InSAR characterization of displacements related to lava flows at Piton de la Fournaise

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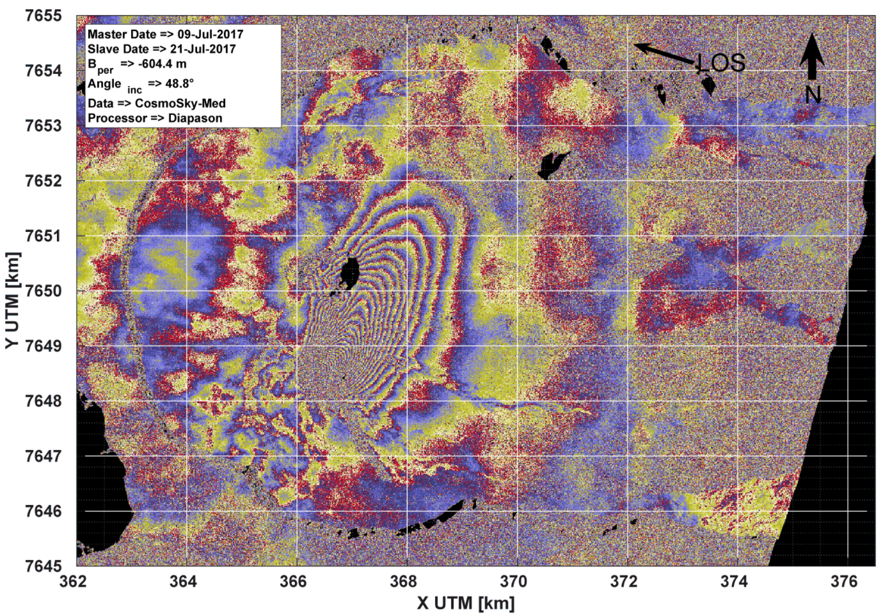

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Summary :

- Introduction
- The October 2010 lava flow
- Methods
- Results
- Discussions
- Some perspectives
- Conclusion

Objectives

Emperical laws to link the displacements and thickness, surface area and slope of lava flows
+
Numerical models by Finite Element Method

Displacements of substratum

Better knowledge of surface rheology (FEM models)

InSAR ground displacements − Models of lava flow displacements = More accurate characterization of deep-source-induced displacements

More accurate InSAR data, filtered for lava flow displacements + Knowledge of surface rheology = Increased knowledge of the geometry of intrusive bodies

Dates of the SAR acquisitions and eruptions of PdF volcano

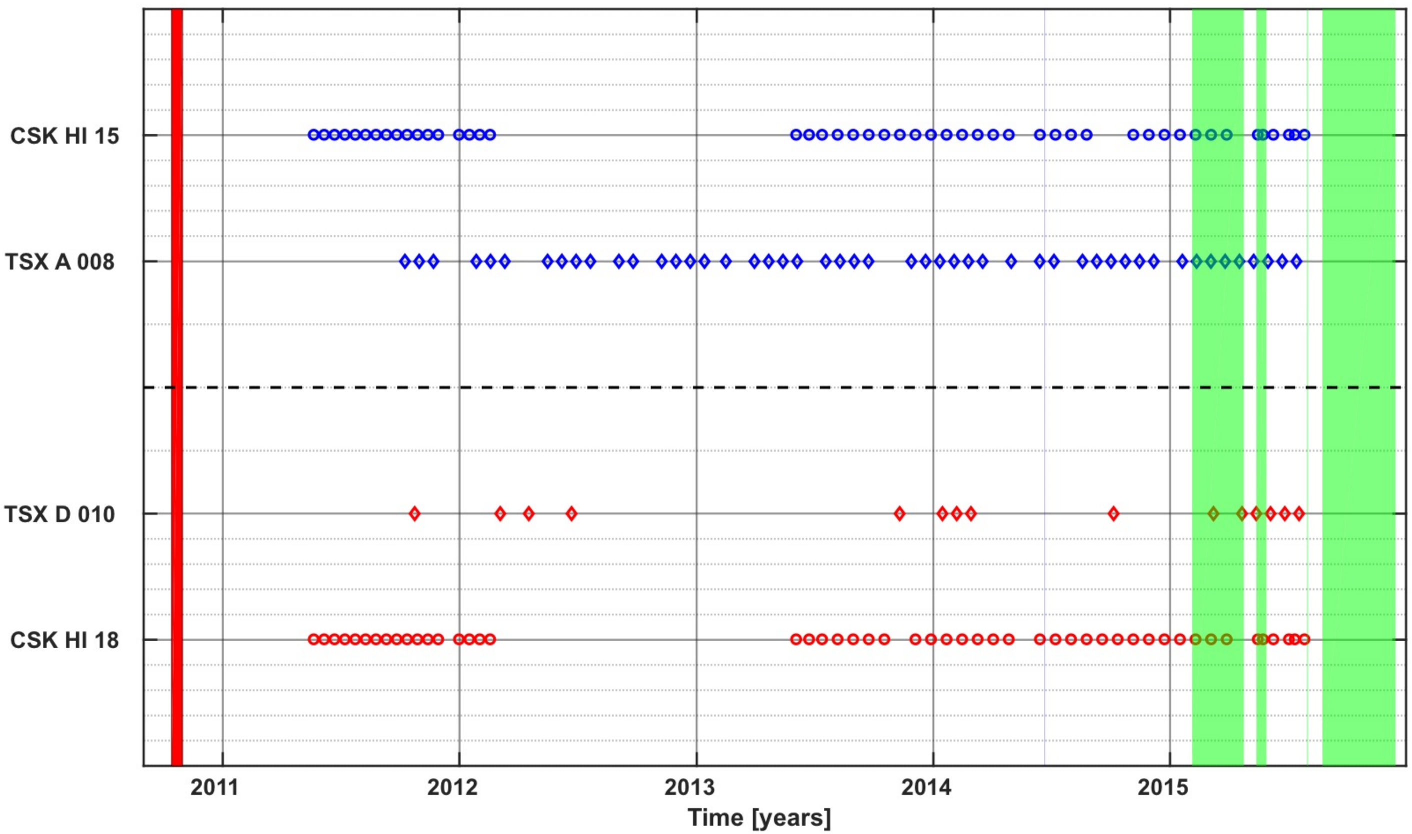


Fig 1. Timeline of the SAR data used in the study. The red line corresponds the October 2010 eruption, the blue line is the date of 2014, and the green thick lines represent the 2015 eruptions.

- 6 months gap between the beginning of Time Series and the eruption, due to the poor coherence of the lava flow.
- End of the Time Series in 2015 due to the 2015 eruptions.
- Used methodology: Small Baselines InSAR with Doris and StamPS

The interests of this lava flow

Fig 2. Map of the lava flows since 1980

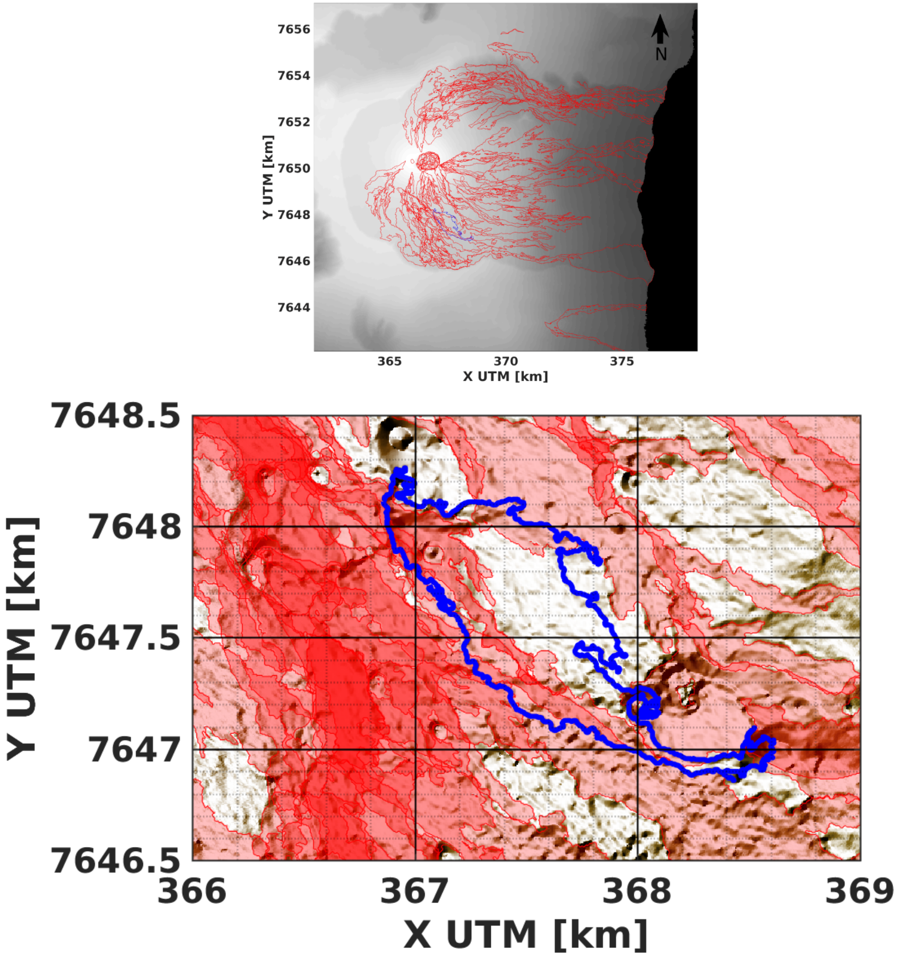
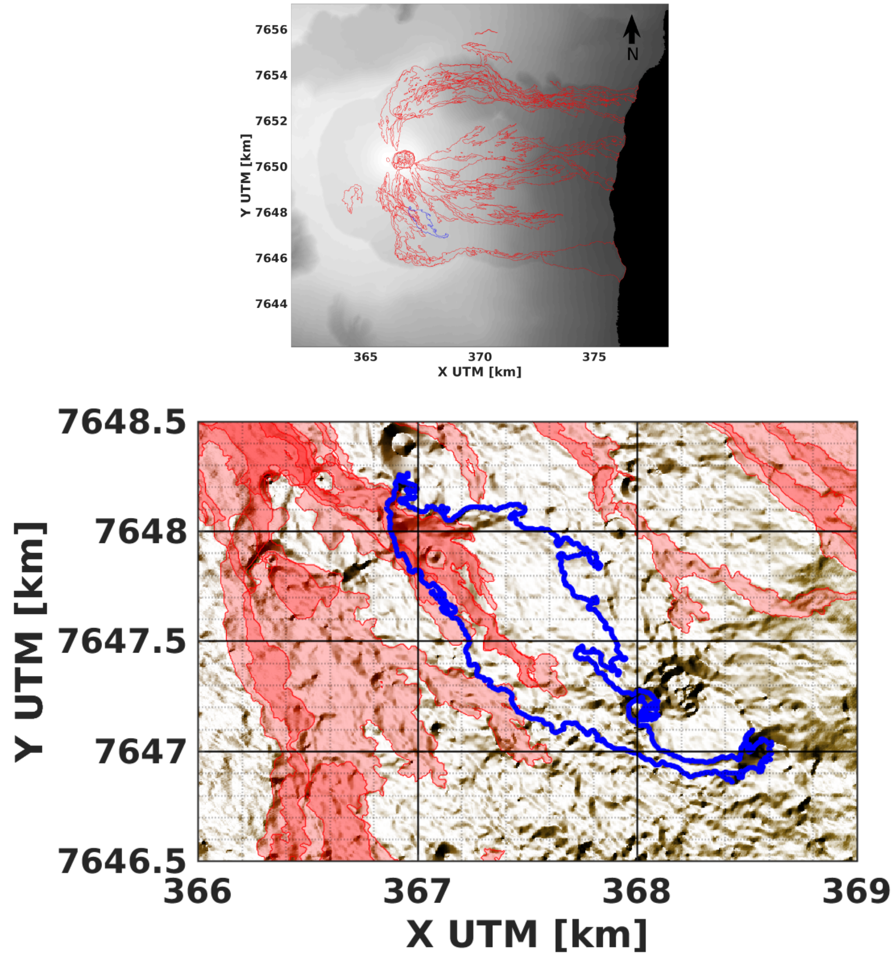


Fig 3. Map of the lava flows since 1998



InSAR signal related to the October 2010 lava flow

Thickness of lava flow by Bato et al (2016)

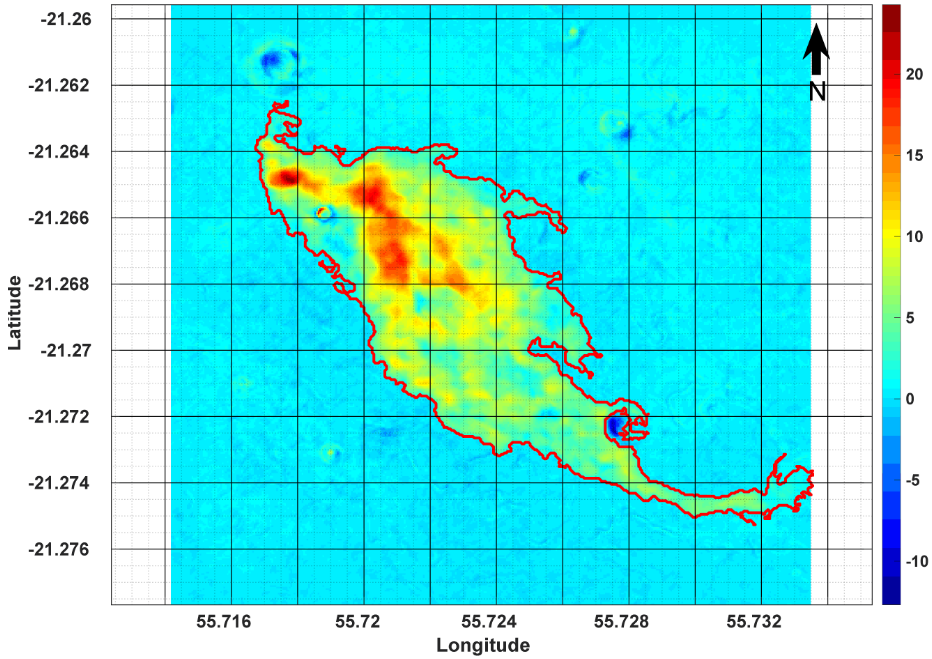


Fig 4. Lava flow thickness obtained by the study of Bato et al (2016). The red line is the boundary of the lava flow.

Displacements related to the lava flow

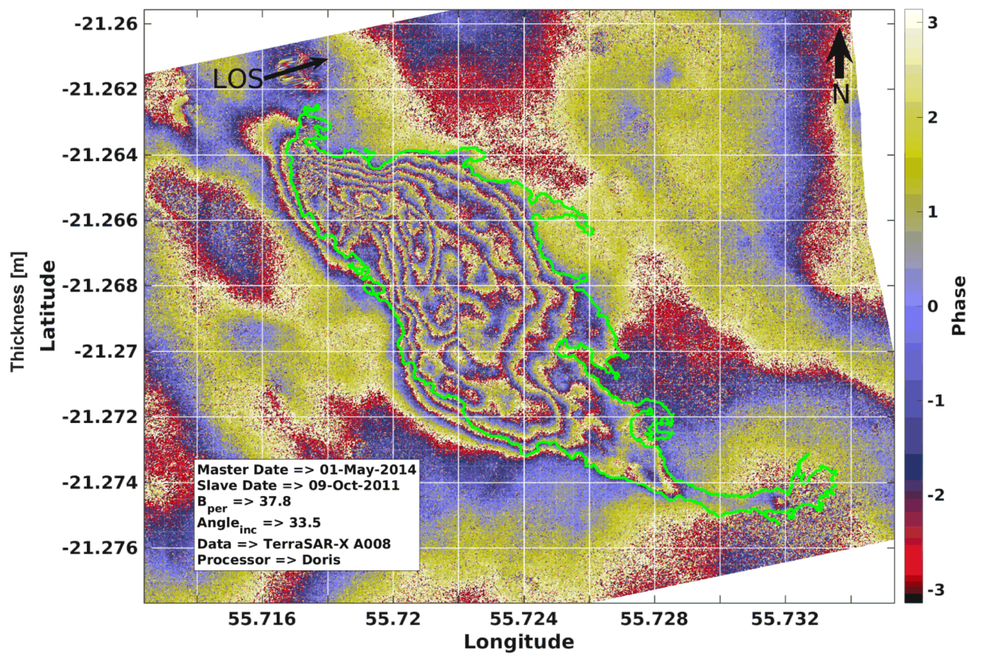


Fig 5. Interferogram TerraSAR-X between October 9th 2011 and May 1st 2014. The green line is the boundary of the lava flow.

Observed displacements for the October 2010 lava flow

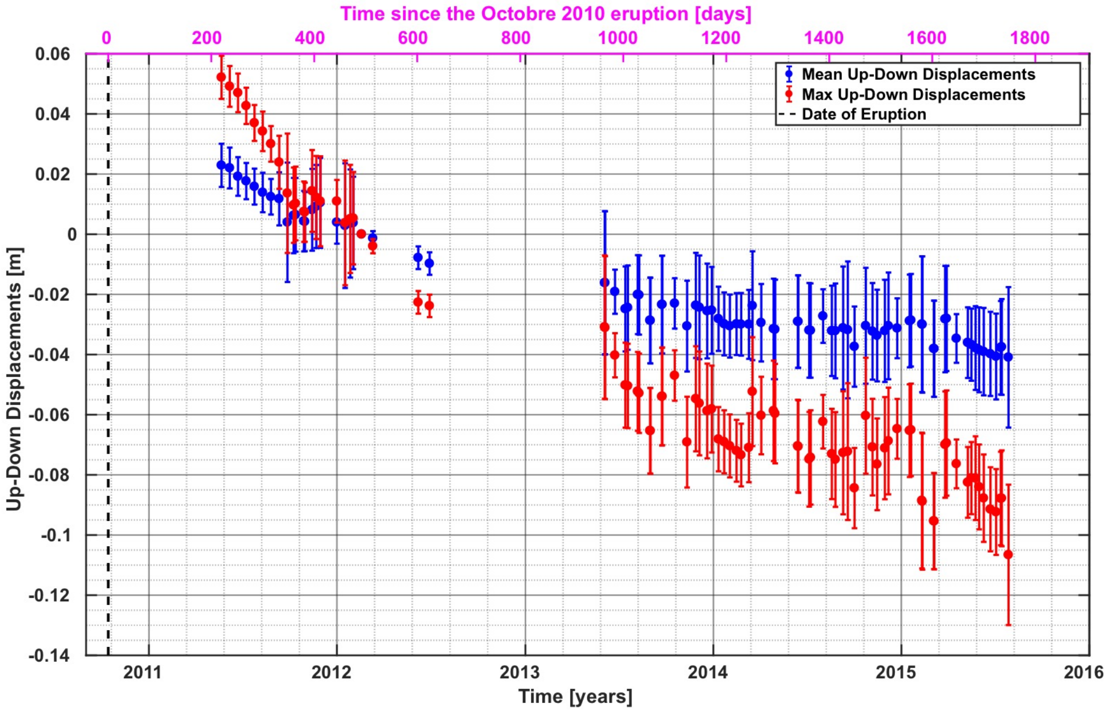
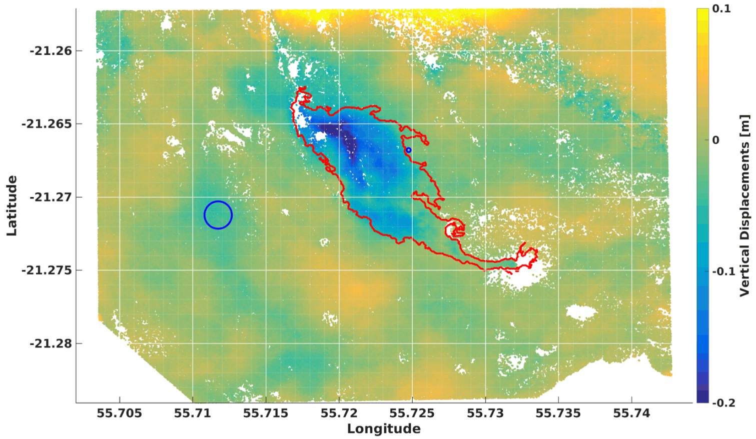
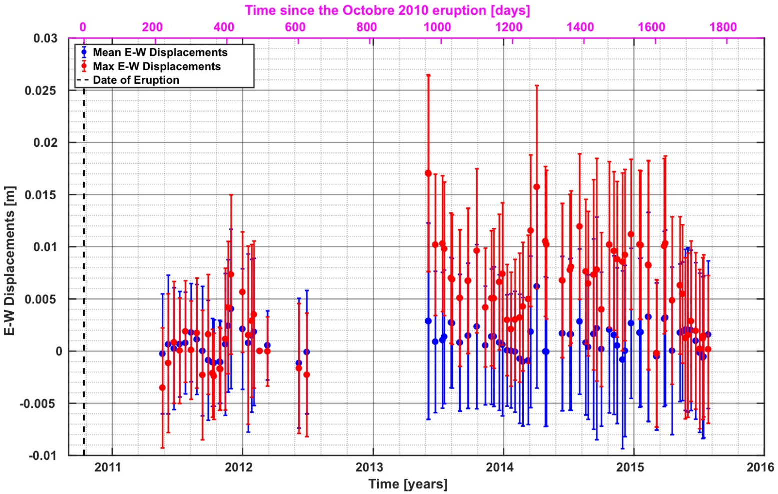


Fig 6. Evolution of observed vertical displacements on the lava flow. The error bars are given at 2 sigma.





- The movement is mainly vertical.
- Subsidence rate decreases with time.
- About 1-3 cm/year.

Fig 7. Evolution of observed E-W displacements on the lava flow. The error bars are given at 2 sigma.

Observed displacements for the flexure of the substratum

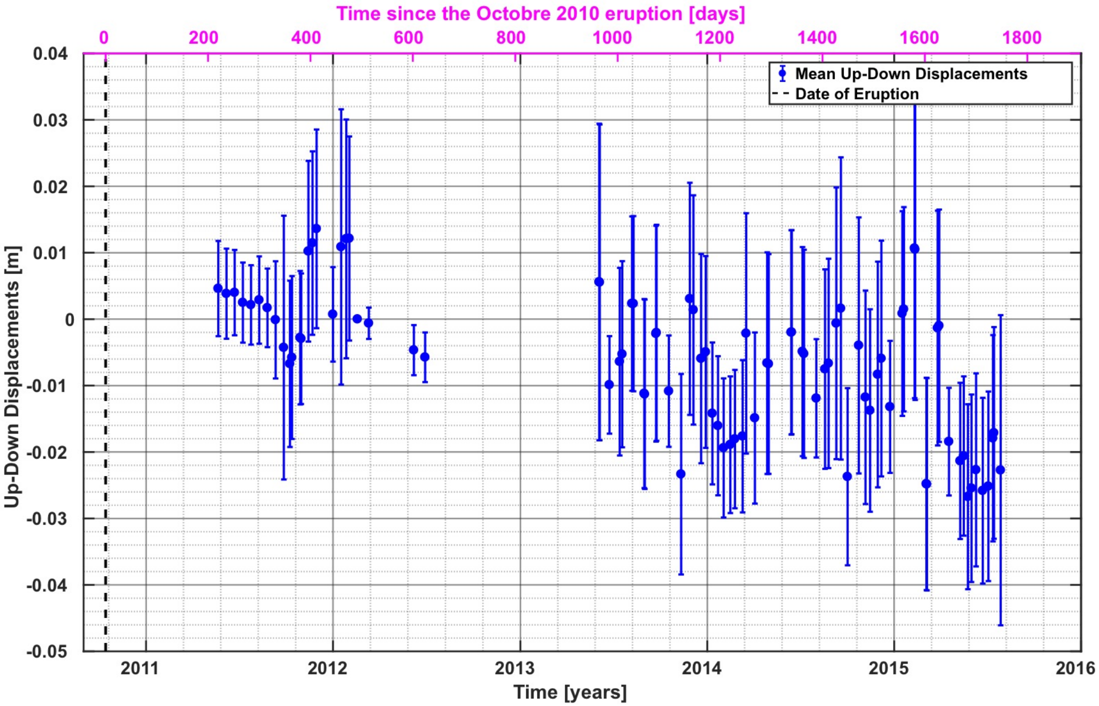
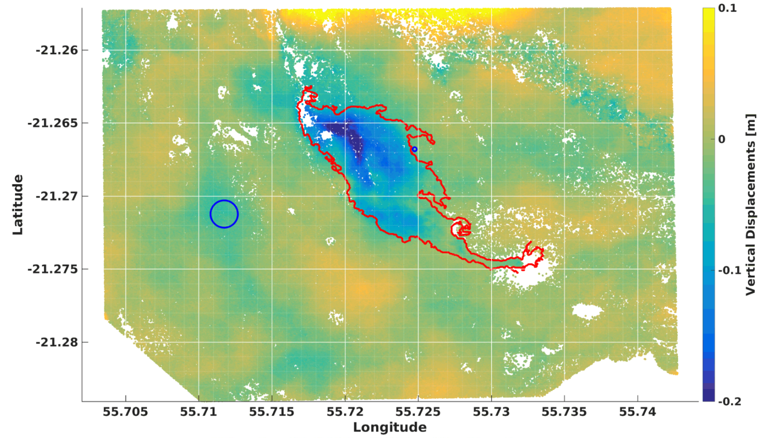


Fig 8. Evolution of observed vertical displacements for the substratum flexure. The error bars are given at 2 sigma.



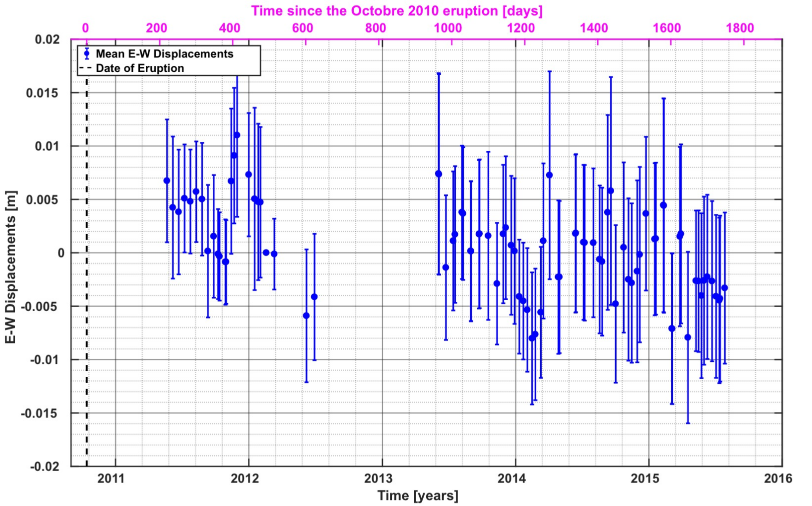


Fig 9. Evolution of observed West-East displacements for the substratum flexure.

- The displacement is mainly vertical.
- The rate globally is constant.
- Around 5 mm/year for the subsidence rate.

Observed displacements for the 2004 and 2006 lava flows

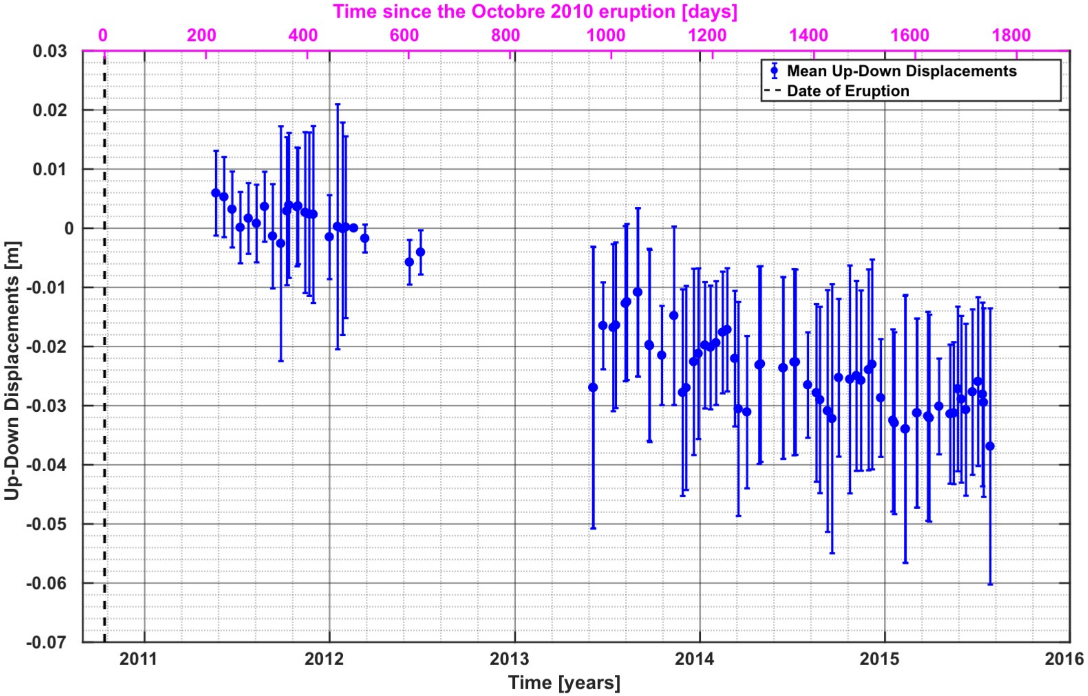
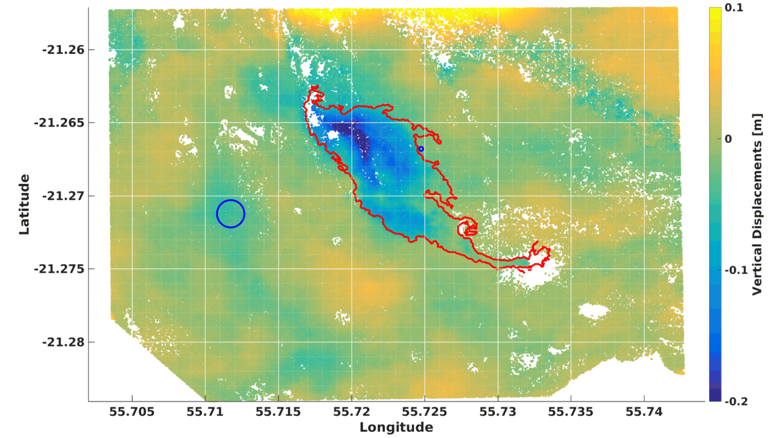


Fig 10. Evolution of observed vertical displacements for the 2004 and 2006 lava flows. The error bar are given at 2 sigma.

- The displacement is mainly vertical.
- The rate: about constant.
- About 1 cm/year for the subsidence rate.



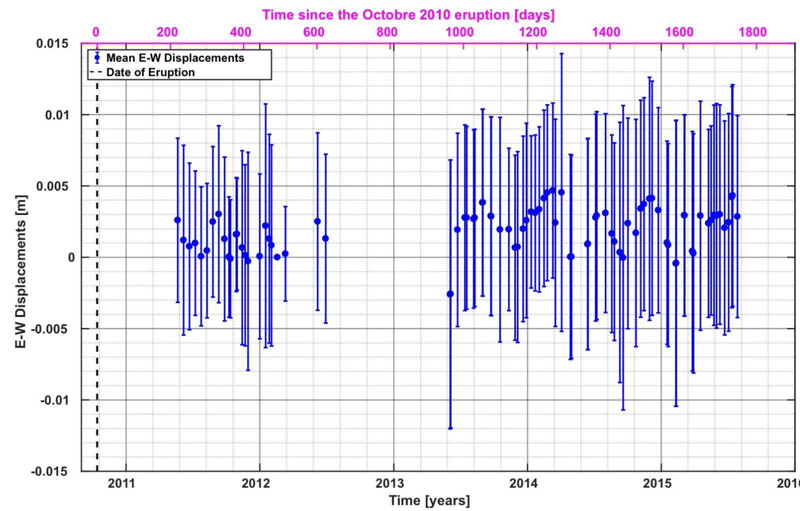


Fig 11. Evolution of observed West-East displacements for the 2004 and 2006 lava flows.

The analysis of the temporal trends

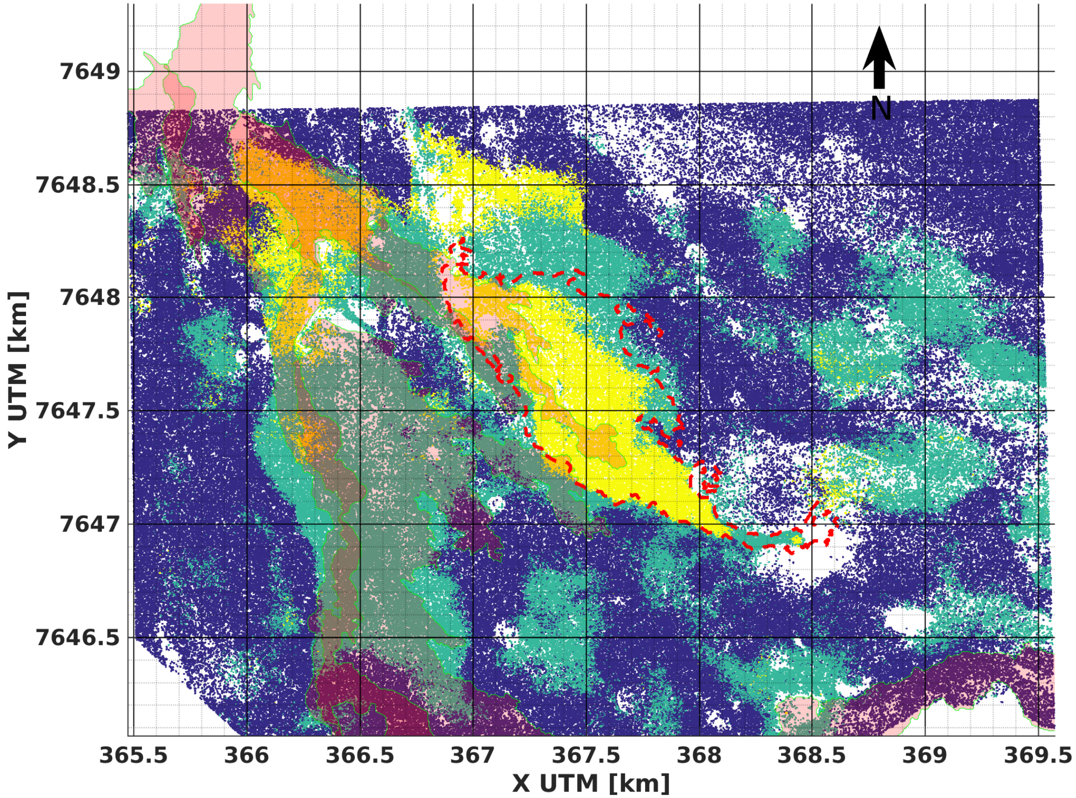


Fig 12. Map of the temporal trend types for the zone of the October 2010 lava flow. The area of 2004 and 2006 lava flows are given by the red polygons.

- Characterisation of the temporal trends was obtained by the algorithm by Berti et al. (2013)

Blue: Uncorrelated
Green: Linear
Yellow: Exponential

- For the linear trends: the characteristic parameter is the subsidence rate.
- For the exponential trends: use of a parameter obtained by the equation of Wittmann et al. (2016)

The lava flow relations between parameter and the thickness

- Use of the linear relation

$$d_{up} = rate_{subsidence} \times t + B$$

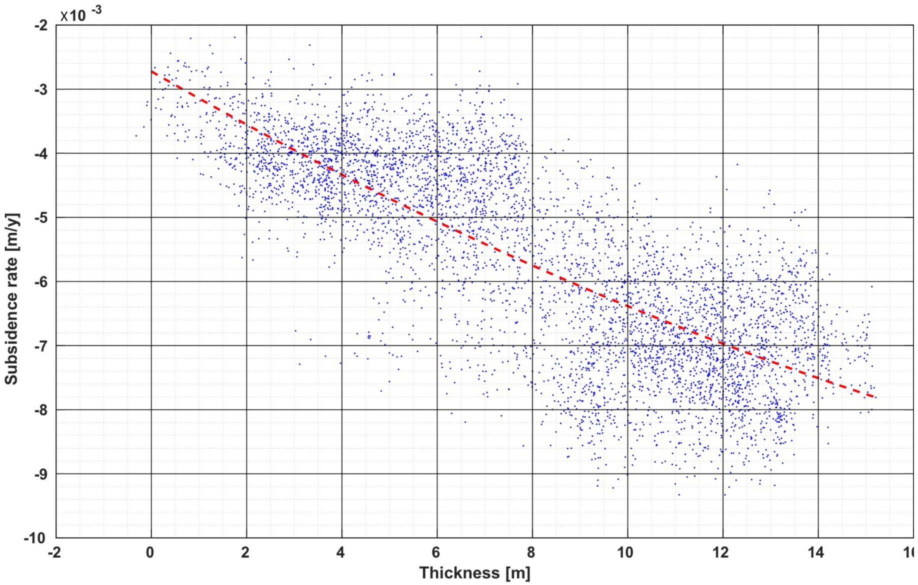


Fig 13. Correlation between the subsidence rate and the thickness of the 2004 lava. Without overlap.

- Use of the relation by Wittmann et al. (2017)

$$d_{up} = \delta y_0 + \delta y_{ts} - A \times b \times e^{\frac{-t}{b}}$$

$$\frac{D_0}{T_{1/2}} = \frac{A}{log(2) \times b^{-1}}$$

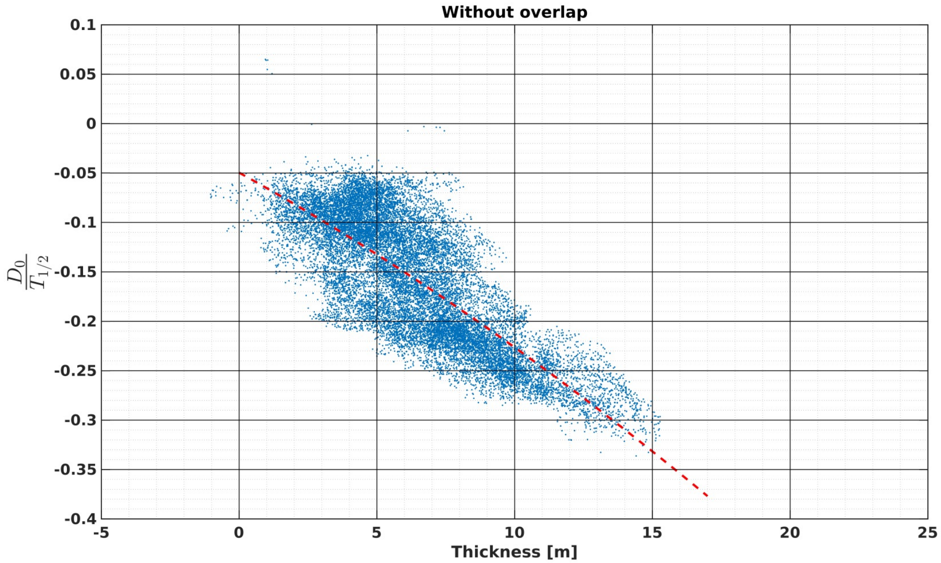


Fig 14. Correlation between the parameter and the thickness of the 2010 lava. Without overlap.

To study the small amplitudes of the displacements

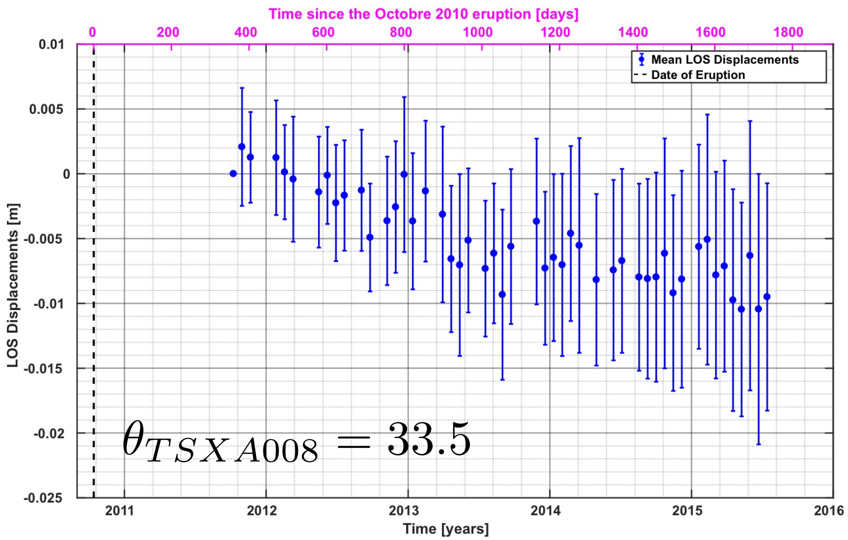


Fig 15. LOS displacements using only the TSX data.

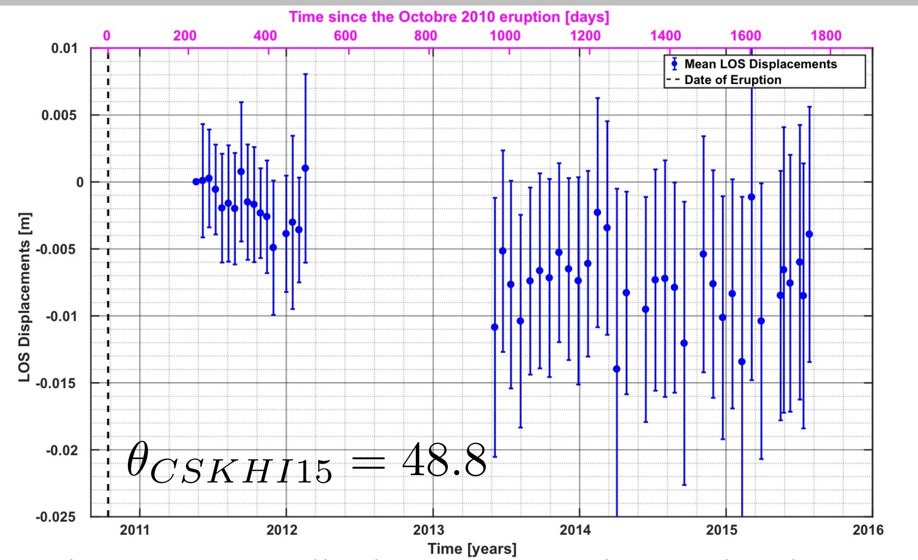


Fig 16. LOS displacements using only the CSK data.

- The sensibility of the geometry acquisition to the vertical displacements takes into account to study the flexure of the substratum. For the second part of the Time Series (from 2014 to mid-2015), the TSX data mean would appear linear. But with the CSK data, the displacements would appear uncorrelated.

The improvement of the relations

- Difficulty to fit the data with the exponential law.
- Great knowledge of the temporal trends.
- Use of the data without a lava overlap.

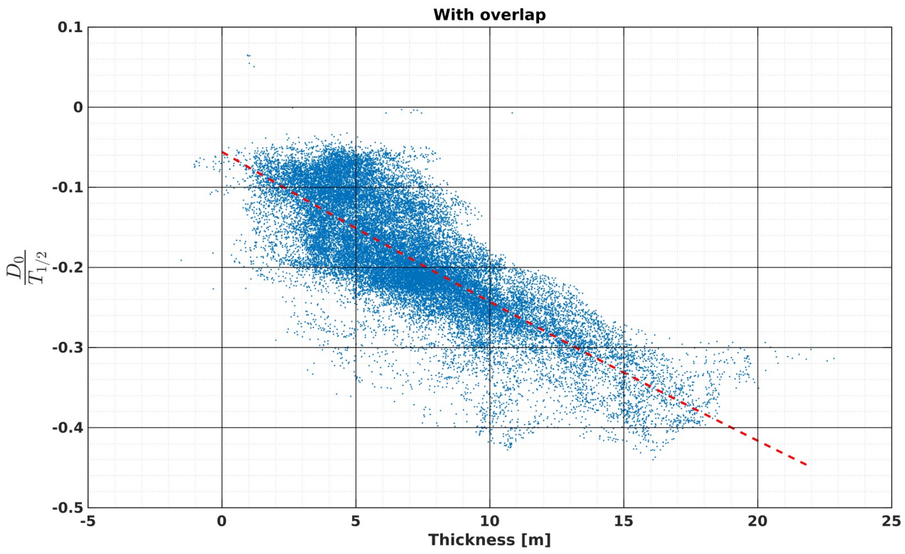


Fig 17. Correlation between the parameter and the thickness of the 2010 lava. With overlap.

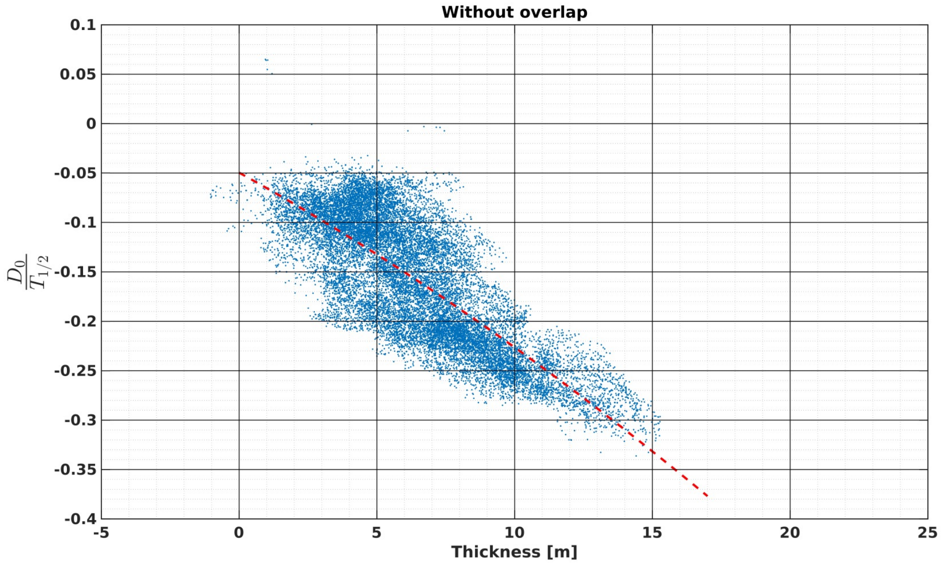


Fig 18. Correlation between the parameter and the thickness of the 2010 lava. Without overlap.

Perspectives

For the lava-flow displacements:

- Analytical and numerical simulations, (Chaussard, 2016; Wittmann et al., 2017).
- Design of a “filter” for the lava flows.

For the flexure of the substratum:

- Analytical and numerical simulations.
- Exploration of rheological models, (viscoelastic, plastic, …)
- Better knowledge of the rheology of the Piton de la Fournaise surface.

Conclusion

- InSAR allow us to map the lava flow displacements.
  1. On the October 2010 lava flow, the subsidence rate varies from 1 to 3 cm/year with an exponential decrease.
  2. Maybe the evolution of the substratum flexure is not linear with a rate around 5 mm/year.
  3. The old lava flows show a linear subsidence with the rate of 1 cm/year.

- The displacements of the lava flows are correlated with the lava thickness but:
  1. A analytical expression of this correlation is related to the temporal trend parameters.
  2. An necessity to work without overlap.

- The study requires a specially build Time Series to study the lava flow displacements

References

Bato, M. G., J. L. Froger, A. J. L. Harris, and N. Villeneuve. 2016. "Monitoring an Effusive Eruption at Piton de La Fournaise Using Radar and Thermal Infrared Remote Sensing Data: Insights into the October 2010 Eruption and Its Lava Flows." *Geological Society, London, Special Publications*. doi:10.1144/SP426.30.

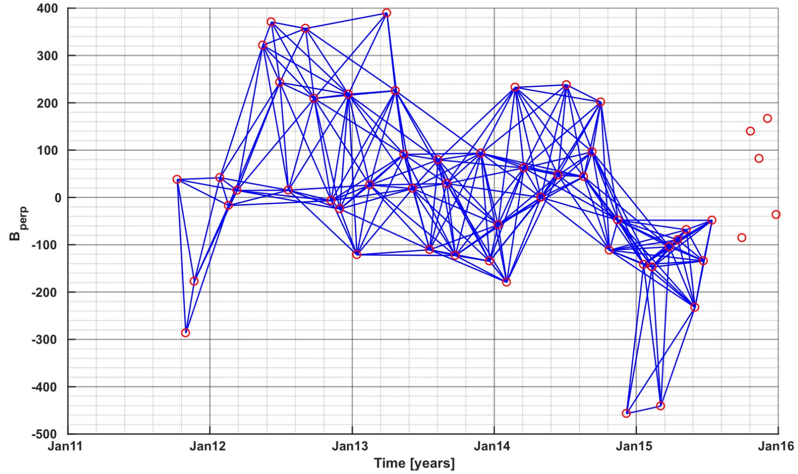
Berti, M., A. Corsini, S. Franceschini, and J. P. Iannacone (2013). Automated classification of Persistent Scatterers Interferometry time series. *Natural Hazards and Earth System Sciences 13(8),* 1945-1958.

Chaussard, E. (2016). Subsidence in the Paricutin lava field: Causes and implications of deformation fields at volcanoes. *Journal of Volcanology and Geothermal Research 320,* 1-11.

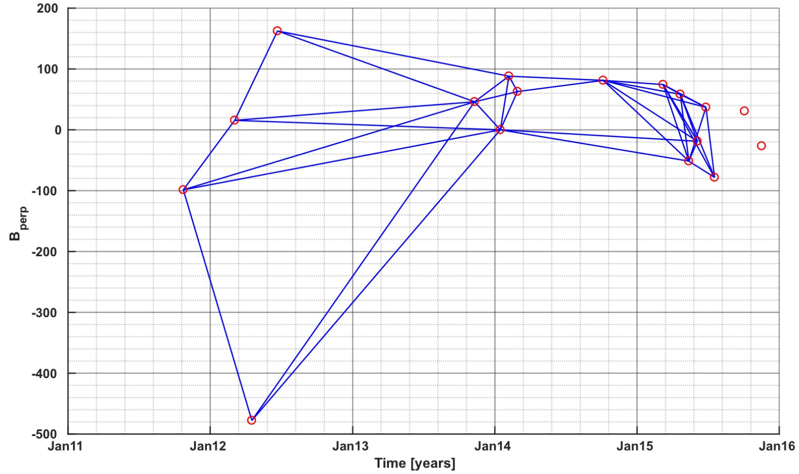
Wittmann, Werner, Freysteinn Sigmundsson, and Yan Lavallée. 2017. "Post-Emplacement Cooling and Contraction of Lava Flows : InSAR Observations and a Thermal Model for Lava Fields at Hekla Volcano , Iceland." *Journal of Geophysical Research B: Solid Earth*, 1–20. doi:10.1002/2016JB013444.

The Small Baselines

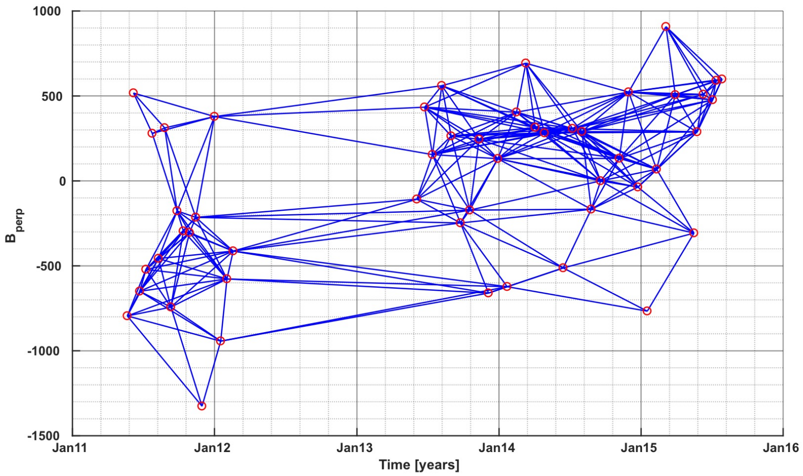
TerraSAR-X A008



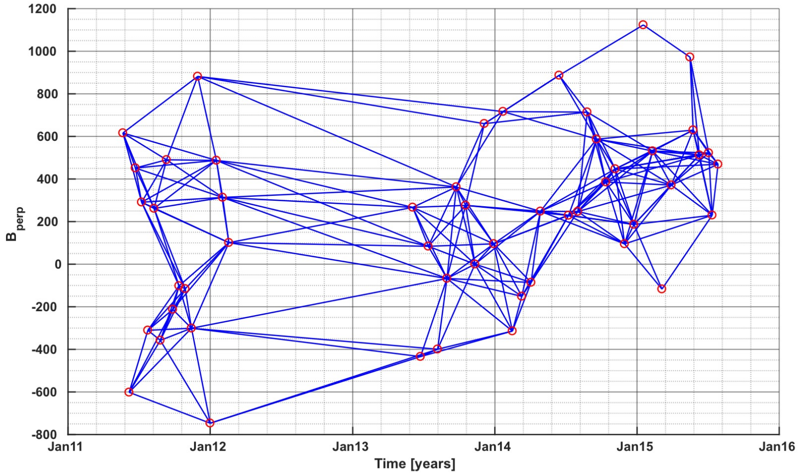
TerraSAR-X D010



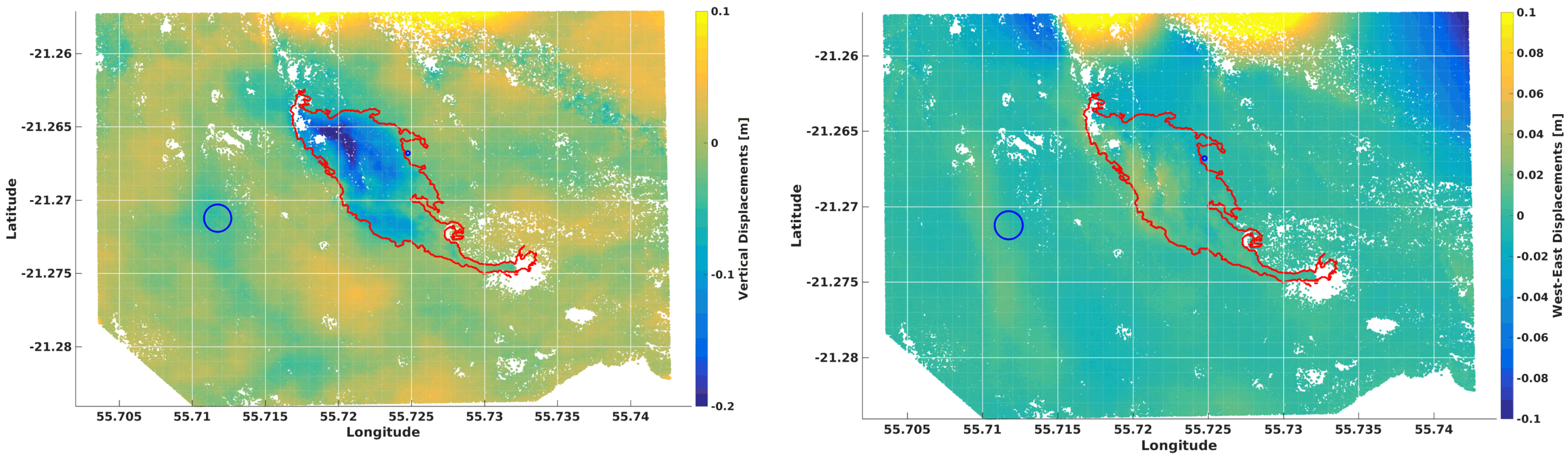
CosmoSky-Med HI 15



CosmoSky-Med HI 18



Map of UP displacements



LOS Displacements: October 2010 lava flow

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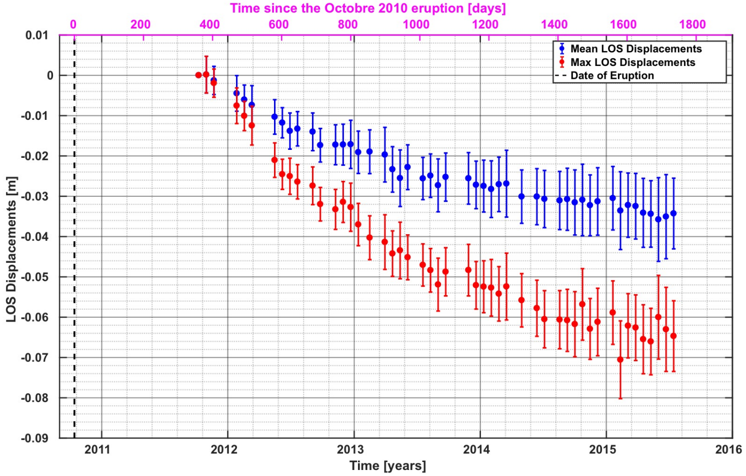

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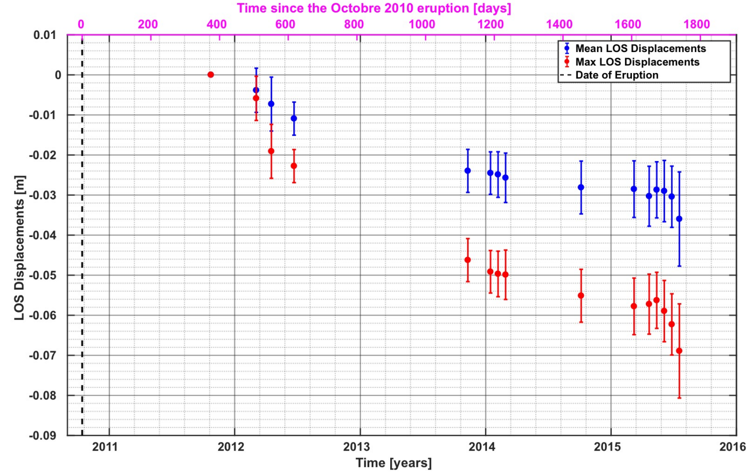
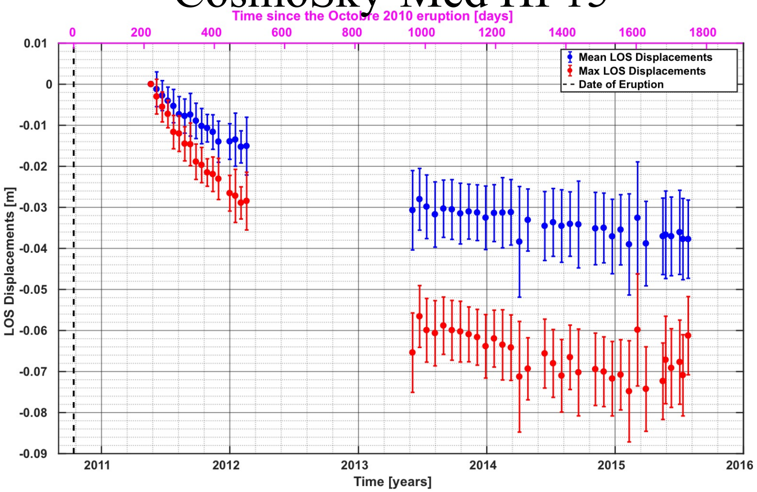


CosmoSky-Med HI 15



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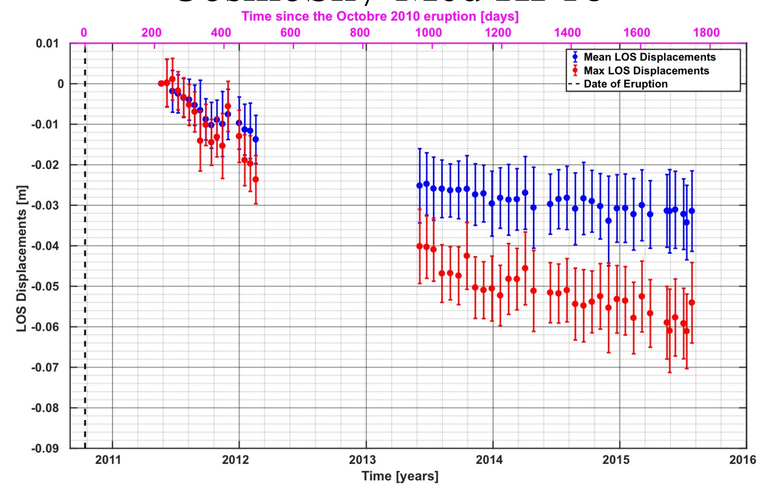
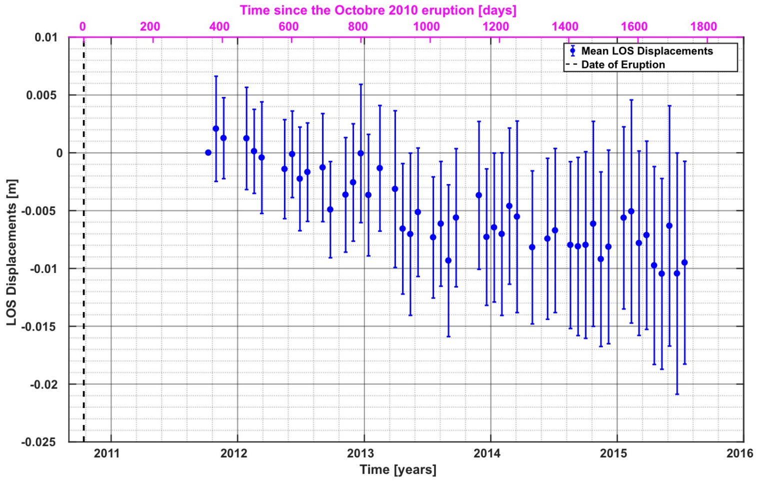


LOS Displacements: Flexure of the substratum

TerraSAR-X A008



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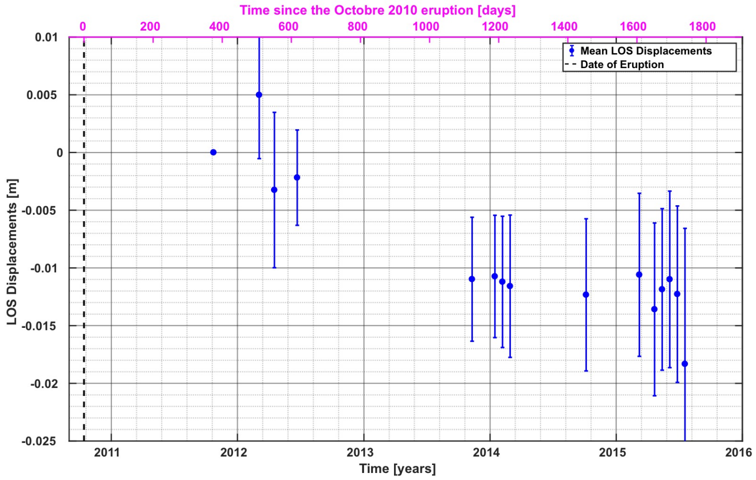

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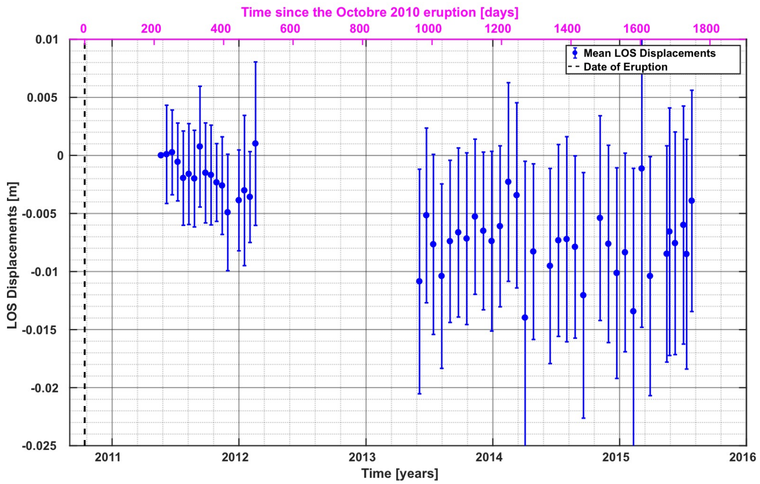

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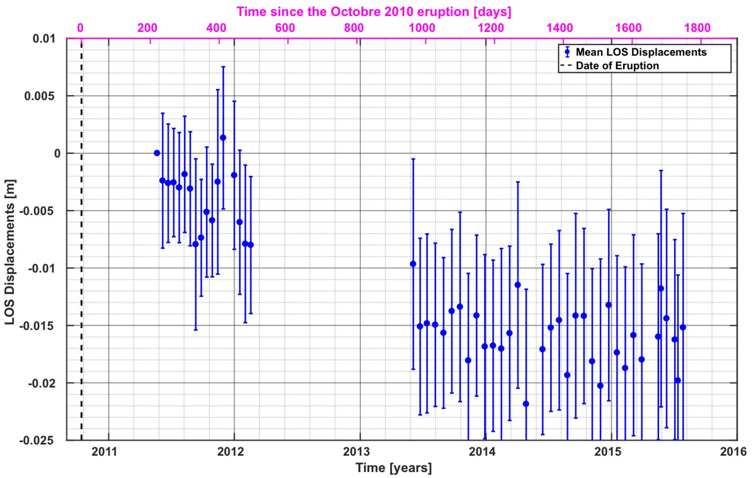
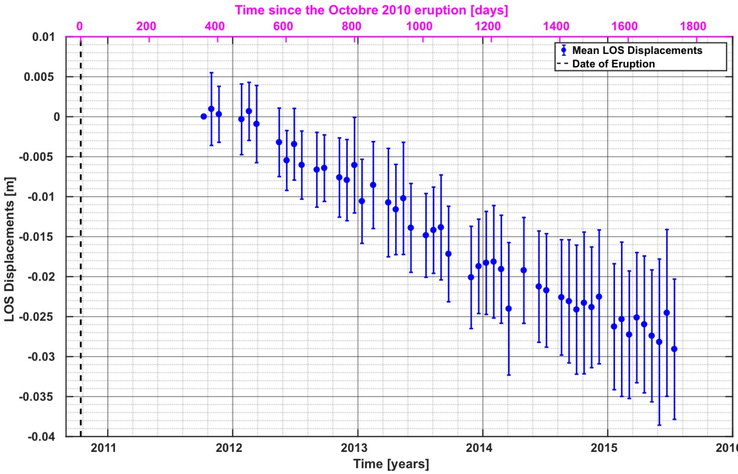


LOS Displacements: 2004 and 2006 lava flows

TerraSAR-X A008



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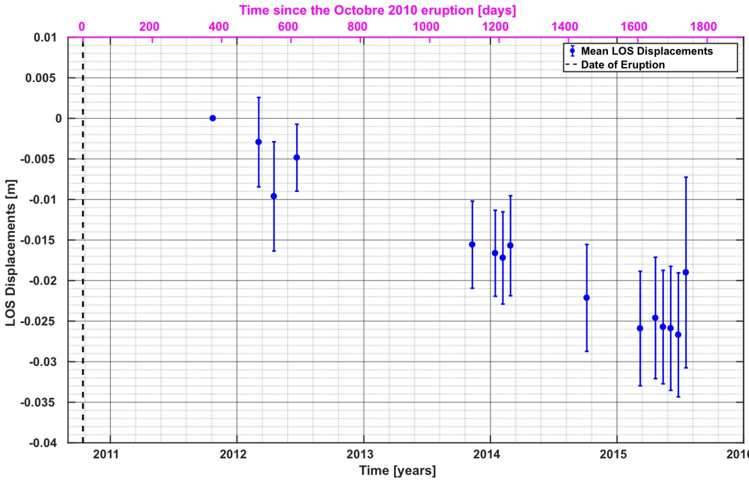

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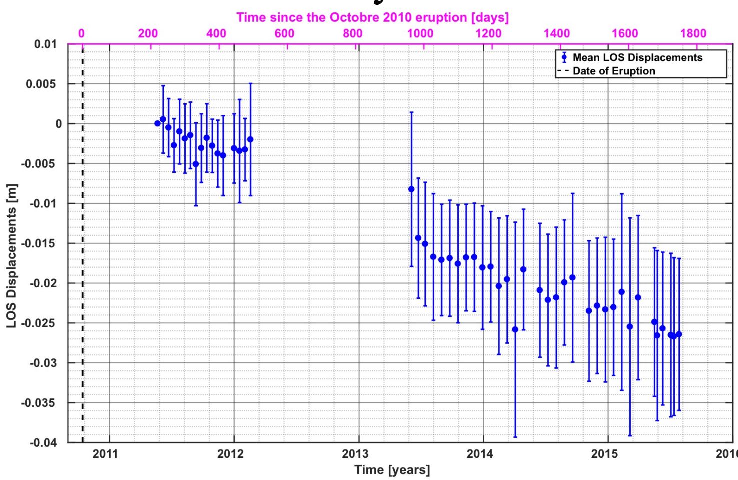

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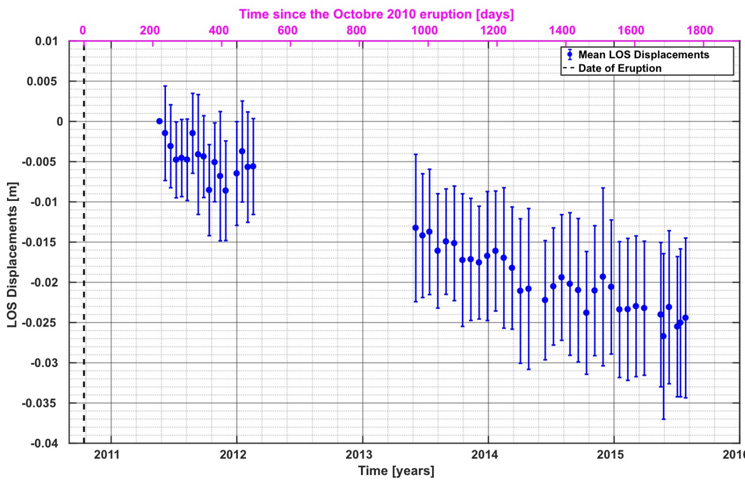
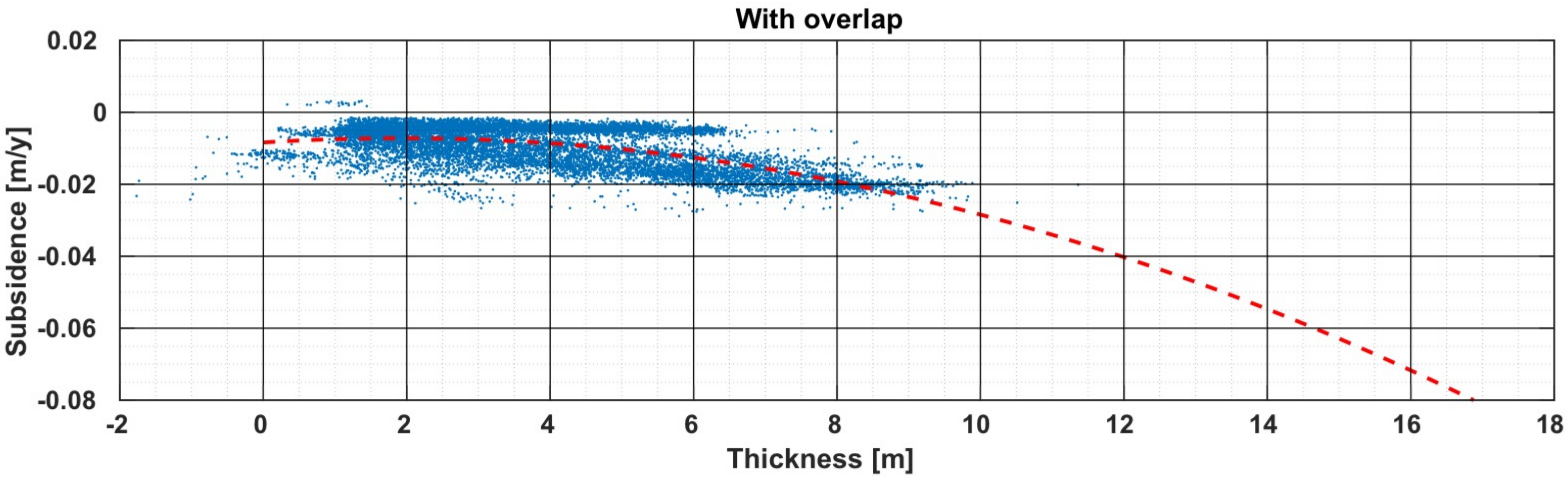
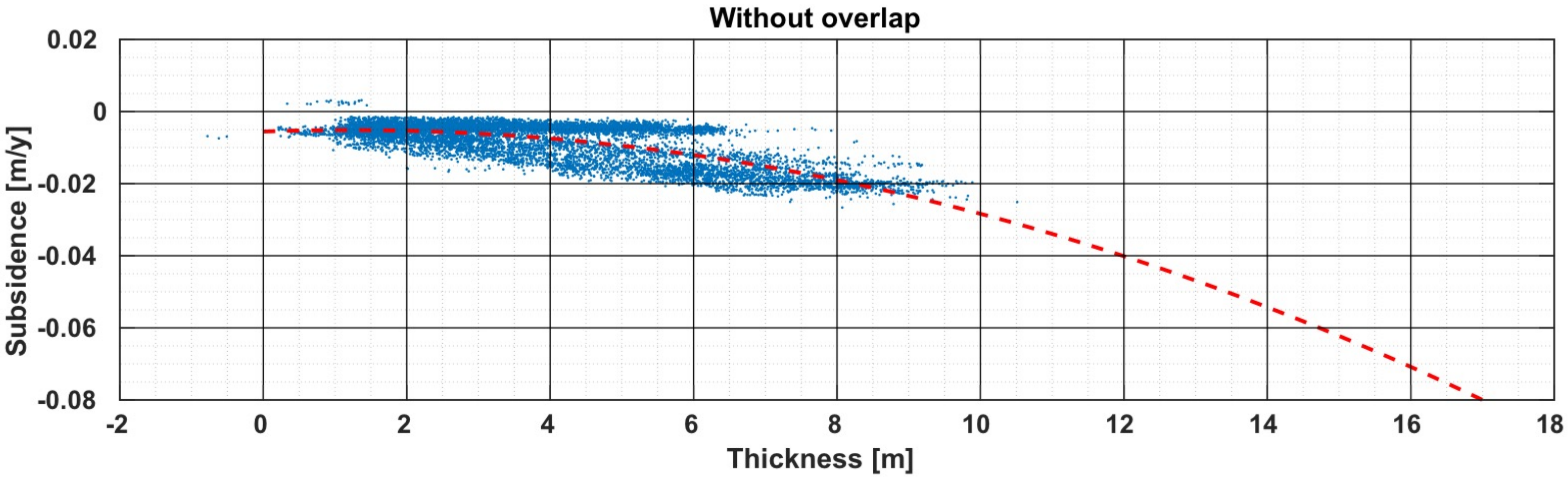


The October 2010 relation: for the linear trends

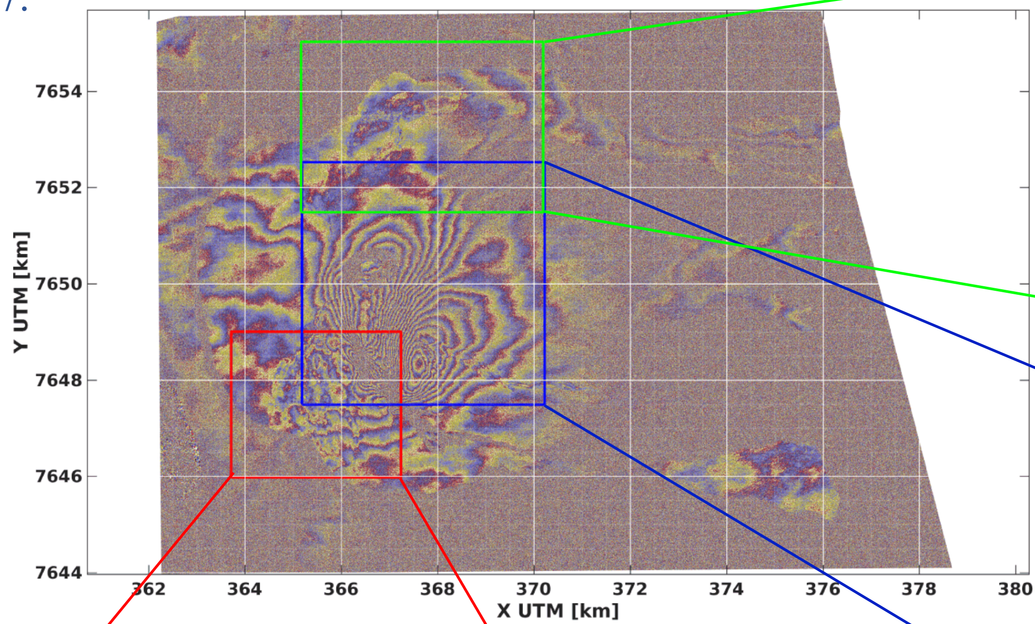


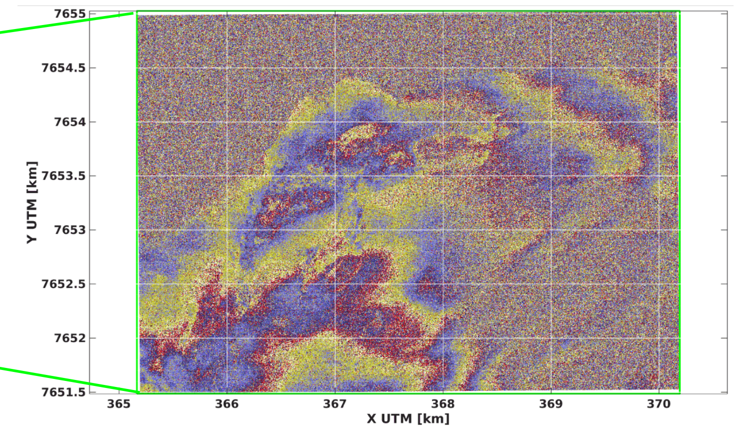


Relation between the subsidence rate of the October 2010 lava flow and the thickness of the lava.

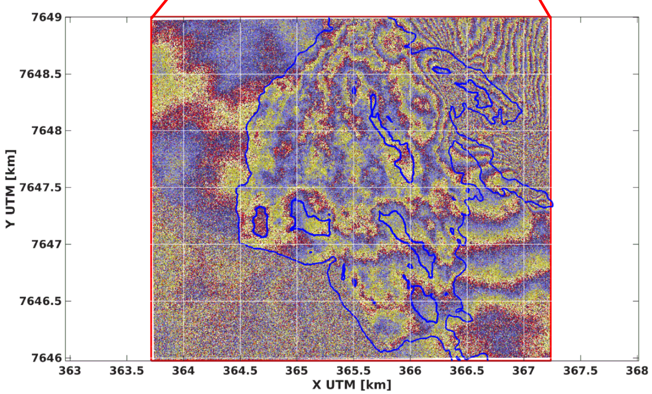
Complexity of InSAR signals

Interferogram CSK HI 15 between Jan 12th 2017 and Feb 7th 2017.

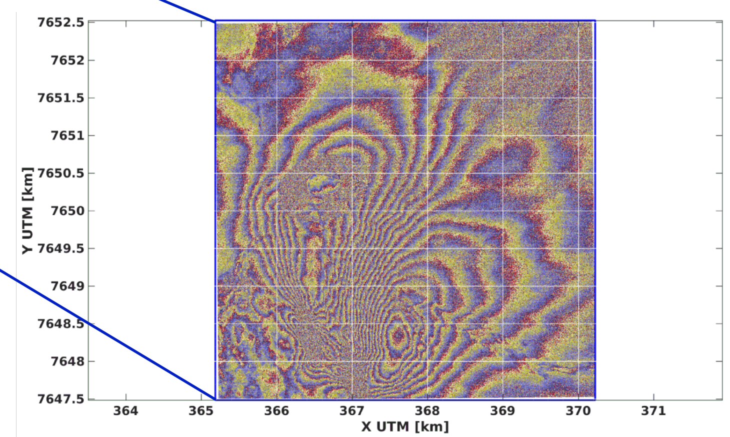




- Atmospheric component?



- Signal related to lava flow (displacements and topographic residues)



- Displacements related to the deep source