The Hot and Cold of Climate

Osher Lifelong Learning Institute
University of Richmond, October 2024 - Part I

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A copy of the course slides in PDF format are available for download on the website
www.dracorex.com/osher/climate

ACKNOWLEGEMENT

The presenter would like to acknowledge his long-time friend and fellow engineer Mike Turco for the use of many of the slides used in this presentation.

Mike's presence in this world is sorely missed.

4

Qualifications?
Who is this guy and why does he think he knows anything about climate?

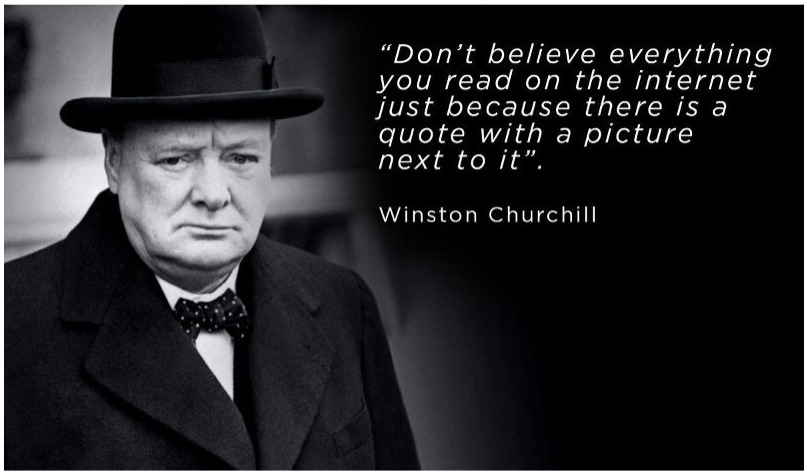
Not only is he not a climatologist,
he's not even a scientist!

- Climatology → Applied Physics of Fluids (liquid, gas)
- Behavior of fluids → Thermodynamics, Heat Transfer and Fluid Mechanics → Mechanical Eng.
- Climatology → Radiation transport → Nuclear Eng.
- Undergraduate degree in Physics
- Graduate degree in Nuclear Engineering
- 15 years teaching undergraduate and graduate courses in Nuclear and Mechanical Engineering including courses in Radiation Transport, Thermodynamics, Energy and Sustainability, Computer Modeling and Statistical Analysis
- Climate models are CFD (Computational Fluid Dynamics) models
- Three decades experience working with CFD models as a Nuclear Engineer

BEWARE!

Argument from Authority

(aka Appeal to Authority)



It is the presenter's contention that he has no dog in this fight

The presenter requests the following of the attendees of this course…

DON'T SHOOT THE MESSENGER!

Your humble presenter

COURSE GOALS

- Better understanding of climate and the controversies associated with climate
- Not possible to even begin to address all the issues, topics, points of debate
- **Attempt** at Objectivity (Not necessarily realizable
- Warning! Just about every argument & graph presented is, to some extent, **Controversial**
- Focus on **DATA** versus opinion (even expert opinion)

FOCUS ON THE DATA

"Without ***DATA***, you're just another person with an opinion." – W. Edwards Deming

It is possible for two knowledgeable people to view the same data, but come to different conclusions about that data.

Weather versus Climate

weather – The state of the atmosphere on a day-to-day basis at a place and time with regards to temperature, precipitation, wind, humidity, and other conditions.

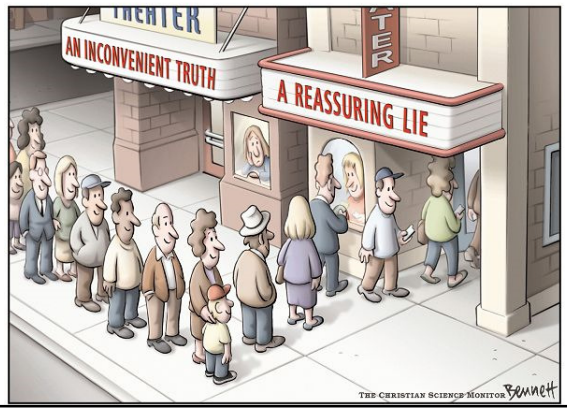
Climate is what you expect, weather is what you get.

climate – Long-term weather pattern of a region. How long? Averaged over 30 years generally accepted.

THE PROPOSITION

The Anthropogenic Global Warming (AGW) Hypothesis

The Earth is warming at a dangerous rate due to the emission of *greenhouse gases* into the atmosphere as a result of human activity. If left unchecked, this poses an 'existential' threat to the future of humanity.



Over the years, the presenter's views on AGW have undergone a near 180° change.

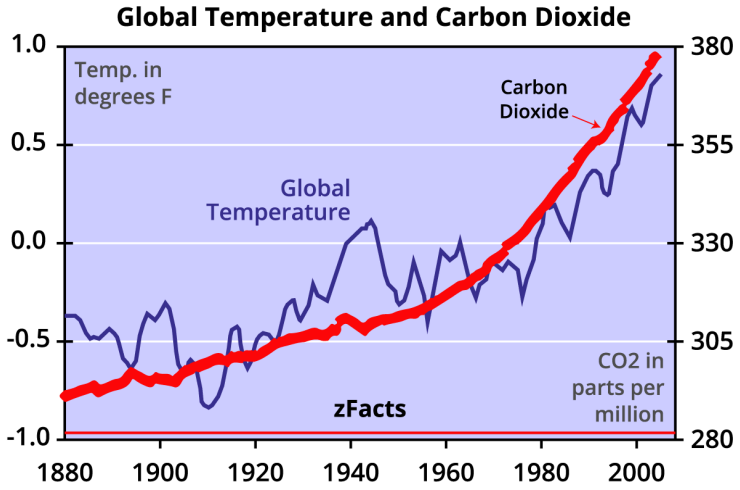
Greenhouse Gases (GHGs)

Gases in Earth's atmosphere thought to raise the planet's surface temperature

Quiz: The most potent GHG is:

1. Methane (CH_4)
2. Water vapor (H_2O)
3. Nitrogen (N_2)
4. Carbon dioxide (CO_2)

The "Proposition" derives from plots like this:



As the concentration of GHGs (greenhouse gases, e.g., CO_2) increases, so does the temperature → Cause-and-effect or Coincidence?

Key Questions:

1. Is the Warming due to Human Activity or Natural?

2. If the warming is mostly due to human activity, does it pose a threat?

3. If a *Threat*, what actions, if any, should be taken to mitigate this *Threat*?

Opinions Vary

"We have at most ten years—not ten years to decide upon action, but ten years to alter fundamentally the trajectory of global greenhouse emissions."
-- Dr. James Hansen, former director of the NASA Goddard Institute for Space Studies

1988 landmark address to Congress

Warmist

"What historians will definitely wonder about in future centuries is how deeply flawed logic … actually enabled a coalition of powerful special interests to convince nearly everyone in the world that CO2 from human industry was a dangerous, planet-destroying toxin. …that CO2, the life of plants, was considered for a time to be a deadly poison."

Skeptic

Richard Lindzen, Alfred P. Sloan Professor of Meteorology at MIT (ret.)

"Global warming is real - it is man-made and it is an important problem. But it is not the end of the world."

Bjorn Lomborg, political scientist, author of the best-selling book *The Skeptical Environmentalist*, and president of the Copenhagen Consensus Center think tank.

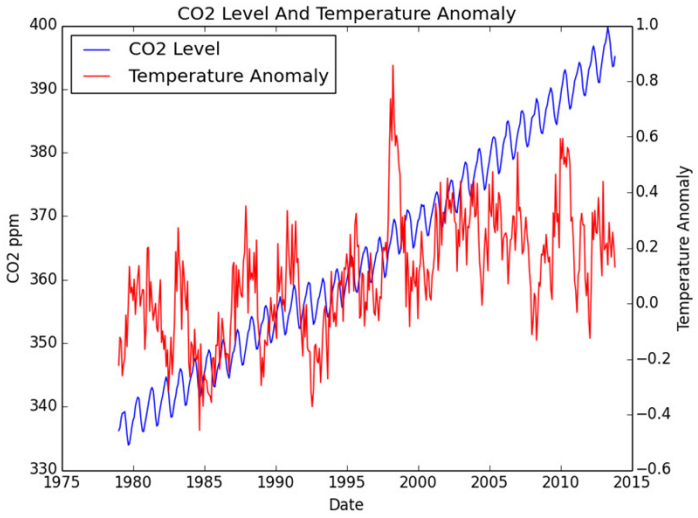
Moderate

Course Organization

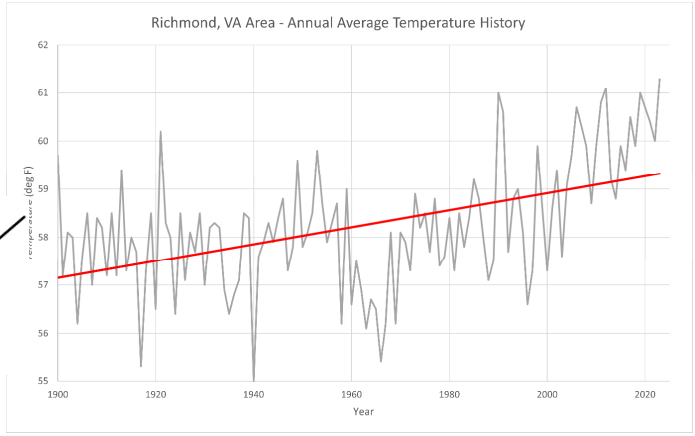
- Part I – Data and Theory
- Part II – Is Warming Human Caused or Natural?
- Part III – What should we do?

Temperatures appear to be increasing as GHG (e.g., CO_2) concentrations increase.

Cause and effect or coincidence?



Little disagreement that, overall, global temperatures have risen of late.

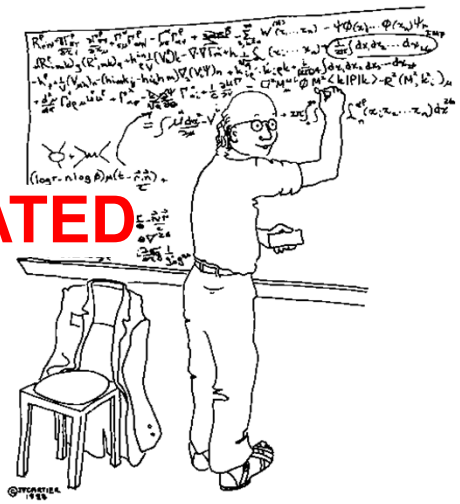


The crux of the debate is: To what extent is this rise in temperature due to human activity versus nature?

BE FOREWARNED!

THE CLIMATE IS

VERY
VERY
VERY
COMPLICATED



"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."

What do we mean by the phrase, "Understanding the climate?"

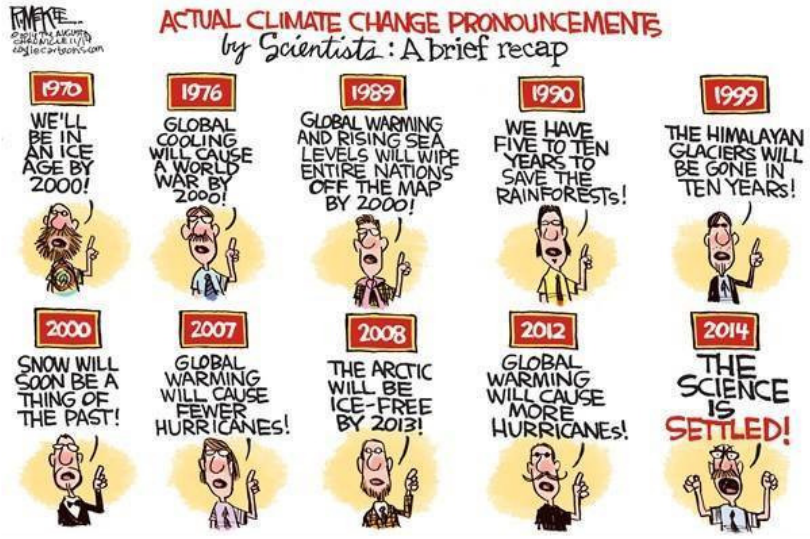
Scientific method:

1. Collect data by observation and experiment → If it can't be measured, it's NOT Science
2. Try to make sense of the data → hypotheses (theories)
3. Weed out the theories through testing their predictions against (new) data

"… the great tragedy of science—the slaying of a beautiful hypothesis by an ugly fact"

-- Thomas Huxley

We will "Understand" the Climate when we can PREDICT IT



But first
we need some basic
Physics

Thermal Energy
Temperature
Heat

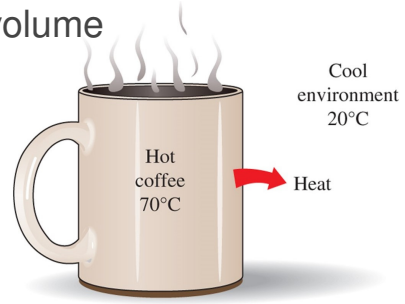
Temperature Versus Heat

- **Thermal Energy** – Amount of Energy stored in a material due to the motion of the atoms and molecules that make up that material. Units of Joules, J. For example, a pound of ice has less thermal energy than a pound of water at room temperature.
- **Temperature** – A measure of the AVERAGE energy of motion of the atoms and molecules that make up a material, i.e., a measure of its thermal energy. Celsius, °C
- **Heat** - Measure of the thermal energy transfer between two materials due to a difference in temperatures. Units of Joules, J.

Consider a bathtub and a cup both full of water at the same temperature.
Although the temperatures are the same, the thermal energy of the water in the bathtub is very much greater than that of the water in the cup.

- Adding more heat (thermal energy) to a material increases its temperature.
- Ability of water to store thermal energy is ~5200x that of an equal volume of air
- Oceans store over 99.9% of the thermal energy contained in the entire ocean/atmosphere system.
- Why! Water is more dense than air → More moelcules in a given volume

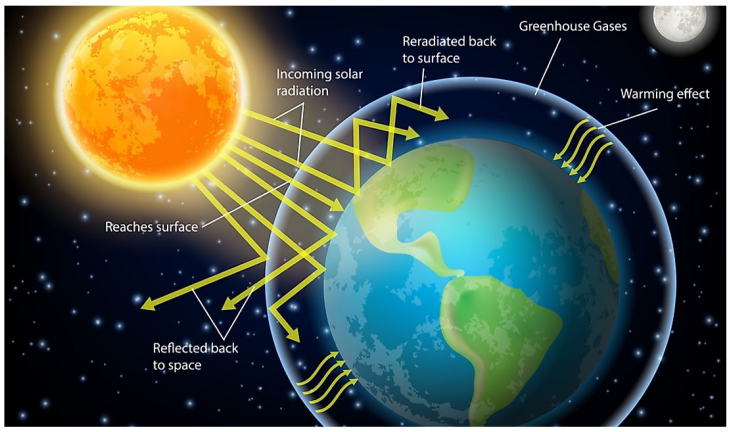
2nd LAW: Natural heat flow is from a body of higher temperature to a body of lower temperature.



- Sun – Source of Energy that drives the Climate
- With no atmosphere, temperature of Earth would be somewhere rough -19°C.
- Actual average temperature of Earth ≈ 15.5 °C

ENERGY BALANCE

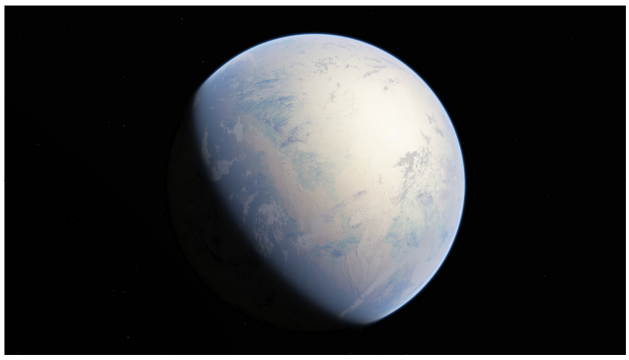
Energy received from the Sun =
Energy reflected back into space
→ Temperature of Earth remains constant



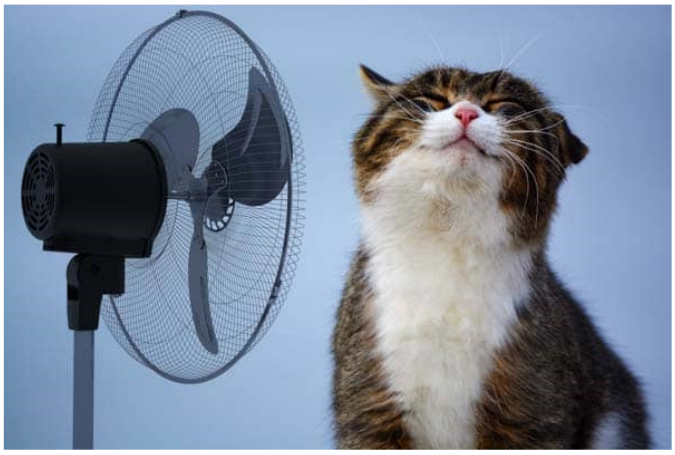
Energy received from the Sun <
Energy reflected back into space
→ Earth Cools

Snowball Earth

Global glaciation before 650 Ma

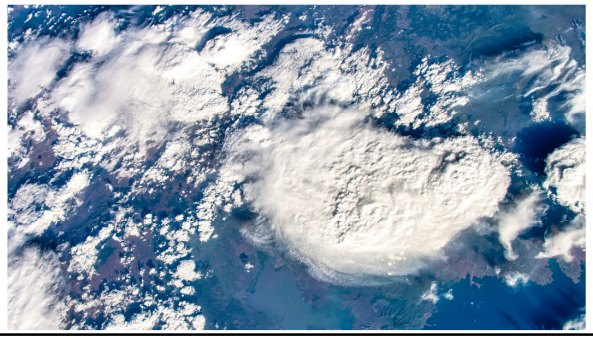


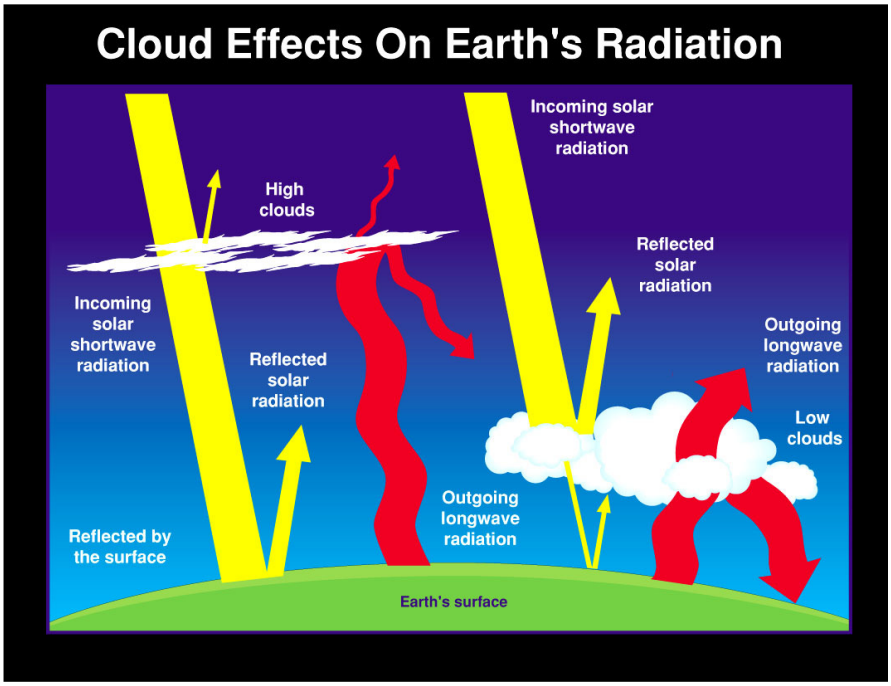
Energy received from the Sun >
Energy reflected back into space
→ Earth Warms



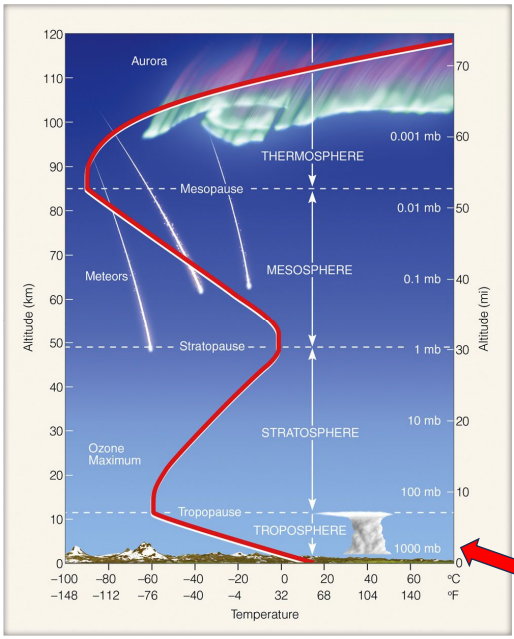
ENERGY BALANCE

- ~30% of solar radiation reflected back into space (clouds, ice, deserts, and water)
- Variation in **Cloud** cover a **Critical** factor in Climate
- Clouds Cool the Earth during the Day- Reflect sunlight
- Clouds Warm the Earth at Night – Capture surface radiation





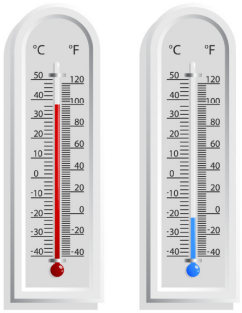
Atmosphere and Weather



Troposphere: Temperature falls with altitude
Convective heat transfer important (wind)
Stratosphere: Temperature rises with altitude (but so what?)
Radiative heat transfer important

WEATHER

- Ideally, we would like to know how the thermal energy content of the atmosphere and hydrosphere (seas and oceans) is changing with time.
- We are stuck with measuring not the thermal energy, but instead TEMPERATURE.
  - How does one determine the change in global average temperature?



Does the concept of a global average temperature even make sense?

"there is no physically meaningful global temperature for the Earth in the context of the issue of global warming" – Essex, McKitrick and Andersen, 2007

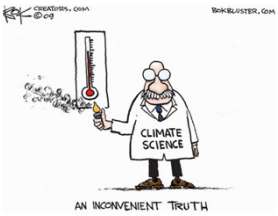
"there are over 100 different ways in which the daily mean temperature has been calculated by meteorologists" – Peterson and Vose, 1997

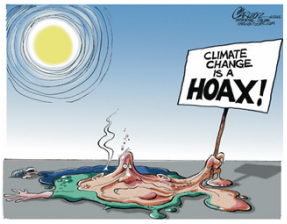
Why is Measuring Temperature So Important!

1. Confirm a key point of AGW that the globe is heating up
2. If it is not, then the theory fails

Source of Temperature Data

1. Land surface temperatures
2. Ocean temperatures at various depths
3. Atmospheric temperatures at various elevations → satellites and weather balloons





Surface Temperature Measurements

- Temperatures change by time and place
- Polar regions most affected
- Tropics show little change
- Three main surface temperature records:
  - GISS (NASA Goddard Institute for Space Studies
  - US National Climate Data Center (NOAA)
  - HadCRUT (IPCC favorite)

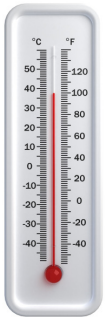
IPCC

- U.N. Intergovernmental Panel on Climate Change (1988), Geneva, Switzerland
- Mission is 'to assess ... the scientific basis of risk of **human-induced climate change**, its potential impacts and options for adaptation and migration
  - Working Group I: Physical science basis
  - Working Group II: Assesses the vulnerability of socio-economic and natural system to climate change
  - Working Group III: Mitigation of climate change
  - Synthesis report
- Annual Assessments: 1990, 1995, 2001, 2007, 2014, 2023

Land Surface Temperatures

- Maximum/Minimum Temperature Sensor (MMTS) – RTD (resistance temperature detector—i.e., thermocouple)
- Housed in a "beehive" – standard 2-meter height
- Lower 2 meters of atmosphere contains 0.00002% of thermal energy.

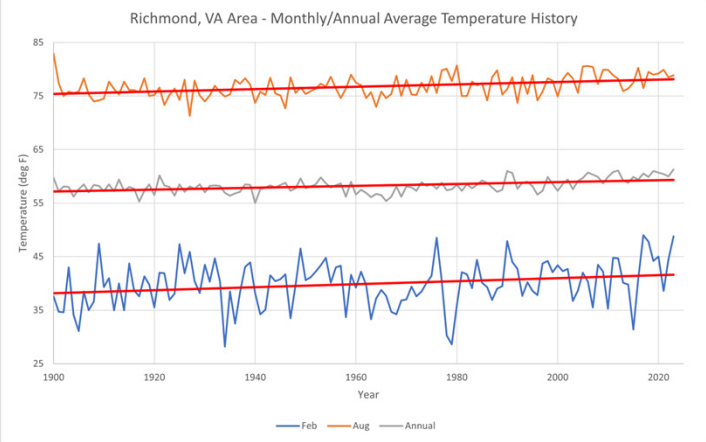
Old



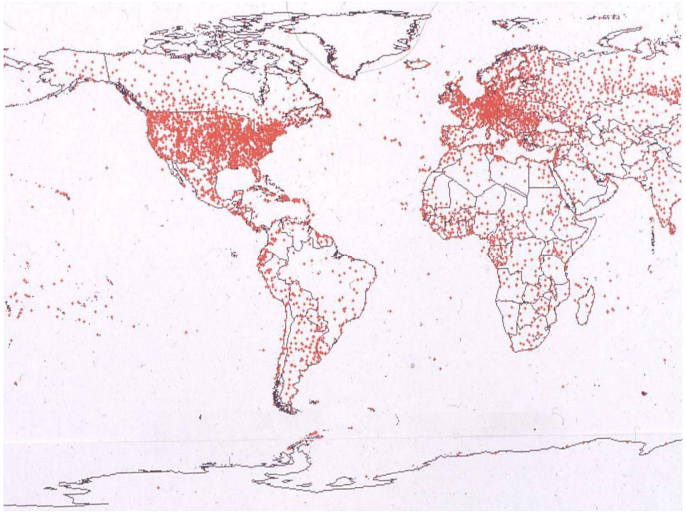
New

National Weather Service is a branch of the National Oceanic and Atmospheric Administration (NOAA)
U.S. Historical Weather Records are available at www.weather.gov

Richmond, VA Maximum, Minimum, and Average Temperatures (°F)
1900 - Today

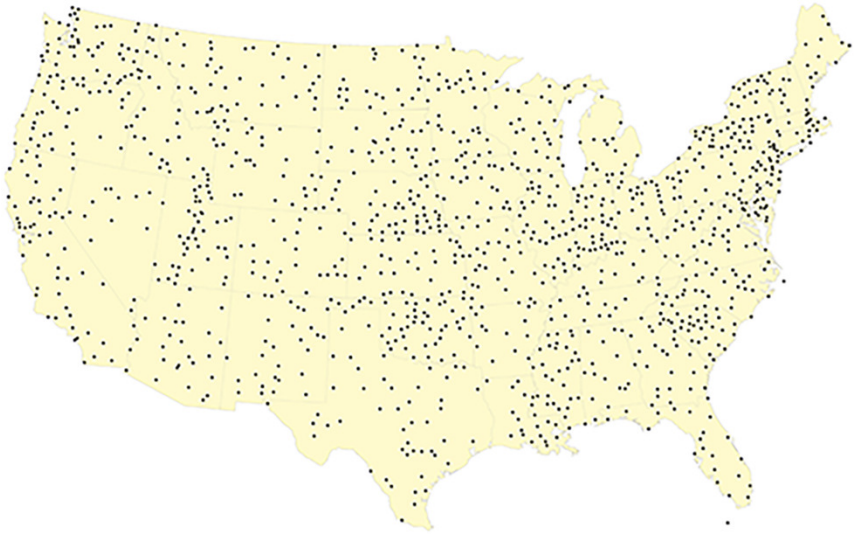


Where Are The Thermometers?

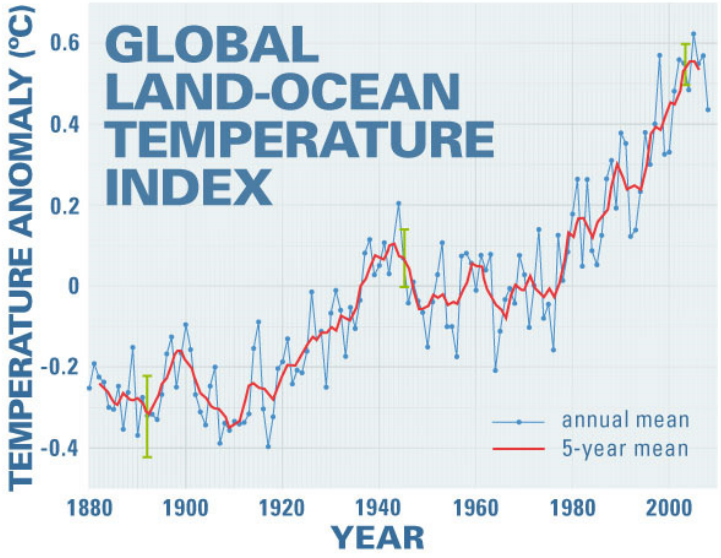


Longest temperature record:
Central England Record since 1650

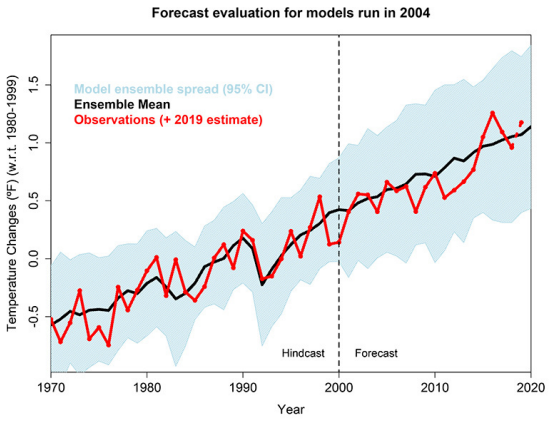
Map of 1218 weather station locations



Temperature plots contain "running averages"

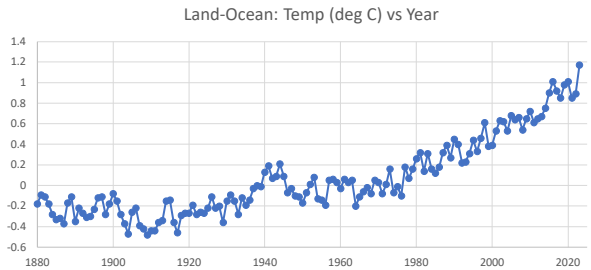


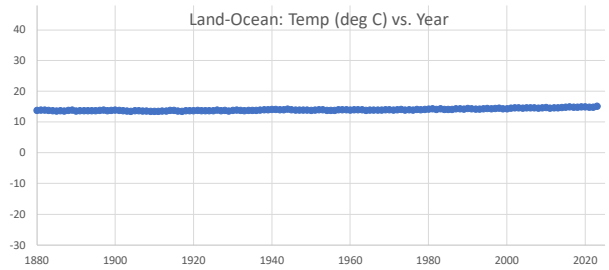
All measurements contain **UNCERTAINTY** → ERRORS!



The process of science is less about collecting pieces of knowledge than it is about reducing the *uncertainties* in what we know.
– Steven Koonin

"There are lies, white lies and statistics!"
How data is presented can vary its perception





Temp Range Comparison

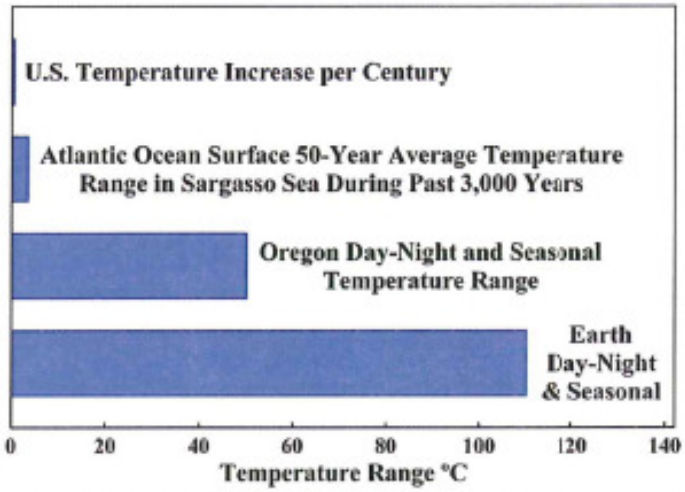
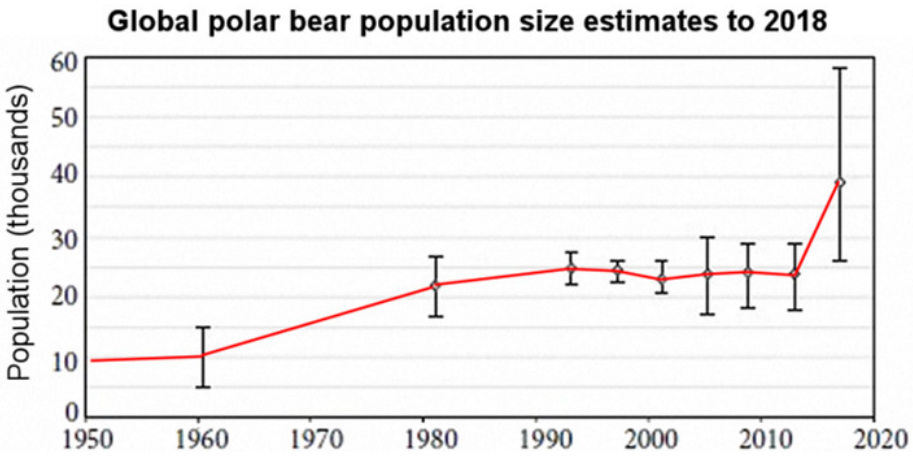


Figure 6: Comparison between the current U.S. temperature change per century, the 3,000-year temperature range in Figure 1, seasonal and diurnal range in Oregon, and seasonal and diurnal range throughout the Earth.

Error Bars



Ocean Temperatures

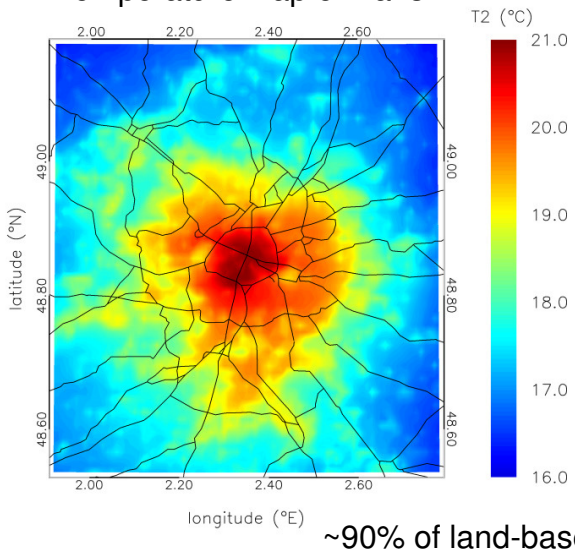
- SST (Sea Surface Temperature) 20 cm depth
- Ship measurements since 19th century.
- Prior to 1940, buckets dropped over side (in many cases method is still used).
- Since 1945, ships fitted with thermistor thermometers on their water-intake ports (reduced uncertainty, but still large)
- 2003 ARGO program. Global array of 3,000 free-drifting, robotic, ocean buoys. Measure temperature and salinity of upper 2000 meter depth of oceans.
- Reasonably accurate SST record since 2005
- HadSST Record → ~0.5°C increase since 1950

Problems With Surface Measurements

- Uneven distribution of data, both with respect to location and time
- Many weather stations poorly located or poorly maintained
- Instrument accuracy and procedure compliance increased over time
- Change increases with increasing latitude; i.e., Tropics show least, Poles most
- Number of stations changes with time
- Ocean and land temperatures begin to diverge ~1900 ➔
- **Urban Heat Island (UHI) Effect**

Urban Heat Island (UHI) Effect

Temperature Map of Paris



- Hard surfaces (e.g., rooftops, asphalt, sidewalks) absorb and retain heat, warming the surrounding air
- Dark surfaces absorb solar radiation, light surfaces reflect

~90% of land-based data now being used are sampled in cities. -- McKitrick

Urban Heat Island

USHCN weather station in a parking lot of the University of Arizona The station had previously been in a grassy area but was moved as the campus grew.

Weather Balloon and Satellite

- Since 1950s, 28 million weather balloons → Temperature versus altitude (That is GOOD!)
- Since 1978 satellite measurements of microwave radiation from atmospheric oxygen converted to temperature
- UAH data (University of Alabama, Huntsville) and the RSS (Remote Sensing Systems) are most prominent satellite data records

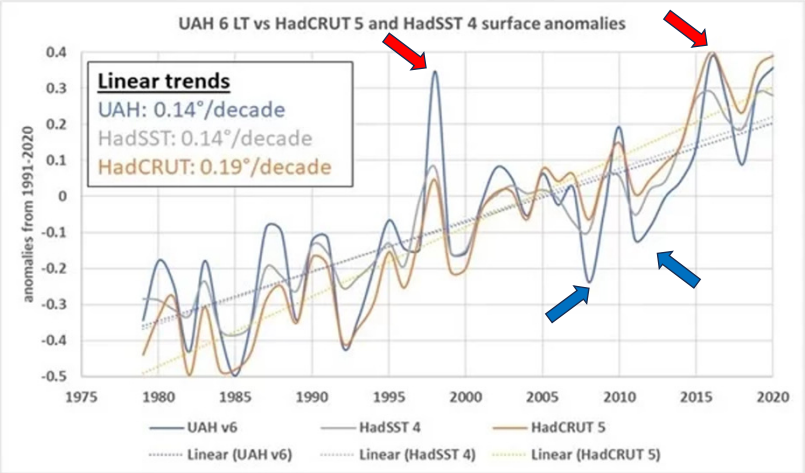
Satellites versus Surface

- Satellite and weather balloon data in good agreement.
- Satellites unable to measure surface temperature due to interference and clouds.
- Satellite data covers larger volume of atmosphere and uniformly more of the globe than surface.
- **~0.14°C/decade** warming for satellite and sea surface data versus **~0.19°C/decade** for land surface temperature data

What Have We Learned From Temperature Measurements?

- Both the atmosphere and ocean appear to be warming (little disagreement about his)
- Northern hemisphere is warming faster than the southern
- Weather systems (like El Nino and La Nina), Volcanic Eruptions, and shifts in Ocean currents can significantly affect temperature readings
- Ocean surface, satellite data and rural land surface temperatures all pretty much in agreement (Good!)
- Urban land surface temperatures significantly higher than the former → Urban Heat Island Effect?

Major weather phenomena such as El Nino and La Nina can have significant impact on temperatures

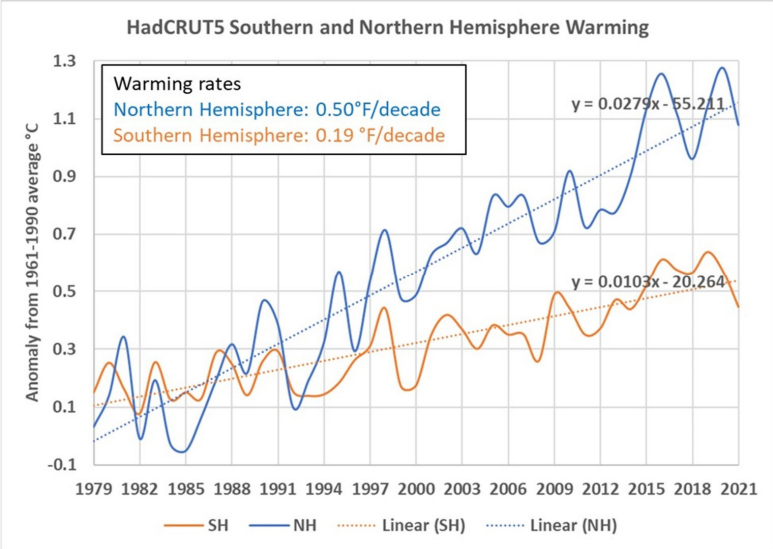


1998 and 2016 peaks due to El Nino

2008 and 2011 troughs due to La Nina

Northern Hemisphere Warming Faster Then Southern

68% of land and 87% of population in Northern Hemisphere

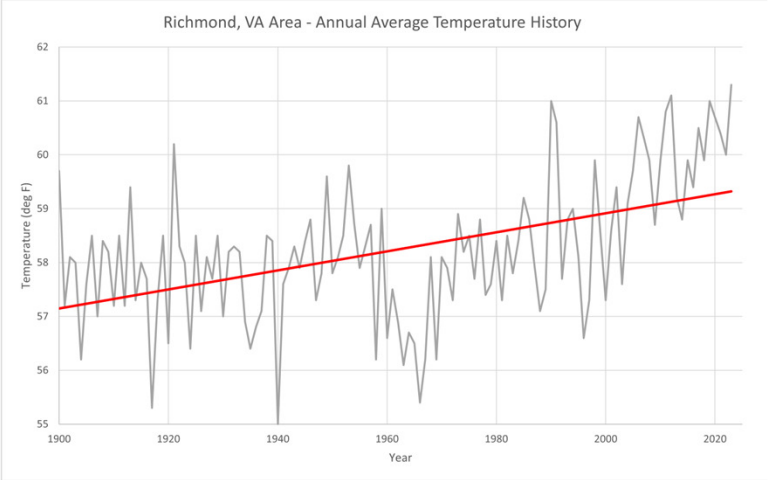


Northern ~0.28 °C/decade

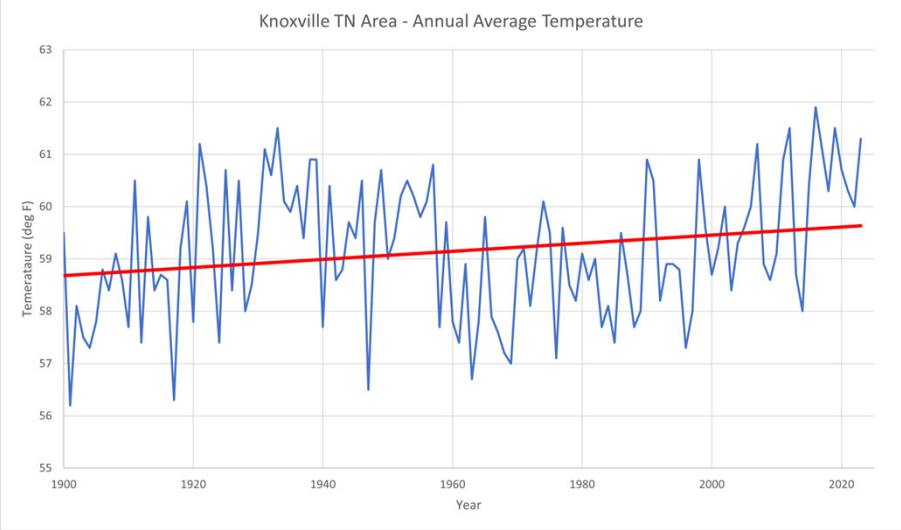
Southern ~0.11 °C/decade

Average ~0.19 °C/decade

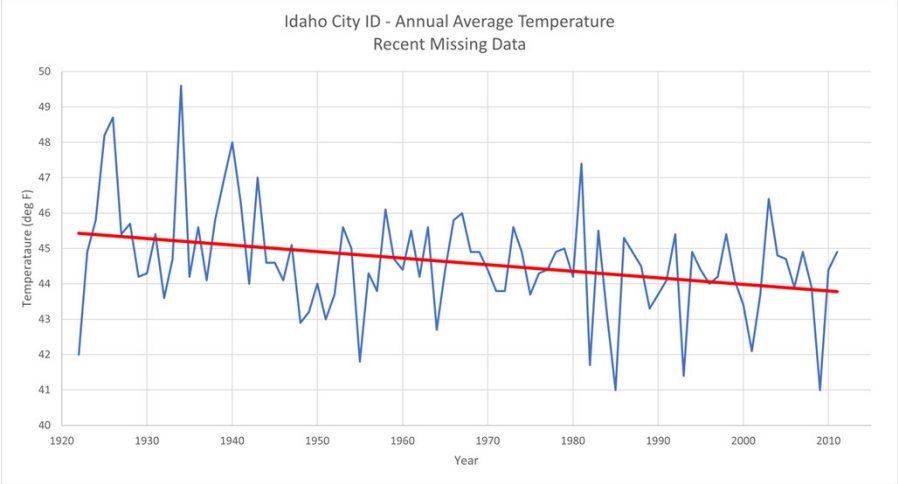
Significant Variance in Data Depending on Location



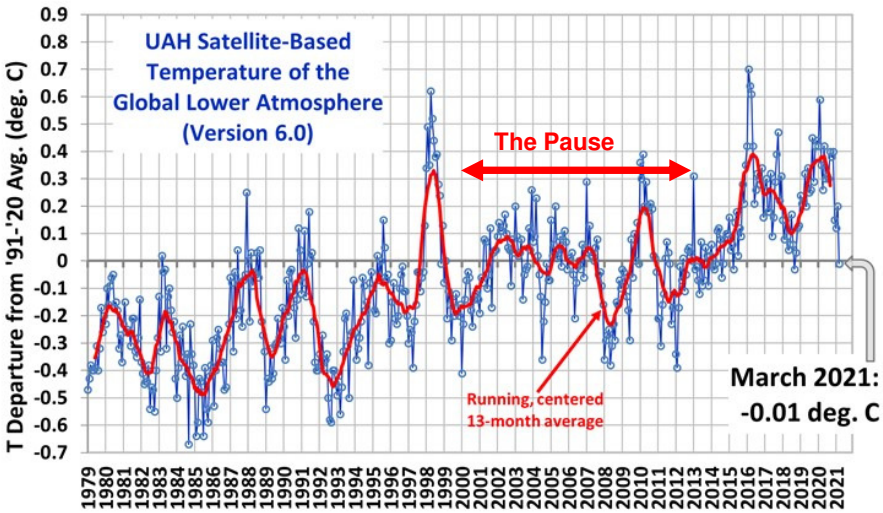
$\Delta T \approx 2.1°F = 1.2\ °C$ over 123 years



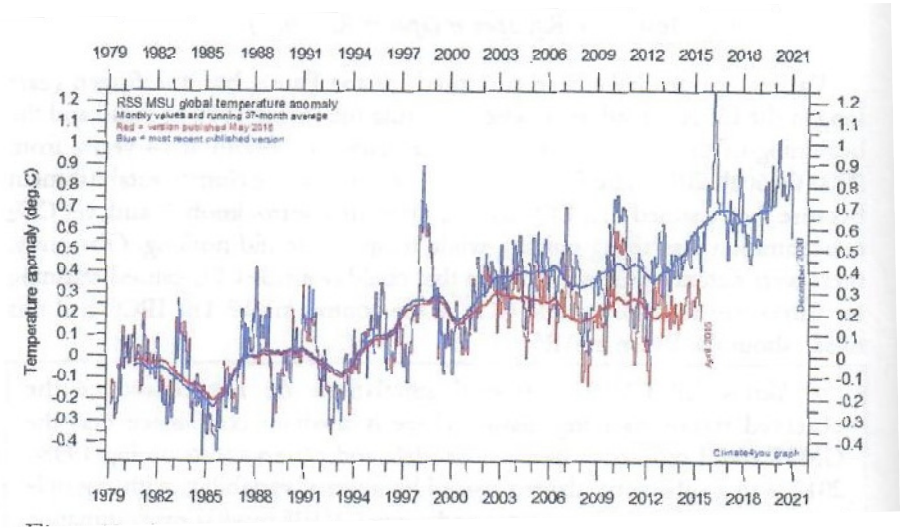
$\Delta T \approx 1.0°F = 0.6\ °C$ over 123 years



$\Delta T \approx -0.7°F = -0.4\ °C$ over 90 years



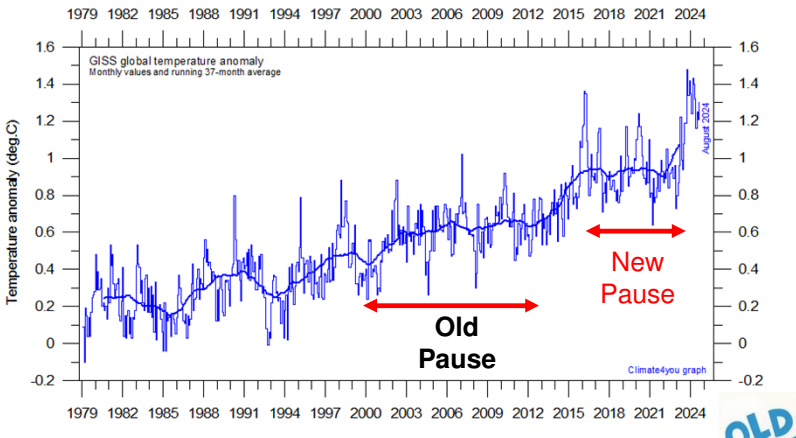
The Pause: 2000 to 2013?



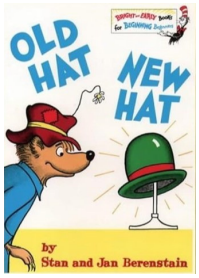
Mysterious Changing Data?

Red line – Original RSS satellite data (2016)

Blue line – "Corrected" data



Old Pause, New Pause?



Sea Level Rise

NOAA (National Oceanic and Atmospheric Administration) tasked with measuring sea level change for U.S.

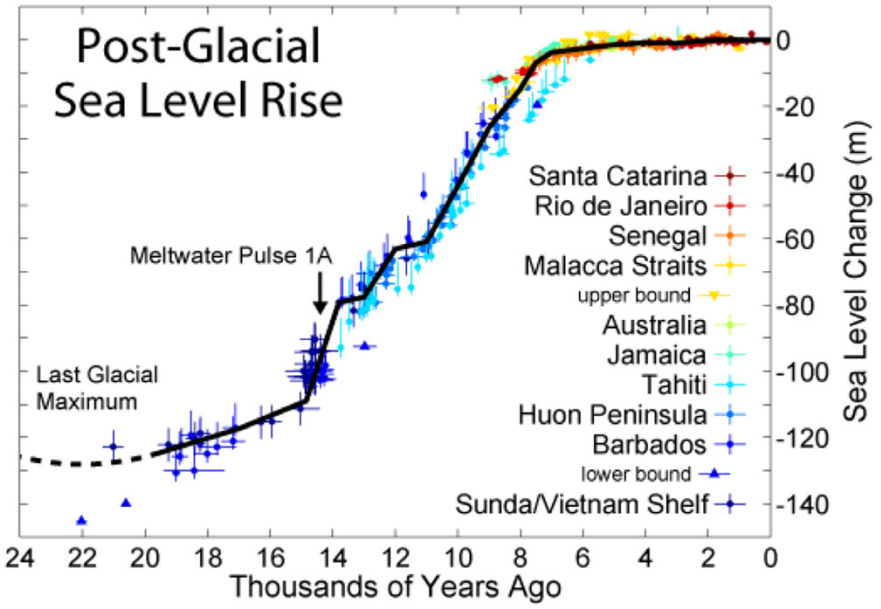
- Tide stations – Measure height of water along the coast relative to a specific point on land
- Satellite measurements provide average height of the entire ocean
- But… Relative Sea Level Rise is the additive product of Vertical Land Movement (VLM) and any change in the actual height of the sea surface.
- As with temperature measurements → **It's Complicated**

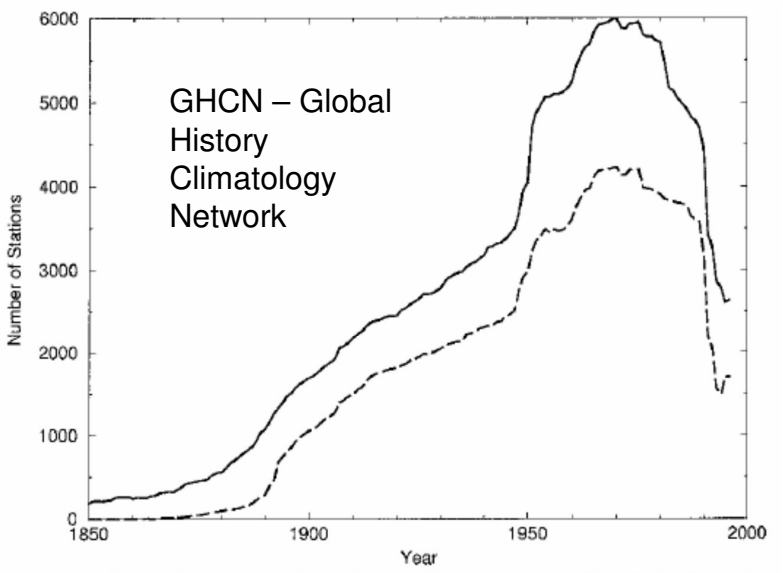
Sea Ice

Sea level rise → expansion of warming water + melting land ice

Melting Sea Ice → No effect

Present estimate → 6 – 9 inches per century





Number of complete or partial weather station records in GHCN v2. Solid line: mean temperature records. Dashed line: Max/min temperature records. Source: Peterson and Vose (1997) Figure 2a.

Other key point of AGW is that global warming is due to human activity—release of GHGs due to burning fossil fuels

Greenhouse Gases (GHGs)

Big Three:

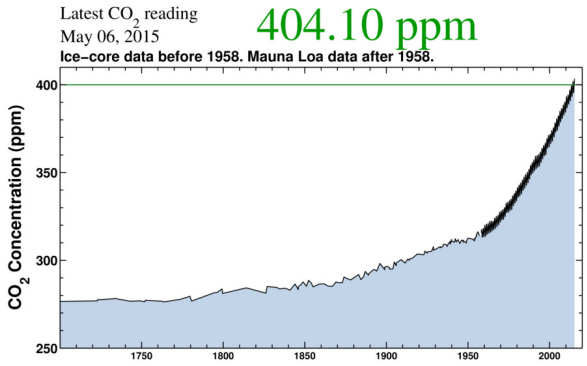
- Water Vapor
- Carbon dioxide (CO_2) *
- Methane (CH_4) – i.e., natural gas

* Often referred to as Carbon
Carbon dioxide is **NOT** Carbon

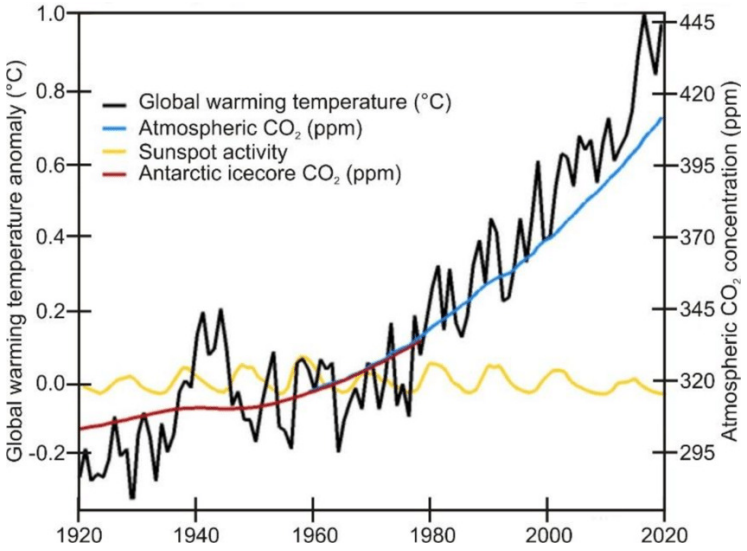
GHGs (Greenhouse Gases)

- Gases in the atmosphere thought to have a warming effect on the planet.
- Water vapor, carbon dioxide (CO_2), methane (CH_4)
- Humidity is a measure of water vapor.
- Relative humidity: Percent of water vapor in air compared to maximum amount of water that air can hold at current temperature *at ground level*.
- Warm air holds more water vapor than cold air.
- When raining, humidity ~90 → 99%

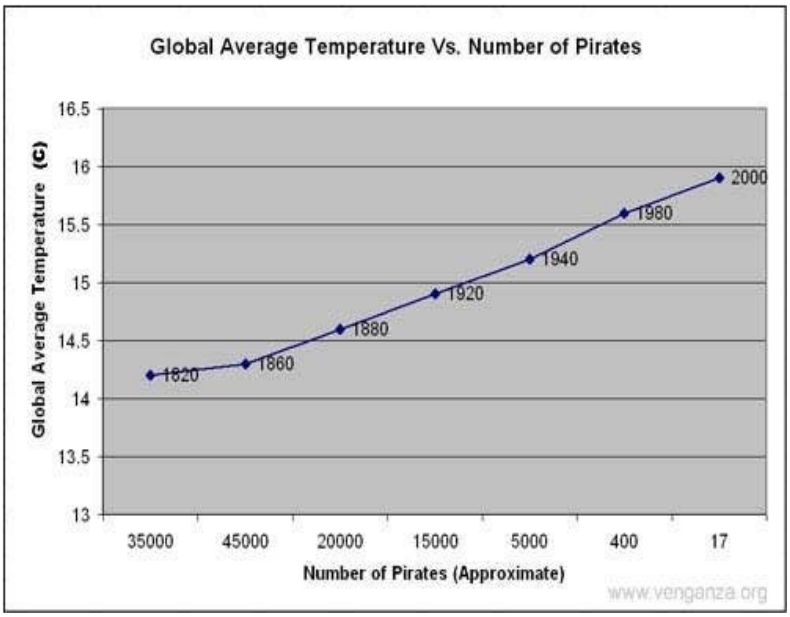
- Other GHGs measured in ppm (parts per million).
- ppm = mass of substance per total mass of solution or mixture (can also be by volume)
- $CO_2 \approx 420$ ppm
- → 0.042% of atmosphere is CO_2



AGW – Correlation between rising CO_2 and temperature is a **Cause-and-Effect**



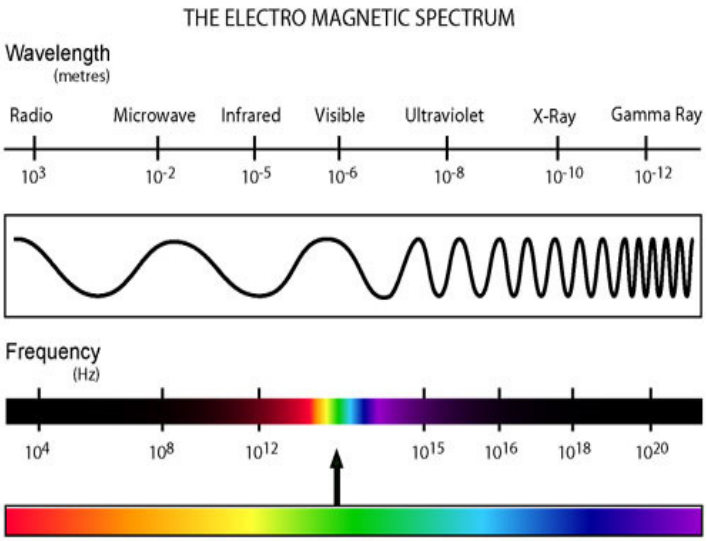
Correlation Does Not Imply Causation



Greenhouse Effect

Misnamed → Not this type of Greenhouse
Glass is opaque to infrared radiation

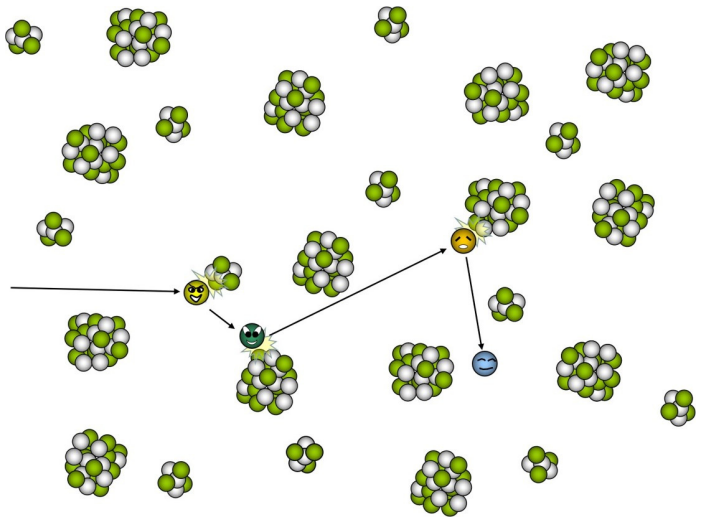
Sunlight is Electromagnetic Radiation



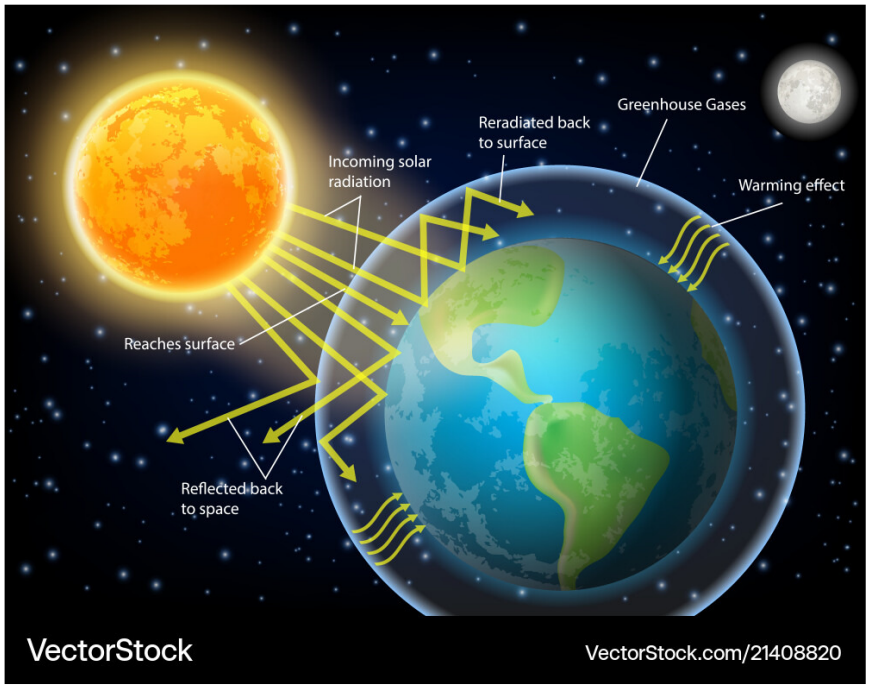
Think of sunlight being composed of small particles → photons

Each scattering collision causes the photon to lose energy

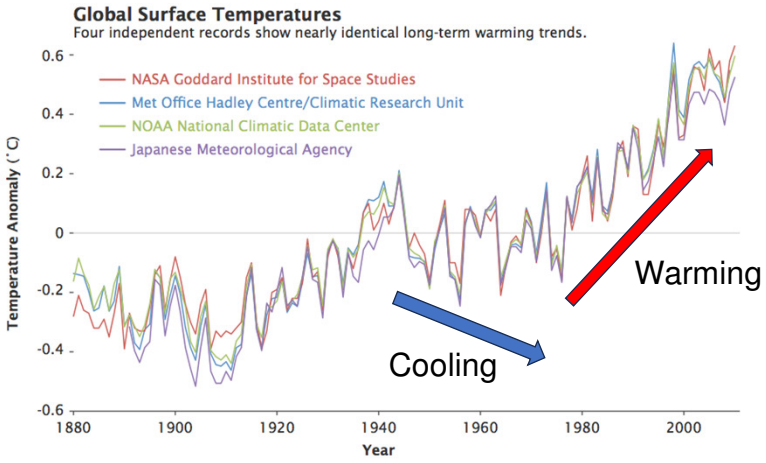
Visible light → Infrared



- Photons (sunlight) absorbed by the Earth's surface is reemitted as lower energy Infrared radiation.
- Energy from sunlight is lost by Infrared radiation escaping to space.
- GHGs are excellent absorbers and emitters of infrared radiation.
- CO_2 molecule passes energy gained from absorbing Infrared radiation to molecules it collides with
- Collisions warms the air
- Increase in absorption of Infrared by GHGs reduces energy escaping to space.
- Energy from sunlight > outgoing Infrared energy
  → **Temperature Increase**
- Greenhouse Effect overall Warms
- Weather processes overall Cool



- Temperatures rose until ~1940, then cooled until ~1975
- Since 1979 satellite and weather balloon data show a rise of ~0.1 C per decade
- Land surface thermometers show a recent warming rate ~3x larger



SUMMARY

Common Agreement that GHGs have a warming effect on the planet.

Significant differences in temperature measurements depending on how the data is measured and who is analyzing the measurements.

Areas of disagreement and *uncertainty*:

- How much of the recent warming has been caused by humans
- How much the planet will warm in the 21st century
- Whether warming is good or bad
- Whether urgently eliminating the use of fossil fuels will improve human well-being

The CLIMATE is

EXTREMELY COMPLICATED