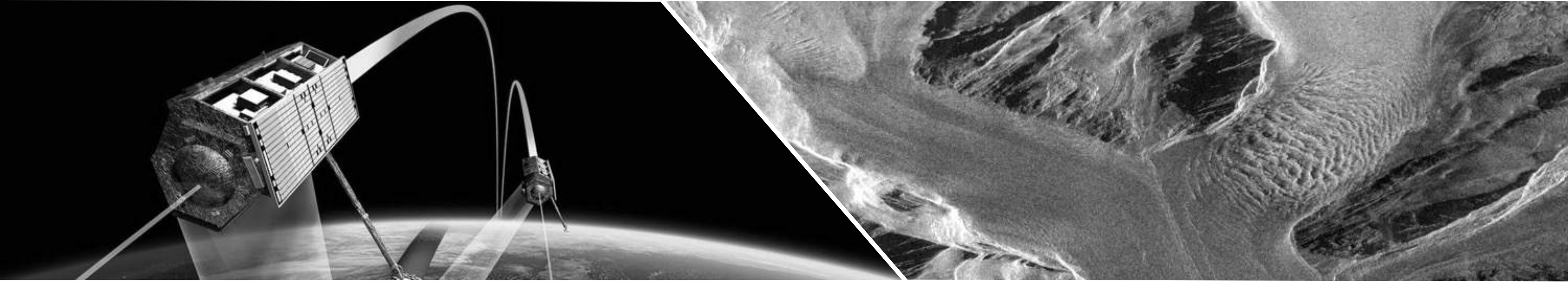

Temporal Stacking of Cross-Correlation for Glacier Offset Tracking

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EGU Sharing Geoscience Online

CR 2.6 - Remote sensing of the cryosphere

07 May, 2020

Earth Observation and Remote Sensing

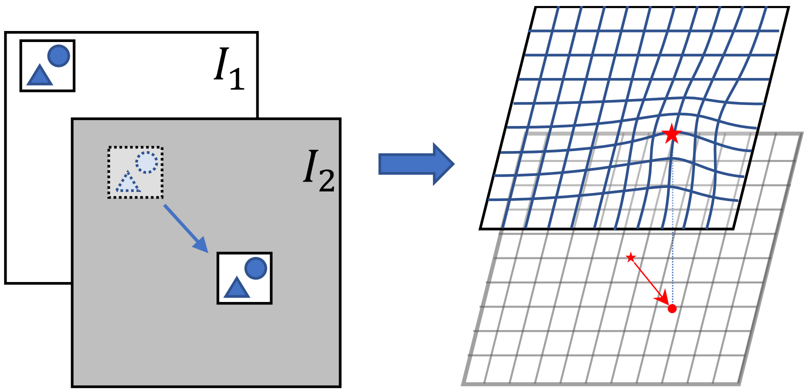
Eidgenössische Technische Hochschule Zürich

Swiss Federal Institute of Technology Zurich

Motivation

Offset tracking has been widely used to measure glacier surface velocities.

In offset tracking, surface displacement offsets are determined by the best matching position between two templates.



CHANLLENGES

Certain template size are required to attain reliable results:

→ Depreciated resolution of velocity field;

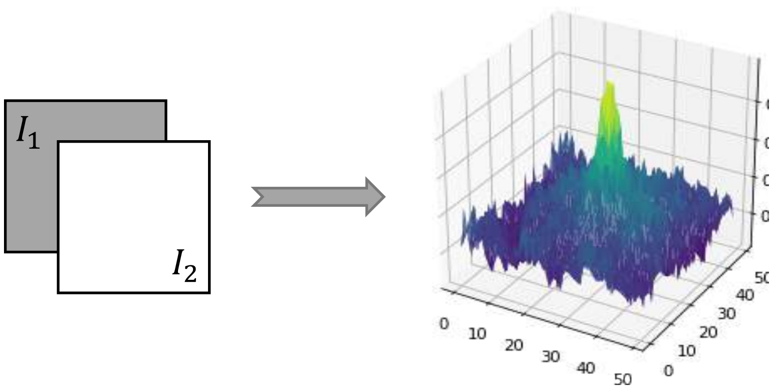
Weakly visible features / Speckles / Image noise / Temporally fast changing content are problematic:

→ Limited coverage of velocity field;

Motivation

Normalized Cross-Correlation (NCC):

$$\gamma_{i,j} = \frac{\sum_{x,y} I_1(x,y) I_2(x+i, y+j)}{\sqrt{I_1^2 \cdot I_2^2}}$$



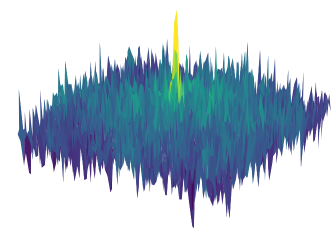
- NCC has been widely used to measure silimarities between templates.
- In an NCC, the offset is determined by its peak. Thus, it is crucial to unambiguously recognize the peak.
- Therefore, the SNR of NCC must be high.

Signal-to-Noise Ratio (SNR):

$$SNR = \frac{C_p^2}{C_f^2}$$

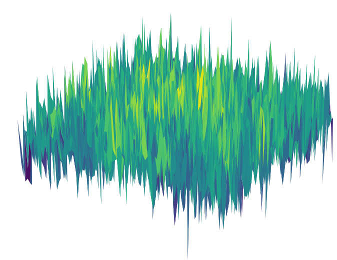
High SNR

NCC peak is clearly identified.



Low SNR

NCC peak cannot reveal itself from ambient noise.



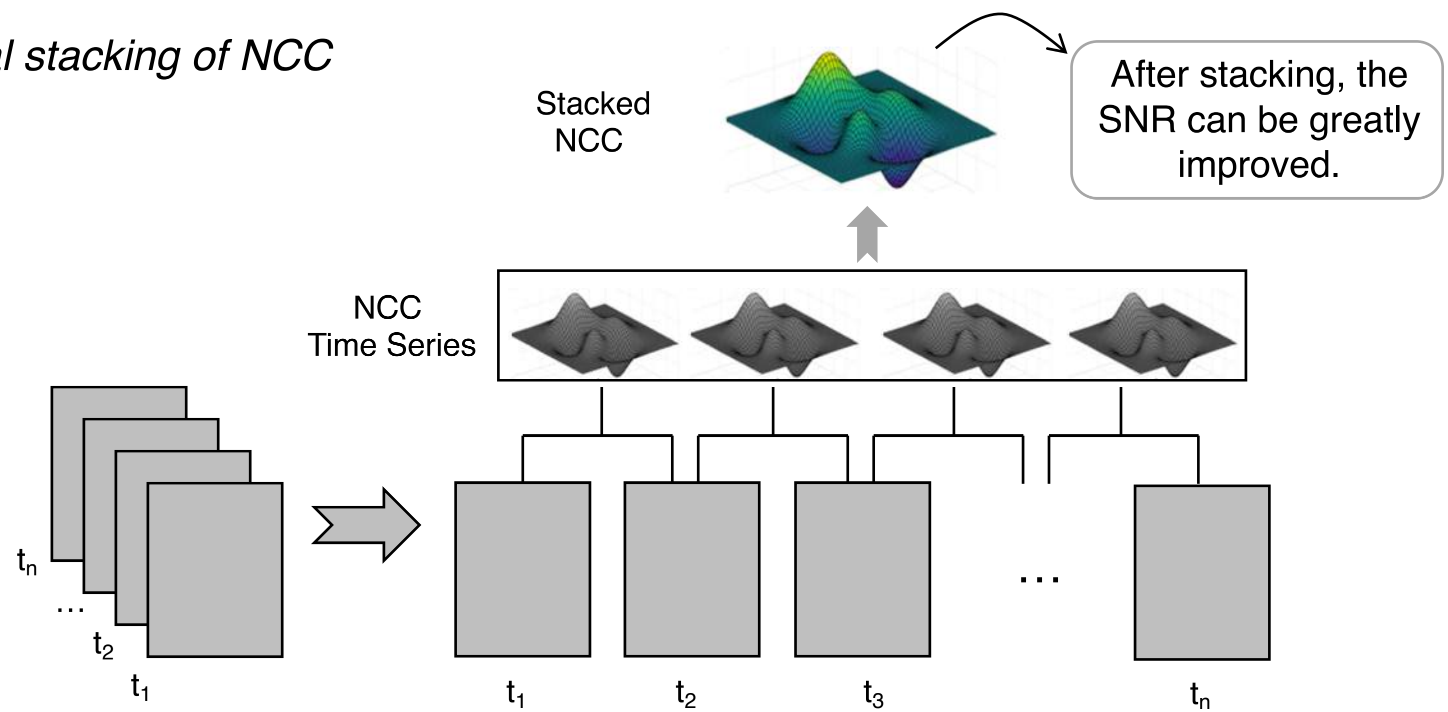
Temporal Stacking of Cross-Correlation

Assumption:

Glacier velocity is constant during data acquisition periods. Hence, offsets in a time series of NCC functions are similar.

- NCC peaks in the time series: more or less on the same position;
- Ambient fields: independent noise that can be suppresed by averaging

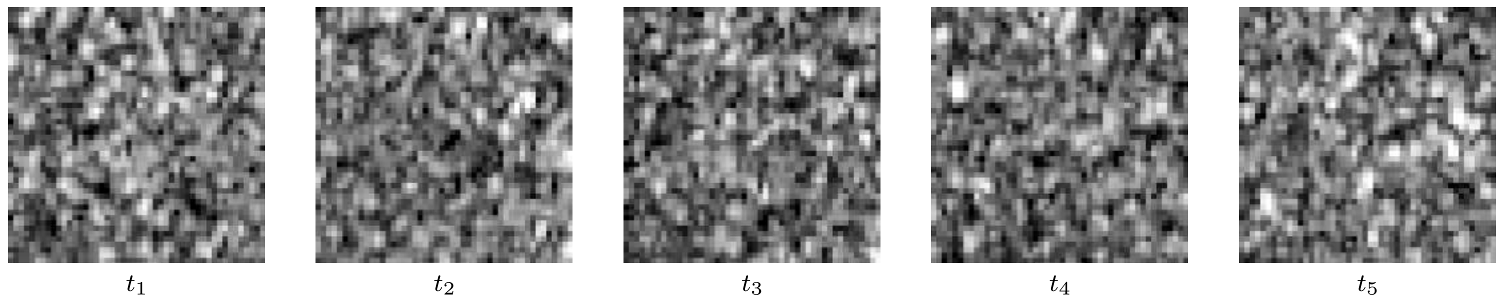
Temporal stacking of NCC



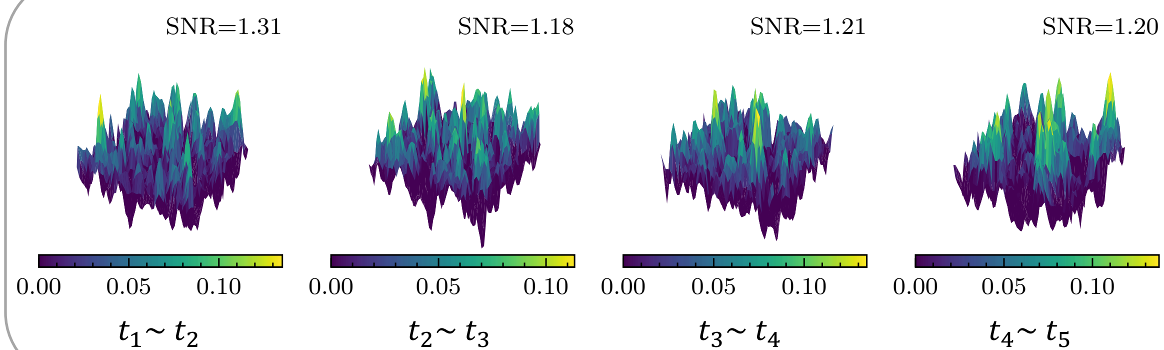
Temporal Stacking – An Example

Example templates

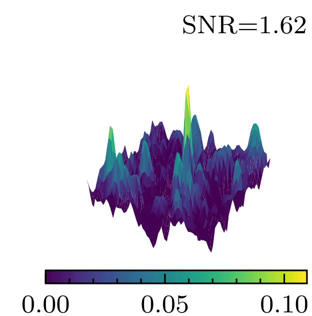
extracted from SAR image series



Pair-wise NCC



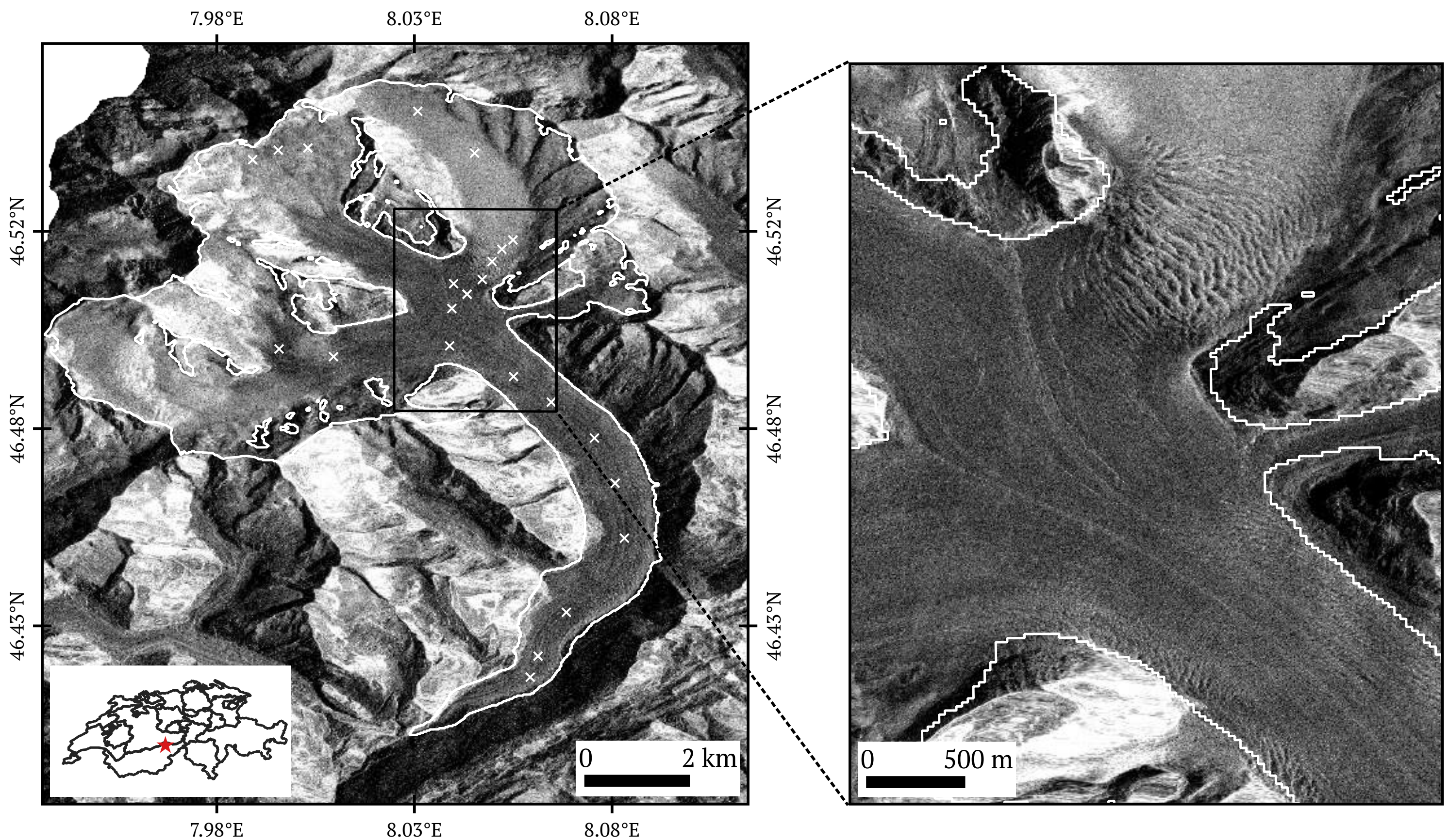
Stacked NCC



Experiment – Study Area

Aletsch Glacier:

- The largest glacier in the Alps;
- Length ~ 23 km; Coverage ~ 81.7 km^2



A SAR image of the Aletsch Glacier. White crosses indicate the location of in-situ velocity measurements.

Experiment – Data and Pre-processing

TanDEM-X
Data Properties

Polarization	Dual Pol (VV, HH)
Incedence Angle	32 degree
Orbit	154 descending
Dates	2017-01-10 2017-01-21 2017-02-01 2017-02-12 2017-02-23 2017-03-06 2017-03-28

GPS Measurements

- In-situ velocity measurement was conducted at 22 points;
- Place stakes on the glacier and measure the displacements after seven days with GPS.
- Measured four weeks after the onset of snowmelt at the glacier tongue (End of March until end of May).

Pre-processing
Steps

1 VV and HH polarization average

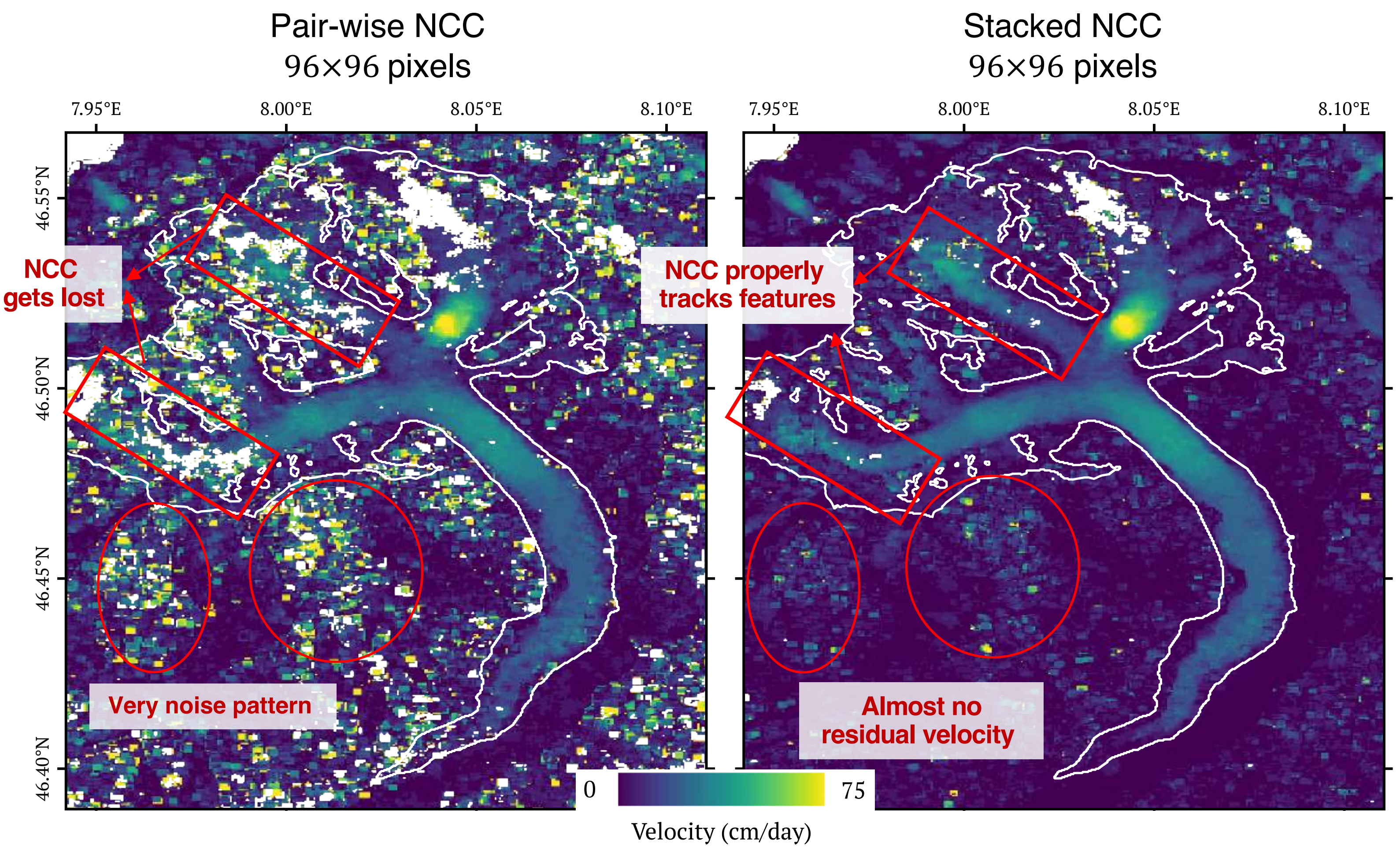
2 Coregistration & Orthorectification (SwissAlti3D elevation model)

3 Gaussian high-pass filtering
kernel size = 51×51, *std* = 17×17

4 Extract templates
48×48 *pixels or* 96×96 *pixels*

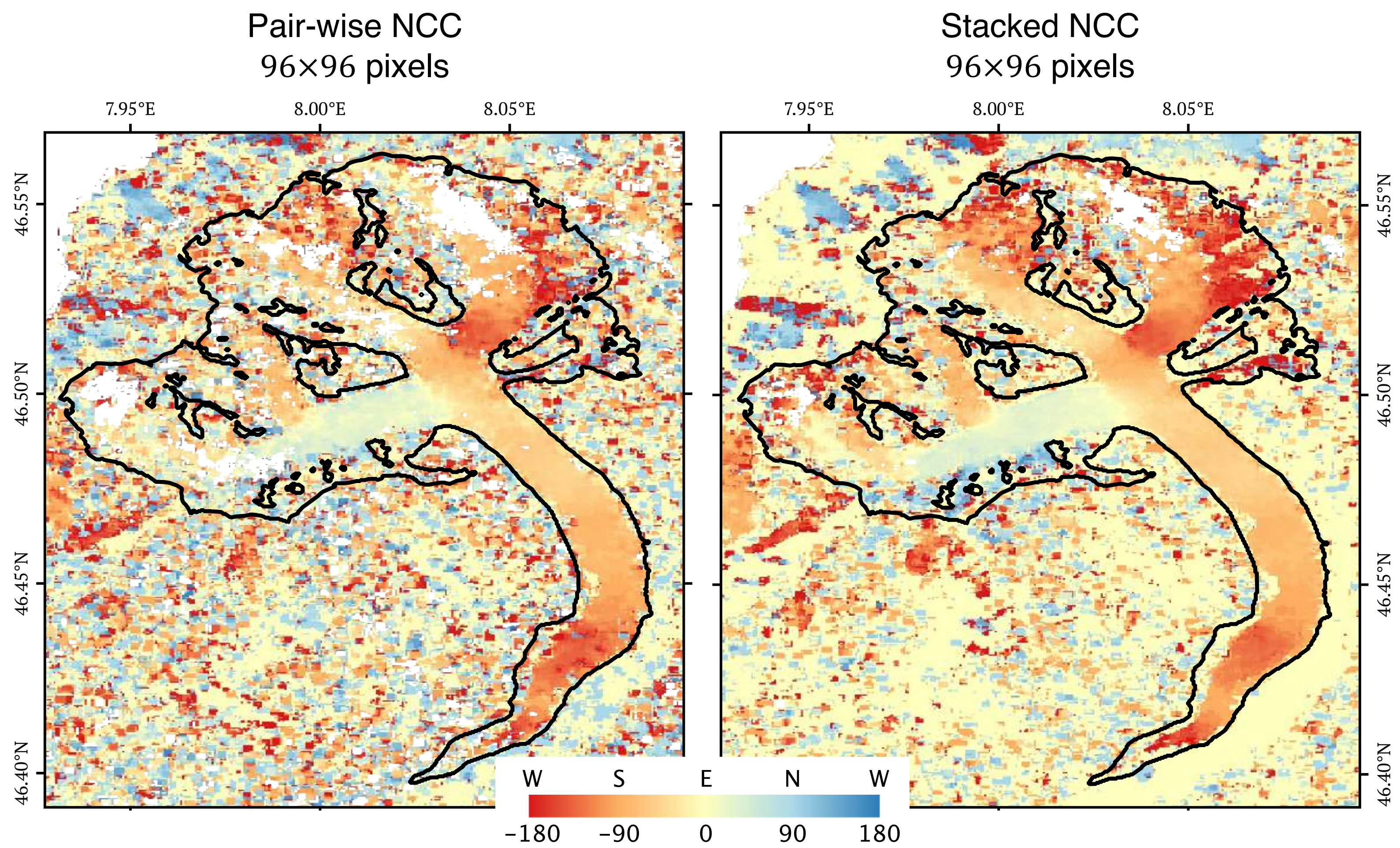
5 Upsampling templates to achieve sub-pixel accuracy
upsampling rate = 4

Results – Velocity Magnitude Maps



Outlier Removel: V > 150 cm/day or SNR < 1

Results – Velocity Direction Maps



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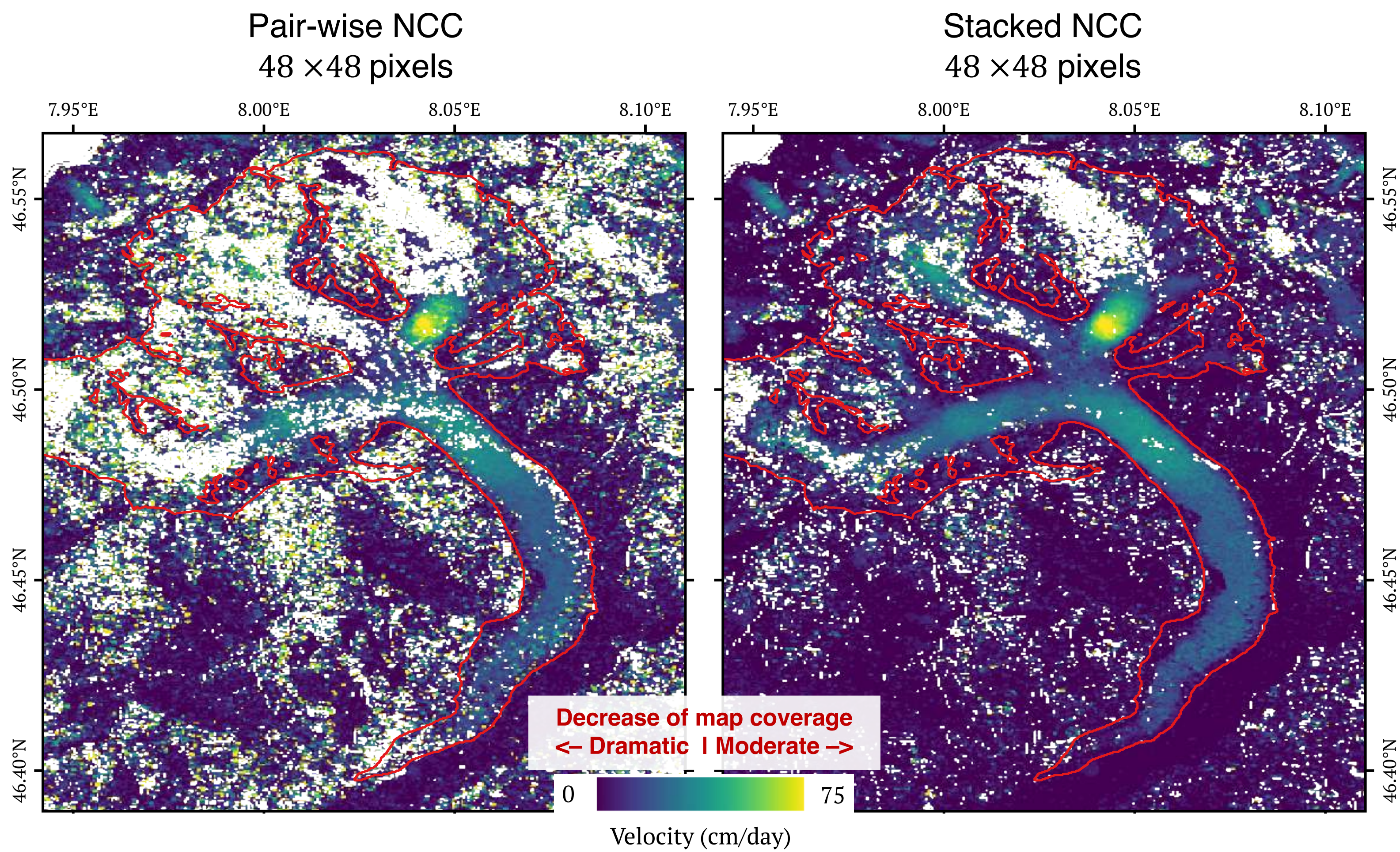
Results – Velocity Magnitude Maps



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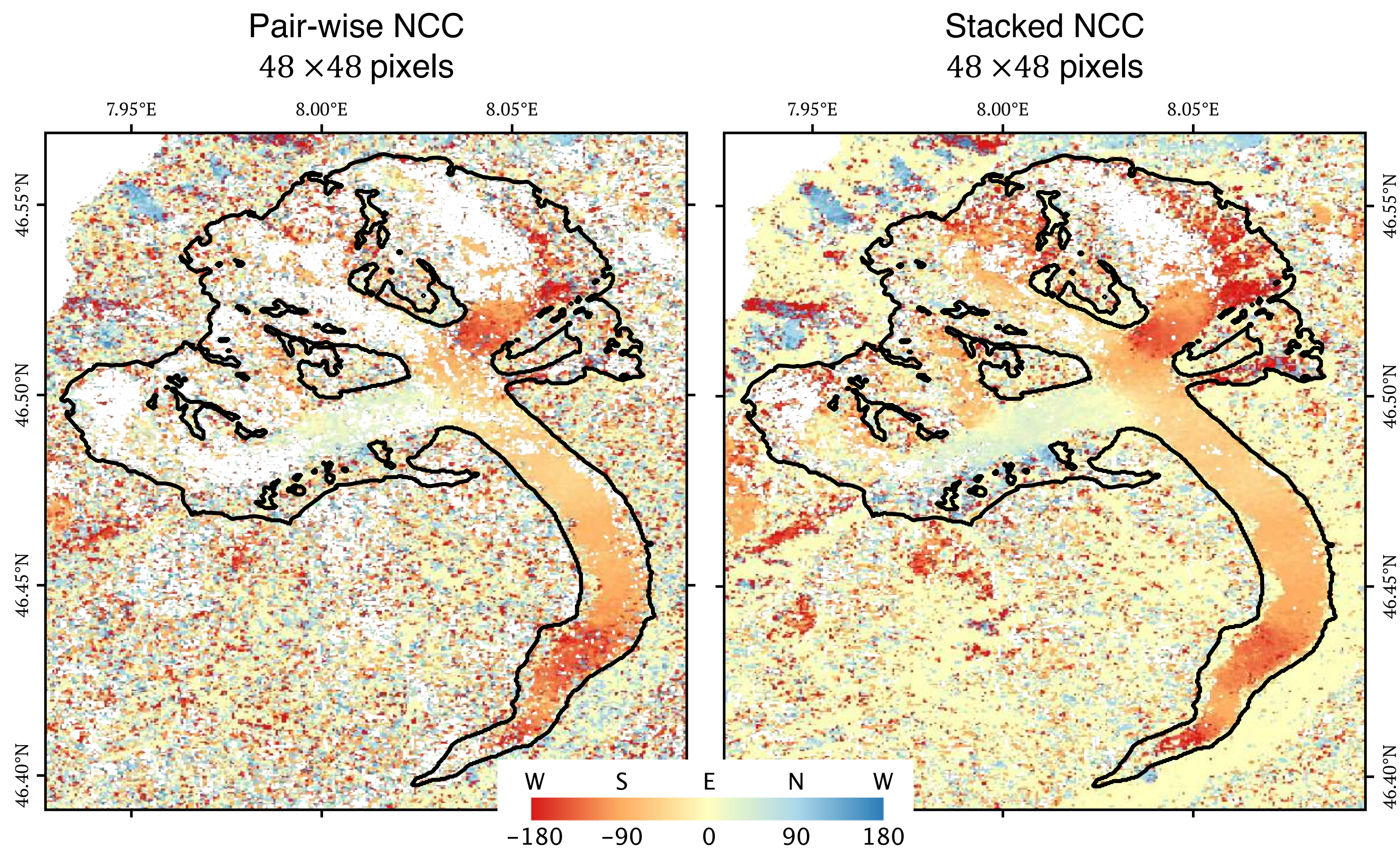
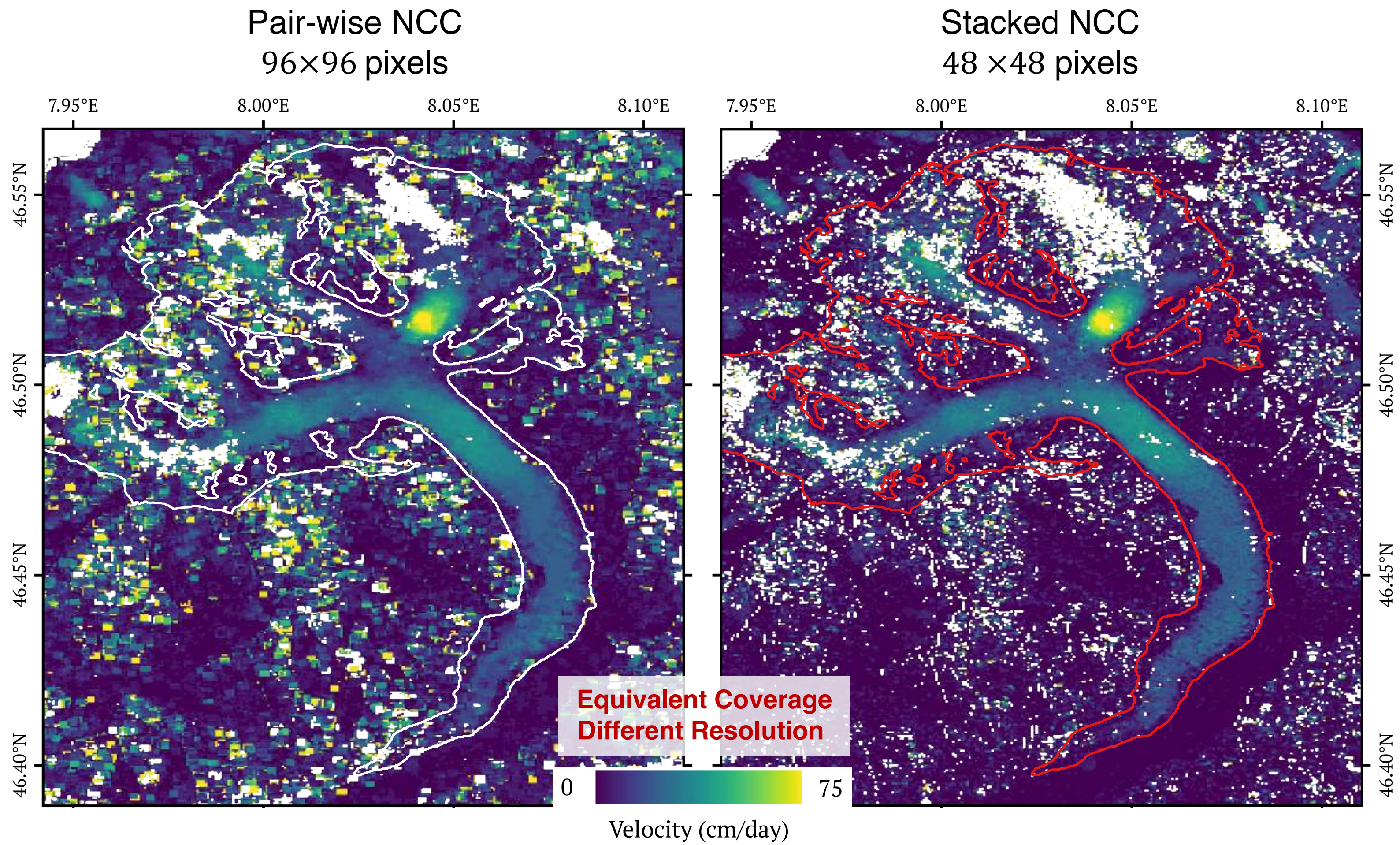
Results – Velocity Direction Maps



Outlier Removel: V > 150 cm/day or SNR < 1

Comparing maps of different template sizes



Outlier Removel: V > 150 cm/day or SNR < 1

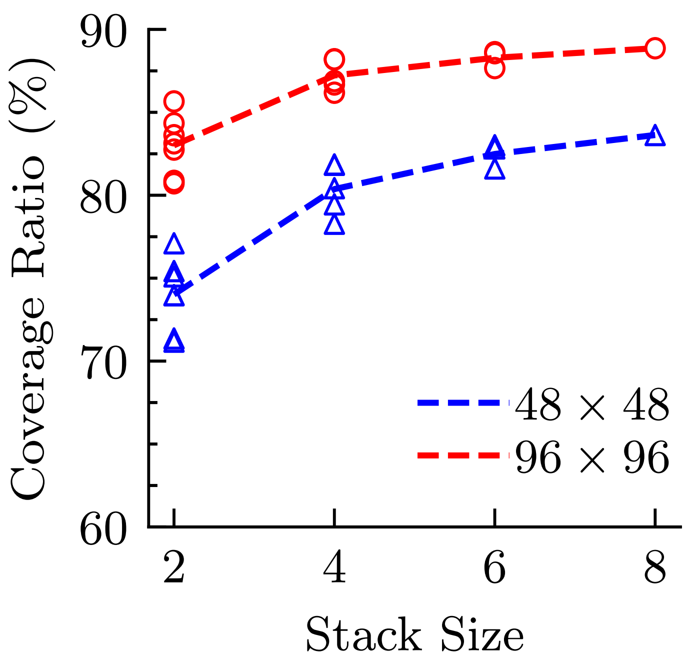
Change of map coverage as stack size changes

Noticing the difference on the coverage of velocity maps over the glacier, it is interesting to quantify the impact of the change of stack size on the coverage.

$$Coverage = \frac{Pixel\ with\ reliable\ velocities}{total\ pixel\ over\ glacier}$$

Here, reliable velocities are the remaining velocity vectors after removing outliers.

Since the aim here is to compare the performance of different methods, the threshold on outlier removal is not optimized, and thus they are not necessarily ensured to be physically reliable.



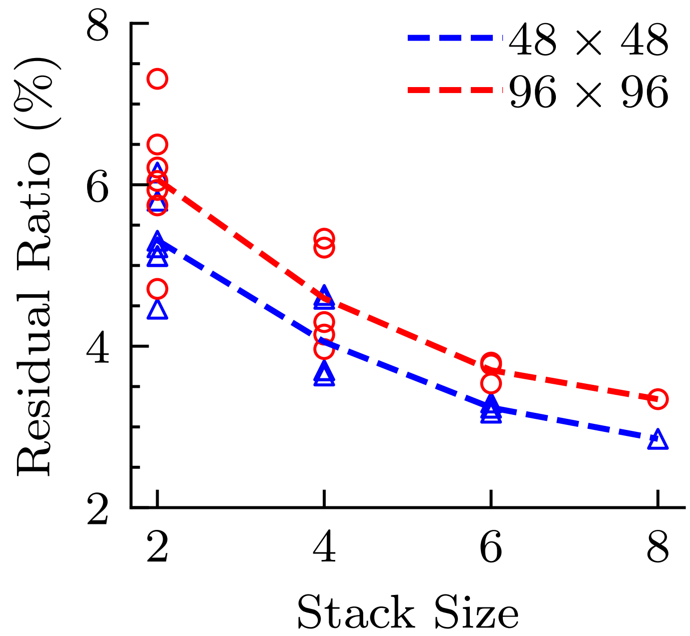
Change of residual velocities as stack size changes

Noticing the difference on the residual velocities over mountainous region, it is also interesting to quantify the impact of the stack size change on velocity residuals.

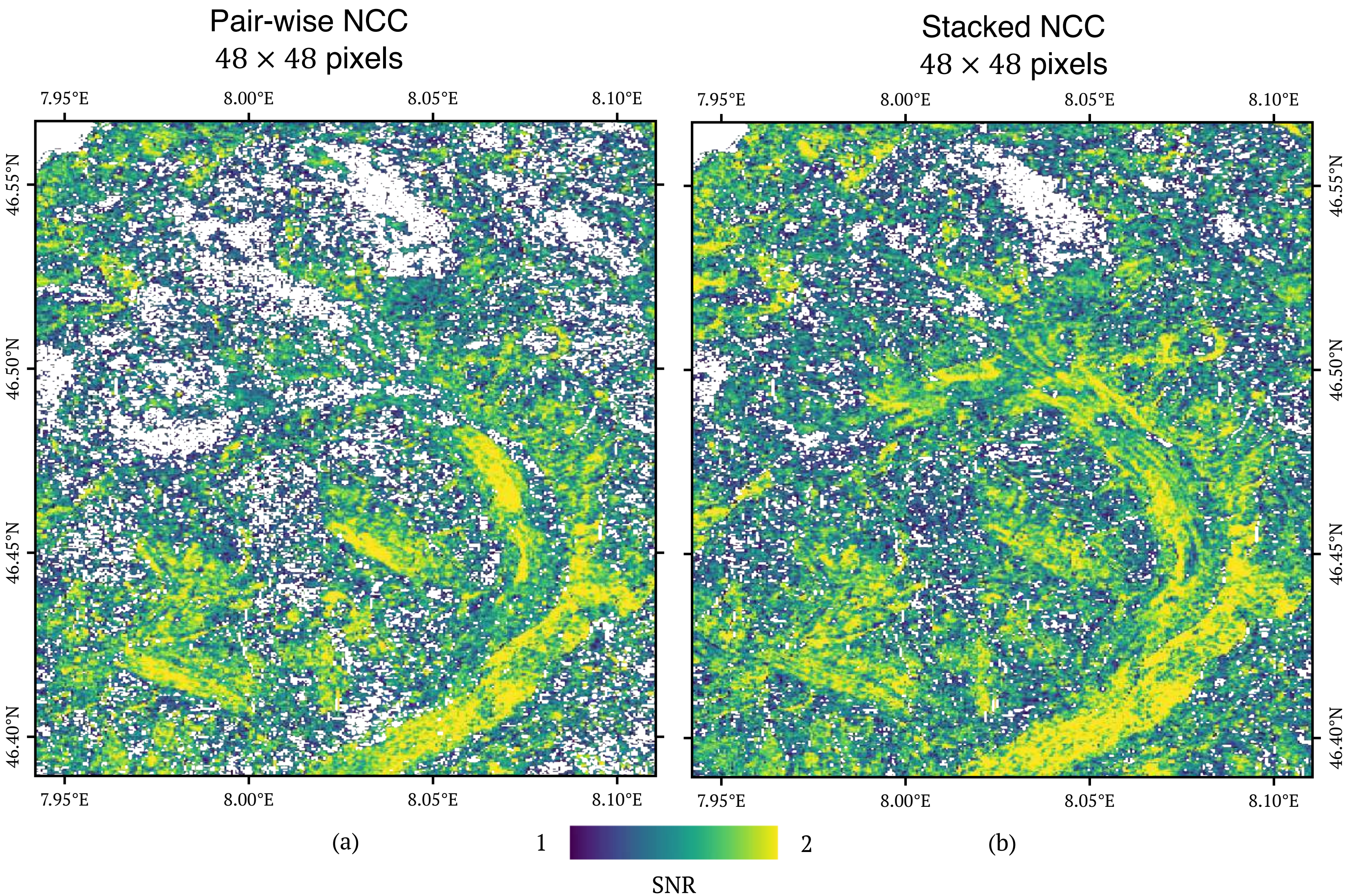
$$Residual = \frac{Pixel\ with\ nonzero\ velocities}{total\ pixel\ over\ mountain\ region}$$

Mountainous regions are considered as static, and thus are often used to assess the tracking accuracy.

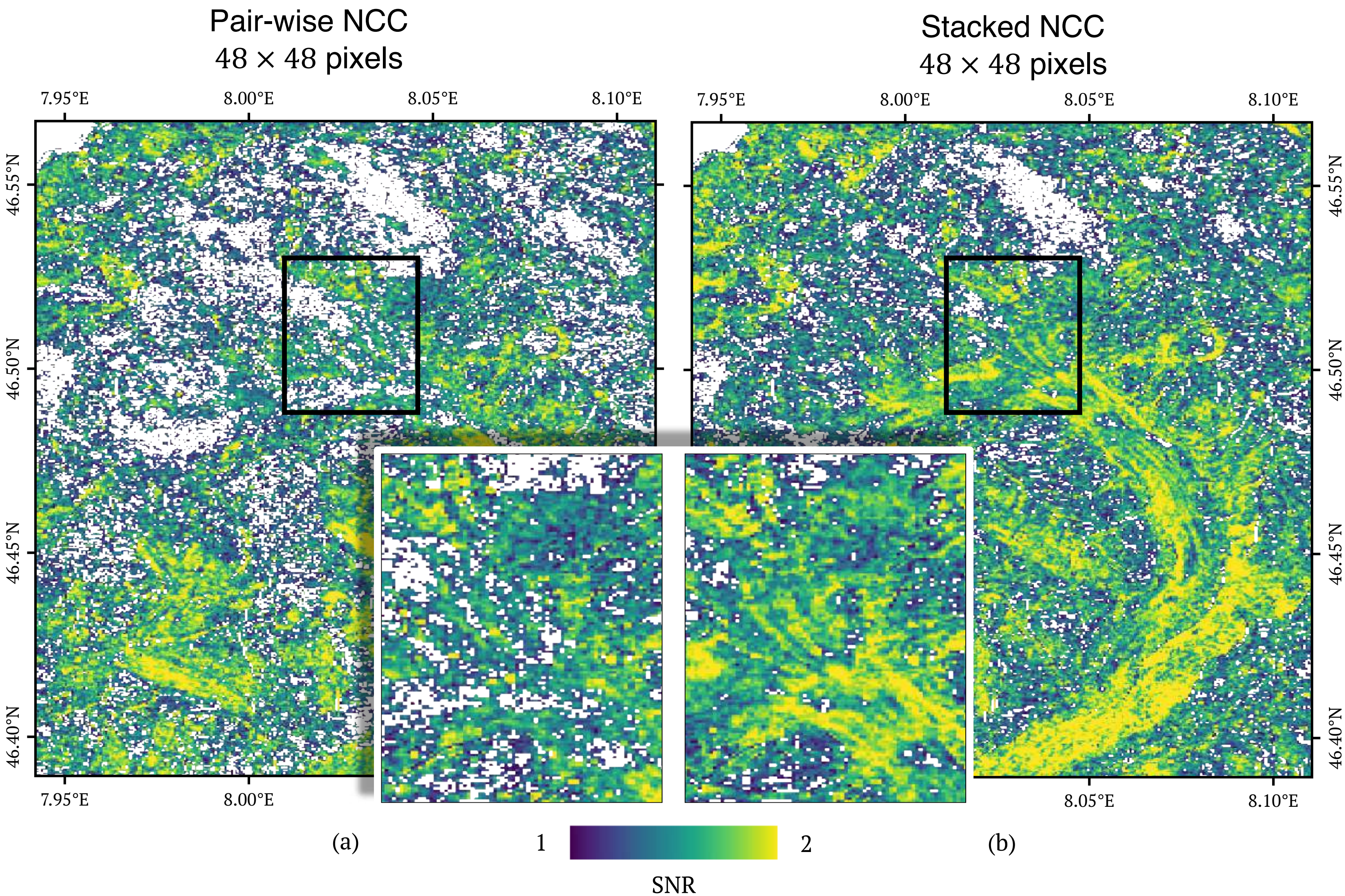
Here, due to the interpolation of velocity maps, the residual rates of velocity maps derived using big templates are higher than that derived from smaller templates. However, it is clear that the residual velocity decreases as stack size increases for both template sizes.



Why the coverage increases? Because SNR improves.

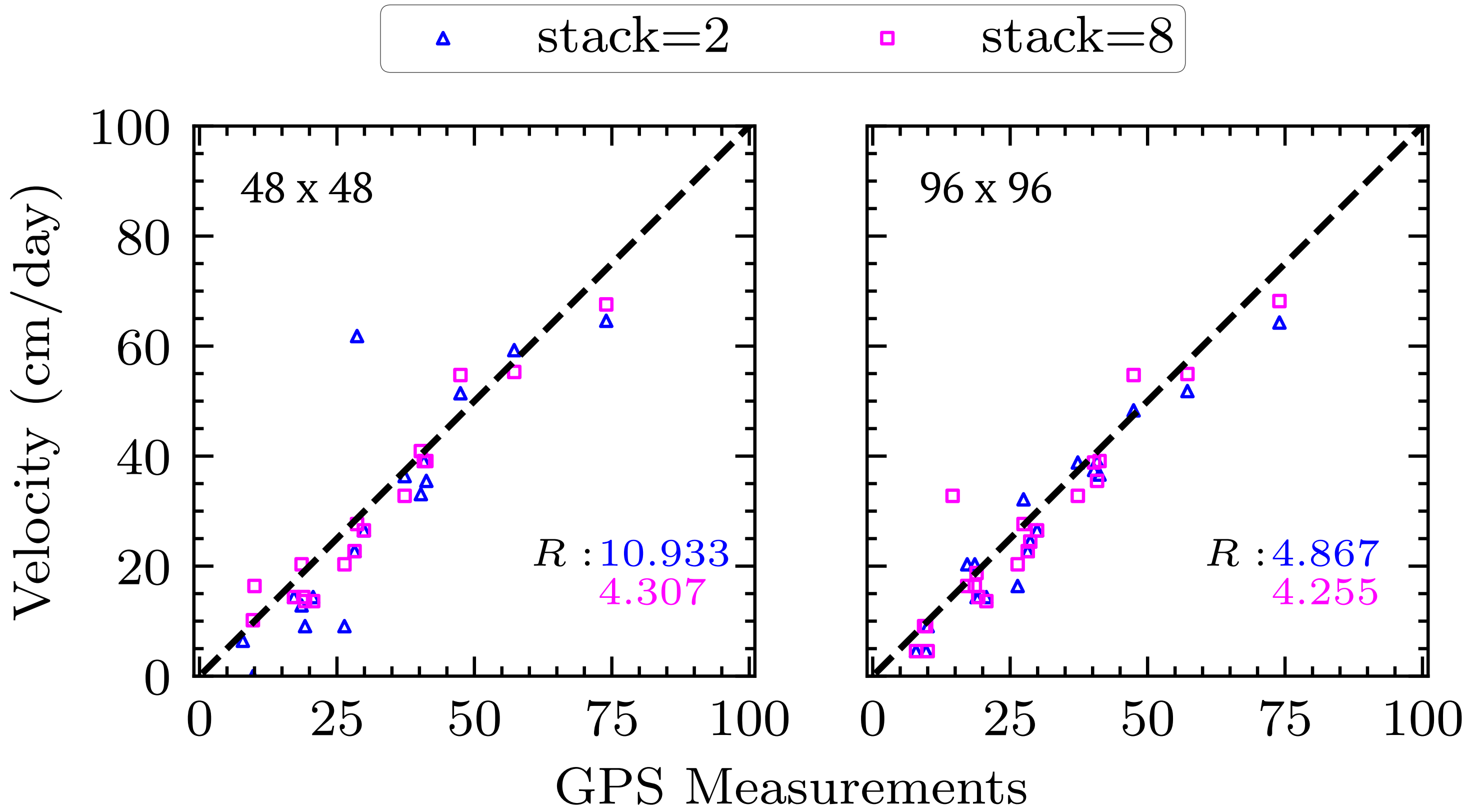


Because SNR improves – A Closer Look



Validate against in-situ GPS measurements

$$R = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(v_i{}^{NCC} - v_i^{GPS})}$$



Conclusion and Outlook

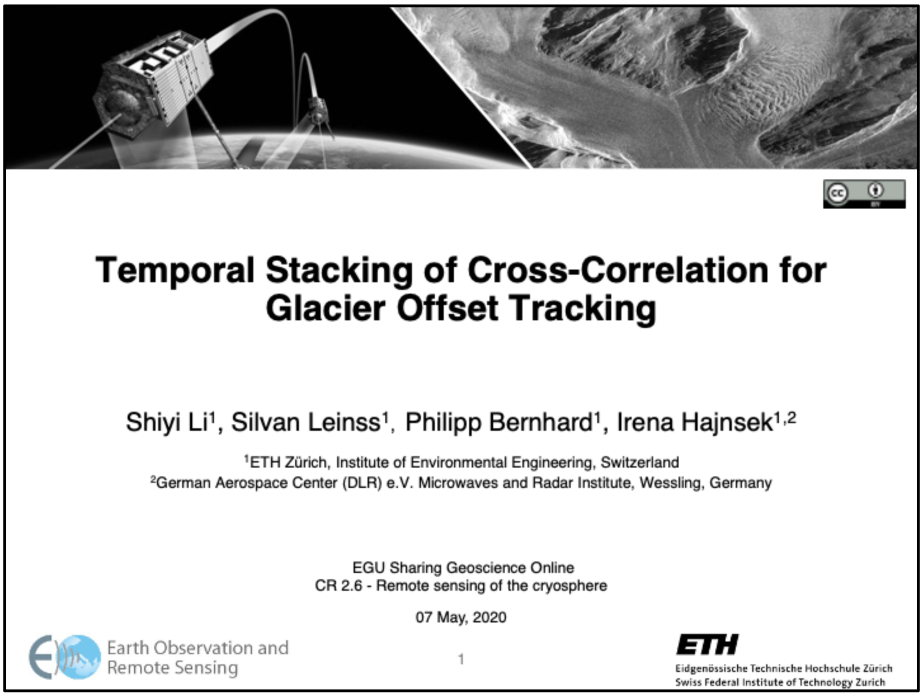
- Effective offset tracking relies on unambiguously identifying the peak of cross-correlations. Temporal stacking of cross-correlations can effectively improve the SNR, and hence can make offset tracking more robust.

- Assuming glacier velocity keeps constant during an acquisition period, a time-series of cross-correlations can be constructed from consecutive image template pairs, and then can be stacked and averaged to attain a temporally stacked cross-correlation.

- Temporal stacking can improve the spatial resolution of velocity maps by allowing using small template sizes. It can also expand the coverage of velocity maps.

- More stacking methods can be developed from data sets containing similar offsets, such as neighboring templates within an image and templates of different polarimetric or spectral channels.

Thank you!

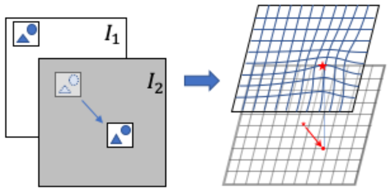


Welcome to the presentation of EGU2020-7348. The work presented here aims at improving glacier velocity measurements by temporally stacking the cross-correlations in offset tracking.

Motivation

Offset tracking has been widely used to measure glacier surface velocities.

In offset tracking, surface displacement offsets are determined by the best matching position between two templates.



CHANLLENGES

Certain template size are required to attain reliable results:
→ Depreciated resolution of velocity field;

Weakly visible features / Speckles / Image noise / Temporally fast changing content are problematic:
→ Limited coverage of velocity field;

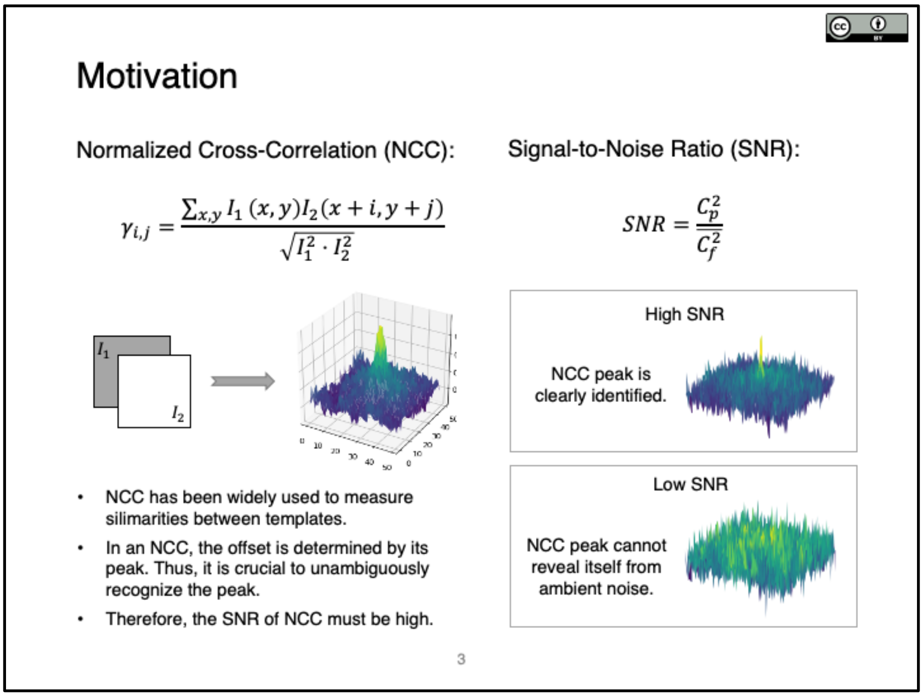
2

Offset tracking is one of the most often used method for galcier velocity measurement. It can be applied to both optical and SAR imagery.

Offset tracking is based on template matching, where the agreement between two templates are eveluated and the best matching position is identified to determine the offsets.

The main challenges for offset tracking involves :

1) the resolution of measured velocity fields: offset tracking requrics sufficiently big templates to attain reliable results, especially when the image condition is not ideal.
2) the coverage of measured velocity fields: when images contains mainly weakly visible features or is strongly containminated by speckles/noise/fast changing contents, offset tracking is very likely to fail and no reliable measurements can be acquired.

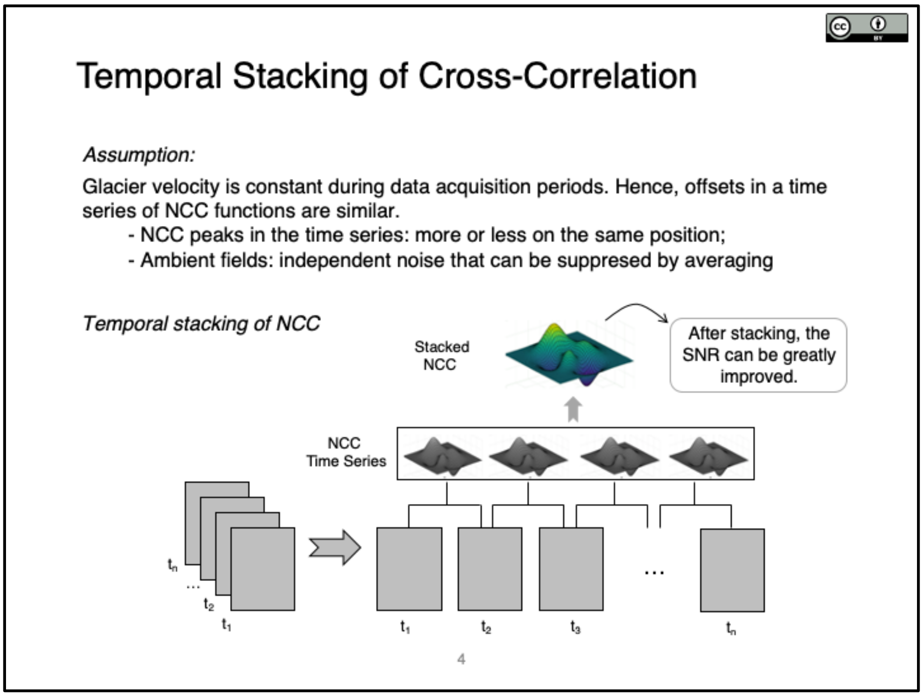


To overcome these issues, we proposed a temporal stacking method in this work.

First let’s look at the nature of an normalized cross-correlation function (NCC). NCC is one of the most often used similarity measure in offset tracking.

In an NCC, the offset is determined by its peak, and thus it is crucial to improve the SNR of an NCC to make the NCC peak identifiable.

Two examples are shown in the slides to illustrage the different scenerios when the SNR is high / low.



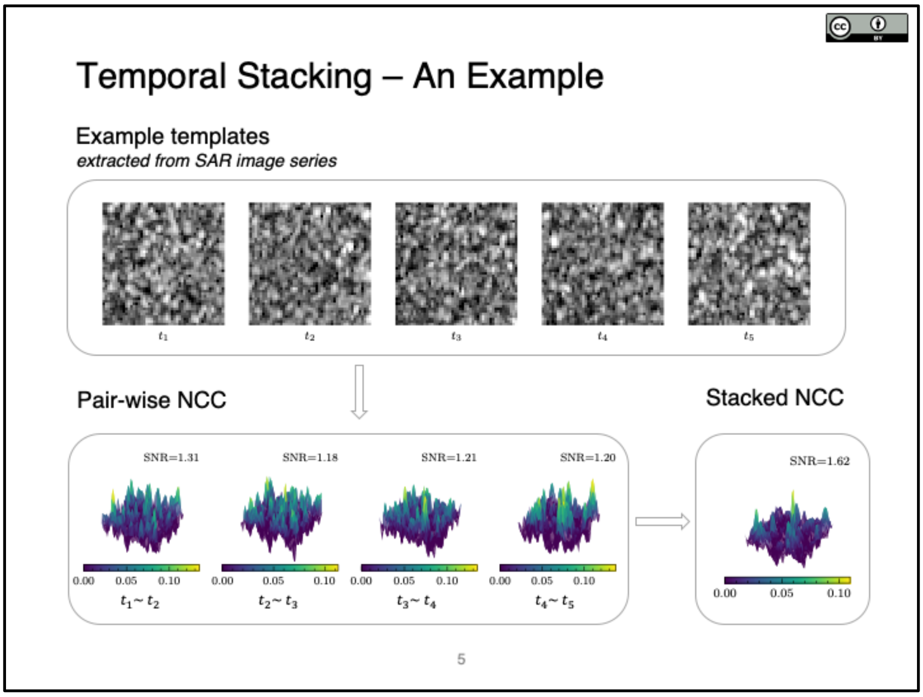
In order to improve the SNR of an NCC, we can employ temporal stacking.

Temporal stacking is based on an NCC time series. As the flow chart in the silde shows, we can construct an NCC time series from every consecutive template pairs of an image time series.

Assuming a glacier flows with constant velocity during the image acqusition period, we can expect that the NCC time series records equal offsets between consecutive template pairs.

Thus, in the NCC time series, NCC peaks are expected to locate at more of less the same postion, and the remaining contents of NCCs can be regarded as independent noise. We can then stack the NCC time series to supress the ambient noise while maintaining the strength of the NCC peak that represents the displacement offsets.

By stacking, we can greatly improve the SNR of the NCC, and thus can use smaller templates for tracking and can make tracking more robust to noise.

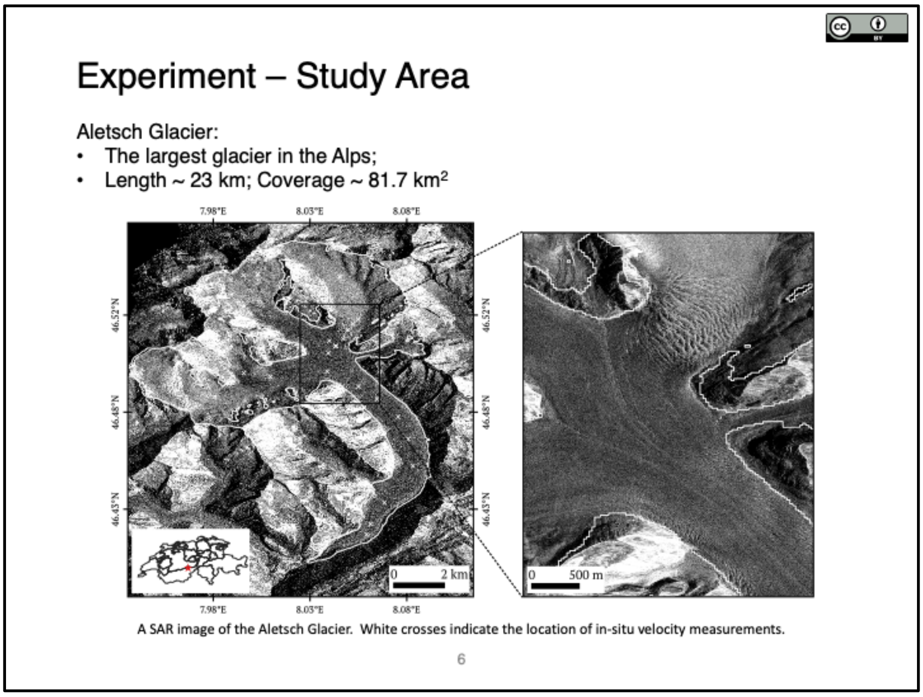


Here we show an example of temporal stacking and how it improves SNR.

We extracted five image templates from a SAR image time series, and constructed an NCC time series from them.

We can see that the pair-wise NCC has very low SNR. They all have multiple peaks, brining large uncertainties to the velocity measurement.

After stacking, the peaks invoked by noise are greatly suppressed, and only one peak that represent the true offset remains strong.



To evaluate the temporal stacking method, we chose the Aletsch Glacier as our study site, and used both pair-wise NCC and stacked NCC for offset tracking to compare their performance.

The map in the slide shows an example SAR image used for tracking. The Aletsch Glacier is the largest glacier in the Alps. Its location is indicated by the inset in the map.

The center region of the Aletsch Glacier is highlighted by the close look on the right, from which we can see strong contrasts caused by the glacier crevasses, and very litte features in the flat region.

Experiment – Data and Pre-processing

TanDEM-X
Data Properties

Polarization	Dual Pol (VV, HH)
Incedence Angle	32 degree
Orbit	154 descending
Dates	2017-01-10 2017-01-21 2017-02-01 2017-02-12 2017-02-23 2017-03-06 2017-03-28

GPS Measurements

- In-situ velocity measurement was conducted at 21 points;
- Place stakes on the glacier and measure the displacements after seven days with GPS.
- Measured four weeks after the onset of snowmelt at the glacier tongue (End of March until end of May).

Pre-processing
Steps

1 VV and HH polarization average

2 Coregistration & Orthorectification (SwissAlti3D elevation model)

3 Gaussian high-pass filtering
kernel size = 51×51, *std* = 17×17

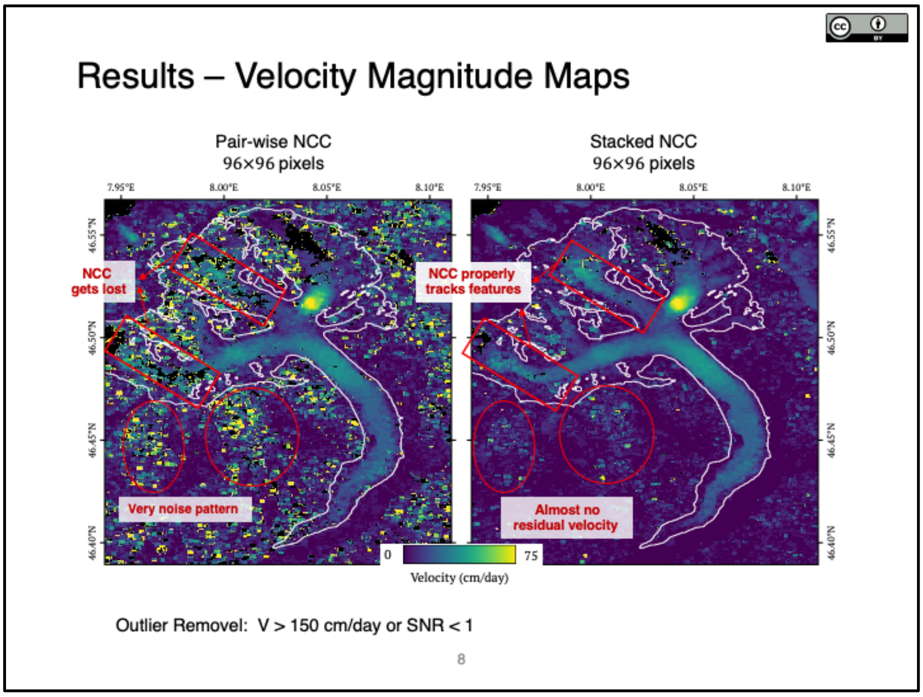
4 Extract templates
48×48 *pixels or* 96×96 *pixels*

5 Upsampling templates to achieve sub-pixel accuracy
upsampling rate = 4

7

In this study, we used eight SAR images obtained by TanDEM-X. We also used in-situ glacier velocity measurements to benchmark the velocity measured from offset tracking.

Steps for data pre-processing is shown in the slide.

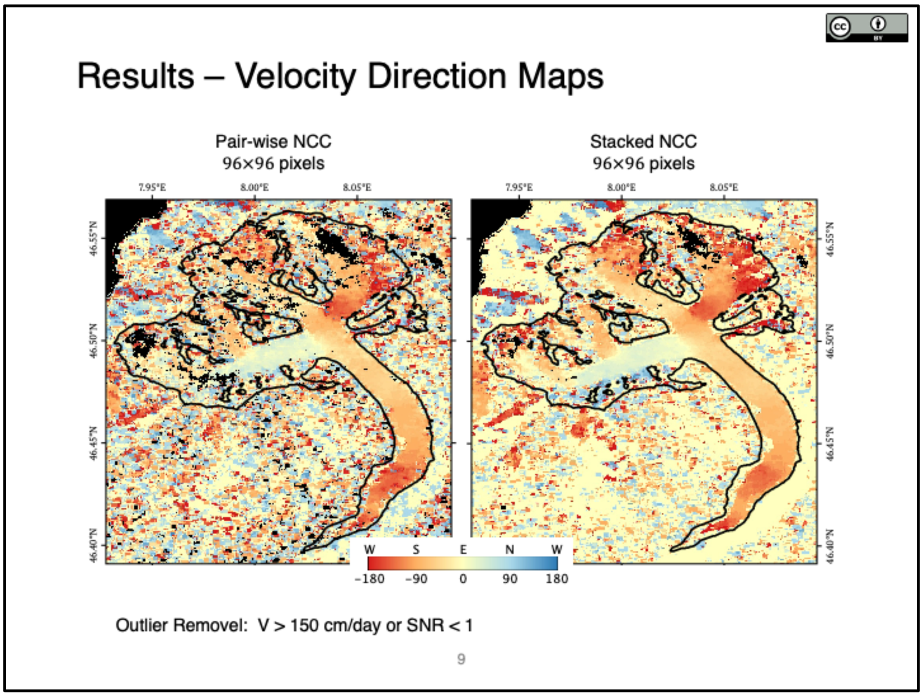


We firstly applied template sizes of 96-by-96 pixels for both pair-wise NCC and stacked NCC.

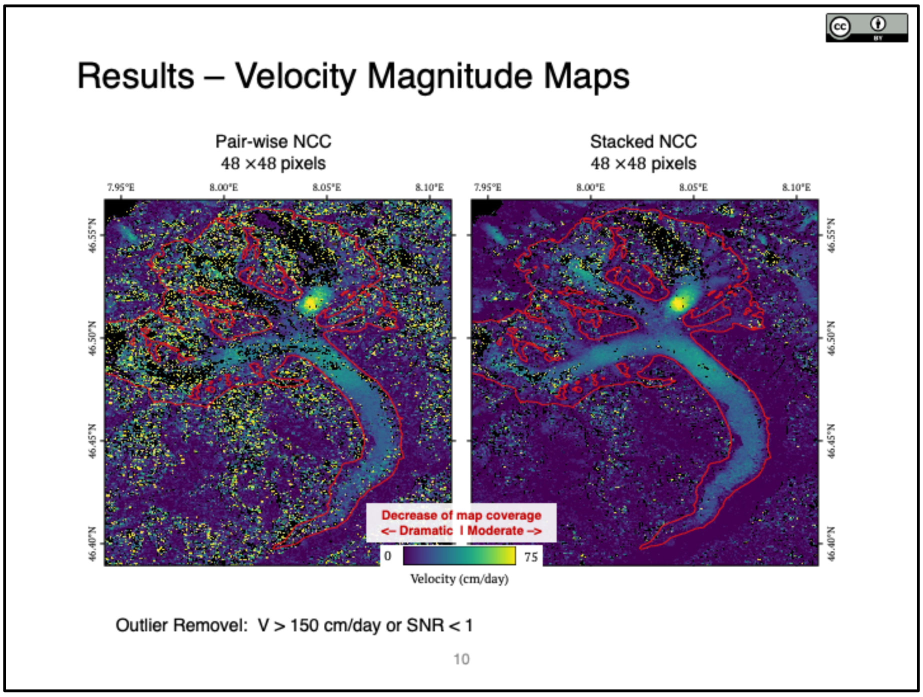
Voids in the velocity maps are caused by outlier removal. Velocity vectors having magnitude higher than 150 cm/day or measured with SNR smaller than one are discarded as outliers.

In the map obtained by pair-wise NCC, we can see the upper part of tributaries are not well tracked, and the static mountainous region is covered by very noise velocity fields.

For stacked NCC, upper tributaries are covered by reliable estimations, and the mountainous regions has almost no residual velocities.



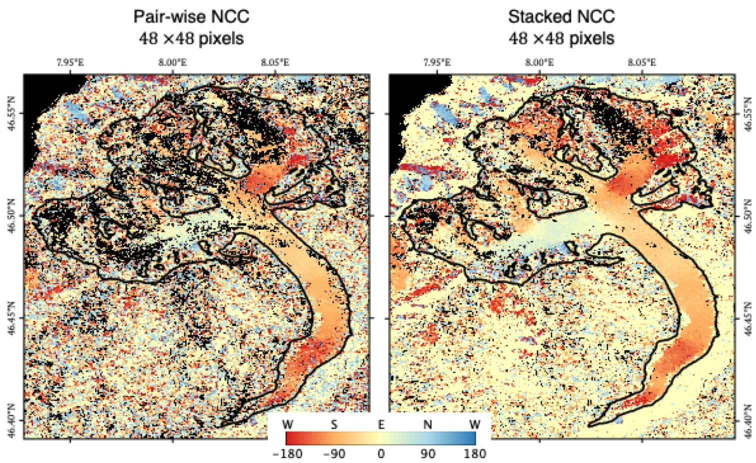
The direction of velocity vectors helps us to further verify the velcoty map.



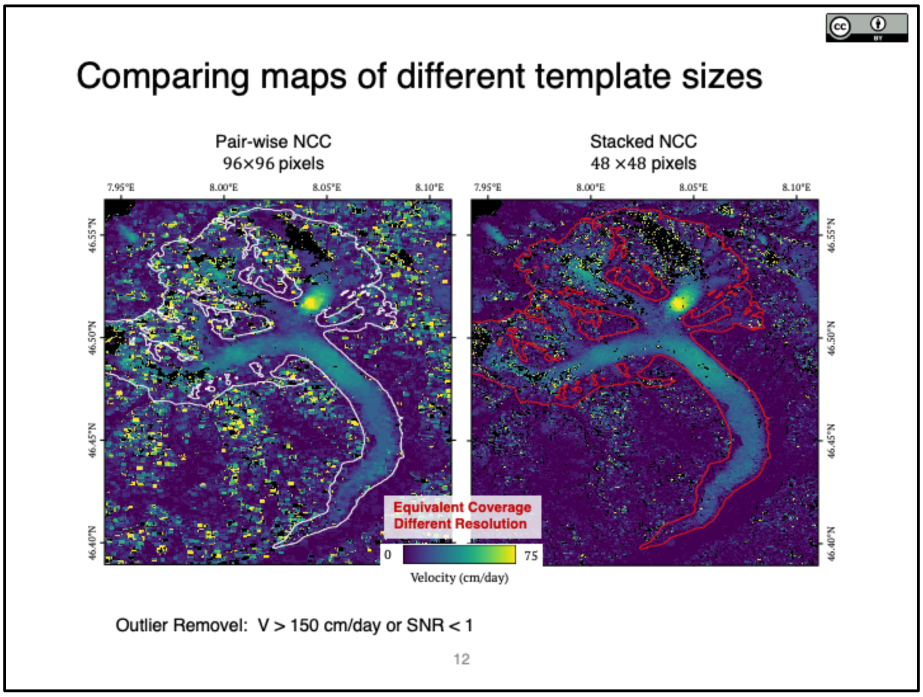
We then applied template size of 48-by-48 pixels to both NCC functions.

As the template size decreases, both NCC perofrm worse than before. However, we can see that the depreciation on velocity map coverage is stronger for pair-wise NCC than for stacked NCC.

Results – Velocity Direction Maps



Outlier Removel: V > 150 cm/day or SNR < 1



And if we compare the velocity map derived from pair-wise NCC using template size of 96-by-96 pixels with the velocity map derived from stacked NCC using template size of 48-by48 pixels, we can find that the two maps have almost equivalent spatial coverage, but the latter has much higher resolution than the former.

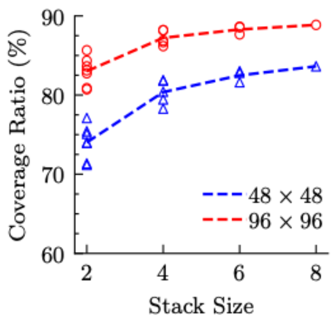
Change of map coverage as stack size changes

Noticing the difference on the coverage of velocity maps over the glacier, it is interesting to quantify the impact of the change of stack size on the coverage.

$$Coverage = \frac{Pixel\ with\ reliable\ velocities}{total\ pixel\ over\ glacier}$$

Here, reliable velocities are the remaining velocity vectors after removing outliers.

Since the aim here is to compare the performance of different methods, the threshold on outlier removal is not optimized, and thus they are not necessarily ensured to be physically reliable.



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By systematiclly examine the change of velocity map coverage as chaning stack size, we can see great improvement on spatial coverage as more NCC are used for stacking.

Change of residual velocities as stack size changes

Noticing the difference on the residual velocities over mountainous region, it is also interesting to quantify the impact of the stack size change on velocity residuals.

$$Residual = \frac{Pixel\ with\ nonzero\ velocities}{total\ pixel\ over\ mountain\ region}$$

Mountainous regions are considered as static, and thus are often used to assess the tracking accuracy.

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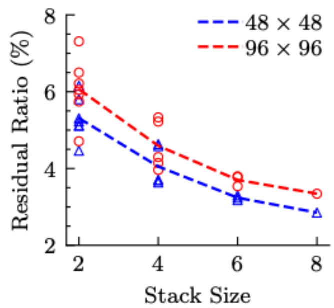
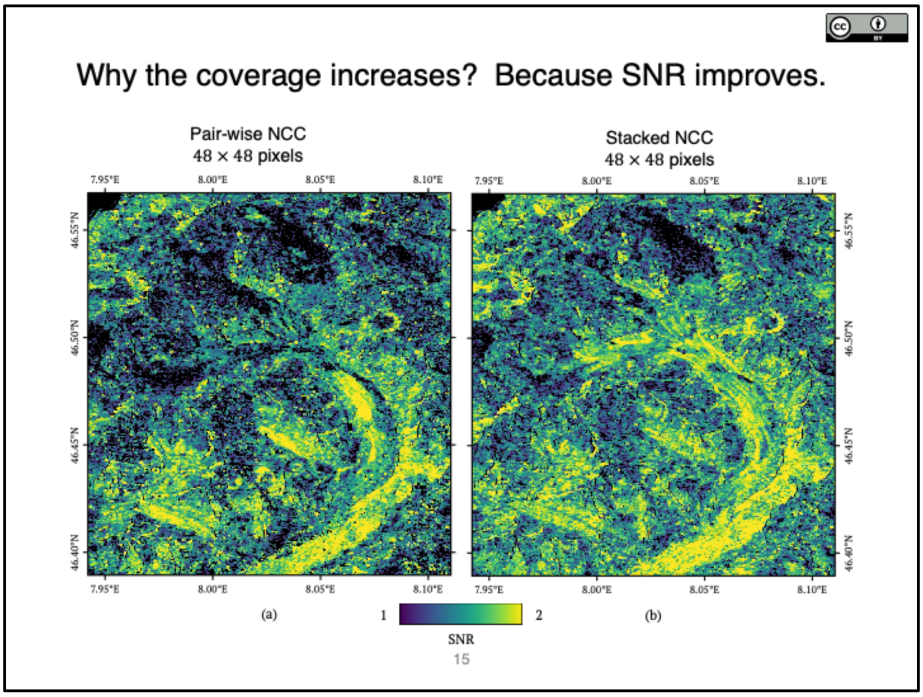


14

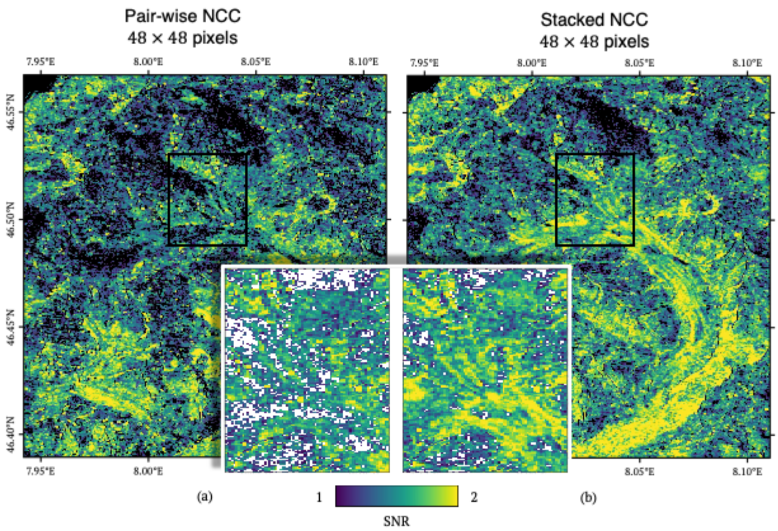
And stacking can also reduce the residual velocities in mountainuous region, indicating that the offset tracking is more accurate after stacking.



So why does the coverage increase and the residual decrease? This can be answered by examining the map of SNR.

Here we can find that stacked NCC has higher SNR than pair-wise NCC, and thus delivers more accurate and reliable results.

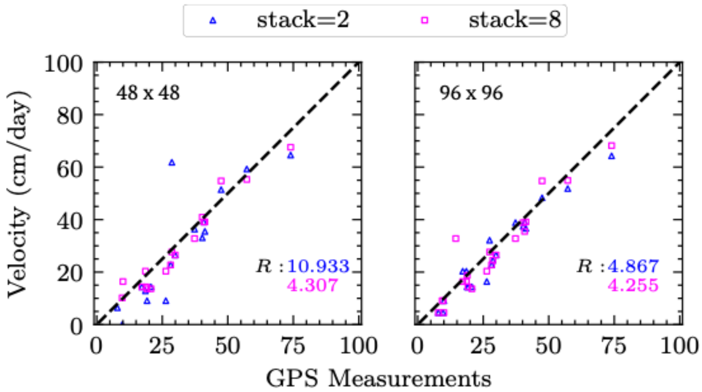
Because SNR improves – A Closer Look



16

Validate against in-situ GPS measurements

$$R = \frac{1}{N}\sqrt{\sum_{i=1}^{N}(v_i{}^{NCC} - v_i^{GPS})}$$



17

Conclusion and Outlook

- Effective offset tracking relies on unambiguously identifying the peak of cross-correlations. Temporal stacking of cross-correlations can effectively improve the SNR, and hence can make offset tracking more robust.
- Assuming glacier velocity keeps constant during an acquisition period, a time-series of cross-correlations can be constructed from consecutive image template pairs, and then can be stacked and averaged to attain a temporally stacked cross-correlation.
- Temporal stacking can improve the spatial resolution of velocity maps by allowing using small template sizes. It can also expand the coverage of velocity maps.
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Thank you!