Climate change in the mathematics classroom: a local approach to a global challenge

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Climate change is affecting planet Earth. The most recent report of the Intergovernmental Panel on Climate Change, the international body that surveys and synthesises evidence from climate science, includes the following statement:

> Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (IPCC, 2013, p. 2)

Our students, perhaps more than us, will be part of the generation that has to deal with the consequences. How can we, as mathematics teachers, prepare our students to engage with the issues surrounding climate change? There are two aspects to my response to this question. The first concerns the role of mathematics in understanding climate change. The second concerns the future role of citizens in dealing with climate change. These two aspects are related.

The mathematics of climate change

The climate is a complex system. It involves more than the atmospheric conditions in any given place. In addition to the atmosphere, it includes the oceans, the cryosphere (the frozen parts of the planet) and the land surface. The living creatures in each of these domains are also implicated in the climate in different ways. For example, forests affect temperature, humidity and other aspects of the atmosphere.

The science of climate change depends on mathematics. It is not possible for any individual to perceive planetary climate change. To get a picture of what is happening, we need mathematics. There are three ways in which mathematics is involved in understanding climate change:

- *Describing climate change*. To see changes in the climate, we need to describe it in different places and over time. Another way to say this is that climate is the statistics of weather. To describe different aspects of the state of the climate involves working with measurements and using statistics to describe what is normal and what is changing. What is measured? Temperature, rainfall, sunshine, snow cover, ocean acidity, sea level, CO_2 levels, the onset of spring etc. These measurements can then be examined using fairly basic statistical techniques, such as averages, measures of variance and graphing. This mathematics is well within the range of the school curriculum.

- *Predicting climate change*. To understand what the future holds for our planet requires much more advanced mathematics. The principal tool used by climate scientists is mathematical modelling. Climate models are extremely complex, based on multiple sets of coupled sub-models, and are based on differential equations, stochastic processes and so on. The models include sub-models of the atmosphere, cloud formation, the oceans, the cryosphere, land surfaces and so on. The coupling of different models also requires modelling of the interaction between different parts of the climate system. For example, models of the interaction between the ocean and the atmosphere.
- *Communicating climate change*. Climate science needs to be communicated, not just within the scientific community, but also for policymakers, planners in different domains (e.g. agriculture, construction, insurance) and the general public. This communication also depends on mathematical literacy, both in the production and consumption of information about climate change for these different audiences. Information is presented in various forms, including text, moving images, charts, tables, graphs and other graphics.

The role of citizens

Climate change is not the kind of scientific problem that can be solved in a laboratory, most obviously because it concerns the entire planet and all life. This includes human life, not just in terms of the impact of climate change on human life, but also in the sense that we are part of the ecosystem and human activity is the main driver of climate change. It is not possible for scientists to run a few experiments and come up with a technological fix.

Scientists, of course, have an important role to play, but research into problems like climate change (and others, such as species loss, energy generation, etc.) must increasingly include citizens in different ways. Indeed, it is clear that conventional laboratory science is not enough: the basic principles of climate change were identified over a century ago, and the evidence of a changing climate has been accumulating for decades. Despite this, little meaningful change to our economy and society has been made. Citizens have made a choice—to prioritise, for the most part, the way we live now, over the impacts of a changing climate in the future.

To engage in the debates and challenges facing us over climate change, citizens need to understand how climate science works. They need to understand, not simply to be passive consumers, waiting for scientists to come up with a fix. They need to understand in order to participate in the debates themselves. Indeed, some have argued that problems like climate change need a new kind of science, one in which citizens play a much greater role (see Barwell, 2013). To participate in this new kind of climate science, citizens must understand the mathematics of climate science. I do not mean that citizens must obtain graduate degrees in mathematics, but that they need a better understanding of how mathematics is used, its strengths and weaknesses, what it can do and what it cannot. In particular, citizens need a critical understanding of mathematics and its role in society.

A critical mathematics perspective

Mathematics is not a neutral tool. Mathematics is a powerful tool, both in the sense of a tool that is able to solve challenging problems effectively and efficiently, and also in the sense that it gives power to those who use it. This includes political power. Recent research in mathematics education has argued that to participate effectively in democratic society, citizens need a critical understanding of mathematics (Skovsmose, 1994). This idea has implications for teaching mathematics.

Skovsmose (1994) highlights some key aspects of a critical mathematics perspective. First, mathematics shapes society and our lives in many, often invisible, ways. To give one simple (and rather trivial) example: internet search engines work through sophisticated algorithms. While these algorithms are amazingly efficient, they are not neutral. They lead us to certain websites and do not show us others, based on the parameters included by whoever designed the algorithm. We may not pay much attention to this when we google something, but mathematics has shaped what we end up looking at (and buying).

Second, and implicit in the first point, mathematics is only one way of describing and organising the world. When a situation is mathematized, we gain tremendous power to examine and manipulate that situation. But we also lose much that cannot be mathematized (or monetarised), such as friendship, values, loss and so on.

And finally, and relatedly, mathematics is a human activity: it is humans that construct models and algorithms, who decide what to include and what to leave out, what to value and what not to value. These decisions advantage some people and disadvantage others. For example, search engine algorithms include sponsored links that lead the searcher to particular commercial sites in preference to others.

These ideas all apply to the mathematics of climate change. Indeed, if students are to be well prepared to participate as active citizens in responding to climate change in the decades to come, they need to develop a critical appreciation of the role of mathematics in understanding climate change…and in creating climate change. And for that, they need mathematics teachers.

Mathematics teaching and climate change: a local approach

It’s been a cold and snowy winter so far (I’m writing in January 2014) in central Canada. Last week saw prolonged temperatures below -30C in many places. Whenever such cold weather occurs, they seem to be accompanied by newspaper articles asking what happened to global warming. Let’s take an opinion piece from the National Post as an example. The article is entitled “For global warming believers, 2013 was the year from Hell” (see ‘weblinks’ at the end of this vignette for the url). I’ll quote a few words:

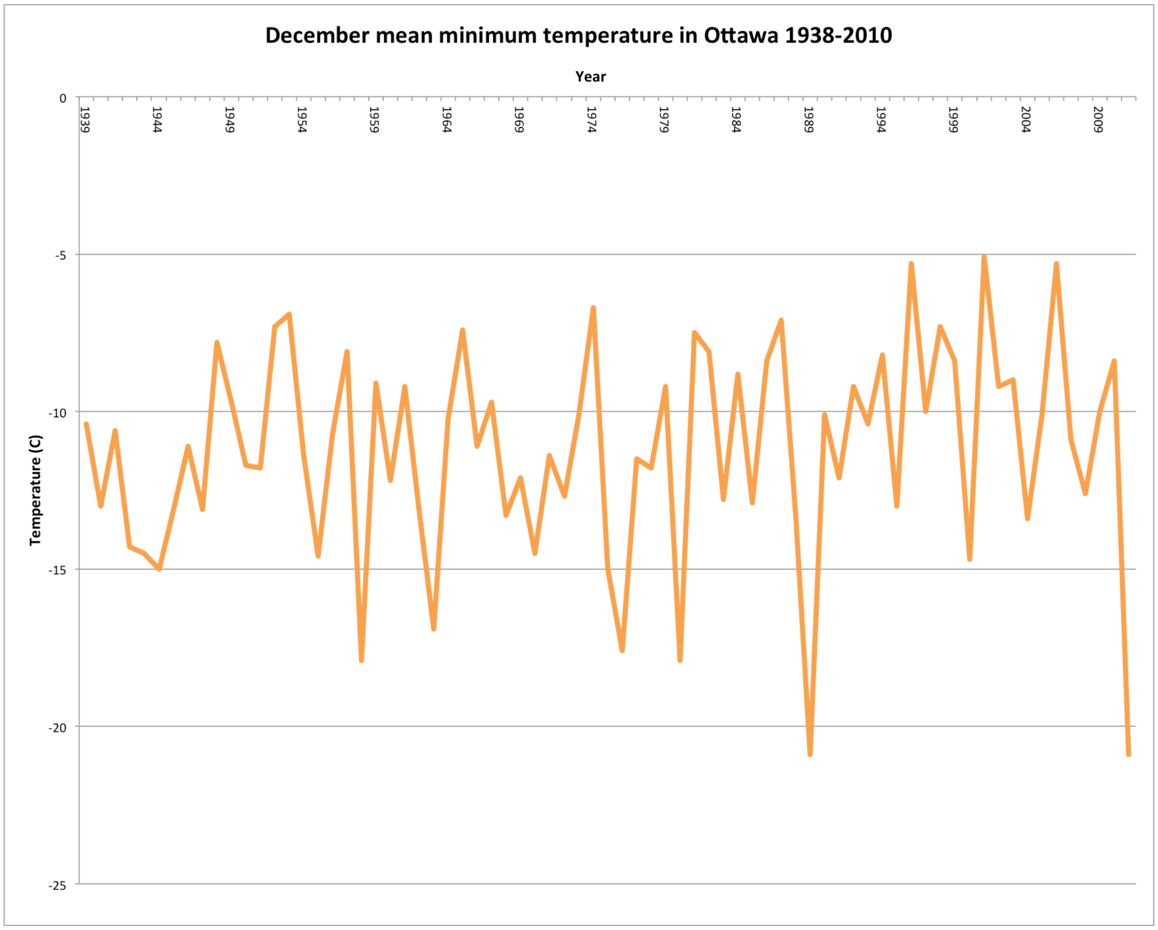
> 2013 has been a gloomy year for global warming enthusiasts. […] In December, US weather stations reported over 2000 record cold and snow days. Almost 60% of the US was covered in snow, twice as much as last year. […] 2013 marks the 17th year of no warming on the planet.

The author is Lawrence Solomon, described as executive director of Energy Probe, a Toronto-based environmental group. He is implying that the cold weather refutes the idea that the climate is changing.

There are some interesting mathematical questions related to these kinds of comments. Is the cold weather this winter unusual? That is, is it unusually cold? How common are such events? What about snow cover? How is climate change affecting the weather in Canada? Has it really stopped? Questions like these can be investigated by students relatively easily, using publicly available weather data. By investigating these or similar questions, students need to develop an understanding of how the nature of data, of methods of data reduction, of methods of summarising and presenting data and methods of interrogating data to answer questions. Students can also engage in questions of how data can be used to make different arguments about climate change (or anything else), and to question and sometimes challenge information they may see on the internet, in print or on television.

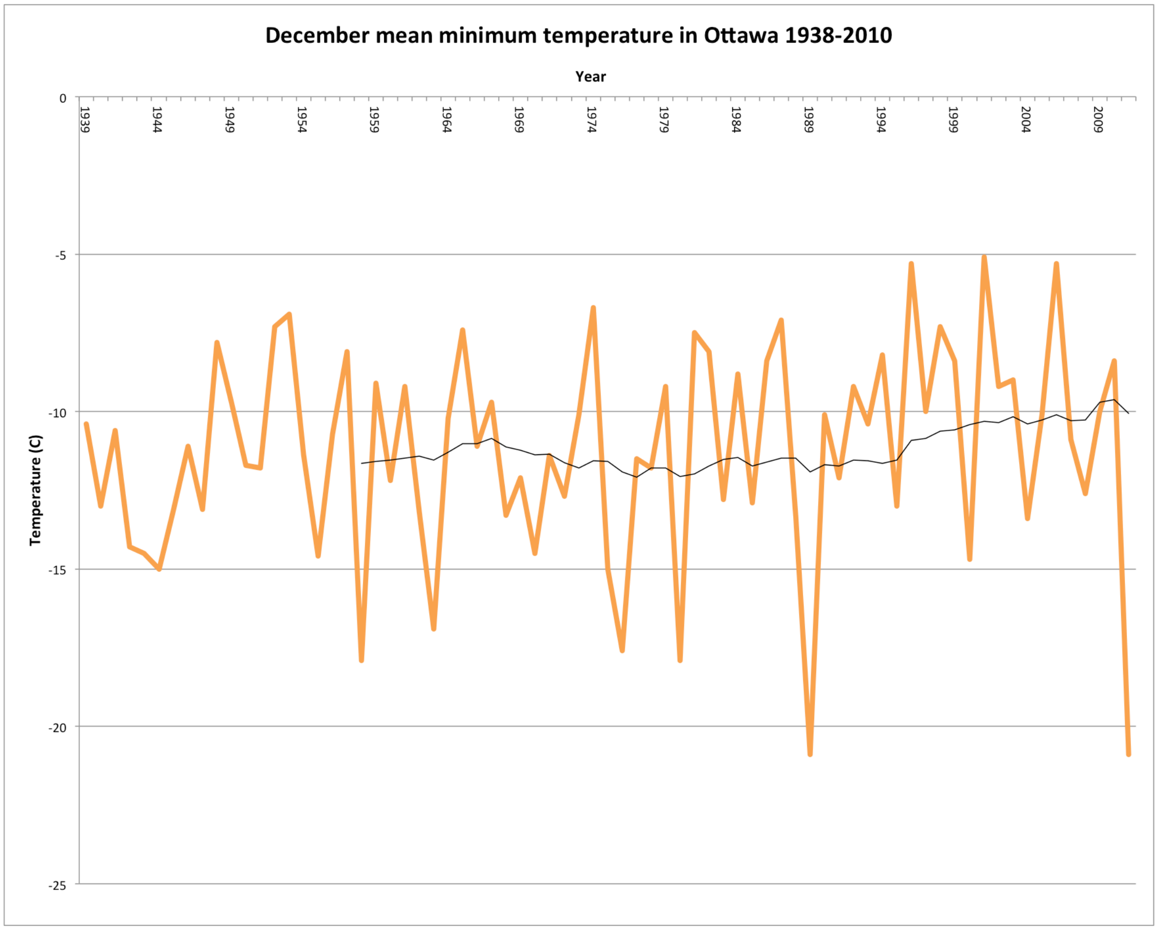
Let’s take an example. The government of Canada publishes historical weather data for over 1500 locations across Canada. The data generally dates back to the 1930s. The data can be obtained from http://climate.weather.gc.ca/ For this example, I entered ‘monthly’, selected a year, and typed ‘Ottawa’ into the search fields. From the results, I selected Ottawa MacDonald-Cartier International Airport—you could select data for where you and your students live. The results for the selected year in Ottawa appear on the screen and include, for each month of the year, the mean maximum and minimum temperatures, extreme maximum and minimum temperatures and total rainfall and snowfall. Above the data, on the right, it is possible to download the data. The download provides a spreadsheet of the same data shown on the screen, for every year from 1938 until 2011.

Consider the question of whether the cold weather in Ottawa in December 2013 was unusual in any way. To investigate this question with a class of students, I might start be looking at the mean minimum, maximum and daily mean temperature for the month of December for the length of the data set. Using Excel, I can plot this information on a graph (see below). Depending on the level of the class, I may include some preparatory work to understand what a monthly mean minimum temperature represents and how it is calculated.



What can you say about the graph? Does it suggest a trend of any kind? The mean minimum temperature for December 2013 in Ottawa was -14.7C (obtained from the same website). Does this mean seem to be unusual in the light of the graph?

One nice way to look at trends is to calculate 'moving averages'. A moving average is perhaps more intuitive than a regression line. It is interesting to examine different moving averages e.g. over 5 years, 10 years, 20 years etc. to compare the kind of information they provide. The graph below shows the mean minimum temperature for December in Ottawa with a 20-year moving average superimposed.



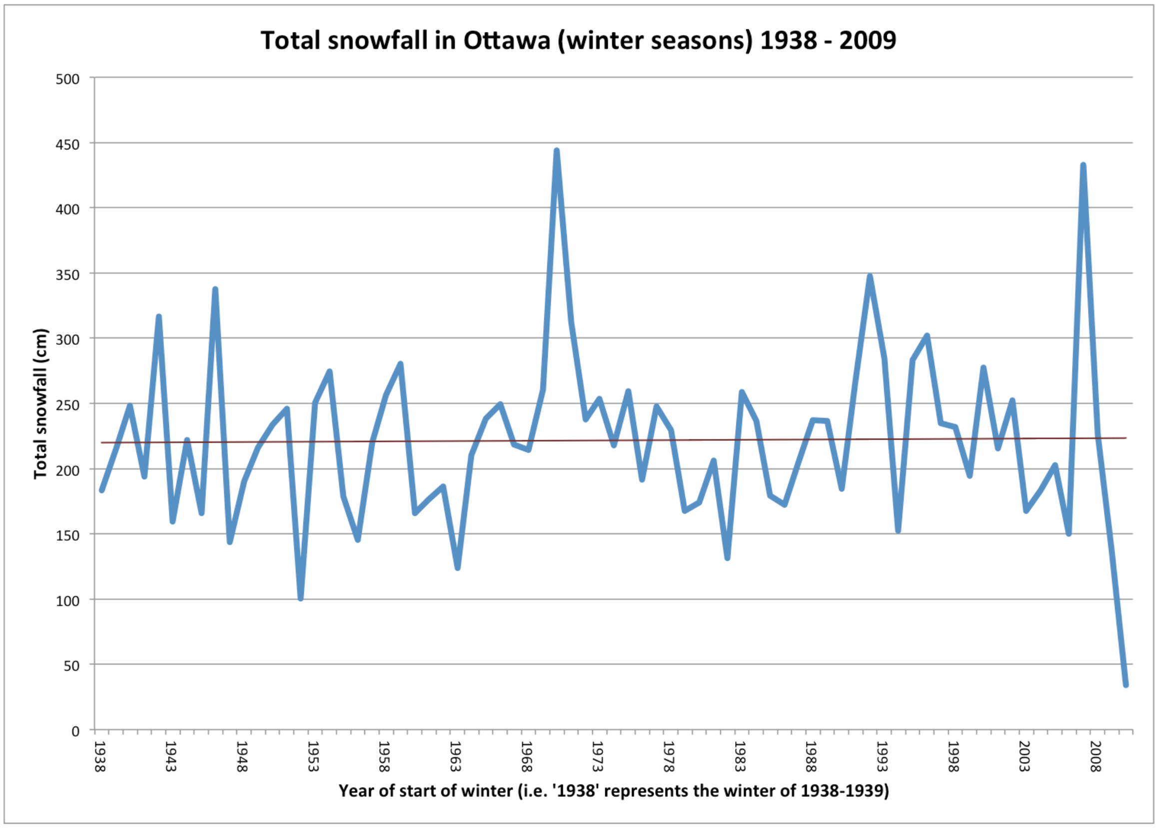
What trend does the moving average suggest? Discussing these graphs and the various questions should allow some important mathematical ideas to be considered. For example, the difference between variation and an underlying trend. Weather will always vary and will generally be above or below long-term norms. This does not necessarily mean that there is no long-term change. This point is worth considering in relation to the newspaper article quoted above. For example, December 2013 in Ottawa had a mean minimum temperature of -14.7C. This point is certainly below the trend line, but a visual inspection suggests that it is not unusually so: similar events have been observed 11 times in the past 70 years.

Meteorologists often work with 30-year periods – when 'normal' temperatures are quoted, they are based on the mean over the most recent 30-year decadal period – currently 1980-2010. Another interesting question to investigate is what happens to the 'normals' if the climate is changing. The same website (http://climate.weather.gc.ca/) provides normals for various measures and for various 30-year periods.

It would be important to explore maximum and mean temperatures for the same month, to obtain a fuller picture. In class, different groups could work on different subsets of the data.

For a fuller picture, the class could also investigate trends for other months of the year. (Similar work to that exemplified above shows substantial long term increases in spring and autumn temperatures, and reasonable increases for winter temperatures. Temperatures in the summer months seem to be more stable.)

Similarly, the question of snow cover can be investigated using the data included in the same spreadsheet. Below is a chart of total winter snowfall for the same period, with a linear regression line superimposed.



Production and subsequent discussion of this graph could discuss the variability of snowfall from year to year and the apparent lack of any discernable trend. This would suggest that the amount of snow this year has little relevance to a discussion of climate change in Ottawa.

Through discussion of news sources, opinion pieces and other comment on climate change, students can understand how data can be analysed, how it can be used to support (or refute) different opinions and how it can be presented. Discussions could further be extended to consider how trends might proceed in future, thus leading to a discussion of mathematical modelling. Questions to discuss here might include whether a linear model is appropriate? If not, what? And how precise a model of future climate in Ottawa (or anywhere else) can reasonably be.

The purpose of the ideas I have presented in this vignette is to give some general suggestions about how students can engage with the topic of climate change in the mathematics classroom (and why this is important). These ideas allow students to understand how mathematics is used to describe the climate and climate change, think a little about how it can be used to predict future climate, and examine how information about climate change can be communicated. It also enables students to think about how data is use to present different points of view and consider how mathematics is not a neutral tool. In particular, the availability of climate data for locations across Canada makes it possible for students to explore such issues from a local, and hence personal, perspective.

Further reading

Coles, A., Barwell, R., Cotton, T., Winter J. & Brown, L. (2013) *Teaching Secondary Mathematics as If the Planet Matters*. Abingdon, UK: Routledge. ISBN 0415688442

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Websites

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http://opinion.financialpost.com/2013/12/19/lawrence-solomon-for-global-warming-believers-2013-was-the-year-from-hell/

Energy Probe

http://ep.probeinternational.org/