Australian Government

OFFICE OF THE CHIEF SCIENTIST

OCCASIONAL PAPER SERIES

ISSUE 8
OCTOBER 2013

CLIMATE CHANGE: THE STORY SO FAR

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While future impacts of climate on global systems remains uncertain, there is increasing evidence that the activities of humans are changing the climate now. This paper provides a summary of the changes to the global climate that are already happening.

Background

Carbon dioxide (CO_2) in our atmosphere helps make our planet a habitable place.

Without CO_2 and other gases creating a 'greenhouse effect', the Earth's entire surface would be frozen — around minus 18°C.[1]

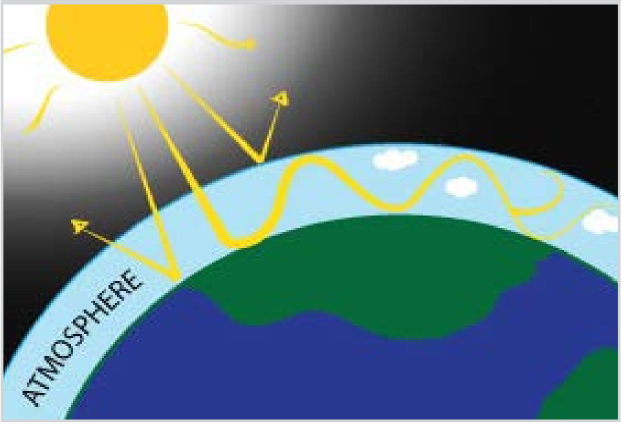
So what is the greenhouse effect?

The energy we receive from the sun — solar radiation — passes through our atmosphere as sunlight and warms the Earth (Figure 1). As the Earth warms it emits energy as infrared radiation. Some of this radiation escapes into space, but some is absorbed by gases such as CO_2, methane and nitrous oxide in the lower atmosphere (the troposhere).[2] By absorbing some of the radiative heat emitted by the Earth, these 'greenhouse gases' cause the surface temperature to increase.

Over recent millennia, we have reached a near equilibrium in the carbon cycle where we survive on a warm planet with about 280 parts per million (ppm) of CO_2. However, our actions disturb that equilibrium; we are pumping more and more CO_2 into the atmosphere.

Simple physics tells us that with more CO_2 in the atmosphere, more heat will be absorbed, and the planet will warm. As it warms, it will have multiple effects on human, animal, plant, and marine life.

Figure 1: *Our climate is powered by radiation from the sun – about 30 per cent is reflected back into space, and the rest warms the Earth's surface.*

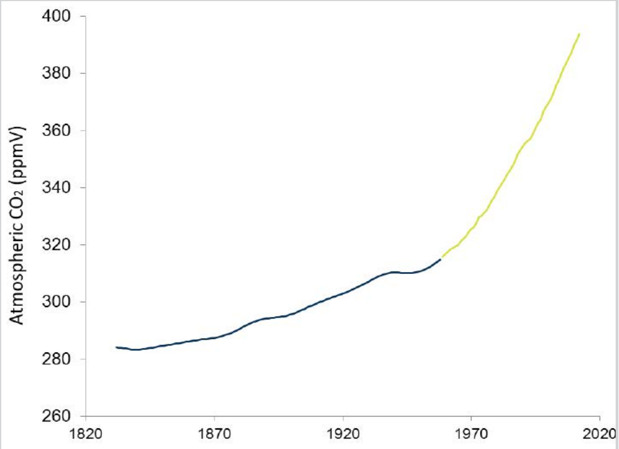


The rise and rise of greenhouse gases

The concentration of greenhouse gases in the atmosphere is now higher than at any other time during the past 800,000 years and is rising far more rapidly than at any time over that interval.[3]

The concentration of CO_2 in our atmosphere has increased by 40 per cent; from approximately 280 parts ppm in the 19th century to 400 ppm measured in May of this year.[4] Since the year 1750, humans have added approximately 1.3 trillion tonnes of CO_2 to the atmosphere as a result of burning fossil fuels, cement production and gas flaring,[5] and a further 0.7 trillion tonnes from land use changes such as deforestation[6] (Figure 2).

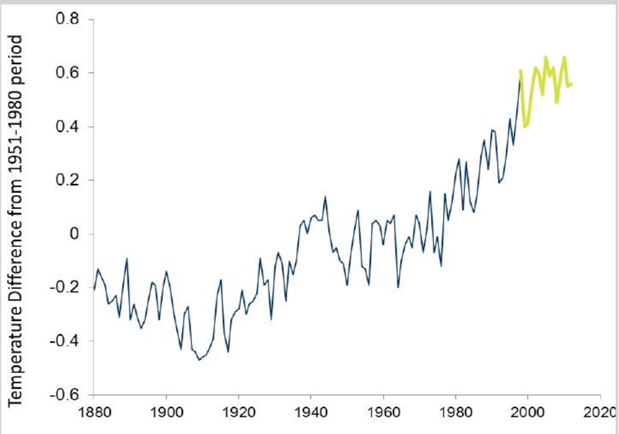
Figure 2: *Increases in concentrations of CO2 coincided with the Industrial Revolution. Measurements are from Antarctic ice cores (blue lines) combined with direct atmospheric measurements (green lines). Data source: NOAA.*[7]



Surface warming – land and ocean

The global average surface temperature has risen approximately 0.89˚C since the start of the 20th century[8] (Figure 3). Furthermore, nearly 50 per cent of this warming — about 0.4˚C — has occurred in the 34 years since 1979.

Figure 3: *Mean annual surface temperatures from 1880 through 2012 (blue line) and from 1997 through 2012 (green line). Data source: NASA.*[9]



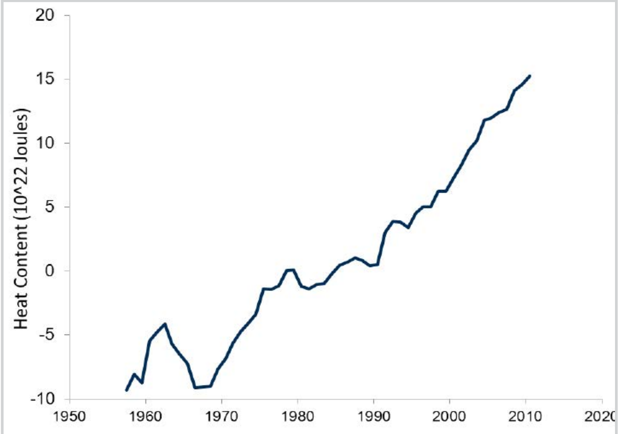
There have been suggestions that global land surface temperature records may be biased by 'urban heat island' effects around expanding cities.[10] However, recent analyses of land temperatures that remove or account for measurements in urban areas show this to be small.[11]

Additionally, the urban heat island effect does not account for the warming of the oceans, a crucial part of how the climate system is changing.

About 90 per cent of the extra heat trapped by greenhouse gases has been absorbed by the oceans[12] and the surface ocean has warmed by about 0.6 ˚C since the 1870s.[13]

The 'heat content' of the ocean has risen almost continuously since the late 1960s (Figure 4).[14] This measurement takes into account not only the amount the ocean has warmed, i.e. the temperature change, but also the density, and specific heat capacity (the amount of heat energy it takes to raise one kg of water by one ˚C) of water.

Figure 4: *Changes in ocean heat content of the upper 2000 metres of the ocean averaged every five years. Data source: NOAA.*[15]



Our understanding of deep ocean temperature change has been greatly increased by the now-global deployment of thousands of autonomous probes known as 'Argo' floats. These drift through the oceans from the surface to thousands of meters deep, measuring temperature and salinity. They occasionally surface and transmit data to shore-based researchers, and have allowed the collection of far more data than was practical using ships (see www.argo.net).

The continuing increase in the amount of heat absorbed by oceans may be part of the explanation for the slower rate of atmospheric warming during the past 15 years.[16]

Has global warming paused?

The past 15 years have seen a slowing in the trend of rising surface temperatures.[17] At the same time, 2012 was one of the hottest years on record,[18] and the 10 hottest years on record have all occurred since 1997.[17]

To understand how all of these statements can be true, it is important to consider the timescales involved. Mean annual global surface temperatures (Figure 3) have risen considerably since the end of the 19th century (blue line) although from 1997 through to 2012, the rate of warming has slowed (green line).

Does the slower warming trend in surface temperature from the last 15 years mean that global warming has stopped? Other indicators of warming show that it has not.[19] New observations suggest that heat continues to be absorbed and stored in the deep ocean (Figure 4) — about 30 per cent of the warming in the oceans has occurred below 700m[14] — and glacial ice continues to melt.[20]

El Niño and La Niña

New analyses of ocean heat content[16] and computer models[21] have shown that El Niño and La Niña ocean cycles may be influencing the deep ocean's capacity for heat storage.[22]

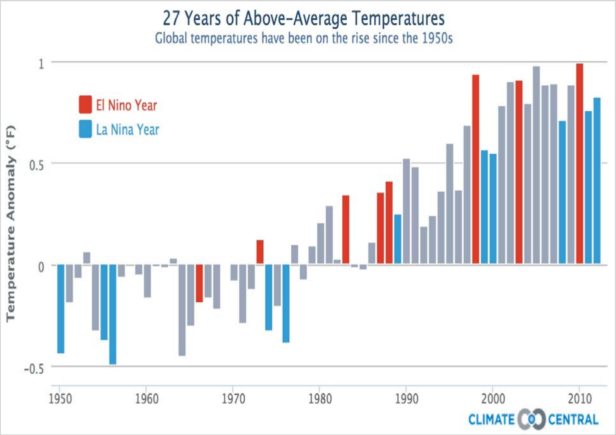
Australians are familiar with both El Niño, and the punishingly dry and hot conditions it can bring, and the heavy rains and floods that accompany La Niña (for example in 2010 and 2012).

Importantly for climate conditions, the wind patterns associated with La Niña cause cooler sea-surface temperature in the tropical Pacific Ocean, which has a large influence on average global surface temperature due to its great area.[23]

La Niña wind patterns also shift the distribution of heat in the ocean by 'driving' heat into deeper layers. This may be one mechanism causing the rate of surface warming to slow while heat continues to be taken up by the deep ocean.[22]

Models suggest that the strong La Niña episodes of the past 15 years may have played a part in off-setting atmospheric warming, with more heat being absorbed into the deep ocean (Figure 5).

Figure 5: *Annual global surface temperature changes referenced to the 1961-1990 period, indicating La Nina years (blue) and El Niño years (red).[24]*



Conversely, 1998 was an especially intense El Niño year, with the third highest temperature recorded (Figure 5). El Niño causes warming over large parts of the tropical Pacific Ocean, thus raising global average surface temperature.

Solar activity

Solar activity tends to follow an 11-year cycle. At the moment we are in a solar minimum, meaning that less solar energy is reaching Earth's surface.[25,26]

Melting ice

Arctic sea ice

In 2012 the lowest sea-ice coverage was recorded in the Arctic since satellite measurements began in the 1970s.[27] Arctic sea ice is shrinking in surface area (Figure 6), and becoming thinner.[28]

Although sea ice grows during the winter months and melts during the summer months, in some regions sea ice remains all year.[29] However, areas of the Arctic Ocean that in the past were covered by thick ice accumulating over many years now have areas with thin ice that persists over just one winter.[30] This melting is likely due to a combination of warmer oceans and warmer air temperatures.[30]

Figure 6: *Sea ice extent in the Arctic in September 2013, compared to the 1981-2010 median extent (pink). Source: NSIDC.[31]*

Antarctic sea ice

By contrast to the Arctic, the area covered by Antarctic sea ice has expanded slightly over the past few decades.[32] Paradoxically, this may also be related to warming.

As opposed to sea ice, which forms when seawater freezes, ice sheets, ice shelves, icebergs, and glaciers all originate on land and are formed from freshwater in the form of snow.

As ice shelves — the parts of the ice sheets extending into the ocean — melt, they add freshwater to the ocean making it less salty and more likely to freeze.[32] The Antarctic Ocean is bordered by more ice shelves than the Arctic, which may drive the formation of more sea ice.

Ice sheets and glaciers

Land-based ice sheets in Greenland and Antarctica — and some glaciers — have also been melting over recent decades. [33]

Sea level rise

Sea level rise has accelerated from about 1mm per year in the early 20th century to about 3mm per year over the past two decades.[34] The rise is caused partly by warming oceans — water expands as it warms — and partly by melting ice on land and the resultant runoff of freshwater into the oceans.

Rainfall patterns

Climate change also shows itself in changed rainfall patterns, with dry areas becoming drier and wet areas becoming wetter.[35]

The effects of changing global rainfall patterns can also be seen in the ocean. In some areas of the ocean evaporation is increasing more than rainfall and the seawater is becoming saltier. In other areas where rainfall is increasing, the seawater is becoming less salty.[36]

In Australia a pattern of increasing tropical rainfall across the north, and decreasing late autumn and winter rainfall across the south is already apparent.[37]

Ocean acidification

The continued rise of CO_2 in the atmosphere has not just affected global warming. Roughly a quarter of the CO_2 that enters the atmosphere is absorbed by the ocean.[38]

As CO_2 dissolves in seawater it forms a weak acid changing the chemistry of the surface ocean — making it less alkaline — a process known as 'ocean acidification'.[39] This has serious implications for ocean life. For example, some marine organisms that are fundamental to ocean food chains are already less able to make their shells due to increased ocean acidity.[40,41]

Regional changes

Climate change patterns are mostly discussed at a global level; however they will be experienced differently depending on location or region. Though global average climate changes may seem subtle, they can result in highly variable local changes.[42]

At the height of the last ice age — about 21,000 years ago — the planet as a whole was on average 5°C cooler than now.[43] However, during this time the tropics cooled by just a few degrees, while large parts of Eurasia and North America were covered by several kilometres of ice.[44]

About three million years ago, the earth was about 2-3°C warmer than present, with the tropics at similar temperatures to present.[45] However, polar regions were warmer by as much as 10 to 20°C,[46] and average sea level was more than 20 metres higher than present.[47]

Both these intervals show that a world with an average temperature just a few degrees cooler or warmer than the current average can be a very different place from the one we inhabit now.

Conclusions

Patterns of increasing global surface temperatures, changing rainfall and ocean acidification have emerged in recent decades. Similarly the ocean surface is warming in a way not explained by natural variability. Sea level is rising, surface ocean salinity patterns are shifting, and Arctic sea ice is decreasing. Ice sheets in the Antarctic and Greenland, and mountain glaciers are, overall, melting.

The climate is a highly complex system subject to human and natural processes such as atmospheric CO_2, solar cycles, wind, and ocean currents. Out of these, the one variable over which we have some control is the amount of CO_2 we pump into the atmosphere.

A proportion of the CO_2 in the atmosphere will stay there for centuries. As we add more CO_2 the Earth will absorb and emit more heat, in a positive, although not linear, relationship. And so the planet will continue to warm. The consequences — accumulation of heat in the ocean, ice sheet melting and ocean acidification — are likely to occur for centuries even millennia to come.

References

A full reference list for this paper is available at chiefscientist.gov.au

About this series

These occasional papers from the Office of the Chief Scientist aim to bring to the public's attention scientific issues of importance to Australian society.

Each issue has been prepared by a multi-disciplinary team and has been through an external review process. We would like to thank Professors David Karoly, Jonathan Overpeck and Julia Cole and the Climate Change Authority for their comments.

Series ISSN: 2201-0025 (print) and 2201-0033 (online)

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