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Climate Change: An Inter-disciplinary Approach to Problem Solving (AOSS 480 // NRE 480)

Richard B. Rood
Cell: 301-526-8572
2525 Space Research Building (North Campus)
rbrood@umich.edu
http://clasp.engin.umich.edu/people/rbrood

Winter 2017
January 17, 2017

Class Information and News

- Canvas site: CLIMATE_480_001_W17
  - Record of course
- Rood's Class MediaWiki Site
  - http://climateknowledge.org/classes/index.php/Climate_Change:_The_Move_to_Action
- Rood's Class Tumblr Site: http://openclimate.tumblr.com

Class News

- GreenJobs, Job Fair, Dana, 1 -5 PM, January 17, 2017

Resources and Recommended Reading

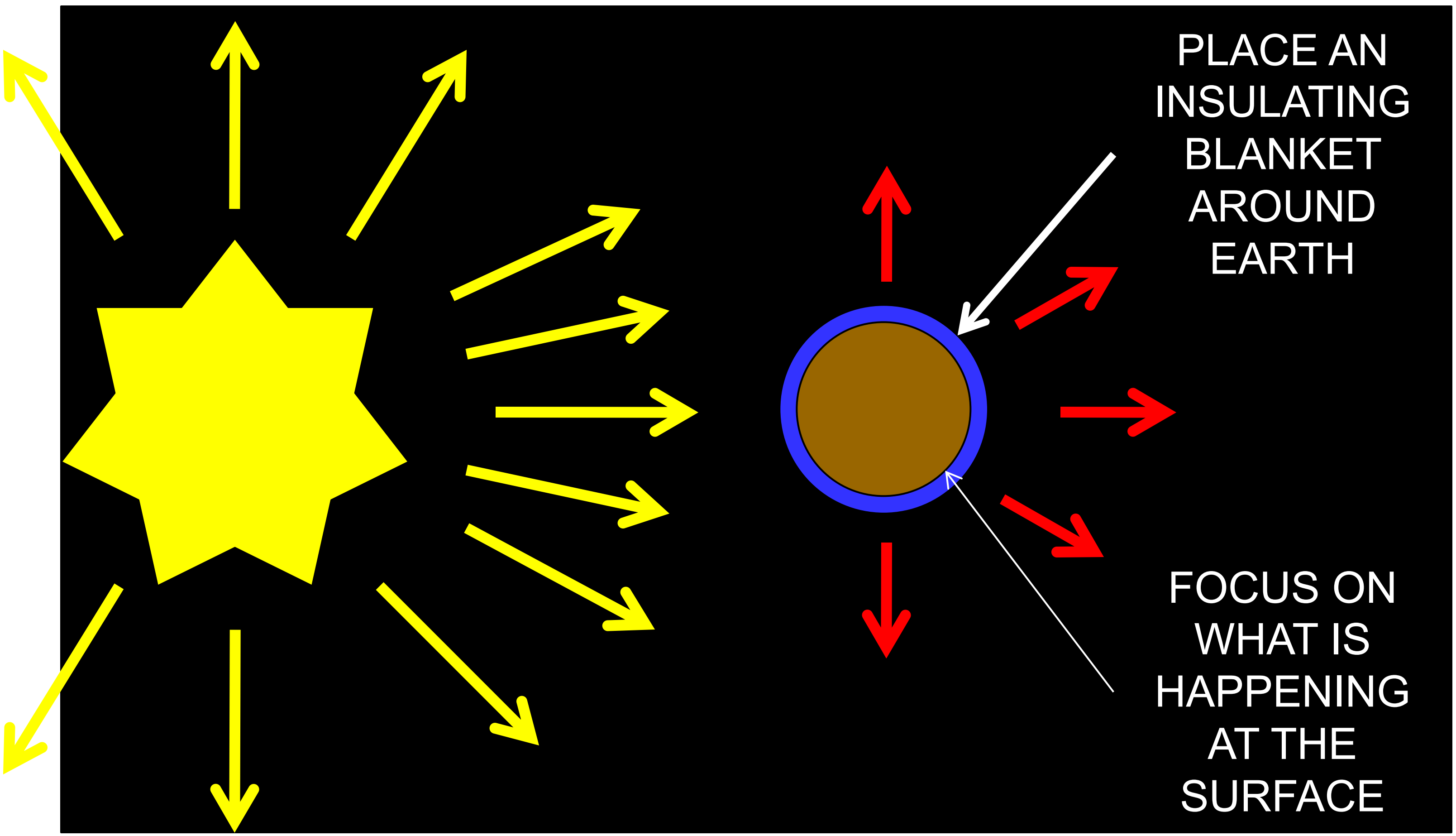
- Models are everywhere
- Ledgers, Graphics and Carvings
- Balancing the budget
- Point of View
- Cloak of Complexity

Outline: Class 4, Winter 2017

- Conservation Principle
  - Budgets
  - Balance
  - Point of view
- Models and Modeling
  - Definition
  - Role in climate science
- Energy in Earth System: Basics
  - Absorption
  - Reflection
  - Moving energy around

Point of View

SUN EARTH



EARTH: EMITS ENERGY TO SPACE → BALANCE

Conservation Principle

Conservation principle

- There are many other things in the world that we can think of as "conserved." For example, money.
  - We have the money that we have.
- If we don't spend money or earn money, then the money we have today is the same as the money we had yesterday.

$$\mathbf{M}_{today} = \mathbf{M}_{yesterday}$$

That's not very interesting, or realistic

Conservation principle (with income and expense)

Income

$$M_{today} = M_{yesterday} + I - E$$

Let’s get some money and buy stuff.

Expense

Conservation principle (with the notion of time)

Income

$$\mathbf{M}_{today} = \mathbf{M}_{yesterday} + N(I - E)$$

Salary

Income per month = *I*

Rent

Expense per month = *E*

N = number of months

I = *N*x*I and* **E**= *N*x*E*

Expense

Some algebra and some thinking

$$\mathbf{M}_{\text{today}} = \mathbf{M}_{\text{yesterday}} + N(I - E)$$

Rewrite the equation to represent the difference in money

$$(\mathbf{M}_{\text{today}} - \mathbf{M}_{\text{yesterday}}) = N(I - E)$$

This difference will get more positive or more negative as time goes on.

Saving money or going into debt.

Divide both sides by *N*, to get some notion of how difference changes with time.

$$(\mathbf{M}_{\text{today}} - \mathbf{M}_{\text{yesterday}})/N = I - E$$

Introduce a concept

- The amount of money that you spend is proportional to the amount of money you have:

$$E = e^{*}\mathbf{M}$$

- How do you write this arithmetically?

Some algebra and some thinking

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

If difference does NOT change with time, then

$$\mathbf{M} = I/e$$

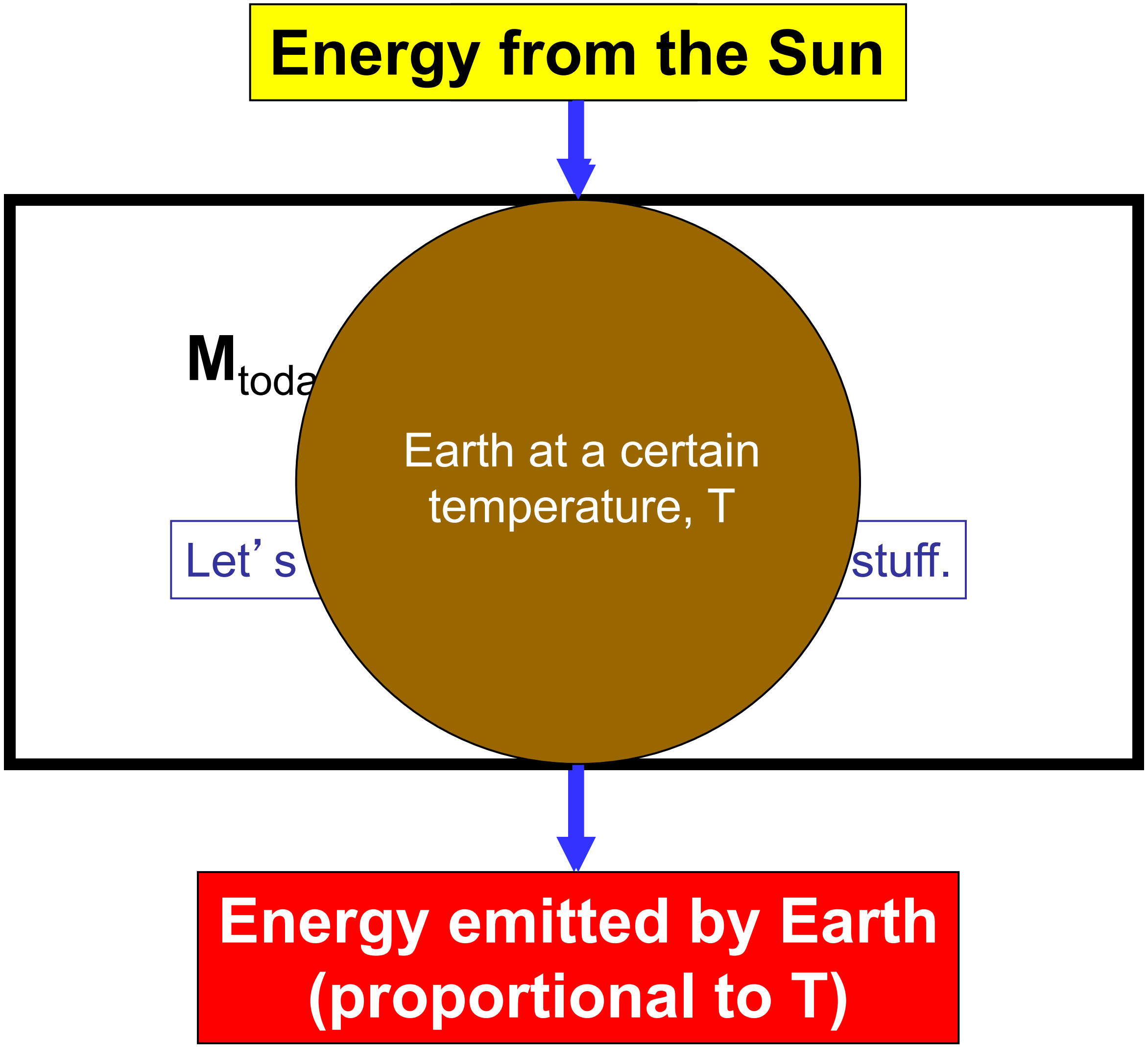
Amount of money stabilizes

Can change what you have by either changing income or spending rate

All of these ideas lead to the concept of a budget:

What you have = what you had plus what you earned minus what you spent

Conservation principle



Some jargon, language

- Income is “production” is “source”
- Expense is “loss” is “sink”
- Exchange, transfer, transport all suggest that our “stuff” is moving around.

Equilibrium and balance

- We often say that a system is in equilibrium if when we look at everything production = loss. There might be "exchanges" or "transfers" or "transport," but that is like changing money between a savings and a checking account.
  - We are used to the climate, the economy, our cash flow being in some sort of "balance."
  - As such, when we look for how things might change, we look at what might change the balance.
  - Small changes might cause large changes in a balance

Conservation of Energy

- Conceptual model of Earth's temperature from space

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

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

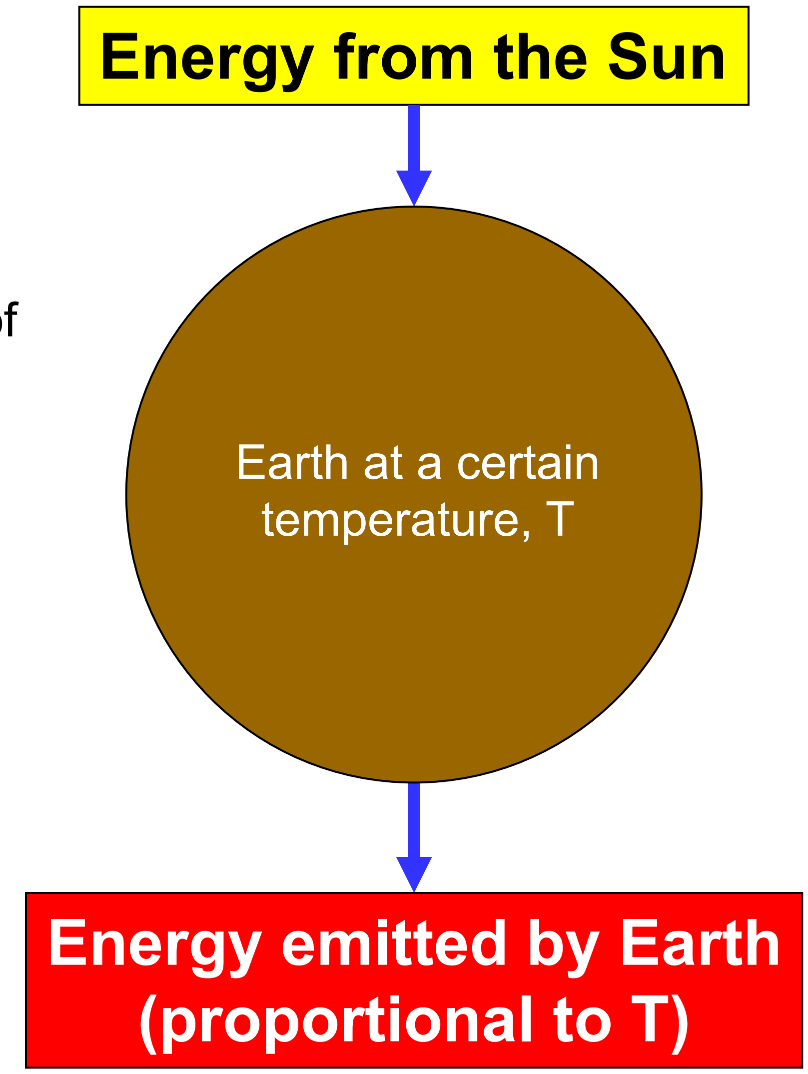
Δ means the change in something, a difference

T is Temperature and t is time

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

Earth: How Change T?

Stable Temperature of Earth could change from how much energy (*production*) comes from the sun, or by changing how we emit energy.



The first place that we apply the conservation principle is energy

- We reach a new equilibrium

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

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

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

Changes in orbit or solar energy changes this

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

Balancing the Budget

- Today's Money =
  Yesterday's Money + Money I Get – Money I Spend

- Today's CO_2 =
  Yesterday's CO_2 + CO_2 I Get – CO_2 I Spend

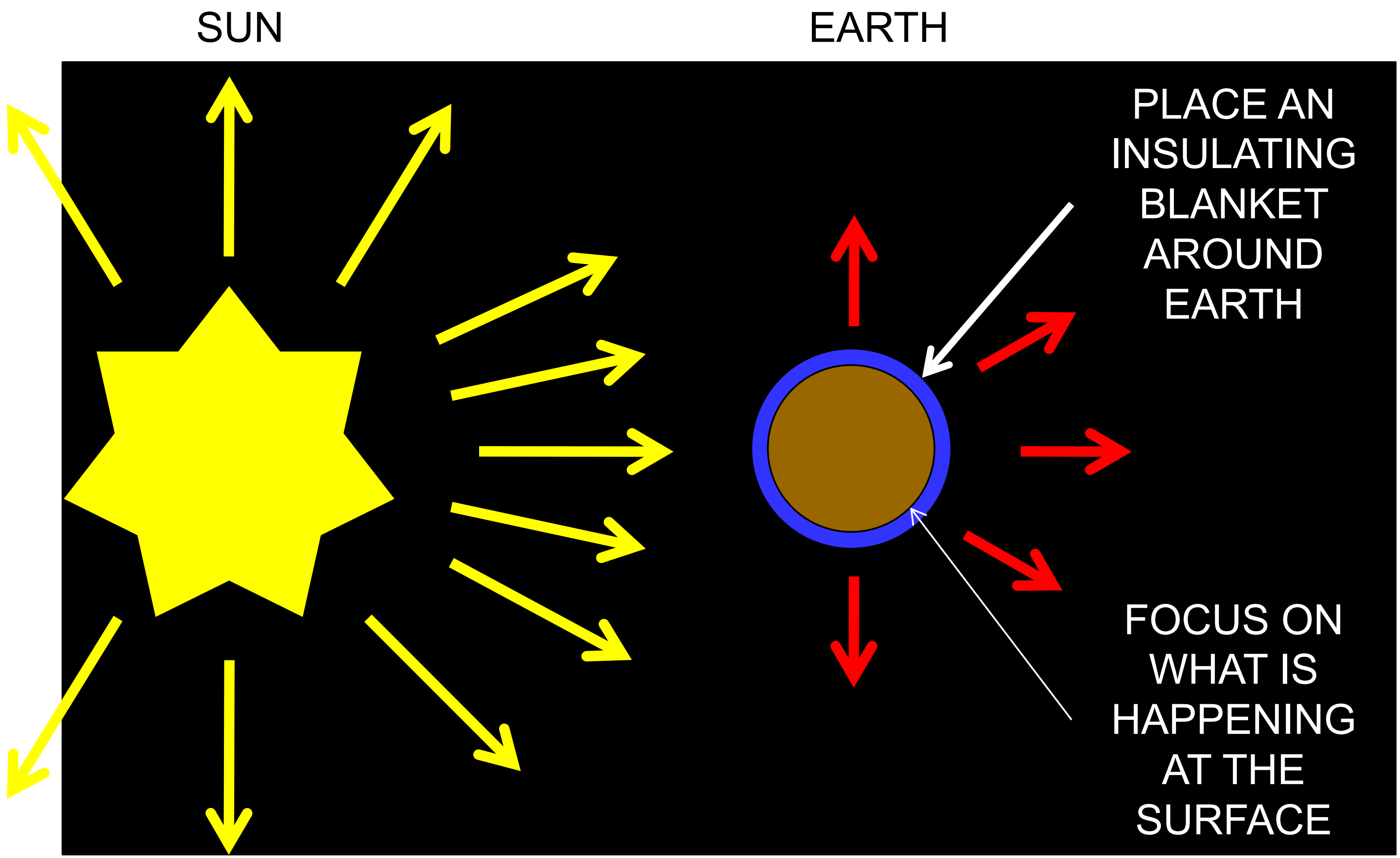
- Today's Energy =
  Yesterday's Energy + Energy I Get – Energy I Spend

Or Tomorrow?

Conservation principle

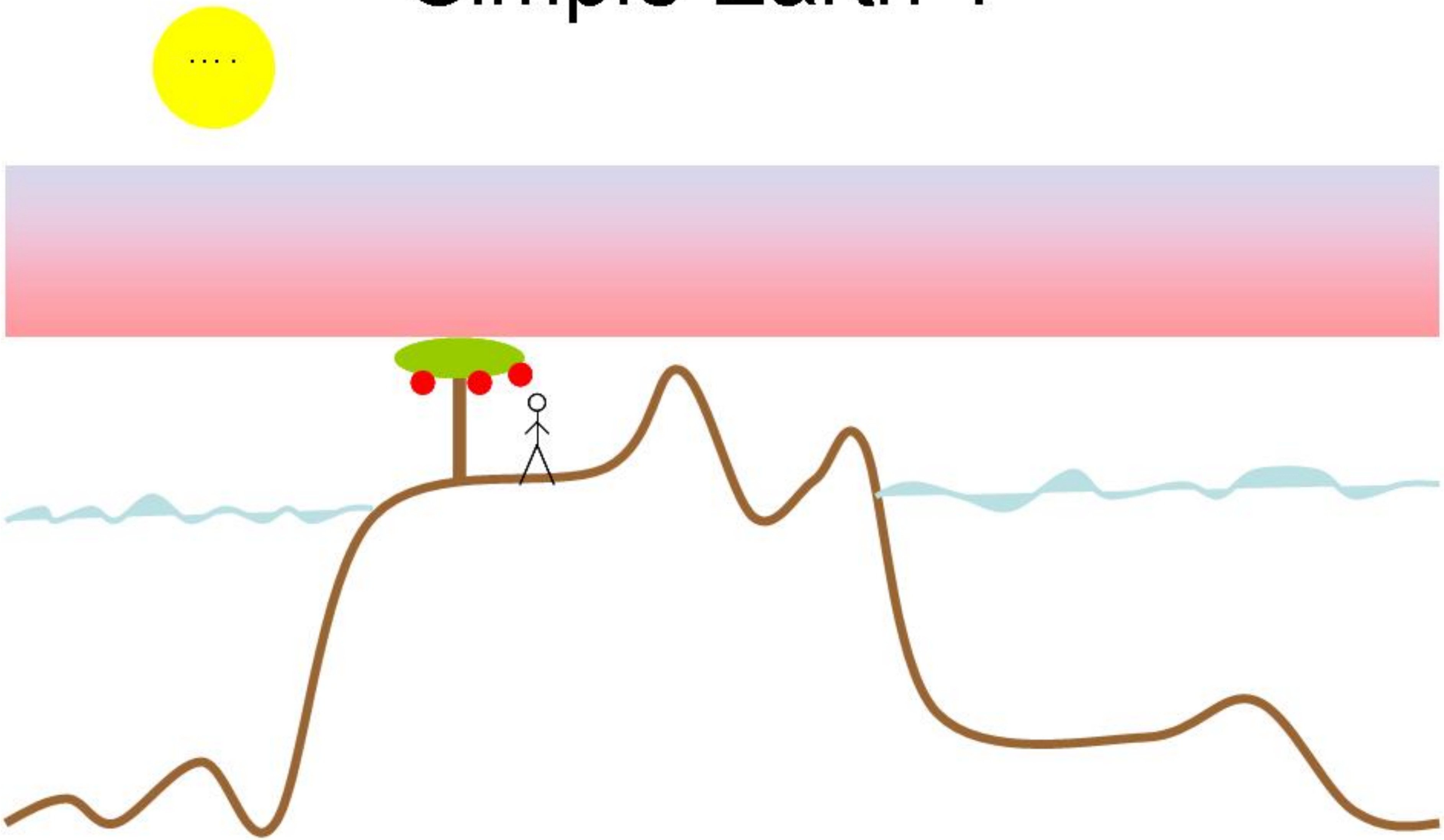
- Conserved Quantities:
  - mass (air, ozone, water)
  - momentum,
  - Energy
- Need to Define System
  - Need to count what crosses the boundary of the system
  - System depends on your point of view

Point of View



EARTH: EMITS ENERGY TO SPACE → BALANCE

Simple Earth 1



Models and Modeling

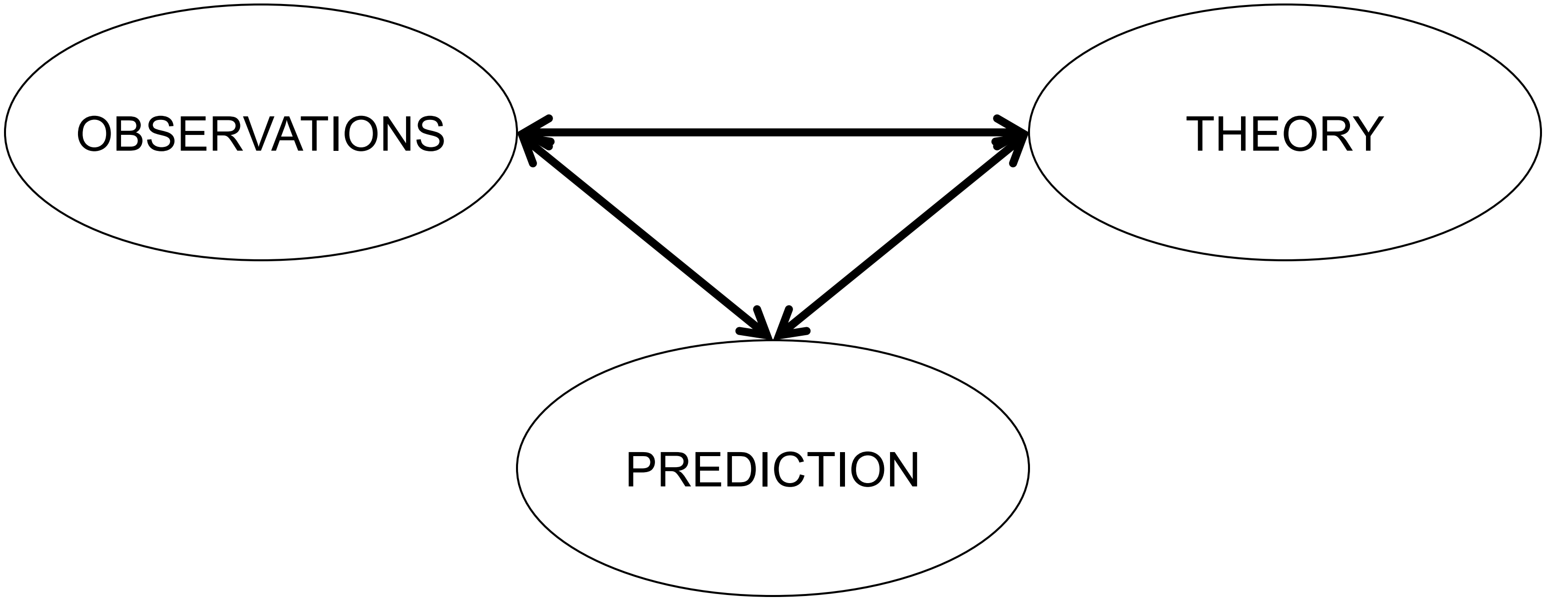
Models

- Blogs on Model Tutorial (Start with #3)
- Models are everywhere
- Ledgers, Graphics and Carvings
- Balancing the budget
- Point of View
- Cloak of Complexity

What is a Model?

- Model
  - A work or construction used in testing or perfecting a final product.
  - A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further studies of its characteristics.
- Numerical Experimentation
  - Given what we know, can we predict what will happen, and verify that what we predicted would happen, happened?

Scientific Investigation



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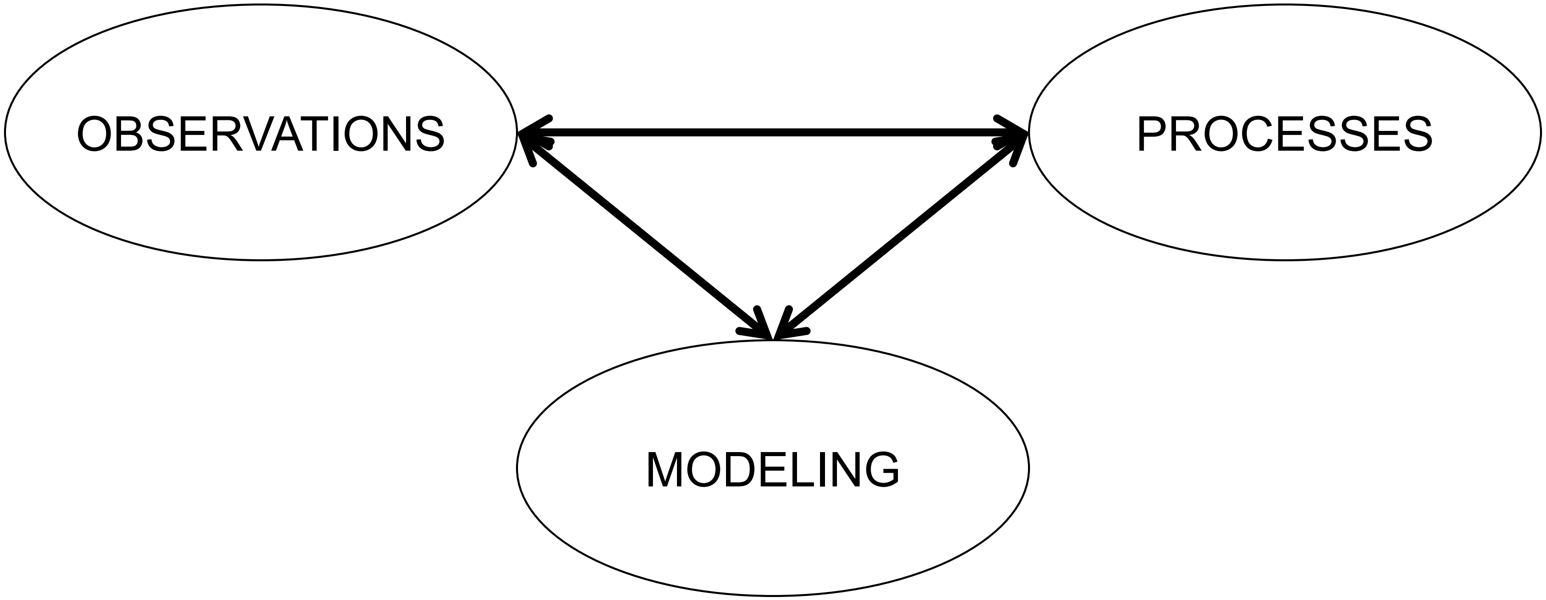
Scientific Investigation



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Models are everywhere

http://www.halfhull.com/main.jpg

How Many Use Spread Sheets?

Ledgers, Graphics and Carvings

- Ledgers
- → Spreadsheets → Computers

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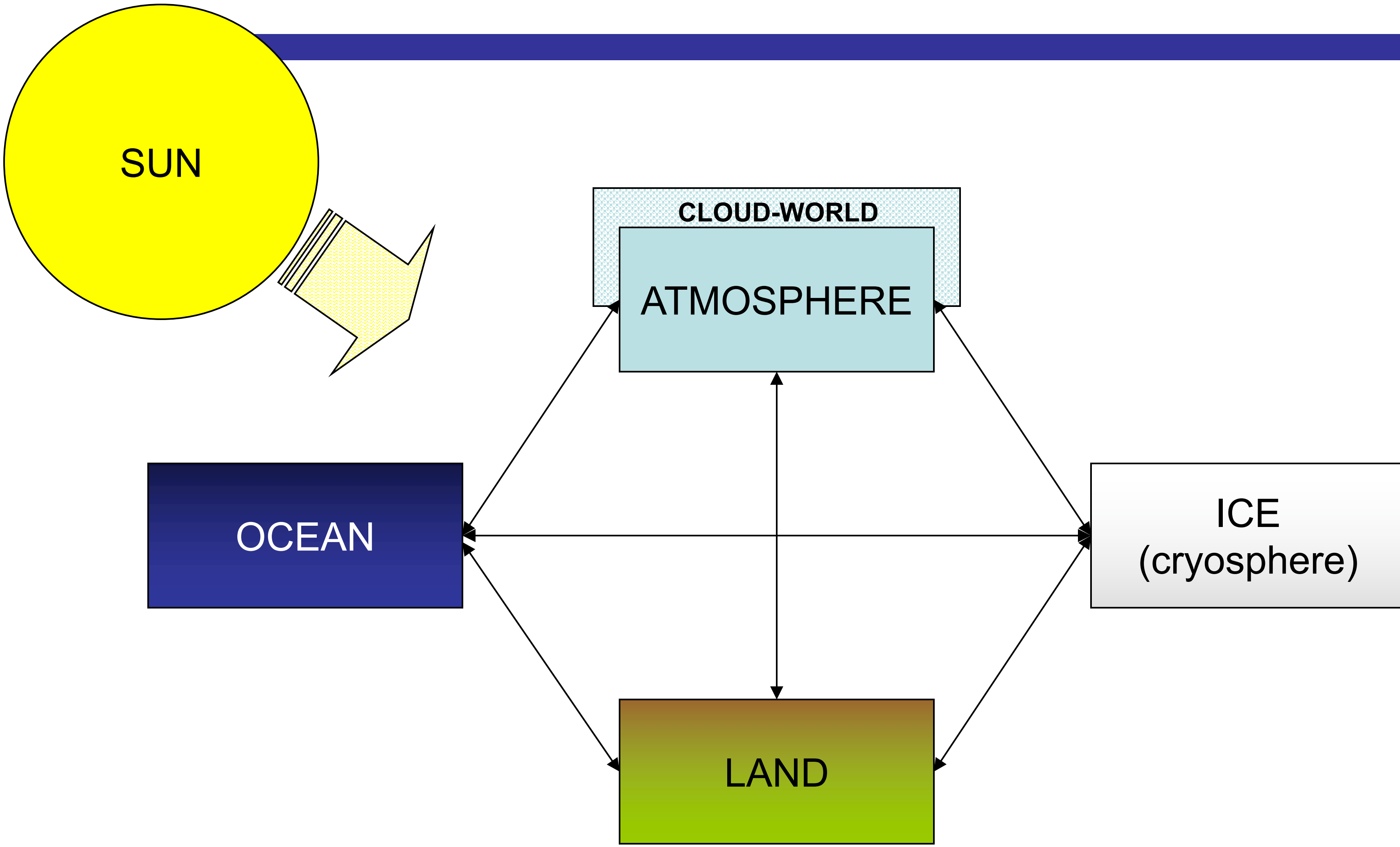
The Earth System



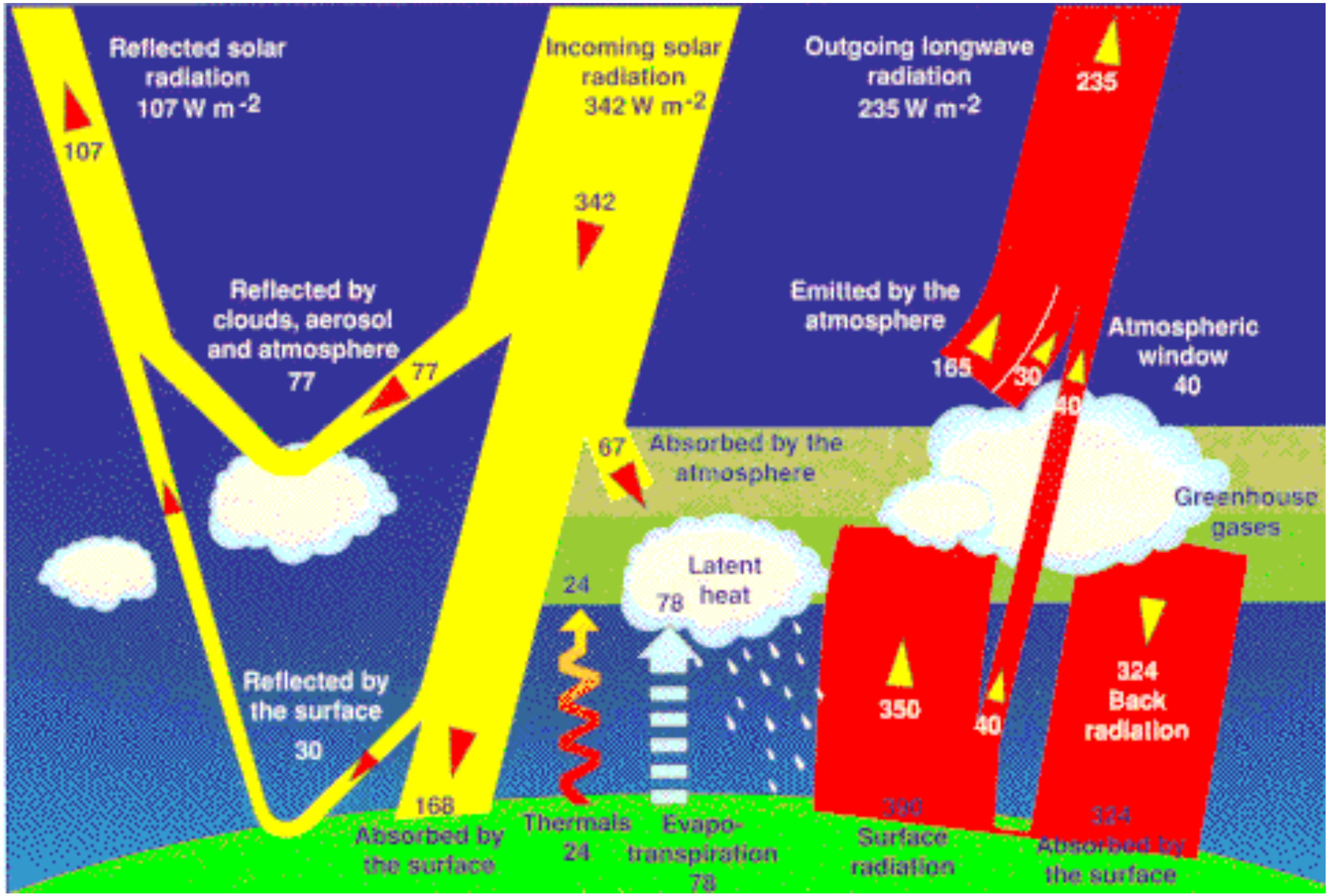
Energy in Earth System: Basics

Science → Observations → Evaluation → Measurement

Can we do the counting to balance the budget?

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

Radiation Balance Figure

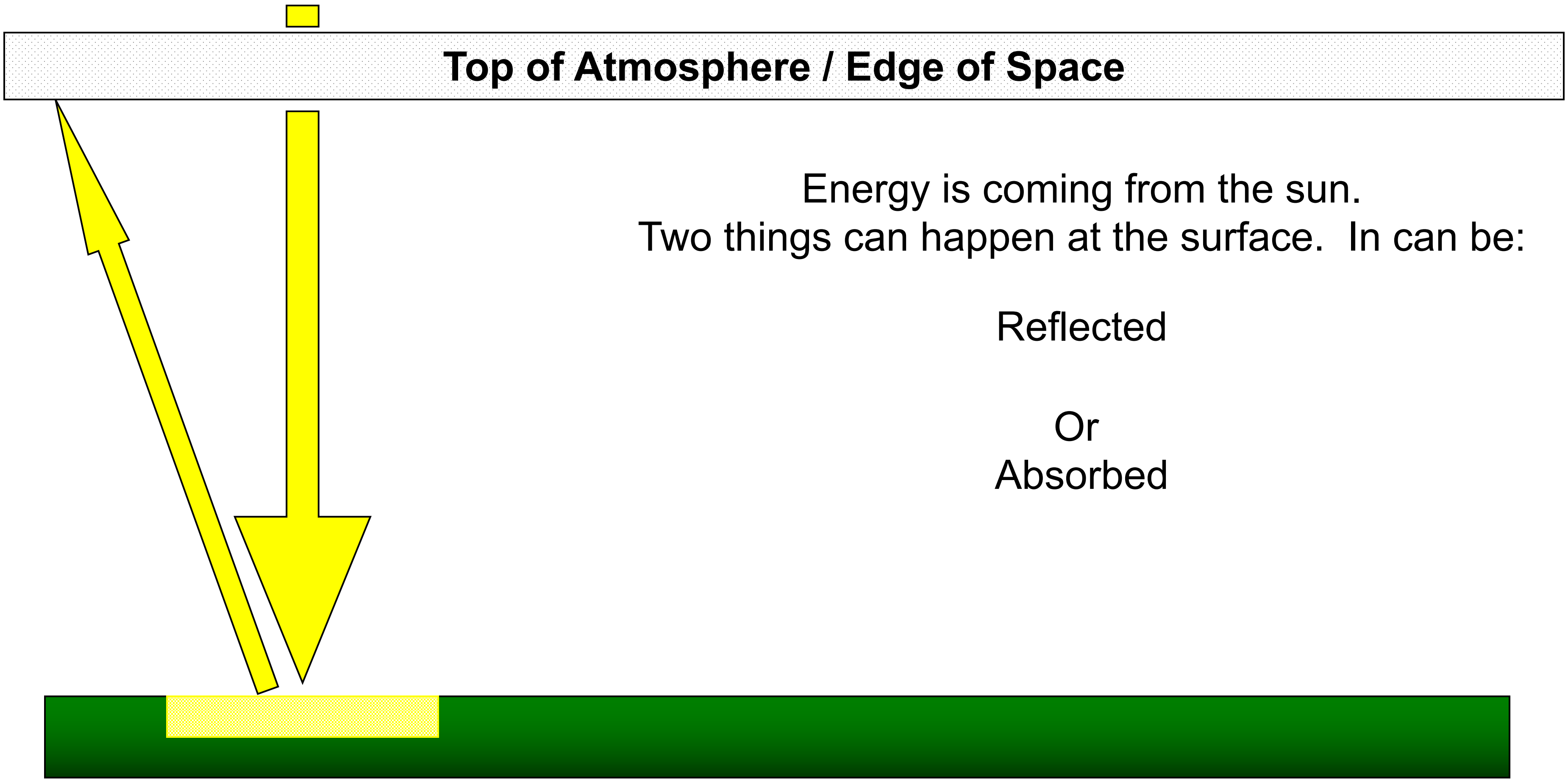


Let's build up this picture

- Follow the energy through the Earth's climate.
- As we go into the climate we will see that energy is transferred around.
  - From out in space we could reduce it to just some effective temperature, but on Earth we have to worry about transfer of energy between thermal energy and motion of wind and water.

Building the Radiative Balance

What happens to the energy coming from the Sun?



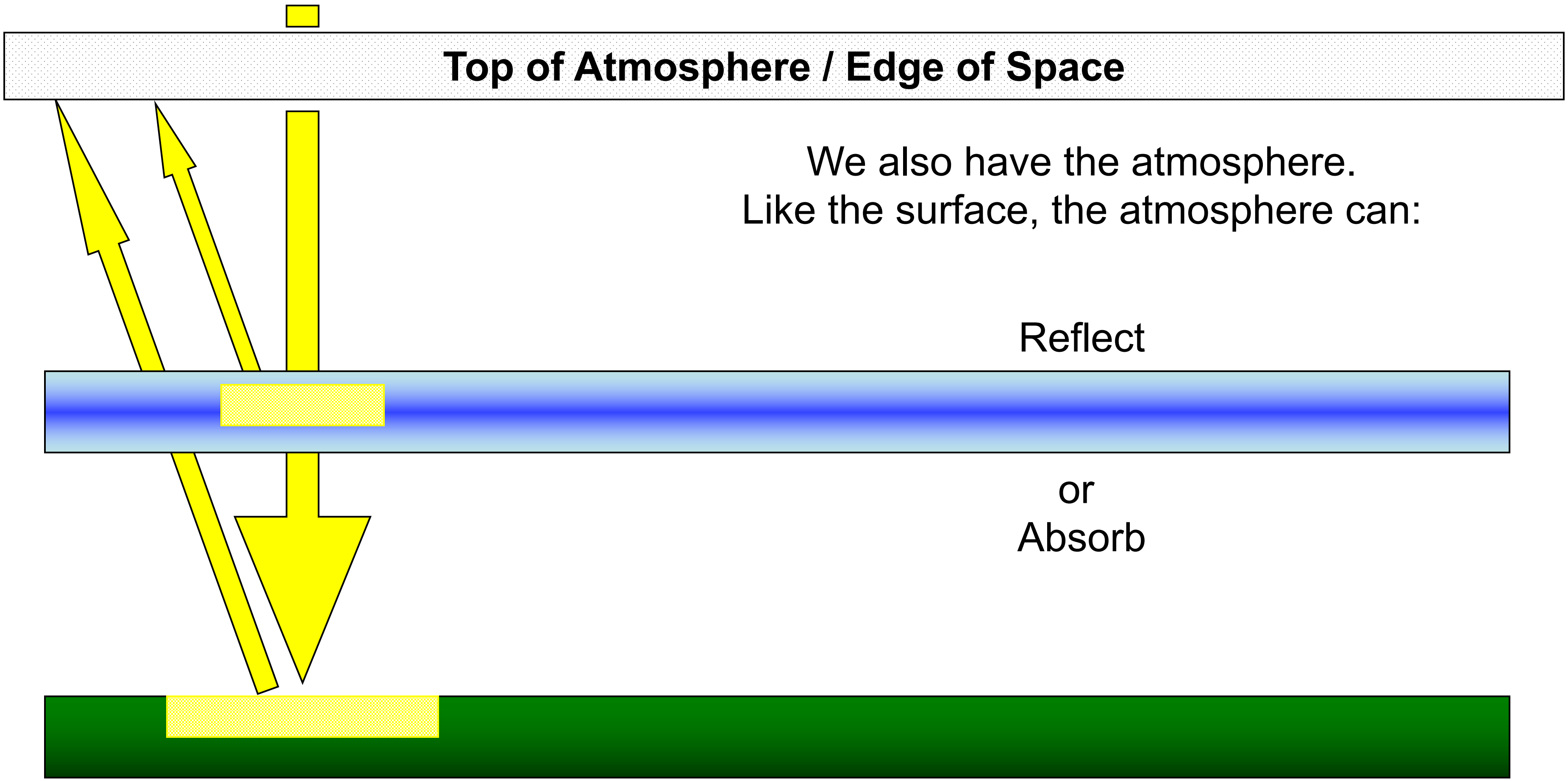
Energy is coming from the sun.
Two things can happen at the surface. In can be:

Reflected

Or
Absorbed

Building the Radiative Balance

What happens to the energy coming from the Sun?



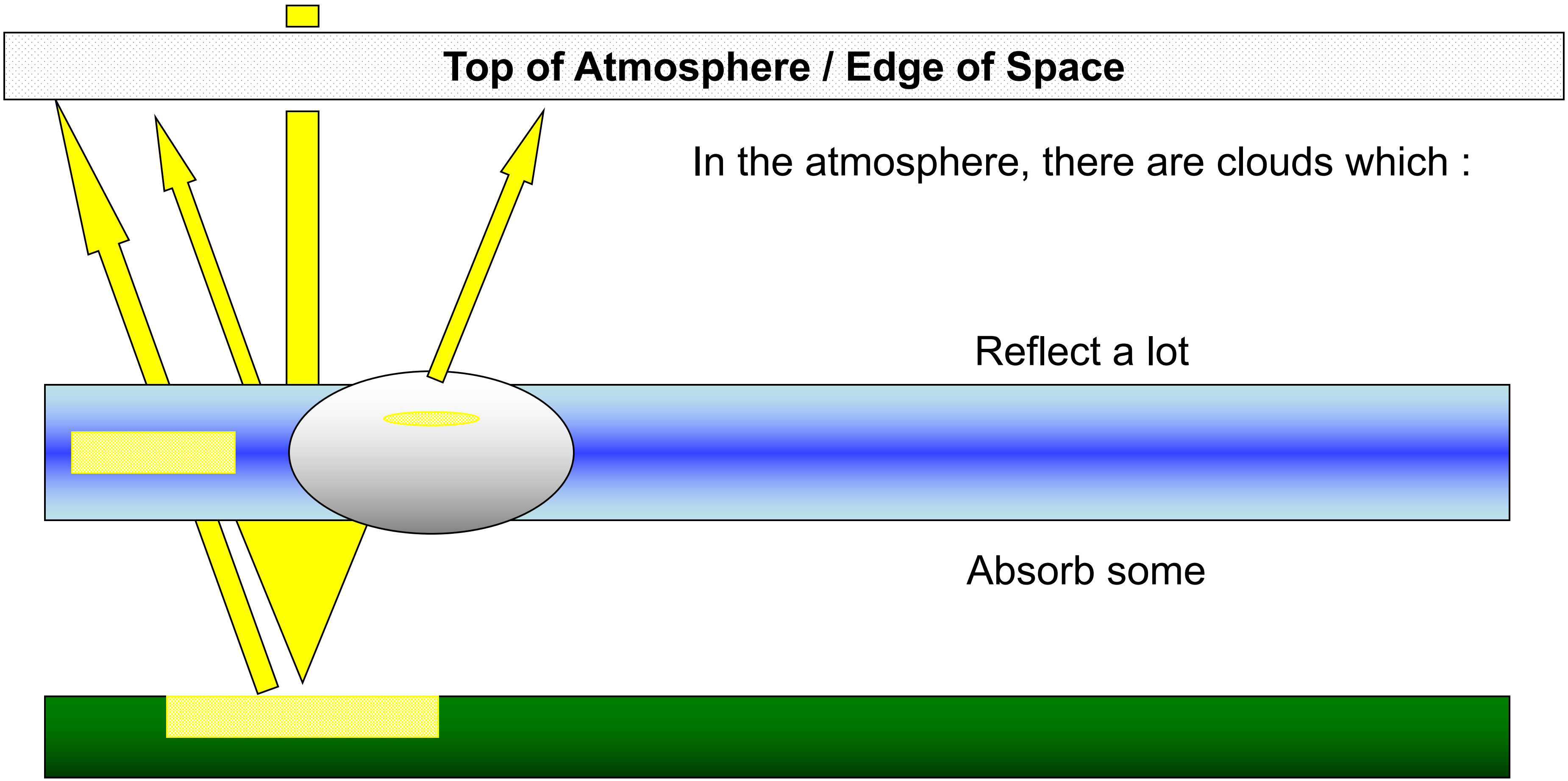
We also have the atmosphere.
Like the surface, the atmosphere can:

Reflect

or
Absorb

Building the Radiative Balance

What happens to the energy coming from the Sun?



In the atmosphere, there are clouds which :

Reflect a lot

Absorb some

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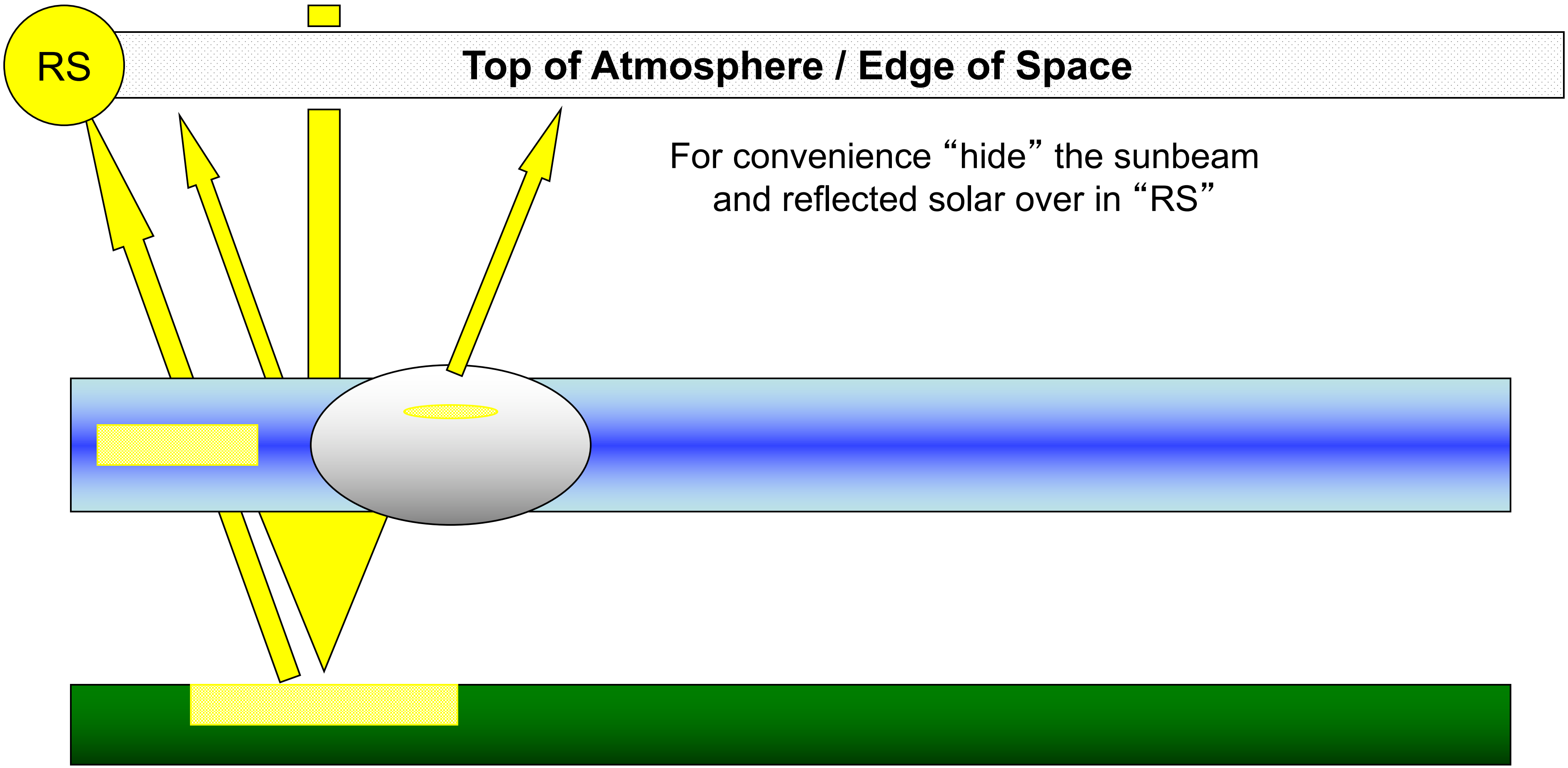
Building the Radiative Balance

What happens to the energy coming from the Sun?



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

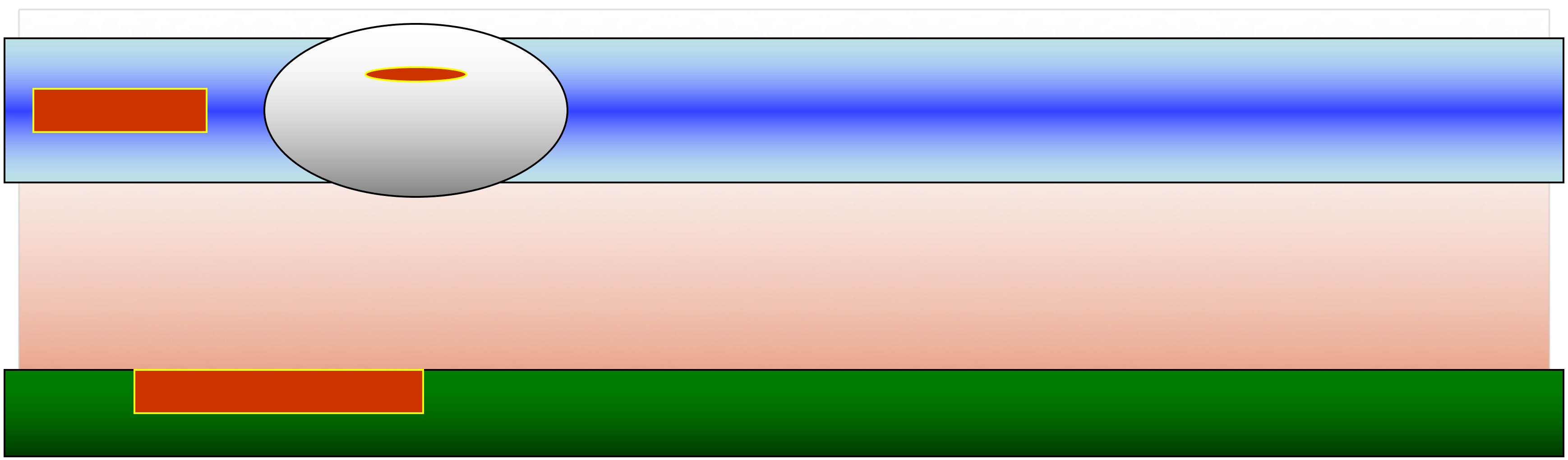
Redistribution by atmosphere, ocean, etc.

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

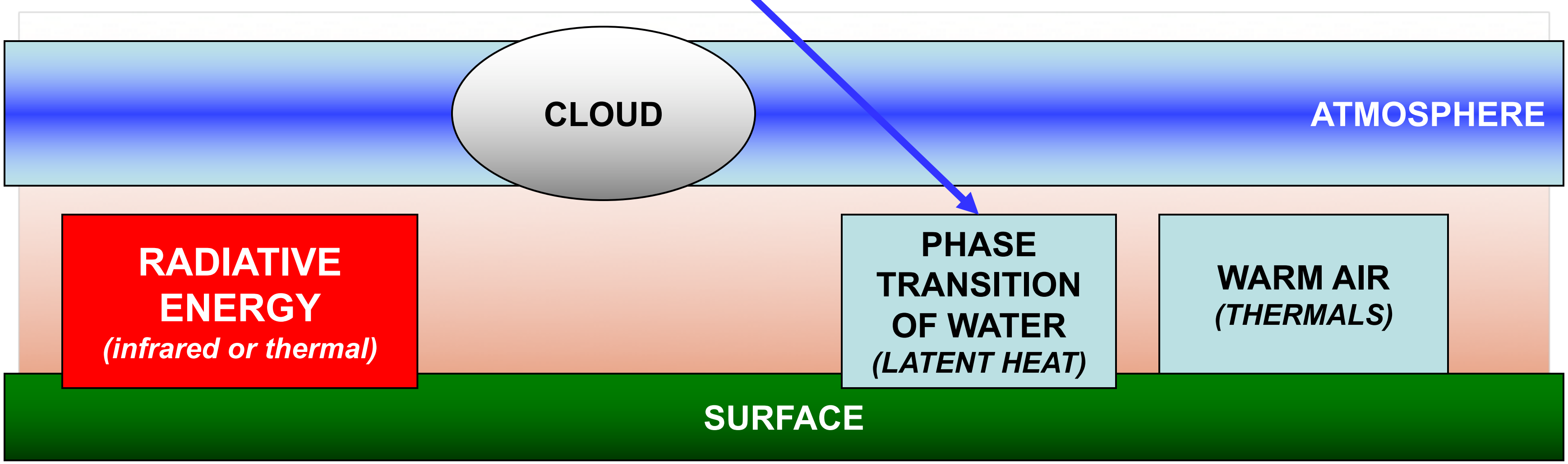
Terrestrial energy is converted/partitioned into three sorts

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)



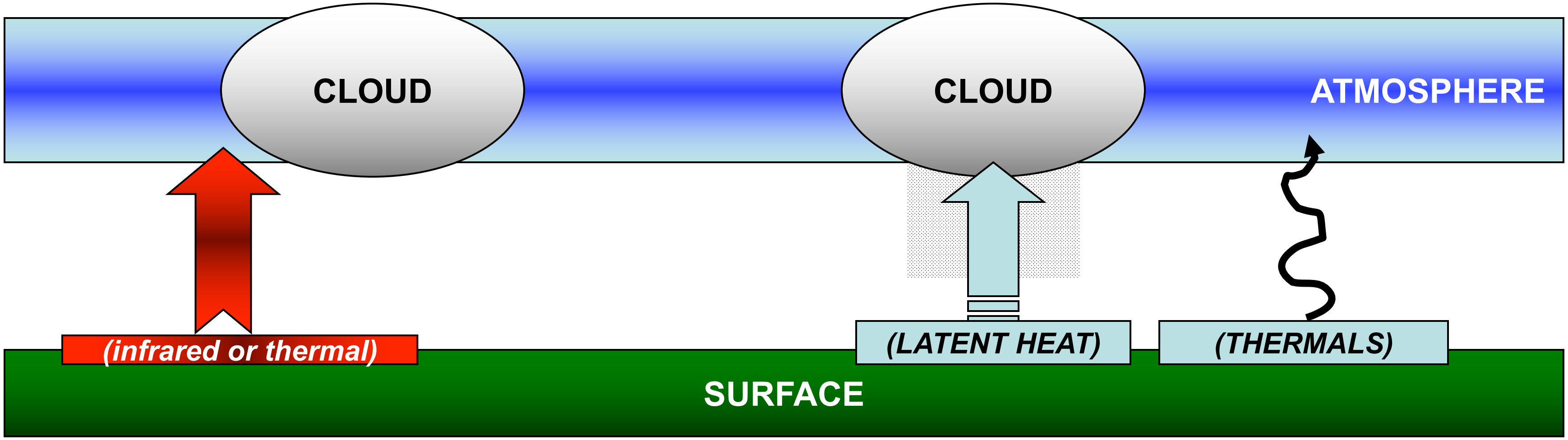
Building the Radiative Balance

Which is transmitted from surface to atmosphere

RS

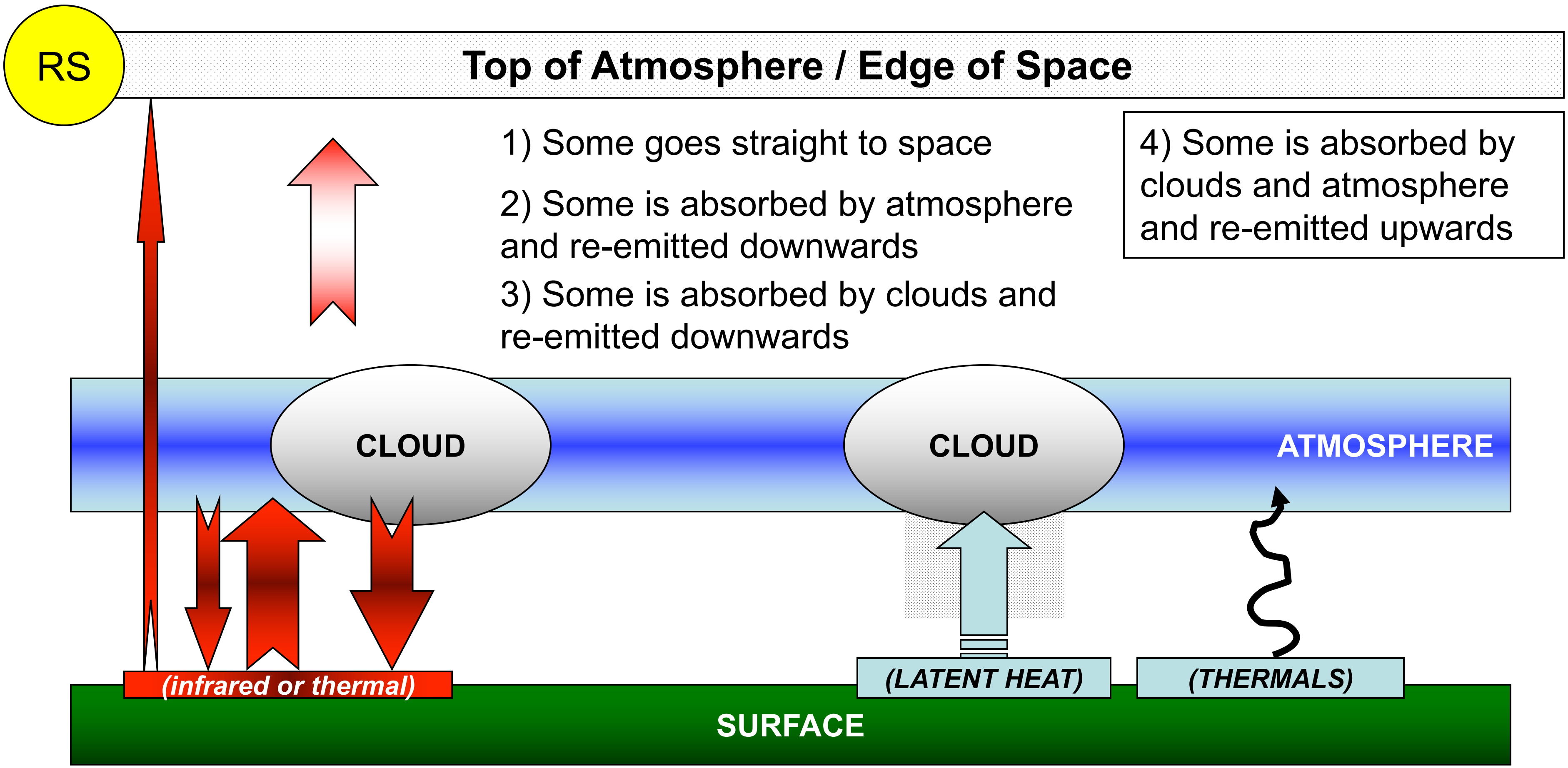
Top of Atmosphere / Edge of Space

3) Terrestrial energy ends up in three reservoirs



Building the Radiative Balance

And then the infrared radiation gets complicated

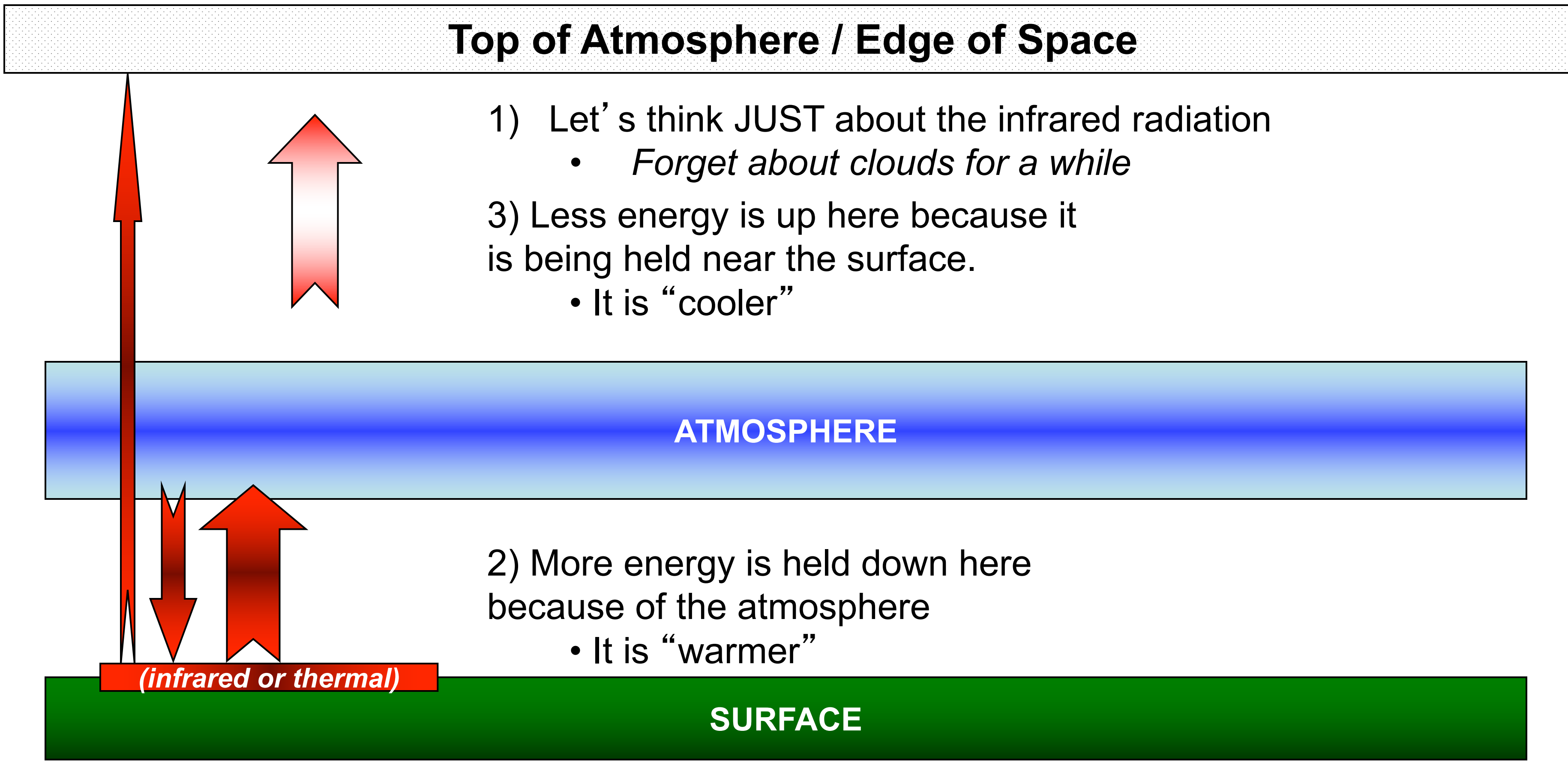


Want to consider one more detail

- What happens if I make the blanket thicker?

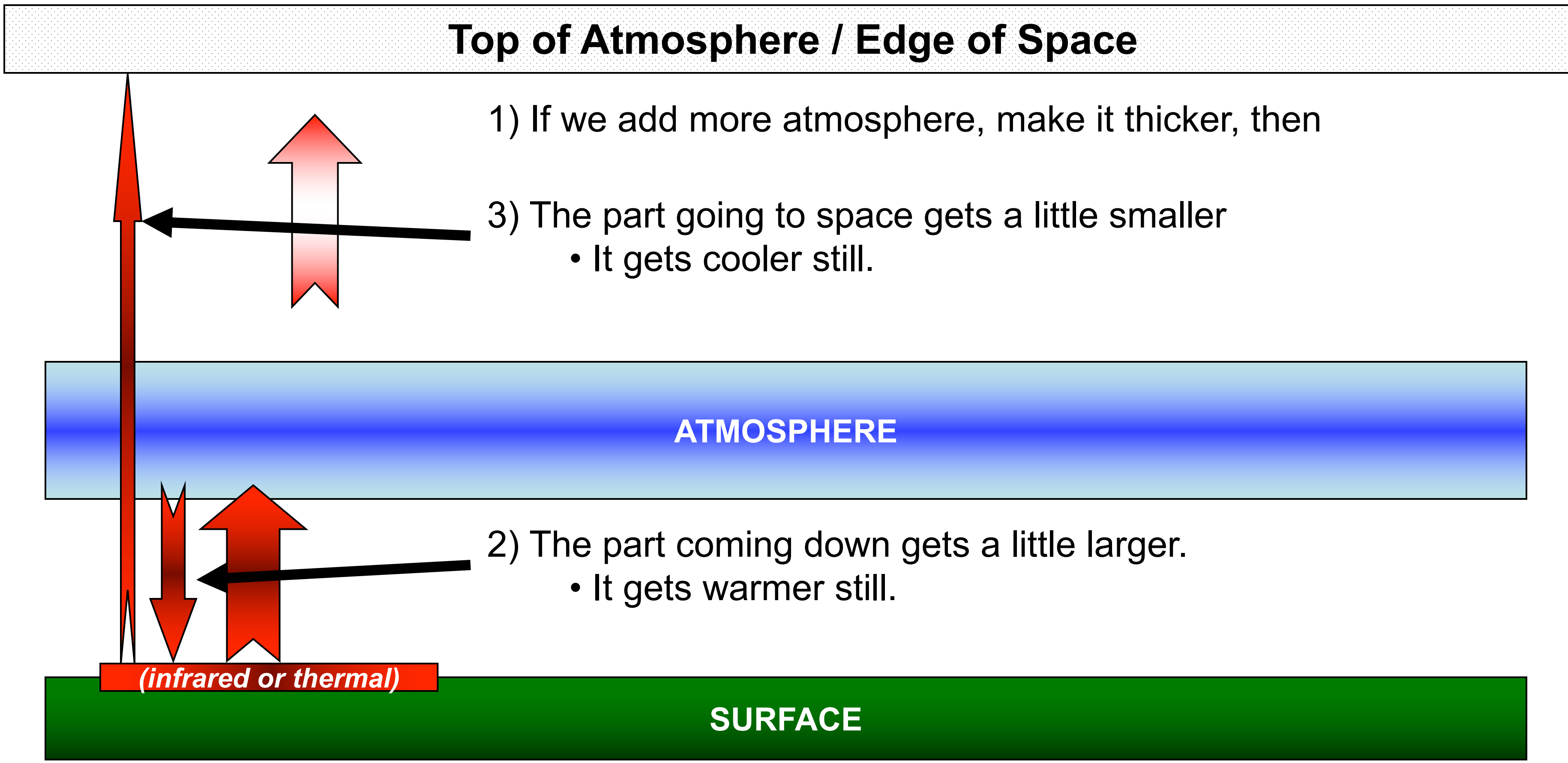
Thinking about the greenhouse

A thought experiment of a simple system.



Thinking about the greenhouse

Why does it get cooler up high?



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

Think about that warmer-cooler thing.

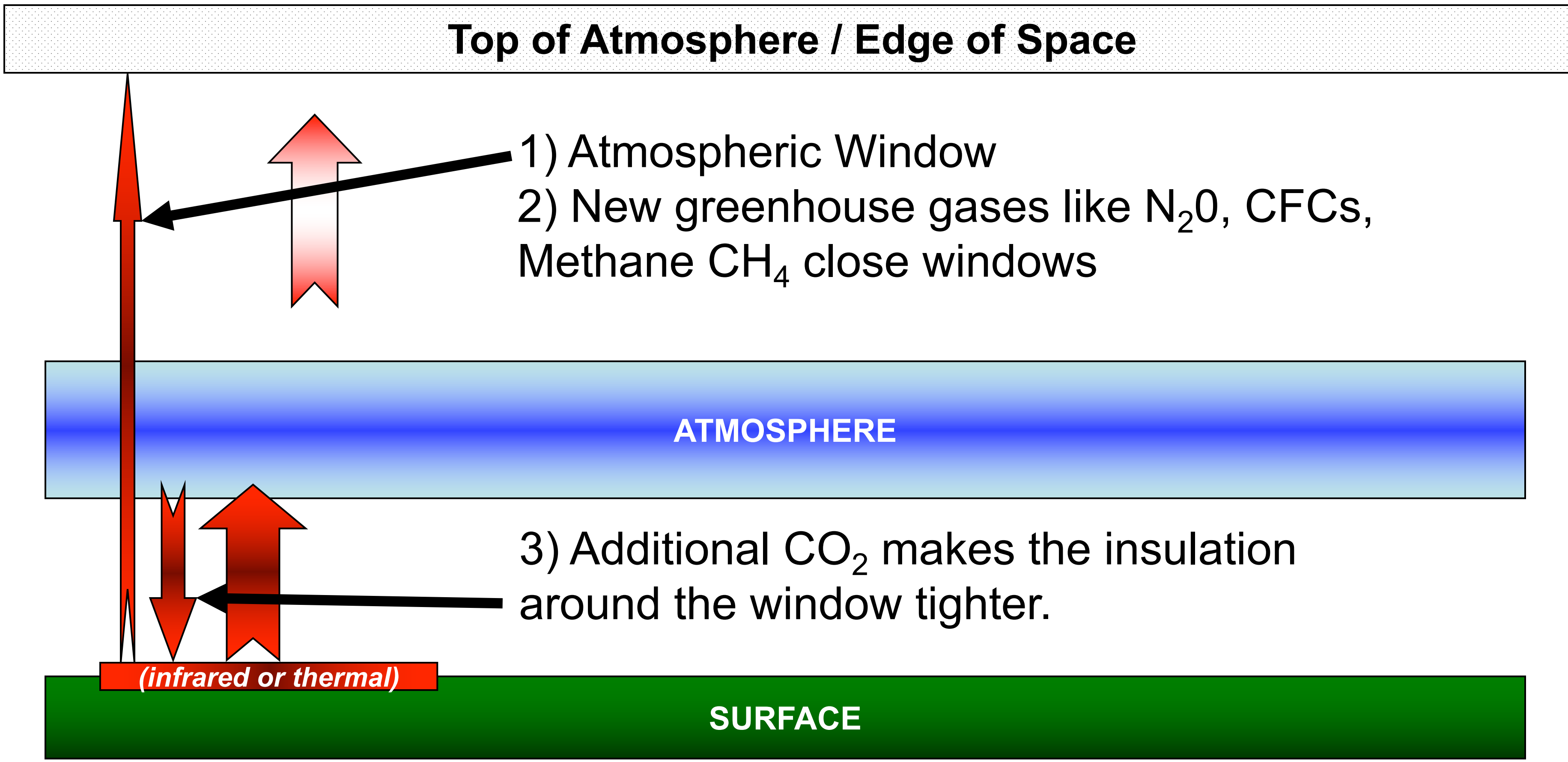
- Addition of greenhouse gas to the atmosphere causes it to get warmer near the surface and colder in the upper atmosphere.
- This is part of a "fingerprint" of greenhouse gas warming.
- Compare to other sources of warming, for example, more energy from the Sun.

Think about a couple of details of emission.

- There is an atmospheric window, through which infrared or thermal radiation goes straight to space.
  - Water vapor window
- Carbon dioxide window is saturated
  - This does not mean that CO_2 is no longer able to absorb.
  - It means that it takes longer to make it to space.

Thinking about the greenhouse

Why does it get cooler up high?



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

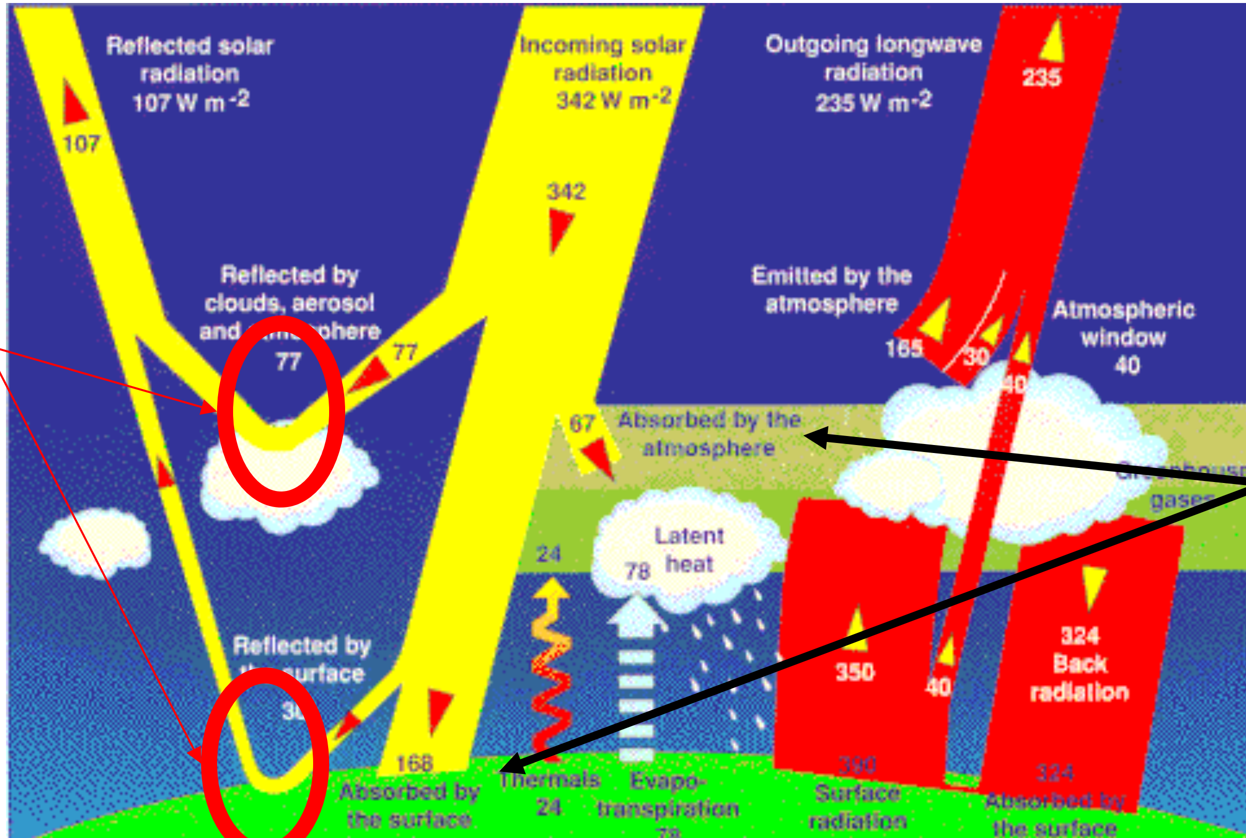
So what matters?

Changes in the sun

THIS IS WHAT WE ARE DOING

Things that change reflection

Things that change absorption



If something can transport energy DOWN from the surface.

Think about the link to models

- energy reflected = (fraction of total energy reflected) X (total energy)
- energy absorbed = total energy - energy reflected = (1-fraction of total energy reflected) X (total energy)
- fraction of total energy reflected →
  - Clouds
  - Ice
  - Ocean
  - Trees
  - Etc.

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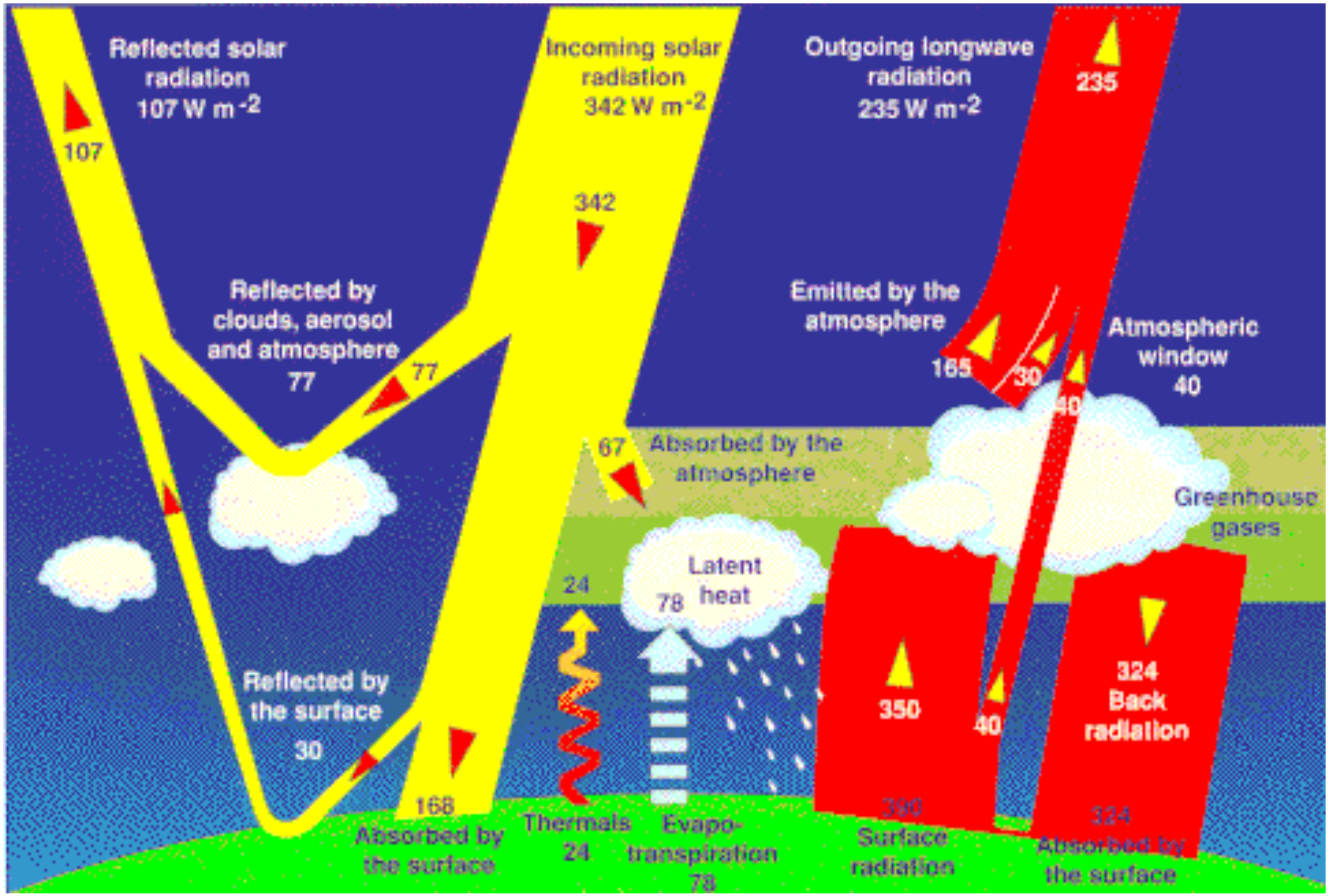
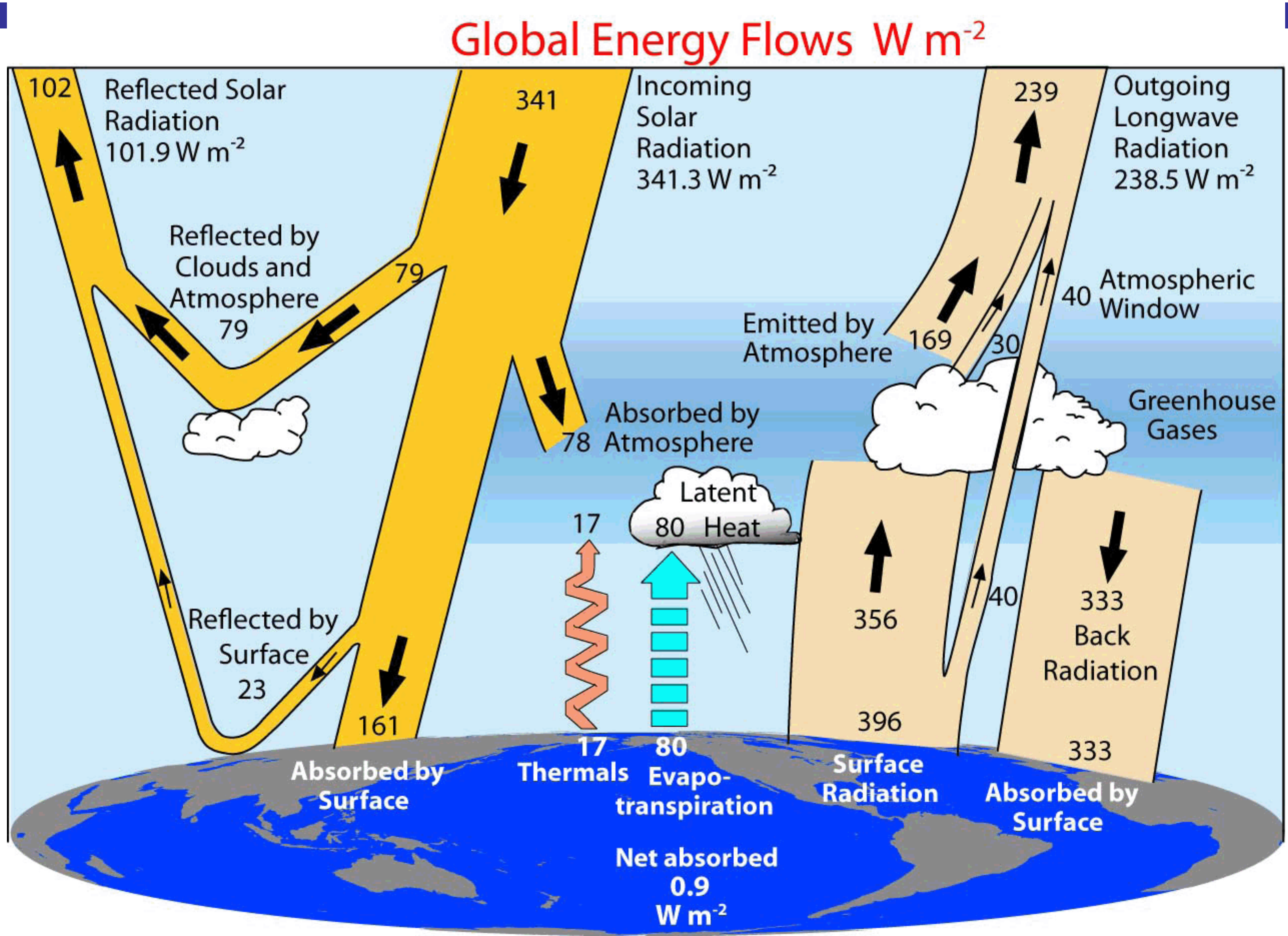
Radiation Balance Figure
In this figure out = in



Radiative Balance (Trenberth et al. 2009)
In this figure out does not = in



Summary: Class 4, Winter 2017

- Basic scientific principle or law used in climate science is conservation of energy
- Models are simply an accounting, or calculating the budget, of
  - Energy
  - Mass
  - Momentum

Summary: Class 4, Winter 2017

- Models are everywhere in our lives and work
  - Architecture
  - Epidemiology
  - Aerospace
  - Computer assisted design
  - Games
  - The bridge over the Huron River
  - Landing things on Mars
  - Investing my retirement account
  - How much rent can I afford
  - My digital thermometer

Summary: Class 4, Winter 2017

- Earth's energy balance
  - Energy from Sun
  - Energy sent back to space
    - Things that absorb
    - Things that reflect
    - Moving energy around
    - Storing energy at the surface of the Earth
      - Greenhouse gases hold the energy a while
      - Oceans pick it up and hold it longer
      - Ice takes it up and melts → balances change

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  - Point of view
- Models and Modeling
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  - Role in climate science
- Energy in Earth System: Basics
  - Absorption
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