Overview of Global Climate Change

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University of Houston
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BE WORRIED. BE VERY WORRIED.
Climate change isn’t some vague future problem—it’s already damaging the planet at an alarming pace. Here’s how it affects you, your kids and their kids as well.

EARTH AT THE TIPPING POINT
HOW IT THREATENS YOUR HEALTH
HOW CHINA & INDIA CAN HELP
SAVE THE WORLD—OR DESTROY IT
THE CLIMATE CRUSADERS
More Recent carbon dioxide
Temperature Scales

Gabriel Fahrenheit
Anders Celsius
William Thomson

\[ T_C = 0.55 \ (T_F - 32) \]
\[ T_F = (1.8 \ * T_C) + 32 \]

Ave Temp = 15 \ C
= 59 \ F

Typical Range = 0° - 30°C
= 32° - 86°F

-460°F
0°F
-273°F

Absolute zero

Sun's surface temperature
Boiling point of water
Freezing point of water
Earth's climate
Earth’s Radiation Budget

- Shortwave solar radiation:
  - 100% incoming
  - 30% reflected and scattered
  - 26% reflected and scattered
  - 23% absorbed
  - 4% reflected
  - 47% absorbed

- Longwave radiation and heat transfer:
  - 70% radiated
  - 65% radiated
  - 109% absorbed
  - 96% radiated back down
  - 5% lost to space
  - Greenhouse effect
  - 29% lost as latent and sensible heat

- Result: 31°C Warmer, 96% longwave
Shortwave vs. Longwave radiation

Note: Earth magnified 2,850,000 times.
Greenhouse effect: Earth and Venus

A. Venus
- Incoming solar radiation: 645 W/m²
- Reflected back to space: 515 W/m²
- 130 W/m² absorbed
- 285°C greenhouse effect
- 460°F at surface
- 96% CO₂

B. Earth
- Incoming solar radiation: 100 W/m²
- Reflected back to space: 342 W/m²
- 242 W/m² absorbed
- 31°C greenhouse effect
- 15°F at surface
- 0.02% CO₂
<table>
<thead>
<tr>
<th><strong>Weather</strong></th>
<th><strong>Climate</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shorter-term fluctuations</td>
<td>Longer-Term Changes</td>
</tr>
<tr>
<td>in atmospheric environment  (e.g., temp, press, ws, wdir, rainfall amount, etc)</td>
<td>broad composite of <strong>average (or mean)</strong> condition of a region (e.g., temp, rainfall, snowfall, ice cover, winds)</td>
</tr>
<tr>
<td>Hours, Days, Weeks</td>
<td>Years (and longer)</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>
Components of Climate System
Interactions between Climate System Components

CAUSES (external forcing)
- Changes in plate tectonics
- Changes in Earth's orbit
- Changes in Sun's strength

CLIMATE SYSTEM (internal interactions)
- Atmosphere
- Vegetation
- Land surface
- Ice
- Ocean

CLIMATE VARIATIONS (internal responses)
- Changes in Atmosphere
- Changes in Ice
- Changes in vegetation
- Changes in Ocean
- Changes in land surface
Some basic reactions

Organic-C + O₂ → CO₂ + H₂O + heat

H₂O + CO₂ → C₆H₁₂O₆ + O₂

Organic-C + O₂ → CO₂ + H₂O + heat + NO + SO₂

NO → HNO₃

SO₂ → H₂SO₄ → sulfate aerosol

NO + Organic-C + sunlight → O₃
Climate System Response

A. Temperature of water (response)
   Source of heat (forcing)

B. Heat turned on
   Heat maintained
   Water temperature
   Cool
   50%
   Warm
   No heat
   Response time
   Time
# Response Times

## TABLE 1.1 Response Times of Various 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>
</tr>
<tr>
<td>Atmosphere</td>
<td>Hours to weeks</td>
<td>Daily heating and cooling</td>
</tr>
<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>
</tr>
<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>
</tr>
<tr>
<td>Vegetation</td>
<td>Hours to decades/centuries</td>
<td>Sudden leaf kill by frost</td>
</tr>
<tr>
<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>
</tr>
<tr>
<td></td>
<td></td>
<td>Historical changes near Iceland</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Slow responses</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<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>
</tr>
<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
Water vapor feedback

Initial change

Climate warming

Increased warming

Increased greenhouse trapping of radiation

Increased atmospheric water vapor
Time Scales of Climate Change

[Diagram showing different time scales of climate change, including:
- A: Tectonic (300 Myr)
- B: Orbital (3 Myr)
- C: Deglacial/millennial (50,000 yr)
- D: Historical (1000 yr)]
Coring Earth’s ice sheets
Bubbles Trapped in ice core
Ice core record
Temperature stations
Change in surface temperature in 20th century
Volcanic cooling and El Niño warming

- 1912: Katmai
- 1963: Agung
- 1981: El Chichón
- 1991: Pinatubo
- 1983
- 1998

Global temperature change (°C)

Year

1900 1925 1950 1975 2000

Volcanic explosions

Strong El Niños
Retreat of mountain glaciers

McCarty Glacier - Alaska

2004

1909
Melting of Greenland Icesheet

2005 Melt Extent
1992 Melt Extent
2,000m Elevation

Courtesy Russell Huff and Konrad Steffen
Global rise in sea level last 20,000 years

Post-Glacial Sea Level Rise

Meltwater Pulse 1A

Last Glacial Maximum

Sea Level Change (m)

Thousands of Years Ago

Santa Catarina
Rio de Janiero
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf

24 22 20 18 16 14 12 10 8 6 4 2 0

0 -20 -40 -60 -80 -100 -120 -140
Global rise in sea level in the 20th century

Recent Sea Level Rise

23 Annual Tide Gauge Records
- Three Year Average
- Satellite Altimetry

Sea Level Change (cm)

1880 1900 1920 1940 1960 1980 2000
Project future rise in sea level

Sea Level Projections

- CGCM1
- CSIRO Mk2
- ECHAM4/OPYC3
- GFDL
- HadCM2
- DOE PCM
- MRI2

Observations

Sea Level Rise (cm)

1950 1975 2000 2025 2050 2075 2100
Anthropogenic CO₂

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

Annual Cycle

Carbon dioxide concentration (ppmv)
Pre-industrial and anthropogenic CO$_2$
Ice core CO$_2$ record

(Chart showing carbon dioxide variations over time, highlighting the industrial revolution's impact on CO$_2$ levels.)
Observed temperature changes

Global Temperatures

- Annual Average
- Five Year Average

Temperature Anomaly (°C)

1860 1880 1900 1920 1940 1960 1980 2000
Natural warming and greenhouse effects
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 (+0.2 °C ?)

Year:
- 1900
- 1920
- 1940
- 1960
- 1980
- 2000

B Natural temperature changes
Temperature increases caused by humans?
Response to abrupt $\Delta$ CO$_2$ and SO$_2$ emissions?
Response to abrupt $\Delta CO_2$ and $SO_2$ emissions?
Response to abrupt $\Delta \text{CO}_2$ and $\text{SO}_2$ emissions?
How does the U.S. rank?
How does the U.S. rank?

Economic Efficiency of Fossil Fuel Usage (world’s 20 largest economies)

GDP Dollars / kg Carbon Emitted

Brazil, France, Italy, UK, Spain, Japan, Germany, India, Indonesia, Mexico, Taiwan, Turkey, Thailand, China, South Korea, United States, Canada, Australia, Iran, Russia

Global Average
Estimated present-day reserves of fossil fuels (mainly coal) should last for another few hundred years and will add far more CO$_2$ to the atmosphere than has accumulated so far.

Unless technology or conservation efforts reduces this excess emission of CO$_2$ to the atmosphere, atmospheric CO$_2$ will increase within the next 200 years to levels 2X – 4X pre-industrial levels.

Resulting in CO$_2$ levels comparable to 10s of millions of years ago in warmer greenhouse worlds.

This warming will overwhelm natural variations in climate and could cause climatic and environmental changes unprecedented in human experience.

As regional patterns of temperature and precipitation change, impacts on human populations will vary from favorable to unfavorable by region and season.

Atmospheric CO$_2$ levels will remain high for 1000 years or more, until the ocean absorbs the excess CO$_2$. 
Greenhouse and natural changes

Inherent uncertainties make it difficult to predict climate over the next few decades.

However, 50 yrs from now, as equivalent-CO$_2$ concentrations approach 2X the pre-industrial value, climate change will have overwhelmed natural variability.

Impact of our unintended experiment should be obvious, and debate over Earth’s sensitivity to ghg will have been settled.
Greenhouse and natural changes

Natural climatic variability over a few years (i.e., El Nino, volcanic eruptions), represent only brief departures from longer-term underlying trends. These short oscillations are irrelevant to projections over next 1000 years.

Global temp. changes produced by all natural causes unlikely to reach 1 C over next 1000 years.

Projected ghg warming for same interval is between 2 -8 C, with a likely value of 4°-5°C.
Projected Carbon Emissions

Atmospheric CO₂ levels continue to rise at rate of 1.5 ppm (0.4%) per year because of fossil fuel combustion and clearing of forests.

Rate of increase will probably accelerate in future, but at unknown rates.

Uncertainties center on two issues:

1) How much carbon will human activities emit?

2) How will Earth system distribute this additional CO₂ among its atmospheric, oceanic and terrestrial reservoirs of carbon?

Projections of future carbon emissions based on three factors:

1) Population

2) Emissions per person

3) Carbon use efficiency (CUE)

%Δ carbon emissions = %Δ population x %Δ emissions/person x %Δ CUE
Emissions per person is linked to the average standard of living.

In many nations, standards of living increase over time, and in the past this process has required more carbon-based fuel for industrialization and day-to-day individual consumption (for cars and home heating or cooling).

In the near term, largest changes will occur in SE Asia as nations moving from semi-industrialized economies to join industrialized nations.

Some developing countries will also move from farm-based economies to semi-industrialized status.
What can you do?

Buy a fuel-efficient car
Take mass transit (bicycle or walk) to work
Car-pool
Take a look at other ways in which you waste energy at home or at work
Education: Learn more about this issue.
What can you do?

Buy products from companies that are trying to reduce their own impact on the climate

(e.g., Wal-Mart, Green Mountain Energy)

In October 2005, CEO H. Lee Scott announced a goal to transform Wal-Mart into a company that runs on 100 percent renewable energy and produces zero waste.

In addition, he recently articulated commitments:

- to cut the corporation's greenhouse-gas emissions by 20 percent over the next seven years,
- double the fuel efficiency of its truck fleet within 10 years,
- reduce solid waste from U.S. stores by 25 percent in the next three years
- double offerings of organic foods this spring, selling them at prices more affordable to the masses.
Websites for more information

www.realclimate.org

www.ipcc.ch  Feb 2nd 2007 Assessment

www.climateark.org

gcmd.gsfc.nasa.gov  Global Climate Change Master Directory

www.globalchange.gov  U.S. Global Change Data and Information System
Global CO “snapshot”

MOPPITT satellite
October 3, 2003
Automatic Weather Station (AWS) Location Map
See http://uwamrc.ssec.wisc.edu/aws/ and ftp://ice.ssec.wisc.edu/pub/biglist for more details

Key for McMurdo Area
1. Cape Bird
2. Ferrell
3. Fogle
4. Jimmy
5. Jimmy
6. Laurie
7. Linda
8. Manning
9. Meesley
10. Minna Bluff
11. Mount Erebus
12. Nancy
13. Pegasus
14. Pegasus North
15. Pegasus South
16. Tiffany
17. White Out
18. White Island
19. White Field
20. Windless Bight
21. Windless Bight

Active AWS
Inactive AWS
Planned AWS

AVHRR Image Mosaic from USGS Map I-2560
Merge by C.A. Shuman
UMD-ESSIC
More Recent carbon dioxide

Global Distribution of $^{13}$C Composition of Atmospheric CO$_2$

NOAA ESRL GMD Carbon Cycle

Three dimensional representation of the latitudinal distribution of the carbon isotopic composition of atmospheric carbon dioxide in the marine boundary layer. The measurements of stable isotope ratios were made at the University of Colorado INSTAAR using air samples provided by the GMD cooperative air sampling network. The surface represents data smoothed in time and latitude. The isotope data are expressed as deviations of the carbon-13/carbon-12 ratio in carbon dioxide from the VPDB-C02 standard, in per mil (parts per thousand). Contact: Dr. Jim White, CU/INSTAAR, Boulder, Colorado; (303) 492-5494, (James.white@colorado.edu, http://www.cmdl.noaa.gov/ccgg).
Number of Days Exceeding One-Hour Ozone Standard

Year

1987 1989 1991 1993 1995 1997 1999 2001 2003

Los Angeles

Houston
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