An Interactive Web Tool to Visualize and Improve USGS Operational Aftershock Forecasts

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Abstract

The USGS Earthquake Hazards Program provides information on potentially damaging earthquakes to the public, including Operational Aftershock Forecasts (OAF). The OAF system evaluates the chance of more earthquakes occurring in the next day, week, month, and year following all M5+ earthquakes in the U.S. and its territories[1]. OAF generates ~70 forecasts per sequence and ~5000 forecasts per year. Forecast information must be accurate because it is used by emergency managers and infrastructure operators to make well-informed decisions. The forecasts also help increase public awareness of potential aftershock dangers, such as building damage. We are using R[6] to create an open-source package to help our team visualize earthquake sequences, improve forecast models, and provide useful information to the public.

Visualizations and Interaction with R

Our R package pulls data from the Comprehensive Earthquake Catalog (ComCat) with a flexible query function that allows the user to find earthquakes of interest.

We use the R Shiny[7] package to build an interactive web tool to display the maps, plots, and tables generated by our R package. Leaflet[8] is used to make maps.

A global map shows all M5+ earthquakes with recent forecasts (Figure 1), pop-ups let the user see basic info on each mainshock with a link to go to the earthquake.usgs.gov event page, and each sequence can be selected for further study with a click.

The web tool currently implements 4 additional visualizations:

- Magnitude-time plot showing source network and magnitude type (Figure 2)
- Cumulative line plot comparing data to the model (Figure 3)
- Local map of a user-defined sequence (Figure 4)
- Magnitude-frequency plot of the aftershocks (Figure 5)

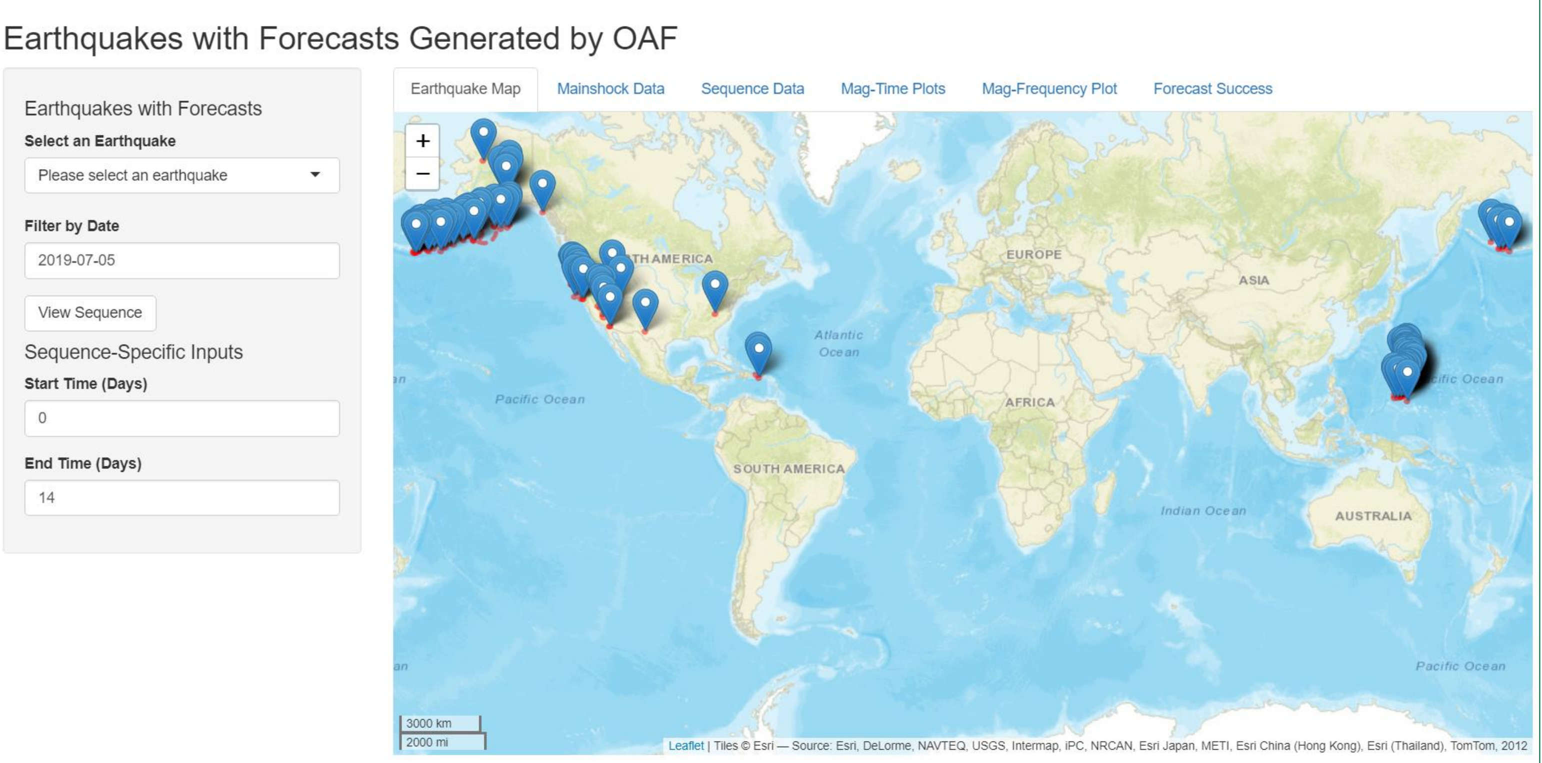

Figure 1: Global map showing the M5+ earthquakes with aftershock forecasts that occurred since Jan 1, 2018.

Emphasizing User Input

- R Shiny can find changes in default parameters and update graphics in real-time
- Updates only happen if input data changes
- Analogous to manually changing the code's variables and re-running an individual line, but it's automatic and much faster!

Who Contributed What?

The new magnitude-time plots (Figure 2) showed inconsistent methods for cataloging earthquakes during the 2021 M6.0 Antelope Valley sequence, such as:

- Lower magnitudes were only being rounded by the Nevada network
- There was an offset between the magnitudes from each network, specifically around magnitude 2

Based on this information, the Northern California network is looking into expanding their use of the local (ML) magnitudes to smaller earthquakes.

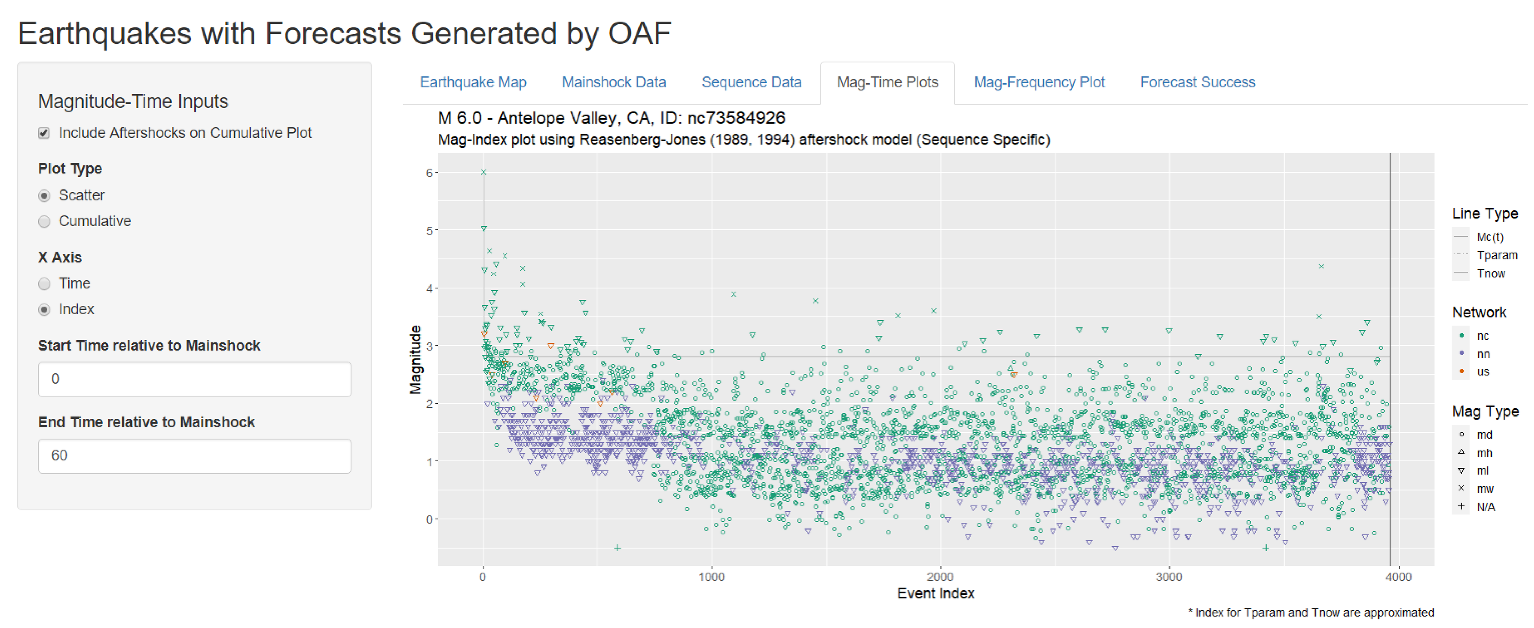

Figure 2: Magnitude-index plot showing network by color and magnitude type by shape for the 2021 M6.0 Antelope Valley sequence in California.

Want to see the web tool in action?

1-Minute Lightning Talk: https://youtu.be/LTfKZm0lTRE

5-Minute Web Tool Demo: https://youtu.be/mzRHyG_AdeU

How Many Earthquakes?

The cumulative number plots compare the sequence data to a Reasenberg-Jones[4] aftershock model. A good fit means that the model parameters correctly capture the productivity and decay of a sequence. Forecasts for a sequence start with a generic model, switch to a Bayesian model automatically, and transition to a sequence-specific one if necessary.

The 2021 M8.2 Perryville, Alaska sequence (red line) in Figure 3 oscillates around the model in a way that suggests a relatively good fit for this simple model (red dotted).

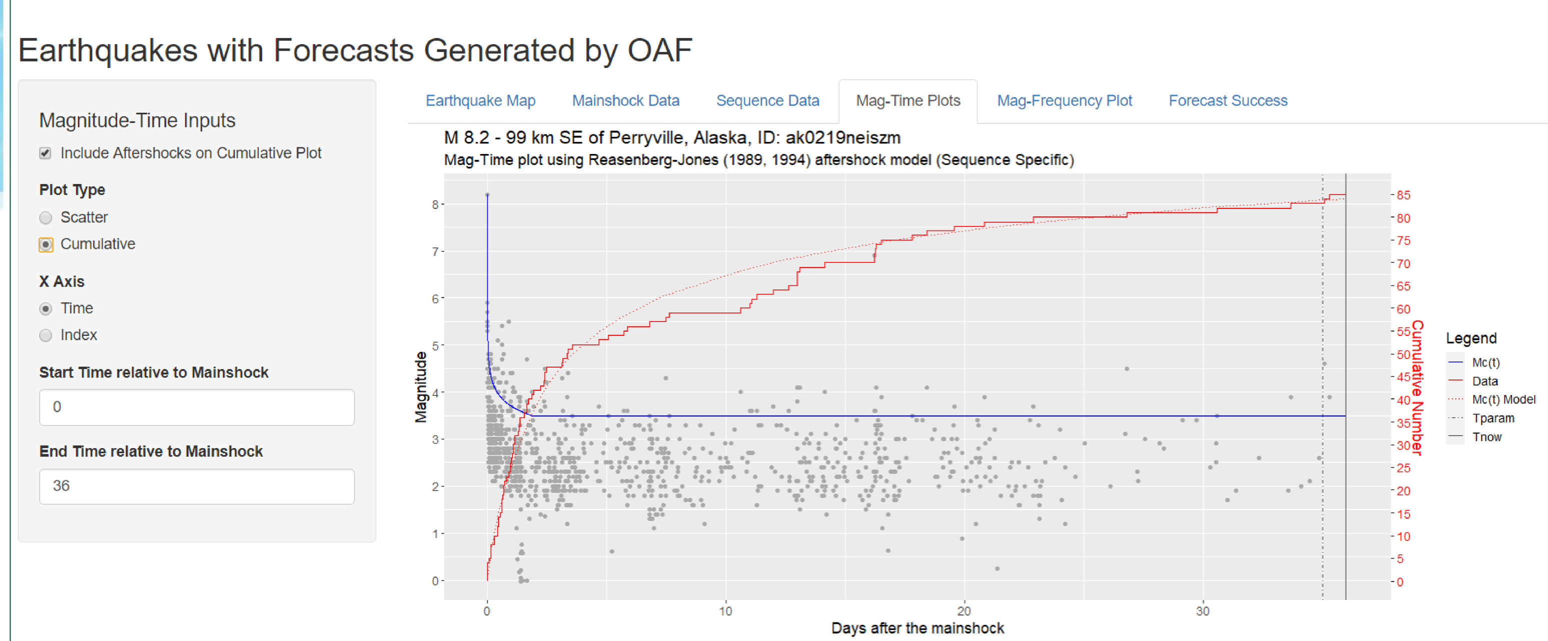

Figure 3: Cumulative number of aftershocks since the M8.2 earthquake near Perryville, Alaska, with the scatter plot of earthquakes included. Note that only earthquakes with magnitudes greater than the blue magnitude of completeness (Mc(t))[2,3,5] line are used to increment the cumulative data line (red line) and compute the model (red dotted line).

Where and When did it Happen?

A map of aftershocks allows the OAF team to understand the geospatial context for the sequence and adjust the search radius used to define the aftershock region[1].

Modifying the time period in the local map (Figure 4) can also show how many foreshocks occurred, which may provide useful information for subsequent data analysis.

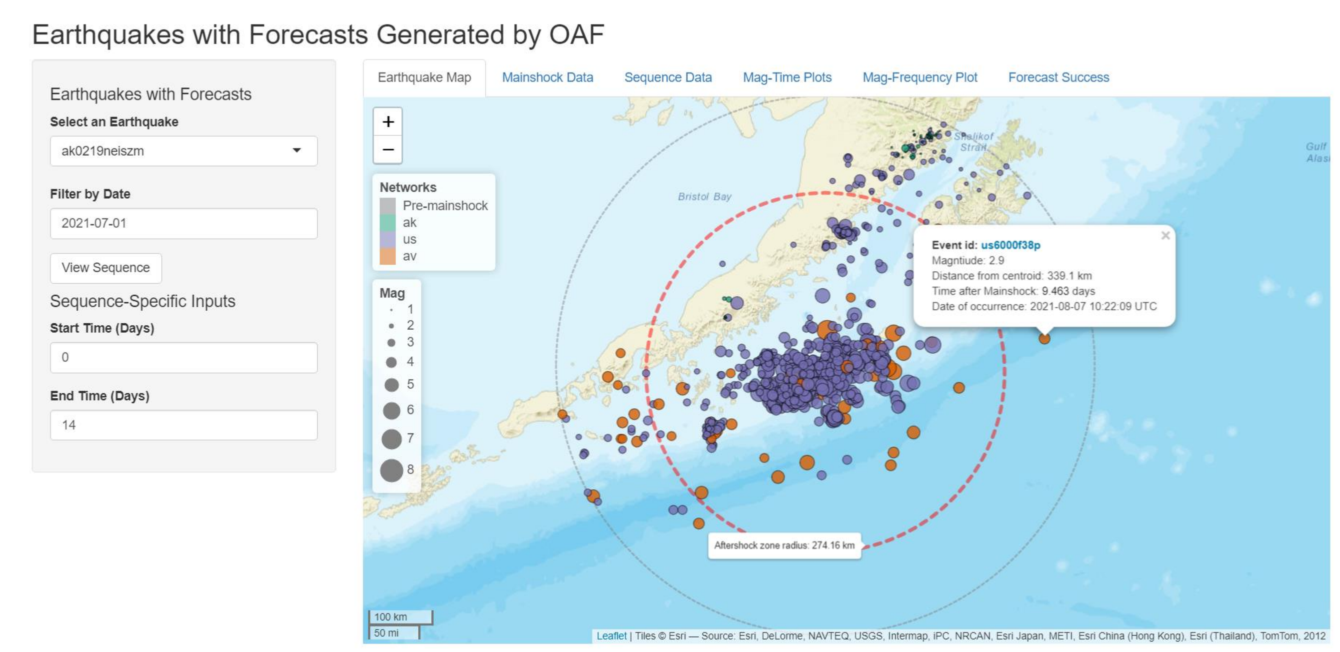

Figure 4: Local map of the 2021 M8.2 sequence near Perryville, Alaska. Each sequence gets its own aftershock zone (red dash), and an expanded search radius (grey dash) is used to ensure that all aftershocks are being accounted for.

How Many Earthquakes of Each Magnitude?

Magnitude-frequency plots allow us to extrapolate to higher magnitudes by comparing the ratio of large to small magnitudes.

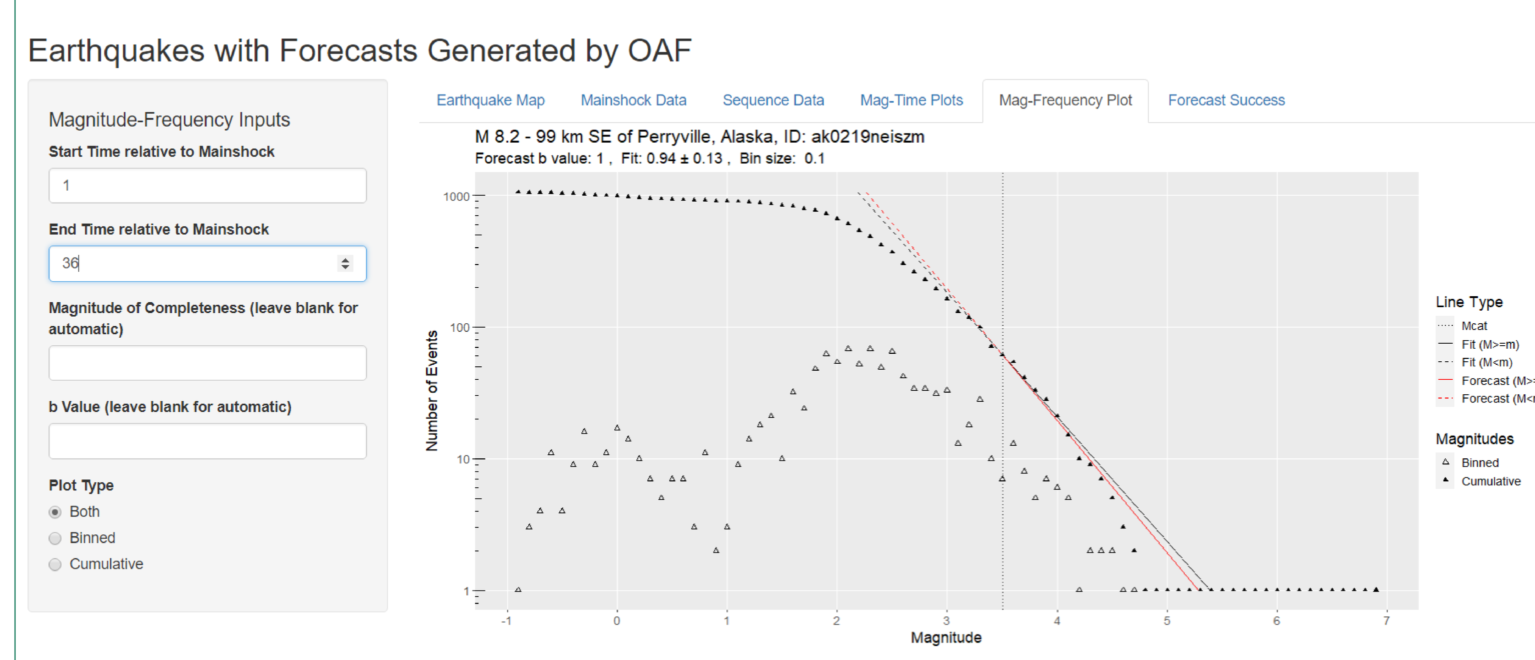

Figure 5: Magnitude-frequency plot showing the calculated fit compared to the forecast for the 2021 M8.2 Perryville, AK sequence.

Why is this Important?

Improving the plots helps seismologists understand complexities in the data, evaluate the spatial region used for the forecast, and improve our ability to communicate with the public and emergency managers. Comparing past forecasts to observations will also help the OAF team improve their system and maintain operational awareness.

Future Work

The next step is to study the success of the forecasts, which will be incorporated into the web tool. The forecast success plots will compare the forecasts with the observations for both individual sequences and integrated across multiple sequences.

References

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