How does the substratum deform under lava flows at Piton de la Fournaise? (La Réunion Island)

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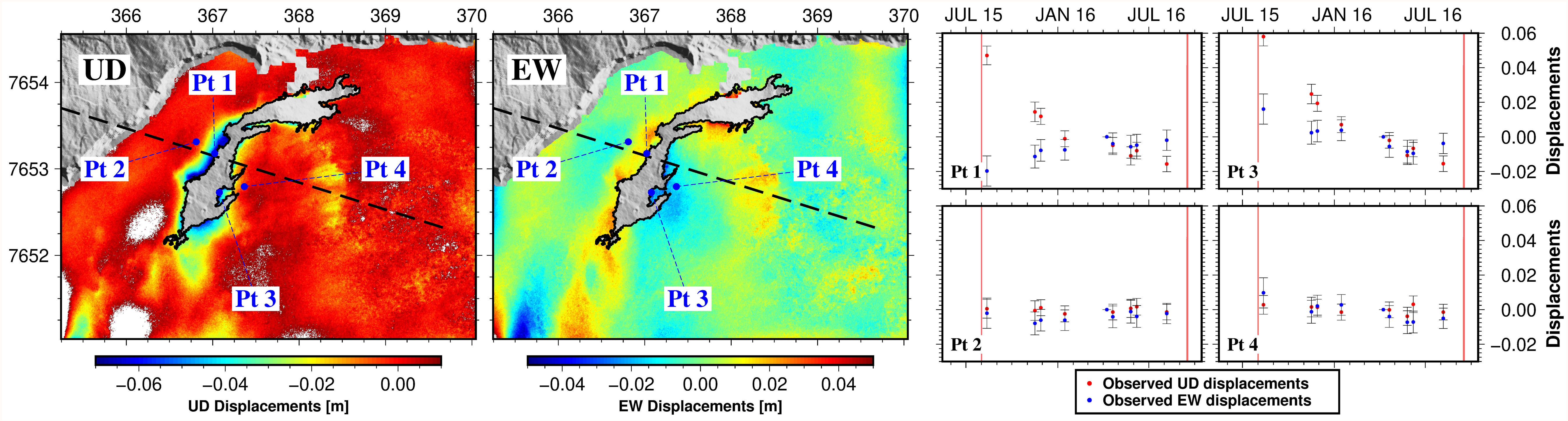
Introduction

At Piton de la Fournaise (La Réunion Island), the monitoring of ground displacements by InSAR is used to quantify the evolution of the deep and superficial volcanic systems and to monitor the edifice over space and time. Recovering the characteristics of magmatic intrusions from the inversions of observed displacements depend on the choice of the appropriate substratum rheology, which is still being debated. However, some displacements as the flexure of substratum under the lava flows are time dependent. These observations are incompatible with the elasticity medium used for instrusive geometry inversion from displacements. Therefore, we used the measured displacements of the substratum induced by the weight of the lava flows at Piton de la Fournaise to characterise the rheology of the substratum.

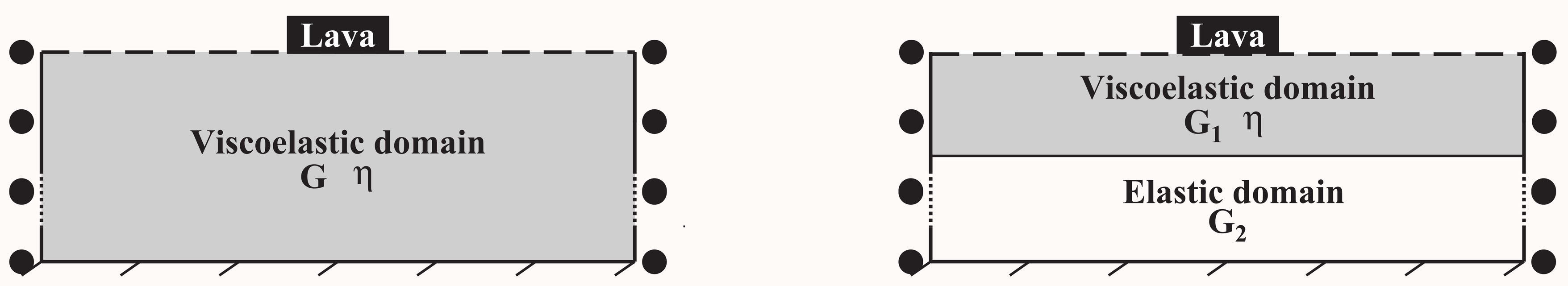
Observations : example of 31th July 2015 lava flow (duration: 2.1 days)



- Average thickness of the lava flow: 2.30 m
- Ground Surface Displacement between 12th Aug. 2015 and 6th Aug. 2016 derived from Sentinel-1 StripMap InSAR data
- Up to 80 mm of substratum flexure during the period of observation

Methods

Viscoelastic rheology:

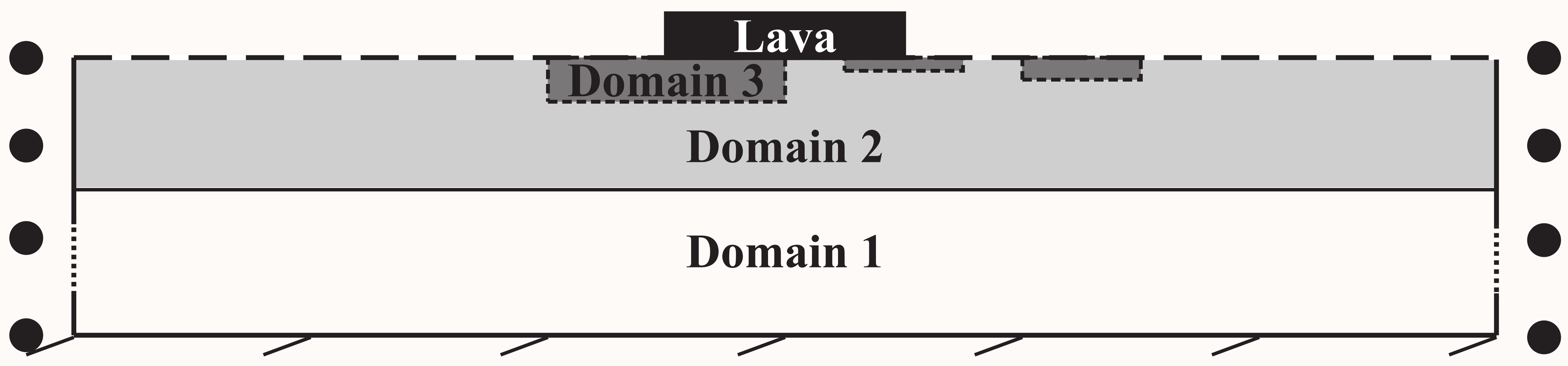


Semi-infinite domain | **Layered domain**

The domain is semi-infinite, homogeneous and isotropic. The rheology is viscoelastic. We use the Boussinesq's solutions of the elastic problem that we modify to operate with the viscoelastic rheology [1, 2, 3].

The domain is layered, homogeneous and isotropic. The rheology of the upper layer is viscoelastic and that of the lower layer is elastic. We use numerical models via COMSOL Multiphysics© (Finite Element Method FEM).

Poroelastic rheology:



Each domain is homogeneous and isotropic. The rheology of the three domains is poroelastic with different degrees of compaction. Domain 1 is the deepest and the most compacted. Domain 2 is the subsurface layer: the compaction is moderate. Domain 3 is composed of the lava flows recently emplaced: their compaction is poor. We adjust the compaction via the porosity and shear modulus of each domain. We use numerical models via COMSOL Multiphysics©.

References

[1] M Bonafede, M Dragoni, and F Quareni. Displacement and stress fields produced by a centre of dilation and by a pressure source in a viscoelastic half-space: application to the study of ground deformation and seismic activity at Campi Flegrei, Italy. *Geophysical Journal International*, 87(2):455–485, 1986.

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[3] Ciro Del Negro, Gilda Currenti, and Danila Scandura. Temperature-dependent viscoelastic modeling of ground deformation: Application to Etna volcano during the 1993–1997 inflation period. *Physics of the Earth and Planetary Interiors*, 172(3-4):299–309, 2009.

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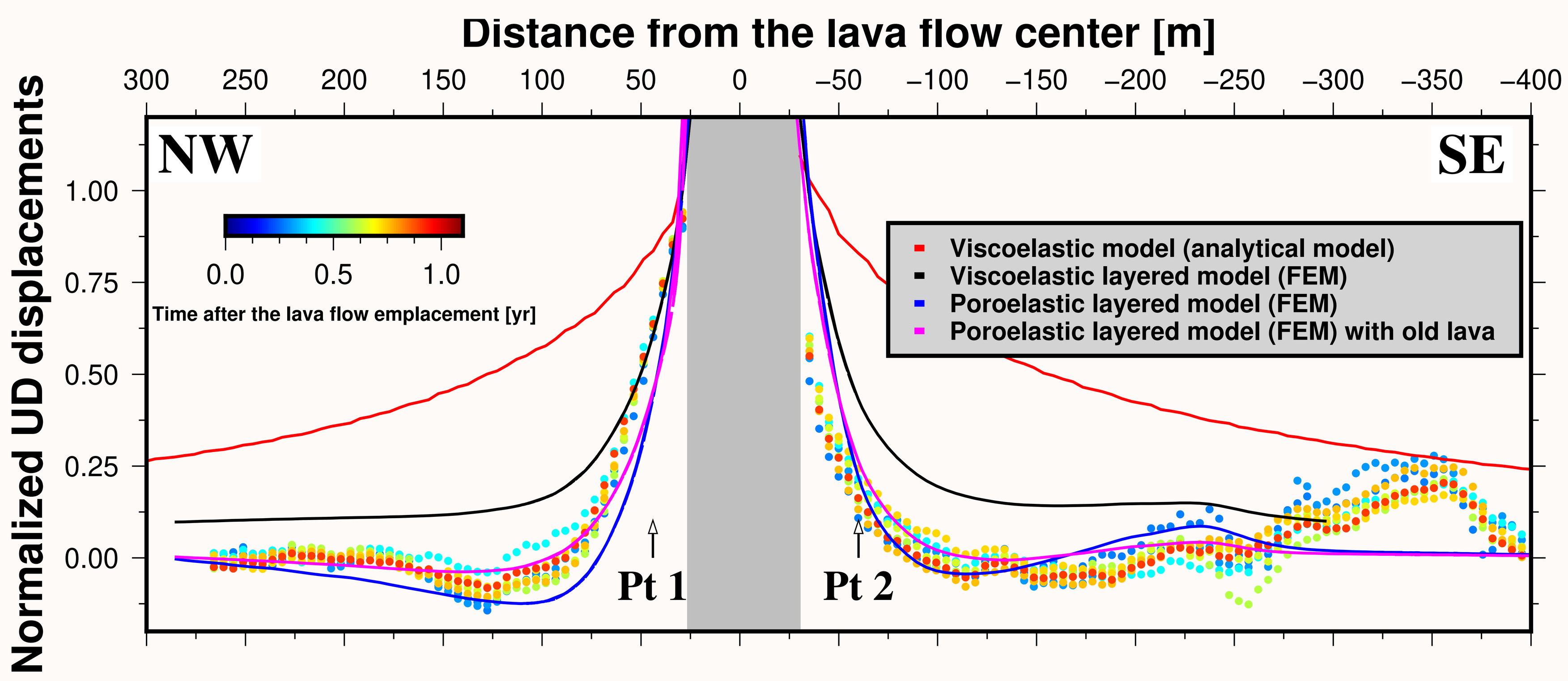
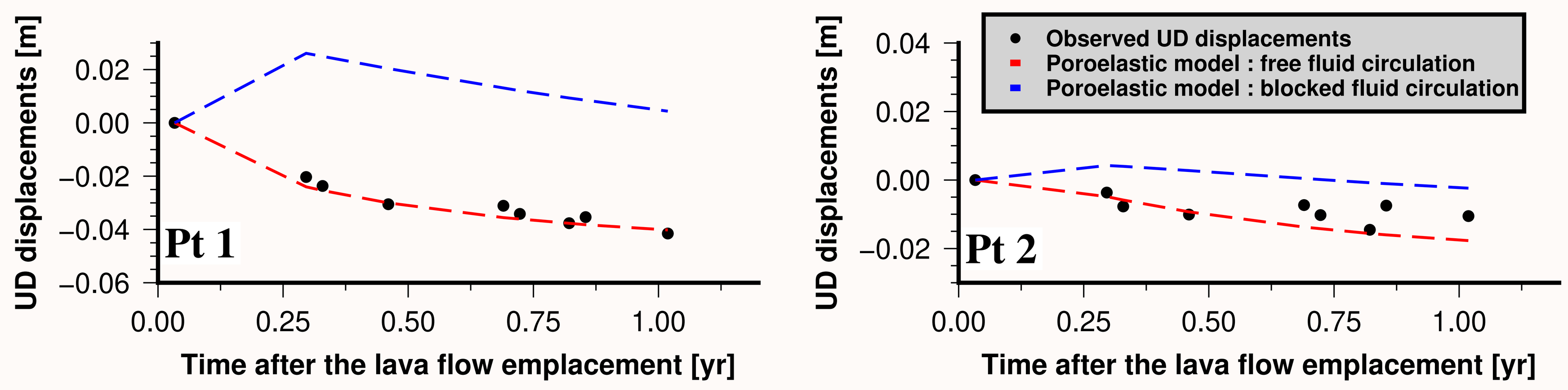
Results

Result 1: spatial evolution of the displacements

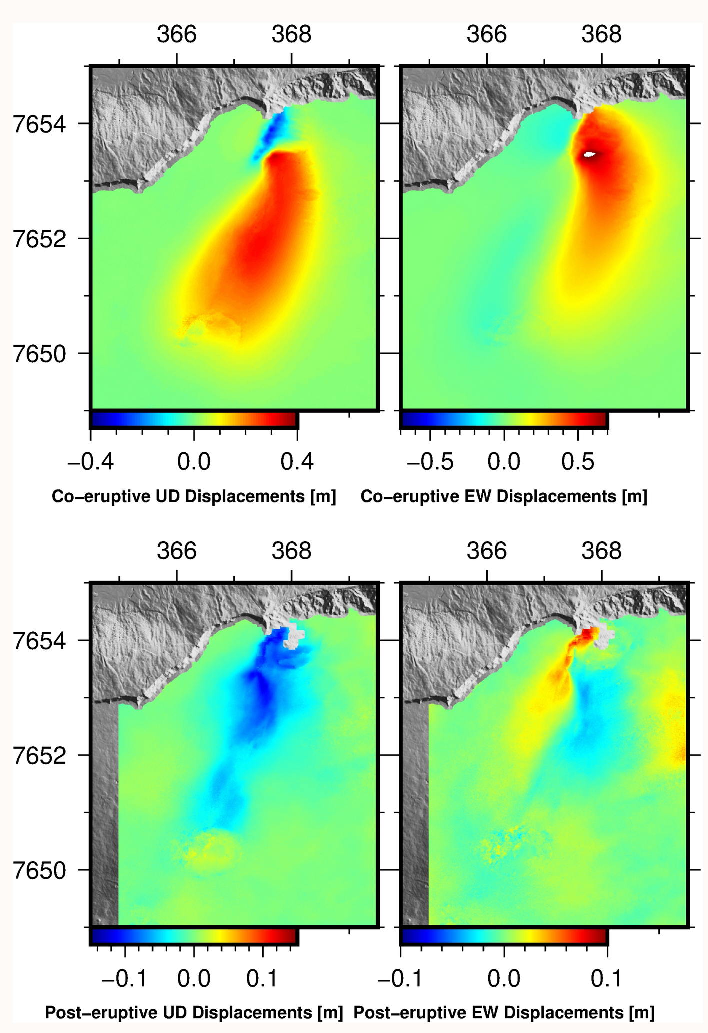


Result 2: time evolution of the displacements



Both rheologies require **a rheological limit at ~100 m depth** to reproduce the displacement profiles. **Only the poroelasticity** enables us to model the time evolution of the observed displacements: an unrealistic viscosity ($10^{13} - 10^{16}$ Pa.s) is required by the viscoelastic rheology.

Discussion: the 3rd April 2018 eruption



The 3rd April 2018 eruption showed large post-eruptive displacements: 20 % of co-eruptive displacements are compensated by the post-eruptive displacements; the intrusive geometry inverted from co-eruptive displacements is incompatible with post-eruptive displacements, which cannot be explained by the thermal relaxation either. **Poroelasticity could explain the observed post-eruptive displacements while being compatible with our observations of the substratum.**