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

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Class News

- Ctools site: AOSS_SNRE_480_001_W14

- Intergovernmental Panel on Climate Change
  - IPCC (2007) Working Group 1: Summary for Policy Makers
  - IPCC (2013) Working Group 1: Summary for Policy Makers

- Seminars this week
  - January 21: Jigar Shah, Creating Climate Wealth: Unlocking the Impact Economy: Tuesday 4:45-5:30pm, Ross School of Business, (6th Floor Colloquium Room)
  - January 23: Jennifer Francis: Rapid Arctic warming and extreme weather events in mid-latitudes: Are they connected? Thursday, 3:30 – 4:30 pm AOSS, Space Research Building, Room 2246

First Reading Response

- IPCC (2013) Working Group 1: Summary for Policy Makers
- Reading responses of roughly one page (single-spaced). The responses do not need to be elaborate, but they should also not simply summarize the reading. They should be used by you to refine your questions and to improve your insight into climate change.
- They should be **submitted via CTools** by next Tuesday and we will use them to guide discussion in class on Thursday. Assignment posted with some questions to guide responses.

This lecture:

- Balance, Budgets and Models

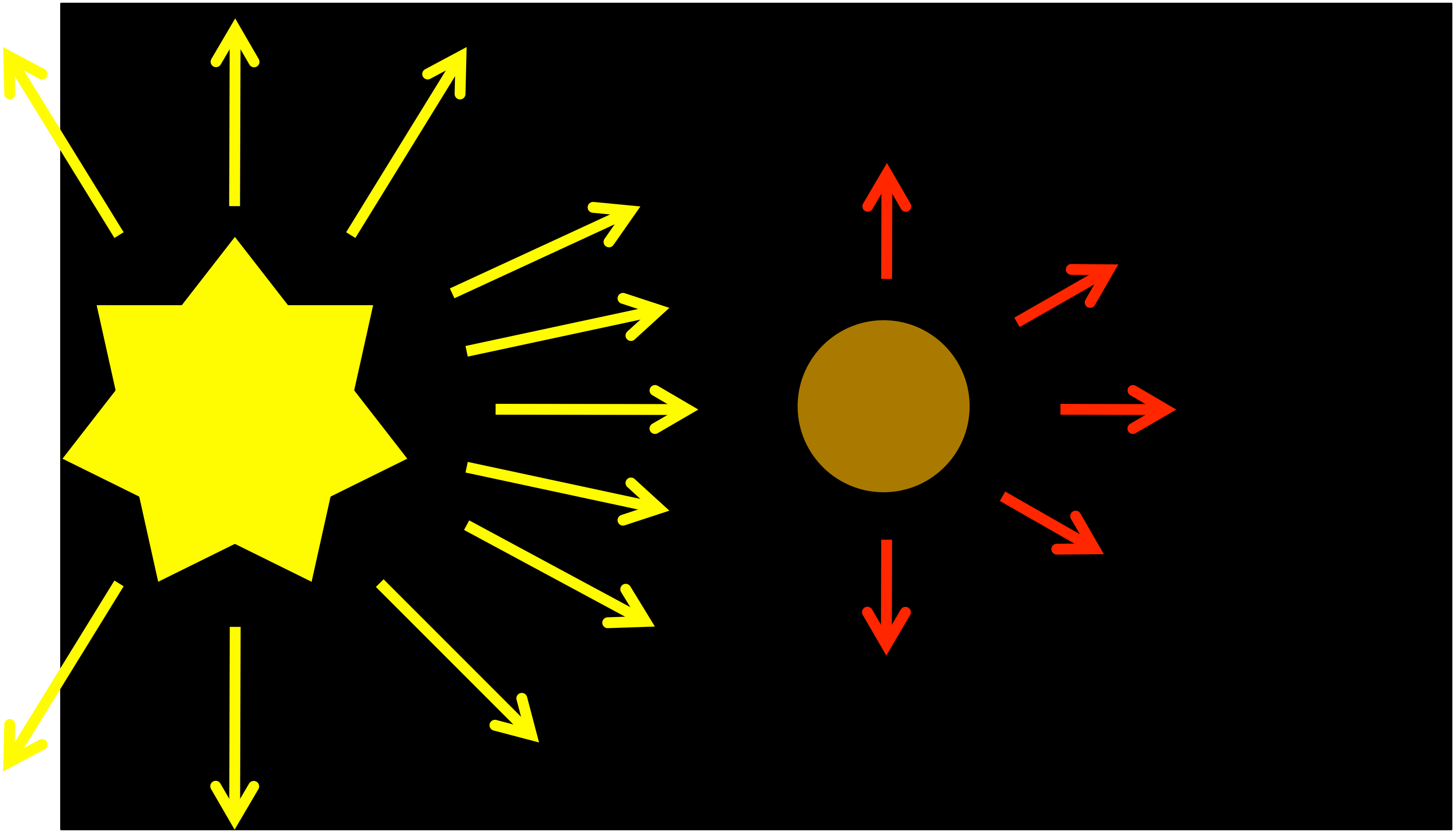
Scientific Method and Earth's Climate

- We will first break the scientific investigation down into pieces.
  - Theory … Draw a Picture
  - Observations
  - Prediction
  - Attribution
  - Impacts
- We will look at the links of climate change to the other parts of the problem.
  - There is not a simple "solution;" we will not solve this problem and walk away from it.
  - We will be required to manage the climate
- We will define ways forward.

Scientific investigation of Earth's climate

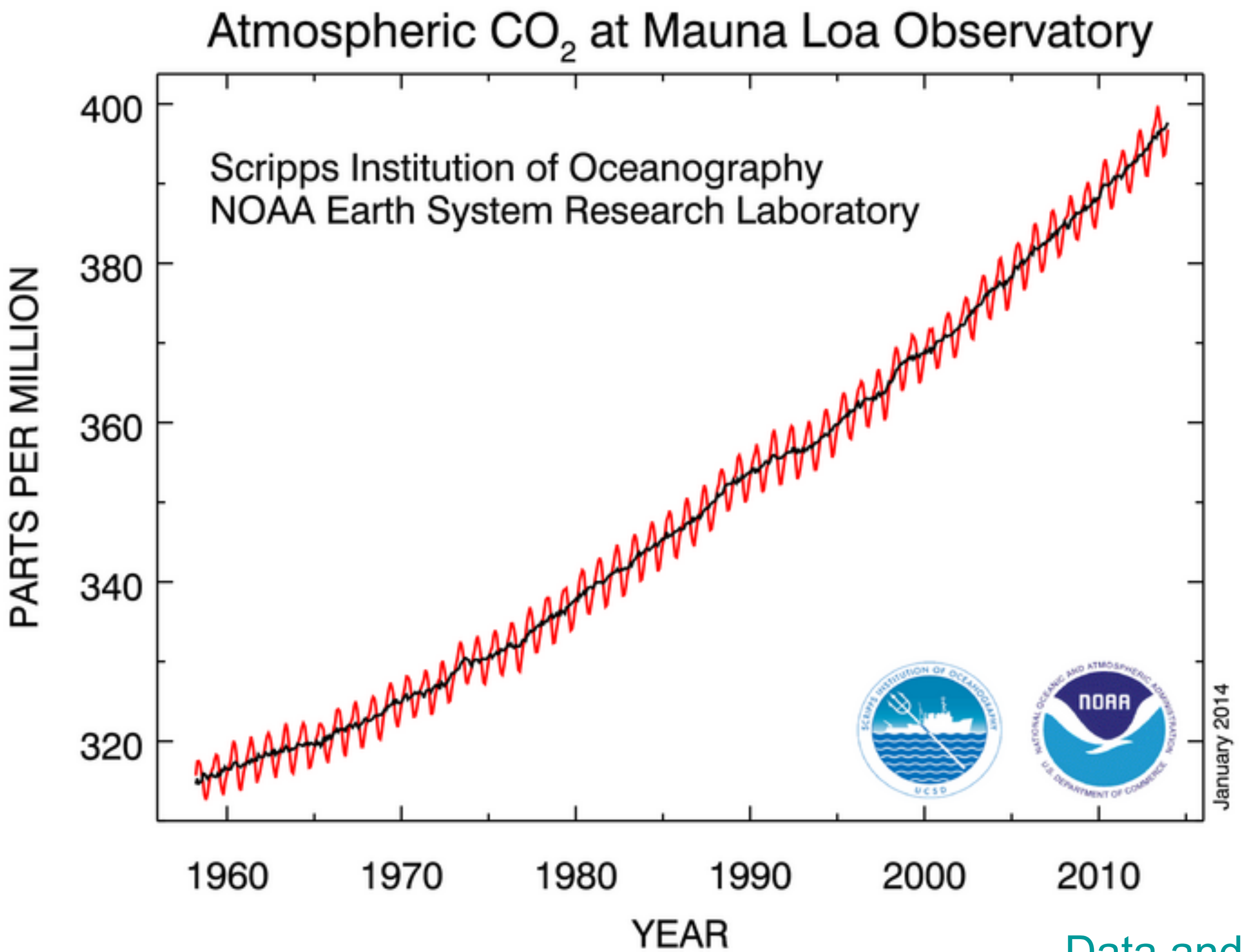
SUN: ENERGY, HEAT

EARTH: ABSORBS ENERGY



EARTH: EMITS ENERGY TO SPACE → BALANCE

Increase of Atmospheric Carbon Dioxide (CO_2)



Primary increase comes from burning fossil fuels – coal, oil, natural gas

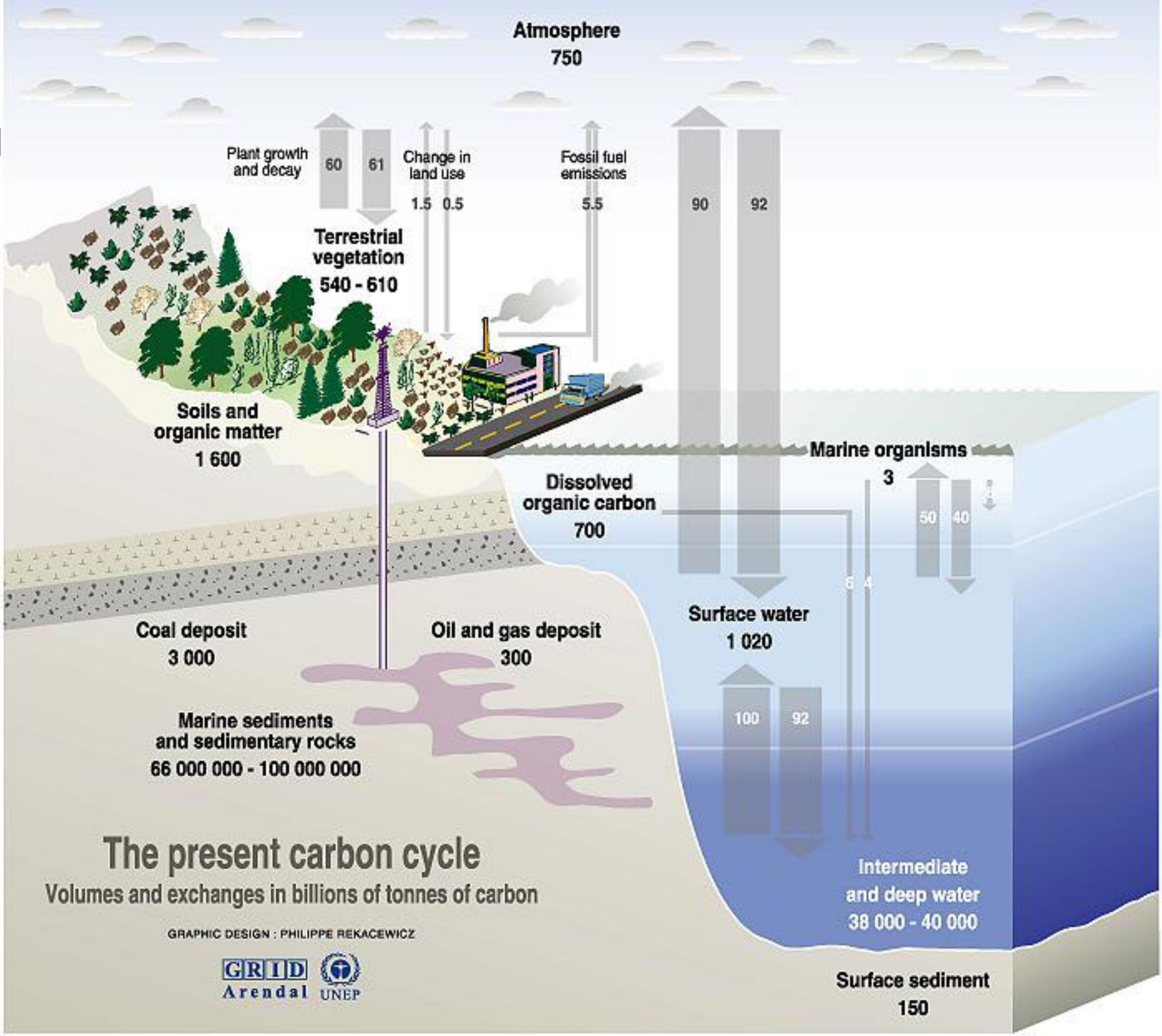
Data and more information

This lecture:

- Carbon dioxide budget

What are the mechanisms for production and loss of CO_2?

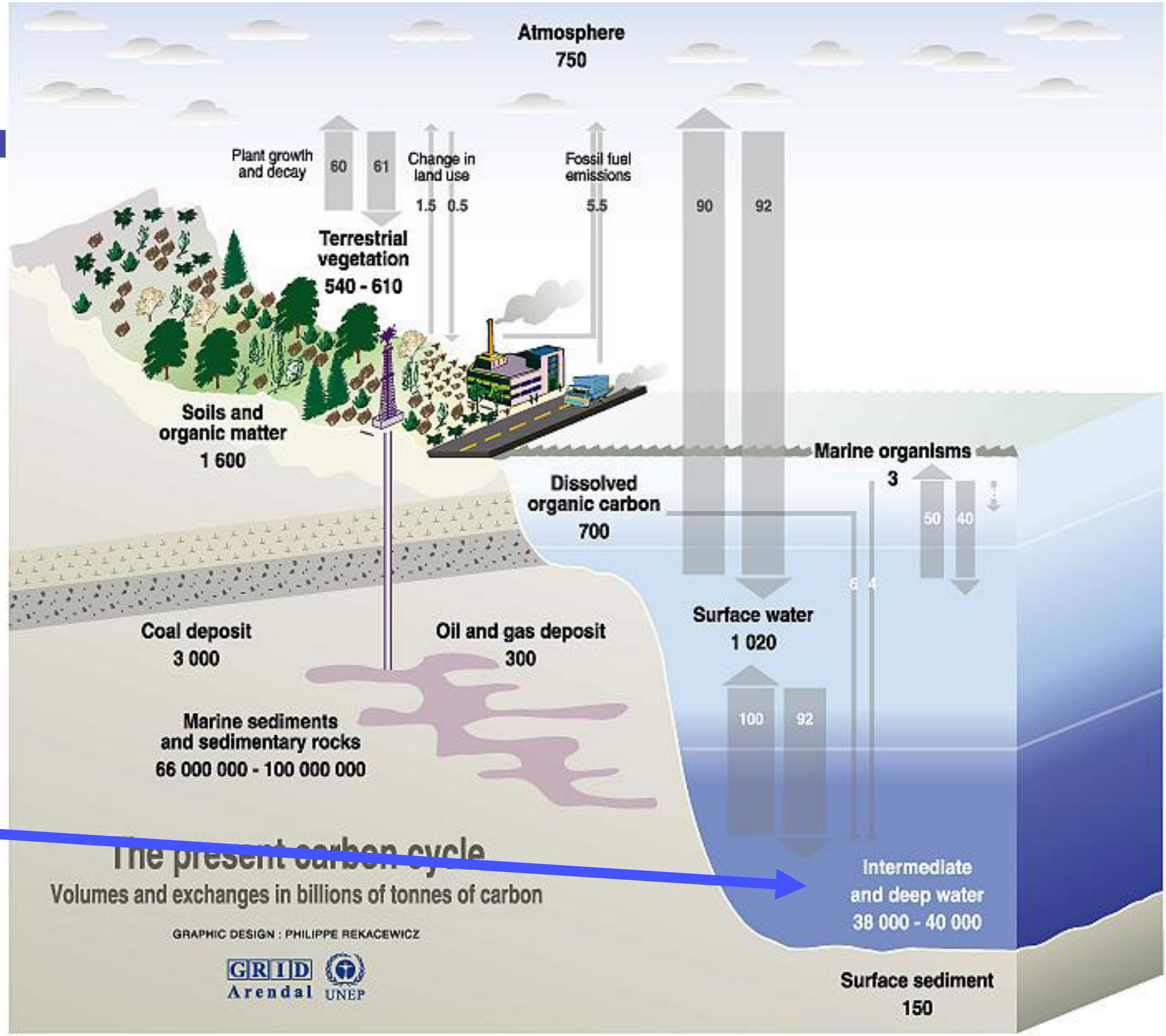
Important things in this figure.



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.

What are the mechanisms for production and loss of CO_2?

Enormous amount of carbon dioxide in the ocean.



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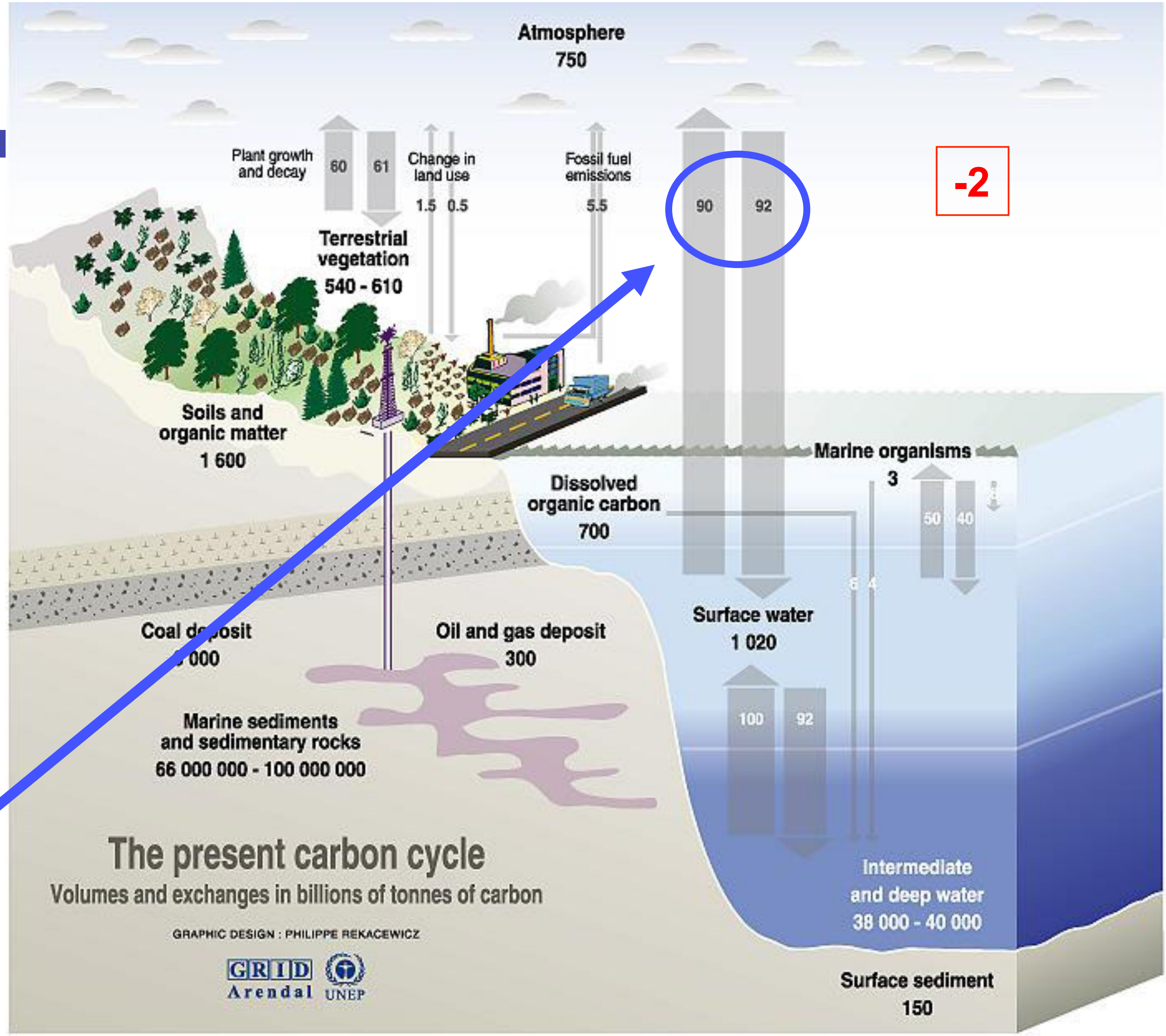
What are the mechanisms for production and loss of CO_2?

Exchange of carbon dioxide between atmosphere and ocean ocean.



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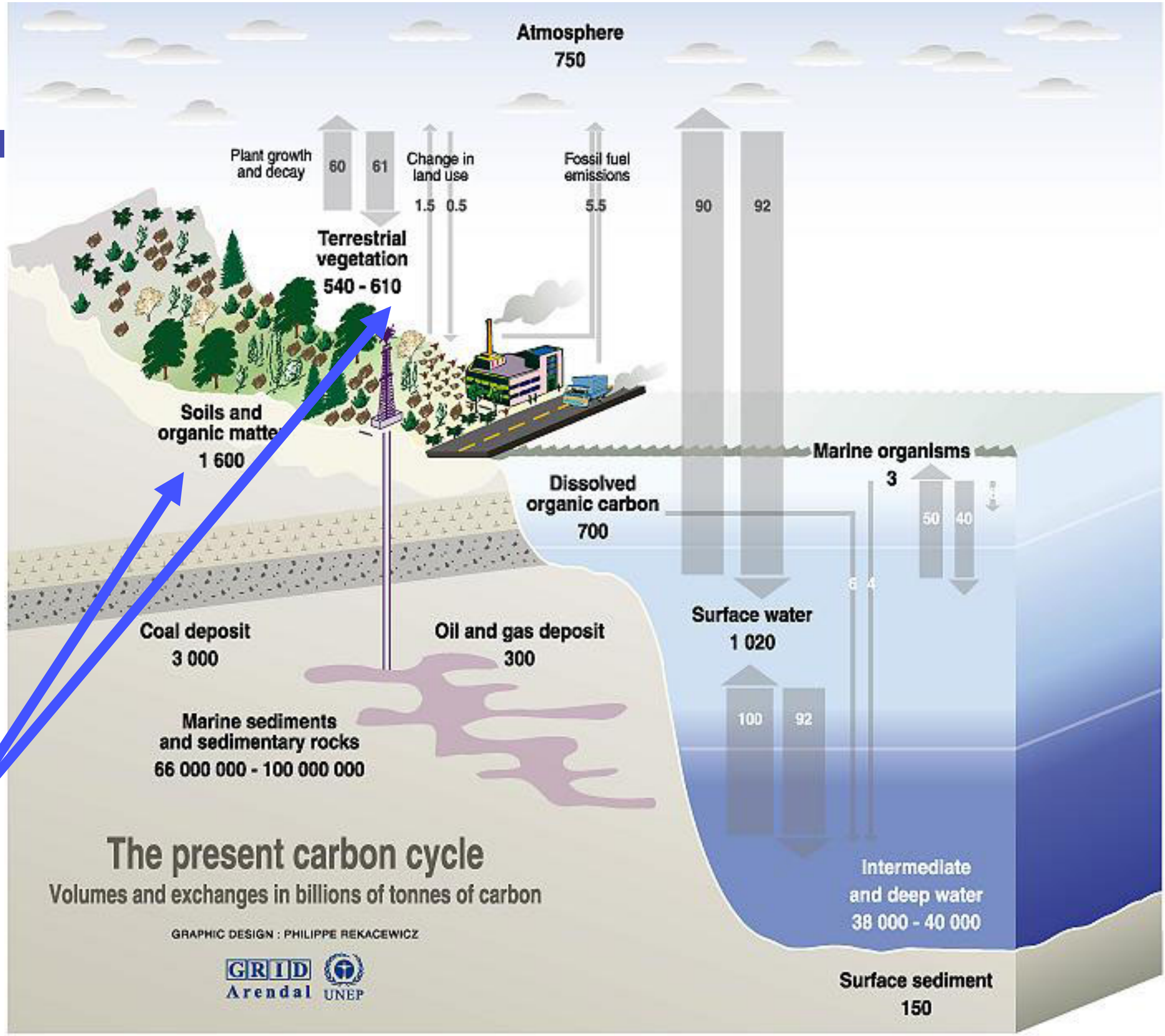
What are the mechanisms for production and loss of CO_2?

Large amount of carbon dioxide in the “soil” and plants



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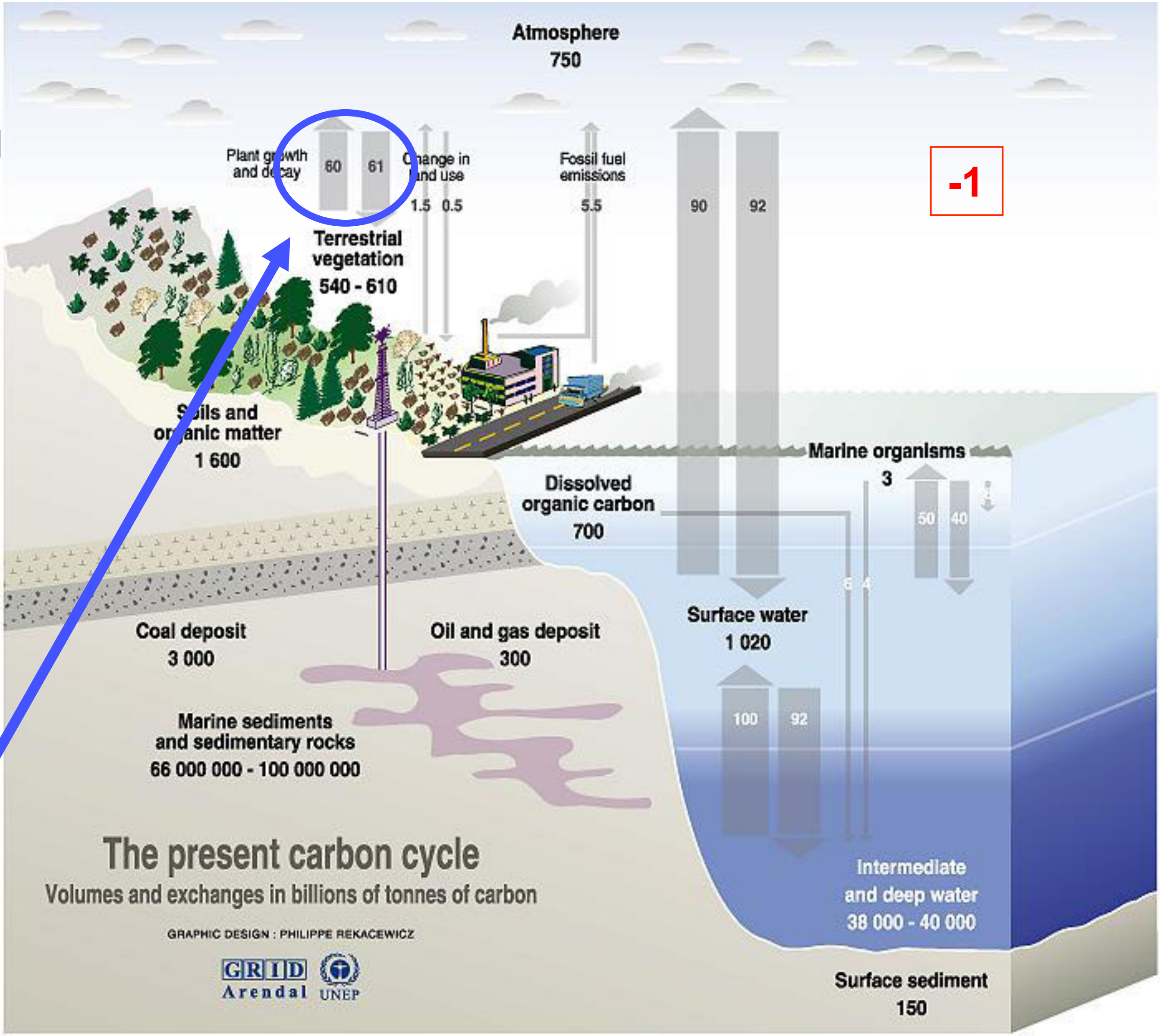
What are the mechanisms for production and loss of CO_2?

Exchange of carbon dioxide between atmosphere and "land."



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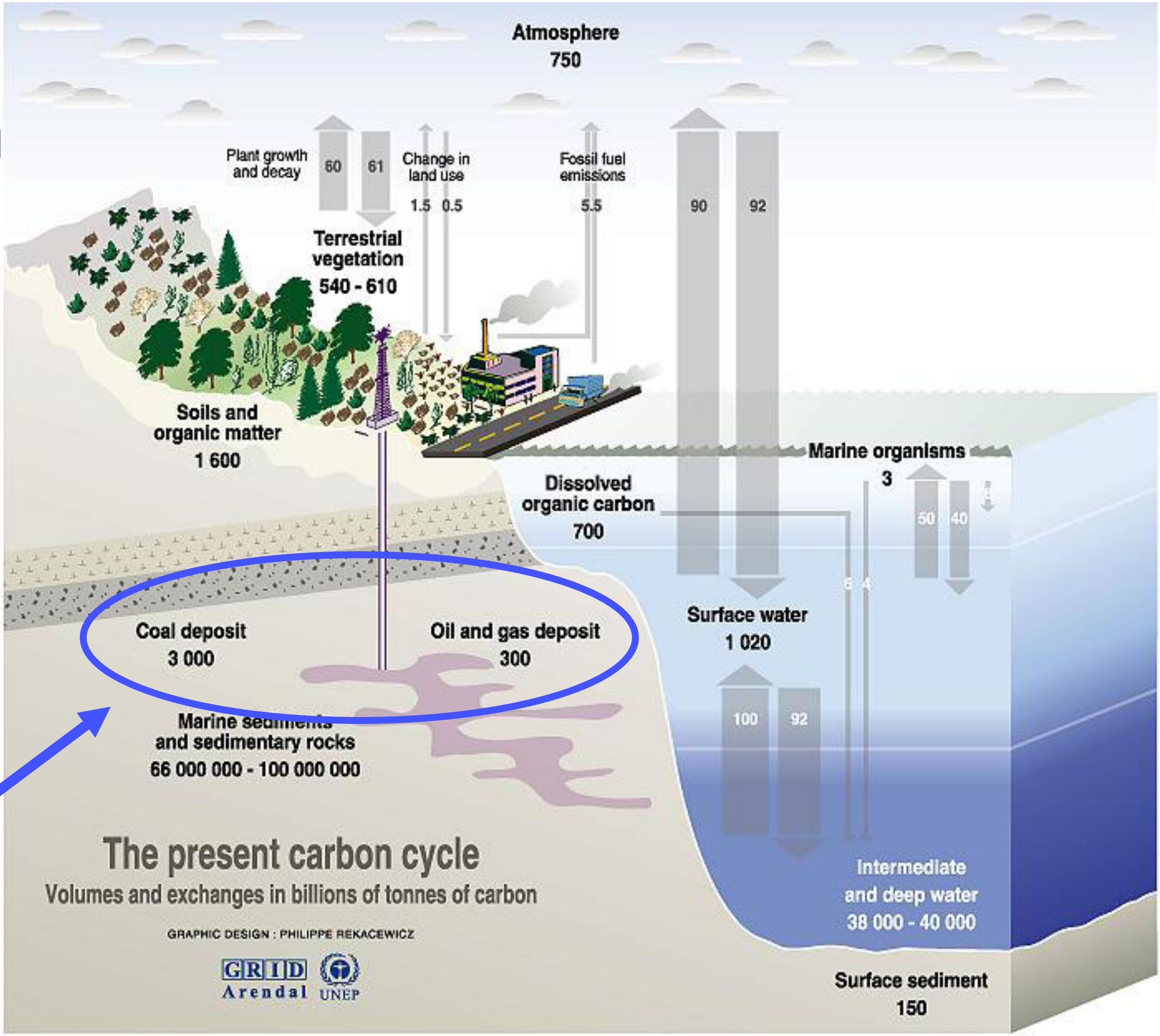
What are the mechanisms for production and loss of CO_2?

Large amount of carbon dioxide in coal, oil, gas



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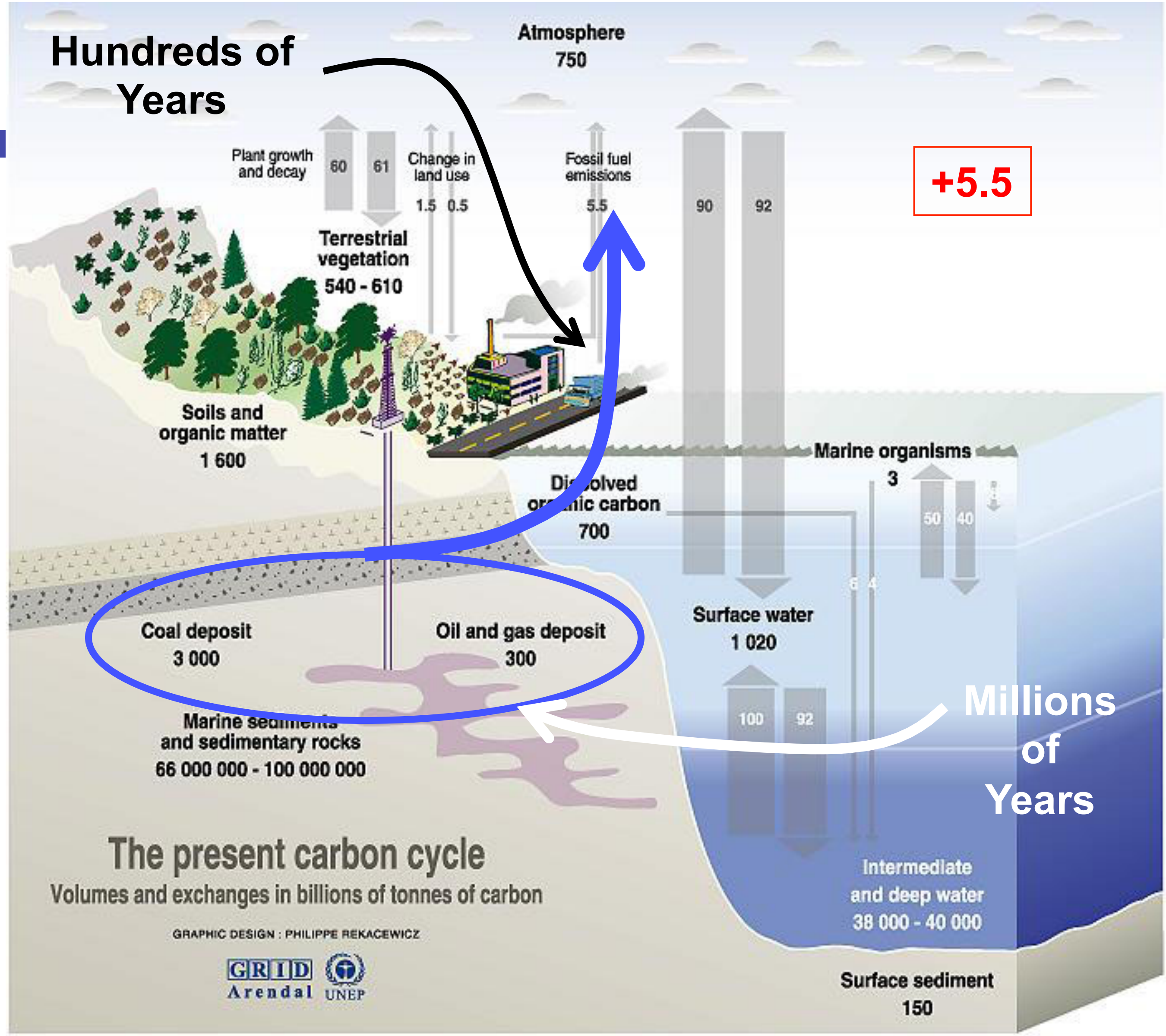
What are the mechanisms for production and loss of CO_2?

Movement of carbon dioxide by burning



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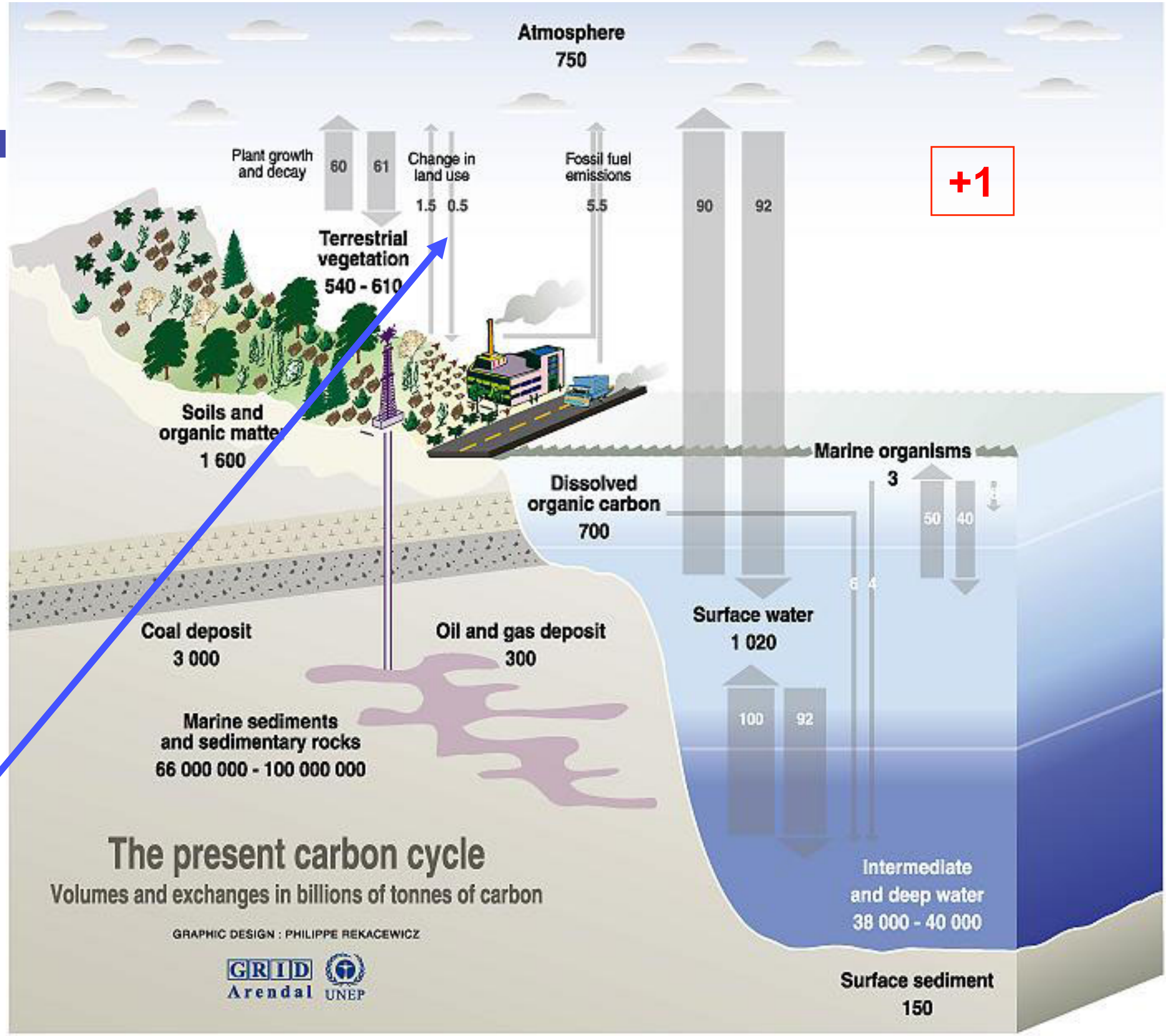
What are the mechanisms for production and loss of CO_2?

Movement of carbon dioxide by land use changes



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Were you counting?

- Net sources into the atmosphere

$\boxed{5.5 + 1 = 6.5}$

- Net removal from the atmosphere

$\boxed{2+1 = 3}$

About carbon dioxide (CO_2)

- CO_2 is increasing in the atmosphere and the oceans.
  - In ocean transfer of CO_2 between CO_2 and calcium carbonate and carbonic acid
- Currently flux of CO2 from the atmosphere to the ocean and land, but the flux is both ways and the sign can change. Especially if the ocean gets warmer.

This lecture:

- Models

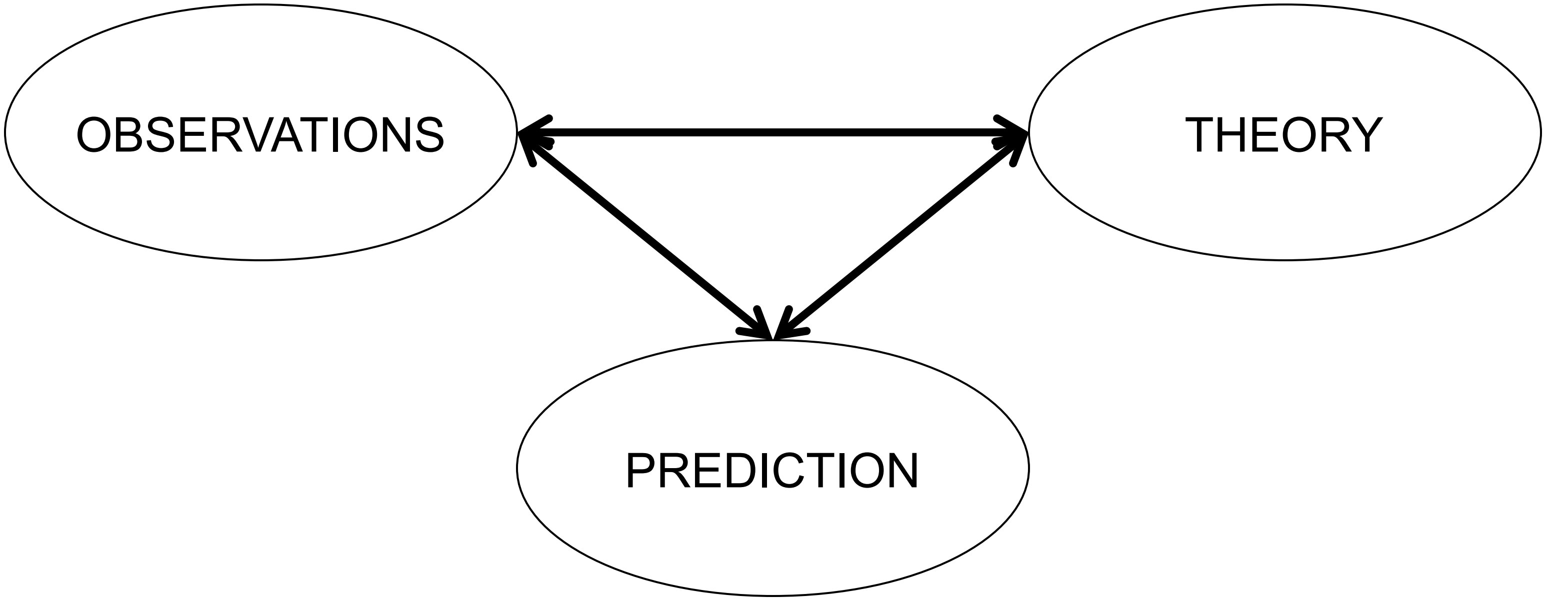
Models

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

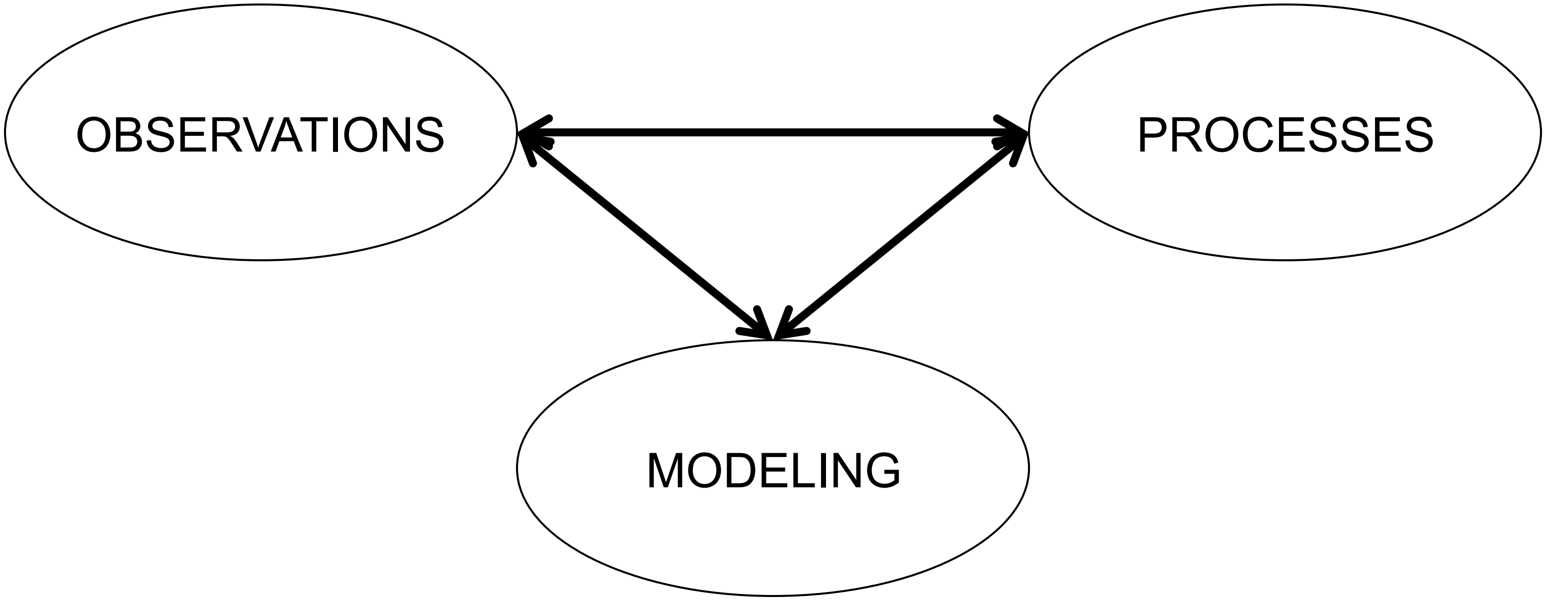
What is a Model?

- 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



Scientific Investigation



Models are everywhere

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

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 make 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 “production” and “loss”)

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

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

Rewrite the equation to represent the difference in money

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

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.

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

Conservation principle (with “production” and “loss”)

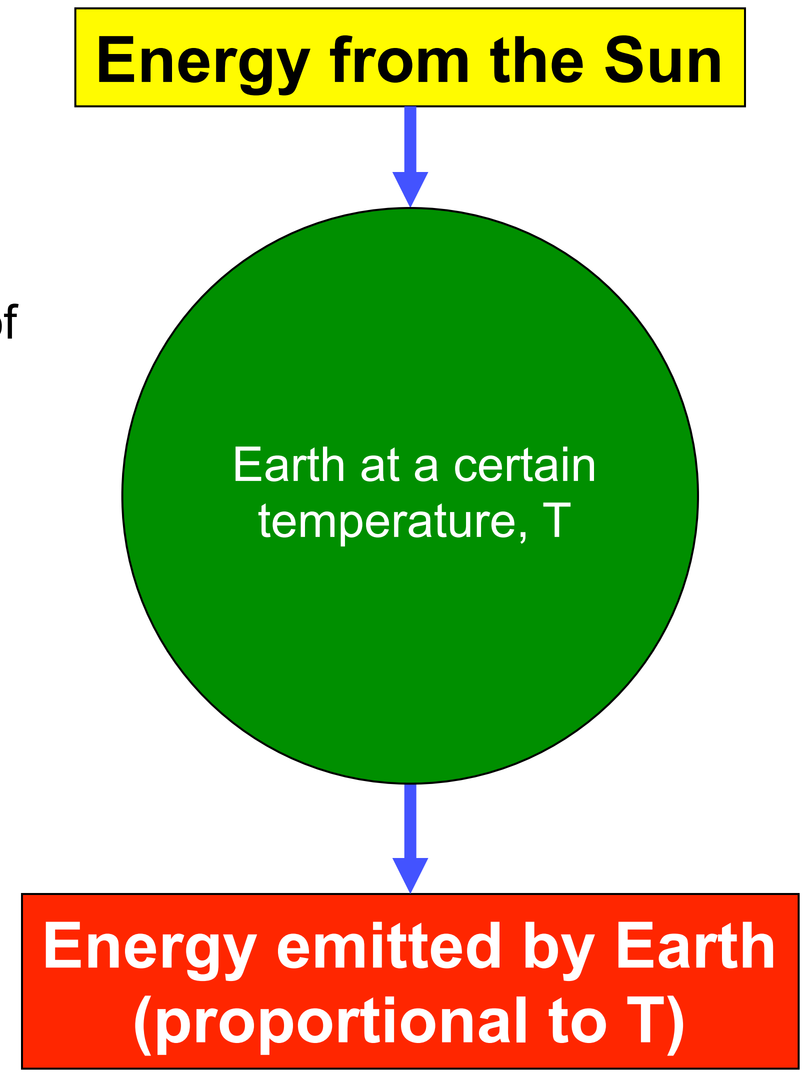
Income

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

Let’s get some money and buy stuff.

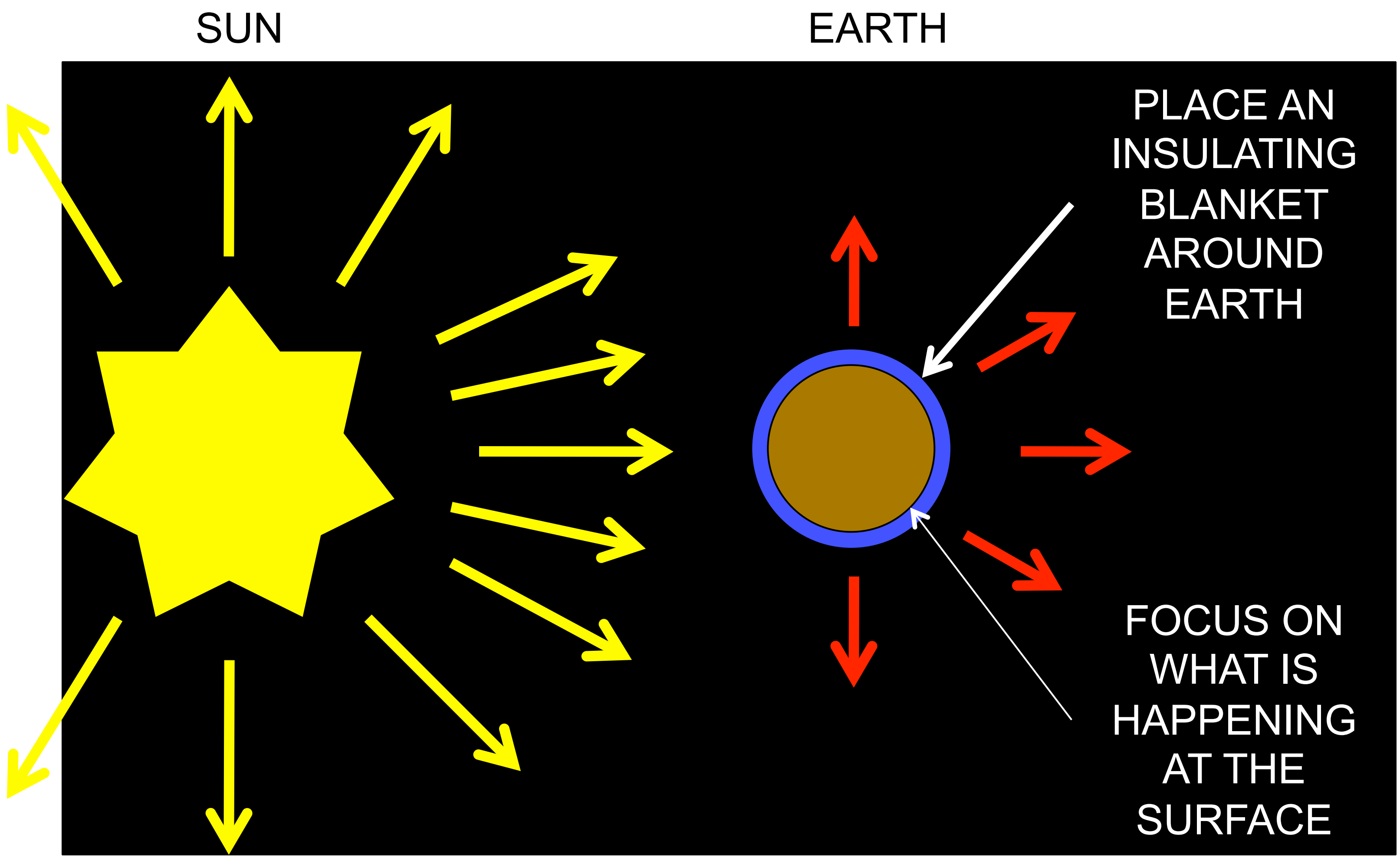
Expense

Conservation: Climate



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

Point of View



EARTH: EMITS ENERGY TO SPACE → BALANCE

Conservation principle

- dM/dt = Income (per time) – Expense (per time)

- What we have done is a dimensional analysis
  - Start out with money (dollars)
  - Then we introduced the idea of time
    - Income per month
    - Expense per month
  - Then we divided by time to get some idea of how things change with time

Conservation (continuity) principle

- There are certain parameters, for example, momentum, mass (air, water, ozone, number of atoms, …), energy, that are conserved.
  - This is "classical" physics
  - 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. That is, nothing new comes into the system – nothing leaves.
  - If you put a boundary around it then nothing crosses the boundary
- Is the Earth an isolated system?

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

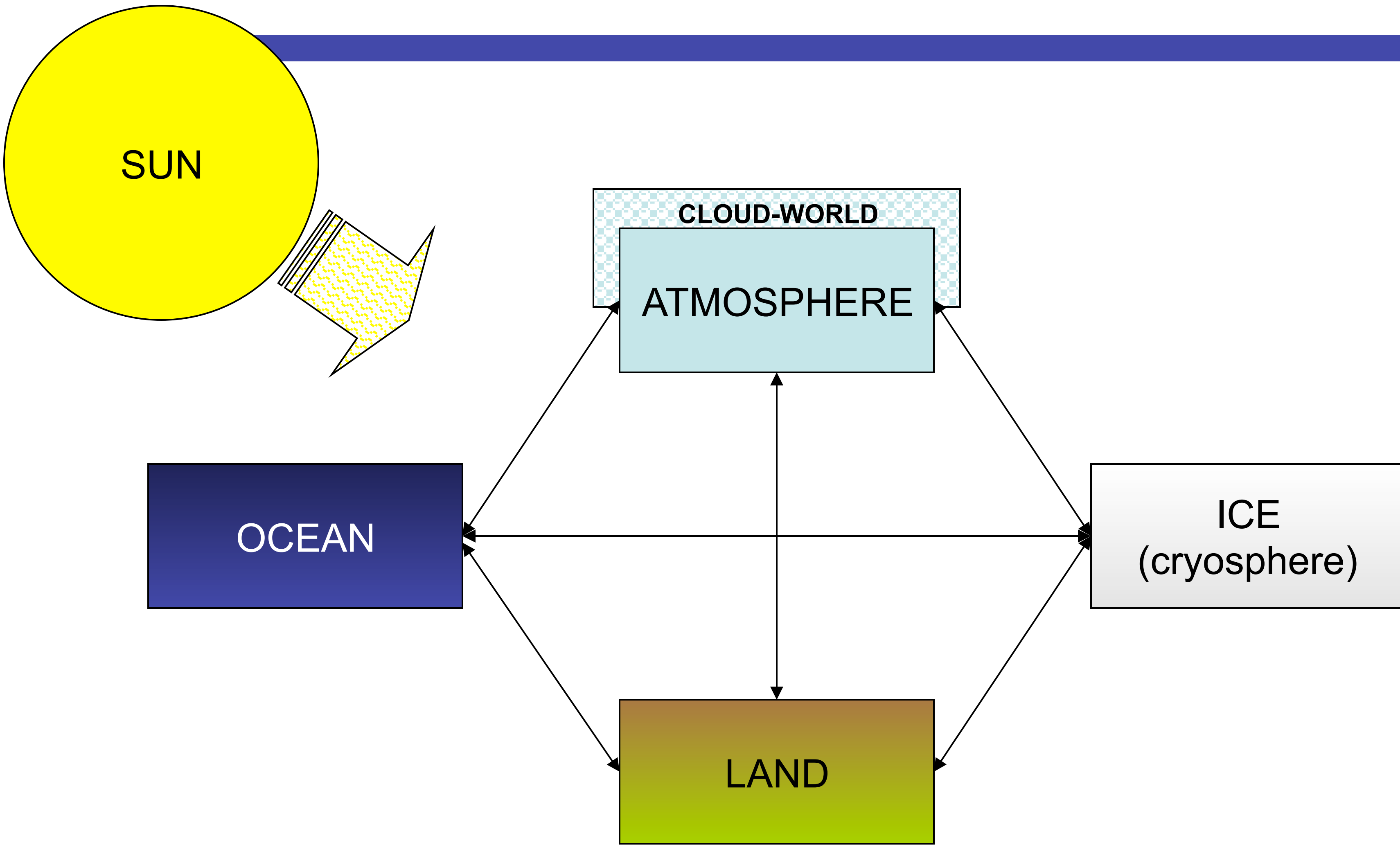
Ledgers, Graphics and Carvings

- Ledgers
- → Spreadsheets → Computers

What do we do?

- We develop models based on the conservation of energy and mass and momentum, the fundamental ideas of classical physics. (Budget equations)
- We break things into pieces, deconstruct, reduce
- We determine the characteristics of production and loss from theory and observations of, for instance, the eruption of a major volcano and the temperature response as measured by the global observing system.

The Earth System



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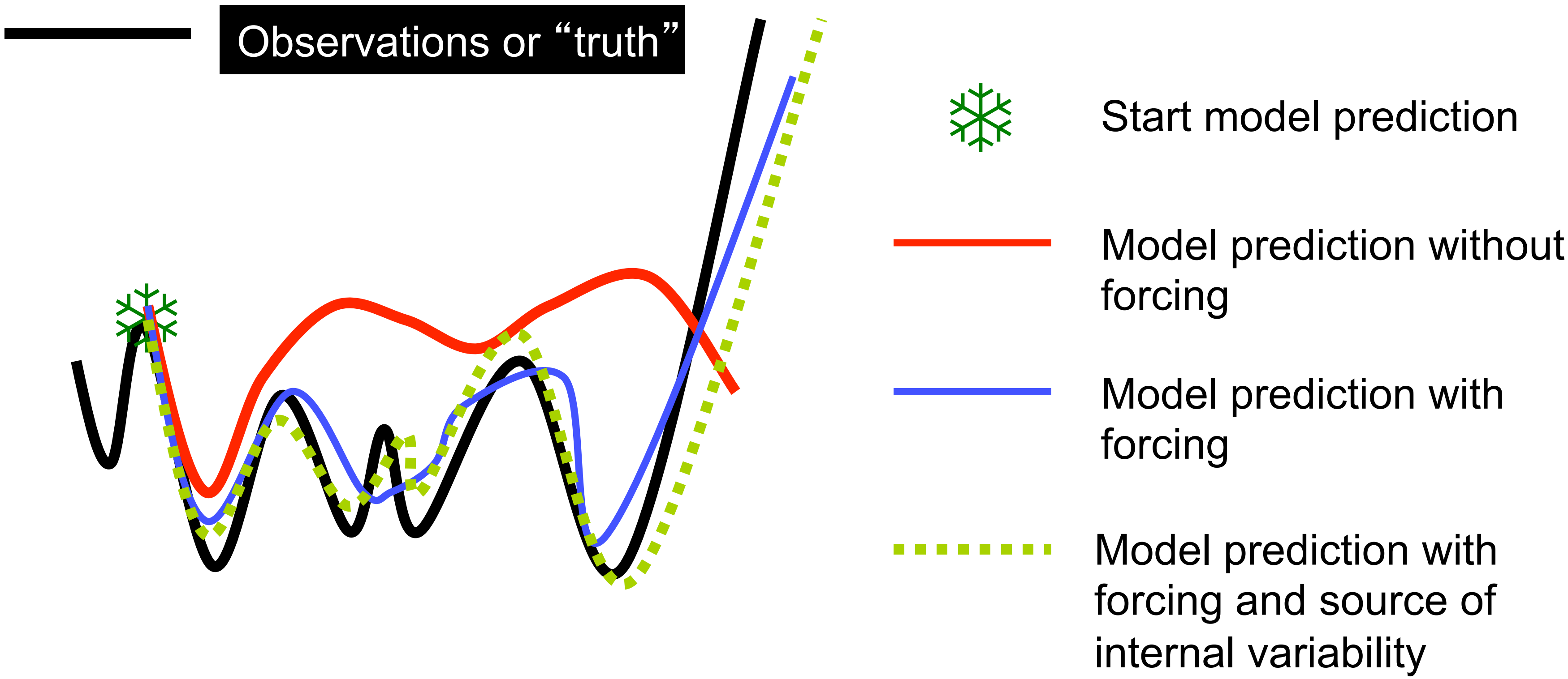
Schematic of a model experiment.

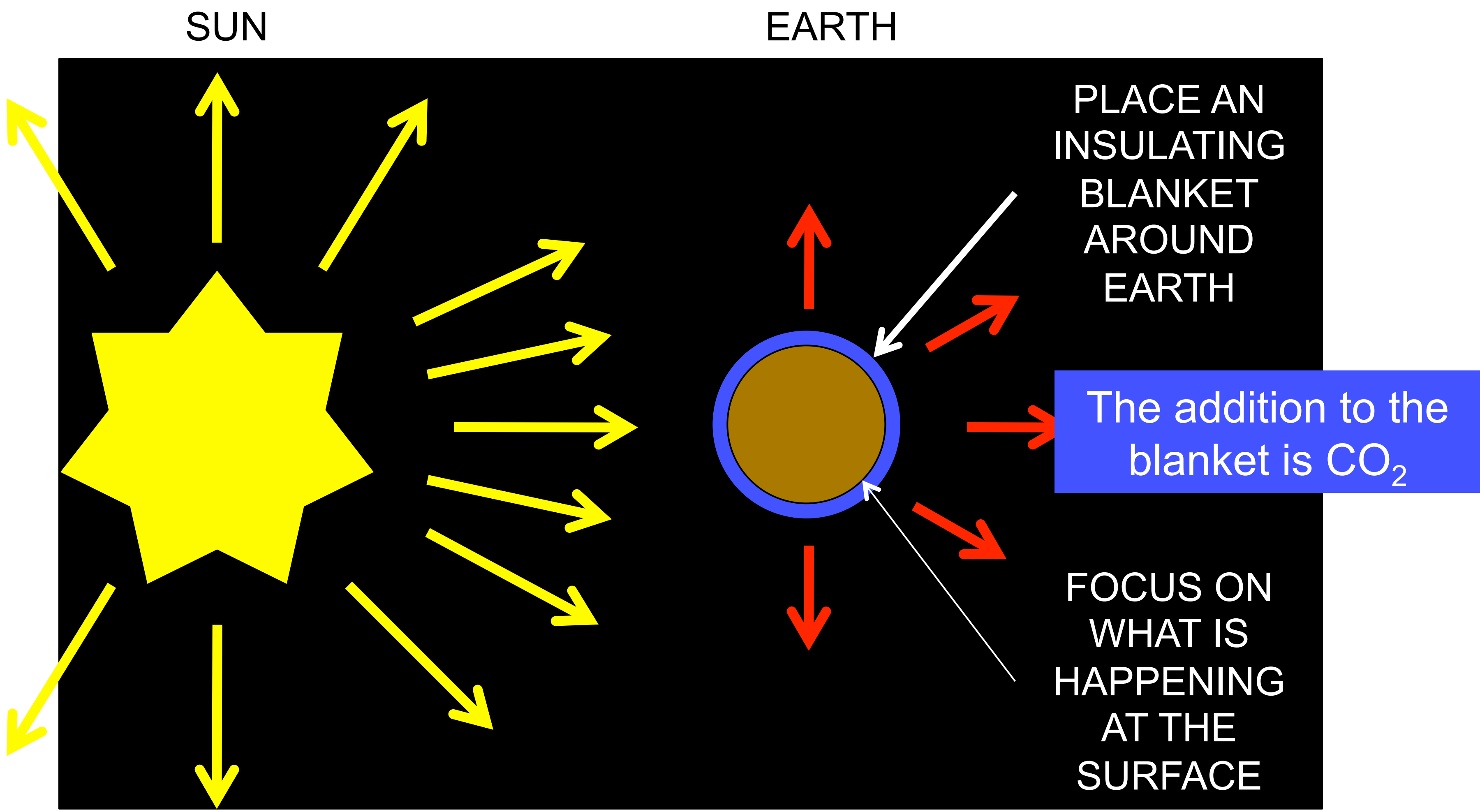


$$\mathbf{E}^{\mathbf{a}}_{t+\Delta t} = \mathbf{E}^{\mathbf{a}}_{t} + \Delta t\big((\boldsymbol{P}^{a} - L^{a}\mathbf{E}^{a}) + (\mathbf{Tr}^{a\leftarrow\rightarrow oil} + \boldsymbol{M}^{a})\big)$$

Today's lecture

- What have we done:
  - Balance
  - Budget
  - Models
    - Demystify models
    - Calculating budgets on a computer

Scientific investigation of Earth's climate



EARTH: EMITS ENERGY TO SPACE → BALANCE

Thinking about these figures and ice ages

- Correlations
- Cause and effect
- Scientific method

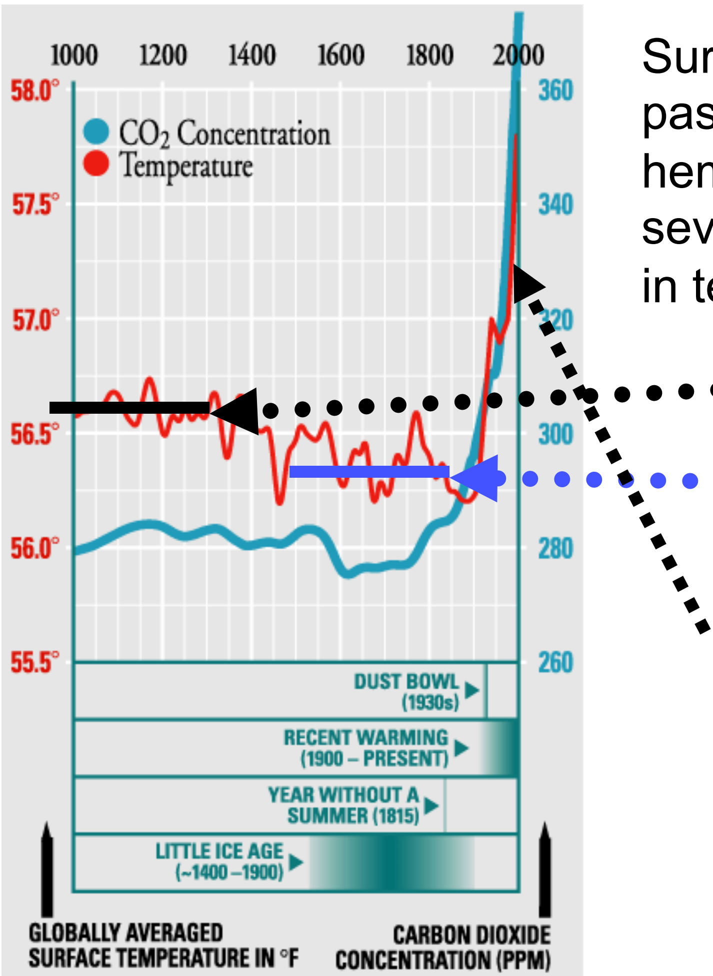
From the Ice Core Data: Questions?

- 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 is different from the stock market, where "past behavior does not indicate future performance?"

Let’s Look at the past 1000 years

- We have more sources of observations.
- We have better observations.
- We have public records and literature and natural history.

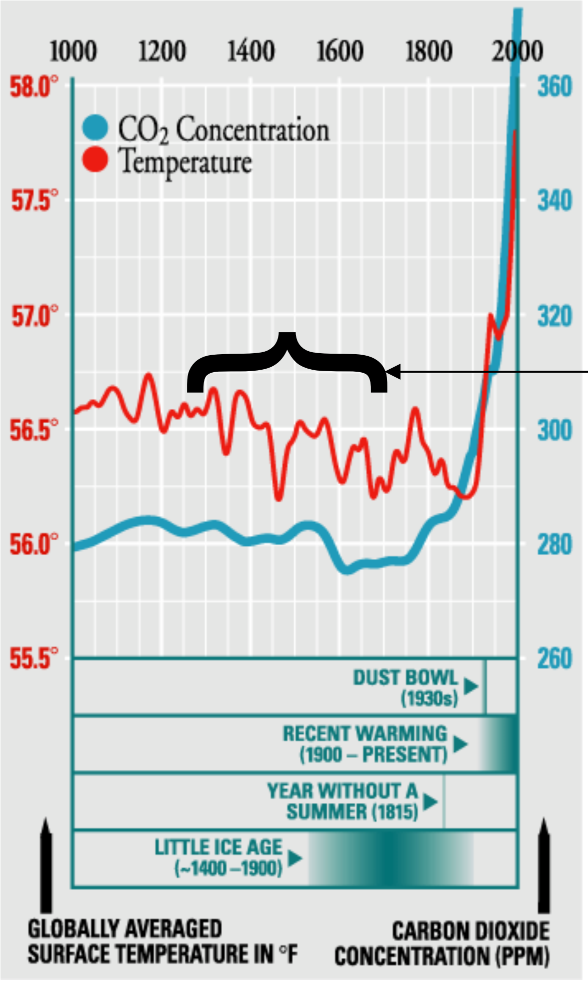
Let' s look at just the last 1000 years



Surface temperature and CO_2 data from the past 1000 years. Temperature is a northern hemisphere average. Temperature from several types of measurements are consistent in temporal behavior.

- ❑ Medieval warm period
- ❑ "Little ice age"
- ❑ Temperature starts to follow CO_2 as CO_2 increases beyond approximately 300 ppm, the value seen in the previous graph as the upper range of variability in the past 350,000 years.

Let's look at just the last 1000 years



Surface temperature and CO_2 data from the past 1000 years. Temperature is a northern hemisphere average. Temperature from several types of measurements are consistent in temporal behavior.

Note that on this scale, with more time resolution, that the fluctuations in temperature and the fluctuations in CO_2 do not match as obviously as in the long, 350,000 year, record.

What is the cause of the temperature variability? Can we identify mechanisms, cause and effect? How?

What do we see from the past 1000 years

- On shorter time scales the CO_2 and T are not as 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 in the past several hundred thousands of years.
  - And the last 10,000 years, which is when humans have thrived in the way that we have thrived.