

Why is predicting an earthquake so difficult?

Juan Segurolo · All Rights Reserved

QUE · Article 018 · Simple Questions, Deep Answers · Version 0.1 EN

We can identify active faults, measure deformation and estimate earthquake probabilities without being able to announce the date, location and magnitude of the next large rupture. Those are different achievements. The difficulty is not simply that an earthquake is underground. It is that the evolving conditions governing rupture are only partly observed, and an apparent warning sign does not necessarily identify which disturbance will become a large earthquake.

A useful answer begins by separating prediction before rupture, probability over an interval, and warning after rupture has already started. Otherwise a successful alert can be mistaken for a successful prediction, and the absence of exact predictions can be mistaken for an absence of useful knowledge.

1. What would count as predicting it?

The US Geological Survey specifies three elements of an earthquake prediction: when, where and how large. Its public assessment does not recognize a reliable method for making such specific short-term predictions of major earthquakes. [1] “An earthquake somewhere near a fault eventually” is too permissive to meet that standard.

The tolerances matter as much as the words. A testable claim must define its geographical area, time window and magnitude range before the outcome is known. Expanding any of them after an event makes apparent successes easier to obtain without improving predictive skill.

This does not require a scientifically serious forecast to promise certainty. It requires clarity about the target. A probability assigned to a specified interval is a probabilistic forecast. A statement that a particular earthquake will occur is a stronger claim. Neither should be assessed as though it were the other.

2. A fault's history is not a countdown

Geologists can recover evidence of earlier rupture. At the Teton fault, for example, the National Park Service describes trenches across fault scarps, displaced sediment layers and age estimates based on organic material. [2] These observations constrain previous events and establish that a landscape has moved repeatedly.

But an interval between two past earthquakes does not become a clock with a hand approaching midnight. Consider a hypothetical record with intervals of 700, 1,100 and 1,200 years. Their mean is 1,000 years. That arithmetic does not specify whether the next interval will be 700, 1,000, 1,200 or something outside the observed range.

Even this toy record assumes that no event was missed and that all three intervals refer to the same kind of rupture. Geological records can be incomplete; definitions of the relevant event can differ. A recurrence model therefore combines observations with assumptions about how those observations relate to the future.

3. The hidden state matters

Knowing the location of a fault is not equivalent to knowing the detailed conditions everywhere on it. Earthquake mechanics concerns stress, resistance to sliding, interactions among patches and the propagation of rupture. A regional deformation measurement constrains part of that problem without revealing the complete state at depth.

The logical difficulty can be stated without assuming that nature is lawless. A physical model may generate a definite outcome once its initial state and parameters are specified. If several unobserved states are compatible with the available data, the same observations can support several future outcomes. Better equations and better observations address related but different limitations.

This is also why explaining an earthquake after it occurs is not the same test as anticipating it. Afterward, rupture and shaking provide information that did not exist in the earlier record. A reconstruction that uses those observations must not be described as though it had made a forecast without them.

4. Why a precursor needs comparison cases

A cluster of small earthquakes before a larger one can look like an obvious signal afterward. The necessary comparison includes clusters that were not followed by a larger event. USGS notes that many proposed precursors occur without a subsequent major earthquake. [1]

A useful test therefore counts failures as well as successes. How often did an alert occur with no target earthquake? How often did an earthquake arrive without an alert? How much of the region and time was placed under warning? A method that declares almost everything alarming can capture many events while contributing little information.

These are requirements for evidence, not a claim that every investigated signal is useless. A signal can alter a probability without uniquely specifying an event. Establishing that narrower achievement requires a comparison against a stated baseline and evaluation on outcomes not used to tune the rule. The seductive mistake is to replace that evaluation with a collection of memorable coincidences.

5. Forecasting remains useful

USGS distinguishes long-term probabilities from shorter-window forecasts, commonly used for aftershocks. The latter exploit regularities in earthquake sequences rather than requiring an exact timetable for each event. [3] A conditional increase in probability is meaningful even if most individual windows contain no large earthquake.

A forecast must also identify whether it concerns the occurrence of a rupture or the shaking at a site. These are not interchangeable outcomes: shaking depends on propagation and local conditions as well as the source. The practical usefulness of probabilistic information does not depend on pretending that it names one future event with certainty.

Nor does a lack of exact prediction erase the evidence of fault activity. In the Teton example, displaced layers remain evidence of past earthquakes regardless of whether they allow an announcement for next Tuesday. Historical reconstruction and prospective prediction impose different demands on the same science.

6. Early warning wins time after the start

An early warning is issued after an earthquake begins, as USGS explicitly states. [3] Instruments detect the developing event, and information can reach some locations before stronger shaking arrives. The opportunity comes from travel and processing times, not from foreknowledge of rupture.

Take an intentionally simplified timing example. Assume a detector registers an event two seconds after rupture starts, processing and delivery require another three seconds, and the relevant shaking reaches a distant location twenty seconds after rupture starts. The notification arrives at second five, leaving fifteen seconds before that shaking. These are invented inputs, not performance figures for an actual system.

At a nearer location where shaking arrives at second four, the same chain gives no advance warning. The example shows both the possibility and its limit. Source geometry, wave propagation, detection and delivery determine the actual interval; a single promised warning time cannot describe every location.

7. What a better answer would require

A stronger prediction method would need prospective evidence that it distinguishes target events from non-events under explicit rules, with its misses and false alarms visible. More detailed monitoring may improve constraints, but its value must be demonstrated rather than inferred from the number of instruments.

The present answer is therefore bounded. Earthquake locations and probabilities can be informed by evidence; exact short-term prediction remains unavailable as a reliable general method. Early warning is a separate, real achievement that begins after rupture. Confusing these categories makes the science look either more powerful or less useful than it is.

Related reading

Article 017, “Why are sea fossils found high in mountains?”, uses the Teton geological record to separate deposition, displacement and exposure. Neither article requires the other as a prerequisite.

References

- [1] US Geological Survey. Can you predict earthquakes? <https://www.usgs.gov/faqs/can-you-predict-earthquakes>
- [2] National Park Service, Grand Teton National Park. Teton Fault. <https://www.nps.gov/grte/learn/nature/faults.htm>
- [3] US Geological Survey. What is the difference between earthquake early warning, earthquake forecasts, earthquake probabilities, and earthquake prediction? <https://www.usgs.gov/faqs/what-difference-between-earthquake-early-warning-earthquake-forecasts-earthquake-probabilities>