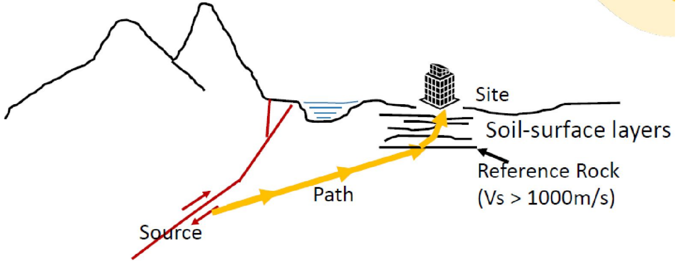
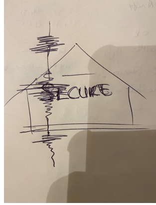




Regional-**S**cale **E**arthquake Ground Motion Predi**C**tions Thro**U**gh Pyhsics-based and Empi**R**ical Approach**E**s: A Case study Central Italy (**SECURE**)

Aybige Akinci (INGV-RM1)

ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA

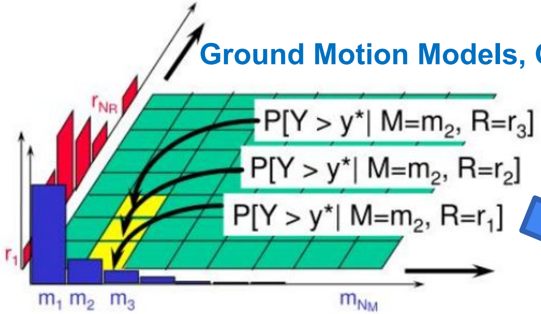
PIANETA
DINAMICO
WORKING EARTH

SECURE is designed to address questions related to predicting ground motions during important seismic events

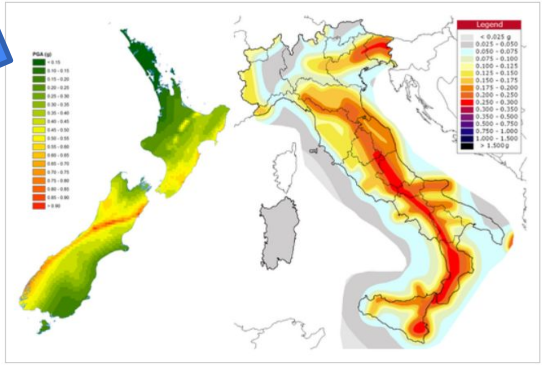
The reliable quantification of earthquake ground motions as a function of magnitude, distance, and frequency is directly linked to seismic hazard analysis for **engineering, civil protection purposes, and systems designed to provide earthquake rapid response and early warning**.

Realistic modeling of earthquake ground motions can be achieved only when the rupture process on causative fault, the **medium property of the seismic wave path, and the local site condition** *are accurately represented*

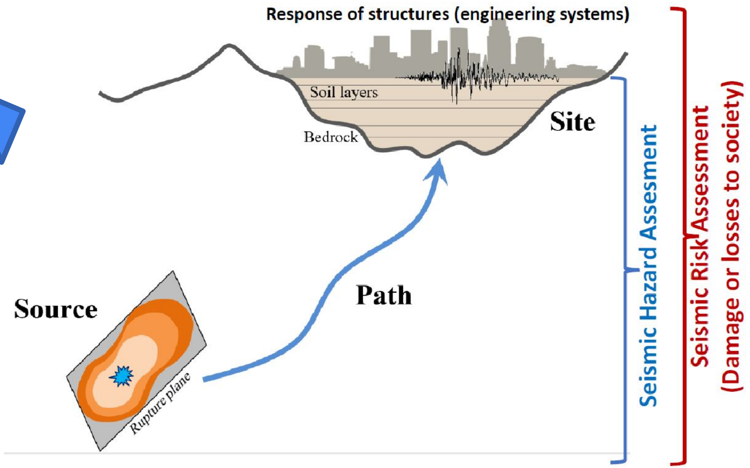
Ground Motion Models, GMMs



Probabilistic Seismic Hazard Maps, PSHA



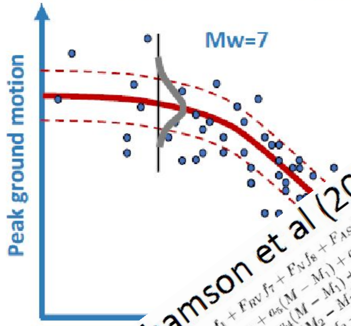
Problem statement for Seismic Hazard and Risk



- Ground ... dictive Equations or Models (GMPE, GMMs) derive from ... on procedure on worldwide strong motion database

- An ergodic assumption is ... made in Probabilis... Seismic Hazard Assessment.

$$\ln(Y) = f_{src}(M, \ldots) + f_{path}(R, M, \ldots) + f_{site}$$



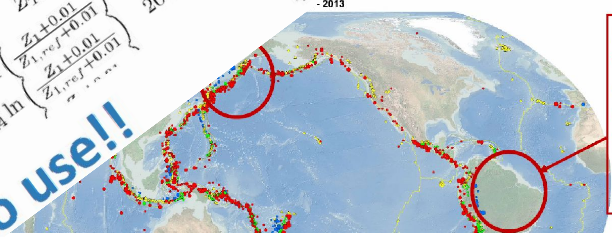
Abrahamson and Young (1992)

Abrahamson et al (2014)

GMPEs are becoming very complex to use!!

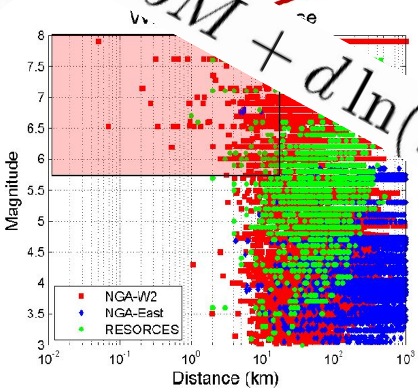
$$+ bM + d\ln(r + c) + eF$$

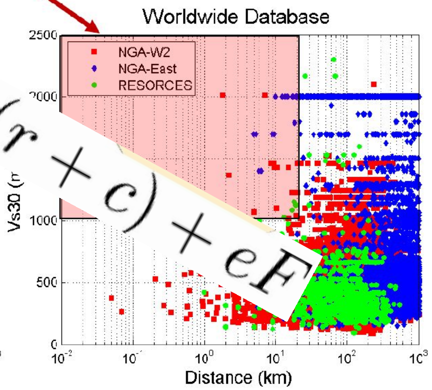
Er... of a process can be deduced ... It means, any sample of the ... f the process as a whole.



In places with no data, we could use the data from other places

...e of major interest used for PSHA





- To c... that c... ...ge dataset ...ces.

- Unfortuna... limited (parti... ...construct GMMs are ...ng events)

Ergodic and non-ergodic process :Ground Motion Variability

Ground Motion Variability of GMPEs

GMPE: $\ln(Y) = f_{src}(M, \ldots) + f_{path}(R, M, \ldots) + f_{site}(Vs_{30} \ldots) + \Delta$

Total variability: $\Delta = \Delta B + \Delta W$

ΔB is the ***between-events variability*** *with* standard deviation τ

- Earthquake-to-earthquake variability
- Represent average source effects
- Effects of stress drop, slip velocity, rupture speed, geometrical fault complexity, etc. not captured by the source terms in the GMPE

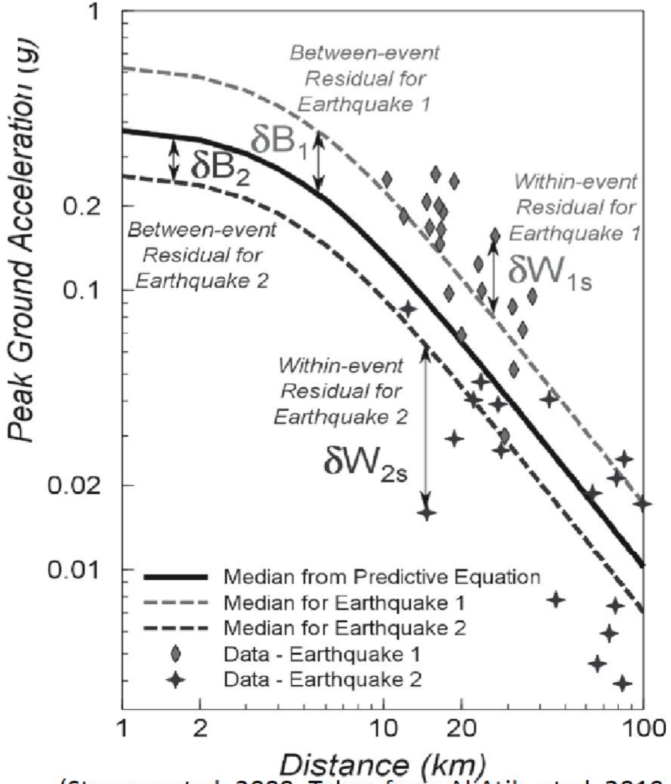
ΔW is the **within-events variability** with standard deviation ϕ

- Record-to-record variability
- Represent azimutal variation in source, path and site effects
- Effects of crustal heterogeneities, deeper geologicat structures, basins, near surface layering, etc, not captured by the path and site terms in the GMPE

ΔB and *ΔW* are uncorrelated, then total standard deviation is

$$\sigma = \sqrt{\tau^2 + \phi^2}$$

Note: The variability or residuals are the deviation of the observed quantity with respect to the median predictor model



(Strasser et al, 2009. Taken from Al Atik, et al, 2010

We c... velop a database of synt... thquakes To fi... f lack of data (D... i, 2011)

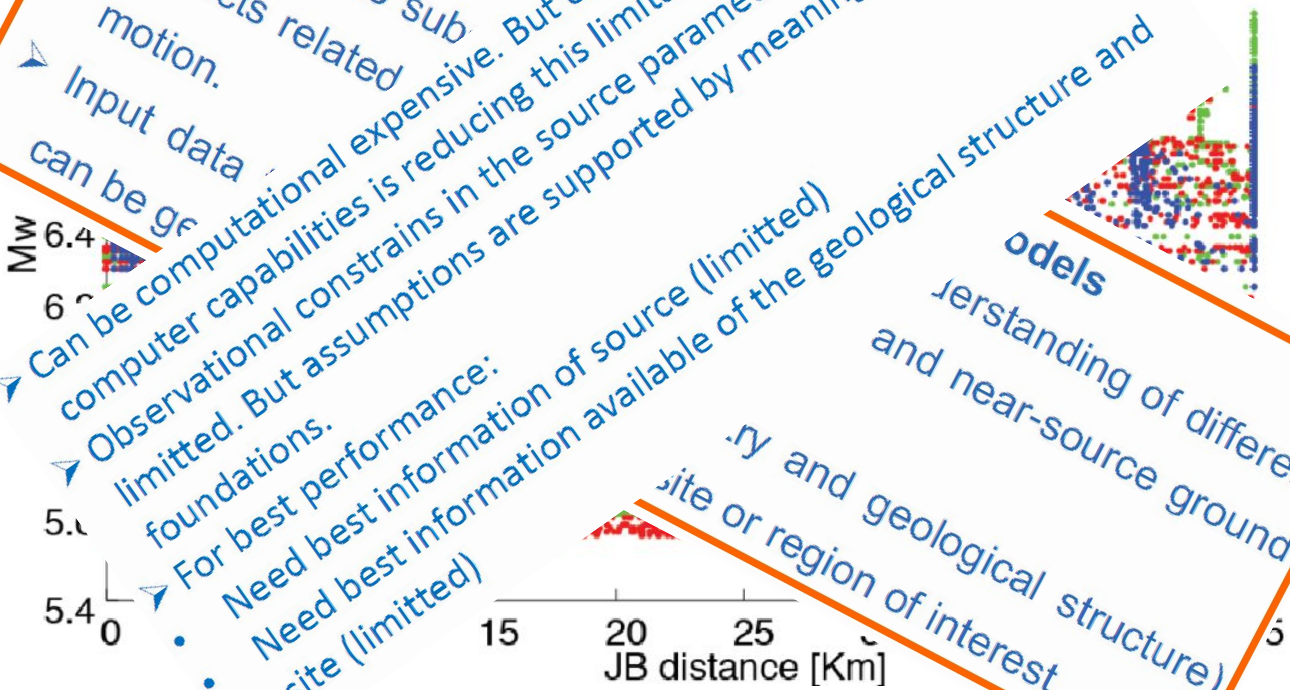
Developments of Ph...

- Contribute to sub... aspects related ... motion.
- Input data ... can be ge...

- Can be computational expensive. But evolution of modern computer capabilities is reducing this limitation
- Observational constrains in the source parameterization are limitted. But assumptions are supported by meaningful physical foundations.
- For best performance:
  - Need best information of source (limitted)
  - Need best information available of the geological structure and site (limitted)

...odels

...derstanding of different ... and near-source ground ... ...ry and geological structure) ... site or region of interest



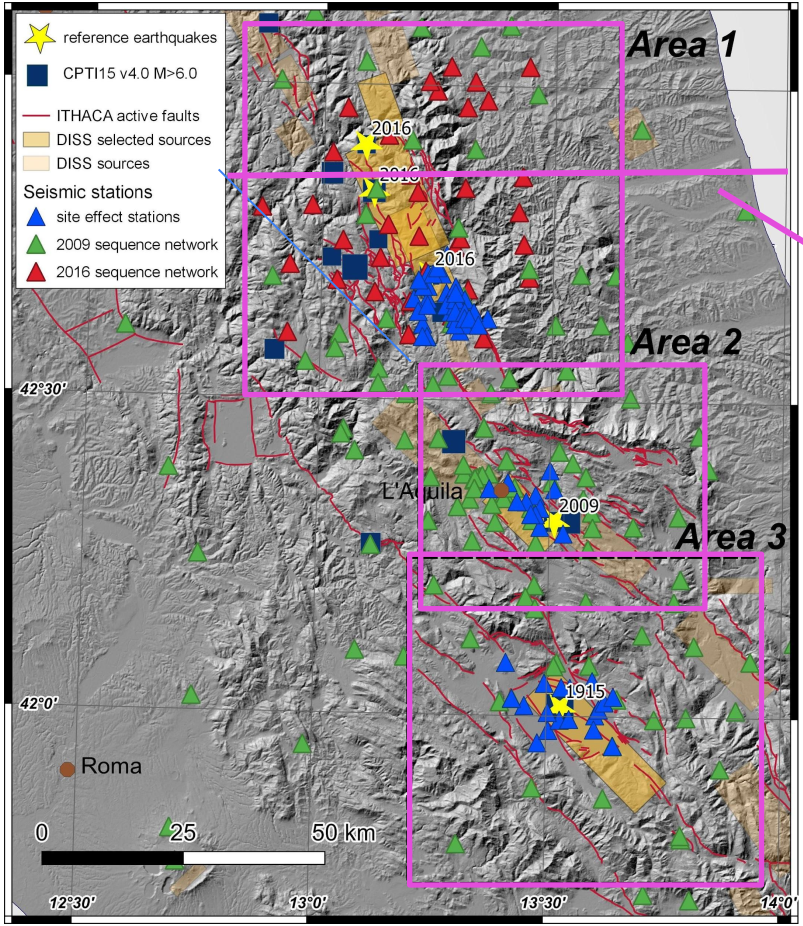
they are intrinsic...ly non-ergodic models

Main Objectives of SECURE

The main goal of **SECURE** is to study earthquake ground motion characteristics, through innovative techniques to improve ground motion predictions for seismic hazard mitigation in the Central Apennines.

- explore the links between earthquake **source physics**, **wave propagation**, and ground motion variability.
- investigate the variability of ground motion both in space and time.
- develop data-driven non-ergodic and physics-based ground-motion models.
- generate physics-based 3D simulations at near-fault regions, (shaking significant, and missing data from large earthquakes).
- test, and validate the predicted ground motions against the seismic recordings, GMMs, and macroseismic intensity (MI) data available in the study area.
- ranking scheme in accordance with well-established engineering metrics (e.g. fragility curves for different types of structure) to provide direct means for engineering applications.

Study Area/s

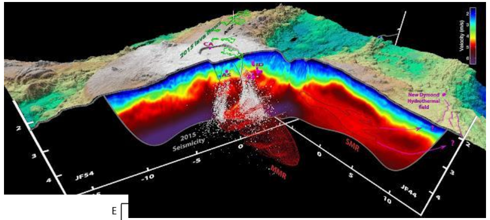


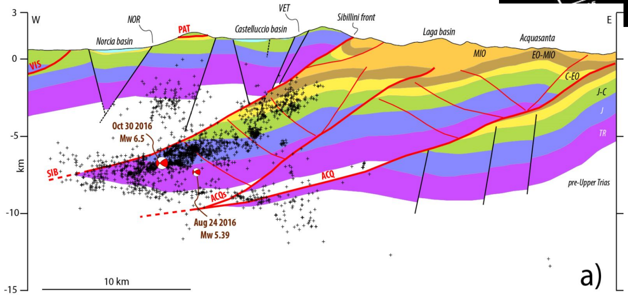
Central&North Central Italy

Area 1 *Amatrice-Visso-Norcia*

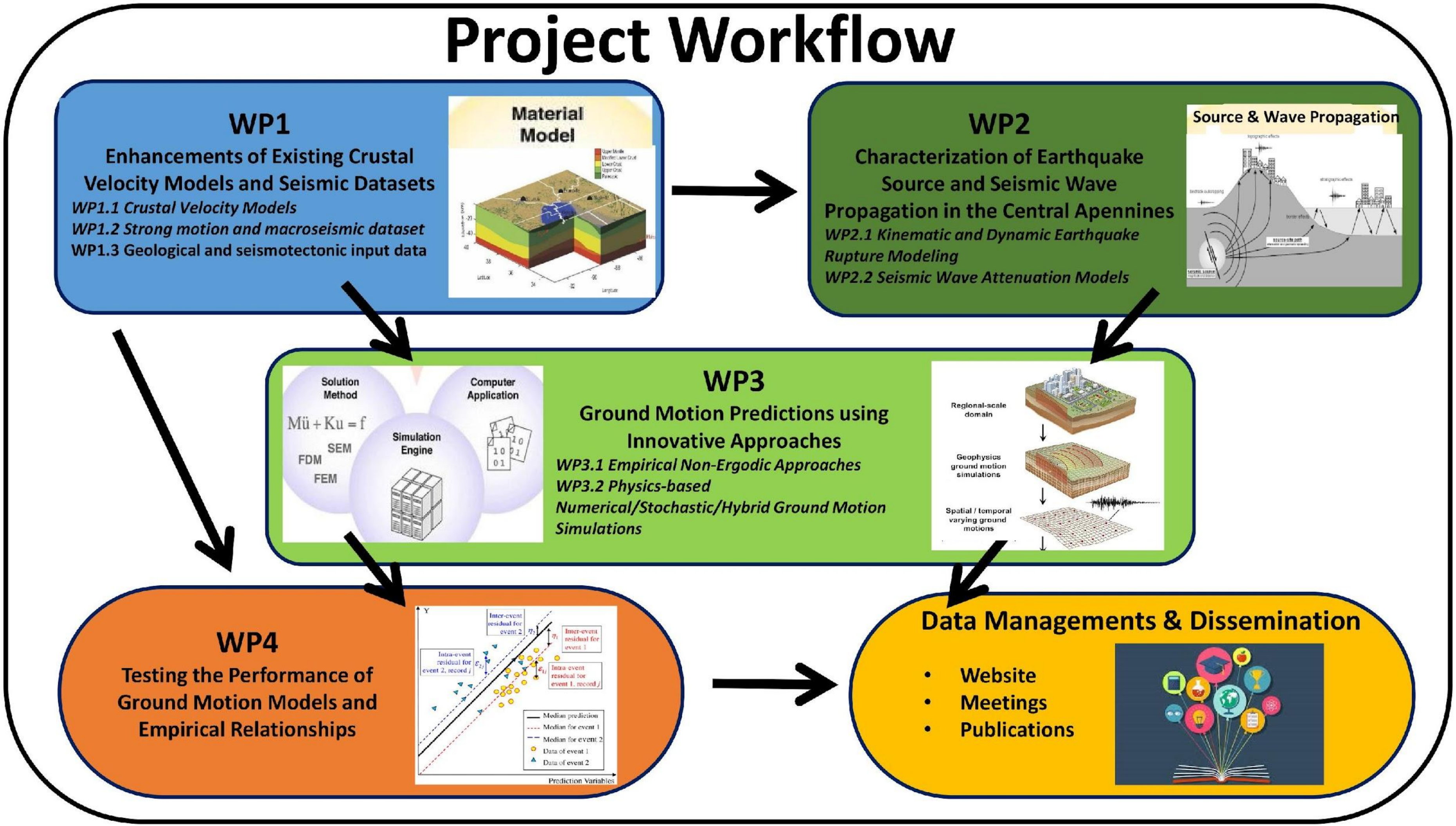
Area 2 *L'Aquila Basin*

Area 3 *Fucino Basin*





Mw ≥ 6.0 earthquakes from the CPTI15 catalog (blue squares; Rovida et al. 2022) and seismic station networks deployed to monitor the space-time evolution of the 2009 and 2016-2017 seismic sequences (green and red triangles). The small blue triangles are temporary stations deployed for measuring site effects after the 2009 and 2016-2017 sequences and, in the Fucino basin, in the frame of the 2008-2009 and 2012 DPC projects The epicenters of the mainshocks of the three sequences are shown as yellow stars. In orange are the individual seismogenic sources of the DISS v3.3.0 database (https://diss.ingv.it/). The "selected" individual sources are those associated with the main shocks of the three sequences. Red lines are the active and capable faults of the ITHACA database.


Project Workflow
WP1
Enhancements of Existing Crustal Velocity Models and Seismic Datasets
WP1.1 Crustal Velocity Models
WP1.2 Strong motion and macroseismic dataset
WP1.3 Geological and seismotectonic input data
Material Model
WP2
Characterization of Earthquake Source and Seismic Wave Propagation in the Central Apennines
WP2.1 Kinematic and Dynamic Earthquake Rupture Modeling
WP2.2 Seismic Wave Attenuation Models
Source & Wave Propagation
WP3
Ground Motion Predictions using Innovative Approaches
WP3.1 Empirical Non-Ergodic Approaches
WP3.2 Physics-based Numerical/Stochastic/Hybrid Ground Motion Simulations
Solution Method
Mü + Ku = f
SEM
FDM
FEM
Simulation Engine
Computer Application
Regional-scale domain
Geophysics ground motion simulations
Spatial / temporal varying ground motions
WP4
Testing the Performance of Ground Motion Models and Empirical Relationships
Inter-event residual for event 2
Inter-event residual for event 1
Intra-event residual for event 2, record j
Intra-event residual for event 1, record j
Median prediction
Median for event 1
Median for event 2
Data of event 1
Data of event 2
Prediction Variables
Data Managements & Dissemination
• Website
• Meetings
• Publications

Working Groups:
29 Internal 10 External participants

WP1 - INGV-ONT (**Ref.** Pasquale De Gori). **Partecipanti (14): WP1.1** Pasquale De Gori, Claudio Chiarabba, Samer Bagh, Francesco P. Lucente, Luisa Valoroso, Mario Anselmi, **WP1.2** Pierfrancesco Burrato, Paola Vannoli, Andrea N. Rovida, Antonio Gomez, Giovanni Lanzano, Vera D'Amico, Sara Sgobba, Aybige Akinci.

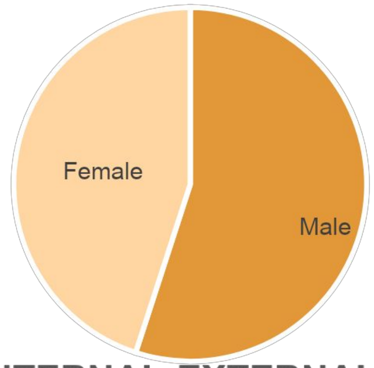
WP2 - INGV-Roma1 (**Ref.** Giovanna Calderoni). **Partecipanti (16): WP2.1** Giovanna Calderoni, Antonella Cirella, Antonella Megna, Paola Morasca, Daniele Spallarossa, Dino Bindi, Matteo Picozzi, Pietro Artale Harris, Frantisek Gallovic, Ali Ozgun Konca, Yasemin Korkusuz Ozturk, **WP2.2** Aybige Akinci, Edoardo Del Pezzo, Luca De Siena, Raul Castro (AR ***Simona Gabrielli, Leonardo Colavitti***)

WP3 – INGV-Milano (**Ref.** Francesca Pacor). **Partecipanti (9)**: **WP3.1** Francesca Pacor, Giovanni Lanzano, Sara Sgobba, **WP3.2** Aybige Akinci, Pietro Artale Harris, Paola Bordoni, Arben Pitarka, Irene Munafò, Daniele Melini

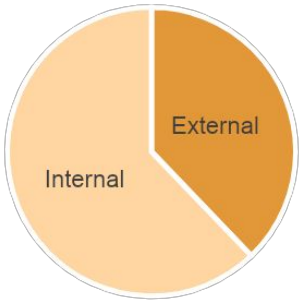
WP4 - INGV-Roma1 (**Ref.** Matteo Taroni). **Partecipanti (6)**: Matteo Taroni, Giovanni Lanzano, Paolo Zimmaro, Gianluca Regina, Ilaria Spassiani, Aybige Akinci

WP Data Management and Dissemination, Partecipanti (3): Fawzi Doumaz, Maurizio Pignone, Aybige Akinci

GENDER BALANCE



INTERNAL-EXTERNAL PARTICIPANTS



Budget 2023

SECURE_rimodulazione_PPD2023_2025_FINAL - Excel

A5 | Acronimo Progetto: Responsabile:

	A	B	C	D	E
7	1.06 RM1	Pubblicazioni (cap. 1.03.01.01.002.)	Spese Riviste	Gruppo WP Roma1 (11 ricercatori)	€ 3,500.00
8	1.06 RM1	Materiale informatico consumabile (cap. 1.03.01.02.006)	2/3 dischi esterni	Gruppo WP Roma1 (11 Ricercatori)	€ 1,500.00
9	1.06 RM1	Prestazioni tecnico-scientifiche a fini di ricerca (cap. 1.03.02.11.009)	Collaborazione di Ricerca - Lawrence Livermore National Laboratory, LLNL, CA, USA	Gruppo WP Roma1	€ 25,000.00
10	1.06 RM1	Indennità di missione e trasferta - Personale INGV (cap. 1.03.02.02.002.02)	Partecipazione riunione, cognvegni nazionale e internazionale	Gruppo WP Roma1 (11 ricercatori)	€ 13,000.00
11	1.06 RM1	Indennità di missione e trasferta - Altro Personale (cap. 1.03.02.02.002.02)	Inviti a ricercatori esterni INGV	Gruppo WP Roma1 (collaboratori esterni)	€ 3,500.00
12	1.06 RM1	Inventariabile: Hardware (cap. 2.02.01.07.999.)	Mac Book Pro 14" + Apple Care	Pietro Artale Harris	€ 4,500.00
13	1.08 ONT	Pubblicazioni (cap. 1.03.01.01.002.)	Spese Riviste	Gruppo WP ONT	€ 3,000.00
14	1.08 ONT	Indennità di missione e trasferta - Personale INGV (cap. 1.03.02.02.002.02)	Partecipazione a convegni	Gruppo WP ONT	€ 7,500.00
15	1.08 ONT	Inventariabile: Hardware (cap. 2.02.01.07.999.)	Pc laptop	Richiedente WP ONT	€ 6,000.00
16	1.03 MI	Pubblicazioni (cap. 1.03.01.01.002.)	Spese Riviste	Gruppo WP MI	€ 3,000.00
17	1.03 MI	Prestazioni tecnico-scientifiche a fini di ricerca (cap. 1.03.02.11.009)	collaborazione di ricerca università (Politecnico Milano, Cicese, Messico, Università di Praga)	Gruppo WP MI	€ 20,000.00
18	1.03 MI	Indennità di missione e trasferta - Personale INGV (cap. 1.03.02.02.002.02)	partecipazione riunione e convegni	Gruppo WP MI	€ 6,000.00
19	1.03 MI	Indennità di missione e trasferta - Altro Personale (cap. 1.03.02.02.002.02)	Inviti a ricercatori estreni INGV	Gruppo WP MI (collaboratori esterni)	€ 3,500.00
20	TOTALE				€ 100,000.00

PIANETA DINAMICO - Spese 2023 | Parametri

WP1. Enhancements of Existing Crustal Velocity Models and Seismic Datasets

Deliverable	Description	Months
WP1_D1	A detailed crustal model with the P and S wave speeds, V_P and V_S, and densities which are assigned to each crustal volume (up to 20-30km depth) including basin structures embedded in tomographic crust and upper mantle	**10 area1** **14 area2** **20 area3**
WP1_D2	Mesh files to be used in WP3.2 and be refined through the SW4. These files contain the values of the model features (P-velocity, S-velocity, density, and optionally the attenuation factors Q_P and Q_S) as a function of depth at points on a regular lattice covering the horizontal extent of the computational domain	**12 area1** **16 area2** **24 area3**

In **WP1.1,** we expect to construct 3D velocity models of the three target regions by merging the results of high resolution 3D tomographic models and detailed geological information for the shallower geological units.

Deliverable	Description	Months
WP1_D3	Macroseismic intensity data linked with measured ground motion parameters	**12**
WP1_D4	Macroseismic intensity data linked with three-dimensional source parameters of the causative earthquakes.	**18**
WP1_D5	A dataset of weak and strong motion recordings in central Italy, classified in mainshock/aftershocks	**12**

In **WP1.2**, the main results are: i) the improvement and enhancement of the comprehension of ground motion propagation in terms of macroseismic intensity; ii) the creation and validation of datasets suitable for testing the results of ground motion scenarios and finite-fault simulations.

Deliverable	Description	Months
WP1_D6	The same GIS repository will also contain the different seismogenic source models published for the earthquake sequences that hit the three study areas, containing some of the ground motion simulation results	**24**

In **WP1.3** we expect to build a GIS repository containing the homogenized publicly available geological and structural data of the three study areas.

WP2. Characterization of Earthquake Source and Seismic Wave Propagation in the Central Apennines

Deliverable	Description	Months
WP2_D1	The source parameters for earthquakes M>3.0 are moment magnitude, stress drop, apparent stress, and radiated energy in the Central Apennines	**12**
WP2_D2	Spatial and temporal variation of the stress drop parameter in the study areas	**24**
WP2_D3	Kinematic earthquake source model for events with M>6, estimated by jointly inverting for seismic and geodetic data	**18**
WP2_D4	A series of stochastic and deterministic/hybrid physics/based kinematic earthquake rupture models for faults activated during M>6.0 earthquakes (L'Aquila M6.2, Amatrice M6.0, Norcia M6.5, and Fucino M7.0) in the Central Apennines	**30**
WP2_D5	Integration of Frequency-dependent directivity effects from seismic sequence into traditional GMMs	**30**

In **WP 2.1**, we expect to estimate several earthquake source-related parameters, such as moment magnitude, stress drop, apparent stress, and radiated energy, that will be determined using independent approaches (spectral ratios, spectral fitting and coda methods).

Deliverable	Description	Months
WP2_D6	The spatial distribution and temporal evolution of the total attenuation of S-waves (Qs) as a function of frequency in the Central Apennines, focusing on the seismic sequences of L’Aquila and Amatrice, Visso, Norcia.	**18**
WP2_D7	Spatial and temporal evolution of spectral decay parameter kappa	**18**

In **WP2.2** we expect to estimate the anelastic attenuation of the S-wave in space and time. This can affect the variability of ground motion in the central Apennines before, during, and after the occurrence of significant earthquakes.

WP3. Ground Motion Predictions using Innovative Approaches

Deliverable	Description	Months
WP3_D1	Stationary NE-ground motion model for central Italy	12
WP3_D2	Stationary NE-ground motion model for Italy	24
WP3_D3	Non-stationary NE-ground motion model	36
WP3_D4	An updated Intensity Prediction Equation (IPE) for the Italian area	24
WP3_D5	A regional intensity attenuation model for central Italy, obtained by means of regional correctives assessed with the analysis of the residuals	36

In **WP3.1,** we expect to produce non-ergodic ground-motion models, with improved accuracy through the inclusion of spatial and temporal non-stationarities.

Deliverable	DESCRIPTION	MONTHS
WP3_D6	Georeferenced shaking scenarios from physics-based ground motion simulations for the selected M>6.0 earthquakes in Central Apennines	34
WP3_D7	Time histories and a series for ground motion parameters including the permanent displacement	34
WP3_D8	Distribution of the simulation codes that developed and used in the project	36

In **WP3.2**, we expect to capture the impact of earthquake source rupture (fault geometry and the kinematics, slip heterogeneity, and nucleation points), seismic wave attenuation (Q(f)), and 3D earth structure (basins, topography) on the ground shaking intensities, particularly in the near field.

WP4. Testing the Performance of Ground Motion Models and Empirical Relationships

Deliverable	Description	Months
WP4_D1	A set of tables and figures presenting the LLH and WLLH values for each ground motion model for the whole dataset as well as for the specific set of information relative to the distance and the magnitude.	36
WP4_D2	A set of tables indicating the specific weights to be associated with each selected ground motion model determined from the whole dataset as well as for the specific set of information relative to the distance and the magnitude	36
WP4_D3	A table with the results of the statistical tests for the empirical relationships between the macroseismic intensities and the observed ground motion parameters.	36
WP4_D4	Final report where we describe the data method and results in detail	36

In **WP4** we will evaluate GMM predictions against independent observations of ground motions. Such tasks will be performed for various IMs such as peak ground acceleration and velocity, PGA and PGV, and spectral accelerations at various periods, Sa(T).

Gantt Chart

MONTHS	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
WP1.1	X	X	X	X	X	X	X	X	X	X	X	X						
WP1.2	X	X	X	X	X	X	X	X	X									
WP1.3	X	X	X	X	X	X	X	X	X	X	X	X						
WP2.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
WP2.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
WP3.1			X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WP3.2				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
WP4				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Expenses Procedure - Pianeta Dinamico

Come PM di Roma1 per il progetto "Pianeta Dinamico" vi invito a controllare e compilare nel dettaglio il file excel "**PER_SEZIONE_RM1_PIANETA DINAMICO 2023**" al seguente link:

https://drive.google.com/drive/u/0/folders/1IXPyC7pNvPMJiDoIhk1dVoCiDjZ-QIFi

In questo file, nello specifico i fogli "spese COMPILARE" e "missioni COMPILARE", sono state inserite le vostre richieste già inoltrate ai responsabili del progetto (vedi foglio "BILANCIO INIZIALE").

Per quanto riguarda le spese per gli inventariabili sarebbe opportuno farle il prima possibile, in accordo con il direttore e con il PM della sezione di Roma1 la scadenza è per venerdì 3 aprile.

In generale i moduli da compilare per la richiesta di acquisti sono i nuovi forms indicati dal direttore di sezione nella sua e-mail del 28 marzo 2023.

Invece per gli acquisti di ws, server, tablet, notebook, desktop e accessori vari per pc, l'intenzione è di fare un unico ordine. A tal fine nel file excel "acquisti_invetaribili_&_consumabili_3_aprile_2023", sempre nello stesso link, è possibile inserire le caratteristiche tecniche del pc che si desidera acquistare (nel foglio "inventariabili"), come pure gli accessori per pc (foglio "consumabili")