Global warming is inevitable
We can only mitigate its consequences

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Contents

1 The seven great mass extinctions

1.1 1. Photosynthesis, oxygen, and death of many anaerobic bacteria

When organisms evolved photosynthesis about 3.4 billion years ago, they first began converting carbon dioxide, water and sunlight into carbohydrates, and expelling oxygen as waste. The toxic oxygen killed off (oxidized) many types of anaerobic bacteria.

The oxygen also oxidized iron in the ferrous state (Fe^{+2}) into the ferric state (Fe^{+3}), which combined to form insoluble iron oxide, which precipitated from the ocean to form the Earth's huge iron deposits.

1.2 2. Ordovician-Silurian extinction event

85% of all species were killed probably by volcanism and reduction of carbon dioxide leading to cooling, glaciation and anoxia (?). This occurred about 444 million years ago.

1.3 3. Late Devonian extinctions

Two extinction events eliminated at least 70% of all species between 372 and 359 million years ago. Anoxia caused many deaths.

1.4 4. Permian-Triassic extinction event

This largest of all extinctions killed 90-96% of all species about 252 million years ago.

1.5 5. Triassic-Jurassic extinction event

70-75% of all species became extinct, leaving the dinosaurs to dominate the land. Birds (a kind of dinosaur) and small mammals evolved.

1.6 6. Cretaceous-Paleogene extinction event

66 million years ago a large asteroid hit the Yucatan penisula, throwing huge quantities of debris into the atmosphere, and causing violent tsunamis. About 75% of all species became extinct, including the dinosaurs (except the birds). Some small mammals survived, and evolved into today's mammals.

1.7 7. Holocene extinction now ongoing

Homo sapiens are causing this extinction. With advanced hunting skills, humans probably exterminated mammoths, saber toothed tigers, dodo birds and passenger pigeons. Buffalo, badgers, wolves, and right whales have greatly declined in number. Overfishing and stream mismanagement have decimated salmon. Herbicides are killing the milkweeds upon which monarch butterfly caterpillers feed.

Because of deliberate or inavertant human activity, at least 1 million plant and animal species out of 8 million total on Earth are threatened with extinction.

I think that this estimate of species loss is much too low as humans rampage during the next centuries.

2 Introduction

Scientists live in the real world where the laws of science determine everything that happens.

Human activity and world politics will go the way they go–more or less with disregard to the best scientific advice.

As this treatise will show, global warming and climate change are real and consequential, despite the opinions of many conservatives.

Furthermore, global warming and climate change CAN NOT BE STOPPED, only mitigated. I am sorry to disappoint my progressive friends.

Describing all the science of global warming, climate change, weather patterns, ecological repercussions etc. is way beyond my pay grade.

Rather, I, an engineer, will consider the Earth as a giant machine. I will try to extrapolate past measured changes out to the year 2100, assuming that worldwide human behavior does not change enough.

This is the same approach as predicting the increased power of a steam engine if the boiler temperature is increased, or the increased speed of an electric motor if the voltage is increased, or the increased speed of a runner after a shot of methamphetamine.

That is, unless the boiler explodes, or the motor burns out, or the runner has ia heart attack!

3 Rise in atmospheric carbon dioxide

The burning of fossil fuels since the start of the industrial age has caused the amount of carbon dioxide to increase (Fig. 1). [1] The increase is accelerating, so I fit the curve with a parabola to extrapolate to the year 2100 (Fig. 2).

I predict that continually more coal will be burned to generate electricity and to refine iron, especially by China and India.

I predict that more natural gas will be used to generate electricity, to heat buildings, and to produce ammonia for fertilizer–until natural gas inevitably runs out.

I predict that more petroleum will be used to produce gasoline, diesel fuel, jet fuel, many organic chemicals, and plastics–until petroleum inevitably runs out.

I predict that more cement will be made, with carbon dioxide being released from producing lime from limestone.

I predict more frequent forest fires with global warming and more destruction of forests, thus releasing more carbon dioxide.

CO_2 will keep rising past 2100.

4 Global temperature rise

Daily temperatures are measured at hundreds of locations around the world and averaged yearly (Fig. 3). By the greenhouse effect, the rising CO_2 levels are the cause of Earth's temperature rise. Temperature has risen 1.0 C (1.8 F) compared to 1960.

I made a parabolic exprapolation to 2100, which gave a predicted temperature increase of 3.0 C (5.7 F)!

CO_2 has a cumulative warming effect, and warming will continue past 2100.

During the progressively worsening heat waves, thousands will die. Air conditioners cost money and use electricity, which the poor lack.

[1] Carbon dioxide concentration at Mauna Loa Observatory

5 Warming in the Arctic and loss of summer sea ice

The Arctic has warmed faster than the rest of the planet. The summer minimum of Arctic sea ice has been decreasing dramatically (Fig. 4). My extrapolated parabolic fit predicts that by 2050 the Arctic will be nearly ice free in summer!

Snow and ice reflect most sunlight back into space, but ocean water looks black, implying that oceans absorb nearly all solar energy shining upon them. This implies that the ice-free Arctic is warming substantially, which melts still more ice–a positive feedback mechanism.

Note: Melting sea ice does not raise the ocean level.

The permafrost is melting, causing buildings and roads to crack. Methane formed from decayed vegetation in the permafrost is bubbling to the surface. Methane is a much more potent greenhouse gas than CO_2, and contributes maybe 10% to warming.

Warming affects all the Arctic fauna and flora. For instance, with no summer Arctic ice, polar bears have trouble hunting seals. Fish populations change as water warms.

6 Melting of glaciers

Measurements of glaciers in Greenland, the Himalayas and elsewhere show progressively increasing shrinkage.

What will happen when the huge amount of Antarctic ice starts melting rapidly?

7 Sea level rise

Mean sea level has risen 20 cm (7.9 inches) since 1880 (Fig. 5), half caused by melting glaciers and half by sea water expanding with rising temperature.

This rise is accelerating, with the sea level along the Gulf Coast and the eastern seaboard rising twice as fast during the past decade. [2]

Humans have built many major cities next to the ocean: Tokyo, Yokohama, Shanghi, Ho Chi Minh City (Saigon), Jakarta, Kuala Lumpur, much of Bangladesh, Mumbai, Alexandria, Venice, much of The Netherlands, London, New York City, New Orleans, Miami, Galveston, Houston, and Charleston SC. All are subject to flooding during storms combined with high tides. Some island nations lie only a few feet above the ocean.

Sea walls as built around The Netherlands and New Orleans can protect valuable land, but there are too many shorelines around the world which are not economically feasible to protect.

Millions will have to move! But where will they go?

[2] C. Mooney and B. Dennis, Seas have drastically risen along southern U.S. coast in past decade, Washington Post, 4/10/2023

8 Warming of the ocean: Hurricanes, storms and droughts

The evaporation (vapor pressure) of water rises exponentially with temperature. A hurricane is a kind of steam engine powered by hot ocean water. A 1-2 C rise in water temperature can change a category 2 hurricane into a category 5.

Weather is an extraordinarily complicated problem to compute, requiring supercomputers, but models predict that some parts of the Earth will become drier, some wetter. Extreme weather events are getting worse in America on average (Fig. 6) and throughout the Earth.

9 Expanding desserts and drying of forests

While climate models predict that some areas will receive increased rainfall, the great desserts of the world such as the Sahara will expand, and our own southwest will become hotter and drier.

Severe forest fires in the American West, Canada and Siberia are now common. An area the size of Florida in Siberia has burned! Even parts of the Amazon has dried and burned! There is nothing anyone can do to stop this trend. Soon fire insurance in the west might become impossible to buy at any price.

10 Acidification of the ocean

CO_2 when dissolved in water forms carbonic acid, a weak acid. More dissolved CO_2 makes the ocean more acidic.

Sulfur dioxide emitted from coal-fired power plants combines with water to form sulfuric acid. Nitrogen and oxygen combine during combustion in engines to form oxides of nitrogen (NO_x or smog), which in turn combines with water to make nitric acid. This is *acid rain*, making the ocean more acidic.

The ocean has been getting more acidic (Fig. 7), [3] i.e., the pH has been decreasing

pH is defined so that the hydrogen ion concentration $[H^+]$, the number of moles of hydrogen ions per liter of water (I won't define this), is:

$$[H^+] = 10^{-pH} \tag{1}$$

The approximately linear increase in $[H^+]$ is graphed in Fig. 8. The measured region is a thick black line, and the extrapolation to the year 2100 is the thin line. Note that this is a semilog plot, so each vertical division is a 10-fold increase in concentration.

Atmospheric CO_2 is moderately soluble in seawater, and much of humam-produced CO_2 eventually goes into the ocean, according to the following reaction:

[3] https://www.eea.europa.eu/ims/

$$atmospheric CO_2 \leftrightarrow dissolved[CO_2] \tag{2}$$

CO_2 is less soluble in warmer water; Fig. 8 shows the equilibrium concentration for 20 C (68 F).

CO_2 can combine with water to form carbonic acid:

$$CO_2 + H_2O \leftrightarrow H_2CO_3 \tag{3}$$

Carbonic acid can dissociate into a hydrogen ion and a bicarbonate ion (baking soda is sodium bicarbonate):

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+ \tag{4}$$

Bicarbonate can dissociate into a carbonate ion and a hydrogen ion:

$$HCO_3^- \leftrightarrow CO_3^{-2} + H^+ \tag{5}$$

Sea animals combine carbonate ions with calcium ions to form their calcium carbonate structure:

$$Ca^{+2} + CO_3^{-2} \leftrightarrow CaCO_3 \tag{6}$$

Calcium leached from limestone rocks and carried by rivers to the ocean also combines with carbonate, and this solid calcium carbonate precipitates to the ocean floor. This is the mechanism by which hundreds of feet of limestone has formed over millions of years.

Under equilibrium conditions in a well-mixed solution, the concentrations of all the above chemicals can be computed from the equilibrium constants (Fig. 8). This is taught in all freshman college chemistry couses.

However, the ocean is far from well mixed. It takes decades for the cooler deep waters to mix with the warmer surface waters all over the Earth.

As I said, Fig. 8 is a semilog plot, and the concentration changes look deceptively small. However, when plotted on a linear plot (Fig. 9), my predicted changes between 1960 and 2100 are:

- $[H^+]$ increases 71%!
- Carbonate decreases 30%.

This spells bad news for shelled animals, coral, and other creatures with calcium carbonate structures.

The increased acidity will also affect many sensitive sea creatures.

11 Fresh water

The greatest use of water is crop irrigation, but clean drinking water is most crucial. In 2022 China suffered the worst drought and heat wave in 50 years. Severe drought also occurred in southern Europe and southwestern America. The inland salty Caspian Sea is drying up because rivers running into it are being diverted for irrigation. The Great Salt Lake in Utah is shrinking for the same reason. The Nile and Mississippi Rivers are running low.

Colorado River water has been 100% allocated to California and Arizona for a century, but due to drought, Lake Mead behind Hoover Dam is at an all-time crisis low. California's rich agricultural production is in jeopardy. Will there even be enough water for the people?

500,00 people have left California in the past two years. [4] Housing costs and high cost of living are major factors, but new houses cannot get water, fire insurance is extraordinarily expensive, and California's agriculture is drying up.

I think that migrations out of drought-stricken areas will affect millions in the coming decades.

Much river and well water is badly polluted. In China and India they dump raw sewerage and industrial wastes directly into rivers! China has even looked at Lake Baikal in Russia for water for its northern thirsty provinces!

Israel desalinates sea water for its dry country. But reverse-osmosis desalination requires enormous amounts of electricity to run the pumps–not an option for energy-starved poor countries.

12 Famine

The Earth's population is still expanding, but future food supplies could be disrupted by droughts, storms, floods, diseases of humans and their animals and plants, and disasters such as tsunamis, earthquakes, volcanoes and wars. With climate change, the 100-year disaster is becoming more and more like the 10-year catastrophy!

Much of agriculture depends upon nitrate fertilizer. Ammonia is made by combining hydrogen and nitrogen via the *Haber process*. The cheapest source of hydrogen is natural gas, which will become much more expensive as world supplies dwindle.

13 Conclusion

The inevitable global warming and climate change will put enormous pressure upon Homo sapiens and upon every other species. Humans are sometimes clever, and the smarter ones will devise mitigating tactics to survive.

By the Theory of Evolution, some but not all species will adopt to the Brave New World.

[4] M. Rynor, Recent data shows California lost 500,000 people over the last two year, abc10./com/article/news/politics/data-california-leaving-state/103-060c979a-8f05-4d04-b561-558bd0a7d4e8, 2/21/2023

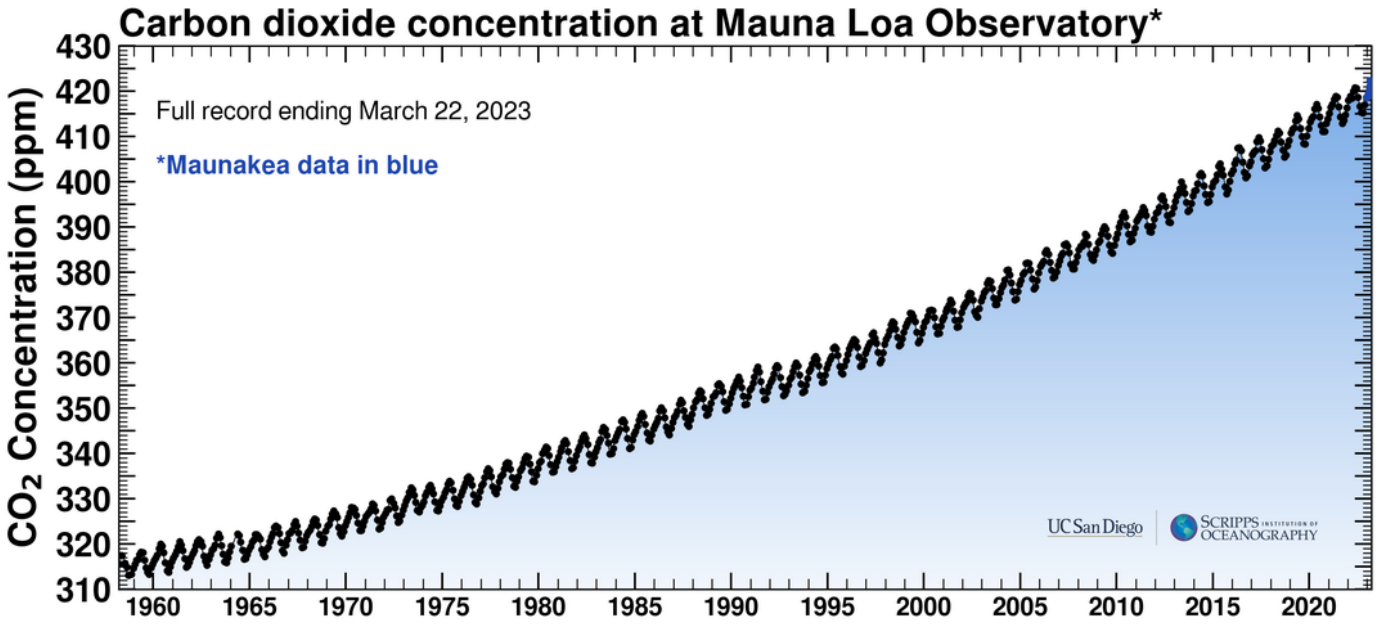

Figure 1: CO_2 was measured at Mauna Loa Observatory on Hawaii far from industrial sources. There were large season-season fluctuations as CO_2 was absorbed during photosynthesis.

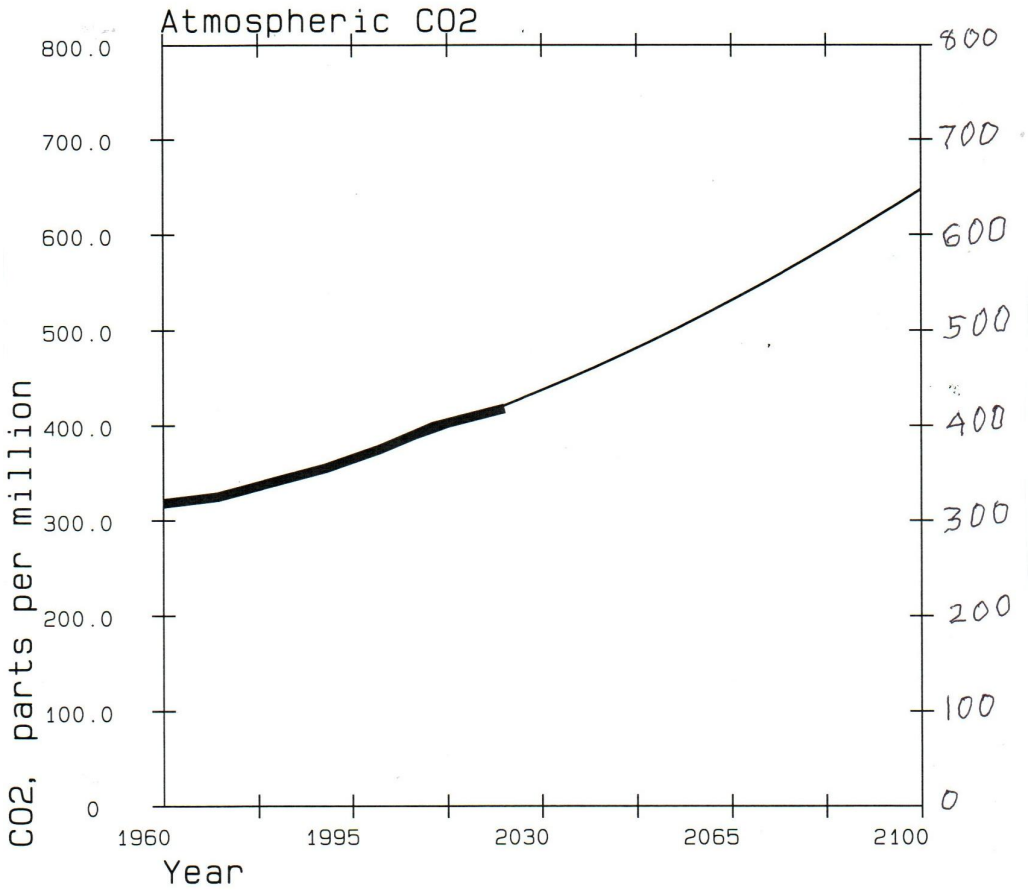

Figure 2: Predicted CO_2: The thick line is the average measured curve. The thin line is the parabolic extrapolation to the year 2100.

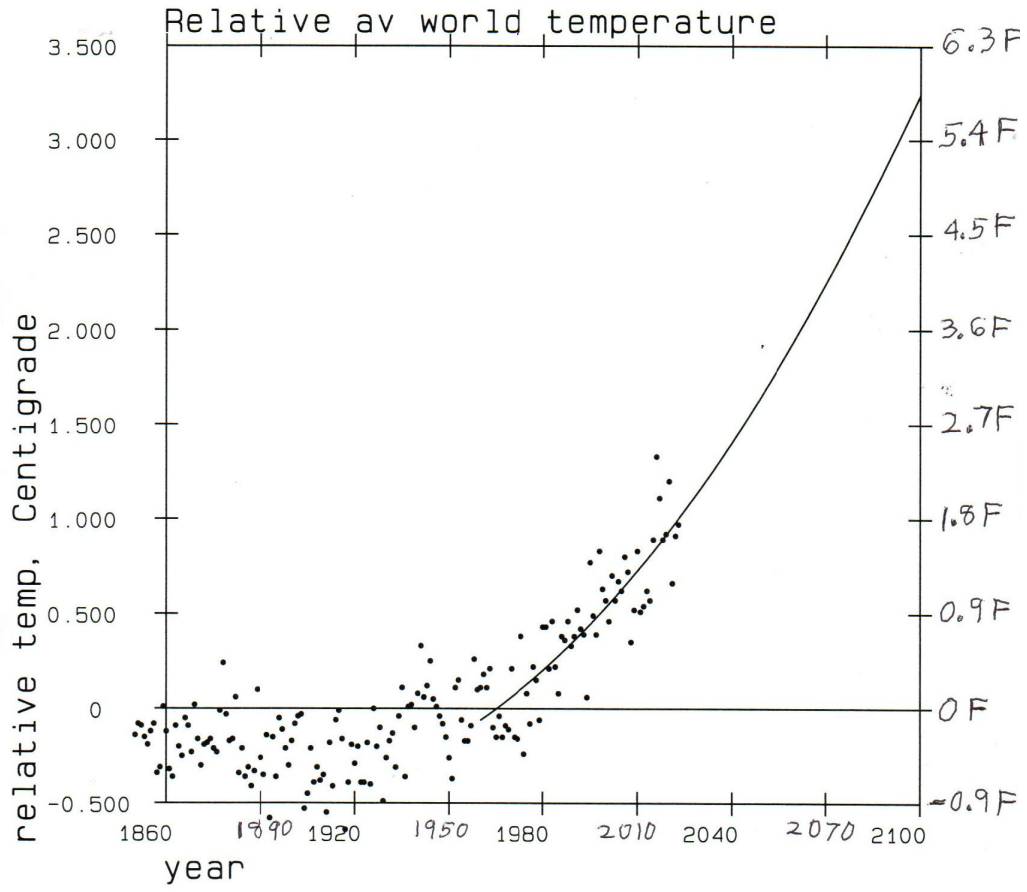

Figure 3: Temperature was measured daily at hundreds of locations throughlout the world and averaged over each year. Some places were sparcely measured, but this is improving. The data after 1960 was fit with a parabola by the least squares method, and the parabola was extrapolated to the year 2100. A temperature rise of 3.2 C or 5.7 F is predicted.

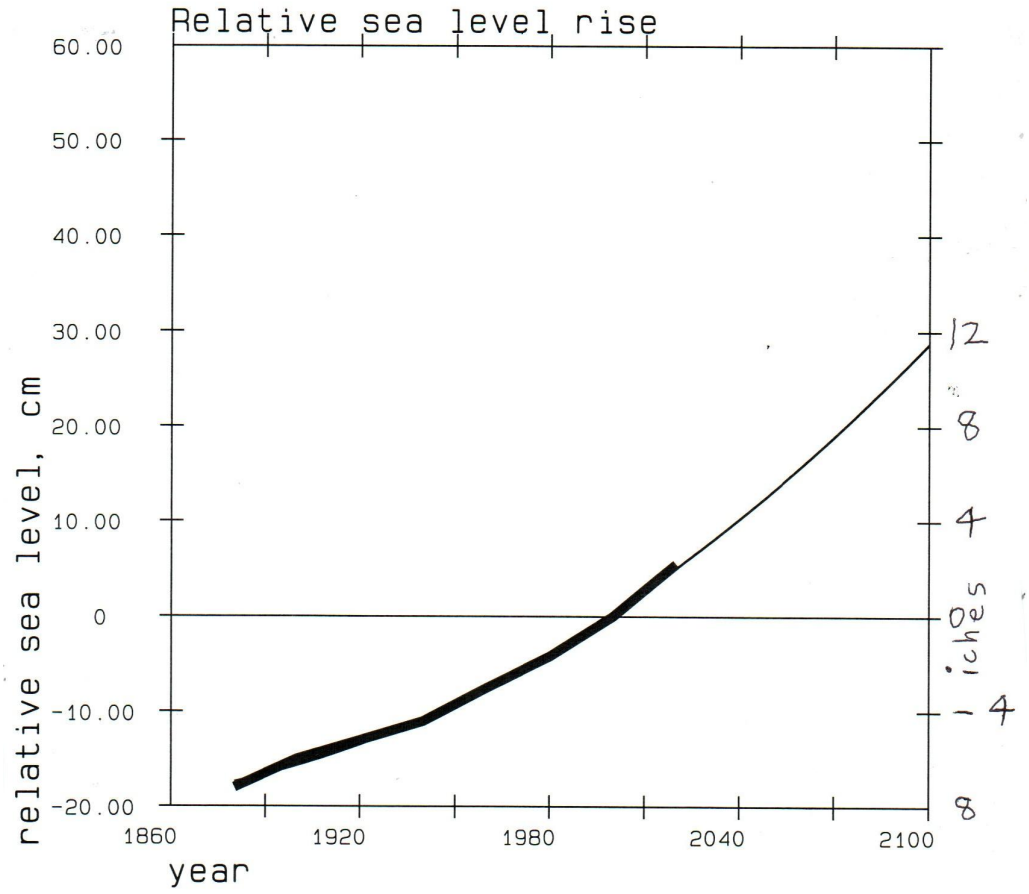

Figure 4: Relative sea level. Thick line is the average of measurements from tide guages. A parabola was fit to the data, and the thin line is the extrapolation to the year 2100. The predicted rise is about 30 cm or 12 inches.

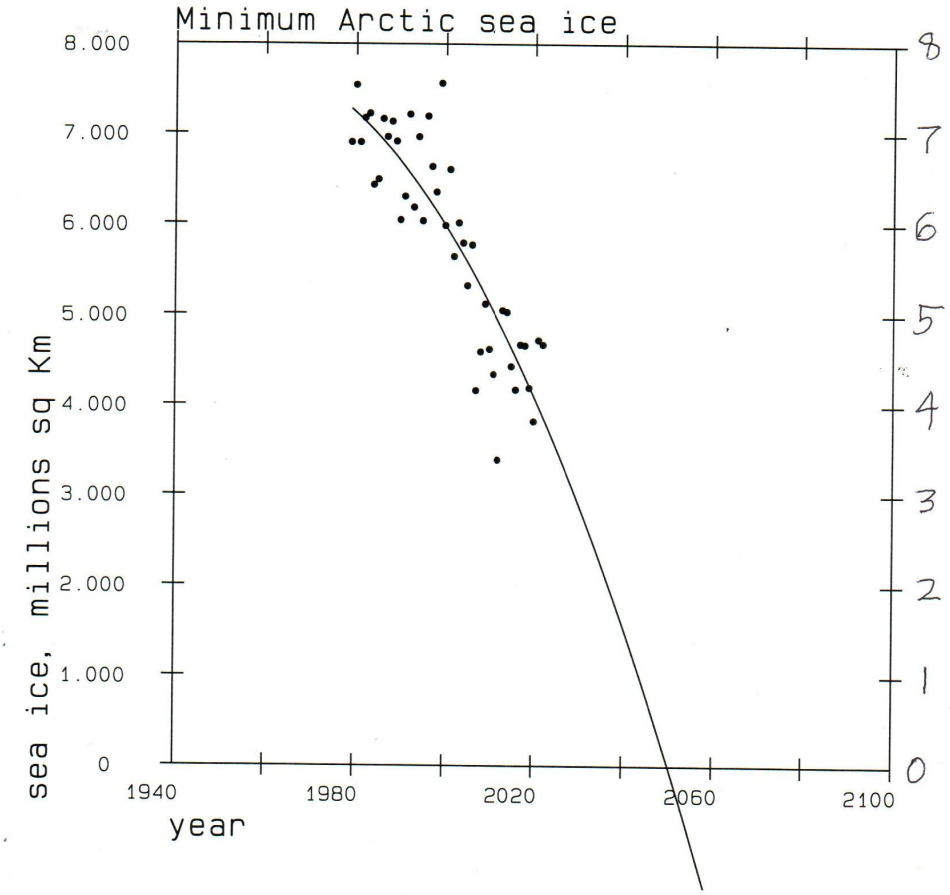

Figure 5: The minimum Arctic sea ice has been decreasing in recent summers (dots). A parabola was fit to the data by the least squares method. The extrapolation (line) predicts almost no ice at all by the year 2050!

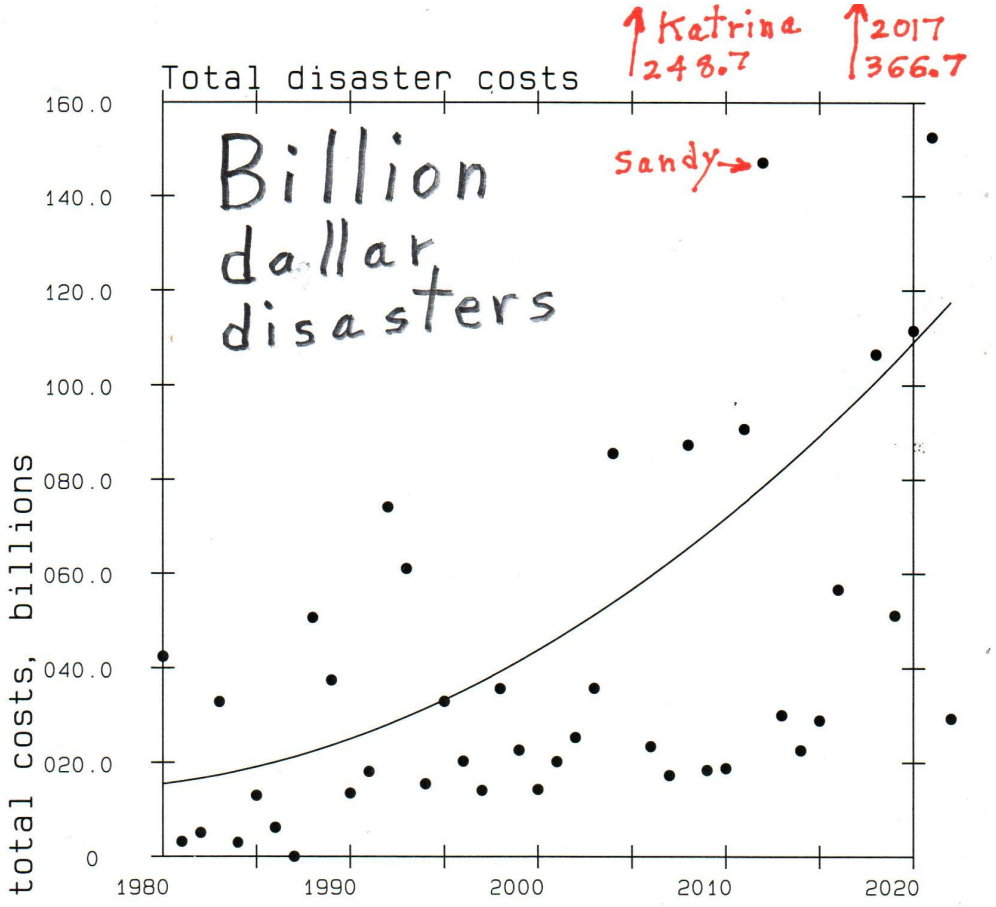

Figure 6: Total annual cost of billion+ disasters in the U.S.: Since 1980 we have suffered more and worse natural disasters, even after adjusting for inflation. These include hurricanes, floods, tornadoes and wind storms, blizzards, droughts, and forest fires. The parabolic curve, fit by the least squares method, shows that disasters are getting worse, fueled almost certainly by global warming. Similar worsening disasters are happening everywhere on Earth.

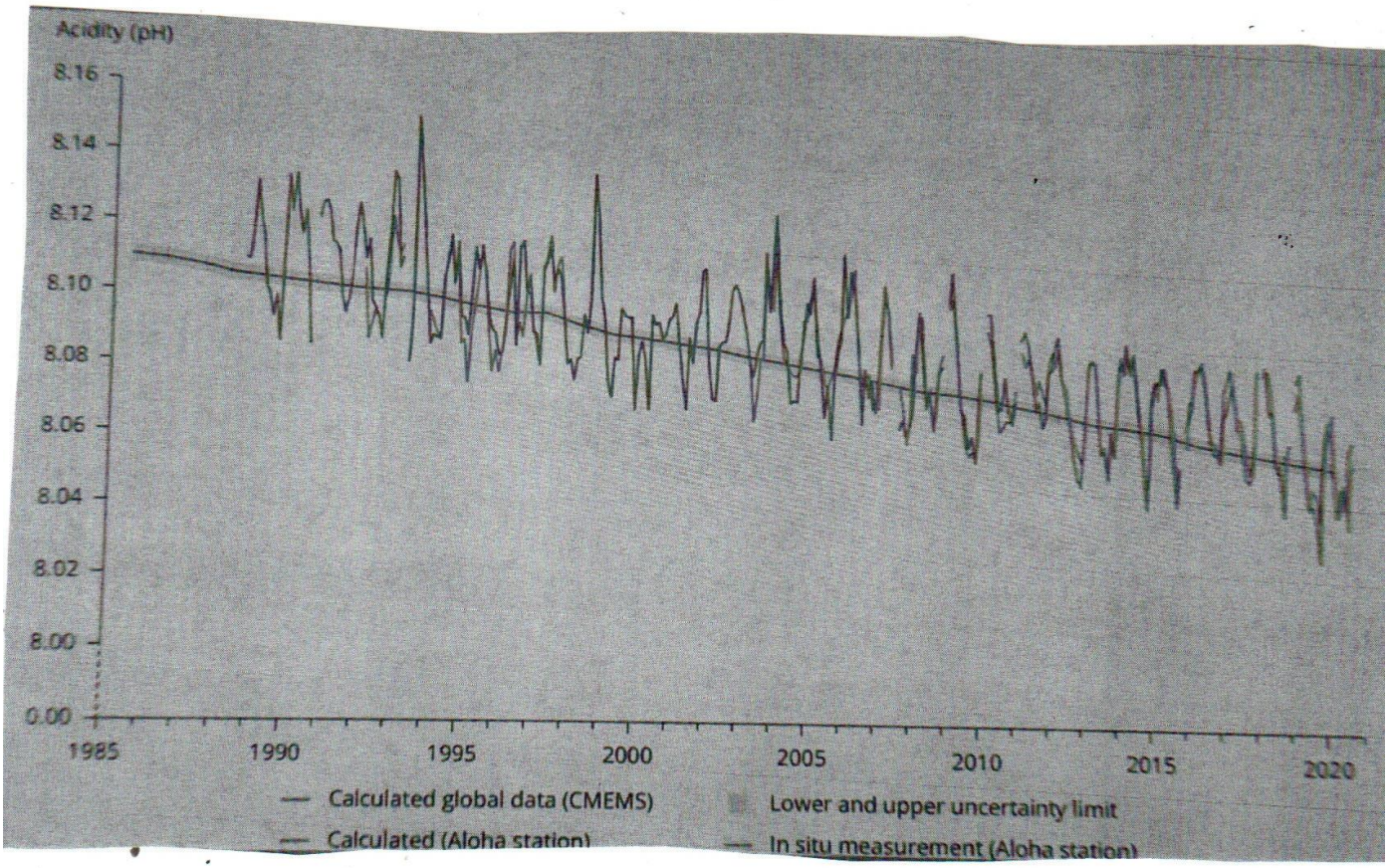

Figure 7: Measured ocean acidity in pH units. pH=0 is strongly acid, while pH=14 is strongly basic (alkali). pH=7 is neutral, the pH of pure water. The ocean is slightly basic, but is becoming more acidic from increasing atmospheric CO_2 and acid rain.

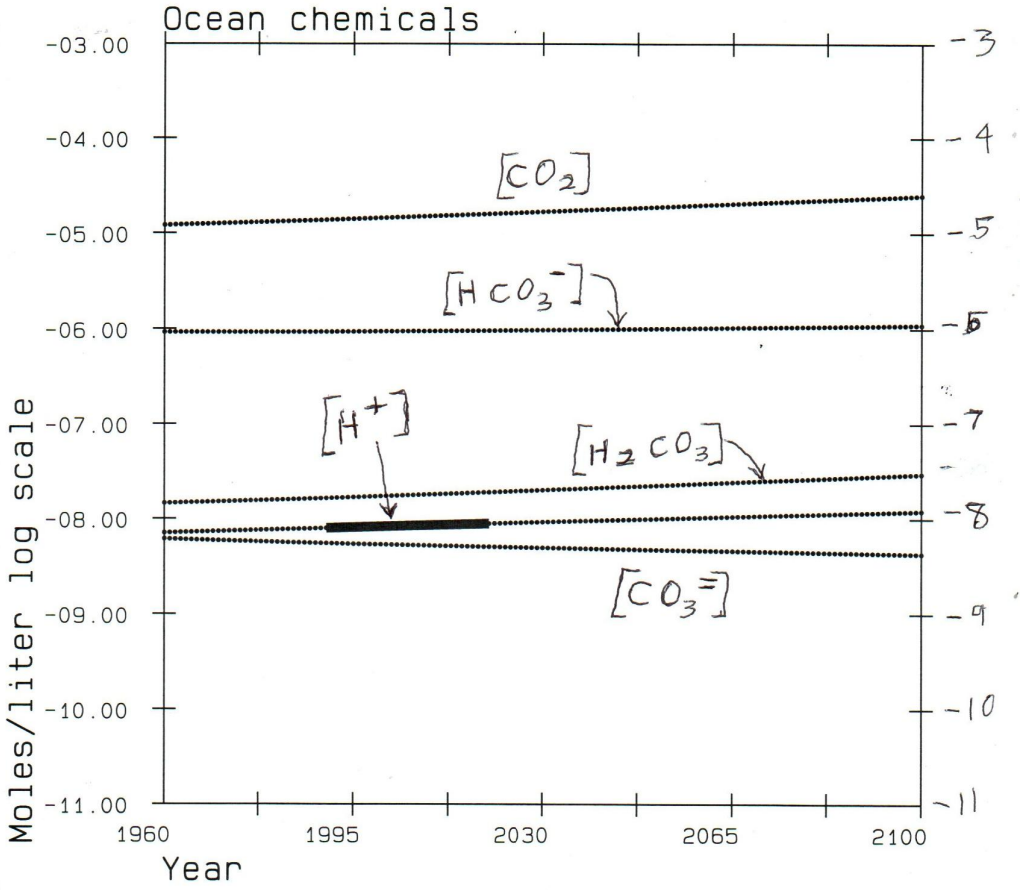

Figure 8: The important ocean chemicals considered here are dissolved CO_2, H_2CO_3 (carbonic acid), HCO_3^- (bicarbonate ion), CO_3^{-2} (carbonate ion), and H^+ (hydrogen ion). This is a semilog graph, so each mark on the vertical scale denotes a 10-fold increase in concentration. These concentrations are in moles per liter, which I won't define. Dissolved CO_2, carbonic acid, and hydrogen ion concentration are predicted to graduattly increase with time. Carbonate ion is predicted to decrease with time–bad news for sea life.

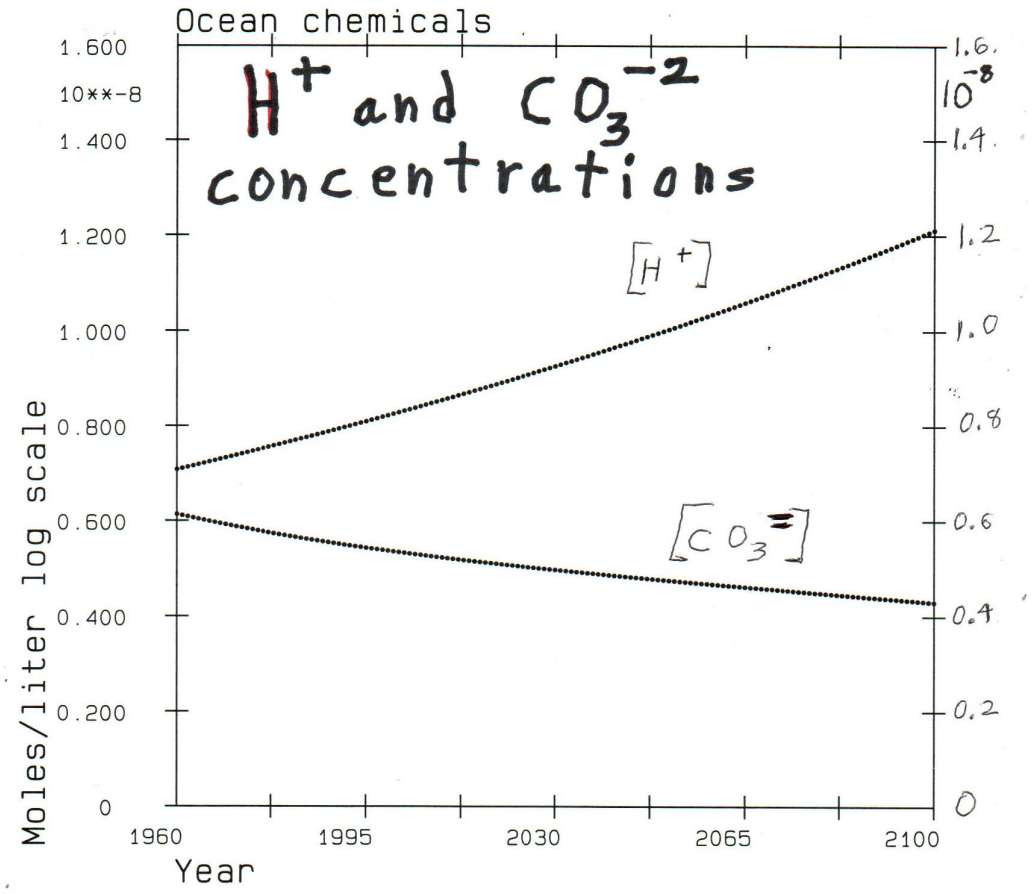

Figure 9: The ocean's concentration of carbonate ion is crucial because mollusks, coral and other organisms use Ca^{+2} and CO_3^{-2} to form $CaCO_3$ (calcium carbonate). This is a linear, not a semilog graph. The carbonate concentration is predicted to drop, making new calcium carbonate formation more difficult. The increase in acidity will tend to dissolve those organisms' calcium carbonate shells, and could eventually kill them!