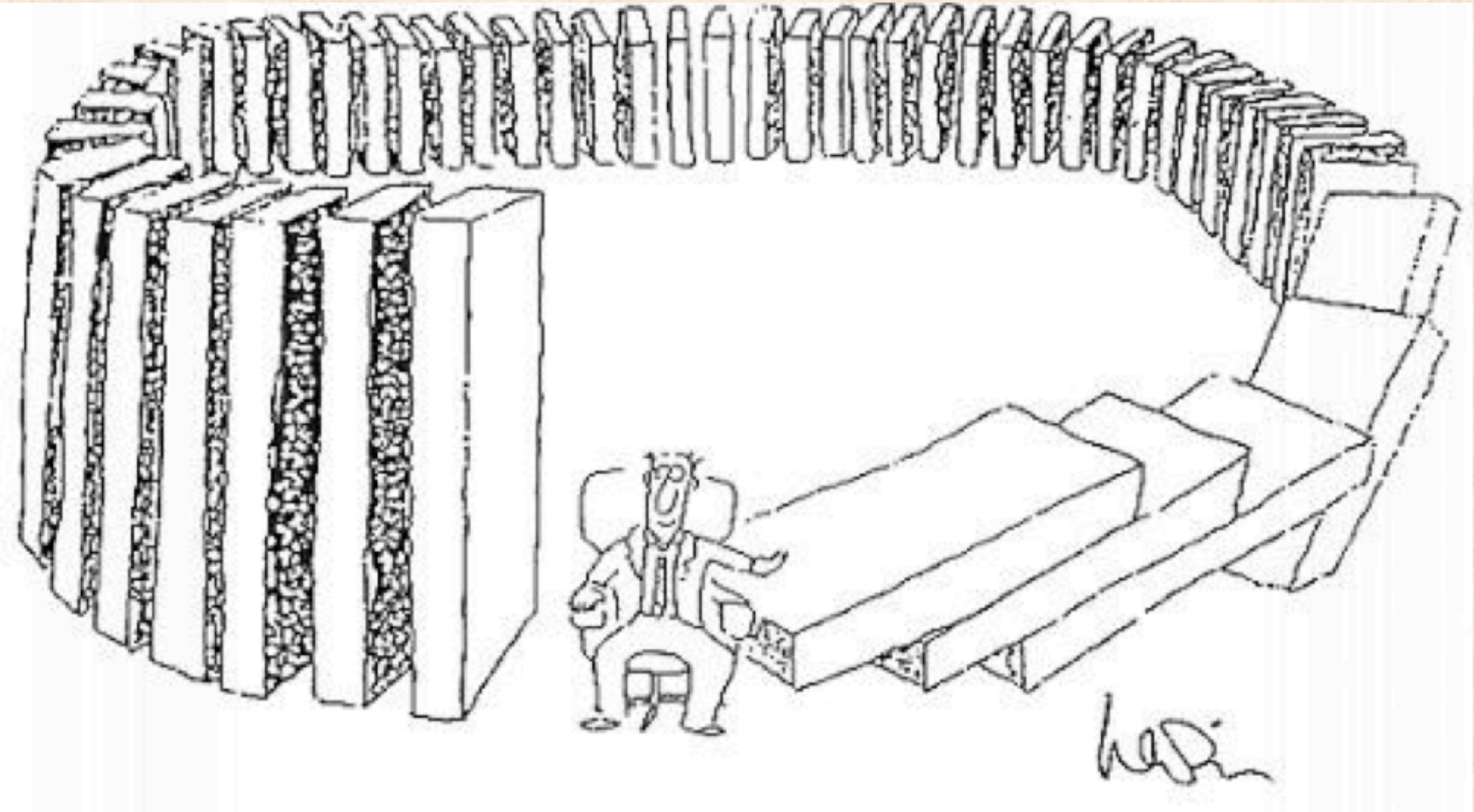
"Climate change may be happening....
but let's just wait and see."



Statements like "wait and see" regarding climate show a basic misunderstanding of systems thinking

System thinkers...

Explore cause and effect relationships

Take the perspective of seeing the big picture

See how things change over time

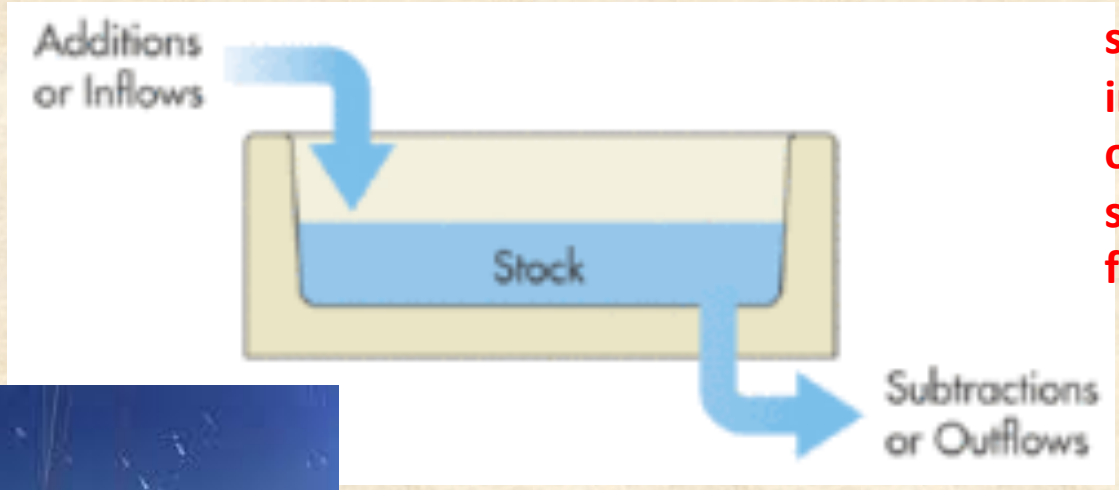
Take the parts and see how they fit into the whole

Use visual tools to find patterns and create mental models

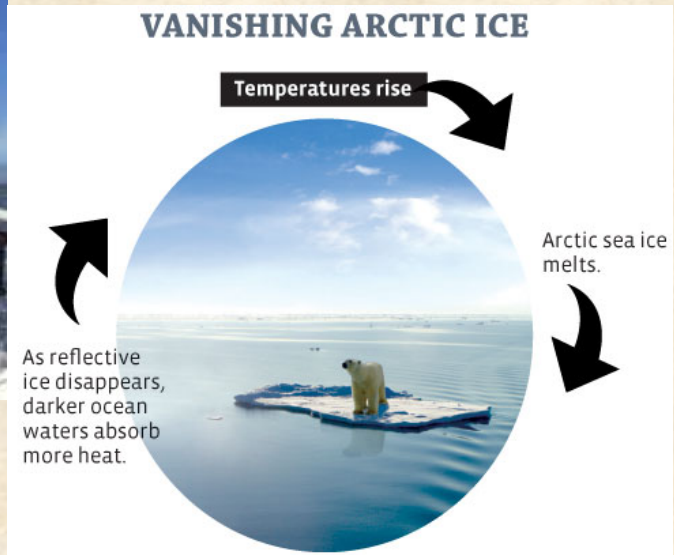
Use systems models to make predictions

Systems thinkers talk in terms of…

Sources and sinks, inflows and outflows, stocks and flows



Time delays

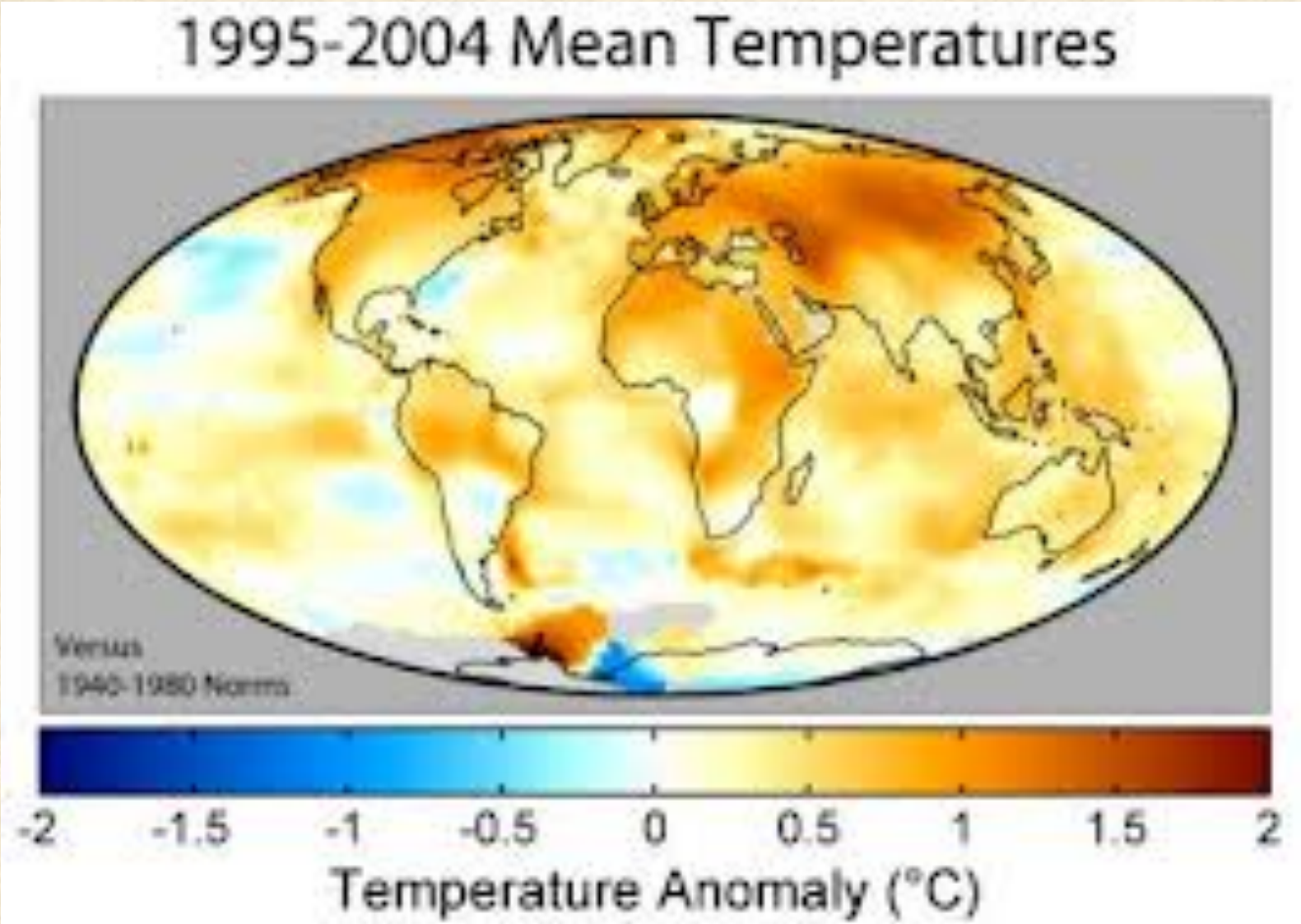


Feedback Loops

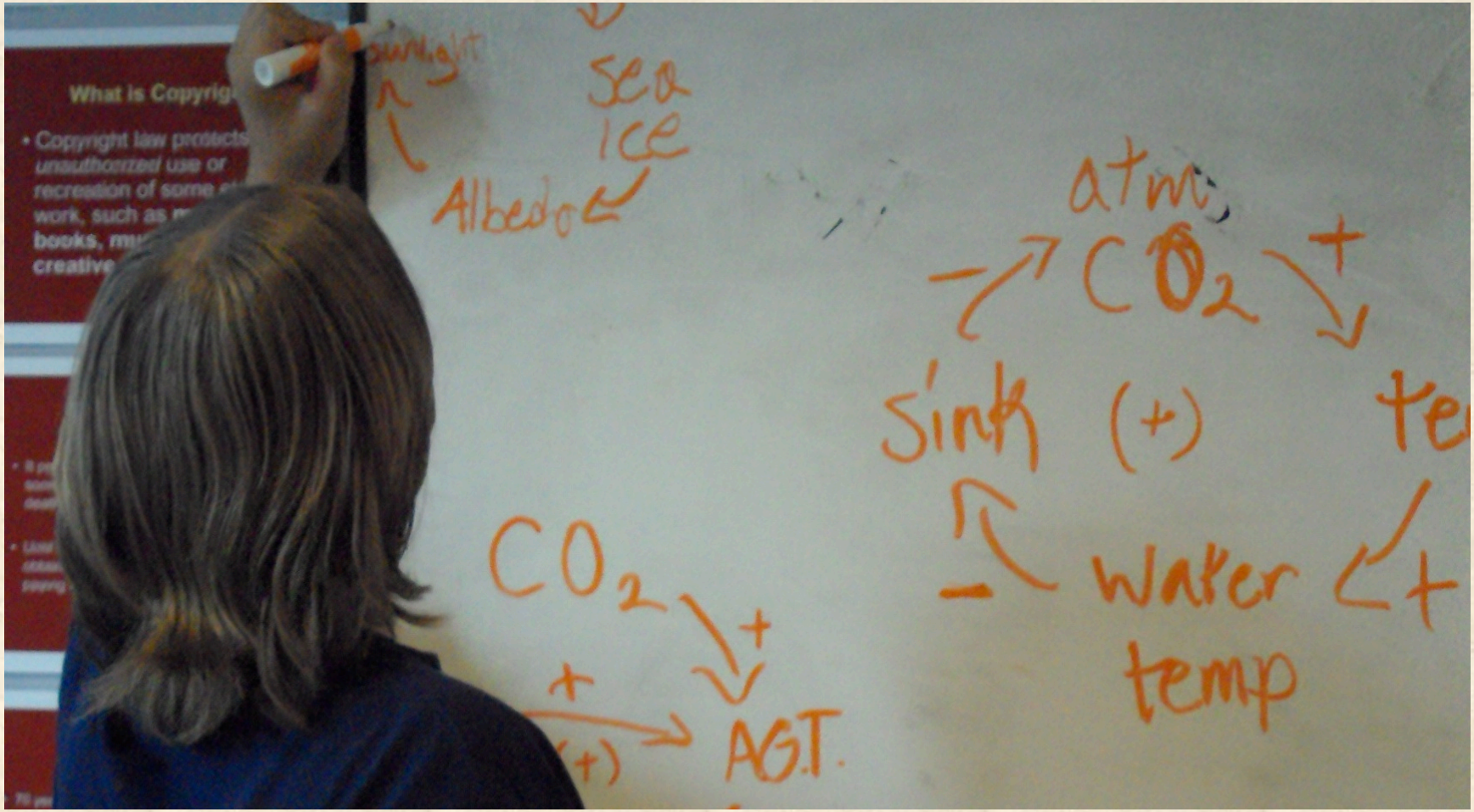
"Wait and see" may work for some problems, but it doesn't work for natural systems whose:

1.) Time scales are large – action must be taken decades before the long term effects

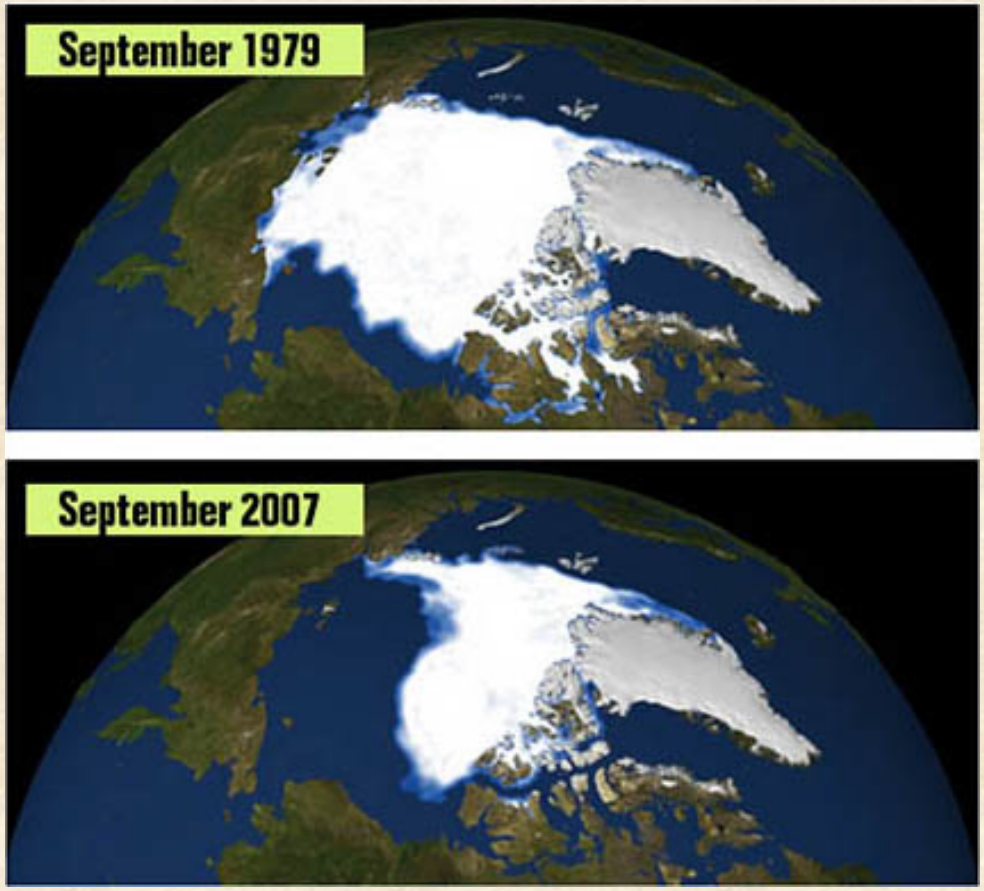
2.) Spatial scales are global



3.) Elements are interconnected with multiple feedback loops that reinforce or stabilize the problem

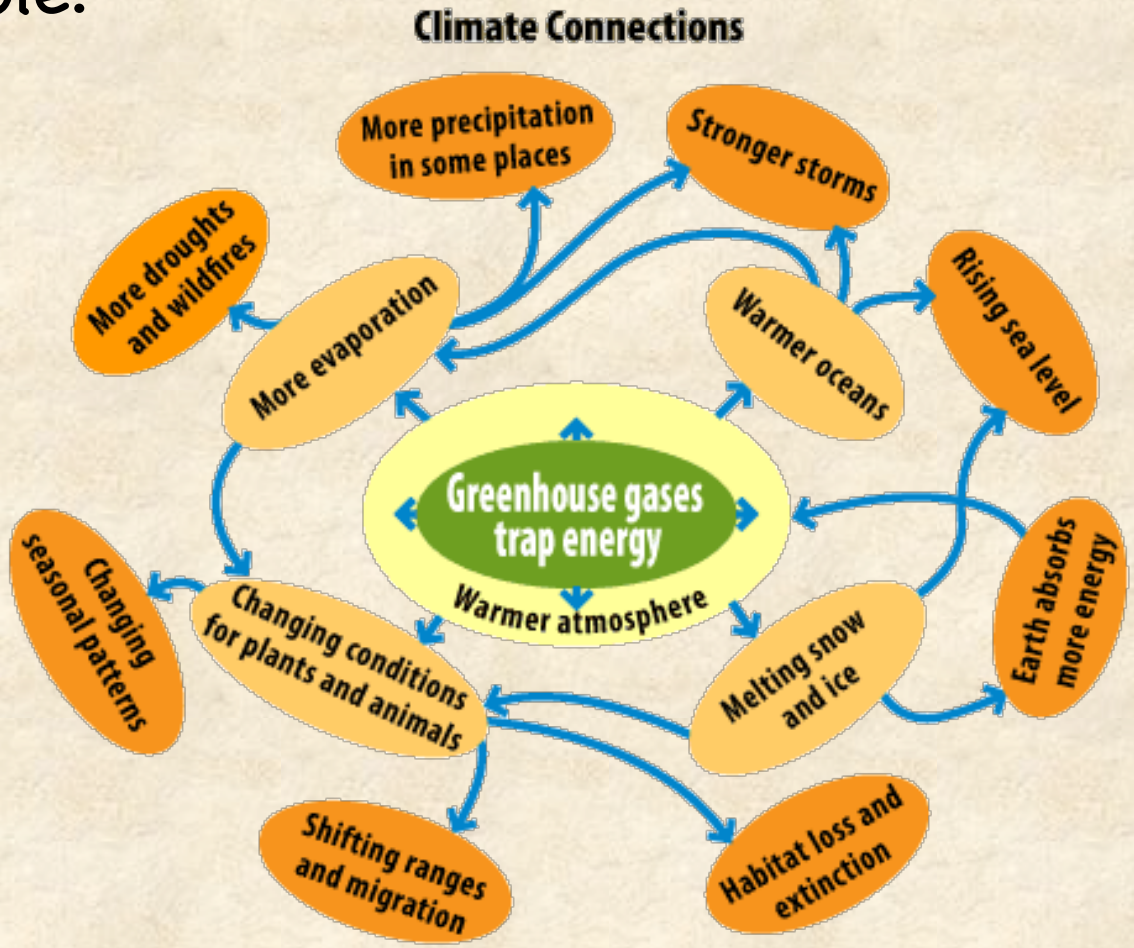


4.) timetable is set by physics, and not reacting soon enough means that some



things can't be "undone."

Climate is a classic "systems" problem. A system is a collection of elements that interact and function as a whole.



"Everything is connected to everything else in a system."

Colorado State standard:

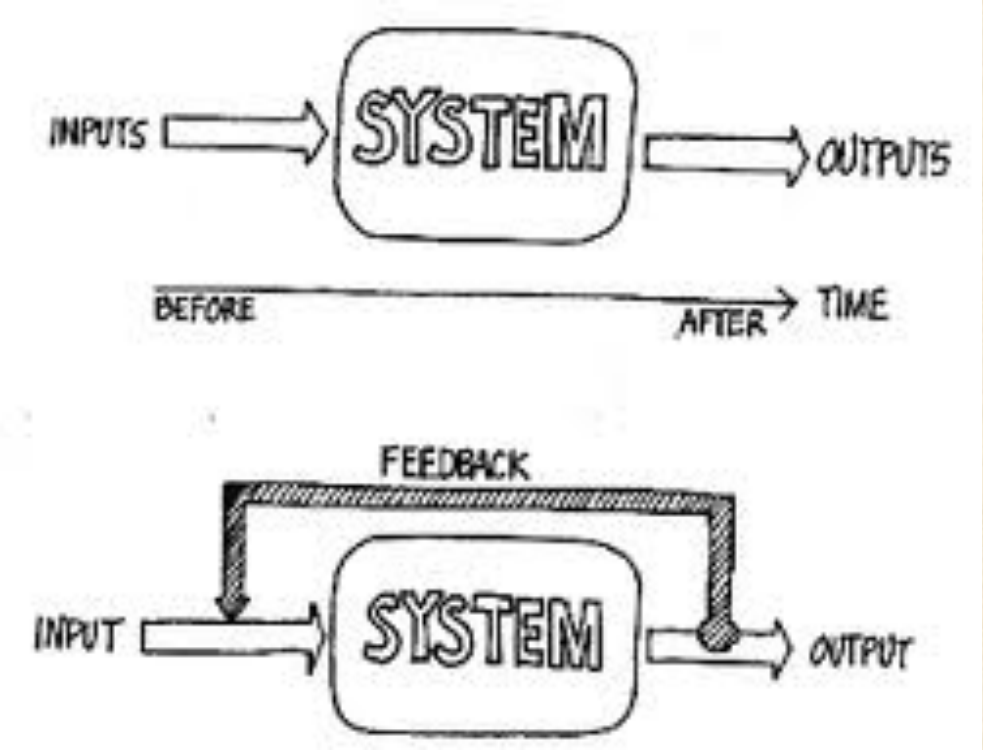
"Evaluate evidence that the Earth's geosphere, atmosphere, hydrosphere, and biosphere interact as a complete system."

Layers of the Atmosphere
EM Radiation
Albedo
Seasons
Weather vs. Climate
Carbon Cycle
Greenhouse gases
Paleoclimates
Ocean Currents

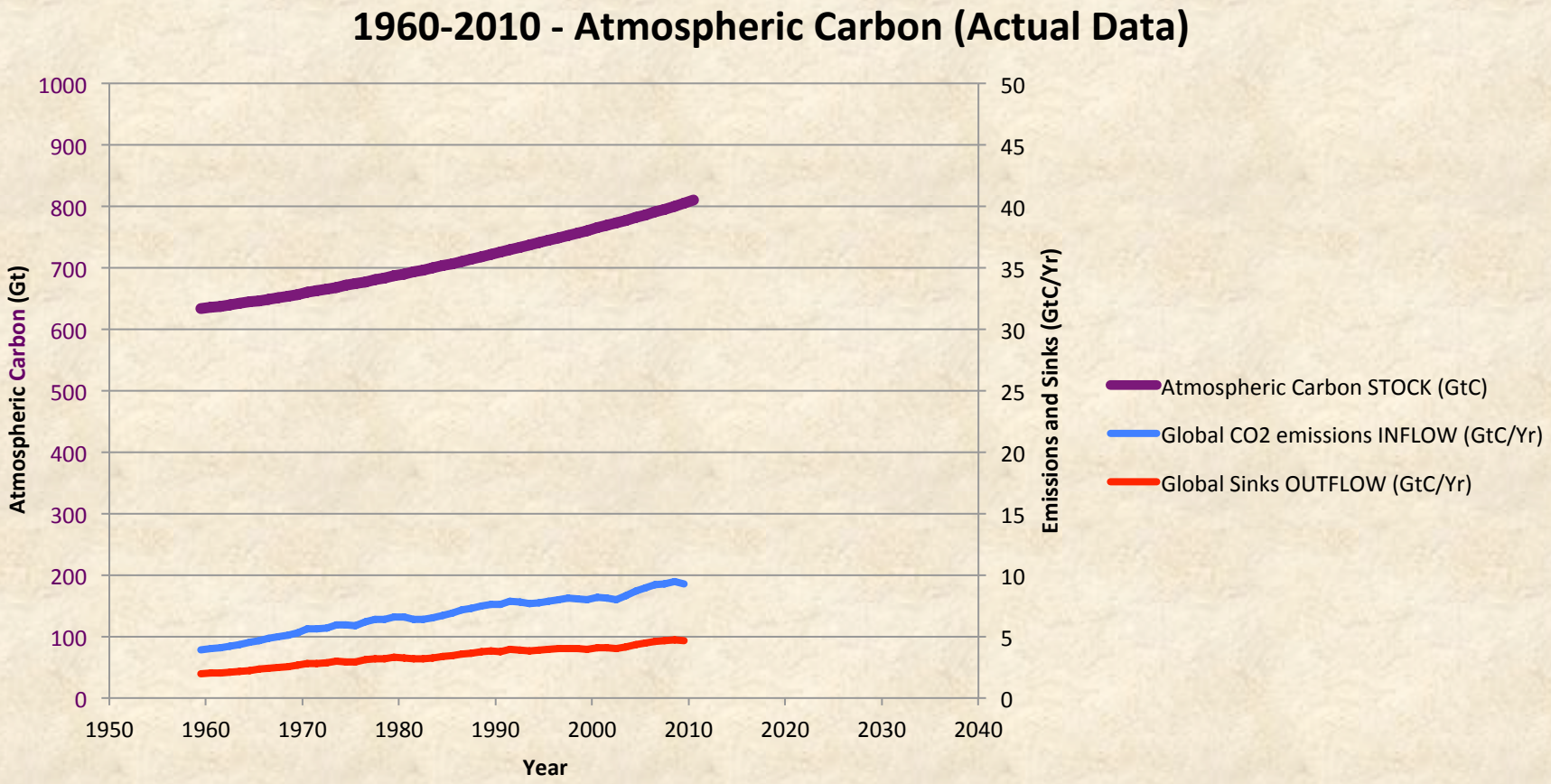
All great concepts!

But students don't walk away with the big picture – the bottom line – and they still don't see how it all works as a "system."

So, for the purposes of illustration "systems thinking" concepts...



Let's explore our intuitive understanding of climate for the purposes of illustrating systems thinking.

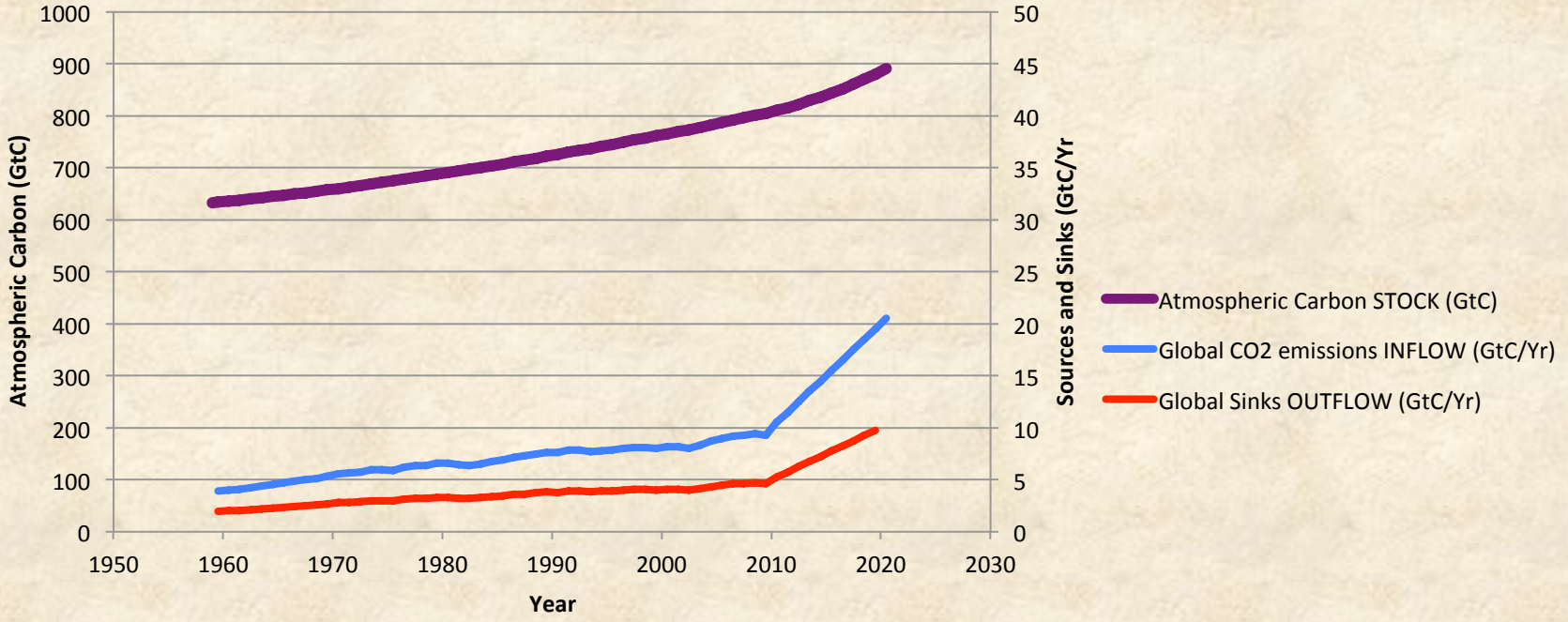


Source carbon data is published online (November 21, 2010) in Nature Geoscience and released via GlobalCarbonProject.org

How would the climate system respond if we INCREASE atmospheric carbon by 10% per year?

(Increase, Decrease, Stabilize)

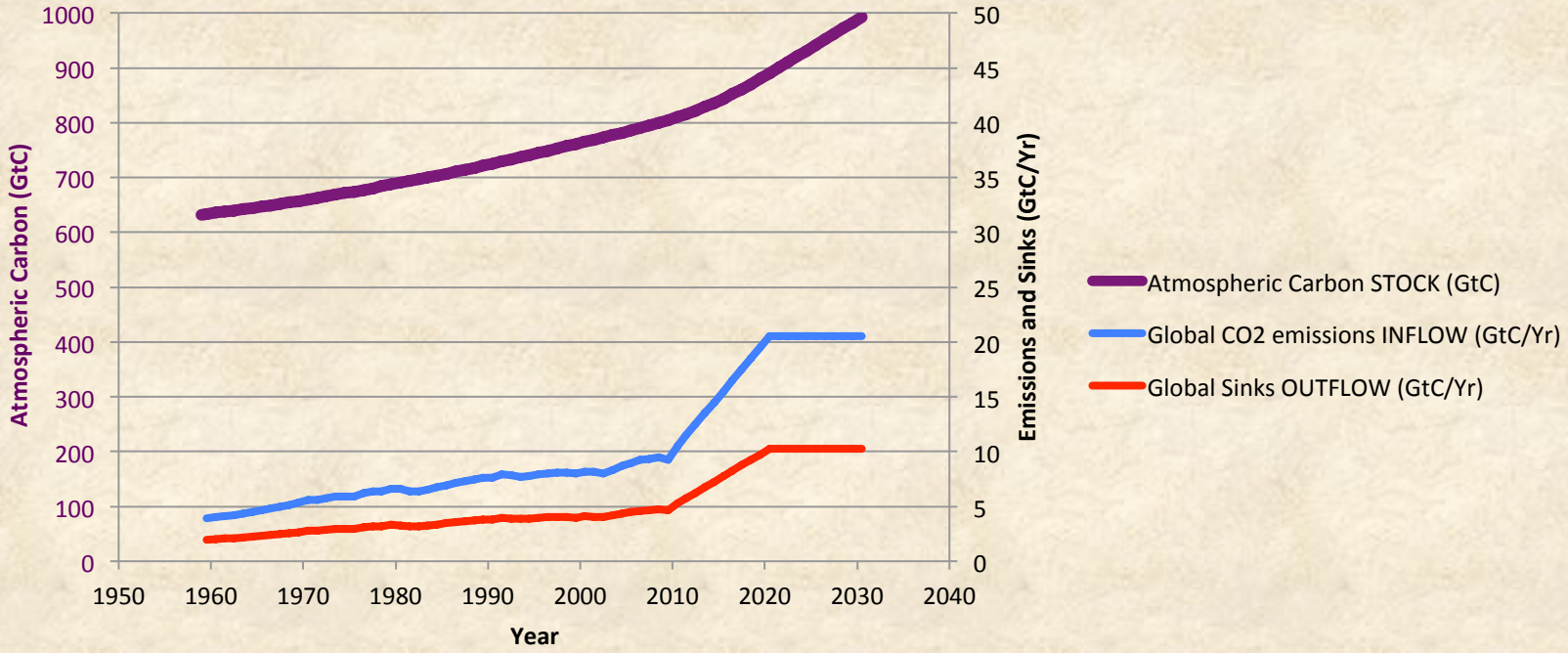
2010-2020
Hypothetical
Increase emissions by 1 Gt/Yr
(Absorption rate = 50% of emission rate)



How would the climate system respond if we STABILIZED emissions?

(Increase, Decrease, Stabilize)

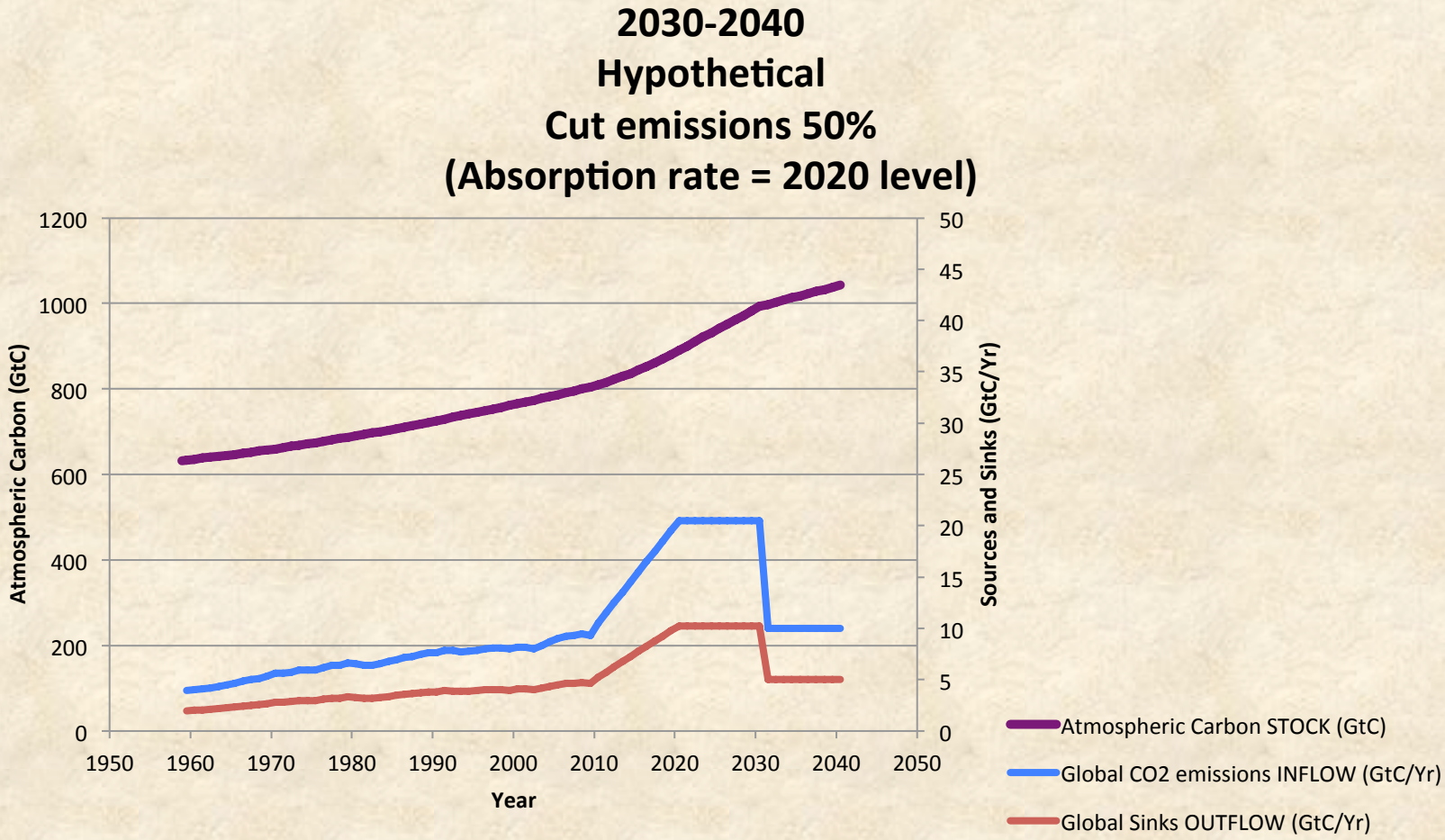
2020-2030
Hypothetical
Stabilize emissions at 2020 level
(Absorption rate = 2020 level)



"It ain't what you don't know that hurts you; it's what you do know that ain't so".

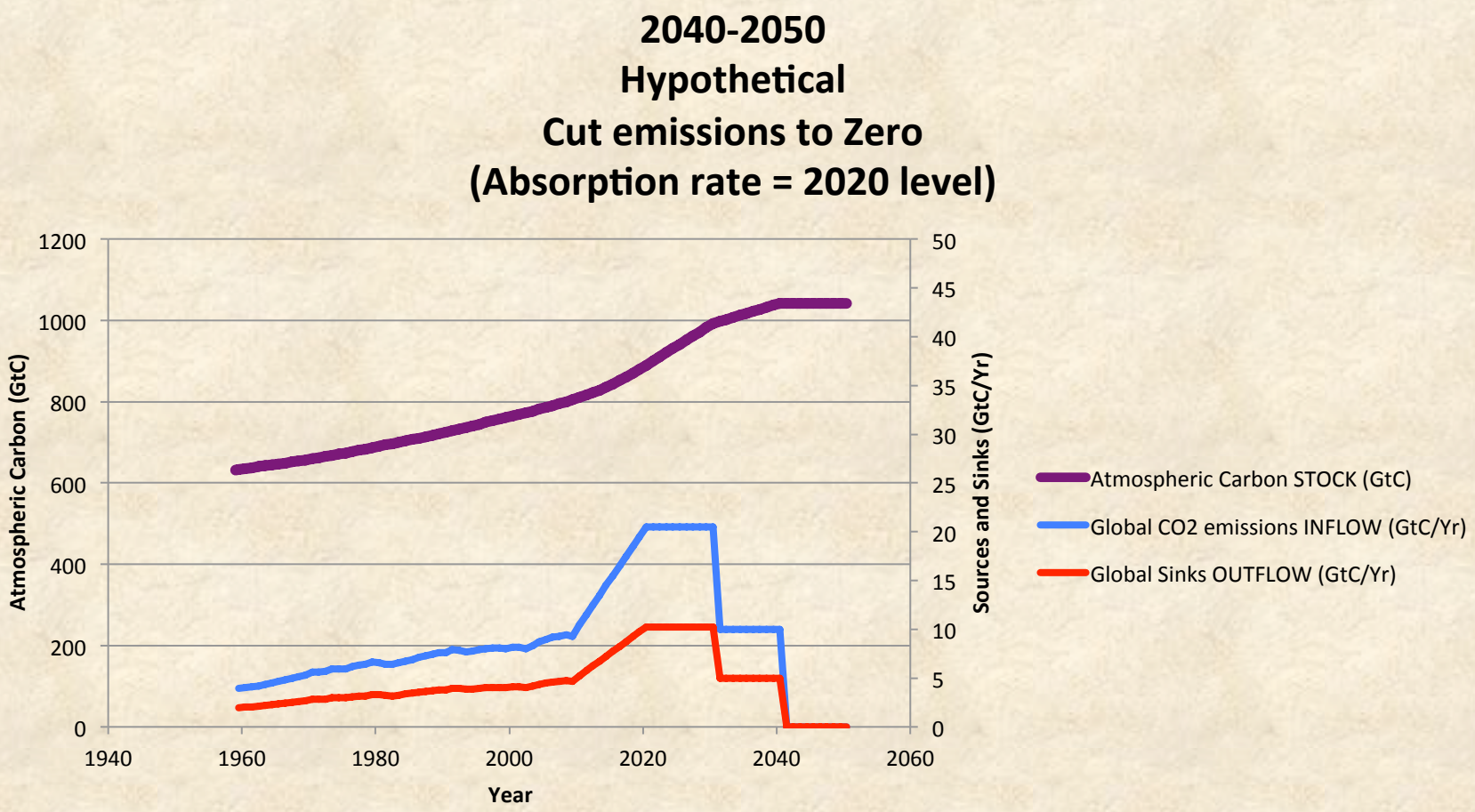
How would the climate system respond if we CUT emissions by 50%?

(Increase, Decrease, Stabilize)



How would the climate system respond if we cut emissions to zero?

(Increase, Decrease, Stabilize)



When graduate students from MIT were asked these questions, they did poorly.

We teach the concepts of climate, but it's the accumulations, rates of flow, time lags, feedbacks to the system that we haven't communicated.

Objectives for Learning

1. Understand basic systems principles

-sources, sinks, stocks, flows (budgets)

- feedbacks

-time delays

2. Understand two important climate systems first before we teach other climate concepts.

- Earth's Heat Budget – an open system
  (energy in = energy out → Climate

- Earth's Carbon Cycle – a closed system

What are the visual tools we need to teach to students?

1. Identify stocks - elements that change over time.

Identify flows - movement into or out of stocks.

2. Identify connections - elements that cause other elements to change.

3. Behavior Over Time Graphs (BOTGs) that show change over time rather than focus on single events.

4. Create Stock-Flow Maps and climate models to make predictions.

1) Stocks and Flows: The Law of Balance

- **Stock-** The current "level" of anything that accumulates or drains.

The amount that has flowed in *minus* the amount that has flowed out.

- **Flow-** the flow rate into or out of the stock.

A simple system: the bathtub

- Stock
  - –The level of water in the tub.
- Flows
  - –Inflow: rate water enters the system from faucet
  - –Outflow: rate water leaves the system through drain

Instructions: Below are rows of variables. Identify which variable is a stock and draw a box around it.

STOCKS

Money in Bank Account Expenses Income

Dumping Plastic in Landfills

Borrowing Returning Library Books Checked Out

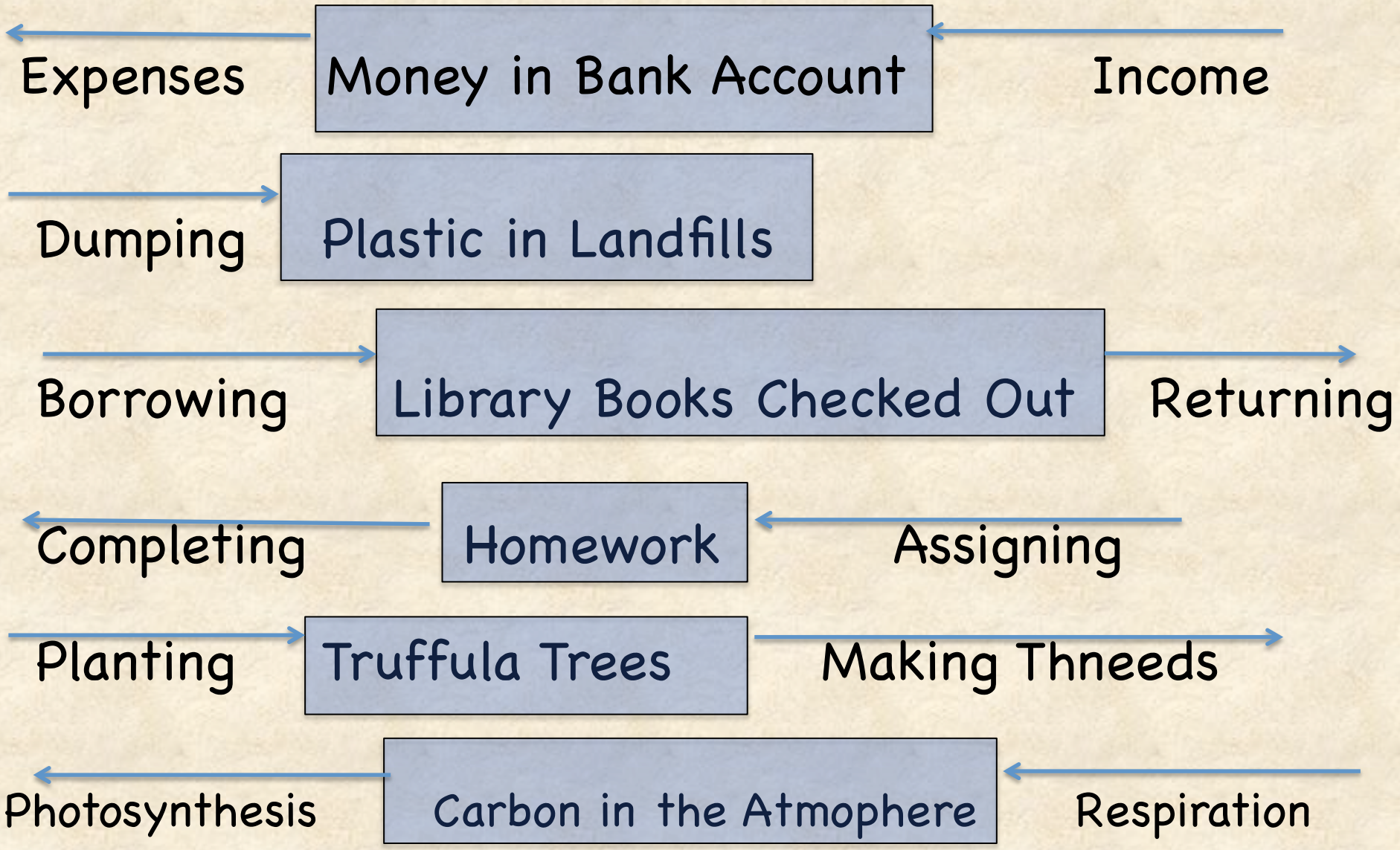
Homework Completing Assigning

Planting Making Thneeds Truffula Trees

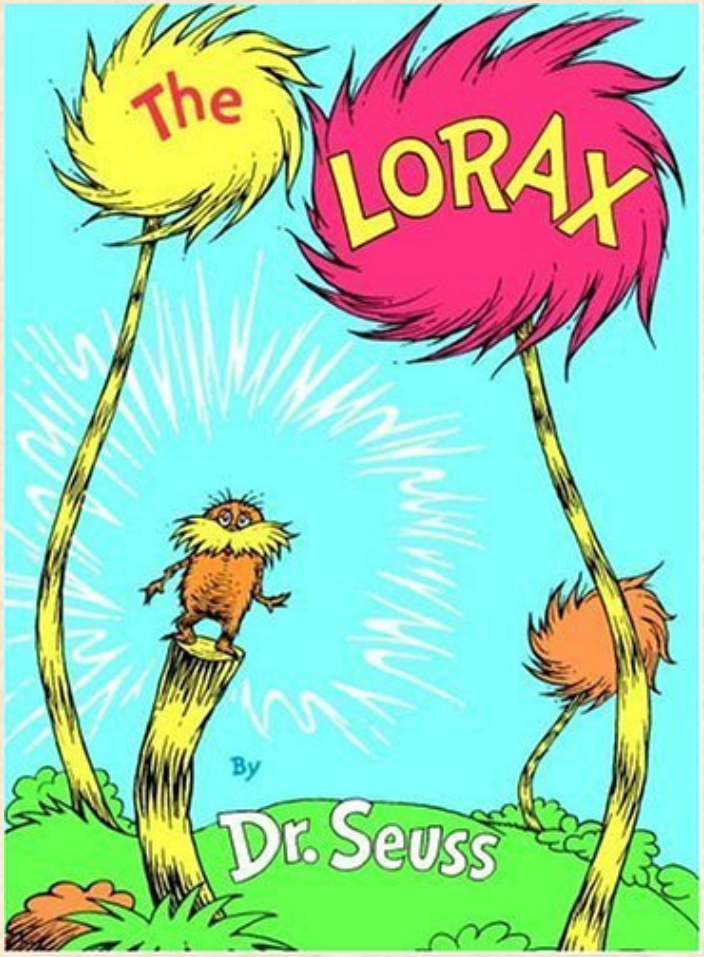
Carbon in the Atmosphere Photosynthesis Respiration

Determine which flows cause the stock to increase (inflows) and which cause the stock to decrease (outflows) by drawing arrows into or out of the stocks

FLOWS:

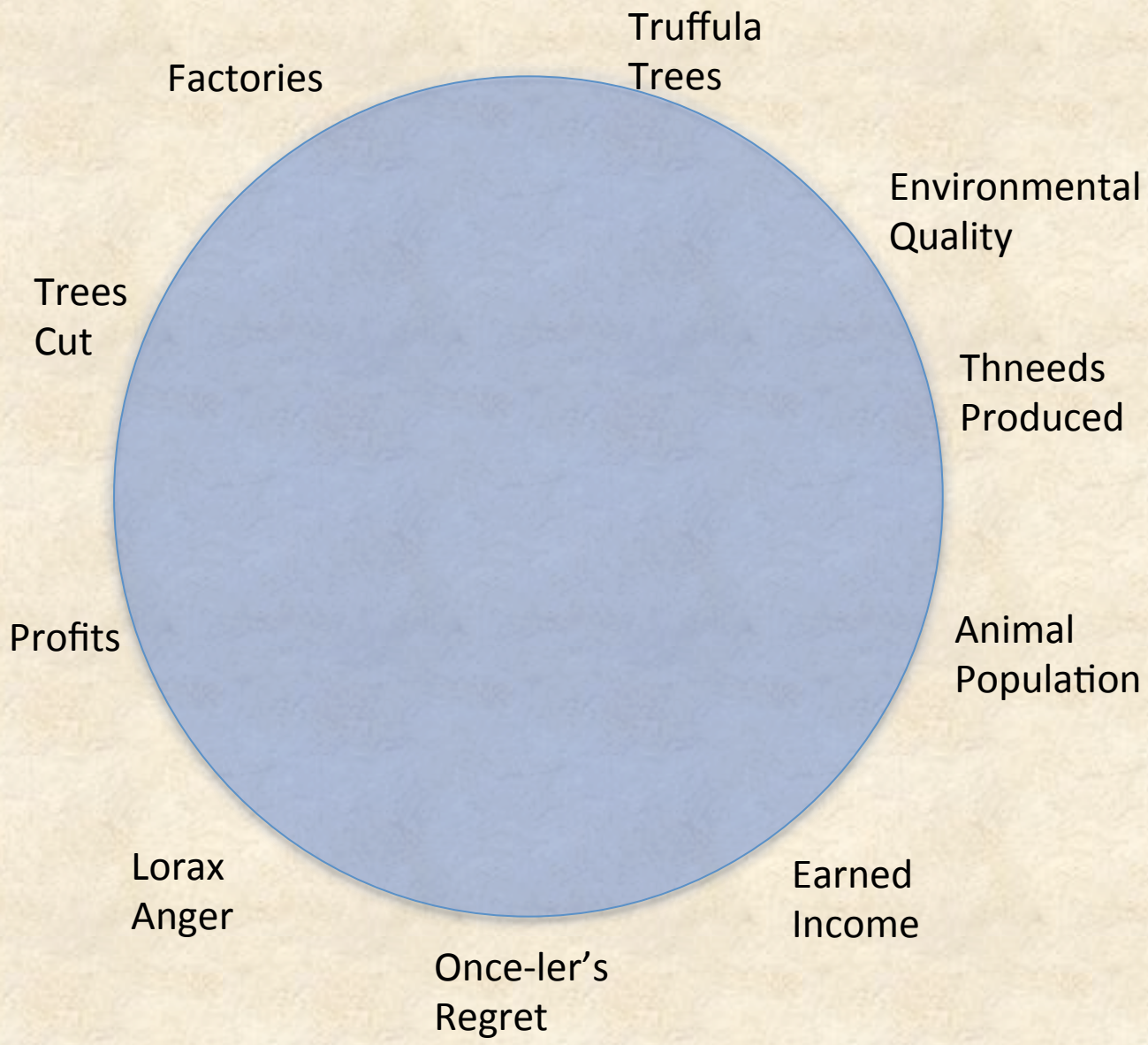


Now, with a little help from...

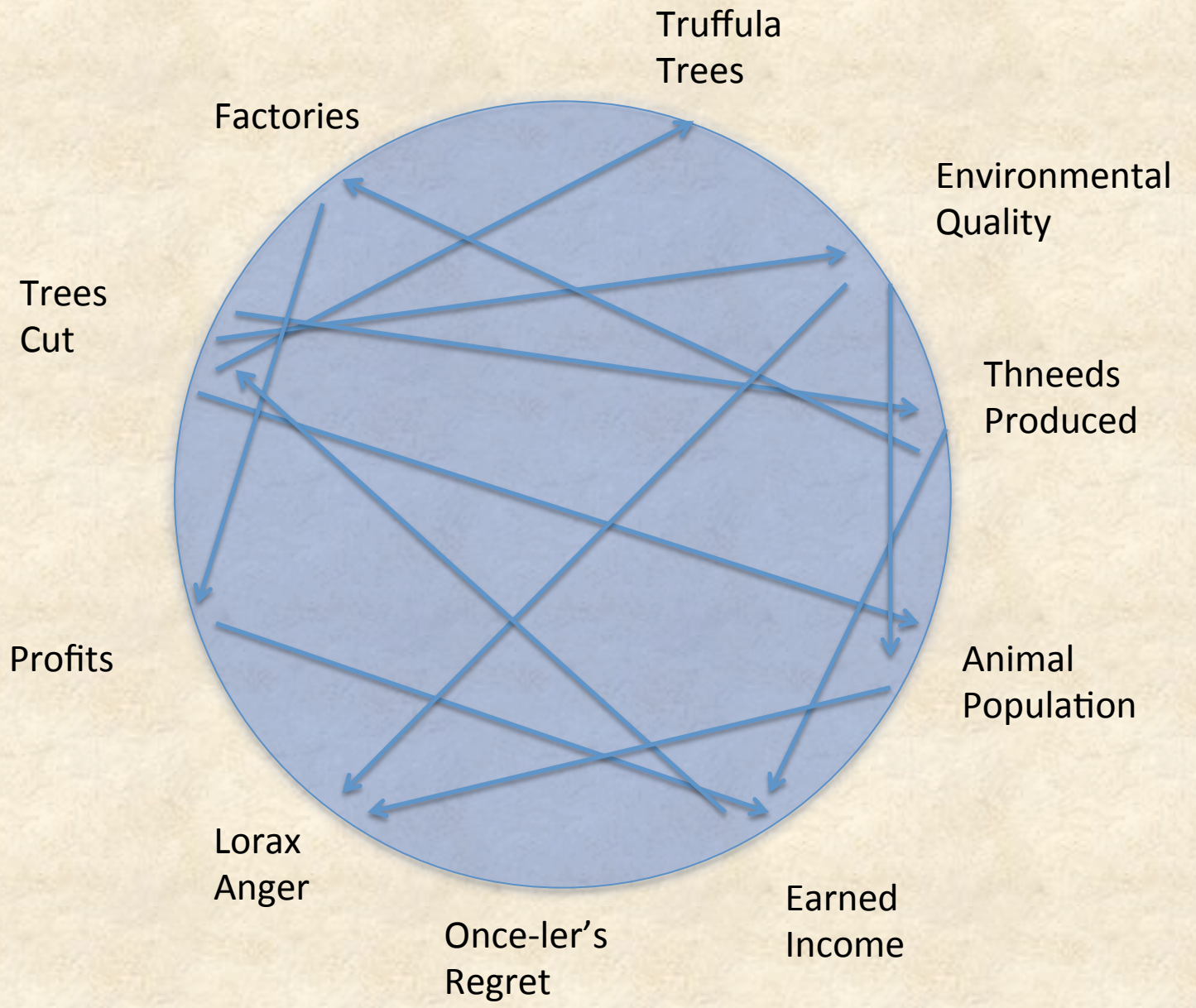


2. Create Connection Circles

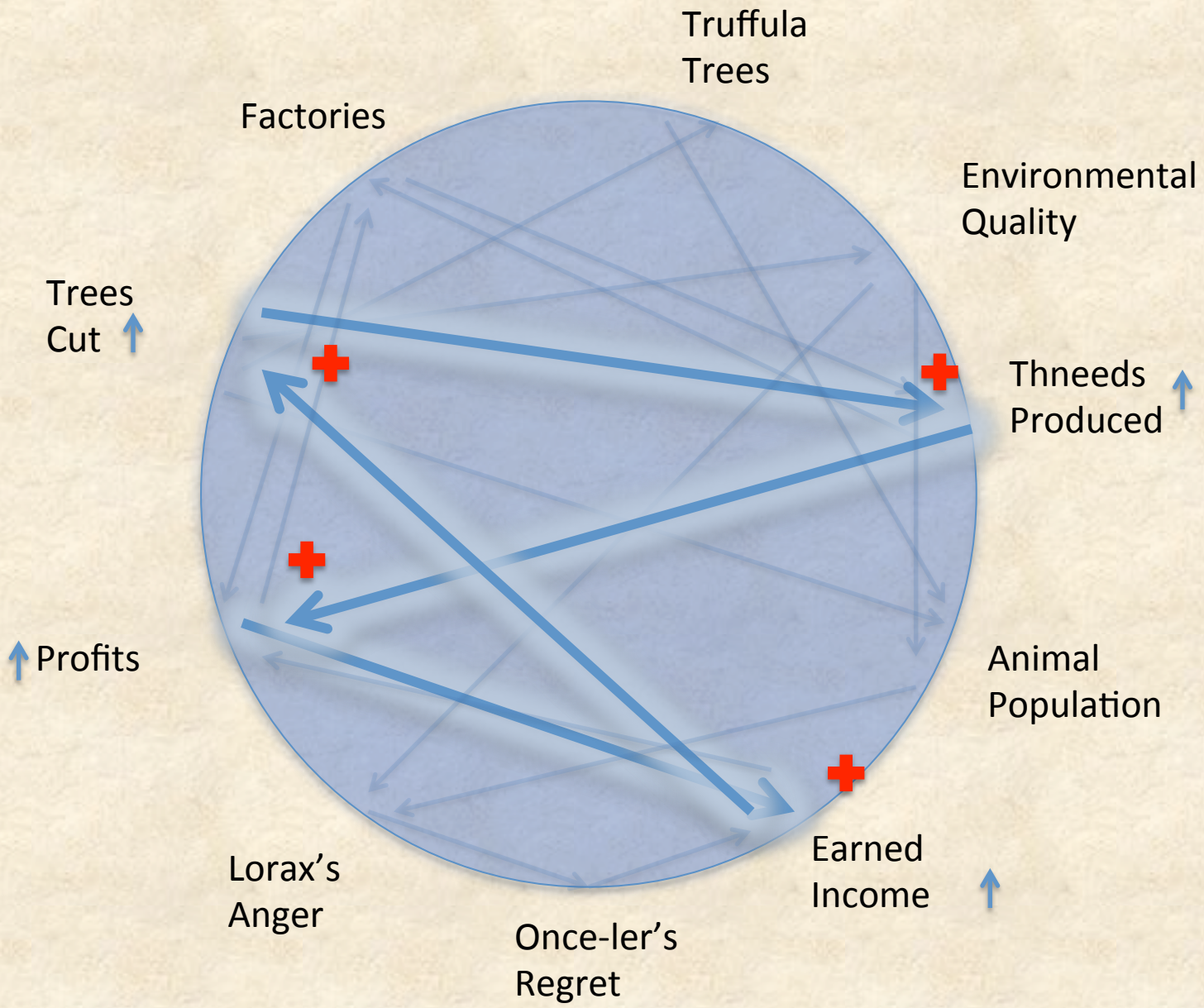
With The Lorax…



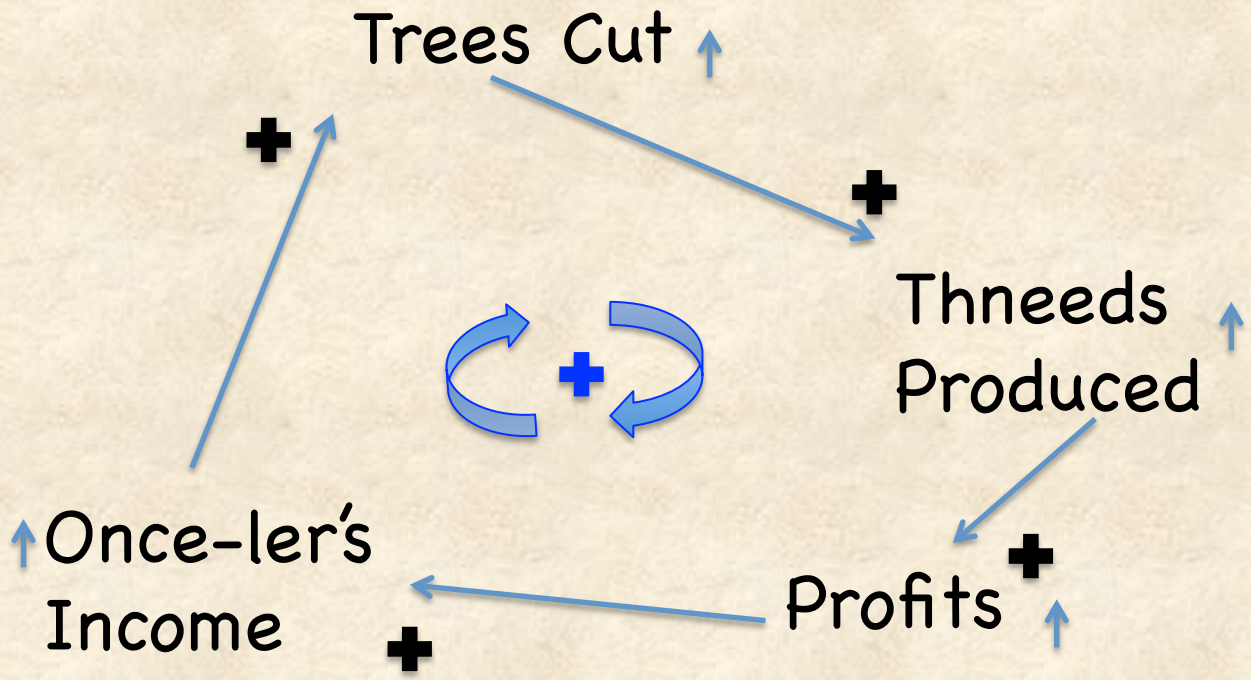
Identify Causes and Effects



Identify Feedback Loops



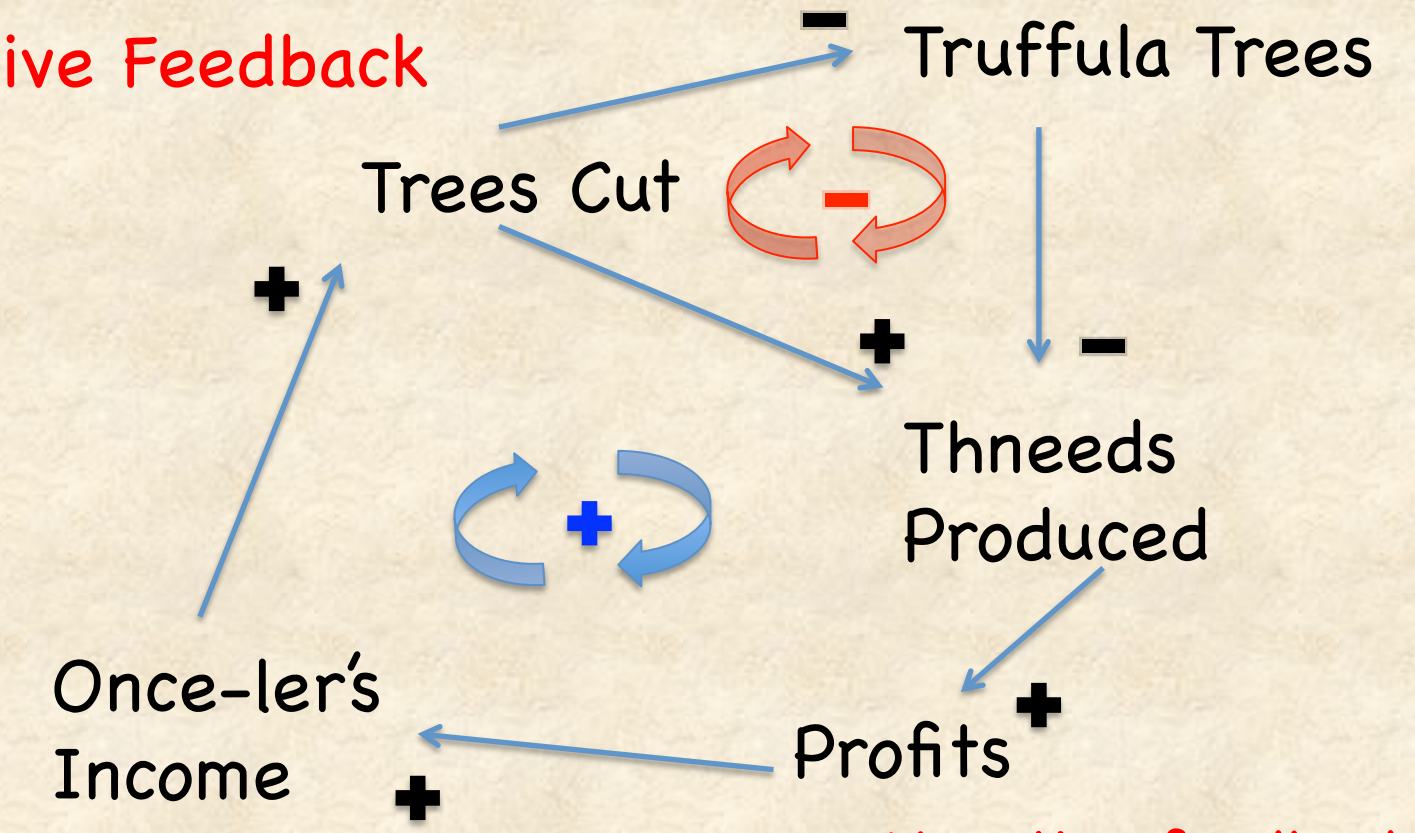
Positive Feedback



Feedback is *positive* if an increase in a variable leads to a further increase in that variable.

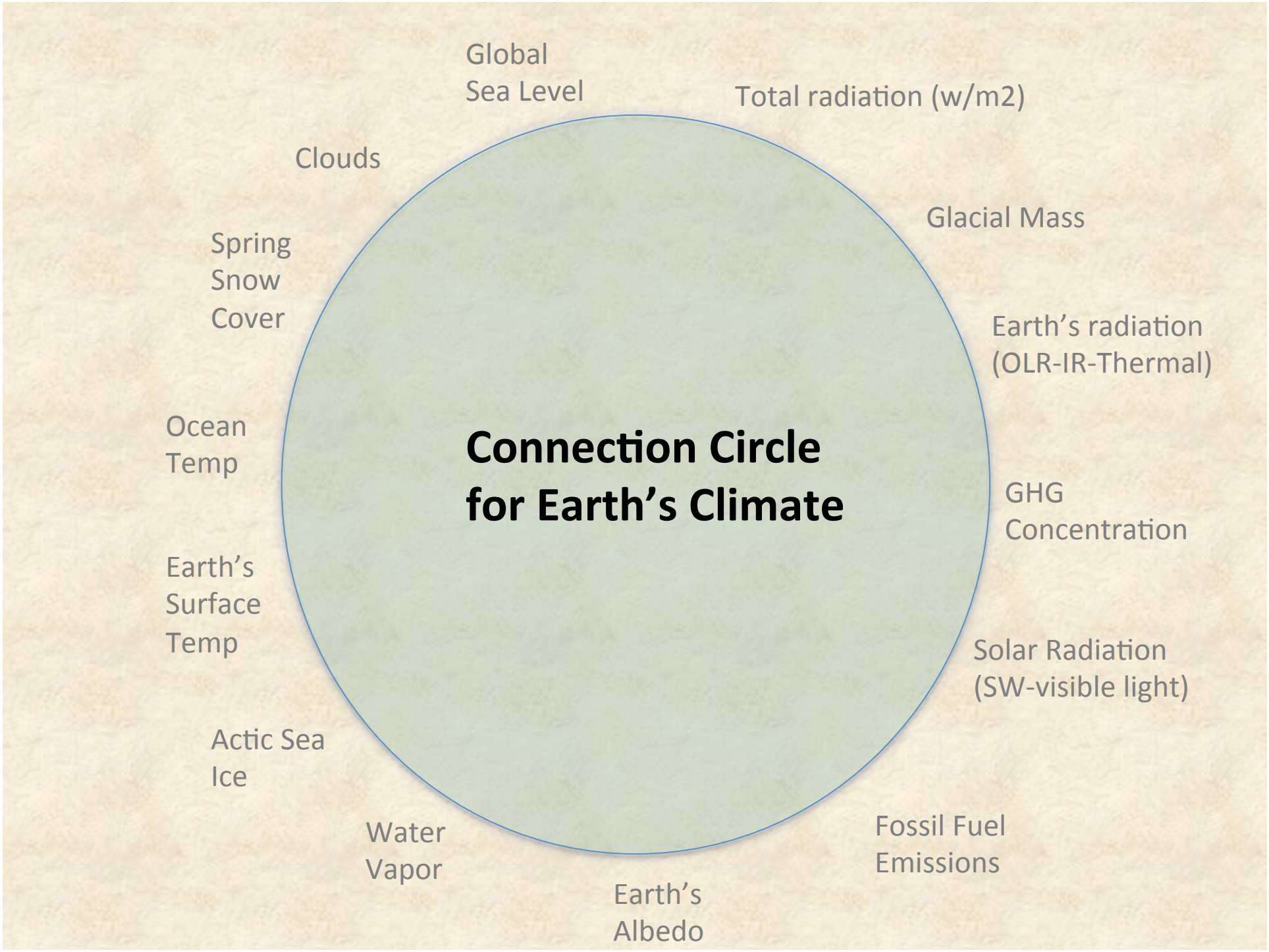
Positive feedback is a reinforcing, compounding, or an amplifying process – exponential, linear

Negative Feedback



Feedback is *negative* if an increase in a variable eventually leads to a decrease in the variable

Negative feedback drives a system to stabilize at a new balance.
- asymptotic or oscillatory


Global
Sea Level
Total radiation (w/m2)
Clouds
Glacial Mass
Spring
Snow
Cover
Earth's radiation
(OLR-IR-Thermal)
Ocean
Temp
Connection Circle
for Earth's Climate
GHG
Concentration
Earth's
Surface
Temp
Solar Radiation
(SW-visible light)
Actic Sea
Ice
Water
Vapor
Fossil Fuel
Emissions
Earth's
Albedo

In-class Activity on Heat Balance

Question 1

- Is the Earth's temperature constant?
- What might cause the Earth's temperature to change? Suggest as many factors as possible which might cause the Earth's temperature to increase or decrease.

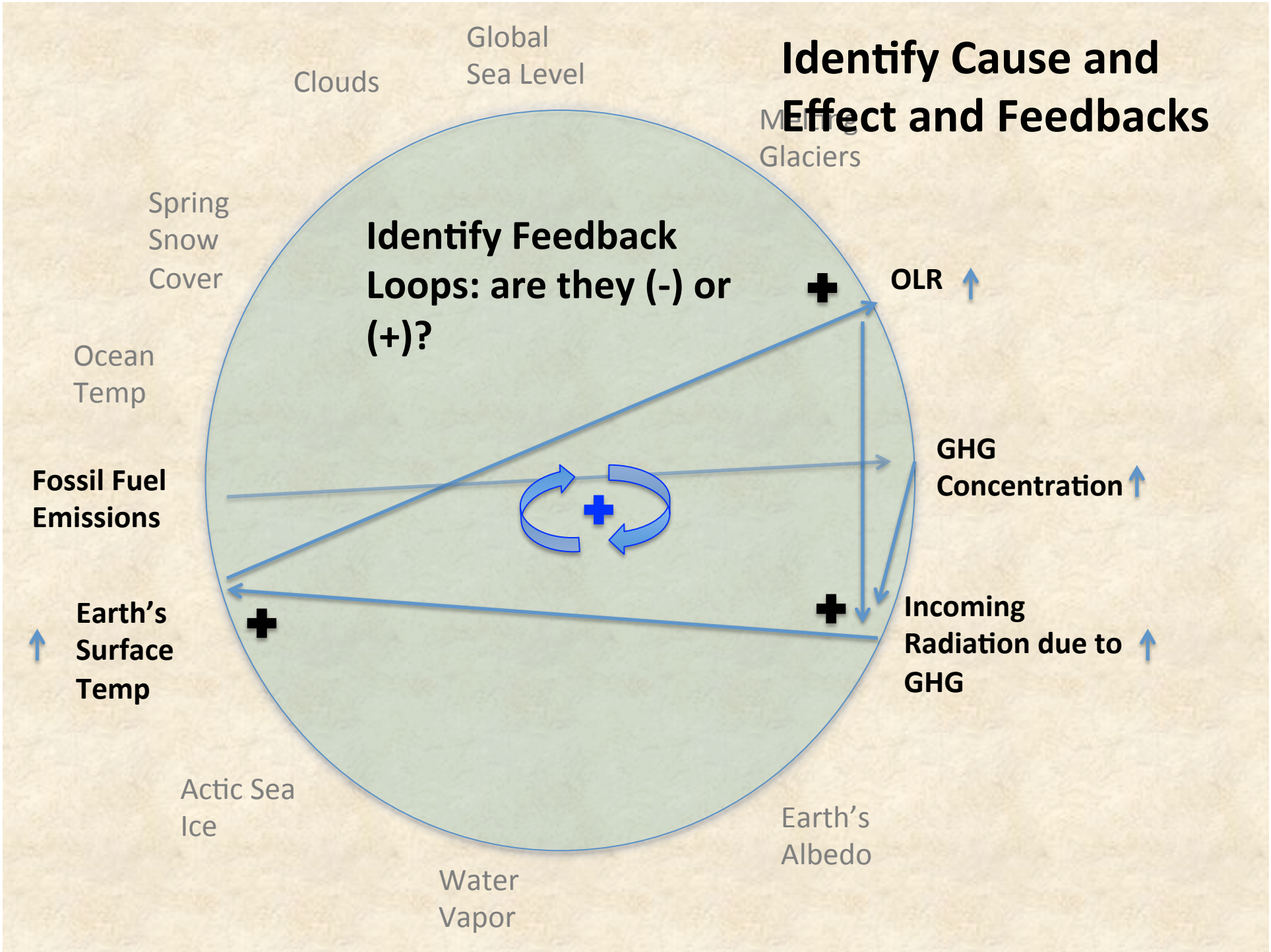
Gaining and losing energy

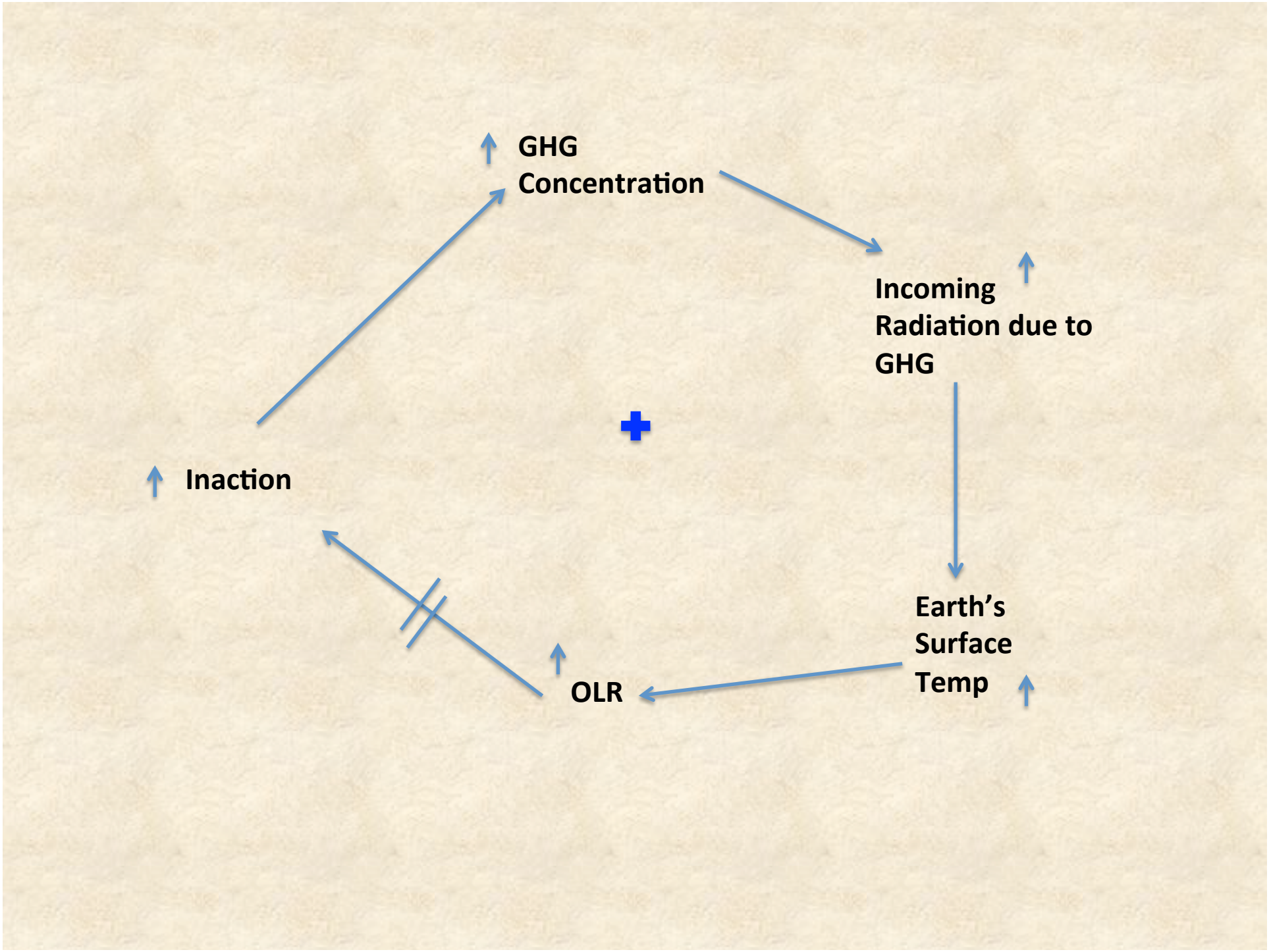
On average, the rate at which radiation reaches the Earth's surface is **364 $Js^{-1}m^{-2}$** (that is, 364 J of energy arrives on every square metre of the Earth's surface every second).

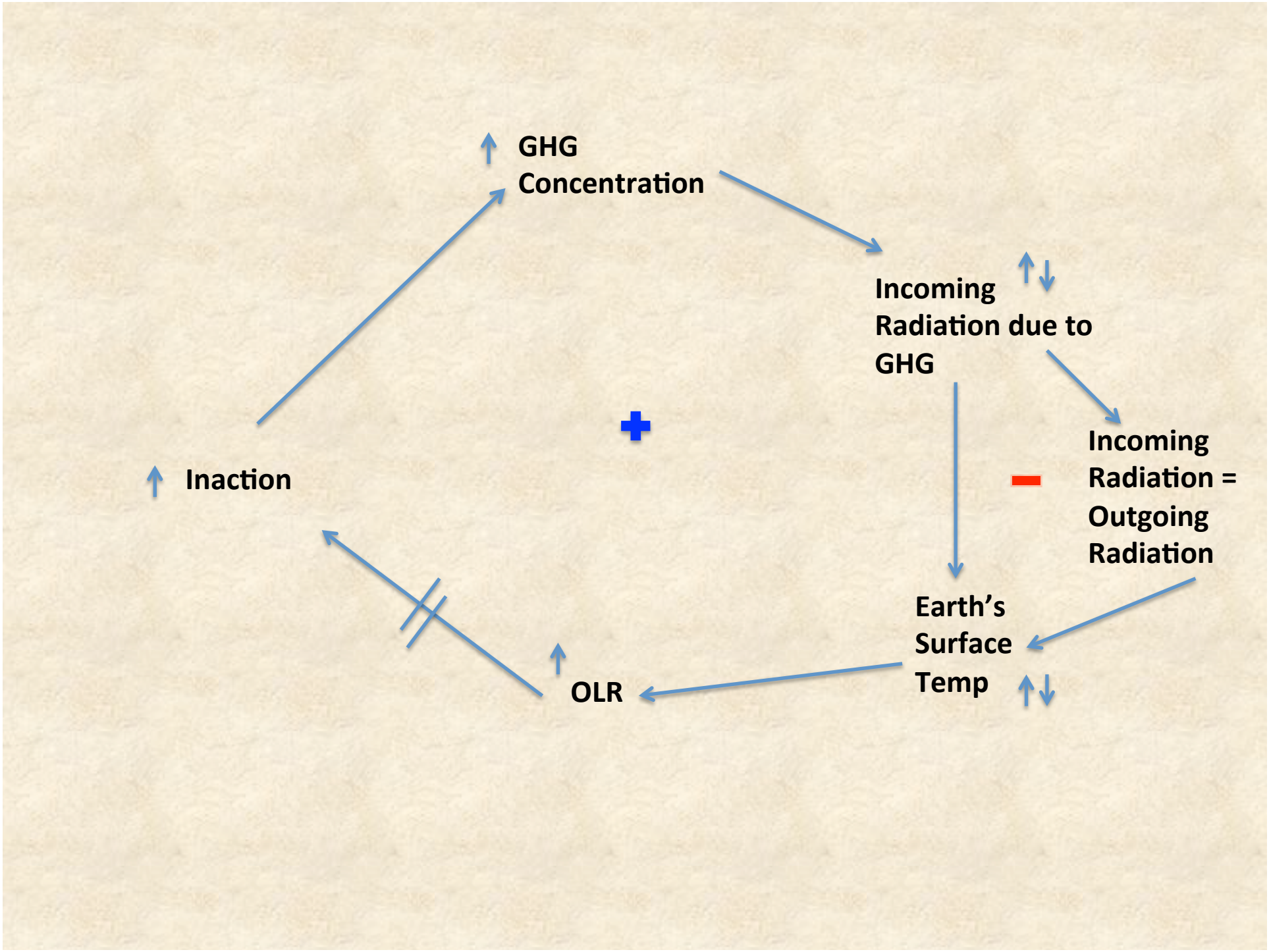
The rate at which the Earth radiates energy back into space depends only on the temperature of the Earth, and is given by the Stefan-Boltzmann Law:

rate of outgoing radiation per square metre = σT^4

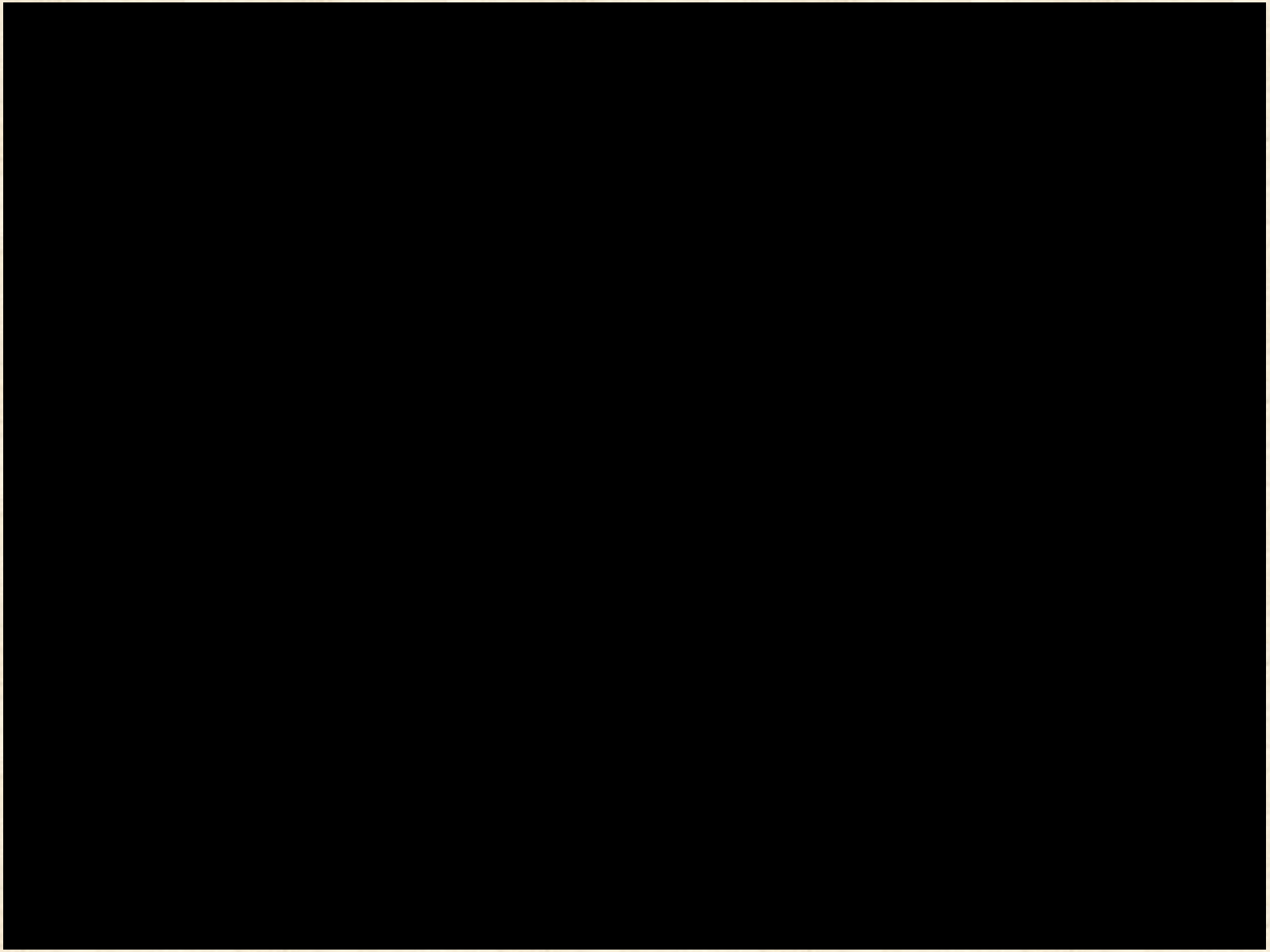
where **$\sigma = 5.67 \times 10^{-8}$ $Js^{-1}m^{-2}K^{-4}$** (the Stefan-Boltzmann constant)


Identify Cause and Effect and Feedbacks
Clouds
Global Sea Level
Melting Glaciers
Spring Snow Cover
Identify Feedback Loops: are they (-) or (+)?
Ocean Temp
OLR
GHG Concentration
Fossil Fuel Emissions
Earth's Surface Temp
Incoming Radiation due to GHG
Actic Sea Ice
Earth's Albedo
Water Vapor


GHG
Concentration
Incoming
Radiation due to
GHG
Earth's
Surface
Temp
OLR
Inaction


GHG
Concentration
Incoming
Radiation due to
GHG
Incoming
Radiation =
Outgoing
Radiation
Earth's
Surface
Temp
OLR
Inaction

All graphs tell a story…



3. Behavior over Time Graphs (BOTGs)

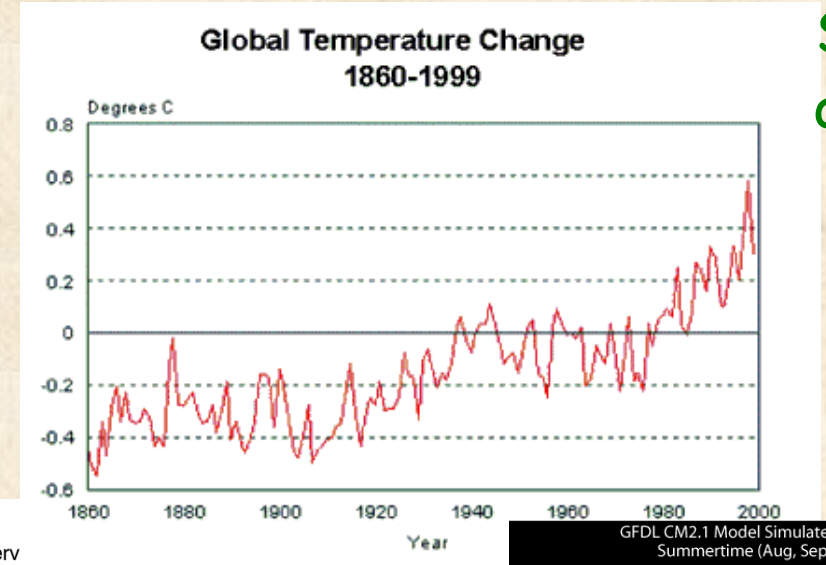
Allow us to keep track of several variables in our minds

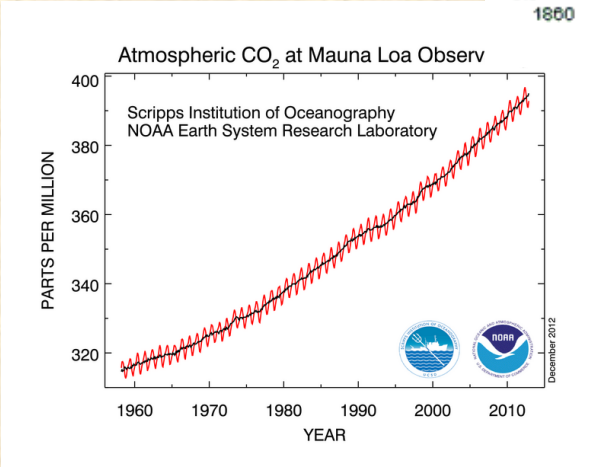
Help students compare and contrast

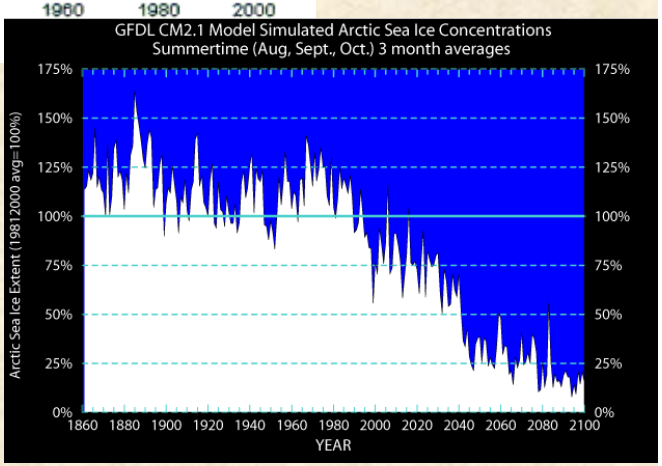
Stimulate discussion

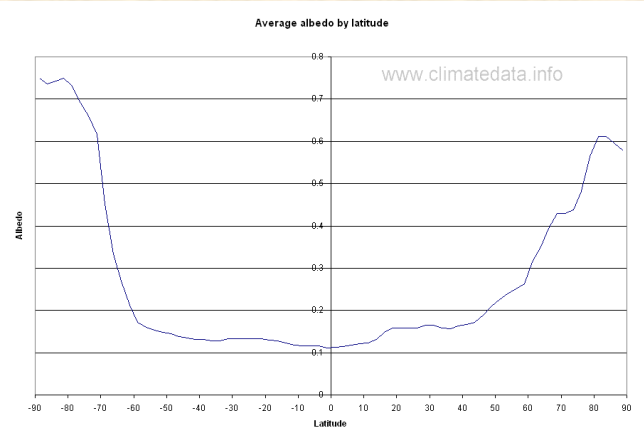
Focus on trends

Always show change over time

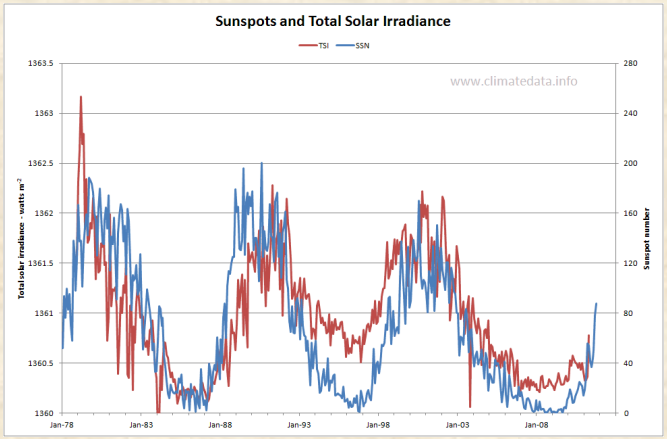


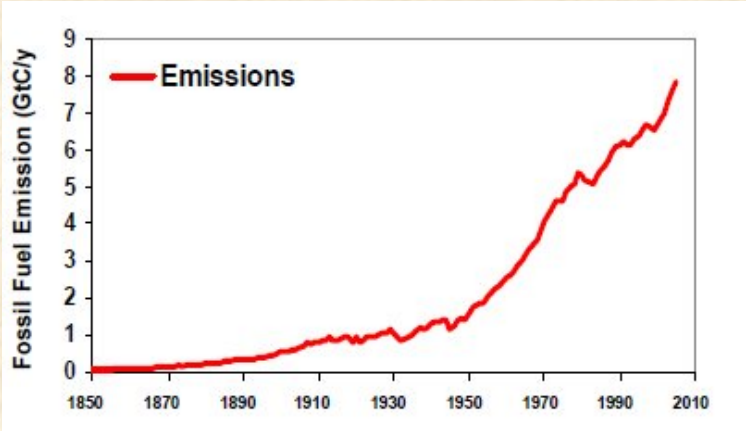






Foster ideas about why things might be happening as they are.





http://www.watersfoundation.org/webed/mod1/video/vid-student1.html

Focus on how related elements change over time.

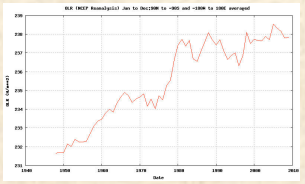
Global
Sea Level

Clouds

Melting
Glaciers

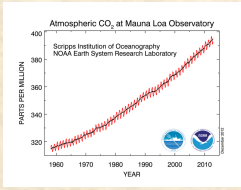
Spring
Snow
Cover

BOTGs can be added to the Connection Circle to improve our mental model



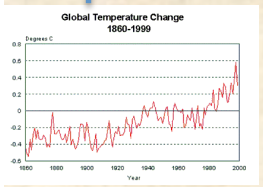
OLR ↑

Ocean
Temp

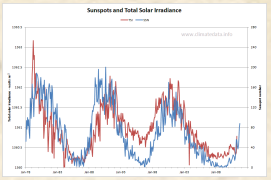


GHG Concentration ↑

Earth's Surface Temp ↑



Incoming Radiation ↑

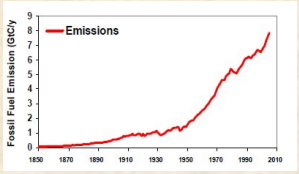


Actic Sea
Ice

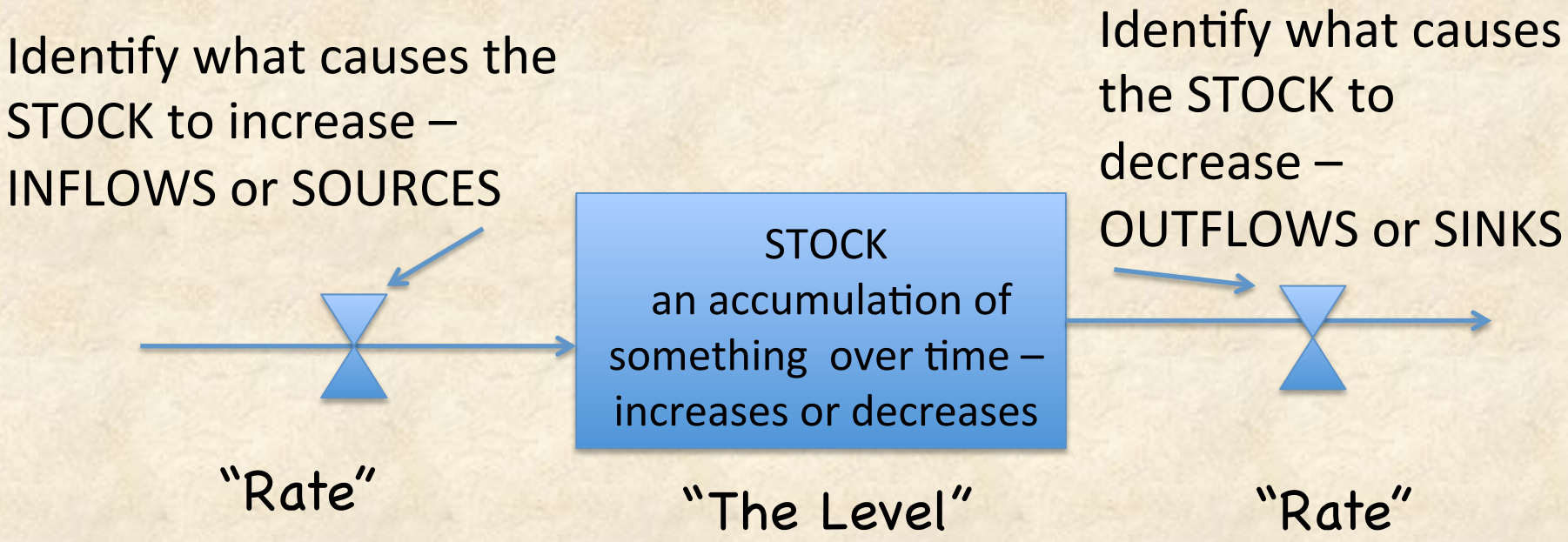
Water
Vapor

Earth's
Albedo

Fossil Fuel Emissions ↑



4. Stock-Flow Models



Stocks are hard to change because their levels are often times very large relative to their rates.

Stock-Flow Simulation Models

People on the Bus
http://insightmaker.com/insight/3694

Carbon Stock-Flow Diagram
http://insightmaker.com/insight/2858

iPad Apps