2-D modeling of topographic effects using three basic geometries and the spectral-element method

Giuseppe Di Giulio
Istituto Nazionale di Geofisica e Vulcanologia, Sede di L'Aquila

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Modellazioni 2D

specfem2D (Codice agli elementi spettrali **)

- https://geodynamics.org/cig/software/specfem2d/

Computational Infrastructure for Geodynamics (CIG) is a community-driven organization that advances Earth science by developing and disseminating software for geophysics and related fields.

[*weak formulation dell'equazione del moto, campo d'onda discretizzato usando high-degree Lagrange polinomi, e l'integrazione basata sul metodo Gauss-Lobatto-Legendre, matrice delle masse diagonale*]

- combina la flessibilità dei metodo agli elementi finiti nel trattare geometrie complesse e condizioni all'interfaccia con l'accuratezza dei metodi spettrali

Vantaggi

- mesh distorte, anche costruite con generatori esterni
- accuratezza, precisione e ridotta dispersione numerica nel propagare onde di volume, onde di superficie e onde convertite.
- ridotte onde fittizie dai bordi (PML: Perfectly matched layers)
- non necessita di CPU particolarmente potenti per modelli 2D semplici

*** **Chaljub, E., D. Komatitsch, J.P. Vilotte, Y. Capdeville, B. Valette, and G. Festa**, 2007, Spectral element analysis in seismology. In R.-S. Wu and V. Maupin, editors, Advances in wave propagation in heterogeneous media, volume 48 of Advances in Geophysics, pages 365–419. Elsevier-Academic Press, London, UK.*

***Komatitsch, D. & J.P. Vilotte**, 1998, The spectral element method: An efficient tool to simulate the seismic response of 2D and 3D geological structures, Bull. Seism. Soc. Am. 88(2), 368-392.*

***Priolo, E., J.M. Carcione, and G. Seriani,** 1994, Numerical simulation of interface waves by high-order spectral modeling techniques. The Journal of the Acoustical Society of America, 95(2), 681-693.*

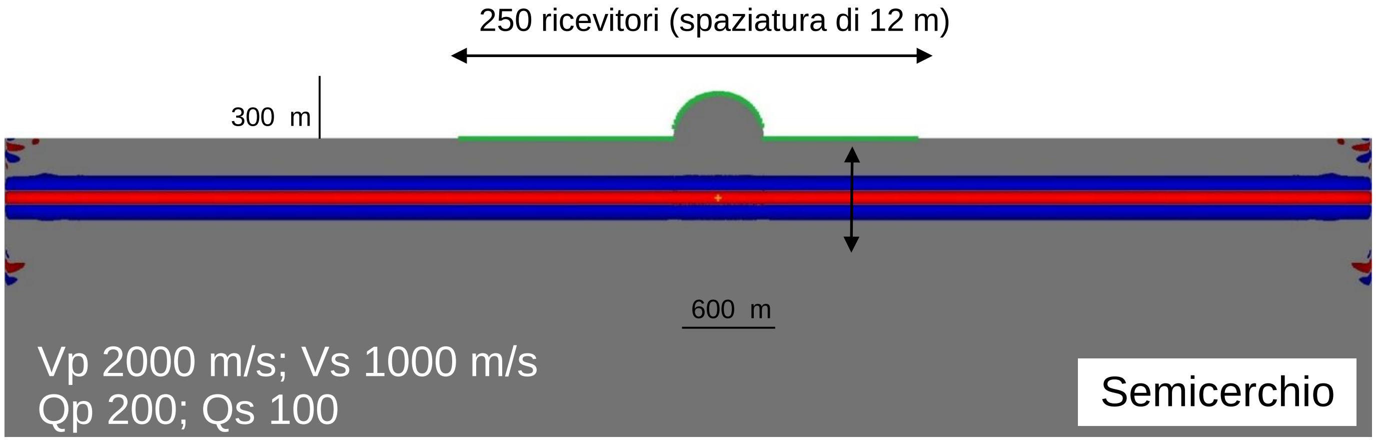
Modellazione numerica (effetto topografico)

Codice Specfem2d

Tre geometrie usate.

Onde piane P-SV verticalmente incidenti.
Input Ricker 5 Hz.
Polarizzazione input P e S tenute separate.

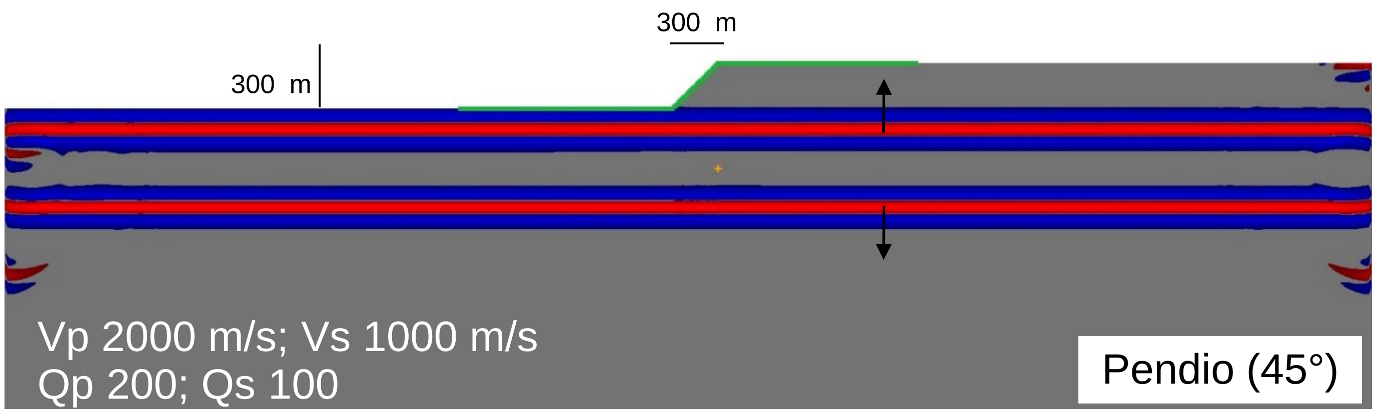
Rosso: ampiezze -
Blu: ampiezze +



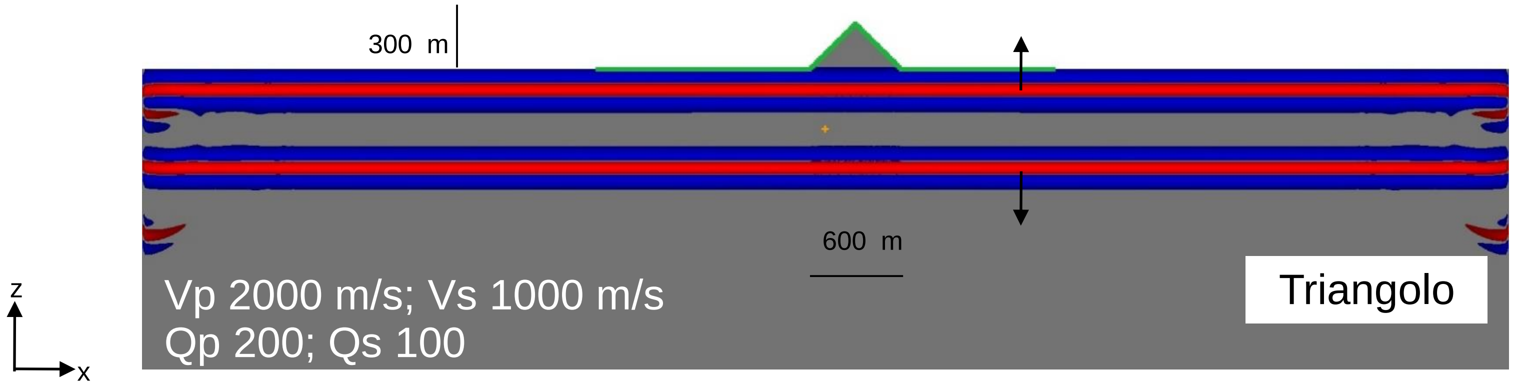
Mesher interno del codice specfem2d
(circa 270000 elementi rettangolari).

$$\Delta t \leq C \frac{h_{min}}{V_{max}}$$

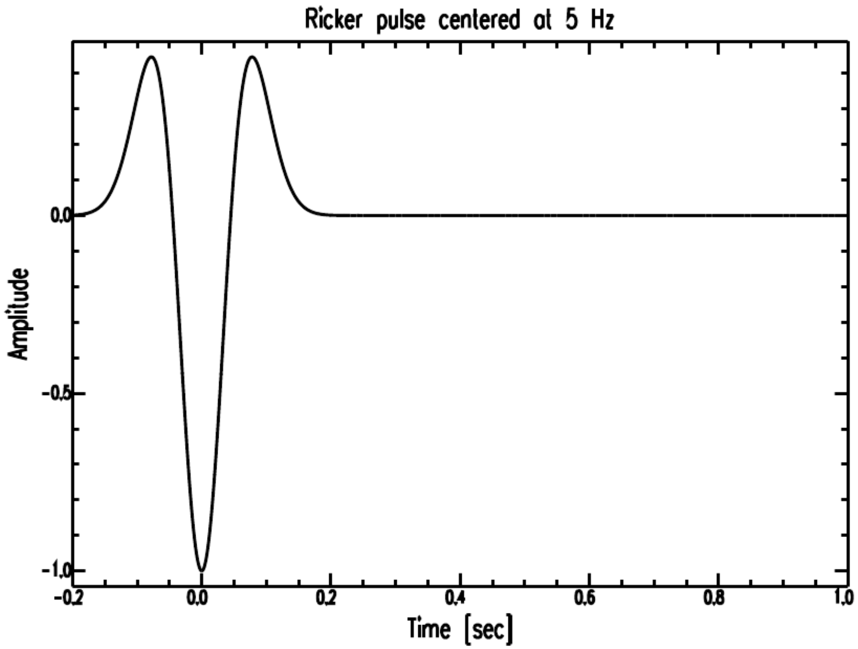
$$d \leq \frac{N \lambda_{min}}{5}$$

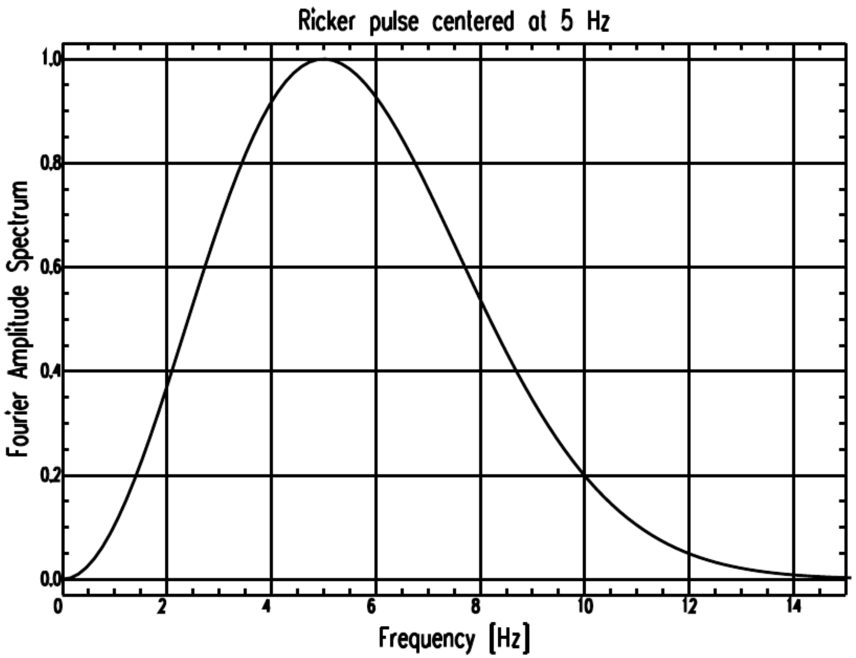


Tre lati del dominio (lato sinistro, destro e inferiore) come strati assorbenti (PML).



Ricker input



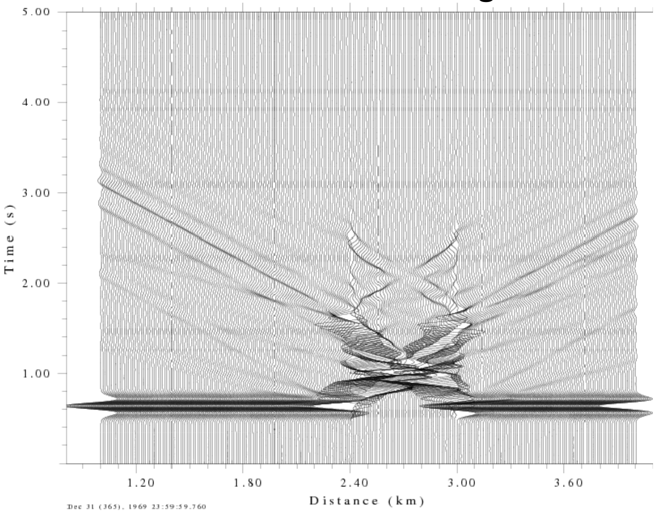


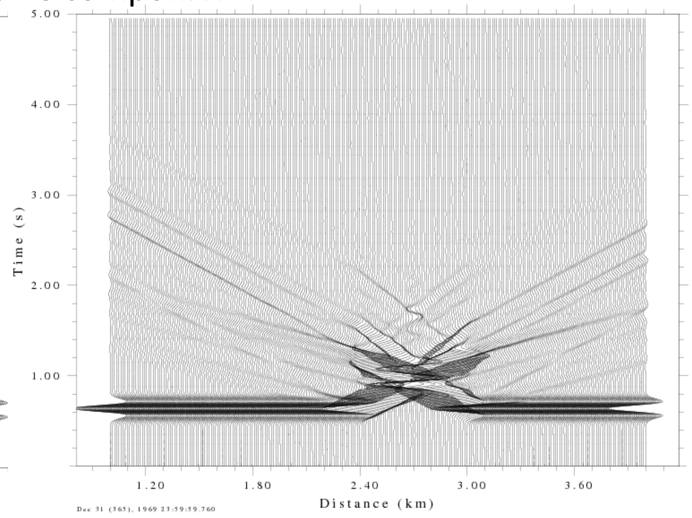
Le polarizzazioni di input P and S sono state tenute separate con distinti run.

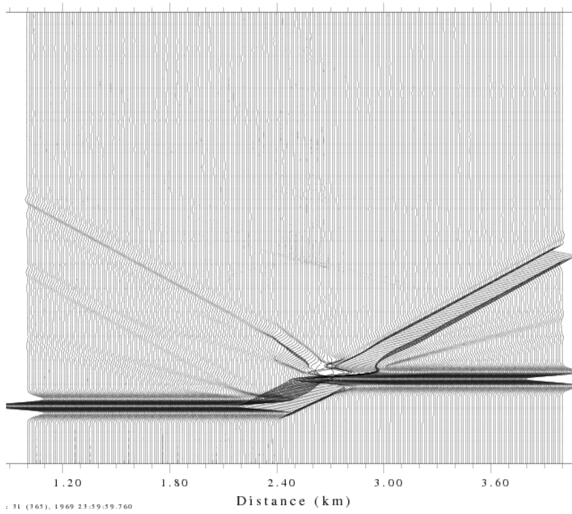
Prima ho considerato un modello con onda in-plane polarizzata S, poi ho ripetuto la modellazione considerando una sorgente polarizzata P.

Semicerchio   Triangolo   Pendio

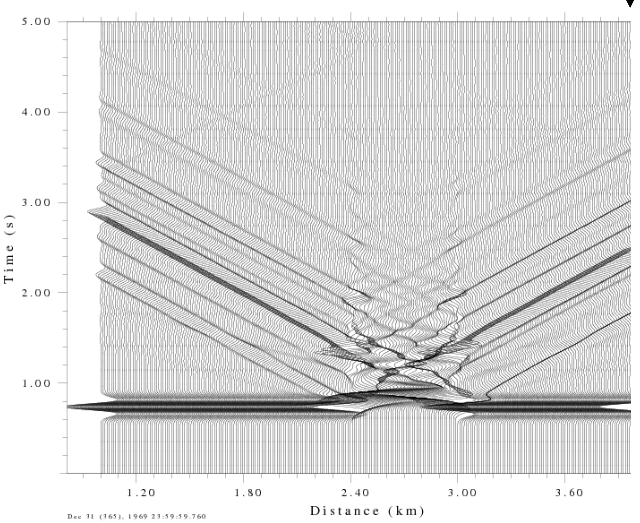
Polarizzazione della sorgente S ↔ e compon. X

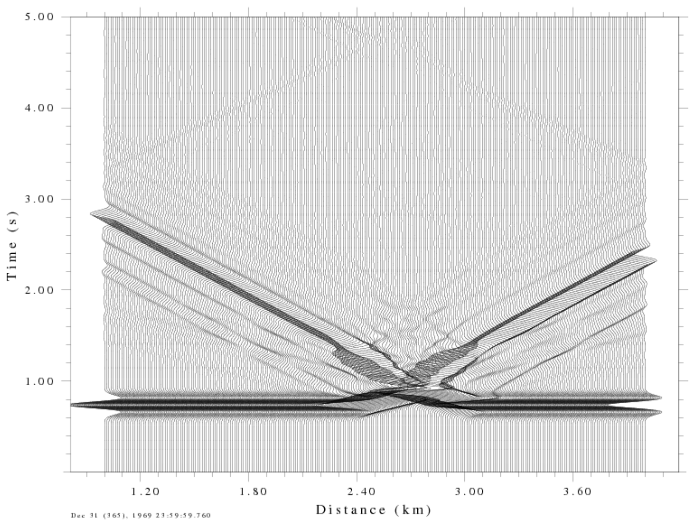


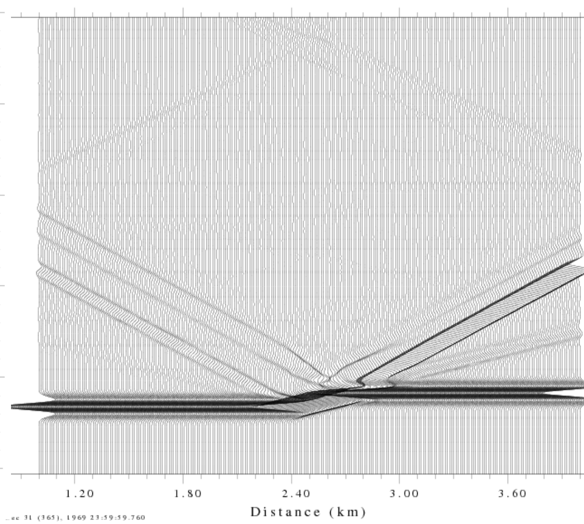




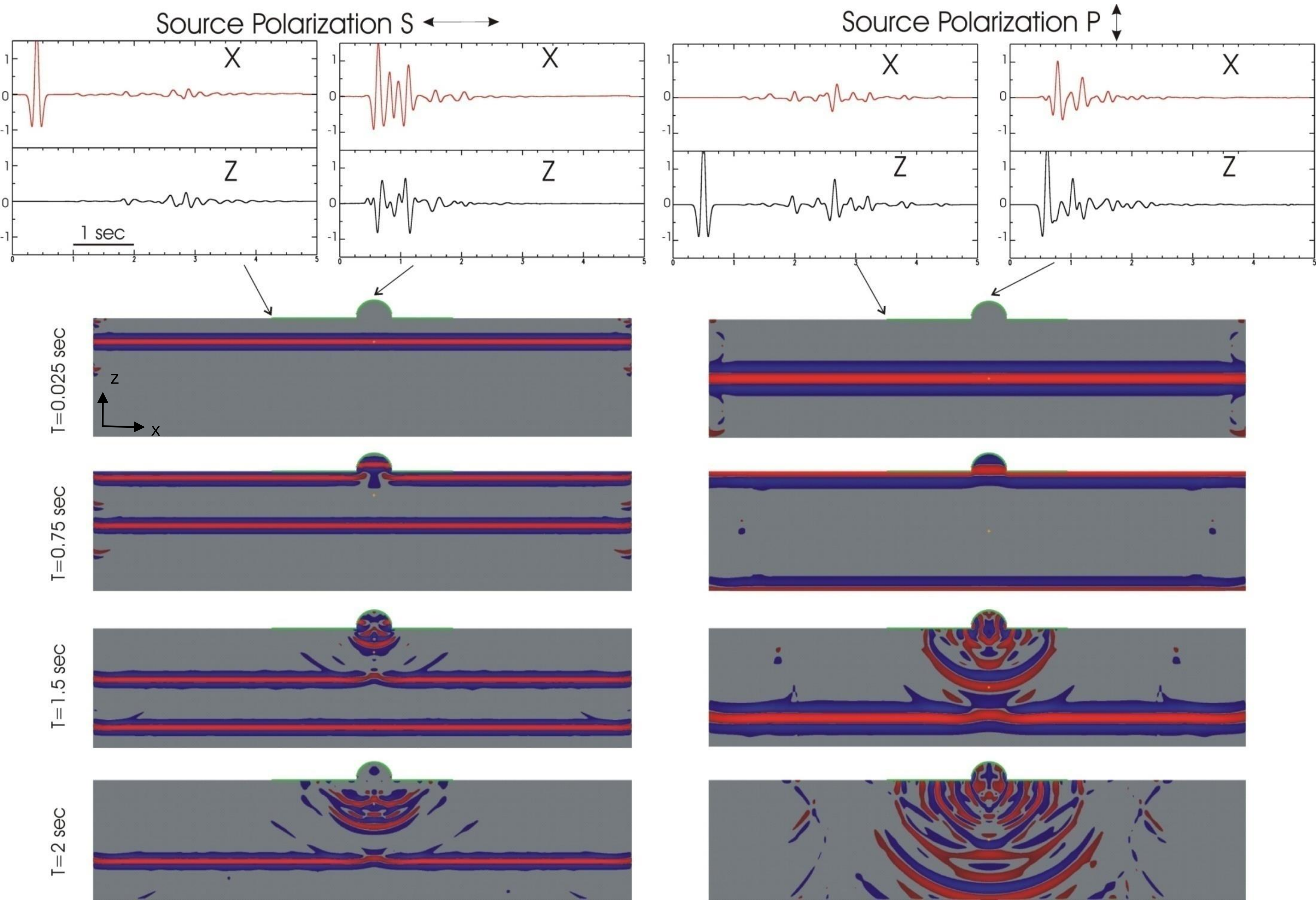
Polarizzazione della sorgente P ↕ e compon. Z



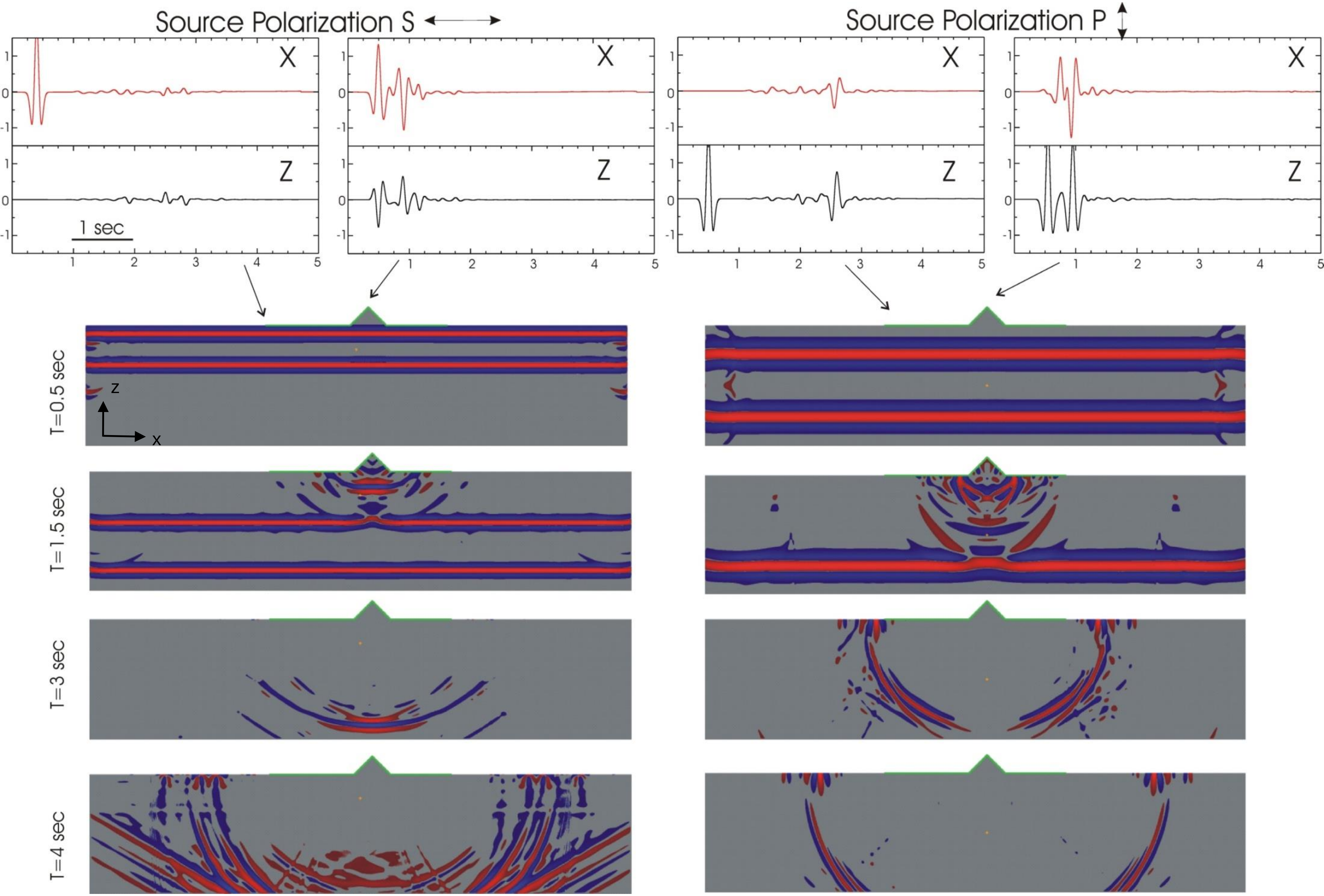




Semicerchio

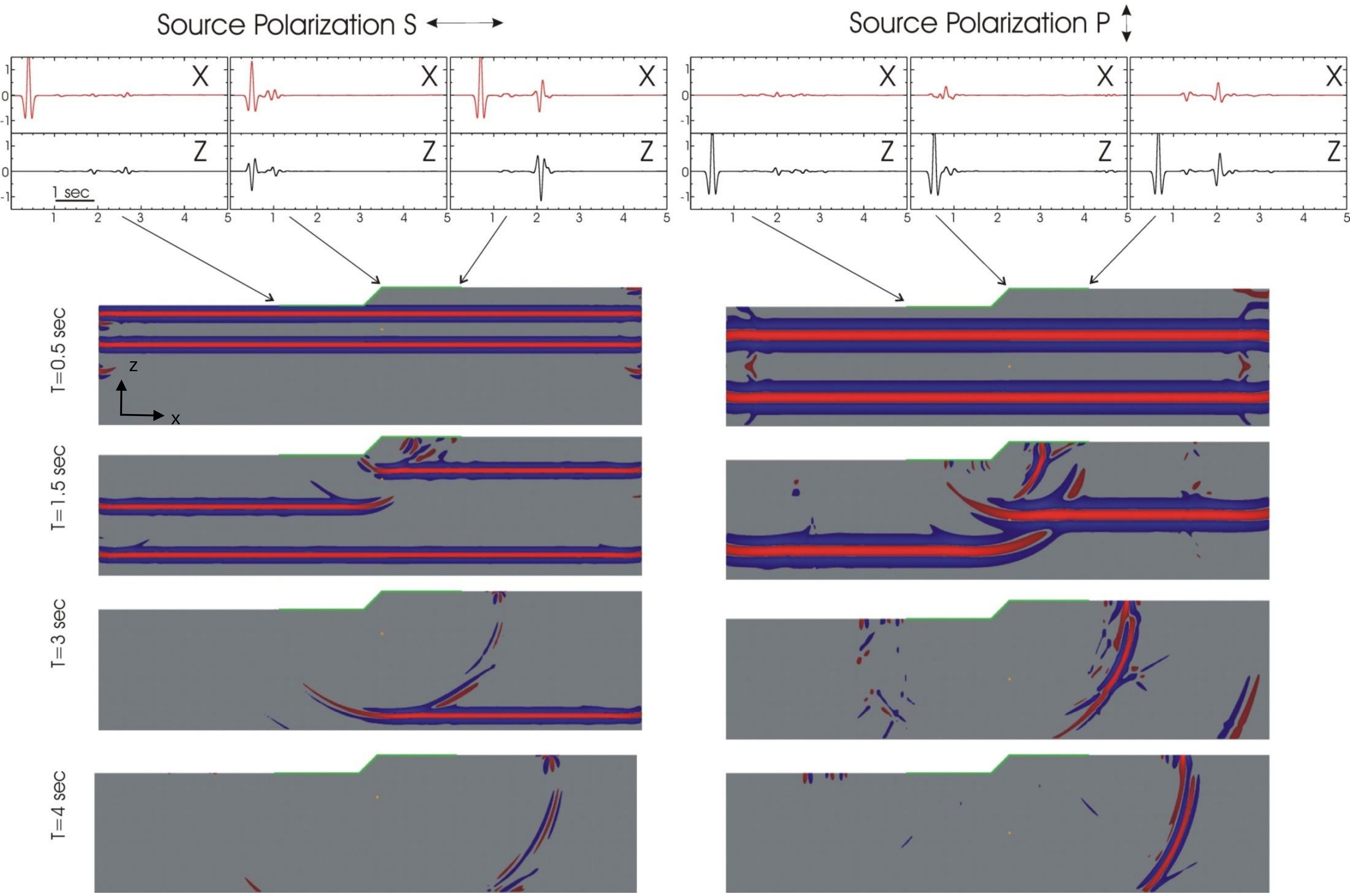


Triangolo



Source Polarization S
Source Polarization P
X
Z
1 sec
T=0.5 sec
T=1.5 sec
T=3 sec
T=4 sec
z
x

Pendio



Source Polarization S
Source Polarization P
X
Z
1 sec
1
0
-1
1 2 3 4 5
T=0.5 sec
T=1.5 sec
T=3 sec
T=4 sec
z
x

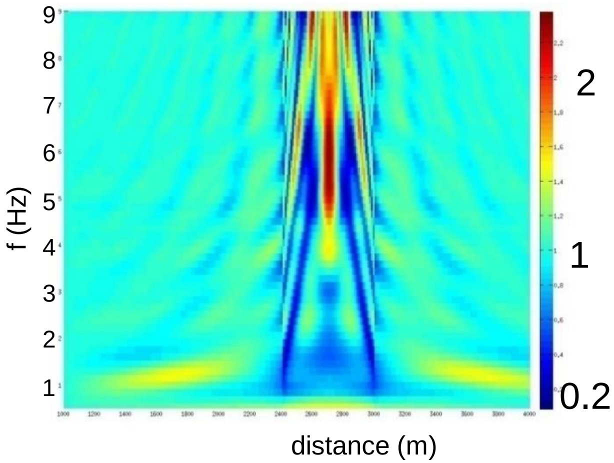
Rapporti spettrali SSR [X/Xref and Z/Zref]

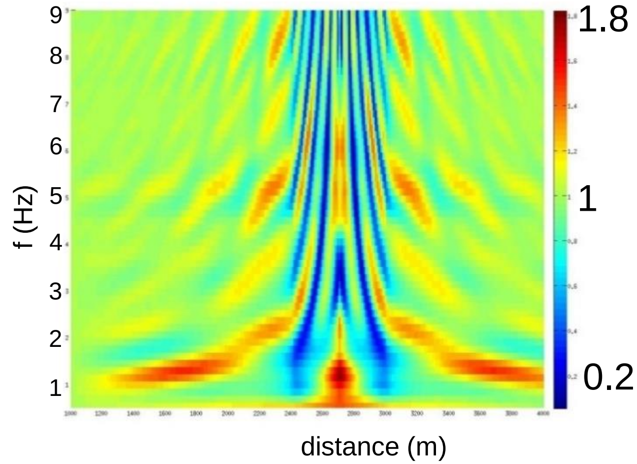
Semicerchio

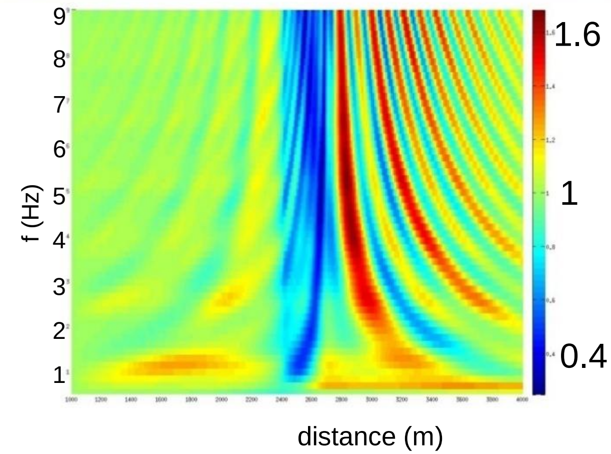
Triangolo

Pendio

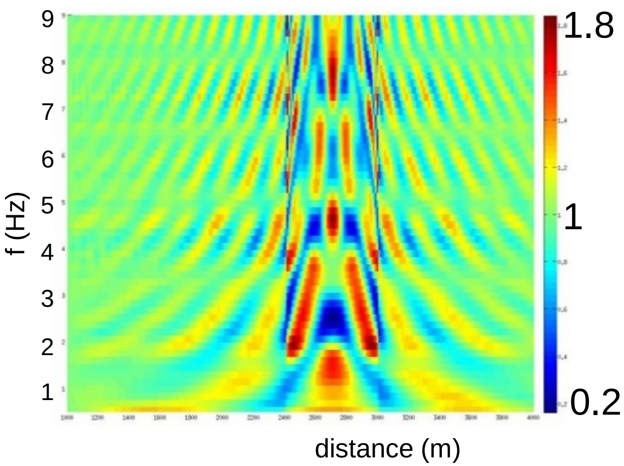
Polarizzazione della sorgente S e compon. X [X/Xref]

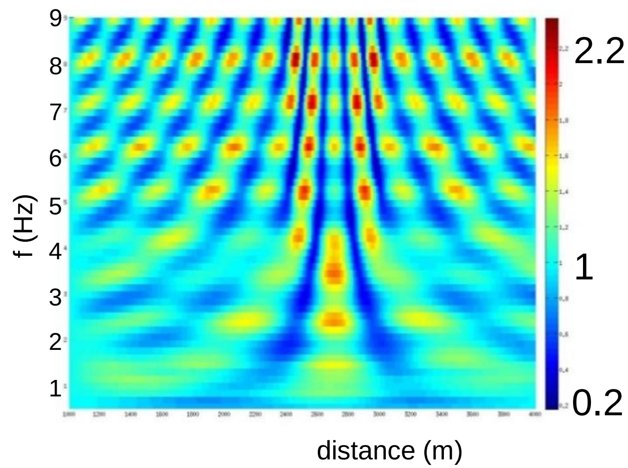


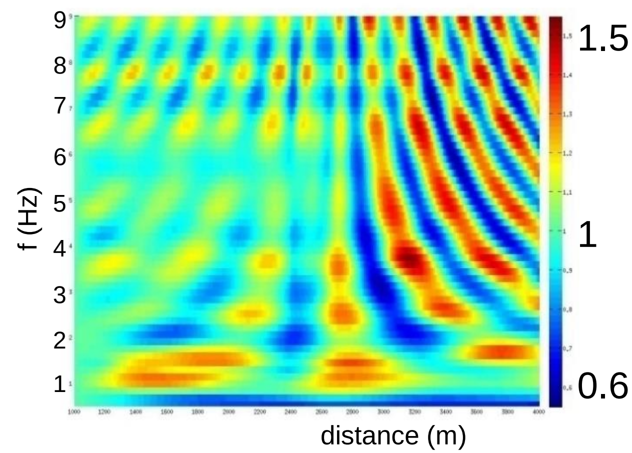




Polarizzazione della sorgente P e compon. Z [Z/Zref]

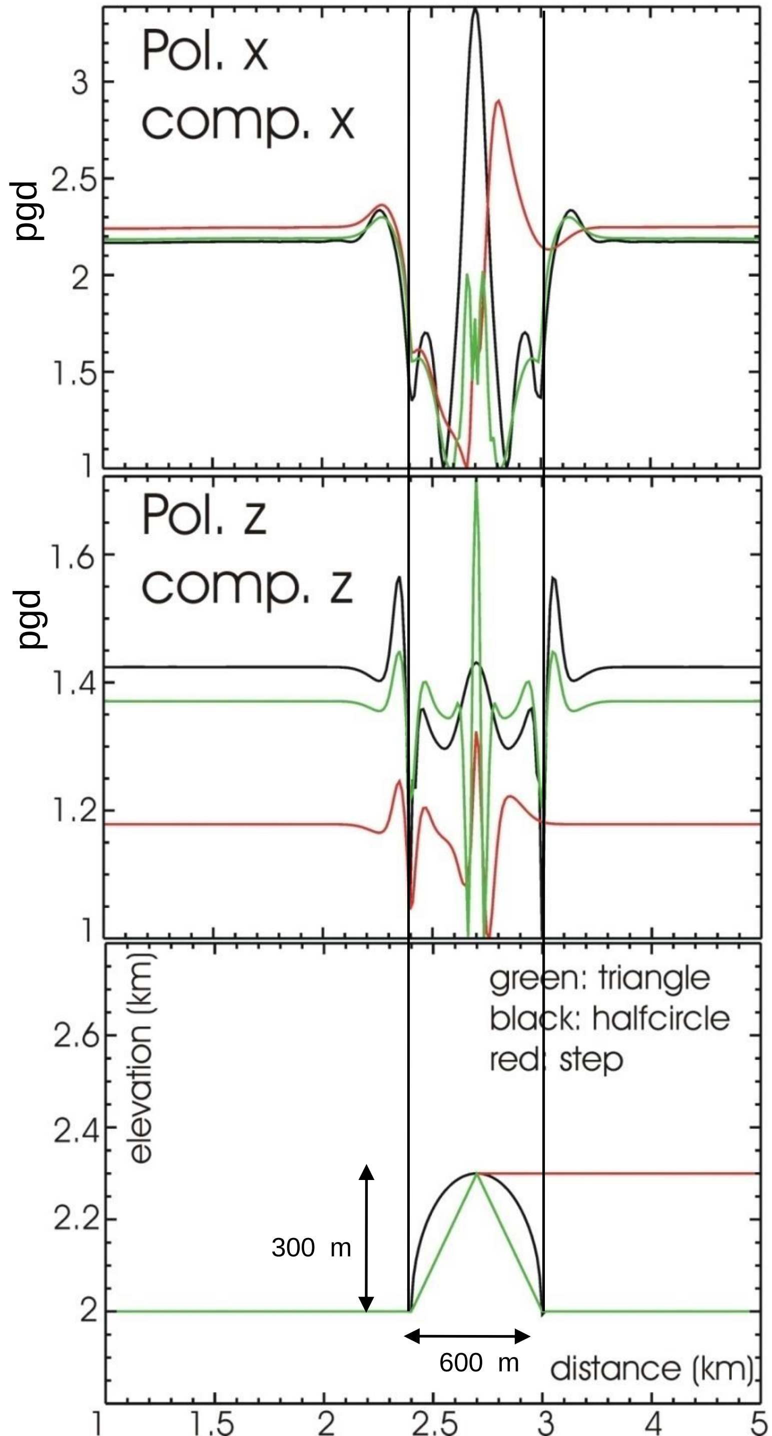




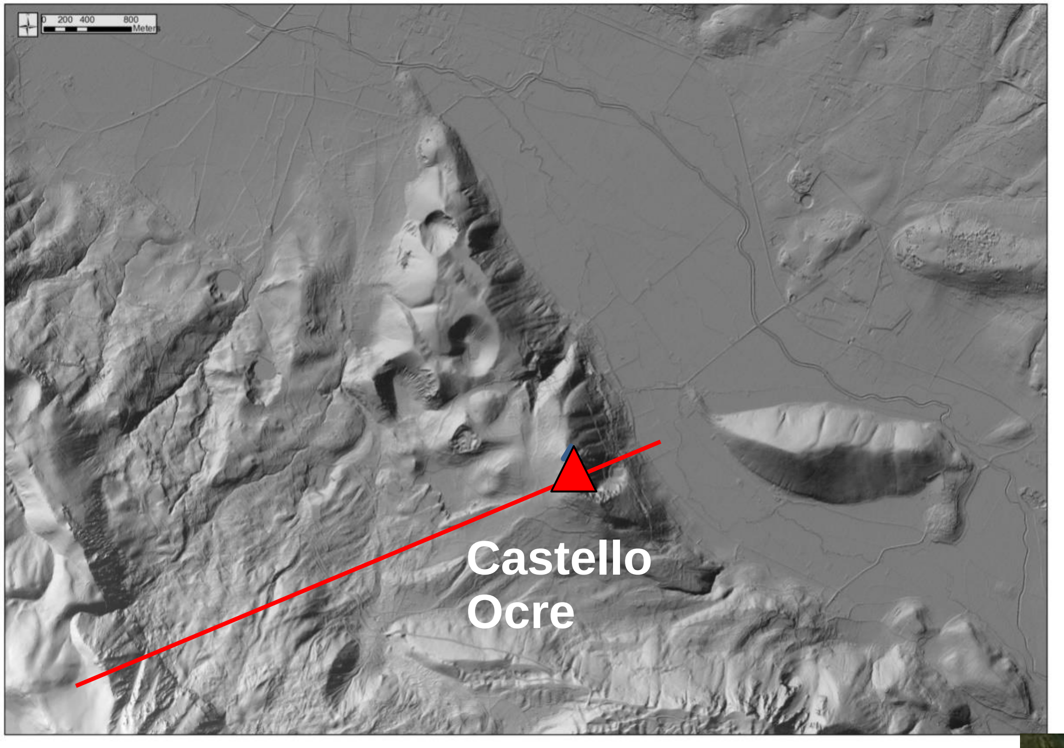


Fattore di aggravio topografico

$$TAF = \frac{X(2D)}{X(1D)}$$



Effetto topografico (Mt. Ocre)



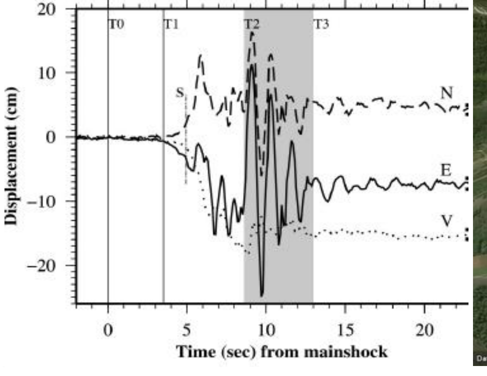
Registrazione del mainshock aquilano tramite una stazione gps ad high rate*

Registrazione di diversi aftershocks della sequenza aquilana tramite una stazione sismica co-locata

misure di vibrazione ambientale in diversi punti nell'intorno

Esperimenti sismici ad hoc (array 2D e 1D) per stimare il profilo Vs

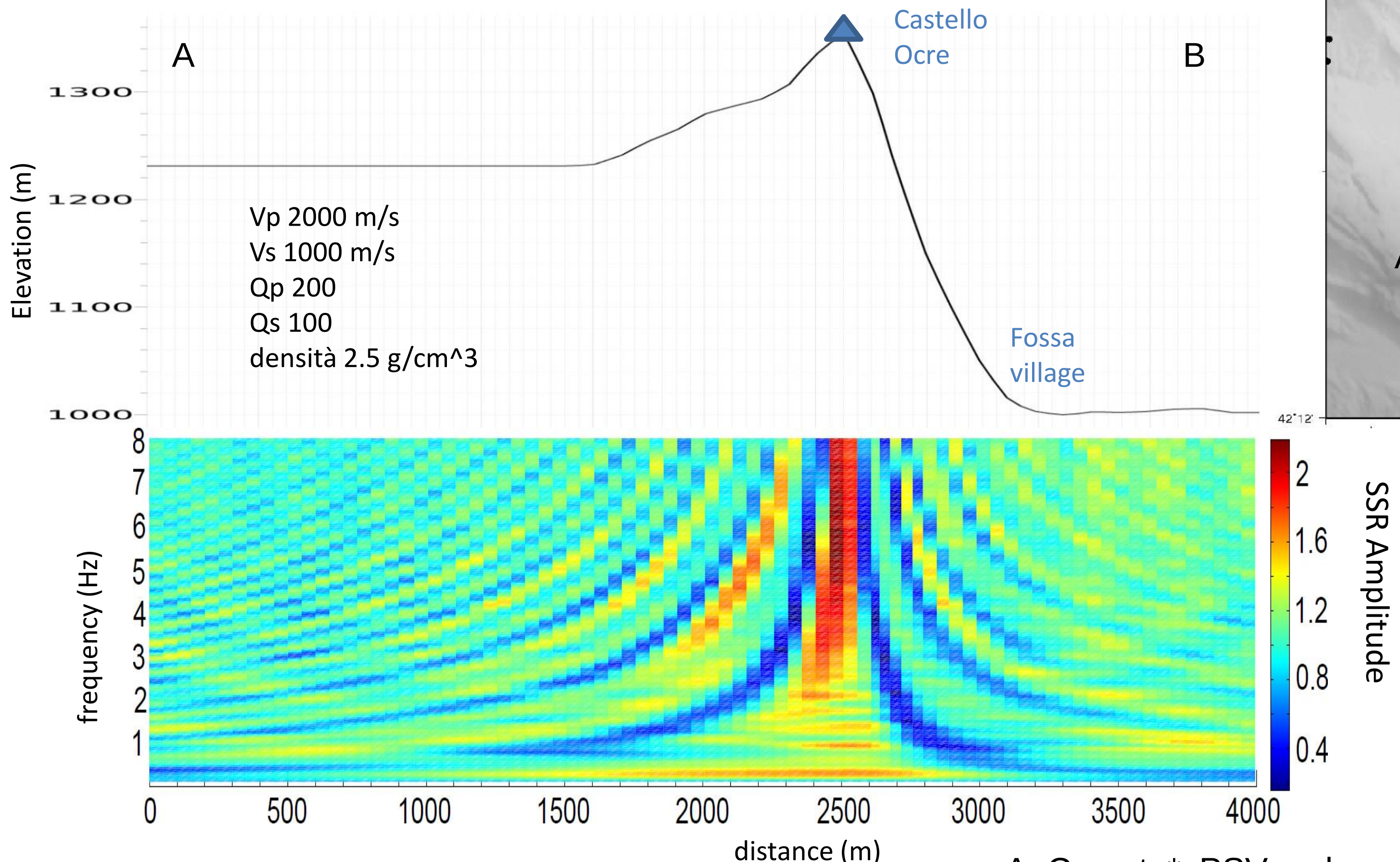
I dati indicano un segnale amplificato e polarizzato N+60° a circa 1Hz

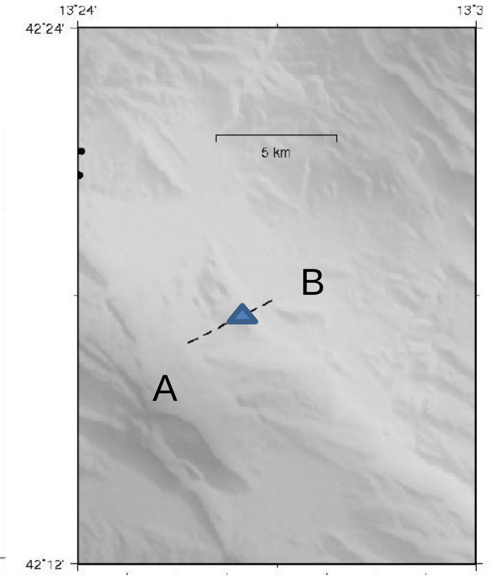


* **Avallone, A. et al., 2011,** Very high rate (10 Hz) GPS seismology for moderate-magnitude earthquakes: The case of the Mw 6.3 L'Aquila (central Italy) event, Journal of Geophysical Research , 116, B02305, doi:10.1029/2010JB007834

Avallone, A. et al., 2014, Waveguide effects in very high rate GPS record of the 6 April 2009, Mw 6.1 L'Aquila, central Italy earthquake. Journal of Geophysical Research, 119(1), 490-501, doi: 10.1002/2013JB010475

Modellazione Mt. Ocre (Caserta code)



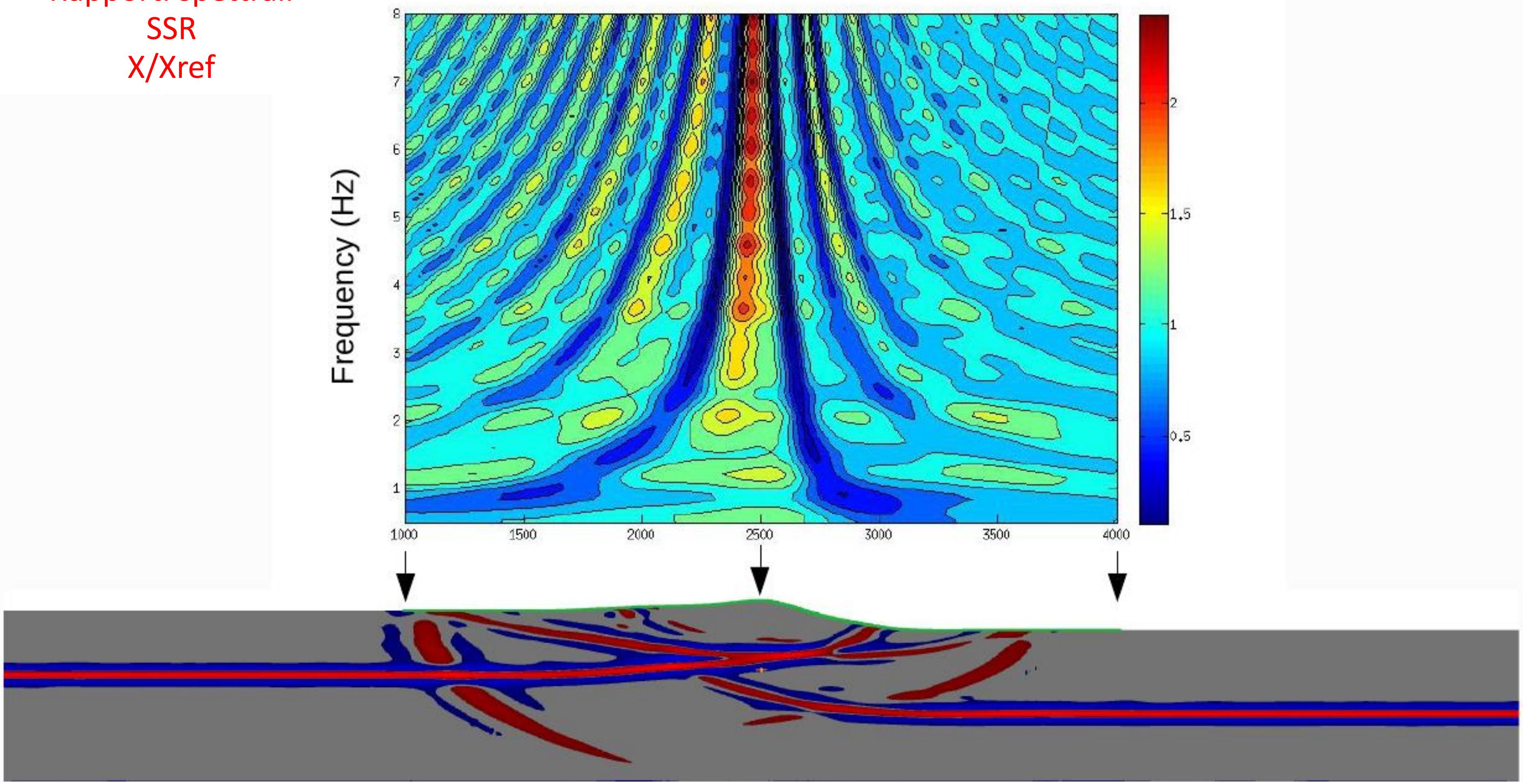


A. Caserta* PSV code
using a triangle mesh generator.
https://www.cs.cmu.edu/~quake/triangle.html

**** Caserta, A. 1998.** A time domain finite-difference technique for oblique incidence of antiplane waves in heterogeneous dissipative media. Annals of Geophysics 41(4), 617-631.*
***Caserta, A. & P. Lanucara, 2000.** Computer animation as a tool to visualize effects of seismic wave propagation inside heterogeneous media. Annals of Geophysics 43(1), 119-134.*
***Caserta, A. et al. , 2002.** Numerical modelling of dynamical interaction between seismic radiation and near-surface geological stuctures: a parallel approach. Computer & Geosciences 28(9), 1069-1077.*

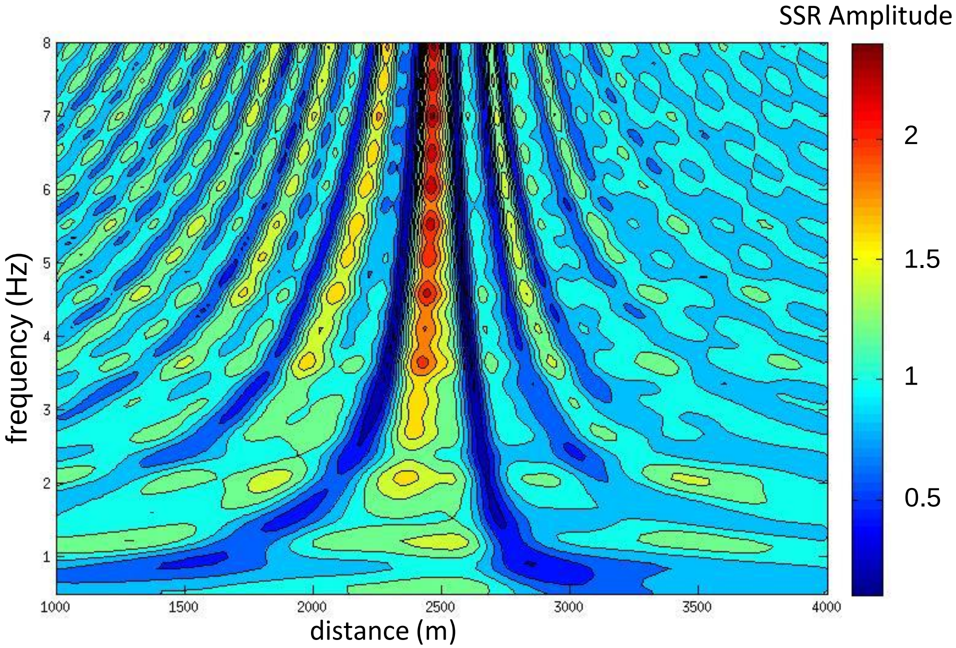
Modellazione Mt. Ocre (*specfem2d* code)

Rapporti spettrali
SSR
X/Xref

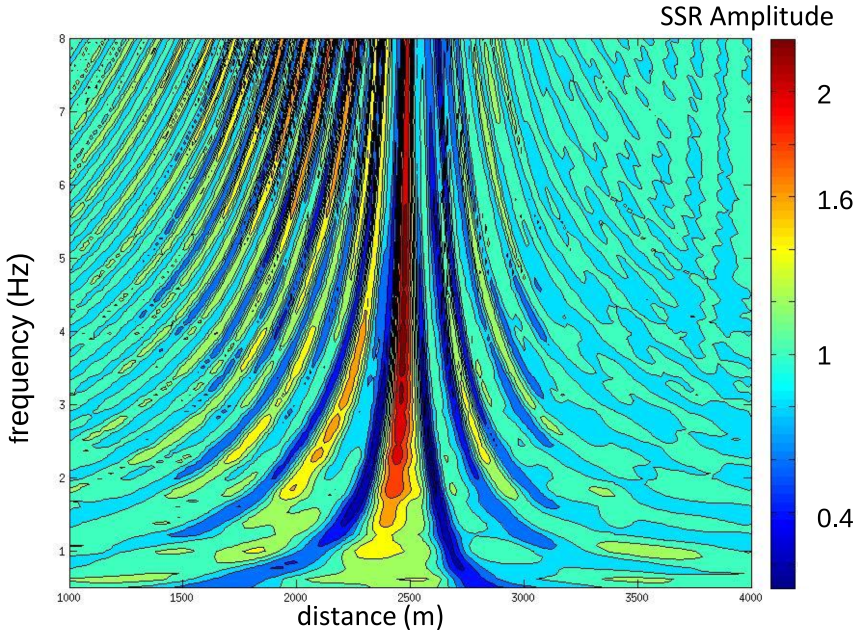


Mt. OCRE variando le velocità

Vp 2000
Vs 1000



Vp 1000
Vs 500

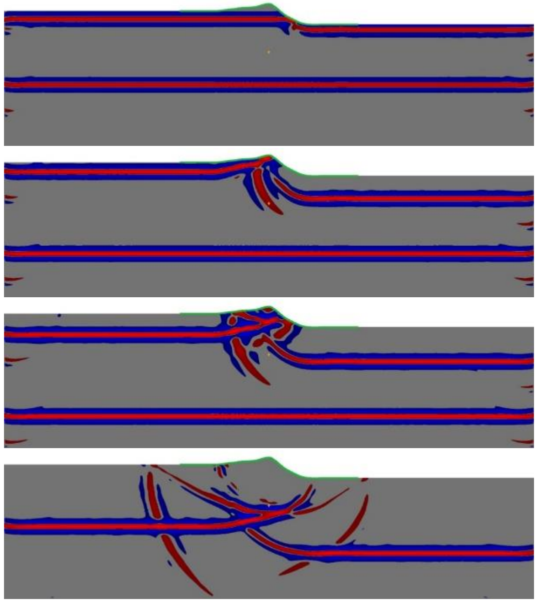


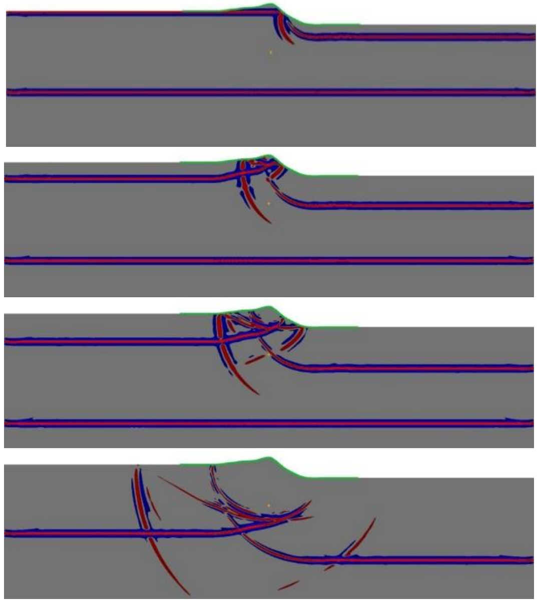
t=0.8 sec

t=1.1 sec

t=1.3 sec

t=2.0 sec





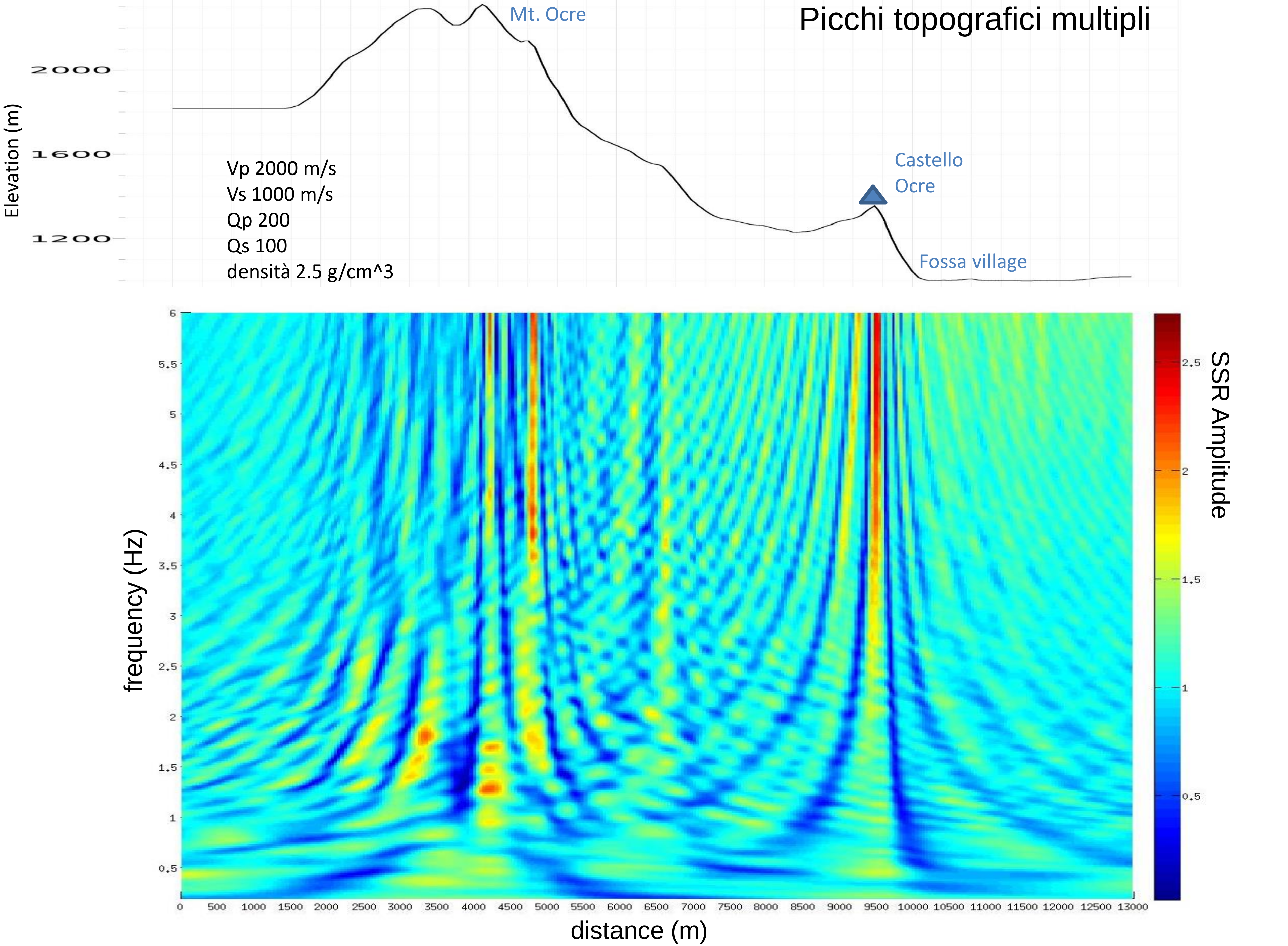
t=1.6 sec

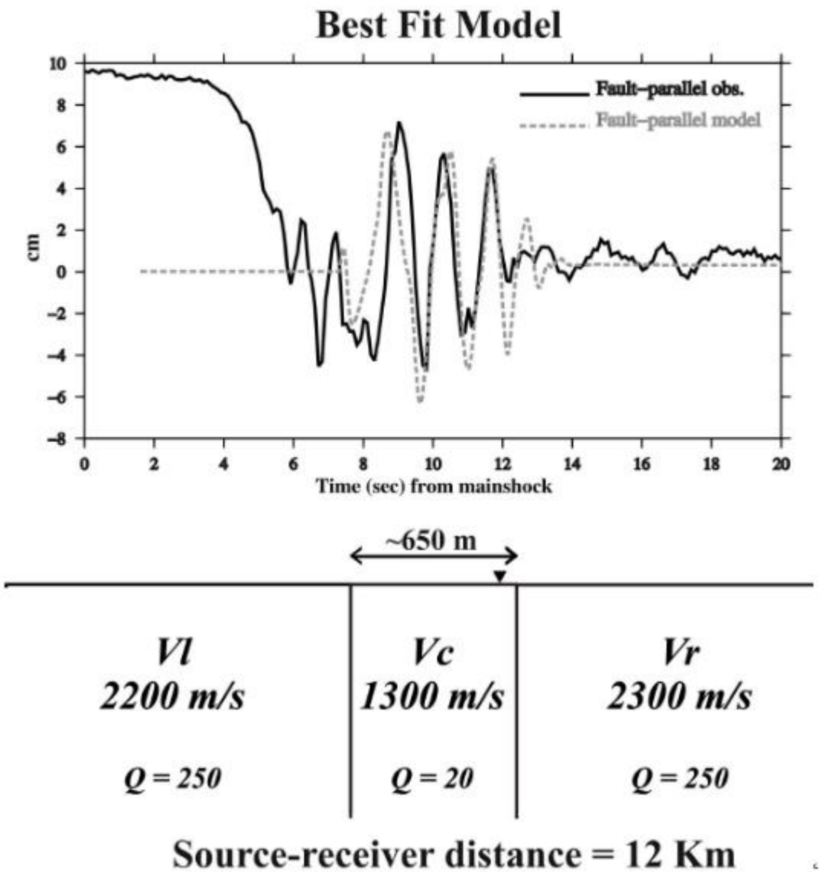
t=2.2 sec

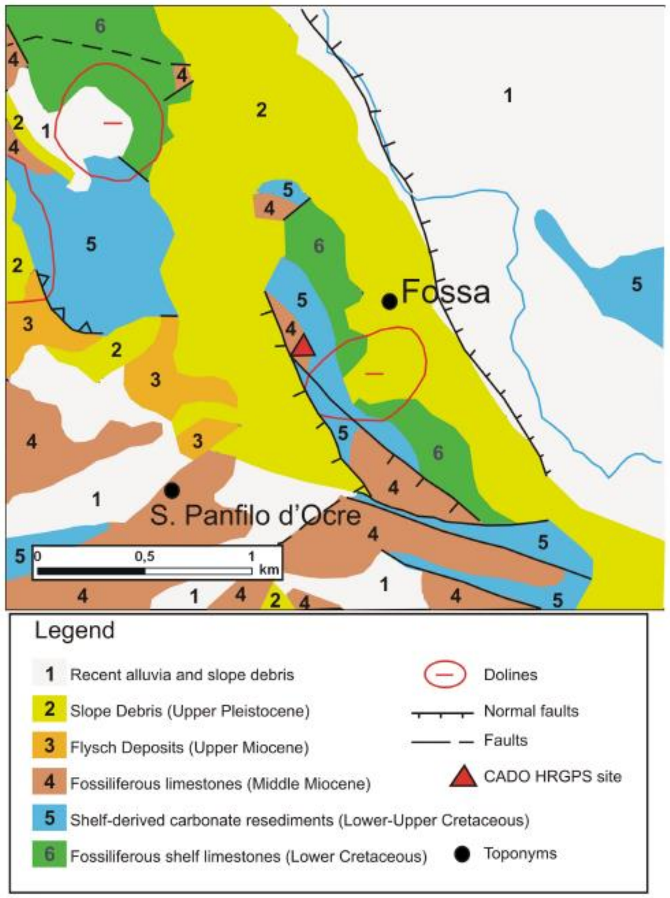
t=2.6 sec

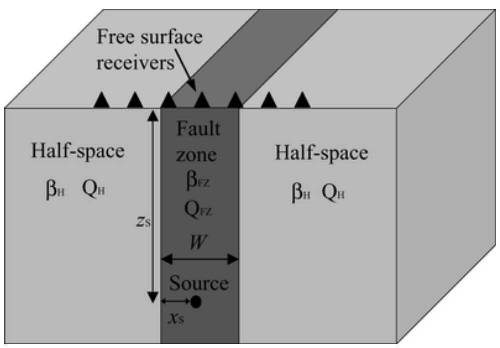
t=4.0 sec

Picchi topografici multipli









Estratto da

Avallone, A. et al., 2014,
Waveguide effects in very high rate GPS record of the 6 April 2009, Mw 6.1 L'Aquila, central Italy earthquake.
Journal of Geophysical Research: Solid Earth, 119(1), 490-501, doi: 10.1002/2013JB010475

Conclusioni

Modellazioni 2D, di onde piane che si propagano in geometrie irregolari, evidenziano pattern di amplificazione e deamplificazione.
Questi pattern dipendono dalla frequenza e dalla geometria.

Modelli omogenei restituiscono un livello massimo di amplificazione (in termini di SSR) di circa 2.

In siti con topografia accentuata dati sperimentali spesso evidenziano polarizzazione (anche in siti su roccia), e amplificazioni maggiori rispetto le modellazioni 2D.
Altre tipologie di amplificazione (faglie, fratturazione degli ammassi rocciosi, eterogeneità geologiche) sono da investigare.
Ad esempio nel caso studio di Ocre, l’effetto di sito osservato è interpretato in termini di una low-velocity fault zone.