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DANGEROUS IMPRESSION

The content of "Earthquake Alarm" [December] by Tom Bleier and Friedemann Freund, as well as the presentation on the cover and contents pages, are of some scientific concern in terms of their effect on public expectations. The authors present an artificial optimism for short-term earthquake prediction (EP) based on precursors ranging from seismic investigations of ultra- and extra-low frequencies to monitoring of the earth's high-frequency electromagnetic fields, ionospheric electron-density disturbances, infrared signatures of mechanical stresses, and so on. The impression is given that these studies are mature and scientifically well established, and the article states that we are only a few years (at most a decade) away from building earthquake early-warning systems.

This impression is extremely dangerous in countries that suffer from poor scientific literacy, where municipalities fearlessly extend city plans right through faults and people often construct weak buildings. It should be noted that it is not earthquakes themselves that kill people; it is the collapse of man-made structures that causes most of the casualties. Therefore, the best way of preparing for strong and devastating earthquakes and mitigating their worst effects is to develop better urban land-use plans and build stronger buildings. If false optimism is imparted via a highly respected journal that earthquake early-warning systems will be ready in a few years, some countries will not take measures to improve building safety but will prefer to protect themselves by relying on so-called experts who ostensibly could predict the time of an earthquake. In general, EP methods can be divided into two types: statistical methods for seismicity, and the observation of precursors to large earthquakes.

The necessary conditions for precursor-based EP are to observe and discriminate among the precursors, to show the causal correlation, and, finally, to build a model. It is not scientific to try to build an earthquake early warning system—that is, a network of hundreds of sensors (magnetometers, electroscopes, etc.)—before showing the causal correlation and understanding the physical phenomena in detail. EP methods are far from mature, and they remain controversial (see an excellent review by R.J. Geller, "Earthquake prediction: A critical review," *Geophysical Journal International*, Vol. 131, pp. 425–450, 1997). All that can be done currently is to try to show that recorded anomalies are related to earthquakes that occurred sometimes a few hours, sometimes several days (or even months) afterward (retrospective correlation!).

What is currently missing in these studies is the falsification principle of Karl Popper—that is, the systematic ruling out of the known natural and artificial sources of signals from among the precursors of the earthquakes. Those who continuously record ionospheric noise, electron content, virtual-layer heights, magnetic-field changes on the earth's surface, static and/or quasistatic electrical and magnetic fields, electromagnetic and infrared radiations, etc., and those who perform EP have almost identical hypotheses: "there is some relation between the anomaly observed and earthquakes, but the mechanism and parameters of this relation are as yet unknown."

Currently, all predictions are vague at best, as was noted by Bleier and Freund. Long-term projections of an earthquake in a specific area and with a high probability of occurrence within some decades is possible by studying historical earthquake records, monitoring the motion of the earth's crust by satellite, and taking measurements with underground strain monitors. This is important for policy-makers. However, short-term EP must state precisely where (hypocenter latitude and longitude), when, at what depth, how strong, and with what probability the earthquake is to occur within the stated error/uncertainty bounds.

Experts who use statistical models prefer to call their studies earthquake forecasts, and they consider the prediction of a single earthquake as a special case of a forecast that has an exceptionally high probability and imminence. More important, they consider their studies and statistical test results to be only a tiny step toward the physical understanding of earthquakes and their occurrence.

Earthquake prediction efforts go back more than a century, and they have attracted attention even in such prestigious journals as *Science* and *Nature*. Although highly optimistic reports have been presented from time to time, none has withstood detailed scientific examination. The February 1999 *Nature* Debates section (<http://www.nature.com/nature/debates/earthquake>) features many papers discussing possible signals representing different phenomena, including seismic, electrical, electromagnetic, and luminosity conditions, that either accompany or are followed by earthquakes. Although views on the topic differ widely, it is commonly accepted that all the EP studies based on a variety of precursors are low-quality, pseudoscientific works. Many exaggerated claims have been made by scientifically unqualified publicity seekers.

Moreover, all of the contributors to *Nature's* debate agreed that deterministic prediction of an individual earthquake, within sufficiently narrow limits to allow for a planned evacuation program, is an unrealistic goal.

The International Association of Seismology and Physics of the Earth's Interior outlined guidelines for precursor-based EP. According to these guidelines, observed anomalies should have a relation to stress, strain, or some other mechanism leading to earthquakes; they should be simultaneously observed on more than one instrument, or at more than one site; and they should bear an amplitude-distance correlation. There should be a persuasive demonstration that the calibration of the instrument is known, and that the instrument is measuring a tectonic signal. Anomaly definitions should be precisely stated so that any other suitable data can be evaluated for the presence of such an anomaly. The difference between anomalous and normal values shall be expressed quantitatively, and there should be an explicit discussion of noise sources and signal-to-noise ratio.

The rules and reasons for associating a given anomaly with a given earthquake must be stated precisely. The probability of a predicted earthquake occurring by chance and matching up with the precursory anomaly must be evaluated. The frequency of false alarms (similar anomalies not followed by an earthquake) and surprises (similar-size main shocks not preceded by an anomaly) should also be discussed. There may, of course, be a variety of earthquake precursors, ranging from acoustic and electromagnetic signals to infrared emissions on the ground, as well as in the ionosphere, in a broad frequency range from millihertz up to megahertz.

Moreover, any phenomena that happen to occur before an earthquake can be called precursors, whether or not they have a causal relation to the earthquake. Therefore, observations of these signals and studies for their correlation with the earthquakes are certainly worthwhile if performed scientifically.

Efforts toward gathering data on earthquakes occurring with and without precursors are extremely important. But jumping directly to the conclusion, based on these very early-stage studies, that accurate early warning capability is within reach within a decade is not scientific.

The scientific goal should be the understanding of the fundamental physics of earthquakes and the physics-based theories regarding the precursors (their causal correlation), and not the reliable prediction of individual earthquakes. In view of the lack of proven forecasting and prediction methods, officials should exercise caution in issuing public earthquake warnings. The efforts should be focused on the elimination from scientific journals of scientifically low-quality works and the exposure of works that contain errors and absurd statements made by scientifically unqualified publicity-seekers.

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