Global CO$_2$ and Climate Change

A deeper look at the carbon dioxide cycle, greenhouse gases, and oceanic processes over the last 200 years

OCN 623 – Chemical Oceanography
17 April 2018

Reading: Libes, Chapter 25
At the completion of today’s section, students should be able to:

1. Know what affects CO$_2$ variability in the atmosphere
2. Describe how has global carbon cycle changed over the past two centuries
3. Describe the long-term fate of anthropogenic Carbon
4. Identify the role of the ocean in climate change
5. Implications of climate change on society
How does CO$_2$ affect climate?

The Earth’s temperature is set by a Radiation Balance:

If more heat arrives from the sun than can escape as infrared (IR) rays, the Earth gets warmer.

CO$_2$ and other greenhouse gases absorb IR, so an increase in CO$_2$ causes an increase in temperature.
Climate Change versus Global Warming

- Changing Rain and Snow Patterns
- Changes in Animal Migration and Life Cycles
- Higher Temperatures and More Heat Waves
- More Droughts and Wildfires
- Less Snow and Ice
- Thawing Permafrost
- Damaged Corals
- Rising Sea Level
- Warmer Oceans
- Changes in Plant Life Cycles
Webster:

“Climate: the average condition of the weather at a place over a period of years as exhibited by temperature, wind velocity, and precipitation”

So “climate” refers not to the weather today or this week or this year, but rather to the range of weather (including hot and cold years, wet and dry years) that is typical of each region.

- Climate change is a natural process that has happened for billions of years
- Human activities are changing the rate of climate change
- Climate change includes many more effects than warming
Are global temperatures linked to atmospheric CO₂?

Vostok Ice Core CO₂ Concentration and Temperature Variation Record

**Challenge of a Changing Earth — July 2001**

**Carbon dioxide** and the **temperature of our planet** from 800,000 years ago until the present day

The year “0” corresponds to the year 2020
Carbon dioxide concentrations are in units of parts per million
Temperature is the difference compared to the average temperature of the past 1000 years in units of degrees Celsius

Figure compiled from the following data sources

In 2014, CO₂ is about 400 ppm

**IPCC**: “Global mean surface temperature has increased more than 0.5°C since the beginning of the 20th century, with this warming likely being the largest during any century over the past 1,000 years for the Northern hemisphere.”
What Drives Climate Change?

Adapted from Sarmiento and Gruber 2002 using Trends online data

Atmospheric CO₂ at Mauna Loa Observatory

Scripps Institution of Oceanography
NOAA Earth System Research Laboratory

Increase 2 ppm/yr

Adapted from Sarmiento and Gruber 2002 using Trends online data
Recent atmospheric carbon dioxide levels

Atmospheric CO₂ levels have risen from ~315 ppmv in 1958 to 404 ppmv in 2017 (~28%)
Rate of increase of atmospheric CO$_2$ is not constant.

Varies with: Economic activity and natural sinks/sources (El Nino, droughts, fires, Volcanic activity)
Carbon Inventories of Reservoirs that Naturally Exchange Carbon on Time Scales of Decades to Centuries

- Oceans contain ~90% of carbon in this 4 component system
- anthropogenic component is difficult to detect in the ocean

Average stocks for 2000-2009:

- Ocean: 38,155 PgC
- Soil: ~2000 PgC
- Plants: ~550 PgC
- Atmosphere: 829 PgC

Preind. Atm. C = 71%

Ocean \( C_{\text{Ant}} = 0.4\% \)

(Ocean \( C_{\text{ant}} < 1.5\% \) of upper 1000 m)
IPCC global carbon cycle and the flows of carbon
Preindustrial C cycle was from the Ocean to the Land
Today we have reversed that flow
Budget Changes Over Time
Averages for last decade (2006-2015)

CO₂ emissions (Gt CO₂/yr)

Fossil fuels and industry

9.3 ± 0.5 PgC/yr (34.1 GtCO₂)

Budget Changes Over Time
Averages for last decade (2006-2015)

CO₂ emissions (Gt CO₂/yr)

1.0 ± 0.5 PgC/yr (3.6 GtCO₂)

Budget Changes Over Time

Averages for last decade (2006-2015)

- **Fossil fuels and industry**: $9.3 \pm 0.5 \text{ PgC/yr (34.1 GtCO}_2$)
- **Land-use change**: $1.0 \pm 0.5 \text{ PgC/yr (3.6 GtCO}_2$

44% of the total budget change is attributed to fossil fuels and industry.
Budget Changes Over Time
Averages for last decade (2006-2015)

Data: GCP

Fossil fuels and industry

- 90%
- 9.3 ± 0.5 PgC/yr (34.1 GtCO₂)

Land-use change

- 10%
- 1.0 ± 0.5 PgC/yr (3.6 GtCO₂)

Atmospheric growth

- 44%
- 4.5 ± 0.2 PgC/yr (16.4 GtCO₂)

Ocean sink

- 26%
- 2.6 ± 0.2 PgC/yr (9.7 GtCO₂)

CO₂ partitioning

- 30%
- 3.2 ± 0.5 PgC/yr (11.6 GtCO₂)

What are the long-term consequences of fossil fuel burning?

Hypothetical scenario: We instantly inject 5,000 Pg of carbon into the atmosphere

Time-scale of a few hundred years: primary storage is atmosphere with ocean and land absorption

Time-scale of a few thousand years: land sink maxed out and ocean becomes primary storage location

Time-scale of ten thousand years: ocean is primary storage location and mineral sink growing

Source: IPCC 5th Assessment Report
97% of Climate Scientists Agree

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia.

Human influence on the climate system is clear. It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

259 authors selected from 39 countries Reviewed by 1089 experts
Increasing Confidence With Each Assessment

1990
The report did not quantify the human contribution to global warming.

1995
“The balance of evidence suggests a discernible human influence on climate.”

2001
Human-emitted greenhouse gases are likely (67-90% chance) responsible for more than half of Earth’s temperature increase since 1951.

2007
Human-emitted greenhouse gases are very likely (at least 90% chance) responsible for more than half of Earth’s temperature increase since 1951.

2013
Human-emitted greenhouse gases are extremely likely (at least 95% chance) responsible for more than half of Earth’s temperature increase since 1951.
**What causes climate change?**

<table>
<thead>
<tr>
<th>Emitted Compound</th>
<th>Resulting Atmospheric Drivers</th>
<th>Radiative Forcing by Emissions and Drivers</th>
<th>Level of Confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>CO₂</td>
<td>1.68 [1.33 to 2.03]</td>
<td>VH</td>
</tr>
<tr>
<td>CH₄</td>
<td>CO₂, H₂O, O₃, CH₄</td>
<td>0.97 [0.74 to 1.20]</td>
<td>H</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>O₃, CFCs, HCFCs</td>
<td>0.18 [0.01 to 0.35]</td>
<td>H</td>
</tr>
<tr>
<td>N₂O</td>
<td>N₂O</td>
<td>0.17 [0.13 to 0.21]</td>
<td>VH</td>
</tr>
<tr>
<td>Anthropogenic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>CO₂, CH₄, O₃</td>
<td>0.23 [0.16 to 0.30]</td>
<td>M</td>
</tr>
<tr>
<td>NMVOC</td>
<td>CO₂, CH₄, O₃</td>
<td>0.10 [0.05 to 0.15]</td>
<td>M</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Nitrate, CH₄, O₃</td>
<td>-0.15 [-0.34 to 0.03]</td>
<td>M</td>
</tr>
<tr>
<td>Short Lived Gases and Aerosols</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aerosols and precursors</td>
<td>Mineral Dust, Sulphate, Nitrate</td>
<td>-0.27 [-0.77 to 0.23]</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>Organic Carbon, Black Carbon</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cloud Adjustments due to Aerosols</td>
<td>-0.55 [-1.33 to -0.06]</td>
<td>L</td>
</tr>
<tr>
<td>Natural</td>
<td>Changes in Solar Irradiance</td>
<td>0.05 [0.00 to 0.10]</td>
<td>M</td>
</tr>
<tr>
<td>Total Anthropogenic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF relative to 1750</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>2.29 [1.13 to 3.33]</td>
<td>H</td>
</tr>
<tr>
<td>1980</td>
<td></td>
<td>1.25 [0.64 to 1.86]</td>
<td>H</td>
</tr>
<tr>
<td>1960</td>
<td></td>
<td>0.57 [0.29 to 0.85]</td>
<td>M</td>
</tr>
</tbody>
</table>

Radiative Forcing relative to 1750 (W m⁻²)
2016 was Warm

Global surface temperature in 2016 was the highest in the period of instrumental measurements. 2016 was +1.26°C (~2.3°F) warmer than in the base period.

2016 Annual Mean Relative to 1880-1920

Source: Hansen et al.
Global Energy Storage

~275 ZJ of additional solar energy have been stored in the earth system over the last 40 years.

Atmospheric warming accounts for about 1% of energy storage.

Melting Ice (including Arctic sea ice) accounts for ~3% of energy storage.

Warming Land accounts for ~3% of energy storage.
Ocean warming accounts for about ~93% of total energy storage.

The heat we are putting in the ocean will be trapped there for many thousands of years.
Loss of Sea Ice in the Arctic

2016 Arctic sea ice summer minimum

NOAA Climate.gov
Data: NSIDC
Some People Think That Changes Are Only Happening in a Few Places
Climate Change Impacts on Human Health

- Civil conflict
- Storms and flooding
- Disease transmission
- Heat
- Air pollutants
- Food supply

- Displacement
- Infectious disease
- Respiratory disease
- Malnutrition
- Illness, injury, and death
The Impacts of Climate Change Show Up in Many Ways

The World Health Organization estimates that over the last two decades climate change has been responsible for an average of 150,000 deaths per year and they expect that rate to double over the next two decades!
Rising T and CO₂ levels are impacting the ocean in many ways

- Changes in food levels
- Reduced calcifying zooplankton
- Reduced particle ballast
- Enhanced recycling in warm ocean
- Increased denitrification
- Reduced reproduction
- Loss of calcifying zooplankton
- Increased N fixation
- Reduced particle ballast
- Reduced calcification
- Increased stratification
- Increased Southern Ocean winds
- Reduced upwelling
- Reduced deep water formation
- Increased carbonate dissolution

Adapted from Sabine and Tanhua 2009