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

ISTO Institut des Sciences de la Terre d'Orléans

PEOPLE

NEMOH

MARIE CURIE ACTIONS

Géosciences pour une Terre durable brgm

Summary

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Objectives

1) Simulation of seismic waves propagation
   a) Complex media
   b) Realistic detailed topography

2) Volcano structural properties

3) Volcano seismic source characterization

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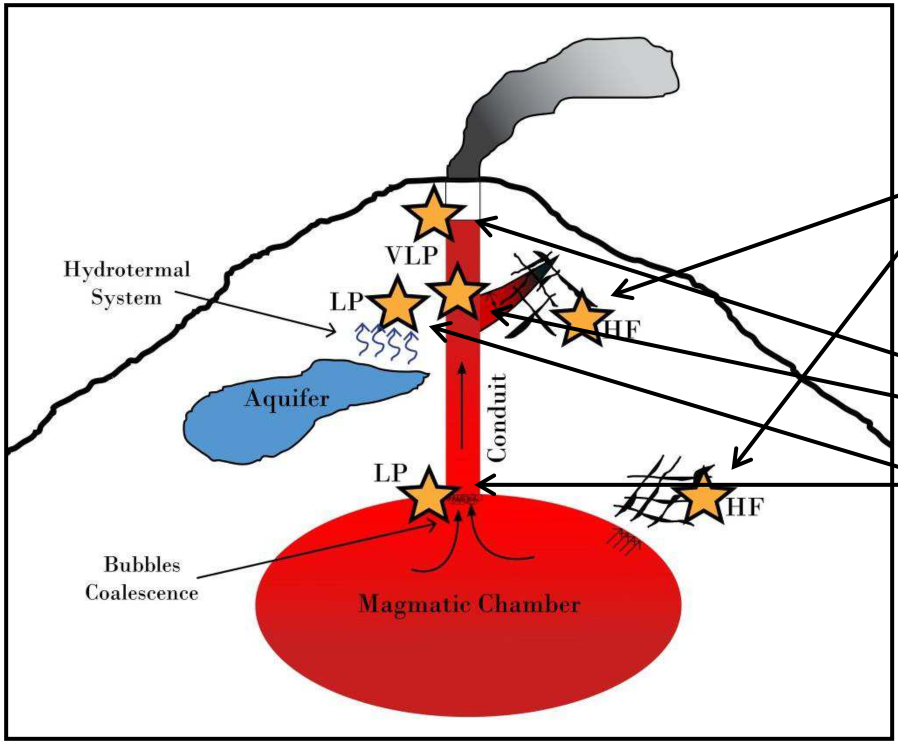
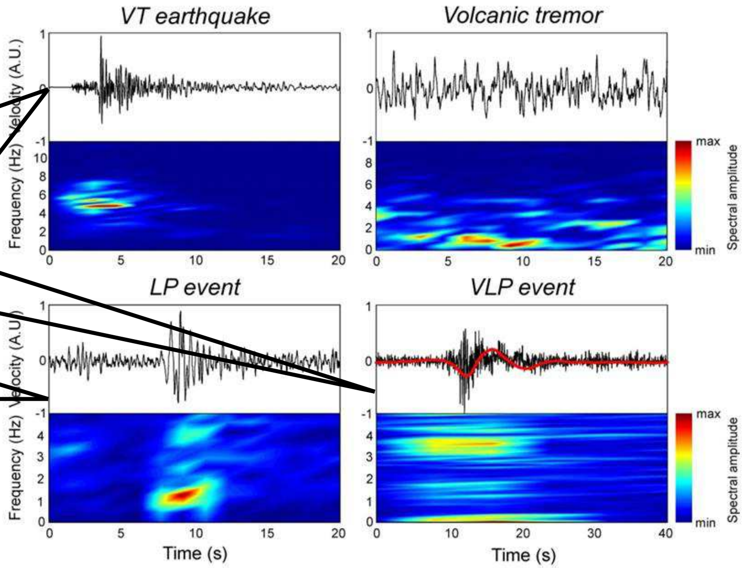
NEMOH (Numerical, Experimental and stochastic Modelling of vOlcanic processes and Hazard) is an Initial Training Network under the European Community FP7 → http://www.nemoh-itn.eu/

Volcano Seismicity

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



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



Patanè D. et al. (2011)

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Geographical setting

- **Tallest** volcano of Europe (3,343 m)
- 1,570 km^2 of covered area (45 km diameter) one of the **largest** world volcanoes
- Many suburban and urban (Catania ~ 7 10^5 inhabitants) communities live nearby the volcanic edifice → High volcanic risk !

Geological evolution

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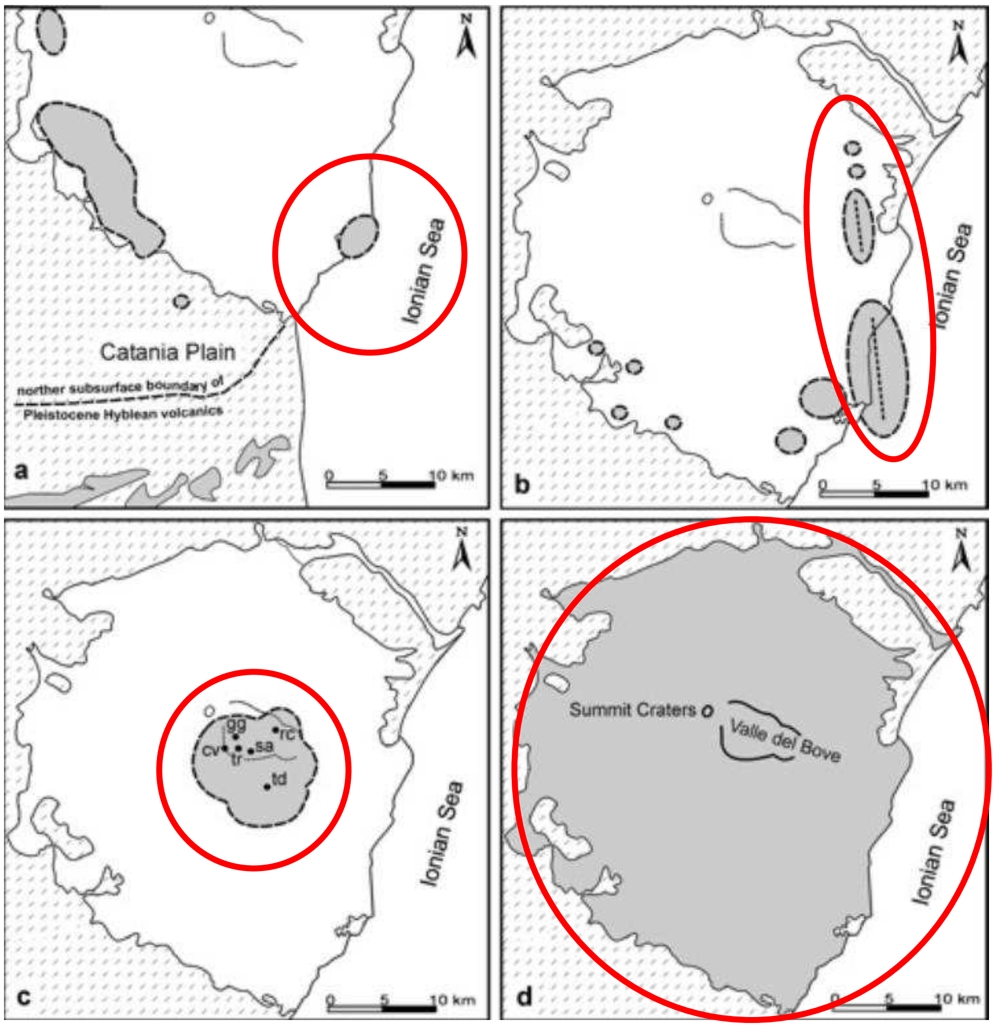


Four main volcanic phases which generated the volcanic edifice (Branca et al., 2004)

a) Basal Tholeiitic phase

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

b) Timpe phase

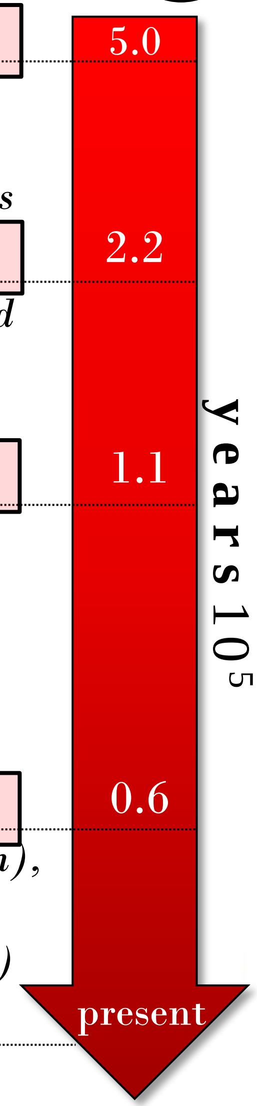
Fissure eruptions, shield volcano. Thoeliitic to alkali basaltic lava

c) Valle del Bove phase

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

d) Stratovolcano phase

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



Tectonic context

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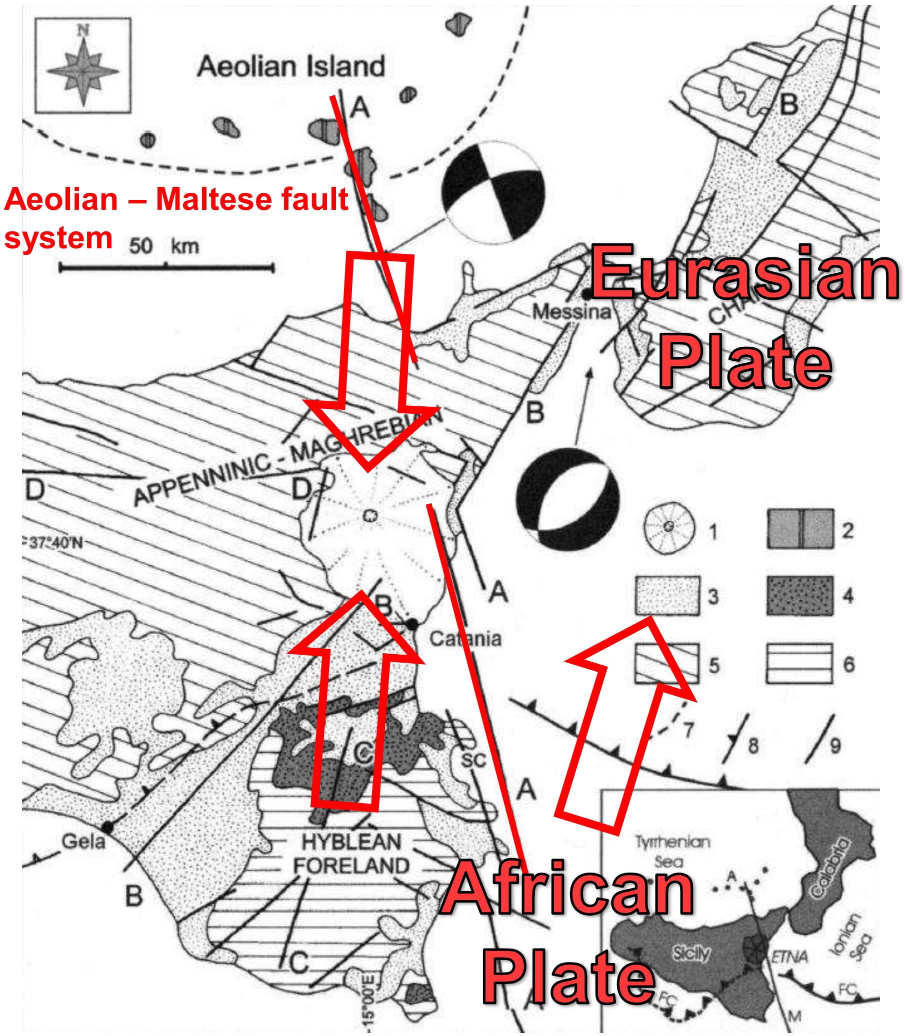
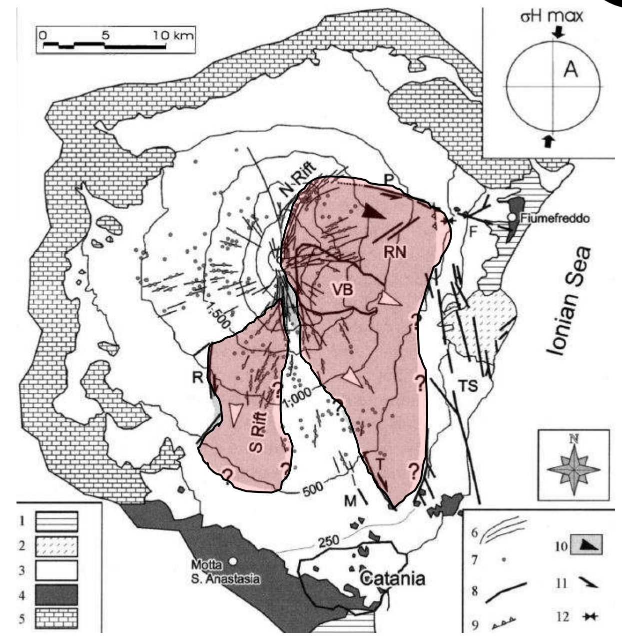
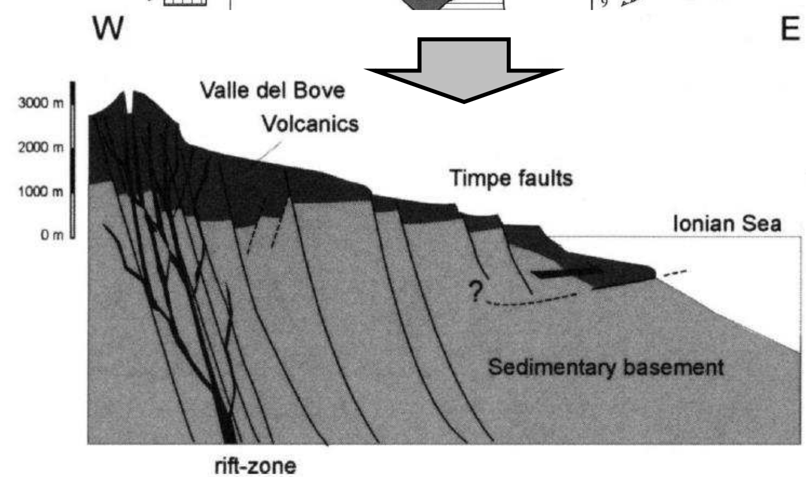


Bousquet & Lanzafame (2004)





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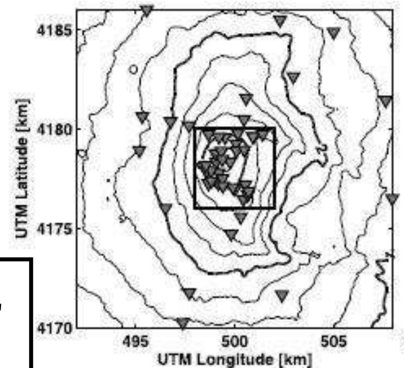
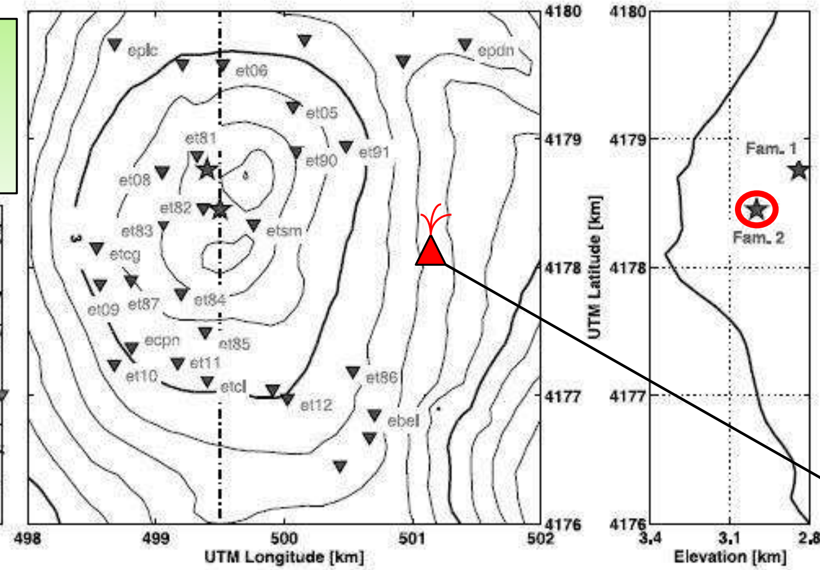
LP events

(June – July 2008)

De Barros (2011)

50 stations deployed
129 LP events recorded

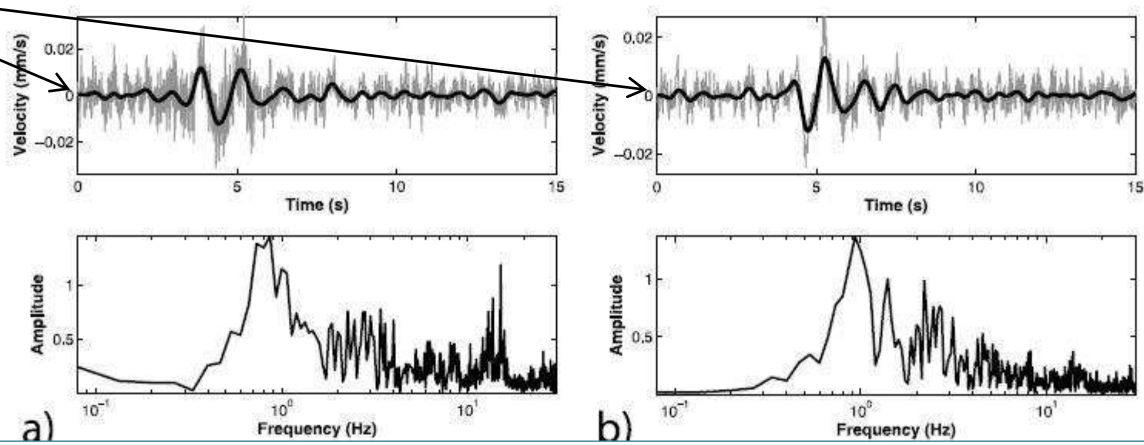




Very good spatial and azimuthal coverage !

Lava fountain occurred during the experiment

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



Family 1
63 events

Family 2
66 events

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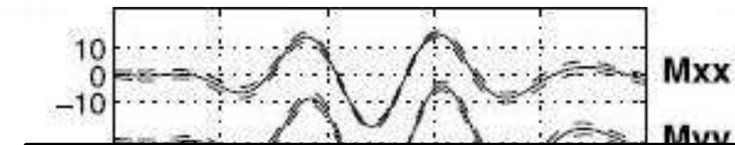
LP Inversion

(Family 2)

De Barros (2011)



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 independents Moment Tensor components and 3 forces

Moment [1 1 2]
Forces – only used to accommodate errors
Physical mechanism related to gas movements

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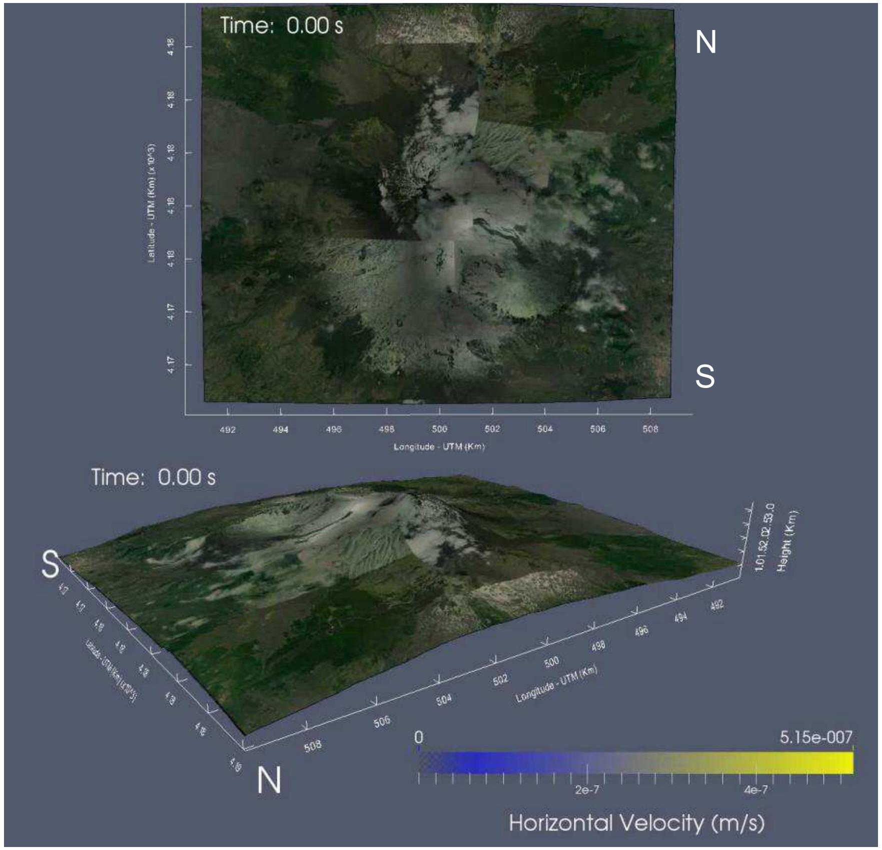
EFISPEC3D

(De Martin, 2011)

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/

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

Geometrical Models

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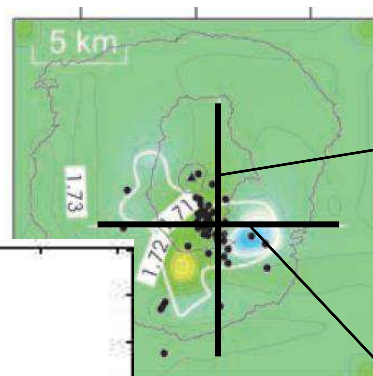
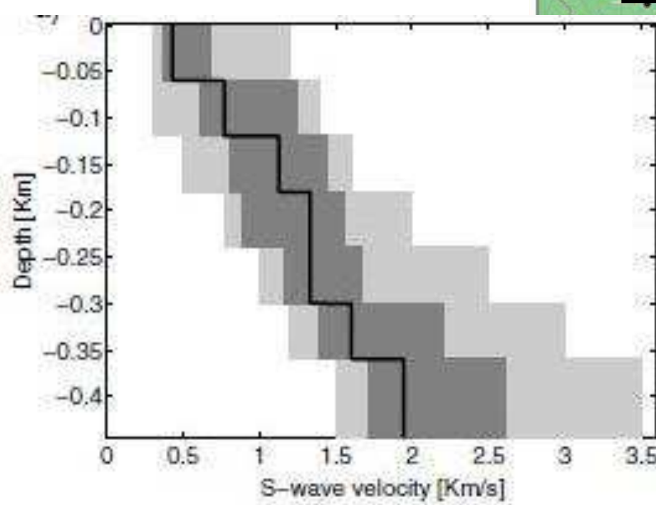
- *Velocity models based on the seismic tomography papers:*

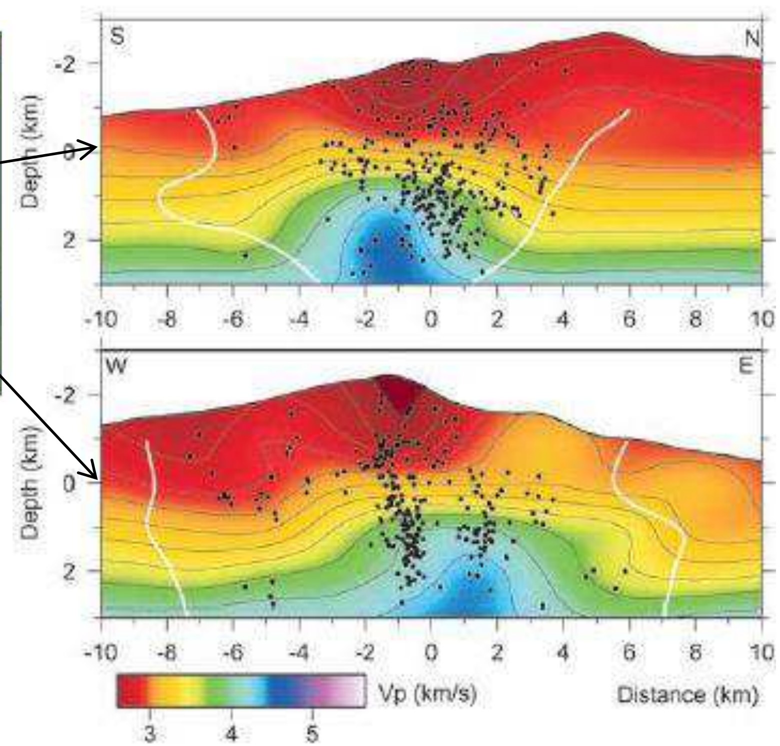
1. ***Cauchie & Saccorotti (2012)*** *→ very shallow velocity gradient*
2. ***Patané et al. (2002)*** *→ velocity until depth*
3. ***Cristiano et al. (2010)*** *→ Vs velocity structure*

Localization of the two profiles (on the right), Patané (2002)



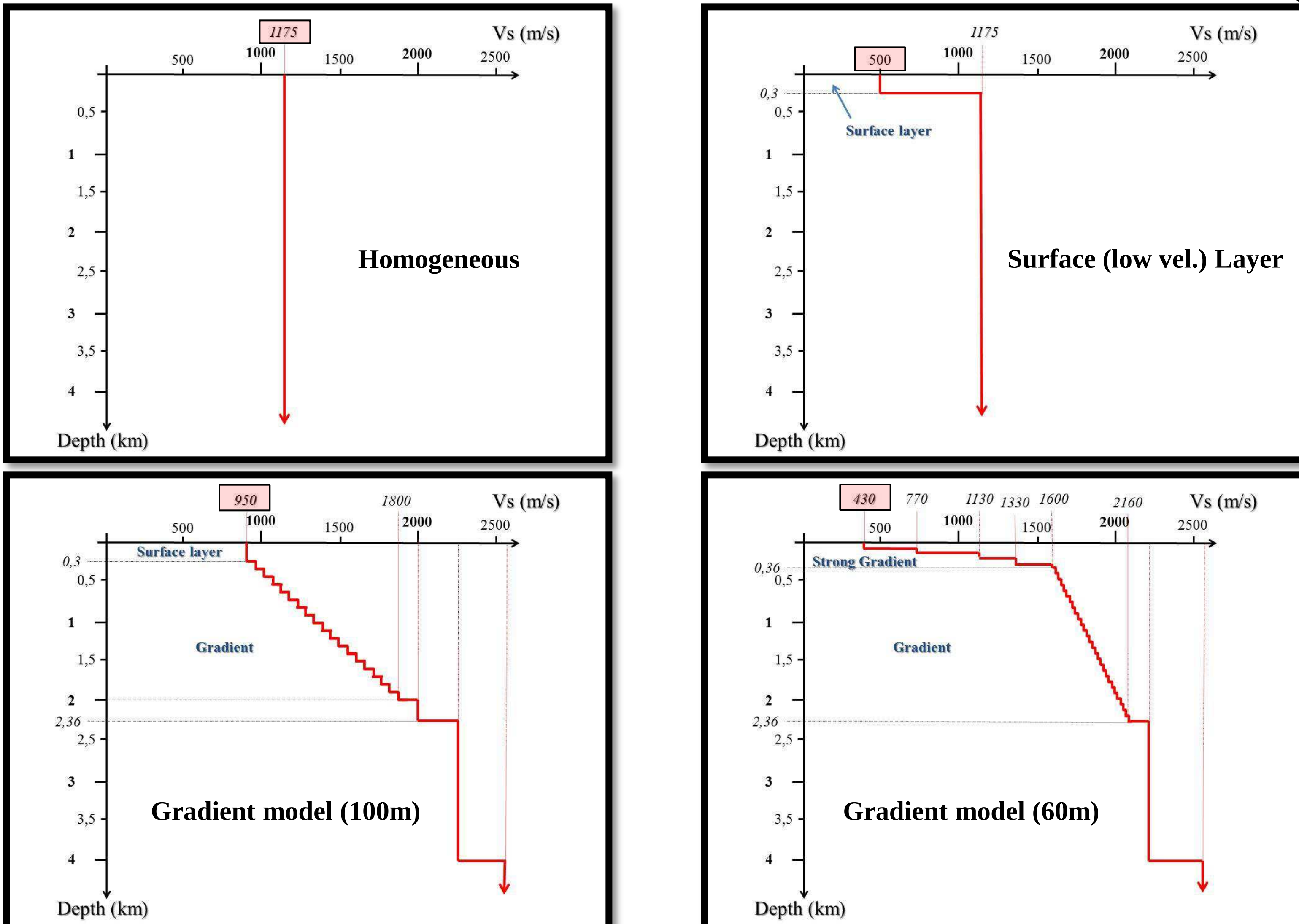


Cauchie (2012)



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

Geometrical Models



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Geometrical Models

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

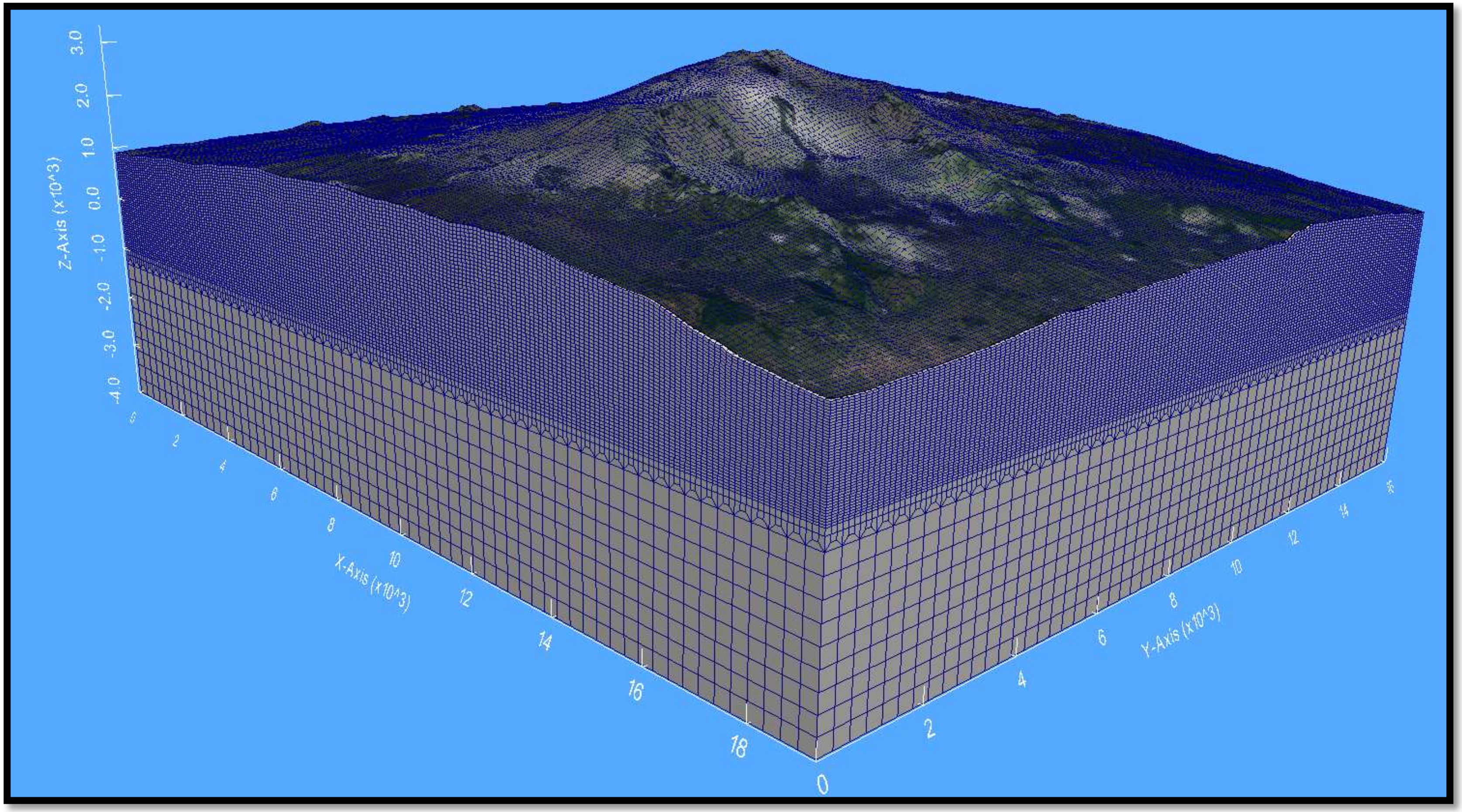
Model	Vp (m/s)	Vs (m/s)	ρ (kg/m³)
Homogeneous	2000	**1175**	2069
Surface (low vel.) Layer	866 / 2000	**500** / 1175	1697 / 2069
Gradient model (100m) 21 layers	1645 → 4503	**950** → 2600	1974 → 2539
Gradient model (60m) 36 layers	744 → 4503	**430** → 2600	1619 → 2539

	CPUs	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*



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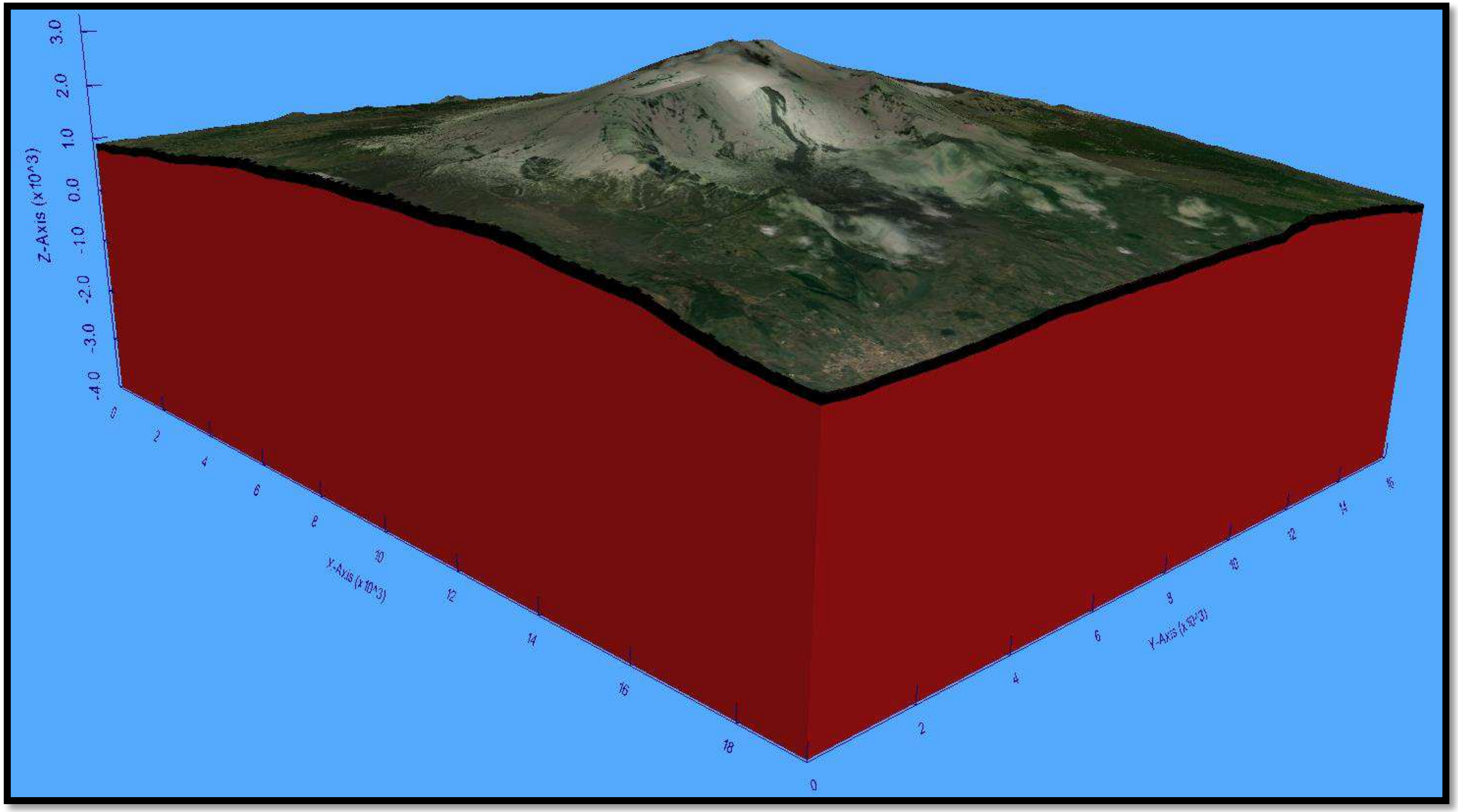
Geometrical Models

(examples (2))

- *Surface (low-velocity) layer*

200 – 300 – 400 m depths



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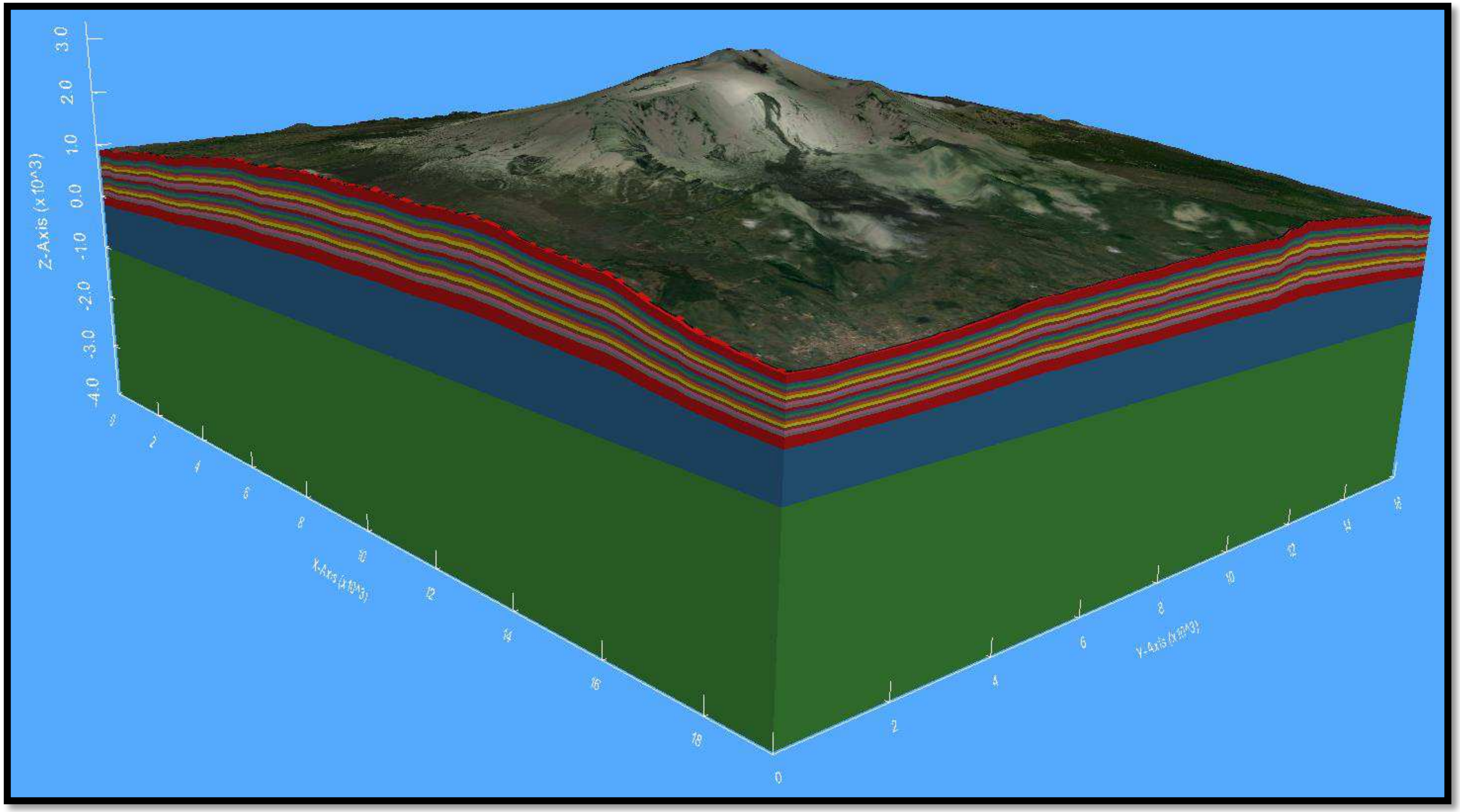
Geometrical Models

(examples (3))

- *Gradient velocity layer (100 m)*



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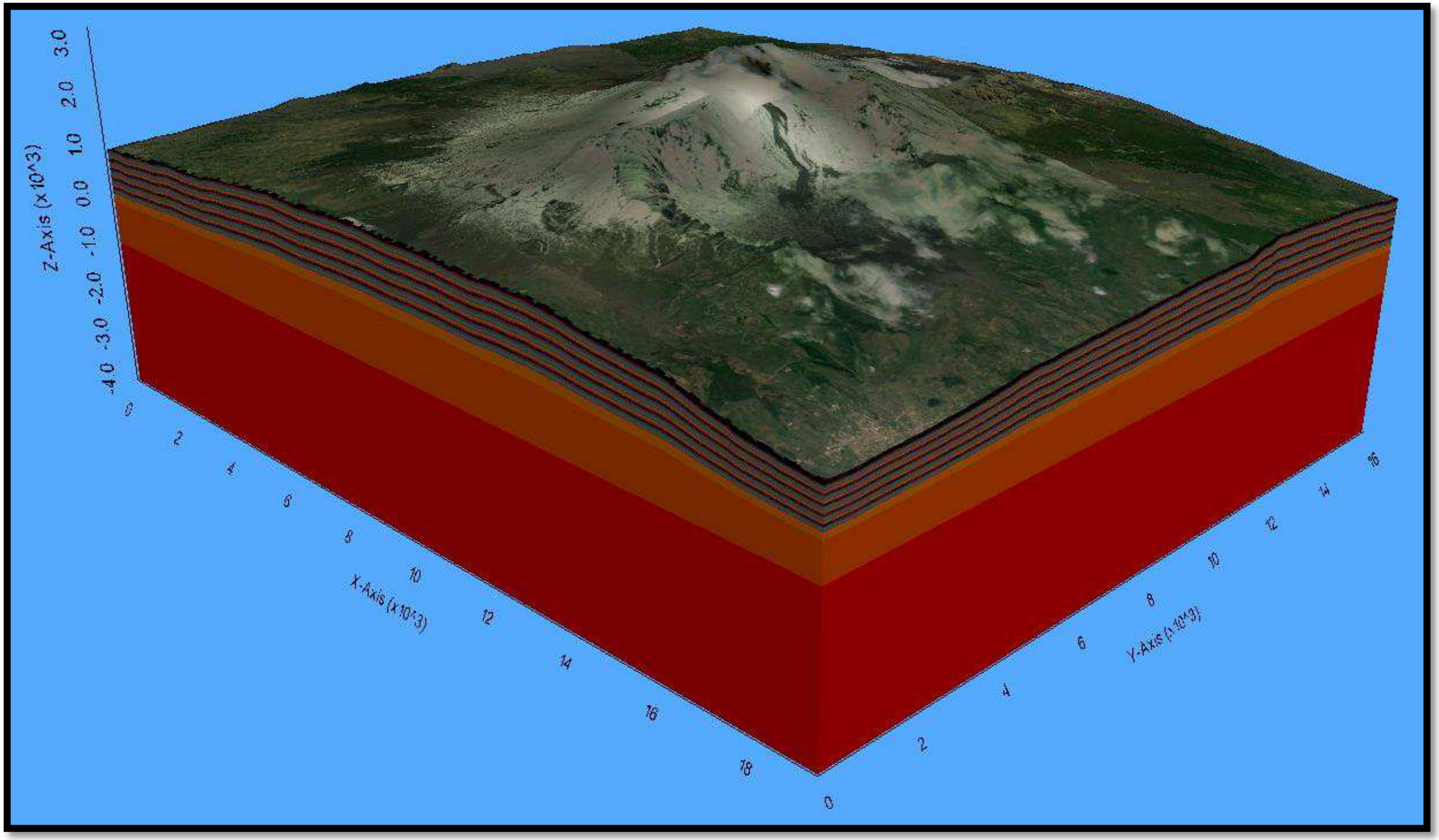
Geometrical Models

(examples (4))

- *Gradient velocity layer (60 m)*



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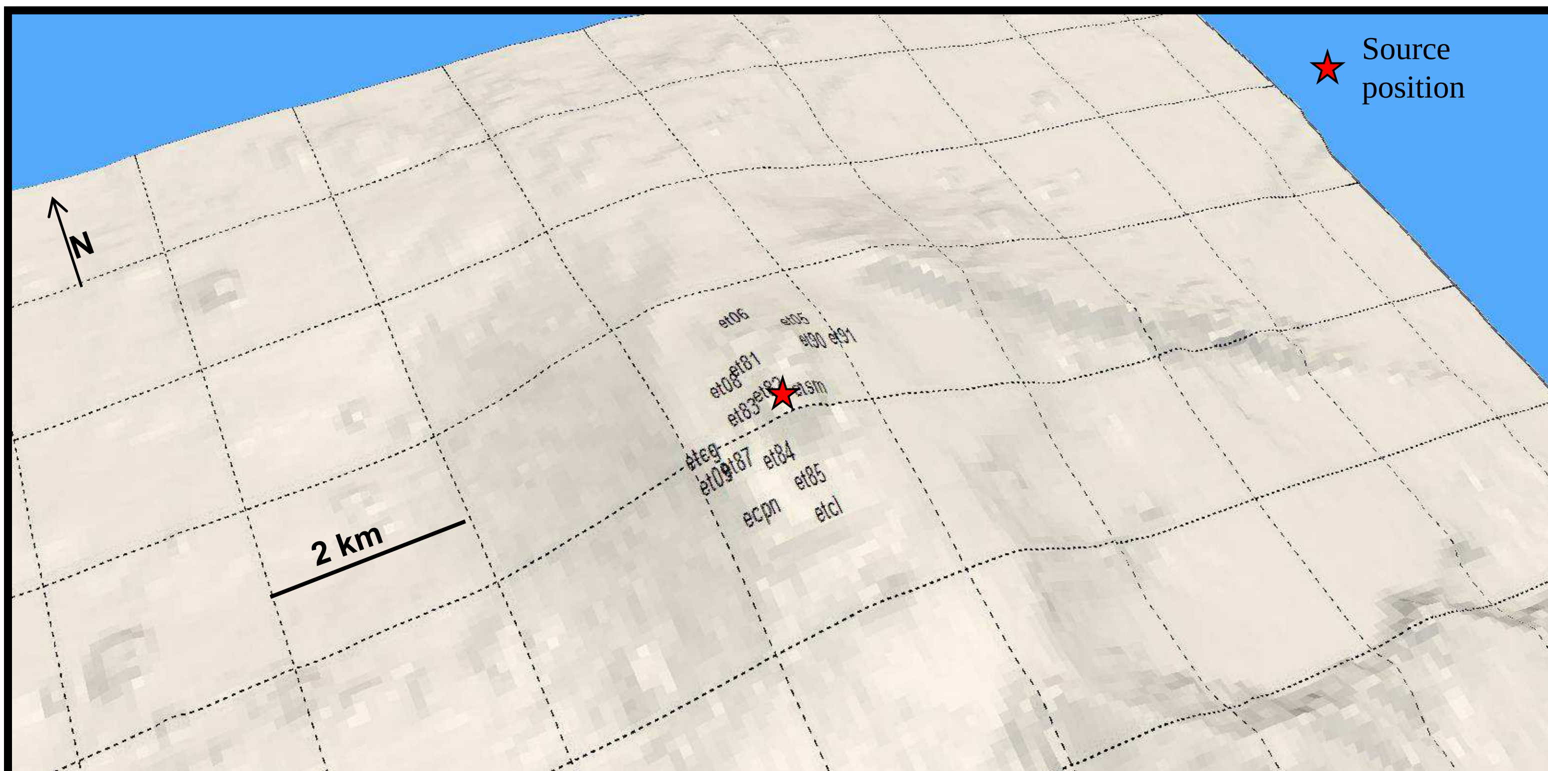
Simulation Parameters

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

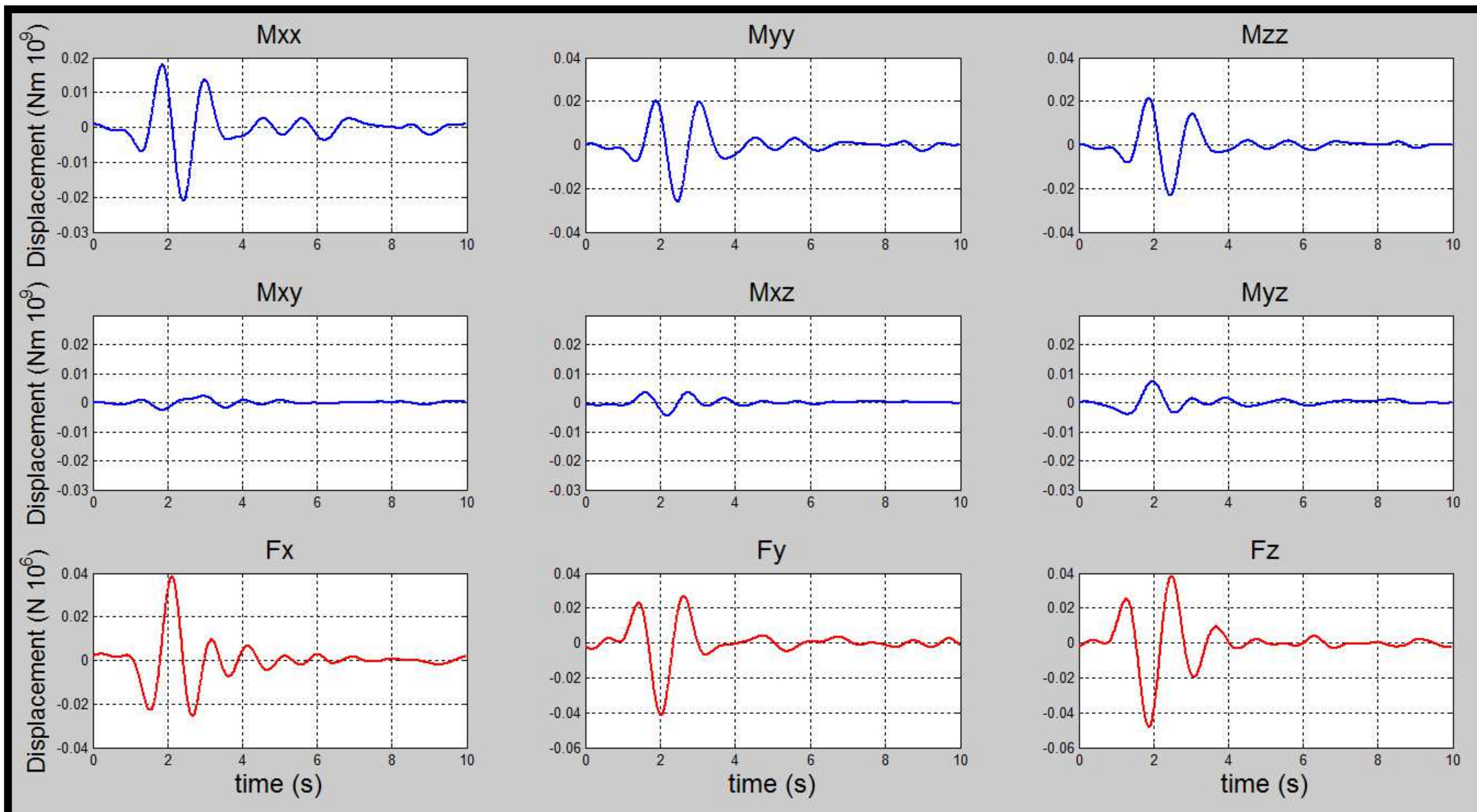


Simulation Parameters

Source time function

- ***Full Moment tensor + 3 Single Forces solution***

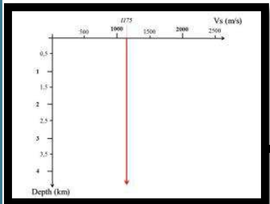
(the one found by De Barros (2011) in their inversion)

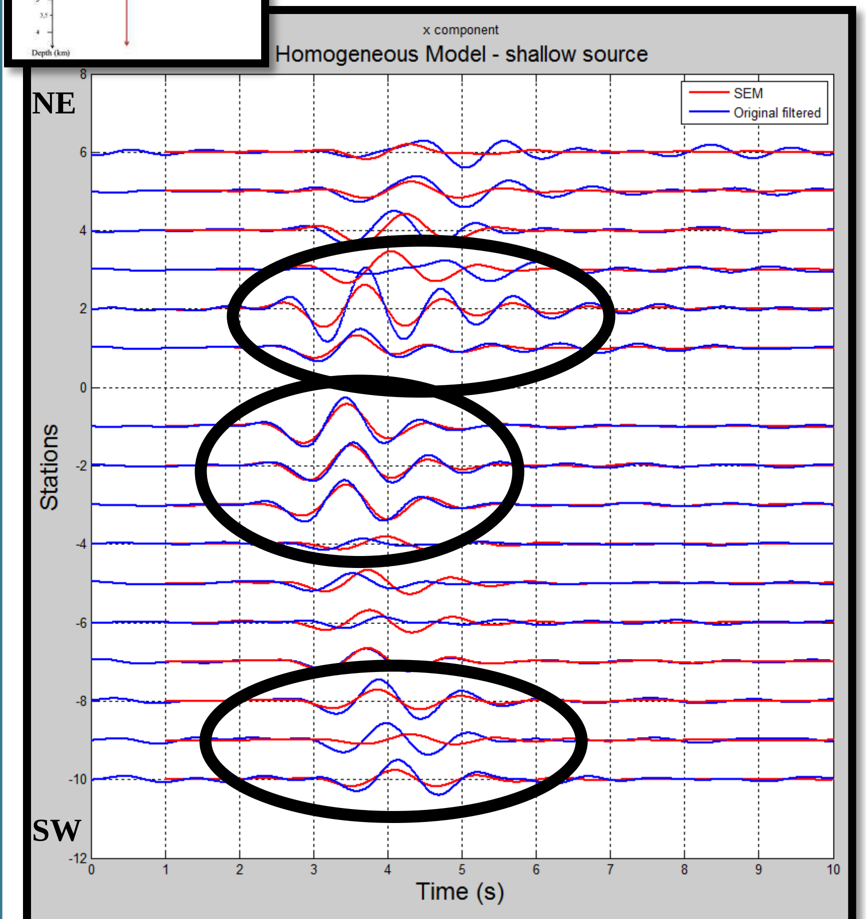


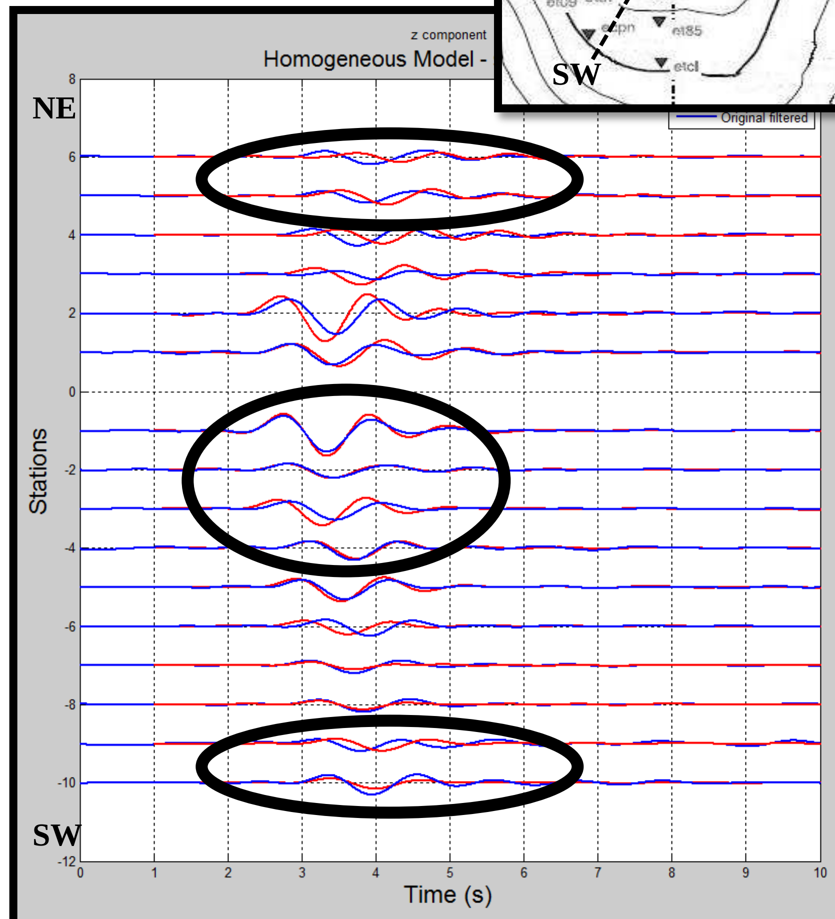
Comparisons

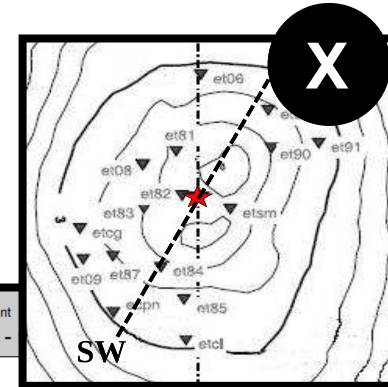
Homogeneous model

X-component & Z-component





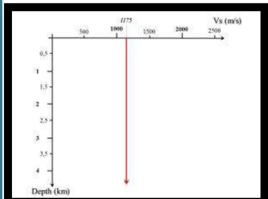


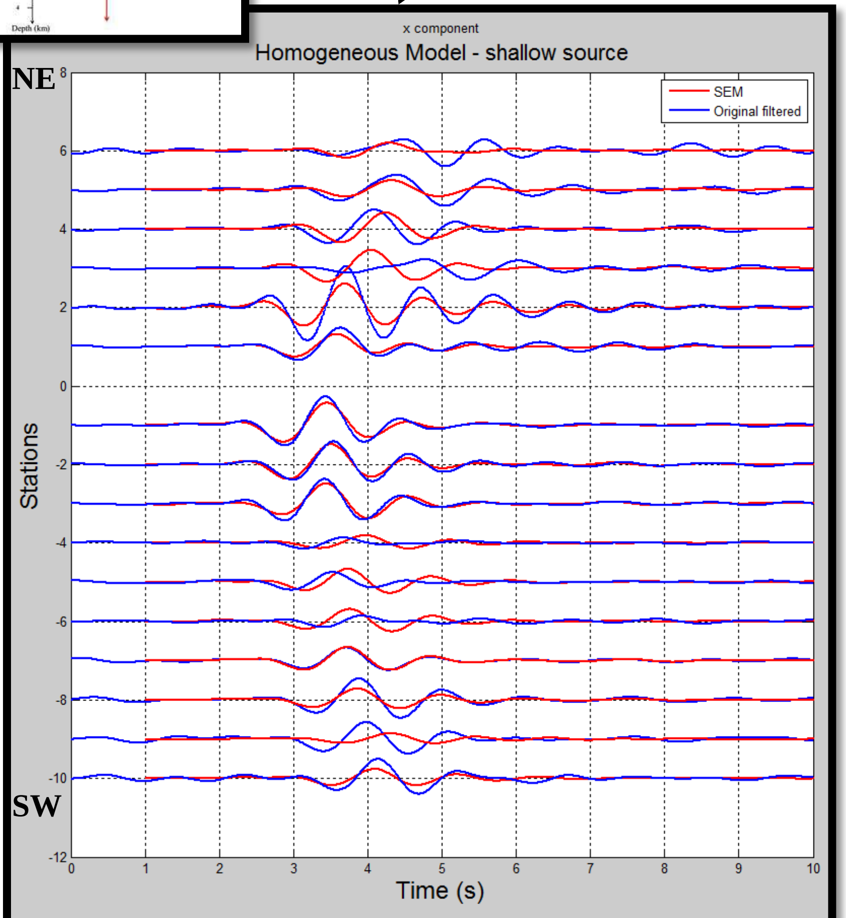


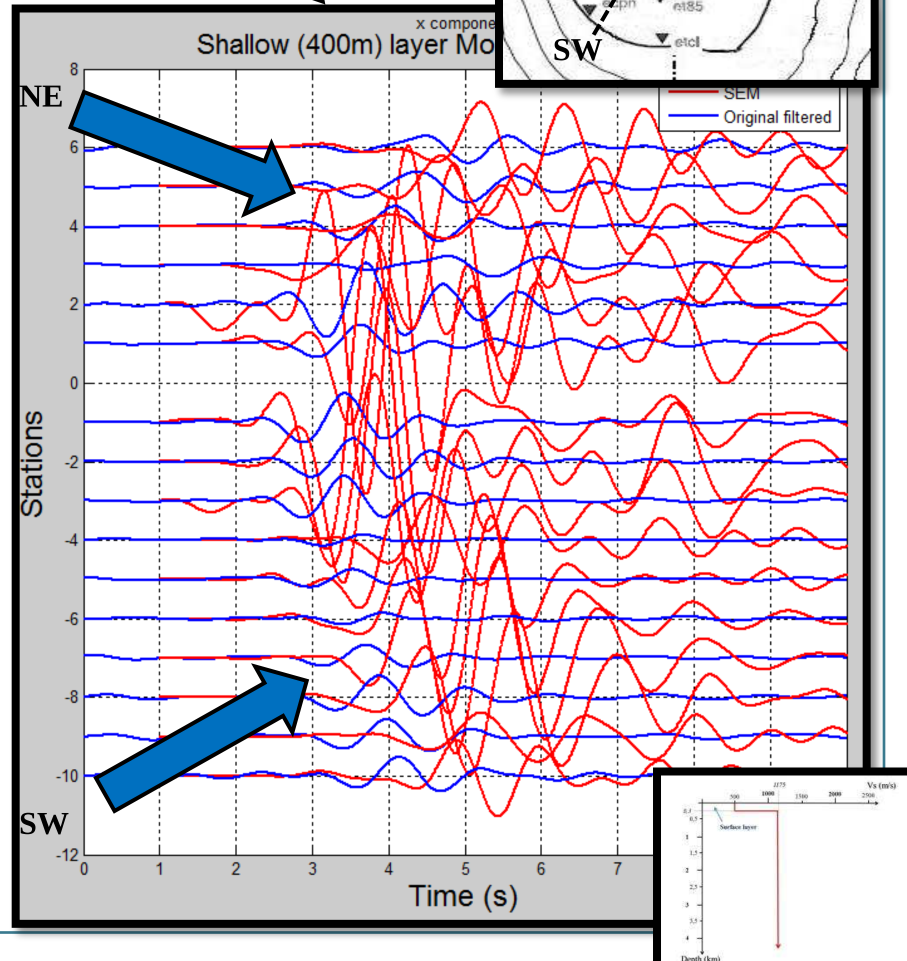
Comparisons

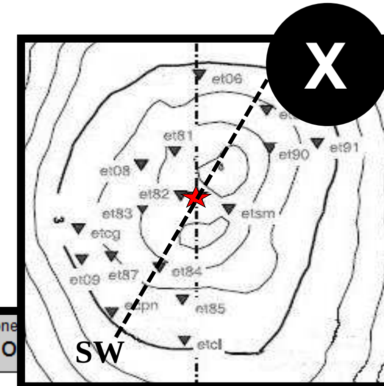
Homogeneous vs Surface layer (400 m)

X-component





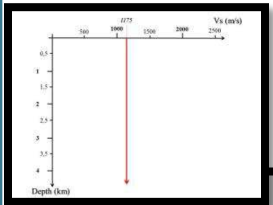


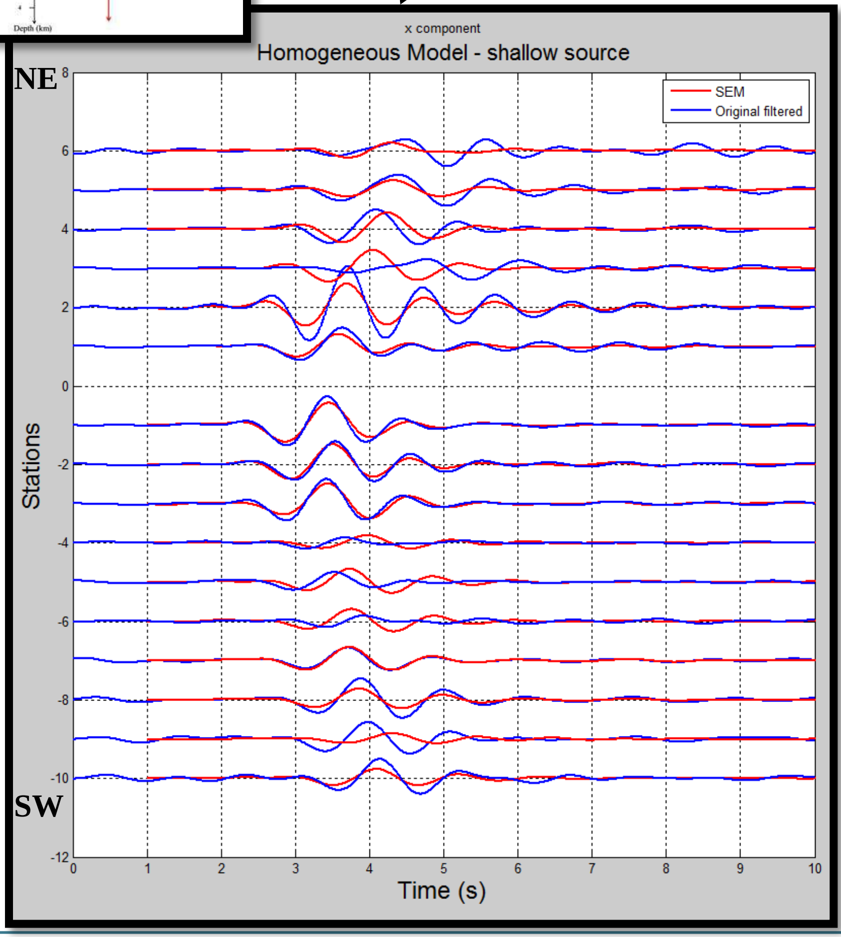


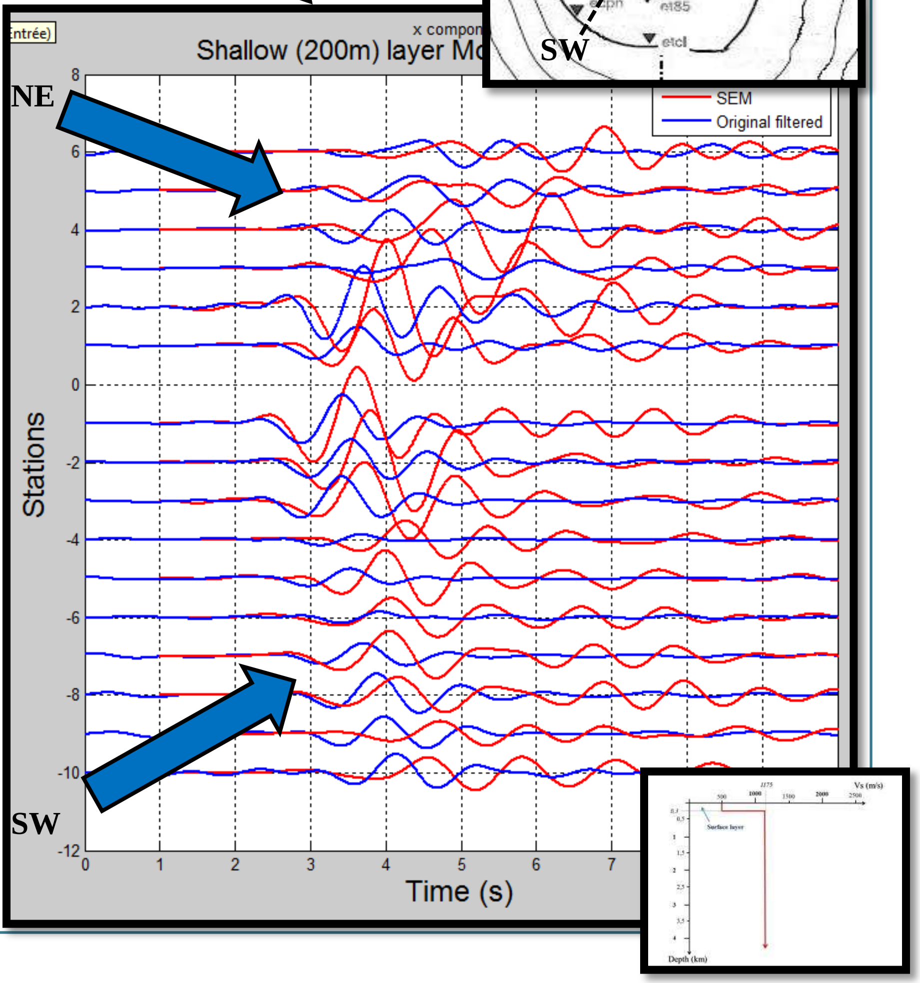
Comparisons

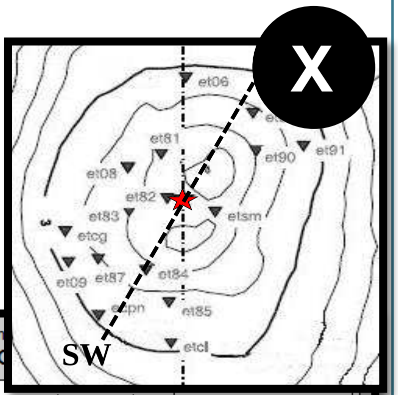
Homogeneous vs Surface layer (200 m)

X-component





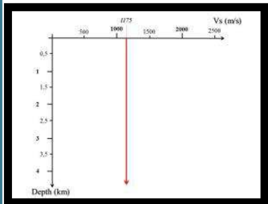


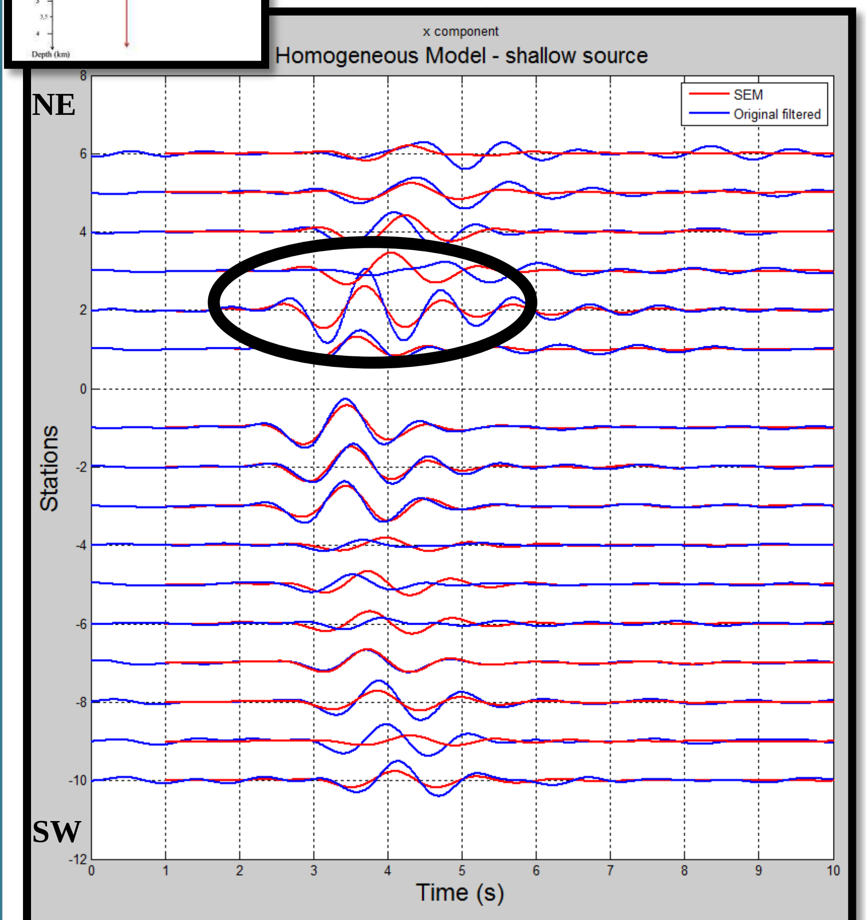


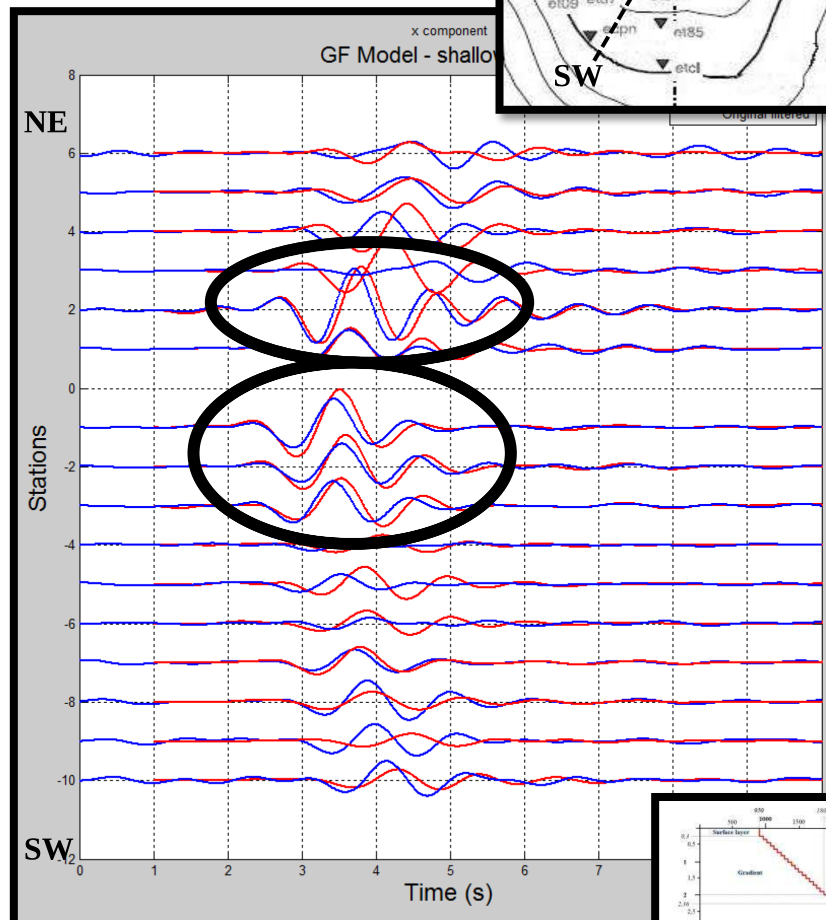
Comparisons

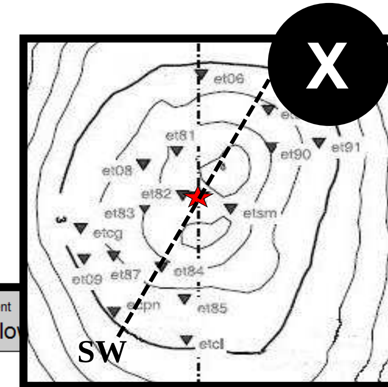
Homogeneous vs Gradient (100 m)

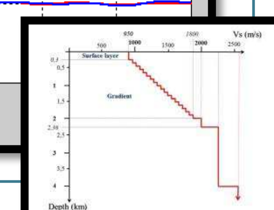
X-component







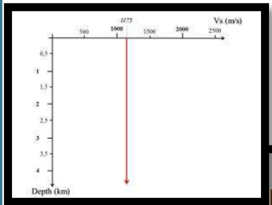


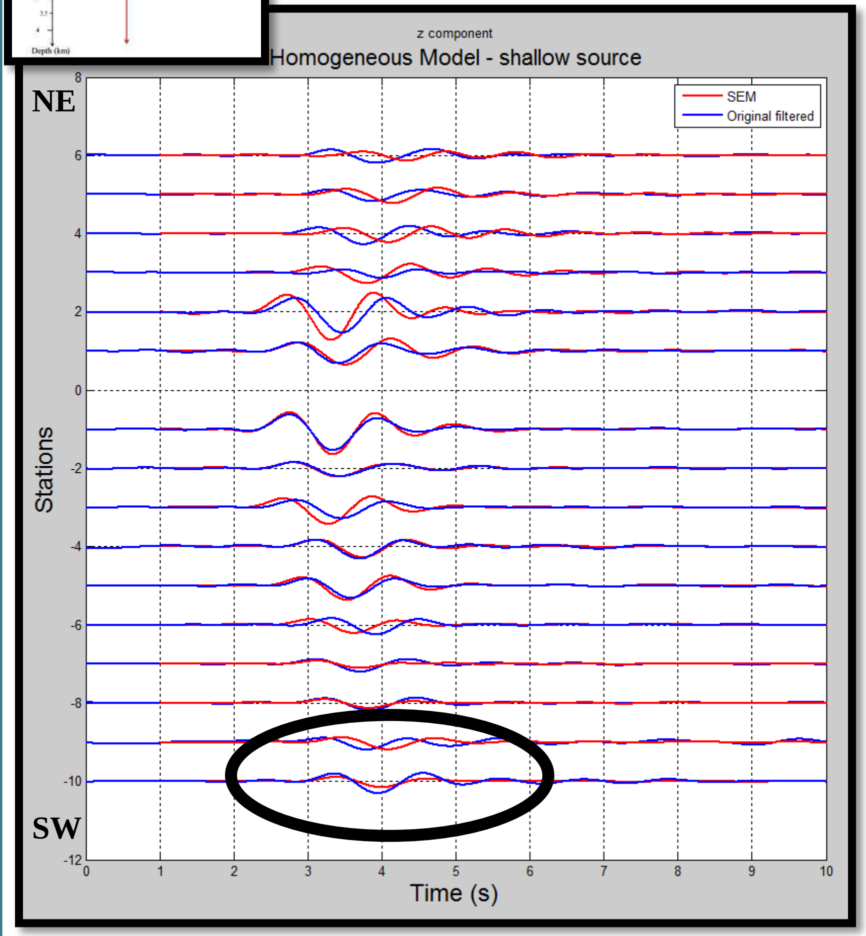


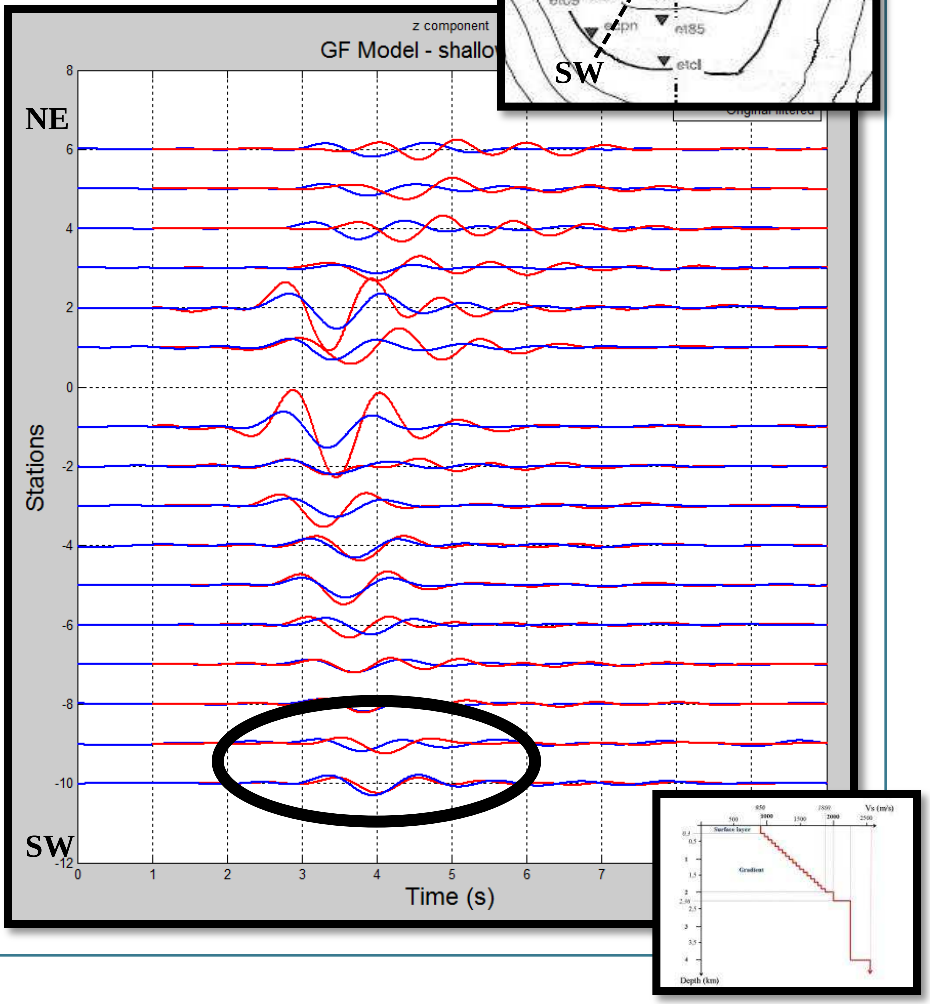
Comparisons

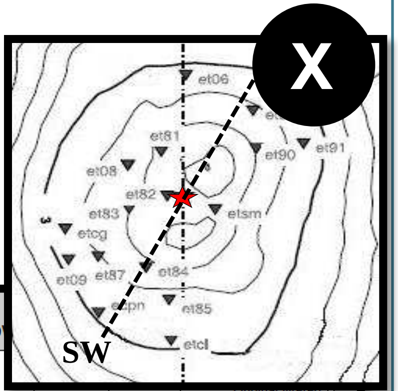
Homogeneous vs Gradient (100 m)

Z-component





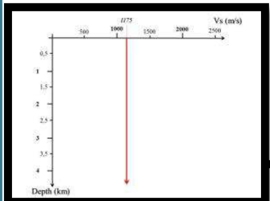


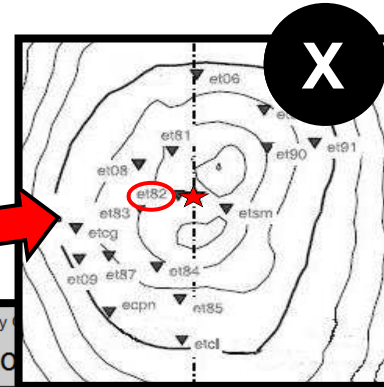


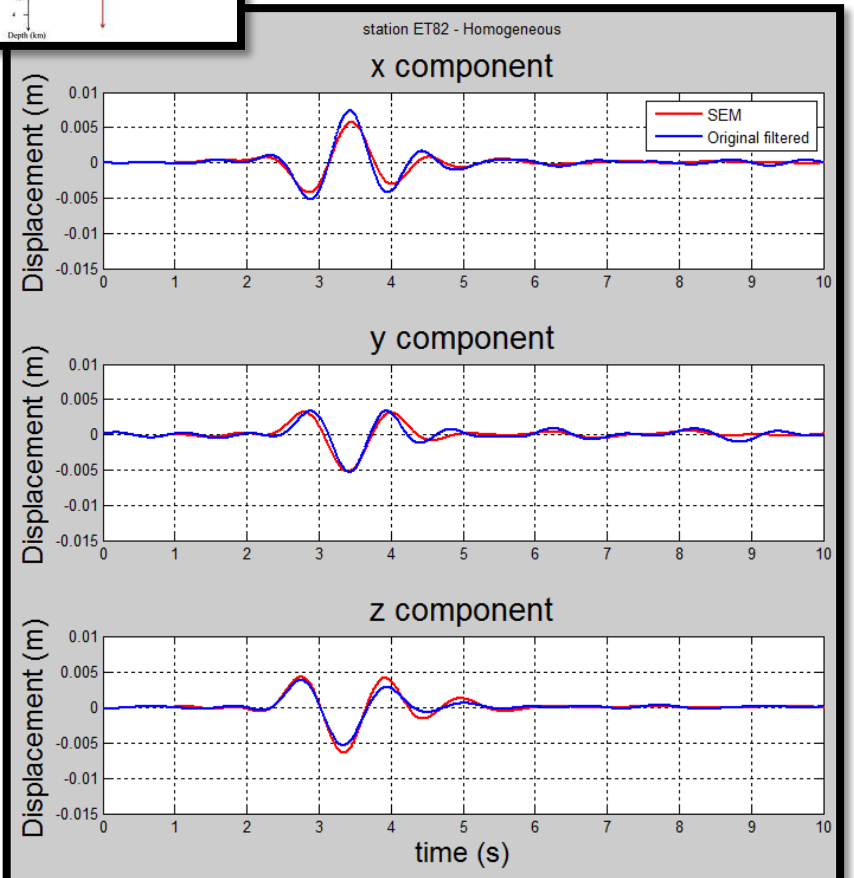
Comparisons

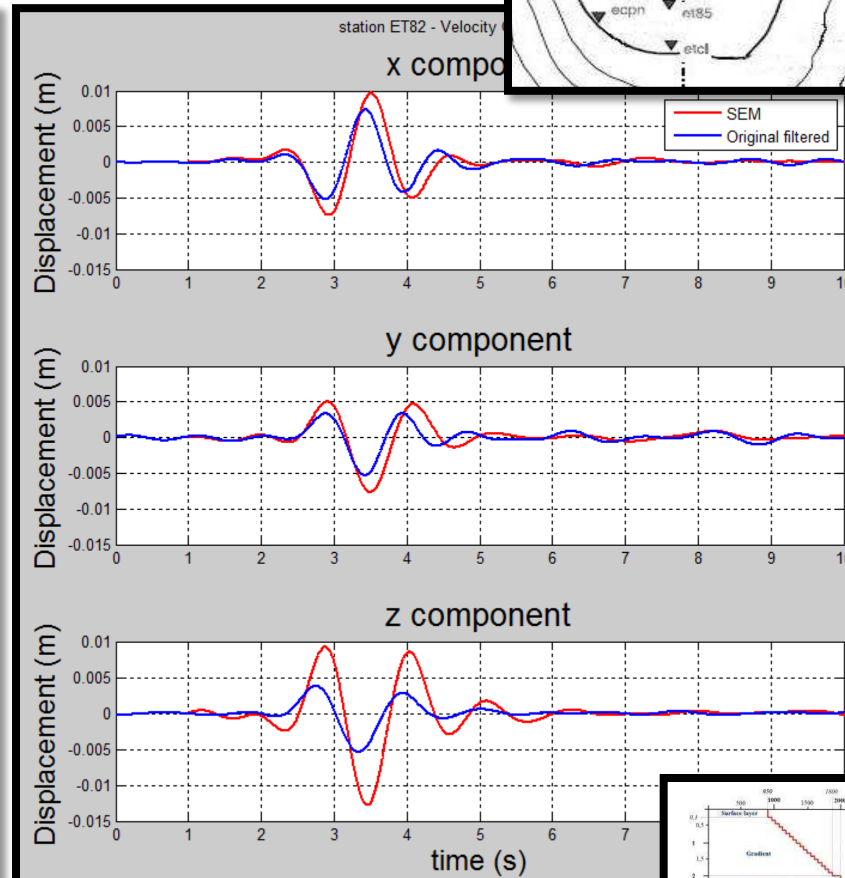
Homogeneous vs *Gradient (100 m)*

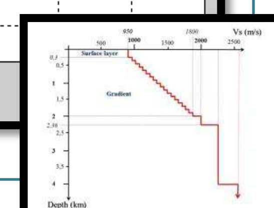
Near station (et82)







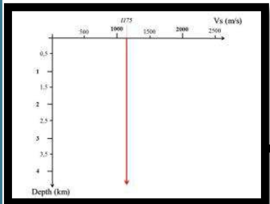


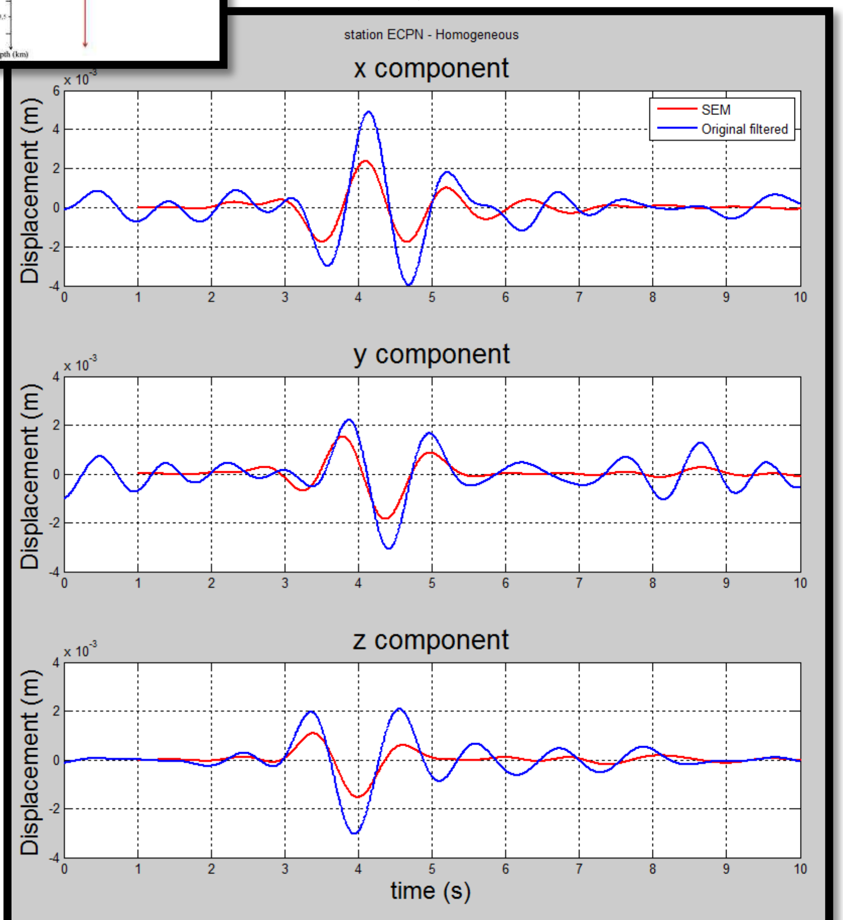


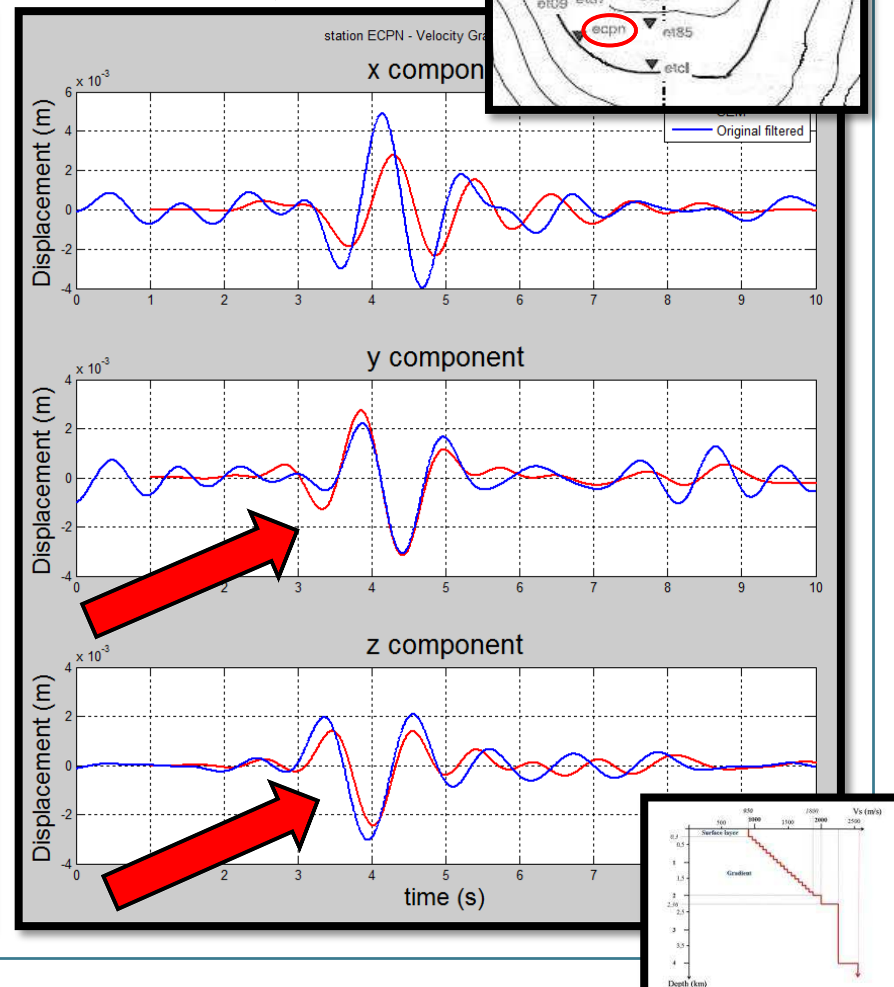
Comparisons

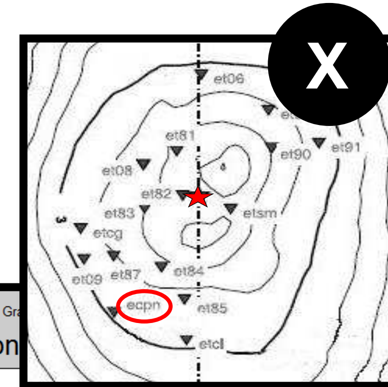
Homogeneous vs Gradient (100 m)

Far station (ecpn)





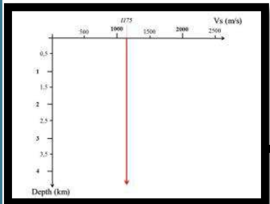


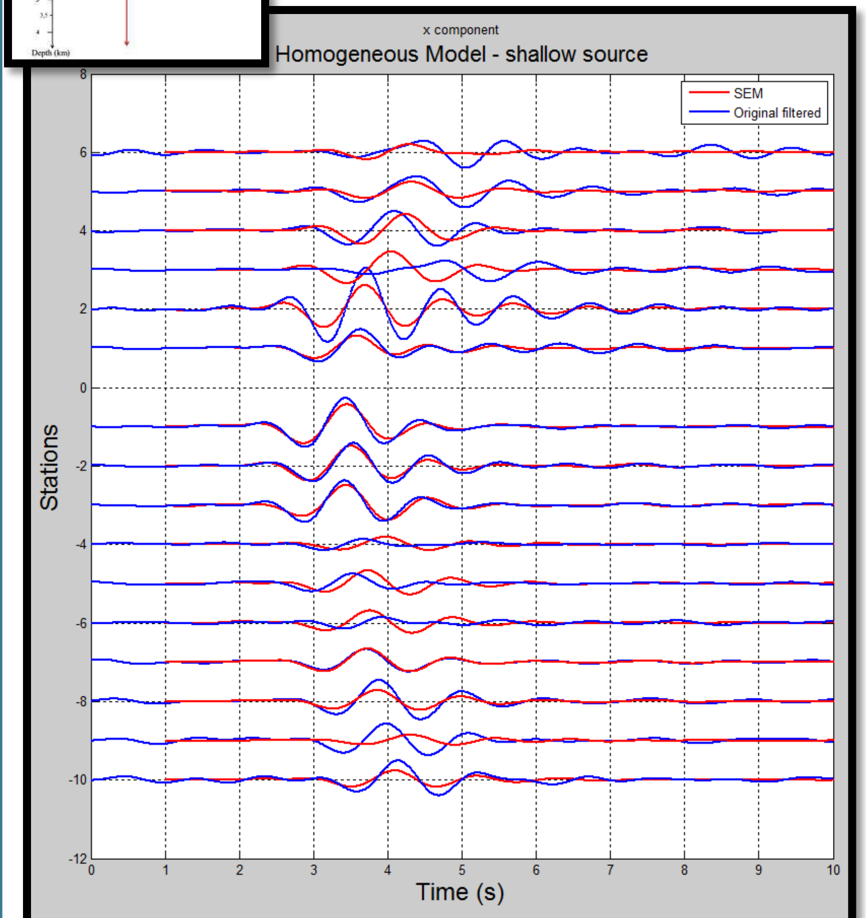


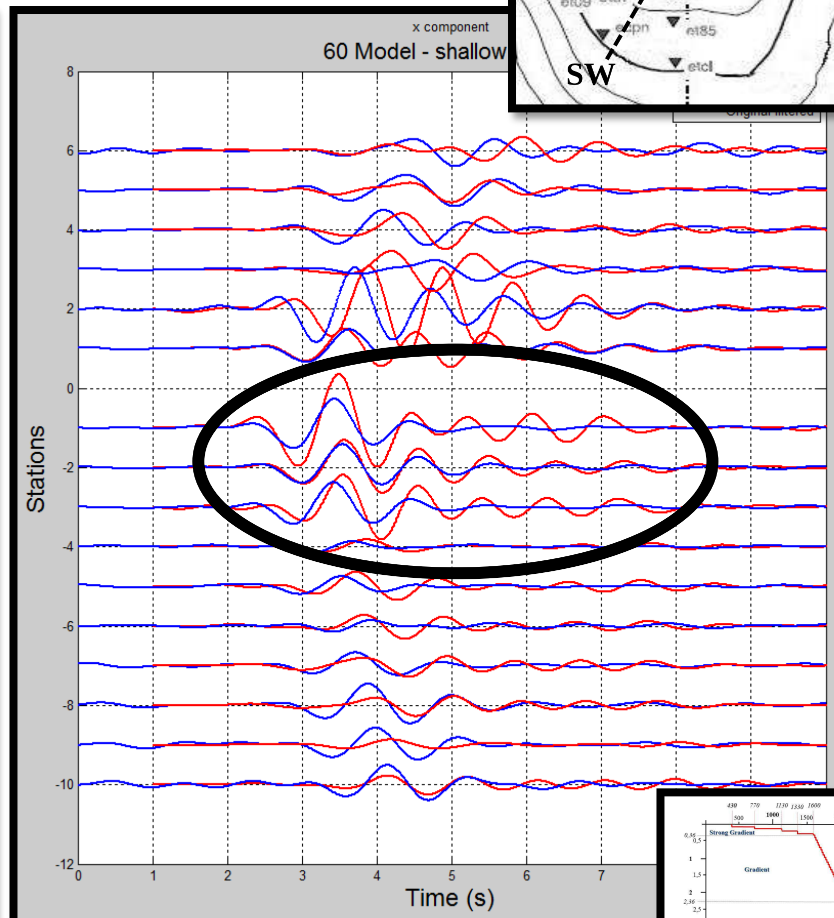
Comparisons

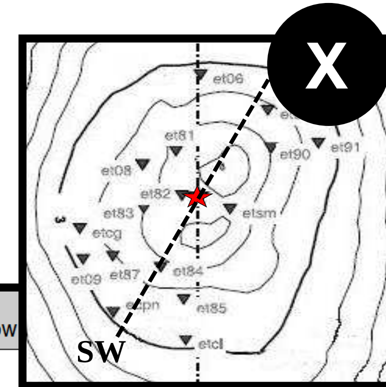
Homogeneous vs *Gradient (60 m)*

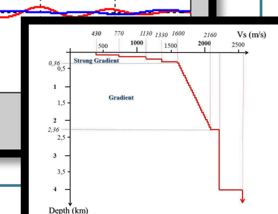
X-component







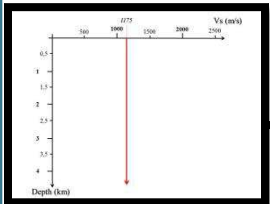


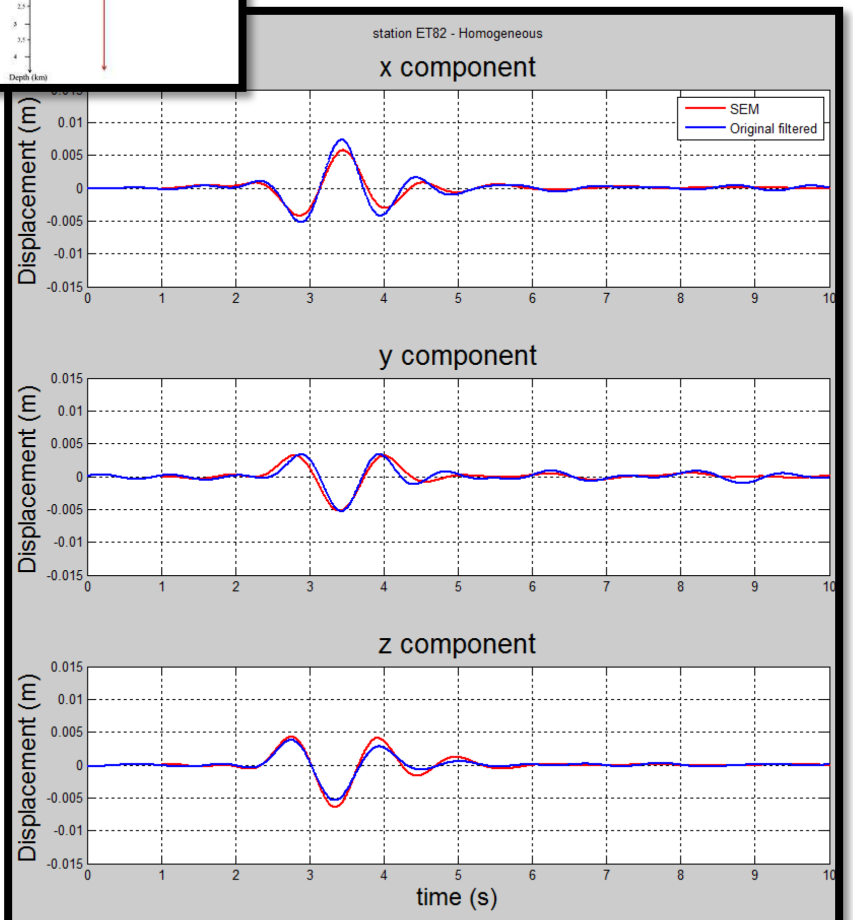


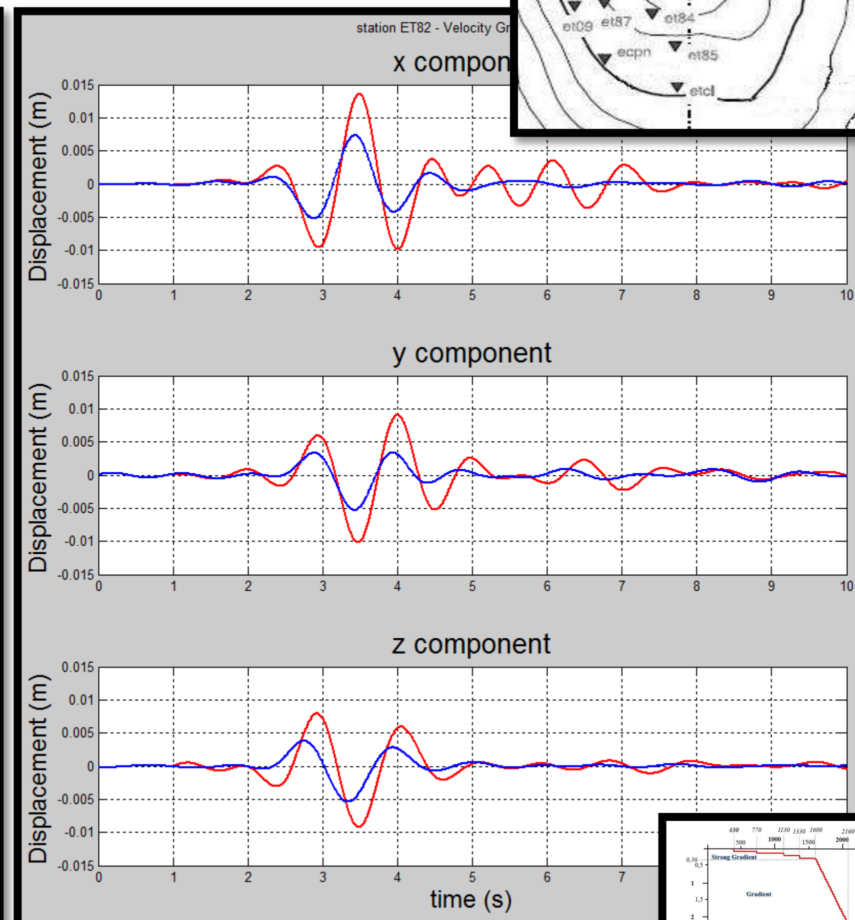
Comparisons

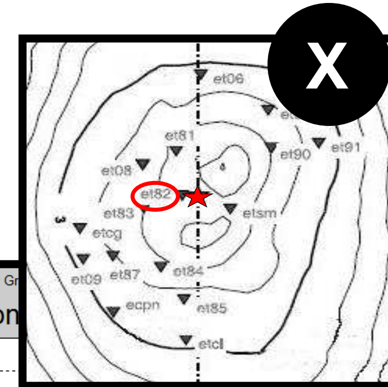
Homogeneous vs Gradient (60 m)

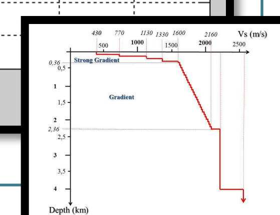
Near station (et82)







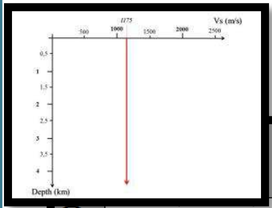


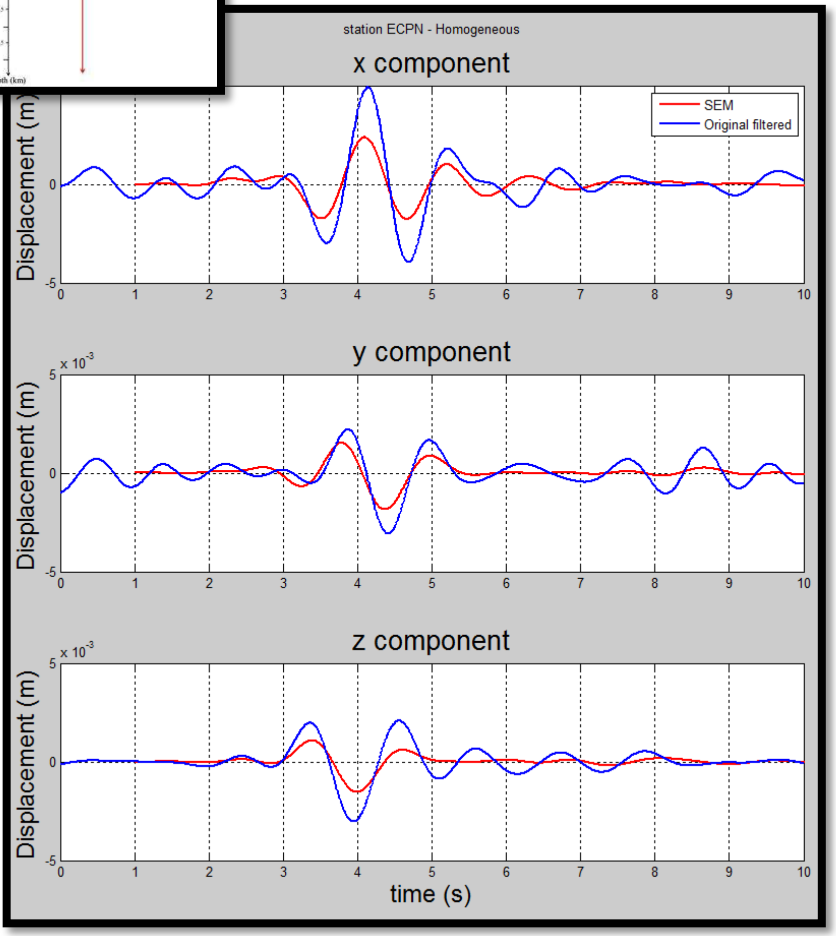


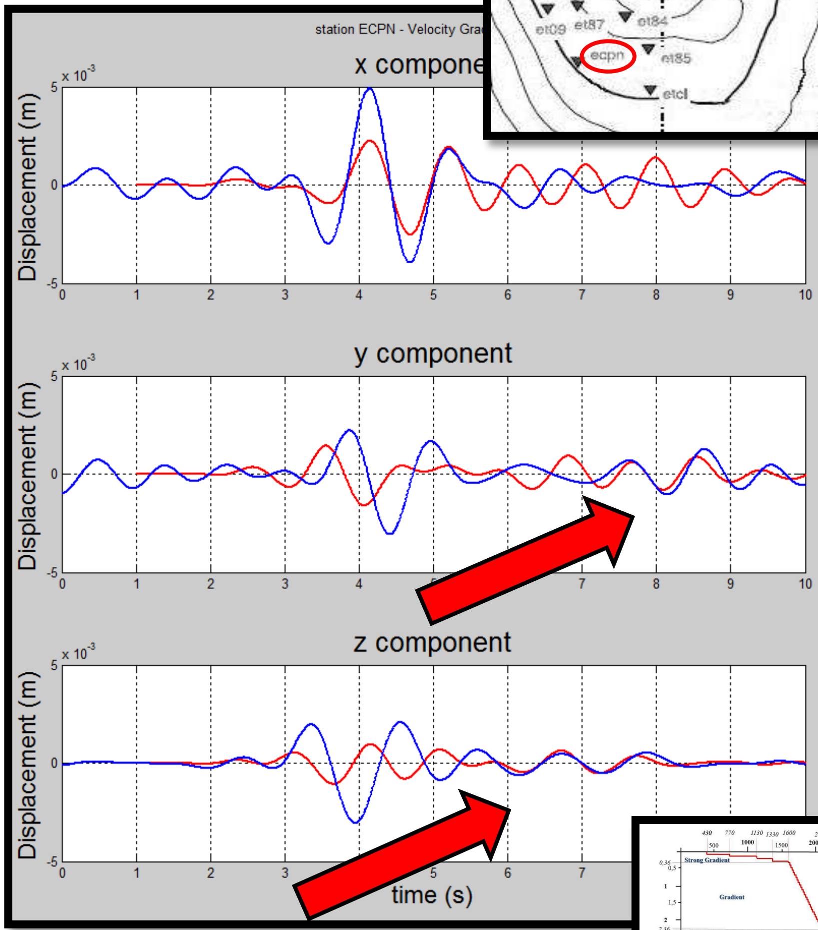
Comparisons

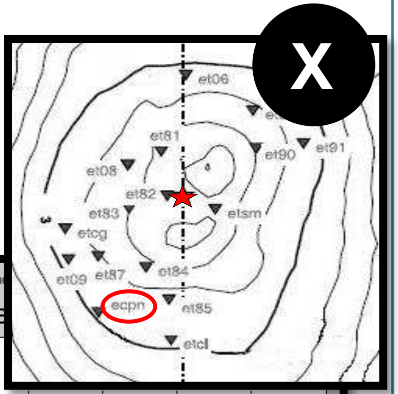
Homogeneous vs Gradient (60 m)

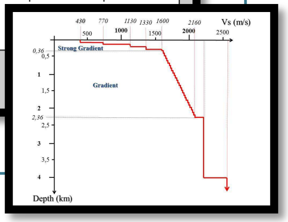
Far station (ecpn)





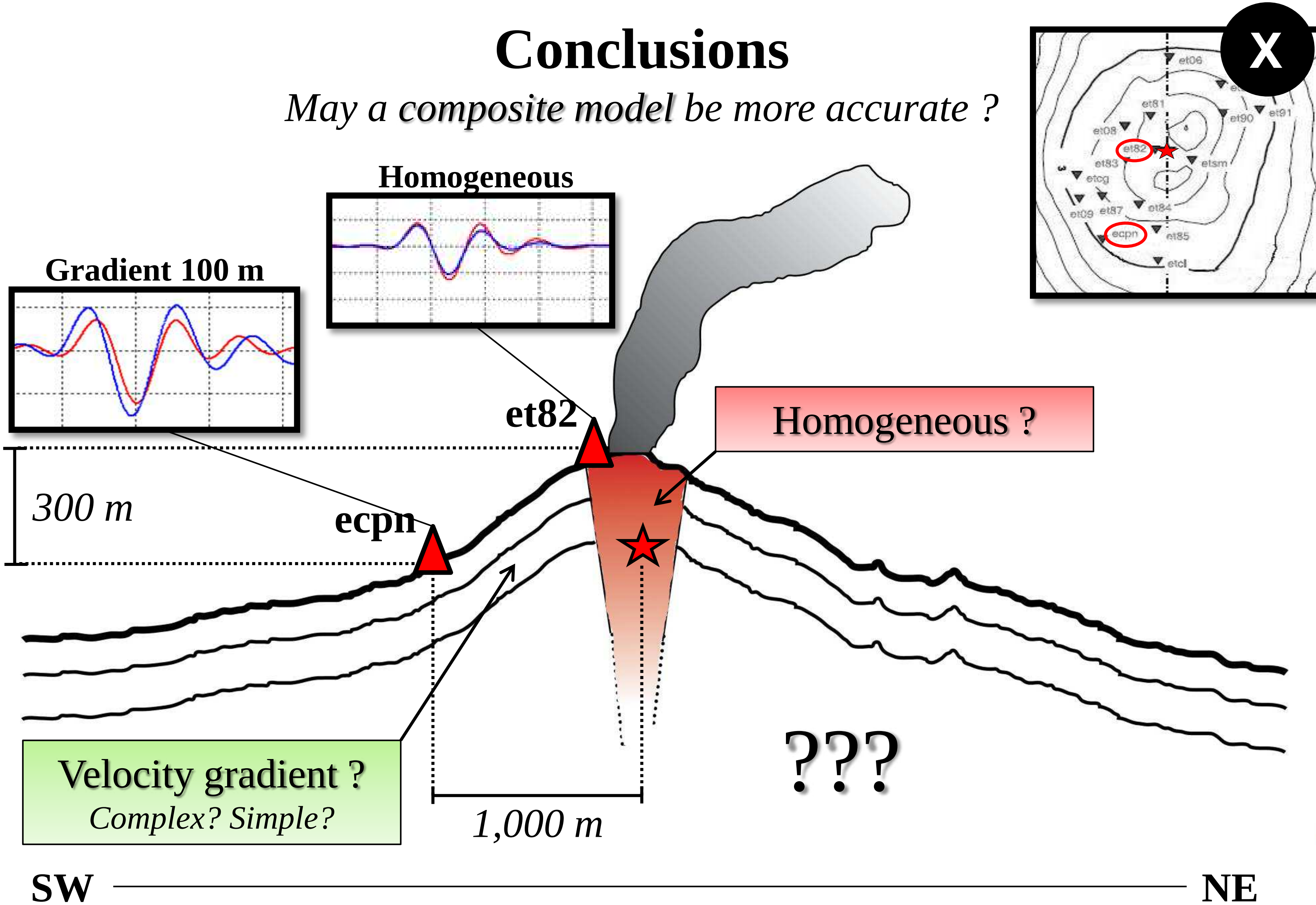






Conclusions

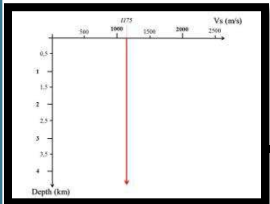
May a composite model be more accurate ?

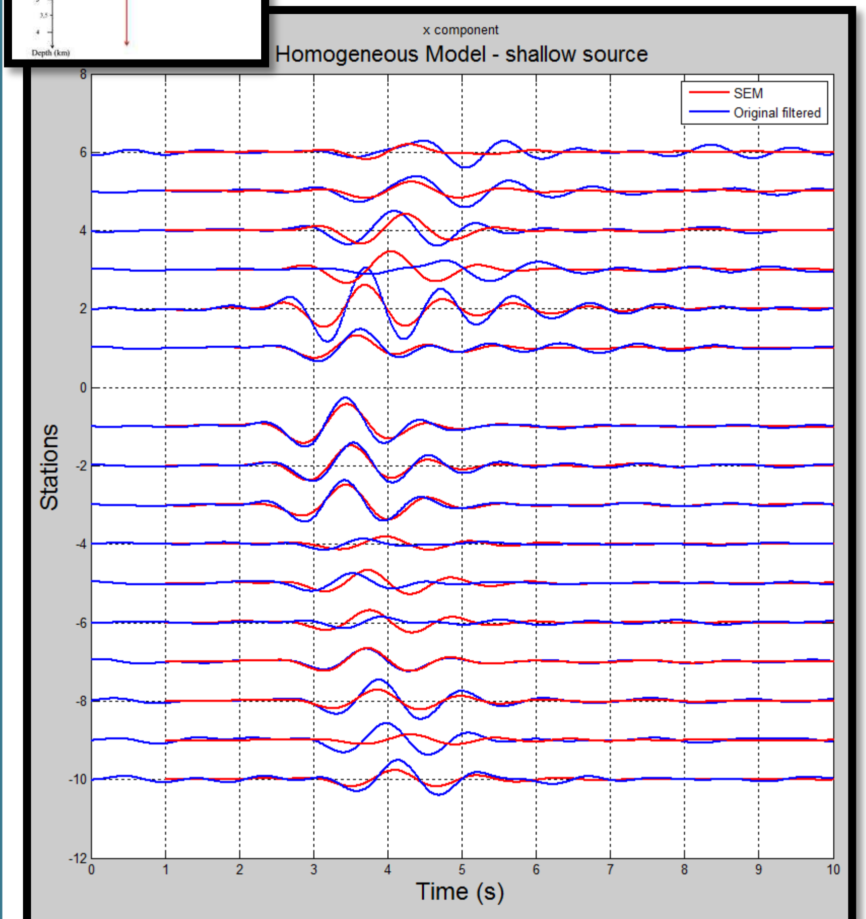


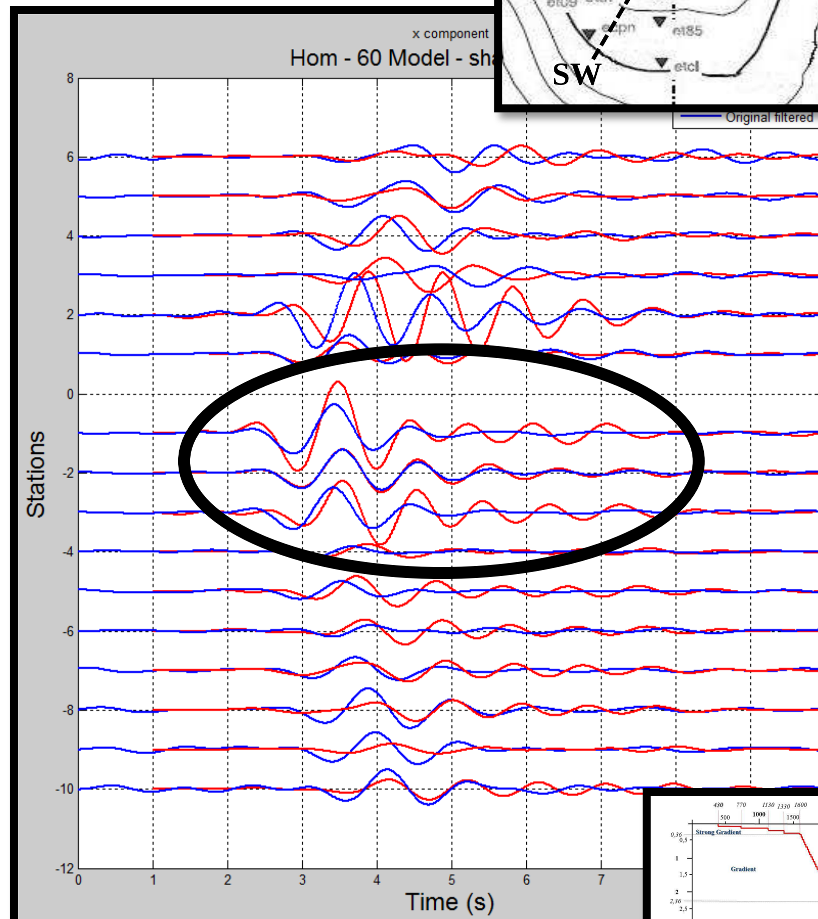
Comparisons

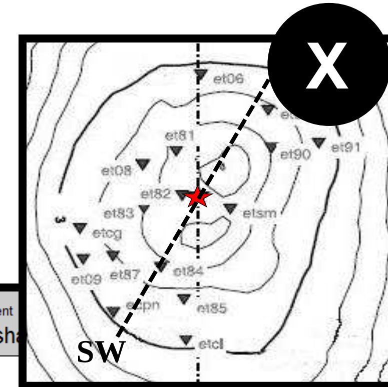
Homogeneous vs *Hom + Gradient (60 m)*

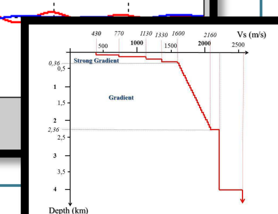
X-component







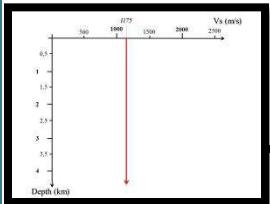


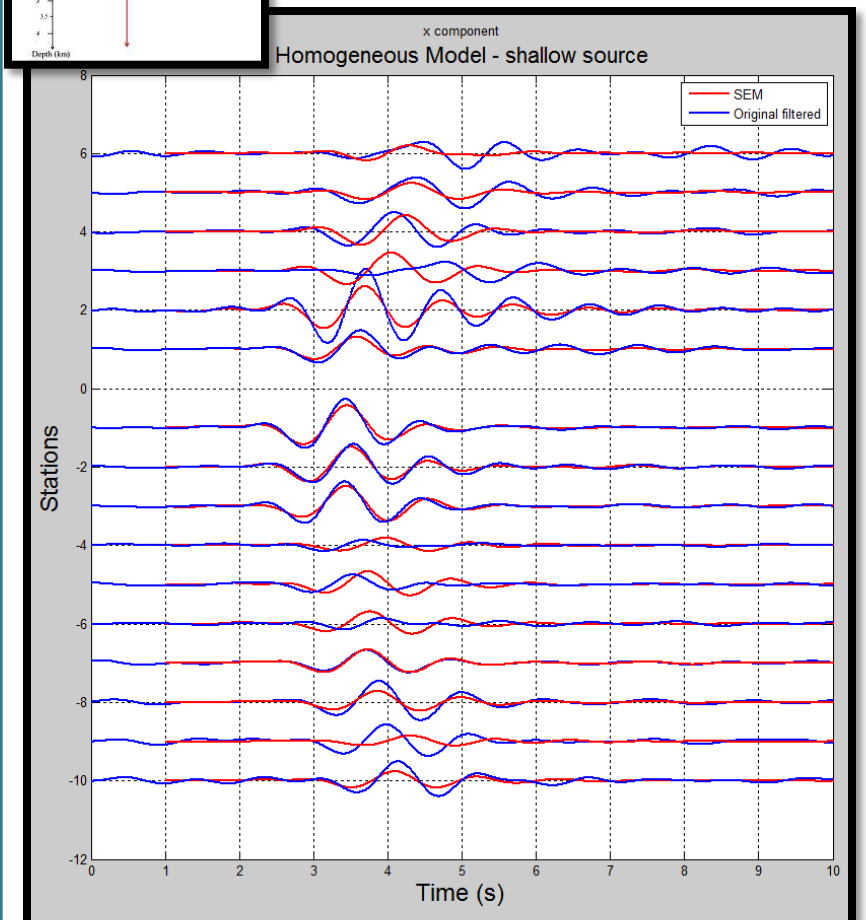


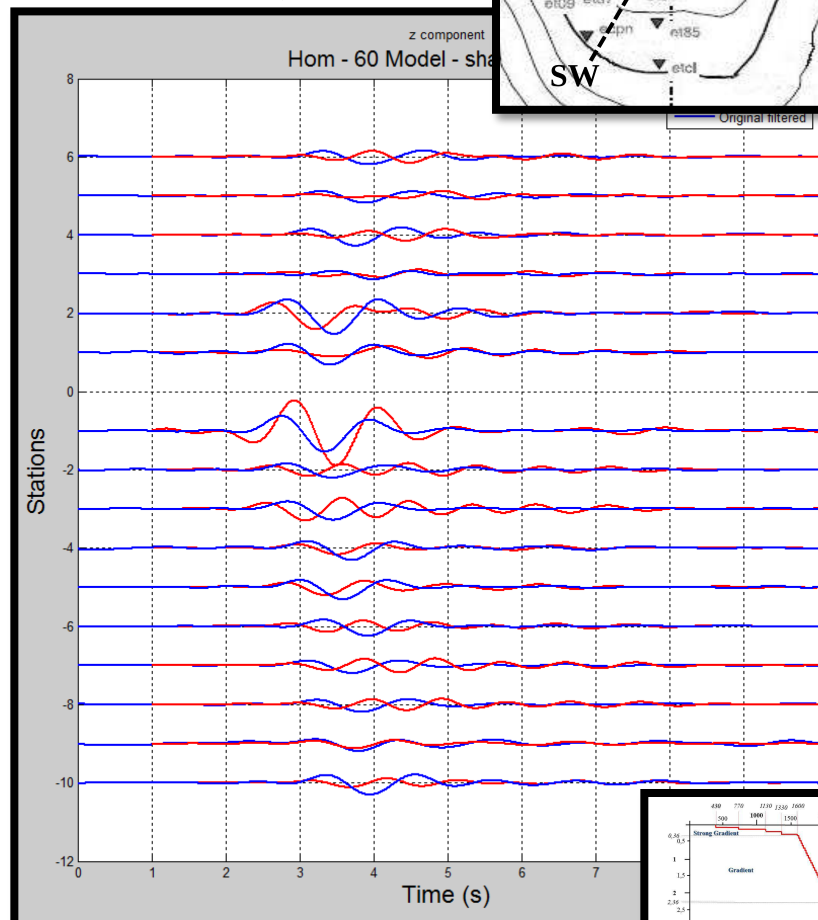
Comparisons

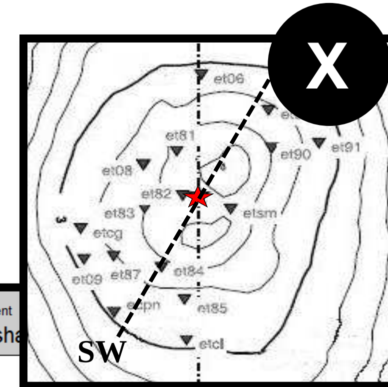
Homogeneous vs *Hom + Gradient (60 m)*

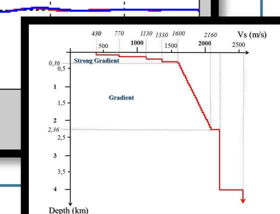
X-component











Perspectives

X

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

Géosciences pour une Terre durable

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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

X

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

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Summary

Homogeneous

Homogeneous – Surface Layer

Homogeneous – 100 m Model

Homogeneous – 60 m Model

Homogeneous – 60 m + central conduit

X

IV. Results

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

V. Conclusions & Perspectives

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