

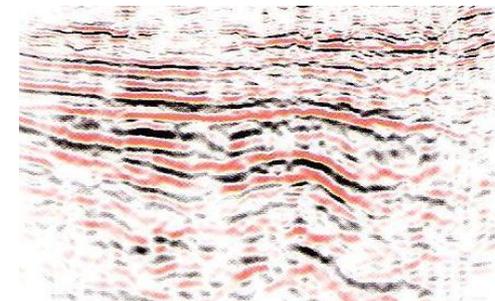
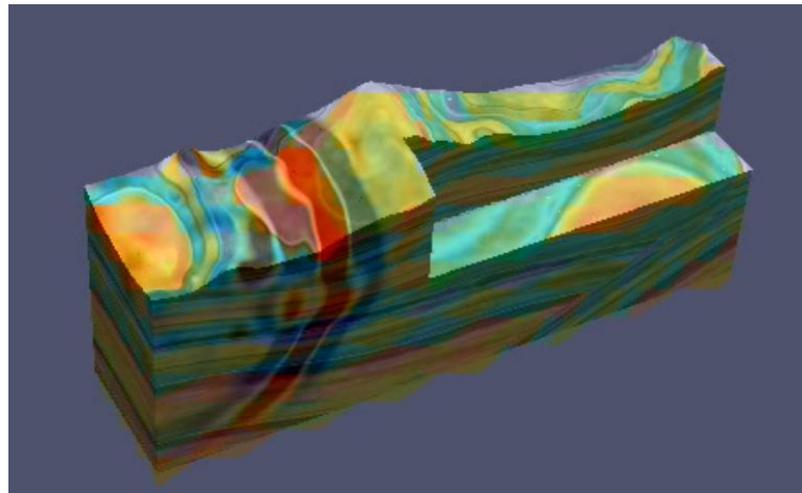
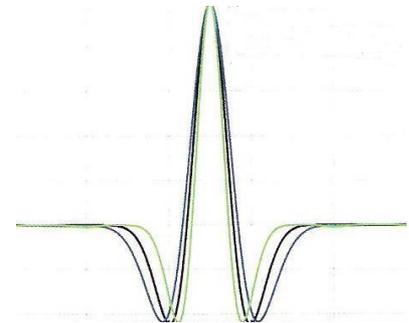
GeoNeurale

# High Resolution Seismic Imaging and the Course of Dimensionality

Computational Seismology Lectures on "Seismic Waves in Heterogeneous Media"

*Jean Virieux*

GeoNeurale – Munich



# High Resolution Seismic Imaging and the Course of Dimensionality

Computational Seismology Lectures on "Seismic Waves in Heterogeneous Media"

*Jean Virieux*

Professor Emeritus at the Univ. Grenoble Alpes  
SEISCANNER

7-8-9 May 2019 (3-days course)

**GeoNeurale**  
Fürstenfeld 12  
82256 Fürstenfeldbruck - München  
Germany

## **3 DAYS INTENSIVE TRAINING**

AUDIENCE: Geophysicists, Geoscientists  
LEVEL: Advanced

### PROPEDEUTICAL:

Online course preparation is offered 3 weeks before course start

Course Fee: 2950 Euro + VAT 19% (Private companies outside Germany can be exempted from VAT TAX . For informations contact:  
Courses@GeoNeurale.com)

ONLINE REGISTRATION: [www.GeoNeurale.com](http://www.GeoNeurale.com)

**Registration deadline: 10 April 2019**

**This is an 3-days advanced course addressed to geoscientists of the oil exploration industry interested in the advanced FWI research field.**

### **COURSE PREPARATION**

Online Propedeutical course preparation is available at request and comprises the following topics:

- AI applications and algorithms for FWI
- Software implementation

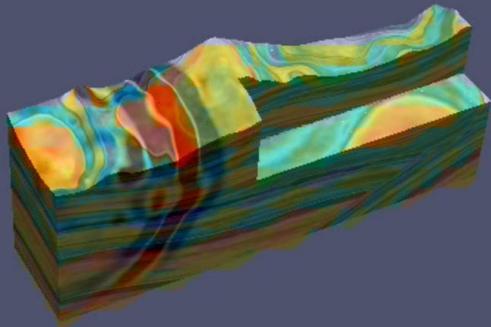
# GeoNeurale

## Forum Fuerstenfeld

### Munich-Fürstenfeldbruck



# COURSE PROGRAM



## High Resolution Seismic Imaging and the Course of Dimensionality

### PROGRAM

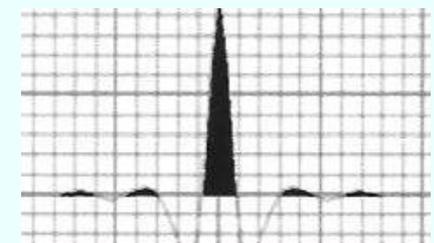
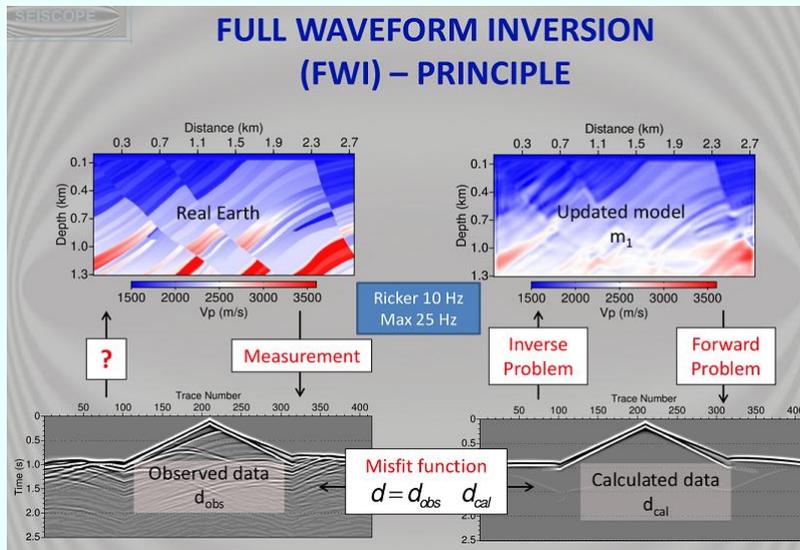
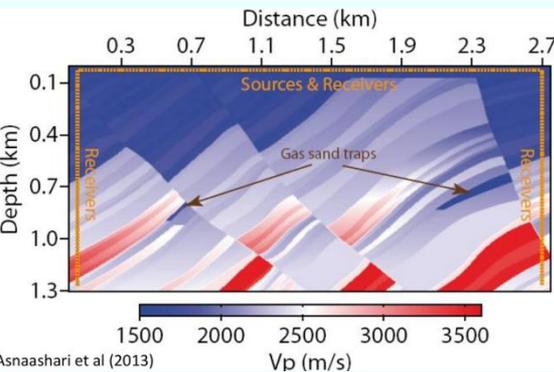
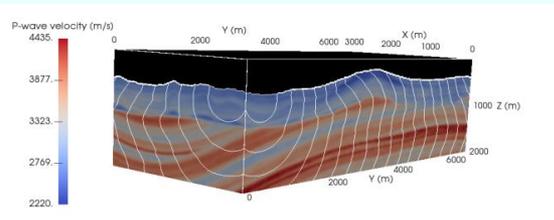
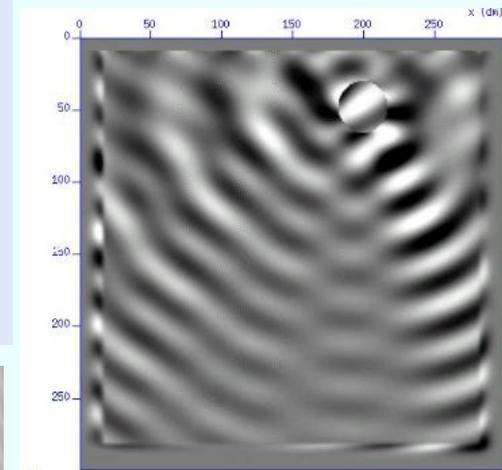
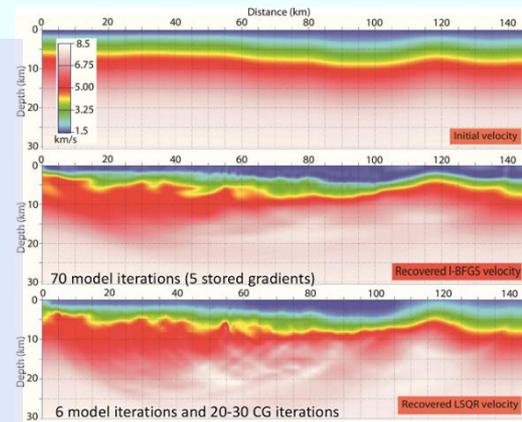
#### Lecture A:

Waves in heterogeneous media (50 mn + break + 50 mn)

A theoretical review of wave propagation in seismology will be performed with strong emphasize on elasticity, anisotropy and attenuation.

Asymptotic wave formulation will be given and finite frequency effects will be appreciated.

Ray tracing (and paraxial approximation) approaches will be investigated as well as Eikonal solvers widely used in tomography.



## Practical training A1

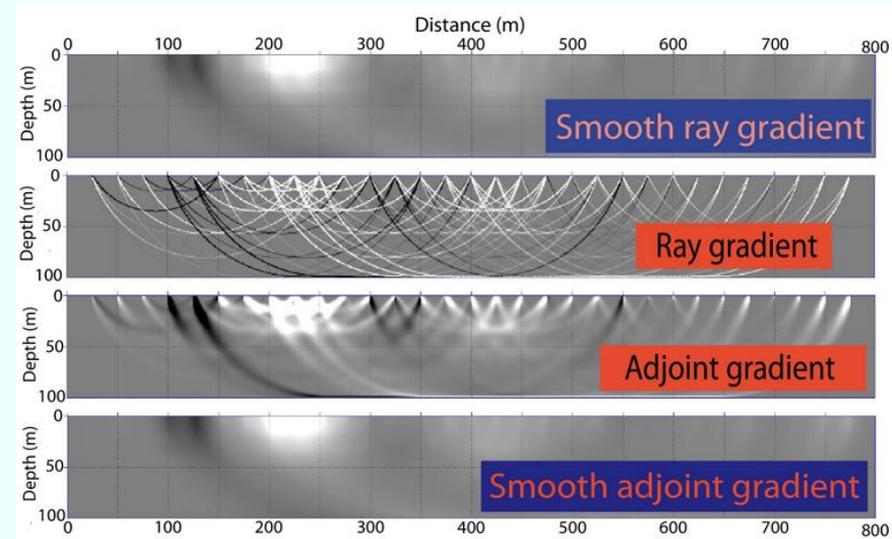
Algorithmic architecture for computing first-arrival travel times (50 mn)  
 Analysis of the fast sweeping method and the local non-linear stencil for solving the Eikonal equation. This will be achieved without computers on blackboards.

BREAK

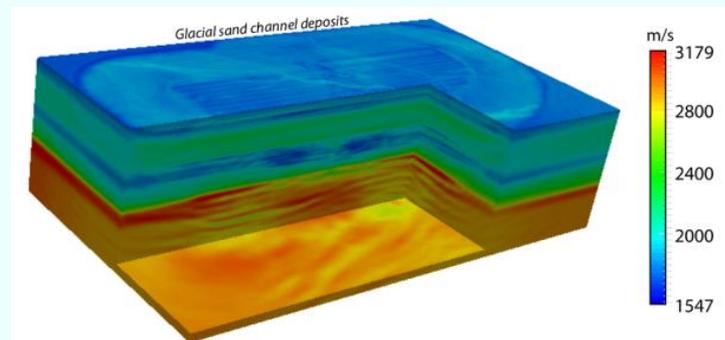
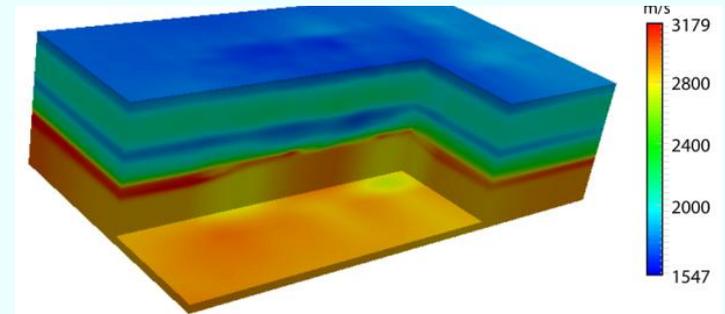
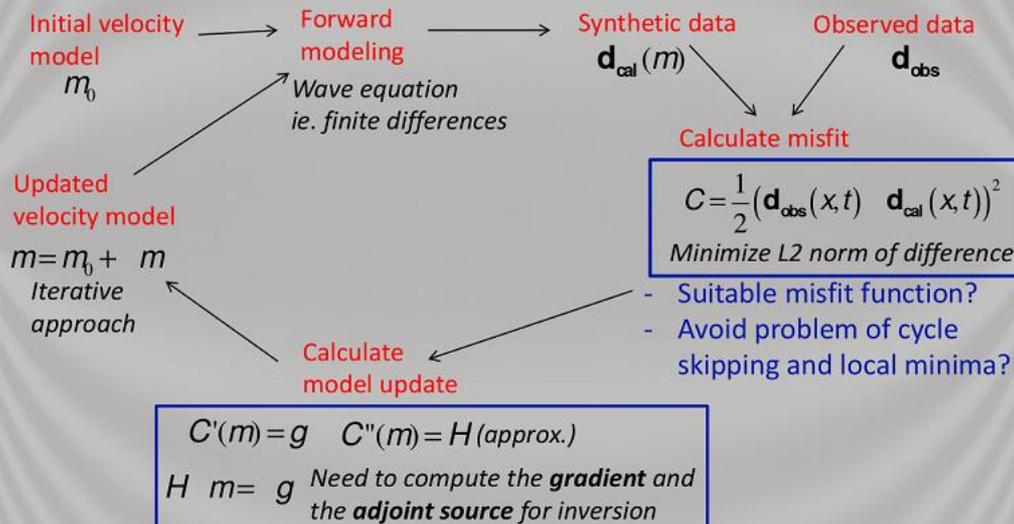
## Practical training A2

Computer code description (50mn) Expected training during an afternoon:

2D Eikonal codes will be presented. Students should perform initial investigation and will be left with additional time for personal attempts.



## FWI – CLASSICAL WORKFLOW



# DAY 2

## Lecture B

**Seismic travel-time tomography (50 mn + break + 50 mn)**  
 We shall introduce the formulation of first-arrival delayed travel-time tomography and we shall see how we should build the inversion problem using a least-squares misfit function of travel-times. The adjoint method will be introduced and differences with Fréchet derivative approach will be highlighted. Extension to slope tomography will be high-lighted. Applications to specific target zones will be provided.

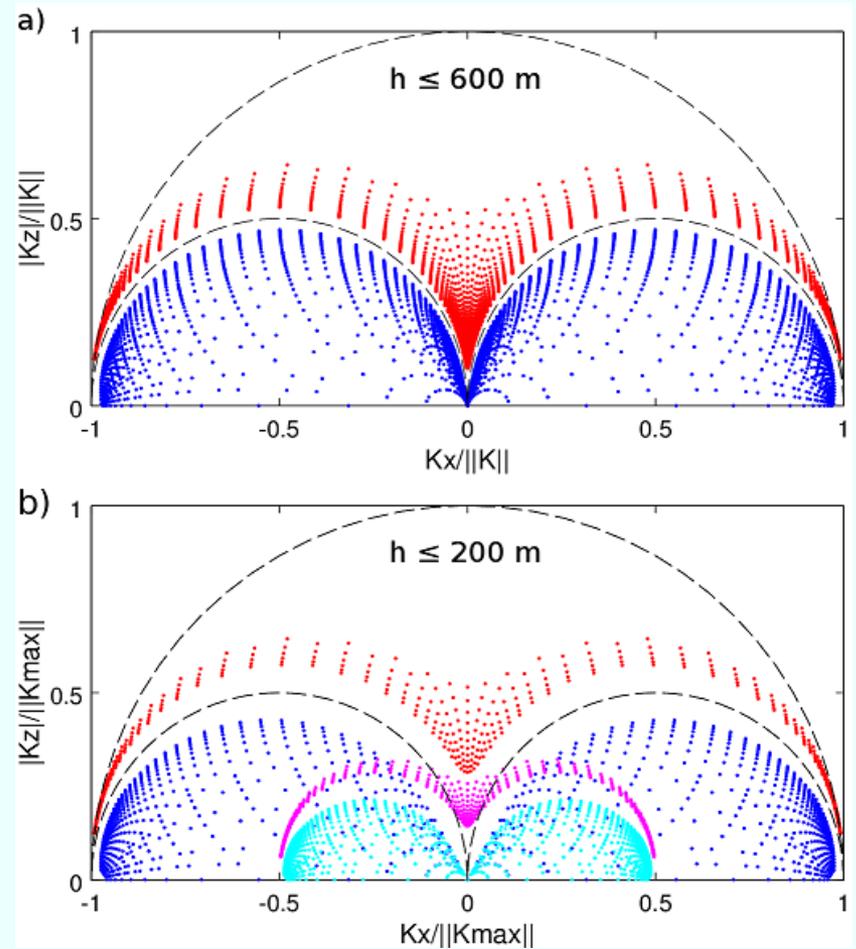
### Practical training B1

**Algorithmic architecture for first-arrival travel-time tomography (50 mn)**  
 The essential steps for doing travel-time tomography will be described on a blackboard with key ingredients regarding the optimization.

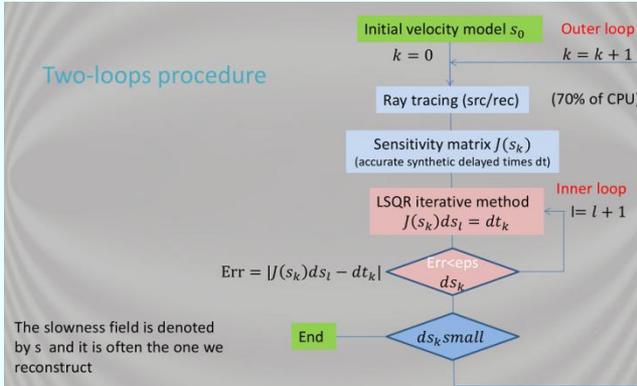
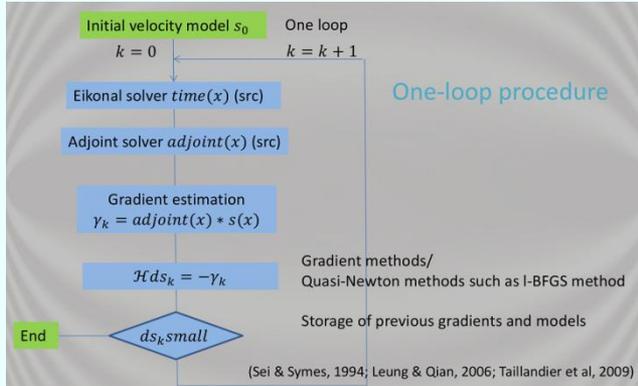
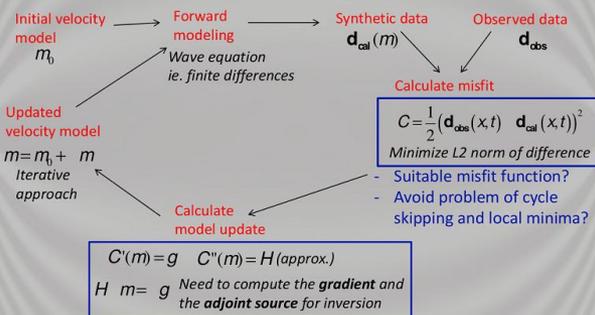
### BREAK

### Practical training B2

**Computer code description (50 mn)**  
 Computer conceptual code of first-arrival travel-time tomography will be put in the hands of students with an example of cross-well tomography. Personal investigation will follow.



### FWI – CLASSICAL WORKFLOW



# DAY 3

## Lecture C:

### Full Waveform Inversion (50 mn + break + 50 mn)

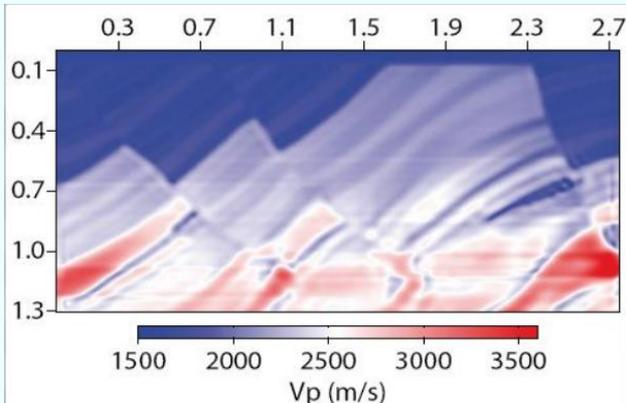
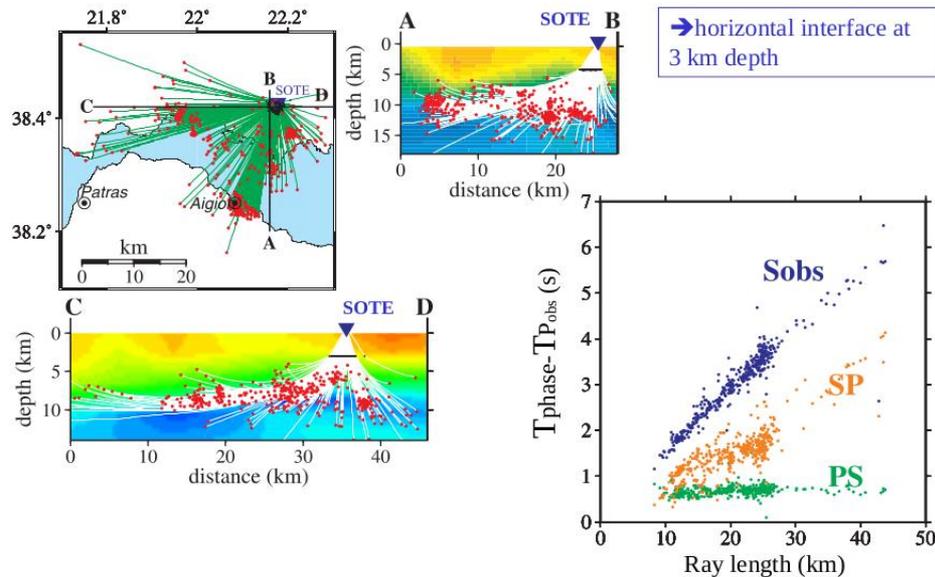
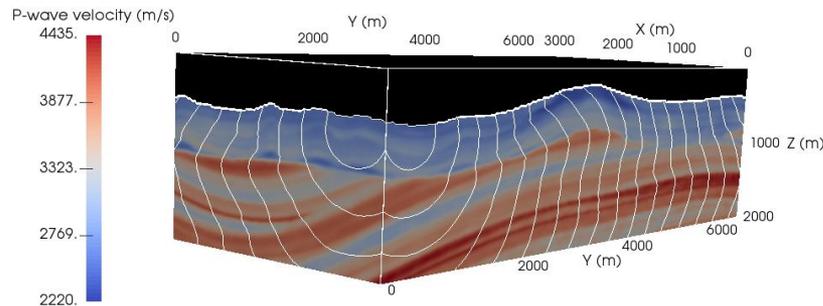
Introduction to high resolution seismic imaging. Understanding the optimization framework, the Lagrangian technique for considering constraints as well as the various numerical implementation will be addressed: this will be described using adjoint method. Complete description of multi-parameter inversion will be provided. Differences and issues when moving from single parameter inversion towards multiple parameter inversion will be stressed.

**Practical training C1 (50 mn):** Algorithmic architecture for wave equation Finite-difference method with time marching and local linear stencil will be described on a blackboard for wave propagation and adjoint propagation. This will be achieved without computers on blackboards.

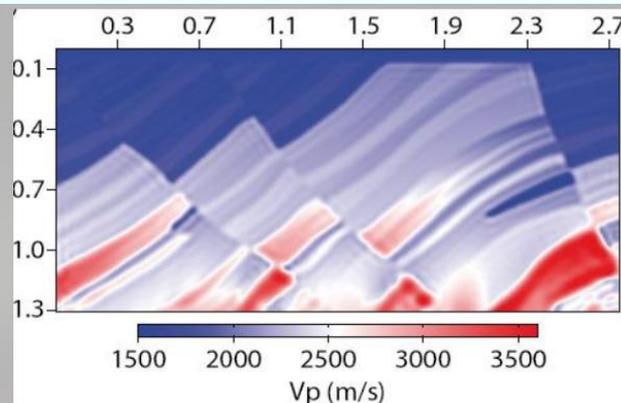
### BREAK

**Practical training C2 (50 mn):**

Computer code description (sensitivity kernel). Applications on simple configurations will help understanding how and when this imaging technique is expected to work. This last computer training will be adapted to the audience depending on the previous computer trainings. At least, the sensitivity kernel will be illustrated and computed in reasonable computer times.



Fixed prior weight

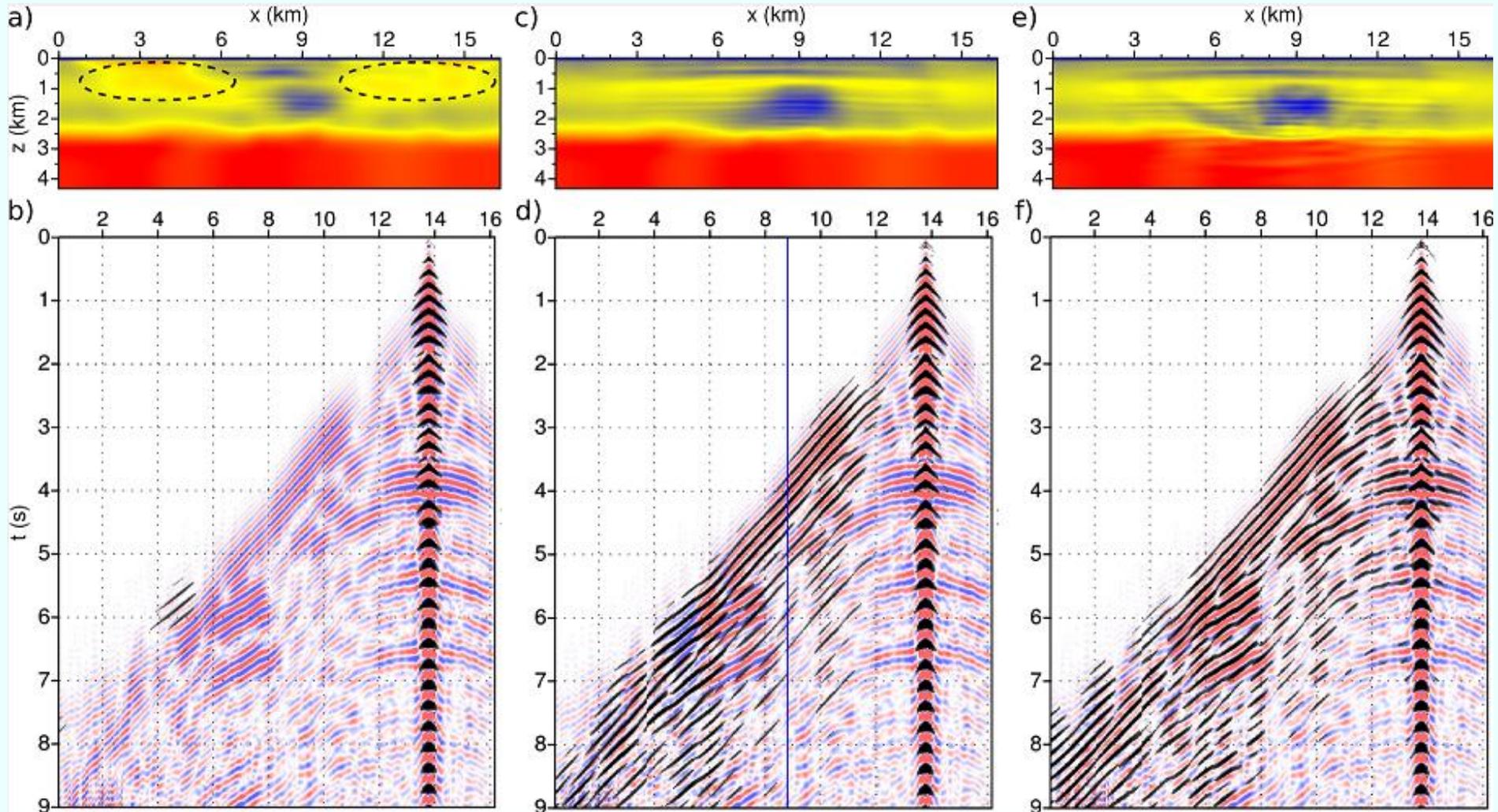


Dynamic prior weight

Figures. Courtesy of:  
A. Asnaashari, R. Brossier, D. Latorre, S. Operto,  
W. Zhou

## Syllabus

These lectures involve an advanced level in mathematics and physics. We shall focus on both mathematical and physical training while emphasizing applications to seismic problems from wave propagation to seismic imaging. These applications will be illustrated through the construction of simple computer programs in FORTRAN 90 for ray tracing and Eikonal, tomography and full waveform inversion (sensitivity kernel). Of course, students can reproduce these constructions in their preferred computer language (C, C++, python, for example).



## ***Biography: Jean Virieux***

Present Position: Emeritus Professor at the Université Grenoble Alpes, Grenoble (France)

### **Education degree Diplomae**

University thesis at the University of Paris 6 on « Seismic rupture source modelling » under the direction of Pr. R. Madariaga, Paris, France, 1979.

State thesis (former PhD thesis) at the University of Paris 7 on « Earthquakes: rupture and waves » under the advice of Pr. R. Madariaga, Paris, France, 1986.

### **Teaching and Research Activity**

1981-1983: Teaching Assistant at the University of Paris 6, France

1983-1990: Assistant-professor at the University of Paris 7, France.

1991- 2007: Full professor at the University of Nice-Sophia Antipolis, Nice, France.

2007-2016: Full professor at the University Joseph Fourier, Grenoble, France.

Since 2017: Emeritus professor at the University Grenoble Alpes, Grenoble, France

### **Affiliations, Committees and Scientific Consulting**

Former member of the National Committee of Centre National de la Recherche scientifique (1996-2005)

Former president of the National funding program on Natural Risks (1996-2000)

Former French representative for the ICG/NEAMTWS of IOC of UNESCO for Tsunami Early warning (2005-2007).

\* Former Vice-Président Earth Sciences for research committee (open junior and senior programs) of the ANR (Agence National de la Recherche)

Former member of comité sectoriel Environnement, climat et systèmes urbains de l'ANR.

Member of various scientific committees (department Terre Atmosphere Ocean –TAO- of the ENS Ulm, of the Institut OGS at Trieste in Italy, of the society EAGE).

Reviewer of many international journals (Journal of Geophysical Research, Geophysical Research Letters, Geophysical Journal International, Geophysics, Geophysical Prospecting, Bull. Seismol. Society of America, Geology etc).

Co-animator of the consortium SEISCOPE (2006-2008/2009-2011) (<http://seiscope.oca.eu>) with Stéphane Operto supported by various enterprises.

Associate editor of Geophys. J. Int. since January 2006.

Lecturer at different 'summer school' in Erice (Italy), ICTP Trieste (Italy).

Member of the American Geophysical Union, Member of the Seismological Society of America, Member of the European Association of Geoscientists and Engineers, Member of the European Geosciences Union, Member of the Society of Exploration Geophysics

Co-animator of the consortium SEISCOPE (2013-2015) (<http://seiscope2.osug.fr>) with Stéphane Operto supported by various enterprises.

### **Award**

Erasmus Award 2013, EAGE

Award Barrabé 2012, Société Géologique de France

Adion Medal 2012, Observatoire de la Côte d'Azur

AGU Fellow 2012.

Grand Award Jaffé, Académie des Sciences, Institut de France, 2009

Bright Spots for « Seismic imaging of complex onshore structures by two-dimensional elastic frequency-domain full-waveform inversion » by R. Brossier, S. Operto and J. Virieux, Geophysics, 74(6), 2009.

Best paper in 2008 for the journal Geophysics. « Velocity model building by 3D frequency-domain full-waveform inversion of wide-aperture seismic data » par H. Ben Hadj Ali, S. Operto and J. Virieux. Geophysics, 73(5), 2008.

Medal CAGNIARD of the EAGE with Stéphane Operto and Jean-Xavier Dessa in 2006.

Former Junior Member of the Institut Universitaire de France (1992-1997).

Former Senior Member of the Institut Universitaire de France (2011-2015).

Grand Award Jaffé, Académie des Sciences, Institut de France, 2009

Bright Spots for « Seismic imaging of complex onshore structures by two-dimensional elastic frequency-domain full-waveform inversion » by R. Brossier, S. Operto and J. Virieux, *Geophysics*, 74(6), 2009.

Best paper in 2008 for the journal *Geophysics*. « Velocity model building by 3D frequency-domain full-waveform inversion of wide-aperture seismic data » par H. Ben Hadj Ali, S. Operto and J. Virieux. *Geophysics*, 73(5), 2008.

Medal CAGNIARD of the EAGE with Stéphane Operto and Jean-Xavier Dessa in 2006.

Former Junior Member of the Institut Universitaire de France (1992-1997).

Former Senior Member of the Institut Universitaire de France (2011-2015).

### **Seismic Expeditions**

SERAPIS project: deployment of a seismic network on land and below the sea in the Bay of Pozzuoli in September 2001 (PI Pr. A. Zollo on the Italian side and PI Pr. J. Virieux on the French side with a specific support of vessel Nadir/IFREMER) which has shown our capabilities for field experiments with dense seismic networks.

3F-CORINTH European project under the principal investigator PI Isabelle Moretti with a deployment of a seismic network of 70 stations (Lithoscope) in the Patras zone in the Gulf of Corinth. The experiment has last from February 2002 to July 2002 in collaboration with Pr. A. Tselentis of the University of Patras in Greece with the most up-to-date seismic tomography of this active area.

### **Recent fundings**

Project Quantitative Seismic Hazard Assessment in the specific call « Catastrophes telluriques et tsunamis » of the « Agence Nationale pour la Recherche » (ANR) (2006-2008): deterministic integrated approach for quantification of the ground motion (€ 450 000).

Consortium SEISCOPE (2006-2008/2009-2011): Seismic imaging for global offset and broadband data (€ 600 000 + € 600 000).

Participation to the project HPP2/CO2 (2008-2011): recovering of porosity parameters of a medium under pressure excitation (€ 140 000) (animator Y. Guglielmi)

Participation to the project CENTURISK (2009-2011): A novel method to identify the faults (animator I. Manighetti).

Participation to the ITN QUEST (2010-2013) led by Heiner Igel.

Project Subduction, standard and slow seismology (S4) (2012-2014) funded by ANR

Consortium SEISCOPE (2013-2015): Seismic imaging for multi-parametric reconstruction (€ 1 950 000).

Consortium SEISCOPE (2016-2018): Seismic imaging for multi-parametric reconstruction (€ 1 350 000) (animators Romain Brossier & Ludovic Métivier).

### **Outreach activities**

European program SSA Na.R.As (Natural Risk Assessment) (PI. Pr. P. Gasparini, 2005-2007): I have been in charge of the workpackage related to the awareness of natural risks. This activity is related to the local initiative « Sismo des Ecoles » while I have initiated at the IUF as a junior member, initiative now at the national level as the project « Sismos à l'Ecole » with more than 40 broadband seismic stations of the national program « Sciences à l'Ecole » (<http://www.edusismo.org>).

Participation to the scientific committee of the project "Sismo à l'école" inside the proposal "Sciences à l'école" of the Ministry of Education led by J.-Y Daniel.

Undergraduate teaching book in French "Physique de la Terre Solide" with Christophe Larroque, Collection Géosciences, Gordon and Breach, 2001, promoted during my position as junior member of Institut Universitaire de France.

# REGISTRATION FORM

Please fill this form and Fax to +49 89 8969 1117 or Email to Courses@GeoNeurale.com

**High Resolution Seismic Imaging and the Course of Dimensionality**  
**Computational Seismology Lectures on "Seismic Waves in Heterogeneous Media"**

Munich , 7-8-9 May 2019  
**(3-days course)**

Course Fee: 2950 Euro + VAT 19% (Private companies outside Germany can be exented from VAT TAX . For informations contact:  
Courses@GeoNeurale.com)

Name:

Company:

Address:

Job Title:

Phone:

Fax:

Email:

SIGNATURE: \_\_\_\_\_

# Registration Details

- Course fee: 2950 Euro + VAT (19%) (No VAT applicable for specific countries, please contact us for further informations )
- Registration deadline : 10 April 2019

## Payment and Registration

Tuition fees are due and payable in Euro upon enrollment in the course by bank transfer to the bank account given below unless another payment form is agreed

Unless otherwise indicated, the payment should be received before the date specified in the invoice as payment term to make the enrollment effective.

To register to the course please fill in the [registration form](#) and fax or email it along with the confirmation of your bank transfer to:

## GeoNeurale

Administration

Am Nymphenbad 8

81245 Munich

T +49 89 8969 1118

F +49 89 8969 1117

ONLINE REGISTRATION: [www.GeoNeurale.com](http://www.GeoNeurale.com)

Please indicate your name and the purpose:

**“High Resolution Seismic Imaging and the Course of Dimensionality“** course fees .

## Provisions

Tuition fees are due and payable in Euro upon enrollment in the course. Unless otherwise indicated, fees do not include student travel costs and living expenses.

Payments are also accepted via personal or company check, traveler's check, credit card, and Company Purchase Orders.

### Cancellations by Participant:

All cancellations are subject to a 100 Euro non-refundable cancellation fee.

Cancellations have to be notified to our office, at least 30 days prior to the course start date to receive a refund (less the 100 Euro cancellation fee).

If the participants are unable to cancel prior to the 31 days notification date, they may substitute another person at their place in a course by notifying us prior to the course start date.

### Course Cancellations:

GeoNeurale reserves the right to cancel the courses if necessary. The decision to cancel a course is made at least two weeks prior to the course start date. If a course is cancelled, the participant will receive a full reimbursement of the tuition fees ( but not of the plane ticket or hotel expenses or any other costs), or will be enrolled in another course upon his decision ( the cost of the original course will be applied to the cost of the replacement course ).

GeoNeurale can not be responsible for any penalties incurred for cancellation or change of airline or hotel reservations .

Refunds: GeoNeurale will promptly remit all refunds of tuition fees due to cancellations or annulment (less any appropriate non-refundable cancellation fee) within 30 days of the course cancellation.

Force Majeure: GeoNeurale can not be responsible for cancellations due to "force majeure" events : strikes, emergency situations, natural catastrophes and all situations and incidents independent or outside the human control that can delay or cancel the course. In case of such events related cancellations the course tuition fees will be refunded to the client .

GeoNeurale is not responsible for any delay or absence caused by the training instructor or training instructor company for reasons which are independent or out of the control of GeoNeurale's decisions.

Upon registration the course participant assumes full responsibility to keep all course material confidential and not to transfer it to any third party.

AGREEMENT: Upon enrollment all parts accept the above mentioned provisions. The above specified provisions shall regulate the agreement between GeoNeurale and the participant and the participant company and will enter into force upon enrollment.

# Training location

**Conference Center - Forum Fürstenfeld  
Room S1 , S5**

**Fürstenfeld 12  
82256 Fürstenfeldbruck - München  
Germany**

