



Numerical Modeling of seismic wave propagation on Etna Volcano (Italy): Construction of 3D realistic velocity structures

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Spectral Element simulation of seismic waves propagation for Long Period (LP) events on Etna volcano (2008). Influence of topography and structural heterogeneities on the simulated waveforms



Summary

I. General Introduction

- a) [Objectives](#)
- b) [Volcano seismic signals](#)

II. Etna volcano

- a) [Geographical and geological setting](#)
- b) [LP events case study De Barros \(2011\)](#)

III. Model setting

- a) [EFISPEC3D \(Spectral element code\)](#)
- b) [Topography and structural features implementation](#)

IV. Results

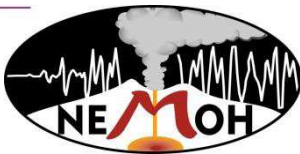
- a) [Real data and synthetics comparison](#)
- b) [Conclusions](#)

V. Perspectives



Objectives

- 1) Simulation of seismic waves propagation
 - a) Complex media
 - b) Realistic detailed topography
- 2) Volcano structural properties
- 3) Volcano seismic source characterization

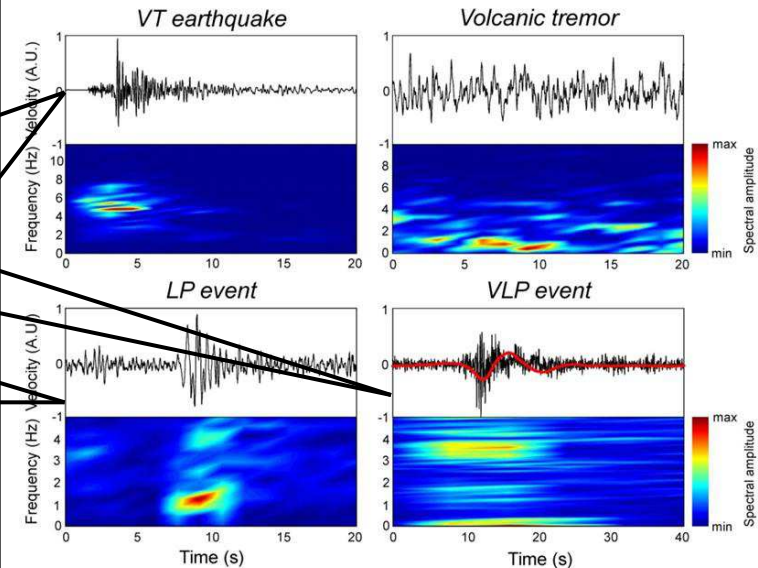
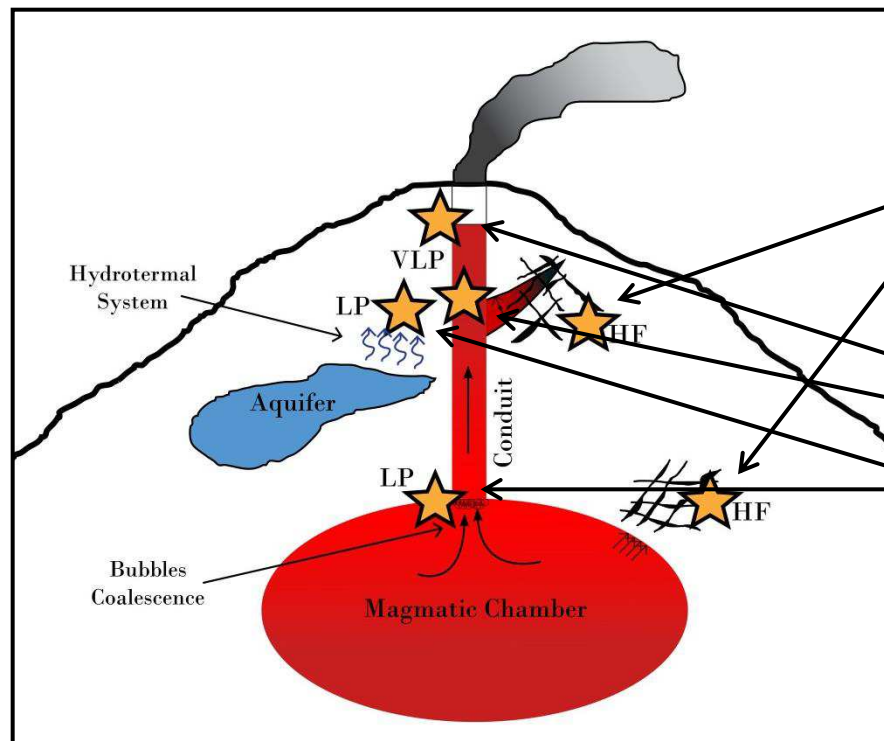


***NEMOH** (Numerical, Experimental and stochastic Modelling of vOlcanic processes and Hazard) is an Initial Training Network under the European Community FP7 → <http://www.nemoh-itn.eu/>*



Volcano Seismicity

1. *Forecasting of eruptions from direct interpretation of different seismic signals*
2. *Investigation of structural properties of volcanoes from physical observations*



Patanè D. et al. (2011)

Volcano-seismic signals classification following Wasserman J. (2011)



Géosciences pour une Terre durable

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Geographical setting



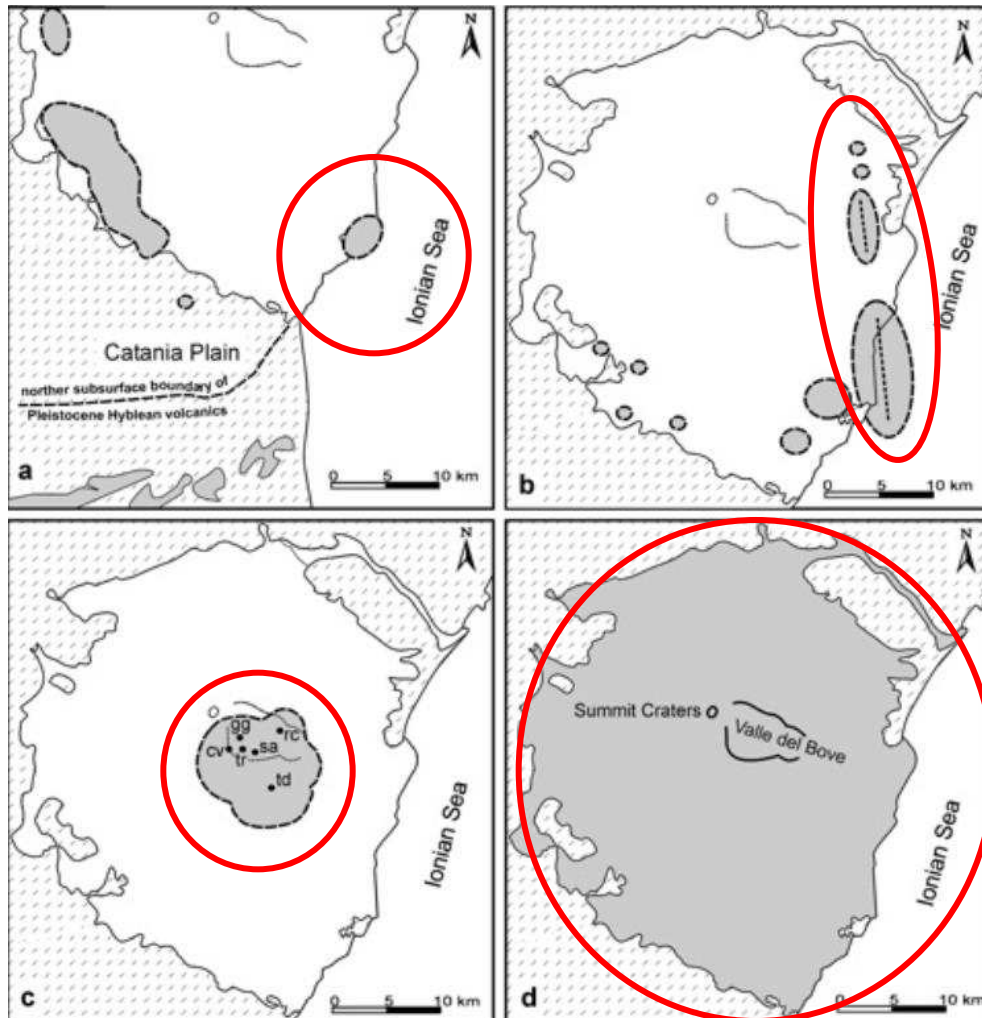
- **Tallest** volcano of Europe (3,343 m)
- 1,570 km² of covered area (45 km diameter) one of the **largest** world volcanoes
- Many suburban and urban (Catania ~ 7 · 10⁵ inhabitants) communities live nearby the volcanic edifice → **High volcanic risk !**





Geological evolution

X



a) Basal Tholeiitic phase

Pre-Etnean gulf, submarine lava (pillow lava), Tholeiitic basalts

5.0

b) Timpe phase

Fissure eruptions, shield volcano. Tholeiitic to alkali basaltic lava

2.2

c) Valle del Bove phase

From fissures to centralized activity. Effusive/explosive episodes, stratovolcano, first Etna edifice

1.1

d) Stratovolcano phase

Ellittico crater (3,800 m), $9 \cdot 10^3$ y edifice collapse (valle del Bove creation) Mongibello crater (actually active)

0.6

present

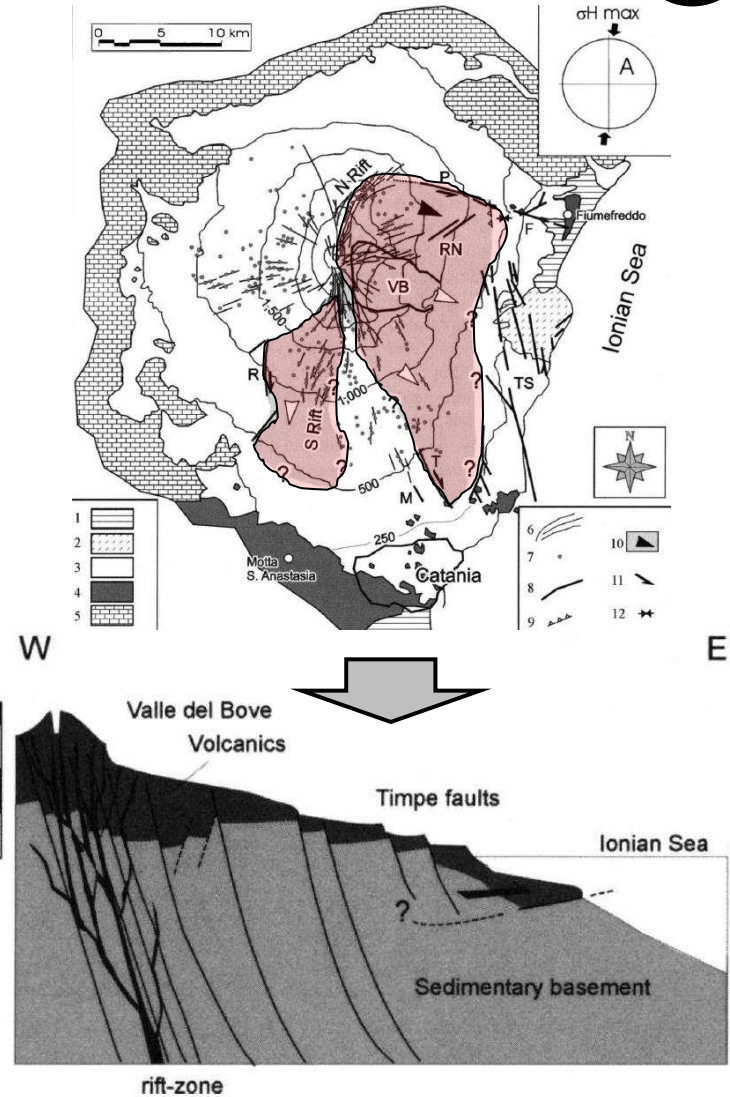
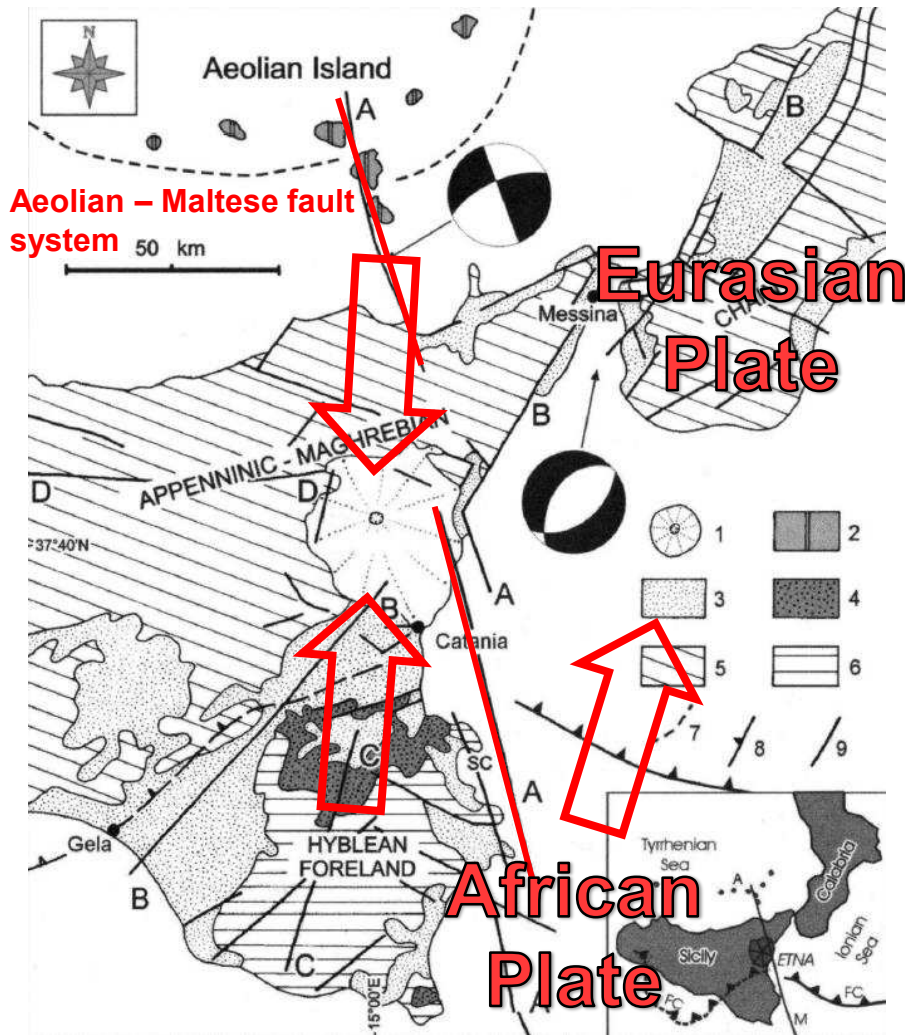
years 10^5

Four main volcanic phases which generated the volcanic edifice (Branca et al., 2004)



Tectonic context

X





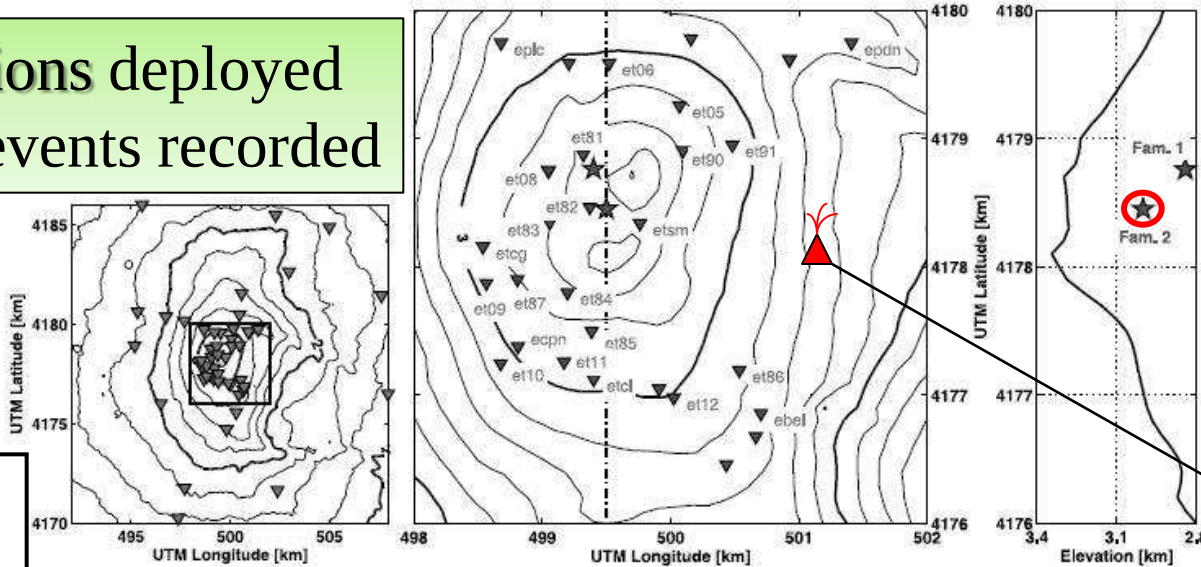
LP events

(June – July 2008)

De Barros (2011)

X

50 stations deployed
129 LP events recorded



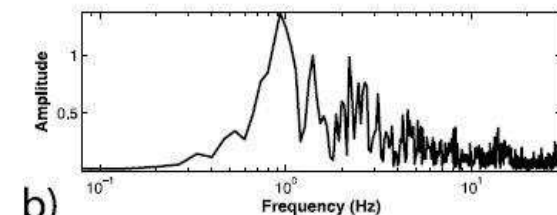
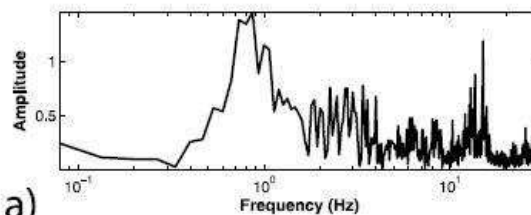
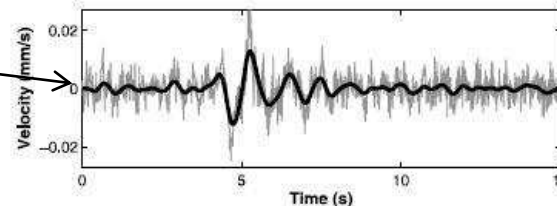
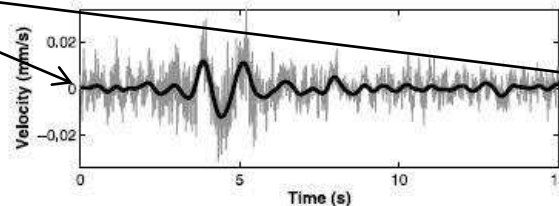
0.2 – 1.2 Hz
filtered
signal
 $\lambda \approx 600 - 5,000$ m

*Very good
spatial
and
azimuthal
coverage !*

*Lava
fountain
occurred
during the
experiment*

*Family 1
63 events*

*Family 2
66 events*



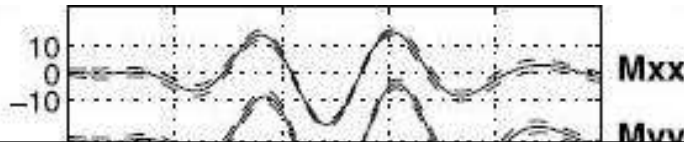


LP Inversion

(Family 2)

De Barros (2011)

X



Inversion performed in a
Homogeneous velocity Model

QUESTION

*How does the (unrealistic?) assumption
for a homogeneous velocity model
influence the inversion (and so the
retrieved physical source mechanism) ?*

Time [s]

Retrieved source time function
for 6 independent Moment
Tensor components and 3 forces

Oriented $\angle \Phi = 110^\circ \quad \theta = 60^\circ$

Moment [1 1 2]

Forces – only used to accommodate errors
Physical mechanism related to gas movements



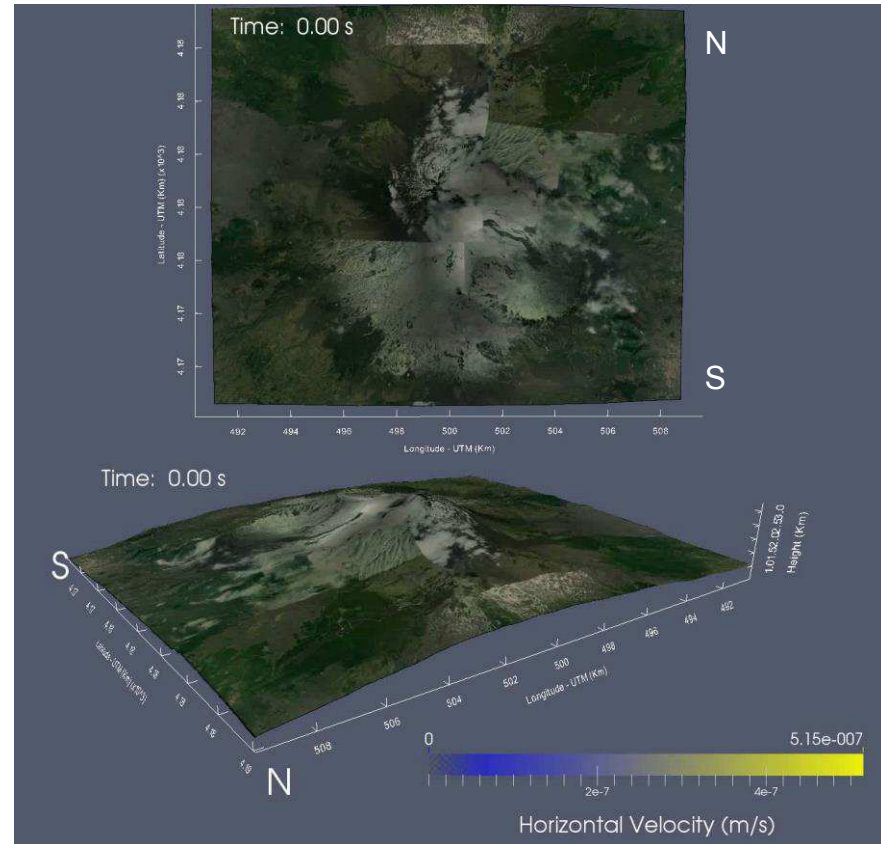
EFISPEC3D

(De Martin, 2011)

X

Spectral Element Code (SEM)

- *3D seismic waves propagation in complex geologic media*
- *Topography implementation*
- *Elastic and Viscoelastic simulations*
- *Programmed in FORTRAN95 and MPI*



Downloadable for free → <http://efispec.free.fr/>

De Martin, *Verification of a Spectral-Element Method Code for the Southern California Earthquake Center*, BSSA, 101, 2011.



Géosciences pour une Terre durable

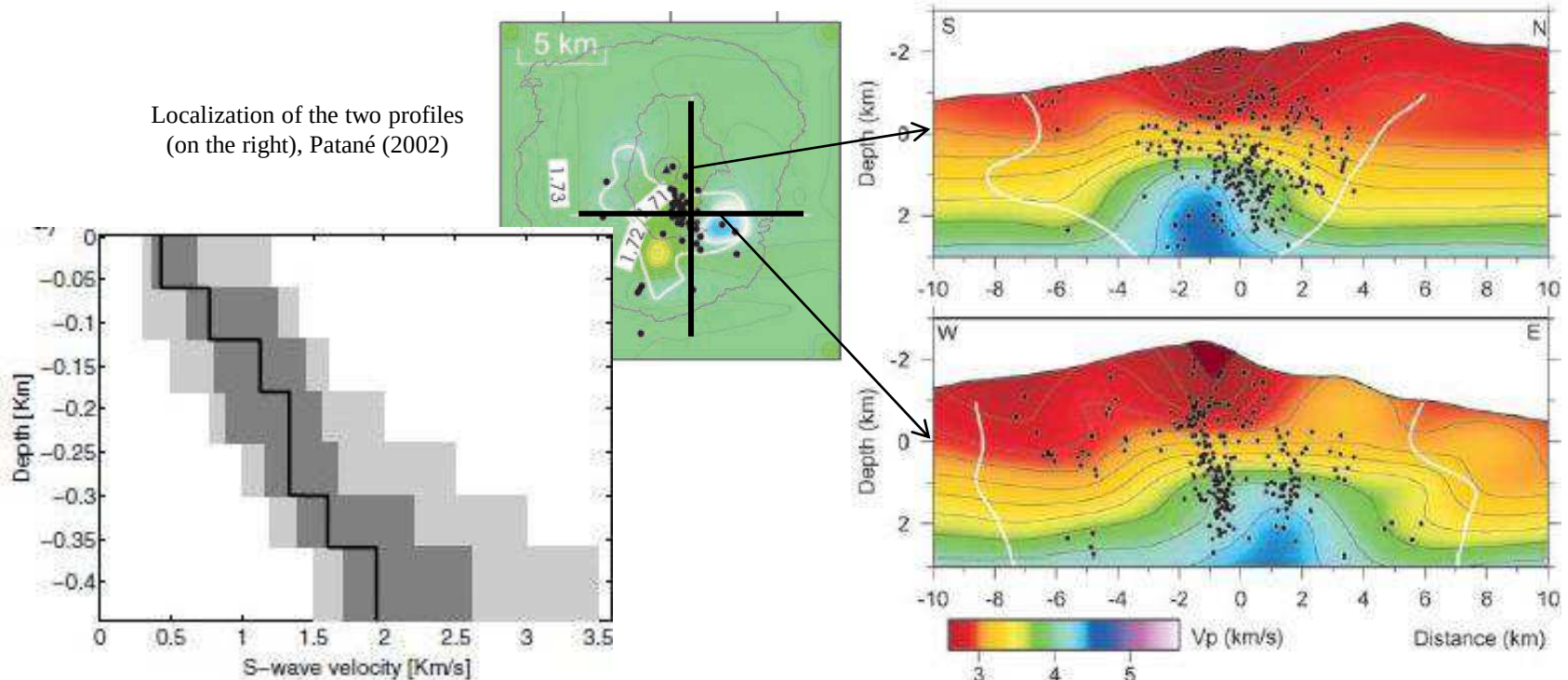
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Geometrical Models

- *Velocity models based on the seismic tomography papers:*

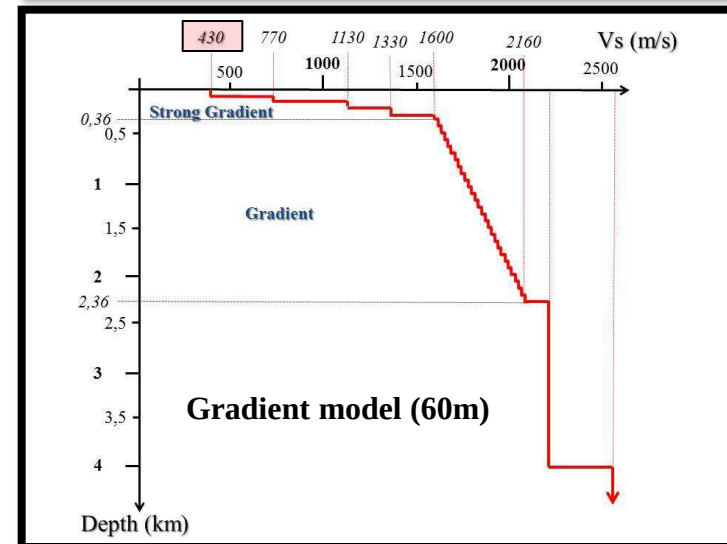
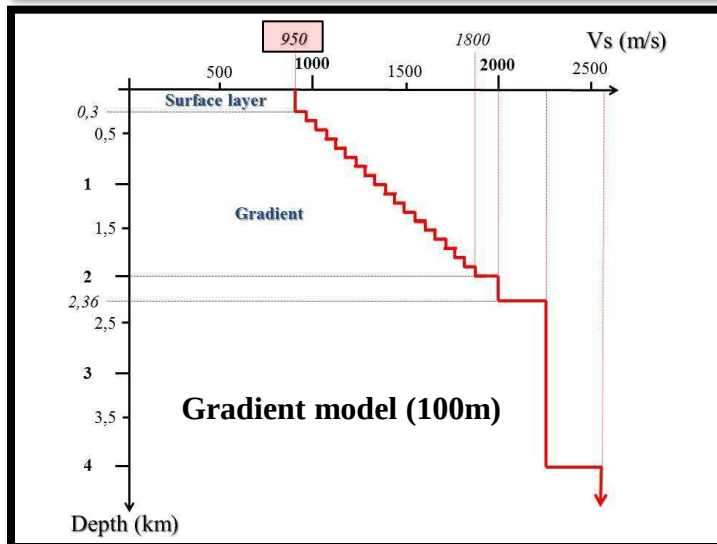
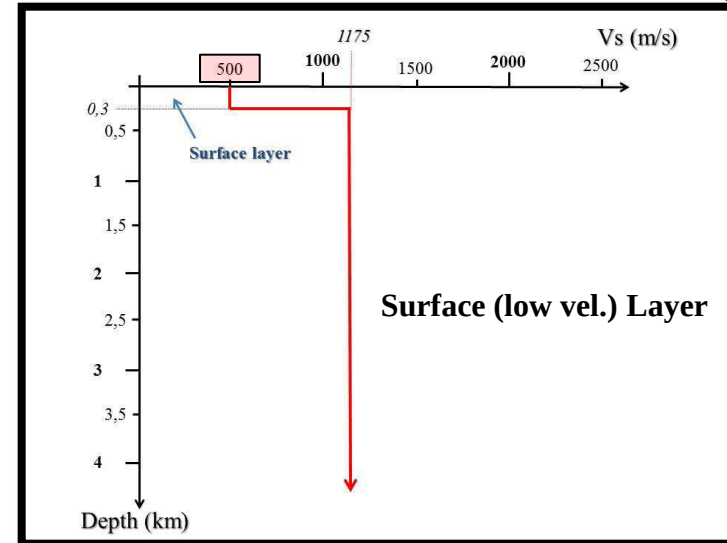
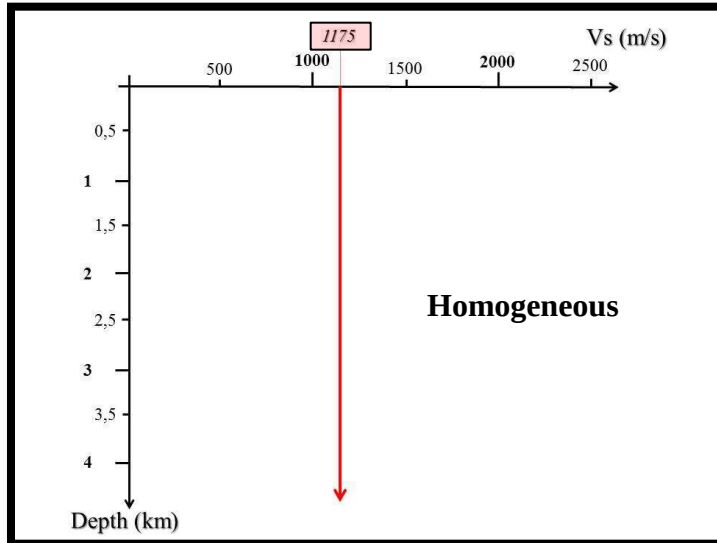
1. *Cauchie & Saccorotti (2012) → very shallow velocity gradient*
2. *Patané et al. (2002) → velocity until depth*
3. *Cristiano et al. (2010) → V_s velocity structure*



Seismic tomography performed on a seismic swarm occurred on Etna volcano in 2001, Patané (2002)



Geometrical Models





Geometrical Models

- *Topography of Etna (100 m grid precision) implemented*
 - *Four velocity structural models (increased complexity)*

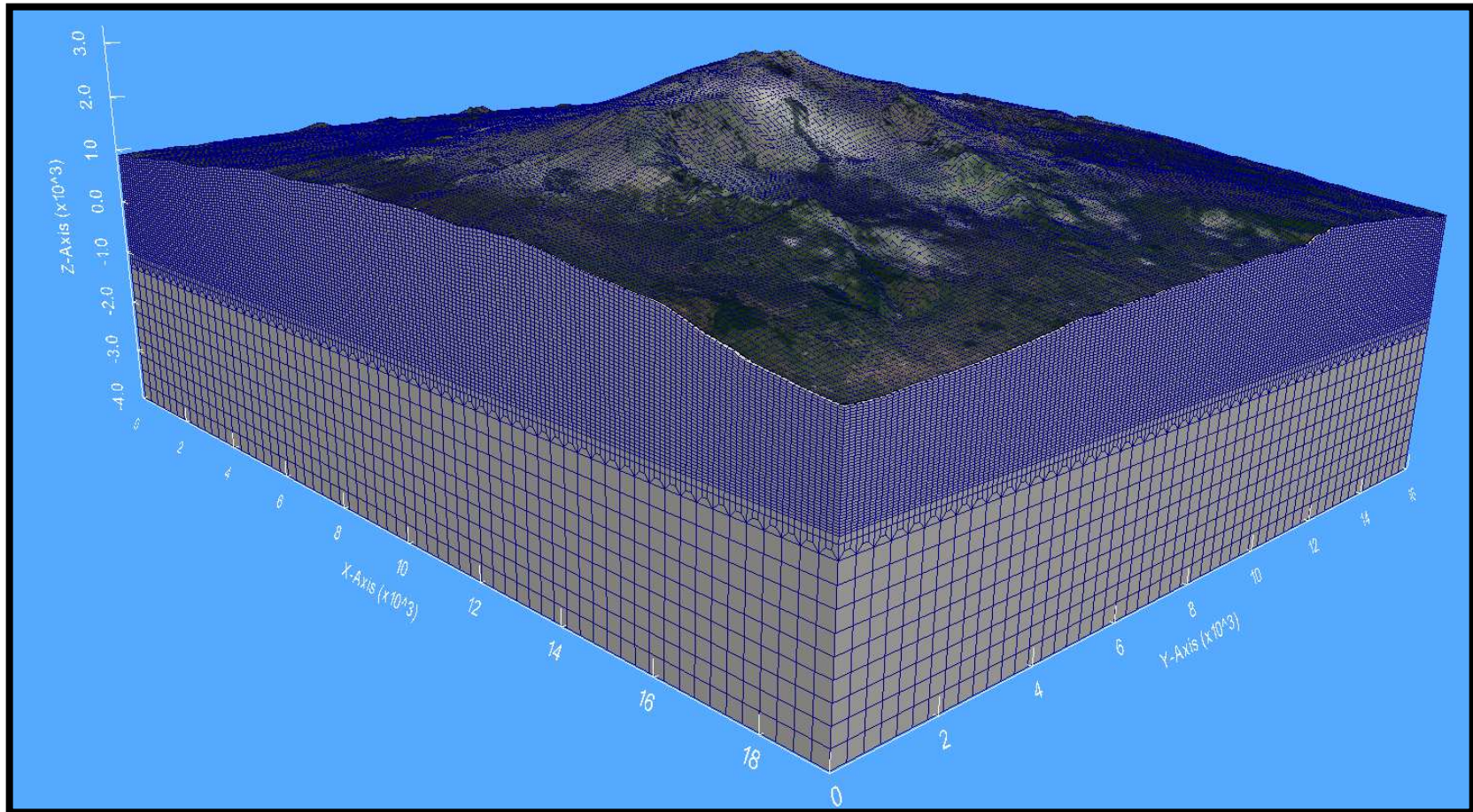
Model	Vp (m/s)	Vs (m/s)	ρ (kg/m³)	
Homogeneous	2000	1175	2069	
Surface (low vel.) Layer	866 / 2000	500 / 1175	1697 / 2069	
Gradient model (100m) 21 layers	1645 → 4503	950 → 2600	1974 → 2539	
Gradient model (60m) 36 layers	744 → 4503	430 → 2600	1619 → 2539	
	CPU	n° elements	Δt (s)	Comput. time
Homogeneous	16	1.418 10 ⁶	0,004	16.3 h
Surface Layer	16	1.418 10 ⁶	0,004	16.3 h
Gradient model (100m)	16	1.418 10 ⁶	0,004	16.3 h
Gradient model (60m)	48	2.272 10 ⁶	0,001	49.9 h



Geometrical Models

(examples (1))

- *Homogeneous velocity model*



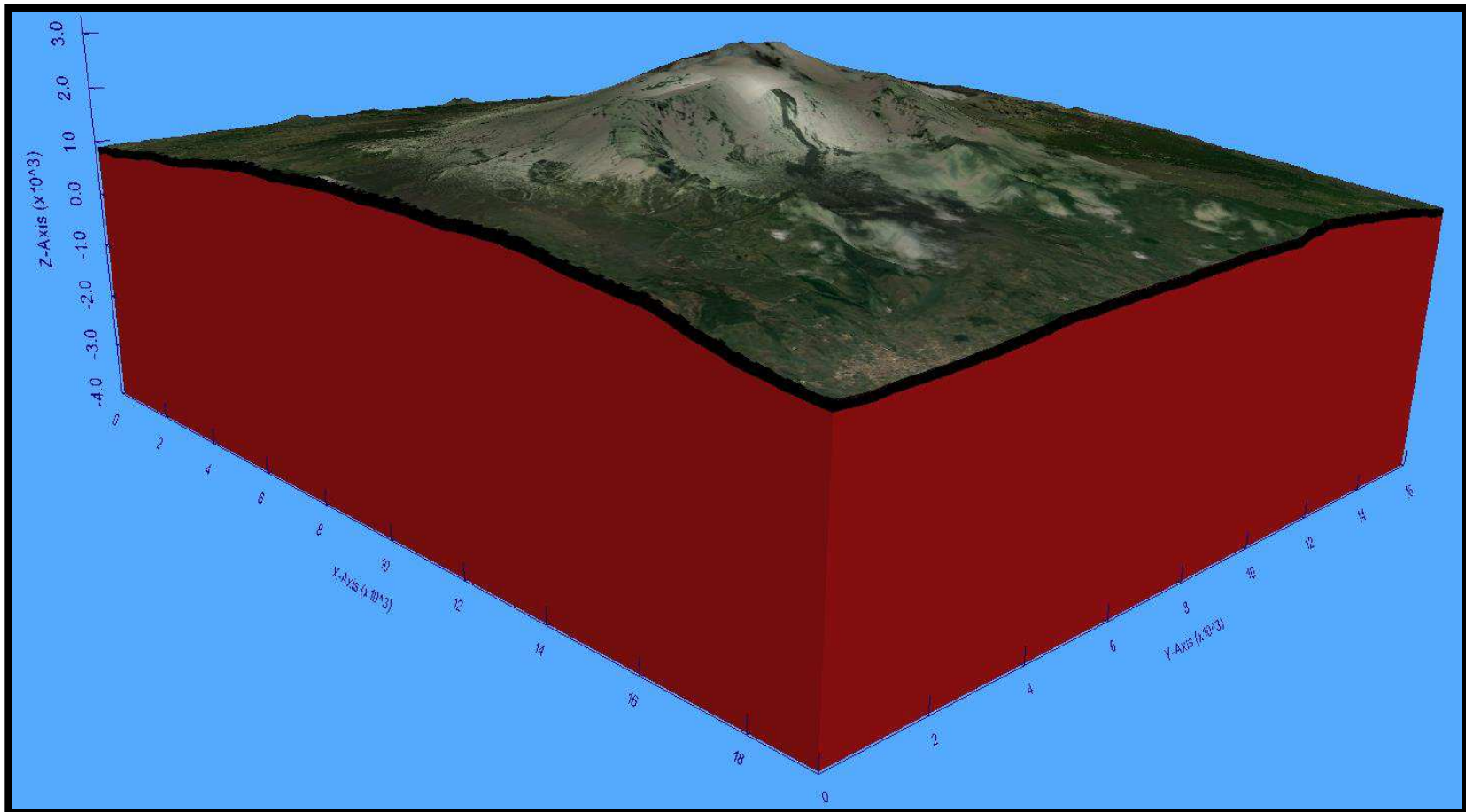


Geometrical Models

(examples (2))

- *Surface (low-velocity) layer*
200 – 300 – 400 m depths

X



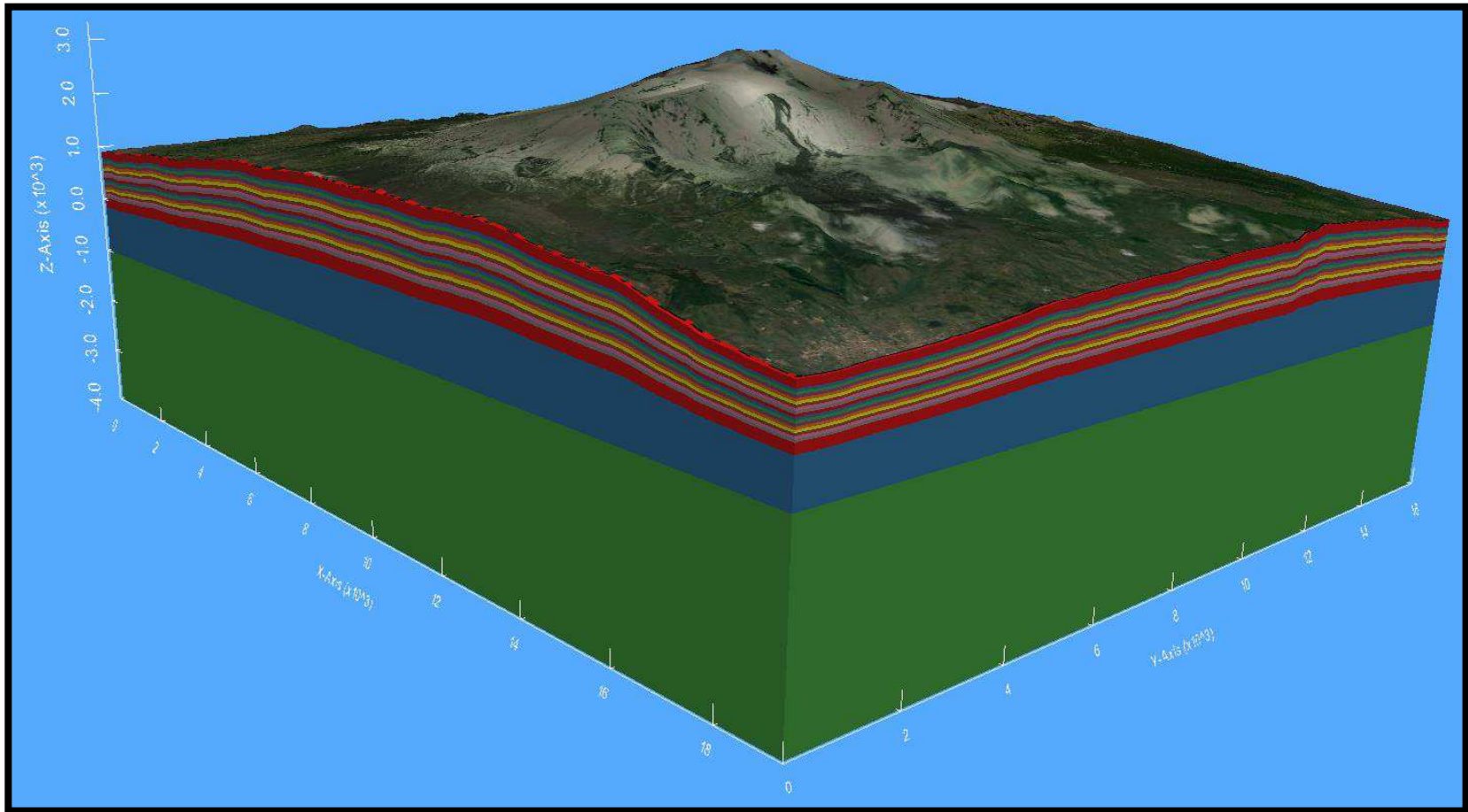


Geometrical Models

(examples (3))

X

- *Gradient velocity layer (100 m)*



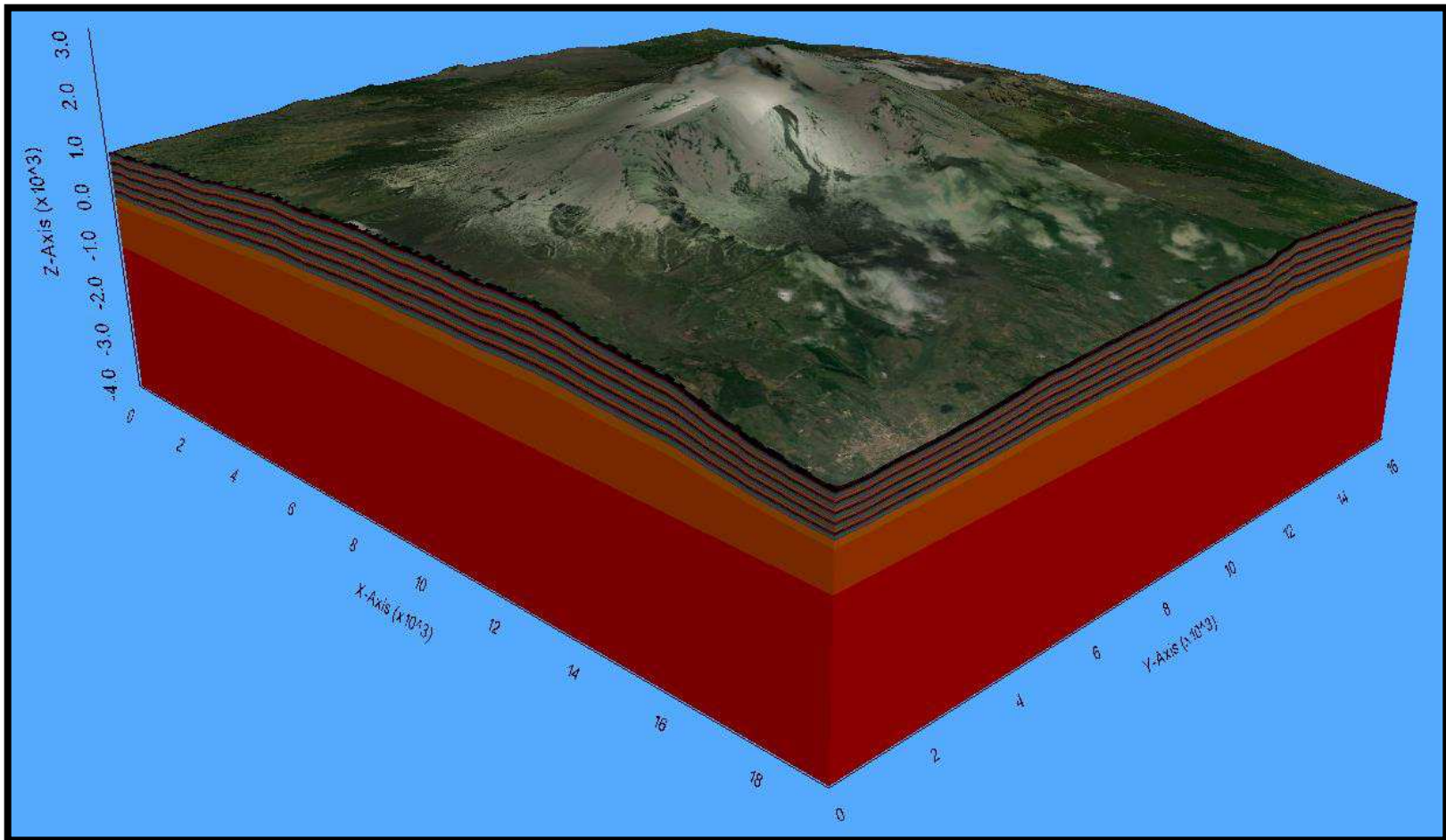


Geometrical Models

(examples (4))

X

- *Gradient velocity layer (60 m)*

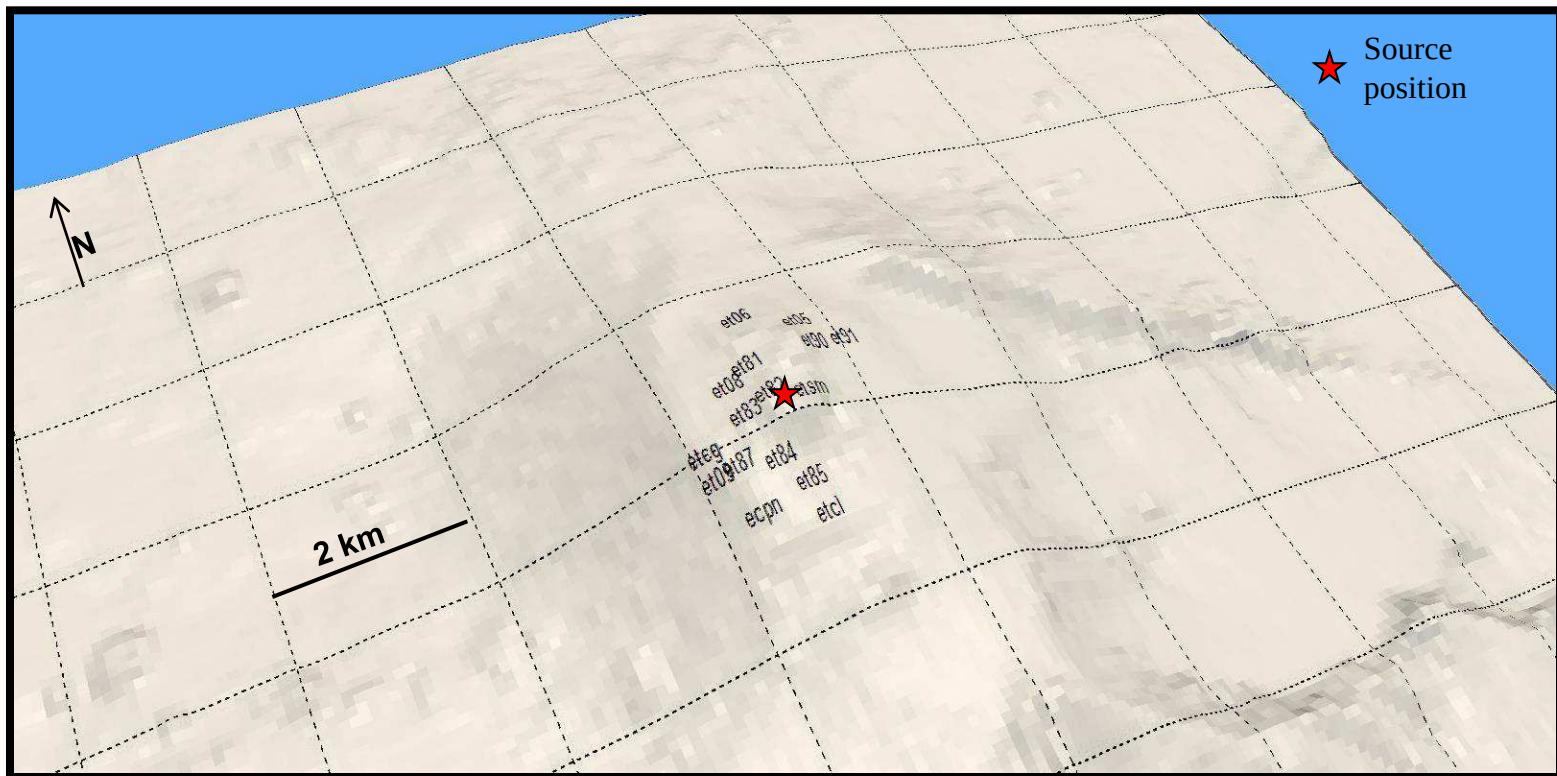




Receivers position

- *16 receivers in the near-intermediate field from De Barros (2011)*

We have not data from far field stations. Future applications will be designed in order to test the influence of complex models on long-travel path waves



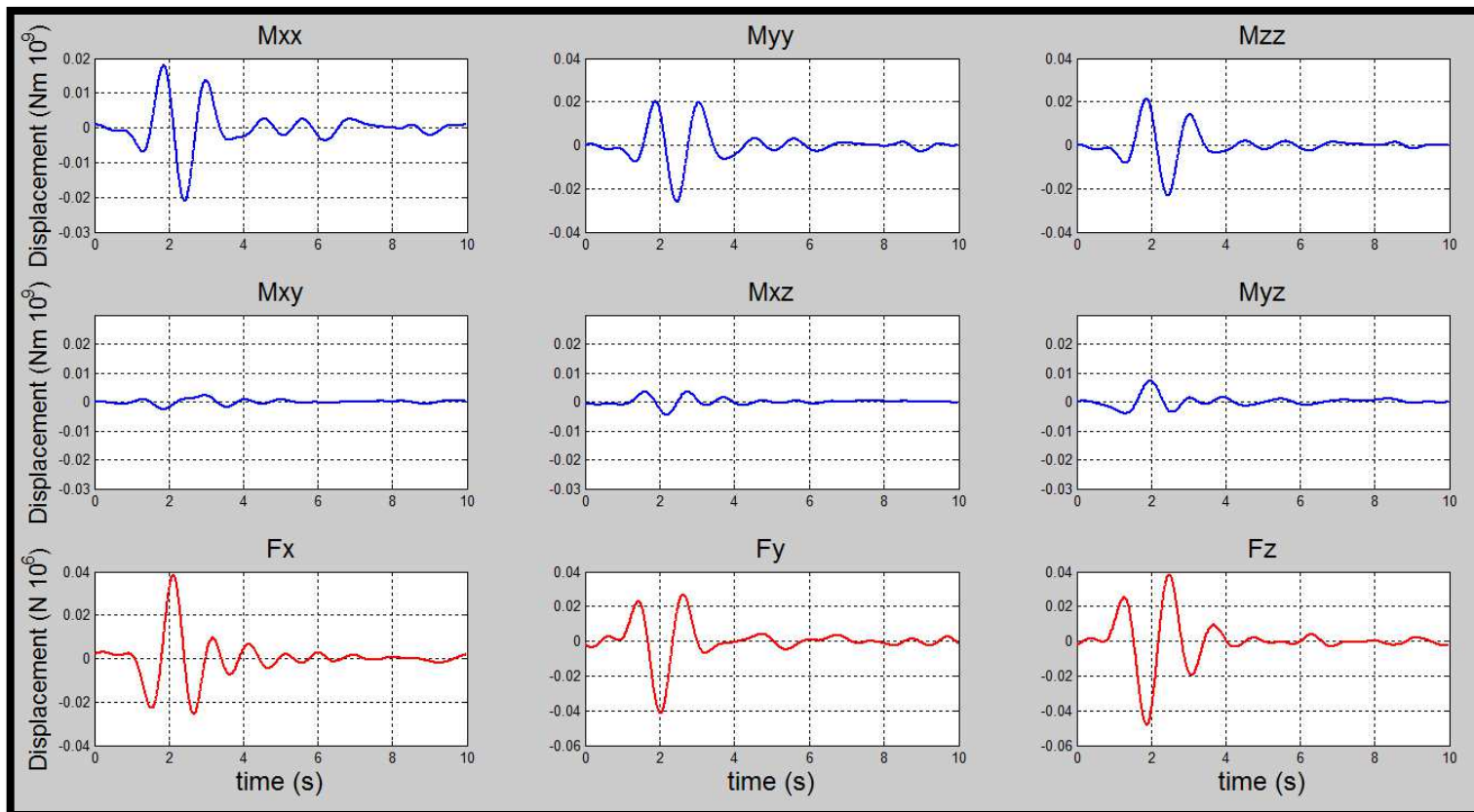


Simulation Parameters

X

Source time function

- *Full Moment tensor + 3 Single Forces solution*
(the one found by De Barros (2011) in their inversion)

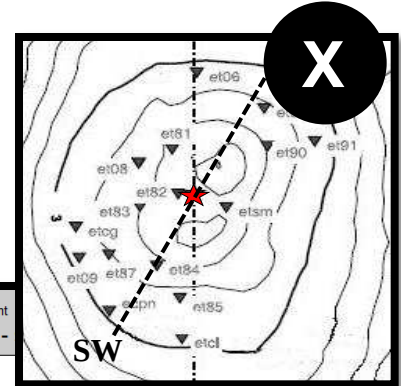
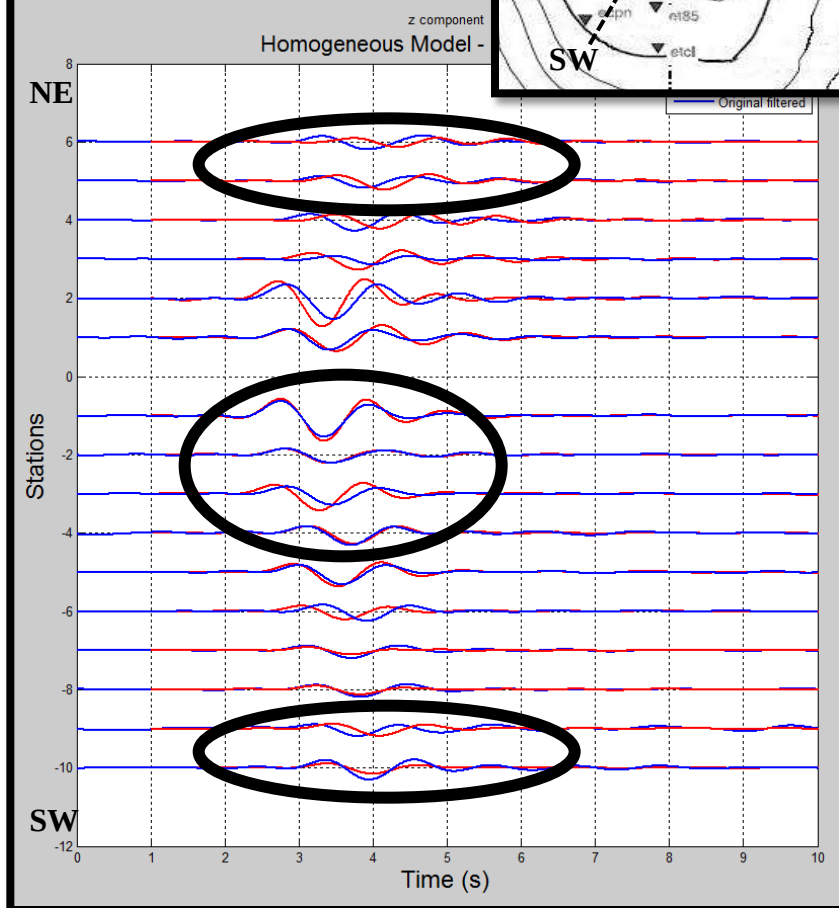
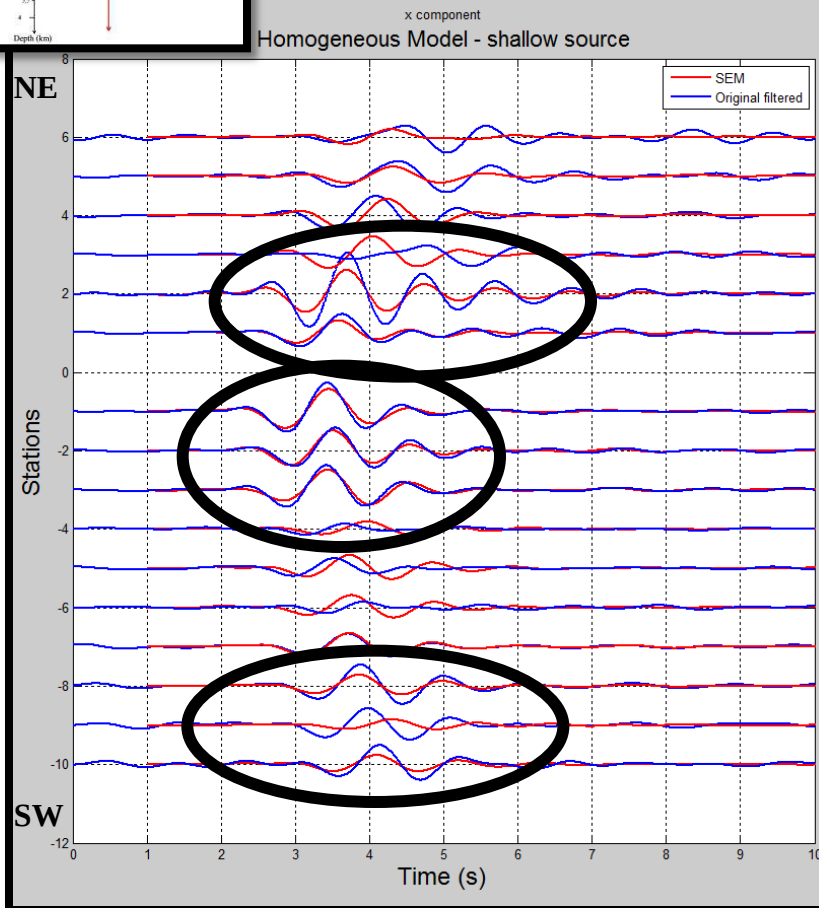
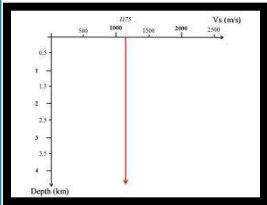




Comparisons

Homogeneous model

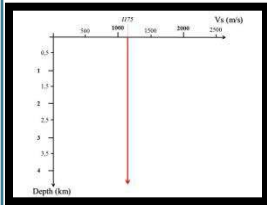
X-component & Z-component



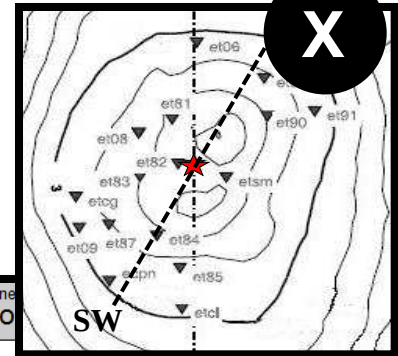
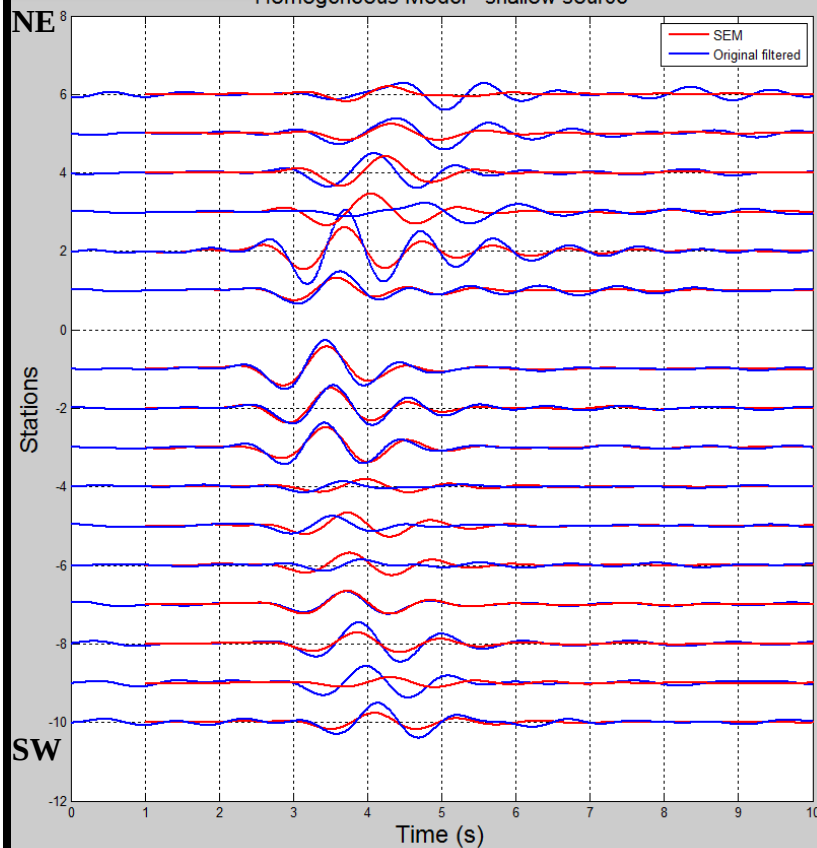


Comparisons

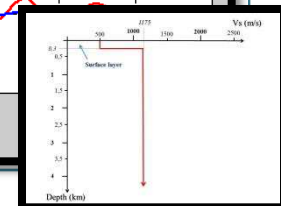
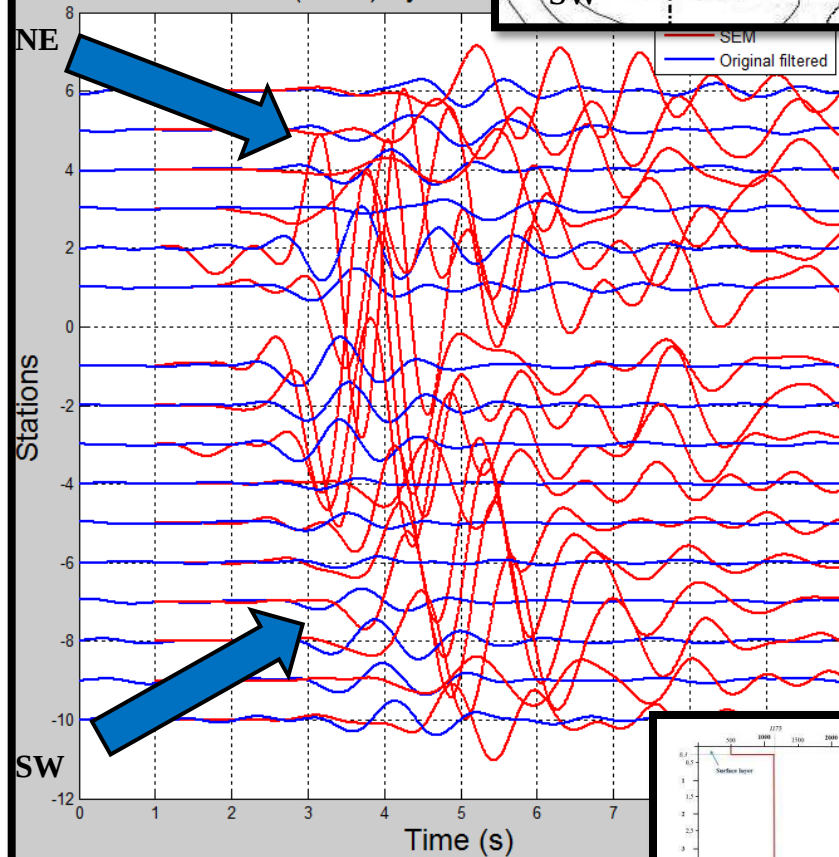
Homogeneous vs Surface layer (400 m)
X-component



x component
Homogeneous Model - shallow source



x component
Shallow (400m) layer Model

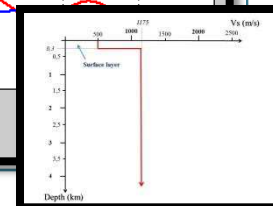
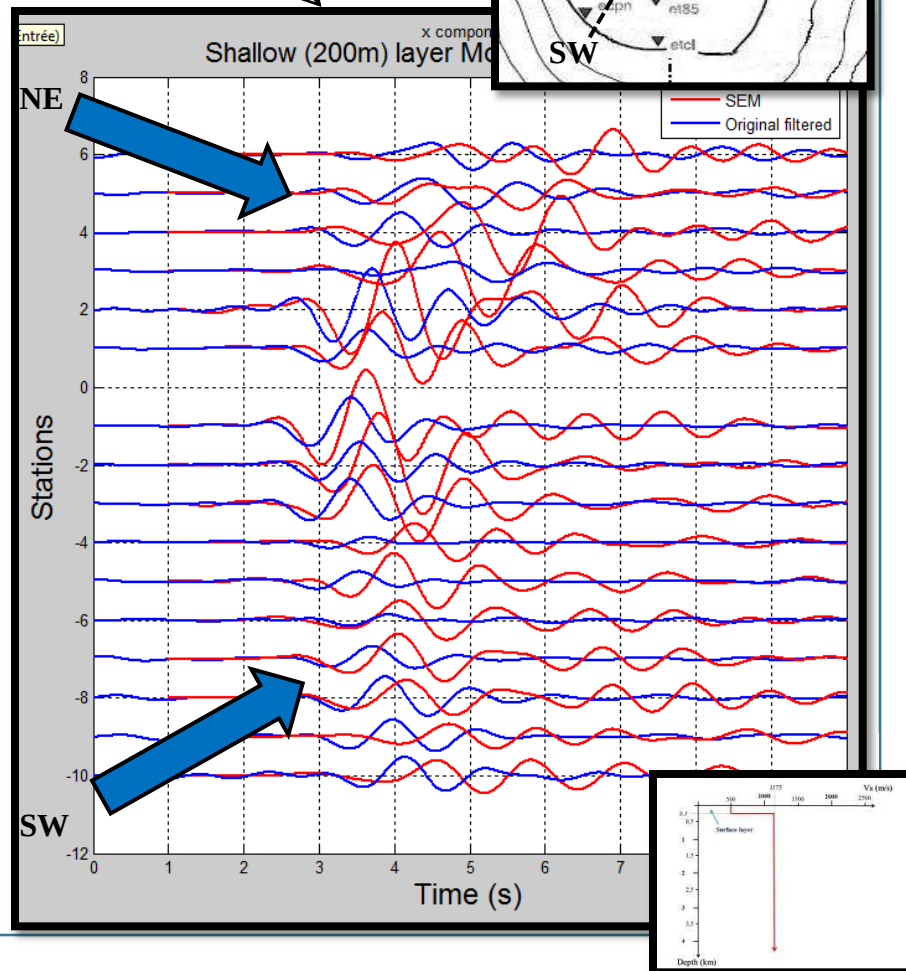
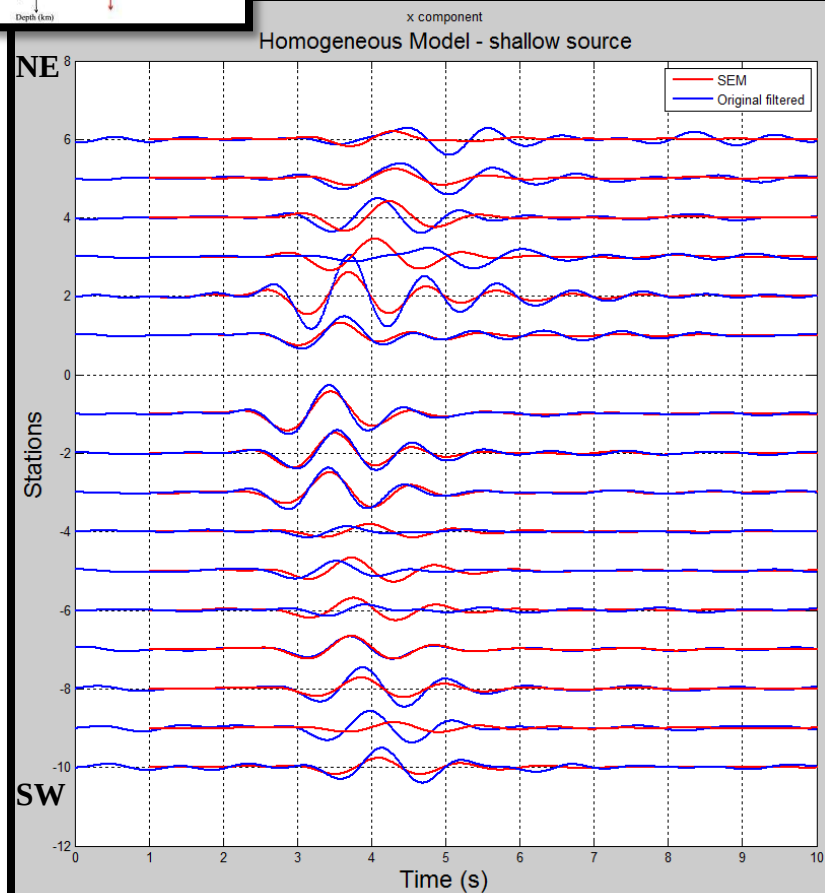
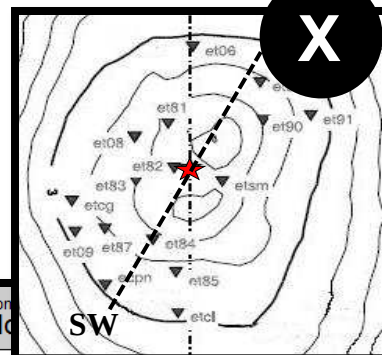
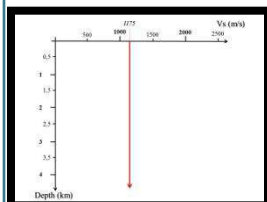




Comparisons

Homogeneous vs Surface layer (200 m)

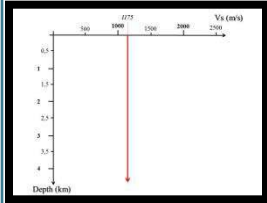
X-component



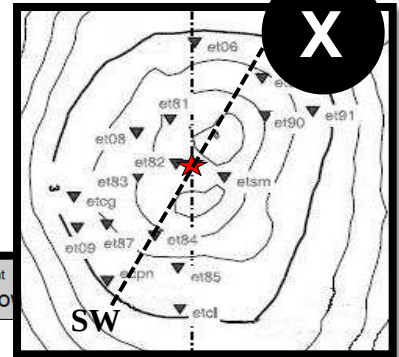
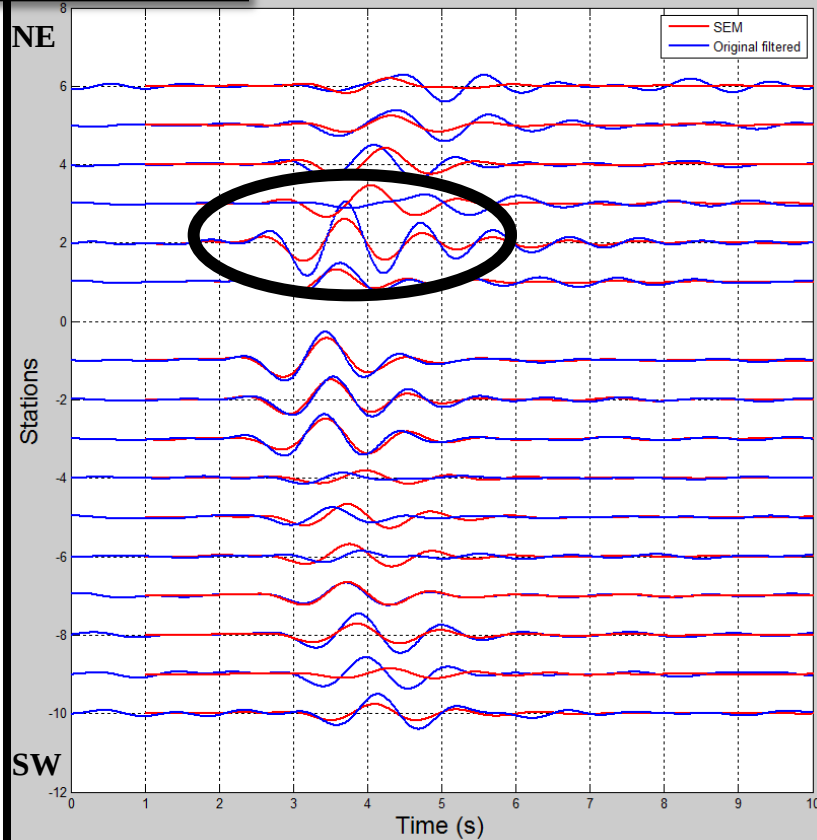


Comparisons

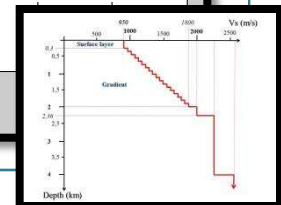
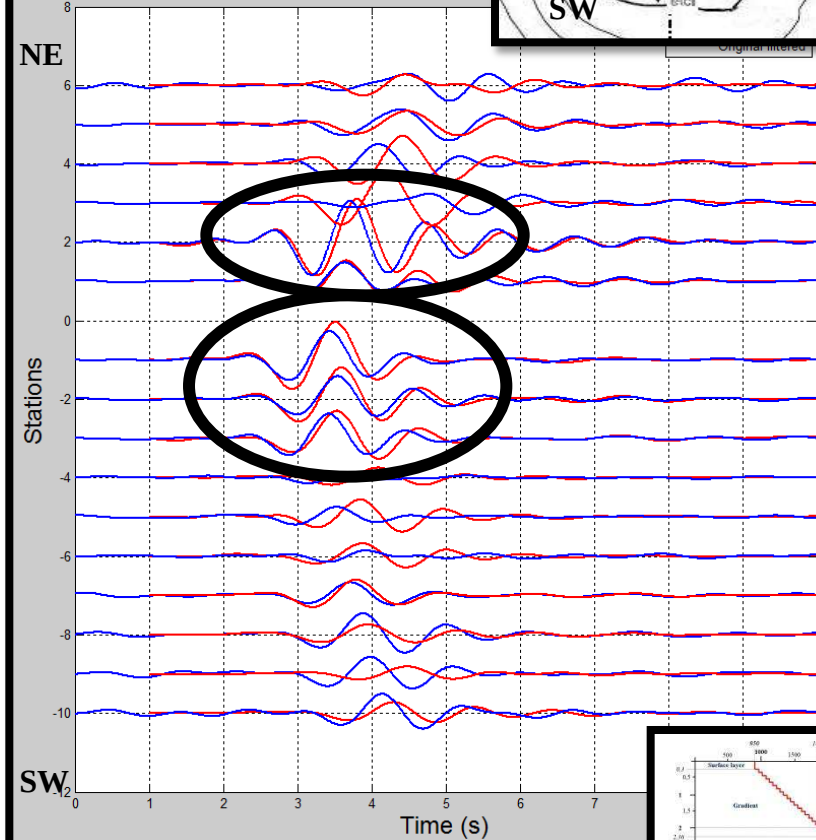
Homogeneous vs Gradient (100 m)
X-component



x component
Homogeneous Model - shallow source



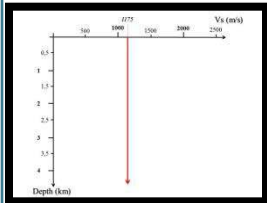
x component
GF Model - shallow



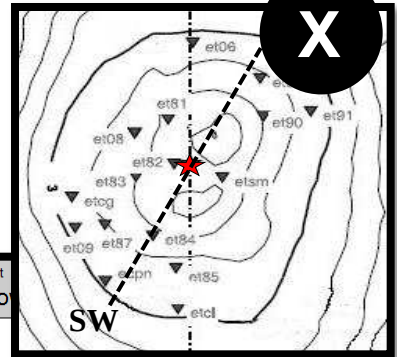
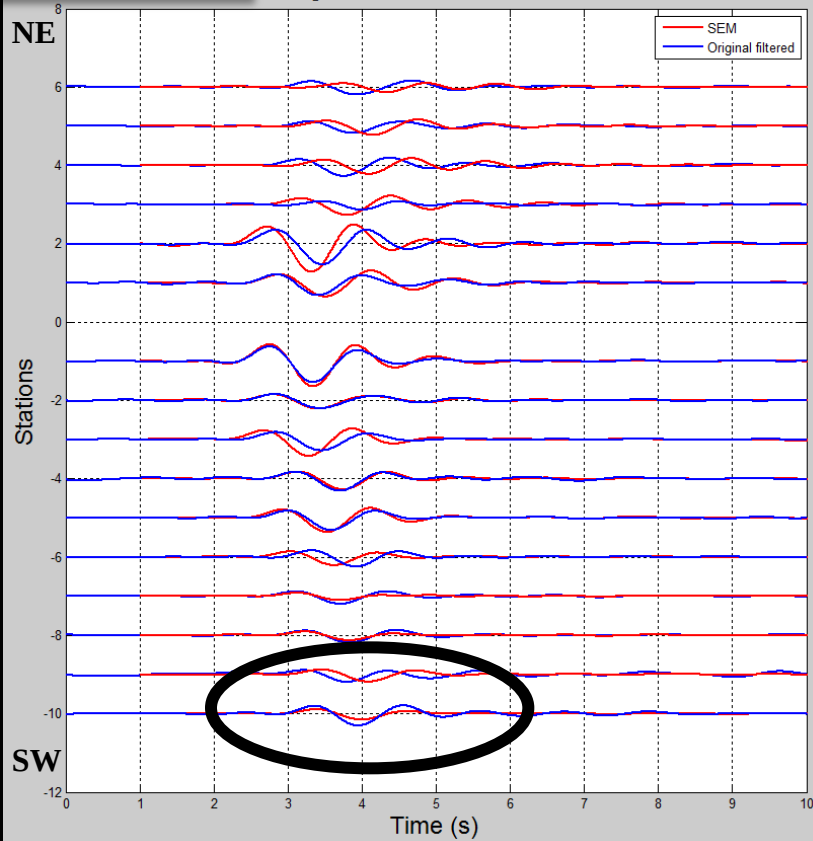


Comparisons

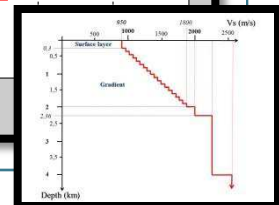
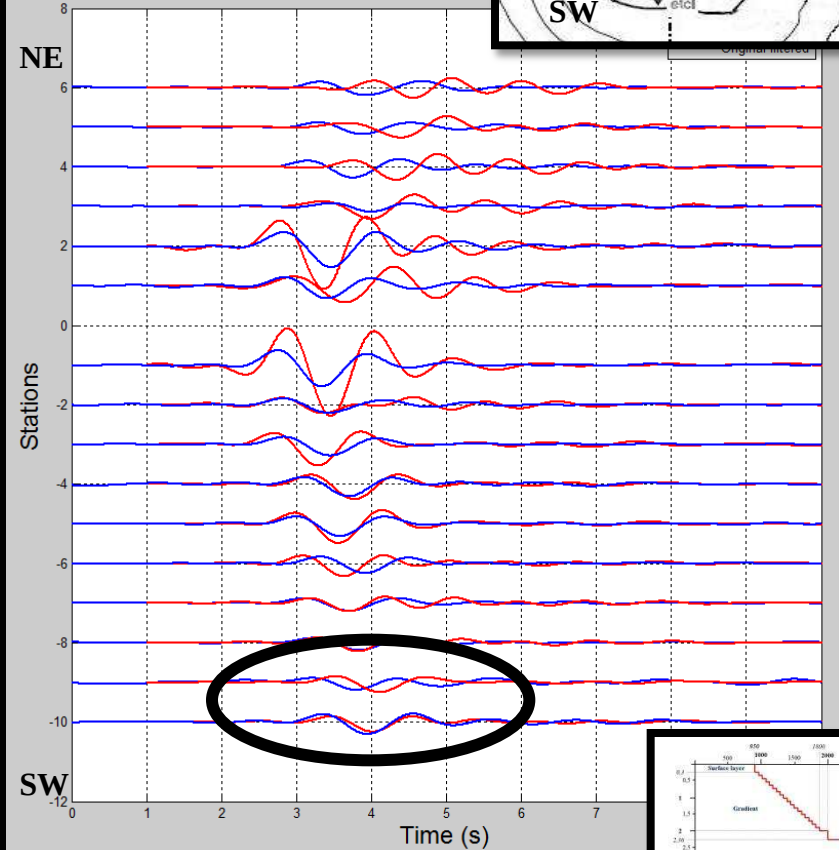
Homogeneous vs Gradient (100 m)
Z-component



z component
Homogeneous Model - shallow source



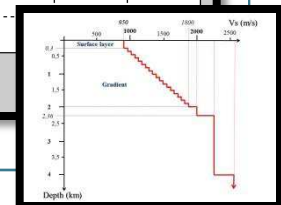
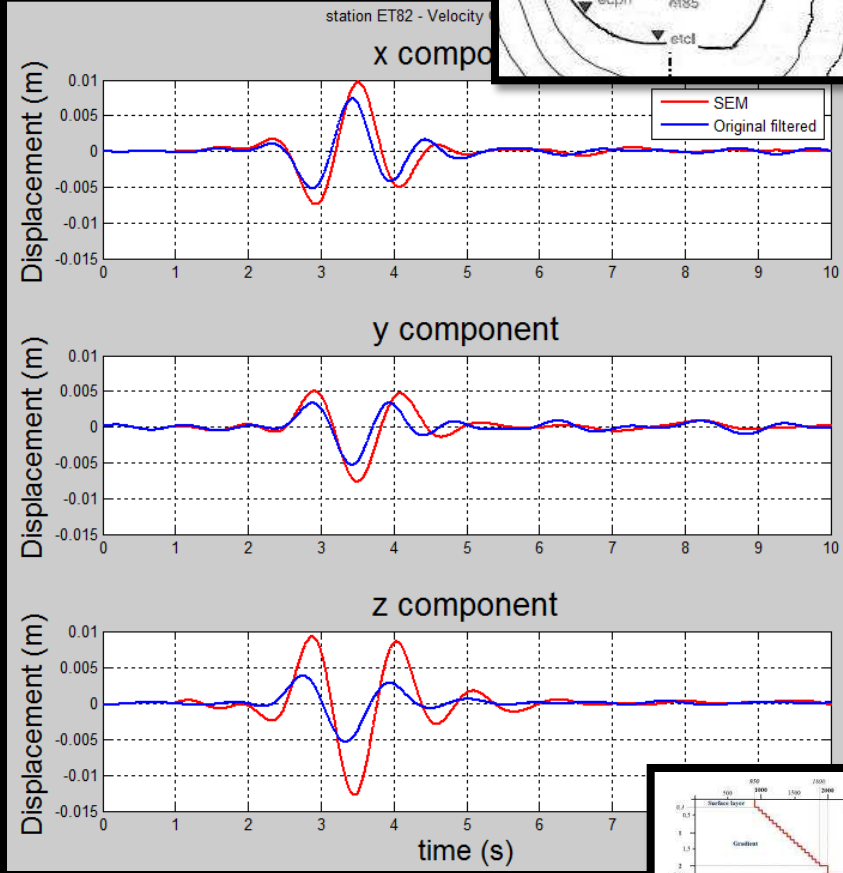
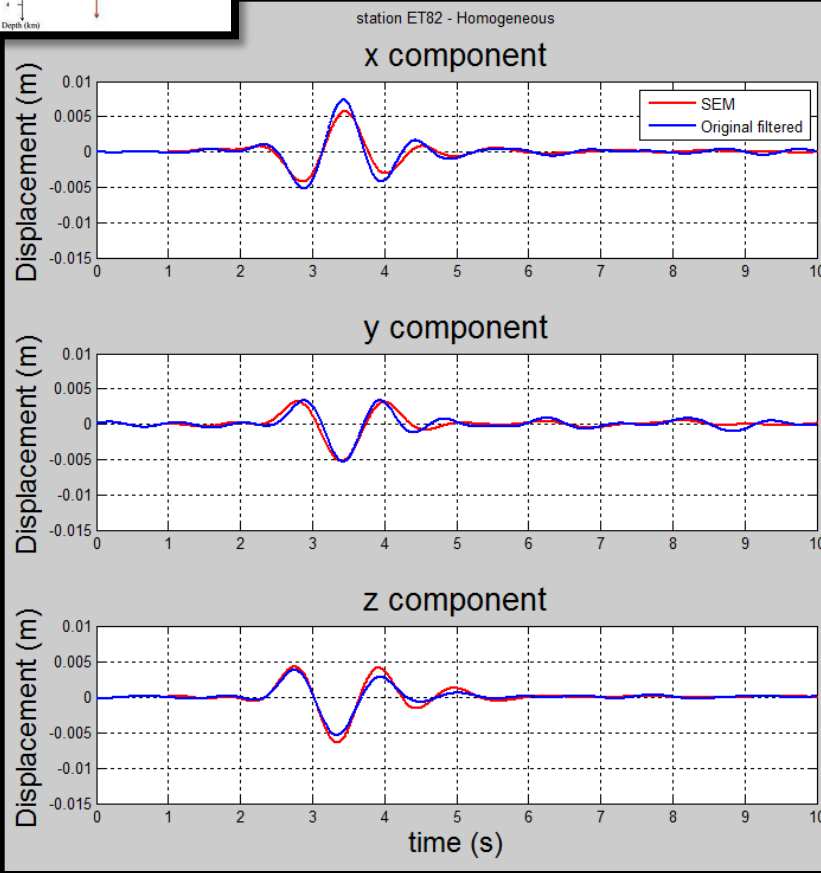
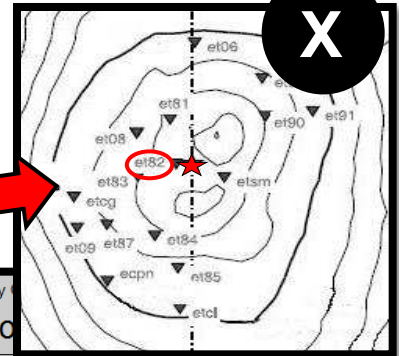
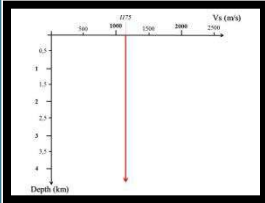
z component
GF Model - shallow





Comparisons

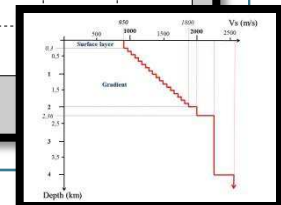
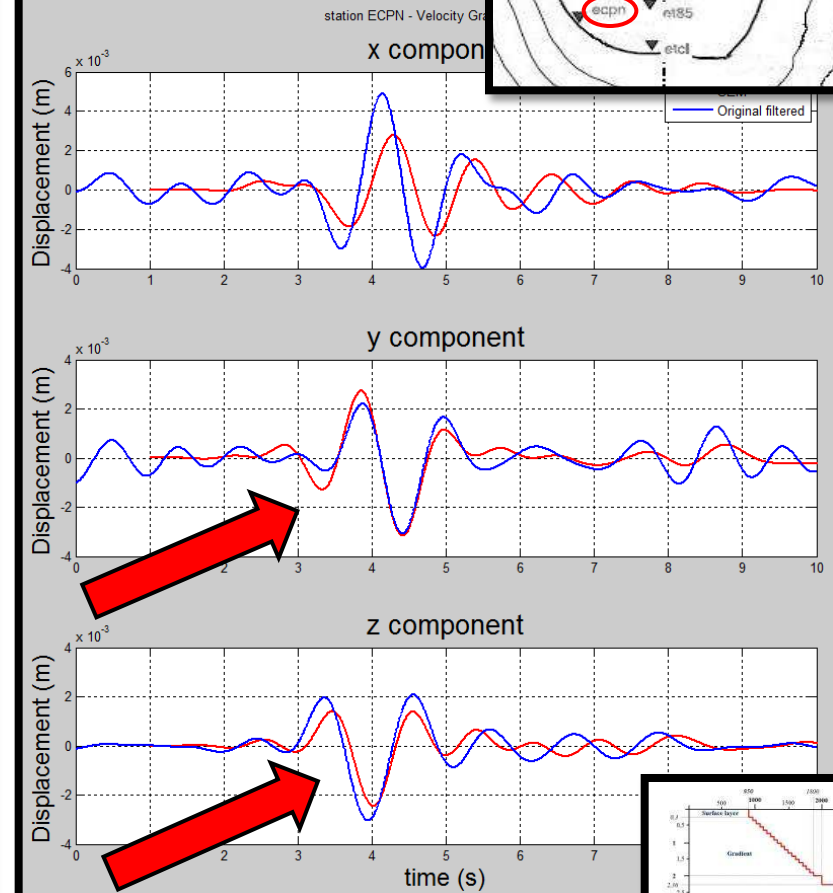
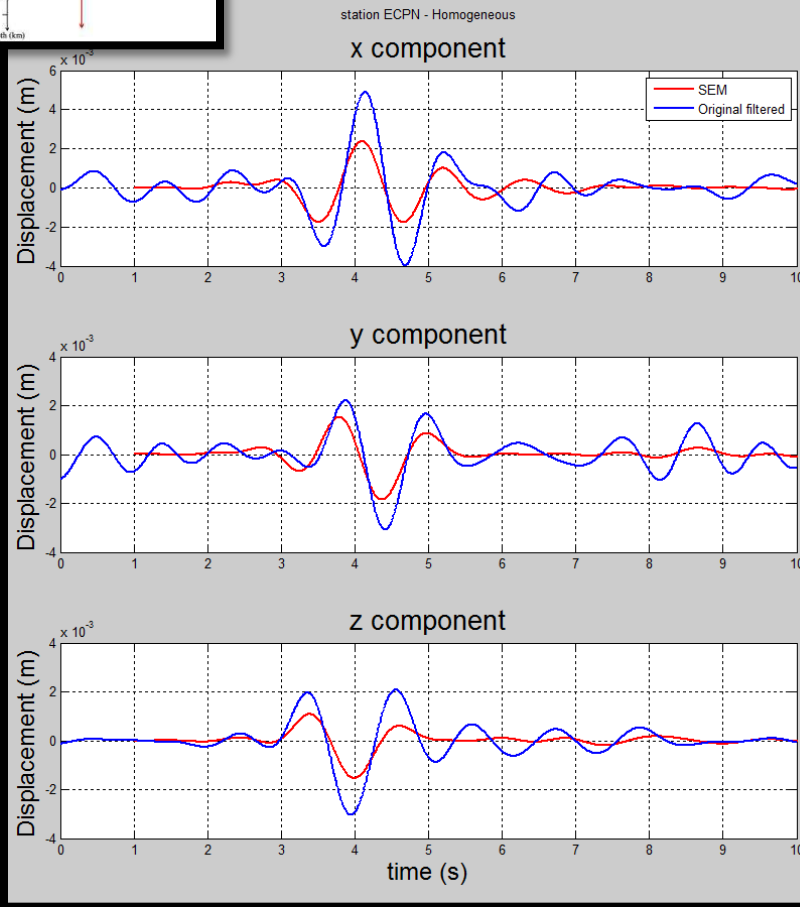
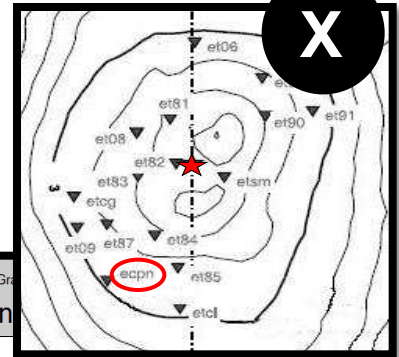
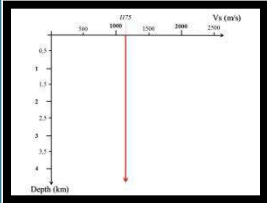
Homogeneous vs Gradient (100 m)
Near station (et82)





Comparisons

Homogeneous vs Gradient (100 m)
Far station (ecpn)

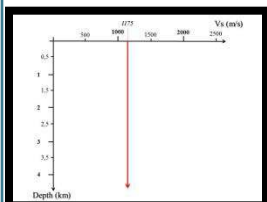




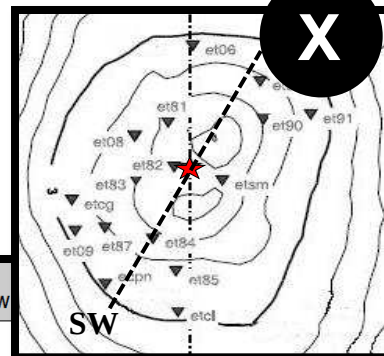
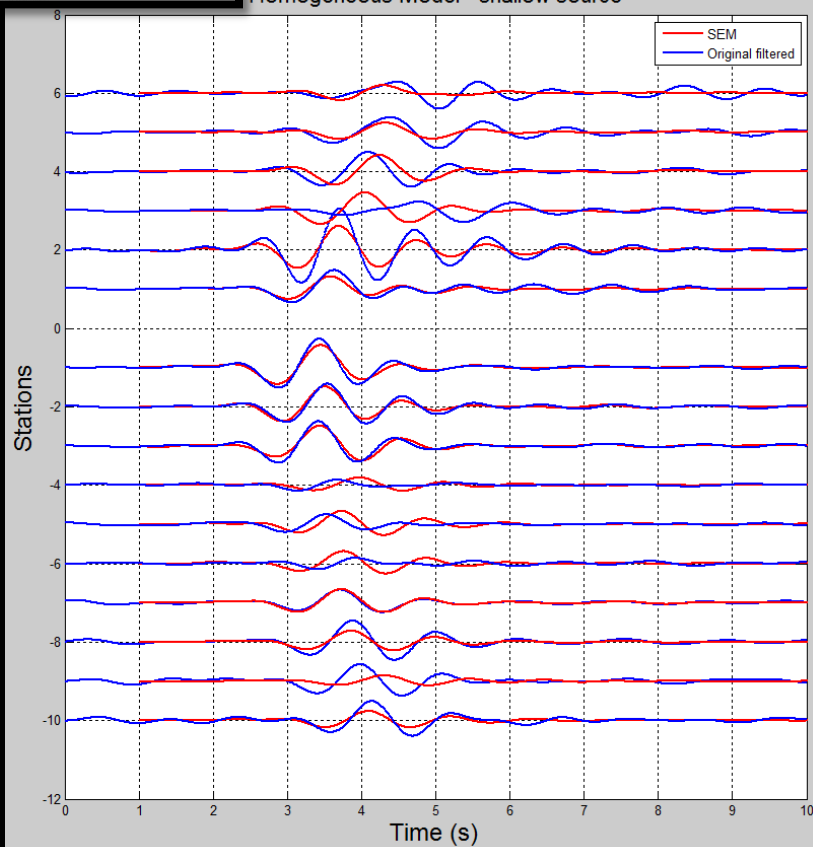
Comparisons

Homogeneous vs Gradient (60 m)

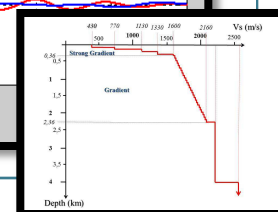
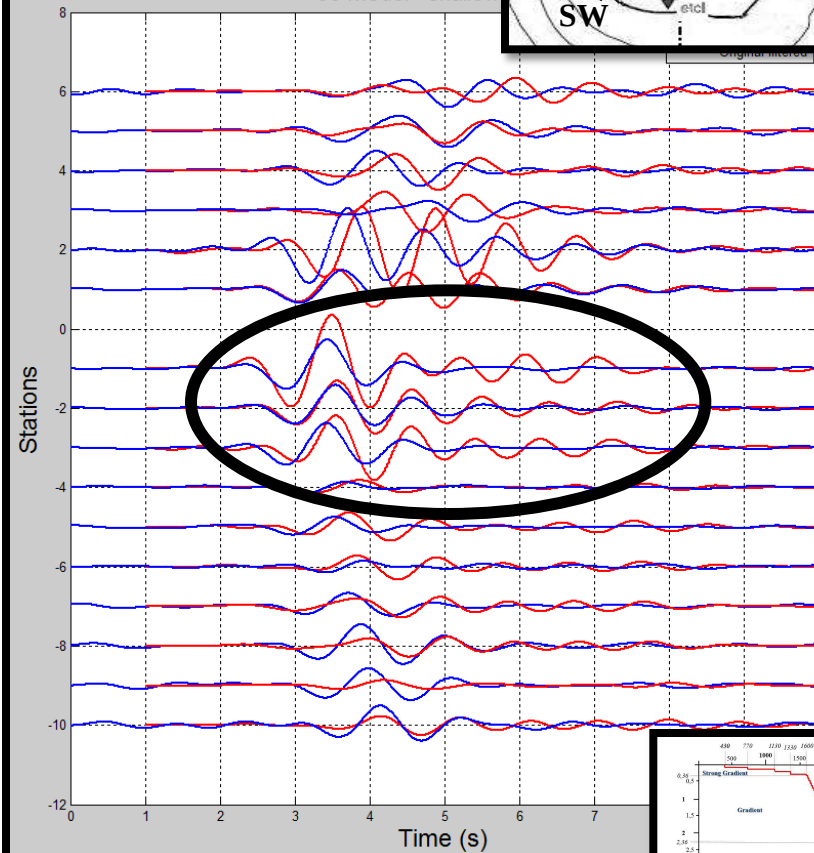
X-component



x component
Homogeneous Model - shallow source



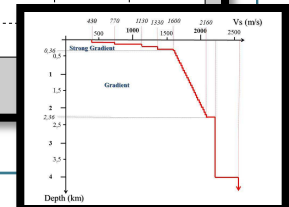
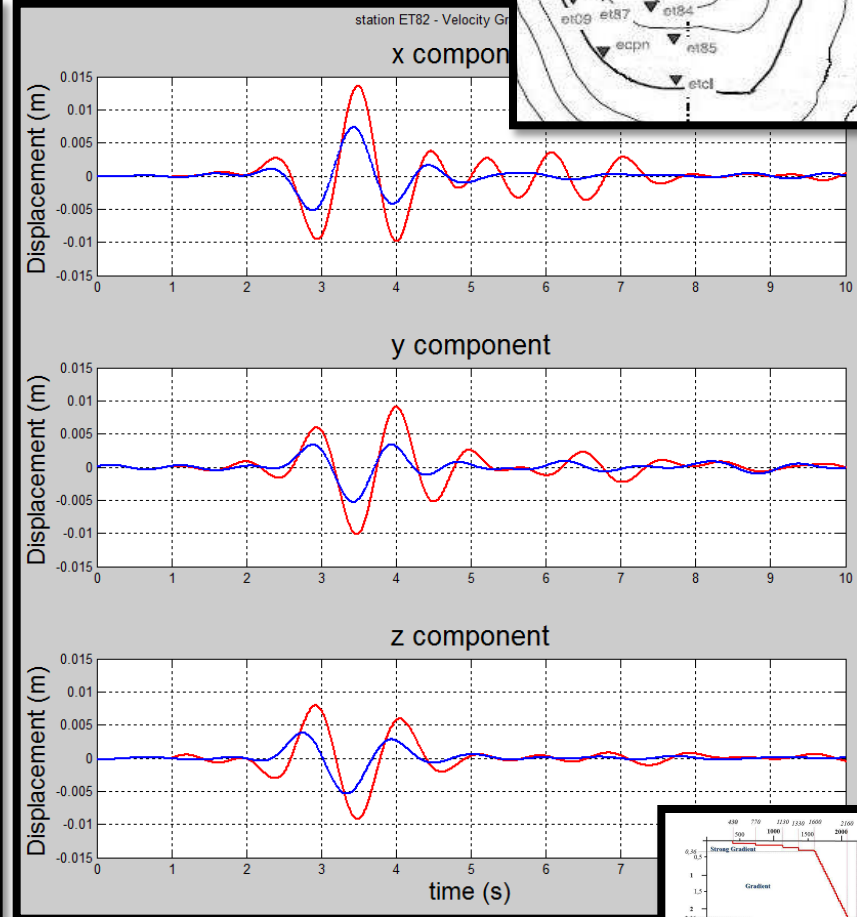
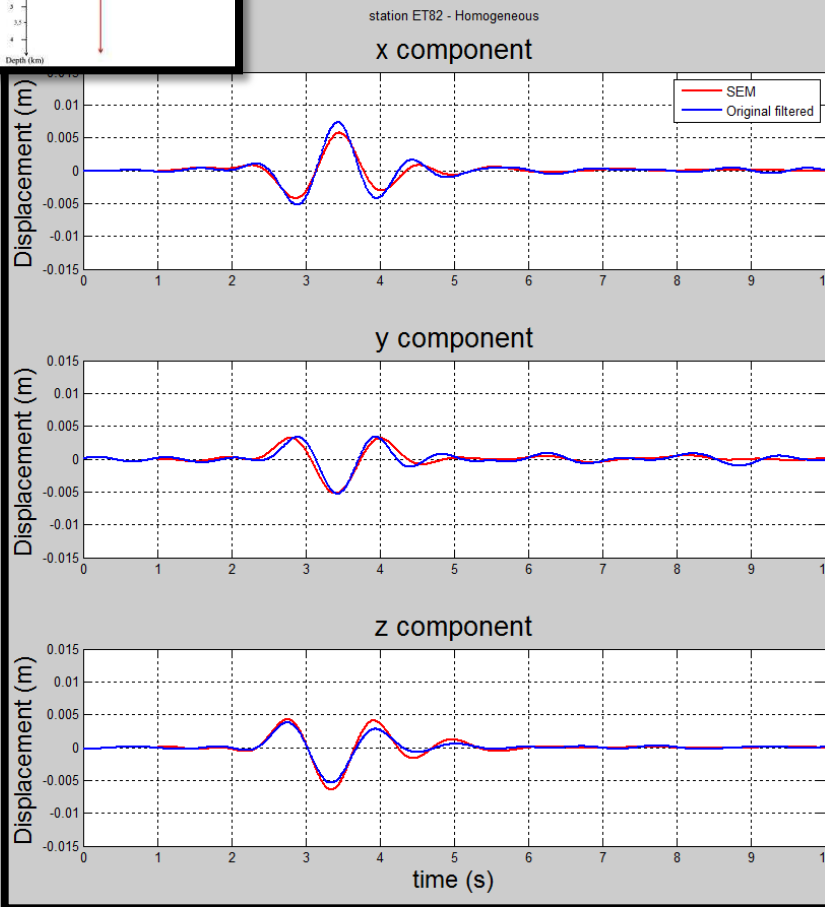
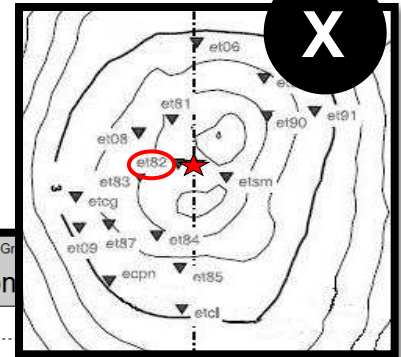
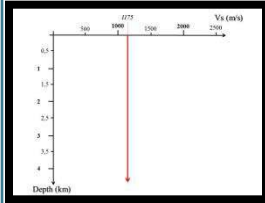
x component
60 Model - shallow





Comparisons

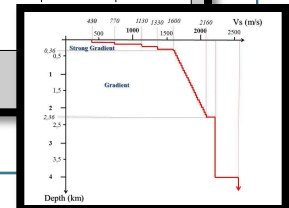
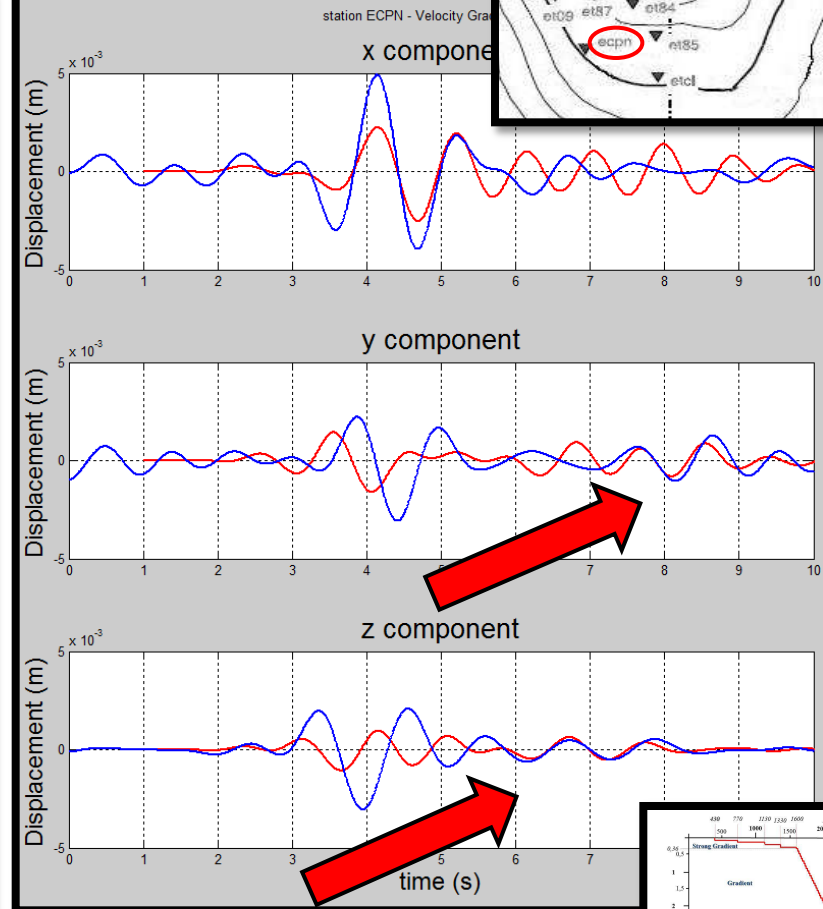
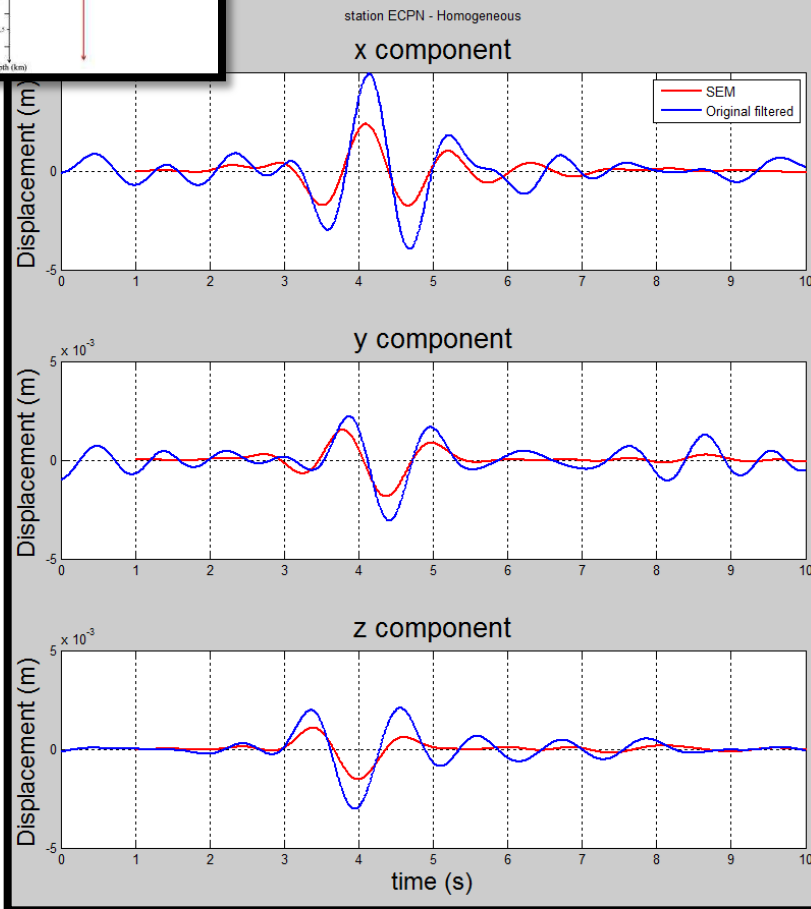
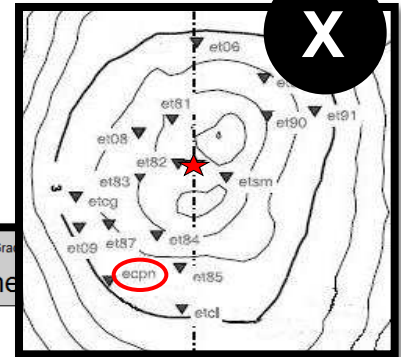
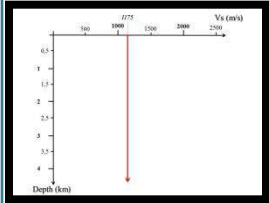
*Homogeneous vs Gradient (60 m)
Near station (et82)*





Comparisons

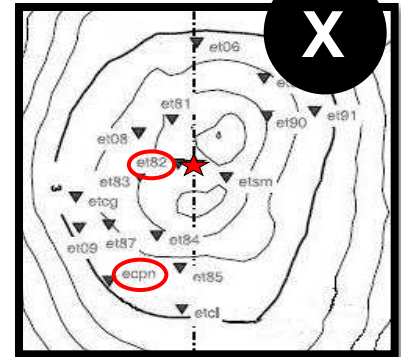
Homogeneous vs Gradient (60 m)
Far station (ecpn)



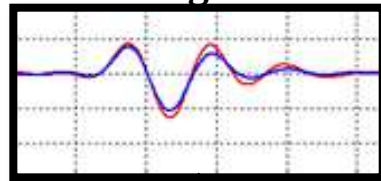


Conclusions

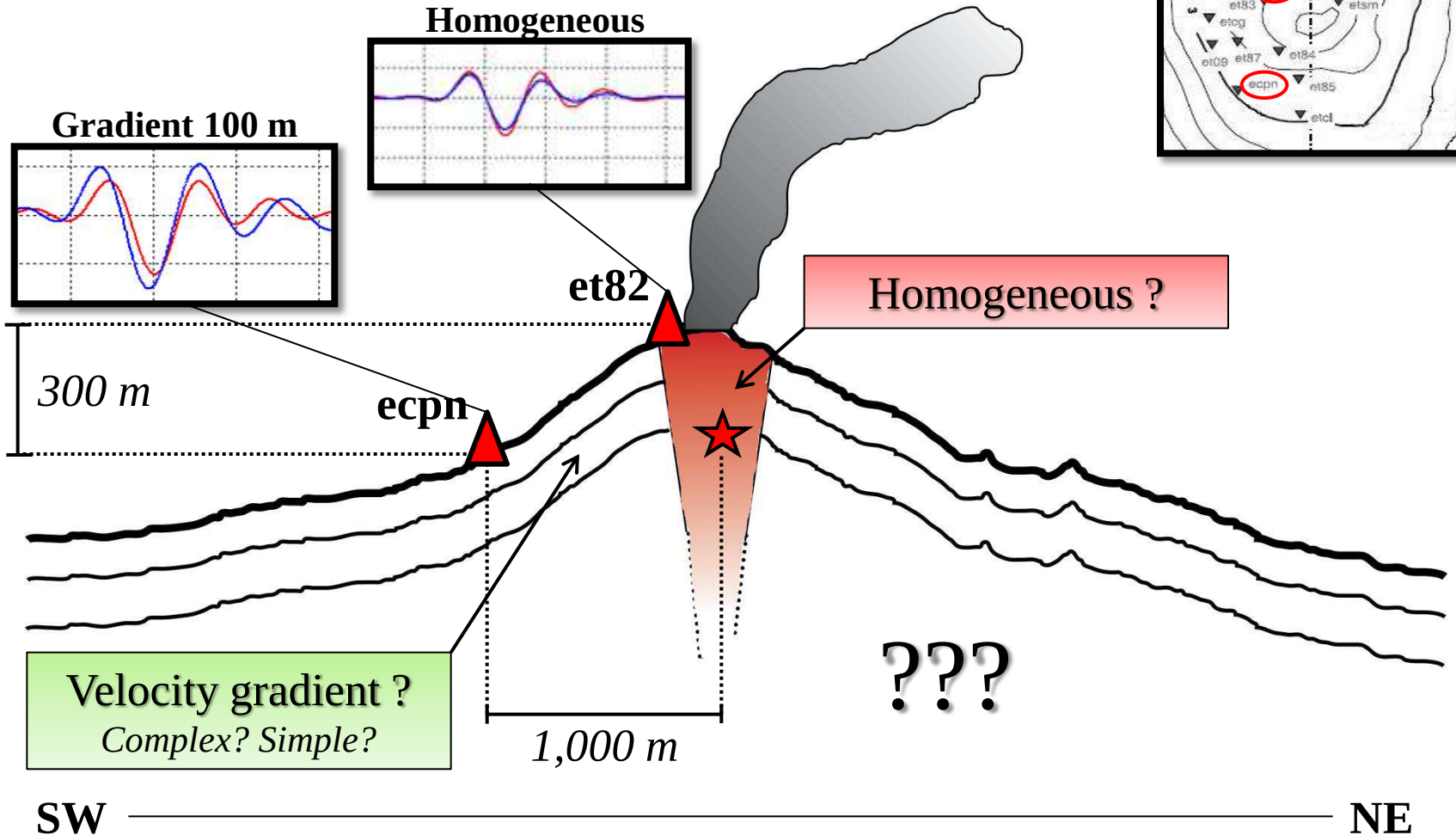
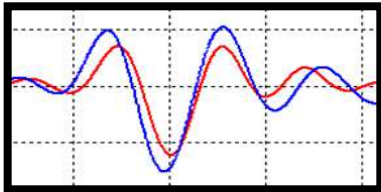
May a composite model be more accurate ?



Homogeneous



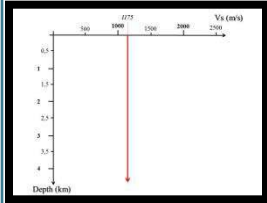
Gradient 100 m



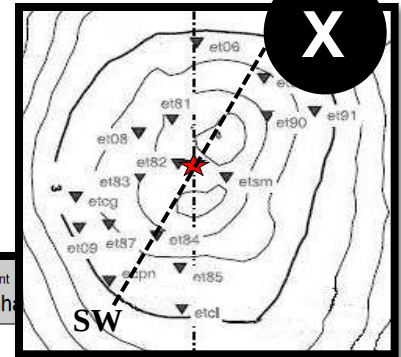
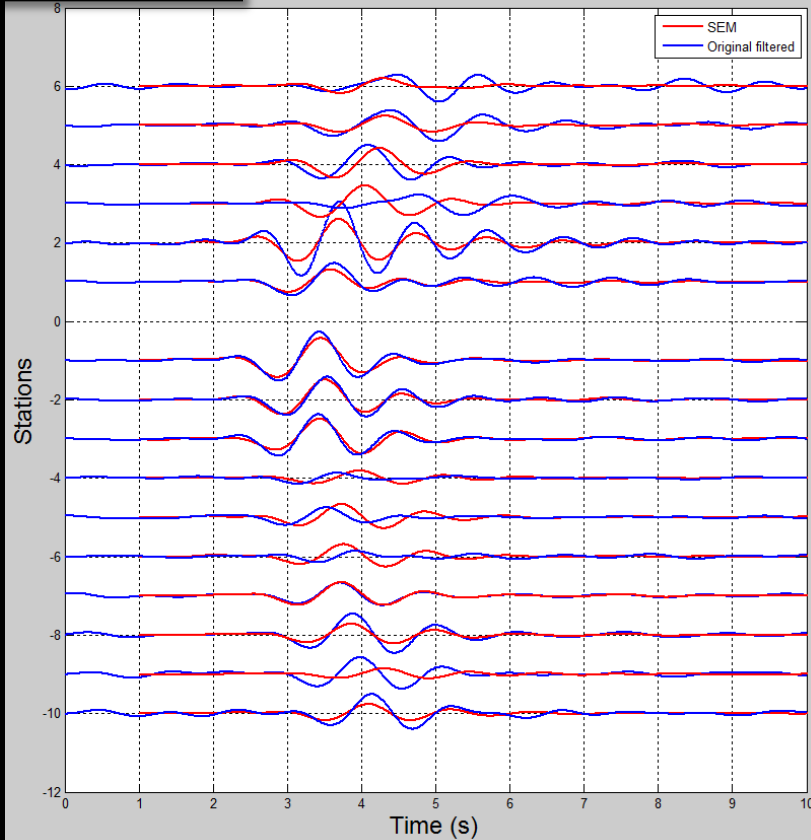


Comparisons

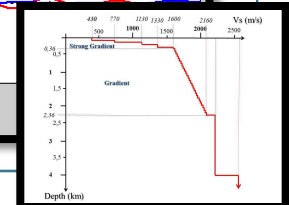
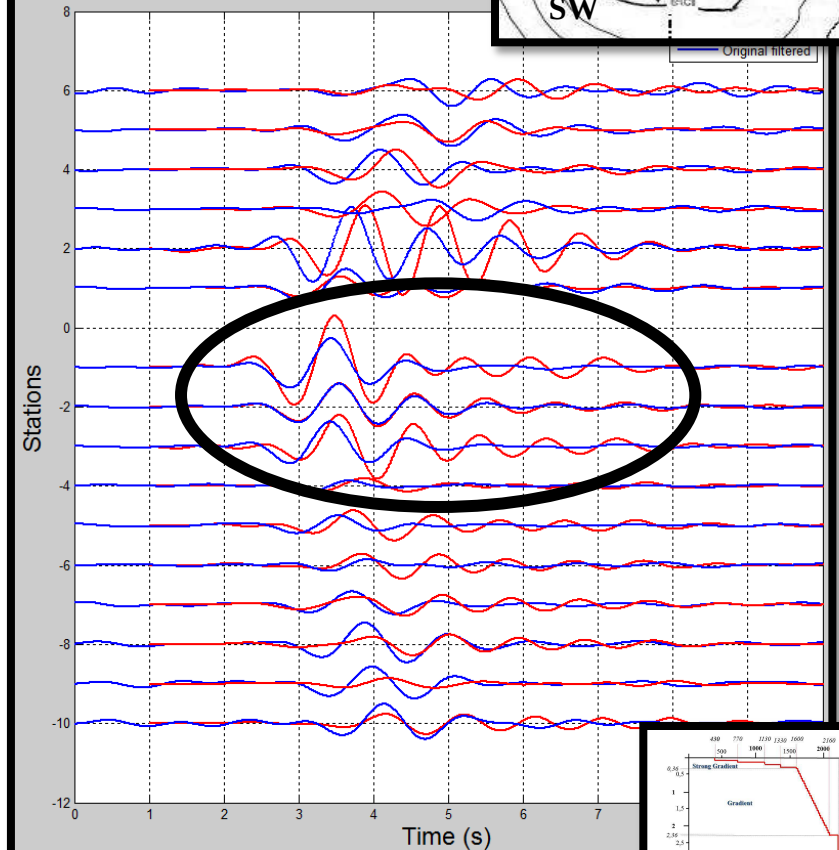
Homogeneous vs Hom + Gradient (60 m)
X-component



x component
Homogeneous Model - shallow source



x component
Hom - 60 Model - sh

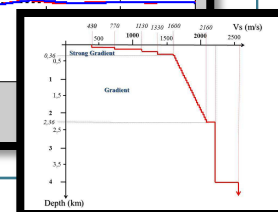
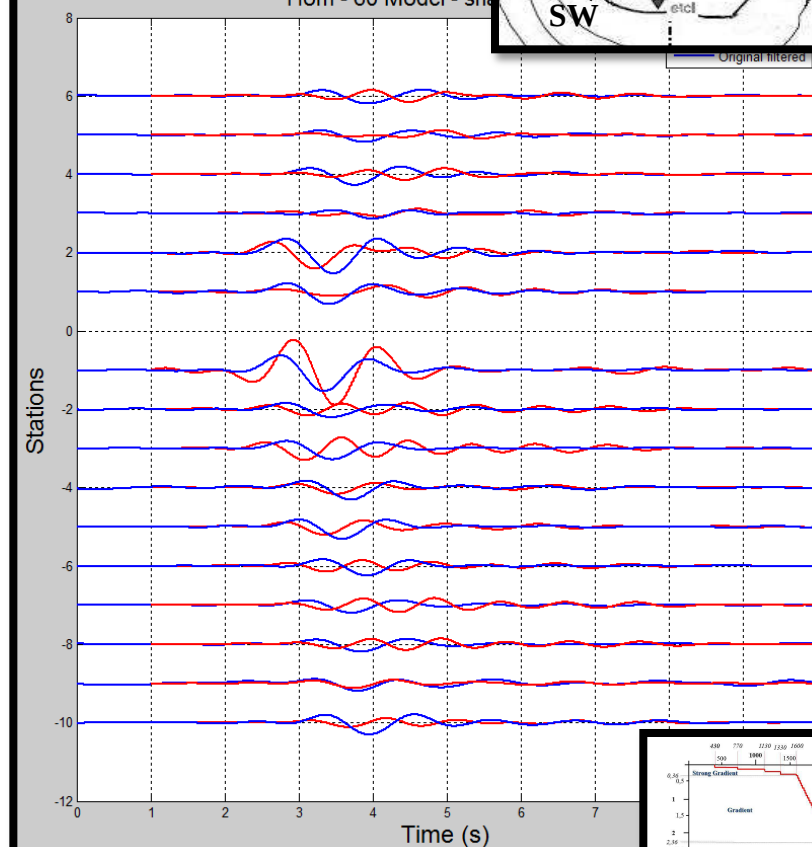
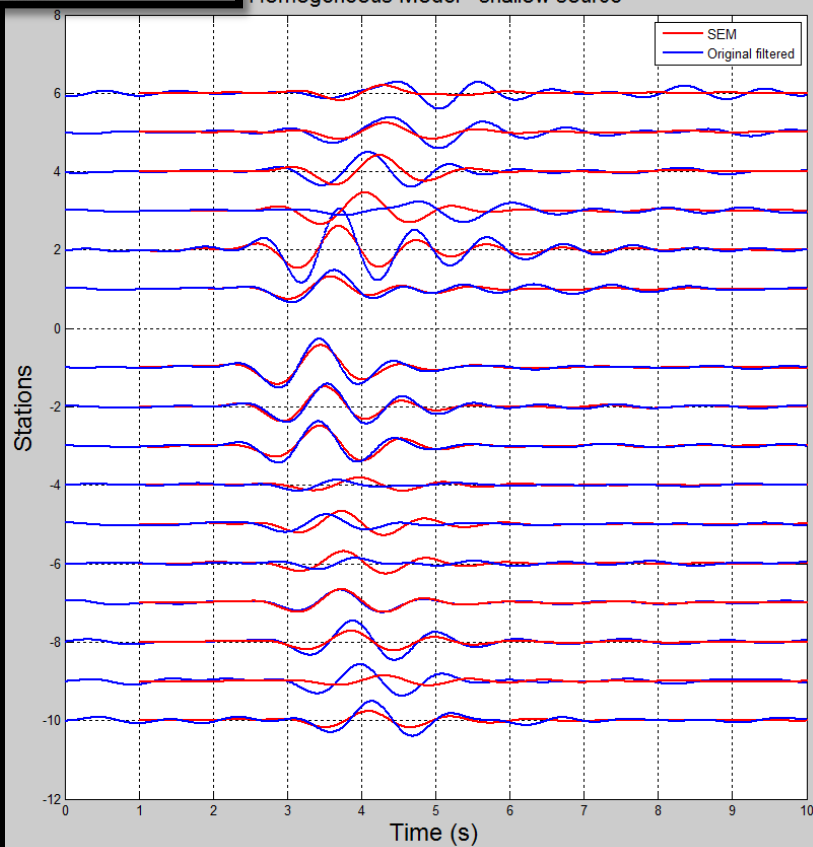
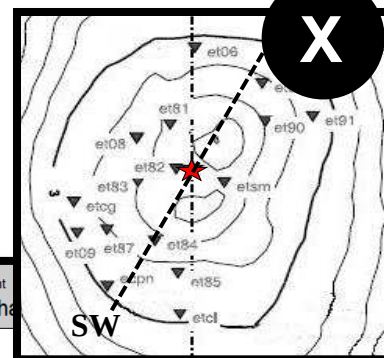
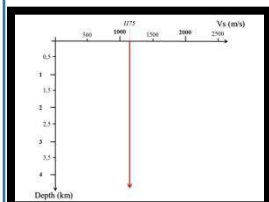




Comparisons

Homogeneous vs Hom + Gradient (60 m)

X-component





Perspectives



- 1) Production of Green Functions in more complex mediums including velocity gradient
- 2) Inversion of real data for different model scenarios
- 3) Extend the comparison to higher frequencies (~ 4 Hz)
- 4) Joint blind test with the INGV of Pisa and university of Dublin in order to test the influence of *a priori* model assumptions on synthetics data



Thank you for your attention!



Explosion on Etna volcano (10/11/2013), view of north flank. Shot taken from the village of Taormina (Sicily, Italy)

Summary

Velocity Models

profiles

examples

Receivers

Source time function

- a) EFISPEC3D (Spectral element code)
- b) Topography and structural features implementation

IV. Results

- a) Real data and synthetics comparison
- b) Observations and results

V. Conclusions & Perspectives



Summary

*Homogeneous**Homogeneous – Surface Layer**Homogeneous – 100 m Model**Homogeneous – 60 m Model**Homogeneous – 60 m + central conduit***IV. Results**

- a) Real data and synthetics comparison
- b) Observations and results

V. Conclusions & Perspectives