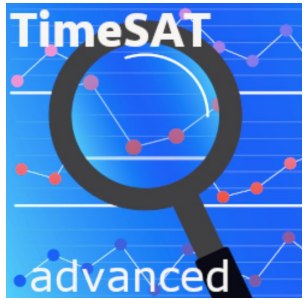
TimeSAT - Ground Motion Pattern Detection and Classification in massive Satellite Image Time Series



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3. Terradue srl., Roma, Italy;
4. Terranum, Bussigny, Switzerland

Context (1)

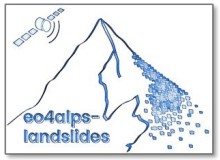
- **Availability of massive ground motion products/datasets (large scales, long observation periods)**
  - from MT-InSAR (e.g. EGMS, P-SBAS, LiCSAR, FLATSIM, SNAPPING, …)
  - from MT-Optical Image Correlation (GDM-OPT, ITS_LIVE, …)

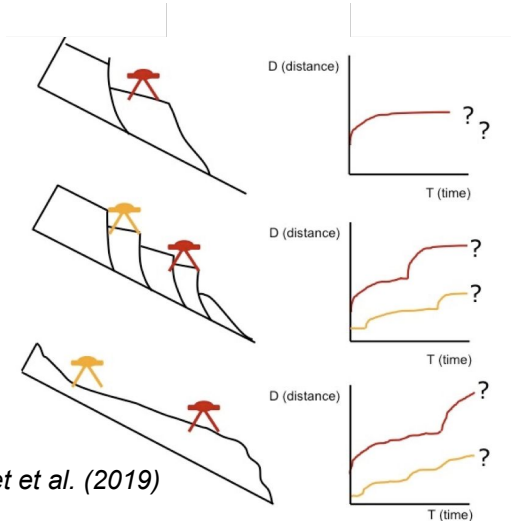
- **But challenges to exploit them and identify relevant signals**
  - noisy observations
  - temporal patterns
  - spatial clusters

- **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**

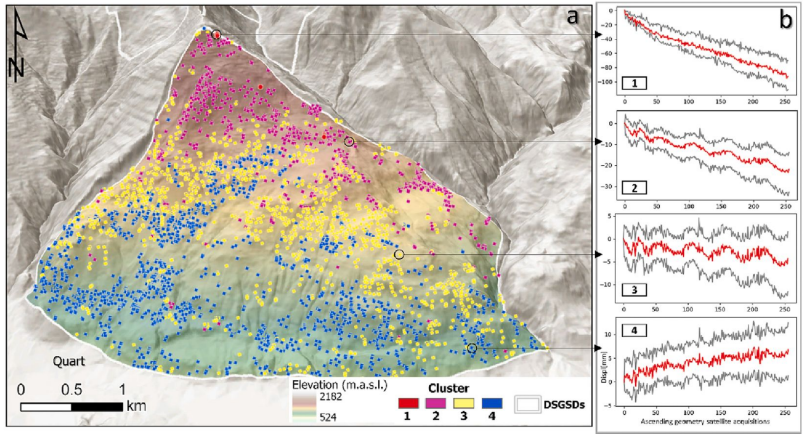




Malet et al. (2019)

Spatial distribution of clusters at the scale of one large landslide

TS with several temporal patterns



Festa et al. (2023)

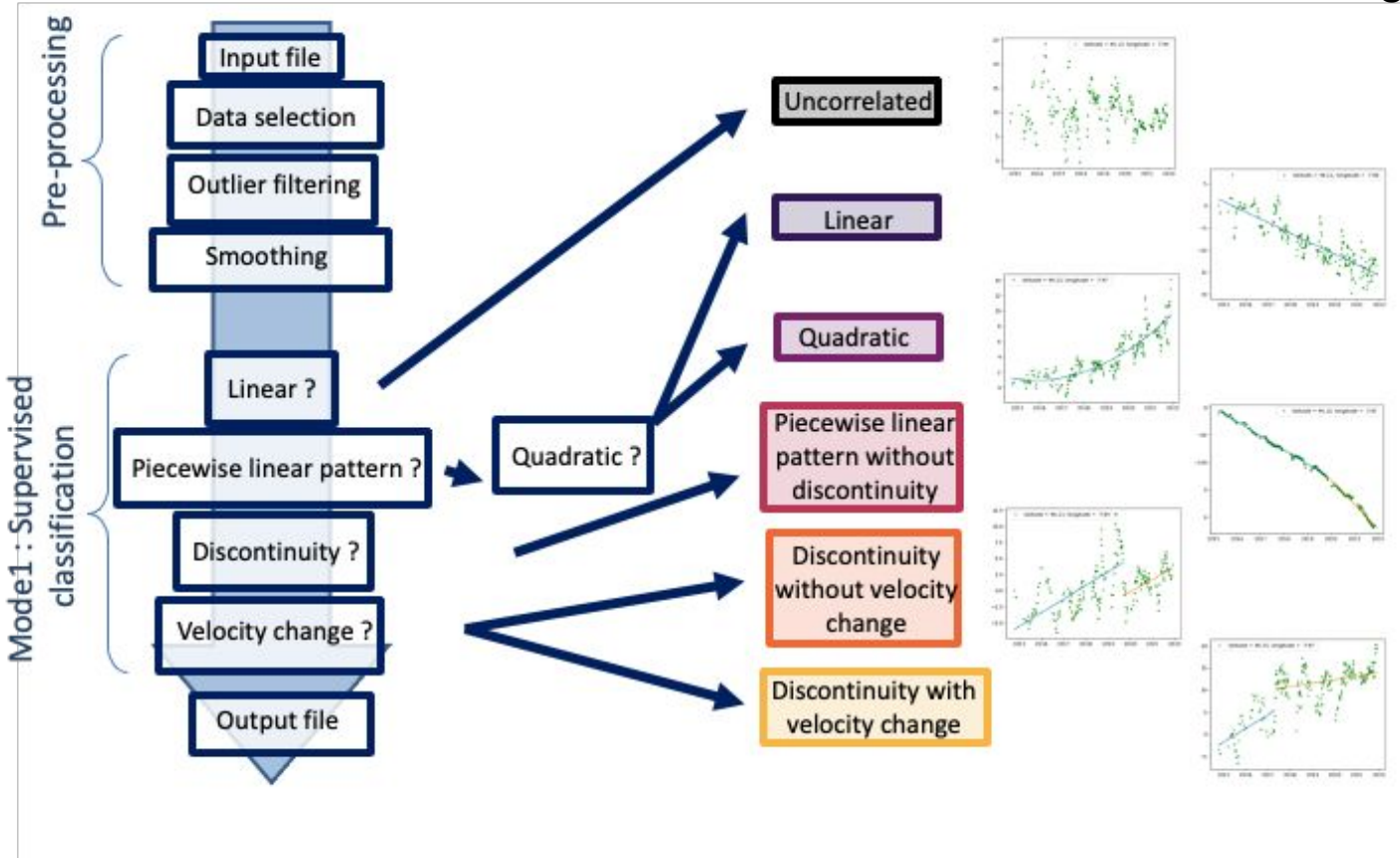
TimeSAT: a satellite TS (time series) processing service on-line

- **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*

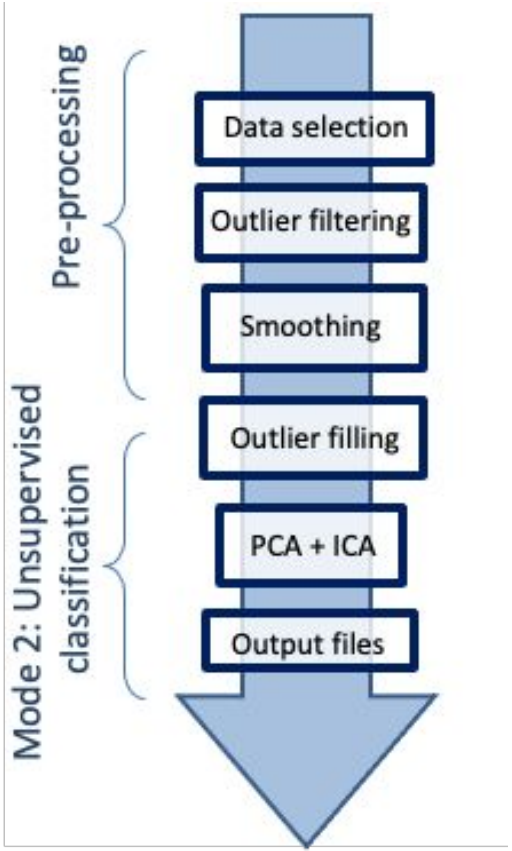
TimeSAT: Mode 1 - Supervised classification



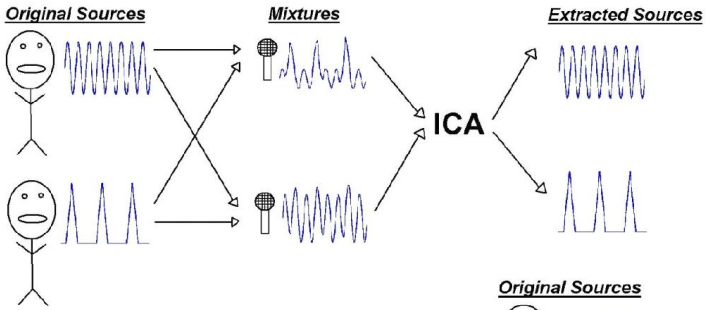
Classification:

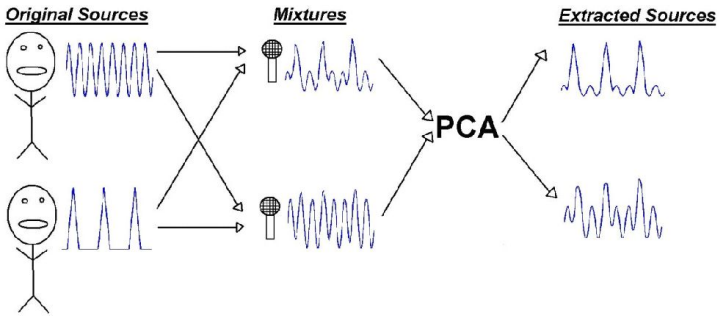
- in six predefined distinctive ground motion trends
- based on a sequence of advanced statistical tests

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.



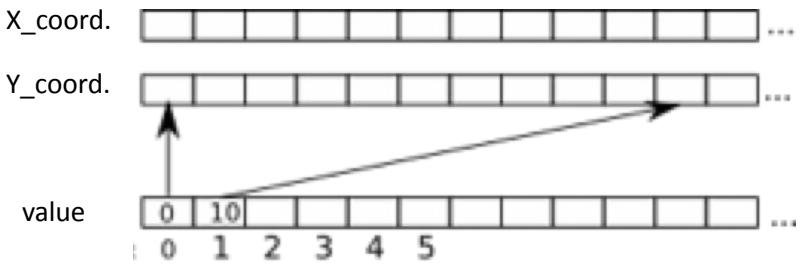


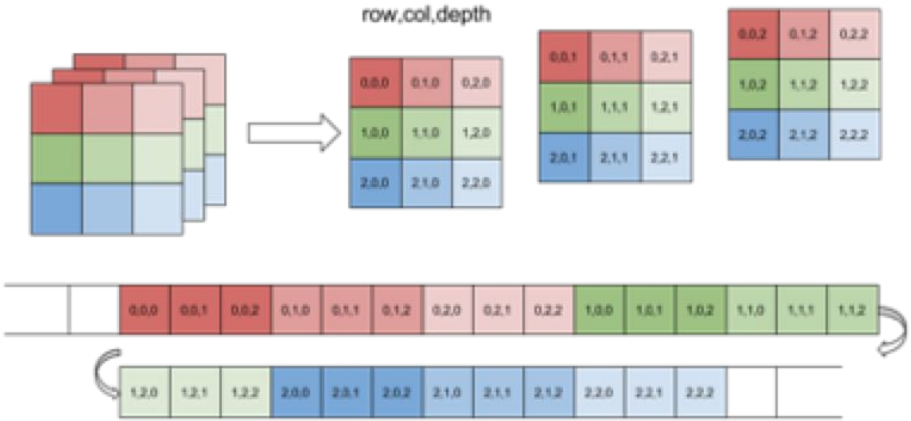
TimeSAT: technological developments for rapid/massive processing

- 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 serie of value need to be contiguous in the computer memory (stride optimization using chunking/blocking strategies)

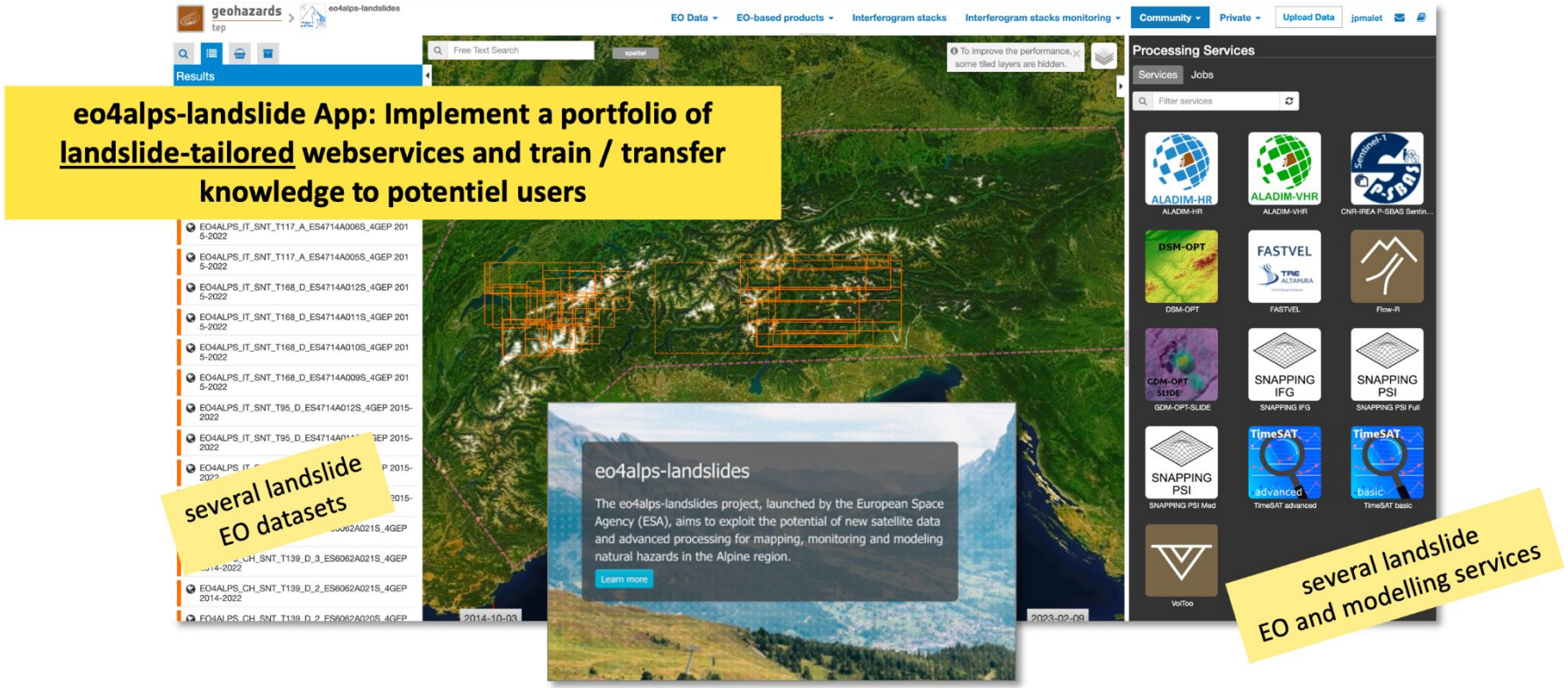
→ ca. 1M PS/DS can be classified 3-5 hours





TimeSAT: Service on GEP

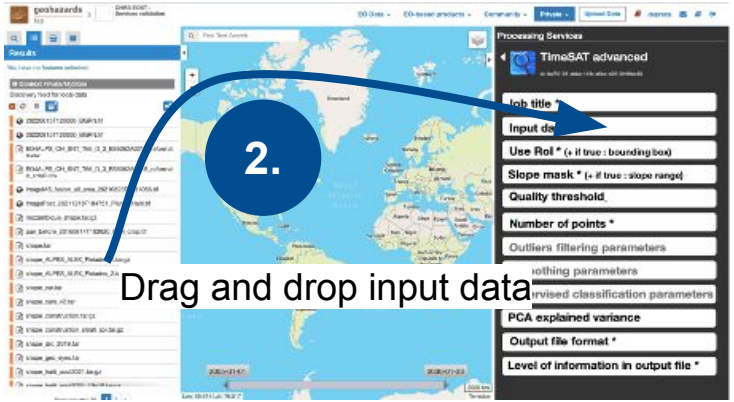
Developed with the support of ESA, and part of the eo4landslides App on GEP



TimeSAT: service on GEP

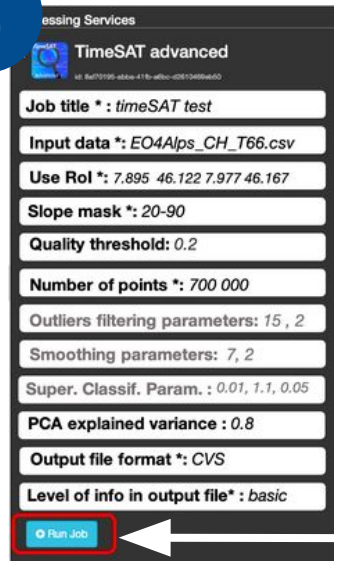
1.

Select the processing service **TimeSAT**



Drag and drop input data

3.



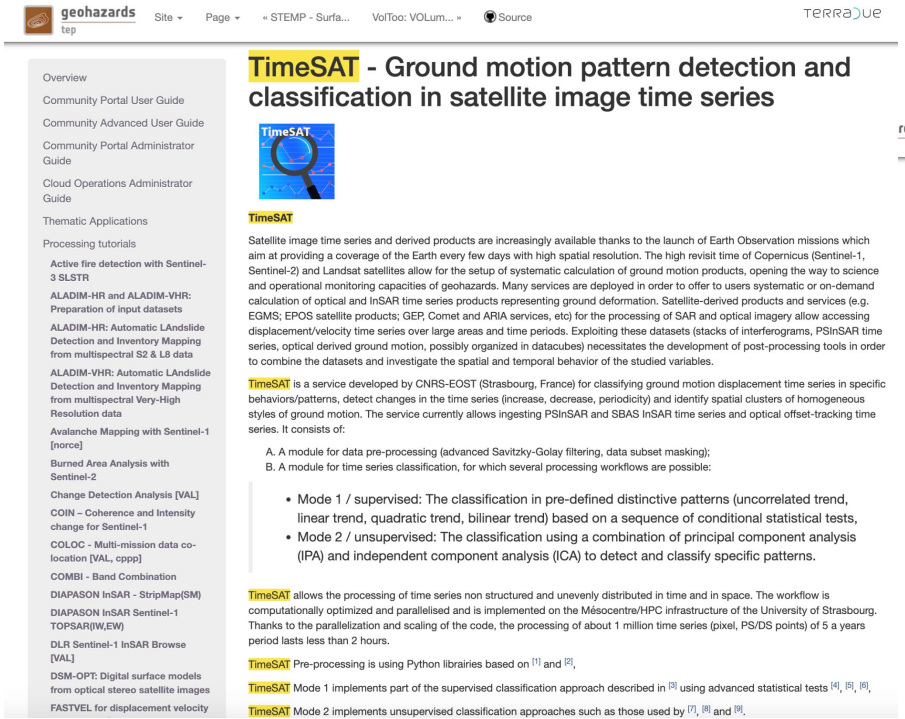
Tune the parameters:

- **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)



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

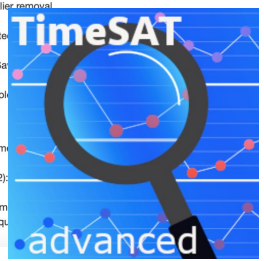
- **Use RoI (Region Of Interest)** If set to *True* the spatial data selection is activated
- **Region Of Interest bounding box** Define the bounding box of the Region of Interest (RoI)
- **Slope mask** If set to *True* the data selection based on the slope in activated (Slope computed using Copernicus 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 dete using Hampel identifier
- **Pre-processing: Length of filtering window for time series smoothing** Defines the length of filtering window (Sa 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 sampl (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 (α1): the tim classified as uncorrelated pattern if α1 < p-value.
- **Supervised classification: Quadratic term level of significance** Defines the quadratic ANOVA test threshold (α2): series is classified as linear pattern if α2 < p-value.
- **Supervised classification: Piecewise linear pattern level of significance** Defines the BIC threshold (Bth): the tim classified as piecewise linear pattern if the minimum BIC of segmented regression models is less than the BIC of qu 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 km^2

Processing parameters:

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

Dataset:

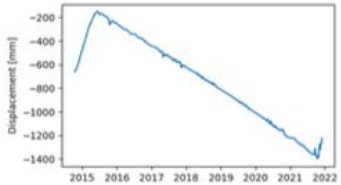
Input file	EO4ALPS_CH_SNT_T66_D_3_ES6062A021S_reformate.csv
Nb of measurement points:	761493
Nb of dates:	257 (2015-06-12 to 2022-05-23)

Results Mode #1 : Supervised classification:

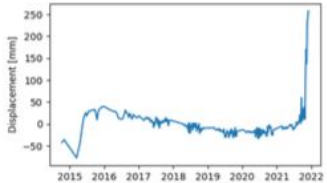
0: uncorrelated	93584	12%
1: linear	0	0%
2: quadratic	1324	0.1%
3: piecewise linear with break point	362376	47%
4: piecewise linear with discontinuity	59946	8%
5: piecewise linear with discontinuity and velocity change	244263	32%

Results Mode #2 : Unsupervised classification:

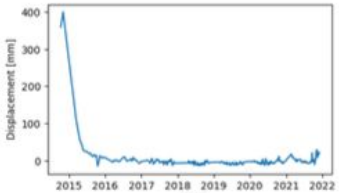
Nb of PCA/ICA components: 25



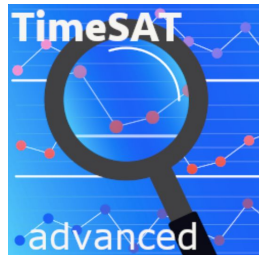
Nb points for PCA 1: 205400 (27%)
Variance explained by PCA 1: 48%



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%

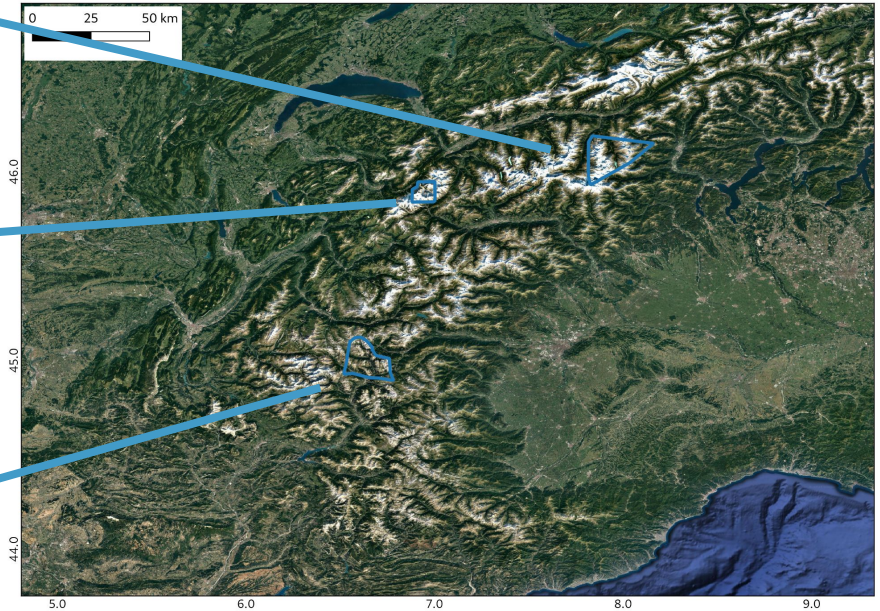


TimeSAT: use cases presented in this work

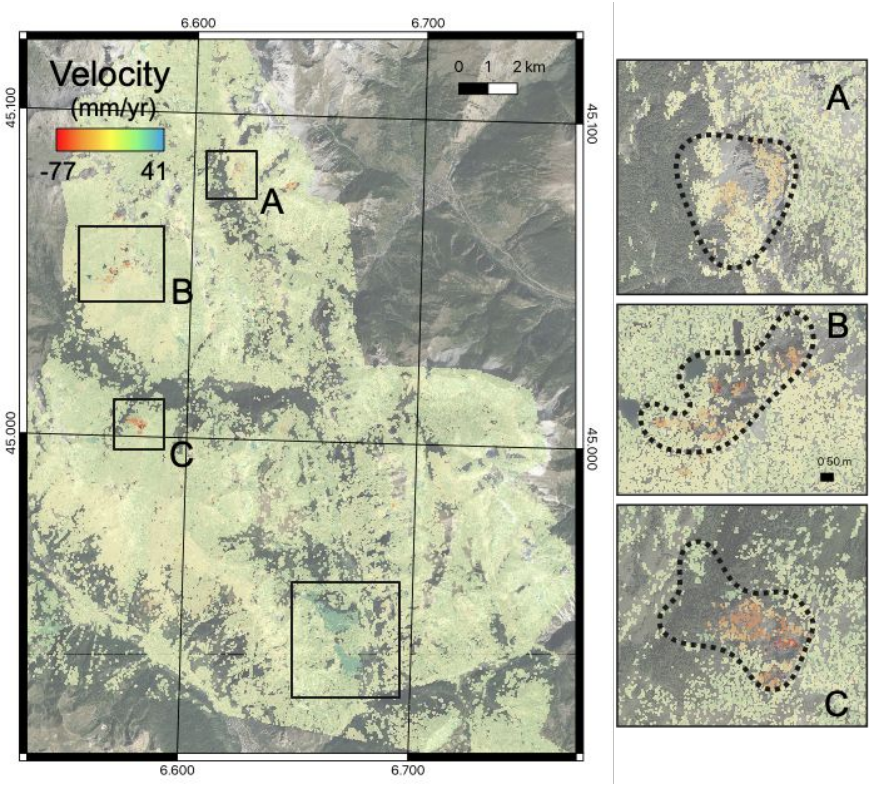
- Wallis Cantoon (Alps, Switzerland)
  - Ground motion time series from InSAR processing *(PS/DS)*
  - > 700.000 points, 257 dates (2014-10-10 to 2022-07-12)

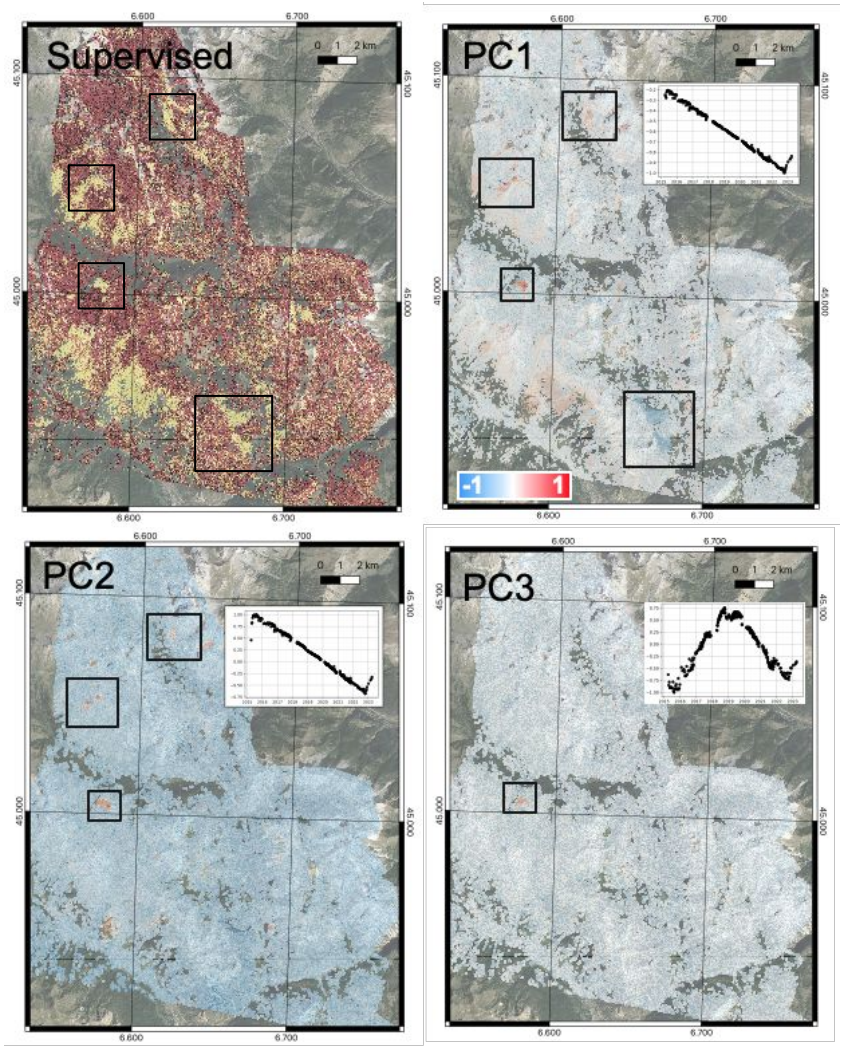
- Mont-Blanc massif (Mer de Glace, France)
  - Optical offset-tracking time series *(GDM-OPT-ICE)*
  - > 300.000 points 158 dates (2015-08-29 to 2023-07-03)

- 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)

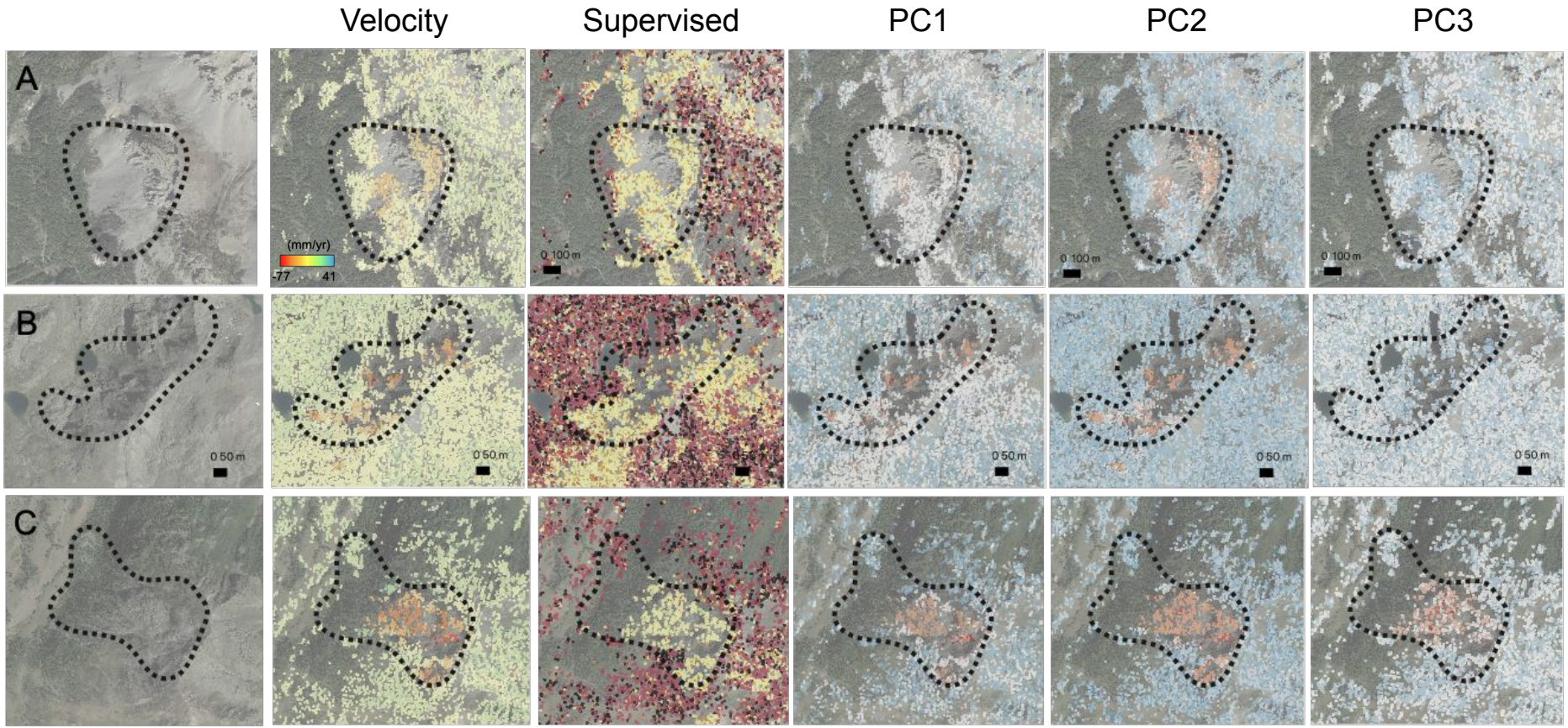


TimeSAT: use case, over Briançonnais with InSAR time series as input



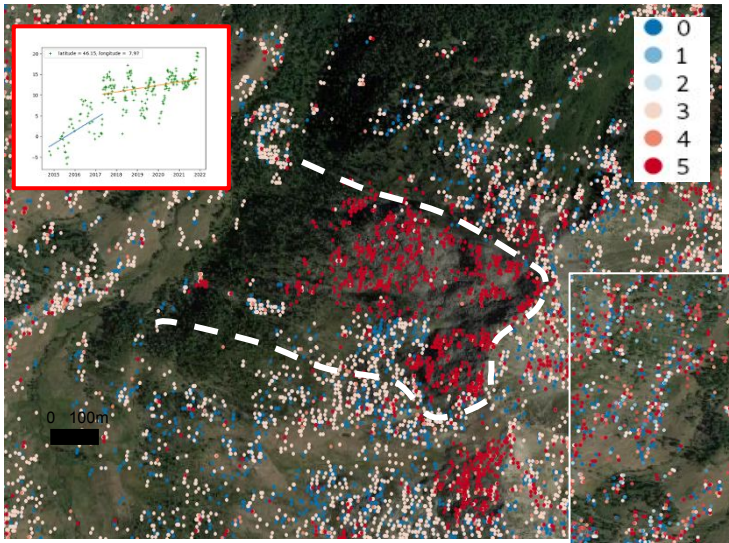


TimeSAT: use case, over Briançonnais with InSAR time series as input



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

TimeSat results, supervised mode

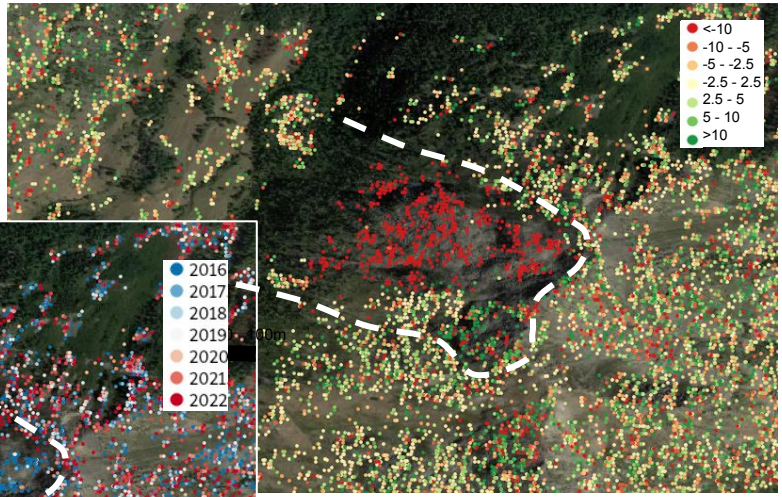


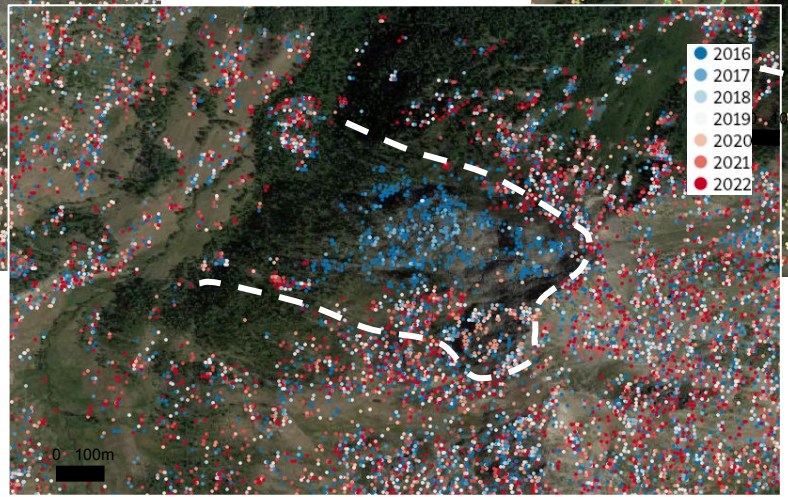
Cluster of points of class 5

(TS with jump(s) and velocity change)

Velocity change (mm/yr)

Significant velocity change before and after the breakpoint

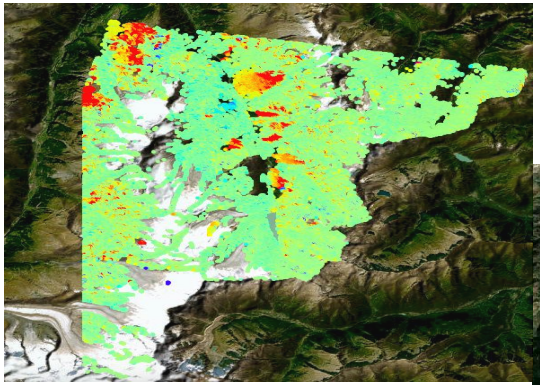




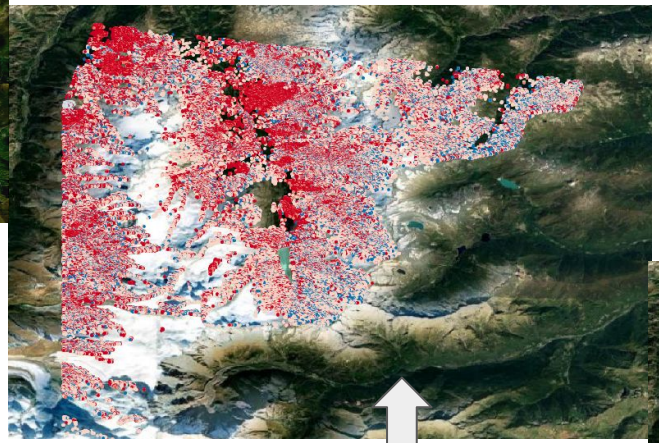
Date of the Breaking Point

(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



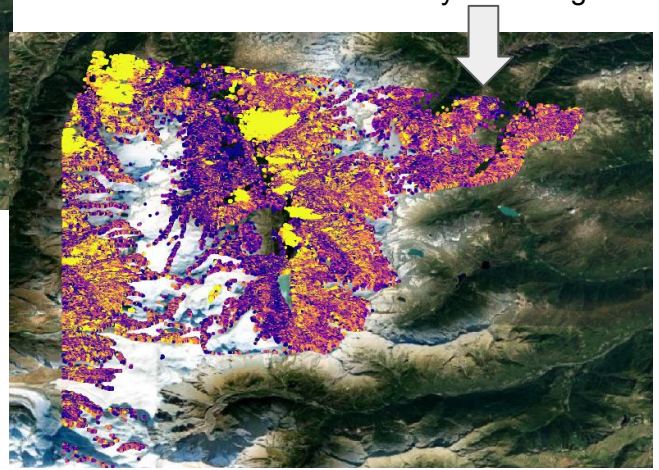
Linear trend of Input data
(SqueeSAR for EO4alps on, ©TreMap)



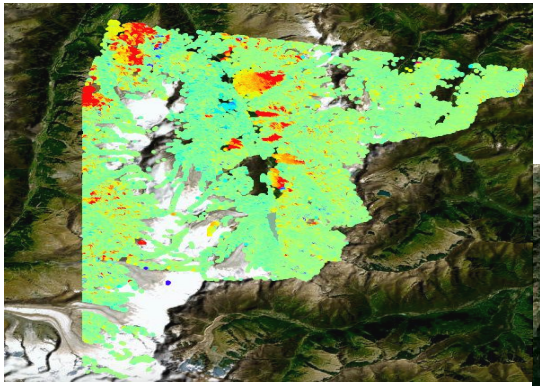
TimeSat results, supervised mode
Class 5 in red highlights the instabilities
(TS with jump(s) and velocity change)

TimeSat results, unsupervised mode

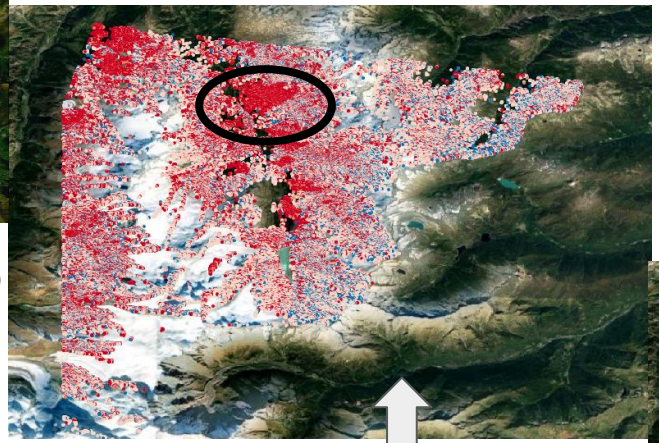
For each point : weight of the first principal component. Max (yellow) and min (dark blue) values allow to identify the instability of the region.



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



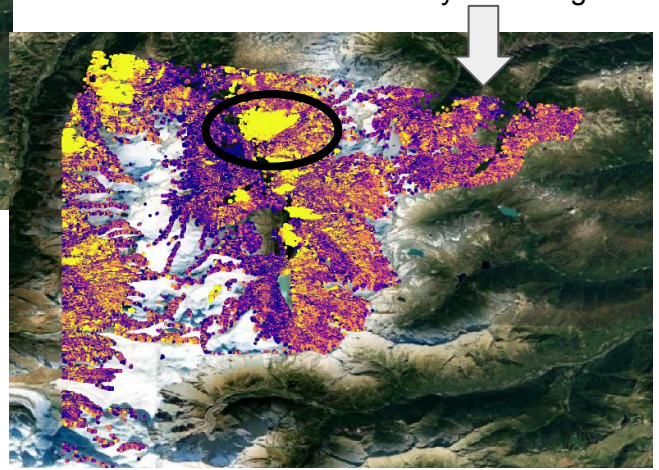
Linear trend of Input data
(SqueeSAR for eo4alps-landslides, ©TRE-A)



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

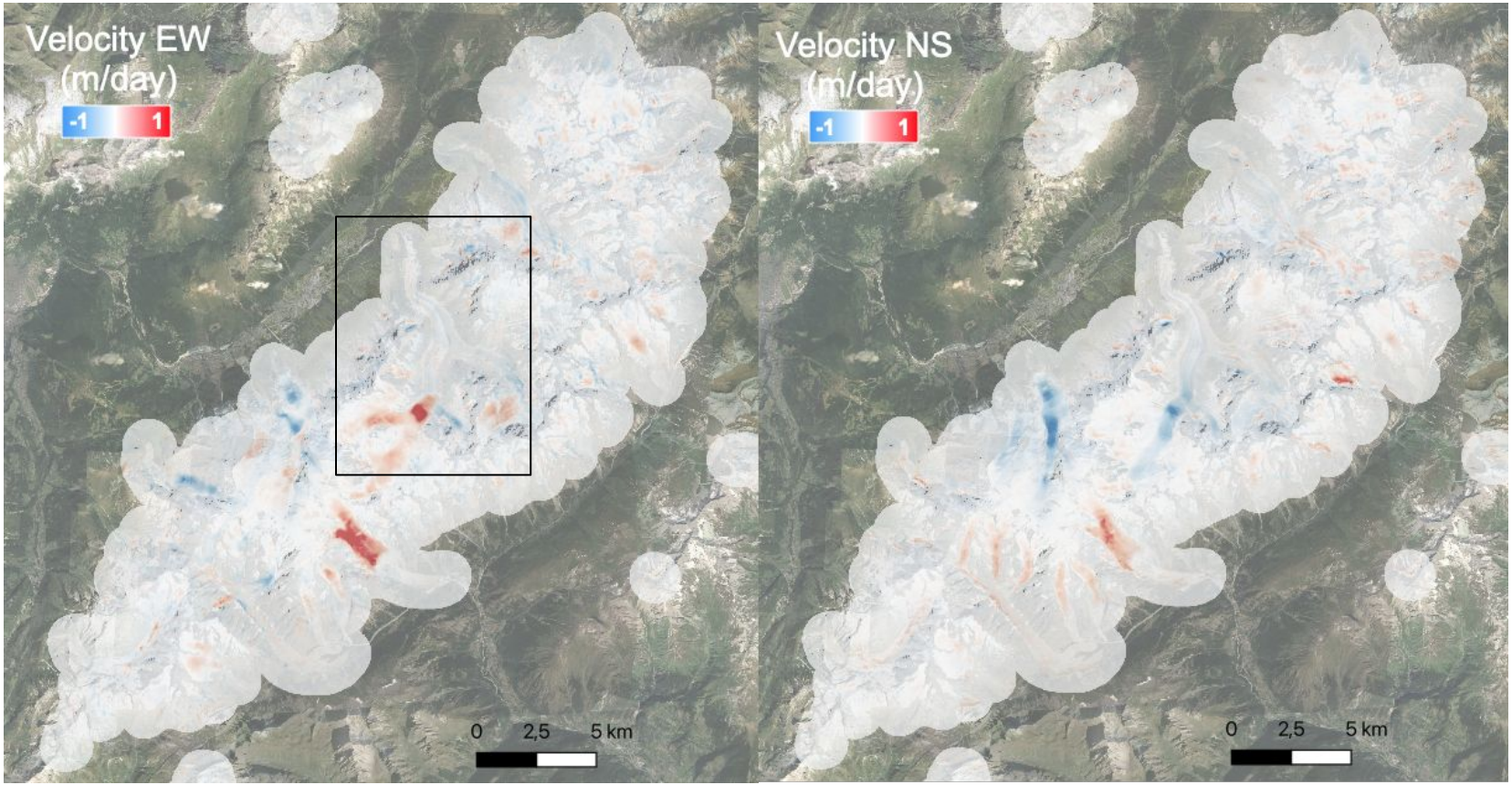
Date of the breaking point

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

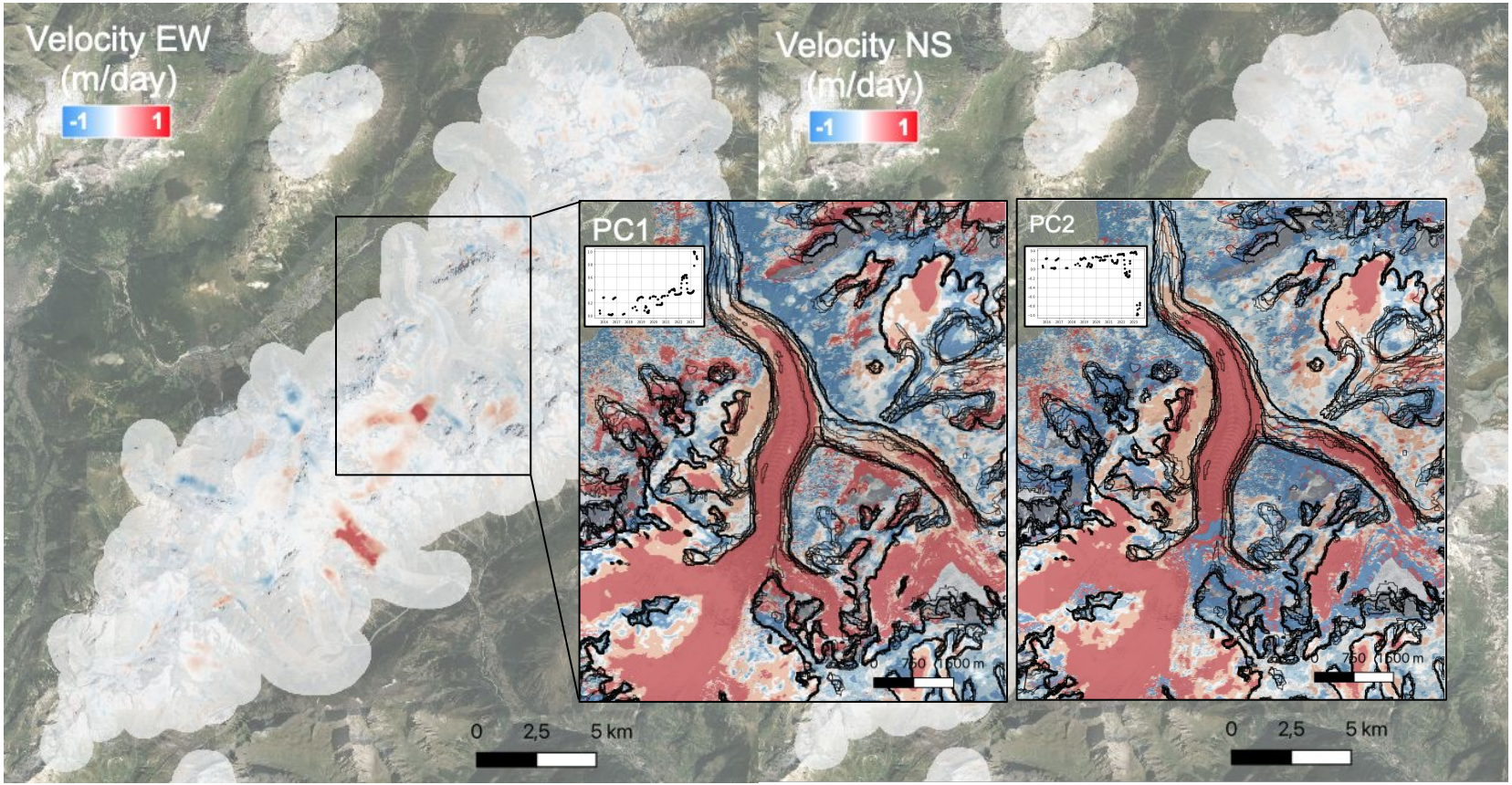
Velocity change (mm.yr-1)

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

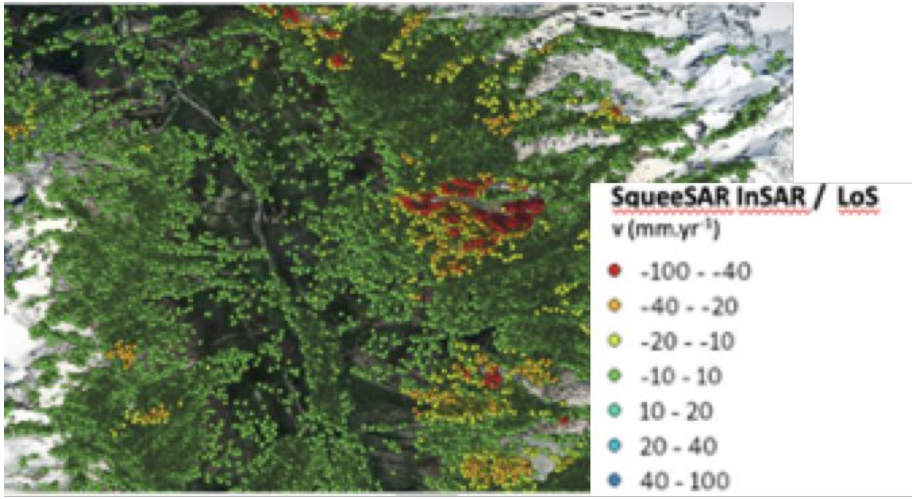


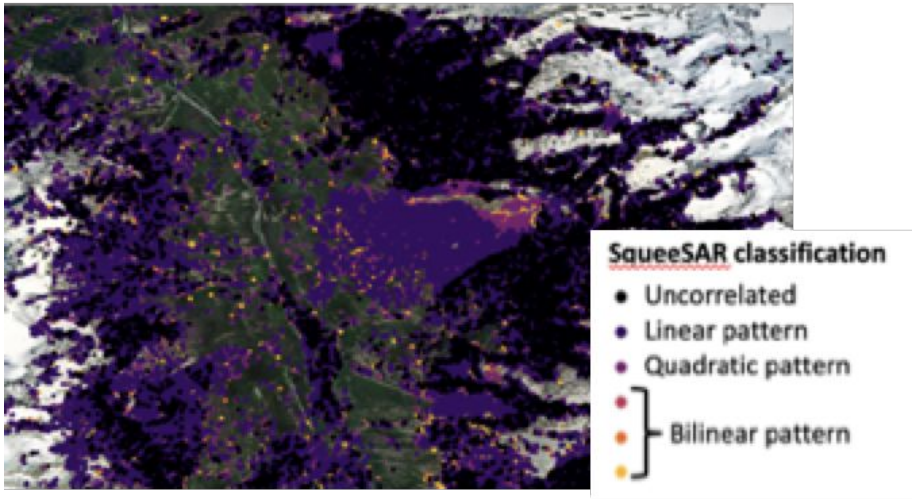
Conclusion and perspectives

- **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!

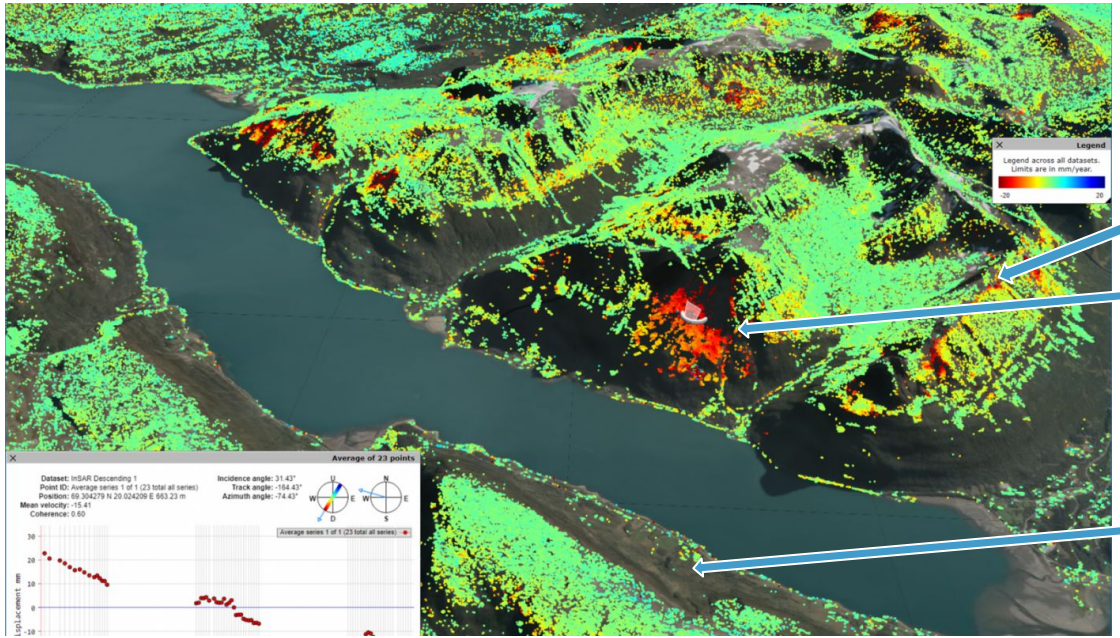




J’avais cela comme ancienne diapo pour Saas-Balen / Valais

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



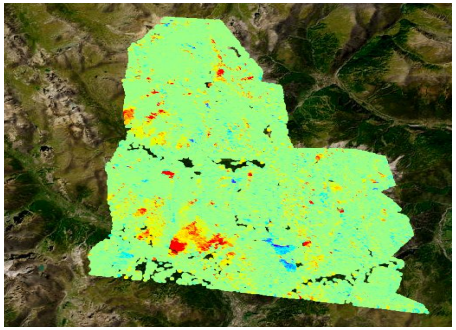
deep-seated slope deformation signal

rockslide signal

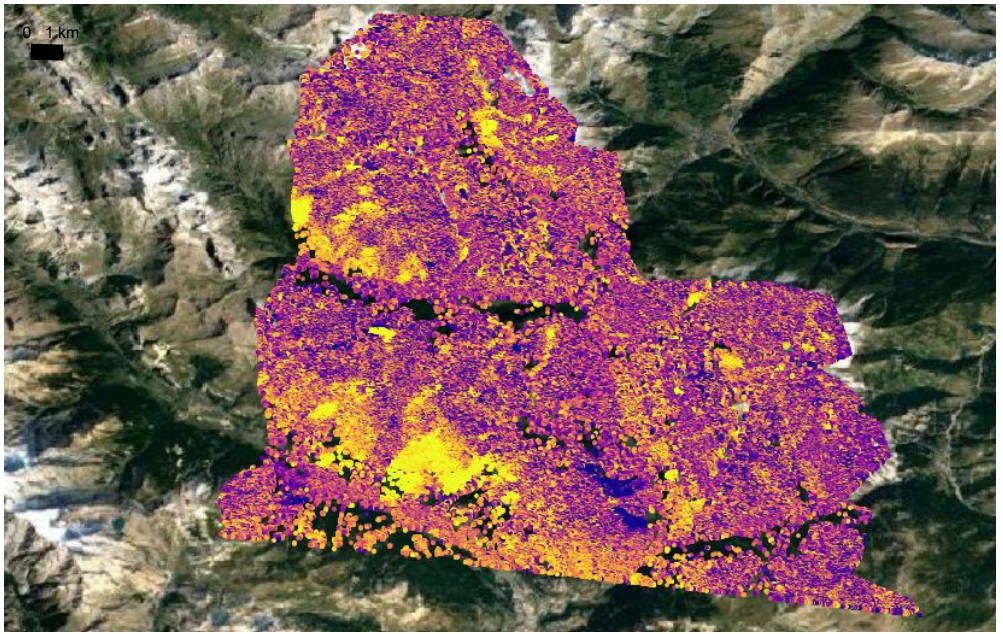
local subsidence signal (in the valley floor)

© InSAR Norway product

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



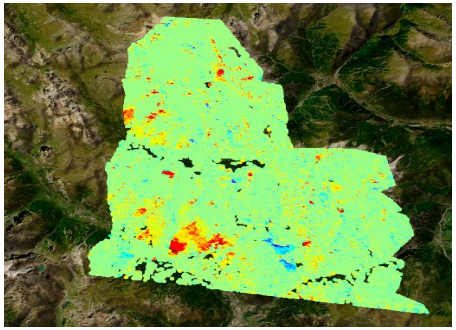
Linear trend of Input data
(SqueeSAR for EO4alps on, ©TreMap)



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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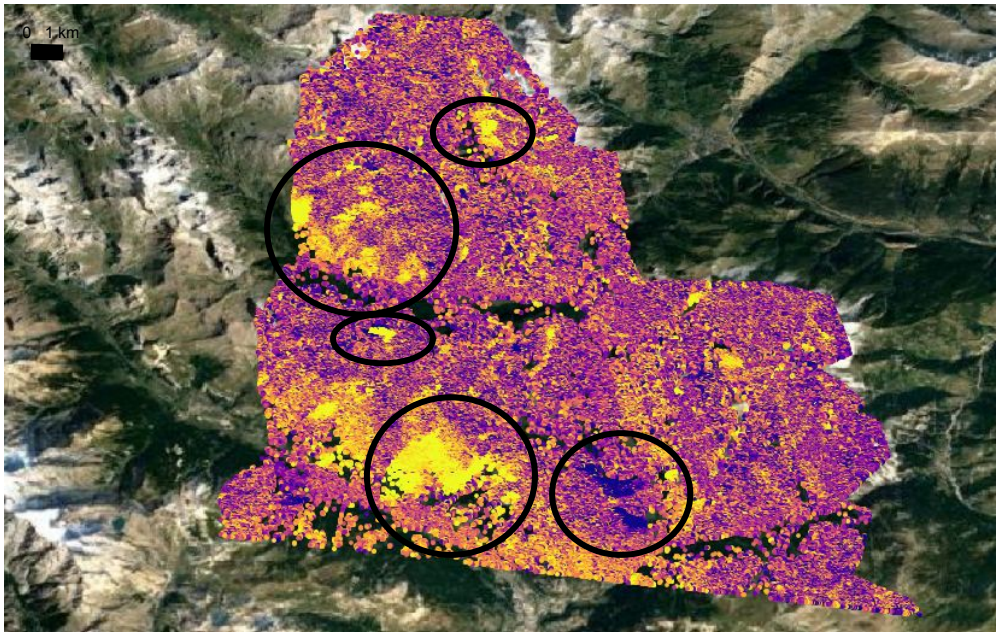

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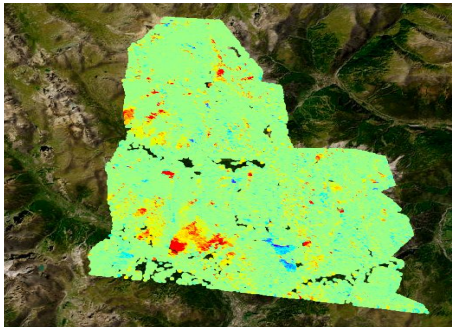

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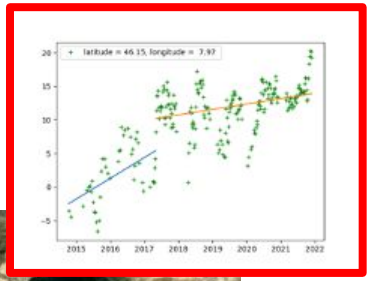
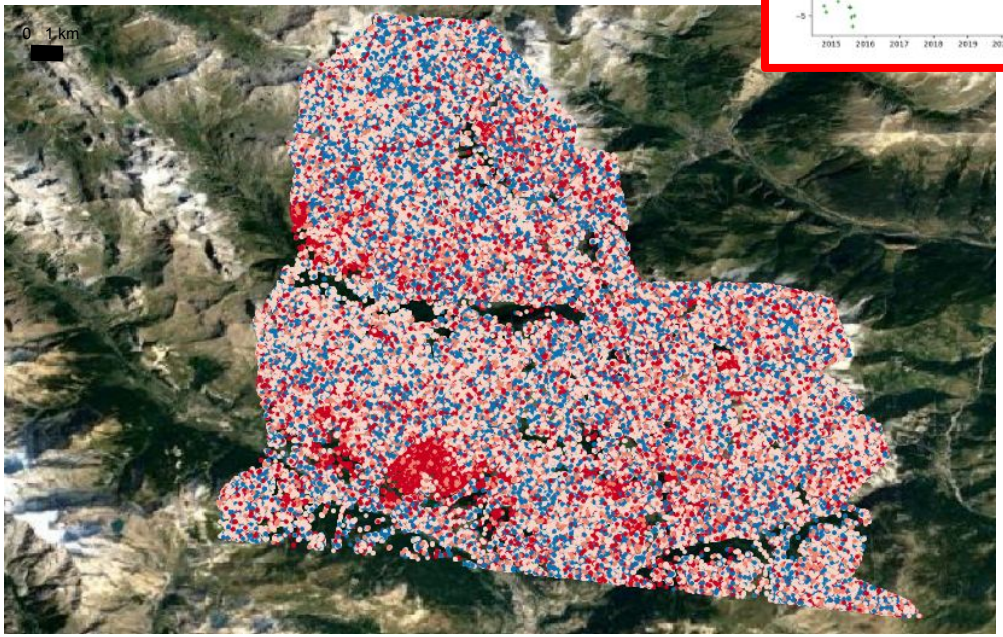


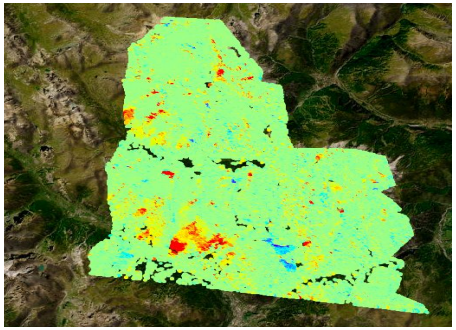


TimeSat results, supervised mode

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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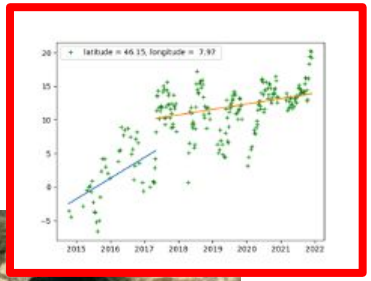

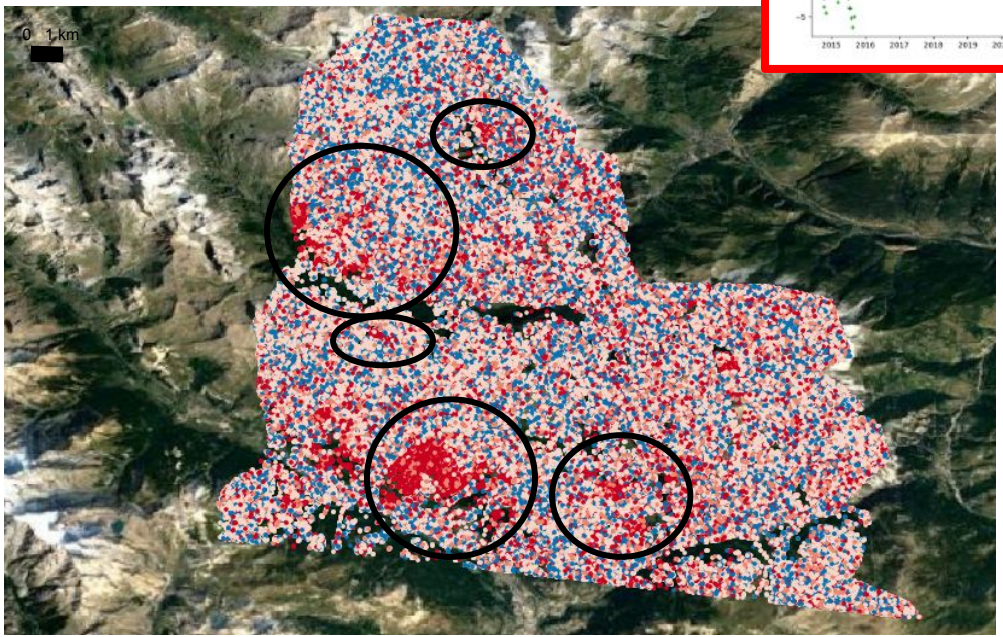

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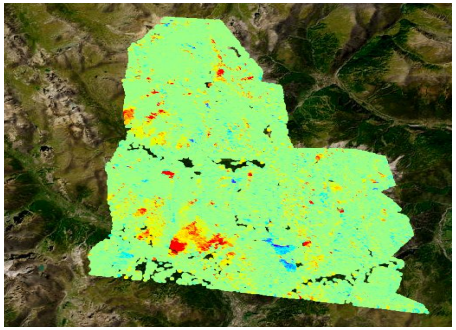

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