Perspectives on the prediction of catastrophic slope failures from satellite InSAR

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Slope failure prediction – local scale

The “Sciara del Fuoco” at the Stromboli volcano

Tha Gallivaggio rockfall

The Monte Beni landslide

Volterra city walls
Satellite InSAR – regional scale

Piano Straordinario di Telerilevamento

Analysis: Regional PSInSAR™
Dataset: ERS descending
Delivery: November 2009
Sentinel-1

Revisiting time of 6 days
Sentinel-1: conflict-free operation mode
Open-pit mine slope instability
Time Xinmo landslide (Sichuan, China)
Failure of a tailings dam at Cadia gold mine (Australia)
Predictive ability

The relative frequency distribution of the errors (i.e. $t_{pf} - t_{af}$, where $t_{pf}$ is the predicted time of failure and $t_{af}$ the actual time of failure) and of the $R^2$ values was also computed to provide a measure of the predictive ability that may be deduced from the three stacks of Sentinel-1 images.
Inverse velocity plot

Example of accelerating trend and resulting inverse velocity regression related to:

(a,b) the failure of the investigated open-pit mine slope;

(c,d) the Xinmo landslide;

(e,f) the failure of the Cadia gold mine northern TSF.

The red dotted lines indicate the actual failure-time.
Continuous monitoring at regional scale

Transition from static satellite analysis, based on the processing of archive images, to dynamic monitoring of ground displacement.
Sentinel-1 monitoring plans
Trend variation analysis

Anomalously point: MP whose time with a change of deformation rate in the last part of the time series ($\Delta V > 10$ mm/yr in the last 150 days)
Landslide acceleration
Landslide acceleration

**Sector 1 - time series**

| Start of acceleration | Latency period | Appearance of anomaly | Disappearance of appearance | Persistency | Life length (days) |
|-----------------------|----------------|-----------------------|-----------------------------|-------------|-------------------|
| 13/01/2018            | 4 acquisitions | 06/02/2018            | 12/06/2018                  | 126         | 150               |
| 12/02/2018            | 5 acquisitions | 14/03/2018            | 06/07/2018                  | 114         | 144               |
| 14/03/2018            | 3 acquisitions | 01/04/2018            | 05/08/2018                  | 126         | 144               |
Conclusions

• SAR data represent a powerful tool for landslide analysis (i.e., mapping, monitoring and modelling)

• Interferometric approach are widely consolidates for the analysis of slow-moving slope deformations

• ESA Sentinel-1 constellation allow a regular and continuous monitoring of ground deformation at regional scale

• Transition from “one-shot” analysis of ground deformation to a sort of continuous monitoring at regional scale using satellite radar data is now possible

• An estimation of the failure time is possible, at least for some typologies of sliding phenomena
Continuous, semi-automatic monitoring of ground deformation using Sentinel-1 satellites

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We present the continuous monitoring of ground deformation at regional scale using ESA (European Space Agency) Sentinel-1 constellation of satellites. We discuss this operational monitoring service through the case study of the Tuscany Region (Central Italy), selected due to its peculiar geological setting prone to ground instability phenomena. We set up a systematic processing chain of Sentinel-1 acquisitions to create continuously updated ground deformation data to mark the transition from static satellite analysis, based on the analysis of archive images, to dynamic monitoring of ground displacement. Displacement time series, systematically updated with the most recent available Sentinel-1 acquisition, are analysed to identify anomalous points (i.e., points where a change in the dynamic of motion is occurring). The presence of a cluster of persistent anomalies affecting elements at risk determines a significant level of risk, with the necessity of further analysis. Here, we show that the Sentinel-1 constellation can be used for continuous and systematic tracking of ground deformation phenomena at the regional scale. Our results demonstrate how satellite data, acquired with short revisiting times and promptly processed, can contribute to the detection of changes in ground deformation patterns and can act as a key information layer for risk mitigation.

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We demonstrate the potential of satellite interferometric Synthetic Aperture Radar (InSAR) to identify precursors to catastrophic slope failures. To date, early warning has mostly relied on the availability of detailed, high-frequency data from sensors installed in situ. The same purpose could not be chased through spaceborne monitoring applications, as these could not yield information acquired in a sufficiently systematic fashion. Here we present three sets of Sentinel-1 constellation images processed by means of multi-interferometric analysis. We detect clear trends of accelerating displacement prior to the catastrophic failure of three large slopes of very different nature: an open-pit mine slope, a natural rock slope in alpine terrain, and a tailings dam embankment. We determine that these events could have been located several days or weeks in advance. The results highlight that satellite InSAR may now be used to support decision making and enhance predictive ability for this type of hazard.

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