IS SCIENCE FICTION A GENRE FOR COMMUNICATING SCIENTIFIC RESEARCH?

A Case Study in Climate Prediction

By T. N. Palmer

Are there situations where science fiction is an effective genre for communicating—for example, to key policy- and decision makers—results from contemporary scientific research? Indeed, might sci-fi sometimes be a more effective genre for communication than conventional means? I want to discuss this question in the context of anthropogenic climate change.

Certainly there have been a number of sci-fi stories that deal with the climate change problem (e.g., by Kim Stanley Robinson and Michael Crichton), including one very memorable movie: *The Day After Tomorrow*. I am sure readers will have mixed feelings about the effectiveness of such works of fiction in promoting the science underlying climate change.

However, it is not the issue of climate change per se I want to discuss here. I will take it as given that we have now reached the stage where the threat of dangerous climate change is taken seriously by our decision- and policy makers. Rather, my concern is somewhat the opposite. How can we scientists more effectively communicate to these same decision- and policy makers the notion that they must not now be complacent that the science of climate change [e.g., as described in the recent highly influential and successful Fourth Intergovernmental Panel on Climate Change (IPCC) assessment] is largely "done and dusted?" My particular concern is that the science of climate prediction is far from done and dusted, and my reason for being concerned is that the current global models represent the equations of motion of climate rather poorly on the regional scale. As discussed below, this is of particular importance as we now start to plan how to adapt to future climate change.

As a child, I read many science fiction stories. I can still vividly recall Isaac Asimov's *Nightfall*, frequently described as the finest science fiction story of all time. *Nightfall* describes a civilization's first encounter with darkness for thousands of years. The civilization inhabits the planet Lagash, which orbits one of six gravitationally-bound suns. *Nightfall* occurs during a total eclipse, when only one of the suns is above the horizon. Lagash's solar system lies in the centre of a giant cluster of stars, and during the short period of darkness, tens of thousands of distant stars shine brightly in the night sky. None of the civilization's astronomers had predicted this. The sudden unforeseen realization of the vastness of the universe, with consequent implications of Lagash's utter insignificance in the cosmos, gives rise to widespread panic and feelings of desperation, leading to a rapid disintegration of civilization.

I recall quite vividly feeling dizzy trying to grasp the utter enormity of what it must have been like to see the night stars for the first time, having had no previous inkling of their existence. In thinking back at this reaction, I started to wonder whether such an overwhelming existential crisis, in experiencing for the first time some dramatic and totally unforeseen natural phenomena, could be brought to bear in communicating my concerns about current uncertainties in the science of climate prediction?

If we use the terminology of Edward Lorenz's classic 1970 paper, then predicting the effects of anthropogenic climate change on the one hand and the effects of the annual cycle of insolation on the other can be both classed as "predictions of the second kind": given a specified change in some prescribed forcing (atmospheric greenhouse gas concentration or insolation), calculate the corresponding change in the probability distribution of regional weather states. By focusing on probability distributions, rather than specific individual weather patterns, predictions of the second kind are intrinsically predictable, even though the underlying climate system is chaotic. By contrast, "predictions of the first kind" are initial value problems and highly sensitive to uncertainties in the initial state, due to the chaotic nature of climate.

Although in this sense climate change is inherently predictable, we don't know how reliable our predictions of climate change are in practice. But what about a prediction of the second kind that we can validate, the annual cycle—is that reliable using today's climate models? In other words, can our global climate models simulate the effects of the annual cycle of insolation? Well, yes, to some extent—the models correctly predict the relative warmth in the summer hemisphere! But would you trust them completely? How about the simulation of precipitation distributions associated with the transition from winter to summer monsoons, or the annual cycle of sea surface temperature in the tropical oceans?

Thinking about this in conjunction with my recollections of *Nightfall* led me to the following thought: Suppose you lived in a world that had been in a perpetual winter state for many generations. However, due to some strange astronomical event, about which the civilization's astronomers are fully aware, the climate is about to flip into a perpetual summer state. The people of this world therefore know that a rather dramatic change in climate is imminent and want some advice on how to adapt. They call on you, their chief meteorologist, to guide them about infrastructure investment to adapt to this new climate. You have available to you output from models from the IPCC AR4 multimodel ensemble (www-pcmdi.llnl.gov/ipcc/about_ipcc.php), properly adapted for the topography and astronomical conditions of this world! [This is the idea developed in the short story "Sunrise" (doi: 10.1175/2010BAMS3187.2).]

I'm afraid your advice turns out to be disastrous! Please read the story for details.

The first message of the story is that reliable predictions of regional climate change are crucially important to guide decisions on infrastructure investment for societies to adapt to future climate change. For example, if our terrestrial models suggest a substantial increase in the frequency of drought for some particular region, then it may make sense (given geopolitical constraints) to invest in infrastructure to store more water, or to pump water from neighboring water-rich areas. Conversely, if models suggest an increase in the frequency of flood events, it may make sense to invest in better flood defenses, storm sewers, and so on. However, such investments will be useless and the corresponding finances squandered if the region predicted to get more drought actually suffers more flooding, and vice versa.

Read Tim Palmer's sci-fi story about climate prediction, "Sunrise," in the *BAMS* Web archive at doi:10.1175/2010BAMS3187.2.

The second message of the story is that if current climate models can systematically misrepresent the regional effects of the annual cycle, they can also misrepresent the regional effects of climate change. Here I am using the notion that both are essentially predictions of the second kind, and hence inherently predictable, as discussed above.

The third message of the story is that climate prediction is a computationally demanding problem. Indeed, I would say there is no more computationally demanding problem in science. In my view, inaccuracies in the current generation of climate models arise less because of uncertainty in our understanding of the equations of motion themselves, and more because of the performance limitations of the computers on which the models are integrated. Because of such performance limitations, the underlying partial differential equations of climate have to be truncated at scales typically of hundreds of kilometers. As a result, processes associated with scales less than the truncation scale are represented in climate models by relatively simple, empirically derived parametrization formulae. It is possible to quantify the errors made by such a truncation/parametrization ansatz (e.g., by comparing parametrized temperature tendencies with those arising from coarse-grained budgets of cloud-resolving models where truncation scales are two orders of magnitude smaller). In general, the errors are substantial (e.g., as shown by Shutts and myself in 2007). Because of the inherent nonlinearity of climate, these truncation-scale errors can induce systematic deficiencies in the simulation of climate fields on scales significantly larger than the truncation scale. It is the inherent nonlinearity of climate and the fact that the state space of climate has such a large dimension that make climate prediction so computationally challenging.

One way to reduce these systematic deficiencies would be to simulate more of the climate system with the proper equations of motion—that is to say, increase the resolution of climate models (e.g., to 1 km so that organized deep convection can be resolved). But increasing resolution is computationally demanding—an increase in resolution by a factor of 2 may require an increase in computing speed by up to a factor of 16 (c.f. the four dimensional nature of space-time). Increasing climate-model resolution to the resolution of contemporary numerical weather prediction models will require dedicated multipetaflop machines. Increasing to 1-km resolution may require exaflop machines. There are good scientific arguments for doing this (see the papers by Shukla et al. and Shapiro et al. in this issue), but how does one convincingly make the case to fund an ultrahigh-performance computing facility dedicated to climate?

This brings us to the fourth and final message of the story. Typical economic metrics to gauge whether some proposed new facility is worth funding involve cost/benefit ratios. What is the cost/benefit ratio of a dedicated multipetaflop or exaflop computing facility for climate? In the case of the civilization of Sunrise, if only your climate models could have been run at higher resolution, you would have been able to save the civilization from disaster! In this case, while the cost of the required computing facility would have been finite, the benefit would have been infinite—making a cost/benefit ratio of zero! Can this analysis be applied to planet Earth? I don't know, but perhaps at least it is time for an analysis of the economic benefit of reliable climate prediction systems to be considered more carefully than has been done to date.

So is sci-fi an effective genre to put over these points? I leave you, the reader, to judge!

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FOR FURTHER READING

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