Date of Submission	26/10/2020

IPL Project (IPL - 221) Annual Report Form 2019

1 January 2019 to 31 December 2019

1. IPL-221 (2017) Title: PS continuous streaming for landslide monitoring and mapping
2. Main Project Fields:
   (X) **Technology Development**
   X. **Monitoring and Early Warning,**
3. Name of Project leader
   Federico Raspini and **Silvia Bianchini,** Researcher
   Affiliation: **Earth Sciences Department of the University of Firenze (DST-UNIFI)**
   Contact: **Via La Pira, 4 - 50121, Firenze, (Italy) - Phone: +39 055 2757551;**
   Mobile: +39 3398929831 E-mail: federico.raspini@unifi.it
4. Core members of the Project: Names/Affiliations: (4 individuals maximum)
   Nicola Casagli, Full Professor, DST-UNIFI
   Veronica Tofani, Researcher, DST-UNIFI
   Matteo del Soldato, Researcher assistant, DST-UNIFI
5. Objectives

The main objective of this project is to perform the transition from historical analysis of radar satellite image archives to real time monitoring of ground deformation at regional scale using radar satellite scenes. To accomplish this objective the short revisiting time and regularity of acquisitions of Sentinel-1 constellation of SAR (Synthetic Aperture Radar) satellite sensors were exploited.

6. Study Area

The study area is the Tuscany Region (Central Italy), specifically selected due to its peculiar geological setting prone to ground instability phenomena. Its territory, mainly hilly (66.5%) with mountainous areas (25.1%) and few plains (8.4%) results to be a very landslide-prone area.

During the 2019 the analysis has been extended to the Veneto Region (Northwest Italy), a large territory with a wide plain area where many subsidence bowls are spotted and with an alpine sector extensively affected by large landslides.

7. Project Duration

The duration of the project is two years.

8. Report

1) Progress in the project

To set up the initial baseline of the continuous monitoring of the Tuscany and Veneto Region, the existing images archive of the ESA Sentinel-1 C-band images was acquired and processed with the SqueeSAR approach. The Sentinel-1A coverage of the Tuscany Region (including the main islands, Elba and Giglio) is achieved by two different frames in ascending and descending geometries, distributed in two tracks along each orbit (track 15 and 117 and track 168 and 95, respectively). For the Veneto Region, the coverage is ensured by track 117 in ascending and track 168 and 95 in descending.

The first ground deformation maps obtained through the processing of the Sentinel-1A archives are shown in Figure 1 for the Tuscany Region and in Figure 2 for the Veneto Region. With almost one million points for each acquisition geometry, these maps include information that can be exploited to scan wide areas, to spot unstable zones and to reconstruct the deformation history of the observed scene back to 2014.

However, despite the reliability of this information, these maps are unsuitable to monitor the deformation occurring in the observed scene as they simply provide a static and retrospective view of the main areas affected by ground motion.

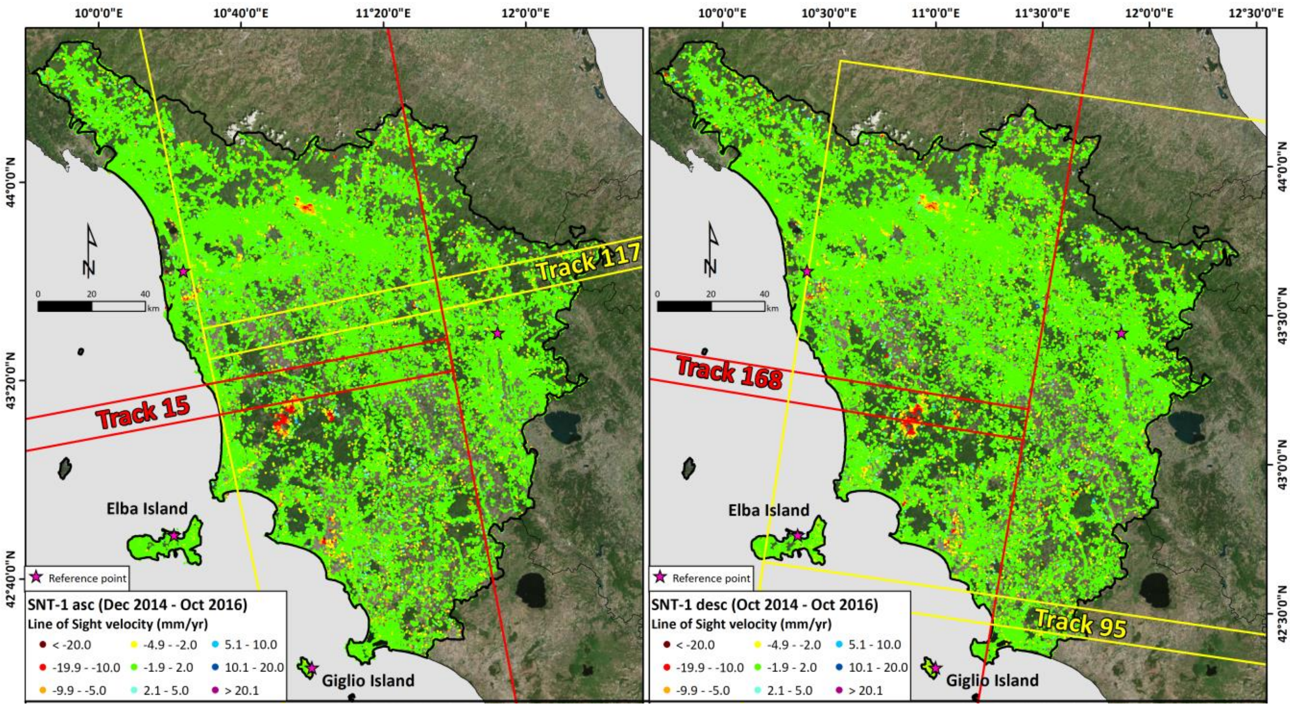


Figure 1 - Archive (2014 - 2018) ground deformation maps for the Tuscany Region obtained with SqueeSAR processing. For ascending (left) and descending geometry (right).

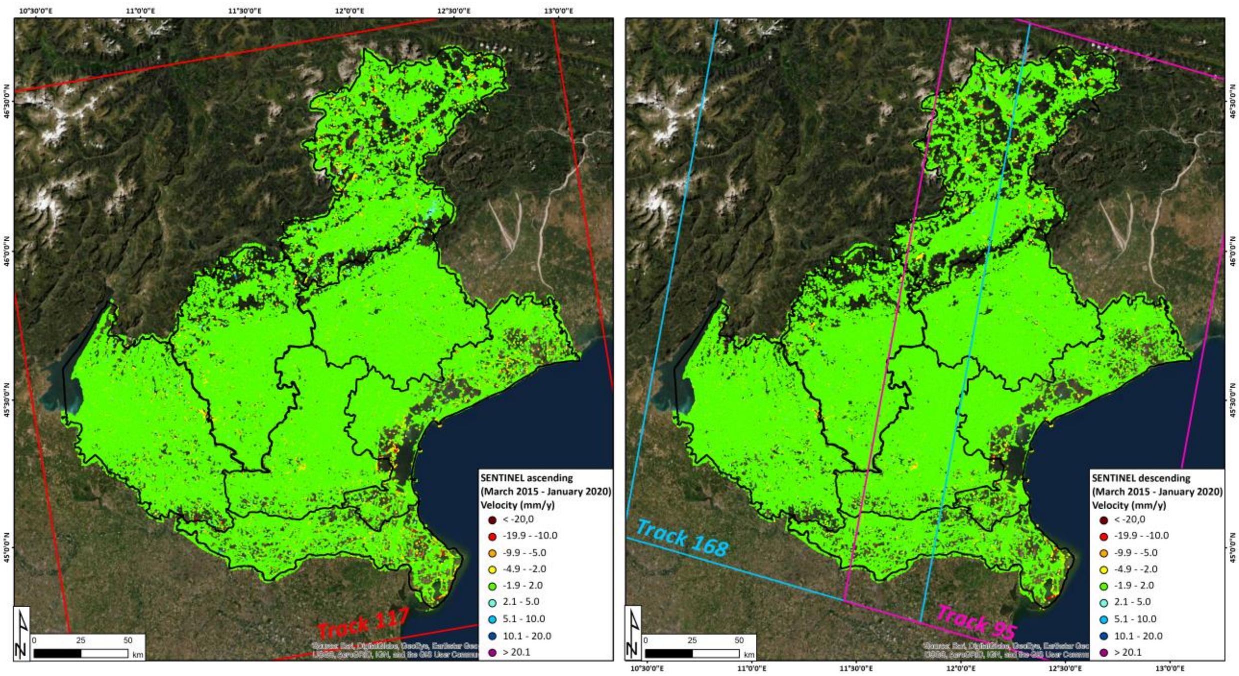
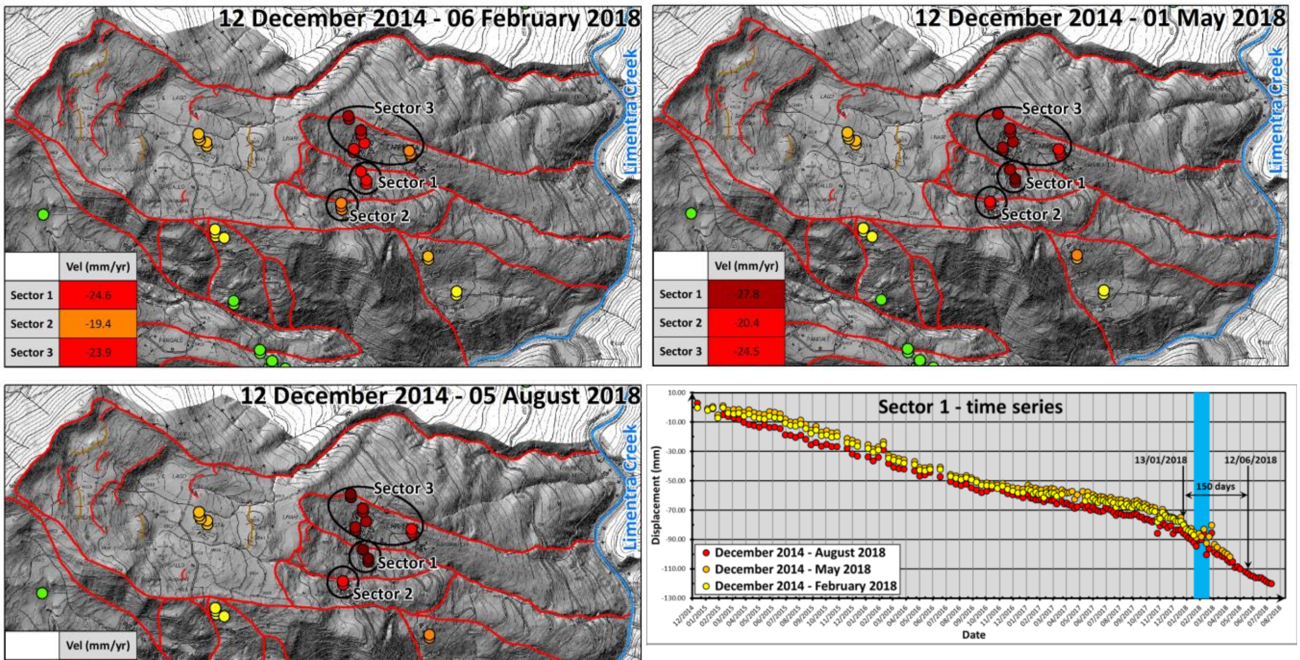


Figure 2 - Archive (2014 - 2019) ground deformation maps for the Veneto Region obtained with SqueeSAR processing. For ascending (left) and descending geometry (right).

To accomplish the transition from historical satellite analysis of radar imagery to a dynamic streaming of displacement at regional scale, a specific processing chain for both ascending and descending geometry has been set. Once a new Sentinel-1 image is available, it is automatically downloaded and added to the existing archive. The new data stack is then entirely reprocessed to generate new ground deformation maps and updated displacement time series. A series of subsequent updating is created every twelve days using Sentinel-1A images. Following each subsequent updating a continuous analysis of time series is regularly performed to identify, in the most recent interval of the time series (i.e., the last 150 days) any change in the deformation pattern. When a change with $|\Delta V|$ higher than 10 mm/yr is identified, the point is highlighted as anomalous. When detected, changes in the deformation pattern are analyzed and interpreted to decide if an anomalous pattern is coherent with real slope dynamics and can be considered worth reporting to regional authorities. The presence of cluster of anomalies along with their temporal persistency are the most important parameters to link registered trend changes and landslide reactivation.

The small cluster of anomalous points (few per update) that appeared during the winter of 2018 in the village of Carpineta (in the municipality of Sambuca Pistoiese in the northern part of Tuscany, (Figure 3) is a representative case of persistent and significant anomalies of movement. This cluster of persistent and significant anomalies is in an area with elements that are at risk (urban areas, roads, infrastructures), indicating a significant level of risk that is considered worth relaying to the authorities, with the need for further analysis and on-site validation surveys.

Systematic analysis of continuously updated deformation time series offers several advantages compared to the simple use of the average yearly motion rate in landslide analysis. In addition to the progressive increase in displacement, the time series indicated that the acceleration affected different parts of the Carpineta landslide at different times. Figure 3 shows that the continuous screening of time series allows the early detection of anomalous variations, whose appearance, persistency and disappearance follow a precise timing. Specifically, measurement points become anomalous after the start of acceleration. This period, defined as the latency of the anomaly, may vary from 3 to 5 acquisitions, depending on the intensity of the acceleration itself. The period of latency is designed to identify only measurement points with a consolidated trend variation and disregard temporary changes in the time series, which are likely due to errors in data processing or intrinsic noise and are not related to real ground motion. After its appearance, the anomaly persists for a certain number of updates. This period of persistency, added to the latency time, covers a period of approximately 150 days, corresponding to the time interval selected for the detection of the anomaly. After 150 days, the anomaly disappears, reappearing only in the case of a new variation (acceleration or deceleration) in the time series.



	Start of acceleration	Latency period	Appearence of anomaly	Disappearance of anomaly	Pesistency (days)	Life lenght (days)
Sector 1	13/01/2018	4 acquisitions	06/02/2018	12/06/2018	126	150
Sector 2	12/02/2018	5 acquisitions	14/03/2018	06/07/2018	114	144
Sector 3	14/03/2018	3 acquisition	01/04/2018	05/08/2018	126	144

Figure 3 - Mean annual deformation rates of the Carpineta landslide obtained through the continuous processing of Sentinel-1 data acquisition. In the lower left insets, the increase over time of mean deformation velocities for the different sectors is shown. Displacement time series for the Carpineta landslide in three different time intervals. The blue bar indicates the presence of snow on the ground. A summary table of the appearance, persistence and disappearance of anomalies in the three sectors of the Carpineta landslide is also shown.

Summarizing, the new monitoring system based on the systematic processing of Sentinel-1 data acquisitions is active over the entire Tuscany and Veneto Region. This system, which provides a continuous stream of processed data, marks the transition from retrospective satellite analysis to the timely monitoring of ground displacement at the regional scale.

Systematic analysis of updated deformation time series allows the prompt identification of a landslide's acceleration, which could be underestimated or, even worse, totally undetected by a visual analysis performed by an operator on the basis of velocity maps only. Advances in the performance of satellite systems, processing algorithms, data mining tools and computational capabilities allow the design of new paradigms for monitoring ground deformation at the regional (or wider) scale, exploiting SAR data to feed a decision support system for hydrogeological risk mitigation strategies.

2) Planned future activities or Statement of completion of the Project

The monitoring of ground deformation over Tuscany and Veneto Region using Sentinel-1 acquisition is currently active. The continuous elaboration of Sentinel-1 images for landslide monitoring and mapping with associated trend variation analysis will continue. Analysis and interpretation of results derived from continuous elaboration of Sentinel-1 images will proceed systematically. Field investigations will be performed in those areas at potential risk and, if necessary, they will be targets for more detailed analysis. Finally, a new area (Figure 4) has been selected for application of InSAR approach to Sentinel-1 images. It is a region in northern Pakistan, one of the most active and unstable areas in the world. A dataset of 85 Sentinel-1 images, collected along ascending orbit (track 27) have been acquired, downloaded and prepared for processing.

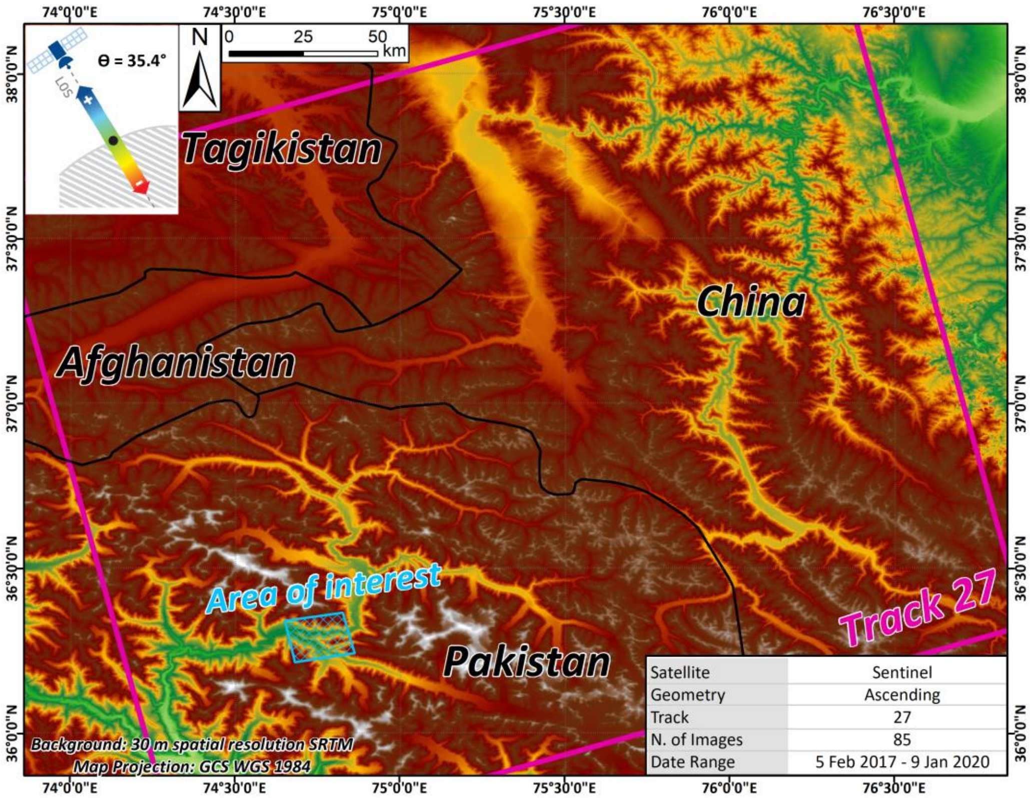


Figure 4 – Localization of the new area of interest for the application of SAR interferometry for landslide mapping and monitoring in Northern Pakistan.

3) Beneficiaries of Project for Science, Education and/or Society

The monitoring system presented in this paper has been requested and supported by the Regional government of Tuscany and Veneto, which are the main end users of this project. The monitoring system has been tested, tuned and refined thanks to the combined effort of a number of geologists and signal processing engineers, as well as with the invaluable input of both Regional and Civil Protection authorities, trying to fulfil their requirements. Information on persistent anomalies affecting elements at risk is routinely delivered to regional authorities in charge of the geohazard management practices in the form of monitoring bulletins. All delivered data can be accessed via a web-service tool. Field investigations are then performed in these areas to determine the severity of the hazard, initiate management of the risk and decide, together with local authorities, the most appropriate actions to mitigate the threats. Overall, this project provides regional authorities continuous information on where, when and how fast the ground is moving. However, prioritization and mitigation of these hazards can be done, starting with issues deemed to be most urgent. Further beneficiaries include Civil Protection Authorities, River basin Authorities, local authorities and any other entities in charge of management of risk posed by landslide.

4) Results

In this section a list of papers and book chapters, sharing content and topic with the IPL project 221 on PS continuous streaming for landslide monitoring and mapping is presented:

The paper "*Continuous, semi-automatic monitoring of ground deformation using Sentinel-1 satellites*" by Federico Raspini et *alii* has been published on Scientific Reports in 2018. https://www.nature.com/articles/s41598-018-25369-w/;

The paper "*From Picture to Movie: Twenty Years of Ground Deformation Recording Over Tuscany Region (Italy) With Satellite InSAR*" by Silvia Bianchini *et alii* has been published on Frontiers in Earth Science in 2018. https://www.frontiersin.org/articles/10.3389/feart.2018.00177/full;

The paper "*Permanent Scatterers continuous streaming for landslide monitoring and mapping: the case of Tuscany Region (Italy)*" by Federico Raspini *et alii* has been published on Landslides in 2019. https://link.springer.com/article/10.1007/s10346-019-01249-w;

The paper "*Monitoring Ground Instabilities Using SAR Satellite Data: A Practical Approach*" by Matteo Del Soldato *et alii* has been published on ISPRS International Journal of Geo-Information in 2019. https://www.mdpi.com/2220-9964/8/7/307;

The paper "*A Sentinel-1-based clustering analysis for geo-hazards mitigation at regional scale: a case study in Central Italy*" by Roberto Montalti *et alii* has been published on Geomatics, Natural Hazards and Risk in 2019. https://www.tandfonline.com/doi/full/10.1080/19475705.2019.1690058;

The paper "*Landslide-Induced Damage Probability Estimation Coupling InSAR and Field Survey Data by Fragility Curves*" by Matteo Del Soldato *et alii* has been published on Remote Sensing in

2019. https://www.mdpi.com/2072-4292/11/12/1486;

The abstract entitled "*Prediction of slope failure at regional scale with Sentinel-1 satellites: possibilities and limitations*" by Federico Raspini *et alii* has been accepted as Oral presentation at the EGU General Assembly 2019 in session NH3.6/GM7.10 - Prediction and forecasting of landslides.

Results of the IPL project 221 has been included into the oral presentation "*Monitoraggio radar dei fenomeni franosi*" provided by Federico Raspini at the CLIMETECH Conference in Ferrara (Italy) on 21 September 2018.

Results of the IPL project 221 has been included into the oral presentation "*Sentinel-1 continuous streaming for ground deformation mapping and monitoring*" provided by Federico Raspini at the EUSpaceWeek in Marsiglia (France) on December 2018.

A chapter entitled "*InSAR data for the continuous monitoring of ground deformation at regional scale*" by Nicola Casagli *et alii*, has been accepted for publication in the Book "*Advances in Remote Sensing for Infrastructure Monitoring*" edited by Springer.

Note:

1) If you will change items 1)-6) from the proposal, please write the revised content in Red.
2) Please fill and submit this form by 30 March 2019 to ICL Network <icl-network@iclhq.org>