2005 Warmest Year on Record

The year 2005 was the warmest year in over a century, according to NASA scientists studying temperature data from around the world. Climatologists at NASA's Goddard Institute for Space Studies (GISS) in New York City noted that the highest global annual average surface temperature in more than a century was recorded in their analysis for the 2005 calendar year. Some other research groups that study climate change rank 2005 as the second warmest year, based on comparisons through November. The primary difference among the analyses, according to the NASA scientists, is the inclusion of the Arctic in the NASA analysis. Although there are few weather stations in the Arctic, the available data indicate that 2005 was unusually warm in the Arctic.

In order to figure out whether the Earth is cooling or warming, the scientists use temperature data from weather stations on land, satellite measurements of sea surface temperature since 1982, and data from ships for earlier years.

Image to right: 2005 was the warmest year since the late 1800s, according to NASA scientists. 1998, 2002 and 2003 and 2004 followed as the next four warmest years. Credit: NASA

Previously, the warmest year of the century was 1998, when a strong El Nino, a warm water event in the eastern Pacific Ocean, added warmth to global temperatures. However, what's significant, regardless of whether 2005 is first or second warmest, is that global warmth has returned to about the level of 1998 without the help of an El Nino.

The result indicates that a strong underlying warming trend is continuing. Global warming since the middle 1970s is now about 0.6 degrees Celsius (C) or about 1 degree Fahrenheit (F). Total warming in the past century is about 0.8° C or about 1.4° F.

"The five warmest years over the last century occurred in the last eight years," said James Hansen, director of NASA GISS. They stack up as follows: the warmest was 2005, then 1998, 2002, 2003 and 2004.

Over the past 30 years, the Earth has warmed by 0.6° C or 1.08° F. Over the past 100 years, it has warmed by 0.8° C or 1.44° F. Current warmth seems to be occurring nearly everywhere at the same time and is largest at high latitudes in the Northern Hemisphere. Over the last 50 years, the largest annual and seasonal warmings have occurred in Alaska, Siberia and the Antarctic Peninsula. Most ocean areas have warmed. Because these areas are remote and far away from major cities, it is clear to climatologists that the warming is not due to the influence of pollution from urban areas.
The Carbon Cycle (part 2)

Sean Davis
Which best describes the biological pump?

b. Respiration vs. Methanogenesis

c. Photosynthesis vs. oxygen production

d. A push up

e. Settling vs. upwelling
...From last time

- Carbon Cycle Overview
- Concepts: reservoirs, steady state, response/residence time
- Land/Atmosphere Cycle
  - Photosynthesis vs. respiration/decomposition
- Marine Cycle - the biological pump
  - Photosynthesis vs. respiration/decomposition
  - Settling vs. Upwelling
Processes: Photosynthesis
Fossil-fuel production
Oxygen production

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

Surface ocean

Upwelling of nutrients

Settling of organic matter

Processes: Decomposition
Nutrient release
Oxygen consumption

\[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

Deep ocean

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Redfield Ratios

• Named after Alfred C. Redfield
• Findings
  – Carbon:Nitrogen:Phosphorous ratio
  – 106:16:1
  – Same in plankton and seawater
  – Nutrient composition of seawater determined by production and decomposition of organic matter (plankton)
The picture so far...

- Going to talk about arrow going into/out of sedimentary rocks (both organic and inorganic)
Organic Carbon Burial

- Organic carbon – leak from short-term cycle
- Leak maintains $O_2$ content in atmosphere
- Atmospheric $O_2$ lost to reduced materials (rocks, volcanic gasses)
- $O_2$ depleted in $10^6$ years w/o new supply
Atmospheric O₂ Balance

**Photosynthesis**
\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2 \]

**Respiration**
\[ \text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

**Decomposition**
\[ 2\text{CH}_2\text{O} \rightarrow \text{CO}_2 + \text{CH}_4 \]
\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \text{ (in atmosphere)} \]
Atmospheric $O_2$ Balance

**Photosynthesis**

$$CO_2 + H_2O \rightarrow CH_2O + O_2$$

**Respiration**

$$CH_2O + O_2 \rightarrow CO_2 + H_2O$$

**Decomposition**

$$2CH_2O \rightarrow CO_2 + CH_4$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$ (in atmosphere)

"Eaten" by Rocks, Volcanic Gas
Atmospheric $O_2$ Balance

**Photosynthesis**
$CO_2 + H_2O \rightarrow CH_2O + O_2$

**Sedimentation of organic carbon**

**Respiration**
$CH_2O + O_2 \rightarrow CO_2 + H_2O$

**Decomposition**
$2CH_2O \rightarrow CO_2 + CH_4$

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (in atmosphere)

"Eaten" by Rocks, Volcanic Gas
Organic Carbon Burial

- Burial products...
  - Coal - terrestrial matter
  - Petroleum – marine sediments
  - Shales
- Eventually, materials are uplifted and oxidized
  - Respiration
  \[ CH_3O + O_2 \rightarrow CO_2 + H_2O \]
- Fossil fuel consumption is acceleration of this process by at least a million times
The Inorganic Carbon Cycle

- Diffusion of CO$_2$ between ocean and atmosphere
- Uptake/cycling of carbon by sedimentary rocks
Ocean/Atmosphere Carbon Exchange

- CO₂ diffuses from high to low concentration ("down the concentration gradient")
- CO₂ is soluble in water (or soda, or beer)
- Water holds more CO₂ at low temperature
- Upwelling brings high CO₂ water to surface
Group Question

Which one of these is a positive feedback?

a. Increase atmospheric CO$_2$, increase gradient between atmosphere and ocean
b. Increase CO$_2$, increase temperature, reduce solubility of CO$_2$

c. Increase CO$_2$, increase temperature, increase glacial melting in Greenland, decrease ocean circulation, reduce upwelling
Which one of these is a positive feedback?

a. Increase atmospheric CO\(_2\), increase gradient between atmosphere and ocean

b. Increase CO\(_2\), increase temperature, reduce solubility of CO\(_2\)

c. Increase CO\(_2\), increase temperature, increase glacial melting in Greenland, decrease ocean circulation, reduce upwelling
Ocean/Atmosphere Carbon Exchange

• Implications:
  – Increase atmospheric $\text{CO}_2 \rightarrow$ ocean becomes sink
  – Power of sink limited...
Chemistry of Inorganic Carbon in Water

- CO$_2$ dissolves in water:
  \[ \text{CO}_2 + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_3 \]

- Reaction goes both ways to make equilibrium!

- Carbonic Acid can *dissociate* into ions
  \[ \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \]

- Bicarbonate can further dissociate
  \[ \text{HCO}_3^- \leftrightarrow \text{H}^+ + \text{CO}_3^{2-} \]
Aside: The pH scale

- Concentration of $H^+$ determines pH
- Lower pH $\rightarrow$ more acidic
- Higher pH $\rightarrow$ more basic
- pH = 7 $\rightarrow$ neutral (distilled water)
- Scale is logarithmic
- pH of 2 has 10 times as much $H^+$ as pH 3
Inorganic Carbon Cycle

• What happens to ocean w/ more atmospheric CO$_2$?
  – More dissolved CO$_2$ $\rightarrow$ more acidic

  \[ \text{CO}_2 + \text{H}_2 \text{O} \leftrightarrow \text{H}_2\text{CO}_3 \]

  \[ \text{H}_2\text{CO}_3 \leftrightarrow \text{H}^+ + \text{HCO}_3^- \]

  – More acidic $\rightarrow$ less carbonate

  \[ \text{H}^+ + \text{CO}_3^{2-} \leftrightarrow \text{HCO}_3^- \]

\textbf{Total:} \hfill \text{CO}_2 + \text{CO}_3^- + \text{H}_2\text{O} \leftrightarrow 2\text{HCO}_3^-

So, more CO$_2$ $\rightarrow$ more uptake of CO$_2$

However, uptake limited by carbonate amounts!

Less carbonate in ocean than fossil fuels $\rightarrow$ uptake is limited
Chemical Weathering

- Rocks slowly ‘dissolve’ from (slightly acidic) rain
- Two basic types of rock weathering:
  - Carbonate
  - Silicate
Carbonate Weathering

• Rain + Rocks
  \[ \text{CaCO}_3 + \text{H}_2\text{CO}_3 \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- \]

• Products transported to rivers, eventually to ocean

• In ocean, organisms create shells:
  \[ \text{Ca}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CaCO}_3 + \text{H}_2\text{CO}_3 \]

More \( \text{H}_2\text{CO}_3 \) \( \rightarrow \) more \( \text{CO}_2 \)

More \( \text{CO}_2 \) counteracts photosynthesis, but not completely

In the end, photosynthesis wins
Carbonate Weathering (cont.)

$\text{CaCO}_3$ rains to bottom of the ocean, forming limestone

Eventually, limestone uplifted, and cycle is complete

$\text{CaCO}_3$ can also be dissolved in deep ocean water
Silicate Weathering

• Silicates – dolomite, granite, and lots lots more...

\[
\begin{align*}
\text{CaSiO}_3 + 2\text{H}_2\text{CO}_3 & \rightarrow \text{Ca}^{2+} + 2\text{HCO}_3^- + \text{SiO}_2 + \text{H}_2\text{O} \\
\text{Ca}^{2+} + 2\text{HCO}_3^- & \rightarrow \text{CaCO}_3 + \text{H}_2\text{CO}_3 \\
\text{CO}_2 + \text{H}_2\text{O} & \rightarrow \text{H}_2\text{CO}_3
\end{align*}
\]

Net Result: \[\text{CaSiO}_3 + \text{CO}_2 \rightarrow \text{Ca}^{2+} + \text{CaCO}_3^- + \text{SiO}_2\]
Carbonate vs. Silicate Weathering

- Carbonate net result is 0
- Silicate net result is to remove $\text{CO}_2$
  \[ \text{CaSiO}_3 + \text{CO}_2 \rightarrow \text{Ca}^{2+} + \text{CaCO}_3^- + \text{SiO}_2 \]
- Would remove all $\text{CO}_2$ in atmosphere in 1 million years
- Why, then, is there $\text{CO}_2$ in the atmosphere?
Carbonate Metamorphism

At high temperatures/pressures

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

This is reverse of carbonate/silicate weathering
Summary of Inorganic Carbon Cycle

Fig. 8-16
Carbonate Metamorphism vs. Weathering

- What keeps weathering ($\text{CO}_2$ removal) and metamorphism ($\text{CO}_2$ addition) in balance?
- A negative feedback loop
Carbon Cycle - Summary

Fig. 8-12
Which of the following carbon reservoirs has the longest residence time?

b. The atmosphere

c. Plants

d. The Ocean

e. Sedimentary limestone