1 How do we know that climate change is happening?

The science behind climate change, clear and simple...
How the greenhouse effect works... How temperatures are rising... Droughts, floods and storms... And how all this fits together.

LET ME TELL YOU a secret. Sometimes – just sometimes – I get jealous of the people who don’t believe in climate change.

On those days, when I hear someone on breakfast radio declaring they have ‘proof’ that climate change isn’t real, I give a cry of joy, leap out of bed and eagerly start investigating this wonderful claim, only to find that – as usual – they’re talking absolute nonsense and the science of climate change is as frustratingly solid as ever.

I hope you don’t blame me for thinking like this. The science isn’t just solid, it’s also pretty darned scary. The idea that the fuels that heat and power our lives – oil, coal and gas – are causing disastrous floods, storms and droughts all around the world is a highly disturbing one. It’s no surprise, then, that 2010 has seen a rise in the number of people in industrialized nations who say they don’t think climate change is a real problem – or that it somehow isn’t humanity’s fault.* As the science has become scarier, the siren voices of the professional climate change deniers – some funded by the fossil-fuel industry, others just

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* In a UK poll by Ipsos Mori in February 2010, only 31% of people said climate change was ‘definitely’ happening. This was a drop from 44% the year before. This isn’t quite as negative a result as it sounds – in answer to the same 2010 question, 29% said climate change ‘was looking like a reality’, 31% thought it was ‘exaggerated’, but only 6% said it wasn’t happening at all (3% answered ‘don’t know’). A US poll by Washington Post-ABC News in November 2009 was more stark in its results: 26% thought that global temperatures were not rising, compared with 18% the year before.
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basking in the limelight of controversy – have become harder and harder to resist.

It doesn’t have to be like this, of course – there is an upside (sort of) to climate change, which is that if we pick the right solutions we could actually make our lives better in many ways, and help to make the world a fairer place. If we can move away from being scared of climate change, and start talking about the benefits of well-built homes, decent transport systems, healthy fresh food, cleaner local energy, and a fairer sharing of the world’s land and resources, then it’s far more likely that people will be active and enthused about climate change and less likely that they will blame it all on invisible sunspots or secret lizard conspiracies.

But before we get to all this, we have to be absolutely clear about the science. This chapter aims to give you a basic grounding in what climate change/global warming is, and how it works. It won’t take long or get too technical, I promise – I’m assuming that like most people (including me), you don’t have a degree in atmospheric chemistry. Luckily, we don’t need one – the fundamental science behind climate change is pretty straightforward and easy to understand. There are five key points that, taken together, show us that climate change is both real and serious:

1) Carbon dioxide is a greenhouse gas
2) We’ve put loads of carbon dioxide (and other greenhouse gases) into the atmosphere
3) The average temperature of the planet has been rising
4) We’ve seen lots of other climate change effects
5) All of these things are connected.

The rest of this chapter examines each of these points in turn, explains the evidence for them and why they’re significant. Each of the five points is accompanied by a ‘Skeptics’ Corner’ box, where I’ll present some common fallacies about climate change and explain what’s wrong with them.
1) Carbon dioxide is a greenhouse gas

Nineteenth-century greenhouses
Back in the 1800s, a number of scientists were mucking about with gases in order to learn more about how the atmosphere worked. The French mathematician Joseph Fourier had realized in the 1820s that there must be something in the air that prevented the Sun’s heat from just bouncing off the Earth and vanishing back into space.¹ In the 1860s, the Irish-born physicist John Tyndall experimented with a number of gases to see which were best at trapping heat – and found that carbon dioxide had the intriguing property of letting visible light pass through, but hanging on to heat.² His work was taken further by the Swedish Nobel Prize winner Svante Arrhenius in 1896, who linked the amount of carbon dioxide in the air to changes in global temperature.³

So the basic science behind climate change is nothing new – but over the last hundred years, scientists have collected a huge amount of evidence so as better to understand and document this phenomenon. Light from the Sun passes through the atmosphere, bounces off the Earth and heads back towards space. Carbon dioxide, water vapor, methane, and other heat-trapping gases hold back some of that reflected energy as heat, and thus the atmosphere – and the planet – warms up. Seemingly small changes in the levels of these ‘greenhouse gases’* can lead to large changes in the Earth’s temperature. Prehistoric records (see the next section) show that a shift in greenhouse gas levels from 0.02 per cent of the atmosphere to 0.03 per cent (from 200 to 300 parts per million) can be the difference between an ice age and what we think of as a ‘normal’ climate.**

* So-called because they reminded early scientists of the glass in a greenhouse.
** The long-term cooling and warming of the Earth over millions of years has been caused by a number of factors (such as fluctuations in the Earth’s orbit and gradual geological shifts), not just greenhouse gas levels. However, greenhouse gases such as carbon dioxide have played a major role in speeding up and augmenting these ancient periods of warming and cooling – see Section 2, below.
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The joys of moderation
This is all well-established, non-controversial stuff. Without the greenhouse effect, the Earth would be a frozen lump of rock like the Moon. At the other end of the scale, Venus’s atmosphere is 96-per-cent carbon dioxide, which, combined with its proximity to the Sun, gives it a balmy surface temperature of around 480°C.

Water is the most abundant greenhouse gas in the atmosphere, and makes the biggest contribution to the ‘natural’ greenhouse effect. However, the amount of water vapor in the atmosphere stays pretty much the same from year to year, so it doesn’t play much of a role in the story of modern climate change (or at least, not yet – see Chapter 2). The second most common greenhouse gas is carbon dioxide – CO₂ for short. This is the one we really need to know about. Even though there’s less CO₂ than water in the atmosphere, it’s still the most important greenhouse gas as far as today’s climate change is concerned, because – unlike water vapor – the CO₂ in the atmosphere is increasing rapidly (see point 2, below), and it stays in the air for a long time (around 200 years). There are several other
important gases which also have a warming effect, as shown in the table below.

<table>
<thead>
<tr>
<th>Greenhouse Gas</th>
<th>Heat absorbed over 100 years (compared to CO₂)</th>
<th>How much is in the atmosphere (in parts per million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide (CO₂)</td>
<td>1</td>
<td>388</td>
</tr>
<tr>
<td>Methane (CH₄)</td>
<td>A kg of methane traps 25 times more heat than a kg of CO₂</td>
<td>1.8</td>
</tr>
<tr>
<td>Nitrous Oxide (N₂O)</td>
<td>A kg of nitrous oxide traps 298 times more heat than a kg of CO₂</td>
<td>0.3</td>
</tr>
<tr>
<td>Artificial industrial gases</td>
<td>A kg of one of these gases can trap between 140 and 24,000 times more heat than a kg of CO₂</td>
<td>Less than 0.001</td>
</tr>
</tbody>
</table>

In the right quantities, greenhouse gases are crucial for keeping the planet within a temperature range that allows life as we know it to survive.

**Skeptics’ corner: CO₂ as a greenhouse gas**
This is basic, well-established science that is very difficult to deny. In fact, you can demonstrate it yourself by filling a plastic bottle with carbon dioxide, shining a lamp on it and measuring its temperature.  

2) We have put loads of extra greenhouse gases into the atmosphere

**Climbing the sawblade**
We now fast-forward from the 1890s to the 1950s, and a young American chemist called Charles Keeling. With no greater aim in mind than setting himself an interesting challenge, he worked out a more
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accurate way of measuring the quantity of carbon dioxide in the atmosphere. In 1958, the US Weather Bureau started using Keeling’s new technique at their monitoring station on Mauna Loa in Hawaii – and were surprised to find that CO₂ levels in the Earth’s atmosphere were increasing at a significant rate, year-on-year.⁵ These measurements have been taken ever since, and form the graph below (also known as the ‘Keeling Curve’).

The sharp little oscillations in the graph are caused by the great forests of the Northern hemisphere; they take in more CO₂ during summer, and release more during winter, turning the graph from a smooth curve into a sawblade.⁶ But the trend is clearly an upward one – and it’s also accelerating. If you compare the left-hand to the right-hand end of the line, you’ll see that the increase has grown gradually sharper over the last 40 years – we’ve been churning out the CO₂ faster and faster as time’s gone on.

Atmospheric CO₂ at Mauna Loa Observatory

**Going with the flow**
But how do we know that this increase is all the fault of humanity? Mightn’t this CO₂ be coming from somewhere else? It’s a reasonable question, and in order to answer it scientists have built up a detailed picture of global carbon flows. The table below shows where all the carbon on the planet is, and how it is currently moving around. At the moment, most of this carbon isn’t in the form of CO₂ – it’s part of the rocks or plants or fossil fuels. To make it easier to compare with everything else in this book, I’ve converted all the carbon in this table to carbon dioxide equivalent.

<table>
<thead>
<tr>
<th>Location</th>
<th>How much carbon is stored there</th>
<th>Amount released to air per year</th>
<th>Amount absorbed from the air/year</th>
<th>Net release to atmosphere /year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth’s Crust</td>
<td>370,000,000</td>
<td>0.4 (from volcanoes)</td>
<td>0.4 (long-term absorption by rocks)</td>
<td>0</td>
</tr>
<tr>
<td>Oceans</td>
<td>141,000</td>
<td>332 (released to the air)</td>
<td>340 (dissolved from the air and washed in by rivers)</td>
<td>-8</td>
</tr>
<tr>
<td>Fossil Fuels</td>
<td>14,000</td>
<td>28 (from humanity burning the stuff)</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td>Plants and Soils</td>
<td>8,500</td>
<td>444 (natural plant respiration plus deforestation, peat cutting etc)</td>
<td>449 (photosynthesis and afforestation)</td>
<td>-5</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>370,163,500</strong></td>
<td><strong>804</strong></td>
<td><strong>789</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

Source: UNESCO/SCOPE/UNEP [http://nin.tl/bcfrhm Gigatonnes of carbon converted into billions of tonnes of CO₂e by my own calculation (multiplied by 3.67)]. All figures are from UNESCO, for 2008. More recent (2010) annual emissions from the burning of fossil fuel were closer to 31 billion tonnes/year. CO₂ from cement manufacture (see below) is not included. Note: while the ‘amount stored’ figures are approximate, the amounts of carbon moving in and out have been studied in detail.
(CO₂e) – in other words, how much CO₂ would be produced if all this carbon was burned and released into the atmosphere.

From this table, you can see that while CO₂ is being released from natural sources – oceans, plants, soils and rocks – these natural carbon stores are in fact sucking up slightly more than they are putting out each year. However, the burning of fossil fuels by humanity has shoved a spanner in the spokes of the carbon cycle, by releasing more CO₂ per year than these natural systems can absorb – which is why this key greenhouse gas is building up in the atmosphere, and why the Mauna Loa measurement is a little bit higher every year.

To be totally certain that all this extra CO₂ is coming from humans, there are two other things we can check. First, we can look at historical records of how much fossil fuel humanity has burned each year, for the last 250 years or so. We know how much CO₂ is emitted for each kg of coal, oil or gas that we burn, which means we can make a graph of humanity’s approximate CO₂ emissions stretching back to 1750.

This tallies neatly with the rising CO₂ levels in the atmosphere.

Finally, just to check that humanity really is the main source, and that there isn’t some giant

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**Fossil fuels**

In prehistoric times, CO₂ levels gradually rose and fell as the gas was absorbed or released by plants, rocks and oceans in response to various natural cycles. Over time, billions of tonnes of CO₂ were removed from the air by the great forests of the carboniferous period, and the carbon was stored underground as coal. Billions more tonnes of carbon were sealed away as oil and natural gas, formed from fossilized sea creatures. When we burn these fuels to power our hedge-trimmers, latte makers and shampoo factories, the carbon combines with oxygen, and CO₂ is released back into the air.
underwater CO₂-spewing volcano the size of Australia that no-one’s discovered yet, we can look at something called the isotopic signature of the carbon dioxide in the air. Without wanting to get too technical, carbon from different sources has some very slight physical differences that we can use to figure out where it’s from. Scientists started checking up on this in the early 1980s, and found that most of the extra carbon appearing in the atmosphere was the type of carbon that comes from fossil fuels.⁷

At the time of writing (August 2010), the average amount of CO₂ in the atmosphere stands at 388 parts per million (ppm).⁸ But ‘parts per million’ doesn’t sound like very much: is that really a high enough level to have a noticeable effect on the world’s climate? We can start to answer this question with a bit of time travel.

**Cold hard facts**

Between 1990 and 1998, a narrow but very deep (3.5-kilometer) column was drilled from the ice
at Vostok, Antarctica. This ‘ice core’ is a piece of frozen history – it contains many tiny bubbles of trapped air dating back through the last 400,000 years. Each of these is a miniature time capsule, and can be analyzed to tell us what gases were in the atmosphere as well as the average global temperature at that point in (pre)history. This allows us to stretch our Keeling graph of CO₂ levels back in time a few eons, and see how current CO₂ levels compare with the past (below).

This graph shows us three interesting (and worrying) things:

1. The Earth’s temperature clearly falls and rises in line with CO₂ levels in the atmosphere.
2. In the last 400,000 years, shifts in CO₂ levels from

![Vostok Ice Core, Antarctica](image)
around 180 ppm to 300 ppm have been associated with very serious changes in climate – the low points on the temperature graph correspond with what we think of as Ice Ages.*

3. We are currently at 388 parts per million of CO₂, right at the top of the graph. This is higher than at any other point in the last 400,000 years. Also, the current rate of increase is so fast that it looks like a vertical line on this graph. Unsurprisingly, CO₂ levels began rising at the beginning of the Industrial Revolution (the late 18th century), when humanity began to burn fossil fuels in earnest and have gradually accelerated ever since. If we zoom in on the last 10,000 years of CO₂ data from more recent ice cores, we can see this quite clearly (see graph above).

* The Vostok Ice Core graph shows changes in Antarctic temperature of up to 12°C. Temperature changes elsewhere on the planet were slightly less drastic than this (though still large enough to cause Ice Ages), because temperatures tend to change further and faster at the planet’s poles.

Sources: First line derived from ice cores obtained at Taylor Dome, Antarctica (www.ncdc.noaa.gov). Second line derived from ice cores obtained at Law Dome, East Antarctica (http://nin.tl/bP17M4). Third line from direct measurements at Mauna Loa, Hawaii (http://nin.tl/a7Fsz0). Graph put together by skepticalscience.com
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The last time CO₂ is believed to have been this high was the mid-Pliocene period, some 3.5 million years ago. At this time, sea levels were 25 meters higher than today. Clearly, the changes we are making to atmospheric CO₂ are in the ‘significant’ range – but then, if CO₂ is at such a (pre)historic high, then why isn’t Europe under water yet? Why isn’t Greenland famous for its tropical beach holidays?

The answer is that – fortunately – there’s a time delay between rising CO₂ and rising atmospheric temperatures. The greenhouse gases need to spend a decent amount of time in the atmosphere, doing their warming thing, before we start to really notice the effects down on Earth. This is because the oceans, rather than the air and the land, are absorbing most of the extra heat. The effects of this oceanic warming are far less immediate and noticeable to us land-dwellers than the effects of a warmer atmosphere. This is something of a double-edged sword. On the plus side, this delayed reaction means that the effects of climate change have been nowhere near as extreme as they would have been if the ocean wasn’t such a great heat trap. However, on the negative side, it means that it’s much harder for the person on the street (or field, or hillside) to see the connection between our CO₂ emissions and the gradual warming of the planet.

Emission omissions
More about this a bit later, but first some more bad news (sorry). So far, we’ve mostly been discussing the CO₂ released from the burning of fossil fuels. However, this isn’t the only way in which humanity is contributing to climate change:
• Cement manufacture brings some extra CO₂ into the equation, because it involves heating calcium carbonate (from rocks) to produce lime and carbon dioxide – in other words, taking carbon from the
‘Earth’s Crust’ store in the table on page 17 and putting it into the air. This releases an extra 0.9 billion tonnes of CO₂ into the atmosphere each year (about three per cent of the annual CO₂ total).¹²

• We’re releasing greenhouse gases other than CO₂ into the air. The most important ones are methane (from livestock, coal mines, rice fields and landfill sites), nitrous oxide (from fertilizers and manufacturing) and small amounts of other powerful warming gases from certain industrial processes. Together, these bonus greenhouse gases add an extra 30 per cent to the warming power of our annual global CO₂ emissions.¹³

• The emissions from airplanes cause a bit of extra warming, because they occur high up in the atmosphere (there’s a more detailed explanation of

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**Skeptics’ corner: Rising CO₂ levels**

The fact that CO₂ levels are increasing is pretty undeniable, because they’re directly measured. Even though they’re measured in parts per million, these relatively small amounts of greenhouse gas are extremely significant – without them, the Earth would be a lump of frozen rock, and none of us would ever have been born. We’ve also seen how relatively small changes in CO₂ levels have, in the past, led to major changes in the planet’s climate.

Some commentators dispute this latter point – they note that, judging by the prehistoric ice core record, when the Earth has warmed in the past the temperature has tended to rise before the CO₂, suggesting that the warming was causing the CO₂ increase rather than the other way around. I’ll be honest – if you’re not familiar with the science, this can be pretty confusing. In reality, it’s a well-established part of climate science – see the ‘Lessons from Prehistory’ box for a full explanation.

Some prominent ‘skeptics’ such as Ian Plimer have made the bizarre claim that volcanoes produce more CO₂ than all of humanity’s activities.¹⁴ Referring back to the table on page 17, we can see that this clearly isn’t true – humanity is responsible for at least 60 times the CO₂ of volcanoes. This point was firmly underlined when the brilliantly named Icelandic volcano Eyjafjallajokull erupted in March 2010; the resulting ash cloud led to the grounding of planes across Europe for several weeks, preventing the release of far more carbon dioxide than the volcano was emitting. It created a net saving of around 50,000 tonnes of CO₂ per day.¹⁵
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Lessons from prehistory: ancient warming cycles and what they can tell us

Scientists are developing more and more powerful computer models to try to predict the effects of climate change, but there’s one model that will always beat them all – the planet Earth itself. By looking at what’s happened when CO₂ levels have risen in the past, we can learn a huge amount about what’s likely to happen in response to our current CO₂-emitting frenzy.

We can gather evidence from ancient ice cores, tree rings, coastlines, and the ocean’s depths that provide us with a pretty decent picture of how temperatures, sea levels, and the amount of CO₂ in the air have changed over the last few tens of millions of years. The results are fascinating – the Earth has swung periodically between colder and warmer periods over the eons (for example, see the the graph on page 20). In the coldest periods (‘glaciations’ or ice ages), the Northern continents were covered with massive ice sheets several kilometers thick; in the warmer periods, there was no ice at the poles and sea levels were up to 75 meters higher than today. These huge changes were initially triggered by tiny fluctuations in the Earth’s temperature – the Sun might go through a slightly warmer or cooler phase, or kinks in the Earth’s orbit might take the planet out a little further or in a little closer. This would result in an incredibly small amount of extra warming or cooling each year. The planet would then warm or cool gradually, over hundreds or thousands of years. Then suddenly, this would transform into rapid change, switching the planet from cool to warm or vice versa.

Why the sudden flip into rapid change? Well, this is where we need to start talking about ‘feedbacks’ – factors which can either speed up or slow down the rate of global warming or cooling. There are three particularly important feedbacks when it comes to prehistoric warming:

1) Carbon dioxide and methane release: As the planet warms up, carbon dioxide and methane are released from plants, soils and oceans. These gases create a greenhouse effect which leads to more warming and thus the release of more CO₂ and so on until the whole climate has changed completely. This has been a very important factor in transforming very slow prehistoric warmings into sudden shifts. This explains why, in the

this in Chapter 4).

• Finally – and vitally – we are messing with the planet’s ability to suck up carbon dioxide. As we saw in the table on page 17, about 789 billion tonnes of CO₂ are absorbed by plants, soils and oceans each year. But we are in the process of cutting down forests faster than at any other point
in history – which is a double climate whammy, because it releases the carbon stored in those trees (and soil) back into the air, and also means there are fewer trees around to suck up CO₂ from that point onwards.¹⁶ This is Not a Good Thing.

There’s more information on all of these emissions sources in Chapter 4. For now, it’s enough to say that
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yes, we have definitely added greenhouse gases to the atmosphere, and in large enough quantities to expect to see an impact on the Earth’s climate.

3) The average temperature of the planet has been rising

Hot news
It’s August 2010, and I’m looking at a series of newspaper headlines from the last few weeks:

‘World feeling the heat as 17 countries experience record temperatures’ – *The Guardian*  
‘Long, hot summer of fire, floods fits predictions’ – Associated Press

‘Warming world records hottest ever June’ – *The Australian*

‘This year warmest on record so far’ – *The Washington Post*

I can’t help having mixed feelings about this. Rising global temperatures are seriously bad news, bringing all sorts of awful effects for people and the natural world (see below). But maybe, just maybe, this year of record temperatures will be the extra shove we need to move enough residents of industrialized nations from dismissal and denial into serious climate action.

Well, let’s hope so (but see Chapter 3 for some reasons why it isn’t quite that simple). In the meantime, 2010’s super-scorcher summer adds another sizeable boulder onto the mountain of evidence for a rapidly warming world:

- The global average temperature has risen by 0.8 degrees since pre-industrial times. This brings us up to an average temperature higher than at any time in the last 100,000 years.

- The rate of warming has been increasing further in the last few decades. The warming trend for the last 25 years is more than double the rate of the previous 100 years, and the 10 hottest years on record have all
occurred since 1990.\textsuperscript{26} 

- Extreme temperature events are also becoming more common – for example, the 2003 European heatwave shattered records and caused 35,000 deaths. 
- The winter of 2006/07 was the warmest across the Northern Hemisphere since records began.\textsuperscript{27} The world downhill ski championships in Austria were thrown into crisis by a lack of snow\textsuperscript{28} and Spanish bears gave up on hibernation.\textsuperscript{29} In the UK, spring flowers popped up in January – and came up even earlier the following winter.\textsuperscript{30} 
- Since 2005, Arctic sea ice has been melting faster than scientists’ predictions,\textsuperscript{31} the Greenland ice shelf’s summer melt period has increased by 16% over the last 30 years\textsuperscript{32} and 2010 has seen the fastest Greenland melt ever recorded.\textsuperscript{33}

**The heat is on**

All of these examples fit into a broader trend, as shown in the next three graphs (below and overleaf).
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**Global temperatures over the last 1000 years**

![Graph showing departures in temperature (°C) from the 1961 to 1990 average for the Northern Hemisphere. Data from thermometers (black) and from tree rings, corals, ice cores and historical records (dark gray).](image)


**Total Earth heat content anomaly from 1950**

![Graph showing heat content anomaly (10^21 Joules) from 1950.](image)

The figures in the top graph opposite show average temperature measurements for the land and the air. However, it’s becoming increasingly clear that these temperature changes are being dwarfed by rising ocean temperatures. The bottom graph shows the latest estimates for how changes in ocean temperatures fit into the picture (corresponding with the final 60 years of the top graph).

How do we know that temperatures are rising?
Taking the Earth’s temperature is a bit of a challenge, because the planet is just so darned big. Anywhere we stick a thermometer will just give us the temperature of that particular location. To get a meaningful global average, we need rather more data than that.

Fortunately, over the last few centuries, local weather agencies have gradually built up a huge network of measurement stations all across the globe. Today, there are more than 7,000 of them, over both land and sea, and their results are collected and compiled by three different organizations. This means that any strange results or anomalies can be checked against a different set of data, and any mistakes are easy to spot. Satellites orbiting the Earth are also increasingly being used for thermal imaging, supplying us with yet more temperature data. There are, inevitably, slight differences between the results from different sources (due to instrumental errors, calculation methods etc) but the overall trend is very clear – the planet is warming. The graphs in this section have been compiled from all of these data sources.

The scientists doing the measuring would be the first to admit that achieving an accurate result isn’t easy. Here are a couple of reasons why:

• Thermometer design and accuracy have changed over the last 150 years.
• The urban ‘heat island effect’ – put simply, towns and cities are warmer than the countryside, and most of the data collection points are located in the industrialized, urbanized world, which creates some slight biases in the data.

These factors are carefully taken into account when calculating global average temperatures. In early 2010, climate scientists were given some unintended help in this area when the notorious anti-climate-science blogger Anthony Watts launched a US-wide survey of temperature measurement stations, rating them ‘good’ or ‘bad’ based on their proximity to towns and other heat sources. He was hoping to prove that the heat island effect was responsible for the rising temperatures on all those official US thermometers – but instead found precisely the opposite. Watts’ results showed that the heat island effect was, in fact, having less of an impact than the scientists had thought, and so caused them to adjust the US temperature record slightly upwards rather than downwards. Whoops.
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Skeptics’ Corner: A warming world
Weirdly, despite the huge body of evidence for rising planetary temperatures, people determined to deny the existence of climate change have focused a lot of their efforts on this topic lately. Here are some common misleading claims, with explanations.

Global warming stopped in 1998! Perhaps 2010’s high temperatures will put paid to this one, but just for the record... The Climate Research Unit at the UK’s University of East Anglia is one of the three organizations that compile surface temperature records. If you look at their data alone, it looks as though 1998 was slightly warmer than the years 1999-2009. Some commentators have seized on this as evidence that global warming has ‘stopped’. However, this is based only on land and air temperatures, and not the total picture – when you look at the land, air and ocean all together (as in the bottom graph on page 28) the warming trend is still clearly heading upwards. In any case, if you look at the average of all the temperature data from across the world (rather than just the CRU data), 2005 was hotter than 1998 overall.

The world cooled down between 1940 and 1970! This isn’t true, but is based on something genuinely interesting. Global warming did plateau for a bit between the 1940s and the 1970s, due to the now widely recognized phenomenon of ‘global dimming’ – a type of industrial pollutant called sulfate aerosols were partially blocking the Sun’s rays. This lasted for a while until the ongoing build-up of greenhouse gases – combined, ironically enough, with a reduction in sulfate pollution from power stations – eventually swamped the dimming effect and the temperature began to rise once more. You can see this flattened period on the graph on page 27.

The temperature measurements are flawed/manipulated/fixed! To tamper with or subvert the data from 7,000 different measure-

So the temperature changes we are feeling on land are small fry (if you’ll pardon the expression) compared to the heating of the oceans. The land and air may be getting sunburned, but the oceans are in the toaster. The full consequences of this remain to be seen.

That’s probably enough for now – suffice to say that yes, the earth is definitely warming at a far greater rate than it has for a very long time.
ment stations and satellites, which are processed via three different major organizations with hundreds of staff, would require an utterly fantastic level of conspiracy which would put a James Bond baddie to shame. Nonetheless, in 2010, a procession of (mostly online) commentators claimed that a series of hacked emails from the Climate Research Unit at the University of East Anglia contained evidence of just such a conspiracy. Three separate independent enquiries trawled painstakingly through the emails and found evidence of nothing more than a few scientists occasionally being a bit rude about some of their colleagues, using some unhelpful jargon and having the odd moan about incessant public requests for information (pretty much like the emails from any other workplace).\textsuperscript{40} However, there was one useful outcome from this: much more of the raw temperature data has since been made public, to avoid similar accusations in the future.\textsuperscript{41}

\textbf{But it’s cold today…}

Although the average global temperature is rising, that doesn’t mean that everywhere is getting hotter at the same rate. The global climate system is complicated; some places are heating up faster than others, and some places may even cool down depending on how ocean currents shift around. There’s also an important difference between \textit{climate} and \textit{weather}. Climate change is a gradual, long-term process; weather is about short-term, day-to-day changes due to local patterns of wind, evaporation, and ocean currents, and is much more chaotic and unpredictable. A few weeks of cold weather in one location tells us little about long-term global temperature change – that’s why we need all those thousands of temperature measurement stations taking decades’ worth of readings. Those measurements are telling us that every time there’s a bit of unusually cold weather somewhere in the world, it’s being outweighed by many more examples of unusually hot weather elsewhere, and so the overall trend is of a warming planet.

\textbf{4) We’ve been seeing lots of other effects}

\textbf{Warm words}

There’s a reason why campaigners tend not to use the term ‘global warming’ these days – not only does it sound a bit too pleasant (who in the industrialized North wouldn’t want a nice bit of warming?), but also it doesn’t describe the full effects that rising
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global temperatures are having on the planet. ‘Climate change’ seems to have become the accepted term to sum up the bundle of different effects we can expect from an overheated planet. As campaigners such as George Marshall have noted, these two words still sound rather innocuous – but more accurate descriptions such as ‘climate carnage’, ‘weather frenzy’ or ‘total stormfest’ probably sound a bit too dramatic to be taken seriously.

As I write this in 2010, Pakistan has just been hit by devastating floods, the worst in the country’s history, killing around 1,600 people (so far) and leaving an estimated 20 million temporarily or permanently homeless. Russia is recovering from a blistering heatwave that saw temperatures consistently at 20°C above normal and caused thousands of deaths. Huge wildfires have been sweeping through northern Portugal, torrential rains have unleashed killer landslides in China, hundreds have been forced from their homes by floodwaters in Iowa, and Niger has just been hit with disastrous floods straight after a crippling drought. Reports like this flash past us all the time these days, and usually seem to be described as the worst in 20, 30, 50, 100 years.

No individual incident can ever be linked directly to climate change – the world’s weather systems are far too complex for that. However, an overall trend of more frequent, and stronger, extreme weather events is exactly what we would expect from a warming world. It’s a bit like cheating at dice. If you put a secret weight inside a die to make a six more likely to come up, then you’ll roll more sixes; but you’ll never be sure which of those extra sixes were due to the weight, and which would have come up anyway.

**Cooking up a storm**

When global temperatures rise, that doesn’t just mean things getting hotter – it means that more and more
energy is being pumped into the climate system. This has all sorts of knock-on effects, including:
- More evaporation from ocean surfaces, leading to more powerful storms
- Greater heat transfer between different bits of the climate system, leading to stronger winds and more extreme temperatures (both high and low) in particular places
- Changes in rainfall patterns, leading to burst river banks in some areas and droughts in others
- Rising sea levels caused by the fact that warm water expands, as well as by the melting of Greenland and Antarctica.

This increase in weather-related disasters has been documented in detail by that well-known group of radical climate campaigners, large insurance companies. Over the page is a graph from the major insurers Munich Re, comparing the number of natural catastrophes per year from 1980 to 2009. The trend is very clear, with more than twice as many disasters in 2009 as in 1980. Meanwhile, 2010 is on track to be as bad as 2009, with 440 disasters recorded between January and June.

It’s also worth noting that the top three bars — all of which contain events which could be linked to
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![Natural catastrophes per year, 1980-2009](chart)

climate change – have grown noticeably. The bottom bar, which records natural disasters not linked to climate change (earthquakes and volcanic eruptions), has not grown in the same way.* The United Nations Environment Programme has found a similar trend stretching back to 1900.45

When interviewed on this topic in 2010, Liz Bentley – a climate scientist from the Royal Meteorological Society – said: ‘Disasters such as the Boscastle flooding [in Cornwall in 2004] are moving from being a once-in-100-year event to a once-in-20-year event.’46 Peter Stott, a climate scientist from Britain’s Met Office, was asked about the 2003 heatwave in

* There is evidence that retreating ice sheets can increase the frequency of volcanic events in some areas, but this is currently limited to a very few places and so its global effect is small.
Europe, which killed around 35,000 people. He said the probability of these kinds of events had ‘likely doubled as a result of human influence...[and] could become considered the norm by the middle of this century.’

The key word here is ‘probability’ – not every natural disaster will be the direct result of global warming, but we can expect the overall number of disasters to increase as climate change progresses. Recent disaster rates are exactly what we would expect from climate change at this point. According to the World Meteorological Organization, ‘The sequence of current events matches [climate scientists’] projections of more frequent and more intense extreme weather events due to global warming.’

These bare statistics don’t really tell the story though, so here are some more specific examples, with a brief explanation of how each type of phenomenon may be linked to climate change.

**Storms from the sea**

Hurricane-force winds can only arise from oceans with a surface temperature of at least 26°C. The warmer the oceans, the more intense and longer-lasting these storms are likely to be. These kinds of tropical ocean storms are called hurricanes, typhoons or cyclones, depending on where you are in the world.

Hurricane Katrina hit the south coast of the US in 2005, causing 1,836 deaths. Later that year, Hurricane Stan hit Guatemala, Mexico, El Salvador, Nicaragua and Costa Rica, causing 1,500 further (but less globally reported) deaths. Some scientists argue that climate change contributed to the strength of these storms, though this is still hotly debated. 2004 saw the first South Atlantic hurricane ever observed hit Brazil, and in 2008 Cyclone Nargis blasted across Burma, killing an estimated 150,000 people and affecting over two million more.
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**Floods from the sky**
Higher temperatures mean more evaporation, which affects global rainfall patterns. As a result, some regions have become dryer and some have become wetter, with a significant increase in extreme rainfall events in the last few decades.\(^5\)

Torrential rains triggered flash floods across Africa in 2007, affecting 22 countries, thousands of hectares of agricultural land and over a million people. Record rainfall in India in July 2005 killed almost 1,000 people; tens of thousands were displaced and hundreds killed by rain-driven floods and mudslides in Brazil in 2004. Record-breaking rains and severe flooding caused serious property damage, mass evacuations and loss of life in New Zealand in 2004 and Britain in 2007 and 2009.

**Fields of dust**
With increased evaporation, there’s another side to the coin: while some places become wetter, others become drier. This has led to droughts becoming more common, especially in the tropics, since 1970; droughts have also become longer and more severe, and are affecting wider areas. Fires and famines are all-too-commonly the result.\(^5\)

Australia has been hit by a series of severe droughts since 2002, with serious effects on agriculture and freshwater availability. In 2006, several consecutive years of drought left more than 17 million people starving in Djibouti, Ethiopia, Kenya and Somalia. 1998 saw one of Indonesia’s worst-ever fire outbreaks, following the failure of the monsoon rains.

**Cracks in the ice**
The Arctic is one of the areas of the planet being hit first and hardest by climate change. Arctic temperatures are on a jagged upward trend – 2007 was the warmest year on record. This is leading to all sorts of changes
to local wildlife movements and is threatening the traditional ways of life of the indigenous Arctic peoples. Arctic sea ice grows and shrinks each year with the changing seasons, reaching its minimum size around September each year. Worryingly, this minimum extent has been on a gradual downward trend for the past 30 years (see graph above). Although – thankfully – the last two years on the graph weren’t as bad as 2007, they still had less summer ice than any other year to date. Things are looking bad again for 2010. The speed of this thaw has shocked climate scientists: it is happening faster than the most extreme predictions made by the Intergovernmental Panel on Climate Change (IPCC).

Elsewhere in the Arctic, Greenland’s ice has also been shrinking much more rapidly than expected. Many observers were stunned in August 2010 when a huge chunk of ice, with an area of 160 square kilometers (four times the size of Manhattan), broke away from one of Greenland’s main glaciers and tumbled into the sea.
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The creeping oceans
As water gets warmer, it expands. This process has already led to a certain amount of sea level rise around the world, and is being augmented by melting Greenland and Antarctic ice. Note that when Arctic sea ice melts it does not make sea levels rise, because it produces just enough water to fill the space it was already occupying in the sea – watch a piece of floating ice melt in a glass of water and you can see this for yourself. Melting ice only adds to sea levels if it’s moving from land to sea.

Sea level rise is difficult to measure – tides and waves mean that the sea doesn’t stay still, and different bits of land around the world are also slowly moving up and down thanks to geological forces. Satellite imaging and tidal gauges have been used to estimate current sea level rise at around three millimeters per year. This doesn’t seem like much, but is already putting low-lying islands and coastlines at risk. Coastal farmers in Fiji are switching to salt-resistant crops, thanks to the surging ocean soaking their soils; meanwhile, the islands of Kiribati and Tuvalu are facing total evacuation as the sea creeps inexorably up through their towns and villages.

Migrating from existence
As areas become warmer, dryer, or wetter, plants and animals are struggling to adapt. In the past, these kinds of changes in local climate have taken place over thousands of years, giving species time to evolve or to shift their range. The sheer pace of current change – combined with the fact that humanity’s roads, towns, pollution and pipelines have seriously limited the number of places where these threatened species can go – is putting countless plants and animals at risk around the world.

The plight of the polar bears is well known – we can see their northern icy habitat melting and cracking beneath them, and so it’s no surprise that several key
populations in vulnerable areas are declining. But any species which is adapted to a very specific set of temperature and/or weather conditions is likely to be affected by climate change, and most of them are less obvious and less well-studied than the polar bear. Our knowledge of exactly how our fellow species are faring is limited – it all depends on which ones we happen to be looking at closely enough.

For example, thanks to the enthusiasm of amateur butterfly-spotters past and present, we have enough data on British butterfly species to know that many of them are shifting their ranges northwards. A lot of people keep an eye on migrating birds, and so we know that many of them are changing their migration times and routes in response to the changing climate. Coral reefs are of huge interest to marine researchers (and holidaymakers), and so we’ve got plenty of information on how increased water temperatures are already killing off coral directly, or indirectly through the faster spread of coral diseases.

But what about all the places where we’re not looking, all the species we aren’t keeping an eye on – or haven’t even discovered yet? For example, around 35 species of barely studied Latin American frog are believed to have been wiped out by climate change, including the extraordinary Golden Toad. There’s no way of telling how many other undiscovered species have gone the same way.

All life on Earth is connected, web-like; everything eats or is eaten by something, and competes with others for food, light or living space, so these changes in various organisms’ range, numbers and behavior will have unpredictable knock-on effects for other species all around the world – including humans.

**Life, limb and livelihood**
As we’ve seen, climate change is not something that might happen in the future – it’s going on right now,
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all around us. For millions of people suffering from droughts, floods and storms, its impacts are already very real. The Global Humanitarian Forum, an agency led by ex-UN Secretary-General Kofi Annan, carried out an assessment in 2009 into the human cost of climate change. It found that 300 million people were

Skeptics’ Corner: Extreme weather

**The Antarctic ice has been growing, not shrinking!** This is true for certain bits of Antarctica – and, intriguingly, it actually gives us *more* evidence for global warming. Increased evaporation caused by higher temperatures has led to more snowfall in some parts of Antarctica, which has led to a thickening of the ice in these areas (usually inland). Elsewhere in Antarctica (mainly the bits near the sea, which is warming faster than the air) the ice is retreating. As we’ve noted before, it’s a complex picture!

**Climate change has good effects, not just bad ones!** Again, this is true – up to a point. Warmer winters in some countries will mean fewer people die from cold. Some places are becoming easier for growing crops thanks to increased temperatures. Sadly, these small pockets of positive effects are hugely outweighed by the negative ones. We have built almost all our settlements in places that are comfortable and fertile in our current climate, and our ways of growing food are carefully adapted to the weather we’ve been used to for thousands of years. Rapid changes in the Earth’s climate are already starting to throw this out of kilter – hence the deaths from storms, floods and famines documented above. Even if climate change makes some places more comfortable to humans, do we expect everyone in the world to migrate to the places where climate change isn’t so bad? What would happen if billions of people found that their countries had become inhospitable and that they needed to move to a new one? It’s always worth thinking these things through...

**Climate change is a problem, but there are bigger problems that we need to tackle first:** This is an argument famously put forward by the Danish statistician Bjorn Lomborg. It ignores several important facts. First, it’s a false choice – we can (and should) tackle such problems as climate change, poverty and health all at the same time. In fact, many of these problems have the same root causes (as we’ll see later), so it makes sense to work on them all together. Second, climate change is making many of the world’s problems much worse – it threatens all eight of the UN Millennium Development Goals. Any progress we make in these areas will be swept away by climate change, unless we act to prevent its worst effects. ■
already feeling the effects, through the loss of their homes, crops, lands or livelihoods; it also estimated that 300,000 people per year are currently being killed by climate change. Of course, these are just estimates – it’s hard to attach precise numbers to such a complex picture – but they do give us some idea of the scale of the crisis that’s quietly unfolding all around us.

5) All these things are connected

So, to summarize what we’ve established so far:
• Carbon dioxide is a greenhouse gas. It has a warming effect on the planet.
• We’ve been pumping lots of extra carbon dioxide (plus some other greenhouse gases) into the atmosphere for the last 150 years. It’s now at a level normally associated with much hotter prehistoric times.
• The air, land and oceans of the earth are heating up.
• We can measure this temperature change directly, and also see its effects in increased weather-related disasters, melting ice sheets and changes in wildlife behavior and numbers.

It’s not hard to join the dots here, and conclude that humanity’s greenhouse gases are causing the planet to heat up and the climate to change. But how can we be totally sure that these things are linked?

There are several very good reasons to make this connection:

* Why would all our CO₂ not be warming the planet?
Why on earth would this powerful greenhouse gas, that we know has a warming effect and has led to major climatic changes in the past, suddenly stop working? We’ve increased it by 40 per cent from pre-industrial levels, to a level associated with prehistoric sea levels many meters higher than today, and we’re supposed to believe it’s having no effect? It’s a pretty incredible thing to claim and would need a pretty amazing
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explanation, with evidence to back it up. No-one has yet presented any such explanation or evidence.

* There’s nothing else that could be causing it
Similarly, if CO₂ isn’t causing the warming, then what on Earth is? It’s true that other things have warmed the planet in the past – kinks in the Earth’s orbit, increased solar activity, changes in ocean circulation, volcanic activity. But there hasn’t been enough of any of these things over the last 150 years to account for all of the warming we’re seeing,⁶⁵ so those things can’t explain the current bout of climate change.*

* CO₂’s fingerprints are all over the crime scene
We’ve already seen that temperatures and CO₂ levels have been rising together throughout the 20th century. That’s decent circumstantial evidence that puts CO₂ in the right place at the right time, but what if we want something firmer? Well, we can also use what’s known as the thermal signature. Using satellites, we can measure and analyze the wavelength of the Sun’s rays as they fall onto, and are reflected back from, the Earth. There are specific wavelengths of radiation that are stopped by greenhouse gases like CO₂ and methane, and we’d expect to see fewer of them bouncing back up through the Earth’s atmosphere if there really were an increased greenhouse effect. In other words, when CO₂ and methane trap heat in the atmosphere, they leave a recognizable ‘signature’ in the surplus rays that make it back out into space.

Recent, repeated satellite measurements have found this signature, growing at just the rate we’d expect.⁶⁶ That’s solid evidence that increased levels of CO₂ and methane are trapping extra heat within the Earth’s atmosphere.

* It’s worth noting that these ‘natural’ effects are causing some warming, but aren’t powerful enough to account for most of what we’re seeing at the moment.
Skeptics’ Corner: The link between CO\textsubscript{2} and global warming

But what about global warming in prehistoric times or on other planets? That can’t have been caused by humanity’s CO\textsubscript{2} emissions! Well, no, of course not – no-one’s saying it was. Planetary temperatures have risen and fallen for all sorts of different reasons in the past (or on Mars or Venus) but here and now it’s humanity’s greenhouse gases that are heating up the Earth rather than orbital cycles or geothermal effects.

It’s all about the Sun/sunspots/solar flares: The Sun does occasionally go through periods of increased activity, where it emits extra heat. However, all the extra sun activity of the last 150 years can only account for a small amount of the warming we’ve seen in that time – the rest must be due to something else. Since 2003, the Sun has, in fact, been cooler than usual. This is all well measured and non-controversial.\textsuperscript{67} So climate change can’t be due to the Sun alone.

It’s cosmic rays/something else: There are other ‘theories’ out there, but with little or no evidence to back them up. Of course, in order to overturn the existing theory of human-made global warming (as detailed in this chapter), they’d need to have a huge mountain of contrary evidence that explains why the current scientific explanation isn’t correct. For example, if you decided that the real reason why all the leaves fall off the trees in winter is that they’re being tugged off by mischievous squirrels, you’d need a bit more evidence than a photo of a squirrel sheepishly clutching an oak leaf. You’d need a lot of new proof to back up your hypothesis\textsuperscript{*} and some very good reasons to discount all of the evidence for the prevailing theory about why the leaves come off the trees, before making that sort of claim. None of the other supposed explanations for climate change can do this.

Very thin climate change ‘explanations’ sometimes get more prominence than they deserve, when publicized by a credulous journalist or unscrupulous TV show. Always ask: who is putting this alternative explanation forward, and what do they stand to gain? There are some excellent science websites that will usually jump on any new hypotheses quite quickly, explaining what they mean and whether they have any credibility: www.realclimate.org and www.skepticalscience.com are usually good places to start.

\textsuperscript{*} Strictly speaking, a ‘theory’ is something that has serious evidence backing it up and has become generally accepted as a good scientific explanation (e.g. the theory of evolution, the theory of human-induced climate change). By contrast, a suggested explanation that has yet to be rigorously tested is called a ‘hypothesis’.
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We’re left with the inescapable conclusion that humanity’s greenhouse gases are causing the climate change we see around us. Which, if you think about it, is a bit of a relief – it means we can do something about it. If all this warming and weather chaos was being caused by forces outside our control, it would be a pretty bleak outlook for humanity. Luckily, it’s being caused by greenhouse gas emissions – and we can do something about those.