Ground motion selection for nonlinear response history analyses of concrete dams

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INTRODUCTION

Aim

1. Review fundamentals of ground motion selection and modification (GMSM)
2. Illustrate GMSM for three components of ground motion (GM)
3. Identify most important inputs to GMSM methodology

Case study for illustration

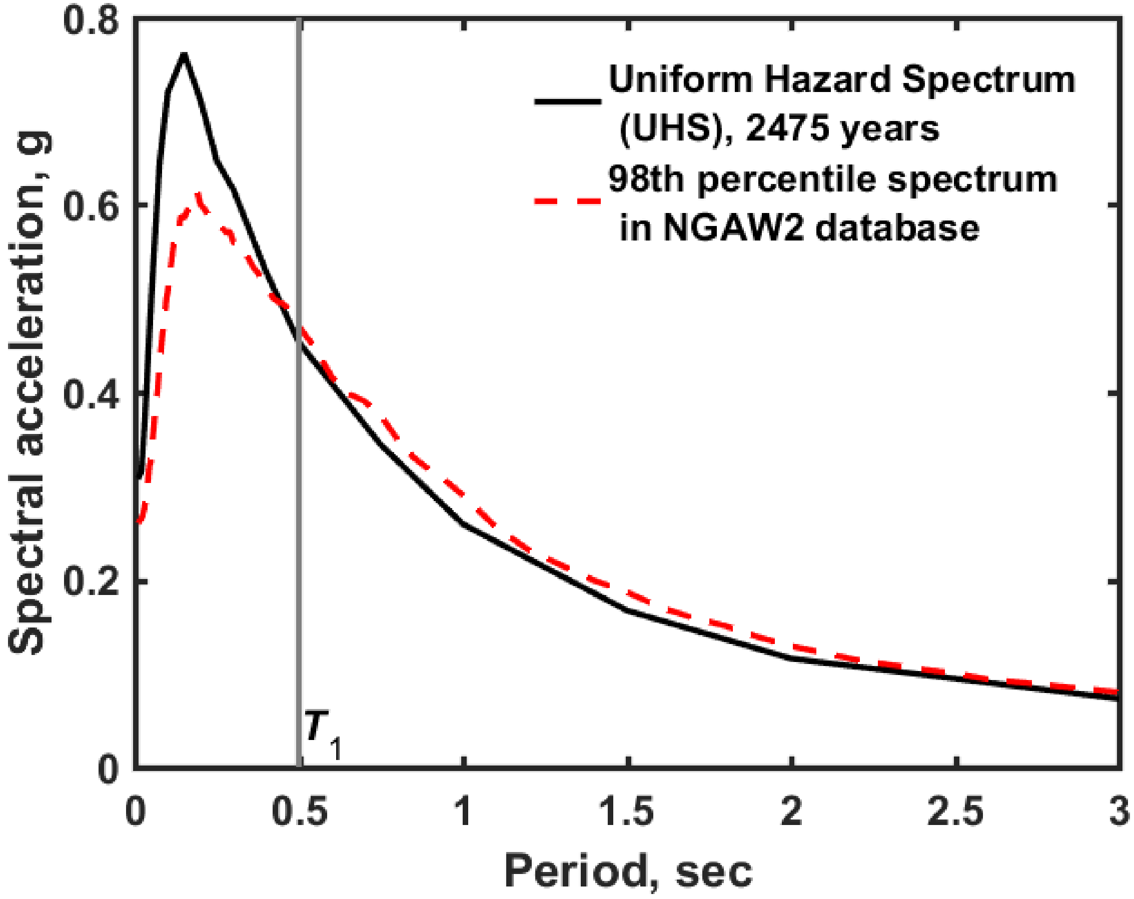
1. Structure with $T_1 = 0.5$ sec
2. Site located in Davis, CA
3. Probabilistic seismic hazard analysis (PSHA) using OpenSHA with 2475-year return period
4. Recorded GMs from PEER NGAW2 database
5. GM selection algorithm using Matlab

Other PSHA software

1. USGS Earthquake Hazards Program
2. OpenQuake
3. EZ-Frisk
4. QuakeManager
5. Proprietary software

GMSM FOR ONE HORIZONTAL COMPONENT OF GM

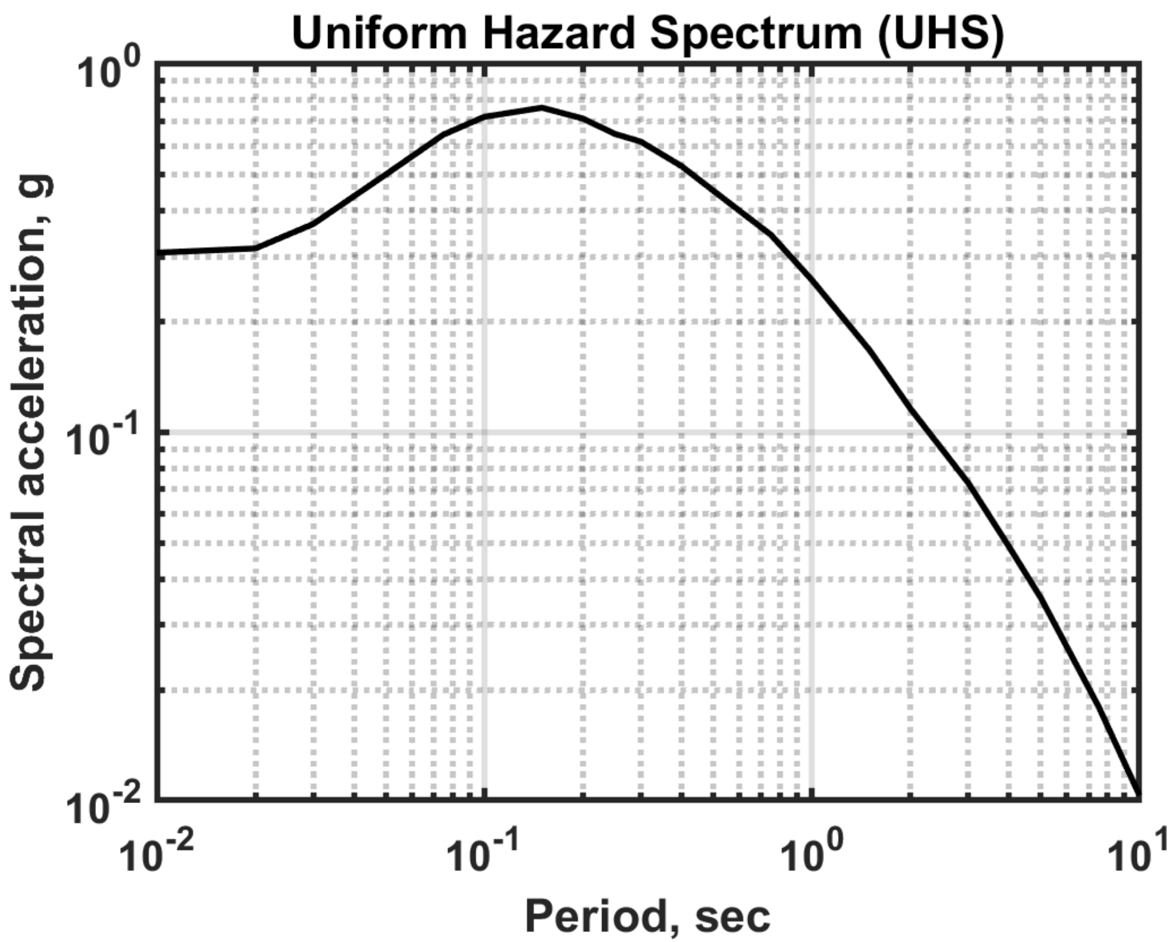
The need for GMSM



Fundamentals of GMSM

1. Target spectrum
2. Selecting and scaling GMs

Target spectrum example



Selecting and scaling GMs

1. Specify GMSM inputs
2. Select and scale GMs to match target
3. Confirm hazard consistency
4. Repeat GM selection with revised database if needed

Specify GMSM inputs

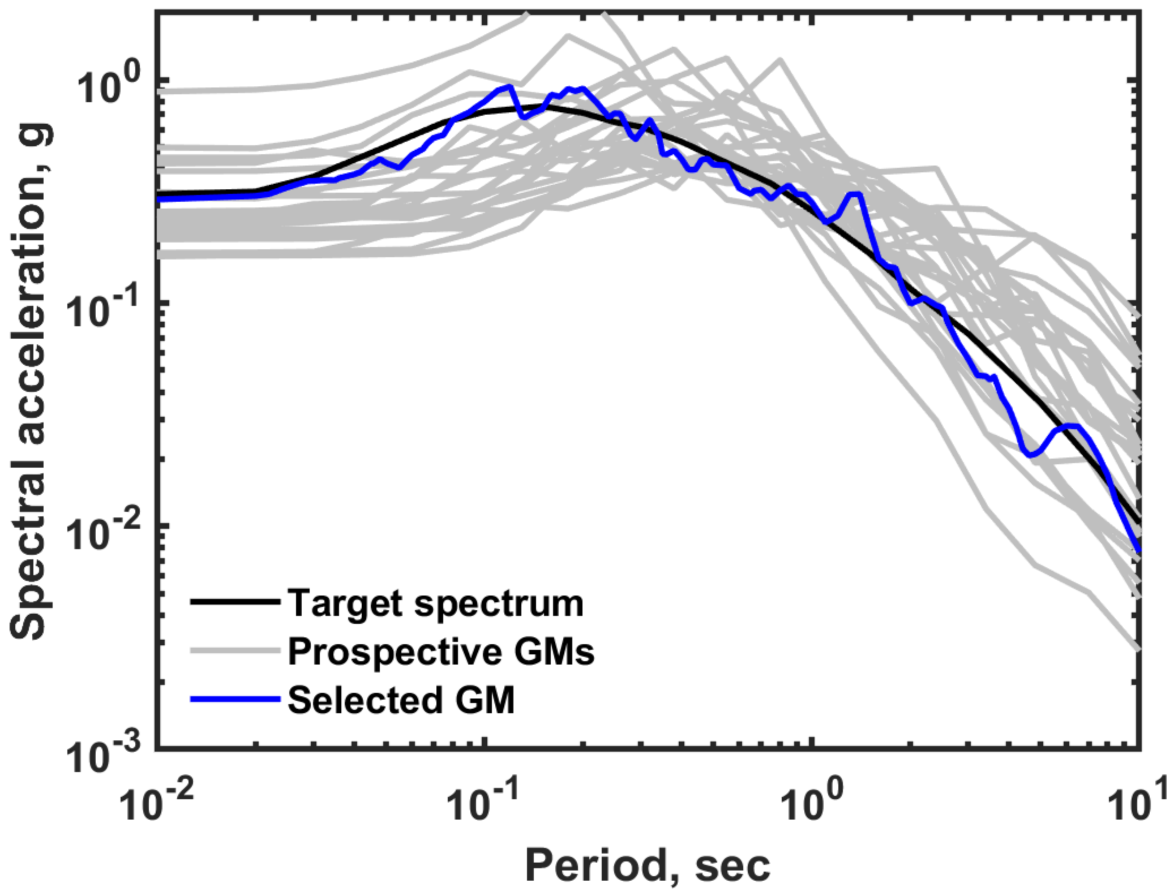
1. Database of prospective GMs (e.g., NGAW2)
2. Number of GMs to be selected (e.g., 11)
3. Limits on metadata (e.g., NGA RSNs, M, R, V_{s30}, etc.)
4. Limits on scale factors (SFs)

Selecting GMs

- To compare response spectra, use sum-of-squared-differences (SSD):

$$SSD = \sum_{j=1}^{N_p} \left(\ln\left[SF \cdot A_0\left(T_j\right)\right] - \ln\left[A_{TS}\left(T_j\right)\right] \right)^2$$

Selecting GMs



Scaling GMs

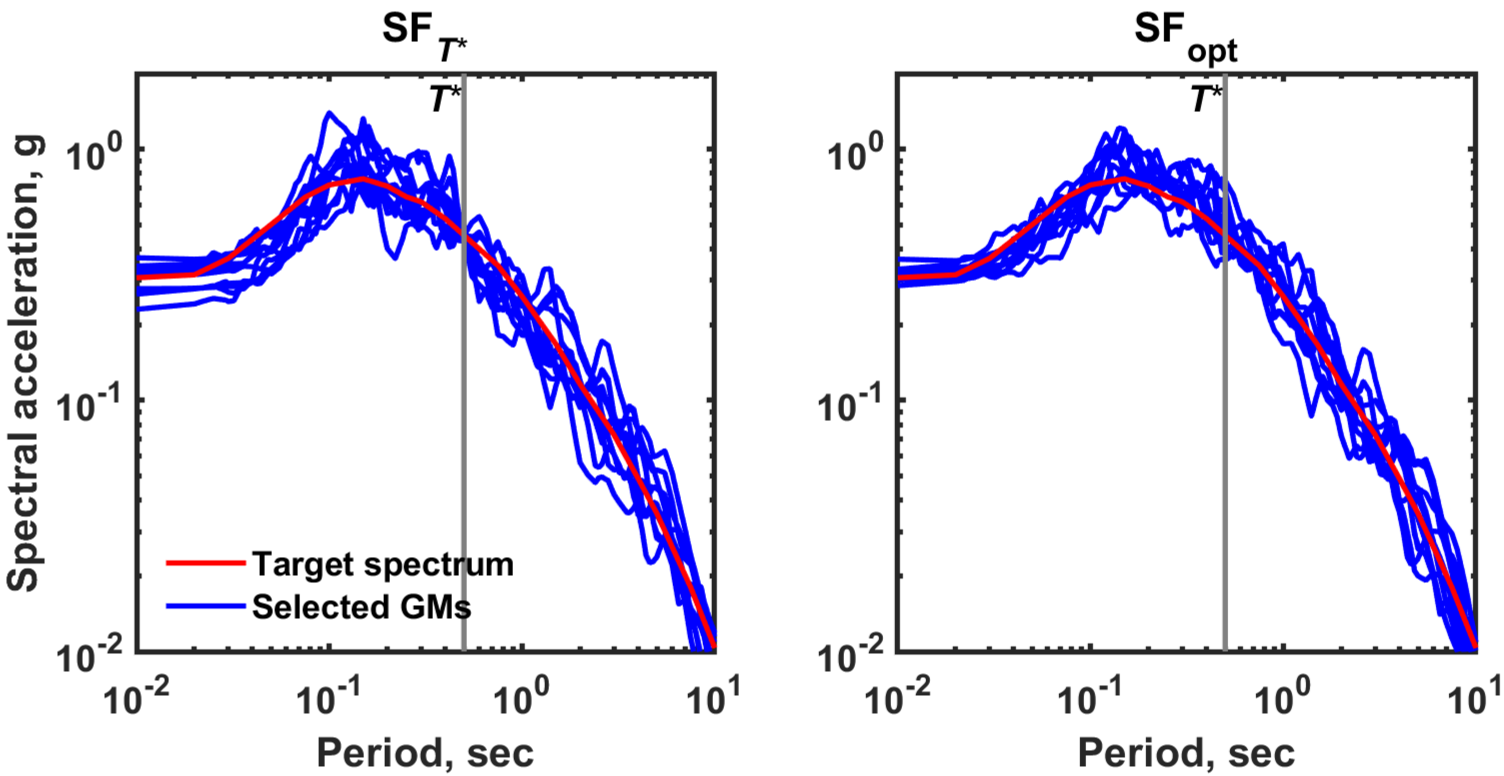
Single period T^*

$$SF_{T^*} = \frac{A_{TS}(T^*)}{A_0(T^*)}$$

Range of $\boldsymbol{N_p}$ vibration periods

$$SF_{opt} = \left[\prod_{j=1}^{N_p} \frac{A_{TS}(T_j)}{A_0(T_j)}\right]^{1/N_p}$$

Scaling GMs

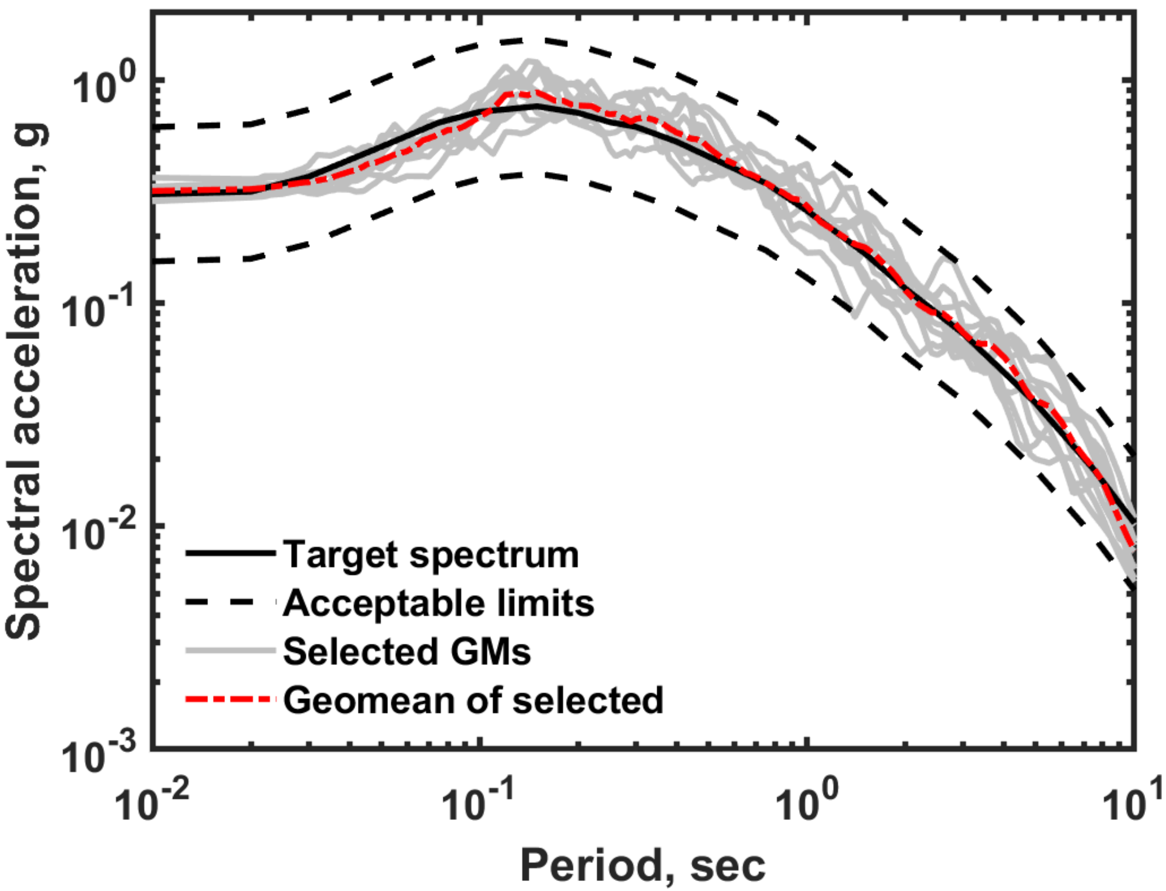


SF$_{T^*}$
SF$_{opt}$
T^*
T^*
Spectral acceleration, g
10^0
10^{-1}
10^{-2}
10^{-2}
10^{-1}
10^0
10^1
Period, sec
Target spectrum
Selected GMs

Confirming hazard consistency

- Standard deviation of logarithm of spectral acceleration, σ, approximately 0.7 units
- Multiplying target spectrum by $\exp(1\sigma) \approx \exp(0.7) \approx 2$
- Acceptable limits defined by multiplying or dividing target spectrum by factor of two

Confirming hazard consistency



Repeat GMSM if needed

- Reasons for repeating:
  1. Selected ensemble is inconsistent with hazard
  2. Unable to retrieve time series
  3. Avoid one earthquake from dominating final selection
- Repeat using revised GM database with new RSNs

Previously, GMSM limited to:

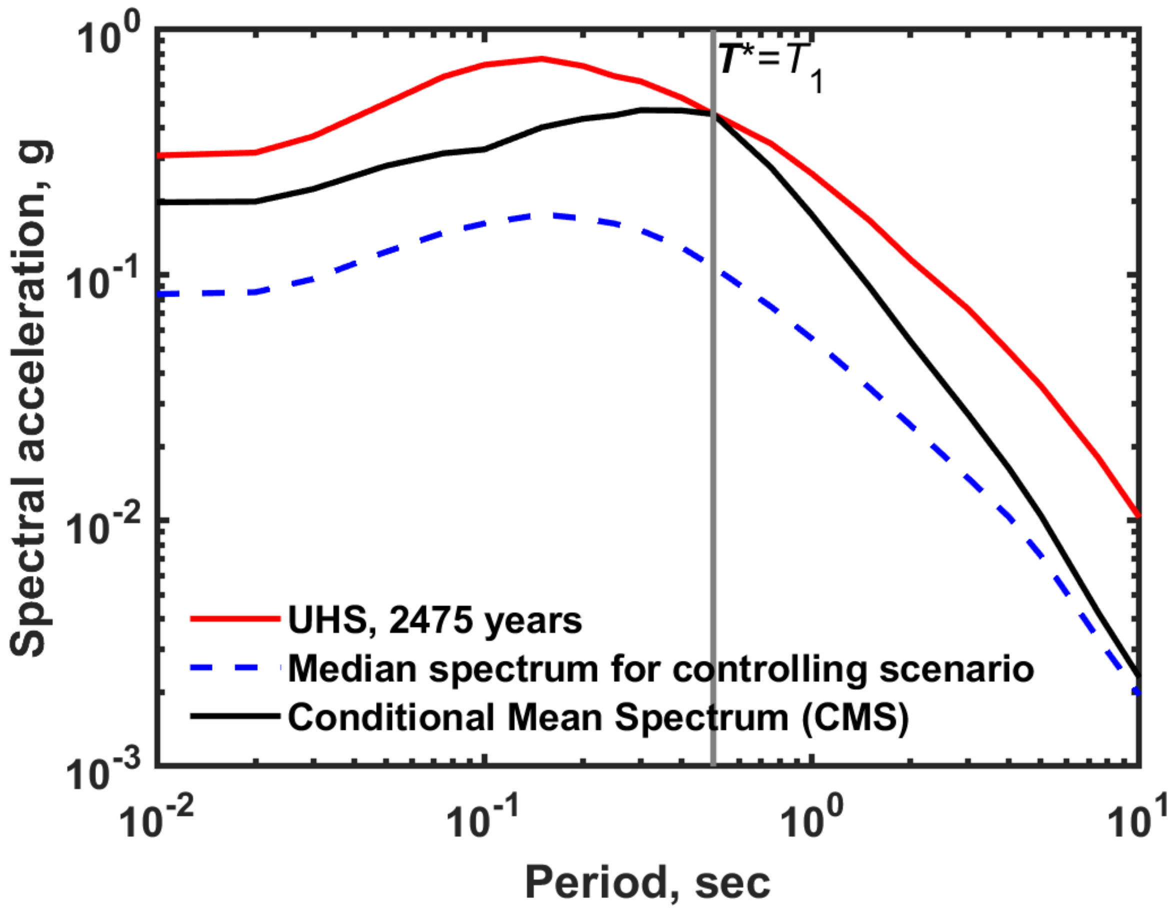
1. One component of GM
2. First-mode dominated structures

Conditional Mean Spectrum (CMS)

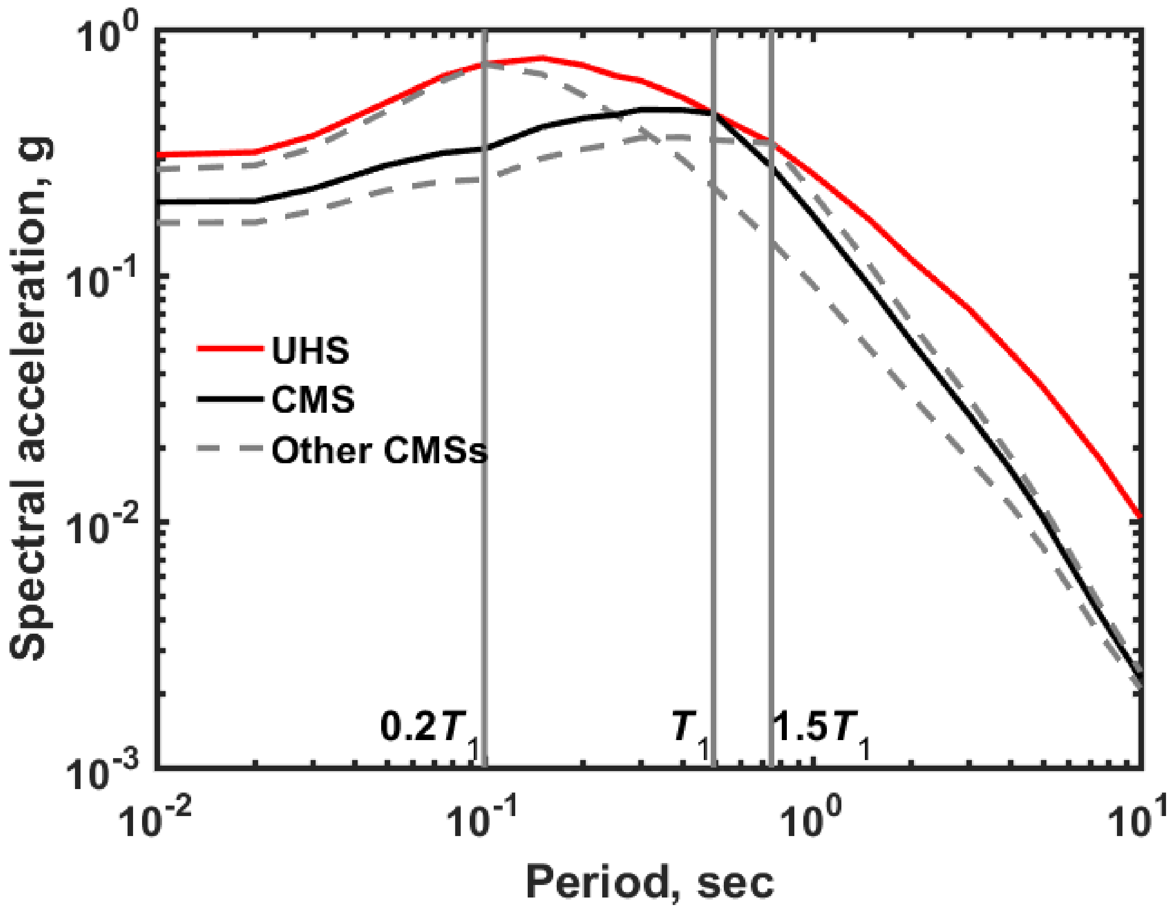
- Alternative target to UHS (Baker & Cornell 2006, Baker 2011)
- More representative of recorded GMs

$$A_{CMS}(T, T^*) \\ = A_m(T) \cdot \exp\left[\varepsilon_H(T^*)\rho_{H,H}(T^*, T)\sigma(T)\right]$$

Conditional Mean Spectrum (CMS)



Multiple CMSs to avoid underestimation

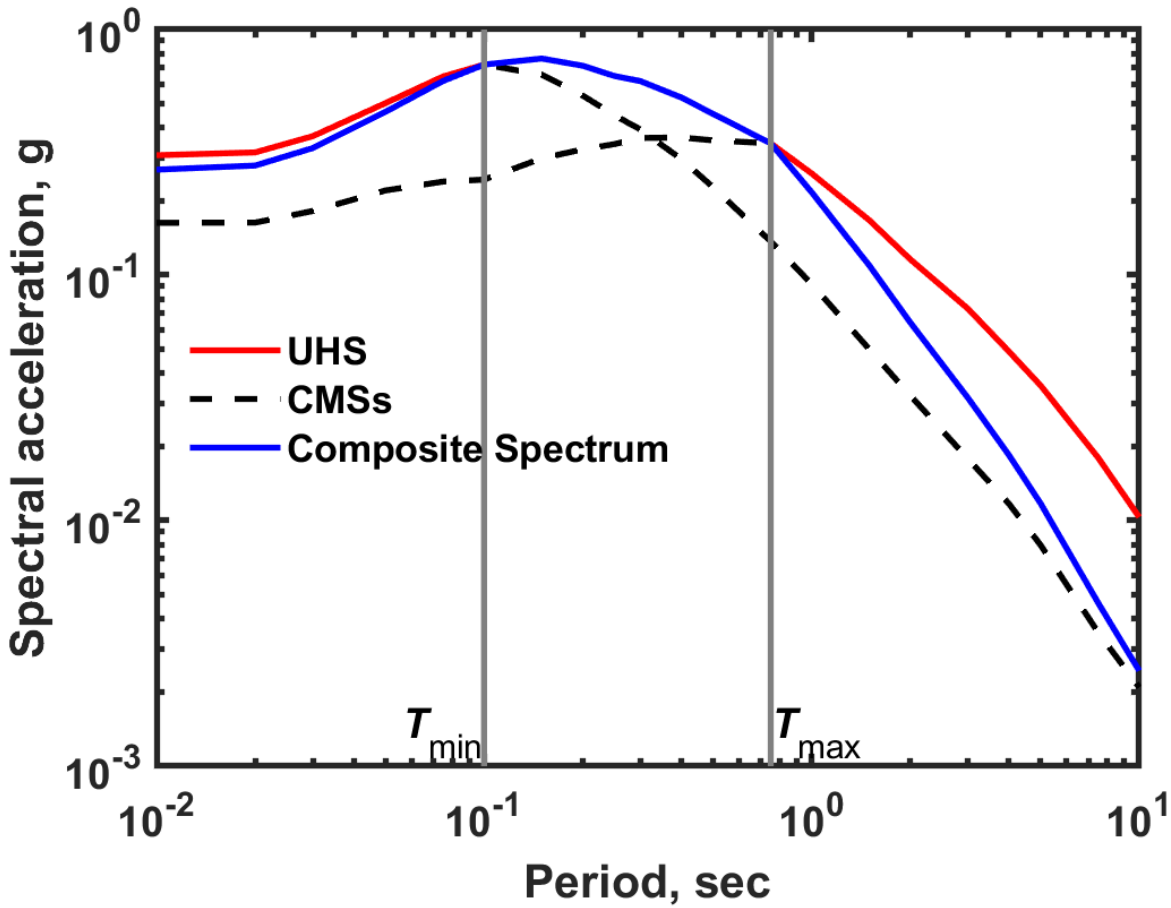


CMS-UHS Composite Spectrum

- Replaces multiple CMSs with single target
- Significantly reduces computational effort
- Combines features from CMS and UHS:

$$A_{Composite}(T) = \begin{cases} A_{CMS}(T, T_{min}) & T \leq T_{min} \\ A_{UHS}(T\ ) & T_{min} < T \leq T_{max} \\ A_{CMS}(T, T_{max}\ ) & T \geq T_{max} \end{cases}$$

CMS-UHS Composite Spectrum



GMSM FOR THREE COMPONENTS OF GM

Nonlinear response history analysis (RHA) of dams requires:

1. Three orthogonal components of GM
2. Consideration of multiple modes of vibration

Composite Spectrum

1. Same target spectrum for each individual horizontal (H) component of GM, defined by RotD50
2. Considers modes via T_{min} and T_{max}

Including the vertical (V) component

1. Scale corresponding V component by same scale factor, or
2. Determine target spectrum for V component of GM

Target spectrum for V component

Extra inputs

1. Ground motion prediction models (GMPMs) for V component of GM
2. Correlation model for H and V components of GM

Outputs

1. Hazard curves
2. UHS
3. CMSs
4. Composite Spectrum

GMPMs for H component

NGA-West2 Ground Motion Model for the Average Horizontal Components of PGA, PGV, and 5%-Damped Linear Acceleration Response Spectra

Kenneth W. Campbell,[a] M.EERI, and **Yousef Bozorgnia,**[b] M.EERI

We used an expanded PEER NGA-West2 database to develop a new ground motion prediction equation (GMPE) for the average (RotD50) horizontal components of PGA, PGV, and 5%-damped linear pseudo-absolute acceleration response spectra at 21 periods ranging from 0.01 to 10 s. In addition to those terms included in our now superseded 2008 GMPE, we include a more-detailed hanging-wall model, scaling with hypocentral depth and fault dip, regionally independent geometric attenuation, regionally dependent anelastic attenuation and site conditions, and magnitude-dependent aleatory variability. The NGA-West2 database provides better constraints on magnitude scaling and attenuation of small-magnitude earthquakes, where our 2008 GMPE was known to be biased. We consider our new GMPE to be valid for estimating RotD50 from shallow crustal continental earthquakes in an active tectonic domain for rupture distances ranging from 0 to 300 km and magnitudes ranging from 3.3 to 7.5–8.5, depending on source mechanism.

NGA-West2 Equations for Predicting PGA, PGV, and 5% Damped PSA for Shallow Crustal Earthquakes

David M. Boore,[a] **Jonathan P. Stewart,**[b] M.EERI, **Emel Seyhan,**[c] M.EERI, **and Gail M. Atkinson,**[d] M.EERI

We provide ground motion prediction equations for computing medians and standard deviations of average horizontal component intensity measures (IMs) for shallow crustal earthquakes in active tectonic regions. The equations were derived from a global database with **M** 3.0–7.9 events. We derived equations for the primary **M**- and distance-dependence of the IMs after fixing the V_{S30}-based nonlinear site term from a parallel NGA-West2 study. We then evaluated additional effects using mixed effects residuals analysis, which revealed no trends with source depth over the **M** range of interest, indistinct Class 1 and 2 event IMs, and basin depth effects that increase and decrease long-period IMs for depths larger and smaller, respectively, than means from regional V_{S30}-depth relations. Our aleatory variability model captures decreasing between-event variability with **M**, as well as within-event variability that increases or decreases with **M** depending on period, increases with distance, and decreases for soft sites.
[DOI: 10.1193/070113EQS184M]

GMPMs for V component

Vertical Ground Motion Model for PGA, PGV, and Linear Response Spectra Using the NGA-West2 Database

Yousef Bozorgnia,[a] M.EERI, **and Kenneth W. Campbell,**[b] M.EERI

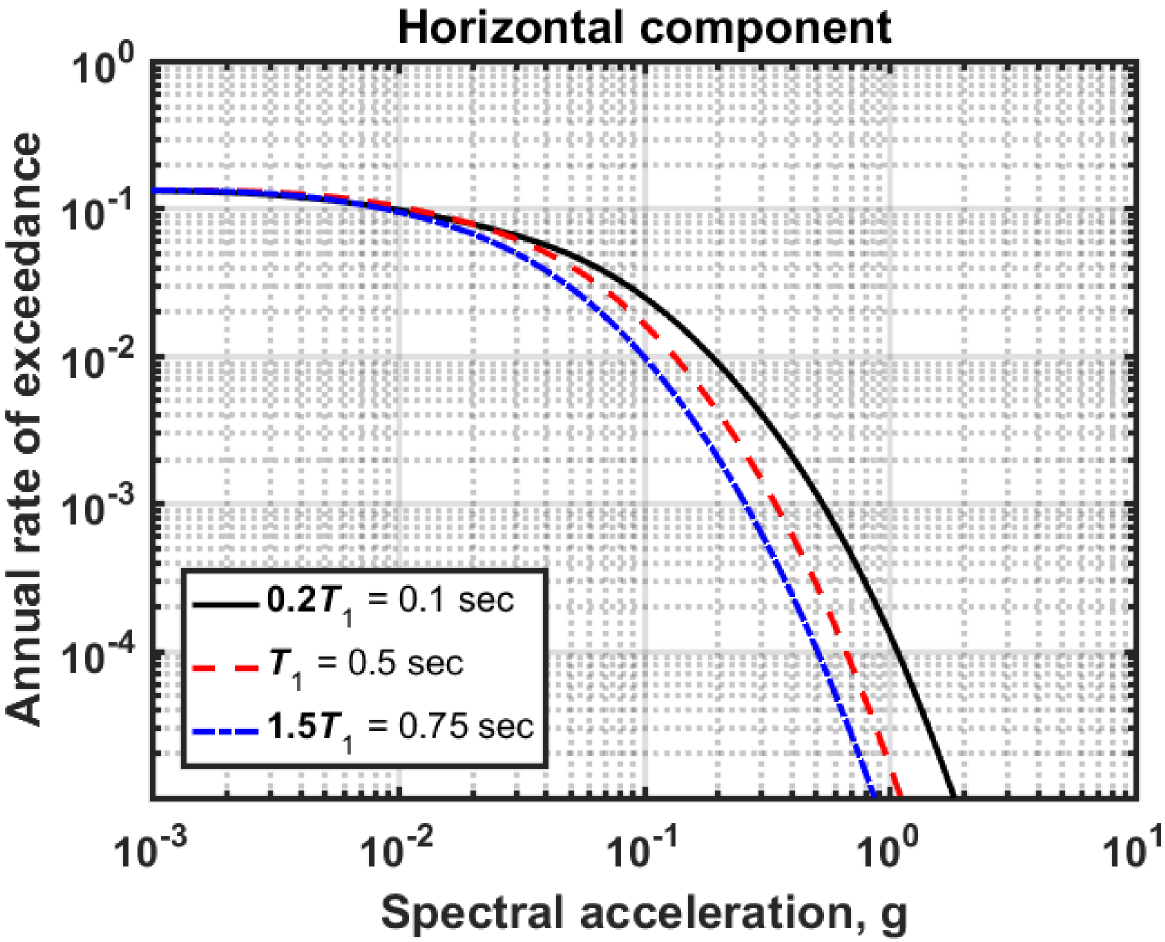
We summarize the development of the NGA-West2 Bozorgnia-Campbell empirical ground motion model (GMM) for the vertical components of peak ground acceleration (PGA), peak ground velocity (PGV), and 5%-damped elastic pseudo-absolute acceleration response spectra (PSA) at vertical periods ranging from 0.01 s to 10 s. In the development of the vertical GMM, similar to our 2014 horizontal GMM, we used the extensive PEER NGA-West2 worldwide database. We consider our new vertical GMM to be valid for shallow crustal earthquakes in active tectonic regions for magnitudes ranging from 3.3 to 7.5–8.5, depending on the style of faulting, and for distances as far as 300 km from the fault. [DOI: 10.1193/072814EQS121M]

Ground Motion Prediction Equations for the Vertical Ground Motion Component Based on the NGA-W2 Database

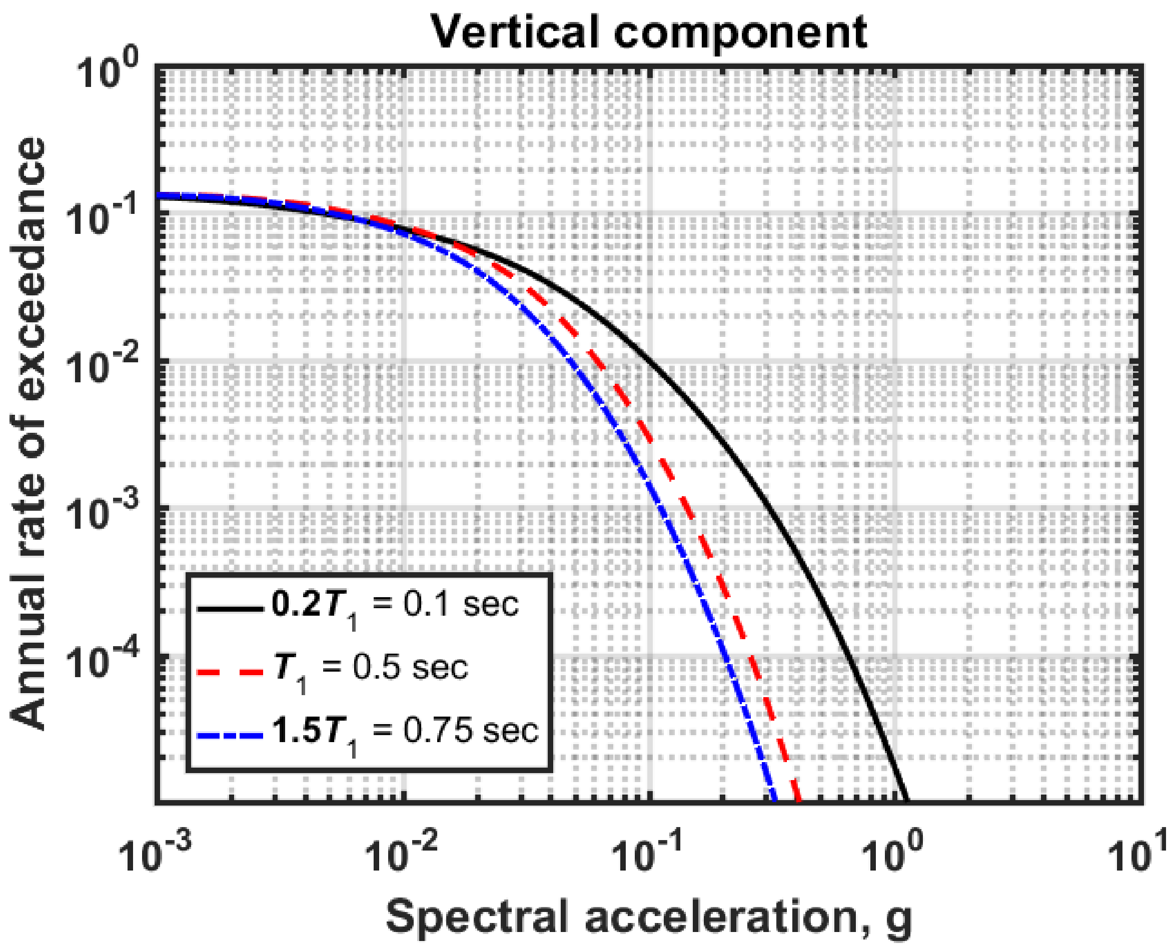
Zeynep Gülerce,[a] M.EERI, **Ronnie Kamai,**[b]
Norman A. Abrahamson,[c] M.EERI, **and Walter J. Silva,**[d] M.EERI

Empirical ground motion models for the vertical component from shallow crustal earthquakes in active tectonic regions are derived using the PEER NGA-West2 database. The model is applicable to magnitudes 3.0–8.0, distances of 0–300 km, and spectral periods of 0–10 s. The model input parameters are the same as used by Abrahamson et al. (2014) except that the nonlinear site response and depth to bedrock effects are evaluated but found to be insignificant. Regional differences in large distance attenuation and site amplification scaling between California, Japan, China, Taiwan, Italy, and the Middle East are included. Scaling for the hanging-wall effect is incorporated using the constraints from numerical simulations by Donahue and Abrahamson (2014). The standard deviation is magnitude dependent with smaller magnitudes leading to larger standard deviations at short periods but smaller standard deviations at long periods. The vertical ground motion model developed in this study can be paired with the horizontal component model proposed by Abrahamson et al. (2014) to produce a V/H ratio. For applications where the horizontal spectrum is derived from the weighted average of several horizontal ground motion models, a V/H model derived directly from the V/H data (such as Gülerce and Abrahamson 2011) should be preferred. [DOI: 10.1193/121814EQS213M]

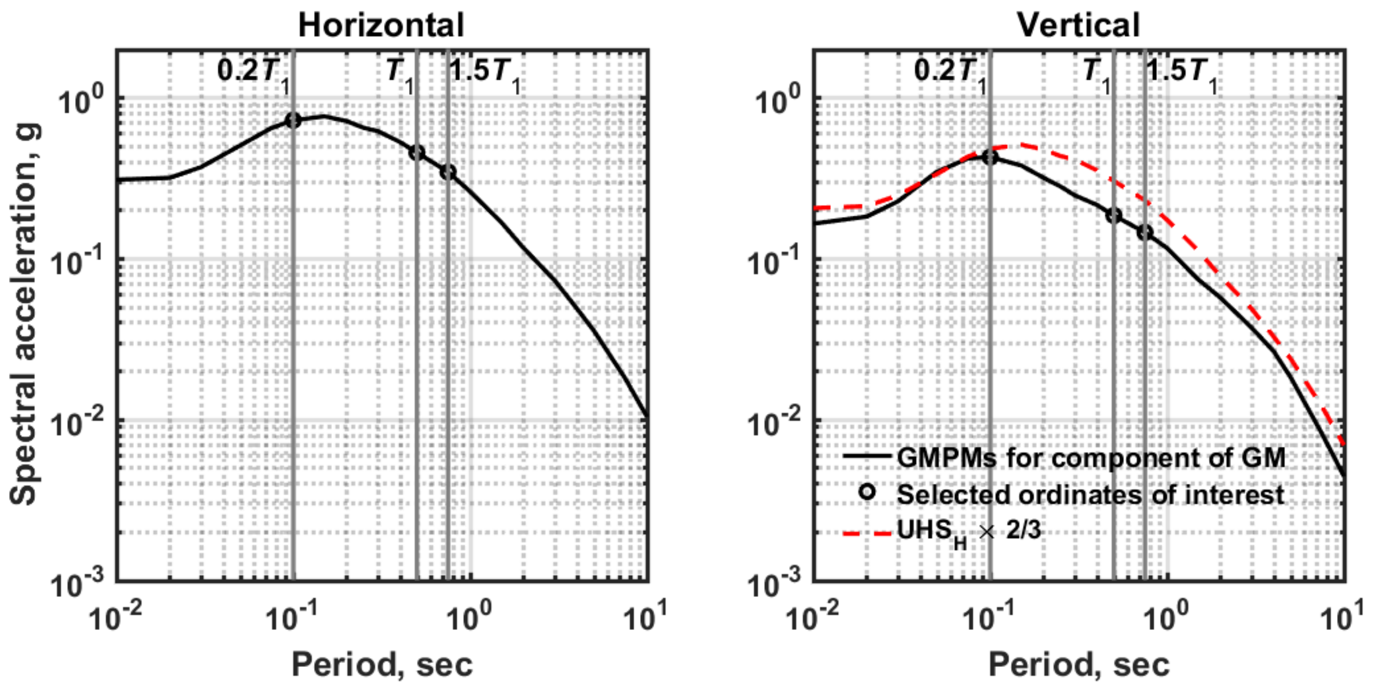
Hazard curves



Hazard curves



Uniform hazard spectra



Target spectrum for V component

Extra inputs

1. Ground motion prediction models (GMPMs) for V component of GM
2. Correlation model for H and V components of GM

Outputs

1. Hazard curves
2. UHS
3. CMSs
4. Composite Spectrum

Correlation between H and V

Bulletin of the Seismological Society of America, Vol. 96, No. 1, pp. 215–227, February 2006, doi: 10.1785/0120050060

Correlation of Response Spectral Values for Multicomponent Ground Motions

by Jack W. Baker and C. Allin Cornell

Abstract Ground-motion prediction (attenuation) models predict the probability distributions of spectral acceleration values for a specified earthquake event. These models provide only marginal distributions, however; they do not specify correlations among spectral accelerations with differing periods or orientations. In this article a large number of strong ground motions are used to empirically estimate these correlations, and nonlinear regression is used to develop approximate analytical equations for their evaluation. Because the correlations apply to residuals from a ground-motion prediction, they are in principle dependent on the ground-motion prediction model used. The observed correlations do not vary significantly when the underlying model is changed, however, suggesting that the predictions are applicable regardless of the model chosen by the analyst. The analytical correlation predictions improve upon previous predictions of correlations at differing periods in a randomly oriented horizontal ground-motion component. For correlations within a vertical ground motion or across orthogonal components of a ground motion, these results are believed to be the first of their kind.

The resulting correlation coefficient predictions are useful for a range of problems related to seismic hazard and the response of structures. Past uses of previous correlation predictions are described, and future applications of the new predictions are proposed. These applications will allow analysts to better understand the properties of single- and multicomponent earthquake ground motions.

Correlation between H and V

- Need correlation models for wide range of vibration periods
- Overcome using GM models for vertical-to-horizontal (V/H) ratios

GM models for V/H ratios

Site-Specific Design Spectra for Vertical Ground Motion

Zeynep Gülerce,[a] M.EERI, and Norman A. Abrahamson,[b] M.EERI

This paper contains ground-motion prediction equations (GMPEs) for the vertical-to-horizontal spectral acceleration (V/H) ratio, and the methods for constructing vertical design spectra that are consistent with the probabilistic seismic hazard assessment results for the horizontal ground motion component. The GMPEs for V/H ratio consistent with the horizontal GMPE of Abrahamson and Silva (2008) are derived using the Pacific Earthquake Engineering Research Center's Next Generation of Ground-Motion Attenuation Models (PEER-NGA) database (Chiou et al. 2008). The proposed V/H ratio GMPE is dependent on the earthquake magnitude and distance, consistent with previous models, but it differs from previous studies in that it accounts for the differences in the nonlinear site-response effects on the horizontal and vertical components. This difference in nonlinear effects results in large V/H ratios at short spectral periods for soil sites located close to large earthquakes. A method to develop vertical design spectra dependent on the horizontal component uniform hazard spectrum that accounts for the correlation between the variability of the horizontal ground-motion model and the variability of the V/H ratio ground-motion model is proposed. [DOI: 10.1193/1.3651317]

Ground Motion Model for the Vertical-to-Horizontal (V/H) Ratios of PGA, PGV, and Response Spectra

Yousef Bozorgnia,[a] M.EERI, and Kenneth W. Campbell,[b] M.EERI

We present a ground motion model (GMM) for the vertical-to-horizontal (V/H) ratios of peak ground acceleration, peak ground velocity, and 5%-damped pseudo-acceleration response spectra at periods ranging from 0.01 s to 10 s. The V/H GMM includes formulations for the median V/H ratio and for the aleatory within-event, between-event, and total standard deviations. The V/H model is based on the GMMs we have developed for the vertical and "average" horizontal components of ground motion using a mathematical formation that accounts for the correlation between these two components. We validated the V/H model against the NGA-West2 empirical database. We consider our V/H model to be valid for worldwide shallow crustal earthquakes in active tectonic regions for moment magnitudes ranging from 3.3 to 8.5, depending on the style of faulting, and for fault rupture distances ranging from 0 km to 300 km. Our V/H model incorporates period-dependent effects of magnitude saturation, style of faulting, hypocentral depth, fault-rupture dip, geometric attenuation, regionally dependent anelastic attenuation and site response, hanging-wall geometry, and magnitude-dependent between-event and within-event aleatory variabilities. The V/H ratios predicted from the model show a strong dependence on spectral period and site response. [DOI: 10.1193/100614EQS151M]

Correlation between H and V

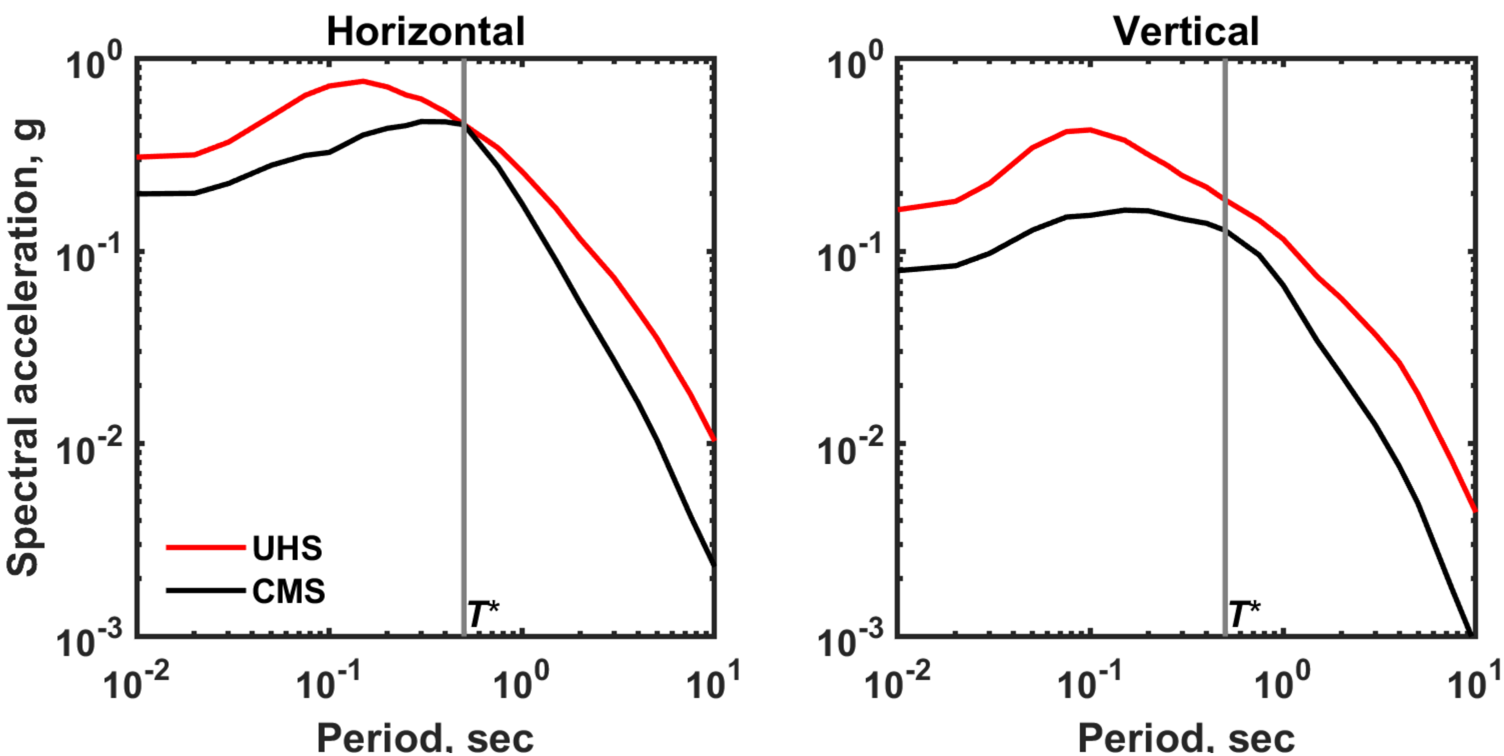
$$\rho_{H,V}(T_a,T_b) = \frac{\sigma_H(T_b)\rho_{H,H}(T_a,T_b) + \sigma_{V/H}(T_b)\rho_{H,V/H}(T_a,T_b)}{\sqrt{\sigma_H^2(T_b) + \sigma_{V/H}^2(T_b) + 2\rho_{H,V/H}(T_b,T_b)\sigma_H(T_b)\sigma_{V/H}(T_b)}}$$

Multicomponent CMS

For kth component of GM (k=H or V):

$$A_{k,CMS}(T,T^*) = A_{k,m}(T) \cdot \exp\left[\varepsilon_H(T^*)\rho_{H,k}(T^*,T)\sigma_k(T)\right]$$

Multicomponent CMS



Multicomponent Composite Spectrum

For kth component of GM (k=H or V):

$$A_{k,Composite}(T) = \begin{cases} A_{k,CMS}(T, T_{min}) & T \le T_{min} \\ \bar{A}_{k,UHS}(T) & T_{min} < T \le T_{max} \\ A_{k,CMS}(T, T_{max}) & T \ge T_{max} \end{cases}$$

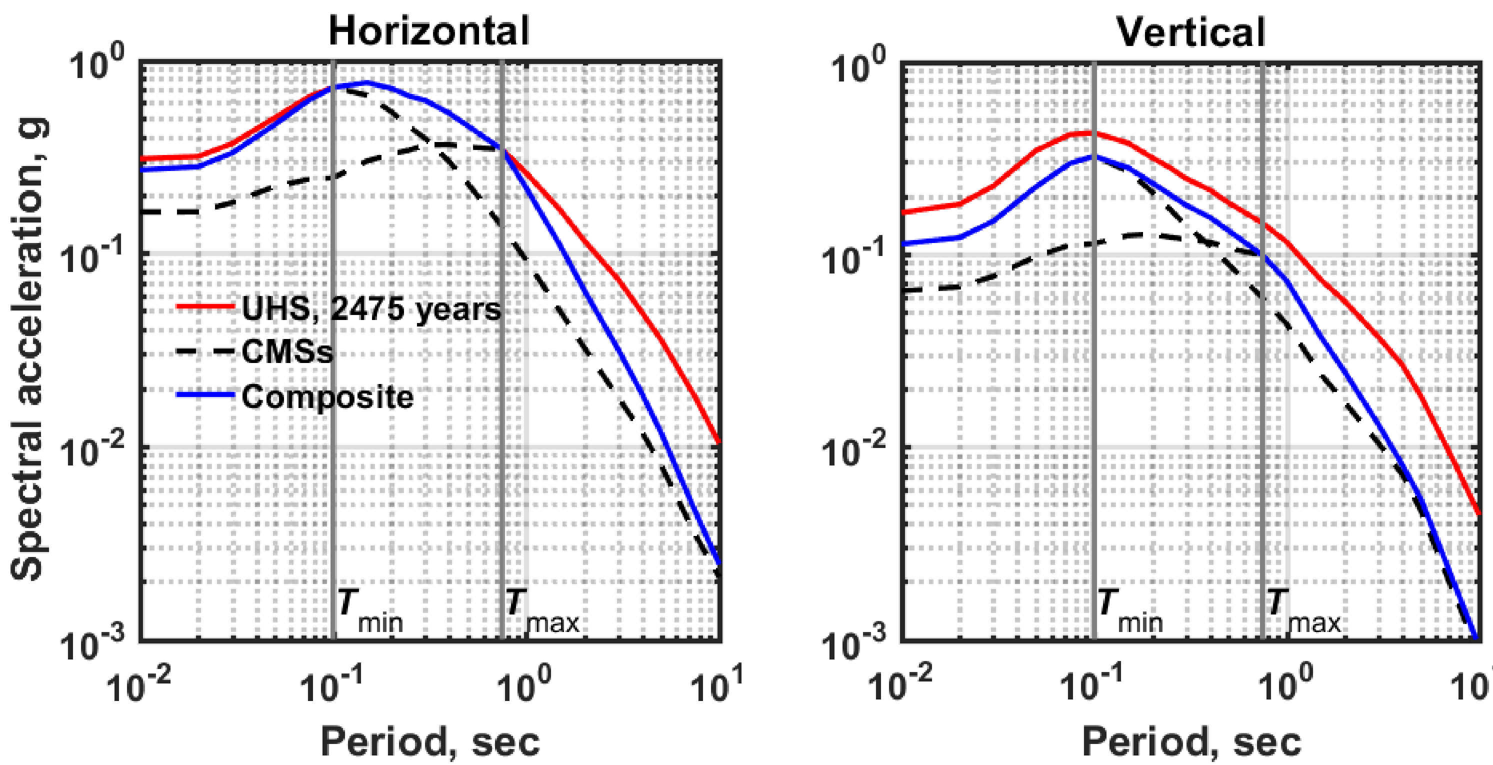
Multicomponent Composite Spectrum

$$\bar{A}_{H,UHS}(T\ ) = A_{H,UHS}(T)$$

$$\bar{A}_{V,UHS}(T\ ) = A_{V,m}(T,\theta_e) \cdot \exp\left[\varepsilon_H(T)\rho_{H,V}(T,T,\theta_e)\sigma_V(T,\theta_e)\right]$$
$$\approx A_{V,m}(T) \cdot \exp\left[\varepsilon_H\left(\overline{T}\right)\rho_{H,V}(T,T)\sigma_V(T)\right]$$

$$\overline{T} = \sqrt{T_{min} \cdot T_{max}}$$

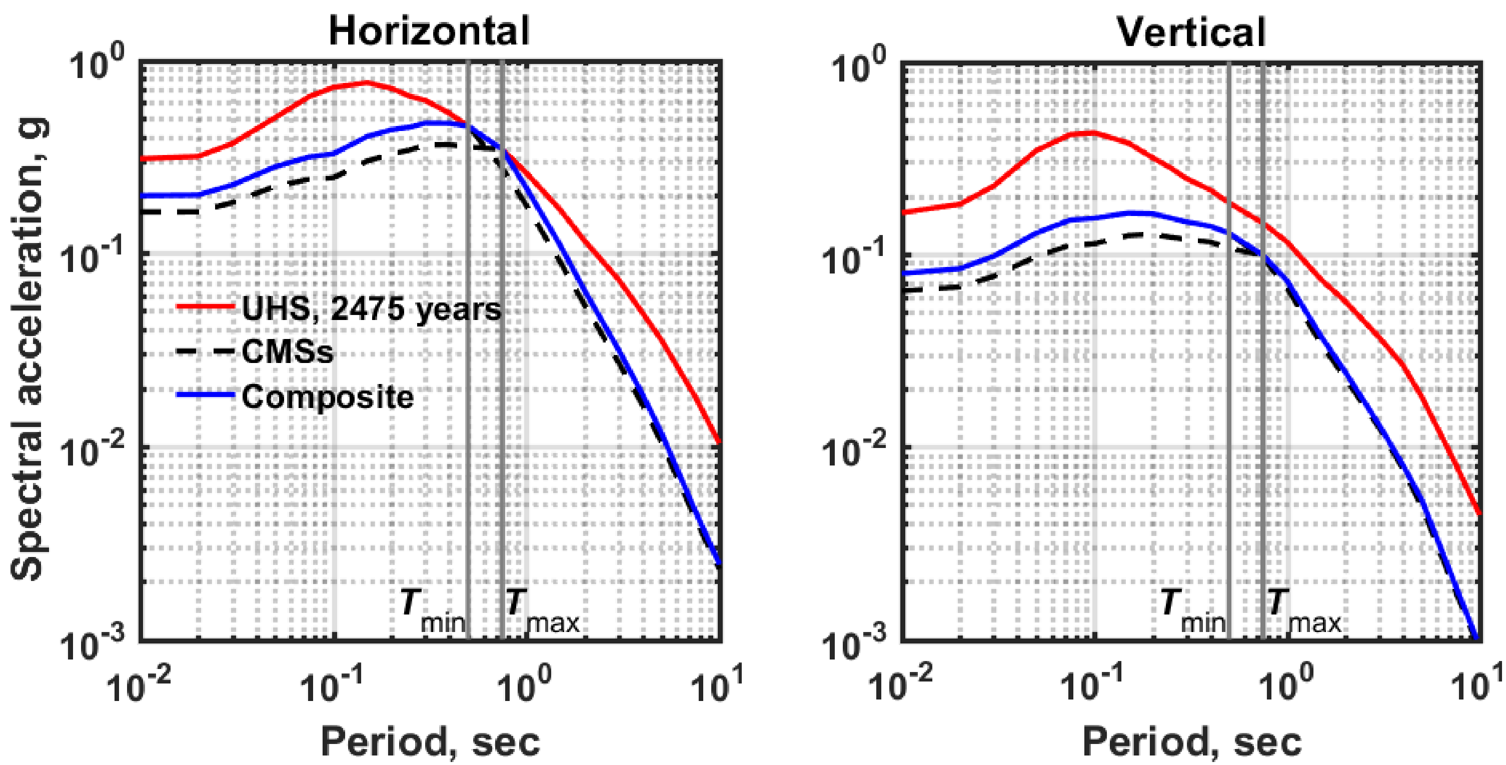
Multicomponent Composite Spectrum



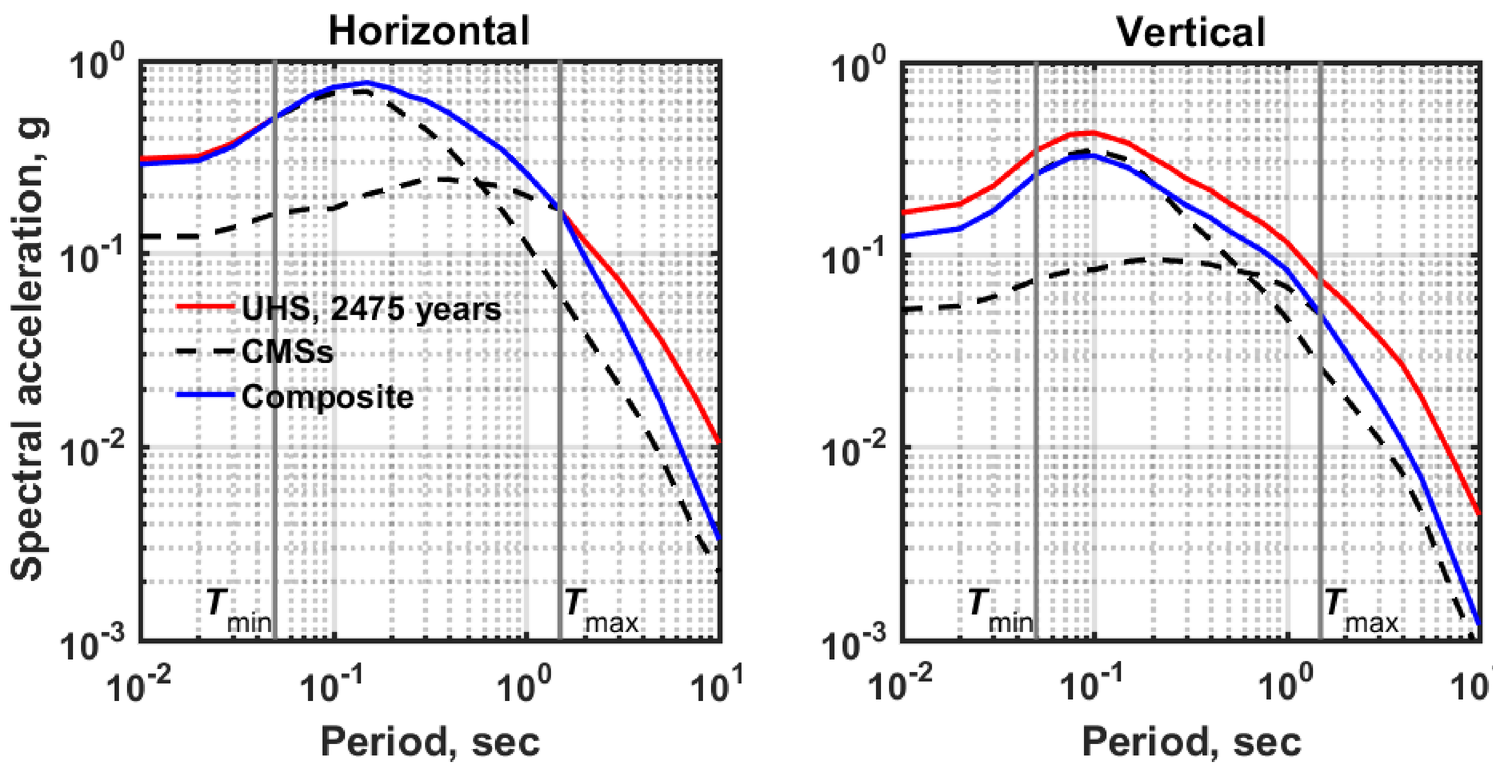
Vibration periods T_{min} and T_{max}

1. When close, approximately CMS
2. When far apart, approximately UHS

$T_{min} = T_1$ and $T_{max} = 1.5T_1$



$T_{min} = 0.1T_1$ and $T_{max} = 3T_1$



SELECTING GMS TO MATCH MULTICOMPONENT TARGET SPECTRUM

Summary of steps

1. Specify GMSM inputs
2. Scale and select GMs to match target
3. Confirm hazard consistency
4. Repeat GM selection with revised database if needed

Extra GMSM inputs

1. Same or different SFs for V components
2. Relative importance of H component

Relative importance of H component, $0 \leq w_H \leq 1$

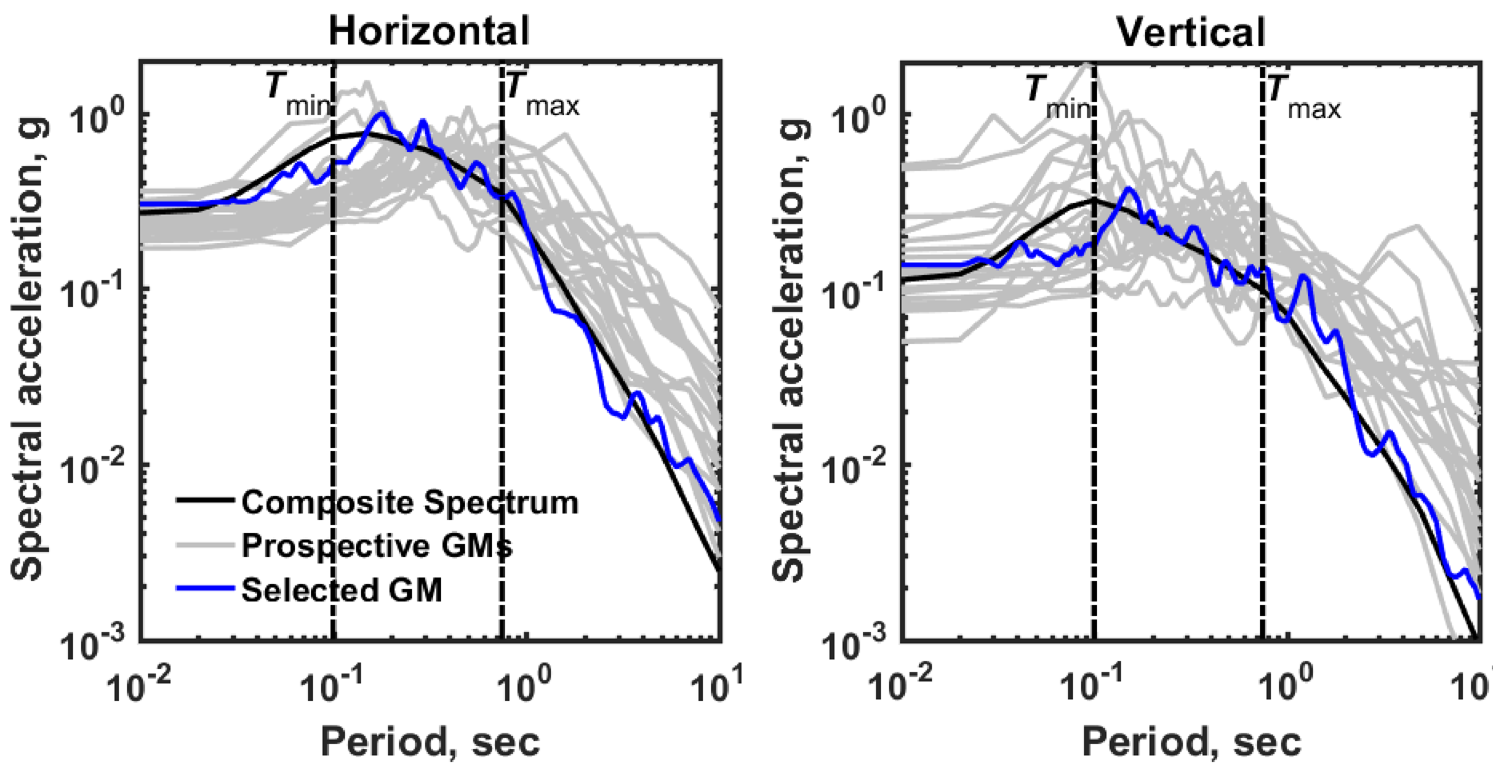
- For kth component of GM (k=H or V):

$$SSD_k = \sum_{j=1}^{N_p} \left(\ln\left[SF_k \cdot A_{k,0}(T_j)\right] - \ln\left[A_{k,TS}(T_j)\right] \right)^2$$

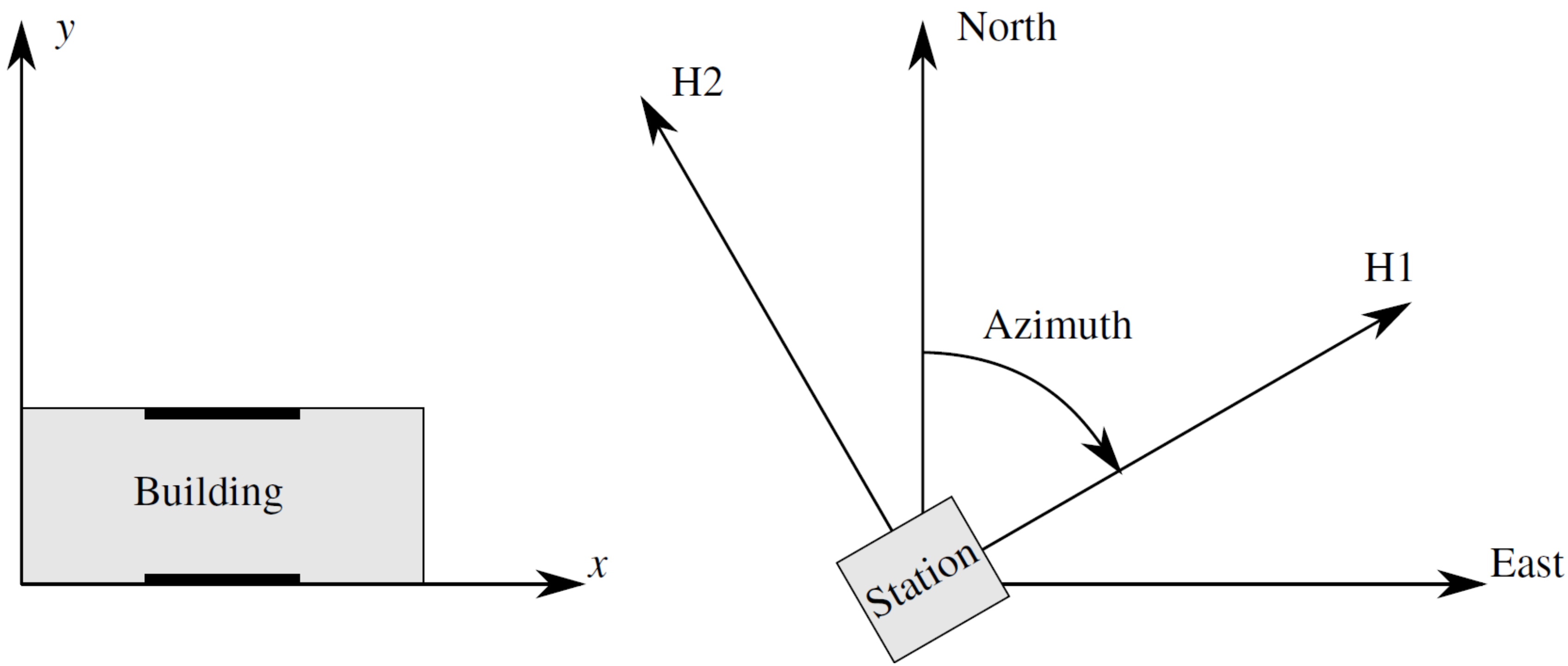
- For both H and V components of GM:

$$SSD_{combined} = w_H SSD_H + (1 - w_H) SSD_V$$

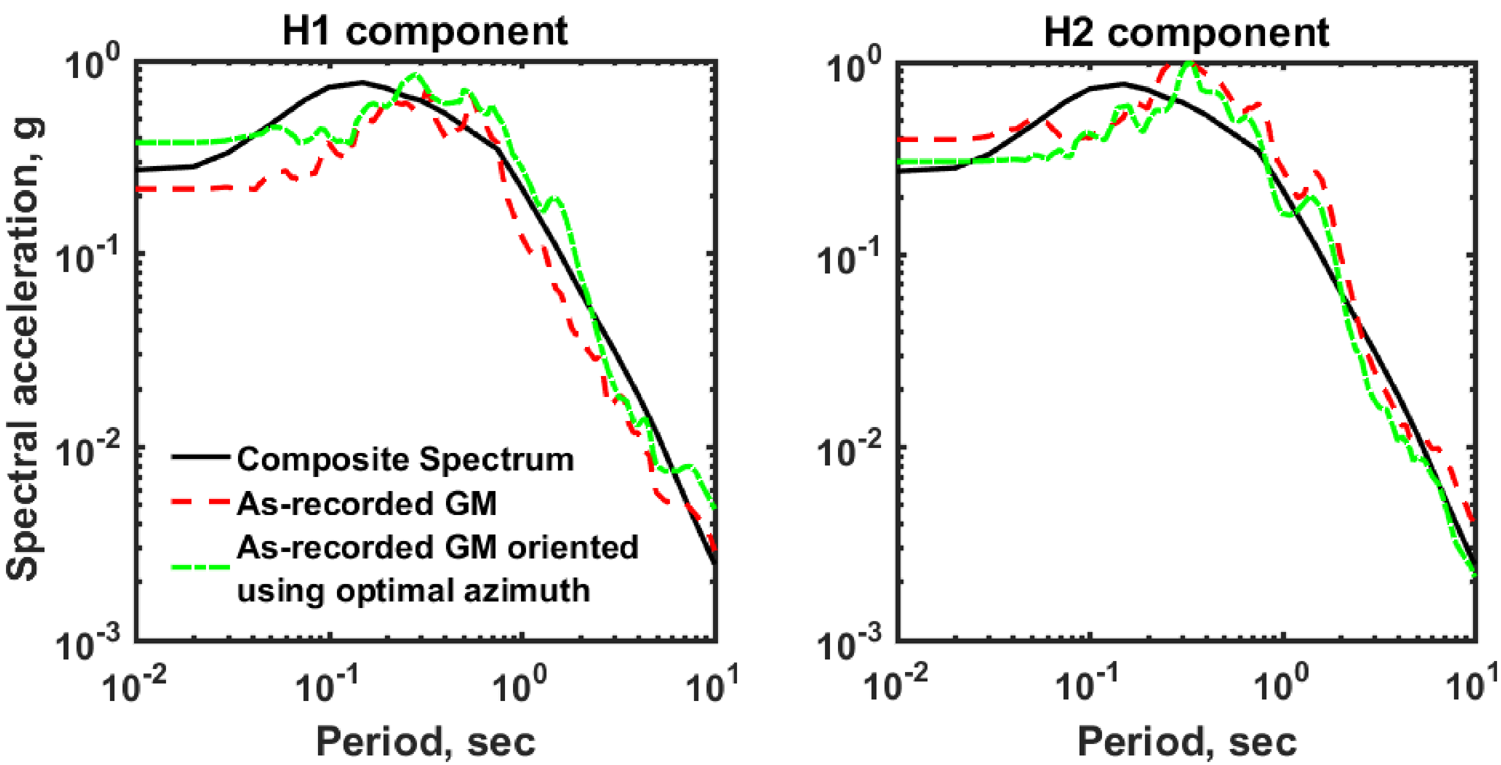
Selecting GMs with $SSD_{combined}$



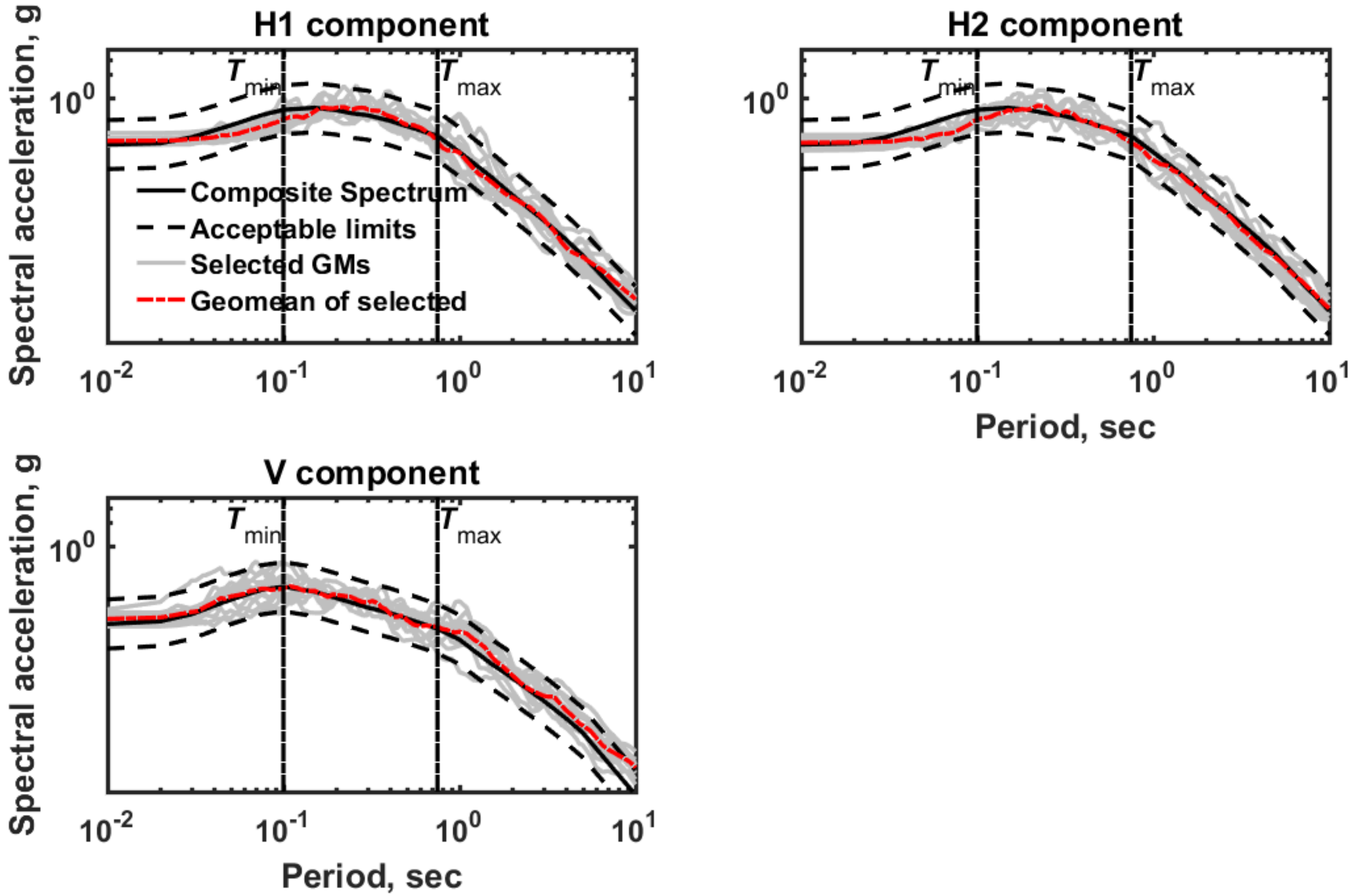
Orienting bidirectional GMs



Determining optimal azimuth



Confirming hazard consistency



Final selection of multicomponent GMs

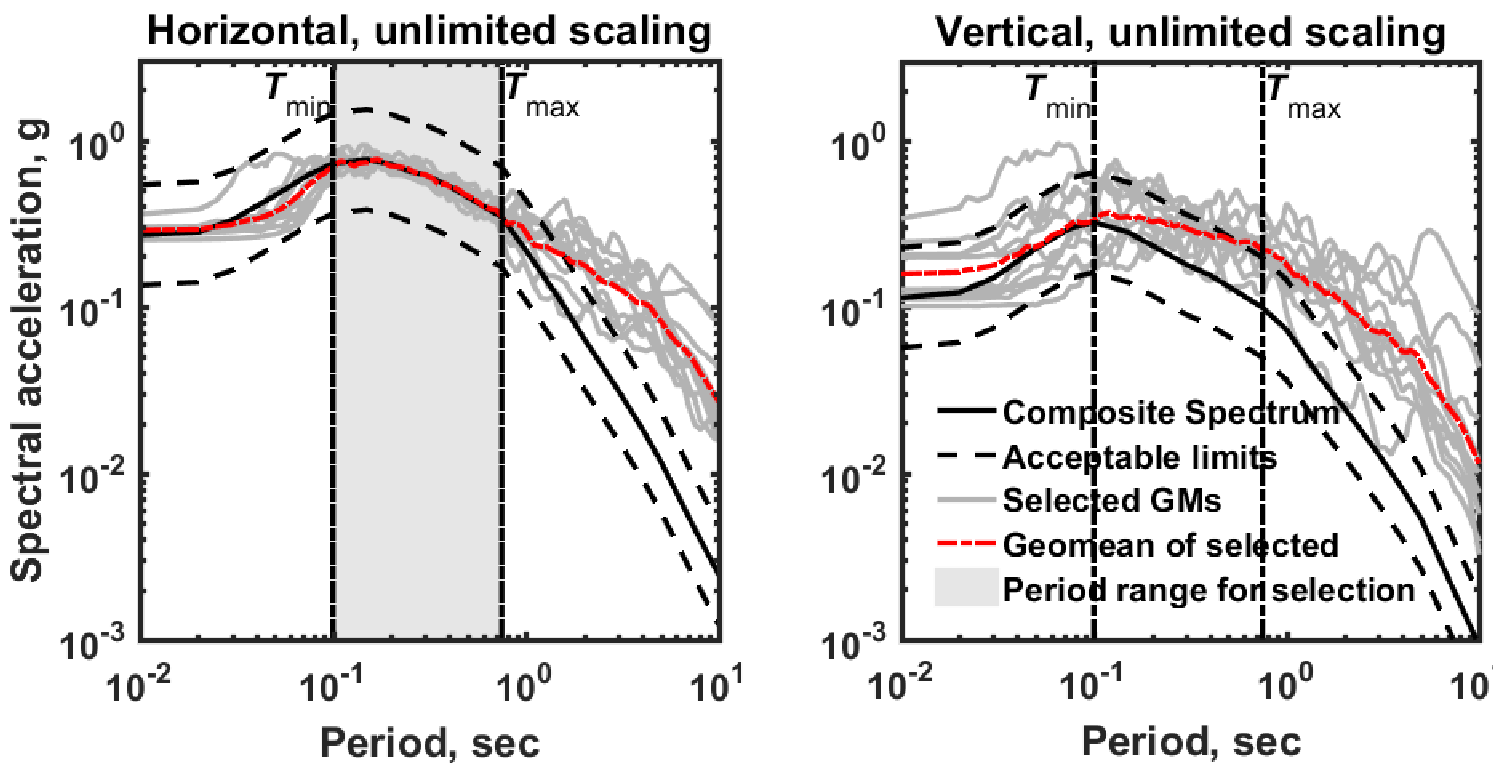
NGA RSN	SF_H	SF_V	Angle for CCW rotation of H components (°)
2623	2.05	2.05	18
2981	3.54	3.54	16
3000	3.48	3.48	60
3002	3.68	3.68	77
3188	2.58	2.58	23
4153	2.18	2.18	15
4212	0.93	0.93	7
5292	3.68	3.68	28
5652	1.07	1.07	2
5672	1.25	1.25	49
5811	1.97	1.97	90

DISCUSSION OF GMSM INPUTS

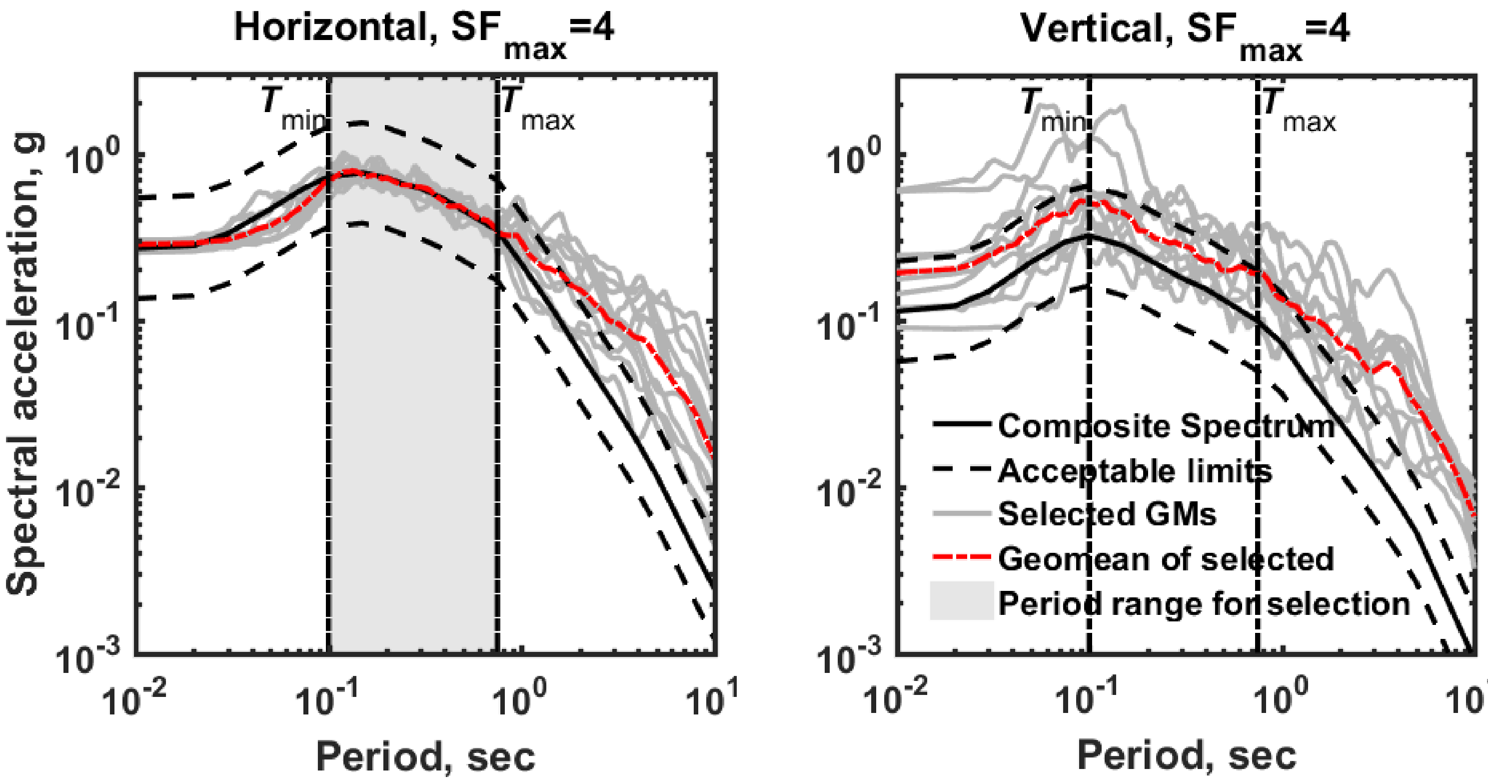
Most important GMSM inputs

1. Period range for selecting GMs
2. Limits on SFs
3. Relative importance of H component w_H

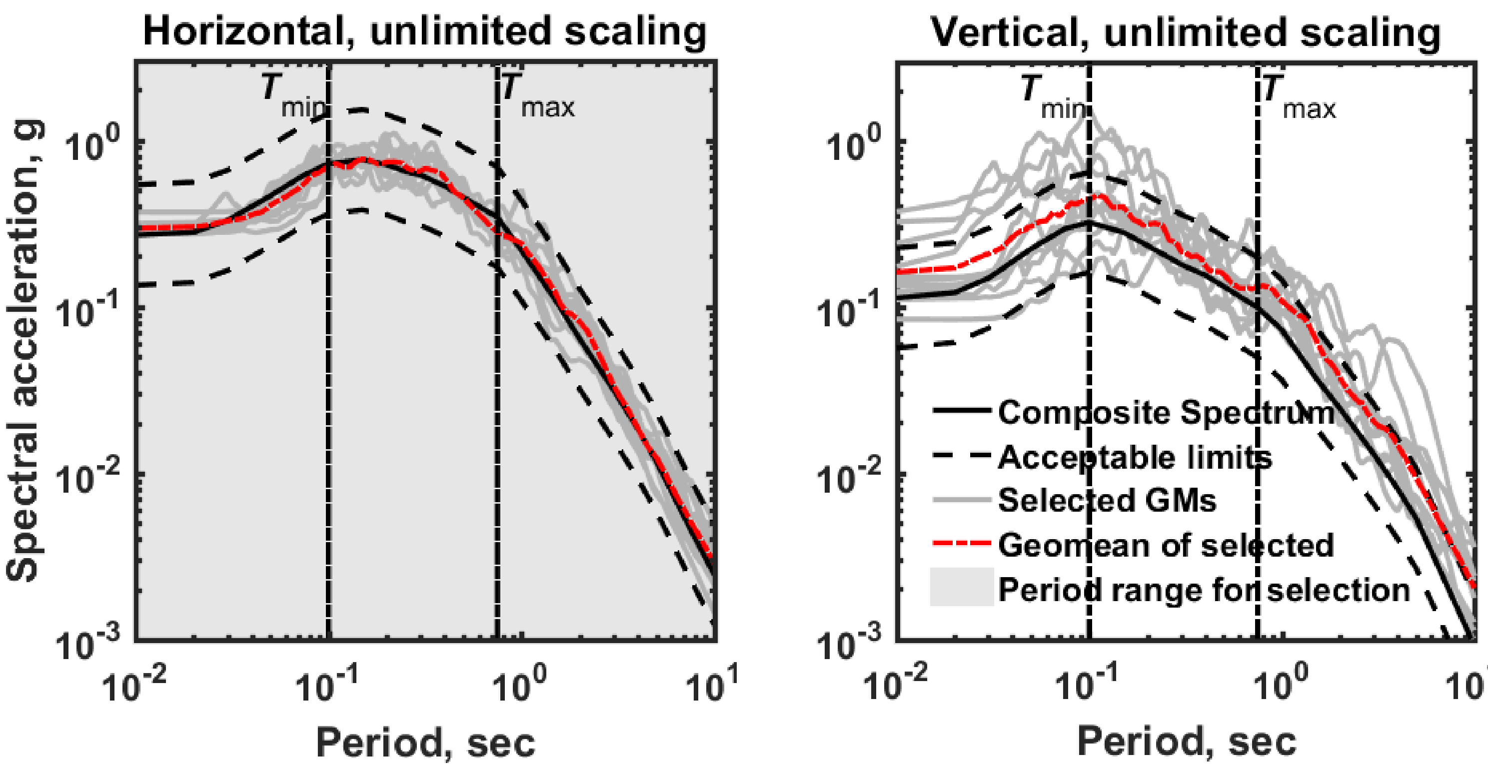
Limits on scale factors



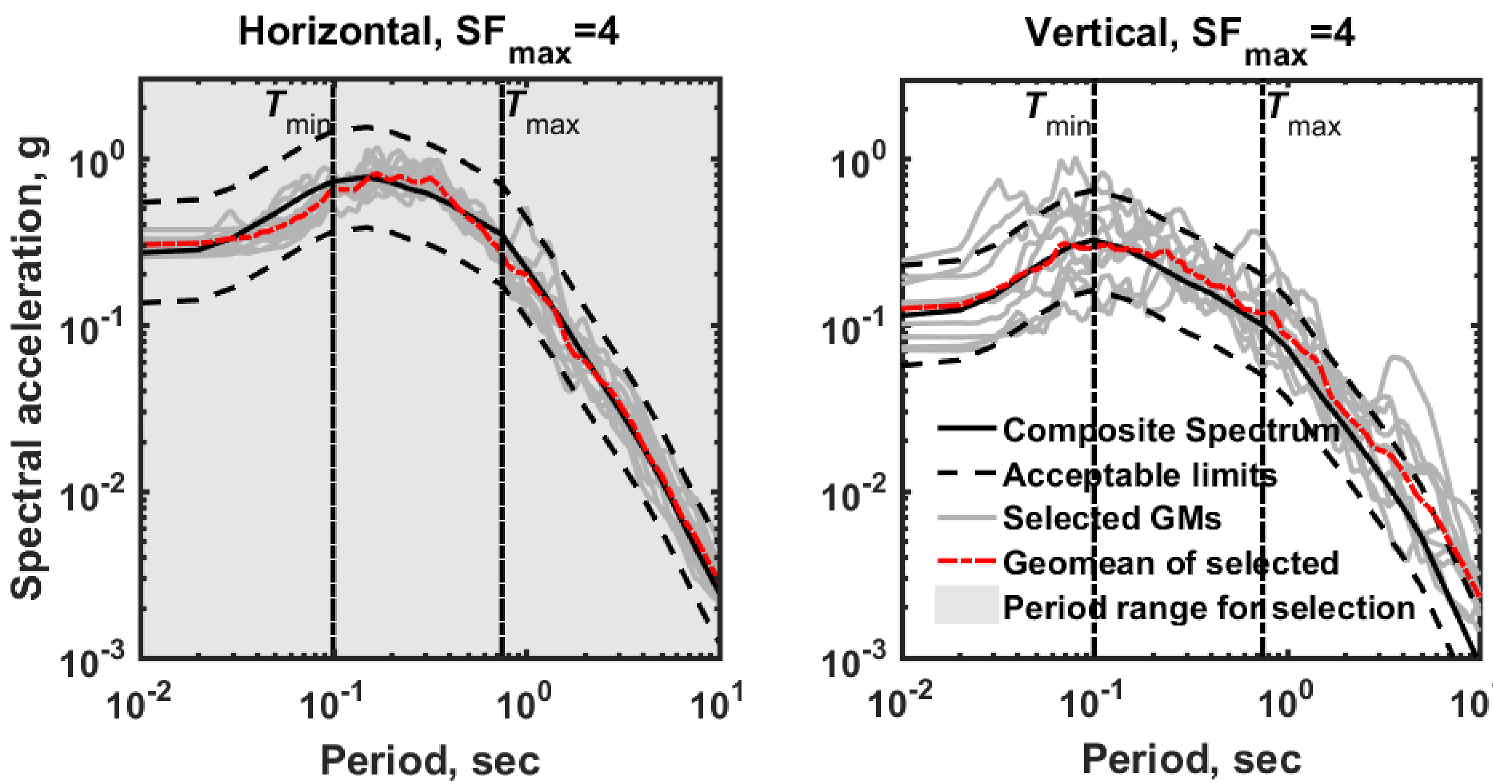
Limits on scale factors



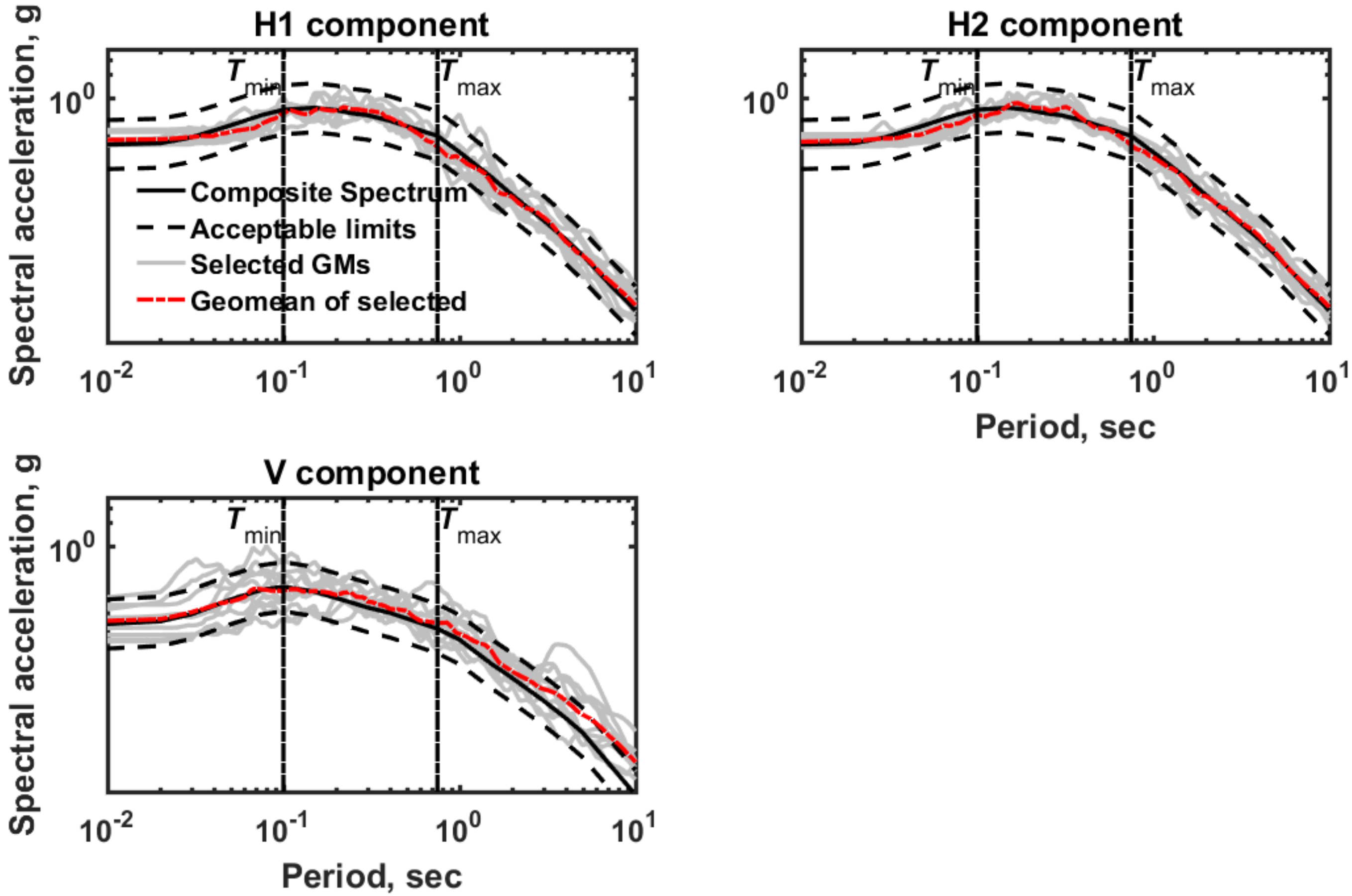
Period range for selecting GMs



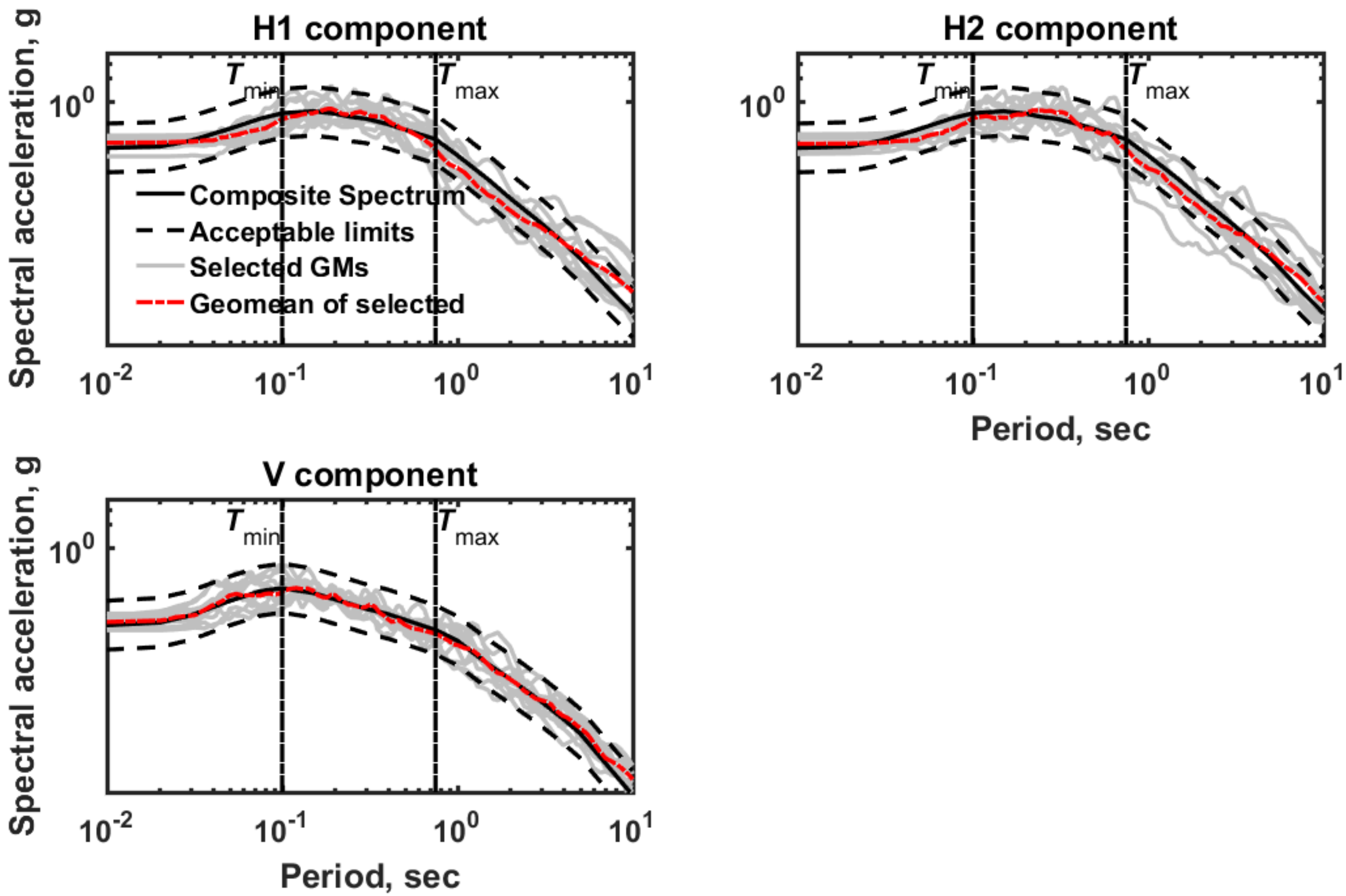
Period range for selecting GMs



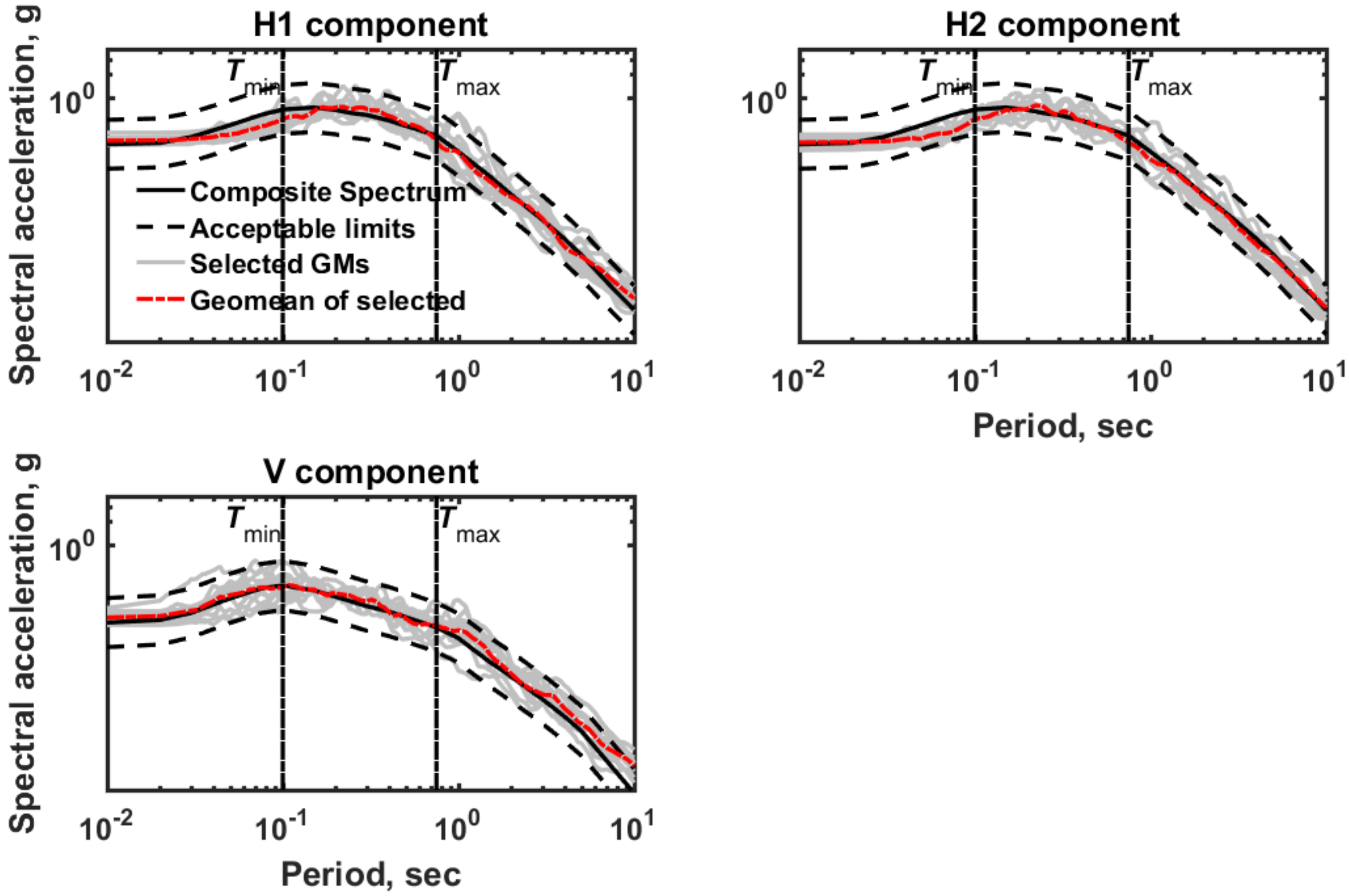
Relative importance of H component: $w_H = 1$



Relative importance of H component: $w_H = 0$



Relative importance of H component: $w_H = 0.5$



Suggestions for GMSM inputs

1. Select GMs using a period range of 0.01 to 10 sec
2. Limit SFs within 0.25 to 4
3. Specify w_H as 0.5

Less important GMSM inputs

1. Limits on metadata
2. Same or different SFs for orthogonal components of GM
3. Metric for comparing response spectra

CONCLUSIONS

Summary

1. To select multicomponent GMs, the V component must be included when:
   a) Conducting PSHA
   b) Determining the target spectrum
   c) Implementing a selection algorithm

Summary

2. Using the CMS-UHS Composite Spectrum reduces the number of multicomponent GMs to be selected, relative to multiple CMSs

Summary

3. Hazard-consistent GMs can be obtained so long as:
   a) A wide period range is used for selecting GMs
   b) SFs are limited; both same and different SFs for V components are reasonable
   c) Both H and V components are included in the selection process with $w_H = 0.5$

Further reading

- Baker, J. W. and Cornell, C. A., 2006. Spectral shape, epsilon, and record selection. *Earthquake Engineering and Structural Dynamics* **35**, 1077-1095.
- Baker, J. W., 2011. Conditional Mean Spectrum: Tool for ground-motion selection. *ASCE Journal of Structural Engineering* **137**, 331.

Further reading

- Kwong, N. S. and Chopra, A. K., 2017. A Generalized Conditional Mean Spectrum and its application for intensity-based assessments of seismic demands. *Earthquake Spectra* **33**(1), 123-143.
- Kwong, N. S. and Chopra, A. K., 2018. Determining bi-directional ground motions for nonlinear response history analysis of buildings at far-field sites. *Earthquake Spectra* **34**(4), 1931-1954.

Further reading

- Kwong, N. S. and Chopra, A. K., 2019. Selecting, scaling, and orienting three components of ground motions for intensity-based assessments at far-field sites. *Earthquake Spectra* (in review).

SUPPLEMENTARY MATERIAL

FORMULATION USING V/H MODELS

CMS for V component of GM

$$A_{V,CMS}\big(T,\varepsilon_H(T^*)\big)$$
$$= A_{H,CMS}\big(T,\varepsilon_H(T^*)\big)\cdot\left[\frac{V}{H}(T)\right]_m$$
$$\cdot\exp\left[\varepsilon_H(T^*)\rho_{H,V/H}(T^*,T)\sigma_{V/H}(T)\right]$$

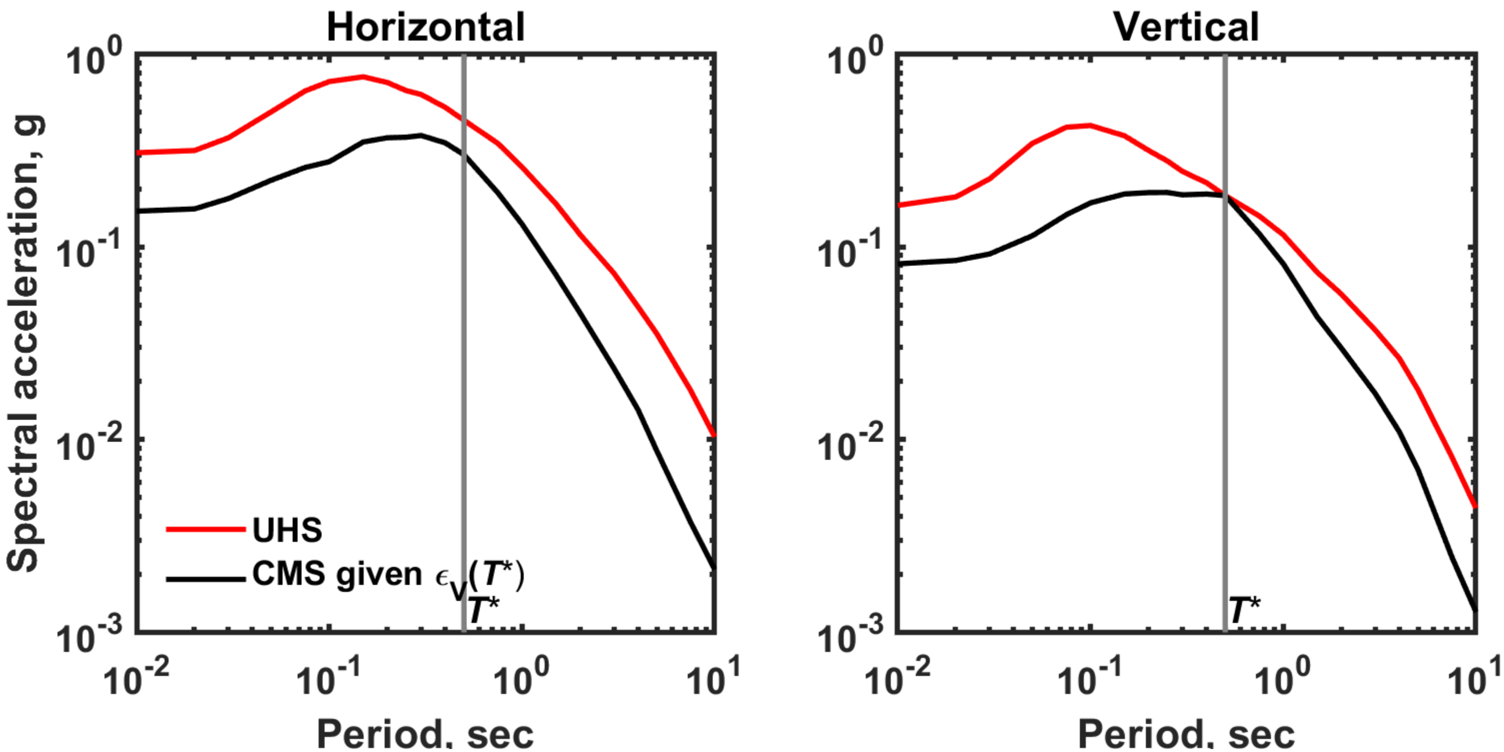
CONDITIONING UPON THE V COMPONENT OF GM

Multicomponent CMS

For kth component of GM (k=H or V):

$$A_{k,CMS}\big(T, \varepsilon_V(T^*)\big) = A_{k,m}(T) \cdot \exp\big[\varepsilon_V(T^*)\rho_{k,V}(T,T^*)\sigma_k(T)\big]$$

Multicomponent CMS



Multicomponent Composite Spectrum

For kth component of GM (k=H or V):

$$A_{k,Composite}(T) = \begin{cases} A_{k,CMS}(T, T_{min}) & T \leq T_{min} \\ \bar{A}_{k,UHS}(T) & T_{min} < T \leq T_{max} \\ A_{k,CMS}(T, T_{max}) & T \geq T_{max} \end{cases}$$

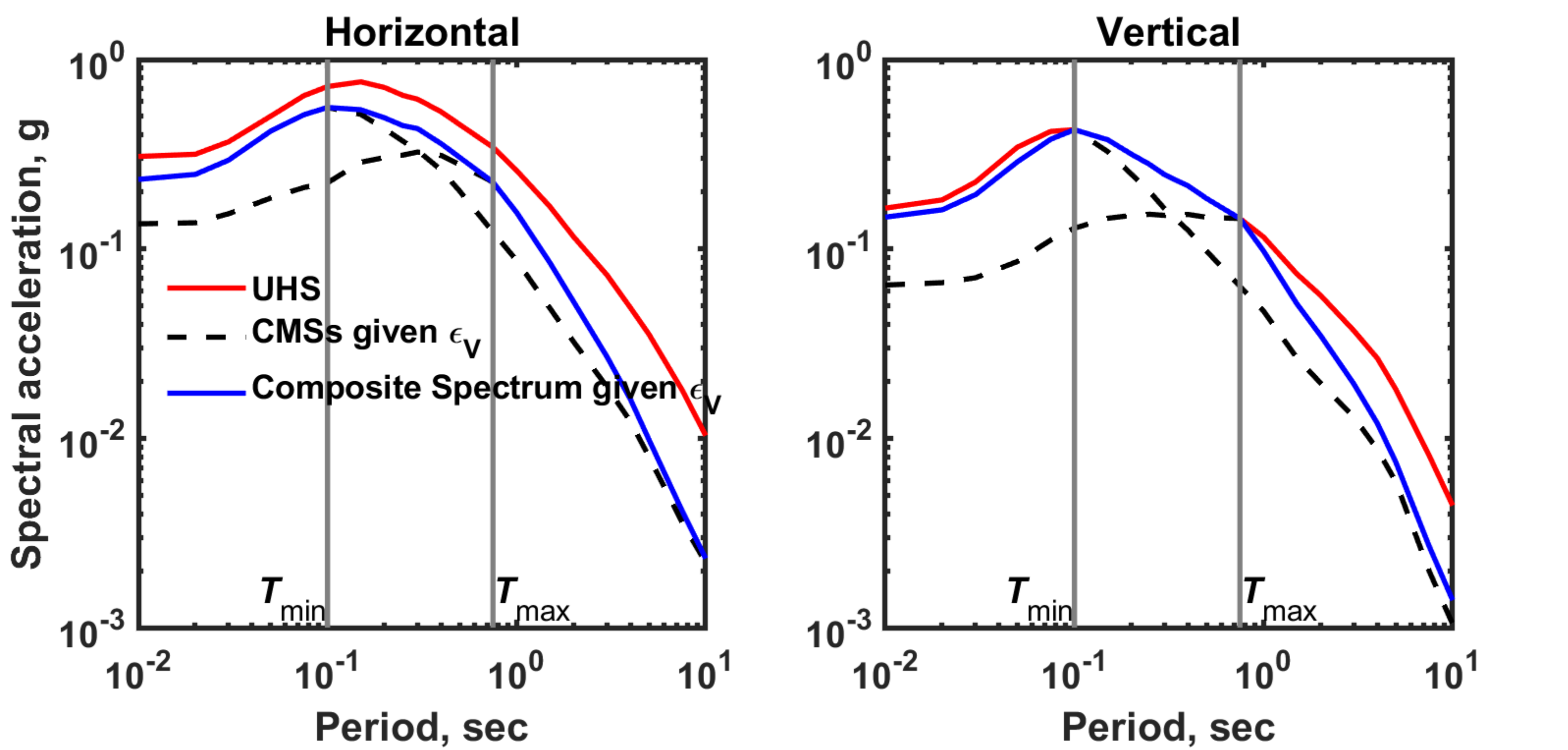
Multicomponent Composite Spectrum

$$\bar{A}_{V,UHS}(T\ ) = A_{V,UHS}(T)$$

$$\begin{aligned}\bar{A}_{H,UHS}(T\ ) &= A_{H,m}(T,\theta_e)\cdot\exp\left[\varepsilon_V(T)\rho_{H,V}(T,T,\theta_e)\sigma_H(T,\theta_e)\right]\\ &\approx A_{H,m}(T)\cdot\exp\left[\varepsilon_V\left(\overline{T}\right)\rho_{H,V}(T,T)\sigma_H(T)\right]\end{aligned}$$

$$\overline{T} = \sqrt{T_{min}\cdot T_{max}}$$

Multicomponent Composite Spectrum



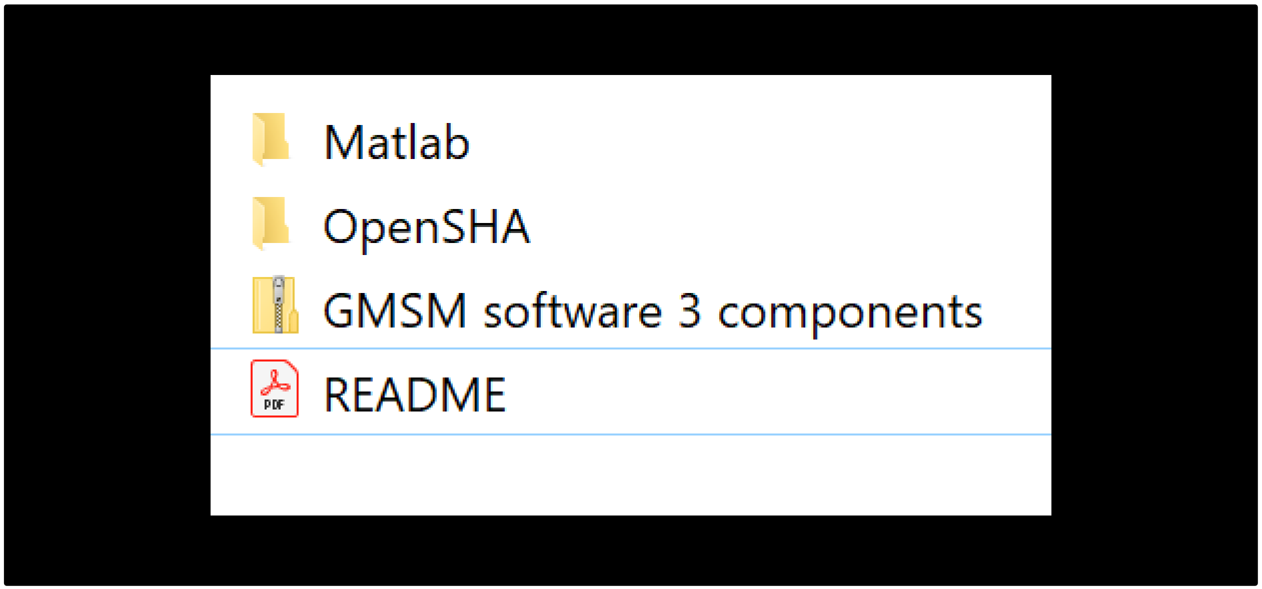
Neal Simon Kwong (nealsimonkwong@berkeley.edu)

ILLUSTRATIVE EXAMPLE

Electronic supplement

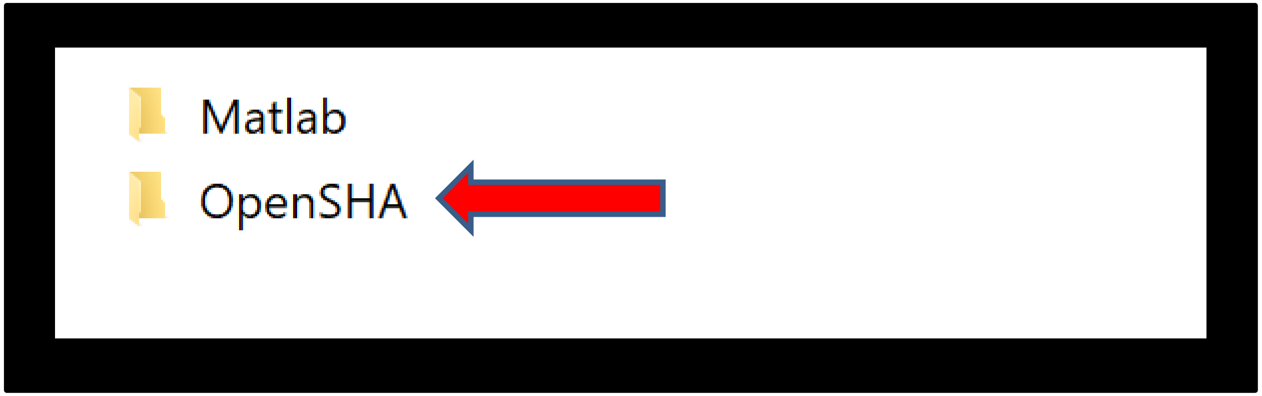
1. Software for conducting PSHA and implementing GMSM of three components is provided
2. Specific numerical example illustrated using OpenSHA and Matlab
3. Subsequent screenshots illustrate use of this software

README file

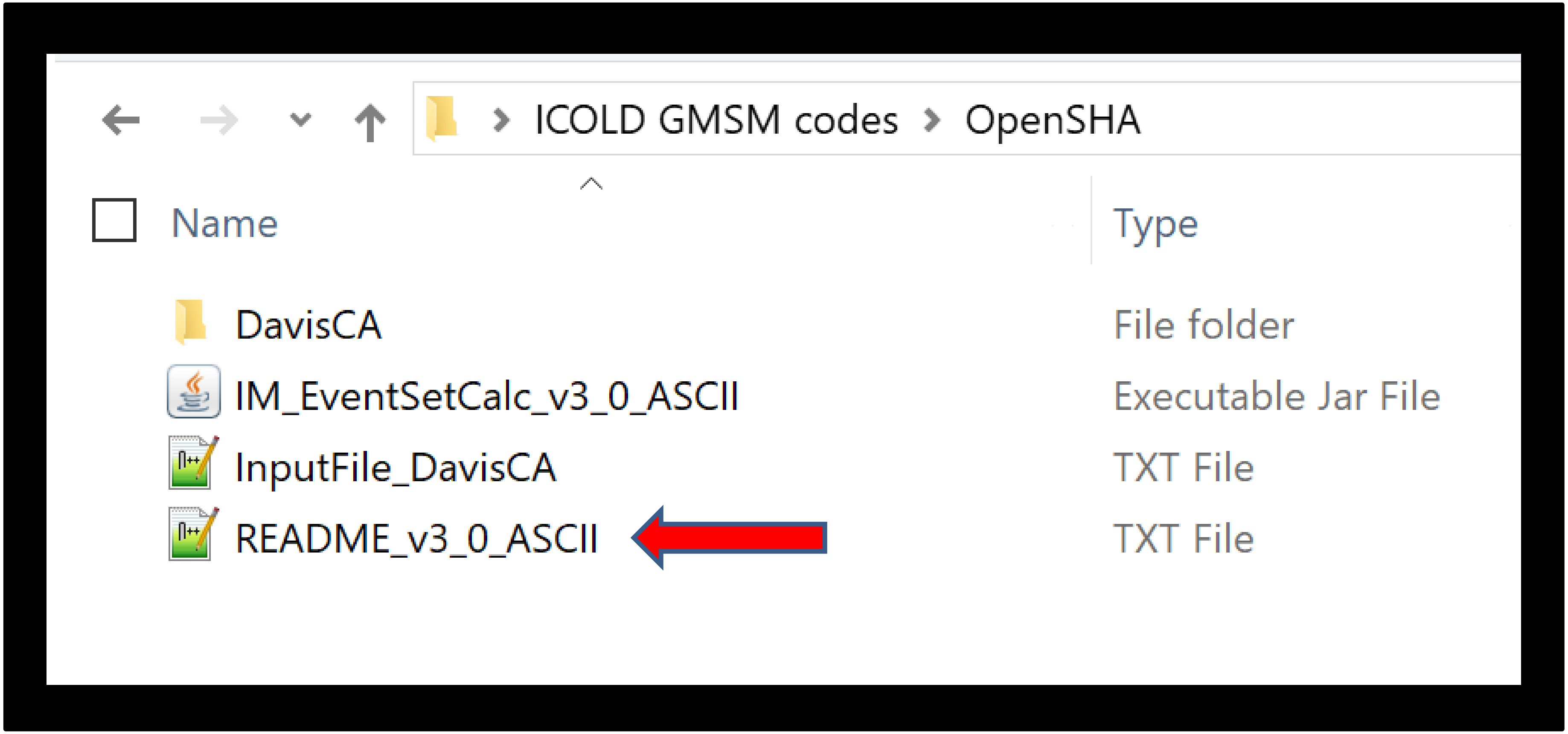


Organization of files

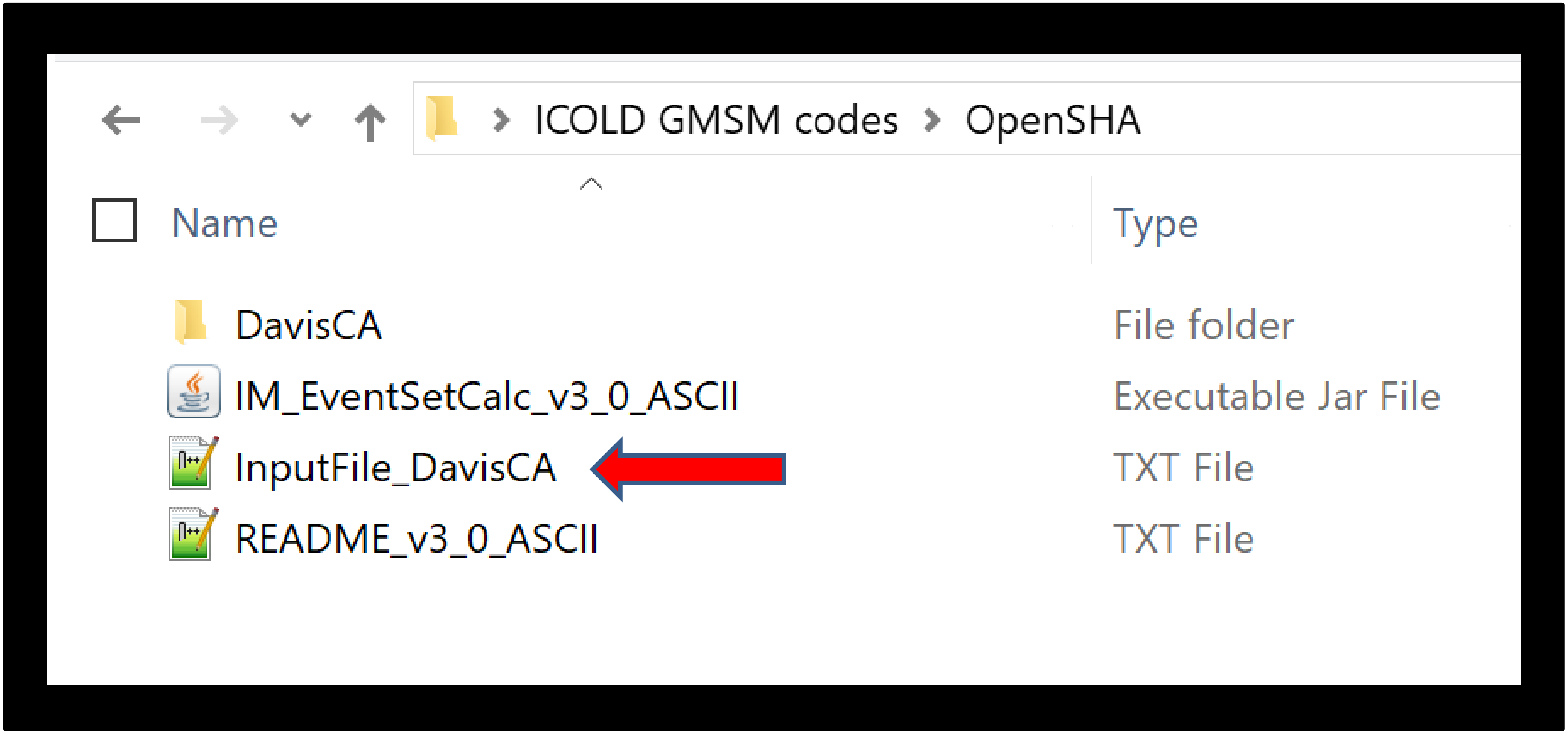
Conduct PSHA



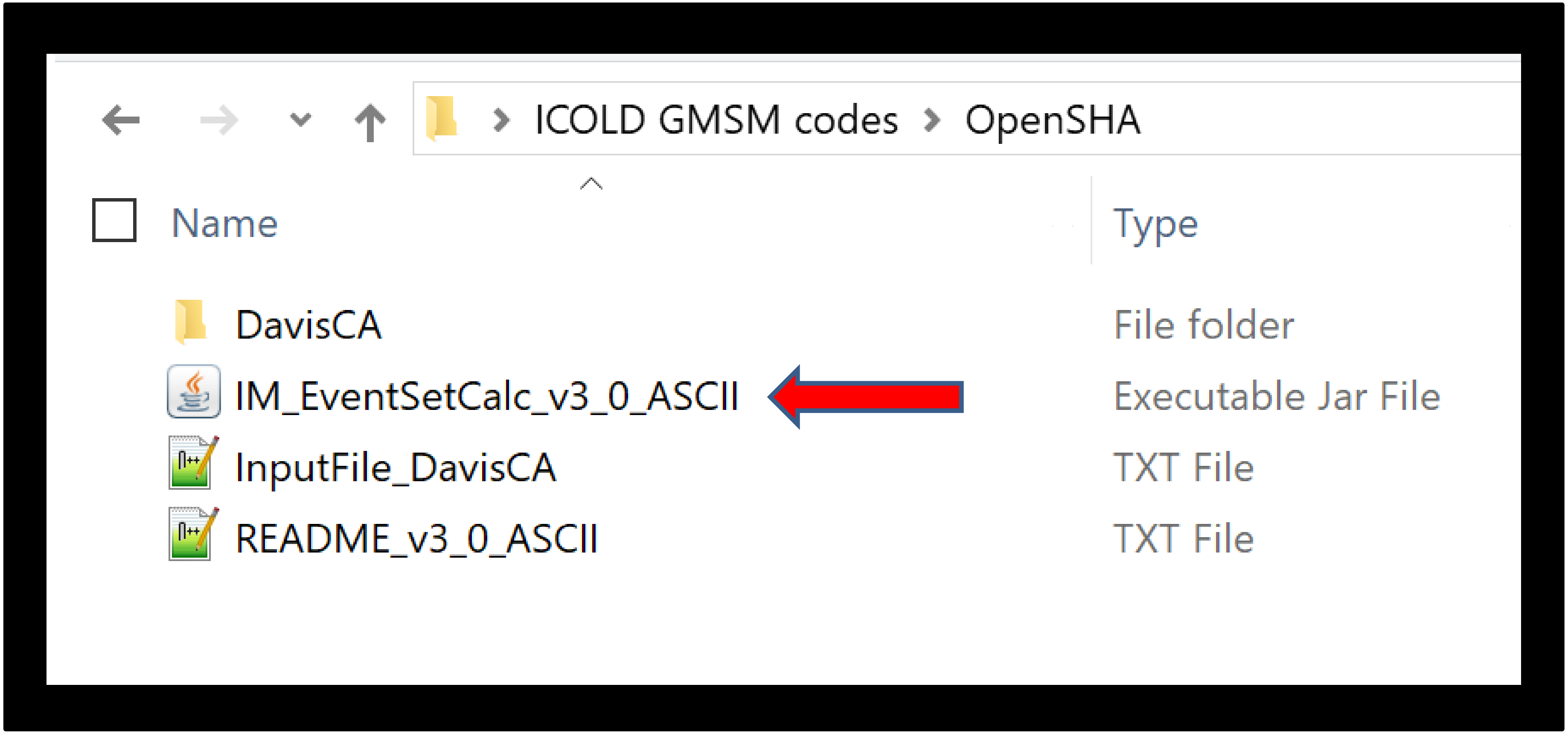
PSHA instructions



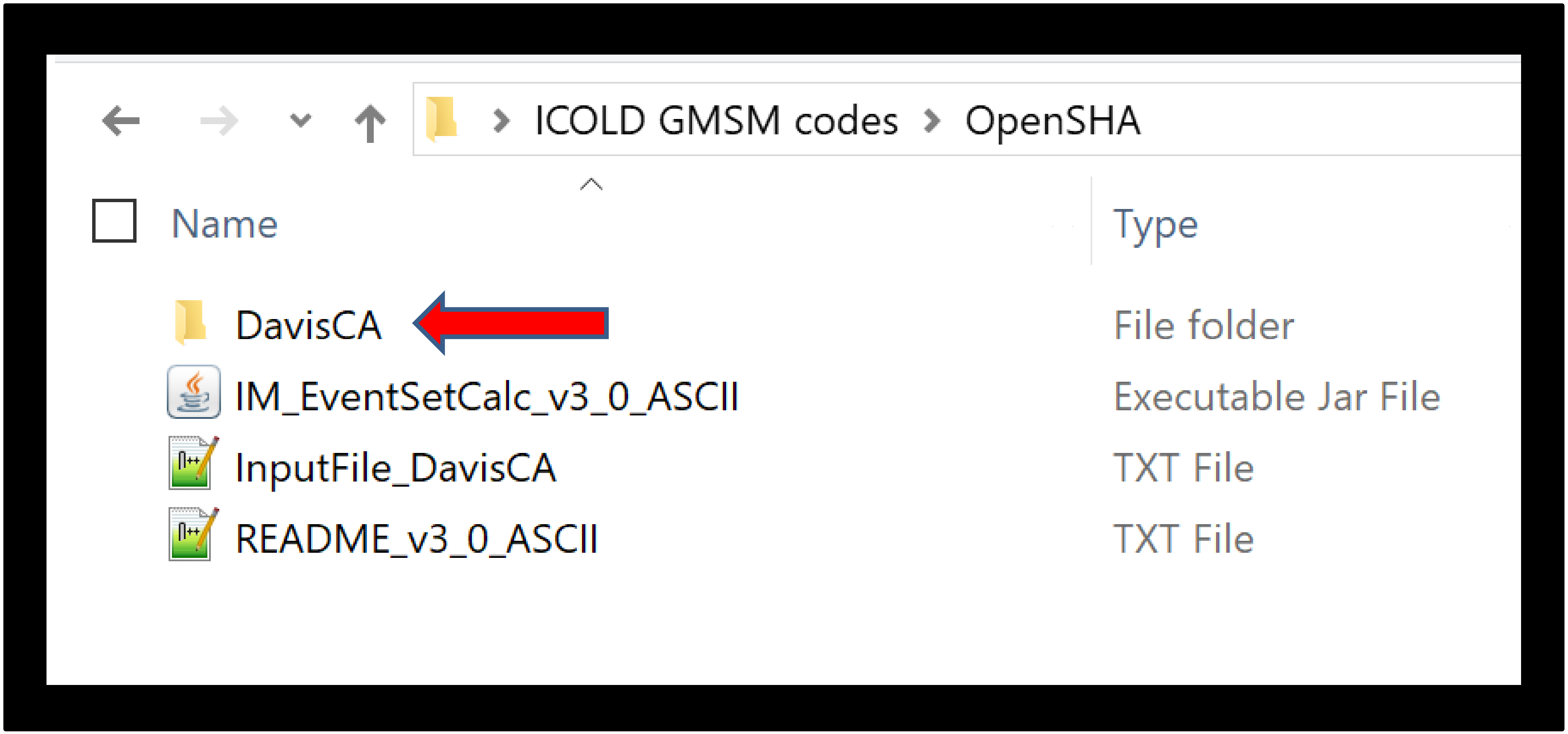
PSHA input


ICOLD GMSM codes
OpenSHA
Name
Type
DavisCA
File folder
IM_EventSetCalc_v3_0_ASCII
Executable Jar File
InputFile_DavisCA
TXT File
README_v3_0_ASCII
TXT File

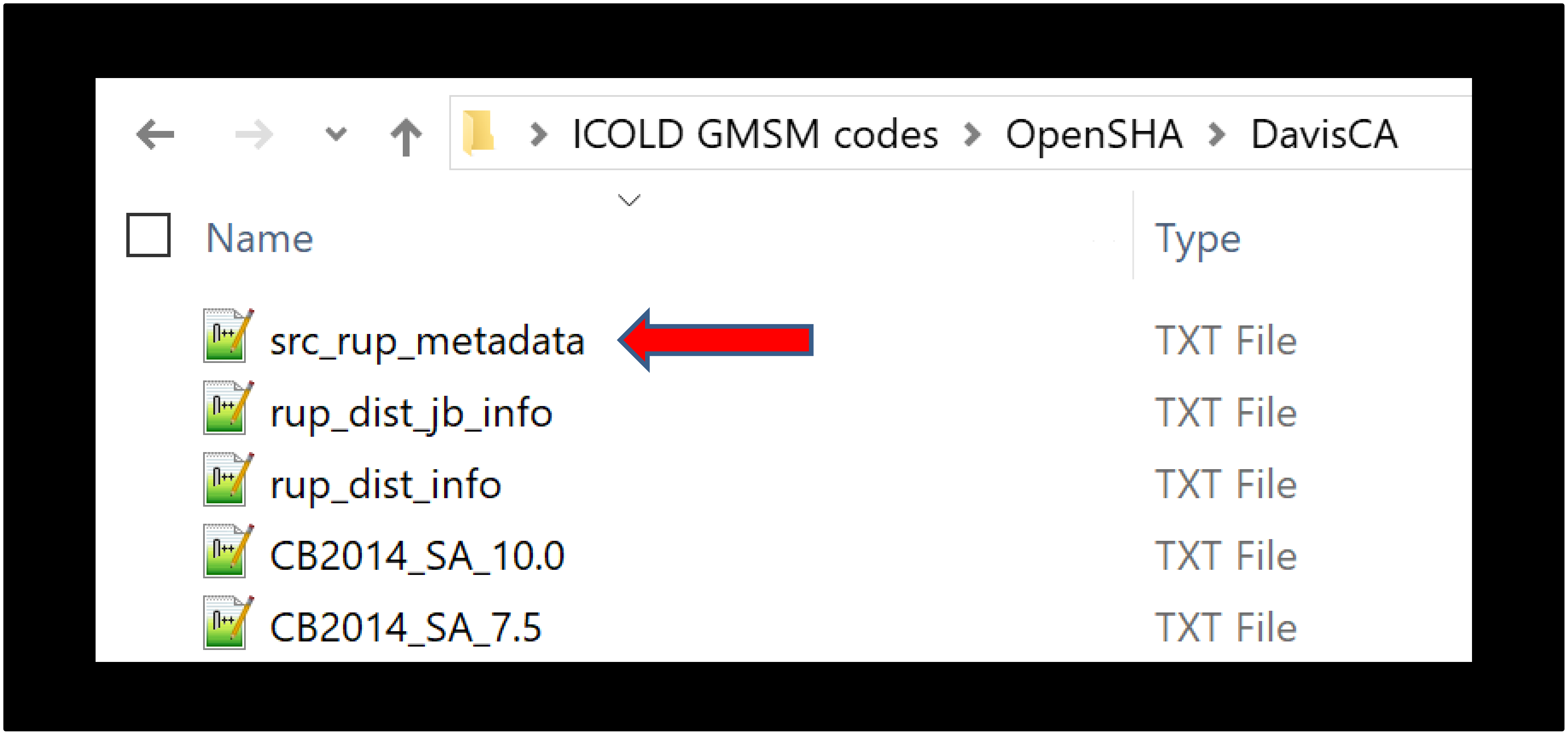
Get earthquake rupture forecast



PSHA output


ICOLD GMSM codes › OpenSHA
Name
Type
DavisCA
File folder
IM_EventSetCalc_v3_0_ASCII
Executable Jar File
InputFile_DavisCA
TXT File
README_v3_0_ASCII
TXT File

Earthquake rupture forecast

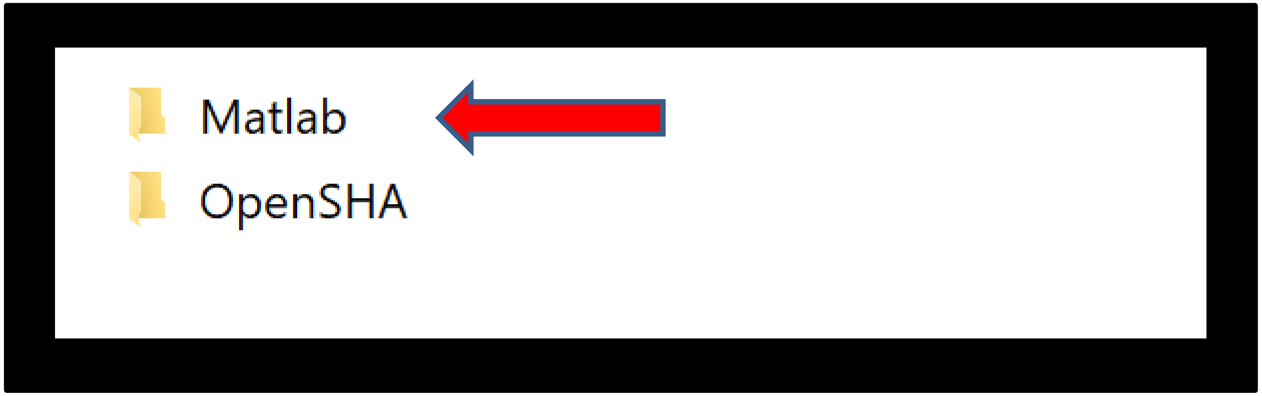


Earthquake rupture forecast

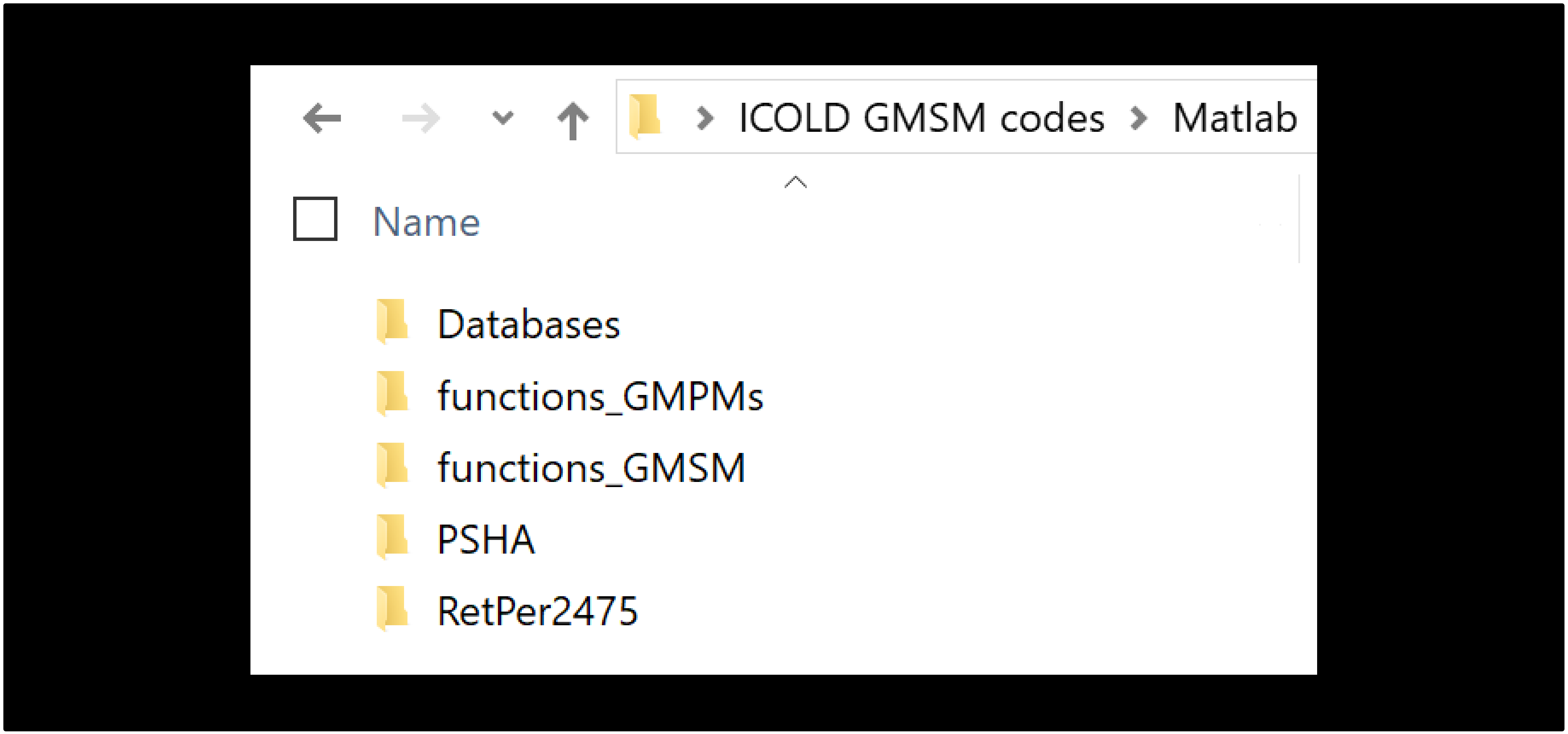
src_rup_metadata.txt

```
62	0	4.7602345E-5	6.15	West Napa (jl0.wnapa) 1	Char
62	1	7.34724E-5	6.2	West Napa (jl0.wnapa) 1	Char
62	2	9.532828E-5	6.25	West Napa (jl0.wnapa) 1	Char
62	3	1.03973085E-4	6.3	West Napa (jl0.wnapa) 1	Char
62	4	1.6690134E-4	6.35	West Napa (jl0.wnapa) 1	Char
62	5	1.8394268E-4	6.4	West Napa (jl0.wnapa) 1	Char
62	6	1.909343E-4	6.45	West Napa (jl0.wnapa) 1	Char
62	7	1.5632994E-4	6.5	West Napa (jl0.wnapa) 1	Char
62	8	1.5528912E-4	6.55	West Napa (jl0.wnapa) 1	Char
62	9	1.2892572E-4	6.6	West Napa (jl0.wnapa) 1	Char
62	10	9.5518444E-5	6.65	West Napa (jl0.wnapa) 1	Char
62	11	2.6116857E-5	6.7	West Napa (jl0.wnapa) 1	Char
62	12	2.394538E-5	6.75	West Napa (jl0.wnapa) 1	Char
62	13	1.8455432E-5	6.8	West Napa (jl0.wnapa) 1	Char
62	14	1.1957169E-5	6.85	West Napa (jl0.wnapa) 1	Char
63	0	5.1935338E-5	6.05	Quien Sabe (bb.quiensabe) 1	Char
63	1	8.016021E-5	6.1	Quien Sabe (bb.quiensabe) 1	Char
63	2	1.0400551E-4	6.15	Quien Sabe (bb.quiensabe) 1	Char
63	3	1.1343721E-4	6.2	Quien Sabe (bb.quiensabe) 1	Char
```

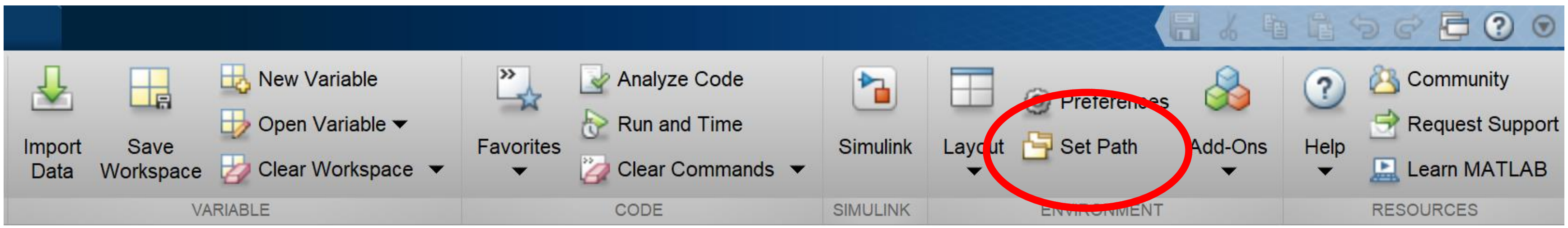
Conduct PSHA with Matlab-GMPMs



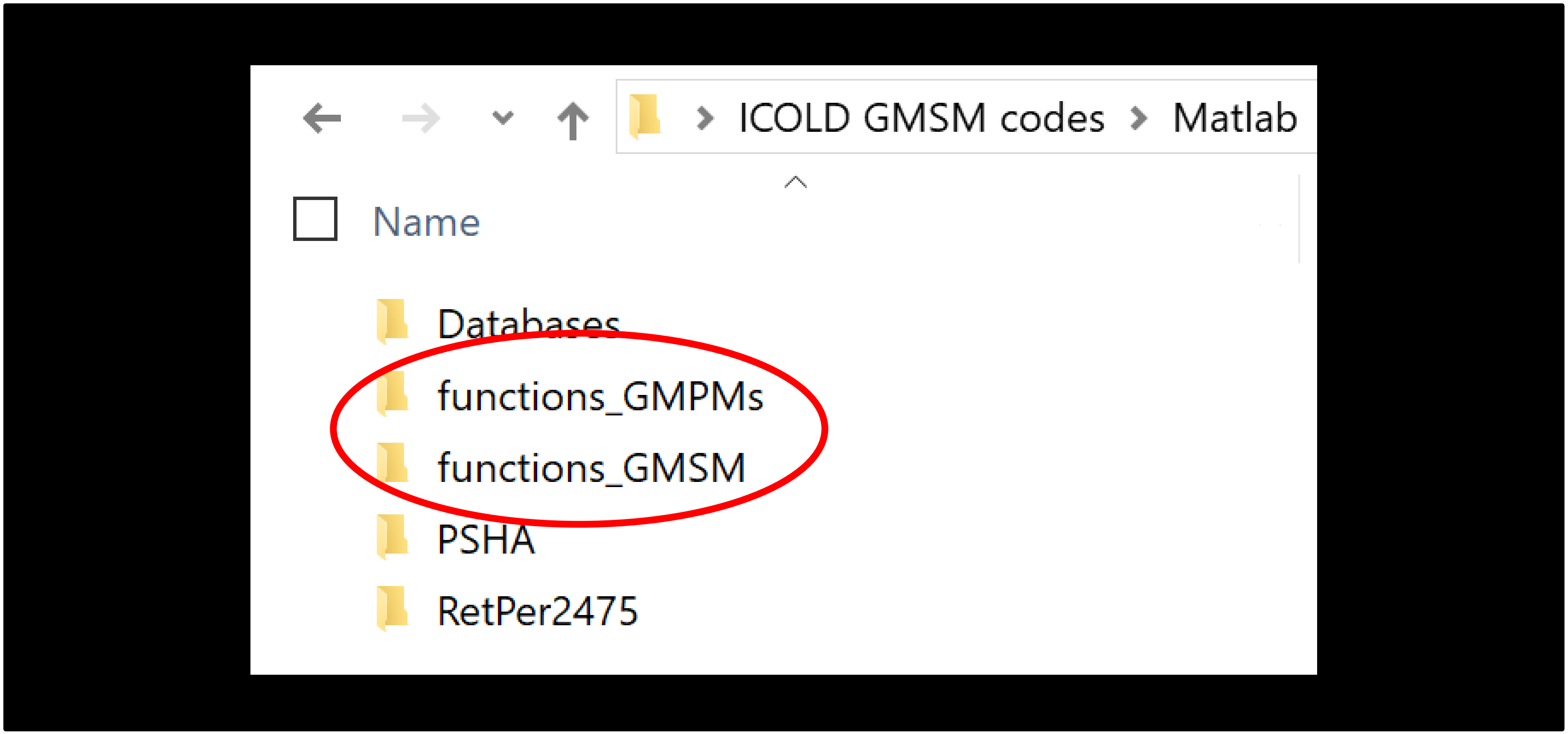
Conduct PSHA with Matlab-GMPMs



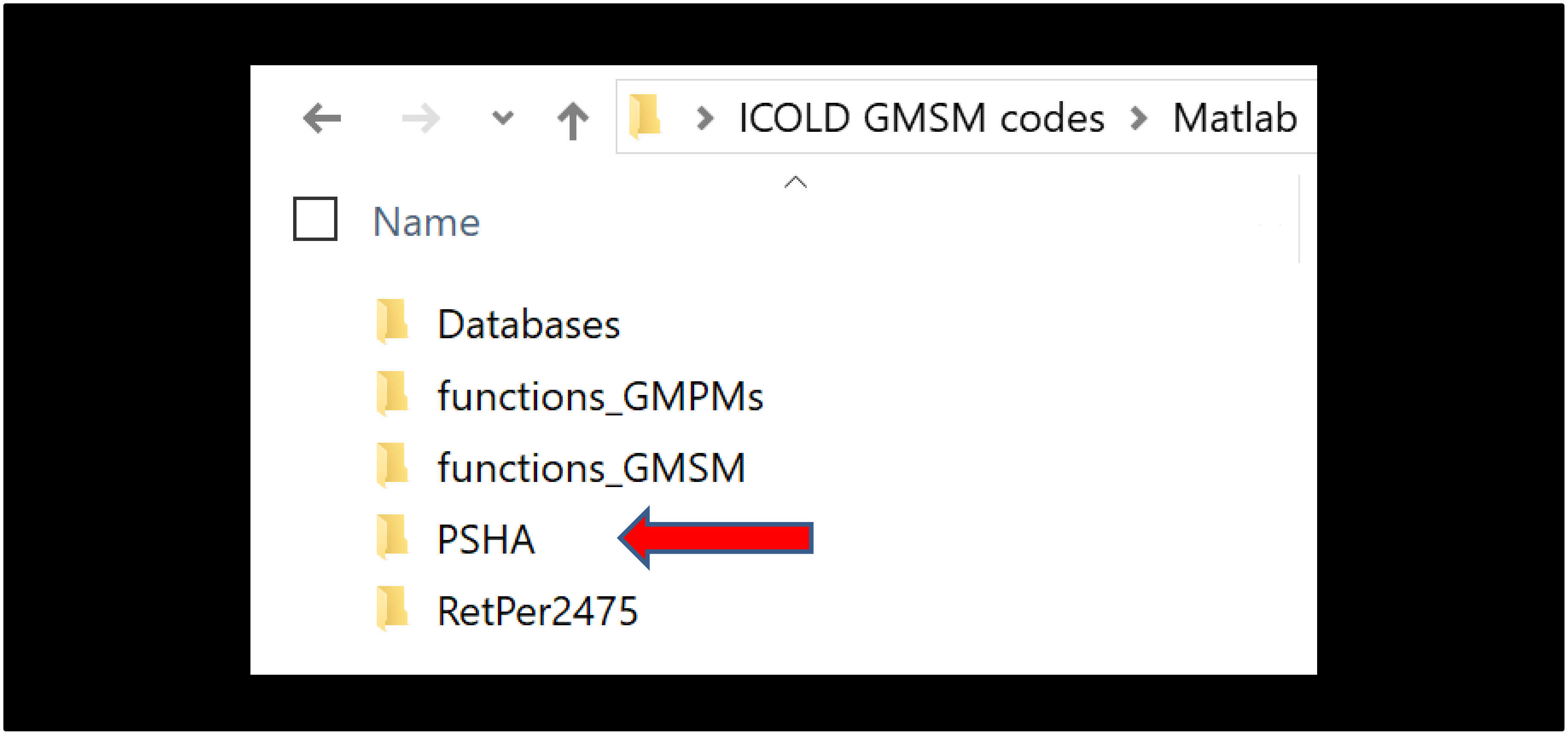
Set path in Matlab



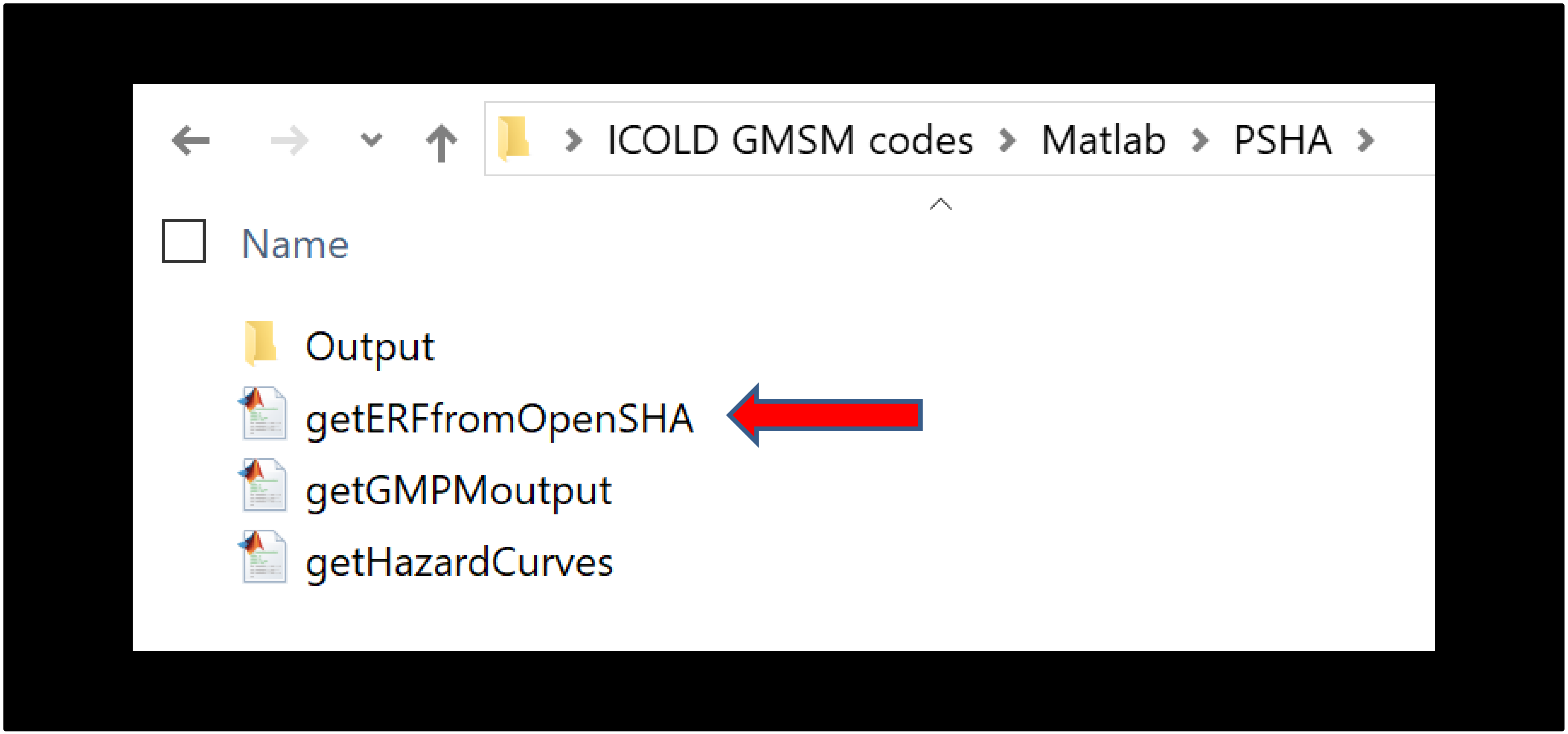
Set path in Matlab



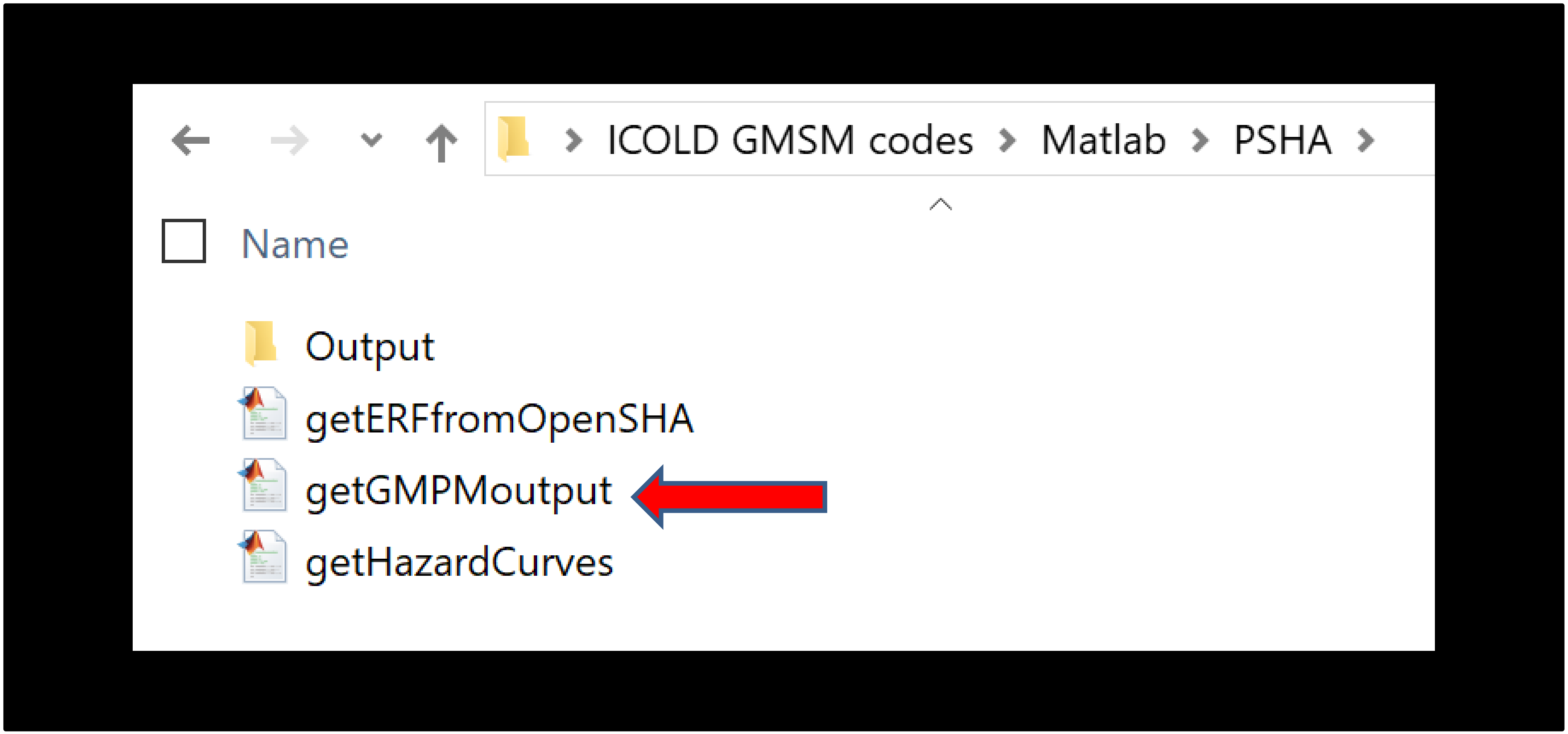
Conduct PSHA with Matlab-GMPMs



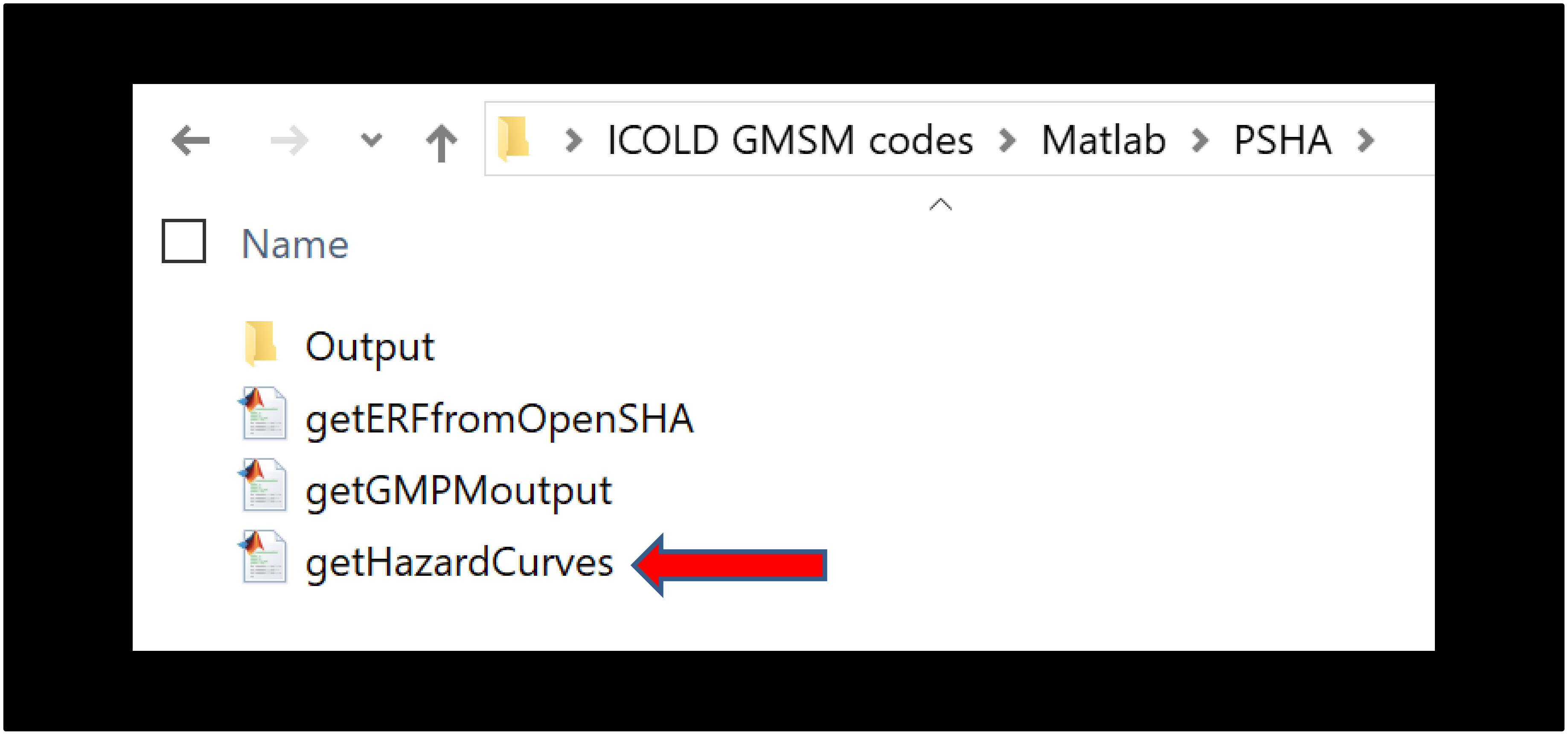
Get earthquake rupture forecast



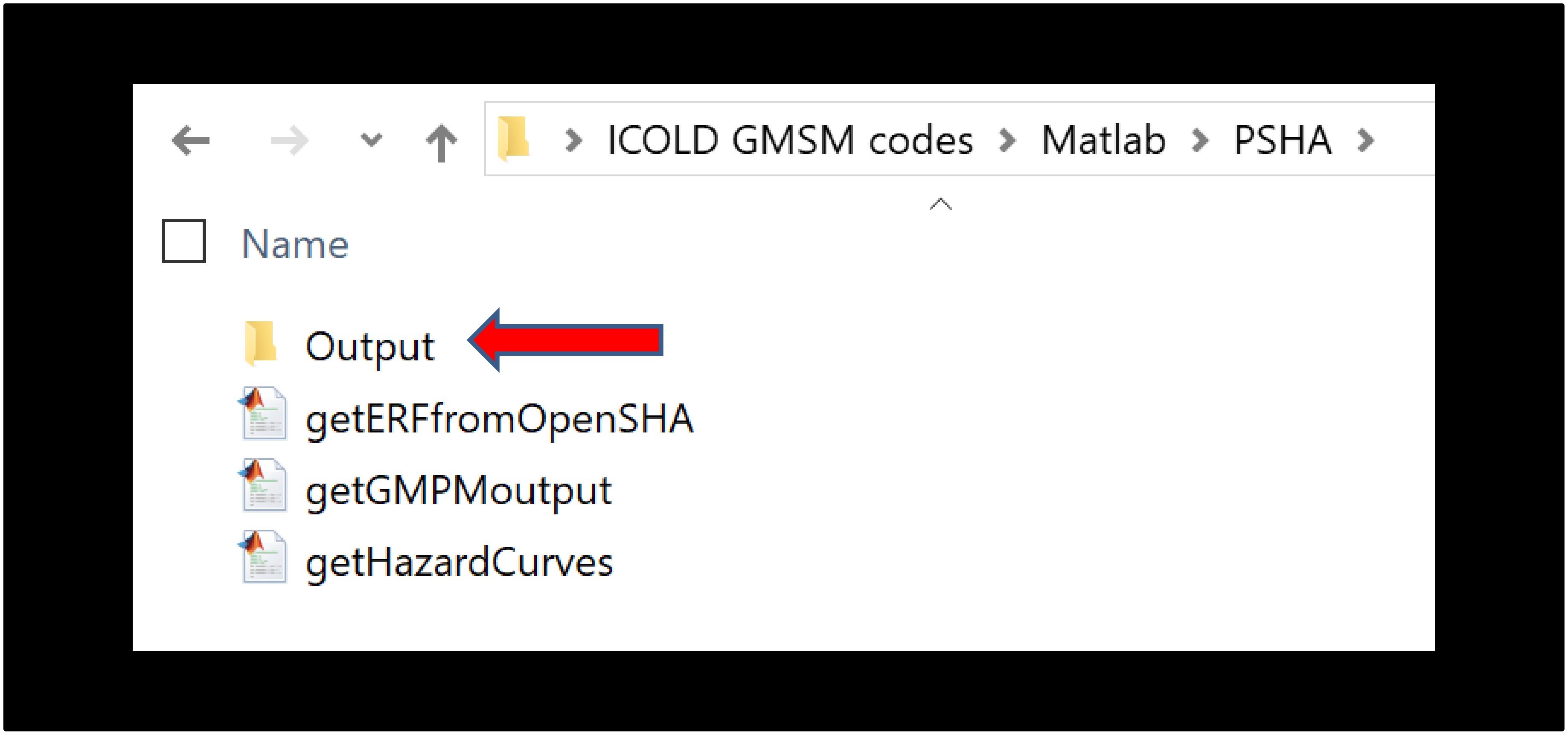
Implement Matlab-GMPMs



Compute hazard curves

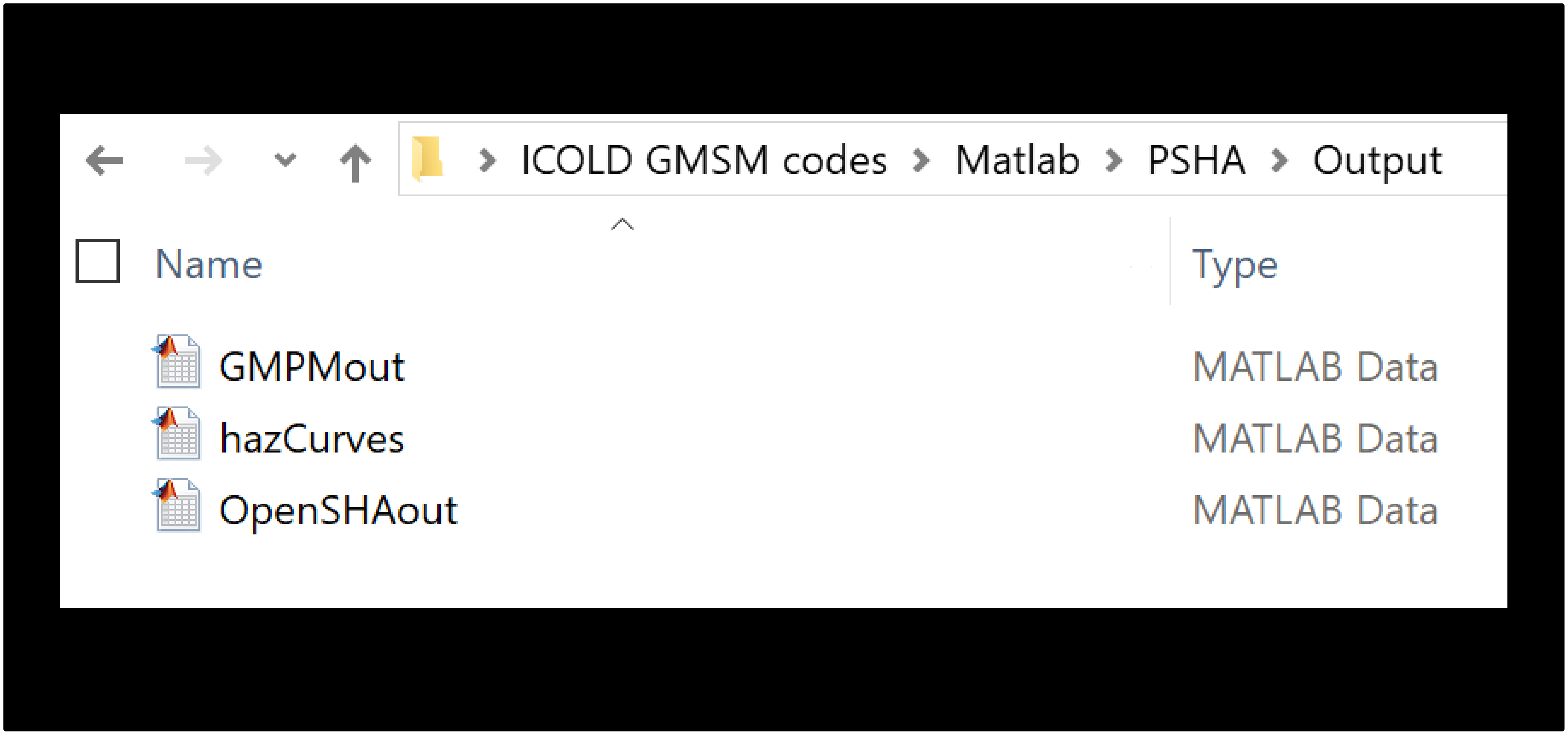


PSHA output

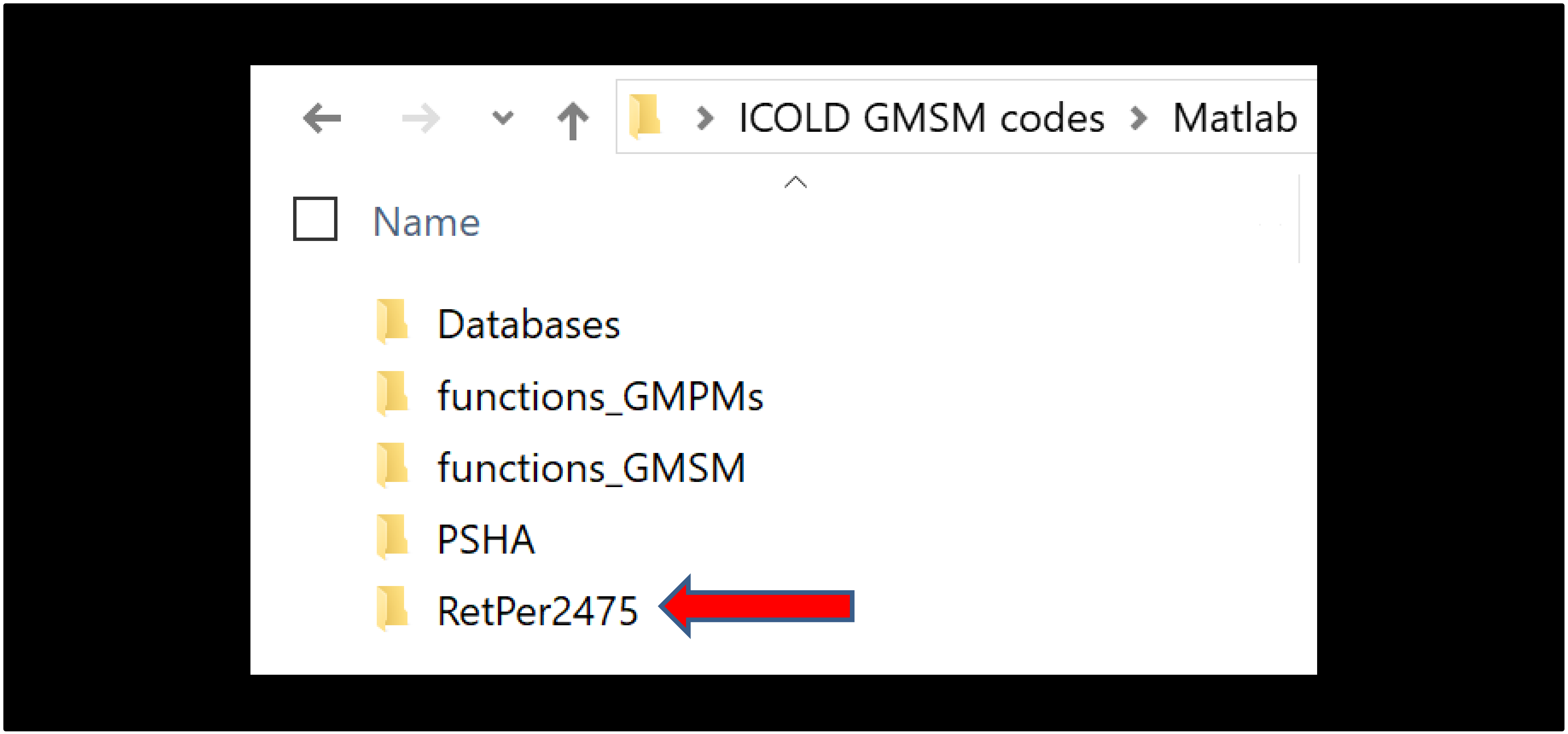


ICOLD GMSM codes › Matlab › PSHA ›
Name
Output
getERFfromOpenSHA
getGMPMoutput
getHazardCurves

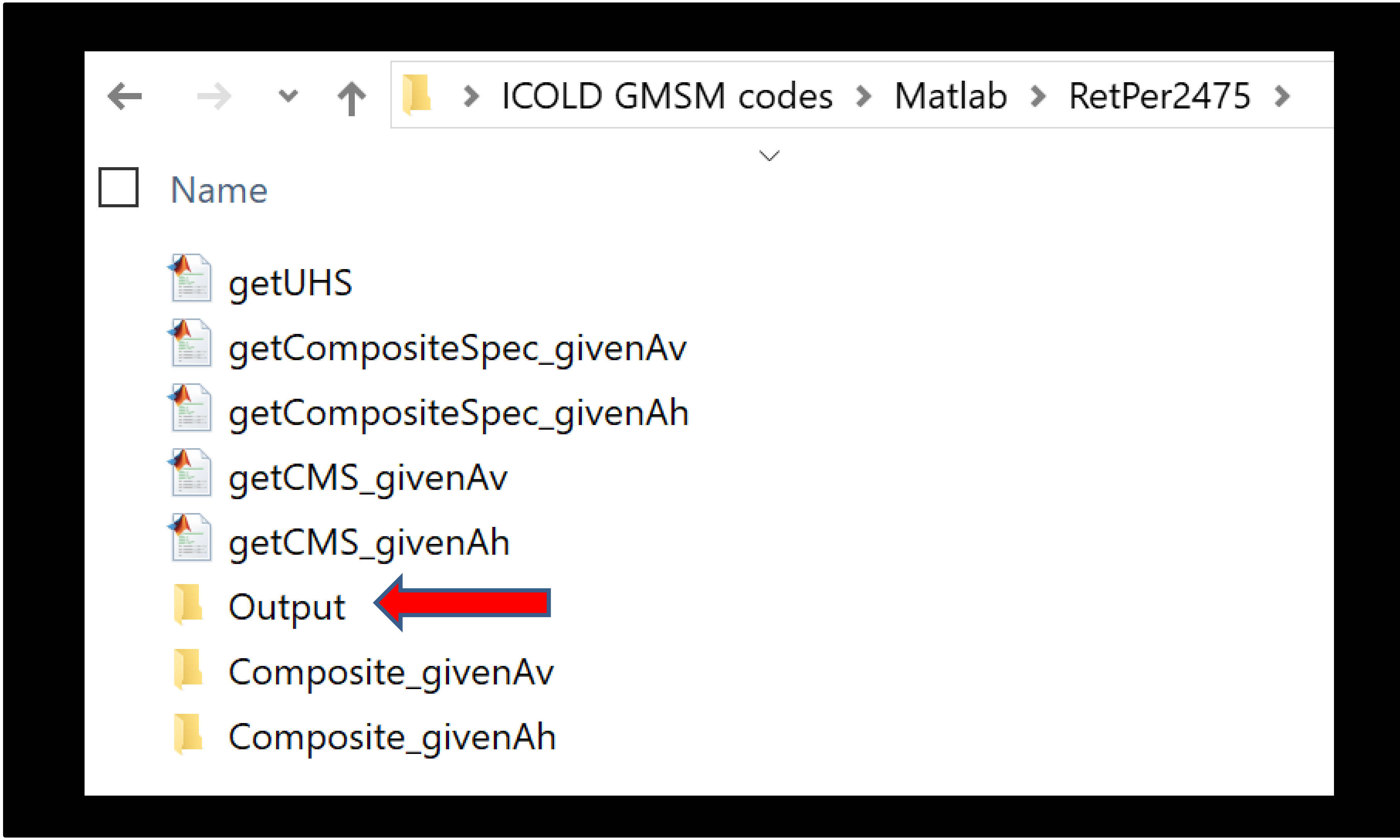
PSHA output


ICOLD GMSM codes › Matlab › PSHA › Output
Name
Type
GMPMout
MATLAB Data
hazCurves
MATLAB Data
OpenSHAout
MATLAB Data

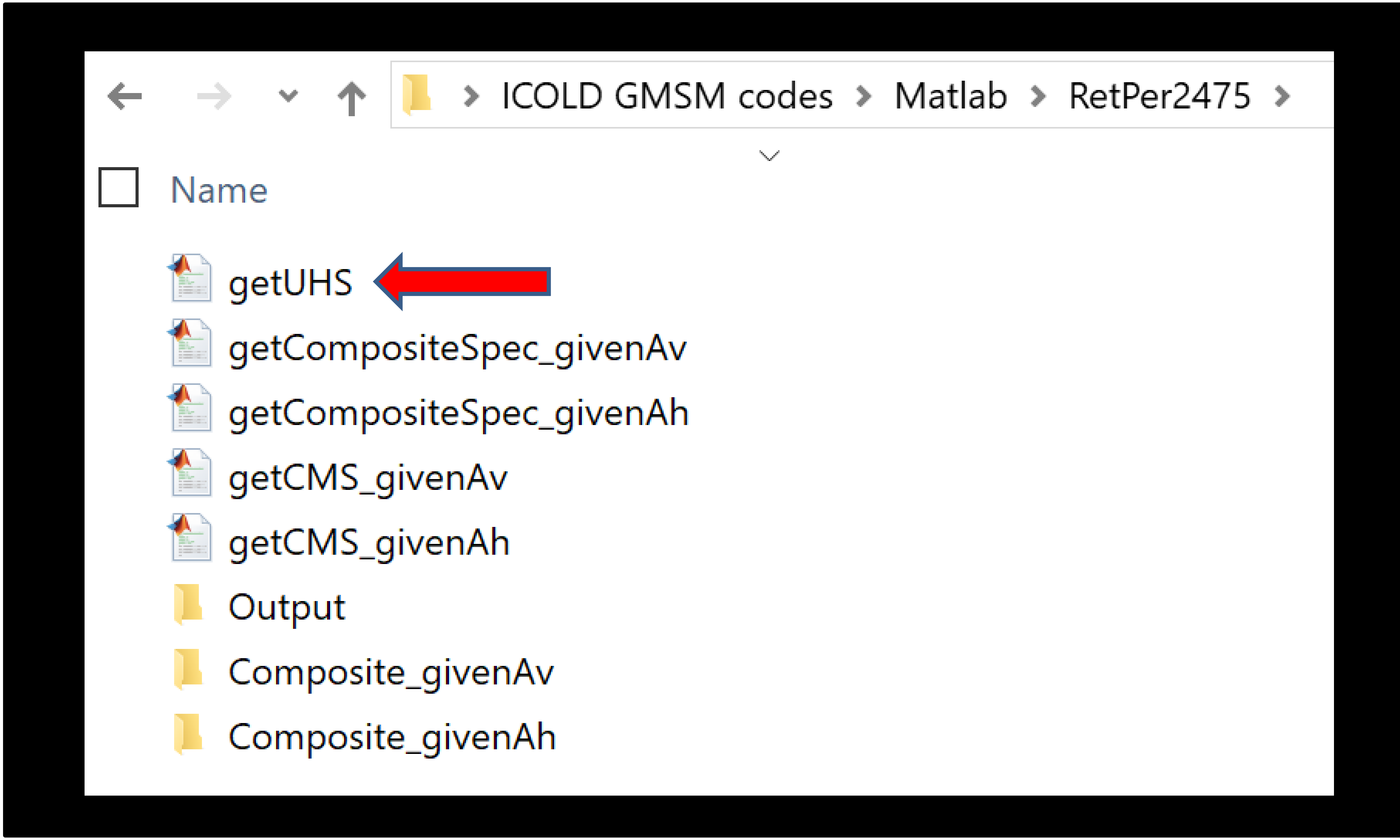
Return period for target spectra



Target spectra output

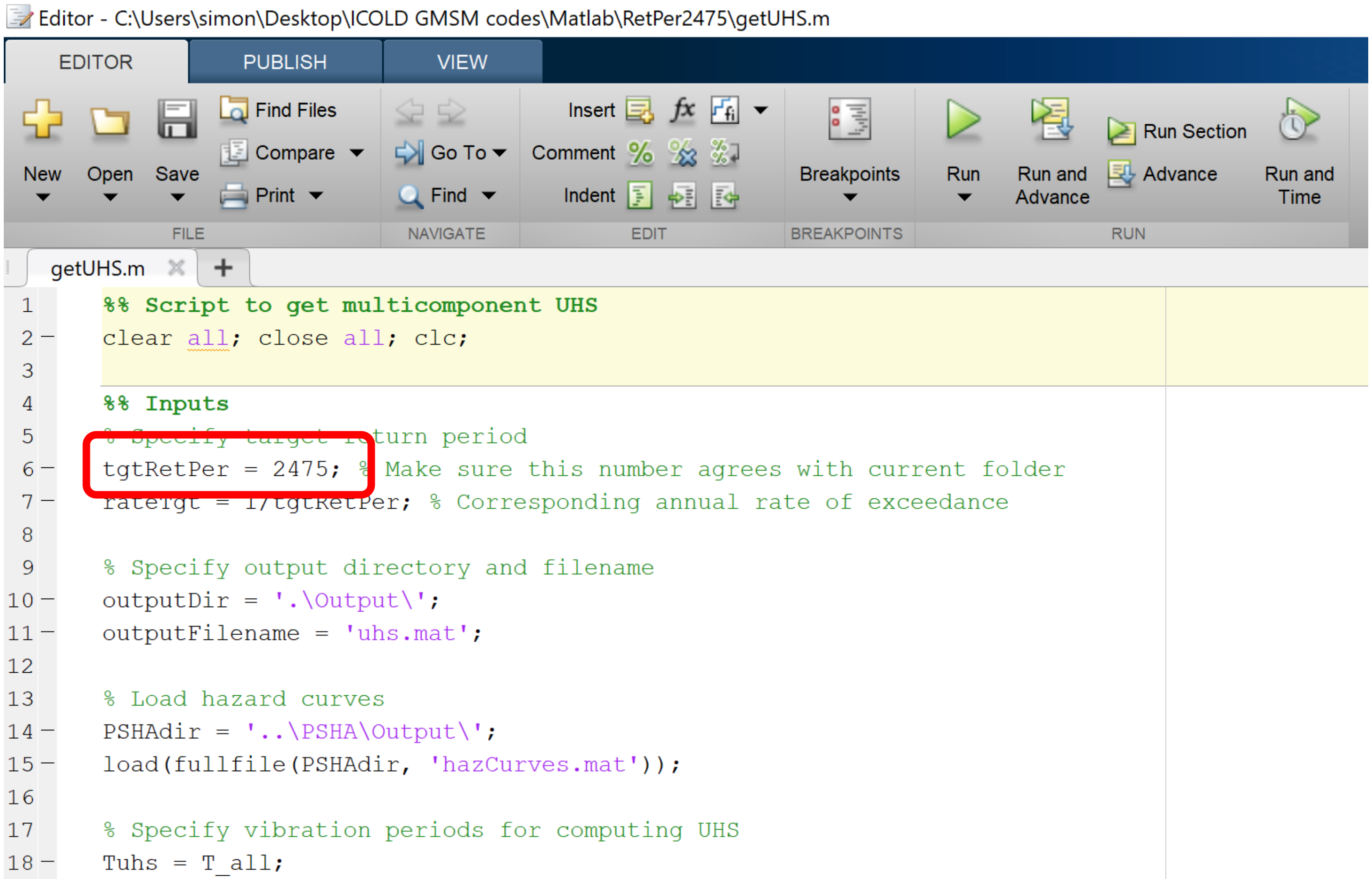


Get UHS

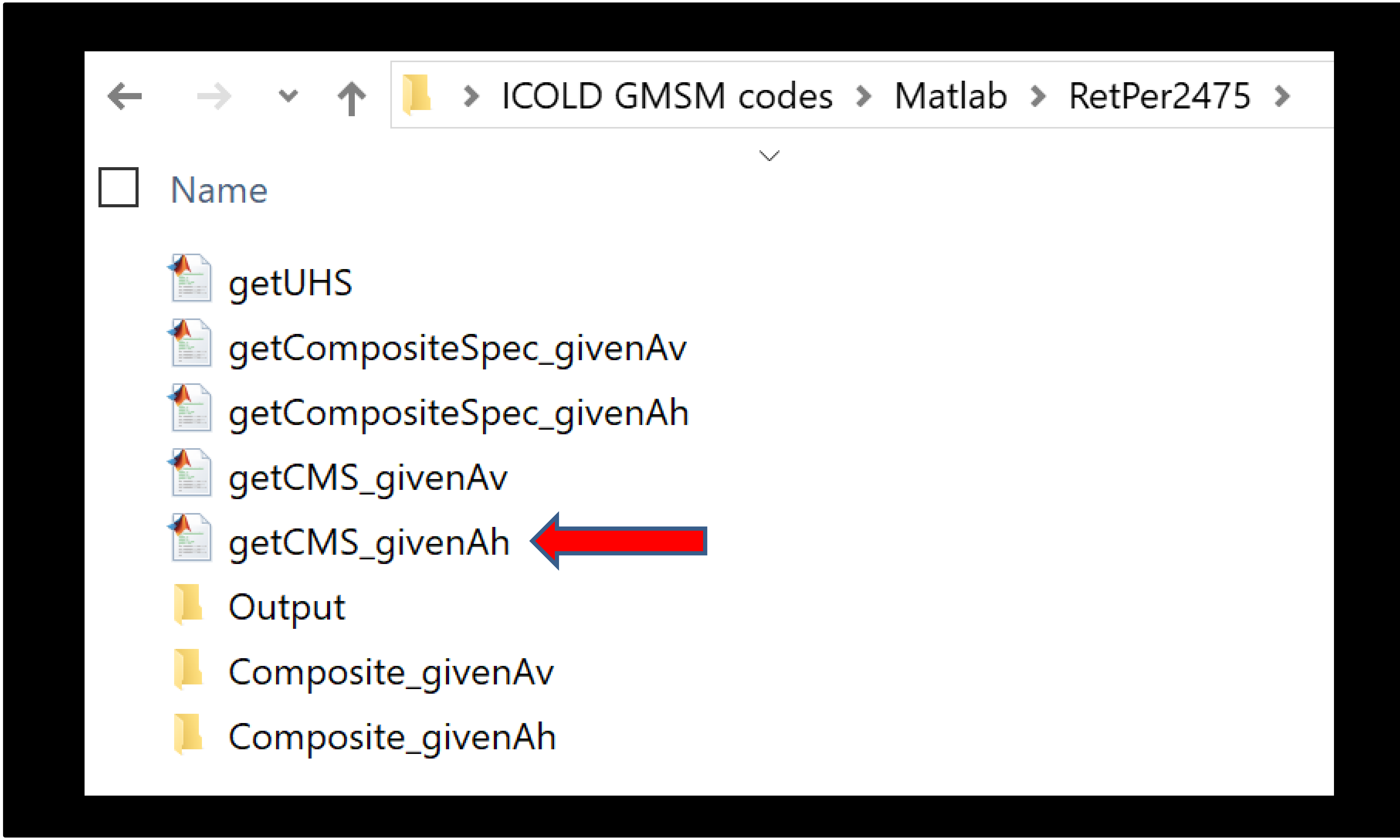


ICOLD GMSM codes › Matlab › RetPer2475 ›
Name
getUHS
getCompositeSpec_givenAv
getCompositeSpec_givenAh
getCMS_givenAv
getCMS_givenAh
Output
Composite_givenAv
Composite_givenAh

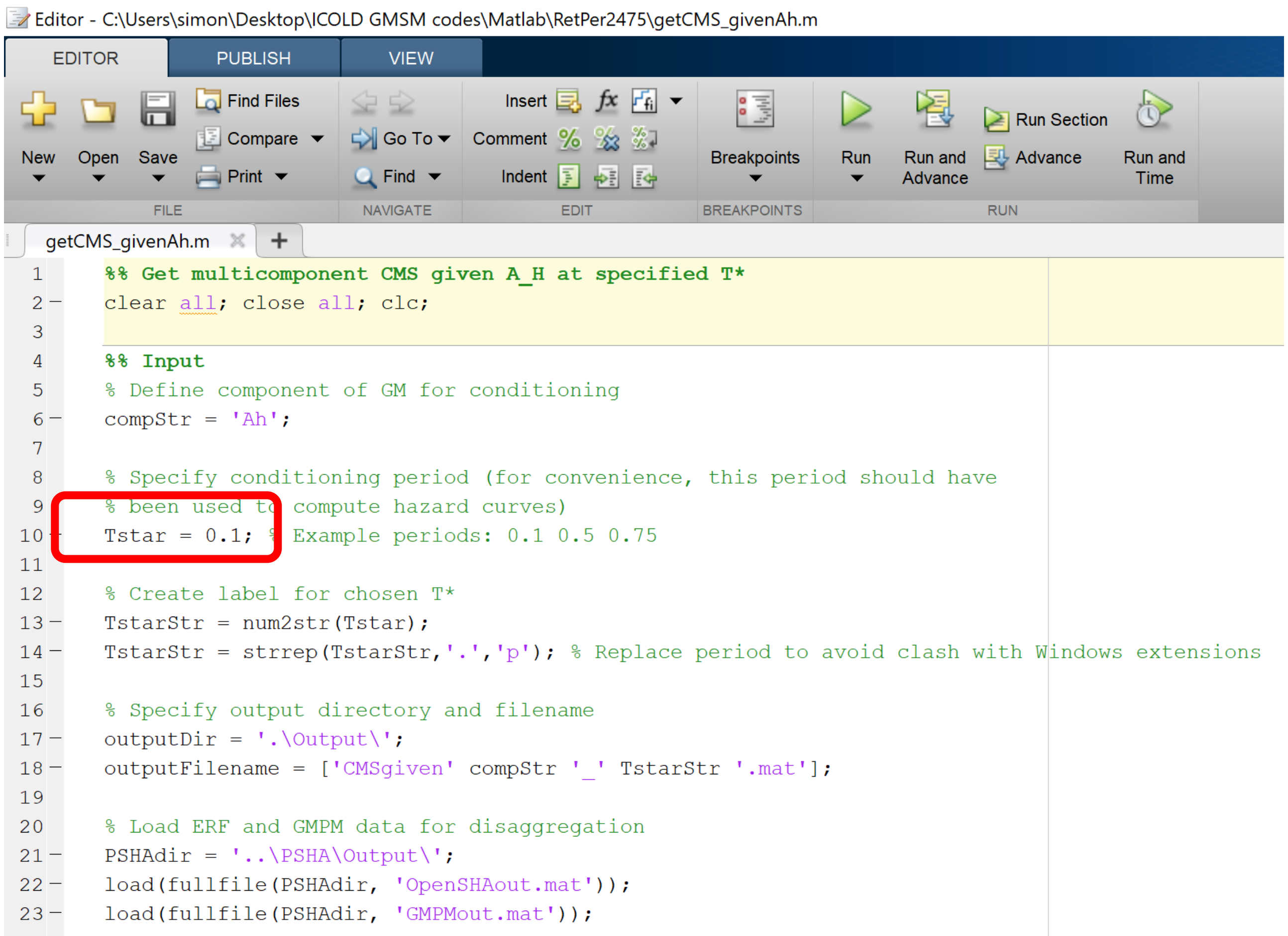
Get UHS


Editor - C:\Users\simon\Desktop\ICOLD GMSM codes\Matlab\RetPer2475\getUHS.m
EDITOR
PUBLISH
VIEW
New
Open
Save
Find Files
Compare
Print
Go To
Find
Insert
Comment
Indent
Breakpoints
Run
Run and Advance
Run Section
Advance
Run and Time
FILE
NAVIGATE
EDIT
BREAKPOINTS
RUN
getUHS.m
%% Script to get multicomponent UHS
clear all; close all; clc;
%% Inputs
% Specify target return period
tgtRetPer = 2475; % Make sure this number agrees with current folder
rateTgt = 1/tgtRetPer; % Corresponding annual rate of exceedance
% Specify output directory and filename
outputDir = '.\Output\';
outputFilename = 'uhs.mat';
% Load hazard curves
PSHAdir = '..\PSHA\Output\';
load(fullfile(PSHAdir, 'hazCurves.mat'));
% Specify vibration periods for computing UHS
Tuhs = T_all;

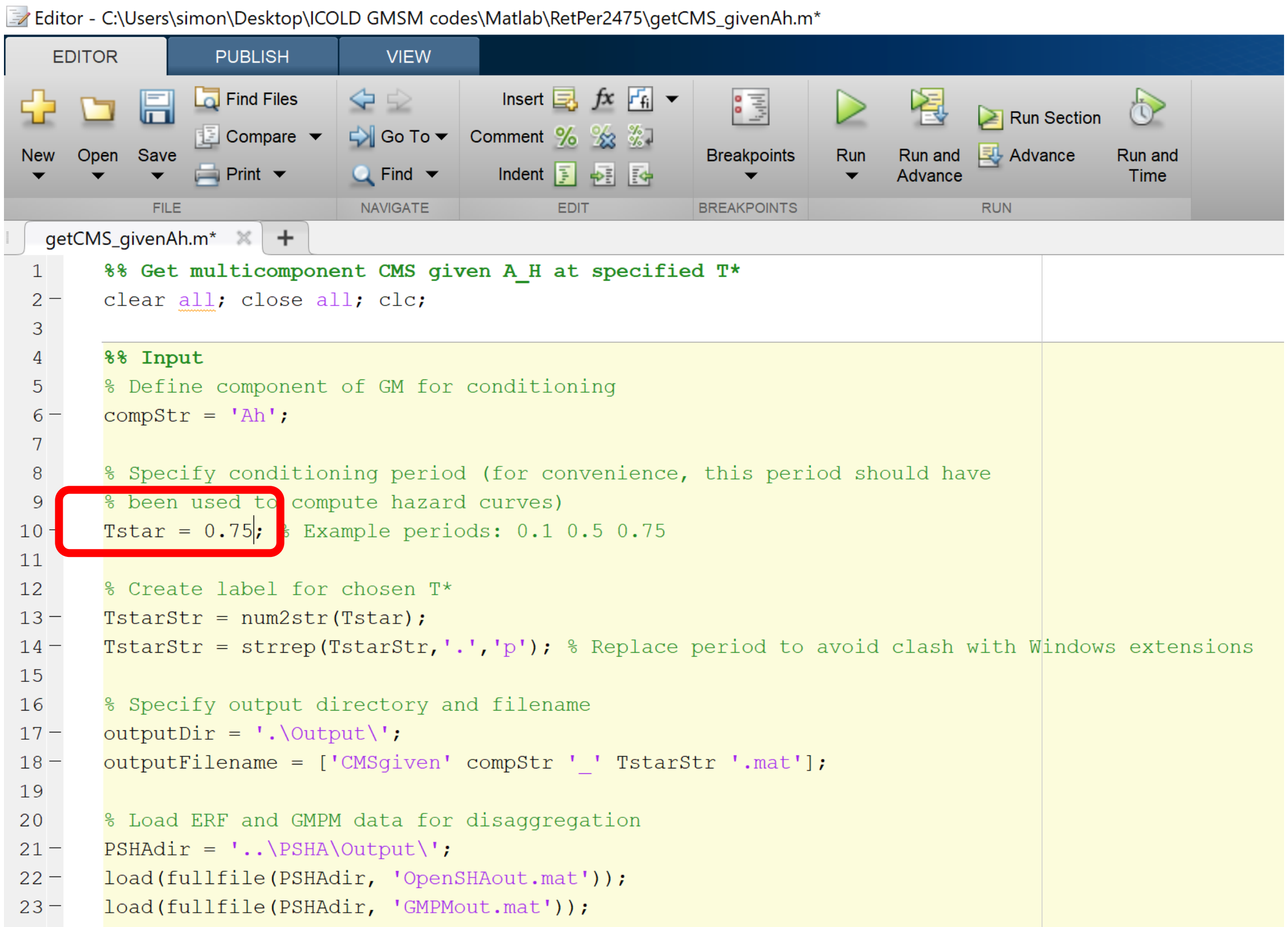
Get CMSs


ICOLD GMSM codes
Matlab
RetPer2475
Name
getUHS
getCompositeSpec_givenAv
getCompositeSpec_givenAh
getCMS_givenAv
getCMS_givenAh
Output
Composite_givenAv
Composite_givenAh

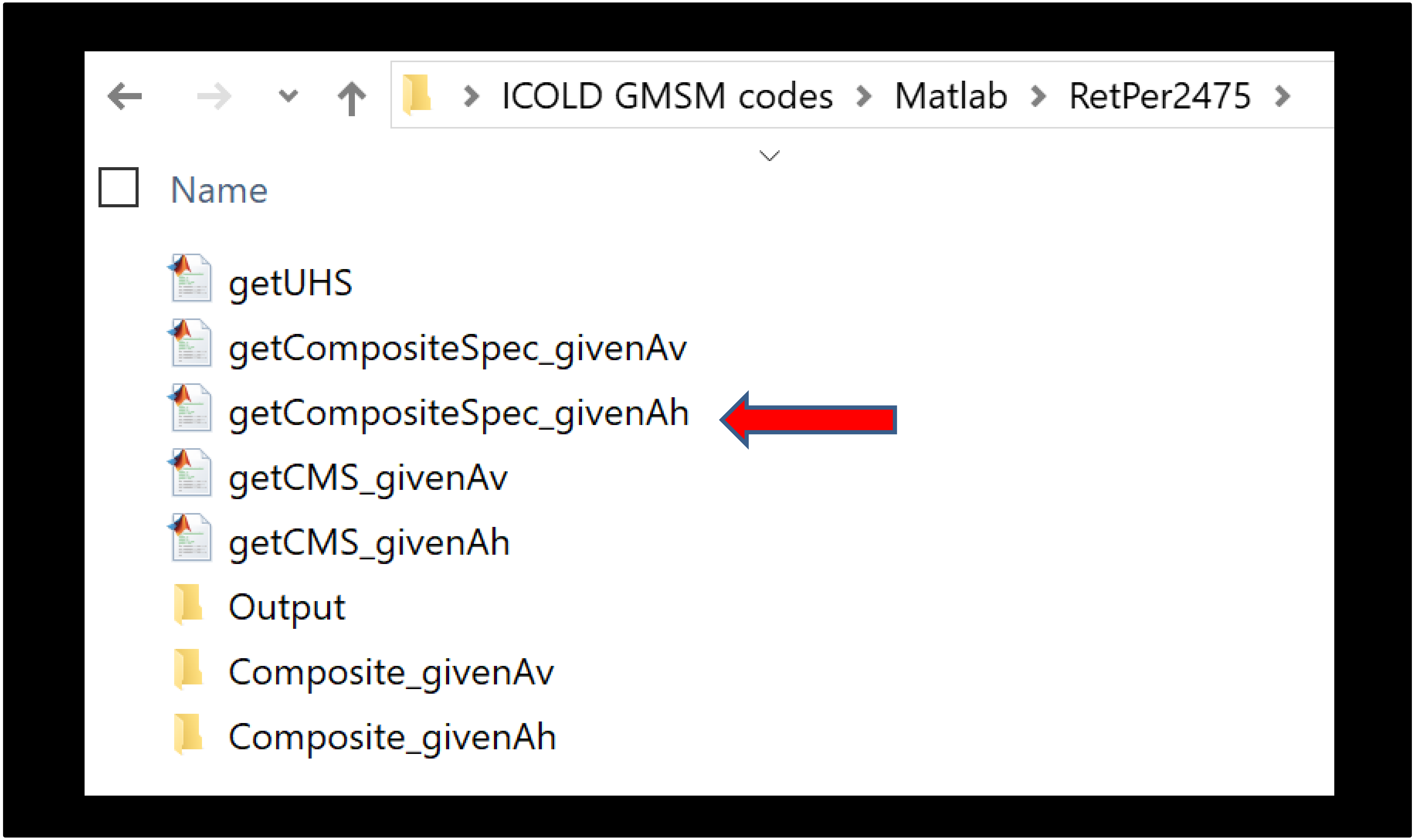
Get CMS for T_{min}



Get CMS for T_{max}

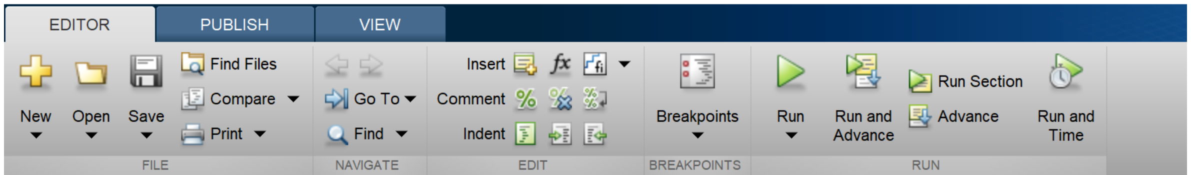


Get Composite Spectrum



Get Composite Spectrum

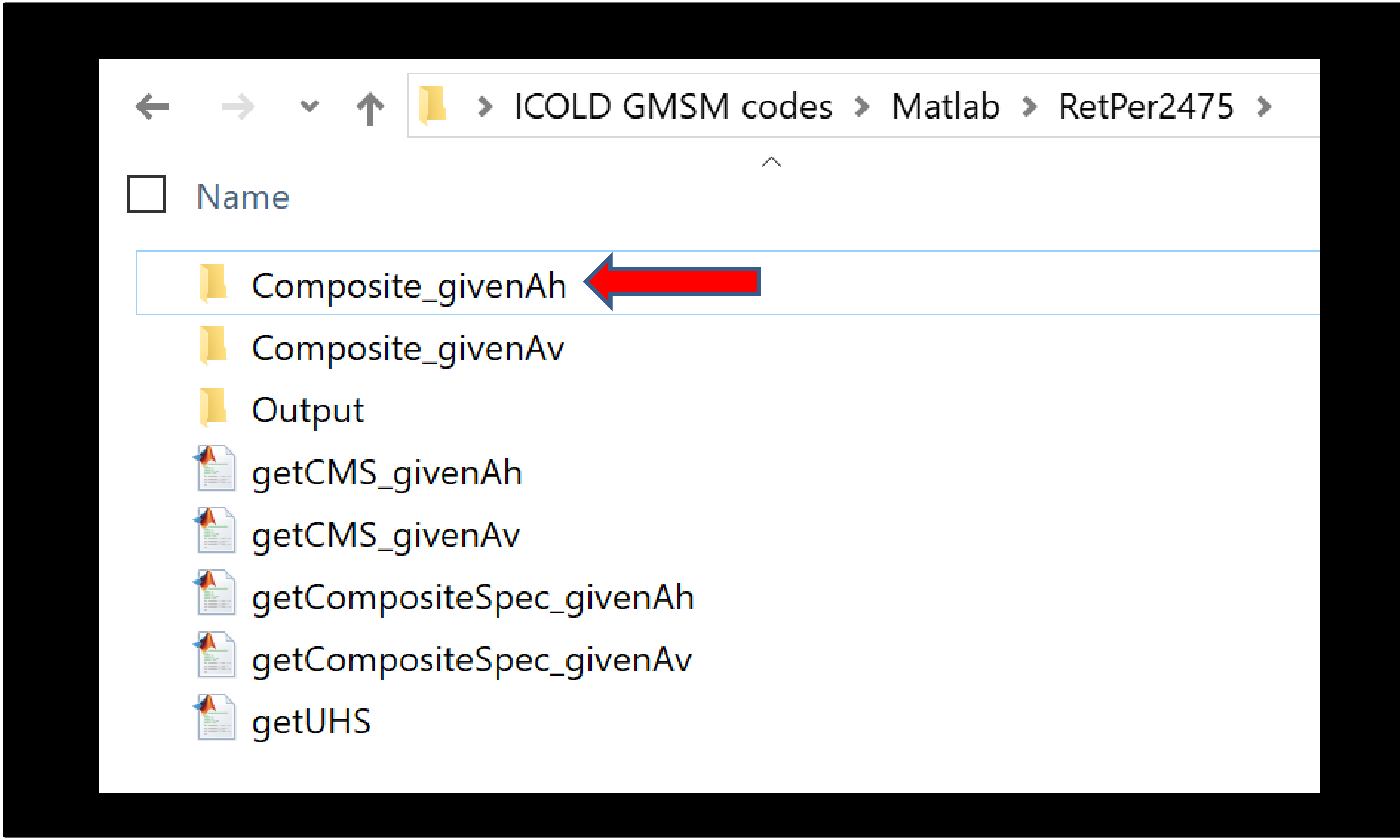
Editor - C:\Users\simon\Desktop\ICOLD GMSM codes\Matlab\RetPer2475\getCompositeSpec_givenAh.m



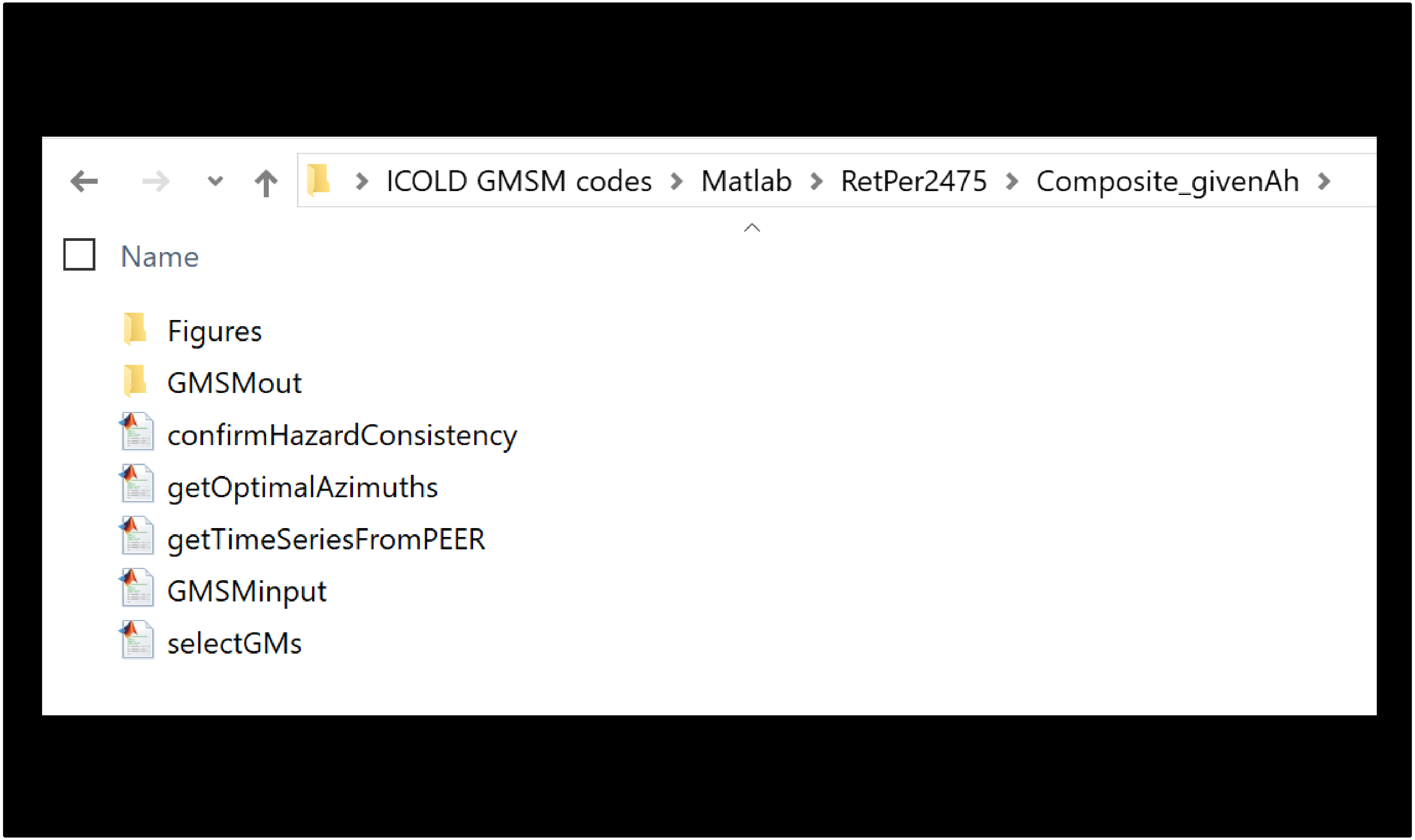
getCompositeSpec_givenAh.m

```matlab
%% Get multicomponent Composite Spectrum given Ah at Tmin to Tmax
% Note: Ensure beforehand that CMSs have been determined for Tmin and Tmax
clear all; close all; clc;

%% Input
% Define component of GM for conditioning
compStr = 'Ah';

% Specify range of vibration periods
Tmin = 0.1; % Make sure CMS has been computed for this period
Tmax = 0.75; % Make sure CMS has been computed for this period

% Create label for chosen Tmin and Tmax
TminStr = num2str(Tmin);
TminStr = strrep(TminStr,'.','p'); % Replace period to avoid clash with Windows extensions
TmaxStr = num2str(Tmax);
TmaxStr = strrep(TmaxStr,'.','p'); % Replace period to avoid clash with Windows extensions

% Specify output directory and filename
outputDir = '.\Output\';
outputFilename = ['CompositeGiven' compStr '_' TminStr '_' TmaxStr '.mat'];

% Load ERF and GMPM data for disaggregation
PSHAdir = '..\PSHA\Output\';
load(fullfile(PSHAdir, 'OpenSHAout.mat'));
load(fullfile(PSHAdir, 'GMPMout.mat'));
```

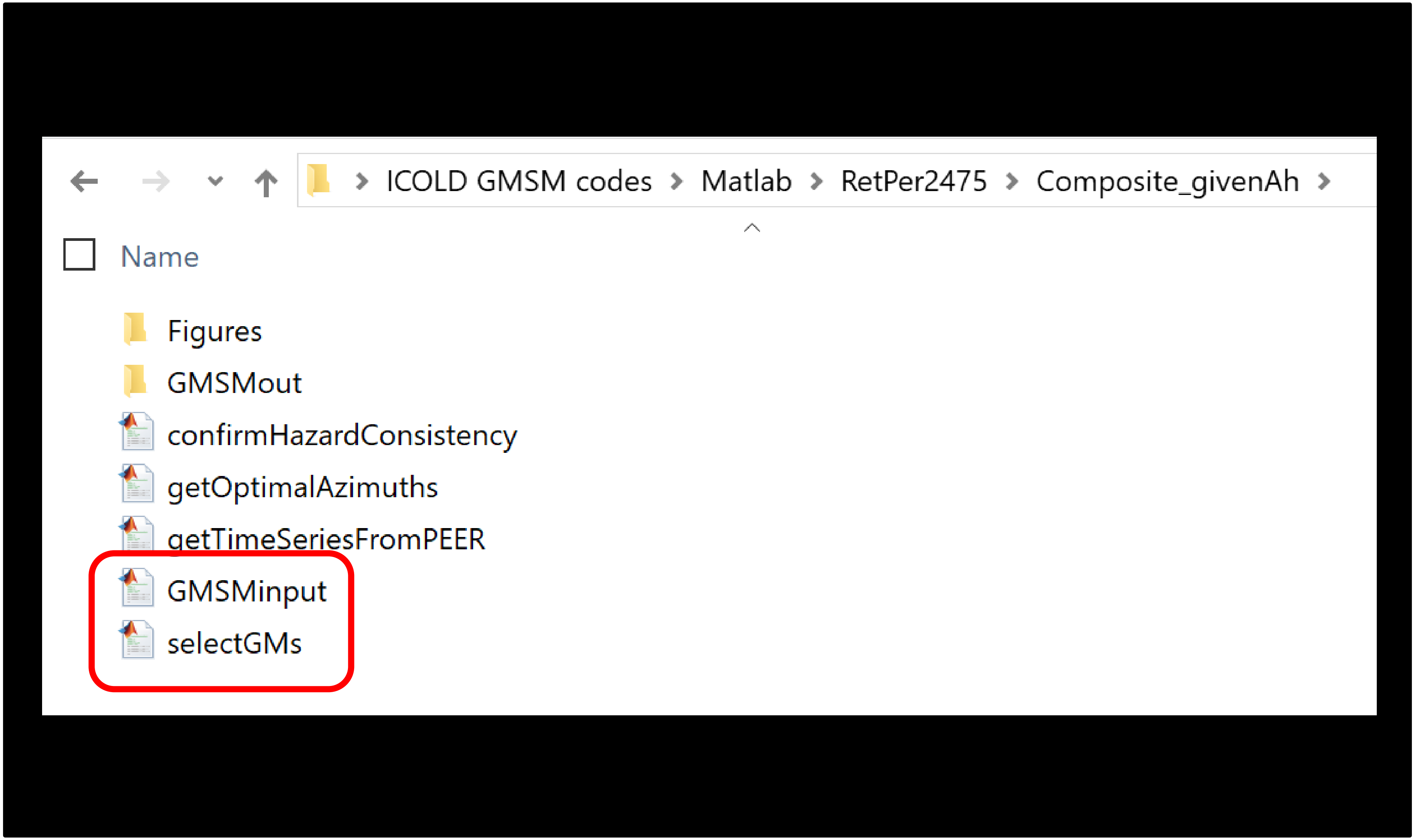
Given target spectrum, select GMs



Given target spectrum, select GMs



Given target spectrum, select GMs



Specify GMSM inputs

GMSMinput.m

```
%% Specify inputs for using scripts under this "target spectrum" folder
% Target spectrum
tgtSpecStr = 'Composite';
compStr = 'Ah'; % Which component to condition upon
compForConditioning = 'H'; % Which component to condition upon

% Conditioning periods
Tmin = 0.1;
Tmax = 0.75;

% GMSM input
isScaledFlag = 1; % =1 scales GMs; otherwise, =0 and set SFlimit to unity
SFlimit = 4; % Limit scale factors (SFs) to within (1/SFlimit) to SFlimit
sameSFflag = 1; % =1 sets SF for V component to be same as SF for H compone
wH = 0.5; % Ranges from 0 (only V component) to 1 (only H component) when c
```

Unique GMSM output folder

selectGMs.m

```
%% Select GMs to match a multicomponent target spectrum
% Matlab files from Prof. Jack Baker modified to include V component of GM
clear all; close all; clc;

%% Specify case to be considered
GMSMinput

% Create labels
TminStr = num2str(Tmin); TminStr = strrep(TminStr,'.','p'); % Replace perio
TmaxStr = num2str(Tmax); TmaxStr = strrep(TmaxStr,'.','p'); % Replace perio
wHstr = num2str(wH); wHstr = strrep(wHstr,'.','p'); % Replace period to avo
caseStr = ['T' TminStr '_' TmaxStr '_SFmax' int2str(SFlimit) '_sameSF' int2

% Input directories
targetSpectraDir = '..\Output\';

% Output directories
outDir = ['.\GMSMout\' caseStr];
figDir = ['.\Figures\' caseStr];
if(~exist(outDir,'dir')); mkdir(outDir); end;
if(~exist(figDir,'dir')); mkdir(figDir); end;

% Output filename
outFn = ['GMSMout.mat'];
NGAidFn = ['NGAid.txt']; % Text file containing NGA Record Sequence Numbers
```

Specify GMSM inputs

selectGMs.m

```
%% Specify GMSM inputs
% Ground motion database and type of selection
selectionParams.databaseDir     = '..\..\Databases';
selectionParams.databaseFile    = 'NGA_W2_meta_data';
selectionParams.RotD            = 50; % Define H component of GM
selectionParams.nGM             = 11; % number of ground motions to be sele

% Spectral periods of interest
selectionParams.cond       = 1; % =1 to include T* into periods for selecti
selectionParams.Tcond      = logspace(log10(Tmin),log10(Tmax),20); % Period
selectionParams.TgtPer     = logspace(log10(0.01),log10(10),20); % Periods

% Parameters for scaling GMs
selectionParams.condComp   = compForConditioning; % ='H' to scale GMs to ma
selectionParams.isScaled   = isScaledFlag; % =1 scales GMs; otherwise, =0 a
selectionParams.maxScale   = SFlimit; % Limit scale factors (SFs) to within
selectionParams.sameSF     = sameSFflag; % =1 sets SF for V component to be

% Relative importance of H component of GM
selectionParams.wH         = wH; % Ranges from 0 (only V component) to 1 (o

%{...%}
% Limits on metadata for filtering GM database
allowedRecs.Mag   = [ 5   Inf];        % upper and lower bound of allowable ma
allowedRecs.Vs30 = [180 Inf];          % upper and lower bound of allowable Vs
allowedRecs.LUF   = [ 0   0.1];        % upper and lower bound of allowable Lo
allowedRecs.D     = [ 15  Inf];        % upper and lower bound of allowable di
allowedRecs.NGAinvalid = [4577:4839 6993:8055 9194]; % Exclude NGA Record S
```

Specify GMSM inputs

selectGMs.m

```
%% Specify GMSM inputs
% Ground motion database and type of selection
selectionParams.databaseDir     = '..\..\Databases';
selectionParams.databaseFile    = 'NGA_W2_meta_data';
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selectionParams.TgtPer     = logspace(log10(0.01),log10(10),20); % Periods

% Parameters for scaling GMs
selectionParams.condComp   = compForConditioning; % ='H' to scale GMs to ma
selectionParams.isScaled   = isScaledFlag; % =1 scales GMs; otherwise, =0 a
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selectionParams.sameSF     = sameSFflag; % =1 sets SF for V component to be

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%{...%}
% Limits on metadata for filtering GM database
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allowedRecs.Vs30 = [180 Inf];         % upper and lower bound of allowable Vs
allowedRecs.LUF   = [ 0   0.1];       % upper and lower bound of allowable Lo
allowedRecs.D     = [ 15  Inf];       % upper and lower bound of allowable di
allowedRecs.NGAinvalid = [4577:4839 6993:8055 9194]; % Exclude NGA Record S
```

Specify GMSM inputs

selectGMs.m

```
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selectionParams.databaseFile    = 'NGA_W2_meta_data';
selectionParams.RotD            = 50; % Define H component of GM
selectionParams.nGM             = 11; % number of ground motions to be sele

% Spectral periods of interest
selectionParams.cond       = 1; % =1 to include T* into periods for selecti
selectionParams.Tcond      = logspace(log10(Tmin),log10(Tmax),20); % Period
selectionParams.TgtPer     = logspace(log10(0.01),log10(10),20); % Periods

% Parameters for scaling GMs
selectionParams.condComp   = compForConditioning; % ='H' to scale GMs to ma
selectionParams.isScaled   = isScaledFlag; % =1 scales GMs; otherwise, =0 a
selectionParams.maxScale   = SFlimit; % Limit scale factors (SFs) to within
selectionParams.sameSF     = sameSFflag; % =1 sets SF for V component to be

% Relative importance of H component of GM
selectionParams.wH         = wH; % Ranges from 0 (only V component) to 1 (o

%{...%}
% Limits on metadata for filtering GM database
allowedRecs.Mag  = [ 5  Inf];      % upper and lower bound of allowable ma
allowedRecs.Vs30 = [180 Inf];      % upper and lower bound of allowable Vs
allowedRecs.LUF  = [ 0  0.1];      % upper and lower bound of allowable Lo
allowedRecs.D    = [ 15  Inf];     % upper and lower bound of allowable di
allowedRecs.NGAinvalid = [4577:4839 6993:8055 9194]; % Exclude NGA Record S
```
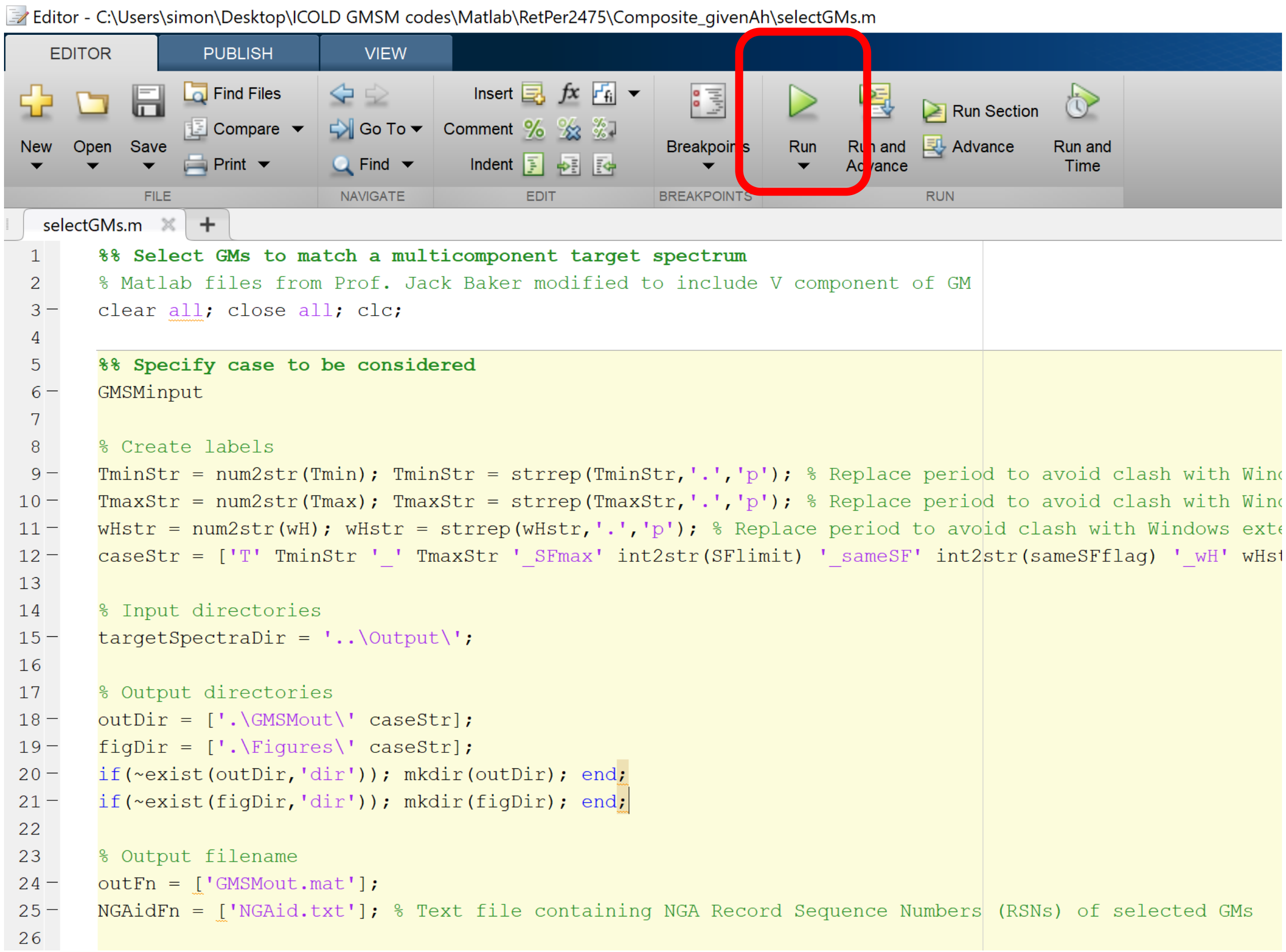
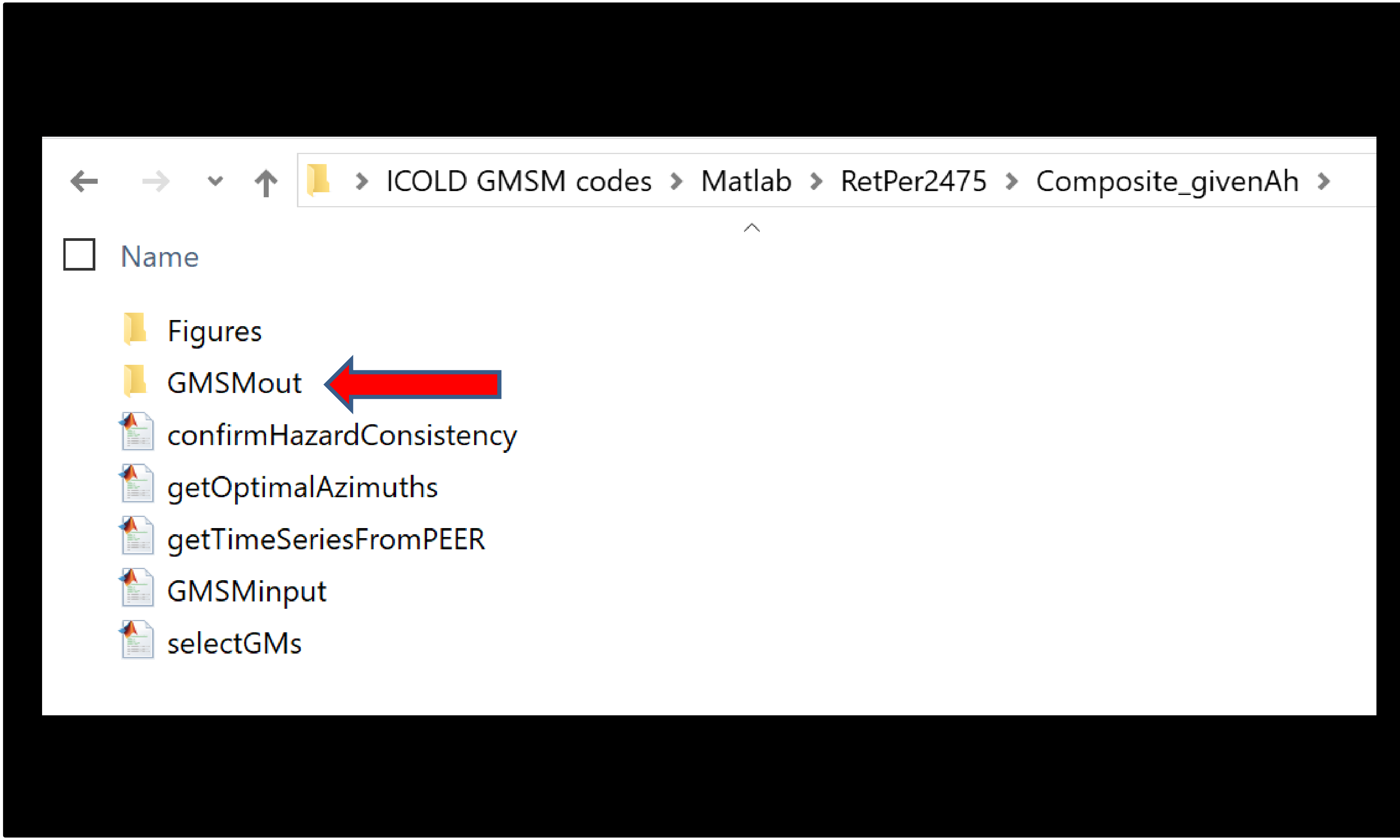

Select GMs

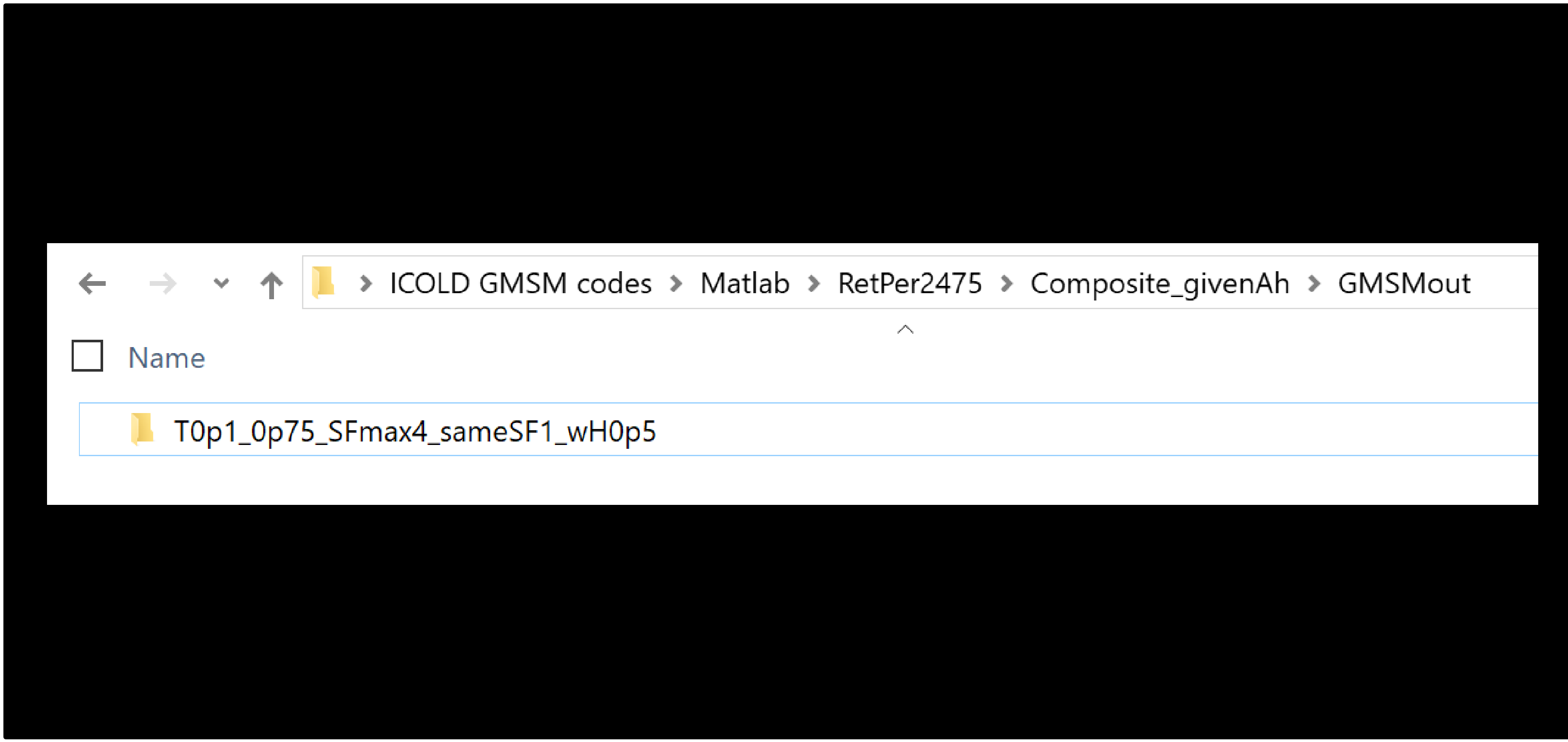


Editor - C:\Users\simon\Desktop\ICOLD GMSM codes\Matlab\RetPer2475\Composite_givenAh\selectGMs.m
EDITOR
PUBLISH
VIEW
New
Open
Save
Find Files
Compare
Print
Go To
Find
Insert
Comment
Indent
Breakpoints
Run
Run and Advance
Run Section
Advance
Run and Time
FILE
NAVIGATE
EDIT
BREAKPOINTS
RUN
selectGMs.m
%% Select GMs to match a multicomponent target spectrum
% Matlab files from Prof. Jack Baker modified to include V component of GM
clear all; close all; clc;
%% Specify case to be considered
GMSMinput
% Create labels
TminStr = num2str(Tmin); TminStr = strrep(TminStr,'.','p'); % Replace period to avoid clash with Win
TmaxStr = num2str(Tmax); TmaxStr = strrep(TmaxStr,'.','p'); % Replace period to avoid clash with Win
wHstr = num2str(wH); wHstr = strrep(wHstr,'.','p'); % Replace period to avoid clash with Windows exte
caseStr = ['T' TminStr '_' TmaxStr '_SFmax' int2str(SFlimit) '_sameSF' int2str(sameSFflag) '_wH' wHst
% Input directories
targetSpectraDir = '..\Output\';
% Output directories
outDir = ['.\GMSMout\' caseStr];
figDir = ['.\Figures\' caseStr];
if(~exist(outDir,'dir')); mkdir(outDir); end;
if(~exist(figDir,'dir')); mkdir(figDir); end;
% Output filename
outFn = ['GMSMout.mat'];
NGAidFn = ['NGAid.txt']; % Text file containing NGA Record Sequence Numbers (RSNs) of selected GMs

GMSM output


ICOLD GMSM codes › Matlab › RetPer2475 › Composite_givenAh ›
Name
Figures
GMSMout
confirmHazardConsistency
getOptimalAzimuths
getTimeSeriesFromPEER
GMSMinput
selectGMs

GMSM output


ICOLD GMSM codes > Matlab > RetPer2475 > Composite_givenAh > GMSMout
Name
T0p1_0p75_SFmax4_sameSF1_wH0p5

GMSM output

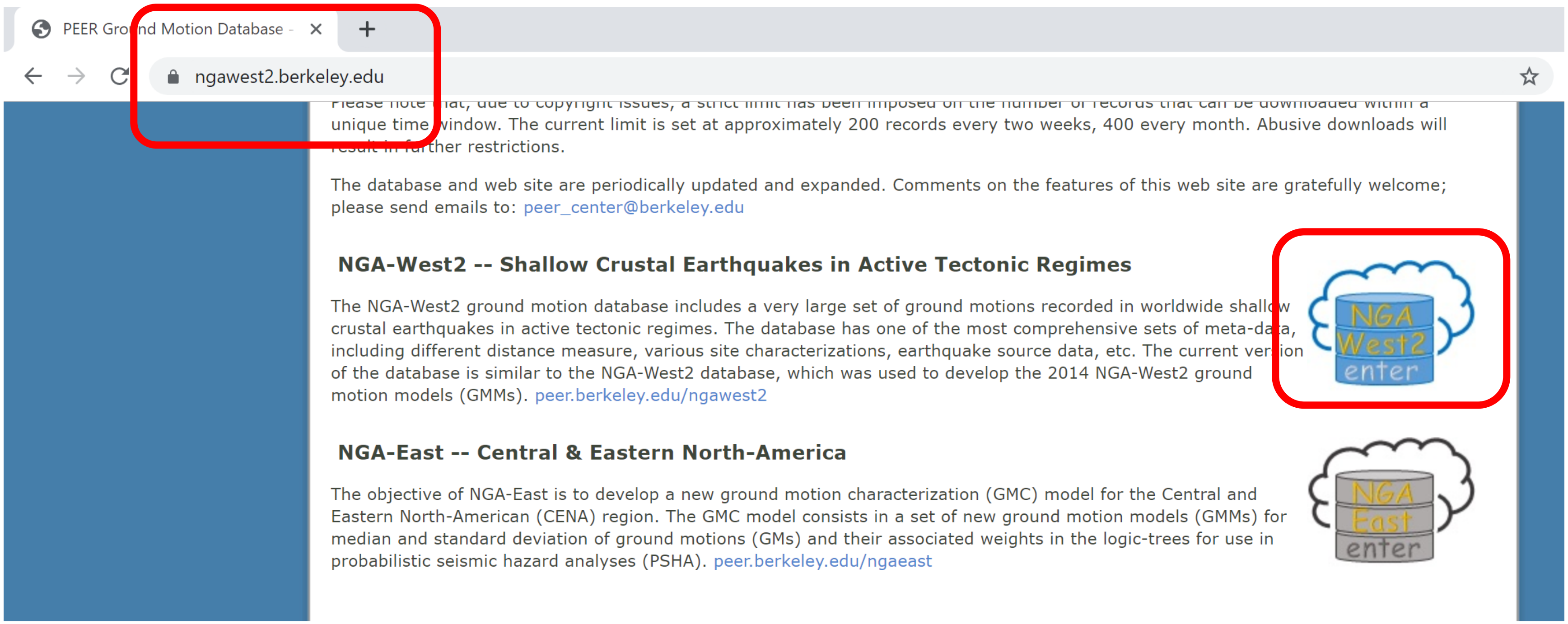
ICOLD GMSM codes > Matlab > RetPer2475 > Composite_givenAh > GMSMout > T0p1_0p75_SFmax4_sameSF1_wH0p5 >
Name
Type
timeSeriesData
MATLAB Data
PEERNGARecords_Unscaled
Compressed (zipped)..
NGAid
TXT File
GMSMout_rotated
MATLAB Data
GMSMout
MATLAB Data
PEERNGARecords_Unscaled
File folder

Get NGA RSNs for time series

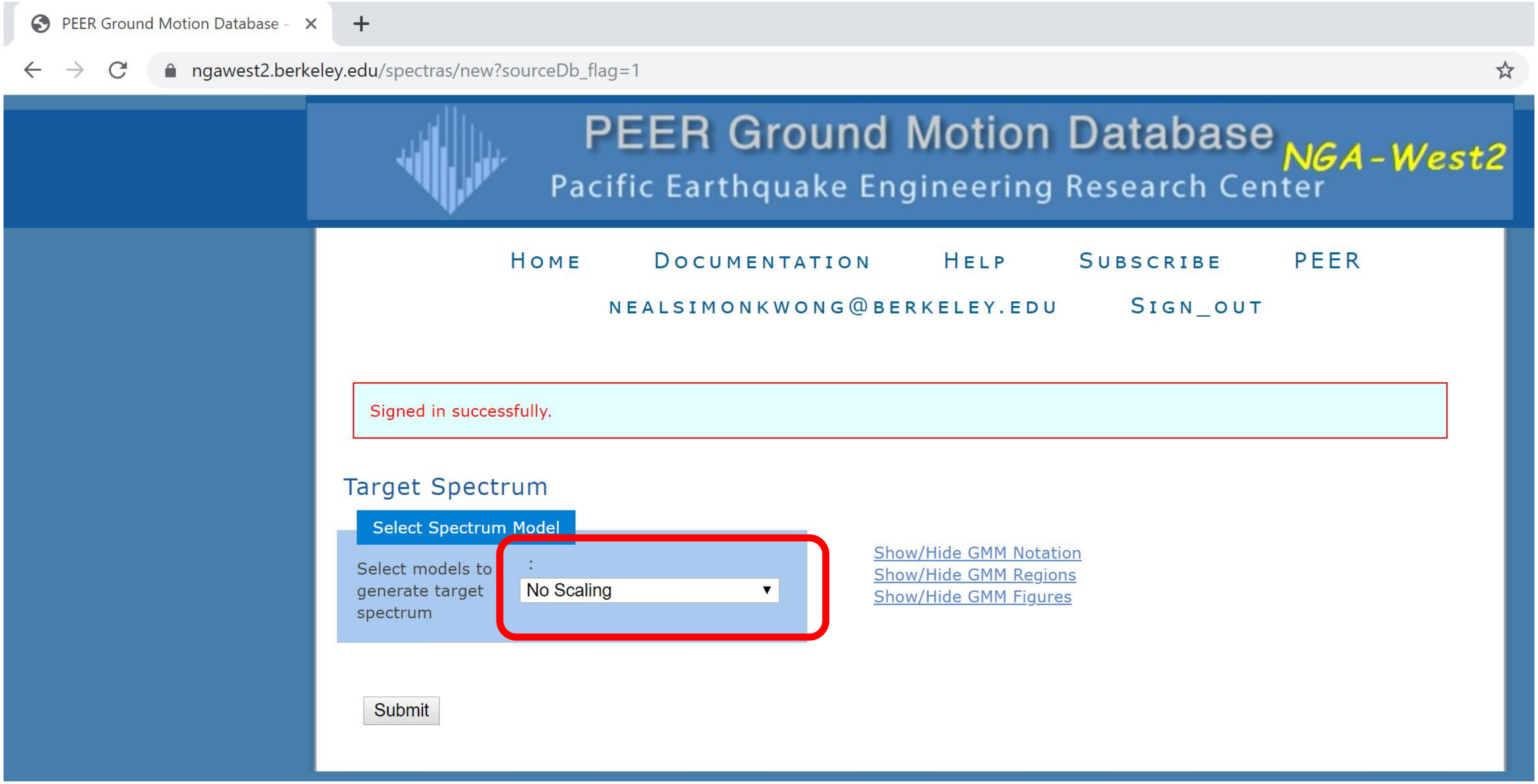
NGAid.txt

```
2623 ,
2981 ,
3000 ,
3002 ,
3188 ,
4153 ,
4212 ,
5292 ,
5652 ,
5672 ,
5811 ,
```

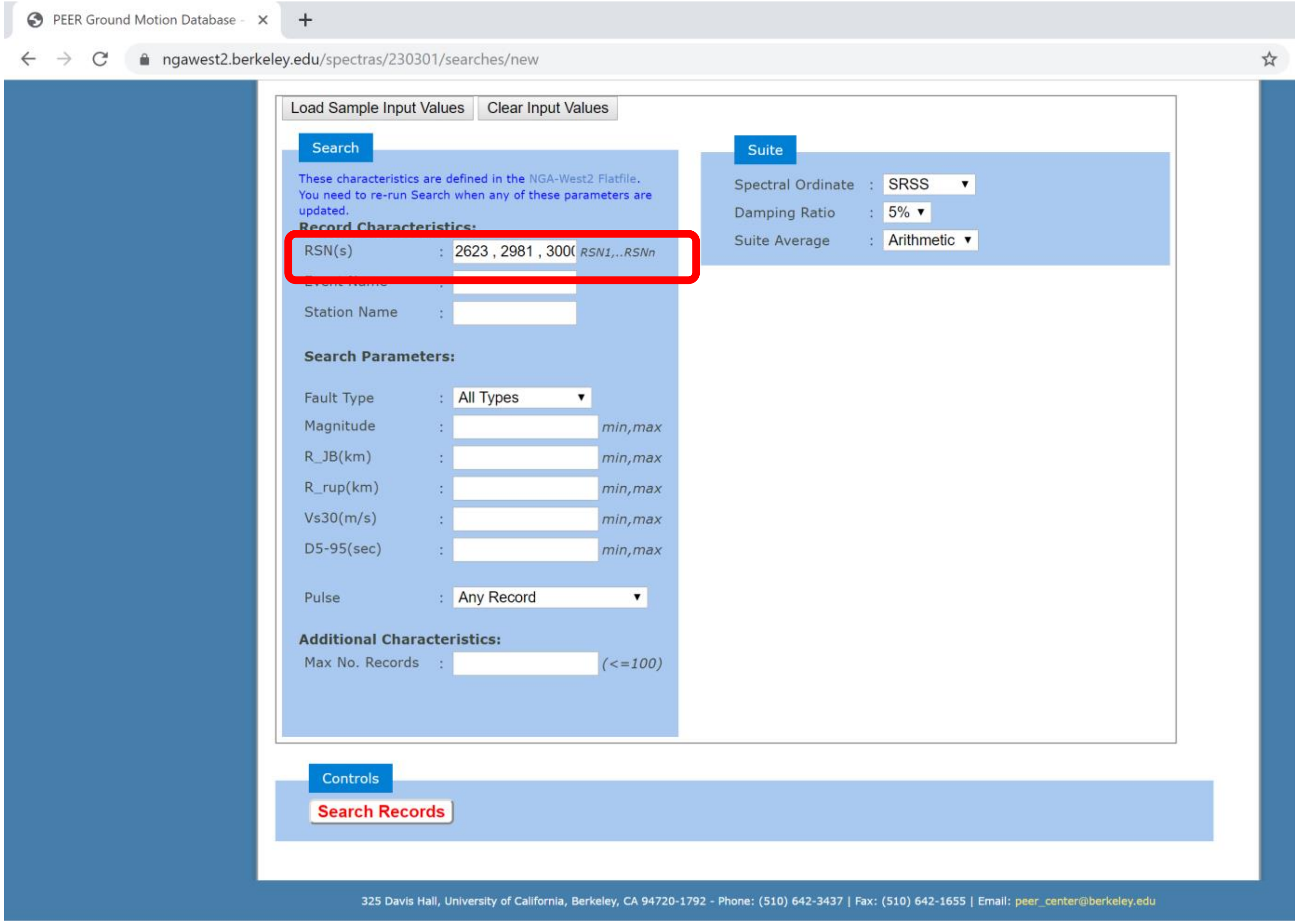
Get time series



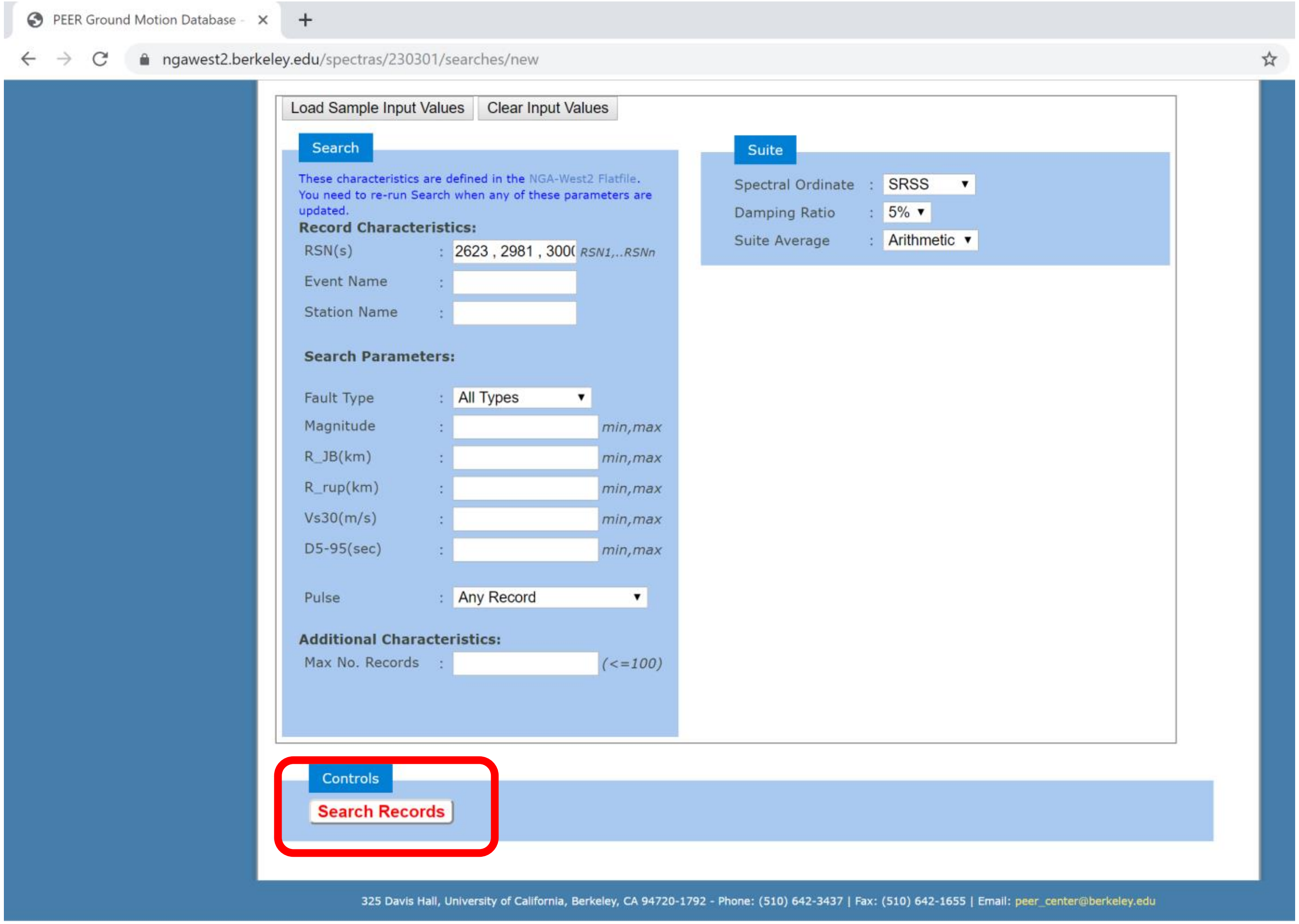
Get time series



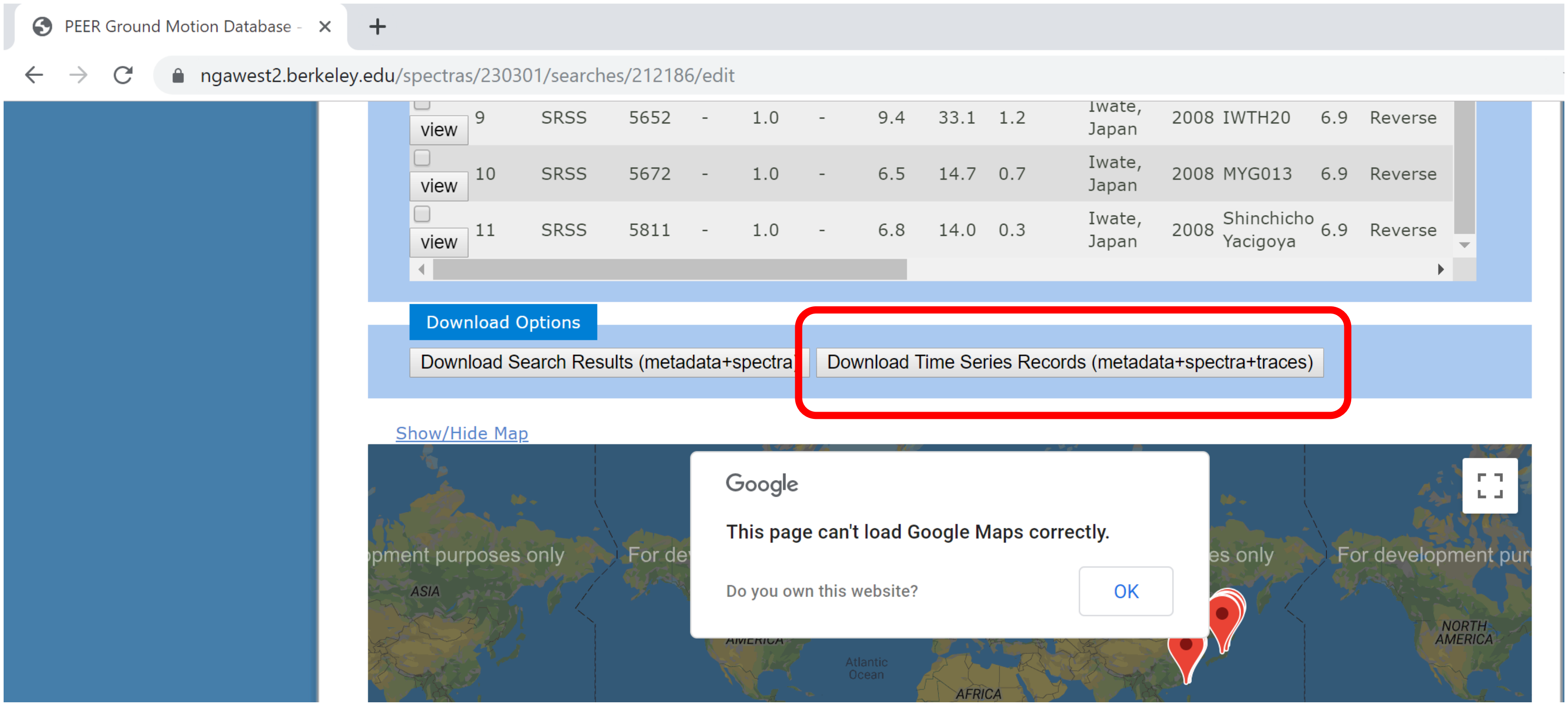
Provide NGA RSNs



Get time series

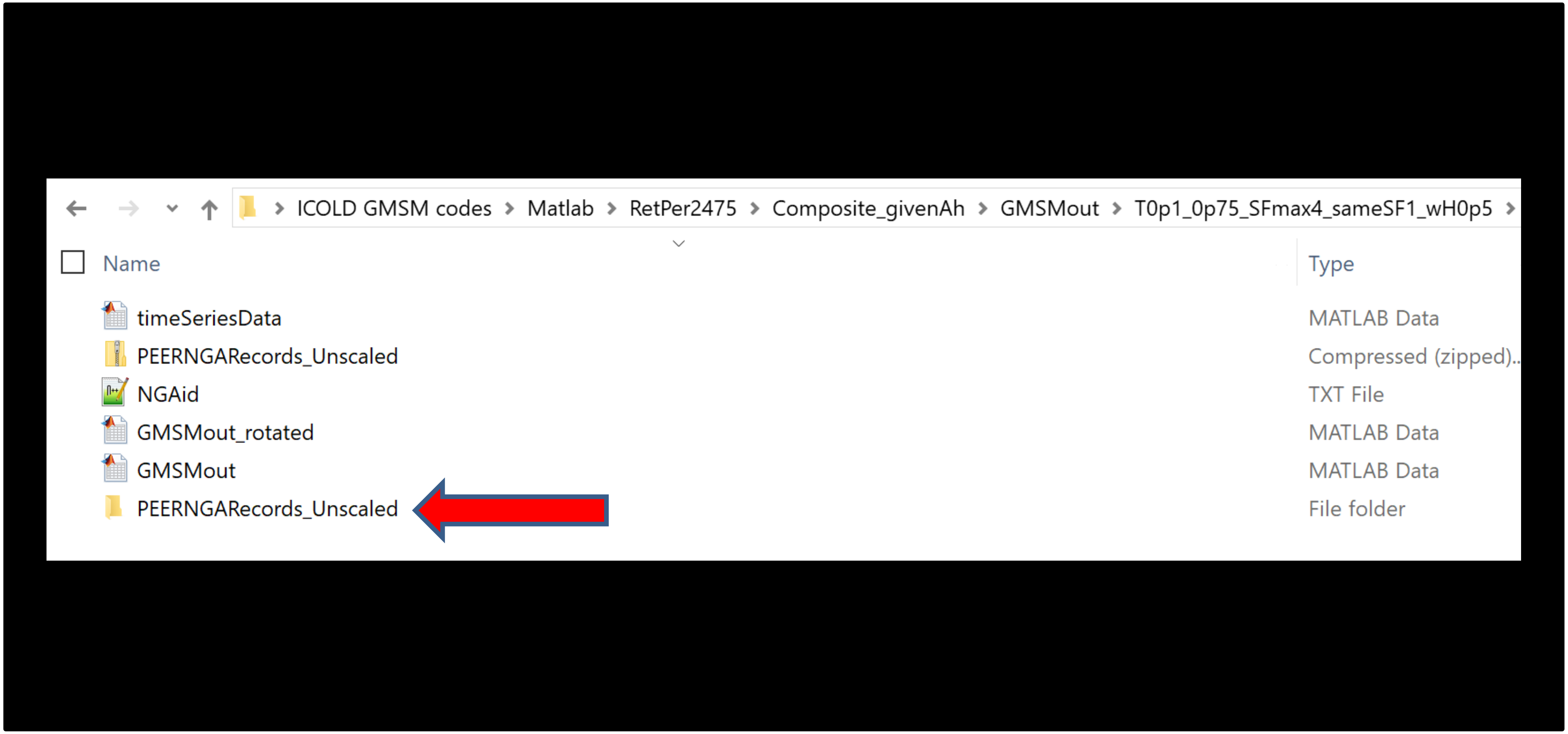


Get time series

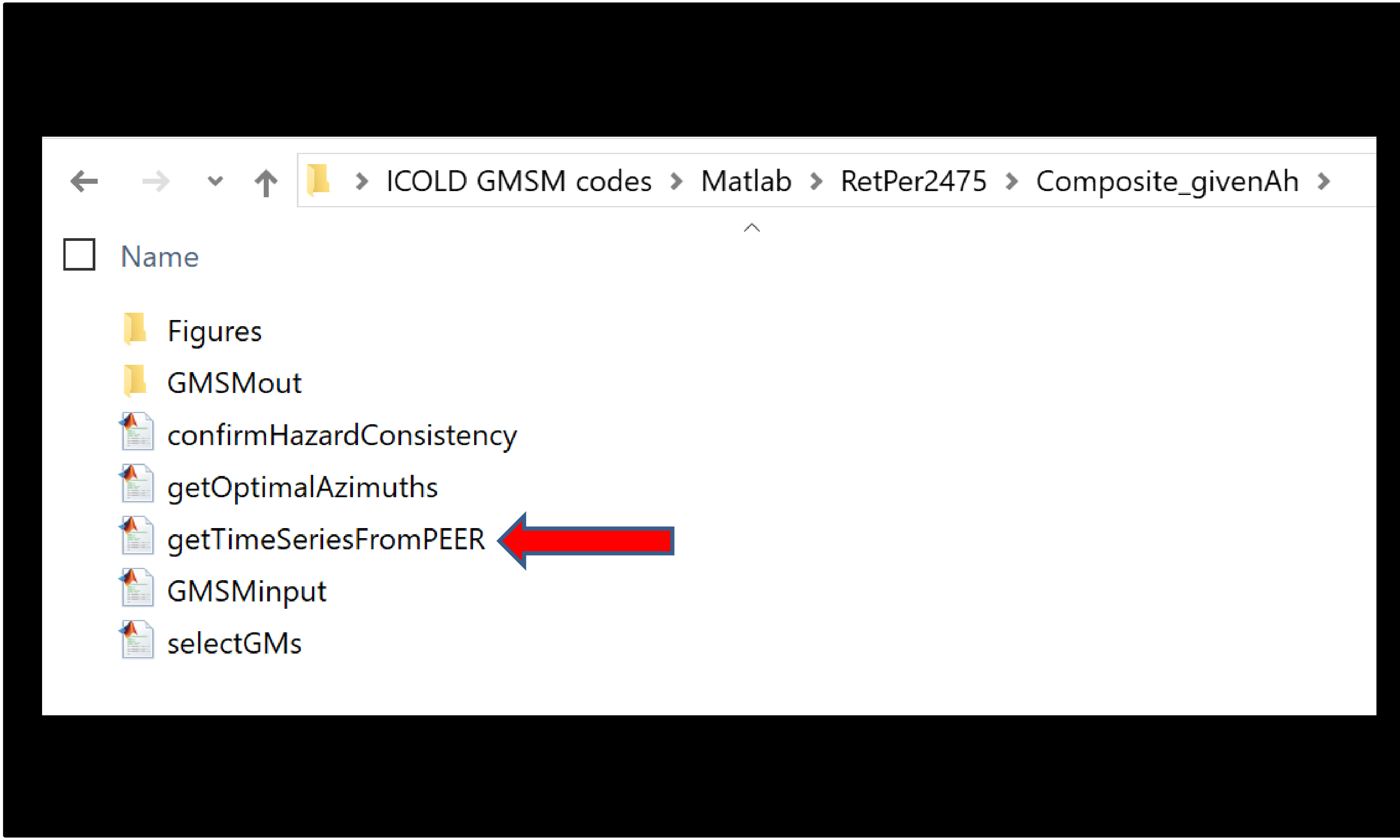


Get time series

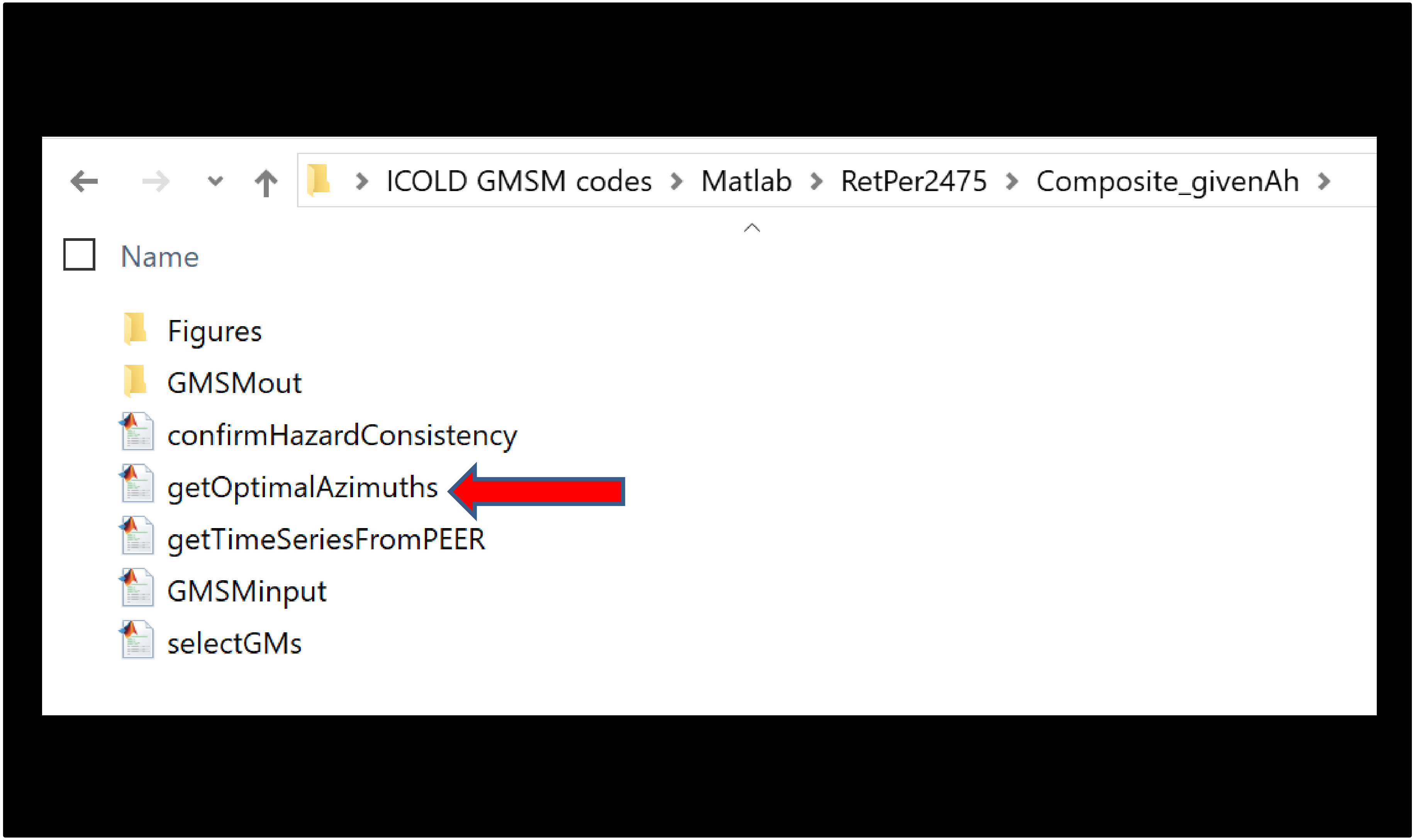
Unzip folder for time series



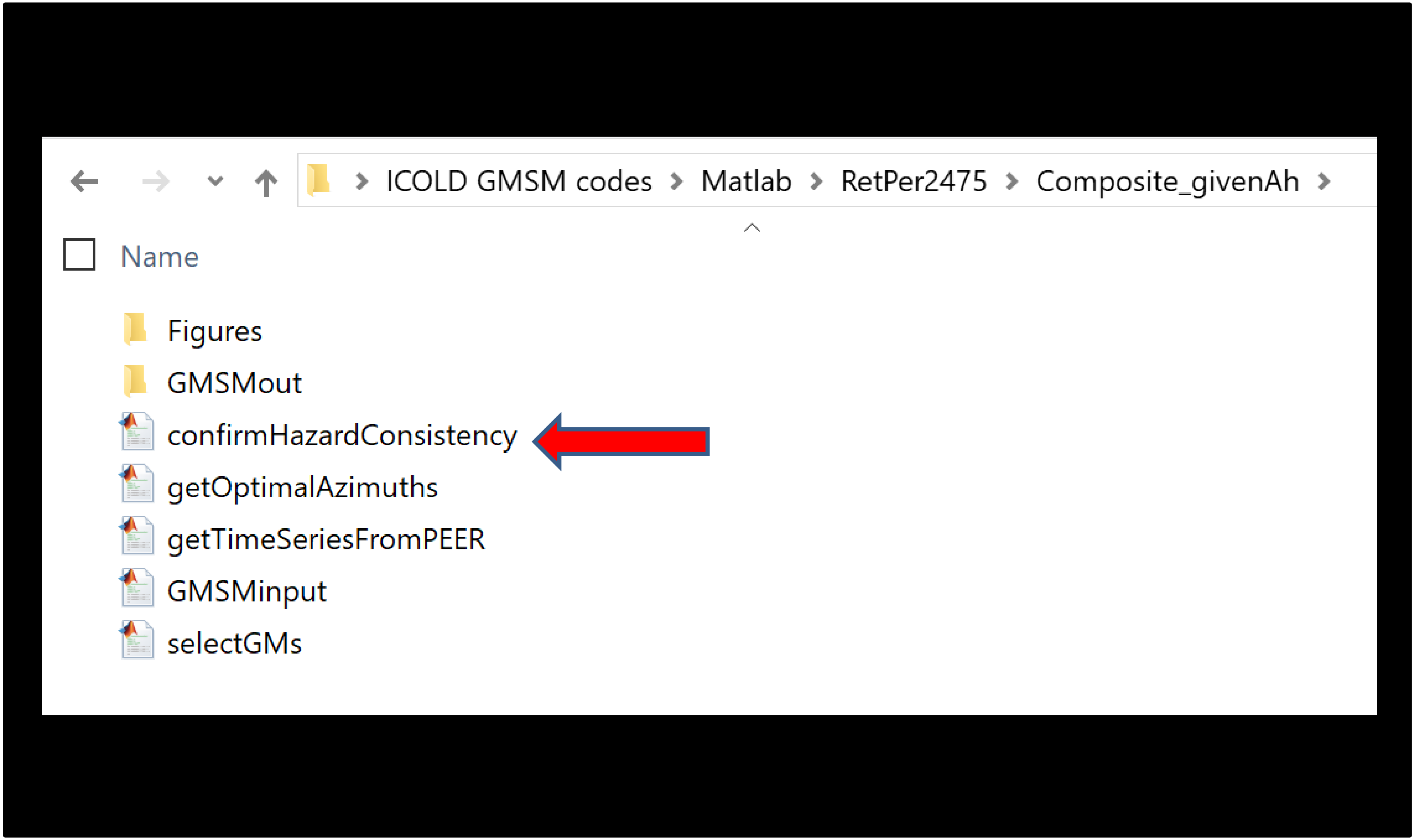
Extract time series data



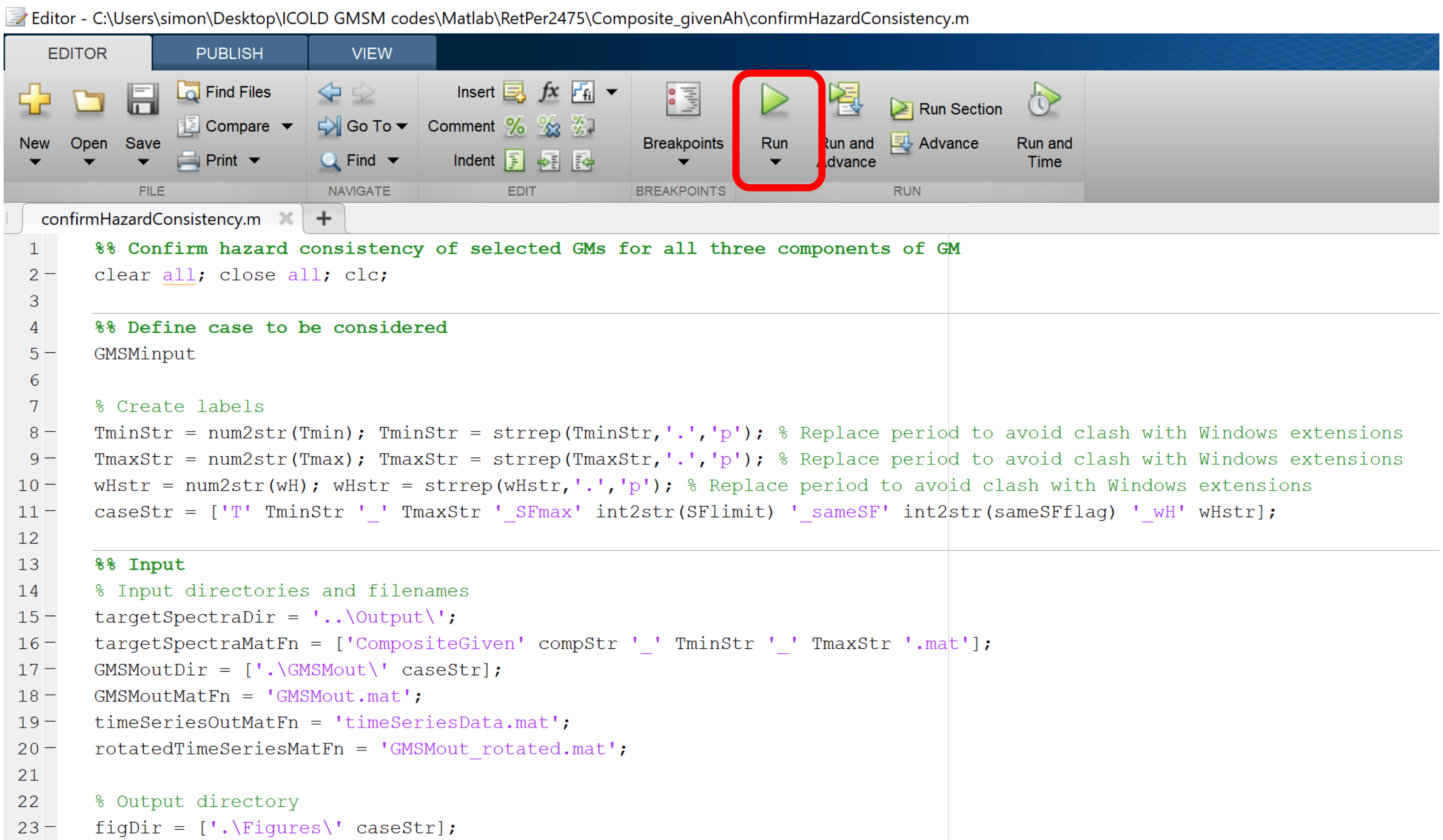
Get optimal azimuths



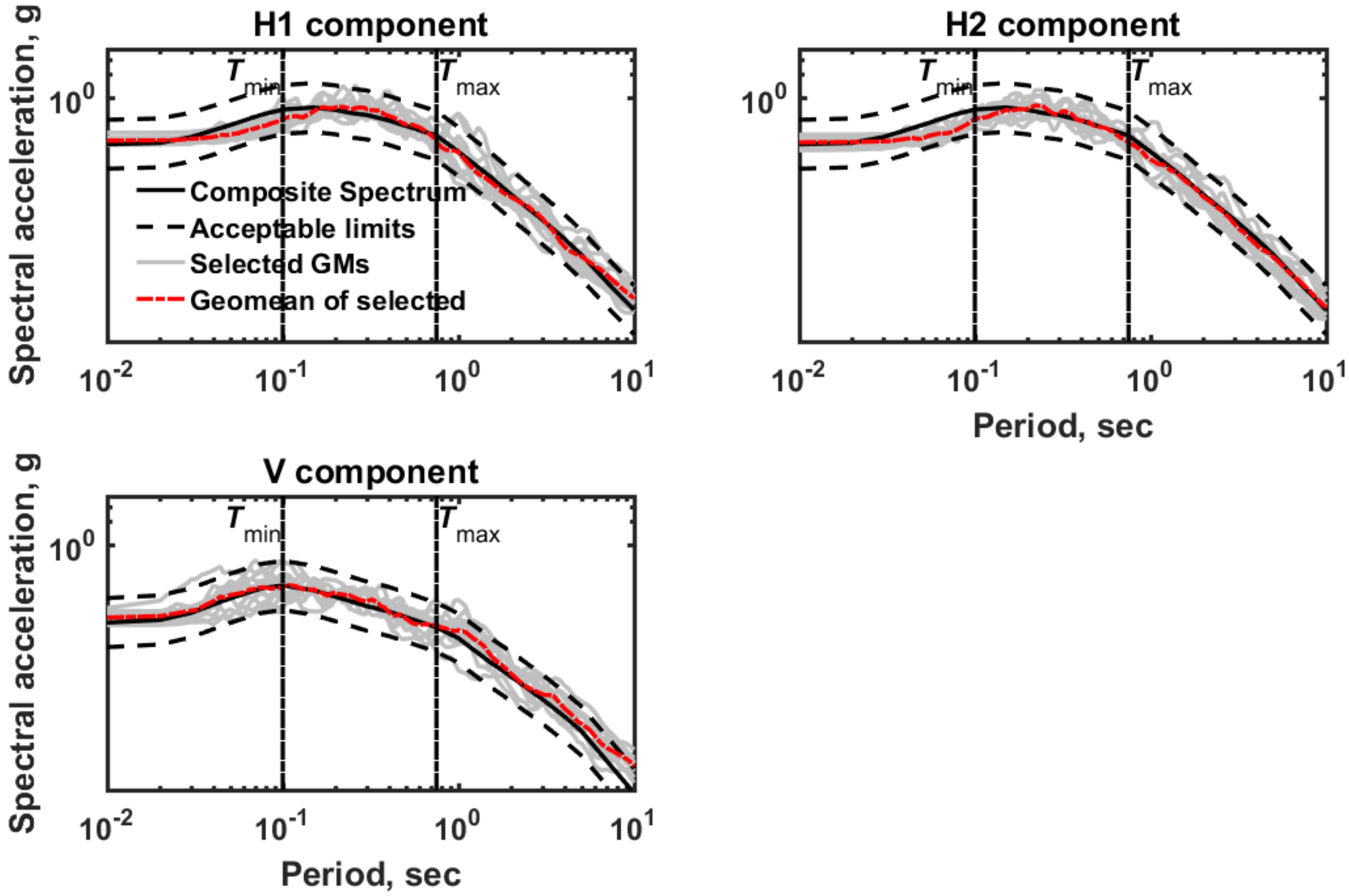
Confirm hazard consistency



Confirm hazard consistency



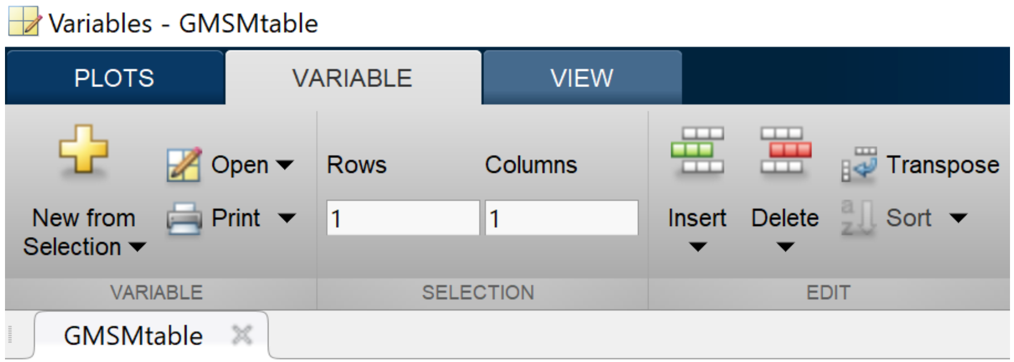
Example hazard consistency



Final GMSM output

```
%% Summarize GMSM
GMSMtable = [NGAselected sfSelected sfSelected_vert thetaOpt_all];
open GMSMtable
```

Final GMSM output



11x4 double

	1	2	3	4	5	6
1	2623	2.0465	2.0465	18		
2	2981	3.5424	3.5424	16		
3	3000	3.4822	3.4822	60		
4	3002	3.6831	3.6831	77		
5	3188	2.5850	2.5850	23		
6	4153	2.1781	2.1781	15		
7	4212	0.9267	0.9267	7		
8	5292	3.6836	3.6836	28		
9	5652	1.0741	1.0741	2		
10	5672	1.2480	1.2480	49		
11	5811	1.9691	1.9691	90		
12						
13						