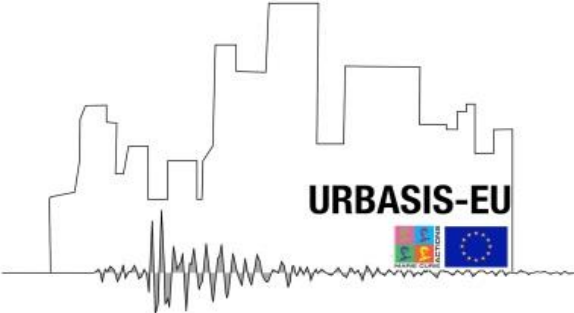




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TESTING NON-LINEAR AMPLIFICATION FACTORS USED IN GROUND MOTION MODELS

A testing framework for non-linear amplification models

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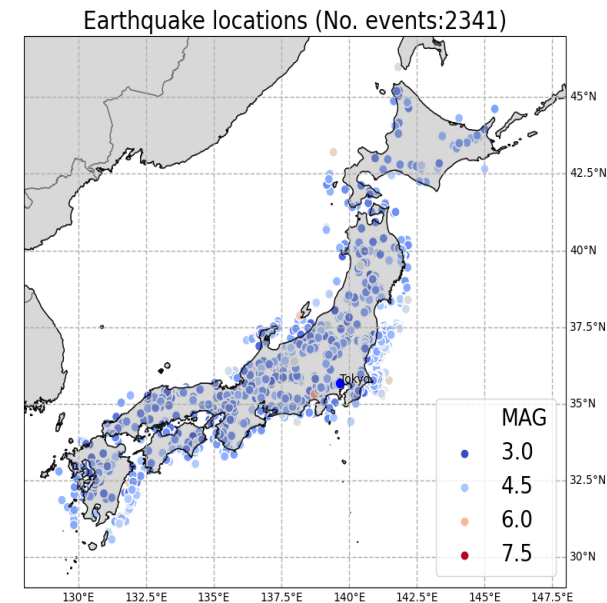
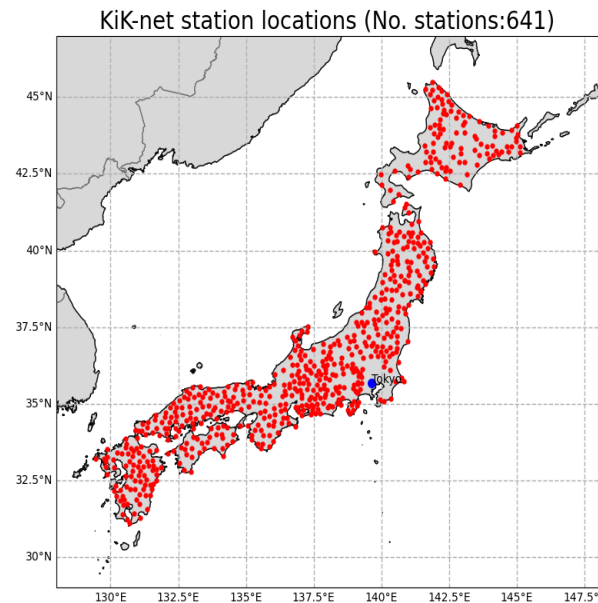
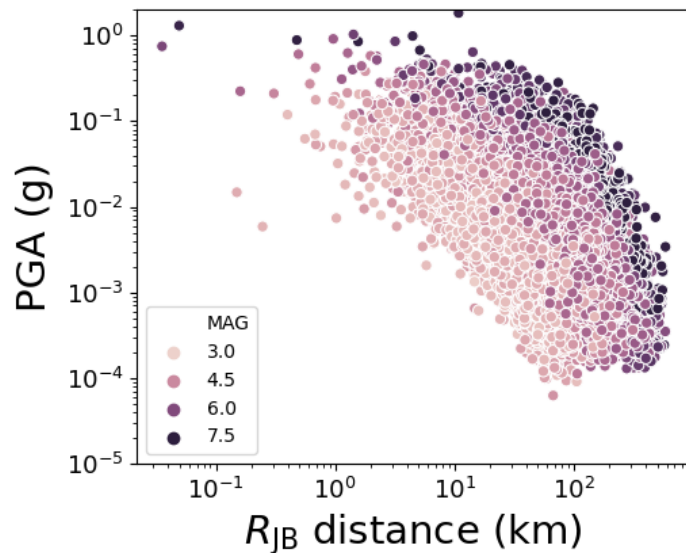
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Motivation

- Non-linear site-amplification is mainly expected for strong ground motions and soft-soil sites where observations are sparse
- Most non-linear amplification models are based on numerical modelling
- New large ground-motion datasets offer an opportunity to test the models against observed site amplification

Dataset by Bahrampouri et al. (2020)

- Updated version of the Dawood et al. (2016) dataset
- Automatic processing protocol
- Contains all KiK-net ground-motion record from earthquakes of magnitude $MW \geq 3$ recorded between 1997 and 2017



Non-linear amplification models

- Predict a decrease in amplification with increasing intensity of predicted ground motions for strong ground motions and soft soils
- Often based on simulated data

Non-linear model	ID	Dataset	Data type	Simulated data
Seyhan and Stewart (2014)	SS14	NGA – West2	Semi-empirical	Kamai et al. (2014)
Abrahamson et al. (2014)	ASK14	NGA – West2	Simulations	Kamai et al. (2014)
Sandikkaya et al. (2013)	SAB13	SHARE SM Databank	Empirical	
Hashash et al. (2020)	H20	NGA – East	Simulations	Harmon et al. (2019)

Method

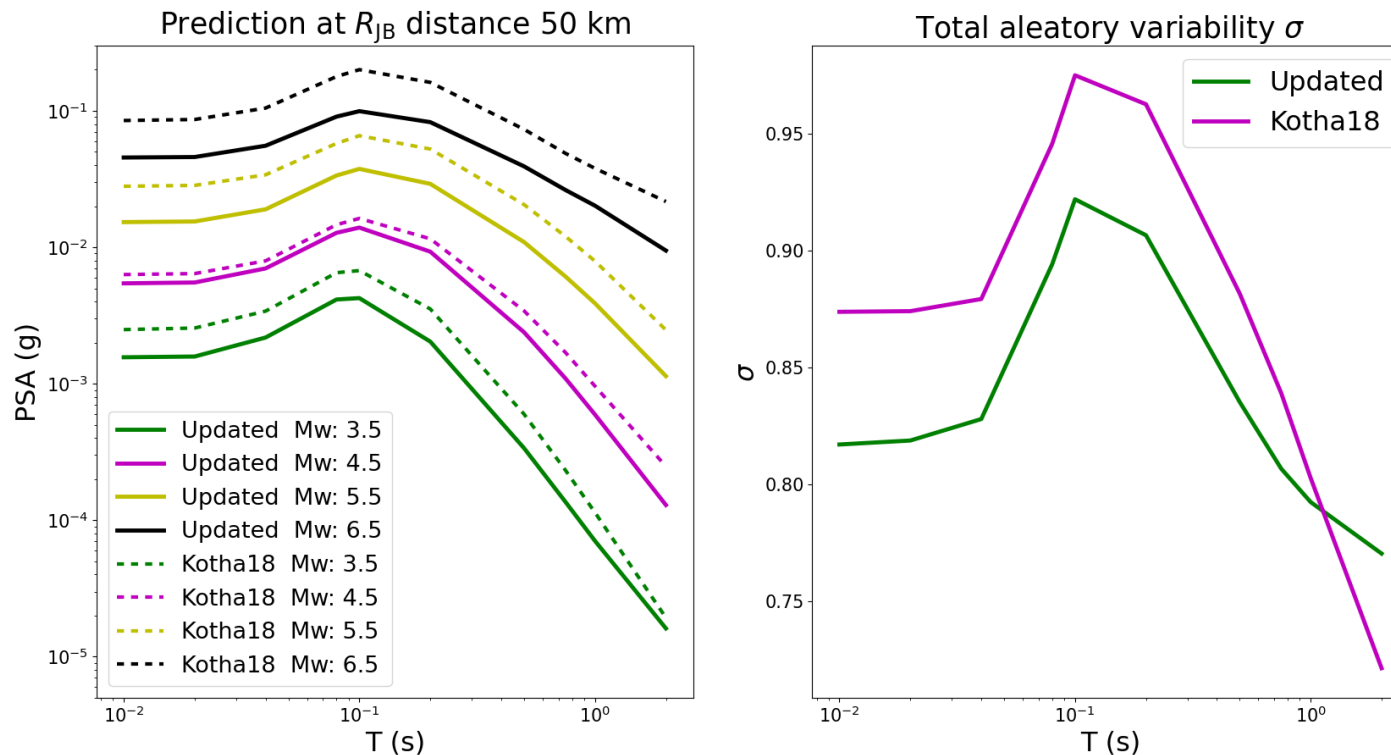
- The method has three steps:
 1. A linear GMM is derived based only on magnitude and distance
 2. The residual between the prediction and observations is split using mixed-effects regression
 3. Non-linear site-amplification models are tested against a linear amplification model on individual stations

1. Linear GMM

- Derived using same method and functional form as Kotha et al. (2018) on the Bahrapouri et al. (2020) dataset:

$$\ln(\text{PSA}) = f_R(M_W, R_{JB}) + f_M(M_W) + \delta B_e + \delta S_2 S_s + \delta W S_{e,s}$$

- No site term, all site information is captured by $\delta S_2 S_s$
- Derived using records that contain only linear soil response; records non-linear in the non-linear range ($V_{S30} < 760$ m/s with $\text{PGA}_{\text{rock}} > 0.05$ g) is omitted



2. Splitting of residuals

- Total residual between the observation $Y_{e,s}$ and the prediction on rock $\mu_{e,s}$ for an event e and site s :

$$\varepsilon_{e,s} = \ln Y_{e,s} - \ln \mu_{e,s}$$

- Mixed-effects regression (Bates et al. 2015) to split the residuals:

$$\varepsilon_{e,s} = \delta B_e + \delta S2S_s + \delta WSe_{e,s}$$

- Within-event residuals:

$$\delta We_{e,s} = \varepsilon_{e,s} - \delta B_e$$

- Record-to-record variability containing any non-linear site response:

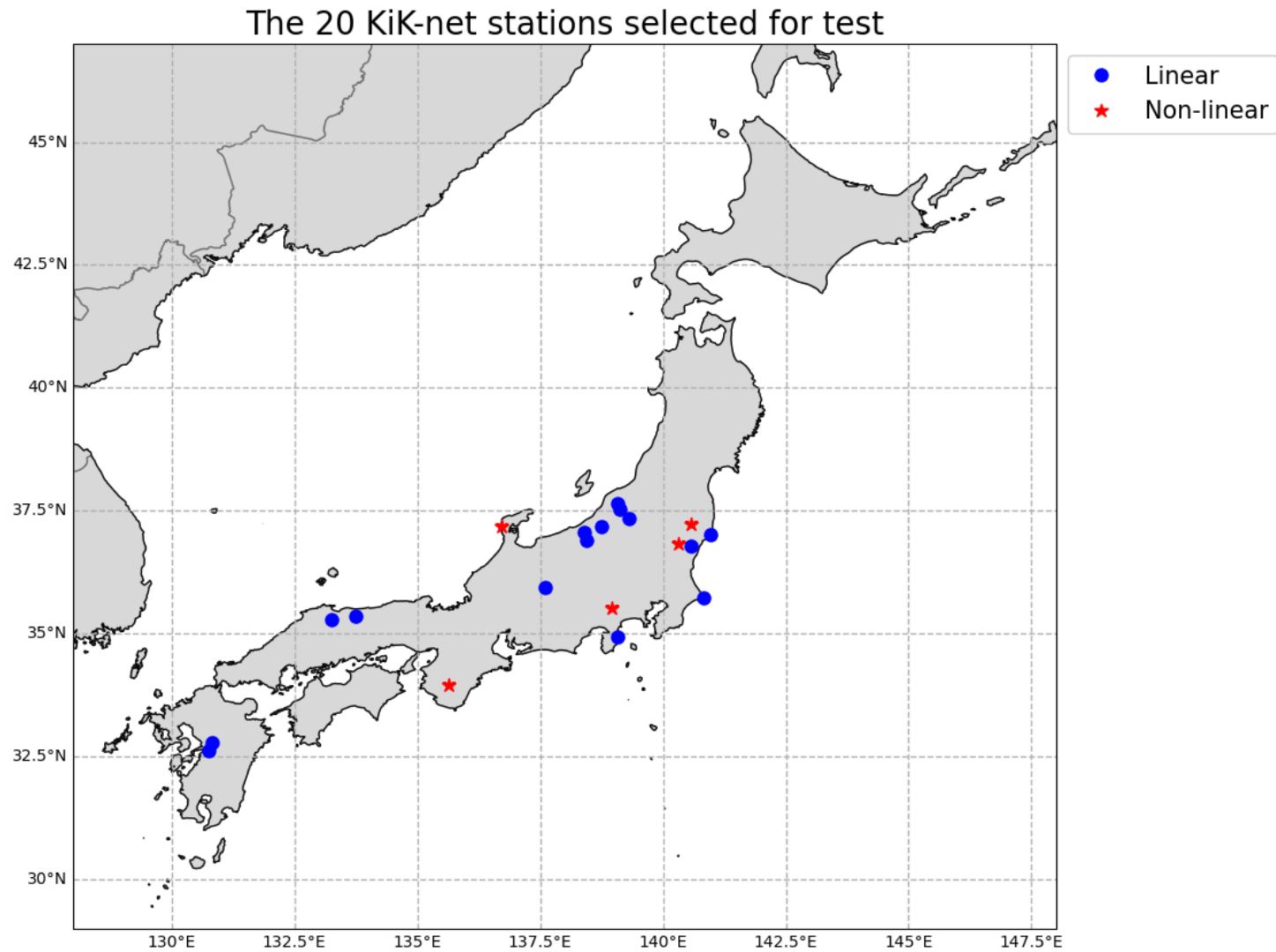
$$\delta WS_{e,s} = \delta We_{e,s} - \delta S2S_{s, \text{linear}}$$

3. Test

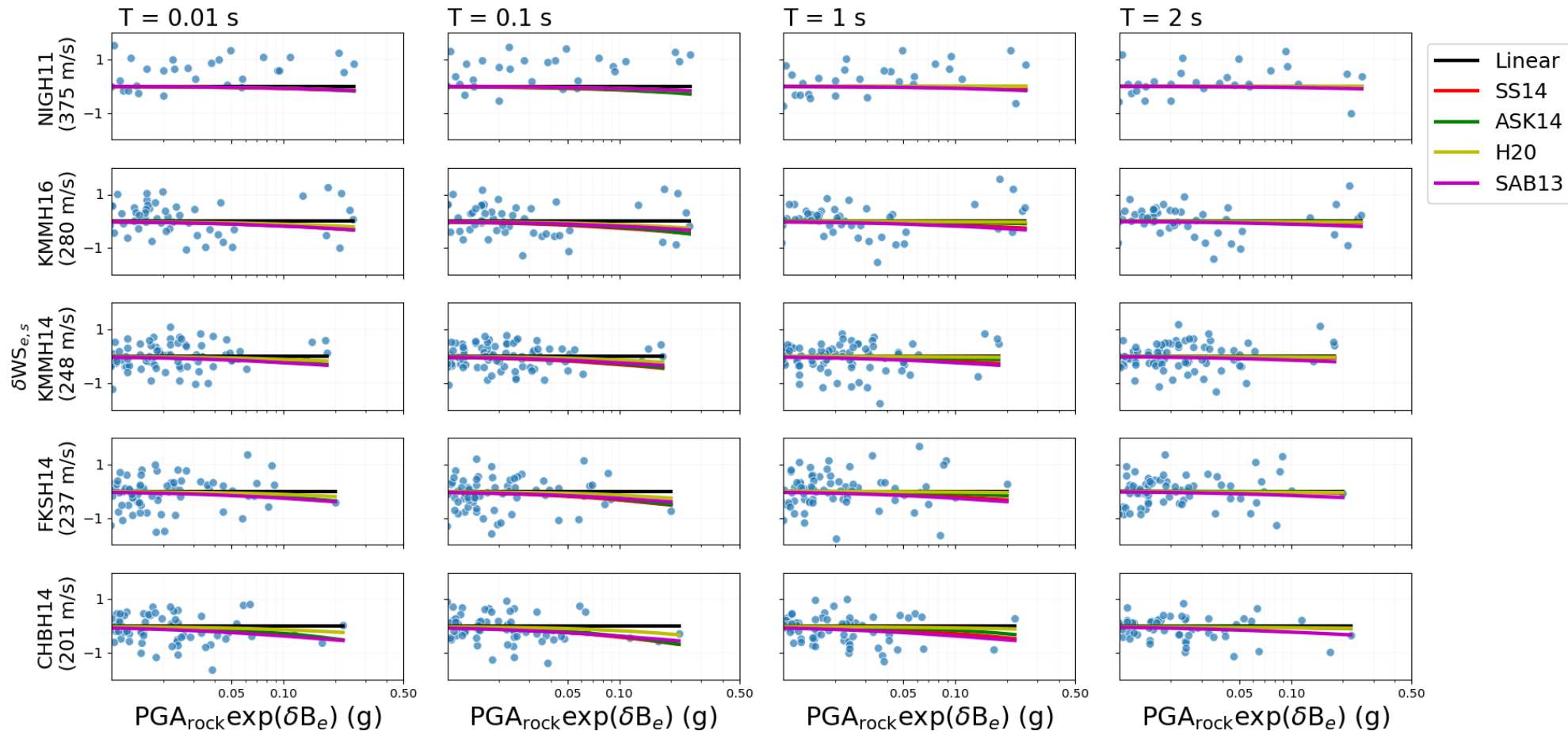
- $\delta W s_{e,s} = 0$ for linear site response
- The non-linear amplification models vs. linear amplification model
- Individual stations with at least 4 records at $\text{PGA}_{\text{rock}} > 0.05 \text{ g}$
- The prediction power is measured in absolute mean error (MAE):

$$\text{MAE}_e = \frac{\sum_e^N \delta W s_{e,s} - F_{e,s}}{N}$$

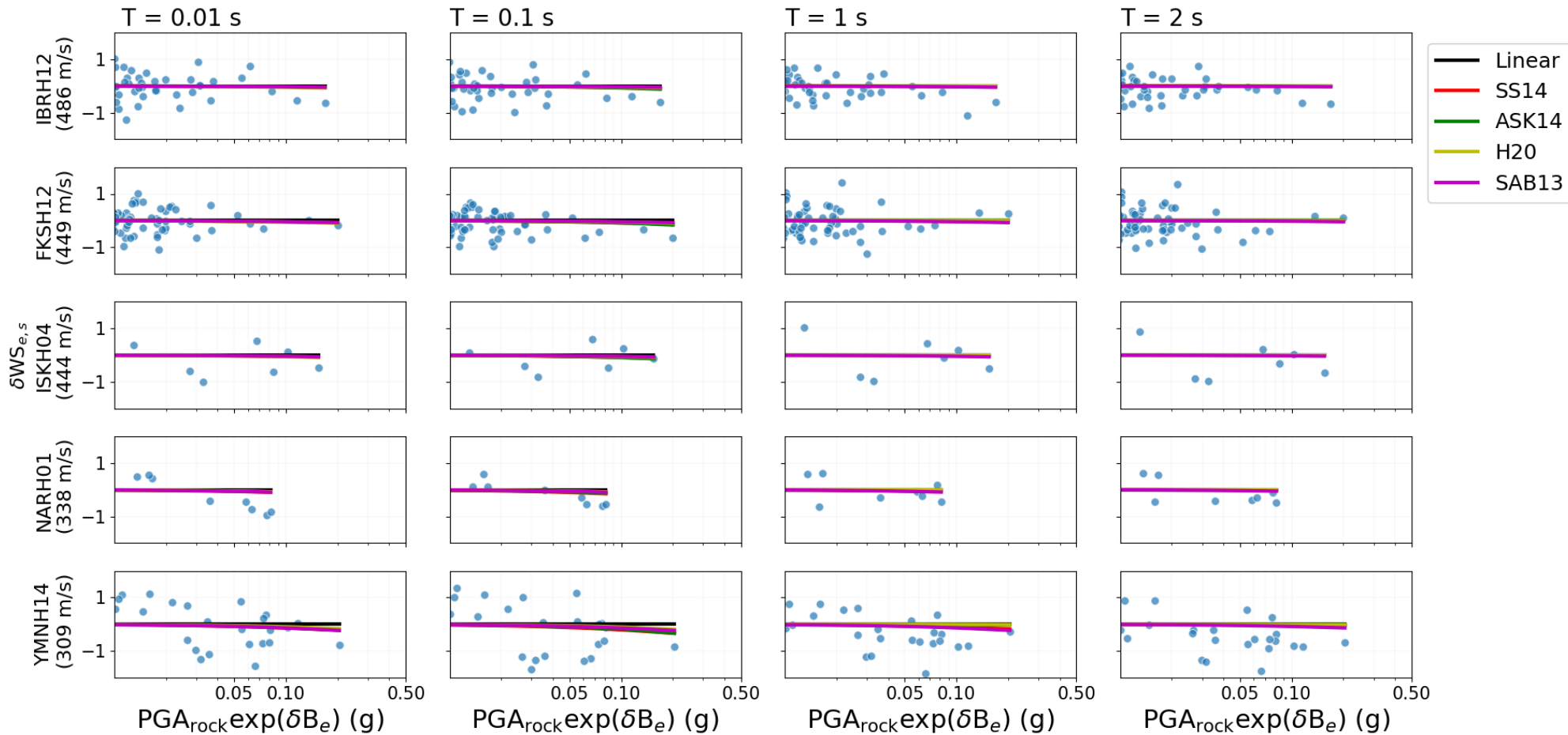
Test - Results



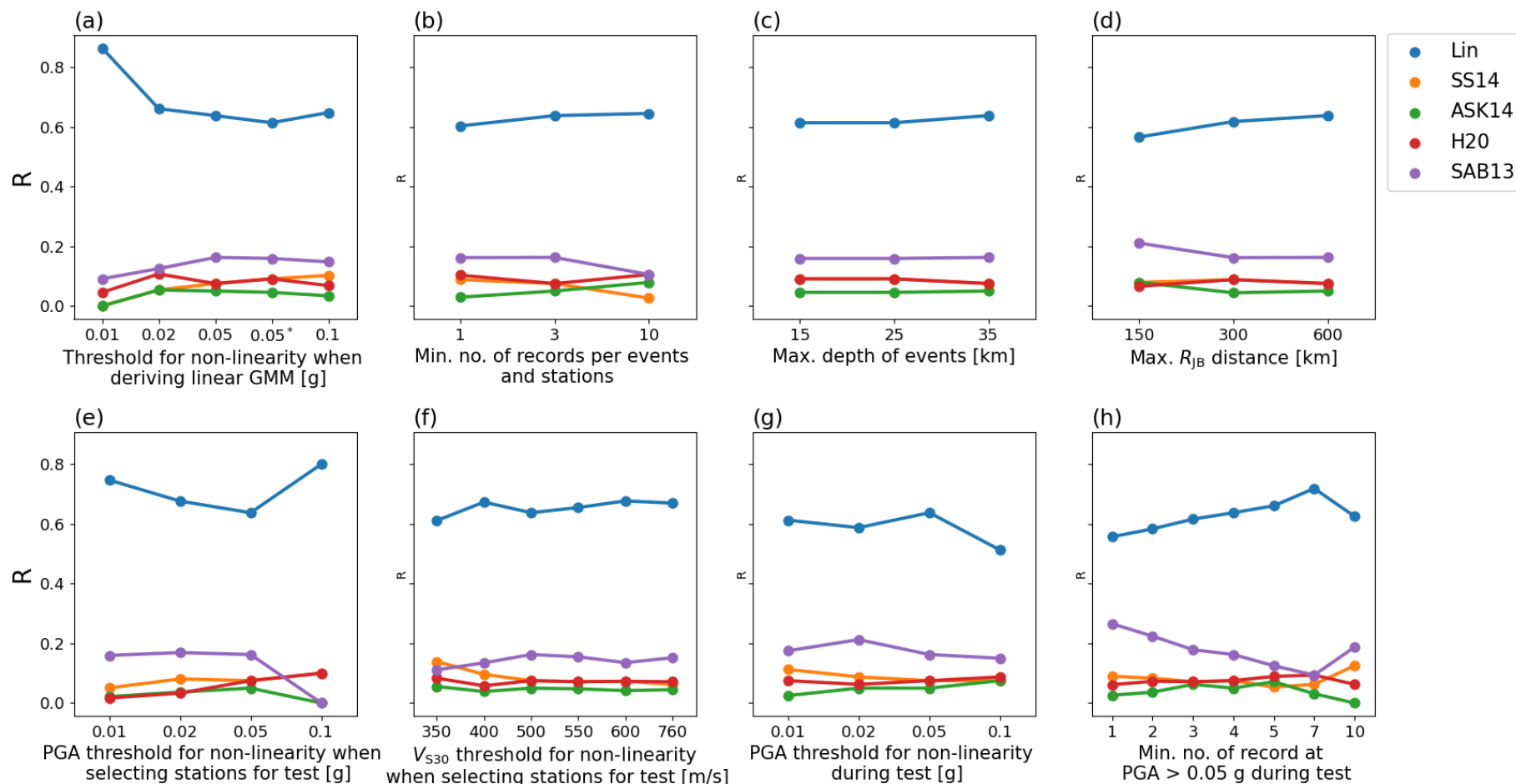
Test – Stations with high number of records



Test – Non-linear stations



Sensitivity test - assumptions



Conclusions

- Non-linear amplification models do not score better than a linear amplification model
- The observed site amplification shows a large variability even within similar site proxies
 - Site proxy V_{s30} not suitable for estimating non-linearity
- The test considers predicted rock ground motions up to 0.2 g
 - Relevant for moderate seismicity countries
- The data does not justify the use of non-linear amplification models in GMMs and building codes at the range of predicted ground motions used in the study

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