境界要素法を用いたInSARデータのモデリング：フルネーズ火山噴火に伴うダイク貫入

Modeling InSAR data using a boundary element method: Dike intrusions associated with eruptions at Piton de la Fournaise

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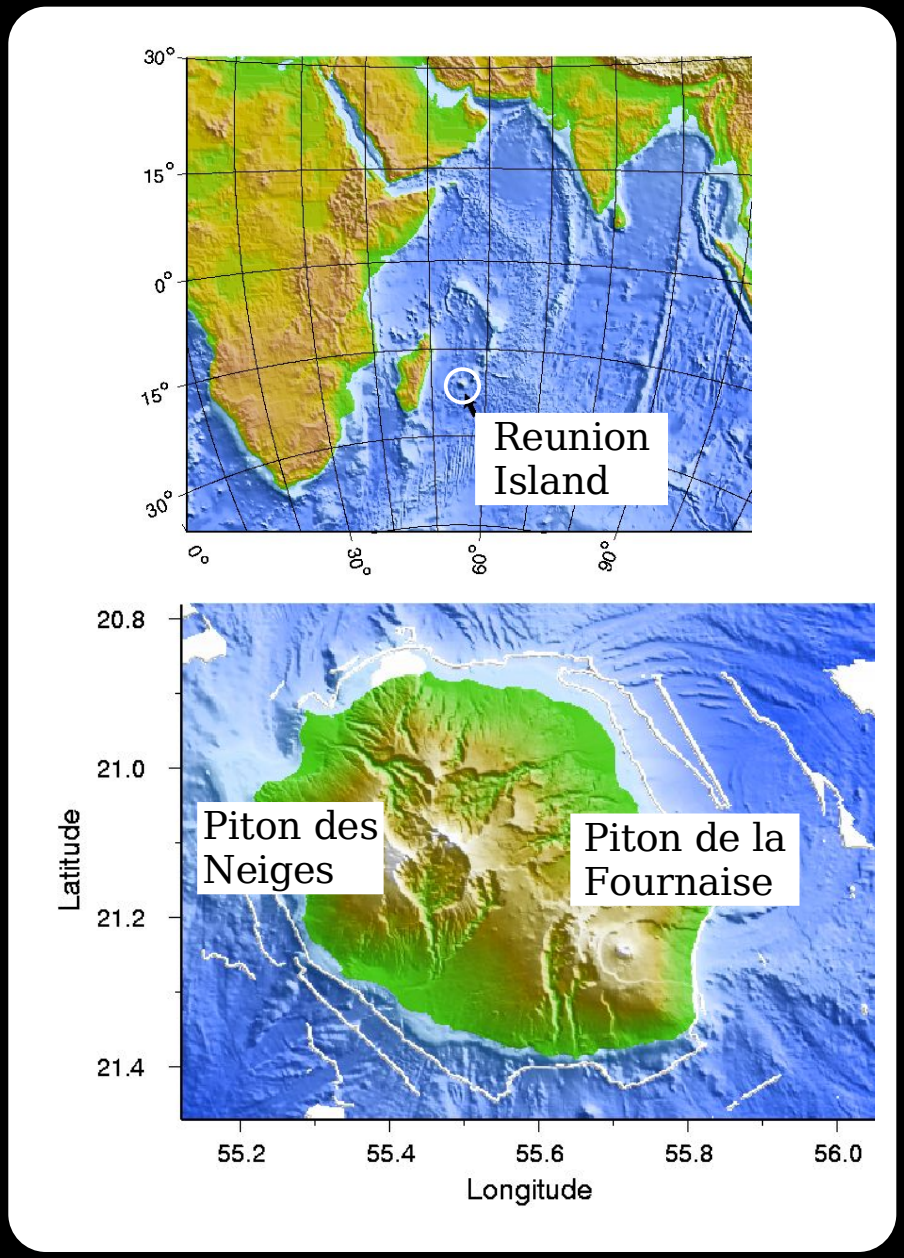
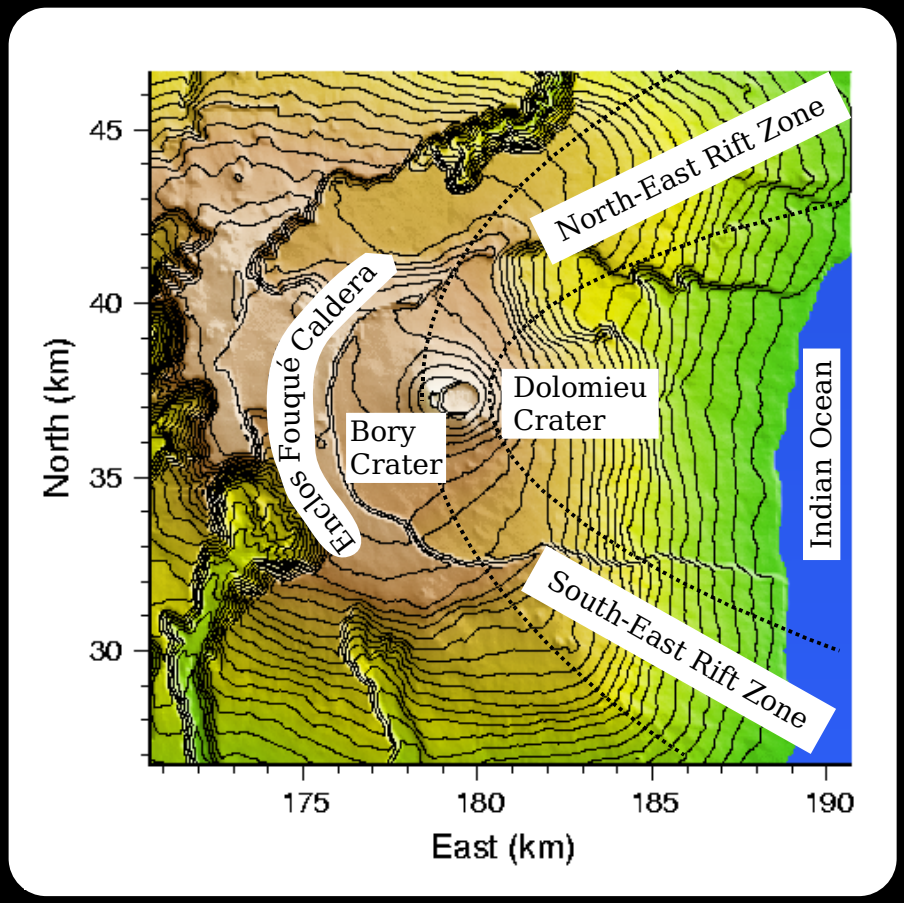
Piton de la Fournaise Volcano





Eruptions at Piton de la Fournaise

Hot spot volcano → Fissure eruptions

Eruption of September 2003

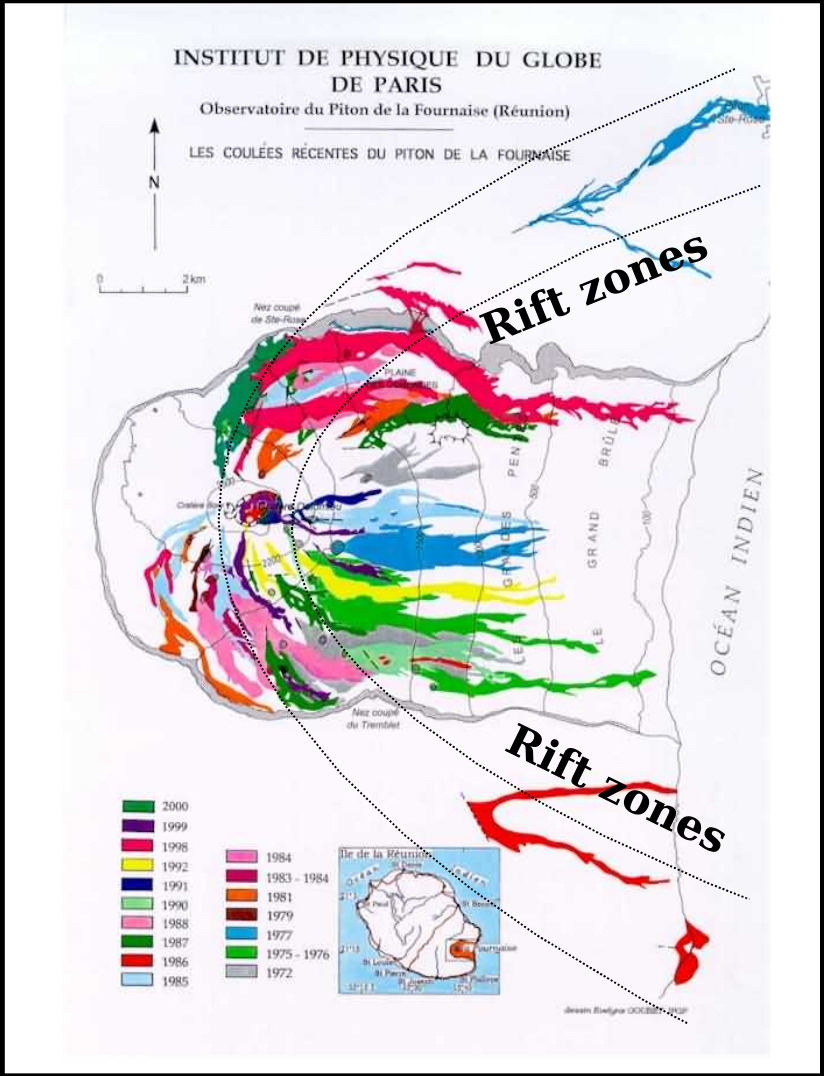
Eruptions at Piton de la Fournaise

Dikes are formed under the ground.

(Photos taken at Piton des Neige volcano)

Eruptions at Piton de la Fournaise

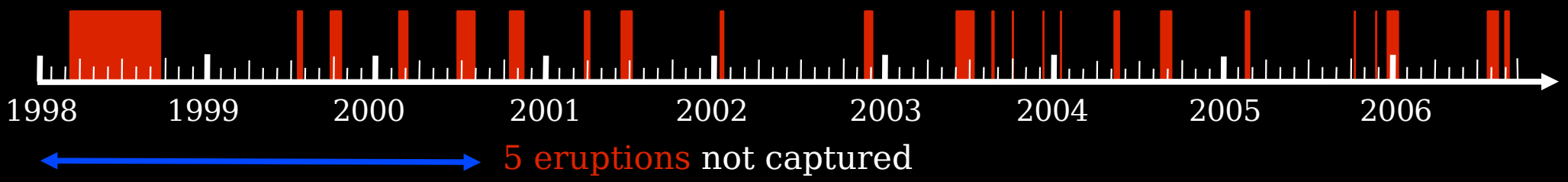
Most of the eruptions occur around the central cone and along the rift zones



Lava flows 1977 - 2000

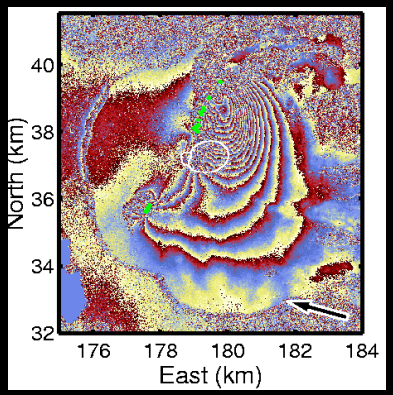
InSAR at Piton de la Fournaise

23 eruptions since 1998

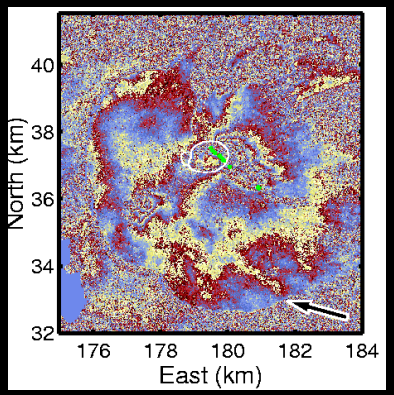


18 interferograms RADARSAT-1
covering 5 eruptions

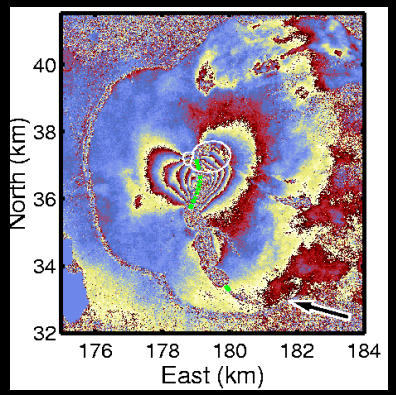
Mar. 1998



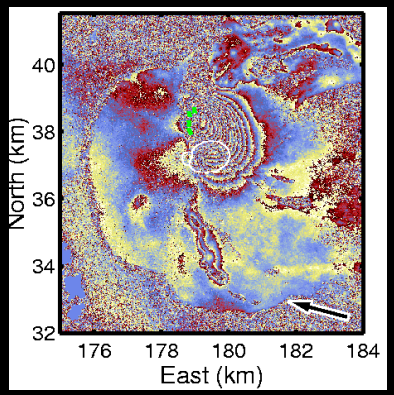
July 1999



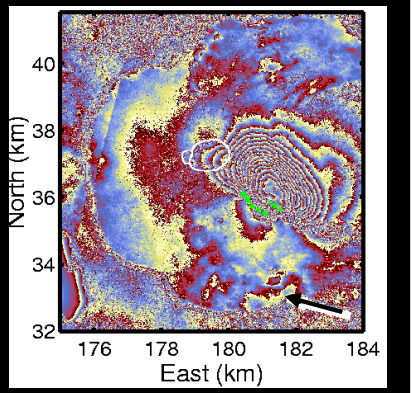
September 1999



February 2000

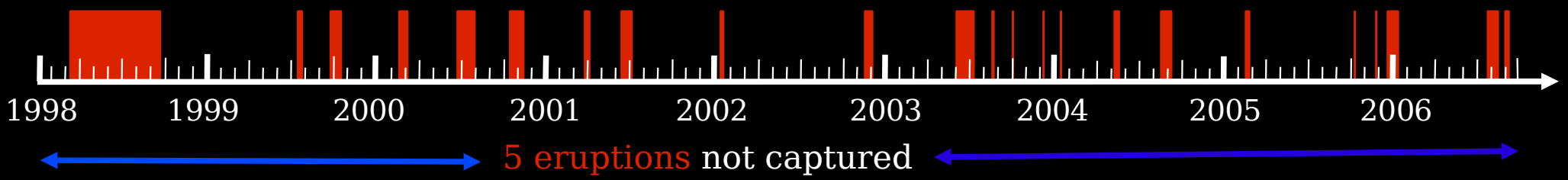


June 2000



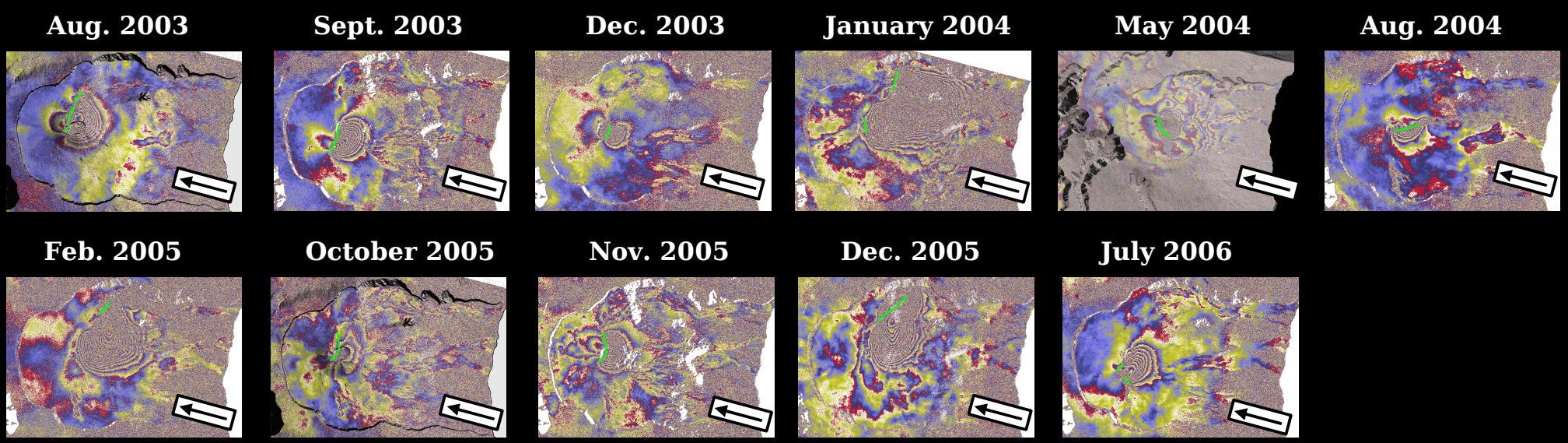
InSAR at Piton de la Fournaise

23 eruptions since 1998



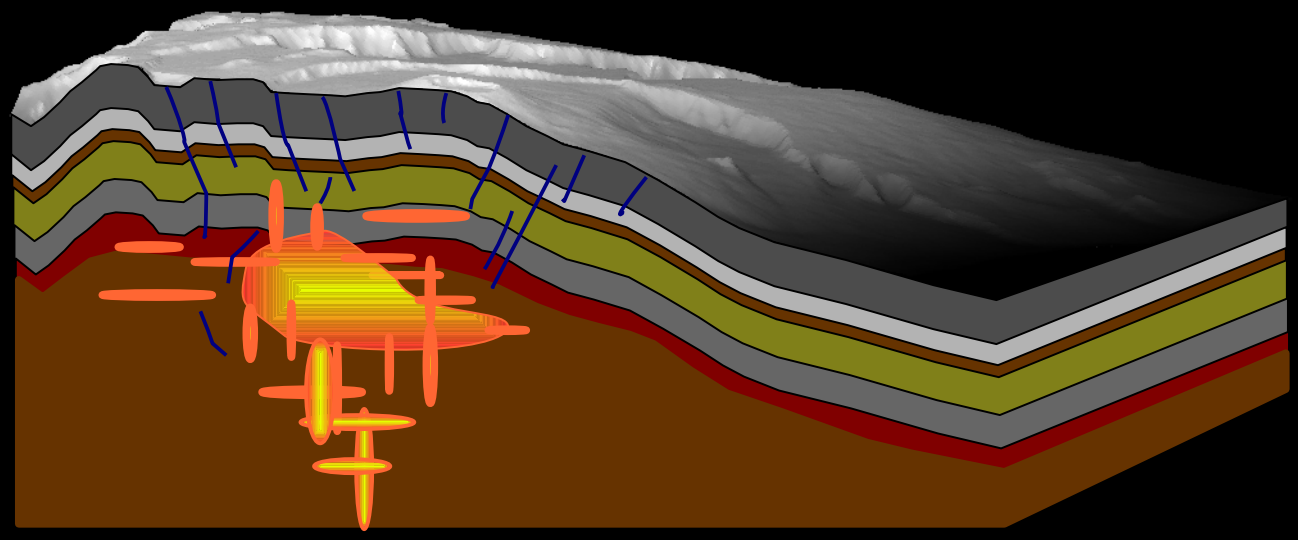
18 interferograms RADARSAT-1
covering 5 eruptions

64 interferograms ENVISAT
covering 11 eruptions

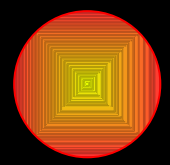


Modeling

Reality

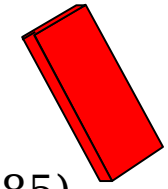


Model



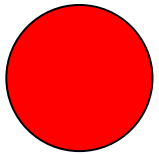
Toward realistic models

Simple models classically used



Uniform opening

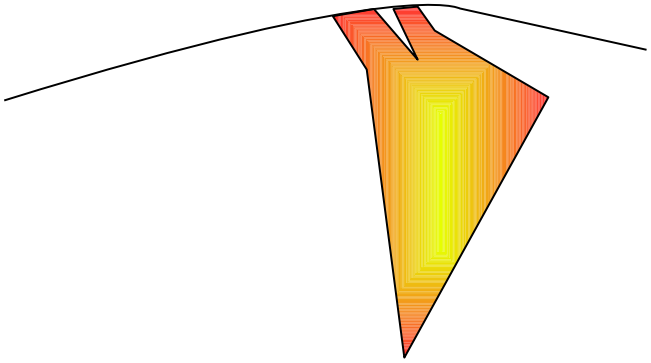
(Okada, 1985)



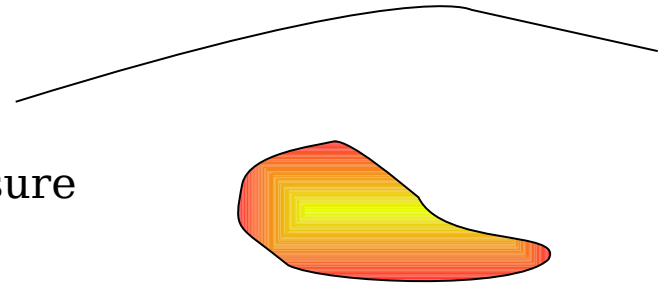
Overpressure

(Mogi, 1958)

InSAR data require more realistic and complex models



Overpressure

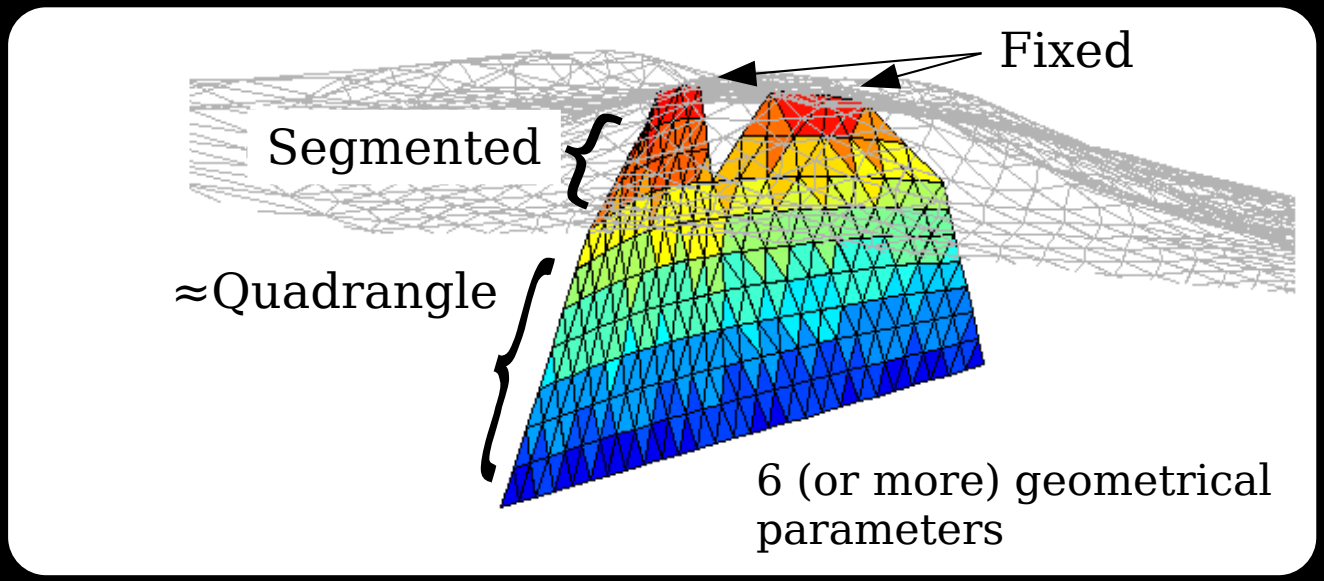


→ **Usage of numerical models**

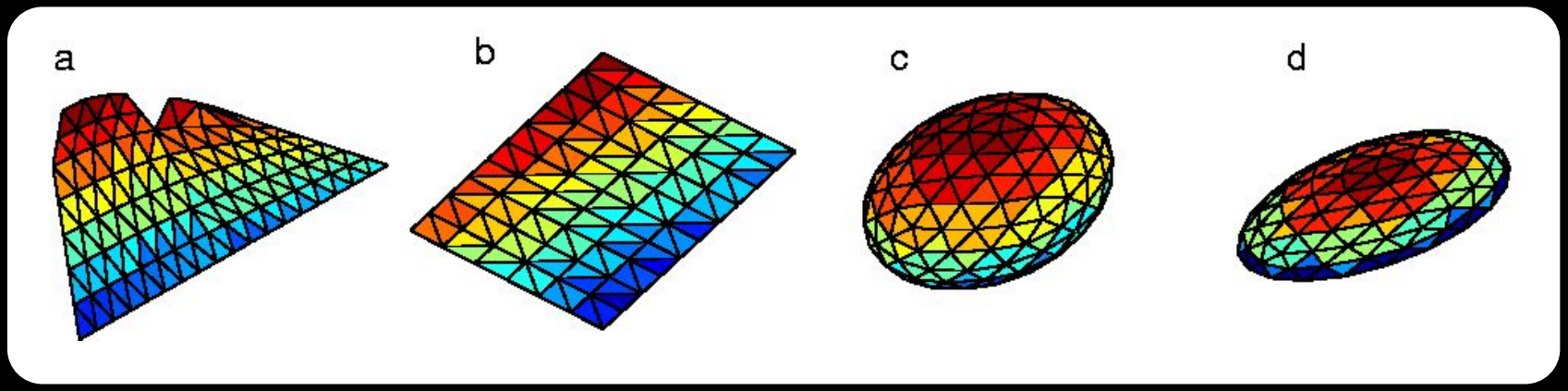
Mixed Boundary Element Method

Cayol and Cornet (1998, JGR)

- Assumptions: elastic, homogeneous and isotropic medium
- We can take into account
  - Complex geometries of pressure sources
  - Topography
- Boundary condition on the dike surface = overpressure
- Treats more than one pressure sources appropriately



Source Types



a) ~Quadrangle, can be connected to the ground surface (for dikes)

b) Rectangle (dikes and sills

c) Oblate ellipsoid (for magmatic chamber)

d) Half oblate ellipsoid (for laccoliths)

Inversion

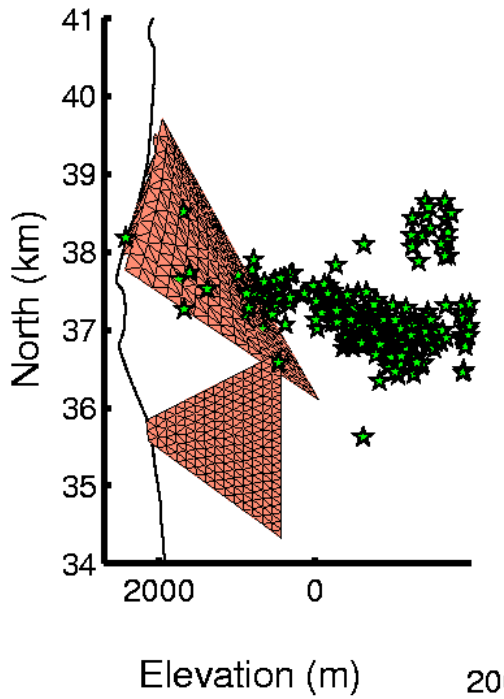
Fukushima et al. (2005, JGR)

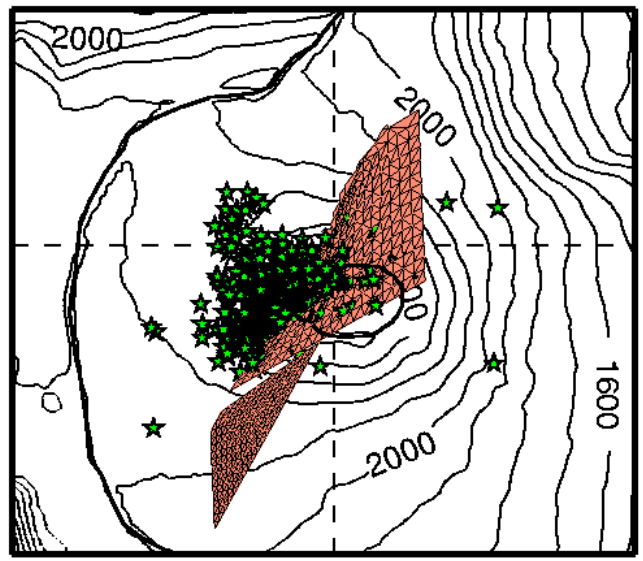
- Neighbourhood Algorithm (Sambridge, 1999, GJI)
- Invert for geometrical parameters + overpressure
- Interferograms are unwrapped and subsampled
- Misfit function = $(\mathbf{u}_o - \mathbf{u}_m)^T C_d^{-1} (\mathbf{u}_o - \mathbf{u}_m)$

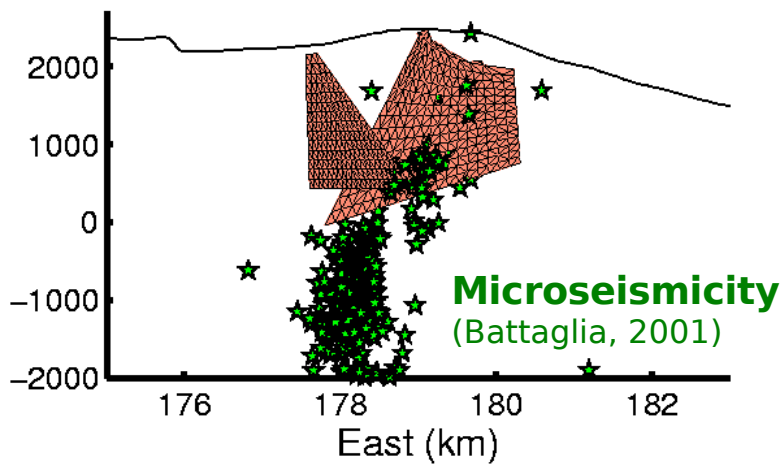
  C_d: Full covariance matrix (noise correlation)
- Model appraisal: confidence intervals, trade-offs

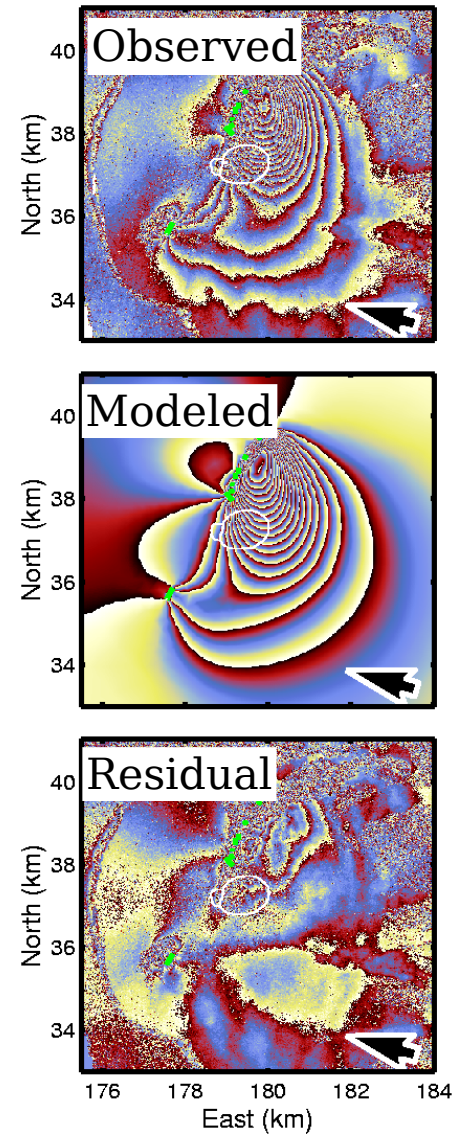
  -> range of possible models
- Synthetic tests -> parameters are well resolved

Dike Model : March 1998 (1)



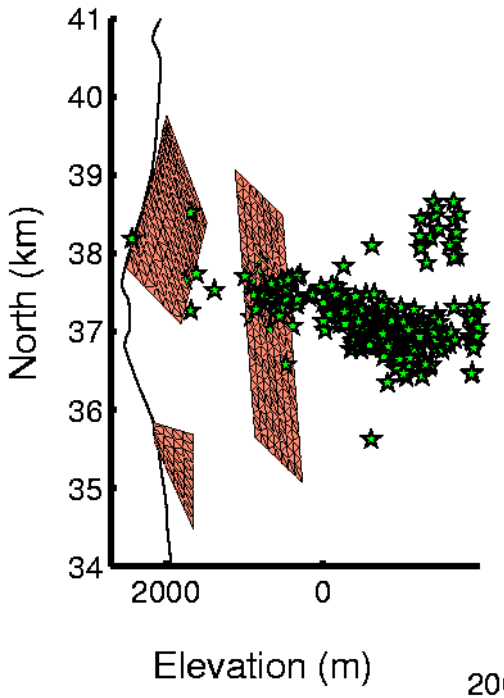


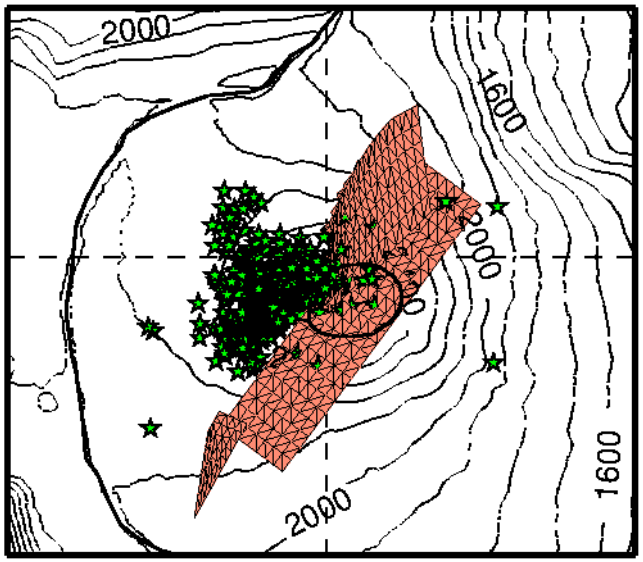


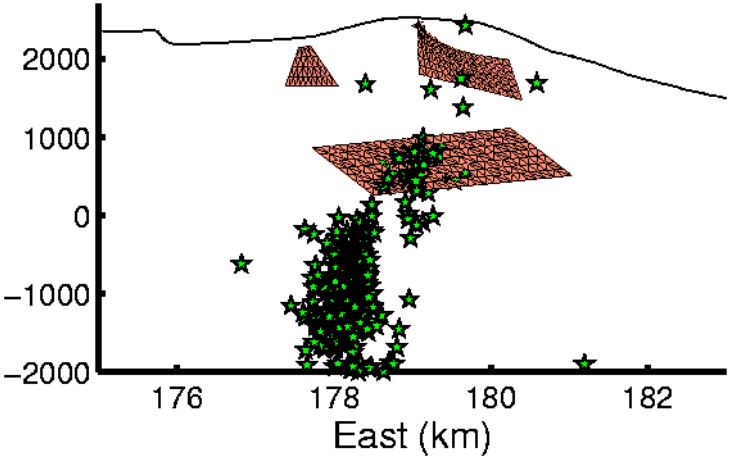


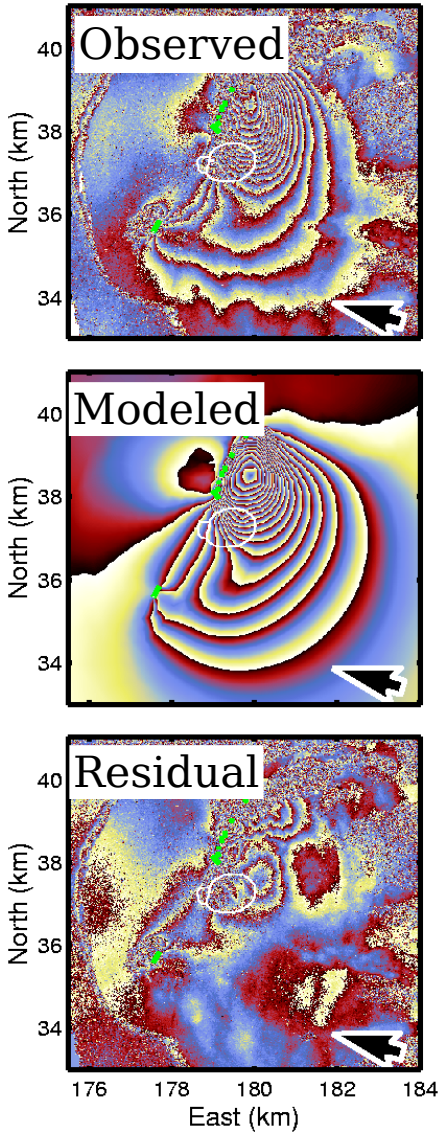
Inversion 8 param.
+
Inversion 5 param.

Dike Model : March 1998 (2)



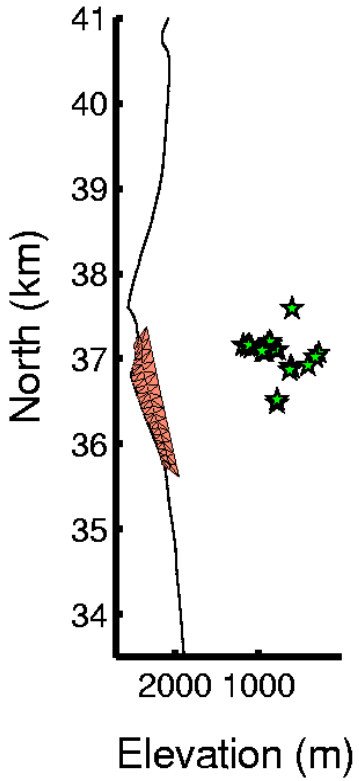


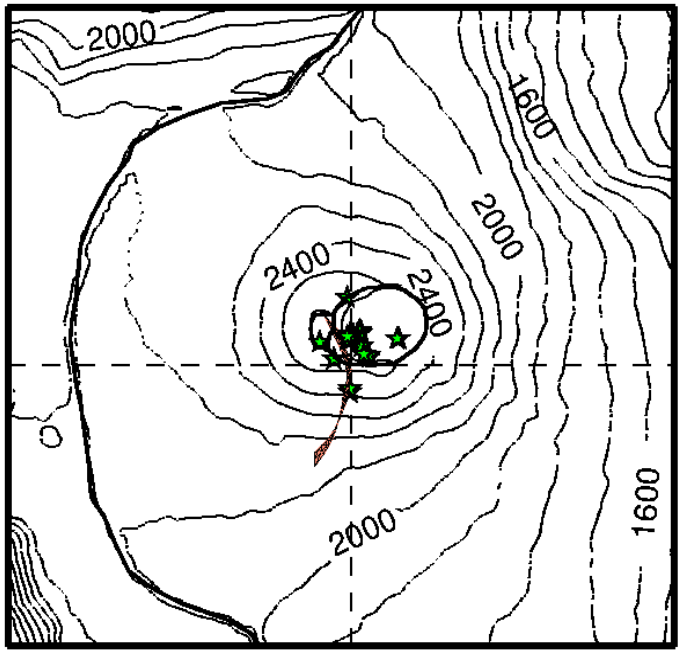


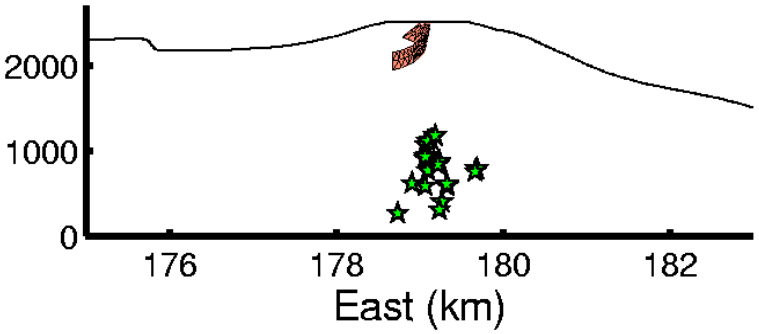


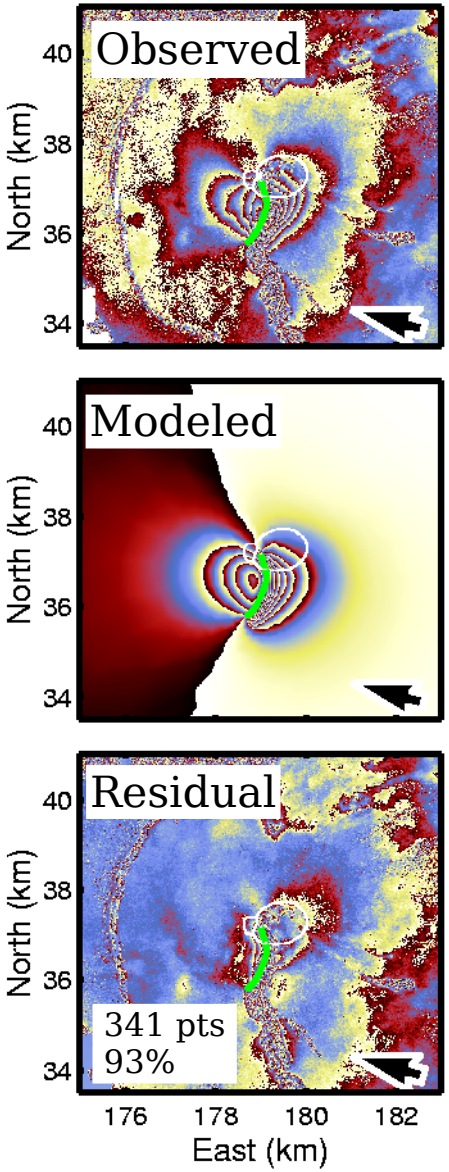
Inversion 9 param. (rectangle)
+
Inversion 8 param. (N)
+
Inversion 5 param. (S)

Dike Model : Sept. 1999 (1)



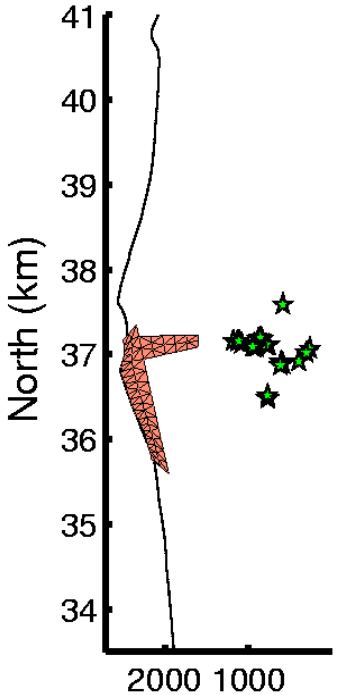


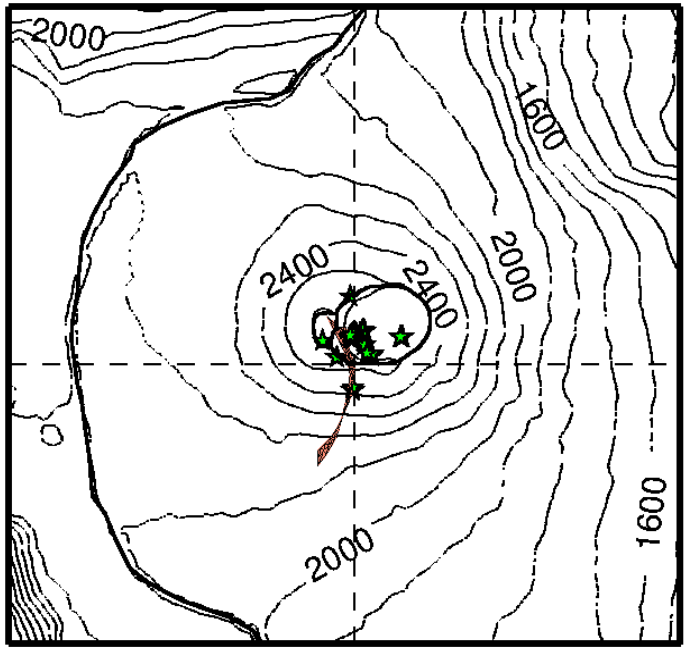


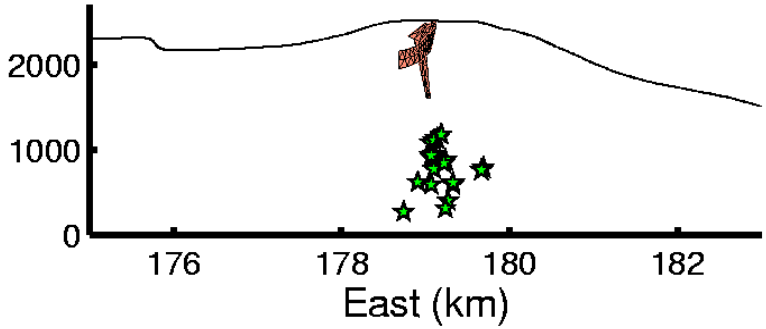


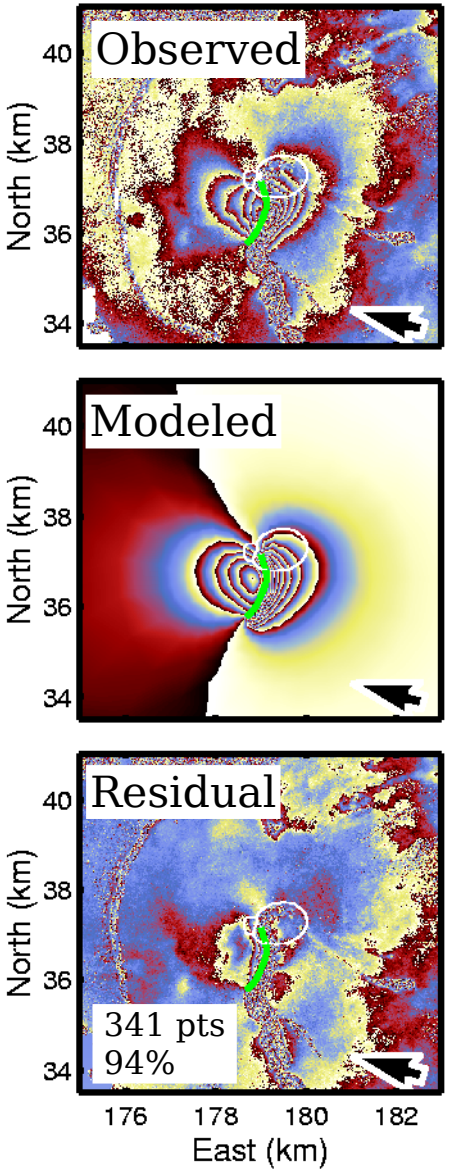
Inversion
7 parameters

Dike Model : Sept. 1999 (2)





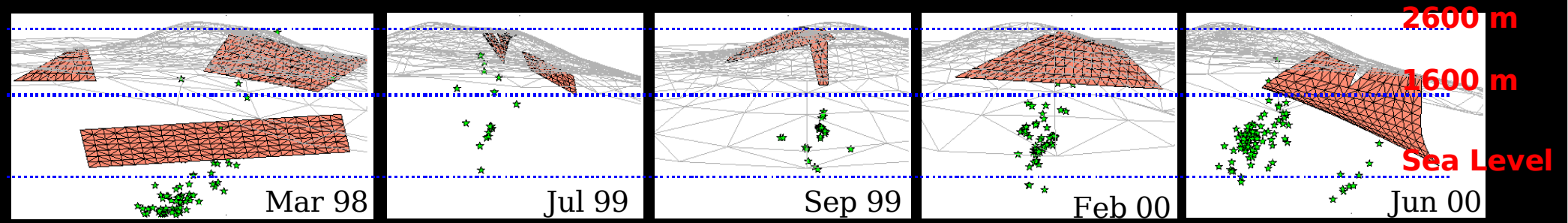




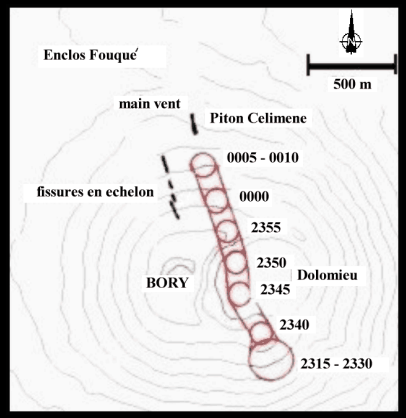
Inversion result
+
Vertical Extension

Eruptions 1998 - 2000

- Interferograms: Dikes are laterally elongated



- Inflation center + visual observation:
  the fissures propagate downslope from the summit region



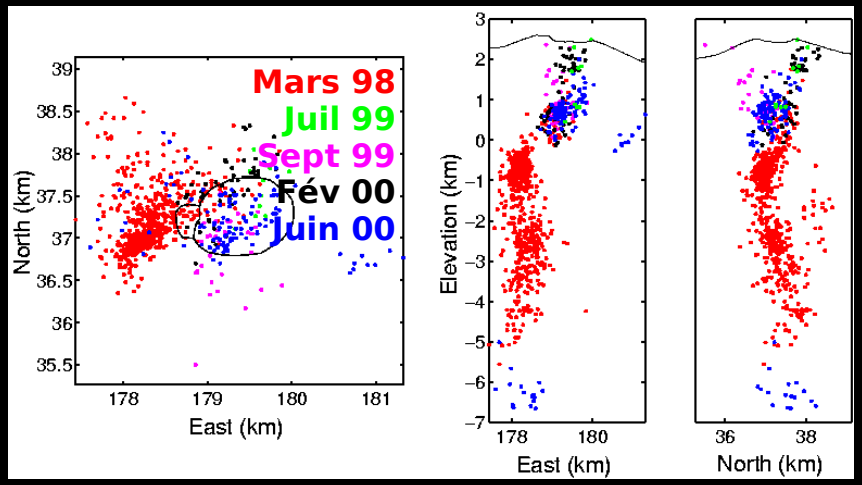
(Staudacher et al., 2000)

→ **Superficially, dikes laterally propagate downslope from the summit**

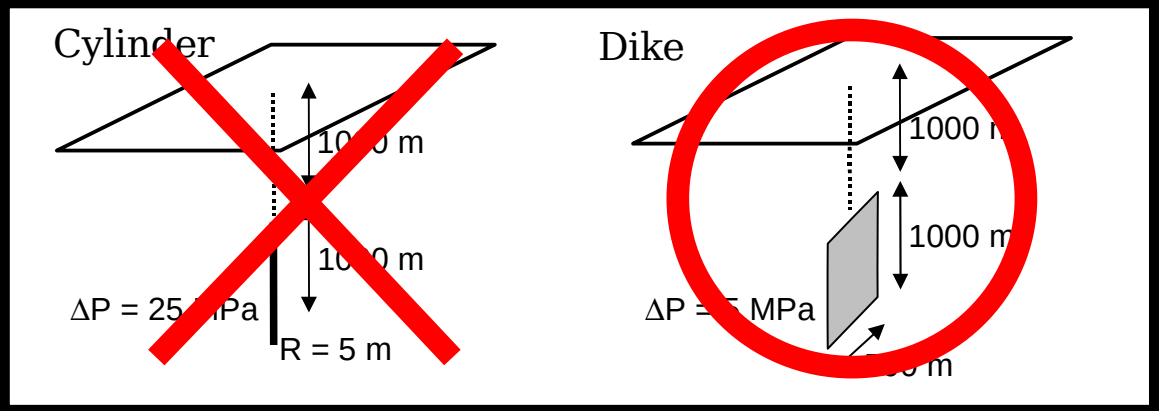
Conduits before eruptions

- Seismic swarms

  → Vertical conduits



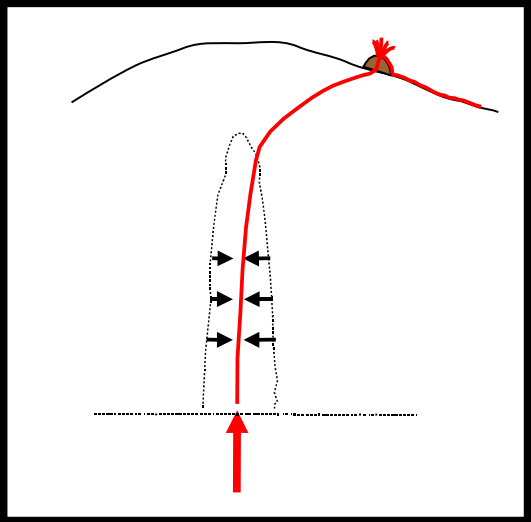
- **Modeling of inclination**



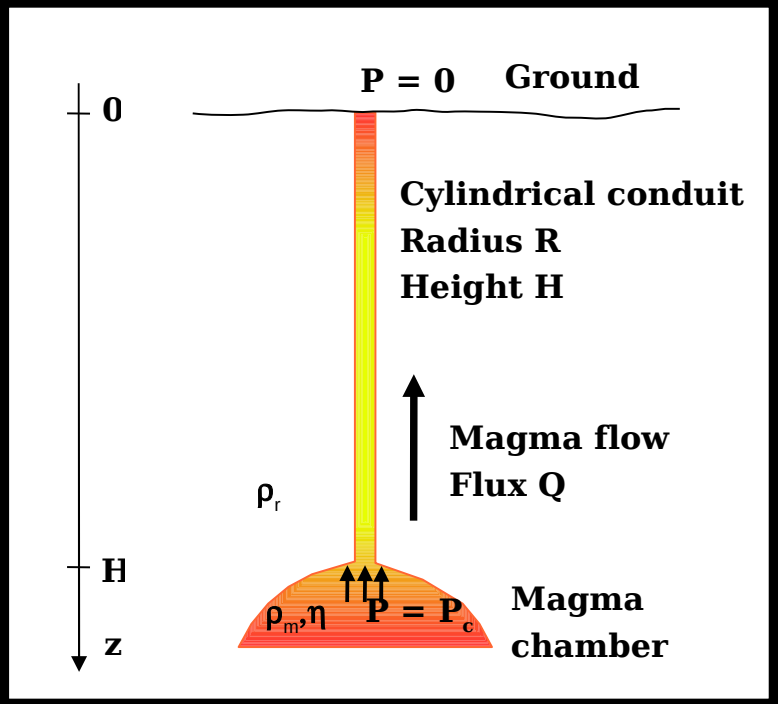
→ **At depth, magma propagates vertically in dikes**

Conduits a few hours after the eruption onset

Conduit is channeled

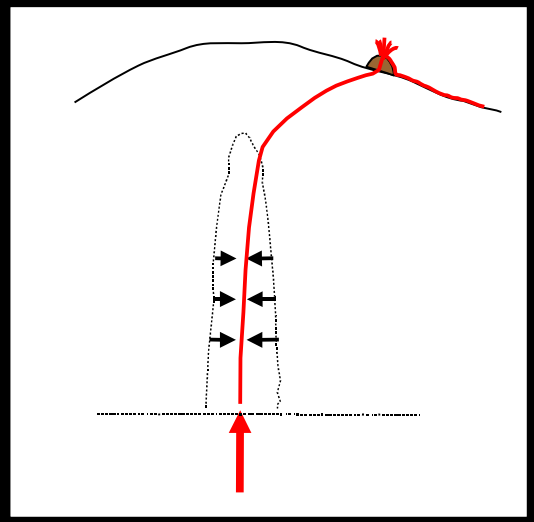


Conduits a few hours after the eruption onset



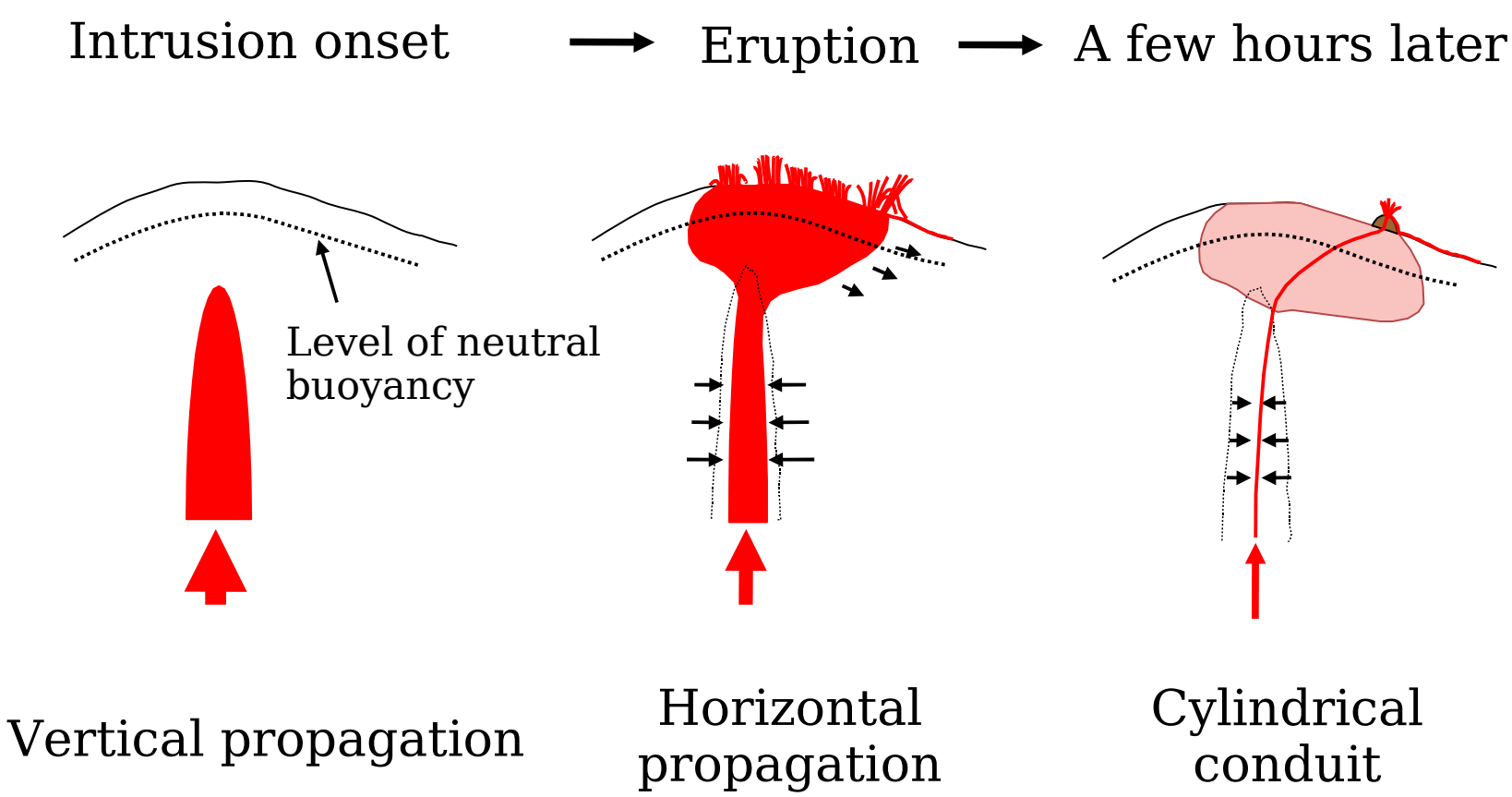
$$Q = -\frac{\pi R^4}{8\eta}\left(\frac{\Delta P_c}{H} + (\rho_r - \rho_m)g\right)$$

Conduit is channeled



Model calculation → **Conduit radius ~ 1 m**

Magma transfer for 1998 – 2000



Summary

<InSAR at Piton de la Fournaise>

- A good database of 16 eruptions for 23 since 1998

<Lessons learned>

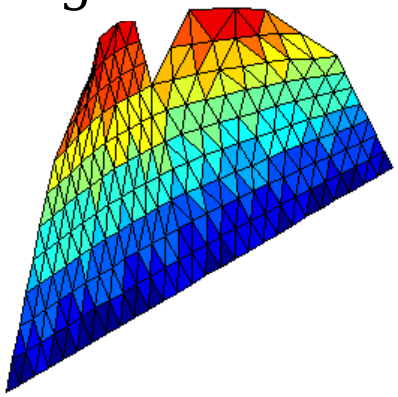
- Even InSAR data have limits to constrain the model. -> Important to integrate other kinds of data.
- Each application requires specific considerations.

<Dike propagation associated with eruptions>

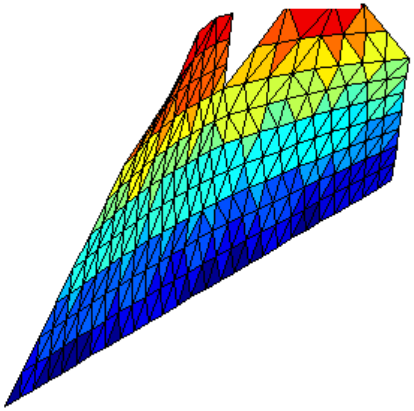
- InSAR + tilt + seismicity for the eruptions 1998 – 2000: magma propagation in vertical dike -> lateral dike -> channeled flow

Model parameters

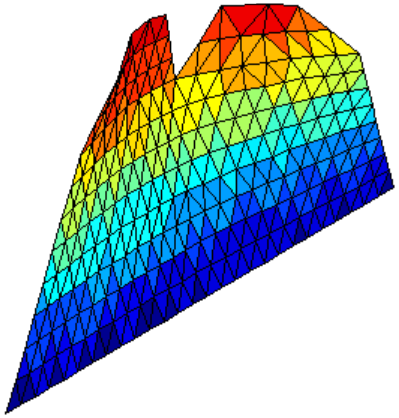
1. Dip angle



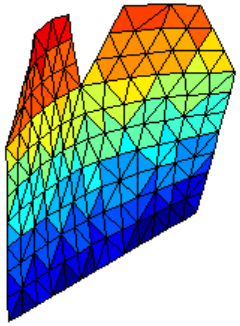
2. Shear angle



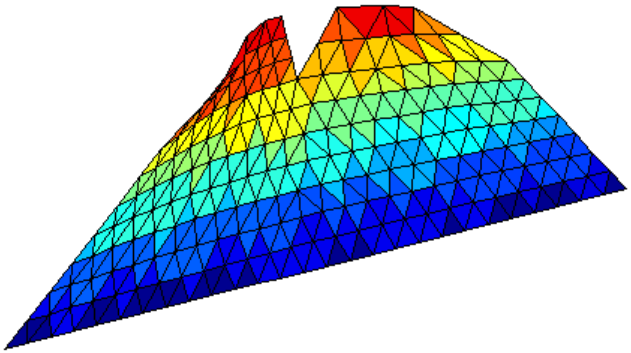
3. Height



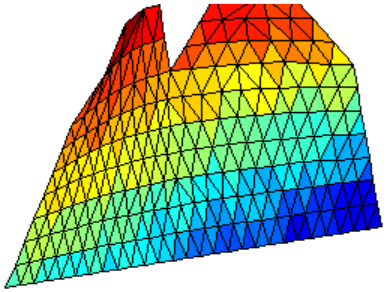
4. Length



5. Torsion



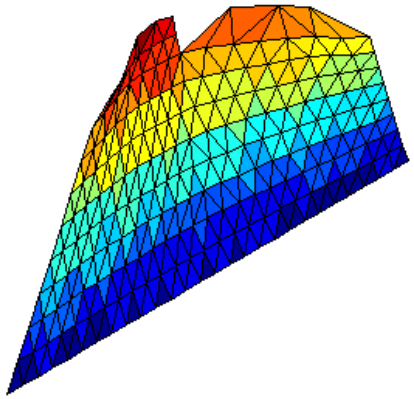
6. Vertical angle



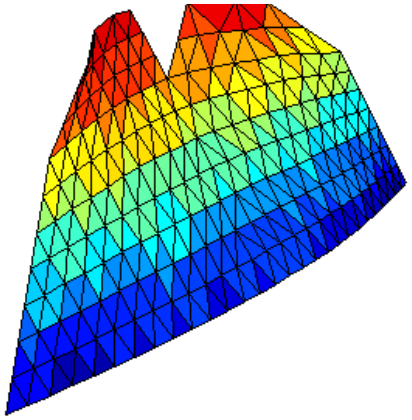
+ Overpressure = 7 param.

Model parameters sometimes used

7. Height of the segments



8. Curvature of the base



9. Vertical curvature