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Correlation models for next-generation amplitude and cumulative intensity measures using artificial neural networks

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Introduction

- Plethora of intensity measures (IMs) to characterise the intensity of a ground motion
  - Traditionally, only ***Sa*** is explicitly considered in seismic risk analyses
  - Filtered incremental velocity, ***FIV*3**, was shown to be an excellent IM in predicting the collapse of structures
  - Average spectral acceleration, Sa_{avg}, was shown to be well-correlated with a wide range of structural response
  - Significant duration, ***Ds***, was found to influence the structural damage due to cumulative effects
- Correlation models between a few aforementioned IMs are still missing from the literature
- Required for vector-based PSHA and ground motion record selection (e.g., GCIM method).
- Predictive models of the empirical correlation coefficients were developed using artificial neural networks (ANNs)

Correlation models developed (IM pairs)

- ***PGA***: peak ground acceleration
- ***PGV***: peak ground velocity
- ***Sa(T)***: 5%-damped spectral acceleration at a vibration period, *T*. Period range: 0.01 s to 5 s
- ***Ds$_{xy}$***: x-y% significant duration. The proposed models include {x, y} = {5%,75%} and {x, y} = {5%, 95%}
- ***Sa$_{avg}$(T)***: average spectral acceleration, for two different period ranges. ***Sa$_{avg2}$***: 0.2*T*-2*T*; ***Sa$_{avg3}$***: 0.2*T*-3*T*. Period range: 0.1 s to 4 s.
- ***FIV3(T)***: filtered incremental velocity, defined by Dávalos and Miranda (2019). Period range: 0.1 s to 4 s

RotD50 for: *PGA*, *PGV*, *Sa*, and *Sa*$_{avg}$

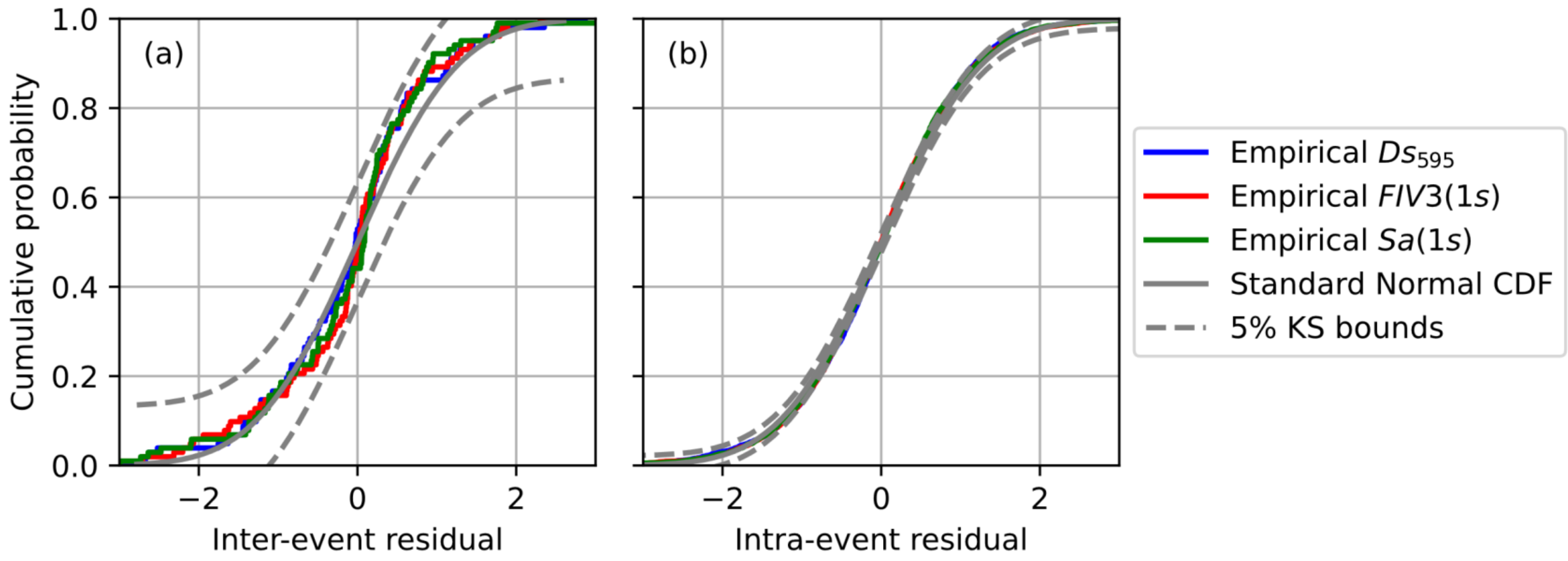
Geometric mean for: *Ds* and *FIV3*

Total of 24 cross-correlation models

IM$_i$ \ IM$_j$	***Sa***	***Sa$_{avg2}$***	***Sa$_{avg3}$***	***PGA***	***PGV***	***Ds$_{575}$***	***Ds$_{595}$***	***FIV3***
Sa	ASO24, BJ08, ASA14, BB17	ASO24, CB14 & BJ08*, CB14 & ASA14*	ASO24, CB14 & BJ08*, CB14 & ASA14*	*BB17, TBB23*	*BB17, TBB23*	ASO24, B11, BB17	ASO24, B11, BB17	ASO24
Sa$_{avg2}$		ASO24	ASO24	ASO24	ASO24	ASO24	ASO24	ASO24
Sa$_{avg3}$			ASO24, DM21	ASO24	ASO24	ASO24	ASO24	ASO24
PGA					*BB17, TBB23*	*BB17, TBB23, B11*	*BB17, TBB23, B11*	ASO24
PGV						*BB17, TBB23, B11*	*BB17, TBB23, B11*	ASO24
Ds$_{575}$							*BB17, TBB23, B11*	ASO24
Ds$_{595}$								ASO24
FIV3								ASO24

Database and ground motion model

- Single generalised ground motion model (GGMM) was used: Aristeidou et al. (2024) – ASO24
- NGA-West2 database, with the same filtering criteria as ASO24
- 4,135 ground motion records from 102 earthquakes
- Empirical distributions of normalised inter- and intra-event residuals are shown in the figure below. They are compared with the Kolmogorov-Smirnov (KS) goodness-of-fit bounds at 5% significant level



Methodology

- From the GMM and filtered ground motion database
- Residuals are computed for each record

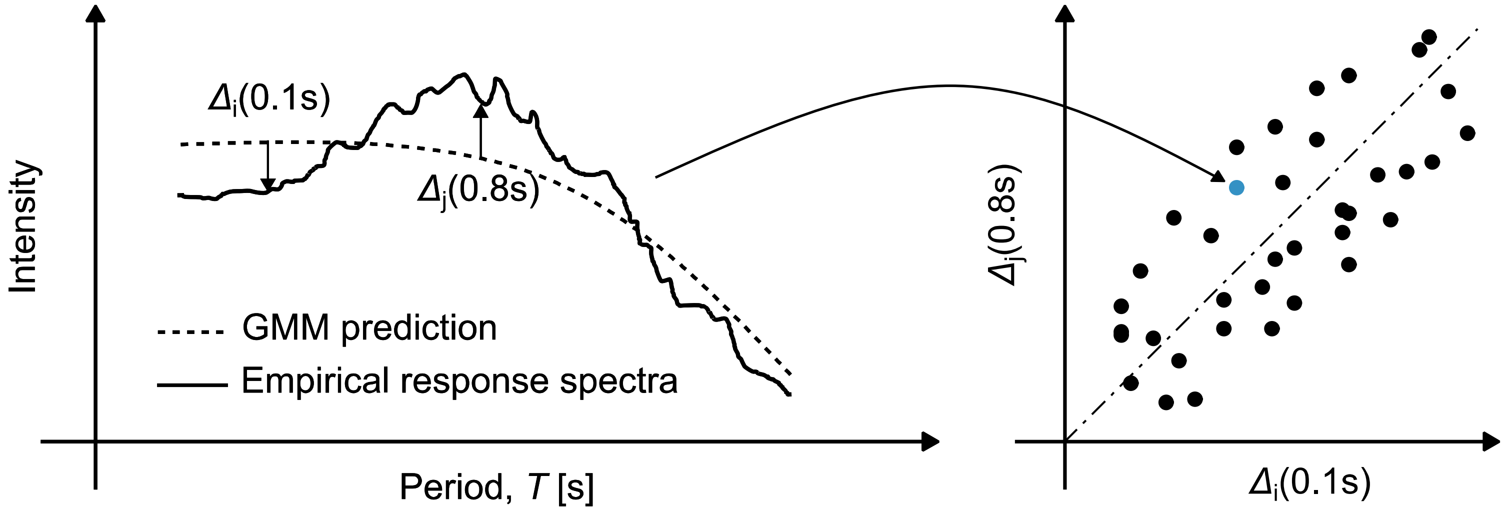
$$\log_{10} IM_i = f_i(\boldsymbol{X}, \boldsymbol{\theta}) + \delta b_i \tau_i + \delta w_i \varphi_i$$

$$\delta_i \sigma_i = \delta b_i \tau_i + \delta w_i \varphi_i$$

$$\delta_{i,g} = \frac{\log_{10} IM_{i,g} - \mu_{\log_{10} IM_i|\boldsymbol{X},\boldsymbol{\theta}}}{\sigma_i}$$

$$\rho_{\delta_i,\delta_j} = \frac{\rho_{\delta b_i,\delta b_j} \tau_i \tau_j + \rho_{\delta w_i,\delta w_j} \varphi_i \varphi_j}{\sigma_i \sigma_j}$$

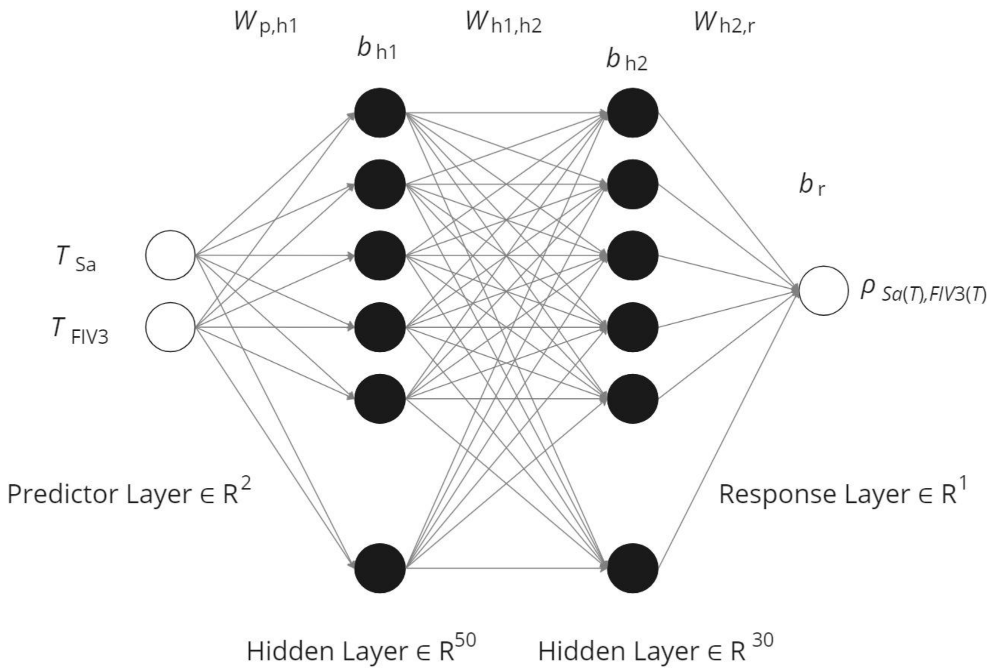
$$\rho_{\log_{10} IM_i|\boldsymbol{X},\boldsymbol{\theta},\, \log_{10} IM_j|\boldsymbol{X},\boldsymbol{\theta}} = \rho_{\delta_i,\delta_j}$$



Artificial neural network architecture

- Empirical correlation coefficient regressed with ANN
- ANN has the advantage of not needing predefined analytical functions
- It minimises the misfit between observed and predicted values
- Optimal hyperparameters for each model were chosen

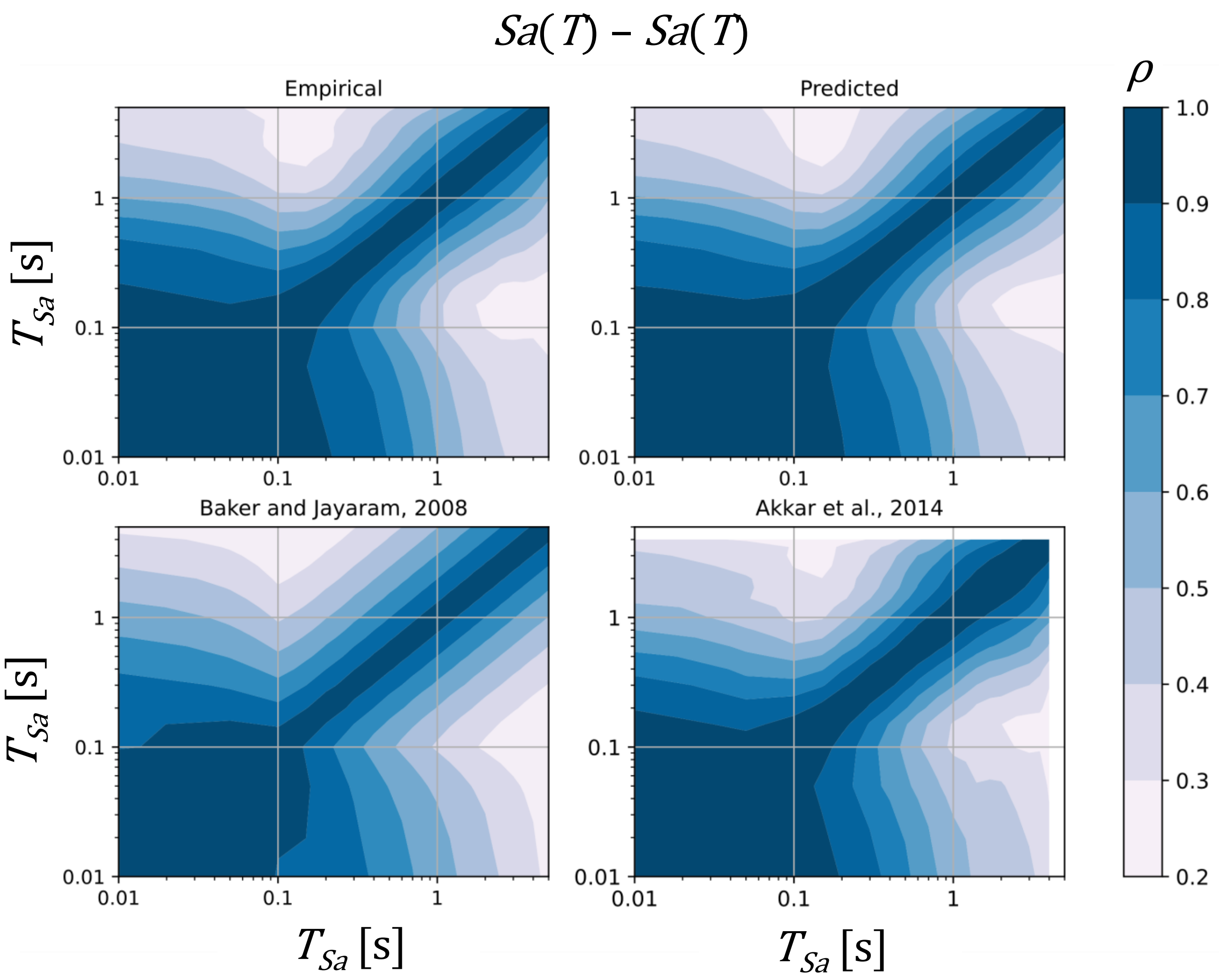
Schematic representation of the network for the case of *Sa*-*FIV*3 correlation model:

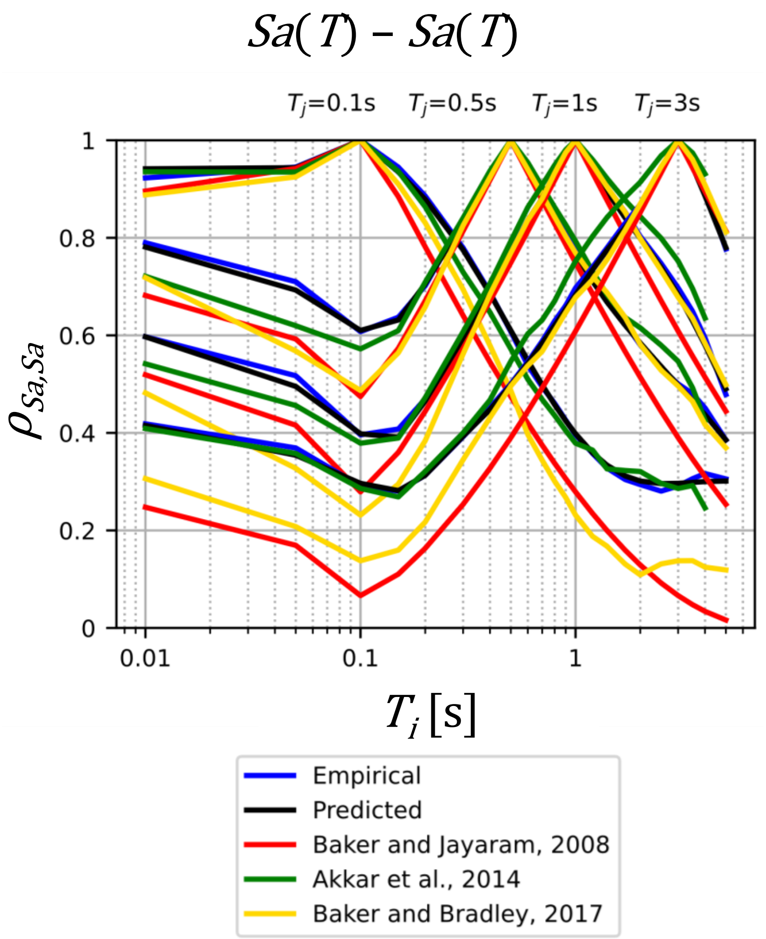


Correlation between an IM_i-IM_j pair for the case of one hidden layer:

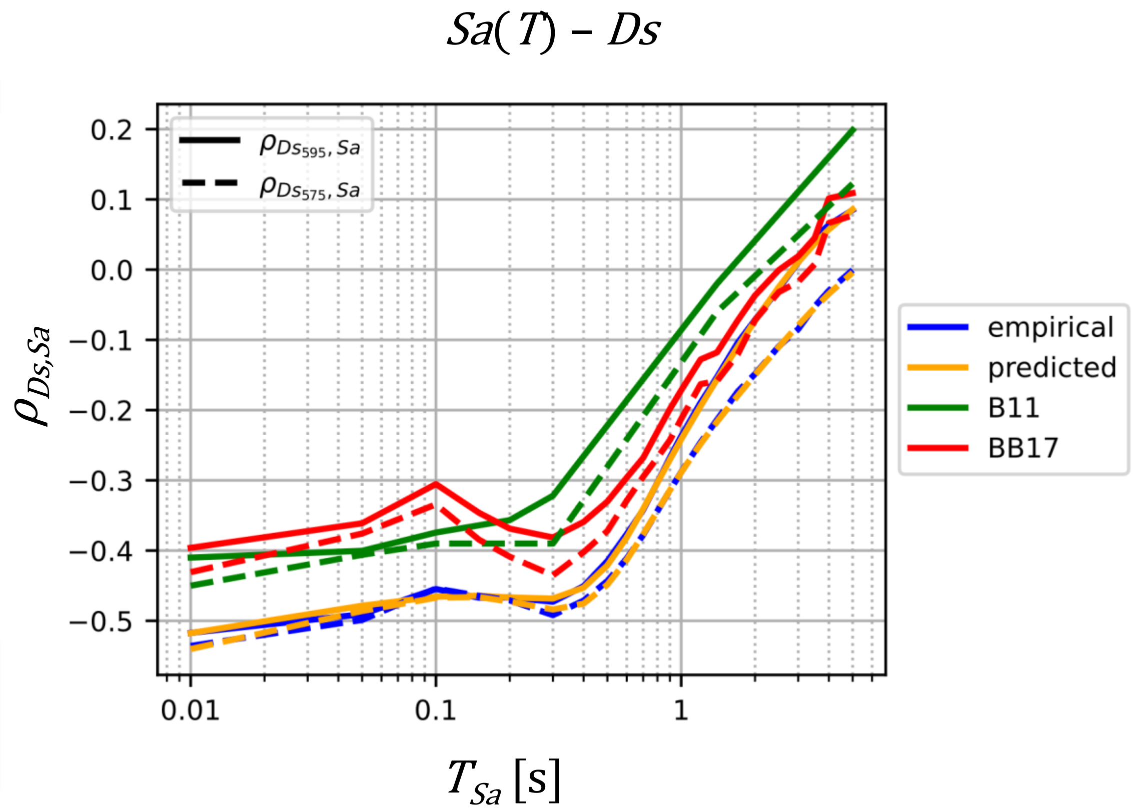
$$\rho_{\log_{10} IM_i, \log_{10} IM_j} = f_{activation2}\left[b_r + \sum_{h=1}^{n_h} W_{h,r} \cdot f_{activation1}\left(b_h + \sum_{p=1}^{n_p} W_{p,h} X_p\right)\right]$$

Results – Correlations between traditional IMs

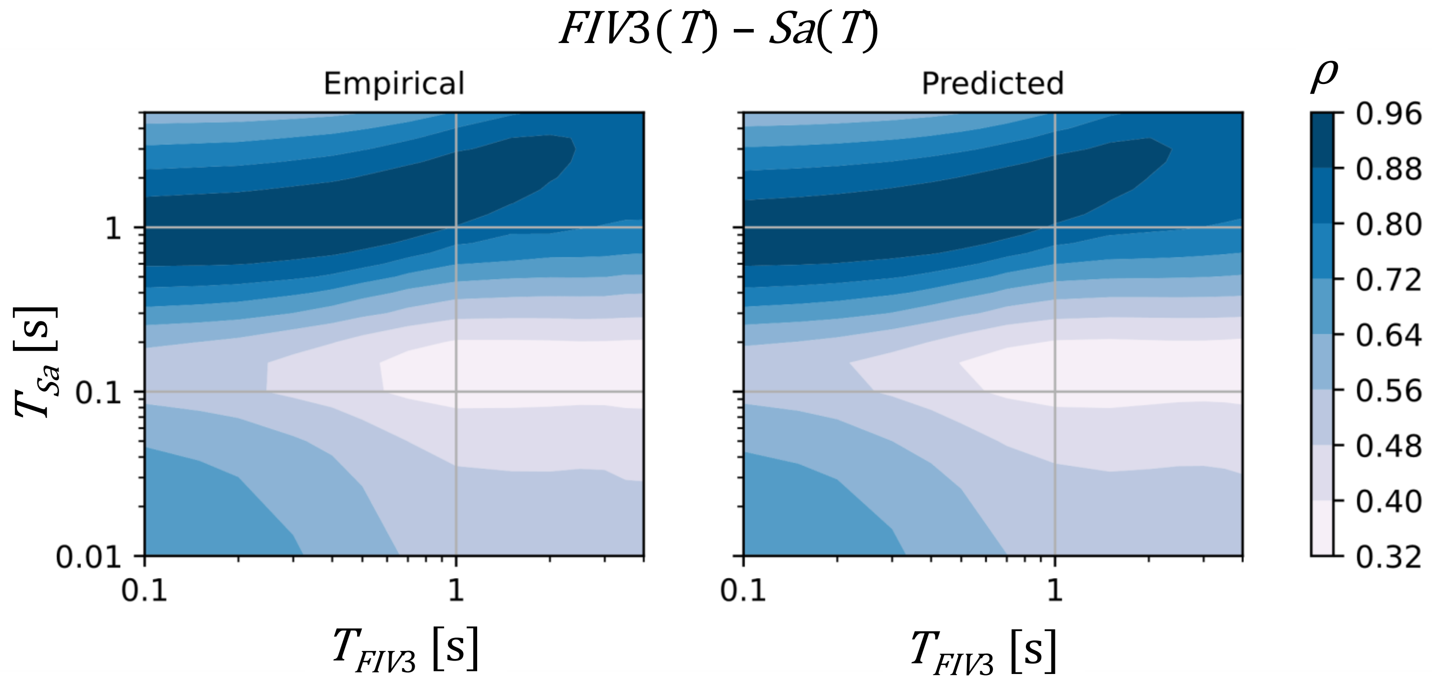


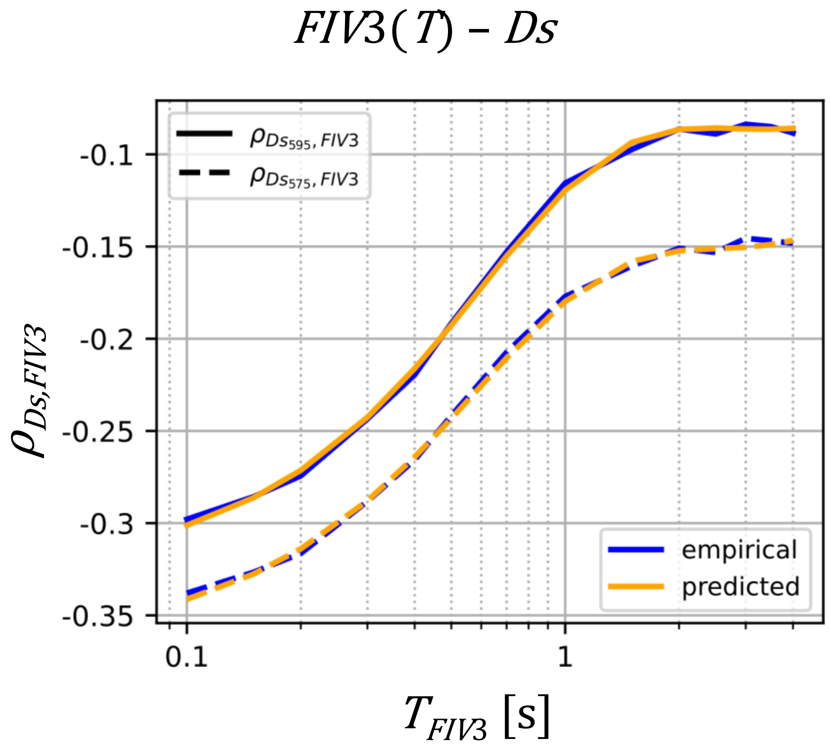


Results – Correlations between traditional IMs



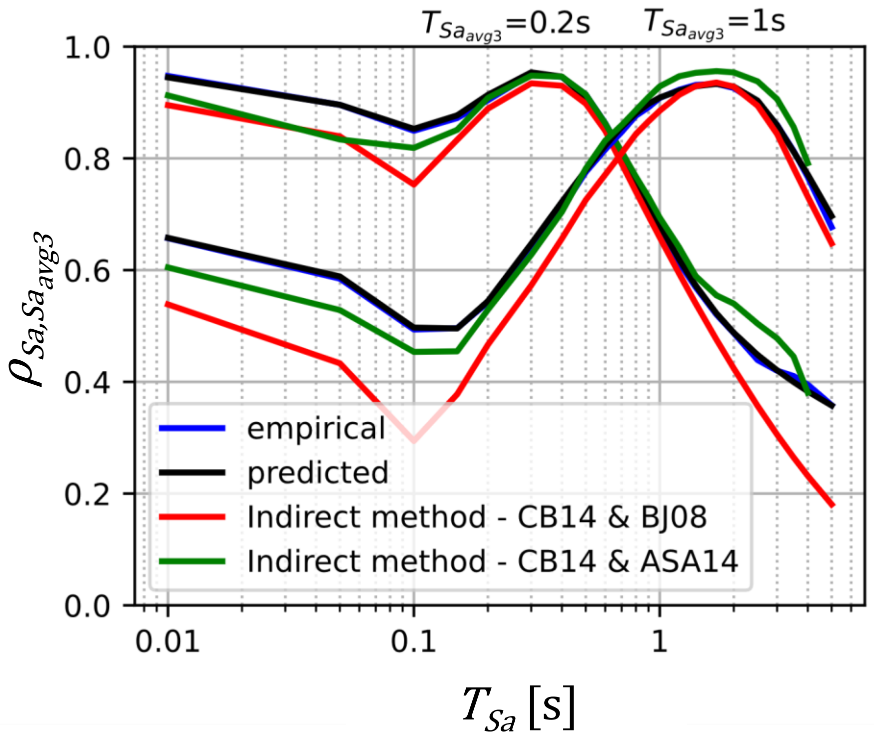
Results – Correlations between traditional and next-generation IMs



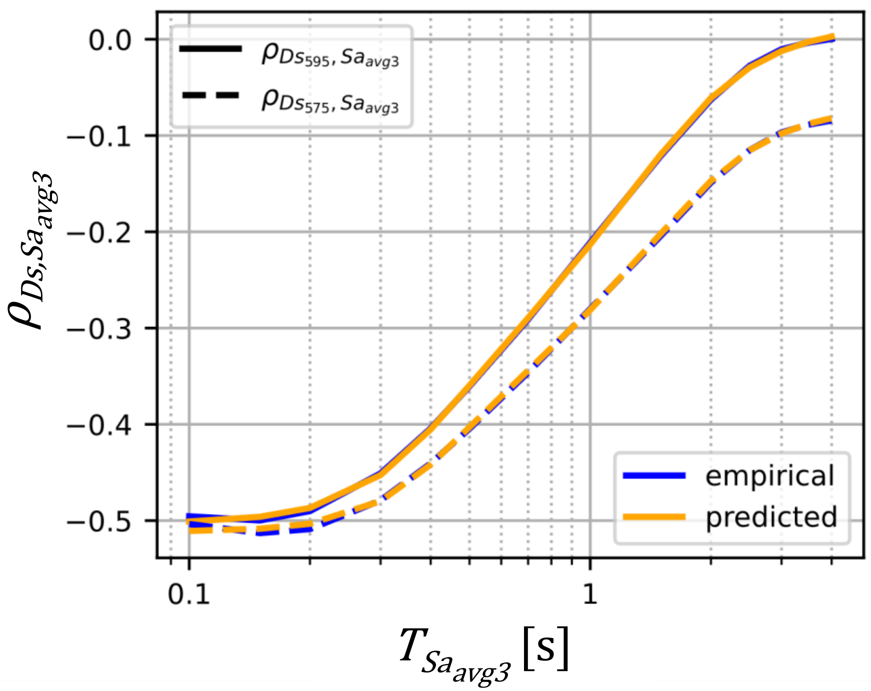


Results – Correlations between traditional and next-generation IMs

$Sa(T) - Sa_{avg3}(T)$

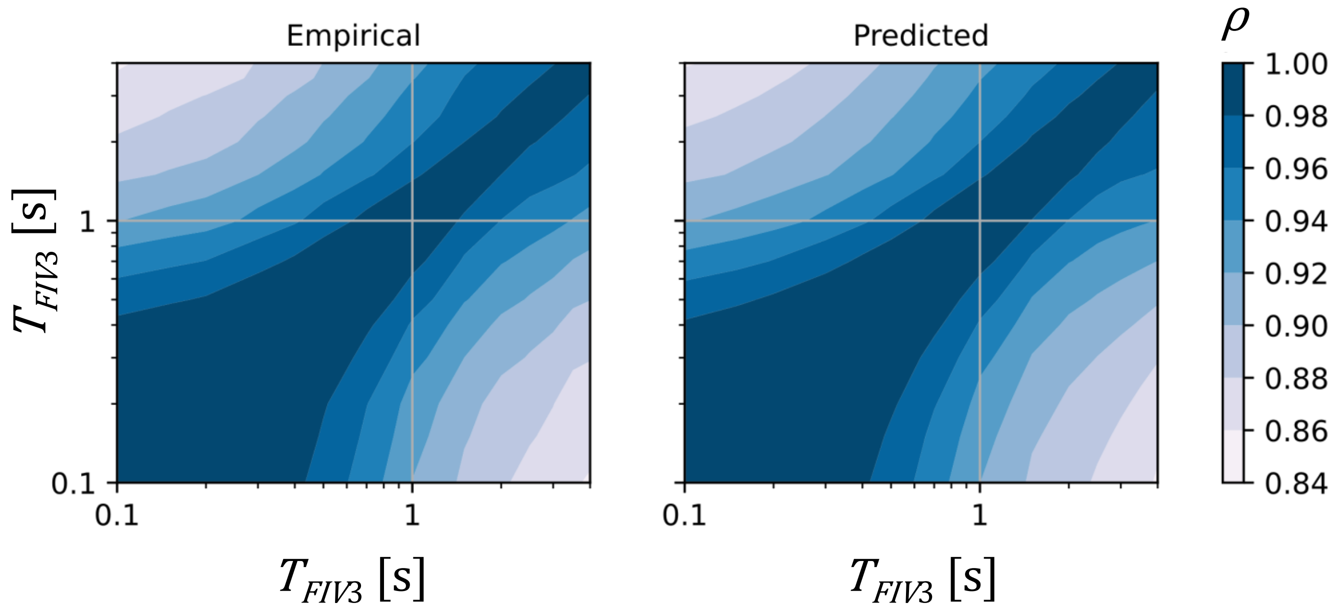


$Sa_{avg3}(T) - Ds$

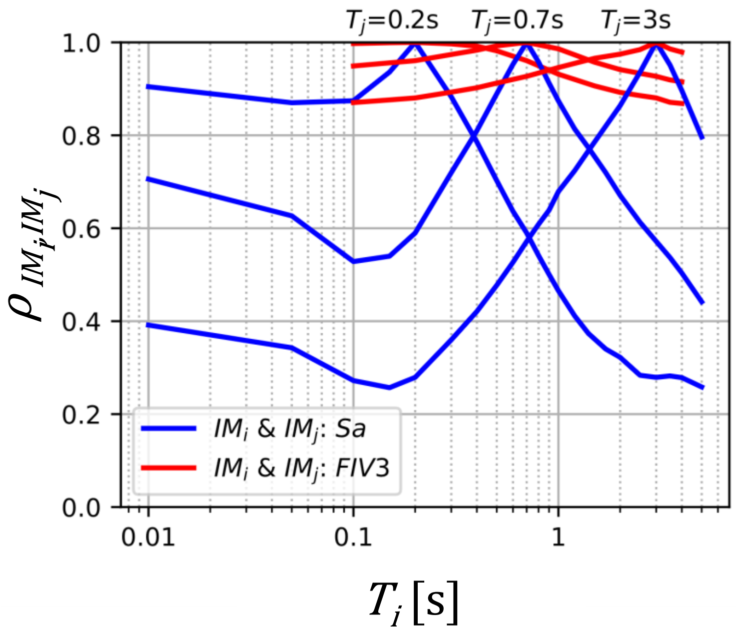


Results – Correlations between next-generation IMs

$FIV3(T) - FIV3(T)$

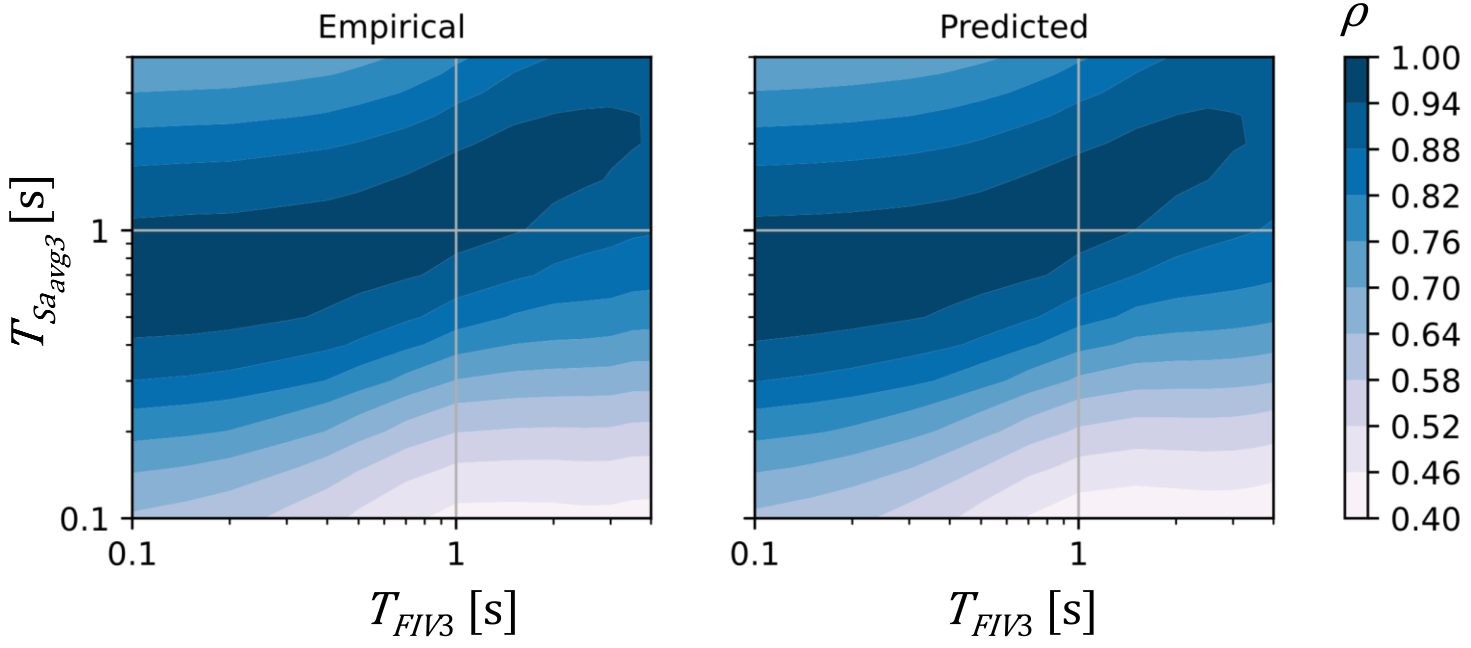


$Sa(T) - Sa(T)$ & $FIV3(T) - FIV3(T)$

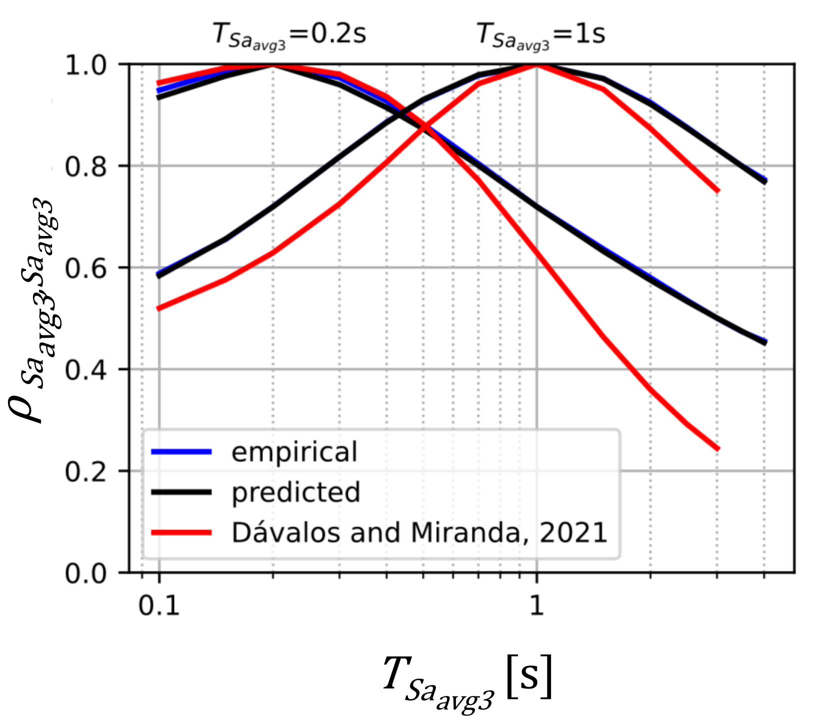


Results – Correlations between next-generation IMs

$FIV3(T) - Sa_{avg3}(T)$



$Sa_{avg3}(T) - Sa_{avg3}(T)$



Discussion and conclusions

- This study presented the empirical correlations between miscellaneous IMs finding use in contemporary risk analyses (24 IM pairs in total)
- Regarding *FIV*3:
  - Strongly correlated with $Sa(T$=0.6-3s)
  - Very well correlated with itself across all periods
  - Weak negative correlation with duration at short periods and near-zero correlation at longer periods
  - *Ds* - *FIV*3 has similar trend with *Ds* - *Sa*, but with a slightly weaker negative correlation (i.e., taking values closer to 0)
  - *FIV*3 - Sa_{avg} very similar with *FIV*3 - *Sa*
- Direct correlation of Sa_{avg} with itself and other IMs → allowing for a more consistent ground motion record selection, rather than the indirect method
- Predictive models based on regression with ANN. Has not been used before for fitting IM cross-correlation models
- The procedure adopted and the network architecture can be seamlessly adapted to develop correlation models for other IMs and/or horizontal component definitions

Aristeidou, S., Shahnazaryan, D. and O'Reilly, G.J. (2024) 'Correlation Models for Next-Generation Amplitude and Cumulative Intensity Measures using Artificial Neural Networks', Earthquake Spectra (Accepted)

Thank you!

Correlations models are available to use at:
https://github.com/Savvinos-Aristeidou/ANN_correlation_models.git

Questions?

OPENQUAKE
calculate share explore

Soon to be implemented in OpenQuake

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