Mesure de la déformation du sol par corrélation de séries temporelles satellitaires optiques : *applications aux déplacements co-sismiques, aux suivis de glaciers et de glissements de terrain*

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(et les groupes de travail « optique » ForM@Ter / Data Terra et GEP / ESA)

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Journée Thématique du PNTS 2021 - les missions Sentinel

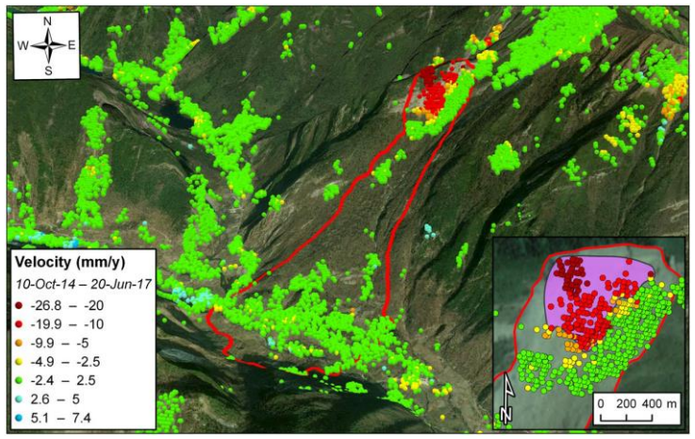
1 avr. 2021 Visioconférence (France)

Quantifying ground motion for geohazards

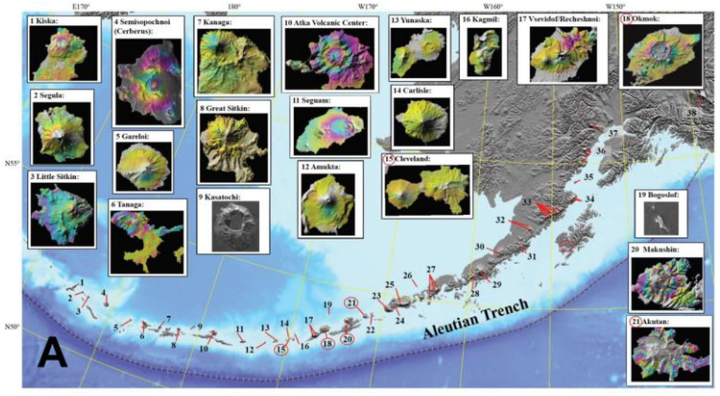
Motivation

Ground motion monitoring is a key source of information for better understanding, modeling and forecasting geohazards such as **volcanoes, landslides or glaciers.**

Risk management and risk reduction

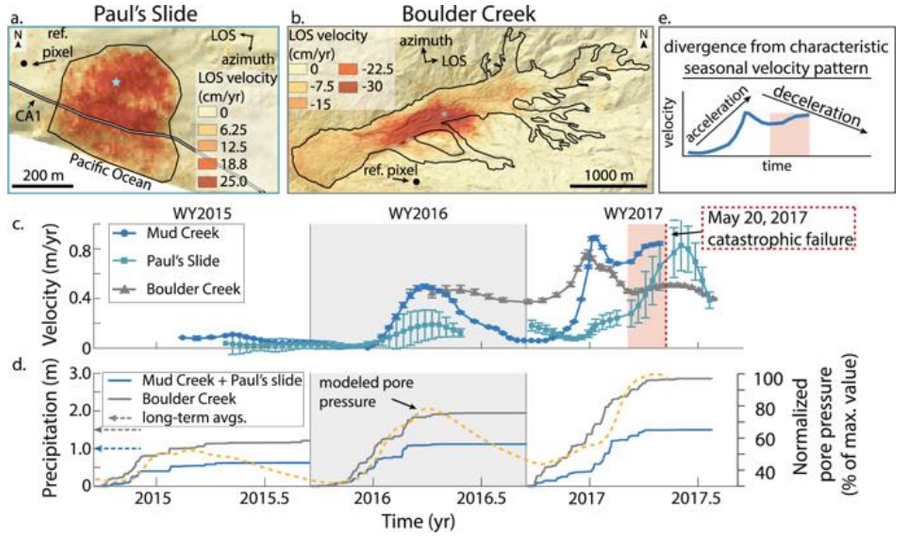


Kang et al., 2019



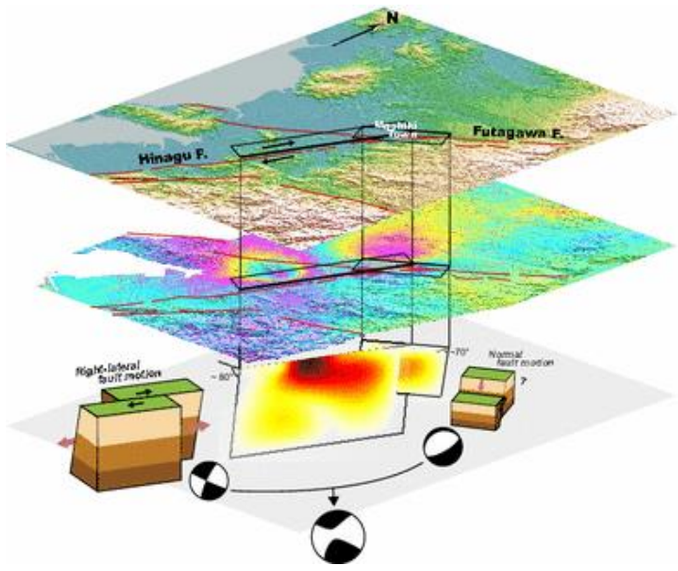
Dzurisin et al., 2019

Better understanding of the mechanisms controlling the phenomena



Handwerger et al., 2019

Modeling of the phenomena



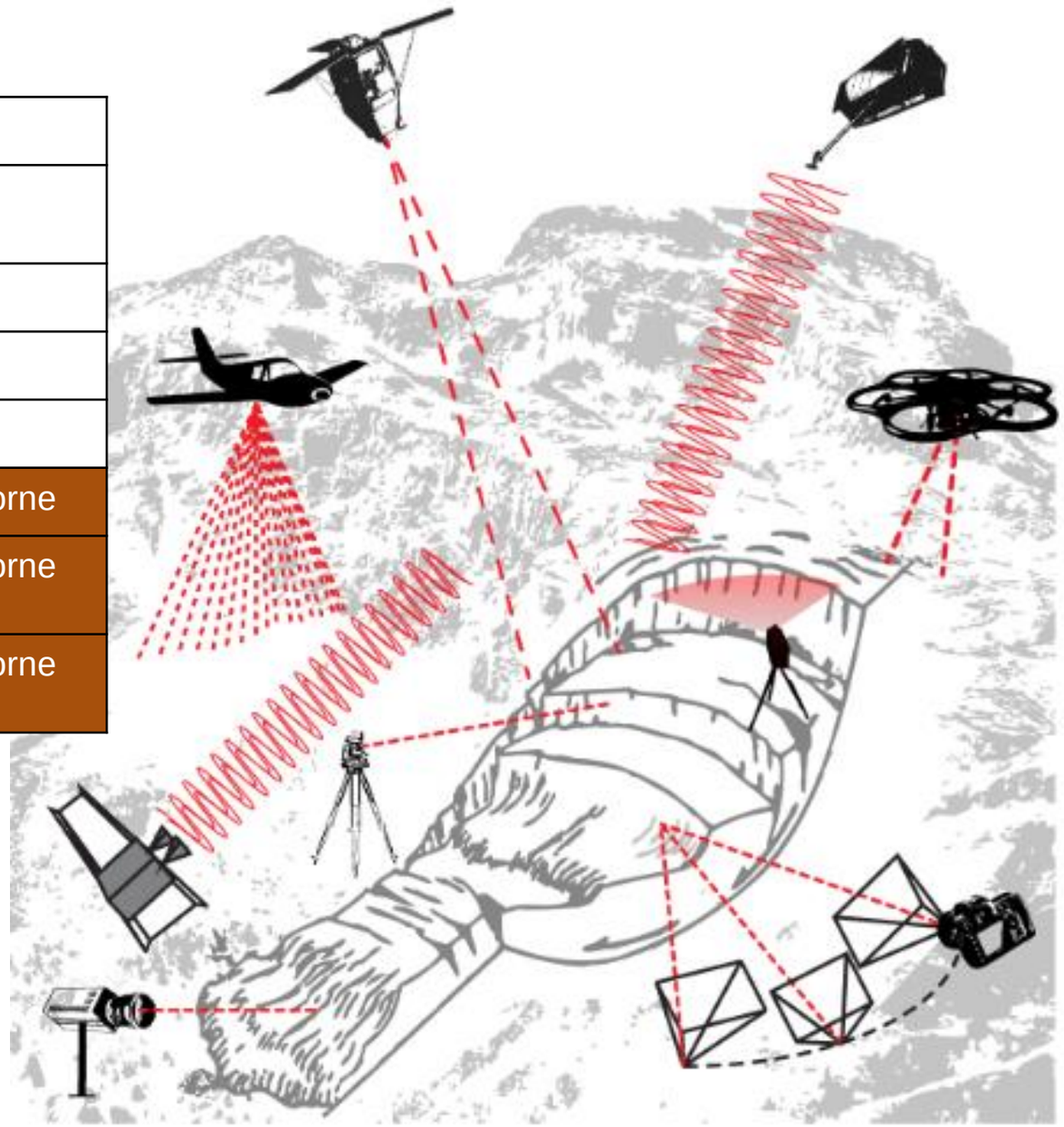
Kobayashi et al,. 2017

Quantifying ground motion for geohazards

Methods for ground motion monitoring

Several instrumentations available **ground-based, air or space-borne** with different spatio-temporal resolution

Methods	Measure	Instrument
GNSS	3D displacement at 1 point	Ground-based
Tacheometer	LOS motion at 1 point	Ground-based
Levelling	Z motion at 1 point	Ground-based
LiDAR	3D reconstruction	Ground-based, airborne
Photogrametry	3D reconstruction	Ground-based, airborne, space borne
InSAR	LOS motion over a large area	Ground-based, airborne, space borne
Image Matching	2D motion in the plane perpendicular to LOS	Ground-based, airborne, space borne



Stumpf et al., 2016

Main advantages of **space-borne** acquisitions:

- non invasive

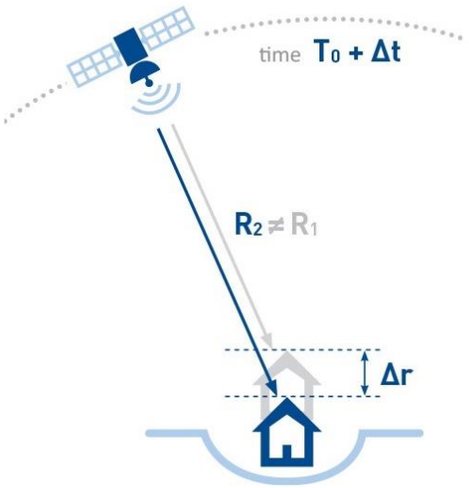
- monitoring of remote areas

- large spatial coverage - synoptic view

Earth Observation: Surface motion monitoring

Two main approaches

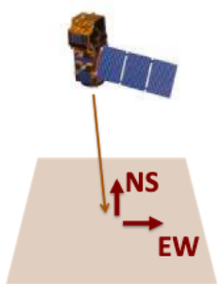
- Radar **Interferometry - InSAR**



- **Sensitive to motion in the LOS** i.e. sensitive to EW and vertical motion. Poorly sensitive to NS motion.
- Millimetric accuracy.
- **Monitoring of very small (mm) to cm motion**. In case of larger motion, decorrelation usually prevents to monitor the deformation.
- Non sensitive to cloud cover.
- **Applicable only to radar acquisitions.**

- **Image Matching – optical / SAR**

- **Sensitive to horizontal movement**, poorly sensitive to vertical motion.
- Sup-pixel accuracy (in general metric to cm).
- **Monitoring of large movement (metric)**. Smaller movement can also be measured depending on satellite pixel size.
- Sensitive to cloud cover.
- **Applicable to radar and optical acquisitions.**



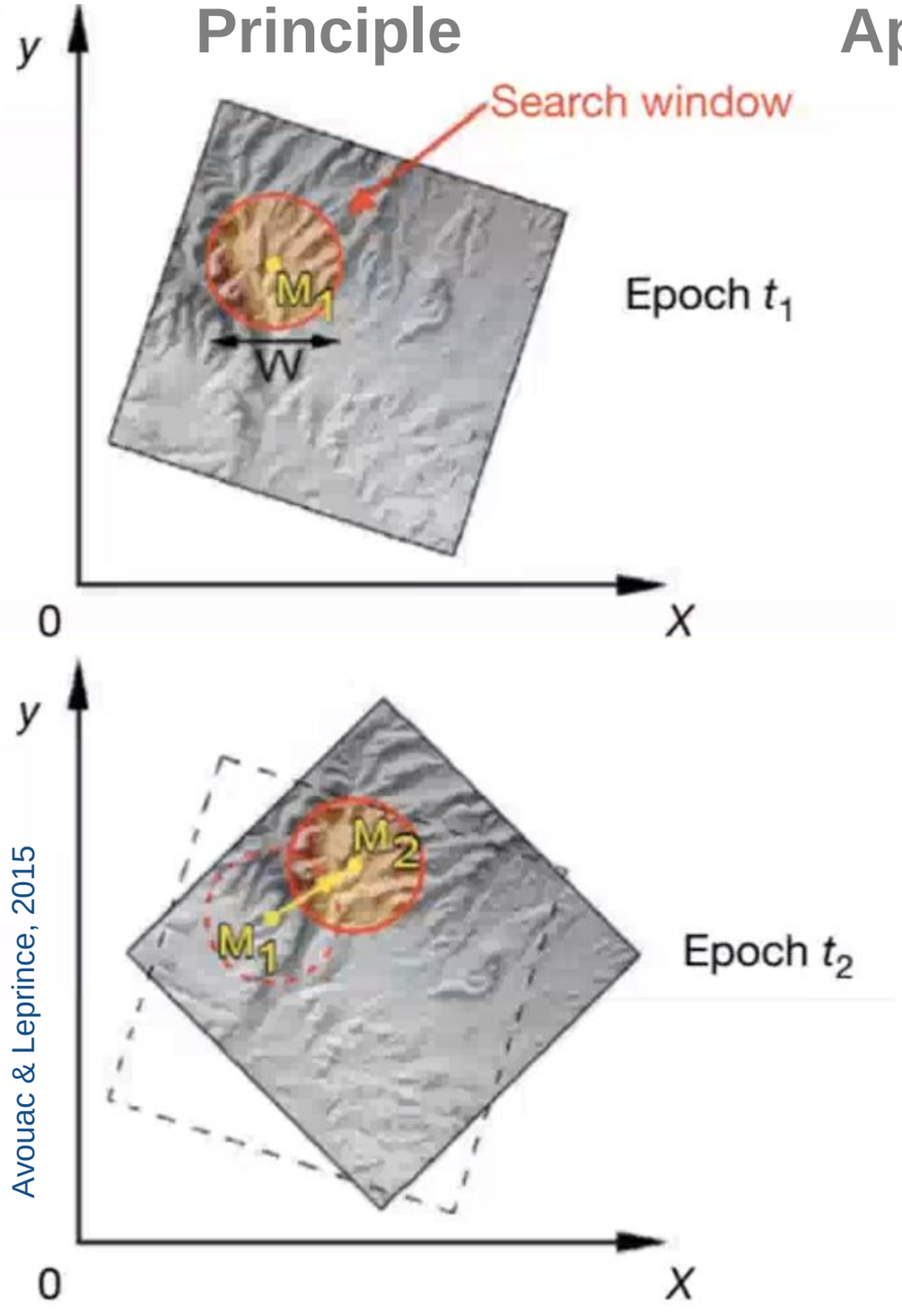
What about image matching and optical data?

Mw-7.5 Palu ETQ, Sulawesi
28/9/2018
Sentinel-2 / L1C

Kerengeru fault and landslides
New Zealand
Sentinel-2 / L2A – color composite

What about image matching and optical data?

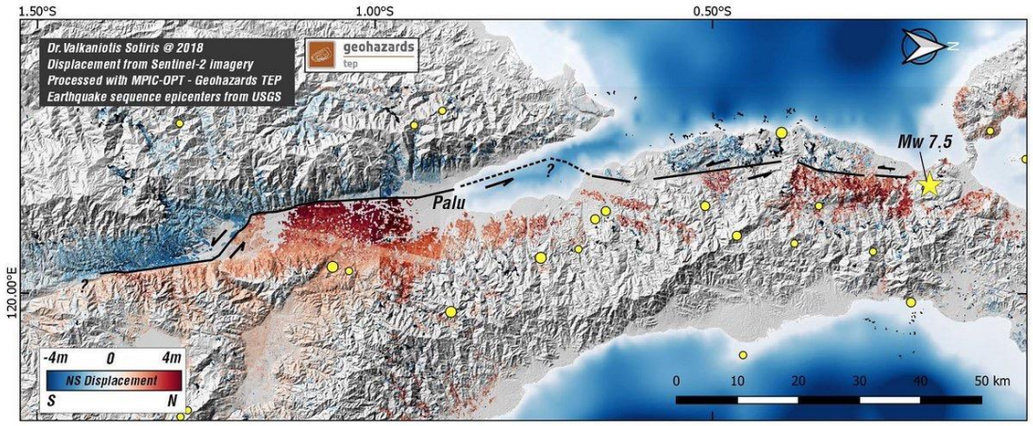
Principle



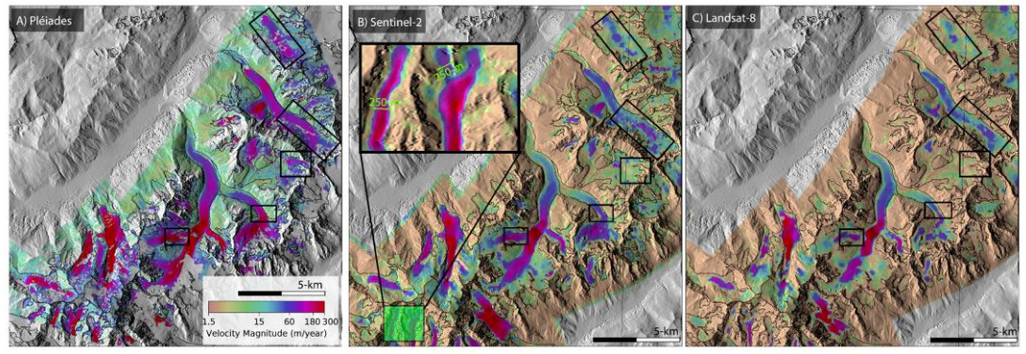
Sensitive to large displacement (cm/yr to m/yr) and horizontal component

Applications

Co-seismic displacement and seismic source modeling

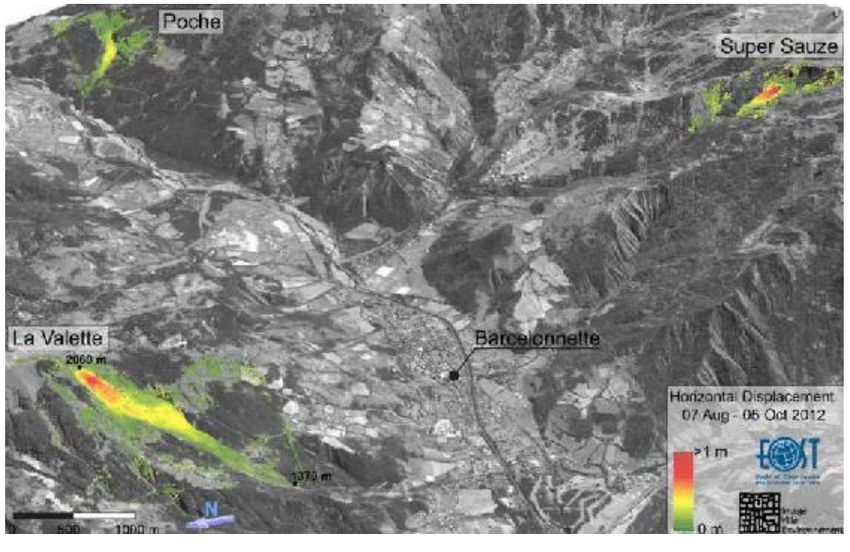


Large/rapid displacements on glaciers and landslides



Millan et al., 2019

Automatic detection of ground instabilities, creation of catalogues, etc.



Stumpf et al., 2017

What about image matching and optical data?

Available image matching algorithms and strategy

1

Catalogues

Sentinel-2
Landsat
…

PlanetsLabs
Tasked VHR

2

Image Matching algorithms

MicMac
CosiCorr
ImCORR
Ampcor
QPEC/Medicis
ImGraft

GeFolki
…

3

Time series Inversion

TIO
MSBAS
ad-hoc

Manual actions on user computer…

Need large storage for data catalogue
Need computing resources for correlation and inversion…
ovn long archives (> 2015)

What about image matching and optical data?

New strategy… fully automated and systematic processing

1

Catalogues

Sentinel-2
Landsat
…

PlanetsLabs
Tasked VHR

2

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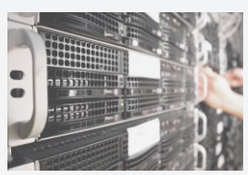
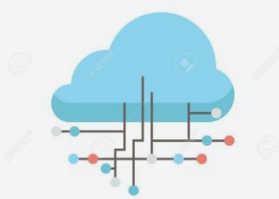


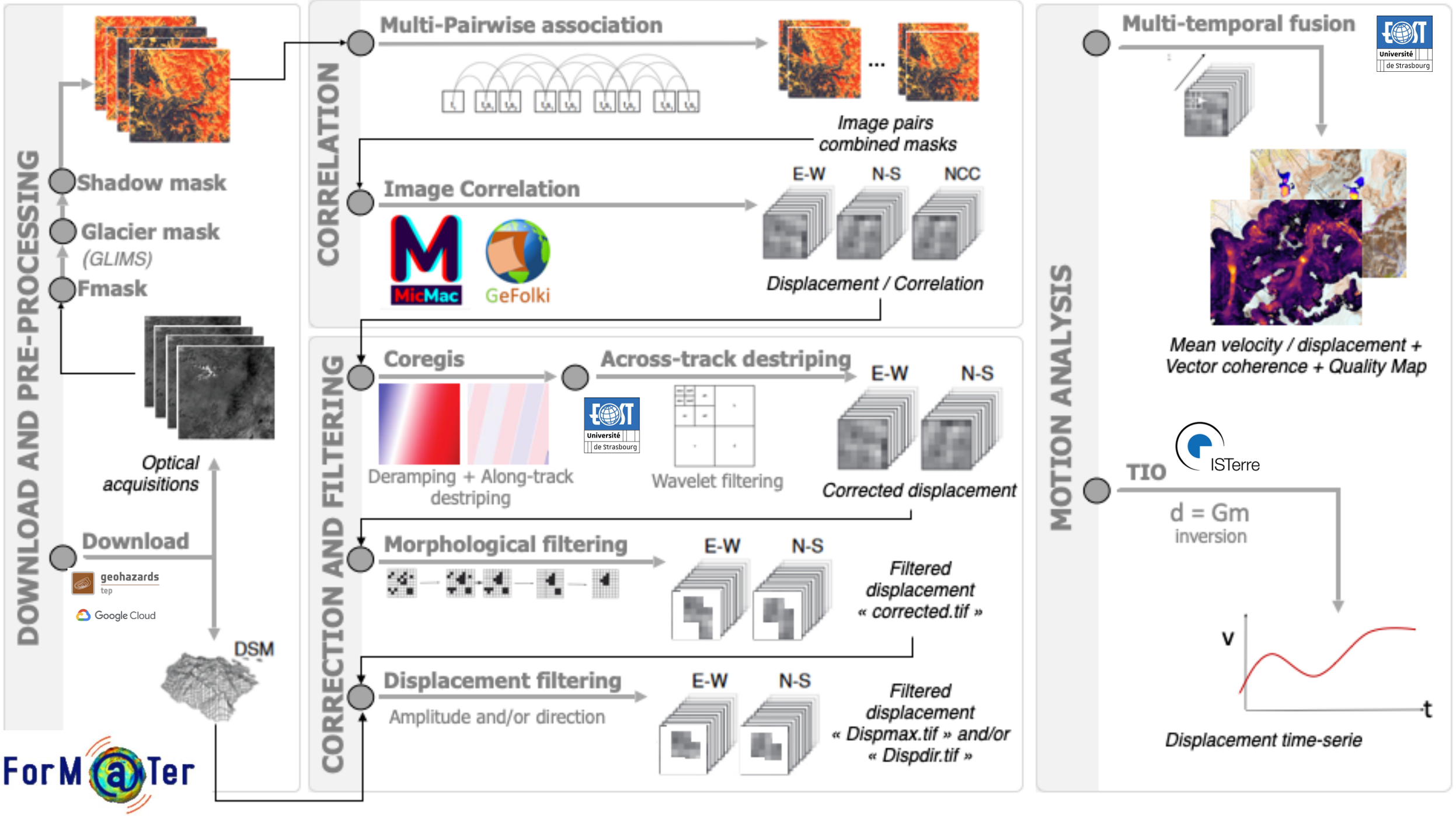


HPC or Cloud environnement

+ Easy access/control of parameters…

GDM-OPT: Ground Deformation Monitoring

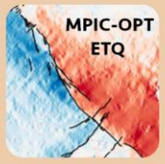
A full processing chain to process Optical images



GDM-OPT: Ground Deformation Monitoring

Three thematic services available on two platforms

GDM-OPT @Mesocentre/Strasbourg



MPIC-OPT EarThQuake

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MPIC-OPT SLIDE

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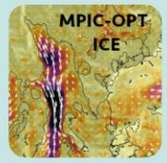

MPIC-OPT ICE

- Tailored for glacier ice sheet displacement monitoring with velocity from 10 cm/day to 10+ m/day with the current archive of Sentinel-2
- Number of input images : 100 maximum
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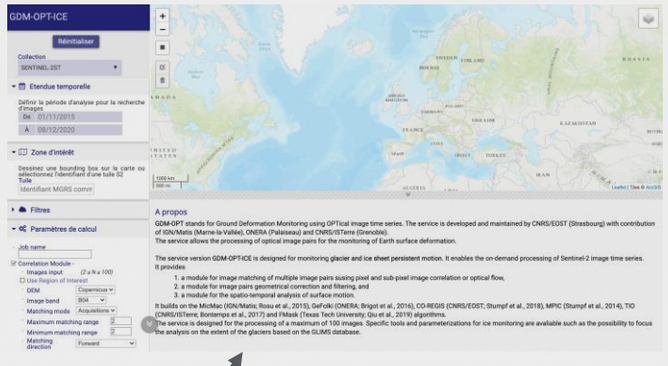
- Mult-temporal stack and detection of persistent motion
- Global glacier mask available from World Glacier Inventory (WGI)

back-end

Send the parameters and the input images

geohazards tep

ForM@Ter



front-end

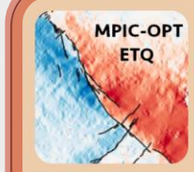
Visualize and download products

GDM-OPT: Ground Deformation Monitoring

Three thematic services available on two platforms

Send the parameters and the input images

GDM-OPT @Mesocentre/Strasbourg



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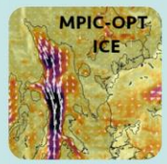

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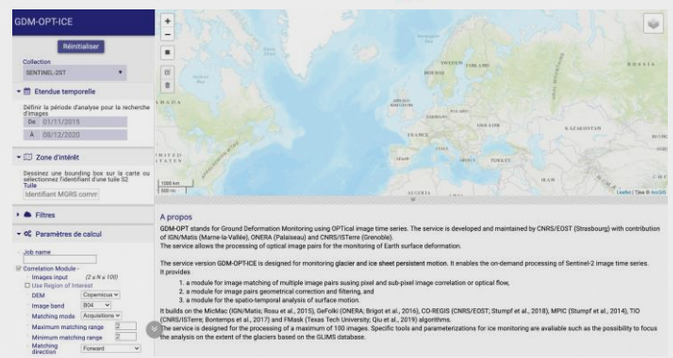
geohazards tep

ForM@Ter



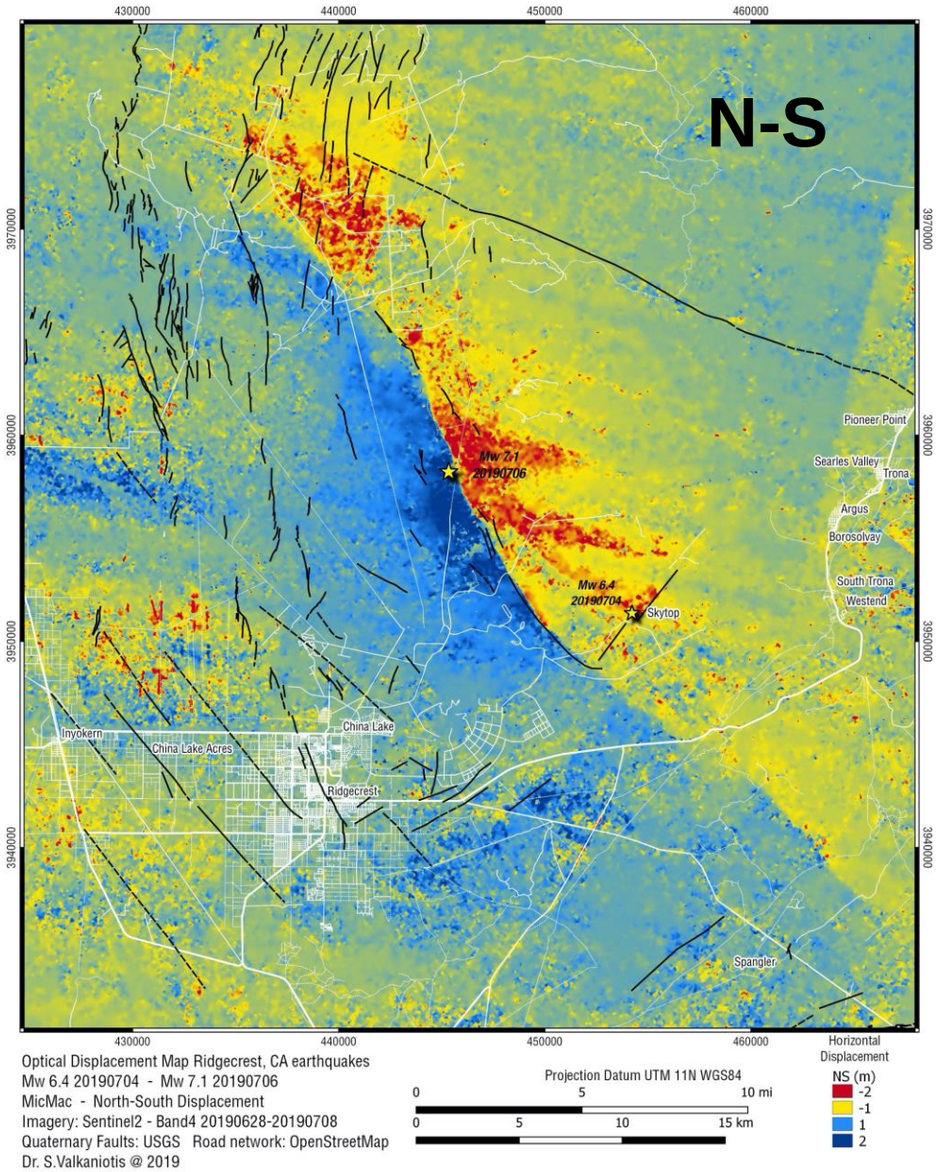
front-end

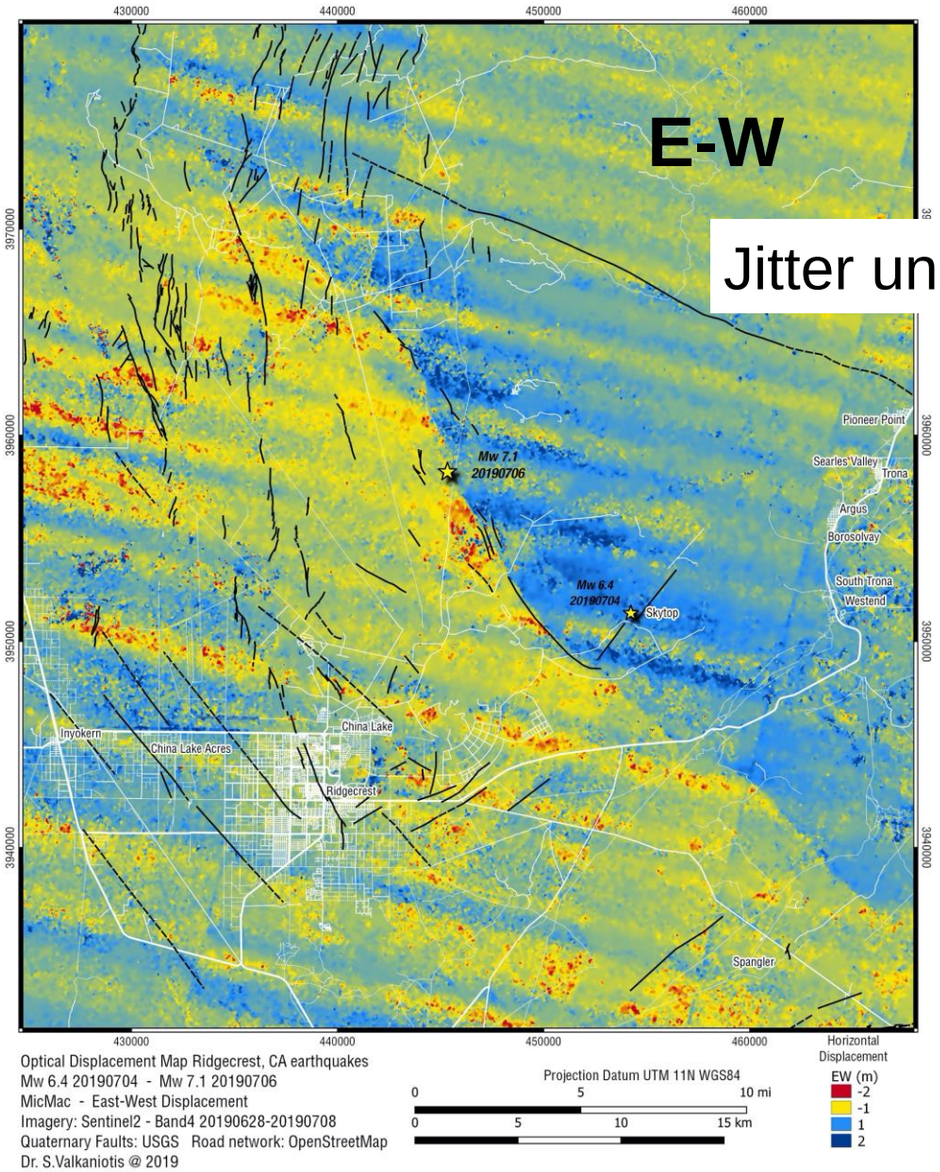
Visualize and download products

GDM-OPT-ETQ: measuring co-seismic displacement

Ridgecrest July 2019

« standard » MicMac co-seismic displacement - Sentinel-2





Jitter undulations

Valkaniotis., 2019

GDM-OPT-ETQ: measuring co-seismic displacement

Jitter undulations on satellite acquisitions

Jitter undulations are caused by platform instability. They are visible in some images with a magnitude ranging from 1 to several meters.

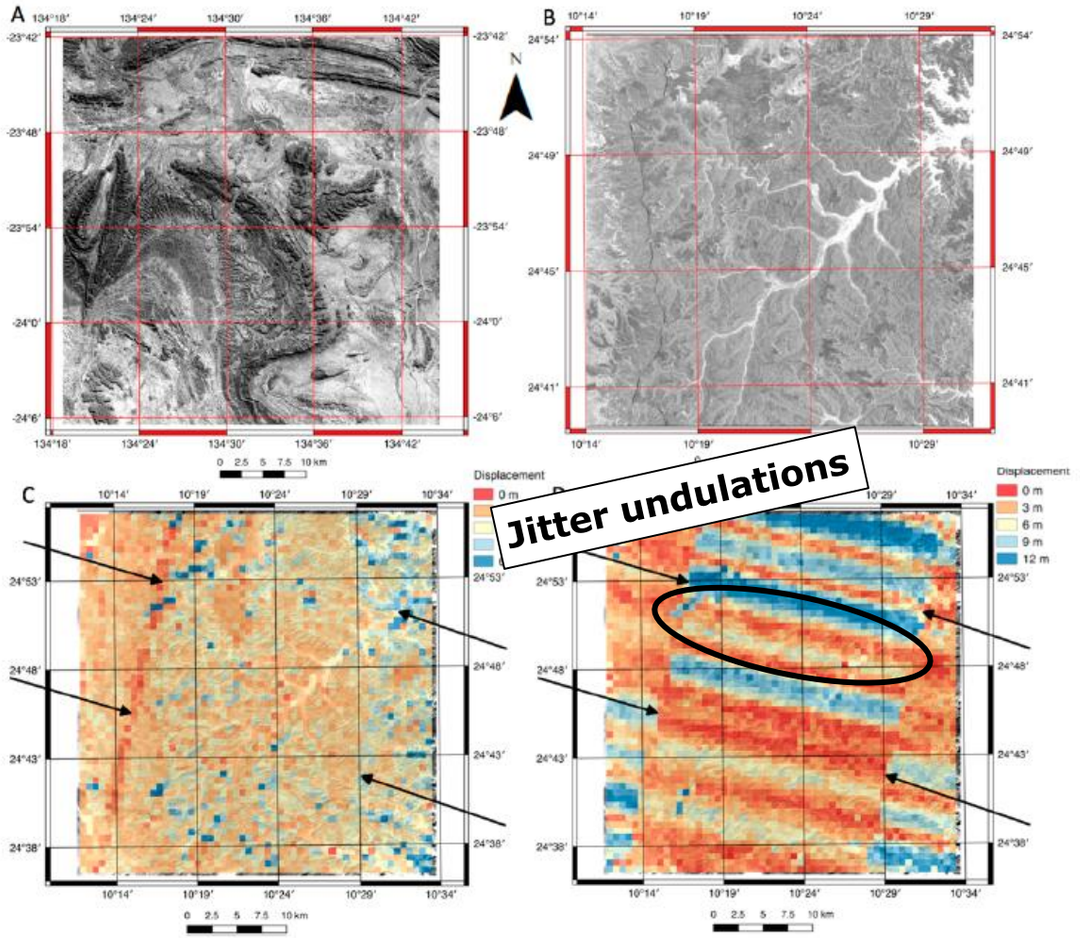


Figure 4. (A) Stable area in Australia; (B) Stable area in Libya; (C) Map of displacement of pair 04.01.2016–14.01.2016 over the stable area in Libya displaying striping in the orbit direction; (D) Map of displacement of pair 06.09.2016–06.10.2016 over the stable area in Libya displaying bands of differential displacement in the cross orbit direction. Arrows in (C) and (D) indicate position of striping in the along track direction.

Nagy et al., 2019

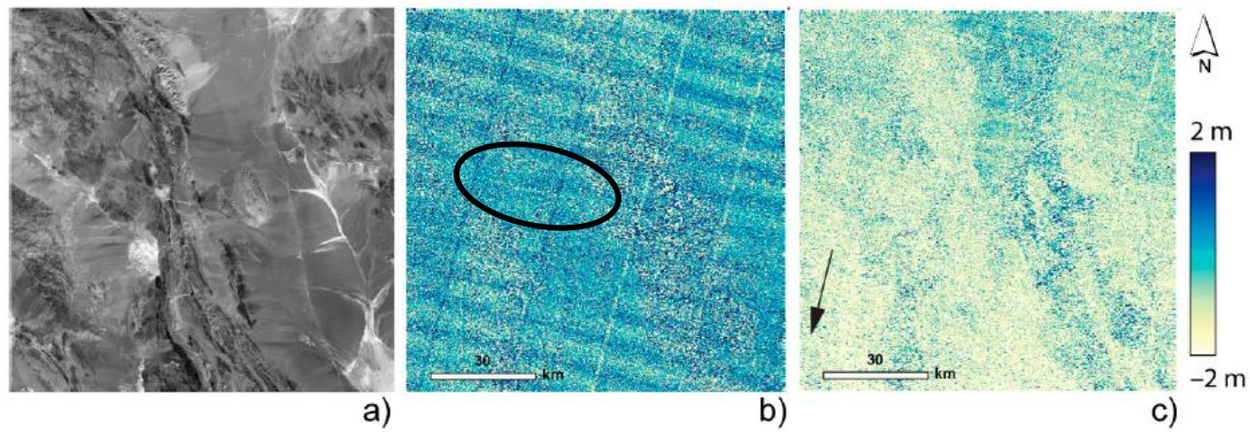


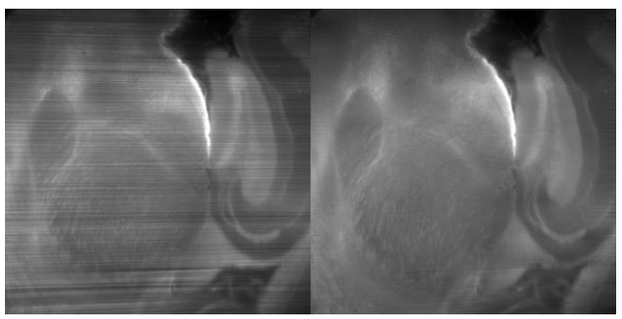
Figure 7. (a–c) Along-track component (middle panel, (b)) and cross-track component (right panel, (c)) of co-registration offsets between Sentinel-2A data from the same orbit, R120, from 30 August 2015 and 9 September 2015 (commissioning phase), showing jitter. Complete UTM-tile T41SKS, border region between Iran and Afghanistan (a). Arrow indicates flight direction.

Kaab et al., 2016

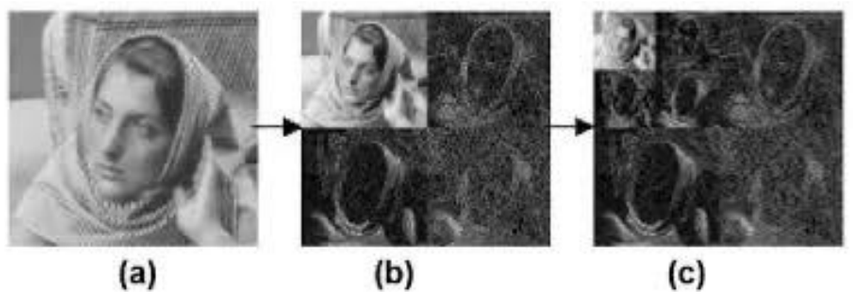
GDM-OPT-ETQ: measuring co-seismic displacement

Correction of the jitter undulations: wavelet filtering

- **Principle:**

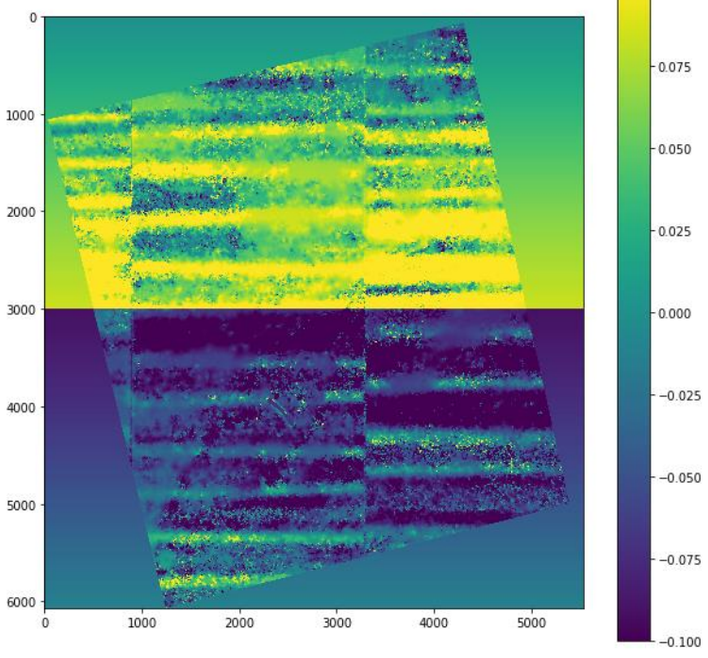


- Commonly used in medical imaging
- Decompose the image into its horizontal, vertical or diagonal components.
- Remove one of the component and reconstitute the image.

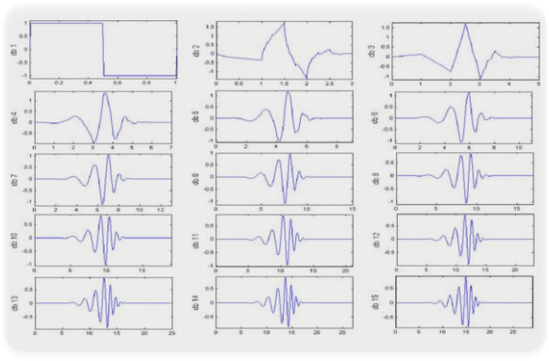


- **Testing:**

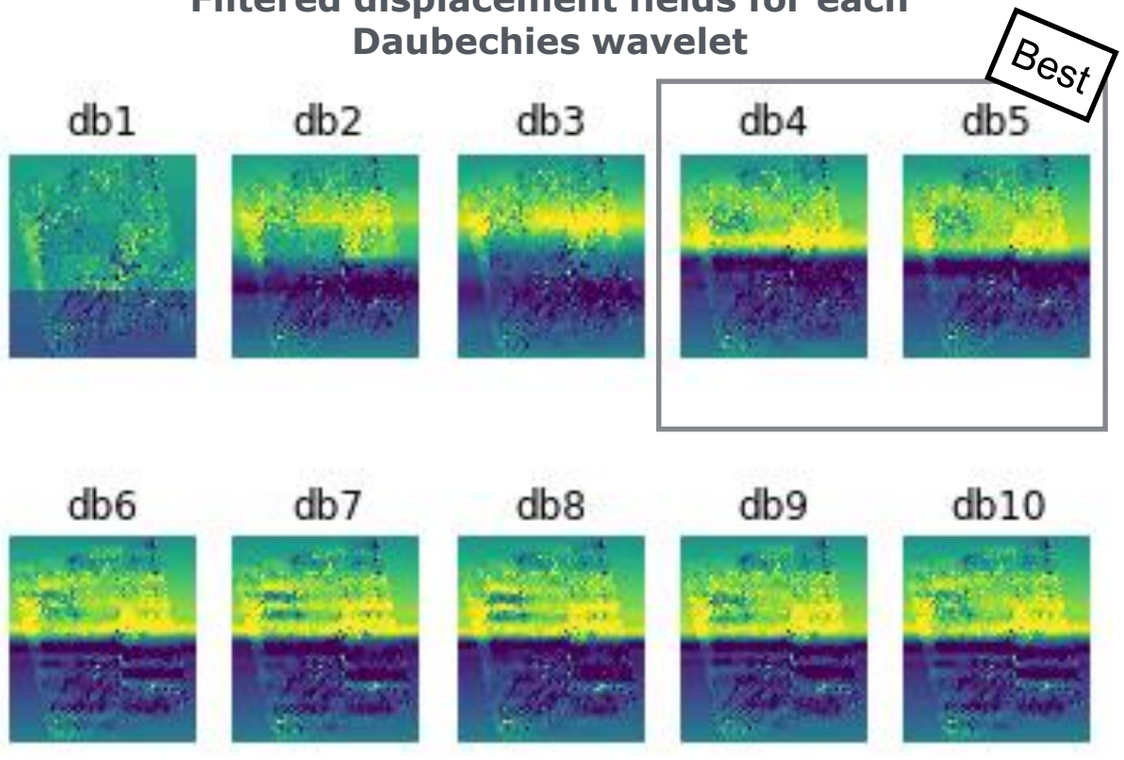
Synthetic displacement field



Daubechies wavelet



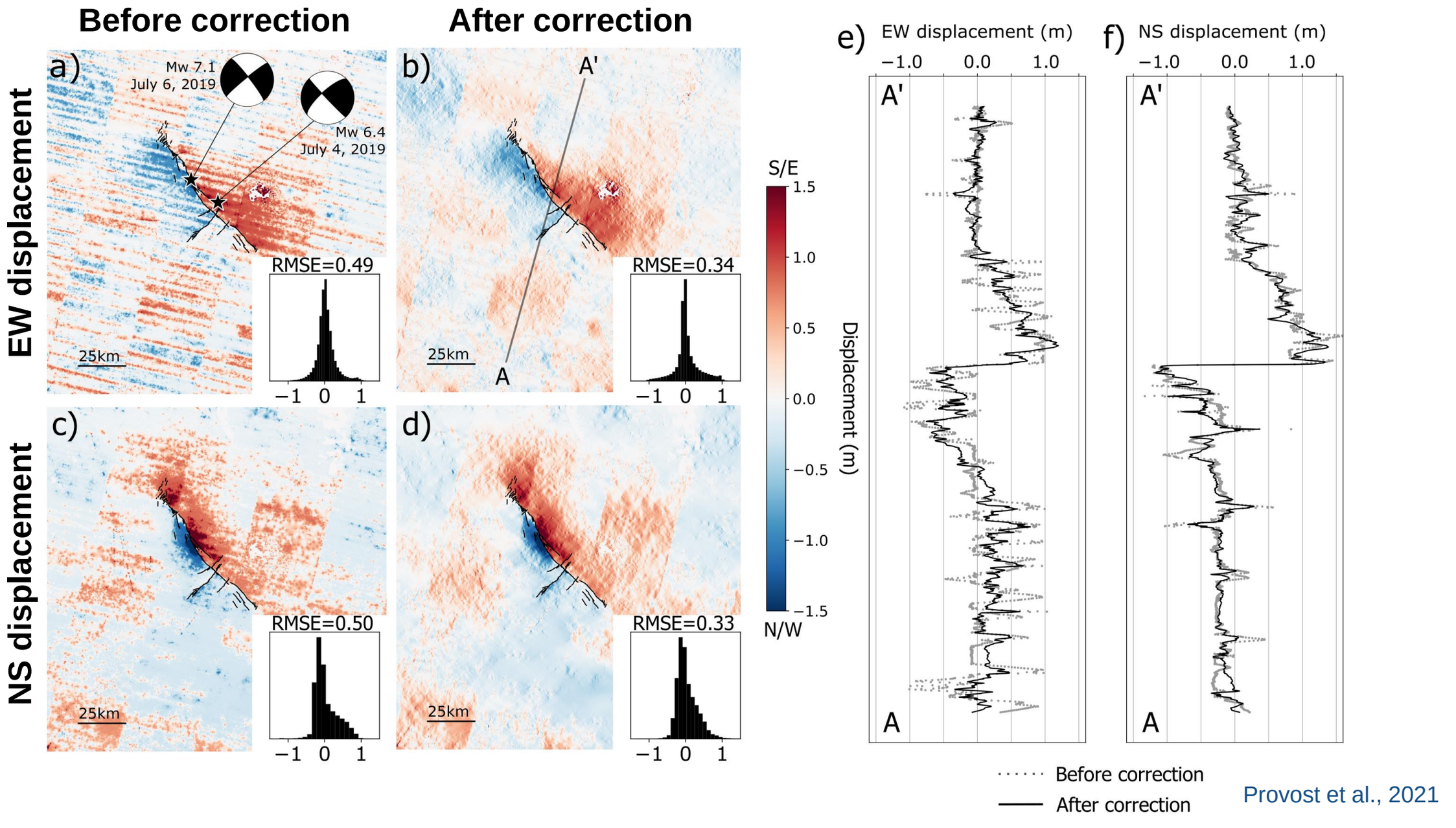
Filtered displacement fields for each Daubechies wavelet



GDM-OPT-ETQ: measuring co-seismic displacement

Correction of the jitter undulations: wavelet filtering

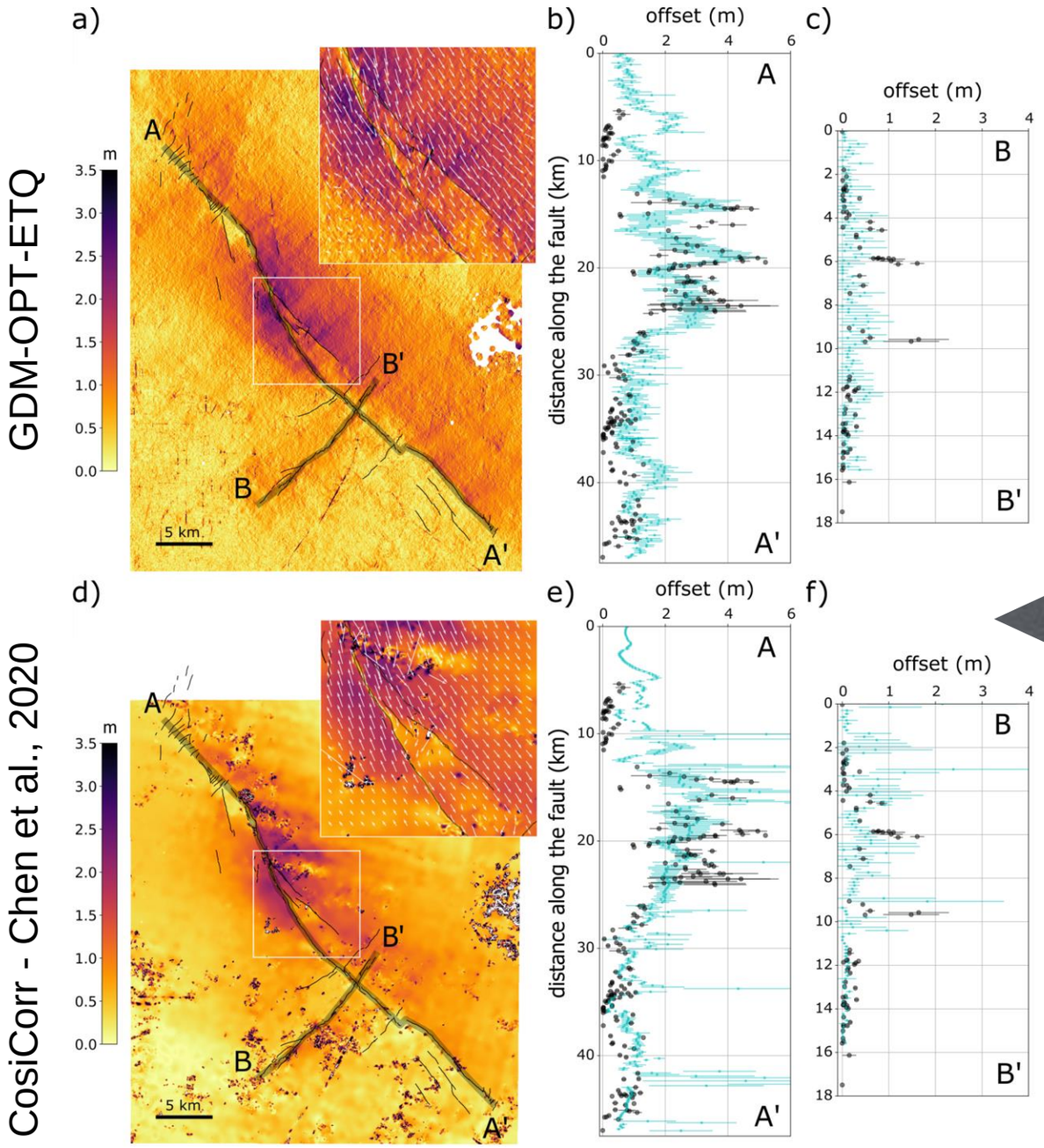
- **Results on Ridgecrest:**



Provost et al., 2021

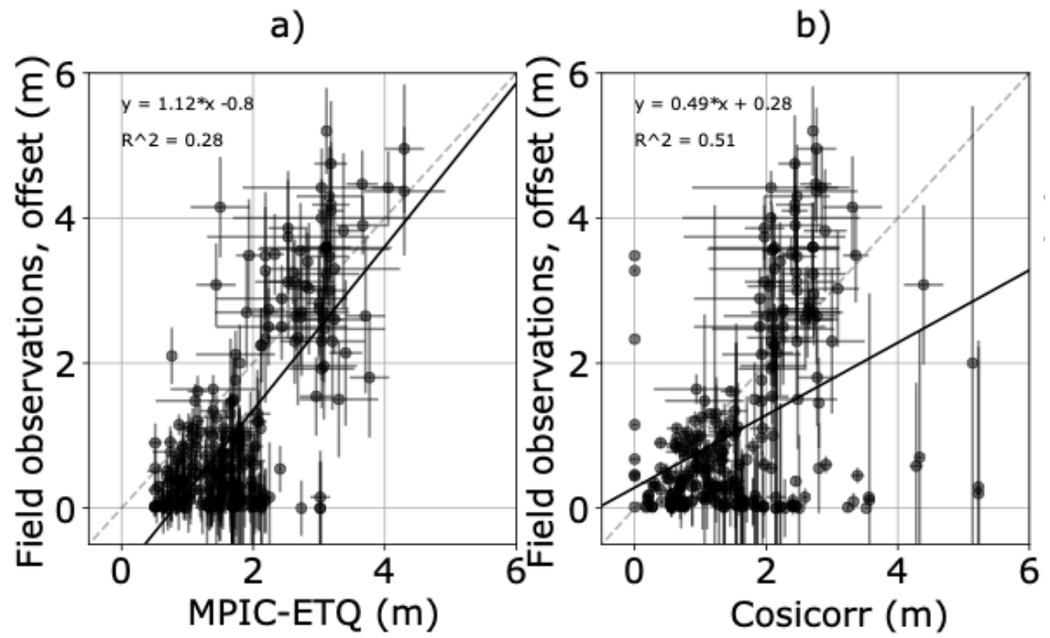
GDM-OPT-ETQ: measuring co-seismic displacement

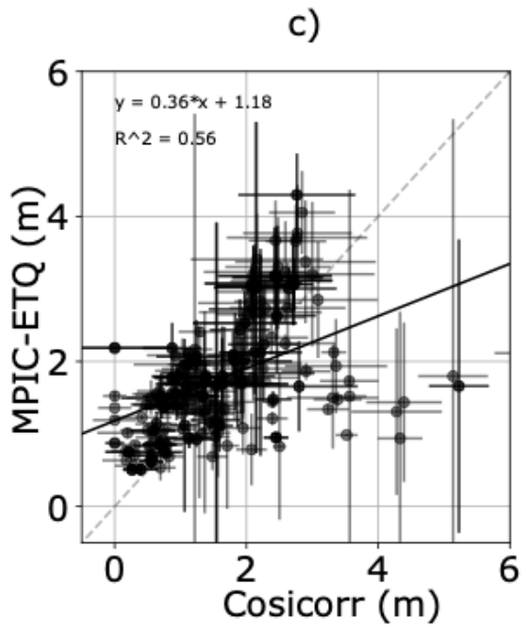
Comparison with field measurements



Field measurements (Du Ross et al., 2019)

Image Correlation

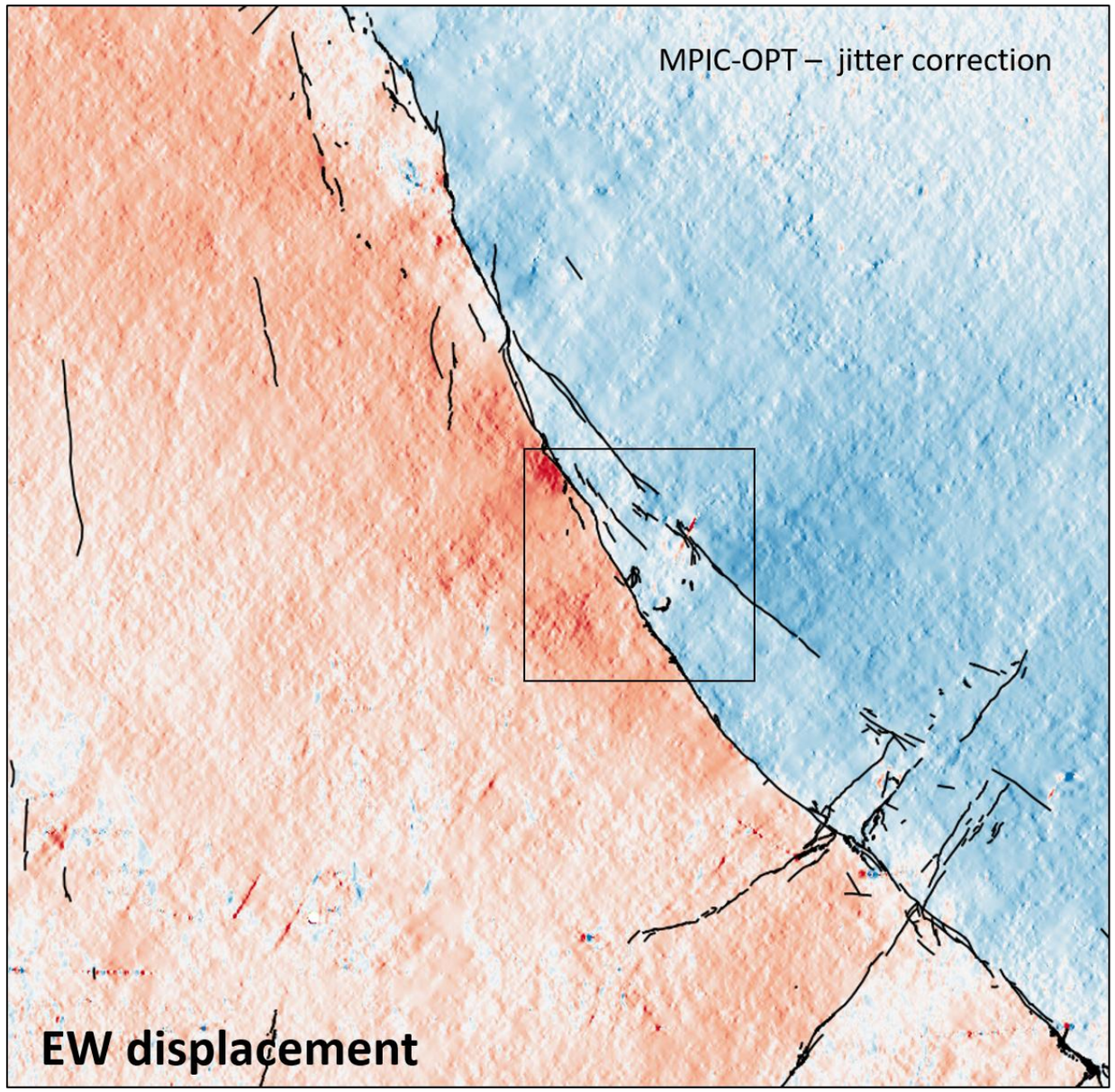




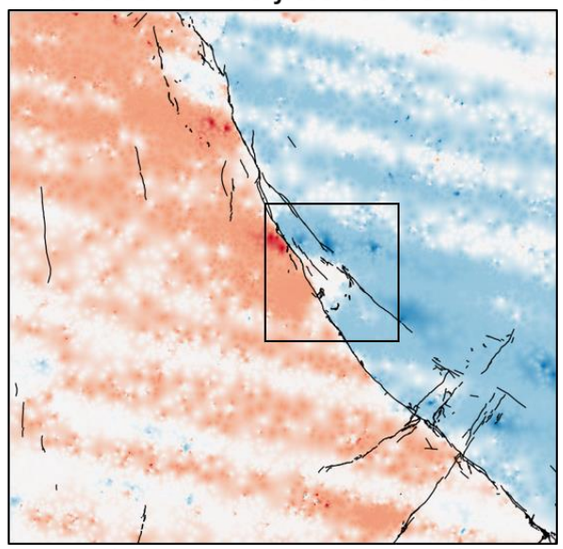
Provost et al., 2021

MPIC-OPT-ETQ: measuring co-seismic displacement

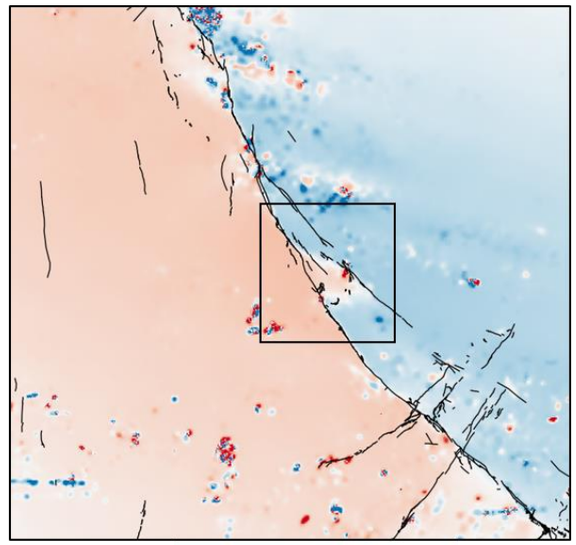
Limitations: filtering of tectonic signal



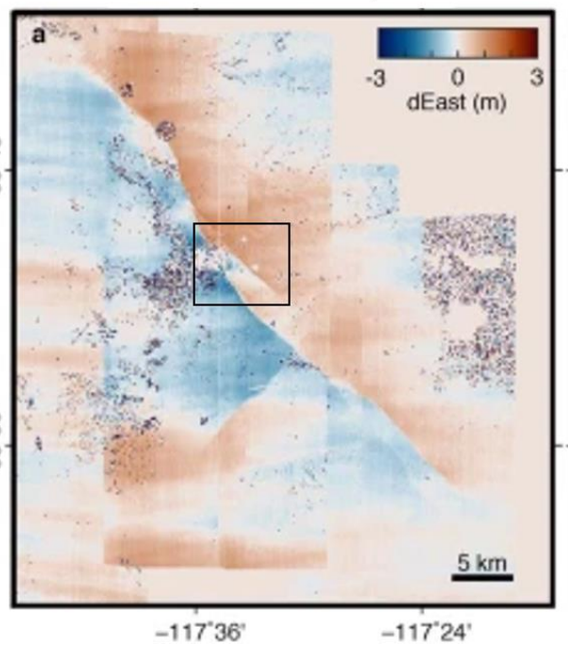
MPIC-OPT – no jitter correction



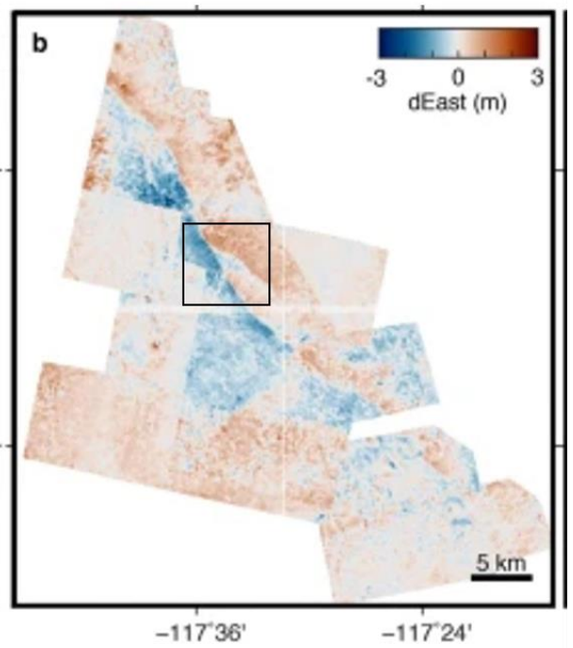
Cosicorr



Worldview - Ampcor



Planet - Cosicorr



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Three thematic services available on two platforms

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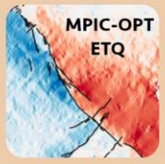

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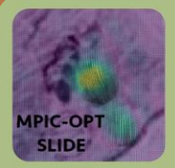

MPIC-OPT SLIDE

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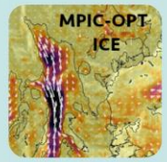
- Mult-temporal stack and detection of persistent motion



MPIC-OPT ICE

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- Mult-temporal stack and detection of persistent motion
- Global glacier mask available from World Glacier Inventory (WGI)

Send the parameters and the input images

geohazards tep

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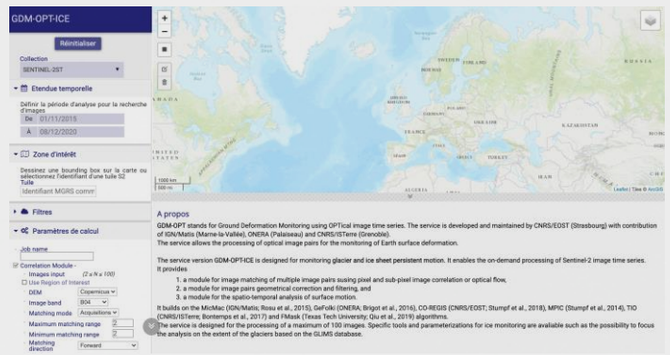


Visualize and download chain outputs

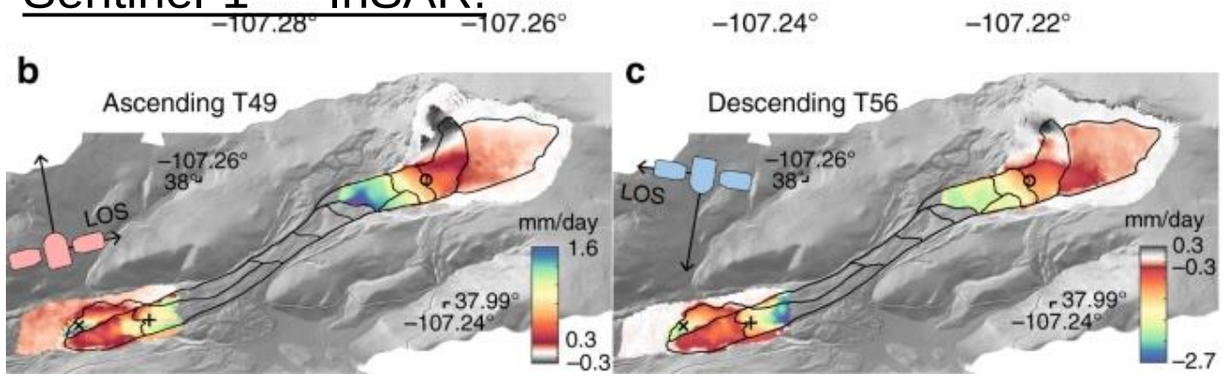
GDM-OPT-SLIDE: measuring landslide velocity

Measuring landslide velocity with the Sentinel-2 archive

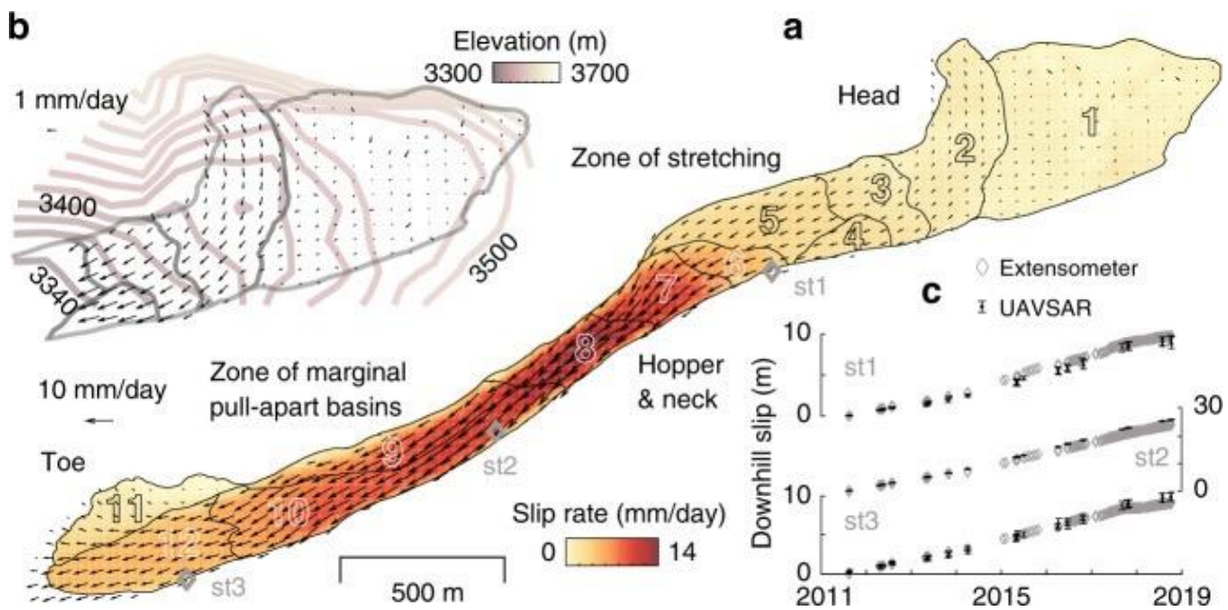
- **Slumgullion landslide:**

- Slow-moving landslide in Colorado (USA)
- Velocity range: about 1.5-2cm.year^{-1}
- Many studies available and in-situ data

- Sentinel-1 — InSAR:



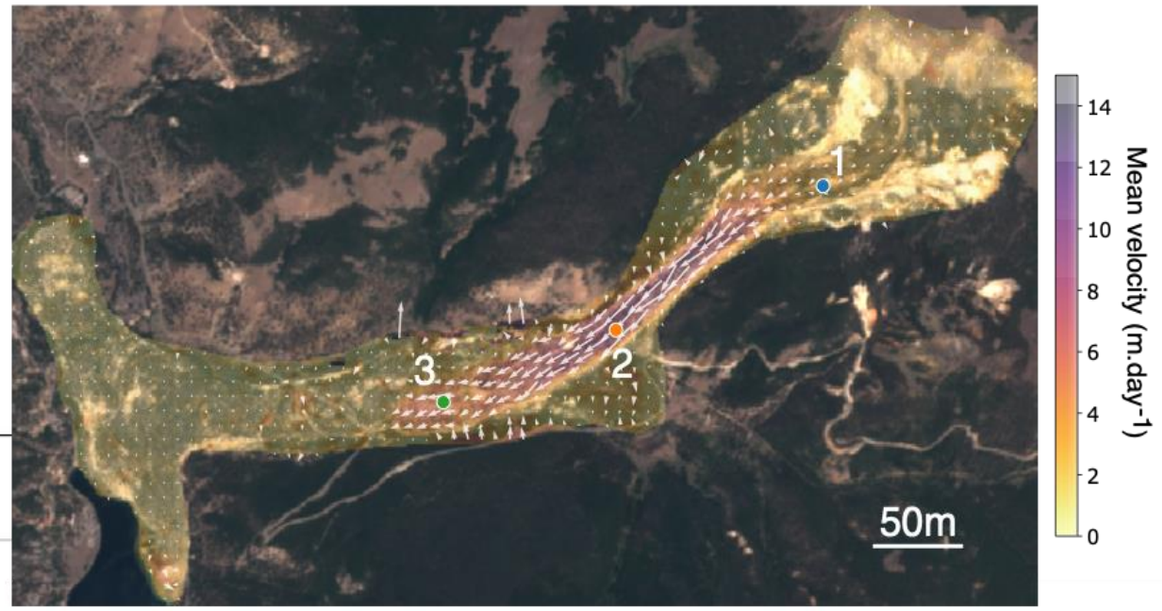
- UAVSAR — Image Matching:



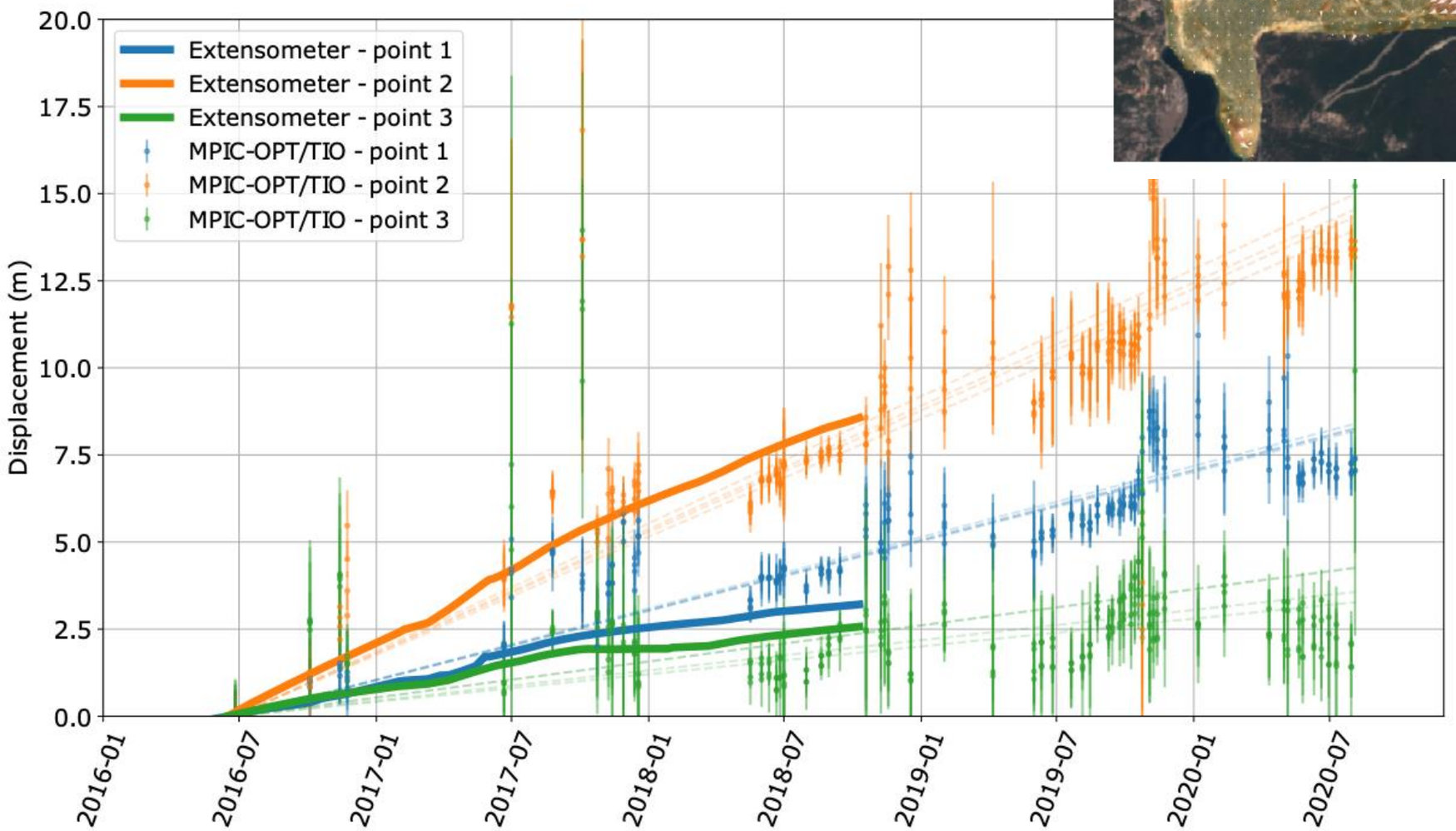
Hu et al., 2020

GDM-OPT-SLIDE: measuring landslide velocity

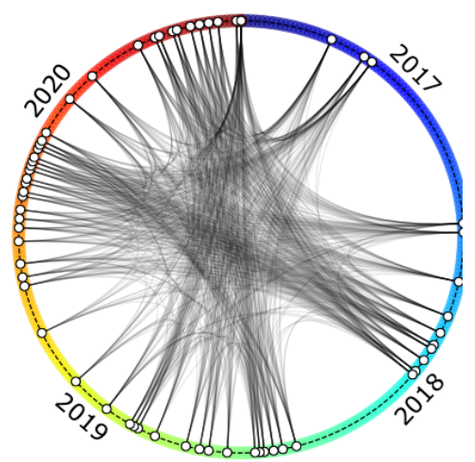
Results of GDM-SLIDE with TIO
(inversion of the displacement time series)



TIO inversion vs. in-situ extensometer measurements

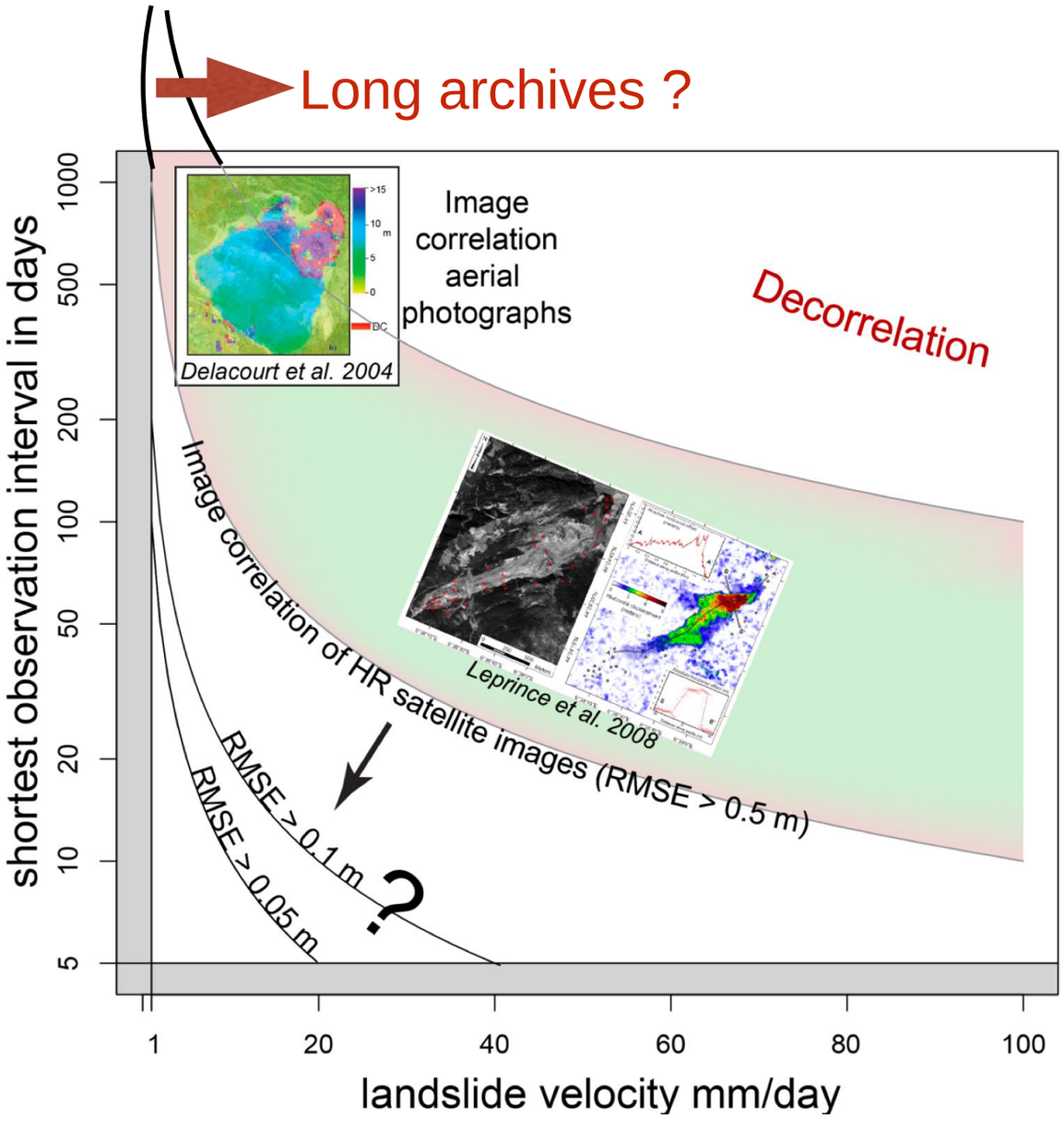


97 acquisitions from 2015-2020
500<T<1500 days



GDM-OPT-SLIDE: measuring landslide velocity

Optical image matching sensitivity



Optical displacement rates measurable depend on:

- the **spatial resolution** of the satellite
- its **frequency of acquisition**
- the **quality of the image geometry**
- the **algorithm** chosen to compute the displacement
- the **length of the archive** vs. the decorrelation of the studied object.

What displacement rates can be measured with high resolution constellation such as Sentinel-2?

GDM-OPT-SLIDE: measuring landslide velocity

Influence of the pairing network

Precision

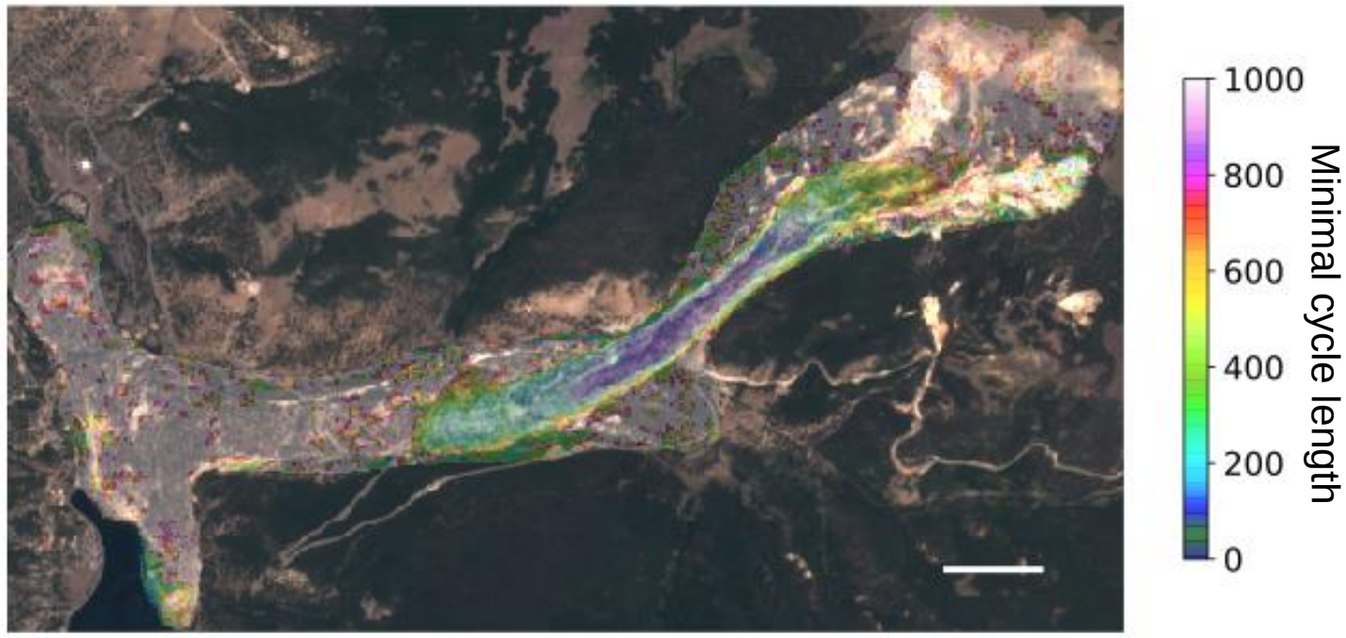
pixel size
= 10 m for S2

$$\delta t > \frac{sp}{v_{obj}}$$

Minimal temporal baseline

velocity of ground

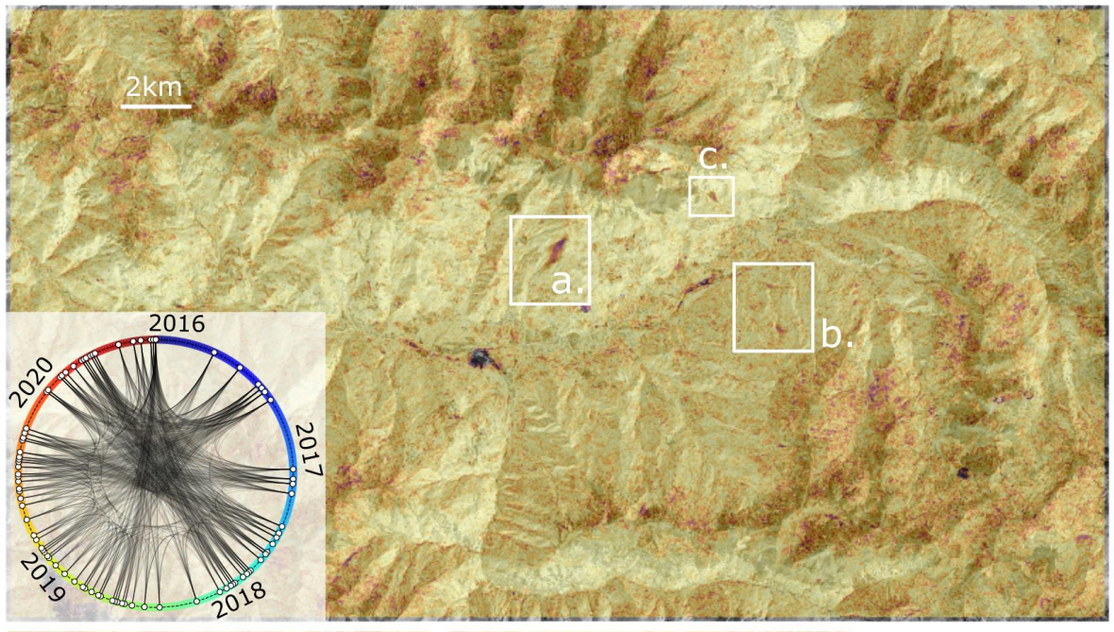
*with **s = 1/10**, estimation from previous studies*

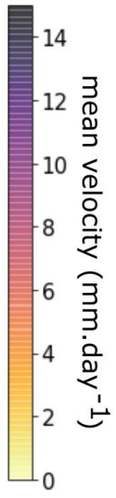


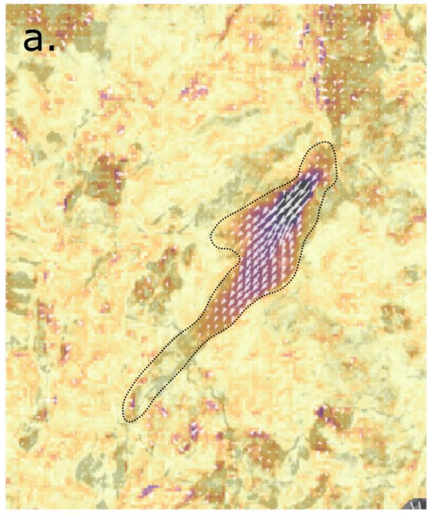
MPIC-OPT-SLIDE: measuring the landslide velocity

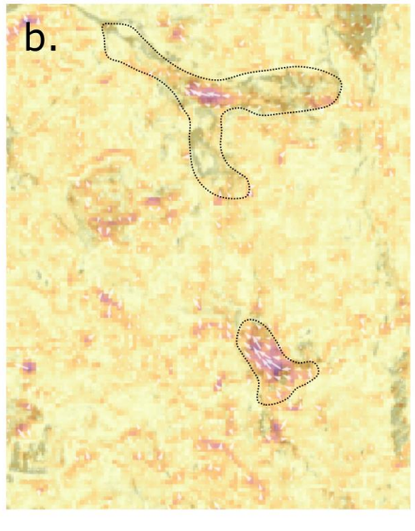
Detecting slow-moving landslide at a regional scale

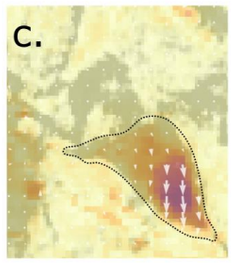
- Ubaye valley (South East Alps)





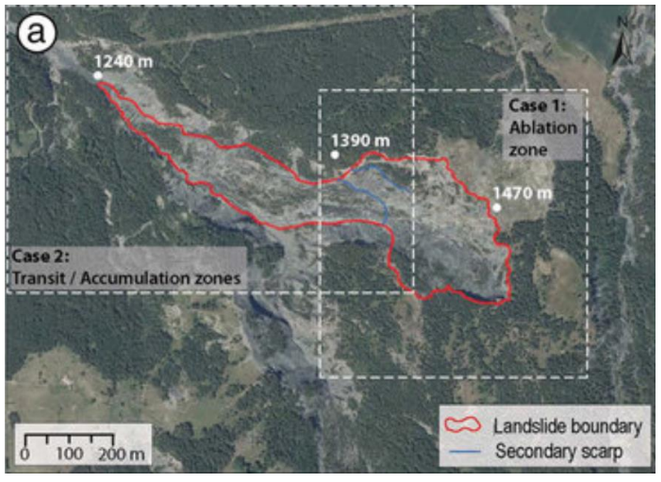






a. La Valette

b. Poche

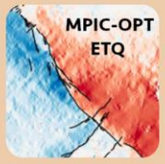


c. Sanières

GDM-OPT: Ground Deformation Monitoring

Three thematic services available on two platforms

GDM-OPT @Mesocentre/Strasbourg

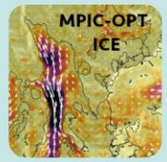


MPIC-OPT EarThQuake

- Tailored for co-seismic displacement larger than 1 meter (for Sentinel-2)
- Reduce number of input images : 4 maximum
- One correlator : MicMac
- Set of corrections to improve the quality of the results (e.g. ramp, destriping, jitter correction)

MPIC-OPT SLIDE

- Tailored for landslide displacement monitoring with velocity from 10s cm/day to m/day with the current archive of Sentinel-2
- Number of input images : 100 maximum
- Two correlator : MicMac / GéFolki
- Mult-temporal stack and detection of persistent motion



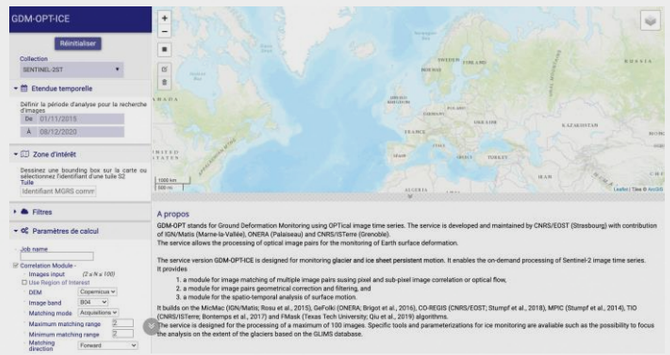
MPIC-OPT ICE

- Tailored for glacier ice sheet displacement monitoring with velocity from 10 cm/day to 10+ m/day with the current archive of Sentinel-2
- Number of input images : 100 maximum
- Two correlator : MicMac / GéFolki
- Mult-temporal stack and detection of persistent motion
- Global glacier mask available from World Glacier Inventory (WGI)

Send the parameters and the input images

geohazards tep

ForM@Ter

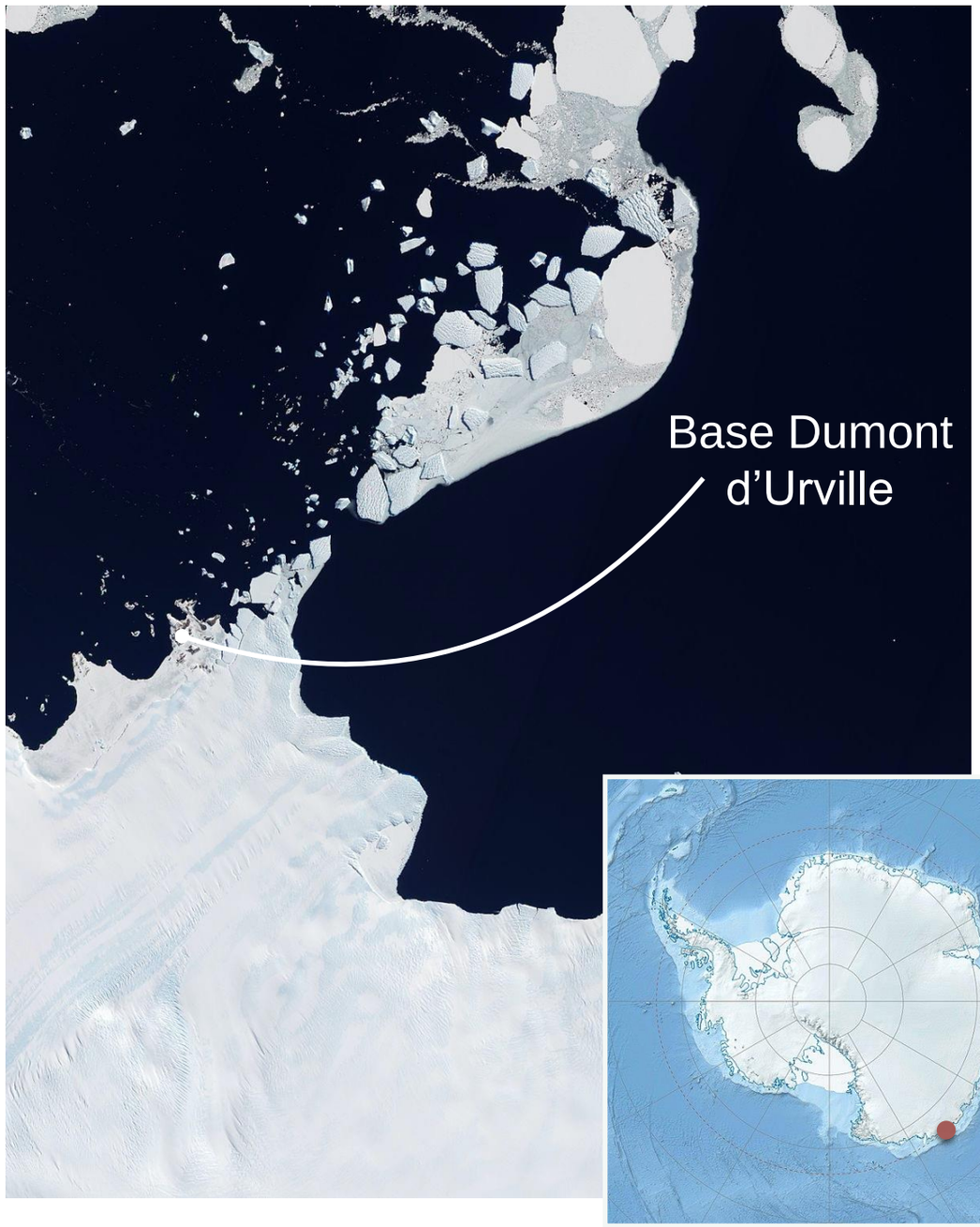


Visualize and download chain outputs

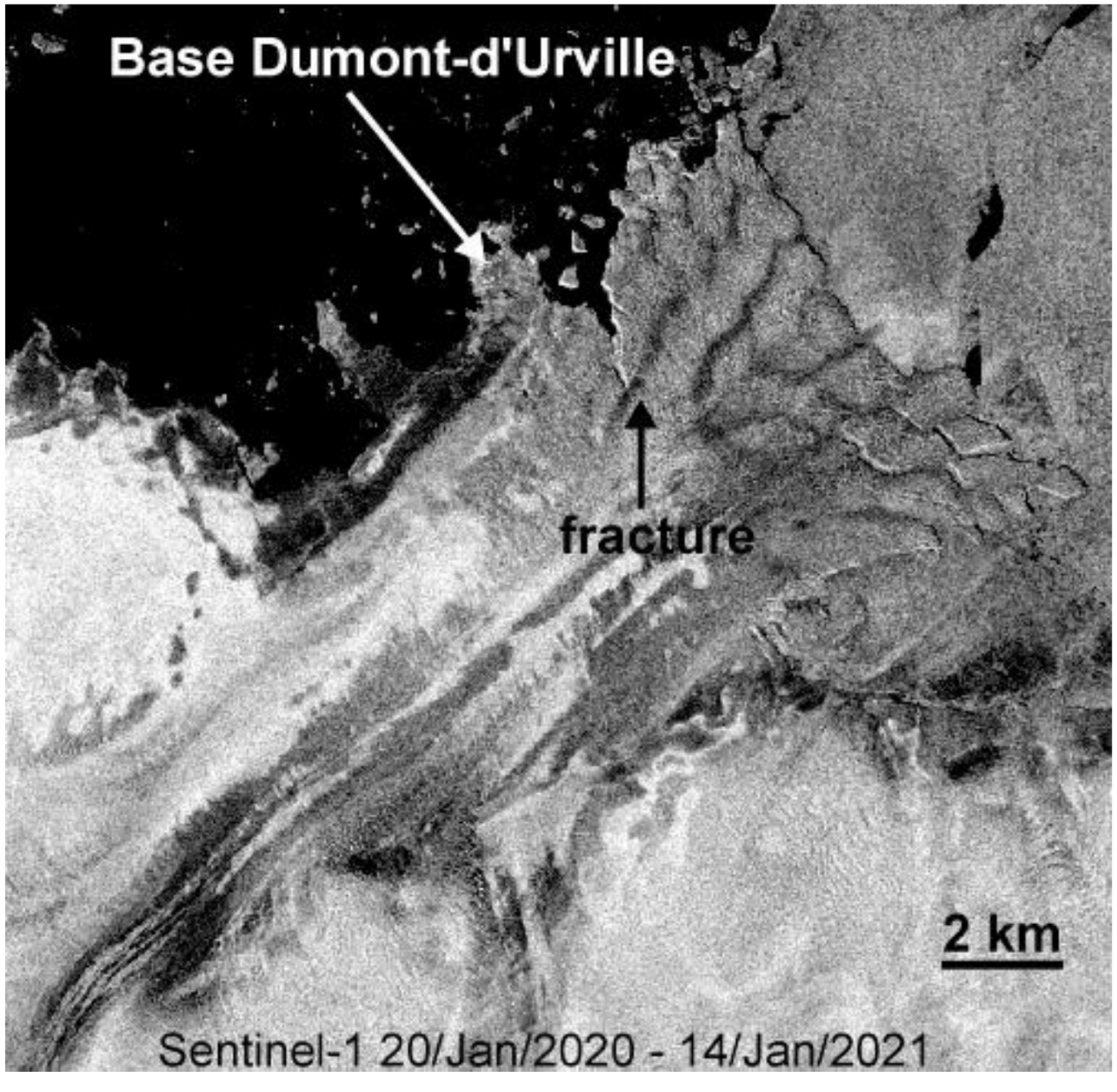
GDM-OPT-ICE: measuring ice velocity

Monitoring ice motion and crevasing with Optical correlation

- **Astrolabe glacier:**



Fracture monitoring — Sentinel-1

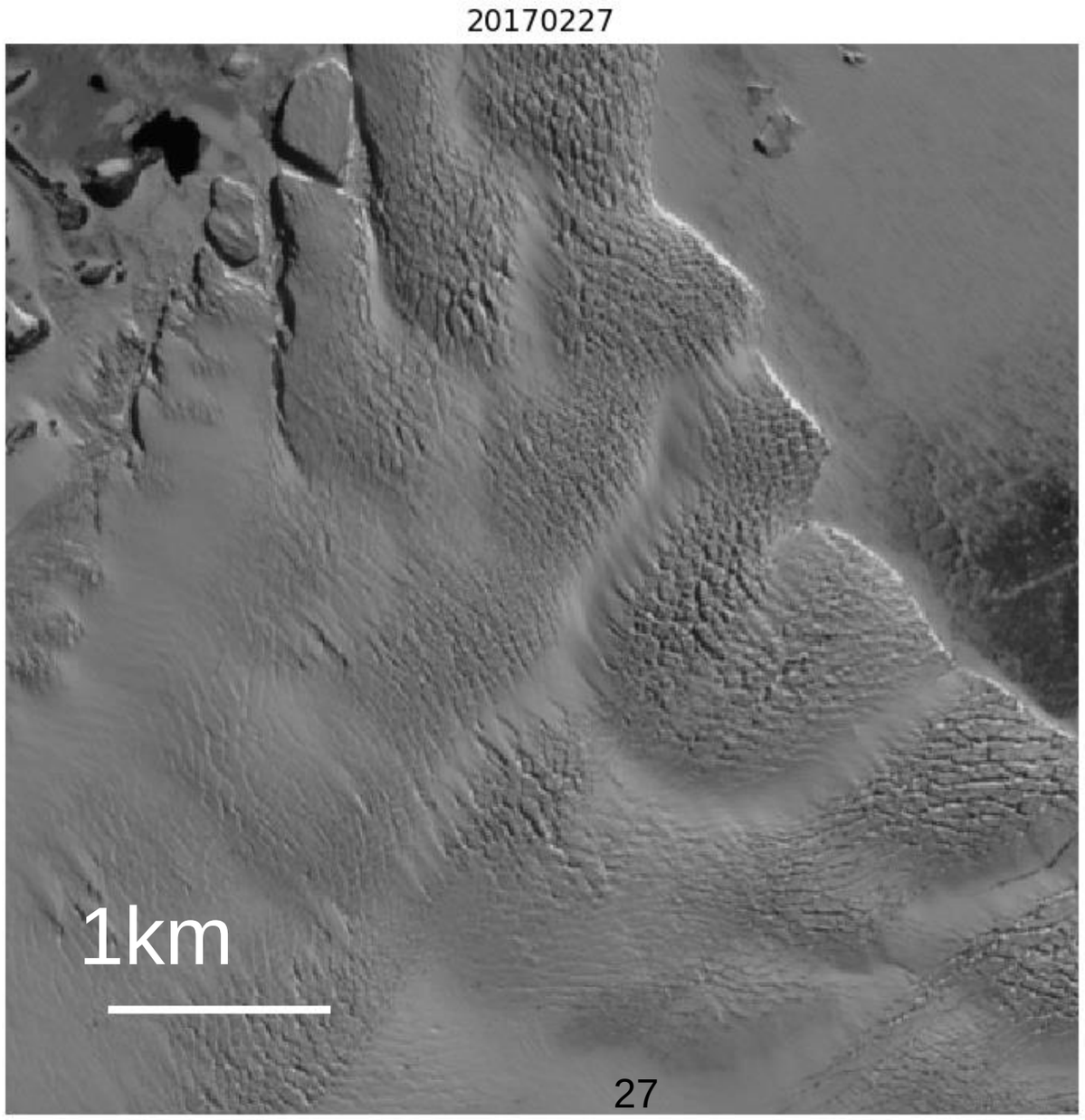


GDM-OPT-ICE: measuring ice velocity

Monitoring ice motion and crevasing with Optical correlation

- **Astrolabe glacier:**

Fracture monitoring — **Sentinel-2** — Band 4

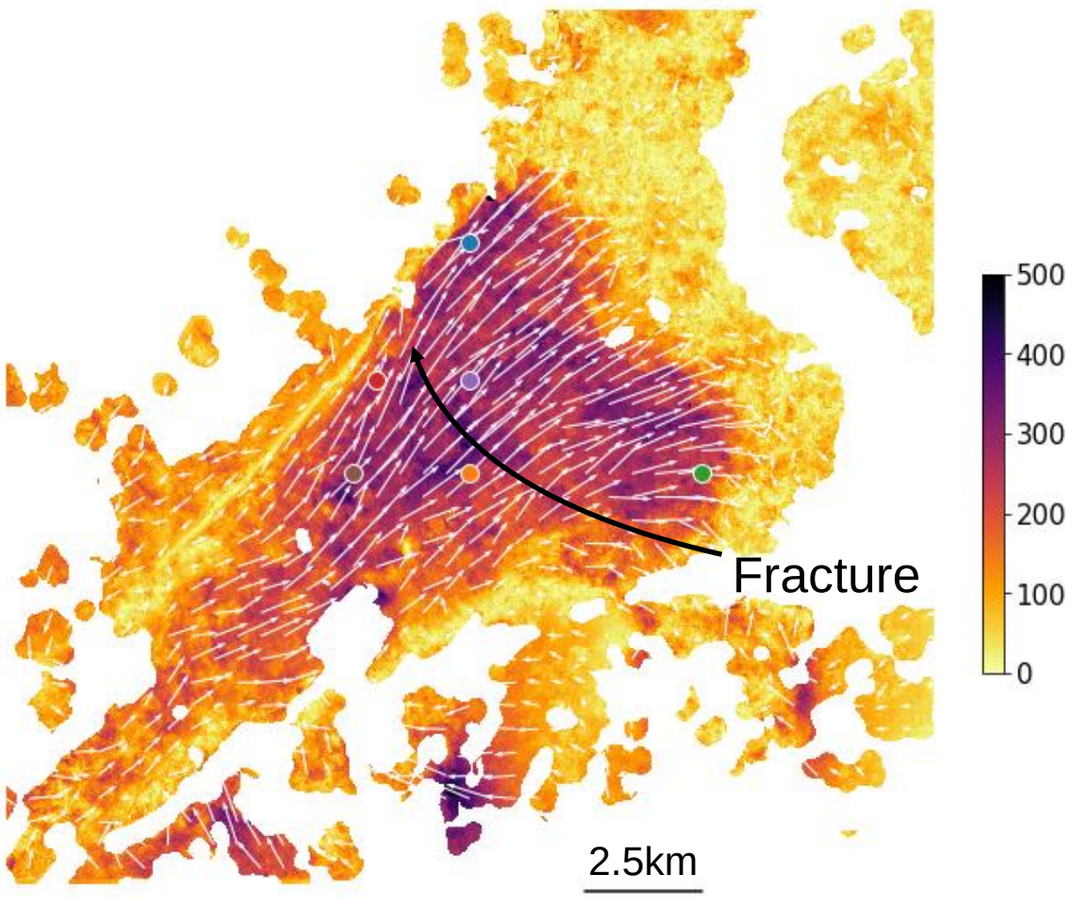


GDM-OPT-ICE: measuring ice velocity

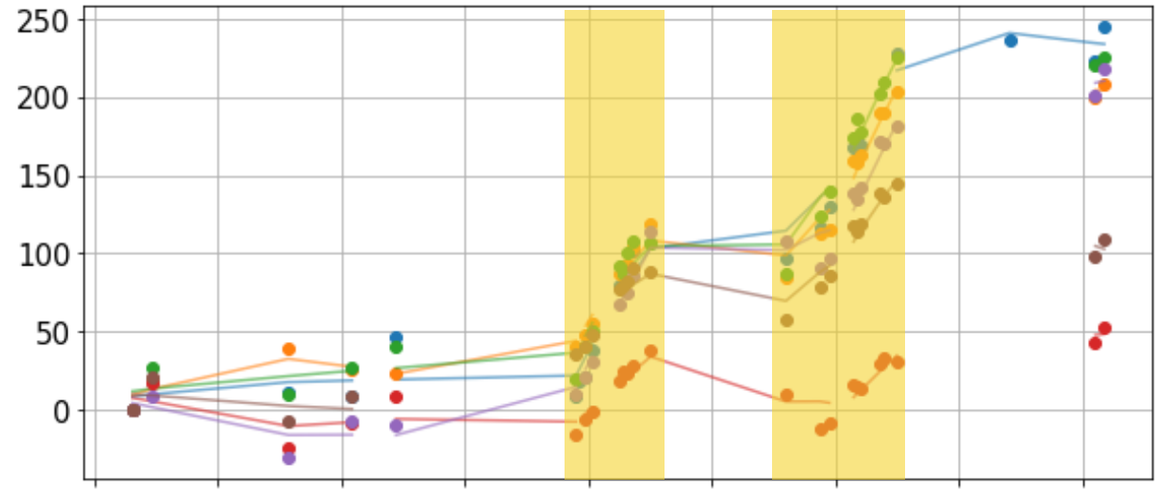
Monitoring ice motion and crevasing with Optical correlation

- **Astrolabe glacier:**

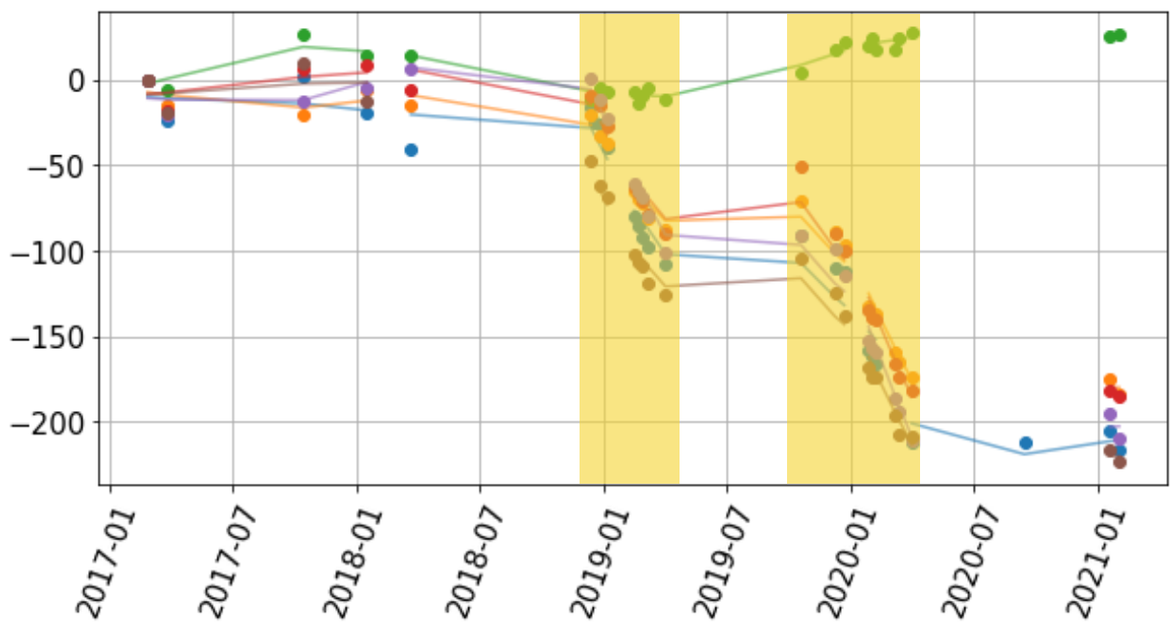
Cumulative displacement (m)



EW displacement (m)



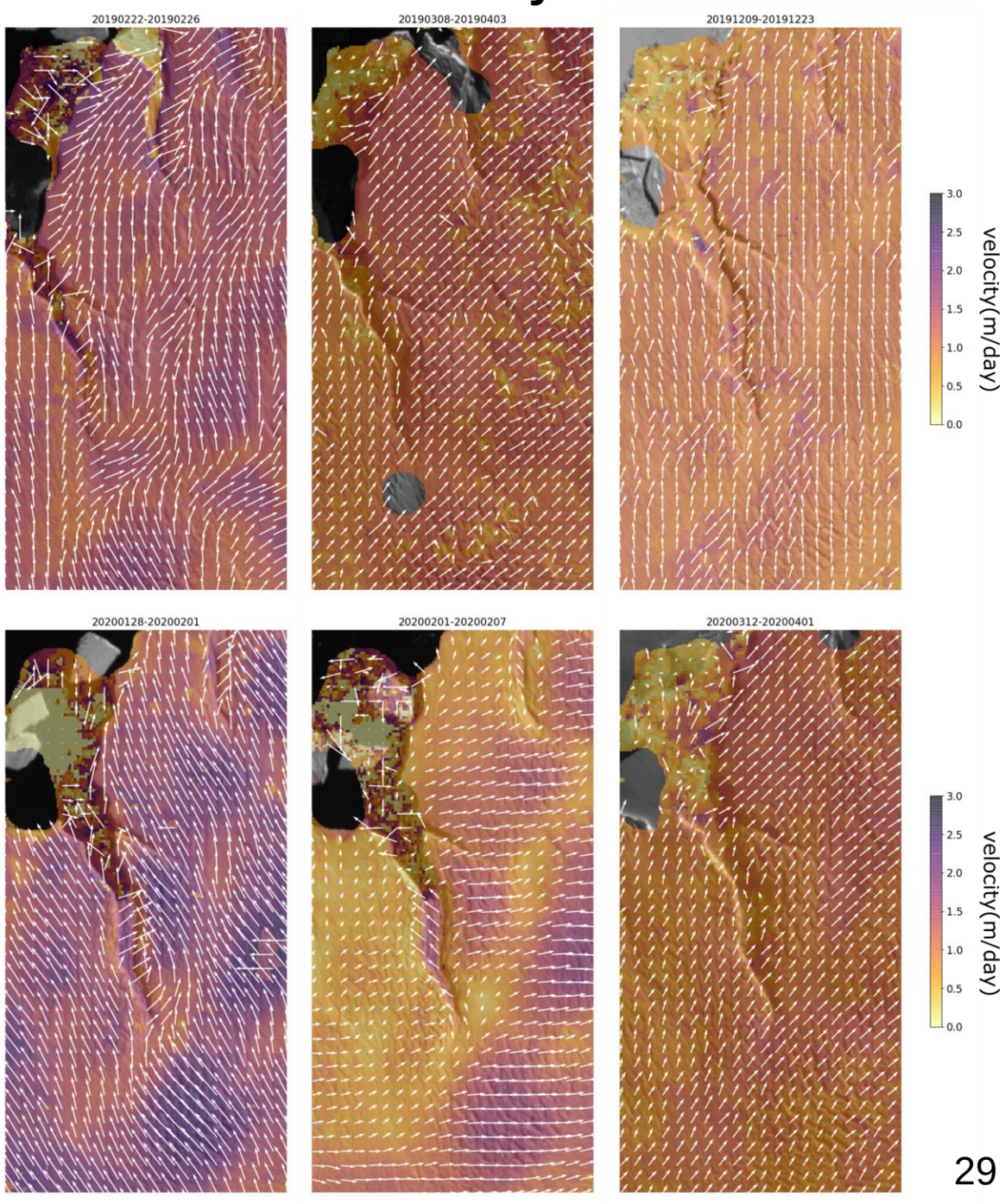
NS displacement (m)



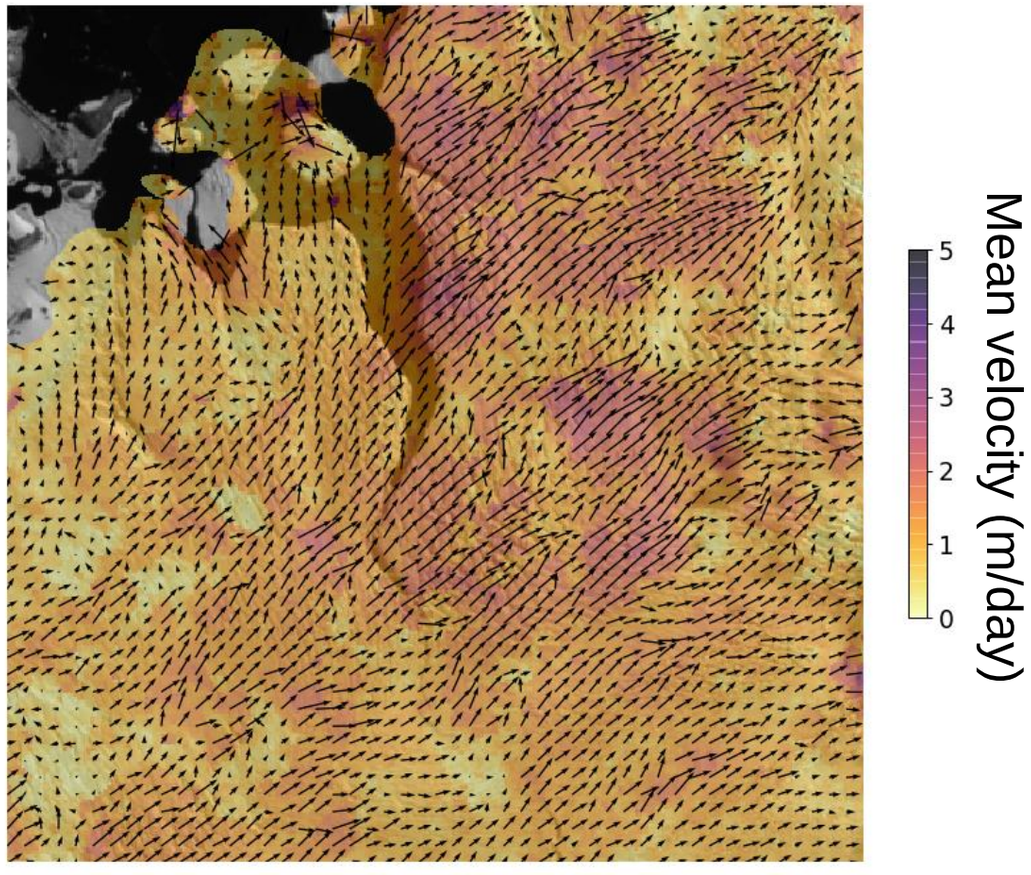
GDM-OPT-ICE: measuring ice velocity

Monitoring ice motion and crevasing with Optical correlation

differential velocity 2019-2020



differential velocity 2021/01-2021/02



Conclusion and perspectives

- We developed an automatic and robust to compute displacement time series from satellite image correlation.
- The service is optimized for large archive processing (Mesocentre HPC clusters) and accessible online through webservices (ForM@Ter, GEP).
- Three versions are available for specific applications (co-seismic displacement measurements, ice and landslide deformation monitoring)
- Displacement from **1.5cm/year to 100s m/year** can be detected and monitored using Sentinel-2 archive of 2015-2020.

[1] *Unit: CPU seconds*

https://en.poleterresolide.fr/services-en/gdm-en

Conclusion and perspectives

- Extension of the algorithm to other optical constellations (e.g. Landsat-8, Planet, Pléiades) and to SAR amplitude data

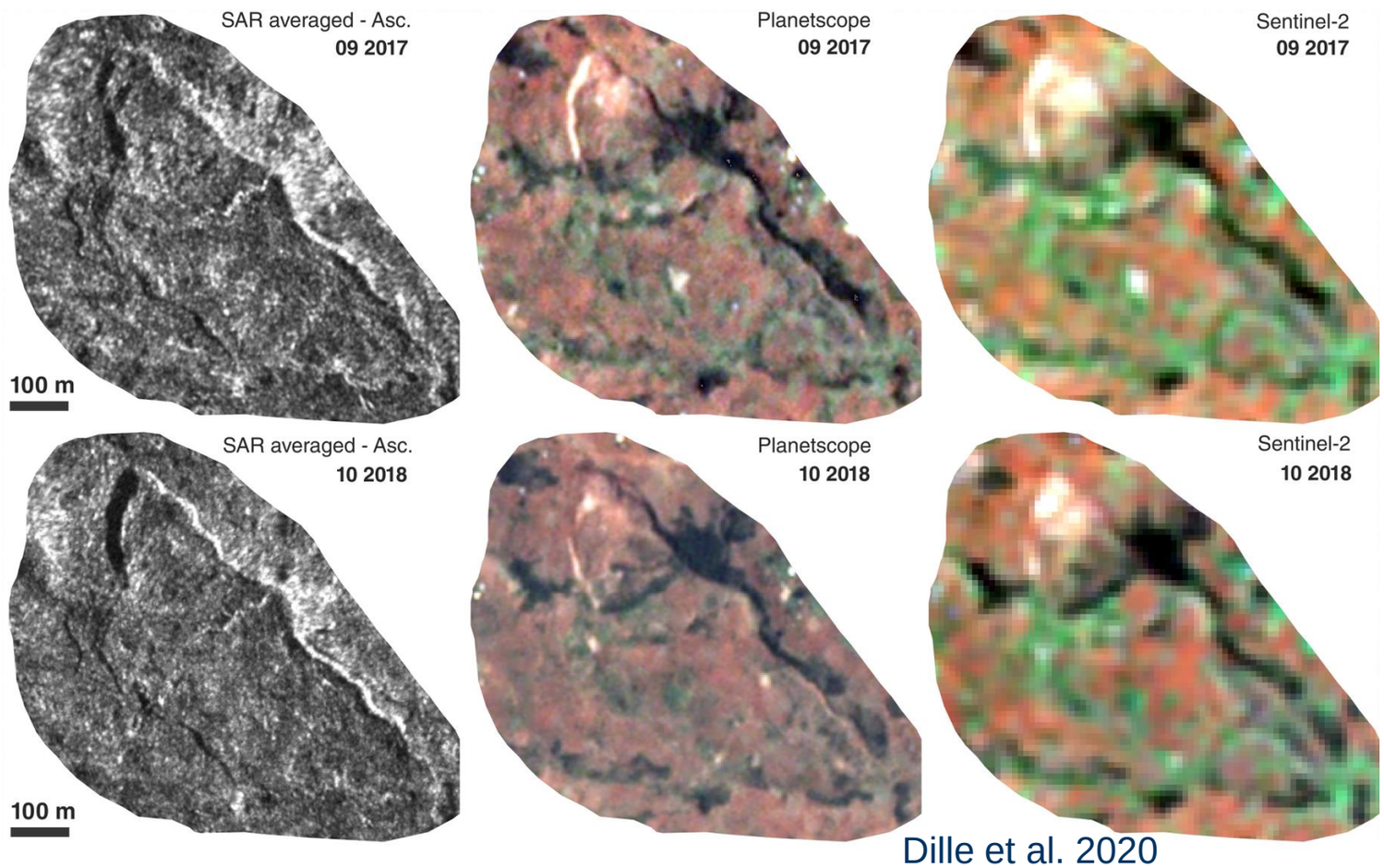
- Re-processing of the Sentinel-2 raw acquisitions (L1B) to improve geometric accuracy using the Copernicus 30m DEM

  > improve results in mountainous regions & allow correlation through different relative orbits.

- Combination of InSAR and Image Matching results from multi-sensors processing

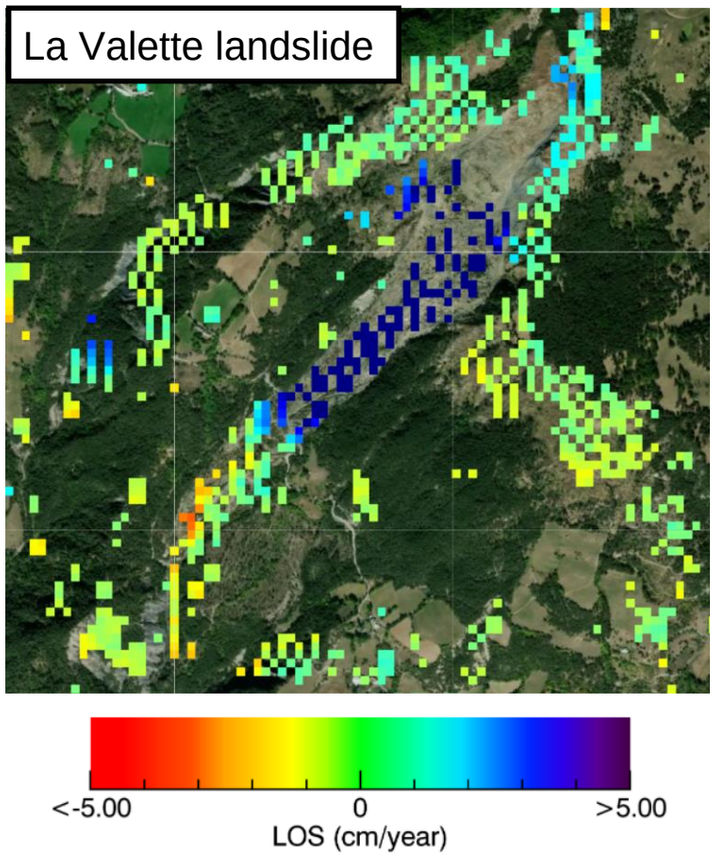
  > retrieve 3D displacement, monitor different kinematic regimes

Multi-sensor GDM



Dille et al. 2020

S1 InSAR + S2 image correlation



Thank you for your attention