Climate Change: Can Mathematics Help Clear the Air?

Does mathematics have a crucial role to play in understanding climate change? At least one third of the students in my First Year Seminar on Mathematics and Climate Change don't think so. And they are bright students who have signed up for a class on the topic! Hopefully their views will shift as the semester progresses, but it's easy to see why this is their first reaction. The physics of global warming is clear: the greenhouse effect means that increasing carbon concentrations reflect more and more of the long wavelength radiation emitted by the Earth itself, thus heating up the atmosphere. The chemistry too is clear: carbon that is the result of human activity can be distinguished by isotope, and it is this type of carbon that is increasing in concentration in the atmosphere. The evidence is now accumulating that the Earth has already warmed significantly. Why do we need to know anything more? For it is in the drive to know more about exactly what will happen that mathematics is brought in.

Prediction and prophesy of future events have fueled human emotions since time immemorial. From fortune-telling and astrology to the great plays of Ancient Greece, the word of those making predictions has carried great authority but has also attracted controversy. We would expect then that predictions of serious climate change would prompt similarly skeptical and severe reactions. But surely founding those predictions on sound mathematical modeling should exempt them from such a furor? One might argue that mathematical models of climate are of no use because we know that the weather is unpredictable after a few days, and the climate models are based on the same equations. So how can we even dream of making predictions decades into the future? The generally held explanation of the breakdown of weather prediction, credited to Lorenz, is that the system is sensitive to initial conditions, i.e., it is chaotic. But climate is about averages, and not specifics like whether it will rain over New York on April 1, 2009; wanted are average annual temperature, rainfall, and sea-level rise in regional climatic zones. This gives us reason for hope, as chaotic systems can have well-defined and robust statistical averages.

Predicting the climate involves modeling the entire Earth system in all its complexity. Beyond the obvious functioning of the atmosphere, critical elements include: sea ice and its dynamics, land ice and the way it might melt, ocean circulation, land use and deforestation, cloud formation and motion, as well as the socio-economics of carbon production. None of these are well understood nor do we have definitive—or, in some cases such as sea ice and clouds—even adequate, models for them. We bravely model the climate system anyway and use whatever information and models are available. This is clearly the right thing to do. But what do we make of the output?

We can certainly infer general trends from these predictions, but the social and political pressures to provide something more concrete are enormous. The response of the scientific community has largely been to focus on producing ever more complex models with ever increasing resolution. This makes good sense if this process of improving approximations is convergent. However, it is not at all clear that this process converges in any sense that we would trust, either mathematically or operationally.

The idea of a convergent prediction process has nevertheless put mathematics on the hot seat of climate change (and I suppose it goes without saying that it will only get hotter). I suspect that the mathematical community has, perhaps unconsciously, shied away from the area for this reason: something is being done in our name with which we are not completely comfortable.

Tunnel vision about climate prediction has obscured the enormous amount we have to offer the study of climate change. As mentioned earlier, critical processes, such as sea ice dynamics, cloud formation, and ocean circulation, are not well understood. Mathematical models will play a crucial role as our understanding of these processes develops and improves. Applied mathematics is about producing ideas for the modeling, analysis, approximation, and computation of models such as these. The models of these climate processes are tremendously complex, multifaceted (think of coupling socio-economic and physical models), and multi-scale, to mention just a few of their complexities. But this all goes toward making them fascinating objects of study.

As a discipline, applied mathematics does not claim to solve the big questions of the universe, and predicting the climate in 2100 may rank as such a question at this point in time. We are highly innovative technicians who get our hands dirty with details and produce ideas that can trigger unimagined advances. This triggering will happen only if we play in the right sandbox, and the sandbox of climate change processes badly needs us to jump in and get our hands into what is frighteningly looking like the sands of time.

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"Mathematics and Climate" is the theme for Mathematics Awareness Month (MAM) 2009. Mathematics departments and individuals across the country celebrate MAM each year in April to highlight the beauty and importance of mathematics. The 2009 MAM theme poster, theme essays, a sample press release, and other resources are available at `http://www.mathaware.org`. The May 2009 issue of the *Notices*, which will appear in mid-April, will also carry an MAM-themed article about modeling sea ice.