NEPEC: National Earthquake Prediction Evaluation Council

Michael Blanpied, USGS Earthquake Hazard Program, mblanpied@usgs.gov
Ramon Arrowsmith, Arizona State University, NEPEC Chair, ramon.arrowsmith@asu.edu

Overview of NEPEC

NEPEC provides advice to the USGS Earthquake Hazards Program on earthquake predictions, time-dependent forecasting, and related research. The Council's recommendations support the USGS's responsibility under NEHRP to assess earthquake risks, improve earthquake forecasts, and issue timely earthquake alerts and warnings. Its members are experts in scientific disciplines that bear on earthquake prediction, forecasting natural hazards, or public and stakeholder response to such forecasts.

NEPEC may be convened either to provide rapid advice during a seismic sequence or other rapidly evolving situations, to evaluate specific predictions, forecasting methods, or lines of related research, or to develop recommendations on other topics brought by the USGS.

NEPEC may invite outside experts to brief the council, or convene workshops to explore a subject area. NEPEC sub-groups may be formed to compile information, conduct research, draft documents, or prepare recommendations on specific topics.

When focused on issues relevant to California, NEPEC coordinates with the California Earthquake Prediction Evaluation Council (CEPEC), which is managed by CGS and reports to the CA Office of Emergency Services (Cal OES).

Current NEPEC members

Members, appointed to three-year terms, represent a broad range of expertise in earthquake science and related fields.

Ramon Arrowsmith, Arizona State University
Chair, deep experience with neo-tectonic and fault geology, geodesy, fault studies, paleoseismology, and scientific earthquake response.

Karianne Bergen, Brown University
Expert in application of machine learning and AI to noisy data with applications to seismology and other fields; training at Harvard, Stanford, MIT and Brown.

Steve Bohlen, Lawrence Livermore National Laboratory
Science-policy interface, experience with both science organizations (USGS, CGS, SCEC) and stakeholder and policy organizations (e.g., Cal OES, insurance).

Camilla Cattania, Massachusetts Institute of Technology
Expert in seismology, earthquake physics, statistical seismology, and modeling; models of aftershock and swarm triggering, role of stress in OEF models.

Matt Gerstenberger, GNS Science, New Zealand
Expertise in creating, testing and deploying short-, intermediate- and long-term forecasting; real-world experience with forecasting during damaging sequences.

Joan Gomberg, USGS Earthquake Science Center, Seattle
Expert in subduction zone science, source scaling, earthquake interactions; experience in working with user & stakeholder groups in Cascadia.

Judith Hubbard, Earthquake Insights
Expert in analysis of earthquakes in their tectonic and historical context; scrutiny of forecast hypotheses; communication to non-expert user groups.

Sarah Minson, USGS Eq Science Center, Moffett Field
Expert in earthquake physics, dynamic rupture, Bayesian analysis, earthquake early warning; experience and interest in outreach and public communication.

David Shelly, USGS Geol. Hazards Science Center, Golden
Seismology, earthquake sequences, analysis of seismicity and related phenomena (tremor, LFEs, etc.) and their tectonic implications. Represents the GHSC.

Nicholas van der Elst, USGS Eq Science Center, Pasadena
Expert in statistical seismology, analysis of earthquake clustering, forecasting methods, training on aftershock forecasting; USGS lead on ETAS-based OAF.

Max Werner, Bristol University, United Kingdom
Expert in the analysis and testing of forecast models, induced seismicity, seismicity, machine learning; long-term lead of CSEP.

NEPEC is a standing subcommittee of the SESAC, a federal advisory committee that provides advice and guidance to the USGS Earthquake Hazards Program.

Scientific Earthquake Studies Advisory Committee (SESAC)
Michael Hamburger, Chair

- Advanced National Seismic System (ANSS) National Steering Committee
  Maureen Long, Chair

- National Earthquake Prediction Evaluation Council (NEPEC)
  Ramon Arrowsmith, Chair

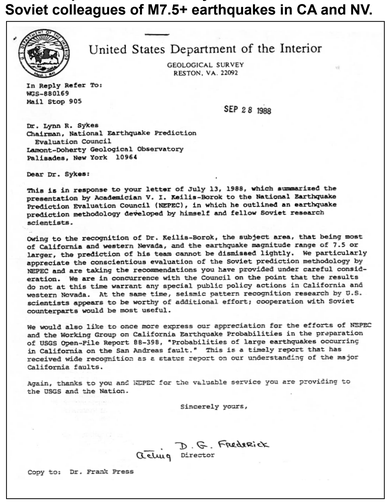
- National Seismic Hazard Model Steering Committee
  Jon Stewart, Chair

NEPEC web site:

NEPEC Recommendations

In the 48 years since its formation, NEPEC has examined a wide swath of topics including the "Palmdale bulge," the Parkfield Prediction Experiment, special fault study areas, statistical forecasting models, the testing and evaluation of predictions, and the communication of forecasts to the public. It has also evaluated specific predictions and prediction methods.

1988: USGS Director's thanks to NEPEC for their review of predictions made by Dr. Keilis-Borok and Soviet colleagues of M7.5+ earthquakes in CA and NV.



United States Department of the Interior
GEOLOGICAL SURVEY
RESTON, VA 22092

In Reply Refer To:
WGS-880169
Mail Stop 905

SEP 28 1988

Dr. Lynn R. Sykes
Chairman, National Earthquake Prediction
Evaluation Council
Lamont-Doherty Geological Observatory
Palisades, New York 10964

Dear Dr. Sykes:

This is in response to your letter of July 13, 1988, which summarized the presentation by Academician V. I. Keilis-Borok to the National Earthquake Prediction Evaluation Council (NEPEC), in which he outlined an earthquake prediction methodology developed by himself and fellow Soviet research scientists.

Owing to the recognition of Dr. Keilis-Borok, the subject area, that being most of California and western Nevada, and the earthquake magnitude range of 7.5 or larger, the prediction of his team cannot be dismissed lightly. We particularly appreciate the conscientious evaluation of the Soviet prediction methodology by NEPEC and are taking the recommendations you have provided under careful consideration. We are in concurrence with the Council on the point that the results do not at this time warrant any special public policy actions in California and western Nevada. At the same time, seismic pattern recognition research by U.S. scientists appears to be worthy of additional effort; cooperation with Soviet counterparts would be most useful.

We would also like to once more express our appreciation for the efforts of NEPEC and the Working Group on California Earthquake Probabilities in the preparation of USGS Open-File Report 88-398, "Probabilities of large earthquakes occurring in California on the San Andreas fault." This is a timely report that has received wide recognition as a status report on our understanding of the major California faults.

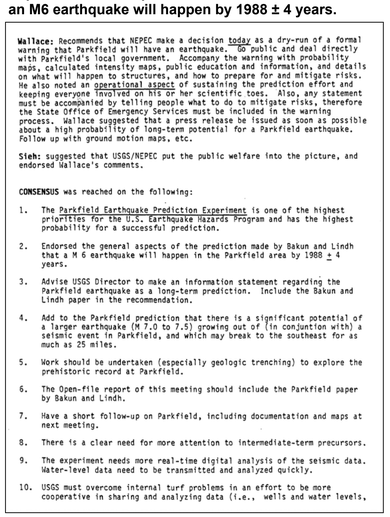
Again, thanks to you and NEPEC for the valuable service you are providing to the USGS and the Nation.

Sincerely yours,

D. G. Fredrix
Acting Director

Copy to: Dr. Frank Press

1984: NEPEC endorsement of the Parkfield Prediction Experiment, and of prediction of Bakun and Lindh that an M6 earthquake will happen by 1988 ± 4 years.



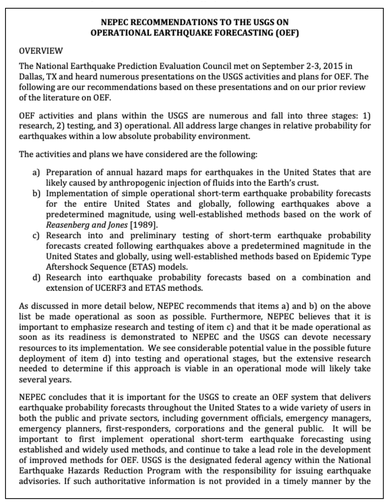
Wallace: Recommends that NEPEC make a decision today as a dry-run of a formal warning that Parkfield will have an earthquake. Go public and deal directly with Parkfield's local government. Accompany the warning with probability maps, calculated intensity maps, public education and information, and details on what will happen to structures, and how to prepare for and mitigate risks. He also noted an operational aspect of sustaining the prediction effort and keeping everyone involved on his or her scientific toes. Also, any statement must be accompanied by telling people what to do to mitigate risks, therefore the State Office of Emergency Services must be included in the warning process. Wallace suggested that a press release be issued as soon as possible about a high probability of long-term potential for a Parkfield earthquake. Follow up with ground motion maps, etc.

Stein: suggested that USGS/NEPEC put the public welfare into the picture, and endorsed Wallace's comments.

CONSENSUS was reached on the following:

1. The Parkfield Earthquake Prediction Experiment is one of the highest priorities for the U.S. Earthquake Hazards Program and has the highest probability for a successful prediction.
2. Endorsed the general aspects of the prediction made by Bakun and Lindh that a M 6 earthquake will happen in the Parkfield area by 1988 ± 4 years.
3. Advise USGS Director to make an information statement regarding the Parkfield earthquake as a long-term prediction. Include the Bakun and Lindh paper in the recommendation.
4. Add to the Parkfield prediction that there is a significant potential of a larger earthquake (M 7.0 to 7.5) growing out of (in conjuntion with) a seismic event in Parkfield, and which may break to the southeast for as much as 25 miles.
5. Work should be undertaken (especially geologic trenching) to explore the prehistoric record at Parkfield.
6. The Open-file report of this meeting should include the Parkfield paper by Bakun and Lindh.
7. Have a short follow-up on Parkfield, including documentation and maps at next meeting.
8. There is a clear need for more attention to intermediate-term precursors.
9. The experiment needs more real-time digital analysis of the seismic data. Water-level data need to be transmitted and analyzed quickly.
10. USGS must overcome internal turf problems in an effort to be more cooperative in sharing and analyzing data (i.e., wells and water levels,

2015: NEPEC recommendations to USGS on development, testing, and deployment of methods for operational earthquake forecasting (OEF).



NEPEC RECOMMENDATIONS TO THE USGS ON OPERATIONAL EARTHQUAKE FORECASTING (OEF)

OVERVIEW

The National Earthquake Prediction Evaluation Council met on September 2-3, 2015 in Dallas, TX and heard numerous presentations on the USGS activities and plans for OEF. The following are our recommendations based on these presentations and on our prior review of the literature on OEF.

OEF activities and plans within the USGS are numerous and fall into three stages: 1) research, 2) testing, and 3) operational. All address large changes in relative probability for earthquakes within a low absolute probability environment.

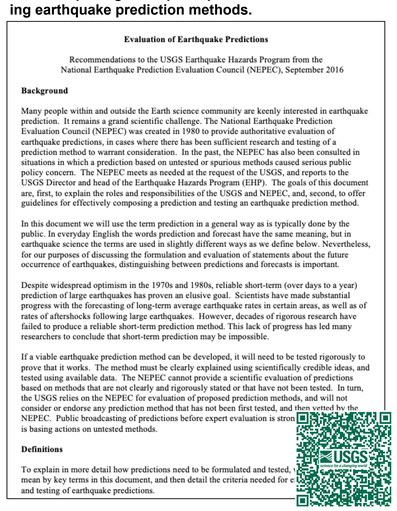
The activities and plans we have considered are the following:

a) Preparation of annual hazard maps for earthquakes in the United States that are likely caused by anthropogenic injection of fluids into the Earth's crust.
b) Implementation of simple operational short-term earthquake probability forecasts for the entire United States and globally, following earthquakes above a predetermined magnitude, using well-established methods based on the work of *Reasenberg and Jones* [1989].
c) Research into and preliminary testing of short-term earthquake probability forecasts created following earthquakes above a predetermined magnitude in the United States and globally, using well-established methods based on Epidemic Type Aftershock Sequence (ETAS) models.
d) Research into earthquake probability forecasts based on a combination and extension of UCERF3 and ETAS methods.

As discussed in more detail below, NEPEC recommends that items a) and b) on the above list be made operational as soon as possible. Furthermore, NEPEC believes that it is important to emphasize research and testing of item c) and that it be made operational as soon as its readiness is demonstrated to NEPEC and the USGS can devote necessary resources to its implementation. We see considerable potential value in the possible future deployment of item d) into testing and operational stages, but the extensive research needed to determine if this approach is viable in an operational mode will likely take several years.

NEPEC concludes that it is important for the USGS to create an OEF system that delivers earthquake probability forecasts throughout the United States to a wide variety of users in both the public and private sectors, including government officials, emergency managers, emergency planners, first-responders, corporations and the general public. It will be important to first implement operational short-term earthquake forecasting using established and widely used methods, and continue to take a lead role in the development of improved methods for OEF. USGS is the designated federal agency within the National Earthquake Hazards Reduction Program with the responsibility for issuing earthquake advisories. If such authoritative information is not provided in a timely manner by the

2016: Recommendations from NEPEC on proper procedures for posing earthquake predictions and for testing earthquake prediction methods.



Evaluation of Earthquake Predictions

Recommendations to the USGS Earthquake Hazards Program from the National Earthquake Prediction Evaluation Council (NEPEC), September 2016

Background

Many people within and outside the Earth science community are keenly interested in earthquake prediction. It remains a grand scientific challenge. The National Earthquake Prediction Evaluation Council (NEPEC) was created in 1980 to provide authoritative evaluation of earthquake predictions, in cases where there has been sufficient research and testing of a prediction method to warrant consideration. In the past, the NEPEC has also been consulted in situations in which a prediction based on untested or spurious methods caused serious public policy concern. The NEPEC meets as needed at the request of the USGS, and reports to the USGS Director and head of the Earthquake Hazards Program (EHP). The goals of this document are, first, to explain the roles and responsibilities of the USGS and NEPEC, and, second, to offer guidelines for effectively composing a prediction and testing an earthquake prediction method.

In this document we will use the term prediction in a general way as is typically done by the public. In everyday English the words prediction and forecast have the same meaning, but in earthquake science the terms are used in slightly different ways as we define below. Nevertheless, for our purposes of discussing the formulation and evaluation of statements about the future occurrence of earthquakes, distinguishing between predictions and forecasts is important.

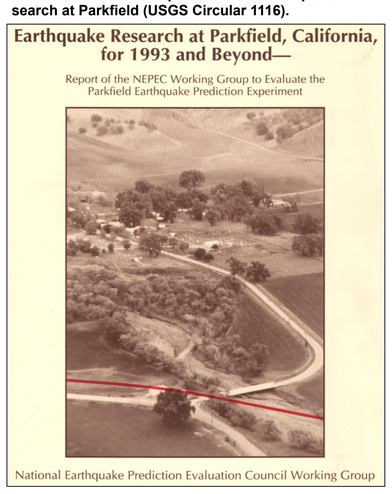
Despite widespread optimism in the 1970s and 1980s, reliable short-term (over days to a year) prediction of large earthquakes has proven an elusive goal. Scientists have made substantial progress with the forecasting of long-term average earthquake rates in certain areas, as well as of rates of aftershocks following large earthquakes. However, decades of rigorous research have failed to produce a reliable short-term prediction method. This lack of progress has led many researchers to conclude that short-term prediction may be impossible.

If a viable earthquake prediction method can be developed, it will need to be tested rigorously to prove that it works. The method must be clearly explained using scientifically credible ideas, and tested using available data. The NEPEC cannot provide a scientific evaluation of predictions based on methods that are not clearly and rigorously stated or that have not been tested. In turn, the USGS relies on the NEPEC for evaluation of proposed prediction methods, and will not consider or endorse any prediction method that has not been first tested, and then vetted by the NEPEC. Public broadcasting of predictions before expert evaluation is strongly discouraged as is basing actions on untested methods.

Definitions

To explain in more detail how predictions need to be formulated and tested, it is necessary to mean by key terms in this document, and then detail the criteria needed for evaluation and testing of earthquake predictions.

1994: Working group report to NEPEC evaluating the Parkfield Prediction Experiment and earthquake research at Parkfield (USGS Circular 1116).

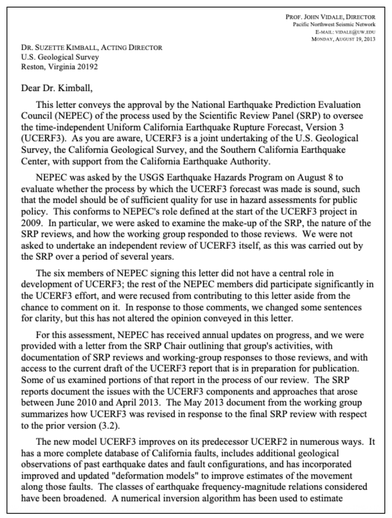


Earthquake Research at Parkfield, California, for 1993 and Beyond—

Report of the NEPEC Working Group to Evaluate the Parkfield Earthquake Prediction Experiment

National Earthquake Prediction Evaluation Council Working Group

2013: NEPEC's evaluation of the UCERF3 earthquake rupture forecast for California, focusing on the nature and quality of the participatory review process overseen by SCEC, USGS, and CGS.



PROF. JOHN VIDALE, DIRECTOR
Pacific Northwest Seismic Network
EMAIL: VIDALE@UW.EDU
MONDAY, AUGUST 19, 2013

DR. SUZETTE KIMBALL, ACTING DIRECTOR
U.S. Geological Survey
Reston, Virginia 20192

Dear Dr. Kimball,

This letter conveys the approval by the National Earthquake Prediction Evaluation Council (NEPEC) of the process used by the Scientific Review Panel (SRP) to oversee the time-independent Uniform California Earthquake Rupture Forecast, Version 3 (UCERF3). As you are aware, UCERF3 is a joint undertaking of the U.S. Geological Survey, the California Geological Survey, and the Southern California Earthquake Center, with support from the California Earthquake Authority.

NEPEC was asked by the USGS Earthquake Hazards Program on August 8 to evaluate whether the process by which the UCERF3 forecast was made is sound, such that the model should be of sufficient quality for use in hazard assessments for public policy. This conforms to NEPEC's role defined at the start of the UCERF3 project in 2009. In particular, we were asked to examine the make-up of the SRP, the nature of the SRP reviews, and how the working group responded to those reviews. We were not asked to undertake an independent review of UCERF3 itself, as this was carried out by the SRP over a period of several years.

The six members of NEPEC signing this letter did not have a central role in development of UCERF3; the rest of the NEPEC members did participate significantly in the UCERF3 effort, and were recused from contributing to this letter aside from the chance to comment on it. In response to those comments, we changed some sentences for clarity, but this has not altered the opinion conveyed in this letter.

For this assessment, NEPEC has received annual updates on progress, and we were provided with a letter from the SRP Chair outlining that group's activities, with documentation of SRP reviews and working-group responses to those reviews, and with access to the current draft of the UCERF3 report that is in preparation for publication. Some of us examined portions of that report in the process of our review. The SRP reports document the issues with the UCERF3 components and approaches that arose between June 2010 and April 2013. The May 2013 document from the working group summarizes how UCERF3 was revised in response to the final SRP review with respect to the prior version (3.2).

The new model UCERF3 improves on its predecessor UCERF2 in numerous ways. It has a more complete database of California faults, includes additional geological observations of past earthquake dates and fault configurations, and has incorporated improved and updated "deformation models" to improve estimates of the movement along those faults. The classes of earthquake frequency-magnitude relations considered have been broadened. A numerical inversion algorithm has been used to estimate

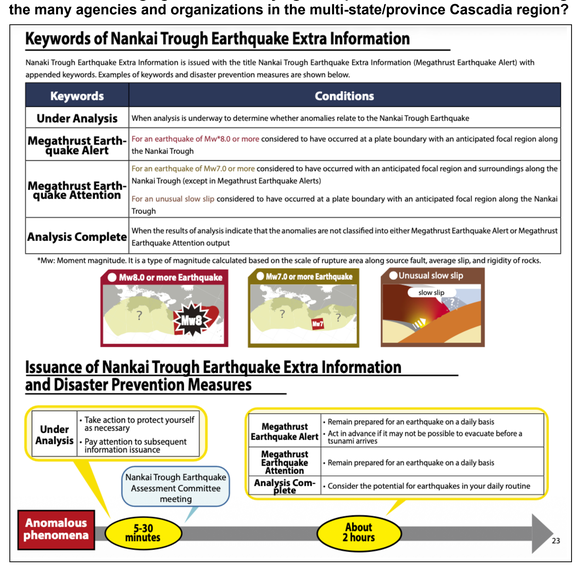
Current areas of focus

Current areas of focus for NEPEC include the use of machine learning and artificial intelligence techniques in earthquake forecasting and prediction, and development of structured communication strategies and advisory frameworks, particularly for use within the Cascadia region.

Cascadia forecast messaging

NEPEC will identify strategies for communcating high-impact, low-probability seismic hazards in the Cascadia region, and develop pre-positioned advisory statements and methods to achieve rapid expert consensus during situations of concern.

Japan Meteorological Agency (JMA) has a formal system for issuing "megaquake advisories" when a Nankai trough earthquake is considered relatively likely, and has done so twice following M7 quakes. Should the U.S. deploy a similar system? How should messaging about time-varying earthquake risk be coordinated among the many agencies and organizations in the multi-state/province Cascadia region?



Keywords of Nankai Trough Earthquake Extra Information

Nankai Trough Earthquake Extra Information is issued with the title Nankai Trough Earthquake Extra Information (Megathrust Earthquake Alert) with appended keywords. Examples of keywords and disaster prevention measures are shown below.

Keywords	Conditions
Under Analysis	When analysis is underway to determine whether anomalies relate to the Nankai Trough Earthquake
Megathrust Earthquake Alert	For an earthquake of Mw*8.0 or more considered to have occurred at a plate boundary with an anticipated focal region along the Nankai Trough
Megathrust Earthquake Attention	For an earthquake of Mw7.0 or more considered to have occurred with an anticipated focal region and surroundings along the Nankai Trough (except in Megathrust Earthquake Alerts) For an unusual slow slip considered to have occurred at a plate boundary with an anticipated focal region along the Nankai Trough
Analysis Complete	When the results of analysis indicate that the anomalies are not classified into either Megathrust Earthquake Alert or Megathrust Earthquake Attention output

*Mw: Moment magnitude. It is a type of magnitude calculated based on the scale of rupture area along source fault, average slip, and rigidity of rocks.

Mw8.0 or more Earthquake · Mw7.0 or more Earthquake · Unusual slow slip

Issuance of Nankai Trough Earthquake Extra Information and Disaster Prevention Measures

Under Analysis	• Take action to protect yourself as necessary • Pay attention to subsequent information issuance	
		Megathrust Earthquake Alert: • Remain prepared for an earthquake on a daily basis • Act in advance if it may not be possible to evacuate before a tsunami arrives
		Megathrust Earthquake Attention: • Remain prepared for an earthquake on a daily basis
		Analysis Complete: • Consider the potential for earthquakes in your daily routine

Nankai Trough Earthquake Assessment Committee meeting

Anomalous phenomena → 5-30 minutes → About 2 hours

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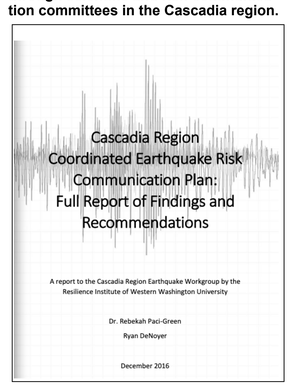
A 2016 report by CREW recommended that coordinated earthquake risk communication be formalized and managed through scientific and risk-communication committees in the Cascadia region.



Cascadia Region
Coordinated Earthquake Risk Communication Plan:
Full Report of Findings and Recommendations

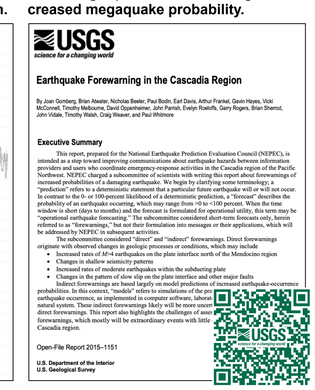
A report to the Cascadia Region Earthquake Workgroup by the Resilience Institute of Western Washington University

Dr. Rebekah Paci-Green

Ryan DeNoyer

December 2016

A NEPEC-commissioned report examined situations, such as increased earthquake rates or patterns of slow slip, which might provide forewarnings of increased megaquake probability.



USGS science for a changing world

Earthquake Forewarning in the Cascadia Region

By Joan Gomberg, Brian Atwater, Nicholas Beeler, Paul Bodin, Earl Davis, Arthur Frankel, Gavin Hayes, Vicki McConnell, Timothy Melbourne, David Oppenheimer, John Parrish, Evelyn Roeloffs, Garry Rogers, Brian Sherrod, John Vidale, Timothy Walsh, Craig Weaver, and Paul Whitmore

Executive Summary

This report, prepared for the National Earthquake Prediction Evaluation Council (NEPEC), is intended as a step toward improving communications about earthquake hazards between information providers and users who coordinate emergency-response activities in the Cascadia region of the Pacific Northwest. NEPEC charged a subcommittee of scientists with writing this report about forewarnings of increased probabilities of a damaging earthquake. We begin by clarifying some terminology; a "prediction" refers to a deterministic statement that a particular future earthquake will or will not occur. In contrast to the 0- or 100-percent likelihood of a deterministic prediction, a "forecast" describes the probability of an earthquake occurring, which may range from >0 to <100 percent. When the time window is short (days to months) and the forecast is formulated for operational utility, this term may be "operational earthquake forecasting." The subcommittee considered short-term forecasts only, herein referred to as "forewarnings," but not their formulation into messages or their applications, which will be addressed by NEPEC in subsequent activities.

The subcommittee considered "direct" and "indirect" forewarnings. Direct forewarnings originate with observed changes in geologic processes or conditions, which may include

- Increased rates of *M*>4 earthquakes on the plate interface north of the Mendocino region
- Changes in shallow seismicity patterns
- Increased rates of moderate earthquakes within the subducting plate
- Changes in the pattern of slow slip on the plate interface and other major faults

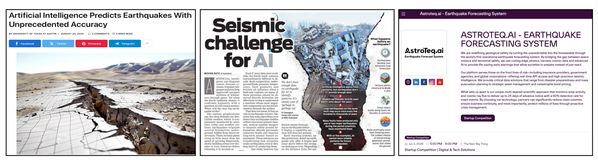
Indirect forewarnings are based largely on model predictions of increased earthquake-occurrence probabilities. In this context, "models" refers to simulations of the pro… earthquake occurrence, as implemented in computer software, laboratory… natural system. These indirect forewarnings likely will be more uncert… direct forewarnings. This report also highlights the challenges of asse… forewarnings, which mostly will be extraordinary events with little… Cascadia region.

Open-File Report 2015–1151

U.S. Department of the Interior
U.S. Geological Survey

AI- and ML-based prediction

There is great interest in AI- and ML-based prediction. What methods, guidelines, and benchmarks exist for evaluating the promise and skill of such models? NEPEC is assessing this topic to identify promising approaches and critical challenges, protocols for evaluating proprietary commercial models, and communication strategies to help the USGS navigate this rapidly evolving field.



Artificial Intelligence Predicts Earthquakes With Unprecedented Accuracy

Seismic challenge for AI

AstroTeq.AI – EARTHQUAKE FORECASTING SYSTEM