

# A practical Short Course on Inversion of geodetic data using the toolbox DefVolc

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6. *INSA, Lyon*
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EUROVOLC



# Requirements

1) To complete the workshop, you require the following:

- a linux laptop
- a recent version of the mesher gmsh  
<http://gmsh.info/>
- matlab Runtime v9.5, compatible with matlab2018b  
<https://fr.mathworks.com/products/compiler/matlab-runtime.html>
- The provided uncompressed archive with executable, and examples

1) To run your computation on UCA Clusters and get updates about new versions, please register on defvolc web site <http://www.opgc.fr/defvolc/>. Ask me ([valerie.cayol@uca.fr](mailto:valerie.cayol@uca.fr)) for a project code

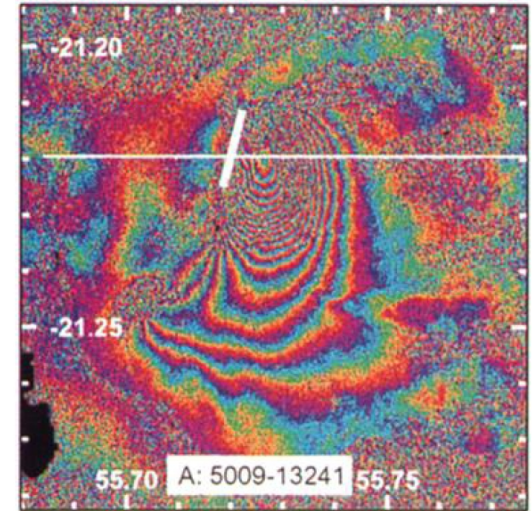
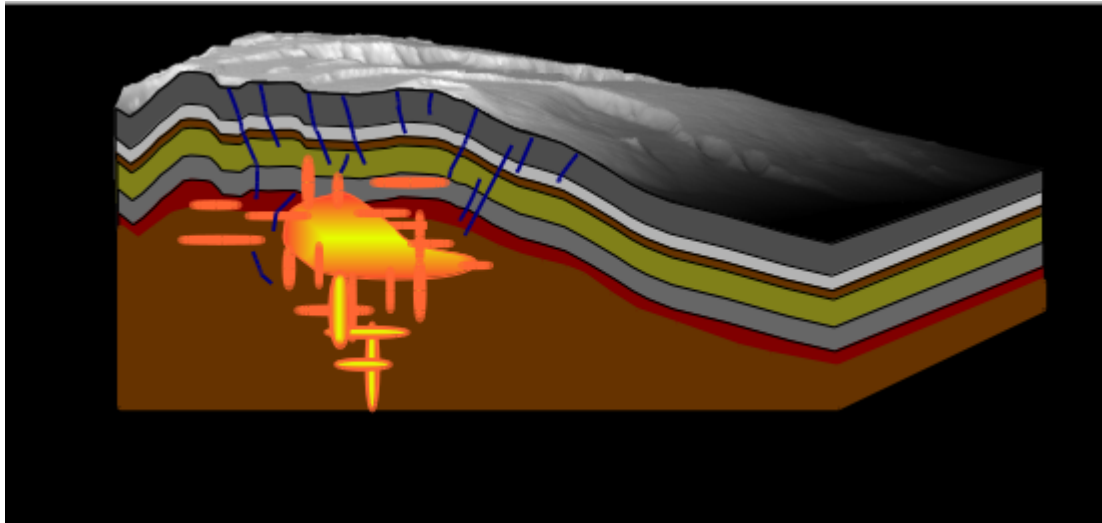
# Objective

The purpose is to provide you with enough information so that you can confidently apply DefVolc to your particular inversion problem

- Inform you on the theory DeVolc is based on;
- Guide you through the use of DefVolc for you inversions of deformation data of volcanoes and faults
- Explain to you the functionalities
- Teach you about the files generated

# Beyond too simple models

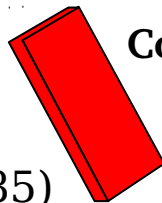
**Reality**



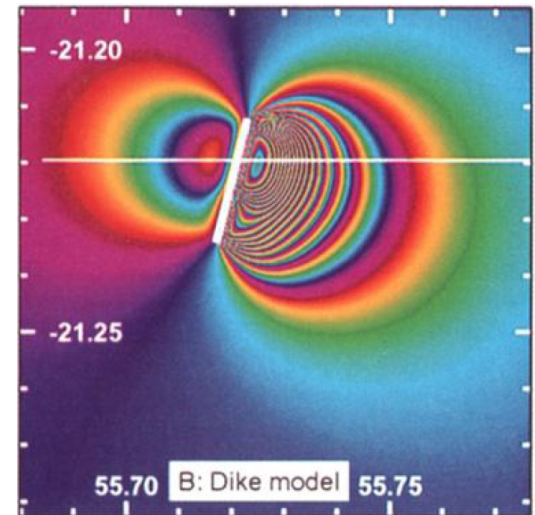
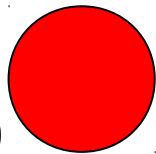
## Analytic Models

**Models**

Constant displacements  
(Okada, 1985)



Overpressures  
(Mogi, 1958)



(Sigmundsson et al., GRL, 1999)

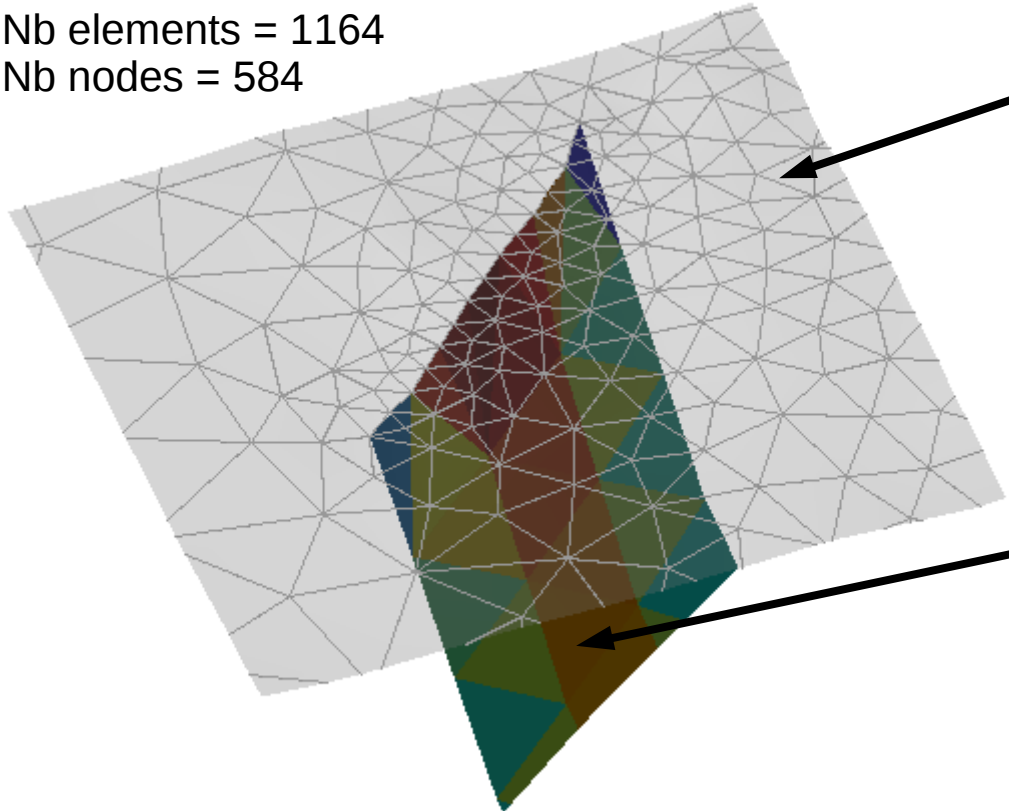
**➡ InSAR data call for more realistic models**

# Modelling with a 3D Mixed Boundary Element Method

(Cayol and Cornet, Int.J. Rock  
Mech. & Min. Sc., 1997)

- **3D Numerical method:**
  - Realistic topographies
  - Any number and geometry of faults and pressure sources
  - treats more than one source appropriately
- **Assumptions:**
  - the volcano is elastic, homogeneous and isotropic
  - dikes, faults reservoirs are submitted to constant stress changes
- **Method: combination of two types of boundary element methods**

Nb elements = 1164  
Nb nodes = 584



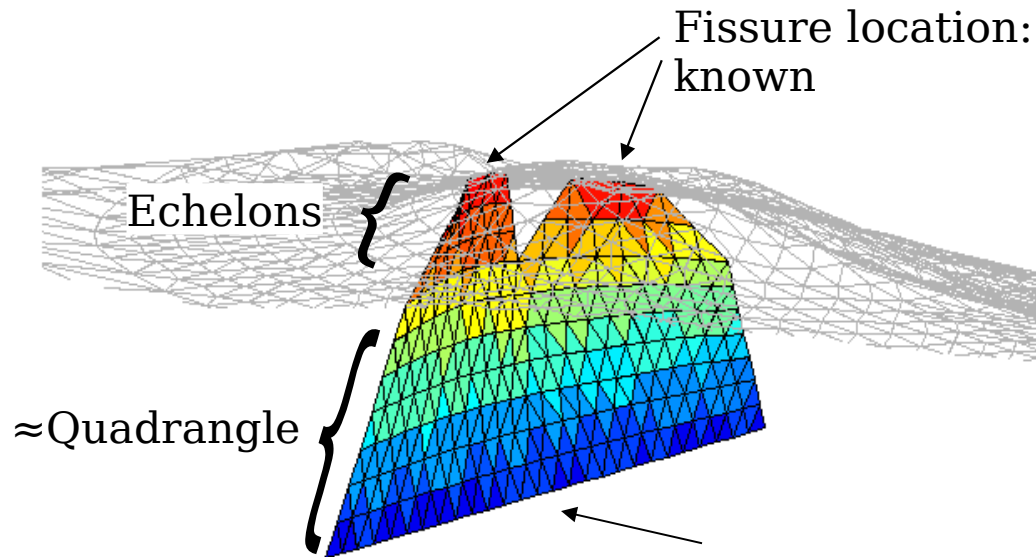
Direct method (Cruse,  
Computers and struct., 1974)  
Linear elements: solutions at  
nodes -> efficient and precise

Displacement discontinuity method  
(Crouch Starfield, 1983)  
Constant elements: solutions at centroid

# Modelling with a 3D Mixed Boundary Element Method

(Cayol and Cornet, JGR, 1998)

- **3D Numerical method:**
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- **Assumptions:**
  - the volcano is elastic, homogeneous and isotropic
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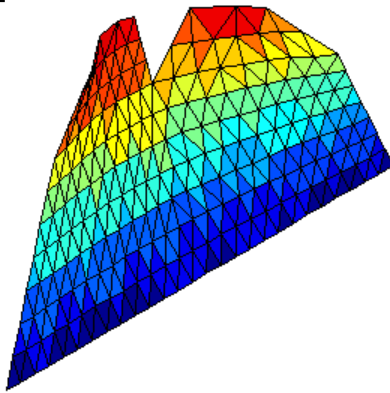
## **Parameters :**

Position and location of the quadrangle bottom line:  
6 à 8 parameters +  
a pressure

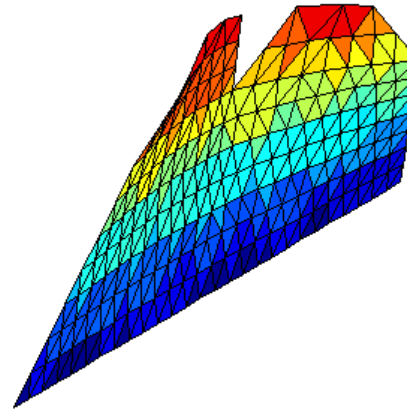
## 3 D Boundary element modelling

### 6 geometrical model parameters for a dike connected to the surface

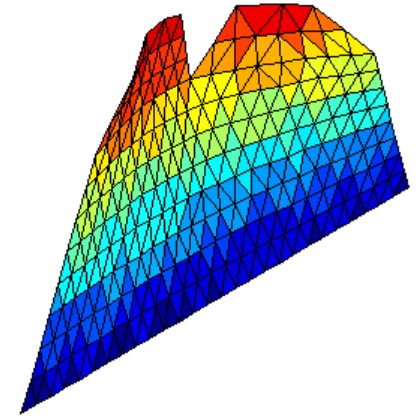
1. Dip



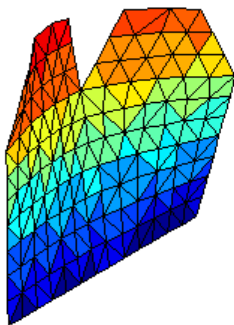
2. Shear



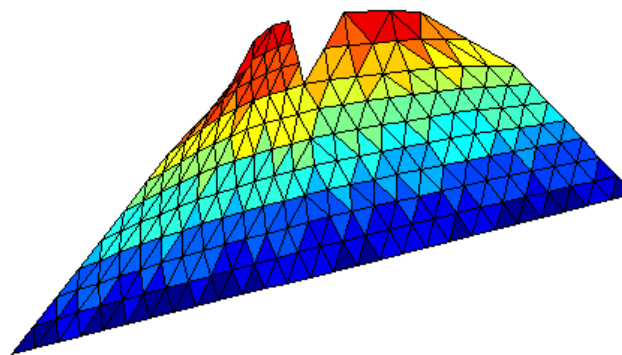
3. Botelv



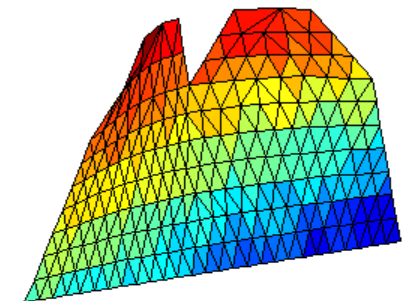
4. Botlen



5. twist

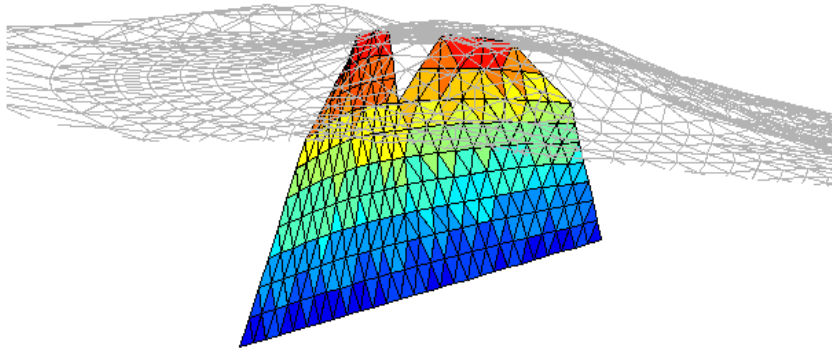


6. Botan

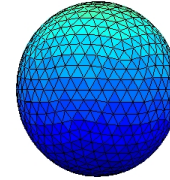


# Available sources

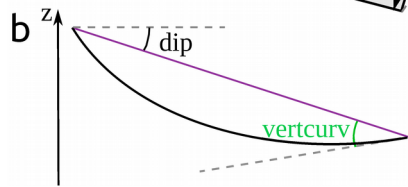
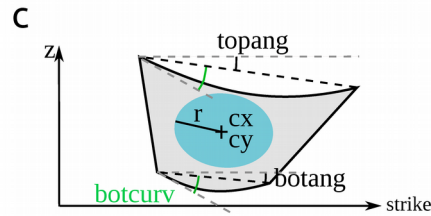
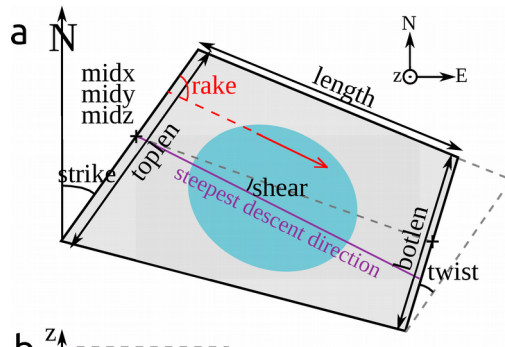
## Dikes or faults



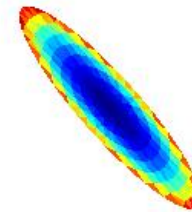
## Massive Reservoirs:



## Curved quadrangular sources



## Planar ellipsoids





# Non-linear inversions with a Neighborhood Algorithm

(Fukushima et al., JGR,2005)

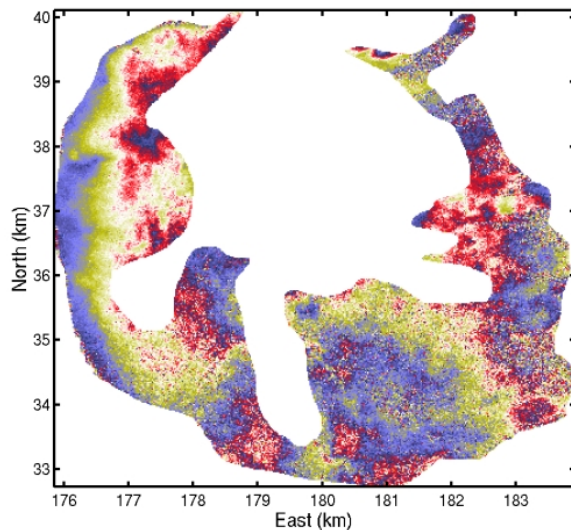
A misfit function which is taking the data noise correlation into account is used:

$$\chi^2 = (\mathbf{u}_o - \mathbf{u}_m)^T \mathbf{C}_d^{-1} (\mathbf{u}_o - \mathbf{u}_m) \quad \text{where } \mathbf{u}_o, \text{ LOS observed displacements}$$

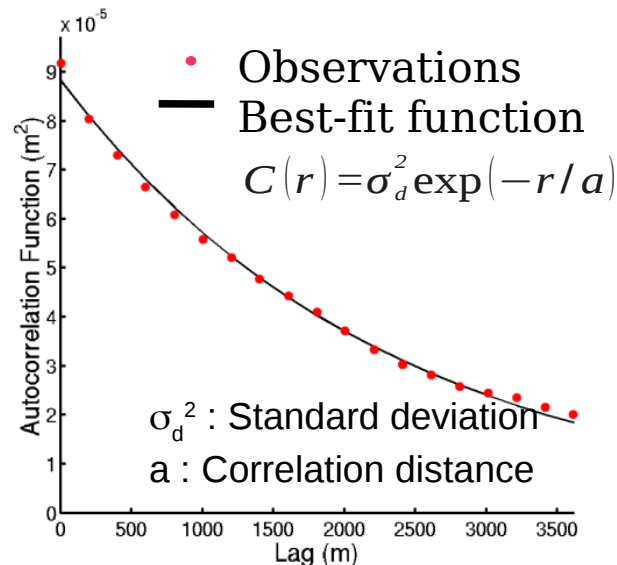
$\mathbf{u}_m$ , LOS modelled displacements

$\mathbf{C}_d$ , Covariance matrix (full matrix)

**Autocorrelation function:** statistical characteristics of randomly correlated data



Undeformed area

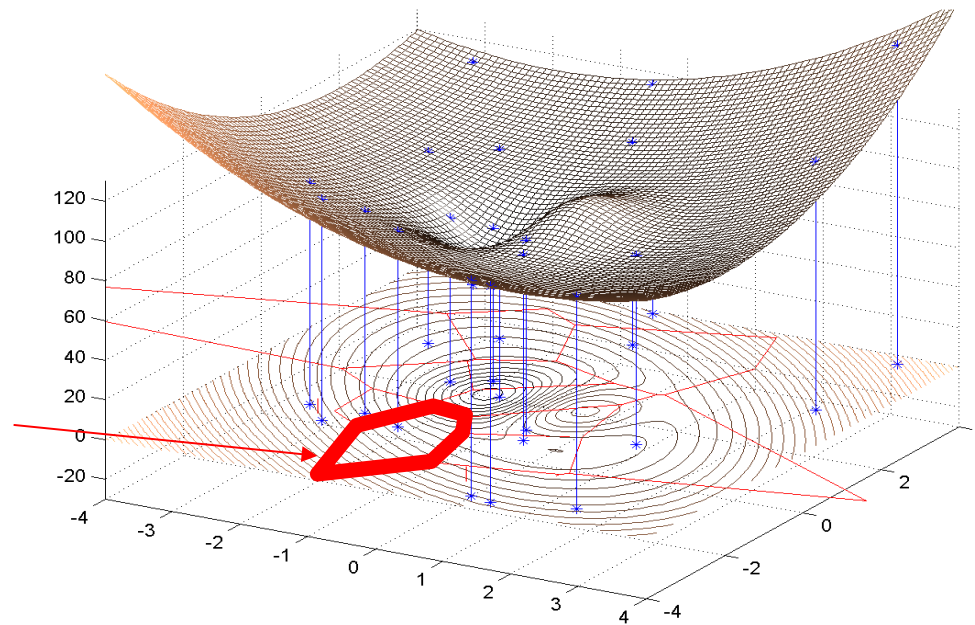


→ Knowing the distance between pairs of points,  $r$ , elements of  $\mathbf{C}_d$  are computed

# NA-MBEM: non-linear inversions with a Neighborhood Algorithm

(Fukushima et al., JGR, 2005)

- Near-neighborhood non linear inversion (Sambridge, JGI, 1999a) to invert for geometrical parameters



Misfit function in a two parameters space

Voronoi cell (neighborhood): region closest to a point than any other point

- Linear inversions of pressure and data shift
- Appraisal of model using Bayesian inference → confidence intervals and trade-offs between parameters (Sambridge, JGI, 1999b)
- Synthetic test → parameters are well resolved within confidence intervals

# NA-MBEM: non-linear inversions with a Neighborhood Algorithm

(Fukushima et al., JGR, 2005)

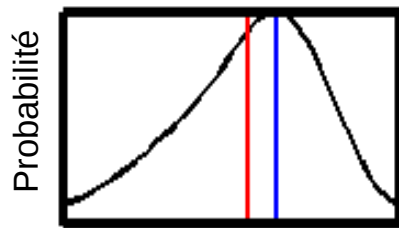
## Appraisal stage

(Sambridge, GJI, 1999)

### Use of models determined at the search stage

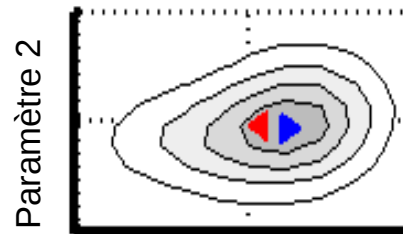
Posterior probability density function (PPD) =  $k \exp(-\chi^2/2)$

Model uncertainties are characterized by marginal PPDs



Param. du modèle

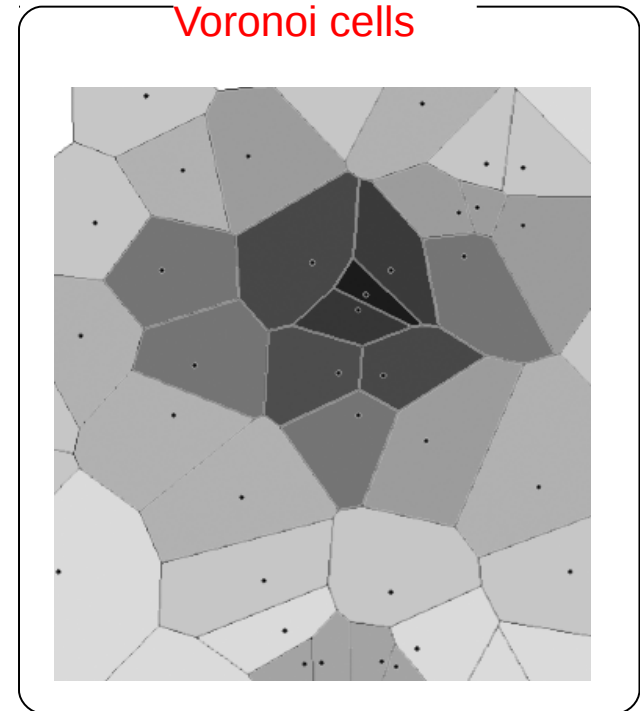
1D marginal PPD:  
Confidence intervals,  
mean model



Paramètre 1

2D marginal PPD:  
Trade-offs

Neighbourhood:  
Voronoi cells



➔ Range of plausible models

# NA-MBEM: Inversions combined with 3D models

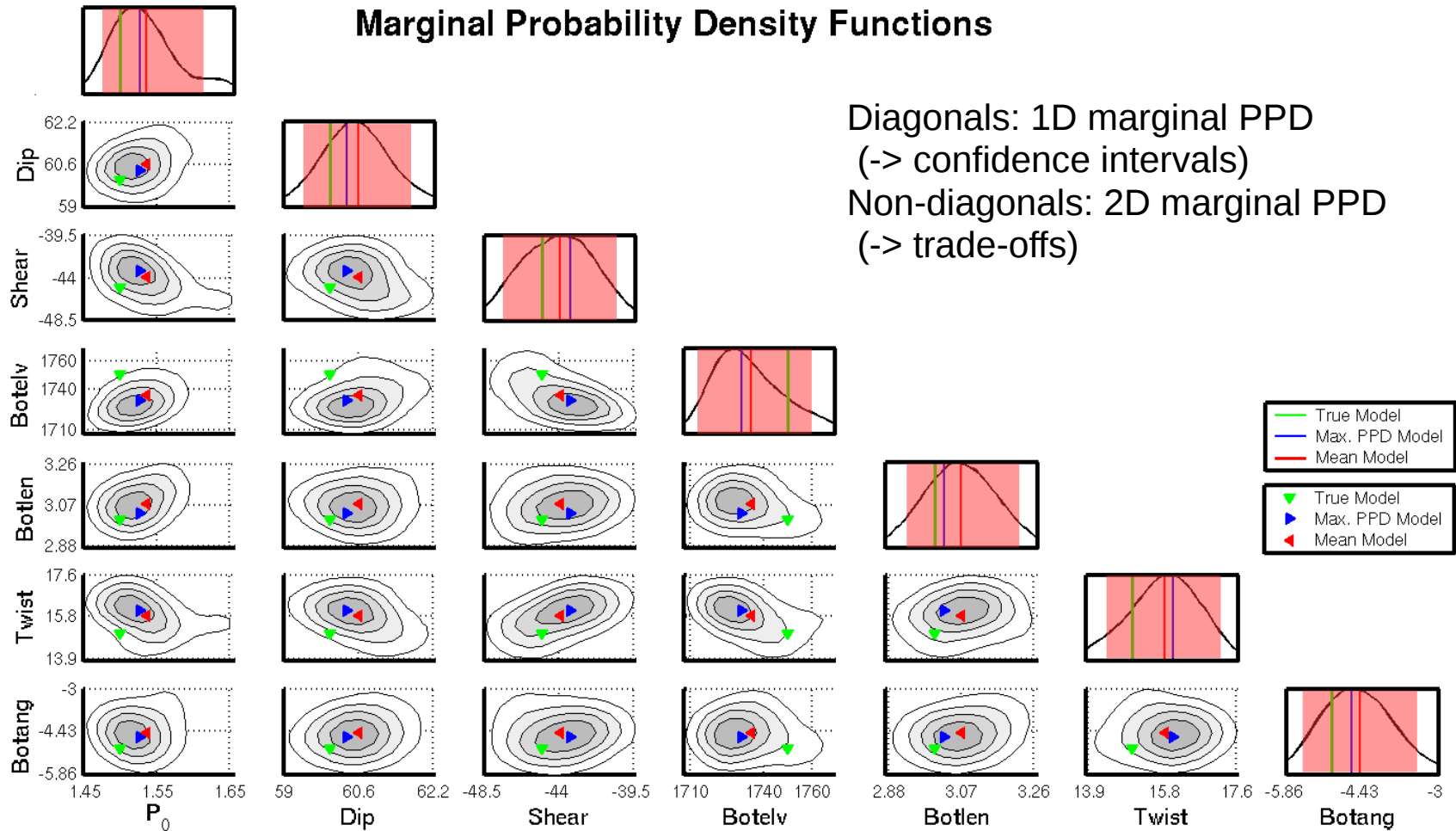
(Fukushima et al., JGR, 2005)

## Synthetic tests



95% confidence intervals

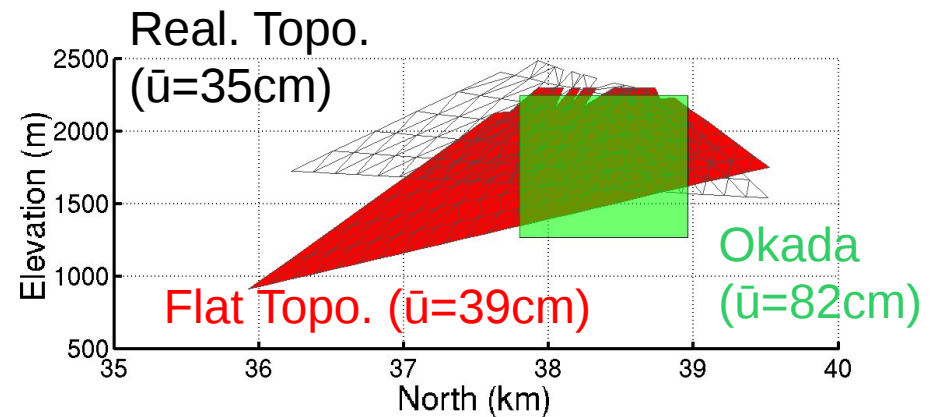
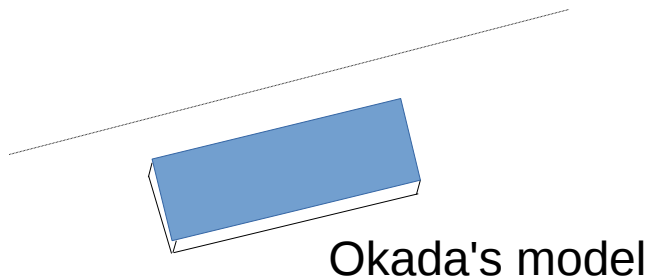
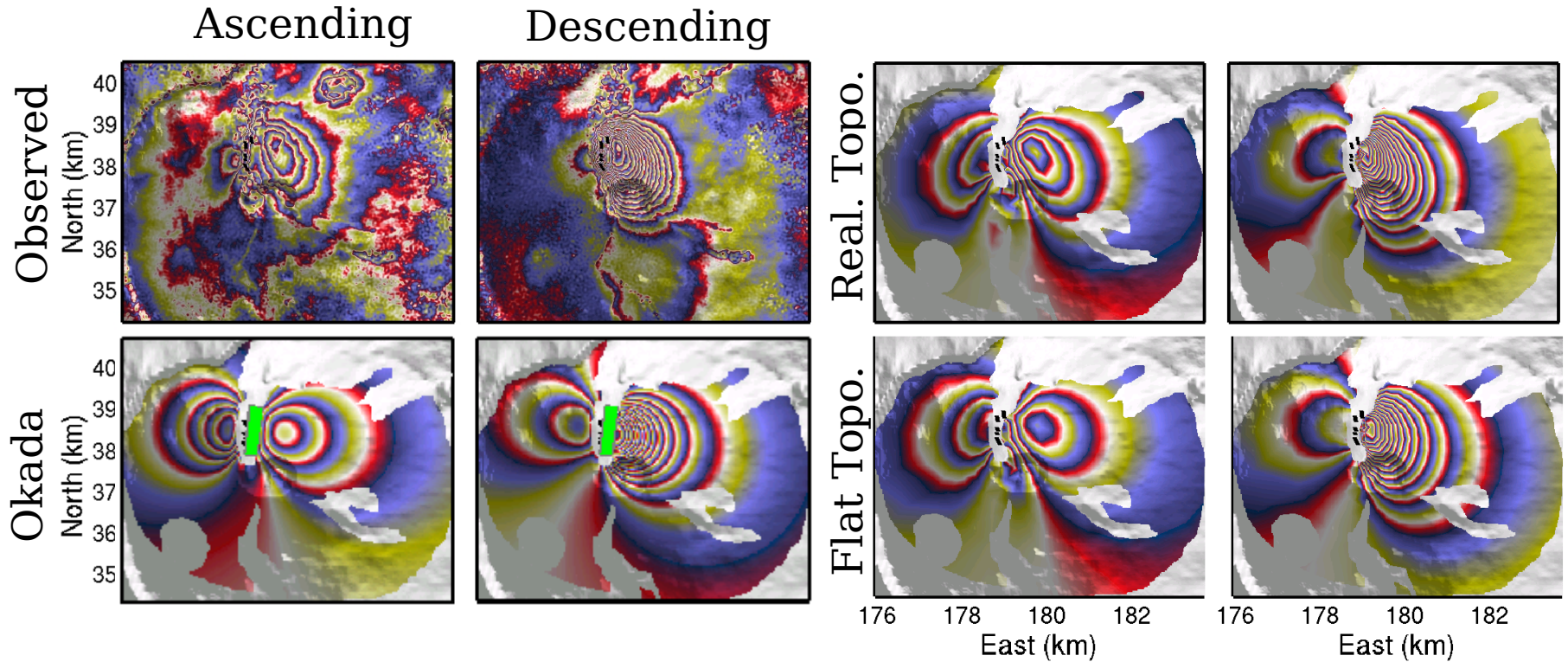
### Marginal Probability Density Functions



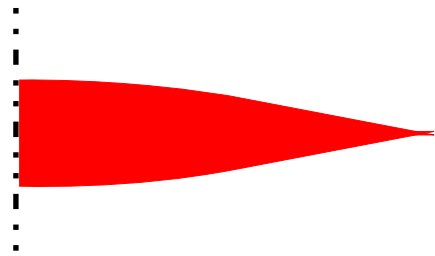
➔ The initial model is within the confidence intervals bounds

# Why taking topography into account ?

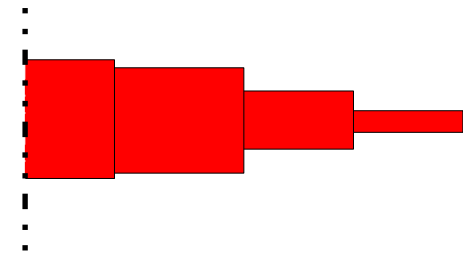
(Fukushima et al., JGR,2005)



# Pressure versus displacement boundary conditions

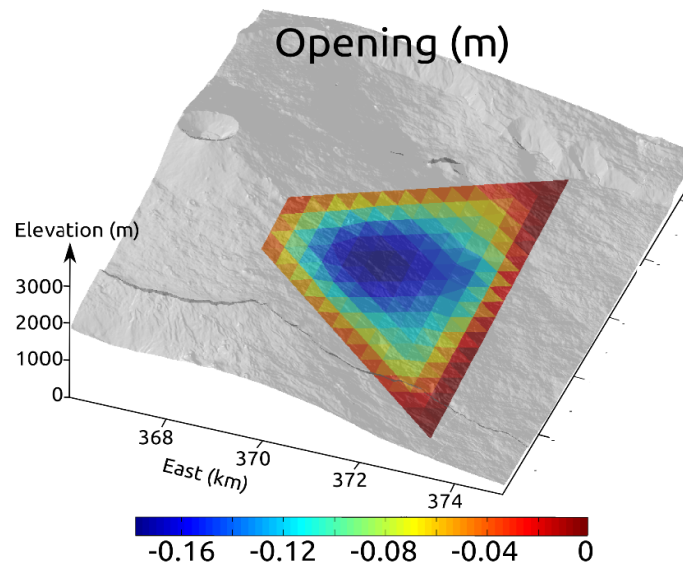


Pressure boundary condition

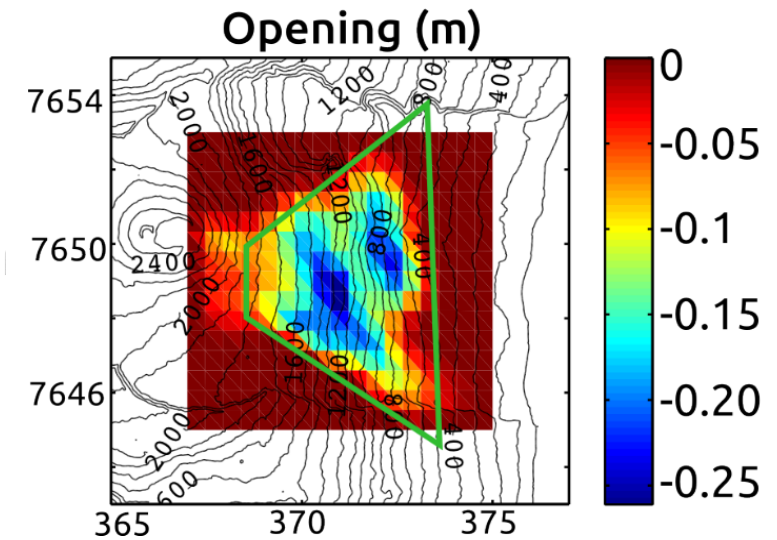


Displacement boundary condition : kinematic models

**Inverted openings**



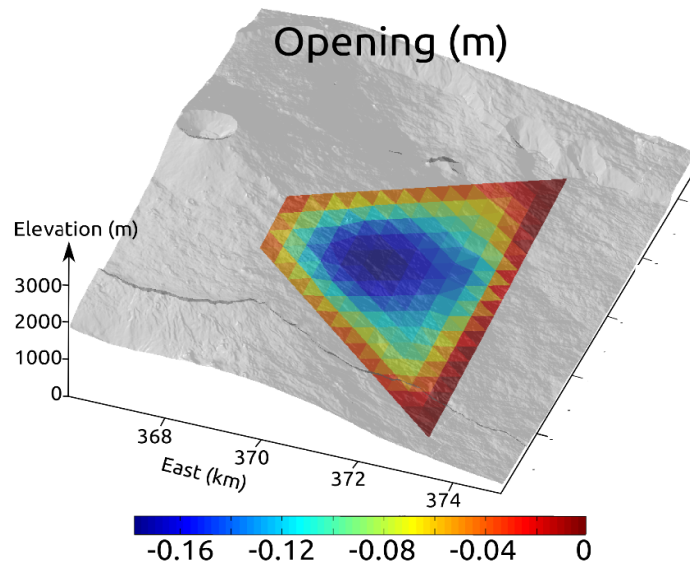
**~ 5 % of inverse models**



**~ 95 % of inverse models**

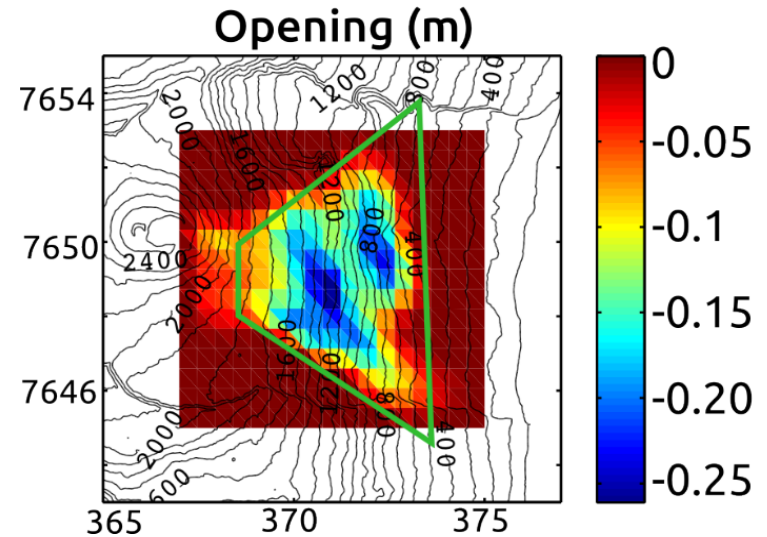
# Pressure versus displacement boundary conditions

Pressure boundary condition



One parameter

Displacement boundary condition



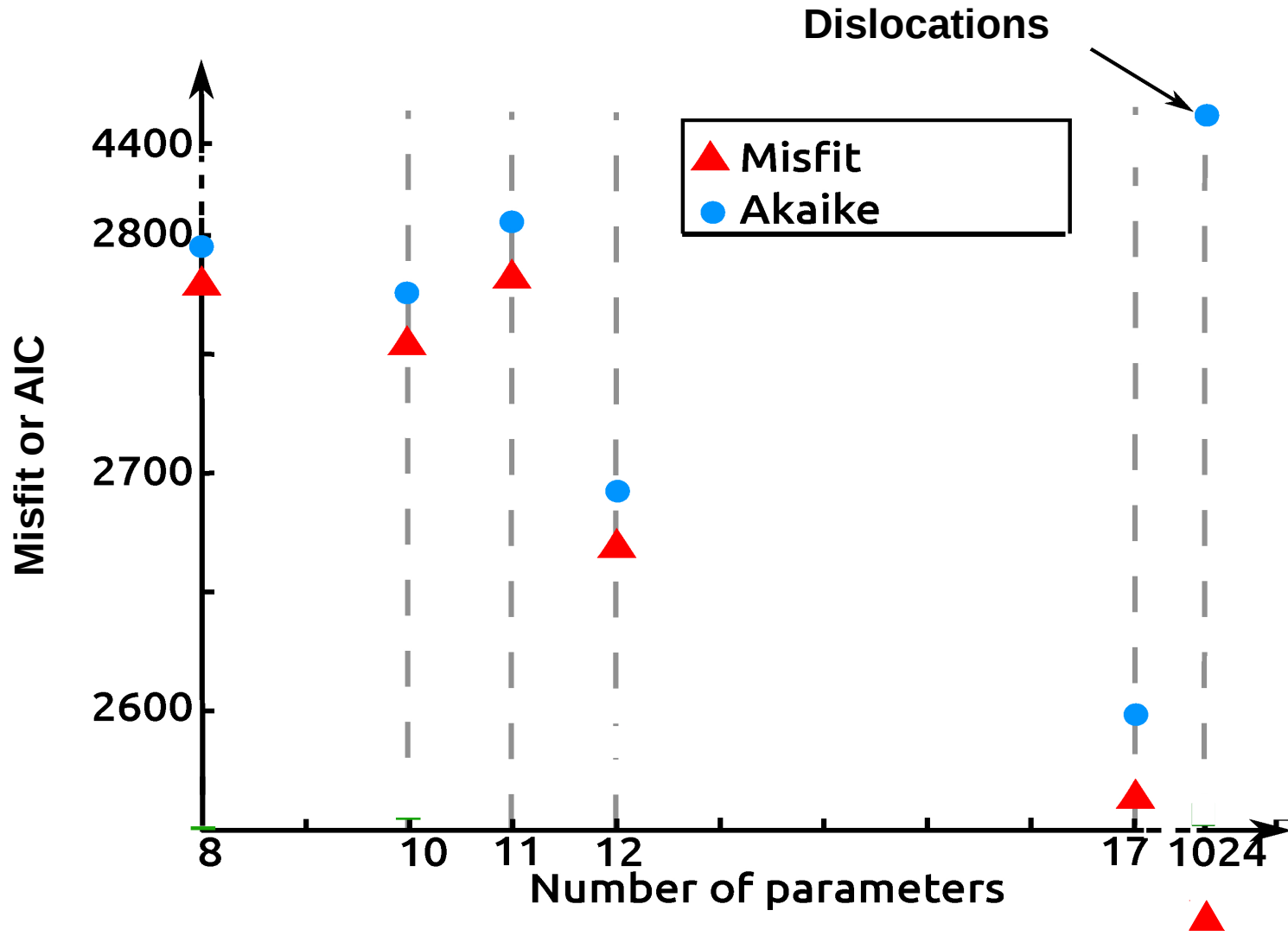
500 parameters



Stress boundary conditions models require less inversion parameters

# AIC, misfit versus number of parameters for post-eruptive displacements

Most likely = lowest AIC =  $2*k + \chi^2 + cst$  with  $k$  = number of parameters and  $\chi^2$  = misfit



→ Inverting for stress leads to more likely models than inverting for dislocation amplitudes



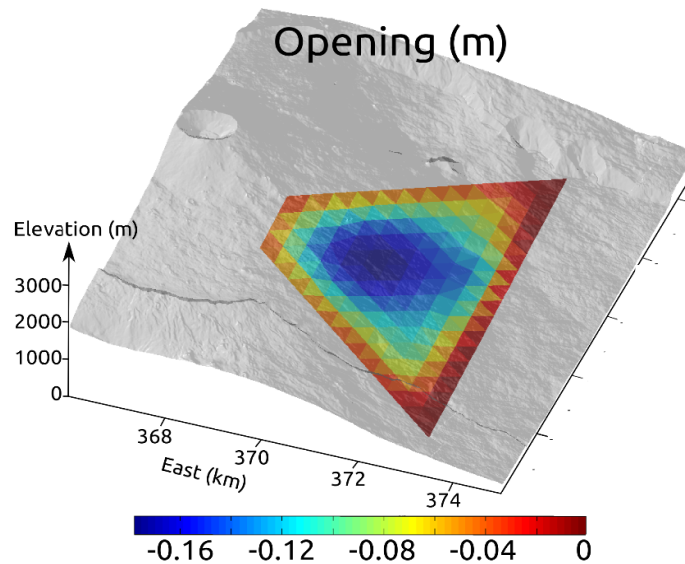
# Stress versus displacement boundary conditions

AIC =  $2*k + \chi^2 + \text{cst}$  with  $k$  = number of parameters and  $\chi^2$  = misfit

Pressure boundary condition

Displacement boundary condition

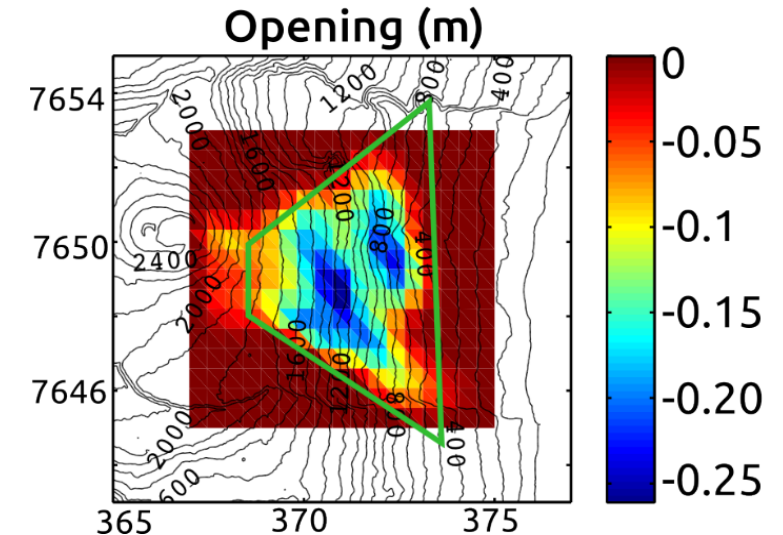
Inverted  
openings



One parameter

$\chi^2 \approx 2784$

AIC  $\approx 2800$



500 parameters

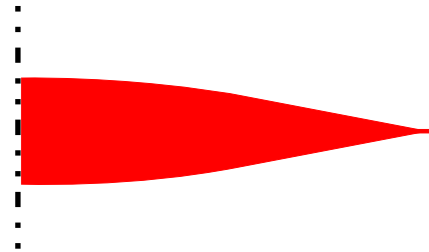
$\chi^2 \approx 2300$

AIC  $\approx 3300$

- ➔ Stress boundary conditions models require less inversion parameters
- ➔ Inverting for stress leads to **more likely** models than inverting for dislocation amplitudes

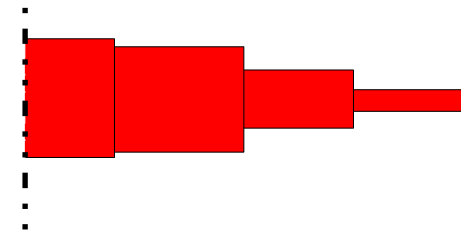
# Pressure versus displacement boundary conditions

## Field observation



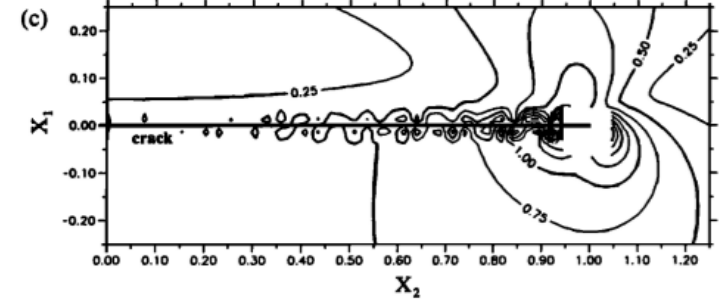
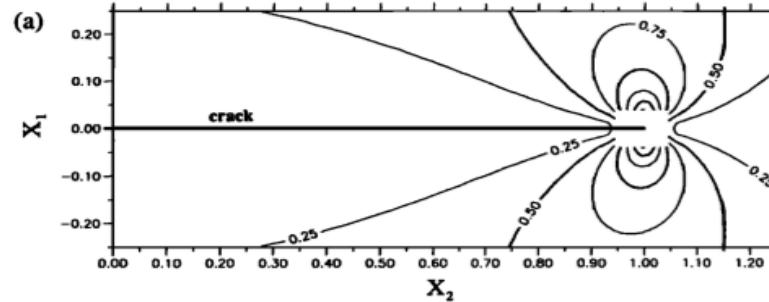
Pressure boundary condition

## Models

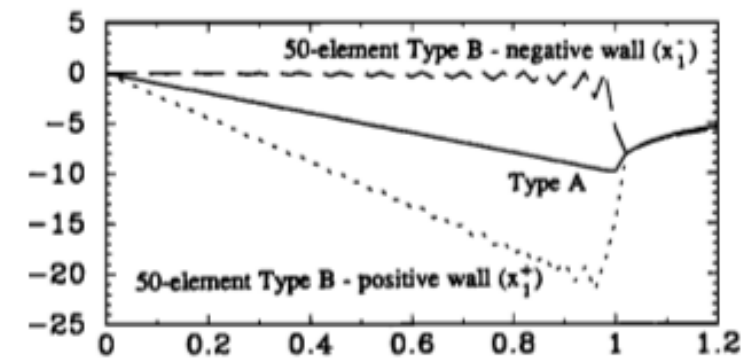
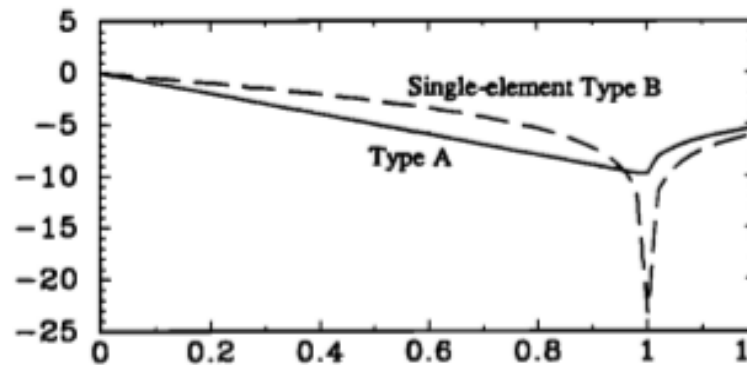


Displacement boundary condition : kinematic models

More stress singularities



Too small shear displacements



(Zeller and Pollard, JGR, 1992)

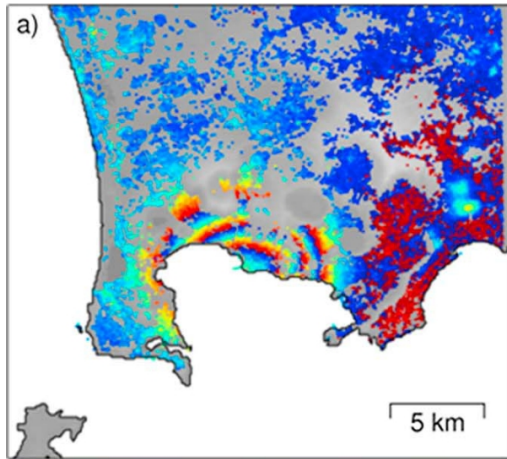


Stress boundary conditions models are closer to the physics

# Stress boundary condition models are more informative

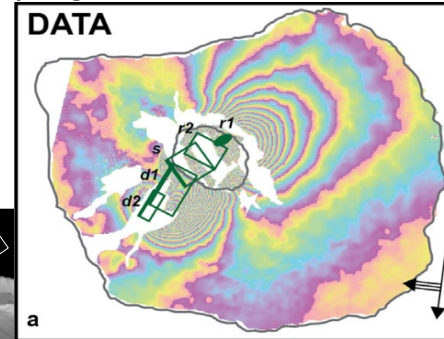
## Hydrothermal systems

(Camacho et al., JGR, 2011)



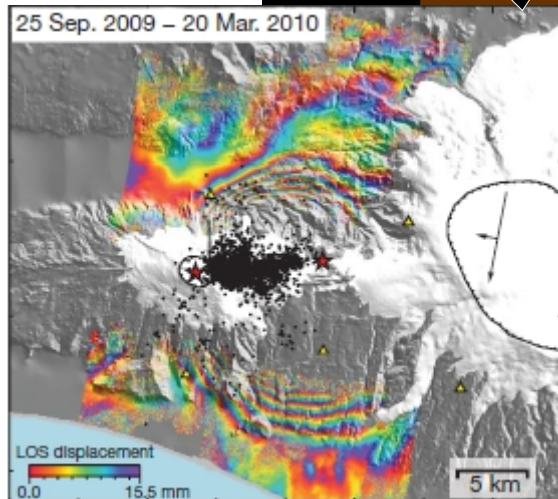
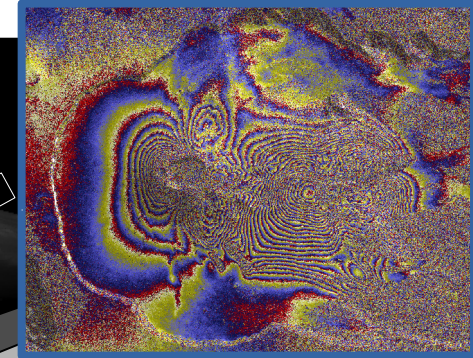
## Intrusion pathways

(Bagnardi et al., EPSL, 2013)



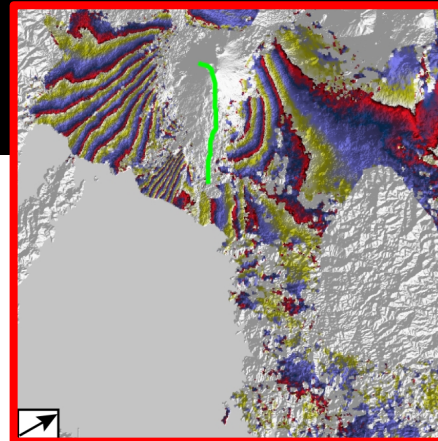
## Flank slip mechanism

(Tridon et al., JGR, 2016)



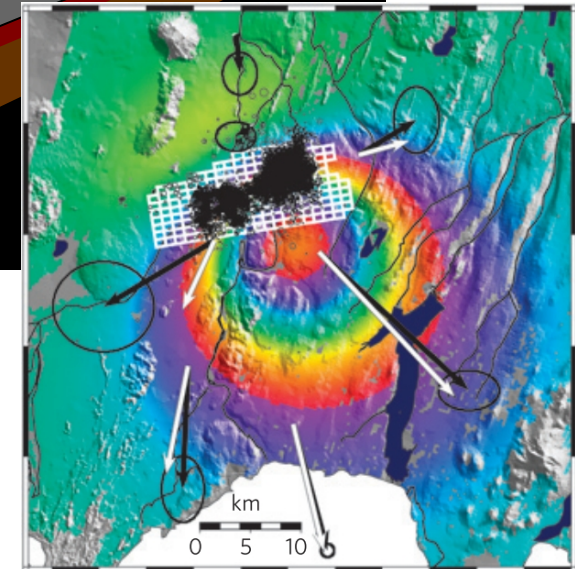
## Magma reservoirs

(Sigmundson et al., Nature, 2010)



## Rift extension drive

(this study)



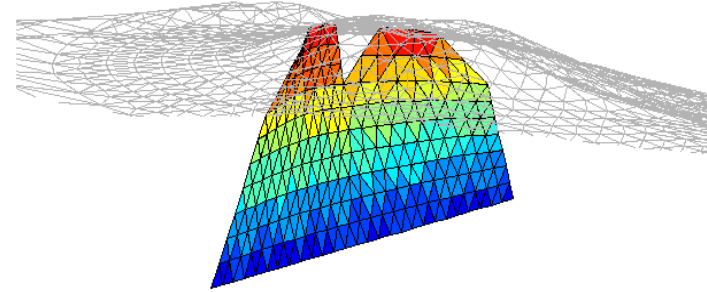
## Glacier retreat influence

(Hooper et al., Nat. Geos, 2011)

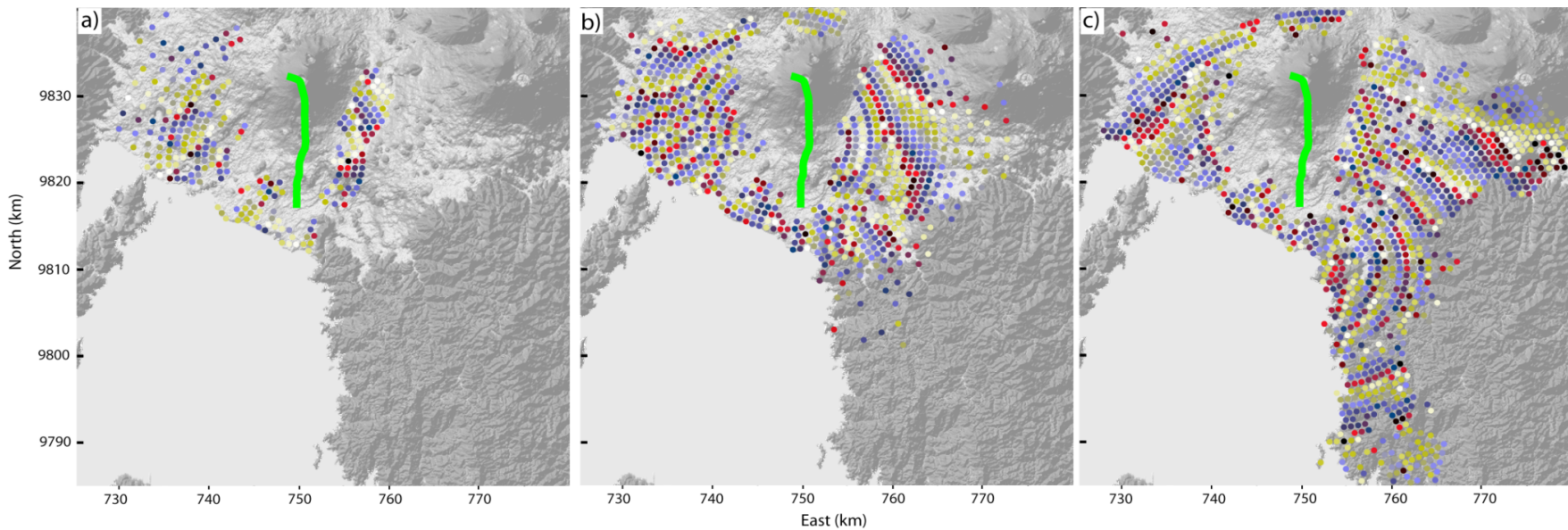
# Faster inversion: 1. Interface

## Launching inversions requires many steps

- model (dike, spherical source, etc) and parameter ranges
- fissures coordinates
- topography file



- data undersampling
- covariance matrix  $C_d$  computation

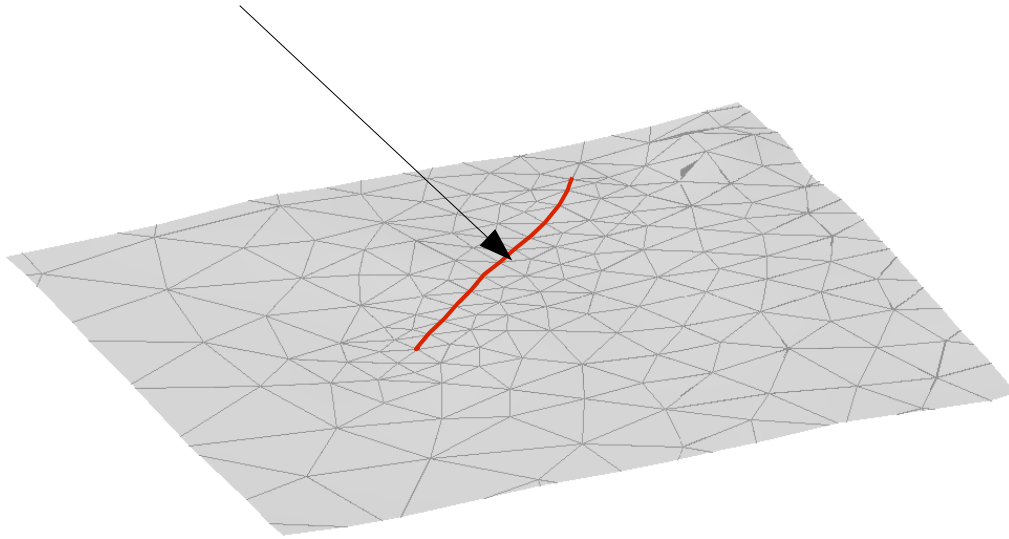


**➡ the user is guided through the steps**

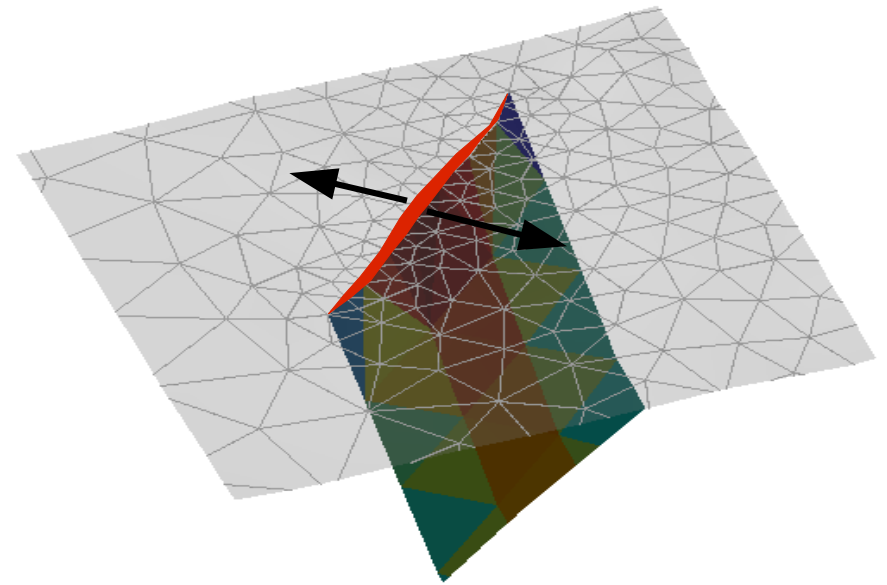
# Faster inversion: 1. Interface

The steps can be imbricated: Eruptive fissures required for topography mesh

Eruptive fissure



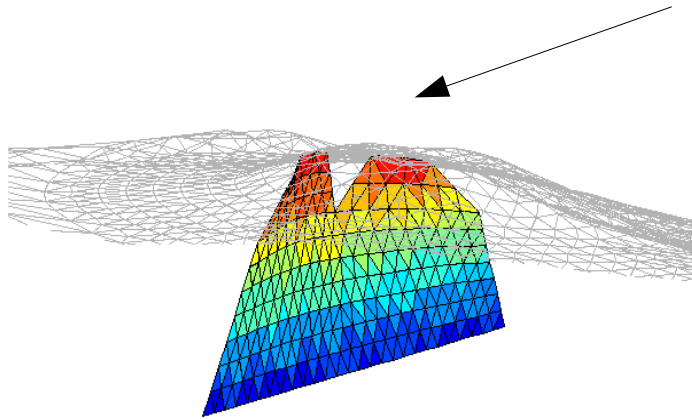
Discontinuity at fissure  $\mathbf{D} = \mathbf{u}^+ - \mathbf{u}^-$



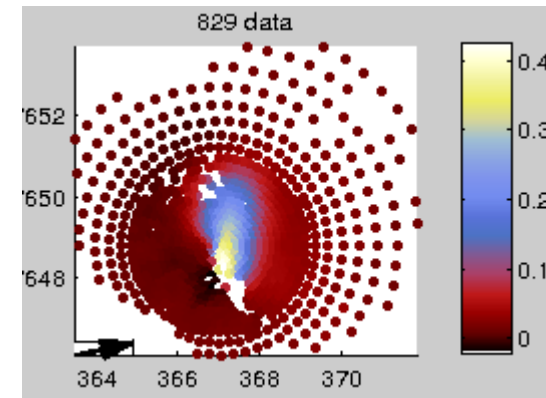
# Faster inversion: 1. Interface

## Imbricated

ex : Eruptive Fissures



Topography and source mesh

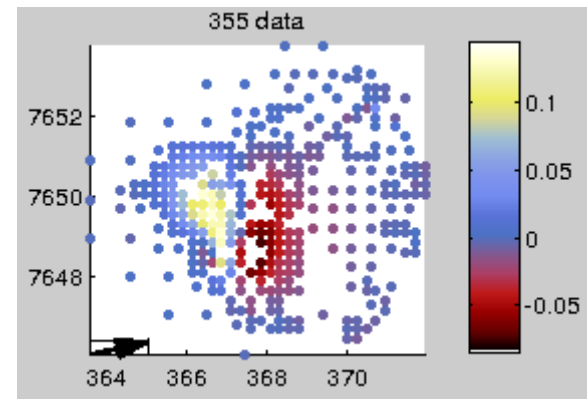
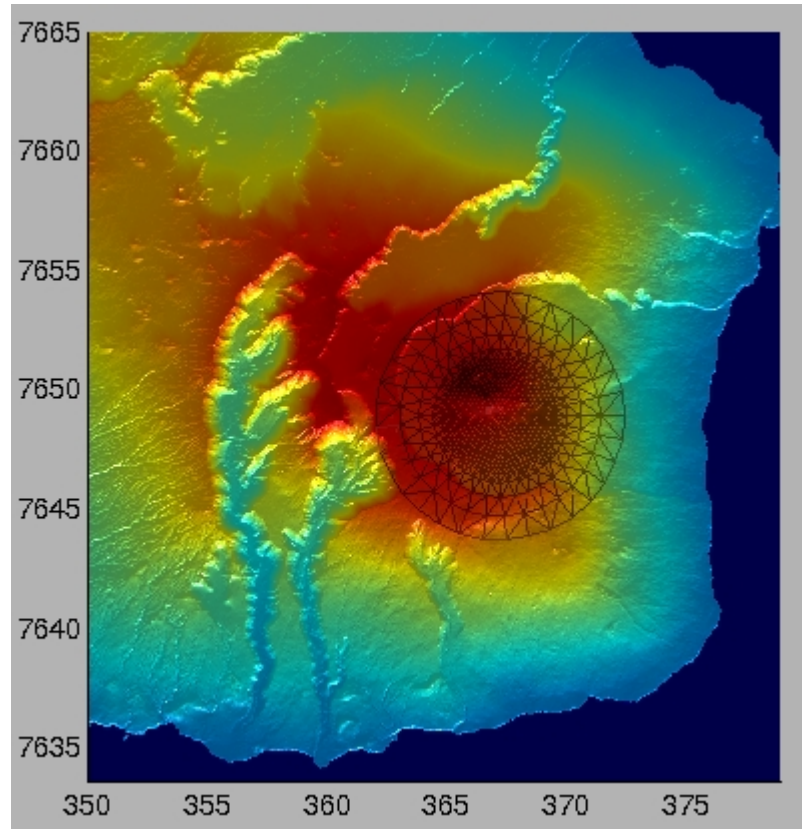


Undersampling

**➔ Imbricated steps are implicitly taken into account**

# Faster inversion: 1. Interface

## Need for a graphical control

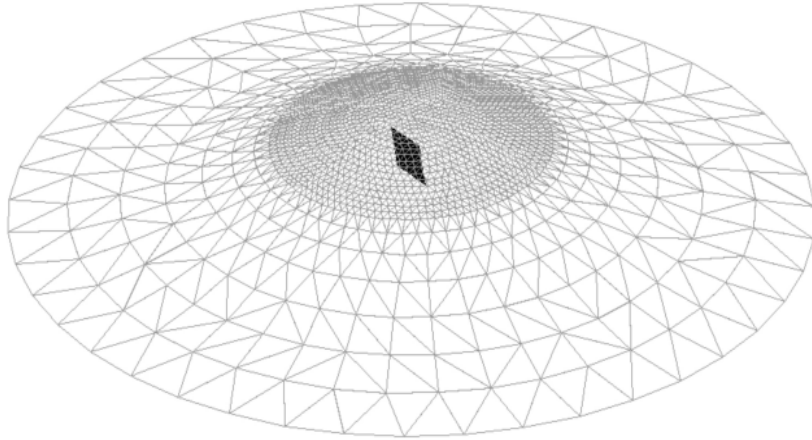


For undersampling parameters

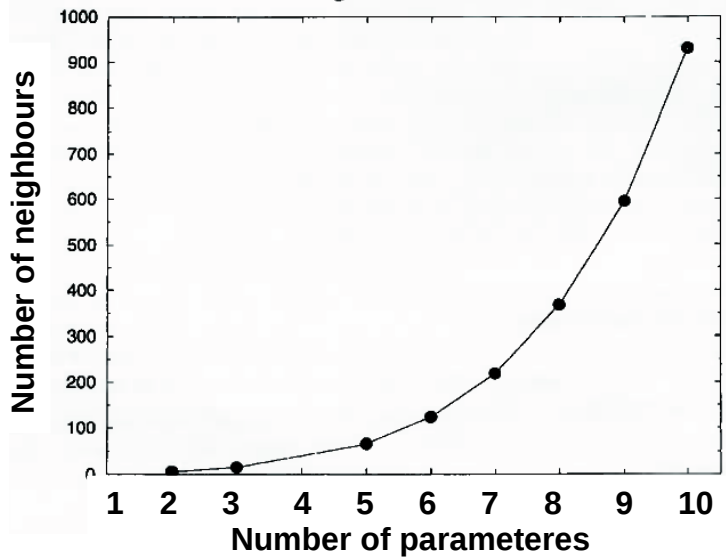
➔ **Graphical control**

# Faster inversion: 1. Interface

## Rules of thumbs to use



Extension of topography mesh with respect to fracture size



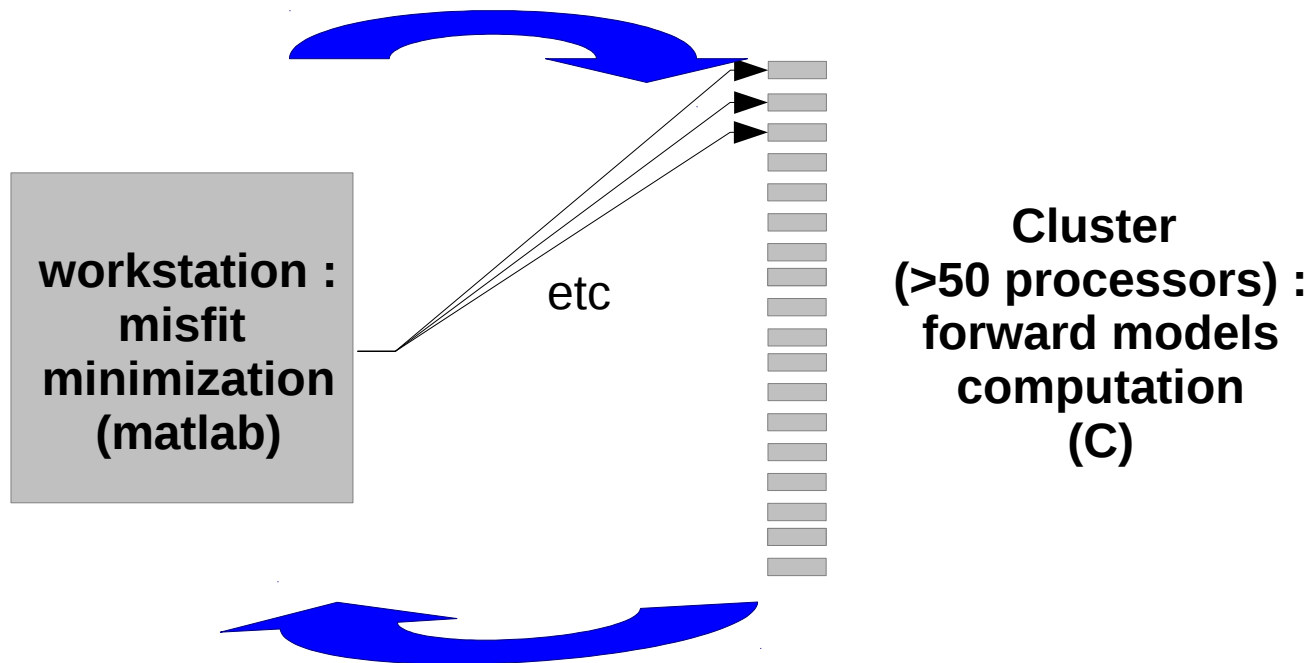
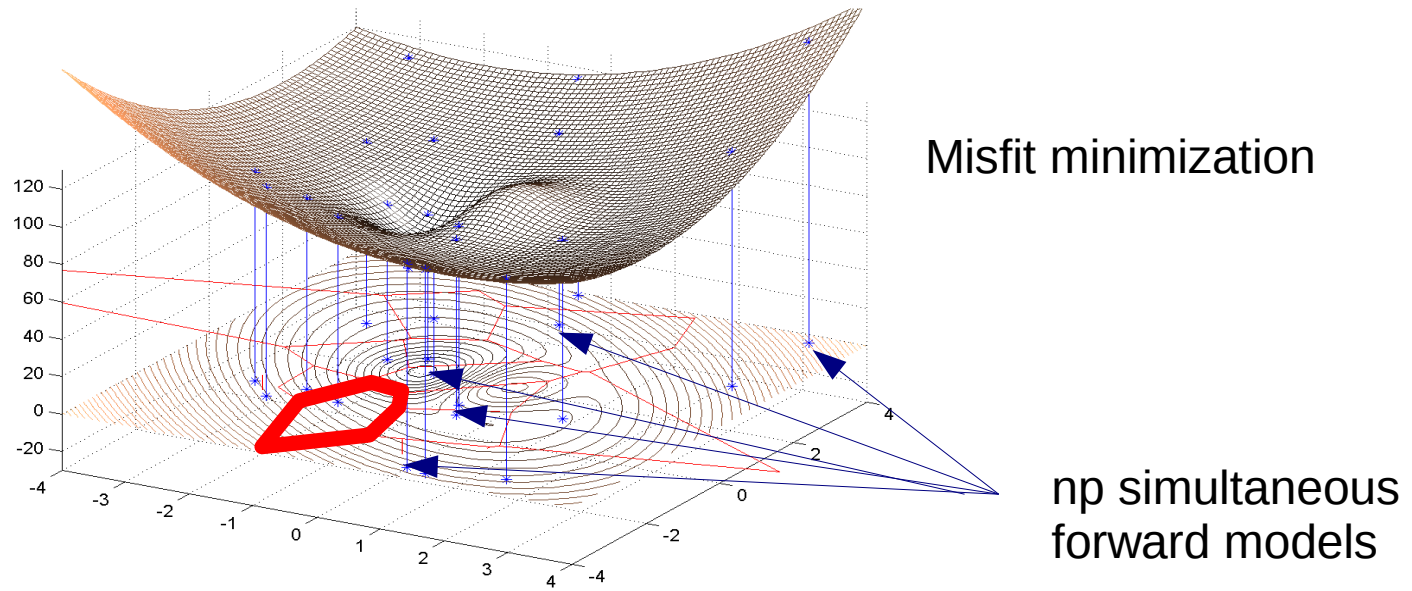
Number of forward models at first iteration is a function of the sources and the associated number of parameters

(Sambridge, 1998)

**➔ Implicitely proposed**

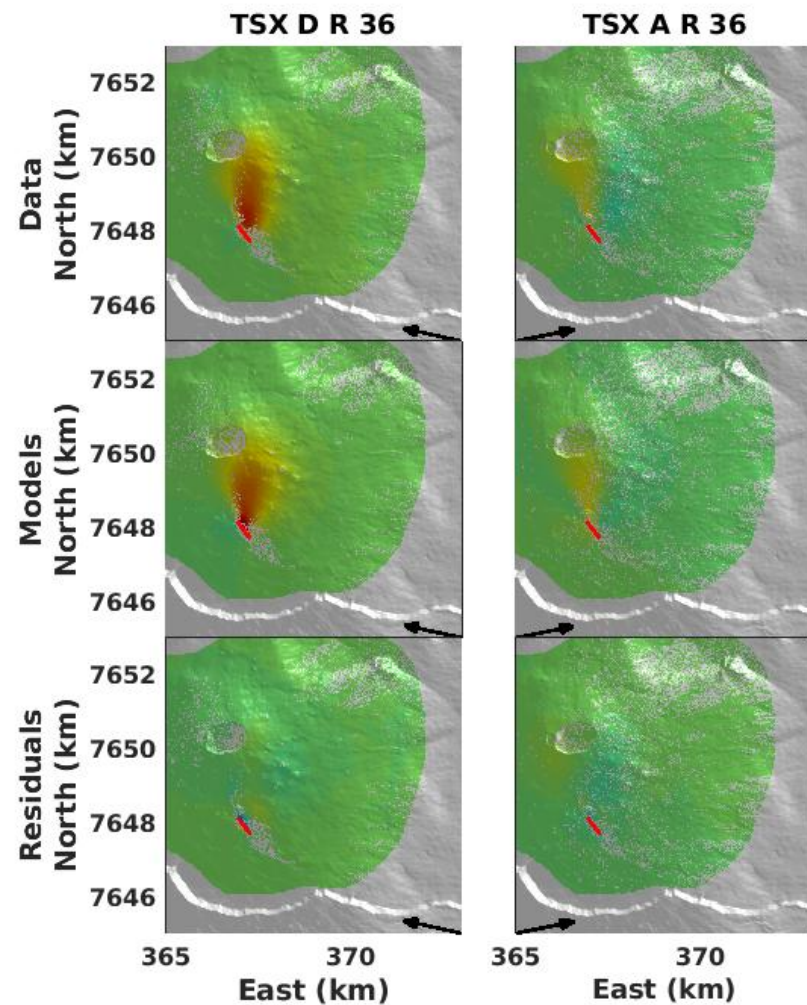


## Faster inversion: 2. Forward models parallelization

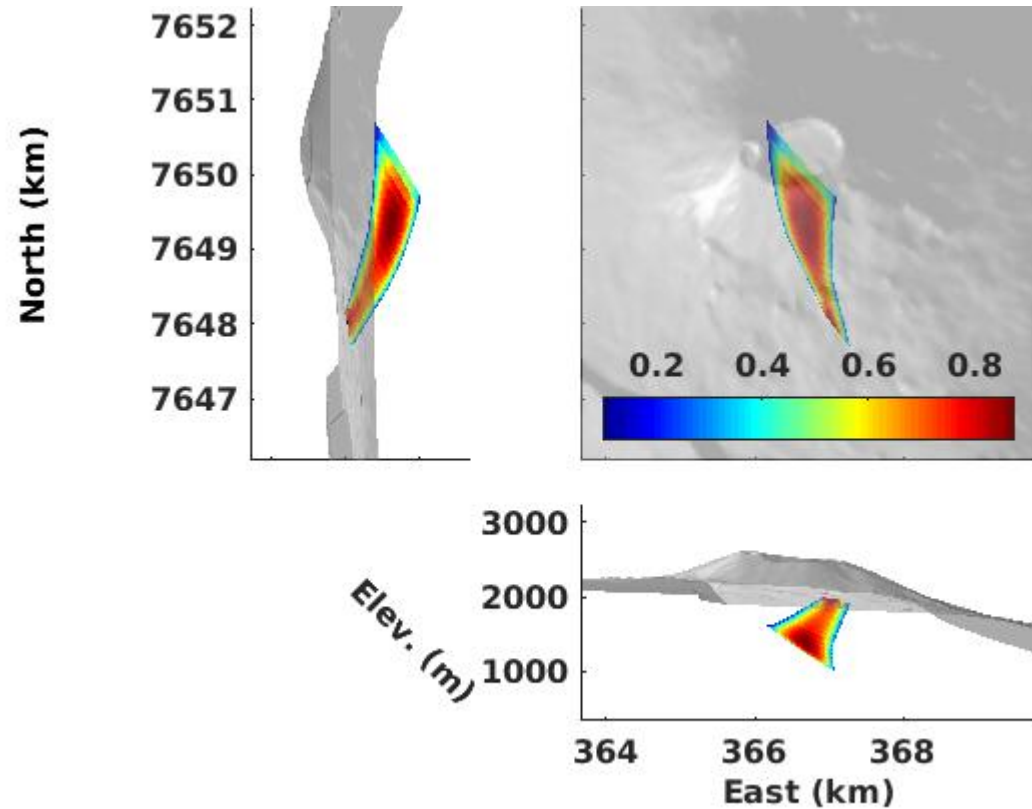


➔ 50 times faster (6 hours against two weeks)

# Example of the Oct. 2010 Piton de la Fournaise eruption



A sill that turns into a dyke ?



50 processors of a cluster : from a few weeks to a few hours (here 4 hours for a 9 parameters model)

# Folder organization

```
cayol@empmetlmv004:~/MATLAB/DEFVOLC/MDIS2019/MDISaDistribuer$ ls *
launch_DefVolc  run_launch_DefVolc.sh

Data:
Pdf_Oct2010_MDIS

Inversions:
Pdf_Oct2010_MDIS

Manuels:
bord.eps      DefVolcShortCourse.odp      Fissure.jpg      MindMapSteps.jpg      planarEll.jpg
bord.jpg      err_eff_bord.jpg            manuelutilisationDEFVOLC.pdf  MindMapSteps.odg      topo.tif

Utils_compiled:
bmp2raw          mergemask          run_bmp2raw.sh      run_meshtest.sh      savemask
demflipud        meshtest           run_demflipud.sh    run_r42grdb.sh
interf2tif       r42grdb           run_interf2tif.sh   run_sarflip.sh
maskfromcoh      readme.txt         run_maskfromcoh.sh  run_savemask.sh
mccExcludedFiles.log  requiredMCRProducts.txt  run_mergemask.sh    sarflip
cayol@empmetlmv004:~/MATLAB/DEFVOLC/MDIS2019/MDISaDistribuer$
```

## Required files (Data folder)

- A custom file that users would make, named INSAR.txt, containing the information on the satellite, orbit, radar wavelength, LOS

```
cayol@empmetlmv004:~/MATLAB/DEFVOLC/defvolc_gitlab/Data/PdF_Oct2010_MDIS$ more INSAR.txt
Satellite Pass Looking Track Wavelength RADARLOOK_X RADARLOOK_Y RADARLOOK_Z
S1 A R 144 0.056 -0.66 -0.17 0.73
TSX D R 036 0.031 0.59 -0.13 0.80
TSX A R 036 0.031 -0.54 -0.11 0.83
CSK A R 15 0.031 -0.73 -0.18 0.66
ALOS2 A L 55 0.236 0.89 0.14 0.44
```

- Interferograms, binary files of floating point numbers ('float32' in matlab), coded on 4 bytes. Extension should be .r4, .nvi, .unwr
- An envi type header file for the interferogram (see files \*.hdr joined), having the same name as the corresponding interferogram and a .hdr extension.
- Masks, binary files coded on a byte as unsigned integer ('uchar' in matlab), with 0 values for masked data and 1 values for visible data. Same dimension as interferograms
- A dem file, with a surfer type header, binary file of floating point numbers ('floats' in matlab), coded on 4 bytes. Extension should be .grd

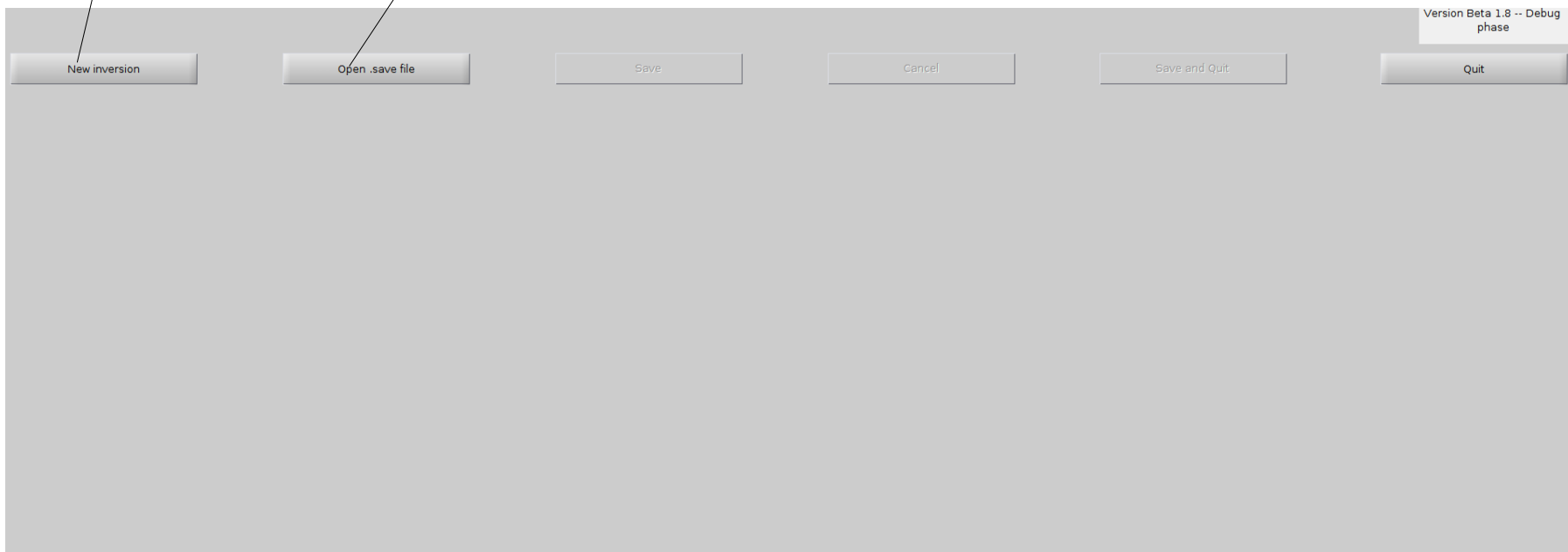
# Launching the compiled interface

From a terminal, do

```
cayol@empmetlmv004:~/MATLAB/DEFVOLC/MDIS2019/MDISaDistribuer$ ./run_launch_DefVolc.sh /usr/local/MATLAB/2018b/v95
```

Asks for the inversion directory : give a folder name in the Inversions directory, /Inversion/Rundir

Loads saved parameters from a previous saved inversion : give the \*.save file name



# 6 Steps

New inversion    Open .save file    Save    Cancel    Save and Quit    Quit

Data preparation    **Model definition**    Topography mesh    Inversion parameter    Inversion    Results visualization

Give number of data set    1    Validate

Give data file name    /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/data.dat    Give covariance file name    /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/covariance.dat    Make concatenated data files

Go to Model definition

# Data subsampling: options for InSAR data

Given once for all interferograms

The screenshot shows a software interface with several tabs: "Data preparation", "Model definition", "Topography mesh", "Inversion parameter", "Inversion", and "Results visualization". The "Data preparation" tab is active. It contains a "Give number of data set" field with the value "1" and a "Validate" button. Below this are two sub-tabs: "1\_data" and "Summary". The "1\_data" sub-tab is active and shows a "Type of data" dropdown menu set to "InSAR" and an "Open InSAR data file" button. A red message "Please indicate InSAR.txt file" is displayed in a light gray box. Below this are three sub-tabs: "data", "subsampling parameters", and "covariance matrix". The "data" sub-tab is active and shows an "Open unwrap file" button and a file selection field. Below this are several input fields: "Columns", "Lines", "X Upper left corner (m)", "Y Upper left corner (m)", "X Interval (m)", and "Y Interval (m)". There is also an "Earth-Sat unit vector" dropdown menu and a "Unit" dropdown menu. The "Unit" dropdown menu is open, showing three options: "meters", "centimeters", and "radians". The "meters" option is selected. To the right of the "Unit" dropdown is an "InSAR data are:" dropdown menu set to "Earth-Satellite distance". At the bottom right of the interface is a "Validate parameter" button.

Depends on your InSAR data

# Data subsampling: options for InSAR data

Software interface for InSAR data processing. The interface is divided into several tabs: Data preparation, Model definition, Topography mesh, Inversion parameter, Inversion, and Results visualization. The 'Data preparation' tab is active.

Give number of data set: 1 [Validate]

1\_data [Summary]

Type of data: InSAR [Open InSAR data file] Please indicate InSAR.txt file

data [subsampling parameters] [covariance matrix]

Open unwrap file: ...

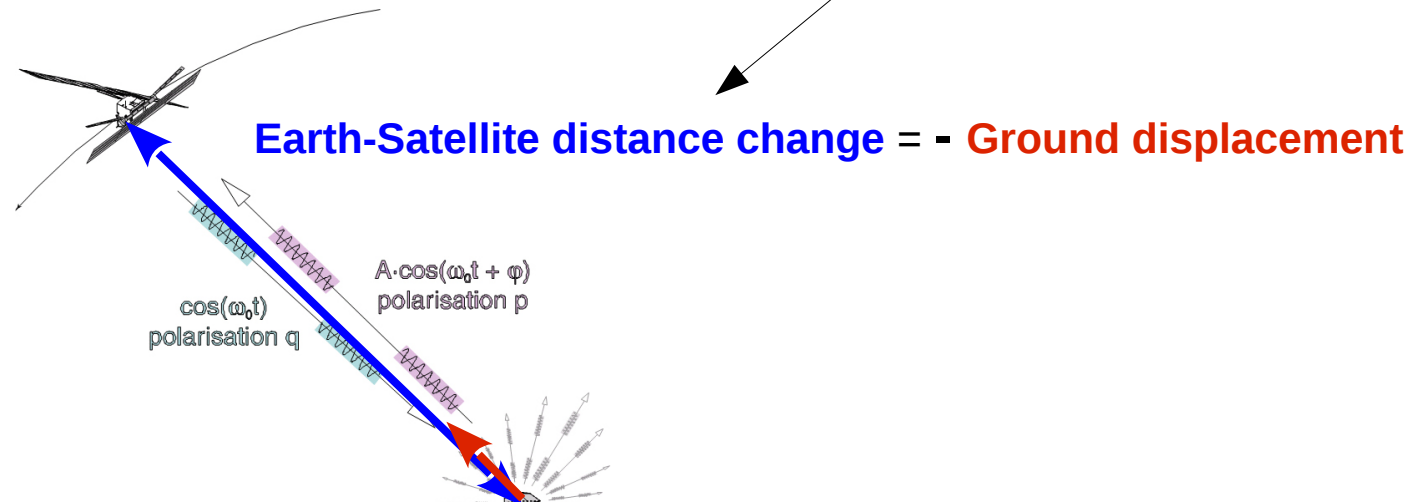
Columns: [ ] Lines: [ ] X Upper left corner (m): [ ] Y Upper left corner (m): [ ] X Interval (m): [ ] Y Interval (m): [ ]

Earth-Sat unit vector: [ ] Unit: meters

Open mask file (Optional): ...

InSAR data are: Earth-Satellite distance (selected), Earth-Satellite distance, Ground displacements

[Validate parameter]





# Data subsampling: 4 subsampling options for InSAR data

Data preparation | Model definition | Topography mesh | Inversion parameter | Inversion | Results visualization

Give number of data set:

Type of data:

Subsampling algorithm:

- circular
- quadtrees
- extract topography node points
- quadrangular

X Center subsampling (m):

Interval (m):

Radius (m):

# Data subsampling: circular subsampling option

1\_data Summary

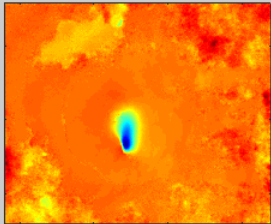
Type of data: InSAR  /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/INSAR.txt

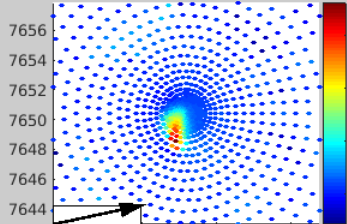
data subsampling parameters covariance matrix

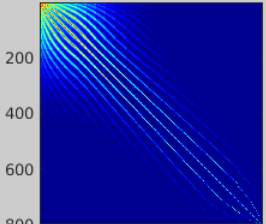
Subsampling algorithm: circular

X Center subsampling (m): 367959 Y Center subsampling (m): 7.65042e+06 Interval (m): 150 Radius (m): 1000

Center of subsampling area Interval for central area Radius of central area

7655 7650 7645 360 365 370 375  0.2 0 -0.2 -0.4 -0.6 -0.8

800 ground displacement points 7656 7654 7652 7650 7648 7646 7644 360 365 370 375  0.6 0.4 0.2 0

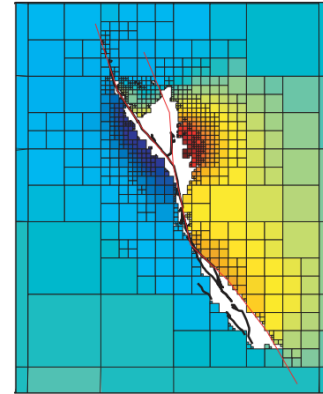
Covariance Matrix  $\times 10^{-4}$  200 400 600 800 200 400 600 800  5 4 3 2 1 0

Data not validated

# Data subsampling: quadtree subsampling option

For the quadtree decomposition method see Welstead, S. T. (1999), *Fractal and Wavelet Image Compression Techniques*, 232 p. and

basinc principle: Incrementally devides cells depending on the displacement gradient and absolute value



Jonsson et al., *BSSA*, 2002

1\_data Summary

Type of data: InSAR  /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/INSAR.txt

data **subsampling parameters** covariance matrix

Subsampling algorithm: quadtree

Minimum block dimension (power of 2): 32    Maximum block dimension (power of 2): 128    Displacement difference threshold (m): 0.05    Displacement threshold (m): 0.05

Nb of pixels in smallest boxes    Nb of pixels in largest boxes    Adds a point in box if max disp. difference > value    Adds a point in box if max disp. > value

7652 7650 7648 364 366 368 370 372

294 ground displacement points

7653 7652 7651 7650 7649 7648 7647 364 366 368 370

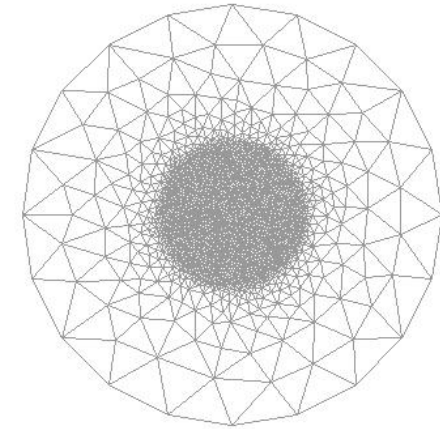
Covariance Matrix  $\times 10^{-4}$

50 100 150 200 250

Data not validated

# Data subsampling: at topography mesh node points

Previously created topography mesh



1\_data Summary

Type of data: InSAR

data subsampling parameters covariance matrix

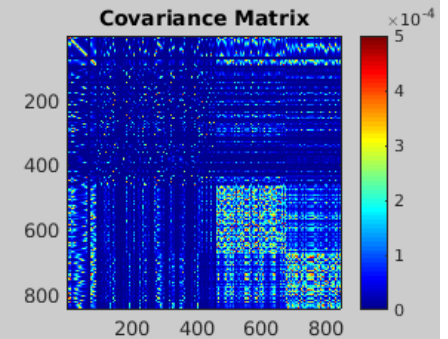
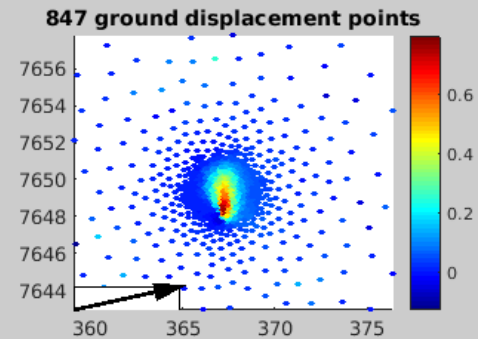
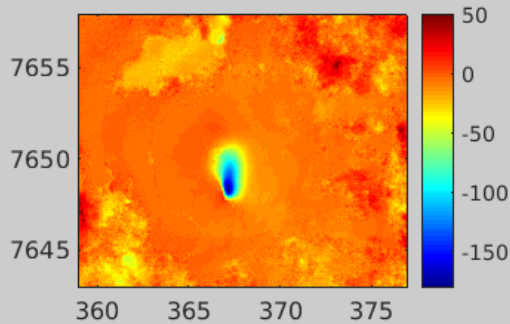
Subsampling algorithm: extract topography node points

Open topography mesh file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/PdF\_Oct2010\_MDIS/topo.ex3

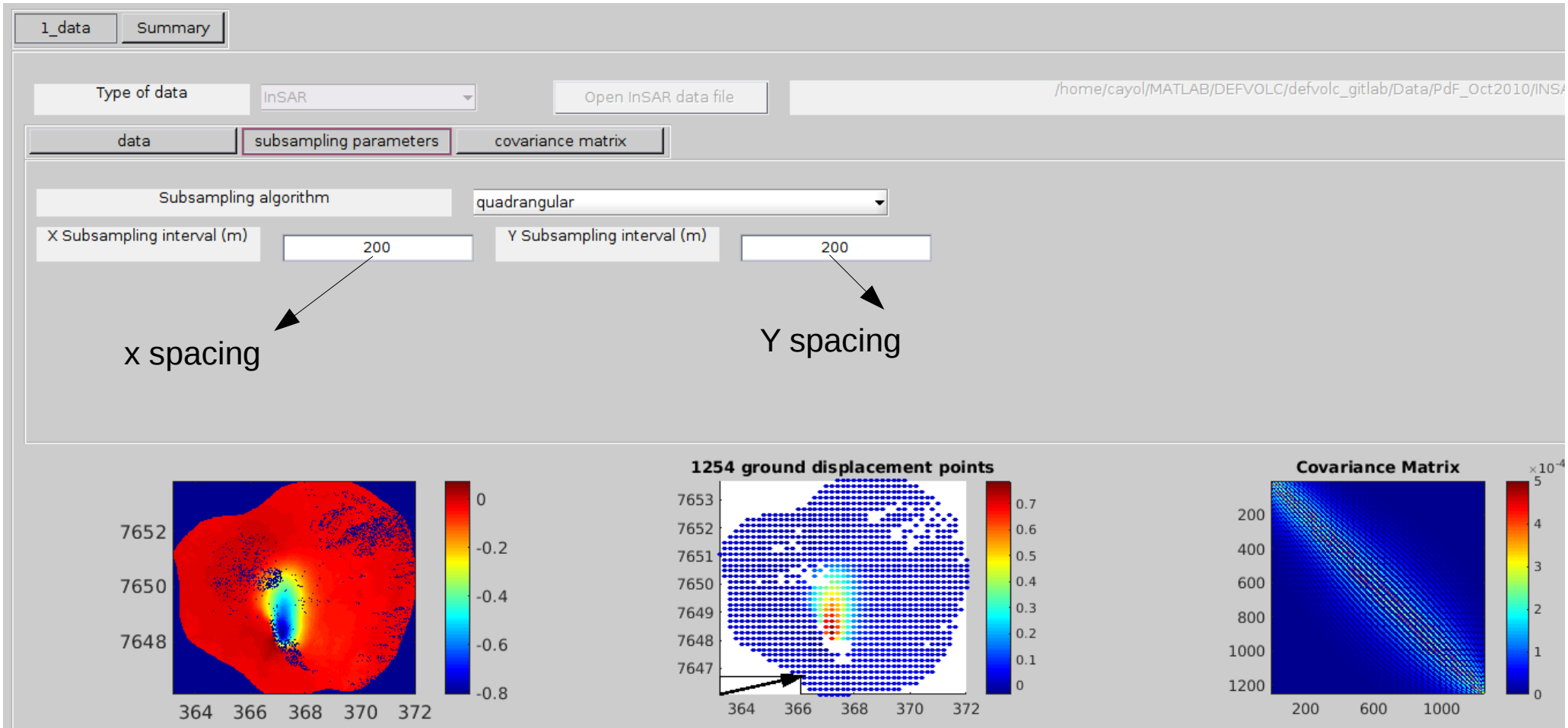
Columns: 2400 Lines: 2000

Shift of topography mesh along X (m): 367232 Shift of topography mesh along Y (m): 7649310

To be read from a previous param.input file (X0, Y0)



# Data subsampling: regular subsampling option



# Data subsampling: covariance matrix

Independant from the subsampling method

1\_data Summary

Type of data: InSAR  /home/cayol/MATLAB/DEFVOLT/defvolc\_gitlab/Data/PdF\_Oct2010/INSAR.txt

data subsampling parameters **covariance matrix**

Default values

Correlation distance (m): 850 Variance (m<sup>2</sup>): 0.0005

See Fukushima et al., JGR, 2005. Take generic values and readjust after inversion or compute using Utils/calcACF.m.

7655 7650 7645 360 365 370 375

800 ground displacement points

7656 7654 7652 7650 7648 7646 7644 360 365 370 375

Covariance Matrix  $\times 10^{-4}$

200 400 600 800 200 400 600 800

Data not validated

# Data subsampling: creating data and covariance files

To create the data (/Inversions/RunDir/data.dat) and covariance (/Inversions/RunDir/covariance.dat) binary files, you need to validate each dataset and press **“Make concatenated data files”**. Names can be changed, but the extension has to be \*.dat.

The interface shows the following details:

- Navigation:** Data preparation (selected), Model definition, Topography mesh, Inversion parameter, Inversion, Results visualization.
- Validation:** Give number of data set: 1. Validate button.
- File Selection:** Type of data: InSAR. Open InSAR data file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/Pdf\_Oct2010/INSAR.txt.
- Parameters:** Correlation distance (m): 850. Variance (m<sup>2</sup>): 0.0005.
- Visualizations:**
  - Ground displacement map (left): Color scale from -0.8 to 0.
  - 493 ground displacement points (middle): Scatter plot with color scale from 0 to 0.7.
  - Covariance Matrix (right): Heatmap with color scale from 0 to 5 (multiplied by 10<sup>-4</sup>).
- Buttons:** Show data and covariance matrix, Data validated, Validate dataset, Make concatenated data files, Go to Model definition.
- File Names:** Give data file name: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/test/data.dat. Give covariance file name: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/test/covariance.dat.

# Sources definition: Stress determination

**cst and 1 value for all data** : Stress changes (Overoressures, shear stress drops) are linear parameters. The stress change value minimizing the misfit on all the data is determined.

**cst and 1 value for each data** : Stress changes are also linear parameters, but their value is adjusted to minimize the misfit of each data set is determined

**parameter** : Stress changes are linear parameters

Software interface for stress determination, showing various parameters and a diagram of an ellipsoid.

**Pressure** dropdown menu options:

- cst & 1 value for all data
- cst & 1 value for all data
- cst & 1 value for each data
- parameter
- Quadrangle normal and shear stress
- Sphere
- Ellipsoid
- Blanarell\_ellipsoid

**Elastic properties**

- Elastic properties: Homogeneous
- Young's module (MPa): 5000
- Poisson's ratio: 0.25
- Allow fracture interpenetration: Yes

**Sources list (1 sources)**

- Ellipsoid

**Total number of inverted variable**: 9

**Tessellation Level**: 1 (80 triangles)

Center E-coordinate (m)		Center N-coordinate (m)		Center Z-coordinate (m)		Semi-axis 1 (100-5000m)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
	366000		7648400		-5000		100
	370000		7652400		0		5000

Semi-axis 2 (100-5000m)		Semi-axis 3 (100-5000m)		Dipdir (0-90°)		Dip (0-90°)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
	100		100		0		0
	5000		5000		90		90

Rotang (0-90°)	
Inverted	Fixed
	0
	90

**Number of inverted parameters**: 9

**Go to topography mesh**

The diagram illustrates an ellipsoid with three principal axes labeled S1, S2, and S3. S1 is the horizontal axis, S2 is the vertical axis, and S3 is the depth axis. The angle between S1 and the horizontal plane is labeled Rotang. The angle between S2 and the vertical axis is labeled Dipdir. The angle between S3 and the horizontal plane is labeled Dip. A coordinate system with Up, North, and East axes is shown in the top right corner.



# Sources definition: fracture interpenetration

**Yes** : The default value. Mathematical solutions allows for fracture interpenetration. This solution might be unphysical if the fracture was initially closed.

**No** : A solution is determined that solves the linear boundary element problem provided

$\mathbf{D} = \mathbf{u}^+ - \mathbf{u}^- > \mathbf{0}$ . This is a constrained optimization problem. See Cayol, V., T. Catry, L. Michon, M. Chaput, V. Famin, **O. Bodart** et al., JGR, 2014, for algorithm.

The software interface shows the following settings and visualizations:

**Pressure:** cst & 1 value for all data

**Elastic properties:** Homogeneous

**Young's module (MPa):** 5000

**Poisson's ratio:** 0.25

**Allow fracture interpenetration:** No

**Total number of inverted variable:** 9

**Sources definition:** 1\_Dyke

**Source Mesh Size (m):** 200

Dip (0-90°)		Shear (-80-80°)		Botelv (m)		Botlen (0.1-10)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
0		-80		-3000		0.2	
90		80		3000		10	

Twist (-70-70°)		Botang (-45-45°)		Dtop (>= 0 m)		Botcurv (-60-60°)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
-70		-45		100		0	
70		45		1000		60	

Vertcurv (-60-60°)	
Inverted	Fixed
0	
60	

**Visualizations:** Four 3D mesh views showing fracture types: Dip, Shear, Twist, and Botlen. Each view includes coordinate axes (z, strike, North, East) and labels for fracture parameters like Vertcurv, Botelv, Botcurv, Botang, and Dtop.

**Number of inverted parameters:** 9

**Go to topography mesh**

# Sources definition: Default source location

For blind sources, the default source location range corresponds to the data center  $\pm 2$  km

Software interface showing source definition parameters and a 3D diagram of an ellipsoid source model.

**Pressure:**  (dropdown menu open showing options: cst & 1 value for all data, cst & 1 value for each data parameter, Quadrangle normal and shear stress, Sphere, Ellipsoid, Planar ellipsoid)

**Elastic properties:** Homogeneous

**Young's module (MPa):** 5000

**Poisson's ratio:** 0.25

**Allow fracture interpenetration:** Yes

**Total number of inverted variable:** 9

**Sources list (1 sources):** Ellipsoid

**Tessellation Level:** 1 (80 triangles)

Center E-coordinate (m)		Center N-coordinate (m)		Center Z-coordinate (m)		Semi-axis 1 (100-5000m)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
	366000		7648400		-5000		100
	370000		7652400		0		5000

Semi-axis 2 (100-5000m)		Semi-axis 3 (100-5000m)		Dipdir (0-90°)		Dip (0-90°)	
Inverted	Fixed	Inverted	Fixed	Inverted	Fixed	Inverted	Fixed
	100		100		0		0
	5000		5000		90		90

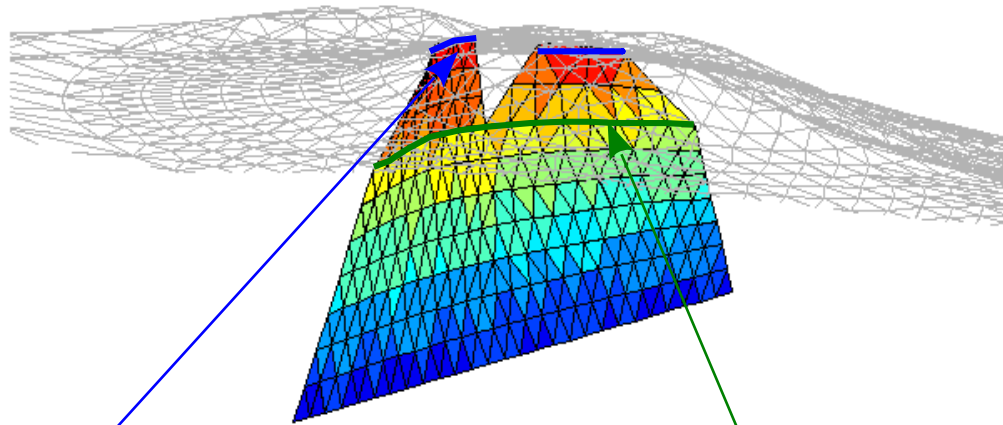
Rotang (0-90°)	
Inverted	Fixed
	0
	90

**Number of inverted parameters:** 9

**Go to topography mesh**

# Topography Mesh: case of an eruptive dyke

Two fractures are required a surface fracture and a quadrangle upper edge



**Fracture definition**

Open unwrapped interfero or coherence file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/interf\_unw\_17823\_18658\_orc\_TRSXD.r4 Loading of header successful

Columns: 2400   Lines: 2000   X Lower left corner (m): 358958.75   Y Lower left corner (m): 7657924.75   X interval (m): 7.5   Y interval (m): 7.5   Unit: meters   Wrap: Unwrap

None    Add Mask    Add DEM

---

**Surface fracture**

Load file   User defined

Echelon :

Add point   Modify point

Remove point   Remove all points

Reorder from South to North

**Define surface fracture / quadrangle upper edge**

360 362 364 366 368 370 372 374 376

7656 7654 7652 7650 7648 7646 7644

50 0 -50 -100 -150

Select rectangular zoom a...   Return to initial zoom

**Quadrangle upper edge**

Same as surface fracture

Load file   User defined

Add point   Modify point

Remove point   Remove all points

Reorder from South to North

Save upper edge

keep    vari    parameter

**Connexion between surface fracture and upper quadrangle**

keep

vari

Length ratio, p, is inverted

$p = l1/(l1+l2)$

Cancel   Prepare mesh

# Topography Mesh: case of an eruptive dyke

**Load File:** The surface fracture (fract\_a.dat) can be loaded from a file.

```
cayol@empnetlmv004:~/MATLAB/DEFVOLC/defvolc_gitlab/Inversions/test$ more fract_a.dat
5 1
367573.80 7647642.30
367505.01 7647709.75
367433.72 7647774.57
367358.67 7647833.67
367303.40 7647912.60
4 1
367123.20 7647948.70
367046.17 7648022.34
366974.70 7648101.16
366907.00 7648183.00
```

A file of east and north coordinates (meters), constructed from observatory data for instance. Each fissure (here there are two) starts with the number of points used to define the fissure + a “1”

**Fracture definition**

Open unwrapped interfero or coherence file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/interf\_unw\_17823\_18658\_ort\_TRSXD.r4 Loading of header successful

Columns: 2400 Lines: 2000 X Lower left corner (m): 358958.75 Y Lower left corner (m): 7657924.75 X interval (m): 7.5 Y interval (m): 7.5 Unit: meters Wrap: Unwrap

None  Add Mask  Add DEM

**Surface fracture**

Load file

User defined

Echelon :

Add point

Modify point

Remove point

Remove all points

Reorder from South to North

Interpolate and proceed

**Define surface fracture / quadrangle upper edge**

360 362 364 366 368 370 372 374 376

7644 7646 7648 7650 7652 7654 7656

Select rectangular zoom a... Return to initial zoom

**Quadrangle upper edge**

Same as surface fracture

Load file

User defined

Add point

Modify point

Remove point

Remove all points

Reorder from South to North

Save upper edge

keep  vari  parameter

**Connexion between surface fracture and upper quadrangle**

d\_top keep

d\_top vari

d\_top

l1 l2

p = l1/(l1+l2) Length ratio, p, is inverted

Cancel Prepare mesh

# Topography Mesh: eruptive fissure

User defined: defined from the data by clicking

Possibility to see the data wrapped

**Fracture definition**

Open unwrapped interfero or coherence file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/Pdf\_Oct2010/interf\_unw\_17823\_18658\_ort\_TRSXD.r4

Columns: 2400 Lines: 2000 X Lower left corner (m): 358958.75 Y Lower left corner (m): 7657924.75 X interval (m): 7.5 Y interval (m): 7.5 Unit: radians Half wavelength: C (2.8 cm) Wrap: Wrap

None  Add Mask  Add DEM

**Surface fracture**

Define surface fracture / quadrangle upper edge

Load file User defined

Echelon :

7649  
7648.5  
7648  
7647.5  
7647  
7646.5

365 365.5 366 366.5 367 367.5 368 368.5 369 369.5

Reorder from South to North

Interpolate and proceed

Select rectangular zoom a... Return to initial zoom

**Quadrangle upper edge**

Same as surface fracture

Load file User defined

Reorder from South to North

Save upper edge

keep  vari  parameter

Connexion between surface fracture and upper quadrangle

keep

vari

Length ratio, p, is inverted

$p = l_1 / (l_1 + l_2)$

Cancel Prepare mesh

Possibility to zoom

# Topography Mesh: eruptive fissure

User defined: defined from the data

Fracture definition

Open unwrapped interfero or coherence file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/Pdf\_Oct2010/interf\_unw\_17823\_18658\_ort\_TRSXD.r4

Columns: 2400, Lines: 2000, X Lower left corner (m): 358958.75, Y Lower left corner (m): 7657924.75, X interval (m): 7.5, Y interval (m): 7.5, Unit: radians, Half wavelength: C (2.8 cm), Wrap: Wrap

None, Add Mask, Add DEM

Surface fracture

Number of echelons: 2, To be reinterpolated with step (m): 100

Echelon: 1 | 2, Number of points: 5

Define surface fracture / quadrangle upper edge

Quadrangle upper edge

Same as surface fracture, Load file, User defined

Connexion between surface fracture and upper quadrangle

keep, vari, parameter

Interpolate and proceed

Dips are positive for eastward dipping fractures provided the fissures are defined from South to North

Interpolate to regular spaced points and save in fract\_a.dat

# Topography Mesh: quadrangle upper edge

Same as surface fracture

Load file: loaded from a file having a list of East and North coordinates (in m)

```
cayol@empmetlmv004:~/MATLAB/DEFVOLC/defvolc_gitlab/Inversions/test$ more fract_b.dat
367428.1      7647662.9
367369.1      7647746.6
367293.6      7647815.9
367219.2      7647886.3
367147.1      7647959.1
367077.3      7648034.2
367006        7648107.7
366918.1      7648160.4
```

User defined: define the fracture by clicking

**Fracture definition**

Open unwrapped interfero or coherence file: /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/interf\_unw\_17823\_18658\_ort\_TRSXD.r4 Loading of header successful

Columns: 2400 Lines: 2000 X Lower left corner (m): 358958.75 Y Lower left corner (m): 7657924.75 X interval (m): 7.5 Y interval (m): 7.5 Unit: radians Half wavelength: C (2.8 cm) Wrap: Wrap

None  Add Mask  Add DEM

**Surface fracture**

Number of echelons: 2  
To be reinterpolated with step (m): 100  
Confirm

Echelon: 1 2  
Number of points: 5  
Select points  
Add point  
Modify point  
Remove point  
Remove all points

Reorder from South to North

Cancel all echelons **Interpolate and proceed**

**Define surface fracture / quadrangle upper edge**

**Quadrangle upper edge**

Same as surface fracture  
 Load file  
 User defined

Add point  
Modify point  
Remove point  
Remove all points

Reorder from South to North

Save upper edge

keep  vari  parameter

Connexion between surface fracture and upper quadrangle

keep  
vari  
Length ratio, p, is inverted  
 $p = l1/(l1+l2)$

Cancel **Prepare mesh**

# Topography Mesh: quadrangle upper edge

3 types of connections between the surface fracture and the quadrangle upper edge

The screenshot displays the 'Fracture definition' software interface. At the top, the title 'Fracture definition' is in blue. Below it, a file path is shown: `/home/cayol/MATLAB/DEFVOLC/defvolc_gitlab/Data/PdF_Oct2010/interf_unw_17823_18658_ort_TRSXD.r4`. A status message on the right says 'Loading of header successful'.

Parameters for the topography mesh are set as follows:  
Columns: 2400, Lines: 2000  
X Lower left corner (m): 358958.75, Y Lower left corner (m): 7657924.75  
X interval (m): 7.5, Y interval (m): 7.5  
Unit: radians, Half wavelength: C (2.8 cm), Wrap: Wrap

Options for mask and DEM are:  None,  Add Mask,  Add DEM

The main interface is divided into three panels:  
1. **Surface fracture**: Includes 'Number of echelons' (2), 'To be reinterpolated with step (m):' (100), and a list of points for 'Echelon 1' and 'Echelon 2'. A central map shows a topographic contour plot with a blue line representing the surface fracture. The map axes range from 365 to 369.5 on the x-axis and 7646.5 to 7649 on the y-axis.  
2. **Quadrangle upper edge**: Includes 'Same as surface fracture', 'Load file', and 'User defined' options. It also has 'Add point', 'Modify point', 'Remove point', and 'Remove all points' buttons.  
3. **Connexion between surface fracture and upper quadrangle**: Shows three options: 'keep', 'vari', and 'parameter'. The 'keep' option shows a dashed line connecting the fracture to the quadrangle. The 'vari' option shows a similar connection with a different geometry. The 'parameter' option shows a connection with a length ratio  $p = l1/(l1+l2)$  and a note 'Length ratio, p, is inverted'. It also has 'Add point', 'Modify point', 'Remove point', and 'Remove all points' buttons.

At the bottom, there are buttons for 'Cancel all echelons', 'Interpolate and proceed', 'Select rectangular zoom a...', 'Return to initial zoom', 'Save upper edge', 'Cancel', and 'Prepare mesh'.



# Topography Mesh: quadrangle upper edge

Data preparation | Model definition | **Topography mesh** | Inversion parameter | Inversion | Results visualization

## Mesh creation: discretization

X Mesh center (m)  Y Mesh center (m)  Radius Fine Mesh (m)  Radius Coarse Mesh (m)  Mesh interval (m)

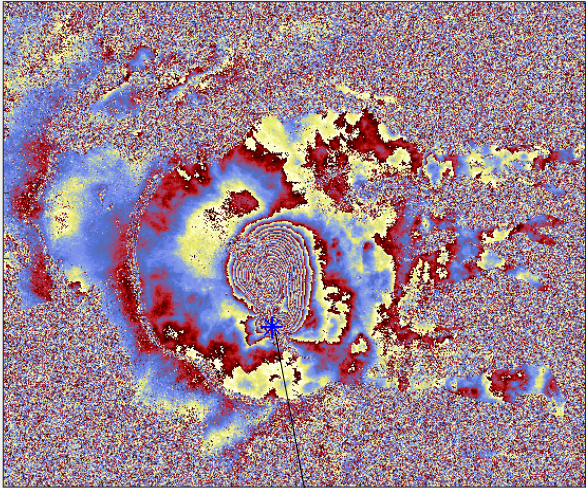
Select mesh element  
Boundary element

Number of mesh nodes  
0

Number of mesh elements  
0

X mesh center  
0

Y mesh center  
0

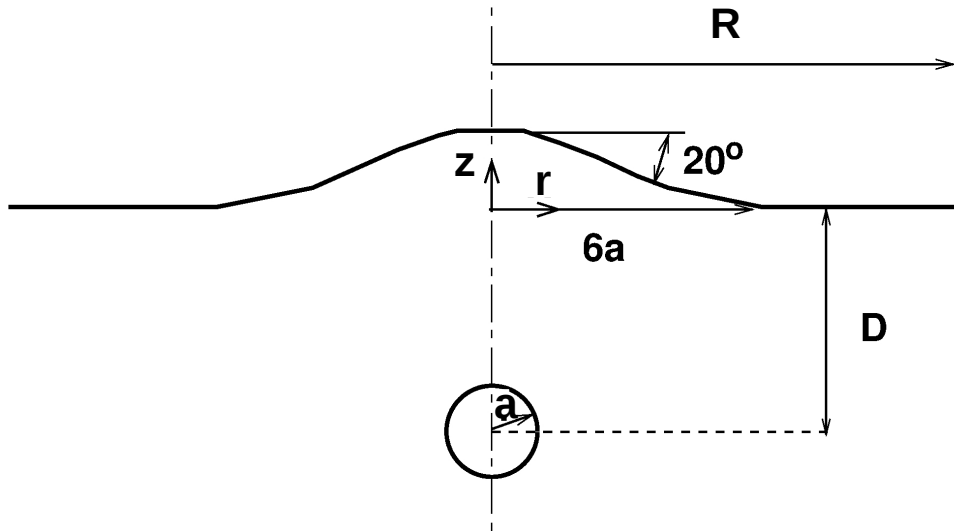


Default mesh center location is the centroid of eruptive fissures (fract\_a.dat)  
An other mesh center can be determined

# Rule of thumb for edge effects

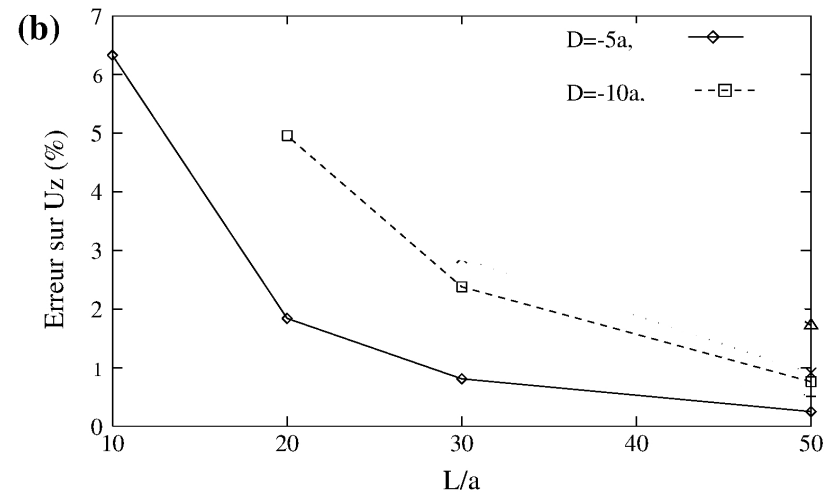
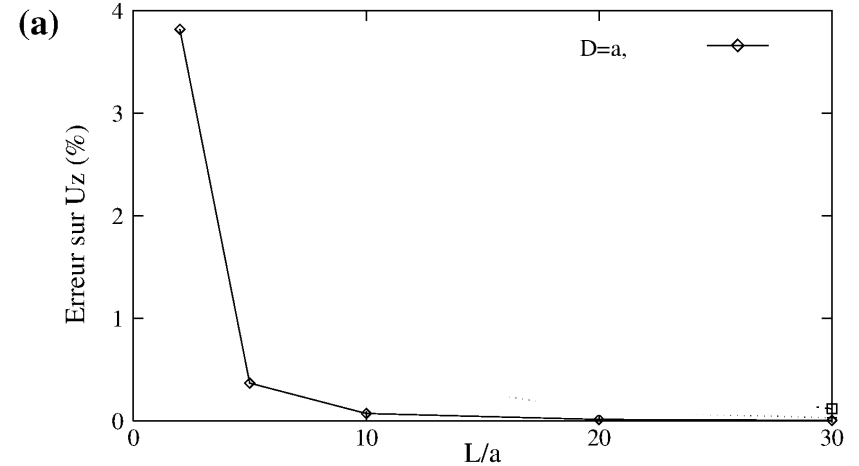
Rule of thumb: no edge effect for topography mesh radii  $>$  five times the source dimension

Practically :



For sources at the ground surface (fissural dykes, this rule applies (Err Uz  $\sim$  0.5%)

For sources at  $D > 5a$ , it is better to have  $L > 10a$  (Err Uz = 6% for  $D = 5a$ )



(Cayol, PhD, 1996)

# Topography Mesh: Mesh creation when eruptive fracture

Default **Radius fine mesh** is  $2 \times$  distance between mesh center and most distant fissure point  
Default **Radius coarse mesh** is  $6 \times$  times the **Radius fine mesh**

Data preparation | Model definition | **Topography mesh** | Inversion parameter | Inversion | Results visualization

### Mesh creation: discretization

X Mesh center (m)  Y Mesh center (m)  Radius Fine Mesh (m)  Radius Coarse Mesh (m)  Mesh interval (m)

Select other mesh center

Open DEM  /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/reunion\_IGN\_gWGS84\_1255X1159.grd

Give topography mesh name  /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/test/topo.ex3

Select mesh element

Boundary element

Create topography mesh

Number of mesh nodes	1203
Number of mesh elements	2402
X mesh center	367204
Y mesh center	7.64933e+06

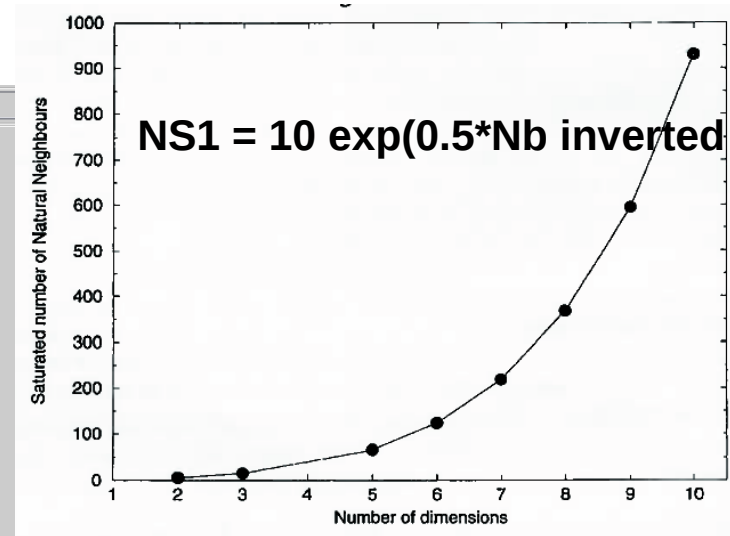
Return to fracture definition

Go to inversion parameter

Generates a topography mesh file with a default name /Inversions/RunDir/topo.ex3.  
Name can be changed, but the extension has to be .ex3

# Inversion parameters

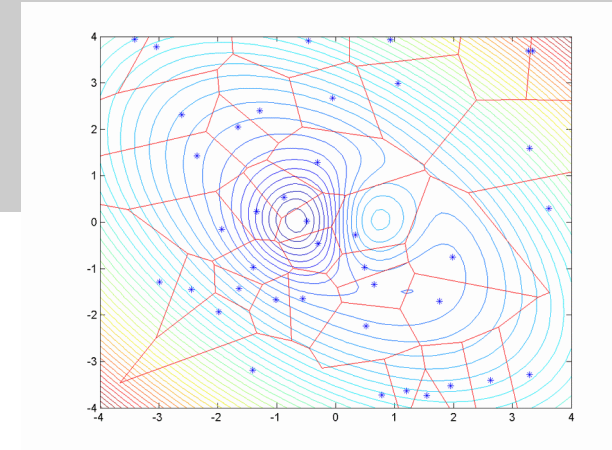
Data preparation	Model definition	Topography mesh	Inversion parameter
<b>First iteration</b>			
Sample size for first iteration	<input type="text" value="378"/>		
<b>Other iterations</b>			
Sample size for other iterations	<input type="text" value="50"/>		
Number of Voronoi cells to resample	<input type="text" value="50"/>		
<b>Stop criteria</b>			
Number of last misfit values that are used to evaluate the standard deviation	<input type="text" value="50"/>		
Maximum number of iterations	<input type="text" value="300"/>		
Standard deviation threshold	<input type="text" value="0.05"/>		
<b>Launching parameters</b>			
Number of processors to use	<input type="text" value="10"/>	<input type="button" value="Evaluate number of processors on local machine"/>	



$$NS1 = 10 \exp(0.5 * N_b \text{ inverted parameters})$$

Sambridge, Inverse Problems, 1998

$$NS2 = NR = 50 \text{ (see Fukushima et al., 2005)}$$

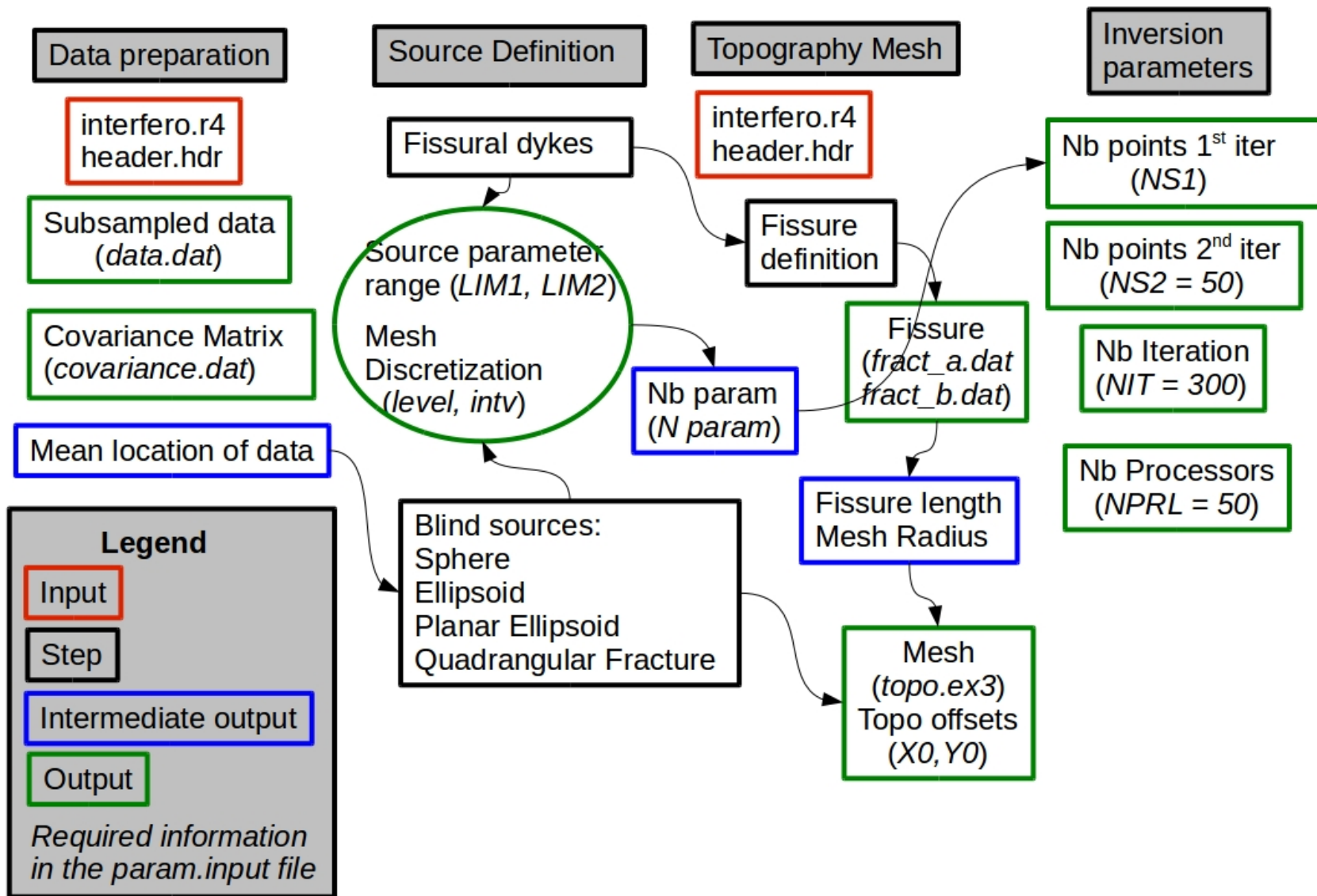


inversion & launch

Iterations stop when one of the following criteria is reached :

- maximum number of iterations
- standard deviation of the misfit
- standard deviation on the parameters normalized by their search interval

# Summary flow chart for the 4 steps of inversion preparation



# Inversion and appraisal

Data preparation | Model definition | Topography mesh | Inversion parameter | **Inversion** | Results visualization

## Summary

Sample size for first iteration: **944** | Sample size for other iterations: **50** | Number of cells to resample: **50** | Maximum number of iterations: **300**

Surface fracture (\*): ...

Quadrangle upper edge (\*): **fract\_b.dat**

Topography file: **topo.ex3**

Data file: **data.dat**

Covariance matrix file: **covariance.dat**

**Generate input files for inversion**  
Generate input files before launching inversion

**Launch inversion on local machine**

**Test mean model and evaluate run time**

**Appraise results on local machine**

**Current inversion processing :**

```
Compute mean model and evaluate run time
*****
*      NA_MBEM      *
*  NA Inversion + MBEM  *
*  Version 1.9, 2015    *
*                    *
* (c) Yo Fukushima, V. Cayol *
* M. Tridon, D. Smittarello *
* Laboratoire Magmas et Volcans *
* 5 rue Kessler *
* 63038 Clermont-Ferrand Cedex *
* France *
*                    *
*****

Inversion launched at 14-Oct-2019 17:56:29
Model parameter values are :
45  0  0  5.1  0  0  550  30  30  10.25

Estimated run time on UCA mesocenter cluster 1.6402 hours

Pres_shift_file successfully written
With weighting by covariance matrix :
Misfit = 3588.8011 - Misfit percent = 117.0875 - RMS error = 0.08978 m
```

Runs inversion corresponding to files in ~/Inversion/RunDir/ A binary file named **result.nares** is created, as well as an ascii file with boundary displacement of the best model (/inversion/RunDir/**best\_mode.res**)

- Runs computation of mean model
  - Prints meshes, openings, shear displacement, displacement vectors, Model-Data-Residuals at subsampled points.
  - Based on this forward model, evaluates inversion duration
- After the inversion has been completed, runs the appraisal. A file named **resamp\_result.nares** is created

Generates ~/Inversion/RunDir/param.input file

# Saving the different steps

At any moment, the different steps can be saved in an ascii file. The default save file is names /Inversions/RunDir/date\_time.save

The screenshot shows the software interface with the 'Inversion' step selected in the top navigation bar. The 'Summary' section displays the following parameters:

- Sample size for first iteration: 378
- Sample size for other iterations: 50
- Number of cells to resample: 50
- Maximum number of iterations: 300

Input files for various steps are listed:

- Surface fracture (\*): fract\_a.dat
- Quadrangle upper edge (\*): fract\_b.dat
- Topography file: topo.ex3
- Data file: data.dat
- Covariance matrix file: covariance.dat

At the bottom, there are four buttons: 'Generate input files for inversion', 'Test mean model and evaluate run time', 'Launch inversion on local machine', and 'Appraise results on local machine'. The 'Generate input files for inversion' button has a sub-label 'Generate input files before launching inversion'.

The terminal window on the right shows the following output:

```
Current inversion processing :
Compute mean model and evaluate run time
*****
*
* NA_MBEM *
* NA Inversion + MBEM *
* Version 1.9, 2015 *
*
* (c) Yo Fukushima, V. Cayol *
* M. Tridon, D. Smittarello *
* Laboratoire Magmas et Volcans *
* 5 rue Kessler *
* 63038 Clermont-Ferrand Cedex *
* France *
*
*****
Inversion launched at 15-Oct-2019 16:17:16
Model parameter values are :
3680007.6504e+06 -2500 2550 2550 2550 45 45 45

Estimated run time on UCA mesocenter cluster 23.9675 hours

Pres_shift_file successfully written
With weighting by covariance matrix :
Misfit = 6368.0661 - Misfit percent = 97.391 - RMS error = 0.19006 m

Source number 1
```



# Running inversions and appraisal on the UCA clusters

Register on defvolc at <http://www.opgc.fr/defvolc/>

The screenshot displays the DefVolc web application interface. At the top, there is a navigation bar with links for "About", "FAQ", "Sign In", and "Register". Below this, the main heading reads "Welcome to DefVolc" followed by the subtitle "3D inverse modelling of deformation data". A "Proceed" button is centered below the text. The main content area features three panels: (a) a topographic map showing a "SW depression" and a "Pit crater" with a blue dot indicating a location; (b) a vertical cross-section plot of "Volume change (10<sup>6</sup> m<sup>3</sup>)" versus "Depth (km)", showing a red and yellow volume change structure; and (c) a horizontal cross-section plot of "Volume change (10<sup>6</sup> m<sup>3</sup>)" versus "East (km)", also showing a red and yellow volume change structure. A color scale legend for "Volume change (10<sup>6</sup> m<sup>3</sup>)" is provided, ranging from -1.6 (blue) to 0.8 (red). At the bottom of the page, a note states "DefVolc will be released on June 3rd 2019".



# Running inversions on the UCA clusters

Admin Edit About FAQ  

## Download this presentation

1 - To prepare and visualize inversions, you will need to pre-process the calculation on your computer with the DefVolc pre- and post-processor. If you do not already have it, download it below:

[Download user's manual](#) [Click here to Download pre-post-processor](#)

---

2 - If you choose our on-demand service, you can next run inversion on your own cluster or on the clusters of UCA computation center. On these clusters, you can run up to 3 simultaneous inversions, each using a maximum of 50 cores. Inversions should not last more than 72 hours.

[Launch inversion and appraisal](#)

[Check inversions in progress](#) [Download results of completed inversions](#)

---

3 - After downloading your results and placing them in your inversion directory, you can visualize them with the DefVolc pre- and post-processor

# Launch inversion and appraisal

www.opgc.fr/defvolc/Vue/ComputingPage.php

Boîte de réception (8... Google Agenda Google Contacts bibCNRS INSU Google Scholar 3.63 MB: ENT de l'Uni... Dashboard DEFVOLC LMV | Laboratoire Ma... Moteur de recherch...

Home Admin Edit About FAQ

**Warning!** You can run up to 3 simultaneous inversions on UCA computation center. Duration estimated using the pre- and post-processor should be less than 72 hours.

Give inversion name

Upload the files generated by the pre and post processor

1. Defvolc inversion and model characteristics	1. Upload param.input
2. Topography mesh file	2. Upload *.ex3
3. Data file	3. Upload data.dat
4. Covariance file	4. Upload covariance.dat
5. Surface fractures (*)	5. Upload fract_a.dat
6. Quadrangle upper edge (*)	6. Upload fract_b.dat

\*Required when inverting a dyke connected to the ground

The inversion duration is estimated from the pre- and post- processor in the inversion tab (in hours)

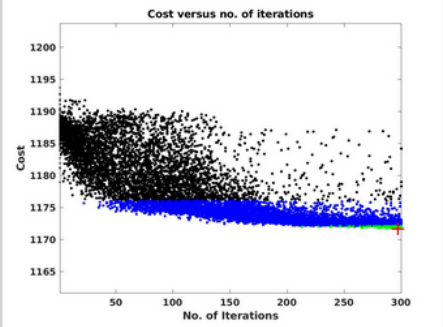
# Check inversion in progress

www.opgc.fr/defvolc/Vue/PageResultInProgress.php

Boîte de réception (8... 23 Google Agenda Google Contacts bibCNRS INSU Google Scholar 3.63 MB: ENT de l'Uni... Dashboard DEFVOLC LMV | Laboratoire Ma... Moteur de recherch...

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Inversions in progress:  Inversion failed or interrupted.




Cost versus no. of iterations

The scatter plot displays the relationship between the number of iterations (x-axis, 0 to 300) and the cost (y-axis, 1165 to 1200). The data points show a general downward trend, with a dense cluster of points between 50 and 150 iterations, where the cost fluctuates between 1175 and 1190. A horizontal line is drawn at a cost of approximately 1172, and the data points below this line are highlighted in blue. A vertical red line is positioned at approximately 280 iterations, indicating the current state of the inversion process.

*DefVolc has been released on June 3rd 2019*

# Download results of completed inversions


The screenshot shows a web browser window with the URL `www.opgc.fr/defvolc/Vue/PageResult.php`. The page content includes a navigation bar with 'Home', 'Admin Edit', 'About', and 'FAQ'. Below the navigation bar, there is a section titled 'Completed inversions:' with a dropdown menu set to 'Reunion\_Oct2018\_MDIS' and a 'Refresh' button. Three buttons are visible: 'Check progress', 'Download result', and 'Delete inversion'. An arrow points from the 'Download result' button to a file dialog box titled 'Opening Reunion\_Oct2018\_MDIS.tar'. The dialog box displays the file name 'Reunion\_Oct2018\_MDIS.tar', its size (4.8 MB), and its source (http://www.opgc.fr). It asks 'What should Firefox do with this file?' and has three options: 'Open with Archive Manager (default)', 'Save File' (which is selected), and 'Do this automatically for files like this from now on.'. 'Cancel' and 'OK' buttons are at the bottom of the dialog.

Completed inversions: Reunion\_Oct2018\_MDIS 

Check progress Download result Delete inversion

Opening Reunion\_Oct2018\_MDIS.tar

You have chosen to open:

-  **Reunion\_Oct2018\_MDIS.tar**  
which is: Tar archive (4.8 MB)  
from: http://www.opgc.fr

What should Firefox do with this file?

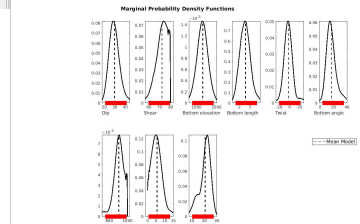
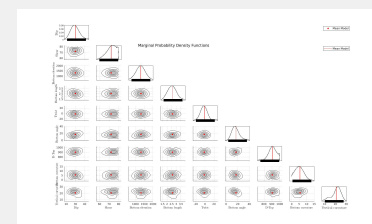
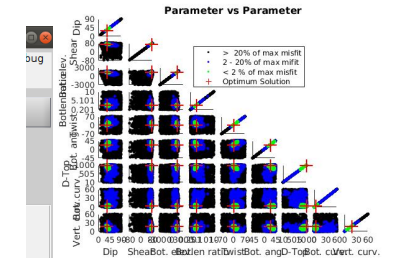
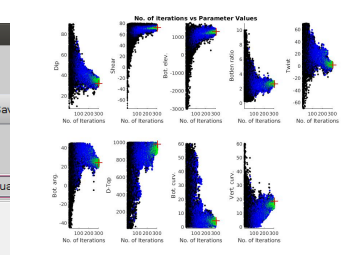
- Open with Archive Manager (default)
- Save File
- Do this automatically for files like this from now on.

Cancel OK

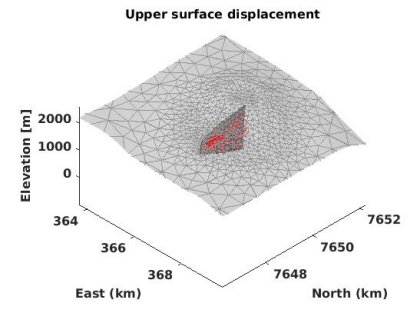
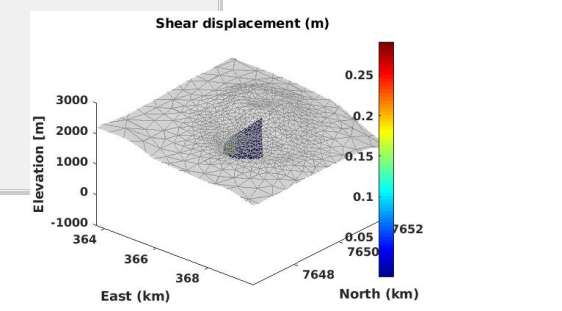
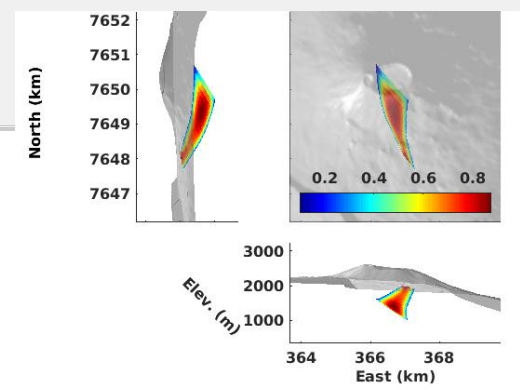
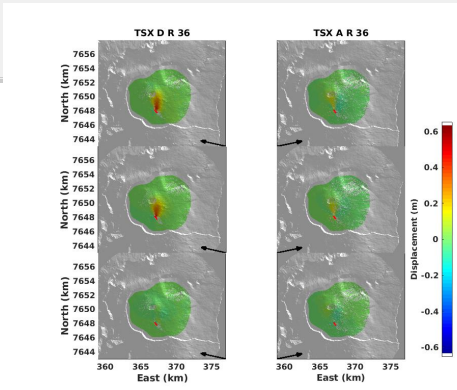
*DefVolc has been released on June 3rd 2019*

# Result visualization

Independant from the other steps: can be used to visualize a previous inversion



etc



# Result visualization: convergence visualization

The image shows a software window titled "Convergence visualization setup". It contains two file selection buttons on the left: "Select .nares file" and "Select param.input file". To the right of the first button is a text field containing the path `/home/cayol/MATLAB/DEFVOLC/MDIS2019/Inversions/PdF_Oct2010_MDIS/result.nares`. To the right of the second button is a text field containing the path `/home/cayol/MATLAB/DEFVOLC/MDIS2019/Inversions/PdF_Oct2010_MDIS/param.input`. At the bottom right is a button labeled "Visualize Convergence".

Annotations with arrows point to the text fields:

- An arrow from "Select .nares file" points to the text: "Binary file generated during the inversion. Contains a list of forward models, with their parameters and misfits".
- An arrow from "Select param.input file" points to the text: "Ascii file generated in the Inversion panel".

Visualize Convergence

# Result visualization: Appraisal visualization

Appraisal setup

Results visualization :

Select param.input file `/home/cayol/MATLAB/DEFVOLC/defvolc_gitlab/Inversions/PdF_Oct2010_MDIS/param.input`

Select resampled nares file `/home/cayol/MATLAB/DEFVOLC/defvolc_gitlab/Inversions/PdF_Oct2010_MDIS/result.nares`

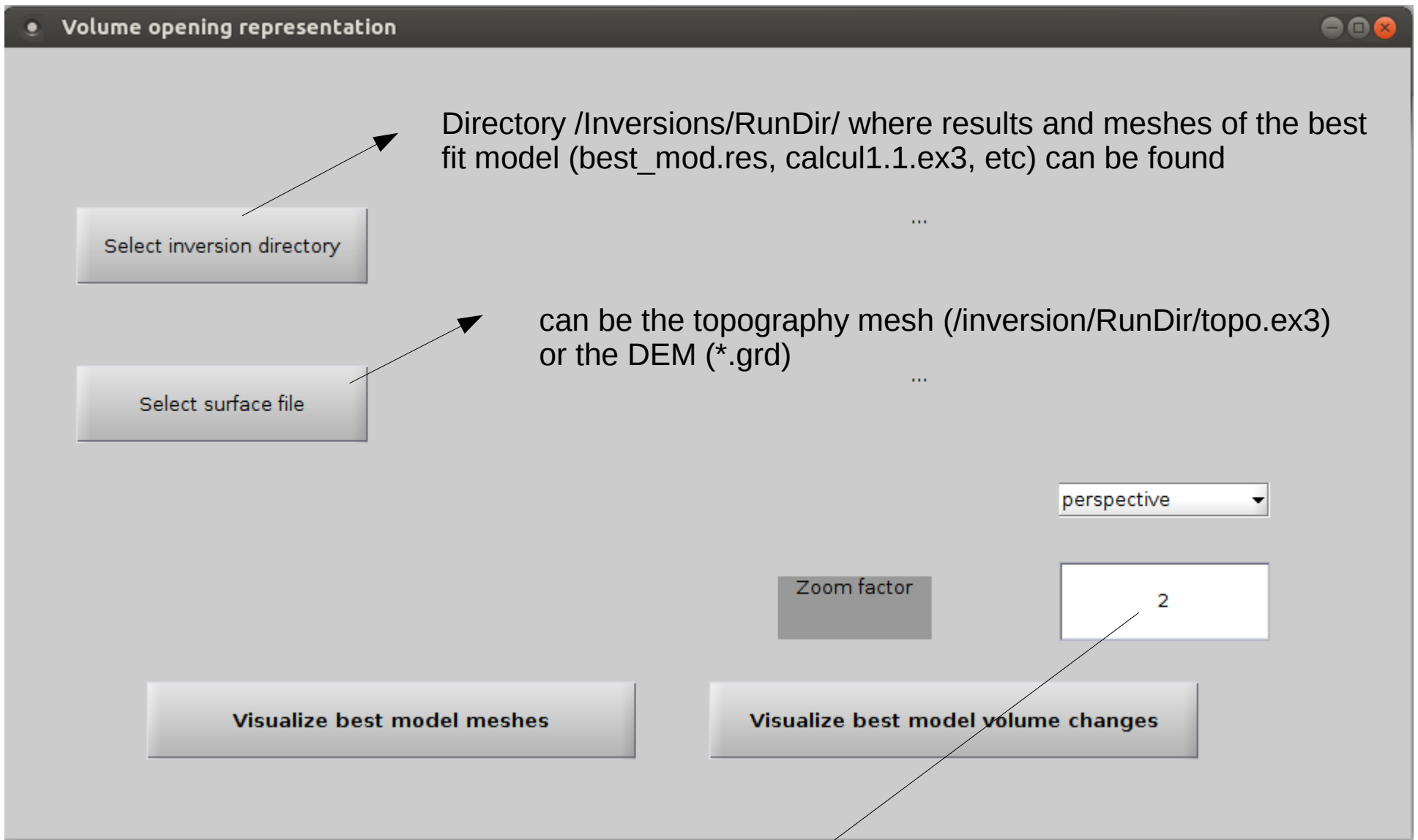
Select the number of figures by screen

Plot max PPD model from original file

Visualize appraisal

File generated during the appraisal step, contains more models generated from the Likelihood of the forward models (See Sambridge, GJI, 1999)

# Result visualization: Volume opening representation



The higher this number the larger the ground surface extension



# Result visualization: data – model comparison

Ascii file where the different steps have been saved (\*.save). From this file the data characteristics are determine

Ascii file corresponding to best-fit model (Inversion/RunDir/best\_model.res), containing boundary displacement

Open .save file /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/PdF\_Oct2010\_MDIS/11-Oct-2019\_15:55:40.save

DEM file /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/reunion\_IGN\_gWGS84\_1255X1159.grd

Topography file /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/PdF\_Oct2010\_MDIS/topo.ex3

Fracture file (Optional) /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/PdF\_Oct2010\_MDIS/fract\_a.dat

Select .res file /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Inversions/PdF\_Oct2010\_MDIS/best\_mod.res

X Mesh Center (offset) (m) 367232 Y Mesh Center (offset) (m) 7649310

X Limits (Min-Max) (km) 359 377 YLimits (Min-Max) (km) 7643 7658

Indicate number of datasets to compare 2

Column\_1 Column\_2

Unwrapped interferogram file /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/interf\_unw\_17823\_18658\_ort\_TRSXD.r4

Mask file (Optional) /home/cayol/MATLAB/DEFVOLC/defvolc\_gitlab/Data/PdF\_Oct2010/mask\_17823\_18658\_tot.raw

Columns 2400 Lines 2000 X Upper left (offset) (m) 358959 Y Upper left (offset) (m) 7.65792e+06 X interval (m) 7.5 Y interval (m) 7.5

Halfwavelength X (1.5 cm) InSAR datas are : Ground displacements Unit radians

Column's title TSX D R 36 Radarlook TSX D R 36 ( 0.59 -0.13 0.80) 0.59 -0.13 0.8

To be shown wrapped

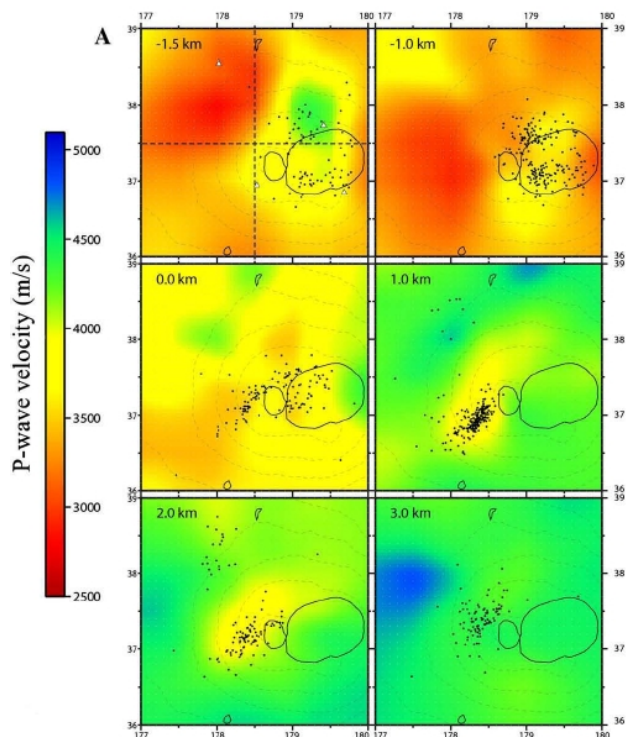
With labels

Compare

# Fictitious domain for fractures in heterogeneous media

## Application to Piton de la Fournaise volcano

P-wave velocity model (Prono et al., JVGR, 2009)

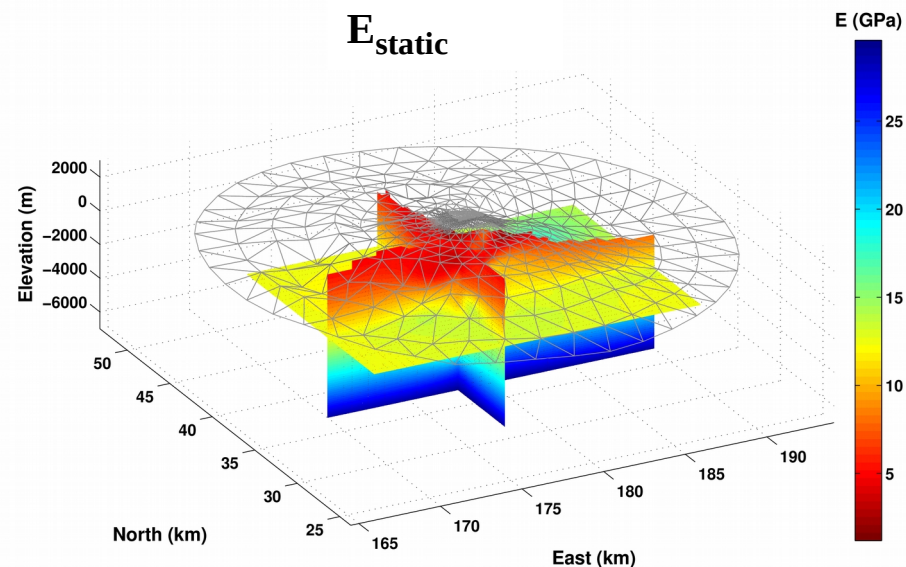


$$E_{\text{dyn}}, \rho, \nu = f(V_p)$$

(Brocher, BSSA, 2005)

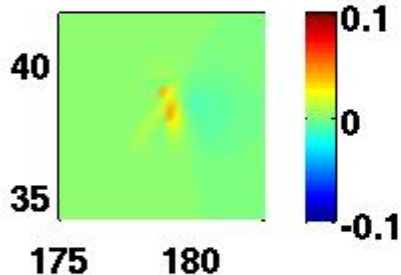
$$E_{\text{static}} = f(E_{\text{dyn}}, P)$$

(Adelinet, GRL, 2010)



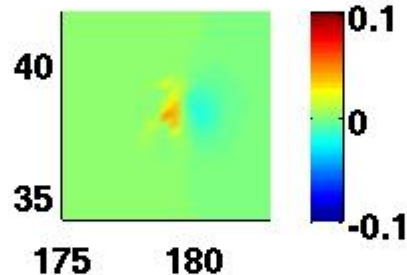
### Comparaison des déplacements de la surface

Homogeneous volcano



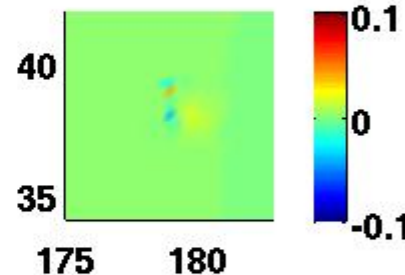
(m)

Heterogeneous volcano



(m)

Difference



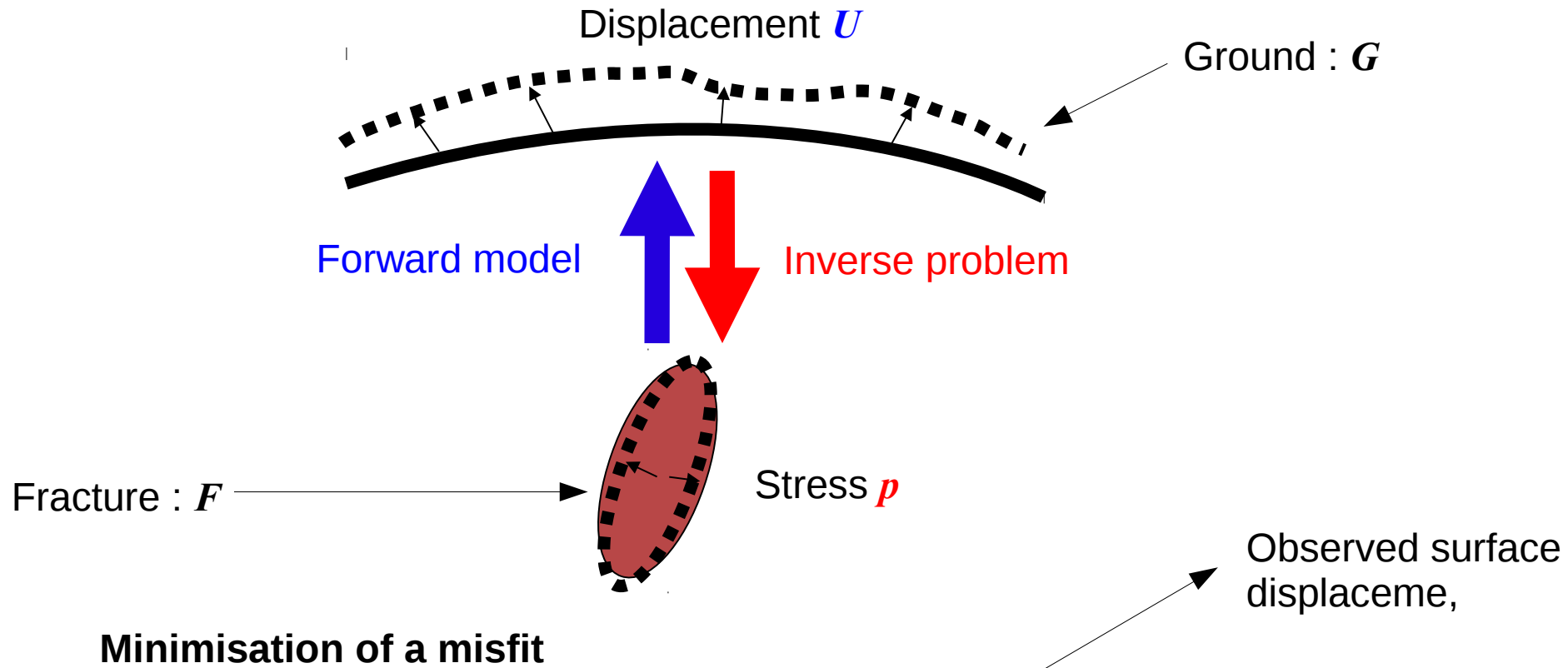
(m)



52 % de différence

# Determination of stress distributions on fractures

Bodart, Cayol, Dabaghi, and Koko, 25DD proceedings



$$J(\mathbf{p}) = \int_G (\mathbf{U} - U_{obs})^T C^{-1} (\mathbf{U} - U_{obs})^T + \alpha \int_F \mathbf{p}^2$$