Ground shaking hazard for Induced Earthquakes

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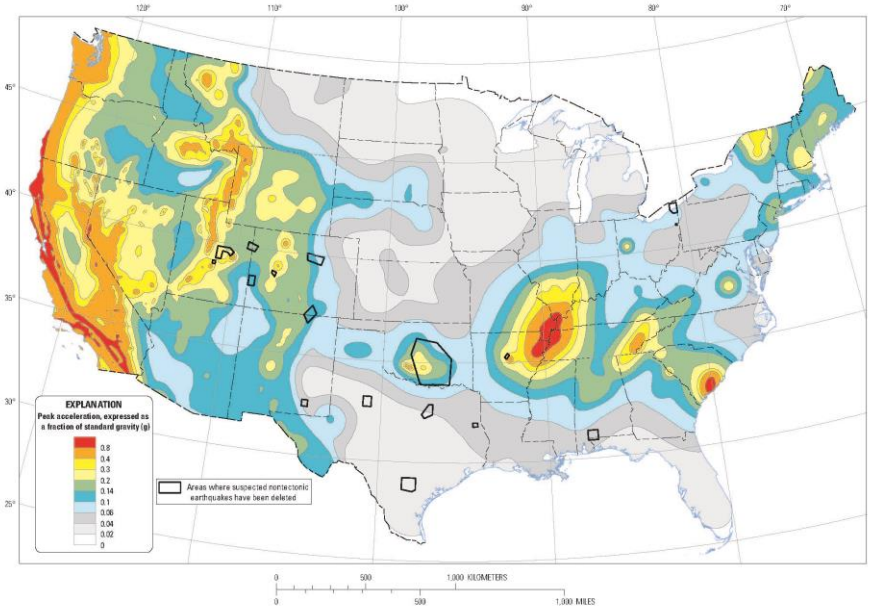
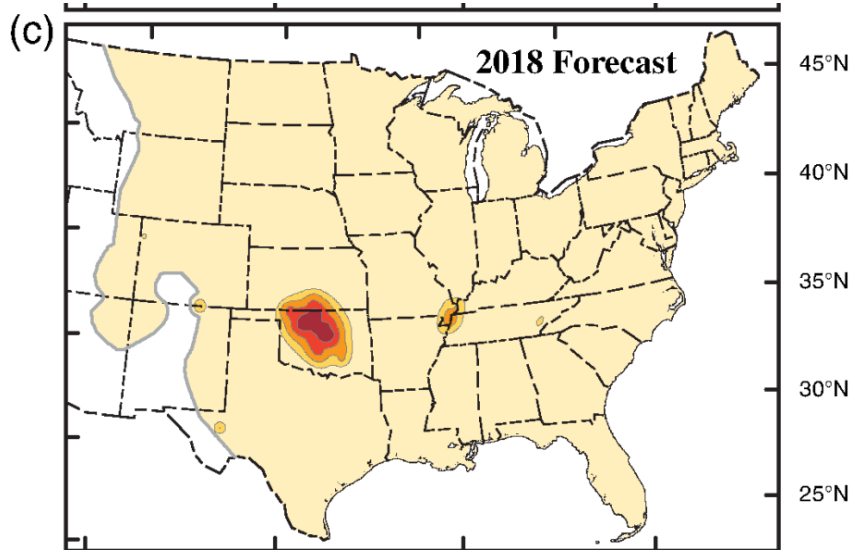
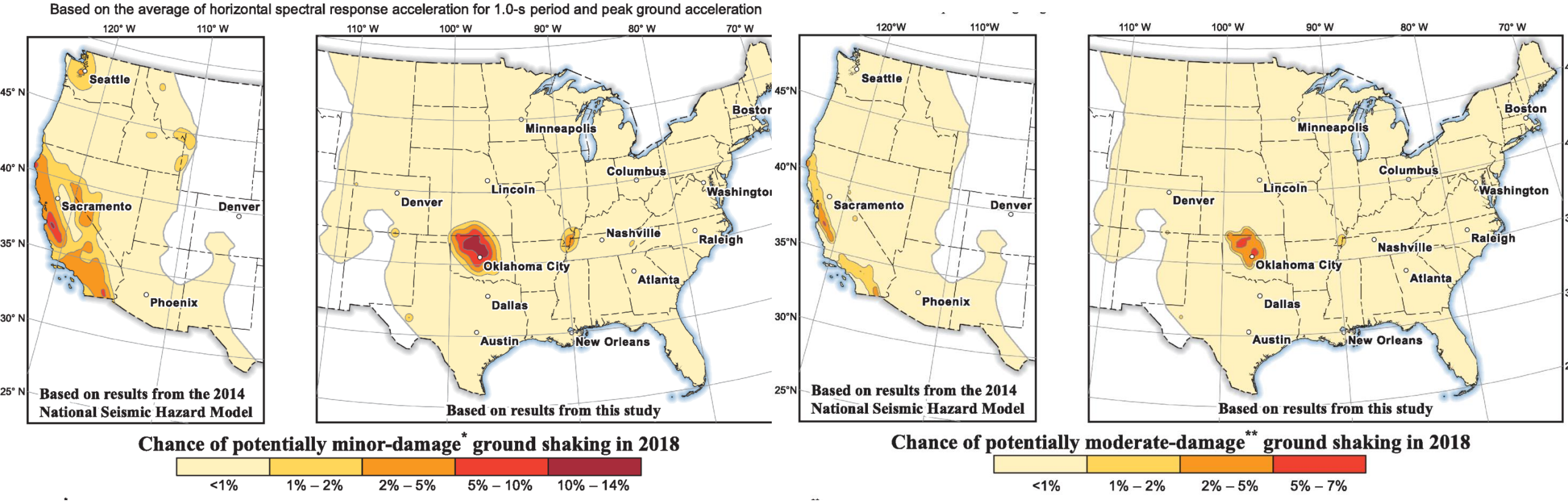
1. We make the long-term (50 year) hazard maps that are applied in the current building codes, risk assessments, policy.
2. Manmade earthquakes are removed from models.
3. For past 3 years (2016-2018) the USGS NSHMP has developed 1-year forecasts that show the chance of damage in one year.





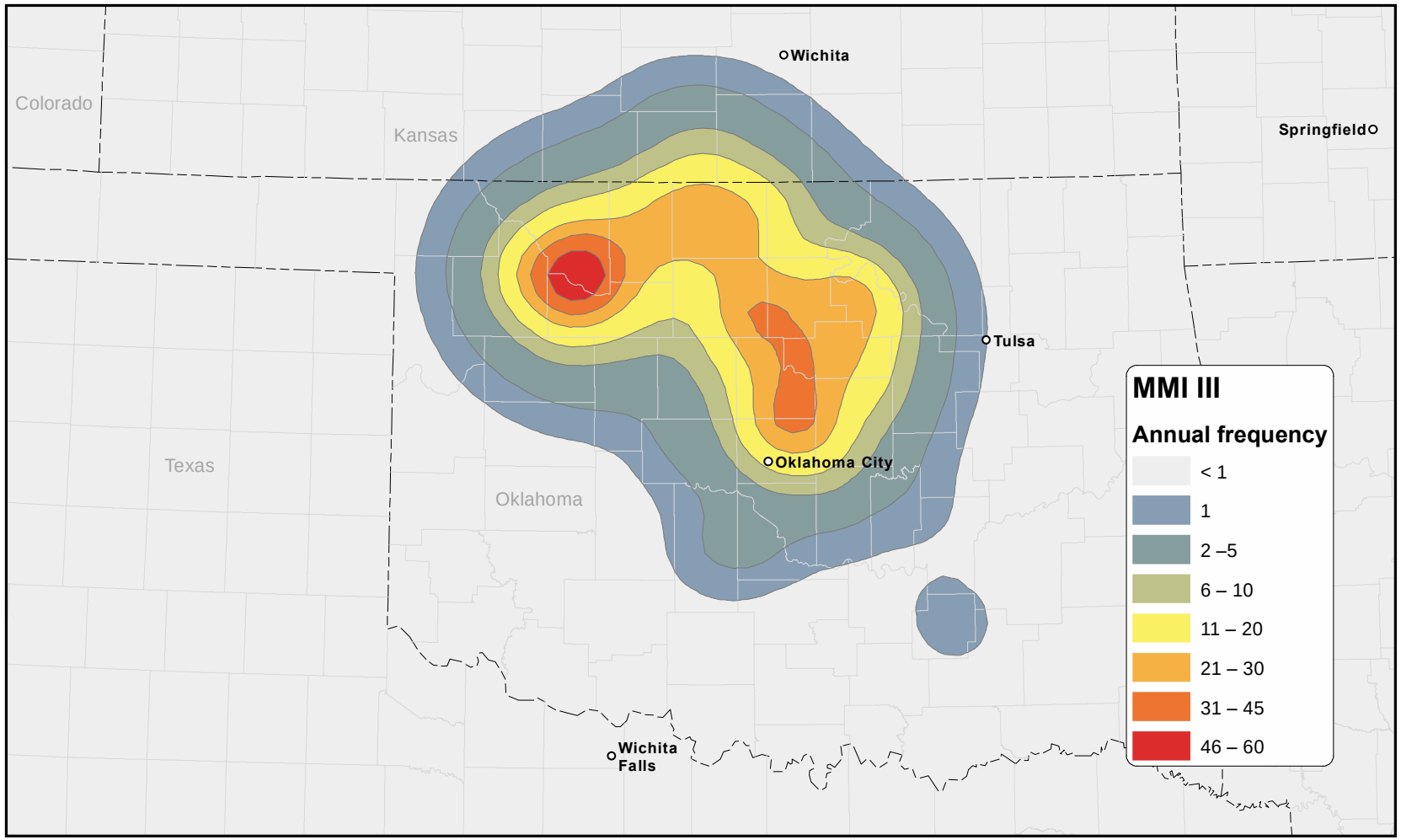
Chance of damaging ground shaking (MMI VI and MMI VII)



1. Models were presented in a variety of different ways for different end users.
2. Models show chance of “minor damage” , “moderate damage”, or “significant damage”
3. Risk models show high losses – methods may need to be modified to get more reasonable estimates

Nuisance maps

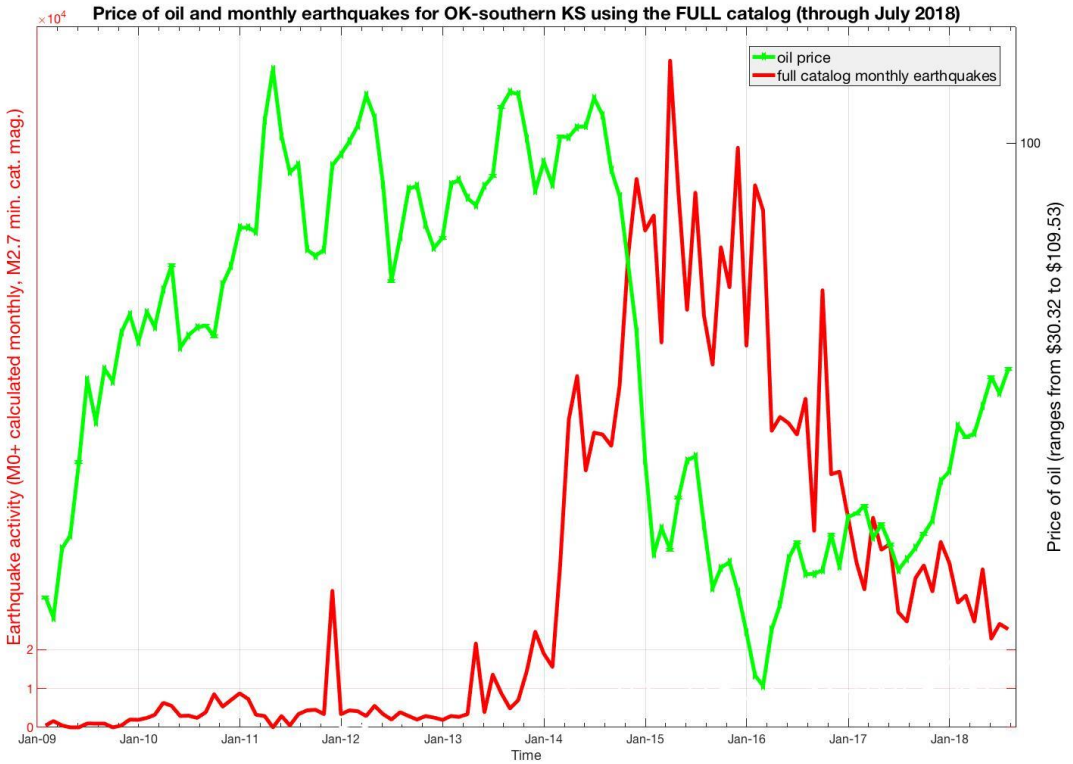
Nuisance maps show the number of times in the 2016 ground shaking might have been felt (based on earthquakes and felt areas >0.1g). Many residents would have felt shaking from 10 to 50 times during 2016.



Oklahoma and Southern Kansas Seismicity and Price of Oil trends

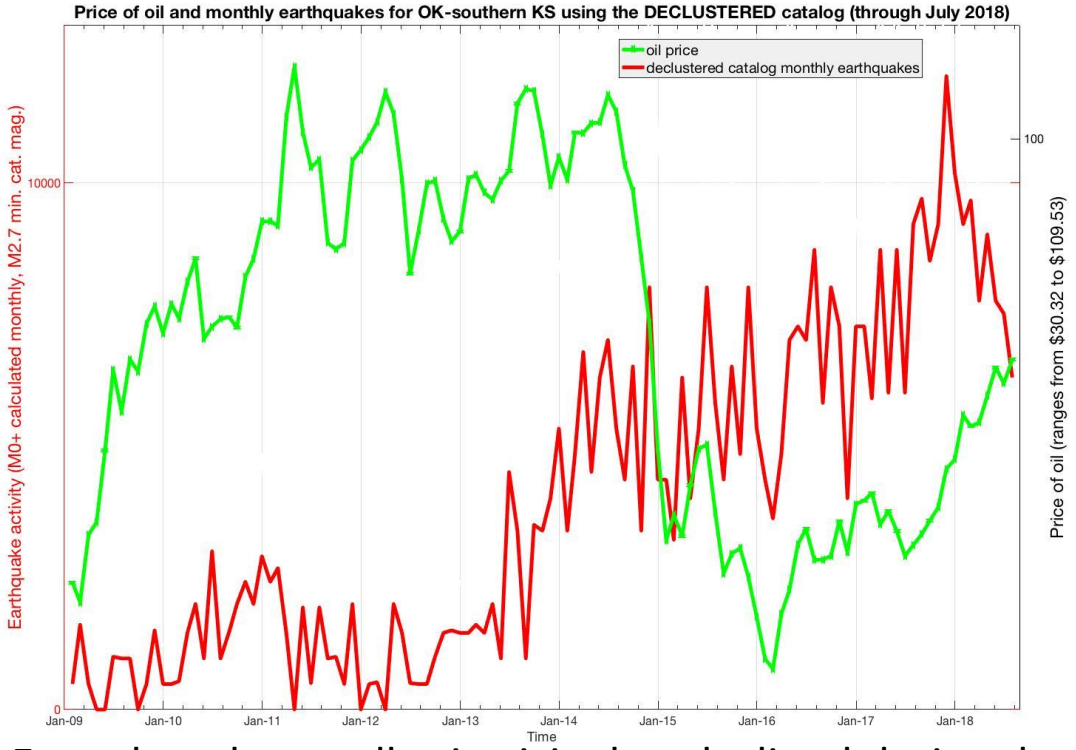
We take out aftershocks (dependent event) in the process of making maps

FULL CATALOG



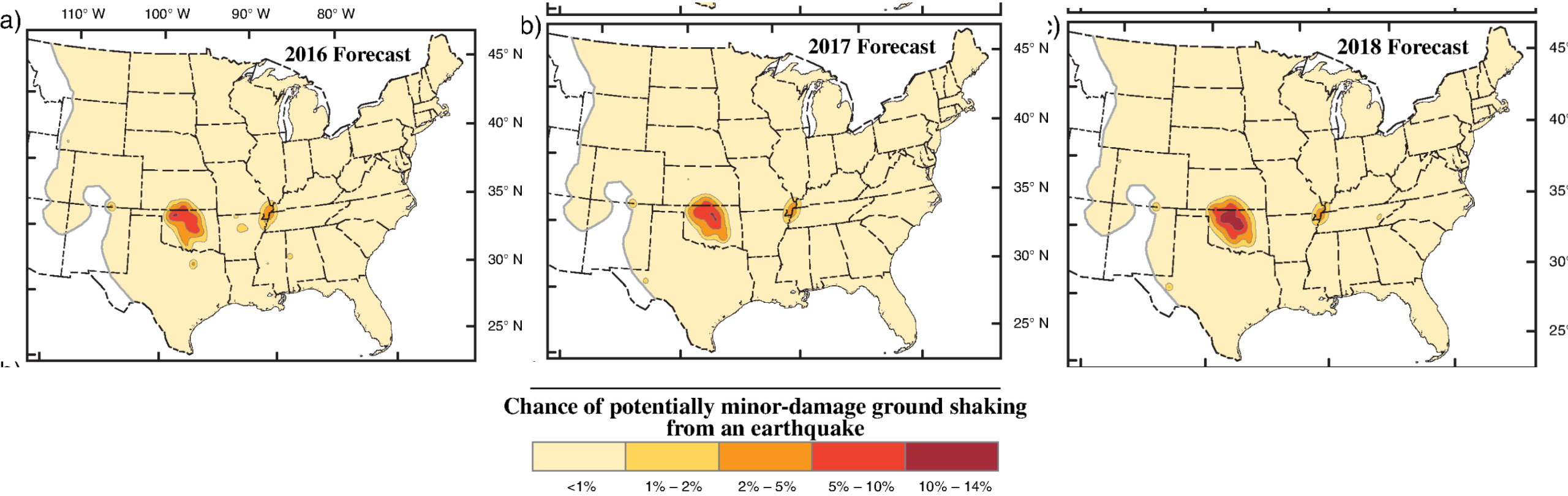
Seismicity increased since 2010 but more rapidly since 2014 and then decreased starting in 2015.

DECUSTERED CATALOG
(removing dependent earthquakes)



Even though overall seismicity has declined during the past couple years, the declustered catalog continued to increase until 2018.

Comparison of 2016, 2017, and 2018 forecasts

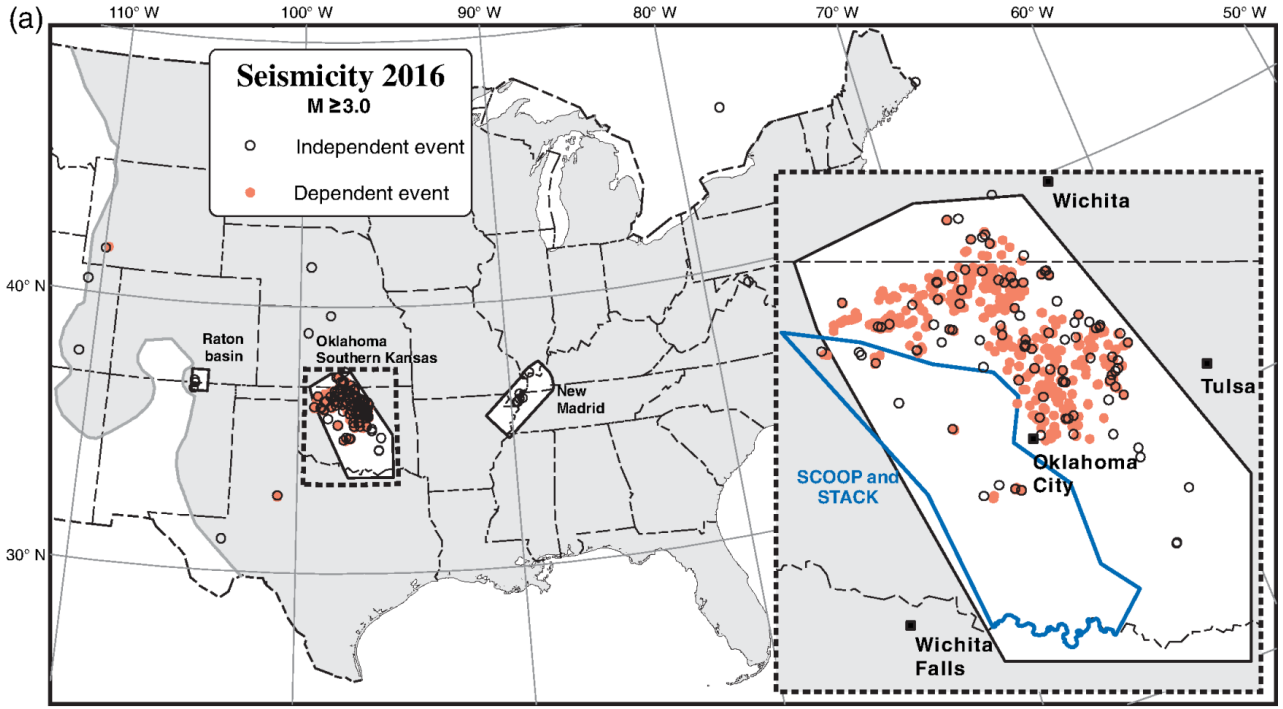


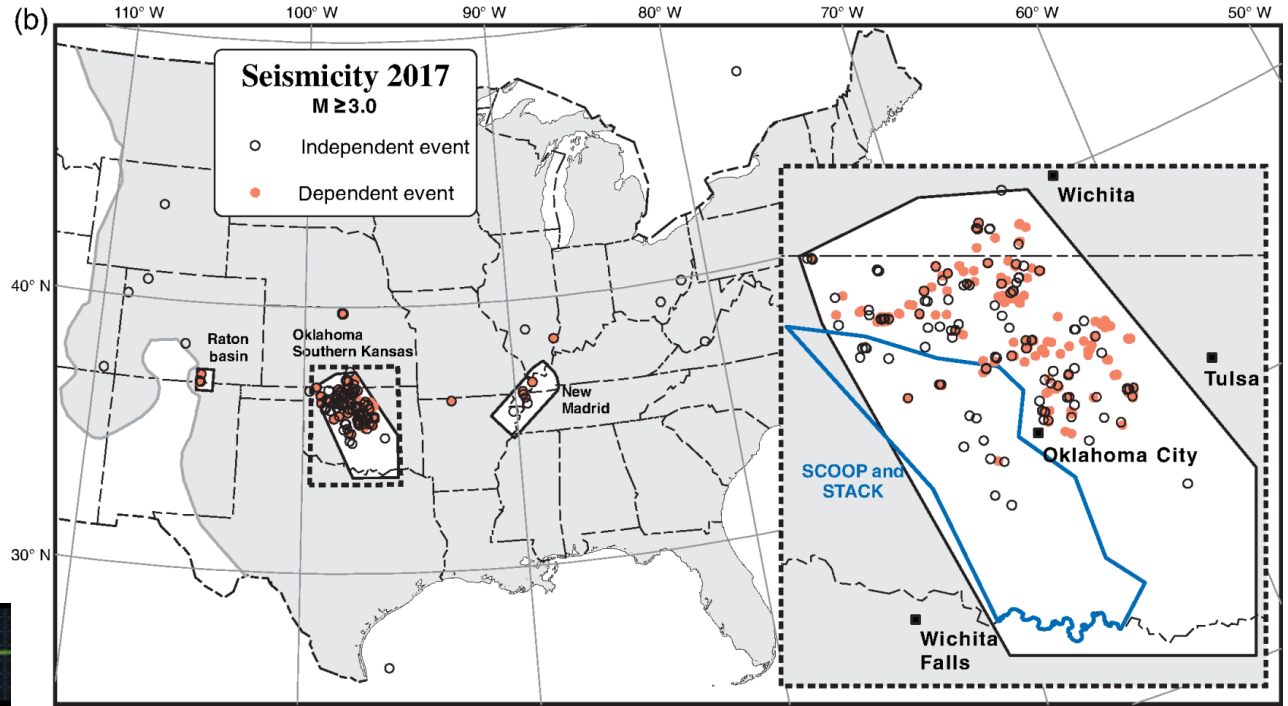
1. Hazard forecasts are quite similar
2. Hazard increases from 2016-218 which raises questions, especially in 2018
3. This is related to the declustering process which is used to get independent events (that do not consider dependent aftershocks)

Comparison of 2016 and 2017 Seismicity applied in 2018 update

We take out aftershocks (dependent event) in the process of making maps

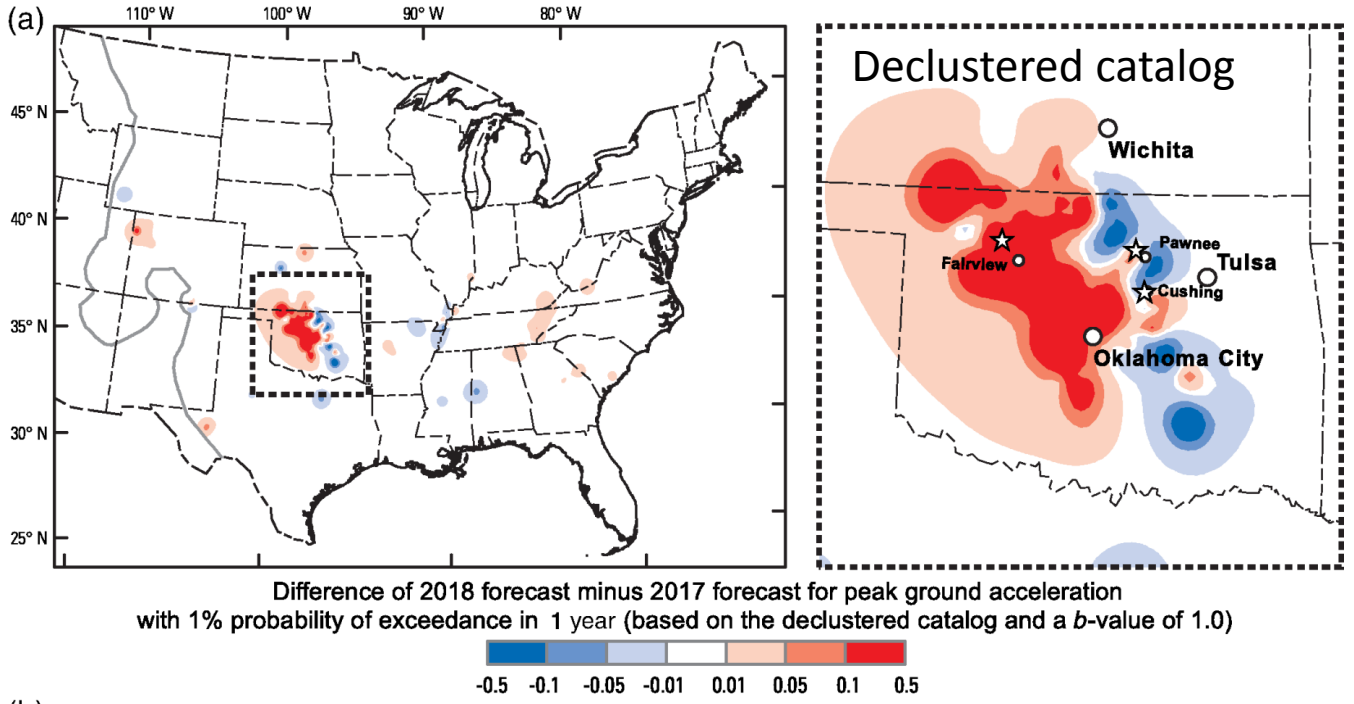
While the total number of earthquakes declined in 2017, the number of dependent earthquakes (declustered) is significantly lower in 2017 compared to 2016. The remaining independent earthquakes increased during 2017. We had a few more earthquakes in the Scoop and Stack.

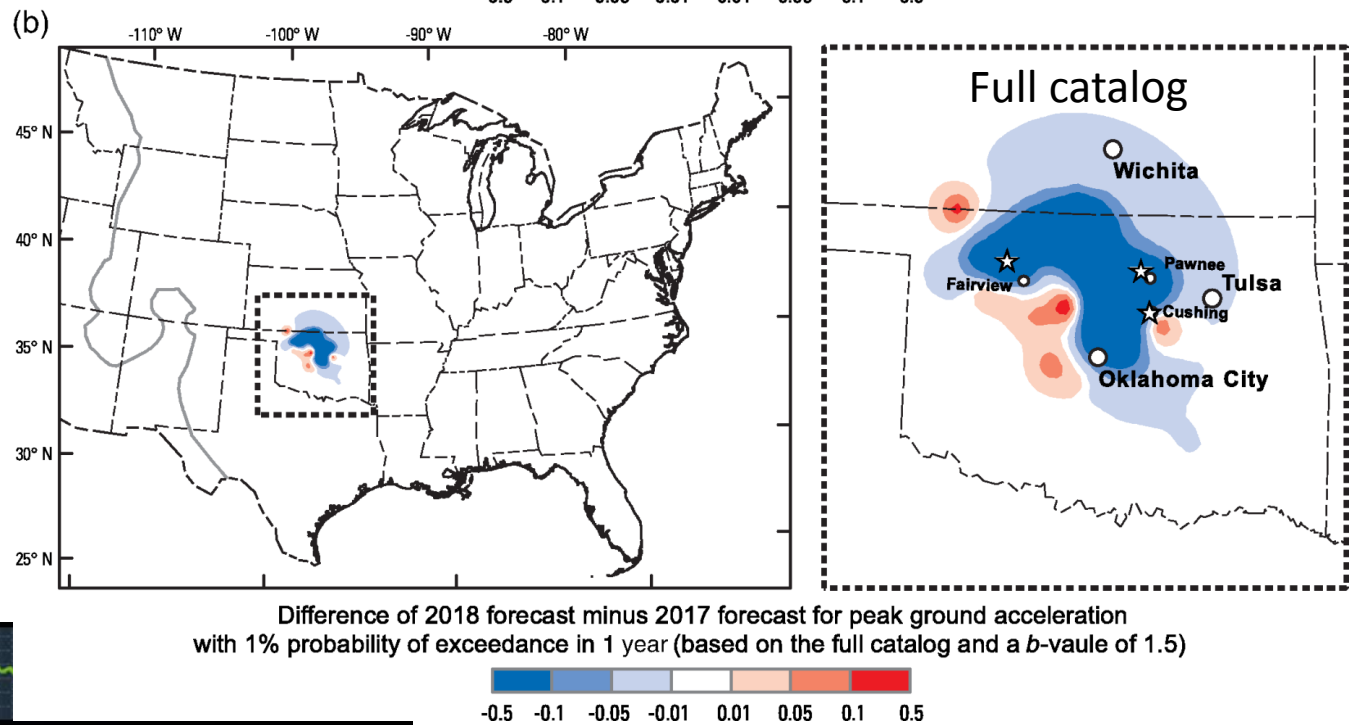




Difference between 2017 and 2018 forecasts for declustered and full catalogs

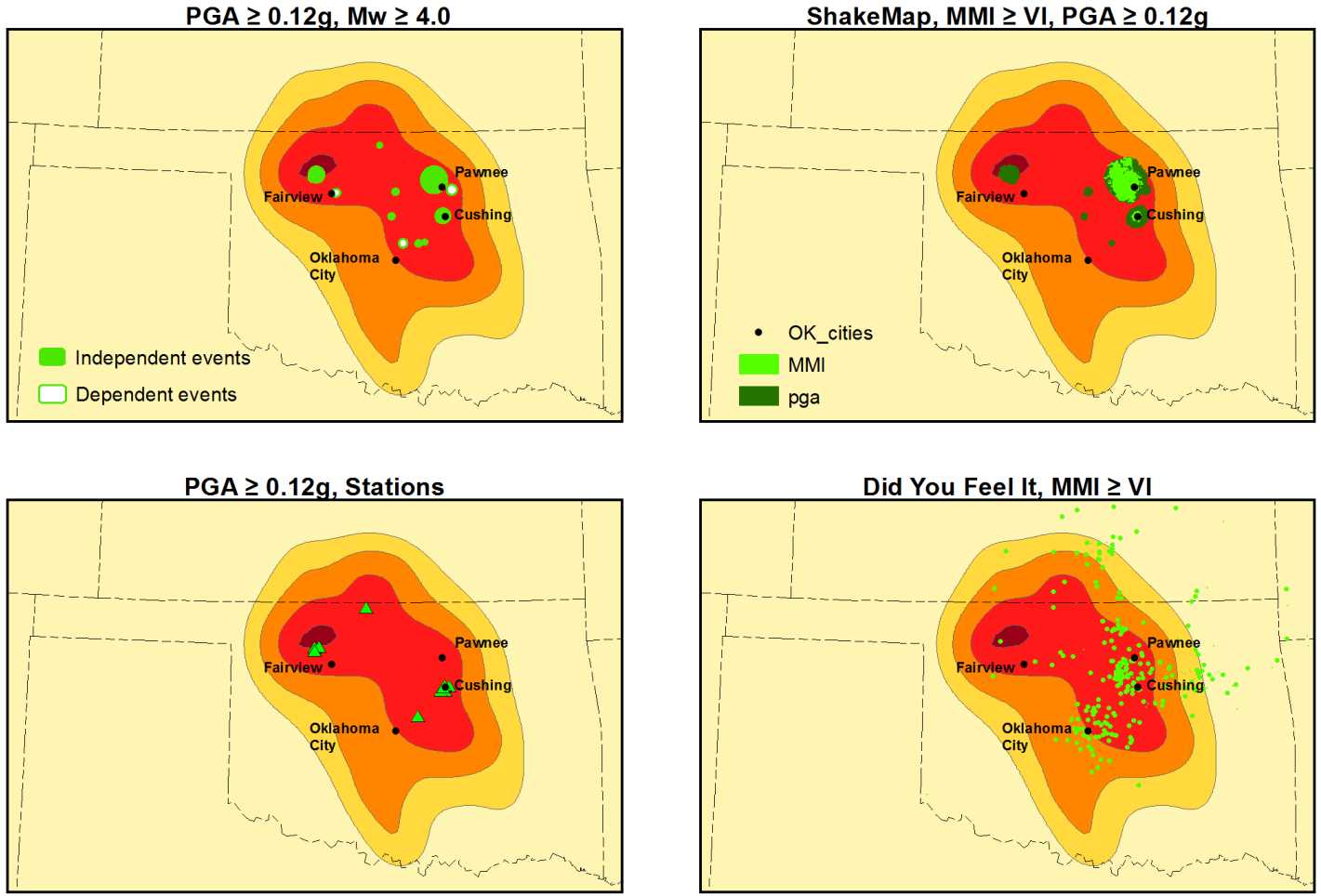
We considered the full catalogs and the declustered catalogs to see what was going on. During 2017 the hazard decreased near 2 earthquakes (M>5) in 2016 (Pawnee and Cushing) in both the decustered and full catalogs) – due to reduced injection. However, because of the timing of Fairview the declustering is complex in this region.



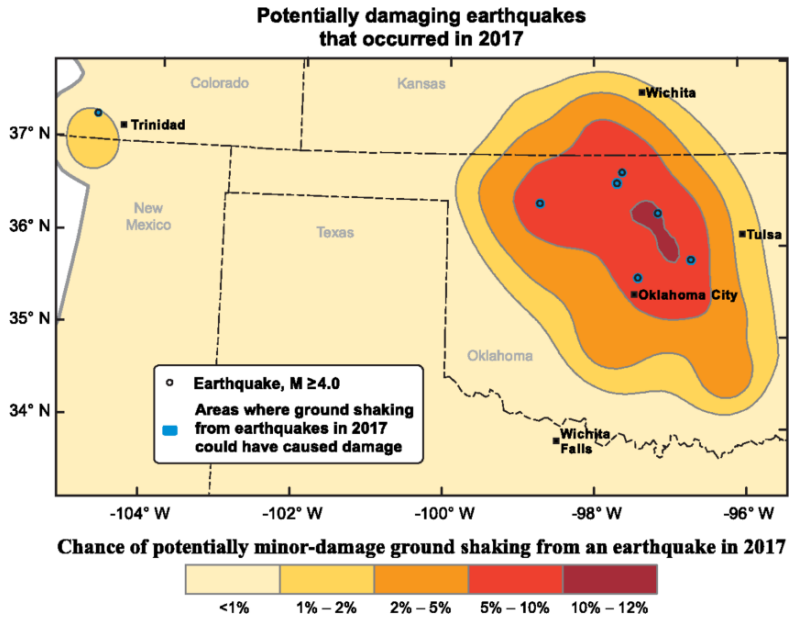


Testing 2016 and 2017 forecasts with M>4 earthquakes

2016

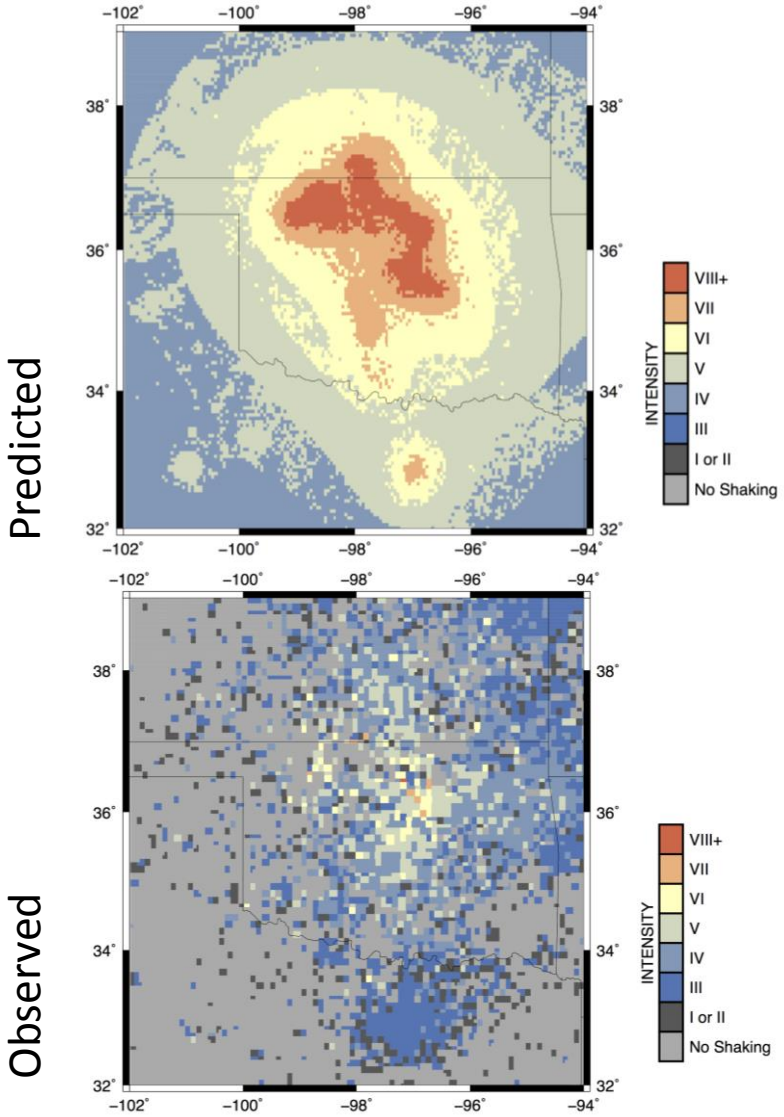


2017



Each year we have tested the models with the earthquakes, strong motion data, and Did you feel it? data.

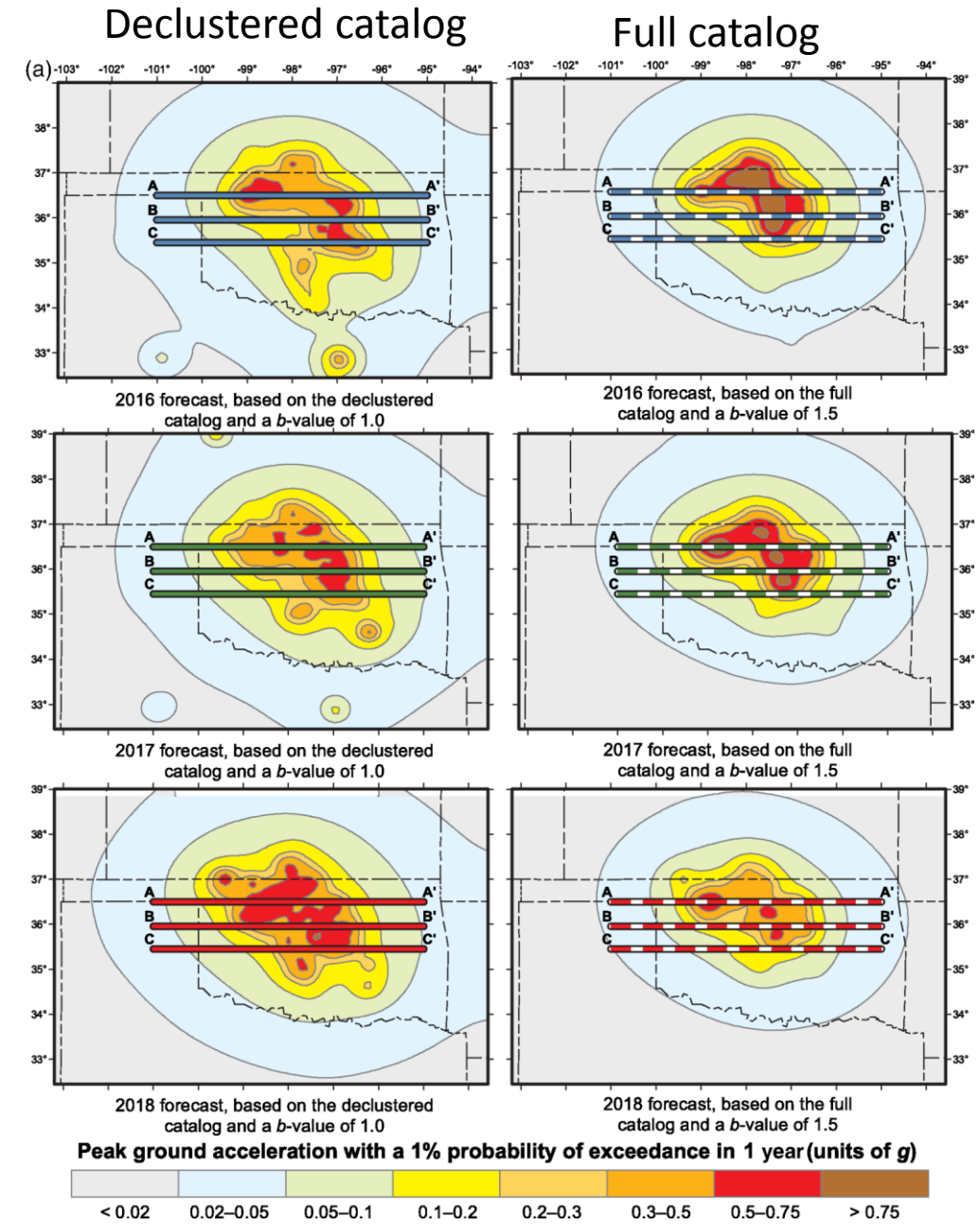
Tests of 2016 model (Brooks et al. 2017; White et al. 2017, Mousavi and Beroza 2018)



Mousave and Beroza: Our results agree with other studies (Brooks et al., 2017; White et al., 2017) and indicate that the observed hazard generally agrees with model forecasts for peak acceleration and spectral acceleration at 1 Hz (except at 5%g) and 5 Hz.

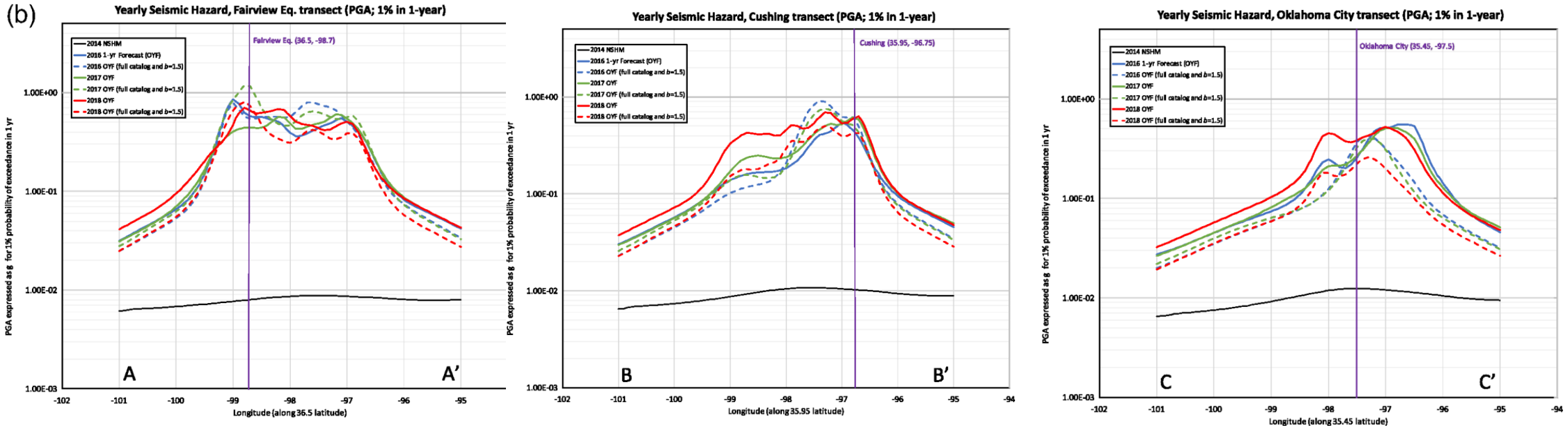
Hazard using declustered and full catalogs for 2016, 2017, 2018

The declustered catalog and full catalog indicate opposite trends of seismicity rate. Nevertheless, If we apply the full catalog we get very high ground motion hazard. The declustered catalog performed very well for these tests. Defining aftershocks is difficult.



Profiles for 6 models shown in previous slide

(b)



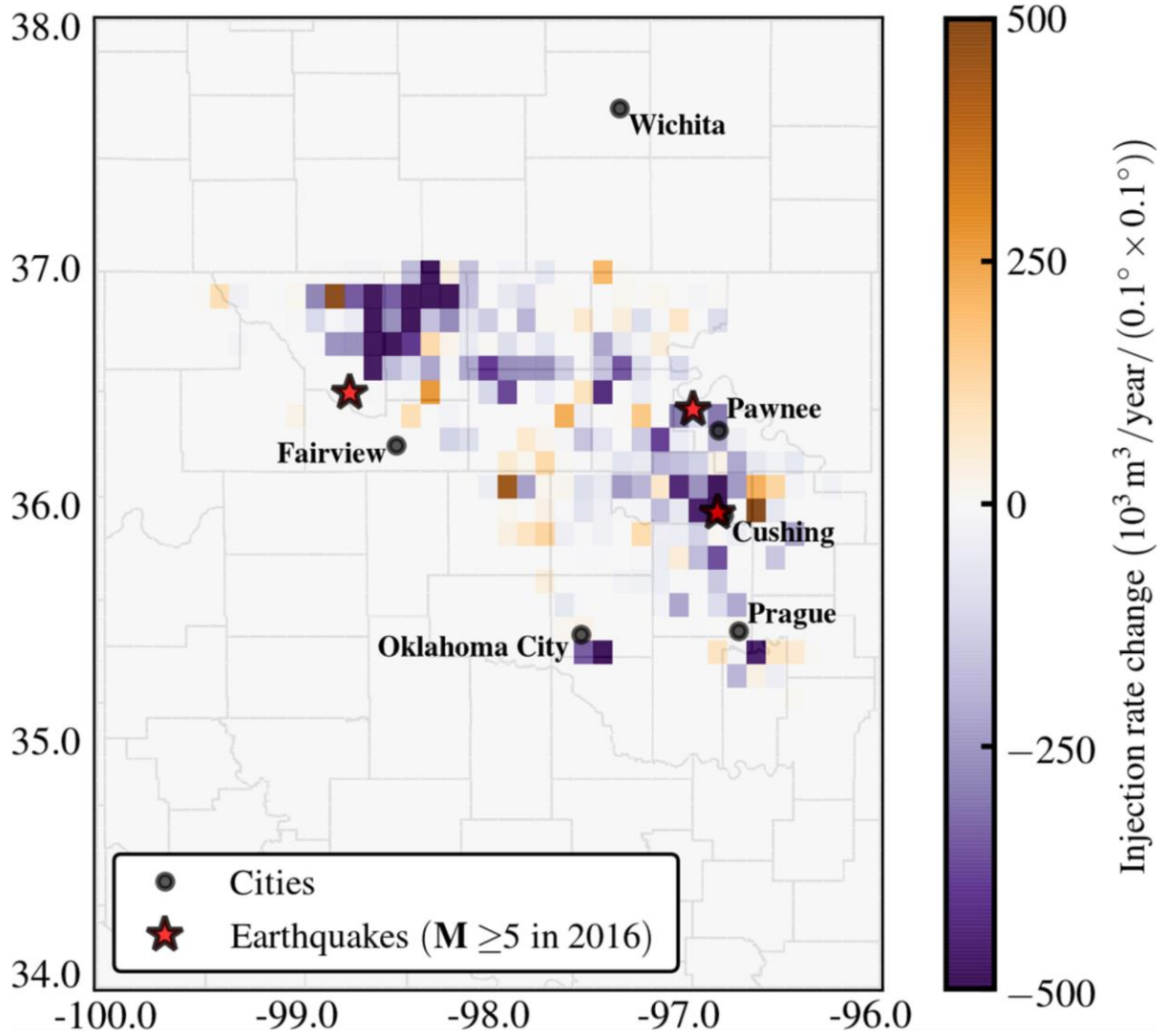
Dashed curves are full catalog, solid curves declustered catalog

We could use the full catalog or declustered catalog in this assessment, but either way the story is that the hazard is much higher than what is portrayed in the 2014 hazard models applied in the building codes.

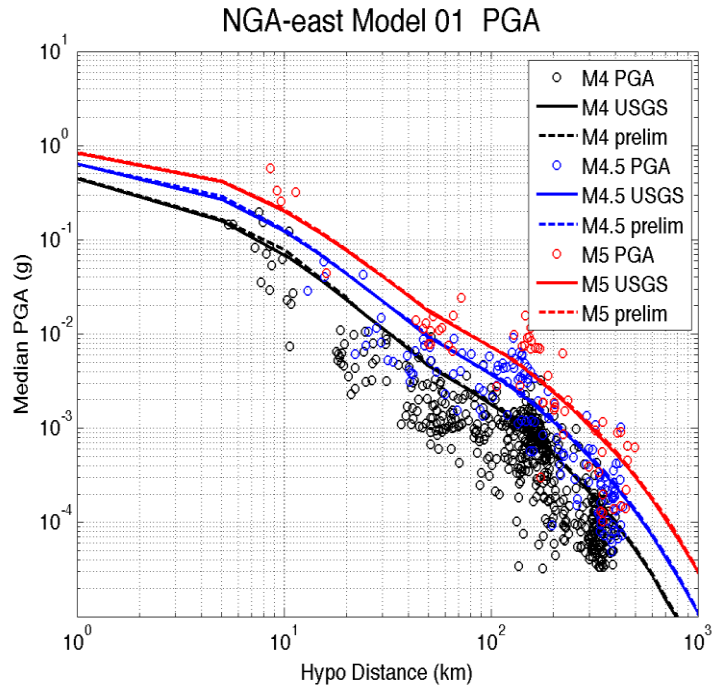
How can we improve the forecast models?

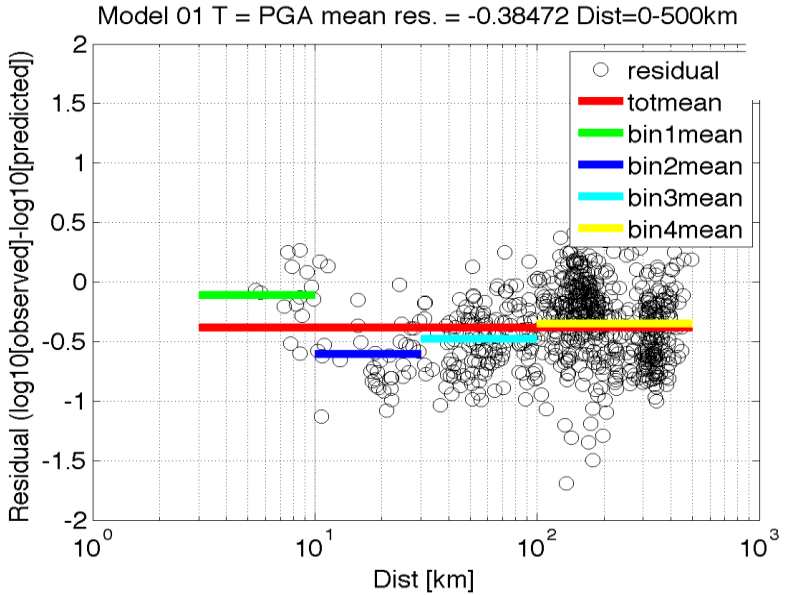
1. New models could incorporate injection rate data. Lower rates near big earthquakes due to state regulations (limiting injection). Justin Rubinstein, Jack Norbeck

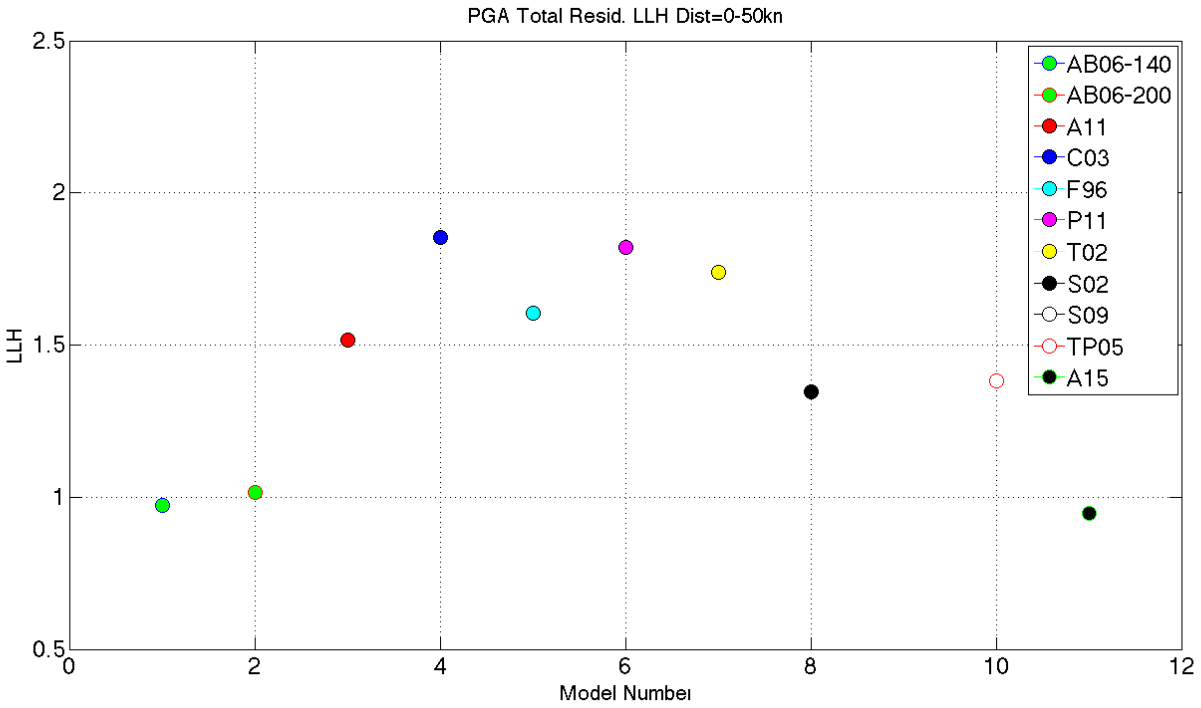
Injection rate changes between 2016 and 2017 in Oklahoma



TESTING GROUND MOTION MODELS (McNamara et al. in review)



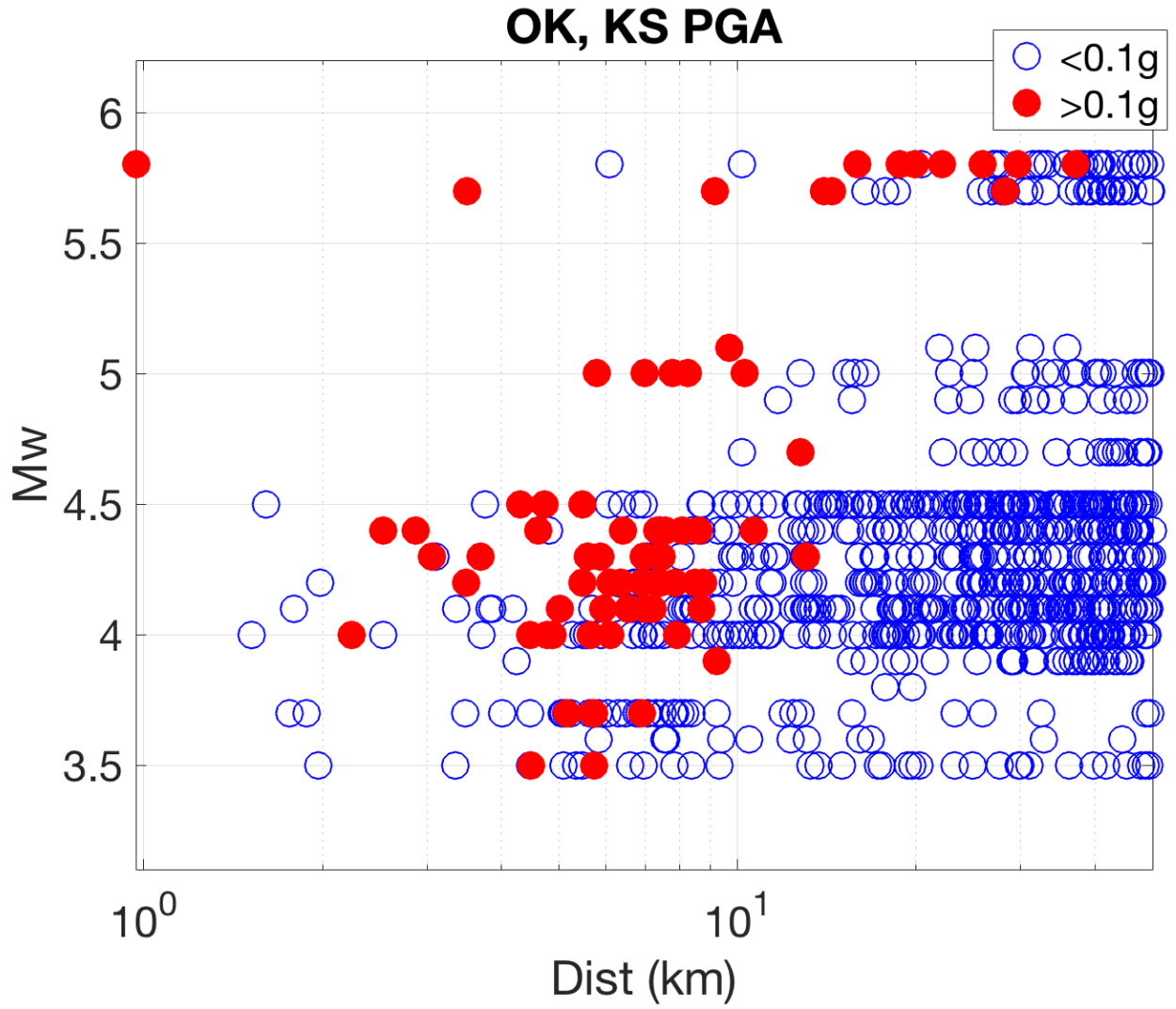




Developed ground motion database for induced earthquakes in OK and KS

To evaluate ground motion models: residuals, LLH scoring methods, Lower LLH (log likelihood) represents a better model. A15 scores well.

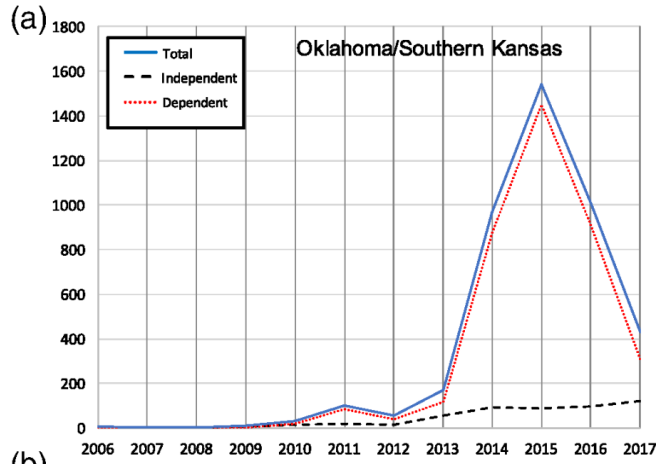
Damaging ground motions with magnitude

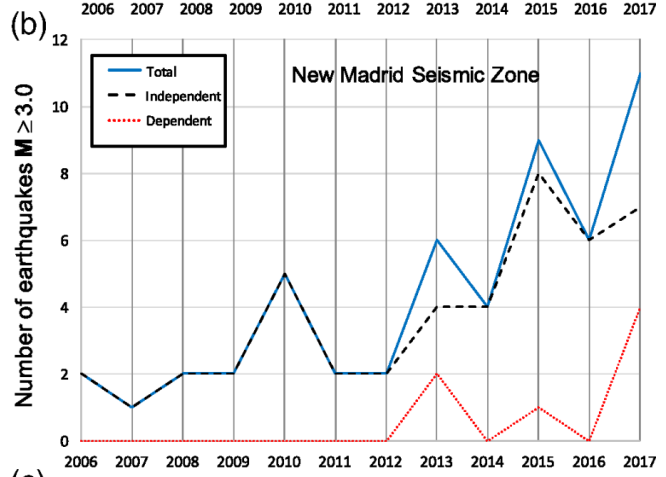


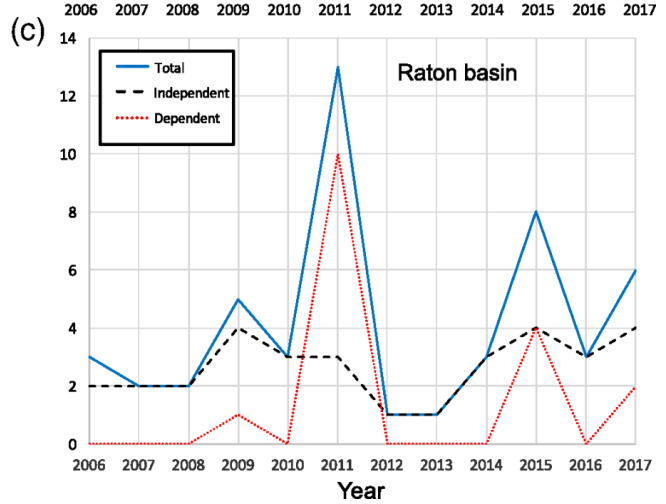
Models show interesting trends

Seismicity Changes in:
(a) Oklahoma/Southern Kansas
(b) New Madrid Seismic Zone
(c) Raton Basin (NM and CO)

Show the need to consider changes in seismicity.





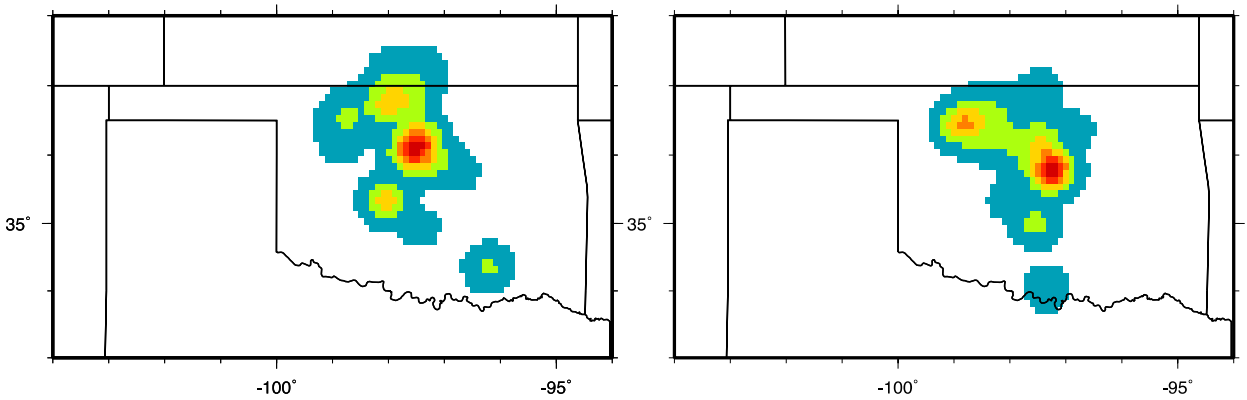


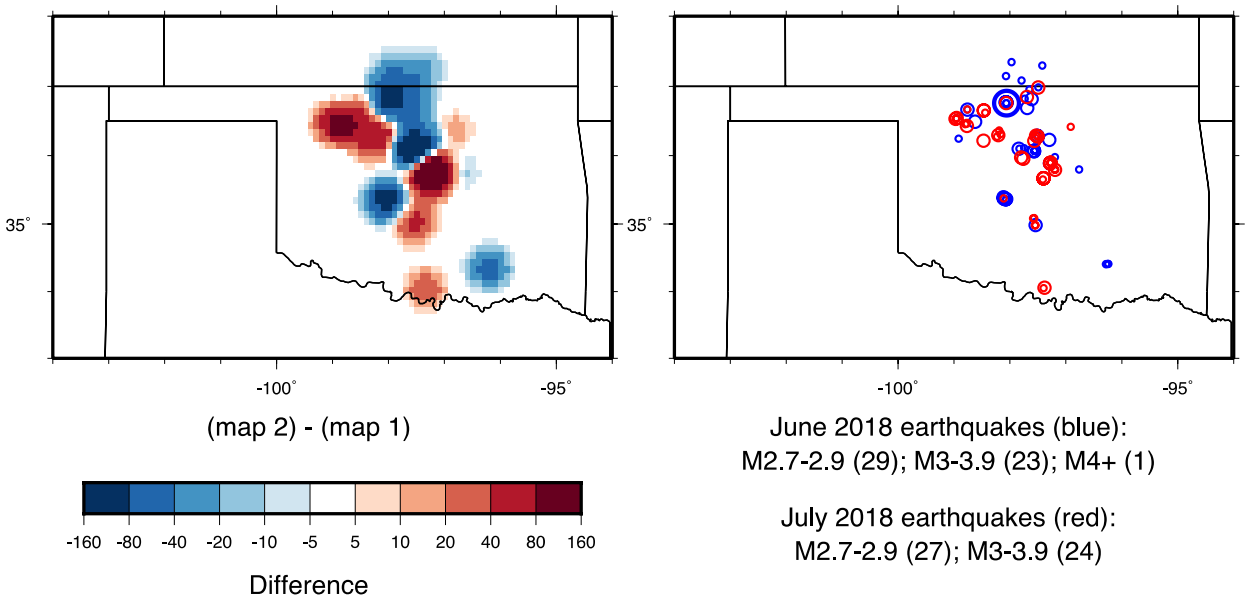
Potential seismicity rate change tool

Compares a-grids for different time periods (one month, 6-months, 12 months)

Tool allows us to monitor changes in seismicity across the country

Monthly Earthquakes for June 2018 and July 2018

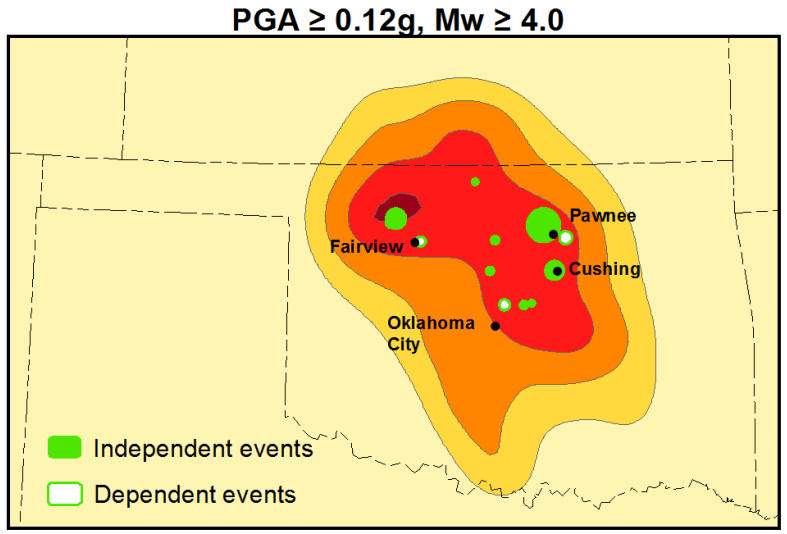




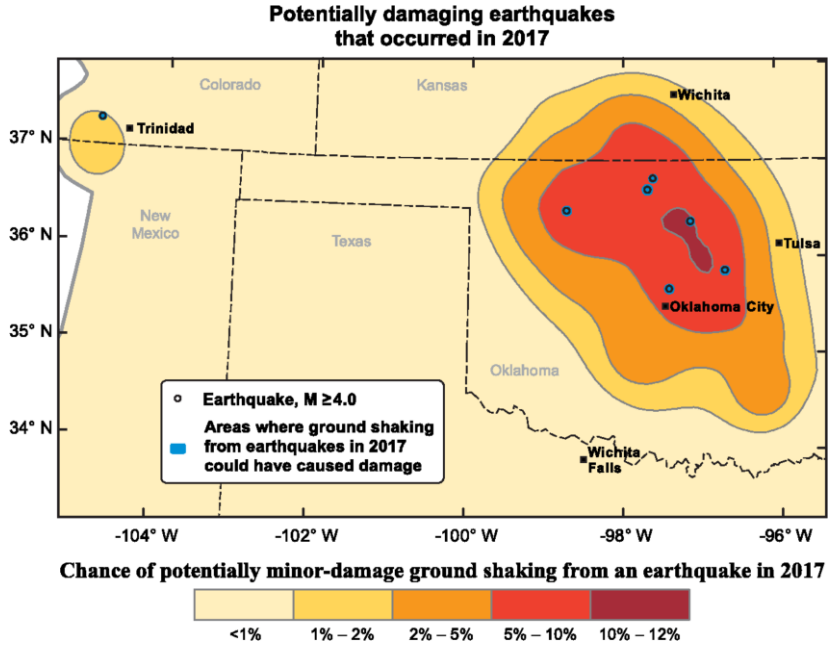
USGS science for a changing world

Testing 2016-2018 forecasts with earthquakes

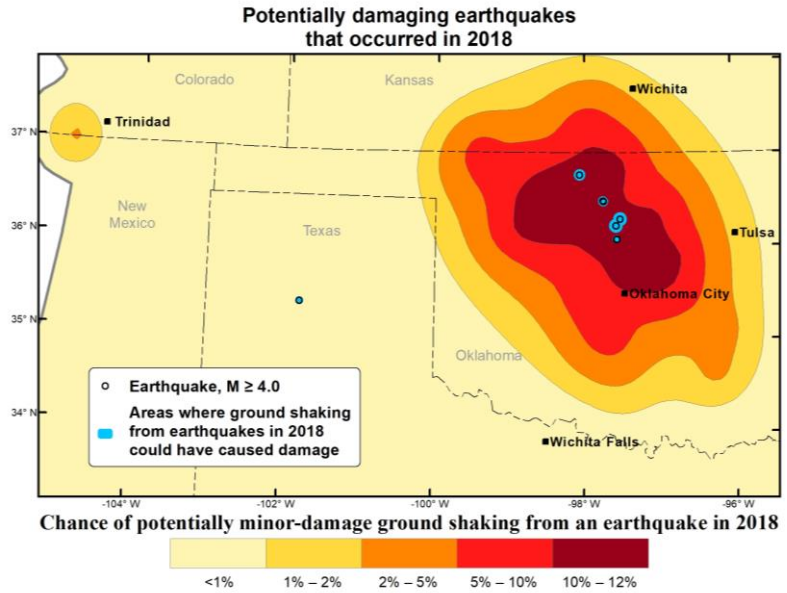
2016



2017



2018



Conclusions

- Seismic hazard remains high in Oklahoma from induced earthquakes
- Models need to be improved to better account for independent and dependent events
- Seismic hazard has decreased in areas where injection has decreased over the past year – this could improve forecasts
- One-year forecast will most likely not be produced in 2019 so that other updates can be finished (e.g., Hawaii, Alaska, Puerto Rico) but we will try to develop new seismicity rate change tools.