Anthropogenic Climate Change is Not “Yes or No”, It’s “How Much”?

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What do I do?

◊ I am a physical oceanographer

◊ I am a climate modeler

◊ I study currents, tides, turbulence—generally, the processes that move water, energy, and pollutants

◊ I use supercomputers, differential equations, statistics, and observations
How'd I get into this?

I was a physics major,
then a theoretical physics grad student,
then...
Work on what you love!
The Earth

Why it matters to me
Why it should matter to you
Why it should matter to your students
Breathing contributes to CO$_2$ buildup?

"Pollution; none of us are supporting putting substances into the atmosphere or the waterways that might be pollutants, but carbon dioxide is not a pollutant. If Senator Wong was really serious about her science she would stop breathing because you inhale air that's got 385 parts per million carbon dioxide in it and you exhale air with about ten times as much, and that extra carbon comes from what you eat. So that is absolute nonsense." (Ian Plimer)
Requires quantitative appreciation

Image: Skeptical Science
Carbon Budget of the 1990s

Reservoir sizes in GtC
Fluxes and Rates in GtC yr⁻¹

Human Impact

Little part of a bigger quantitative budget

Red shows measured Human Impact

Image: IPCC, 2013
Residence time: $Bucks in the Bank$$$

- **Steady-state:**
  - Income = pay/time = expenses/time = outflow
    - Steady savings in account (constant $ reservoir)

- **What if you lose your job?**
  - How long does it take to deplete the account?
    - Savings/(expenses/time) = Savings/Outflow = Drain time

- **Get a new job, and save EVERYTHING!**
  - How long does it take to build up back up savings?
    - Savings/(pay/time) = Savings/Income = Build time

- In steady-state, Income = Outflow, so
  - Drain time = build time = residence time
The "Keeling" curve. Shows our carbon budget is not balanced! Updated here by Pieter Tans, NOAA.
Breathing contributes to CO$_2$ buildup?

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Dilution is the Solution to Pollution...

- **Pollutant:** Any substance present in the environment in harmful concentration, which adversely alters the environment.

- **Qualitative Pollutant versus Quantitative Pollutant** Requires quantitative understanding
So, in a nutshell...

- The Earth is capable of absorbing some excess atmospheric carbon (land, life, ocean, rocks).
- It is the rate of emission that's the problem.
- Burning fossil fuels globally means taking millions of years worth of buried fossils and putting them in the atmosphere fast!
Global warming isn't just a carbon problem, though...

Carbon toxicity isn't the problem (except ocean acidification), it's that carbon dioxide affects energy on Earth.

Is Energy A Pollutant????
Quantitative: Surface Energy Budget

Category A) T change caused by forced $Q_{TOA}$

Category B) T change caused by unforced $Q_{TOA}$

Category C) T change caused by unforced $Q_{BML}$

$$\frac{dT}{dt} = \frac{Q_{net}}{C_m} = \frac{-Q_{TOA} + Q_{BML}}{C_m}$$

Slide: Brown et al., 2014
Superbuggets: Global Climate Models

A collection of physical, chemical, biological, and geological relationships and budgets—often constructed using sets of nonlinear partial differential equations solved numerically on a model grid.

Requires quantitative appreciation!!!!
Why do we want climate models?
Understanding, Experiments, Projections.
Source: IPCC AR4, 2007 via Kasting, Kump & Crane

Anthropogenic and Natural Forcing
- Observations
- Models

Temperature anomaly (°C)


(a) Santa Maria, Agung, El Chichon, Pinatubo

Modeling Planet A, our home!
Source: IPCC AR4, 2007 via Kasting, Kump & Crane

Natural Forcing Only
- Observations
- Models

Temperature anomaly (°C)

Santa Maria
Agung
El Chichon
Pinatubo

Modeling Planet B, Without us.

Year
1900 1920 1940 1960 1980 2000
How awesome are climate models?

These include *everything we know* about the atmosphere, ocean, cryosphere, biosphere, and lithosphere that might affect the climate!

Any one of these systems is enormously complicated—way too hard to solve the equations by hand—but using supercomputers we can experiment with the modeled system as a whole.

“All models are wrong, but some models are useful.” — Statistician George Box, 1978
Satellite altimetry view of energy in mesoscale eddies

AVISO: $\log_{10}(0.5(u^2 + v^2))$ on 19940101
What it may take to get a model to have these eddies:
We can't even forecast the weather two weeks ahead. How can we project the climate a century ahead?
Well, weather forecasts are getting better and better! (Magnusson & Kallen 2012), But...
Weather, Atmosphere
Fast
Ocean, Climate
Slow
3.4m of ocean water has same heat capacity as the WHOLE atmosphere

ECCO Movie: Chris Henze, NASA Ames

tau / qflx / theta200m / kppMLD  Jan 1  00:30  2001
Weather, Atmosphere

Fast

Ocean, Climate

Slow

3.4m of ocean water has same heat capacity as the WHOLE atmosphere

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tau / qflux / theta200m / kppMLD

Jan 1  00:30  2001
What's the same among the As? the budgets

Category A) T change caused by forced $Q_{TOA}$

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$$\frac{dT}{dt} = \frac{Q_{net}}{C_m} = -\frac{Q_{TOA} + Q_{BML}}{C_m}$$

Slide: Brown et al., 2014
Prediction & Attribution: Effects of Anthropogenic Forcing

Radiative forcing of climate between 1750 and 2011

Forcing agent:
- Well Mixed Greenhouse Gases
  - CO₂
  - Other WMGHG (CH₄, N₂O)
  - Halocarbons
- Ozone
  - Stratospheric
  - Tropospheric
- Stratospheric water vapour from CH₄
- Surface Albedo
  - Land Use
  - Black carbon on snow
- Contrails
  - Contrail induced cirrus
- Aerosol-Radiation Interac.
- Aerosol-Cloud Interac.
- Total anthropogenic
- Natural
  - Solar irradiance

Confidence Level:
- Very High
- High
- Medium
- Low
- High/Low

Radiative Forcing (W m⁻²):
- -1 to 3
Biggest Uncertainty: What will humans choose?
Don’t trust the models?
How do we observe that there’s excess energy? One important way: Sea Level Rise

Most of the excess energy ends up in the oceans

Water expands when it warms

Melting ice & snow on land takes up energy and also adds ocean water
Another reason to care about ocean warming—and to observe it (by subtraction): Sea Level Rise

\[
\text{(Sea Level)-(Ocean Mass)/Density/Area}=\text{Thermosteric Expansion}
\]

IPCC AR5, 2013
OK—there's a problem
What can we do?
What can we do? Teach!

“When I do teach about climate change, I emphasize...”

- the scientific consensus that recent global warming is primarily being caused by human release of greenhouse gases from fossil fuels.
- that many scientists believe that recent increases in temperature are likely due to natural causes.

<table>
<thead>
<tr>
<th>Agree or strongly agree</th>
<th>Disagree or strongly disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed messages 31%</td>
<td>Scientific consensus 54%</td>
</tr>
</tbody>
</table>

Disagree or strongly disagree

- Denial 10%
- Avoidance 5%

Teachers’ emphasis. Teachers reported emphasis on causes of global warming, among those devoting an hour or more to the topic (see SM for details on calculation).

Survey: Do you think human activity is a significant contributing factor in changing mean global temperatures? (Doran & Zimmerman 2009)

![Graph showing survey responses]

Fig. 1. Response distribution to our survey question 2. The general public data come from a 2008 Gallup poll (see http://www.gallup.com/poll/1615/Environment.aspx).
Alternative or Disinformation?
How many of you got one of these?

- Who is the NIPCC?
- Are they the same as the IPCC?
- Didn’t they win a Nobel Prize with Al Gore?
IPCC vs. NIPCC?

- The gold standard of recording climate change consensus
- United Nations Intergovernmental Panel on Climate Change
- (UN IPCC, not NIPCC)
Question: By Show of Hands Indicate Whether You Have Heard that the IPCC is

- A) Wrong
- B) Independent Police Complaints Commission of England & Wales
- C) Together with Al Gore, they invented the internet
- D) The Intergovernmental Panel on Climate Change, a nonpolitical group that reviews peer-reviewed climate science and summarizes it for policymakers, who won a Nobel Peace Prize shared with Al Gore.
Sowing Climate Doubt Among Schoolteachers

By CURT STAGER  APRIL 27, 2017
Teach Accurate Sources!

- realclimate.com, desmogblog.com, skepticalscience.com

Better Yet (but require quantitative appreciation!):

- Scientific Societies: AMS, AGU, AAAS, National Academies, etc.
- Gov't & Public-funded Research: US National Parks, NOAA, NASA, EPA, ONR, WMO, UN Intergovernmental Panel on Climate Change (IPCC)
Does consensus matter? Doesn't it matter more who is correct?

Einstein

Tesla

Vaughn, Jackson, Johnson

Musk

Noether

Carson

Johnston
We can all hope for a genius to save us...

But, we can all do our part to make the job easier...
What can we do?

Greenhouse Gas Emissions by Economic Sectors

Direct Emissions
- Electricity and Heat Production: 25%
- AFOLU: 24%
- Buildings: 6.4%
- Transport: 14%
- Industry: 21%
- Other Energy: 9.6%

Indirect CO₂ Emissions
- Energy: 1.4%
- Industry: 11%
- Transport: 0.3%
- Buildings: 12%
- AFOLU: 0.87%

Total: 49 Gt CO₂ eq (2010)

IPCC AR5, 2013
Solve the problem with changes in one industry?

**Dieting equivalent:**

Lose weight by only eliminating desserts.
Climate “Wedges”


Diet equivalent: Consistently make good choices

benefits from quantitative appreciation
Obama-Era Plans to satisfy Paris Agreement

Source: NYTimes
Obama-Era Plans to satisfy Paris Agreement
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“Carbon Dividends” make polluters pay a “dividend” to everyone else to buy the ability to emit carbon.

“On-again-off-again regulation is a poor way to protect the environment.”

How to reduce carbon isn’t a science question, it’s a political one!
What can we do?

GeoEngineering

- If ENERGY is the problem, maybe change the energy cycle (a.k.a. GeoEngineering):
  - Green roofing/albedo modification
  - Ecosystem modification—plant trees, alter carbon pathways...
  - Inhibit solar input (cloud brightening, stratospheric aerosols...)

“First, Do No Harm”: Side Effects?

Diet equivalent: Weight loss pill
WHAT WE CAN’T DO: NOTHING

We can ignore the problem for now...then adapt.

We are affecting the global climate.

We can choose paths to reduce the effect, or we will adapt to the changing climate.

Diet equivalent to adaptation: Treat the diseases that come with obesity
How to handle climate change is part science, part technology, part politics.

All require quantitative thinking.

What we can do is teach our students quantitative skills and an appreciation for accurate, precise information.