A CLIMATE CHANGE CODE RED

Introduction

In August 2021, the Intergovernmental Panel on Climate Change (IPCC) issued a report **Climate Change 2021: The Physical Science Basis**. This is the Sixth Assessment Report (AR6) covering the physical science of climate change. The report was written by 284 scientists from 66 countries. This is the first major international assessment of climate-change research since AR5 in 2013.

Because of the importance of this report, we developed this plain English summary to make the report more accessible to the general reader. The original report is 3,800 pages long with an Executive Summary and a summary of Frequently Asked Questions.

AR6 was issued in advance of the next major international climate conference, COP26, to be held in Glasgow in November 2021. It will be a gathering of representatives from almost every nation in the world to update commitments to reduce the greenhouse gas emissions. These commitments were made as part of the 2015 Paris Agreement. The Paris Agreement's objective is to limit future global temperature increases to 2.0°C (3.6°F) and try to limit increases to 1.5 °C (2.7°F). This requires that net zero be reached by 2050, about 30 years from now.

Major conclusions

1. It is indisputable that human activities are causing climate change.
2. Rising greenhouse gas concentrations are driving profound changes to the earth's system.
3. Climate change is already affecting every inhabited region across the globe with many changes in weather extremes.
4. Recent changes are unprecedented over many thousands of years.
5. Global warming of 1.5°C and 2°C will be exceeded during this century unless deep reductions in carbon dioxide and other greenhouse gas emissions occur in the coming decades.
6. To stop global warming it is necessary to achieve net zero, no net emissions of carbon dioxide and other greenhouse gases.
7. Without aggressive actions, the earth's temperature could reach or exceed 3.0 °C by the end of this century and sea level could increase as much as I to 3 feet.
8. Some changes, such as a rising sea level, will persist for centuries.

THE EARTH'S CLIMATE

Net zero

The IPCC report stresses the need to reach net zero. That is reducing emissions of CO_2 and other greenhouse gases as low as practical. Any emissions that cannot be eliminated have to be offset by removing CO_2 and other greenhouse gases from the atmosphere by artificial or natural means, such as by planting billions more trees. Only by eliminating human-caused greenhouse gases can global warming be stopped. Even then, much of the CO_2 already in the atmosphere will stay there for hundreds of years until slowly removed by natural processes.

- Total global greenhouse gas emissions are about 50 billion metric tons/year which includes CO_2 emissions of about 40 billion metric tons/year.*
- Fossil fuel use is responsible for about 75 percent of greenhouse gas emissions which accounts for almost all CO_2 emissions and a large share of methane and nitrous oxide emissions. Agriculture, mainly cattle raising, and land use changes such as deforestation account for most of the remainder.
- CO_2 is about 75 percent of greenhouse gases and stays in the atmosphere for hundreds of years, followed by methane and nitrous oxides that dissipate more quickly.
- About 50 percent of greenhouse gases in the atmosphere were put there in only the last 30 years.

* A metric ton is 1,000 kilograms or about 1.1 U.S. tons.

The earth's surface temperature

The earth's surface temperature is the key indicator of the overall state of the earth's climate. The likely total human-caused temperature increase of the earth's average surface temperature is 1.07°C (1.9°F) as of 2019 [The temperature in 2021 is 1.17°C (2.1°F)]. The average temperature for 1850 to 1900 is used as a baseline by the IPCC.

The temperature increase is larger over land (1.59°C or 2.8°F) than over the ocean (0.88°C or 1.6°F). It is virtually certain that the land surface will continue to warm 1.4 to 1.7 times or more than the ocean surface.

It is unequivocal that human influence, mainly through the emission of greenhouse gases, has warmed the atmosphere, ocean and land. Global surface temperature has increased faster since 1970 than in any other 50-year period over at least the last 2,000 years. It is higher now than it has been for over 1,000 years.

Natural, nonhuman-caused, global warming is not significant.

The heat produced by global warming since the 1970s has mainly gone into warming the ocean (91%), followed by warming of land (5%) and the melting ice sheets and glaciers (3%). The atmosphere has warmed substantially since 1970, but because it is comprised of gases it has absorbed only 1% of this heat.

Greenhouse gas warming has been partly masked by aerosol cooling. Total warming contributions equals approximately 1.5°C with the cooling effect amounting to approximately 0.4°C, leaving the net increase approximately 1.1°C.

The global surface temperatures in any single year can vary above or below the long-term human-induced trend due to substantial natural variability.

There are at least four major differences between the recent warming and that of the past:

1. It is warming almost everywhere.
2. It is warming very rapidly.
3. Recent warming reverses a long-term global cooling trend.
4. It has been a long time since it has been this warm.

Atmospheric greenhouse gas concentrations

Increases in greenhouse gas concentrations since the start of the industrial revolution are unequivocally caused by human activities. Concentrations reached an annual average of 410 parts per million (ppm) for carbon dioxide in 2019. (Concentrations reached 415 ppm in 2021.)

In 2019, atmospheric CO_2 concentrations were higher than at any time in at least 2 million years. Concentrations of methane and nitrous oxides were higher than at any time in at least 800,000 years.

Precipitation over land

The frequency and intensity of heavy precipitation events have increased since the 1950s over most land area where measurements are sufficient to establish trends. Monsoon precipitation has increased in some areas and decreased in others.

Global retreat of glaciers

The global nature of glacier retreat is unusual with almost all the world's glaciers retreating synchronously since the 1950s. Mountain and polar glaciers will continue melting as long as the earth's temperature is elevated.

The Arctic

The Arctic is warming faster than anywhere else on earth. It is virtually certain that the Arctic will continue to warm more than two times faster than the global average.

Late-summer Arctic sea ice is now smaller than at any time in at least the past 1,000 years. The Arctic is likely to be practically ice free in September at least once before 2050 with more frequent occurrences for higher warming levels. The Greenland ice sheet will continue to lose ice for the rest of this century and beyond.

The Arctic is the biggest climate-sensitive carbon pool on earth, storing twice as much carbon in its frozen soils, or permafrost, than is currently stored in the atmosphere. Arctic warming could release greenhouse gases to the atmosphere and therefore significantly amplify climate change. Loss of permafrost carbon following permafrost thawing is irreversible.

The loss of sea ice and snow cover reduces the Arctic's ability to reflect heat and contributes to warming of the Arctic.

The Antarctic

There has been no significant trend in Antarctic sea ice area from 1979 to 2020 due to regionally opposing trends and large local variability. Antarctic sea ice is not expected to decrease. However, NASA's Grace satellite measurements indicate that the Antarctic ice cap is declining and has lost about 2,500 billion tons of ice since 2005.

Ocean warming

It is virtually certain that the upper ocean (depths of 0-700 m or 0-2,300 ft) has warmed since the 1970s. The ocean has warmed faster over the past century than since the end of the last deglacial transition, around 11,000 years ago.

Ocean acidification

Man-made carbon dioxide emissions are the main cause of global acidification of the open ocean. This acidification is unusual in the last 2 million years. Ocean acidification and ocean deoxygenation will continue and changes are irreversible over centuries or longer.

Increasing sea level

Global mean sea level increased by 0.2 meters (7.9 inches) between 1901 and 2018. Thermal expansion explained 50 percent of sea level rise during 1971 to 2018, while ice loss from glaciers contributed 22 percent, from ice sheets 20 percent, and changes in land water storage 8 percent. The average rate of sea level rise was 1.3 mm (0.05 inches) per year between 1901 and 1971 but has increased to 3.7 mm (0.15 inches) per year between 2000 and 2018. The global mean sea level has risen faster since 1900 then over any preceding century in at least the last 3,000 years. Sea level rise will continue throughout this century.

Approximately two-thirds of the global coastline will see sea level rise within +/- 20 percent of the global increase. Due to sea level rise, extreme sea level events that occurred once per century in the recent past are projected to occur at least annually at more than half of all tide gauge locations by the end of this century.

In the longer-term, sea level is committed to rise for centuries or longer due to continuing deep ocean warming and ice sheet melt and could rise as much as 2-6 m (6.6- 20 ft).

Changes to the land

Climate zones have shifted poleward in both hemispheres. The growing season has on average lengthened by up to two days per decade since the 1950s in the northern hemisphere, excluding the tropics.

Weather extremes

Human-caused climate change is already affecting many weather and climate extremes in every region across the globe. Observed changes in extremes such as heat waves, heavy precipitation, droughts, and tropical cyclones (hurricanes and typhoons) are occurring. The frequency of these unprecedented extreme events will increase with increasing global warming.

Compound events are likely to be more common such as when two weather events occur simultaneously. This includes increases in the frequency of concurrent heat waves and droughts on the global scale, fires enhanced by weather in some regions of all inhabited continents, and compound flooding in some locations.

Latency and irreversible effects

Latency, the delay between cause and effect, is likely with many of the climate-induced changes the earth is experiencing. It takes a very long time for the earth to fully adjust to climate change. If greenhouse gas emissions were to stop today, it could be decades before the full effects of past emissions become apparent.

Many changes due to past and future greenhouse gas emissions are irreversible for centuries, especially changes in the ocean, ice sheets and the sea level.

Carbon budgets

A carbon budget is the amount of cumulative CO_2 that can be released for a given increase in the earth's average temperature. About 2,390 billion metric tons CO_2 have been released into the atmosphere by human activities between 1850 and 2019.

For every 1,000 billion metric tons of CO_2 emitted, the temperature rise is likely to be about 0.45°C.

The IPCC estimates that the remaining carbon budget to reach 1.5 °C is about 400 billion metric tons and to reach 2.0 °C is about 1,150 billion metric tons. Today's annual CO_2 emissions are about 40 billion metric tons per year and increasing. At this rate, it will take about 10 years for the earth's temperature to reach 1.5°C and less than 30 years to reach 2.0°C.

Carbon sinks

About 45 percent of greenhouse gas emissions remain in the atmosphere, causing the greenhouse effect. The ocean and land have taken up the remainder, about 55 percent, over the past sixty years. This fraction is expected to decline in the future if CO_2 emissions continue to increase, causing more CO_2 to remain in the atmosphere.

It is becoming apparent that the natural processes are beginning to respond to increasing CO_2 emissions in a way that will weaken nature's capacity to take up CO_2 in the future. Land and ocean become less effective in absorbing emissions. If a higher proportion of emitted CO_2 remains in the atmosphere it would accelerate global warming.

The ability to remove CO_2 from the atmosphere is under development. The technical and economic feasibility of removing enough CO_2 from the atmosphere to make a difference has not yet been demonstrated.

Effects of continued greenhouse gas emissions

There is a near-linear relationship between cumulative man-made CO_2 emissions and the global warming they cause. Global warming extremes become larger in frequency and intensity with every increment of greenhouse gas emissions.

Increasing emissions increase the frequency and intensity of hot extremes, marine heat waves, heavy precipitation, agricultural ecological droughts in some regions, and the intensity of tropical cyclones as well as reductions in Arctic sea ice, snow cover and permafrost.

Effect of Covid-19

Emissions reductions in 2020 associated with measures to reduce the spread of COVID-19 led to temporary but detectable reductions of air pollution. Global and regional climate responses to this temporary event are, however, undetectable above natural variability. Atmospheric CO_2 concentrations continued to rise in 2020, with no detectable decrease in observed CO_2 growth rate.

POSSIBLE CLIMATE FUTURES

To assess the future, the IPCC used a number of computer models to develop scenarios depicting the range of realistic possibilities, depending upon the global response to global warming. AR6 states that these scenarios are not predictions. They provide “what-if’” investigations of various realistic future developments. They span the range of possibilities from “business as usual” with no real effort to reduce greenhouse gas emissions, to aggressive global efforts to limit global warming to no more that 1.5 or 2.0 °C. The scenarios are summarized in Table 1.

Table 1: Brief summary of IPCC scenarios

Scenario	Definition	Reach net zero	°C by 2100
1	Aggressive action to limit to 1.5 °C	By 2050	1.0 to 1.8
2	Aggressive action to limit to 2.0 °C	Later	1.3 to 2.4
3	Meet national goals established under Paris Agreement	No	2.1 to 3.5
4	A medium high scenario. Emissions double by end of this century	No	2.8 to 4.6
5	Business as usual. Emissions double by 2050 and triple by 2080	No	3.3 to 5.7

Climate change futures

The IPCC scenarios resulted in a wide range of climate futures, largely dependent upon the rate at which greenhouse gas emissions are reduced. The first two scenarios represent what could happen if aggressive actions are taken immediately to reduce emissions. The last two represent what could happen if less aggressive or no real efforts are taken. The middle scenario is what would happen if the current Paris Agreement targets are met.

According to this analysis, global warming of 1.5°C and 2°C will be exceeded during this century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades. (The authors of this summary believe the earth's temperature will exceed 2°C)

If global net negative CO_2 emissions were to be achieved and be sustained, the global CO_2 induced surface temperature increase would be gradually reversed but other climate changes would continue in their current direction for decades to thousands of years. For instance, it would take several centuries or longer for global mean sea level to reverse course even under large net negative CO_2 emissions.

Many regions are predicted to experience an increase in the probability of compound events with higher global warming. In particular, concurrent heat waves and droughts are likely to become more frequent.

Tipping points

It is unlikely that major tipping points will be exceeded this century. Many systems have natural or structural thresholds. If conditions exceed those thresholds, the result can be sudden changes or even collapses in health, productivity, utility or behavior. The probability of low likelihood but high impact outcomes increases with higher global warming levels. Abrupt responses and tipping points of the climate system, such as increased Antarctic ice sheet melt and forest dieback cannot be ruled out.

Time required to see effects of any reductions

Due to the fact that greenhouse gases in the atmosphere, especially CO_2, will stay there for a very long time, it would take time before reduced global surface warming would be detectable, about twenty to thirty years.

Benefits of reduced emissions

Very low or low greenhouse gas emission scenarios would have rapid and sustained effects to limit human caused climate change compared with scenarios with high or very high greenhouse gas emissions effects. A near term benefit would be reduced air pollution and improved public health.

ACTIONS REQUIRED

The specific actions needed to reduce greenhouse gas emissions were beyond the scope of the IPCC report.

Prepared by Craig Smith and Bill Fletcher, coauthors of *Reaching Net Zero: What It Takes To Solve The Global Climate Crisis*, Oxford UK: Elsevier 2020. (This article also submitted for publication in *Peace Magazine*).