

Short-term earthquake prediction by reverse tracing of lithosphere dynamics

Abstract

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1. Most of existing earthquake prediction methods are aimed at intermediate-term and long-term predictions, with a lead time *years and tens of years* respectively. Here, we describe a new methodology for the short-term (*months* in advance) prediction. It is named Reverse Tracing of Precursors (*RTP*), since it traces premonitory phenomena in reverse order of their appearance.

2. Prediction is aimed at the “space-time of an alarm”, that is the area and time interval, within which a target earthquake will occur. Unlike the classical problem of predicting continuous processes, our problem is predicting the rare point events; the predictor is a discrete sequence of alarms, while predictor of continuous processes is also a continuous function. Probability of errors is estimated on the basis of error diagrams.

3. RTR consists of two steps. First we detect the “candidates” for short-term precursors. Those are newly introduced chains of small earthquakes that reflect the premonitory increase of the earthquakes’ correlation range; qualitatively, these chains are the dense, long, and rapidly formed sequences of small and medium earthquakes. We have found that such candidates precede within months most of the target earthquakes. However, up to 90% of the chains are not followed so closely by strong earthquakes and in prediction they would cause false alarms. Their rate is reduced on the second step. We determine whether certain intermediate-term precursors have occurred in the vicinity of each candidate within few years preceding it. If (and only if) yes, the chain is regarded as a precursor. Then a short-term alarm is declared in the vicinity of the chains for several (so far - nine) month.

4. San Simeon earthquake in Central California (magnitude 6.5, Dec. 22, 2003) and Tokachi-oki earthquake in Northern Japan (magnitude 8.1, Sept. 25, 2003) have been predicted by this methodology six and seven months in advance, respectively. Retrospective application of RTP to 25 more strong earthquakes in California, Japan, Eastern Mediterranean, and Italy is also encouraging. Decisive validation of methodology requires further advance predictions.

5. *Physical model* underlying *PRT* stems from the basic conditions of generation of an earthquake: accumulation of sufficient energy that the earthquake will release; and accumulation of sufficient instability triggering this release. Energy is carried by the *stress* field, instability – by the (*stress minus strength*) field. Here, we detect both processes by of premonitory seismicity patterns, found in the modeled and observed seismicity. Chains signal the fast surge of instability. Intermediate-term patterns show that this rise was preceded by accumulation of energy and instability in the same area over preceding years.

6. *Methodological advantage of RTP* over a direct analysis is in drastic reduction in dimensionality of parameter space where precursors are looked for. We have found here the precursors formed in narrow areas different from case to case, whose shape might be complicated, and size - diverse. Search for these areas by usual trial-and-error procedure would require trying one by one different shapes, sizes, chains and locations, which is hardly realistic. Reverse analysis resolves this impasse, determining from the start a limited number of the areas to consider.

7. *On other data.* It seems promising to apply *RTP* to other data relevant to earthquake prediction, such as InSAR, GPS, electromagnetic fields, fluid regime.... The first highly successful applications have been obtained with precursors gauging *interaction between the ductile and brittle layers of the Earth crust*; this established an important link of geodynamics and nonlinear dynamics.

8. *On other disasters.* The principles of *RTP* are not specific to earthquakes and might be applicable to critical transitions in a wide class of hierarchical non-linear systems.

9. Results, reviewed in this talk are described in the following papers:

- Aki, Keiiti, 2003. Introduction to Seismology for Earthquake Prediction. Preprint, Proc. of the Seventh Workshop on Non-Linear Dynamics and Earthquake Prediction, International Center for Theoretical Physics, Trieste.
- Gabrielov, A., Zaliapin I., Newman W., and Keilis-Borok, V., 2000. Colliding cascades model for earthquake prediction, *Geophysical Journal International*, 143, pp. 427-437. <http://www.math.purdue.edu/~agabriel/cc2.pdf>
- Keilis-Borok, V., Shebalin, P., Gabrielov, A., and Turcotte, D., 2004. Reverse detection of short-term earthquake precursors, *Physics of the Earth and Planetary Interiors*. In print. http://www.sciencedirect.com/science?_ob=GatewayURL&_method=citationSearch&_uokey=B6V6S-4CG0SN6-1&_origin=SDEMFRASCI&_version=1&md5=b71d74d3de7f9566042390b93f4e643f
- Shebalin, P., Keilis-Borok, V., Zaliapin, I., Uyeda, S., Nagao, T., and Tsybin, N., 2004. Short-term advance prediction of the large Hokkaido earthquake, September 25, 2003, magnitude 8.1: A case history, *Earth, Planets and Space*. In print. Preprint: <http://www.geocities.co.jp/Technopolis/4025/030925eq.pdf>
- Zaliapin, I., Keilis-Borok, V.I., and Axen, G., 2002. Premonitory spreading of seismicity over the faults' network in southern California: Precursor Accord. *J. Geophys. Res.*, 107(B10): 2221.
- Zaliapin, I., Keilis-Borok, V., and Ghil, M., 2003. A Boolean delay equation model of colliding cascades. Part II: Prediction of critical transitions, *Journal of Statistical Physics*, 111, pp. 839-861. <http://www.igpp.ucla.edu/mcdonnell/papers/bde2s.ps>

Earlier studies in the adjacent problem of intermediate-term prediction are reviewed in:

- Keilis-Borok, V., 2002. Earthquake prediction: state-of-the-art and emerging possibilities, *Annu. Rev. Earth Planet. Sci.*, 30, 38 p. <http://arjournals.annualreviews.org/doi/full/10.1146/annurev.earth.30.100301.083856>
- Keilis-Borok, V. I., and Soloviev, A. A. (eds.), 2003. *Nonlinear Dynamics of the Lithosphere and Earthquake Prediction*, Springer-Verlag, Heidelberg, 337 p.