



ExchangeRisk

EXperimental & **C**omputational **H**ybrid **A**ssessment of **N**atural
Gas Pipelines **E**xposed to Seismic **R**isk



UNIVERSITÀ DEGLI STUDI
DI NAPOLI FEDERICO II

WP5 - Multi-damage seismic risk assessment of soil- NG pipeline networks



Project Workshop 18/06/2018

REgionAl, Single-SitE and Scenario-based Seismic hazard analysis



OBJECTIVE

D5.2. Comprehensive methodology & software for generating seismic scenarios of NG pipelines

REASSESS V 2.0

RegionAl, Single-SitE and Scenario-based Seismic hazard analysis
 (c) Iunio Iervolino, Eugenio Chioccarelli, Pasquale Cito and Massimiliano Giorgio
 Dipartimento di Strutture per l'Ingegneria e l'Architettura, Università degli studi di Napoli Federico II

Intensity Measure

Selected IM Hazard Curve (black line)
 Other IM Hazard Curves (grey lines)
 Selected Return Period (Tr) (red line)

Sa(T=0s)=8.05E-02g

SINGLE-SITE OUTPUT

Spectra
 Tr [yrs]: 465

 Disaggregation
 Tr [yrs]: 465 T [s]: 0
 Type:
 Exceedance
 Occurrence

INPUT

1. Analysis
 PSHA SPSHA MSPSHA

2. Site(s) Definition
 Long [°]: 14.246 Lat [°]: 40.856
 Vs30 [m/s]: Default 800

3. GMPM and IM range
 Logic tree: No
 Branches: 1 GMPMs:
 GMPM: Akkar&Bomme...
 min: 0 max: 0.2 n° step: 65

4. IM(s)

 Zones from Databases
 User-Defined Zones
 Individual Faults

5. Seismic Sources
 Zones from Databases
 User-Defined Zones
 Individual Faults

6. Logic Tree Branches

MULTISITE OUTPUT

(I) Joint probability (P) of observing a given number of exceedances at the sites in a given time interval
 P:

(II) Distribution of total number of exceedances in a given time interval

(III) Distribution of total number of exceedances given the occurrence of an earthquake

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Secondment duration:

17/07/2017 to 17/08/2017 (one month)

Planned 07-09/2018 (two months)



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Pasquale Cito, Structural Engineer, Ph.D. Student in Structural, Geotechnical and Seismic engineering

Research interests: Seismic hazard assessment.



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**Secondment duration:
28/08/2016 to 28/09/2016 (one month)**



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Eugenio Chioccarelli, Structural Engineer, Ph.D.
Researcher at the Construction Technology Institute



(Italian National Research Council , ITC – CNR; affiliate of UNAP in the project)

Research interests: Long- and Short-Term Seismic Risk Assessment for Civil Structures, Engineering Seismology, Probability Seismic Hazard Analysis in Far-Field and Near-Source Conditions, Characterization of Seismic Input



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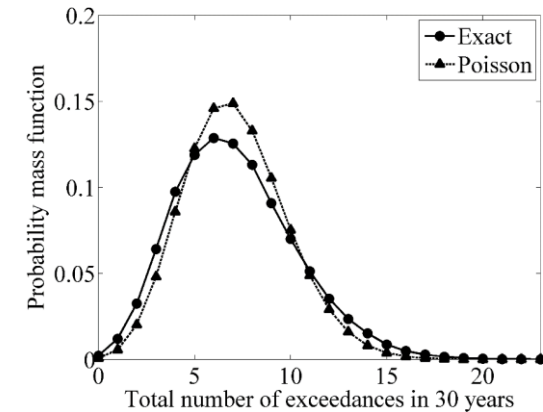
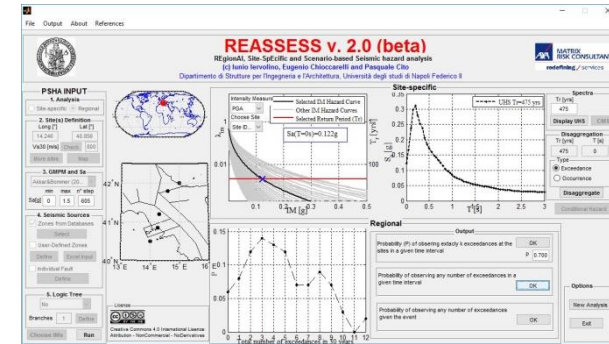
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Outline of research activities during secondments



Eugenio Chioccarelli, Ph.D.
One month from University of Naples
to Norwegian Geotechnical Institute

- Risk estimation calculations for distributed systems such as buried pipelines require **multiple-site (regional) probabilistic seismic hazard analysis (PSHA)** that takes spatial correlation of seismic intensity measures into account.
- **Multisite PSHA** accounts for the stochastic dependence among the site-specific processes counting the number of exceedance of a ground motion intensity measure threshold at single site.
- These secondments have contributed to the elaboration of a user-friendly and **stand-alone software**, named **REASSESS**, for the probabilistic seismic hazard assessment of single- and multiple-sites.



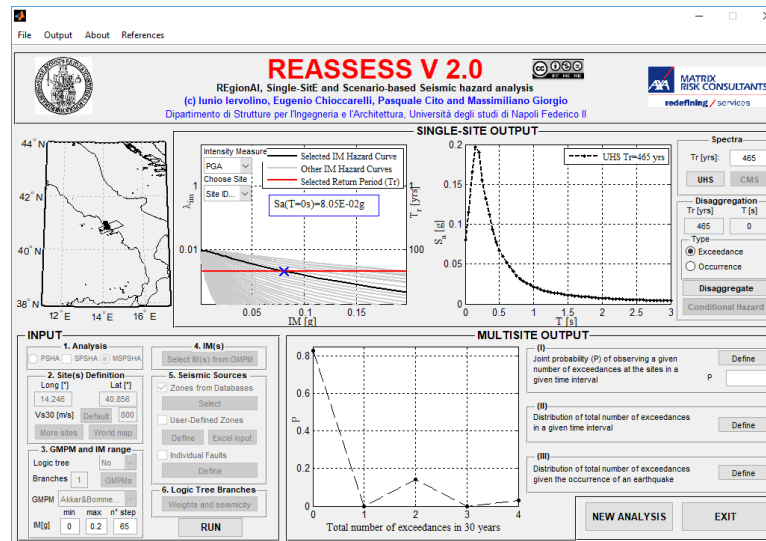
Pasquale Cito, Ph.D. Student
Three months from University of Naples
to Vienna Consulting Engineers

Anticipated publication:
E. Chioccarelli, P. Cito, I. Iervolino, M. Giorgio. “REASSESS V2.0: software for single- and multi-site probabilistic seismic hazard analysis”, submitted to the Bulletin of Earthquake Engineering

REgionAl, Single-SitE and Scenario-based Seismic hazard analysis

UPDATES IMPLEMENTED DURING AND AFTER SECONDMENTS:

- ✓ Procedure for sequence-based PSHA*;
- ✓ Spatial cross-correlation of spectral accelerations at multiple periods is taken into account in multisite PSHA**;
- ✓ Conditional hazard also provides the distribution of a secondary **intensity measure** (e.g., PGV) given the occurrence of a primary one (e.g., S_a);
- ✓ Possibility of PSHA for advanced IMs (I_{NP} and S_{avg}).



* Implemented in part during the first secondment at VCE (from July 17th to August 17th, 2017)

** Spatial correlation implementation closed during the first secondment at VCE. Spatial-cross correlation implementation to be optimized during the second secondment at VCE (from July 9th to September 27th 2018)

SOFTWARE AVAILABILITY VIA WEBPAGE <http://wpage.unina.it/iuniervo/>



Università degli Studi di Napoli
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REASSESS

(05.26.2017) REASSESS V2.0 (beta) HAS BEEN RELEASED: REASSESS software is a stand-alone user-friendly software for the probabilistic assessment of seismic hazard. REASSESS V 2.0 performs (i) site-specific and (ii) multi-site seismic hazard analysis. For (i) it computes hazard curves, uniform hazard spectra, disaggregation and conditional mean spectra at a specific site. For (ii) it computes the probability of observing any given number of joint exceedances of a ground motion intensity measure at a set of sites in a given time interval, the total number of exceedances at multiple locations in any time interval, and the number of sites experiencing at least one exceedance in a given time interval. Seismic sources can be either zones or individual faults. REASSESS also is able to account for model uncertainty, in fact, logic trees can be built based on alternatives for the source's annual rate of earthquake occurrence, magnitude distribution and ground motion prediction equation.



REFERENCES: The current main reference for REASSESS is: [Iervolino L., Chioccarelli E., Cito P. \(2016\). REASSESS v1.0: a computationally-efficient software for probabilistic seismic hazard analysis. Proc. of VII European Congress on Computational Methods in Applied Sciences and Engineering, ECCOMAS, Crete Island, Greece, 5-10 June.](#)

DISCLAIMER: REASSESS may be used for free (FOR NON-COMMERCIAL PURPOSES ONLY). The authors have made every effort in order to ensure that the software functions accurately; all responsibility regarding the correctness of obtained results resides with the user.

APPLY [HERE](#) TO TEST THE BETA VERSION OF REASSESS

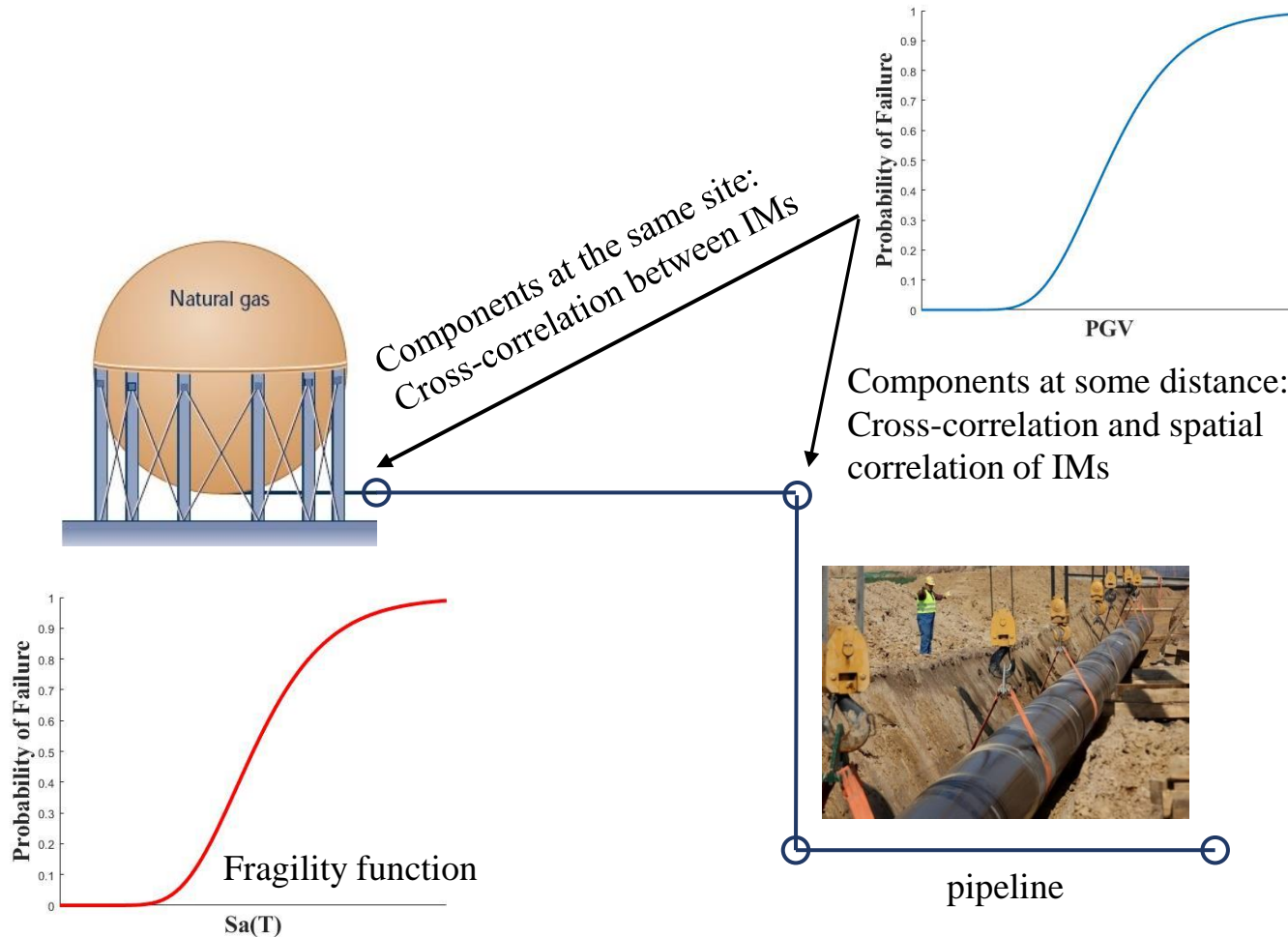
The map of institutions testing REASSESS

www.unina.it

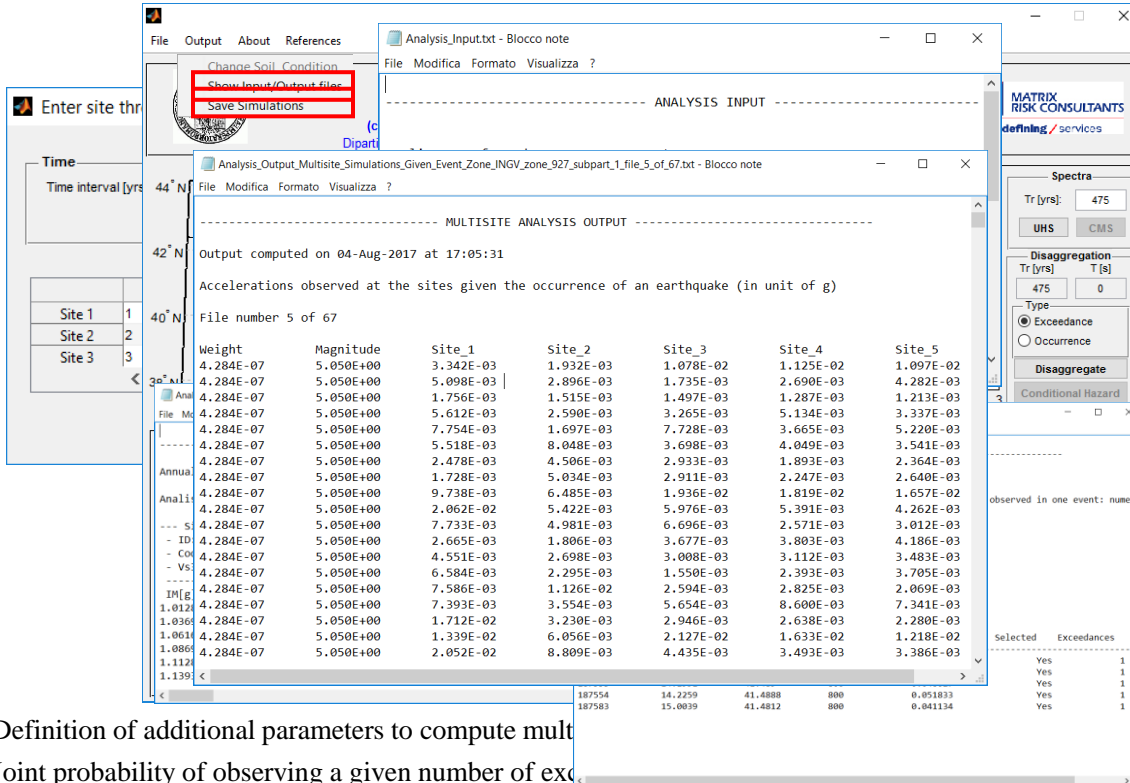
RegionAl, Single-SitE and Scenario-based Seismic hazard analysis

Network component fragilities expressed in terms of different intensity measures for different component types: Risk assessment can be performed by using **conditional hazard** (distribution of the secondary IM given a certain value of the primary IM).

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Graphical interface and multisite outputs



The screenshot shows the software's graphical interface. On the left, there is a sidebar with 'Enter site thr' and 'Time' sections. The main window displays 'ANALYSIS INPUT' and 'MULTISITE ANALYSIS OUTPUT'. A table of results is shown, with columns for Weight, Magnitude, and Site 1 through Site 5. A 'Show Input/Output files' button is highlighted with a red box. On the right, there are panels for 'Spectra' and 'Disaggregation'.

| Weight | Magnitude | Site_1 | Site_2 | Site_3 | Site_4 | Site_5 |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 4.284E-07 | 5.050E+00 | 3.342E-03 | 1.932E-03 | 1.078E-02 | 1.125E-02 | 1.097E-02 |
| 4.284E-07 | 5.050E+00 | 5.098E-03 | 2.896E-03 | 1.735E-03 | 2.690E-03 | 4.282E-03 |
| 4.284E-07 | 5.050E+00 | 1.756E-03 | 1.515E-03 | 1.497E-03 | 1.287E-03 | 1.213E-03 |
| 4.284E-07 | 5.050E+00 | 5.612E-03 | 2.590E-03 | 3.265E-03 | 5.134E-03 | 3.337E-03 |
| 4.284E-07 | 5.050E+00 | 7.754E-03 | 1.697E-03 | 7.728E-03 | 3.665E-03 | 5.220E-03 |
| 4.284E-07 | 5.050E+00 | 5.518E-03 | 8.048E-03 | 3.698E-03 | 4.049E-03 | 3.541E-03 |
| 4.284E-07 | 5.050E+00 | 2.478E-03 | 4.506E-03 | 2.933E-03 | 1.893E-03 | 2.364E-03 |
| 4.284E-07 | 5.050E+00 | 1.728E-03 | 5.034E-03 | 2.911E-03 | 2.247E-03 | 2.640E-03 |
| 4.284E-07 | 5.050E+00 | 9.738E-03 | 6.485E-03 | 1.936E-02 | 1.819E-02 | 1.657E-02 |
| 4.284E-07 | 5.050E+00 | 2.062E-02 | 5.422E-03 | 5.976E-03 | 5.391E-03 | 4.262E-03 |
| 4.284E-07 | 5.050E+00 | 7.733E-03 | 4.981E-03 | 6.696E-03 | 2.571E-03 | 3.012E-03 |
| 4.284E-07 | 5.050E+00 | 2.665E-03 | 1.806E-03 | 3.677E-03 | 3.803E-03 | 4.186E-03 |
| 4.284E-07 | 5.050E+00 | 4.551E-03 | 2.698E-03 | 3.008E-03 | 3.112E-03 | 3.483E-03 |
| 4.284E-07 | 5.050E+00 | 6.584E-03 | 2.295E-03 | 1.550E-03 | 2.393E-03 | 3.705E-03 |
| 4.284E-07 | 5.050E+00 | 7.586E-03 | 1.126E-02 | 2.594E-03 | 2.825E-03 | 2.069E-03 |
| 4.284E-07 | 5.050E+00 | 7.393E-03 | 3.554E-03 | 5.654E-03 | 8.600E-03 | 7.341E-03 |
| 4.284E-07 | 5.050E+00 | 1.712E-02 | 3.230E-03 | 2.946E-03 | 2.638E-03 | 2.280E-03 |
| 4.284E-07 | 5.050E+00 | 1.339E-02 | 6.056E-03 | 2.127E-02 | 1.633E-02 | 1.218E-02 |
| 4.284E-07 | 5.050E+00 | 2.052E-02 | 8.809E-03 | 4.435E-03 | 3.493E-03 | 3.386E-03 |

- Definition of additional parameters to compute mult
- Joint probability of observing a given number of exc
- Distribution of the total number of exceedances at the sites in a given time interval
- Distribution of the total number of exceedances at the sites given the occurrence of an earthquake
- Export input and output files
- Save simulations

RegionAl, Single-SitE and Scenario-based Seismic hazard analysis

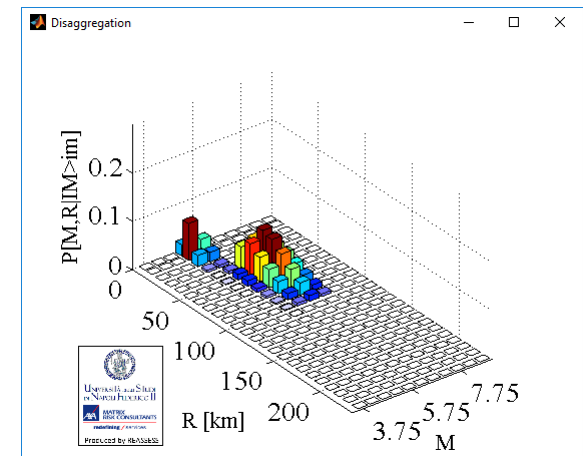
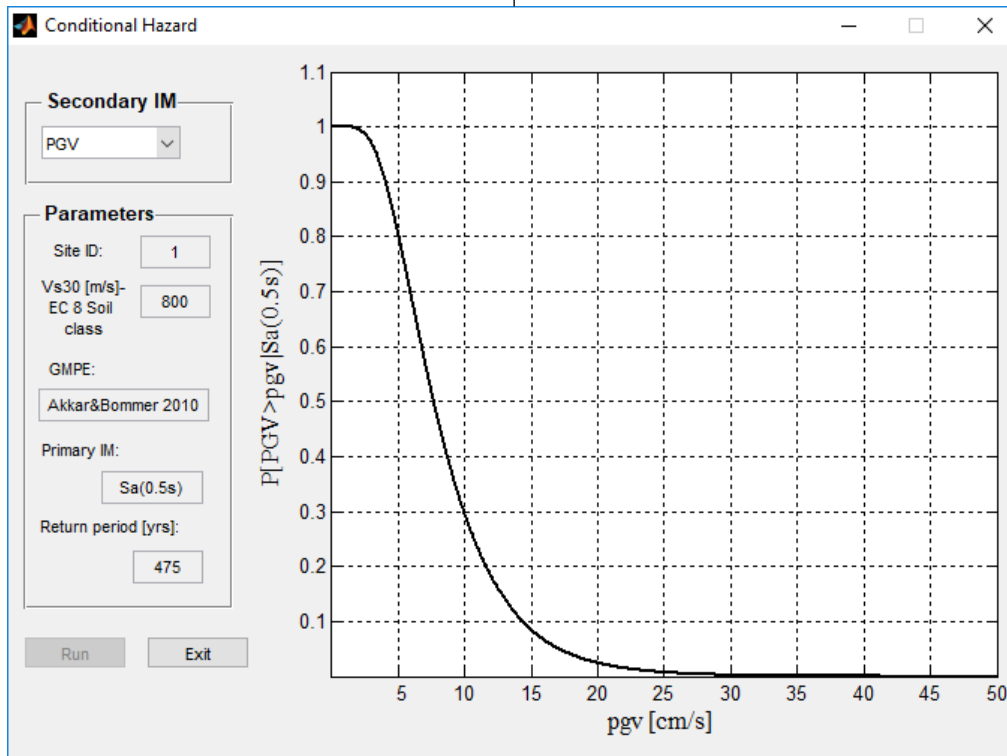
Distribution of peak ground velocity (PGV) conditional on the occurrence of a primary intensity measure (IM_1):

$$f_{\log PGV|IM_1}(\log pgv) = \int \int_M \int_R f_{\log PGV|IM_1, M, R}(\log pgv | im_1, m, r) \cdot f_{M, R|IM_1=im}(m, r) \cdot dm \cdot dr$$

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Distribution of $\log(PGV)$ given IM_1 , magnitude and distance.

Disaggregation of magnitude and distance given the occurrence of IM_1 .



Goals for upcoming secondment (optimization of software implementation)

Multisite PSHA which involves k pseudo spectral accelerations at k spectral periods (T) as intensity measures (IM) at n sites ($h_{l,n}$ is the inter-site distance between site l and site n)

The logs of IMs at the sites assumed to follow a multivariate normal distribution

Covariance matrix: $\Sigma = \Sigma_{INTER} + \Sigma_{INTRA}$

σ_i : standard deviation of the intra-event residual of $\log(\text{IM}_i)$

ρ : spatial cross-correlation between the intra-event residuals of the log of IMs

$n \times n$ matrix (variance of the inter-event residual of $\log(\text{IM}_1)$)

$$\begin{matrix} \eta(T_1, T_1) \cdot \tau_1^2 & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots \\ \eta(T_1, T_1) \cdot \tau_1^2 & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \eta(T_1, T_1) \cdot \tau_1^2 & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots & \eta(T_1, T_1) \cdot \tau_1^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \end{matrix}$$

$\Sigma_{INTER} =$

symmetric

$n \times n$ cross-correlation matrix of the inter-event residuals of $\log(\text{IM}_1)$ and $\log(\text{IM}_k)$

$$\begin{matrix} \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots \\ \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots & \eta(T_1, T_k) \cdot \tau_1 \cdot \tau_k & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \end{matrix}$$

$$\begin{matrix} \eta(T_k, T_k) \cdot \tau_k^2 & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots \\ \eta(T_k, T_k) \cdot \tau_k^2 & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \eta(T_k, T_k) \cdot \tau_k^2 & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots & \eta(T_k, T_k) \cdot \tau_k^2 & \cdots \end{matrix}$$

$n \times n$ spatial cross-correlation matrix of the intra-event residuals of $\log(\text{IM}_1)$ at sites

$$\begin{matrix} \sigma_1^2 & \rho(T_1, T_1, h_{1,2}) \cdot \sigma_1^2 & \cdots & \rho(T_1, T_1, h_{1,n}) \cdot \sigma_1^2 & \cdots \\ \rho(T_1, T_1, h_{2,1}) \cdot \sigma_1^2 & \sigma_1^2 & \cdots & \rho(T_1, T_1, h_{2,n}) \cdot \sigma_1^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \rho(T_1, T_1, h_{n,1}) \cdot \sigma_1^2 & \rho(T_1, T_1, h_{n,2}) \cdot \sigma_1^2 & \cdots & \sigma_1^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \end{matrix}$$

$\Sigma_{INTRA} =$

symmetric

$n \times n$ spatial cross-correlation matrix of the intra-event residuals of $\log(\text{IM}_1)$ and $\log(\text{IM}_k)$ at sites

$$\begin{matrix} \rho(T_1, T_k, h_{1,1}) \cdot \sigma_1 \cdot \sigma_k & \rho(T_1, T_k, h_{1,2}) \cdot \sigma_1 \cdot \sigma_k & \cdots & \rho(T_1, T_k, h_{1,n}) \cdot \sigma_1 \cdot \sigma_k & \cdots \\ \rho(T_1, T_k, h_{2,1}) \cdot \sigma_1 \cdot \sigma_k & \rho(T_1, T_k, h_{2,2}) \cdot \sigma_1 \cdot \sigma_k & \cdots & \rho(T_1, T_k, h_{2,n}) \cdot \sigma_1 \cdot \sigma_k & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \rho(T_1, T_k, h_{n,1}) \cdot \sigma_1 \cdot \sigma_k & \rho(T_1, T_k, h_{n,2}) \cdot \sigma_1 \cdot \sigma_k & \cdots & \rho(T_1, T_k, h_{n,n}) \cdot \sigma_1 \cdot \sigma_k & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \end{matrix}$$

$$\begin{matrix} \sigma_k^2 & \rho(T_k, T_k, h_{1,2}) \cdot \sigma_k^2 & \cdots & \rho(T_k, T_k, h_{1,n}) \cdot \sigma_k^2 & \cdots \\ \rho(T_k, T_k, h_{2,1}) \cdot \sigma_k^2 & \sigma_k^2 & \cdots & \rho(T_k, T_k, h_{2,n}) \cdot \sigma_k^2 & \cdots \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \rho(T_k, T_k, h_{n,1}) \cdot \sigma_k^2 & \rho(T_k, T_k, h_{n,2}) \cdot \sigma_k^2 & \cdots & \sigma_k^2 & \cdots \end{matrix}$$

$n \times n$ spatial cross-correlation matrix of the intra-event residuals of $\log(\text{IM}_k)$ at sites

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