Fundamentals of Climate Change (PCC 587): The Ocean

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The Ocean

- Ocean acidification
  - “The other CO\textsubscript{2} problem”
- Sea level rise
- Thermohaline circulation
- El Nino
Ocean Acidification

- Carbon dioxide can dissolve in water
  - *Carbonated* drinks: pressurized CO$_2$ is dissolved in water
    - When opened at normal pressure, it releases CO$_2$ bubbles

- Higher atmospheric CO$_2$ means more CO$_2$ dissolves in seawater
Chemistry of Ocean Acidification

- When carbon dioxide is dissolved in water, some carbonic acid is formed ($\text{H}_2\text{CO}_3$)
- Water becomes more acidic
  - And the pH of the ocean has been decreasing as CO$_2$ levels have risen

pH has been dropping at this Hawaii station (and globally as well)
Ocean Acidification

- Pre-industrial (1700s) 8.18
- Recent past (1990s) 8.10
- 2050 ($2 \times \text{CO}_2 = 560 \text{ ppm}$) 7.95
- 2100 (IS92a) 7.82
How much more acidic?

- pH is a logarithmic scale, so the observed drop in pH corresponds to **30% more** hydrogen ions

- Who cares about a more acidic ocean?
Acids

What kinds of things react with acids?

- Well, TUMS, for instance...

- Tums has calcium: calcium carbonate \( \text{(CaCO}_3 \text{)} \) that is...

- This is actually relevant to the ocean: calcium carbonate is what marine organisms of all types use to build shells, skeletons, etc
Coral reefs at risk

In your stomach or in the ocean, the chemistry is the same

Just as the Tums react with acid, creatures with shells also react...

Not just clams & lobsters though!

Even low on the food chain organisms like **phytoplankton** are affected. Phytoplankton are responsible for 1/3 of all photosynthesis on the planet and feed the marine food web.
Ocean acidification is likely to impair shell formation in plankton and corals.
Acidification of the Ocean

Increasing the acidity of the ocean has a negative impact on many types of biology:

- Coccolithophore (single-celled algae, protists and phytoplankton)
- Pteropods (small molusks)
- Shellfish
- Coralline (red) algae
20th Century Sea Level Rise

Sea level rise since 1870 has been around 12-22 cm (5-9”)

red = “reconstructed” from tide gauges and other sources
blue = tide gauges
black = satellite altimetry
What affects sea level rise?

- These **don’t contribute** to sea level rise:
  - Sea ice
  - **Ice shelves** (these are connected to ice sheets but floating on ocean)
- **Contribute only a tiny amount:**
  - Permafrost
  - Snow cover
What affects sea level rise?

- These **do contribute** to sea level rise:
  - **Thermal expansion** of sea water
    - Water expands when it warms
    - This is the **main contributor** to sea level rise so far
  - Mountain glaciers
  - **Ice sheets** (Greenland and Antarctica)
Natural Influences on Sea Level

- Tides
- Ocean currents
- Winds
- Tectonic activity
  - Some locations are rising/falling
  - Northern part of the Olympic Peninsula is rising
    - Means it will experience less sea level rise than other locations
- These influences + spotty data means it’s been hard to track global sea level accurately!
From sticks to satellites: measuring sea level

**Tide gauges** are measuring sticks or floats in wells

- Always coastal
- Few long records
From sticks to satellites: measuring **sea level**

**TOPEX-Poseidon Radar Altimetry**

Instrument emits a short radar flash and measures the time-of-flight of its reflection from earth. 1,000 times per second.

Measures **sea level** and ice sheet height
Sea level rise from TOPEX-Poseidon Radar Altimetry

Most accurate satellite measurements: just under 6 cm (2.4”) rise in last 19 years
Contributions to sea level rise

- IPCC AR4 Figure 5.21.

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1961 to 2003 (blue)
1993 to 2003 (brown)

Older data (blue) didn’t add up properly

Recent rise (brown) can be almost entirely explained

Mostly thermal expansion so far.
Thermal Expansion

- Thermal expansion is primary contribution so far to sea level rise (60%)
- Due to ocean heat content increases
  - Water expands as it warms

Ocean heat content has been steadily increasing in recent decades

How do we know this?
Monitoring the ocean

Many instruments are used to measure ocean heat content.
Argo floats

Stephen Riser,
UW Oceanography
Monitoring the **ocean heat content**

Argo floats, since ~2000 measure to 2000m depth
Monitoring the **ocean heat content**

Expendable Bathythermographs (XBT)

About 70 Voluntary ships toss them overboard 14,000 each year (they are cheap, even these figures are ugly) measure down to 1500 m, in use since 1962
Mountain glaciers currently contribute 25% to rising sea levels.

Greenland + Antarctica currently contribute 15%.
What will sea level be by the end of the 21st century?
Estimate from **IPCC Report**

20-50 cm (8-20") for 3 intermediate scenarios

But had no increase in **calving** from Greenland and Antarctica!

Criticized by James Hansen
Some recent estimates **including** increases in **calving:**

- **0.5 to 1.4 m** by considering past SLR to warming dependence with IPCC estimates of future warming (Rahmstorf 2007)
- Accelerated but plausible dynamic thinning could give **0.8-2 m** (Pfeffer et al. 2008)
Speed of Sea Level Rise

- Sea level rise is a **very slow** process
  - Takes an **extremely** long time to melt Greenland/Antarctica
    - In the long term, ice sheets will be the main problem, but this will take **centuries to happen**
    - We’re closely monitoring for any surprises due to calving (extra ice breaking off)

- What places are most vulnerable to sea level rise?
Population Distribution

11 of the 15 largest cities in the world are along coasts or estuaries

“It was estimated that in 2003, approximately 153 million people (53 percent of the nation’s population) lived in the 673 U.S. coastal counties, an increase of 33 million people since 1980.”

The population living within 1 m of sea level is unknown
**Low Lying Island Nations**

**Tuvalu:** highest point is 4.5 m above sea level

**Maldives:**
Max elev = 2.5 m  
Average elev: 1.5 m

**Some Caribbean nations are also quite vulnerable**

**Bahamas:** 80% within 1.5 m of sea level

These nations could **disappear**!
$30 billion of taxable property within 3 feet of high tide level in FL (not including Miami-Dade County)

Source: Surging Seas Report
Climate Central analysis
Costs of Sea Level Rise

- Main problems will likely be from large storm surges on top of the sea level rise

- Costs:
  - Wetland loss
  - Salinization of aquifers/crops
  - Constructing barriers
  - Relocation
How Might Ocean Circulation Change?

- Will currents change?
  - We’ll discuss the **thermohaline circulation**
    - And why claims of **Europe freezing over** with global warming are **overblown**
  - And **El Niño**
    - El Niño cycles are the most important **natural** climate variation
The Gulf Stream transports heat. It's driven by winds and is not subject to stopping.

Colors show Temperature.

AVHRR satellite.
Surface Flux (Ocean to Atmos)

2001~2010 ERA-I MSE Divergence minus CERES TOA Budget
(Implied Upward Surface Flux)
Thermohaline circulation, driven by heavy water sinking, also moves heat

This **could slow down** with global warming...
Atlantic circulation

North Atlantic Drift:
Part of thermohaline circulation driven by sinking of dense water near Greenland

Circulation could slow as surface water gets warmer & fresher at high latitudes (freshening from more rain & melting ice)

Less dense water $\Rightarrow$ Less sinking $\Rightarrow$ Slower circulation

If this weakened it would cause Europe to warm less
Natural Climate Variability: El Niño

Big warming of tropical Pacific during El Niño

Where would the rising motion shift to?
El Niño Rain Changes

- **Rain shifts** along with the warmer waters
- Coast of Peru (normally desert-like) becomes very rainy & tropical plants grow
  - It peaks around Christmas & fishermen liked it
  - “El Niño” = the Christ child

**More rain**
El Niño/Southern Oscillation

**La Niña conditions**

- Trade Winds
- Water heated by the sun
- Upwelling
- Thermocline

**Winds keep warm water to the west during La Niña**
Winds slacken, and the warm water/rising motion shift into the central Pacific.
El Niño Onset

Giant scale waves that move exactly on the equator are key for setting El Niño in motion!

Much smaller height changes than typical ocean waves – but huge in scale!
El Niño Impacts

- Drought in India/Australia, floods in S. America
- Pacific NW weather is affected significantly

- La Niña impacts are opposite to this
Another view of ENSO impacts
El Niño Affects Global Temperature

- Much warmer water in the Pacific during El Niño
- Enough to raise global temperature by 0.1-0.2 °C

Highlighted years are some recent El Niño events

Big ovals are the two biggest events of the century (1982-83, 1997-98)
ENSO Since 1950

- ENSO over last 60 yrs
Future of El Niño

- Very uncertain how El Niño will change in the future
- Could change regional precipitation responses
  - Also strongly affects things like local warming and precipitation
Summary of Ocean Circulation

- Gulf Stream will not slow down
  - It’s wind-driven
- North Atlantic Drift will likely slow some
  - This won’t freeze Europe, but may cause less warming there
- El Nino/Southern Oscillation
  - Very important for regional precipitation patterns
  - Uncertain how this will change with global warming