Climate Change: The Move to Action
(AOSS 605 (480) // NRE 501.076)

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LECTURE NUMBER 5
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Class News

- There is a ctools site (AOSS 480 001 W07)
  - Lectures have all been added
- Seek good times to make up lectures.
  - Fridays are most likely.
- Some climate stuff
  - The Bar Scene: Thanks, and was it useful?
- Tonight: 7:30 236 Hutchins (Law)
  - The Law and Policy of Global Warming

Class News

- February 2, 2007, the official summary for IPCC should be released. The rest of the report will follow over the year.
- Next Reading: Parts of The Scientific Basis of the 2001 Report
  - http://www.grida.no/climate/ipcc_tar/
    - Chapters 9, 10, 11
    - We will compare and contrast with the new report

Ideas and Things

- Anyone hear or read any news they want to discuss.
  - Climate Action Partnership
  - State of the Union
- Projects?

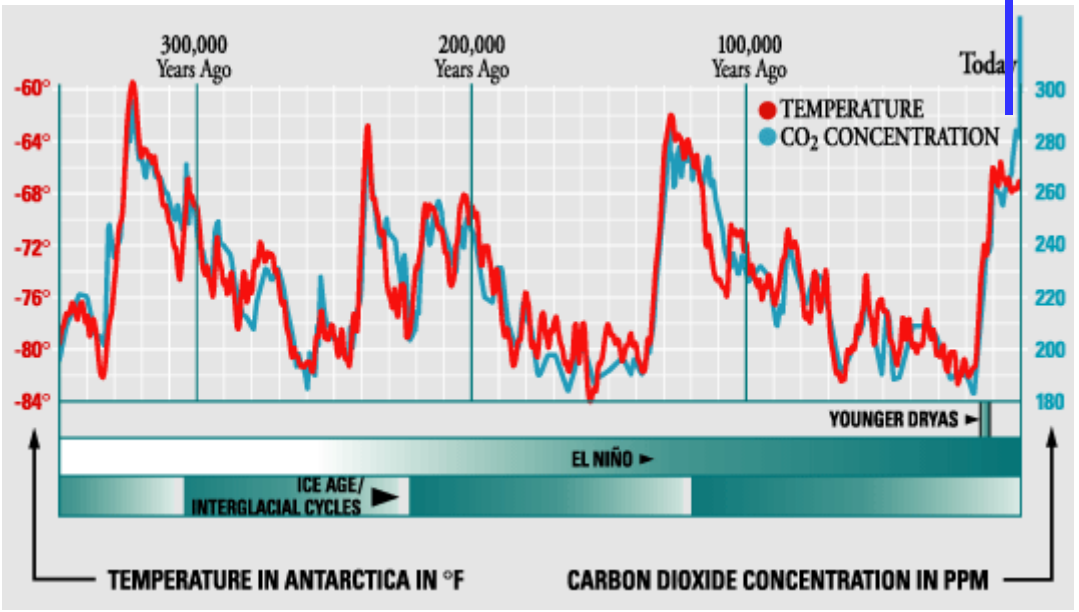
Science Basis of Climate Change (2)

CO_2 and T Variation

460 ppm CO_2 2100

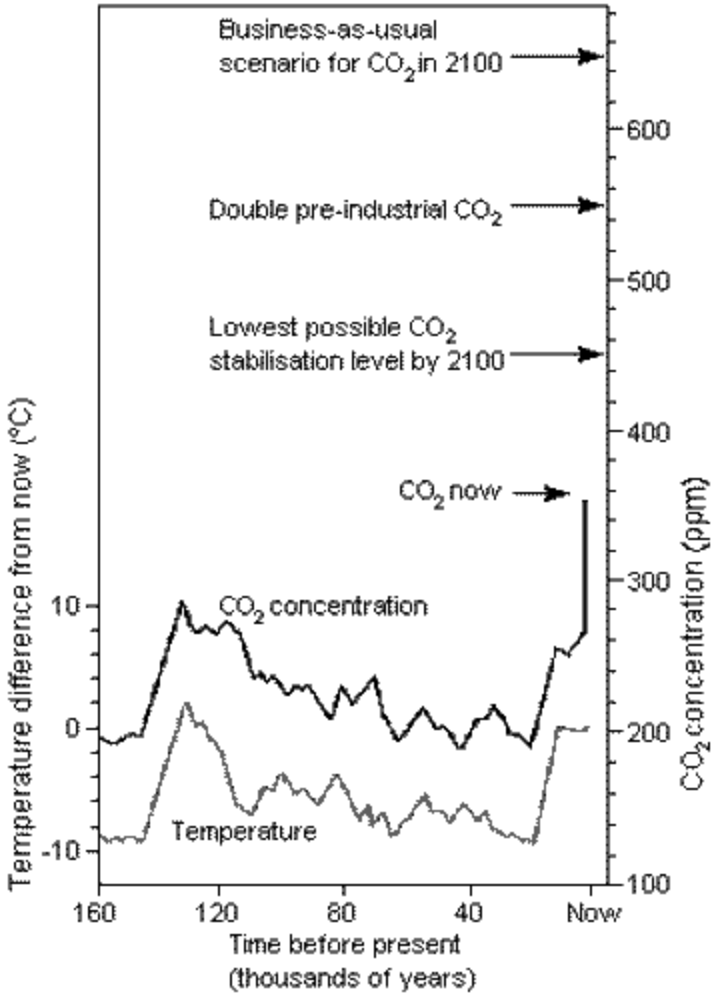
360 ppm CO_2 2005

350,000 years of Surface Temperature and Carbon Dioxide (CO_2) at Vostok, Antarctica ice cores



- Carbon dioxide is, because of our emissions, much higher than ever experienced by human kind
- Temperature is expected to follow
  - New regimes of climate behavior?
  - Humans are adapted to current climate behavior.
- The change is expected to happen rapidly (10 -100 years, not 1000's)

What about the CO_2 increase?



How do we get these numbers?

From the Ice Core Data: Questions?

- We see a relationship between carbon dioxide (CO_2) and Temperature (T)
  - What is the cause and effect?
  - Why do we bounce between these two regimes?
  - Dynamic equilibrium?
- Are these oscillations forced in some way by an external force?
  - Are there other parameters or attributes which are correlated with this behavior?

What do we see from the past 1000 years

- On shorter time scales the CO_2 and T are not cleanly related.
- Periods on noted warmth and coolness are separated by changes in average temperature of only 0.5 F.
- Changes of average temperature on this scale seem to matter to people.
  - Regional changes, extremes?
- Recent changes in both T and CO_2 are unprecedented.

Conservation (continuity) principle

- There are certain parameters, for example, energy, momentum, mass (air, water, ozone, number of atoms, …) that are conserved.
  - "classical" physics, we're not talking about general or special relativity!
  - Simple stuff, like billiard balls hitting each other, ice melting
- Conserved? That means that in an isolated system that the parameter remains constant; it's not created; it's not destroyed.
- Isolated system? A collection of things, described by the parameter, that might interact with each other, but does not interact with other things. Nothing comes into or goes out of the system … or, perhaps, nothing crosses the boundary that surrounds the system.

Conservation Principle seem intuitive for money

- The conservation principle is posited to apply to energy, mass (air, water, ozone, ...), momentum.
- Much of Earth science, science in general, is calculating budgets based on the conservation principle
  - What is the balance or imbalance
    - If balanced, then we conclude we have factual information on a quantity.
    - If unbalanced, then there are deficiencies in our knowledge. Tangible uncertainties.

Conservation Principle
(Developed with idea of money: a budget)

What you have = what you had + what you earned - what you spent

$$(\mathbf{M}_{\text{tomorrow}} - \mathbf{M}_{\text{yesterday}})/N = \mathbf{\Delta M/\Delta t} = I - e\mathbf{M}$$

Δ ≡ Difference *i.e.* $M(t_2)-M(t_1)$

Income

Expense

Change per unit time

$$\frac{\Delta \mathrm{M}}{\Delta \mathrm{t}} = I - e\mathrm{M} = \text{Production - Loss}$$

Continuous equation in limit of small Δt

$$\frac{d\mathrm{M}}{d\mathrm{t}} = P - L$$

Conservation Principle
"in balance"

If a quantity is conserved or "in balance" then

Change per unit time = 0

$$\frac{\Delta \mathrm{M}}{\Delta \mathrm{t}} = \frac{d\mathrm{M}}{d\mathrm{t}} = 0$$

$$P = L$$

Production = Loss

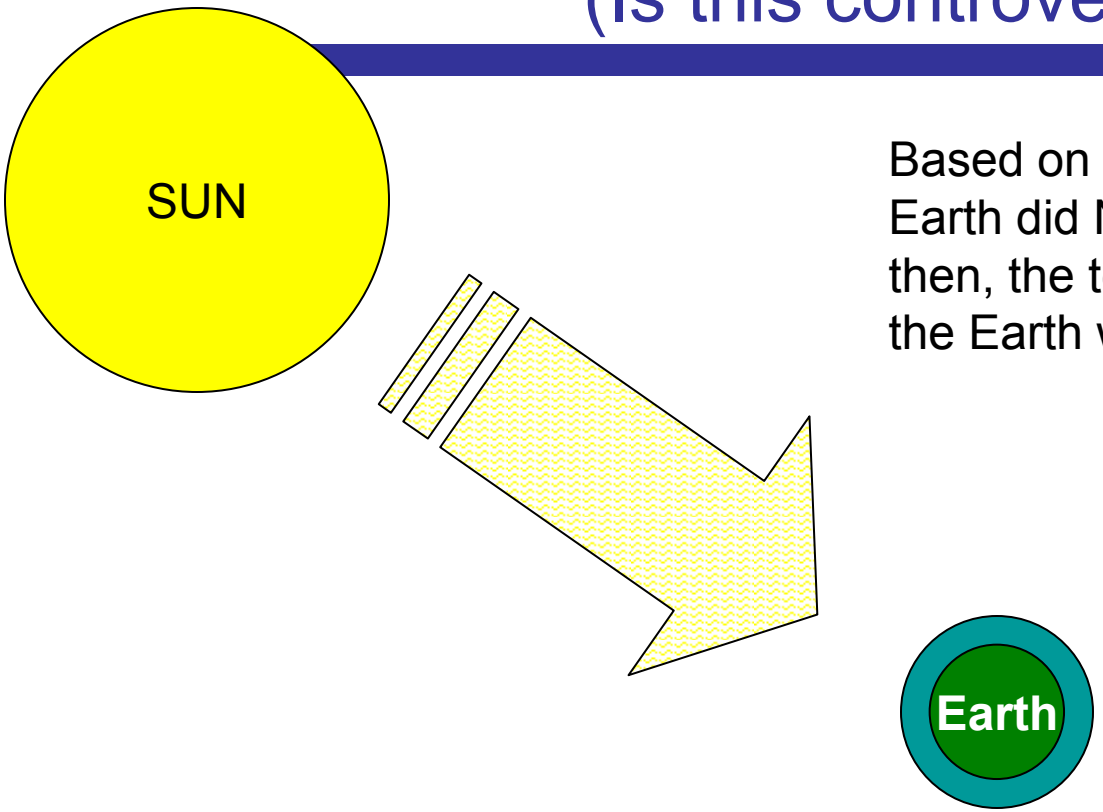
The first place that we apply the conservation principle is energy

- Assume that Energy is proportional to T, if the average temperature of the Earth is stable, it does not vary with time.

$$\frac{\Delta T}{\Delta t} = 0 = \text{Production - Loss}$$

$$\text{Production} = \text{Loss}$$

The Greenhouse Effect (Is this controversial?)



Based on conservation of energy: If the Earth did NOT have an atmosphere, then, the temperature at the surface of the Earth would be about -18 C (~ 0 F).

But the Earth's surface temperature is observed to be, on average, about 15 C (~59 F).

This greenhouse effect in not controversial.

This temperature, which is higher than expected from simple conservation of energy, is due to the atmosphere. The atmosphere distributes the energy vertically; making the surface warmer, and the upper atmosphere cooler, which maintains energy conservation. We are making the atmosphere "thicker."

The first place that we apply the conservation principle is energy

- If we change a greenhouse gas e.g. CO_2, we change the loss rate. For some time we see that the Earth is NOT in balance, that is $\Delta T/\Delta t$ is not zero, temperature changes.

$$\frac{\Delta T}{\Delta t} = H - \lambda T$$

$$H = \text{Heating} = \text{Production} = \text{Loss}$$

$$\lambda T = \text{Cooling} = \text{Loss}$$

The first place that we apply the conservation principle is energy

- We reach a new equilibrium

$$\frac{\Delta T}{\Delta t} = 0 = H - \lambda T$$

$$\text{Production} = \text{Loss}$$

$$T = \frac{H}{\lambda}$$

Changing a greenhouse gas changes this

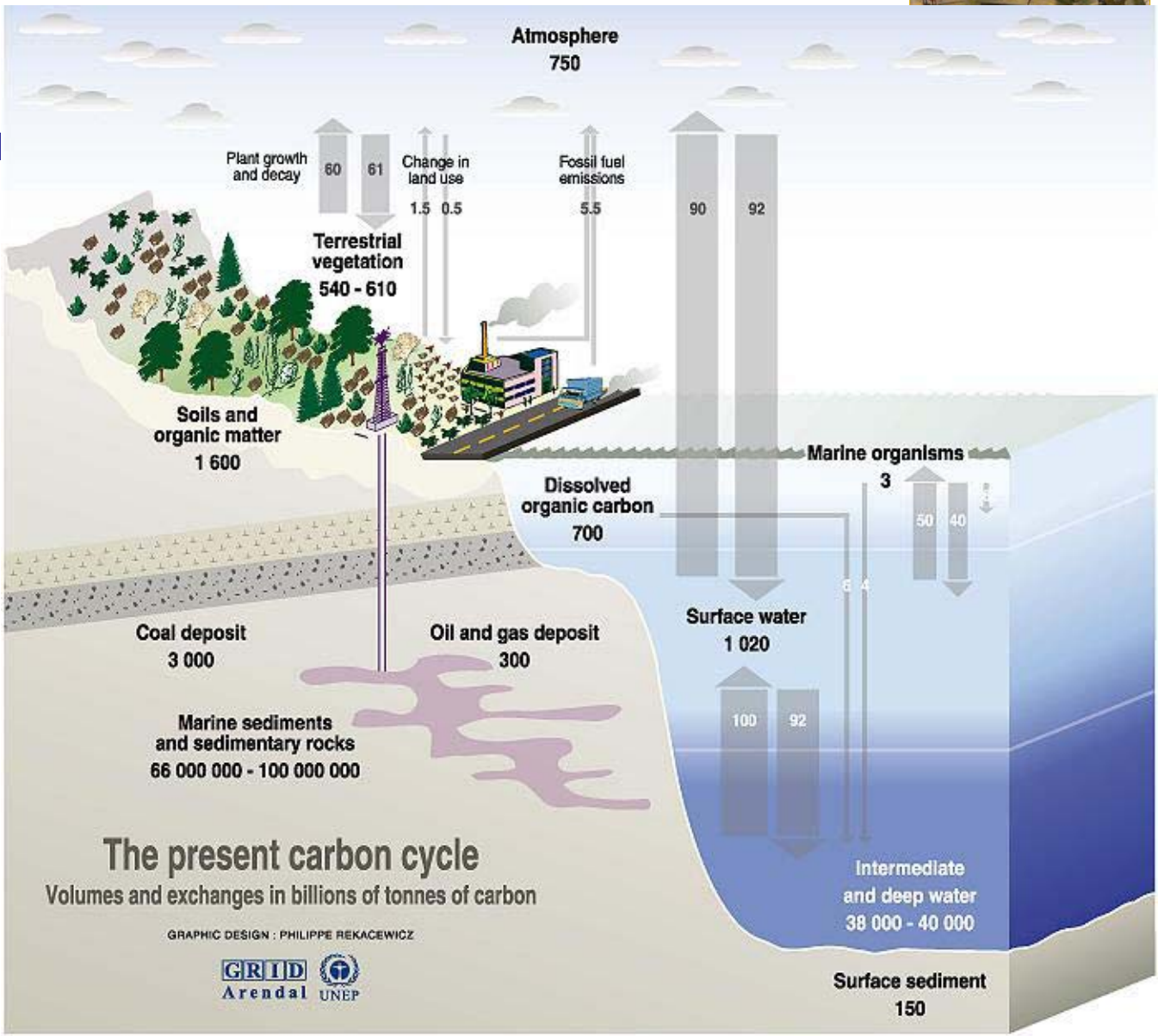
Still there are many unanswered questions

- We have a plausible role for CO_2, but do we have cause and effect?
- Why those big oscillations in the past?
- What about the relation between CO_2 and T in the last 1000 years?
- Greenhouse gases other than CO_2?

Conservation principle for CO_2

$$\frac{\Delta CO_2}{\Delta t} = \text{Production} - \text{Loss}$$

What are the mechanisms for production and loss of CO_2?



Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

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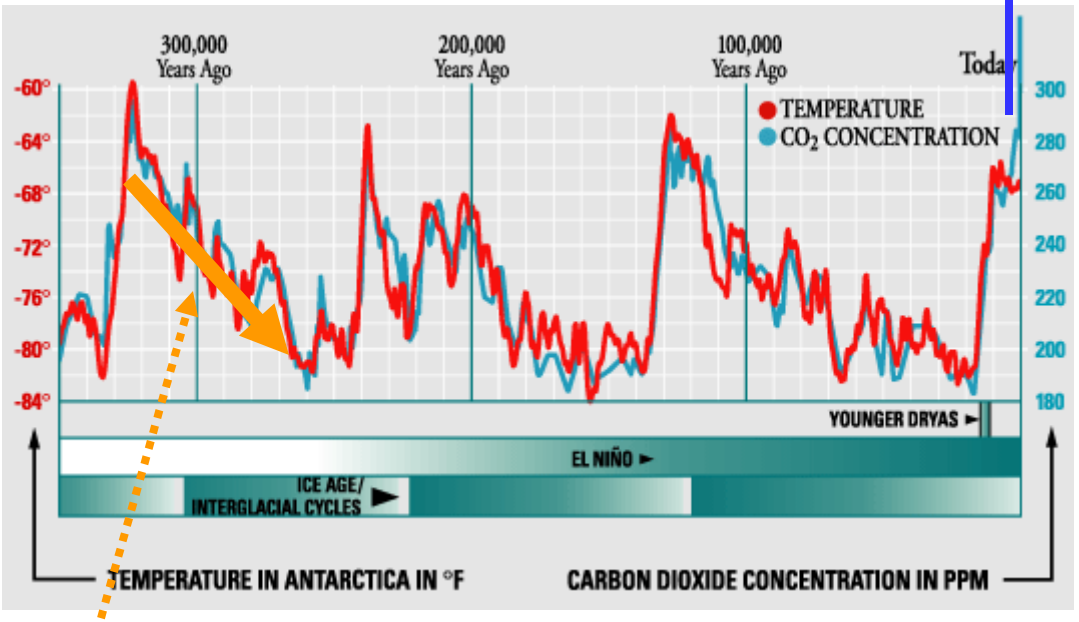
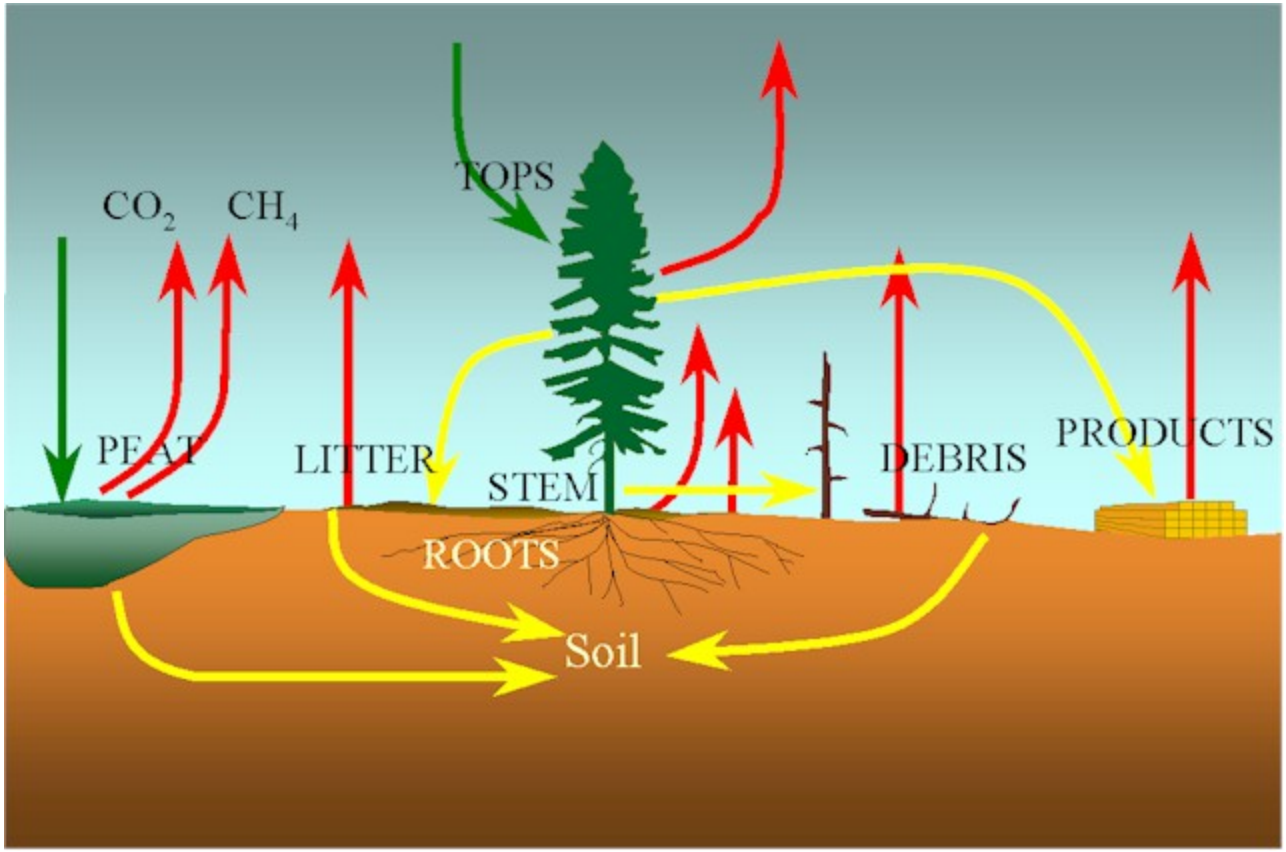
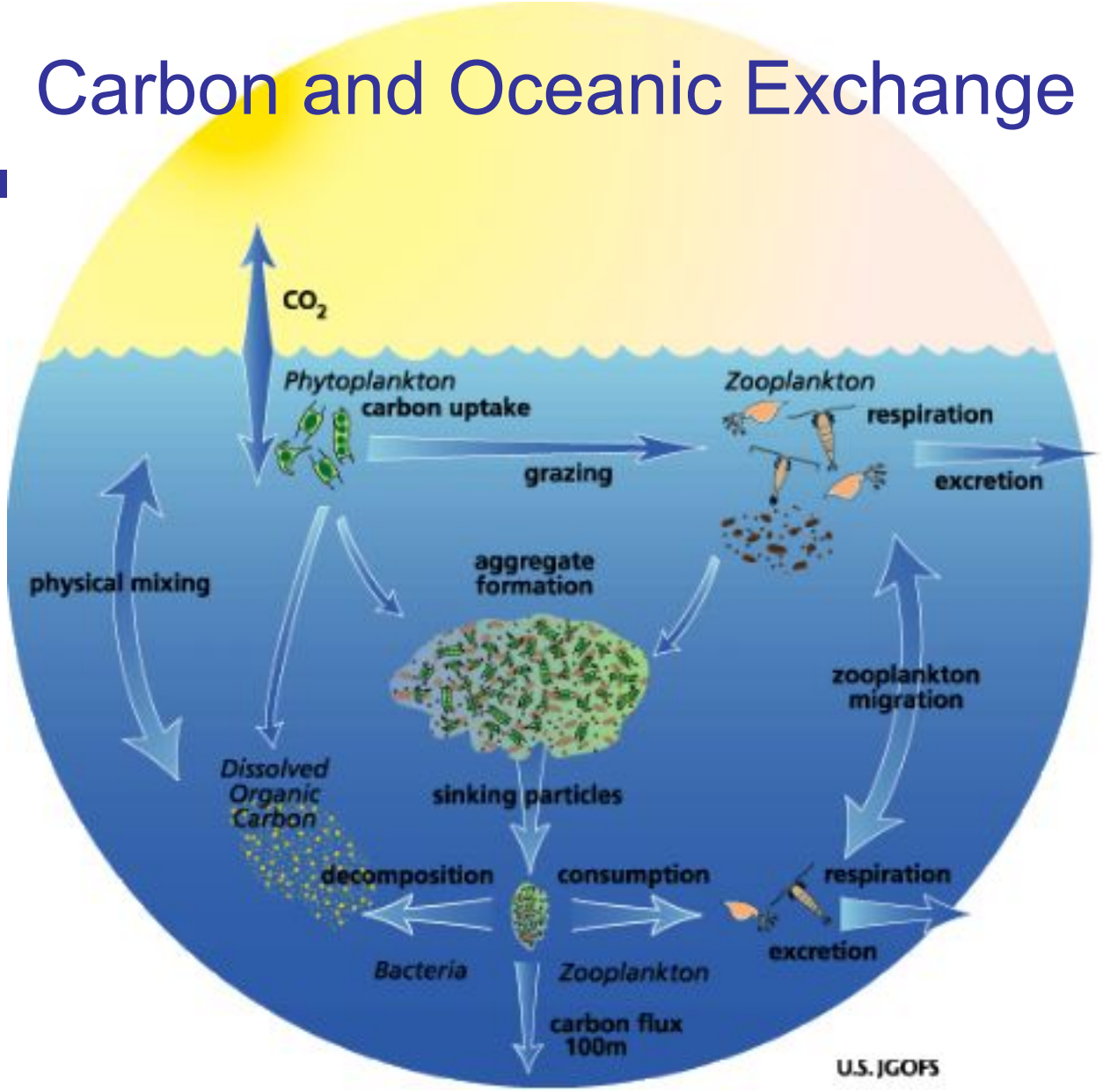


NEED TO EXPLAIN THIS REDUCTION OF CO_2

Carbon and Terrestrial Exchange



Carbon and Oceanic Exchange



Reduction in CO_2

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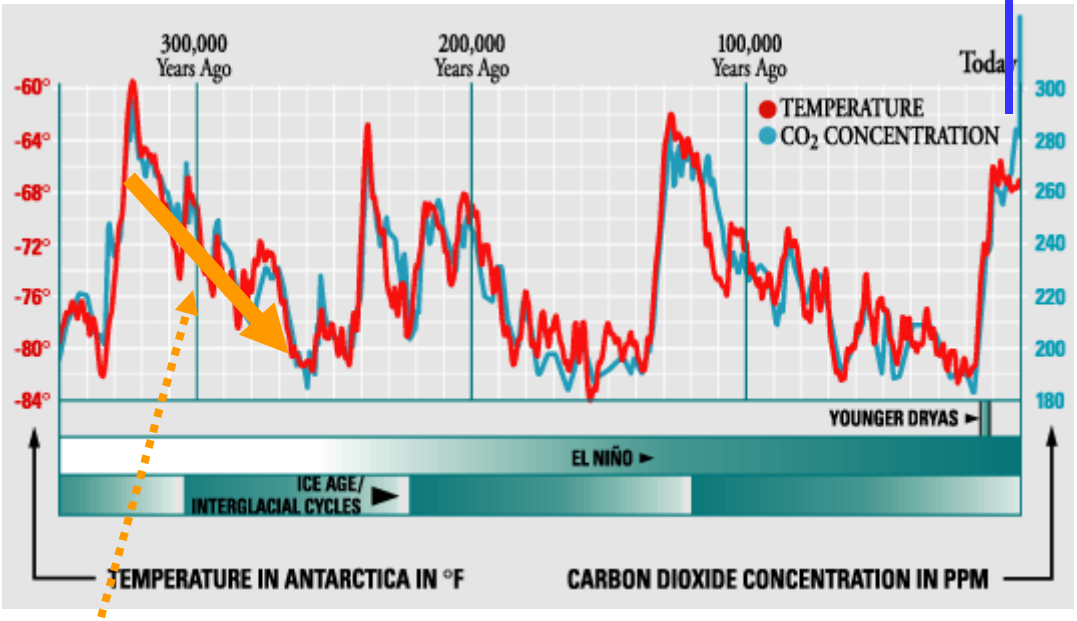


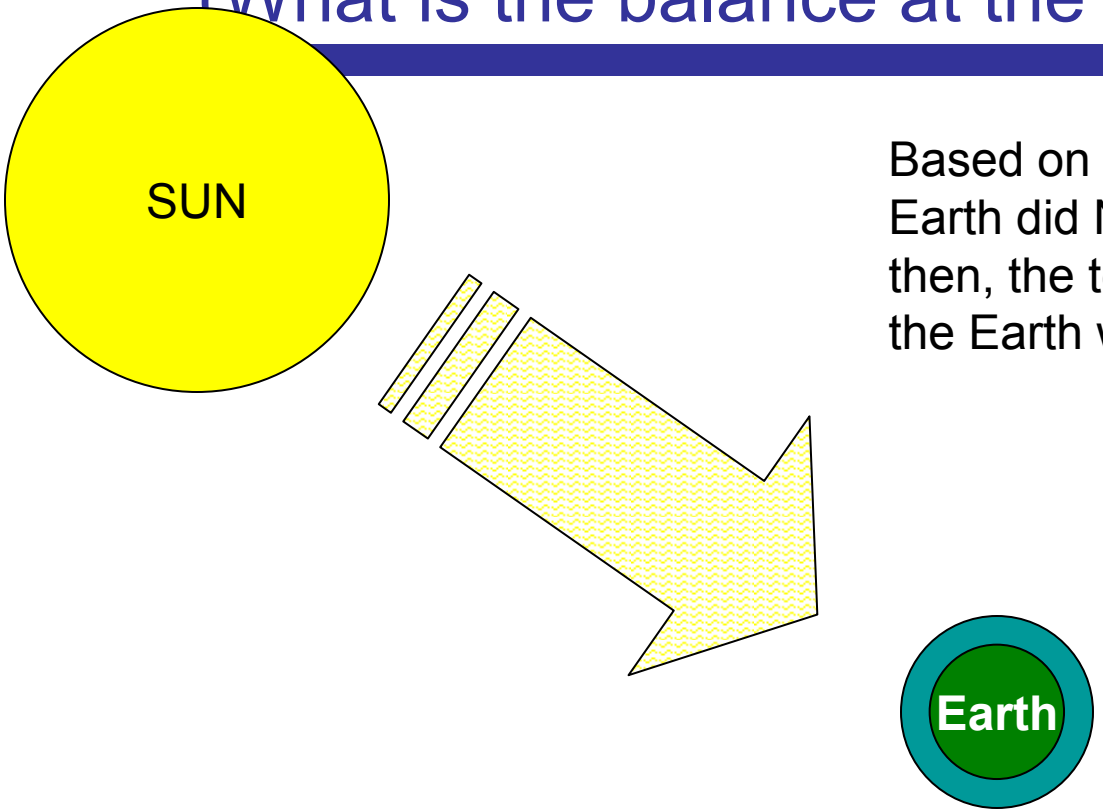
THIS REDUCTION OF CO_2 IS RELATED TO BIOLOGY.
Dominance of the oceanic sink?

A summary of sorts

- We have the plausible reduction of CO_2 from the oceanic sink
- We have the change in the Earth's cooling rate due to changes in CO_2 (or other greenhouse gases)

- Still though: Do we have cause and effect and an understanding of the past oscillation between ice ages and temperate periods?

The sun-earth system
(What is the balance at the surface of Earth?)



Based on conservation of energy: If the Earth did NOT have an atmosphere, then, the temperature at the surface of the Earth would be about -18 C (~ 0 F).

What else could be happening in this system?

But the Earth's surface temperature is observed to be, on average, about 15 C (~59 F).

This greenhouse effect in not controversial.

Conservation of Energy

- The heating could change. That is the sun, the distance from the sun, ...

$$\frac{\Delta T}{\Delta t} = H - \lambda T$$

$$H = \text{Heating} = \text{Production} = \text{Loss}$$

$$\lambda T = \text{Cooling} = \text{Loss}$$

The first place that we apply the conservation principle is energy

- We reach a new equilibrium

$$\frac{\Delta T}{\Delta t} = 0 = H - \lambda T$$

Can we measure the imbalance when the Earth is not in equilibrium?

Production = Loss

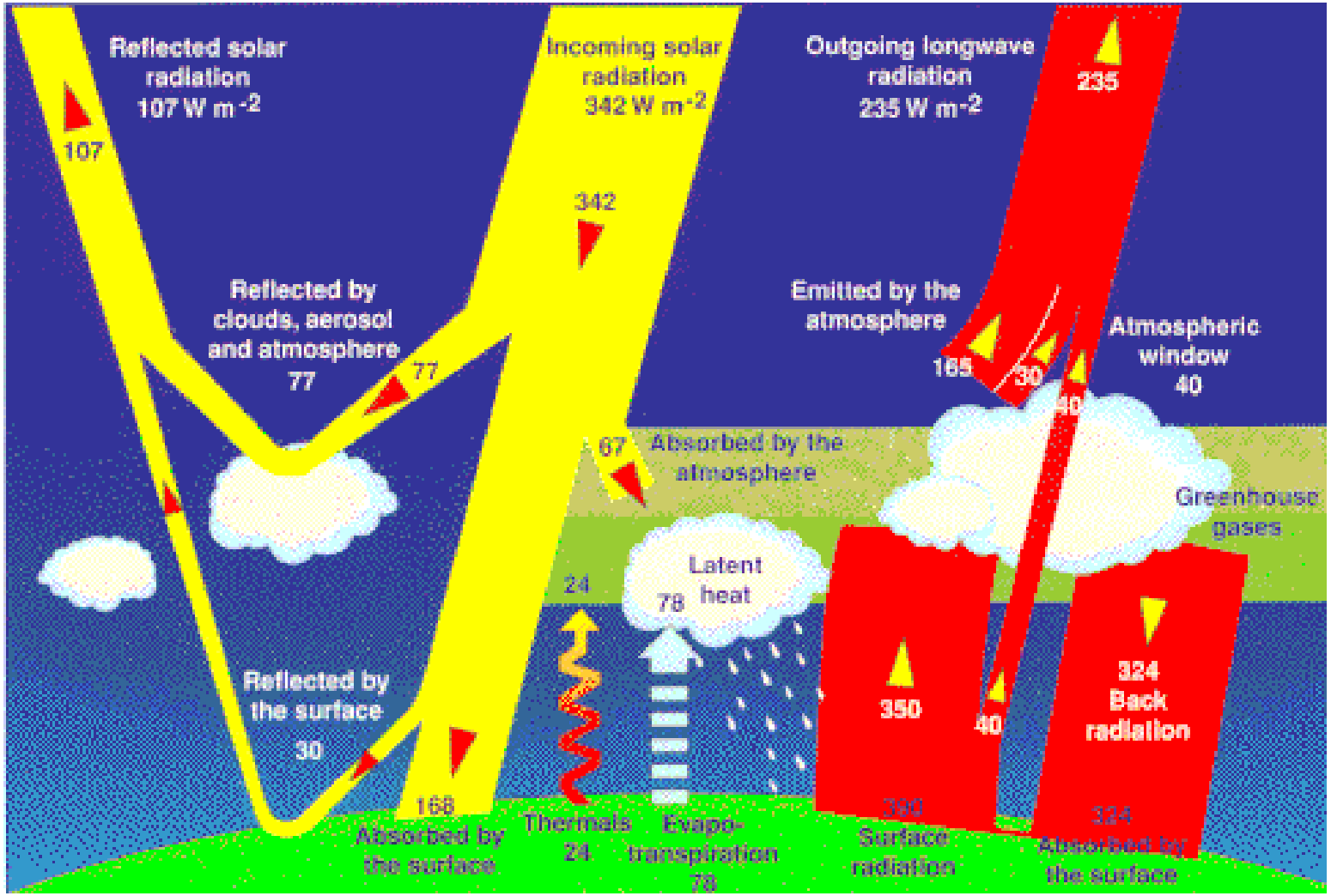
$$T = \frac{H}{\lambda}$$

Changes in orbit or solar energy changes this

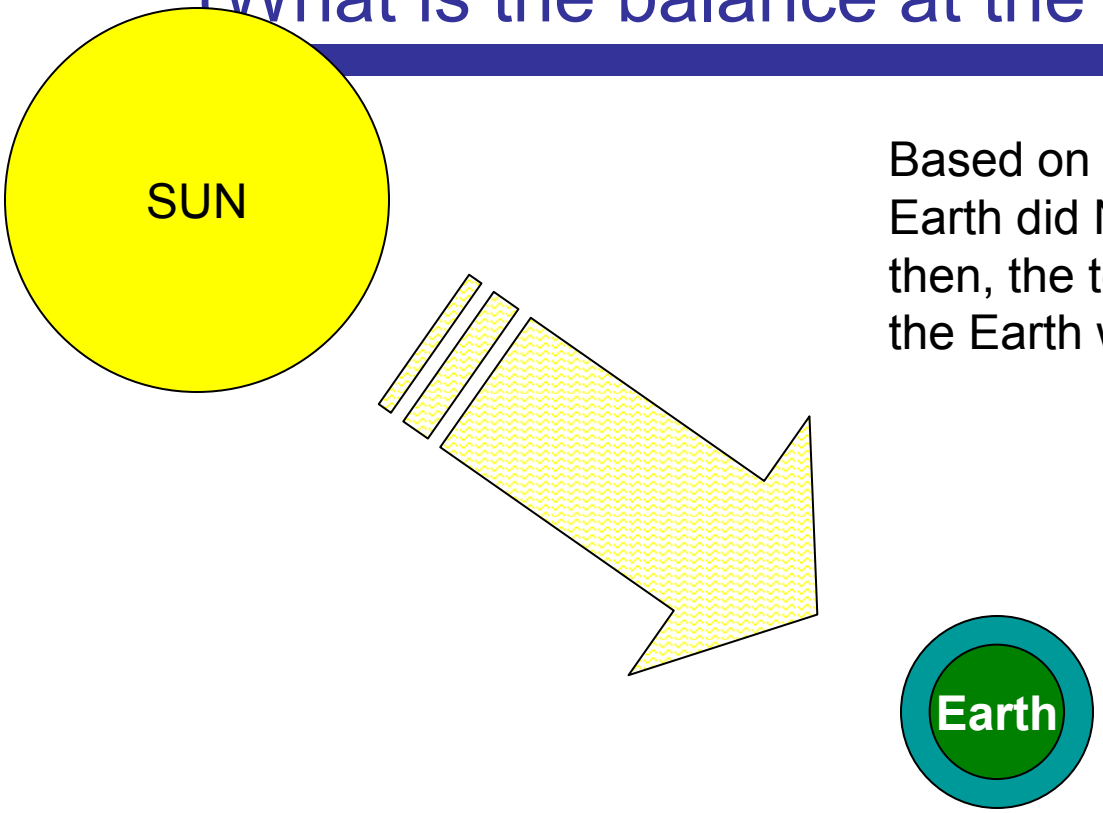
Radiative Balance of The Earth

- Over some suitable time period, say a year, maybe ten years, if the Earth's temperature is stable then the amount of energy that comes into the Earth must equal the amount of energy that leaves the Earth.
  - Energy comes into the Earth from solar radiation.
  - Energy leaves the Earth by terrestrial (mostly infrared) radiation to space.
    - (Think about your car or house in the summer.)

Radiation Balance Figure



The sun-earth system
(What is the balance at the surface of Earth?)



Based on conservation of energy: If the Earth did NOT have an atmosphere, then, the temperature at the surface of the Earth would be about -18 C (~ 0 F).

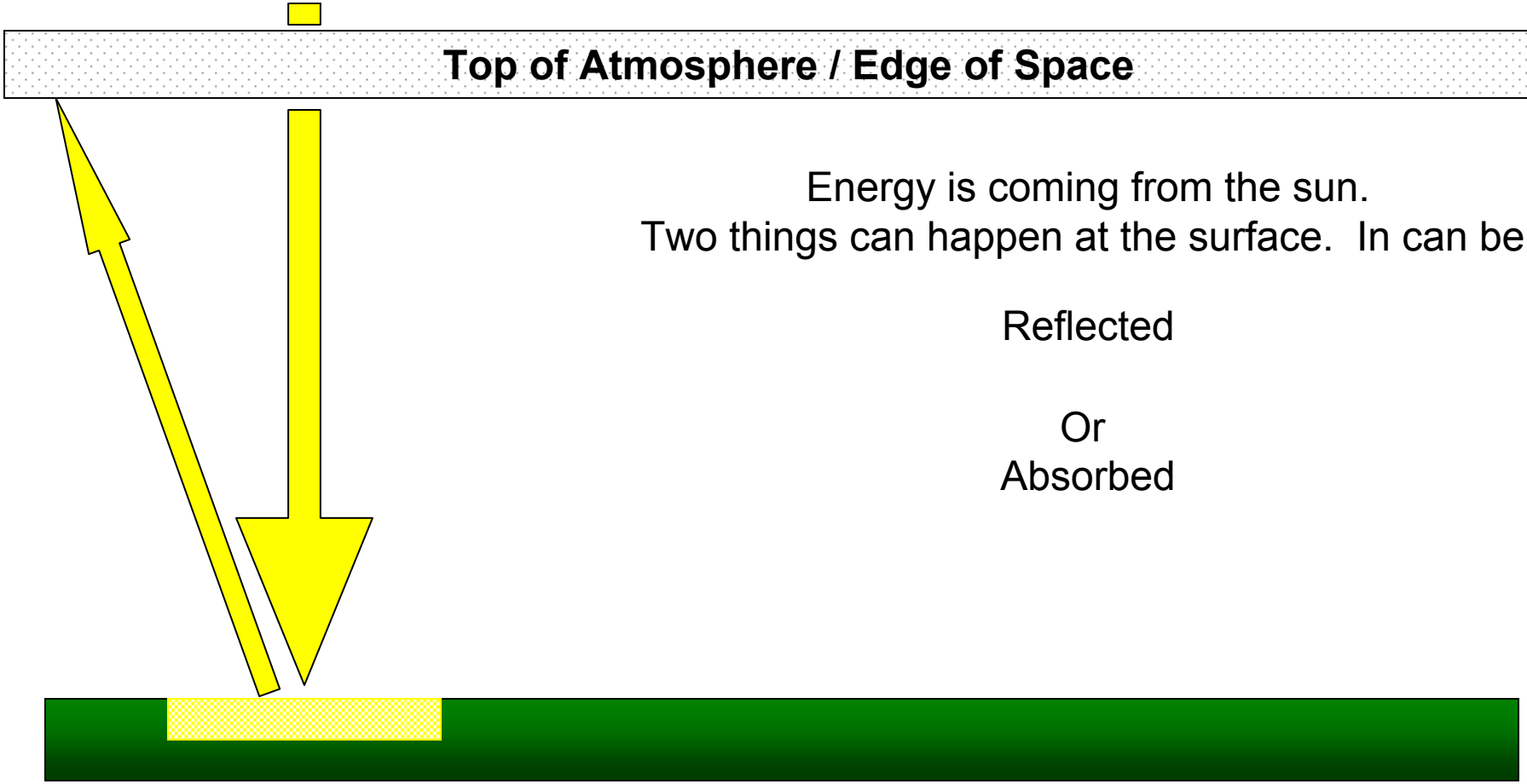
(will revisit this) Welcome Back

Radiative Balance. This is conservation of energy, which is present in electromagnetic radiation.

But the Earth's surface temperature is observed to be, on average, about 15 C (~59 F).

Building the Radiative Balance

What happens to the energy coming from the Sun?



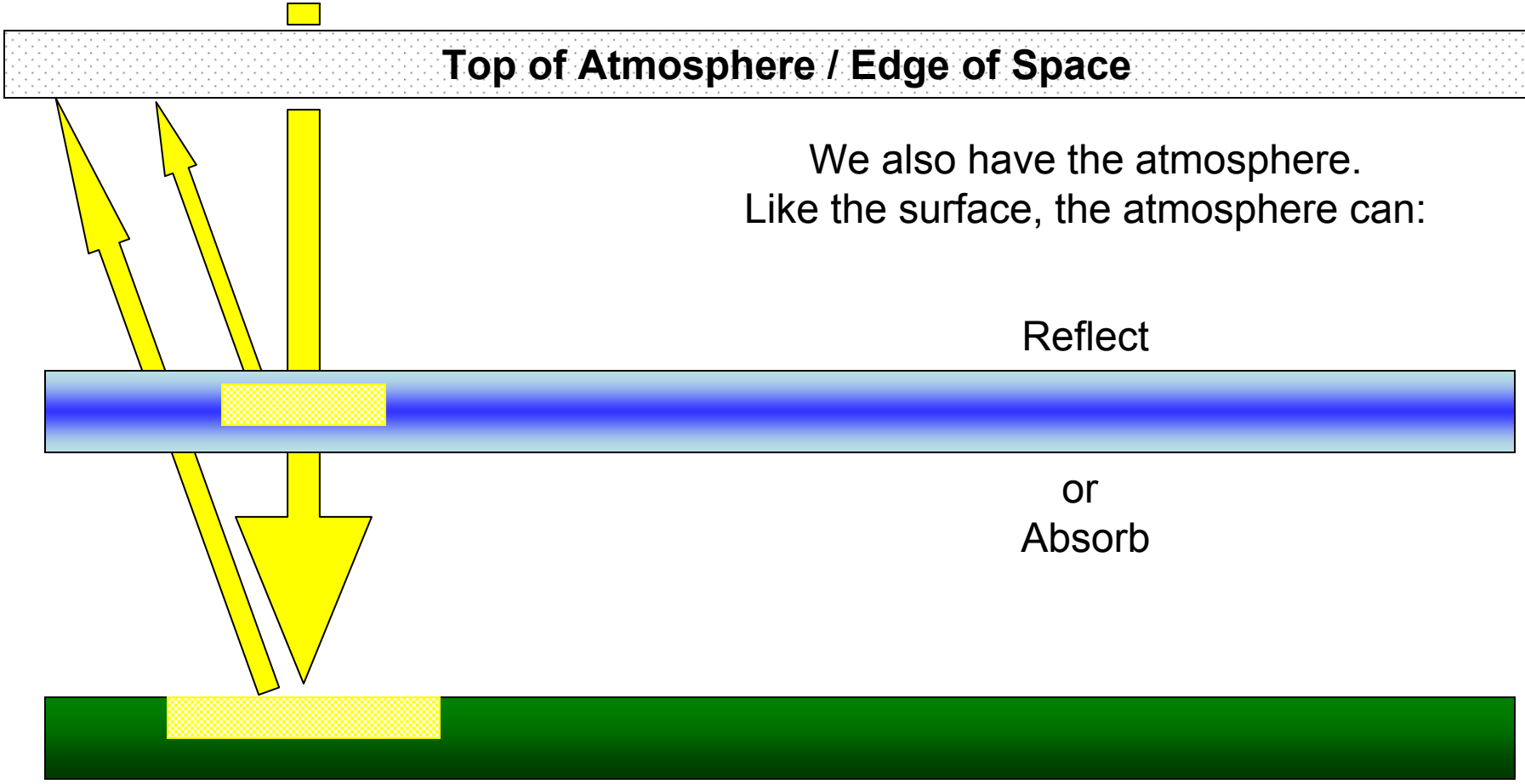
Energy is coming from the sun.
Two things can happen at the surface. In can be:

Reflected

Or
Absorbed

Building the Radiative Balance

What happens to the energy coming from the Sun?



We also have the atmosphere.
Like the surface, the atmosphere can:

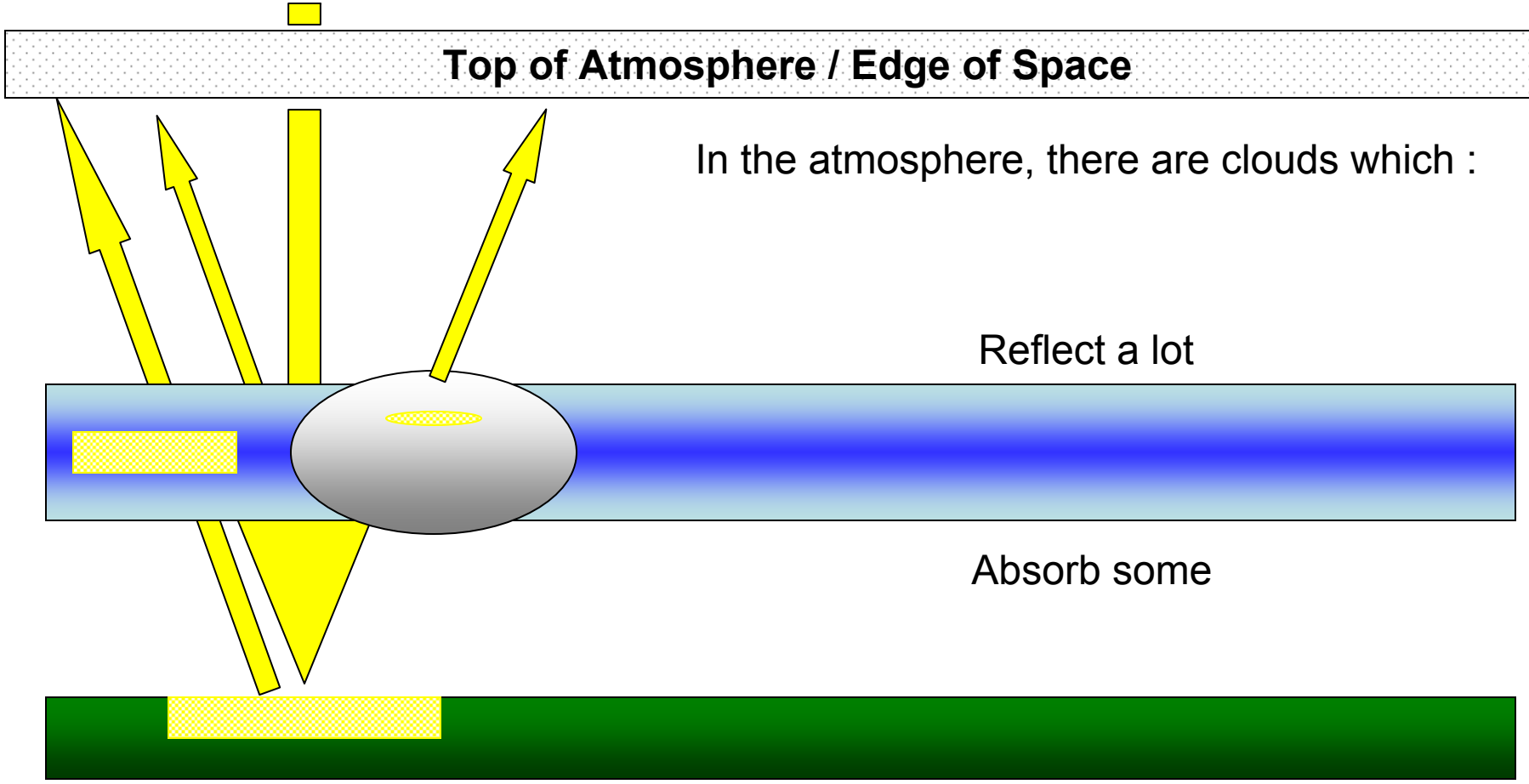
Reflect

or

Absorb

Building the Radiative Balance

What happens to the energy coming from the Sun?



Building the Radiative Balance

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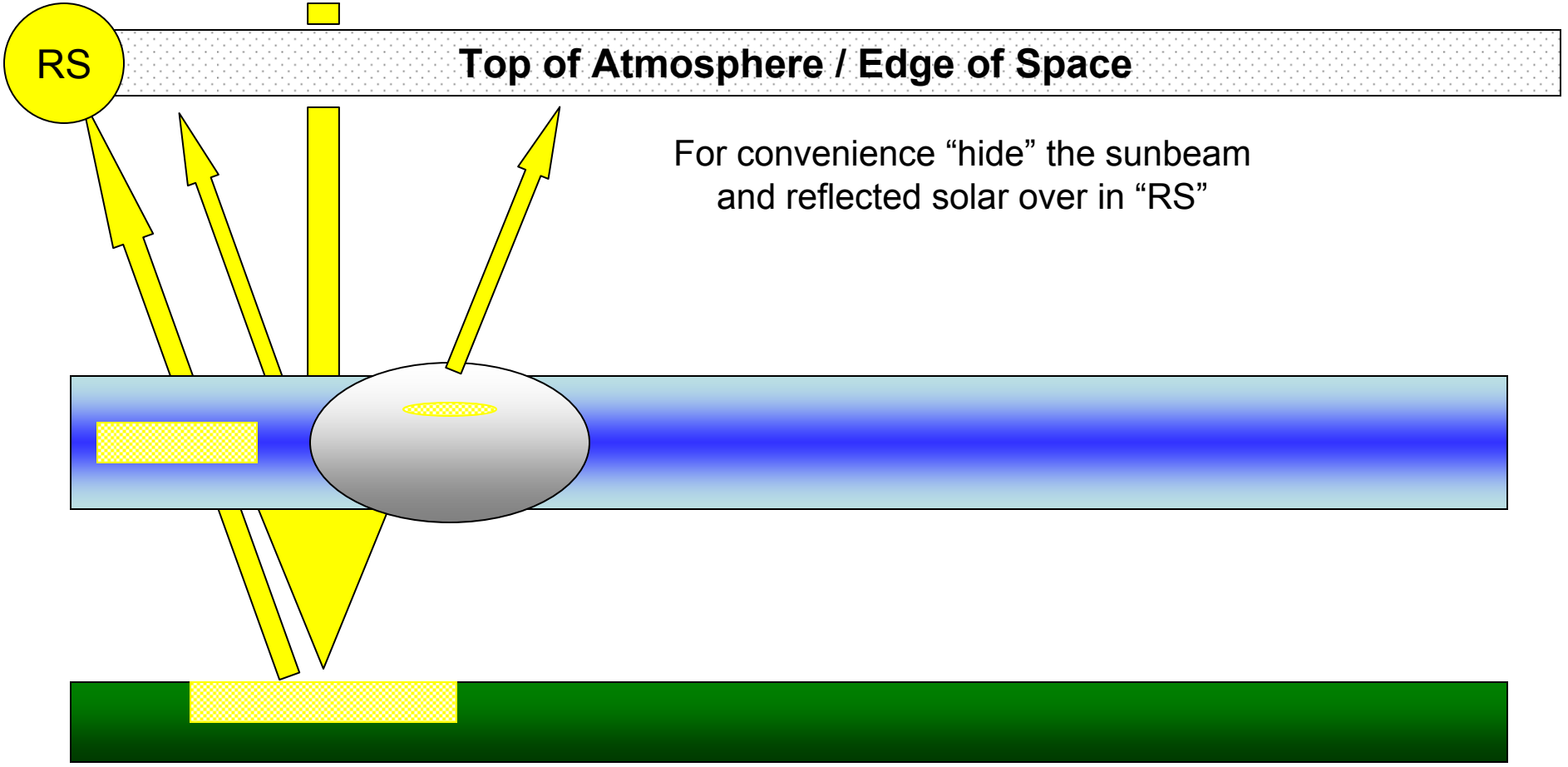


For convenience “hide” the sunbeam and reflected solar over in “RS”

Building the Radiative Balance

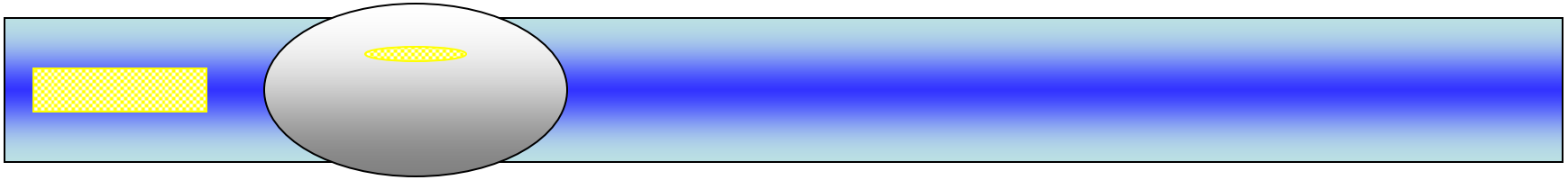
What happens to the energy coming from the Sun?

RS

Top of Atmosphere / Edge of Space

Consider only the energy that has been absorbed.

What happens to it?



Building the Radiative Balance

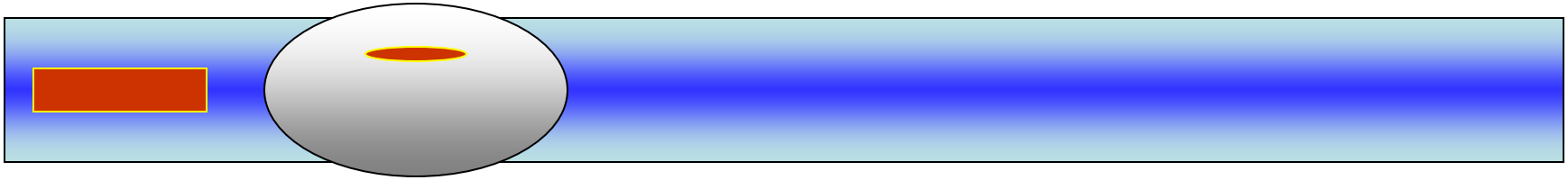
Conversion to terrestrial thermal energy.

RS

Top of Atmosphere / Edge of Space

1) It is converted from solar radiative energy to terrestrial thermal energy.

(Like a transfer between accounts)



Building the Radiative Balance

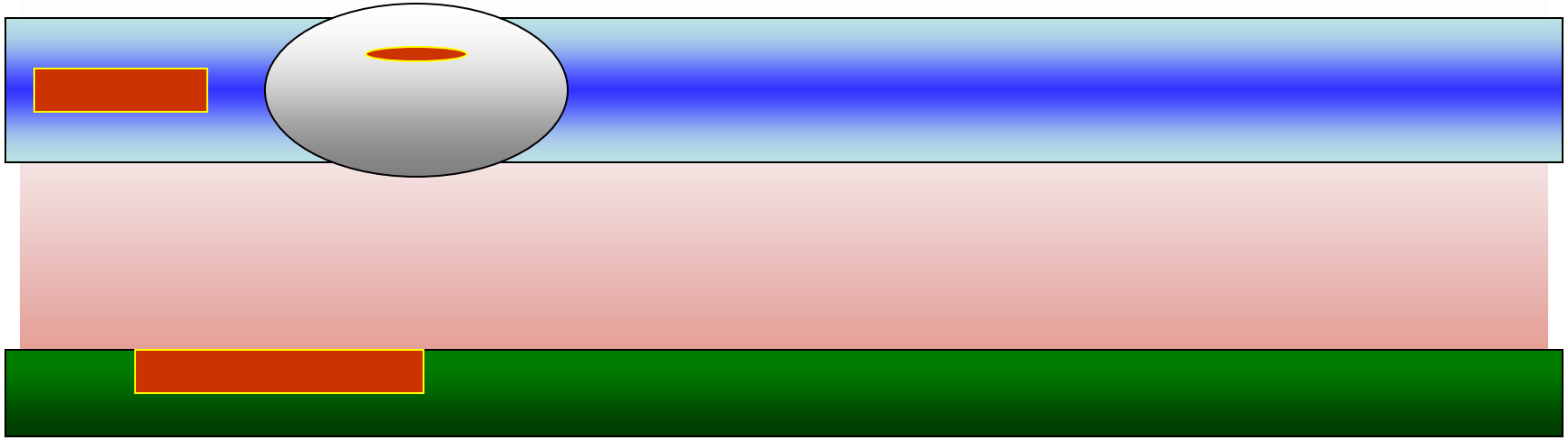
Redistribution by atmosphere, ocean, etc.

RS

Top of Atmosphere / Edge of Space

2) It is redistributed by the atmosphere, ocean, land, ice, life.

(Another transfer between accounts)



Building the Radiative Balance

Terrestrial energy is converted/partitioned into three sorts

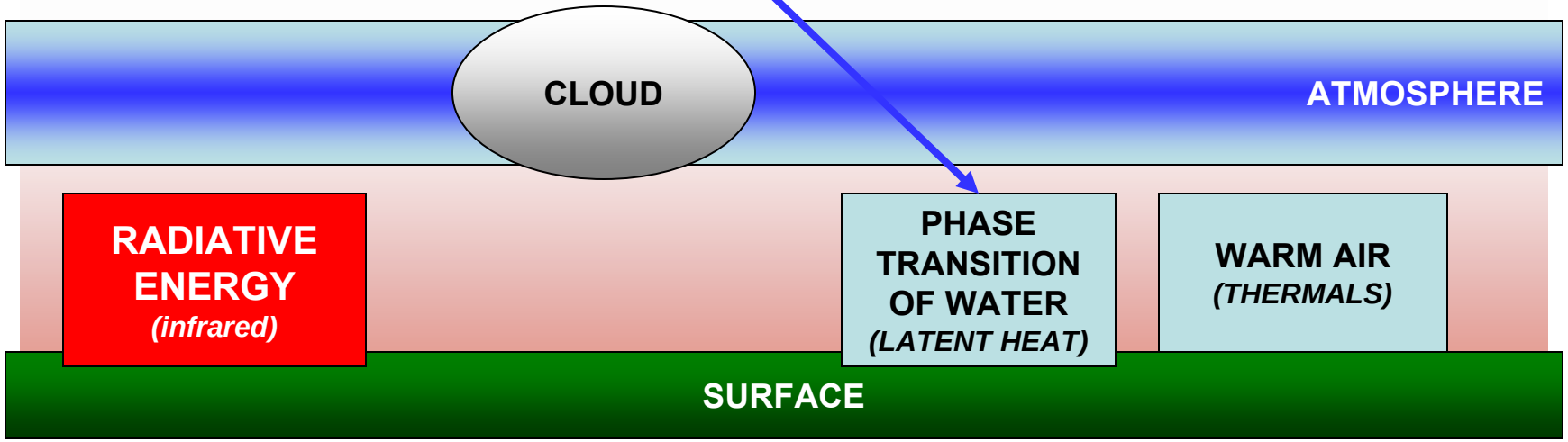
RS

Top of Atmosphere / Edge of Space

It takes heat to
- Turn ice to water
- And water to "steam;" that is, vapor

3) Terrestrial energy ends up in three reservoirs

(Yet another transfer)



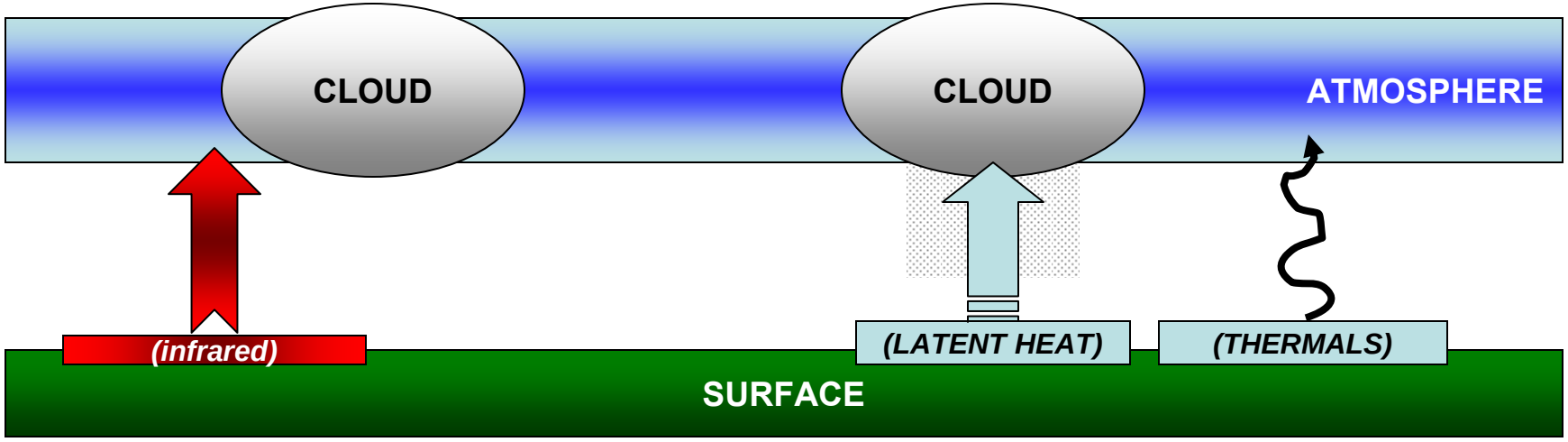
Building the Radiative Balance

Which is transmitted from surface to atmosphere

RS

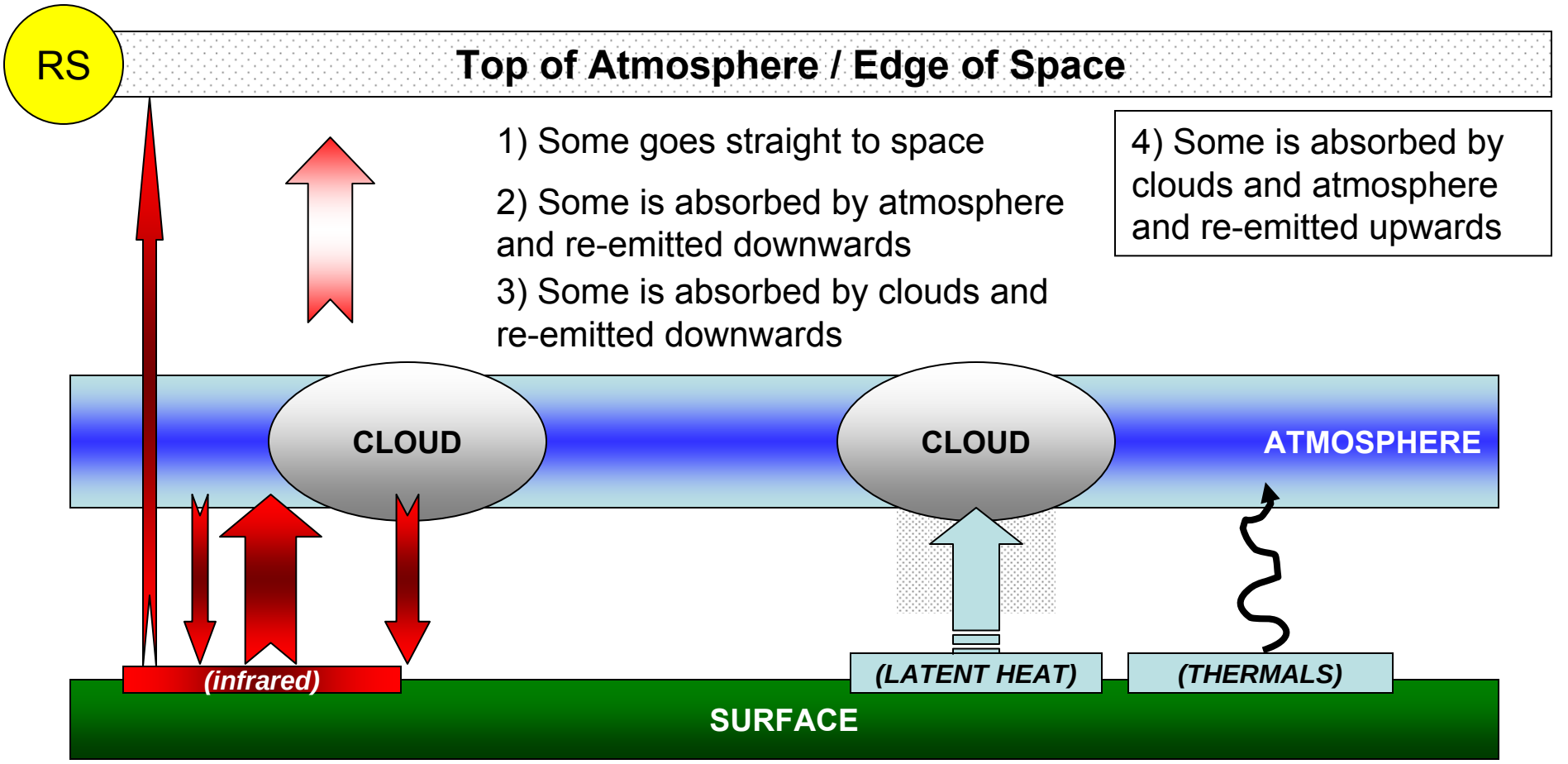
Top of Atmosphere / Edge of Space

3) Terrestrial energy ends up in three reservoirs

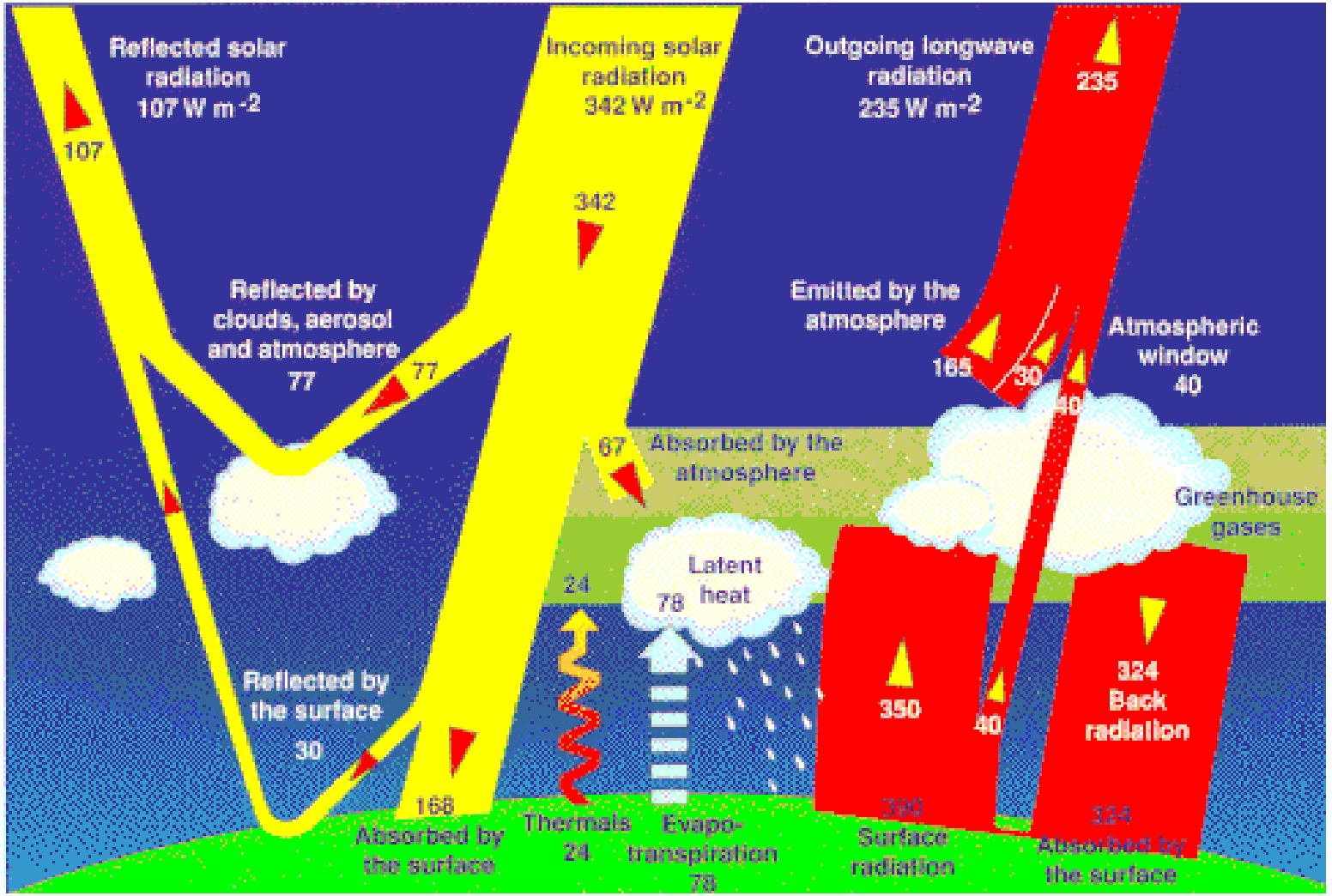


Building the Radiative Balance

And then the infrared radiation gets complicated



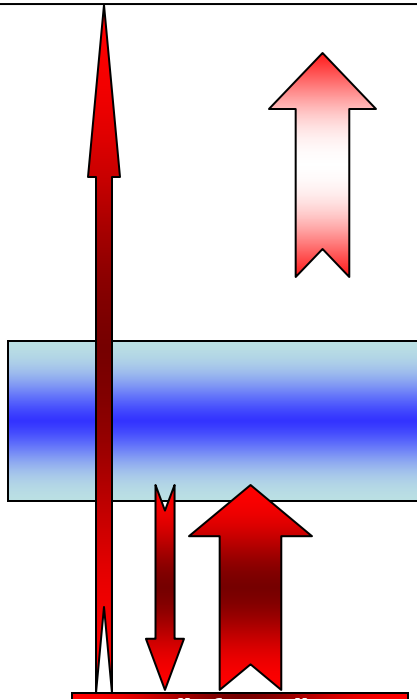
Put it all together and this what you have got. The radiative balance



Thinking about the greenhouse

A thought experiment of a simple system.

Top of Atmosphere / Edge of Space



1) Let's think JUST about the infrared radiation
   - *Forget about clouds for a while*

3) Less energy is up here because it is being held near the surface.
   - It is "cooler"

ATMOSPHERE

2) More energy is held down here because of the atmosphere
   - It is "warmer"

SURFACE

Thinking about the greenhouse

A thought experiment of a simple system.

Top of Atmosphere / Edge of Space

1) Remember we had this old idea of a temperature the Earth would have with no atmosphere.
   - *This was ~0 F. Call it the effective temperature.*
   - *Let's imagine this at some atmospheric height.*

3) Up here it is cooler than $T_{effective}$ $T < T_{effective}$

ATMOSPHERE

$T_{effective}$

2) Down here it is warmer than $T_{effective}$ $T > T_{effective}$

(infrared)

SURFACE

Thinking about the greenhouse

Why does it get cooler up high?

Top of Atmosphere / Edge of Space

1) If we add more atmosphere, make it thicker, then

3) The part going to space gets a little smaller
- It gets cooler still.

ATMOSPHERE

2) The part coming down gets a little larger.
- It gets warmer still.

(infrared)

SURFACE

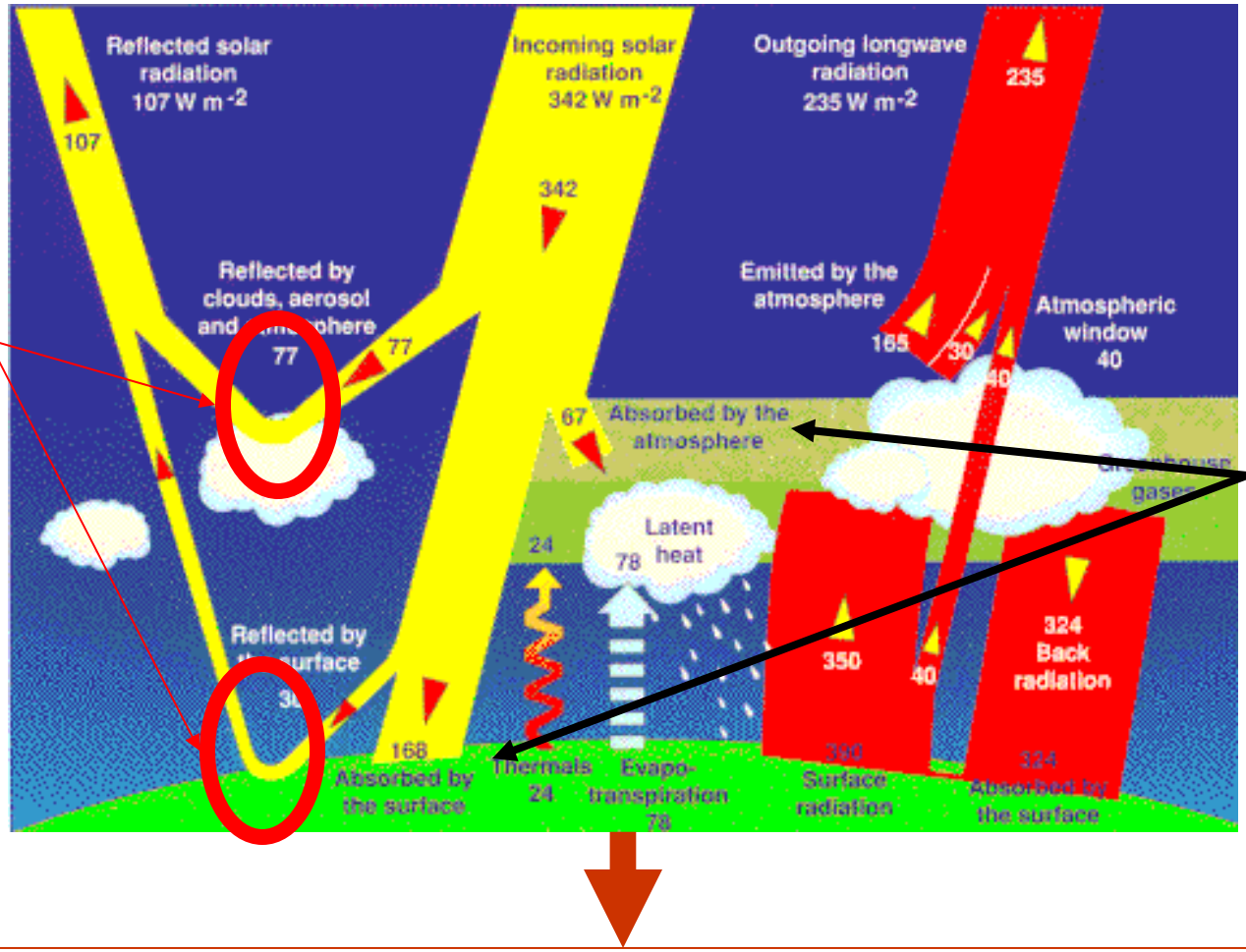
The real problem is complicated by clouds, ozone, ….

Changes in the sun

So what matters?

THIS IS WHAT WE ARE DOING

Things that change reflection



Things that change absorption

If something can transport energy DOWN from the surface.

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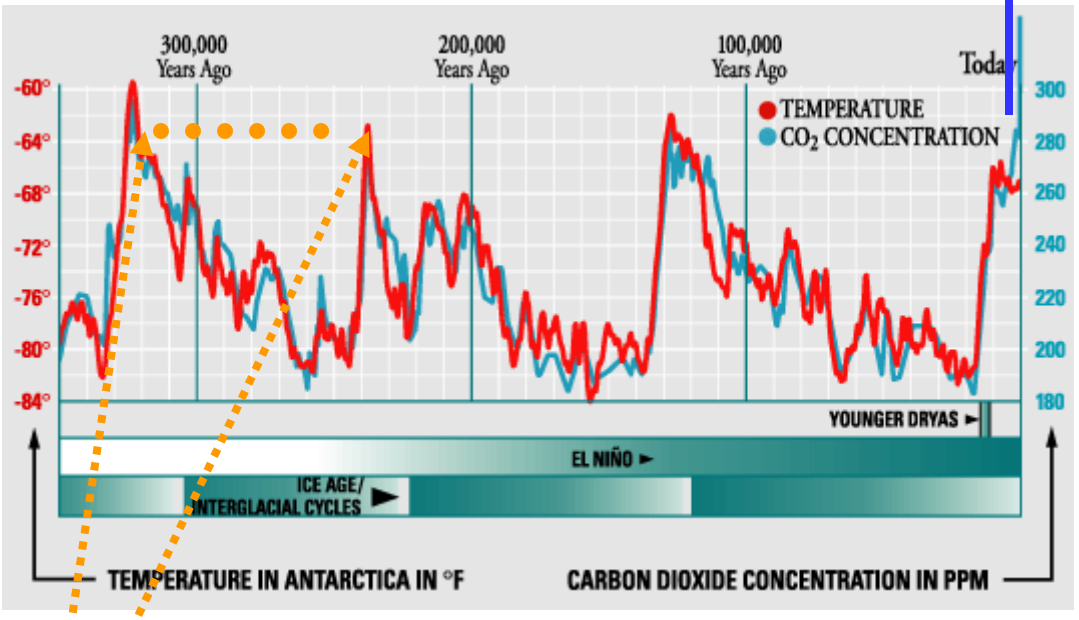

CHANGES IN SOLAR HEATING DUE TO ORBITAL CHARACTERISTICS ARE AT THIS PERIOD

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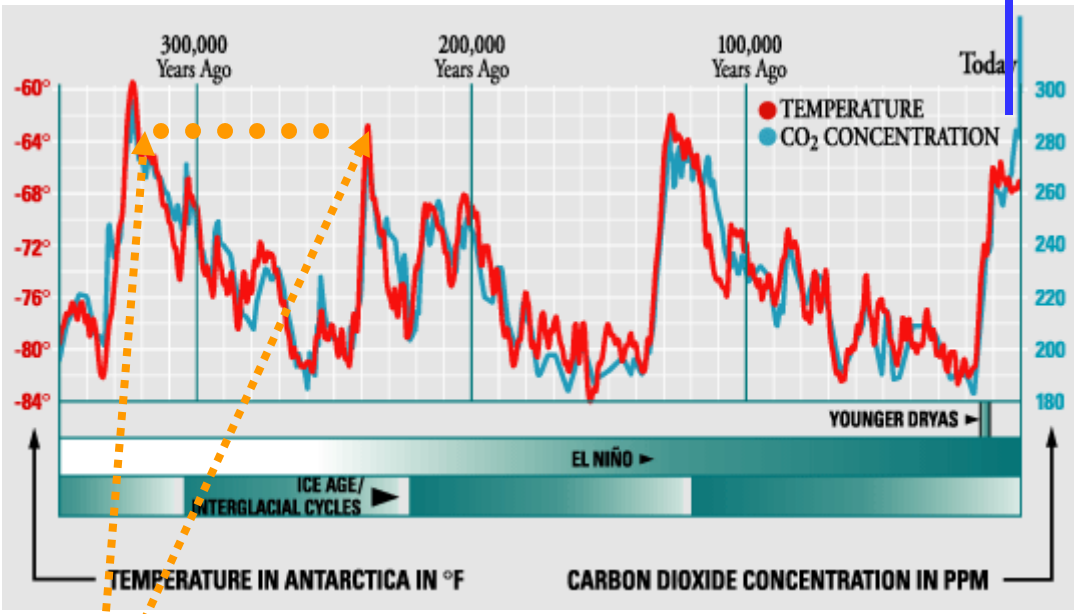


THIS OSCILLATION IS (BELIEVED TO BE) FORCED BY ORBITAL VARIABILITY AND INTERACTION WITH THINGS ON EARTH THAT REFLECT. ICE (SNOWBALL EARTH / ICE COVERED EARTH?)

DISTANT PAST RECORD

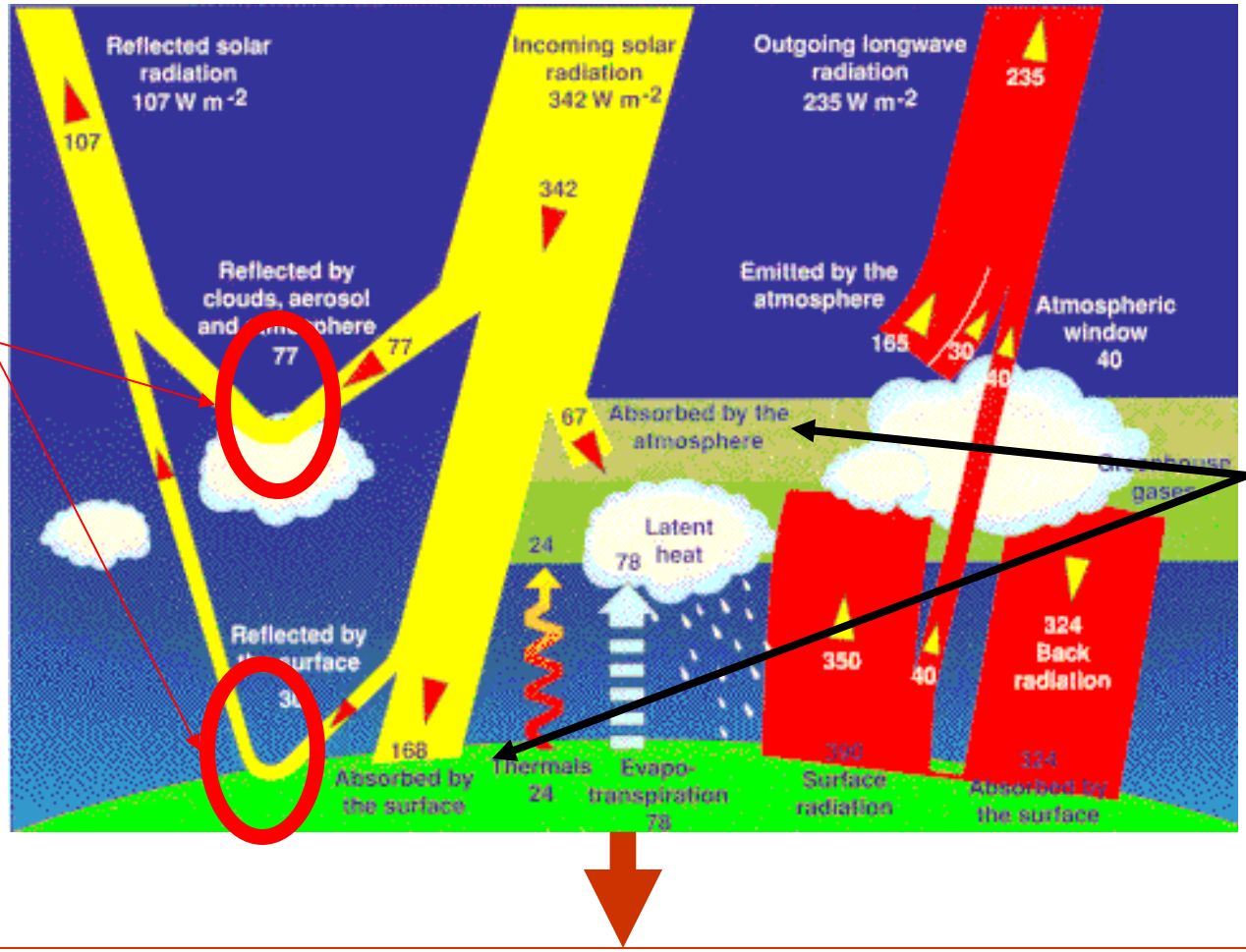
- SENSITIVE TO SOLAR RADIATIVE ENERGY (through changes in orbital parameters)
- COOLING ACCELERATED BY CHANGES ICE ON THE SURFACE
- CO2 CHANGES BECAUSE BALANCE OF PRODUCTION AND LOSS CHANGES. (SOURCES AND SINKS)

Changes in the sun

So what matters?

THIS IS WHAT WE ARE DOING

Things that change reflection



Things that change absorption

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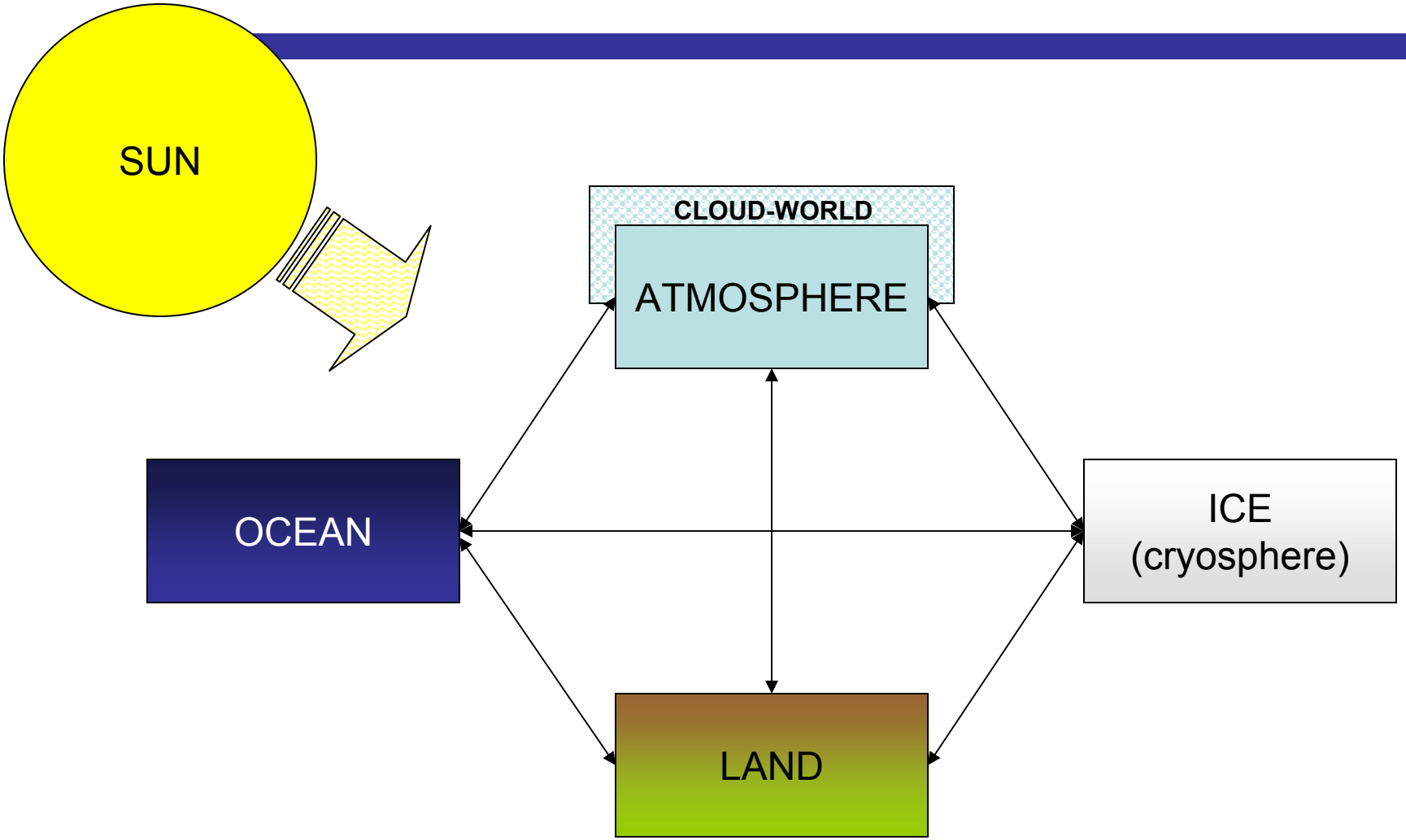
The Earth System



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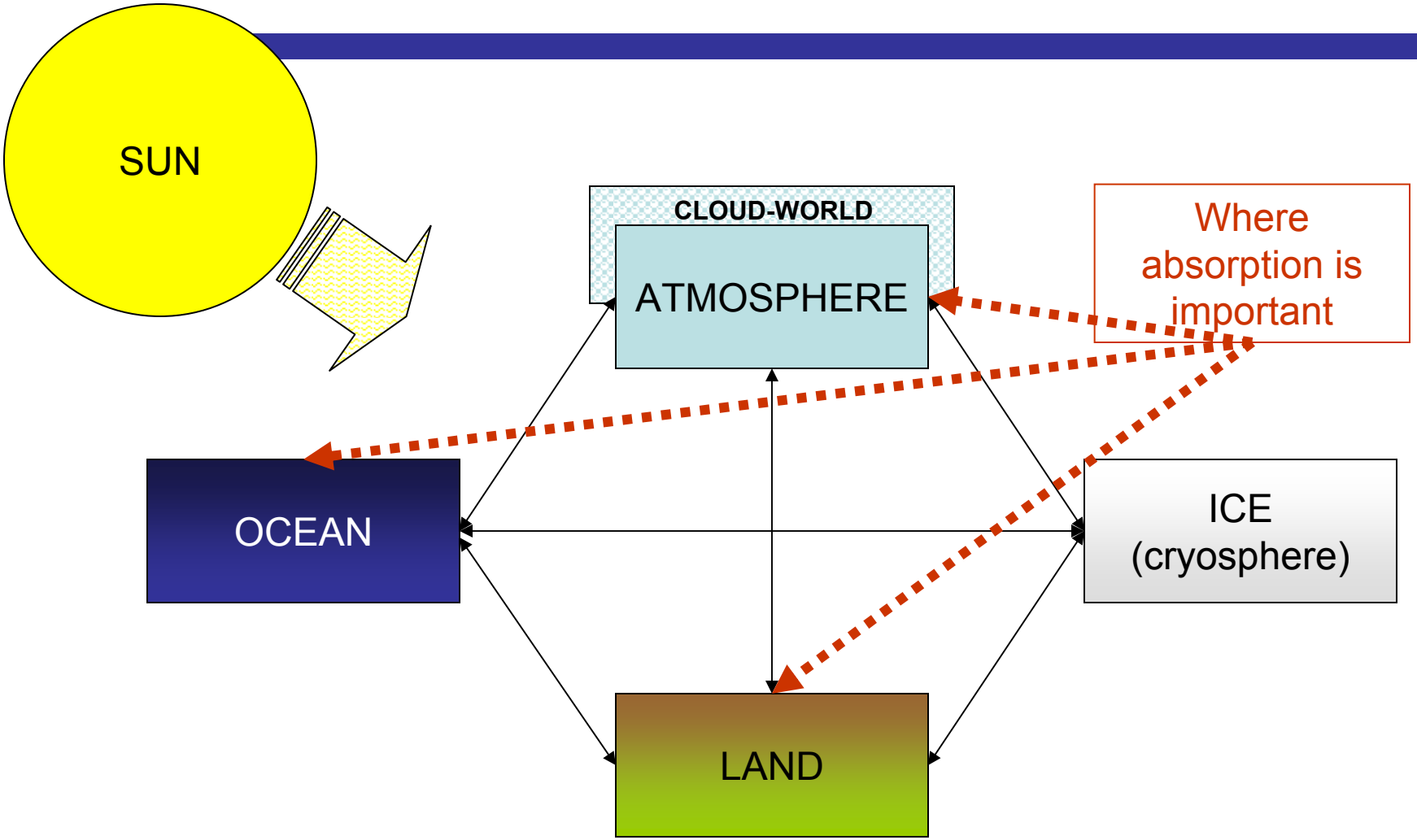

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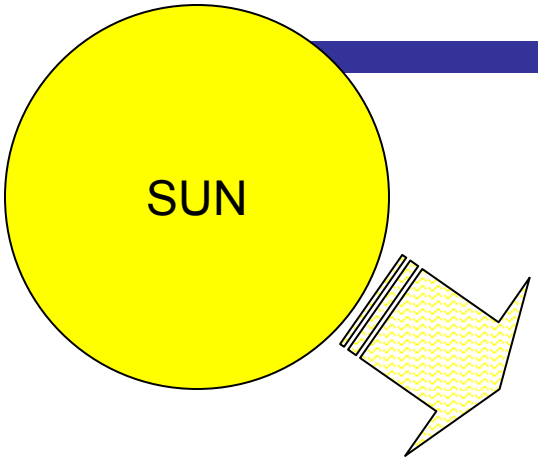

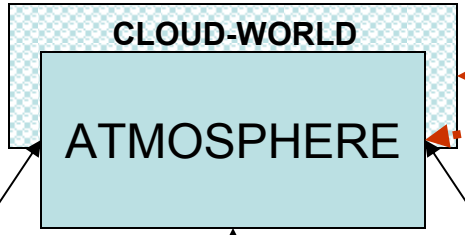

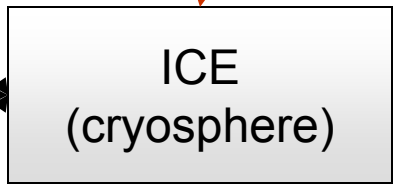

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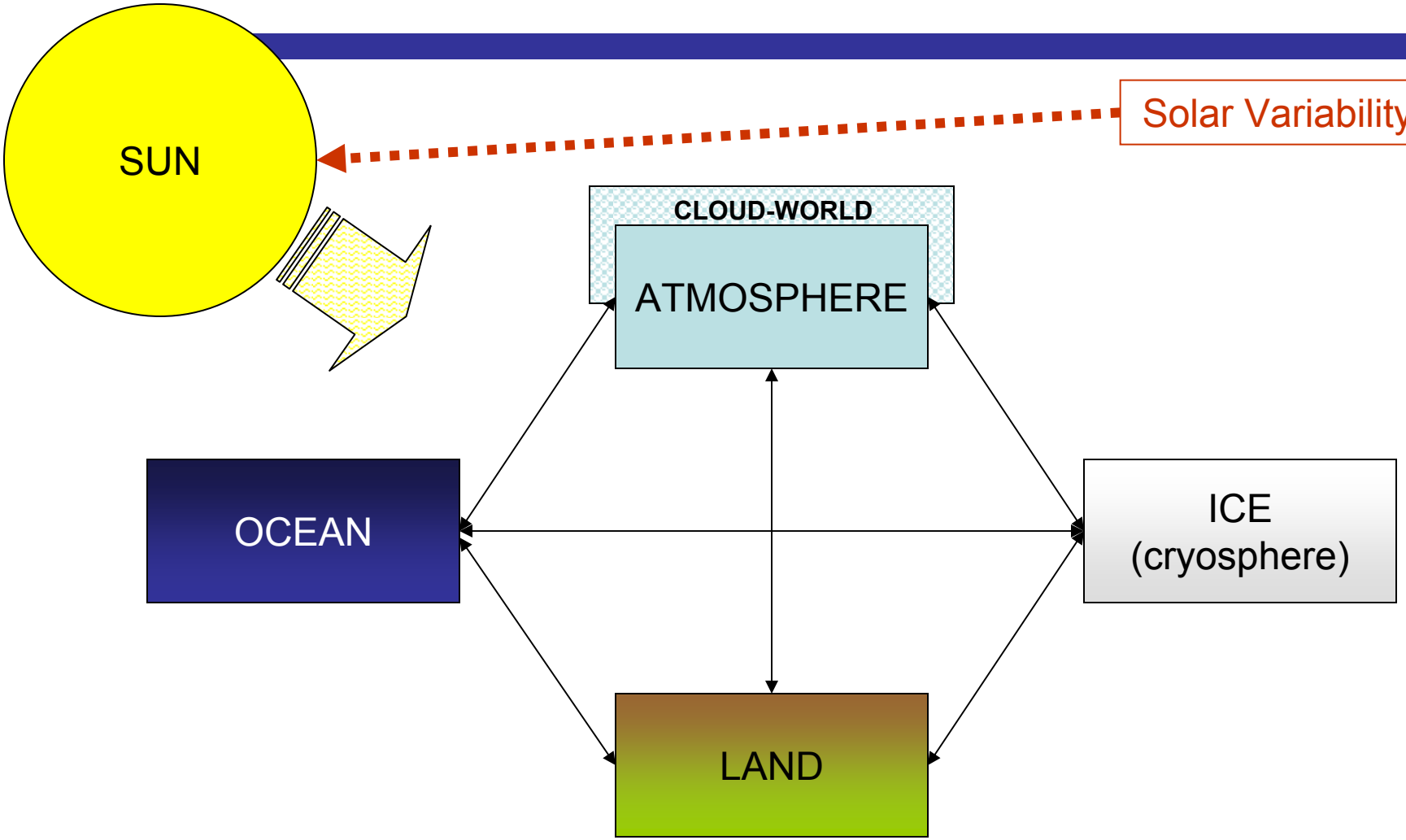
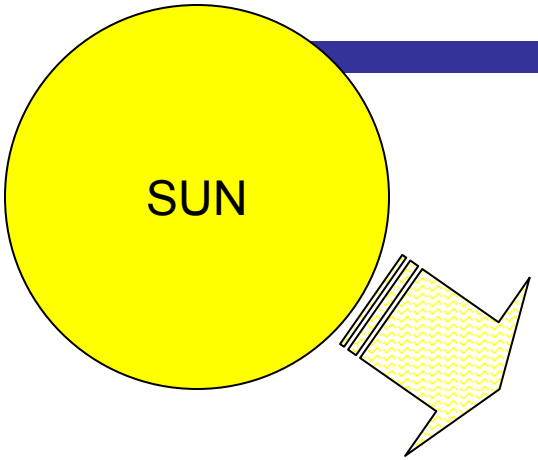
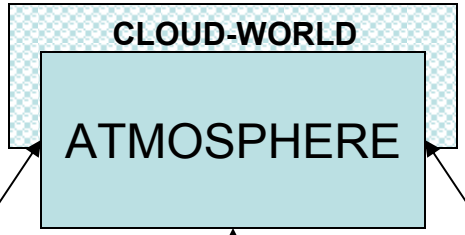
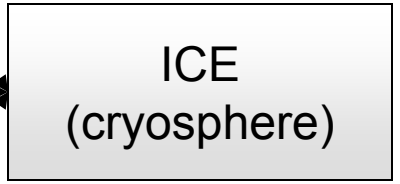
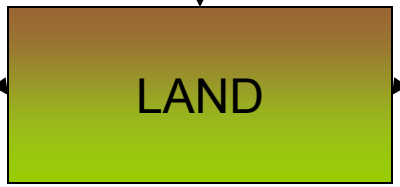


The Earth System

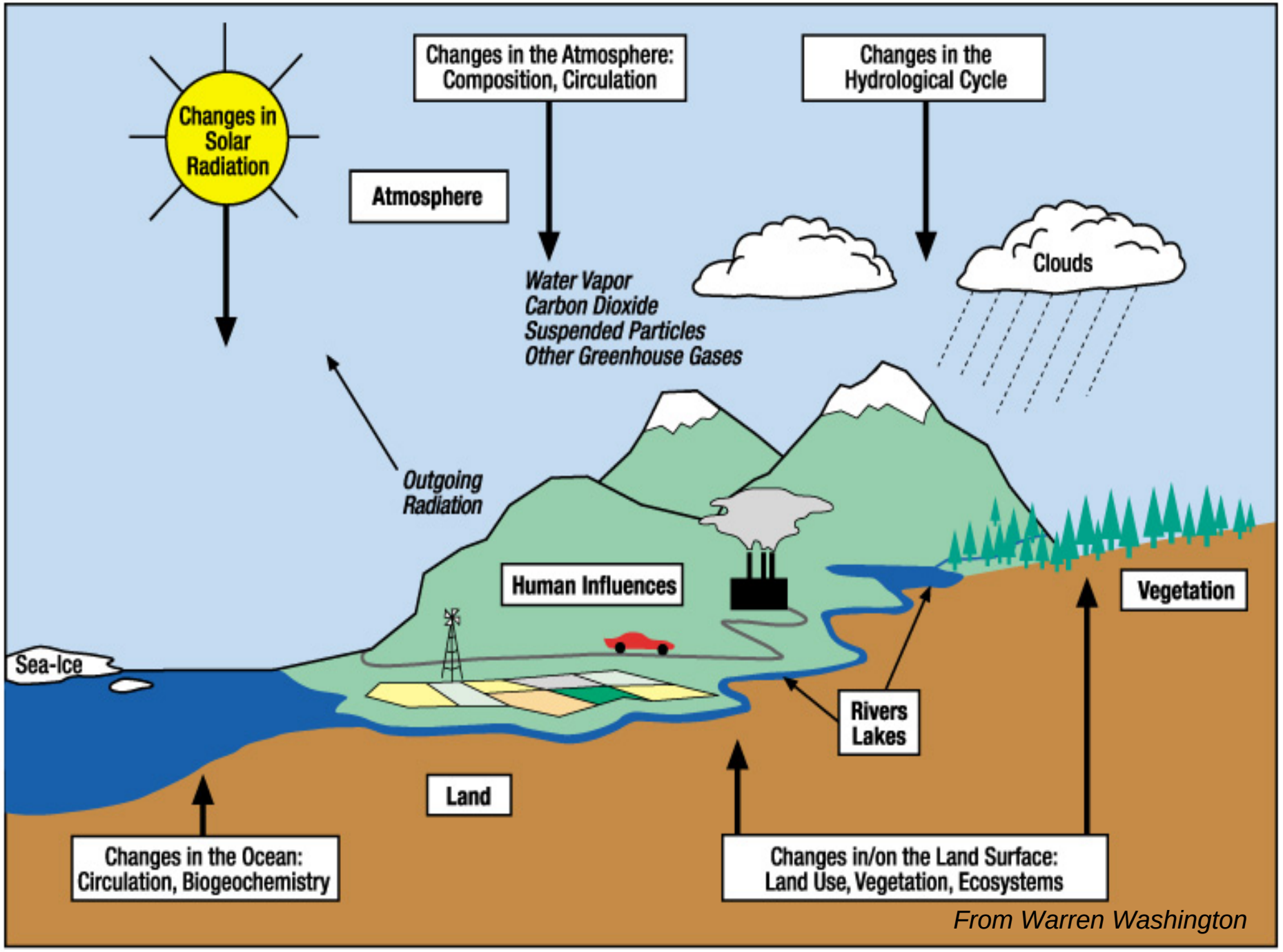








Possibility of transport of energy down from the surface



From Warren Washington