Climate Dynamics: Why Does Climate Vary?

The Recent Global Warming: Observations, Theories, and the Science and Art of Modeling

http://www.esrl.noaa.gov/psd/people/dezheng.sun/lectures/ATOC7500.html
The MCA (MWP) & LIA

Global Surface Temperature over the last 2000 years
(relative to the 1961 to 1990 mean)
Temperature Anomalies
of MCA (950-1250) & LIA (1400-1700)
Relative to 1961-1990

Mann et al. 2009
Temperature Difference Between MCA and LIA

Trenberth (1990)
Mechanisms
Variability in Sunspot Activity

[Graph showing the variability in sunspot activity over time, marked with significant periods such as Oort Minimum, Medieval Max., Spörer Minimum, Maunder Minimum, and Modern Max.]
Mechanisms
Variability in Volcanic Activity
Mechanisms
Thermohaline Circulation Variability
A Role for ENSO?

Coral Reconstructed MCA SST has a PDO-like Pattern

ENSO activity was weak during MCA
The Recent Global Warming

Annual anomalies of global surface air temperature (°C) (relative to the 1961 to 1990 mean)

From IPCC
The Recent Global Warming

Annual anomalies of global surface air temperature over land (°C) (relative to the 1961 to 1990 mean)
The Recent Global Warming

Annual anomalies of global Sea Surface Temperature (°C) (relative to the 1961 to 1990 mean)
The Recent Global Warming

Annual anomalies of hemispheric Sea Surface Temperature (°C) (relative to the 1961 to 1990 mean)
The Recent Global Warming

Zonal Mean Temperature Anomalies (°C)
The Recent Global Warming

Surface air temperature trends over 1901—2005 and 1979-2005
The Recent Global Warming

*Surface and tropospheric temperature trends over 1979--2005*
The 11 indicators of global warming
In the image, there are two main graphs illustrating increases in greenhouse gases in the atmosphere. The first graph (a) shows the increase in GtCO₂-eq/year from 1970 to 2004, with marked increases each decade. The second graph (b) is a pie chart that breaks down the sources of CO₂, with fossil fuel use being the largest contributor at 56.6%. The sources include CO₂ from deforestation, decay of biomass, etc., at 14.3%; CO₂ from other sources at 2.8%; N₂O at 7.9%; CH₄ at 19.4%; and F-gases at 1.1%. The third graph (c) shows the allocation of greenhouse gas emissions, with energy supply accounting for 25.9%, transport 13.1%, residential and commercial buildings 7.9%, agriculture 13.5%, industry 19.4%, and forestry 17.4%.
Added Radiative Forcing

Radiative Forcing Components

- CO$_2$
- CH$_4$
- N$_2$O
- Halocarbons
- Stratospheric aerosols
- Tropospheric aerosols
- Black carbon on snow
- Direct effect
- Cloud albedo effect
- Linear contrails
- Solar irradiance
- Ozone
- Albedo
- Net Anthropogenic Component
Projections of Future Climate Change
Projections of Future Climate Change
relative to the period 1980 to 1999

Global Average Surface Temperature Change (°C)

2020 - 2029

2090 - 2099

°C
CO2: A Cause of the Ice Age?

\[
\frac{1}{2} \text{CO}_2 \rightarrow -4 \, ^\circ\text{C}
\]

\[
2\text{CO}_2 \rightarrow +4\, ^\circ\text{C}
\]

From IPCC
The Decadal Warming of 1930s

Guy Callendar

$2X\text{CO}_2 \rightarrow 2 \, ^{\circ}\text{C}$

From IPCC
The Revival of CO2 Theory in 1950-60s

From IPCC

Bert Bolin

From IPCC

CO2?
The Revival of CO2 Theory in 1950-60s: The Keeling Measurements

Atmospheric Carbon Dioxide
Measured at Mauna Loa, Hawaii

From IPCC
The Cooling in 40s and 60s

Ice Age Coming?

From IPCC
Future Climate Change Predicted in the 1970s: Returning to Ice Age

1965-1975 Mean Temperatures vs 1937-1946

Temperature anomaly (deg C)
The Greenhouse Effect

Solar radiation: 343 Watts per m²

Some of the solar radiation is reflected by the atmosphere and the Earth's surface.

Outgoing solar radiation: 103 Watts per m²

Some of the infrared radiation passes through the atmosphere and out into space.

Outgoing infrared radiations: 240 Watts per m²

Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules.

Radiation is converted to heat energy, causing the emission of longwave (infrared) radiation back to the atmosphere.

From IPCC
Major Greenhouse Gases In The Atmosphere

From IPCC
The Energy Balance of the Climate System
1) Calculate the rate of increase of temperature of a mixed layer ocean of a depth of 50 m when it is subjected to a net heating of 1.5 W/m².

2) Estimate the rate of increase of the mean temperature of a troposphere confined between 1000 mb and 200mb when it is subjected to a net heating of 1.5 W/m².

3) Same as (1), except that the heating rate increases with the increase of the temperature at a rate of 1.5 W/m²/°C. Assuming the initial temperature is 15 °C, what would be the temperature after 25 years, 50 years, and 100 years respectively?

4) (see next slide--)

Homework
Homework

4) ((bonus question))

The radiative forcing from a doubling of CO2 is about 4 W/m$^2$. Assuming that earth’s surface radiates as a black body and there are no other processes in the climate system participating in the adjustment to new equilibrium in response to the radiative forcing from the doubling of CO2 (i.e., no feedbacks involved), what is the increase in the earth’s surface temperature after the climate system re-equilibrates with the increased CO2 in the atmosphere?
Recommended Reading For the Next Lecture


- Chapter 8, Climate Change 2007: Working Group I: The Physical Science Basis