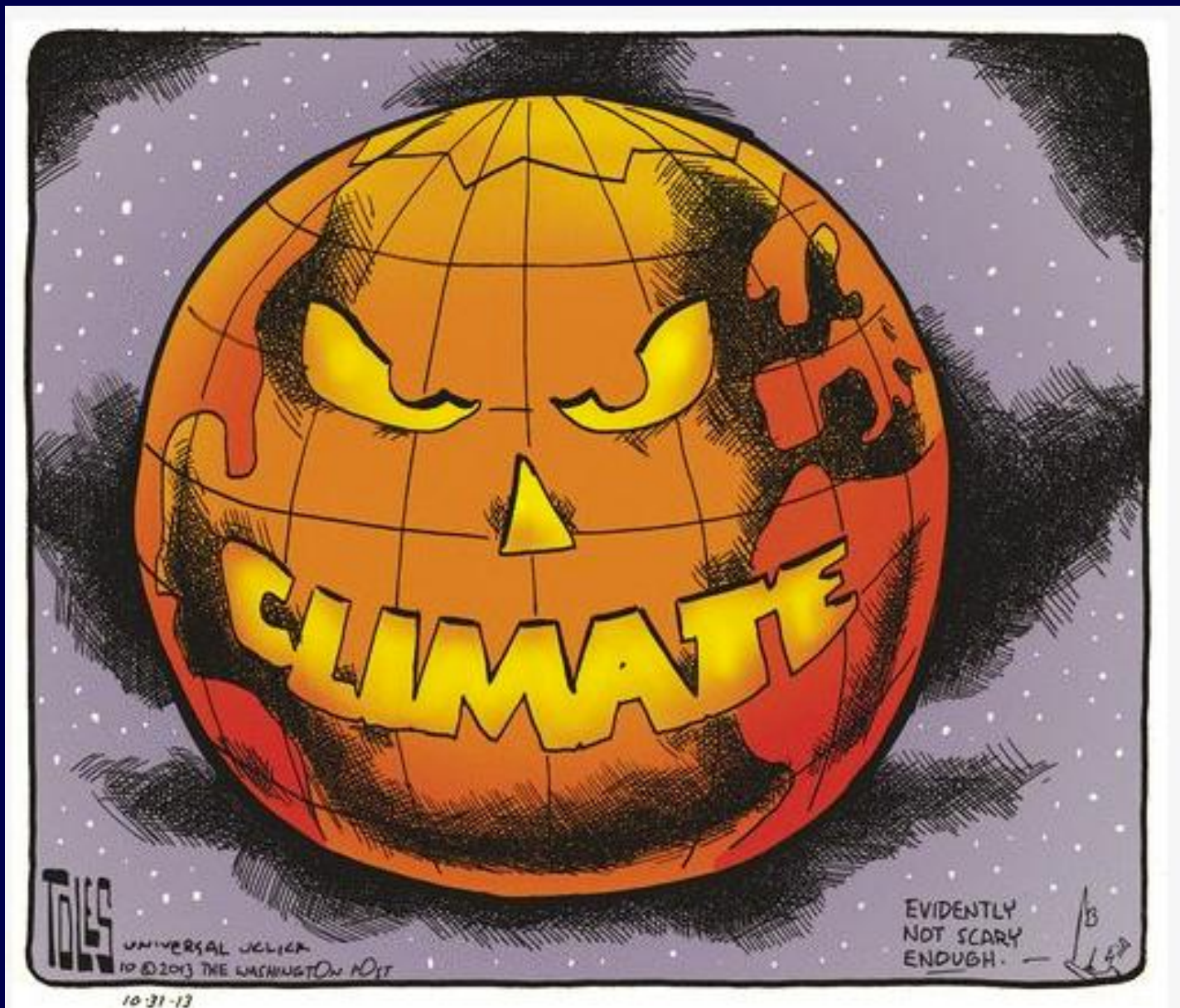


Topic # 12

HOW CLIMATE WORKS

A “Primer” on
How the Energy Balance Drives
Atmospheric & Oceanic Circulation,
Natural Climatic Processes

Starts on p 67 in Class Notes



“Evidently, not scary enough.”

How do we get energy from this



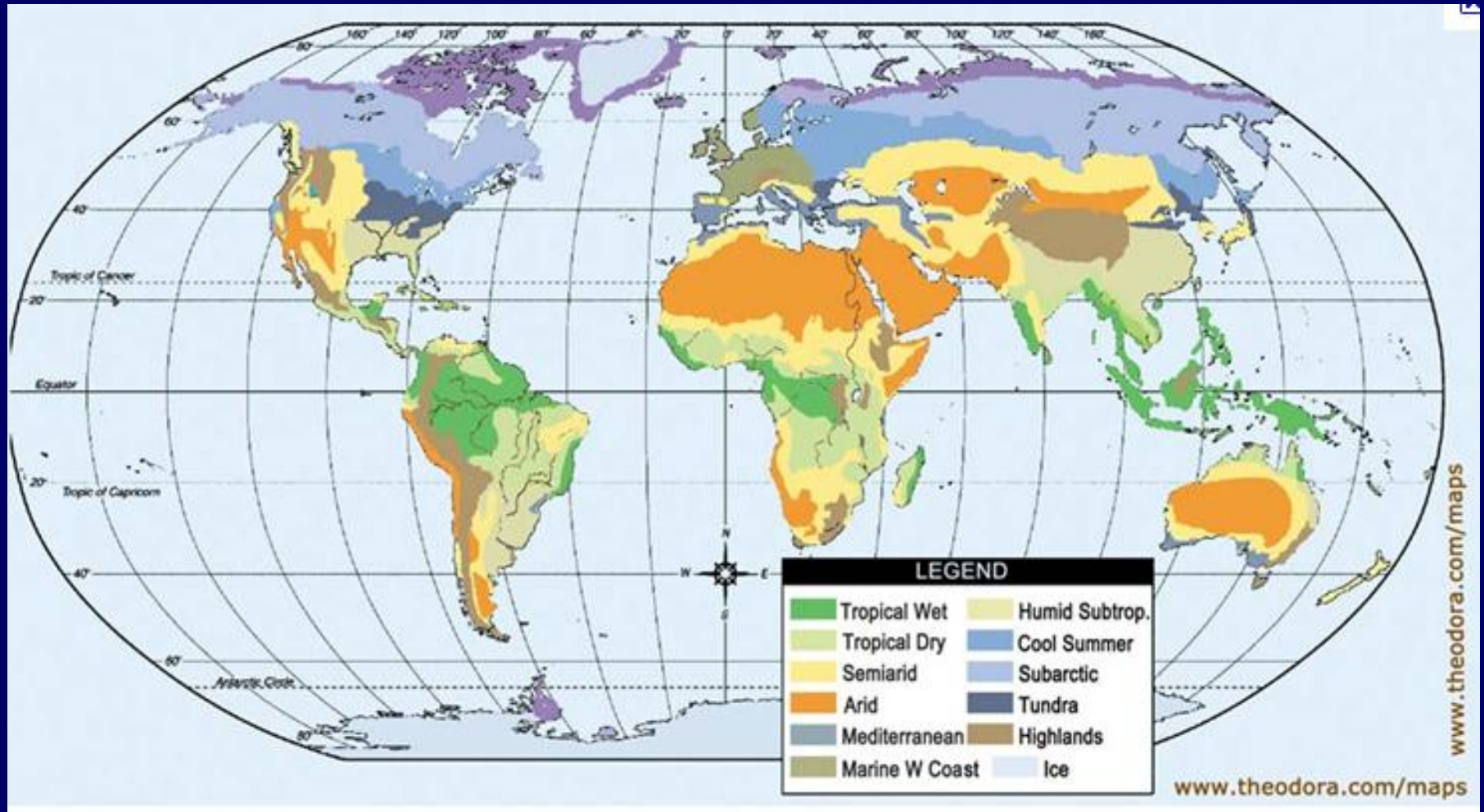
. . . . to drive this ?

... or this ?



<http://www.vets.ucar.edu/vg/T341/index.shtml>

...which leads to **Global Climatic Regions:**



...and **CHANGES** in these regions!

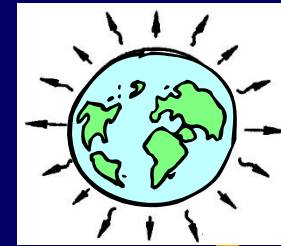
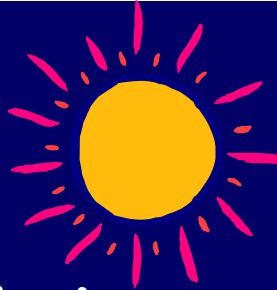
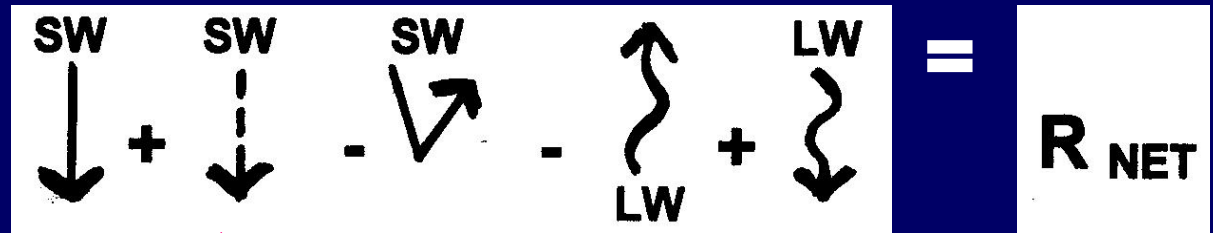
It all happens
because of changes
in the
RADIATION / ENERGY
BALANCE!

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

It all happens because of changes in the RADIATION / ENERGY BALANCE!

“Radiation Balance” part

Start out here, with energy from the SUN radiated to Earth and so forth . . .



The R_{NET} is then able to be used in thermal energy “heat transfer” processes which manifest themselves as weather & climate!

“Energy Balance” part

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

Thermal Energy Review

Heat (def) = the thermal energy that is transferred from one body to another because of a temperature difference. **Conduction, Convection . . .**

. . . and PHASE CHANGES!

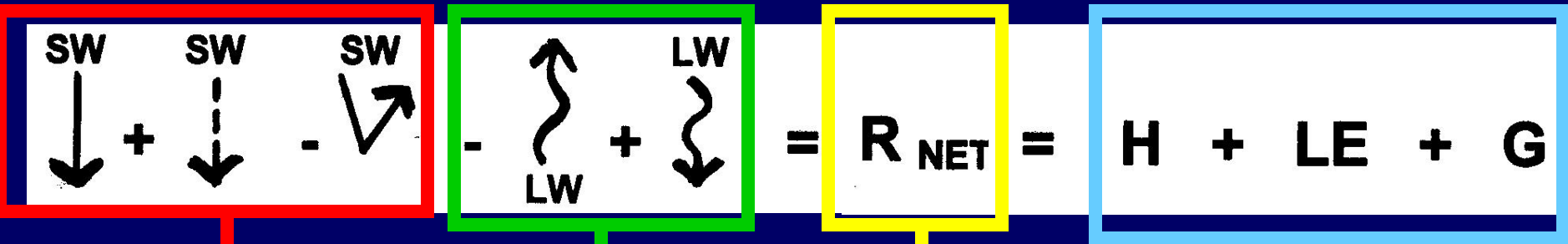
- **Sensible Heat transfer (H)**
- **Latent Heat transfer (LE)**

*plus (after transfer) thermal energy can be **STORED (G)***

H + LE + G

Review

ENERGY IN THE EARTH-ATMOSPHERE SYSTEM



Ultimate source of energy is the SUN (SW)

After absorption of SW, LW energy is radiated in & out by EARTH & Atmosphere

Any NET (leftover) energy

Goes into the HEAT TRANSFER processes that drive WEATHER & CLIMATE!

The Earth [as viewed from space] . . .

has the organized,
self-contained look
of a live creature,
full of information,
marvelously skilled
in handling
the **SUN**.

- Lewis Thomas



LINKING THE ENERGY BALANCE TO ATMOSPHERIC CIRCULATION:

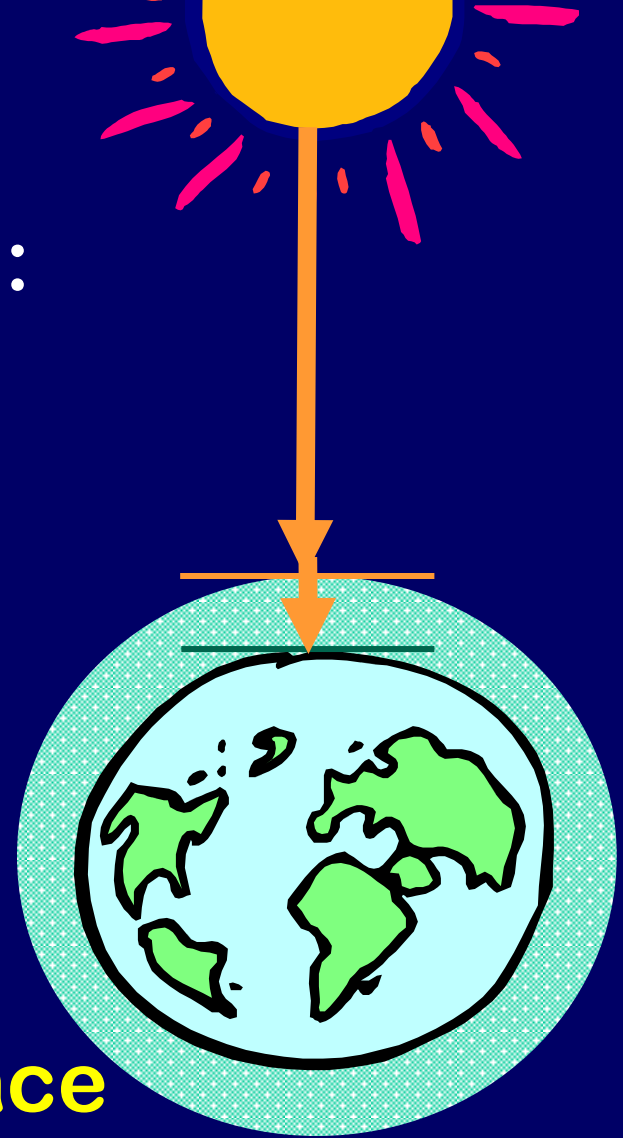
We'll start with the SUN:

SOLAR INSOLATION

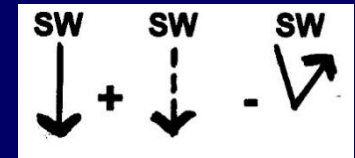
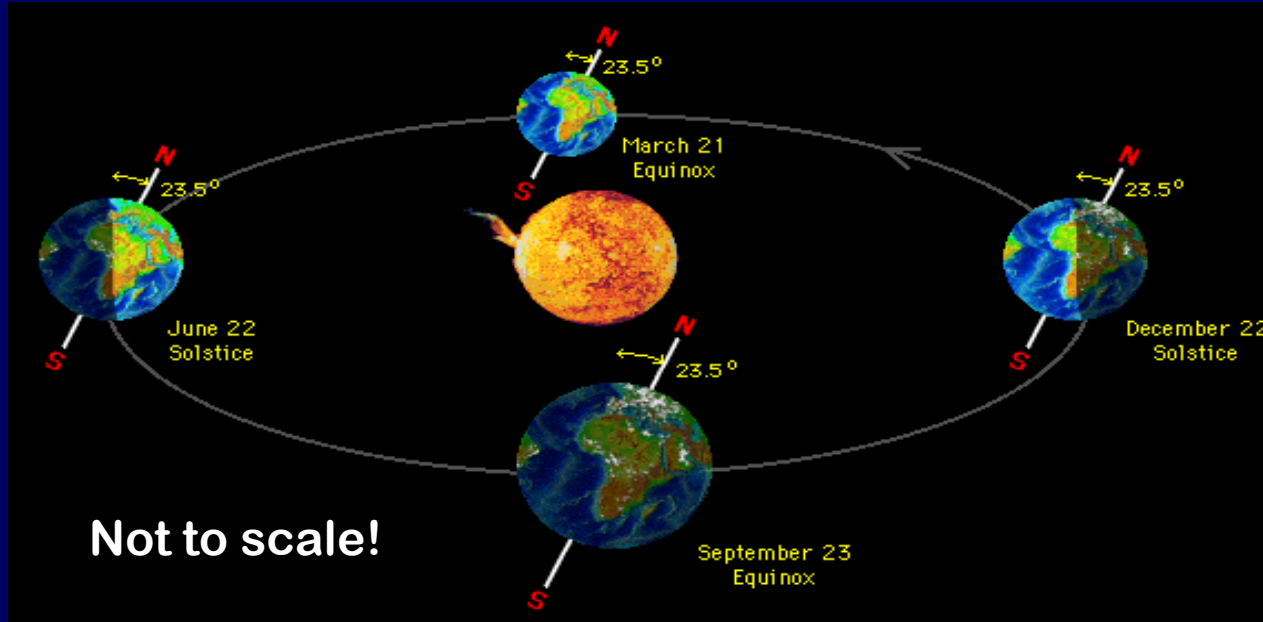
IN – **SOL** - ATION

= the amount of incoming solar radiation received by a horizontal surface

(e.g. at the top of the atmosphere, at the tropopause, at the Earth's surface, etc.)



To drive the circulation, the initial source of energy is from the Sun:



EARTH-SUN Relationships

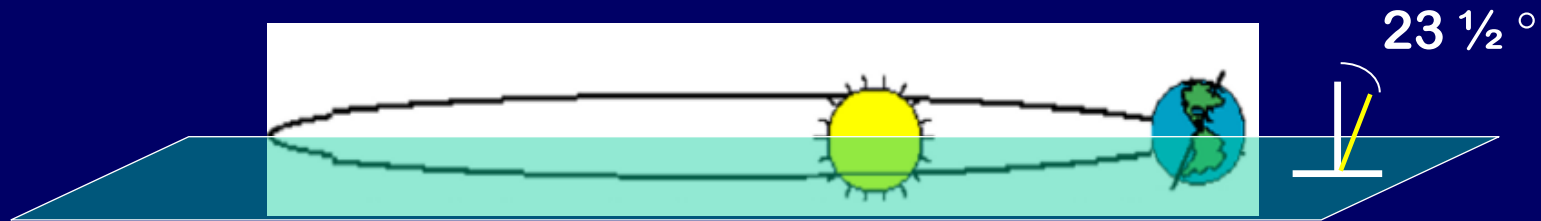
4 Things to Know about Earth-Sun Relationships:

- 1) Earth orbits Sun
- 2) Orbit not a perfect circle
- 3) Orbit traces "a plane"
- 4) Earth's axis tilts



You can take notes on p 66

The “4 Things to Know” about Earth-Sun Relationships:



- 1) Earth orbits Sun in one year
- 2) Orbit is not a perfect circle = an ellipse
- 3) Earth's orbit around Sun can be “traced” on a plane (“Plane of the Ecliptic” – plane passes thru the center of Sun & Earth)
- 4) Earth's axis **tilts 23.5°** from a \perp to the “Plane of The Ecliptic”

These 4 Earth-Sun “orbital” properties lead to 2 key factors that determine the AMOUNT OF SOLAR INSOLATION at any spot on Earth as the seasons progress:

(1) INTENSITY of sun's rays

Depends on AXIS TILT and how

Earth's SURFACE RECEIVES Sun's rays

[Most intense = perpendicular rays \perp]

(2) DURATION of insolation (day length)

Depends on LATITUDE & SEASON

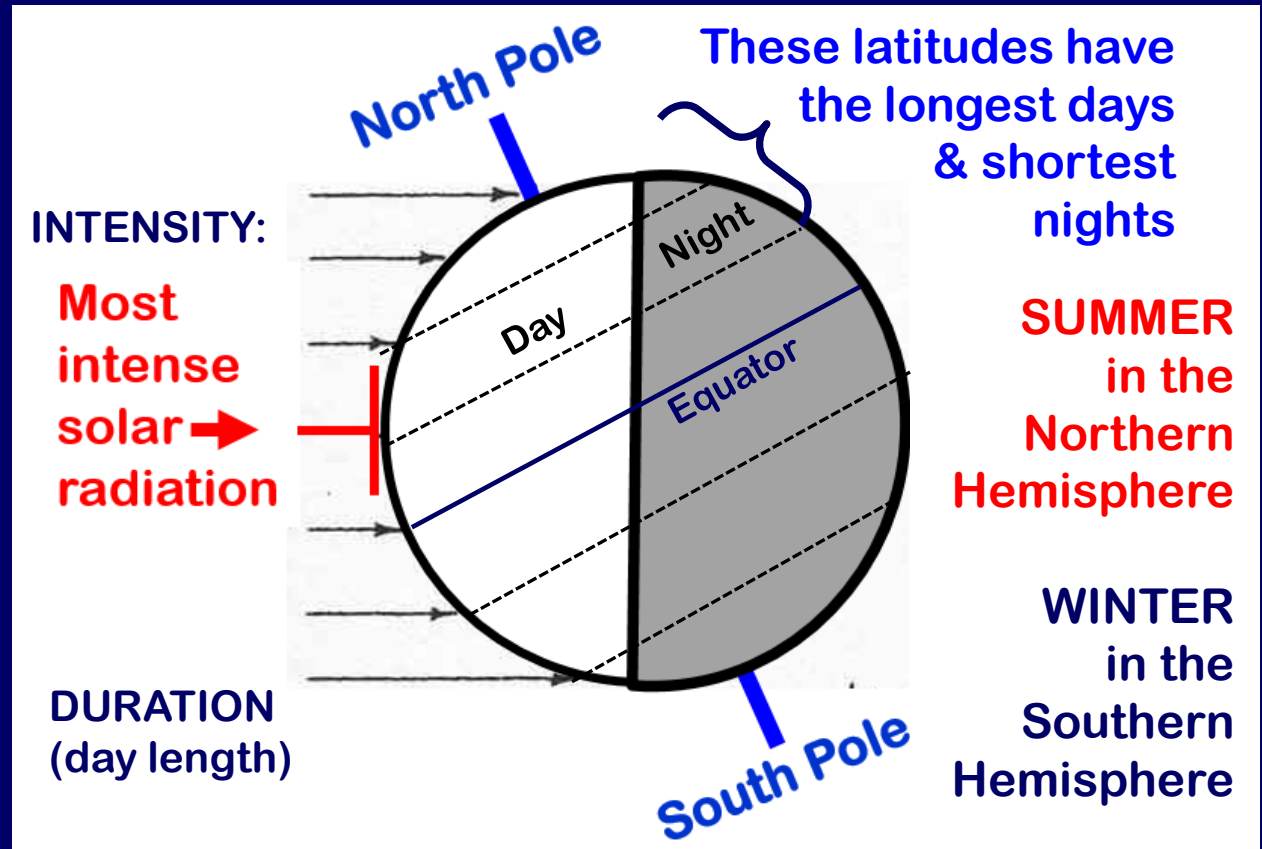
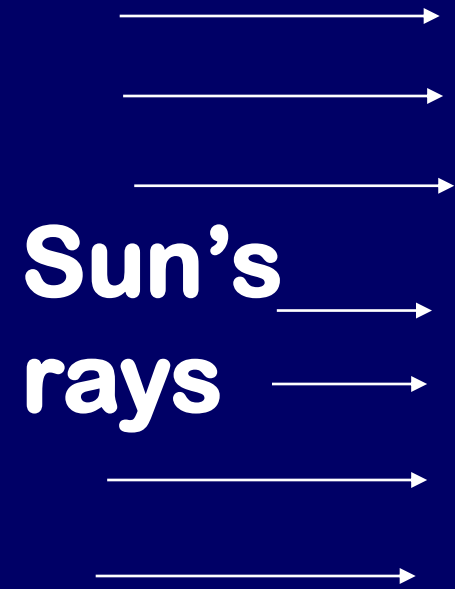
→ *Intensity & Duration vary
with LATITUDE & TIME OF YEAR*

Box on p 67

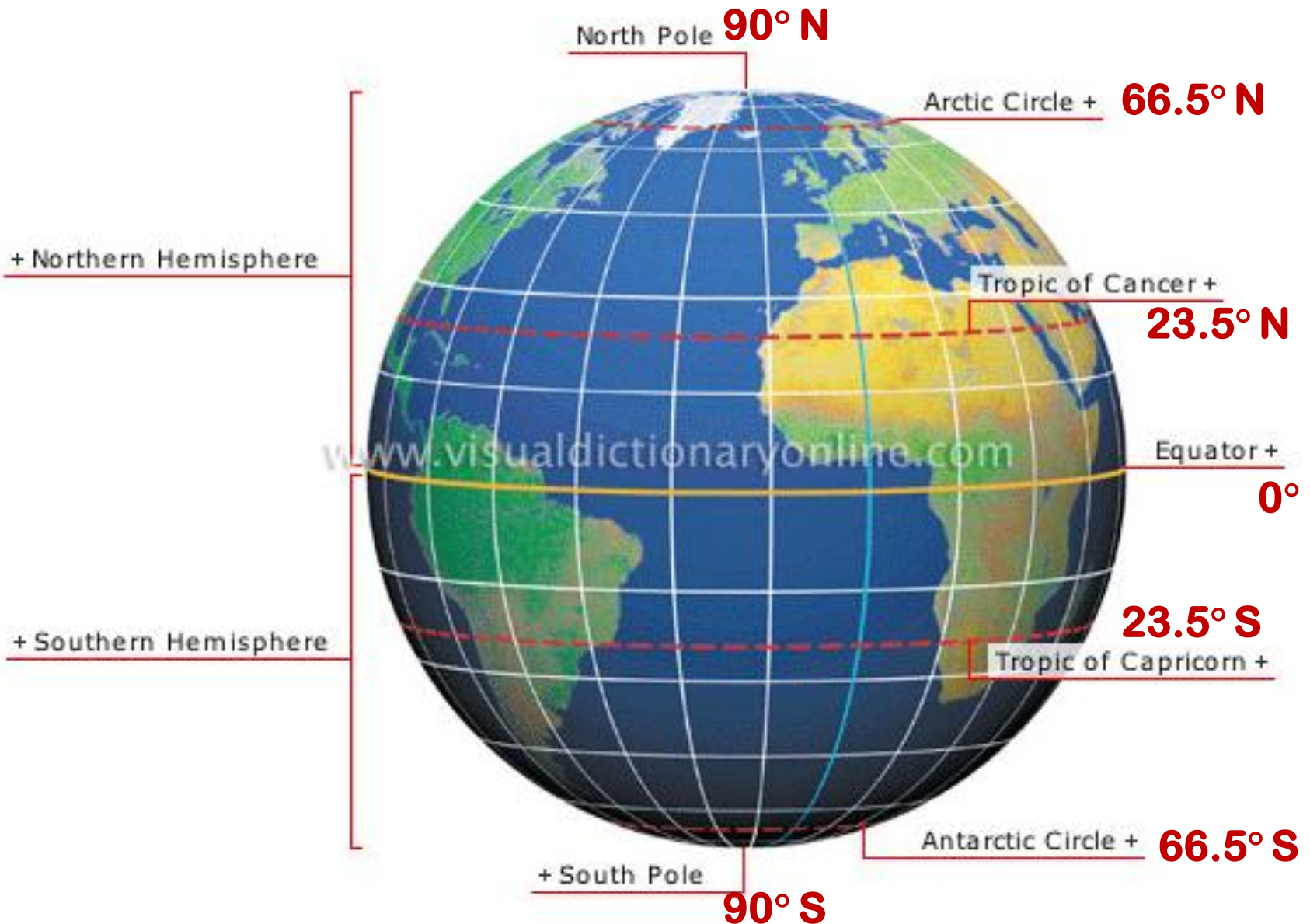
INTENSITY + DURATION

INTENSITY of sun's rays: depends on axis tilt and how earth intercepts sun's rays

DURATION of daily insolation (day length): depends on where circle of illumination intersects latitude band



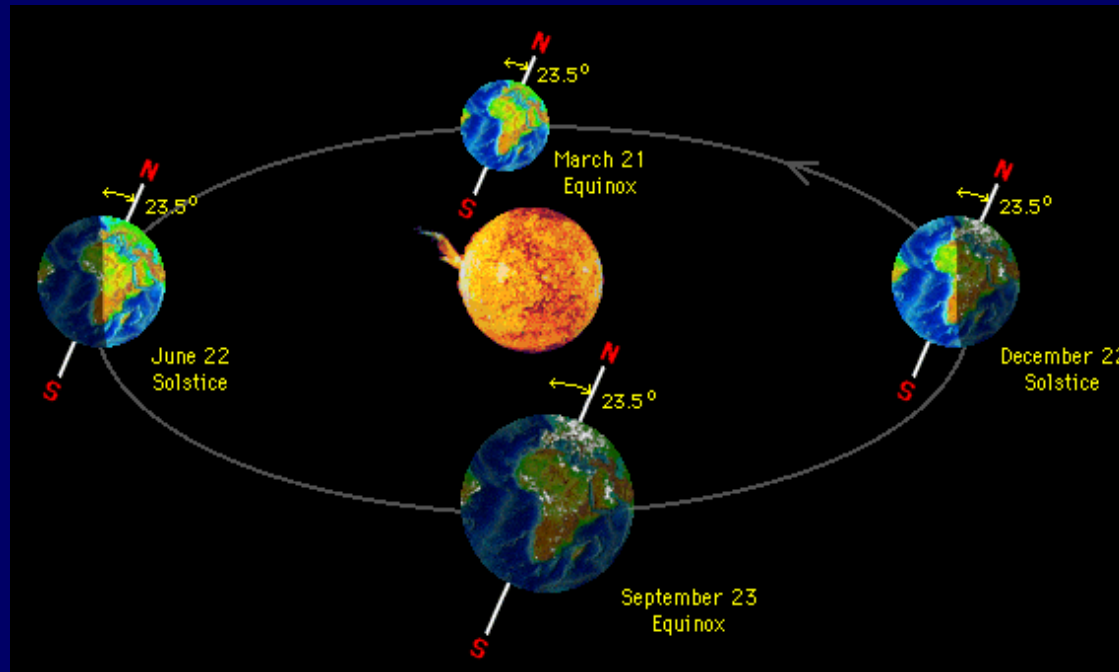
QUICKIE LATITUDE REVIEW:



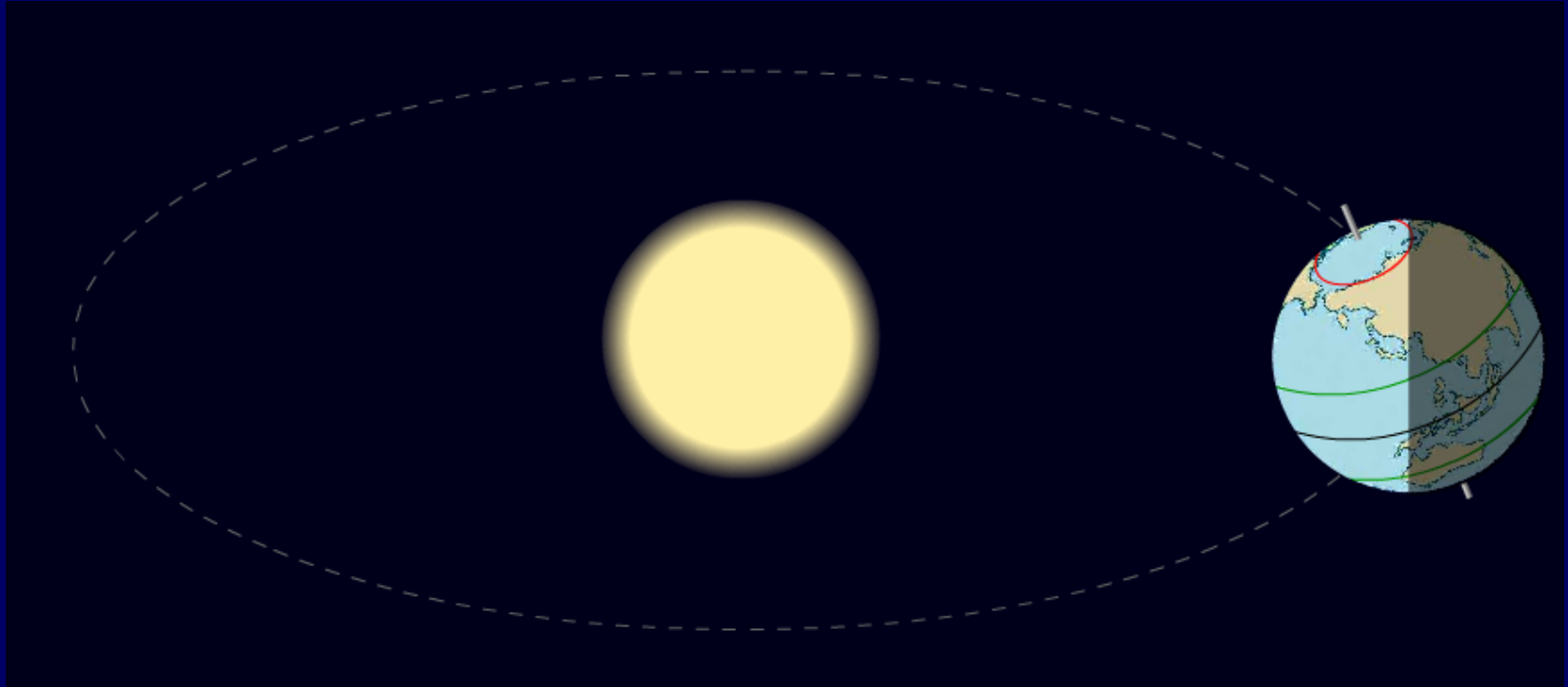
EARTH-SUN RELATIONSHIPS & The SEASONS:

VIEW THE ANIMATION:

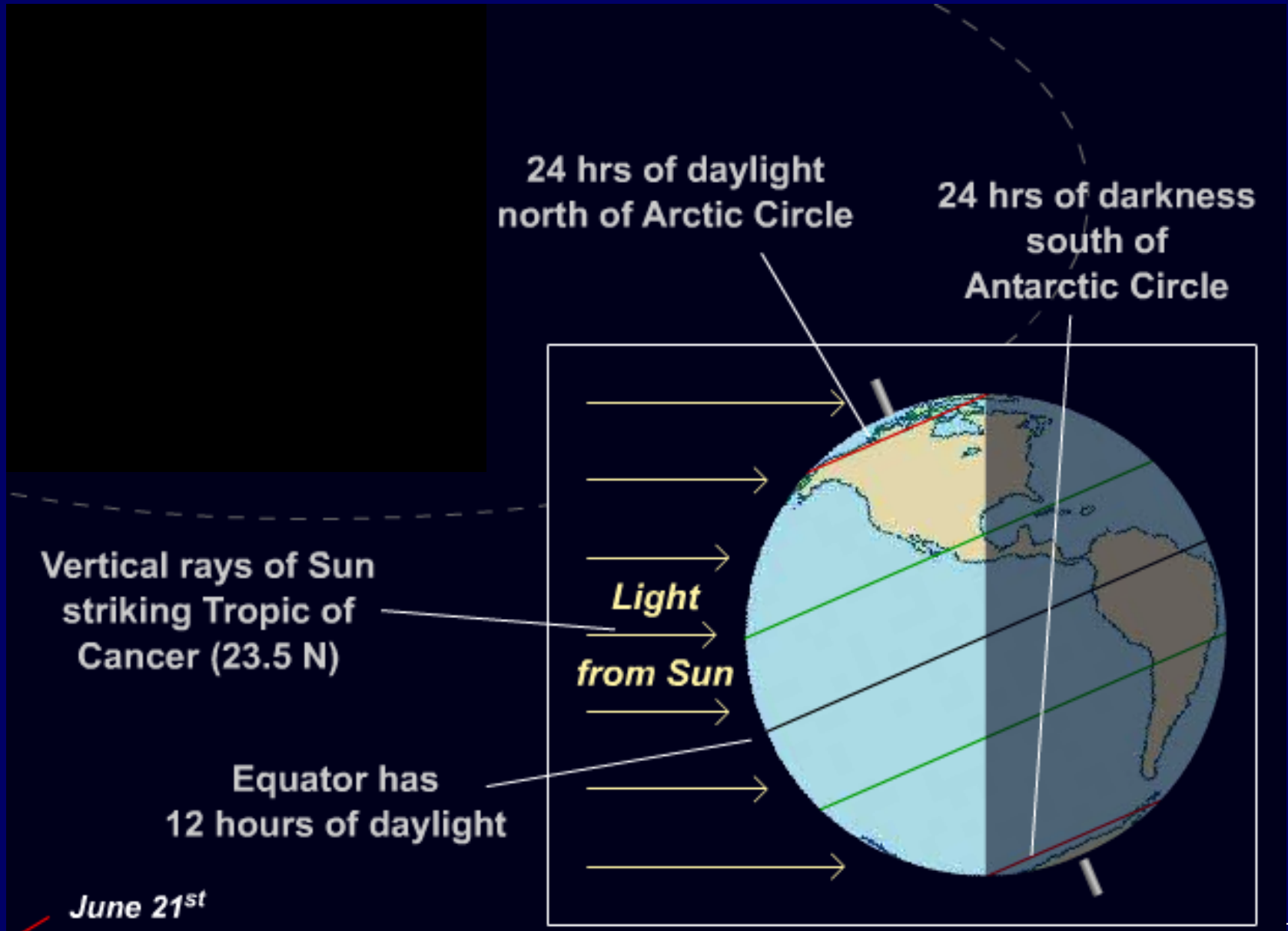
http://mesoscale.agron.iastate.edu/agron206/animations/01_EarthSun.html



JUNE SOLSTICE



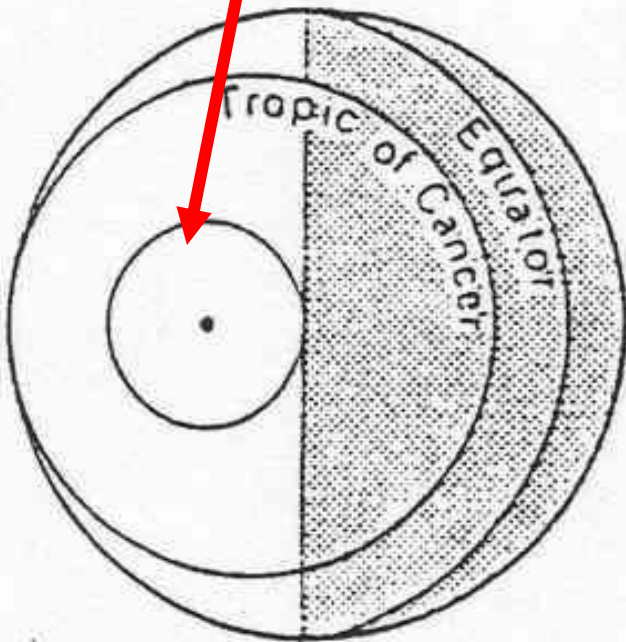
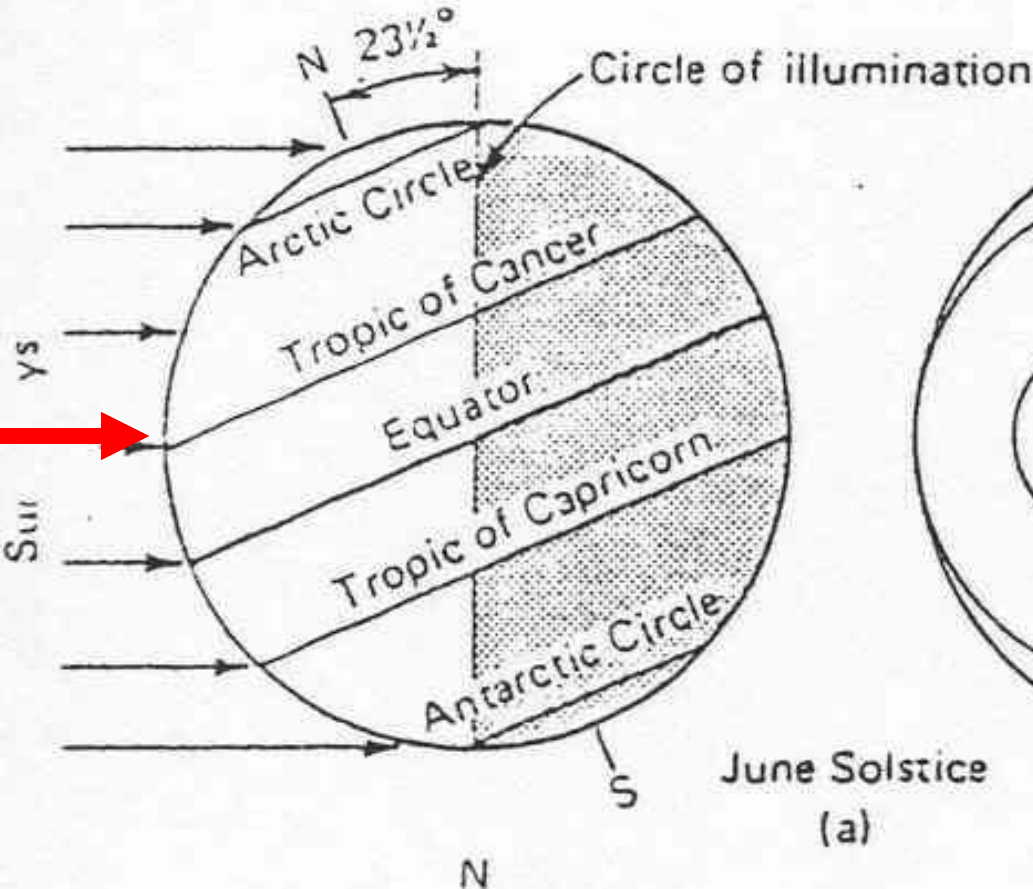
JUNE SOLSTICE



JUNE SOLSTICE

24 hours of sunlight

Most intense solar radiation



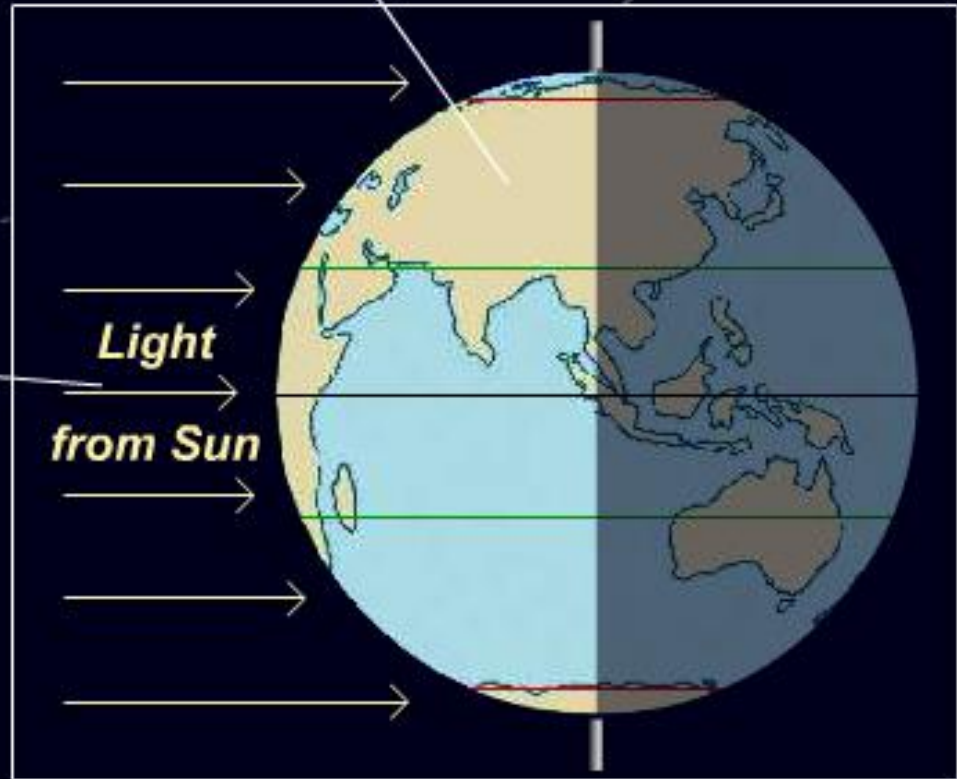
MARCH EQUINOX

**Equinox =
“equal night”**

All locations on
Earth experience
12 hours of daylight

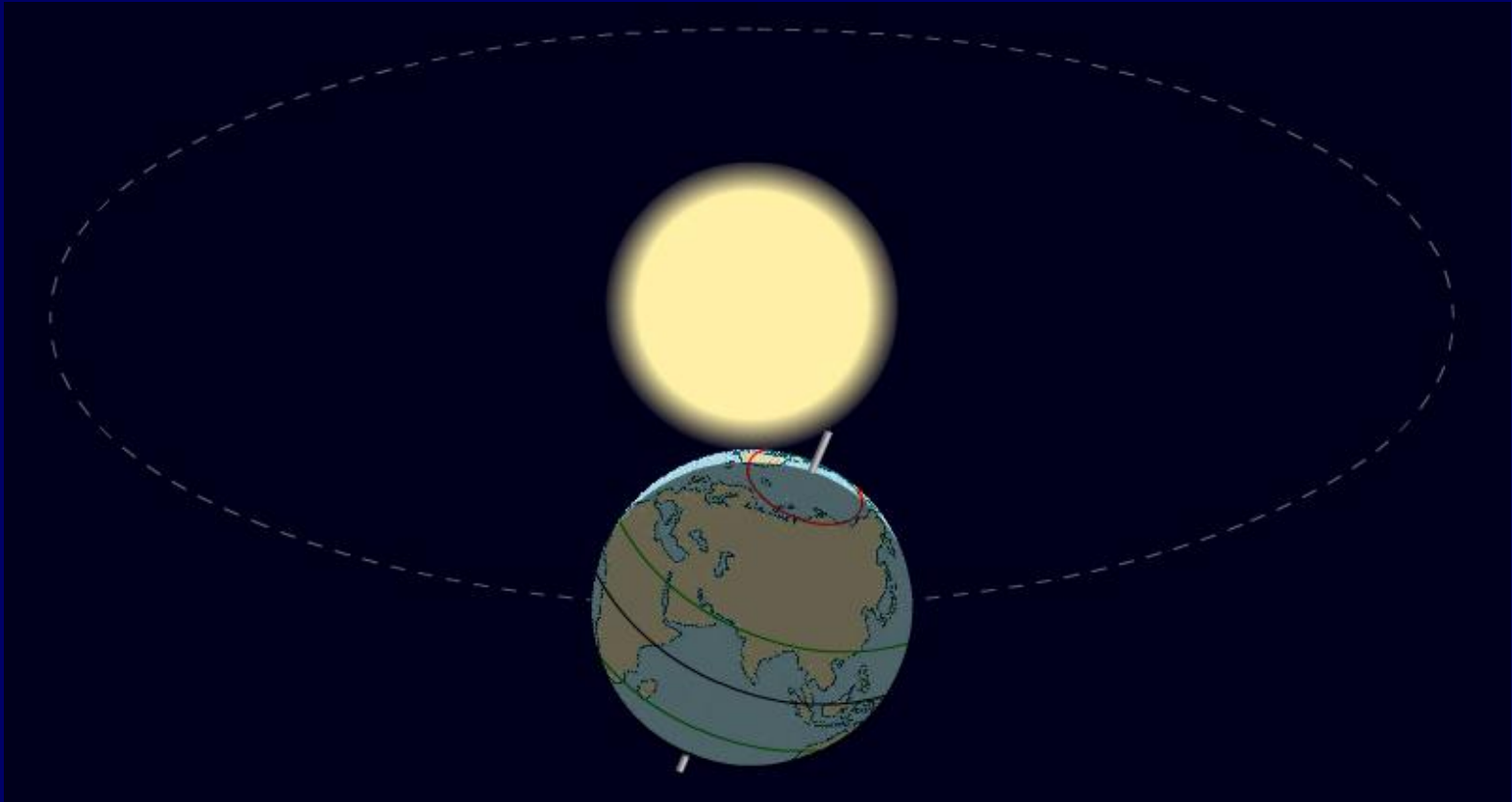
Vertical rays of Sun
striking equator

*Light
from Sun*



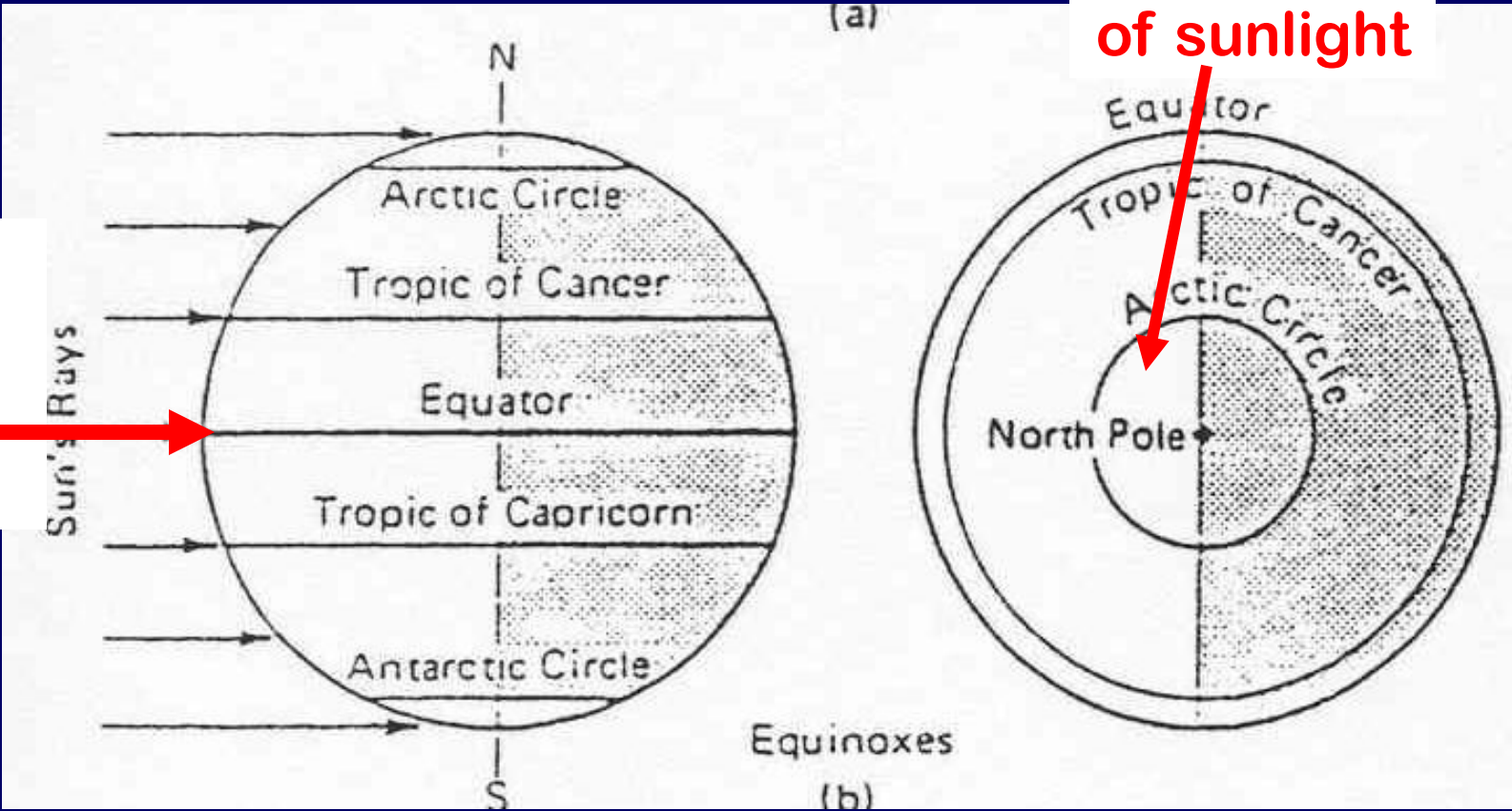
SEPTEMBER EQUINOX

different seasonal position in orbit . . .



. . . but same latitudinal
insolation as March Equinox

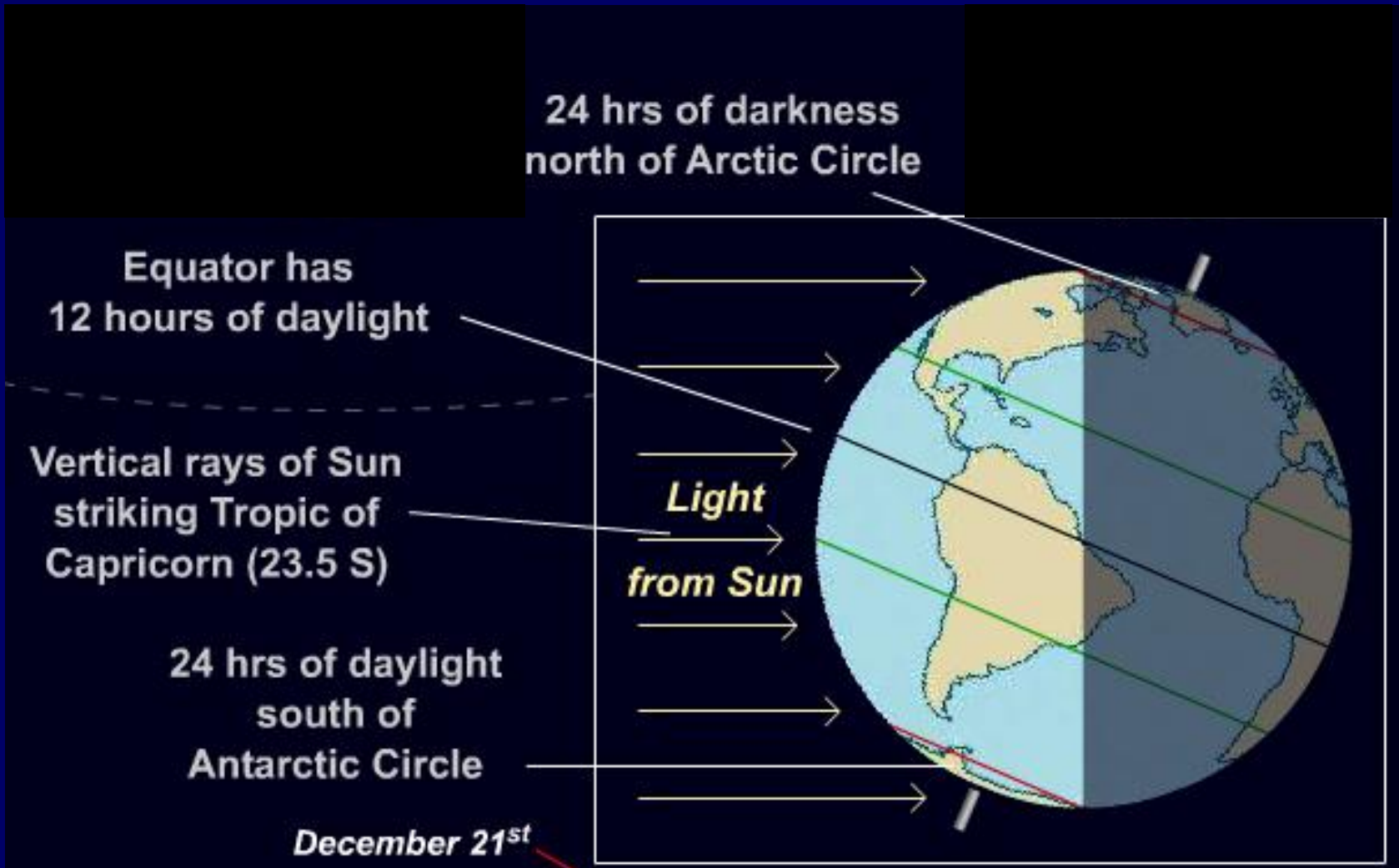
MARCH & SEPTEMBER EQUINOXES



Most intense solar radiation

12 hours of sunlight

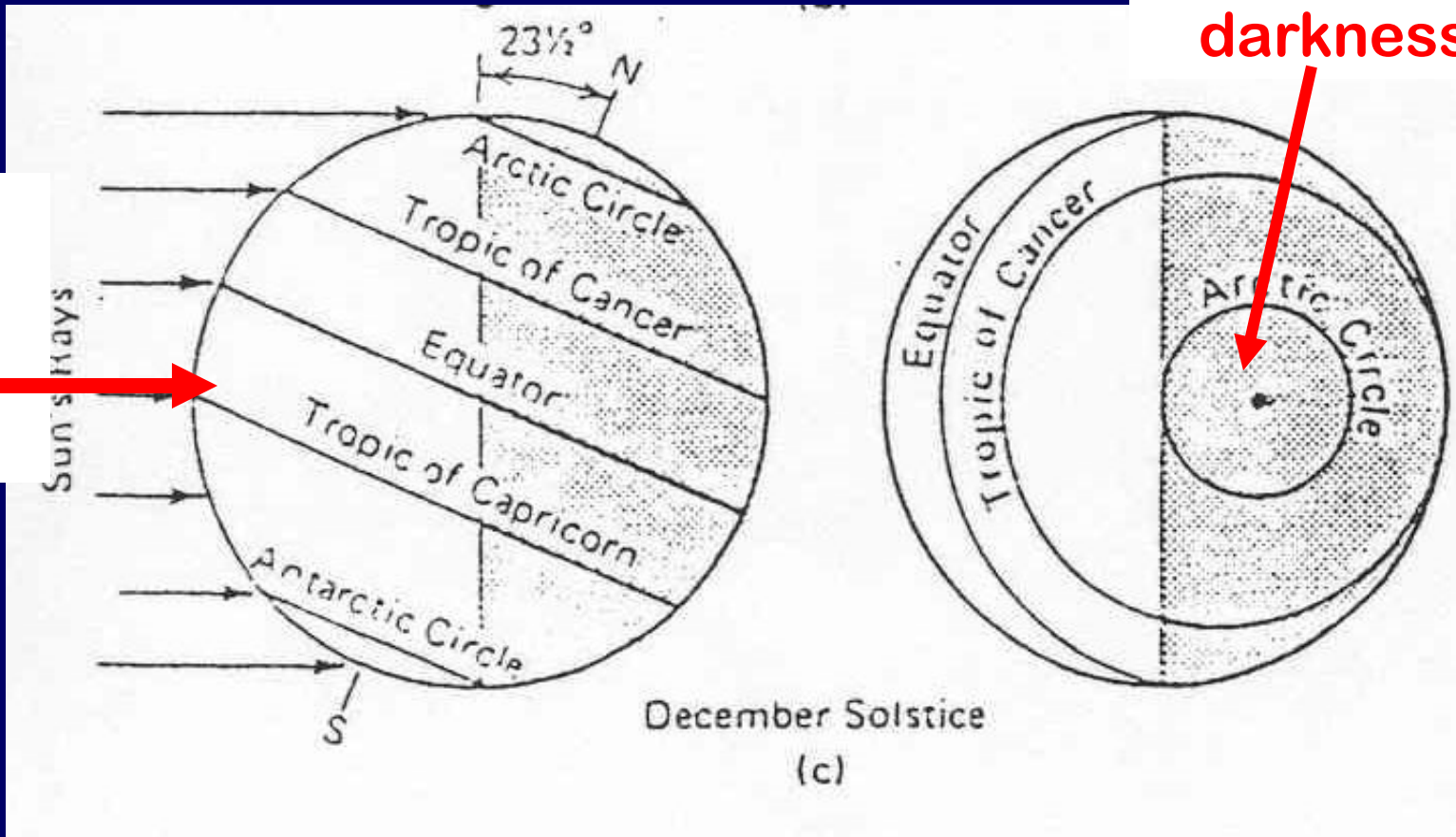
DECEMBER SOLSTICE

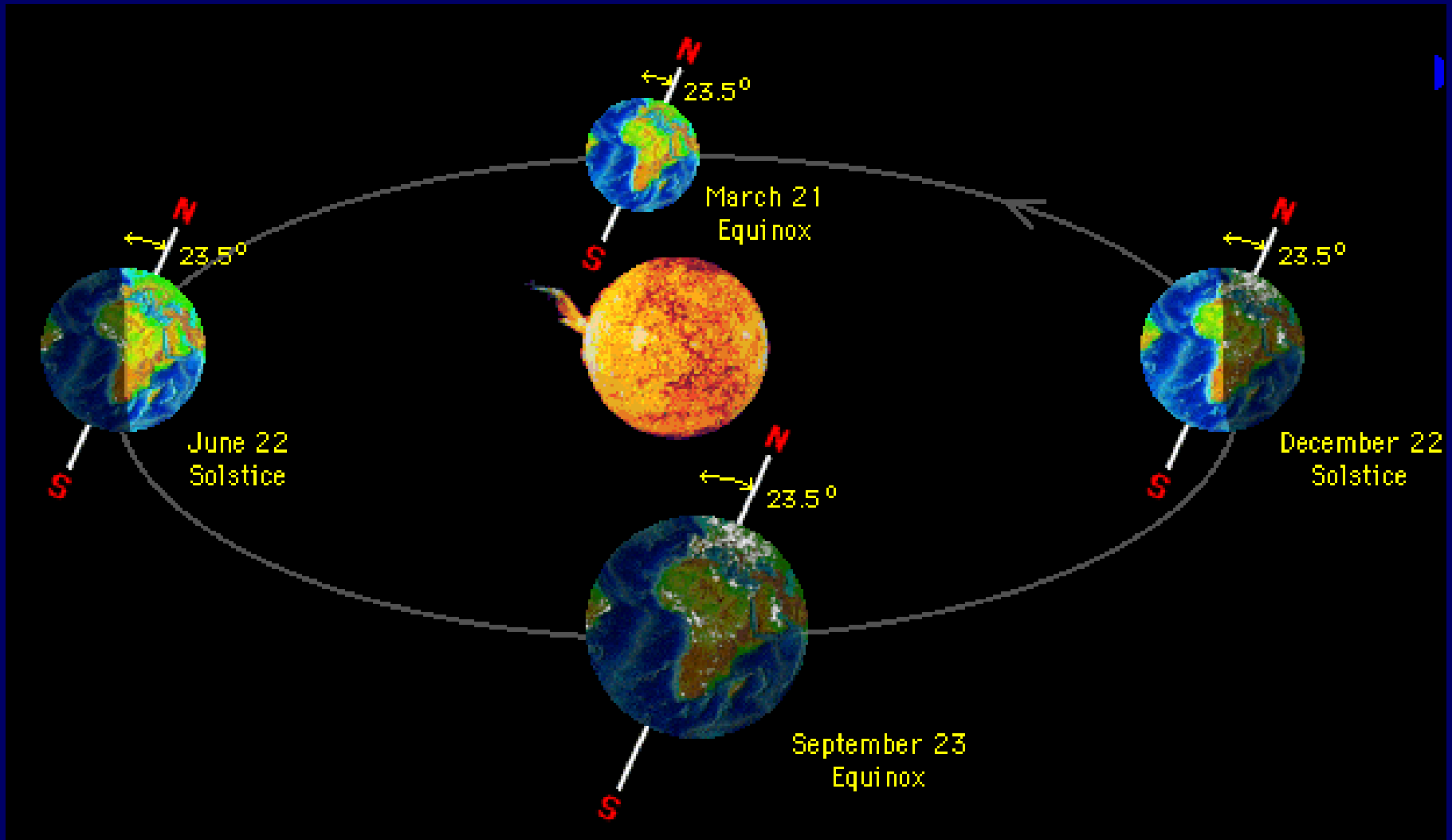


DECEMBER SOLSTICE

24 hours of darkness

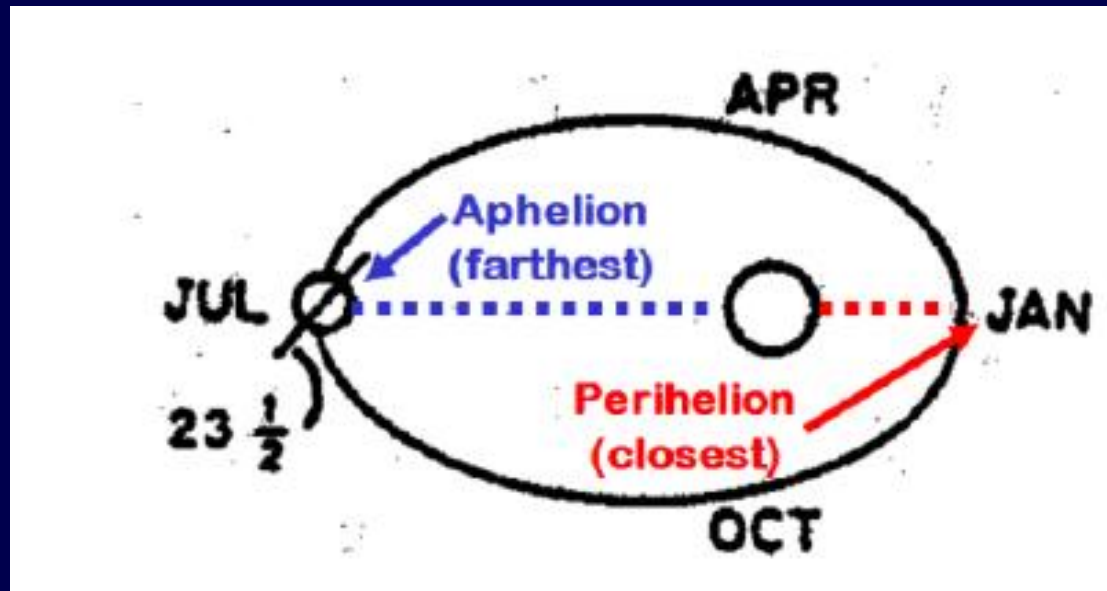
Most intense solar radiation





Earth's Axis Tilt & Elliptical Orbit →

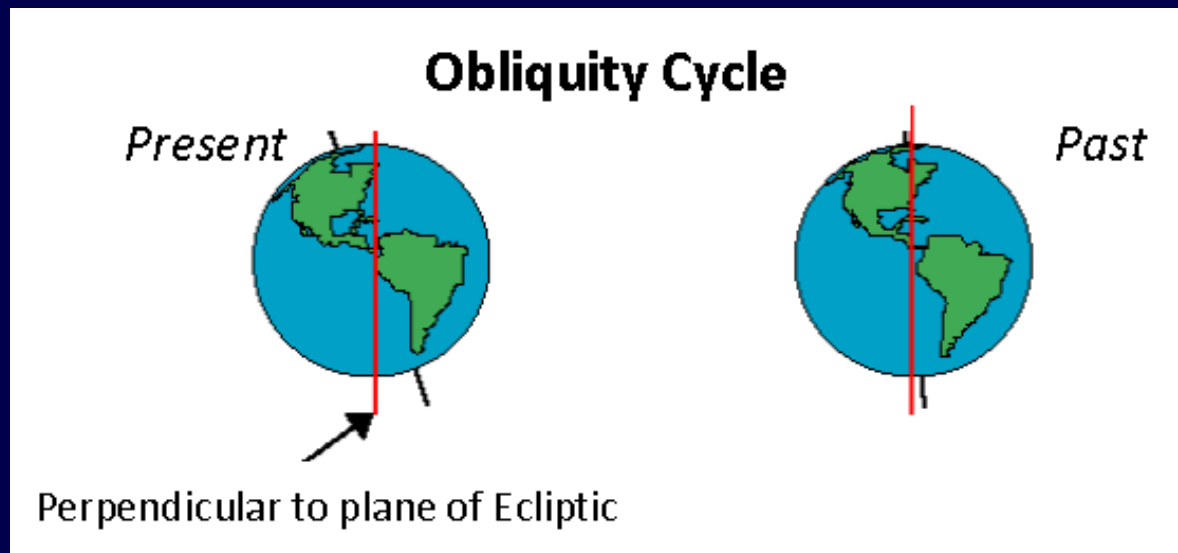
Contrast in Northern vs. Southern Hemisphere:



NATURAL CLIMATIC FORCING: Milankovitch Cycles: (Lesson 2 tutorial)

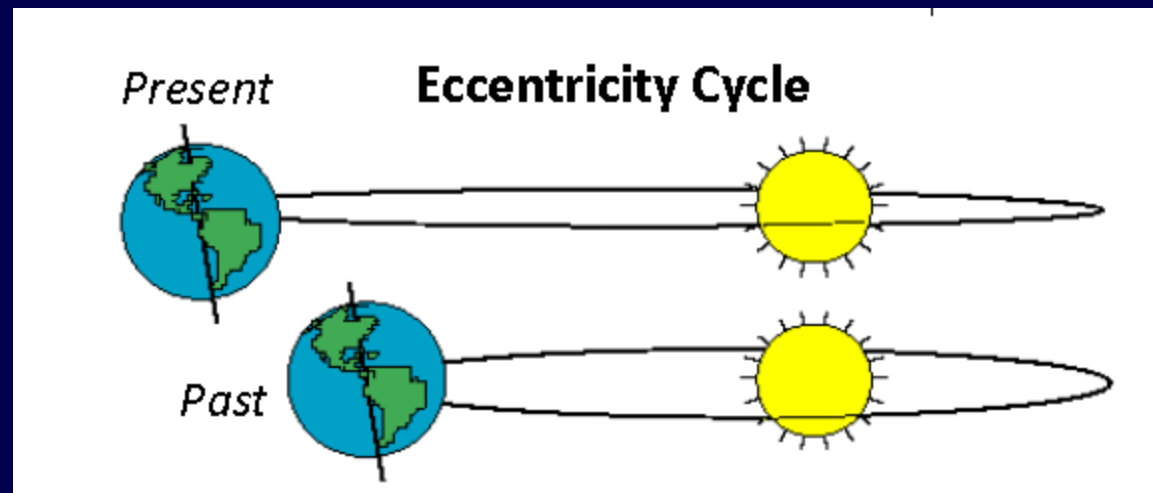
1. OBLIQUITY OF EARTH'S AXIS

*Axis "tilts" 23.5 degrees from plane of ecliptic;
causes the seasons; tilt angle varies over time*



2. ECCENTRICITY OF ORBIT

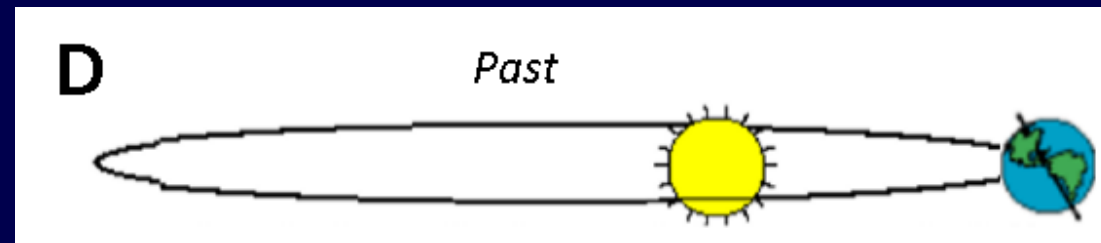
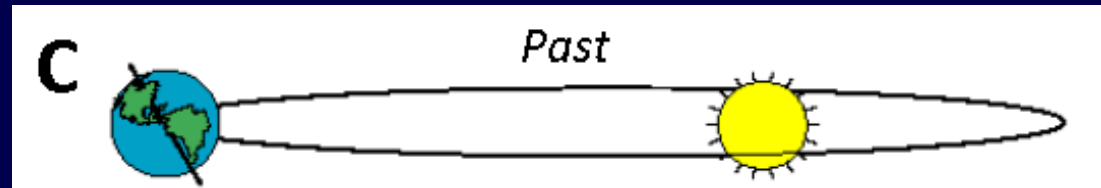
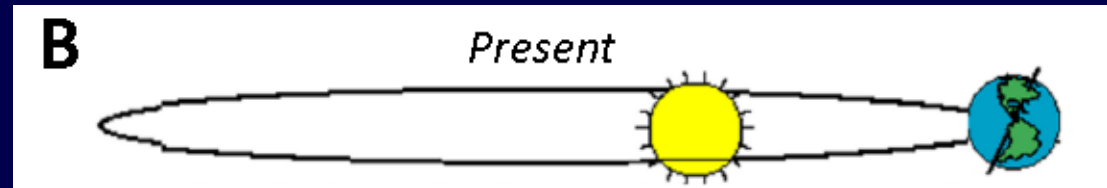
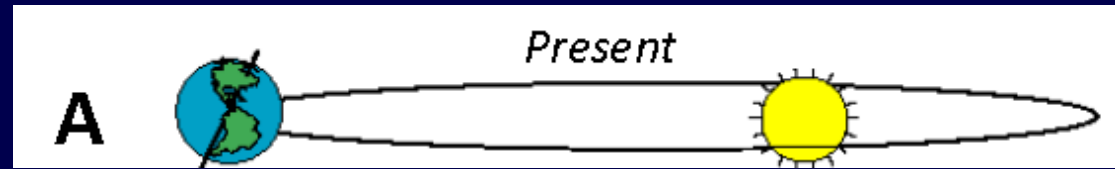
*Earth's orbit around sun is not symmetrical;
varies from elliptical => circular shape over time*



3. Timing of Seasons in Relation to Orbit:

Q1 – Which diagrams represent **SUMMER** in the Southern Hemisphere?

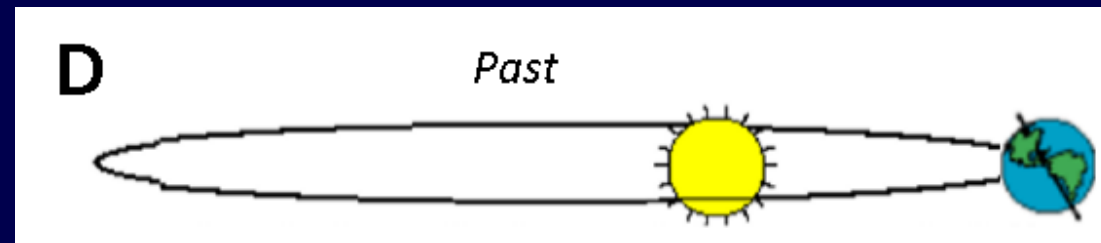
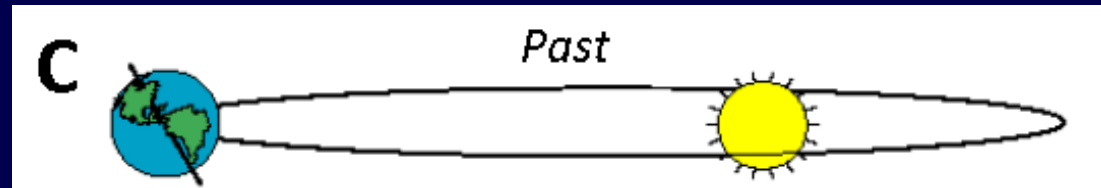
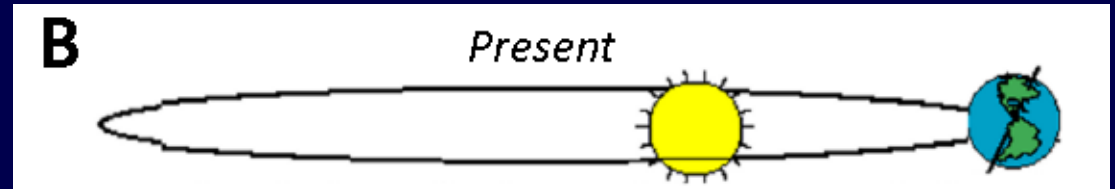
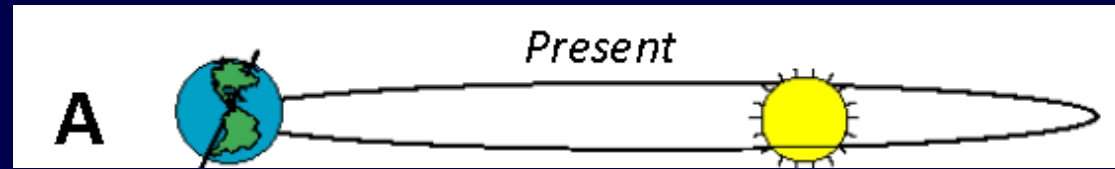
- 1) A & B
- 2) C & D
- 3) B & C
- 4) A & D



3. Timing of Seasons in Relation to Orbit:

Q1 – Which diagrams represent **SUMMER** in the Southern Hemisphere?

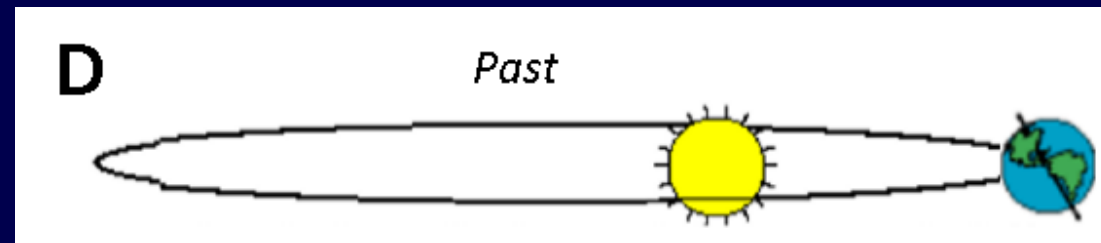
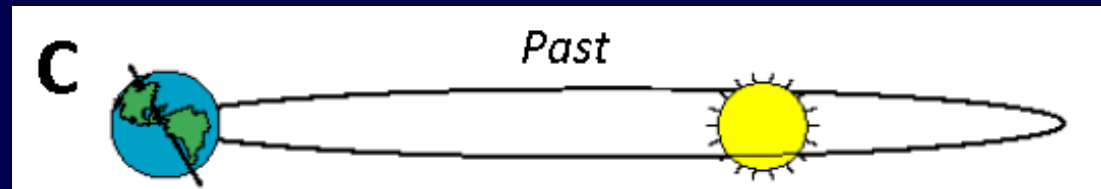
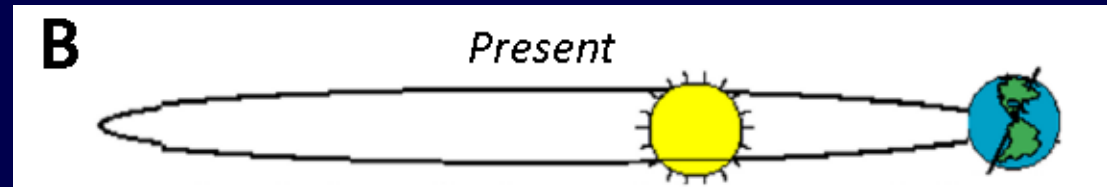
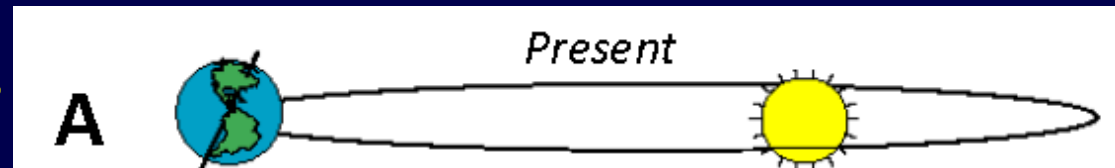
- 1) A & B
- 2) C & D
- 3) B & C
- 4) A & D



3. Timing of Seasons in Relation to Orbit:

Q2 – Which diagram represents the time when the Northern Hemisphere receives the GREATEST amount of insolation?

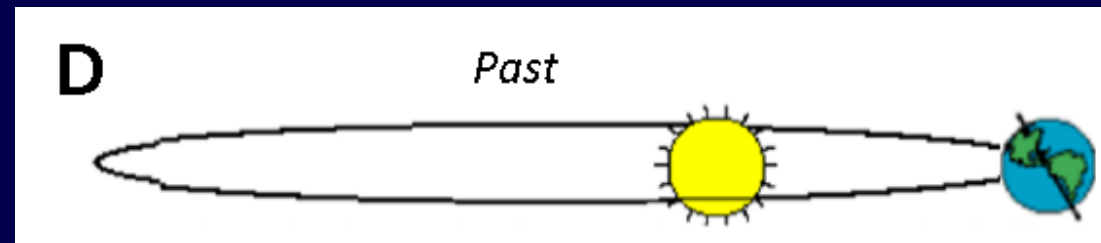
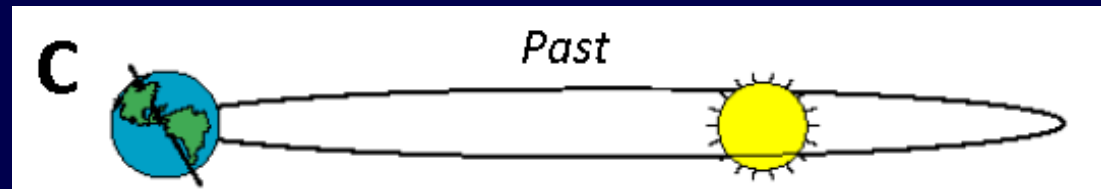
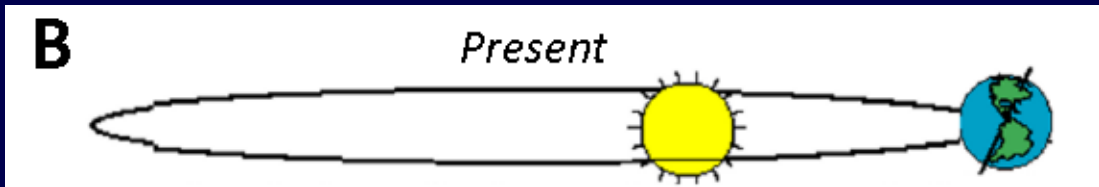
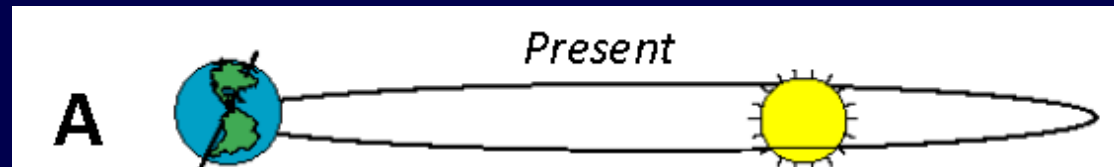
A B C D



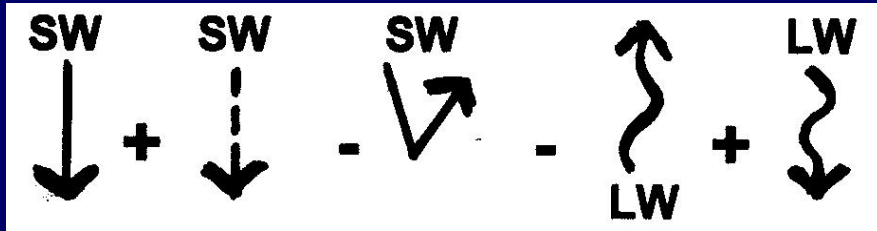
3. Timing of Seasons in Relation to Orbit:

Q2 – Which diagram represents the time when the Northern Hemisphere receives the GREATEST amount of insolation?

A B C **D**



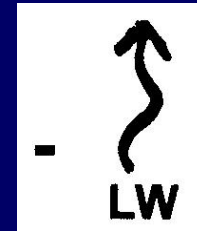
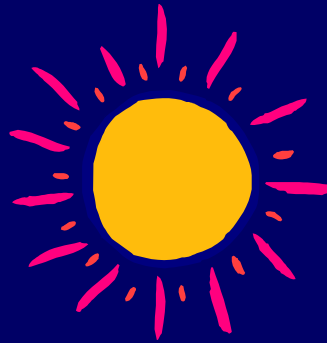
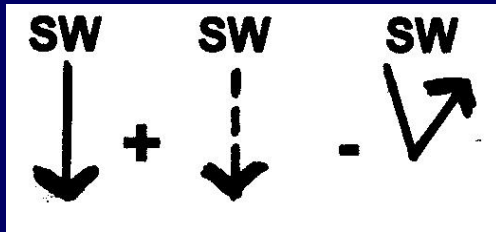
THE RADIATION BALANCE



**& THE GENERAL
CIRCULATION OF THE
ATMOSPHERE**



HOW IT ALL FITS TOGETHER:



Over the course of a year . . .

The amount of **INCOMING SW** (Insolation) absorbed by EARTH **varies by LATITUDE**

(**MORE** comes in near the Equator, less near the Poles)

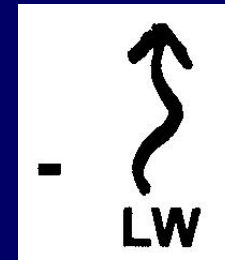
→ **LOW LATITUDES** absorb **MORE** energy than **HIGH LATITUDES**

The amount of outgoing **TERRESTRIAL LW / IR** varies by latitude too --

MORE **LW / IR** is emitted at warmer **LOW LATITUDES**, **LESS** in cooler **HIGH LATITUDES**

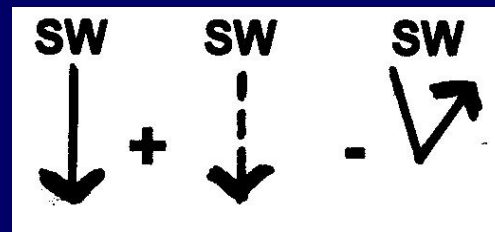
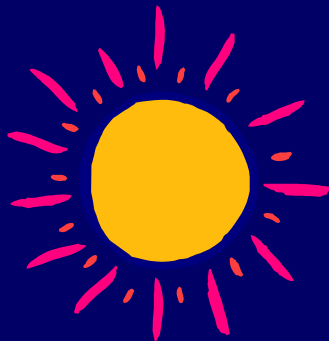
HOWEVER . . .

The EQUATOR-POLE
DIFFERENCES of what
goes OUT from the
EARTH

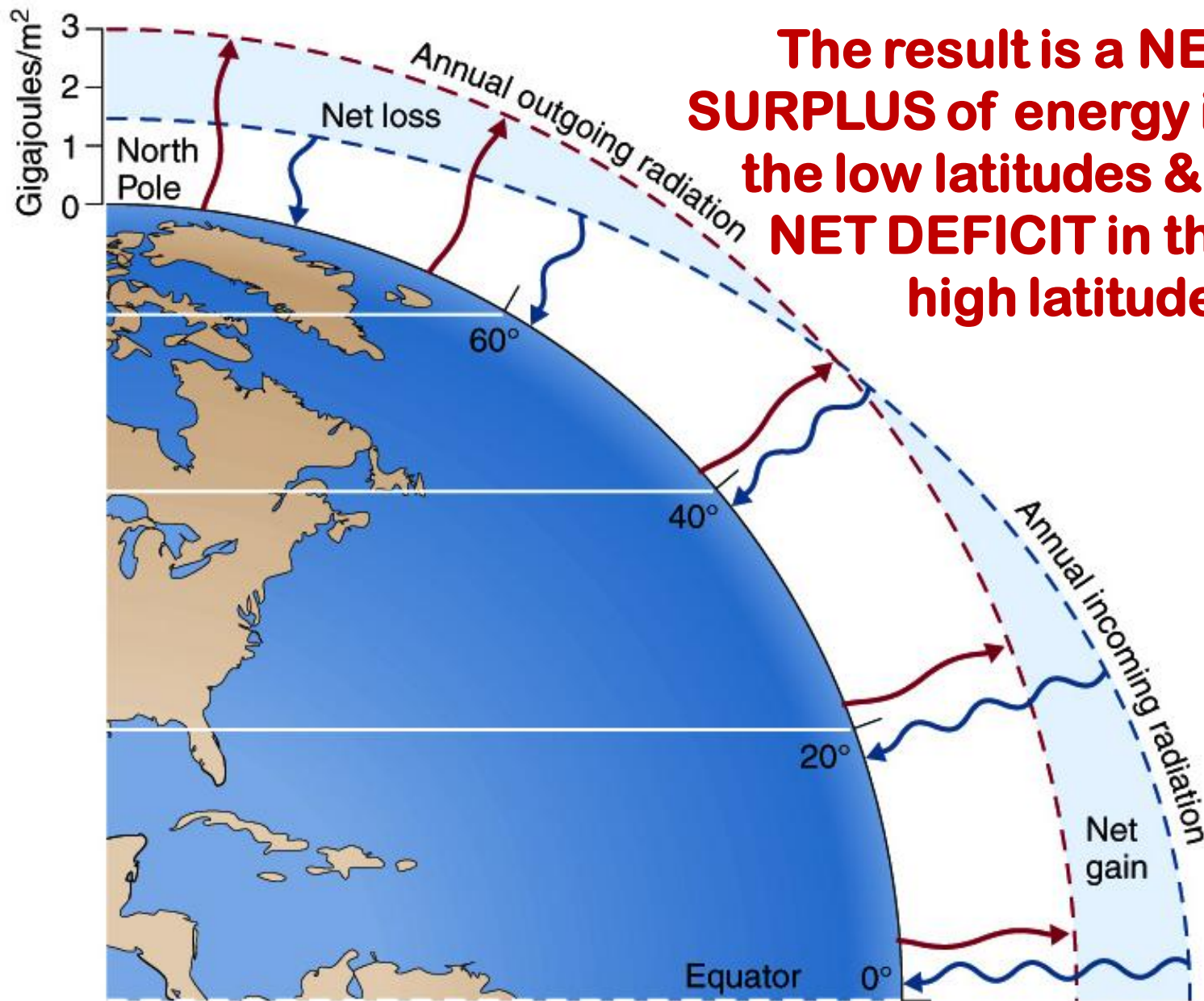


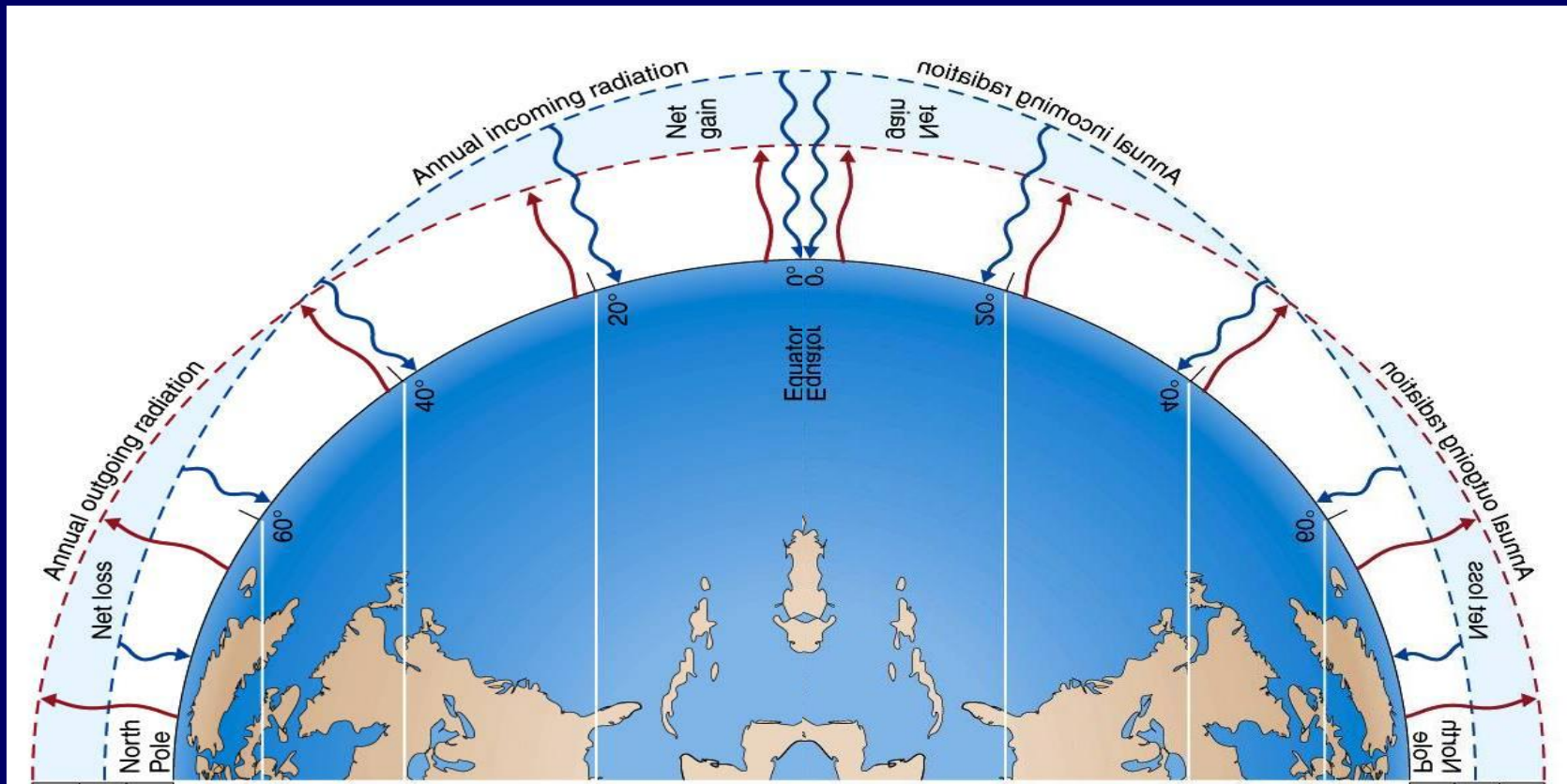
are less than the

EQUATOR-POLE
DIFFERENCES of what
comes IN from the SUN



The result is a **NET SURPLUS** of energy in the low latitudes & a **NET DEFICIT** in the high latitudes



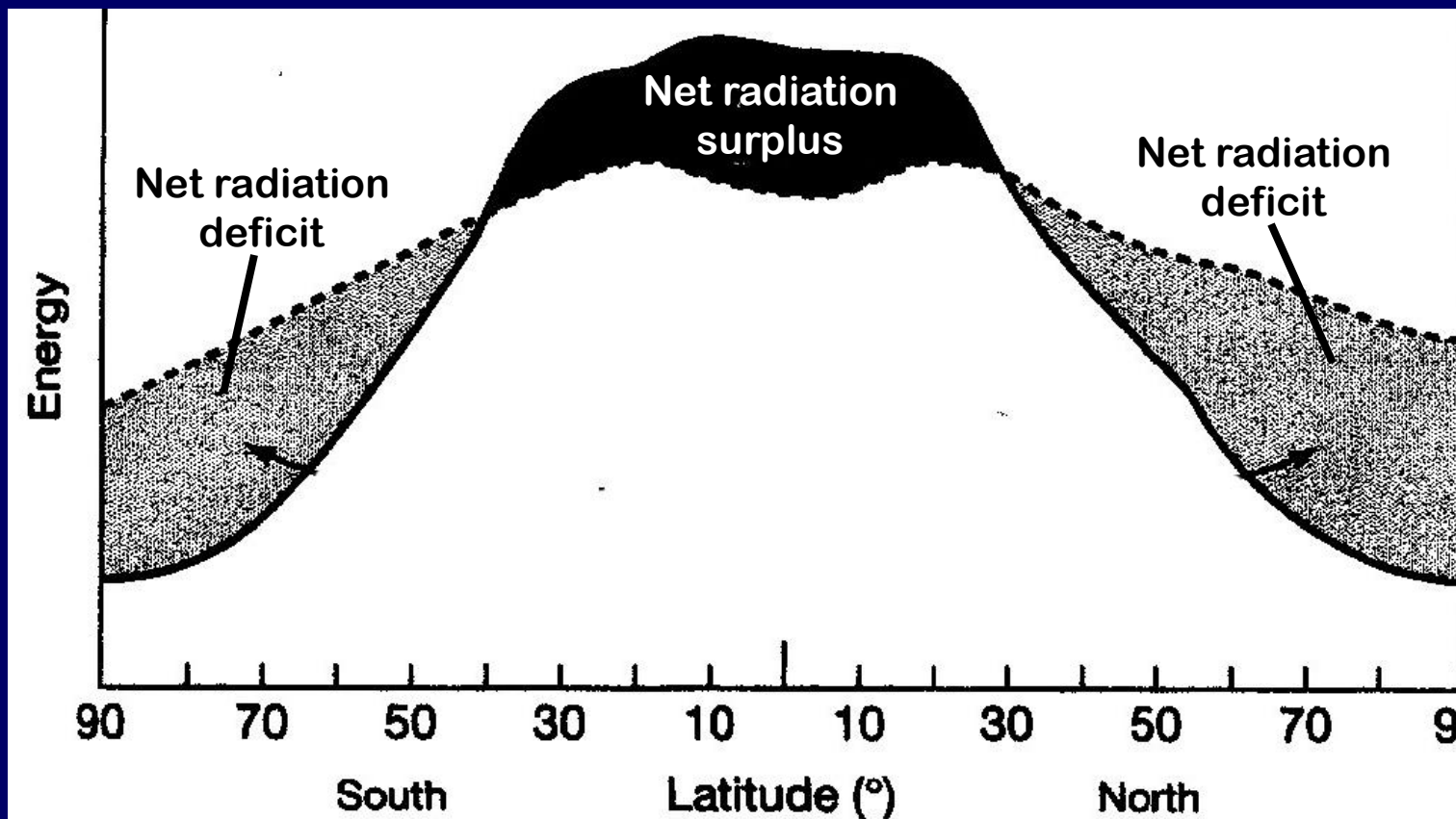


POLE

EQUATOR

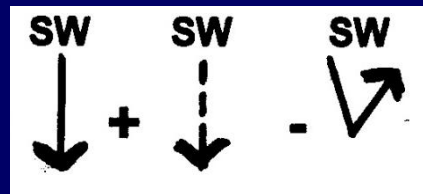
POLE

Now lets look at a Pole to Pole Transect

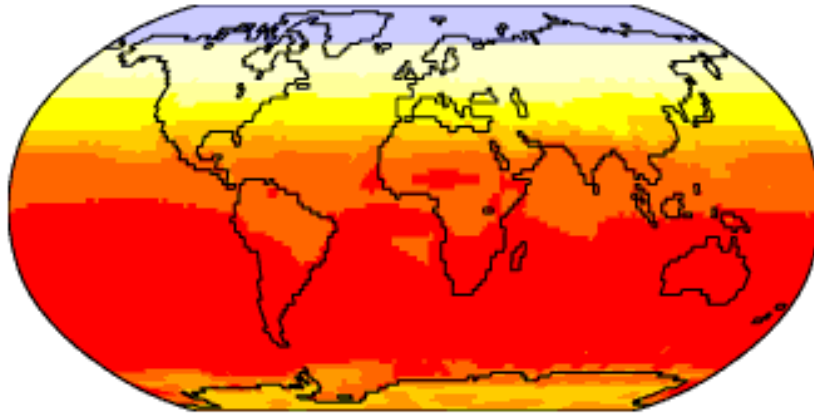


———— Absorbed solar energy

----- Emitted infrared energy
(at top of atmosphere)

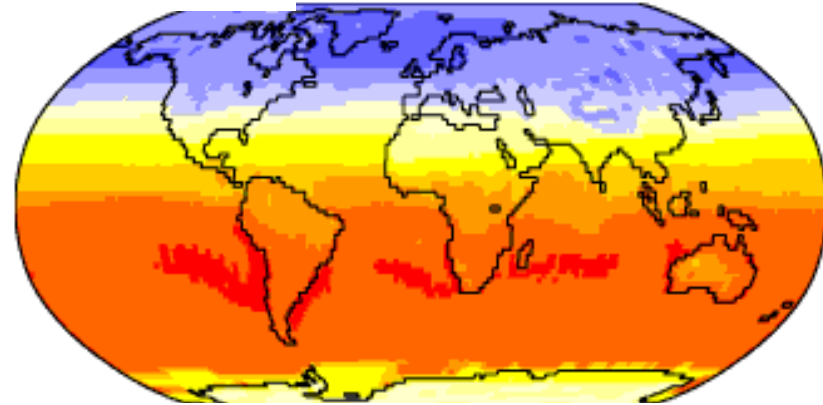
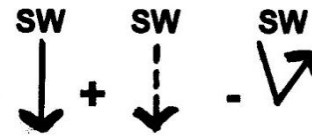


Short-Wave Radiation



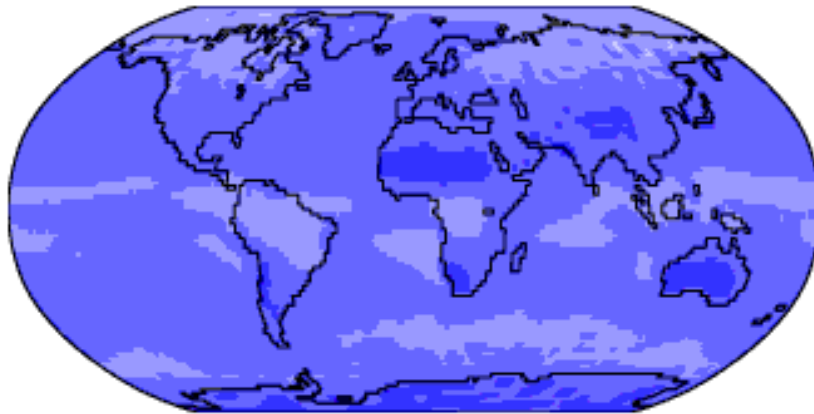
Dec

Absorbed solar energy

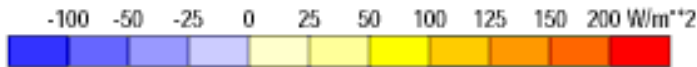


Net Radiation R_{NET}

Long-Wave Radiation



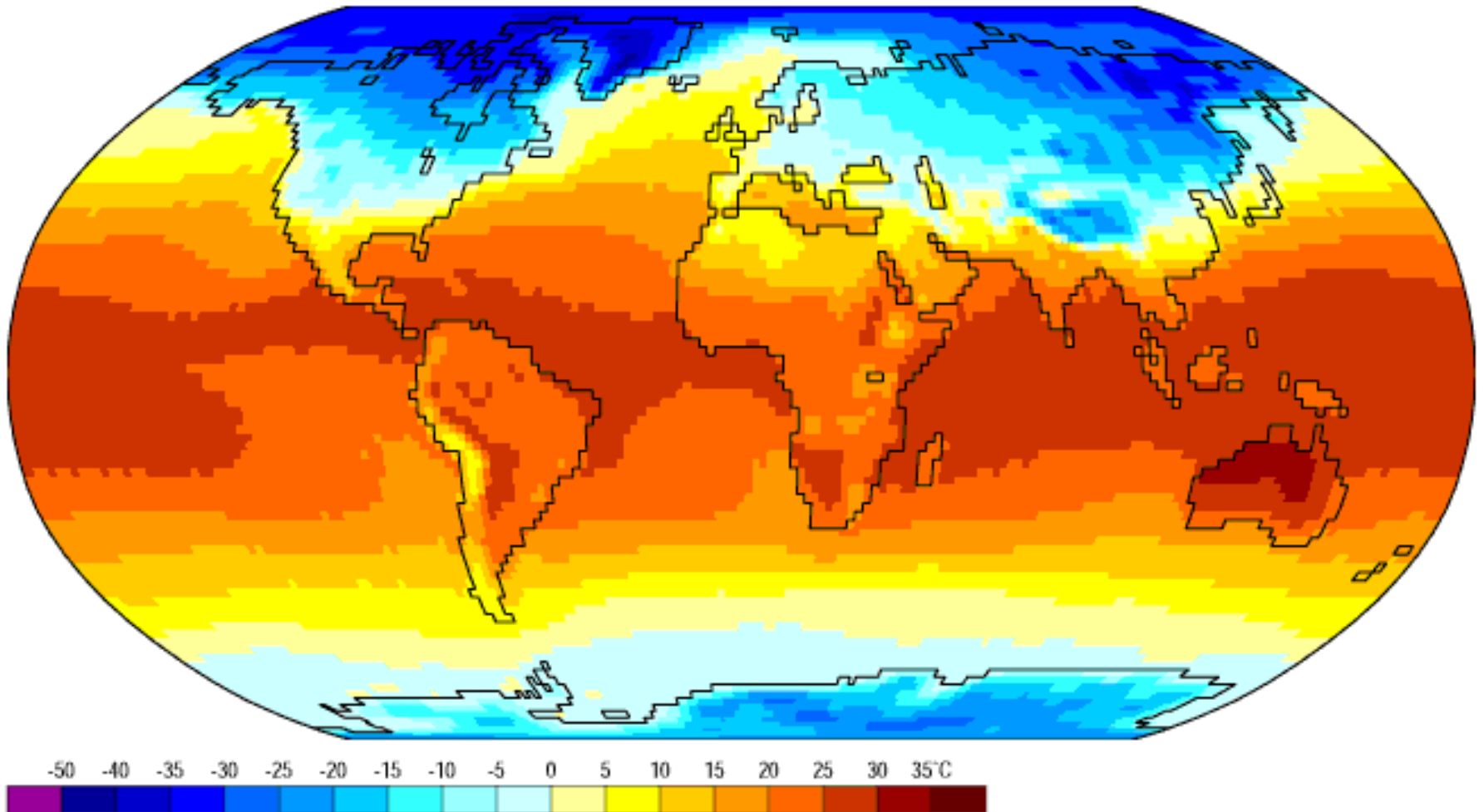
Emitted infrared energy



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
 Animation: Department of Geography, University of Oregon, March 2000

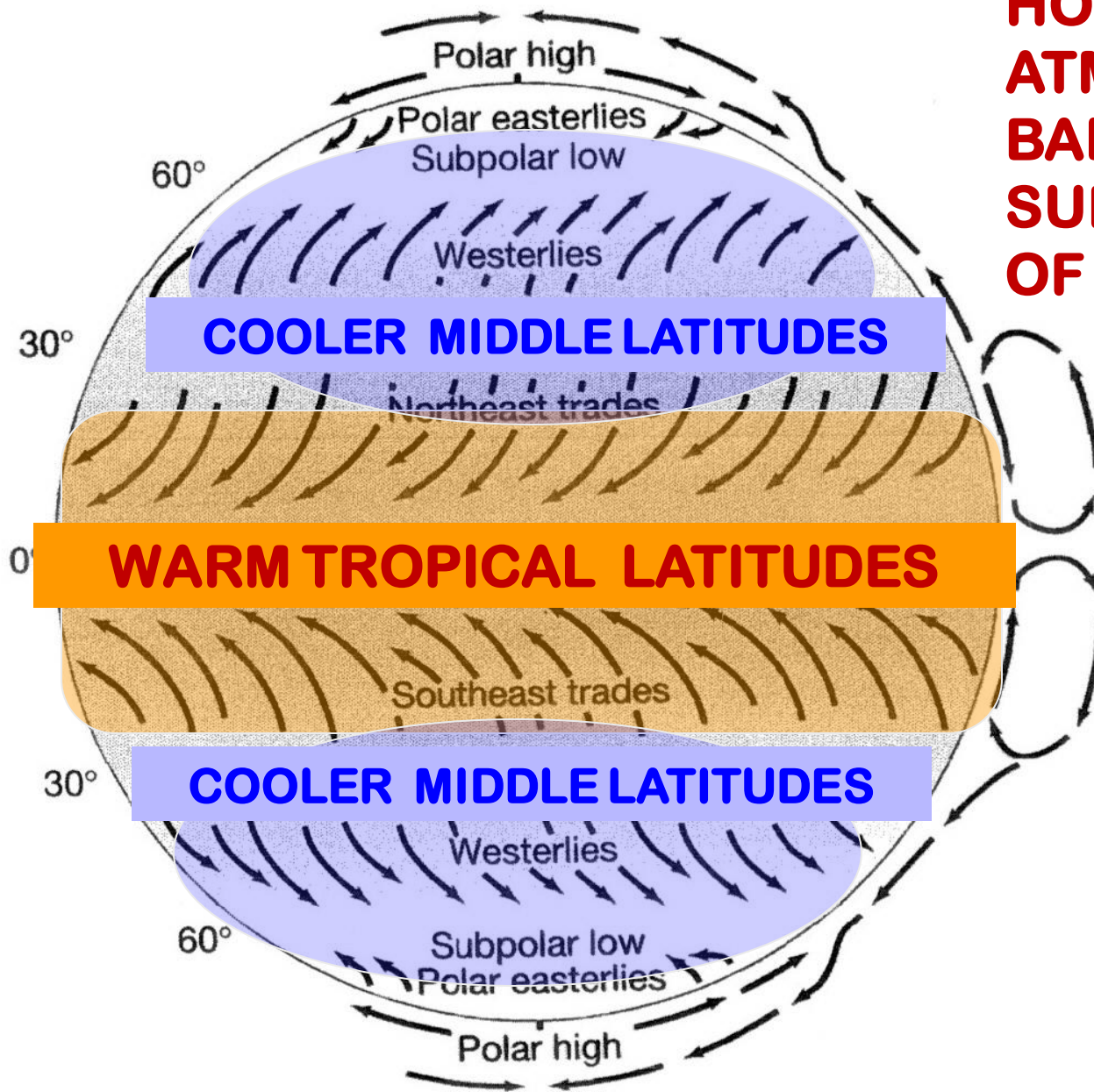
Surface Air Temperature

Dec



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000

HOW DOES THE ATMOSPHERE BALANCE OUT THE SURPLUS & DEFICIT OF ENERGY??



COOLER MIDDLE LATITUDES

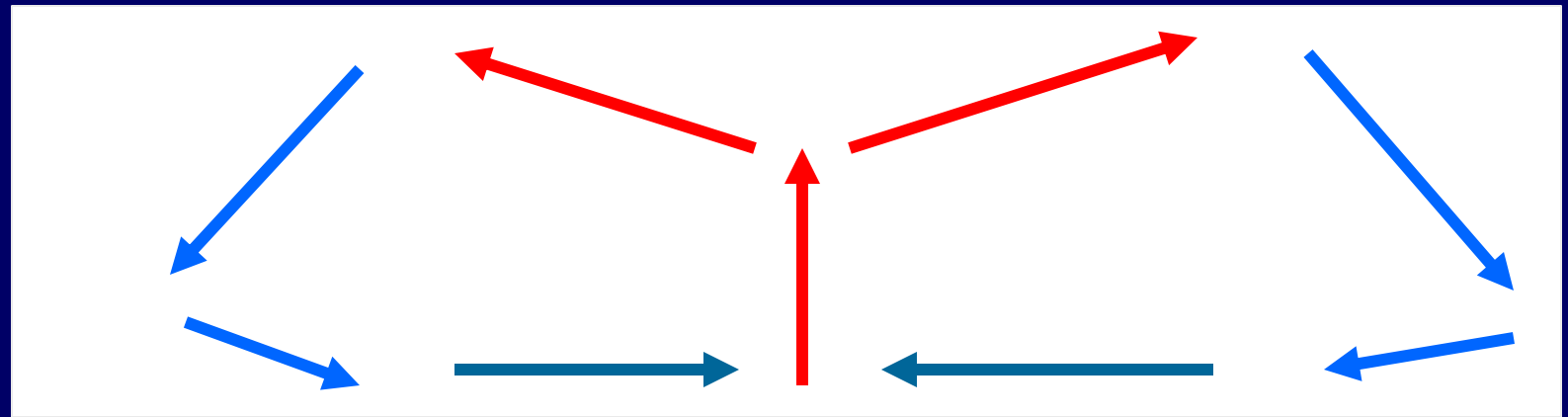
WARM TROPICAL LATITUDES

COOLER MIDDLE LATITUDES

Energy Transfer via Convection Cells

Figure from SGC E-text Chapter 4

GIANT CONVECTION CELLS driven by thermal differences:



90

60

30

0

30

60

90

Northern Hemisphere

EQUATOR

Southern Hemisphere

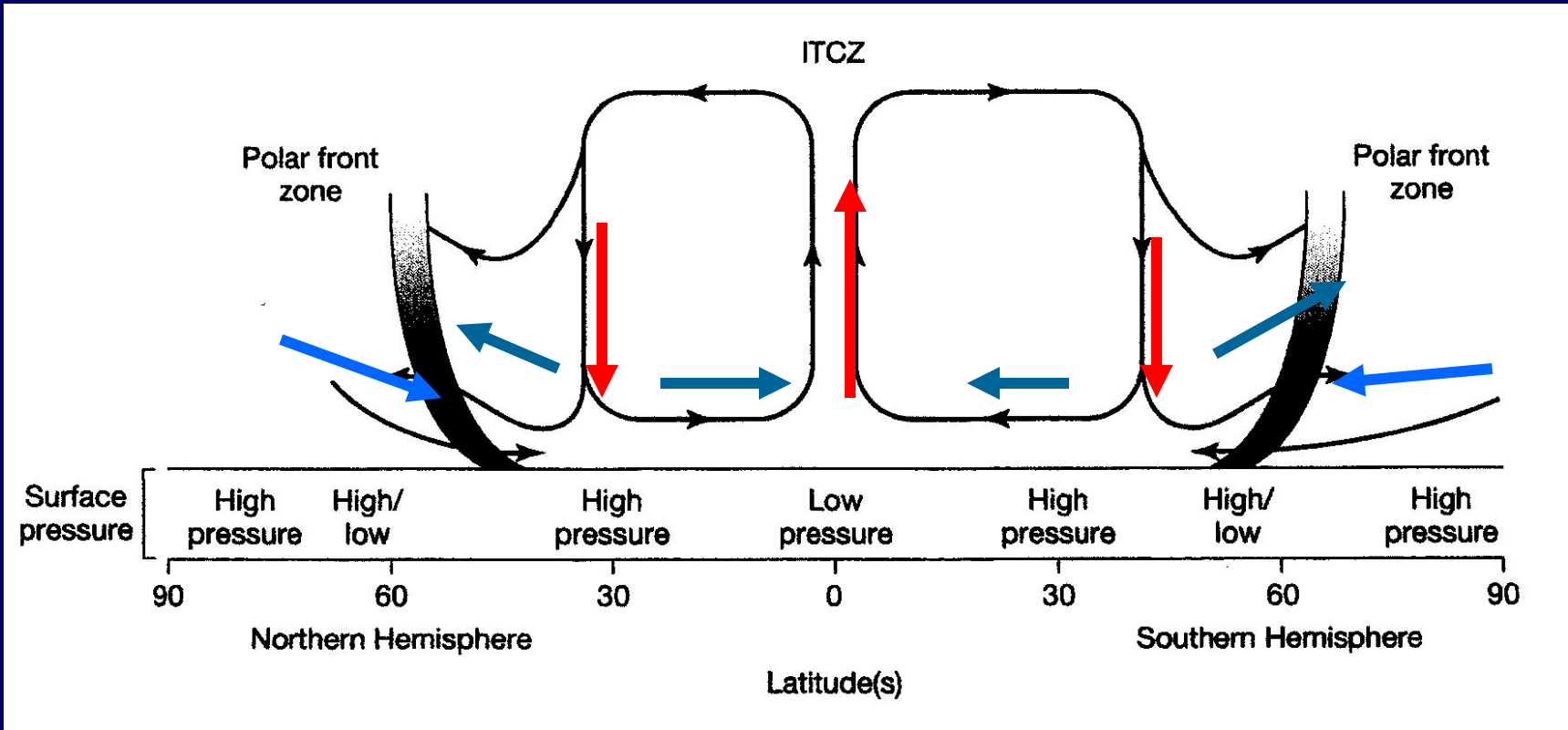
COLD POLAR
REGIONS

HOT TROPICS

COLD POLAR
REGIONS

“HADLEY CELL”
← TRANSPORT →





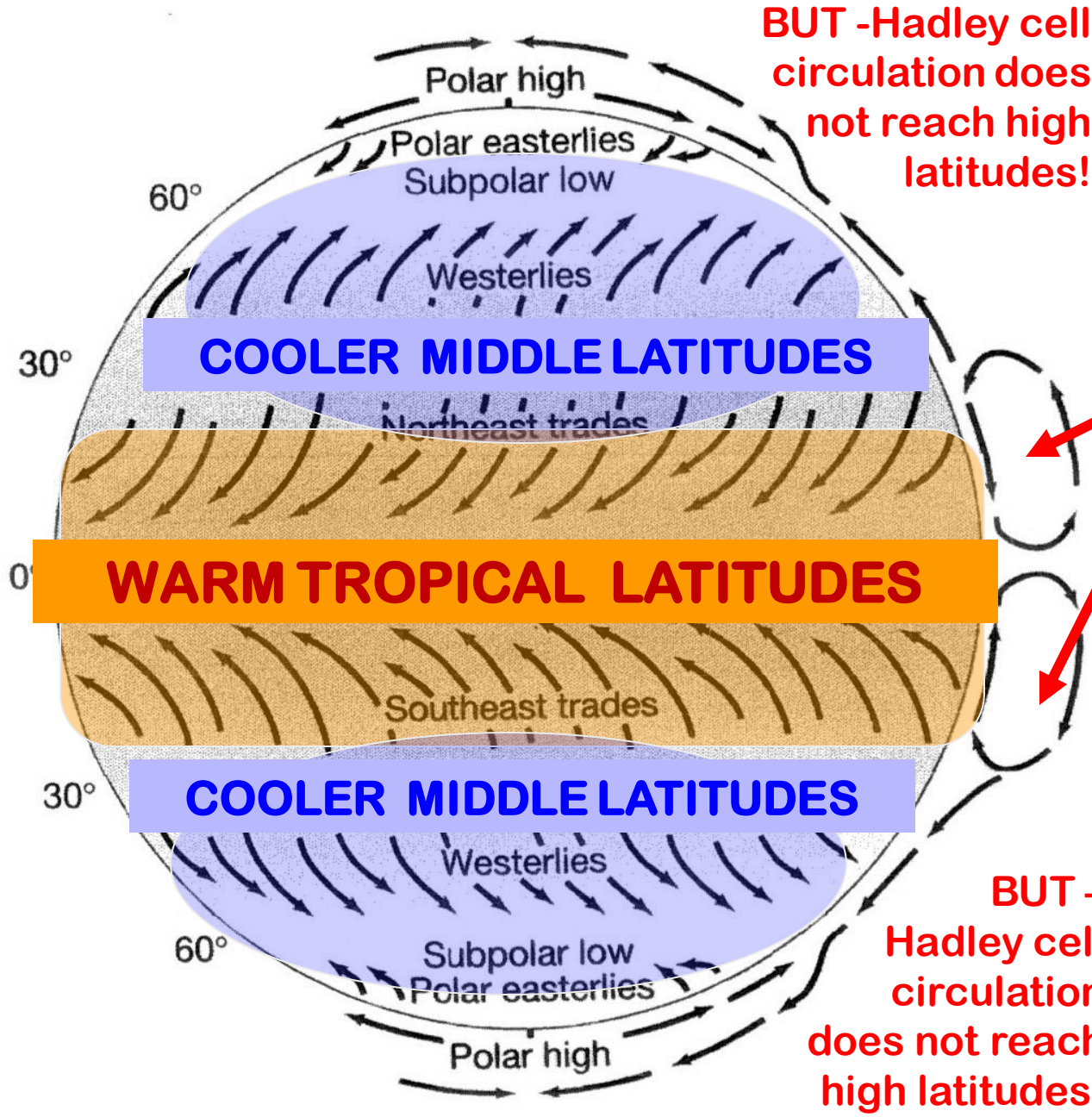
**COLD POLAR
REGIONS**

HOT TROPICS

**COLD POLAR
REGIONS**

**“HADLEY CELL”
← TRANSPORT →**

From SGC Chapter 4



BUT -Hadley cell circulation does not reach high latitudes!

Hadley Cells transport warm air poleward as SENSIBLE HEAT

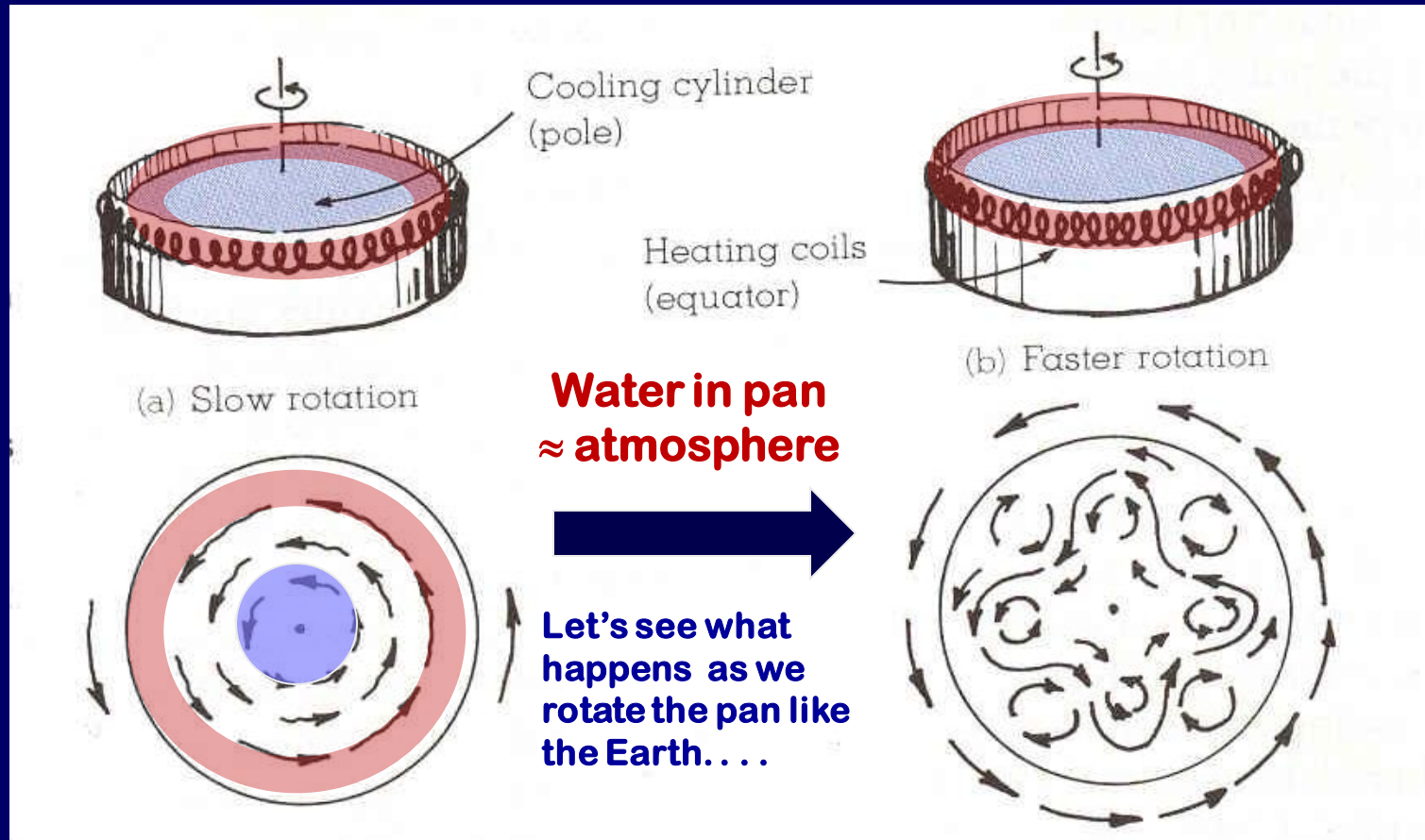
HADLEY CELLS = key drivers!

Convection cell transfer of thermal energy from low latitude area of energy **SURPLUS** to higher latitude area of energy **DEFICIT**

BUT - Hadley cell circulation does not reach high latitudes!

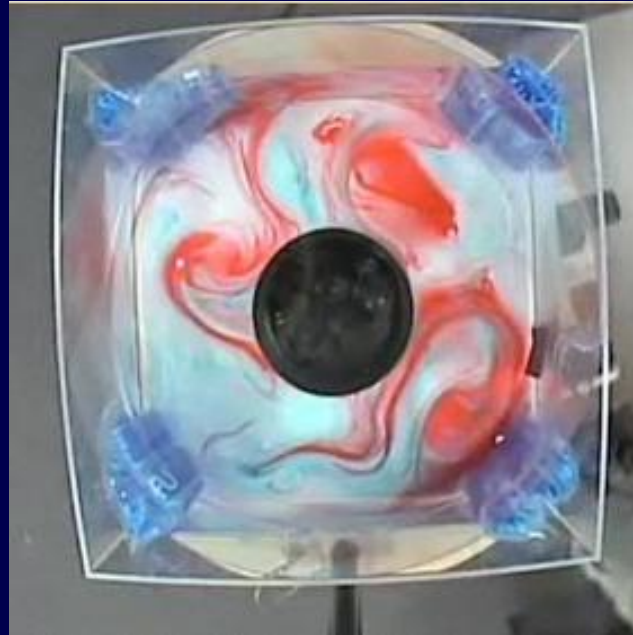
ENERGY TRANSFER BY CONVECTION

Another way energy gets transported from the hot surplus areas to the cold deficit areas:



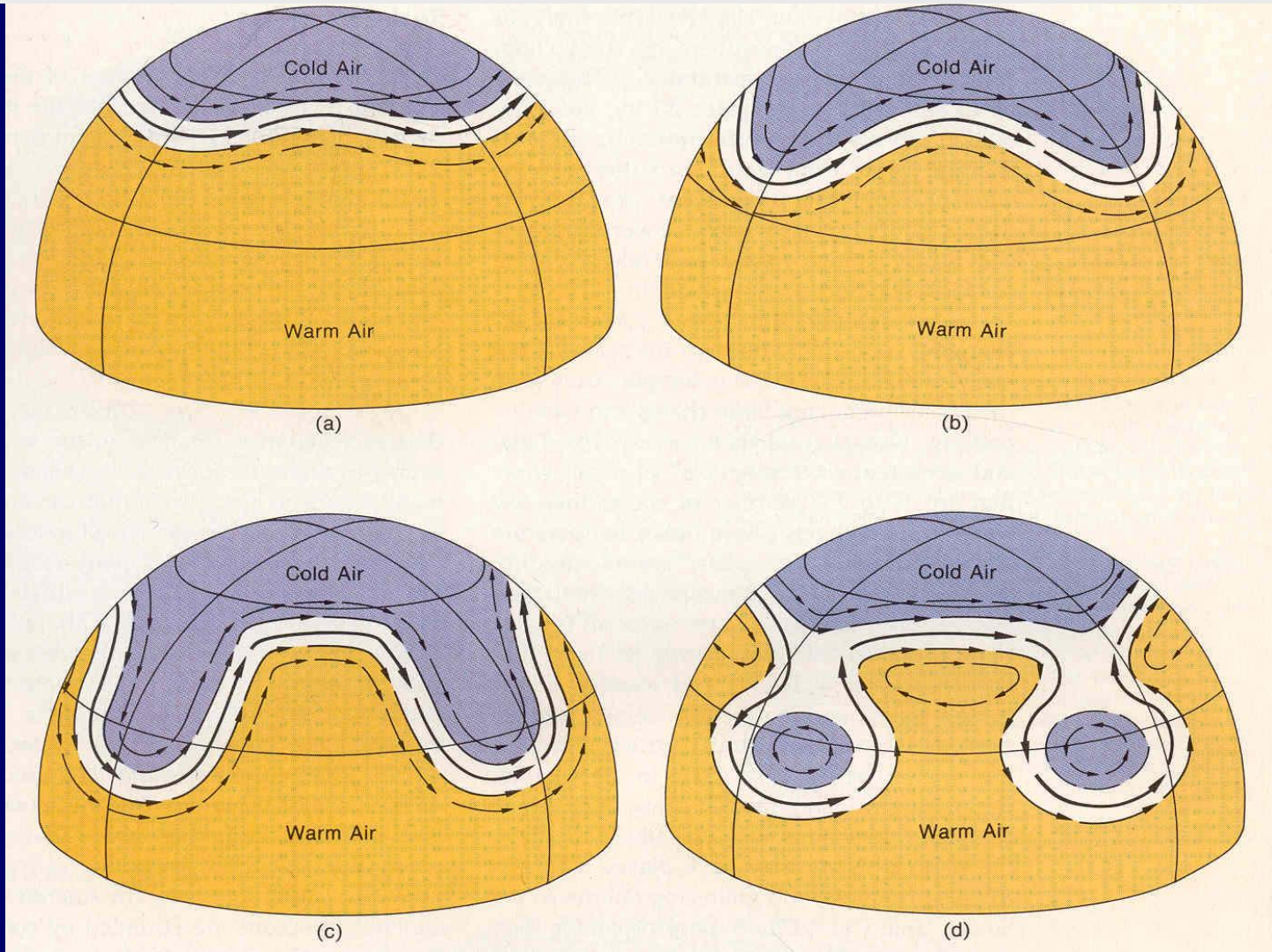
Demo of a simple “dishpan” model of atmospheric circulation

A DEMONSTRATION OF THE DISHPAN



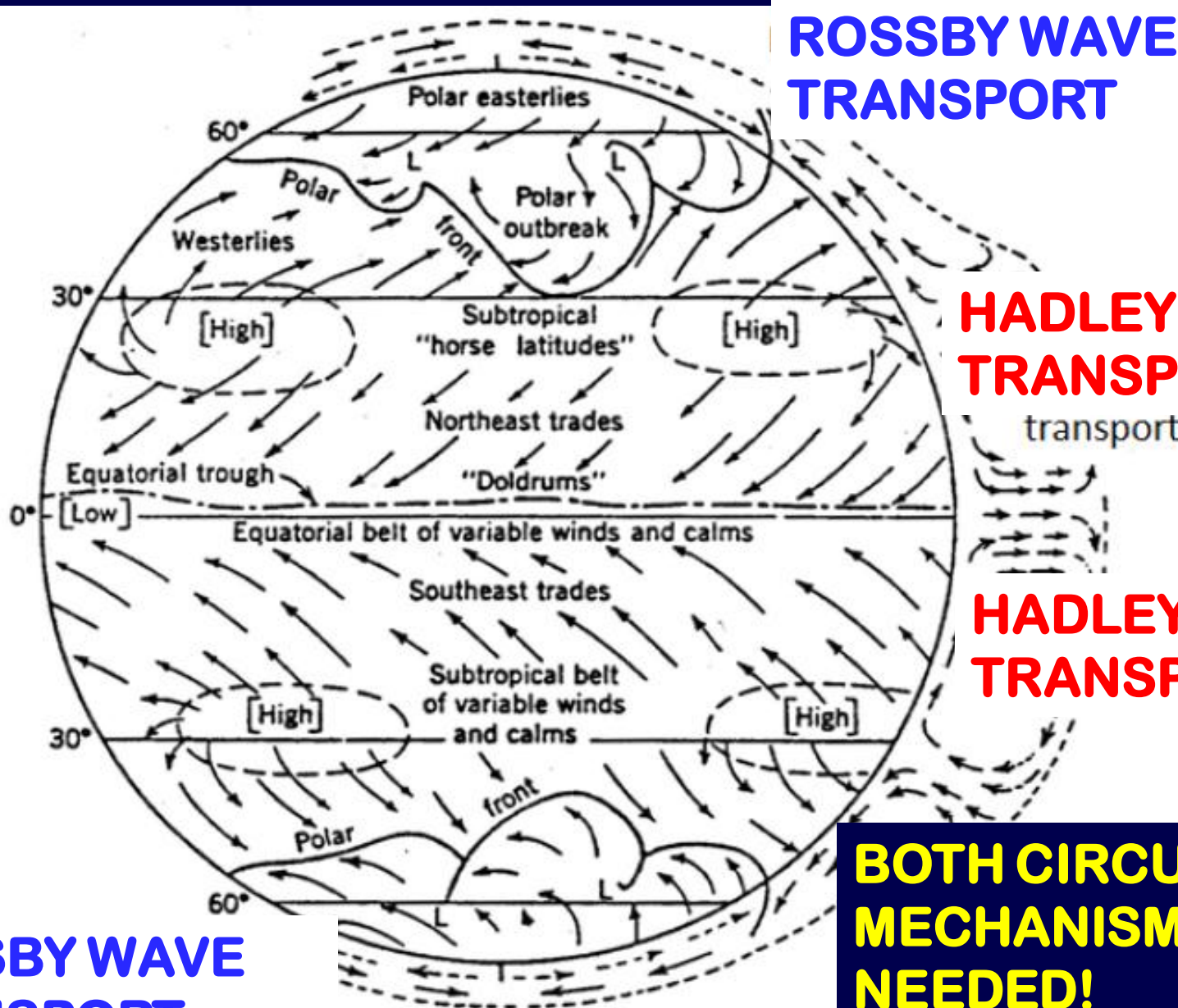
http://www.windows2universe.org/earth/Atmosphere/global_circulation_Isop_video.html

UPPER LEVEL “ROSSBY WAVE” CIRCUMPOLAR WINDS !



“Wave” transport of Energy as SENSIBLE HEAT
(in lobes of warm air)!

The "GENERAL CIRCULATION OF THE ATMOSPHERE"



ROSSBY WAVE TRANSPORT

HADLEY CELL TRANSPORT

HADLEY CELL TRANSPORT

BOTH CIRCULATION MECHANISMS ARE NEEDED!

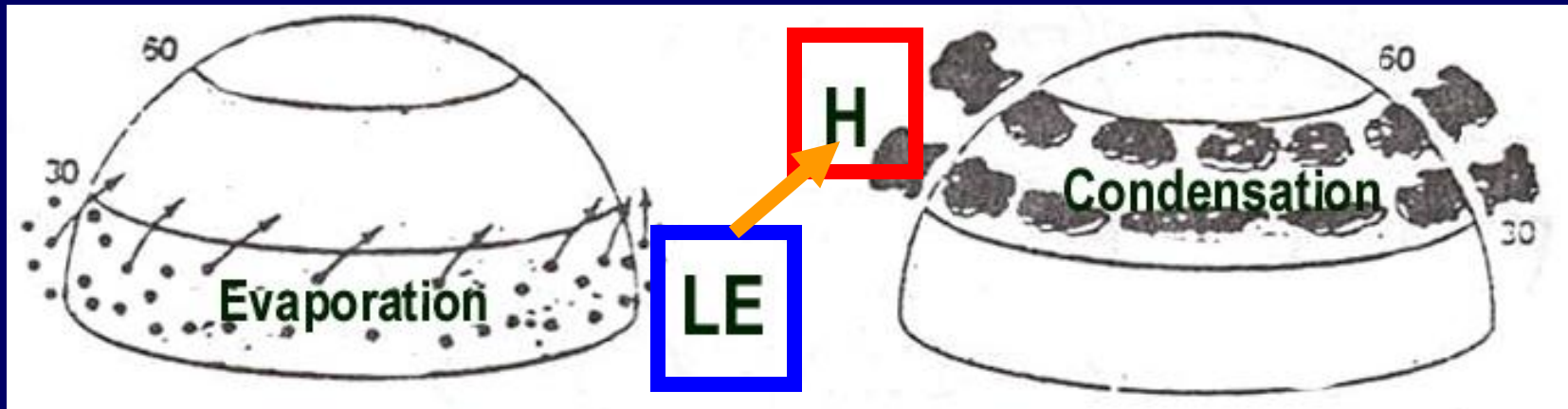
ROSSBY WAVE TRANSPORT

ENERGY is transported from areas of surplus to deficit via

Warm Air transport : H (sensible heat)



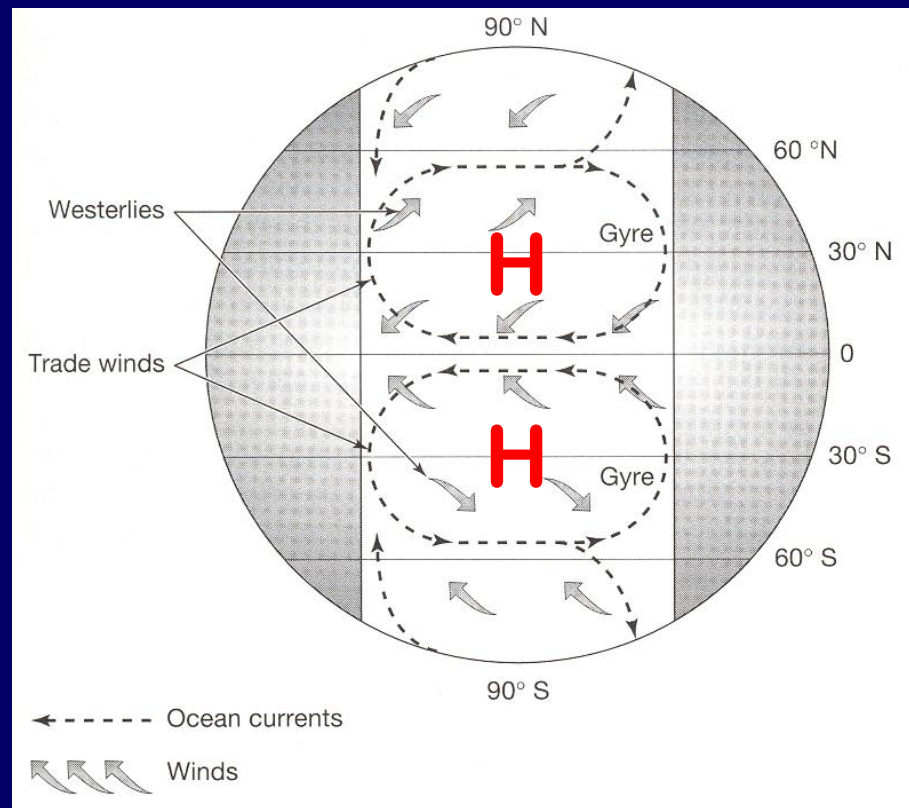
& LE (Latent Energy) transport



H + LE

WHAT ABOUT OCEAN CIRCULATION?

→ Large OCEAN GYRES are driven by Trade Winds & Westerly Winds in Oceanic Subtropical High Pressure Cells

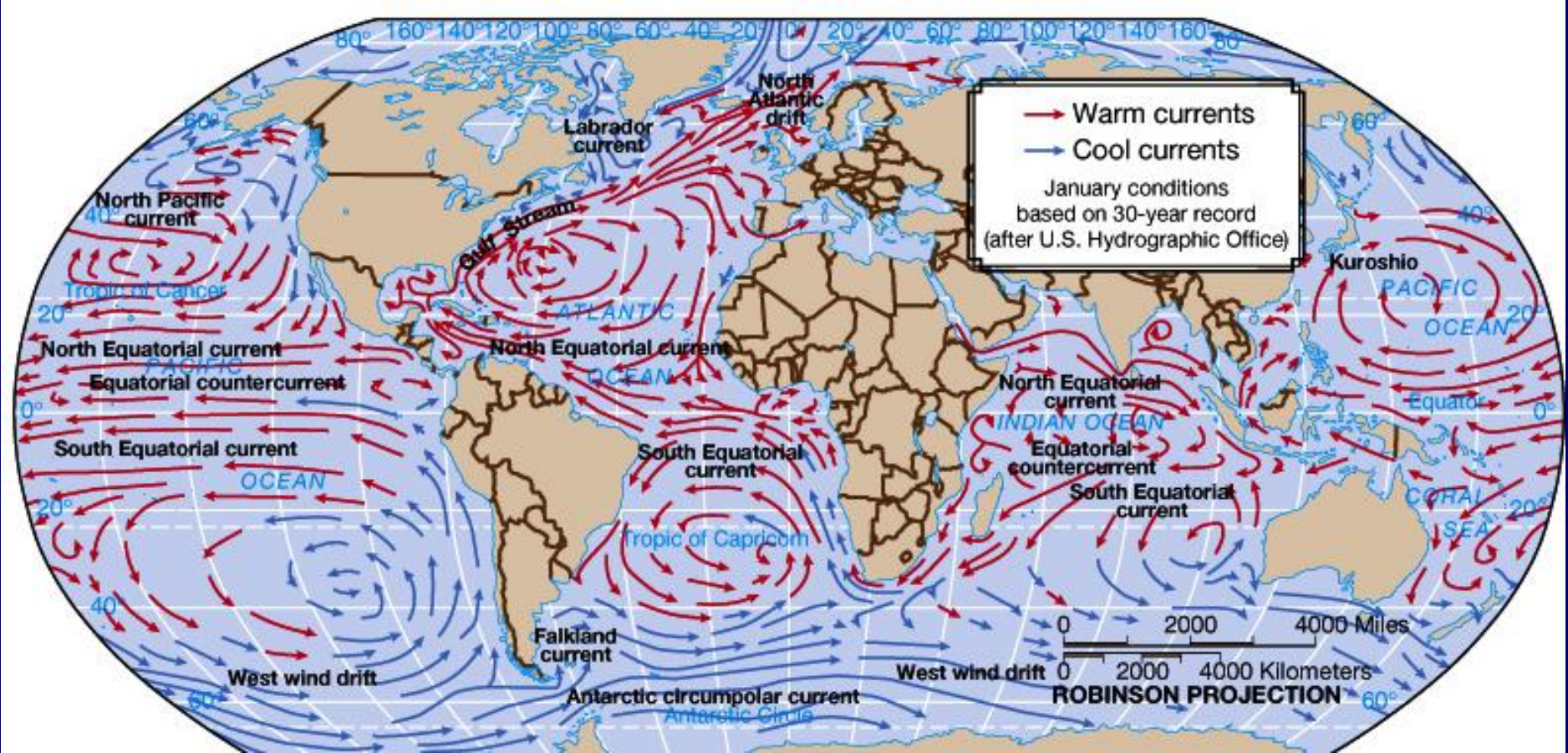


Leads to SURFACE ocean currents

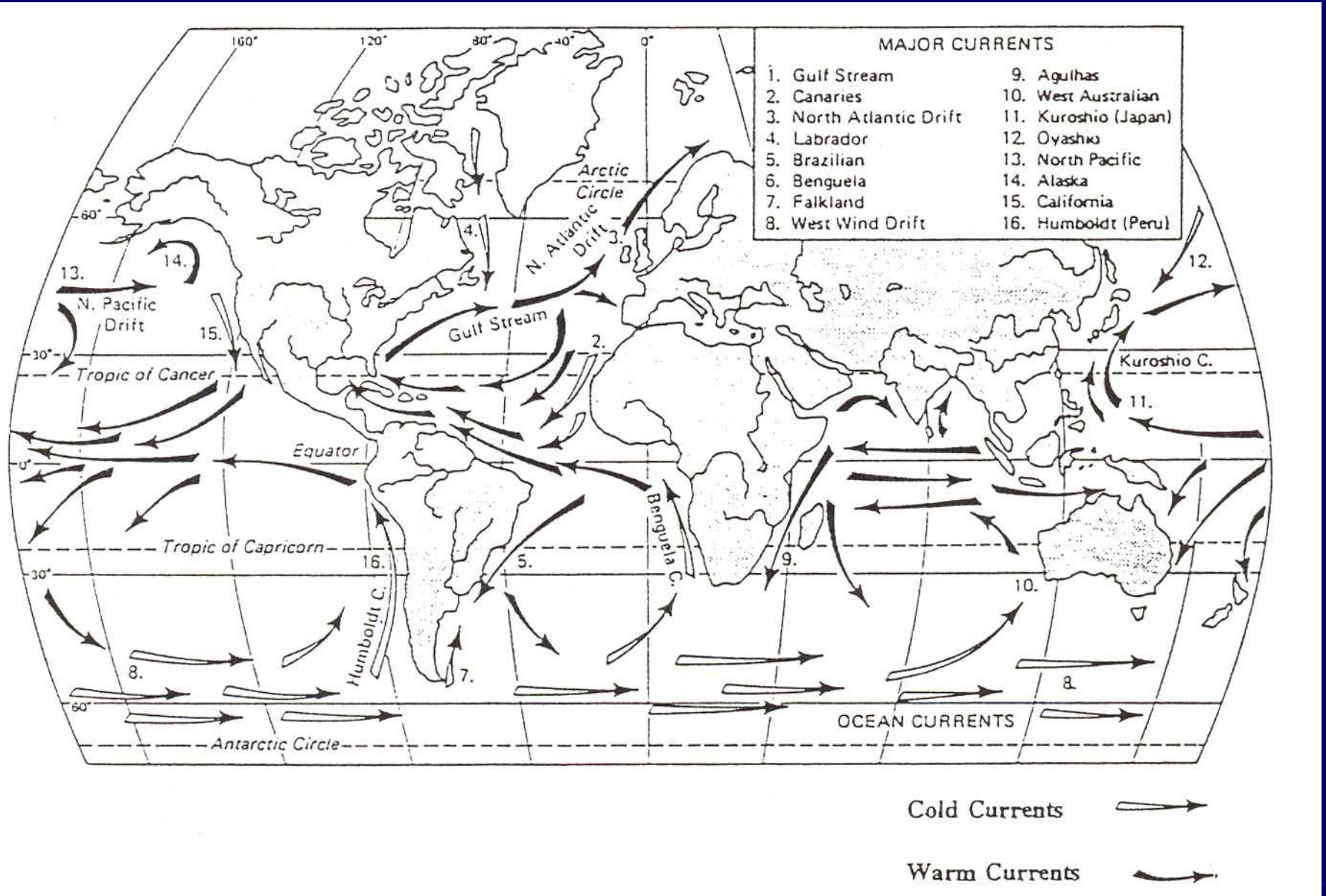
ENERGY TRANSFER IN THE OCEAN

H + LE + G

Energy stored in the OCEAN (as **G**), can later be transported via ocean currents as **H**!

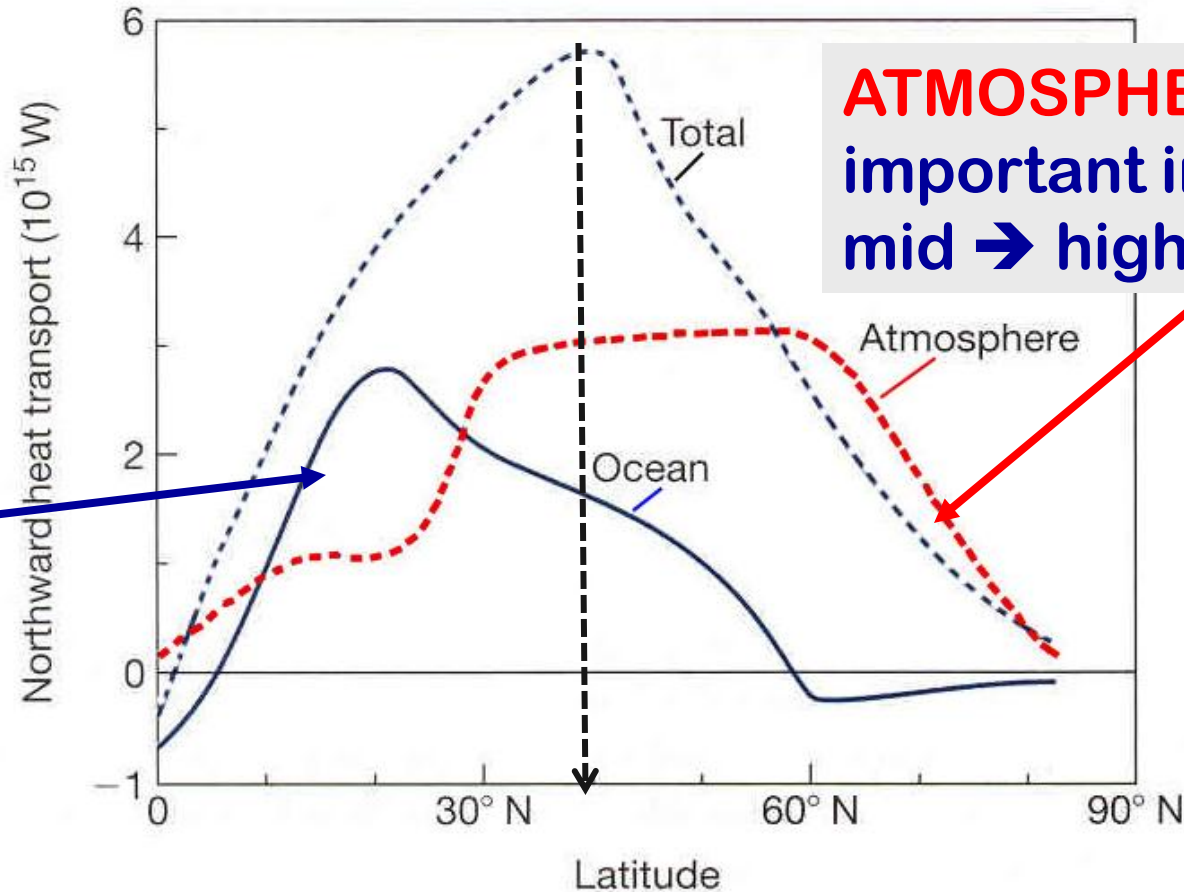


WARM & COLD SURFACE OCEAN CURRENTS:



Both **ATMOSPHERE** & **OCEAN** play important roles in **BALANCING OUT ENERGY SURPLUS & DEFICIT AREAS**:

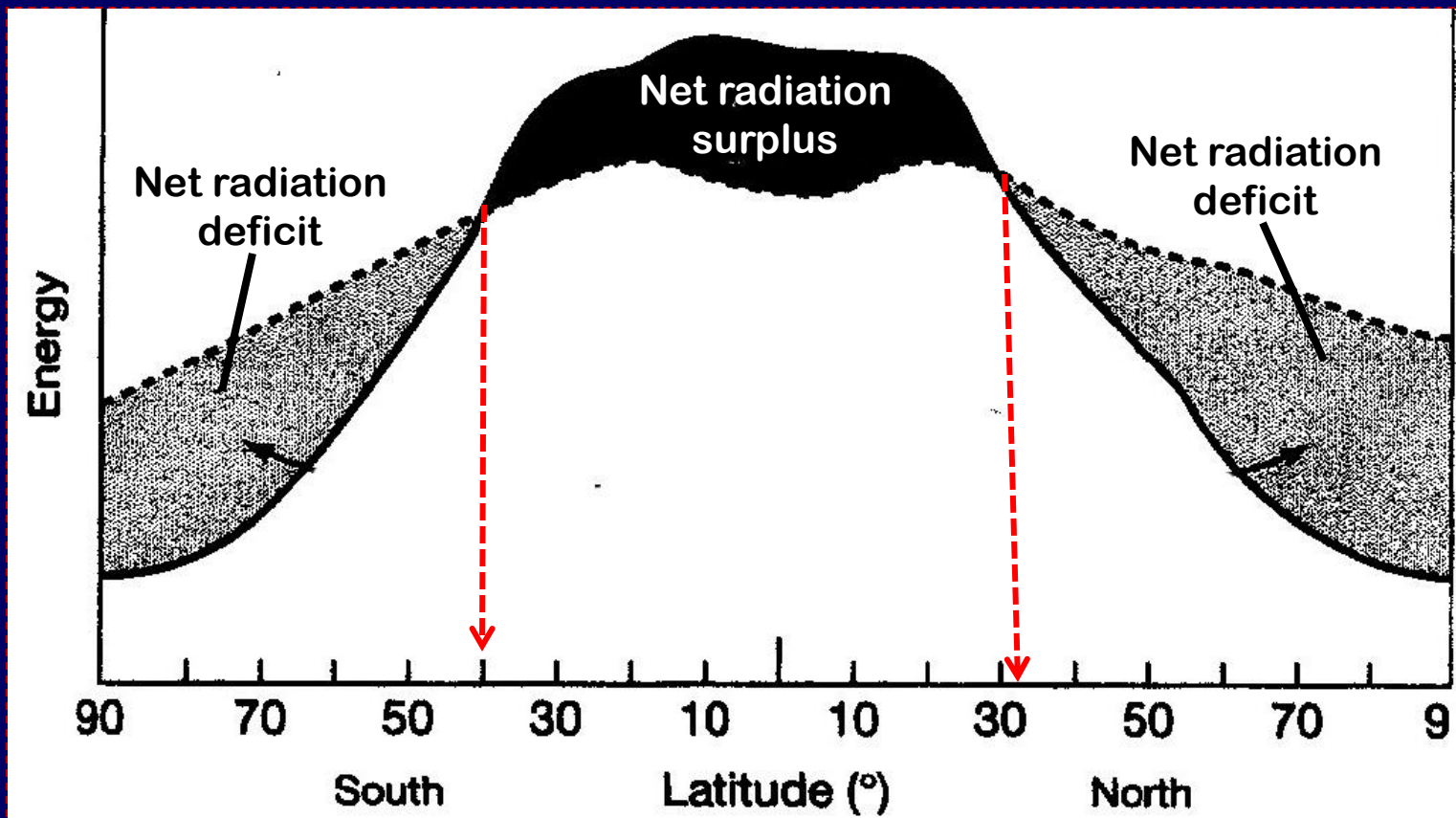
OCEAN transports **MOST** of the energy in **LOW** → subtropical latitudes



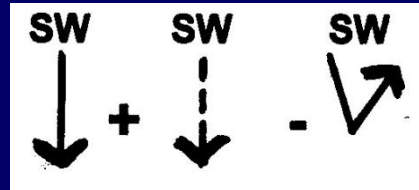
ATMOSPHERE more important in mid → high latitudes

Poleward transport of energy in N.H.





———— Absorbed solar energy



----- Emitted infrared energy
 (at top of atmosphere)



TOO HOT NOT TO HANDLE

TOO HOT NOT TO HANDLE



Global Warming Is The Most Urgent
Threat Facing Humanity Today

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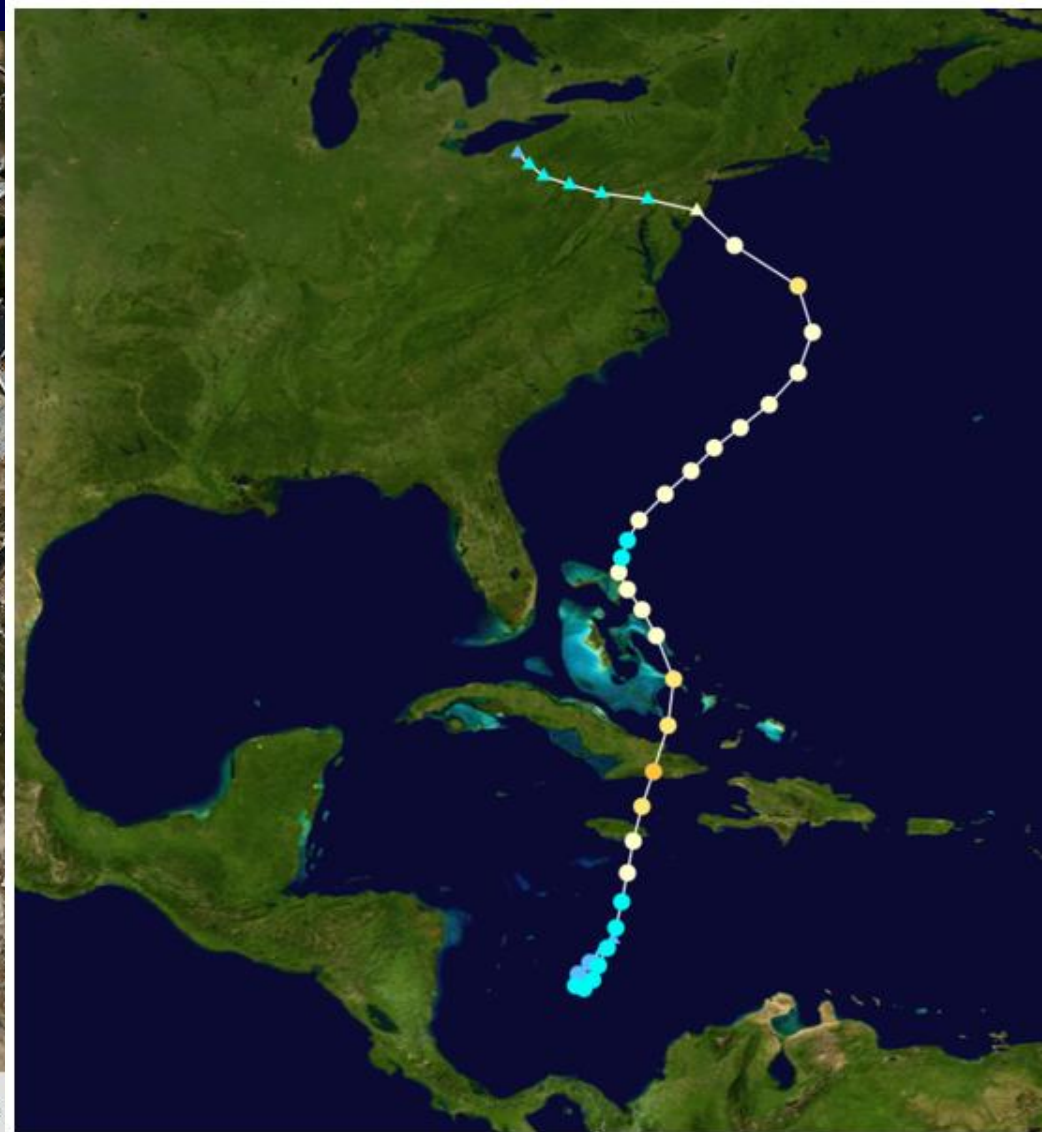


In Sandy's Wake, Flood Zones And Insurance Rates Re-Examined

<http://www.npr.org/2013/10/30/241690144/in-sandys-wake-fema-re-examines-flood-insurance-rates>



One Year Ago: Homes in Mantoloking, N.J., sit in ruin at the end of a bridge



“Superstorm Sandy” late October 2012

In Sandy's Wake, Flood Zones And Insurance Rates Re-Examined



LINKING-TO-LIFE
Part C

Your “project”

QUESTIONS?



ENERGY “VAMPIRES”

One tenth of the
electricity devoured
in our homes
Vanishes as
“standby power”

See: **Natural Resources Defense Council (NRDC)**
“Halloween Energy Survival Guide”

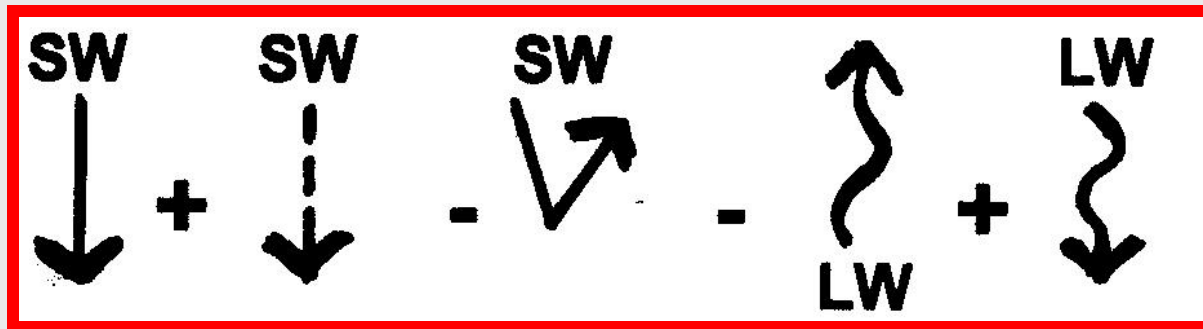
http://switchboard.nrdc.org/blogs/nhorowitz/vampire_slaying_and_more_nrdcs.html

WRAP-UP of G-5 ASSIGNMENT

Applying the Energy Balance Terms

Which component or components working together are most directly related to or responsible for the observed phenomenon???

1 – #12 : Left side of equation

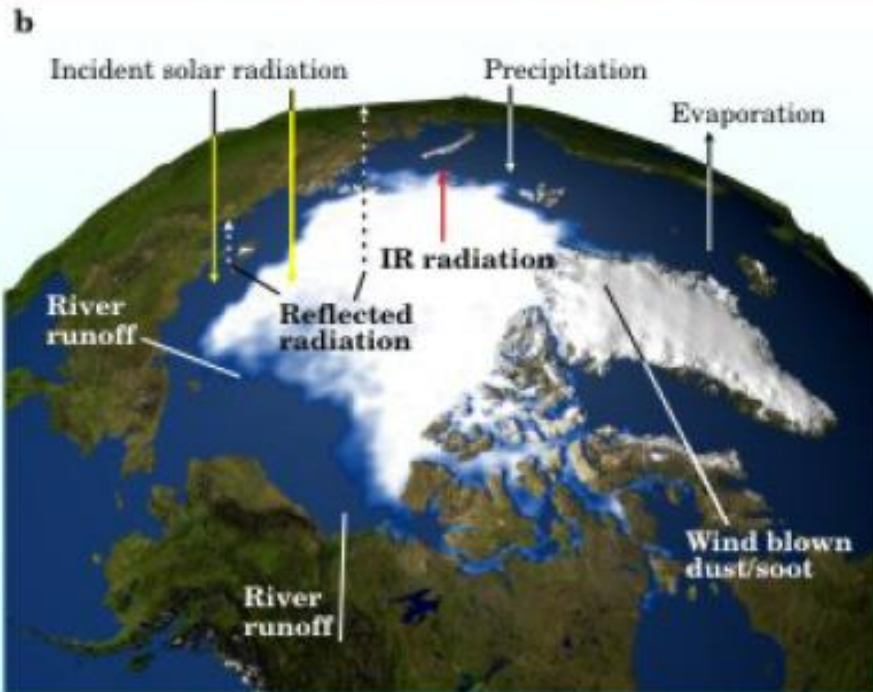
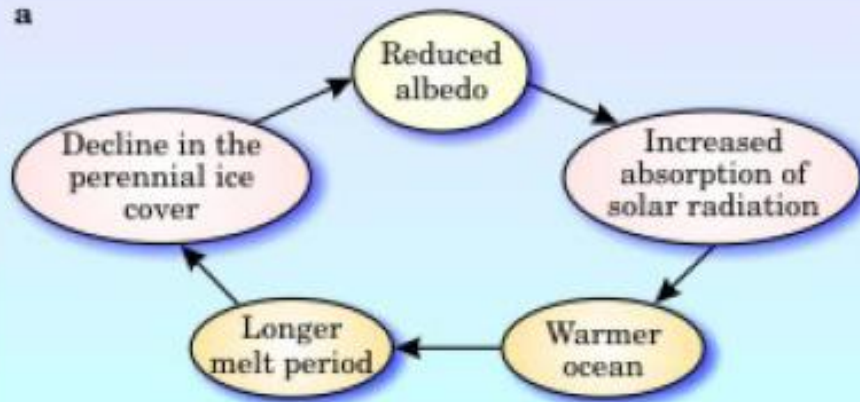


13 - #15: Right side of equation

H + LE + G

REMEMBER FEEDBACK LOOPS:

Is this one positive or negative?



BONUS POINT CHALLENGE :

NOW – on the back of the paper, in your group, complete the feedback loop on **page 65** by linking the components with the proper coupling arrow symbols as used in the SGC text

albedo

START
HERE

Extent of
ice cover

SW
radiation
absorbed



Amount of
melting

Ocean
temperature