Satellite Pre-Failure Detection and In Situ Monitoring of the Landslide of the Tunnel du Chambon, French Alps

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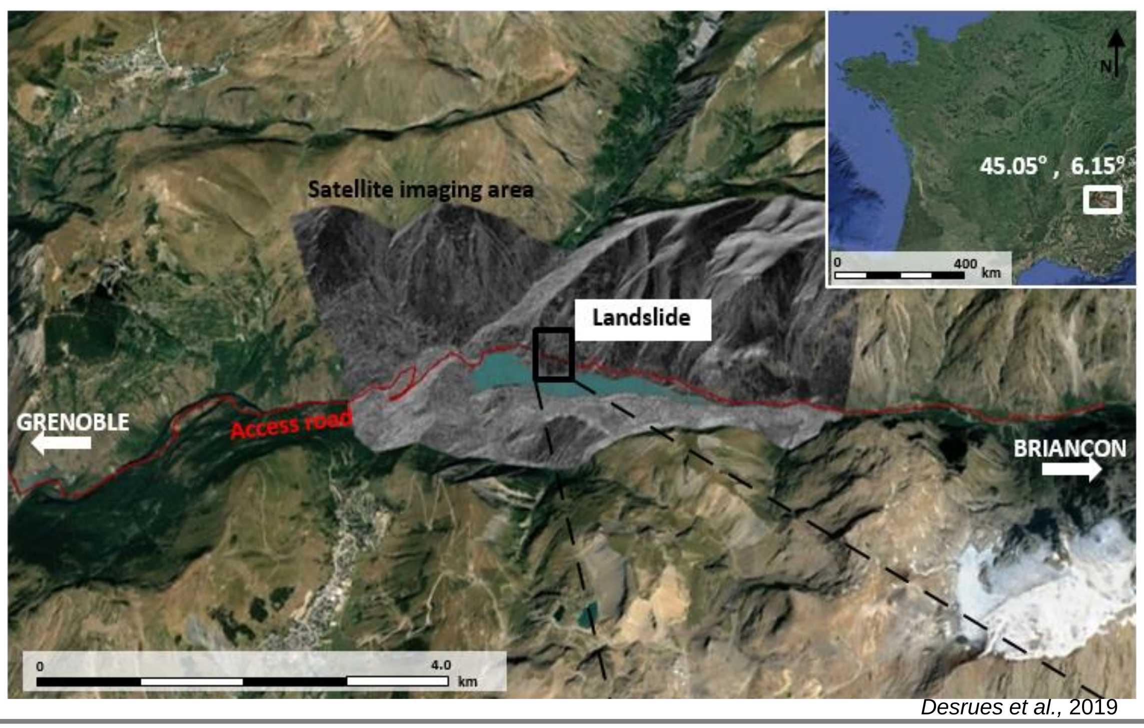
Abstract

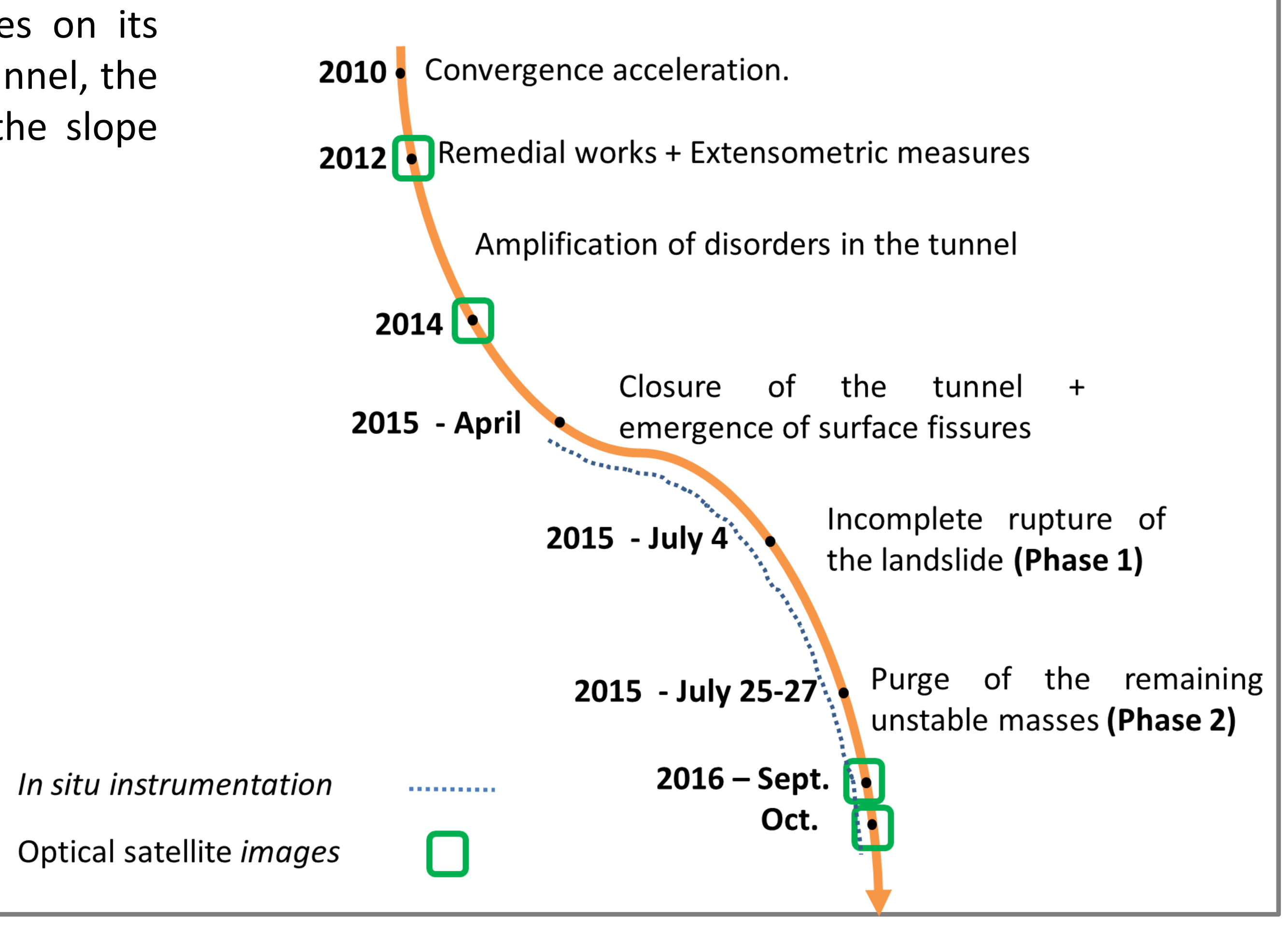
Recent studies using satellite data have shown a growing interest in detecting and anticipating landslide failures. However, their value for an actual landslide prediction has shown variable results. Here, we study the landslide of the Tunnel du Chambon in the French Alps that ruptured in July 2015, generating major impacts on economic activity and infrastructures. To evaluate the contribution of very high-resolution optical satellite images to characterize and potentially anticipate the landslide failure, we conduct here a retro analysis of its evolution. Two time periods are analyzed: September 2012 to September 2014, and May to July 2015. We combine Pléiades optical images analysis and geodetic measurements from in situ topographic monitoring. Satellite images were correlated to detect pre-failure motions, showing 1.4-m of displacement between September 2012 and September 2014. In situ geodetic measures were used to analyze motions during the main activity of the landslide in June and July 2015.

A) Study site

The landslide of the Tunnel du Chambon is located in the French Alps along the Chambon artificial lake reservoir. It affects the tunnel of a major road. Since the tunnel's construction (1935) several damages are recorded. The tunnel was monitored by convergence measures on its walls. Due to the visible surface scarps and rockfalls inside the tunnel, the tunnel closed in April 2015. Few months after, in July 2015, the slope failure occurred.

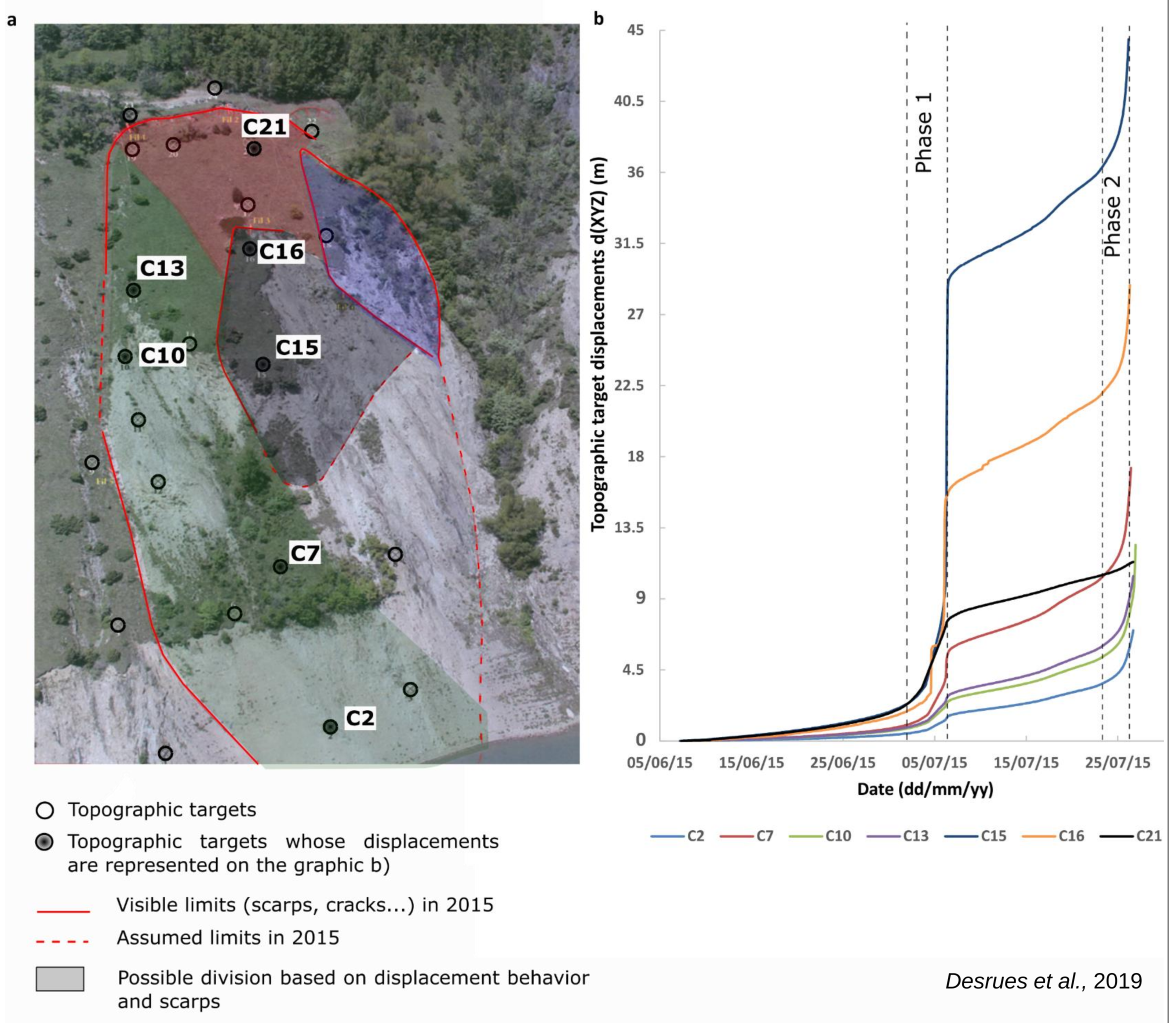


Geology: lower Jurassic sedimentary rocks (Lias),
Length: 250m // **Width:** 100m
Volume involved: 600 000m³ // **Max. thickness:** 25m

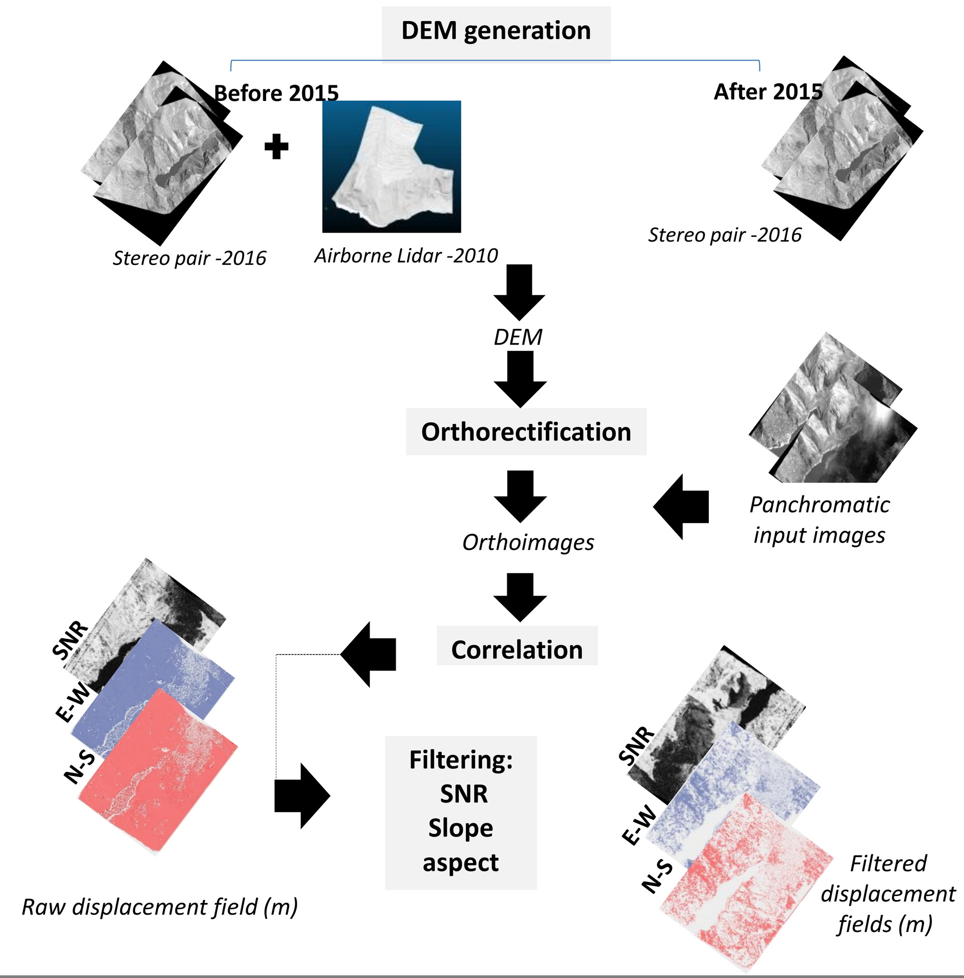


B) Data & Method

- A **network of 24 topographic targets** was set up on the landslide in June 2015 by the SAGE society. The measurement frequency was 1,5h with a precision of 2mm.



- We processed the **Pléiades images** (res. 0.7m at nadir, panchromatic mode) to measure ground displacements at multiple times : 28-09-2012, 26-09-2014, 19-07-2016 and 22-02-2016 (stereo with B/H ratio 0.3). The two latest acquisitions were suitable for generating fine Digital Elevation Model (DEM). No DEMs could have been generated before July 2015. This is why we used available data from an airborne Light Detection And Ranging method (LiDAR), a DEM acquired in 2010 over the landslide area.

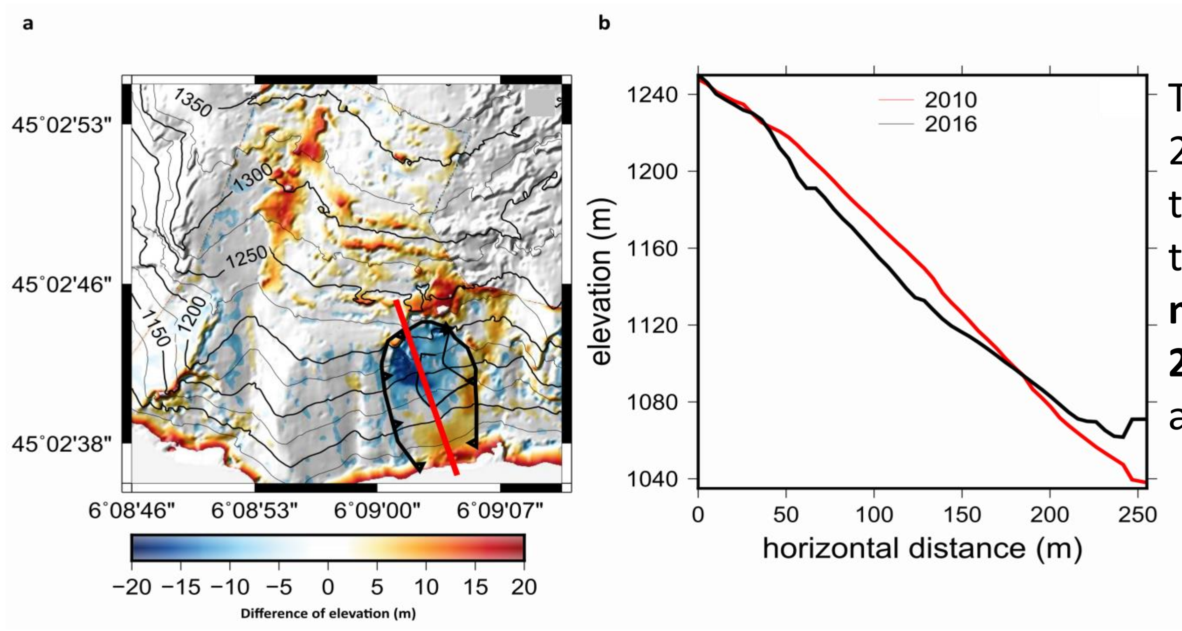


C) Results & Discussion

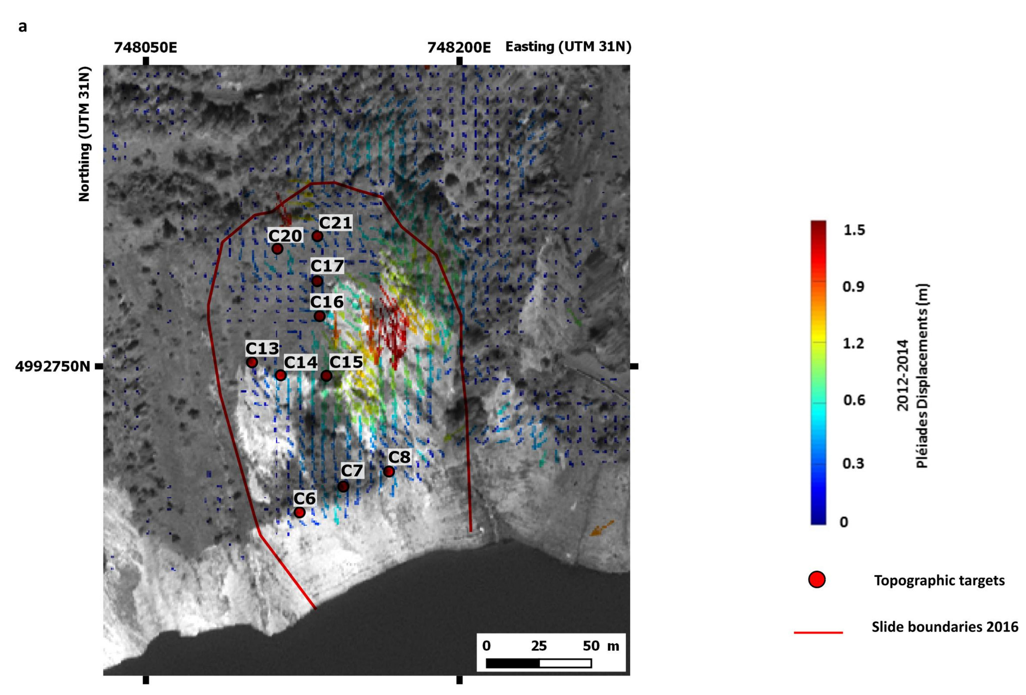
- ***Landslide characterization:*** Based on the topographic targets, we identify different areas based on the displacement behaviors (d(XYZ)) :

Green: d(XYZ) don't exceed a few meters before the 1st phase
Black: d(XYZ) > 10m before the 1st phase
Red: d(XYZ) also important but are not affected by the 2nd phase
Blue: Collapse during the 1st phase

The motion of the topographic targets which shows **some subsidence at the top and a global slide along the slope** is consistent with a **rotational movement.**



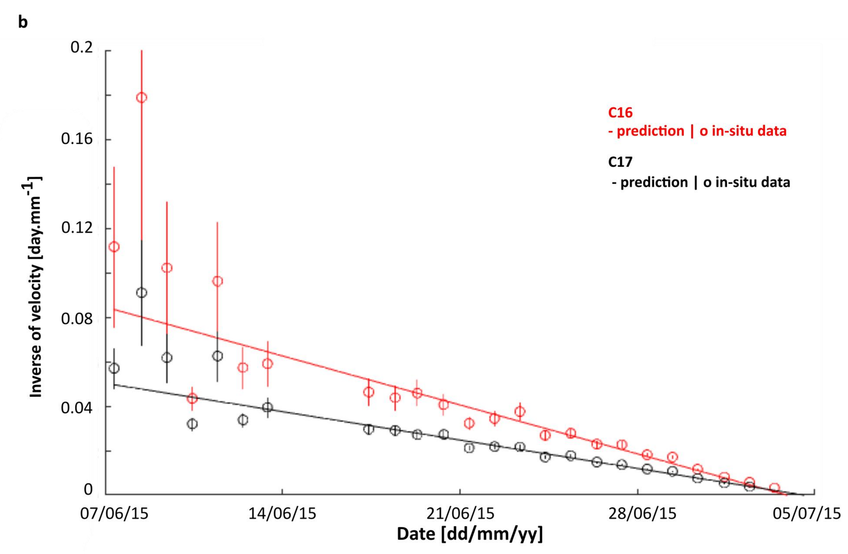
The difference in DEM from 2010 to 2016 clearly shows the development of the landslide head scarp at the top and the bulging at the slope toe. The **maximum altitude difference** shows a **20m erosion** close to the head scarp and **15m of accretion** at its toe.



- ***Landslide Prediction:*** The correlation between the images prior to the crisis (from September 2012 to September 2014) clearly indicates significant motions over the landslide. The maximum displacement detected on the landslide is 1.50 +/- 0.11 m.

The motions observed in the month before the main failure display a classical pattern of acceleration versus time (Eq. (1)):

$$d_{t_1-t_2} = \frac{1}{a} * \log\left(\frac{at_2+b}{at_1+b}\right), \qquad (1)$$



Where $d_{t_1-t_2}$, t_1 and , a and b are the theoretical displacement between 2012 and 2014, the interval time span and the parameters of the linear functions.
The RMSE associated with the linear fit (over 10 targets available) is under 10^{-3}mm. The **fits agree with a main rupture occurring between 1 July and 5 July.**

Results for 10 targets indicate a predicted motion between 3 and 117cm over two years (between 2012 and 2014) which compares well with the Pléiades motions observed at these different points. **Differences between retroactive prediction and Pléiades displacements are between 2 and 40 +/- 11cm.** This comparison suggests that **the landslide could have entered into tertiary cree for at least 2,5 years**.

D) Conclusion

This study shows that the Chambon landslide is a deep landslide of 20-m thickness. It presents **rotational movements** and segmented areas of deformation, with at least **three areas that evolved differently**. Two different periods of strong activity are visible on the displacement curves from theodolite measurements. Those two periods are provoked by **two distinct forcings**. The first one seems to be the **final stage of tertiary creep of a gravitational rupture**, whereas the second is linked to **anthropogenic massive purges** caused by the lake level increase. The monitoring of the Chambon landslide with the Pléiades images and the comparison with in situ data shows its long history and seems to indicate that it entered into tertiary creep more than 2.5 years before its main failure in July 2015. This suggests that the fault zone was mature for several years.

Acknowledgments

Authors would like to gratefully acknowledge the SAGE society for providing theodolite measurements as well as their expertise. We also thank the CNES for sharing optical satellite images through the KALIDEOS project.

Desrues, M., Lacroix, P., & Brenguier, O. (2019). Satellite Pre-Failure Detection and In Situ Monitoring of the Landslide of the Tunnel du Chambon, French Alps. *Geosciences*, *9*(7), 313.