Temporal Multi-Looking of SAR Image Series for *Glacier Velocity* Determination and Speckle Reduction

(click title for abstract)

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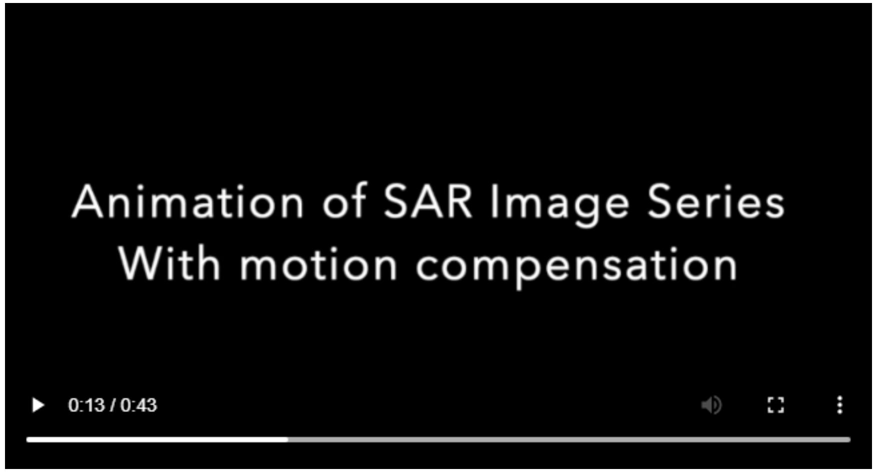
Sneak preview:



But don't forget to check out the slides to learn the method behind "motion compensation".

https://n.ethz.ch/~sleinss/downloads/Aletsch_Motion_Compensation.mp4

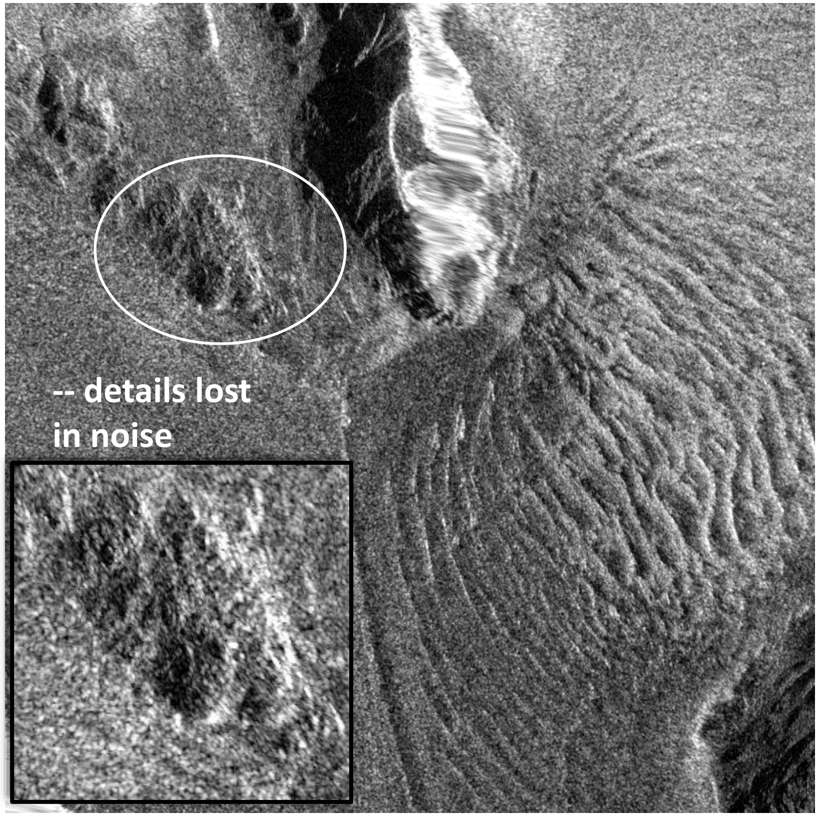
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Earth Observation and Remote Sensing

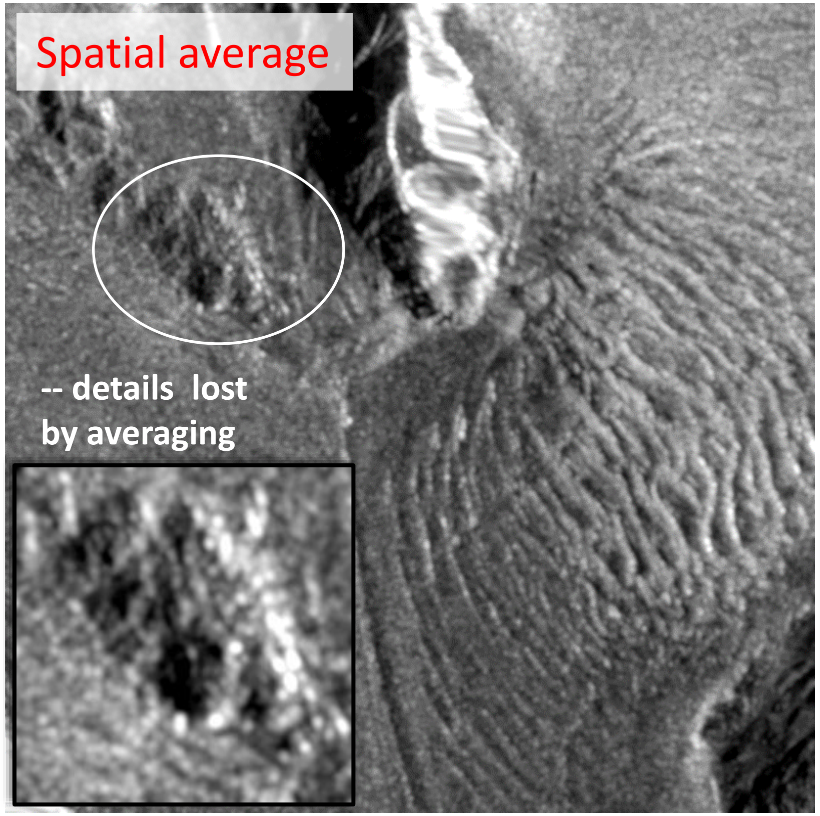
Motivation

Problem: Glacier velocity estimation from synthetic aperture radar (SAR) images requires relatively large image template for offset tracking due to radar speckle which appear as uncorrelated noise.

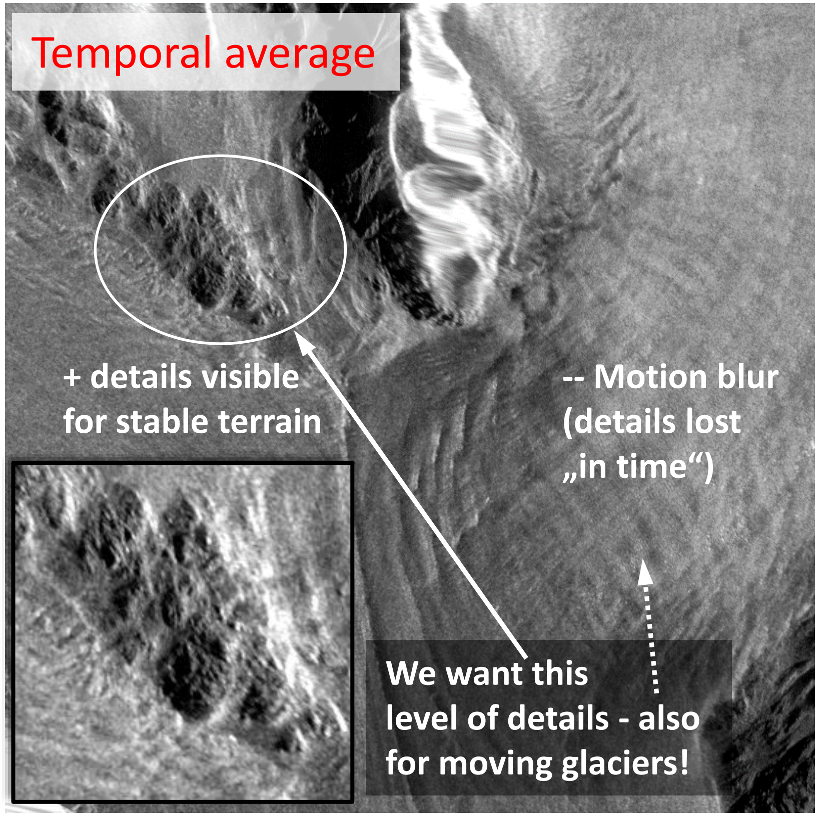
Question: Can we combine *time series* of SAR images to create high-resolution, speckle-reduced radar images with enhanced visibility of surfaces features, and to *estimate simultaneously* the *glacier surfaces velocity* field?



Single radar image (TanDEM-X):
-- strong radar speckle (noise).



Single image, 5x5 lowpass speckle filter:
+ speckle reduced,
-- details lost.



Average of 12 image:
+ stable features well visible
-- glacier surface shows motion blur.

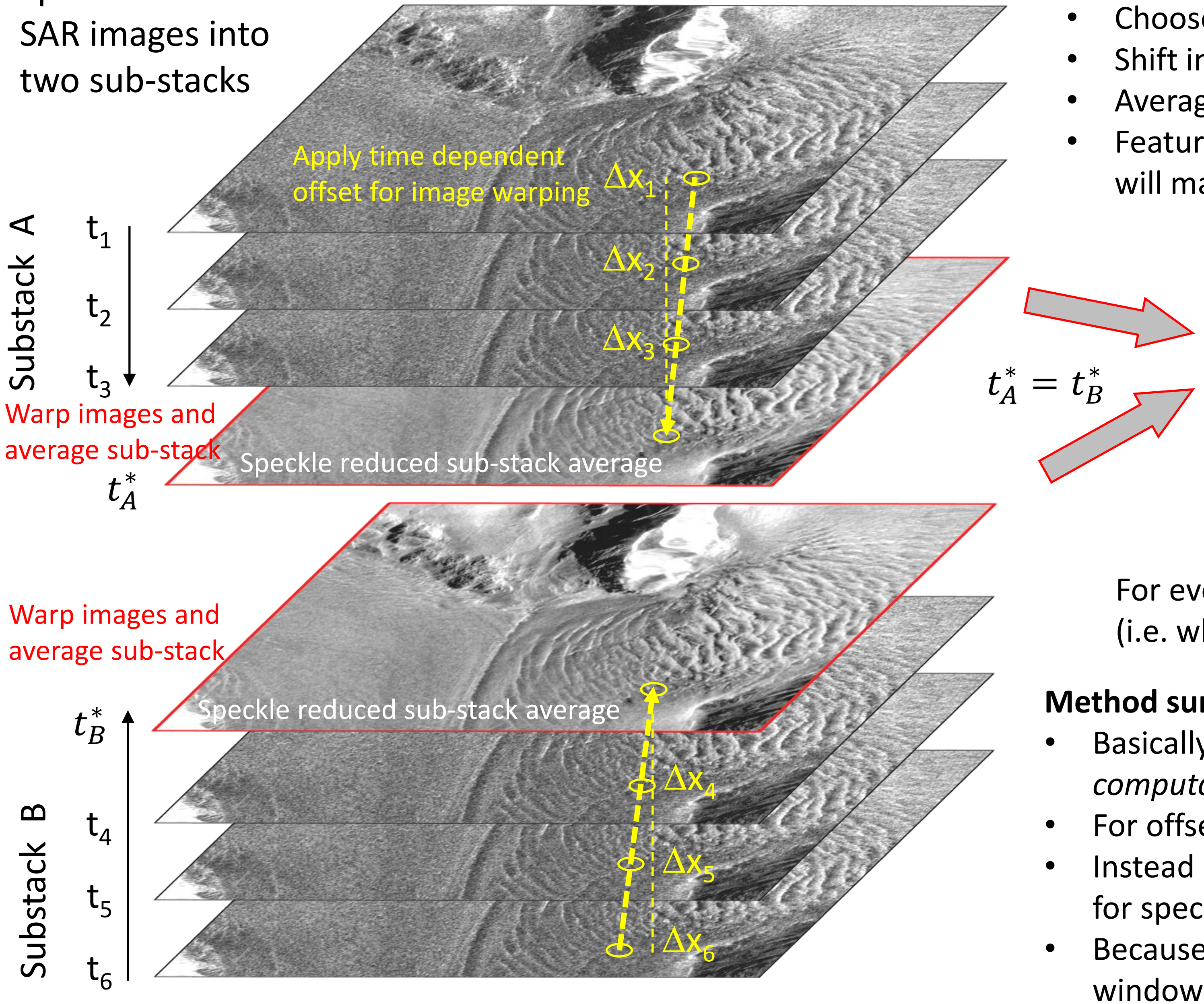
Idea: motion-compensated time-averaging

The camera *follows the motion* of the car:
+ the car is focused
– the background is blurred.
➔ Shift SAR images locally to *follow the motion* of the glacier.

We want the entire image focused!
➔ Apply auto-tracking for every pixel (define a velocity-sensitive autofocus method).
Our method is motivated by video processing for image stabilization.

Method: motion-compensated time-averaging to determine surface velocity

Split stack of N SAR images into two sub-stacks



- Choose a 2D velocity v_{test}
- Shift images *i* locally by the offset $\Delta x_i = (t^* - t_i)\, v_{test}$
- Average shifted (interpolated) images in sub-stacks
- Features which move with $v = v_{test}$ appear focused and will match.

Calculate local
Normalized Cross Correlation: NCC (v_{test})
between templates of sub-stacks.
(Similar to autofocus of digital cameras).

For every pixel, find v_{test} which maximizes NCC
(i.e. where the templates match best).

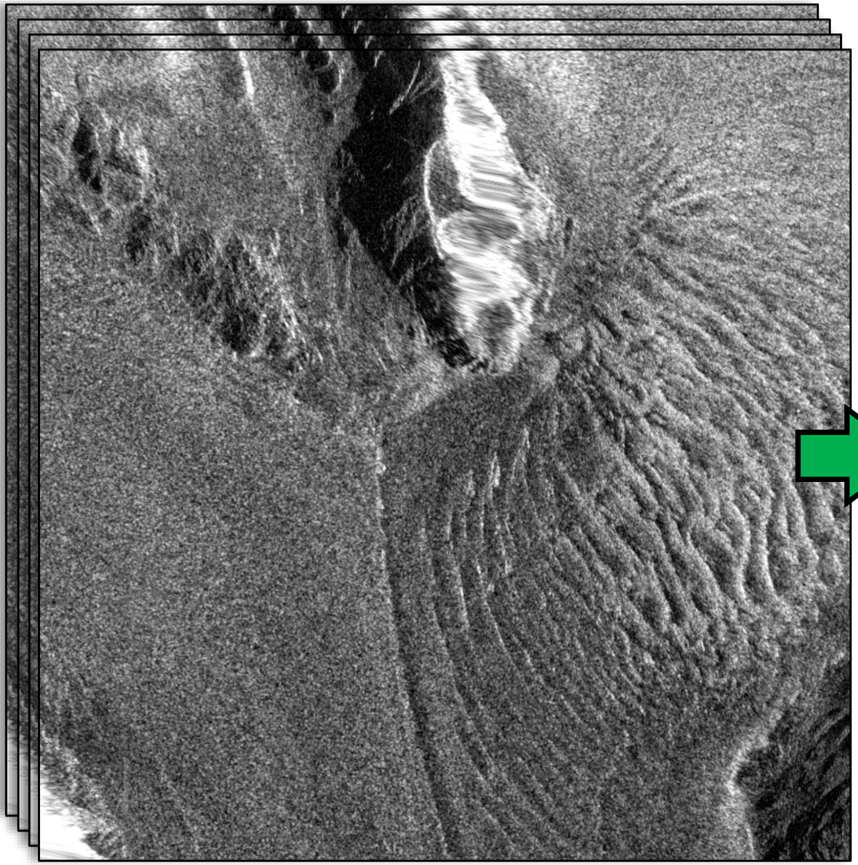
iterate v_{test} in a defined sampling domain

Method summary:

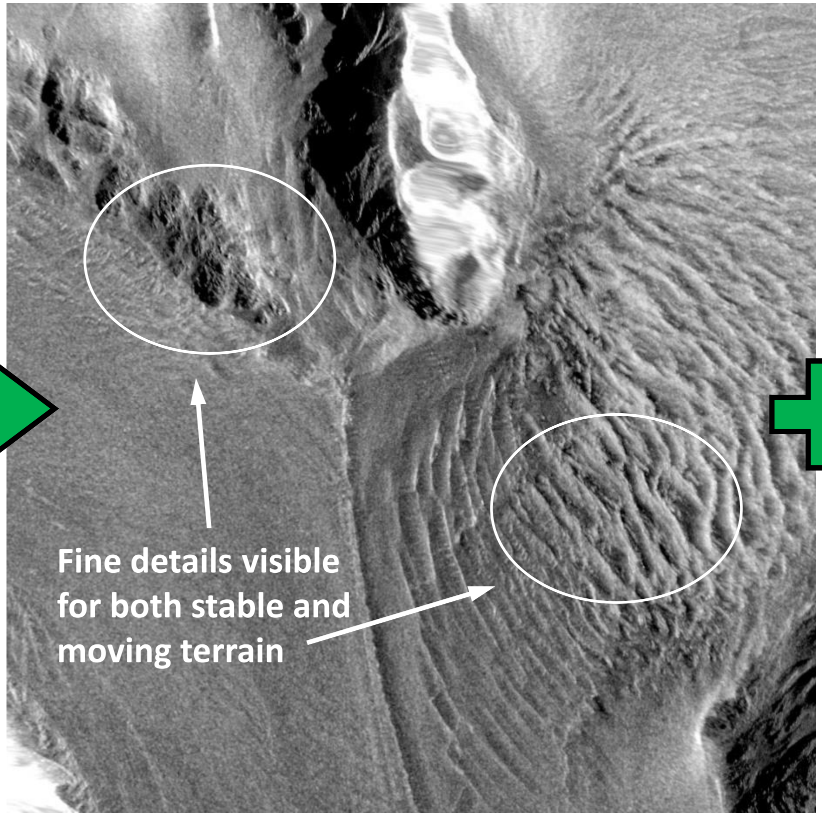
- Basically, we sample the NCC in the spatial domain. Therefore, a *computationally efficient optimization* is required (pyramids).
- For offset estimation we *assume a* *<u>locally constant velocity</u>*.
- Instead of correlation of image pairs, we first average N/2 images for speckle reduction and correlate then the averaged sub-stacks.
- Because we reduce speckle we can use smaller correlation windows (30x30 px, instead of e.g. 96 x 96 px).

Results I/IV

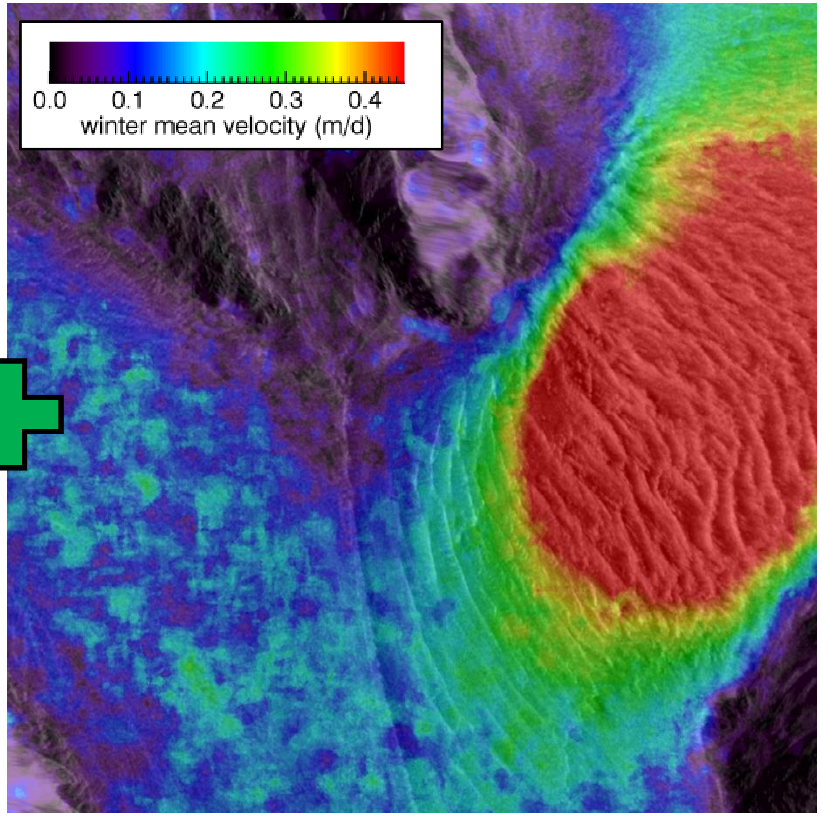
We correlate “speckle-reduced” radar images (sub-stacks) → surface feature better visible
→ Improved cross correlation → smaller template size required for image matching
→ Result: High resolution velocity maps + high coverage also in difficult areas.



Stack of radar images:
Speckle deteriorate pair-wise cross correlation; few surface features visible.



Motion-compensated time average of sub-stack
+ strong speckle reduction
+ details visible in stable and moving area
+ good tracking of features



Velocity estimated from a stack of 12 images.
+ 30 pixel resolution (= 70 meter resolution)
+ much higher coverage (→ next slide)

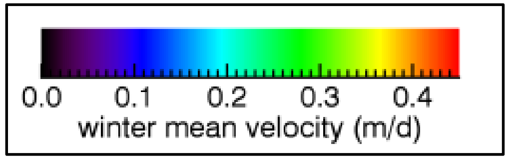
Results II/IV

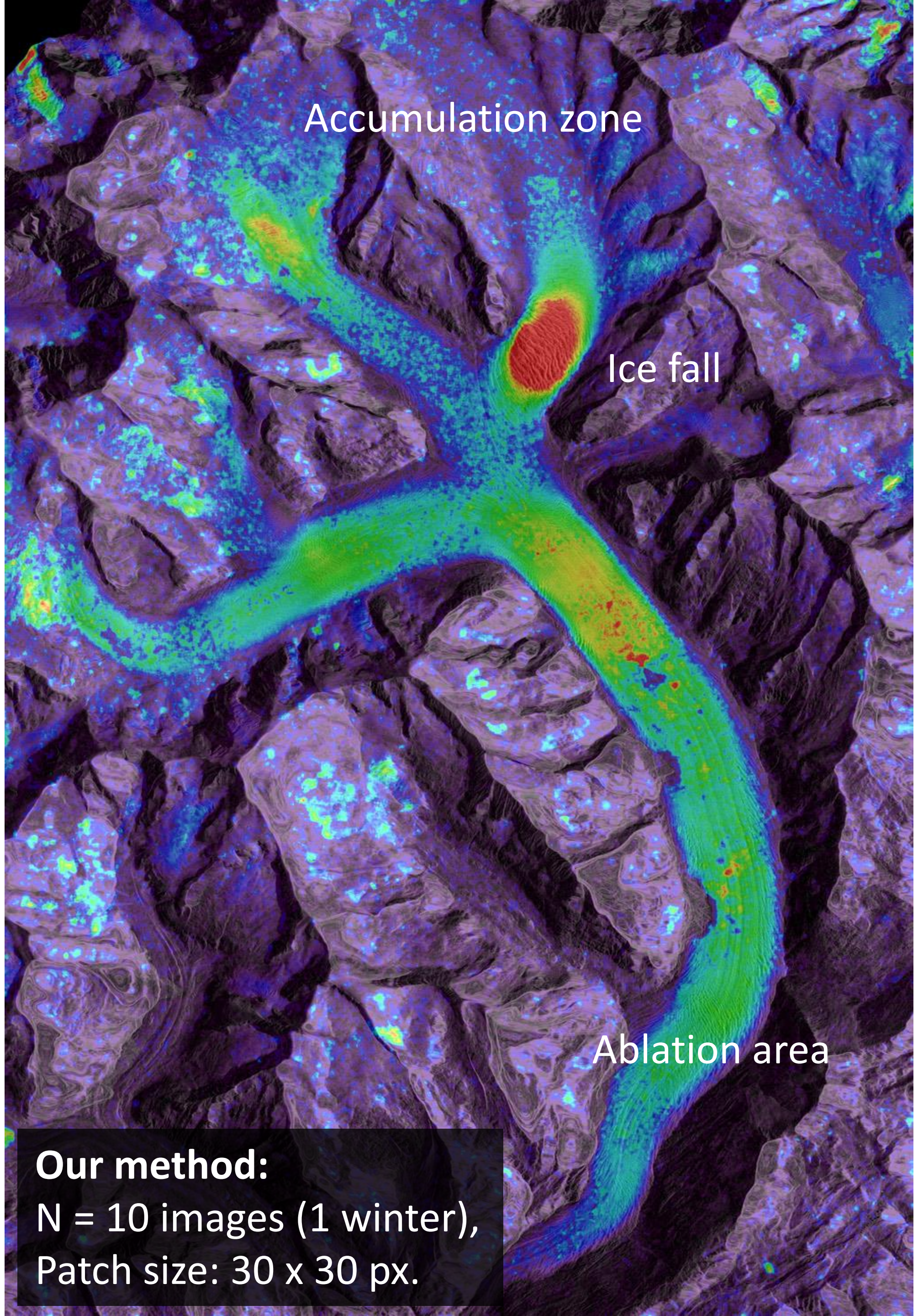
Velocity magnitude

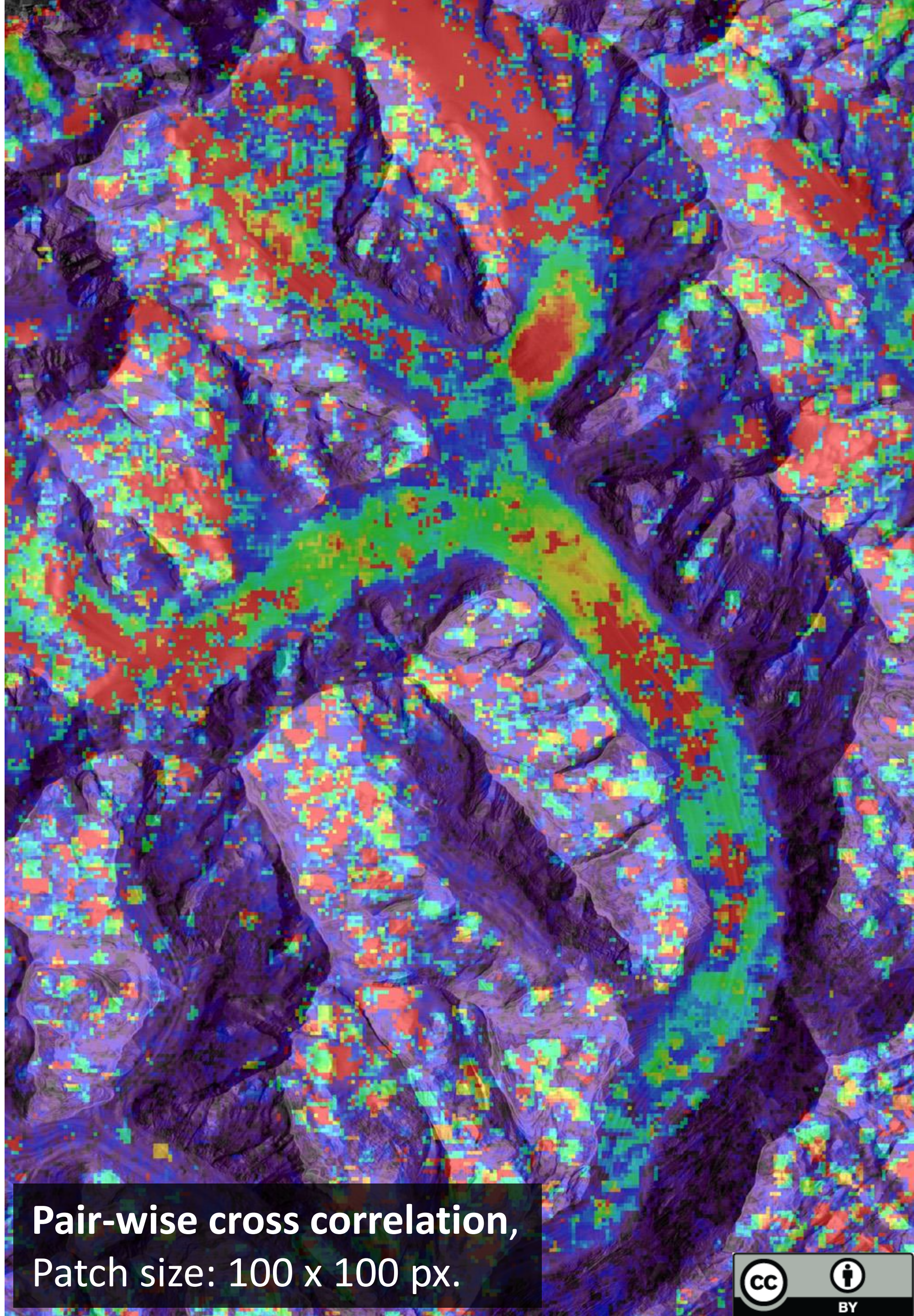
Test site:
Aletsch Glacier, Switzerland
Radar images:
TanDEM-X
Winter 2011/2012
(11 days repeat cycle).

Our method (left) provides robust velocity estimates (even in the accumulation zone) with high area coverage and high spatial resolution.

With **pair-wise cross-correlation** (right) many areas cannot be tracked, even at lower resolution.



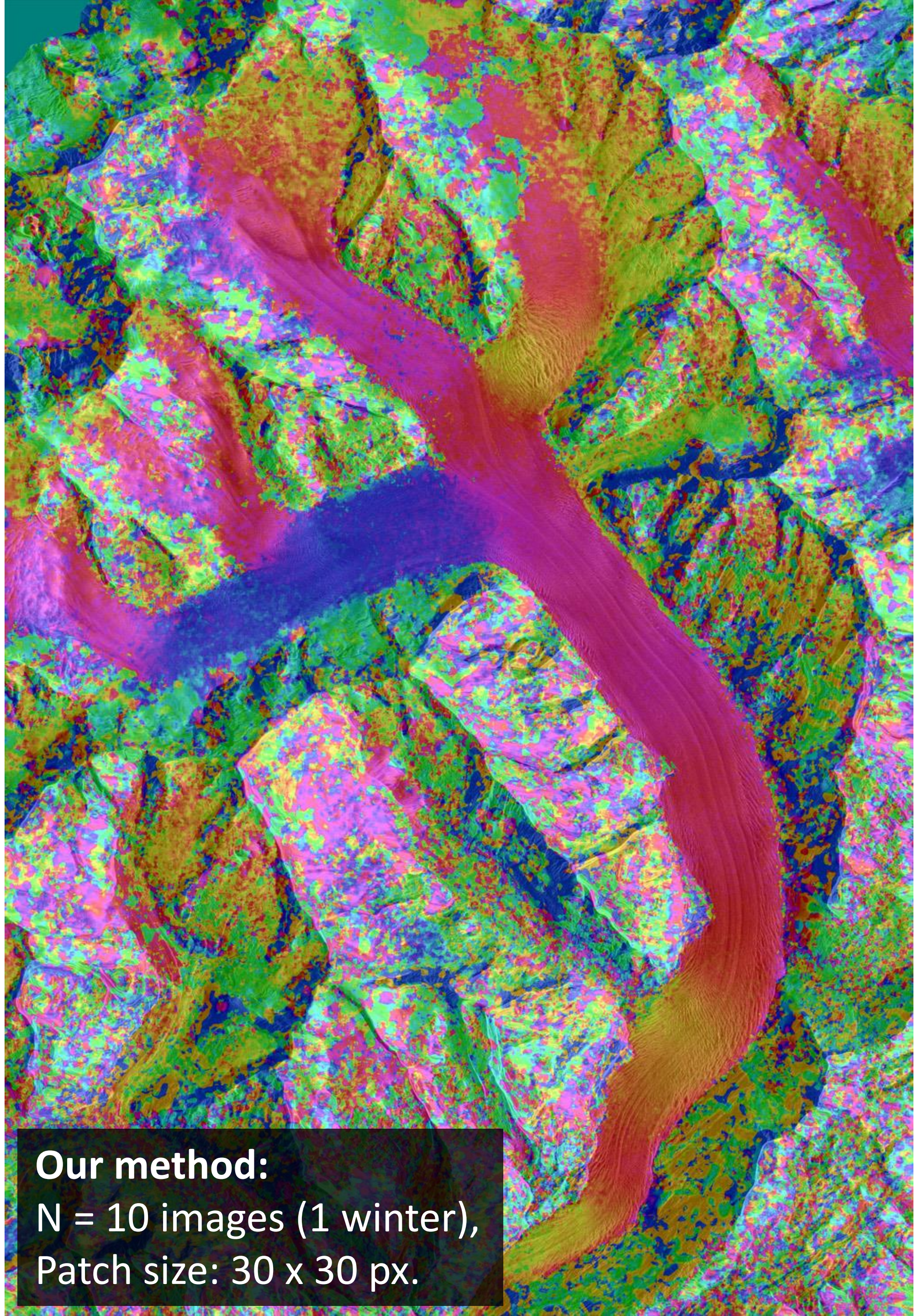


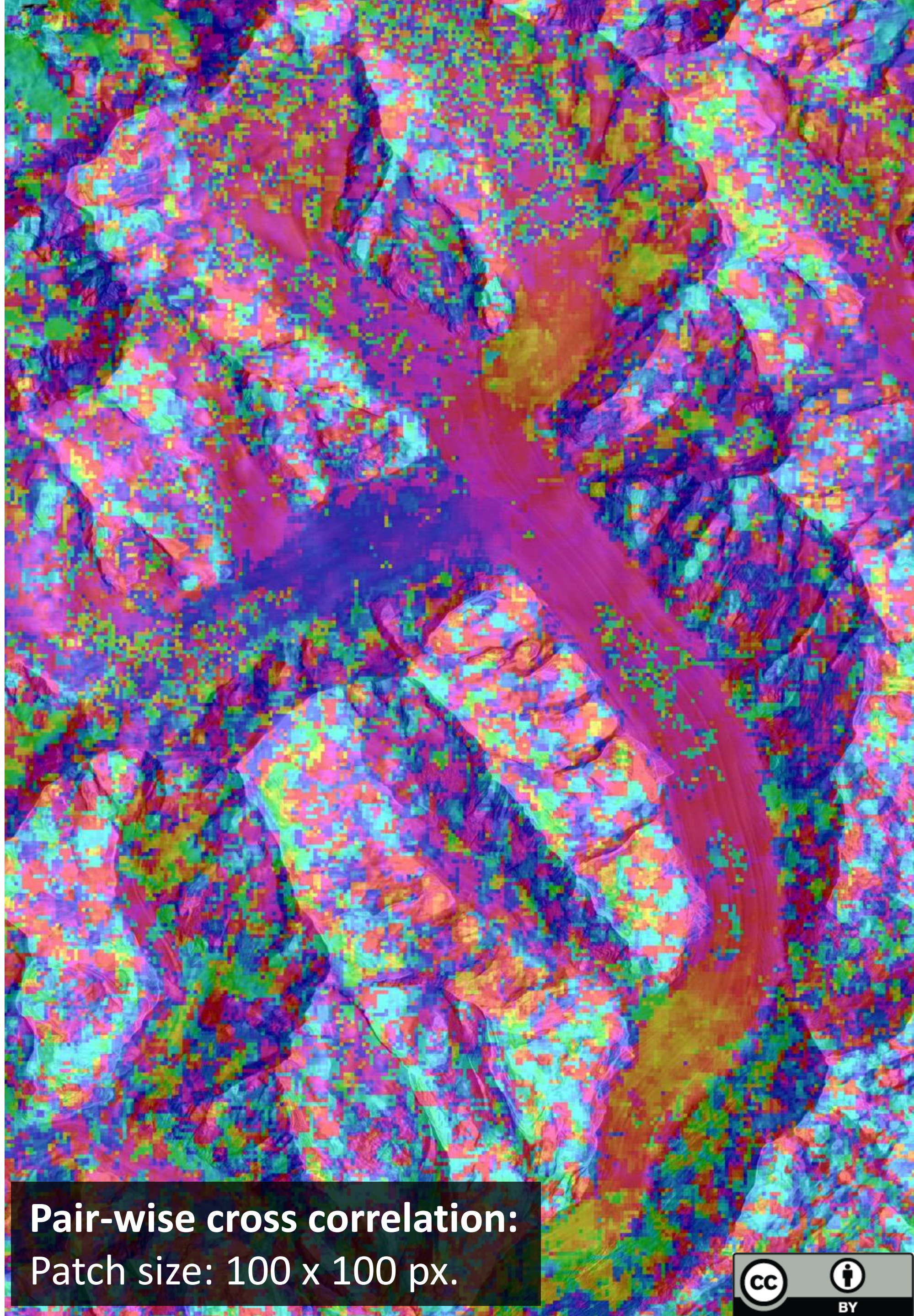


Results III/IV

Velocity orientation

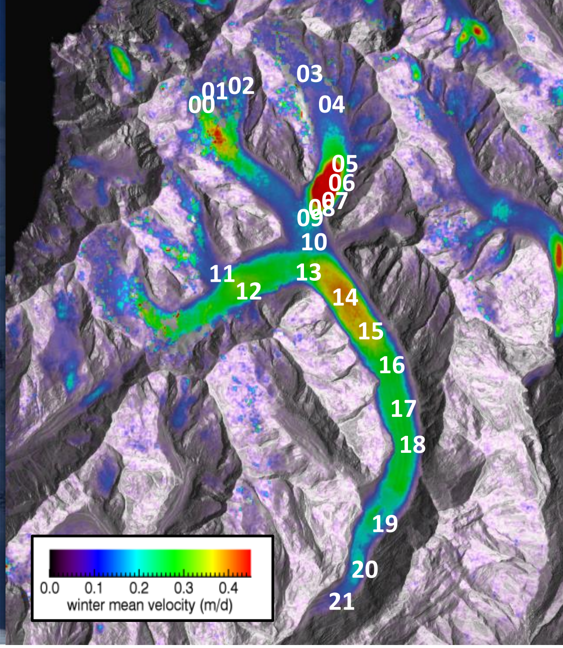
The orientation of the velocity vectors is a good indicator how well the glacier surfaces can be tracked.

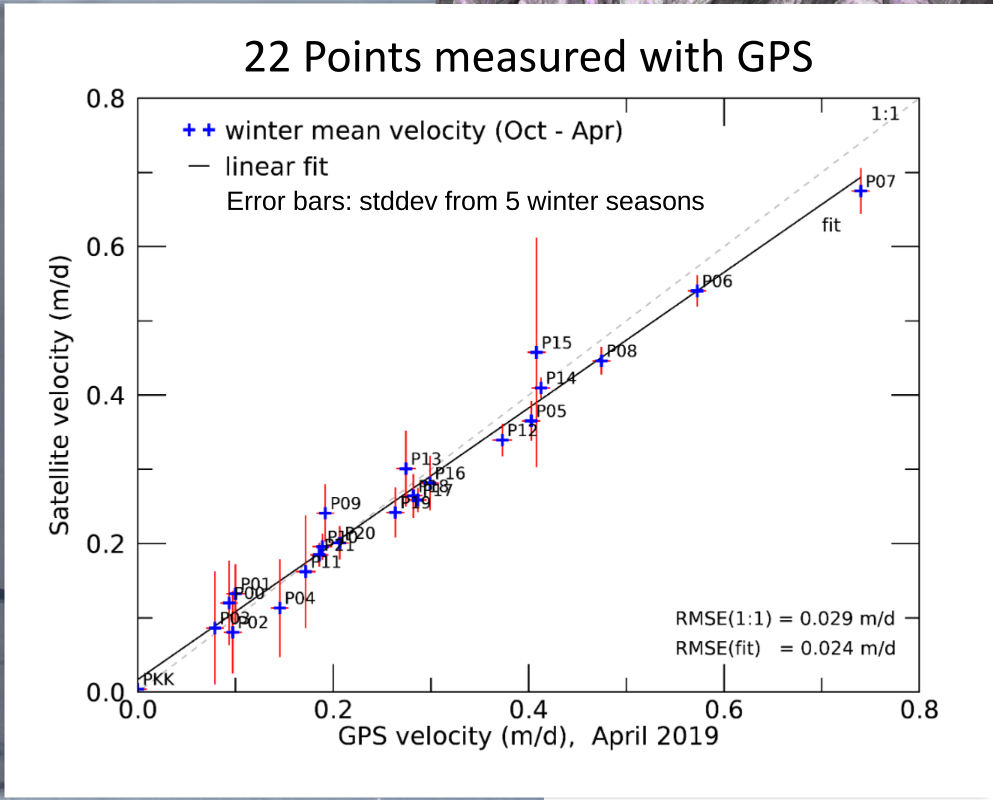




Results IV/IV: Validation of velocity field with GPS

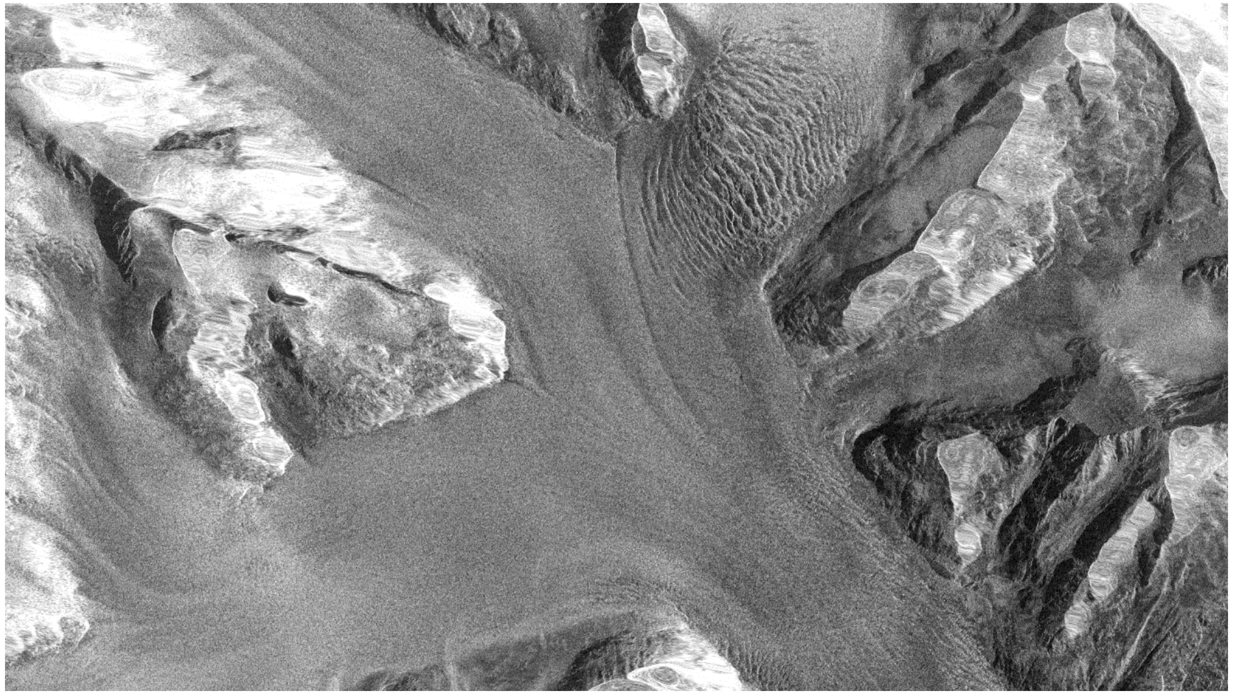
GPS campaign in April 2019

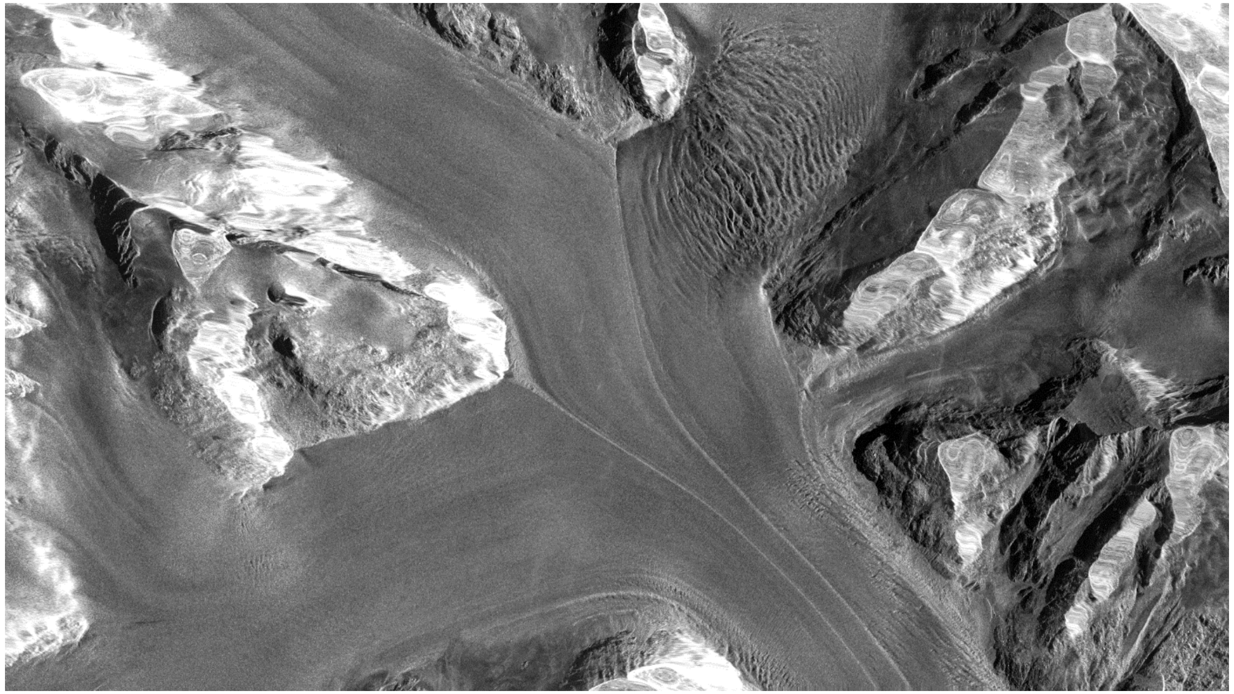




Animation of glacier flow field

The time *t** for which a sub-stack is averaged can be arbitrarily chosen.
Therefore smooth movies can be created from time series containing gaps based on the obtained velocity field.





Click here to watch the smooth, speckle-free animation - based on computed velocity fields and stack averaging:
https://n.ethz.ch/~sleinss/downloads/flowcompensated-aletschglacier-tandemx-2011-2018-timelapse-h264.mp4
2 meter resolution "radar zoom": https://n.ethz.ch/~sleinss/downloads/fc-konkordia-tdm-2011-2018-timelapse-h264.mp4

Click here to watch the standard (stop-motion) animation of input image time series:
https://n.ethz.ch/~sleinss/downloads/input-aletschglacier-tandemx-2011-2018-timelapse-h264.mp4

Summary and Conclusion

- For pair-wise cross correlation with SAR images relatively large image templates (~100x100 pixels) are required due to radar speckle. This limits the spatial resolution of obtained velocity fields. Cross-correlation often fails when no clearly trackable features are visible in the speckle-affected radar images.
- In our method we estimate the *mean velocity* from a (not necessarily equidistant) time series of about N = 8...16 images.
- The time series is split into two sub-stacks of N/2 images. Then every pixel in each SAR image is shifted according to an estimated time-dependent offset with respect to an arbitrarily chosen reference date (preferably the average time of all images). Then the two substacks are averaged along the time axis. Speckle are highly reduced.
- If the estimated offset agrees with the true offset (i.e. the true velocity was found), image features don't show motion blur and the cross-correlation of the two averaged sub-stacks is maximized.
- Time-averaging reduces the temporal resolution of velocity fields but enhances the spatial resolution (we use a template size of only 30 x 30 pixels for SAR images).
- Compared to pair-wise cross correlation our method is more robust to (speckle-) noise. Therefore, velocity fields can be estimated even in terrain which shows very weakly trackable features (e.g. the accumulation zone of glaciers). However, we *assume a constant surface velocity* during the stack acquisition period.
- The reference date, to which the sub-stacks are averaged, can be arbitrarily chosen. Therefore, smooth, speckle-reduced surface flow animation of the glacier surface can be generated based on a limited (and even unevenly spaced) number of SAR images.
- The presented method is motivated from video processing for image stabilization. It could improve future tracking methods and is well suited to exploit the large number of emerging free and globally available high resolution SAR image time series.