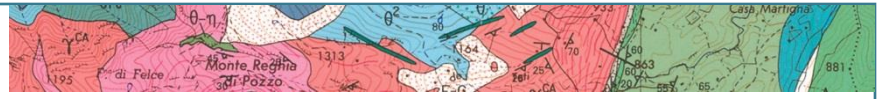
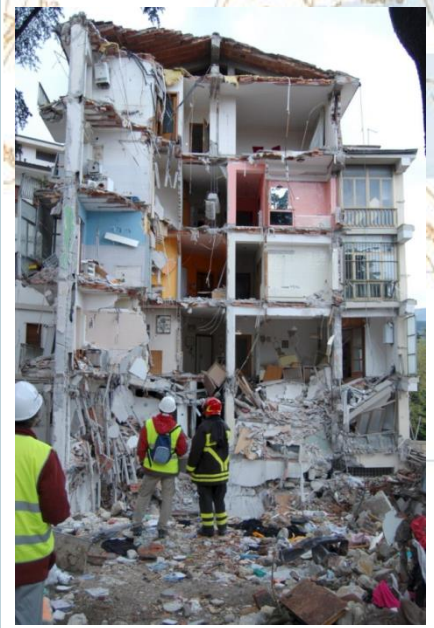


Getting better insights in the influence of uncertainties in seismic risk. Application to L'Aquila earthquake (2009)



A. Benaichouche, J. Rohmer, D. Monfort, C. Bellier,
BRGM, Unité risque sismique et volcanique

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Presentation plan

- Seismic Hazard Model
- L'Aquila earthquake (2009)
- Uncertainties propagation and GSA
- New approach for Sobol' indices estimation
- Conclusions and further works

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Seismic Hazard Model

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Seismic Hazard Model

Prevention specialists are interested to seismic risk, they are the damages on buildings and infrastructures cause by earthquake

It's necessary to :

1 – Evaluate the geographical area, its exposure to earthquake (intensity and probability of occurrence)

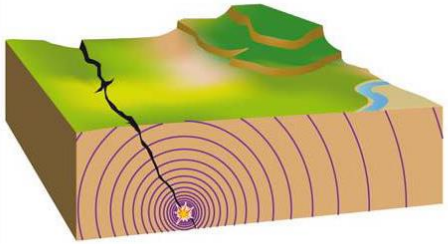
✓ **Seismic Hazard**

2 – Know the exposed elements (issues), and the possible damage related to earthquake

✓ **Vulnerability analysis**

Hazard evaluation

Seismic hazard: possibility for a site to be exposed to earthquake

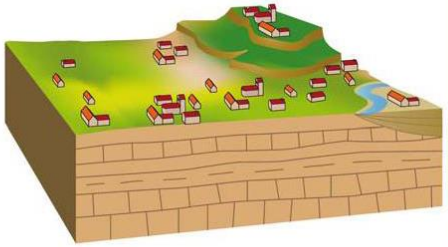


Regional hazard:
- Seismic source,
- Magnitude
- Localization of epicenter
- Local depth

Local hazard:
- Site effects

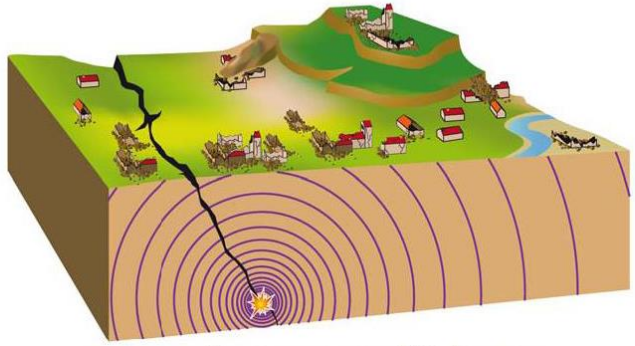
Vulnerability evaluation

Vulnerability: damage degree of an exposed element to earthquake

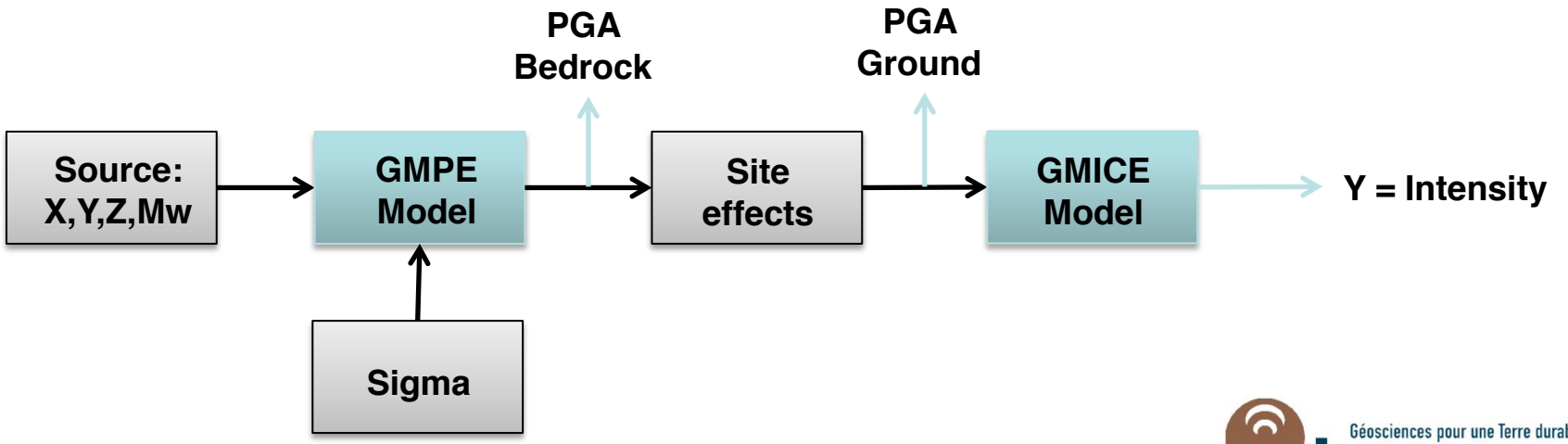


Exposed elements:
Persons, patrimonial…

Issues:
Value attributed to exposed elements for a given hazard



Seismic Hazard Model



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Seismic Hazard Model

Armagedom software:

Sedan et al.,2013

2 categorical variables

- **GMPE Model**
- **GMICE Model**

6 continuous variables

- **X**
- **Y**
- **Z,**
- **Mw**
- **Sigma**
- **Lith**

Seismic Hazard Model → **Y = Intensity**

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L’Aquila Earthquake (2009)

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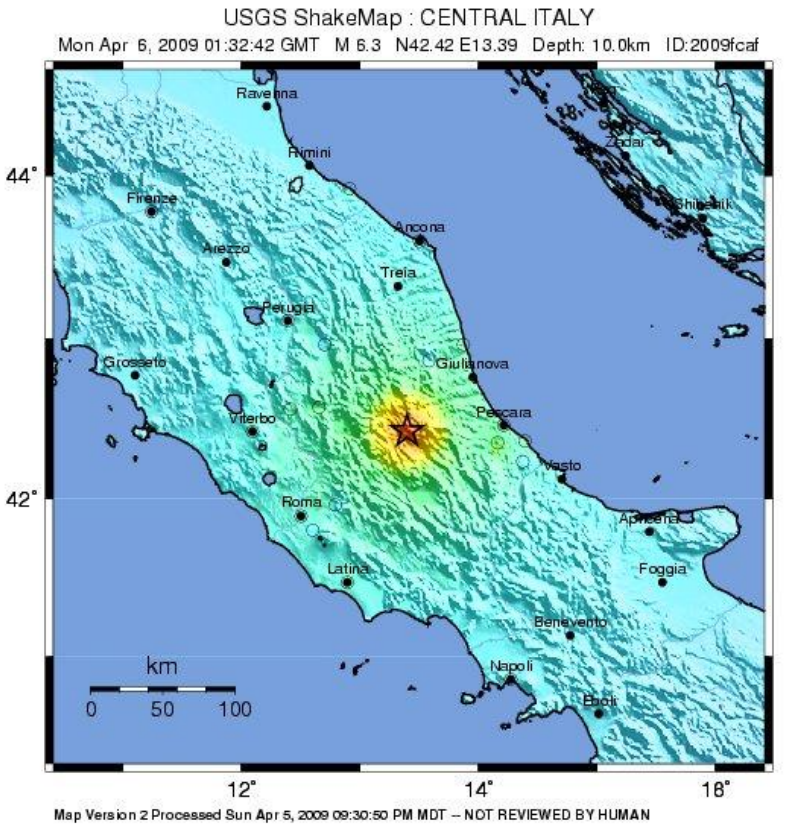
L'Aquila Earthquake (2009)



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	*<.17*	*.17-1.4*	*1.4-3.9*	*3.9-9.2*	*9.2-18*	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	*8.1-16*	*16-31*	*31-60*	*60-116*	*>116*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

- **Mw 6.3, April, 6th 2009**
- **Aquila city very impacted but also the neighborhood cities**
- **L'Aquila (67000 hab), very big city:**
  - L'Aquila center (red after earthquake)
  - ~50 villages : Paganica, Onna, Banno, Roio…
- **308 deaths**
- **EMS Intensity X in several cities (Onna), between VIII-IX in the historical city of L'Aquila.**

Uncertainty propagation and GSA of Seismic Hazard Model. Case: Aquila earthquake

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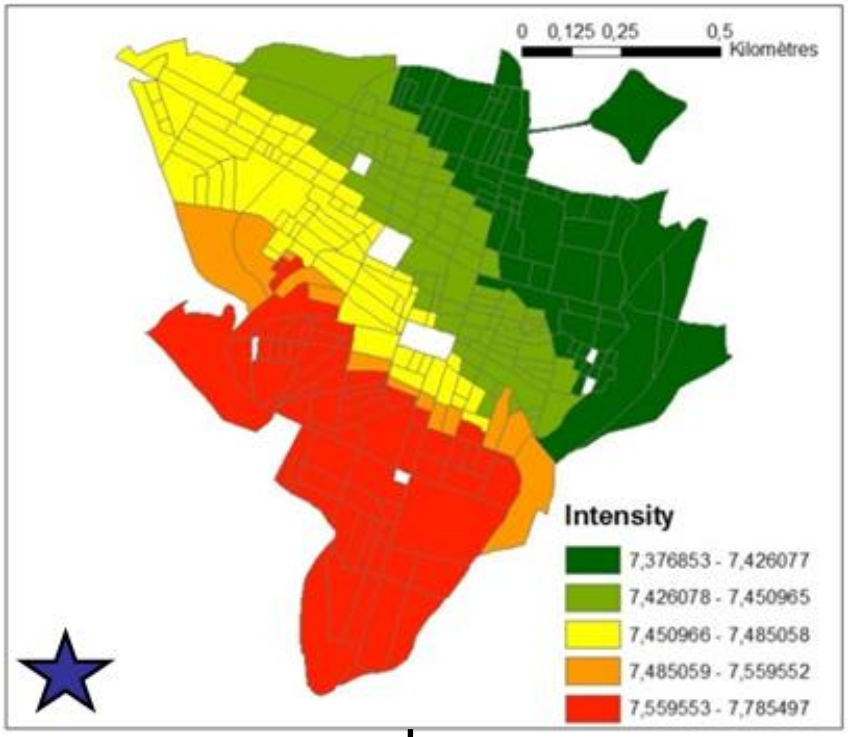
GSA scenario: L'Aquila Earthquake (2009)

Seismic Hazard Scenario

Inputs	Variation range
X (km)	X_0 ± **10**
Y (km)	Y_0 ± **10**
Z (km)	10 ± **5**
Mw	6,3 [**5,5** – **6,5**]
Sigma	[**-0,5** – **0,5**]
GMPE	**"AB_10_N"** **"AB_10_R"** **"AB_10_S"** **"B_al_14_R"** **"B_al_14_N"** **"B_al_14_S"** **"CF_08_All"**
LITH (8)	A_0 ± **0,3**
GMICE	**"AS_00"** **"W_al_99"** **"F_M_10"**

Basé sur Douglas, Montfort et al., 2015 + discussions team RSV/DRP

1 simulation result



Y: average intensity

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GSA with MC method

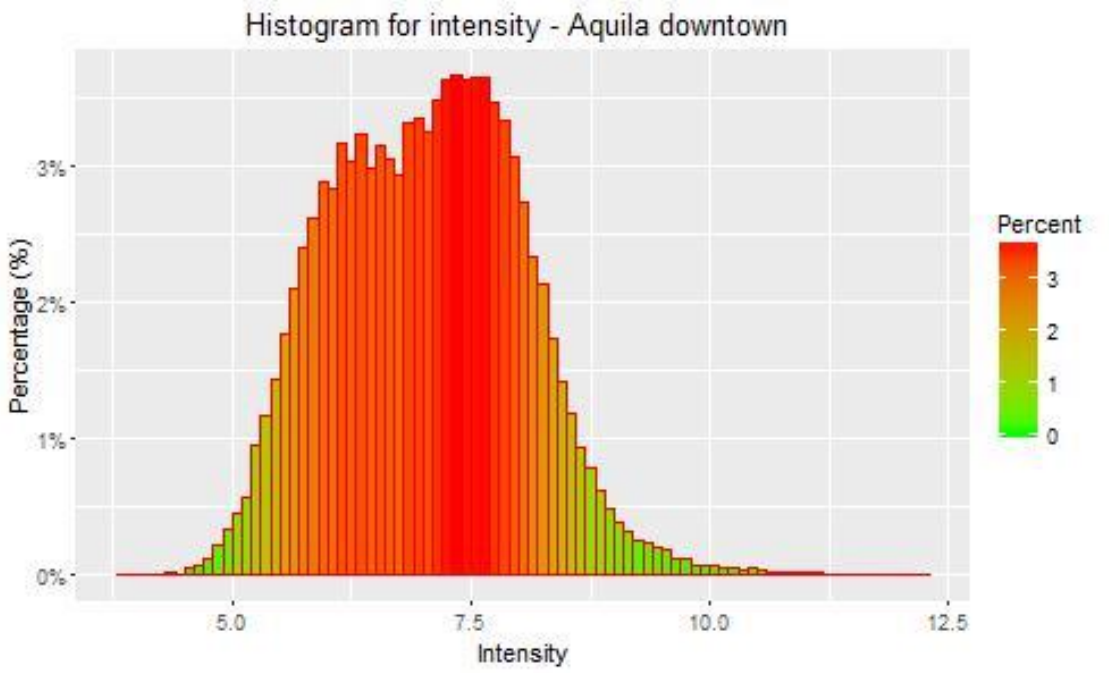
2 categorical variables

- GMPE Model
- GMICE Model

6 continuous variables

- X
- Y
- Z,
- Mw
- Sigma
- Lith

Sobol2002 method
200K model run



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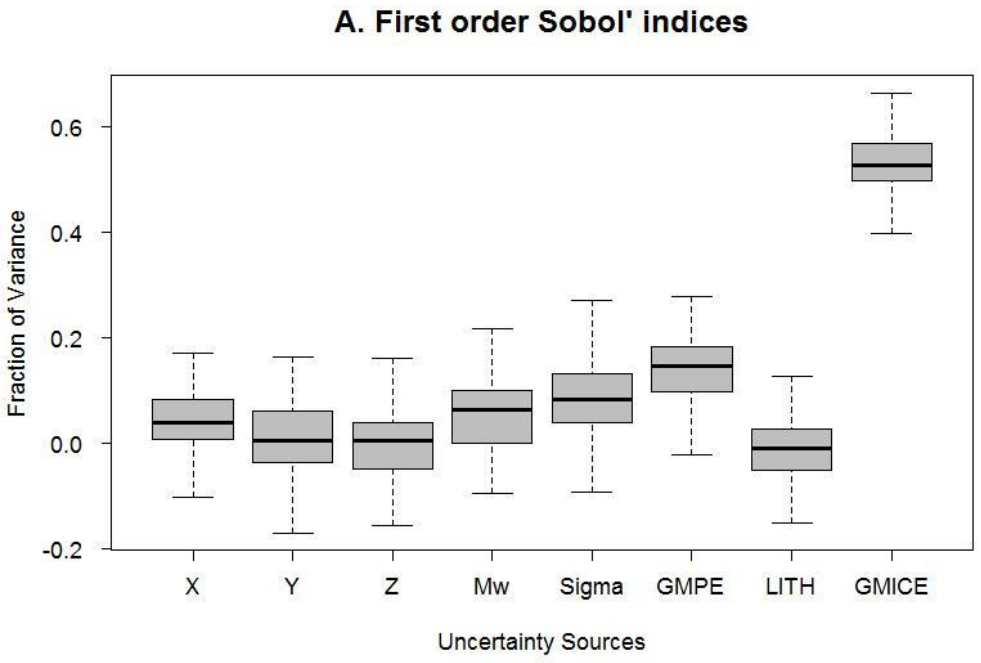

- **Additive model (sum main effects is 95%) -> %5 interaction between parameters**
- **The most influential inputs: GMICE (55%)**
- **GMPE (14%).**

New approach for Sobol' indices estimation

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New approach for SI computation

$$S_i = \frac{V\left[E[(Y|x_i)]\right]}{V[Y]}$$

$$V[Y] = V\left[E[(Y|x_i)]\right] + E\left[V[(Y|x_i)]\right]$$

$$S_i = 1 - \frac{E\left[V[(Y|x_i)]\right]}{V[Y]}$$

Compute the *expectation of the variance* rather then the variance of expectation !

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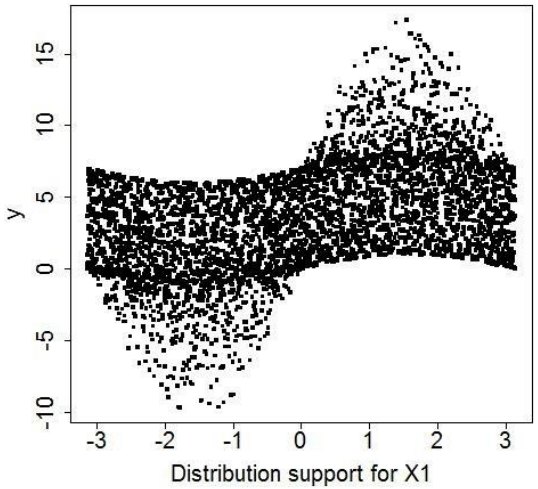
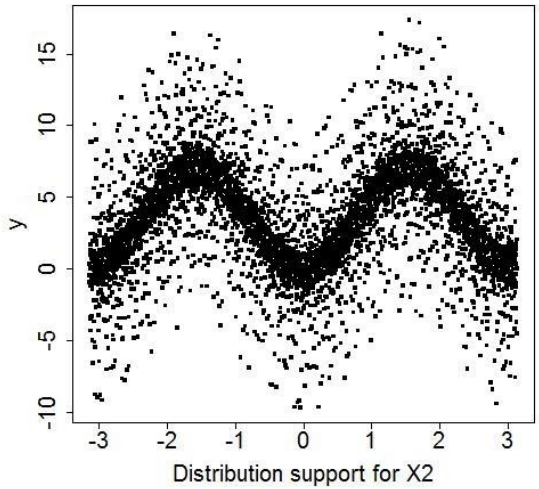
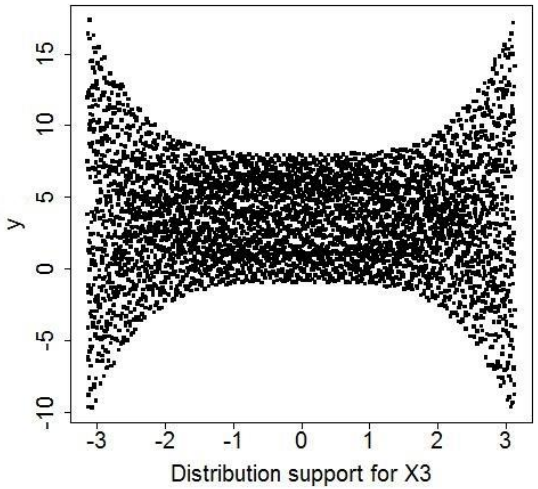
New approach for SI computation

$$y = \sin(x_1) + 7\sin^2(x_2) + 0.1x_3^4 \sin(x_1), \quad where\ x_i \sim U(-\pi, \pi)$$







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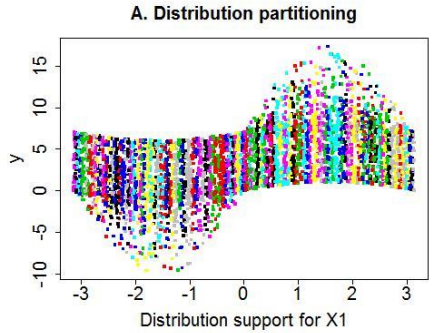
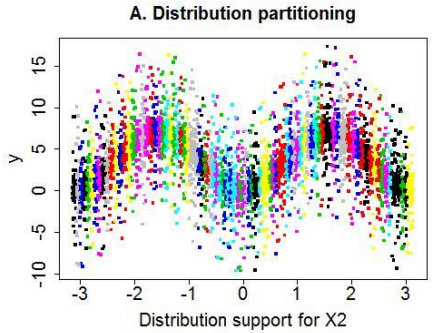
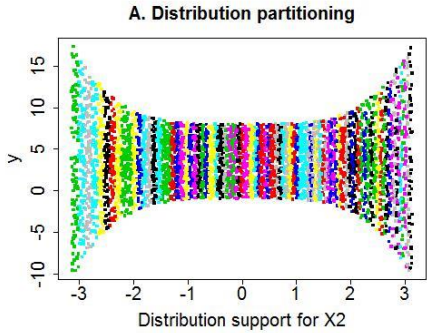
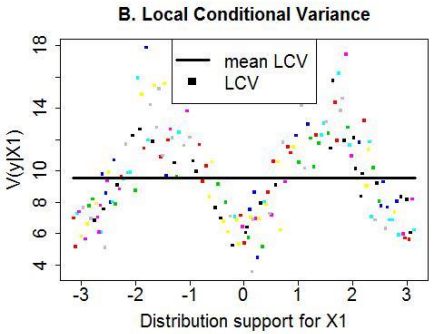
New approach for SI computation

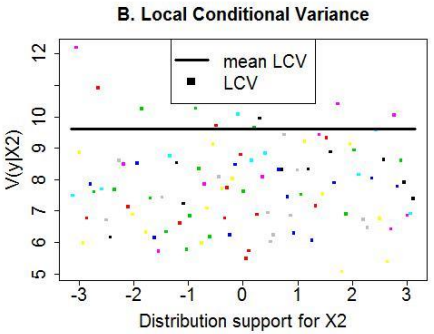


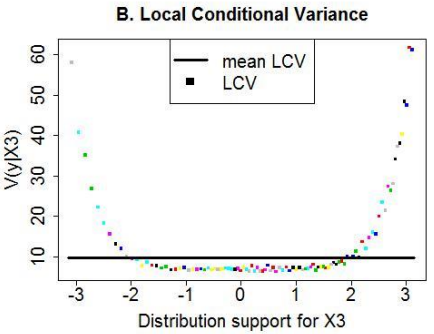




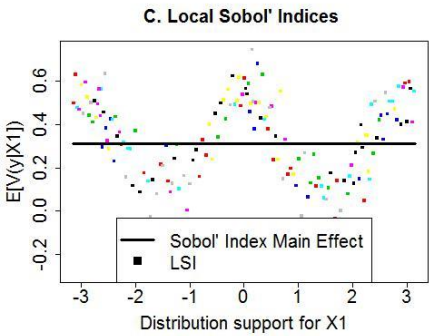
$$\|X\| \leq \delta$$

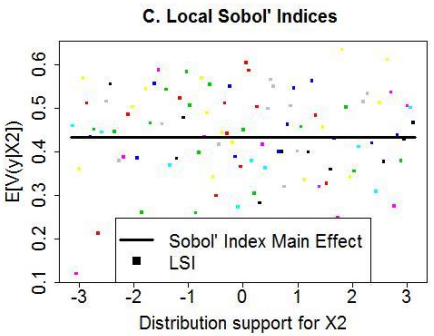


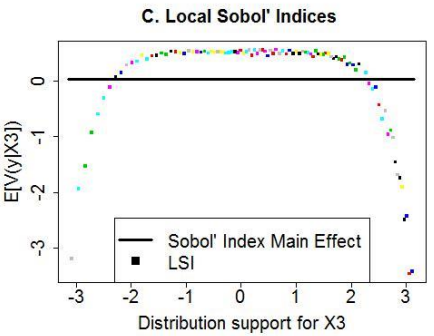




$$V[Y|X_3^*]$$







$$1 - \frac{V[Y|X_3^*]}{V[Y]}$$

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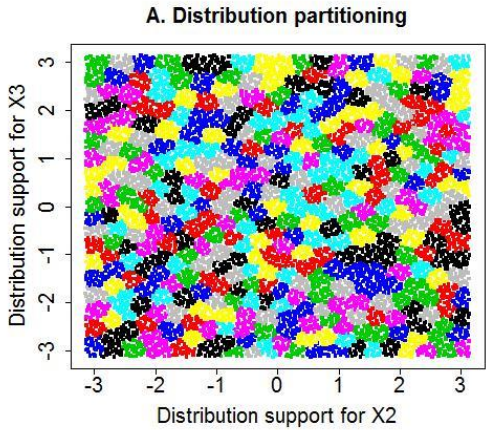
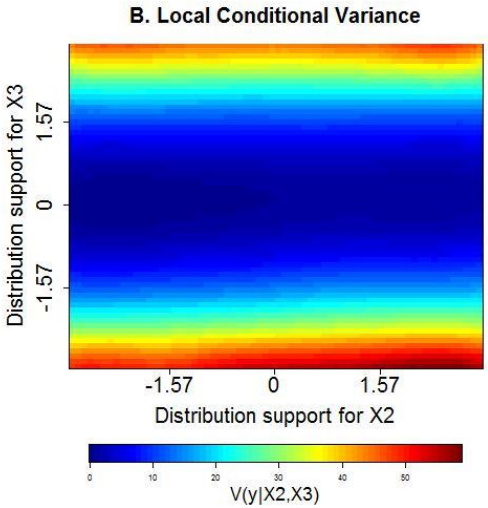
New approach for SI computation

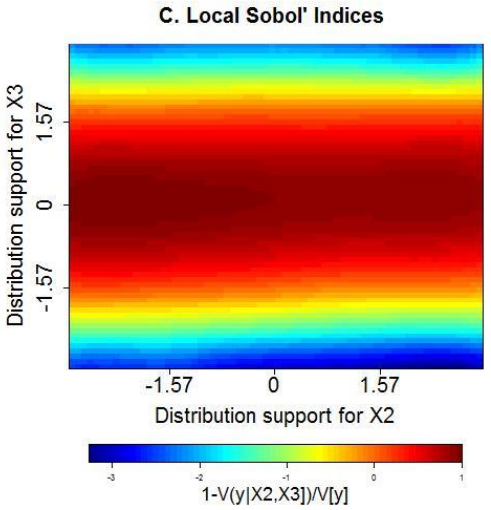
$$\left\|\left(X_2, X_3\right)\right\| \leq \delta$$

$$V[Y|(X_2^*, X_3^*)]$$

$$1 - \frac{V[Y|(X_2^*, X_3^*)]}{V[Y]}$$







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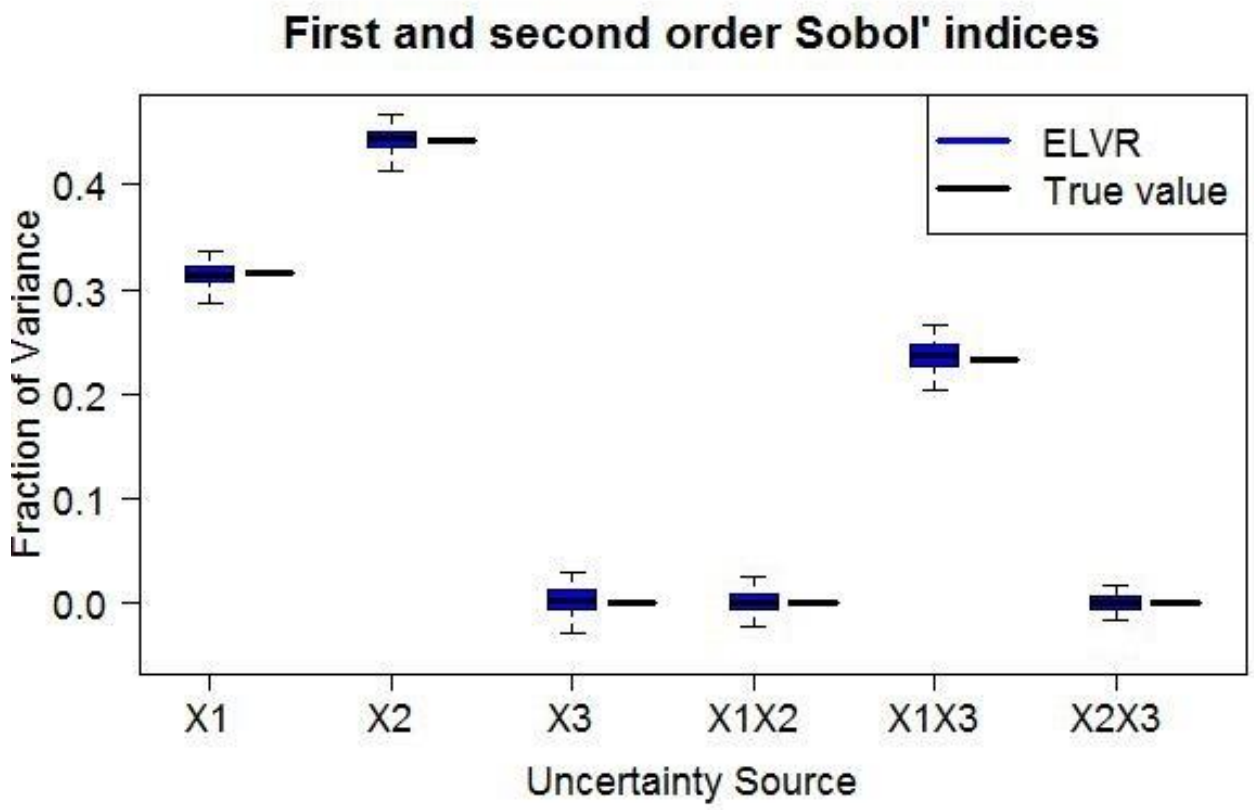
New approach for SI computation



1000 model run for main effect

5000 model run for the second order effect

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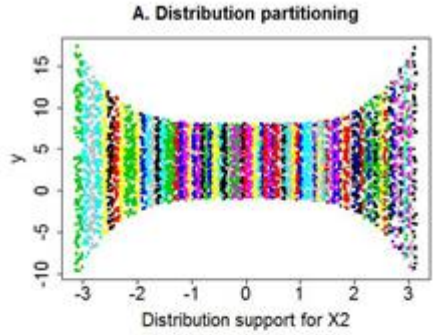
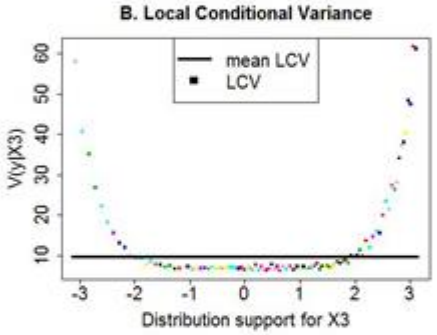
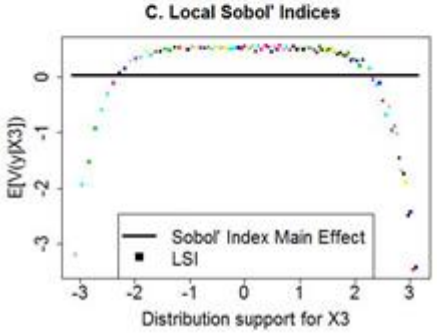
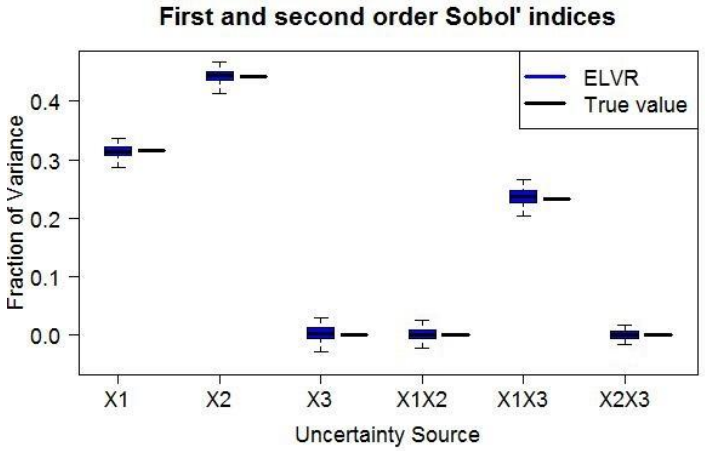
New approach for SI computation

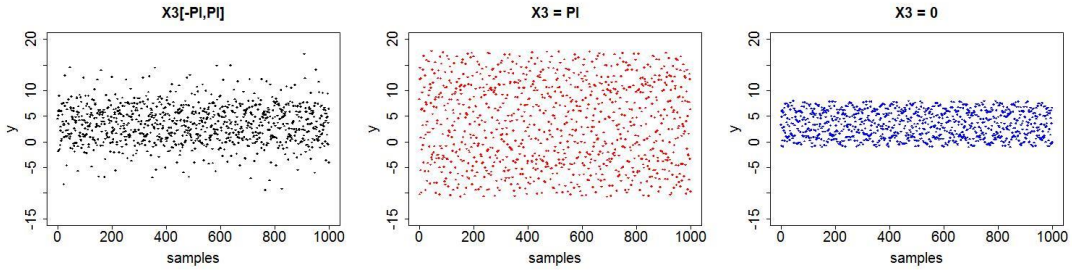








Increasing Vt by 460% → **Reducing Vt by 48%** →



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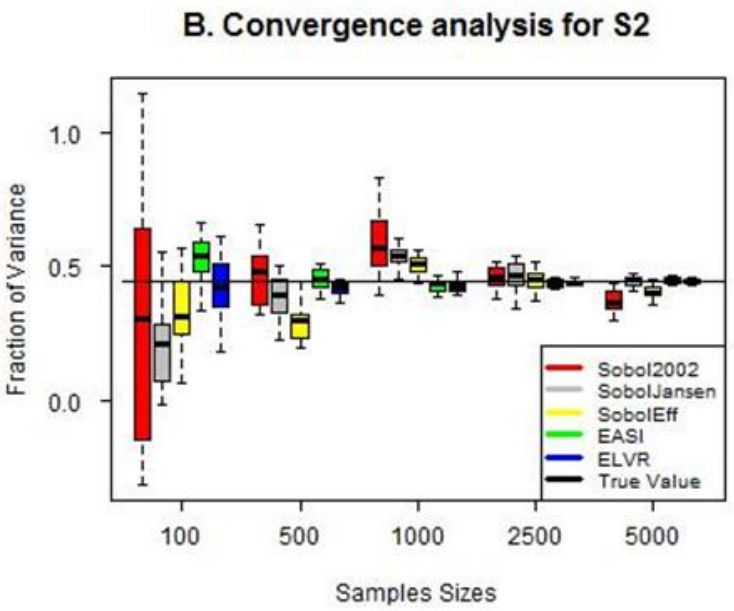

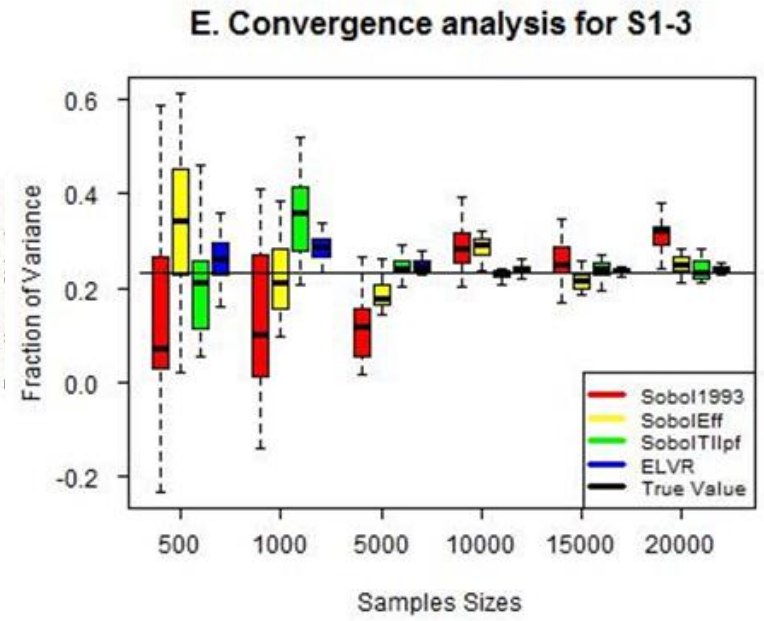

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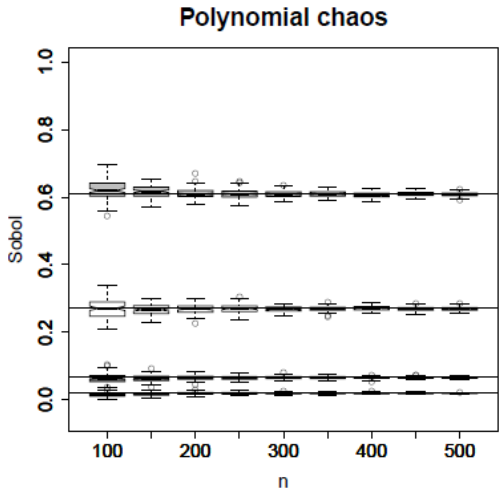
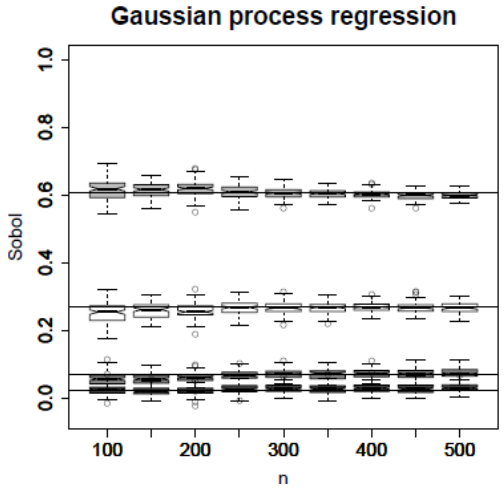
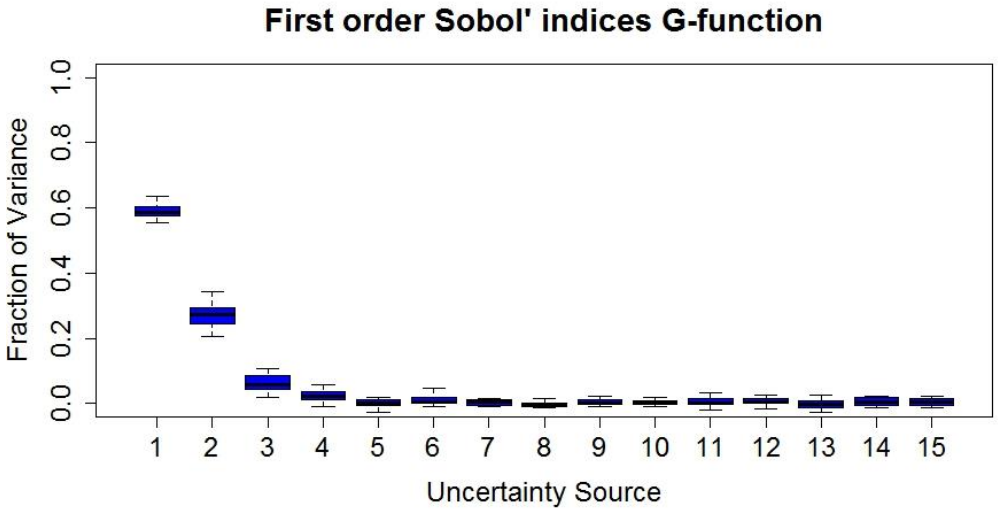
Comparison with surrogate model

L. Le Gratiet, S. Marelli, B. Sudret (2016)





Sobol' function 15 inputs



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Back to Aquila Earthquake

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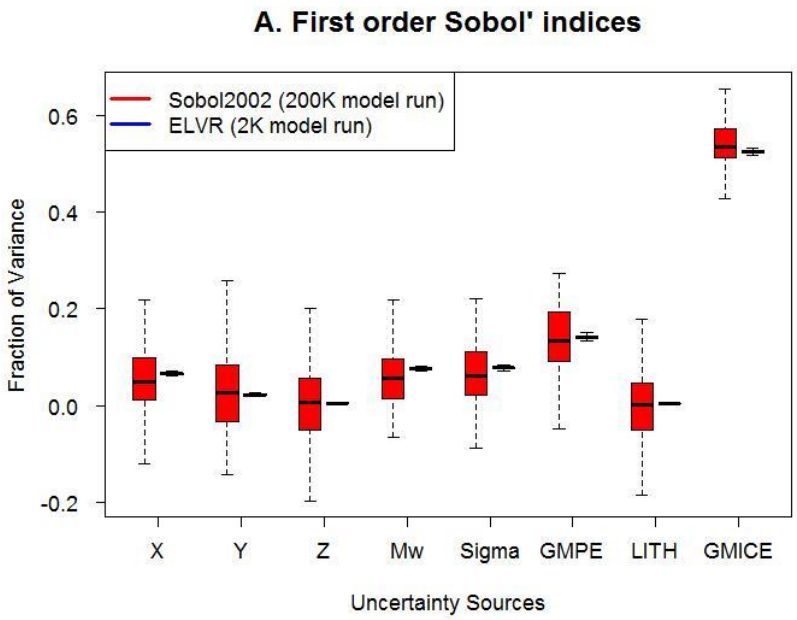
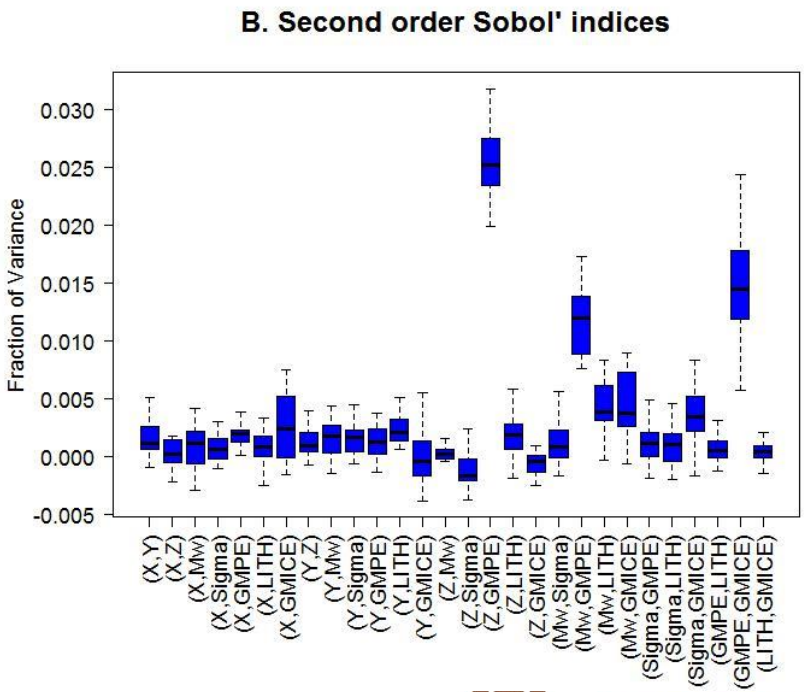
Application to L'Aquila earthquake

❖ Sobol' indices (average intensity) :





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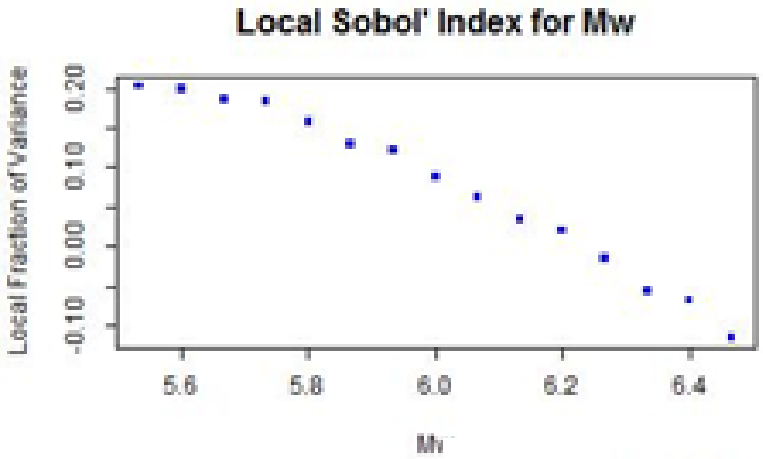
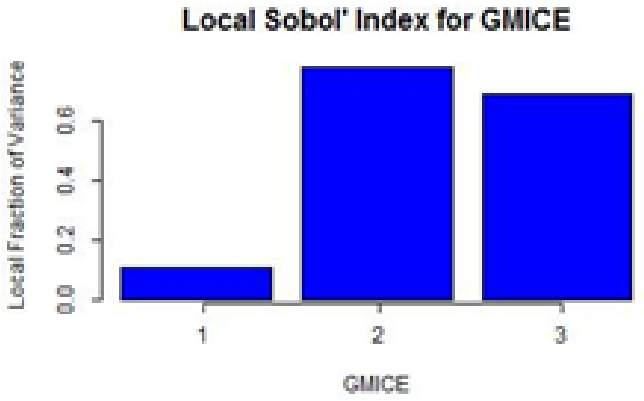
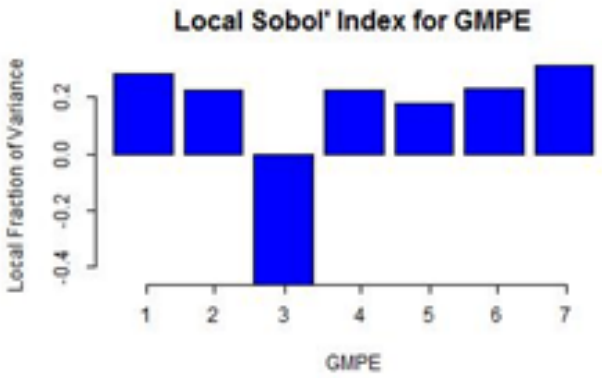
Application au séisme de L'Aquila :

❖ Local Sobol' indices (average intensity) :







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Conclusions and further works

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Conclusions and further works

❖ For Seismic Hazard modeling (Aquila earthquake)

- ✓ Predicting the date, the place and the intensity of an earthquake is not possible today.
- ✓ Additive model (sum main effects is 95%) -> weak interaction between parameters.
- ✓ The most influential inputs: GMICE (58%) -> GMPE (14%). We suggest, an appropriate choice of GMICE and GMPE should be prioritized in future investigations.

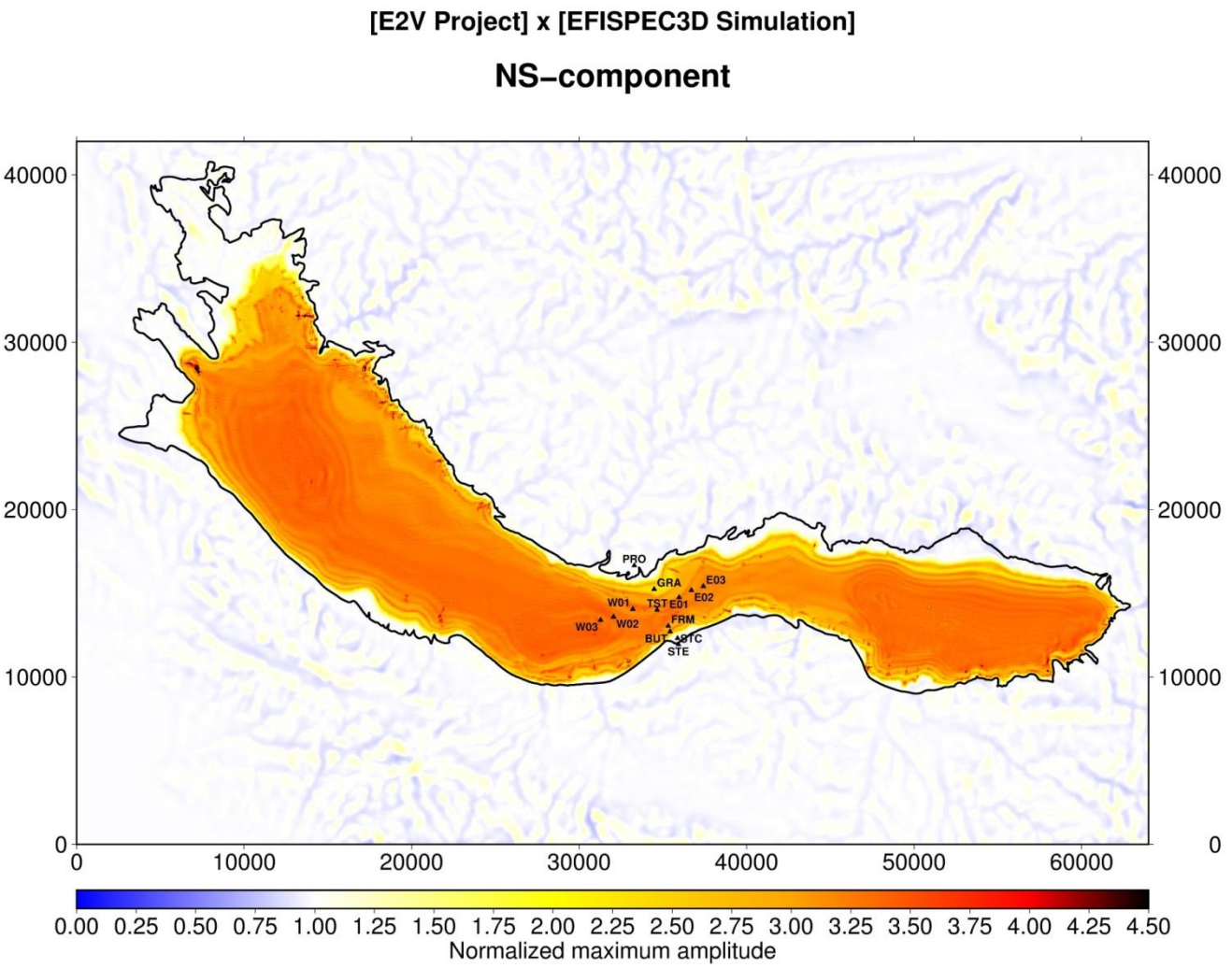
❖ The new approach for Sobol' indices estimation

- ✓ 1K and ~5K for the estimation of the first and second order effets
- ✓ Independence from sampling scheme and the dimension of the inputs parameters space
- ✓ Global and local insight on uncertainties sources

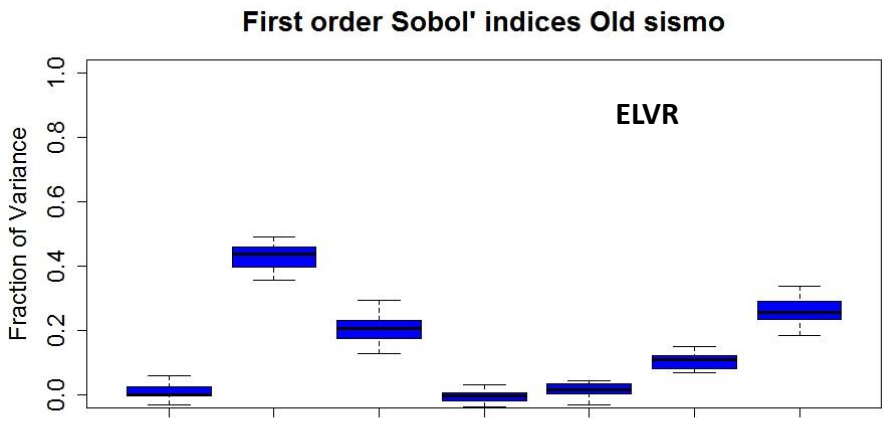
➢ Generalization on spatial input/output parameters

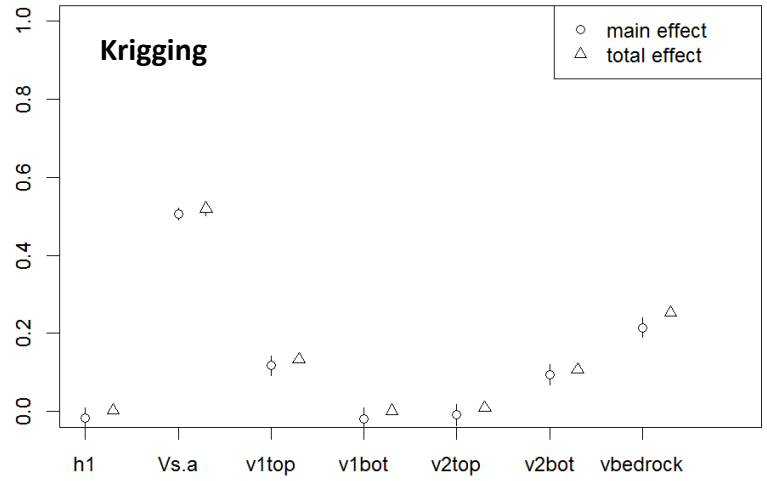
spatial: Marrel et al., 2009;
dynamic: Rohmer et al., 2016;
generic: Gamboa et al. 2013

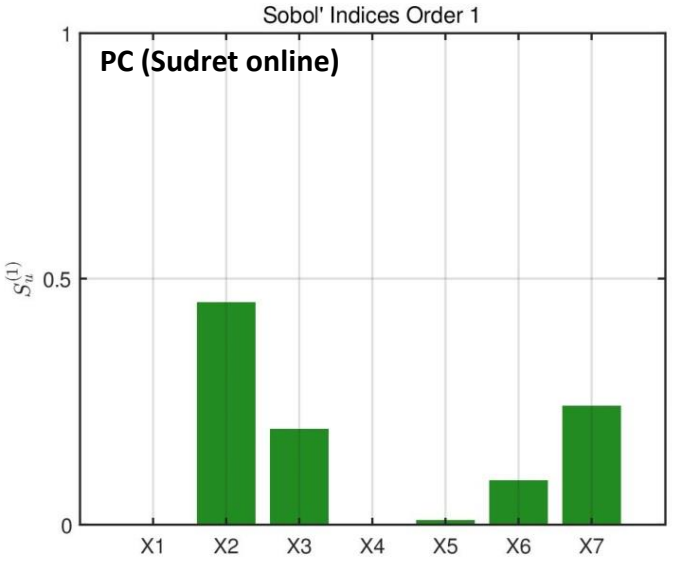
Comparison with surrogate model for real case



Comparison with surrogate model for real case







Diagnostics

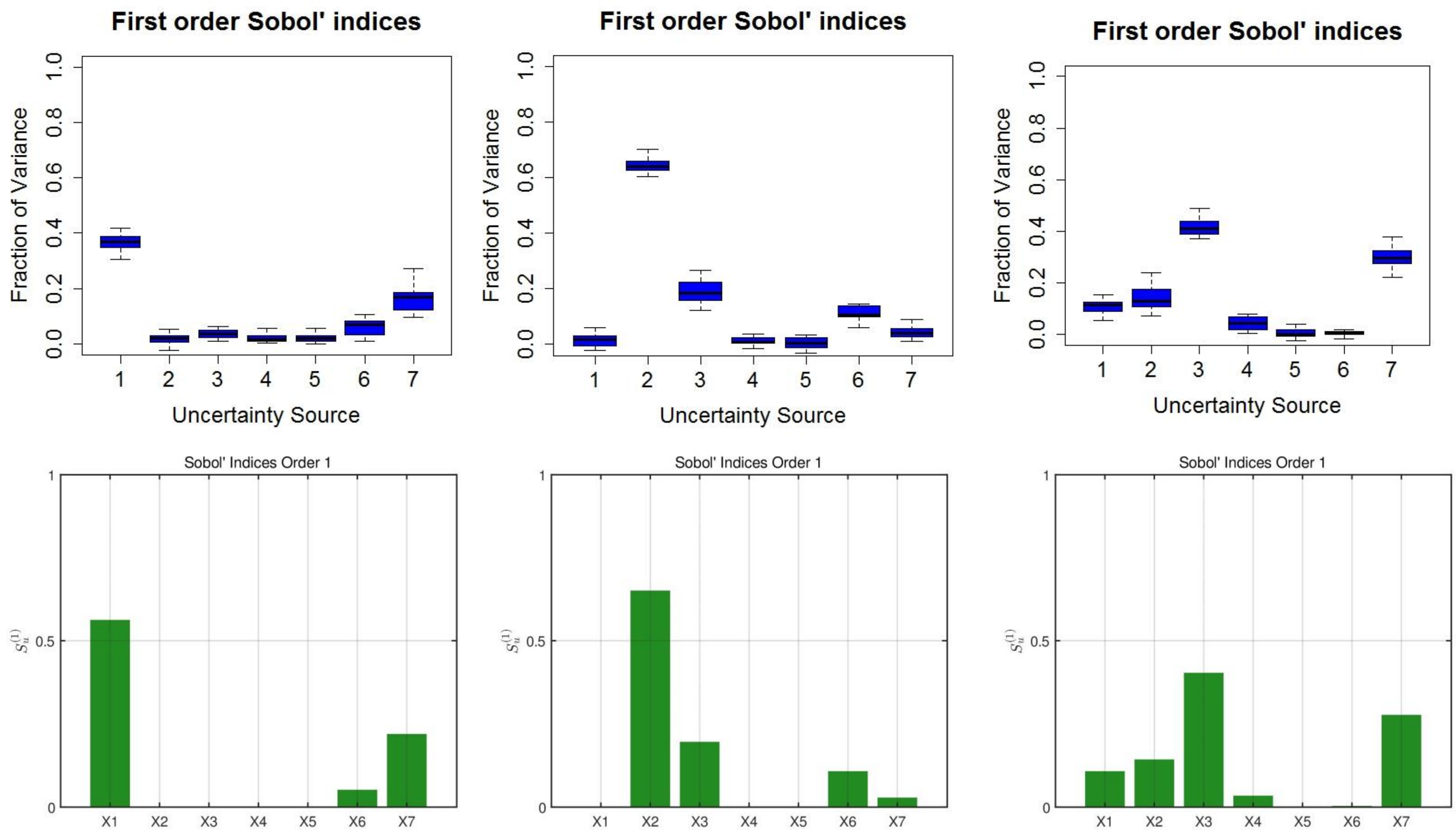
Uniformity of inputs	100%	
Accuracy of PCE	98.8%	

Sparse Polynomial Chaos Expansion

Maximal Degree	5
q-norm	0.80
Size of full basis	1310
Size of sparse basis	54
Samples	350
Leave-one-out error	1.1975276e-02

Estimateur de Jansen
10,000 tirages aléatoires de type uniforme classique

Comparison with surrogate model for real case



Thank you!!

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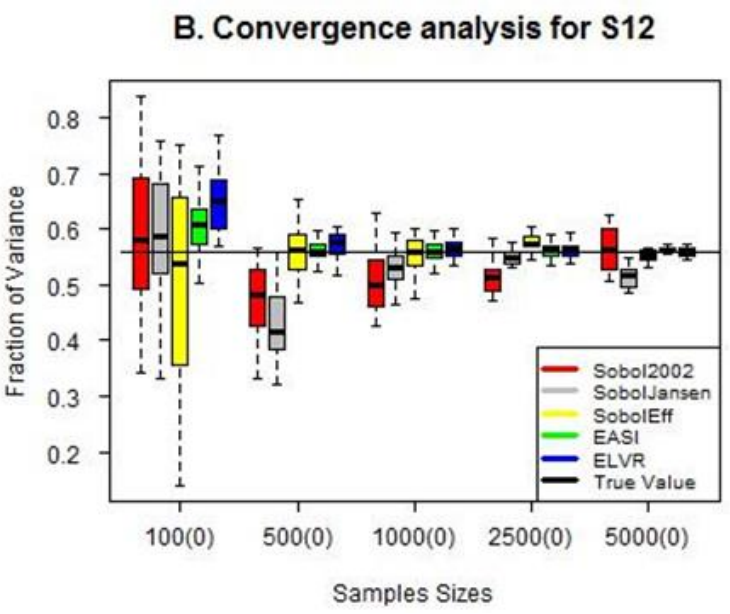
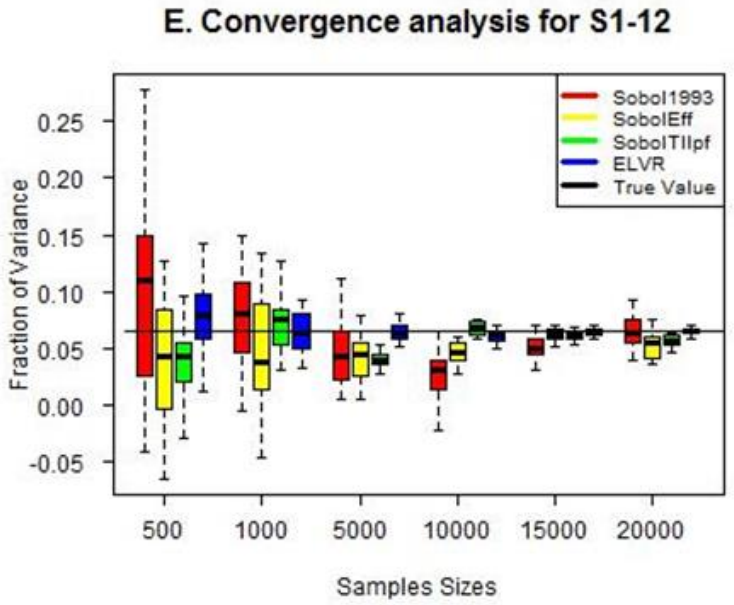
New approach for SI computation

$$y = \frac{5x_{12}}{1+x_1} + 5(x_4 - x_{20})^2 + x_5 + 40x_{19}^3 - 5x_{19} + 0.05x_2 + 0.08x_3 - 0.03x_6 + 0.03x_7 - 0.09x_9$$
$$-0.01x_{10} - 0.07x_{11} + 0.25x_{13}^2 - 0.04x_{14} + 0.06x_{15} - 0.01x_{17} - 0.03x_{18} \quad where\ x_i \sim U(-0.5, 0.5)$$





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