The Hot and Cold of Climate
University of Richmond Osher Course - Fall Semester, 2024

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The Hot and Cold of Climate takes a look at the scientific debate over climate change. Does it pose an existential threat or are proposed solutions worse than the problem? Course topics include data, the physics of climate, human impacts, past climates, climate models, renewables, the smart grid, nuclear power, electric vehicles, green hydrogen, and possible effects of climate policy on energy, food, water, sustainability, and economic development.

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

The Presenter

James Miller is a nuclear engineer with over 35 years of experience in the nuclear industry. Following his retirement from Dominion Energy, for the next 15 years he taught courses in nuclear and mechanical engineering as a professor in the Department of Mechanical and Nuclear Engineering at Virginia Commonwealth University. Since December 2021, he has presented a number of courses at the Osher Lifelong Learning Institute at the University of Richmond.

Course Background

The climate debate centers around the theory of **Anthropogenic Global Warming (AGW)**. Basically, the theory (or proposition) states that 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.

According to its proponents, the most important piece of evidence in support of the theory is the correlation between temperature and CO_2 (carbon dioxide) concentration in the atmosphere, an example of which is shown below. The main source of the carbon dioxide is postulated to be from the burning of fossil fuels (coal, natural gas, and petroleum).

Temperature measurements are of three types: land surface temperatures, atmospheric temperatures from both satellites and weather balloons, and ocean and sea temperatures, both surface and at differing depths.

How *global average temperatures* are determined and the validity of such measurements are key areas of controversy, especially since all measurement (data) contains uncertainty.

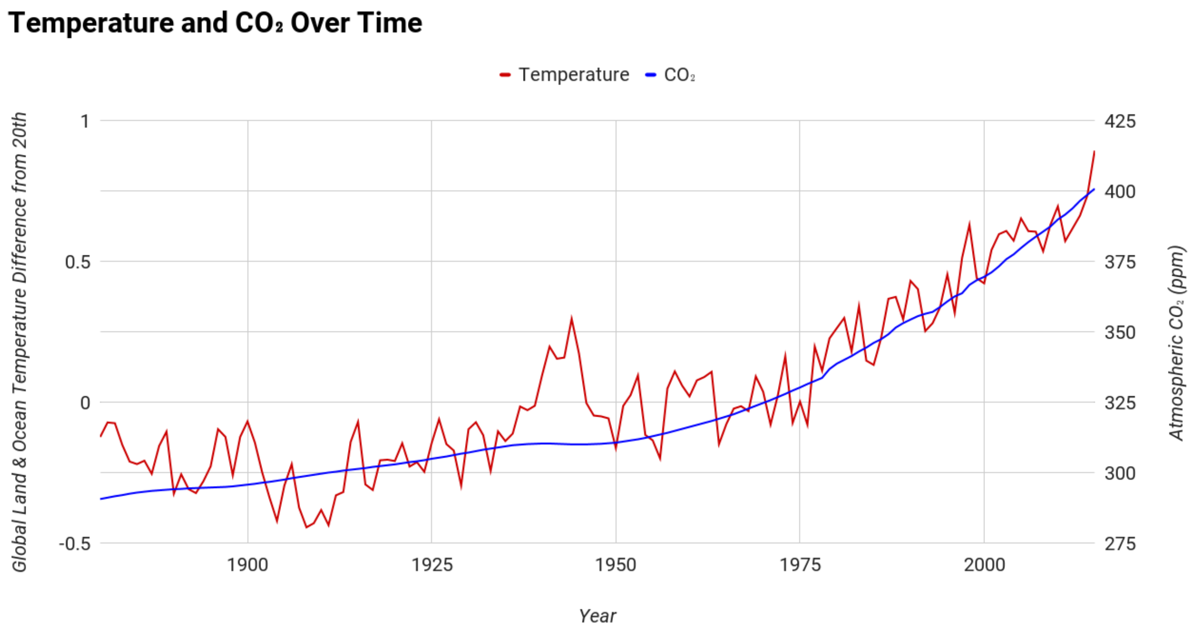


Figure – Graph depicting the correlation between land and sea surface temperatures and global CO_2 concentrations in the atmosphere. The temperature values are based on the difference in the average of temperature measurements and some arbitrarily selected value of temperature. Concentrations of CO_2 are given in ppm (parts per million by weight). For example, 400 ppm corresponds to 0.04% of the atmosphere being composed of CO_2.

A key point of disagreement between people who support the AGW theory and the skeptics is the ***degree to which the warming is due to human activity versus nature***. It is the presenter's view that we presently do not have enough understanding of the climate to resolve this controversy.

Weather versus **climate**. Weather deals with 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, on the other hand, characterizes the long-term weather pattern of a region. How long is long term? An average over 30 years is generally accepted.

Greenhouse gases (GHGs) are thought to warm the Earth's atmosphere, surface, and oceans by blocking the return to space of a portion of the solar energy reaching the Earth. Although named after the greenhouse, the physics behind a warming atmosphere is different from that of a greenhouse. The most important greenhouse gases are carbon dioxide, methane (i.e., natural gas) and water vapor. Of these, water vapor by far has the greatest effect.

Units of Measurement Throughout the course we will be using metric (or SI, International System) units of measurement. Why? Because the presenter prefers metric.

Common metric units are the kg (kilogram) for mass, m (meter) for distance, J (joule) for energy, W (watt) for power and °C (degree Celsius) for temperature. The metric ton (often denoted as *tonne*) is equal to 1000 kg or 2205 lb, not to be confused with the English (American) ton which can be either a long ton (2240 lb) or a short ton (2000 lb).

A change in temperature of 1°C is equivalent to a change in temperature of 1.8°F (Fahrenheit).

Water boils at a temperature of 100°C and freezes at 0°C under normal atmospheric pressure.

Trust me, metric units are a lot easier to deal with thanks to a standardized set of prefixes, a partial list of which follows.

Prefix	Symbol	Factor
kilo	k	1,000
mega	M	1,000,000 (million)
giga	G	1,000,000,000 (billion)
tera	T	1,000,000,000,000 (trillion)

Don't believe me? How many meters are in a kilometer? Easy—1000. Now, quickly, how many yards are in a mile?

The good news is that both the metric and the English (American) systems use the same units for time, that is, seconds, minutes, hours, days, etc.

Energy and Power

A key element of the climate debate is the future of energy production. If increasing concentrations of GHGs in the atmosphere due to human activity pose an existential threat to humanity, then replacing fossil fuels with emission-free energy sources (i.e., sources that produce no GHGs) becomes a critical policy decision. Hence, the push by governments throughout the globe for more reliance on emission-free energy production, that is, solar, wind, hydroelectric, and nuclear.

Energy is a measure of the ability to do work, that is, the ability to make things move, keep you from freezing to death, grow food, and so on. It's one of the most important concepts in science and engineering since it is *measurable* and it is *conserved* as described by the First Law of Thermodynamics. Common units of energy used in this course are the kWh (kilowatt-hour) and J (joule).

Power is a measure of the amount of energy expended over some period of time. In the course we refer to power in units of kW (kilowatt), MW (megawatt), GW (gigawatt) and TW (terra-watt). By the way, a watt is an expenditure of one joule of energy over one second.

Energy = Power × Time

For example, the power rating of a 100-watt light bulb is equal to one-tenth of a kilowatt, that is, 0.1 kW. Powering this light bulb for one hour requires (0.1 kW)×(1 hour) = 0.1 kWh of energy.

Your electric bill tracks how much electrical energy you use from the electric power grid in units of kWh. Presently I'm paying about 13 cents per kWh. This includes not only the cost of generation, transmission and distribution but a number of additional charges approved by the SCC (State Corporation Commission) such as various taxes, Coal Ash Closure charge, Renewable Energy Program, etc. There's even a charge for Off-shore Wind of which we presently have none!

The 'size' of a power plant producing electricity is defined by its installed or *rated capacity*. A plant's capacity is equal to the maximum rate at which it can produce energy, that is, its maximum *power* output. Large power plants typically have electrical capacities on the order of 1000 MW (megawatts) or more.

The *capacity factor* of a plant power is the ratio of the amount of energy produced by that plant over some standard period of time (typically a year) and how much energy would have been produced by the plant if it had operated at rated capacity the entire year.

Wind and solar have the lowest capacity factors of any type of power plant, typically on the order of 35% and 25% respectively (in a good year). Nuclear plants have the highest capacity factors of any energy source, typically above 90%.

The concepts of power and energy are often confused, especially by people who should know better, like lawmakers and public policy advisers. Energy can be stored. **Power cannot be stored**. Battery storage is usually given in units of volts, for example, a 12-volt battery. A volt is equal to one joule of stored energy per one coulomb of electric charge.

The Electric Power Grid

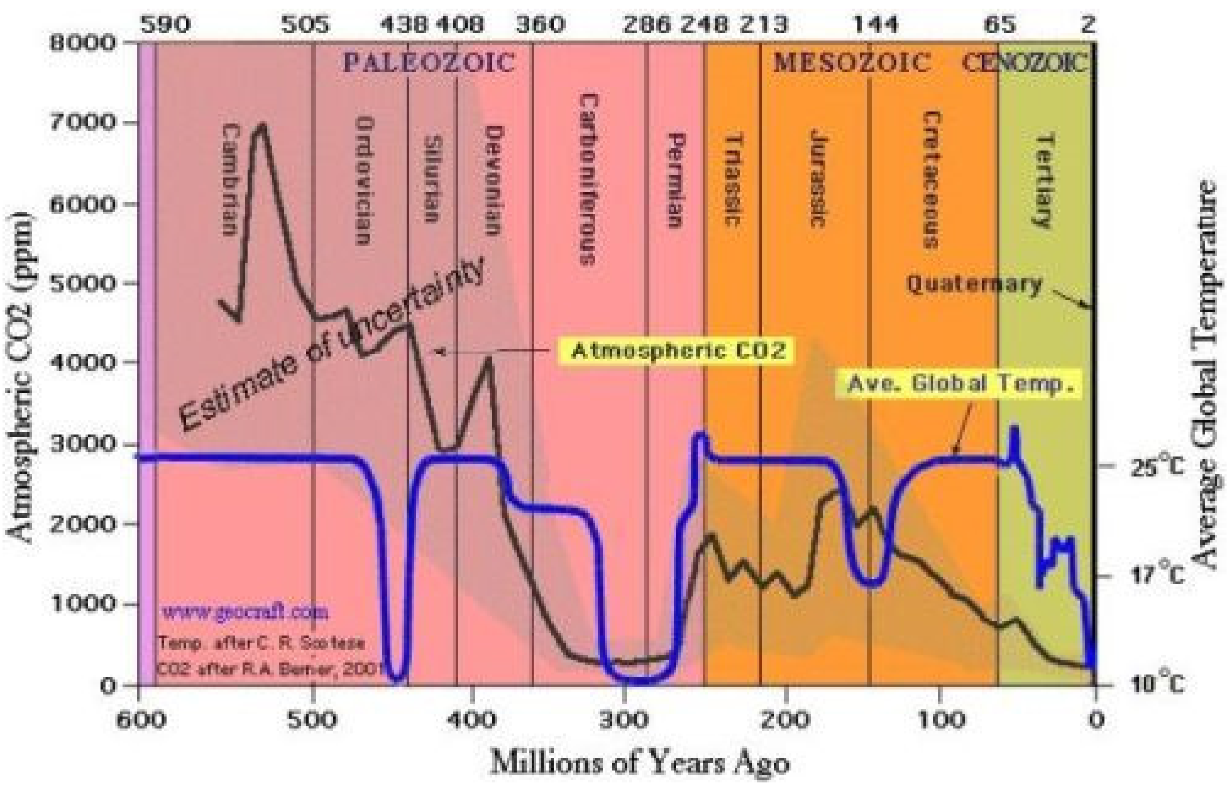
To maintain a stable power grid, **electricity demand and production must be in constant balance**. The electric power grid **cannot** store energy. If the demand for electric power exceeds the supply or the supply exceeds the demand, something has to change to bring demand and supply back into balance fairly quickly else a **blackout** will occur. Blackouts are bad. Extended blackouts are VERY BAD.

In the U.S., the electric power grids run on an alternating current frequency of 60 Hz (hertz) or sixty cycles per second. In Europe and much of the rest of the globe, the grid frequency is 50 Hz. More supply than demand increases the grid frequency, more demand than supply decreases it. A grid frequency that deviates too far from the target 60 or 50 Hz (depending on the grid) is what triggers a **blackout**.

Since wind and solar are not *dispatchable* means of energy production and neither contribute to grid stability, over penetration of such unreliable energy sources into an electric power grid threatens blackouts and even possible grid collapse. The collapse of a major electric power grid would be a disaster of the greatest magnitude.

Paleo-Climate

An important field of study that bears heavily on the understanding of climate and the associated debate is paleoclimatology, the attempt by scientists to reconstruct ancient (prehistoric) climates, especially in terms of the global temperature and carbon dioxide levels. As a result, we often encounter reconstructions like the following.



For approximately the past two million years, the Earth has been in an Ice Age. During this time humans evolved from Australopithecines to Homo sapiens. We are presently in an interglacial warm period called the Holocene.

Although reconstructions of prehistoric climates such as depicted in the above chart contain large uncertainties, one thing does standout. Since the start of the 'fossil record' (about 550 million years ago), the time in which we are now living is unusual due to its exceptionally low temperatures and carbon dioxide levels.

Further Reading

Some suggested sources for more information.

For data:

www.weather.gov For historical temperature data for any location in the U.S.

www.eia.gov Energy Information Agency (as mentioned in the presentation, the instructor has found some of the data on this website to be suspect)

www.skepticalscience.com Warmist website

www.realclimate.org Warmist website

www.wattsupwiththat.com Skeptics website

www.co2coalition.org Skeptics website

www.climate4you.com Skeptics website

Books: The amount of literature on climate change is overwhelming, with most books taking either an AGW viewpoint or a skeptical *viewpoint*. A notable exception is *The Great Climate Change Debate* by Andy May which documents a debate between noted climate authorities William Happer and David Karoly (the latter being replaced midway through the debate by Glenn Tamblyn). Much of the material is heavily technical as any serious debate on the topic must be.

Two excellent resources on power production and specifically the electric power grid are:

- *Shorting the Grid: The Hidden Fragility of Our Electric Grid* by Meredith Angwin, 2020. In over 400 pages, Angwin attempts to explain the damage our political class has done to the U.S. electric power grid. The amount of information and data crammed into this book is truly amazing. Highly recommended to those who have the stamina to get through it.
- *Power Density* by Vaclav Smil, 2016. Smil has published a number of books on energy. Lots of data and analysis of that data.

Glossary

(Students may wish to keep this page available for convenient reference during the presentation.)

AGW – Anthropogenic Global Warming.

Carbon – In discussions on climate, the term 'carbon' is often used to refer to carbon dioxide. Carbon dioxide is NOT carbon, but a molecule made up of an atom of carbon and two atoms of oxygen.

Climategate - 2009 scandal wherein thousands of emails were leaked (or perhaps hacked) from the Climate Research Unit of the University of East Anglia. The emails revealed that certain senior members of the research community were capable of deliberately selecting data in order to overstate the case for dangerous climate change, as well as discussing means of controlling the research journals so as to deny publication of any material that went against the orthodox dogma, including the sacking of recalcitrant editors.

CO2 – Carbon dioxide ("carbon"), CO_2

Convection – The transfer of heat by the bulk movement of molecules or atoms in a fluid (liquid or gas). Weather is mostly the result of convective heat transfer.

COP – Conference of the Parties. The ***supreme*** decision-making body of the UN Framework Convention on Climate Change (UNFCCC).

El Nino – An important reoccurring but unpredictable weather pattern.

ENSO - El Nino-Southern Oscillation

GCM - General circulation climate model

GHCN - Global Historical Climate Network (NOAA)

GHG – Greenhouse gas. A gas found in the atmosphere thought to having a warming effect on the planet. The three most important are water vapor, carbon dioxide (CO_2), and methane (CH_4).

GISS - Goddard Institute for Space Studies

HadCRUT - Name given to the combination of the temperature data sets of two organizations, namely the Hadley Centre of the UK Met Office and the Climatic Research Unit (CRU) at the University of East Anglia

Heat – A measure of the amount of thermal energy that flows from one body to anohter due to a temperature difference in those bodies. Measured in units of Joules.

IPCC - Intergovernmental Panel on Climate Change

La Nina – An important reoccurring but unpredictable weather pattern.

Little Ice Age – A period of global cooling from the late 14^{th} century to mid-18^{th} century.

Medieval Climate Optimum – A period of warm temperatures from the mid-10^{th} century to the mid-13^{th} century. Also known as the Medieval Warming period.

Milankovitch Cycles – Describe the collective effects of changes in the Earth's motion, including its axial tilt, on the climate.

NOAA - US National Oceanic and Atmospheric Administration

PDO - Pacific Decadal Oscillation. An important reoccurring weather pattern.

Power – The rate at which energy is used or created per unit time. Measured in units of Watts. One watt is equal to the creation or use of one Joule of energy per second.

Radiation – The transfer of heat by the movement of small atomic particles or electromagnetic radiation (photons). Heat transfer through a vacuum is only possible by radiation.

RSS - Remote Sensing Systems - Satellite temperature measurements

SST – Sea surface temperature measurement

Stratosphere - The atmospheric layer above the troposphere. Little water vapor, circulation or convection occurs in this layer.

Temperature – A measure of the average kinetic energy (thermal energy) of the particles making up a substance. Not to be confused with heat (above). We will use units of degrees Celsius (°C) throughout the presentation. A change in temperature of 1°C is equal to a change of 1.8°F.

Troposphere – The lowest layer of the atmosphere. It is where weather and convective heat transfer occur. Height of troposphere varies with latitude: ~11 km mid-latitudes, as low as 6 km at the poles, 17-18 km at the equator.

UAH - University of Alabama - Satellite temperature measurements

UHI – Urban Heat Island.