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

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

LECTURE NUMBER 4
January 23, 2007

# Class News

- There is a ctools site (AOSS 480 001 W07)
  - Lectures have all been added
- Seek good times to make up lectures.
- Some climate stuff
  - The Bar Scene:  Tap Room, Arbor Brewing Company, January 24, 2007
    - Perry Samson and I will perform
      - Reception at 5:30.  Introductions at 6:00.  Ends at 7:30.

# Class News

- Next Reading:  Radiative Balance
  - Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties (2005)
    Board on Atmospheric Sciences and Climate (BASC) Chapter 1
    - http://www.nap.edu/books/0309095069/html

# Catching up

- Did anyone go to the energy symposium?
  - Complexity, Role of Market
  - Wind, Sequestration (forest)
- Anyone hear or read any news they want to come to the front.
- Do you read blogs?
  - Would you like to contribute to a blog?

# Science Basis of Climate Change (1)

# What is science, the scientific method?

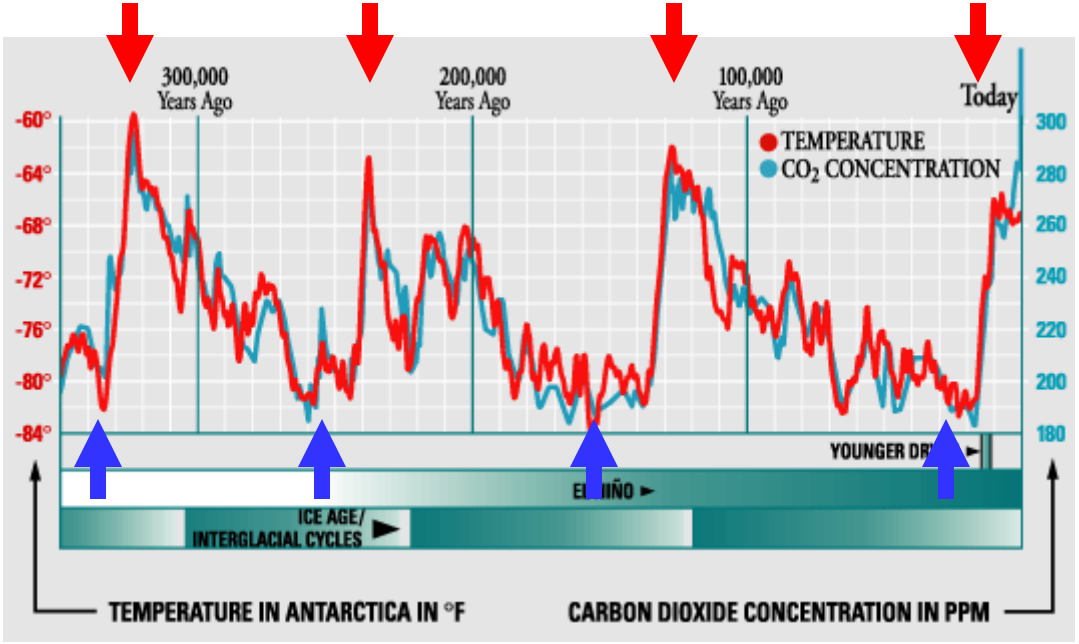
- Elements of the scientific method
  - Observations of some phenomenon.
  - Identification of patterns, relationships and the generation of suppositions, hypotheses.
  - In principle, hypotheses are testable:
    - Experiments: cause and effect
    - Prediction instead of experiments?
  - Development of constructs, theory, which follow from successful hypothesis.
    - Predict behavior, what does the next observation might look like?
  - Development of tests, experiments that challenge the hypotheses and predictions.
    - Validate or refute theory and elements from which the theory is constructed.

# The Basics of Climate Change (Back to the Past)

# 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

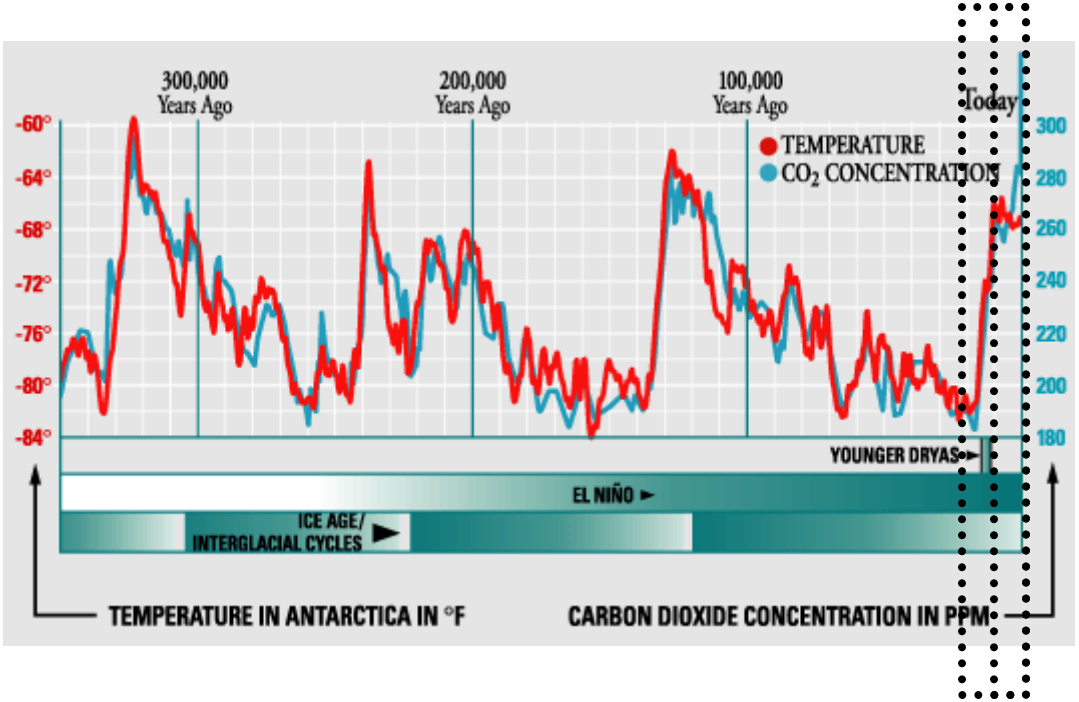
This has been extended back to > 700,000 years




- During this period, temperature and $CO_2$ are closely related to each other
- Times of low temperature have glaciers, ice ages ($CO_2$ <~ 200 ppm)
- Times of high temperature associated with $CO_2$ of < 300 ppm

# 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



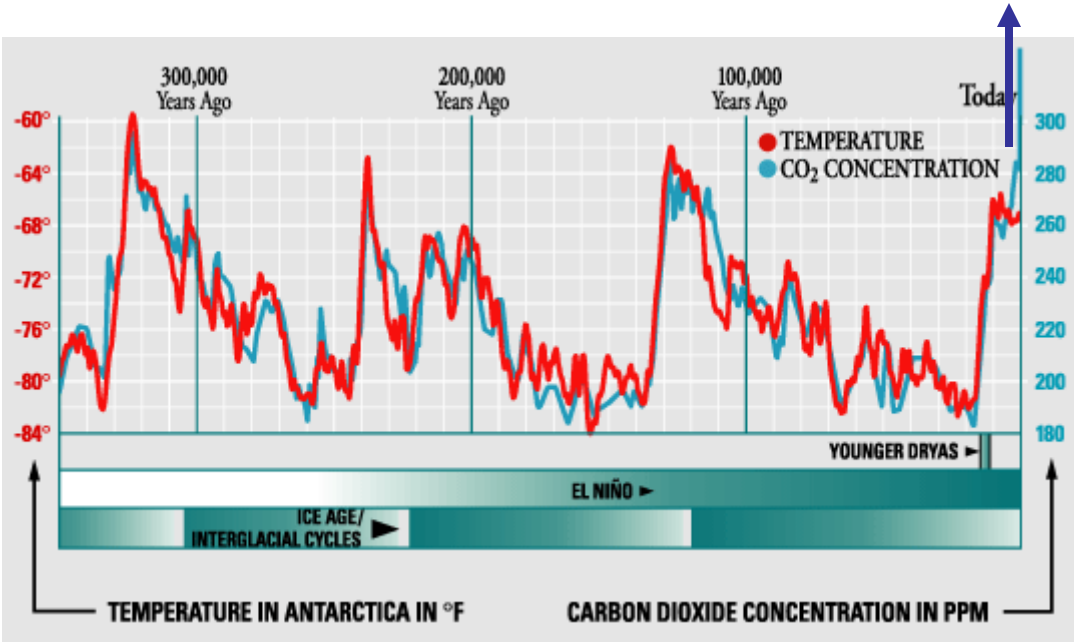

- During this period, temperature and $CO_2$ are closely related to each other
- It's been about 20,000 years since the end of the last ice age
- There has been less than 10,000 years of history "recorded" by humans (and it has been relatively warm)

460 ppm $CO_2$ 2100

# So what are we worried about?

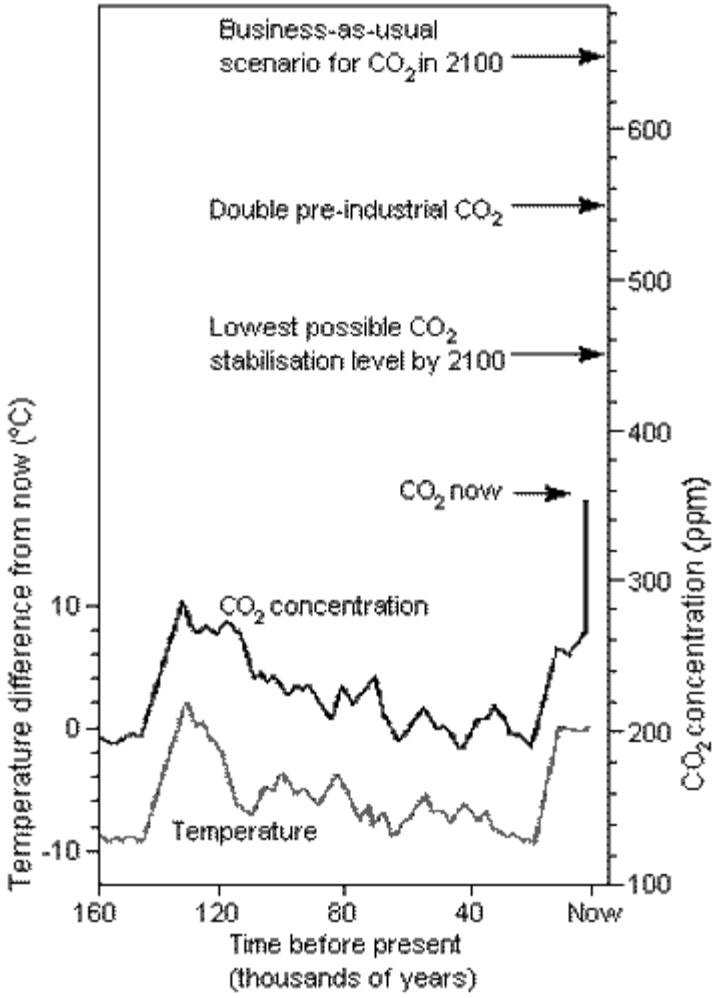
360 ppm $CO_2$ 2005

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?



# New Regimes of Climate Behavior?

**Differences for the Future (100-200 years)**

- ~100 ppm $CO_2$ (Already)
  - > 200-300 ppm $CO_2$ certain
- ~ xx C polar T difference
- ~ xx C global average T difference

NEW AGE?

CURRENT (Temperate)

ICE AGE

Behavior of water; Phase change

**Differences from Past (20,000 years)**

- ✓ ~100 ppm $CO_2$
- ✓ ~ 20 C polar T difference
- ✓ ~ 5 C global average T difference

***Time gradient of $CO_2$ changes, 2 orders of magnitude (100 times) larger.***

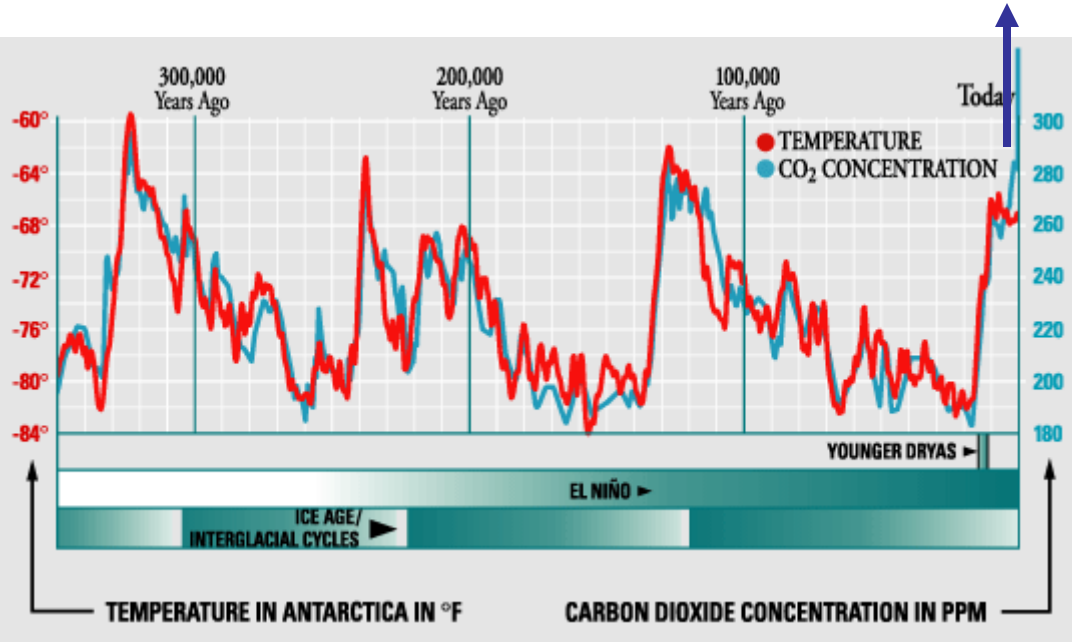
# From the Ice Core Data: Questions

460 ppm $CO_2$ 2100

# So what are we worried about?

360 ppm $CO_2$ 2005

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




➢ If the normal pattern were to continue, without additional carbon dioxide, what would we expect?

# Is this reasonable?

- Should we try to manage the $CO_2$ to prevent the next ice age?
- What of the argument that the Earth will naturally cool and take care of itself?

# Global cooling?

Why do we think that our predictions today are more robust than these predictions from the 1970s?

SCIENCE

## The Cooling World

There are ominous signs that the earth's weather patterns have begun to change dramatically and that these changes may portend a drastic decline in food production—with serious political implications for just about every nation on earth. The drop in food output could begin quite soon, perhaps only ten years from now. The regions destined to feel its impact are the great wheat-producing lands of Canada and the U.S.S.R. in the north, along with a number of marginally self-sufficient tropical areas—parts of India, Pakistan, Bangladesh, Indochina and Indonesia—where the growing season is dependent upon the rains brought by the monsoon.

The evidence in support of these predictions has now begun to accumulate so massively that meteorologists are hard-pressed to keep up with it. In England, farmers have seen their growing season decline by about two weeks since 1950, with a resultant over-all loss in grain production estimated at up to 100,000 tons annually. During the same time, the average temperature around the equator has risen by a fraction of a degree—a fraction that in some areas can mean drought and desolation. Last April, in the most devastating outbreak of tornadoes ever recorded, 148 twisters killed more than 300 people and caused half a billion dollars' worth of damage in thirteen U.S. states.

**Trend:** To scientists, these seemingly disparate incidents represent the advance signs of fundamental changes in the world's weather. The central fact is that after three quarters of a century of extraordinarily mild conditions, the earth's climate seems to be cooling down. Meteorologists disagree about the cause and extent of the cooling trend, as well as over its specific impact on local weather conditions. But they are almost unanimous in the view that the trend will reduce agricultural productivity for the rest of the century. If the climatic change is as profound as some of the pessimists fear, the resulting famines could be catastrophic. "A major climatic change would force economic and social adjustments on a worldwide scale," warns a recent report by the National Academy of Sciences, "because the global patterns of food production and population that have evolved are implicitly dependent on the climate of the present century."

A survey completed last year by Dr. Murray Mitchell of the National Oceanic and Atmospheric Administration reveals a drop of half a degree in average ground temperatures in the Northern Hemisphere between 1945 and 1968. According to George Kukla of Columbia University, satellite photos indicated a sudden, large increase in Northern Hemisphere snow cover in the winter of 1971-72. And a study released last month by two NOAA scientists notes that the amount of sunshine reaching the ground in the continental U.S. diminished by 1.3 per cent between 1964 and 1972.

To the layman, the relatively small changes in temperature and sunshine can be highly misleading. Reid Bryson of the University of Wisconsin points out that the earth's average temperature during the great Ice Ages was only about 7 degrees lower than during its warmest eras—and that the present decline has taken the planet about a sixth of the way toward the Ice Age average. Others regard the cooling as a reversion to the "little ice age" conditions that brought bitter winters to much of Europe and northern America between 1600 and 1900—years when the Thames used to freeze so solidly that Londoners roasted oxen on the ice and when iceboats sailed the Hudson River almost as far south as New York City.

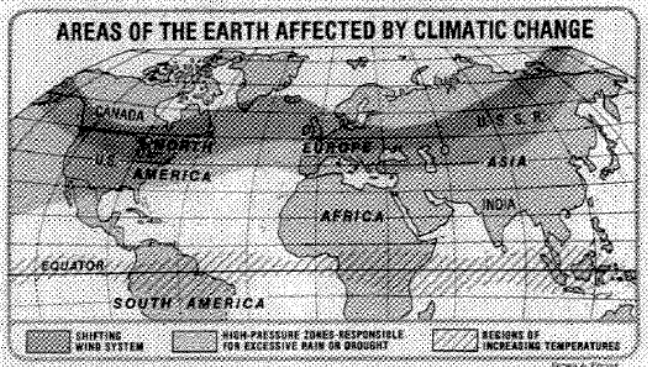
Just what causes the onset of major and minor ice ages remains a mystery. "Our knowledge of the mechanisms of climatic change is at least as fragmentary as our data," concedes the National Academy of Sciences report. "Not only are the basic scientific questions largely unanswered, but in many cases we do not yet know enough to pose the key questions."

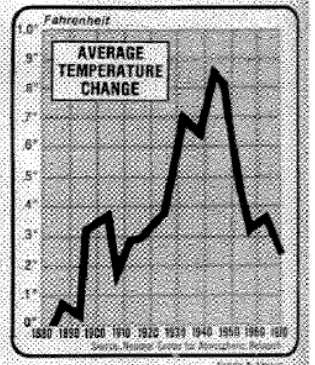
**Extremes:** Meteorologists think that they can forecast the short-term results of the return to the norm of the last century. They begin by noting the slight drop in over-all temperature that produces large numbers of pressure centers in the upper atmosphere. These break up the smooth flow of westerly winds over temperate areas. The stagnant air produced in this way causes an increase in extremes of local weather such as droughts, floods, extended dry spells, long freezes, delayed monsoons and even local temperature increases—all of which have a direct impact on food supplies.

"The world's food-producing system," warns Dr. James D. McQuigg of NOAA's Center for Climatic and Environmental Assessment, "is much more sensitive to the weather variable than it was even five years ago." Furthermore, the growth of world population and creation of new national boundaries make it impossible for starving peoples to migrate from their devastated fields, as they did during past famines.

Climatologists are pessimistic that political leaders will take any positive action to compensate for the climatic change, or even to allay its effects. They concede that some of the more spectacular solutions proposed, such as melting the arctic ice cap by covering it with black soot or diverting arctic rivers, might create problems far greater than those they solve. But the scientists see few signs that government leaders anywhere are even prepared to take the simple measures of stockpiling food or of introducing the variables of climatic uncertainty into economic projections of future food supplies. The longer the planners delay, the more difficult will they find it to cope with climatic change once the results become grim reality.

—PETER GWYNNE with bureau reports

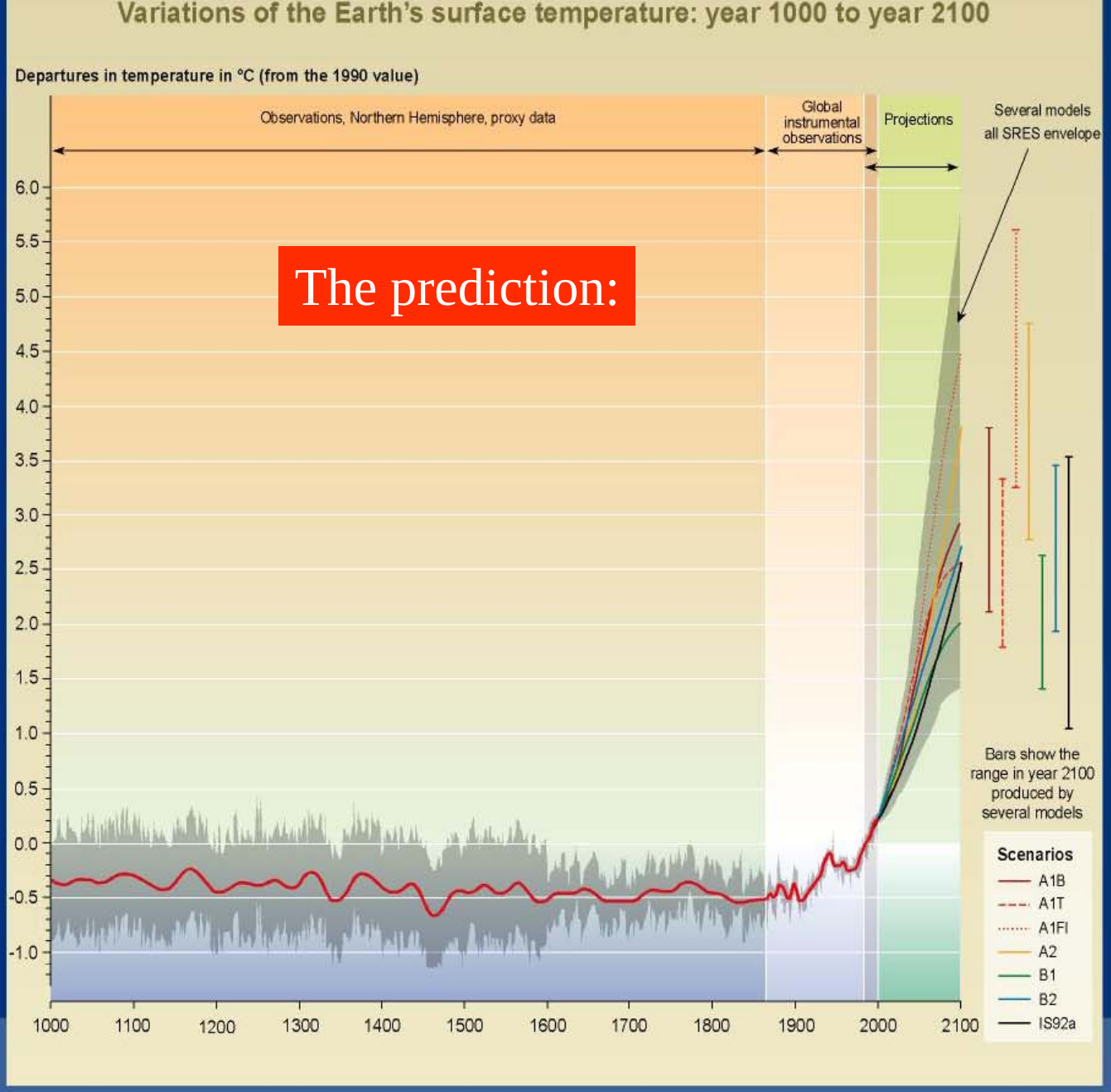


# What about consistency?

- We already have seen the IPCC predictions.

Basic physics of temperature increase is very simple, non-controversial.

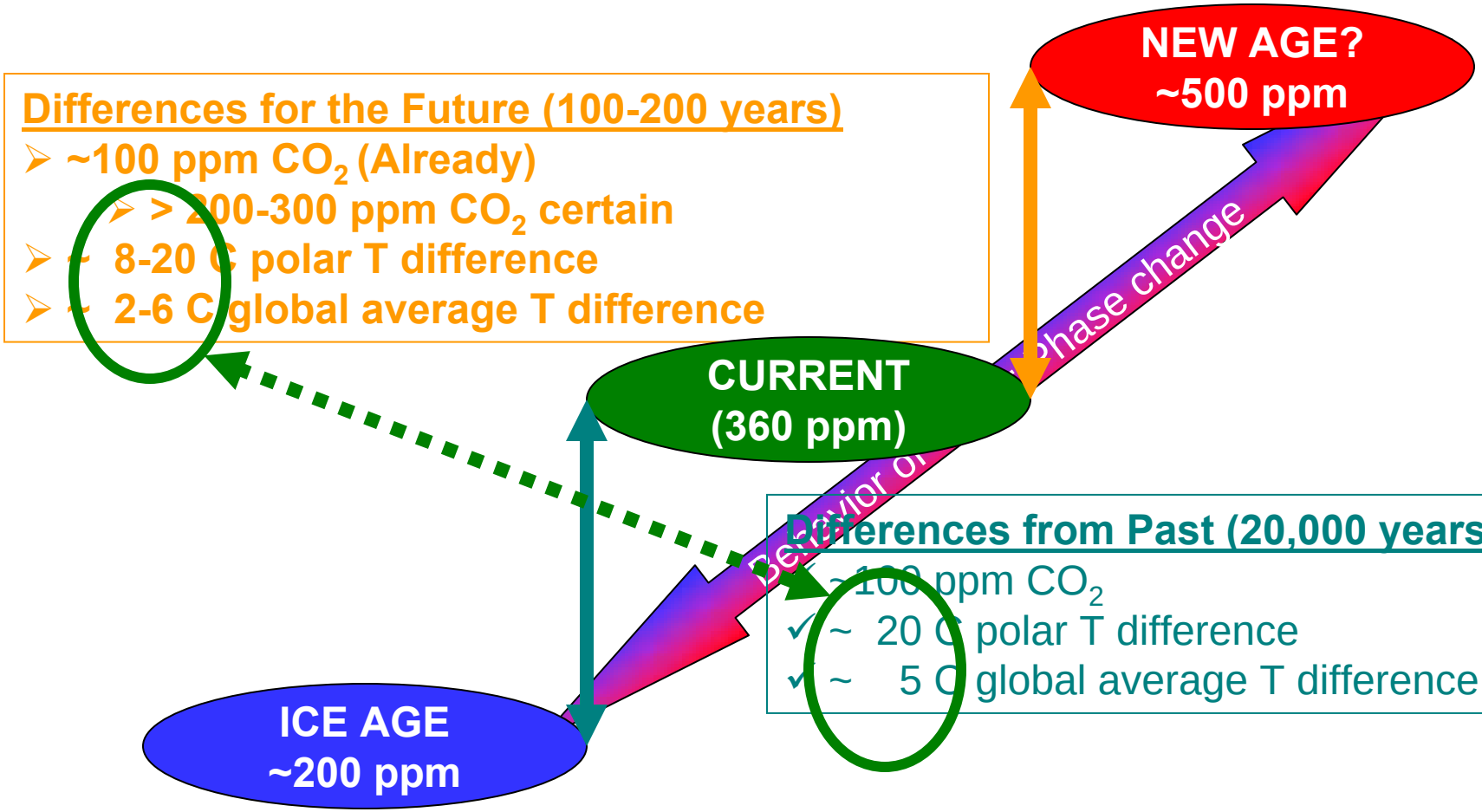



SYR - FIGURE 9-1b

Note: There i consistency from many models, man scenarios, that there wil be warming. (1.5 – 5.5 C)

Also, it's still going up in 2100!

# These numbers are in reasonable relation.




*Time gradient of $CO_2$ changes, 2 orders of magnitude (100 times) larger.*

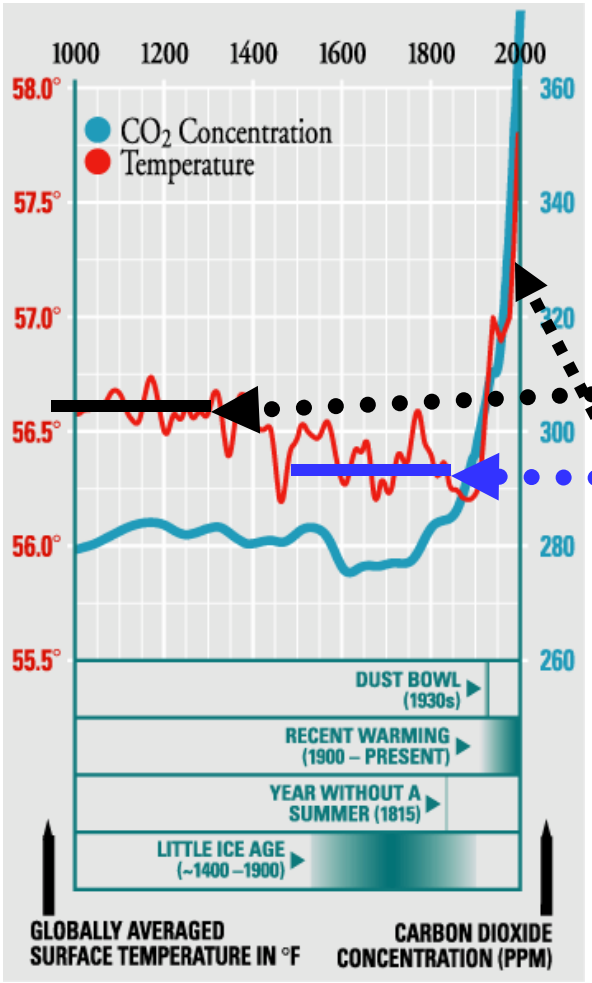
# From the Ice Core Data: Questions?

- 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.

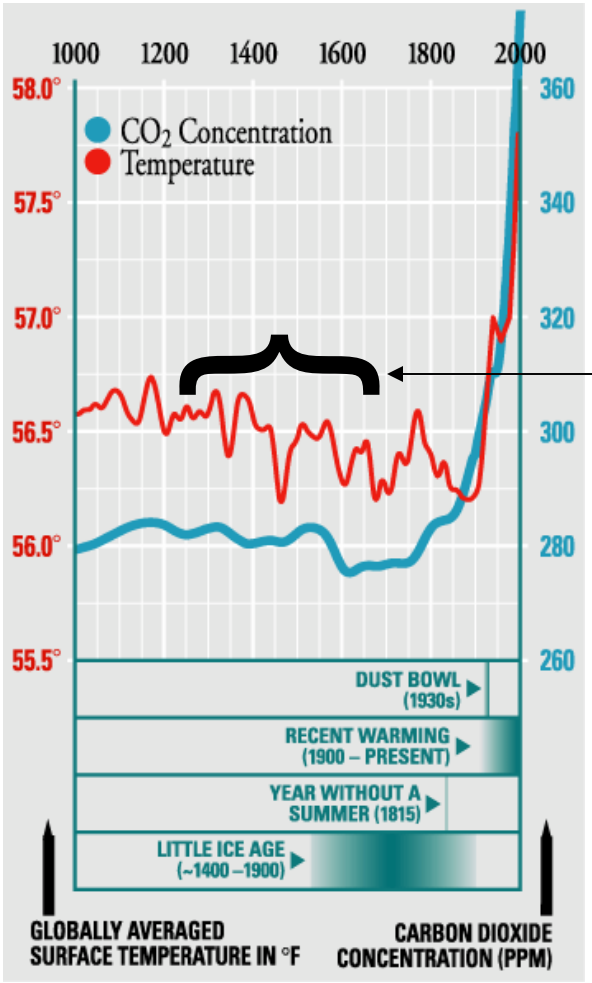
# Let's look at just the last 1000 years




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 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.

# How do we develop the hypotheses and theories to investigate these phenomena?

# 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 (continuity) 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 tomorrow is the same as the money we had yesterday.

$$\mathbf{M}_{\text{tomorrow}} = \mathbf{M}_{\text{yesterday}}$$

***That's not very interesting.***

# Conservation (continuity) principle

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

Living in splendid isolation

# Conservation (continuity) principle

**I**ncome

$$\mathbf{M}_{tomorrow} = \mathbf{M}_{yesterday} + \mathbf{I} - \mathbf{E}$$

Let's get some money and buy stuff.

**E**xpense

***This is not so satisfying either.***

# Conservation (continuity) principle

**I**ncome

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

And let's get a car
Expense per month = *E*
Get a job
Income per month = *I*
*N = number of months*
**I** = *NxI and* **E**= *NxE*

**E**xpense

# Some algebra and some thinking

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

Rewrite the equation to represent the difference in money

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

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.

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

# Some algebra and some thinking

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

If difference does NOT change with time, then

$$I = E$$

*Income equals Expense*

With a balanced budget, how much we spend, *E*, is related to how much we have:

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

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

# Some algebra and some thinking

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

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

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

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

**If Δ ≡ difference operator,**
**then, for example,** $N$ = *(February – January)* ≡ **Δt (time)**

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

# Conservation Principle

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

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

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

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

# 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.

# 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.

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

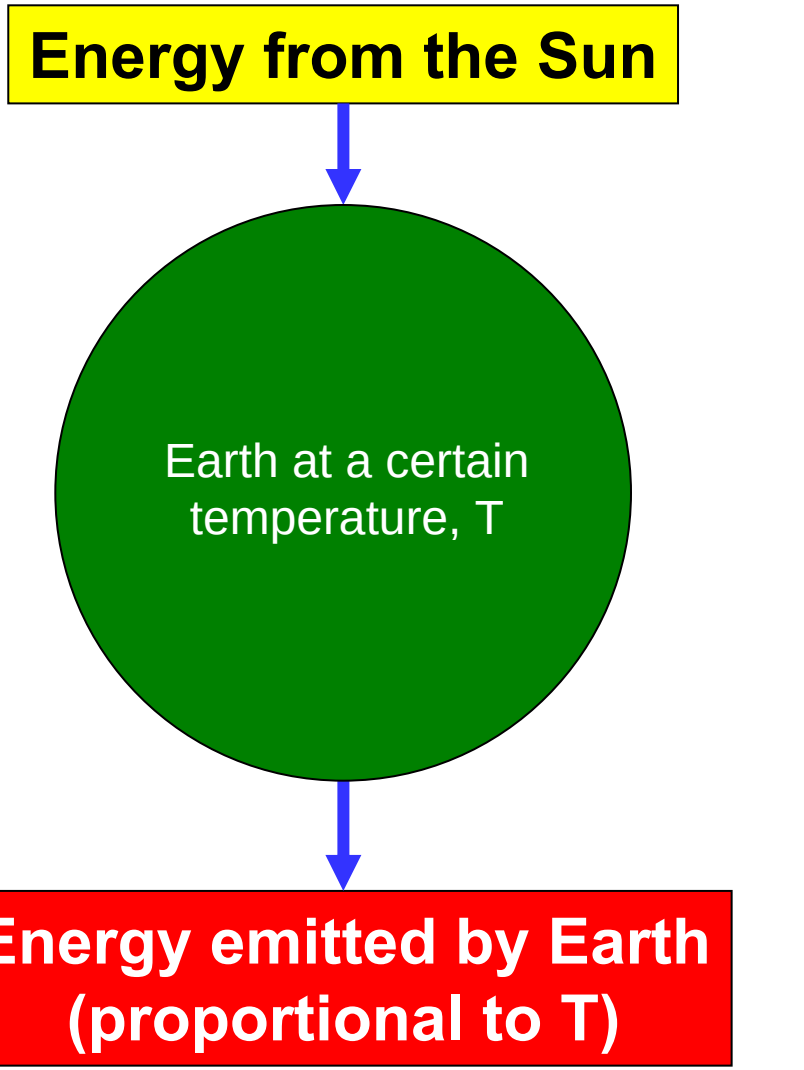
$$\text{Production} = \text{Loss}$$

# Two concepts

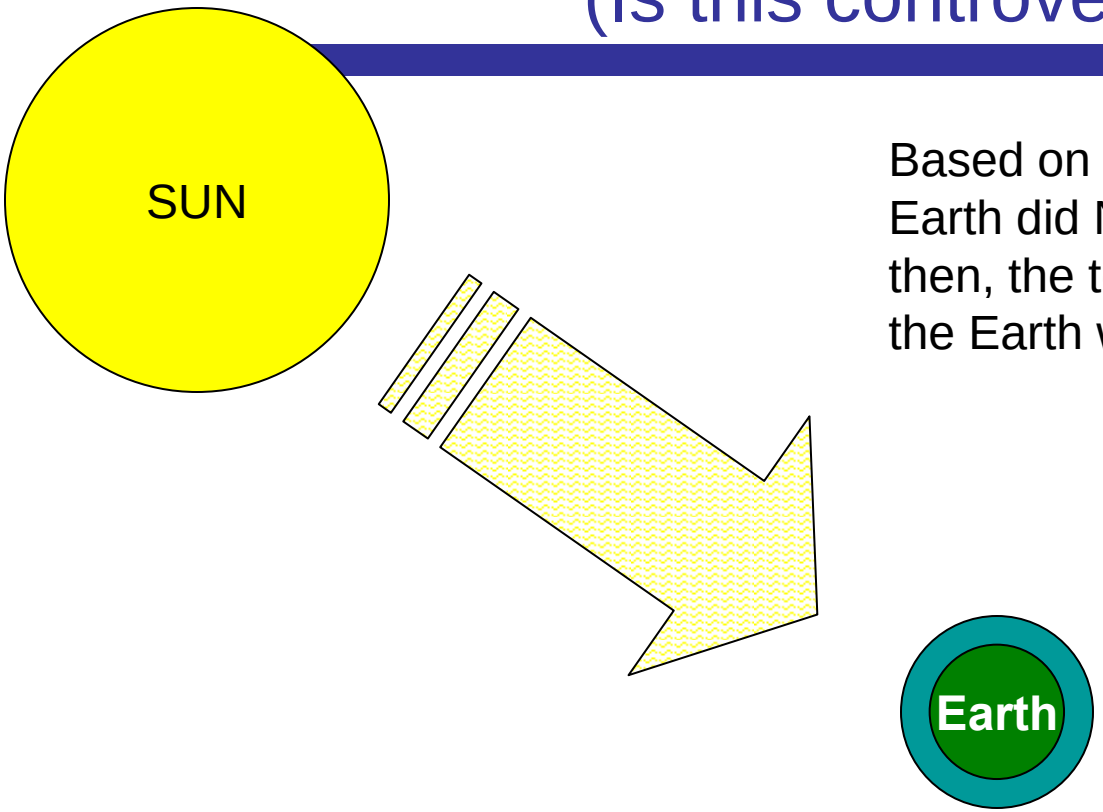
- First, the expression of the conservation principle as an equation is a model.
- Second, in the good practice of science one of the first things to do is to draw a picture.

# Earth's Energy Conservation

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



# 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).

**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. (will revisit this)**

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

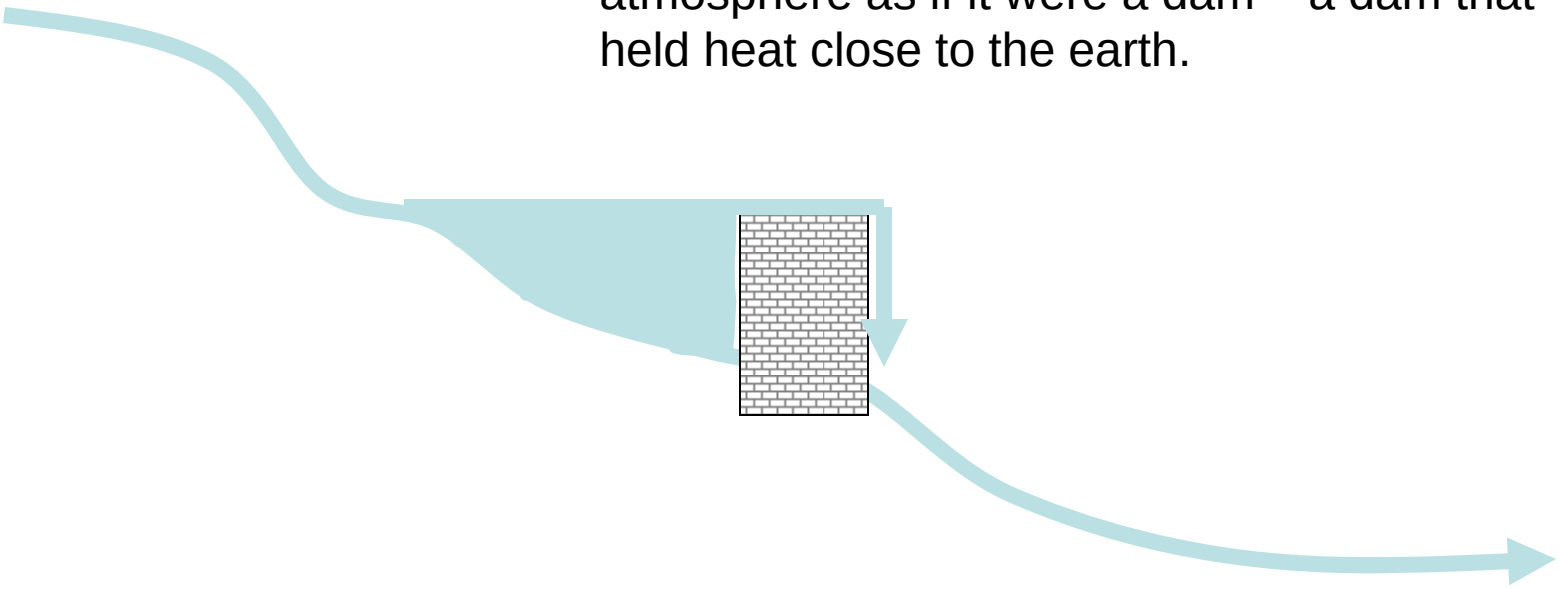
***This greenhouse effect in not controversial.***

# Some history.

- The greenhouse effect, that the surface was warmer than it “should be,” was recognized in the early 1800s.
- Recognized over the course of the 1800s that water and carbon dioxide were important greenhouse gases.
- In 1896, Arrhenius, trying to explain the ice ages, speculated that $CO_2$ changes were important. Also made a speculative calculation of what would happen if $CO_2$ was doubled. (estimated ~ 6 C warming)

# Thinking about the greenhouse effect

Early on, 1820, scientists thought about the atmosphere as if it were a dam – a dam that held heat close to the earth.

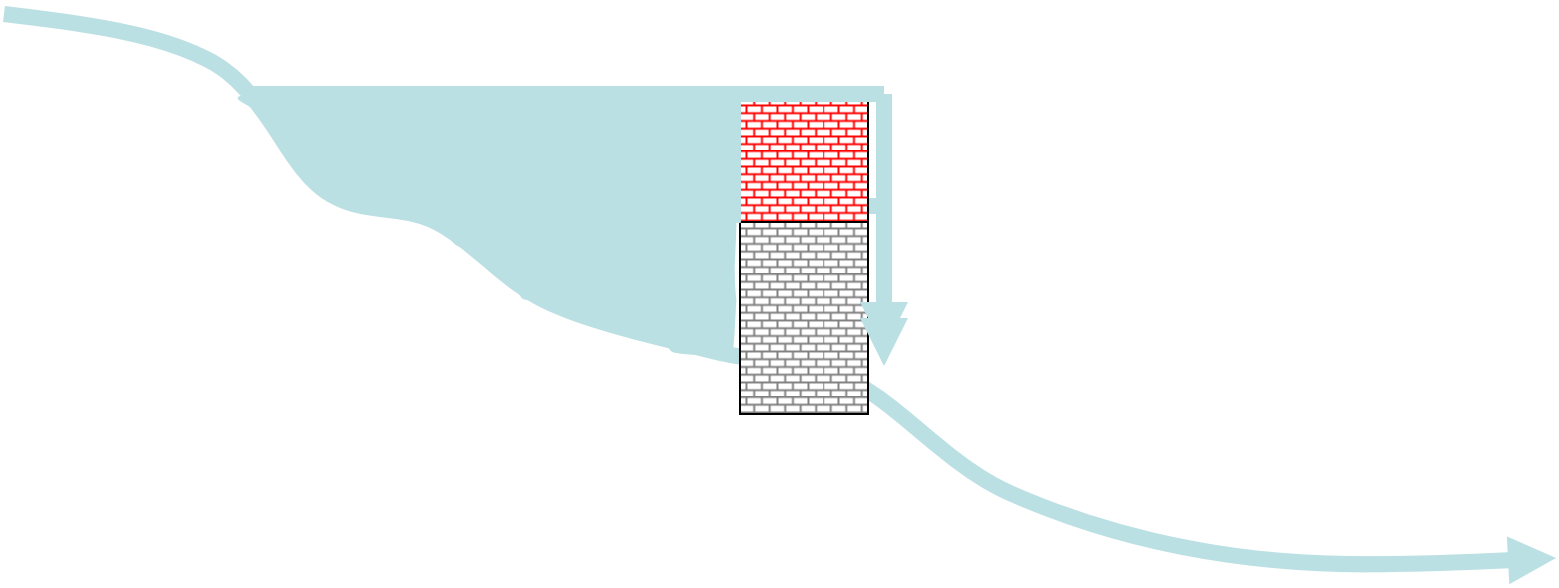


# A little more history

- In the 1940's and 1950's a British combustion scientist, Callendar, realized that enough $CO_2$ could come from combustion to increase the atmospheric concentration substantially.
- In the early 1960's a Soviet scientist, Budyko, made the first statements that use of fossil fuels by humans would ultimately lead to generalized warming of the planet. He developed a simple, but useful model, to estimate changes in latitude bands.
  - Followed from considering a number of ambitious plans in the Soviet Union to make the country warmer and wetter.
  - Viewed that, in the short term, melting of Arctic ice would be a good thing … imagine the trading opportunities … would make the Northwest Passage!

# Thinking about global warming

In the 1960's the notion of man-made global warming was brought into the general thinking of people who studied the climate.

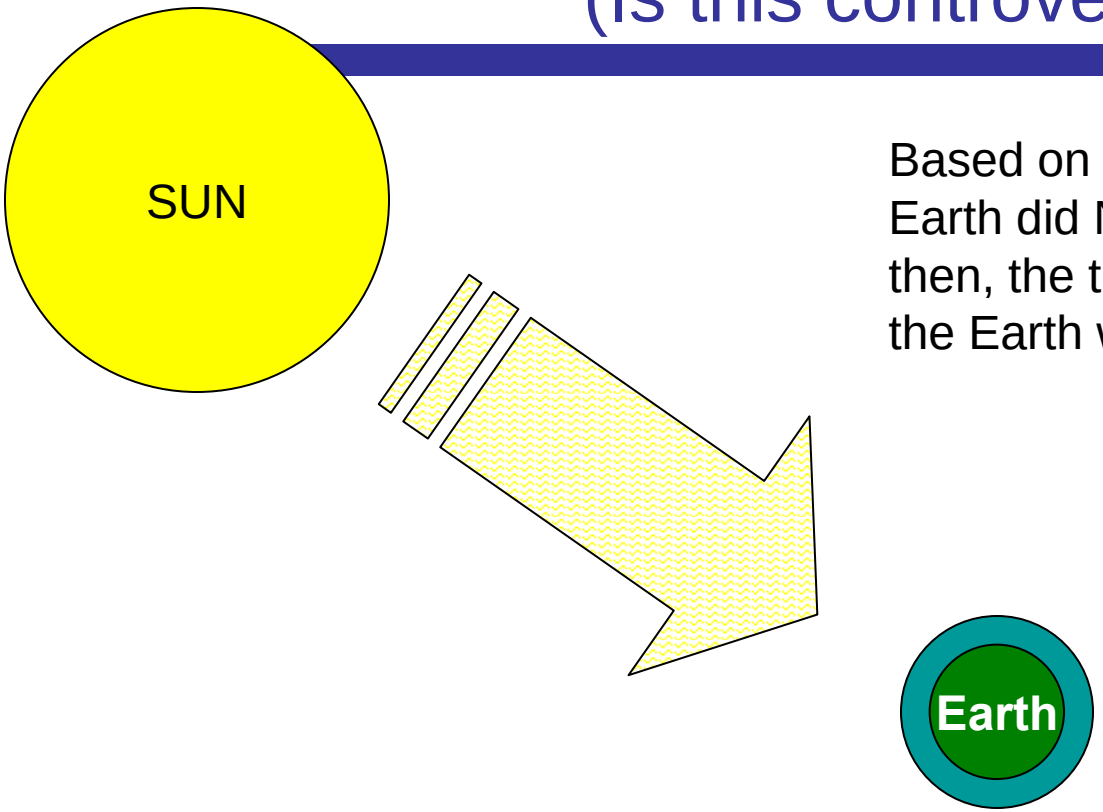


***Until early 1970's there were serious papers about being on the edge of an ice age!***

# Models Again

- This idea of the greenhouse gases as a dam is also a model – a heuristic model. Conceptually strong, but perhaps weak in its quantitative potential.
- Other heuristic models
  - Car sitting in the sun
  - Person in bed under the blankets

# The Greenhouse Effect (Is this controversial?)



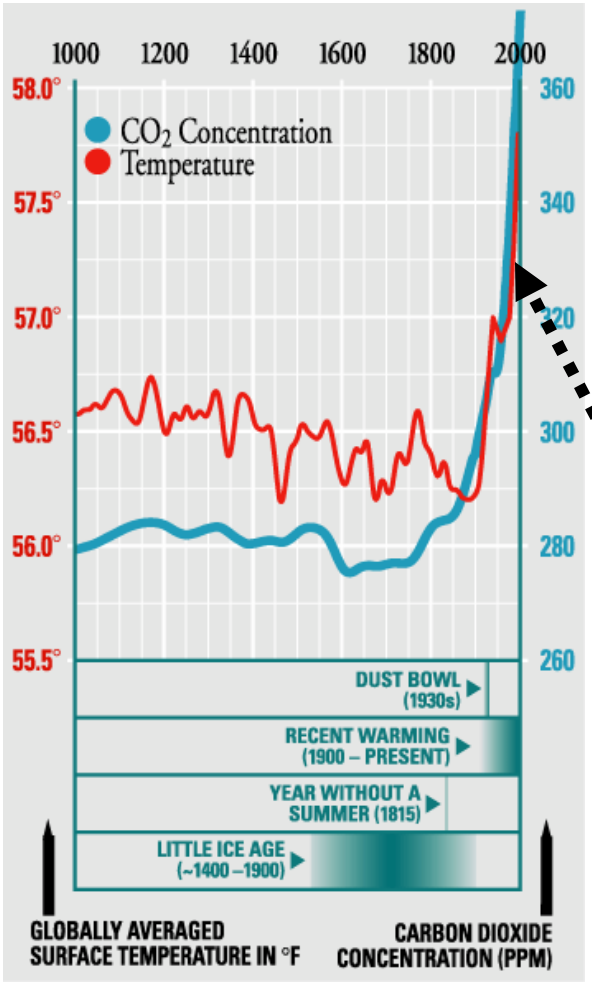

Based on conservation of energy: If the Earth did NOT have an atmosphere, then, the temperature at the surface of the Earth would be about -18 C ( ~ 0 F).

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."**

# 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.

- Addition of CO2 to the atmosphere alters the loss rate in the conservation equation. It will change the vertical redistribution of energy in the atmosphere. Surface, lower atmosphere will be warmer. Upper atmosphere will be cooler.

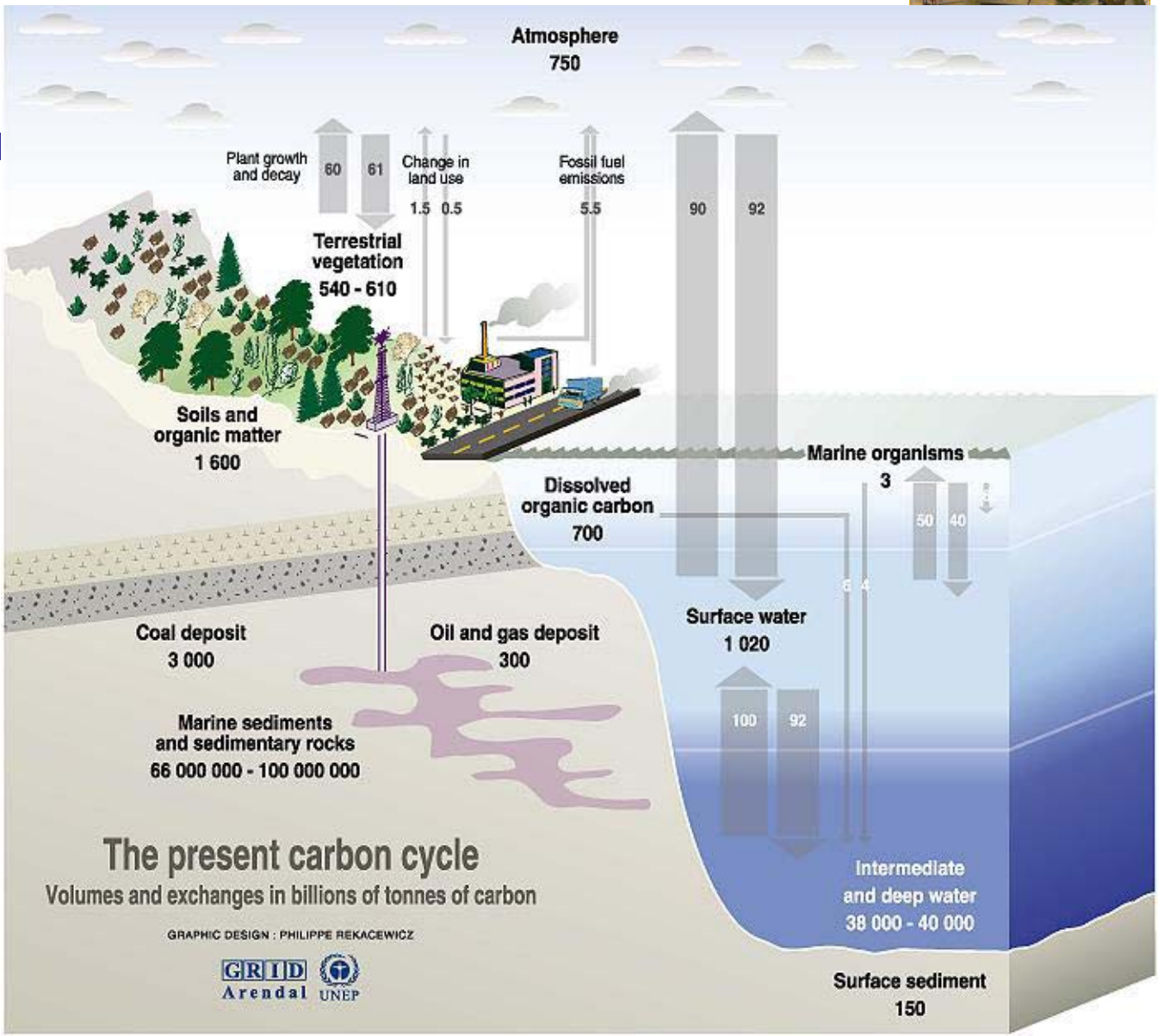
# Still there are many unanswered questions

- 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.

# Class News

- There is a ctools site (AOSS 480 001 W07)
  - Lectures have all been added
- Seek good times to make up lectures.
- Some climate stuff
  - The Bar Scene:  Tap Room, Arbor Brewing Company, January 24, 2007
    - Perry Samson and I will perform
      - Reception at 5:30.  Introductions at 6:00.  Ends at 7:30.

# Class News

- Next Reading:  Radiative Balance
  - Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties (2005)
    Board on Atmospheric Sciences and Climate (BASC) Chapter 1
    - http://www.nap.edu/books/0309095069/html