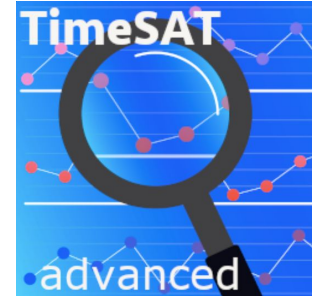


TimeSAT - Ground Motion Pattern Detection and Classification in massive Satellite Image Time Series



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3. Terradue srl., Roma, Italy;

4. Terranum, Bussigny, Switzerland



TERRADUE



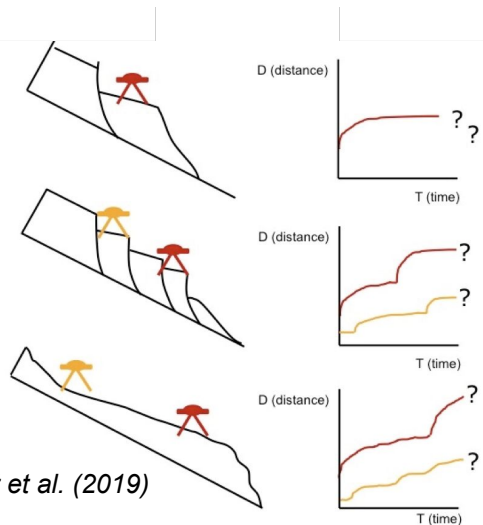
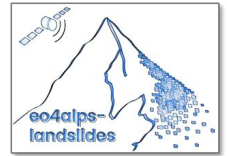
geohazards
tep

Context (1)

- **Availability of massive ground motion products/datasets (large scales, long observation periods)**
 - from MT-InSAR (e.g. EGMS, P-SBAS, LiCSAR, FLATSIM, SNAPPING, ...)
 - from MT-Optical Image Correlation (GDM-OPT, ITS_LIVE, ...)
- **But challenges to exploit them and identify relevant signals**
 - noisy observations
 - temporal patterns
 - spatial clusters
- **Cloud/HPC processing for “rapid” analysis**
 - signal processing challenges: discrete vs. non discrete information, outlier detection, time series transformation, ...
 - technical processing challenges: scaling up, datacube formatting, ...

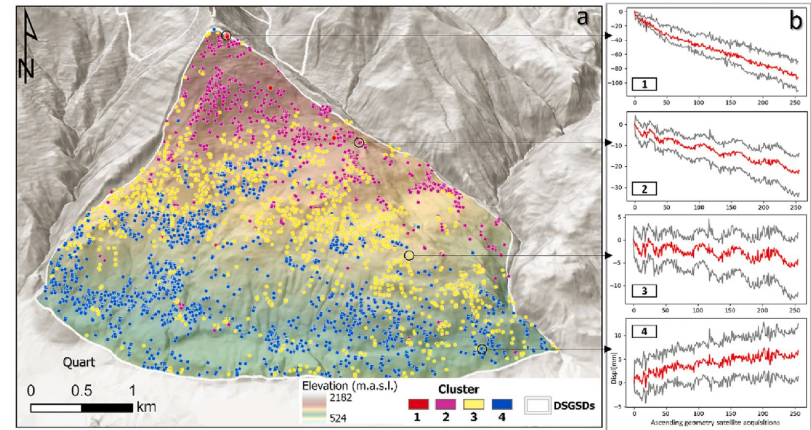
Context (2)

- **Several identification and classification approaches:**
 - The user knows which signal(s) is(are) of interest: *supervised learning*
 - The user wants to discover unknown signals: unsupervised approaches
- **Service developed initially for landslide signals detection**
 - e.g. ESA eo4alps-landslides project - eo4alps-landslides.eu
- **But usable for any ground deformation analysis**



Spatial distribution of clusters at the scale of one large landslide

TS with several temporal patterns



TimeSAT: a satellite TS (time series) processing service on-line

- **Goal**

- Identify temporal and spatial clusters of homogeneous styles of ground motion

- **Input dataset**

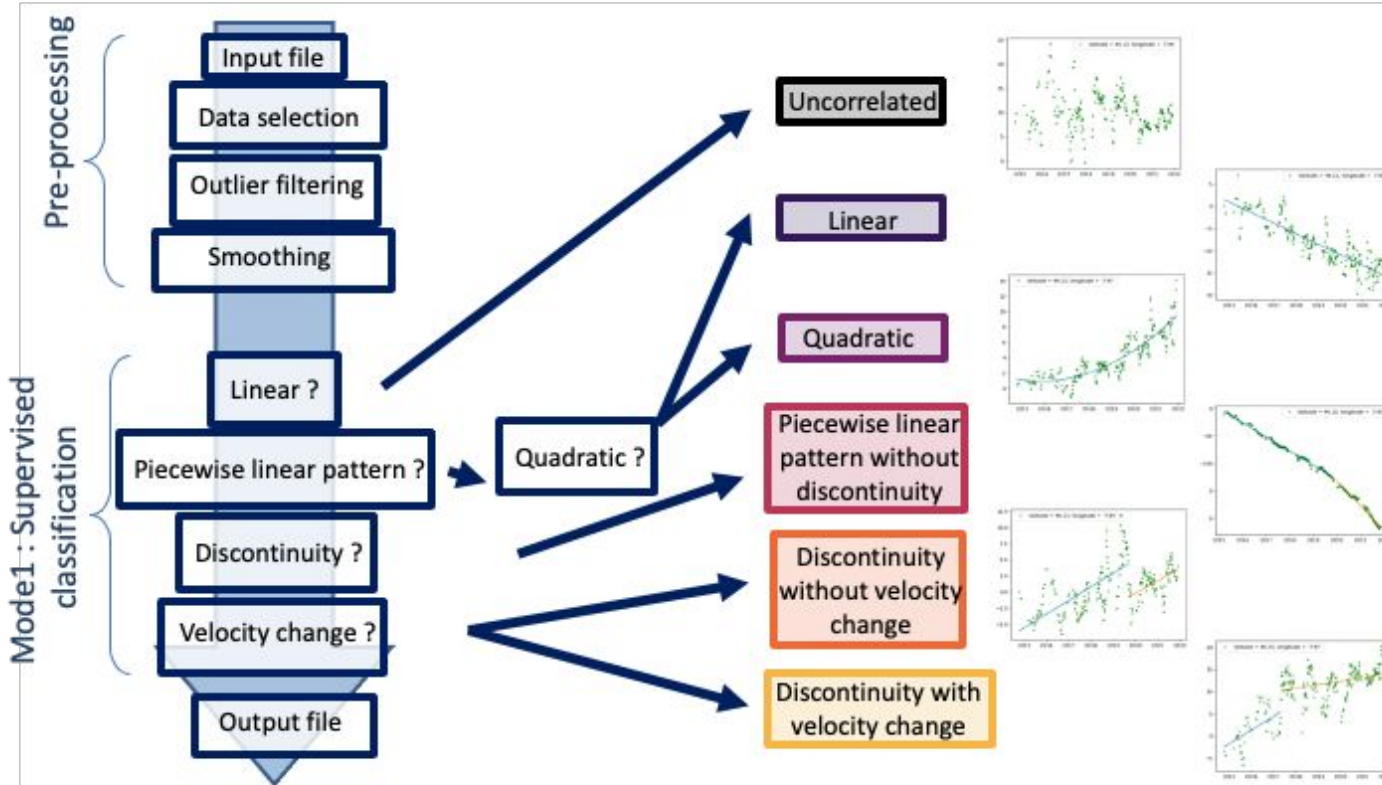
- *discrete*: points clouds (e.g. ground motion time series from PS/DS InSAR)
- *continuous*: datacube of optical offset-tracking time series
- Input data in .csv or asset/stac compliant formats

- **The service includes several components**

- *Pre-processing module*: outlier detection, smoothing, data selection
- *Temporal time series module*: two modes of clustering / classification (based only on the temporal information)
- *Spatio-temporal time series module*: clustering / classification (integrates spatial information from the features) - *ongoing work*

TimeSAT: Mode 1 - Supervised classification

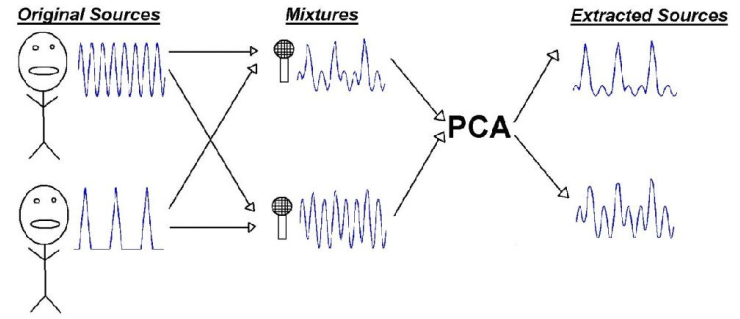
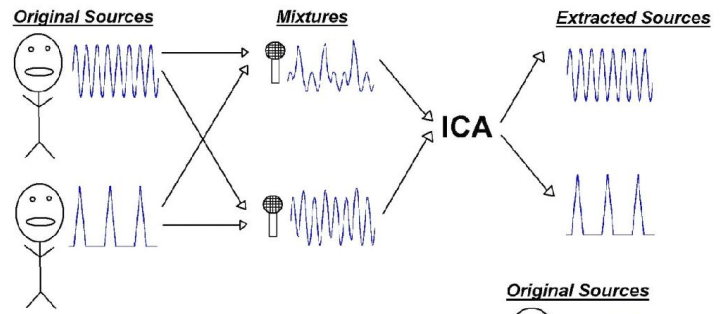
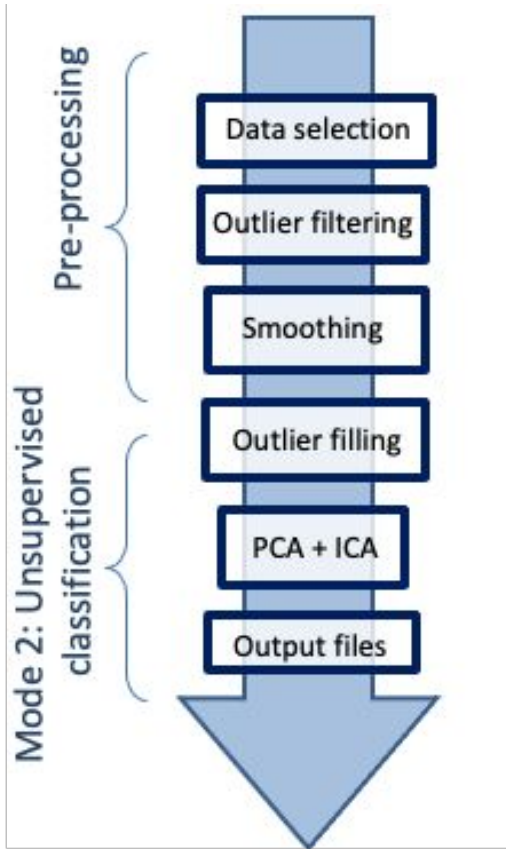
Classification:



- in six predefined distinctive ground motion trends
- based on a sequence of advanced statistical tests

TimeSAT: Mode 2 - Unsupervised classification (ICA/PCA)

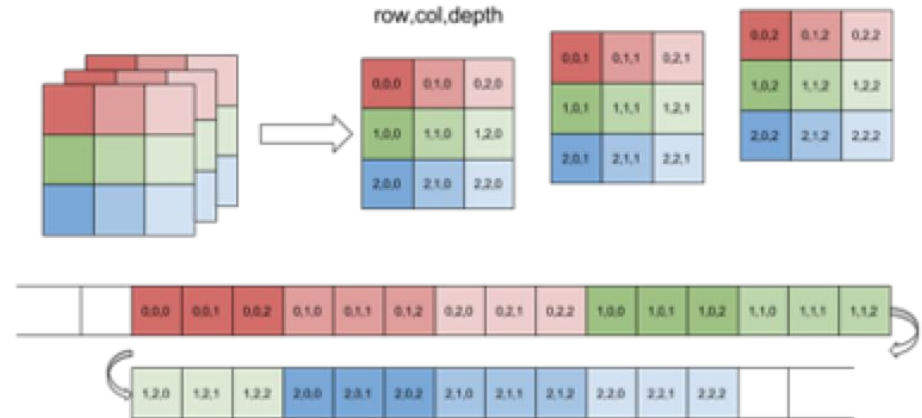
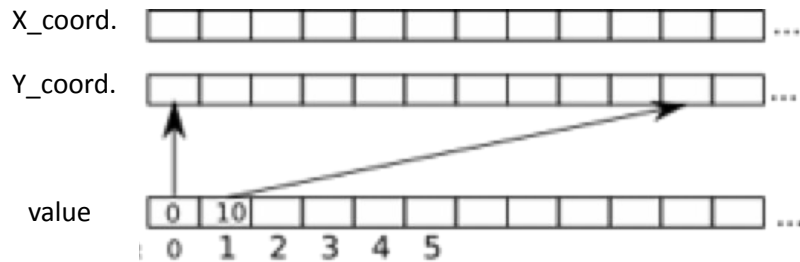
Classification: using a combination of principal component analysis (PCA) and independent component analysis (ICA) to detect and classify specific patterns.



TimeSAT: technological developments for rapid/massive processing

- All datasets are re-organized, prior to the TimeSat processing, in optimized datacubes (Zarr format) for easy transformation of the dimensions
 - spatial coordinates - time - value
 - time - spatial coordinates - value
 - value - time - spatial coordinates
- The time series of value need to be contiguous in the computer memory (stride optimization using chunking/blocking strategies)

→ ca. 1M PS/DS can be classified 3-5 hours



TimeSAT: Service on GEP

Developed with the support of ESA, and part of the eo4landslides App on GEP

eo4alps-landslide App: Implement a portfolio of landslide-tailored webservices and train / transfer knowledge to potentiel users

The screenshot displays the geohazards tep web application interface. At the top, there are navigation menus for 'EO Data', 'EO-based products', 'Interferogram stacks', and 'Interferogram stacks monitoring'. A search bar is visible with the text 'Free Text Search'. The main area shows a satellite map of the Alps with several orange rectangular bounding boxes overlaid on the terrain. On the left side, there is a list of datasets with identifiers like 'EO4ALPS_IT_SNT_T117_A_ES4714A006S_4GEP 2015-2022'. On the right side, there is a 'Processing Services' panel with a grid of service icons including ALADIM-HR, ALADIM-VHR, DSM-OPT, FASTVEL, Flow-R, GDM-OPT SLIDES, SNAPPING IFG, SNAPPING PSI, SNAPPING PSI Full, SNAPPING PSI Med, TimeSAT advanced, TimeSAT basic, and VorToO.

several landslide EO datasets

eo4alps-landslides
The eo4alps-landslides project, launched by the European Space Agency (ESA), aims to exploit the potential of new satellite data and advanced processing for mapping, monitoring and modeling natural hazards in the Alpine region.
[Learn more](#)

several landslide EO and modelling services

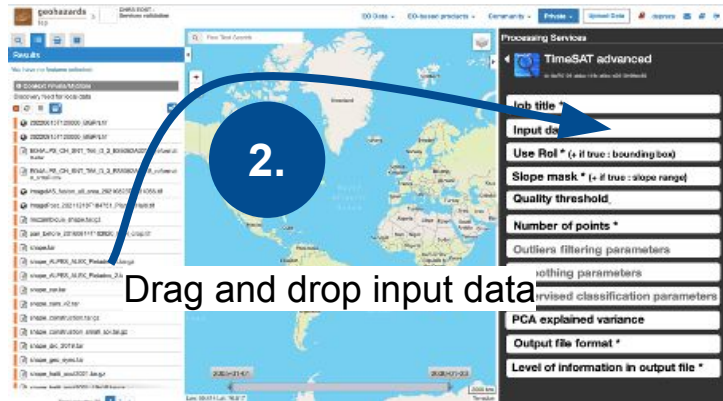
TimeSAT: service on GEP

1.



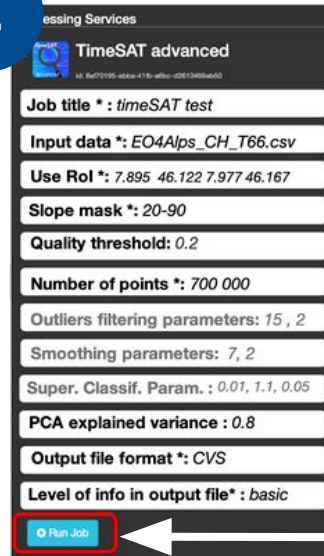
Select the processing service **TimeSAT**

2.



Drag and drop input data

3.



Tune the parameters:

- **Job title:** Defines the title of the job
- **Input data:** Input data in csv or kml format + nb of points
- **Time series classification approach:** Type of classification approach (e.g. supervised / mode 1 or unsupervised / mode 2 pattern identification or both)
- **Data selection:** quality mask, AOI, slope mask
- **Pre-processing parameters:** filtering, smoothing, ...
- **Output:** format, level of information

4.

Run the service

TimeSAT: tutorial on GEP

(docs.terradue.com/geohazards-tep/tutorials/timesat.html)



- Overview
- Community Portal User Guide
- Community Advanced User Guide
- Community Portal Administrator Guide
- Cloud Operations Administrator Guide
- Thematic Applications
- Processing tutorials
 - Active fire detection with Sentinel-3 SLSTR
 - ALADIM-HR and ALADIM-VHR: Preparation of input datasets
 - ALADIM-HR: Automatic Landslide Detection and Inventory Mapping from multispectral S2 & L8 data
 - ALADIM-VHR: Automatic Landslide Detection and Inventory Mapping from multispectral Very-High Resolution data
 - Avalanche Mapping with Sentinel-1 [noice]
 - Burned Area Analysis with Sentinel-2
 - Change Detection Analysis [VAL]
 - COIN - Coherence and Intensity change for Sentinel-1
 - COLOC - Multi-mission data collocation [VAL, cppp]
 - COMBI - Band Combination
 - DIAPASON InSAR - StripMap(SM)
 - DIAPASON InSAR Sentinel-1 TOPSAR(IW,EW)
 - DLR Sentinel-1 InSAR Browse [VAL]
 - DSM-OPT: Digital surface models from optical stereo satellite images
 - FASTVEL for displacement velocity

TimeSAT - Ground motion pattern detection and classification in satellite image time series



TimeSAT

Satellite image time series and derived products are increasingly available thanks to the launch of Earth Observation missions which aim at providing a coverage of the Earth every few days with high spatial resolution. The high revisit time of Copernicus (Sentinel-1, Sentinel-2) and Landsat satellites allow for the setup of systematic calculation of ground motion products, opening the way to scientific and operational monitoring capacities of geohazards. Many services are deployed in order to offer to users systematic or on-demand calculation of optical and InSAR time series products representing ground deformation. Satellite-derived products and services (e.g. EGMS; EPOS satellite products; GEP, Comet and ARIA services, etc) for the processing of SAR and optical imagery allow accessing displacement/velocity time series over large areas and time periods. Exploiting these datasets (stacks of interferograms, PSInSAR time series, optical derived ground motion, possibly organized in datacubes) necessitates the development of post-processing tools in order to combine the datasets and investigate the spatial and temporal behavior of the studied variables.

TimeSAT is a service developed by CNRS-EOST (Strasbourg, France) for classifying ground motion displacement time series in specific behaviors/patterns, detect changes in the time series (increase, decrease, periodicity) and identify spatial clusters of homogeneous styles of ground motion. The service currently allows ingesting PSInSAR and SBAS InSAR time series and optical offset-tracking time series. It consists of:

- A. A module for data pre-processing (advanced Savitzky-Golay filtering, data subset masking);
- B. A module for time series classification, for which several processing workflows are possible:

- **Mode 1 / supervised:** The classification in pre-defined distinctive patterns (uncorrelated trend, linear trend, quadratic trend, bilinear trend) based on a sequence of conditional statistical tests,
- **Mode 2 / unsupervised:** The classification using a combination of principal component analysis (IPA) and independent component analysis (ICA) to detect and classify specific patterns.

TimeSAT allows the processing of time series non structured and unevenly distributed in time and in space. The workflow is computationally optimized and parallelised and is implemented on the Mésocentre/HPC infrastructure of the University of Strasbourg. Thanks to the parallelization and scaling of the code, the processing of about 1 million time series (pixel, PS/DS points) of 5 a years period lasts less than 2 hours.

TimeSAT Pre-processing is using Python libraries based on [1] and [2],

TimeSAT Mode 1 implements part of the supervised classification approach described in [3] using advanced statistical tests [4], [5], [6],

TimeSAT Mode 2 implements unsupervised classification approaches such as those used by [7], [8] and [9].



Set the processing parameters

Some processing parameters can be adjusted. When hovering over the parameter fields, you will see a short explanation for each of the parameters.

General

- **Job title:** Defines the title of the job
- **Input data:** Input data in csv or kml format
- **Time series classification approach:** Type of classification approach (e.g. supervised / mode 1 or unsupervised / mode 2 pattern identification or both)

Data selection

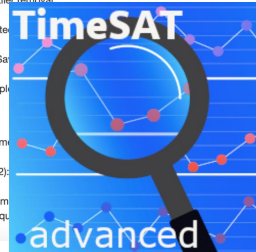
- **Use RoI (Region Of Interest):** If set to *True* the spatial data selection is activated
- **Region Of Interest bounding box:** Define the bounding box of the Region of Interest (RoI)
- **Slope mask:** If set to *True* the data selection based on the slope in activated (Slope computed using Copernicus DEM)
- **Slope mask: range minimum / maximum:** Defines the slope range for which the points are keeping
- **Minimum quality threshold (coherence or correlation):** Defines a minimum InSAR interferogram coherence OR coefficient of correlation for image correlation for which the points are keeping

Pre-processing

- **Pre-processing: Length of filtering window for outlier removal:** Defines the length of the sliding window for outlier removal using Hampel Identifier
- **Pre-processing: Standard deviation value for outlier removal:** Defines the number of standard deviations to detect using Hampel Identifier
- **Pre-processing: Length of filtering window for time series smoothing:** Defines the length of filtering window (Savitzky-Golay filter): the value must be less than or equal to the number of dates in the time series
- **Pre-processing: Polynomial order for time series smoothing:** Defines the order of the polynomial used for sampling (Savitzky-Golay filter): the value must be less than the length of the filtering window.

Mode 1: Supervised classification

- **Supervised classification: Linear term level of significance:** Defines the linear ANOVA test threshold (α_1): the time series is classified as uncorrelated pattern if $\alpha_1 < p$ -value.
- **Supervised classification: Quadratic term level of significance:** Defines the quadratic ANOVA test threshold (α_2): series is classified as linear pattern if $\alpha_2 < p$ -value.
- **Supervised classification: Piecewise linear pattern level of significance:** Defines the BIC threshold (Bth): the time series is classified as piecewise linear pattern if the minimum BIC of segmented regression models is less than the BIC of quadratic linear models and if the evidence ratio is $> Bth$.



TimeSAT: processing report

TimeSAT Report

Job : TimeSAT_Advanced_XXXX

Date: 2023-08-08
Author: (c) CNRS-EOST (ForM@Ter)
Type of input data: InSAR
Location:



Country: Switzerland
AOI: center = (lon: 7.99, lat: 46.069), surface = 753 km²

Processing parameters:

slope mask	[0.0,90.0]
Quality threshold	0.5
% of explained variance	0.981

Dataset:

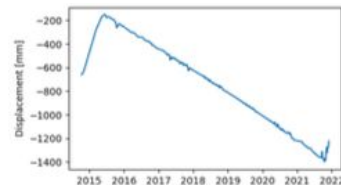
Input file	EO4ALPS_CH_SNT_T66_D_3_ES6062A021S_reformate.csv
Nb of measurement points:	761493
Nb of dates:	257 (2015-06-12 to 2022-05-23)

Results Mode #1 : Supervised classification:

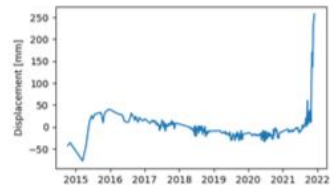
0: uncorrelated	93584	12%
1: linear	0	0%
2: quadratic	1324	0.1%
3: piecewise linear with break point	362376	47%
4: piecewise linear with discontinuity	59946	8%
5: piecewise linear with discontinuity and velocity change	244263	32%

Results Mode #2 : Unsupervised classification:

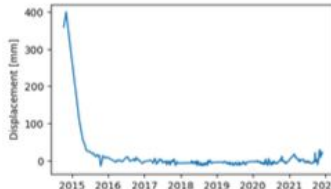
Nb of PCA/ICA components: 25



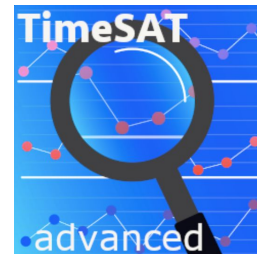
Nb points for PCA 1: 205400 (27%)
Variance explained by PCA 1: 48%



Nb points for PCA 2: 175386 (23%)
Variance explained by PCA 2: 36%

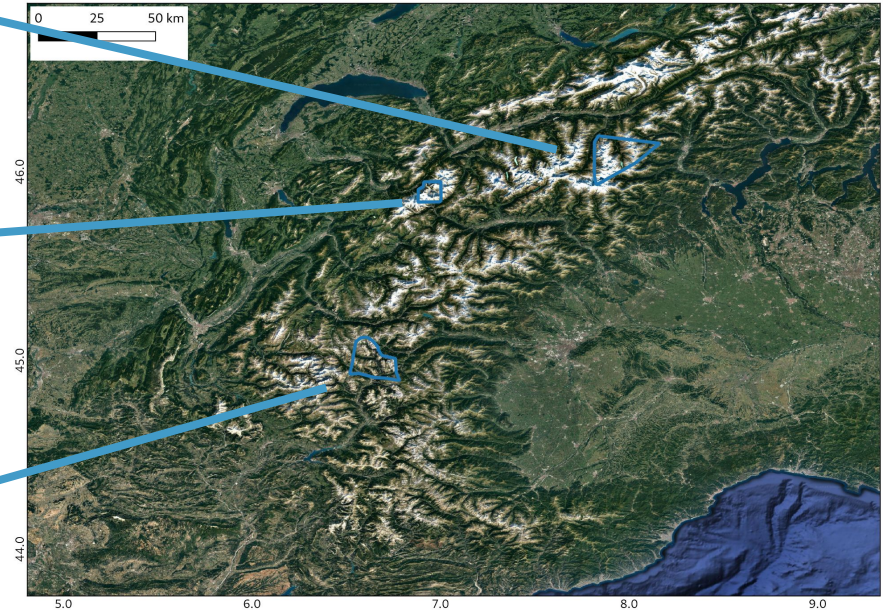


Nb points for PCA 2: 22931 (3%)
Variance explained by PCA 2: 12%

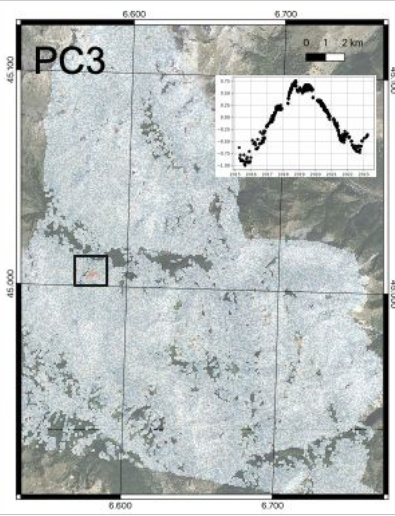
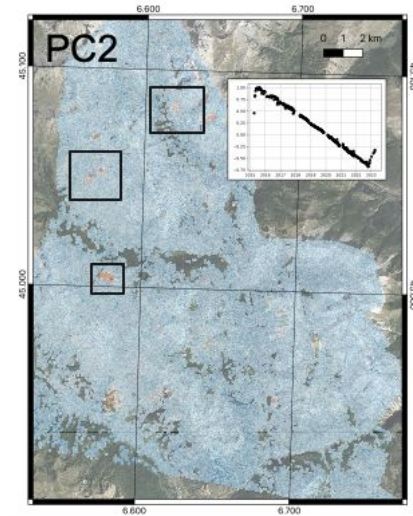
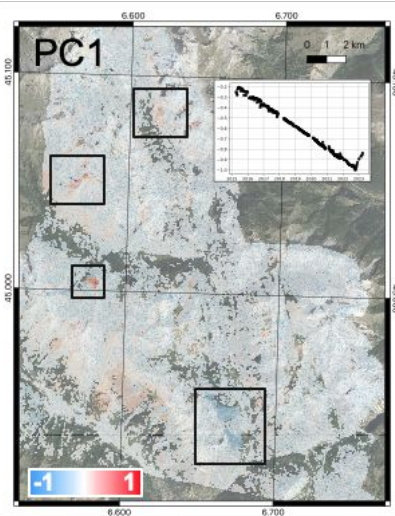
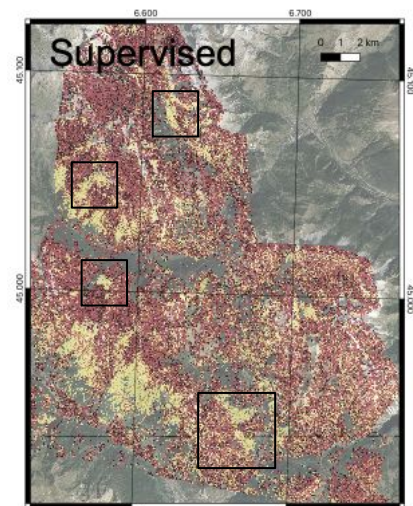
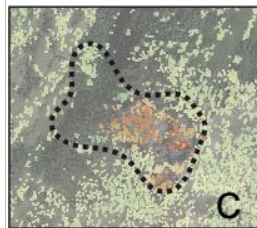
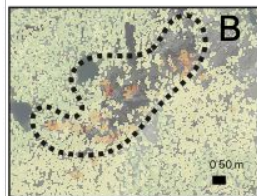
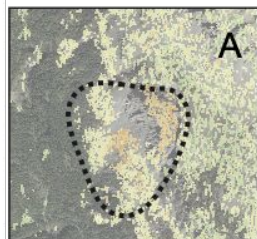
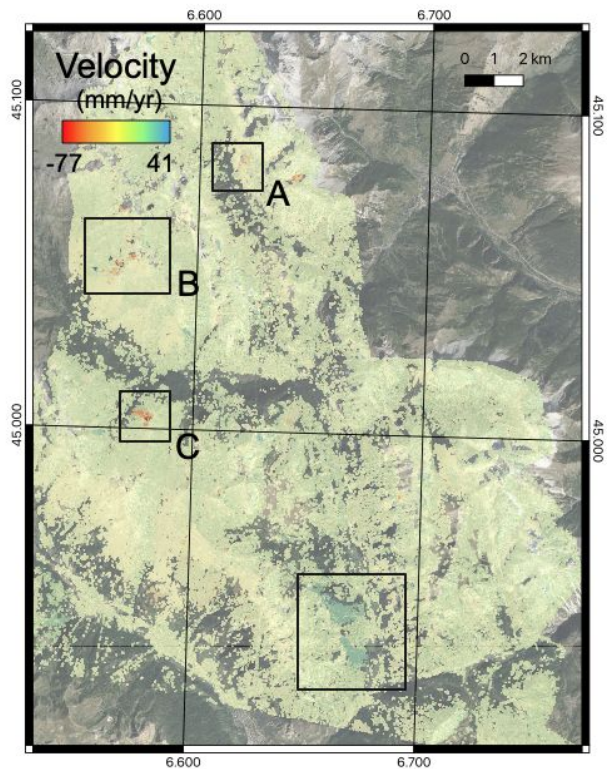


TimeSAT: use cases presented in this work

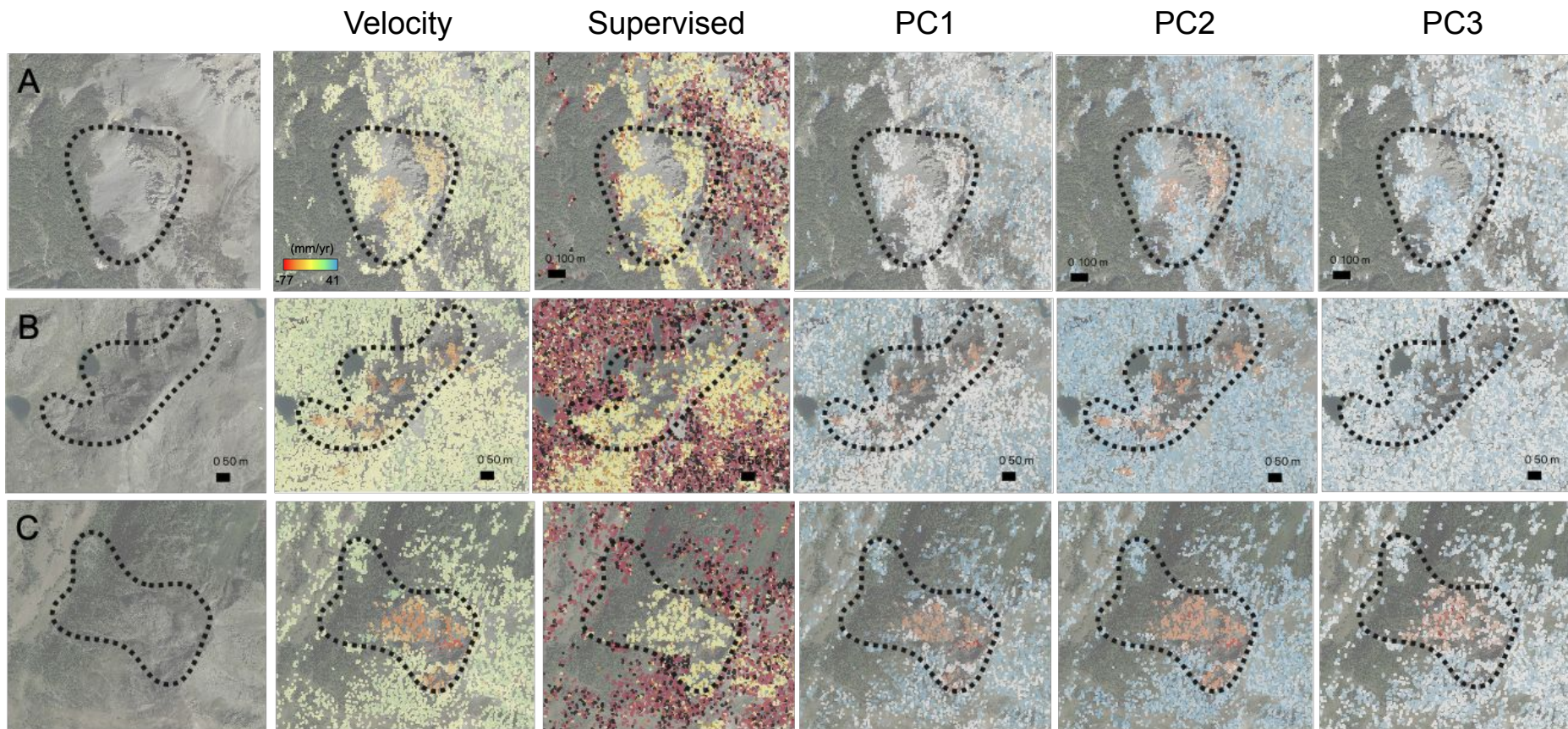
- Wallis Canton (Alps, Switzerland)
 - Ground motion time series from InSAR processing (*PS/DS*)
 - > 700.000 points, 257 dates (2014-10-10 to 2022-07-12)
- Mont-Blanc massif (Mer de Glace, France)
 - Optical offset-tracking time series (*GDM-OPT-ICE*)
 - > 300.000 points 158 dates (2015-08-29 to 2023-07-03)
- Briançonnais Massif (Alps, France)
 - Ground motion time series from InSAR processing (*PS/DS*)
 - >600.000 points, 298 dates (2015-04-08 to 2023-04-02)



TimeSAT: use case, over Briançonnais with InSAR time series as input

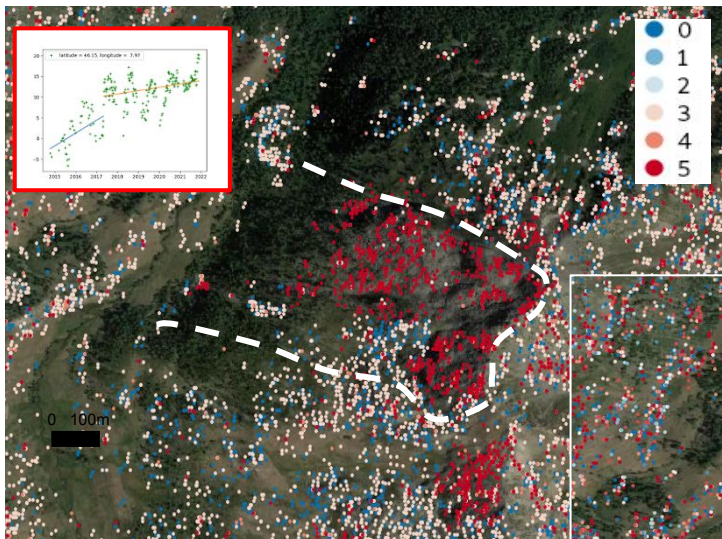


TimeSAT: use case, over Briançonnais with InSAR time series as input



TimeSAT: use case, over Briançonnais with InSAR time series as input

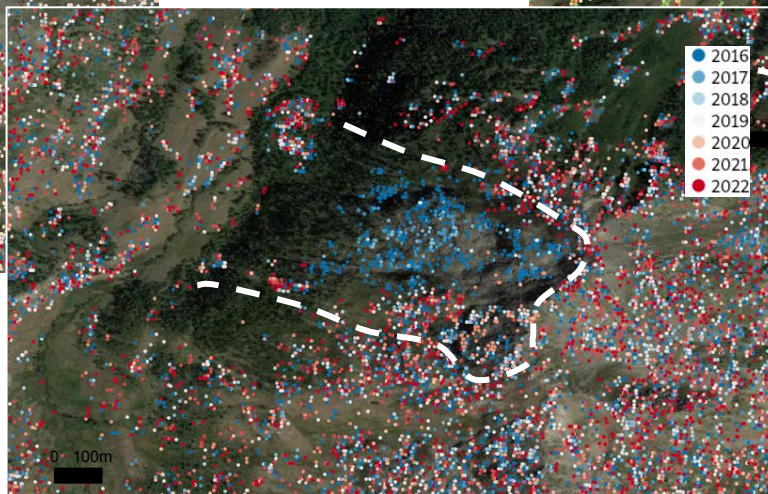
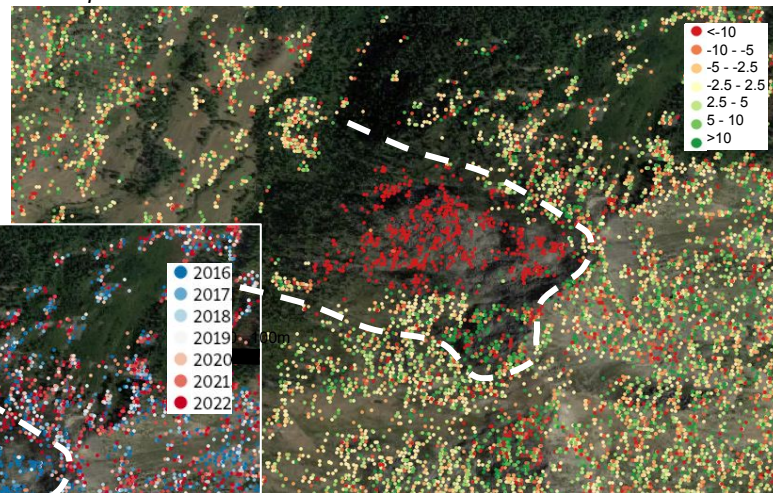
TimeSat results, supervised mode



Cluster of points of class 5
(TS with jump(s) and velocity change)

Velocity change (mm/yr)

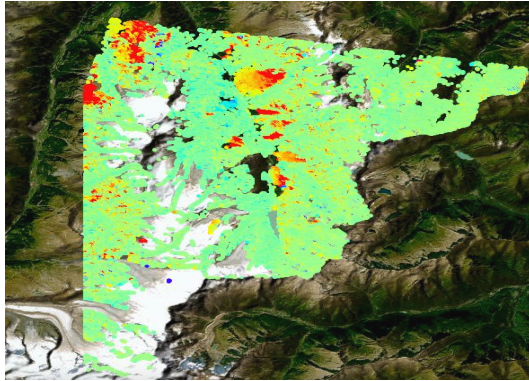
Significant velocity change before and after the breakpoint



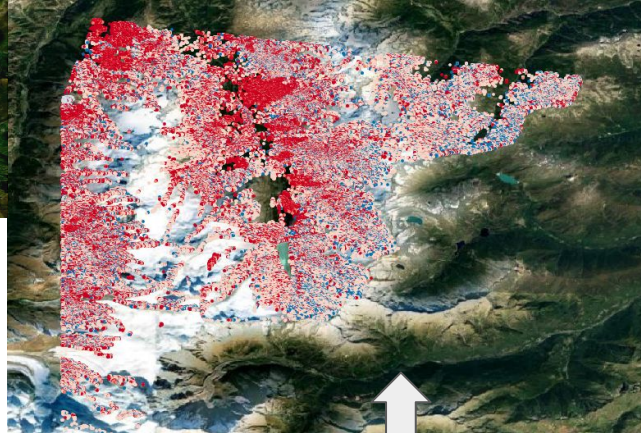
Date of the Breaking Point

(All points of the cluster highlight a breakpoint around a same date: spring 2016)

TimeSAT: use case, over Wallis with InSAR time series as input



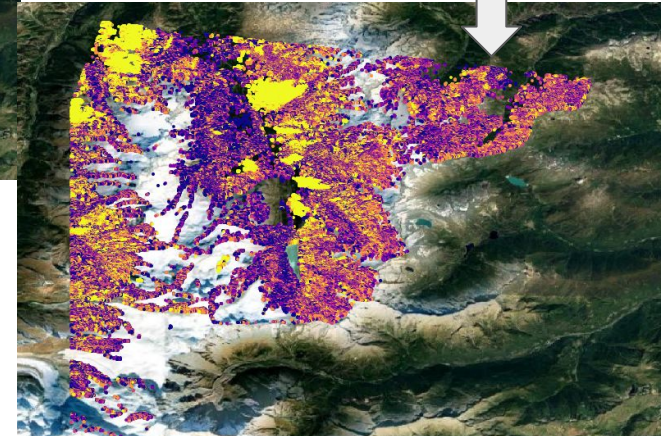
Linear trend of Input data
(SqueeSAR for EO4alps on, ©TreMap)



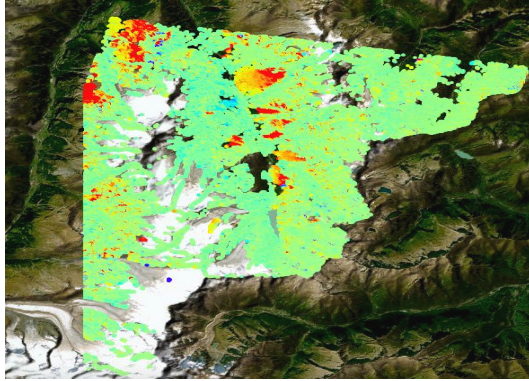
TimeSat results, supervised mode
Class 5 in red highlights the instabilities
(TS with jump(s) and velocity change)

TimeSat results, unsupervised mode

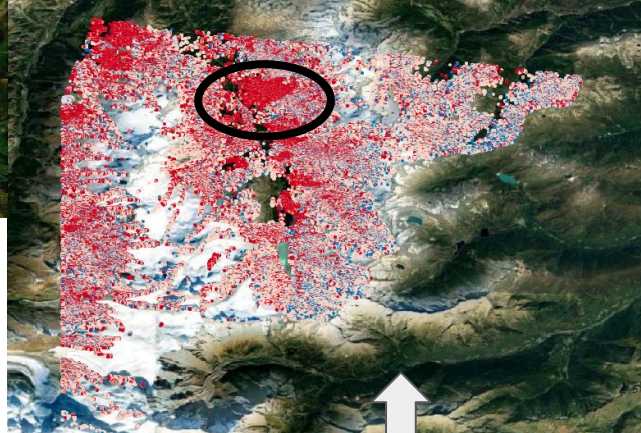
For each point : weight of the first principal component. Max (yellow) and min (dark blue) values allow to identify the instability of the region.



TimeSAT: use case, over Wallis with InSAR time series as input



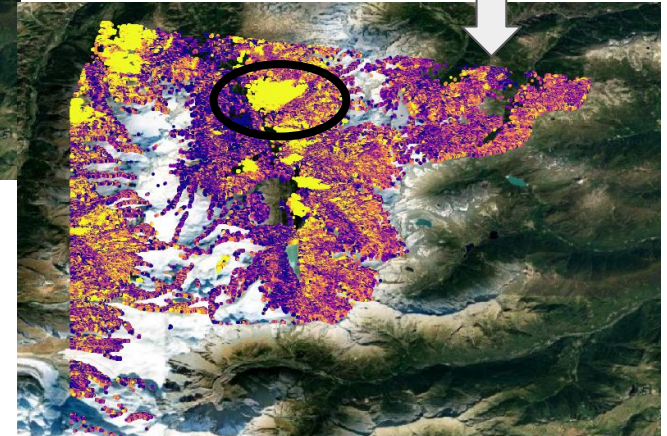
Linear trend of Input data
(SqueeSAR for eo4alps-landslides, ©TRE-A)



TimeSat results, supervised mode
Class 5 in red highlights the slope instabilities
(TS with jump(s) and velocity change)

TimeSat results, unsupervised mode

For each point : weight of the first principal component. Max (yellow) and min (dark blue) values allow to identify the instability of the region.



TimeSAT: use case, over Wallis with InSAR time series as input

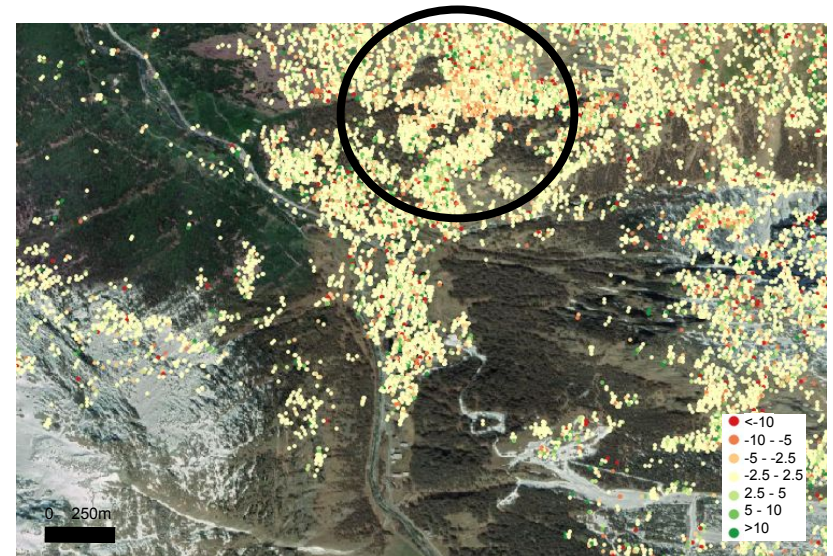
TimeSAT results, supervised mode



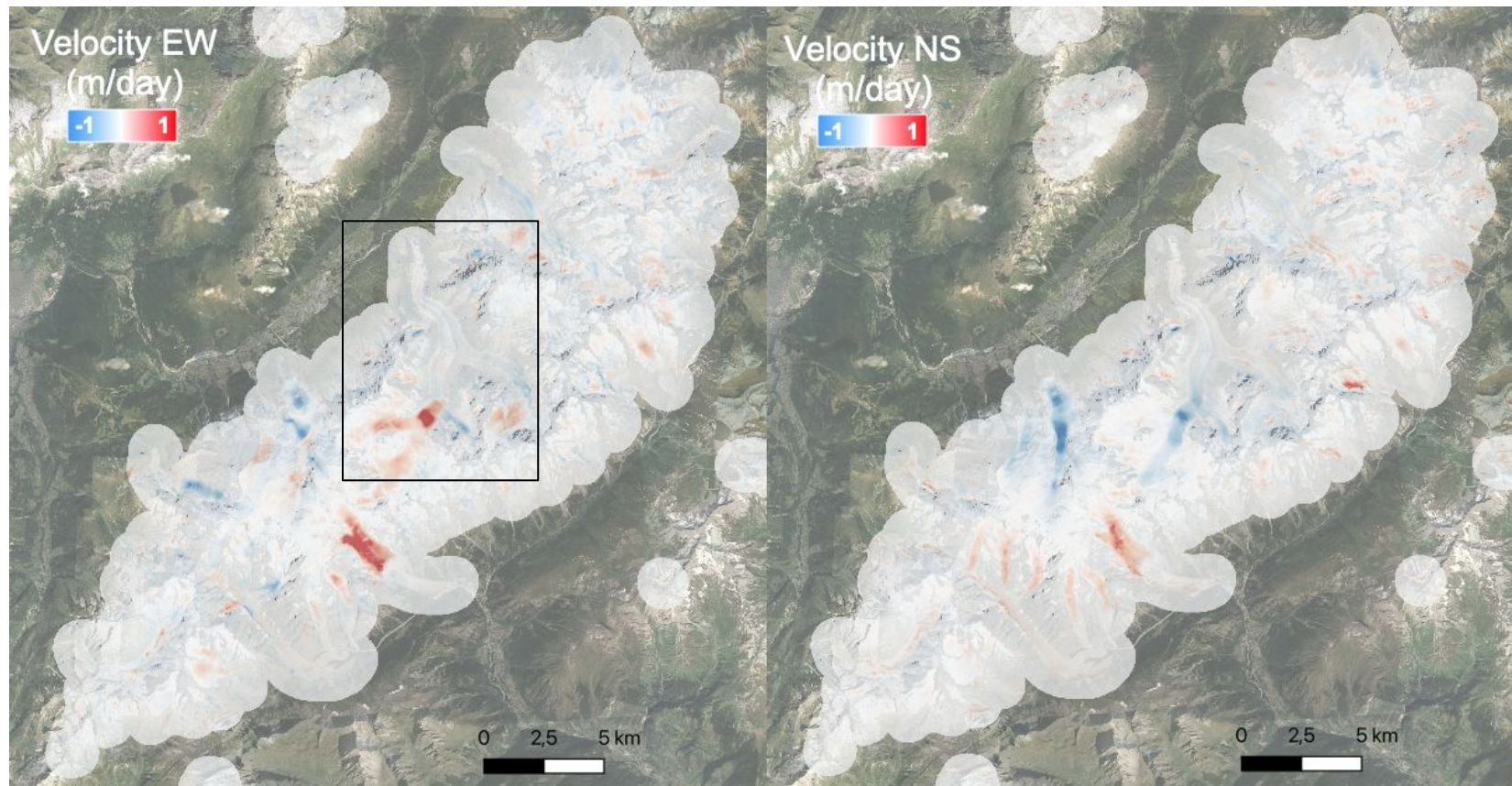
Date of the breaking point

(All points of the cluster highlight a breakpoint around a same date: spring 2018)

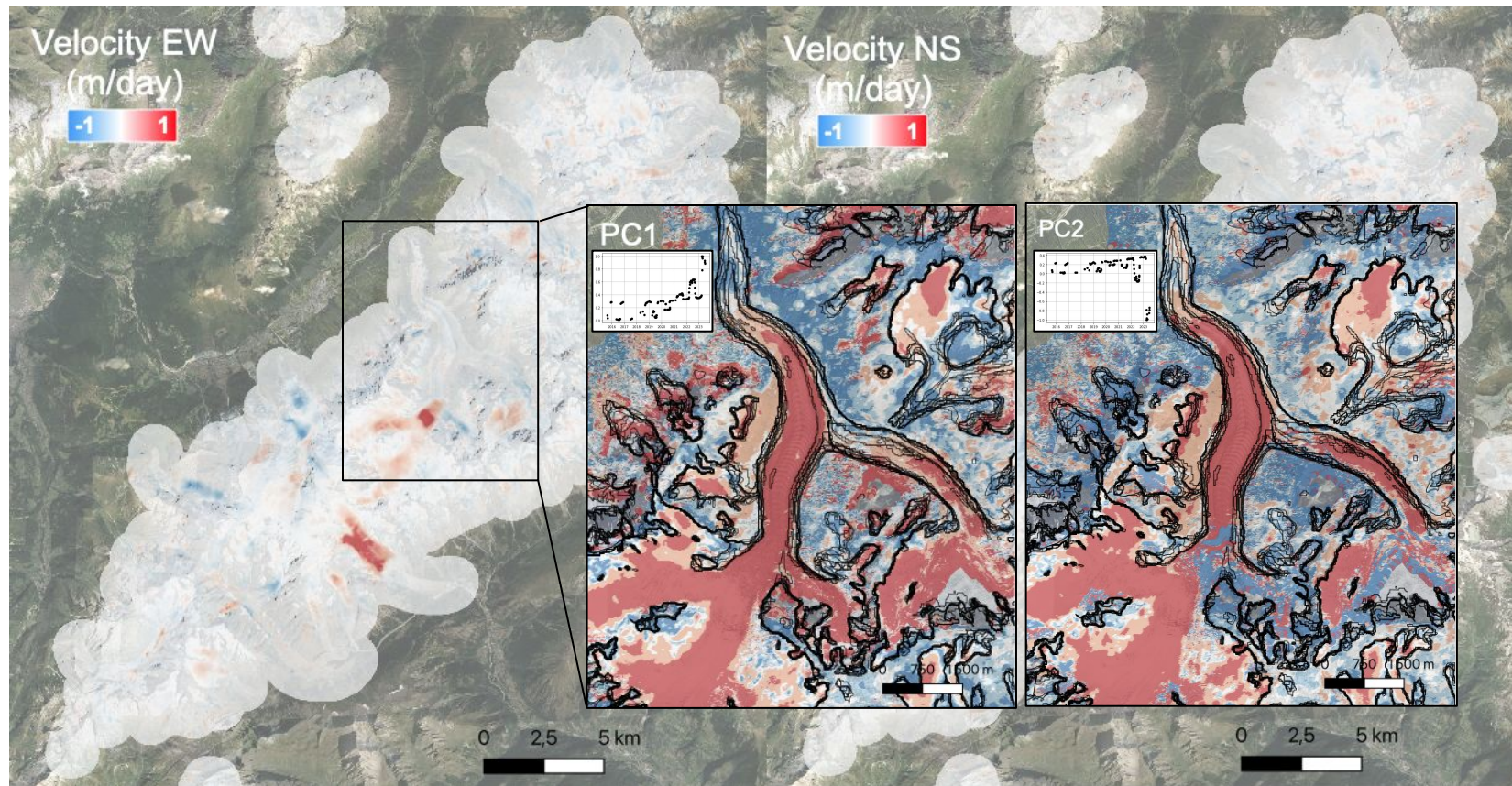
Velocity change (mm.yr-1)
Velocity change before and after the breakpoint less significant than the previous example



TimeSAT: use case, over Mont-Blanc glaciers, preliminary results



TimeSAT: use case, over Mont-Blanc glaciers, preliminary results

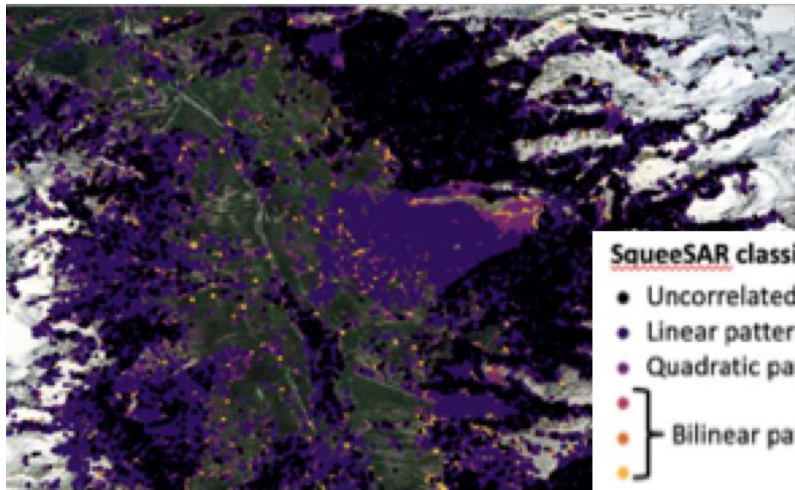
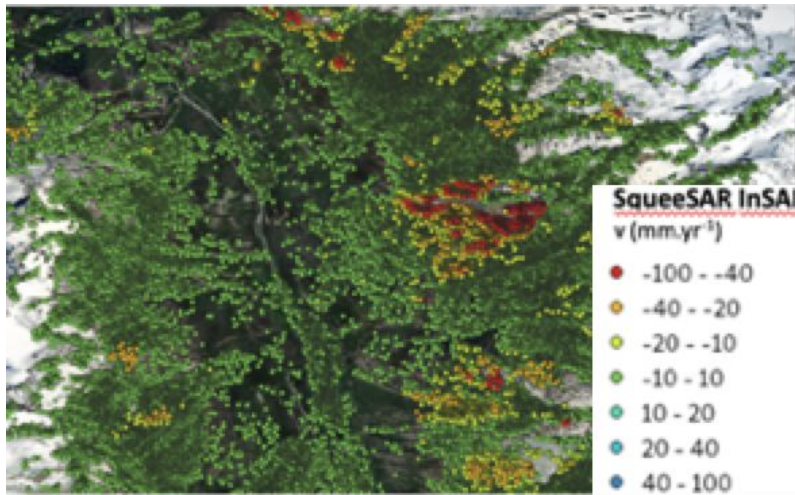


Conclusion and perspectives

- **TimeSAT is accessible on GEP since mid-2023**
 - testers and feedbacks are welcome
 - many information are delivered to the user: class, breaking point date, velocity, etc.
 - Current limitation: no clustering of the PCA/ICA
- **Regular updates of the service**
 - selection of one deformation pattern for the supervised classification
 - integrate other deformation pattern in the supervised classification
 - integrate methods for spatial and component clustering
 - at mid-term: towards a multi-source aggregator of motion measurements



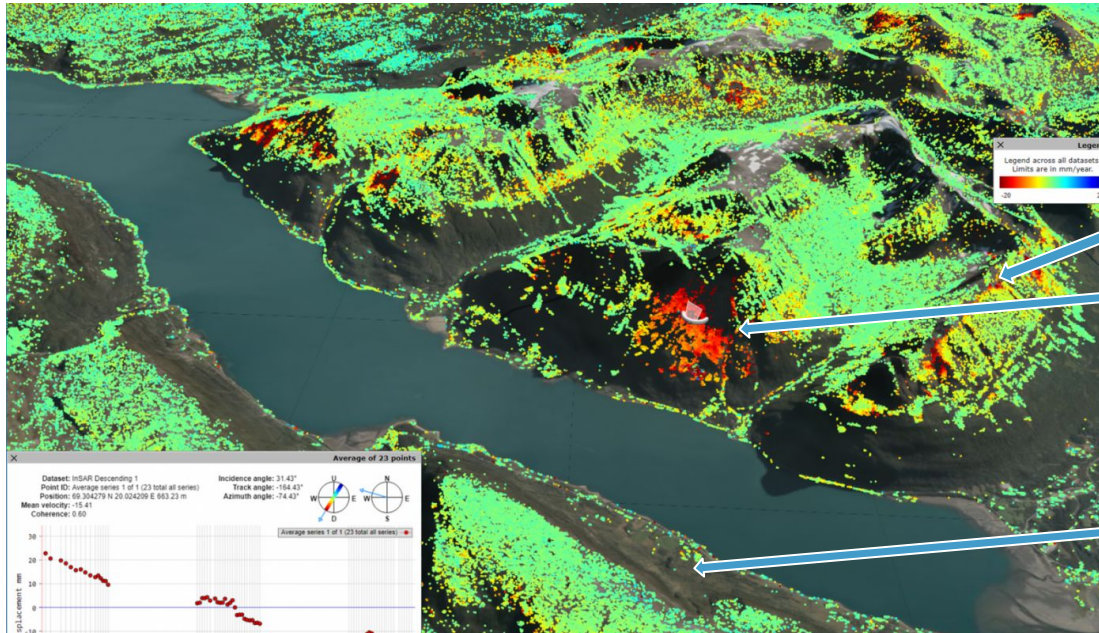
Thanks for your attention!



J'avais cela comme ancienne diapo pour Saas-Balen / Valais

Context (2)

- Several identification and classification approaches:
 - The user knows which signal(s) is(are) of interest: *supervised learning*
 - The user wants to discover unknown signals: unsupervised approaches

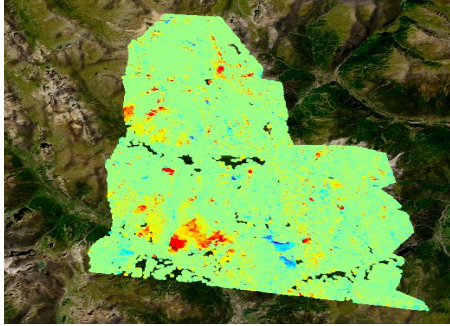


*deep-seated slope
deformation signal*

rockslide signal

*local subsidence signal
(in the valley floor)*

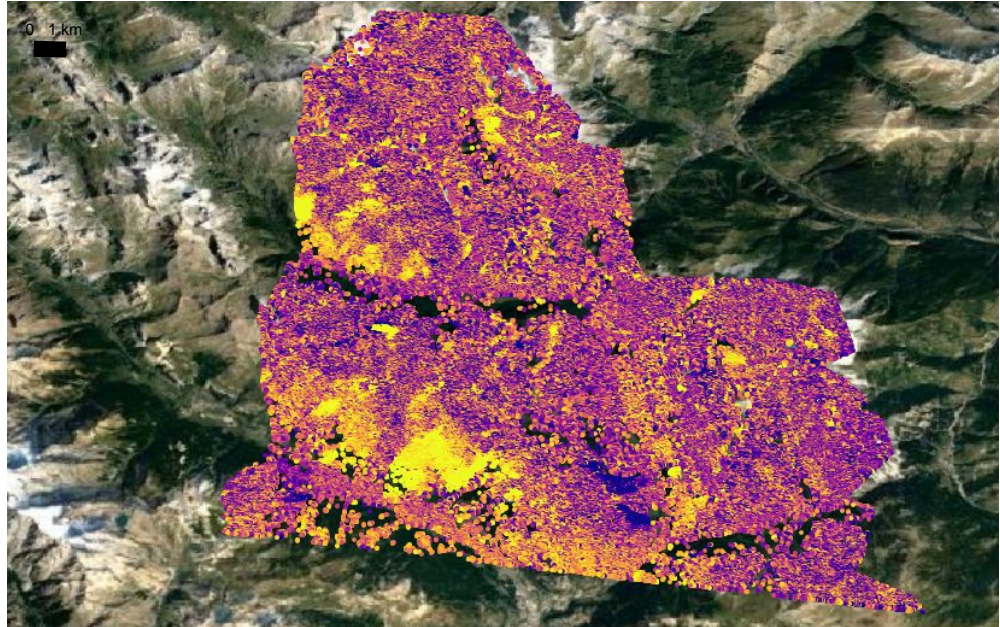
TimeSAT: use case, over Briançonnais with InSAR time series as input



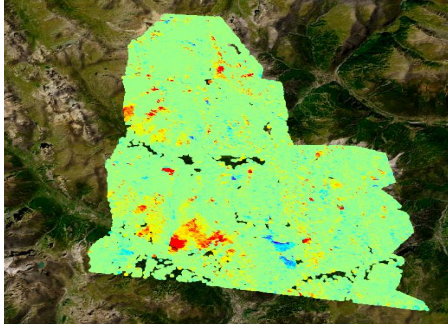
Linear trend of Input data
(SqueeSAR for EO4alps on, ©TreMap)

TimeSat results, unsupervised mode

For each point : weight of the first principal component. Max (yellow) and min (dark blue) values allow to identify the instability of the region.



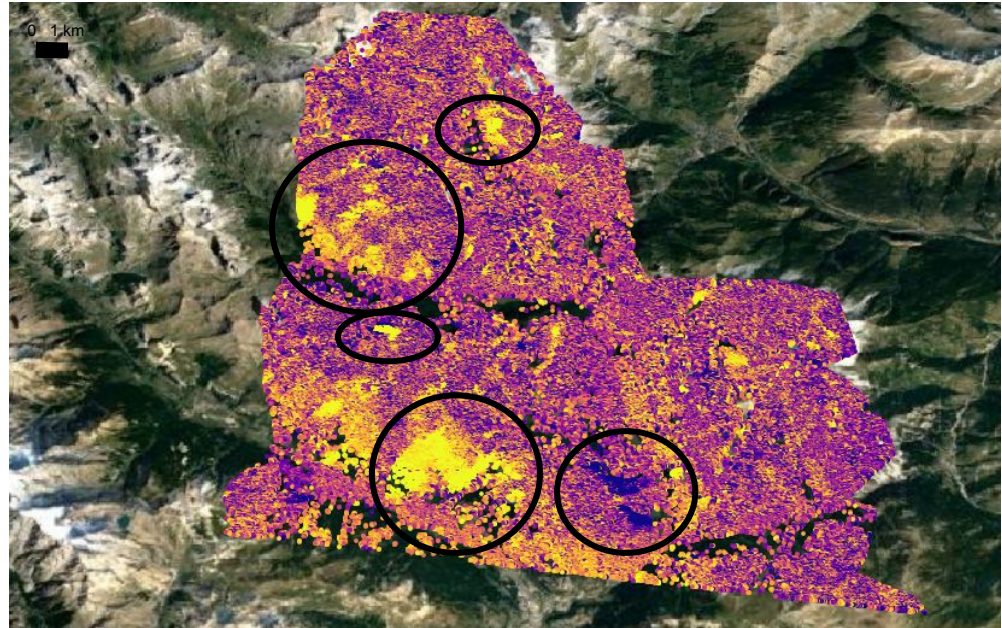
TimeSAT: use case, over Briançonnais with InSAR time series as input



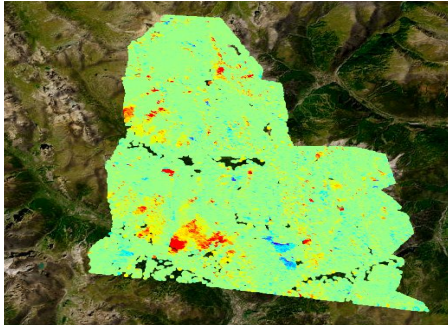
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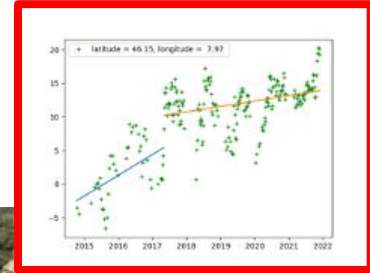
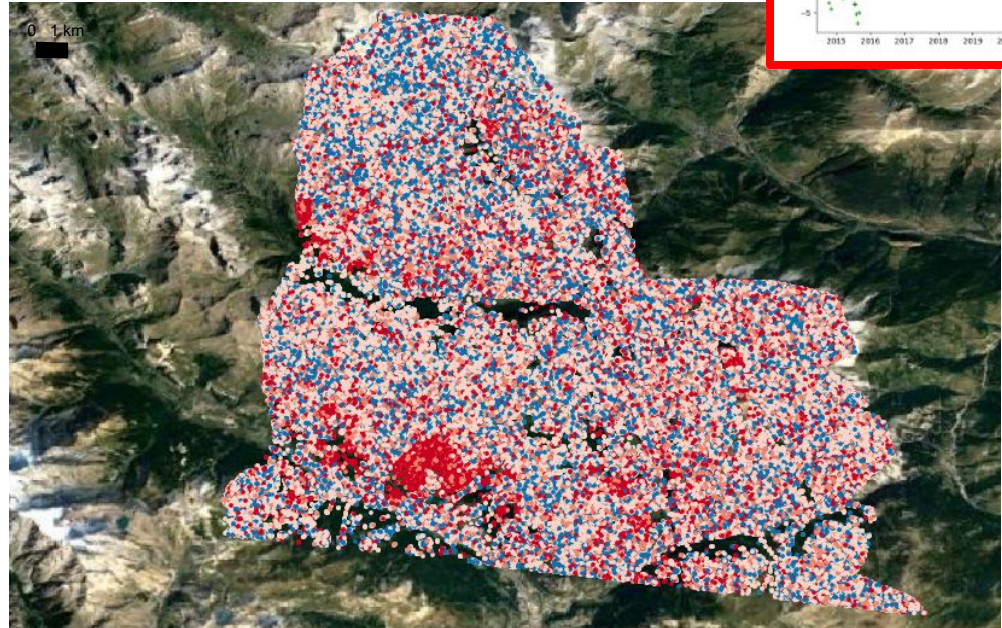


Linear trend of Input data
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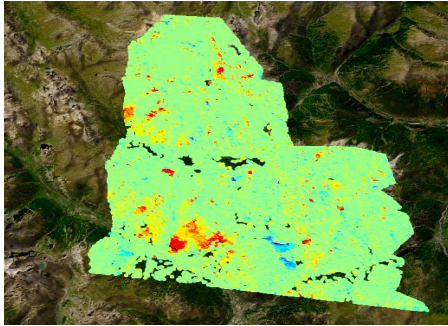
TimeSat results, supervised mode

Class 5 in red highlights the
instabilities

(TS with jump(s) and velocity change)



TimeSAT: use case, over Briançonnais with InSAR time series as input

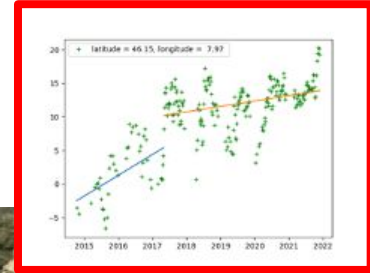
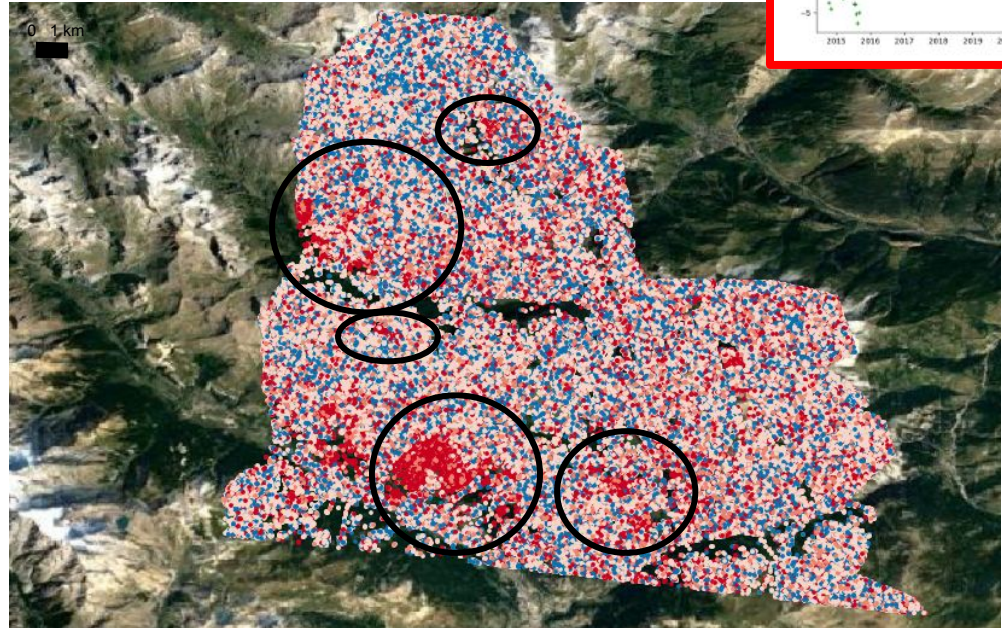


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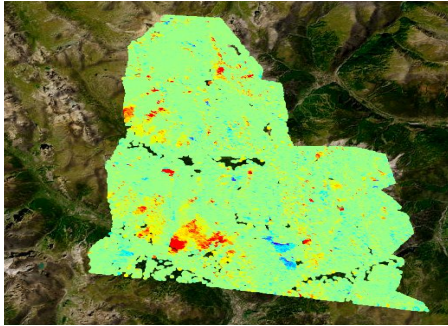
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