Atmosphere, Water, People, Climate

OCN 623 – Chemical Oceanography

Most slides from Barry Huebert and/or IPCC
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.

Webster:

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

• Climate change is a natural process that has happened for billions of years
• Human activities are changing the rate of climate change
• Aerosols affect the climate, sometimes offsetting part of the greenhouse gas warming.
• Climate change includes many more effects than warming
“In case we had forgotten, because we keep hearing that 2014 has been the warmest year on record, I ask the chair, do you know what this is? It’s a snowball, just from outside here. It’s very, very cold out.”
Combined average temperature over global land and ocean surfaces for February 2015 was the second highest for February in the 136-year period of record.
LOL "SCIENCE" SAYS THE SHIP IS SINKING
MY END IS UP 200FT
Is Climate Change / Global Warming happening or not?
Global mean surface temperature has increased >0.5°C in this time.
Is this natural variability or anthropogenic climate change?

Global Land and Ocean Temperature Anomalies, March

global & hemispheric anomalies are provided with respect to the period 1901-2000, the 20th century average
Likely Impacts

Why should we worry about global warming?

Would an extra degree or two of warming hurt anything?

What changes might we see?

Global mean surface temperature has increased $>0.5^\circ$C in this time. Is this natural variability or anthropogenic climate change?
Would an extra degree or two of warming hurt anything?

YES!! It’s NOT just warming.

“Climate Change” includes:

Sea-level Rise

Droughts & Flooding

Severe Storms Increasing

Diseases Spread to New Areas
A warmer climate melts glaciers, expands the ocean, and submerges many islands.

**Temperature Rise**

+1 to 3°C

↓

**Sea Level Rise**

+10 to 90 cm (5 to 37”)

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It’s **NOT** just warming.
- Sea-level Rise
- Severe Storms Increasing

“**Climate Change**” includes:
- Droughts & Flooding
- Diseases Spread to New Areas
How does climate change work?

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.

CO₂ and other greenhouse gases absorb IR, so an increase in CO₂ causes an increase in temperature.
Radiation Balance and Greenhouse Gases
### Solar Energy Budget

(kilocalories/yr)

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy from sun to earth</td>
<td>$1.3 \times 10^{21}$</td>
</tr>
<tr>
<td>30% reflected</td>
<td>$3.9 \times 10^{20}$</td>
</tr>
<tr>
<td>47% to heating atmosphere and earth's surface</td>
<td>$6.1 \times 10^{20}$</td>
</tr>
<tr>
<td>23% used in evaporation</td>
<td>$3.0 \times 10^{20}$</td>
</tr>
<tr>
<td>0.2% used in generating winds, waves and currents</td>
<td>$2.6 \times 10^{18}$</td>
</tr>
<tr>
<td>0.0023% used in photosynthesis</td>
<td>$3 \times 10^{17}$</td>
</tr>
</tbody>
</table>

70% of the sun’s energy is absorbed at the Earth’s surface, where it drives the hydrologic cycle.
The average Albedo (reflectivity) of Earth is 0.3.

The majority of outgoing IR comes from gases.

~50%
Latest CO$_2$ reading
April 19, 2015
403.65 ppm

Carbon dioxide concentration at Mauna Loa Observatory

CO$_2$ Concentration (ppm)

Full Record ending April 19, 2015
Latest CO$_2$ reading
April 19, 2015

403.65 ppm

Latest CO₂ reading
April 19, 2015

403.65 ppm

From the Terra satellite, you can actually see the regions where IR radiation escapes (left) and solar radiation is absorbed (right).

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. CO₂ and other greenhouse gases absorb IR, so increase in CO₂ causes increase in T.
Positive Feedback: Warming Causes *More* Warming!

1. Light colored ice reflects back the Sun’s energy efficiently.
2. Exposed land is darker and absorbs more energy; warming.
3. As the ice melts, more land is exposed. This absorbs more heat, melting more ice, and causing further warming.
4. The altitude of the melting ice is reduced so it becomes harder for new ice to form (esp for Greenland).

Melt water flows to the base of the Greenland ice sheet.

Ice is melting MUCH faster than glaciologists had forecast.

Positive Feedback can cause Runaway Warming, by darkening originally-light surfaces.

The climate system is full of feedbacks.
“The annual circulation of \( \text{H}_2\text{O} \) is the largest movement of a chemical substance at the surface of the Earth”

<table>
<thead>
<tr>
<th>Source of Water</th>
<th>% of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>97.25</td>
</tr>
<tr>
<td>Ice caps and glaciers</td>
<td>2.05</td>
</tr>
<tr>
<td>Groundwater</td>
<td>0.68</td>
</tr>
<tr>
<td>Lakes</td>
<td>0.01</td>
</tr>
<tr>
<td>Soils</td>
<td>0.005</td>
</tr>
<tr>
<td>Atmosphere (as vapor)</td>
<td>0.001</td>
</tr>
<tr>
<td>Rivers</td>
<td>0.0001</td>
</tr>
<tr>
<td>Biosphere</td>
<td>0.00004</td>
</tr>
<tr>
<td>Total</td>
<td>100 %</td>
</tr>
</tbody>
</table>
Three-cell model of atmospheric circulation

1. Polar cells
2. Midlatitude cells
3. Hadley cells
Idealized vs. actual zonal pressure belts

Non-uniform surface = uneven heating
Unstable windflow = eddies
Sun doesn’t remain over the equator year-round = 23.5N-23.5S
Weakening of the vortex, H over Greenland detachment
Movement of \( \text{H}_2\text{O} \) through the atmosphere determines the distribution of rainfall; global average precip \( \sim \) 943mm
Net evaporation from the surface ocean affects surface water salinity in the ocean and increases surface water density controls thermohaline circulation of ocean.
Surface water salinity in the Atlantic Ocean

The maxima in evaporation-precipitation results in the highest surface water salinities in the mid-latitudes around 30° N and 30° S.
Remember the Thermohaline Circulation and this Global Conveyor Belt?

Freshening the North Atlantic (due to melting of Greenland and Arctic ice) could **Shut it Down**
Weakening of the THC in the Atlantic reduces poleward heat transport. This leads to a minimum in the surface warming in the northern North Atlantic and/or in the circumpolar Ocean.
The last time the polar regions were significantly warmer than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 6 metres of sea level rise.
Arctic Sea-Ice Extent is Shrinking Rapidly
Change from 1980 to 2009
Arctic sea ice has lost half its thickness.
Warming IS having effects on other parts of the Earth System.

*Science*, 23 Mar 06:

"Although the focus of our work is polar, the implications are global," says Otto-Bliesner. "These ice sheets have melted before and sea levels rose. The warmth needed isn't that much above present conditions."

The two studies show that greenhouse gas increases over the next century could warm the Arctic by 5-8 degrees Fahrenheit (3-5 degrees Celsius) in summertime. This is roughly as warm as it was 130,000 years ago, between the most recent ice age and the previous one.
Greenland Ice Sheet

1.71 million km$^2$ &
volume of 2.85 million km$^3$

sea level equivalent of +7.4 m
A warmer climate would melt glaciers, expand the ocean, and submerge many islands!!

Temperature Rise  +1 to 3°C  

Sea Level Rise  +10 to 90 cm (5 to 37”)
1. Stable glacier and ice shelf

- **Glacier flow** driven by gravity
- **Buoyant** (hydrostatic) force at ice shelf front partially supports ice mass

2. Two effects of warmer temperatures

**a)** **Melt water** percolates through glacier; glacier speeds up (summer only)

**b)** **Water-filled** fractures carve through ice shelf; shelf disintegrates

3. Unstable glacier front after ice shelf collapse

- As shelf retreats past grounding line **buoyant** support decreases at front but **glacier flow** continues and glacier front calves rapidly

4. Glacier acceleration

- **Old surface**
- **New surface**
- **Calved icebergs**

- Lower part of glacier steepens, accelerates, and loses mass
The number of Category 4 and 5 hurricanes worldwide has nearly doubled over the past 35 years, even though the total number of hurricanes has dropped since the 1990s. The shift occurred as global sea surface temperatures have increased over the same period. This is compelling evidence that global climate change is making tropical storms more powerful and more damaging.
Distributions of wind speeds for Atlantic tropical storms and hurricanes

There is an increase in the number of the very strongest simulated storms in the warm climate, relative to the control

Knutson et al. (2008)
Most carbon has been stored in the ocean*. It plays a huge role in controlling greenhouse gases and climate.

*although most of the CO$_2$ man has released is still in the atmosphere.

Since 1800 - Sources: Land Use Chg 140; Fossil Fuel 265 Gt C
Uptake: Oceans 115; Terrestrial 110; Atmosphere 189 Gt C
Burning of coal, oil, and natural gas is converting fossil C to CO$_2$. Much stays in the air!
Our fuel burning is converting fossilized carbon (coal, oil, and natural gas) into CO₂. 45% of it stays in the air.

We can look at ice cores to see that CO₂ was pretty constant for the last 1000 years. The rapid increase began about the time of the industrial revolution.

The diagram shows CO₂ emissions and uptake since 1800 (Gt C). CO₂ emissions from various sources are shown, including Land use change (140 Gt), Fossil emissions (265 Gt), Coal, Oil, Natural gas, and Cement making. The diagram also shows where the CO₂ goes: Atmosphere (180 Gt), Oceans (115 Gt), and Terrestrial (110 Gt). 28% of CO₂ has gone into the ocean.
Climate models are of necessity *gross simplifications of reality.*

By comparing them with the past behavior of the planet, as found in paleoclimate records such as sediments and ice cores.
We can look at ice cores to see that \( \text{CO}_2 \) was pretty constant for the last thousand years.

The rapid increase began about the time of the **industrial revolution**.
Are global temperatures linked to atmospheric CO₂?

Vostok Ice Core CO₂ Concentration and Temperature Variation Record

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 can we learn from these records?

Does CO$_2$ *cause* temperature change, or is it a *response* to temperature change?

Temperature and CO$_2$ vary in concert over the last 400,000 years.

Petit et al *Nature* 399, 439-46
The Earth is now in a NO-ANALOG zone!

The **inhabited** Earth has *never before* dealt with these conditions.

Therefore, paleo records cannot be 100% reliable tests of climate models. Yikes!

What can we learn from these records?
Does CO₂ *cause* temperature change, or is it a *response* to temperature change?
What about the recently-rising temperatures - are they natural variability? **No way!**

Maybe it is not surprising that the Earth’s temperature is now outside the range seen in the last thousand years.

The Earth is now in a NO-ANALOG zone! The inhabited Earth has *never before* dealt with these conditions. Therefore, paleo records cannot be 100% reliable tests of climate models.
Model predictions from IPCC:

“Global temperature will rise from 1.4-5.8°C over this century unless greenhouse gas emissions are greatly reduced.”
Those predictions come from **Numerical Computer Models** to synthesize all our quantitative knowledge of the Earth’s energy flows, greenhouse gases, land use changes, etc.

This is an extremely complex system, so the models are of necessity *gross simplifications of reality*.

How can we be sure models are giving us realistic predictions?

By comparing them with the past behavior of the planet, as found in paleoclimate records such as sediments and ice cores.
Climate Forcing vs Response

**Climate Forcing** is a change from pre-industrial radiation budget values, for either incoming shortwave (solar) radiation or outgoing longwave (thermal IR) radiation. It is a straightforward energy flux measure. The forcing depends on gas and aerosol concentrations as well as cloud distributions and properties, so it is not independent of the response.

**Climate Response** is the climatic result of forcing plus all the related feedback processes that determine winds, precipitation, and temperatures. The response can only be determined by models that simulate the whole range of processes affecting climate.
Why is the light at Miyajima different in these two photos?
Beijing “haze alerts”
Radiative Forcing by Tropospheric Aerosol

Partial Reflection and Absorption of Incoming Solar Radiation

Direct

Indirect

Aerosol Haze → Clouds

Dust

SO₂

Soot

Land Use Changes

Industrial Emissions

Biomass Burning
Models do much better when they include aerosols, even using crudely understood aerosol effects.

Climate Models didn’t do a very good job of reproducing temperature trends in the last 150 years when they did not include aerosol impacts.
Not every place is warming, though - the blue spots are areas that have been cooling.

How could that be?

Each of these areas is polluted with aerosols.

Model predictions from IPCC: Global temperature will rise from 1.4-5.8°C over this century unless greenhouse gas emissions are greatly reduced.
Smoke and dust both affect the climate

The whitest things (most reflective of sunlight) in this SeaWiFS image are clouds.

Changing the extent or density of clouds is called the radiative indirect effect on climate.

Dust can impact climate, both by reflecting light to space and by absorbing light. Where dust is, there is more light reflected back to the satellite than over the dark ocean.
“Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.”

“Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.”
“Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (high confidence), with only about 1% stored in the atmosphere. On a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by 0.11 [0.09 to 0.13] °C per decade over the period 1971 to 2010. It is virtually certain that the upper ocean (0–700 m) warmed from 1971 to 2010, and it likely warmed between the 1870s and 1971.”
“Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901 (medium confidence before and high confidence after 1951). For other latitudes, area-averaged long-term positive or negative trends have low confidence.

Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean (medium confidence). It is very likely that regions of high salinity, where evaporation dominates, have become more saline, while regions of low salinity, where precipitation dominates, have become fresher since the 1950s.

Since the beginning of the industrial era, oceanic uptake of CO2 has resulted in acidification of the ocean; the pH of ocean surface water has decreased by 0.1 (high confidence), corresponding to a 26% increase in acidity, measured as hydrogen ion concentration.”
The contemporary carbon budget is well constrained, by $[\text{CO}_2]_{\text{Atm}}$, isotopic, and precise $\text{O}_2/\text{N}_2$ measurements.

In 2013, global $\text{CO}_2$ emissions due to fossil fuel use (and cement production) were 36 gigatonnes ($\text{GtCO}_2$); this is 61% higher than 1990 (the Kyoto Protocol reference year) and 2.3% higher than 2012.

Carefully note GtC vs. Gt$\text{CO}_2$
How Can Climate be Stabilized?

Must Restore Planet’s Energy Balance

Modeled Imbalance:  $+0.75 \pm 0.25 \text{ W/m}^2$
Ocean Data Suggest: $+0.5 \pm 0.25 \text{ W/m}^2$

Requirement Might be Met Via:

Reducing CO$_2$ to 350 ppm or less
&
Reducing non-CO$_2$ forcing $\sim 0.25 \text{ W/m}^2$
Four RCPs were selected and defined by their total radiative forcing.

Each RCP could result from different combinations of economic, technological, demographic, policy, and institutional futures.

e.g., the second-to-lowest RCP could be considered as a moderate mitigation scenario.
The nature of our future environment depends strongly on which “scenario” forecasters use. The scenarios differ only in the extent of society’s effort to conserve and reduce fossil-fuel use.

Multi-model results show that limiting total human-induced warming to less than 2°C relative to the period 1861–1880 with a probability of >66%7 would require cumulative CO₂ emissions from all anthropogenic sources since 1870 to remain below about 2900 GtCO₂ (with a range of 2550 to 3150 GtCO₂ depending on non-CO₂ drivers). About 1900 GtCO₂ had already been emitted by 2011.
Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Surface temperatures will remain approximately constant at elevated levels for many centuries after a complete cessation of net anthropogenic CO$_2$ emissions. A large fraction of anthropogenic climate change resulting from CO$_2$ emissions is irreversible on a multi-century to millennial timescale, except in the case of a large net removal of CO$_2$ from the atmosphere over a sustained period.

There is high confidence that ocean acidification will increase for centuries if CO$_2$ emissions continue, and will strongly affect marine ecosystems.

It is virtually certain that global mean sea level rise will continue for many centuries beyond 2100, with the amount of rise dependent on future emissions. The threshold for the loss of the Greenland ice sheet over a millennium or more, and an associated sea level rise of up to 7 m, is greater than about 1°C (low confidence) but less than about 4°C (medium confidence) of global warming with respect to pre-industrial temperatures. Abrupt and irreversible ice loss from the Antarctic ice sheet is possible, but current evidence and understanding is insufficient to make a quantitative assessment.
(a) Risks from climate change...

(b) ...depend on cumulative CO₂ emissions...

(c) ...which in turn depend on annual GHG emissions over the next decades