THE BEACONS GUIDES TO CLIMATE CHANGE

GUIDE ONE -
CLIMATE CHANGE: THE FACTS

CONTENTS

GUIDE ONE INTRODUCTION

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AIM

The aim of this guide is to help the reader answer three crucial questions about climate change.

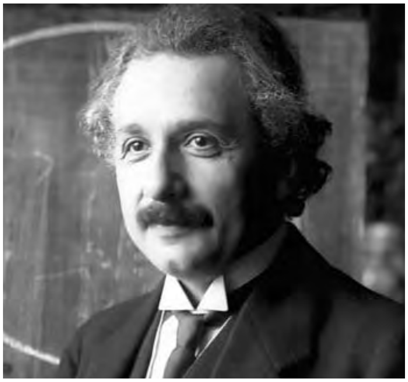
We outline the evidence and take you through such topics as the greenhouse effect and global warming.

Chapter nine: The science – what, and how, do we know is new and will be of interest to those who would like to know more about the bases for climate science.

There is a good deal of controversy over many assertions made and policies pursued, sometimes very heated. We try to summarise the different arguments and points of view in as objective a manner as we can. We also try to avoid getting bogged down in technical details.

THINK FOR YOURSELF

Here is someone who did...



"Learn from yesterday, live for today, hope for tomorrow. The important thing is to not stop questioning."

Albert Einstein

BEWARE OF PROPAGANDA

As the political battle over climate change has heated up, so has the propaganda campaign. On one side, green activists sometimes exaggerate claims about the possible consequences of global warming. On the other, sceptics seize upon anything that appears to suggest that climate change is not happening, is not due to human emissions, or will not be a problem. The sceptics, often called climate change deniers, are very much in the minority as far as scientific opinion is concerned, but that, of course, does not automatically make them wrong.

One final point before you begin: please let the editor know of any mistakes or facts that seem to be wrong, or of wording that is not clear, or of any other criticisms you have, by emailing terrydroit@aol.com

The great advantage of having this Guide on-line only is that changes can be made at any time.

INTERNATIONAL AGREEMENT

Since 1992 there have been annual UN conferences aimed at getting all nations to agree a binding treaty on reducing CO_2 emissions. Agreement seemed close at Copenhagen in 2009 but the conference ended in failure.

A great deal of work was done by the UN and individual nations since then, culminating in an Agreement being unanimously agreed at Paris in December 2015. The aim of the Agreement is to reduce net greenhouse gas emissions to zero by the end of the century. Full details of the Agreement and progress in implementing it are in Guide Two, Chapter Four.

The politics of a treaty and the context of the other challenges facing humanity are outlined in Guide Two, and the part being played by the UK in Guide Three. This Guide aims to give the factual background in a clear and objective manner.

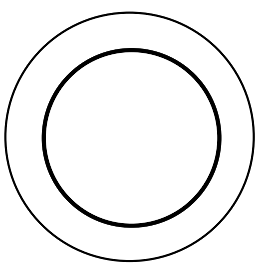
CHAPTER ONE:

HOW WE GOT TO WHERE WE ARE – A BRIEF OUTLINE

Global temperatures have always varied over time. To assess how much difference is made by CO_2 and other emissions as a result of human activities, the extent to which natural cycles are distorted since industrialisation has to be estimated. The problem is that natural cycles are over thousands or millions of years while greenhouse gas emissions are over at most four centuries.

It is not easy to get one's mind round such vast time scales. To try and do so we drew a circle and imagined it as a clock face with once round corresponding to 60 minutes or the 4.6 billion years our planet has existed. This proved to be instructive so we recommend you do the same.

Start with a sheet of A4. Draw two concentric circle as in this diagram but large enough to fill the page



Assuming once round is 60 minutes or 4.6 billion years, mark on it where you think the following should be:

1. Life first appears
2. Human beings first appear
3. The start of civilisation, taking this to mean living in cities
4. The start of industrialisation, that is, the industrial revolution.

Consequent calculations gave the following – do check the arithmetic!

Life on earth started after 800 million years, or after 10.4 minutes on the clock face.

The first definite human animals appeared 200,000 years ago, or one sixth of a second ago on our clock face.(* See below)

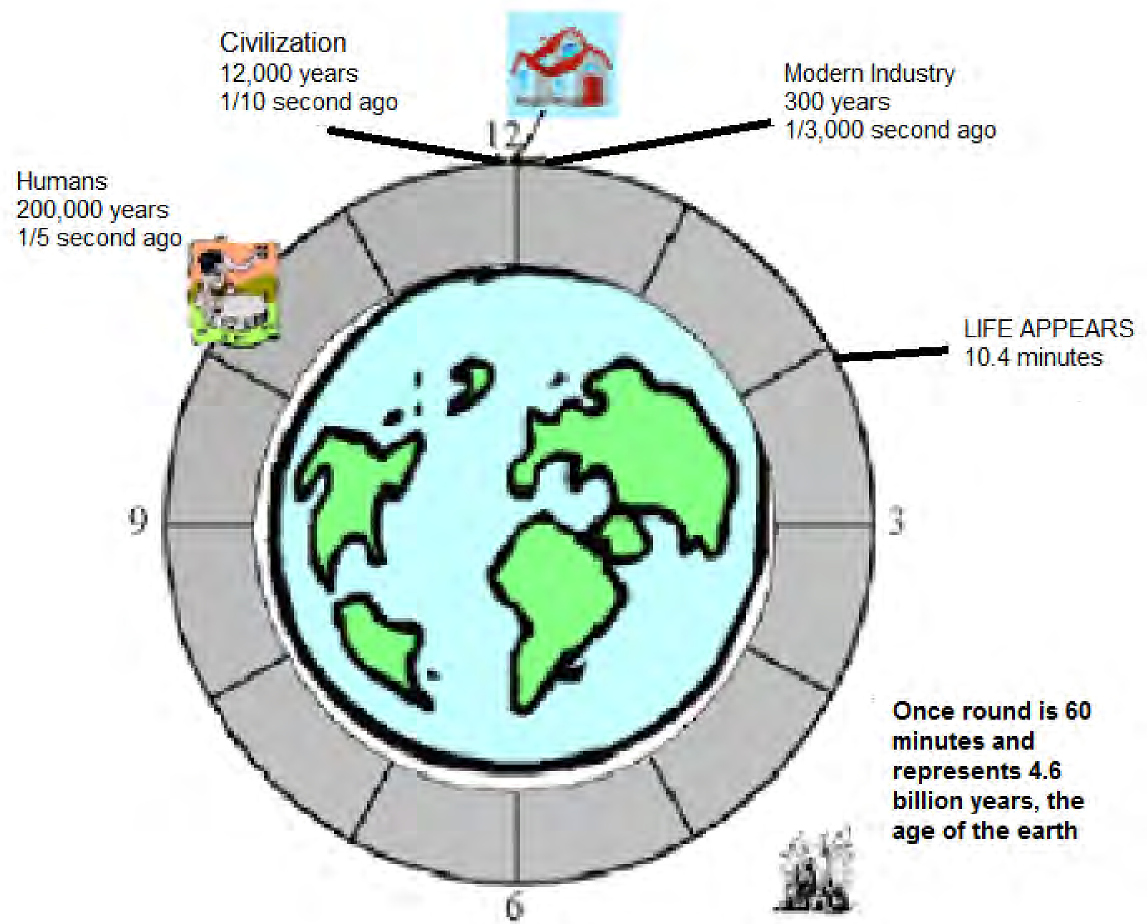
Civilisation, that is cities, probably started about 12,000 years ago, or one hundredth of a second ago on the clock face.

And modern industrialisation began around 300 years ago, or 1/3,000th of a second ago on the clock face.

Our chart is on the next page.

**According to 'The Vital Question' by Nick Lane, 2015, there is now much less certainty about when the first humans appeared. Some experts now think it could be as early as 100,000 years ago.*

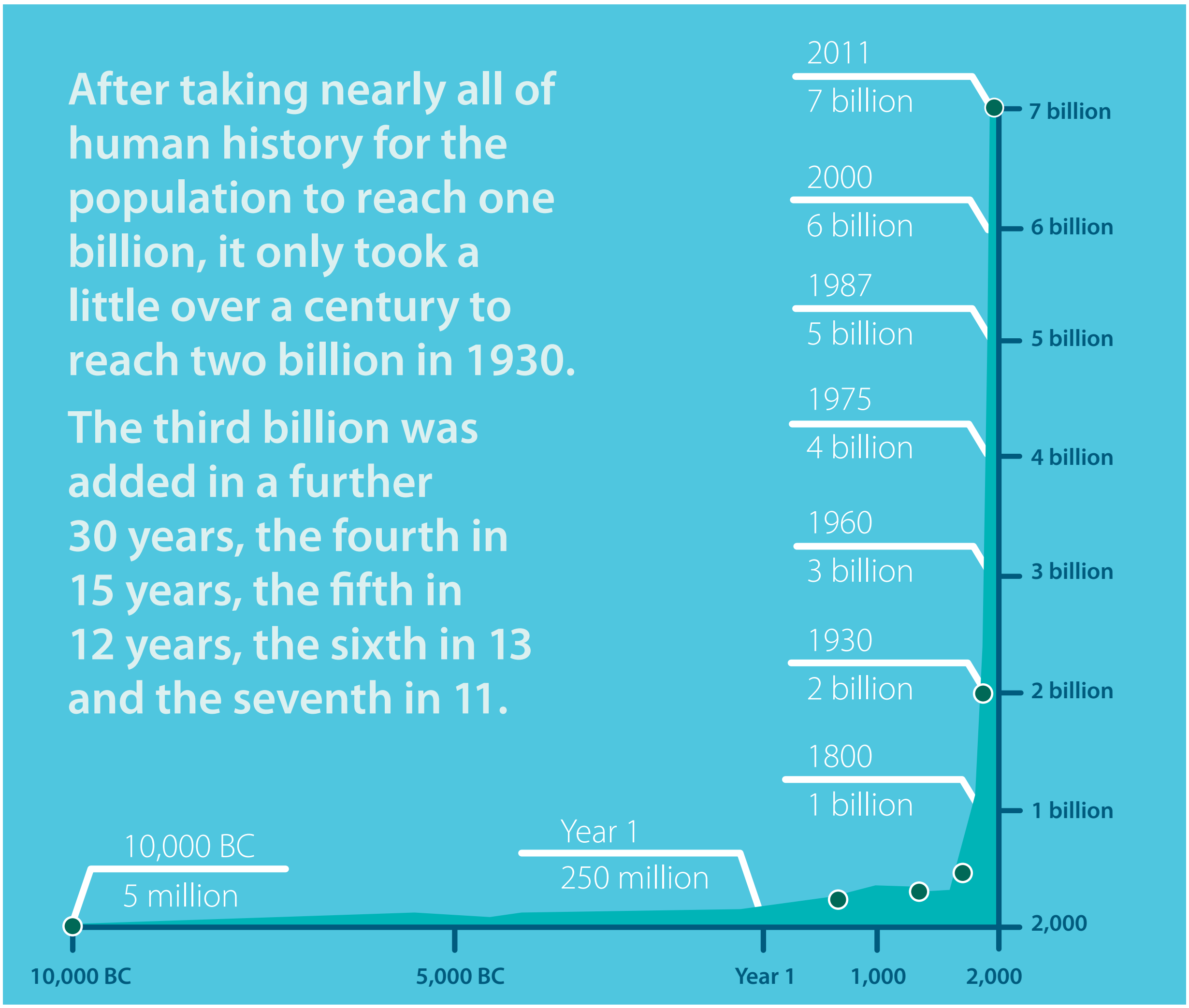
So our clock face should look like this...



So our modern world has only been in existence for 1/3,000th of a second. But in that 1/3,000th of a second quite a lot has happened!

For a start there are rather more of us than there were!

United Nations Population Division

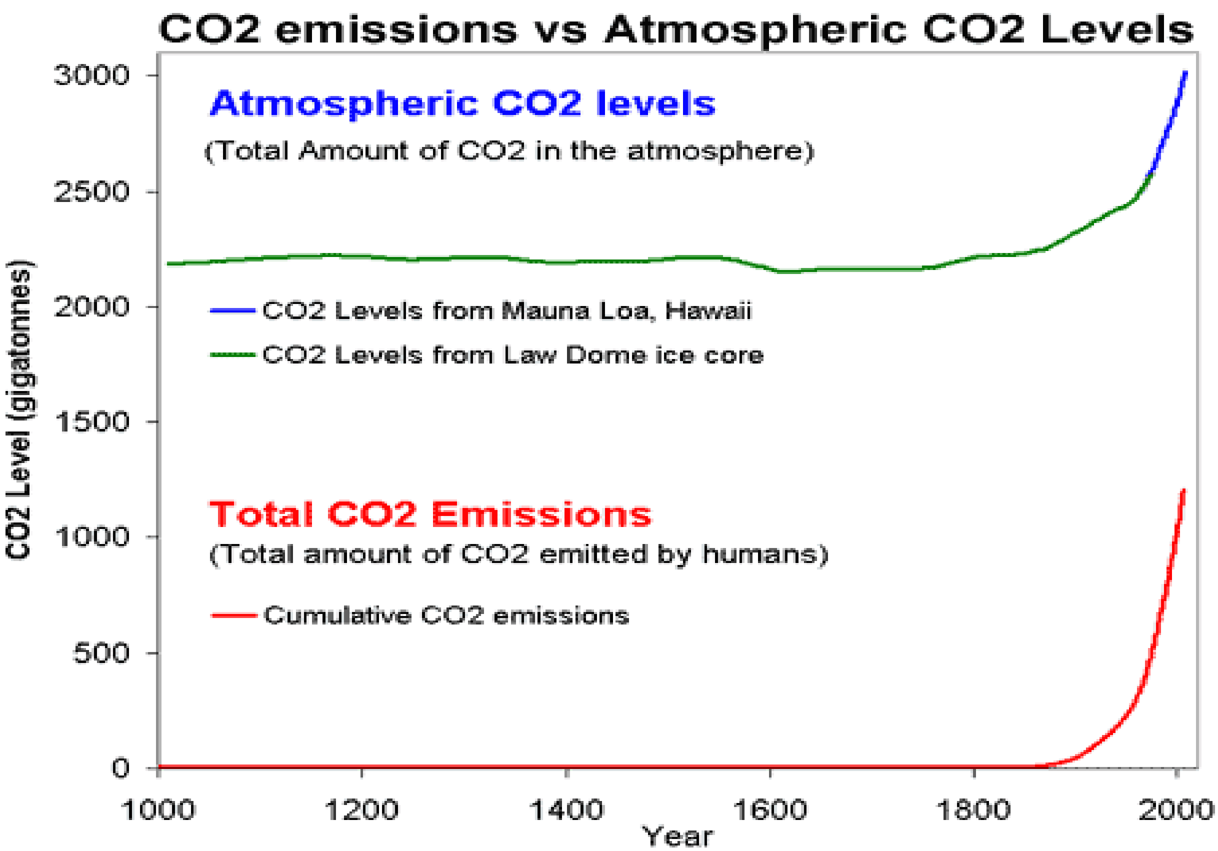


The UN Population Division estimates the world population in 2017 to be 7.6bn and is projected to be 8.5bn in 2030 and 9.7bn in 2050.

The History of Atmospheric Carbon Dioxide on Earth

Plants use photosynthesis to make themselves from water, carbon dioxide and energy from the Sun. Atmospheric oxygen is a by-product of photosynthesis. Animals reverse photosynthesis. They eat plants or they eat animals that eat plants. Animal metabolism consumes oxygen and releases carbon dioxide and water. The net effect of all this is a constant movement of carbon between plants, animals and the atmosphere.

Carbon dioxide and water vapour are the most important greenhouse gases. Without greenhouse gases, Earth would be an ice planet and there would be no life. But since the beginning of the Industrial Revolution there has been a dramatic change in atmospheric carbon dioxide as the chart below shows.



www.skepticalscience.com/Comparing-CO2-emissions-to-CO2-levels.html

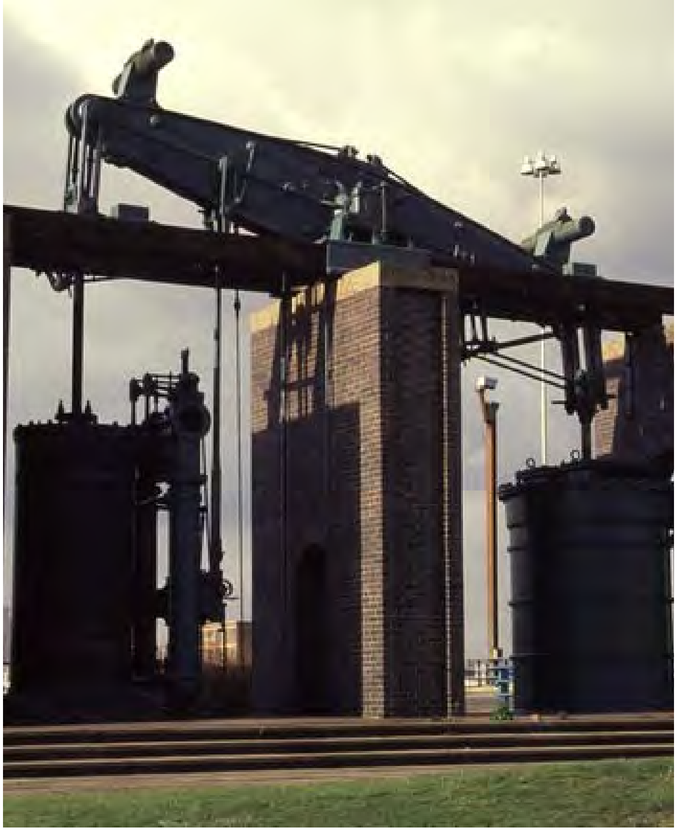
What happened in 1769 that might explain the rapid increase in CO_2 since then?

James Watt, contrary to what (no pun intended) is sometimes said, did not actually invent the steam engine but in 1769 he saw how to make a radical change to the design that vastly improved its efficiency.

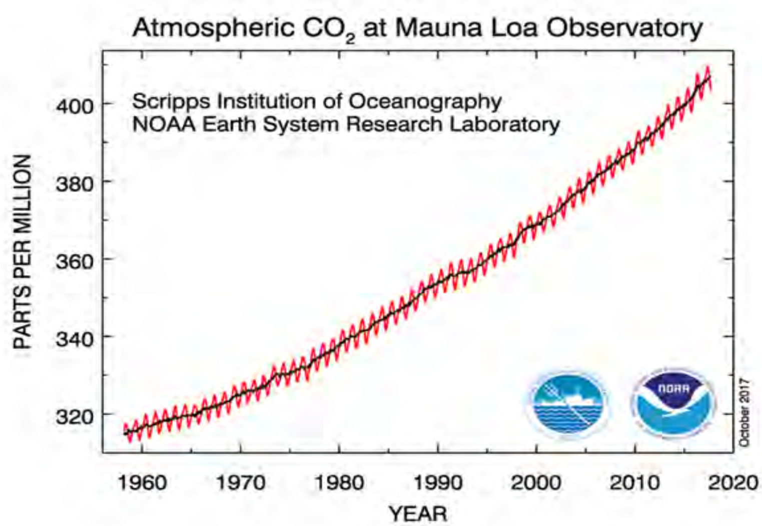
Previous steam engines, known as Newcomen atmospheric steam engines after the Cornish mine owner who invented them, had been in existence for about 50 years and were used for pumping water out of mines. They used steam to expel air from a piston and then air pressure drove the piston back. Watt's inspiration was to use steam directly to drive the piston.

The story that this came to him as a result of seeing a kettle on a hob blowing the lid up as it boiled could be true, as could the legends about Newton and the apple and Archimedes and the bath.

Below is a Boulton & Watt beam blowing engine re-erected on the Dartmouth Circus roundabout, on the A38(M) in Birmingham, UK. It was built in 1817 and used in Netherton at the ironworks of M W Grazebrook.



CO_2 was steady at about 285 parts per million by volume (ppmv) but has risen rapidly in the last 200 years to over 400 ppmv now - in other words, today carbon dioxide makes up 0.04% of the content of the atmosphere.



The carbon dioxide data (red curve) on Mauna Loa constitute the longest record of direct measurements of CO2 in the atmosphere.

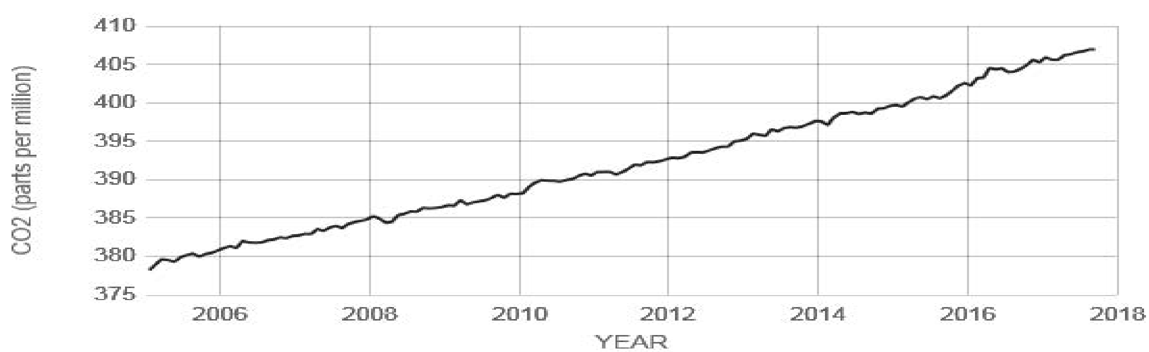
The black curve represents the seasonally corrected data.

https://www.esrl.noaa.gov/gmd/ccgg/trends/full.html

Below, Chart from https://climate.nasa.gov/vital-signs/carbon-dioxide/
The average seasonal cycle has been removed from these measurements.

DIRECT MEASUREMENTS: 2005-PRESENT

Data source: Monthly measurements. *Credit: NOAA*



Source: climate.nasa.gov

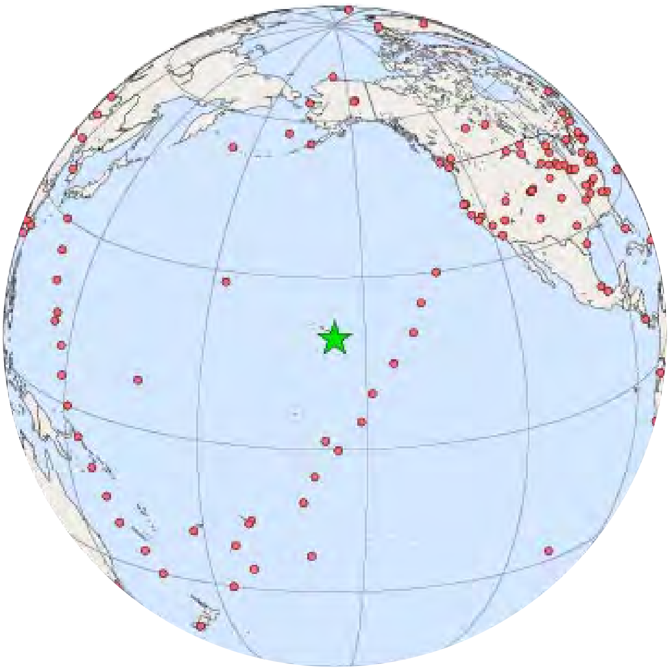
CHAPTER TWO:
MAUNA LOA

Mauna Loa Observatory (MLO) is a premier atmospheric research facility that has been continuously monitoring and collecting data related to atmospheric change since the 1950s. The undisturbed air, remote location, and minimal influences of vegetation and human activity at MLO are ideal for monitoring constituents in the atmosphere that can cause climate change.

As the above quote from their website implies, they monitor many aspects of the atmosphere, but CO_2 is the one that gets the most attention. The readings for CO_2 fluctuate from month to month. This is caused by plants absorbing CO_2 in the growing season. For a full explanation go to
https://scripps.ucsd.edu

In 2016, for the first time, readings were above 400ppm for the whole year. The readings for the week ending 27 July 2016 were 403.83ppm. For the same week in 2006 the reading was 381.96ppm and for the same week in 1996, 363.55ppm reflecting the continuous overall rise.
http://www.esrl.noaa.gov/gmd/ccgg/trends/monthly.html

In addition the observatory collects information on air quality across the globe. On the map, on page 17 the green star is Mauna Loa, the red dots on land are weather stations and those on the ocean are taken from a weather ship that sails the route regularly taking measurements.



And, finally, here is a photo of their weather station at the South Pole

http://www.esrl.noaa.gov/gmd/

NOT ONLY CO_2 - OCEANS, LAKES AND COASTS FOR EXAMPLE

Although best known for its CO_2 measurements, the Mauna Loa station also covers many other environmental indicators, including for example, water on the planet. They provide scientific results to help manage and understand fisheries, conserve and protect coasts, and support marine products and businesses, such as biotechnology and sustainable aquaculture. They also study changes in oceans and lakes due to natural and human activities.

CHAPTER THREE:
GREENHOUSE GASES

As mentioned previously, the amount of carbon dioxide or CO_2 in the atmosphere is only 0.04% - so how on earth can such a small amount cause such enormous concern?

THE AIR WE BREATHE

The air we breathe is almost entirely made up of two gases. Nitrogen is easily the biggest component, making up about 80% of the total for dry air at ground level, with oxygen the other main gas at about 19%. However in reality air is never normally completely dry and, in general, water vapour is the next largest component, varying from zero to 5%.

The amount of air above us in the atmosphere is constantly applying pressure to everything – to us, and to the air around us. As we travel to altitudes higher than sea level, the amount of air above us in the atmosphere reduces, so the air at our level is less compressed – the pressure reduces and the air is thinner. The components of air, and the amounts of those components, do not change, but there is simply less air surrounding us. (source: http://www.altitude.org/why_less_oxygen.php)

The American website About.com Chemistry http://chemistry.about.com/od/chemistryfaqs/f/aircomposition.htm gives the following...

Nearly all of the Earth's atmosphere is made up of only five gases: nitrogen, oxygen, water vapor, argon, and carbon dioxide. Several other compounds also are present. Although this table does not list water vapor, air can contain as much as 5% water vapor, more commonly ranging from 1-3%. The 1-5% range places water vapor as the third most common gas (which alters the other percentages accordingly).

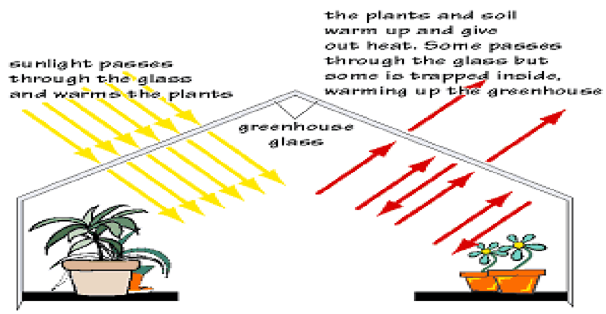
This is composition of air in percent by volume, at sea level at 15°C and 101325 Pa.

Nitrogen (N_2)	78.084%
Oxygen (O_2)	20.9476%
Argon (Ar)	0.934%
Carbon Dioxide (CO_2)	0.0314%
Neon (Ne)	0.001818%
Methane (CH_4)	0.0002%
Helium (He)	0.000524%
Krypton (Kr)	0.000114%
Hydrogen (H_2)	0.00005%
Xenon (Xe)	0.0000087%
Ozone (O_3)	0.000007%
Nitrogen Dioxide (NO_2)	0.000002%
Iodine (I_2)	0.000001%
Carbon Monoxide (CO)	trace
Ammonia (NH_3)	trace

From http://chemistry.about.com/od/chemistryfaqs/f/aircomposition.htm The figure for CO_2 is clearly out of date as it is now 400ppm by volume or 0.04%. With the readings included here, this data seems to be from about 1960.

HOW A GREENHOUSE WORKS

Everyone, of course, knows how a greenhouse works. Or do they?



Radiation from the sun in the form of sunlight and ultra violet radiation is not itself hot, which is why the air outside an aeroplane when in flight is very cold. This radiation passes through the transparent glass, but when it strikes a non-transparent object (e.g. the floor, or the contents of the greenhouse) some of it is absorbed. The object heats up and re-emits infra-red radiation that heats up anything it strikes, so the air in the greenhouse gets warm. The glass walls and roof stop this hot air escaping, so everything in the greenhouse is warmed. That is why the outside glass of a greenhouse on a cold day is colder than the inside.

But, this is NOT how the Greenhouse Effect works.

THE GREENHOUSE EFFECT

WHAT IS IT?

The short answer is that while the infrared radiation reflected upwards from the ground passes straight through nitrogen and oxygen, CO_2 and other greenhouse gases send some of it back to earth.

Wikipedia gives a slightly longer explanation:

‘Solar radiation at the high frequencies of visible light passes through the atmosphere to warm the planetary surface, which then emits this energy at the lower frequencies of infrared thermal radiation. Infrared radiation is absorbed by greenhouse gases, which in turn re-radiate much of the energy to the surface and lower atmosphere. The mechanism is named after the effect of solar radiation passing through glass and warming a greenhouse, but the way it retains heat is fundamentally different as a greenhouse works by reducing airflow, isolating the warm air inside the structure so that heat is not lost by convection.’

WARM, BUT NOT TOO WARM

It is estimated that if there were no greenhouse gases, everywhere would be about 33^{0}C colder, which would probably mean that humans would never have evolved.

So the Greenhouse Effect is vital. The problem is that adding to the amount of greenhouse gases risks making the planet too hot and, possibly, causing dangerous climate change. (See also pp73 – 78.)

Global land temperatures have increased by 1.5^{0}C over the past 250 years. But this increase is not spread evenly; temperatures at the poles have increased by at least five times the average.

The existence of the greenhouse effect was first suggested by Joseph Fourier in 1824. The argument and the evidence was further strengthened by Claude Pouillet in 1827 and 1838, definitely proved experimentally by John Tyndall in 1859, and explained by Svante Arrhenius in 1896. (See also Chapter 9, especially pp 69 & 70.)

IT'S TOO HOT!!
OR A TALE OF TWO BLANKETS

Jean Baptiste Joseph Fourier was French and lived from 1768 to 1830.He was a mathematician who made important contributions to the development of the subject.

Anyone who takes mathematics or physics at university will study Fourier analysis which is fundamental to everything from quantum theory to file compression on our computers and to MP3 players.

In the early 1820s he made a remarkable calculation of what the temperature should be at the surface of the Earth based on the amount of Sun's radiated energy that strikes the Earth. When he found that his answer was much lower than the actual figure, he didn't simply assume that there was something wrong with his calculation. Instead he asserted that there must be other factors, one of which could be that the atmosphere is acting like a blanket and making the Earth warmer than it would otherwise be. This is the origin of The Greenhouse Effect although he was not able to give a chemical explanation. It didn't help that the greatest chemist of the day, Lavoisier, had been accused of selling impure tobacco and guillotined during the French Revolution, the judge saying, allegedly, 'the Republic has no need of chemists'. Three years later he was declared innocent. A bit late.

Although not as unfortunate as Lavoisier's, Fourier's life came to an abrupt end in 1830 as a result of his eccentric practice of wrapping himself in a large blanket when indoors. (perhaps copying the effect of the earth's atmosphere). One day he tripped on it while at the top of the stairs and fell to the bottom. Fin. As the French say.

But why some gases and not all? The answer is that most gases whose molecules are made up of three or more atoms, such as CO_2 and H_2O (water vapour) absorb infrared and then re-emit it in all directions equally, so some of the infrared that comes from the ground is sent straight back again.

The molecules of the two main gases in air, nitrogen and oxygen, are made up of two atoms of the same element and allow infrared to pass through unhindered.

Why this should be so is beyond the scope of this guide - the full explanation is definitely university level and beyond. If you want to go further into this, we recommend the website of the American National Oceanic and Atmospheric Administration National Climatic Data Center.
http://www.noaa.gov/

OTHER GREENHOUSE GASES

WATER VAPOUR

Carbon dioxide is the one everyone knows about, but it is by no means the only one. Water vapour is one, but is usually omitted from estimates, perhaps because it is not well understood.

Here is an edited extract from the American National Oceanic and Atmospheric Administration National Climatic Data Center website:
http://www.ncdc.noaa.gov/monitoring-references/faq/greenhouse-gases.php

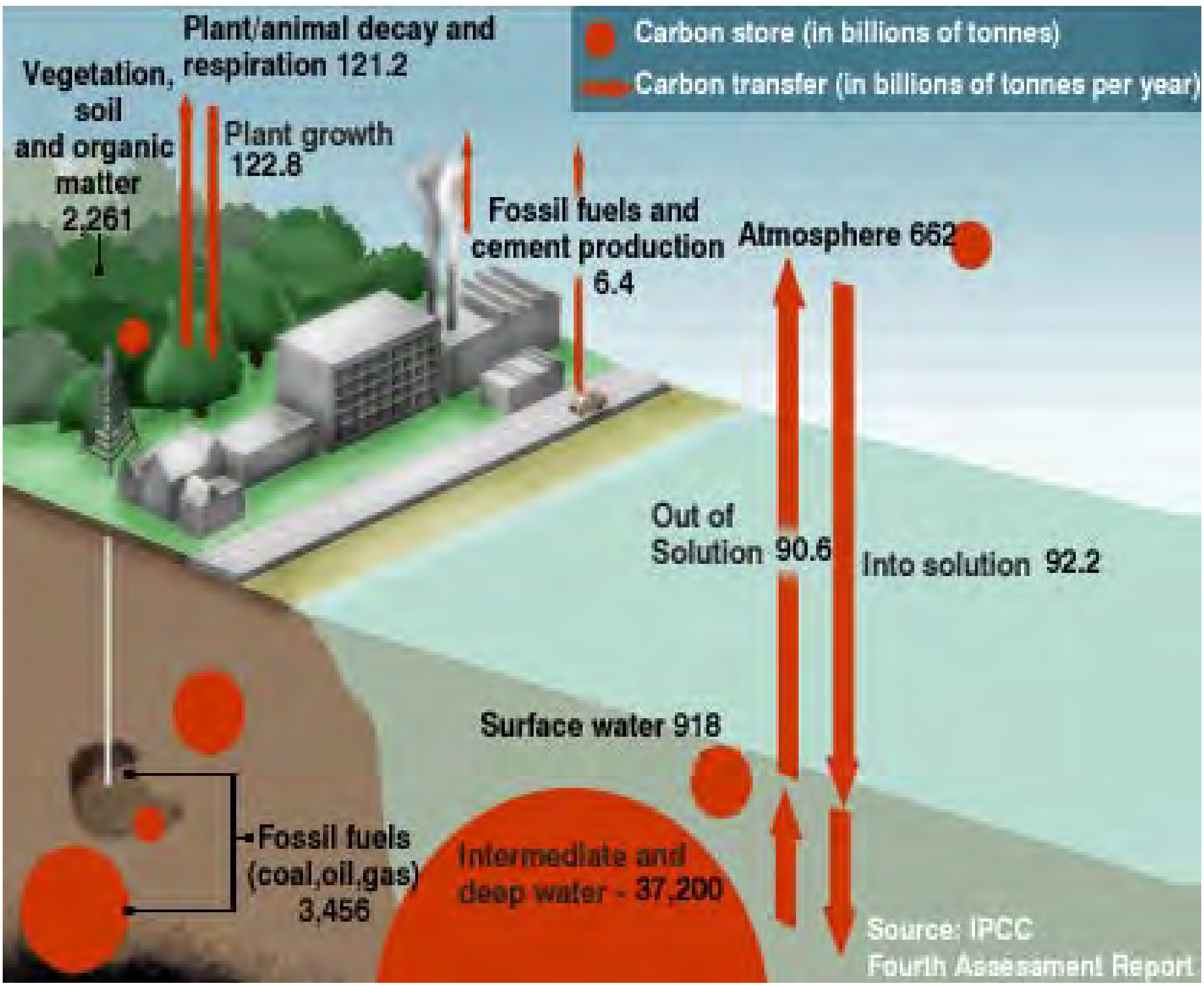
“Water Vapor is the most abundant greenhouse gas in the atmosphere, which is why it is addressed here first. However, changes in its concentration is also considered to be a result of climate feedbacks related to the warming of the atmosphere rather than a direct result of industrialization. The feedback loop in which water is involved is critically important to projecting future climate change, but as yet is still fairly poorly measured and understood.”

January 2018

BLACK CARBON OR SOOT

Not a gas at all, of course. But The Economist for January 19, 2013 reported that a study has shown it is second only to CO2 as a damaging greenhouse agent and twice as bad as previously thought. It is also very bad for health, as the Chinese know from the thick smog gripping Beijing.

MAJOR CARBON STORES AND TRANSFERS



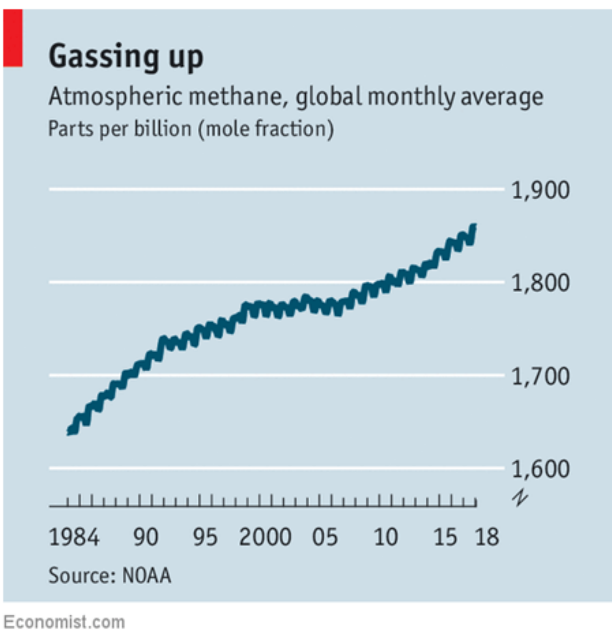
METHANE

Methane is the main constituent of natural gas, and when burnt emits little more than half of what coal does. But if it escapes into the atmosphere, it is a greenhouse gas that is about 25 times as powerful as CO_2.

MORE METHANE IN THE AIR; SHOULD WE BE WORRIED?

(Based on an article in The Economist for April 28th, 2018)

In April 2018 the American National Oceanic and Atmospheric Administration, a leading research institution, published the graph shown below, reproduced in The Economist, showing recent large increases in atmospheric methane.



DOES THIS AMOUNT OF METHANE MATTER?

A mole fraction is the number of molecules of a constituent divided by the total number of all molecules and for methane in air it roughly equates to parts per billion. Thus, to change to percentages, divide by 10^9 *and multiply by* 10^2*, that is, divide by* 10^7 *So 1,800ppb = 0.00018%. As methane is about 25 times as powerful a GHG than* CO_2*, this is equivalent to about 0.004% of* CO_2*. The amount of* CO_2 *in the atmosphere is currently just over 400ppm or 0.04%.*

So methane currently accounts for about a tenth of global warming, and it does indeed matter.

WHAT IS CAUSING THIS INCREASE?

This increase is worrying, and it is obviously crucially important to find out its source if we are to have any chance of arresting the increase.

Possibilities include:

1. increasing numbers of cattle in India and China (see page 18)
2. more rice paddies in South-East Asia
3. increase in tropical wetlands
4. a decline in bushfires
5. increasing leakage from oil and gas plants
6. warming of Arctic tundra (frozen soil)

It probably isn't number 6, which is a relief as the amount of methane in the tundra is estimated to be equivalent to more than twice all the CO_2 emitted by human activities since 1800. If it were released it could set off a vast new burst of global warming. There are two reasons for thinking the methane increase is not caused by melting tundra. First, chemical analysis indicates that the source is probably biological. And, second, analysis of Siberian air shows no sign of its methane rising any faster than in the rest of the world.

At present there are no reliable figures for possibilities 1 to 4 above. Urgent research is being carried out to try and get accurate data.

Nor are there currently reliable data for possibility 5. A new satellite is planned to address this.

In summary, the increase in methane in the atmosphere is a mystery. But one that we need to solve.

CATTLE AND METHANE

Cattle emit large quantities of methane, from both ends. Attempts to catch the methane by a tube to the poor animal's inside and a bag on its back were, mercifully, a failure. Currently scientists are trying to modify cattle diets to reduce emissions.

CHAPTER FOUR:

HOT TOPIC: FACTS AND OPINIONS

RATIONAL ARGUMENT

THE GOOD

The method is simple. First everyone agrees on what the relevant facts are, and then different inferences are suggested and either agreed or not. Thus an agreed position is reached which is supported by most if not all involved.

THE BAD

An alternative is that everyone knows in advance what conclusion they want to be reached and then advances only facts that support this conclusion...

AND THE UGLY

or, worse still, lies about what the facts are.

All these methods are on display in arguments about climate change.

CLIMATE SCIENCE

Climate is studied at universities and research institutes across the world, and masses of papers are produced – far more than a politician or journalist, or just a concerned non-expert, could possibly manage to read. It is of course enormously important that those who make decisions that could decide the future of the human race should be guided by the facts. That is why, in 1988, all the nations of the world, through the United Nations, set up the Intergovernmental Panel on Climate Change or IPCC(http://www.ipcc.ch/) to collate all research on climate change and produce reports to guide international policy making.

THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

- So that governments can make sense of the vast amount of relevant research going on, the United Nations set up in 1988 the Intergovernmental Panel on Climate Change (the IPCC).
- The IPCC does not carry out research of its own. Instead, it is a forum of over 2000 leading experts and civil servants from across the world.
- Its role is to sift and assess current research worldwide. It is generally considered the most authoritative body on climate change in the world.
- In 2014 the IPCC published a series of long and immensely detailed reports. But essentially they did not come to any different conclusions than in previous reports. In their overall summary they stated:

  Human influence on the climate system is clear, and recent anthropogenic emissions of green-

  house gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.

  Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, and sea level has risen.

  There is much more at http://www.ipcc.ch/

- The IPCC does have its critics. Some feel that in its efforts to reach a report acceptable to all nations it underestimates the gravity of the situation. Others take the opposite view and accuse it of distorting the science in order to persuade governments that urgent action is vital.

CLIMATE CHANGE DENIERS

While a large majority of climate scientists accept the conclusions of the IPCC, a vociferous minority, made up largely of people who are not climate scientists, do not. But the fact that they are not climate scientists does not of itself invalidate their views.

THE GLOBAL WARMING POLICY FOUNDATION or GWPF

The most prominent UK organisation devoted to questioning the majority view is the Global Warming Policy Foundation (GWPF) http://www.thegwpf.org launched by Lord Lawson, a former chancellor of the exchequer (finance minister) in November 2009 in the run-up to the Copenhagen UN Climate Summit of December 2009. He describes the science of global warming as 'contested'. Most climate scientists would say that it is established.

BEACONS and the GWPF - a note from the Editor

In 2013 I entered into correspondence with the Director of the Global Warming Policy Foundation, Dr Benny Peiser.

Two matters are relevant here.

1. Dr Peiser told me that my original text on the GWPF was 'riddled with factual errors' but declined to tell me what they were.

2. In view of the GWPF's casting doubt on the integrity of scientists they call 'climate alarmists' by implying they distorted their results in order to get academic grants, and of The Guardian's failure to get the GWPF to reveal its sources of funding, I asked Dr Peiser to state what they are. To date I have not received an answer. On a personal note, I wish to make it clear that I do not think that one should ever assume dishonesty simply because of the source of funding, but complete transparency should be the norm. After all, funding has to come from somewhere.

CLIMATEGATE

Lord Lawson of Blaby is now 84. As Nigel Lawson he was Conservative chancellor of the exchequer from 1983 to 1989 under prime minister Margaret Thatcher and is the father of celebrity cook Nigella Lawson and of journalist Dominic Lawson.

www.parliament. uk/ biographies

The founding of the GWPF followed a Times article by Lord Lawson. Hacked internal emails of the University of East Anglia Climatic Research Unit (CRU), seemed to show that the CRU had deliberately falsified data to show a continuing rise in global temperatures. The effect was dramatic. The CRU director, Phil Jones, was suspended. Two enquiries subsequently exonerated him and he was re-instated. The GWPF maintains they were whitewashes.

Professor Phil Jones, Director, the CRU

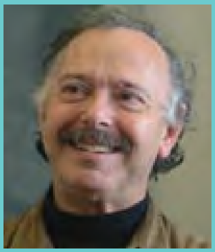
Photo:
The Guardian 2010

WHY ADDING 'GATE' DENOTES A SCANDAL

The origin is a political scandal during the 1970s in the United States. President Richard Nixon, a Republican, authorised a break-in at the Watergate office complex in Washington, D.C., the HQ of the Democrats. The Nixon administration denied any involvement at first, but the truth came out as the result of the determined, and courageous, investigation by two Washington Post reporters, Bob Woodward and Carl Bernstein. Effects of the scandal eventually led to the resignation of Richard Nixon, the President of the United States, on August 9, 1974; the only resignation of a U.S. President. The scandal also resulted in the indictment, trial, conviction and imprisonment of 43 people, including dozens of top Nixon administration officials.

The next time a scandal hit the headlines, the media wittily added 'gate' to its name. And have been doing so ever since even though many reporters were not even born at the time of Watergate. Hence 'Climategate' etc, etc..

BERKELEY EARTH



Richard Muller, a professor of astrophysics at the University of California at Berkeley, USA.

Following Climategate, he set up his own research team to investigate the facts. He concluded that Professor Jones had indeed misused the statistics, possibly inadvertently through lack of statistical expertise. However, he concluded that the conclusions were broadly right. He then founded a climate research group, Berkeley Earth. We recommend its website, **http://berkeleyearth.org/** and his book, Energy for Future Presidents.

IPCC ERRORS

It didn't help that, separately from the East Anglian affair, two mistakes in the IPCC report for 2007 were revealed in 2010. The first, a simple factual error, was in the proportion of the Netherlands that is below sea level. The second, and more serious, was the attribution to a renowned Indian glaciologist, Dr Pachauri, who is also chairman of the Intergovernmental Panel on Climate Change, of the statement that all the Himalayan glaciers could be gone by 2030. He denies he ever said any such thing and, along with other glaciologists, says that it would take at least 300 years for this to happen.

Dr Pachauri resigned in 2015 and the current Chair is Dr Hoesung Lee, a professor in the economics of climate change, energy and sustainable development at Korea University in Seoul, South Korea. For a description of the latest report, 2014, of the IPCC, please see page 22.

UK PUBLIC OPINION

An Ipsos MORI poll in January 2015 found that Britons are more likely to agree the climate is changing than at any time in recent years, with nearly nine in 10 people saying climate change is happening and 84% attributing this somewhat or entirely to human activity. This is a huge increase from 2011 when the figure was only 21%. Three quarters of people said they supported the UK signing up to international agreements to limit emissions, with 14% neutral and only 7% opposed, but only 14% said they would contact their local MP on the issue.

http://www.itv.com/news

http://www.huffingtonpost.co.uk/

CHAPTER FIVE:
IS THE PLANET GETTING WARMER?

You might think this is a bit of a daft question...

WHY NOT SIMPLY MEASURE THE TEMPERATURE?

There are thousands of weather stations all over the globe which will have been recording temperatures over many years. So why don't we simply look at the records and see? Well, this is indeed done, but there are major problems.

"Is the planet getting warmer?" is a deceptively simple question. The first and most obvious method of examining this is to look at the temperature records of all the weather stations across the globe. However, while there is plenty of data from some stations, there are some issues with this approach:

- Not all weather stations will have equally reliable records. How can we know how accurate the thermometer was at any weather station many decades ago? Or how carefully the readings were recorded?
- The longest series of continuous temperature records is for central England and goes back to 1659. It is difficult to know how accurate the earlier readings were, not least because they simply give one 'average' reading for the whole day.
- Weather stations are not distributed evenly across the globe, and were even less so in the past.
- The local environment of many weather stations has changed significantly since they were first

operational. In particular, many that were surrounded by green fields originally are now swallowed up by towns, which makes a big difference to temperature. This is known as the heat island effect.

- Clearly temperature changes differently in different places. Some places may be getting colder while others get warmer. So a single average temperature for each year for the whole planet may not, on its own, mean very much. Indeed, one climate scientist remarked that trying to calculate an average temperature for all the figures available would be about as meaningful as working out the average phone number in a telephone directory.

SO IS IT POSSIBLE TO WORK OUT A SINGLE FIGURE FOR GLOBAL TEMPERATURE RISE?

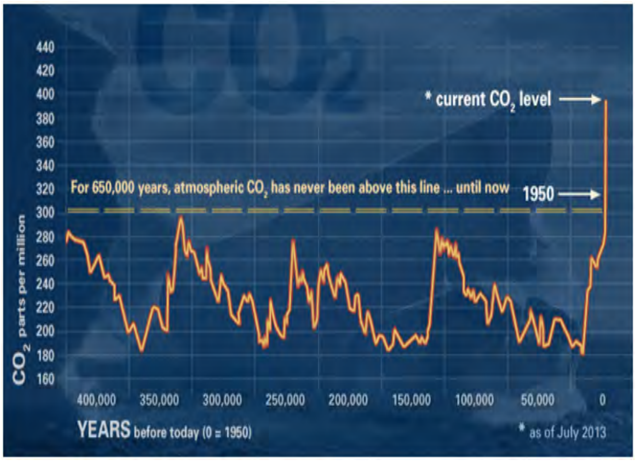
The short answer appears to be: Yes. Here is how it is explained on the website of the Met Office, http://www.metoffice.gov.uk by Dr Peter Stott.

There are three centres which calculate global-average temperature each month.

- *Met Office, in collaboration with the Climatic Research Unit (CRU) at the University of East Anglia (UK)*
- *Goddard Institute for Space Studies (GISS), NASA (USA)*
- *National Climatic Data Center (NCDC), part of the National Oceanic and Atmospheric Administration (NOAA) (USA)*

They all agree global-average temperature has increased over the past century and this warming has been particularly rapid since the 1970s.

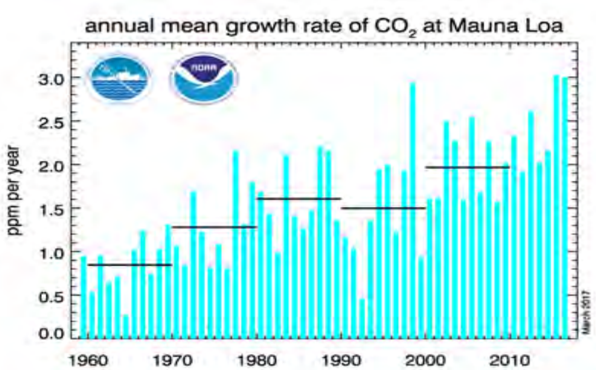
GLOBAL TEMPERATURES AND CO_2



Atmospheric CO_2 concentration from 650,000 years ago to near present, using ice core proxy data and direct measurements.

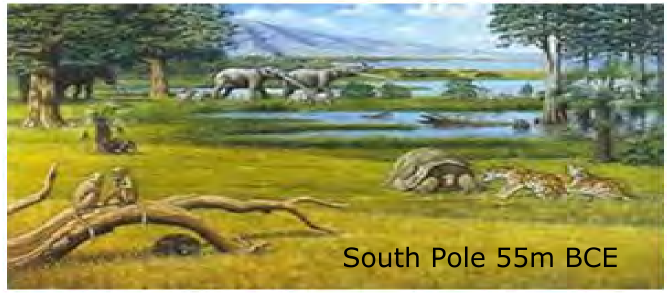
http://climate.nasa.gov/evidence/

The CO_2 reading at Mauna Loa (see p14) for February 2017 was 406.42ppm, an increase of 2.38ppm from February 2016. The readings vary in a regular way during the year, going down in spring and summer as plant growth absorbs CO_2. Annual increases have gone up threefold in the last 66 years but in a much less regular way, as the chart below shows.



https://www.esrl.noaa.gov/gmd/ccgg/trends/gr.html

THE PLEOCENE-EOCENE THERMAL MAXIMUM (PETM)


South Pole 55m BCE

In the 1980s, geologists drilling into rocks under the Antarctic ice sheet found evidence from the strata of rapid* temperature rise around 55 million years ago. Fossilised remains of leaves are major clues – jagged ones like those pictured below were originallly only found in hot climates. (*In geological terms that is in only 100,000 years!*)

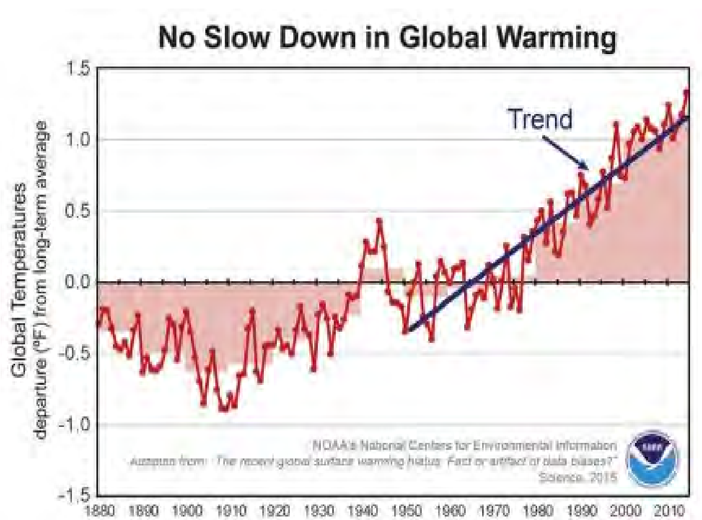
At the time the poles must have been like the tropics are today. The average global temperature then seems to have been about 6º C above today's, which would make much of the planet uninhabitable. But the amount of CO_2 was at least 2,000 ppm compared with 400 ppm today. The PETM has been studied worldwide ever since it was discovered, most notably to see what lessons there are for us. One unresolved question is whether the high level of CO_2 was the cause or an effect of the high temperature.

(Main source: BBC4, Melvyn Bragg 'In our time' March 6, 2017 available on BBC iplayer)

THE HIATUS

Starting in 1998 the rise in temperatures fell to only a tenth of what it was. No-one forecast this. Seized on by sceptics, it was a considerable embarrassment to climate scientists although only a blip compared with temperature charts covering centuries, let alone millennia.

Then, in June 2015, the American National Oceanic and Atmospheric Administration (NOAA) published figures showing that the Hiatus was no more than a statistical blip. Here is the graph they gave to illustrate their data.



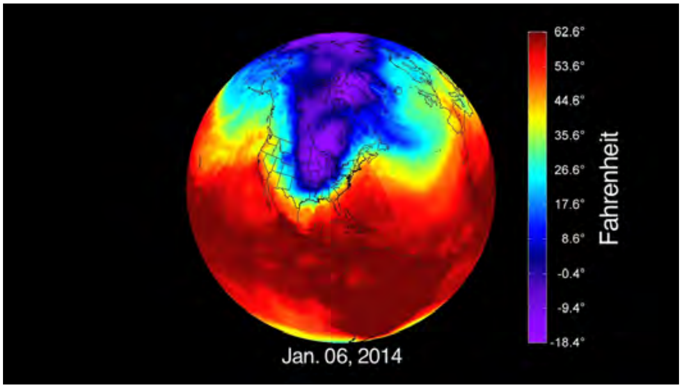
HOW ARE TEMPERATURE READINGS ANALYSED?

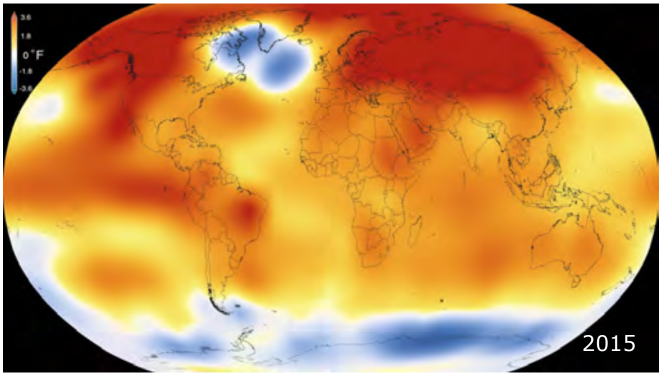
'Tens of thousands of temperature observations are taken across the globe, on land and at sea, each day. Land stations use these daily readings to create a monthly average, which is then sent off for use by climate researchers.

Individual ship and buoy observations are transmitted on the Global Telecommunication System.

The monthly updates are combined with archives of historical observations that have been gathered over the past 160 years.

The historical data are adjusted to minimise the effects of changes in the way measurements were made. (see the note on the next page). The HadCRUT3 record, which is produced by the Met Office in collaboration with the Climatic Research Unit, takes in observationsfrom about 2,000 land stations each month. The figures for each one are checked both by computer and manually to find and remove any problems. Sea-surface temperature observations come from about 1,200 drifting buoys deployed across the world's oceans and around 4,000 ships in the Voluntary Observing Ship programme. There are also numerous moored buoys in the tropics and in coastal regions, principally around the US. Together they take around 1.5 million observations each month. These are checked by computer and any obviously inaccurate readings are excluded.' Source: Met Office





WHY ARE THE READINGS GIVEN AS 'ANOMALIES' AND WHAT IS AN 'ANOMALY' ANYWAY?

The Met Office website, http://www.metoffice.g v.uk/climate-change/guide/science/explained/temp-records gives Dr Stott's explanation as follows...

Absolute temperatures are not used directly to calculate the global-average temperature. They are first converted into 'anomalies', which are the difference in temperature from the 'normal' level. The normal level is calculated for each observation location by taking the long-term average for that area over a base period. For HadCRUT3, this is 1961–1990.

For example, if the 1961–1990 average September temperature for Edinburgh is 12°C and the recorded average temperature for that month in 2009 is 13°C, the difference of 1°C is the anomaly and this would be used in the calculation of the global average.

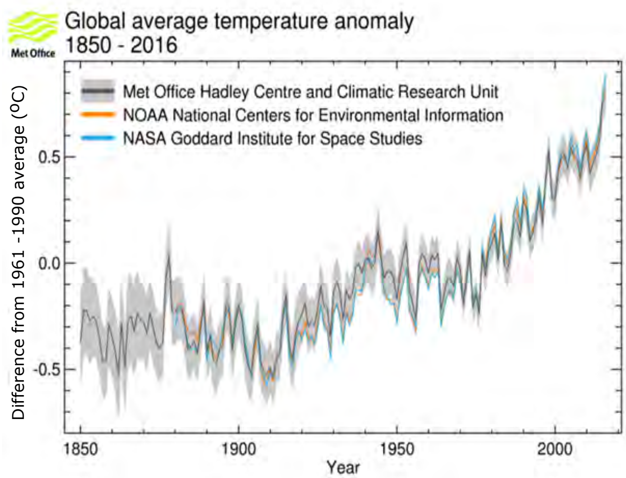
One of the main reasons for using anomalies is that they remain fairly constant over large areas. So, for example, an anomaly in Edinburgh is likely to be the same as the anomaly further north in Fort William and at the top of Ben Nevis, even though there may be large differences in absolute temperature for each of these locations.

Lochaber area, Scotland Wikipedia

The anomaly method also helps to avoid biases. For example, if actual temperatures were used and information from an Arctic observation station was missing for that month, it would mean the global temperature record would seem warmer. Using anomalies means missing data such as this will not bias the temperature record.

GLOBAL TEMPERATURE TREND

The chart below from the UK Met Office shows the results of the three main world temperature monitors.



http://www.metoffice.gov.uk/research/monitoring/climate/surface-temperature

The chart amalgamates separate charts for sea surface and ground temperatures. You can find these at the website address above. In general, temperatures have risen least in the South and most in the North. Indeed, in the last two winters, temperatures at the North Pole have reached 10^0 C above normal. The spiky nature of the lines reflects the many other factors than GHG emissions affecting temperatures. But the trend is clear. Upwards. You can see the reduction in this upward trend between about 1998 and 2010.

Cambridge scientists studying the north polar ice cap in summer 2011.

EFFECTS OF NORTH POLAR WARMING ON FLORA AND FAUNA

One species of sedge emerges 26 days earlier than it did a decade ago - the greatest increase in the timing of emergence on record in the Arctic, according to the researchers.

The earlier arrival of plants can have knock on effects on other species such as caribou who come out to forage at the same time each year and eat the earlier emerging plants which are less nutritious than they were at first growth, resulting in fewer calves born and more calf deaths.

Caribou in a Greenland meadow

Researchers based at the University of California, Davis, studied the emergence dates of certain species of plants over a period of 12 years.

Read more: http://www.dailymail.co.uk/sciencetech/article-4257392/Global-warming-speeding-nature-Arctic.html#ixzz4ZskQFHnl

CHAPTER SIX:
DEFINITE SIGNS OF RISING TEMPERATURES

What are the distinct changes which indicate a general rise in temperatures across the planet?

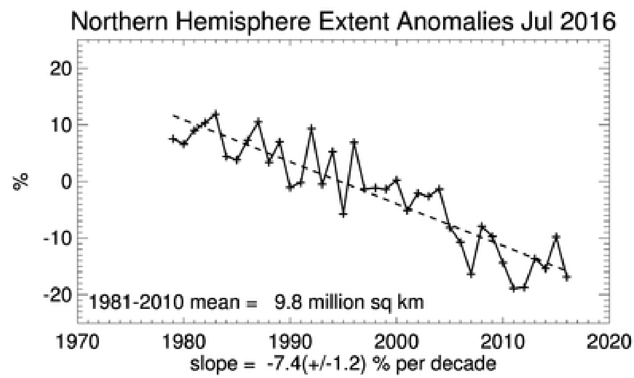
- Arctic sea ice is getting less
- Species are gradually moving north in the northern hemisphere
- Most, but not all, glaciers in the world are in retreat. (See pages 38 to 40)

Perhaps you are surprised at the brevity of the list, and likely you gave many more, such as rising sea levels, droughts in some areas, more hurricanes and other extreme weather, and polar bears becoming extinct. We will say something about each of these later, and why it is thought they cannot count as being definitely the result of global warming. But first the three items we do consider genuine evidence.

ARCTIC SEA ICE

There is no doubt that Arctic sea ice is getting less. The chart opposite comes from the US National Snow and Ice Data Center (NSIDC).

Average Monthly Arctic Sea Ice Extent
March 1979 - 2016



Monthly March ice extent for 1979 to 2016 shows a decline of 2.6% per decade relative to the 1981 to 2010 average.
http://nsidc.org/data/seaice_index/

The monthly average Arctic sea ice extent for March was the lowest in the satellite record.

WHAT ABOUT THE ANTARCTIC?

Whereas the North Pole is in an ocean surrounded by land, the South Pole is on a vast land mass surrounded by sea. Antarctic sea ice is increasing even though temperatures are rising, largely because snowfall is increasing and becoming compressed as ice.

For more on polar ice see next chapter.

THE SCRAMBLE FOR THE ARCTIC

The consequences of the opening up of the Arctic Ocean are considerable. There are vast deposits of oil and gas, and all the major oil companies are either drilling already or are planning to start soon. Furthermore there are deposits of rare earths needed in mobile phones and other electronic equipment.

And just as planes flying from America to Europe or Asia fly over the North Pole because it is much shorter, so shipping will also take the polar route more and more as the ice melts. In 2010 just four ships passed through the Arctic Ocean; in 2014 it was 41.

IS THERE A RISK OF WAR?

So far all eight bordering nations – The USA, Russia, Finland, Norway, Sweden, Denmark, Iceland and Canada - are working together harmoniously and the chance of conflict seems slight.

Nevertheless, most are moving some military forces to the far north. These nations have been meeting since 1996 as the Arctic Council in a few temporary rooms and with half a dozen staff in the northern Norwegian city of Tromsø. They agreed at the outset that they would admit others with a genuine interest. Many have now applied to join, including China (rare earths), Singapore (worried about its future as a shipping centre) and Greenpeace (concerned about the risks of oil spills). The Council will undoubtedly move to grander accommodation before long.

In November 2016, President Obama banned drilling in the Arctic for five years. President Trump has vowed to reverse this, and signed an executive order aiming to begin this process in April 2017. However, drilling may not take place as a fall in the price of oil may make it unprofitable to do so.

AOL image

ARCTIC DANGERS

Drilling for oil presents the obvious risk of a damaging oil spill. The oil companies and the Arctic Council say safety precautions are very good and the risk negligible. Many, including Greenpeace, don’t agree.

SPECIES MOVING NORTH IN THE NORTHERN HEMISPHERE

There are a great many examples of species which are moving further north in the northern hemisphere.

The following is from the FT for August 26, 2011...

GLOBAL WARMING HAS WILDLIFE ON THE MOVE

Research shows species have moved to higher latitudes – where conditions are cooler – faster than scientists had appreciated...

Cetti's warbler is now found 150km farther north than when it first colonised England in the 1970s.

While climatologists and politicians argue about the extent to which human activity is heating up the world, biologists charting the movements of plants and animals have no doubt that global warming is having a real impact on wildlife.

The most comprehensive study so far, published in the journal Science, shows that species have responded to climate change – by moving to higher latitudes and elevations where conditions are cooler – two to three times faster than scientists had appreciated. The researchers, based at York University, analysed the response of 2,000 plant and animal species. They found that on average they have moved to higher altitudes by 12.2 metres per decade and to higher latitudes by 17.6 metres per decade.

Many different factors are involved in wildlife population shifts. But this study is the first to prove that climate change is a key driver, by showing that species have moved furthest where conditions have warmed the most.

Individual species show great variation in their movements, depending on other ecological factors and on their sensitivity to local aspects of climate change such as an increase or decrease in rainfall. In Britain, for example, as well as Cetti's warbler noted on the previous page, the distribution of the Comma butterfly has moved 220km north from central England to Edinburgh in two decades. But special factors have knocked a few species back in the opposite direction.

The Cirl bunting retreated southward by 120km, probably in response to the intensification of UK agriculture.

Next is this charming creature...

The photo above is of an American pika in Desolation w ilderness, in El Dorado County, Calif., near Lake Tahoe.

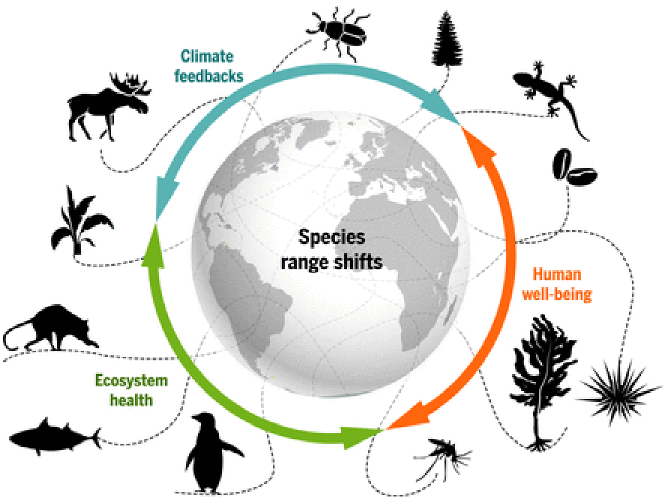
ScienceDaily, an American magazine stated the following in April 2011 — Local extinction rates of American pikas have increased nearly five-fold in the last 10 years, and the rate at which the climate-sensitive species is moving up mountain slopes has increased 11-fold since the 20th century, according to a study soon to be published in Global Change Biology.

But before you get too attracted to the pika and would like to own one, note this: 'For the first time a new study suggests that when exposed in their natural ecosystem, wild pikas (a species closely related to rabbits) are mammalian hosts of H5N1 subtype avian influenza viruses.'

Try butterflies instead! Species in the Northern Hemisphere are conspicuously moving north, or higher up mountains. To a lesser extent, the same but to the south is happening in the Southern Hemisphere.

The Comma butterfly (see photo at top of next page) in the UK is one of many species moving north in response to climate change.

The movement of species is of more than academic interest to us humans. We depend on agriculture for our food and global warming affects both farm animals and crops as this diagram shows.



GLACIERS

Glacial ice is the largest reservoir of freshwater on Earth. Many glaciers are a water source that is especially important for plants, animals and human uses when other sources may be scant.

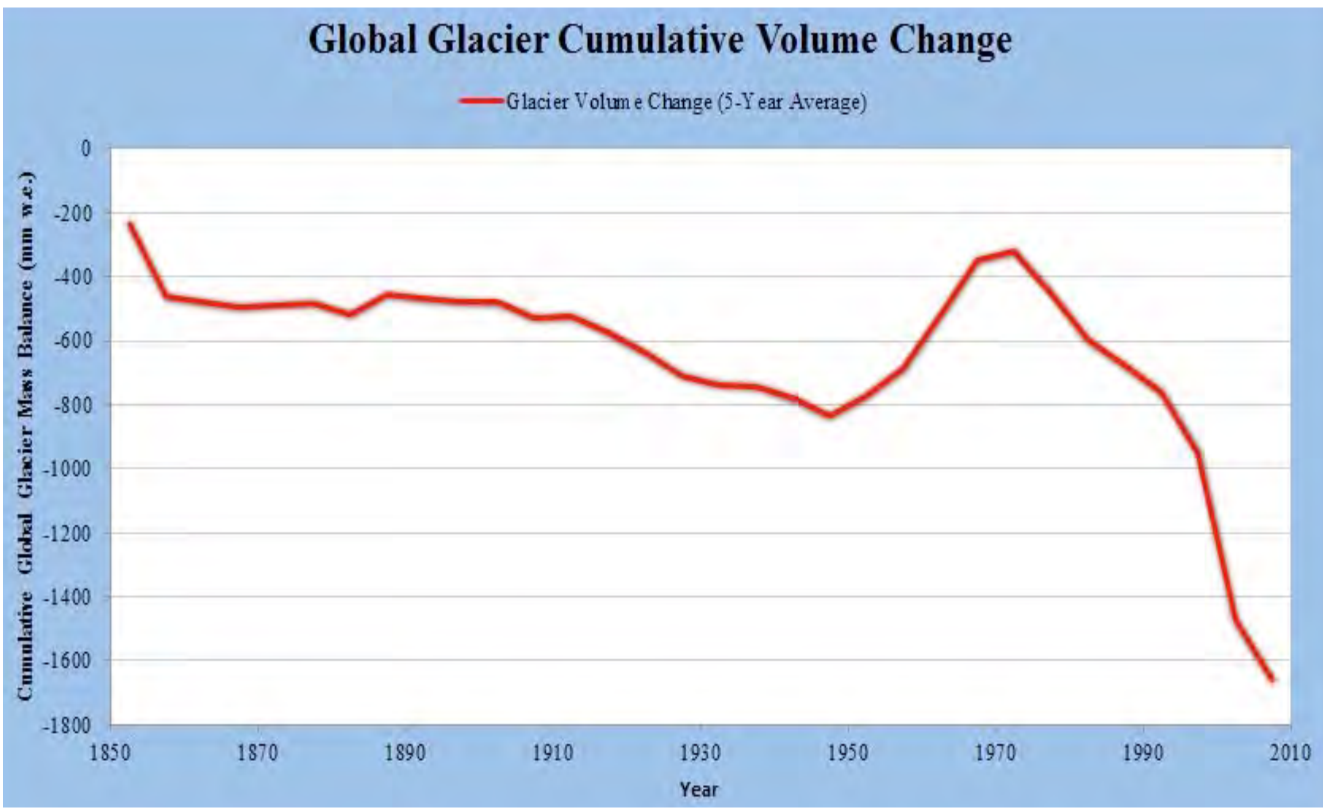
The Baltoro Glacier in the Karakoram, Baltistan, Northern Pakistan. At 62 kilometres (39 mi) in length, it is one of the longest alpine glaciers on earth. *Wikipedia*

Here are some extracts from the website of the World Glacier Monitoring Service

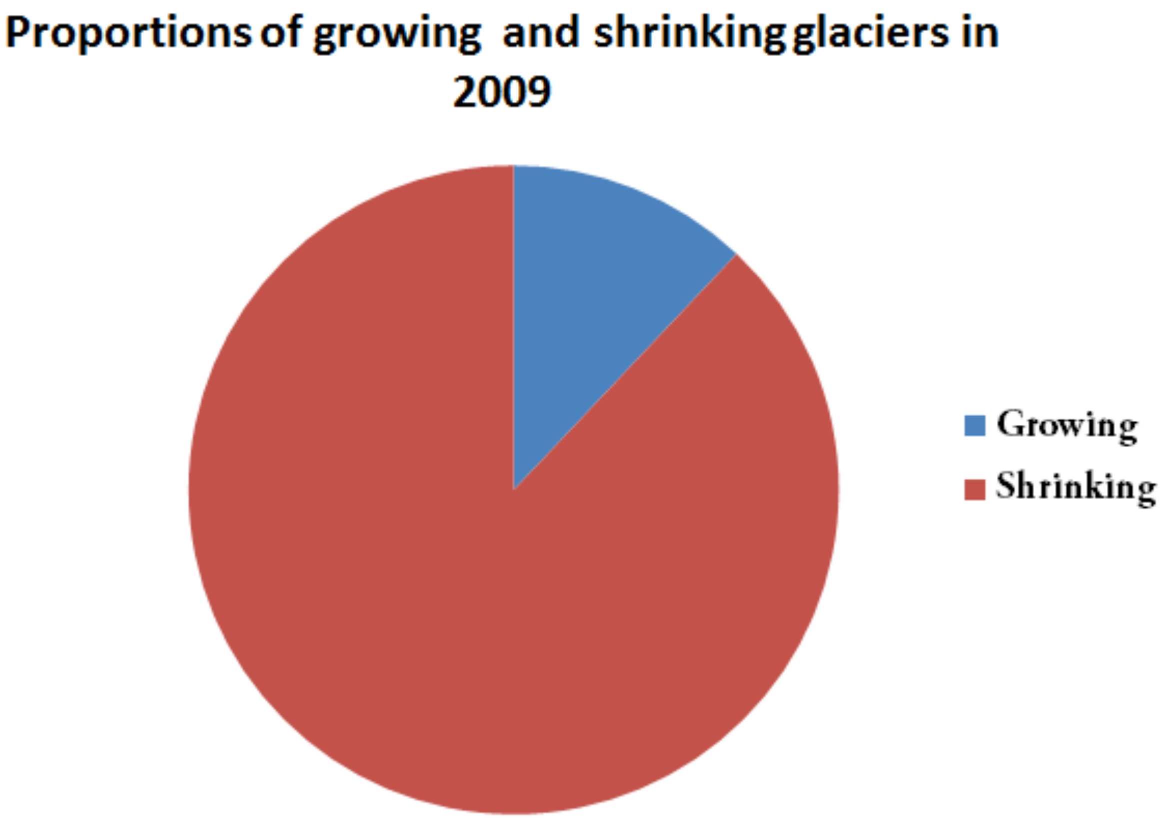
http://www.wgms.ch/

'The answer is not only clear but it is definitive and based on the scientific literature. Globally glaciers are losing ice at an extensive rate). There are still situations in which glaciers gain or lose ice more than typical for one region or another but the long term trends are all the same, and about 90% of glaciers are shrinking worldwide.'

'It is also very important to understand that glacier changes are not only dictated by air temperature changes but also by precipitation.'



Therefore, there are scenarios in which warming can lead to increases in precipitation. These variations are superimposed on a clear and evident long term global reduction in glacier volume which has accelerated rapidly since the 1970s.'



Source: World Glacier Monitoring Service - Glacier Mass Balance Bulletin 08/09, released 14/12/2011

BUT WHAT ABOUT THE POLAR BEARS?

Despite their world-wide popularity and cuddly appearance, polar bears are of course the world's largest land carnivore and can be very dangerous – devastatingly proven in the summer of 2011 when one got into a sixth form expedition camp on the Norwegian archipelago of Svalbard. One student was killed and several injured before the bear was shot. If you visit Longyearben, the only Norwegian town on Svalbard, as the editor has, you will find that it is forbidden to leave the town without having a trained and armed shot with you.

Polar bears are the poster animals of climate change, listed as 'vulnerable to extinction' by the International Union for Conservation of Nature (IUCN) and often highlighted in the media, photographed on melting icebergs or in ice-free arctic lands. It is widely believed that their population is rapidly declining. But according to the latest research this is not actually true. With the reduction in summer sea ice in the Arctic, their habitat and hence their hunting techniques are changing, but their overall population numbers are reasonably consistent, though it is true that this is as some populations are growing while others are declining.

In January 2018 the IUCN published a report which concluded that while some of the 19 distinct polar bear populations are declining, the overall population is currently stable at about 26,000. It is also worth noting that population numbers are often disputed and difficult to determine, but overall species numbers have risen since the Agreement on the Conservation of Polar Bears was signed in 1973, bringing in restrictions

on hunting and baiting of bears, and banning it completely for non-native populations.

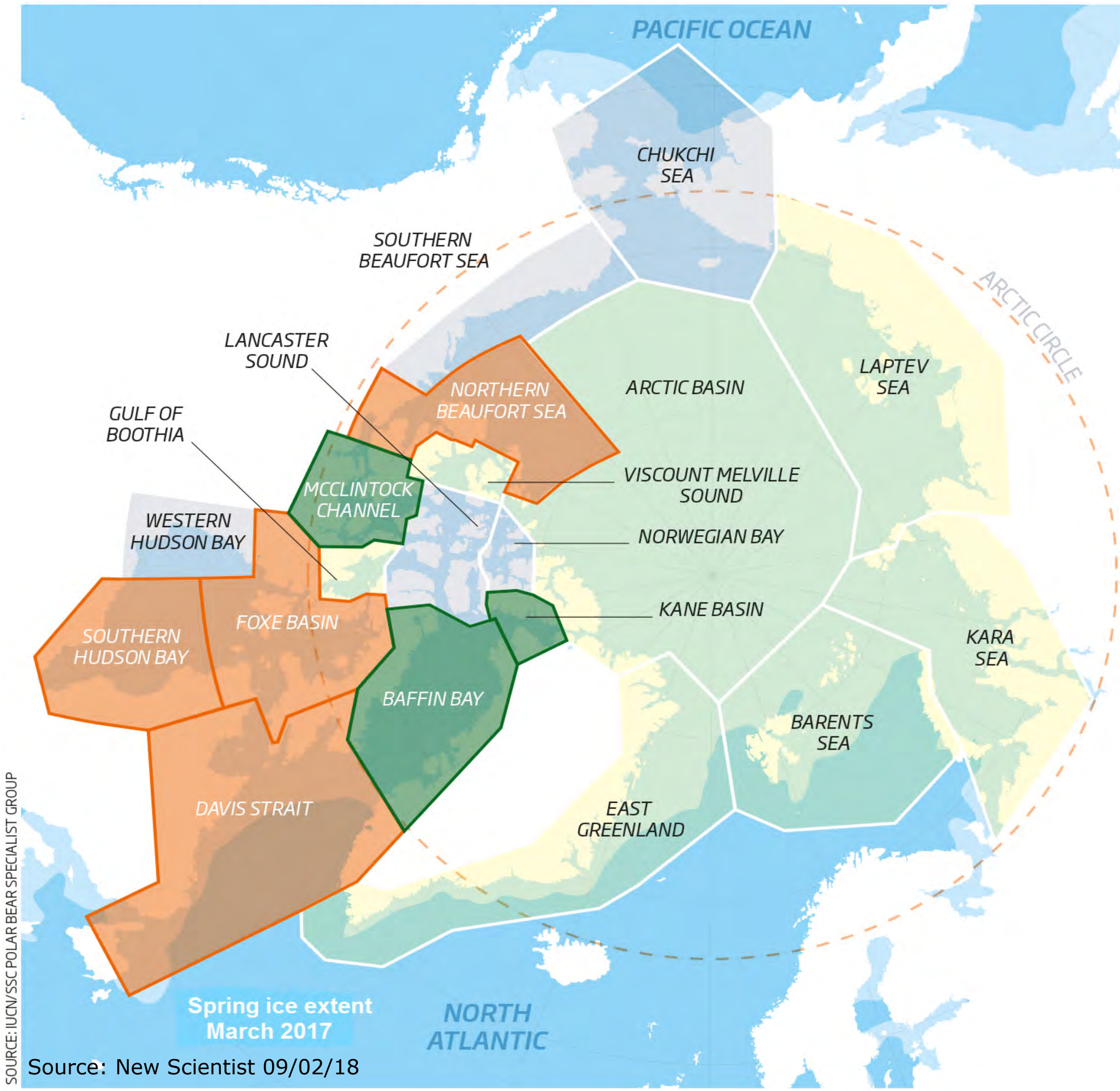
Polar bears are excellent swimmers and are in little danger of drowning. A much bigger threat to them is that they will be unable to kill seals on the edges of ice or in air holes if the ice continues to diminish and that they will have to swim further to hunt. However, there is already evidence that the bears are changing their lifestyles – with some travelling further north to stay with the ice edge, while others stay south as always, waiting out the summer until the ice returns. Hudson Bay's southern shores were nearly completely ice free for four summer months in 2017, over a month longer than 30 years ago, forcing the bears to survive on a diet of mainly berries and vegetation, that they struggle to digest efficiently – resulting in a decline in their weight and physical condition. As the ice-free season extends, the bears will struggle to last the months before their natural hunting conditions return.

The reduction in sea ice means that their future is bleak, and the IUCN concluded that if sea ice continues to shrink, polar bears are likely to become extinct. But not in the way one might expect. More and more it seems they are mating with Grizzlies to produce a hybrid species – sometimes called 'Grolars' or 'Pizzlies' These are more brown than white, so maybe polar bears which evolved from brown bears will now evolve back to where they came from.

Bearing up

There is a lot of uncertainty over how many polar bears there are across the 19 Arctic subpopulations, but in some places numbers are stable or increasing. Records are particularly limited in Russian territories

Increasing population Stable Decreasing Unknown



Source: New Scientist 09/02/18

CHAPTER SEVEN:
OF ICE AND WATER

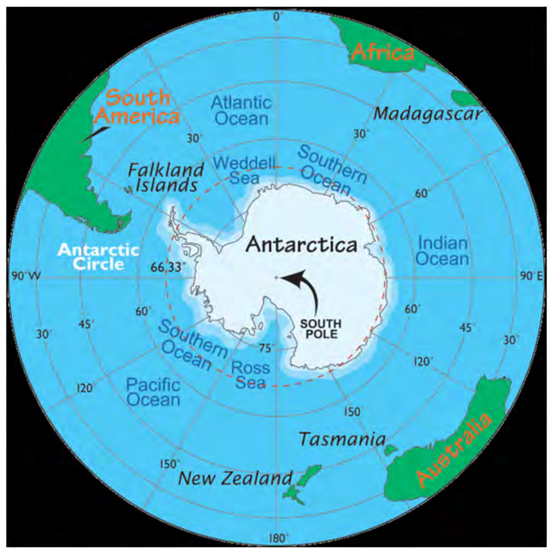
INTRODUCTION

As the planet warms, we would expect sea levels to rise, for two reasons. First, because water expands as it warms (except between 0 and 4 degrees Celsius, which is why ice forms at the surface of water not at the bottom). And second because of the melting of land ice (not sea ice, or more accurately only very slightly, as ice is fresh water which is lighter than sea water and hence occupies a slightly larger volume; apart from this, floating ice doesn't affect water level when it melts as you can check by putting some ice in a glass of water and marking the water level before and after it melts.)

In this chapter we will start by looking at land ice on the planet and then what is known about sea levels. Nearly all land ice is in Antarctica or on Greenland, but a small but very important amount is in glaciers in the Himalayas and elsewhere.

One other point before we start. Antarctica and the Arctic are in one crucial way mirror images of each other. Antarctica is a land surrounded by sea while the Arctic is sea surrounded (or nearly surrounded) by land.

ANTARCTICA



aol.co.uk/aol/image

Antarctica is a vast, mountainous land mass buried under an ice sheet up to 3 miles (4.8 km) thick, and surrounded by frozen seas. It has no countries and no permanent population. With winter temperatures falling to –122°F (–80°C), its sole inhabitants are visiting research scientists.

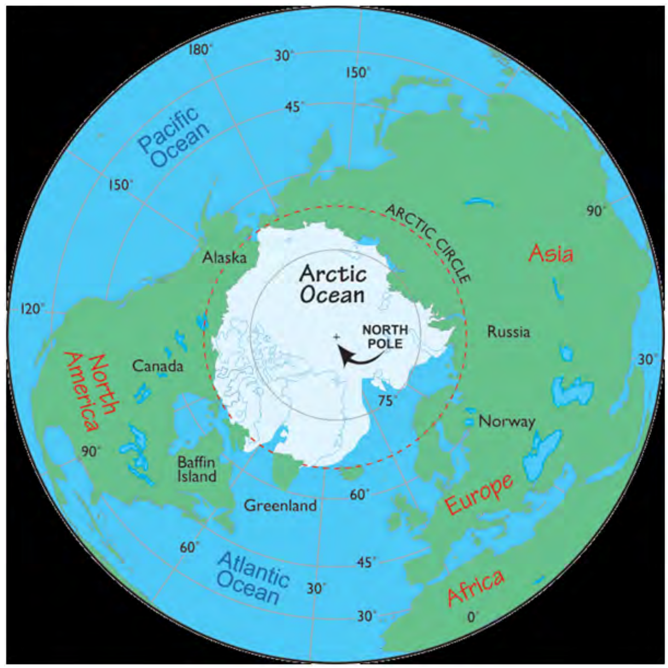
Technically a desert and as big as the USA and Mexico combined, Antarctica is estimated to contain 90% of the world's fresh water, ten times as much as the Greenland ice sheet which has 9%, leaving only 1% for all the other fresh water on the planet.

If both great ice sheets melted sea levels would rise by about 90 metres, which would submerge many of the great cities of the world, including London. Here is what a map of the British Isles would look like, with the blue bits now part of the sea.

But don't panic. Even in the worst case scenario it would take several centuries for this to happen. But we could get a sudden rise of 10 centimetres or so if part of the ice sheet came away and slid into the sea.

WHO OWNS THE ANTARCTIC?

The answer is everyone and no one. Antarctica is subject to an international treaty which prohibits individual countries from owning or exploiting its land.Today, Antarctica is designated as "a continent for science," and should be used for peaceful purposes only.



Worldatlas.com

WHO OWNS THE ARCTIC?

The nations bordering the Arctic Ocean own everything within 200 nautical miles of their coast. This leaves the area within the dotted red line on the map owned by no one.

ARE THE GREAT ICE SHEETS MELTING?

This is an enormously important question. The polar regions are crucial drivers of the world's climate. If the great ice sheets melt, sea levels will rise, obviously. But that is not all. Dark meltwater pools absorb warmth from the sun which white ice would reflect back into space, accelerating global warming. The melted ice is fresh water. When this flows into the sea, ocean currents and the living conditions for marine organisms are affected.

So, are they melting? And if so, how fast?

Until recently, this was virtually impossible to answer with any degree of precision.

But for the last 20 years satellites have been monitoring the Greenland and Antarctic ice sheets, using different technologies from radar to gravity measurements. A study published in 2012 (http://www.nature.com/nclimate/index.html), supported by NASA and European Space Agency ESA, combined all the data from different satellite missions.

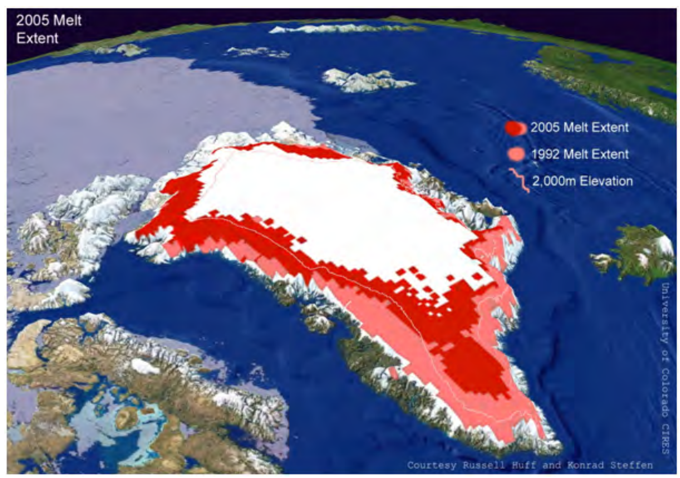
The conclusion? According to the study, melting ice from both poles has been responsible for a fifth of the global rise in sea levels since 1992, 11 millimetres in all. The rest was caused by the thermal expansion of the warming ocean, the melting of mountain glaciers, small Arctic ice caps and groundwater mining. The share of the polar ice melt, however, is rising.

http://www.nature.com/nclimate/journal/v6/n9/full/nclimate3120.html

Professor Andrew Shepherd from the University of Leeds, one of the authors of the report said,"*We are now able to say with confidence that Antarctica has lost ice for the whole of the past 20 years. In addition to the relative proportions of ice that have been lost in the northern and southern hemispheres, we can also see there's been a definite acceleration of ice loss in the last 20 years. So together Antarctica and Greenland are now contributing three times as much ice to sea levels as they were 20 years ago."*

GREENLAND VERSUS ANTARCTIC ICE MELT

The pattern of change differs considerably between the Arctic and the Antarctic. Two thirds of the ice loss is happening in Greenland. "T*he rate of ice loss from Greenland has increased almost five-fold since the mid-1990s*", says Erik Ivins, who coordinated the project for NASA.



Although the Greenland ice sheet is only about one tenth the size of Antarctica, today it is contributing twice as much *ice* to sea levels, according to Shepherd: *"It's certainly the larger player, probably just because it is at a more equatorial latitude, further from the North pole than Antarctica from the South pole."*

The ice on Greenland is also melting on the surface, because of increasing air temperatures.

DIFFERENT CONDITIONS IN THE ANTARCTIC

AOL image

The South Pole taken from the buildings there.

In the Antarctic, the situation is a more complex one. Scientists distinguish between the West and East, which are being affected differently by climate change. West Antarctica is losing ice at an accelerating rate. Many of the region's glaciers are by the sea, which is warming. It is only to be expected that the ice is melting faster here, says Shepherd.

© International Polar Foundation

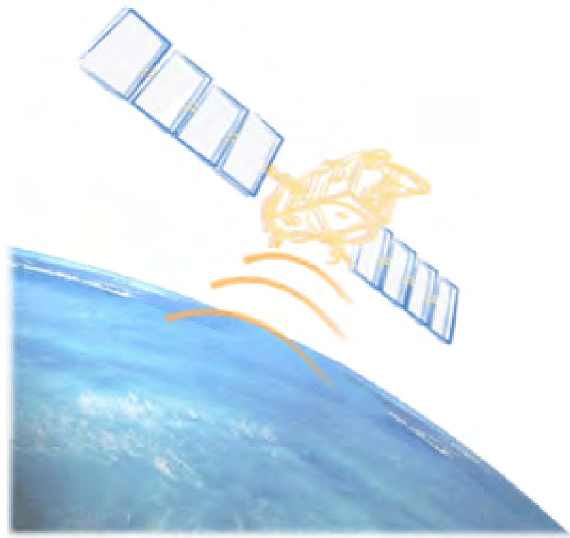
Scientists examine the condition of the ice at Antarctic stations like Belgium's Princess Elisabeth Antarctica.

In the huge area of East Antartica, the ice is mostly above sea level, Shepherd explains. The air temperature is also much lower, and the experts do not expect the ice to melt on account of rising temperatures. In this part of Antarctica, the ice sheet is actually growing as a consequence of increased snowfall. This has led some critics to question the global warming theory. However for Shepherd and his colleagues, the changes are all consistent with patterns of climate warming, which leads to more evaporation from the oceans and in turn more precipitation, which falls as snow on the ice sheets.

"*20 years is a very short time-scale to draw conclusions about climate change. We are just beginning an observational record for ice,*" said co-author of the study, Ian Joughlin, a glaciologist at the University of Washington. "*This creates a new long-term data set that will increase as new measurements are made.*"

But the scientists are convinced the relatively new technology is the best way to keep track of climate change in inaccessible polar regions. Earth observation expert Shepherd is sure global warming is the only possible explanation for the accelerating polar ice melt. He sees especially the rapid melt in West Antarctica as a signal and a result of direct changes in the local balance between the ice sheet, the ocean and the atmosphere.
If the west Antarctic ice sheet should become unstable, it could trigger abrupt changes globally.

Joughlin sees the recent ice activity in the region as a reason to pay attention, but not to panic.



The question of how the satellite data will influence predictions of sea level rise is not easy to answer, says Andrew Shepherd: Any model is only as reliable as its data. He hopes the more accurate satellite measurements will help improve the models. He does, however, have one reservation. The main uncertainty in climate projections is not to do with the physics or processes, the scientist says. It is the uncertainty as to what emissions scenarios nations will adopt in the future.

But one thing is certain: for all the ice sheets to melt would take centuries.

For how satellite altimetry works, see the box on the next page.

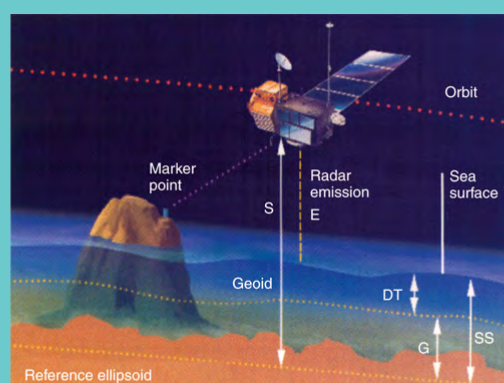
SATELLITE ALTIMETRY

The summary below was written by Professor Chris Rapley CBE, Department of Earth Sciences, University College London. He is an authority on climate change generally and on satellite altimetry in particular, and has been an adviser to the BEACONS Guides to Climate Change.

The radar altimeter emits microwave pulses which rebound from the Earth's surface. The time difference between the emitted pulse and its reflection gives a measure of the height of the satellite above this part of the surface. Modern equipment is so sensitive that, depending on the nature of the surface, this height can be measured to a precision of about 1 cm. As the satellite's orbit is a smoothly varying ellipse, and is known with great accuracy, the variations of the Earth's surface are recorded. Computer analysis of the data, including corrections for atmospheric and surface effects, produce an averaged reading referenced the Earth's centre of gravity. In the case of sea levels, this resolves the problem of distinguishing between sea rising and land sinking, which is problematical for tide gauges, and provides an estimate of global mean sea level to a fraction of a mm.

This technology can distinguish sea ice from ice-free water and hence gives an accurate measure of seasonally changing sea ice extent in both the Arctic and the Antarctic.

To estimate changes in the thickness of the great ice sheets, a gravimeter is used as well. This is a device which measures minute changes (of the order of g10^{-12}!) in the earth's gravitational field. As ice is less dense than the rock on which the ice sheet rests, variations in the thickness of the ice can be deduced from changes in gravity.



See also p48 and pp 85, 86 & 87

SATELLITE GRAVIMETRY

By Newton's Second Law, Force equals Mass times Acceleration, or F=ma. The one implication of this is that, if the force of gravity is the same, all objects will fall at the same rate, provided air resistance is negligible. Hence Galileo's famous, and probably apocryphal, demonstration from the Leaning Tower of Pisa that if two unequal lead weights, one much heavier than the other, are dropped together they hit the ground at the same time.

AOL

http:search.aol.co.uk/aol/imagq=leaning+tower+of+pisa+pics&v_t=keyword_rollover

Another inference is that changes in the gravitational force can be measured by measuring changes in the acceleration due to gravity. At the surface of the earth this is about 9.8 metres per second per second (ms^{-2}).

Modern atomic clocks can measure intervals of time of only 10^{-12} seconds (that is 0.000000000001 seconds) and it is therefore possible to measure differences in the time a body falls to the same degree of accuracy, and hence similarly minute changes in the force of gravity. An instrument that does this is called a gravimeter.

Wikipedia

https://en.wikipedia.org/wiki/Gravimeter

Gravimeters, using quantum effects, have been developed, most notably at the University of Birmingham and elsewhere, and are now commercially available.

The Quantum Technology Hub gravity sensing team at the University of Birmingham

http://quantumsensors.org/news/quantumgravimeters-leaving-laboratory/

Gravimeters have now been made with a stable inertial platform that compensates so successfully for the effects of motion and vibration that they can be used in satellites.

AOL images

http://search.aol.co.uk/aol/image?v_t=keyword_rollover&page=10&q=satellite+pics&brand=aol&oreq=e7e82331d3ad414bbbf61ef87c81ce0c

One application of gravimeters in satellites is to measure the thickness of the Greenland and Antarctic ice sheets, which was previously possible only by drilling through to the rock beneath. Ice is less dense than the rock it rests on and the force of gravity is reduced by an amount proportional to the thickness of the ice.

There are many other applications of this new technology. One of several websites that lists uses is

https://www.ngdc.noaa.gov/mgg/bathymetry/predicted/explore.HTML

NASA, Greenland Ice Sheet from Space

SATELLITES AND SEA LEVELS

Established in 1958, the **National Aeronautics and Space Administration (NASA)** is an independent agency of the United States government responsible for the civilian space program. Most US space exploration has been led by NASA, including the Apollo moon-landing missions, the Skylab space station, and the Space Shuttle. Currently, NASA is also heavily involved in climate research by satellite.

https://www.nasa.gov

Launched in 2002, the Gravity Recovery and Climate Experiment (GRACE) mission uses a pair of satellites equipped with altimeters and gravimeters and is run jointly by NASA and the German Deutschen Zentrum für Luft-und Raumfahrt (DLR). Results are made public.

GLOBAL SEA LEVELS

RECENT SEA LEVEL RISE

The chart opposite, from the NASA website, shows changes in global mean sea level as measured by satellite altimetry.

It also shows something that may surprise you.

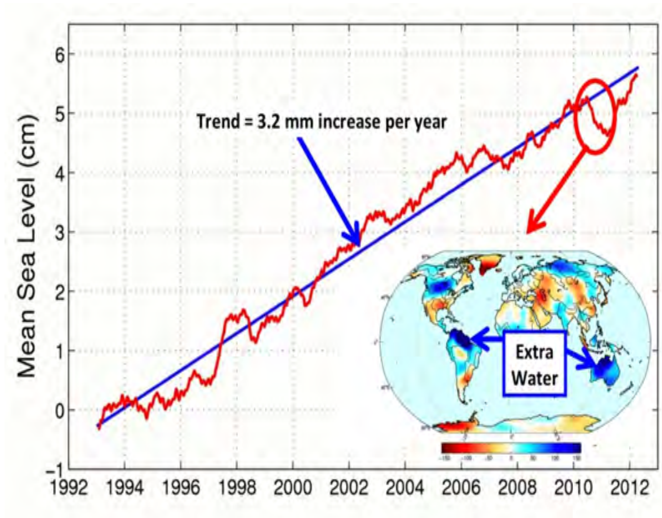


Image credit: NASA/JPL-Caltech/CNES

HEAVY RAIN CAN CAUSE SEA LEVELS TO FALL!

If altimetry shows a fall in sea levels, as happened in 2010/2011, gravimetry shows where the water has gone.

The inset shows changes in Earth's water mass from the beginning of 2010 to mid 2011. Blue colours indicate an increase in water mass over the continents.

Most of the sea level drop in 2010-11 [red circle] was a result of exceptional rainfalls brought on by the 2010/11 La Niña . By mid-2012, global mean sea level had recovered by more than the 5 millimeters it dropped in 2010/11.

CAUSES OF SEA LEVEL RISE

The total amount of water on the planet doesn't alter, but the volume it occupies, and its location and whether liquid, solid or gaseous, does. Above 4^0C water expands when it warms up, the oceans expand and sea level rises. The melting of sea ice has a negligible effect as floating ice displaces the same (or very nearly the same) volume of water that it will occupy when it melts. But if land ice, especially the great ice sheets on Greenland and Antarctica, melt then sea levels do rise. (By at least 70 metres if it all melted, but this would take many centuries to happen. And as we have seen, water on land, in rivers and lakes does make a difference, albeit only a relatively small one.

Nearly all current sea level rise is caused by the oceans warming and land ice melting. How much each contributes is not known with any certainty at the moment, however about 50:50 is the answer Professor Rapley gave when asked. For the latest authoritative estimate see http://nsidc.org/cryosphere/sotc/sea_level.html


Greenland

THE ARCTIC AS IT IS KNOWN TODAY IS ALMOST CERTAINLY GONE

This is the heading of an article in *The Economist* for April 29, 2017. Selected extracts below are in italics.

In the past 30 years, the minimum coverage of summer ice has fallen by half; its volume has fallen by three-quarters. On current trends, the Arctic Ocean will be largely ice-free in summer by 2040.

Economist.com

DOES THIS MATTER?

The right response is fear. The Arctic is not merely a bellwether of matters climatic, but an actor in them.

More carbon dioxide equals more warming - a simple equation. Except it is not simple. A number of feedback loops complicate matters. Some dampen warming down; some speed it up. Two in the Arctic may speed it up quite a lot.

One is that seawater is much darker than ice. It absorbs heat rather than reflecting it back into space. That melts more ice, which leaves more seawater exposed, which melts more ice. And so on. This helps explain why the Arctic is warming faster than the rest of the planet. The second feedback loop concerns not the land. In the Arctic much of this is permafrost. If it melts its organic contents can escape as a result of fire or decay, in the form of carbon dioxide or methane. This will speed up global warming directly - and the soot from the fires, when it settles on the ice, will darken it and thus speed its melting still more.

POSSIBLE CLIMATE EFECTS

The world's winds are driven in large part by the temperature difference between the poles and the tropics. If the Arctic heats faster than the tropics, this difference will decrease causing erratic behaviour of the northern jet stream leading to blizzards and heatwaves in unexpected places at unexpected times. Ocean currents, too, may slow, with effects on everything from the Indian monsoon to the pattern of El Niño in the Pacific Ocean.

The scariest possibility of all is that something happens to the ice cap covering Greenland.

SUMMARY

The hard truth, however, is that the Arctic as it is known today is almost certainly gone. Efforts to mitigate global warming by cutting emissions remain essential. But the state of the Arctic shows that humans cannot simply undo climate change. They will have to adapt to it.

WHY ARCTIC WARMING MAKES US COLDER

The answer is the Gulf Stream.

Also known as the North Atlantic Drift, or, by scientists, the pithy name of the Atlantic meridional overturning circulation (AMOC), this is a flow of warm water from the Gulf of Mexico to Western Europe. It is caused by cold water from the Arctic flowing into the Gulf and displacing warm water, which then flows across the Atlantic. *See diagram below and next page.*

Image source: S.Rahmstorf (Nature 1997), taken from http://sciencenordic.com/vital-pattern-ocean-circulation-about-shut-down

Why is the Gulf Stream important?

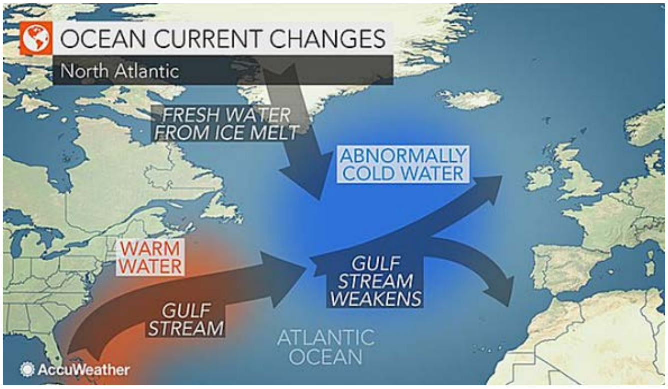
Because UK and Western European winters would be an estimated average of 5 degrees colder without the Gulf Stream, its weakening could lead to considerable changes in the climate and precipitation patterns throughout the northern hemisphere.

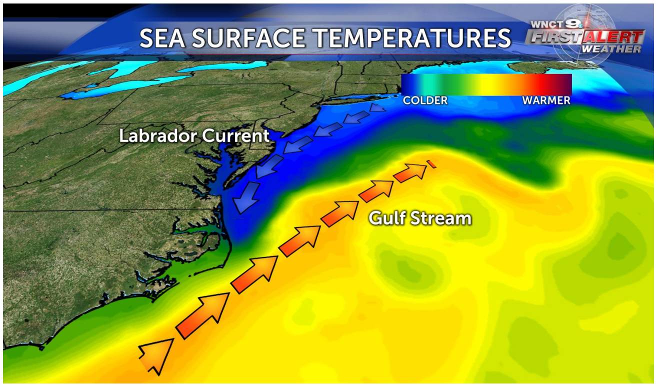
Is it getting weaker and if so why?

Two recent studies have shown that the Gulf Stream is weaker now than recently, and is still declining. However, it has only been directly monitored since 2004, so both studies had to rely on indirect measurement methods to make their assessments.

The research points to an increased amount of freshwater being introduced into the North Atlantic, as a result of, among other causes, the melting of land ice and increased rainfall. This reduces the salt concentration in the ocean, so the cooling water does not sink as much and therefore does not drive the flow of the Gulf Stream to the same extent.

However they disagree about the underlying cause of the weakening. The first study says it is "most likely" that the entire slowdown is a direct result of human activity, while the second study suggests that while human activity has sustained and/or enhanced this process, the underlying trend began in the mid-19th century as greater quantities of ice which had built up during the Little Ice Age began to melt.





What should be done?

This new research makes the case for continued investment and monitoring of the AMOC, as a longer record of direct measurements is crucial to be able to draw accurate conclusions.

Is the recent cold spell a sign of things to come, or a one-off?

Maybe; or maybe not

The two papers referenced:

Caesar, L. et al. (2018) Observed fingerprint of a weakening Atlantic Ocean overturning circulation, Nature. Thornalley, D. J. R. (2018) Anomalously weak Labrador Sea convection and Atlantic overturning during the past 150 years, Nature.

CHAPTER EIGHT:
WHAT ABOUT THE WEATHER?

IS GLOBAL WARMING CAUSING MORE EXTREME WEATHER?

This is two questions really

1. Are we getting more extreme weather – droughts, floods, unusually cold or unusually hot spells, forest fires, hurricanes or typhoons?

2. If so, is this because of global warming?

In late December 2015 there was severe flooding in the north of England, with great damage to property and misery and a ruined Christmas for thousands. Ten months later many people were still unable to return to their homes.

But there was no agreement on whether this flooding was sufficiently out of the ordinary as to need an explanation. And, even if it was, whether global warming was to blame or something else.

The aim of the rest of this chapter is to outline what is known and what is reasonable to suppose, and if the answer to each question is yes, what is being done and what needs to be done globally.


THE TIMES
Is he worth it?
Floods caused by global warming, says minister
Brown takes top job as economic adviser
Daily Mail
COMMENT
A FLOOD OF LIES
Global warming zealots are fibbing to promote their own propaganda: this rainfall WASN'T unprecedented
by Christopher Booker
DAILY EXPRESS
Global warming is not to blame for northern floods
James Delingpole
'Met Office hijacked by green ideologues'

ARE EXTREME WEATHER EVENTS GETTING MORE EXTREME OR MORE FREQUENT?

WERE THE DECEMBER 2015 FLOODS IN THE NORTH OF ENGLAND CAUSED BY GLOBAL WARMING?

Was this severe flooding unprecedented? The answer to this question is crucial. For if they were worse than anything that has occurred in the past, or if such floods are happening more frequently, it becomes much more credible to say they are a consequence of global warming.

The photo of an edition of the *Daily Mail* on the previous page is of an article by the journalist Christopher Booker in which he claims that some, whom he describes as 'climate zealots', have falsely claimed that the serious flooding in northern England in December 2015 was unprecedented.

Is he right to say that these floods were not unprecedented? Or was the minister right?

Before revealing the expert answer, is it the case that each has given the answer they prefer? The *Daily Mail* and the *Daily Express* have general policies of denying much of what is asserted by climate scientists. So if floods as bad as these have occurred in the past, they can convincingly claim that climate change is not the cause.

But why would the minister quoted in *The Times* prefer the opposite answer? Quite simply, because if nothing as bad as this had occurred previously, one can hardly blame the government for not having taken precautions.

Which answer do you think is likely to be correct?

THE EXPERT INQUIRY

A team of experts from the Universities of Aberystwyth, Cambridge and Glasgow was set up after the floods to try to find out whether these floods were indeed unprecedented.

Their conclusion, after studying historical records, evidence from deposits going back hundreds of years and the science of river flows, was not the one most people were expecting.

On the next page are some extracts from their report

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Dr Tom Spencer from the University of Cambridge said: *"In the House of Commons the Environment Secretary called the flooding in north-west England 'unprecedented' and 'consistent with climate change trends'. But is this actually true?*

"Conventional methods of analysing river flow gauge records cannot answer these questions because upland catchments usually have no or very short records of water levels of around 30 or 40 years. In fact, recent careful scientific analysis of palaeoflood deposits (flood deposits dating back hundreds of years) in the UK uplands shows that 21st-century floods are not unprecedented in terms of both their frequency (they were more frequent before 1960) and magnitude (the biggest events occurred during the 17th–19th centuries)."

Professor Mark Macklin, an expert in river flooding and climate change impacts at Aberystwyth University, said: *"UK documentary records and old flood deposits dating back hundreds of years indicate that these floods are not unprecedented. In some areas, recent floods have either equalled or exceeded the largest recorded events and these incidences can be ascribed to climate variability in Atlantic margin weather systems."*

Dr Larissa Naylor from the University of Glasgow said: "These floods and the 2013/14 storms have shown us that our landscape is dynamic rather than static – where rivers reshape floodplains and erosion remodels our coastline – with large economic and social costs. We need to urgently consider how we plan our cities and towns, and rebuild in the wake of large flood and storm events, to live safely in our changing landscape."

The full report is at *https://www.cam.ac.uk/research/news/unprecedented-storms-and-floods-are-more-common-than-we-think*

So the conclusion of the experts is that the minister was wrong and the Daily Mail columnist right – **THE FLOODS WERE NOT UNPRECEDENTED.**

COMMENTS

1. The experts were studying these floods only. So their report says nothing at all about whether or not other extreme weather events were unprecedented.
2. You might think that this report settles the question as to whether these floods were unprecedented. But, if you go to the report at the web address on P57 and look at the comments that follow, you will see that some people were so certain that the floods were unprecedented that they accuse the scientists of deliberately falsifying their results - without advancing any evidence whatsoever for this accusation. Such a response is not unique. Some people hold views on climate change so strongly that they become a sort of Holy Writ which must not be challenged whatever the evidence. A main aim of these Guides is to counter such irrational attitudes.
3. Floods are not weather. They are an effect of weather, in this case rain. So could it be that the rainfall that month was unprecedented although the floods were not? Maybe drainage has improved so that exceptional rainfall does not cause exceptional flooding. But from the comments of Dr Naylor, the other way round seems more likely.
4. The extracts quoted here show the difficulty of deciding the causes of any particular weather event. Dr Spencer doubts whether these floods had anything to do with global warming; Professor Macklin says they can be attributed to normal climate variability; while Dr Naylor seems to think that bad town planning is to blame.

WHAT IS CLEAR IS THAT IT IS VERY DIFFICULT TO DETERMINE THE ROOT CAUSE OR CAUSES OF ANY EXTREME WEATHER EVENT. YET IT IS CRUCIAL TO BE ABLE TO DO SO IF WE ARE TO PLAN BETTER IN THE FUTURE. IN AN ATTEMPT T0 MEET THIS CHALLENGE A WHOLE NEW SCIENCE HAS ARISEN.

THE SCIENCE OF ATTRIBUTION

Storms, droughts, heavy rain, heatwaves and other extreme weather events are of huge interest to society because of their often disastrous consequences for people and property.

Prof Myles Allen, head of the climate research programme at Oxford University's Environmental Change Institute, first proposed the idea of extreme weather attribution in a 2003 paper. His basic

premise was that scientists could use climate models to work out what proportion, if any, of a given extreme weather event could be pinned on human activity.

In the US, the National Academy of Sciences, Engineering and Medicine have set up a special Committee on Extreme Weather Events and Climate Change Attribution.

The National Academy of Sciences, Washington DC

In October 2016 it published its first report under the title of 'The Attribution of Extreme Weather Events in the context of Climate Change'. Here is the introduction.

'As climate has warmed over recent years, a new pattern of more frequent and more intense weather events has unfolded across the globe. Climate models simulate such changes in extreme events, and some of the reasons for the changes are well understood. Warming increases the likelihood of extremely hot days and nights, favors increased

atmospheric moisture that may result in more frequent heavy rainfall and snowfall, and leads to evaporation that can exacerbate droughts.

Even with evidence of these broad trends, scientists cautioned in the past that individual weather events couldn't be attributed to climate change. Now, with advances in understanding the climate science behind extreme events and the science of extreme event attribution, such blanket statements may not be accurate. The relatively young science of extreme event attribution seeks to tease out the influence of human-cause climate change from other factors, such as natural sources of variability like El Niño, as contributors to individual extreme events.

Event attribution can answer questions about how much climate change influenced the probability or intensity of a specific type of weather event. As event attribution capabilities improve, they could help inform choices about assessing and managing risk, and in guiding climate adaptation strategies.'

Comment. You will notice that they seem to assume that the world is experiencing more frequent and more intense weather events as a consequence of global warming.

About 43 schools in Derbyshire had to close at lunchtime due to the heavy snow. BBC January 29, 2015

So how do they go about working out whether human activity is partly responsible for extreme events, such as floods, storms, droughts and heatwaves? (See next page.)

They do it mainly by computer modelling to re-run the last 200 years or so to see whether extreme weather around the world would look any different if we could replay the period, without human-caused greenhouse gases. In addition, factors of the type used in the inquiry into the north of England floods are considered. And historical weather records are examined but they are often of dubious reliability.

Dr Heidi Cullen, chief scientist at the US Climate Central leading the World Weather Attribution program, goes further. She said,

'*The days of saying no single weather event can be linked to climate change are over. For many extreme weather events, the link is now strong*.'

Note that Dr Cullen says 'linked', not 'caused'. *As another scientist put it: 'If a weather or climate event is truly extreme in the present climate…it requires unusual meteorological conditions, which means that climate change is at most only a contributing factor.'*

THE SCIENCE OF ATTRIBUTION IS IMPORTANT AND INTERESTING, BUT IT DOESN'T TELL US WHAT WE SHOULD DO.

A woman and a dog are rescued from flood waters in Chennai, India, 04 December 2015. © BABU/epa/Corbis

COPING WITH CATASTROPHE

Hurricane Matthew

At the beginning of October 2016 a powerful hurricane struck Haiti, the Dominican Republic and Cuba before battering the Bahamas and Florida.

The photos below are all from *The International Business Times*

Residents work clearing a house destroyed by Hurricane Matthew in Les Cayes, Haiti

Andres Martinez Casares/Reuters

A man clears debris after Hurricane Matthew in Les Cayes, Haiti   Andres Martinez Casares/Reuters

Three weeks later, Wikipedia reported: Over 1,600 estimated deaths have been attributed to the storm, including 546 to 1,600 in Haiti, 1 in Colombia, 4 in the Dominican Republic, 1 in Saint Vincent and the Grenadines, and 49 in the United States.

The devastation in the Dominican Republic and Cuba was similar to that in Haiti. But notice the remarkable difference in the death tolls. Probably over 1,000 in Haiti, 4 in the Dominican Republic and none at all in Cuba.

A woman cries amid the rubble of her home, destroyed by Hurricane Matthew in Baracoa, Cuba Ramon Espinosa/ AP

Why did Matthew kill no one in Cuba?

Here is what *The Economist* for October 15th said

'The town of Jérémie,(Haiti) home to about 30,000 people, has been largely destroyed; perhaps 1,000 are dead.

Like Jérémie, Baracoa in Cuba was devastated by Matthew's winds of about 225kph (140mph). But unlike Jérémie, no deaths have been reported in Baracoa. Cuba's communist government has a well-rehearsed drill. State-controlled media warn residents for days of approaching hurricanes; schools are closed and turned into shelters. State-owned buses are dispatched to evacuate residents. Local party snoops, known as the Committee for the Defence of the Revolution, with representatives on every block, make sure the elderly or infirm are not left behind.

In contrast with Cuba's authoritarian state, Haiti's government barely functions. The infrastructure is poor, with few solid buildings. Haiti's media are chaotic. High crime rates mean residents refuse to leave their homes unattended.'

The lesson of Hurricane Matthew is clear. Whether or not climate change is going to be responsible, disasters like this hurricane are likely to occur in the future. They cannot be prevented, but they can be forecast in time for effective life- saving measures to be taken.

But there is a problem. The Cuban government could force people to leave their homes; a democracy can only persuade. Which no doubt accounts for the 49 deaths in the USA.

CHAPTER NINE:

THE SCIENCE – WHAT, AND HOW, DO WE KNOW?

1. THE DEBATE

'Scientific beliefs are tentative, not dogmatic; they are based on evidence, not on authority or intuition.'

Bertrand Russell

One would expect that any debate among scientists would be calm, rational and courteous, with opinions advanced that are based on evidence.

The climate change debate has been very different. Climate scientists have become entangled in an acrimonious political debate that has divided the scientific community into two sides; the majority who are labelled believers or, by their opponents, alarmists and a minority labelled sceptics or, by their opponents, deniers. And all too often even climate scientists have dismissed the views of those in the other camp with little or no consideration of the evidence put forward.

Furthermore, there has been pressure for climate scientists to conform to the so-called consensus. This pressure comes not only from politicians, but from federal funding agencies, universities and professional societies, and those scientists who are green activists.

The majority view has become known as the scientific consensus, and includes an overwhelming majority of scientists as well as all the major scientific bodies in the world. Yet history tells us that some of the greatest advances in science were opposed by equally overwhelming majorities at the time – Copernicus, Galileo, Darwin and Einstein for example. And no one, Tyndall included (see Section 3 below, expected Tyndall to find that there are greenhouse gases which partially reflect infrared radiation. The consensus is not always right.

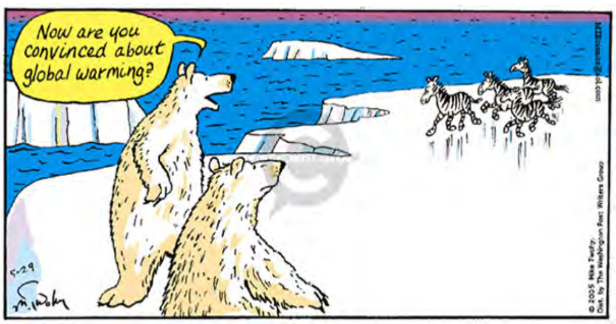
BEACONS is not going to enter this debate. We are an independent educational charity not a scientific body. In our Guides to Climate Change our aim is to present the facts and the evidence and leave it to the reader to decide what view to take.

Previous chapters have described what we know about climate change. This chapter will expand on the evidence on which our knowledge is based, referring back to previous sections as appropriate.

2. GLOBAL WARMING: IS IT HAPPENING?

General

There is ample evidence that the northern hemisphere is getting warmer, from the temperature record to observable changes in Arctic summer sea ice. The southern hemisphere is also warming but the evidence is less apparent – the extent of Antarctic sea ice is much the same as it was a century ago.



http://cartoonistgroup.com/subject/The-Global+Warming-Comics-and-Cartoons.php

Measuring global temperatures

What follows are edited extracts from a paper in December 2016 by Dr Zeke Hausfather, a climate scientist and energy systems analyst at Berkeley Earth and adds to what is given in

Berkeley Earth is a small group of physicists, statisticians and climate scientists formed in 2010 by Professor Richard Muller, professor emeritus (i.e. retired) at the University of California, to study climate change. They 'pursue objectivity without concern for policies of government, industry or philanthropic ventures'.
http://berkeleyearth.org/
See also page 25.

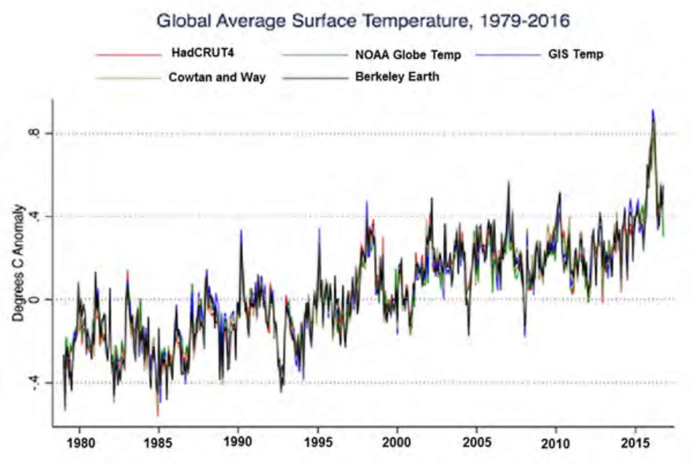
Dr Hausfather, also an environmental economist, was previously the chief scientist at an energy management and efficiency company and has published papers in the fields of environmental economics, energy modelling, and climate science.

'The easiest and most accurate way to measure the Earth's surface temperature is with thermometers.'

'Various groups have put together long term temperature records using data from weather stations, ships, and floating ocean buoys. They largely agree, despite using differing approaches where data is lacking.'


El Nino, Pacific Ocean

Temperature records from five groups are shown below.



'Here we can clearly see both the long-term warming trend over the past 30 years, as well as the effect of El Niño events (the small jumps up) and their sister La Niña events (the small jumps down). (See box for descriptions of El Niño and La Niña)

'The large El Niño of 2015/2016 stands out, but it's clear that the overall record is of rapid warming, even without the El Niño event. In the past few months temperatures have fallen a bit from the El Niño peak, but are still quite high by historic standards.'

EL NIÑO AND LA NIÑA

El Niño and La Niña are terms which describe the biggest fluctuation in the Earth's climate system and can have consequences across the globe. The fluctuation sees changes in the sea-surface temperature of the tropical Pacific Ocean which occur every few years.

The name 'El Niño' nowadays is widely used to describe the warming of sea surface temperature that occurs every few years, typically concentrated in the central-east equatorial Pacific. 'La Niña' is the term adopted for the opposite side of the fluctuation, which sees episodes of cooler-than-normal sea surface temperature in the equatorial Pacific.

http://search.aol.co.uk/aol/image?q=el+nino&v_t=keyword_rollover

CAN SATELLITES BE USED TO MEASURE GLOBAL TEMPERATURES?

'Yes, but, satellites can only measure the temperature of the lower troposphere, a layer of the atmosphere about 2 miles (4 km) high.

'Furthermore, new satellites are launched every few years as old satellites' orbits decay. As the orbits change, the temperature readings from satellites will change a bit, and need to be adjusted. Similarly, when new satellites are launched their instruments need to be calibrated against the readings from old satellites. All of these introduce uncertainties that are much larger than those in the surface record.

'In addition satellites have particular difficulty accurately measuring tropospheric temperatures over land. Over time, the satellites' orbits drift, resulting in measuring different locations at different times of day. Correcting for these differing observation times can be difficult, as different parts of the world will have very different day/night temperature cycles.

'If we remove the El Niño spike, 2014, 2015 and 2016 have been the three warmest years on record not because of a large El Niño, but because of a long-term warming trend.'

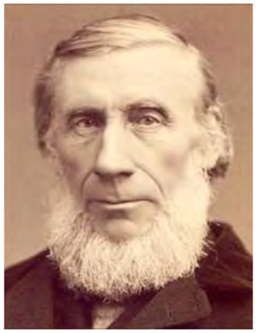
The complete text of Dr Hausfather's article can be found at http://berkeleyearth.org/

3. THE GREENHOUSE EFFECT: HOW DO WE KNOW WHICH ARE GREENHOUSE GASES AND HOW MUCH WARMING EACH IS RESPONSIBLE FOR?

As described on pages 18 and 19, in the 1820s the great French mathematician and physicist, Joseph Fourier, calculated that the Earth is much warmer than one would expect from the amount of energy reaching it from the Sun, and he suspected that this was because the Earth's atmosphere was acting like a blanket.

He explained it by analogy with a box with a glass lid. In time this became known as the Greenhouse Effect, despite the fact that this analogy is not at all accurate.

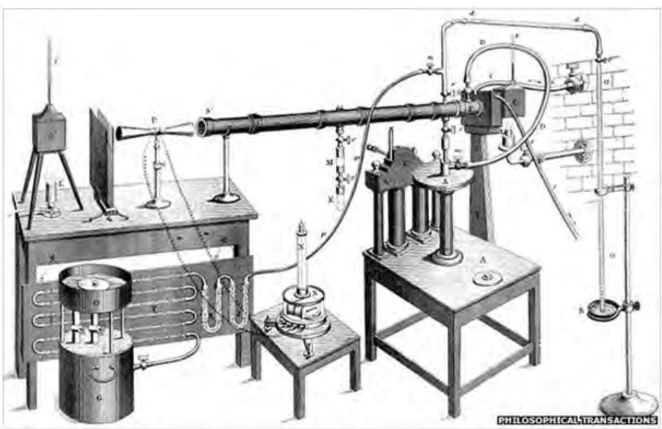
In the 1850s, an Irish physicist who deserves to be better known, John Tyndall, set out to discover in his laboratory whether the atmosphere does indeed trap heat radiated from the Earth and, if so, how.



John Tyndall. BBC

He designed equipment that would send infrared radiation through a tube of gas and into a detector, a thermopile, which would translate temperature differences into electrical current.

Here is a diagram of the apparatus he constructed.



After many setbacks, he was ready to try various gases to see if any of them absorbed infrared radiation. Oxygen, nitrogen, and hydrogen were all tried and found to have no impact. This was what he had expected. Tyndall, like all other scientists at the time, believed that all gases were perfectly transparent to heat.

But when a trace of ozone went in with the oxygen,Tyndall saw a significant absorption.

That was dwarfed, though, by what happened when he tried ethylene (C_2H_4), a gas used in various industrial processes. To his astonishment, about 81% of the radiation was blocked, totally contradicting the unanimous consensus. At first Tyndall couldn’t believe the result and looked for a fault in his apparatus. Finding none, he repeated the experiment hundreds of times before daring to publish the result.

What he had demonstrated was that gases in the atmosphere absorb heat to very different degrees; he had discovered the molecular basis of the greenhouse effect.

This was revolutionary, or would have been had anyone taken notice. Maybe he should have chosen a more snappy title than '*On the Absorption and Radiation of Heat by Gases and Vapours, and on the Physical Connexion of Radiation, Absorption, and Conduction*'.

To learn more about Tyndall, go to http://www.bbc.co.uk/news/science-environment-15093234 for the article on which the above is based.

In the second half of the 19th century, Tyndall's work was developed by the Frenchman, Claude Pouillet and the Swede, Svante Arrhenius. It was discovered that only gases with three atoms or more to the molecule have this effect. These became known as greenhouse gases. Dry air is about 79% nitrogen (N_2) and 20% oxygen (O_2) each of which has only two atoms to the molecule and is transparent to greenhouse gases. But carbon dioxide (CO_2), methane (CH_4), water vapour (H_2O) and many other trace gases are greenhouse gases.

A complete theoretical basis to these facts involves quantum theory and was not made until the 1940s – for further information, see forecast.uchicago.edu/chapter4.pdf

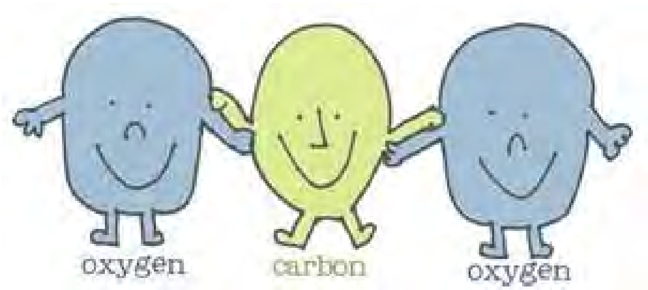
Claude Pouillet

Svante Arrhenius

The warming effect of a greenhouse gas (GHG) depends on the nature of the gas and how much of it there is in the atmosphere. In estimating by how much emissions need to be reduced, it is also crucial to know how long emitted gases stay in the atmosphere. For CO_2 this is usually said to be over a century. The next section explores how we know this.

HOW DO WE KNOW HOW LONG A GAS REMAINS IN THE ATMOSPHERE?

Molecules are not like this



http://search.aol.co.uk/aol/image?q=co2+molecule+cartoon&v_t=keyword_rollover

and obviously we cannot track individual ones.

So what can we do? There are essentially two methods:

Method 1 If we know how much of a particular gas has been put in the atmosphere and when, and we know how much is there now, it must be possible to work out how long, on average, a single molecule remains there.

At first glance this doesn't seem particularly difficult. For CO_2 we need to estimate

1. How much was in the atmosphere at some time in the past
2. How much has been emitted since then
3. How much is in the atmosphere now

These can be calculated as follows

1. Ice core samples reveal that there were 280 parts per million (ppm) in, for example, pre-industrial times. Multiplication by the volume of the atmosphere gives the required total.
2. An estimate of how much fossil fuels have been burnt since then and knowing how much CO_2 is emitted as a consequence enables the total quantity put in the atmosphere to be calculated.
3. The current figure is just over 400 ppm, so we can calculate the total amount now there.

Simple isn't it? Well, no. Both the total volume of the atmosphere and how CO_2 is distributed are necessarily very rough estimates. And how much coal, natural gas and oil have been burnt since the start of the industrial revolution can obviously be no more than an educated guess.

Then, what about other sources of CO_2? Volcanoes for example. Furthermore the sinks which absorb CO_2 – mainly the oceans, plants and rocks – will also vary over time.

Method 2 By computer modelling. Climate data world wide for a particular year or period - including data on CO_2 and equations from the laws of physics relating things like temperature and pressure - are fed into a very powerful computer together with assumptions about CO_2 emissions and residence (how long it stays in the atmosphere. The model is then run forward to a more recent period and the computer forecast compared with actual data. Other factors, such as volcanic activity, ocean acidity and so on are also taken into account. The variables for CO_2 residence are adjusted until a best fit is obtained.

This is a much simplified description. The best account we have found of computer modelling and its application to climate science is at

http://www.explainthatstuff.com/how-computer-models-work.html

Perhaps it's not surprising that estimates vary. But it is perhaps surprising by how much, from 3 years in 1972 to 100 plus years in the 2007 Intergovernmental Panel on Climate Change (IPCC) (see also p25) Fourth Assessment.

SO WHAT IS THE ANSWER – HOW LONG DO GHGS STAY IN THE ATMOSPHERE?

Here is what the 2014 IPCC Fifth assessment (http://www.ipcc.ch/index.htm) said

PRE AND POST INDUSTRIAL GHG AMOUNTS IN THE ATMOSPHERE

Over the millennium before the Industrial Era, the atmospheric concentrations of greenhouse gases remained relatively constant. Since then, however, the concentrations of many greenhouse gases have increased directly or indirectly because of human activities.

Table 1 below provides examples of several greenhouse gases and summarises their 1750 and 1998 concentrations, their change during the 1990s, and their atmospheric lifetimes.

Table 1: *Examples of greenhouse gases that are affected by human activities.*

	CO_2 (Carbon Dioxide)	CH_4 (Methane)	N_2O (Nitrous Oxide)	CFC-11 (Chlorofluoro-carbon-11)	HFC-23 (Hydrofluoro-carbon-23)	CF_4 (Perfluoro-methane)
Pre-industrial concentration	about 280 ppm	about 700 ppb	about 270 ppb	zero	zero	40 ppt
Concentration in 1998	365 ppm	1745 ppb	314 ppb	268 ppt	14 ppt	80 ppt
Rate of concentration change [b]	1.5 ppm/yr [a]	7.0 ppb/yr[a]	0.8 ppb/yr	-1.4 ppt/yr	0.55 ppt/yr	1 ppt/yr
Atmospheric lifetime	5 to 200 yr [c]	12 yr [d]	114 yr [d]	45 yr	260 yr	>50,000 yr

[a] *Rate has fluctuated between 0.9 ppm/yr and 2.8 ppm/yr for CO_2 and between 0 and 13 ppb/yr for CH_4 over the period 1990 to 1999.*
[b] *Rate is calculated over the period 1990 to 1999.*
[c] *No single lifetime can be defined for CO_2 because of the different rates of uptake by different removal processes.*
[d] *This lifetime has been defined as an adjustment time that takes into account the indirect effect of the gas on its own residence time.*

If you find the explanation above for the enormous range of atmospheric life time for CO_2 unsatisfactory, here is what is said by Skeptical Science https://skepticalscience.com/co2-residence-time.htm

"Individual carbon dioxide molecules have a short life time of around 5 years in the atmosphere."

"However, when CO_2 molecules leave the atmosphere, they're simply swapping places with carbon dioxide in the ocean. The final amount of extra CO_2 that remains in the atmosphere stays there on a time scale of centuries."

OTHER GREENHOUSE GASES

VERY SMALL AMOUNTS CAN MAKE A BIG DIFFERENCE

As explained on pages 14 to 15, radiation from the sun is largely ultraviolet, the sort that causes sunburn. On striking the Earth, some is reflected back into the atmosphere as infrared, which is the type that causes most heating. A greenhouse gas (GHG) is a gas in the atmosphere which reflects back to the ground some of this, thereby contributing to global warming.

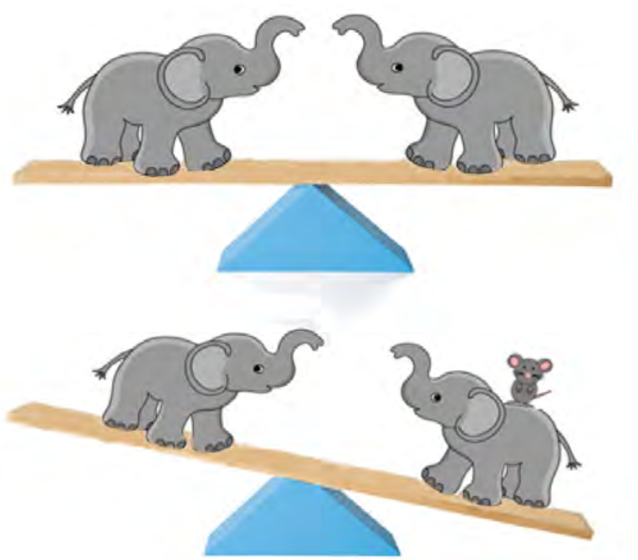
The best known GHG is, of course, carbon dioxide, CO_2 , produced when fossil fuels - coal, oil or natural gas - are burnt. But it is far from the only one.

The atmosphere is mainly made up of two gases, neither of which is a GHG, Nitrogen (78% in dry air at sea level) and Oxygen (21% ditto) – see also p13.

In Table 1 on the previous page, ppm means parts per million, ppb parts per billion and ppt parts per trillion. For comparison purposes it would have been clearer if the concentrations of the different greenhouse gases (GHGs) had all been given in the same units. The figures in Table 1 for 1998 translated to ppm are CO_2 ,365 (it is of course over 400 now); CH_4, 1.745; N_2O, 0.314; CFC-11, 0.000268; HFC-23, 0.000014; and CF_4 , 0.00008.

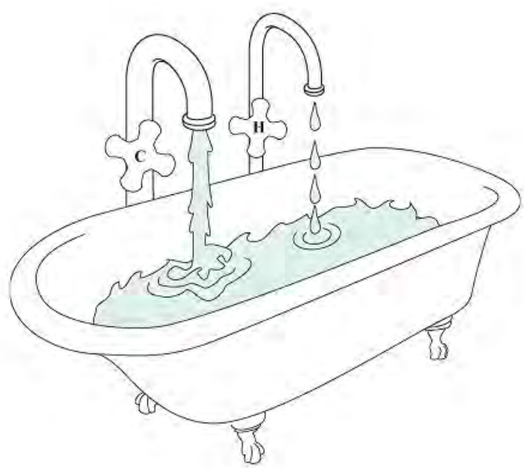
To change ppm to percentages, simply divide by 10,000, to get, respectively 0.0365%, 0.0001745%, 0.0000314%, 0.0000000268%, 0.0000000014% and 0.000000008%. This shows just how trace all the GHGs are. Even CO_2 is less than a half of a tenth of one percent. It seems scarcely credible that such minute amounts of these gases can cause the whole planet to warm up. But they undoubtedly do.

In fact even a very small amount will make a difference over time. Before industrialisation, the amount of GHGs added to the atmosphere by natural causes was balanced by the amount absorbed by plants, the oceans, rocks etc. When fossil fuel burning adds relatively small amounts of GHGs, this balance is upset. If two elephants of equal weights were sitting at opposite ends of a seesaw, the seesaw would be horizontal. Should a mouse creep on at one end, the balance would be upset and that end would go down (assuming negligible friction, of course).



A better analogy would be of a bath with the cold tap running and the plug out so that exactly the same amount is entering from the tap as is leaving from the plughole. The water level would then stay the same.

Now suppose the other tap starts to drip so that very slightly more water is entering as is leaving. Eventually the bath will overflow.



The warming effect of different GHGs obviously depends on these three things:

1. how powerful a GHG it is (this is called its radiative forcing*) compared with equal volumes of other GHGs
2. how much is being put into the atmosphere
3. how long it stays there

(Note The best website we have found for an explanation of the underlying chemistry of radiative forcing is that of the American Chemical Society

https://www.acs.org/content/acs/en/climatescience/atmosphericwarming/climatsensitivity.html)

On page 16, it was said that only gases with three or more atoms to the molecule exhibit the greenhouse effect, that is absorb or disperse infra red radiation. (The explanation of this phenomenon involves quantum effects and is well beyond the scope of these guides.

However, this is slightly misleading. Some gases are not themselves GHGs but in the atmosphere interact with other gases to produce GHGs. For example, carbon monoxide (CO is not a GHG, but in the atmosphere some of it adds an extra molecule to become carbon dioxide which is.

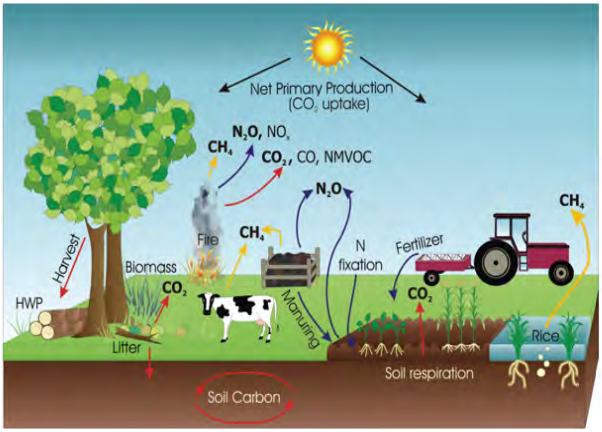
Now to a bit more about some gases other than CO_2

METHANE (CH_4)

Methane, CH_4, is the main component of natural gas. When it is burnt, CO_2 and H_2O result. Per unit of heat, when burnt it produces only a little more than half of what coal does. However, methane that leaks into the atmosphere is 70 times more powerful a GHG than CO_2 but remains there for only about 25 years compared with 100 or so for CO_2.

The main sources of atmospheric methane are leaks from the oil and gas industries, especially from fracking, and from agriculture.

Here is a diagram to illustrate the contribution of agriculture to GHGs.

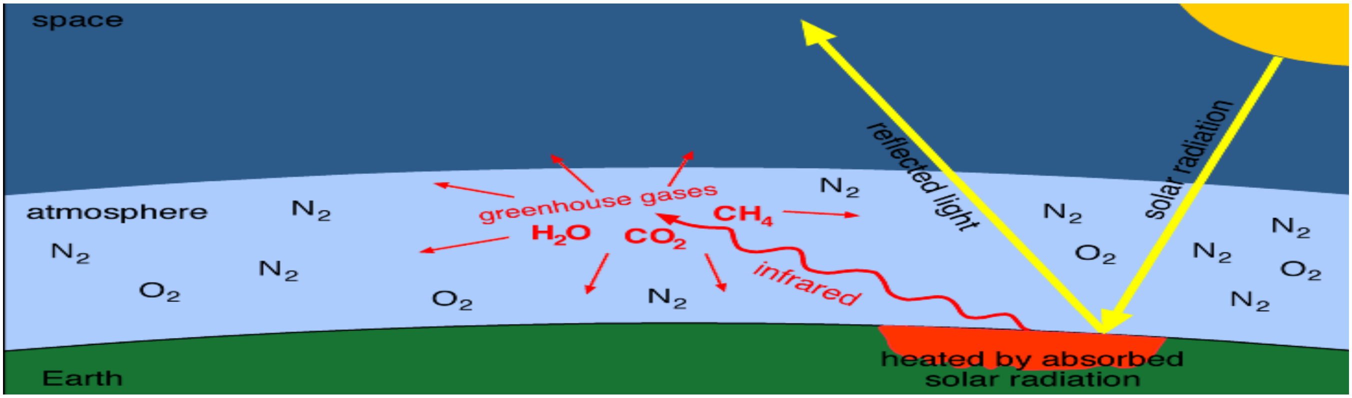


http:/www.techienews.co.uk/9743131/agricultural-emissions-should-be-slashed-to-prevent-planet-warming/

It is estimated that as much as a fifth of the greenhouse effect is caused by agriculture. The other GHG produced by agriculture is

NITROUS OXIDE (N_2O)

Methane is produced by the cattle as part of their digestion process and is emitted mostly through belching, while nitrous oxide is produced by the addition of natural or synthetic fertilisers to the soils. Nitrous oxide used to be known as laughing gas because of the effect it had on those who inhaled small quantities.



In larger doses it is an anaesthetic, and indeed was the first anaesthetic discovered – by pure chance. It is nearly 300 times more powerful a GHG than CO2 but there is only a thousandth as much of it currently in the atmosphere (see Table 1).

Considerable research is being conducted in several universities into ways of reducing GHGs from agriculture. Co-author of a report in 2016, Prof Pete Smith of the University of Aberdeen said

'*Reducing emissions in agriculture without compromising food security is something we know how to do. A lot can already be done with existing best management practices in agriculture. The tough part is how to reduce emissions by a further two to five times and support large numbers of farmers to change their practices in the next 10 to 20 years.'*

HUMAN-MADE GASES

Since the middle of the 20th century, small amounts of man-made gases, mostly chlorine- and fluorine-containing solvents and refrigerants, have been added to the mix. Because these gases are not condensable at atmospheric temperatures and pressures, the atmosphere can pack in much more of these gases. Even more serious was the discovery that these gases deplete the ozone layer, a vital shield against harmful ultraviolet radiation from the Sun.

This led to the **Montreal Protocol on Substances that Deplete the Ozone Layer** in 1987.

As a result the ozone hole in Antarctica is slowly recovering. It was the first universally ratified treaty in United Nations history. Kofi Annan, UN Secretary General at the time called this treaty 'perhaps the single most successful international agreement to date'.

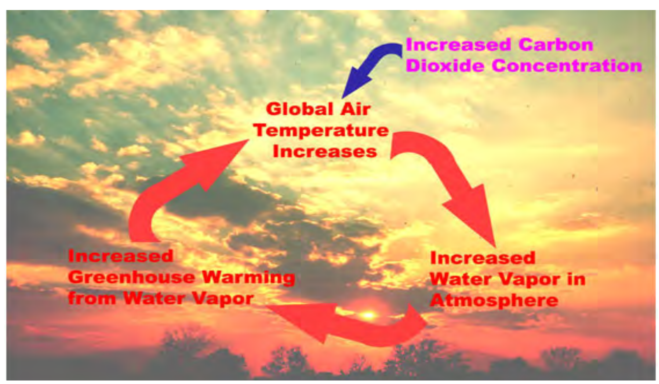
WATER VAPOUR AND CLOUDS (H_2O, of course)

The role of water vapour is complex and not fully understood. Here are some extracts about water vapour (vapor in American spelling) from the American Chemical Society's website https://www.acs.org/content/acs/en.html

Water vapor is the largest contributor to the Earth's greenhouse effect. On average, it probably accounts for about 60% of the warming effect. However, water vapor does not control the Earth's temperature, but is instead controlled by the temperature. This is because the temperature of the surrounding atmosphere limits the maximum amount of water vapor the atmosphere can contain. If a volume of air contains its maximum amount of water vapor (about 5%) and the temperature is decreased, some of the water vapor will condense to form liquid water. This is why clouds form as warm air containing water vapor rises and cools at higher altitudes where the water condenses to the tiny droplets that make up clouds.

The addition of GHGs causes the temperature to increase and this leads to an increase in water vapor that further increases the temperature. This is an example of a positive feedback effect.

There is also a possibility that adding more water vapor to the atmosphere could produce a negative feedback effect. This could happen if more water vapor leads to more cloud formation. Clouds reflect sunlight and reduce the amount of energy that reaches the Earth's surface to warm it. If the amount of solar warming decreases, then the temperature of the Earth would decrease. In that case, the effect of adding more water vapor would be cooling rather than warming. But cloud cover does mean more condensed water in the atmosphere, making for a stronger greenhouse effect than non-condensed water vapor alone – it is warmer on a cloudy winter day than on a clear one. Thus the possible positive and negative feedbacks associated with increased water vapor and cloud formation can cancel one another out and complicate matters. The actual balance between them is an active area of current climate research.



HOW ARE A COUNTRY'S GHG EMISSIONS MEASURED?

You obviously cannot put a canopy over an entire country and measure directly the quantity of different gases being emitted.

Instead, the only option is to use the country's government statistics to make an estimate.

The main sources of emissions will be

- Burning of different sorts of fossil fuels – coal, natural gas, oil (including as petrol or diesel in vehicles, planes and ships)
- Cement manufacture and other chemical processes
- Agriculture, especially cows and fertiliser use

From the total emissions must be subtracted an estimate of the total of the different GHGs absorbed, including by

- Trees
- Lakes and seas
- Rocks and soil

The Intergovernmental Panel on Climate Change (IPCC) [see Guide Two, p 22] has an agreed formula for estimating a country's GHG emissions. Unsurprisingly, it is immensely complicated. It is in five volumes, each of around 60 pages. You can find them at http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html

The results are given in gigatons (billions) or millions of tons of carbon dioxide equivalent.

The biggest emitters of GHGs in 2011 were given in *The Guardian* as

1. China: 7,216 MT or 16.4%
2. US: 6,931 MT or 15.7%
3. Brazil: 2,856 MT or 6.5%
4. Indonesia: 2,046 MT or 4.6%
5. Russia: 2,028 MT or 4.6%
6. India: 1,870 MT or 4.2%
7. Japan: 1,387 MT or 3.1%
8. Germany: 1,005 MT or 2.3%
9. Canada: 808 MT or 1.8%
10. Mexico: 696 MT or 1.6%

But per person the biggest were

1. Qatar: 36.9 tonnes
2. United States: 17.3 tonnes
3. Australia: 17.0 tonnes
4. Russia: 11.6 tonnes
5. Germany: 9.3 tonnes
6. UK: 7.8 tonnes
7. China: 5.4 tonnes
8. India: 1.4 tonnes
9. Ethiopia: 0.1 tonnes

All other countries < 0.1 tonnes

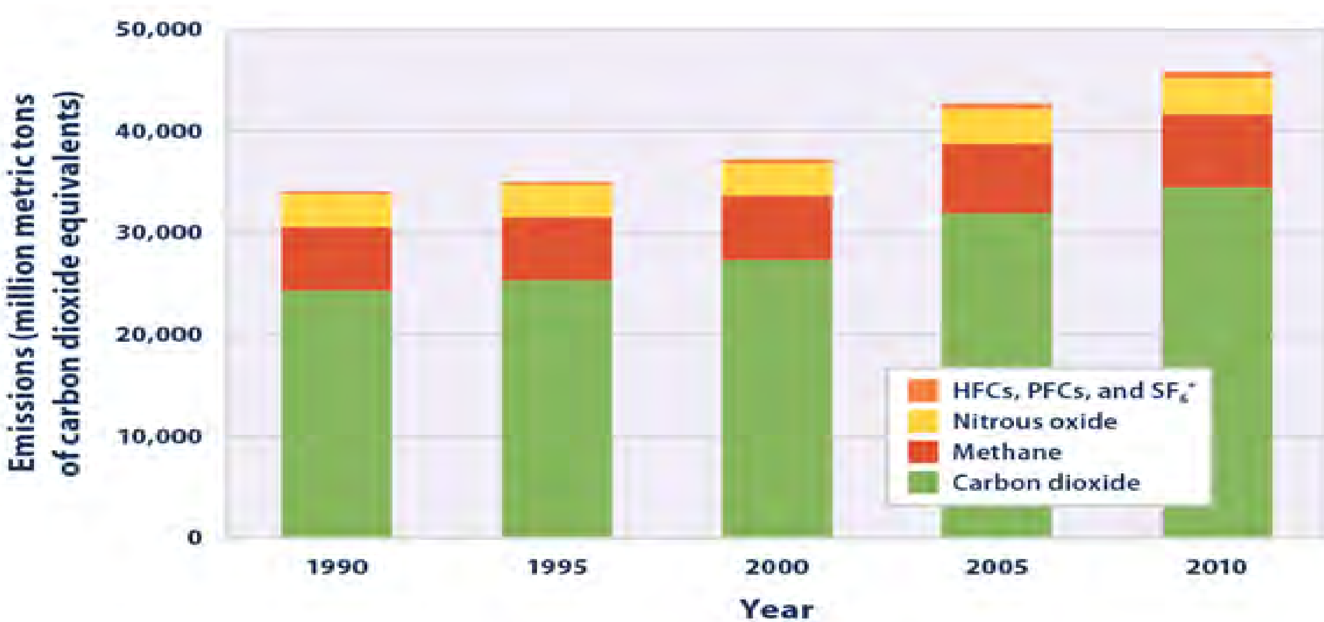
The chart below shows the results for the world up to 2010.

HOW GOOD ARE THESE ESTIMATES?

Gregg Marland at Oakridge National Laboratory in the US said:

'For countries like those in the EU or the US or Japan, my guess is that the error margin is something in the order of plus or minus 5%. For those discharging smaller quantities of CO_2, the error I think can be as high as 20 to 25% and in China they are maybe as large as 15 or 20%.'

https://www.thenakedscientists.com/articles/questions/how-do-you-measure-carbon-dioxide-emissions



http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol1.html

COMMENT

Does the uncertainty about the emission figures for a country matter?

Perhaps not. It is the trend that is important. The same is true of population figures. Please go to the website whose address is on page 75 to see how immensely complicated and difficult it is to estimate emission figures.

CARBON EMISSIONS FROM ENERGY PRODUCTION

In March 2017 the International Energy Agency (IEA) reported that carbon dioxide emissions from energy had not increased for three years in a row even though the global economy grew.

The biggest drop was seen in the USA, where carbon dioxide emissions fell by 3 per cent, while the economy grew 1.6 per cent, as a result of coal being displaced by shale gas and renewables.

Carbon emissions fell by 1 per cent in China, and were stable in Europe, offsetting increases in most of the rest of the world, the IEA said.

TWO KEY QUESTIONS – AND UNCERTAINTY IN THE ANSWERS

The unanimous outcome of the Paris conference of December 2015 was essentially based on agreement

1. That a global temperature increase since pre-industrial times of 2^0C will risk causing catastrophic climate change
2. That global warming is mainly caused by CO_2 emitted by burning fossil fuels and we know by how much these emissions must be reduced to keep global warming below 2^0C

As Chapter 8 makes clear, it is in fact far from straightforward to attribute particular weather events to global warming, and it is equally difficult to describe with any certainty what might happen to the weather if global warming reaches 2^0 C above pre-industrial levels. (It has of course already reached half that as measured at Mauna Loa- see Chapter Two)

And despite various organisations publishing charts showing how much fossil fuel can be burnt if we are to keep below 2^0, so-called carbon budgets, this also is not at all certain.

Professor Myles Allen

The current knowledge was summed up in an interview the BBC had in December 2016 with Professor Myles Allen, Head of the Climate Dynamics Group at Oxford University. Here is an edited version:

"But researchers do acknowledge that there are several outstanding questions on the amount of carbon that can be emitted in the future and the likely response of the climate system to those emissions.

"Aspects of the debate are far from settled - if you ask me how much carbon can we afford to dump in the atmosphere and keep temperatures well below two degrees, I would say there is an uncertainty in that number of a factor of three," BBC 08/12/16

Scientists attempt to forecast the effects on global temperatures of future GHG emissions by climate modelling on very powerful computers. The next section outlines this.

GLOBAL CLIMATE MODELLING

On a theoretical globe representing the Earth, a grid is superimposed, with each cell of the grid having sides of 100km to 200km. Climate data such as temperature, wind, humidity, atmospheric pressure, rainfall, and for land cells, vegetation, ice or snow, and for ocean cells, oceanic circulation, heat and moisture exchange with the atmosphere, for a particular date are then given for each cell. The evolution of each of these data is then described by mathematical equations. These equations are far too complicated to be solved mathematically and instead are approximated by computer. The model is tested by putting in data for some time in the past and seeing how well it predicted later actual data.

AOL images

Every stage of this process involves making assumptions, the accuracy of which cannot be known. There are thousands of such assumptions that have to be made. Modelling essentially serves two purposes: gaining understanding of how the whole climate system works; and forecasting future climate and its relationship with carbon dioxide and other GHG emissions.

A particular problem is estimating the future of processes which are non-linear, that is, there is no simple proportional relationship between cause and effect. There is a set of equations, based on established physics and known as the Navier-Stokes equations, which describe such relationships, but no one has yet succeeded in solving them. Indeed the Clay Mathematics Institute is offering a prize of $1 million for their solution. You can easily find the equations on the Internet if you fancy having a go!

CLIMATE/CARBON SENSITIVITY

This is defined as how much the average global temperature would rise if the amount of carbon dioxide doubled for its present 400ppm to 800 ppm. Around 20 climate models contributed to the latest report from the IPCC, the fifth assessment published in 2014. The conclusion? Sensitivity was probably somewhere in the range of 1.5 to 4.5^{0} C. A factor of three, as Professor Myles Allen said in December 2016.

SUMMARY OF CURRENT KNOWLEDGE - A note from the Editor

NOTE It is a sad fact that the world of climate science has become dominated by two rival camps, often labelled Believers and Deniers, with discussion between members of these groups characterised by acrimony and accusations of conspiracy, dishonesty and even of fraud.

I am pleased to say that this lamentable state of affairs appears to be lessening. But any climate scientist who dissents from majority opinion is in danger of attracting abusive comments from some. So it is with some hesitation that I advance what is necessarily a personal view, especially as I am not a climate scientist, or even a scientist; merely someone who did a maths degree a long time ago and has tried to follow the science and politics of climate change as a concerned amateur, and to outline the facts in these three Guides. So here very briefly is where I think we are:

1. **Greenhouse gases (GHGs) and global temperatures**

   We certainly know which gases are GHGs and how much of each is in the atmosphere at Mauna Loa, and that the increase in CO_2 and other GHGs is a consequence of human activity. We also know that global temperatures have increased since pre-industrial times, and that GHGs are a significant cause. But there is less agreement on how much of the rise in temperatures is attributable to GHGs, and to *which* GHGs. Few scientists, however, would deny that CO_2 is a major cause. There is far less agreement on the relationship between temperature rise and amounts of CO_2 in the atmosphere. If CO_2 levels went from their current 400ppm to 800ppm, how much would the average temperature rise? Probably somewhere between 1.5^0 and 4.5^0 C, said the latest report of the IPCC.

2. **Consequences for the climate of global warming**

   Global temperature undoubtedly affects the climate, but precisely how is impossible to say with any certainty. The Paris Agreement of December 2015 assumes that we need to keep the increase well below 2^0 C from pre-industrial times if we are to have a good chance of avoiding catastrophic change.

SATELLITE ALTIMETRY IN DETAIL

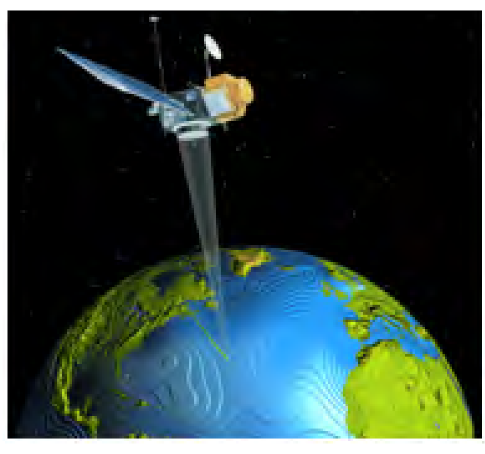
The following is an expansion in March 2018 by Deborah Harris of the summary by Professor Rapley on p50.

Since 1992, sea levels have been measured by a network of satellites circling the Earth. These use satellite altimeters, which measure the time it takes for an electromagnetic wave emitted by the altimeter antenna to travel to the surface of the Earth and back again to the receiver on the satellite. The magnitude and shape of the reflected electromagnetic wave can be interpreted to provide information about the surface the satellite has been looking at, and this information is used to categorise land types, such as tracking complex river systems or looking at ice sheets, as well as providing information on the sea surface and waves.

However, converting the time taken by the signal into the distance from the satellite to the ocean surface, and from there to knowing the height of the sea, is very complex.

Corrections need to be made for:

- The delay experienced by the electromagnetic wave as it passes through the atmosphere, caused by,among other things, the density of air and the presence of water vapour. This involves three separate corrections – one for the ionosphere (which is the upper part of the atmosphere), one for the wet troposphere and one for the dry troposphere. The troposphere is the lower part of the atmosphere, and is where nearly all of our weather takes place.
- The state of the sea (how rough or calm it is, the size, shape and distribution of the waves). Wave troughs tend to reflect the electromagnetic wave better than wave crests.
- The tides
- Variations in the atmospheric pressure and the response of the ocean to this.



Satellite Altimetry

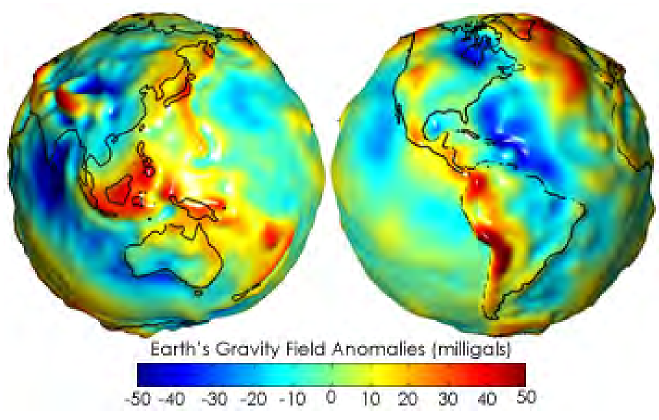
http://www.seos-project.eu/modules/oceancurrents/oceancurrents-c06-p03.html

Once all these corrections have been made, the travelling time of the electromagnetic wave can then be converted to a distance. However, just knowing the distance between the satellite and the surface isn't enough to know the height of the sea. To know this, reference to a mean sea level height is required.

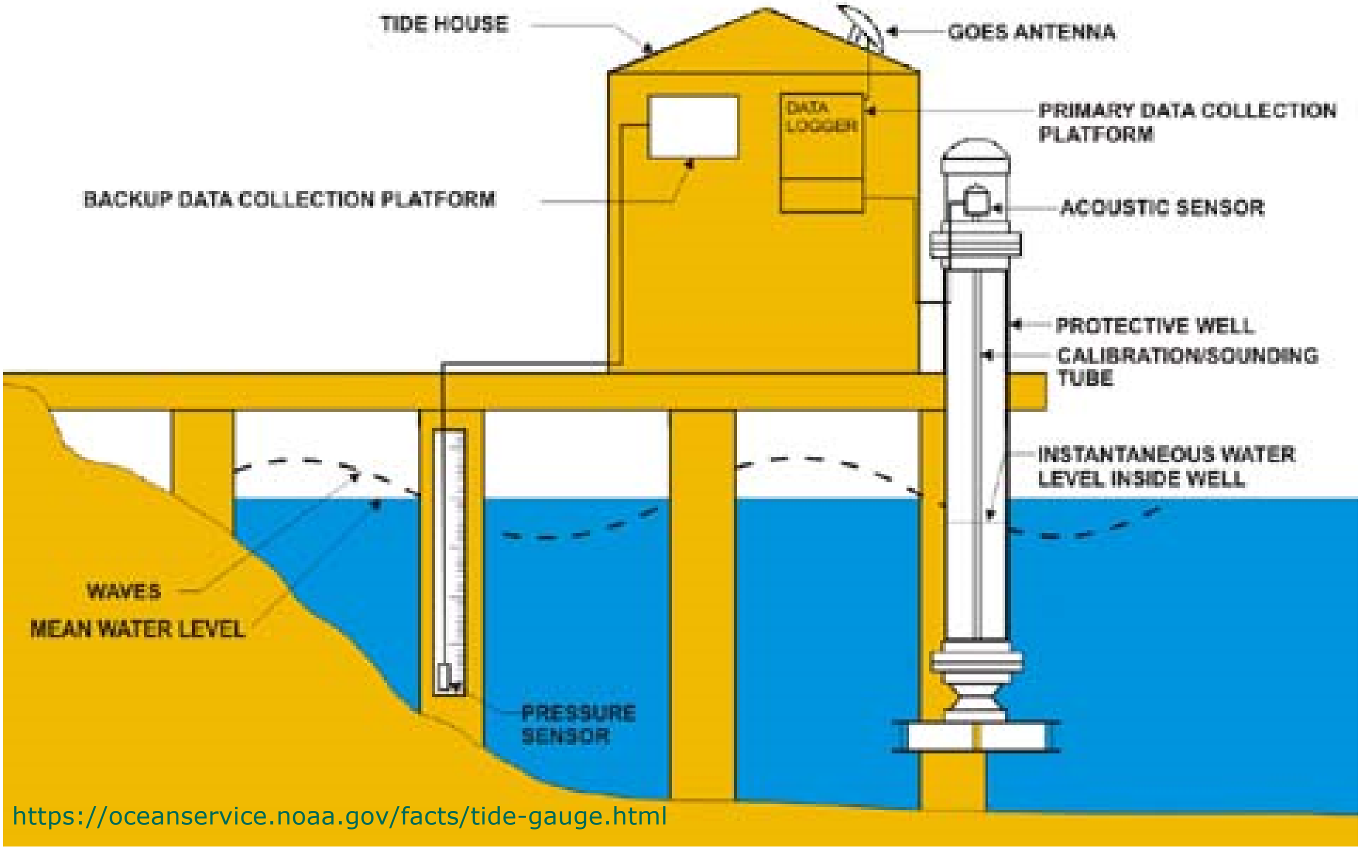
This is worked out through using a gravimeter, also on the satellite. A gravimeter maps the gravity field of the Earth by measuring the distribution of mass on the Earth. Gravity is affected by changes in density inside the Earth, topographical features such as mountain ranges on the surface, and the Earth's rotation.

Once this is mapped, this data can be used to calculate the geoid. This is the shape that the oceans would take across the Earth if there were no land masses at all. This means that it's the shape that the oceans would take if they were only affected by the Earth's gravity and rotation. As gravity varies across the Earth because of the changes in density, this would not be a uniform shape and there would be different depths of ocean at different points across the globe.

The difference between the geoid height and the height measured by the altimeter is the "sea surface height anomaly", and by collecting data from all over the globe using the satellite network, the global mean sea level can be worked out. Each point is recalculated every 10 days, when the satellites pass back over it.



Before satellites, tide gauges were used. A tide gauge is essentially a vertical drain pipe with a small hole on one side which evens out the waves. On the next page is a diagram of a modern one.



Their fundamental defect is that over time they cannot distinguish between sea level rising and land level falling.

Tide gauges have been used to measure the sea level long before satellites, and the altimeter network has been calibrated against them. This has allowed for the identification and correction of a number of drifts and bias in the data over the past twenty five years, improving the accuracy of altimetry and measurements of the changes in sea height.

The image aboves shows the NOAA San Francisco Tide Station, in operation for more than 150 years.

APPENDIX:

RECENT DEVELOPMENTS

WHO REALLY DISCOVERED GREENHOUSE GASES?

Until very recently, all climate scientists and historians of science would have agreed that it was the Irish scientist, John Tyndall (see pp 71/72). And indeed many climate research labs are named after him.

But now it seems that this may be wrong. A virtually unknown American female scientist may have discovered GHGs three years earlier.

The Editor writes:-

Until I read the recent book on sustainability, The World we'll leave behind by William Scott and Paul Vare (Routledge 1918 and strongly recommended), I had been under the impression that John Tyndall was the discoverer of the greenhouse effect. Not so. He was pipped to the post by a female scientist.

Three years before Tyndall's experiments a Mrs Eunice Foote conclusively demonstrated the greenhouse effect and wrote up her results in a brief but definitive two page paper, 'Circumstances affecting the heat of the sun's rays', which she submitted to the eighth annual meeting of the American Association for the Advancement of Science held in New York in 1856. The AAAS was unusual in allowing women to attend, but although her paper was favourably commented on, it subsequently disappeared from history. The only photo I can find of her is the one below, from Wikipedia.

Eunice Foote 1819 to 1888

My colleague Deborah Harris also did not know of her and says she does not feature in the excellent Headstrong: 52 Women Who Changed Science-And the World, by Rachel Swaby (I've just ordered a copy from Amazon, £11.34 including postage.)

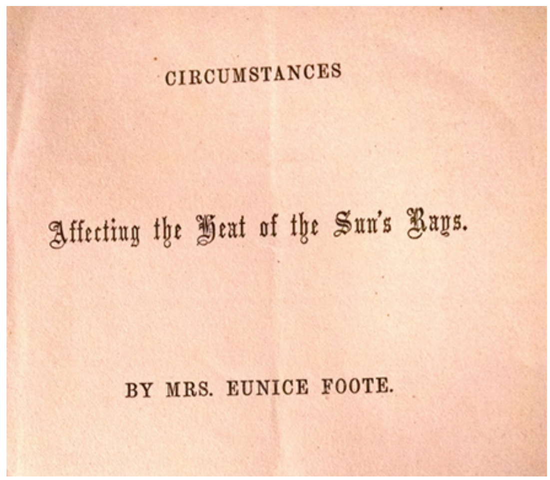
Here is an extract from the website of The Smithsonian, America's premier scientific society. (www.smithsonianmag.com)

Foote's paper demonstrated the interactions of the sun's rays on different gases through a series of experiments using an air pump, four thermometers, and two glass cylinders. First, Foote placed two thermometers in each cylinder and, using the air pump, removed the air from one cylinder and condensed it in the other. Allowing both cylinders to reach the same temperature, she then placed the cylinders with their thermometers in the sun to measure temperature variance once heated and under various states of moisture. She repeated this process with hydrogen, common air and CO_2, all heated after being exposed to the sun.

Of the gases tested, she concluded that carbonic acid trapped the most heat, having a final temperature of 125°F.

Foote was years ahead of her time. What she described and theorized was the gradual warming of the Earth's atmosphere—what today we call the greenhouse effect.

The Smithsonian have what may well be the only copy left of Mrs Foote's paper. This is a photograph of part of it.

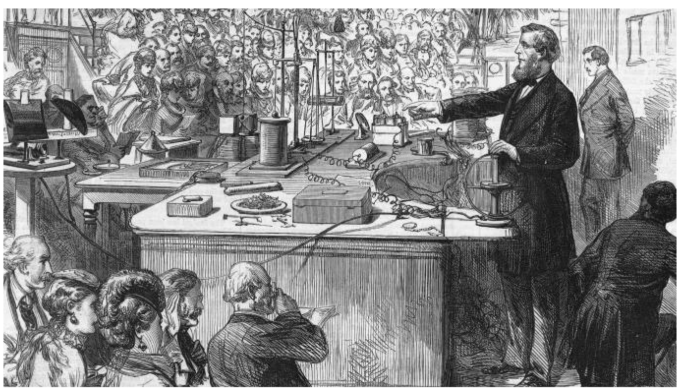

CIRCUMSTANCES

Affecting the Heat of the Sun's Rays.

BY MRS. EUNICE FOOTE.

Three years later John Tyndall carried out his experiments. He does not seem to have been aware of Mrs Foote's work. This is not surprising as, although the AAAS commented favourably on her paper, they neither published it or mentioned it in the report of the conference. Today Tyndall's work is widely accepted as the foundation of modern climate science, while Foote's remains in obscurity.

Recently several academics have tried to find out more about Eunice Foote. One is Roland Jackson, biographer of John Tyndall, and he has put the results of his research on a special website, https://www.rolandjackson.co.uk/single-post/2018/05/19/The-saga-of-Eunice-Foote-and-John-Tyndall. There are several other websites about her which you can easily find by Googling her name.



Women attending a science lecture

Although in the 21st century global warming is considered an issue of great importance it is interesting to note that, early in the 20th century, others were also aware of the potential risks.

Opposite is an extract from a newspaper letters column dated 1912.

The Rodney & Otamatea Times

WARKWORTH, WEDNESDAY,

AUGUST 14TH 1912

Science Notes & News.

COAL CONSUMPTION AFFECTING CLIMATE

The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

It makes you wonder why it has taken us so long to move on this!