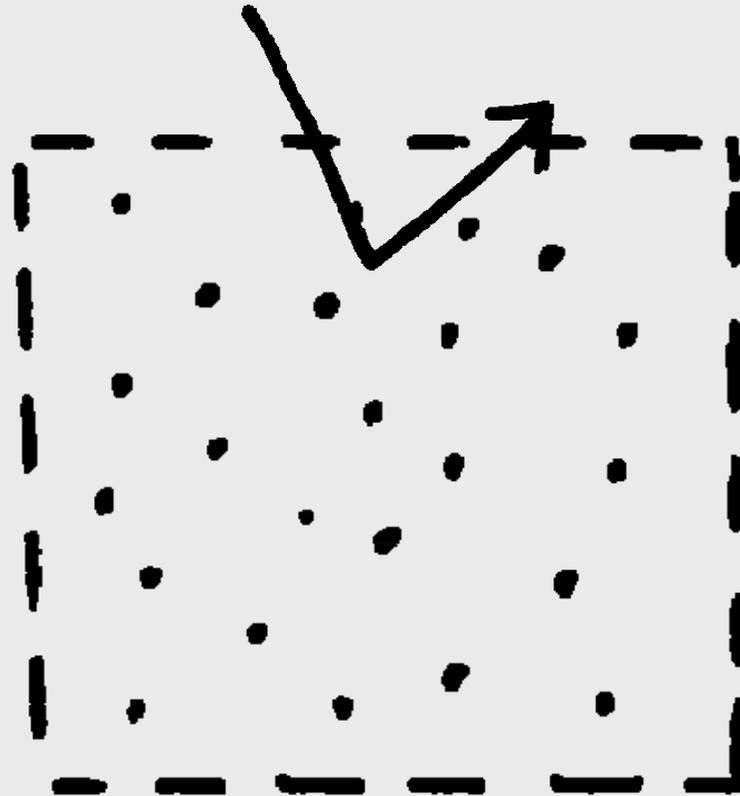
By
Earth's
surface



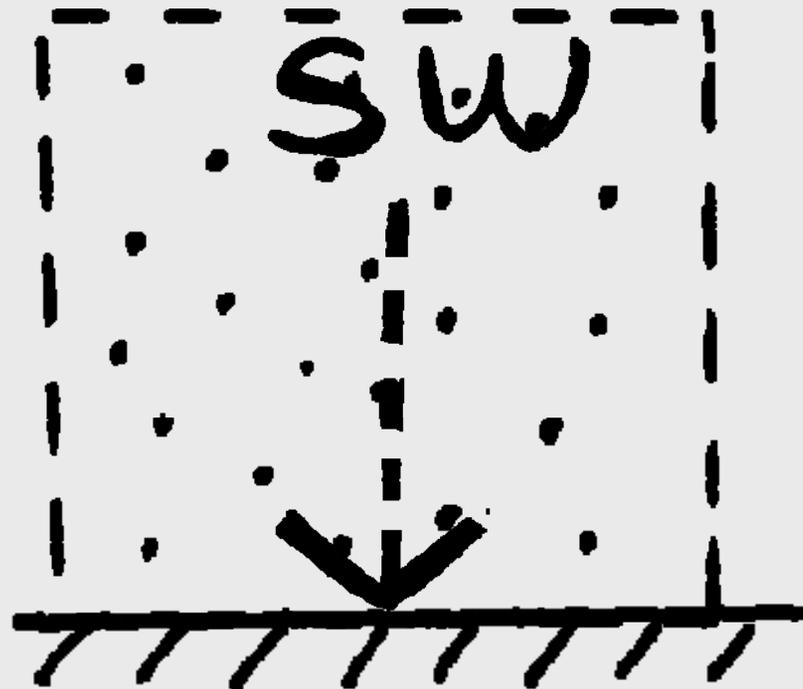
This is determined by
the ALBEDO of the
clouds or surface

SW SCATTERED BACK TO SPACE BY ATMOSPHERE:

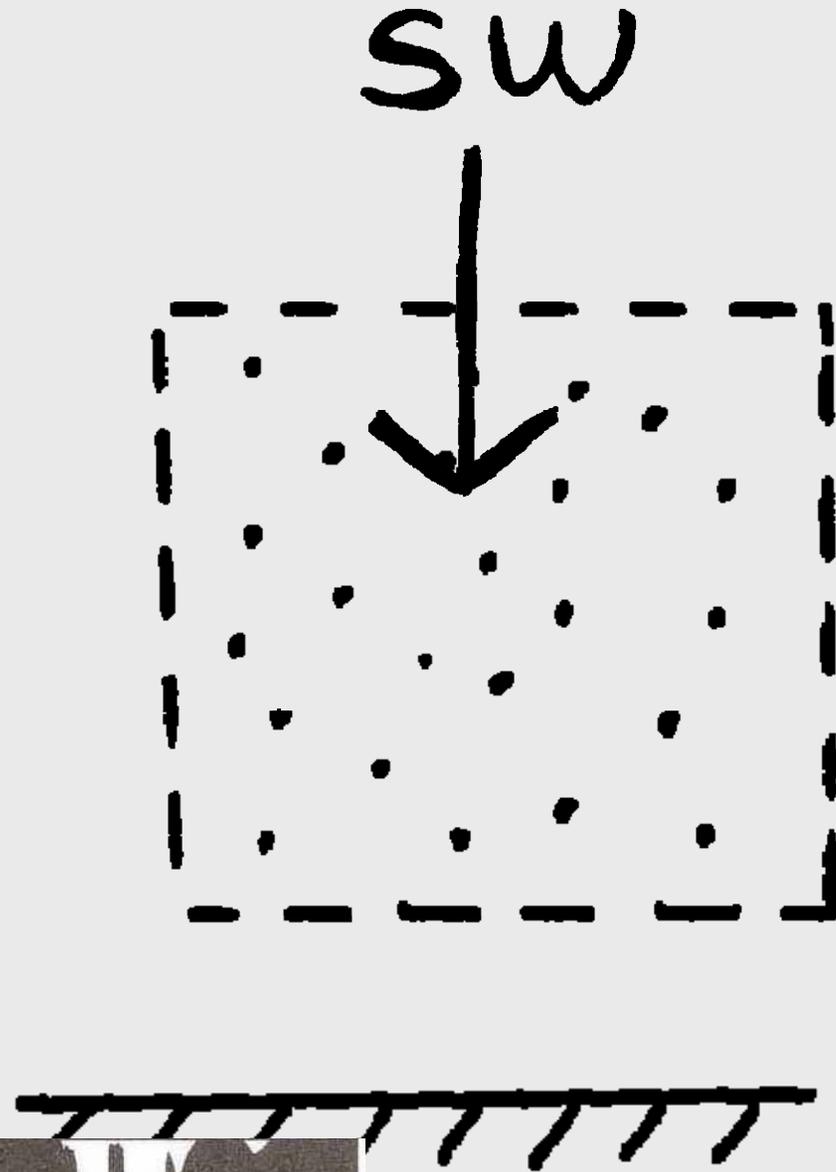
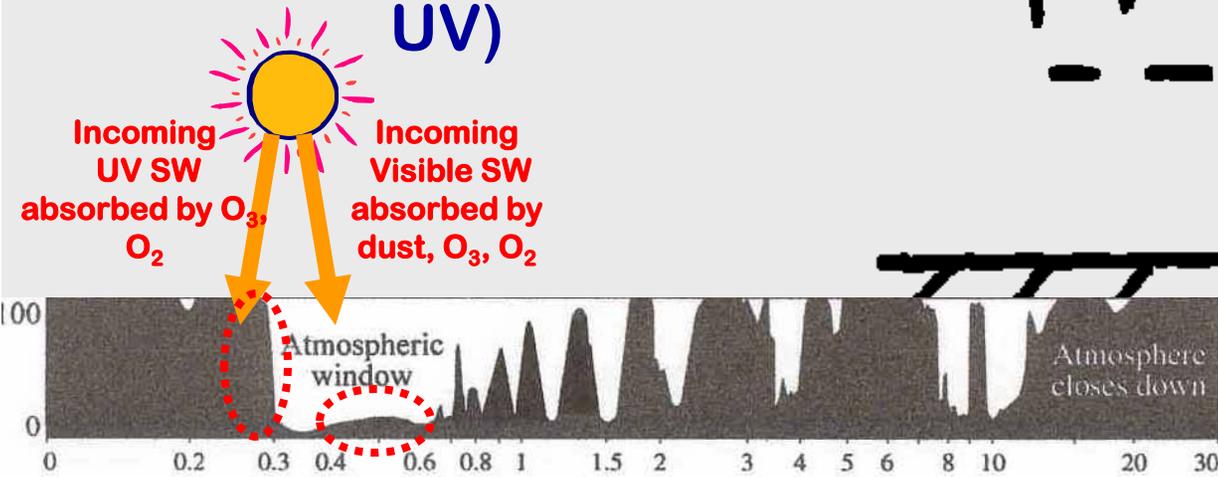
SW



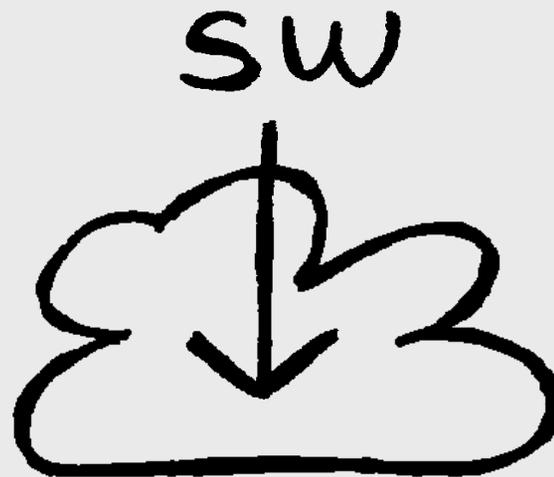
SW SCATTERED DOWN TO EARTH'S
SURFACE where it is absorbed



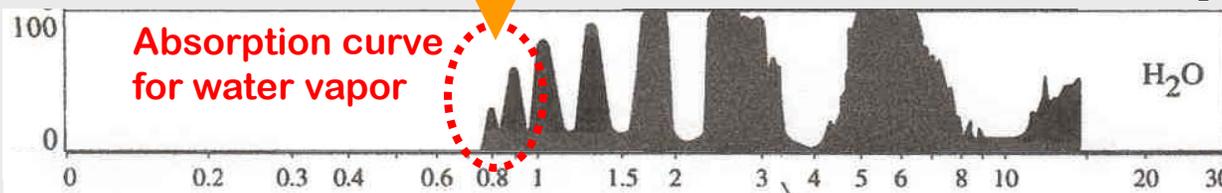
**SW ABSORBED
IN ATMOSPHERE
BY GASES,
DUST, etc.**
(including Ozone
absorbing shortwave
UV)



**SW ABSORBED
In ATMOSPHERE
BY CLOUDS &
H2O vapor:**



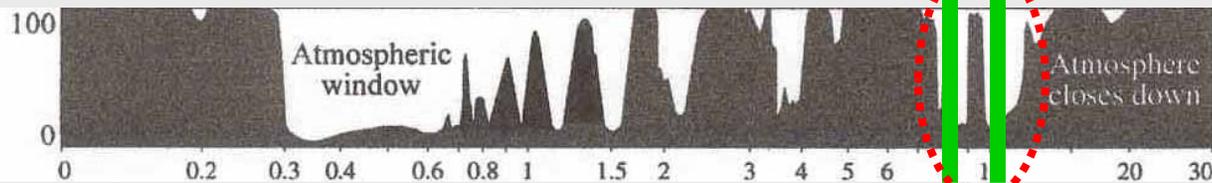
(NOTE: clouds are made up of tiny droplets of water surrounded by lots of water vapor)



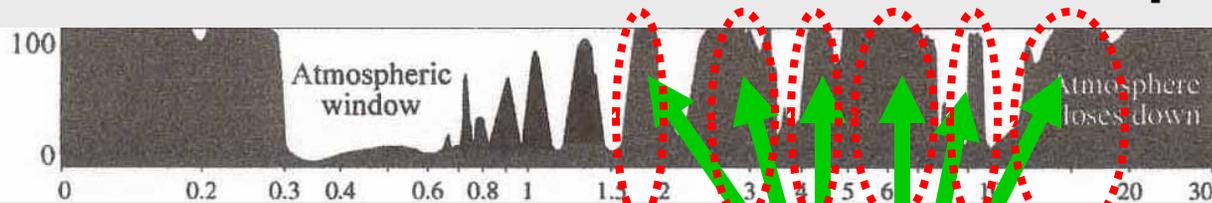
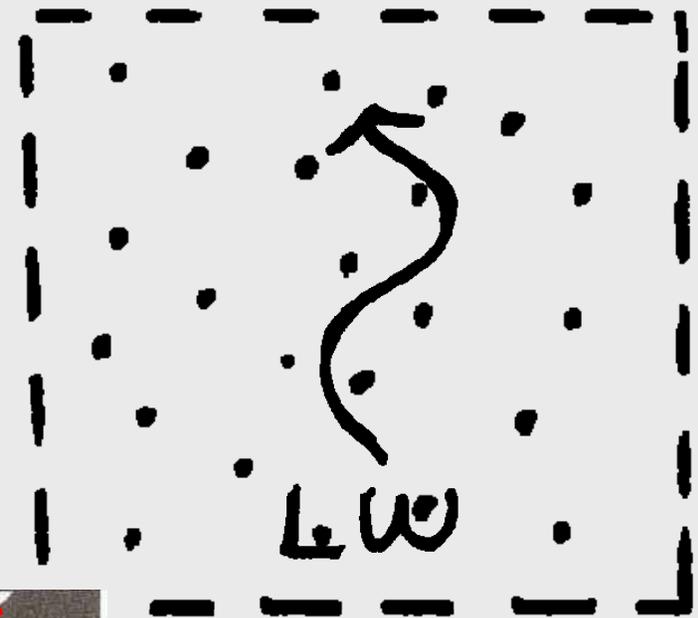
LW

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

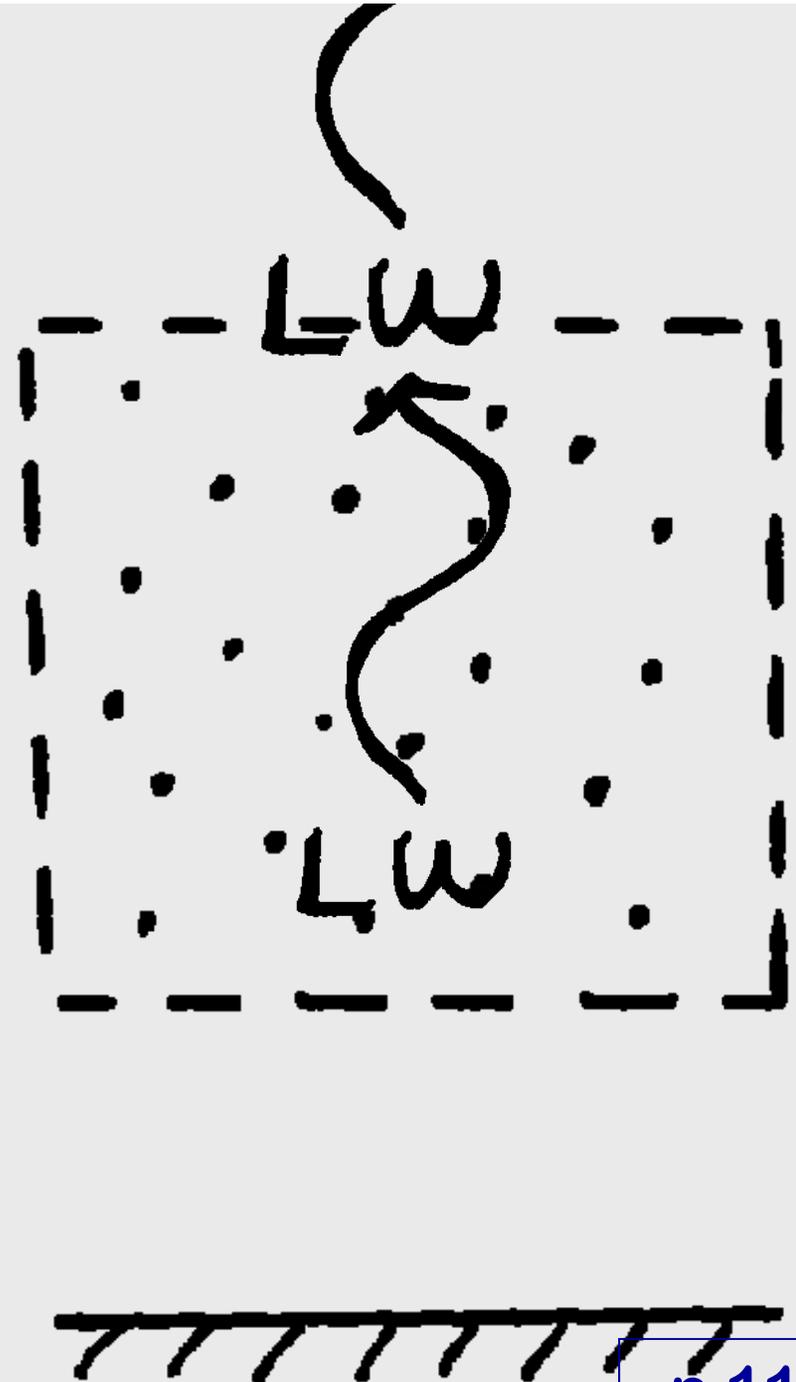
Outgoing LW



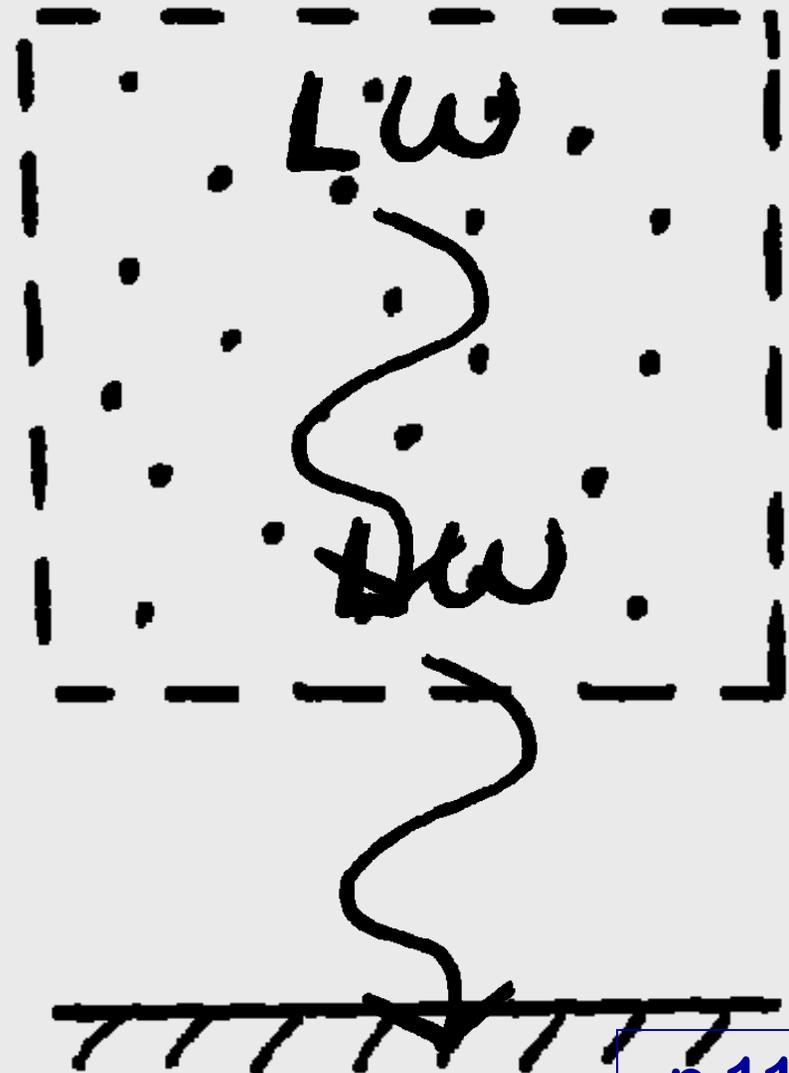
**IR EMITTED FROM
EARTH'S SURFACE
BUT ABSORBED IN
THE ATMOSPHERE
BY GREENHOUSE
GASES (H₂O, CO₂,
CH₄, ETC.)**



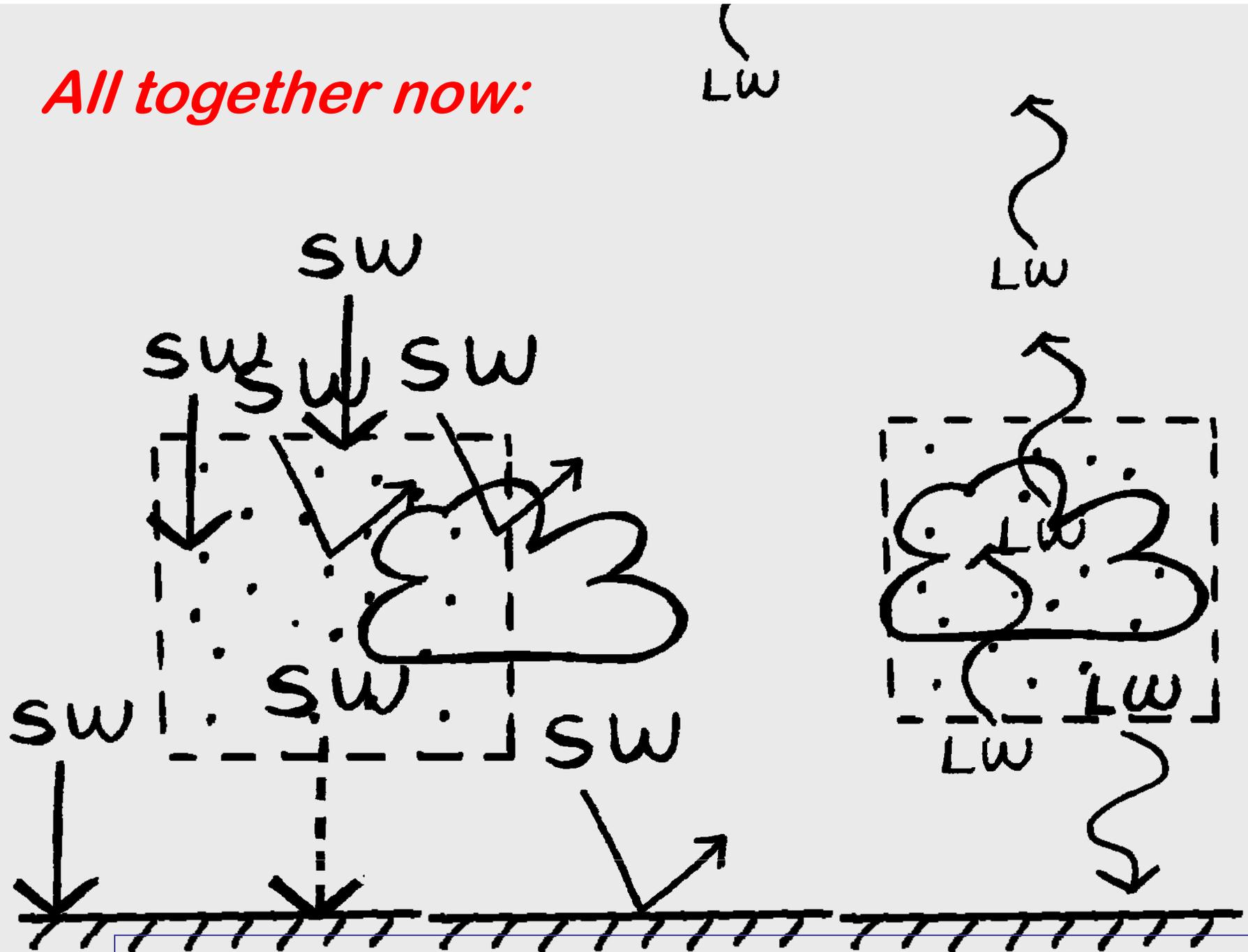
**IR EMITTED
FROM
ATMOSPHERE
ESCAPING TO
SPACE**



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 117

LW

Compare with
simpler model of
energy balance
with NO
atmosphere:



LW

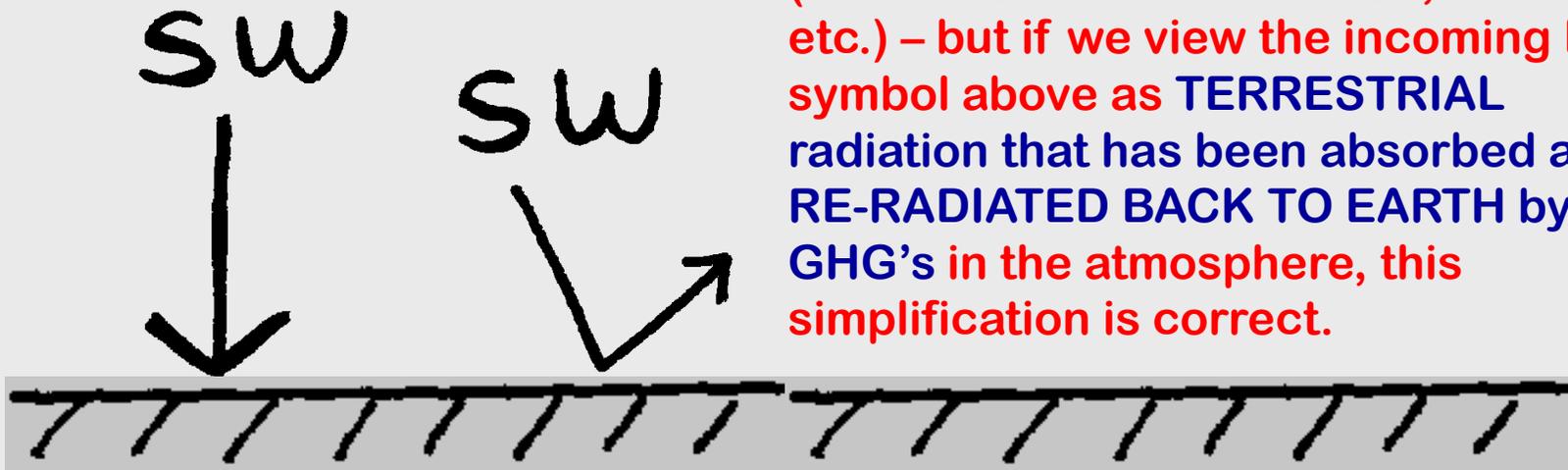
Which terms are not involved?

No scattering by atmosphere



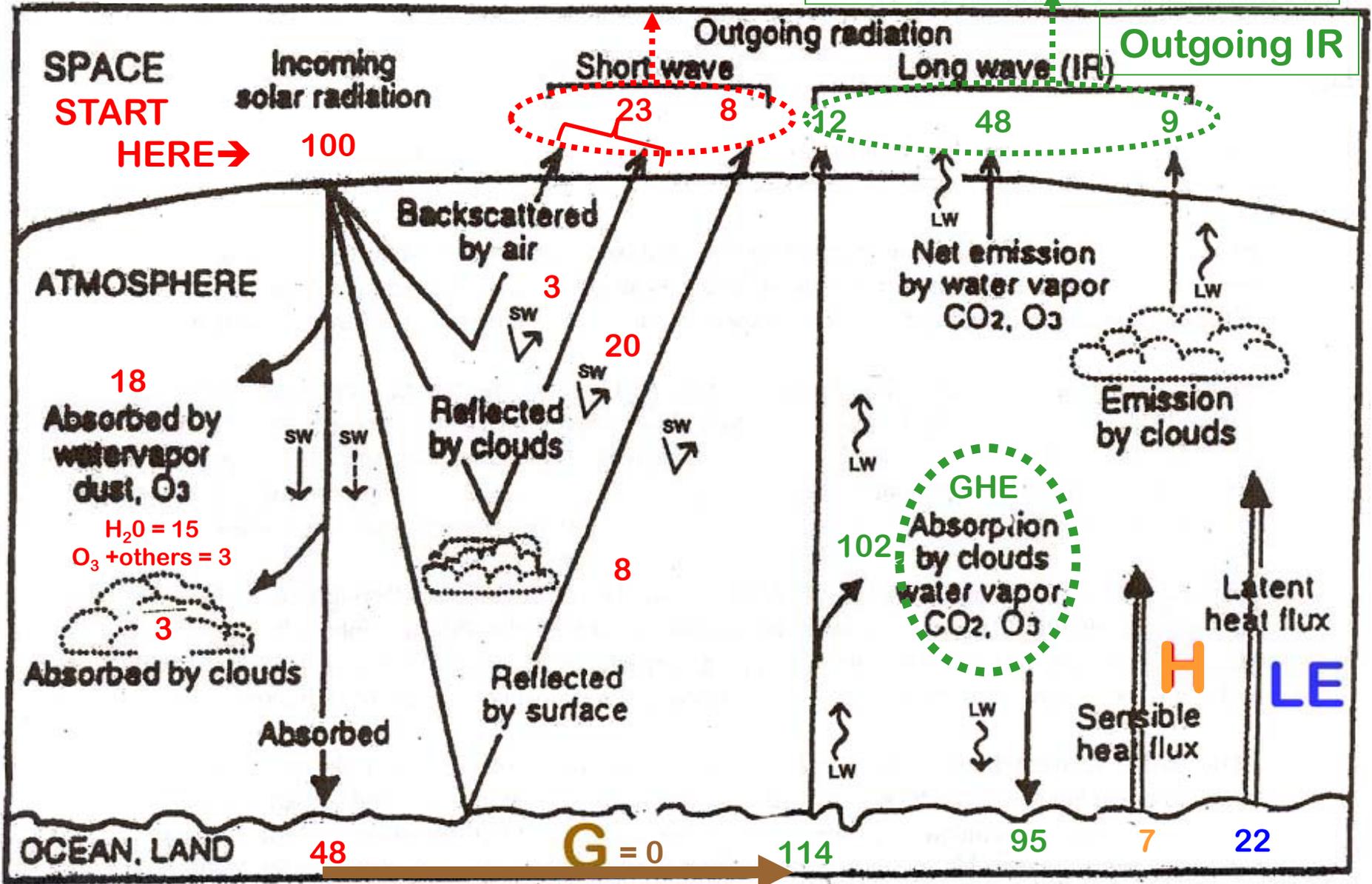
No re-radiation of infrared by GHG's

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.



Earth's average albedo: $23 + 8 = 31$

$12 + 48 + 9 = 69$



$$48 \downarrow - 114 \uparrow + 95 \downarrow = 29 \rightarrow$$

$$G + H + LE$$

$$0 + 7 + 22 = 29 = R_{net}$$

Back to p 52

Two Energy Balance Animations

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

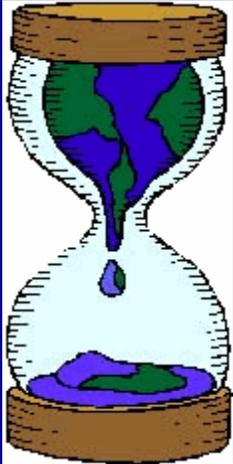
GLOBAL ENERGY BALANCE & PATHWAYS:

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

SHORTWAVE & LONGWAVE ENERGY FLOW & BUDGET:

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





**Time for
SUSTAINABILITY
SEGMENT #1!**

Solar Popcorn Popper!



a competition to design, build, and operate the most attractive and energy-efficient solar-powered house



UA's Entry!

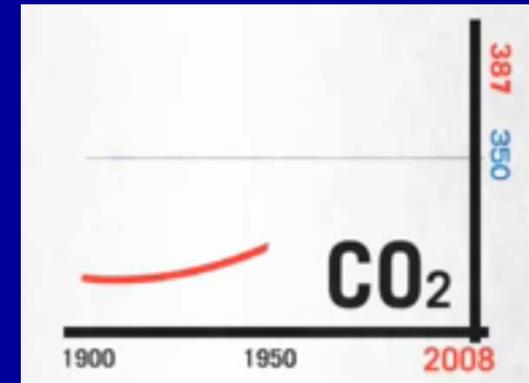
<http://www.solardecathlon.org/>

<http://uanews.org/node/28039>

Remember 350.org?

International Day of Climate Action Video:

<http://www.youtube.com/v/dqof641pWys;autoplay=1>



TUCSON'S 350 Extravaganza

Media | Contact | Donate

350

24 OCTOBER 2009
INTERNATIONAL DAY OF CLIMATE ACTION

04 Days Left

3891 Actions
164 Countries

ABOUT | DAY OF ACTION | SPREAD THE WORD | PEOPLE

Tucson's 350 Extravaganza

24 October 2009 - 10:00am - 1:00pm

October 24th is the International Day of Climate Action. Connect with others in our community and thousands of communities across the planet who are building a movement to lift public awareness about Global Warming.

Let's show the world what Tucson is doing to make policymakers aware of the scientific evidence that says the atmospheric concentration of carbon dioxide must be lowered to 350 ppm if we are going to avoid a catastrophic ecological tipping point. Meet us at the Tucson Chinese Cultural Center, 1288 West River Road (near La Cañada) in Tucson on October 24, 2009. You will have an opportunity to:

- be part of a "human sculpture" in the form of a giant "350"— photo will be sent to 350.org and become part of a collection of similar images from around the world that will be delivered to the media and world leaders;
- participate in a "Green TEA Party", gathering 350 or more petitions to influence local officials to endorse a viable foundation for sustainable development (TEA = Tucson Ecological Action);
- hear short comments by local dignitaries;
- talk to representatives of various local non-profit organizations about products and

The Science of 350

CO₂ +387*
2009 ▶

Scientists say that 350 parts per million CO₂ in the atmosphere is the safe limit for humanity. Learn more about 350 – what it means, where it came from, and how to get there. [Read More »](#)

WE'RE HERE:
387 ppm

WE NEED TO GET BELOW:
350 ppm

CO₂ in the Atmosphere

<http://www.350.org/node/6874>

**BACK TO
THE
BALANCE!**

NET RADIATION = In – Out =

Whatever
is left
over

$$R_{NET} = \begin{array}{c} \text{SW} \\ \downarrow \\ \text{+} \\ \text{SW} \\ \downarrow \\ \text{-} \\ \text{SW} \\ \swarrow \\ \text{-} \\ \text{LW} \\ \uparrow \\ \text{+} \\ \text{LW} \\ \downarrow \\ \text{=} \end{array}$$

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).

FINAL PART OF TOPIC #10:

**The RIGHT side of the
ENERGY BALANCE
EQUATION . . .**

Left side of equation

$$R_{NET} = \begin{array}{c} \text{SW} \\ \downarrow \\ \text{SW} \\ \downarrow \\ \text{SW} \\ \searrow \\ \text{LW} \\ \uparrow \\ \text{LW} \\ \downarrow \end{array} + \begin{array}{c} \text{SW} \\ \downarrow \\ \text{LW} \\ \downarrow \end{array} - \begin{array}{c} \text{SW} \\ \searrow \\ \text{LW} \\ \uparrow \end{array} - \begin{array}{c} \text{LW} \\ \uparrow \\ \text{LW} \\ \downarrow \end{array} + \begin{array}{c} \text{LW} \\ \downarrow \end{array} = H + LE + G$$

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.

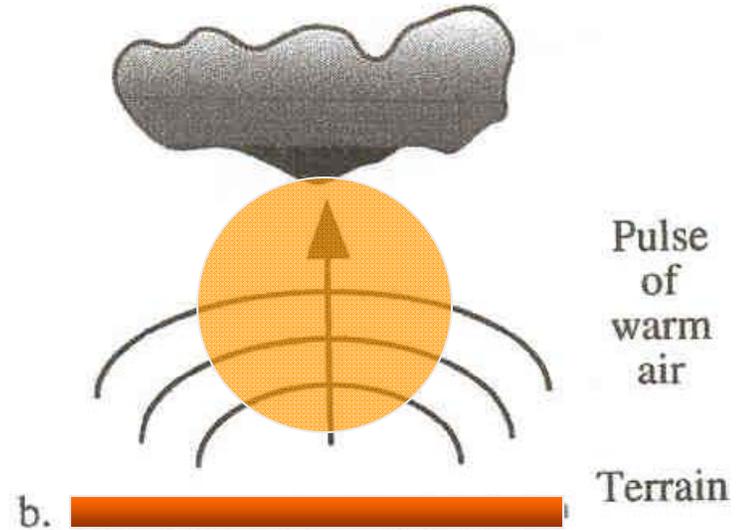
Radiation = the transfer of thermal energy by electromagnetic radiation. The only one of the three mechanisms of heat transfer that does not require atoms or molecules to facilitate the transfer process, i.e., **does not even need MATTER as a medium to transfer energy!**

CONVECTION

Mass of warm air or liquid heats, expands, rises

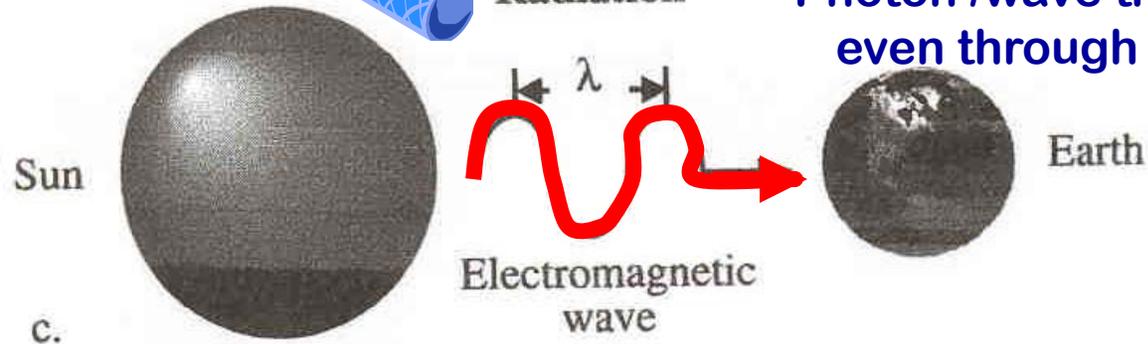
CONDUCTION

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



RADIATION

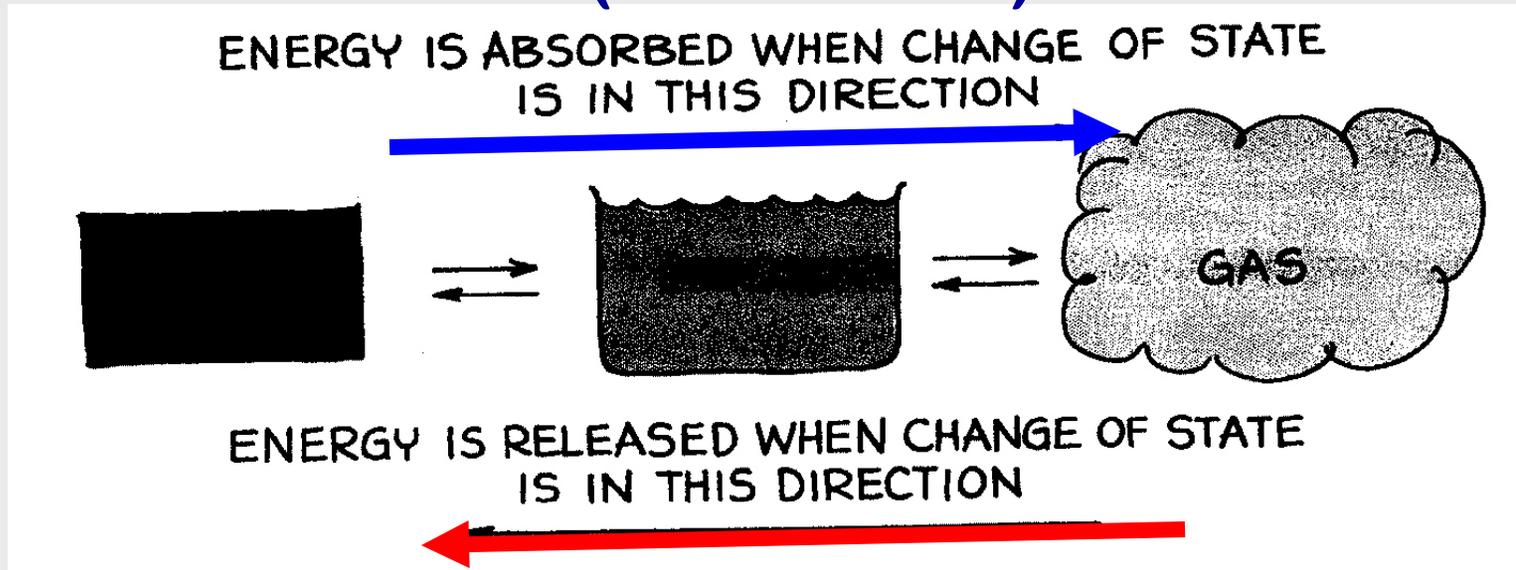
Photon / wave transport:
even through a void!



review

HEAT TRANSFER & STORAGE DURING PHASE CHANGES: LE & H

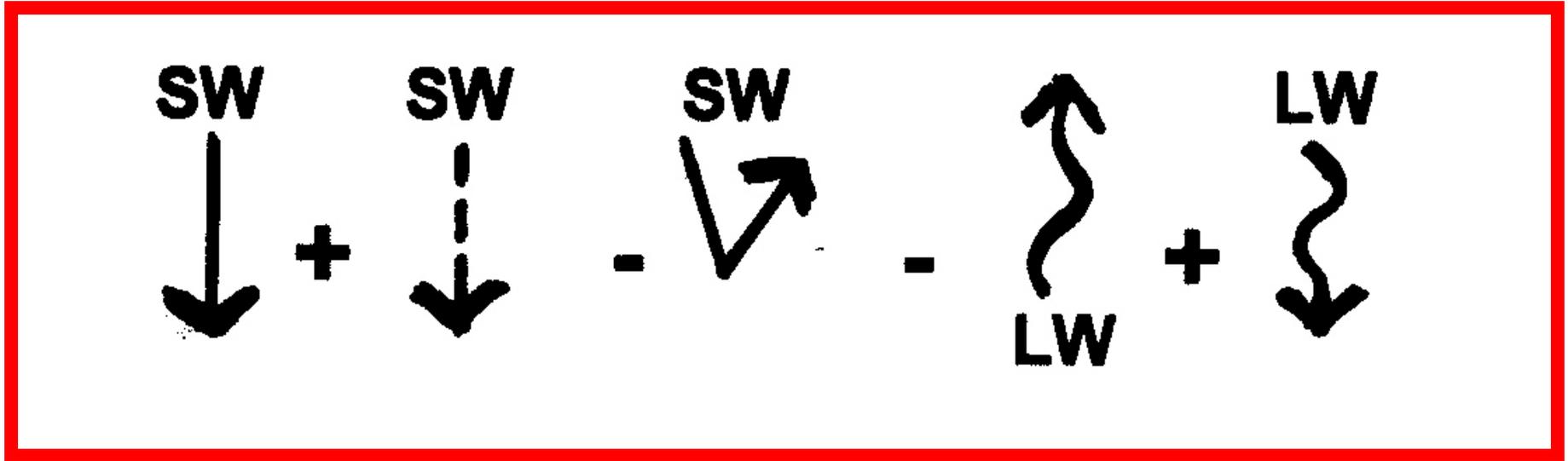
LE = LATENT (hidden) ENERGY
(LE stored)

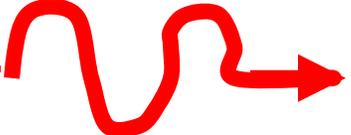


(LE released, hence it can be sensed as H)

H = SENSED (via thermometer) ENERGY

Link to the Left Side of Equation:



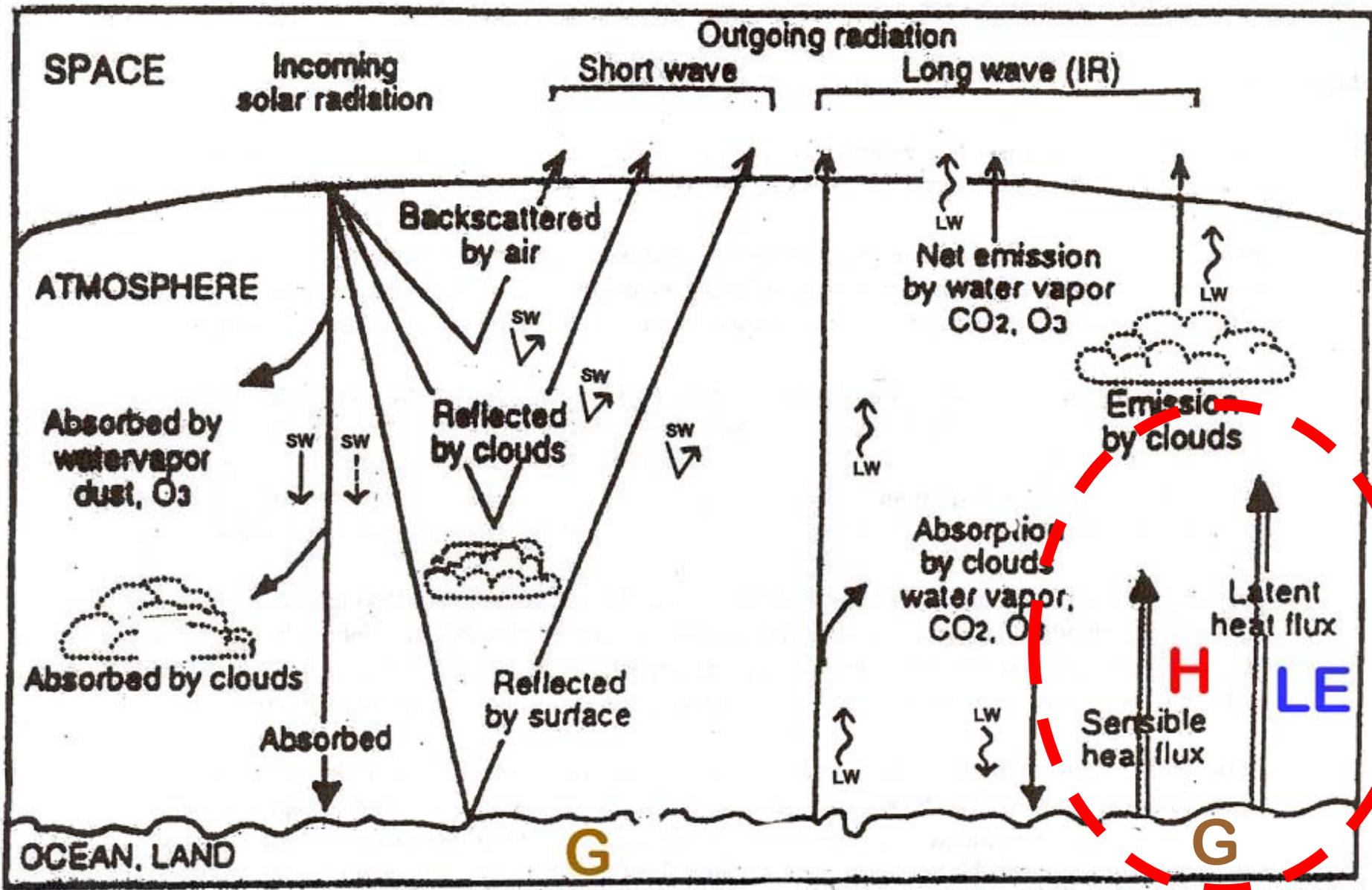
Radiation = the transfer of heat by *electromagnetic radiation*. 

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.)



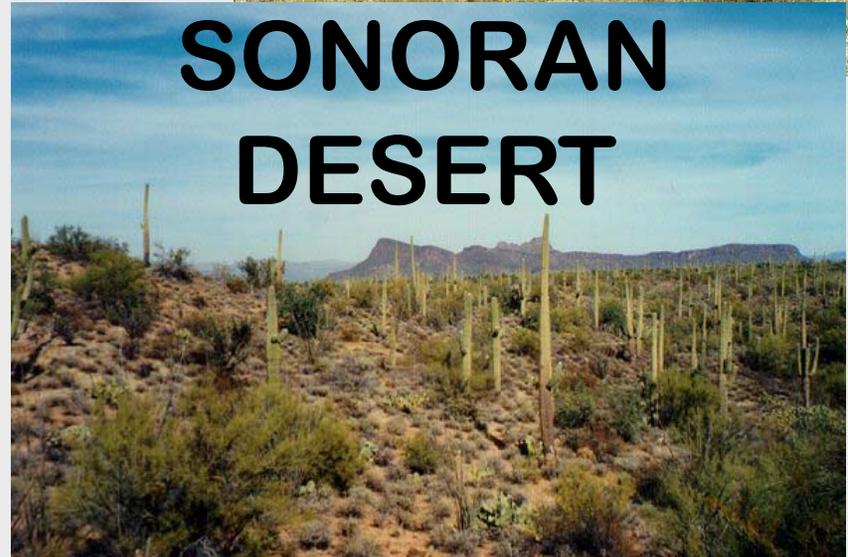
[Back to p 52](#)

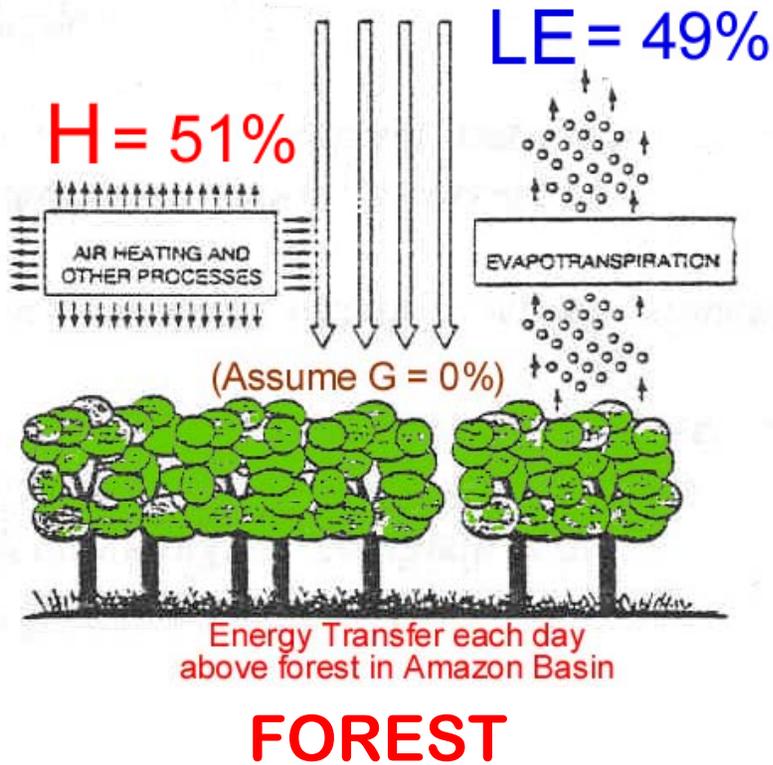
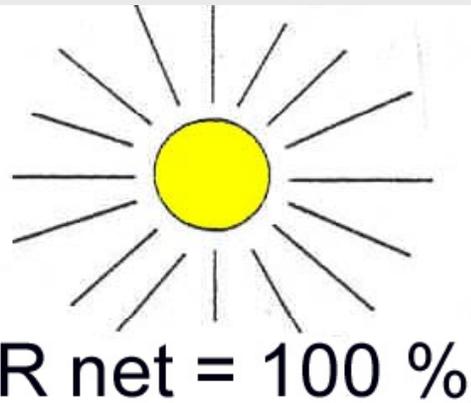
SOME APPLICATIONS OF THE ENERGY BALANCE IN DIFFERENT PARTS OF THE GLOBE:



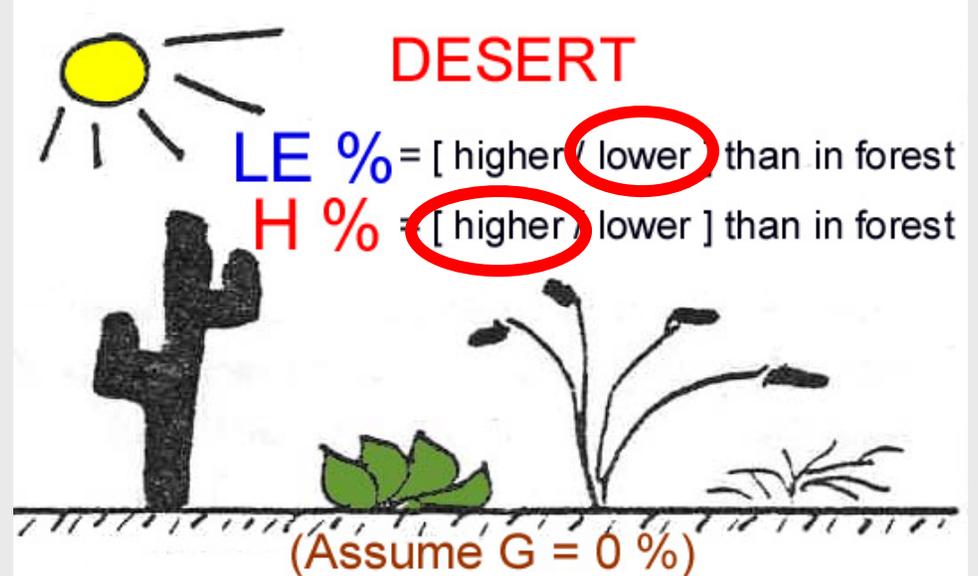
<http://www.earthweek.com/>







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

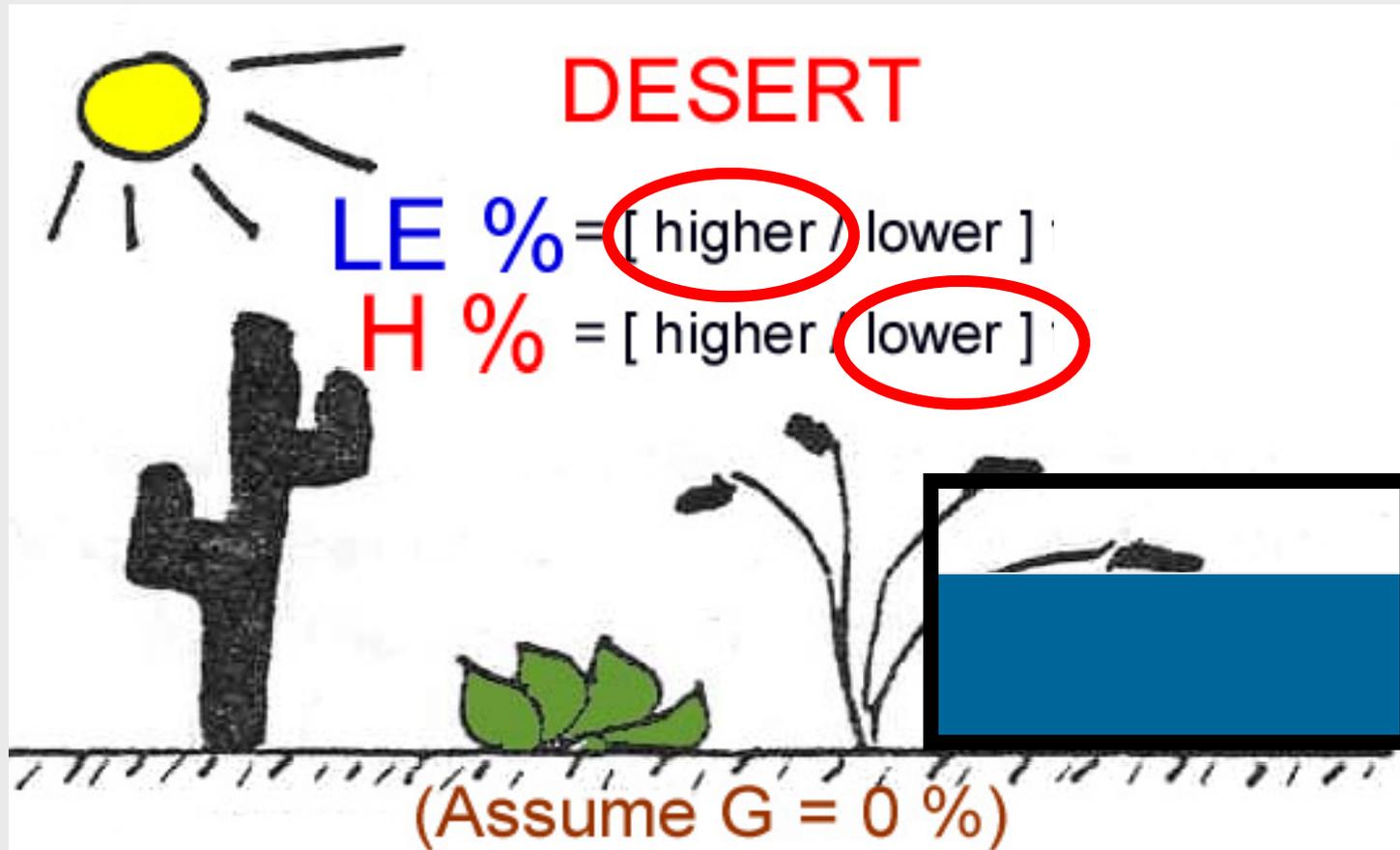


**What if humans put
in canals (CAP),
lakes, & artificial
water bodies in a
desert?**



Central Arizona Project (CAP) Canal



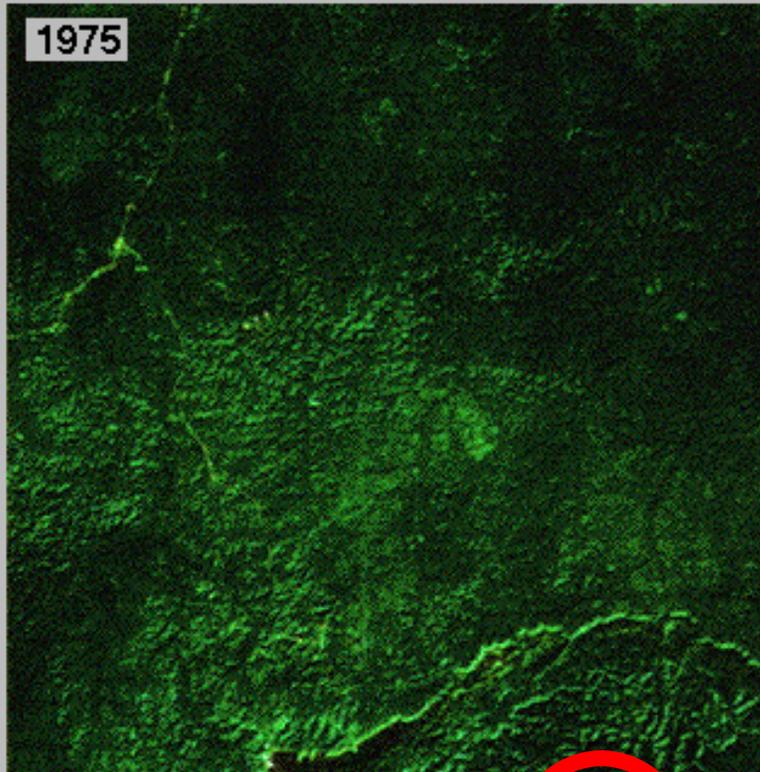


What if humans put in canals (CAP), lakes, & artificial water bodies in a desert?

How would the % of LE in the Desert change?



How does DEFORESTATION change the local energy balance???



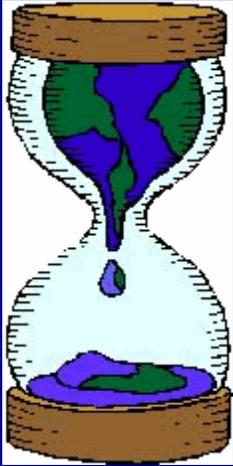
$$R_{NET} = \begin{matrix} SW \\ \downarrow \end{matrix} + \begin{matrix} SW \\ \downarrow \end{matrix} - \begin{matrix} SW \\ \nearrow \end{matrix} - \begin{matrix} LW \\ \updownarrow \end{matrix} + \begin{matrix} LW \\ \downarrow \end{matrix} = \begin{matrix} H \end{matrix} + \begin{matrix} LE \end{matrix} + G$$

The diagram illustrates the energy balance equation $R_{NET} = SW + SW - SW - LW + LW = H + LE + G$. The terms are represented by arrows: two solid downward arrows for incoming shortwave radiation (SW), one dashed upward arrow for outgoing shortwave radiation (SW), one wavy upward arrow for longwave radiation (LW), and one solid downward arrow for outgoing longwave radiation (LW). The net result is heat (H) and latent heat (LE). The outgoing SW term is circled in red, and the H and LE terms are circled in red and blue respectively. The word "Less" is written above the LE term.

More → cooler temperatures?

More → warmer temperatures?





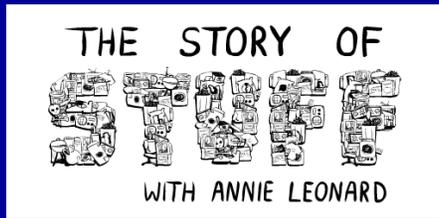
SUSTAINABILITY SEGMENT #2!

THE STORY OF



WITH ANNIE LEONARD

<http://www.storyofstuff.com/>



Disclaimer: Draw your own opinion – you are free to agree or disagree with it – It's meant to get you thinking!

After class visit the “Stuff” webpage to watch it again if you like and also find :

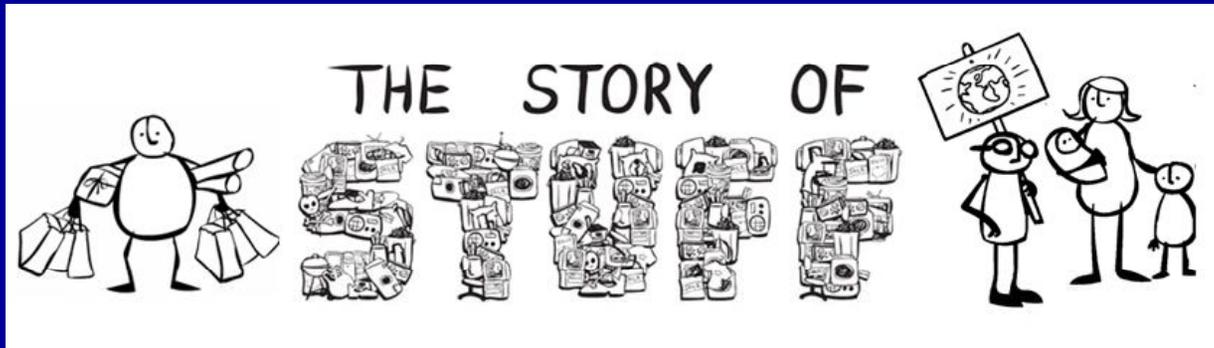
- **A Fact Sheet**
- **Glossary**
- **Annotated Script with footnotes**
- **plus more**

<http://www.storyofstuff.com/>

ABOUT THE AUTHOR:

Annie Leonard is an expert in international sustainability and environmental health issues.

She is an American scholar on international trade, development, international sustainability and environmental health issues, with more than 20 years of experience investigating factories and dumps around the world.



Use the index card to write out
your reaction to the film
– and get a bonus point for
attending class today!

We'll discuss it afterwards . . .



Keep the discussion going

See you in class on THURSDAY!

Don't FORGET RQ-5!!