

Climate change

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The Intergovernmental Panel on Climate Change (IPCC), the UN-organised body that reviews scientific research on climate change, concluded in its most recent assessment that ‘Warming of the climate system is unequivocal’ (IPCC 2008: 72). The NASA website states ‘The evidence for climate change is compelling’ (NASA 2012). The UK’s Met Office (2009) recently stated, ‘It is now clear that man-made greenhouse gases are causing climate change. The rate of change began as significant, has become alarming and is simply unsustainable in the long term’ (p. 2).

These quotes highlight two things. First, that there is a widespread scientific consensus that climate change is caused by human activity and is a major threat. Second, that there is a huge amount of information about climate change available to anyone with an internet connection. Climate change is now the frequent topic of reports in newspapers, in broadcast media, on blogs and websites. Al Gore’s film *An Inconvenient Truth*, which shows Gore travelling around North America giving a presentation on climate change, even won an Oscar. In all these diverse sources of information and opinion, mathematics is a constant, if often unremarked, presence. This observation leads to several questions:

- What mathematics is involved in understanding climate change?
- How is mathematics used or misused in arguments and debates about the need for action?
- What mathematics do ‘consumers’ of information about climate change need to know to be able to make informed judgments about what they are reading?
- How do the interests of authors of information about climate change influence their use of mathematics?

One of the purposes of this chapter is to make visible the role of mathematics in understanding and reporting climate change. More than this, however, the chapter will examine how mathematics in some sense makes climate change real. Without mathematics, it would be difficult to have a global view of climate change. Mathematics is, therefore, crucial to our understanding of climate change. At the same time, mathematics, including the mathematics embedded in technology, is implicated in causing climate change and in what we understand climate change to be. Finally, as argued in Chapter 1, issues like climate change are not just scientifically complex, they are socially complex. As such, any response to climate change must be developed with the participation of all of us – not just as teachers, but as citizens – since it will potentially involve significant changes to how we live (see Hulme 2009). And to participate, we all need to understand some of the mathematics of climate change and, in particular, so will our students. So, as well as exploring some of the mathematics of climate change, this chapter suggests some ways in which this mathematics could be used in the classroom.

Climate change and mathematics

First, an important distinction: *weather* refers to the meteorological conditions at a specific time and place. Look outside and note the temperature, wind conditions, cloud cover, precipitation and so on – that is the weather where you are. *Climate* is simply statistics: the statistics of weather. For example, to say that the climate of Scotland is cooler than that of England is to make a statistical statement. More precisely, the statement means that the mean temperature of Scotland over a given, reasonably long period of time is lower than the mean temperature of England over the same period. On specific days, however, the temperature may be much higher or lower than the long-term mean and the temperature in Scotland may be higher than the temperature in England (see Table 3.1 for an example).

This definition of climate as the statistics of weather can be extended to climate *change*. Here is a definition of climate change proposed by the IPCC in their most recent report:

a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

(IPCC 2008: 30)

Climate change is thus described in terms of changes in means as identified by statistical tests. These techniques are applied to a wide variety of data, including air and sea temperature recordings and other standard meteorological readings, as well as records of such things as glacial melting or sea level (both are increasing; see IPCC 2008: 30). It is worth noting that much of this mathematics is well within the scope of school mathematics curricula.

In Chapter 1, I discussed the mathematics of description, prediction and communication. The description of climate change, then, makes great use of (often

Table 3.1 Comparing the climate and weather of Edinburgh and London

	Climate	Weather
	Mean daily maximum temperature (°C) 1971–2000	Maximum temperature (°C) 25 October 2011
Edinburgh	12.2	9.5
London (Greenwich)	14.8	16.8

Source: <http://www.metoffice.gov.uk/climate/uk/averages/19712000/> and <http://weather.lgfl.org.uk/Default.aspx>

basic) statistics, both to establish long-term average conditions, as well as to examine climate variability. The mean daily maximum temperature in Edinburgh only tells us part of the story of Edinburgh's climate: it is also useful to know how much the daily maximum varies from this mean and how frequently. How often will Edinburgh experience sub-zero temperatures, for example? Or extreme heat? In addition to the statistical description of the climate, similar mathematics is involved in assessing greenhouse gas emissions, as well as the wider impact of climate change on our society.

The prediction of climate change uses more advanced mathematics. Developing predictions about future global, regional or local effects of climate change draw on a range of advanced mathematics, including mathematical modelling, differential equations, non-linear systems and stochastic processes (McKenzie 2007: 22–3). Several different climate models have been developed to relate greenhouse gas emissions to changes in the Earth's climate. Various mathematical techniques are used to validate these models, such as testing them on historical data.

The communication of climate change also involves mathematics. Climate change is now explained or discussed in a wide range of non-scientific contexts, including the mass media, official websites, blogs, official publications, reports and so on. Interpreting and, in some cases, participating in the production of these texts entails some level of engagement with the mathematics used to describe and predict climate change. Additionally, a degree of 'mathematical literacy' is also necessary, in relation to the use and interpretation of data, graphs and accounts of the mathematics involved. Newspaper articles, for example, now regularly include graphs or other mathematical graphics showing global temperature changes, emissions data and so on. Moreover, there are several examples of public debate in which mathematical considerations have been significant. Such considerations include arguments about the misrepresentation of data, about the status of predictions made on the basis of mathematical climate models and discussion about the concept of a long-term trend (in the light of particularly cold winter weather, for example). Policy makers, public servants, business and the general public are all, increasingly, consumers of information (and, in some cases, polemic) about climate change. The central role of mathematics in climate science, along with the increasing political and public attention that climate change is attracting, suggests an important role for education in general and mathematics education in particular.

Critical mathematics education and climate change

Without information technology, our understanding of climate change would be severely limited. Even the basic mathematical processes involved in calculating long-term norms or trends would be time-consuming and unwieldy when faced with the huge quantities of time-series data generated by multiple weather stations on multiple occasions. And without mathematical modelling and the mathematics of differential equations, non-linear systems, stochastic processes and so on, scenarios for the future of the climate of the planet, such as those presented by the IPCC (2008), would be more or less impossible to produce. Climate models, for example, typically include over a million lines of computer code and need to run for many days to generate modelling data representing a few decades of global climate (Weaver 2008).

The projections derived from these models are, however, already more than abstract scientific theories. They are having tangible social effects, from discussion and debate, to changing individual and organisational behaviour, to the creation of new national and international structures (see DEFRA 2009 for some examples). The description and prediction of climate change are thus good examples of the formatting power of mathematics: through mathematisation, social reality is changed. In this case, however, mathematical communication is a particularly important channel for this power. The formatting power of the mathematics of climate change arises somewhat differently from the formatting power of the airline ticket sales model (Skovsmose 2001, see Chapter 1), in which the model is embedded within the technology and the technology is then embedded within social practice. In the case of climate change, the mathematics is embedded in technology used by scientists, not by the general public. The outcomes of scientists' work are then transformed, through communication, to appear within a range of different discourses (political, governmental, mass media). It is these mathematical communications that are then embedded within social practice.

The mathematics of climate change involves all three of Skovsmose's forms of knowing (again, see Chapter 1). Mathematical knowing concerns the mathematics involved in describing or predicting climate change, as well as in communicating climate change, as summarised earlier in this paper. Technological knowing involves knowing how to construct the mathematical tools necessary for understanding climate change. In describing climate change, for instance, the calculation of global temperature increases involves some specific ways of using recorded temperatures and arithmetic means (see Example 1: What is normal?). Technological knowing also involves knowing how to use these tools, such as how to interpret the resulting means. Given the central role of mathematics in the communication of climate change, we can also include technological knowing relating to the construction and interpretation of graphical or linguistic representations of climate changes or the related mathematical processes. Being able to make sense of a graph showing three possible future climate scenarios (related to three different emissions scenarios) is as much a part of technological knowing as being able to construct the models that lead to these projections.

Reflective knowing about the mathematics of climate change potentially involves an awareness of several different issues. These issues include the following points.

- An awareness of the effects of the various decisions made in the mathematisation of climate processes, such as what is included or excluded from a model. Given some of the (sometimes bizarre) debates that are taking place, it is important that mathematical modelling, for example, is understood as a general process.
- An awareness of the formatting power of mathematics in relation to climate change. As argued above, this power is derived from communication processes. Critical citizens need to be able to interpret and participate in discussion and debate about climate change; they also need an awareness of how particular mathematical representations of climate change may be linked to the (potentially political) interests of the author.
- An awareness of the nature of the relationship between mathematics and science. While scientists generate data and physical models of the climate and the planetary ecosystem more broadly, their understanding of the specific nature of human-induced climate change is almost entirely due to mathematics.
- An awareness of human impacts on the climate. As Skovsmose recognises (1994: 170–4), mathematics provides a powerful way for learners and citizens to interpret and participate in society. In the context of climate change, mathematics provides a means to examine, for example, current emissions by country, by activity, or by individuals. In all three areas, wide disparities and inequities exist.

In the rest of this chapter, some of these ideas are illustrated through three examples. In the first example, which focuses on the mathematics of describing climate change, I look at how long-term climate statistics are calculated. The second example looks at some aspects relating to the predicted frequency of extreme weather events in a warming global climate. In the third example, which focuses on communicating climate change, I examine data on greenhouse gas emissions to consider how different ways of representing data can tell different kinds of story.

Example 1: What is normal?

Climate change is increasingly in the news. Look at the selection of headlines and extracts below. What mathematics is involved?

Flood warnings: hottest year confirms global warming say experts

The two most respected national weather services in the US, NASA and the National Oceanic and Atmospheric Administration (NOAA), agreed that 2010 tied with 2005 as the hottest since records began in 1880.

Overall 2010 and 2005 were 1.12°F (0.62°C) above the 20th century average when taking a combination of land and water surface temperatures across the world.

(Daily Telegraph, 13 January 2011)

Met Office: 2010 was second warmest year on record

Last year was the second warmest on record after 1998, the Met Office announced today. With a mean temperature of 14.5°C, 2010 was 0.5°C warmer than the

global average from 1961–1990, according to data from the Met Office and the University of East Anglia.

The UK recorded its coldest year since 1986 and its coldest December in 100 years, according to the Met Office. However, very few parts of the world were significantly colder than normal during 2010.

(The Guardian, 20 January 2011)

Forget the chill, 2010 was India's hottest year on record

NEW DELHI: Severe cold may well be making headlines in the past two weeks, but here's the big picture: 2010 was the warmest year ever in India since weather records began in 1901. The Indian Meteorological Department announced on Thursday that the mean annual temperature in the country during 2010 was as much as 0.93 degrees Celsius higher than the long term (1961–1990) average.

IMD officials said the record heat in 2010 was a continuation of the warming trend in the past decade that can only be attributed to global warming. The last decade has been the warmest in the country's history. The previous warmest year was 2009, when the annual mean temperature was 0.913 degrees C above the long term average.

(Times of India, 14 January 2011)

How do you take the temperature of a planet? It turns out, perhaps not surprisingly, that you do not. The above reports are based on analysis of millions of temperature records from weather stations around the world. While the quantity of data is mind-boggling, much of the mathematics is fairly straightforward. There are two key concepts that underlie most of the calculations.

Long-term averages refer to the arithmetic mean of climate data (e.g. temperature, precipitation, hours of sunshine) over a given period of time. The World Meteorological Organisation stipulates the use of 30-year periods, although sometimes 100-year periods are also used. Thirty years is considered to be the minimum period necessary to eliminate the effects of year-to-year variation. In the UK, these long-term averages are updated every decade (see Met Office n.d.). For example, the long-term monthly average minimum and maximum temperatures for Sheffield for the period 1971–2000 are shown in Table 3.2.

Anomaly refers to the difference between a given data point and a long-term average. So, for example, a recorded maximum temperature in Sheffield on 3 October 2011 of 24.7°C represents an anomaly of 11.4°C with respect to the long-term October average. Anomalies can also be calculated for means: the mean maximum temperature for October 2011 can be compared with the long-term average mean. The anomaly is simply the difference between them. Table 3.3 shows temperature anomalies in annual means in Sheffield for the period 1981–2010.

Anomalies can be averaged across multiple locations, providing they all relate to the same 30-year period. The advantage of working with anomalies rather than actual temperatures is that they eliminate the effects of local geography. A weather station in the mountains will record cooler temperatures than a weather station in the lowlands, even if they are quite close together (e.g. at the top of Snowdon *vs.* in Bangor on

Table 3.2 Average minimum and maximum temperatures for Sheffield for the period 1971–2000

	Max Temp (°C)	Min Temp (°C)
January	6.4	1.6
February	6.7	1.6
March	9.3	3.1
April	11.8	4.4
May	15.7	7.0
June	18.3	10.0
July	20.8	12.4
August	20.6	12.1
September	17.3	10.0
October	13.3	7.2
November	9.2	4.2
December	7.2	2.6
Year	13.1	6.4

Data source: <http://www.metoffice.gov.uk/climate/uk/averages/19712000/sites/sheffield.html>

the coast). By calculating a long-term average for each location and then calculating anomalies in relation to that long-term average, we might see, for example, that each location has recorded temperatures 1°C above the long-term average, even if the actual temperatures were different.

The 30-year long-term average, then, is the standard definition of ‘normal’. In a stable climate, we might expect any 30-year period to produce similar norms, with even less variation apparent when considering 100-year norms. And in a stable climate, we might also expect the anomalies to be fairly evenly distributed around the long-term averages. In the case of temperature, for example, some years are hotter, some years are cooler, but over the long-term, the hotter and cooler years balance out.

A quick glance at the anomalies columns in Table 3.3, however, is enough to see that there are more negative anomalies in the top half of the table compared with the bottom half. Representing the anomalies in graph form bears this out (see Figures 3.1 and 3.2). The graphs also include linear regression lines. The equations for these regression lines suggest that over the 30-year period, there is a mean increase in the annual mean temperature in Sheffield of 0.03°C per year, with an overall increase of a little under 1°C. An alternative representation of the long-term trend is also provided: the dotted lines represent five-year averages, which smooth out annual fluctuations. This line also shows a general increasing trend, although with a dip in the last part of the graph. Which of the two trend lines is more realistic? Does the linear regression line ‘hide’ a more recent cooling? How reasonable is it to construct a linear regression, given that the climate is a non-linear system? It is perhaps worth pointing out that the recent dip is still entirely above the long-term mean.

Table 3.3 Annual mean daily maximum and minimum temperature anomalies for Sheffield, UK, 1981–2010, relative to 1981–2010 norms.

	Maximum temperatures (°C)			Minimum temperatures (°C)		
	Annual mean max temp	Long-term average annual max temp (1981–2010)	Anomaly	Annual mean min temp	Long-term average annual min temp (1981–2010)	Anomaly
1981	12.5	13.4	-0.9	6.8	6.6	0.2
1982	13.5	13.4	0.1	6.4	6.6	-0.2
1983	13.2	13.4	-0.2	6.7	6.6	0.1
1984	13.3	13.4	-0.1	6.2	6.6	-0.4
1985	12.3	13.4	-1.1	5.8	6.6	-0.8
1986	12.1	13.4	-1.3	5.3	6.6	-1.3
1987	12.4	13.4	-1.0	5.8	6.6	-0.8
1988	13.1	13.4	-0.3	6.5	6.6	-0.1
1989	14.2	13.4	0.8	6.9	6.6	0.3
1990	14.3	13.4	0.9	7.3	6.6	0.7
1991	13.0	13.4	-0.4	6.3	6.6	-0.3
1992	13.3	13.4	-0.1	6.4	6.6	-0.2
1993	12.6	13.4	-0.8	5.9	6.6	-0.7
1994	13.3	13.4	-0.1	6.5	6.6	-0.1
1995	14.0	13.4	0.6	6.8	6.6	0.2
1996	12.4	13.4	-1	5.8	6.6	-0.8
1997	14.0	13.4	0.6	7.0	6.6	0.4
1998	13.5	13.4	0.1	7.0	6.6	0.4
1999	14.1	13.4	0.7	7.2	6.6	0.6
2000	13.5	13.4	0.1	6.9	6.6	0.3
2001	13.3	13.4	-0.1	6.4	6.6	-0.2
2002	13.9	13.4	0.5	7.2	6.6	0.6
2003	14.4	13.4	1	6.7	6.6	0.1
2004	13.9	13.4	0.5	7.5	6.6	0.9
2005	13.9	13.4	0.5	7.2	6.6	0.6
2006	14.2	13.4	0.8	7.4	6.6	0.8
2007	13.8	13.4	0.4	7.2	6.6	0.6
2008	13.4	13.4	0	6.9	6.6	0.3
2009	13.6	13.4	0.2	7.1	6.6	0.5
2010	12.4	13.4	-1	5.9	6.6	-0.7

Data source: <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt>

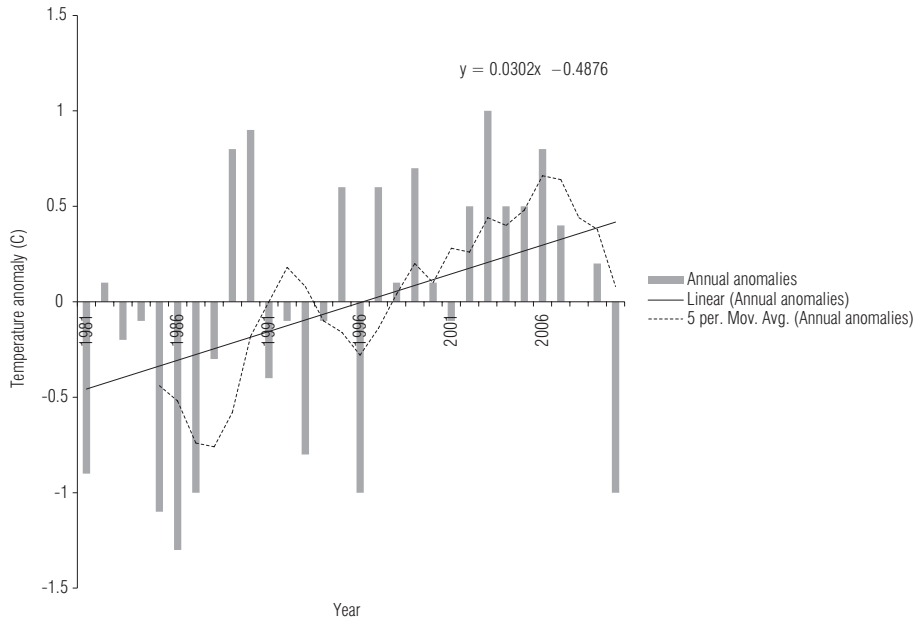


Figure 3.1 Annual mean maximum temperature anomalies for Sheffield, UK (1981–2010 baseline) (Based on data sourced from <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt> /)

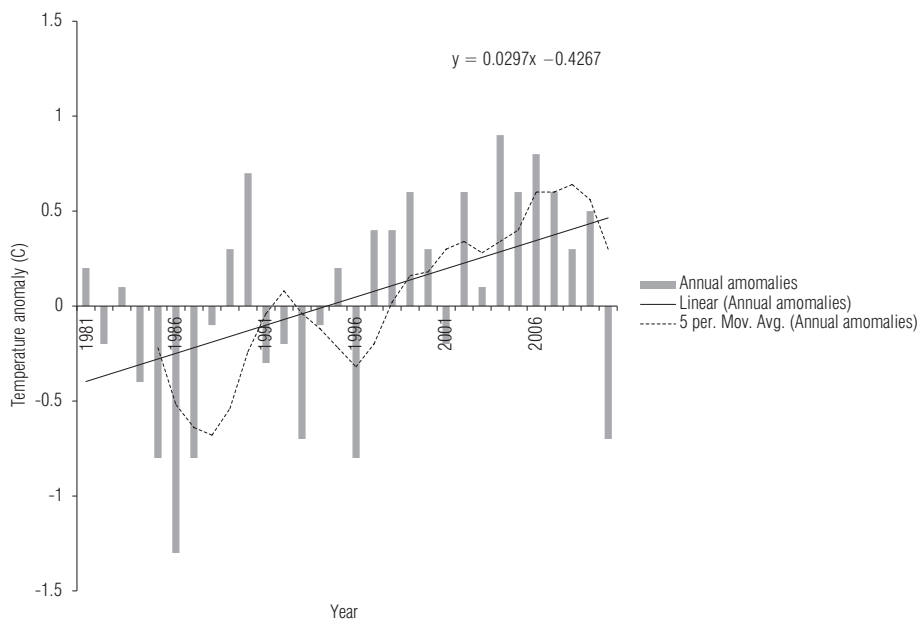


Figure 3.2 Annual mean minimum temperature anomalies for Sheffield, UK (1981–2010 baseline) (Based on data sourced from <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt> /)

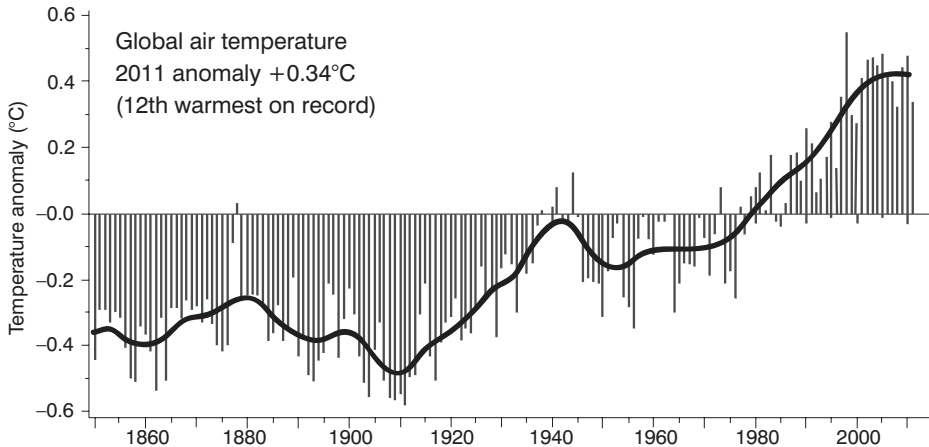


Figure 3.3 Global temperature anomalies 1880–2010

Source: Jones (2011) see <http://www.cru.uea.ac.uk/cru/info/warming> © Copyright 2012, Climatic Research Unit.

Furthermore, the long-term norms for 1971–2000 are below those for 1981–2010. Indeed, a similar graph for global data for the whole of the last century looks very similar to the graphs for Sheffield (see Figure 3.3). This data is based on averaging temperature anomalies across the globe.

These graphs suggest that both locally and globally, temperatures are steadily rising. The purpose of the preceding account is not particularly to persuade you that our planet is warming, although it might do this. Its purpose is more to give some sense of how meteorological data is, and can be, collated and examined to find out about long-term trends.

In terms of mathematics teaching, there are a couple of points of interest. First, with the exception of linear regression, all the preceding information is based on arithmetic means and basic arithmetic. Second, meteorological data for many locations in the UK are available online. And there is something powerful and immediate about analysing data for where *you* live. The information about temperatures in Sheffield was obtained from the Met Office website which provides monthly mean maximum and minimum temperatures. Using a spreadsheet, annual means, long-term means and anomalies were calculated. The graphs and trendlines were also prepared using a spreadsheet.

The above methods raise many questions that could form starting points for classroom investigation. What happens if different long-term norms are calculated? e.g. 10-years? 20-years? 50-years? What happens to running averages, as shown in Figures 3.1 and 3.2, if different periods are used? e.g. 2-year, 5-year or 10-year? What trends are apparent in other meteorological data? e.g. rainfall? How do these trends relate to the trends in temperature? These kinds of questions are about both mathematics and climate change. Exploring them should lead to a better understanding of both. An understanding of the mathematics of temperature trends will better equip students to participate in the associated debates about the nature of climate change and about the kind of action that might be necessary to respond to it.

Example 2: If the planet is warming, why was the winter of 2010–2011 so cold?

Hardly a snowfall goes by in the UK without opinion pieces appearing in the newspapers telling us that there is no climate change. The winter of 2010–2011 was the coldest for several years and there were suggestions that it indicated the start of a cooling trend. In fact, there are good mathematical reasons to expect some extreme cold weather events as a result of global warming (as others have already argued: see Weaver 2008, and Whiteley 2011).

Consider the range of temperatures experienced where you live. Some days are warmer, some are cooler, some are about average. The varying temperatures can be thought of as distributed around the long-term average. Extreme heat or extreme cold occur much more rarely than temperatures close to the long-term average. In fact this kind of pattern is apparent in the data shown for Sheffield. Most of the anomalies are clustered close to 0, with only a few extremes standing out in the graphs shown in Figures 3.1 and 3.2.

If the climate is warming, however, as we have seen, the long-term average will itself shift to a higher value. Perhaps in 30 years' time, the long-term average in Sheffield will be another 1°C above its current value. What would this mean for the distribution of temperatures from day to day or week to week? A starting assumption would be that the whole distribution as currently experienced would simply shift 1°C further up. This assumption is illustrated in Figure 3.4(a), which shows a 'current' distribution of temperatures and a 'future' distribution shifted along the x -axis. The figure also shows that in this scenario, we would expect to experience more extreme heat events and no extreme cold. This scenario corresponds to many people's expectations of the effects of climate change.

The climate is, however, not that simple (in mathematical terms, it is non-linear). In particular, an increase in global temperature means that there is more energy in the atmosphere. More energy results in greater variability, whether in terms of wind, precipitation or temperature. Consider, for a moment, what would happen if our starting distribution (e.g. of temperatures in Sheffield) was affected by an increase in variance, but not of temperature. As the total number of readings is fixed, the effect would be to flatten the distribution, spreading it out at the ends. In other words, there would be an increase in frequency of weather at the extremes, both hot and cold. This scenario is illustrated in Figure 3.4(b).

Increasing temperature will result in increased variance, however, so the two preceding scenarios need to be combined. Our initial distribution will shift along the x -axis, but the distribution will also flatten as variance increases. This scenario is illustrated in Figure 3.4(c). Depending on the x -axis shift, the resulting scenario could conceivably include a slightly greater number of extreme cold events, in addition to an increase in the number of extreme heat events. The combination shown in Figure 3.4(c) implies a similar frequency of extreme cold events, and a large increase in hot and extreme heat events. Hence it is entirely expectable that global warming will still involve unusually cold weather from time to time. Of course this scenario does not make it possible to predict precisely when extreme hot

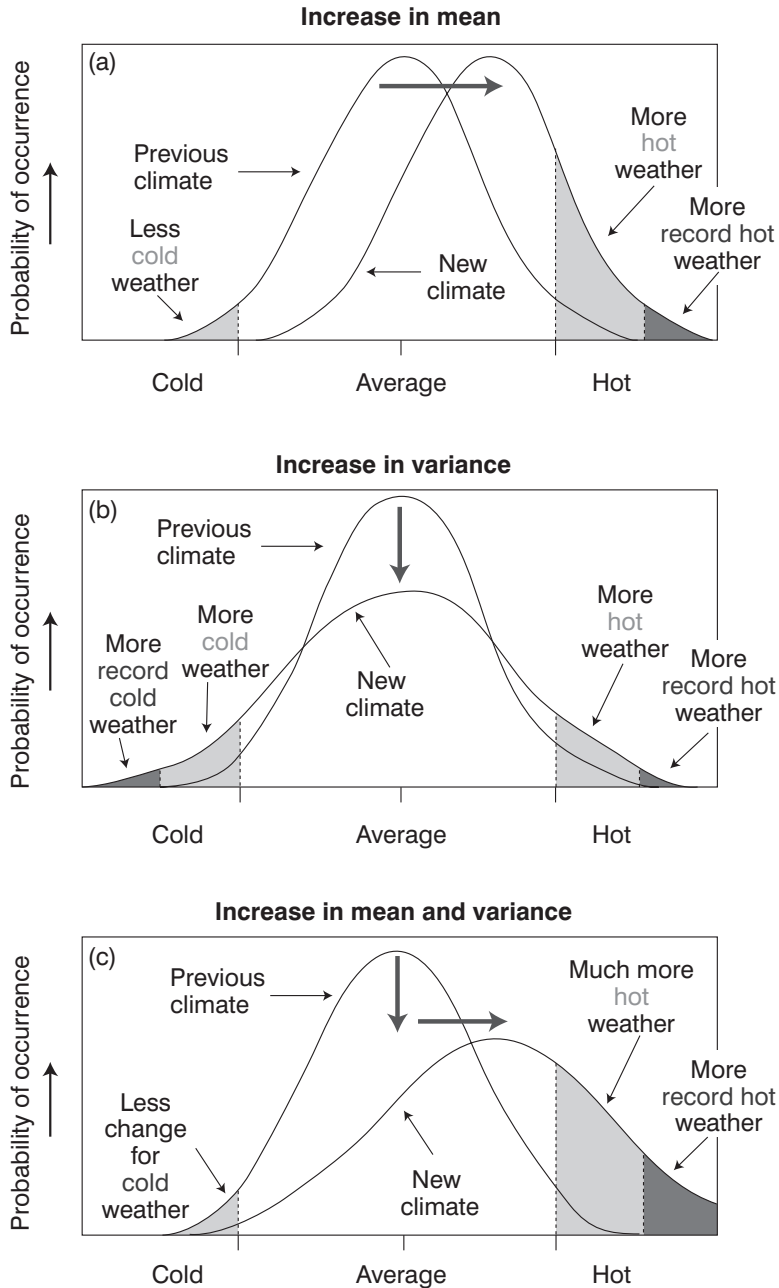


Figure 3.4 Schematic showing the effect on extreme temperatures when (a) the mean temperature increases, (b) the variance increases, and (c) when both the mean and variance increase for a normal distribution of temperature.

Source: *Climate change 2001: the scientific basis*. Contribution of Working Group I to the Third assessment report of the Intergovernmental Panel on Climate Change, Figure 2.32. Cambridge: Cambridge University Press

Table 3.4 Mean maximum and minimum temperatures and standard deviations for two 30-year periods in Sheffield, UK

	Mean maximum temperature (°C)	Standard deviation (°C)	Mean minimum temperature (°C)	Standard deviation (°C)
1901–1930	12.6	0.51	6.0	0.39
1981–2010	13.4	0.66	6.6	0.56

Data source: <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt>

or cold events might occur; it just gives information about the likely frequency of such events.

The argument above is a theoretical one, based on mathematical reasoning (about distributions) and physics (the effects of adding energy to the climate system). The argument can easily be tested. The Met Office data for Sheffield go back to the nineteenth century. Table 3.4 shows the long-term mean maximum and minimum temperatures and associated standard deviations for two thirty-year periods: 1901–1930 and 1981–2010.¹

These calculations fit with the argument made above. Not only has the mean temperature increased in Sheffield, so has the variation in temperature, as indicated by the standard deviation. If annual mean temperatures are normally distributed around the long-term mean, we would expect 67 per cent of annual mean temperatures to be within one standard deviation of the long-term mean. And we would expect 95 per cent of annual mean temperatures to be within two standard deviations of the long-term mean. Extremely warm or cool years could be defined as the 5 per cent of years that fall outside of two standard deviations. These distributions are interpreted in Tables 3.5a and 3.5b.

The annual mean minimum temperature records fit closely the projection made above: over the past century, while the annual mean minimum temperature in Sheffield has increased by 0.6°C, the point representing two standard deviations below the mean has hardly changed. This means that the frequency of unusually cool years has not significantly changed, even though the majority of years have higher mean minimum temperatures than before. At the other end of the scale, the likelihood of years with much higher mean minimum temperatures has become much greater.

The calculations for annual mean maximum temperatures suggest that there has been a greater shift in mean maximum temperatures with less flattening of the distribution. Nevertheless, years in which the mean maximum temperature is below 12.0°C have not disappeared, but they have become much less likely, down from 15 per cent of years in 1901–1930 to 2.2 per cent of years in 1981–2010.

There are a couple of points to highlight here with respect to teaching mathematics. As with the previous example, the data used in this example are available online and the calculations were made using a spreadsheet. The mathematics involved is more advanced than the calculation of long-term averages, involving consideration of frequency distributions, variation and the calculation and meaning of standard

Table 3.5a Mean maximum temperature distributions for two 30-year periods in Sheffield, UK

	-2 standard deviations	-1 standard deviation	Mean maximum temperature (°C)	+1 standard deviation	+2 standard deviations
1901–1930	11.5	12.0	12.6	13.1	13.6
1981–2010	12.1	12.7	13.4	14.0	14.7

Data source: <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt>

Table 3.5b Mean minimum temperature distributions for two 30-year periods in Sheffield, UK

	-2 standard deviations	-1 standard deviation	Mean minimum temperature (°C)	+1 standard deviation	+2 standard deviations
1901–1930	5.3	5.6	6.0	6.4	6.8
1981–2010	5.4	6.0	6.6	7.2	7.7

Data source: <http://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/sheffielddata.txt>

deviation. The mathematics has several points of mathematical interest, which could form useful starting points for students' work. For example, what happens to distributions of temperature data over time? Or over longer long-term periods? What happens to other meteorological data, such as precipitation or wind speed? What counts as 'extreme'? How frequently have extreme weather events been recorded? How have these frequencies changed over time? Again, these kinds of questions are about both mathematics and climate change. An understanding of the mathematics can enable students to critically evaluate newspaper reports of the end of climate change and to contribute to the associated debates.

Example 3: Who is to blame?

One of the major sticking points in international negotiations for action to minimise climate change comes down to an issue of fairness. Rich industrialised countries have become rich through burning fossil fuels to power their economies. Now that the effects on the climate have become apparent, the goal is to reduce fossil fuel emissions across the globe. Poorer countries and countries with emerging economies have argued that they cannot allow reductions in carbon emissions to stop the process of industrialisation, through which they hope to make life better for their citizens. They argue that since it is the industrialised nations that have polluted the atmosphere for well over a century, it is the industrialised nations that should carry the greater burden. In this section, I look at different ways of presenting emissions data to explore this issue. I focus on two nation-states: the UK and India. As with Example 1, the data

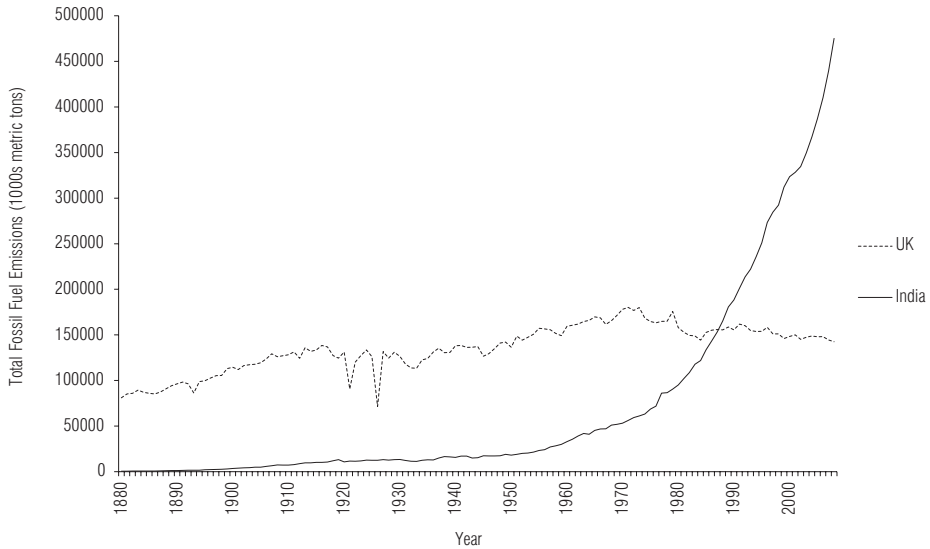


Figure 3.5 Annual fossil fuel emissions for the UK and India (1880–2008) (data source: http://cdiac.ornl.gov/ftp/ndp030/nation.1751_2008.ems)

used to produce the graphs are available online (at cdiac.ornl.gov) and the graphs were constructed using a spreadsheet.

First, look at Figure 3.5, which shows annual fossil fuel emissions for the two countries. This graph tells an interesting story. The UK's emissions have been relatively stable, approximately doubling over a period of 100 years, and declining slightly in the past 30 years. This decline may be attributed to a reduction in manufacturing in the UK, as well as to a shift from coal-fired to gas-fuelled power stations. In India, by contrast, emissions have increased sharply in an approximately exponential fashion. This sharp increase may be attributed to a growing level of industrialisation and consumption, combined with a rapidly increasing population. The graph also suggests that India is now a much bigger source of greenhouse gases than the UK (India is the third biggest emitter in the world). Now look at Figure 3.6, which shows *cumulative* emissions, based on the same data over the same period.

This graph presents things in a rather different light. The UK's relatively constant output over more than a century adds up to a vast quantity of greenhouse gas emissions. Carbon dioxide, the main greenhouse gas, remains in the atmosphere for at least a century, so that UK emissions from the first half of the twentieth century are still affecting the global climate now. India's emissions, by contrast, while now at a much higher annual rate than the UK's, are still cumulatively less. If current trends continue, however, India's cumulative emissions should overtake those of the UK in a fairly short time. So soon India will be a bigger polluter than the UK both annually *and* cumulatively – and it could therefore be argued that India is more 'to blame'. But what happens when we take into account the populations of the two countries? Look at Figure 3.7.

This graph shows a different picture again: while the UK's emissions per capita have fallen over the past decades, they remain five times higher than India's. Each

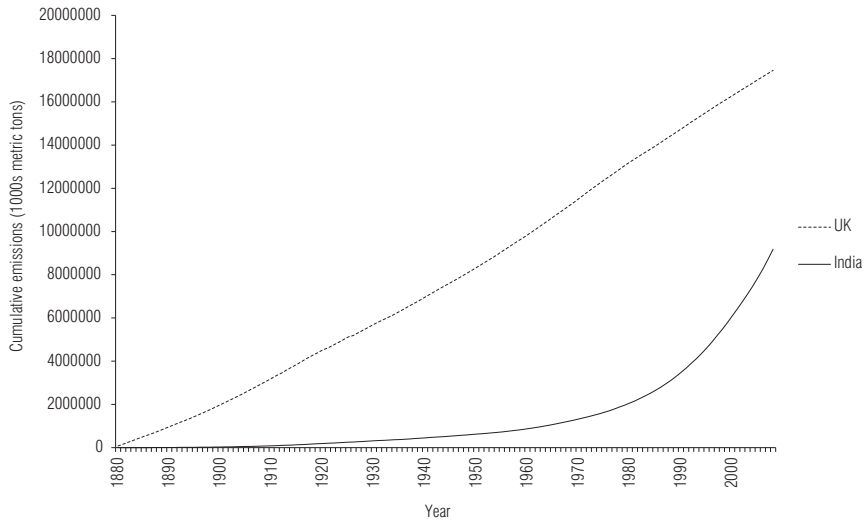


Figure 3.6 Cumulative fossil fuel emissions for the UK and India (1880–2008) (data source: http://cdiac.ornl.gov/ftp/ndp030/nation.1751_2008.ems)

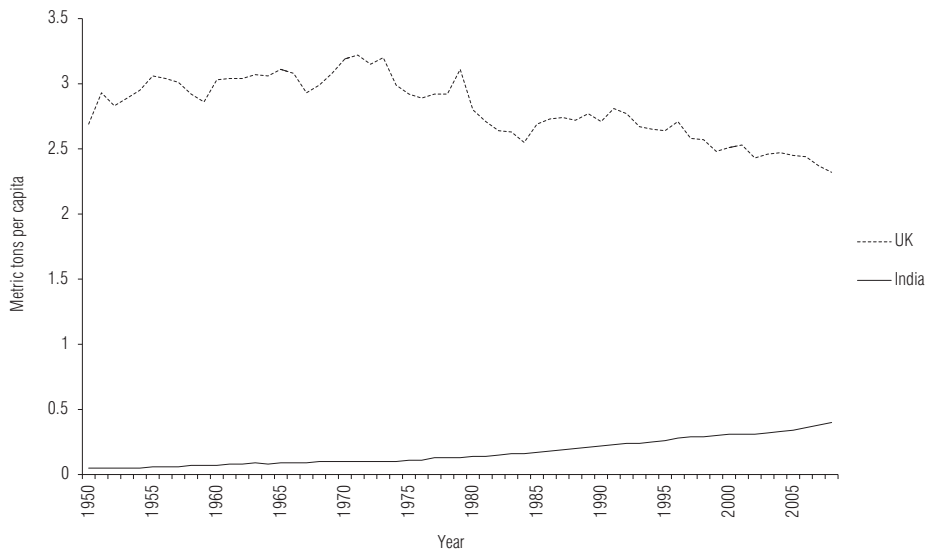


Figure 3.7 Annual fossil fuel emissions per capita for UK and India, 1950–2008 (data source: http://cdiac.ornl.gov/ftp/ndp030/nation.1751_2008.ems)

person in the UK produces on average five times more emissions than each person in India. On the other hand, India's per capita emissions have approximately quadrupled in the past 60 years. What might the future bring? UK per capita emissions seem to be declining somewhat, although they remain much higher than India's. In India, by contrast, the trend seems to be upward. It seems likely that if Indian consumption

reaches industrialised levels, the per capita emissions will increase quite dramatically, with potentially disastrous effects on our planet.

I have presented just three representations of greenhouse gas emissions. Others could be considered. In particular, emissions data does not generally take into account ‘offshore’ emissions. Much of the emissions from China, for example, arise from manufacturing goods for export to North America and Europe. If these emissions are tallied under the totals for the country of consumption, greater differences are apparent. Recent analysis by Davis, Peters and Caldeira (2011) suggests that around 40 per cent of the emissions relating to the goods and services in the UK economy are produced overseas.

As with the previous examples, the above discussion suggests several starting points for mathematical investigation. These different graphs, for example, are based on the same data. Which gives a ‘truer’ picture? Perhaps the truest picture comes from looking at all of them. Nevertheless, consideration of the differences between the three graphs shows how they highlight different things. Now imagine you represent India in international climate negotiations: which graph would you present to support your case? What about if you represented the UK? Graphs are not entirely neutral. Part of a critical mathematics education is about learning to interrogate not only the data, but also the way it is represented, and to consider whose interests might be served by the particular choices that have been made.

Conclusions and future directions

Climate change is an issue of global concern that is increasingly likely to affect our lives in the coming century. Future citizens need a critical understanding of the role of mathematics in understanding climate change and a critical awareness of the ways that mathematics is communicated if they are to participate in the development of a global societal response. Mathematics education has a role to play in developing this critical awareness (Barwell 2013). Climate change is not an issue that we can simply leave to scientists to solve and tell the rest of us what measures we need to take to make the problem go away. The climate is a planetary-scale system, in which humans are one part of the biosphere. Interventions or actions to try to stop climate change or mitigate its effects cannot be introduced in isolation. For example, some governments have started to implement carbon taxes on air travel. But air travel is by its nature international, so this taxation has effects on the airline market. Or, to take another example, a decision to close coal-fired power stations would have a much greater impact on some countries than others. China’s recent growth and the associated rise in living standards for many Chinese has been accompanied by a huge programme of power station construction. Thus the nature of climate change means that we all need to be involved in tackling the problem, not just in changing our behaviour, but in participating in the discussion and debate about what to do (Hulme 2009). And participating in this discussion requires a degree of mathematical understanding. The purpose of this chapter has been to show a little of the nature of this mathematics and show how it relates to an understanding of some aspects of climate change. As mathematics teachers, we have an important role to play in educating our students to participate in the debate.

Further reading

- The London Grid for Learning Weather Monitoring System includes detailed historical weather data as well as real-time records for many locations around the UK: <http://weather.lgfl.org.uk/Default.aspx> (accessed 19 July 2012).
- Met Office Climate Averages – 1971–2000 averages for several different climate variables for many locations around the UK: <http://www.metoffice.gov.uk/climate/uk/averages/> (accessed 19 July 2012).
- The American Mathematical Society’s Mathematics Awareness Month for 2009 was on ‘Mathematics and Climate’. It consists of a set of short essays and podcasts on a variety of topics related to this theme, all available online: <http://www.mathaware.org/mam/09/essays.html> (accessed 19 July 2012).

Note

- 1 The data for Sheffield consist of monthly mean minimum and maximum temperatures. The record for 1901–1930 is incomplete: the data for some months are missing in 1918, 1919 and 1923. These entire years were therefore not included in calculations of means and standard deviations. The standard deviations were calculated using a spreadsheet.

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