ETAS Aftershock Forecast
for Nepal earthquake near Kathmandu (m=7.8, April 2015)

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Materials available at:
http://hatton.physics.ucdavis.edu/public/nepal_2015_update/

Overview:

The attached figures show contours of expected aftershock rate-densities in the region of the April 2015 m=7.8 earthquake near Kathmandu in Nepal. Aftershock densities are calculated using a variant of the venerable "epidemic type aftershock sequence" (ETAS) model, originally published by Ogata, (1989), developed by Yoder et al. (2014). In brief summary, ETAS constitutes a family of models in which post-seismic aftershock rates are estimated based on various earthquake scaling relations – most pointedly Omori scaling, which states that aftershock rates decay in time (following a mainshock) approximately as 1/t:

$$\frac{dN}{dt} = \frac{1}{\tau} \cdot \frac{1}{(t_0 + t)^p} \quad , \tag{1}$$

where τ, t_0, and the temporal scaling exponent p are, more or less, fitting parameters. Similarly, the spatial distribution of aftershocks can be described by an Omori-like radial function,

$$\frac{dN}{dr} = \frac{1}{\chi} \cdot \frac{1}{(r_0 + t)^q} \quad , \tag{2}$$

where again the parameters χ, r_0, and q are fitting parameters. The spatial distribution Eq. (2) is not as well understood as the temporal distribution Eq. (1), but Eq. (2) has been shown to be a reasonable and useful approximation of aftershock radial distributions.

The Yoder et al. (2014) formulation of ETAS differs from most contemporary implementations in that it derives the initial rate $dN/dt(t=0) = 1/\tau t_0^p$ and spatial density $dN/dr(r=0) = 1/\chi r_0^q$ of an earthquake's aftershock sequence from the mainshock's (parent event's) magnitude m, rupture length L_r, and other physical properties. This facilitates fast, objective (minimal or no "expert opinion" input from the operator) calculations of ETAS (aftershock) productivity and aggregation over large catalogs. The figures below consist of the ETAS contributions of all earthquakes in the shaded (contoured) area over a 5 year period and with 0.1 x 0.1 degree spatial resolution. In other words, the ETAS contribution for each earthquake in a 5 year catalog over the region shown is calculated and aggregated for each 0.1 x 0.1 "bin" in the study region.

Interpretation:

In its raw form (shown here), the aggregated ETAS output shows the expected rate-density (number of earthquakes per area per unit time of aftershock seismicity at each location in the study area. Obviously, these can be scaled to any set of units and for any reference magnitude (for example, earthquakes per m^2 per second with m>3 can be rescaled to earthquakes per km^2

per day with m>5). Note that ETAS seismicity from subsequent events in the region (typically aftershocks from the mainshock) is automatically incorporated, so the aggregated map evolves with the post-seismic sequence.

In general, ETAS can be considered to provide useful and accurate estimates of *aftershock* seismicity, with the understanding that the relationship between aftershock seismicity and mainshock triggering is not well understood. In other words, ETAS is not (understood to be) a good predictor of earthquakes larger than the mainshock. Nonetheless, ETAS is quite useful for large earthquakes, where damaging aftershocks are expected. For the Nepal $m=7.8$ event, for example, invoking Bath's law, we expect the largest aftershock to be of m~6.8 (specifically, we expect 1 event with m>6.8), and from Gutenberg-Richter statistics, we further expect 10 events with m>5.8, and 100 aftershock events with m>4.8 – all of which can cause significant damage if they are located in or near a populated, built-up area.

Relative Intensity: Figures 1 and 2 show the relative intensity of expected aftershock seismicity in the region. Note that in addition to the mainshock, two large ETAS ”halos”, presumably from large aftershocks, are visible to the east and east-north-east of the mainshock. In general, these figures present a compact representation of recent seismicity. Large earthquakes create large, strong ETAS halos that decay relatively slowly; a recently occurred smal earthquake will produce a strong ETAS signature, but it will be relatively compact and its strength will decay quickly. Similarly, “lingering” sequences or earthquake swarms (an extended sequence of spatio-temporally concentrated small events) produce a recognizable signature.

Applications under development: Perhaps the most significant question that can be answered (or for which the answer can be improved) using ETAS is, What is the probability of an $m>m_0$ earthquake within some specific region over some finite time period. In this case, perhaps, m_0=5.0, the region is within 10 km of the Kathmandu city center, and a reasonable time frame might be the next few days to a week – the logic here being that, particularly given the current condition of the city, we can expect m>5 earthquakes to cause measurable damage. The time-frame is based on an interval that is anecdotally useful (allows rescue and repair crews to prioritize resources), and is tractable given the fact that aftershock rates and densities are constantly changing.

The simplest approach to this problem is to choose a probability distribution (a Poisson for simplicity), calculate the aggregated rate in the given region (simply sum the ETAS contributions in the designated area), and calculate a probability for the given time range. Some subjectivity remains (for example applying a prior based on the known decay of seismicity from the mainshock event), but for short time intervals, this approach should provided reasonable approximations.

Another improvement being investigated is based on recent research (Yoder et al. 2014, Tahir et al. 2012, Zalohar 2014, and some others) that place large aftershocks outside the rupture area of the mainshock. Significant improvements can potentially be made by estimating hazard from the probability of large earthquakes, as opposed to all earthquakes indiscriminately. At this time, however, these relationships are not well understood, and ultimately, the question becomes somewhat subjective for large events like the Nepal earthquake, for which m>5 (of which we expect nearly 100) events can be considered to be a significant threat.

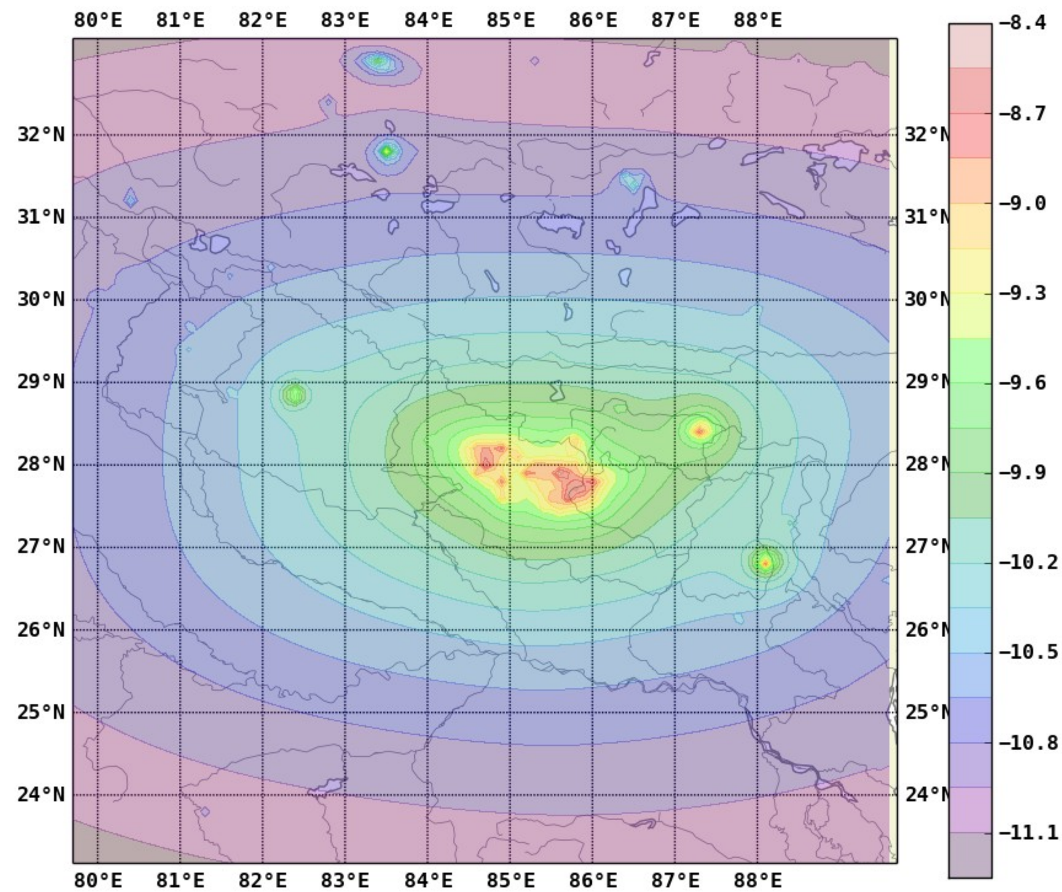

Figure 1: ETAS contours (aftershock seismicity rate-density contours) for the April 2015 m=7.8 earthquake in Nepal, as viewed rendered by MatplotLib.pyplot Python library.

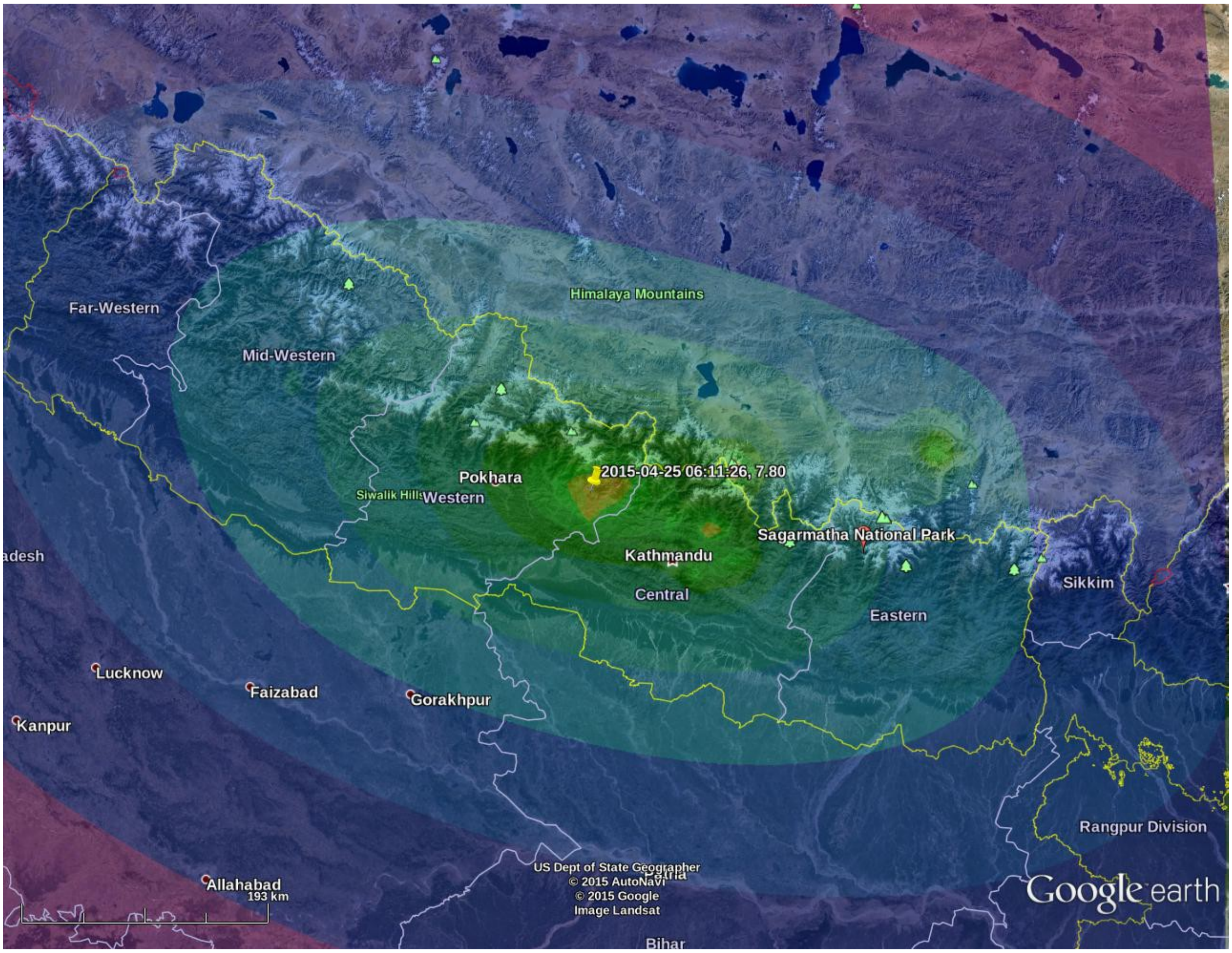

Figure 2: ETAS contours (aftershock seismicity rate-density contours) for the April 2015 m=7.8 earthquake in Nepal, as viewed in GoogleEarth.