UiO : Department of Geosciences
University of Oslo

Ice surface velocities using SAR

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ESA Cryosphere Remote Sensing Training Course 2018
UNIS Longyearbyen, Svalbard
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Outline

Synthetic Aperture Radar (SAR) theory

Coverage / geometric resolutions / geometric distortions

Surface properties / speckle / SAR glacier zones

Advantages / disadvantages

Offset tracking

Preprocessing / cross correlation / post processing

Examples from Svalbard

Preview of practical

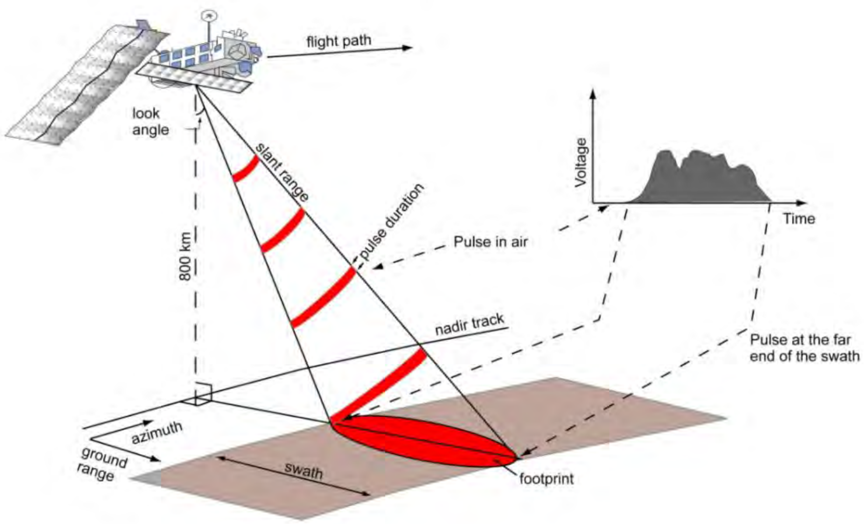
Interferometric SAR

Processing steps of 2-Pass D-InSAR of ERS-1/2 tandem pair

Take aways

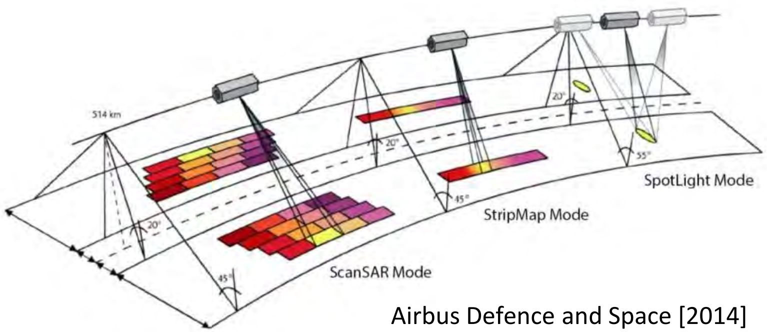
Imaging geometry / Acquisition modes

Microwave sensors: Side-looking radar



K. Langley, 2007

Acquisition modes



Airbus Defence and Space [2014]

Geometric resolution

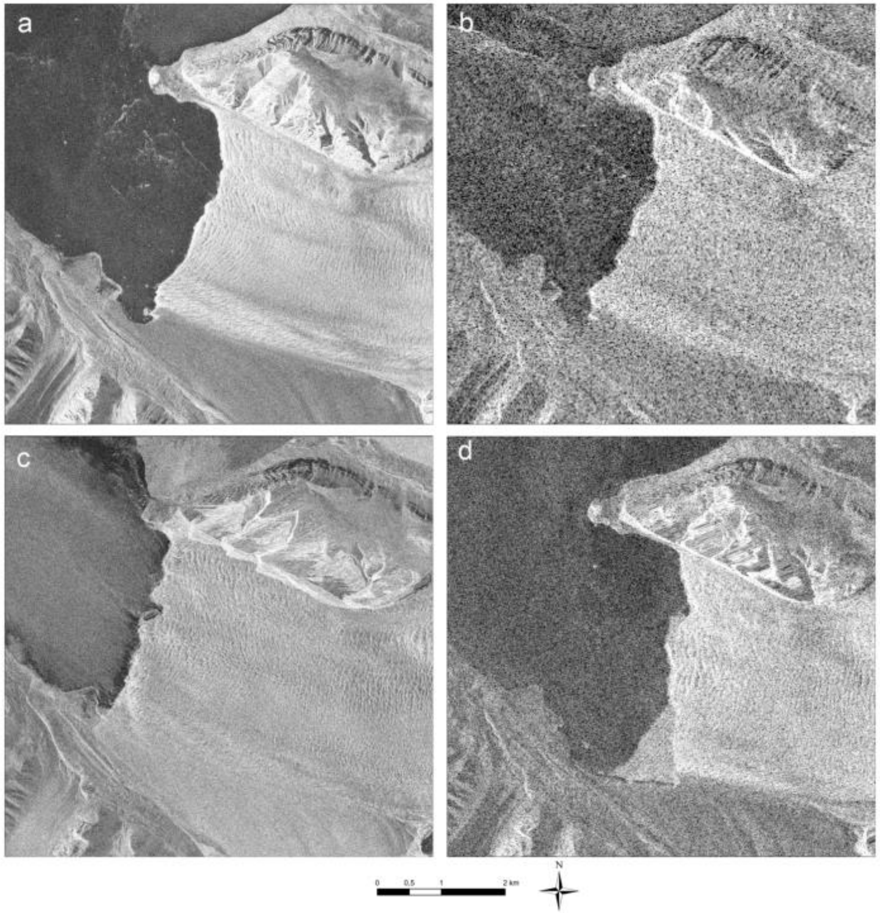
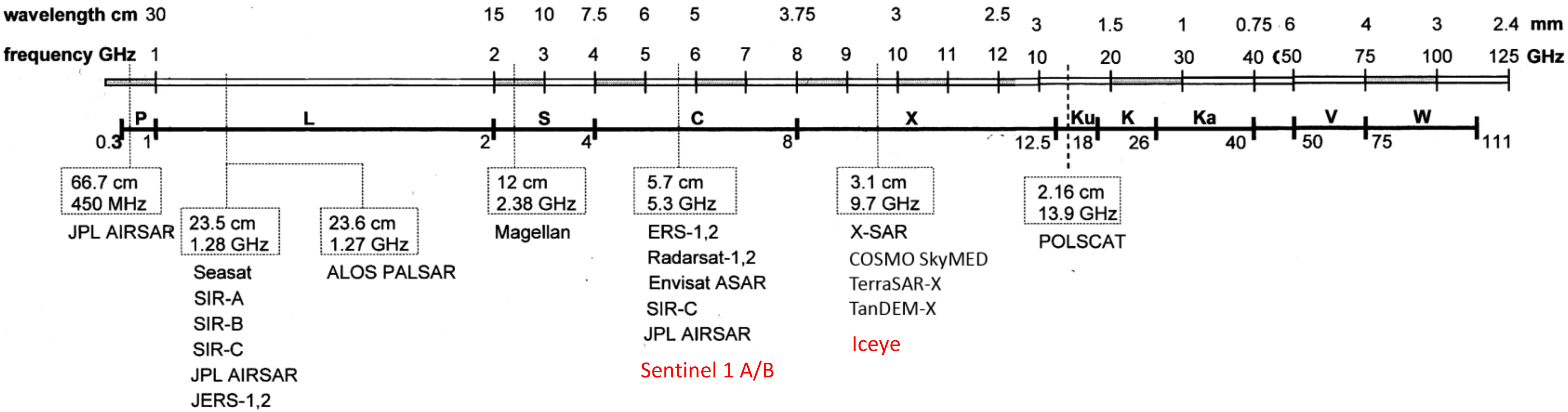


Figure 2.10: SAR intensity images of Kronebreen:
(a) Radarsat-2 Ultrafine Mode, 18th October 2013, 2 m geometric resolution.
(b) Radarsat-2 Wide Mode, 9th October 2013, 20 m geometric resolution.
(c) TerraSAR-X StripMap, 27th April 2008, 2 m geometric resolution.
(d) Radarsat-2 Wide Fine Mode, 23rd November 2015, 8 m geometric resolution.

SAR Sensors

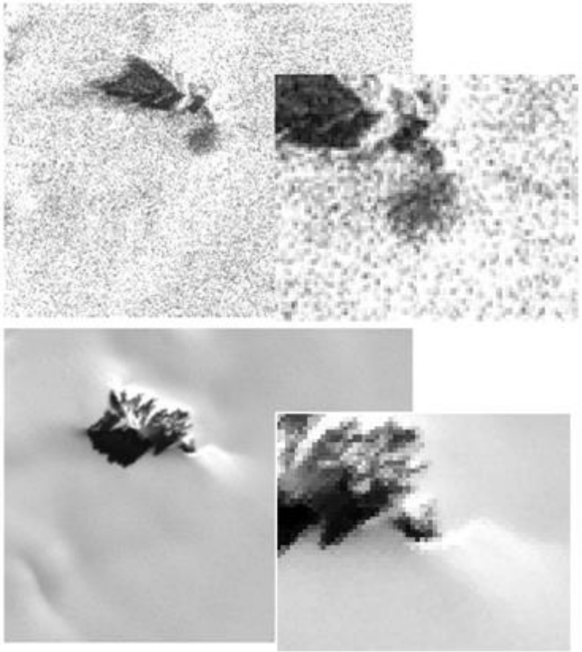


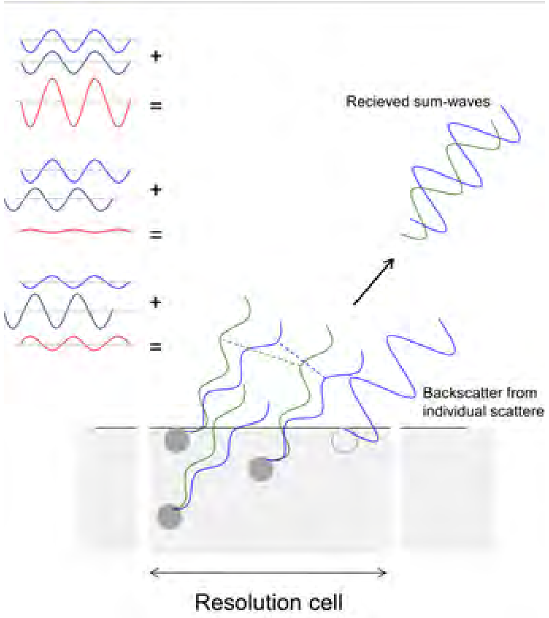
Microwave sensors and their technical specifications: frequency, wavelength, waveband (modified after Richards, 2009).

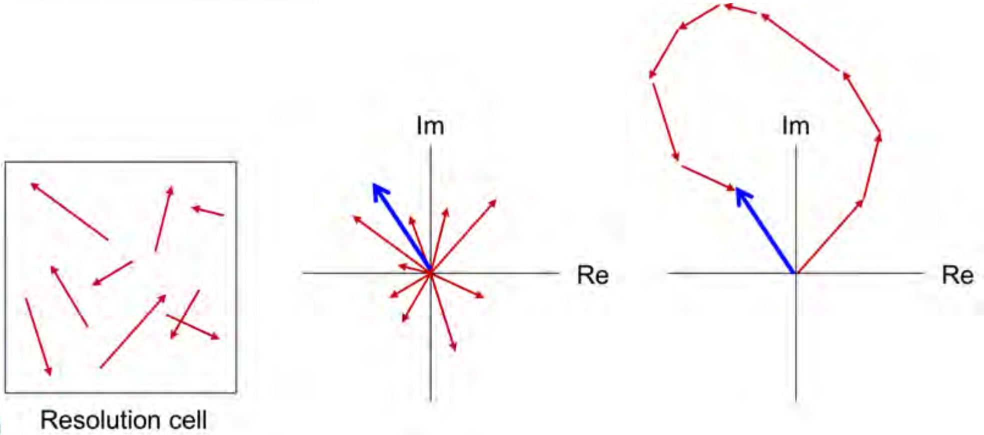
SAR Theory - Speckle

SAR

Optical







Kääb

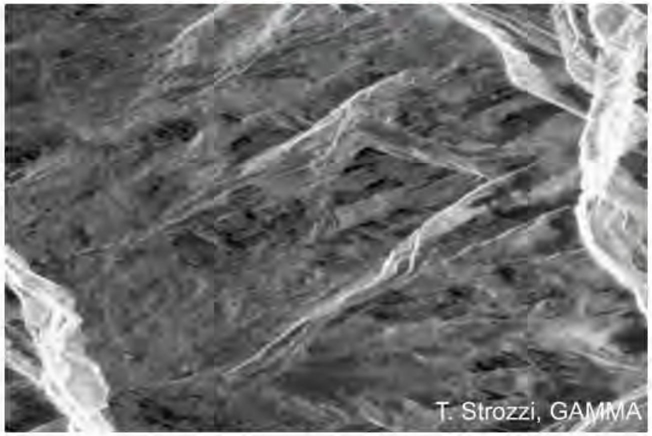
Interferometric SAR theory

Single Look Complex

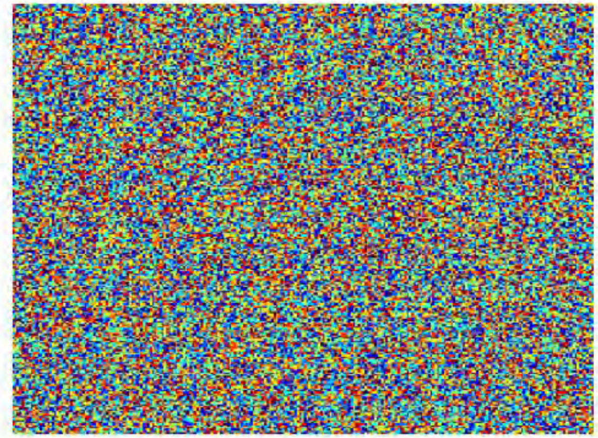
Amplitude |s|

Phase φ

azimuth



slant range



$$\mathbf{s} = a + ib$$

$$\mathbf{s} = |\mathbf{s}|(\cos\varphi + i\sin\varphi)$$

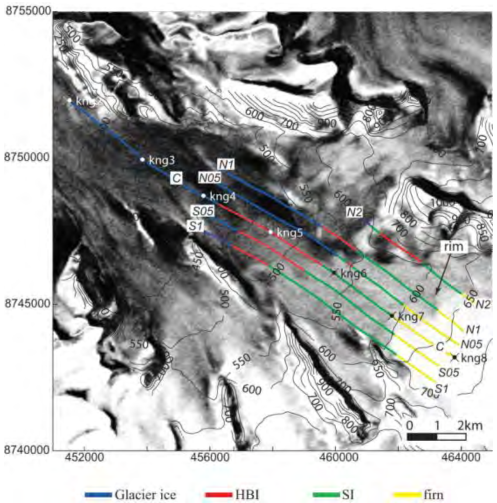
$$= |\mathbf{s}|(\cos(\varphi + 2k\pi) + i\sin(\varphi + 2k\pi))$$

$$\mathbf{s} = |\mathbf{s}|e^{i\varphi}$$

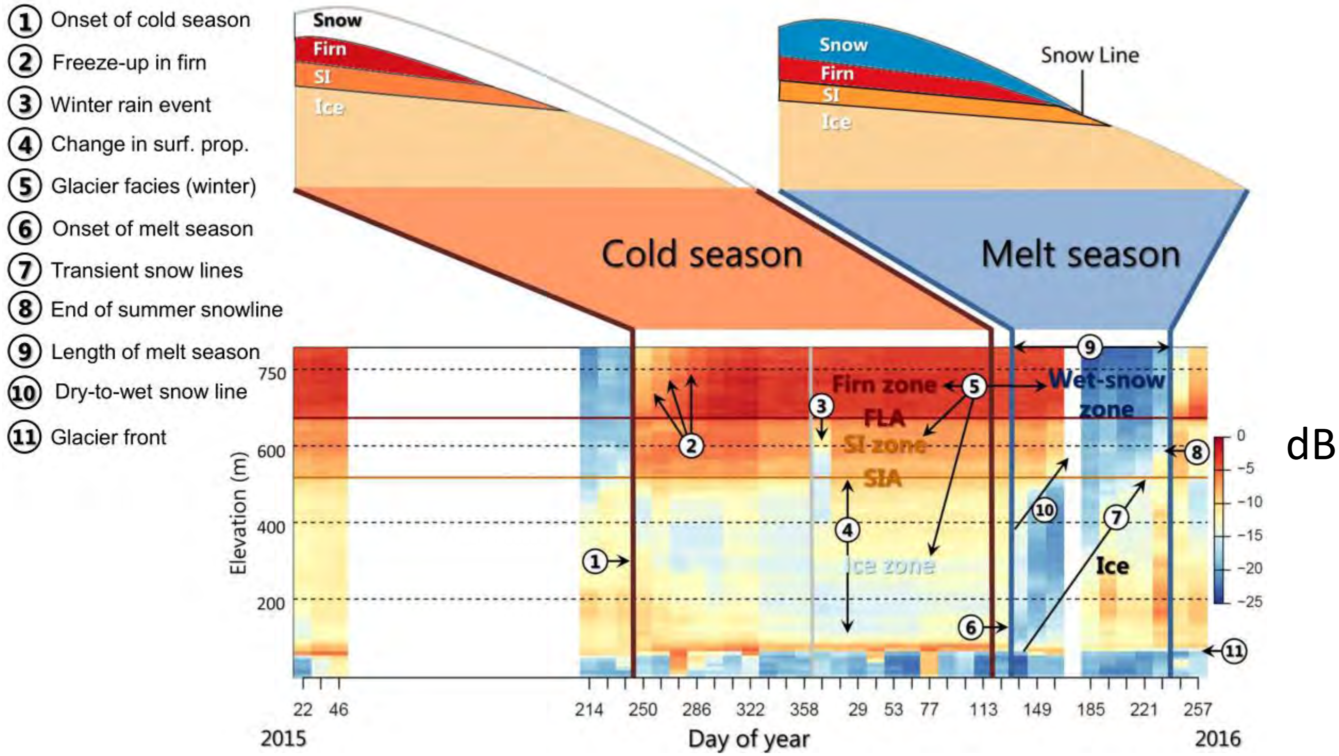
a : *real part*; b : *imaginary part*

φ : *phase angle*; $|\mathbf{s}|$: *magnitude, amplitude*

SAR glacier zones



Langley et al., 2008

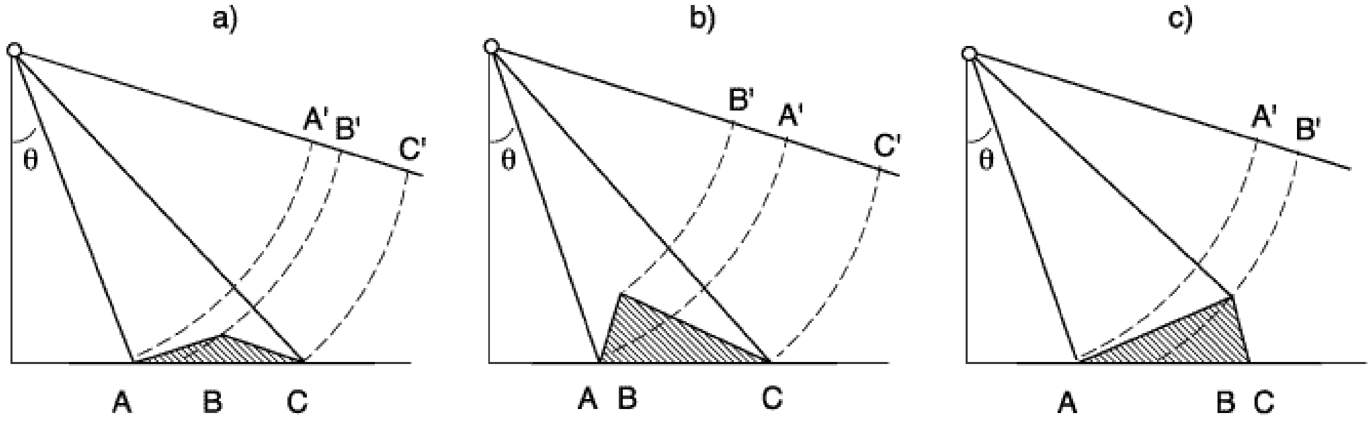


SAR backscatter time series from RS-2 and Sentinel-1

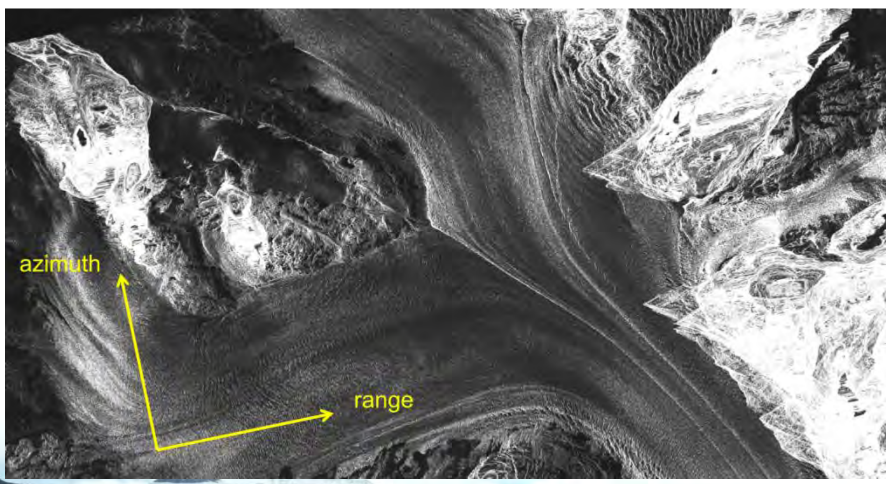
Winsvold et al., 2018

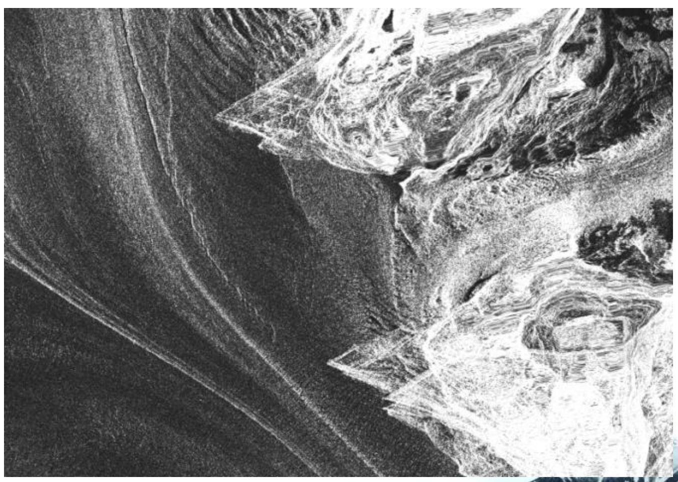
Geometric distortions

Foreshortening | Layover | Shadow



Kääb





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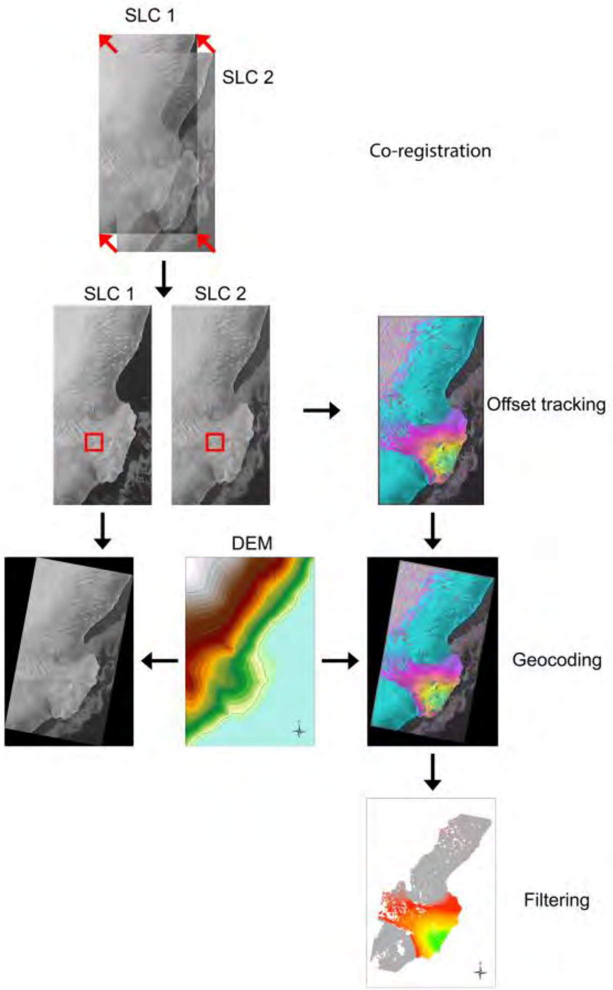
SAR offset and speckle tracking



Scheme of the offset tracking workflow:

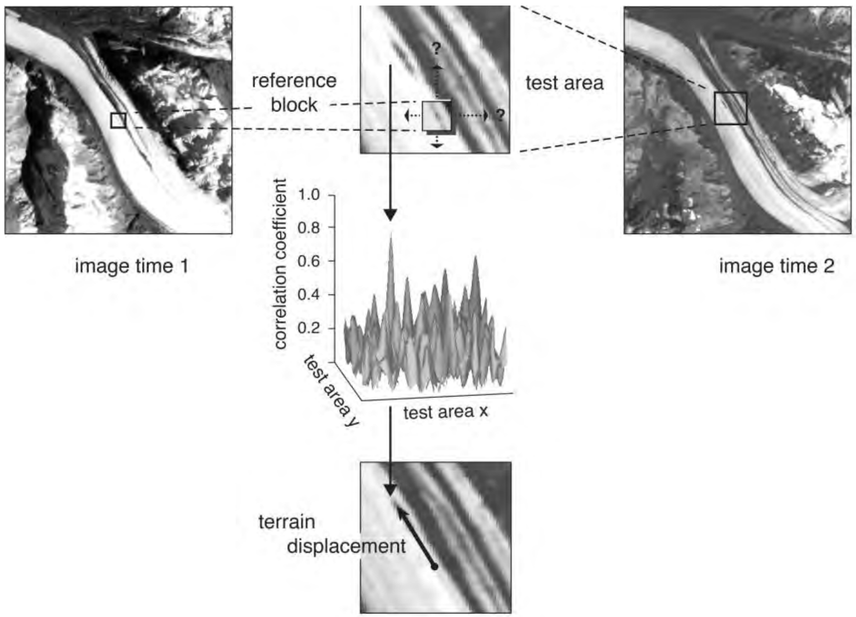
1. Co-registration of two single-look complex (SLC) images
   e.g. using orbital parameters or correlation

2. Offset tracking (correlation)

3. Geocoding of the velocity map

4. Filtering of the velocity map
   - manual filtering based on amplitude and direction
   - automated filtering (e.g. maximum velocity, standard deviation)

SAR offset and speckle tracking



Principle of offset tracking / image matching
From: Kääb [2005], modified

Cross-correlation in the spatial domain

$$\mathrm{CC}(i,j) = \frac{\sum_{k,l}(s(i+k,j+l)-\mu_s)(r(k,l)-\mu_r)}{\sqrt{\sum_{k,l}(s(i+k,j+l)-\mu_s)^2\sum_{k,l}(r(k,l)-\mu_r)^2}}$$

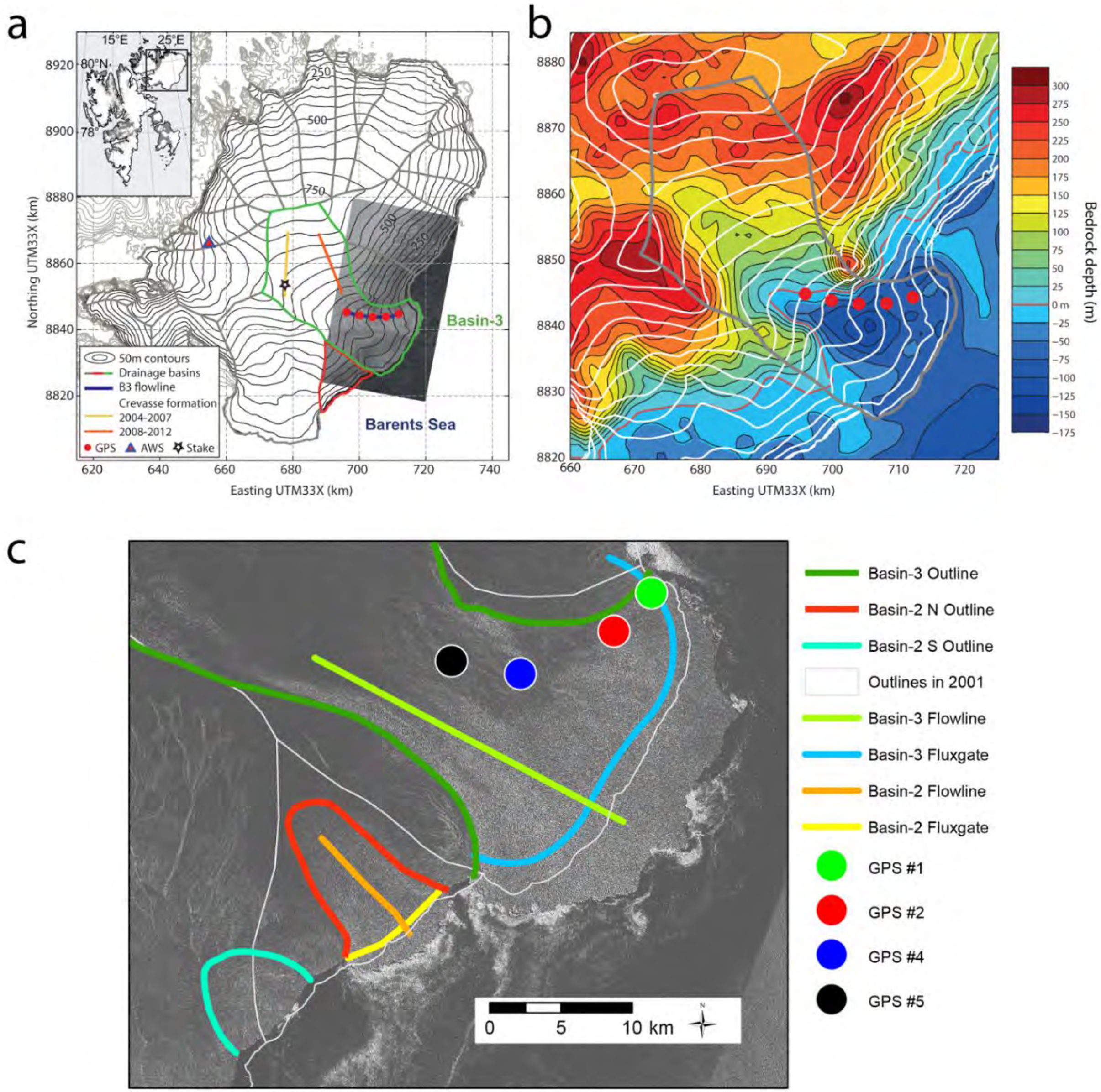
i,j indicates the position in the search area,
k,l the position in the reference area,
r the pixel value of the reference chip,
s the pixel value of the search chip
μ_r the average pixel value of the reference chip
μ_s the average pixel value of the search chip.
-> peak of the cross-correlation surface indicates the displacement between the images

Cross-correlation in the frequency domain

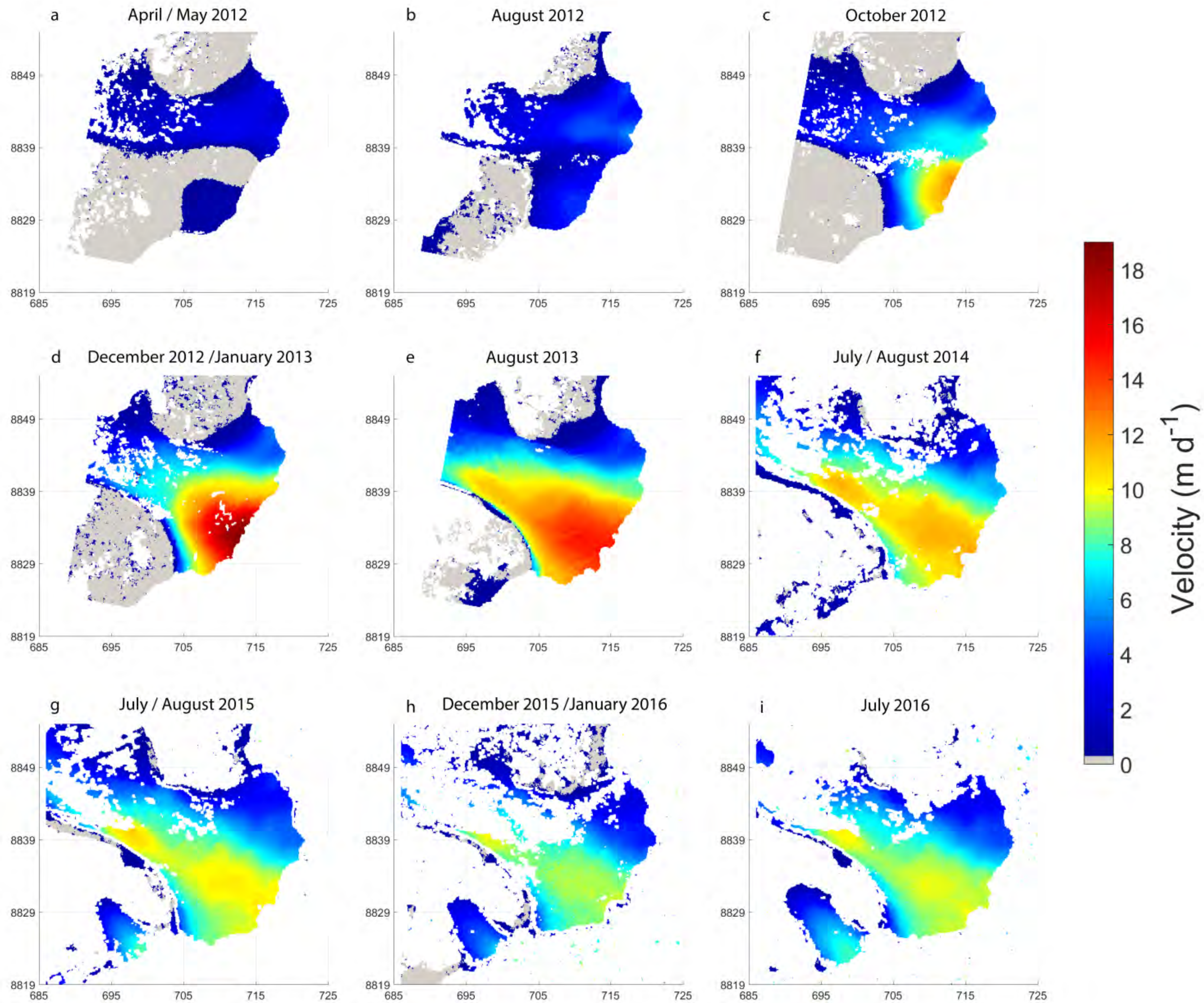
$$CC(i,j) = IFFT\left(F(u,v)G^*(u,v)\right)$$

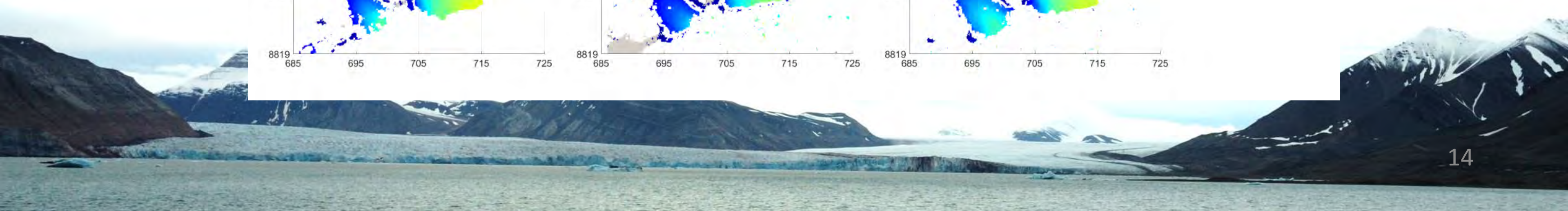
F(u,v) is the FFT of the matching window from the image at time t = 1,
G(u,v) is the FFT of the matching window from the image at time t = 2,
$*$ denotes the complex conjugated and IFFT is the Inverse Fast Fourier Transform.

Basin-3 / Basin-2

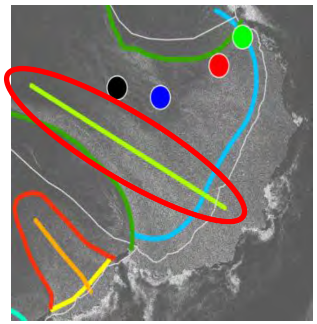


Surface velocity of Basin-3 from SAR (2012 -2016)





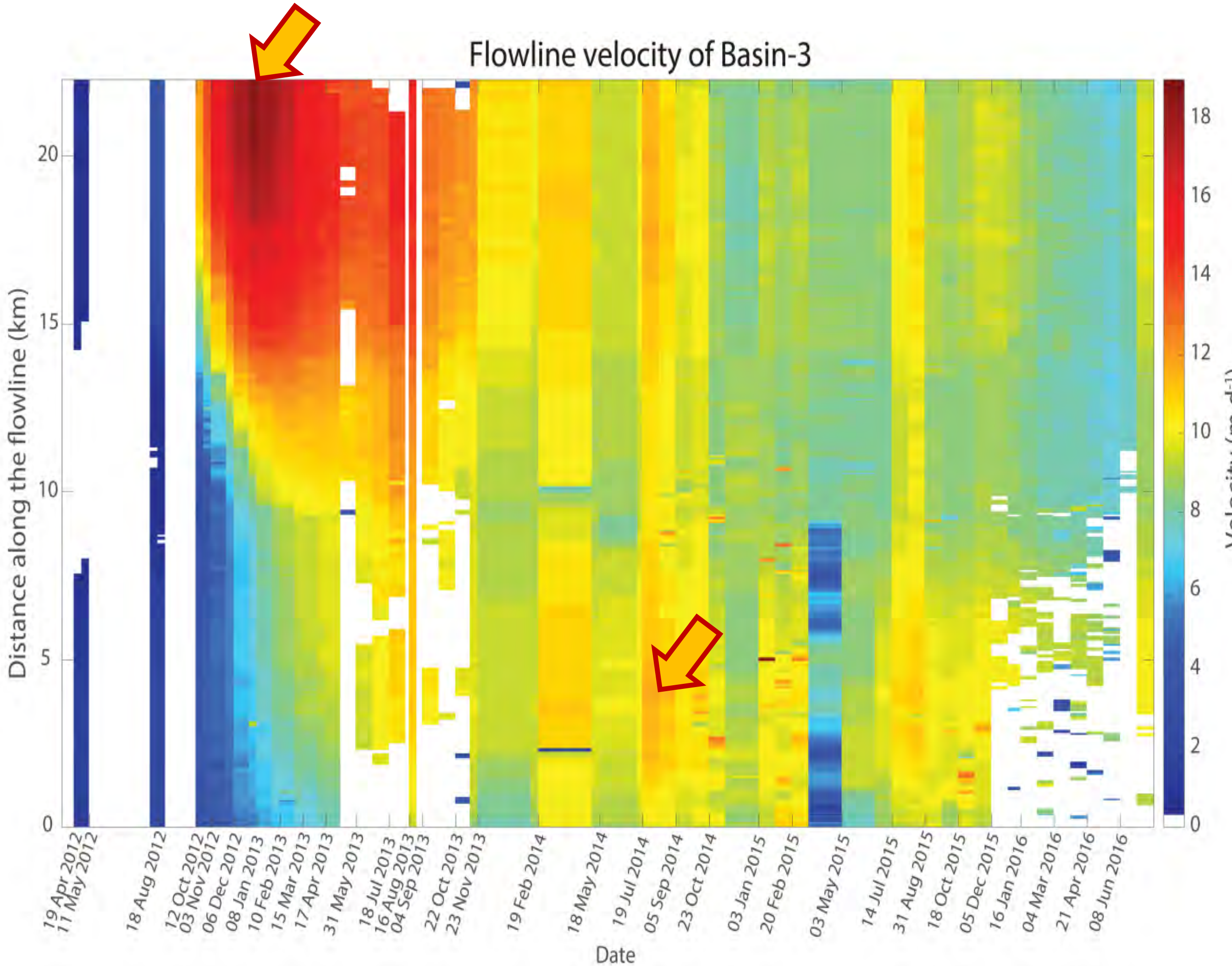
Surface speed of Basin-3



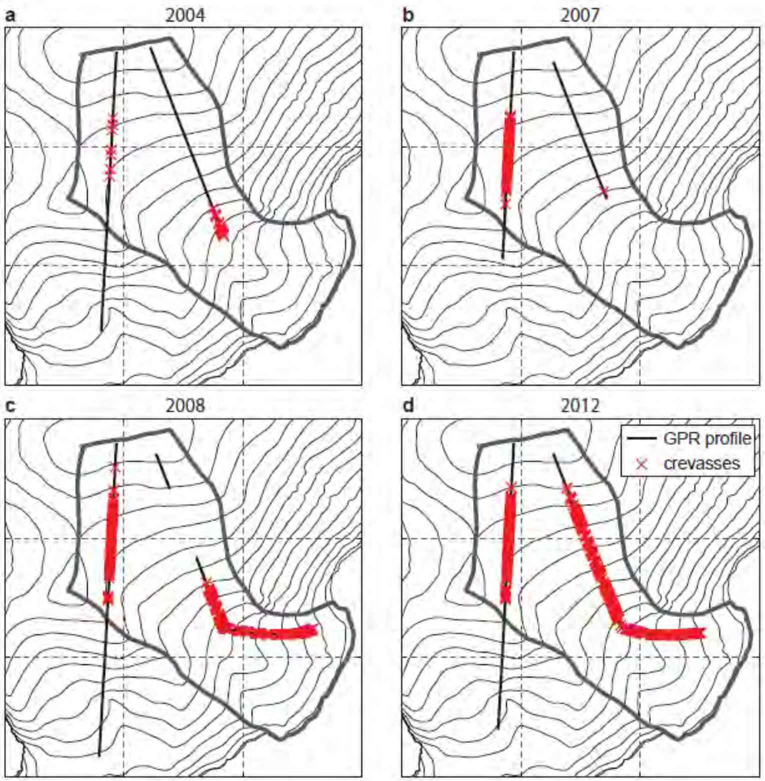
Maximum speed:

18.8 m d^{-1}

Dec 2012 / Jan 2013

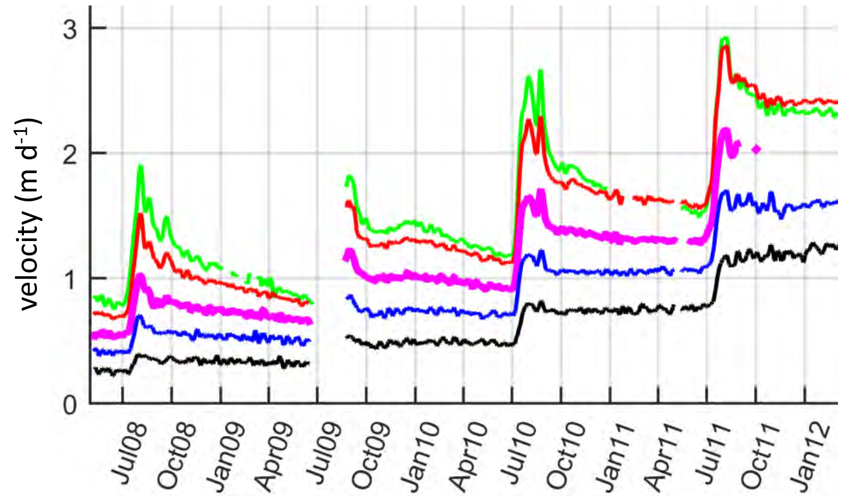


The beginning…

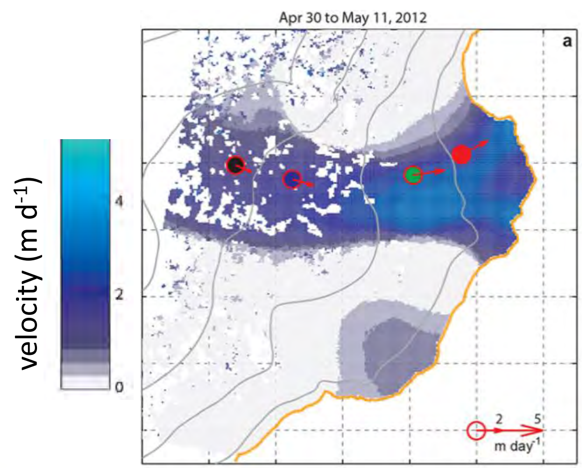


Crevasse formation on Basin-3 in 2004–2012 from GPR

Dunse et al., 2015

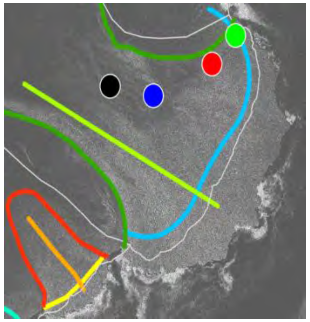


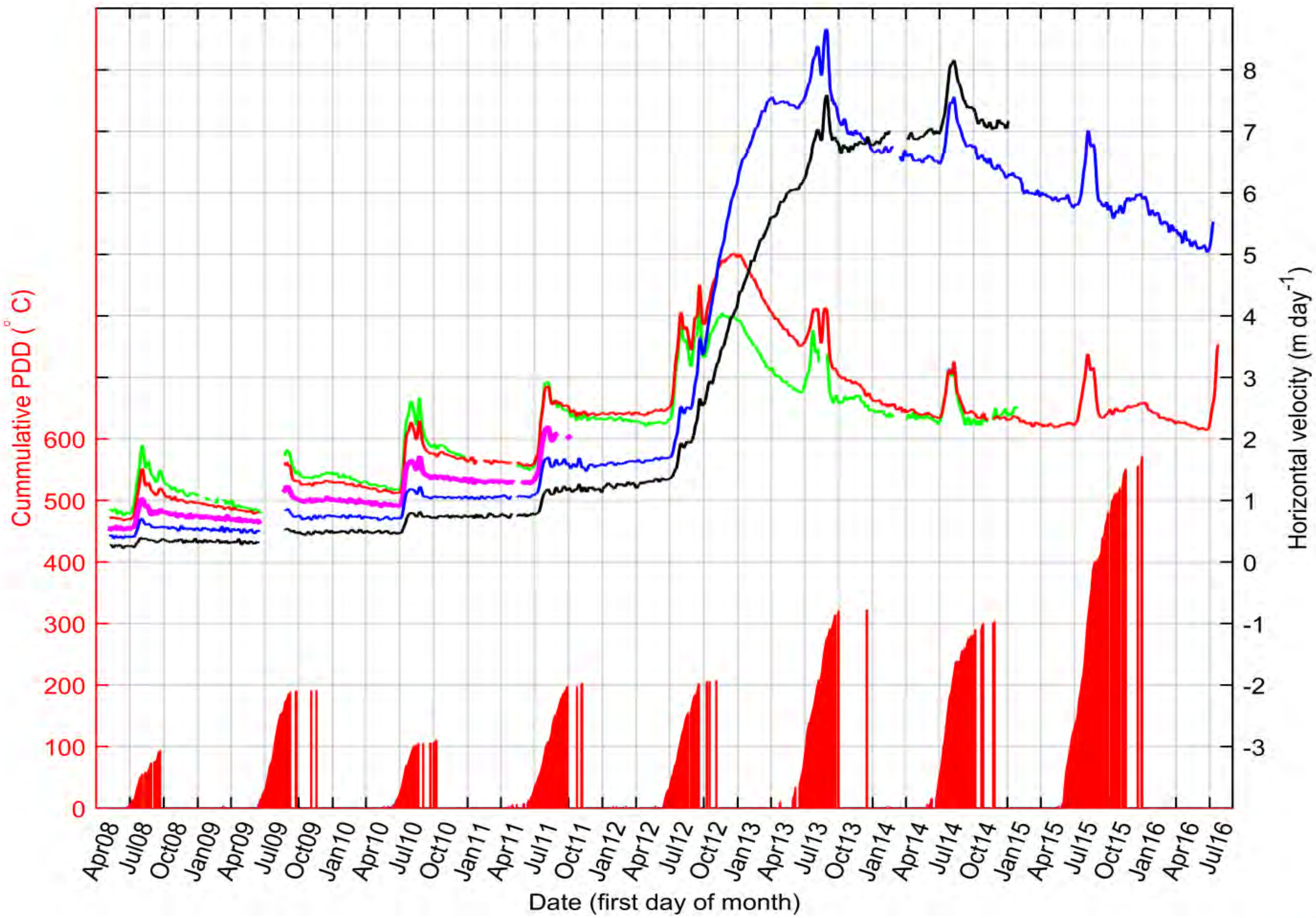
GPS velocity - Basin-3 (2008 - 2012)



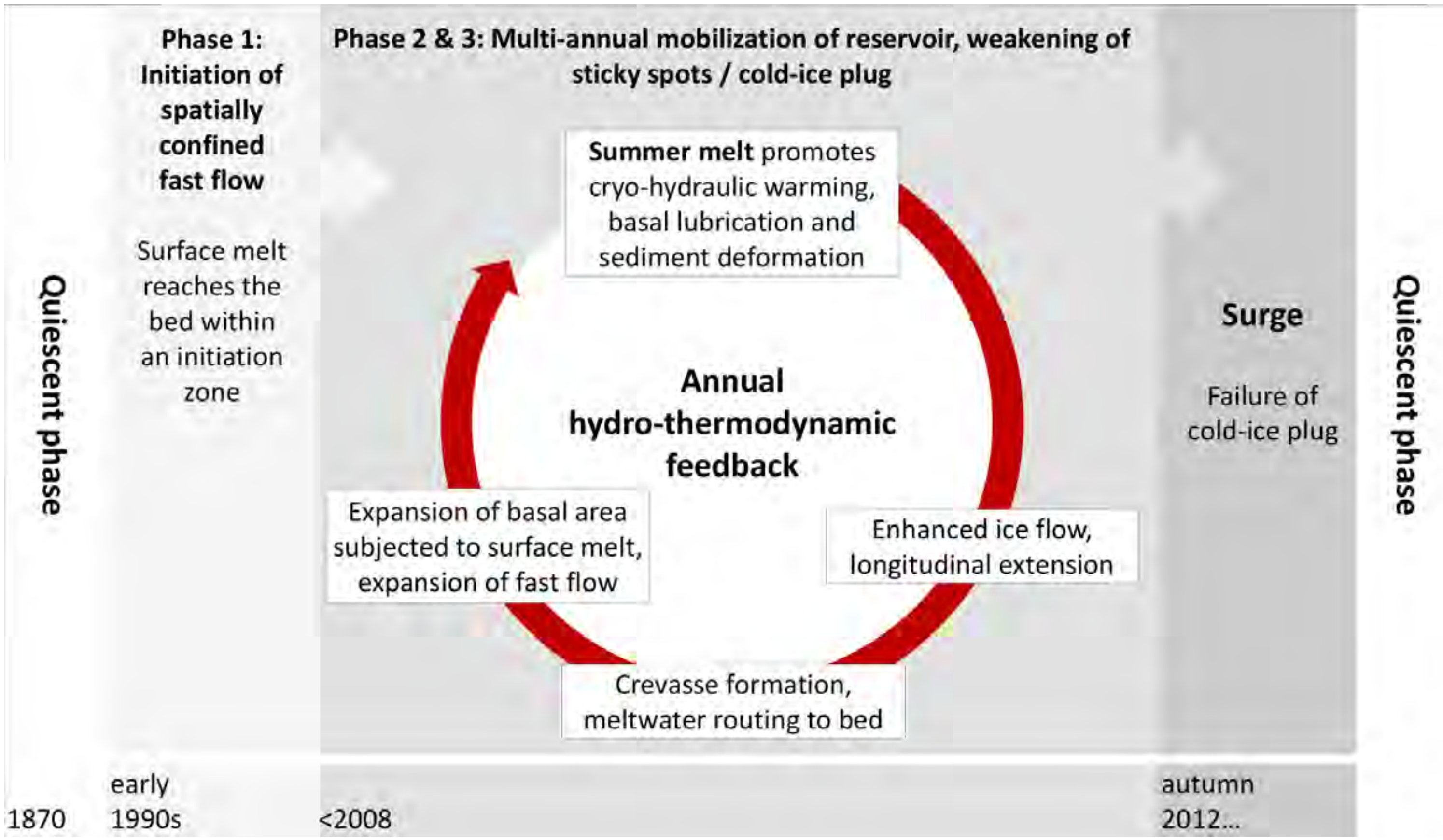
Surface velocity April/May 2012

Surface velocity of Basin-3 from GPS

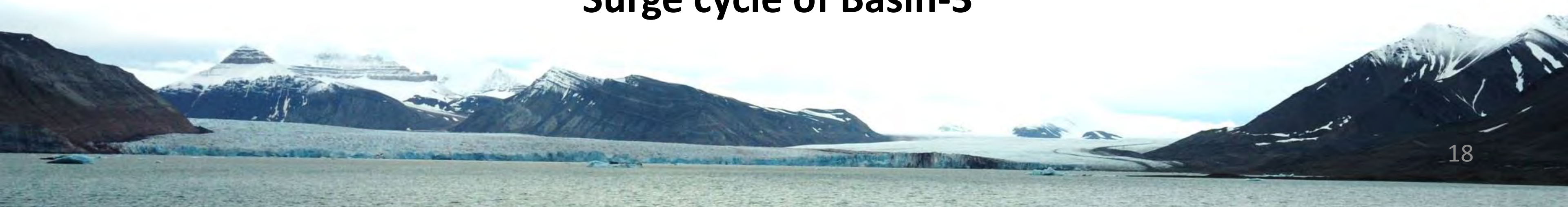




Hydro-thermodynamic feedback

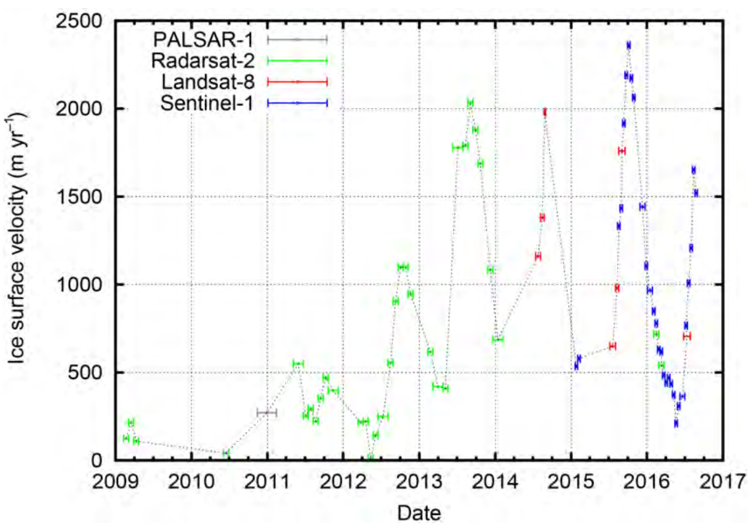


Surge cycle of Basin-3

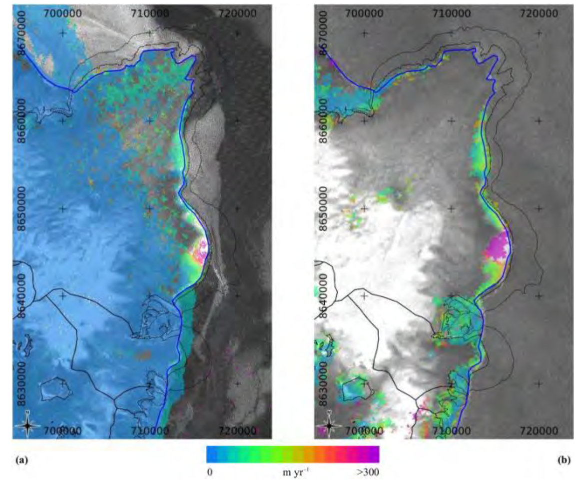


Stonebreen, Edgeoya

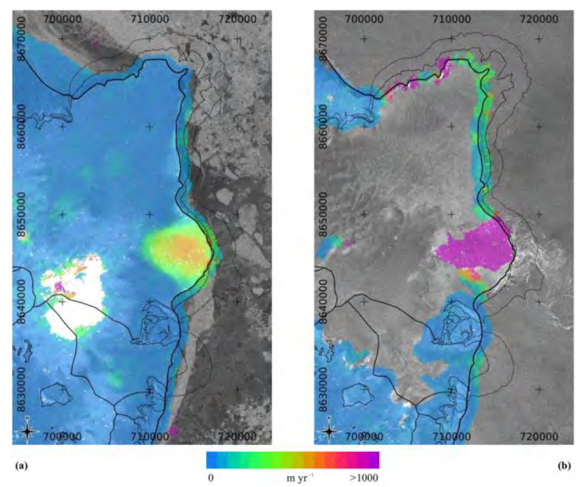
SE-Svalbard



Strozzi et al., 2017



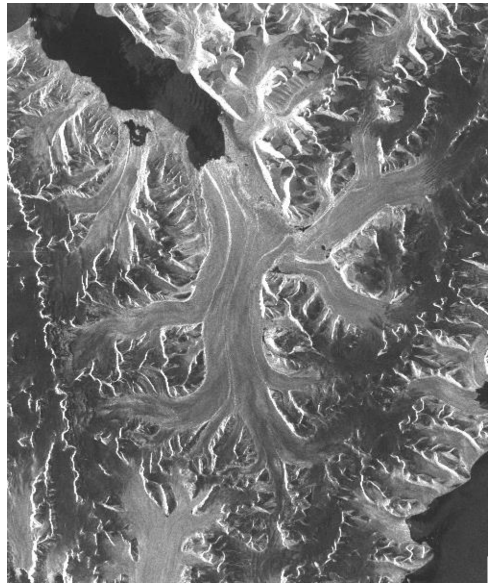
ALOS PALSAR & Radarsat-2 data autumn winter



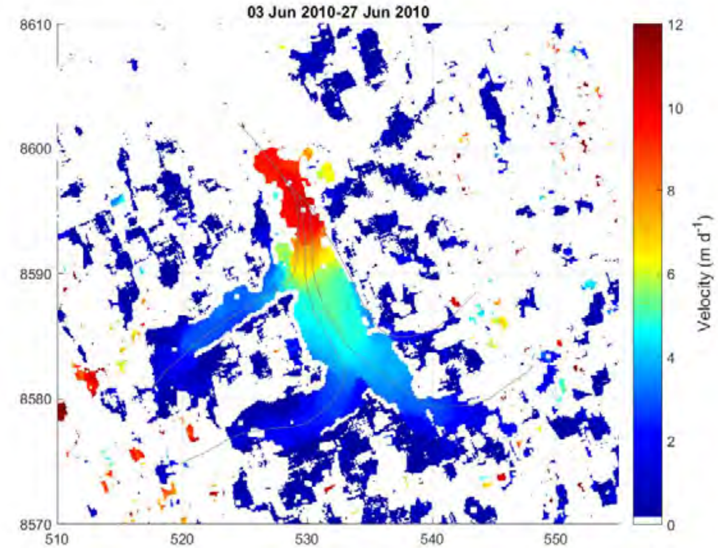
Sentinel-1 winter 2015 / Autumn 2015

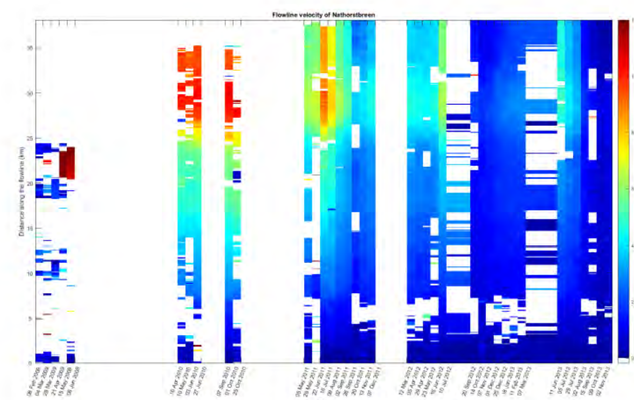
Nathorstbreen surge

Radarsat-2 8 Feb 2009



Radarsat-2 29 July 2013

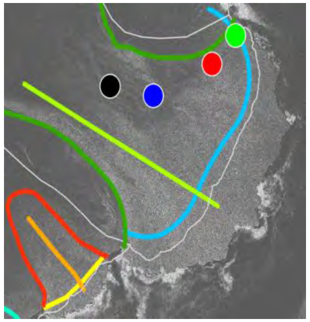


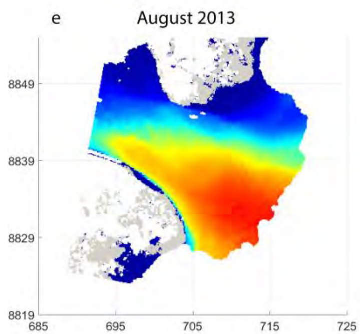


Maximum velocity > 40 m/day
→ Eventually the fastest glacier on Earth at that time
→ No offset tracking possible (→ advance)

Frontal ablation of Basin-3

April 2012 - July 2016





Frontal ablation components	($Gt\ yr^{-1}$)
Ice mass flux, Q_{fg}	7.8 ± 2.7
Terminus mass change, Q_t	2.6 ± 0.8
Terminus-seawater replacement, Q_{tsw}	2.1 ± 0.7
Total frontal ablation	
Mb perspective, $Q_{mb} = Q_{fg} - Q_t$	5.2 ± 1.9
SLR perspective, $Q_{sl} = Q_{mb} + Q_{tsw}$	7.3 ± 2.6

<u>Total Svalbard</u>

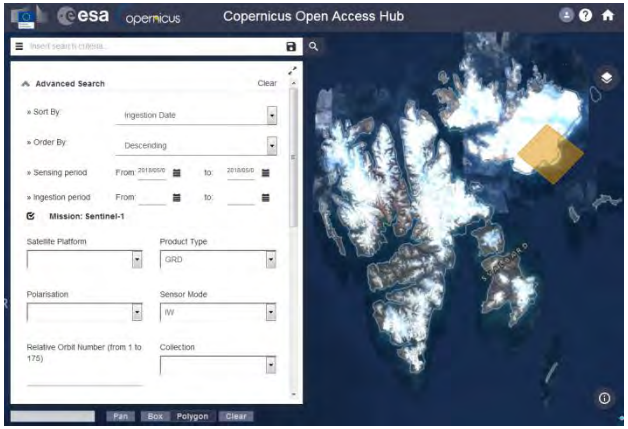
6.8 ± 1.7 Gt y^{-1}

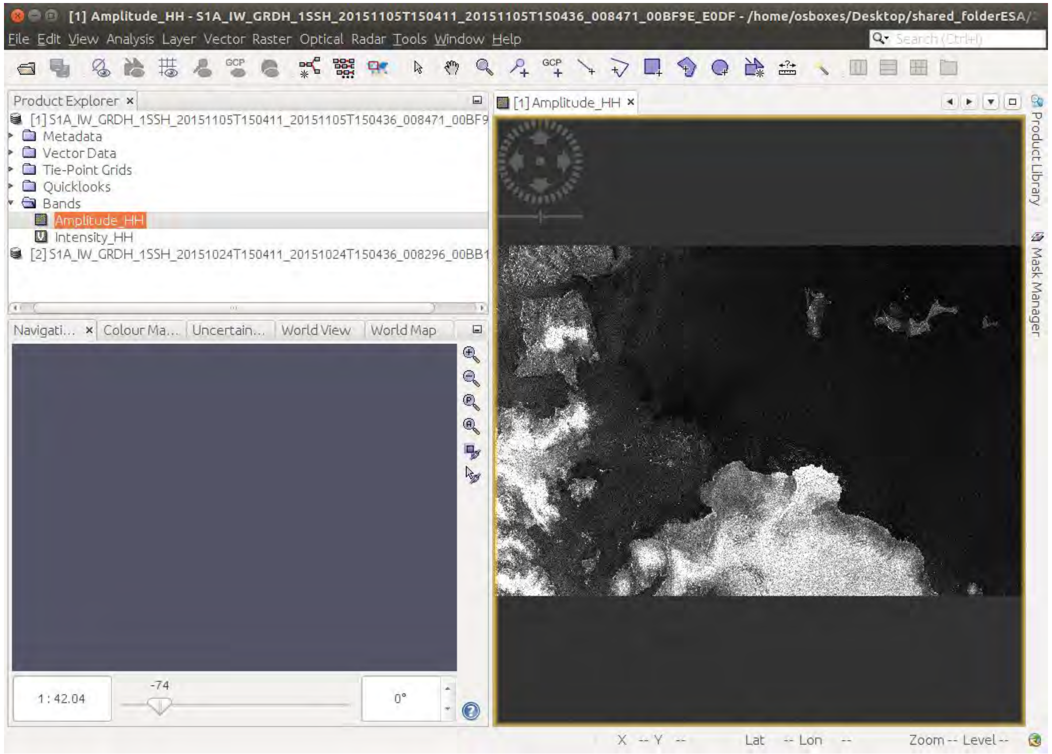
(Blaszczyk et al., 2009)

2 l drinking water

for every human being – daily!

SAR practical – Sentinel-1 offset tracking of Basin-3 using the ESA SNAP Sentinel-1 Toolbox





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Take aways

2-pass D-InSAR workflow

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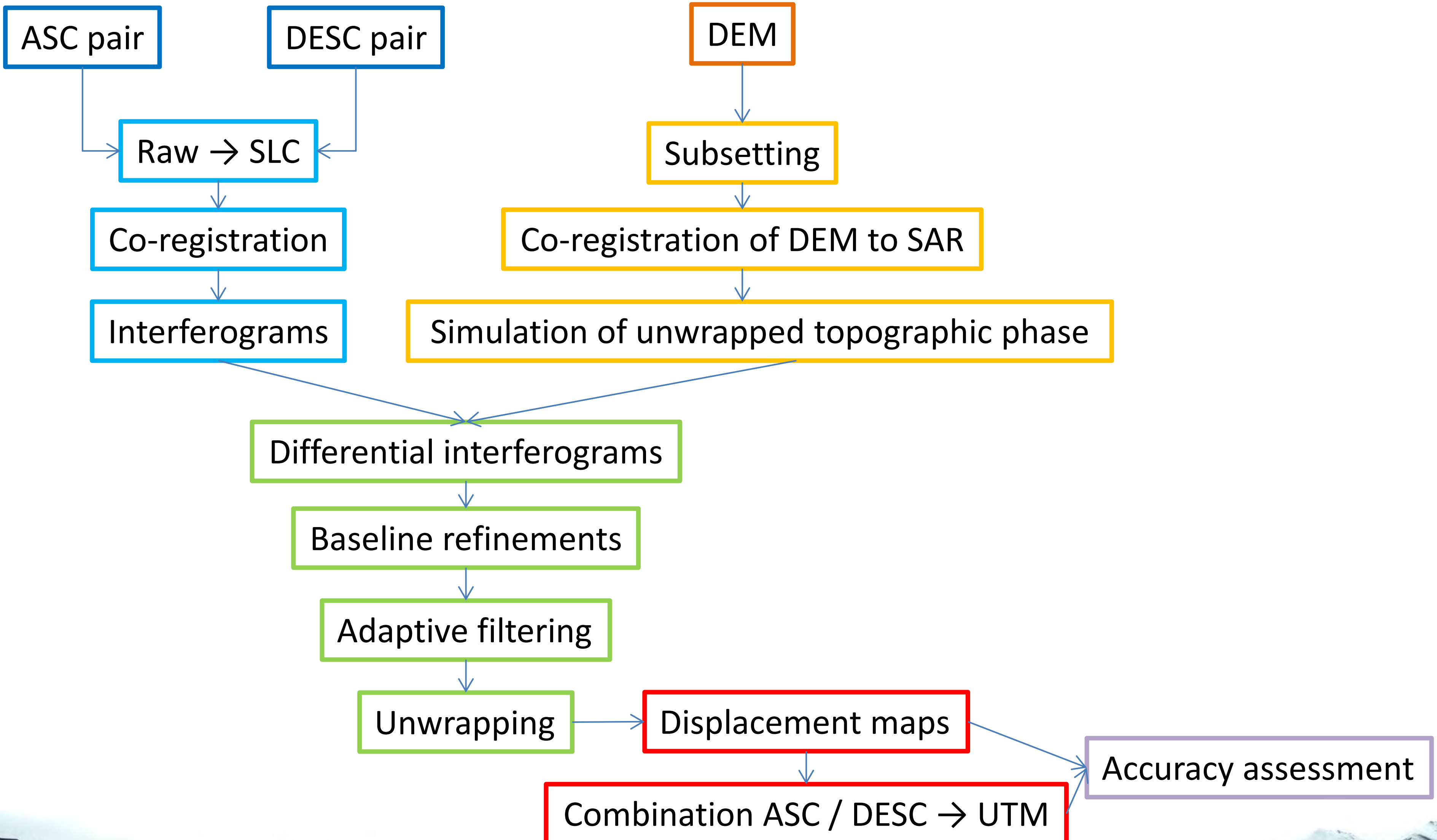
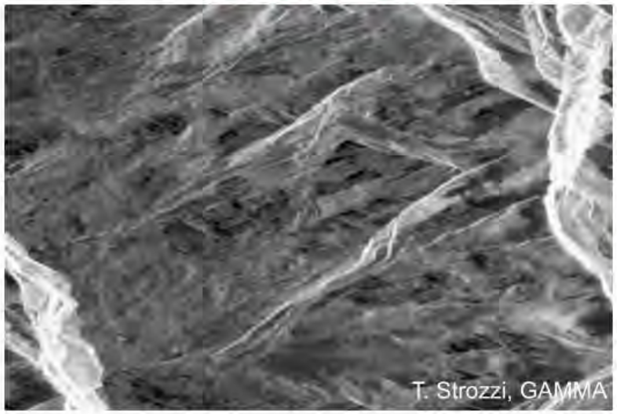


Interferometric SAR theory

Single Look Complex

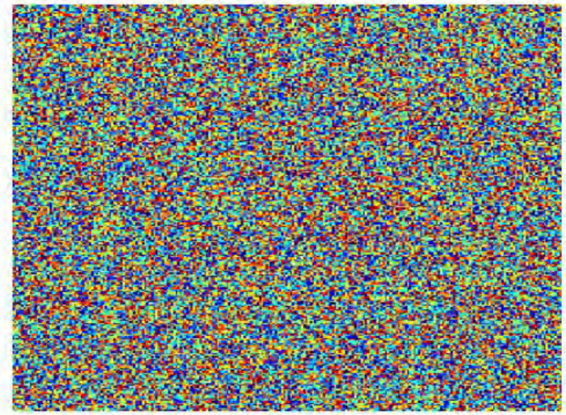
Amplitude |s|

azimuth



slant range

Phase φ



$$\mathbf{s} = a + ib$$

$$\mathbf{s} = |\mathbf{s}|(\cos\varphi + i\sin\varphi)$$

$$= |\mathbf{s}|(\cos(\varphi + 2k\pi) + i\sin(\varphi + 2k\pi))$$

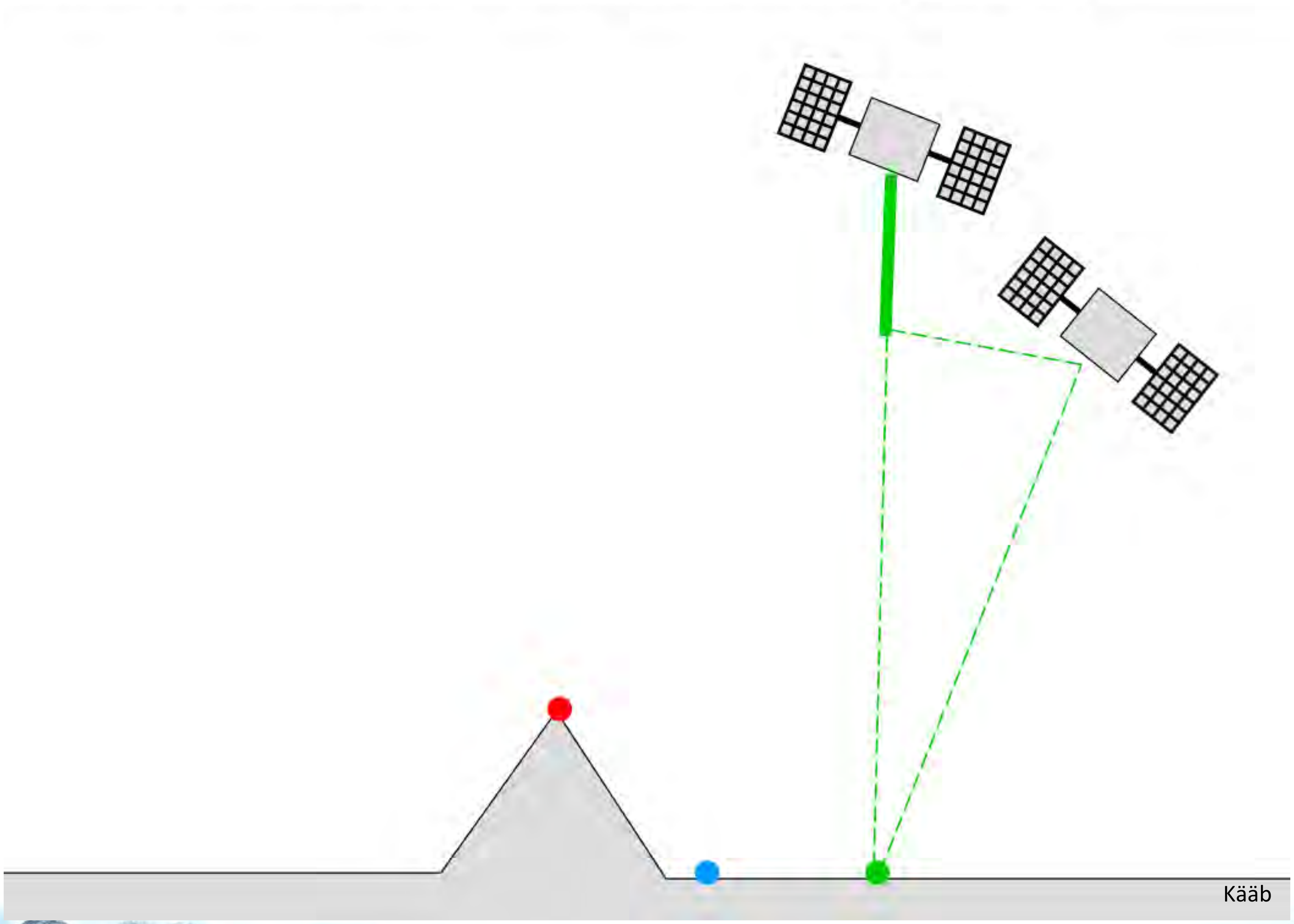
$$\mathbf{s} = |\mathbf{s}|e^{i\varphi}$$

a : *real part*; b : *imaginary part*

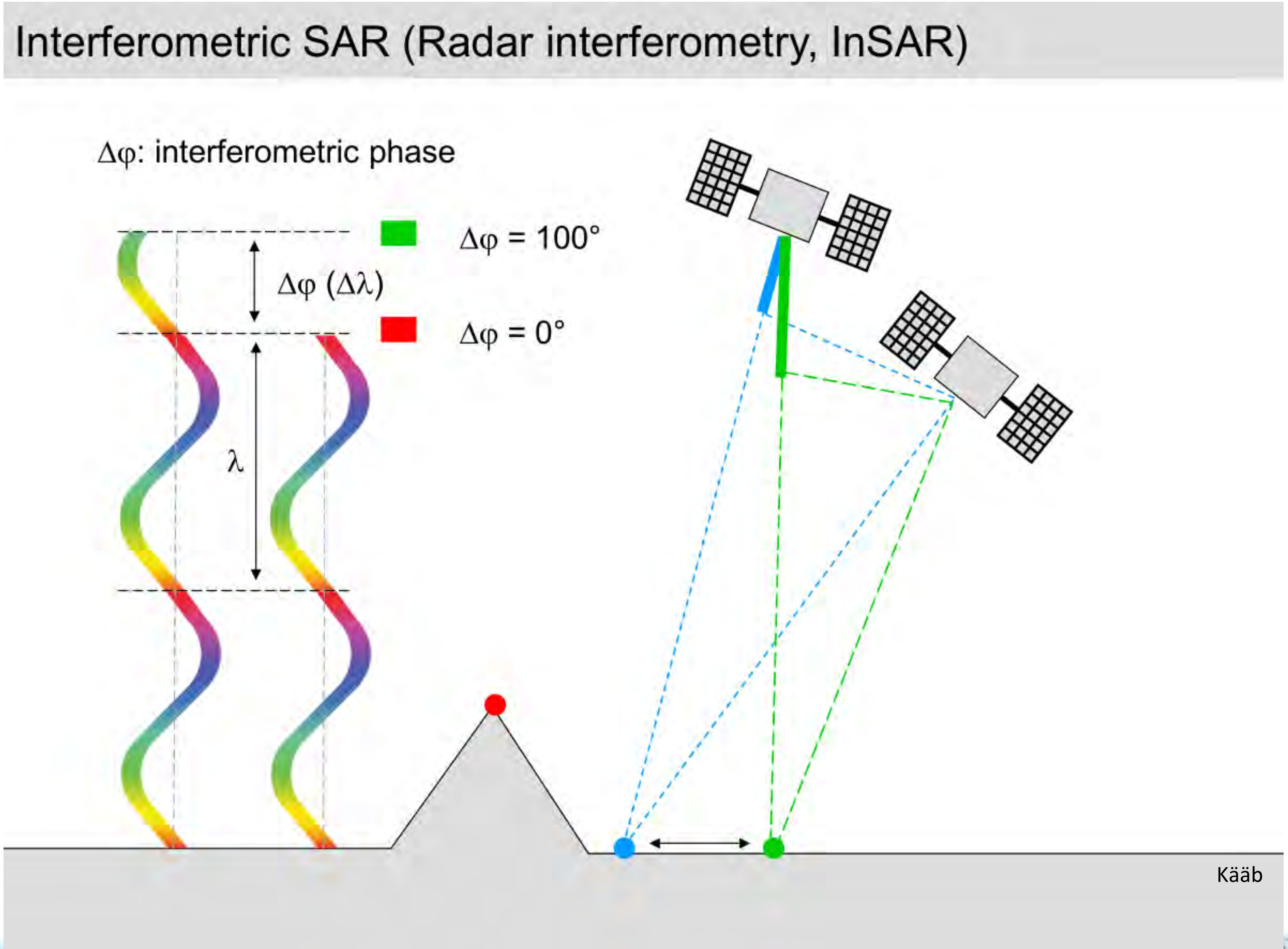
φ : *phase angle*; $|\mathbf{s}|$: *magnitude, amplitude*

Interferometric SAR theory

Interferometric SAR (Radar interferometry, InSAR)

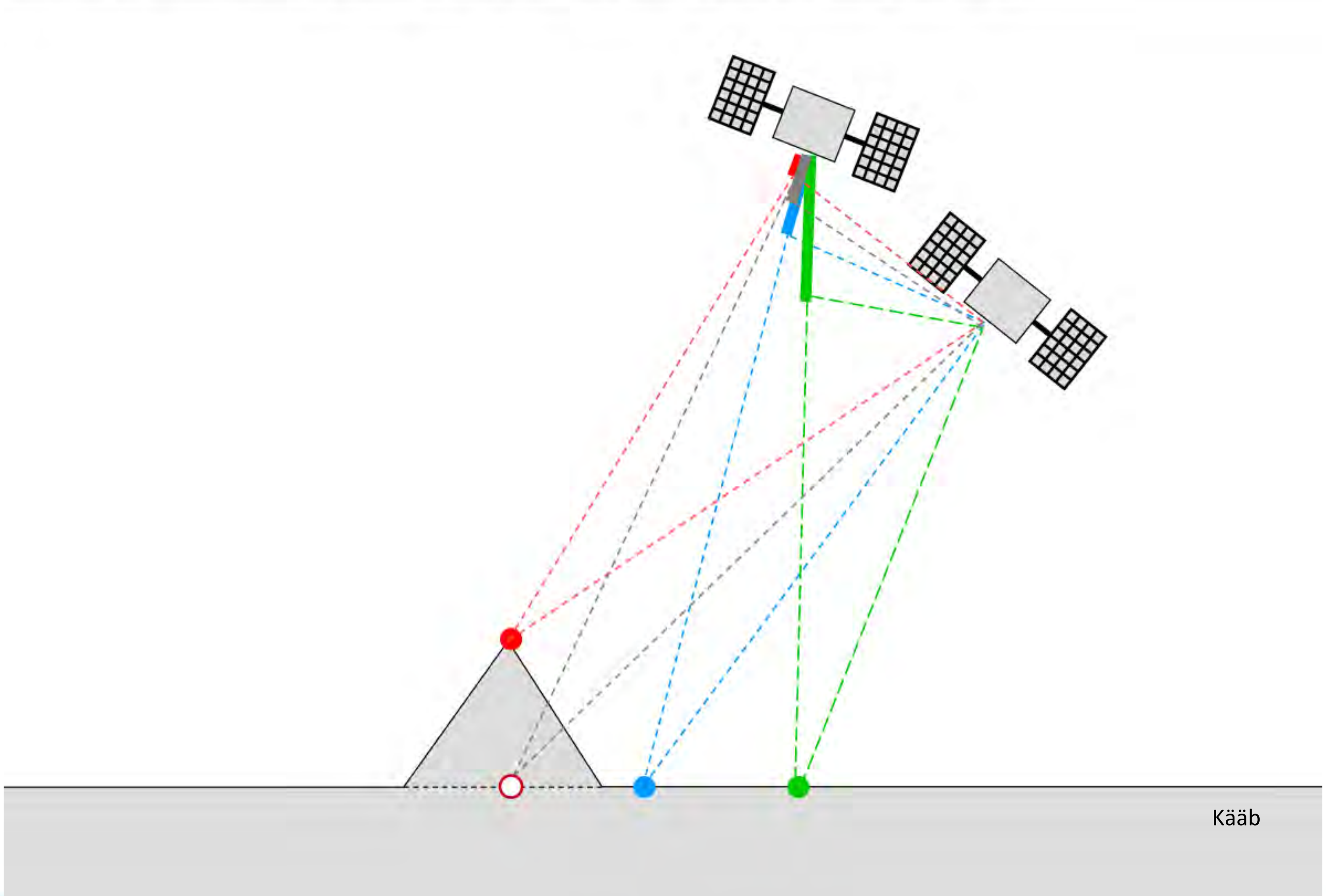


Interferometric SAR theory

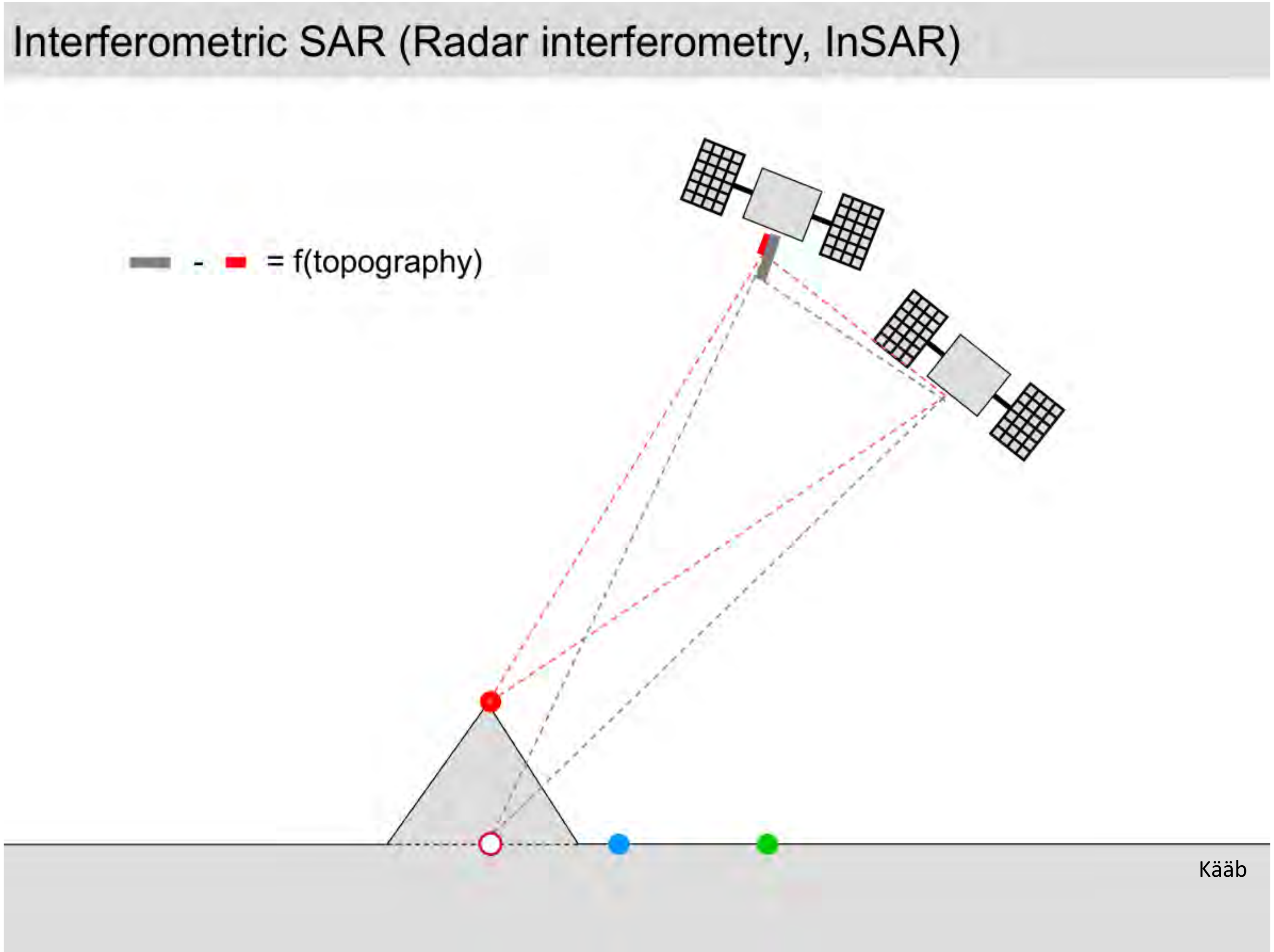


Interferometric SAR theory

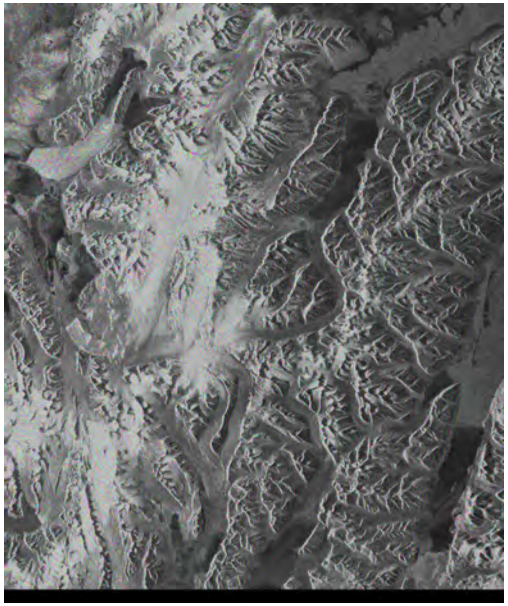
Interferometric SAR (Radar interferometry, InSAR)



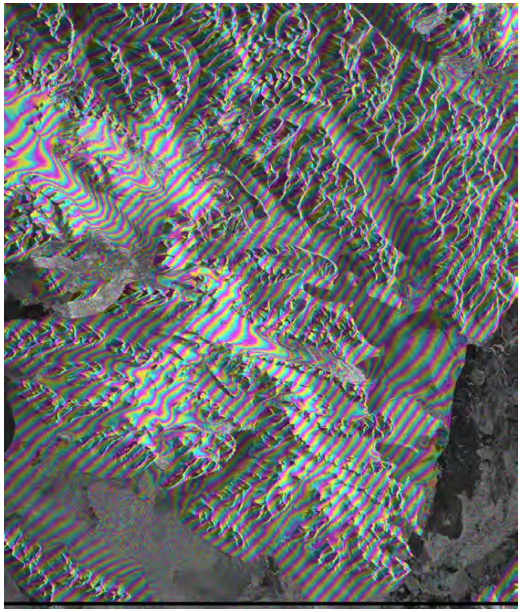
Interferometric SAR theory



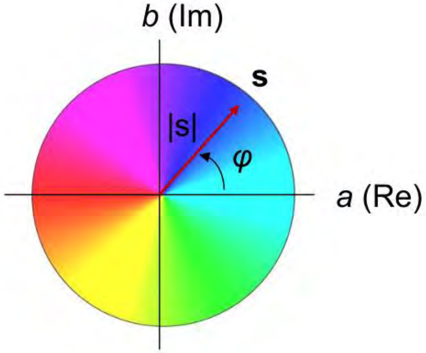
Interferometric processing of ERS-1/2 tandem pair



Interferogram ASC

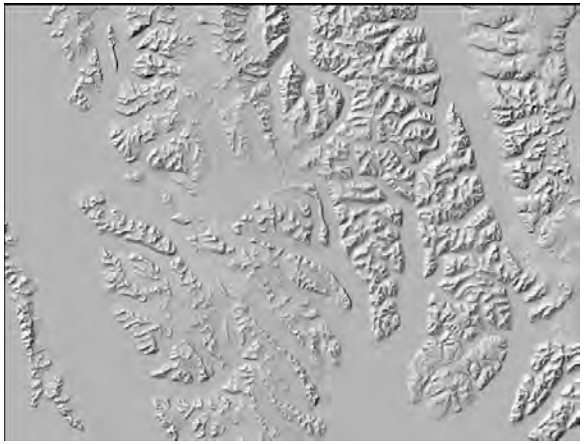


Interferogram DESC

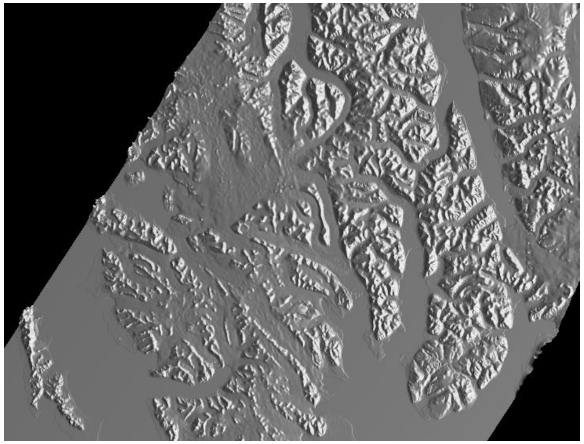


* ERS-1/2 data from ESA / Romsenter PRODEX project "ICEDIVIDE"

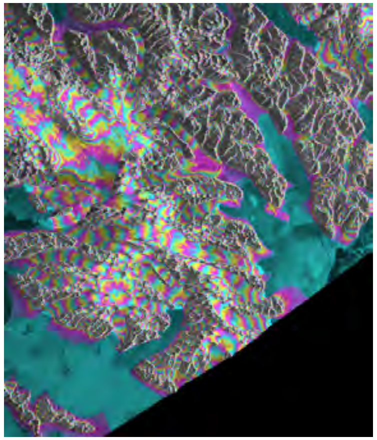
DEM preparation



DEM hill shade



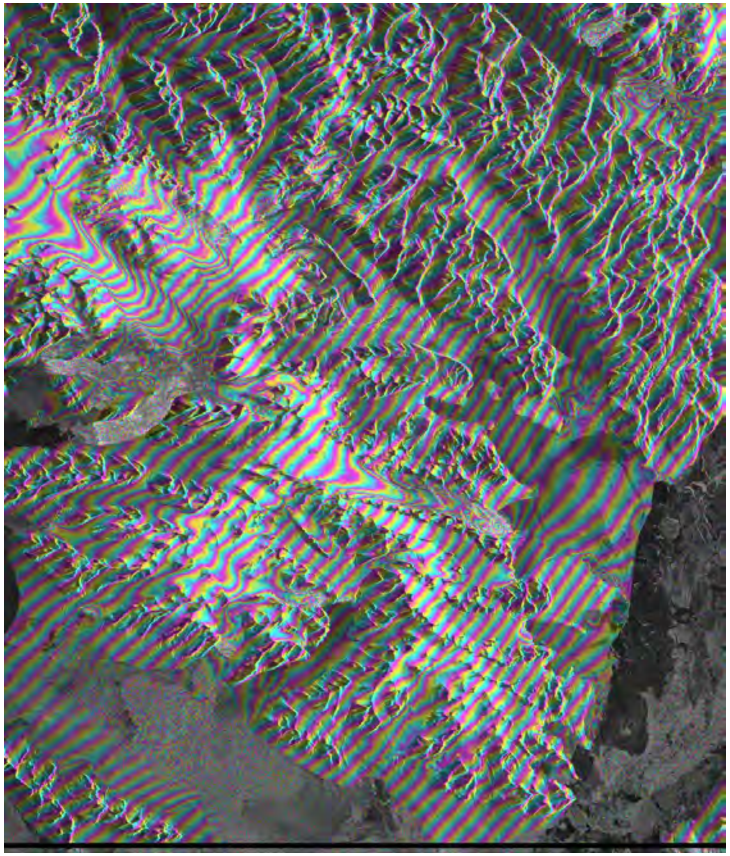
Simulated SAR image



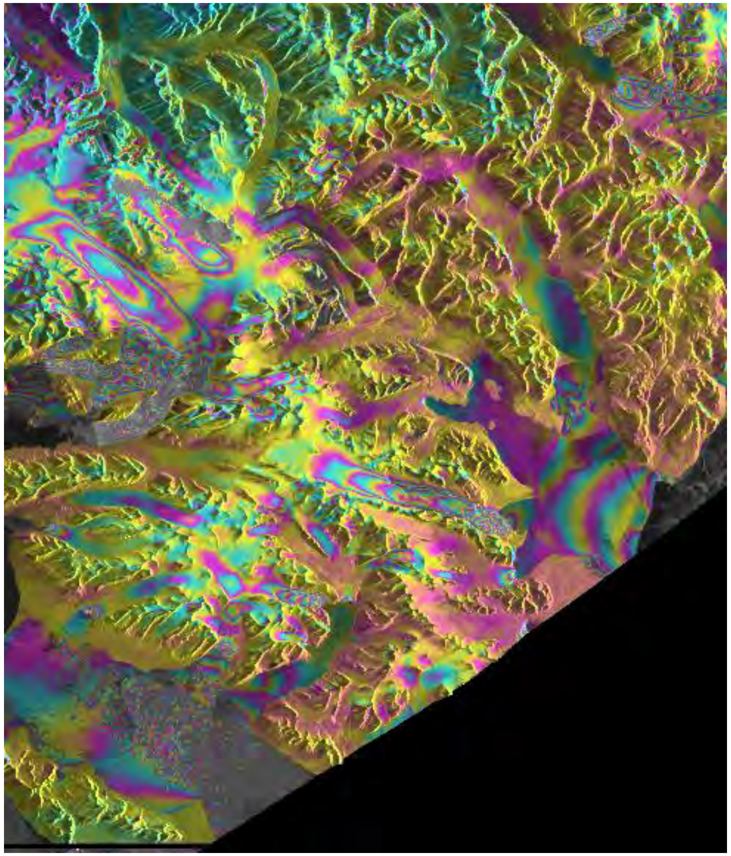
SAR height

Simulated unwrapped phase

Subtraction of topographic phase



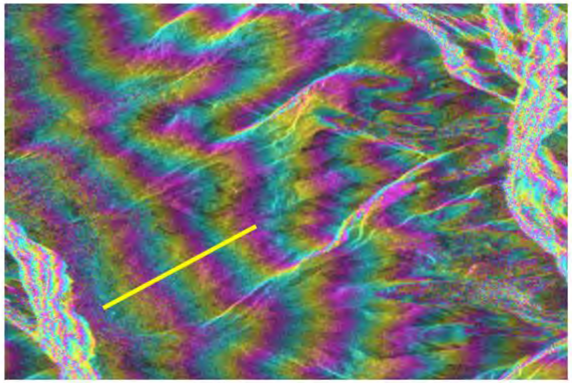
Interferogram #2

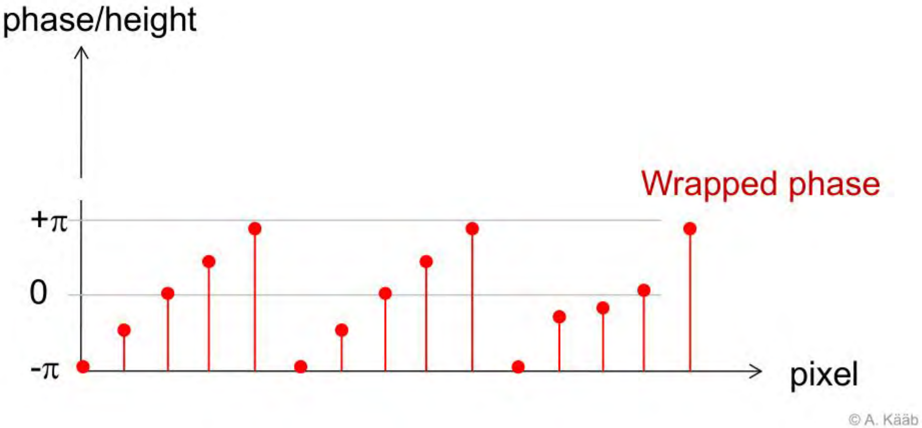


Differential Interferogram

Unwrapping

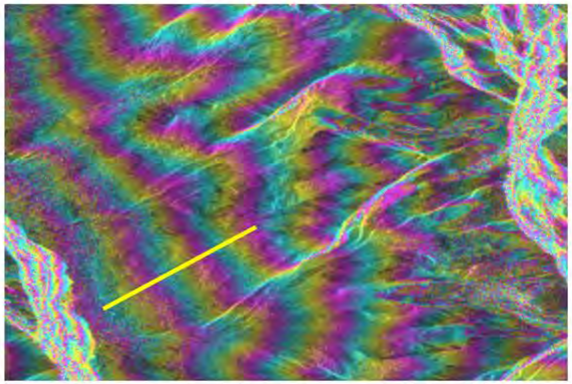
Phase unwrapping: up-slope example



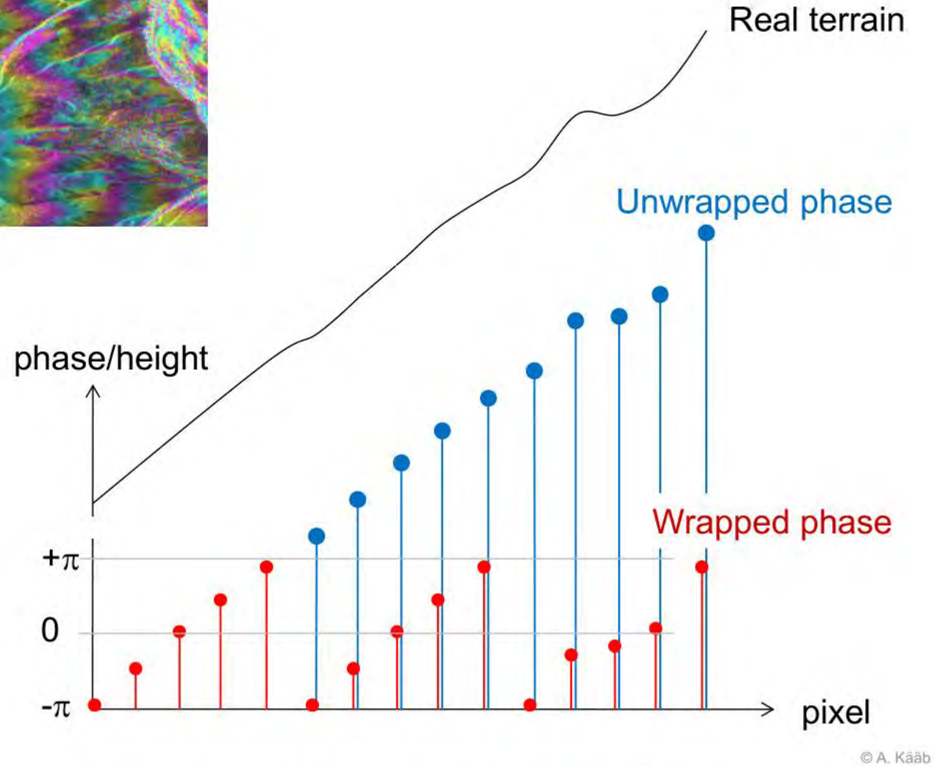


Unwrapping

Phase unwrapping: up-slope example

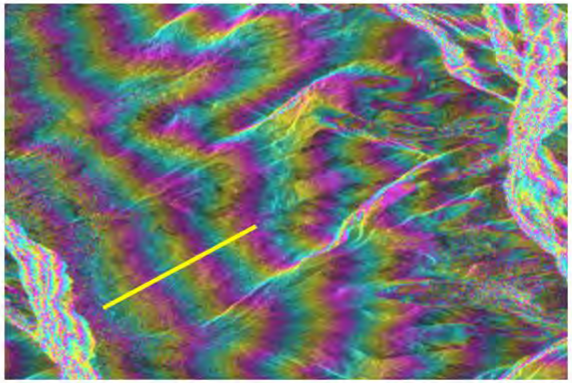


2 ambiguities:
- π - ambig
- Integration constant



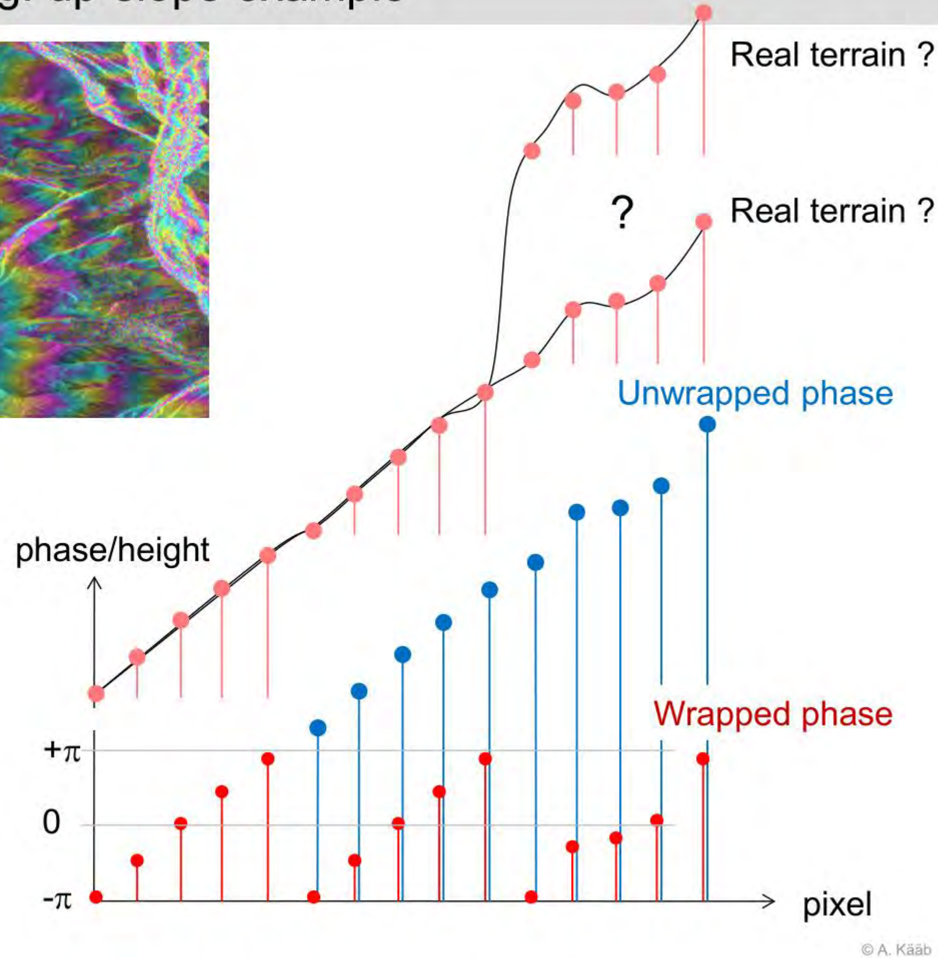
Unwrapping

Phase unwrapping: up-slope example



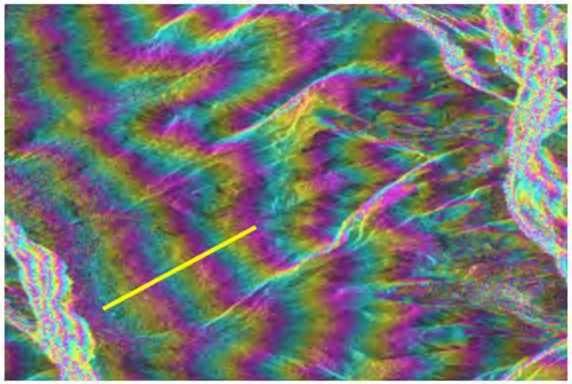
2 ambiguities:
- π - ambig.
- Integration constant

Only Δh or displacement < 2π between two pixels can be measured



Unwrapping

Phase unwrapping: noise

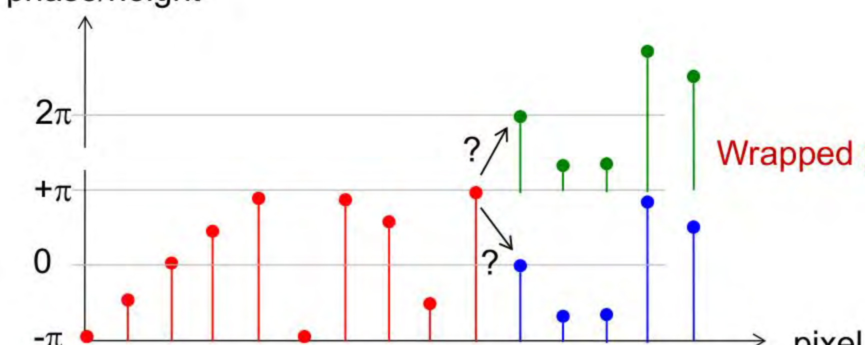


2 ambiguities:
- π - ambig.
- Integration constant

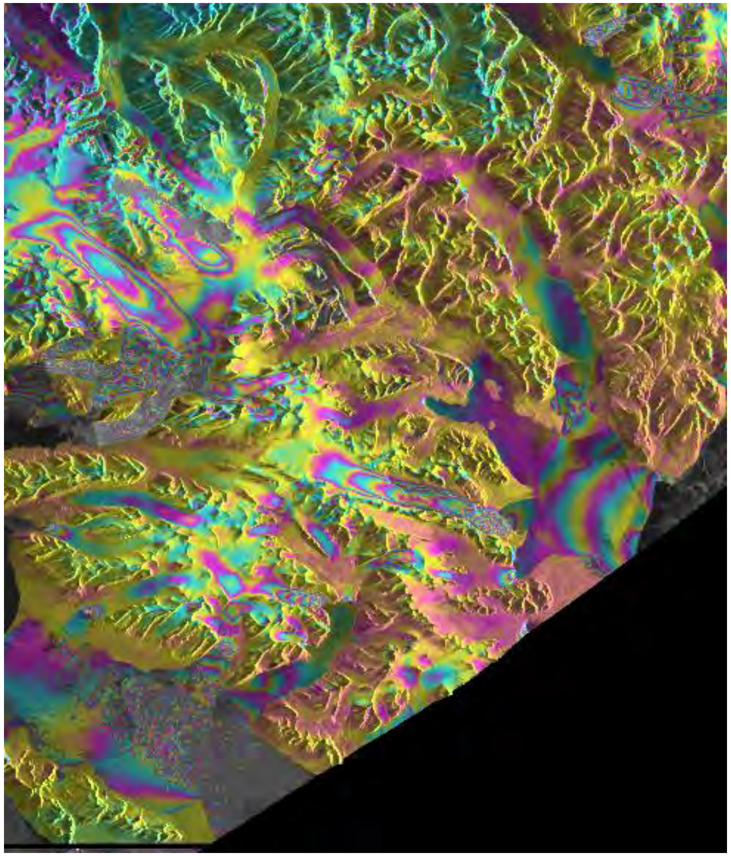
Only Δh or displacement < 2π between two pixels can be measured

= Integration of

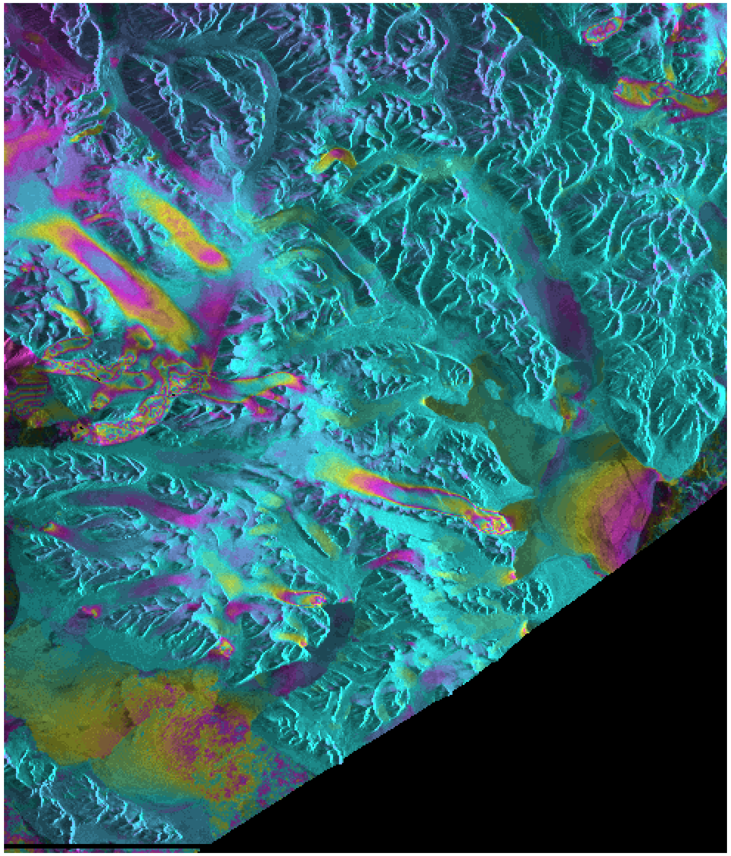
$$\frac{\partial \phi}{\partial z} = \frac{4\pi}{\lambda} \frac{B_{z'}}{y' \sin\theta}$$



Unwrapping

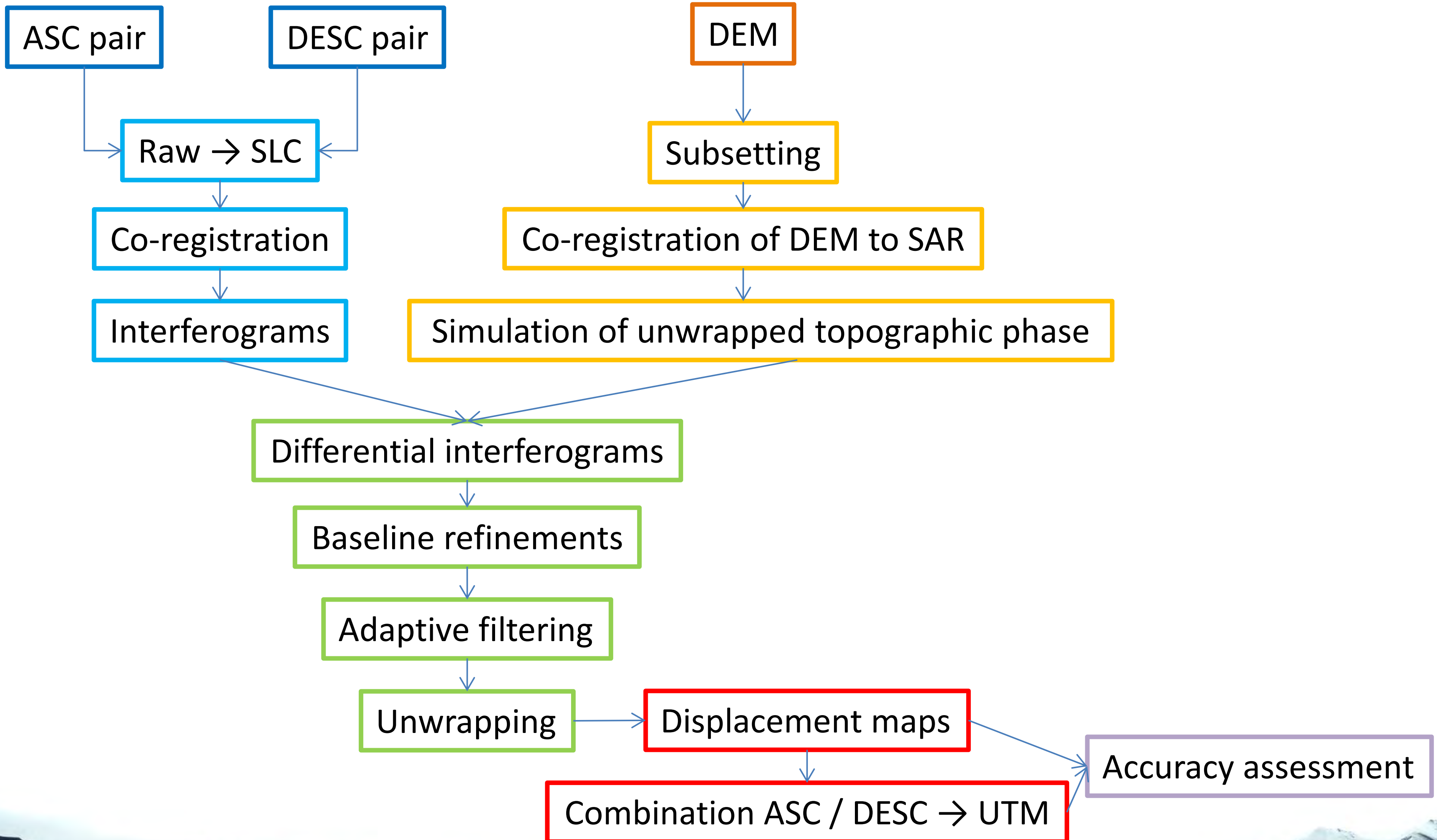


Differential interferogram

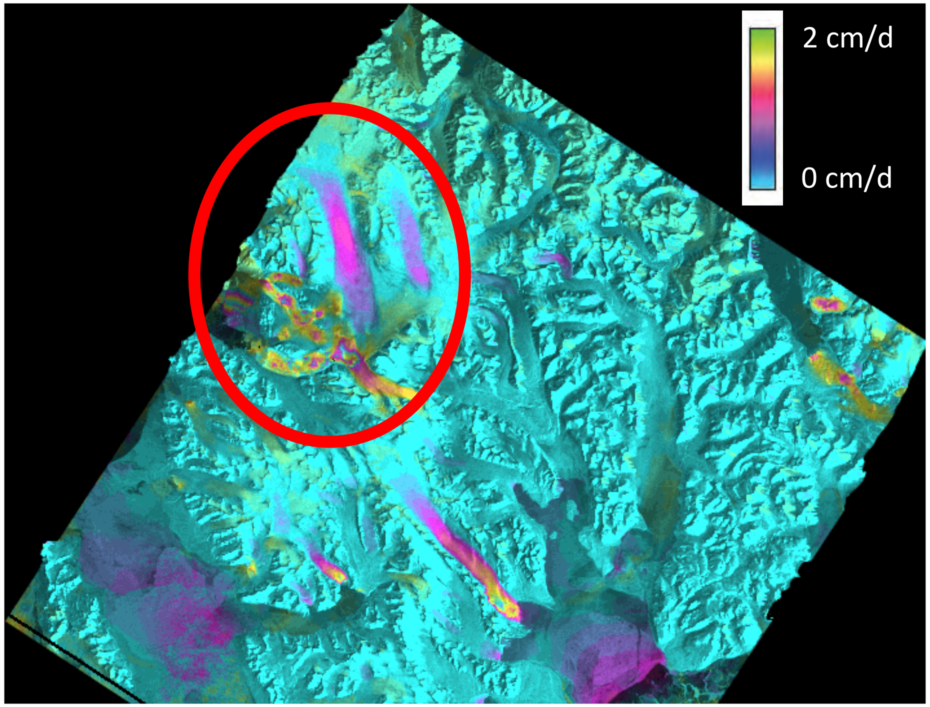


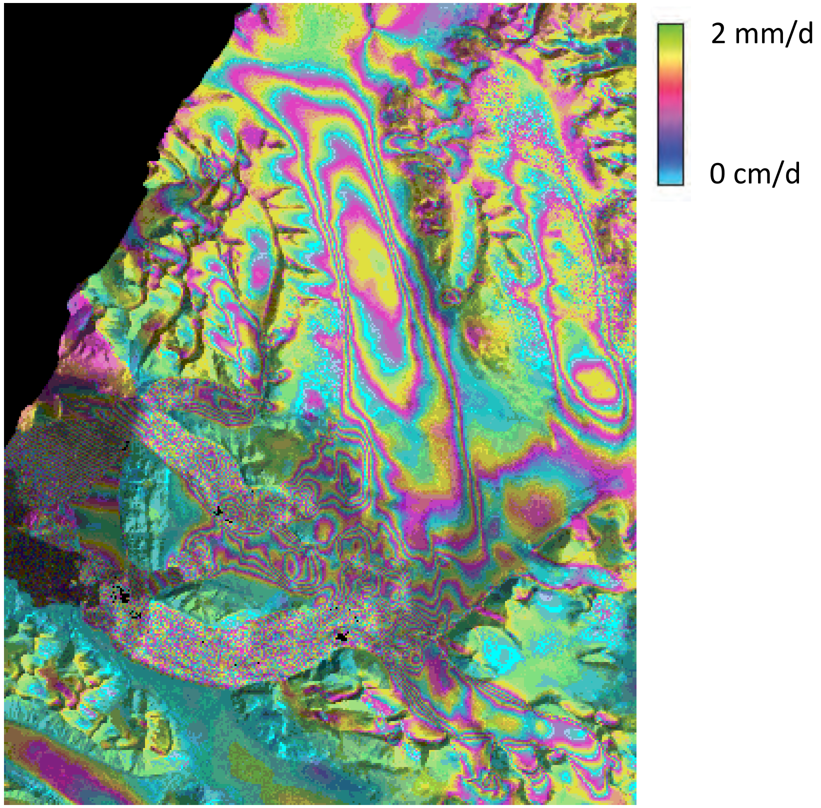
Differential unwrapped interferogram

2-pass D-InSAR workflow



Velocity map – line of sight

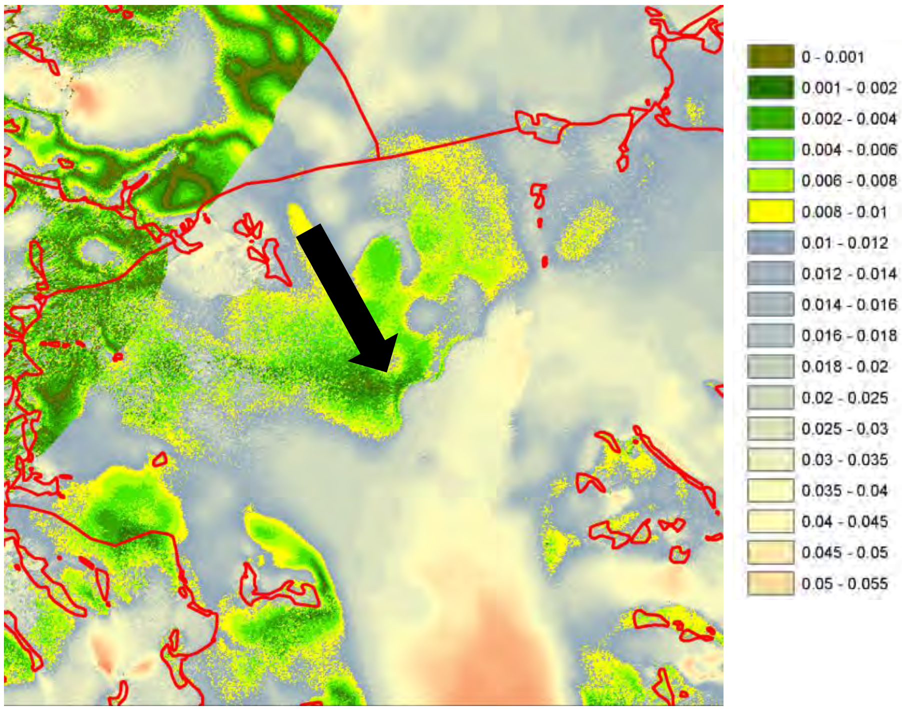




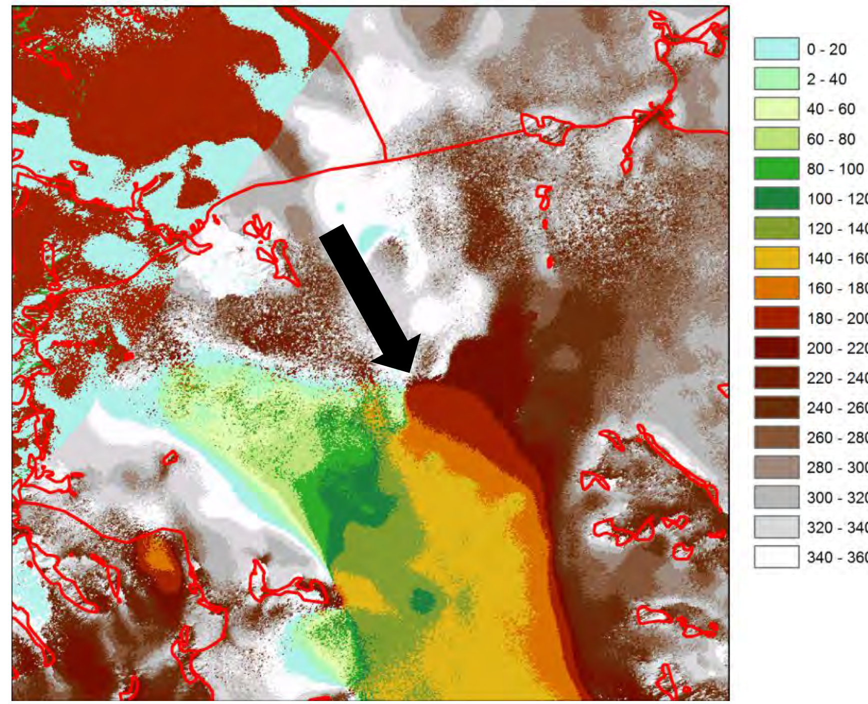
UiO : Department of Geosciences
University of Oslo

2D velocity map
Icedivide between Kongsbreen and Monacobreen

Speed (m/d)



Direction (N = 0°, clockwise)

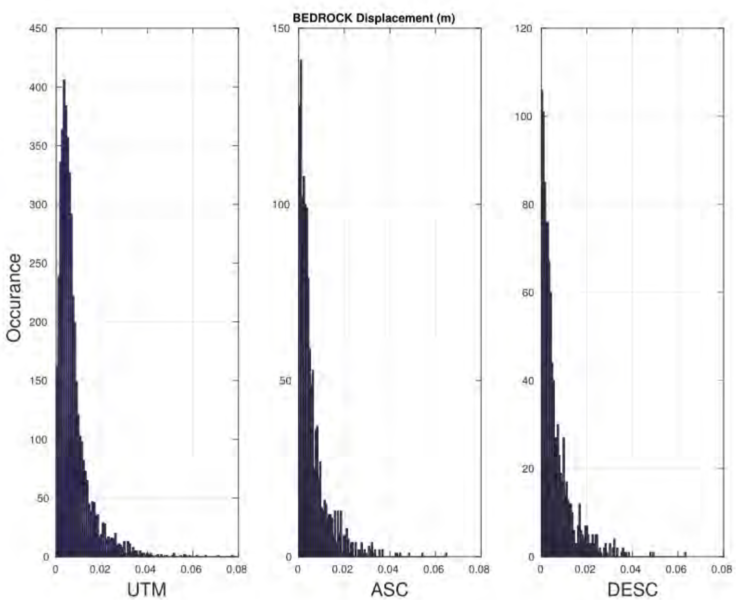


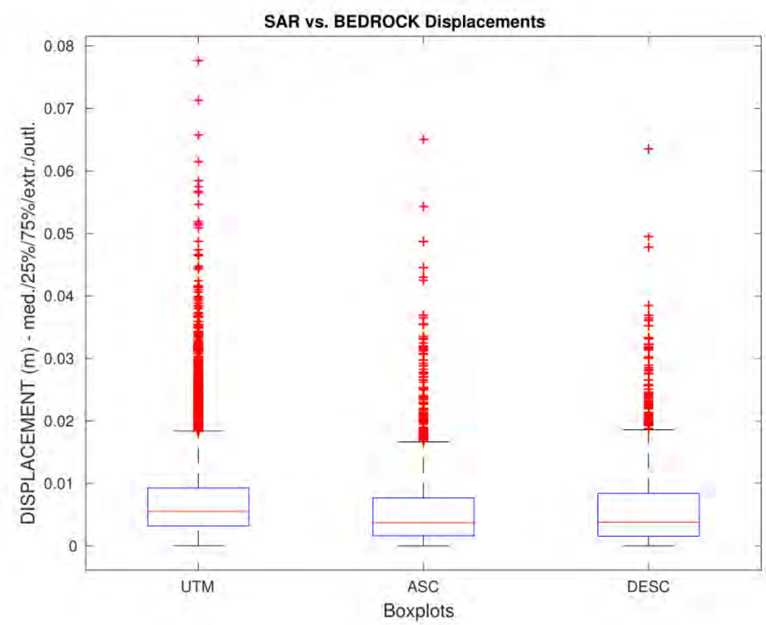
Influence of the surge?

Acuuracy assesment

InSAR Accuracy (bedrock displacement in meter) of **Jostedalsbreen** 20/21 Jan 1996 – 6/7 Mar 1996

	V_median	V_mean	V_std
UTM	0.00552	0.00764	0.00732
ASC	0.00372	0.00606	0.00702
DESC	0.00381	0.00636	0.00728





Take aways

SAR Limitations
- Side-looking sensor (complicated image geometry)
- Backscatter difficult to interpret visually
- Some penetration into the ground
- Sensitive coherence (repeat pass)
- Much analysis know-how necessary

Offset tracking
- robust method for fast moving glaciers
- Accuracy ~1/10 of a pixel

InSAR
- for slow displacements
- accuracy in the range of cm
- many parameters to tune

Thank you!