Combining InSAR and GNSS to model magma transport during the May 2016 eruption of Piton de la Fournaise Volcano (La Réunion Island).

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Magma transport at basaltic volcanoes

Dikes and Sills propagation lead to fissural eruptions

Eruptive Fissure, July 14, 2017, Piton de la Fournaise

Eruptive Fissures, July 13, 2018, Piton de la Fournaise

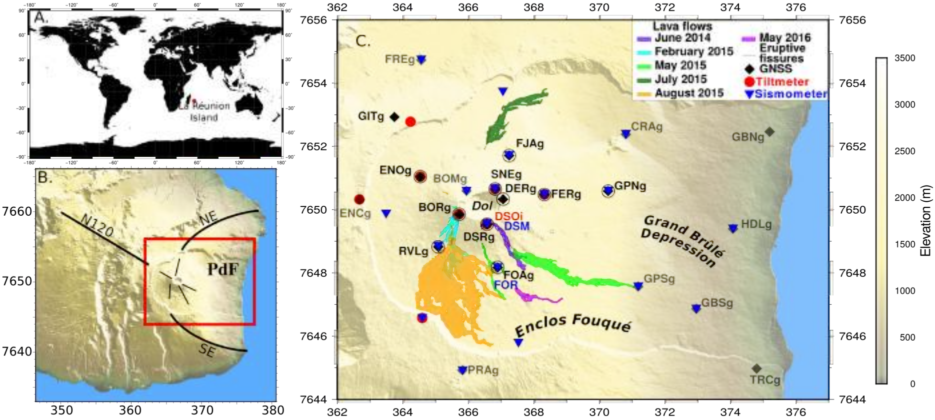
Magma transport at basaltic volcanoes

Magma can propagates tens kilometers potentially reaching inhabited areas and man-made infrastructures.

Eruptive fissures and lava flows,
May 2018,
Leilani Estate, Hawaii (USA)
(Photos USGS)

Mitigating this risk implies a better understanding of what happens between the reservoir and the surface

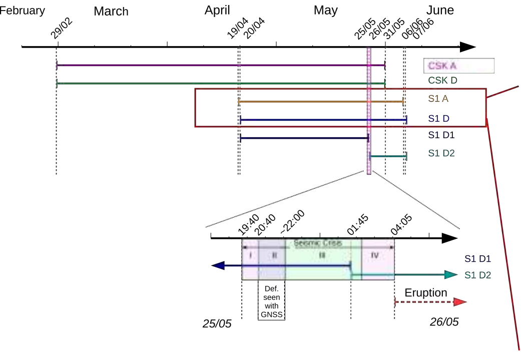
An active and well monitored volcano



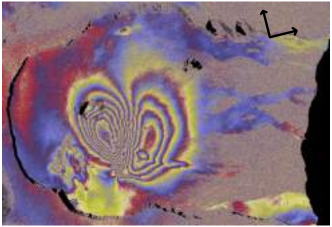
18 eruptions since 2014

The May 2016 eruption lasted 27 hours producing 0.5 Mm^3 of lava flow

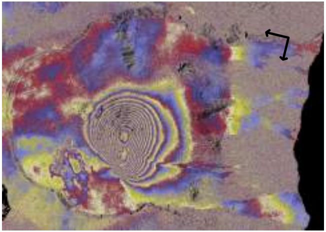
InSAR Data provide high spatial resolution



Sentinel Ascending 19/04 – 06/06



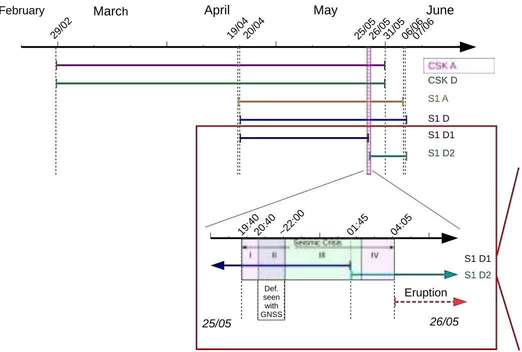
Sentinel Descending 20/04 – 07/06



May 2016 :

- 6 interferograms
(Sentinel et Cosmo Sky Med)
along 4 different LOS:
ascending and descending

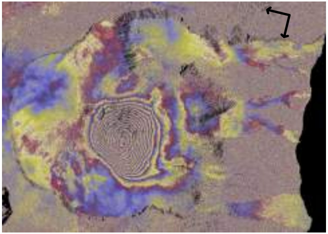
InSAR Data provide high spatial resolution



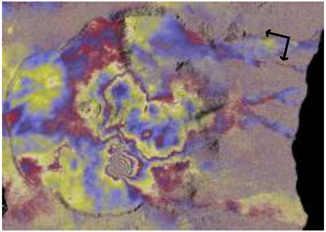
May 2016 :

- 6 interferograms
(Sentinel et Cosmo Sky Med)
along 4 different LOS:
ascending and descending

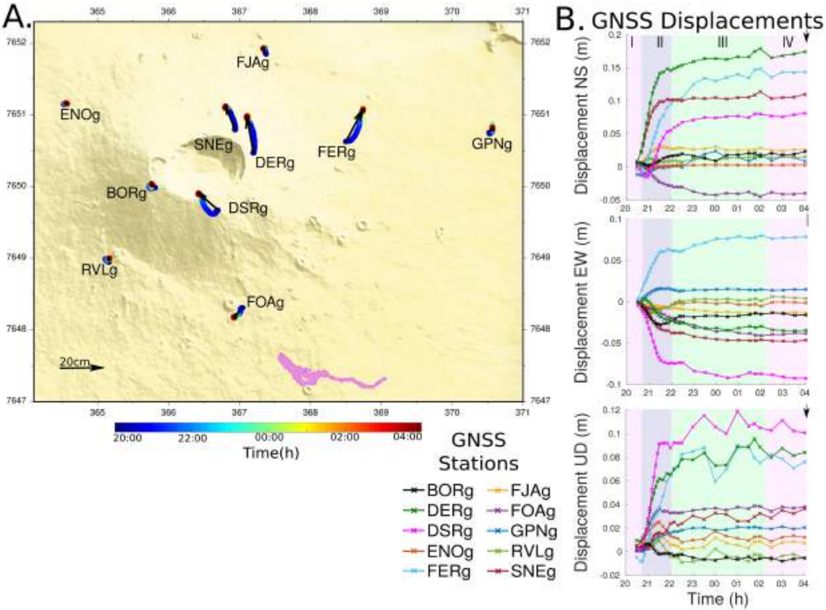
Sentinel Descending 20/04 – 25/05



Sentinel Descending 25/05 – 07/06



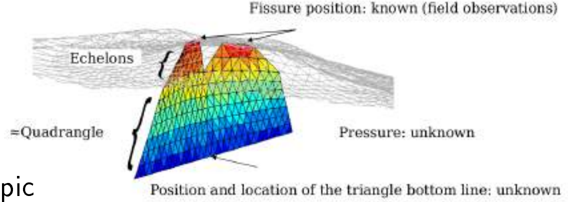
GNSS Measurements provide high temporal resolution



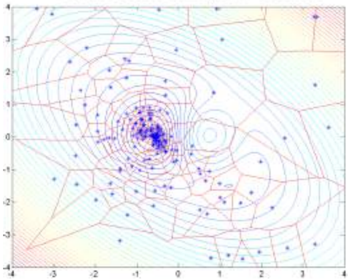
How to combine spatial and temporal information from InSAR and GNSS ?

Forward modeling : Mixed Boundary Elements Method (*Cayol and Cornet*, 1997)
→ Topography
→ Complexe fracture

Hypotheses :
→ Linear elasticity
→ Homogeneous and isotropic medium

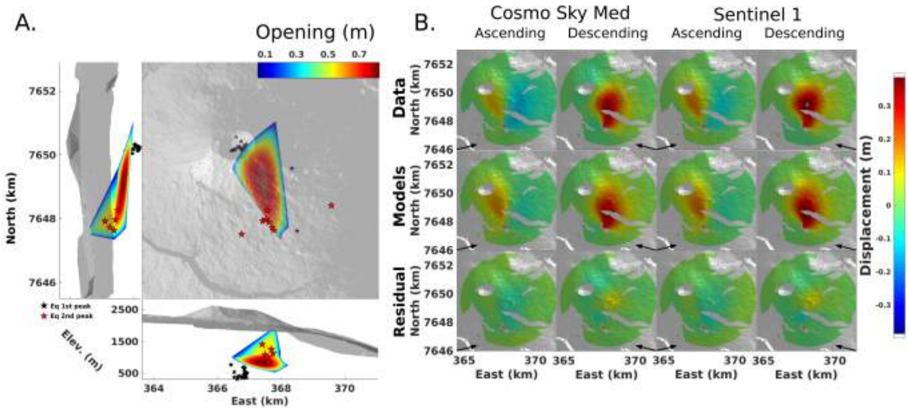


Iterative search example: 7th iteration



Non linear Inversion:
Neighbourghood Algorithm (*Sambridge*, 1999)
Minimizing cost function

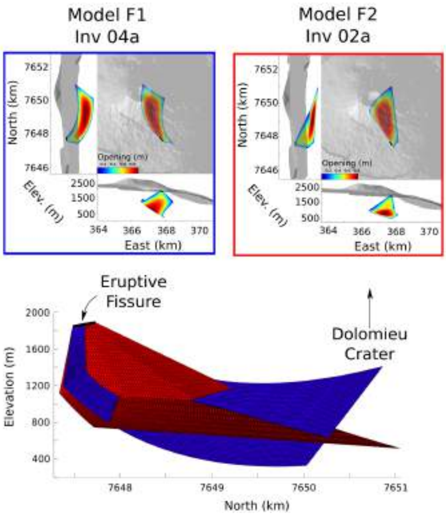
$$U = (d_o - Gm)^T C_d^{-1} (d_o - Gm)$$



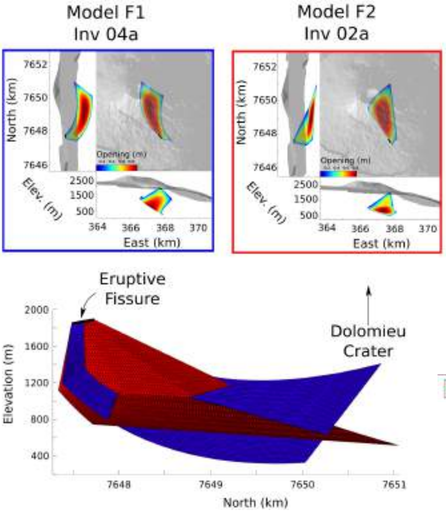
A Sill turning into a Dike

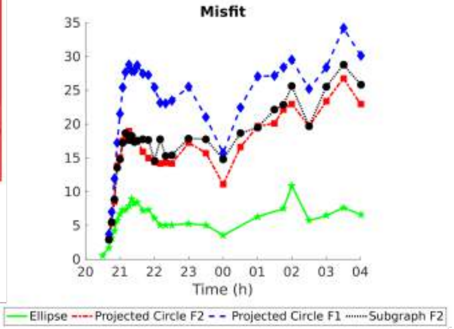
Volume 2.5Mm^3

Two model families - same misfit



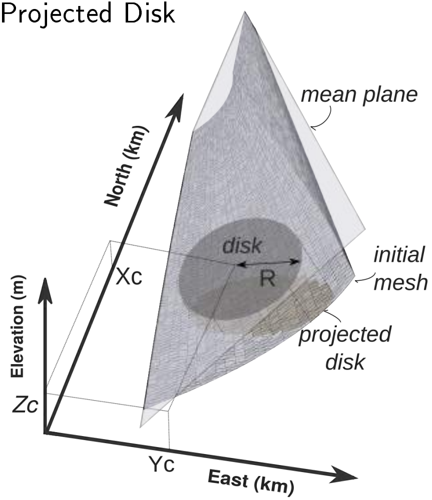
Two model families - same misfit



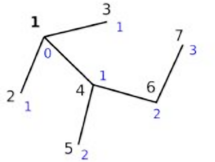


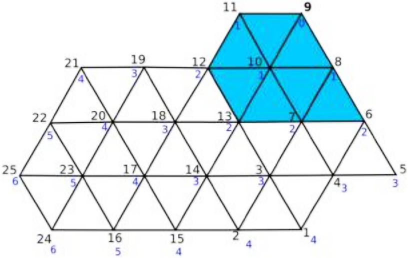
InSAR provides geometrical *a priori*

Projected Disk

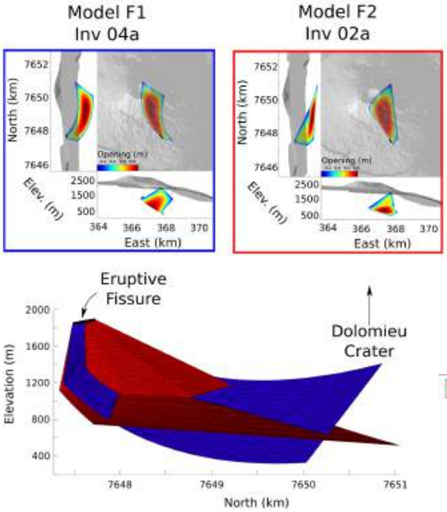


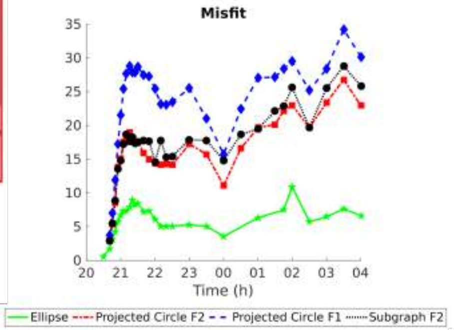
Subgraph



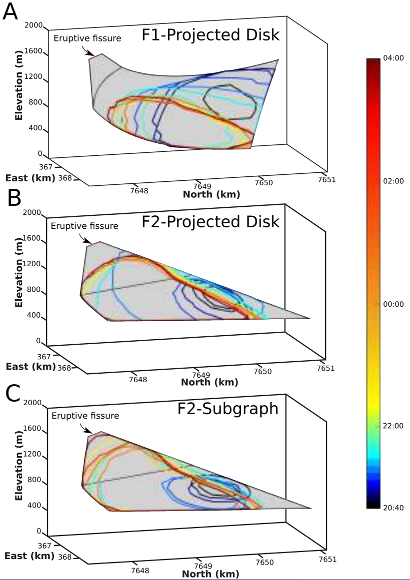


GNSS temporal information helps solving modeling ambiguities



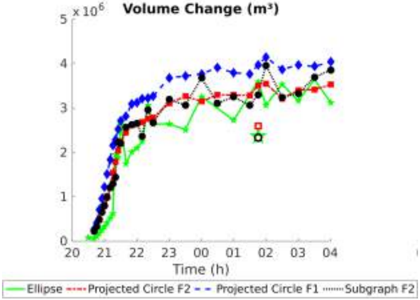


A step-wise lateral propagation of a single small batch of magma disconnected from its feeding reservoir.



- Mean horizontal velocity : $0.6\ m.s^{-1}$
- Max horizontal velocity : $2\ m.s^{-1}$

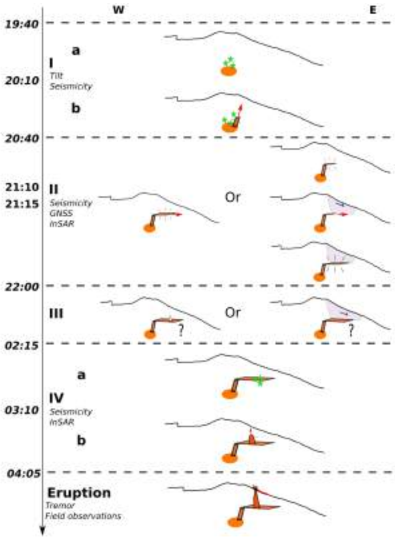
Quick lateral propagation, arrest then vertical propagation



Conclusions

Methods

- InSAR provides high spatial resolution => geometrical a priori required for GNSS inversion
- GNSS discriminates between families of equally likely models => timing
- Advantages of both datasets characteristics.



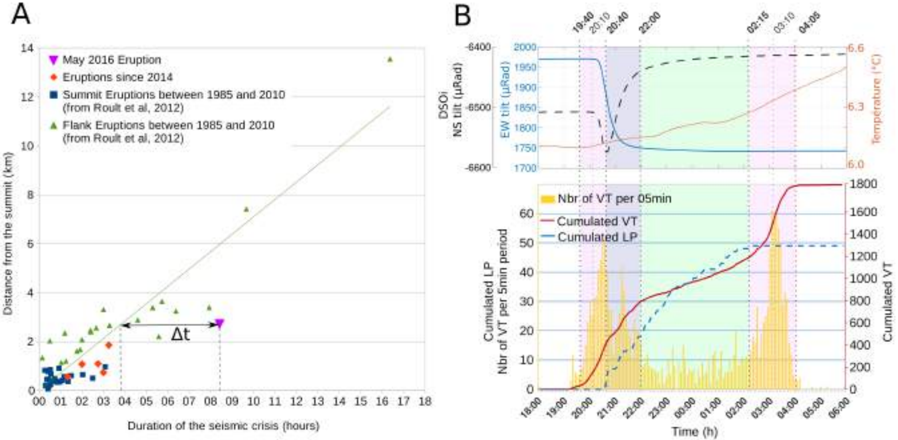
Process

- A small amount of magma was trapped into a sill (*preexisting discontinuity ?*)
- External change of the stress field *(east flank sliding ?)*
- Internal change of buoyancy *(gas accumulation ?)*

Smittarello, D.; Cayol, V.; Pinel, V.; Peltier, A.; Froger, J.L.; Ferrazzini, V. Magma Propagation at Piton de la Fournaise From Joint Inversion of InSAR and GNSS. *J. Geophys. Res. Solid Earth* **2019**, 124, 1361–1387. doi:10.1029/2018JB016856

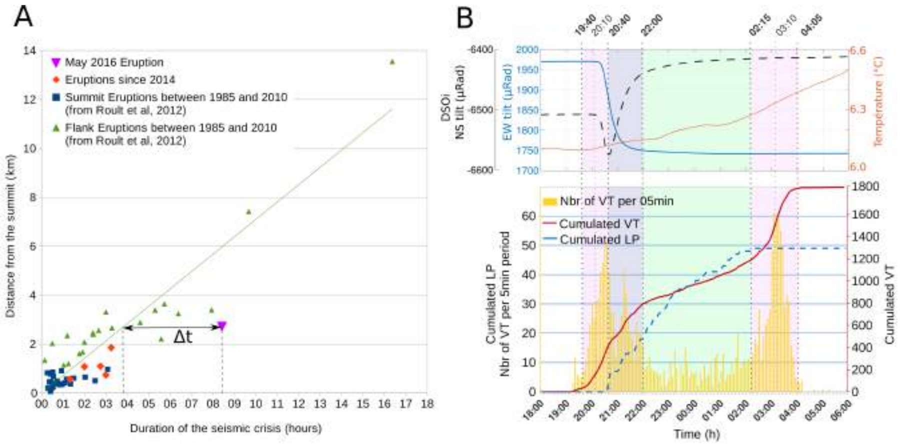
Smittarello, D.; Cayol, V.; Pinel, V.; Froger, J.L.; Peltier, A.; Dumont, Q. Combining InSAR and GNSS to Track Magma Transport at Basaltic Volcanoes. *Remote Sens.* **2019**, 11, 2236. doi:10.3390/rsxx010005

An atypical seismic crisis starts on May 25, 2016



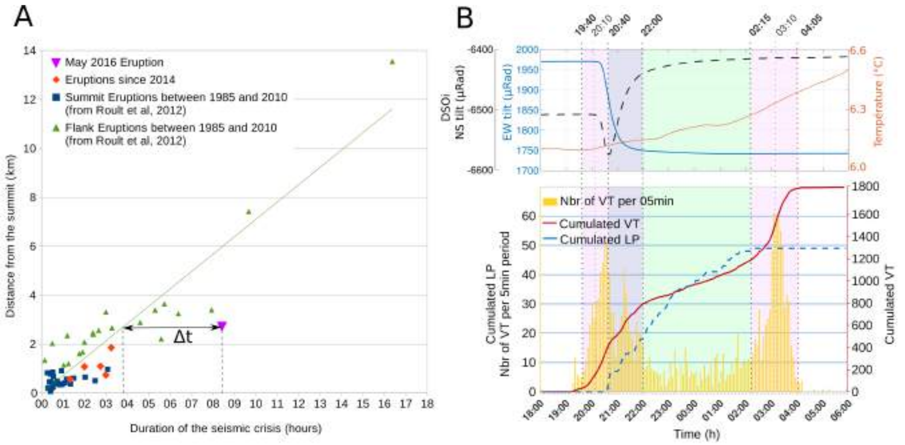
- A long crisis : 8h25min
- An eruptive vent not so far : 2.8km
- 2 peaks of seismic activity

An atypical seismic crisis starts on May 25, 2016

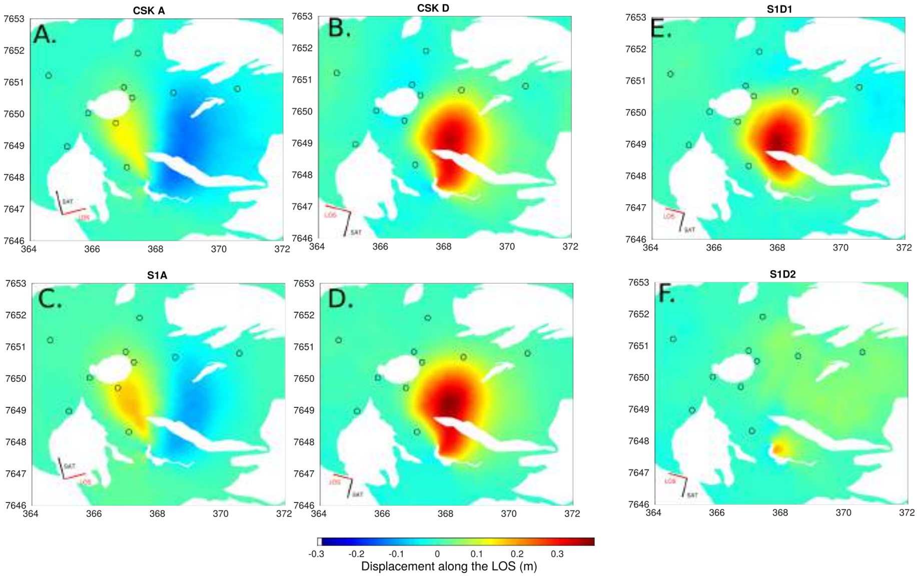


Why is the magma trapped
for 5h before erupting ?

An atypical seismic crisis starts on May 25, 2016



What finally triggered the eruption ?


CSK A
CSK D
S1D1
S1A
S1D2
A.
B.
C.
D.
E.
F.
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
Displacement along the LOS (m)