Global Warming 2021

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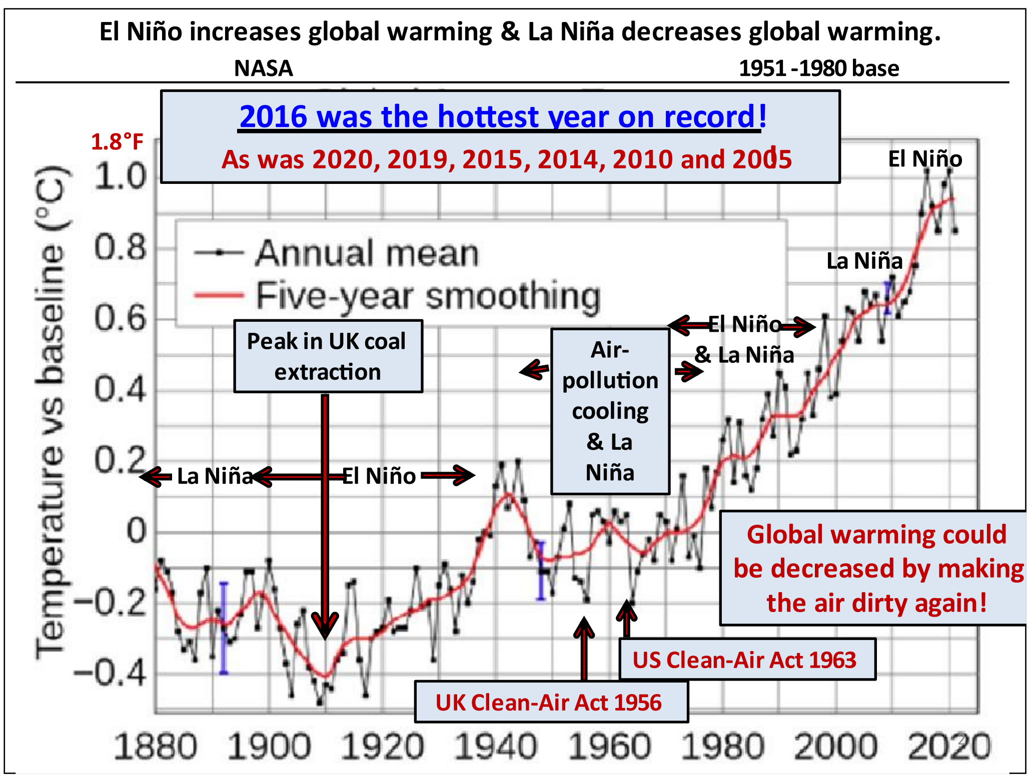
Introduction

For a very detailed study of global warming see http://roperld.com/science/GlobalWarming_2022.pdf. This document is a much briefer study of some of the most important data about global warming:

- Global average temperature, global ocean temperature, USA temperature
- Carbon-dioxide atmospheric concentration
- Temperature vs latitude
- Methane atmospheric concentration
- Accumulated cyclone energy of Atlantic/Pacific oceans
- US Climate Extremes Index
- Global mean sea level.
- Precipitation rate vs latitude
- World and USA fossil-fuels extraction rates
- Diurnal temperature rate

Average Earth Temperatures

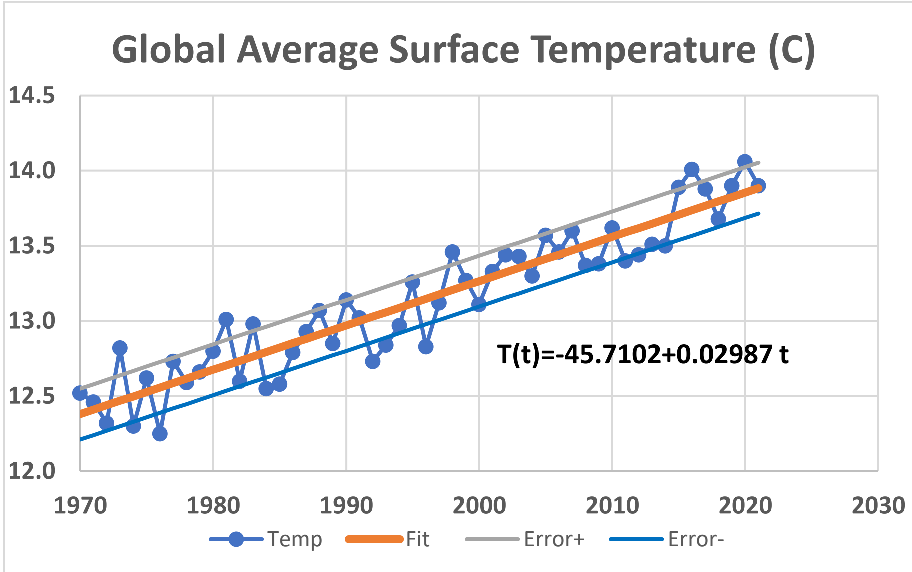
Until about 1970, global warming, due to the industrial-revolution carbon-dioxide and methane emissions, was often masked by particulate and sulfur dioxide emissions cooling, as shown here:



Modern global warming began at about 1970, after "air pollution" was greatly reduced by declining coal burning and clean-air acts in the UK and the USA. For the rest of this document only data after 1970 will be considered. I call this time period, **1970-2022** "**Modern Global Warming**" or "**Current Global Warming**."

In the following graphs C = Celsius temperature scale. [Fahrenheit (F) = Celsius (C) x 9 / 5 + 32]

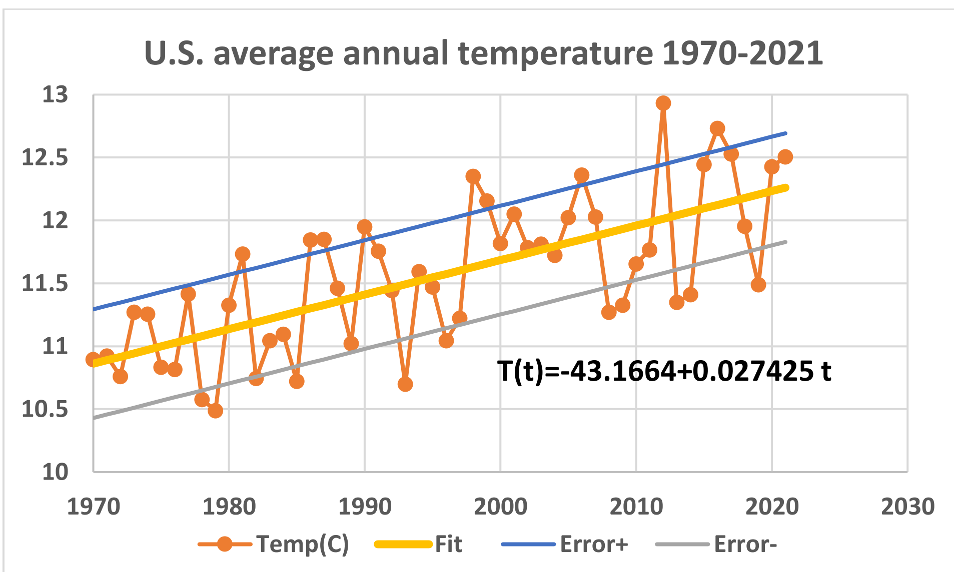
The average Earth surface temperatures since 1970 are:



Note that a linear fit to the data, the red line, is a reasonable representation of the data. The two narrow lines are the calculated standard deviation error ($\sigma = \sqrt{\frac{\chi^2}{n-m}}$, $\chi^2 = 1.44$, $n =$ number of data $= 53$, $m =$ number of parameters $= 2$) of the fit.

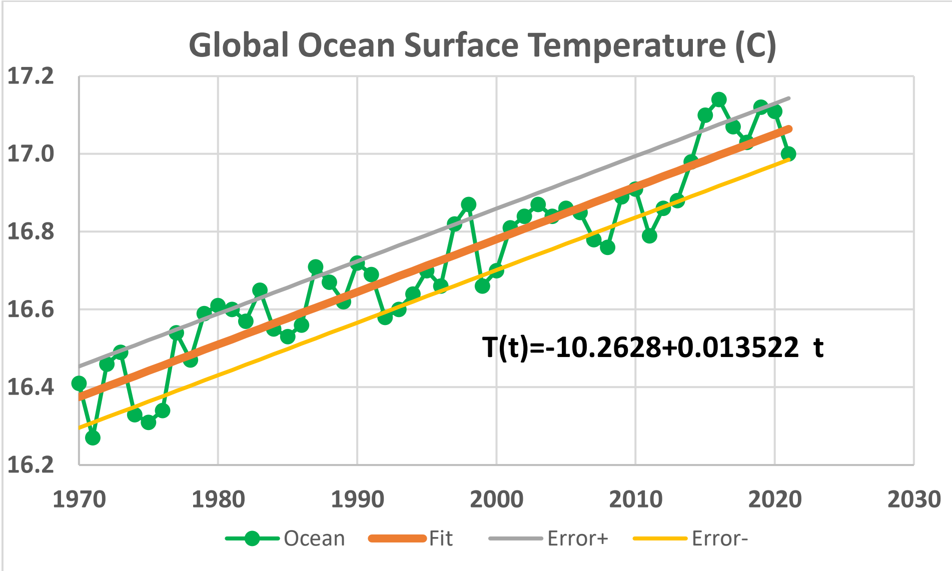
The correlation between the data and the linear fit is 0.934.

A specific location may have a completely different curve; for the United States the curve is:



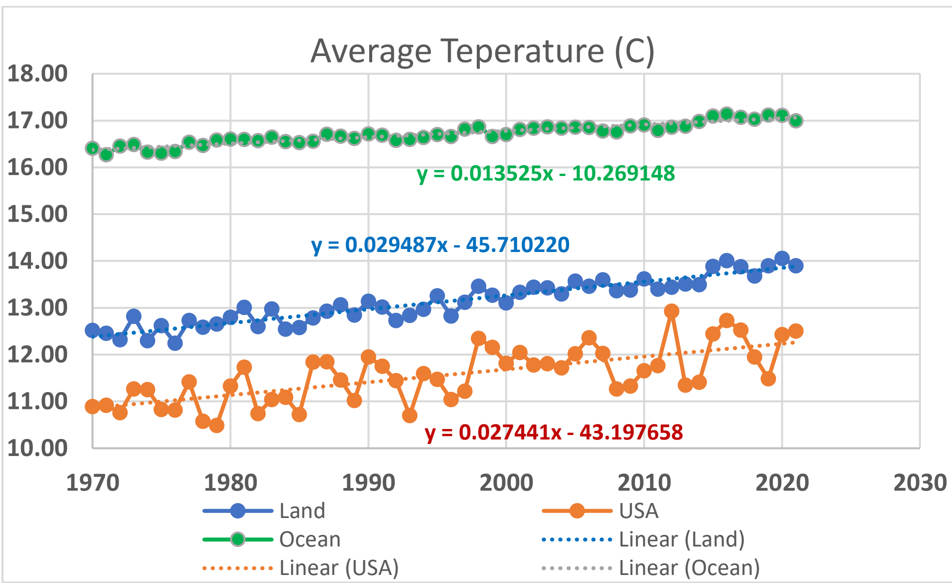
The correlation between the data and the linear fit is 0.697.

Another important set of data is the average surface ocean temperature:



The correlation between the data and the linear fit is 0.936.

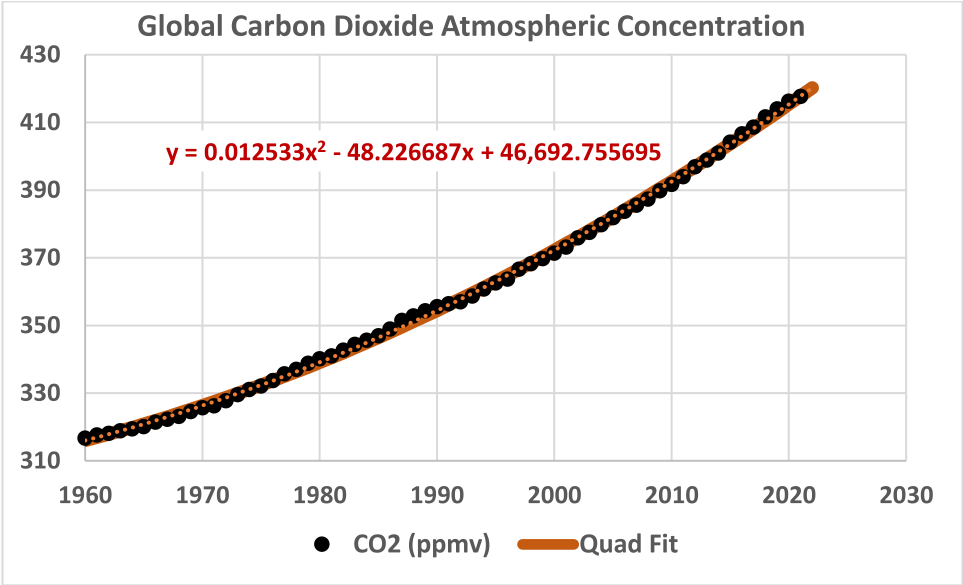
Plotting these three curves together:



Note that the ocean surface temperature is larger than the land surface temperature, but increases about half as fast (**0.0135 C/year** vs **0.0295 C/year**), and the USA surface temperature is increasing almost as fast as the land surface temperature (**0.0274 C/year** vs **0.0295 C/year).**

Carbon-Dioxide (CO_2) Atmospheric Concentration

The main cause of global warming is the emission of carbon dioxide, mostly from burning fossil fuels (coal, crude-oil liquids and natural gas). This graph shows the average atmospheric concentration of carbon dioxide (ppmv) and a quadratic fit to it:

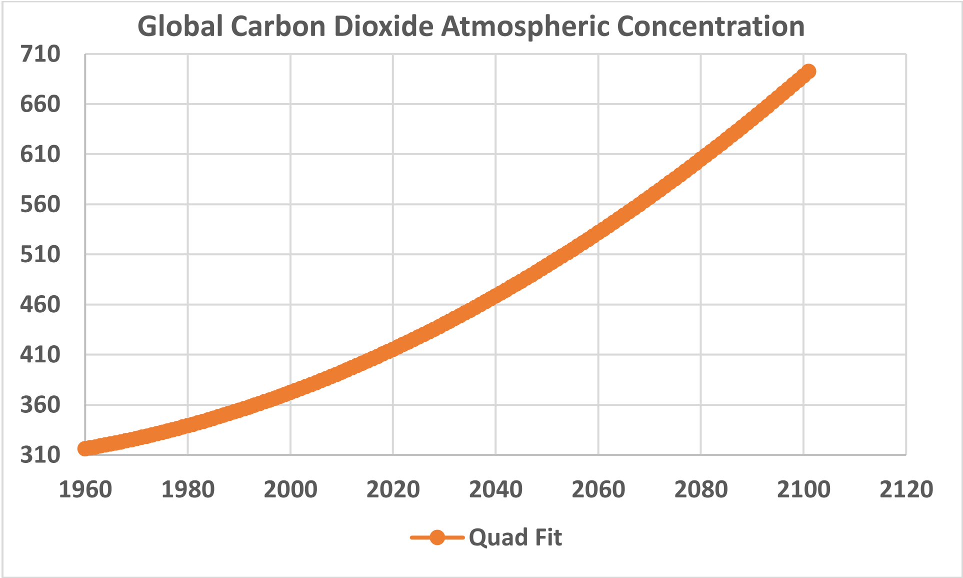


The standard-deviation error curves are within the width of the plotted red curve.

An exponential fit to the data is an over ten times worse fit (chi-square) than a quadratic fit.

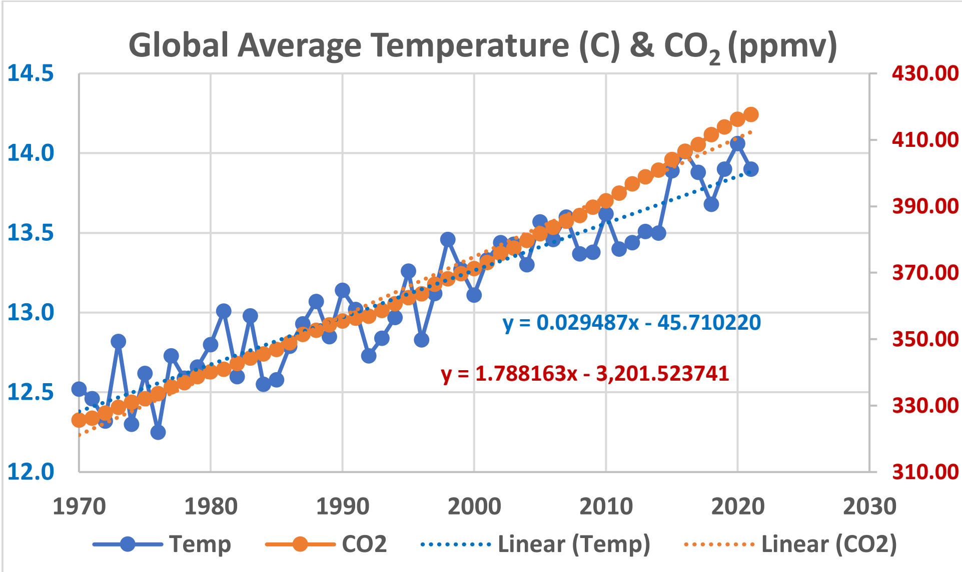
We know that this carbon-dioxide concentration in the atmosphere comes mostly from burning fossil fuels, because it mostly consists of carbon-12 instead of carbon-13, which was mostly the carbon-dioxide in the atmosphere before the industrial revolution.

Projecting this quadratic fit to year 2100 yields:



It will probably peak at about 500-ppm near year 2050, because of the finiteness of fossil fuels. (See Appendix.) The standard deviation is within the width of the drawn curve.

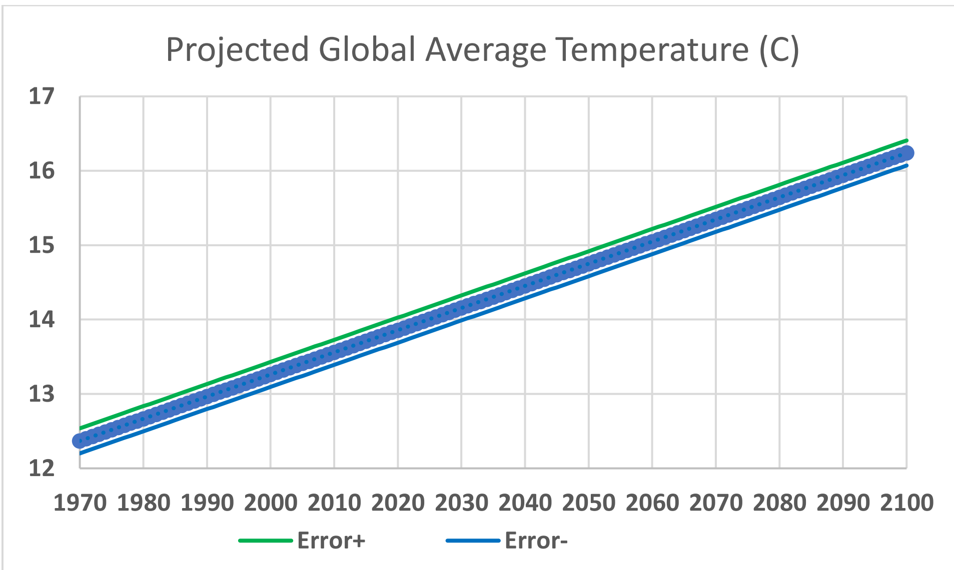
This a plot of global temperature and CO_2 atmospheric concentration:



The correlation between global temperature and CO_2 concentration is 0.945. Note that the latter is increasing much faster than the former; this is probably due to global cooling due to particulates and noxious gases in the atmosphere.

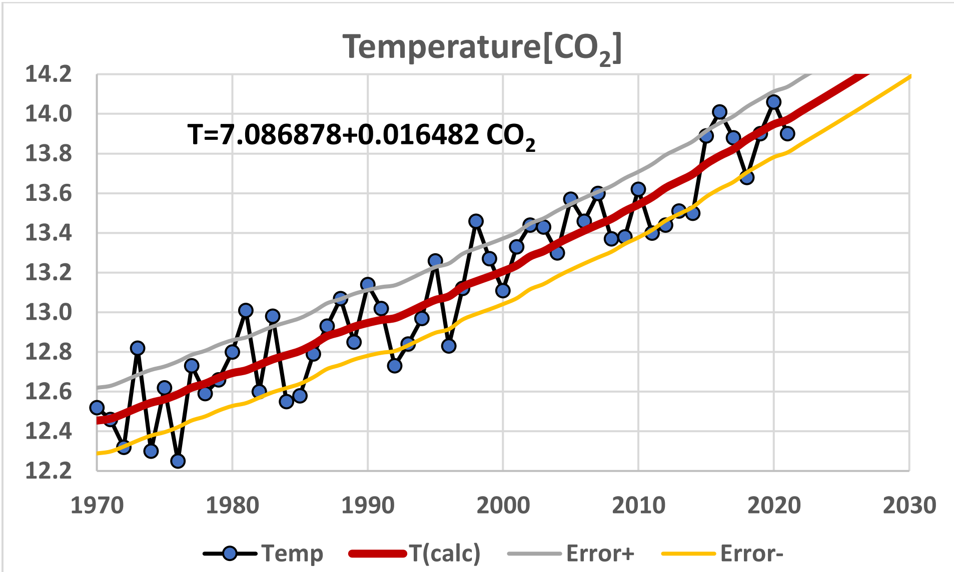
Global Temperature Projection to Year 2100

The linear equation projection for future temperatures:

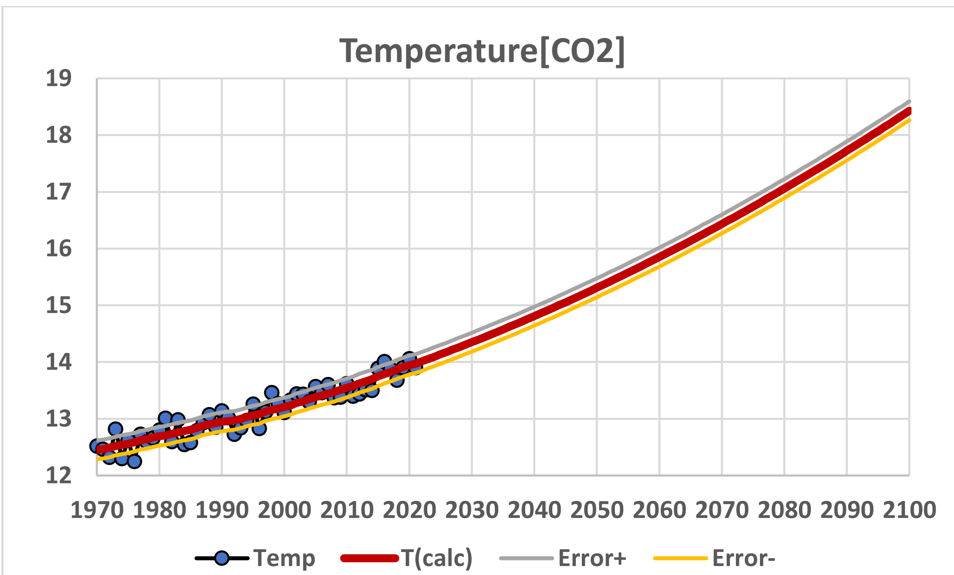


However, it will probably peak at about 15-C near year 2050, because of the finiteness of fossil fuels. (See Appendix.)

Perhaps a more accurate way to project the global temperature to year 2100 is to fit it to the CO_2 concentration and project that fit out to 2100. The fit is:



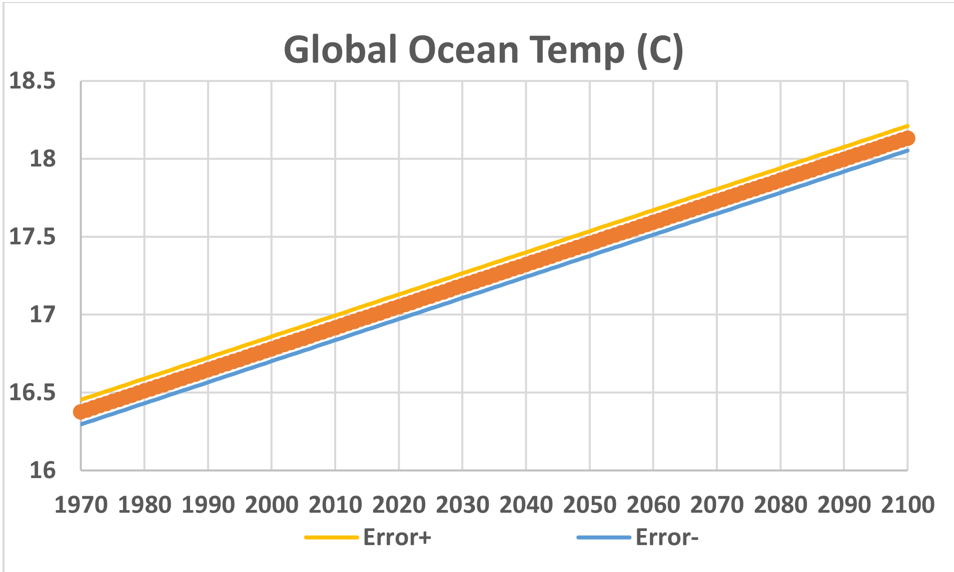
Then the projection is:



This is about 2-C higher than the linear projection at year 2100.

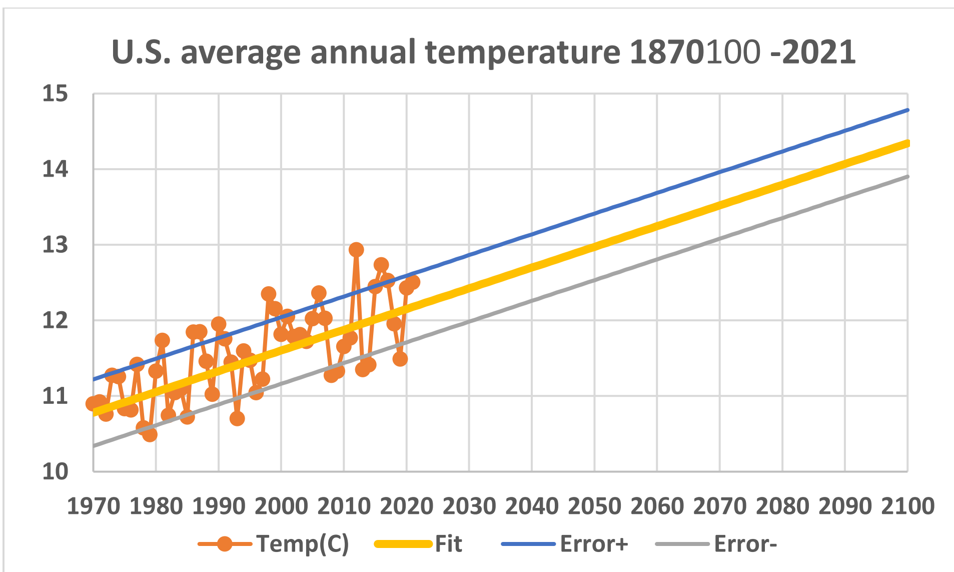
Global Ocean Temperature Projection to Year 2100

The linear equation projection for future temperatures:



However, it will probably peak at about 17.5-C near year 2050, because of the finiteness of fossil fuels. (See Appendix.)

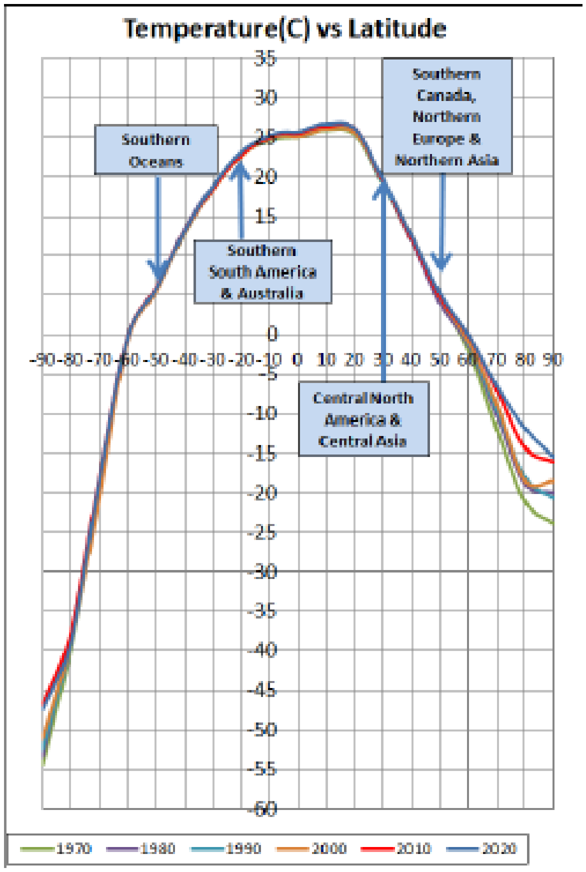
Similarly, the USA average temperature's linearly fit can be projected to year 2100:



However, it will probably peak at about 13-C near year 2050, because of the finiteness of fossil fuels. (See Appendix.)

Temperature vs Latitude

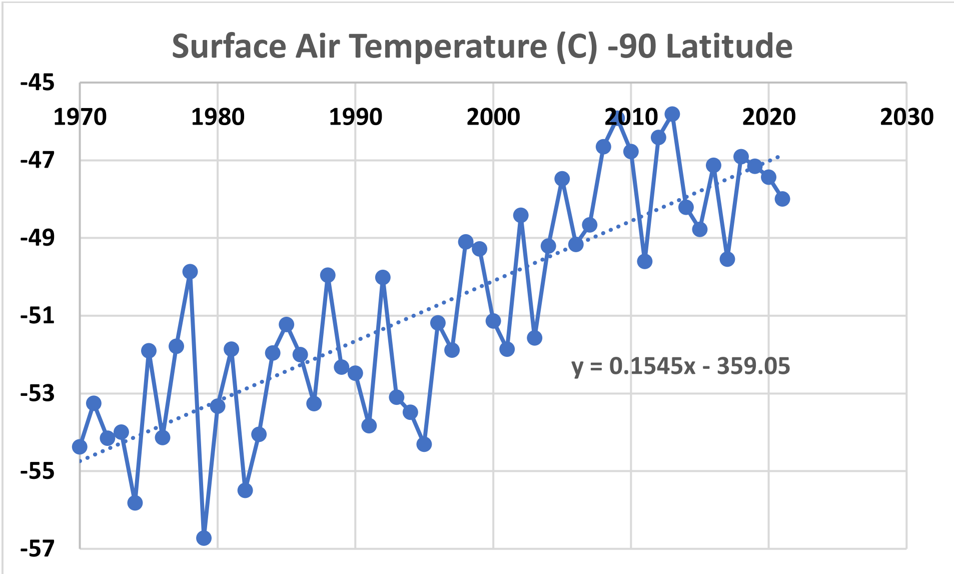
The temperature (C) varies with latitude; here it is vs latitude since 1970:

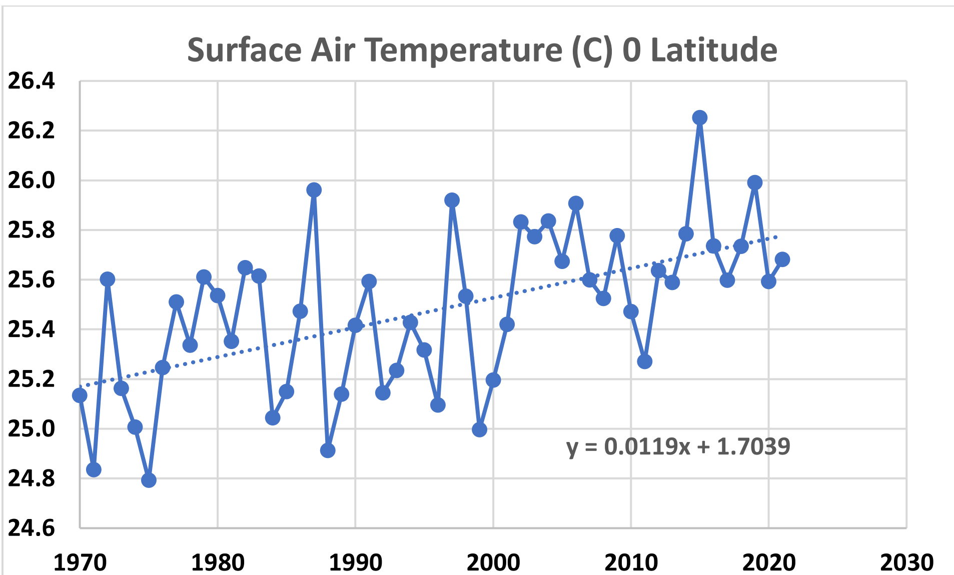


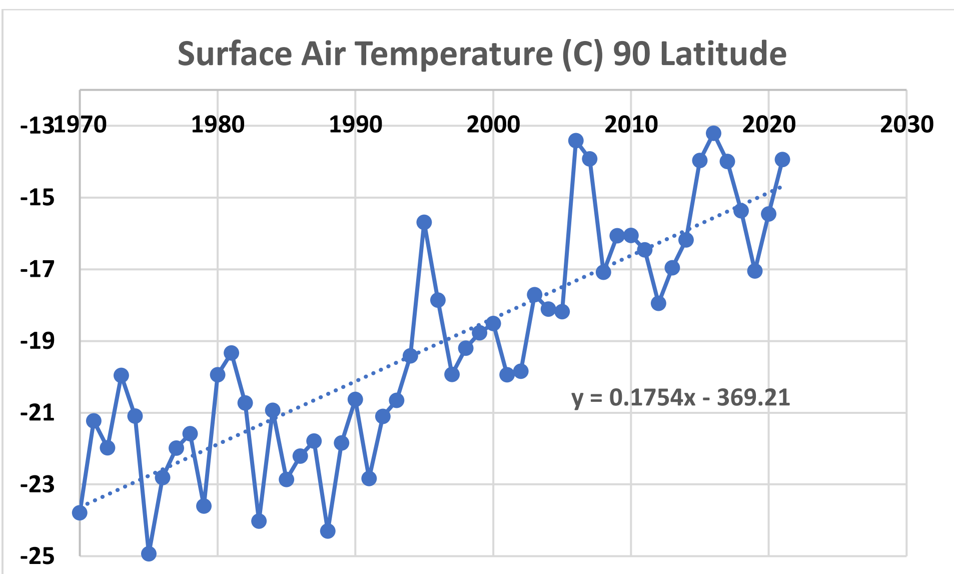
The data are averaged over each year and over longitude.

Note that temperature increases, due to glabal warming, faster at the North Pole (90) than it is at the South Pole (-90) and much faster than it is at the Equator (0).

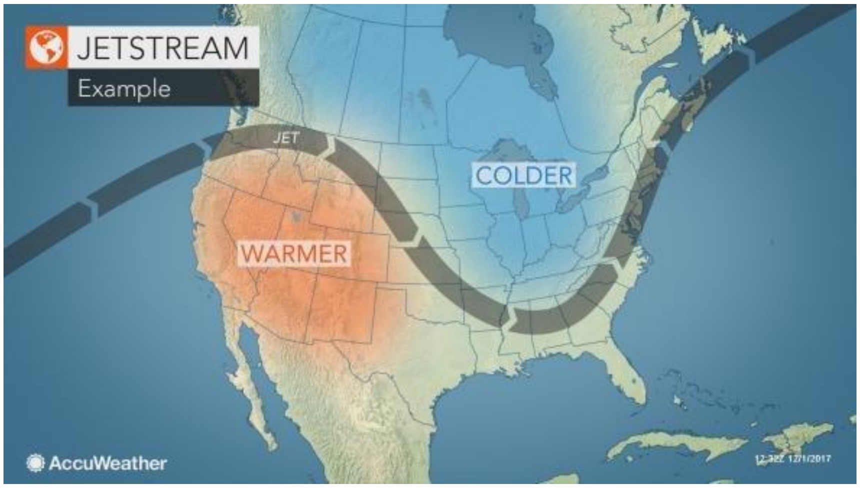
Here are graphs of the temperature versus date at latitude degrees (-90,0,90) (averaged over each year and longitude):







The temperatures of all three of these latitudes (South Pole, Equator, North Pole) increase with time; the North Pole temperature varies with time about 15 times faster than at the Equator and it varies slightly faster than at the South Pole. Such reduction in temperature differences between the north middle latitudes and the Arctic cause erratic movement of the jet stream, which movement often creates extreme weather events in north middle latitudes, such as the USA location:

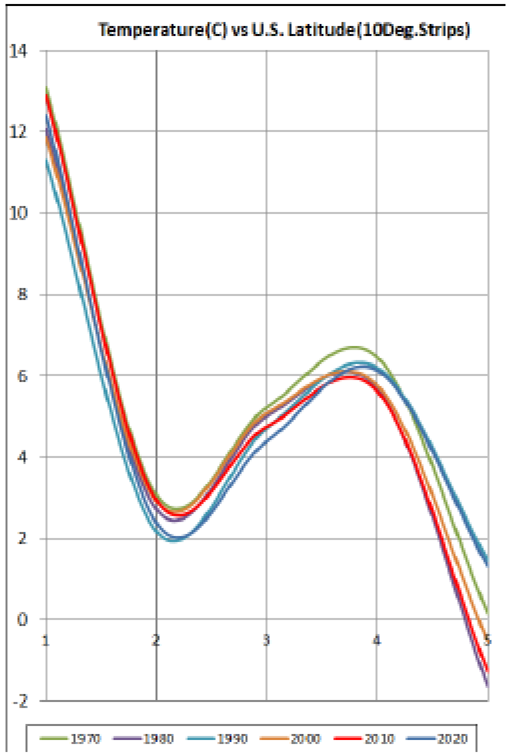


U.S. Temperature vs Latitude

It is interesting to plot U.S. temperature for 10-degrees latitude strips averaged over longitude and years:

US latitudinal 10-degrees strips

	Latitude	Longitude	States
1	25-30	80-105	FL-STX
2	30-35	80-120	SC-CA
3	35-40	75-125	VA-CA
4	40-45	70-125	NewE-OR
5	45-50	85-125	MI-WA

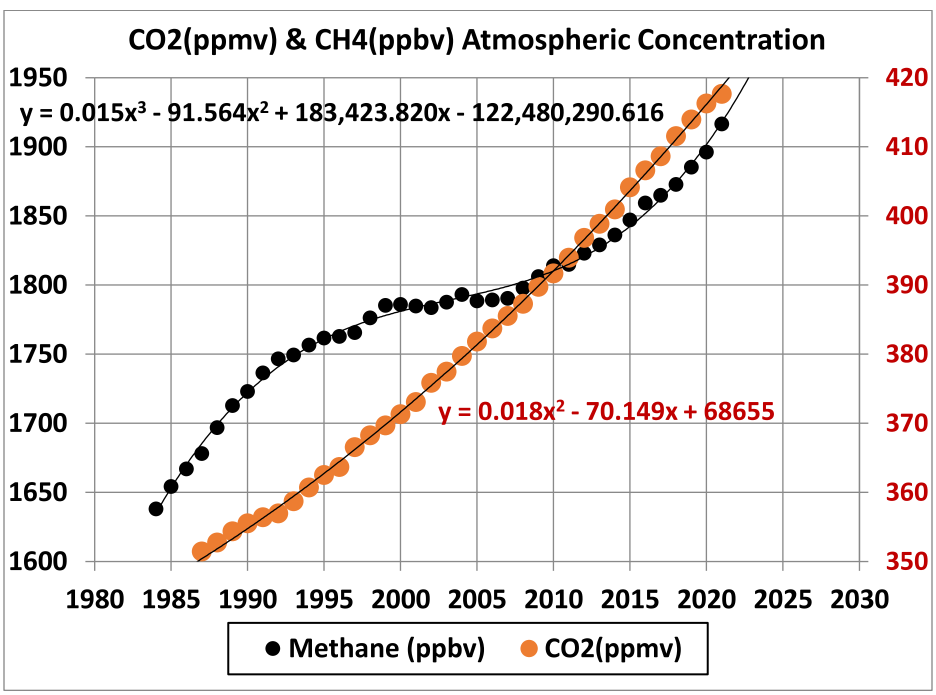


Of course, the southernmost latitude strip (1=FL-STX+large GulfMex) has the highest temperature and the northernmost latitude strip (5=MI-WA) has the lowest temperature. Note that the northernmost strip has the greatest variation over time.

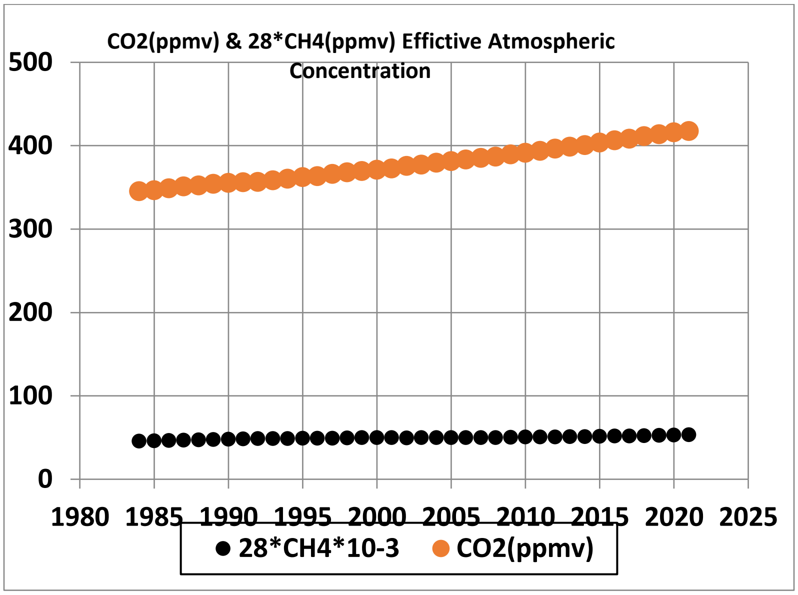
Methane (CH_4) Atmospheric Concentration

There are several other atmospheric gases that, when emitted, increase global warming at about half the rate of carbon-dioxide; the largest of which is methane, which increases global warming at about one-fourth the rate of carbon-dioxide. For simplicity, these gases are not considered here.

Here is a comparison of the CO_2 and [CH_4 atmospheric-concentration data]:



The CO_2 curve is well fitted by a quadratic equation and the CH_4 curve is well fitted by a cubic equation. Note that the CH_4 unit is ppbv, 1000 times smaller than the CO_2 unit, ppmv. Also, CH_4 is about 28 times more effective in warming the atmosphere over 100 years than is CO_2; therefore, the measured CH_4 data are about 28 x 1.8 / 390 = 0.129, or about 13%, as effective as the CO_2 data. This graph shows the GW-effective CO_2 and CH_4 atmospheric concentrations:



So, the approximation of using only CO_2 data to project into the future, as done above, is a reasonable approximation.

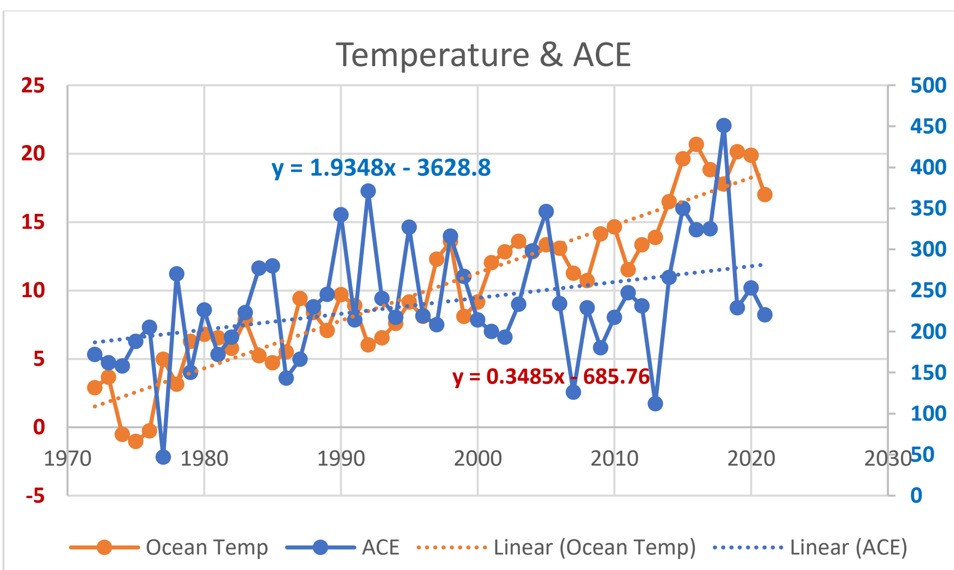
One must consider the fact that methane in the atmosphere reacts with water to produce carbon dioxide, with a half-life of about 9 years:

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2.$$

So, about half of methane emitted nine years ago has been converted to carbon dioxide, which has a lifetime in the atmosphere of over 100 years. Thus, a sizeable fraction of the carbon dioxide in the atmosphere now was methane about a decade ago. Therefore, considering only carbon dioxide as the main cause of global warming is a decent approximation. The situation is further complicated by the reaction removing water vapor from the atmosphere, which is a potent cause of global warming! Thus, the methane-water reaction not only reduces the methane in the atmosphere, but also reduces the water vapor; this makes the carbon dioxide in the atmosphere even more the dominant cause of global warming.

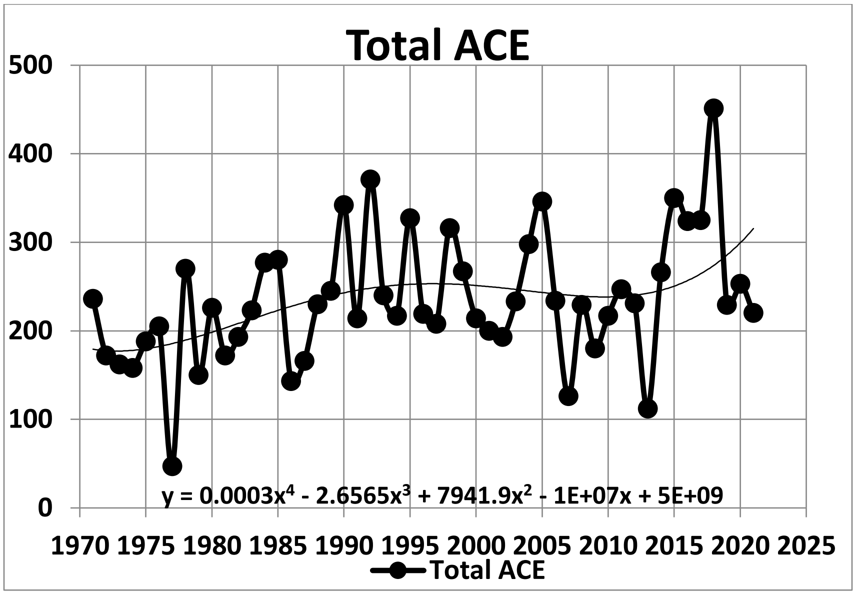
Hurricanes/Cyclones

Warming ocean-surface temperature leads one to expect that the Accumulated Cyclone Energy (ACE) for the Atlantic and Pacific oceans should have increased:

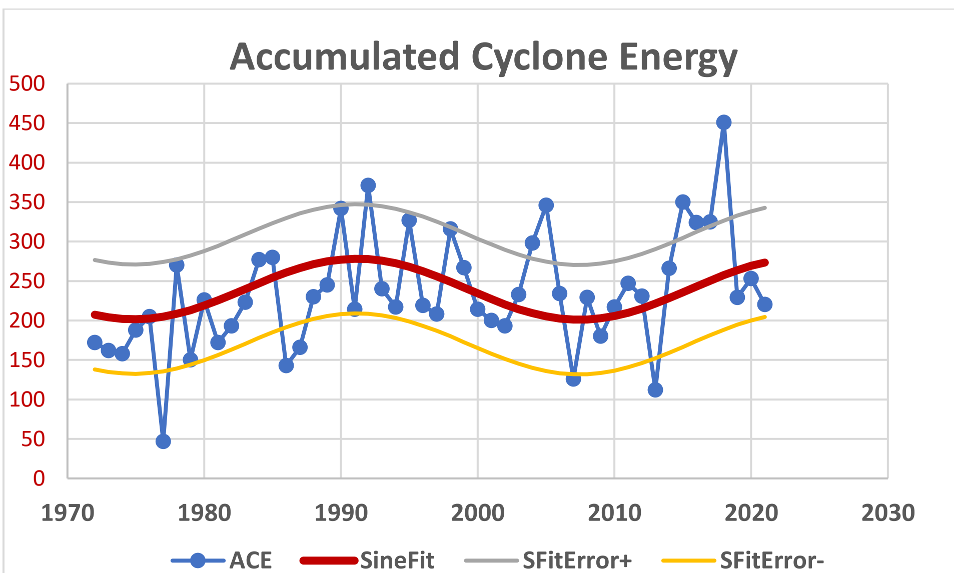


It is interesting that the ACE has increased, according to the linear fit, but has much larger variations than the ocean temperature has.

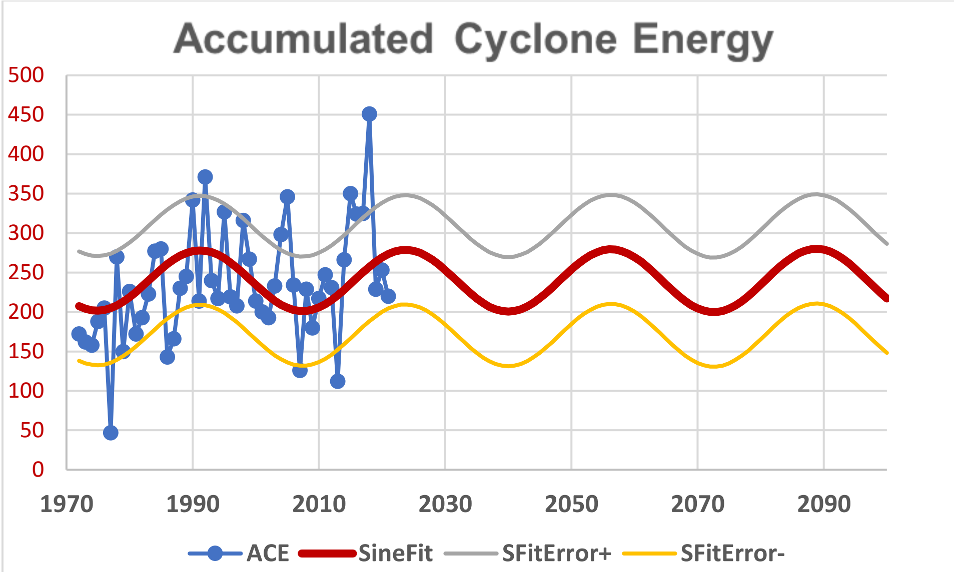
There are other factors, in addition to surface ocean temperature, that are involved in cyclone creation; wind shear is one of them. Of course, the heat not used to create cyclones over a few years may be available for more powerful cyclones over the next few years, if it has not gone into deep ocean or into the atmosphere. That may be what is happening as shown in the following graph:



Perhaps a modulated sinusoidal equation would be a better reasonable fit to the data. Here is such a fit:



Here is a projection of the fit to year 2100:

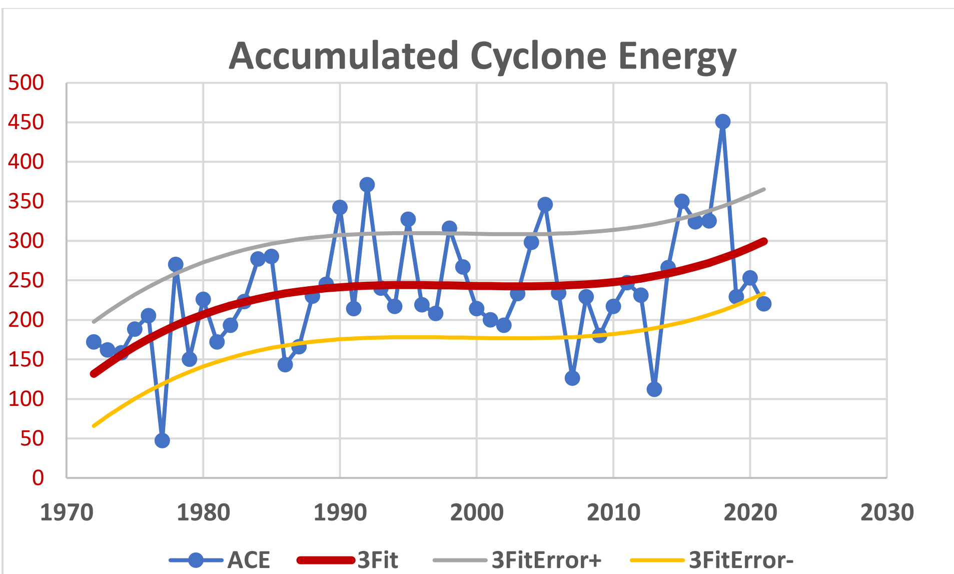


The equation is $ACE = 239.75 - 0.01928t\sin\left(2\pi\left[t - 436.47\right]/32.559\right)$.

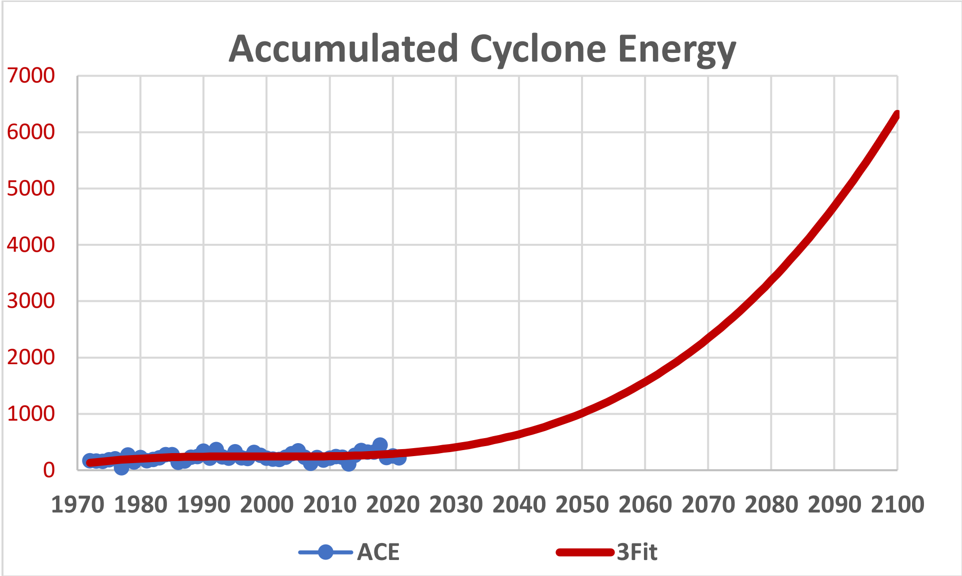
Note that the peaks' amplitude increase is quite small.

Year	Maximum
1992	278.13
2024	278.71
2056	279.35
2089	280.00

This oscillatory interpretation of the data does not seem possible, since the ocean surface temperature is rising so quickly. A better fit to the data is a cubic equation:



Projection out to year 2100 yields:

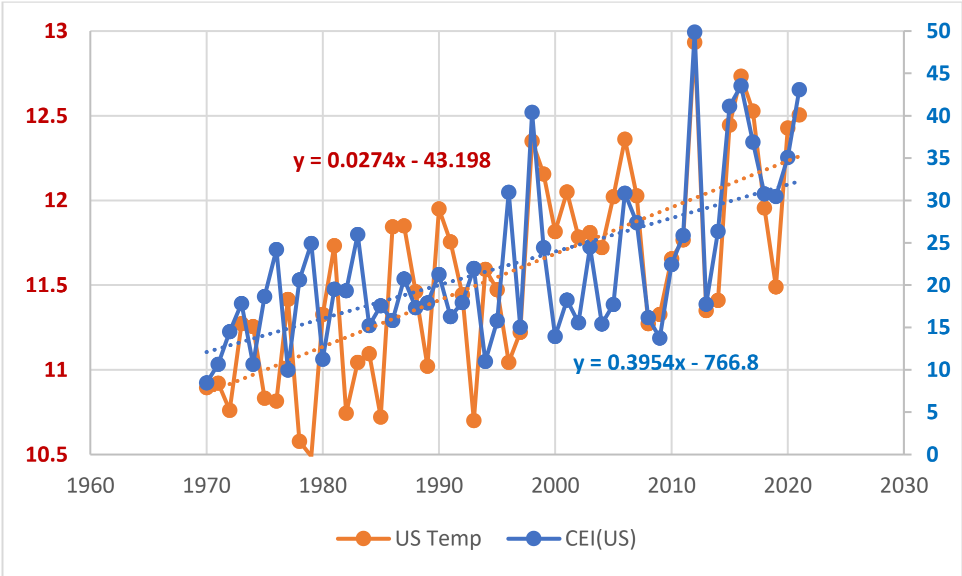


The errors are too small to be visible.

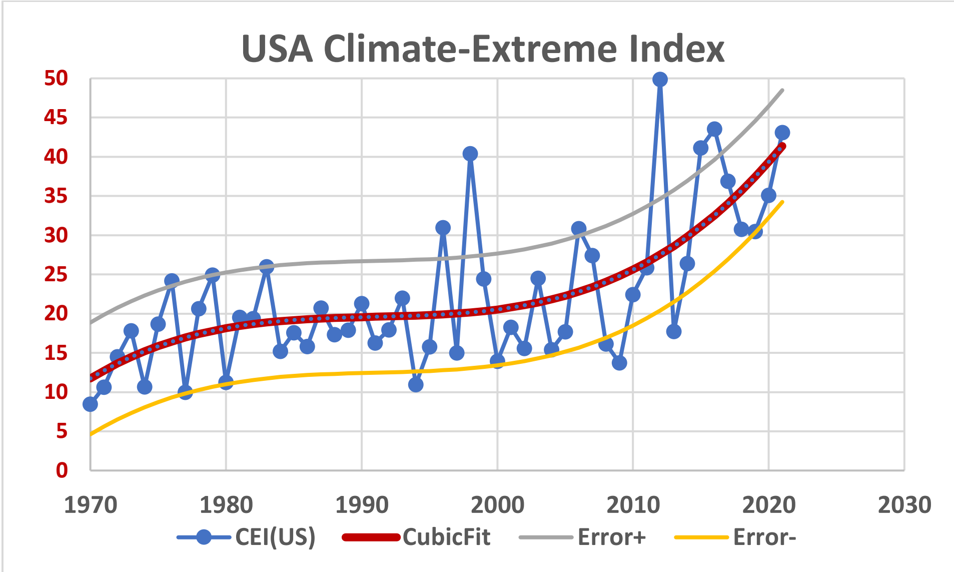
However, it will probably peak at about 1000 ACE near year 2050, because of the finiteness of fossil fuels. (See Appendix.)

US Climate-Extremes Index (CEI)

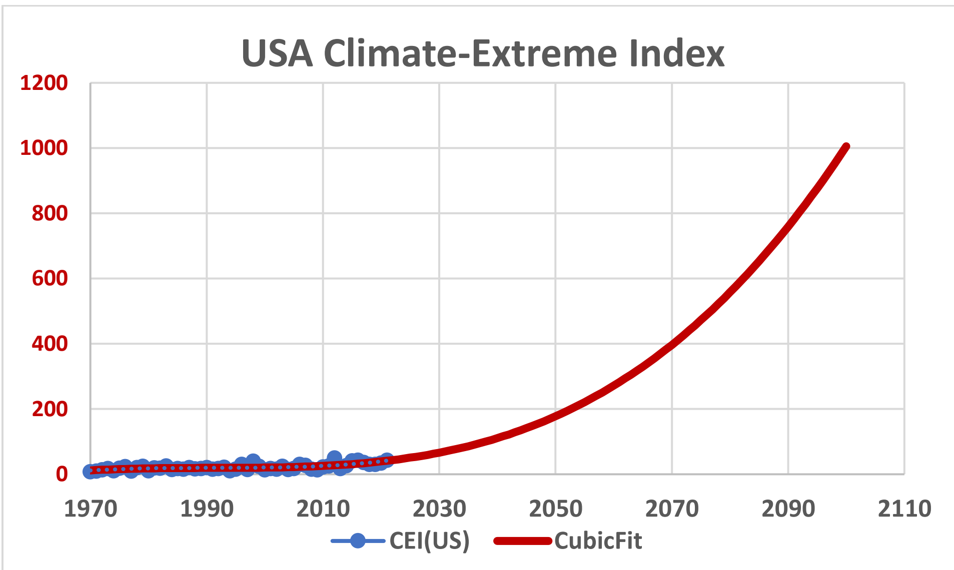
The author could not find a global climate-extremes index. Since the USA average temperature has been rising since 1970, slightly slower than the global average temperature, and there is a US Climate-Extremes Index (CEI), it is worthwhile to study the US CEI:



There is an average large increase in CEI with large variations. A better fit is to a cubic equation:



This fit, projected to year 2100 is:

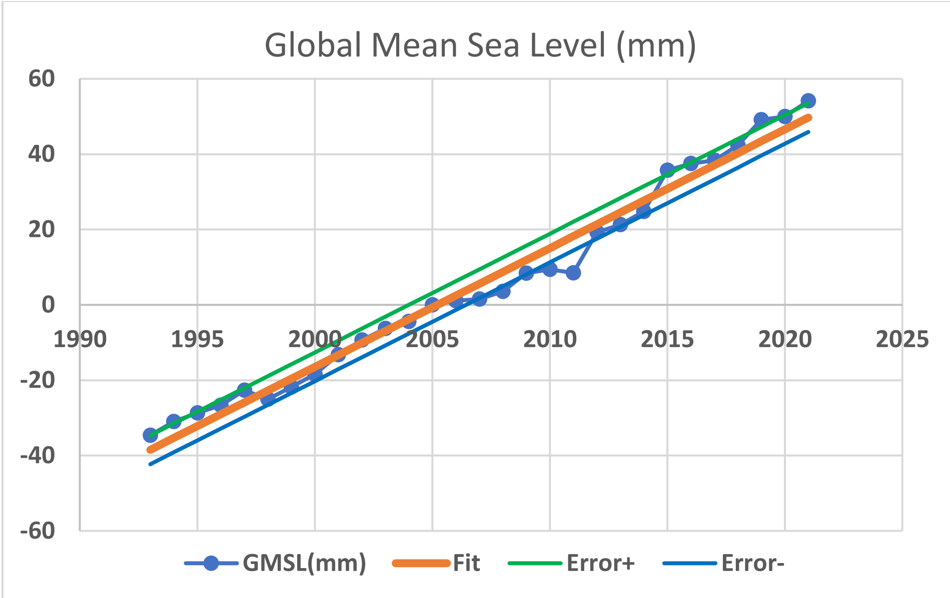


The errors are too small to be visible.

However, it will probably peak at about 200 CEI near year 2050, because of the finiteness of fossil fuels. (See Appendix.)

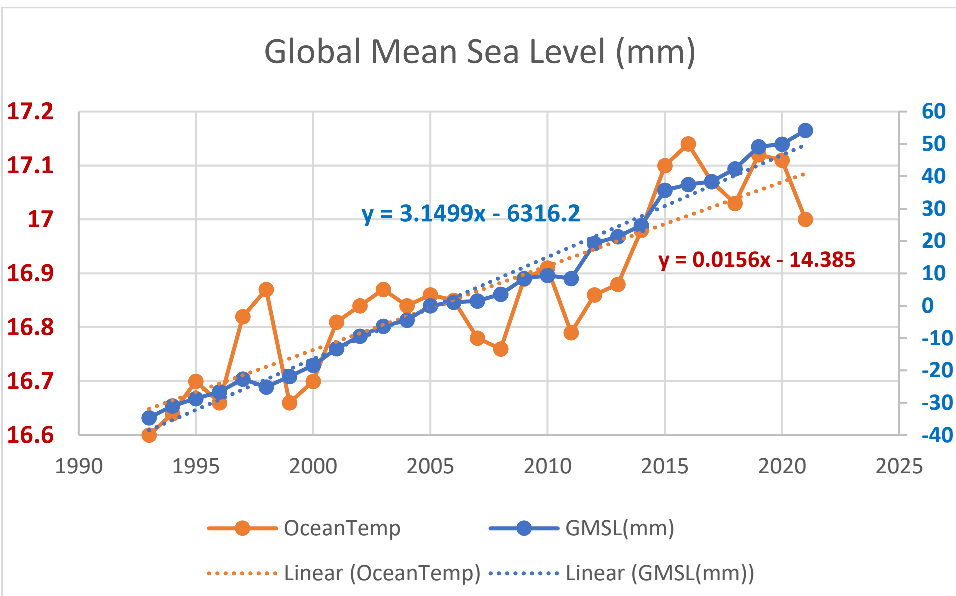
Global Mean Sea Level

Global mean sea-level data, relative to a recent 20-year average, are available from NASA:



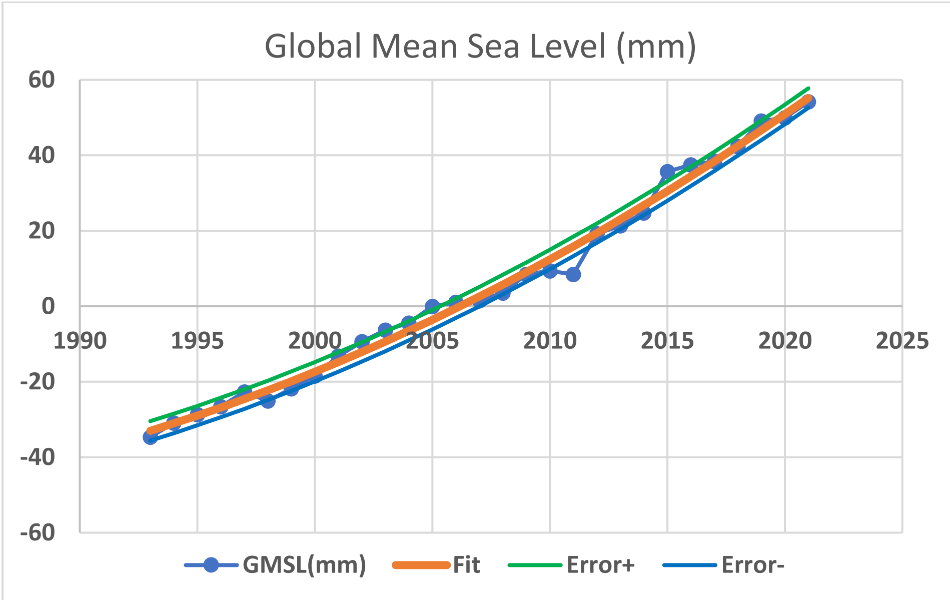
The correlation between the mean-sea-level data and the linear fit is 0.996.

The correlation between the mean-sea-level data and the CO_2 atmospheric concentration is 0.995.



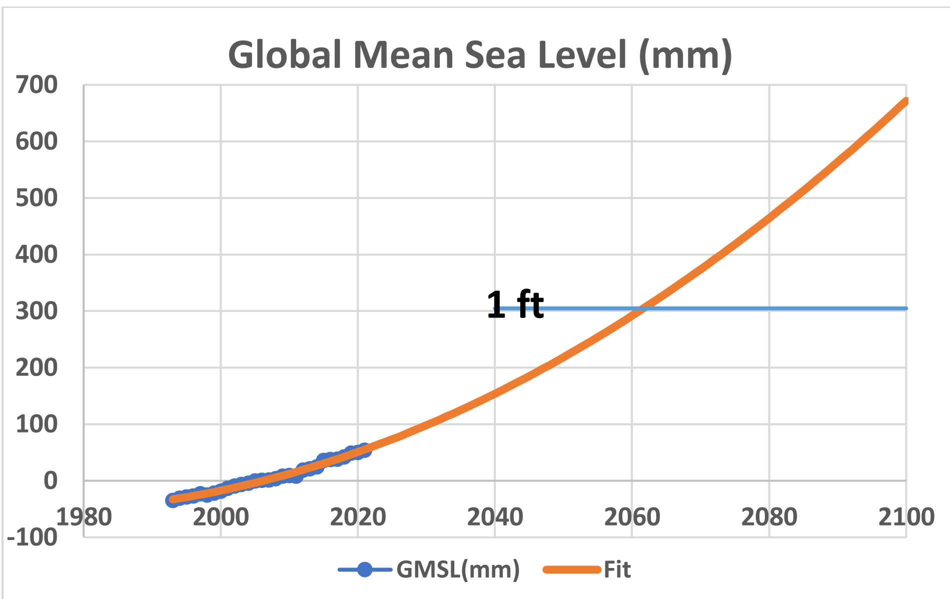
The correlation between the mean-sea-level data and the ocean temperature is 0.898.

A quadratic equation is a better fit to the data than a linear fit:



The correlation between the mean-sea-level data and the quadratic fit is 0.996.

Here is the projected sea-level to year 2100:

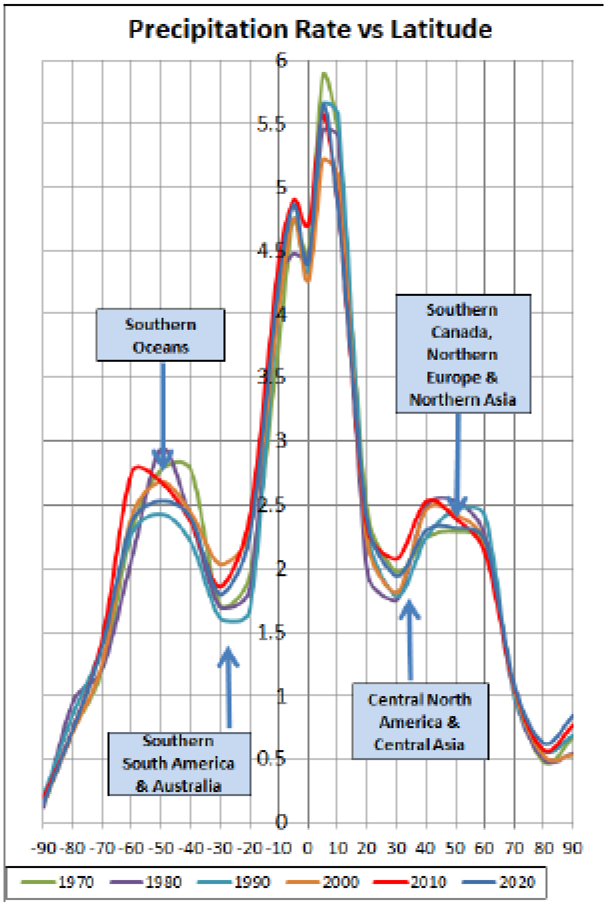


The errors are too small to be visible.

It will probably peak at about 200-mm near year 2050, because of the finiteness of fossil fuels.

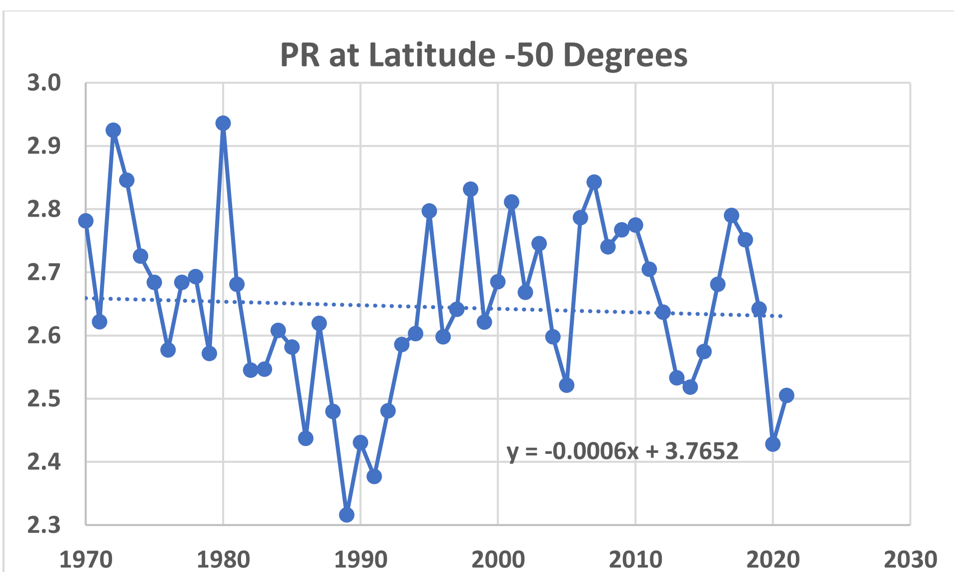
Precipitation Rate vs Latitude

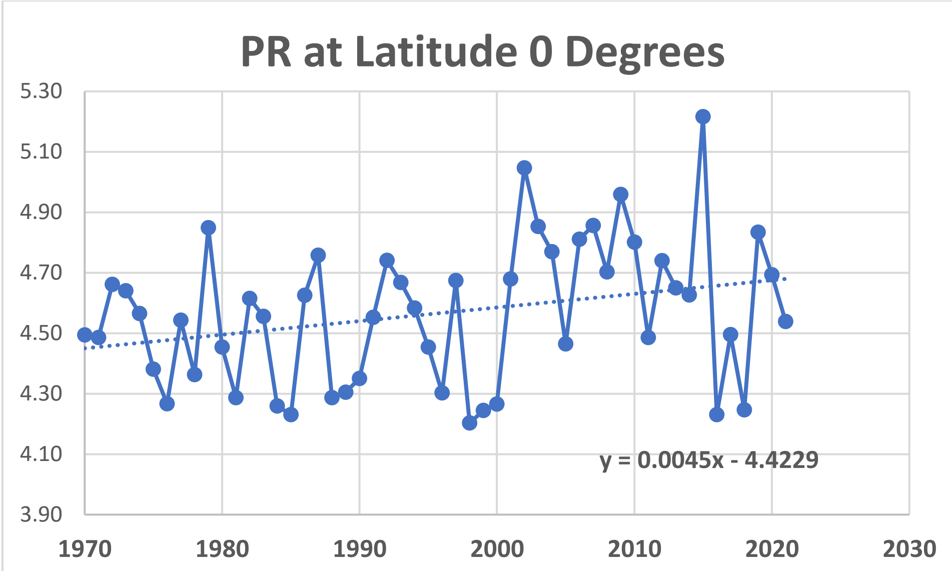
The precipitation rate (PR) (Kg/m^2/s) varies with latitude due to global warming; here is PR vs latitude since 1970:

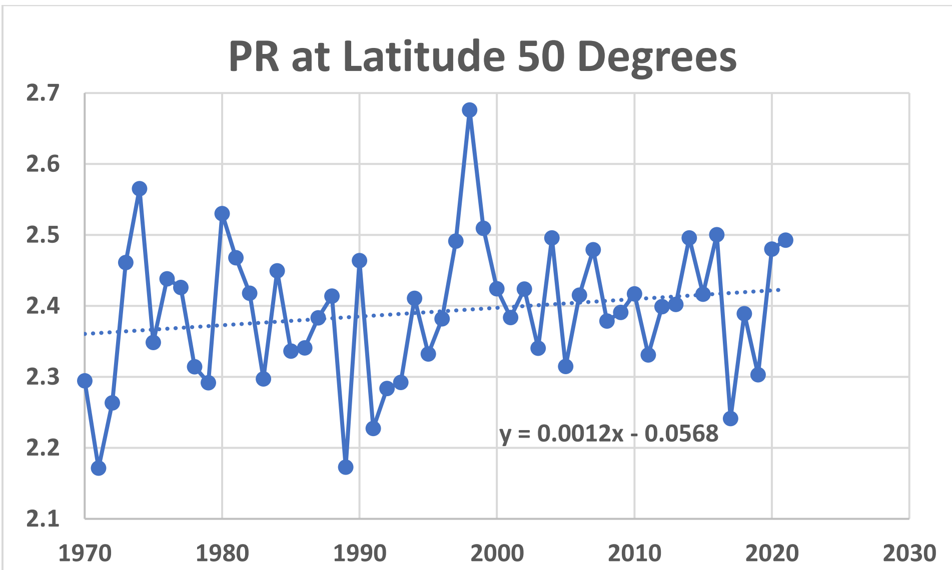


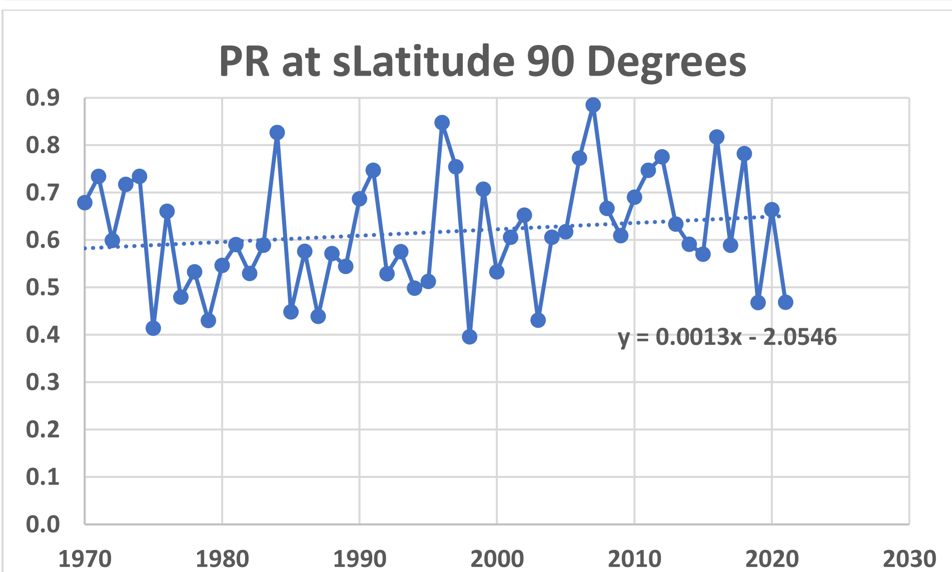
The data are averaged over each year and longitude.

Here are graphs of the PR versus time at latitude degrees (-50,0,50,90):









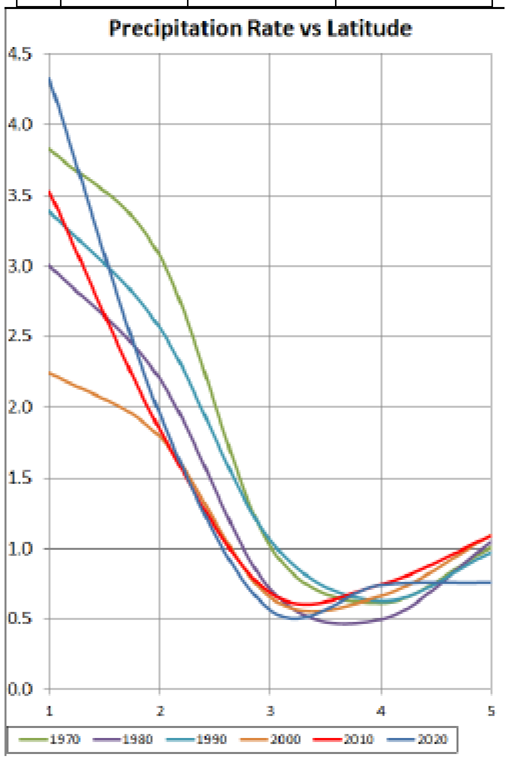
Note that PR decreases with time for -50 degrees latitude and increases with time for 0-, 50- and 90-degrees latitude; although the changes are now large.

U.S. Precipitation-Rate vs Latitude

It is interesting to plot U.S. precipitation-rate (PR) for 10-degrees latitude strips averaged over longitude and years:

US latitudinal 10-degrees strips

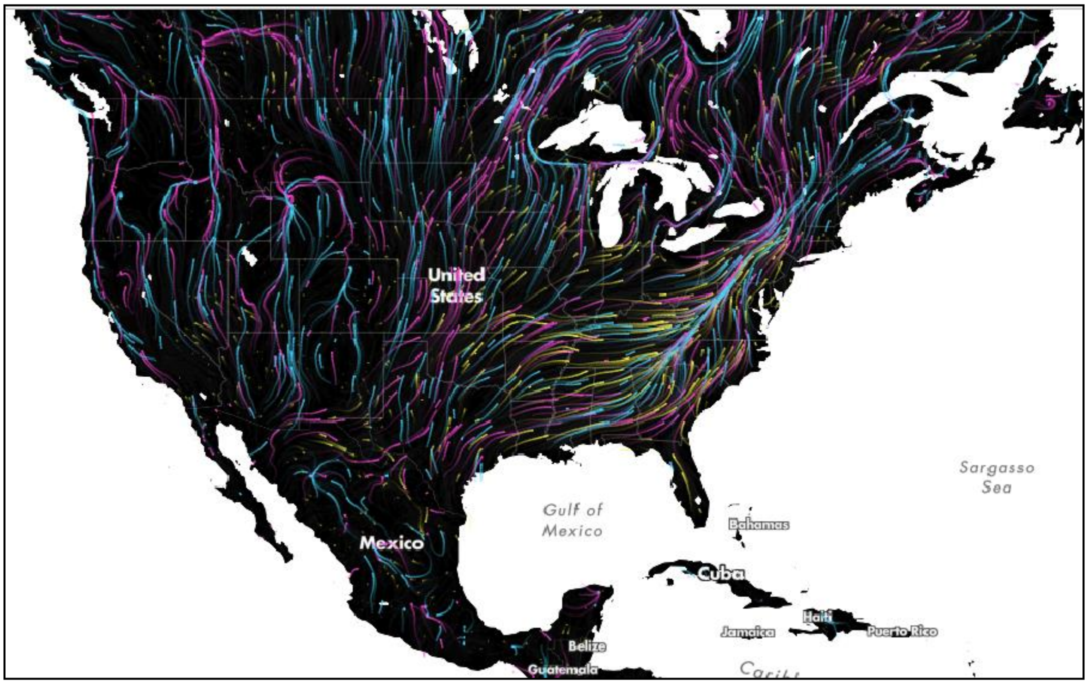
	Latitude	Longitude	States
1	25-30	80-105	FL-STX
2	30-35	80-120	SC-CA
3	35-40	75-125	VA-CA
4	40-45	70-125	NewE-OR
5	45-50	85-125	MI-WA



Note that the greatest variation in PR occurs in the two southernmost latitude strips (FL-STX+large Gulf & SC-CA).

Animal and Plant Migration

At temperatures increase, animals, including humans, and plants will migrate to cooler locations. Here is a [map of the likely migration paths]():



Conclusion

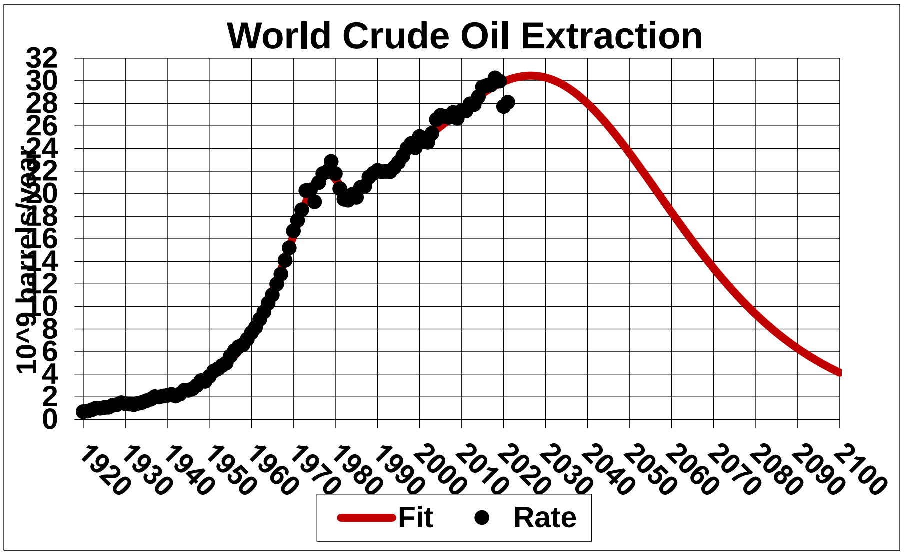
This document is a study of some of the most important data about global warming:

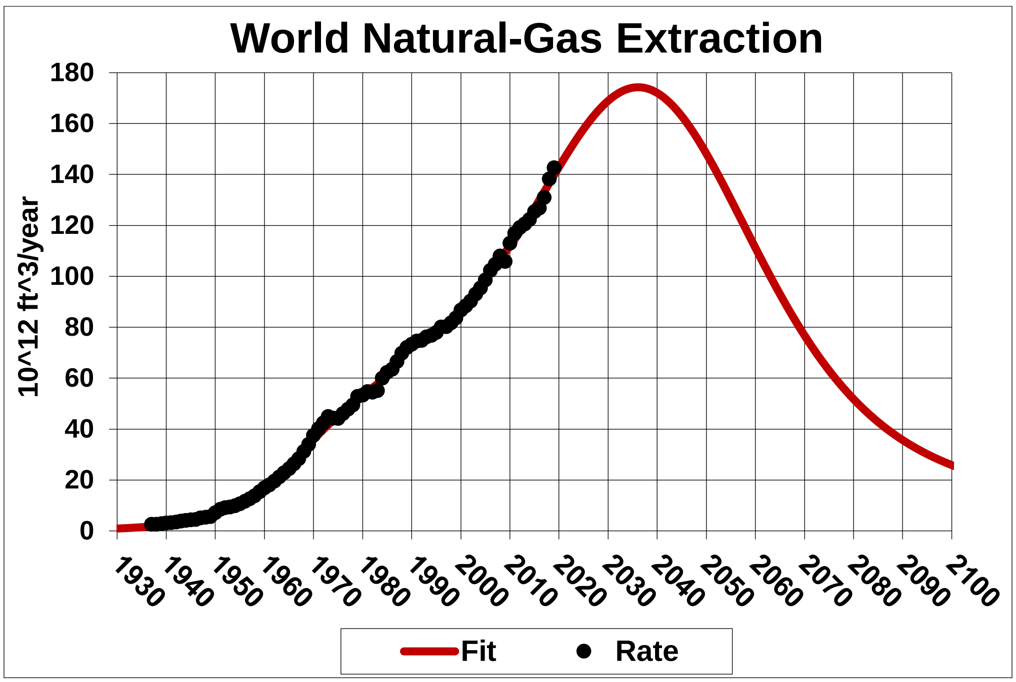
- Global average land temperature, including a projection into the future
- Global average ocean temperature, including a projection into the future
- Atmospheric carbon-dioxide concentration, including a projection into the future
- Methane atmospheric concentration
- Temperature vs latitude
- Accumulated cyclone energy of Atlantic/Pacific oceans
- US climate extreme events
- Precipitation rate vs latitude
- Global mean sea level, including a projection into the future
- Migration of humans from southern location to northern locations as temperatures increase

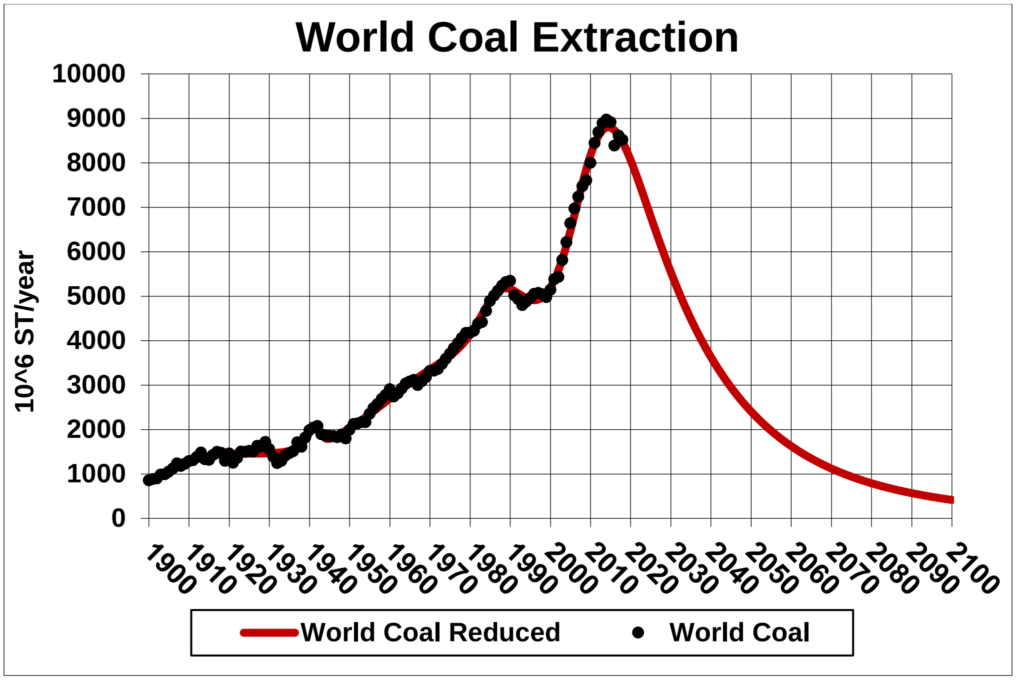
Inclusion of emissions of methane and other greenhouse gases, deforestation and etc. would increase the future amounts of the items listed above. So, the projections given here are minimal estimates.

For a very detailed study of global warming see http://roperld.com/science/GlobalWarming_2022.pdf.

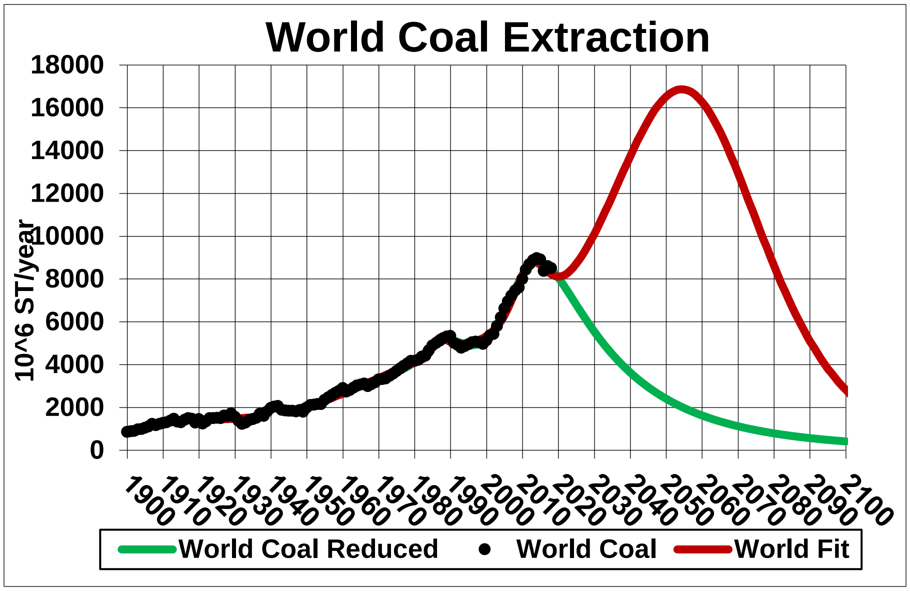
Appendix: Fossil-Fuels Extraction

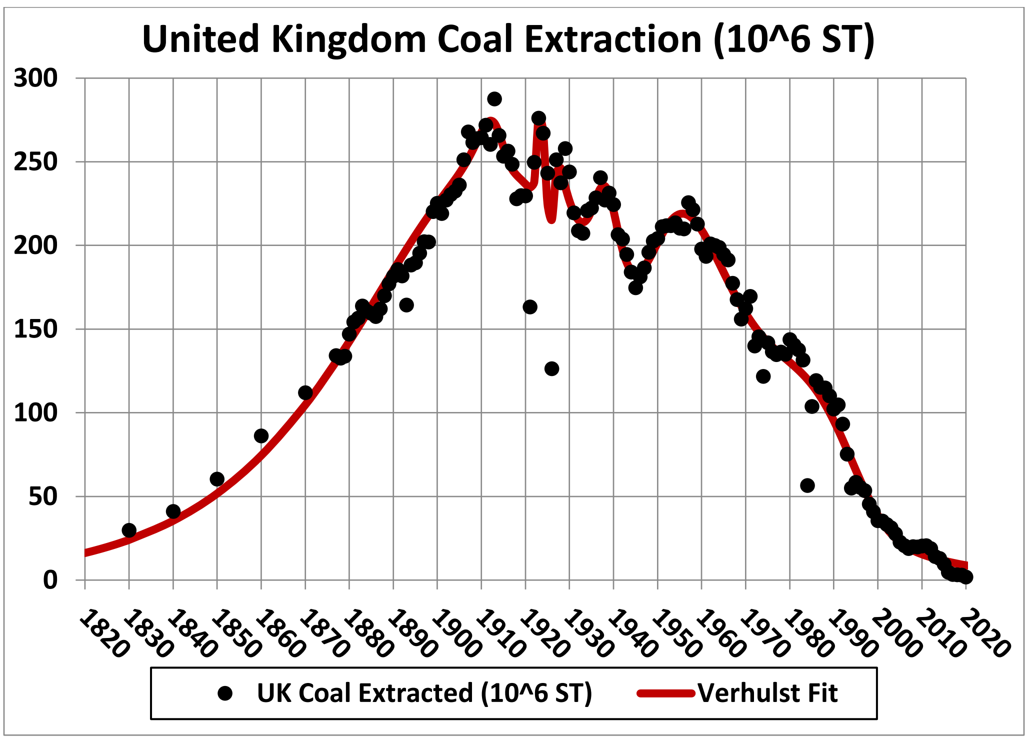





World Coal Extraction
10^6 ST/year
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
World Coal Reduced
World Coal

If all known coal deposits are mined:



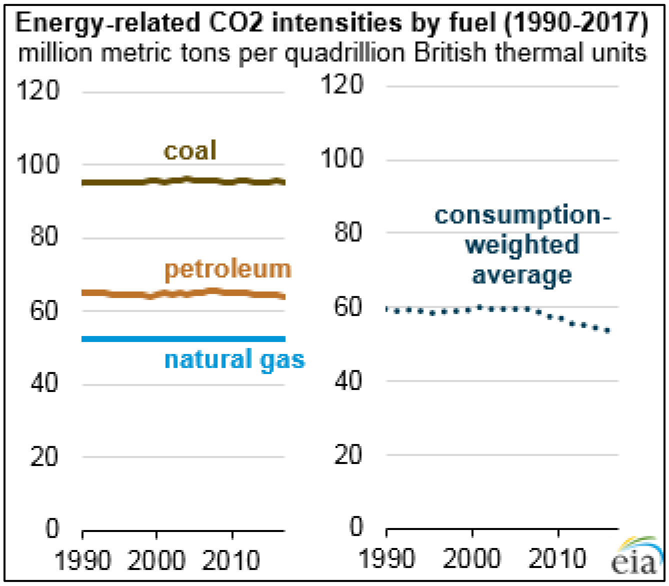


Burning Fossil Fuels

Burning fossil fuels (**coal, crude oil, natural gas**) releases energy (**coal short tons->19.26x10^6, oil barrels-> 5.691x10^6, gas ft^3>995.36**) in BTU.

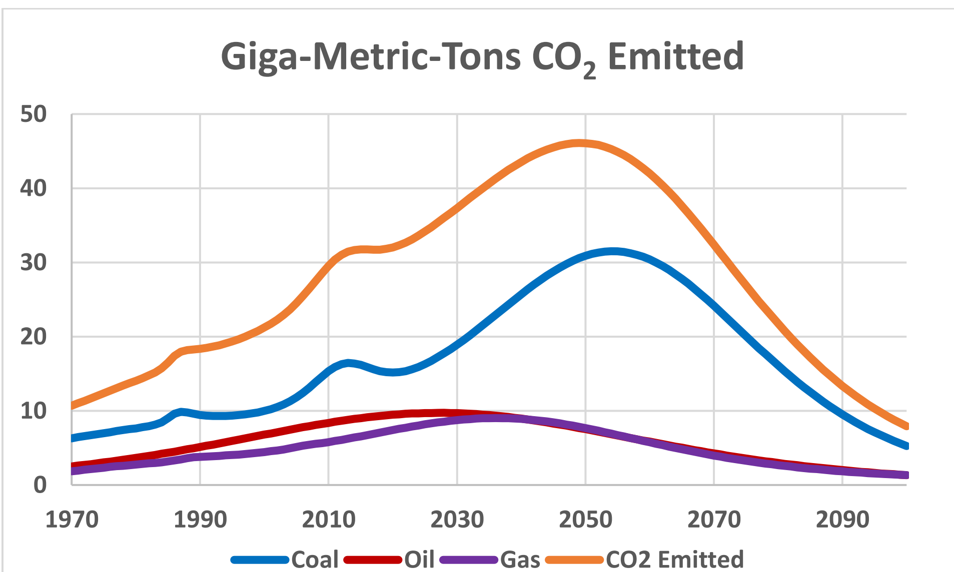
Carbon-Dioxide Emissions

The energy in BTU created by burning fossil fuels is accompanied by emissions of carbon dioxide:



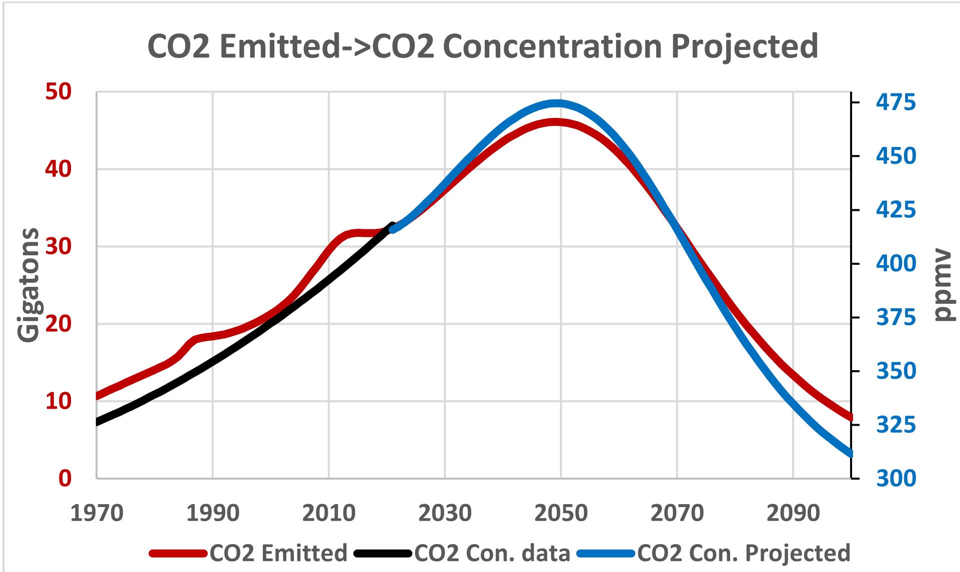
https://www.eia.gov/todayinenergy/detail.php?id=27552

Using (**97, 67,52**) for (**coal, crude oil, natural gas**) CO_2 intensities from the diagram above and appropriate units' conversions, the calculated giga-metric-tons of CO_2 emissions for the three fossil fuels and the sum of all three are shown in this graph:

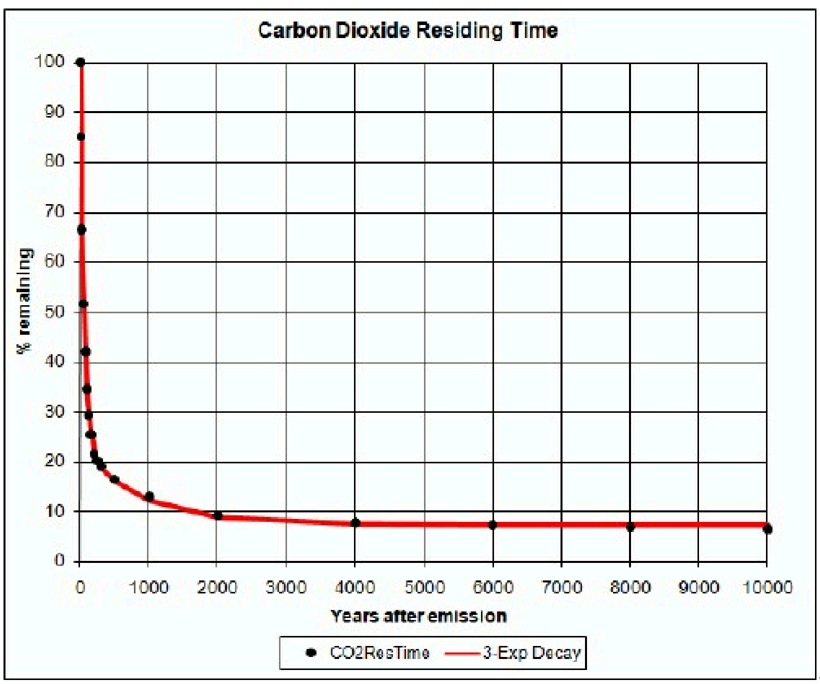


Assuming that all available coal is burned, the maximum yearly emissions is about 47 giga-metric-tons at about year 2050.

Fitting a projected CO_2 atmospheric concentration to the CO_2 emission calculation up to year 2040 with the equation **CO2ConP = 4.27174 * CO2E + 277.6901**, where CO2E= calculated CO_2 emission of global coal, crude oil and natural gas, the following graph is obtained:

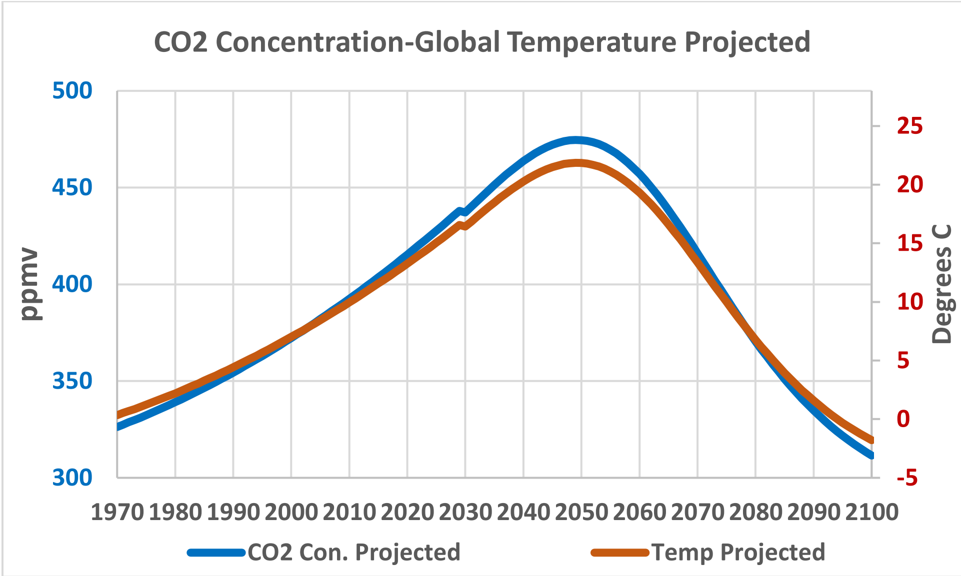


If all available coal is burned, CO_2 atmospheric concentration would peak at about 470 ppmv at about year 2050. However, it will decline much slower than the blue curve projects. Carbon emissions control how fast atmospheric carbon concentration increases, but not how fast it declines. Here is a graph of the carbon-dioxide residing time:



s

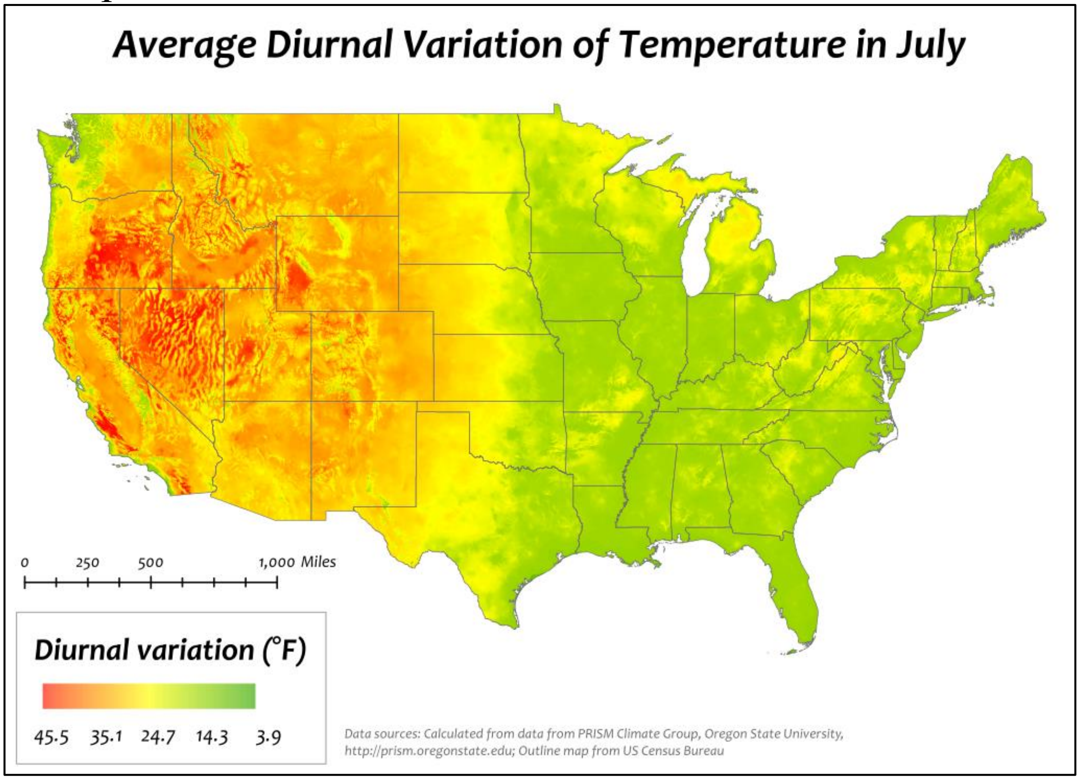
Fitting a projected global average temperature to the CO_2 projected atmospheric concentration up to year 2030 with the equation **TProj = 0.145026 * CO2ConP -46.9704** the following graph is obtained:



If all available coal is burned, global average temperature would peak at about 22-C at about year 2050. The CO_2 concentration and temperature do not decline as fast as this red curve projects. The current average global temperature is about 14-C; so, the peak temperature would be about 8-C above current temperature!

There are other sources of carbon in the atmosphere beside fossil fuels, so, we must stop quickly burning coal for energy.

Appendix: Diurnal Temperature Variation



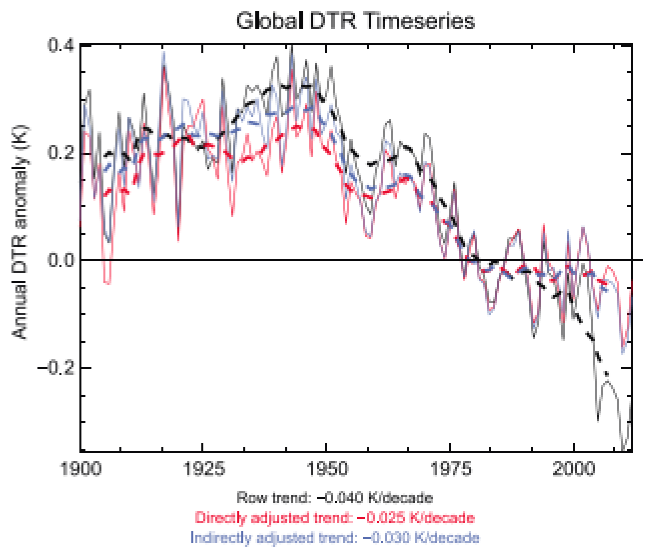
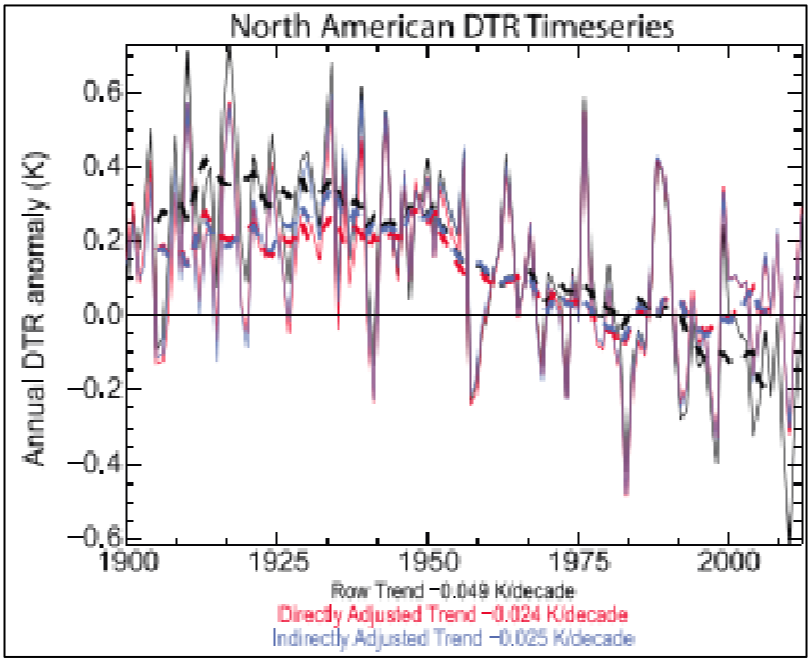
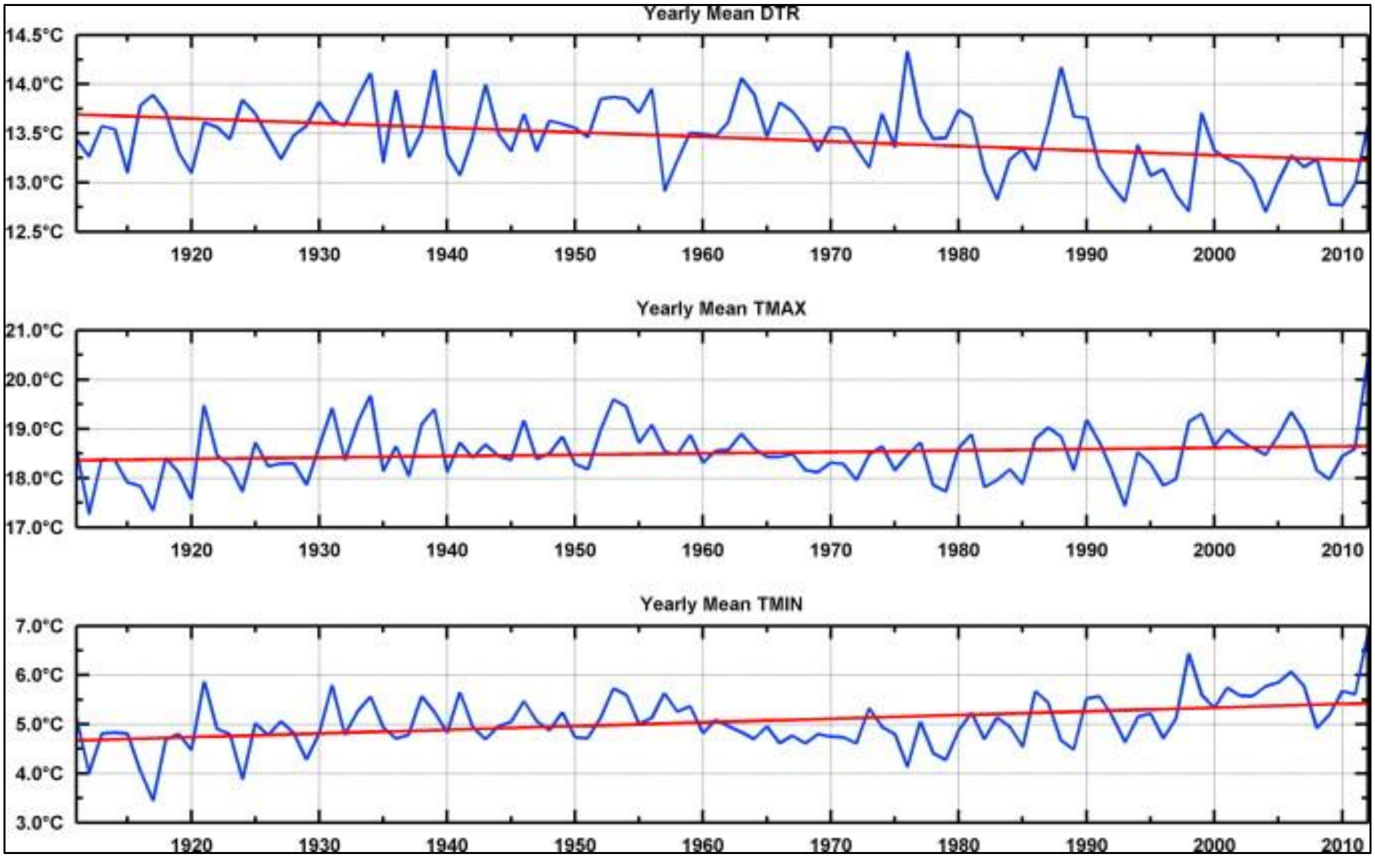


Figure 12. Globally averaged DTR behavior. Each monthly DTR average has been defined by a simple cos(lat) weighted average of all grid boxes reporting data in the given month. Then annual means (solid) and running decadal means (dashed) calculated. Data are globally incomplete (Figure 6) and vary substantially in density and trend behavior regionally over time (Figures 7–10). Black is raw data, red is homogenized directly, and blue is homogenized indirectly. Trend estimates from OLS are given below the figure panel for the whole period of record. See Table 2 for their 5–95% confidence intervals (CIs) and a comparison to those for other periods and the regions in Figure 13. Close agreement during 1971–2000 is in part an artifact of the data shown being anomalies from this base period.

DTR = Diurnal Temperature Range



Note that the anomaly numbers are relative to the base period 1971-2000.



The Modern Global Warming period, 1970-2022, has extremely low diurnal variation, which [can be dangerous to plants and animals](). It is interesting that the global and North American DTR started declining rapidly about 1950, twenty years before global temperature starting increasing rapidly.

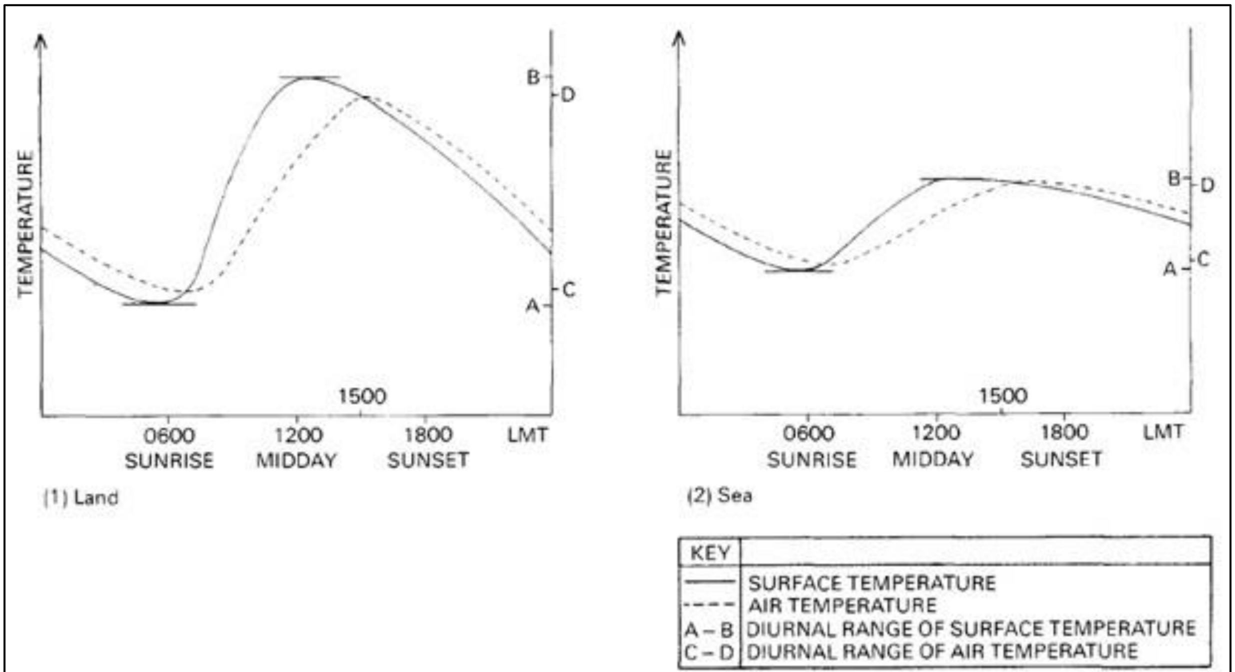


Fig. 3.4 Diurnal variation and range of temperatures.

References

- https://www.sciencedirect.com/topics/veterinary-science-and-veterinary-medicine/diurnality. "Ambient air temperature can provide some cues to distinguish day and night."
- Diurnality-Wikipedia "The timing of activity by an animal depends on a variety of environmental factors such as the temperature, …"
- Global Data DTR "Changes in diurnal temperature range (DTR) over global land areas are compared from a broad range of independent data sets. All data sets agree that global-mean DTR has decreased significantly since 1950, with most of that decrease occurring over 1960–1980."
- Diurnal Temperature Range "Changes in DTR have multiple possible causes (cloud cover, urban heat, land use change, aerosols, water vapor and greenhouse gases)."
- DTR in USA "…diurnal air temperature range variations of the continental United States over the past one hundred years were investigated to discover the temporal trend and spatial patterns."
- DTR Excess Mortality "Projections of excess mortality related to diurnal temperature range under climate change scenarios: a multi-country modelling study"