

The Science of Climate Change

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Tim Del Sole and Mike Reed started with two pieces of typing paper and a half meter of masking tape . . .

A Dynasty At Parkland

Third Straight Win
In "Physics Olympics"

By STEPHEN BRICK
Special Staff Reporter

Physics is a team sport at Parkland. *Senior Staff Writer*

Last week, 15 Parkland students coached by Bob Bartmann, the school's physics teacher, won the regional "Physics Olympics" at the University of North Carolina at Greensboro. By taking first place for the third year in a row, they retained the Olympic trophy.

The opponents of the Parkland team, Tim Del Sole and Mike Reed, apparently set a national record when they took two sheets of typing paper and a half meter (16.7 inches) of masking tape and built a tower 9 feet, 4 inches tall.

Their tower, which had to be finished within 20 minutes and had to stand without support for 20 seconds, was 26 inches from the floor to the top.

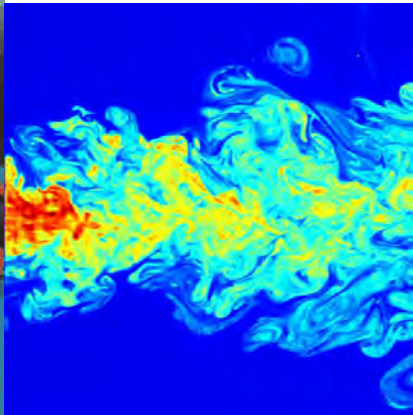
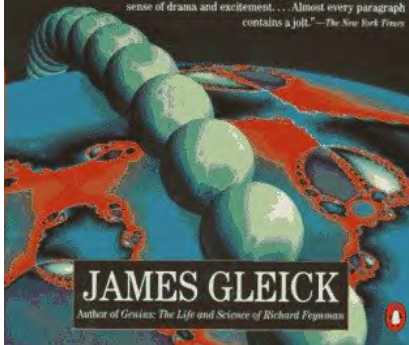


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CHAOS

MAKING A NEW SCIENCE

"These are fascinating stories of insight and discovery, told with a keen sense of drama and excitement. . . . Almost every paragraph contains a jolt."—*The New York Times*



Climate Change

Humans Burn Fossil Fuels



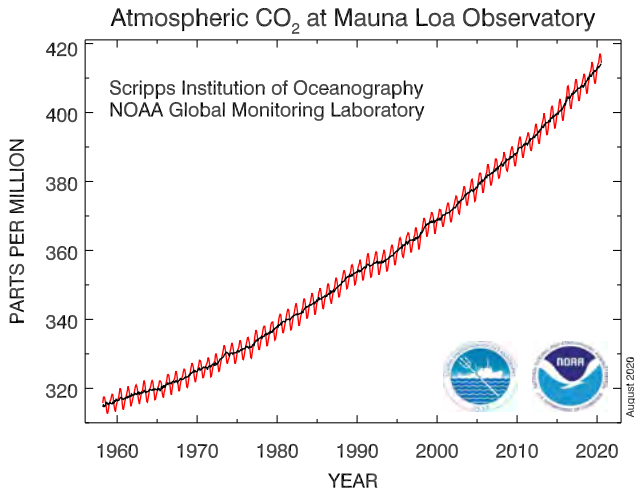
4 billion tons C
per year

1.8 billion tons C
per year

3.2 billion tons C
per year

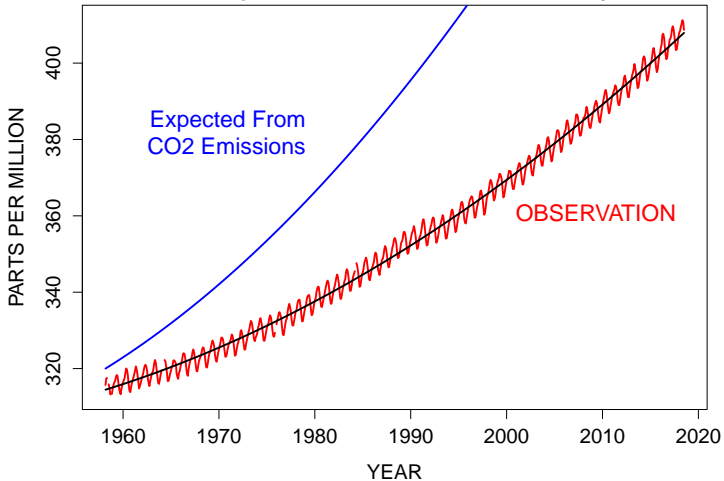
figure from <https://socratic.org/questions/what-are-some-examples-of-fossil-fuels-1>; numbers from Carbon Dioxide Information Analysis Center http://cdiac.ess-dive.lbl.gov/trends/emis/tre_glob_2014.html

Atmospheric CO₂ Concentration is Rising



1ppm = 7.8B tons <http://www.esrl.noaa.gov/gmd/ccgg/trends/>

Atmospheric CO2 at Mauna Loa Observatory



The Change is Unprecedented over the Past 800,000 years

CO₂ during ice ages and warm periods for the past 800,000 years

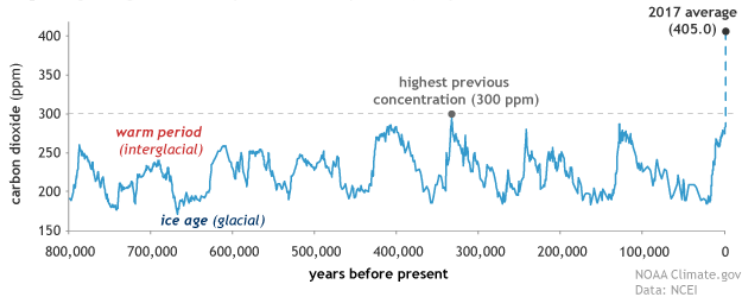


figure from <http://www.android-games.download/ice-age-carbon-release>

The Change is Unprecedented over the Past 800,000 years

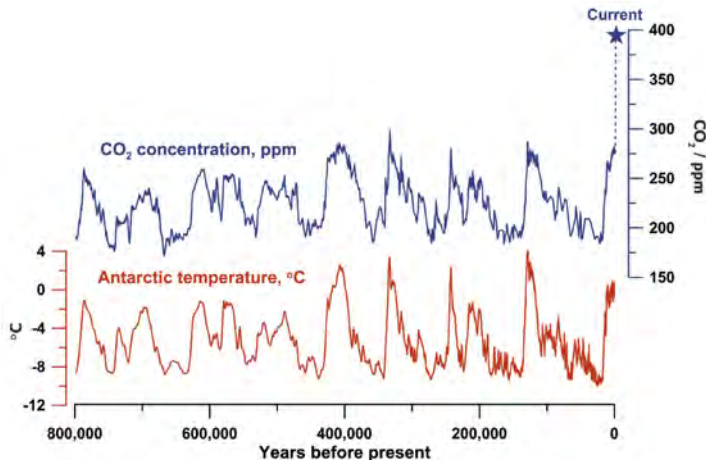
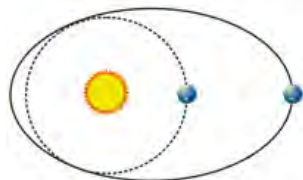


figure from <http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/>

What Caused the Ice Ages?

Milankovitch Cycles



Eccentricity

100,000 years



Obliquity

41,000 years



Precession

26,000 years

figure from

<http://www.skepticalscience.com/co2-lags-temperature-intermediate.htm>

Orbital Parameters and CO2

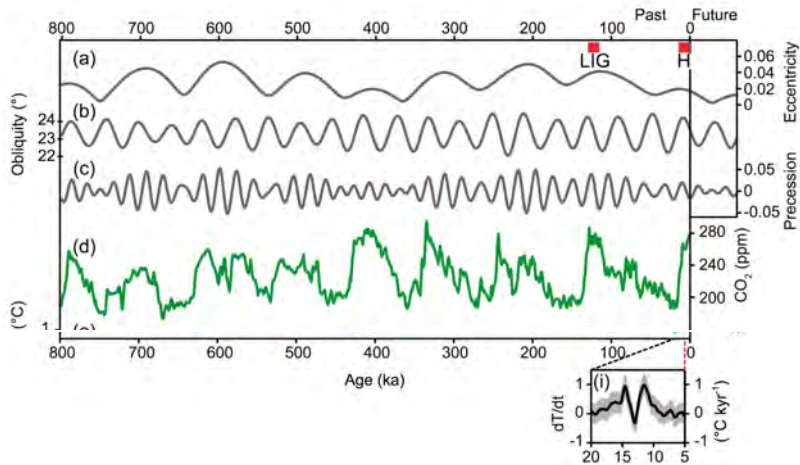
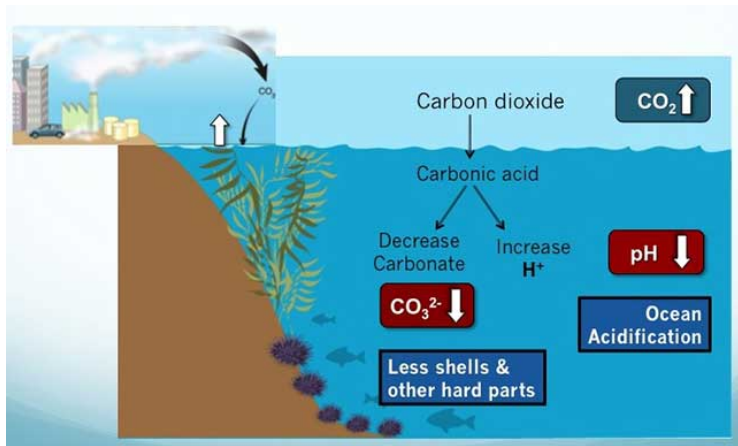


figure 5.3 of IPCC WG1-AR5 report

Impact of Increasing Atmospheric CO₂

Impact of Increasing CO₂: Ocean Acidification



<http://marinesciencetoday.com/2014/03/12/ocean-acidification-the-devastating-truth/>

Ocean pH

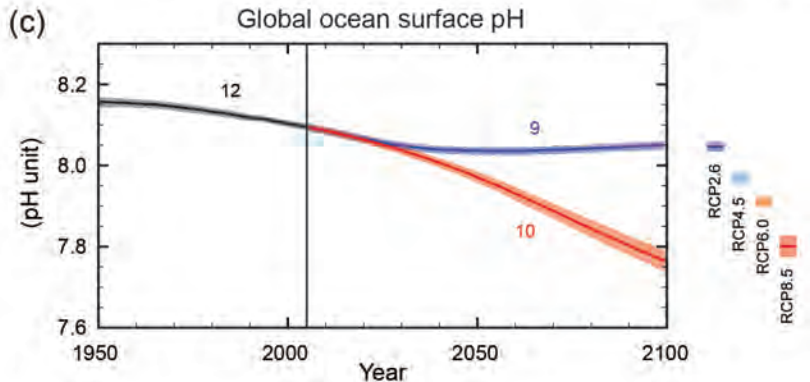


figure 7 in Summary for Policy Makers of IPCC WG1-AR5 report

Impact of Ocean Acidification

A mollusc shell dissolves after 45 days when placed in seawater with pH and carbonate levels projected by models for the year 2100.



Carbon Dioxide is a Greenhouse Gas

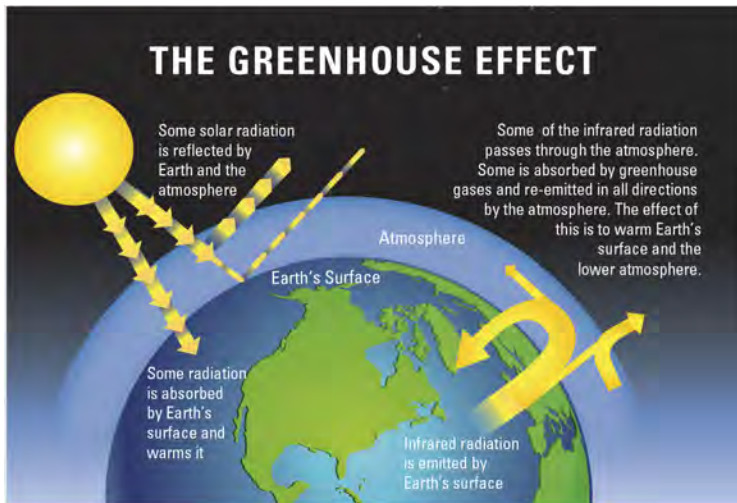
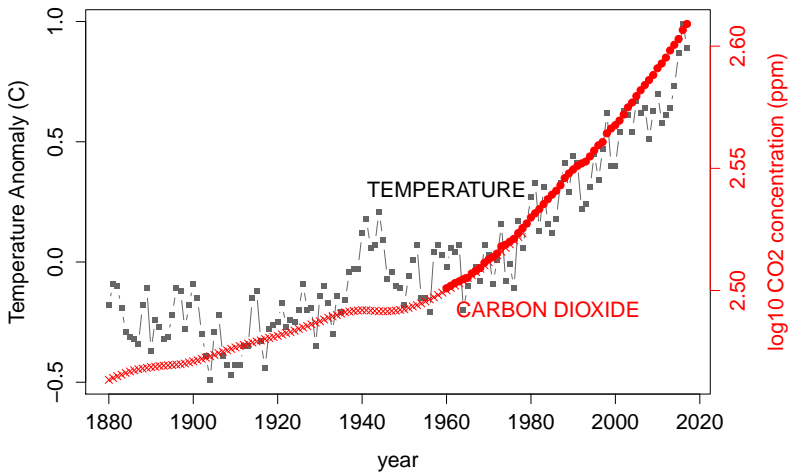


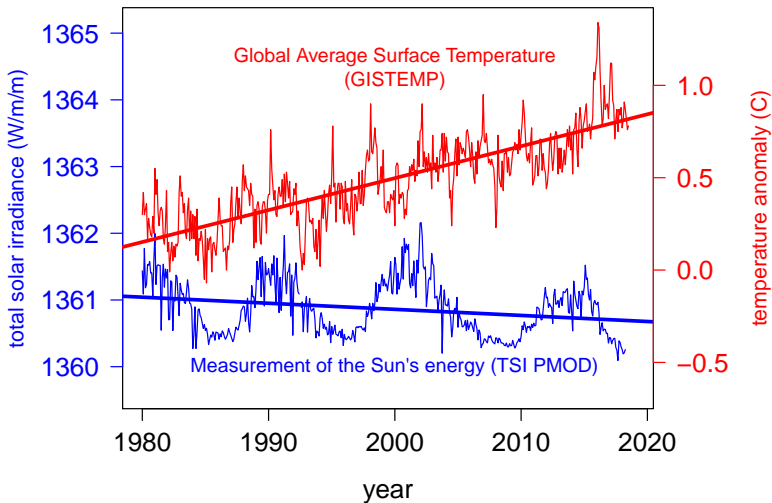
figure from <http://nas-sites.org/americasclimatechoices/events/a-discussion-on-climate-change-evidence-and-causes/>



Other Plausible Causes of Warming

- ▶ natural causes (like those associated with ice ages)
- ▶ volcanic eruptions (these COOL the planet)
- ▶ solar variations (like those associated with sun spots)
- ▶ natural causes (like those associated with year-to-year changes)

Observed Warming is Inconsistent with Solar Causes



**How Do We Know the Warming is Not Natural?
Climate Models offer an Independent Approach.**

Laws of Physics



Momentum



Mass



Thermodynamics

<https://commons.wikimedia.org/wiki/File:GodfreyKneller-IsaacNewton-1689.jpg>
<https://www.britannica.com/biography/Antoine-Lavoisier/images-videos>
https://commons.wikimedia.org/wiki/File:PSM_V35_D010_Rudolf_Julius_Emanuel_Clausius.jpg

► **Conservation of Momentum**

$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla \bar{p} + \mu \nabla^2 \mathbf{u} + \frac{1}{3} \mu \nabla (\nabla \cdot \mathbf{u}) + \rho \mathbf{g} \\ - \rho \left(2\boldsymbol{\Omega} \times \mathbf{u} + \boldsymbol{\Omega} \times (\boldsymbol{\Omega} \times \mathbf{x}) + \frac{d\mathbf{U}}{dt} + \frac{d\boldsymbol{\Omega}}{dt} \times \mathbf{x} \right)$$

► **Conservation of Mass**

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = 0$$

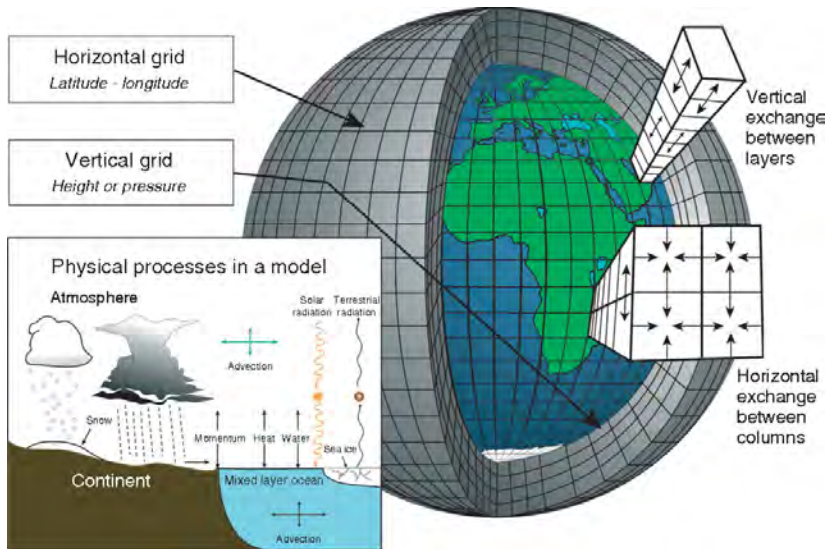
► **Conservation of Energy**

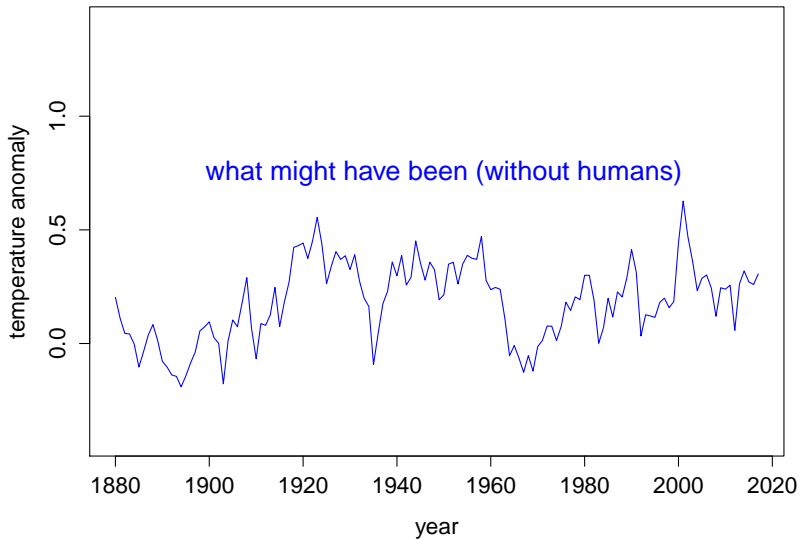
$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + \nabla \cdot (k \nabla T) + \Phi$$

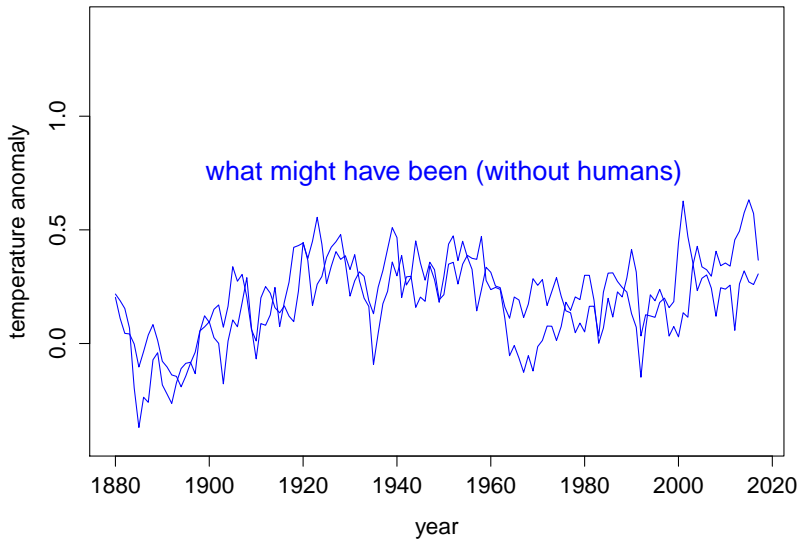
► **Radiative Transfer**

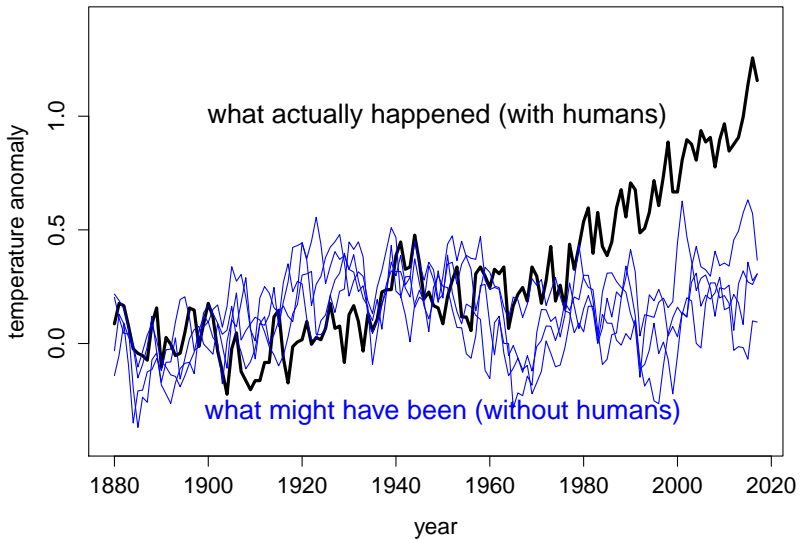
$$\frac{1}{c} \frac{\partial}{\partial t} I_\nu + \hat{\boldsymbol{\Omega}} \cdot \nabla I_\nu + (k_{\nu,s} + k_{\nu,a}) I_\nu = j_\nu + \frac{1}{4\pi} k_{\nu,s} \int_{\Omega} I_\nu d\Omega$$

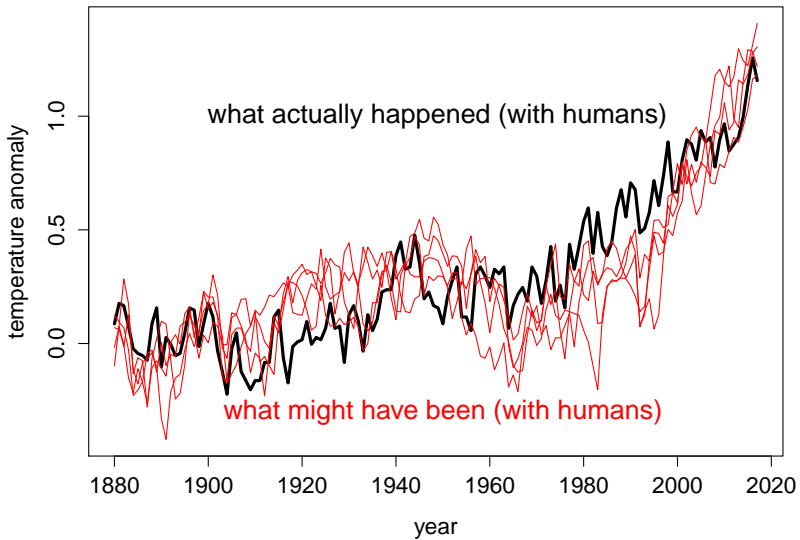
Parameterizations











Climate Models Simulate Observed Temperature Changes

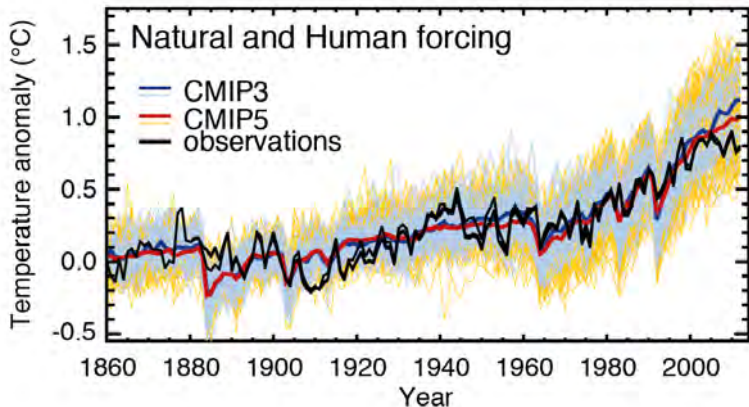


figure FAQ 10.1-1 of IPCC WG1-AR5 report

Climate Models without Anthropogenic Forcing

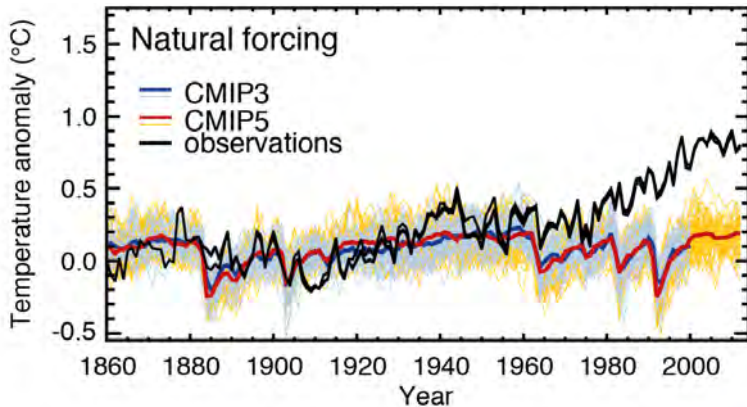


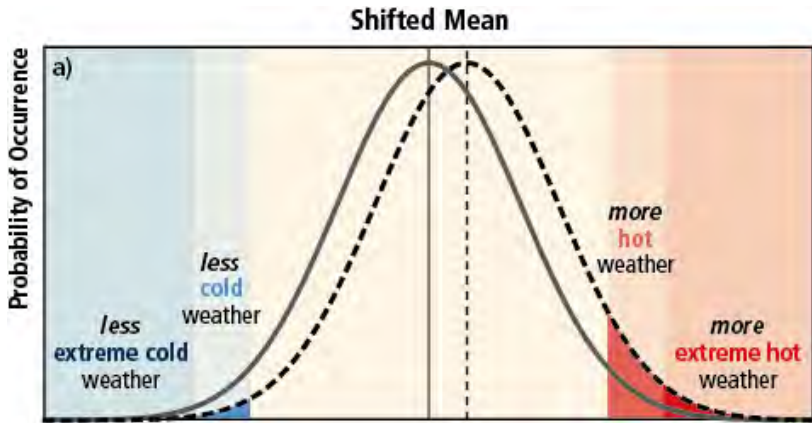
figure FAQ 10.1-1 of IPCC WG1-AR5 report

Global warming observed over the past half century is

- ▶ consistent with expectations for man-made warming
- ▶ impossible to explain by volcanic and solar variations
- ▶ very unlikely due to natural internal variability (less than 1 out of 500 million chance)

Expected Consequences of Global Warming

Virtually certain there will be more frequent hot and fewer cold temperature extremes over most land areas as global mean temperatures increase. Heat waves will very likely occur with higher frequency and duration. Occasional cold winter extremes will continue to occur.



Water Expands When it Warms

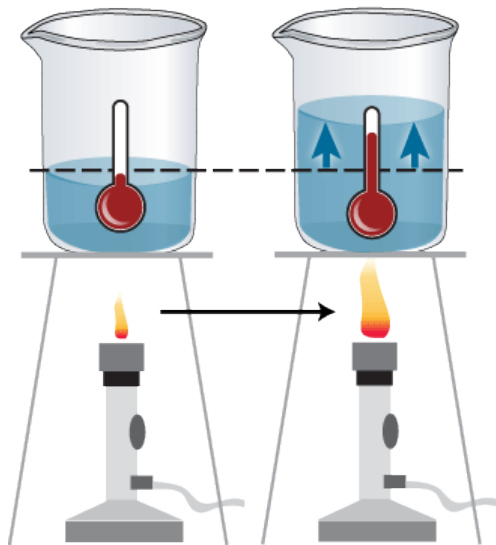


figure from http://www.teachoceanscience.net/teaching_resources/education_modules/barrier_islands_and_sea_level_rise/learn/

Land Ice Melts When it Warms

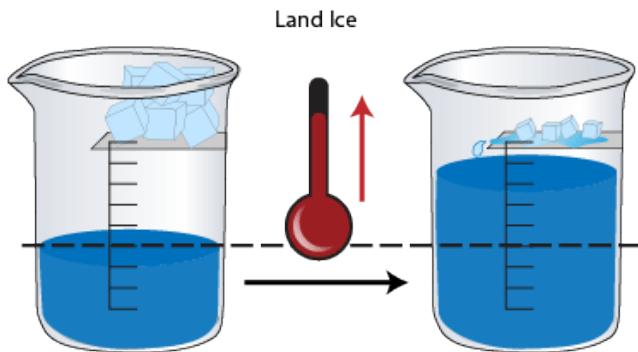


figure from http://www.teachoceanscience.net/teaching_resources/education_modules/barrier_islands_and_sea_level_rise/learn/

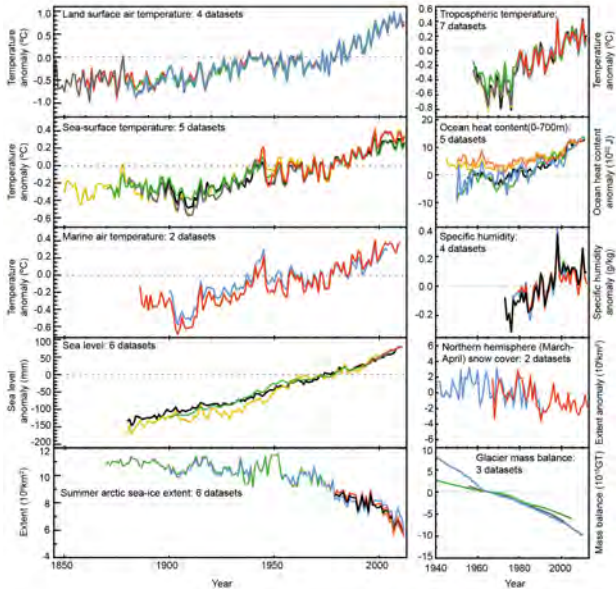
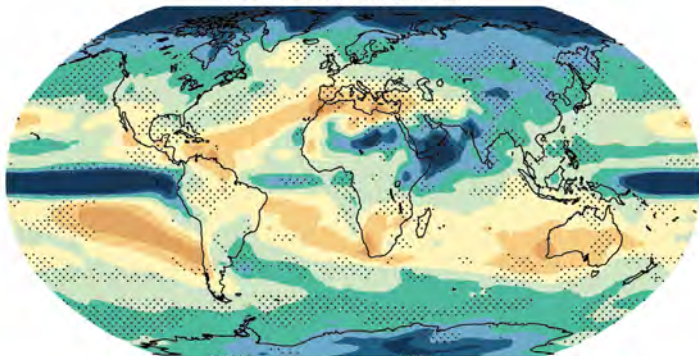


figure FAQ2.1 of IPCC WG1-AR5 report

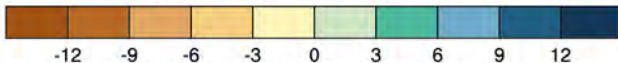


- ▶ Warmer climate means more evaporation.
- ▶ Increased land evaporation makes crops more susceptible to drought.
- ▶ Warmer air holds more water, increasing chance of heavy rainfall.

CMIP5 : 2081-2100



(% per °C global mean change)



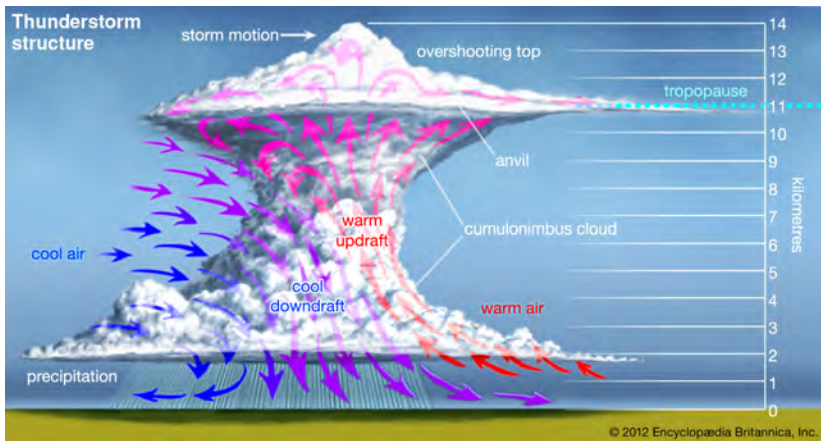
percent precipitation change scaled by the corresponding global average temperature changes. dots show significance change.

Another Consequence of Warming

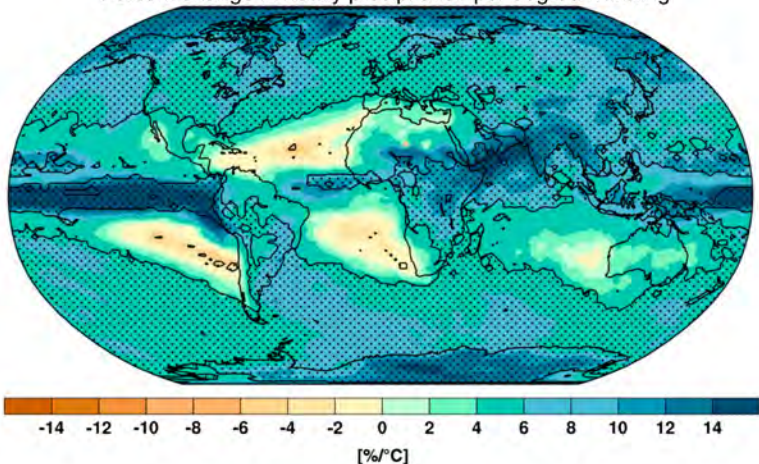
Warm air can hold more water vapor than cold air.



figure from http://wonderopolis.org/wp-content/uploads/2012/01/breathing-horse_shutterstock_20263039-640x385.jpg

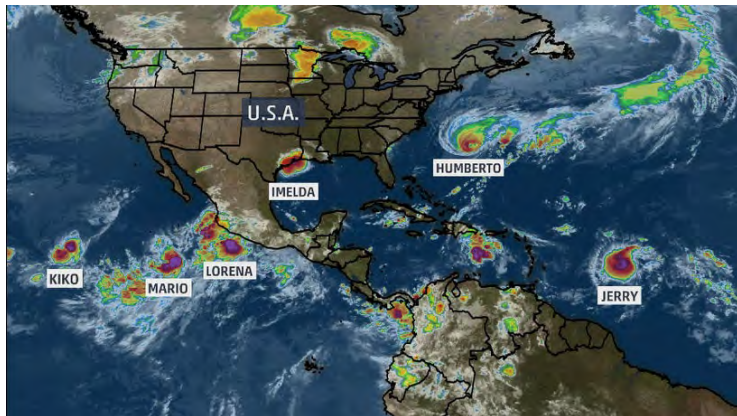


Percent change in heavy precipitation per degree warming



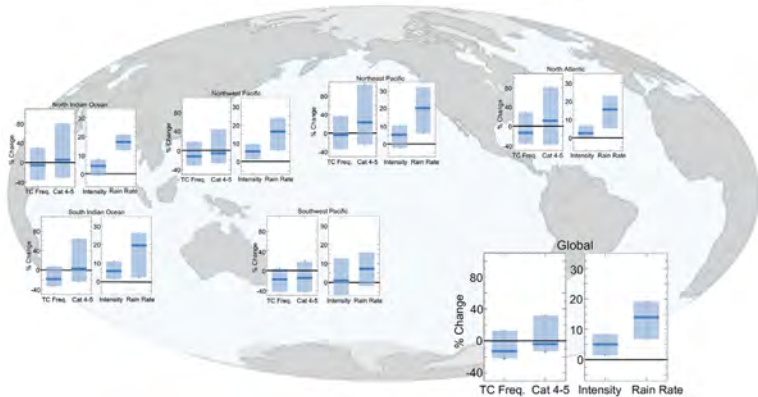
Fischer et al. 2014, *Geophys Res Lett*, maximum 1 day precipitation in a year, <https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2014GL062018>,

Record 6 Named Storms at Once in Atlantic and E. Pacific



September 18, 2020 <https://weather.com/storms/hurricane/news/2019-09-18-six-named-storms-ties-record-atlantic-eastern-pacific>

Tropical Cyclone Projections (2°C Global Warming)



What Should Be Done?

Reduce Carbon in the Atmosphere

Put a Price on Carbon

- ▶ Cap and trade?
- ▶ Carbon Tax?

Republicans and Democrats agree on many climate change fixes

- ▶ increasing energy efficiency
- ▶ modernizing the electric grid
- ▶ investing in research to remove CO2 from the atmosphere
- ▶ expand reforestation efforts
- ▶ create nationwide system of low pollution, high-speed trains.

<https://www.usatoday.com/story/news/nation/2020/01/24/climate-change-poll-republicans-democrats-agree-solutions/2838696001/>

Taxes



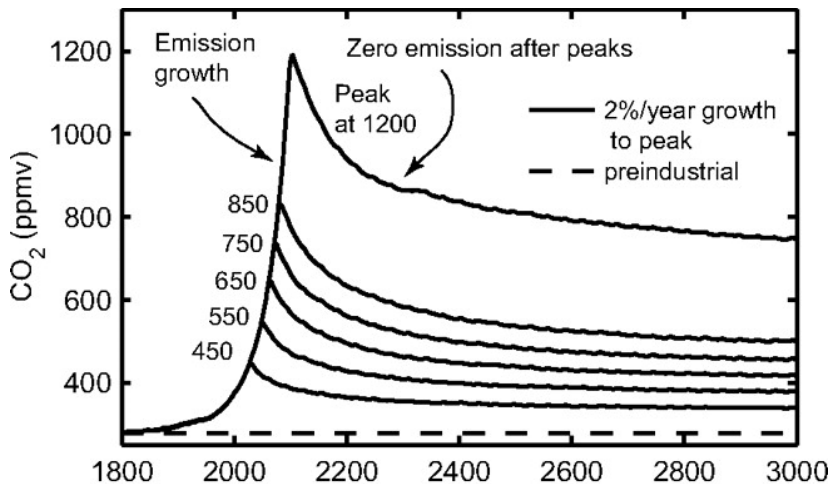
Free Resources Will Be Exploited in a Competitive Market



<http://www.nationalgeographic.com/environment/global-warming/pollution/>
<http://www.cleanwateraction.org/2016/08/04/we-must-protect-potomac-river-toxic-sewage-dumping>



<http://www.environmentmagazine.org/archives/back%20issues/november-december%202010/not-co2-emission-full.html>



from fig. 1 of Solomon et al., 2009: Irreversible climate change due to carbon dioxide emissions. PNAS, 106, 1704-1709

Support for a Price on Carbon

- ▶ Republican Climate Leadership Council
 - ▶ James A. Baker III, treasury secretary for Reagan
 - ▶ Henry M. Paulson Jr., treasury secretary for George W. Bush
 - ▶ George P. Shultz, secretary of state for Reagan
 - ▶ Thomas Stephenson, a partner at Sequoia Capital, venture-capital firm
 - ▶ Rob Walton, chairman of Walmart for 23 years
- ▶ Revenue-neutral carbon tax can be structured so most tax-payers receive more refunds than they pay in higher energy prices: free market solution, doesn't grow government, actually increases GDP
- ▶ Consensus among economists with expertise in climate
- ▶ British Columbia imposed revenue-neutral carbon tax: reduced consumption, lower income tax, no loss of jobs/economic growth.

Summary

1. the earth is warming.
2. the warming is primarily due to human activity.
3. there is no real scientific reason to hope that future climate impacts won't be costly overall.
4. there are reasonable win-win policies to change direction.