



RGIK RoGI kinematic approach: InSAR-based Moving Area detection, delineation and velocity characterisation

Line Rouyet, Yan Hu, Francesco Brardinoni

PermaCOST Training School | Trafoi, 2 September 2026



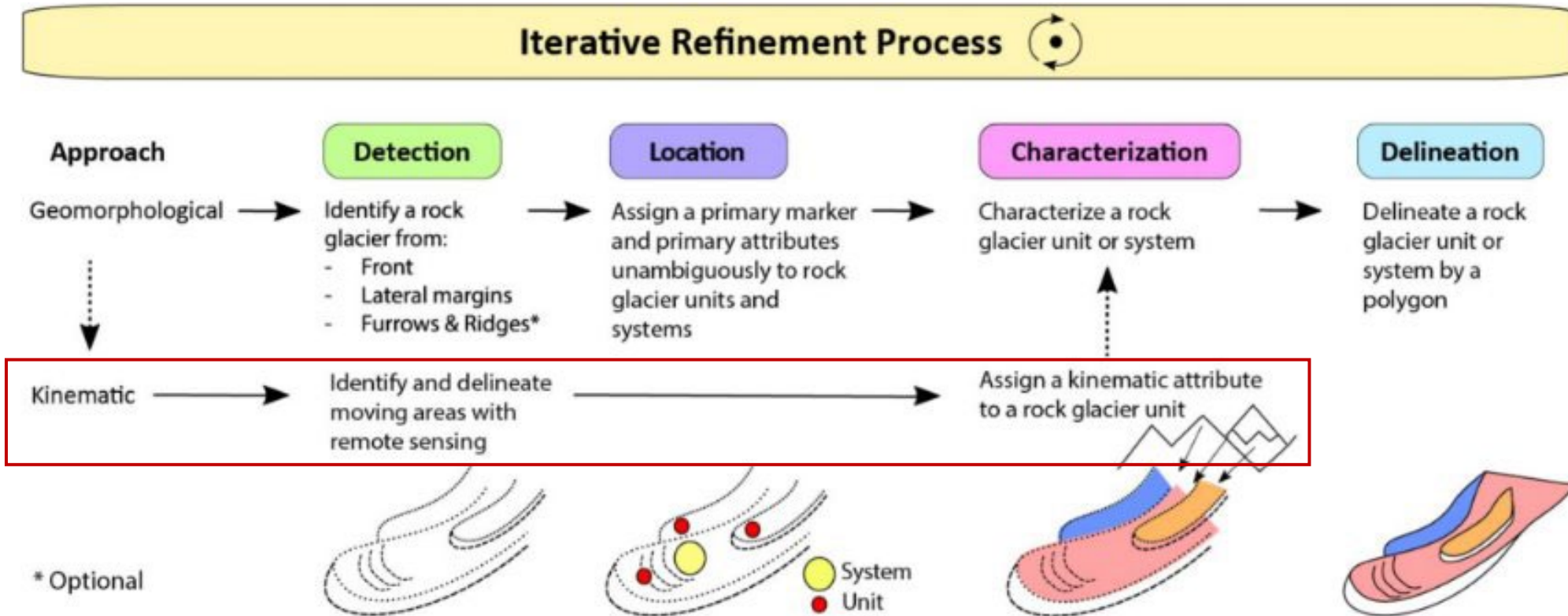
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permacost.eu & cost.eu/actions/CA24157

RoGI kinematic approach



- As a complement to the geomorphological approach, we analyse **where/how the ground surface is moving (kinematic approach)** and relate such observations to the permafrost creep to **refine the rock glacier detection and characterisation**.
- Any type of ground movement info is valuable, but **we need remote sensing to perform the analyse at a regional scale**.

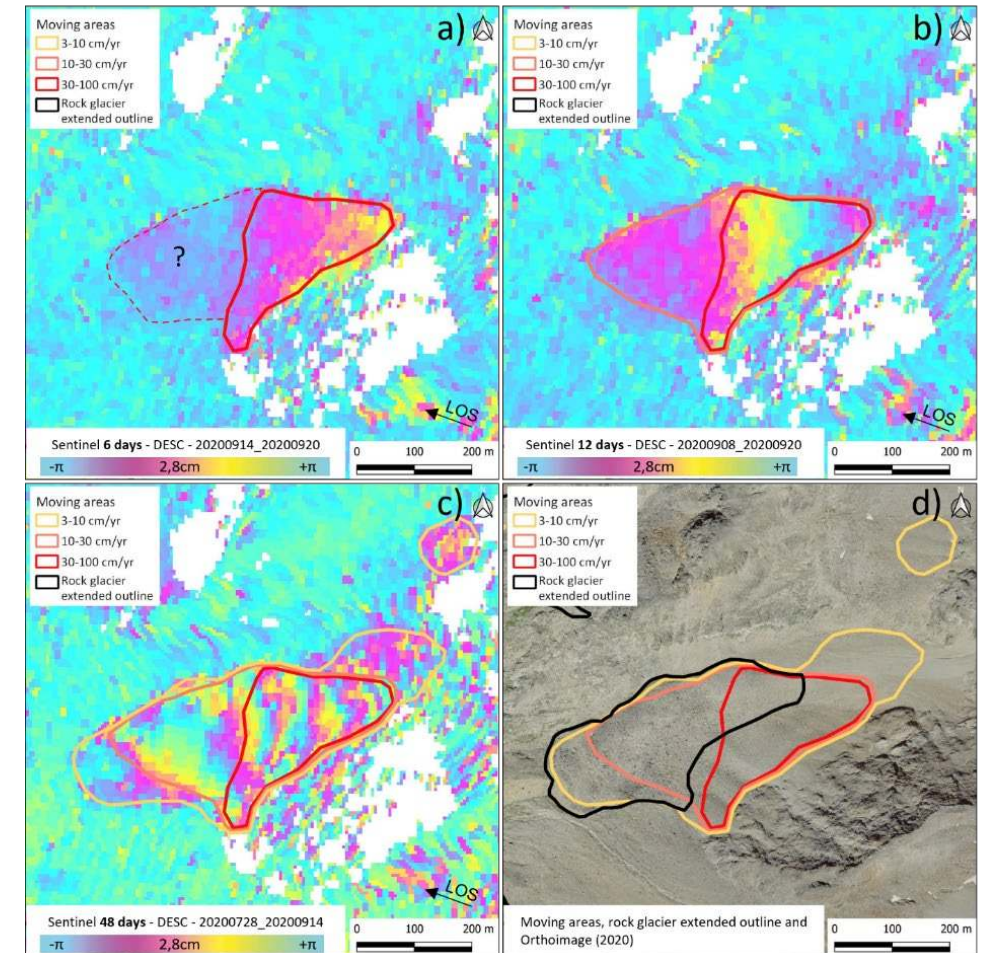
Focus on the use of **Spaceborne Interferometric Synthetic Aperture Radar (InSAR)** products to:

- 1) Detect ground surface movement related to rock glacier permafrost creep.
- 2) Delineate the Moving Areas (MAs) and characterise the velocity.
- 3) Use the MA information to assign a kinematic attribute (KA) to the Rock Glacier Units (RGUs) in the inventory.
- 4) Use the KA to assess the activity of the RGUs.

RGIK Resources

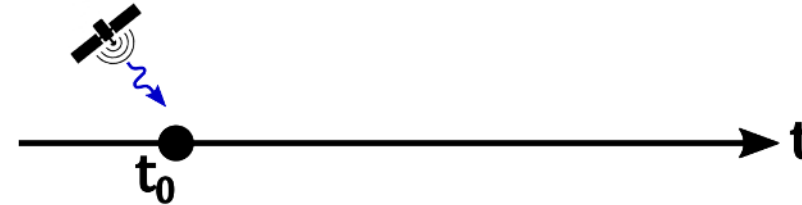
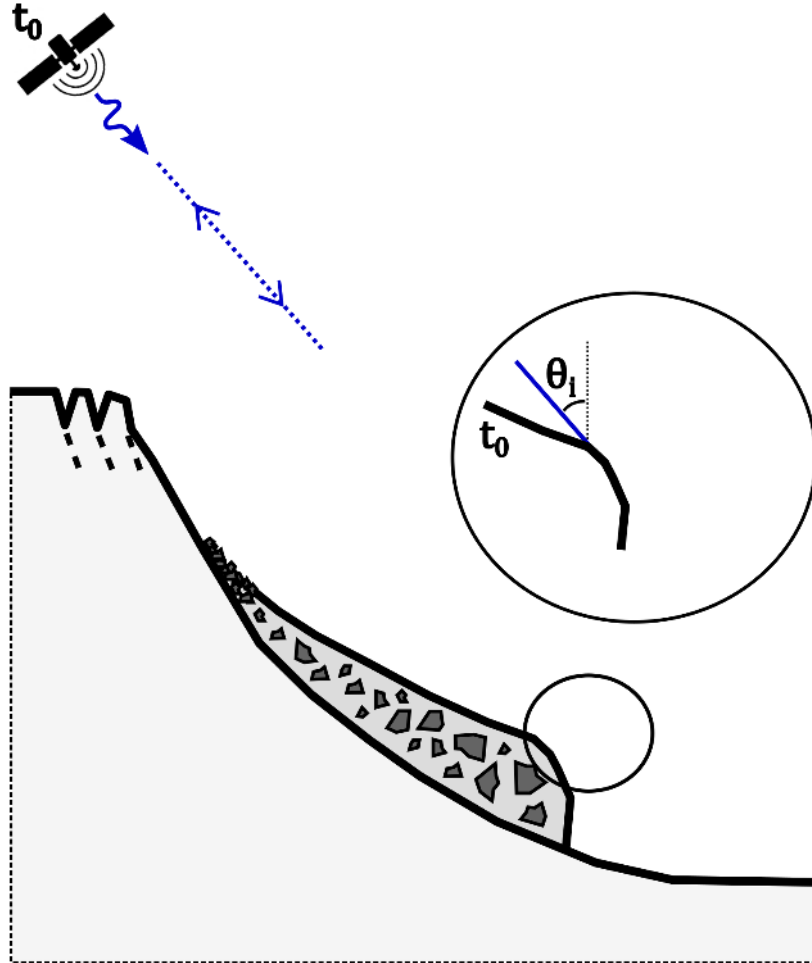
Baseline Concepts and Guidelines	QGIS Tools	Datasets	RGIK Reports
Guidelines for Inventorying Rock Glaciers (RoGI) Baseline and Practical Concepts Version 1.0 (Last Updated: 28 December 2023) Download Practical InSAR Guidelines Version 4.0 (Last Updated: 31 May 2023) Download			

<https://www.rgik.org/resources/>



What is SAR?

Sentinel-1

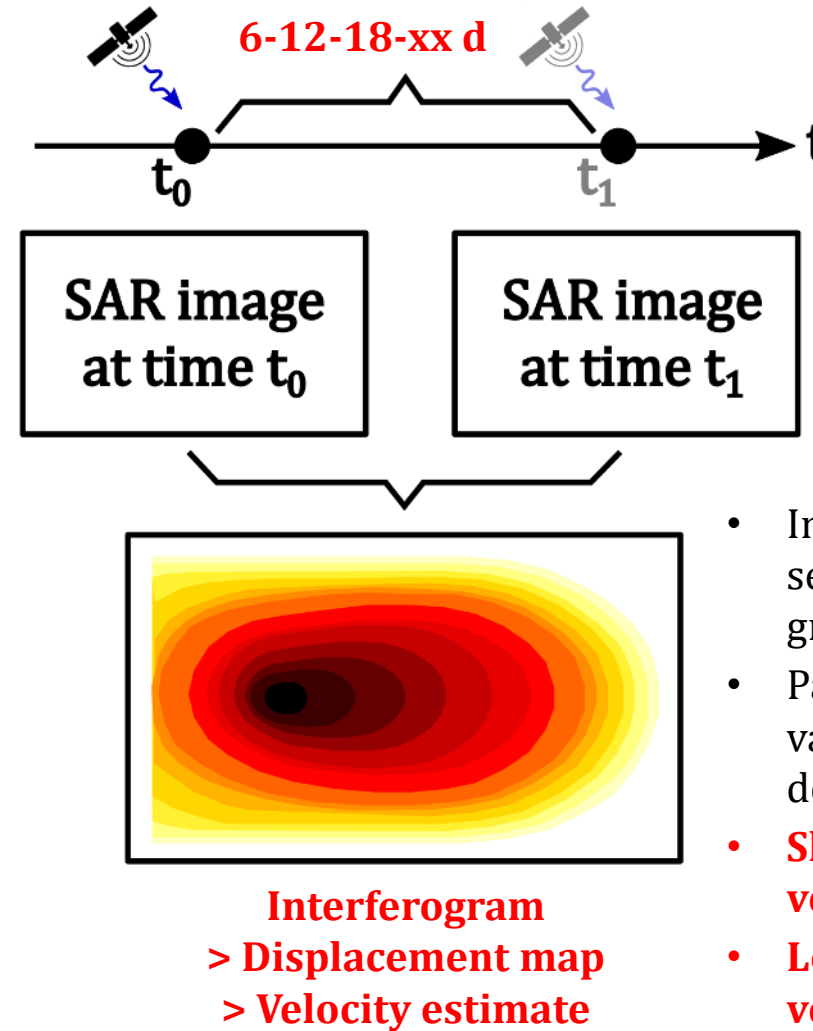
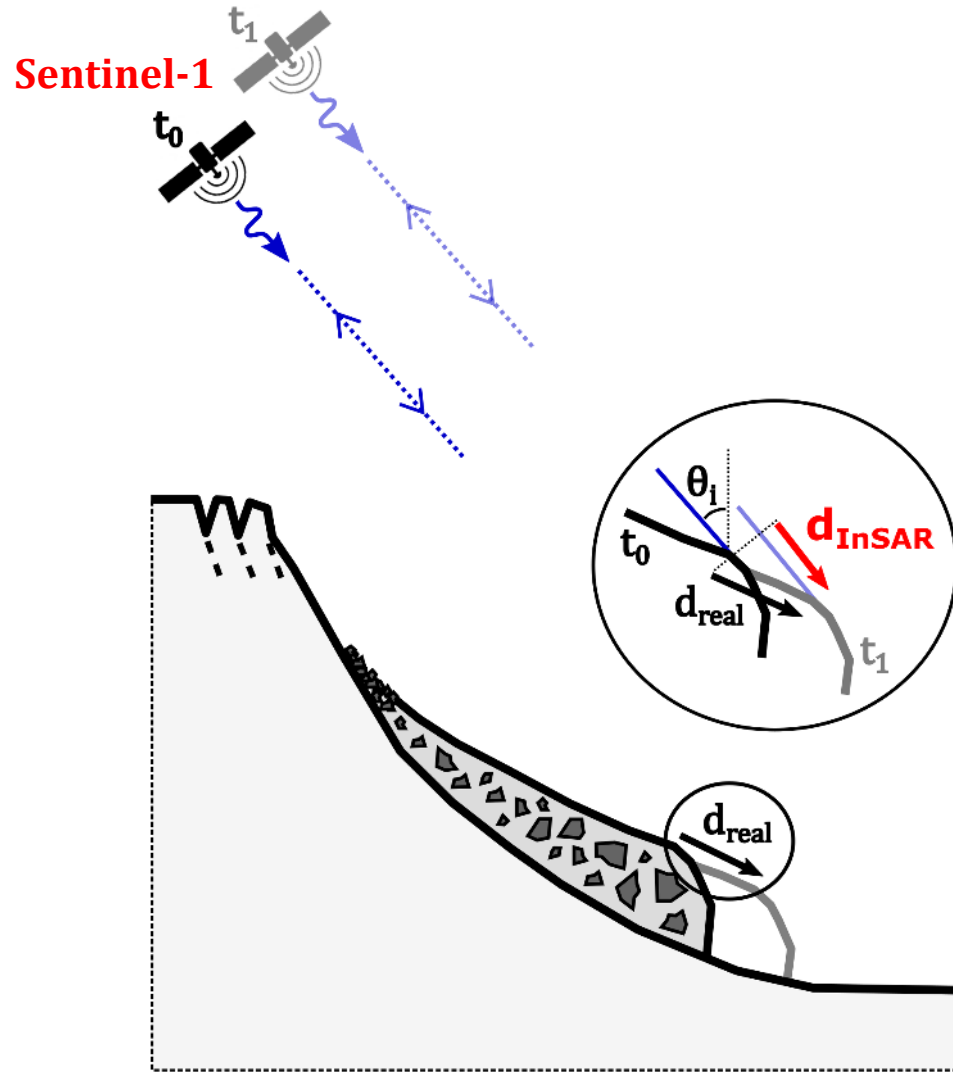


SAR image
at time t_0

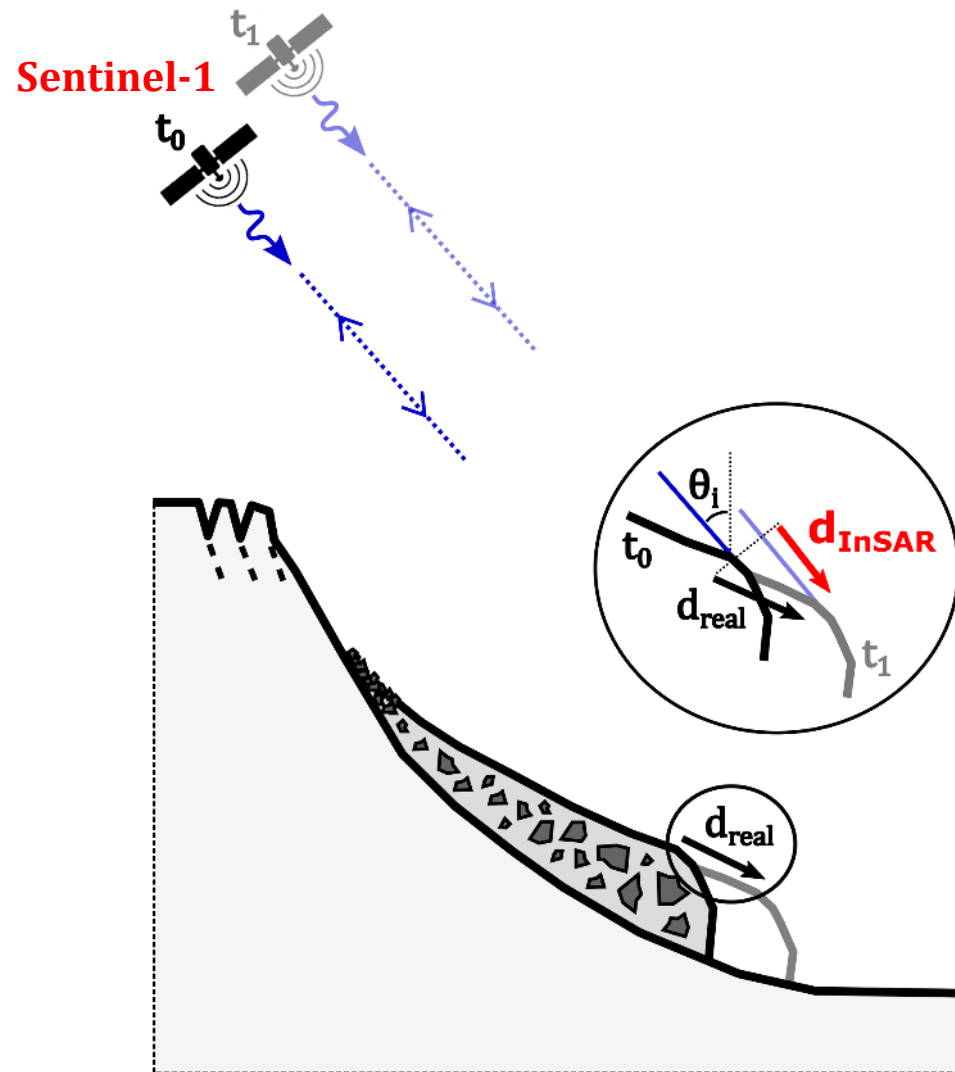


- InSAR uses active microwave sensors: **Synthetic Aperture Radar (SAR)**.
- Mounted on satellites, a SAR can image the Earth over 10s-100s km².
- With Sentinel-1, images are taken at the same location every 6-12 days.

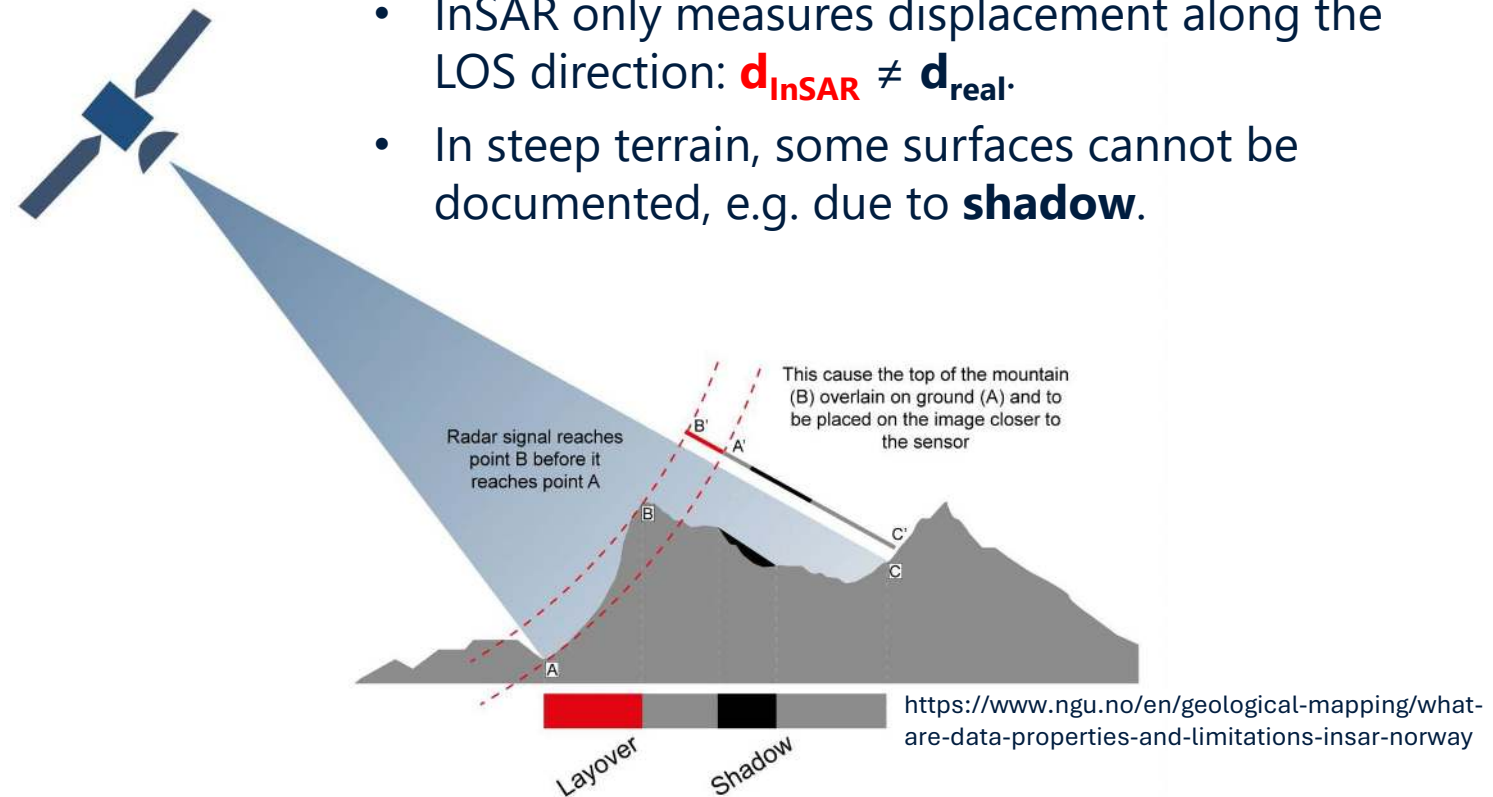
What is InSAR?

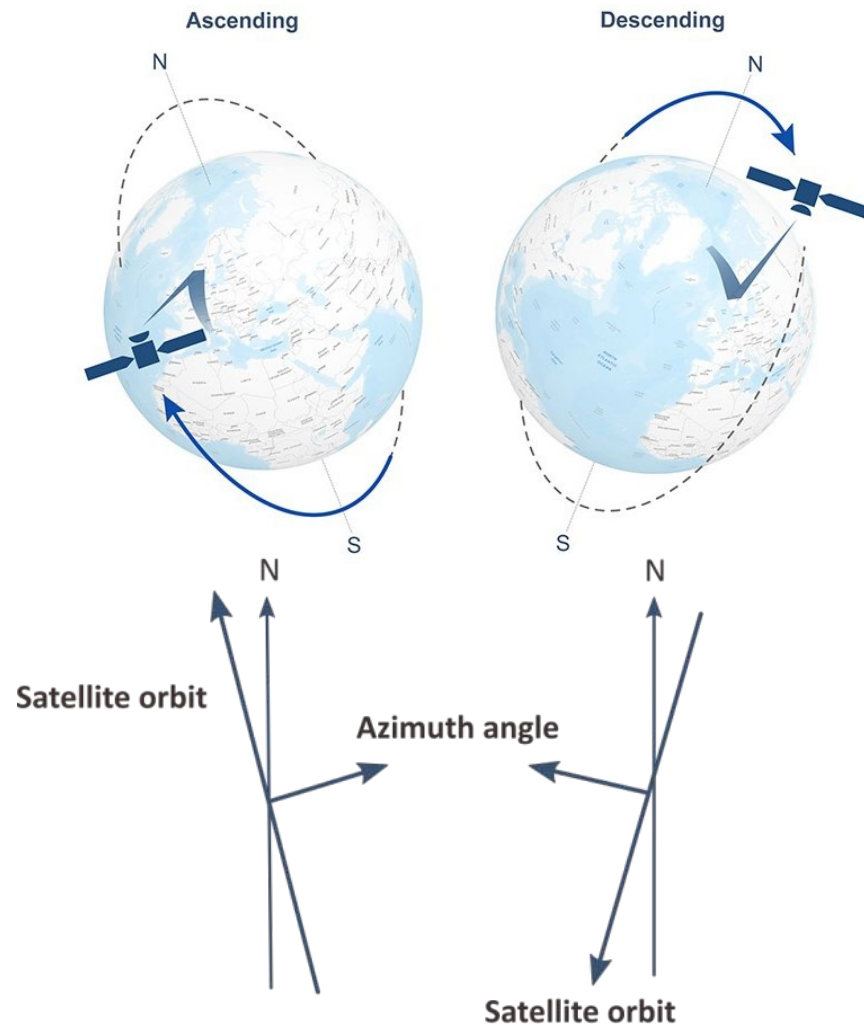


- Interferometric SAR compares several SAR images to measure the ground surface movement.
- Pair of images (interferograms) with variable time intervals are used to document different velocity ranges.
- **Short time intervals for high velocity, e.g. 6d, 12d, 24d**
- **Long time intervals for low velocity, e.g. 1 or 2 year(s)**



- SAR sensors are **side-looking** (oblique view).
- InSAR measurements are **1D** along the radar **line-of-sight (LOS)**.
- InSAR only measures displacement along the LOS direction: $d_{InSAR} \neq d_{real}$.
- In steep terrain, some surfaces cannot be documented, e.g. due to **shadow**.



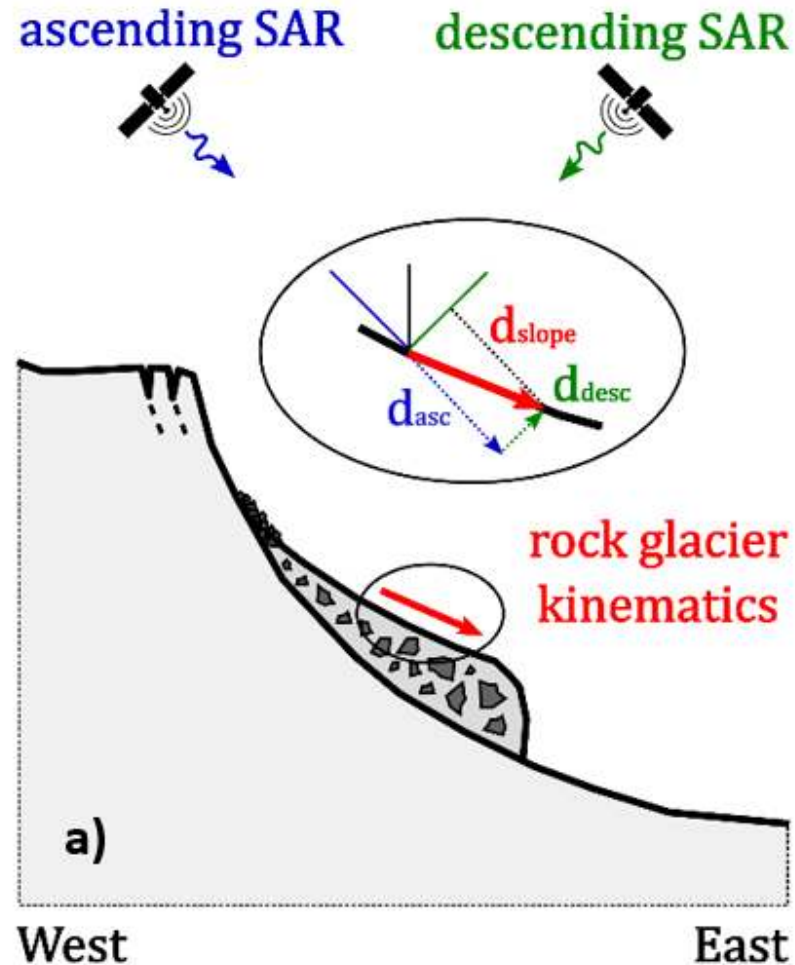


<https://www.ngu.no/en/geological-mapping/what-insar>

Because the satellite is flying around the Earth, there are **two measurement geometries** available, with **two viewing directions**.

With Sentinel-1 (right-looking SAR):

- When flying **from S to N (ascending orbit)**, the sensor is looking eastwards
- When flying **from N to S (descending orbit)**, the sensor is looking westwards.



Because the satellite is flying around the Earth, there are **two measurement geometries** available, with **two viewing directions**.

With Sentinel-1 (right-looking SAR):

- When flying **from S to N (ascending orbit)**, the sensor is looking eastwards
- When flying **from N to S (descending orbit)**, the sensor is looking westwards.

It is usual better to **choose the viewing geometries best aligned with the slope** you are studying:

- From rock glaciers on **east-facing slopes**, look first at **ascending** InSAR data
- For rock glacier on **west-facing slopes**, look first at **descending** InSAR data.

Optimal conditions...

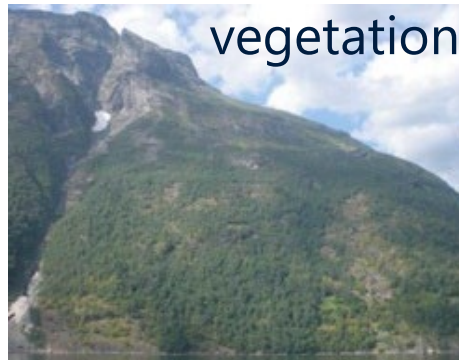


desert



bare rock

and limitations...



vegetation



steep terrain
fast movement



snow

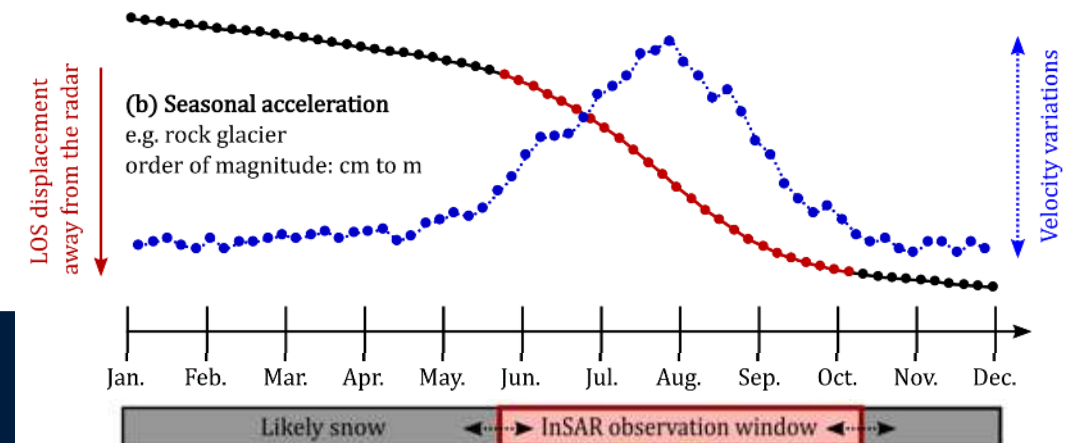


water

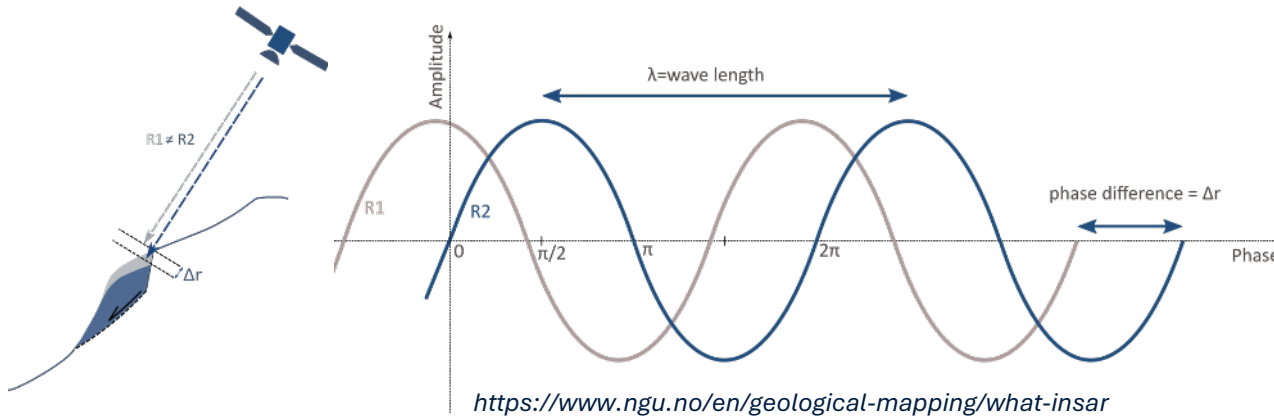
The snow is the main limitation in mountains.

It reduces the observation window to the summer season.

- Fewer images usable -> less data redundancy for quality check.
- Potential overestimation of the rock glacier annual velocity if the landform has seasonal acceleration.

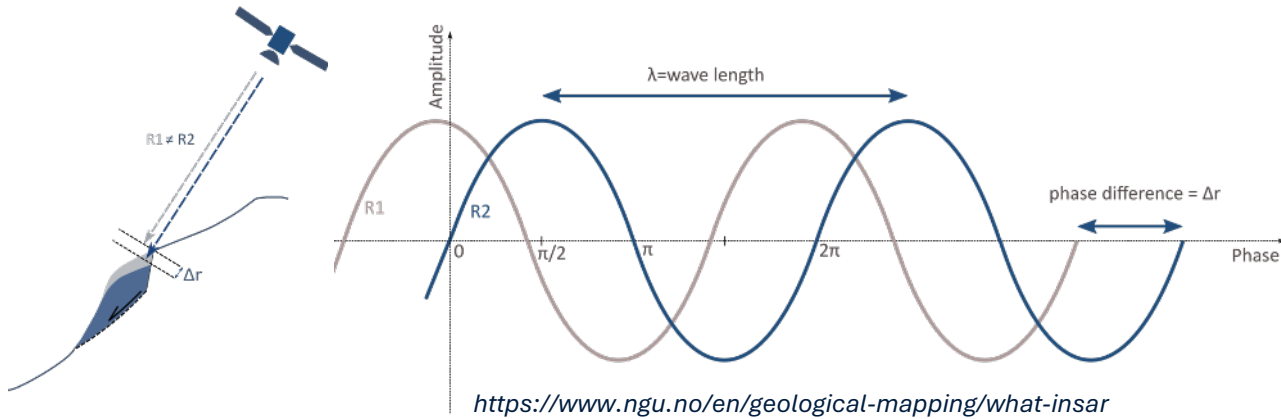


Interpretation of interferograms

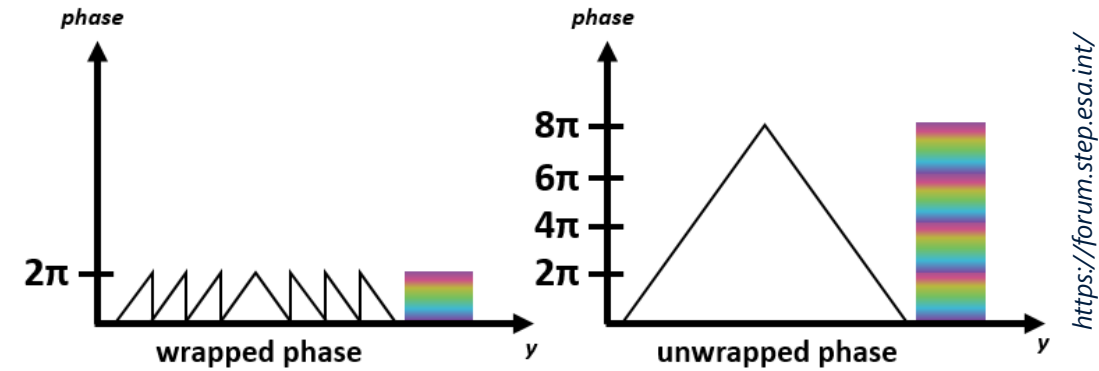


- InSAR uses the **phase** of the radar signal, proportional to the **two-way travel path** between the sensor and the surface.
- Ground movement is measured as phase differences, which depends on the **radar wavelength** λ (~ 5.5 cm for Sentinel-1)
- The maximum displacement measurable between two images is **half the wavelength** (~ 2.75 cm for Sentinel-1).

Interpretation of interferograms

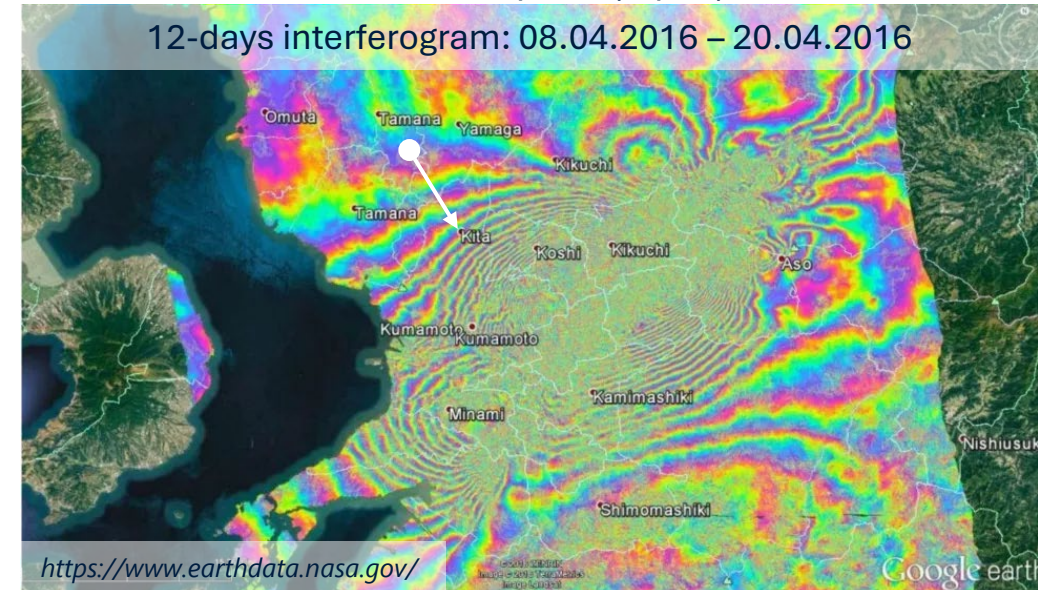


- Initial InSAR results from image pairs are represented as **wrapped interferograms**, i.e. maps with **colour cycles (fringes)**, representing **half the wavelength ($\lambda/2$)**.
- To estimate the displacement on wrapped interferograms, we **count the fringes** from a location assumed to be stable (e.g. white dot) until the area of interest (e.g. Kita).
- Example with Sentinel-1 (wavelength λ : ~5.5 cm):**
 - 3 fringes in 12 days = $3 \times 2.75 \text{ cm} = 8.25 \text{ cm}$
 - Extrapolated annual velocity = $(8.25/12) \times 365 \approx 251 \text{ cm/yr}$



2016 Kumamoto earthquake (Japan) 16.04.2016

12-days interferogram: 08.04.2016 – 20.04.2016

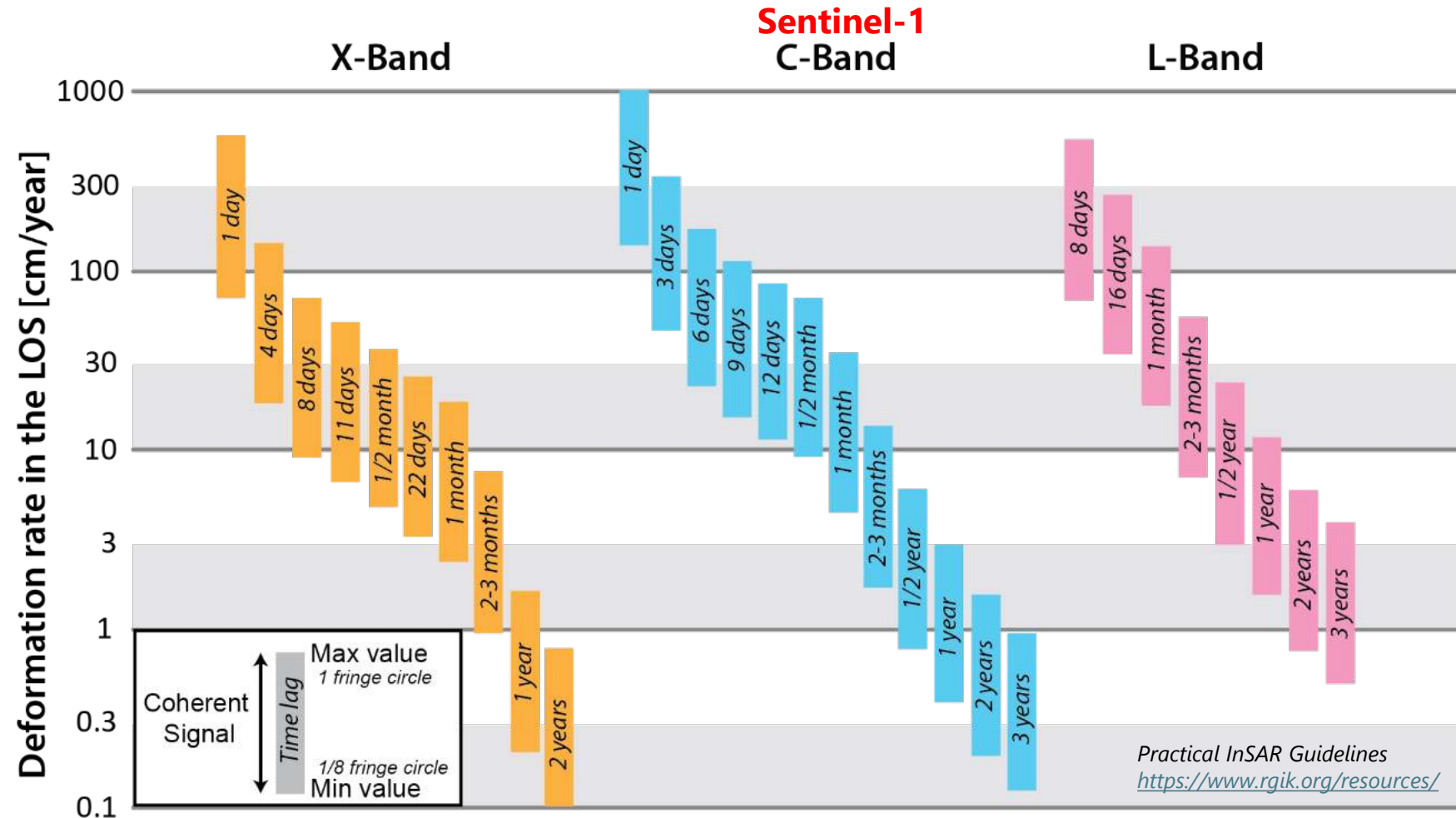


Interpretation of interferograms



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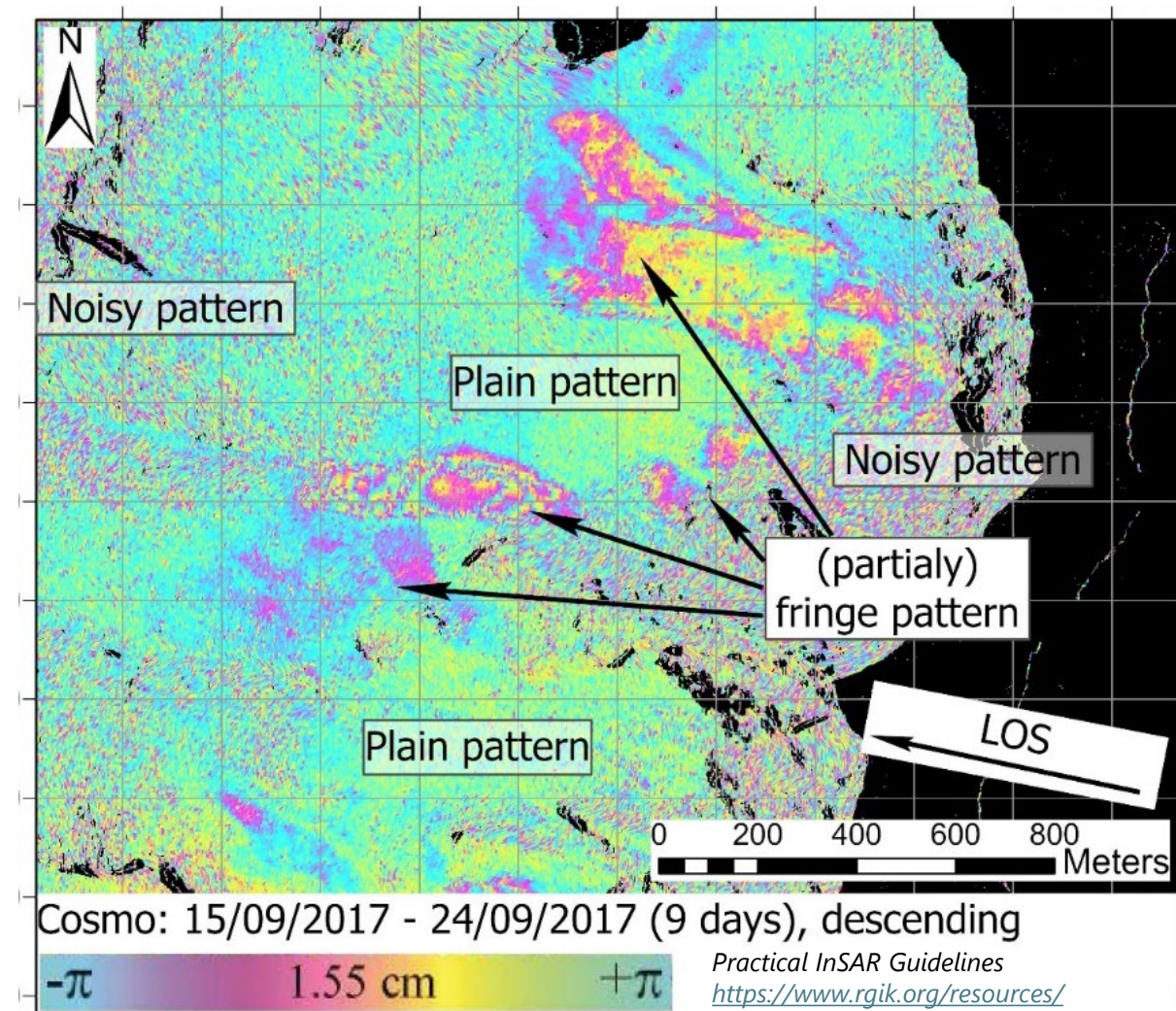
- **Combine different interferograms** to have a wide range of detection capability.
- The detectable velocity depends on the **wavelength** and the **time interval** used to build the interferograms.
- **Short time intervals for high velocity, e.g. 6d, 12d, 24d**
- **Long time intervals for low velocity, e.g. 1 or 2 year(s)**



Interpretation of interferograms

How to interpret InSAR data for rock glaciers?

- **Select the SAR geometry the best suited** to the rock glaciers under study (aligned with the slope).
- **Look at interferograms and analyse the patterns.** Ideally several interferograms with different time intervals from different satellites.
- **Three types of patterns:**
 - (1) no change defined by a plain pattern, i.e. no significant movement
 - (2) smooth change with a (partly) fringe pattern, i.e. movement rate within the detection range
 - (3) decorrelated signal with a noisy pattern, i.e. unreliable areas due to snow, vegetation, water or movement rate above the max detection limit.



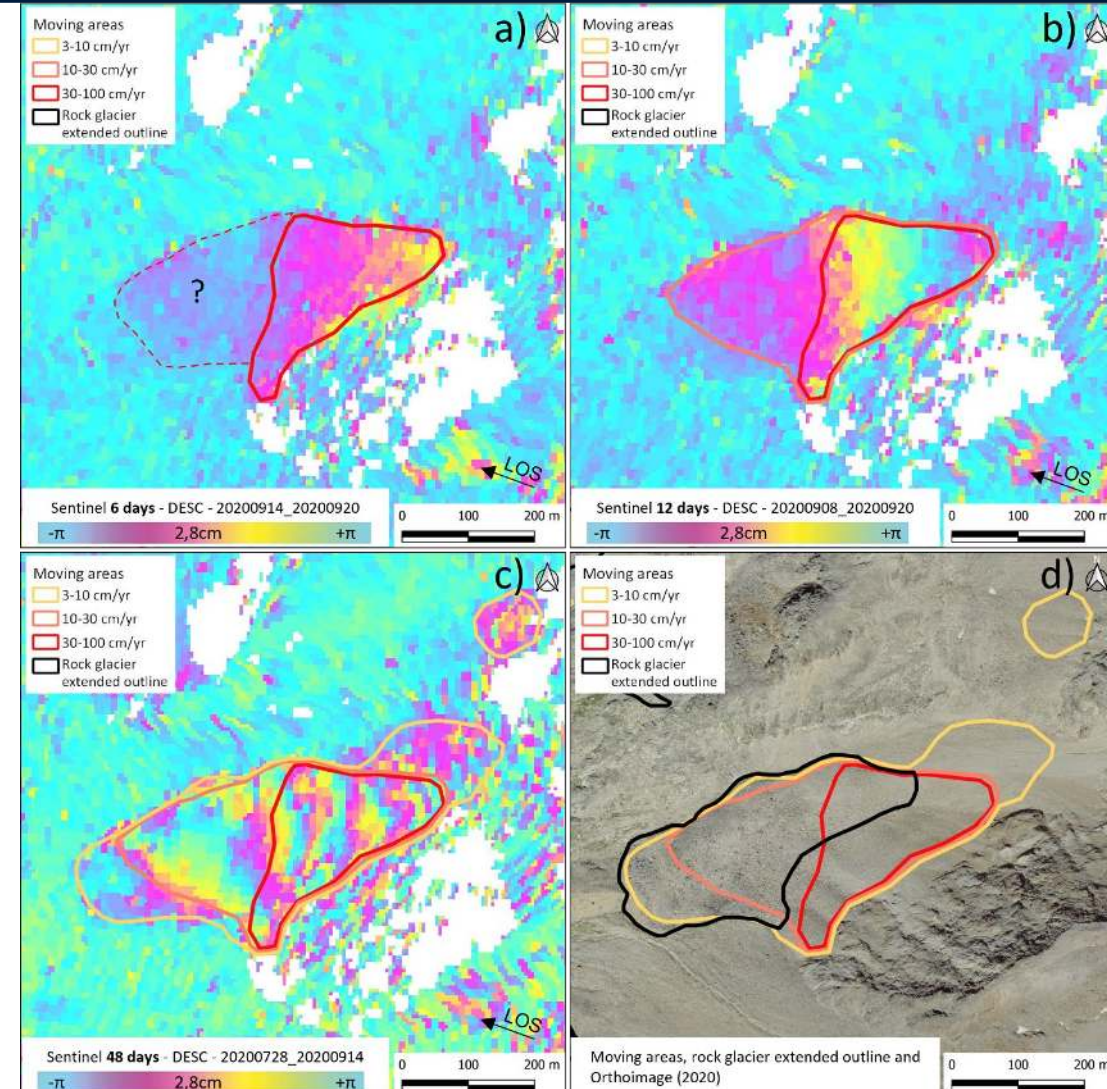
Moving Areas (MAs)

An area at the surface of a rock glacier in which the observed direction and velocity of the **flow field** are **spatially consistent and homogeneous** during a documented time.

It must represent **the downslope movement rate of the rock glacier (permafrost creep)**. Avoid confusion with movements related to other processes (e.g. melt-induced subsidence or subjacent landslide).

Standard velocity classes:

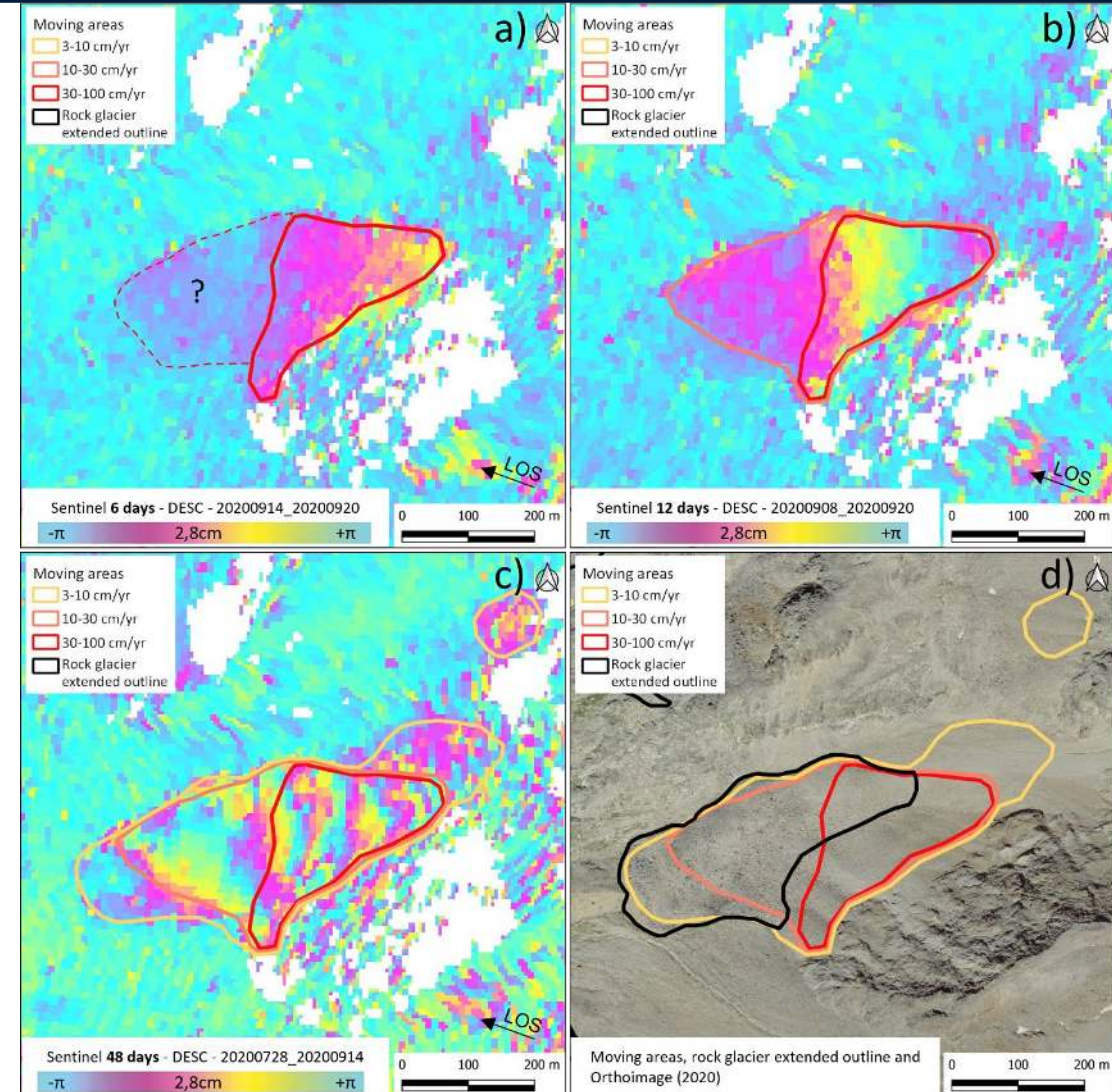
- ☒  RoGI_MovingAreas_SouthernVenosta
- ☒  < 1 cm/yr (no movement up to some mm/yr)
 - ☒  1-3 cm/yr
 - ☒  3-10 cm/yr
 - ☒  10-30 cm/yr
 - ☒  30-100 cm/yr
 - ☒  > 100 cm/yr
 - ☒  Undefined
 - ☒ 



Manually draw polygons around relevant InSAR patterns.

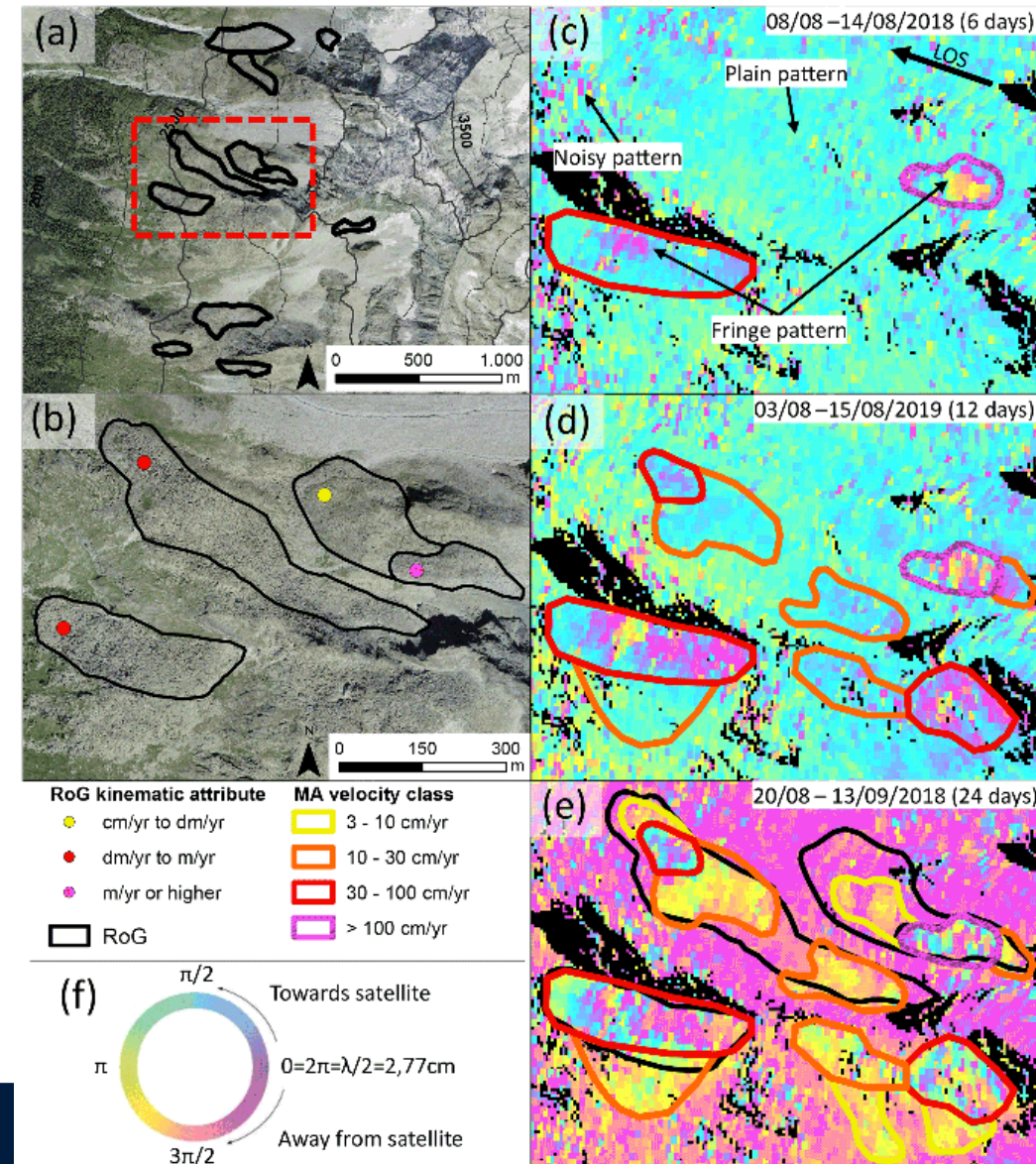
How to draw Moving Areas (MAs) on rock glaciers?

- **Start with short intervals (6-12d)** to detect high velocity MAs. The partial or full fringes appearing on rock glaciers are related to fast movement (30-100 cm/yr and > 100 cm/yr).
- **Gradually look at longer intervals (months-years)** to detect lower velocity MA (1-30 cm/yr).
- **Draw the MA polygons** based on the clearest interferograms and **assign the velocity class** depending on the fringe patterns and the days.
- **Check several available interferograms** to confirm that the patterns are consistent. Big differences may indicate seasonal variability and/or noise in the data.

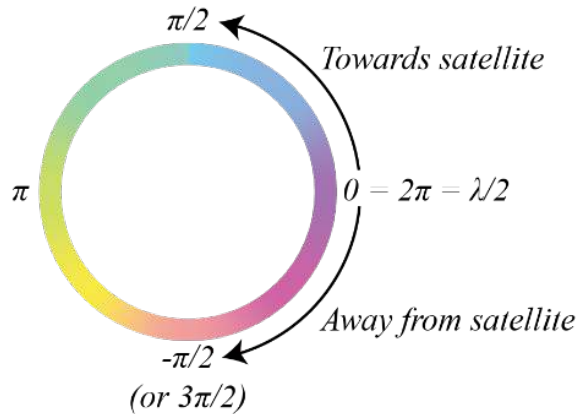


InSAR MA Delineation

- A rock glacier can be covered by **several MAs** and some rock glaciers have **no MA** (not all rock glaciers are moving).
 - The InSAR MAs only document **where/how the ground surface is moving**. Remain critical to interpret why it is moving.
 - The MA polygons are **not always following the rock glacier outlines** due to data gaps (noise/shadow) and/or movement heterogeneities (stable parts).
 - InSAR might help **detecting new rock glaciers**, which were not found using orthophotos only.
 - But InSAR might also detect movement related to **other periglacial processes than permafrost creep**.
- The geomorphological and kinematic approaches are **complementary** and ideally performed **together**.



Velocity estimation



Annual velocity (cm/yr) is calculated as **disp / time * 365**

disp = displacement shown on the interferogram

1 colour cycle (fringe) = 2.75 cm (Sentinel-1)

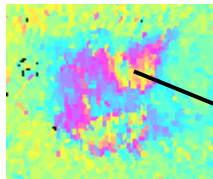
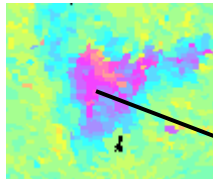
1/2 colour cycle (fringe) = 1.38 cm (Sentinel-1)

1/4 colour cycle (fringe) = 0.69 cm (Sentinel-1)

time = interval (days) used to generate the interferogram.

For 1 entire fringe cycle on a Sentinel-1 12 days interferogram, the corresponding annual velocity is:

$$\frac{\lambda/2}{12} * 365 = \frac{2.75}{12} * 365 = 83.6 \text{ cm/yr} \rightarrow \text{velocity class 30-100}$$



SENTINEL-1 (cm/yr) lambda		5.5											
Fringe/days		6	12	18	24	36	48	54	60	66	96	120	365
1/5	0.20	33.5	16.7	11.2	8.4	5.6	4.2	3.7	3.3	3.0	2.1	1.7	0.6
1/4	0.25	41.8	20.9	13.9	10.5	7.0	5.2	4.6	4.2	3.8	2.6	2.1	0.7
1/3	0.33	55.8	27.9	18.6	13.9	9.3	7.0	6.2	5.6	5.1	3.5	2.8	0.9
1/2	0.50	83.6	41.8	27.9	20.9	13.9	10.5	9.3	8.4	7.6	5.2	4.2	1.4
2/3	0.67	111.5	55.8	37.2	27.9	18.6	13.9	12.4	11.2	10.1	7.0	5.6	1.8
3/4	0.75	125.5	62.7	41.8	31.4	20.9	15.7	13.9	12.5	11.4	7.8	6.3	2.1
4/5	0.80	133.8	66.9	44.6	33.5	22.3	16.7	14.9	13.4	12.2	8.4	6.7	2.2
1	1.00	167.3	83.6	55.8	41.8	27.9	20.9	18.6	16.7	15.2	10.5	8.4	2.8
RGIK Velocity class													
cm / yr		< 1	1-3	3-10	10-30	30-100	> 100						

Courtesy: Diego Cusicanqui, CNES / ISTERre / RGIK

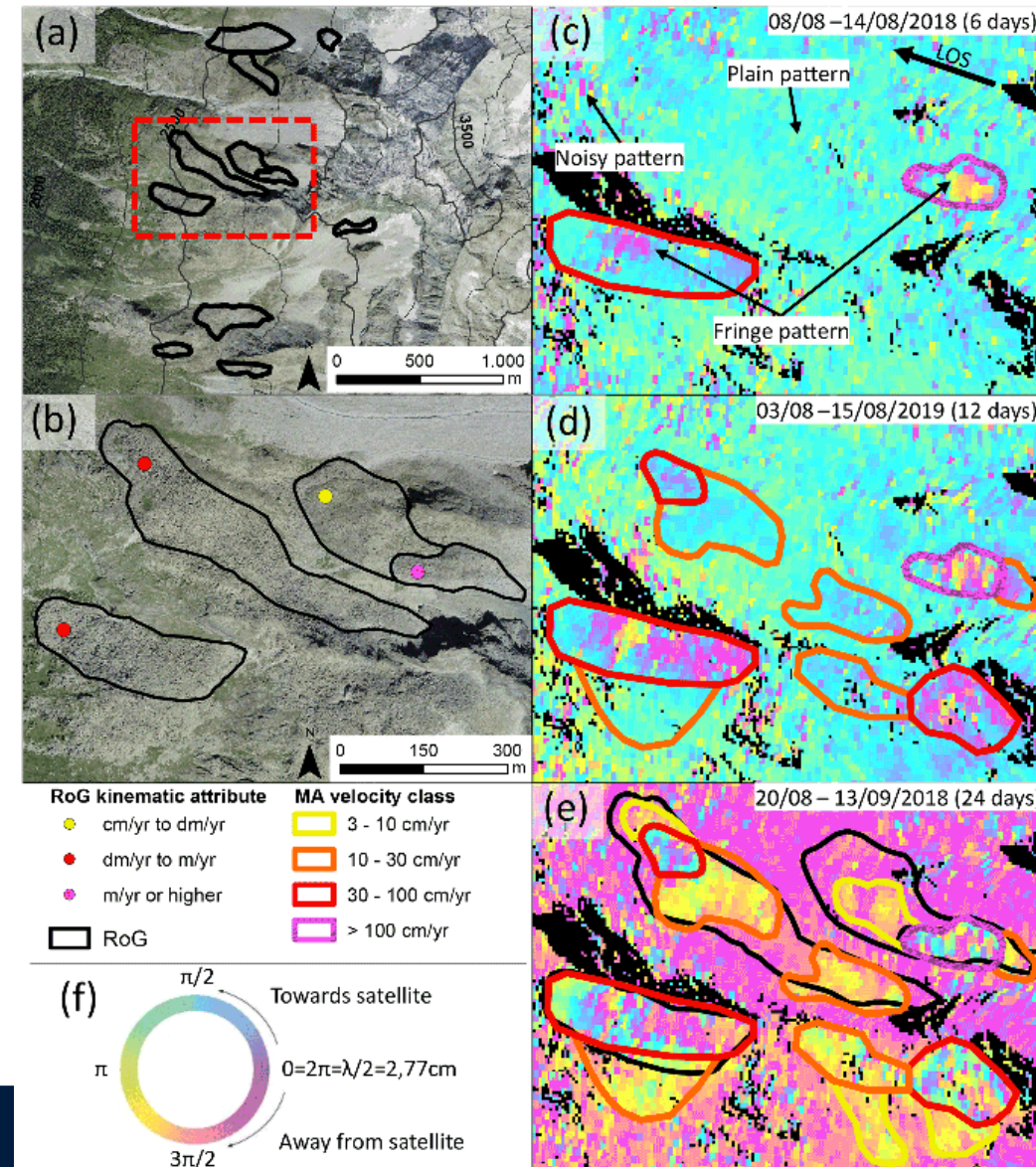
Velocity estimation

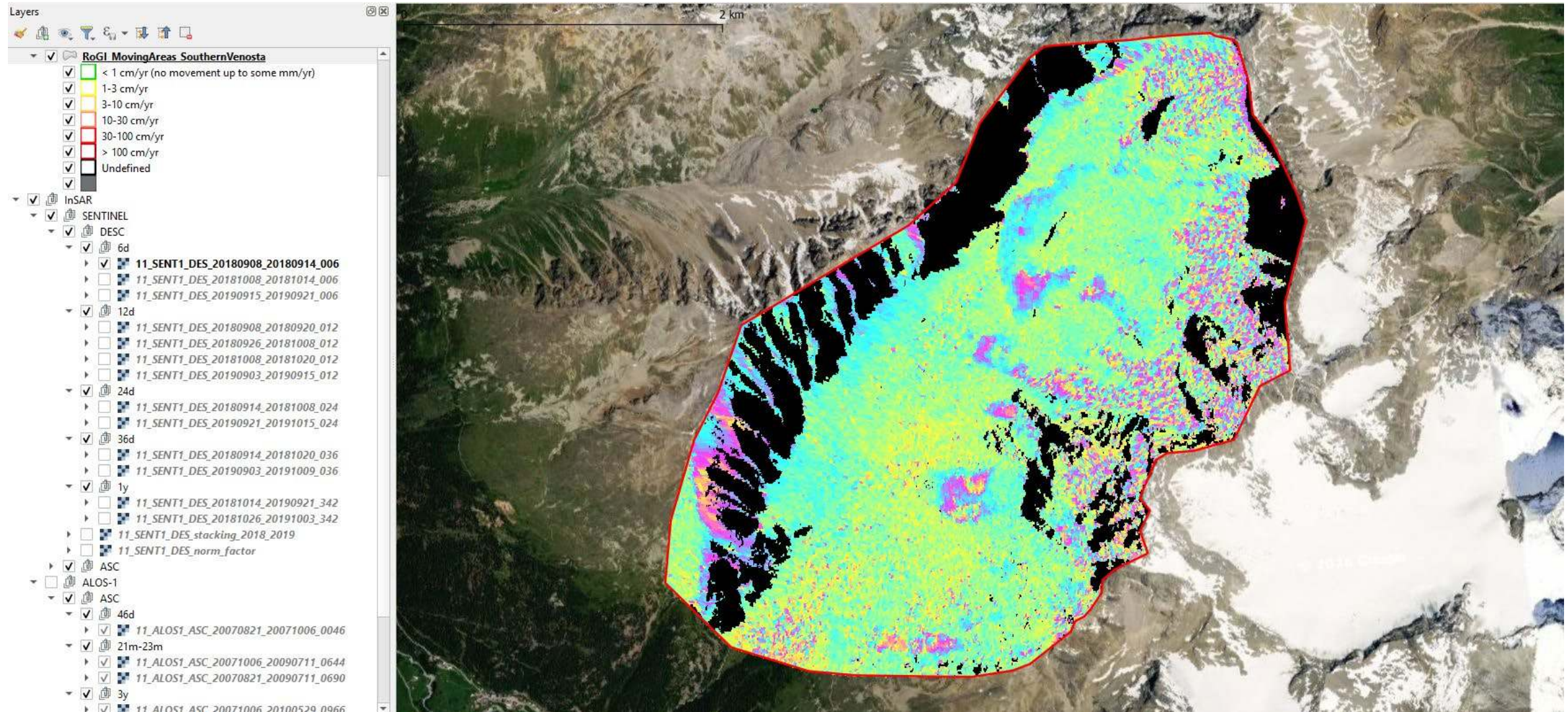


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Some examples/tips (rule of thumb):

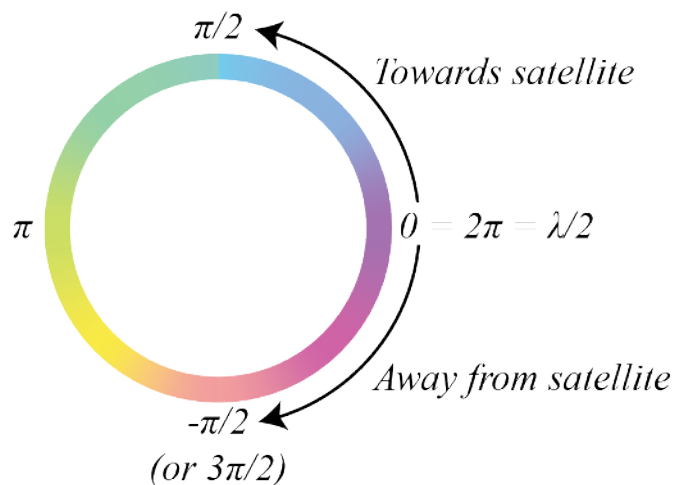
- Areas with 1 or more fringe(s) on 6-days S1 interfero or already decorrelated (noisy pattern): **> 100 cm/yr**
- Areas with partial fringe on 6-days S1 interfero, 1 or more fringe(s) on 12-days interfero and decorrelated on monthly interfero: **30-100 cm/yr**
- Areas not visible on 6 days, gradually showing up with partial fringe on 12-24d interfero, and 1 fringe for monthly interfero: **10-30 cm/yr**
- Areas not visible before monthly interfero, 1 or more fringe(s) after several months: **3-10 cm/yr**
- Areas not visible before several months to 1 year: **1-3 cm/yr**





Check list / Summary (MA)

- Choose the SAR geometry according to the slope/rock glacier orientation
 - East-facing: best looking at Ascending Interferograms
 - West-facing: best looking at Descending Interferograms
 - North/South-facing: careful with the interpretation, the velocity is likely underestimated.
- Go through several interferograms with different intervals to cover several velocity ranges
 - Start with small intervals (6-12d) suited for fast movement. Gradually increase the intervals.
 - Fast moving areas might show clear fringes with short interferograms but become decorrelate with longer intervals (months-years).
 - Slow moving areas might show no pattern on short interferograms (6-12d) but a signal might become visible with longer intervals (months-years).
- Select the clearest interferograms to draw the MA and assign the velocity depending on the fringe/days.
 - Important to confirm that the signal is consistent across several interferograms before drawing.
 - If there is no clear signal, best not to draw. Some rock glaciers might remain without any MA.
 - Repeat the process with various intervals for slower/faster MAs. One rock glacier can be covered by several MAs (contrasting velocities).



SENTINEL-1 (cm/yr) lambda		5.5											
Fringe/days		6	12	18	24	36	48	54	60	66	96	120	365
1/5	0.20	33.5	16.7	11.2	8.4	5.6	4.2	3.7	3.3	3.0	2.1	1.7	0.6
1/4	0.25	41.8	20.9	13.9	10.5	7.0	5.2	4.6	4.2	3.8	2.6	2.1	0.7
1/3	0.33	55.8	27.9	18.6	13.9	9.3	7.0	6.2	5.6	5.1	3.5	2.8	0.9
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4/5	0.80	133.8	66.9	44.6	33.5	22.3	16.7	14.9	13.4	12.2	8.4	6.7	2.2
1	1.00	167.3	83.6	55.8	41.8	27.9	20.9	18.6	16.7	15.2	10.5	8.4	2.8
RGIK Velocity class													
cm / yr		< 1	1-3	3-10	10-30	30-100	> 100						



RGIK RoGI kinematic approach: InSAR-based Kinematic Attribute and Activity Assessment

Line Rouyet, Yan Hu, Francesco Brardinoni

PermaCOST Training School | Trafoi, 3 September 2026

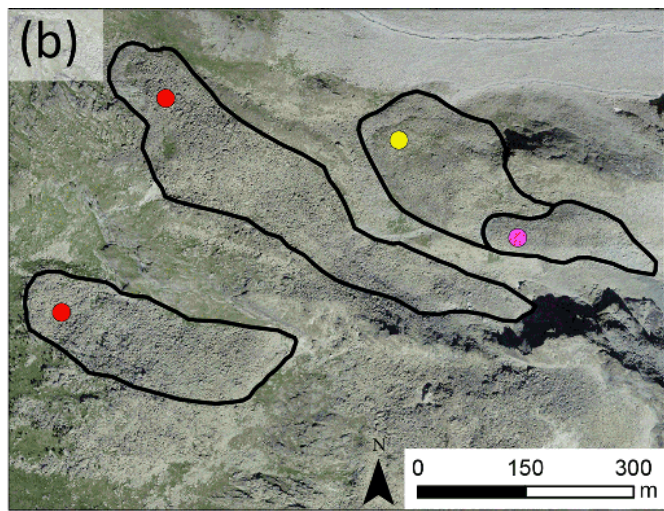
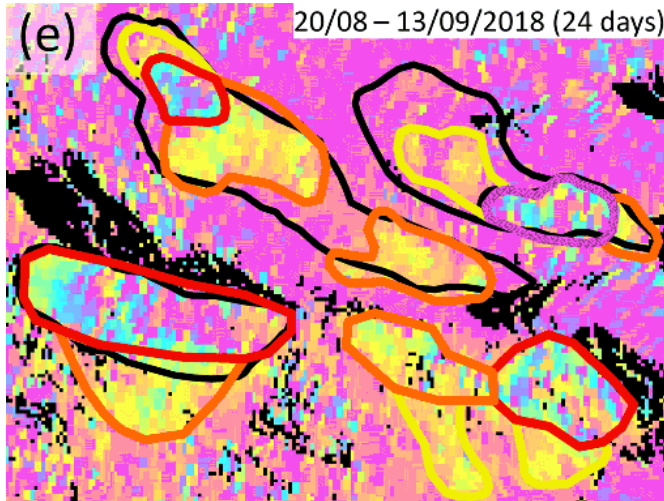


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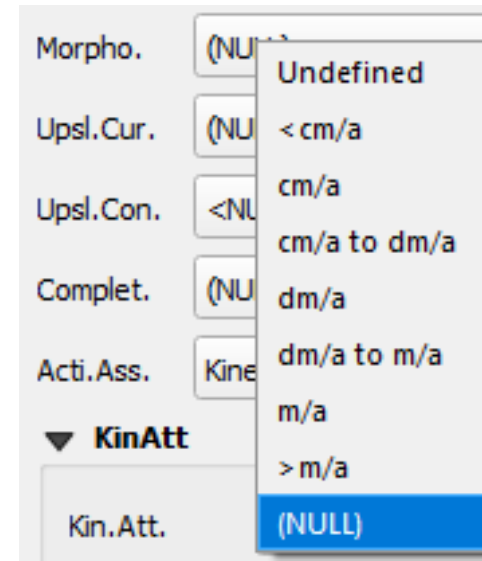
permacost.eu & cost.eu/actions/CA24157



The KA documents **the overall kinematic state of the rock glacier unit (RGU) at the time of the inventory.**

The KA consists of **semi-quantitative categories** expressing the **multi-annual downslope velocity of an entire RGU.**

Objective: summarise/simplify the kinematic info from the MA(s) to a single attribute representative of the entire unit.



The KA is an optional attribute.

It remains undefined when:

- No (reliable) kinematic info is available.
- MAs have been detected but they have an undefined or unreliable velocity.
- The kinematic information is too heterogeneous (many MAs with different velocities).

Simple case:

- InSAR performed on back-facing slopes well aligned with the rock glacier creep direction.
- Dominant part of the rock glacier unit covered by one single MA.

A) MAs based on annual interferograms

Velocity classes (annual)

1. < 1 cm/yr
2. 1–3 cm/yr

Kinematic attribute

1. < cm/yr
2. cm/yr

B) MAs based on seasonal interferograms

Velocity classes (summer)

3. 3–10 cm/yr
4. 10–30 cm/yr
5. 30–100 cm/yr
6. > 100 cm/yr

Velocity classes (annual)

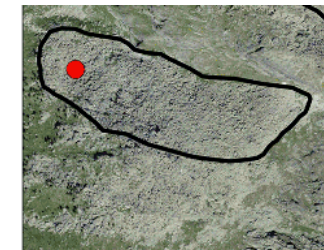
- 4–8 cm/yr
- 8–24 cm/yr
- 24–80 cm/yr
- > 80 cm/yr

Kinematic attribute

3. cm/yr to dm/yr
4. dm/yr
5. dm/yr to m/yr
6. or 7. m/yr or > m/yr *



- MA velocity class**
- 3 - 10 cm/yr
 - 10 - 30 cm/yr
 - 30 - 100 cm/yr
 - > 100 cm/yr



- RoG kinematic attribute**
- cm/yr to dm/yr
 - dm/yr to m/yr
 - m/yr or higher
- RoG

If the MA is based on summer interferograms only, the velocity estimate must account for seasonal acceleration. Per default, the annual velocity is estimated 20% lower than the summer velocity.

Complex cases

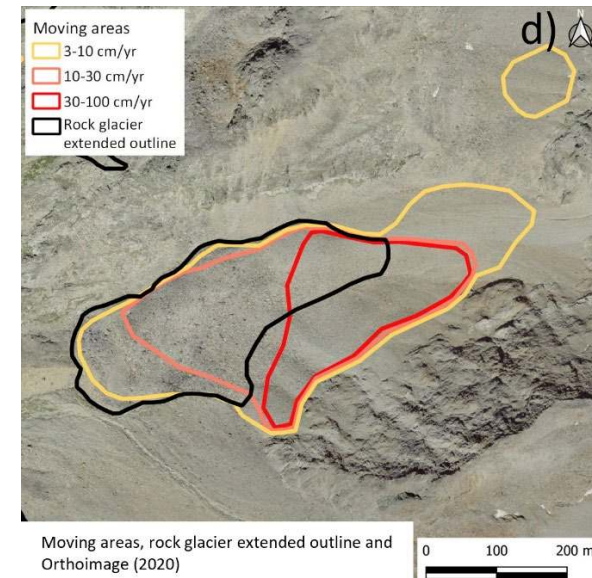
- Several MAs covering the rock glaciers.
- Partial coverage.

Translation rules:

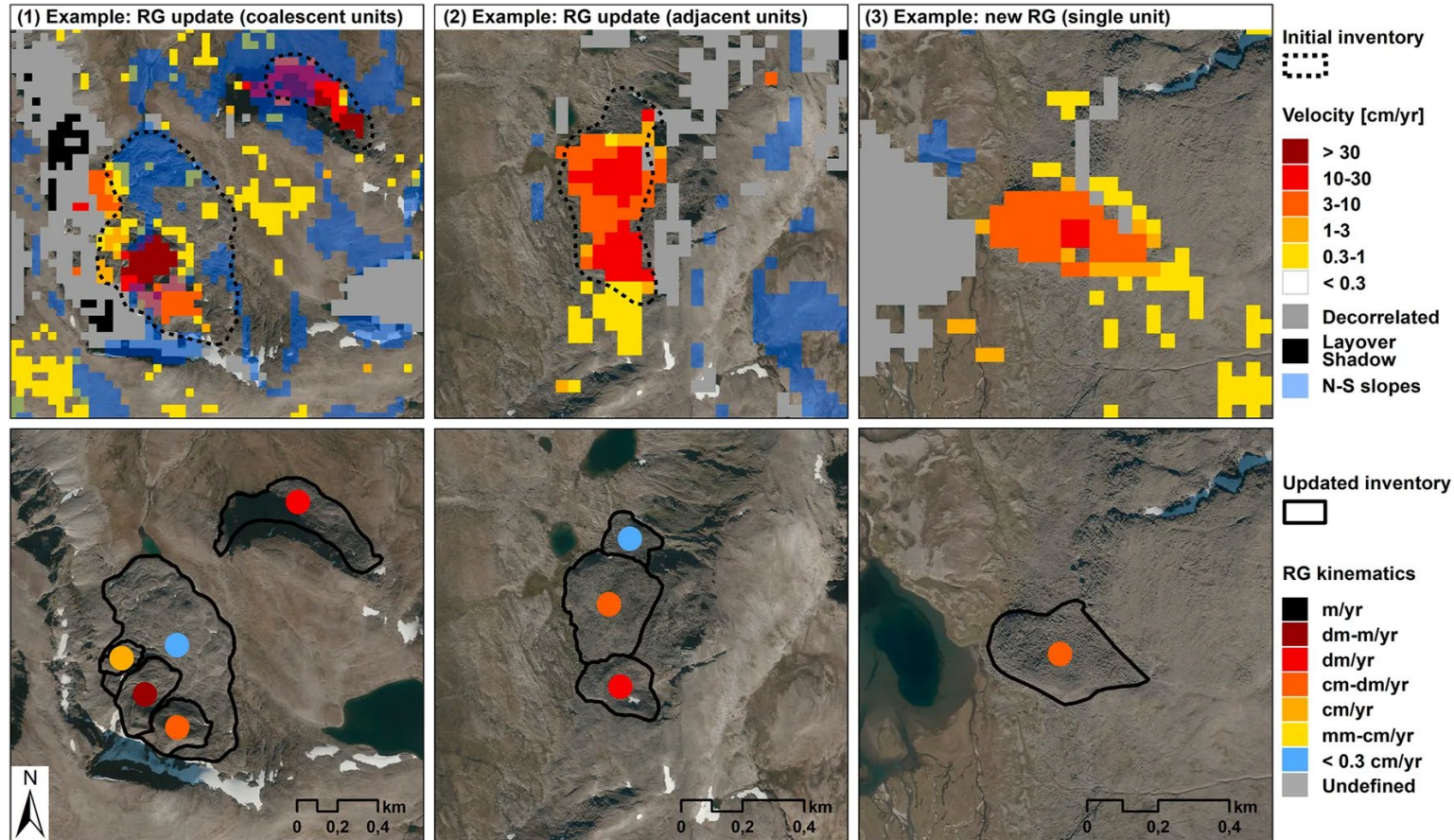
- The category should represent **the dominant velocity class of the RGU**.
- In case of two equally dominant but directly adjoining KA categories (e.g. 4 and 5), **the category of the area closer to the front is favoured**.
- In case of a larger spread of equally dominant categories on the same RGU (e.g. 4 and 6), **the median category** (e.g. 5) **should be used**.
- If MAs show a large heterogeneity over the unit (e.g. > 3 MAs with various velocity categories), **the category "0. Undefined"** should be chosen.

Metadata linked to KA to document reliability and uncertainties:

- The KA reliability ("Rel.Kin" field): Low, Medium, High (based on the MA quality, coverage and heterogeneity)
- Multi-year validity time period ("Kin.Period" field).
- The type of data ("TypeOfData" field) used to assign the KA.
- Additional information regarding the datasets and the quality of the attribution ("Kin.Comment" field)



**MA 10-30 cm/yr
(dominant & median)
KA -> dm/yr**



The MA/KA info might help updating rock glacier location and outlining:

- **Split one unit into several** if the kinematic info highlights different velocities that fit with morphological evidence (multiple lobes)
 - 1) Coalescent units with variable movement rates -> update of the units
 - 2) Adjacent units with variable movement rates -> update of the units
- **Discover new landforms**, missed using the geomorphological approach alone
 - 3) Newly detected rock glacier

Rouyet et al. 2021 - <https://doi.org/10.3389/feart.2021.681088>

Activity definition:

Efficiency of sediment conveyance, expressed by the surface movement, at the time of observation. It should not be used to infer any ground ice content.

Kinematic info is useful to assess the activity.

Category	Label	Comment	Related activity
0.	Undefined	(default category)	
1.	< cm/yr	(no up to very few movement)	relict
2.	cm/yr	(order of magnitude ≈ 0.01 m/yr)	transitional
3.	cm/yr to dm/yr	(order of magnitude ≈ 0.05 m/yr)	transitional
4.	dm/yr	(order of magnitude ≈ 0.1 m/yr)	active
5.	dm/yr to m/yr	(order of magnitude ≈ 0.5 m/yr)	active
6.	m/yr	(order of magnitude ≈ 1 m/yr)	active
7.	> m/yr	(more than ≈ 3 m/yr per year)	active

Three Activity categories:

- **Active:** rock glacier moving downslope over most of its surface.
- **Transitional:** rock glacier with slow movement or movement restricted to areas of non-dominant extent.
- **Relict:** Rock glacier with neither geomorphological evidence nor detection of current movement associated with permafrost creep.

Rock glacier activity / Active

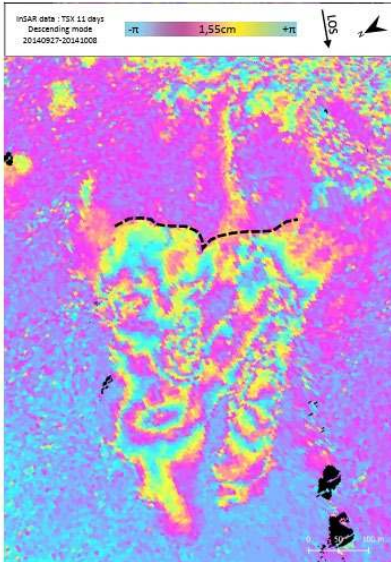
Comment:
Steep front and lateral margins with both freshly exposed material. The two colors at the front are a good sign for indicating the over-steepening that occurs at the front of many active rock glaciers.



Piz da las Sterias,
Switzerland
46.5130°N, 9.9600°E
2700-2900 m.a.s.l.

Rock glacier activity / Active

Comment:
Active talus-connected rock glacier with steep front and partly lateral margins both exposing fresh material. Most of the landform exhibits a motion rate of several decimeters per year (right) (one color fringe/cycle means a displacement rate of about 0.5 m/year in the line-of-sight (LOS) of the space-borne SAR sensor).



Active: rock glacier moving downslope over most of its surface.

If no kinematic data is available: geomorphological evidence of downslope movement such as a steep front (steeper than the angle of repose) and possibly lateral margins with freshly exposed material on top.

If kinematic data is available: coherent downslope movement over most of its surface. As an indication, the velocity typically range dm/yr to m/yr or > m/yr.

Illustrations of the RGIK RoGI guidelines
<https://doi.org/10.51363/unifr.srr.2023.002>

Examples of Transitional Rock Glaciers

Rock glacier activity / Transitional

Comment:
Transitional rock glacier with mostly smoothed front and lateral margins exposing fresh material in many sections. The development of trees can be often associated with surface stability.



Mount Evans, United States of America
46.0579°N, 113.1866°W
2600-2800 m.a.s.l

Rock glacier activity / Transitional

Comment:
Transitional rock glacier with a mostly smoothed front exposing fresh material only locally. A downward motion related to permafrost creep may be absent on some parts of the rock glacier. Only adequate kinematic data can confirm its activity.



Fish Peak, United States of America
46.0141°N, 113.3436°W
2600-2800 m.a.s.l

Transitional: rock glacier with slow movement or movement restricted to areas of non-dominant extent.

If no kinematic data is available: less distinct geomorphological evidence of current downslope movement than active rock glaciers in the same regional context

If kinematic data is available: little to no downslope movement over most of its surface. As an indication, the velocity is typically $< \text{dm/yr}$

Illustrations of the RGIK RoGI guidelines
<https://doi.org/10.51363/unifr.srr.2023.002>

Examples of Relict Rock Glaciers

Rock glacier activity / Relict

Comment:
The landform presents a subdued topography, mainly covered by vegetation with smooth and stable margins. The uppermost lobes are maybe constituting a distinct unit in a transitional state, which only adequate kinematic data can confirm.



Valea Rea, Romania
45.3746°N, 22.8933°E
2300-2500 m.a.s.l.

Comment:
Relict rock glaciers masked by forest (A) remotely detectable only with the help of an airborne Lidar-based high-resolution DEM hillshade (B).



Drevenase, Switzerland
46.2660°N, 6.8910°E
1500-1700 m.a.s.l.

Comment:
Easy to identify and delineate. The landform presents a subdued topography, and its mainly covered by vegetation with stable fronts and margins.

One should note that in other environmental contexts than in the Alps (mid-latitude, almost humid), the development of a tundra-type vegetation cover or even trees does not necessarily infer the absence of movement and the relict state of the landform. Conversely, the absence of a well-developed vegetation cover does not necessarily indicate any movement occurrence.

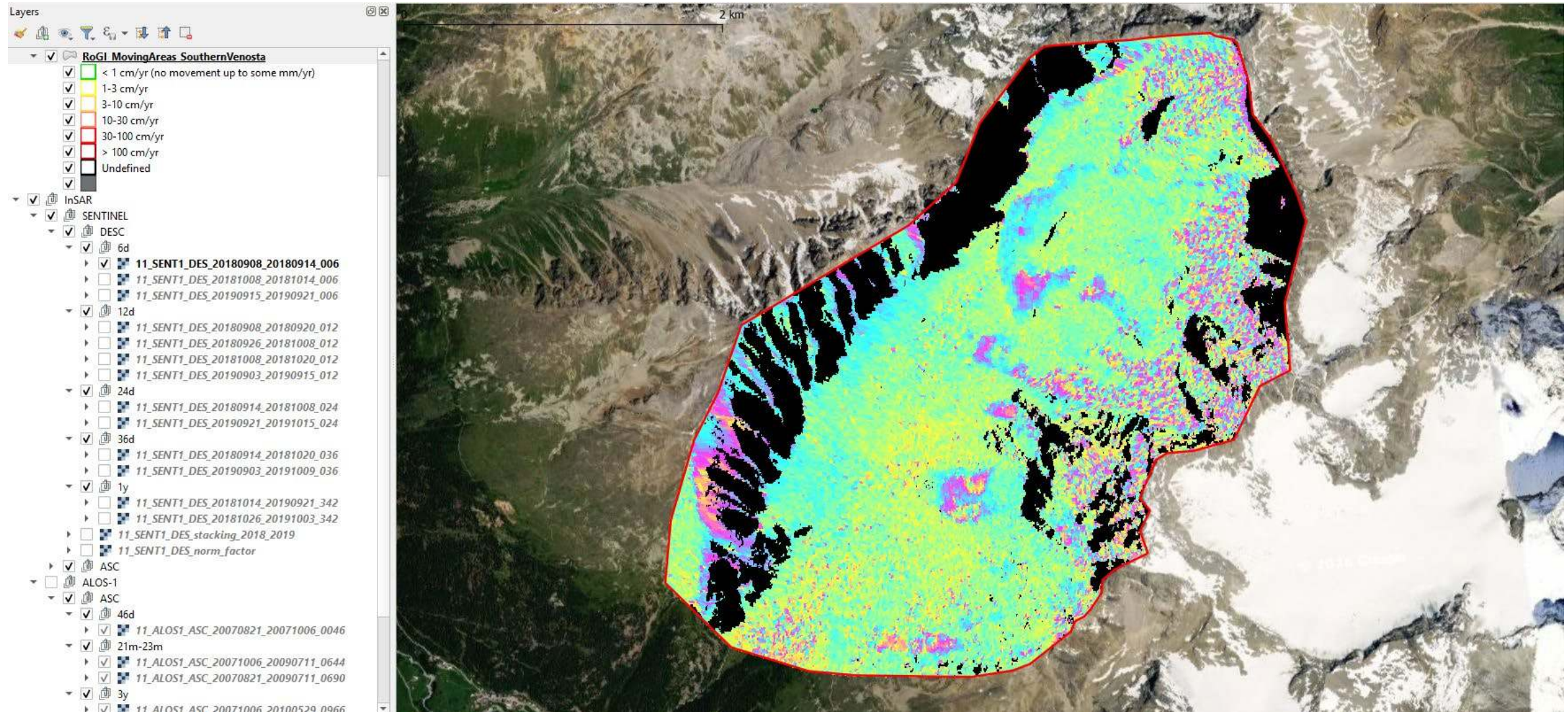
Lanseria, France
45.3471°N, 6.8410°E
2300-2500 m.a.s.l.



Relict: Rock glacier with neither geomorphological evidence nor detection of current movement associated with permafrost creep.

If no kinematic data is available: no geomorphological evidence of recent movement. Subdued topography, smoothed lateral and frontal slopes/margins, development of vegetation and soil cover.

If kinematic data is available: no detectable downslope movement over most of its surface



Check list / Reminder (KA-Activity)

MA to KA (simple cases):

Velocity classes (annual)

1. < 1 cm/yr
2. 1–3 cm/yr

Kinematic attribute

1. < cm/yr
2. cm/yr

Velocity classes (summer)

3. 3–10 cm/yr
4. 10–30 cm/yr
5. 30–100 cm/yr
6. > 100 cm/yr

Kinematic attribute

3. cm/yr to dm/yr
4. dm/yr
5. dm/yr to m/yr
6. or 7. m/yr or > m/yr *

MA to KA (complex cases):

- The category should represent **the dominant velocity class of the RGU**.
- In case of two equally dominant but directly adjoining KA categories (e.g. 4 and 5), **the category of the area closer to the front is favoured**.
- In case of a larger spread of equally dominant categories on the same RGU (e.g. 4 and 6), **the median category** (e.g. 5) **should be used**.
- If MAs show a large heterogeneity over the unit (e.g. > 3 MAs with various velocity categories), **the category “0. Undefined”** should be chosen.
- **Document the KA reliability and uncertainties.**

KA to Activity:

Category	Label	Comment	Related activity
0.	Undefined	(default category)	
1.	< cm/yr	(no up to very few movement)	relict
2.	cm/yr	(order of magnitude ≈ 0.01 m/yr)	transitional
3.	cm/yr to dm/yr	(order of magnitude ≈ 0.05 m/yr)	transitional
4.	dm/yr	(order of magnitude ≈ 0.1 m/yr)	active
5.	dm/yr to m/yr	(order of magnitude ≈ 0.5 m/yr)	active
6.	m/yr	(order of magnitude ≈ 1 m/yr)	active
7.	> m/yr	(more than ≈ 3 m/yr per year)	active