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

Richard B. Rood
734-647-3530
rbrood@umich.edu

LECTURE NUMBER 6
January 30, 2007

Class News

- February 2, 2007, the official summary for IPCC should be released. The rest of the report will follow over the year.
- Senate hearings on climate change today
  - Opened to all senators to speak

Speakers subject to scheduling

- Maria Carmen Lemos
- Andy Hoffman
- Barry Rabe
- Nina Mendelson
- Justin Felt
- Meredith Fowlie
- Marie O'Neill
- Phil Rasch
- Sabrina McCormick
- Henry Pollack
- Rosina Bierbaum
- Others

Class News

- Next Reading: Parts of The Scientific Basis of the 2001 Report
  - http://www.grida.no/climate/ipcc_tar/
    - Summary for Policy Makers
      - http://www.grida.no/climate/ipcc_tar/wg1/005.htm
    - Technical Summary // Future (section F)
      - http://www.grida.no/climate/ipcc_tar/wg1/029.htm
    - We will compare and contrast with the new report

Ideas and Things

- NEWS: Anyone hear or read any news they want to discuss.
  - Climate Action Partnership
    - http://www.onpointradio.org/shows/2007/01/20070129_a_main.asp
  - State of the Union
  - Criticism / Discussion of IPCC
    - http://hosted.ap.org/dynamic/stories/C/CLIMATE_REPORT?SITE=ENCCOM&SECTION=HOME&TEMPLATE=DEFAULT
- Projects?

Science Basis of Climate Change (3)

- Introduced the idea of conservation and used the conservation of energy and CO_2 to investigate the ice core data

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.* $M(t_2)$-$M(t_1)$

Change per unit time

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

Income

Expense

Conservation Principle
"in balance"

If a quantity is conserved or "in balance" then

Change per unit time = 0

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

$$P = L$$

Production = Loss

For exampled, we considered the conservation of energy and CO_2 in the ice core data

CHANGES IN SOLAR HEATING

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

CHANGES IN CO_2, WHICH CHANGE THE RATE OF COOLING

$$\frac{\Delta CO_2}{\Delta t} = P_{CO_2} - L_{CO_2}$$

DISTANT PAST RECORD

- SENSITIVE TO SOLAR RADIATIVE ENERGY (through changes in orbital parameters)
- COOLING ACCELERATED BY CHANGES ICE ON THE SURFACE
- CO_2 CHANGES BECAUSE BALANCE OF PRODUCTION AND LOSS CHANGES. (SOURCES AND SINKS)

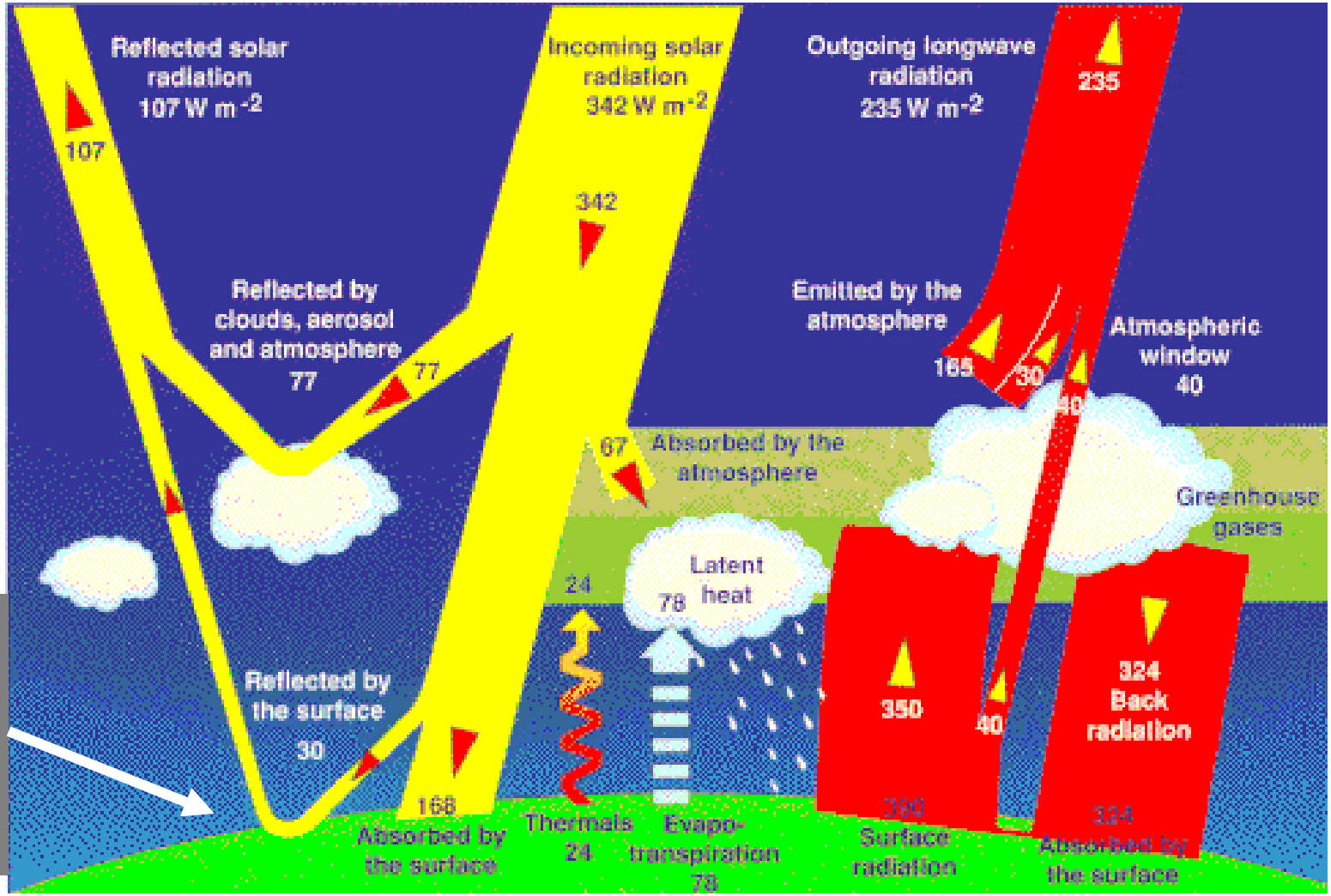
Science Basis of Climate Change (3)

- Introduced the idea that in a stable climate, the heating and cooling of the Earth is in balance over some suitable time period.

Heating = Cooling

Heating comes from solar radiation and cooling is by emission of infrared radiation to space

Radiation Balance Figure

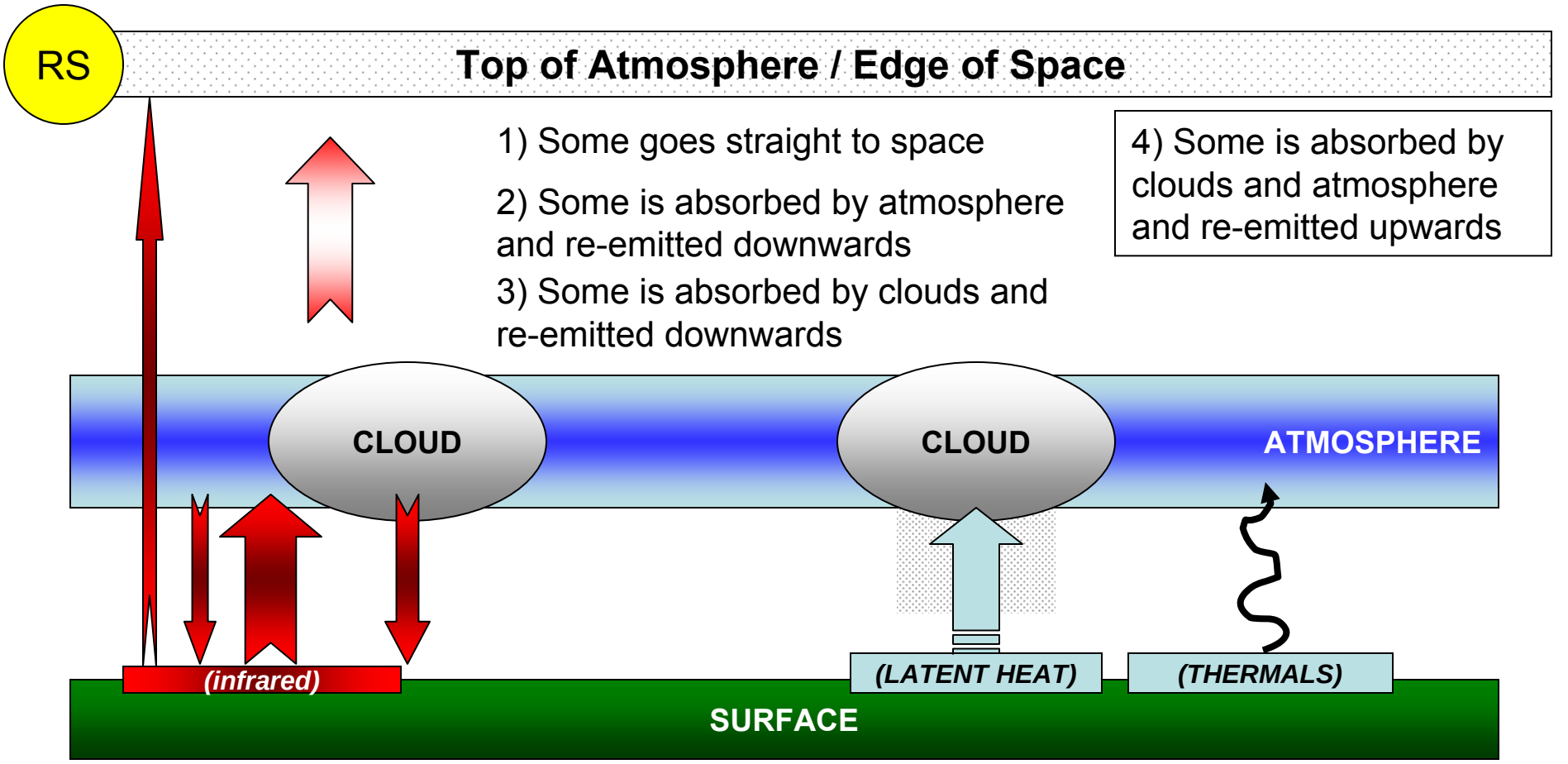


WE ARE INTERESTED IN THE SURFACE

CHANGES OF, SAY, 2 W m^{-2}

Building the Radiative Balance

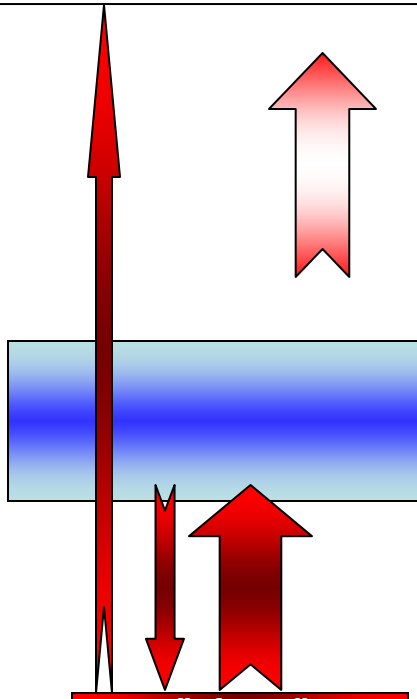
And then the infrared radiation gets complicated



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"

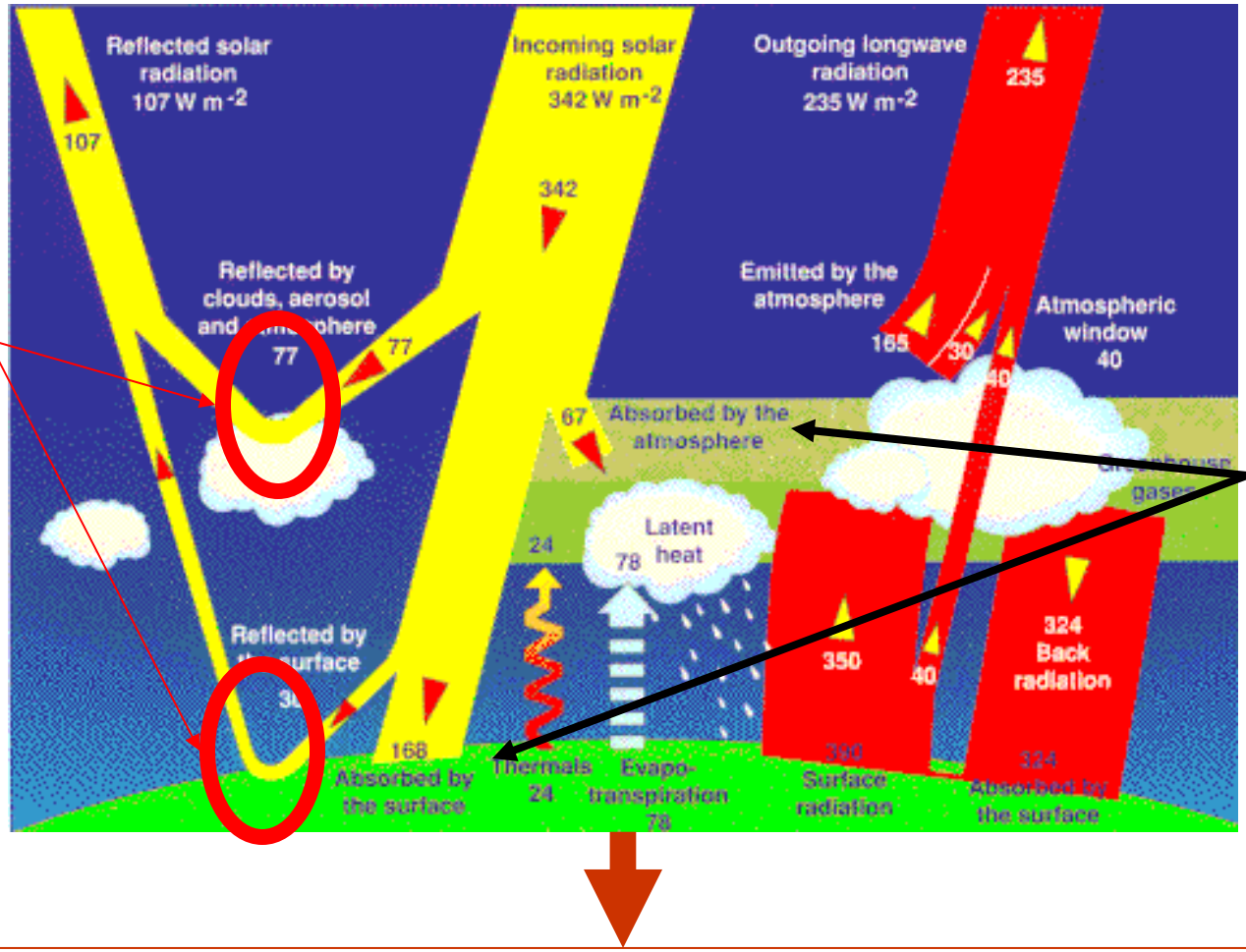
SURFACE

Changes in the sun

So what matters?

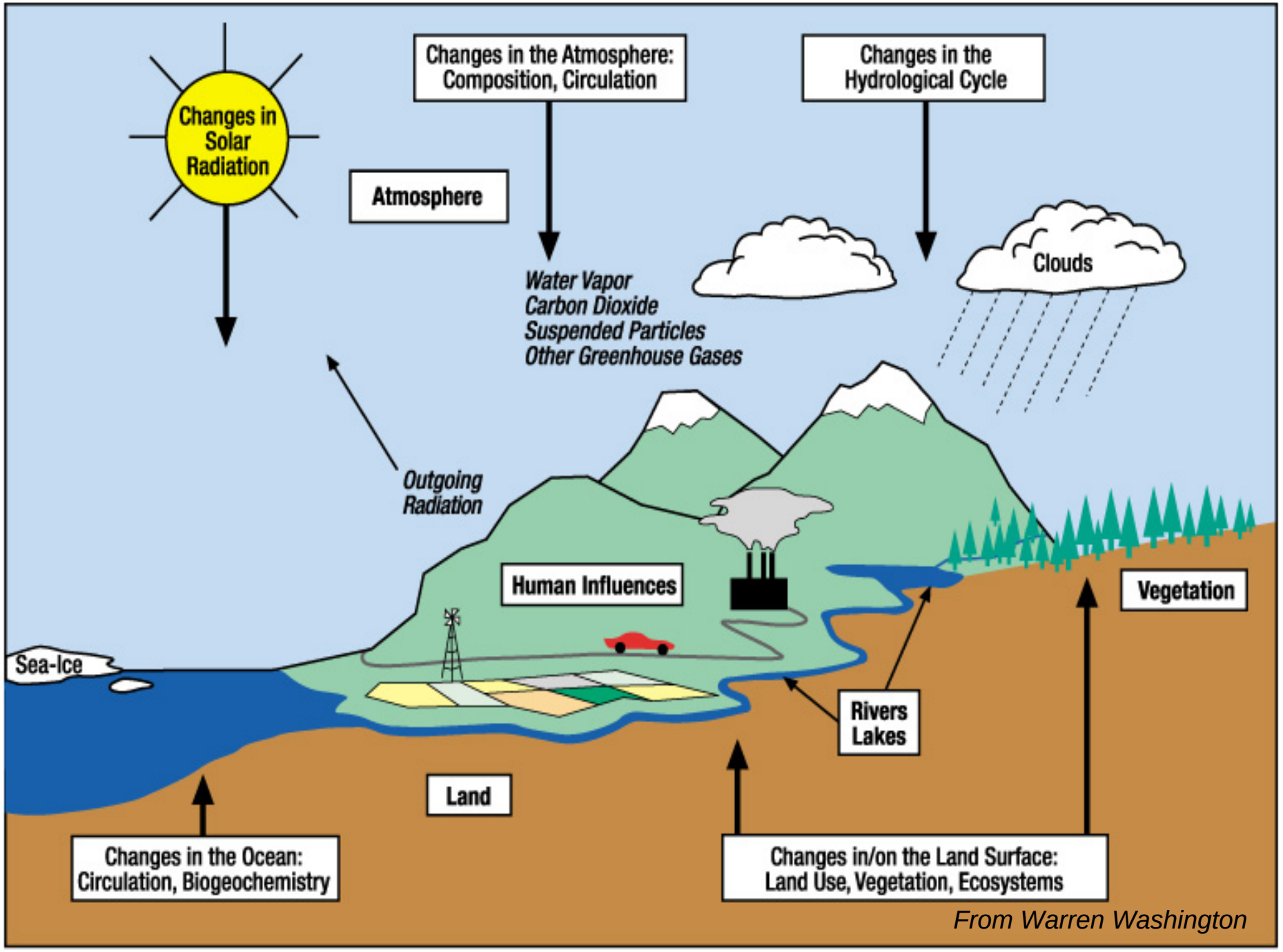
THIS IS WHAT WE ARE DOING

Things that change reflection



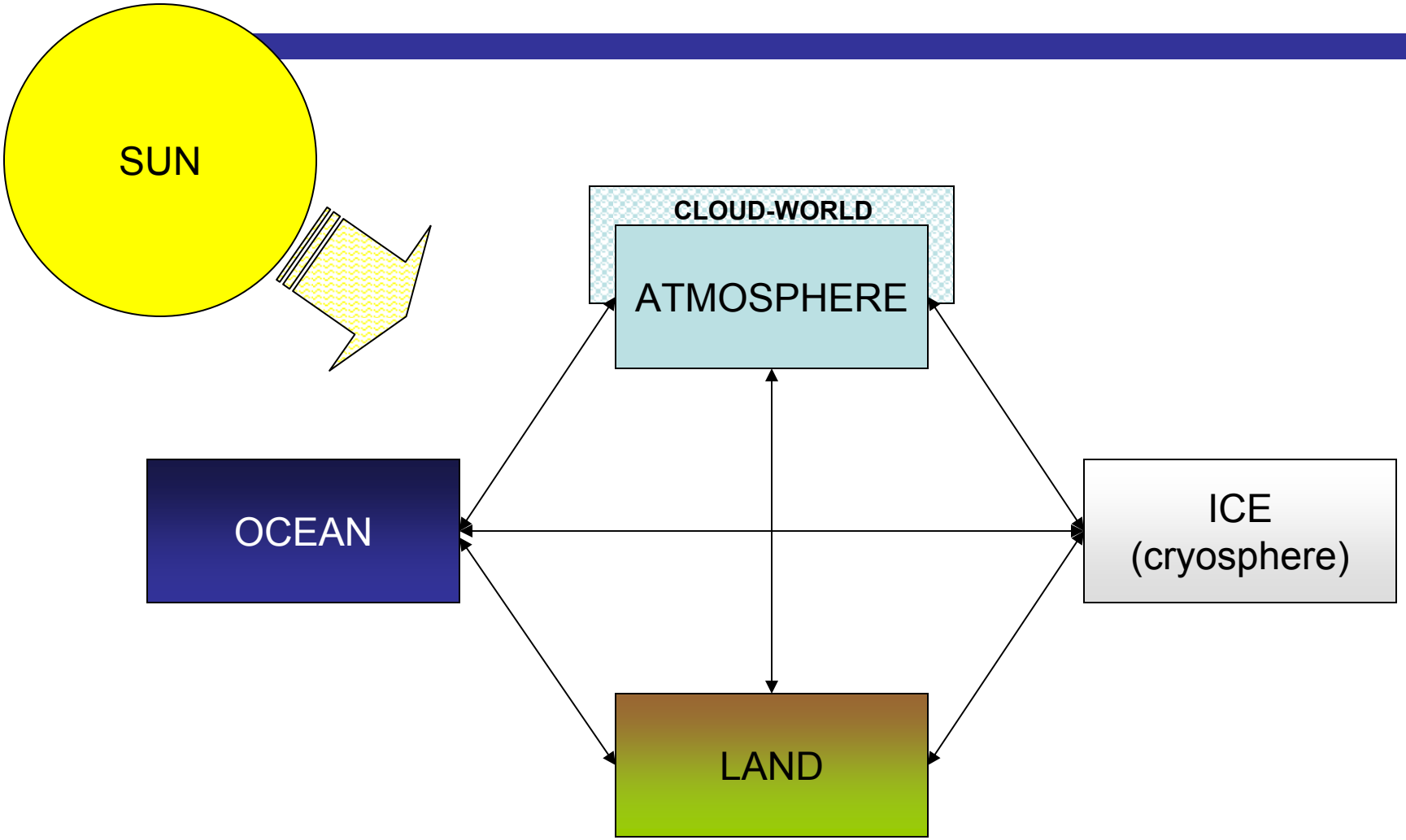
Things that change absorption

If something can transport energy DOWN from the surface.

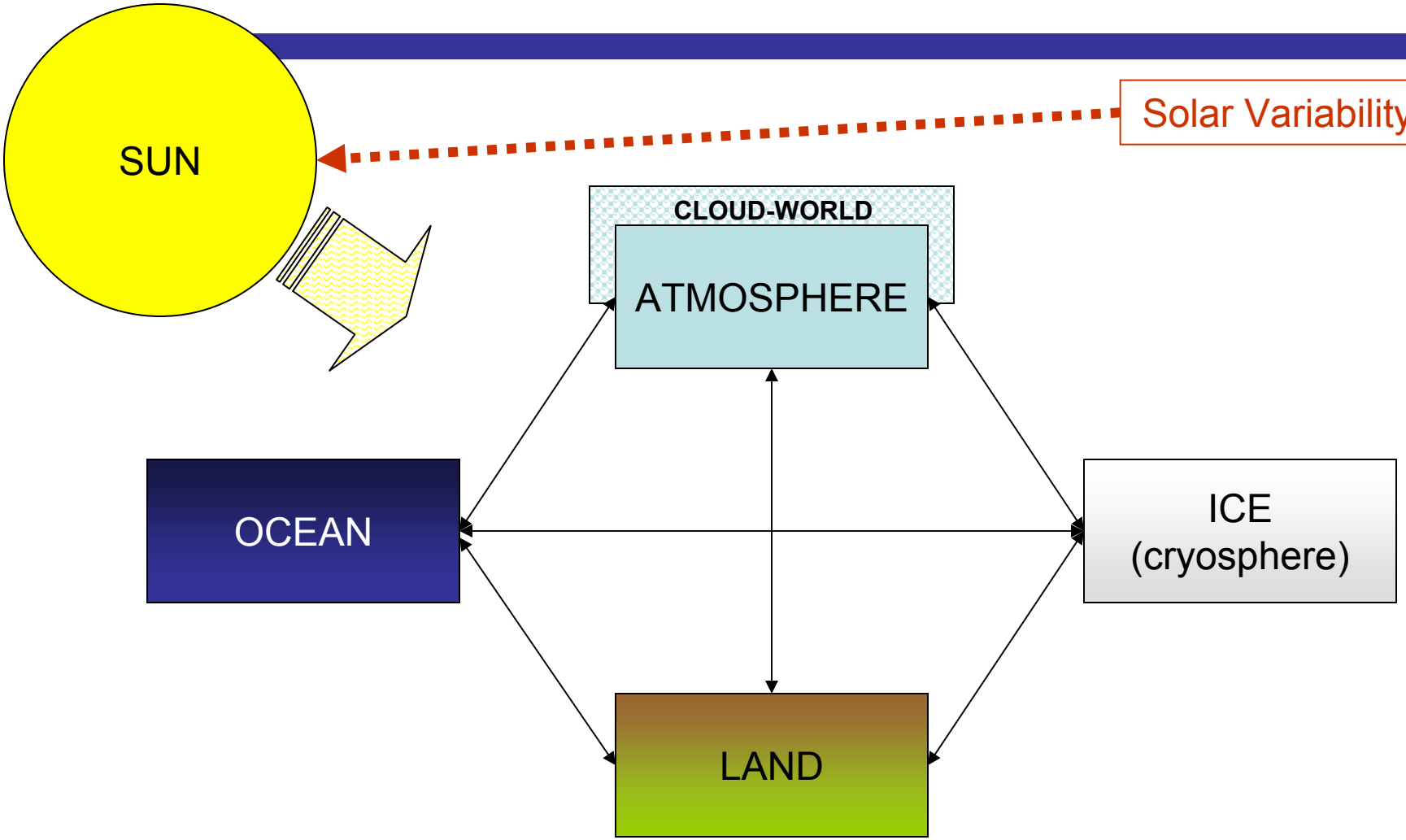


From Warren Washington

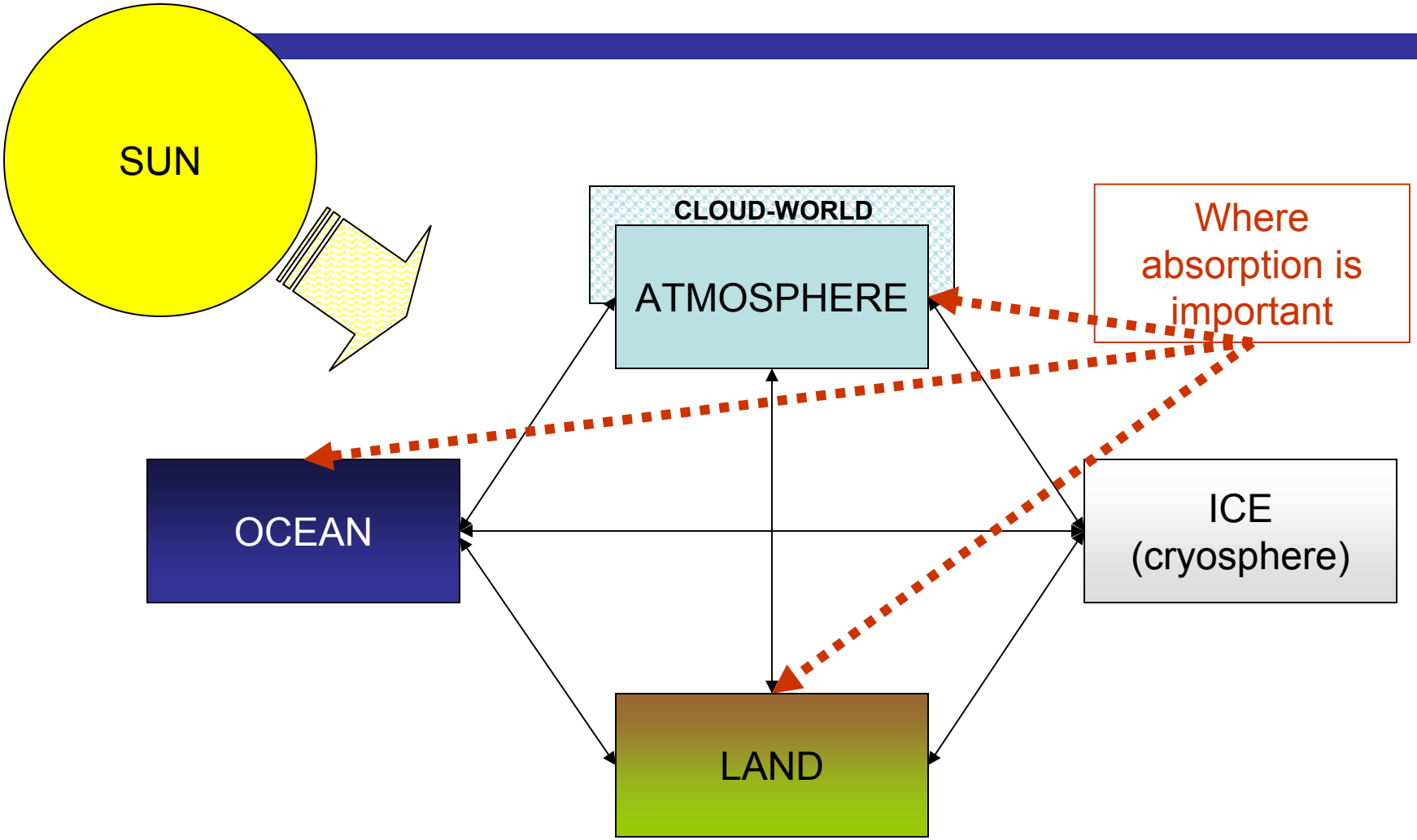
The Earth System



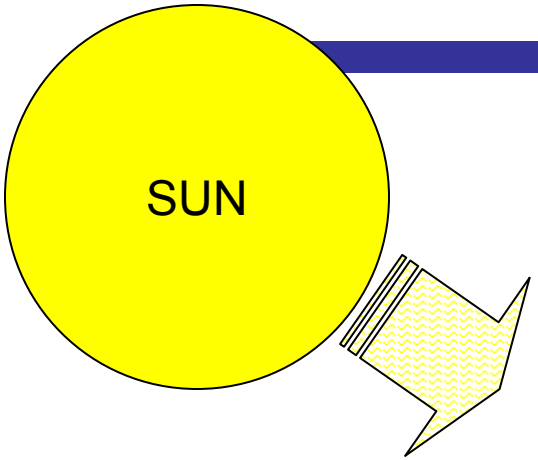
The Earth System

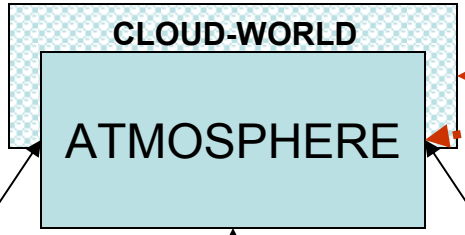


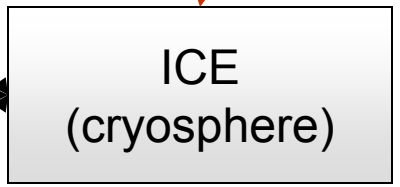
The Earth System



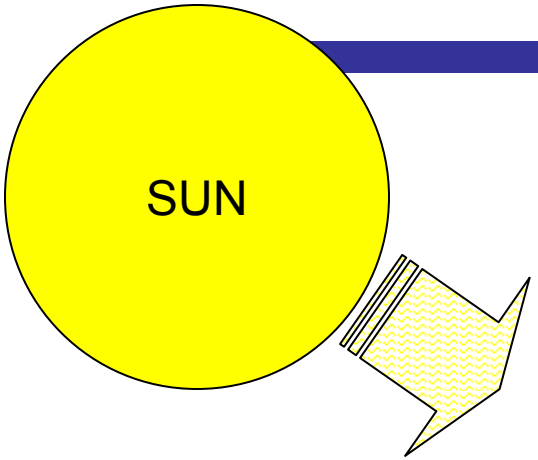
The Earth System

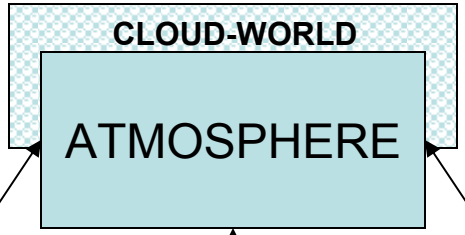


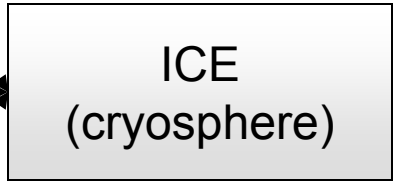


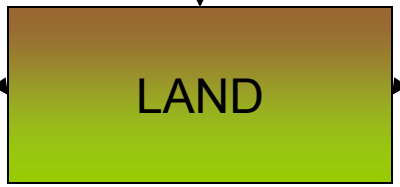


The Earth System



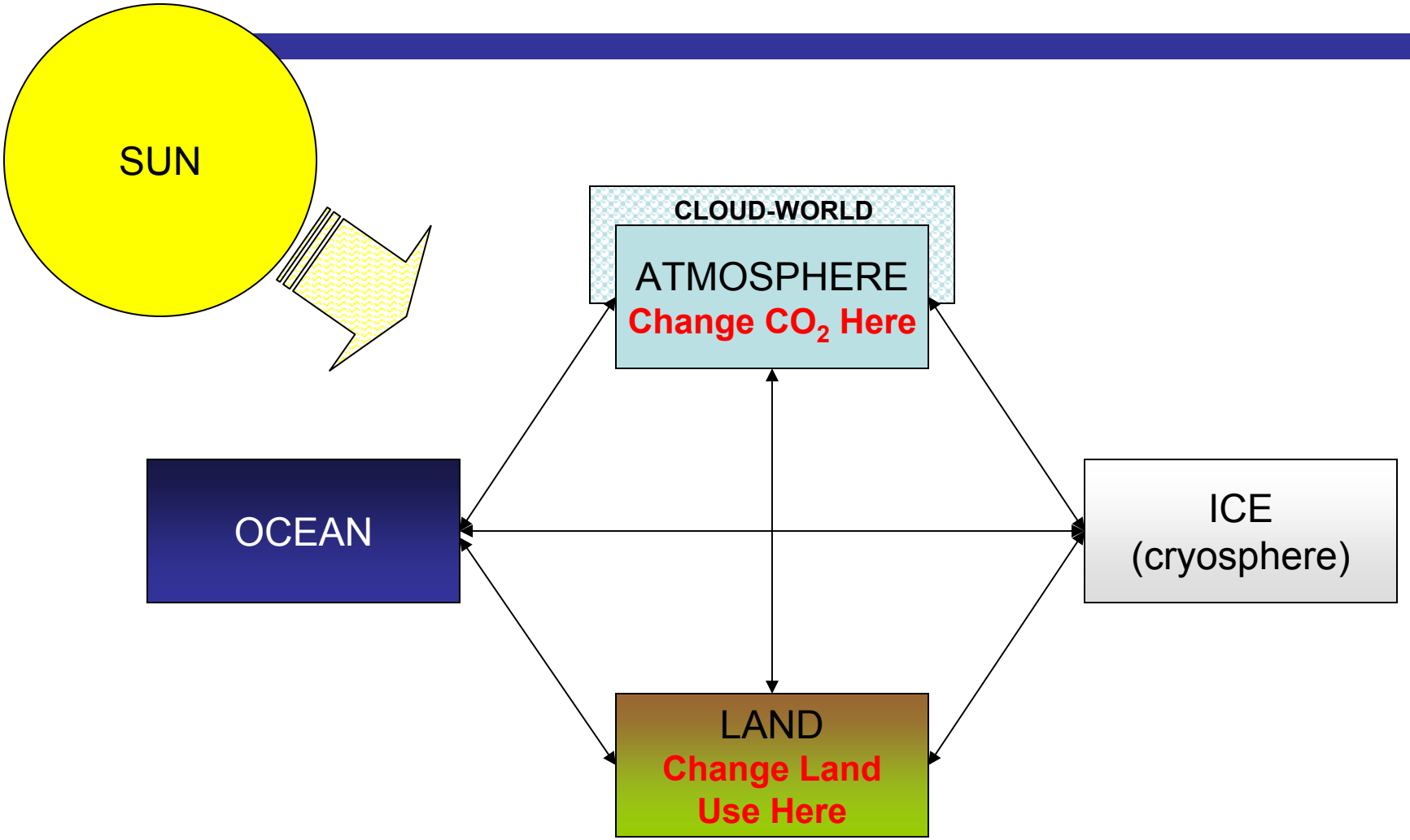






Possibility of transport of energy down from the surface

Where we directly make changes



Transport of heat poleward by atmosphere and oceans

- This is an important part of the climate system
- One could stand back far enough in space, average over time, and perhaps average this away.
- This is, however, weather ... and weather is how we feel the climate day to day
  - It is likely to change because we are changing the distribution of average heating

While Building the Radiative Balance Figure

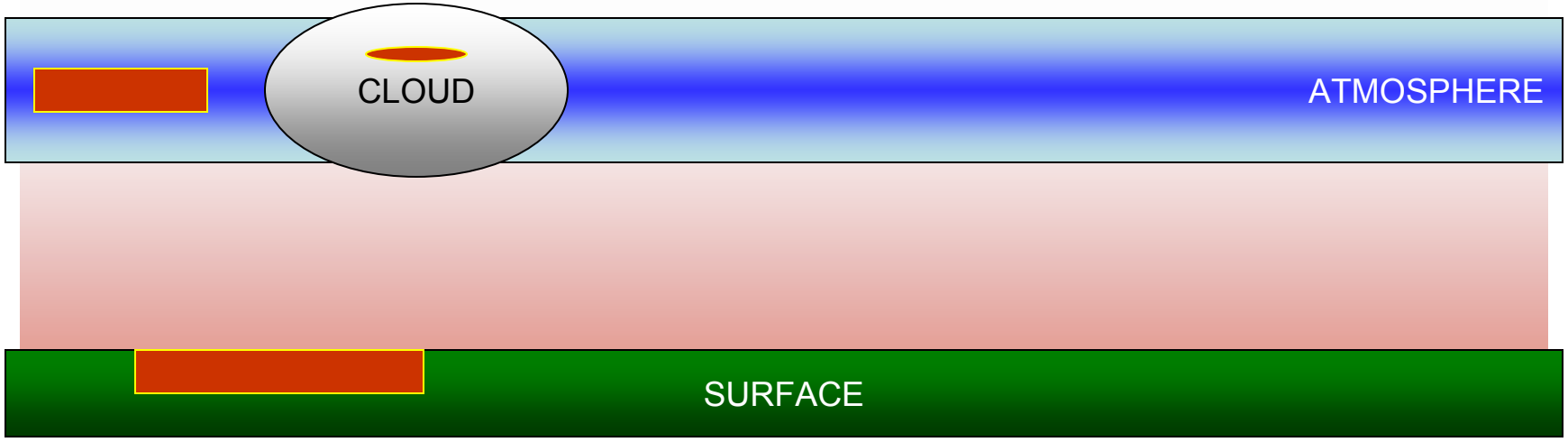
Redistribution by atmosphere, ocean, etc.

RS

Top of Atmosphere / Edge of Space

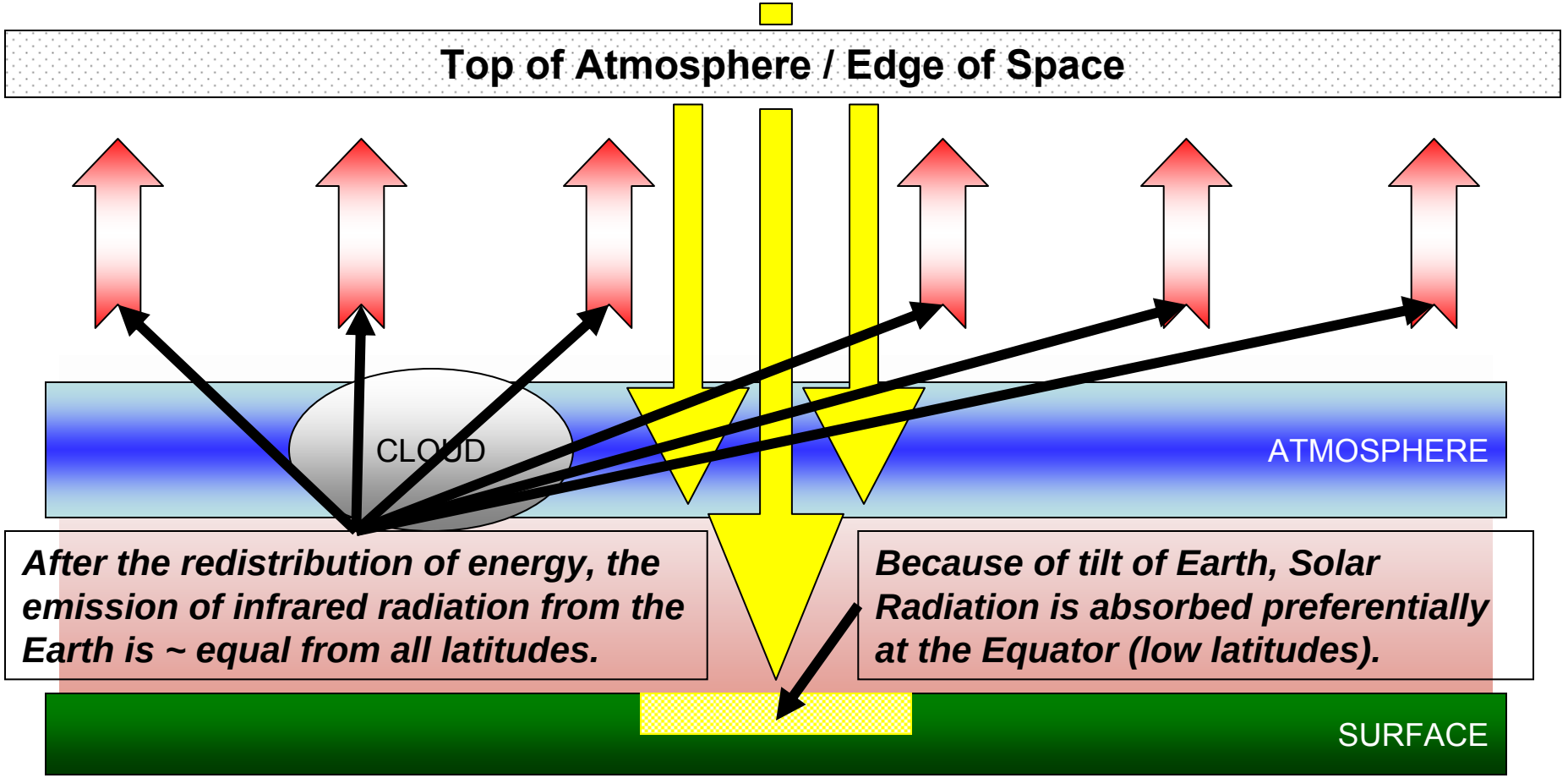
1) The absorbed solar energy is converted to terrestrial thermal energy.

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



Another important consideration.

Latitudinal dependence of heating and cooling

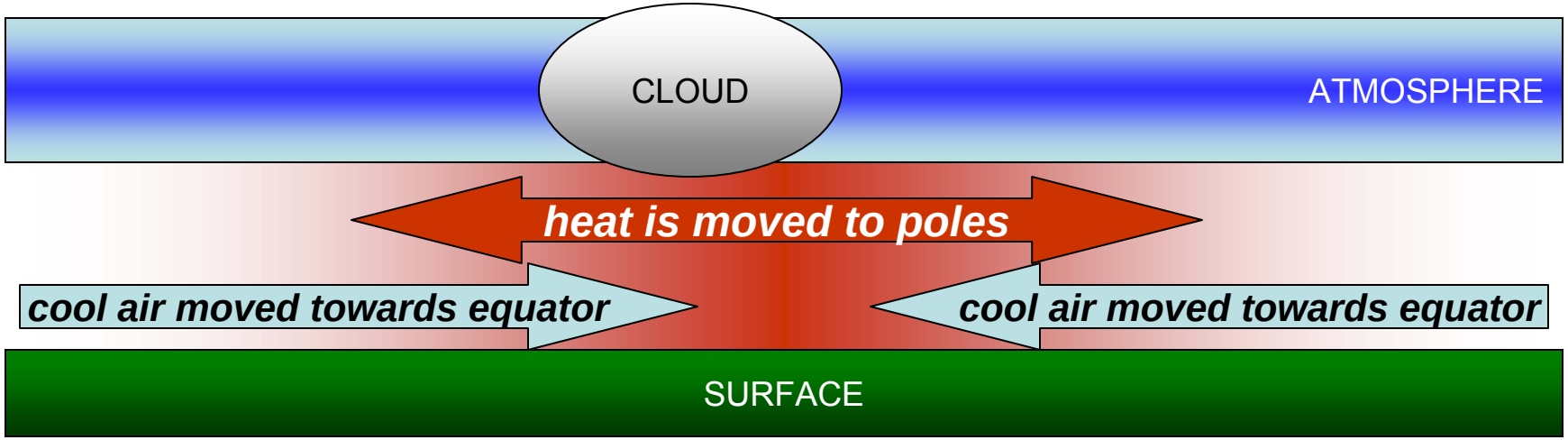


Transfer of heat north and south is an important element of the climate at the Earth's surface.

Redistribution by atmosphere, ocean, etc.

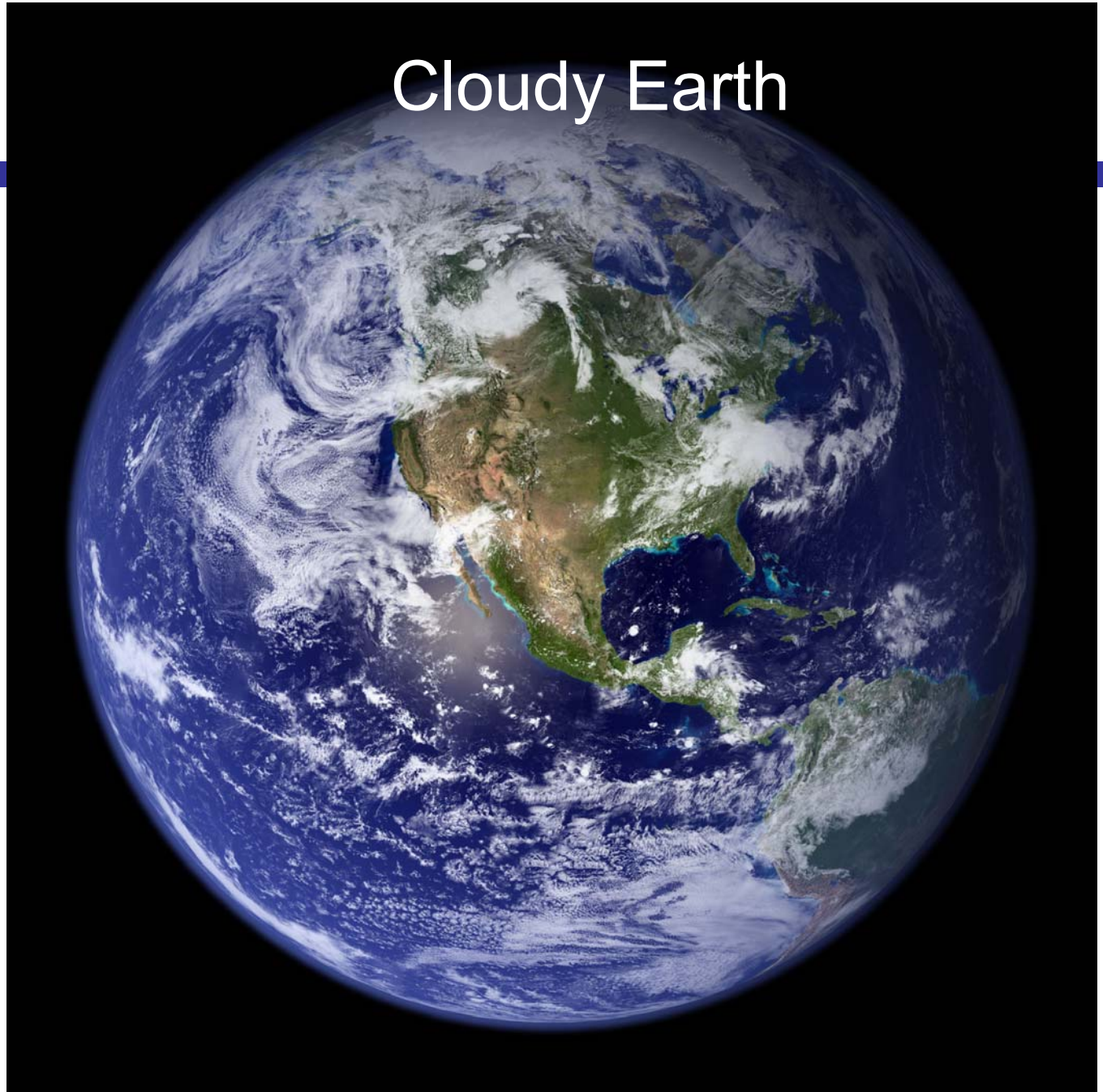
Top of Atmosphere / Edge of Space

This predisposition for parts of the globe to be warm and parts of the globe to be cold means that measuring global warming is difficult. Some parts of the world could, in fact, get cooler because this warm and cool pattern could be changed.

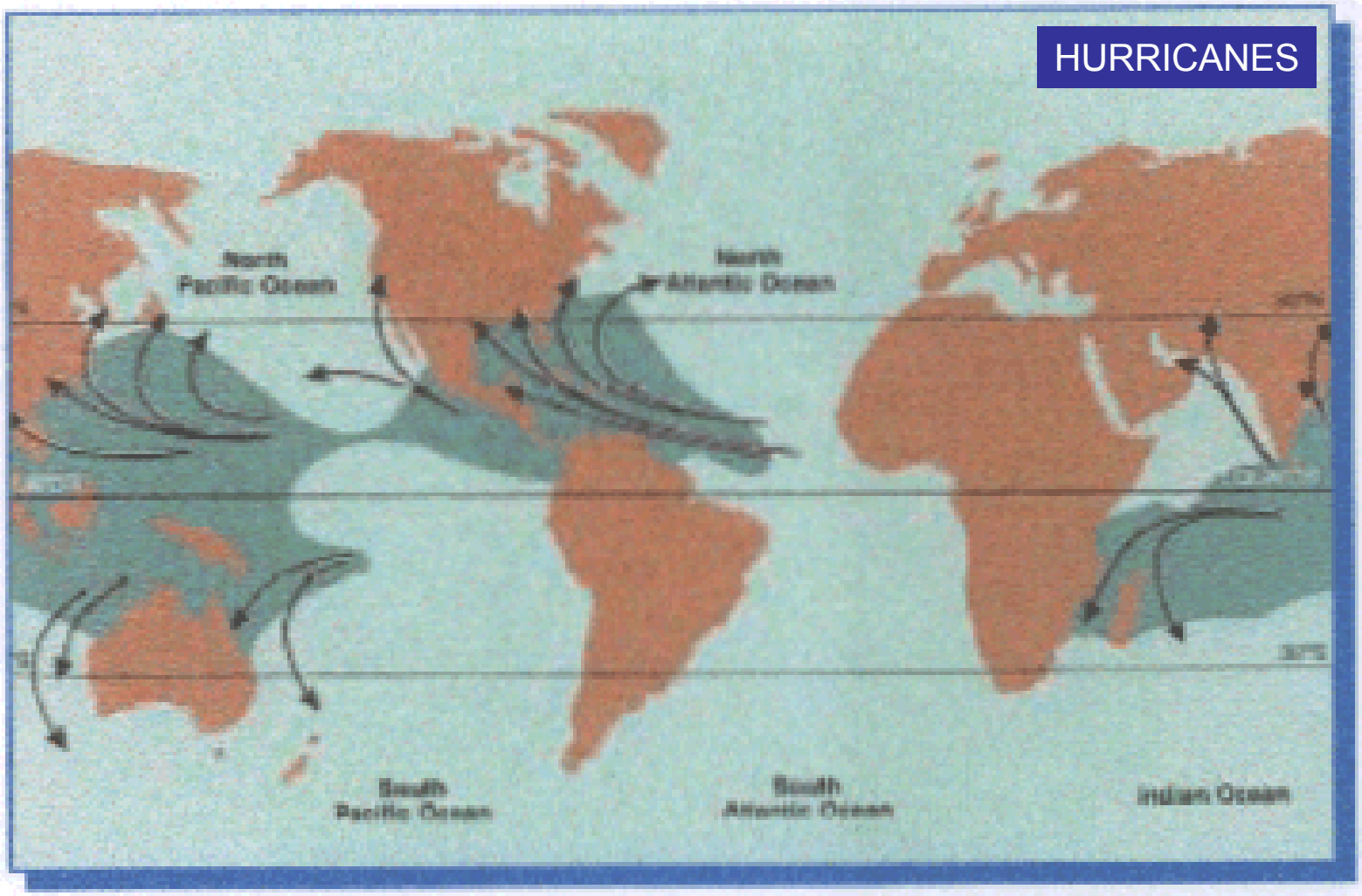


This is a transfer. Both ocean and atmosphere are important!

Cloudy Earth

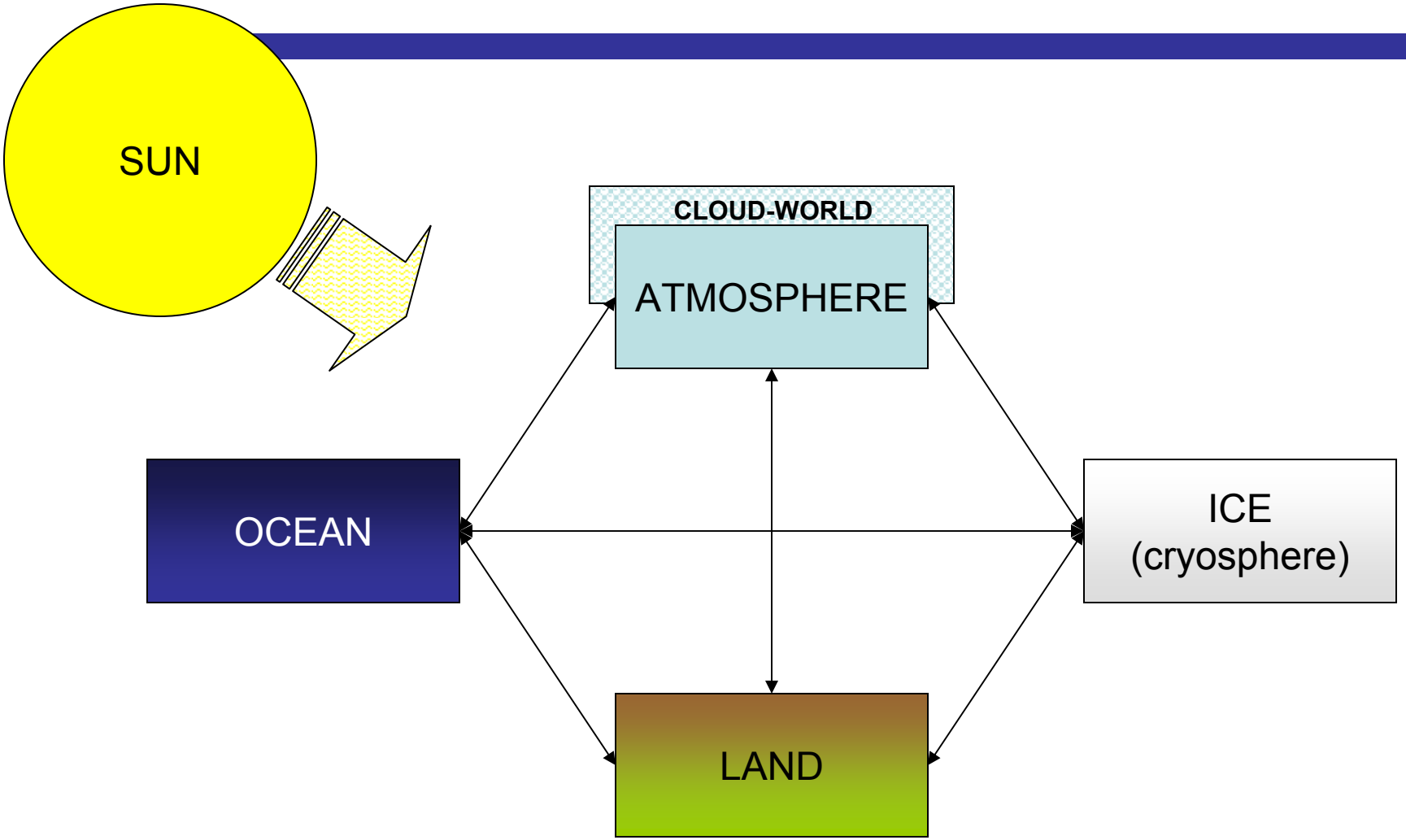


Weather Moves Heat from Tropics to the Poles

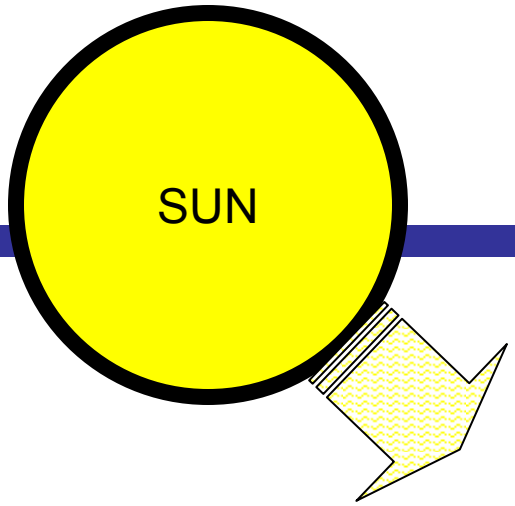


Planet Earth: Storm/Bill Hezlep © 1982 Time-Life Books, Inc.

The Earth System



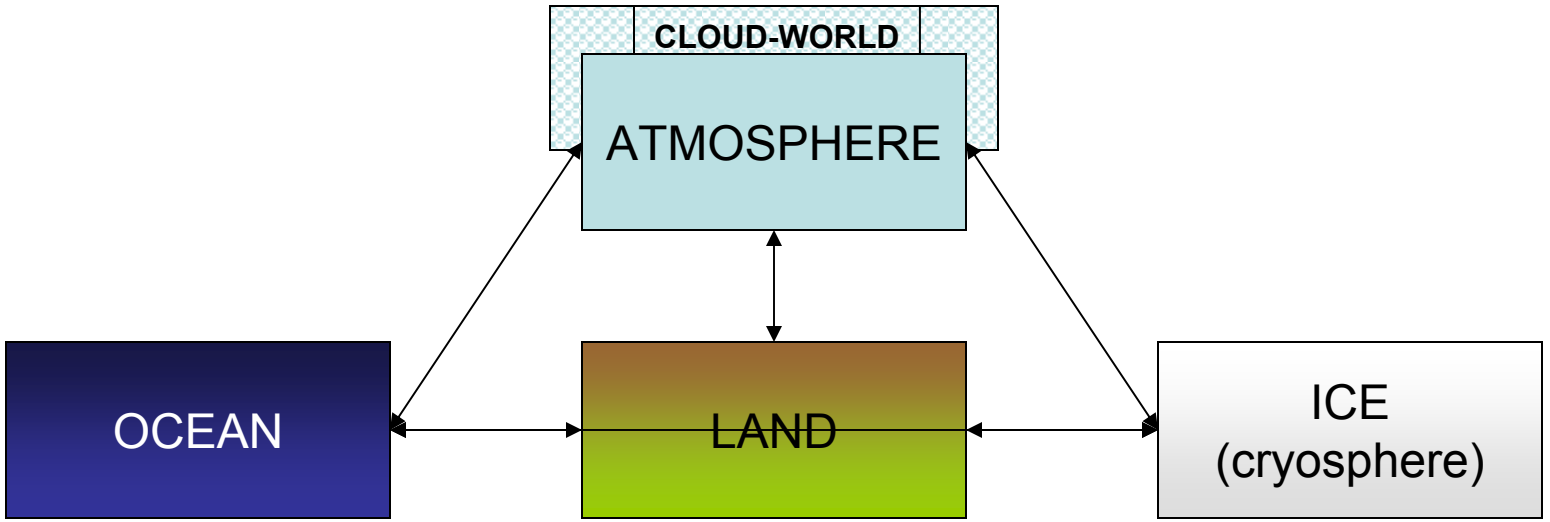
Earth System: Sun



Lean, J., Physics Today, 2005

SUN:

- Source of energy
- Generally viewed as stable
- Variability does have discernable signal on Earth
- Impact slow and small relative to other changes



Earth System: Atmosphere

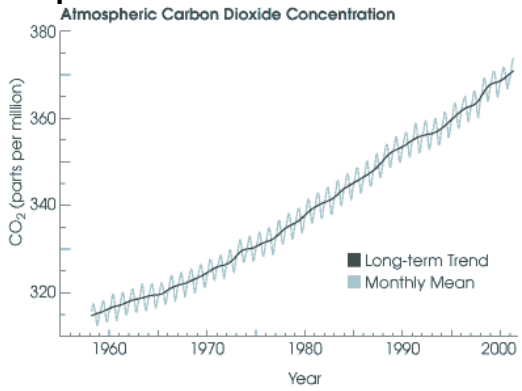
SUN

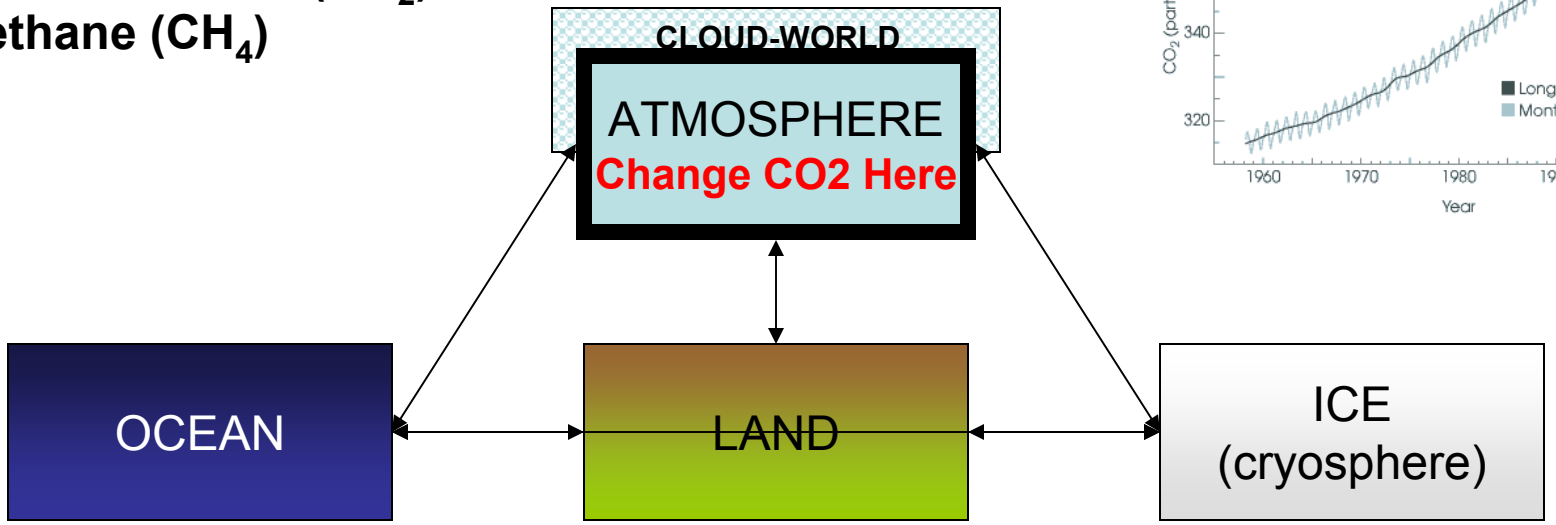
What are the most important greenhouse gasses?

- **Water (H_2O)**
- **Carbon Dioxide (CO_2)**
- **Methane (CH_4)**

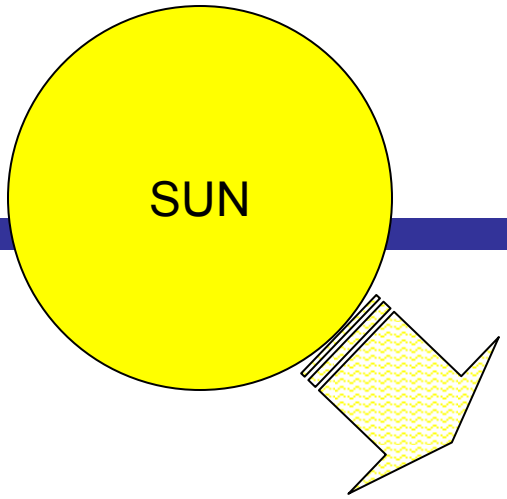
The Atmosphere:

- Where CO_2 is increasing from our emissions
- Absorption and reflection of radiative energy
- Transport of heat between equator and pole
- Weather: Determines temperature and rain





Earth System: Cloud World

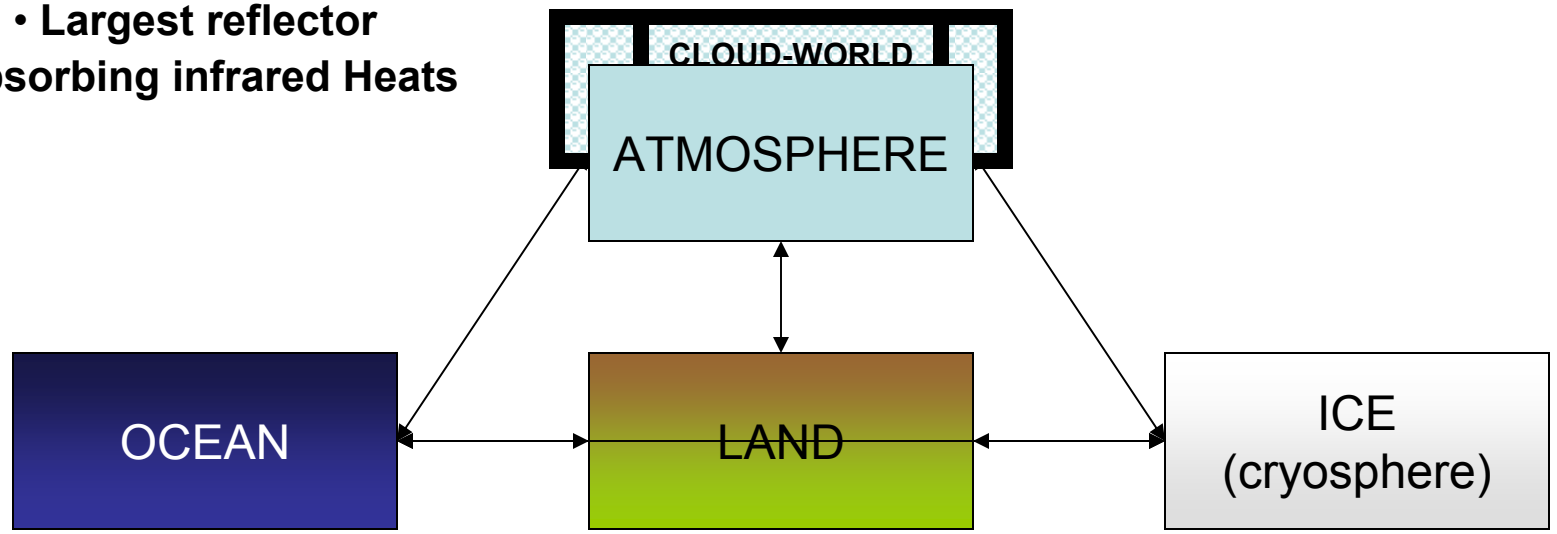


Most uncertain part of the climate system.

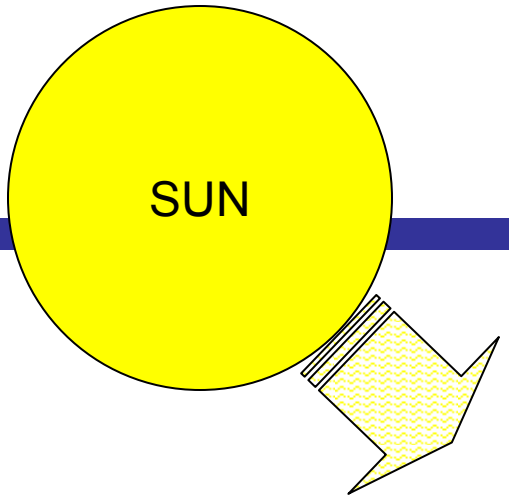
Cloud World:

- Very important to reflection of solar radiation
- Very important to absorption of infrared radiation
  - Acts like a greenhouse gas
- Precipitation, latent heat

- **Reflecting Solar Cools**
  - **Largest reflector**
- **Absorbing infrared Heats**



Earth System: Land



Land where consequences are, first and foremost, realized for people.

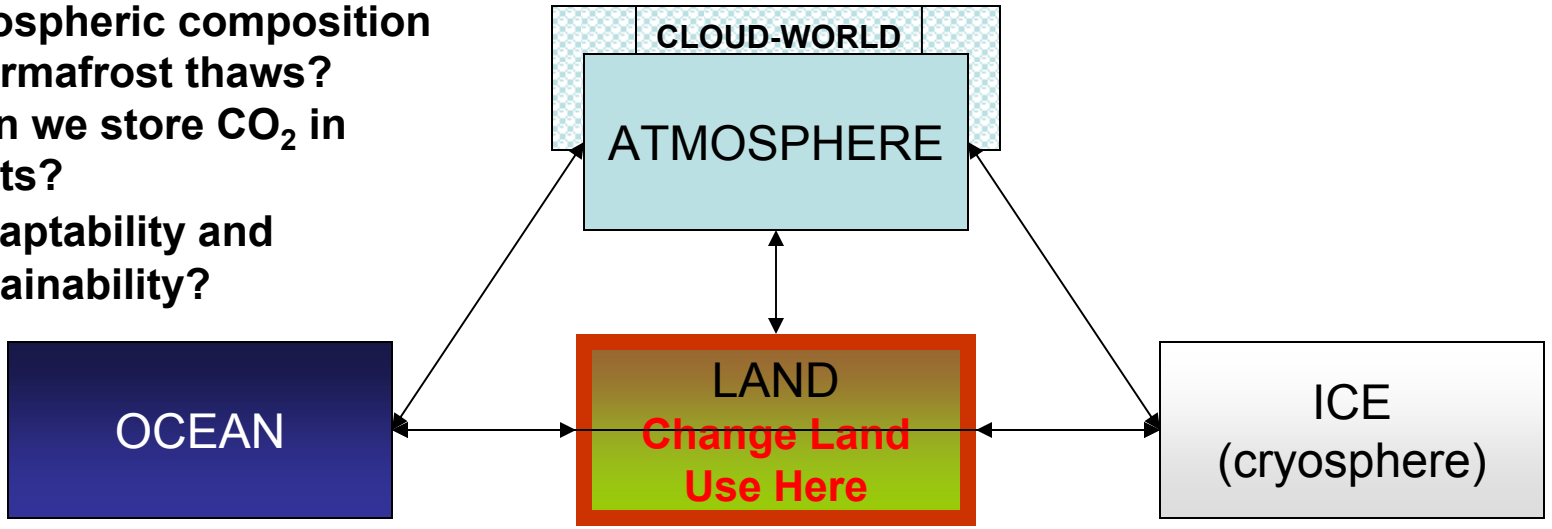
Land:

- Absorption of solar radiation
- Reflection of solar radiation
- Absorption and emission of infrared radiation
- Plant and animal life
  - Impacts H_2O, CO_2 and CH_4
- Storage of moisture in soil
- CO_2 and CH_4 in permafrost

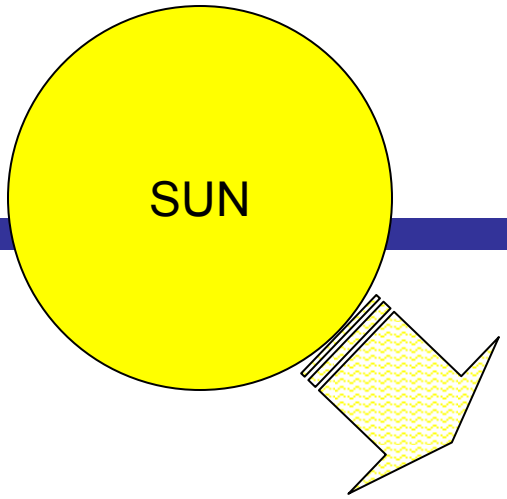
•What happens to atmospheric composition if permafrost thaws?

• Can we store CO_2 in plants?

• Adaptability and sustainability?



Earth System: Ocean



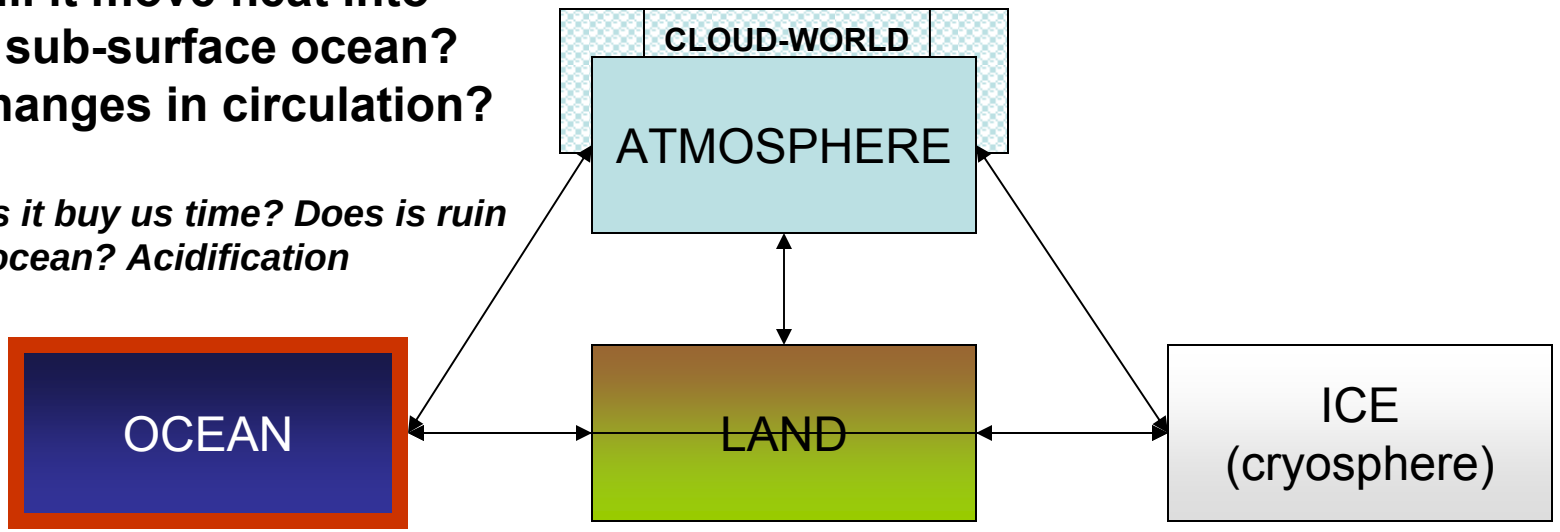
What will the ocean really do?

• Will it absorb all of our extra CO_2?
• Will it move heat into the sub-surface ocean?
• Changes in circulation?

Does it buy us time? Does is ruin the ocean? Acidification

Ocean:

- Absorption of solar radiation
- Takes CO_2 out of the atmosphere
- Plant and animal life
  - Impacts CO_2 and CH_4
- Takes heat out away from surface
- Transport of heat between equator and pole
- Weather regimes: Temperature and rain

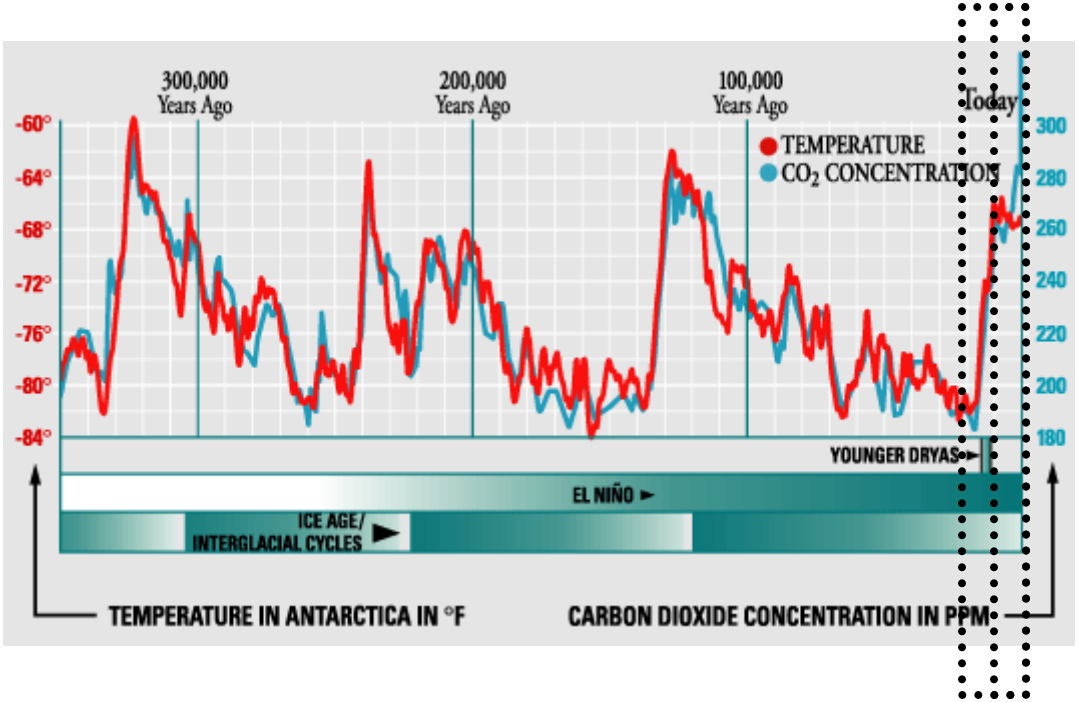


Do you know about the Younger Dryas?

http://www.ldeo.columbia.edu/res/pi/arch/examples.shtml

Bubbles of gas trapped in layers of ice give a measure of temperature and carbon dioxide

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

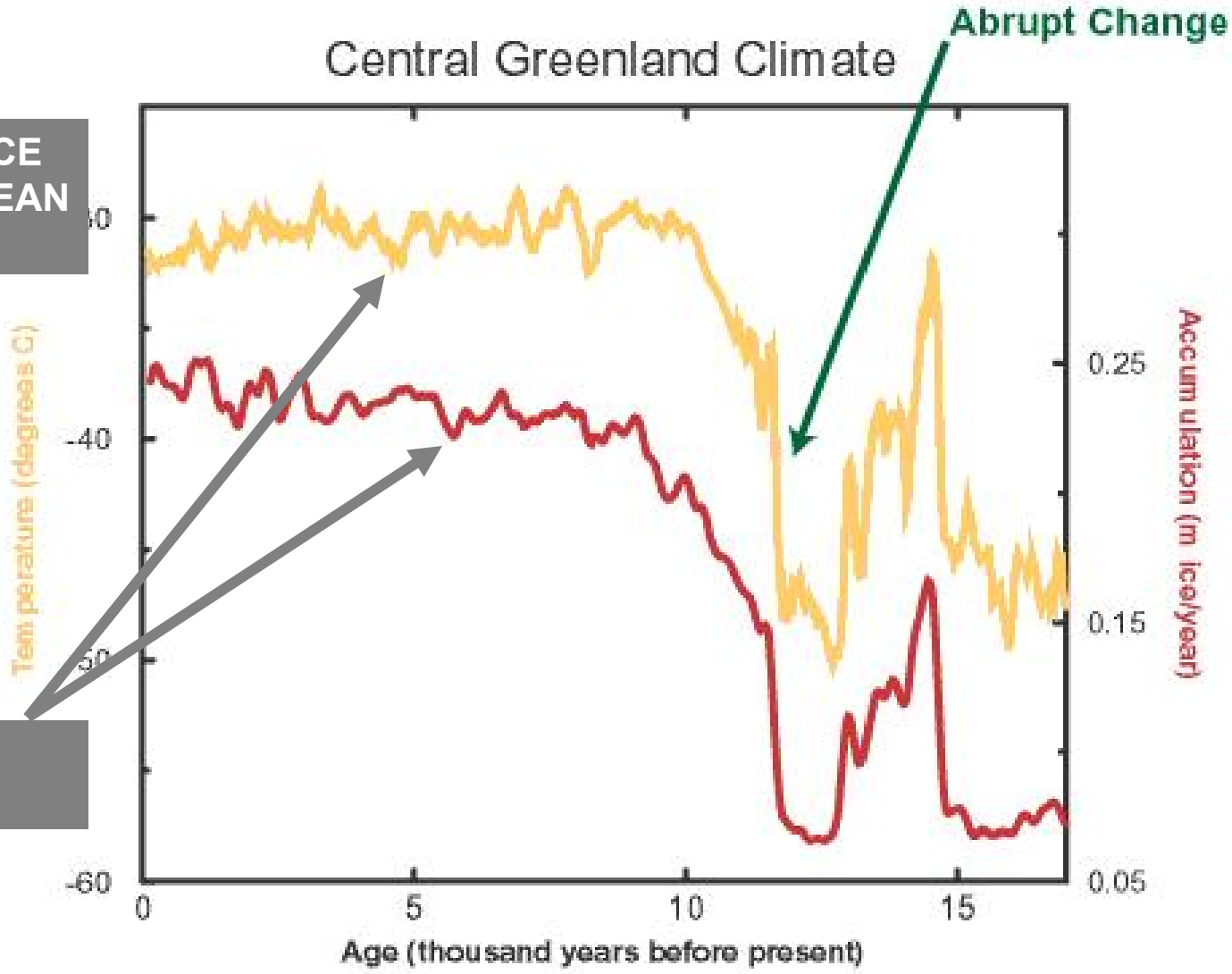


- During this period, temperature and CO_2 are closely related to each other
- It's been about 20,000 years since the end of the last ice age
- There has been less than 10,000 years of history "recorded" by humans (and it has been relatively warm)

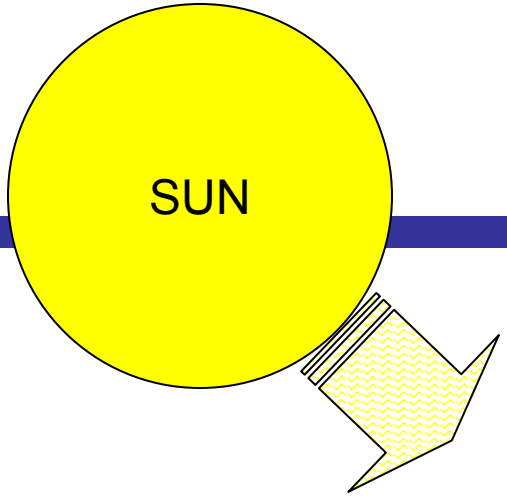
Younger Dryas

POSSIBLE EVIDENCE OF CHANGE IN OCEAN CIRCULATION

WHAT DOES THIS MEAN?



Earth System: Ice



Ice impacts both radiative balance and water – oceans and water resources on land.

.

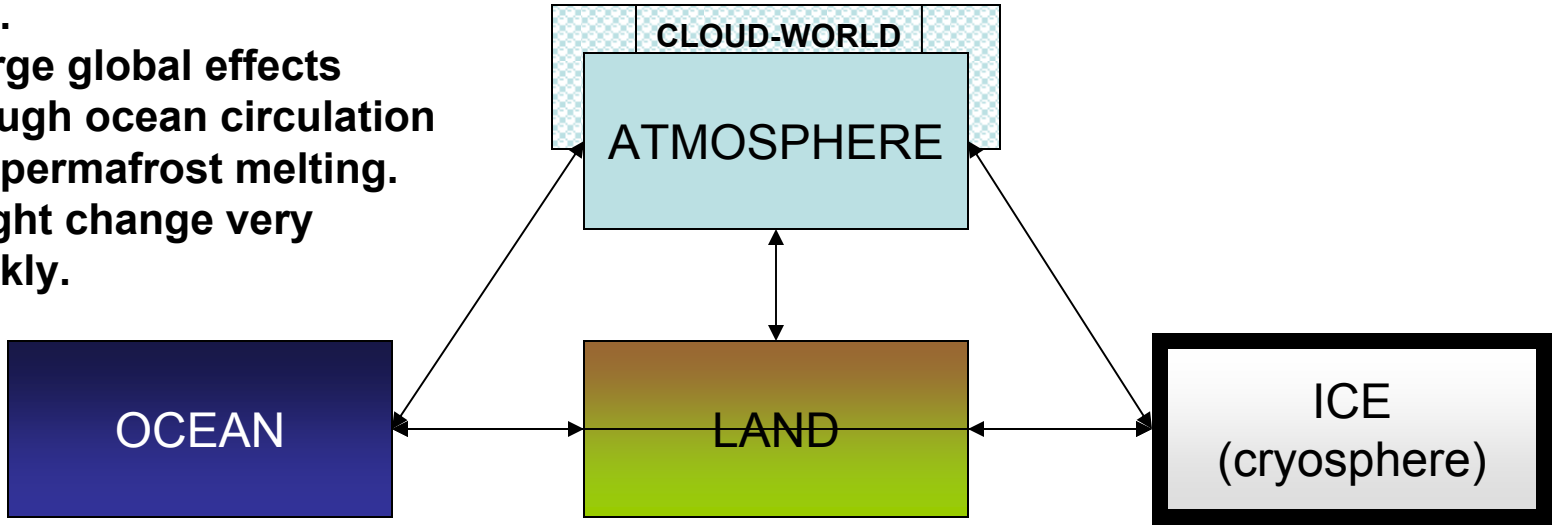
• Large "local" effects at pole.

• Large global effects through ocean circulation and permafrost melting.

• Might change very quickly.

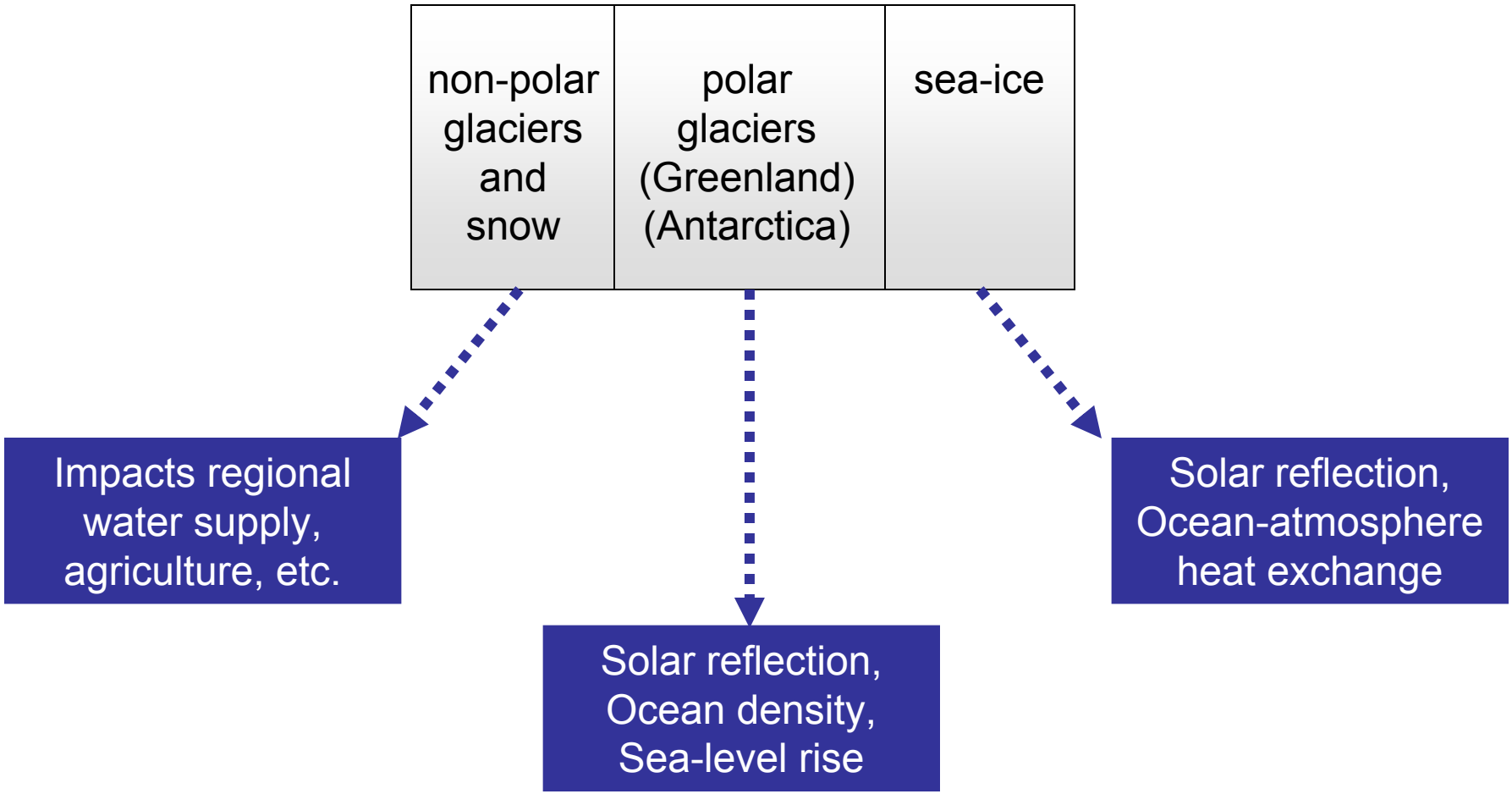
ICE:

- Very important to reflection of solar radiation
- Holds a lot of water (sea-level rise)
- Insulates ocean from atmosphere (sea-ice)



The Earth System: ICE

(Think a little more about ice)



(Tour of the cryosphere, Goddard Scientific Visualization Studio)

The Cryosphere

- A MOVIE

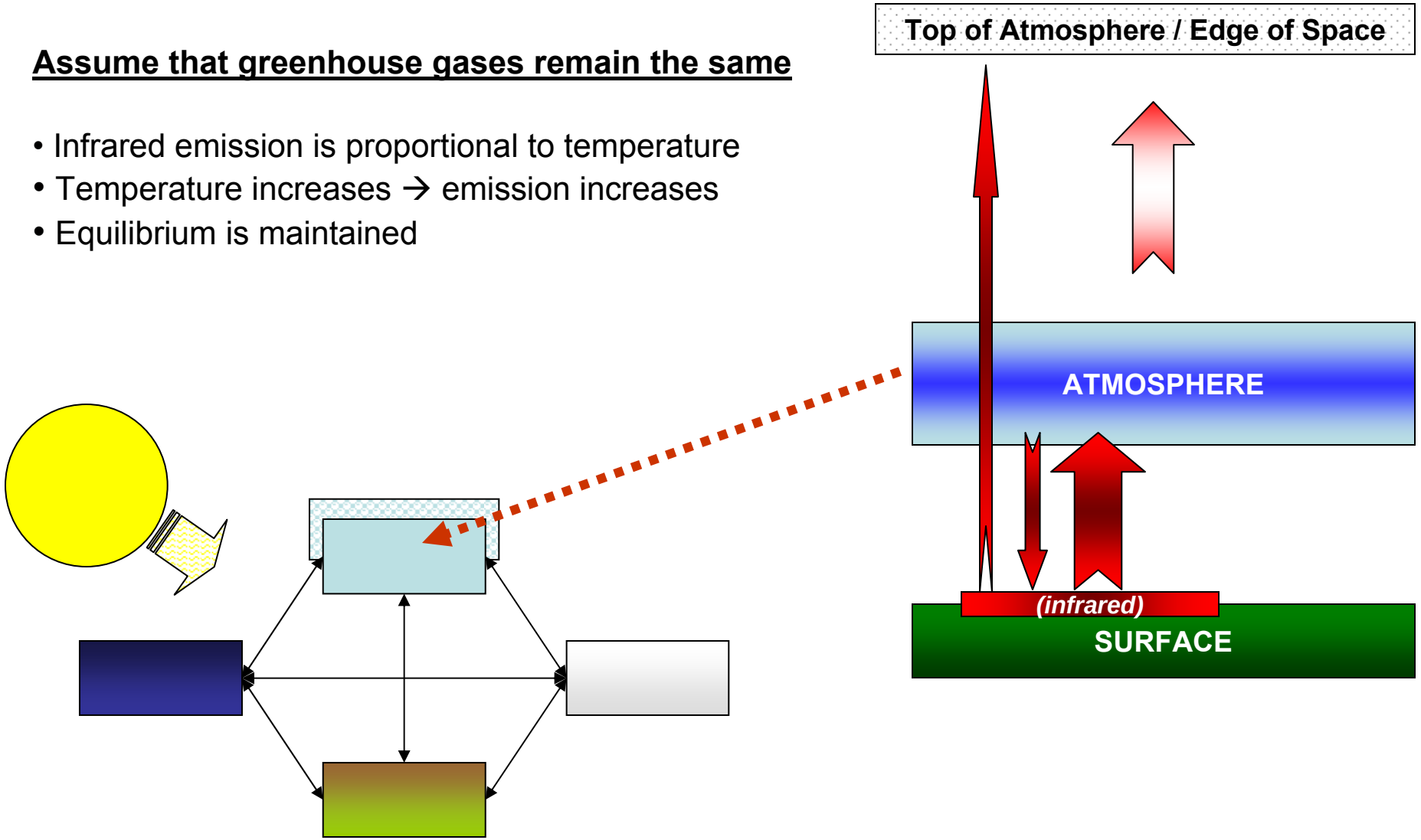
More consideration of infrared in the atmosphere

- FEEDBACKS ....
  - The idea that one thing causes a second thing to happen.
    - That second thing then does something to the first thing
      - It damps it, negative feedback
      - It amplifies it, positive feedback

The Earth System: Feedbacks 1
Infrared Proportional to Temperature

Assume that greenhouse gases remain the same

- Infrared emission is proportional to temperature
- Temperature increases → emission increases
- Equilibrium is maintained

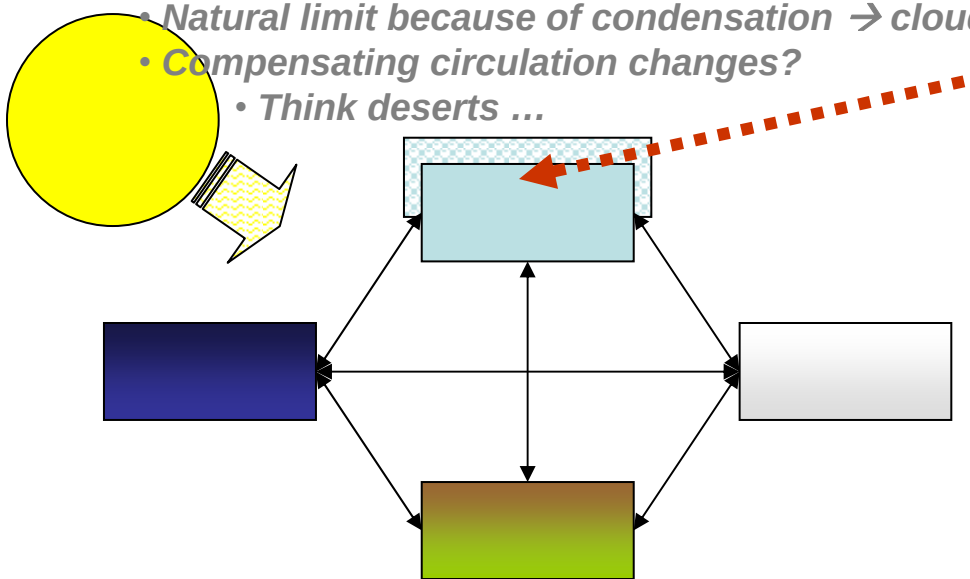


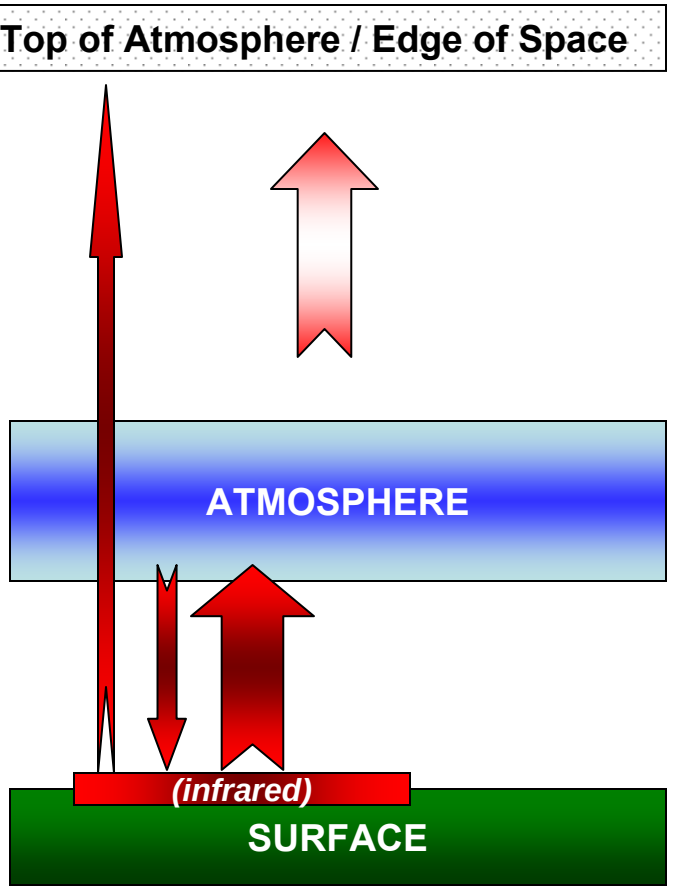
The Earth System: Feedbacks 2
Water Vapor

When it gets warmer more water, a greenhouse gas, will (in principle) be in the atmosphere

- Higher temperature increases evaporation from land and ocean
- Higher temperature allows air to hold more water
- Increase of water increases thickness of blanket – increases temperature more

- *This could runaway!*
- *Natural limit because of condensation → clouds, rain?*
- *Compensating circulation changes?*
- *Think deserts …*



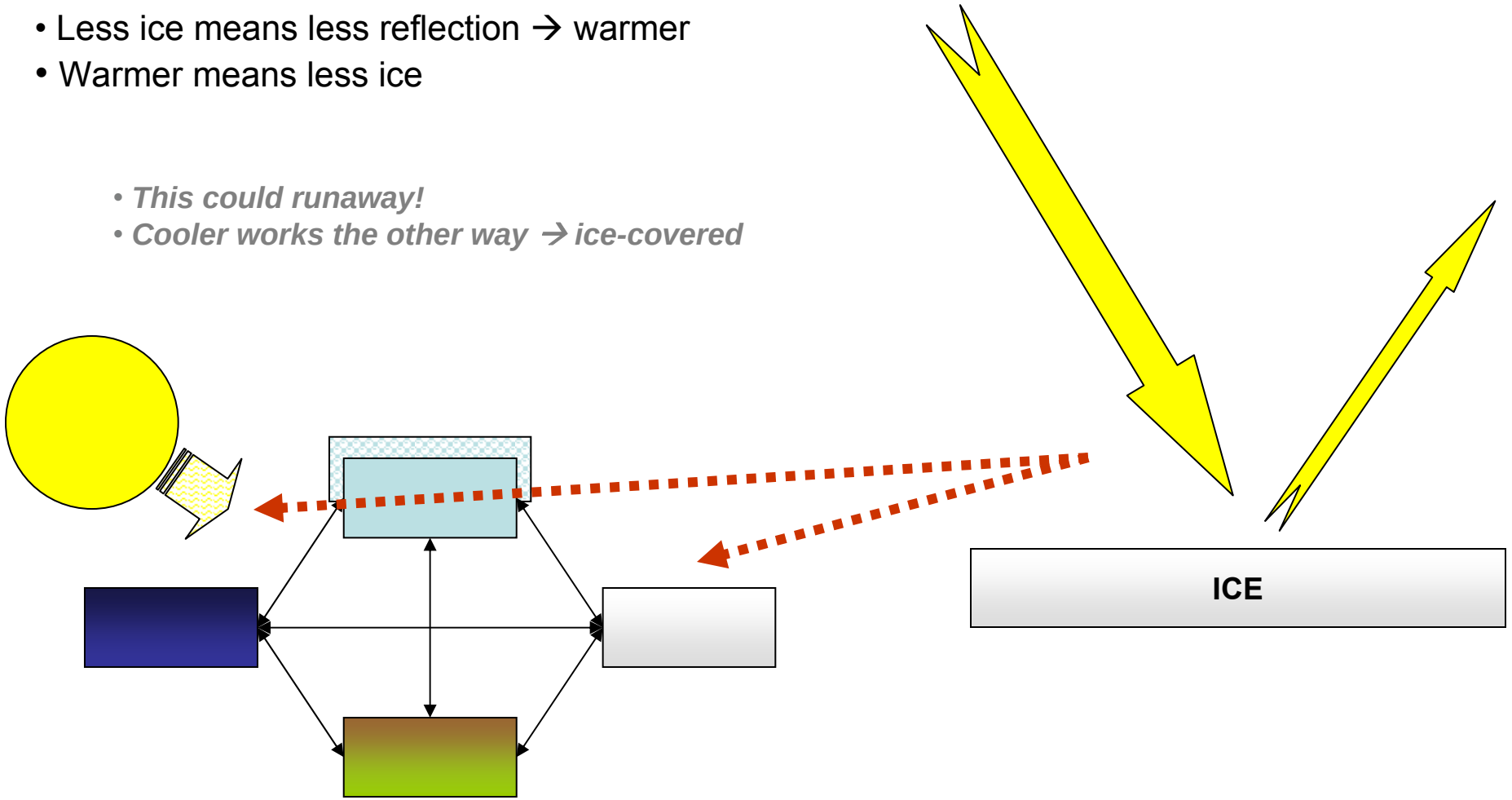


The Earth System: Feedbacks 3
Ice - Albedo

When it gets warmer less ice

- Less ice means less reflection → warmer
- Warmer means less ice

- *This could runaway!*
- *Cooler works the other way → ice-covered*

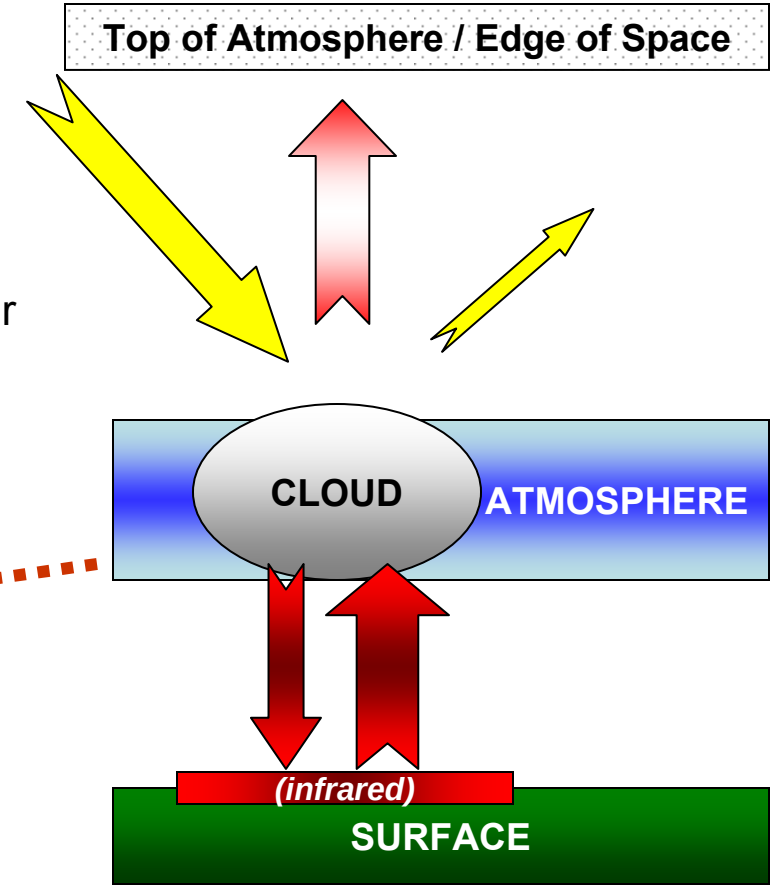


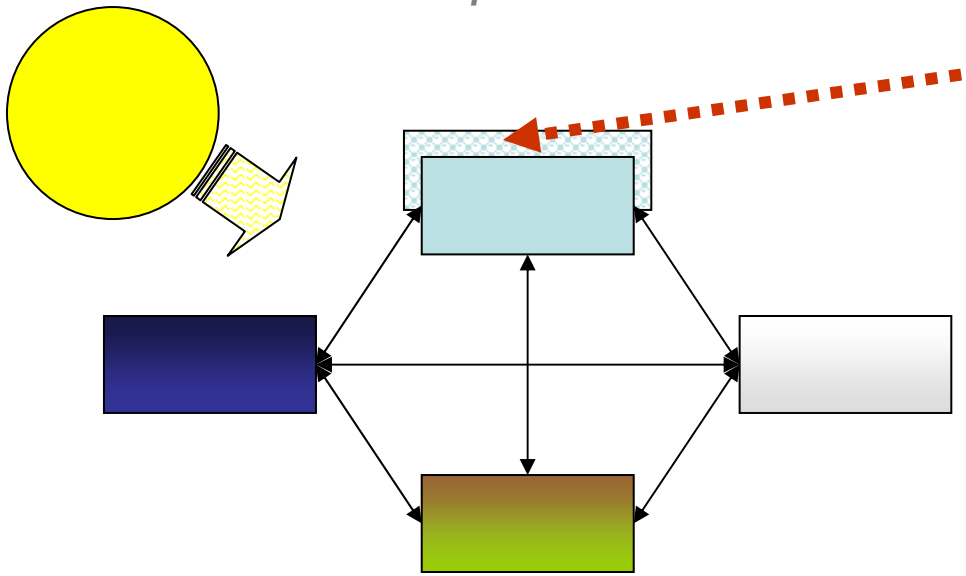
The Earth System: Feedbacks 4 Clouds?

Clouds are difficult to predict or to figure out the sign of their impact

- Warmer → more water → more clouds
- More clouds mean more reflection of solar → cooler
- More clouds mean more infrared to surface → warmer
- More or less clouds?

  - *Does this stabilize?*
  - *Water in all three phases essential to stable climate*

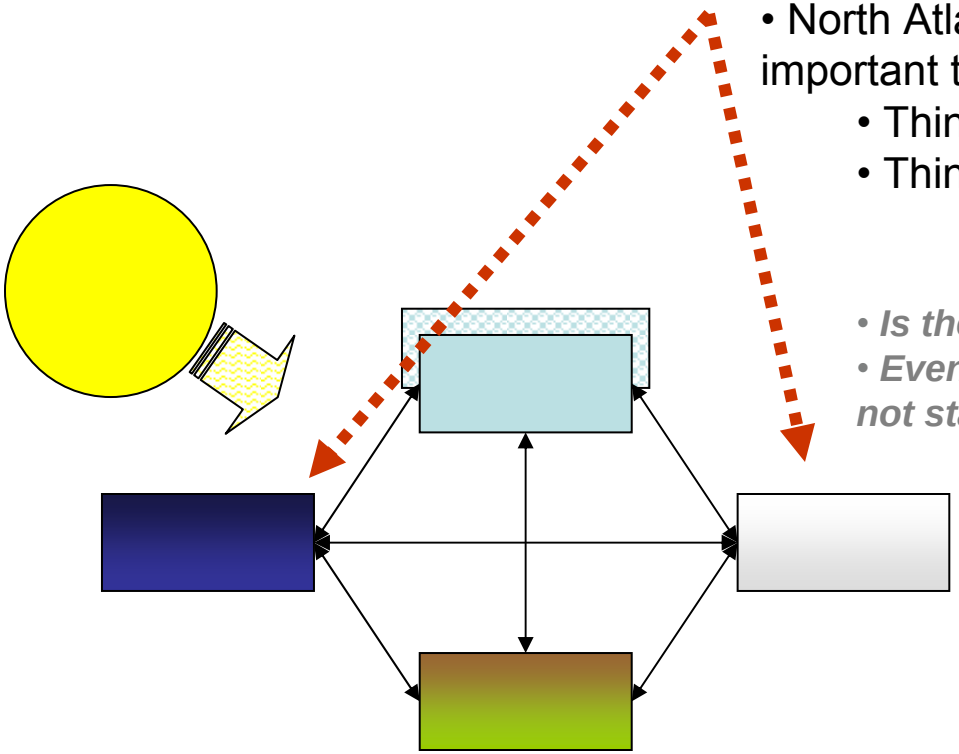




The Earth System: Feedbacks 5 Something with the Ocean?

Is there something with the ocean and ice?

- Land ice melting decreases ocean salinity (density)
- Sea-ice impacts heat exchange between ocean and atmosphere
- Sea-ice impacts solar absorption of ocean
- North Atlantic sea-ice and ocean interaction very important to the climate
    - Think Gulf Stream
    - Think climate and people and economy



- ***Is there a natural feedback that stabilizes climate?***
- ***Even if there is, it would be very disruptive, perhaps not stable from a societal point of view.***

Cloud-Ice-Atmosphere Feedback

- Some carry away messages
  - This is where much of the discussion about uncertainty resides.
  - The Earth is at a complex balance point
    - That balance relies on water to exist in all three phases.
      - Too warm could run away to “greenhouse” vapor
      - Too cold run away to “snowball” ice
  - How clouds change is not well understood and much argued.
  - Is there anything here that actually compensates for warming by increasing greenhouse gases?

Another carry away message

- What do we do with “abrupt climate change?”