T-RELM Testing Center: Rigorous testing of probabilistic earthquake forecast models

RELM

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Introduction

Testing probabilistic earthquake models is becoming an increasingly important task in seismology.

So far, models have only been tested:
- Pseudo-prospectively
- Using different testing methods (no standards)
- Using non-transparent (non-reproducible) methods
- Not comparatively

With RELM we want to achieve:
- Setting a new standard of rigorous forecast tests
- Establish community-accepted testing rules
- Truly prospective 5-years tests
- Comparative tests between each model
- Data-consistency tests
- Set up a central Testing Center

With the Testing Center we can:
- Re-run the codes with alternative options
- Re-run the codes in case of bugs or additional tests
- Document each models code and changes (CVS)
- Track the modeler's additional data
- 'Certify' all steps of testing

Grid-based Testing (Likelihood Testing)

- A bin defines a volume (cell), magnitude range, and range of focal mechanism angles.
- In each bin: **Expectation** λ
  Observation ω
- Proposed default binning: Lon/Lat 0.1° x 0.1°; Depth 0-50km; Magnitude 0.1; Focal Mech. None (30°)
- Test model's consistency with the data (**L-/N-Test**)
- Test model's relative performance compared to other models (**R-Test**)

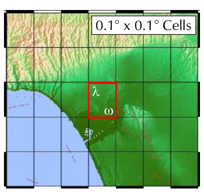

Figure 1: Example of a grid (0.1° x 0.1° cells). Each cell is additionally divided into bins spanning the magnitude range for testing. In each bin, the expectation λ is tested against the observation ω.

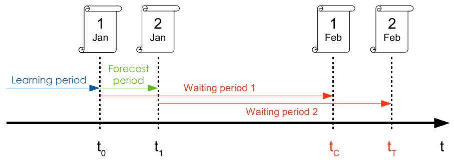

Figure 2: Timing for testing earthquake forecasts. During the **Learning Period**, modelers can deposit any data their models need to generate forecasts. After **Waiting Period 1** at time t_C, the Central Dispatcher (see Fig. 3) provides 'authorized' data to the time-dependent models. The models generate forecasts for the **Forecasting Period**. After **Waiting period 2** at time t_T, the Central Dispatcher tests the models against revised data.

Testing Contests

1. Quasi-stationary models provide 5-years forecasts (M5-M9) for:
- general hazard studies, building codes, etc.

2. Time-dependent models provide daily forecasts (M4-M9) for:
- short-term predictability after larger main shocks.
- emergency services and rescue teams.
- understanding of time dependence of earthquakes

3. Same as 1 but with yearly updates for:
- insurance companies
- understanding intermediate-term time dependence

4. Contests 2 & 3 will be expanded by also testing the models using real-time (not revised) data for forecast generation (Real-time test) for:
- testing practical applicability

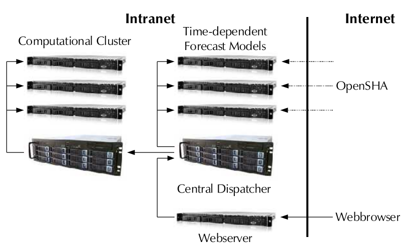

Figure 3: Schema of the computer setup for the Testing Center. The Central Dispatcher is conducting the tests and storing the results. Each time-dependent model runs on a model computer, additionally accessible from the internet via OpenSHA. All results will be presented on the webserver.

Area of Testing and Data Collection

- Collection area from which data is collected and provided to the models for forecast generation.
- Area for which models are tested

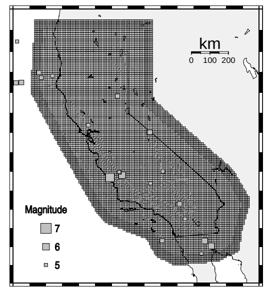

Figure 4: Testing and data collection bins. Testing bins are plotted as white patches. The collection area additionally contains the bins plotted as dark gray patches. Light gray patches indicate events of magnitude M ≥ 5 of the last 5 years.

Data Sources

- 'Authorized' data (independent sources) is provided by the Testing Center
- Non-'authorized' data can be provided by the modelers. This data needs to be submitted to the Testing Center during the learning period.

Independence Probabilities and Parameter Uncertainties

We account for the following uncertainties:
- Earthquake parameter uncertainties: Longitude, latitude, magnitude, time, focal mechanism angles
- Probability of independence of events

Time-dependent models:
- Test against non-declustered catalogs with bootstrapped uncertainties.

Quasi-stationary models:
- R-Test uses non-declustered catalogs with bootstrapped uncertainties.
- L-Test and N-Test use bootstrapped independence probabilities (generated by bootstrapping parameters of the declustering algorithm by [Reasenberg, 1985]) and bootstrapped uncertainties.

Presentation of Results

All results will presented on a website:
- Simulation results
- Development of significance values over time
- Spatial analysis of model performances.
- Magnitude range performance of models.
- Highscore list

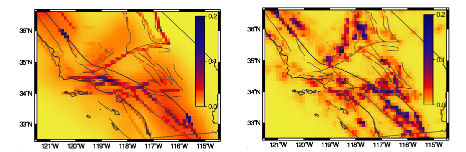

Figure 5: Examples for model expectations. (Left) Nodewise sum of expectations of a grid-based model derived from the USGS 1996 model [Frankel et al., 1996]. (Right) Nodewise sum of expectations of the model from [Helmstetter et al., submitted].

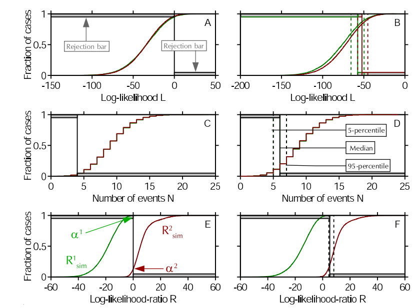

Figure 6: Examples for results of a 5-years test comparing the models shown in Figure 5. Green lines indicate CDF's of simulations of the model by [Frankel et al., 1996], red lines of the model by [Helmstetter et al., submitted], respectively. The vertical lines indicate the observed values (including bootstrap over uncertainties). (Left column) Results from the L-Test, N-Test, and R-Test using a undeclustered catalog. (Right column) Results from the L-Test, N-Test, and R-Test using a catalog with independence probabilites.

From T-RELM to CSEP (Collaboratory for the Study of Earthquake Predictability)

We are planning to extend the T-RELM capabilities by:
- Introducing testing of alarm-based models
- Introducing testing of fault-based models.
- Expanding the model space
- Integrating more regions and forecast periods
- Integrating new authorative data sources (e.g., automatic slip distributions)

References: Frankel, A. et al.: USGS OFR 96-532, 1996. Helmstetter, A. et al.: Bull. Seimol. Soc. Am., submitted. Reasenberg, P.: J. Geophys. Res., 90, 5479-5495, 1985. Schorlemmer, D. et al.: Seismol. Res. Letts., submitted.