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The Korumburra Earthquake Sequence - What Next?

The Gippsland town of Korumburra is experiencing a sequence of earthquakes this year (Table 1). The sequence began on Jan. 12 with a magnitude 3.5 earthquake, with two events of magnitude 4.6 each occurring on March 6 and March 18. Earthquakes can cause damage if their magnitudes exceed about 5. Is a damaging earthquake likely to occur in Korumburra?

Table 1. The Korumburra Earthquake Sequence to date

Date	Time (UTC)	Latitude	Longitude	Depth	Magnitude
12/01/2009	08:48:42	-38.442	145.851	4	3.5
06/03/2009	09:55:37	-38.39	145.79	8	4.6
06/03/2009	11:49:42	-38.466	145.829	6	2.9
06/03/2009	15:53:12	-38.515	145.771	13	3.7
06/03/2009	23:14:36	-38.443	145.833	12	3.6
09/03/2009	06:39:05	-38.426	145.829	14	3.3
13/03/2009	17:47:09	-38.423	145.892	10	2.8
18/03/2009	05:28:20	-38.39	145.8	18	4.6
18/03/2009	11:05:58	-38.409	145.857	19	3.1
18/03/2009	19:03:32	-38.443	145.84	17	2.7
20/03/2009	10:46:38	-38.45	145.826	8	2.5

Source: http://www.ga.gov.au/bin/listQuakes

The Korumburra earthquake sequence does not fit the usual pattern of an earthquake sequence. Usually, an earthquake sequence consists of a large earthquake, called the mainshock, followed by a series of aftershocks. Sometimes, the mainshock is preceded by one or more smaller events, called foreshocks, which occur a few hours or days before the mainshock.

Larger earthquakes have more and larger aftershocks. The larger the mainshock the larger will be the largest aftershock, on average. The difference in magnitude between the mainshock and largest aftershock varies widely but averages 1.2, so a M 5.7 mainshock would generate aftershocks as large as M 4.5 on average. Smaller aftershocks are more numerous than large ones.

An earthquake is usually followed by several aftershocks within the first hour. The rate of aftershocks dies off quickly with time, and is proportional to the inverse of time since the mainshock. Thus the second day will have approximately 1/2 the number of aftershocks of the first day and the tenth day will have approximately 1/10 the number of the first day. These patterns describe only the statistical behavior of aftershocks; the actual times, numbers and locations of the aftershocks are random, while tending to follow these patterns.

Clustering of earthquakes usually occurs near the location of the mainshock. The stress on the fault that caused the mainshock changes drastically during the mainshock, and that fault produces most of the aftershocks. This causes a change in the regional stress, the size of which decreases rapidly with distance from the mainshock. Sometimes the change in stress caused by the mainshock is great enough to trigger aftershocks on other, nearby faults. While there is no hard cutoff distance beyond which an earthquake is totally incapable of triggering an aftershock, the vast majority of aftershocks are located close to the mainshock. As a rule of thumb, we consider earthquakes to be aftershocks if they are located within a characteristic distance from the mainshock. This distance is usually taken to be the length of the fault rupture associated with the mainshock. For example, if the mainshock ruptured a 10 km length of a fault, subsequent earthquakes up to 10 km away from the mainshock rupture would be considered aftershocks.

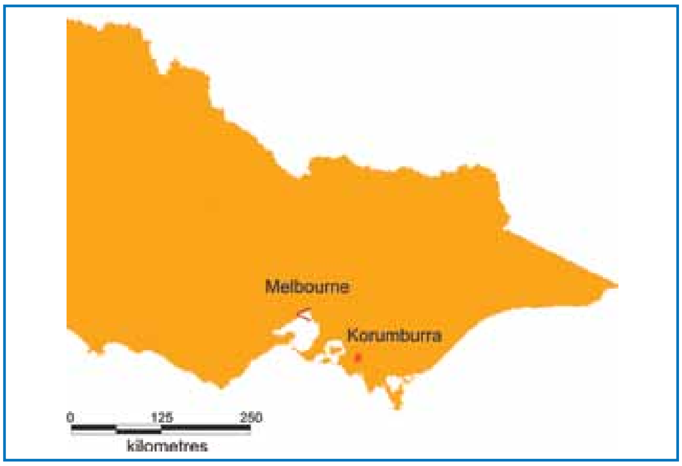

Figure 1: Location of Korumburra, Victoria.

Shallow Australian earthquakes usually have foreshocks and usually have many aftershocks, while deeper events (10 to 18 km deep) often do not have foreshocks, and often have few aftershocks. The aftershock characteristics of earthquakes in Western Australia are reasonably consistent with those in other regions including New Zealand and California. However, earthquakes in the Sydney Region have much weaker aftershock sequences.

The Korumburra earth quakes do not easily fit a foreshock – mainshock – aftershock pattern. Each of the three largest events has had its own aftershock sequence, but there is no identifiable mainshock of the whole sequence, and it is unclear how the sequence will end. Instead, the Korumburra earthquake sequence is better described as a swarm consisting of a large number of events that occur in a temporal and spatial cluster.

Earthquake swarms, with many events up to magnitude 3, 4, or 5, but without a clear main shock, seem to be more common in Australia than in other regions. They often occur at very shallow depths. Shallow earthquake swarms occur at a rate of about one per year in Australia. Such shallow earthquake swarms are usually not precursory events to large earthquakes, rarely producing an event larger than magnitude 4.5 to 5.0.

Shallow earthquake swarms are frequent in Western Australia, including the Kellerberrin swarm of 1995-2001, the Burakin swarm of 2000–2001, and the ongoing swarm northwest of Beacon which began on January 30, 2009. There were no known events in Kellerberrin before the swarm began in 1995. The Burakin swarm occurred near the aftershock zone of the M 5.9 1979 Cadoux earthquake, but it is unclear how these two earthquake sequences are related. The Eugowra, NSW, swarm, which occurred during 1994-1995, was also very shallow, occurring at depths between 0.1 to 1.2 km, and was confined to an area of 2 x 2 km.

Unlike these other swarms, the Korumburra events are quite deep, with the two largest events having depths of 8 and 18 km. Since large earthquakes usually nucleate at depths in this range, and not at the shallow depths of a few km that characterize the other earthquake swarms, it seems possible that the Korumburra earthquake swarm could generate a larger earthquake.

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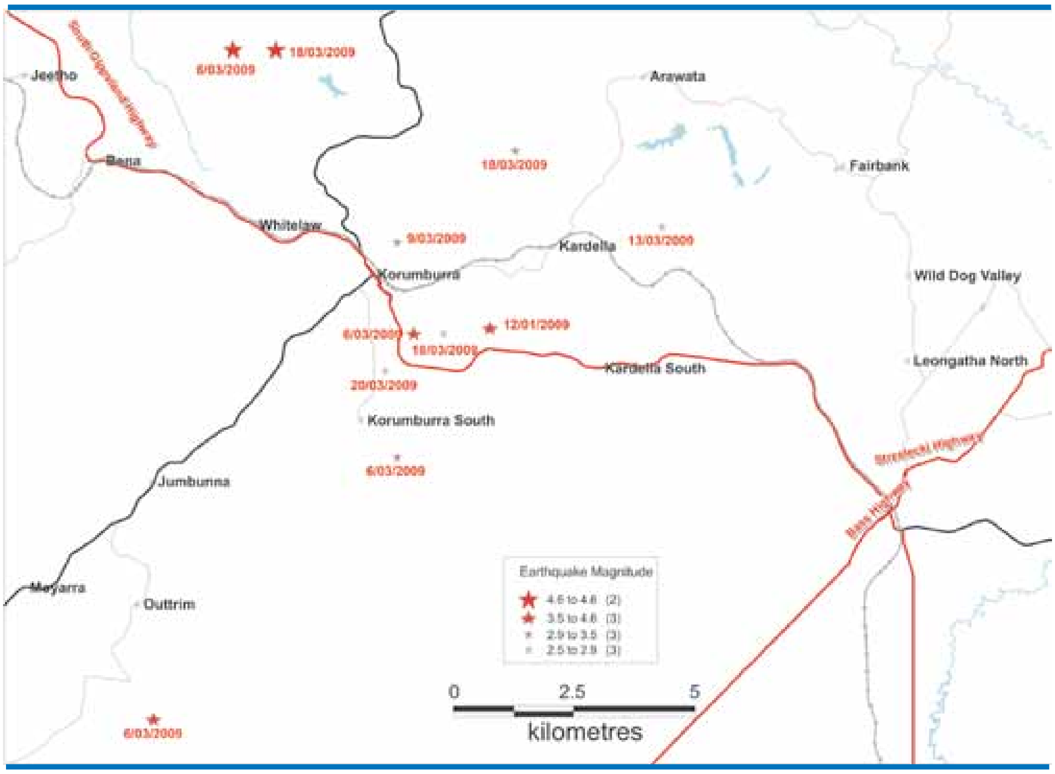

Figure 2: Locations of the Korumburra earthquakes.

Do We Need Better Predictions to Adapt to a Changing Climate?

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"Many scientists have called for a substantial new investment in climate modeling to increase the accuracy, precision, and reliability of climate predictions. Such investments are often justified by asserting that failure to improve predictions will prevent society from adapting successfully to changing climate. This Forum questions these claims, suggests limits to predictability, and argues that society can (and indeed must) make effective adaptation decisions in the absence of accurate and precise climate predictions.

Climate Prediction for Decision Making

There is no doubt that climate science has proved vital in detecting and attributing past and current changes in the climate system and in projecting potential long-term future changes based on scenarios of greenhouse gas emissions and other forcings. The ability of climate models to reproduce the time evolution of observed global mean temperature has given the models much credibility. Advances in scientific understanding and in computational resources have increased the trustworthiness of model projections of future climates.

Many climate scientists, science funding agencies, and decision makers now argue that further quantification of prediction uncertainties and more accuracy and precision in assessments of future climate change are necessary to develop effective adaptation strategies. For instance, the statement for the May 2008 World Modelling Summit for Climate Prediction (http://wcrp.ipsl.jussieu . fr/ Workshops/ ModellingSummit/Documents/ FinalSummitStat _ 6 _ 6 . pdf) argues that "climate models will, as in the past, play an important, and perhaps central, role in guiding the trillion dollar decisions that the peoples, governments and industries of the world will be making to cope with the consequences of changing climate." The statement calls for a revolution in climate prediction because society needs it and because it is possible. The summit statement argues that such a revolution "is necessary because adaptation strategies require more accurate and reliable predictions of regional weather and climate extreme events than are possible with the current generation of climate models." It states that such a revolution is possible because of advances in scientific understanding and computational power.

If true, such claims place a high premium on accurate and precise climate predictions at a range of geographical and temporal scales as a key element of decision making related to climate adaptation. Under this line of reasoning, such predictions become indispensable to, and indeed are a prerequisite for, effective adaptation decision making. Until such investments come to fruition, according to this line of reasoning, effective adaptation will be hampered by the uncertainties and imprecision that characterize current climate predictions.

Limits of Climate Prediction

Yet the accuracy of climate predictions is limited by fundamental, irreducible uncertainties. For climate prediction, uncertainties can arise from limitations in knowledge (e.g., cloud physics), from randomness (e.g., due to the chaotic nature of the climate system), and from human actions (e.g., future greenhouse gas emissions). Some of these uncertainties can be quantified, but many simply cannot, leaving some level of irreducible ignorance in our understanding of future climate.

An explosion of uncertainty arises when a climate change impact assessment aims to inform national and local adaptation decisions, because uncertainties accumulate from the various levels of the assessment. Climate impact assessments undertaken for the purposes of adaptation decisions (sometimes called end-to-end analyses) propagate these uncertainties and generate large uncertainty ranges in climate impacts. These studies also find that the impacts are highly conditional on assumptions made in the assessment, for example, with respect to weightings of global climate models (GCMs) - according to some criteria, such as performance against past observations - or to the combination of GCMs used.

Future prospects for reducing these large uncertainties remain limited for several reasons. Computational restrictions have thus far restricted the uncertainty space explored in model simulations, so uncertainty in climate predictions may well increase even as computational power increases. The search for objective constraints with which to reduce the uncertainty in regional predictions has proven elusive. The problem of equifinality (sometimes also called the problem of "model identifiability") - that different model structures and different parameter sets of a model can produce similar observed behavior of the system under study - has rarely been addressed. Furthermore, current projections suggest that the Earth's climate may soon enter a regime dissimilar to any seen for millions of years and one for which paleoclimate evidence is sparse. Model projections of future climate therefore represent extrapolations into states of the Earth system that have never before been experienced by humanity, making it impossible to either calibrate the model for the forecast regime of interest or confirm the usefulness of the forecasting process.

In addition, climate is only one of many important processes that will influence the success of any future adaptation efforts, and often it is not the most important factor. Our current ability to predict many of these other processes—such as the future course of globalization, economic priorities, regulation, technology, demographics, cultural preferences, and so forth—remains much more limited than our ability to predict future climate. This raises the question of why improved climate predictions ought to be given such a high priority in designing adaptation policies.

Alternatives to Prediction

Individuals and organizations commonly take actions without having accurate predictions of the future to support those actions. In the absence of accurate predictions, they manage the uncertainty by making decisions or establishing robust decision processes that produce satisfactory results. In recent years, a number of researchers have begun to use climate models to provide information that can help evaluate alternative responses to climate change, without necessarily relying on accurate predictions as a key step in the assessment process. The basic concept rests on an exploratory modeling approach whereby analysts use multiple runs of one or more simulation models to systematically explore the implications of a wide range of assumptions and to make policy arguments whose likelihood of achieving desired ends is only weakly affected by the irreducible uncertainties.

As one key step in the assessment process, such analyses use climate models to identify potential vulnerabilities of proposed adaptation strategies. These analyses do not require accurate predictions of future climate change from cutting-edge models. Rather, they require only a range of plausible representations of future climate that can be used to help organizations, such as water resources agencies, better understand where their climate change–related vulnerabilities may lie and how those vulnerabilities can be addressed. Even without accurate probability distributions over the range of future climate impacts, such information can prove very useful to decision makers.

Such analyses generally fall under the heading of “robust decision making.” Robust strategies perform well compared with alternative strategies over a wide range of assumptions about the future. In this sense, robust strategies are insensitive to the resolution of the uncertainties. A variety of analytic approaches, such as exploratory modeling, have been proposed to identify and assess robust strategies.

Climate and Science Policy Implications

Given the deep uncertainties involved in the prediction of future climate, and even more so of future climate impacts, and given that climate is usually only one factor driving the success of adaptation decisions, we believe that the “predict-then-act” approach to science in support of climate change adaptation is significantly flawed. This does not imply that continued climate model development cannot provide useful information for adaptation. For instance, such development could further inform the plausible range of impacts considered when crafting a robust adaptation strategy. However, further scientific effort will never eliminate uncertainty; it may in fact increase uncertainty. For example, 3 decades of research on climate sensitivity (the global mean temperature change following an instantaneous doubling of carbon dioxide in the atmosphere) have not reduced, but rather have increased, the uncertainty surrounding the numerical range of this concept. The lack of climate predictability should not be interpreted as a limit to preparing strategies for adaptation.

By avoiding an analysis approach that places climate prediction at its heart, successful adaptation strategies can be developed in the face of deep uncertainty. Decision makers should systematically examine the performance of their adaptation strategies over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political, and cultural factors. They should choose a strategy they find sufficiently robust across these alternative futures. Such an approach can identify successful adaptation strategies without accurate and precise predictions of future climate.

Our arguments have significant implications for science policy. At a time when government expects decisions to be based on the best possible science (e.g., evidence-based policy making), we suggest that climate science is unlikely to support prediction-based decisions. Overprecise climate predictions can also lead to maladaptation if the predictions are misinterpreted or used incorrectly. From a science policy perspective, it is worth reflecting on where investments by science funding agencies can best increase the societal benefit of science. Efforts to justify renewed investments in climate models based on promises of guiding decisions are misplaced.

The World Modelling Summit for Climate Prediction called for a substantial increase in computing power (an increase by a factor of 1000, at the cost of more than a billion dollars) to provide better information at the local level. We believe, however, that society will benefit more from having a greater understanding of the vulnerability of climate-influenced decisions in the face of large irreducible uncertainties, and the various means of reducing such vulnerabilities, than from any plausible and foreseeable increase in the accuracy and precision of climate predictions.

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Whoops!

Our sincere apologies for the following errors in our last quarterly newsletter Volume 8, Issue 2.

Article 1, paragraph 3
Cyclone Mahina occurred in 1899 (not 1889)

Table 1, row 4
should read February 7, 1967 (not January)