1. Damaging aftershocks are mostly associated with moderate to big events affecting losses at long return periods, whereas allowing aftershocks artificially overestimate losses at low return periods and aal

Usually, sequences of earthquakes are more complicated than a mainshock followed by a series of aftershocks with epicentres on the rupture of the mainshocks. The sequences in Italy, Turkey-Syria, New Zealand mentioned during the presentation are just some examples. These sequences have foreshocks and other vents whose ruptures are NOT on the fault segment that generates the mainshock. They do affect a larger region than that impacted by the mainshock. Also, they may occur many months before or after the mainshocks, as we have seen. The only defensible way to realistically assess risk is to include such sequences in the stochastic catalogues of possible future events.

After these premises, I am unclear what is the reason why aftershocks would overestimate the losses at low return periods. They would if they were added in a Poissonian fashion and, therefore, occur in isolation. This method is sometimes adopted but it is wrong. However, if aftershocks are added within a sequence and, therefore, in conjunction with the occurrence of mainshocks, they would have the effect you describe. Mainshocks, by virtue of their large magnitude, do occur rarely. To summarize, years in which a sequence with foreshocks, mainshocks, triggered events occur are rare. Adding sequences increase the right tail of the loss distribution, not the left one. The AAL is affected because of that but not because the left tail is raised.

1. Can you run an etas simulation on each de-clustered event in a stochastic catalogue? How do you avoid double counting?

ETAS is a method that is fed with the information of past seismicity in a region, exactly as traditional mainshock only models. However, the ETAS model digests the information regarding all earthquakes and not just mainshocks, which in the traditional models are artificially extracted from all the others in the historical/instrumental catalogue using declustering techniques. To be more precise, the ETAS model uses the rates of occurrence of all earthquakes of any magnitude, and their temporal and spatial distributions during sequences while the traditional models only use the rates of occurrence of the mainshocks with large magnitudes, nothing else. With this information the ETAS model produces stochastic catalogues of possible future seismicity that includes sequences whose earthquakes have the same statistical rate of past ones and the same temporal and spatial distributions of the sequences that have occurred in that region (the parameters of those distributions are empirically derived from historical seismicity). The traditional approach generates stochastic catalogues of mainshocks whose rates are statistically consistent with those occurred in the past but all the other earthquakes have vanished, they are not there. Loosely speaking, if we were to decluster the stochastic catalogs with sequences produced by the ETAS model we would obtain the traditional stochastic catalogs with mainshocks only utilized by legacy models.

To conclude, there is no double counting. ETAS does not add a earthquakes after mainshocks, it produces sequences in the stochastic catalog that have rates and temporal/spatial characteristics statistically consistent with the historical events occurred in the region. Legacy model, on the other hand, use stochastic catalogs that have mainshocks with rates that are statistically consistent with the historical mainshocks that occurred in the region (as ETAS does). Everything else is disregarded (unlike in ETAS), it happened in the past but it is not contemplated in what can happen in the future.

1. Many model vendors opt to remove aftershocks in the modelling, however UCERF3 can include aftershocks. Do you expect model vendors to include aftershocks going forward?

Yes, slowly and perhaps by cutting some corners.

1. Will the inclusion of aftershocks in the upcoming time-dependent USGS model be enough impetus for model vendors to adopt aftershock modelling?

There will be inertia in adopting more complex models that include sequences. However, I would expect large vendor models to gradually veer towards such models but perhaps adopting simpler, less accurate approaches (such as Mainshock + “proper” aftershocks occurring in the same place as the mainshock perhaps added in a Poissonian fashion) than that described during the session.

1. How often do you need to recalibrate your aftershock model?

I am not sure whether this is related to the ETAS-based model or not. Regarding the ETAS case, a model providing a long-term view of the risk with sequences (namely the EQM+ model mentioned in the presentation) does not need to be updated more often than a normal legacy model (hence, 3-5 years). The ETAS model that, by design, is intended to provide the medium-term view of the risk (e.g., in the 12 months from a fixed date, say Dec 31, 2025, and therefore for year 2026 – namely the EQM++ mentioned in the presentation) uses a stochastic catalog that contains many realizations of the 2026 seismicity that are specifically informed by the seismicity observed in the region until Dec 31, 2025. Hence, if the observed seismicity in 2025 is lower than average on a fault and higher than average on another fault, the hazard and therefore the risk will be, respectively, lower and higher than average in the nearby regions. Therefore, the medium-term ETAS model (EQM++) needs to be updated every year.

1. How much extra loss % could be caused by aftershocks associated with a M7.x rupture in the San Francisco bay area?

Difficult to say because it depends on where along the different faults in the SFBA the M7 occurs and the quality of the construction in the area more severely affected by the mainshock (weaker buildings are more prone to damage accumulation). My guesstimate based on analyses done elsewhere is a number from 20% to 50%.