The science of climate change

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UH Law Center
The science of climate change

I. Basics of Earth System Science
II. Climate change on geologic and historical time scales
III. Natural and anthropogenic causes of climate change
IV. Consequences of future climate change
Studies Say Airborne Particulates Increase Risk of Death

A study published August 2 in the journal Environmental Health Perspectives, finds a positive correlation between black carbon pollution levels and mortality in US cities. A mixture of substances emitted by combustion from cars, trucks, factories and the burning of organic matter, particulate matter pollution exacerbates and contributes to respiratory illnesses. Scientists from the Johns Hopkins and Harvard Schools of Public Health and the Yale School of Forestry studied the causes of mortality between 2000 and 2005 in 72 urban areas, focusing on the relationship between the individual pollution components and the mortality rate. The findings indicate that some forms of particulate matter are more harmful than others, leading the authors to suggest that current air pollution regulations that regulate only the amount of particulate matter are inefficient at protecting human health. Public health officials are also concerned about the effect that climate change will have on human populations, increasing heat stroke, respiratory illness, even famine. Dr. Linda Rudolph, of the Public Health Institute, an Oakland, California non-profit, commented on the link between climate change and public health, stating, “if we don't act urgently and dramatically to reduce greenhouse gas emissions, climate change will undermine many of our other public health efforts and have many grave health consequences.”

For additional information see: Environmental Health News, Study, San Francisco Gate
Northern forest growth slowing down

In related news, a recent study published August 18 in Nature Climate Change found that European forests have reached their carbon saturation point as trees are being destroyed in insect infestations, fires and extreme weather events. After WWII, Europeans planted thousands of trees during a continent-wide effort to replenish damaged forests, but the aging trees are no longer absorbing as much carbon, and are releasing stored carbon as they die. The study concludes that the carbon saturation point of forests could be passed in 2030, unless European governments took action to rebuild forests. The authors of the report stated, "These regrowing forests have shown to be a persistent carbon sink, projected to continue for decades, however, there are early signs of saturation. Forest policies and management strategies need revision if we want to sustain the sink."

For additional information see: LA Times, Science Daily, Science Magazine, Sydney Morning Herald, Study
All climate scientists agree that:

1) Earth’s average surface temperature has warmed by 0.7°C since 1900, a conclusion based on direct measurements.

2) Concentrations of CO$_2$, CH$_4$, N$_2$O, and other greenhouse gases have built up in the atmosphere over the last 100 years due to human activities.

The issue at the heart of the greenhouse debate is not whether rising greenhouse gas levels have contributed to the warming, but rather the magnitude of the amplification of the warming by various feedbacks.
### Climate vs. Weather

<table>
<thead>
<tr>
<th>Weather</th>
<th>Climate</th>
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<tbody>
<tr>
<td>Shorter-term fluctuations</td>
<td>Longer-Term Changes</td>
</tr>
<tr>
<td>Current atmospheric conditions (e.g., temp, press, ws, wdir, rainfall, etc.)</td>
<td>Broad composite of average (or mean) condition of a region (e.g., temp, rain, snowfall, ice cover, winds)</td>
</tr>
<tr>
<td>Hours, Days, Weeks</td>
<td>Years (and longer), Typically 30 yr ave.</td>
</tr>
<tr>
<td>Specific location for specific time</td>
<td>Mean state of a specific region (e.g., continent, ocean, or entire planet)</td>
</tr>
</tbody>
</table>
What is a greenhouse gas?

[Diagram showing radiation transmitted by the atmosphere, with spectral intensity and wavelength on the axes. The diagram includes layers indicating the percent absorbed and scattered radiation, with specific gases listed: water vapor, carbon dioxide, oxygen and ozone, methane, nitrous oxide, and Rayleigh scattering.]
Greenhouse gas warming

Earth’s Ave. Temperature = 15°C
Natural GH Effect = 31°C Warming

240 Arriving in climate system
343 W/m²

240 Radiated to space
150 W/m²

103

Reflected and scattered

390 Back radiation

Natural greenhouse effect

2.5 W/m²
Enhanced greenhouse effect

Ruddiman, 2008
Greenhouse gas warming

\[ \frac{P}{a} = T^4 = 476 \text{ W/m}^2 = E_{\text{out}} \]

\[ T_{\text{one-layer}} = 4 \sqrt{\frac{476}{5.67 \times 10^{-8}}} = 302.7K \]
Greenhouse gas warming

\[ T_{\text{two_layers}} = 4 \sqrt{\frac{714}{5.67 \times 10^{-8}}} = 335K = 62°C \]
Some basic “reactions”

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{heat} \]

\[ \text{H}_2\text{O} + \text{CO}_2 + \text{sunlight} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

\[ \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{heat} + \text{NO} + \text{SO}_2 \]

\[ \text{NO} \rightarrow \text{NO}_2 \rightarrow \text{HNO}_3 \]

\[ \text{SO}_2 \rightarrow \text{H}_2\text{SO}_4 \rightarrow \text{sulfate aerosol} \]

\[ \text{NO}_x + \text{VOCs} + \text{sunlight} \rightarrow \text{O}_3 \]

\[ \text{CO}_2 + \text{H}_2\text{O} = \text{HCO}_3^- + \text{H}_2\text{CO}_3 \]
Where does atmospheric CO$_2$ go?

- Atmosphere: 55%
- Biosphere: 15–20%
- Shallow ocean: 25–30%

Ruddiman, 2008
Geochemical reservoir and fluxes

At Steady-State Input = Output

Residence time = Reservoir size / Flux rate in (or out)

Ruddiman, 2008
How long is CO$_2$ in the atmosphere?

Carbon Dioxide Residence Time

New Equilibrium is Achieved After A Few Centuries

Portion in Atmosphere (%)

Years Since CO$_2$ Release

Unfavorable Feedbacks

Favorable Feedbacks

CO$_2$ lifetime in the atm-ocean system

Full Geological Elimination Takes Hundreds of Thousands of Years
Climate system response

[Diagram showing the relationship between heat source and water temperature response over time]

- Temperature of water (response)
- Source of heat (forcing)
- Heat turned on
- Heat maintained
- Warm
- Water temperature
- 50%
- No heat
- Cool
- Response time
- Time
# Response times of climate system components

<table>
<thead>
<tr>
<th>Component</th>
<th>Response time (range)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fast responses</strong></td>
<td></td>
<td></td>
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<tr>
<td>Atmosphere</td>
<td>Hours to weeks</td>
<td>Daily heating and cooling</td>
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<tr>
<td></td>
<td></td>
<td>Gradual buildup of heat wave</td>
</tr>
<tr>
<td>Land surface</td>
<td>Hours to months</td>
<td>Daily heating of upper ground surface</td>
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<tr>
<td></td>
<td></td>
<td>Midwinter freezing and thawing</td>
</tr>
<tr>
<td>Ocean surface</td>
<td>Days to months</td>
<td>Afternoon heating of upper few feet</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Warmest beach temperatures late in summer</td>
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<tr>
<td>Vegetation</td>
<td>Hours to decades/centuries</td>
<td>Sudden leaf kill by frost</td>
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<td></td>
<td></td>
<td>Slow growth of trees to maturity</td>
</tr>
<tr>
<td>Sea ice</td>
<td>Weeks to years</td>
<td>Late-winter maximum extent</td>
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<tr>
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<td>Historical changes near Iceland</td>
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<tr>
<td><strong>Slow responses</strong></td>
<td></td>
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<tr>
<td>Mountain glaciers</td>
<td>10–100 years</td>
<td>Widespread glacier retreat in 20th century</td>
</tr>
<tr>
<td>Deep ocean</td>
<td>100–1500 years</td>
<td>Time to replace world’s deep water</td>
</tr>
<tr>
<td>Ice sheets</td>
<td>100–10,000 years</td>
<td>Advances/retreats of ice sheet margins</td>
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<tr>
<td></td>
<td></td>
<td>Growth/decay of entire ice sheet</td>
</tr>
</tbody>
</table>
Albedo-temperature feedback

Initial change

Climate cooling

Greater cooling

Increased snow and ice: higher reflectivity

Less solar radiation absorbed at surface
Albedo-temperature feedback
Albedo-temperature feedback

Source: NASA
Another positive feedback

Increase in greenhouse gases → Global warming → Increased warming → Melting of frozen CH₄ → Increase in CH₄ gas
Positive and negative feedbacks

Doubling of atmospheric CO₂ → +1.25°C

Increased CO₂ trapping of radiation in clear sky
Time scales of climate change

A. Tectonic

B. Orbital

C. Deglacial/millennial

D. Historical

1900 A.D.

1400 A.D.

Ruddiman, 2008
Ocean sediment core record

Five Million Years of Climate Change From Sediment Cores

δ¹⁸O Benthic Carbonate (per mil)

100 kyr cycle

41 kyr cycle

Equivalent ΔT (°C)

Millions of Years Ago

Lefer 19 – ii. past climates

GlobalWarming Art (t), Ruddiman, 2008 (b)
Coring Earth’s ice sheets

Lefer 20 – ii. past climates
Bubbles trapped in ice core
Ice core proxy T, CO$_2$, dust record
Anthropogenic CO$_2$

![Graph showing Anthropogenic CO$_2$ emissions from 1800 to 2000. The graph indicates a significant increase in emissions, particularly from fossil fuels and land clearance, with a steep rise in emissions post-1900.](image)

- **Land clearance**
- **Fossil fuels**
Anthropogenic CO$_2$

Global Fossil Carbon Emissions

- Total
- Petroleum
- Coal
- Natural Gas
- Cement Production

Million Metric Tons of Carbon / Year

1800  1850  1900  1950  2000
Global Temperature Anomaly

Global Temperature (meteorological stations)

Temperature Anomaly (°C)

Annual Mean
5–year Running Mean

1880 1900 1920 1940 1960 1980 2000
Global Temperature Anomaly

Global Land–Ocean Temperature Index

- Annual Mean
- 5–year Running Mean

Temperature Anomaly (°C)

Year:
1880 1900 1920 1940 1960 1980 2000

NASA GISS
Temperature Change for Three Latitude Bands

Northern Latitudes
(90°N–23.6°N)

Temperature Anomaly (°C)

(a)

Low Latitudes
(23.6°N–23.6°S)

Temperature Anomaly

(b)

Southern Latitudes
(23.6°S–90°S)

Temperature Anomaly

(c)

1900 1920 1940 1960 1980 2000
Global Temperature Anomaly - April 2013

July 2013

L-O
tl(°C) Anomaly vs 1951–1980

0.53

-4.4 -4 -2 -1 -0.5 -0.2 0.2 0.5 1 2 4

NASA GISS
Volcanic cooling and El Niño warming

Lefer 29 – iii. natural & anthro cc
Ruddiman, 2001
Natural warming and greenhouse effects

A

Observed warming
Greenhouse effect
No natural change

B

Observed warming
Smaller greenhouse effect
Natural warming

C

Observed warming
Larger greenhouse effect
Natural cooling

Time
Modeling climate change attribution

![Graph showing temperature change and attribution](http://www.globalwarmingart.com/)

Lefer 32 – iii. natural & anthro cc
Natural temperature changes

- Tectonic cooling (-0.00002 °C)
- Orbital cooling (-0.02 °C)
- Millennial warming? (<0.02 °C)
- Millennial cooling? (<0.02 °C)
- Solar warming (<0.07 °C)

Ruddiman, 2008
Natural interannual variability
Apple Stock Price – Past Year

490.90  +2.31 (0.47%)

After Hours: 490.41  -0.49 (-0.10%)
Aug 28, 5:55PM EDT
NASDAQ real-time data - Disclaimer
Currency in USD

Range  486.00 - 495.80  Div/yield 3.05/2.49
52 week  385.10 - 705.07  EPS  40.04
Open  486.00  Shares  908.44M
Vol / Avg.  10.97M/12.39M  Beta  1.00
Mkt cap  445.95B  Inst. own  61%
P/E  12.26

Compare: Enter ticker here  Add  Dow Jones  Nasdaq  HPQ  MSFT  INTC  SSNLF  more »

Zoom:  1d  5d  1m  3m  6m  YTD  1y  5y  10y  All

Aug 29, 2012  - Aug 28, 2013  -172.33 (-25.98%)

Volume (mil / 1d)

Lefer 34 – iii. natural & anthro cc
Apple Stock Price ~ 30 years

490.90 +2.31 (0.47%)

After Hours: 490.41 -0.49 (-0.10%)
Aug 28, 5:55PM EDT
NASDAQ real-time data - Disclaimer
Currency in USD

Comparisons: Enter ticker here Add Dow Jones Nasdaq HPQ MSFT ITC SSNLF

Zoom: 1d 5d 1m 3m 6m YTD 1y 5y 10y All

Dec 19, 1980 - Aug 28, 2013 +487.3 (13559.52%)

Range: 486.00 - 495.80
52 week: 385.10 - 705.07
Open: 486.00
Volume: 10.97M/12.39M
Market cap: 445.95B
P/E: 12.26
Dividend yield: 3.05/2.49
EPS: 40.04
Shares: 908.44M
Beta: 1.00
Institutional ownership: 61%

NASDAQ, 2013
Rate of global temperature rise

Period | Rate | ±
--- | --- | ---
25 | 0.177 | 0.052
50 | 0.128 | 0.026
100 | 0.074 | 0.018
150 | 0.045 | 0.012

Kevin Trenberth, 2008
Radiative forcing of recent warming

- CFCs
- \( \text{N}_2\text{O} \)
- \( \text{CH}_4 \)
- \( \text{CO}_2 \)
- Tropospheric ozone
- Sulphate
- Organic carbon from fossil fuels
- Biomass burning
- Aerosol indirect effect
- Land use (albedo only)
- Solar

Level of scientific understanding:
- High
- Medium
- Low
- Very low

Box 18-1b
*Earth’s Climate: Past and Future, Second Edition*
© 2008 W.H. Freeman and Company
Response to abrupt $\Delta CO_2$ and $SO_2$ emissions?
Response to abrupt $\Delta \text{CO}_2$ and $\text{SO}_2$ emissions?
Response to abrupt $\Delta$CO$_2$ and SO$_2$ emissions?

![Graph showing temperature change over time](image_url)
A future global temperature forecast

![Graph showing projected temperature increase over the years 2010 to 2090, with shaded areas indicating uncertainty ranges for the decades 2001-2010 and 2016-2031.](image-url)
Another future global temperature forecast

2070-2100 Prediction vs. 1960-1990 Average

Based on HadCM3

Temperature Increase (°C)
**Projected impacts of climate change**

<table>
<thead>
<tr>
<th>Global temperature change (relative to pre-industrial)</th>
<th>0°C</th>
<th>1°C</th>
<th>2°C</th>
<th>3°C</th>
<th>4°C</th>
<th>5°C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Food</strong></td>
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<td>Falling crop yields in many areas, particularly</td>
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<td>developing regions</td>
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<td>Possible rising yields in some high latitude regions</td>
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<td>Falling yields in many developed regions</td>
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<td><strong>Water</strong></td>
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<td>Small mountain glaciers disappear – water supplies</td>
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<td>threatened in several areas</td>
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<td>Significant decreases in water availability in</td>
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<td>many areas, including Mediterranean and Southern</td>
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<td>Africa</td>
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<td>Sea level rise threatens major cities</td>
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<td><strong>Ecosystems</strong></td>
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<td>Extensive Damage to Coral Reefs</td>
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<tr>
<td>Rising number of species face extinction</td>
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<td><strong>Extreme Weather Events</strong></td>
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<td>Rising intensity of storms, forest fires, droughts,</td>
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<td>flooding and heat waves</td>
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<td><strong>Risk of Abrupt and Major Irreversible Changes</strong></td>
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<td>Increasing risk of dangerous feedbacks and abrupt,</td>
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<td>large-scale shifts in the climate system</td>
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</table>
Questions? Thank you.

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Beals, 2008