Prototyping Earthquake Aftershock Forecast Maps Based on User Needs

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Background

Shortly after large earthquakes, agencies like the United States Geological Survey (USGS) may release aftershock forecasts, which give the expected number or probability of aftershocks of different magnitudes for different future periods (e.g., day, week, month). Aftershock forecasts are based on spatiotemporal statistical models built from seismological laws. These models, such as the Epidemic Type Aftershock Sequence (ETAS) model (Ogata 1998), describe how aftershock rates decay in time and space. Forecasted rates can be combined with ground motion prediction equations to probabilistically forecast the shaking caused by aftershocks. This information can help professionals make real-time decisions, for example on how and when to assess damaged buildings or resume business operations (Becker et al., 2019).

Forecasts are communicated through **forecast products** and scholars argue that aftershock forecasts products should be designed around the needs of users (Becker et al., 2019). In earlier work, we elicited user needs from a dozen professional groups (e.g., emergency managers, civil engineers, geoscientists, public information officials) in three workshops in the U.S., Mexico, and El Salvador (Schneider et al., 2023a). While user needs varied between groups and somewhat between country, forecasted shaking maps were widely requested across user groups. Users also specified needs they have of the forecast product (colors, key forecast metrics, additional map layers, etc.) to support the use of aftershock forecasts in their work. Our goal is to produce prototypes of shaking forecast maps that satisfy distinct user needs elicited at these workshops.

Prototyping Shaking Forecast Maps

We calculated probabilistic shaking forecasts for aftershocks following recent earthquakes in the U.S., Mexico and El Salvador using the AftershockForecaster software (van der Elst et al., 2022). Forecast maps either show

- the intensity of the forecasted shaking in Modified Mercalli Intensity (MMI) with a 10% chance of being exceeded in the next period ("MMI maps")
- the chance of strong shaking (intensity level VI or greater) within the next period ("probability maps")

In order to turn user needs into a visual aspect of a map, we translated them into **design parameters**, or a visual aspect of the map that can be chosen to suit a specific need. The table below shows this process for some user needs (Schneider et al., 2023a reports which user groups and use cases each user need corresponds to):

User Need	Use colors from other hazard products	Use red to signify risk	Simplify the map	Make danger zones immediately visible on the map by using few colors	Relate forecast to impacts	Communicate worst case scenarios	Explain map's scale for non-scientific audiences	Map previously-occurring aftershocks	Add faults, topography
Design Parameter	Color palette	Color palette	Classification scheme	Classification scheme	Caption	Title	Scale labels	Layers	Layers
Choice for Parameter	USGS/National Seism. Service of Mexico ShakeMap colors (MMI map)	"Shades of red" colors (probability map)	Eight bins (simplified from 10+)	Three bins	Description of impacts on buildings of strong ground shaking (MMI VI)	Maximum value in the forecast map	Verbal labels describing shaking levels (MMI map)	Layer showing previous aftershocks as black circles	Layer showing mapped fault lines

Using the 'ggplot2' package in R, we built a function that took design parameters as inputs and outputted map prototypes, as described below:

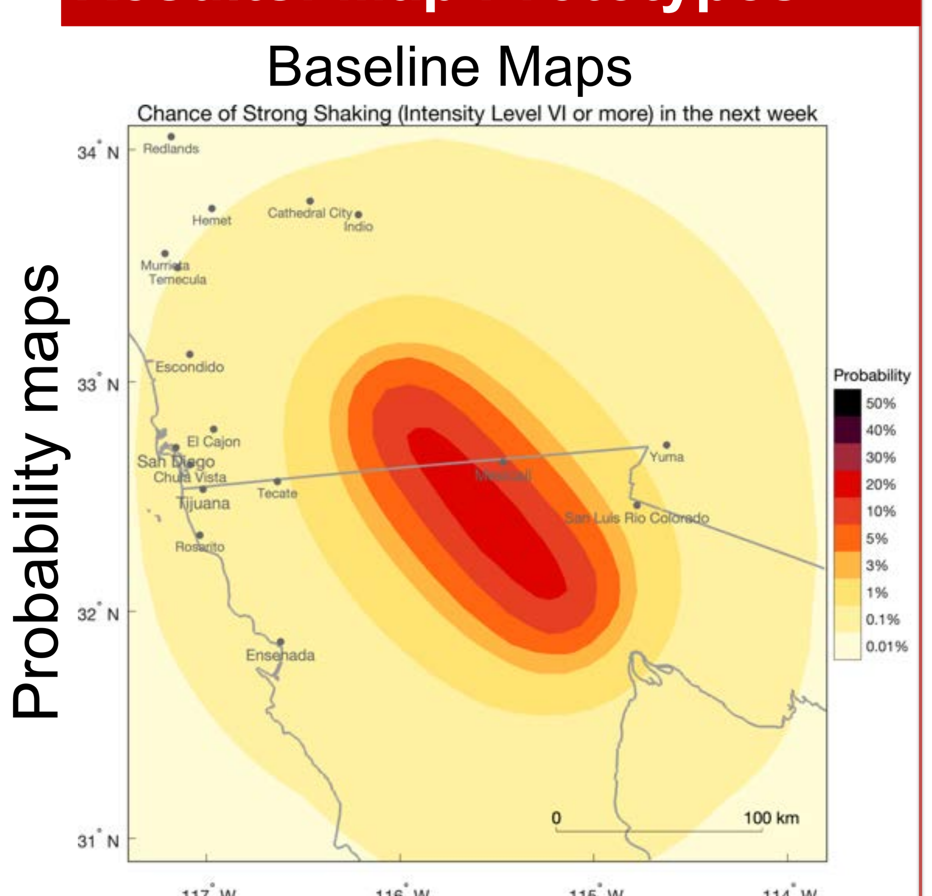
- Plot the variable over space as a heat map, using a classification scheme to map the variable into a palette of discrete colors
    - Color palettes were chosen to be discriminable, perceptually ordered and uniform, following literature-based best practices (Schneider et al., 2023b)
    - Classification schemes were chosen based on user needs (see table)
- Mark national and state borders and a small number of cities
- Add a gold star at the location of the mainshock
- Add other layers (e.g., faults, topography), carefully choosing colors to be distinct from heat map colors
- Add previous aftershocks as black circles, with size scaled by magnitude

After constructing map prototypes, we solicited review from the Operational Aftershock Forecasting team at the USGS, the GNS Science (New Zealand) earthquake forecasting team and other project partners in Mexico, El Salvador and New Zealand. Four review sessions were held between June 2023-June 2024 and prototypes were revised based on colleague suggestions.

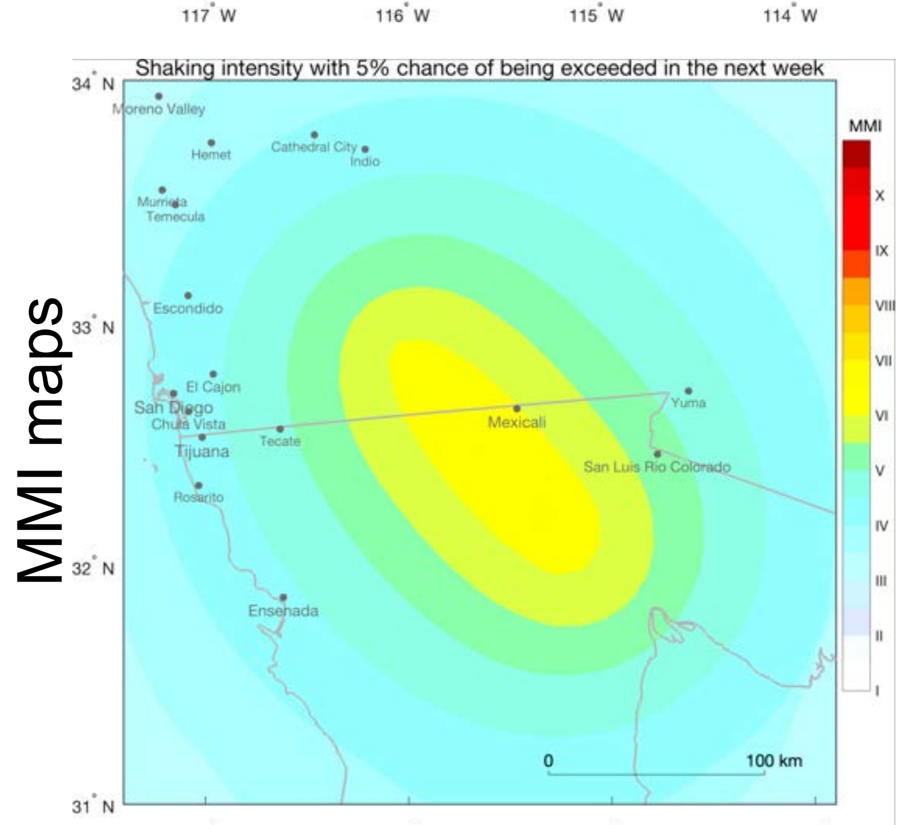
Results: Map Prototypes

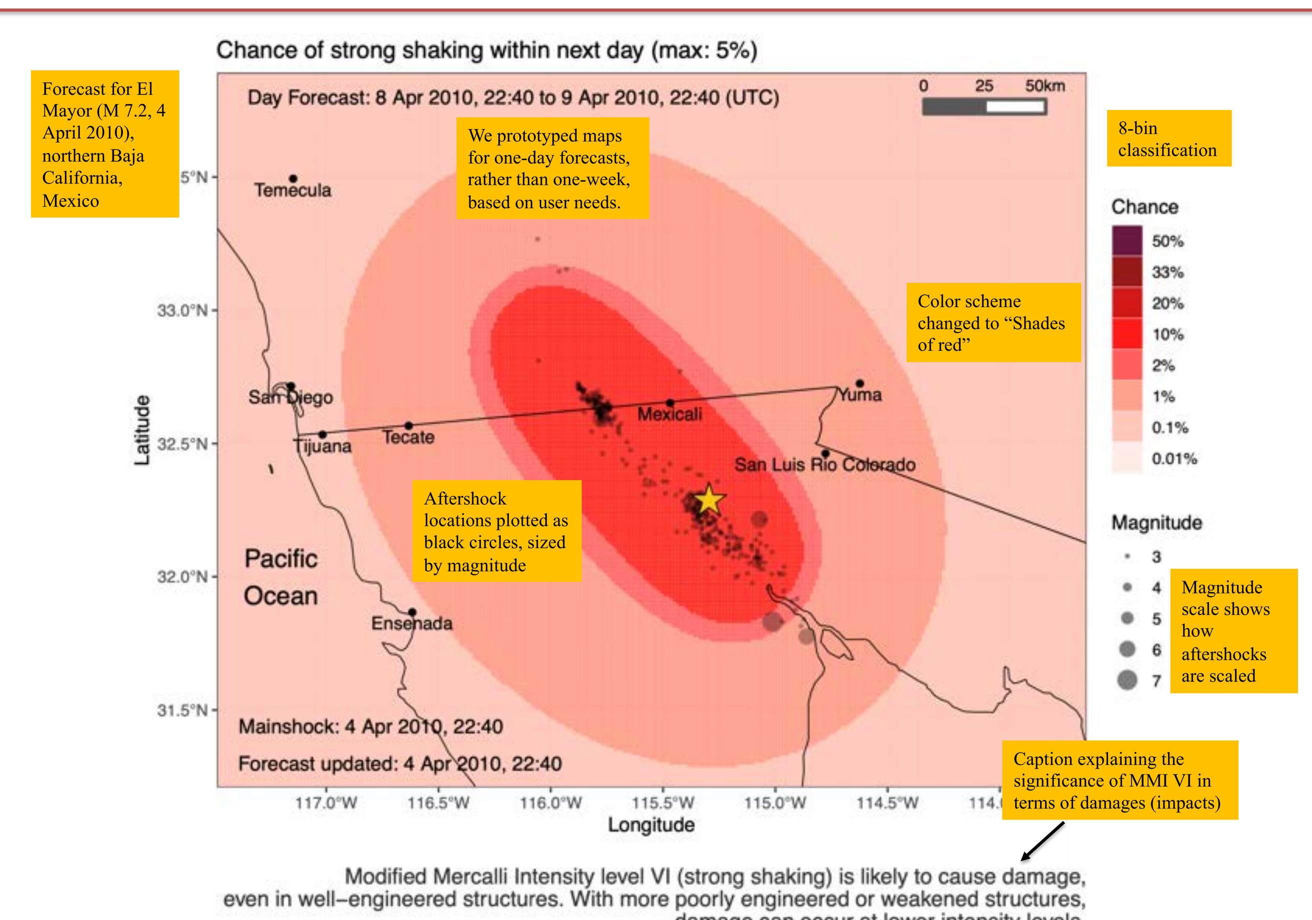
Baseline Maps

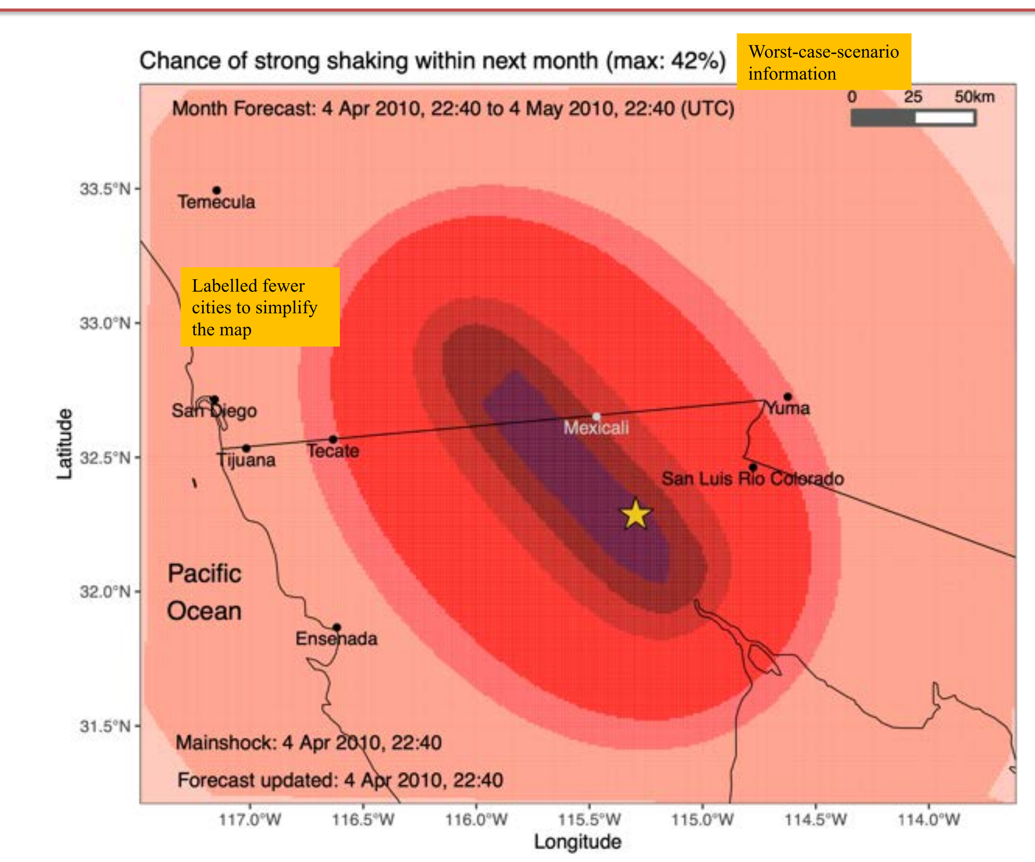
Probability maps

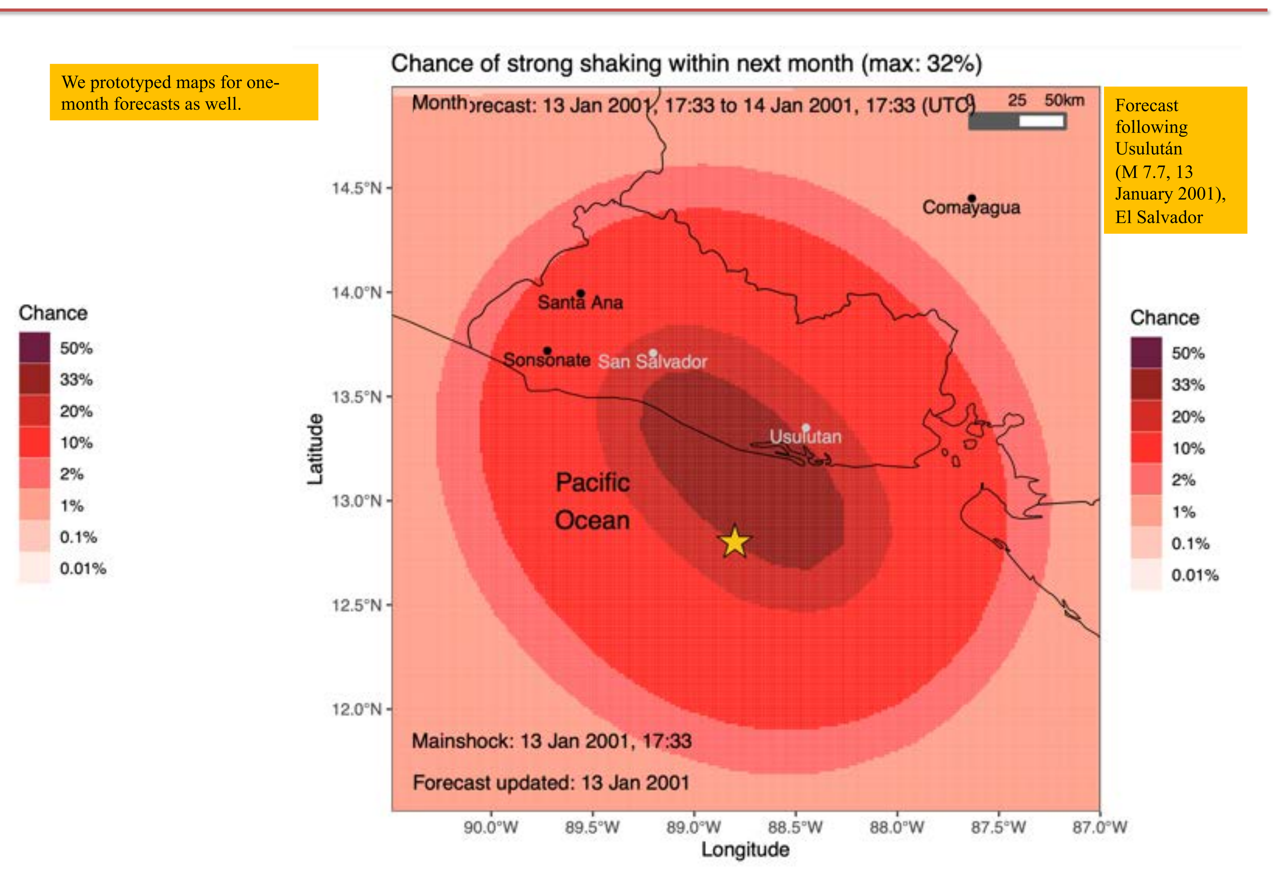


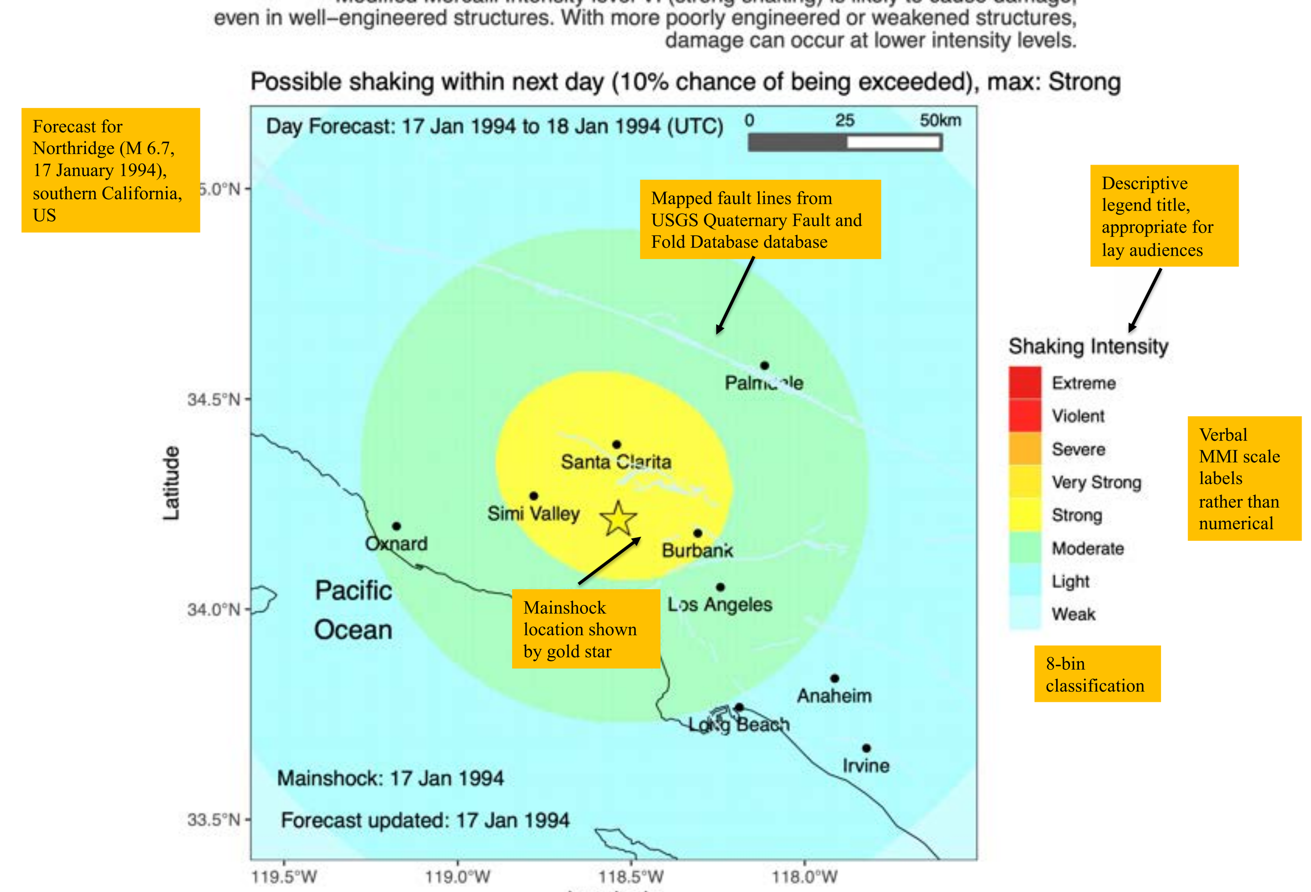
MMI maps

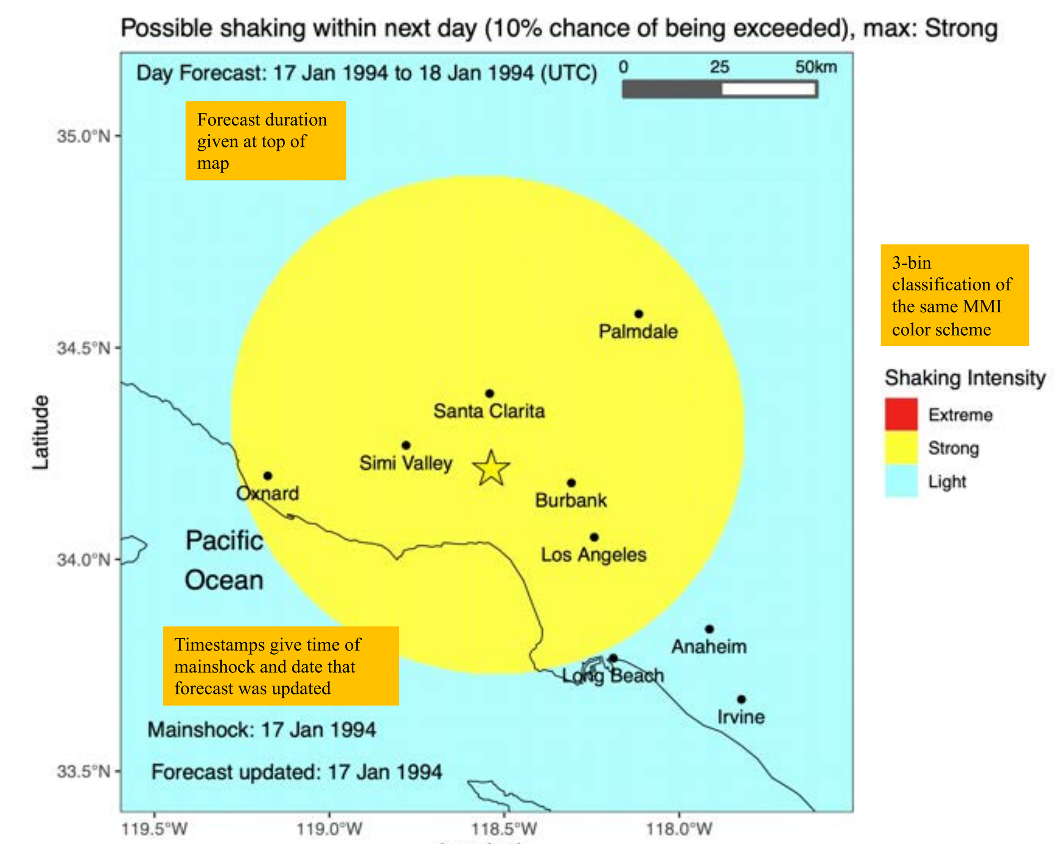


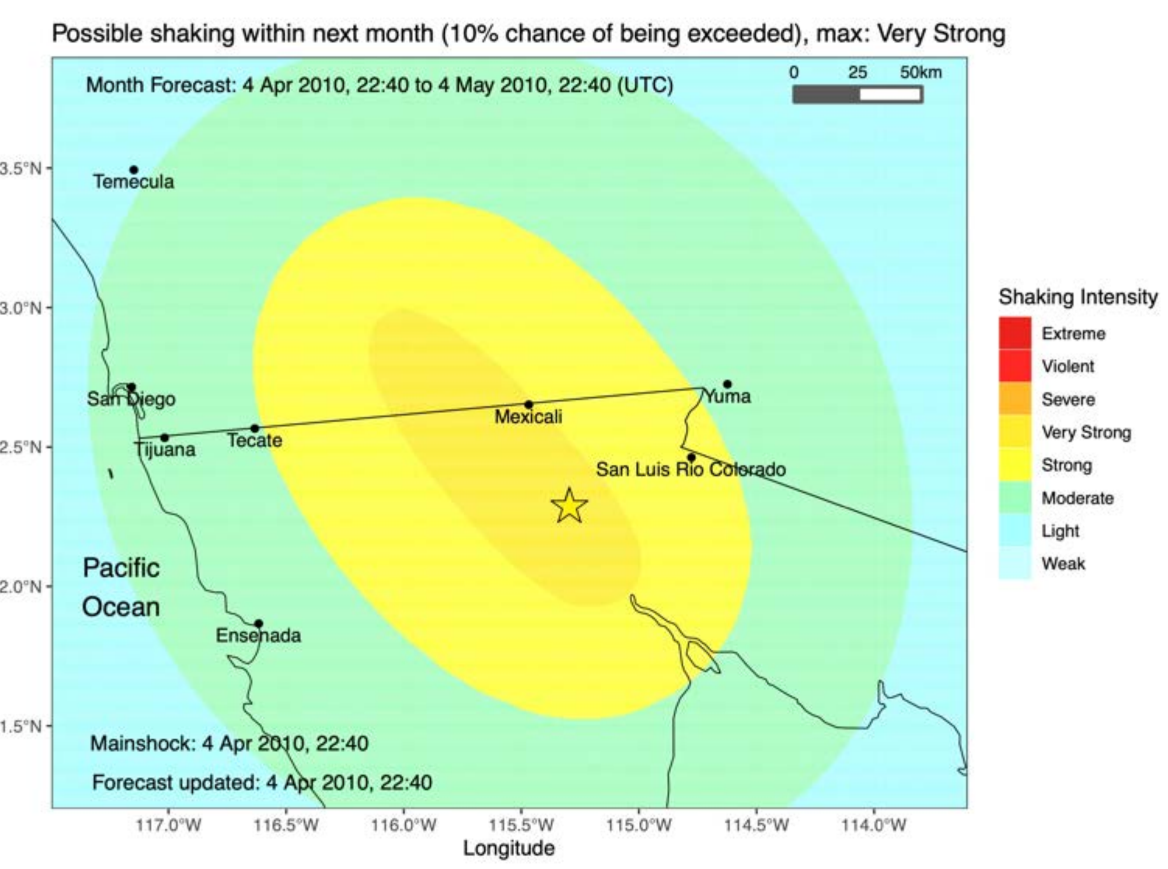












Discussions and Next Steps

- We aim to improve seismic forecast communication by designing forecast products centered on the needs of real users, while using data visualization research to guide our process
- Our programmatic, modular approach to developing map prototypes based on design parameters allows new prototypes to be created as new user needs are discovered
- We will continue this work in the following steps:
    - Prototype animations of shaking map at sequential time steps (commonly requested forecast product), making design decisions based on user needs
    - Prototype non-spatial products (e.g., temporal dynamics, forecast table binned by magnitude/forecast duration), making design decisions based on user needs
    - Focus group with original participants from three workshops to evaluate product prototypes
    - Test most promising map prototypes in a task-based experiment: participants perform tasks that measure how well the products facilitate common decisions aftershock forecasts are used for
    - Design an interactive dashboard so users can toggle on additional map layers and change other design parameters

References

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