Prospectively Evaluating the Collaboratory for the Study of Earthquake Predictability: An Evaluation of the UCERF2 and Updated Five-Year RELM Forecasts

*Anne Elizabeth Strader[1], Max Schneider[2,1], Danijel Schorlemmer[1], Maria Liukis[3]

1.GFZ Potsdam, 2.Universität Potsdam, 3.USC

The Collaboratory for the Study of Earthquake Predictability (CSEP) was developed to rigorously test earthquake forecasts retrospectively and prospectively through reproducible, completely transparent experiments within a controlled environment (Zechar et al., 2010). During 2006-2011, thirteen five-year time-invariant prospective earthquake mainshock forecasts developed by the Regional Earthquake Likelihood Models (RELM) working group were evaluated through the CSEP testing center (Schorlemmer and Gerstenberger, 2007). The number, spatial, and magnitude components of the forecasts were compared to the respective observed seismicity components using a set of consistency tests (Schorlemmer et al., 2007, Zechar et al., 2010). In the initial experiment, all but three forecast models passed every test at the 95% significance level, with all forecasts displaying consistent log-likelihoods (L-test) and magnitude distributions (M-test) with the observed seismicity. In the ten-year RELM experiment update, we reevaluate these earthquake forecasts over an eight-year period from 2008-2016, to determine the consistency of previous likelihood testing results over longer time intervals. Additionally, we test the Uniform California Earthquake Rupture Forecast (UCERF2), developed by the U.S. Geological Survey (USGS), and the earthquake rate model developed by the California Geological Survey (CGS) and the USGS for the National Seismic Hazard Mapping Program (NSHMP) against the RELM forecasts. Both the UCERF2 and NSHMP forecasts pass all consistency tests, though the Helmstetter et al. (2007) and Shen et al. (2007) models exhibit greater information gain per earthquake according to the T- and W- tests (Rhoades et al., 2011). Though all but three RELM forecasts pass the spatial likelihood test (S-test), multiple forecasts fail the M-test due to overprediction of the number of earthquakes during the target period. Though there is no significant difference between the UCERF2 and NSHMP models, residual scores show that the NSHMP model is preferred in locations with earthquake occurrence, due to the lower seismicity rates forecasted by the UCERF2 model.

Keywords: forecast, likelihood, statistical seismology

Collaboratory for the Study of Earthquake Predictability - Global and Regional Results

*Thomas Beutin[1], Danijel Schorlemmer[1], Naoshi Hirata[2], Hiroshi Tsuruoka[2], Matt Gerstenberger[3], Anne Elizabeth Strader[1]

1.GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, 2.Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan, 3.GNS Science, 1 Fairway Drive, Avalon 5010, Lower Hutt 5040, New Zealand

The Collaboratory for the Study of Earthquake Predictability (CSEP) aims to improve our understanding about the physics and predictability of earthquakes through rigorous and prospective testing of earthquake forecast models. CSEP operates four testing centers in California, New Zealand, Japan, and Europe running prospective, automated evaluations of more than 430 models. These testing centers are the technical infrastructure of CSEP and implement all procedures and protocols for rigorous testing and evaluation of earthquake prediction experiments. These experiments run in various testing regions and comprise forecast periods of 30 minutes to many years.
The CSEP software system as the basis for all CSEP testing centers is now being used for earthquake early warning systems and geodetic transient detectors. The Testing and Evaluation group of the Global Earthquake Model (GEM) project at GFZ Potsdam is expanding this system to test intensity prediction equations and ground-motion prediction equations.
We present results and the key lessons learned from all major CSEP and GEM experiments, and we give an overview of recent and ongoing developments, as well as new experiments.

Keywords: Earthquake forecasting, Seismic hazard, Statistical seismology, Earthquake statistics, Forecast testing, Software

Some development on predicting earthquake swarms using volumetric strain records

*Takao Kumazawa[1], Yosihiko Ogata[1,2], Kazuhiro Kimura[3], Kenji Maeda[3], Akio Kobayashi[3]

1.The Institute of Statistical Mathematics, 2.Earthquake Research Institute, 3.Meteorological Research Institute

Off the east coast of the Izu Peninsula in Japan, there is a submarine volcanic region where earthquake swarms occur caused by magma intrusions. We investigated the background seismicity rates of the swarm activity by removing the triggering effect of aftershocks. We found that such background rate changes coincide with the changes of exponentially weighted averages of volumetric strain increments at the Higashi-Izu station. We further found that such a relationship consistently depends on the distance between the strainmeter station and the location of the swarm onset. The quantitative relationships revealed here may be used to monitor magma intrusions that drive the stress changes. The models we adopted here are purely statistical, but we added some comparisons of their performances with those by physically reasonable models.

Keywords: Earthquake swarm, Volumetric strain, Background seismicity, ETAS model

Regional evolution of network detection completeness in Japan

*Danijel Schorlemmer[1,2], Naoshi Hirata[3], Yuzo Ishigaki[4], Kazuyoshi Nanjo[5], Hiroshi Tsuruoka[3], Thomas Beutin[1], Fabian Euchner[6]

1.GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, 2.Department of Earth Sciences, University of Southern California, Los Angeles, USA, 3.Earthquake Research Institute, University of Tokyo, Tokyo 113-0032, Japan, 4.Seismological and Volcanological Department, Japan Meteorological Agency, Tokyo 100-8122, Japan, 5.Institute of Advanced Science, Yokohama National University, Yokohama 240-8501, Japan, 6.Institute of Geophysics, ETH Zurich, Zurich, Switzerland

An important characteristic of any seismic network is its detection completeness, which should be considered a function of space and time. Many researchers rely on robust estimates of detection completeness, especially when investigating statistical parameters of earthquake occurrence like earthquake rates. Contrary to traditional approaches, we do not estimate completeness using methods in which the completeness magnitude is defined as the deviation of the frequency-magnitude distribution from the linear Gutenberg-Richter relation. Here, we present a method based on empirical data only: phase data, station information, and the network-specific attenuation relation. For each station of the network we estimate a time-dependent distribution function describing the detection capability depending on magnitude and distance to the earthquake. For each point in time, maps of detection probabilities for certain magnitudes or overall completeness levels are compiled based on these distributions. Therefore, this method allows for inspection of station performances and their evolution as well as investigations on local detection probabilities even in regions without seismic activity.
We present a full history of network detection completeness for Japan and discuss details of this evolution, e.g. the effects of the Tohoku-oki earthquake sequence. For practical purposes we deliver completeness estimates for catalog data of selected regions and document the conservative completeness estimates researchers can use when investigating the JMA catalog in different regions over different periods. All presented results are published on the CompletenessWeb (www.completenessweb.org) from which the user can download completeness data from all investigated regions, software codes for reproducing the results, and publication-ready and customizable figures.

Keywords: Seismic Networks, Data Quality, Completeness, Earthquake Statistics, Statistical Seismology, Earthquake Hazard

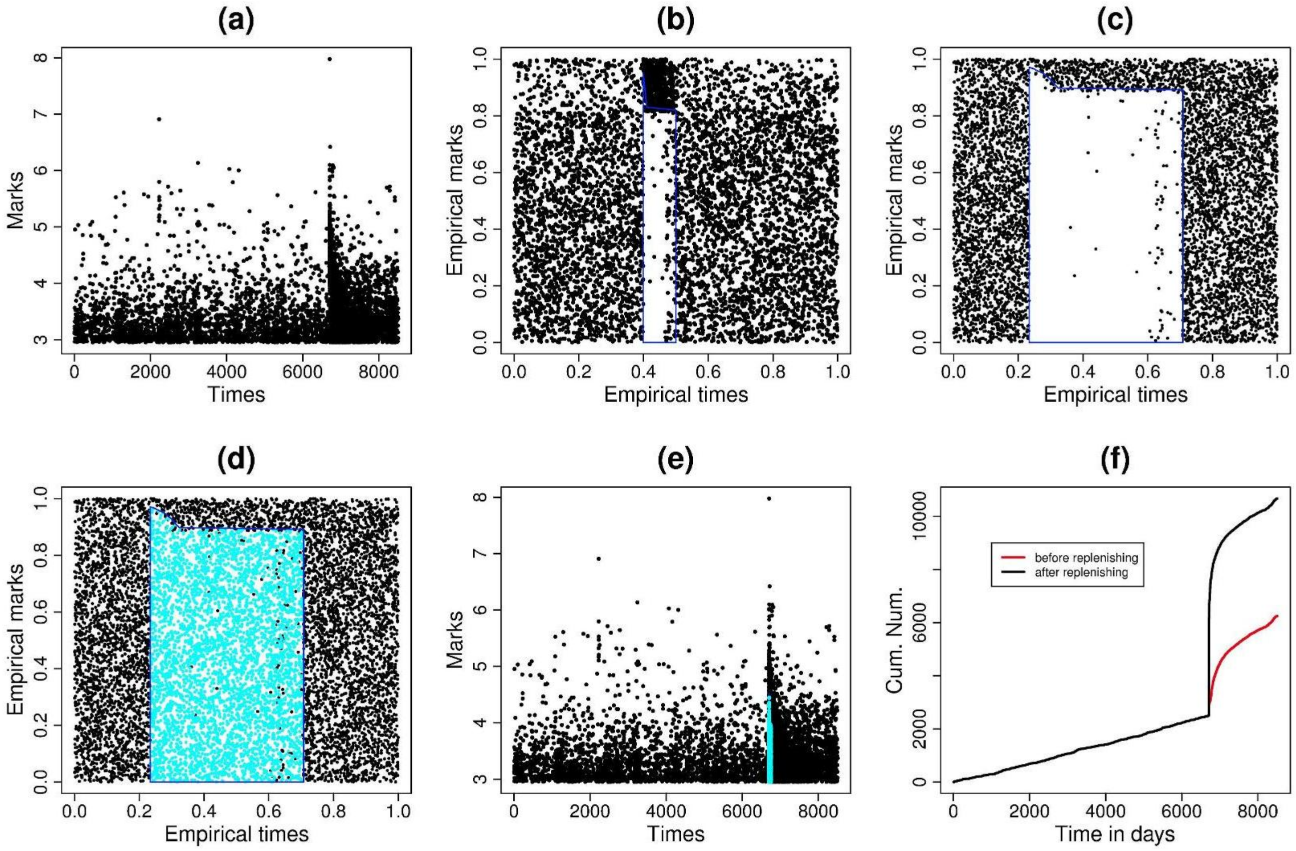
Correcting biases in the estimates of earthquake clustering parameters caused by short-term missing of aftershocks

*Jiancang Zhuang[1], Ting Wang[2]

1.Institute of Statistical Mathematics, 2.University of Otago

Short-term missing of aftershock in the early stage after the mainshock always biases the estimates of earthquake clustering models such as the ETAS model and the Omori-Utsu formula. For example, the parameters c and p in the Omori-Utsu formula change with the cutoff magnitude threshold. To correct the biases caused by such short-term aftershock missing, we apply a method developed by Zhuang et al (2016) to replenishing missing data. The basic idea of this method is that, if a temporal point process with time independent marks is completely observed, the whole process can transformed into a homogeneous Poisson process on the unit square by a biscale empirical transformation. Using this method, we can simulate the missing events and re-estimate model parameter with the replenished dataset. For example, applying this method to the aftershock sequence following the 2008 Wenchuan Ms7.9 earthquake in southwestern China, the results show that the Omori parameters c and p do not change with magnitude threshold anymore and that the missing of small events in the early stage of the aftershock sequence causes the inconsistent estimate of the earthquake clustering models.
Figure: Results from applying the replenishment algorithm to the earthquake data from Southwest China. (a) Marks (magnitudes) versus occurrence times of the earthquakes.
(b) Empirical distribution of marks (magnitudes) versus empirical distribution of occurrence times of the recorded events. (c) Rescalled marks (magnitudes) versus rescaled occurrence times of the combination of the observed events, with the rescaling based the empirical distributions of events in the time-magnitude range with complete observation. (d) Rescalled marks (magnitudes) versus rescaled occurrence times of the observed events and replenished events. (e) Marks (magnitudes) versus occurrence times of the observed events and the replenished events. (f) Cumulative numbers of events against occurrence times. Blue polygon is corresponding to the time-magnitude range in which the missing events fall. Blue dots are the replenished events.
Reference:
Zhuang, J., T. Wang and K. Kiyosugi, (2016) Detection and replenishment of missing data in marked point processes, *in preparation*.

Keywords: ETAS model, Omori-Utsu formula, missing data, aftershock

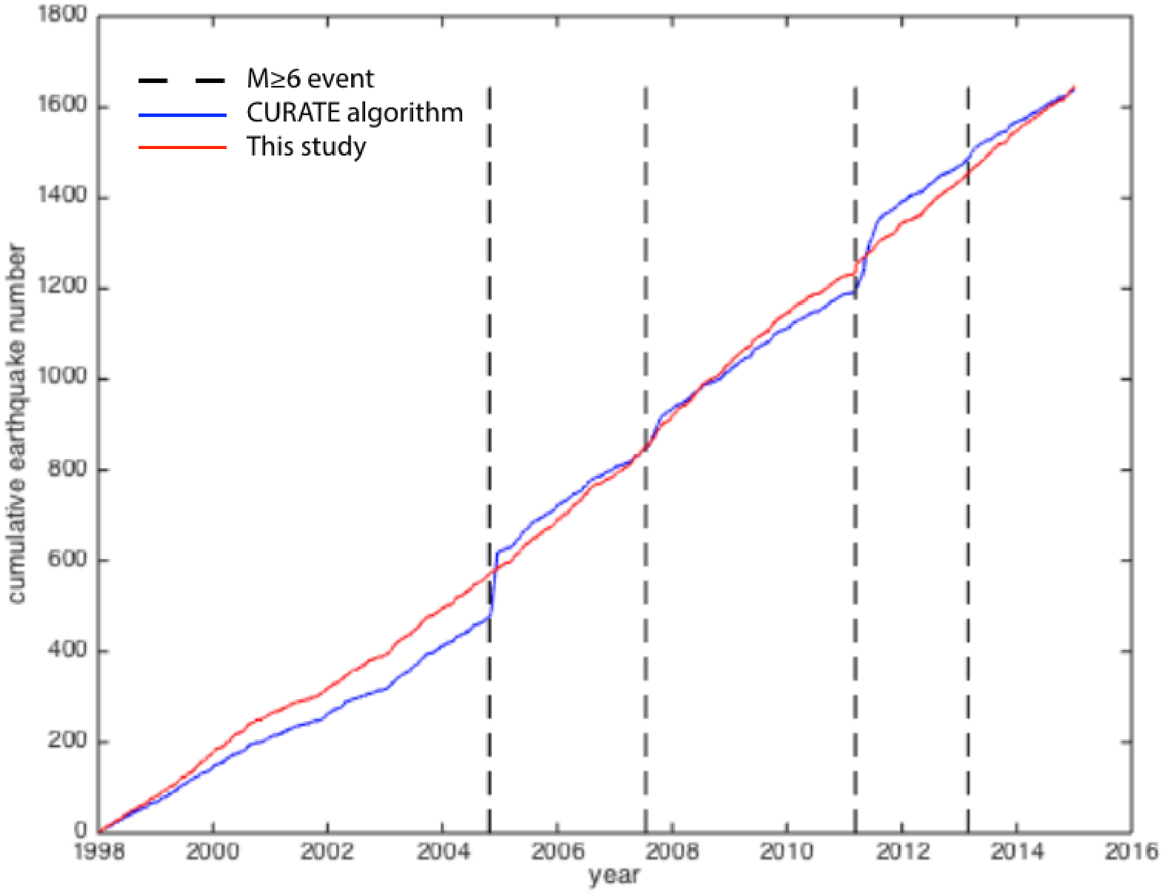

(a)
Marks
Times
(b)
Empirical marks
Empirical times
(c)
Empirical marks
Empirical times
(d)
Empirical marks
Empirical times
(e)
Marks
Times
(f)
Cum. Num.
Time in days
before replenishing
after replenishing

A new algorithm to find earthquake clusters using neighboring cell connection and tests in northern Honshu, Japan

*Wei Peng[1], Shinji Toda[2]

1.Graduate School of Science, Tohoku University, 2.International Research Institute of Disaster Science, Tohoku University

To study the earthquake interaction, it is important to find a group of earthquakes occurred closely in space and time objectively and quantitatively. Earthquake clusters are chosen with previous clustering techniques that characterize them as mainshock-aftershock sequences or swarm sequences with empirical laws such as Omori-Utsu law or direct assumptions about physical processes such as rate/state Coulomb stress transfer, transient stress loading, fluid migration, and structural heterogeneity. Recently several papers proposed non-parameterized techniques such as kernel-based smoothing methods (e.g., Helmstetter & Werner, 2012). The cumulative rate clustering method (CURATE, Jacobs et al., 2013) is one of the approaches without any direct assumptions. The CURATE method was applied in Central Volcanic Region of New Zealand and provided a good result for selecting the swarm sequence comparing with ETAS models. However, it is still difficult to choose a proper confined area and a proper time interval for combining sequences. To reduce the arbitrary and subjective choices of space and time parameters in the CURATE method, here we propose a new method modifying the CURATE approach. We first identify the spatial clusters by looking into the spatial distribution with time in a 2-D cell-gridded map. The spatial clusters defined as a cell size (S) which contains earthquakes and connecting its neighborhood cells if the neighborhood cells also contain earthquake events in a time window T. From the selected spatial clusters, we then evaluate temporal clustering which is defined as the increase of the transient seismicity rate at a target event comparing to the rate from the target event to the end of the sequence. This approach gives only two free parameters, T and S, for the declustering process. We tested this method for the JMA catalog and focus on the Chuetsu region (Niigata Prefecture), with earthquakes shallower than 20 km and magnitude range from 2 to 6.9. We choose the parameter ranges from T = 1 to 100 days and S = 0.01°to 0.1°, the results show that the number of the cluster events increases with longer T and larger S. By choosing the T = 30 days and S = 0.05°, we successfully selected the long aftershock period sequences associated with the 2004 M6.8 Chuetsu earthquake and 2007 M6.8 Chuetse-oki earthquake, while other empirical physical models and CURATE method fail to select. It suggests that this method better finds the seismic clusters including secondary aftershocks, and thus shows better declustering performance than the others.


M≥6 event
CURATE algorithm
This study
cumulative earthquake number
year
0
200
400
600
800
1000
1200
1400
1600
1800
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016