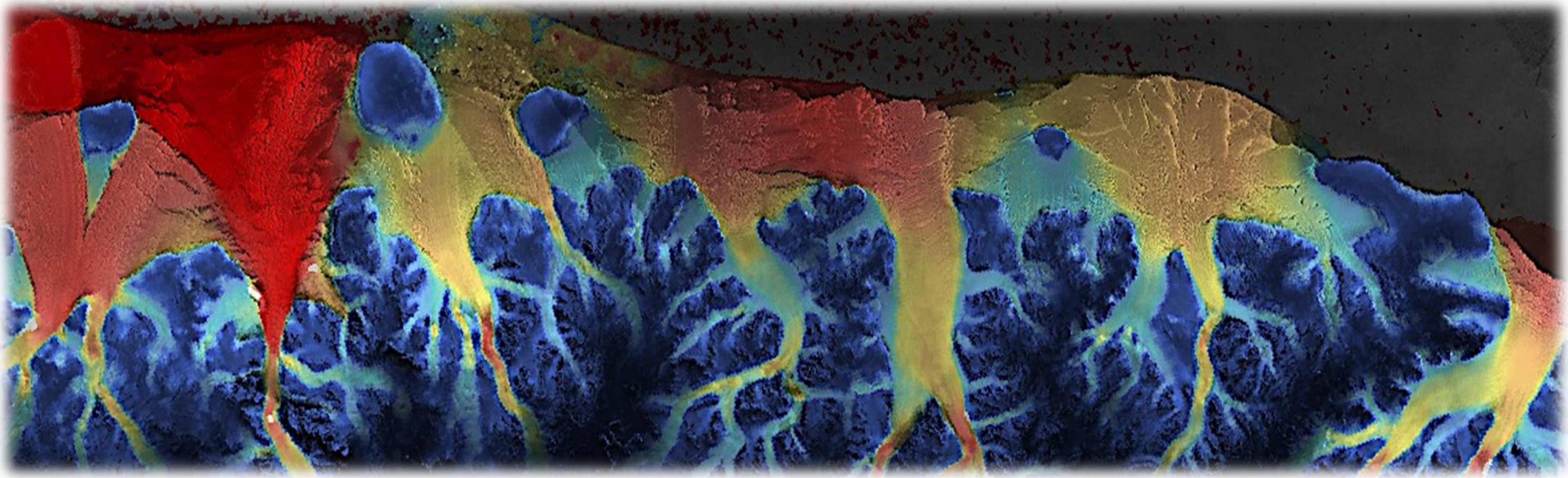


Status and challenges for monitoring ice motion and deformation with satellite constellations

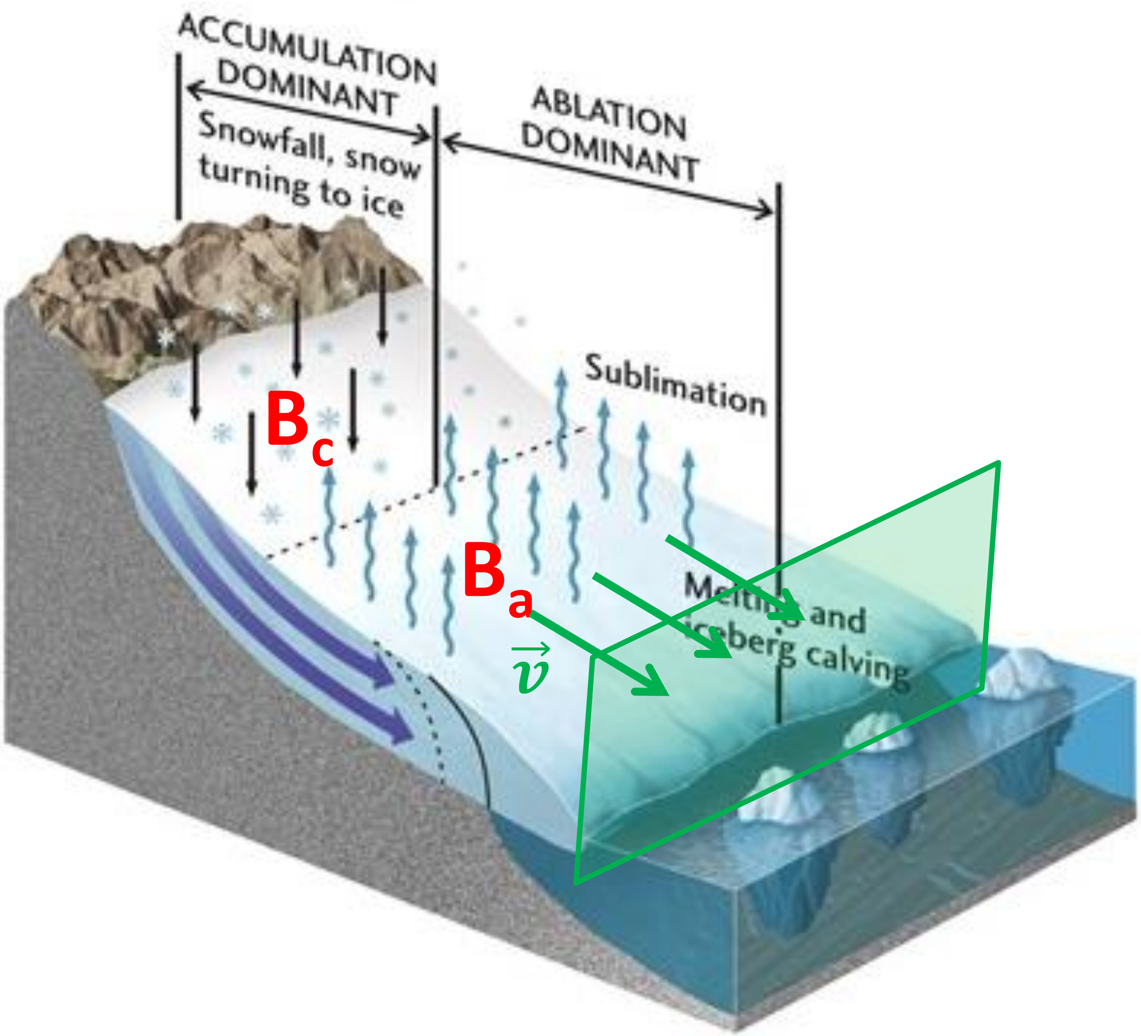
L. Libert, T. Nagler, H. Rott, J. Wuite, M. Hetzenecker, S. Scheiblauer, L. Keuris, G. Schwaizer, J. Nemec

ENVEO, Innsbruck, Austria

MDIS, 16-18 October 2019, Strasbourg

enveo

Why are we interested in polar ice masses ?



Polar ice masses are a key element in **climate change** and contribute to **sea level rise**.

Precise measurements of ice masses and velocity define boundary values for ice dynamic models and are needed for improving **forecasts**.

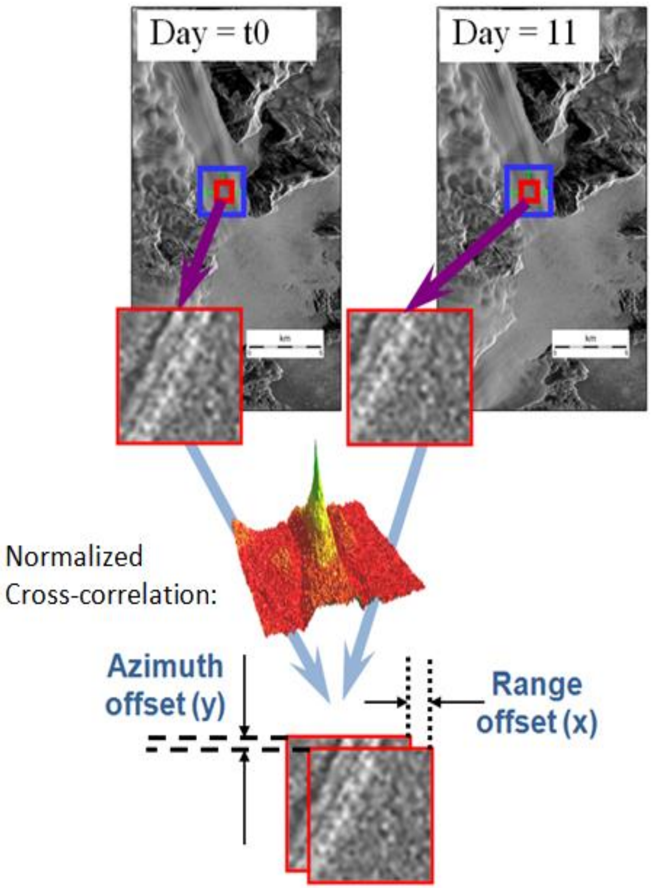
Outline

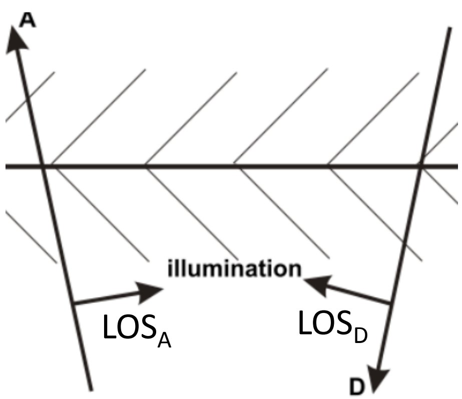
- Methods for observing ice dynamics from SAR
- Standard ice velocity products for polar regions
- 3D ice velocity
- Mass change estimation from InSAR DEM differencing
- Summary for ice monitoring with SAR
- Upcoming missions

SAR Offset Tracking for Ice Motion

Matching of image templates by cross correlation

Amplitude correlation / speckle tracking / coherence tracking





$(d_{az,A}, d_{LOS,A})$

$(d_{az,D}, d_{LOS,D})$

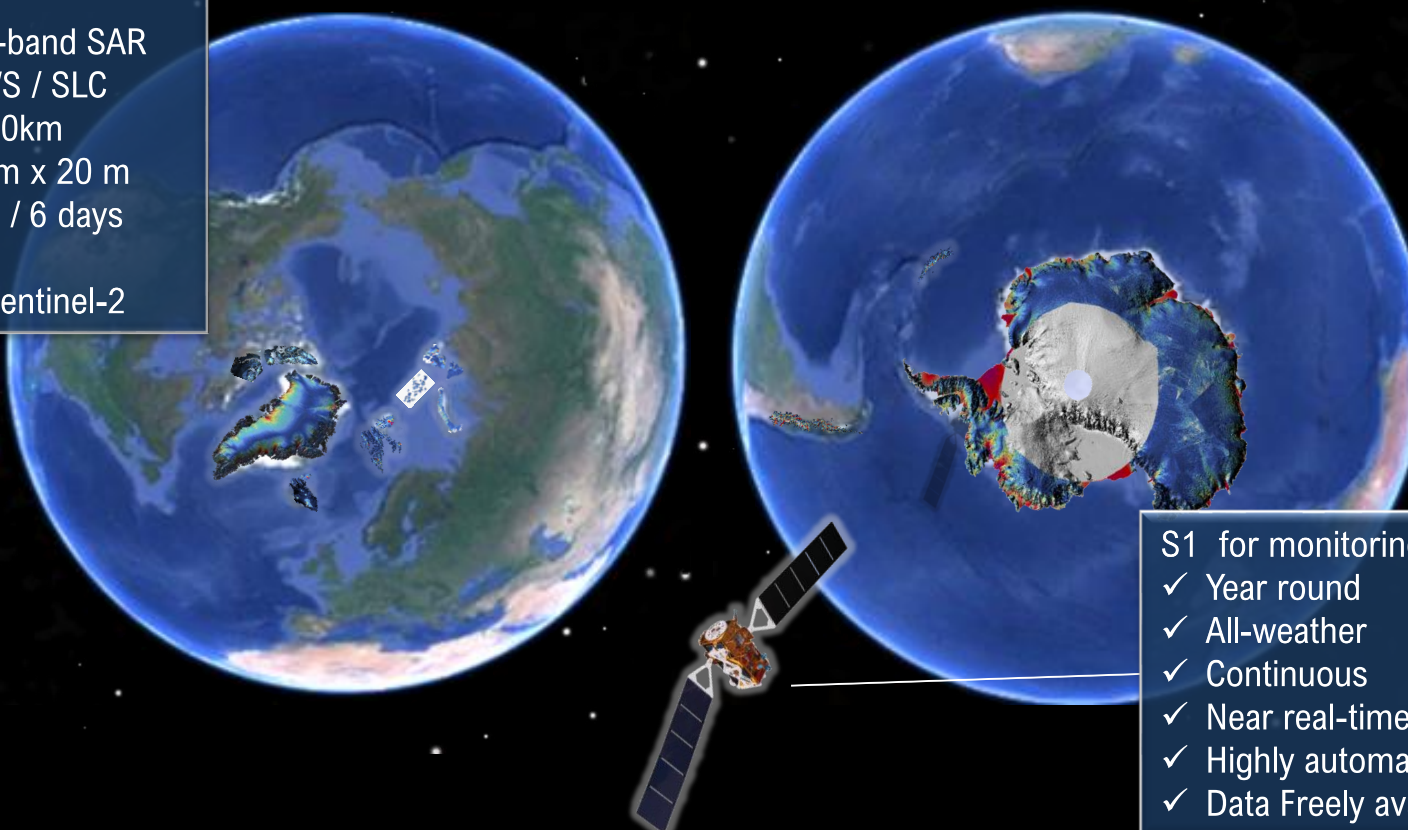
« Simultaneous » ascending and descending passes:

4 displacement components to solve 3-D motion

Polar Ice Velocity Monitoring using Sentinel-1

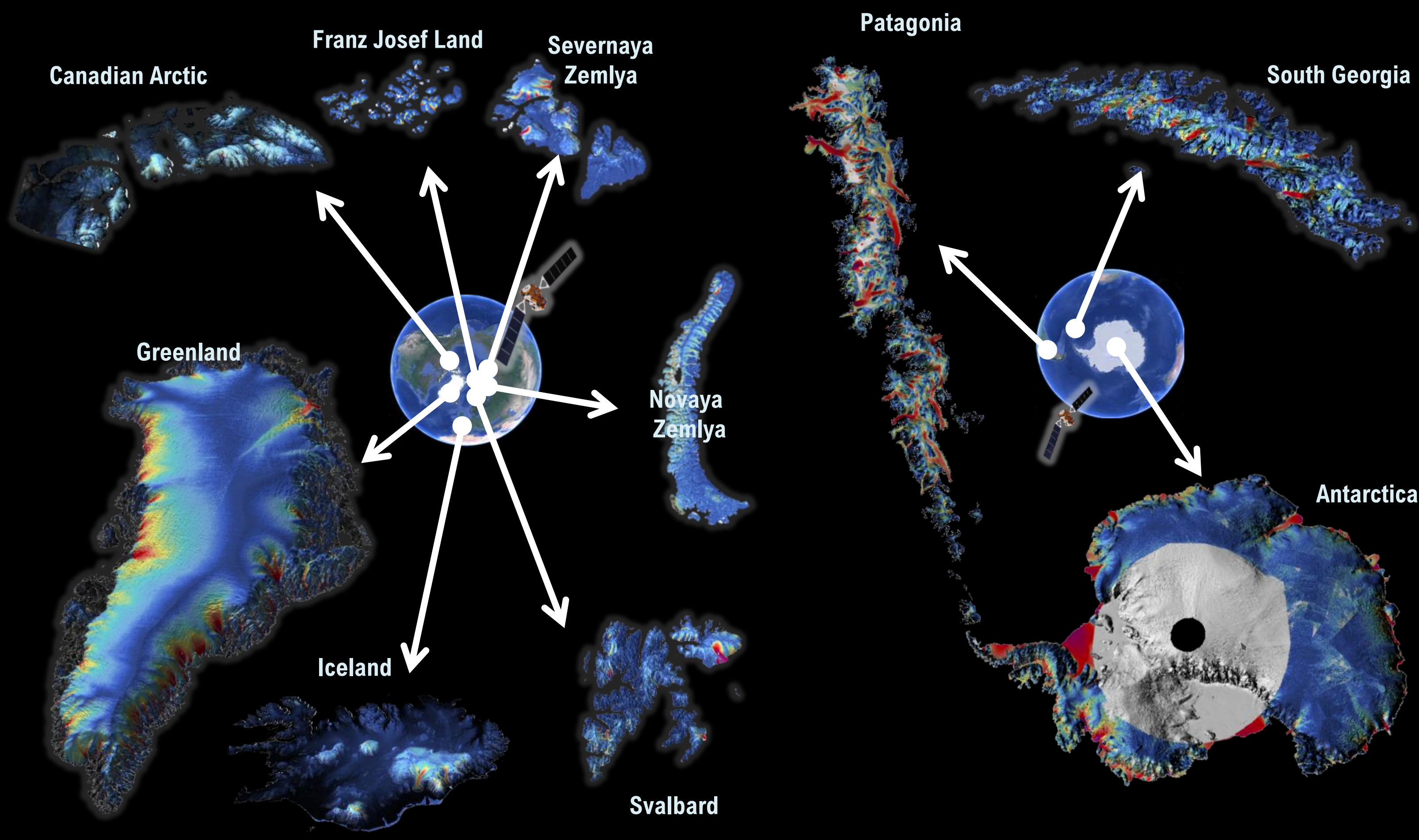
Platform: Sentinel-1A/1B
Launch: April 2014/2016
Sensor: C -band SAR
Mode / Product: IWS / SLC
Swath width: 250km
Resolution: 5 m x 20 m
Repeat cycle: 12 / 6 days

Complemented by Sentinel-2 MSI

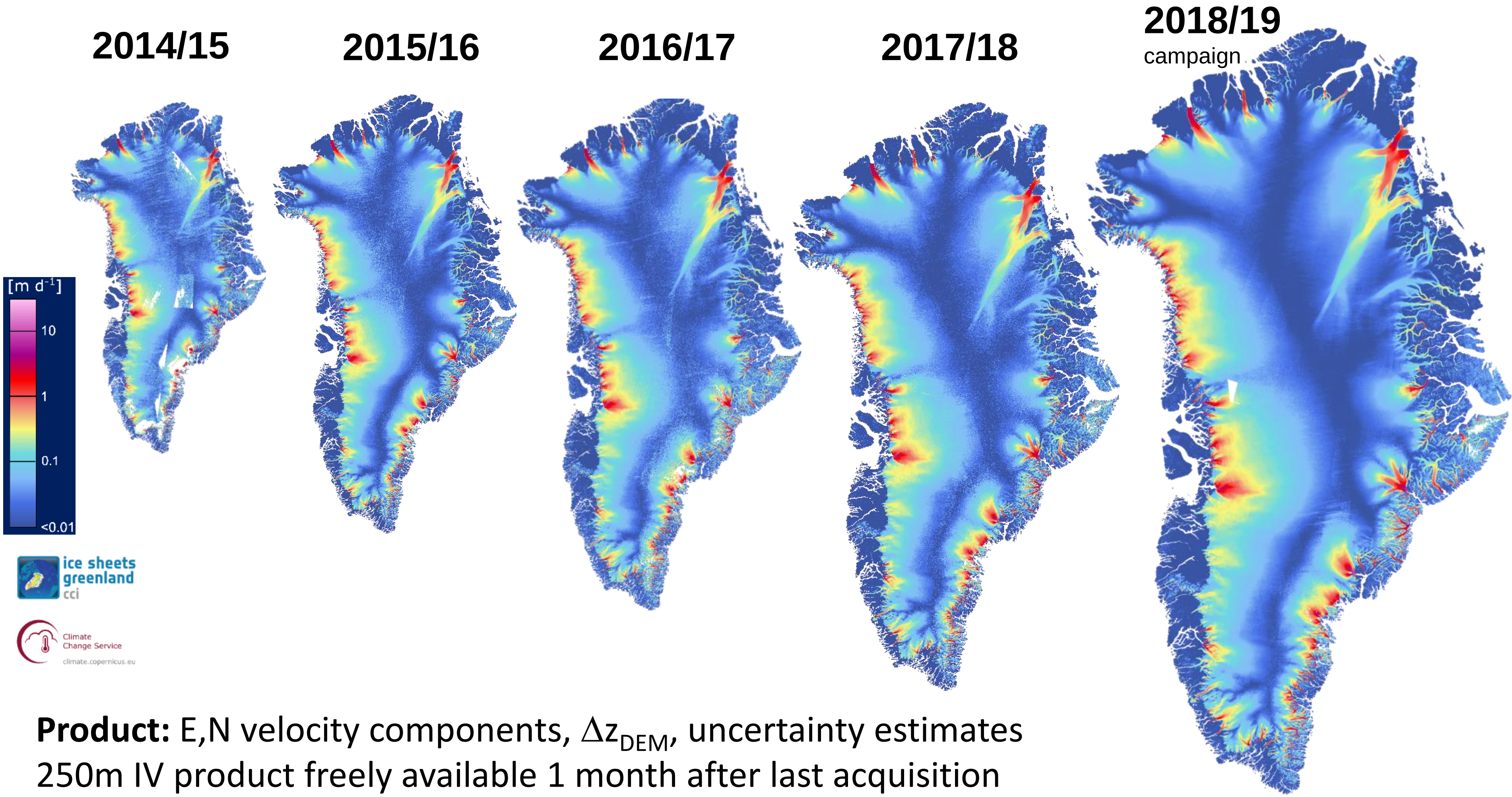


S1 for monitoring:
- ✓ Year round
- ✓ All-weather
- ✓ Continuous
- ✓ Near real-time
- ✓ Highly automated
- ✓ Data Freely available

Polar Ice Velocity Monitoring using Sentinel-1



Sentinel-1 Greenland Annual Ice Sheet Velocity Maps



ice sheets greenland cci

Climate Change Service
climate.copernicus.eu

Product: E,N velocity components, Δz_{DEM}, uncertainty estimates
250m IV product freely available 1 month after last acquisition

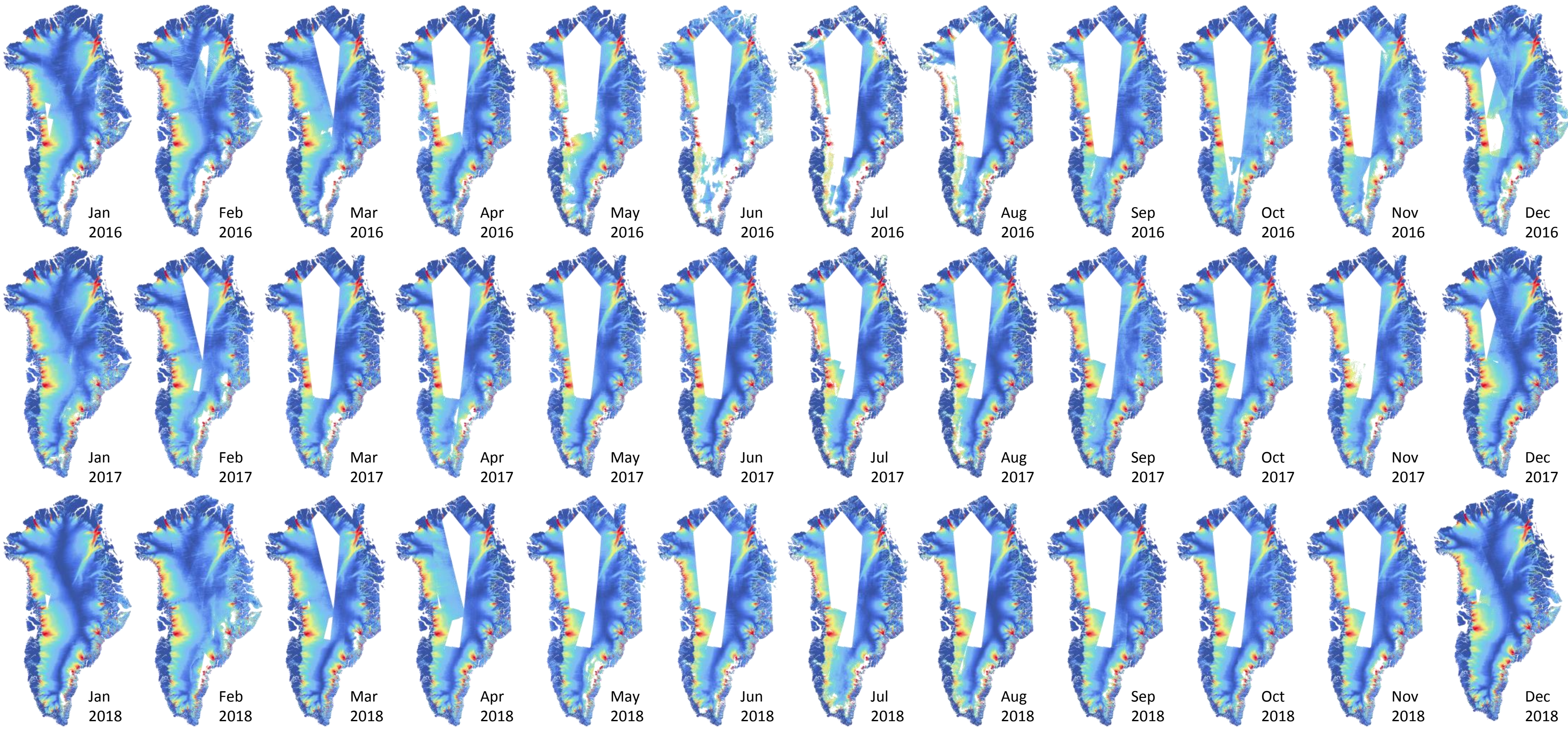
Method: Coherent and Incoherent Offset Tracking

http://cryoportal.enveo.at

Nagler et al. 2015

enveo

Monthly Ice Velocity Products - since October 2014



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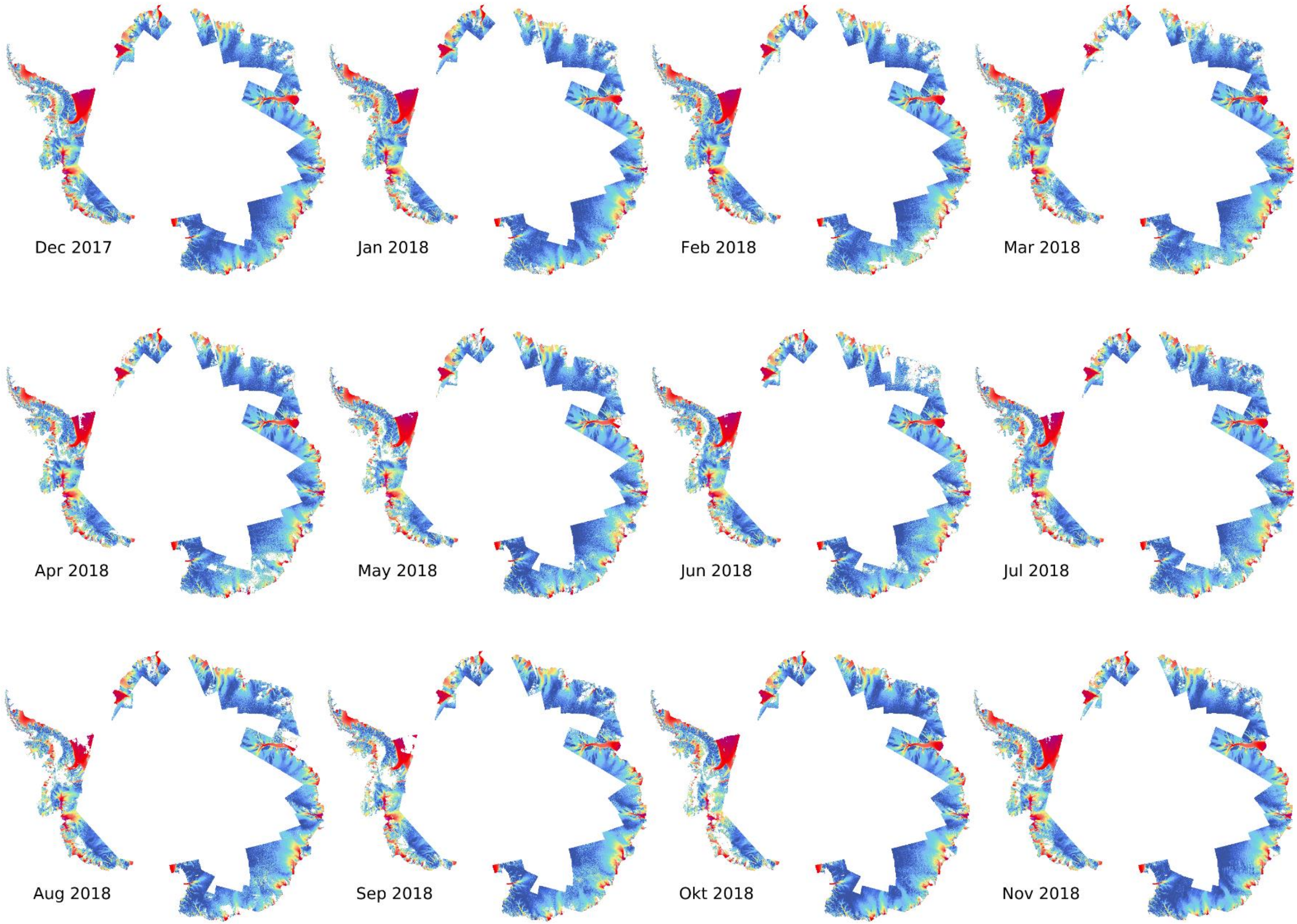
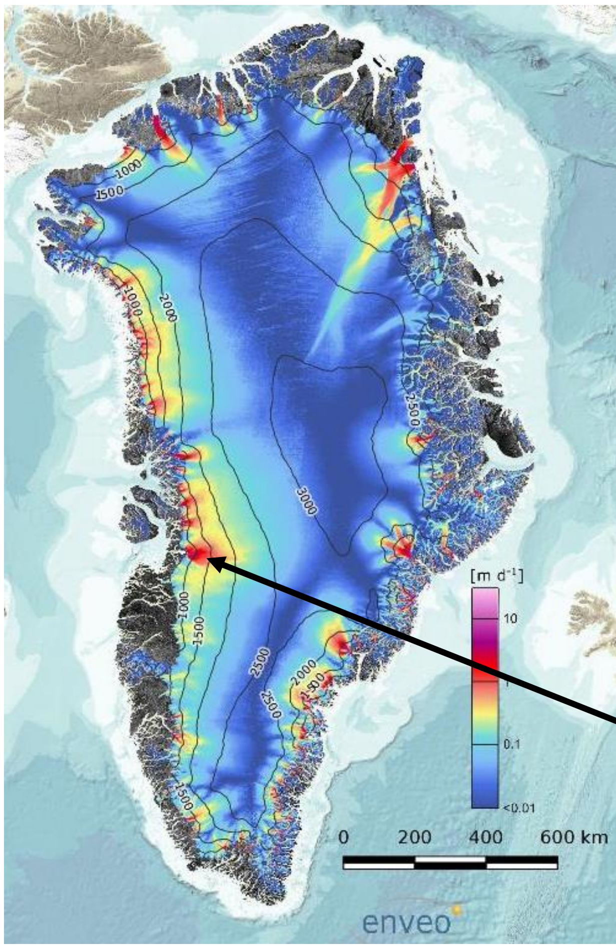
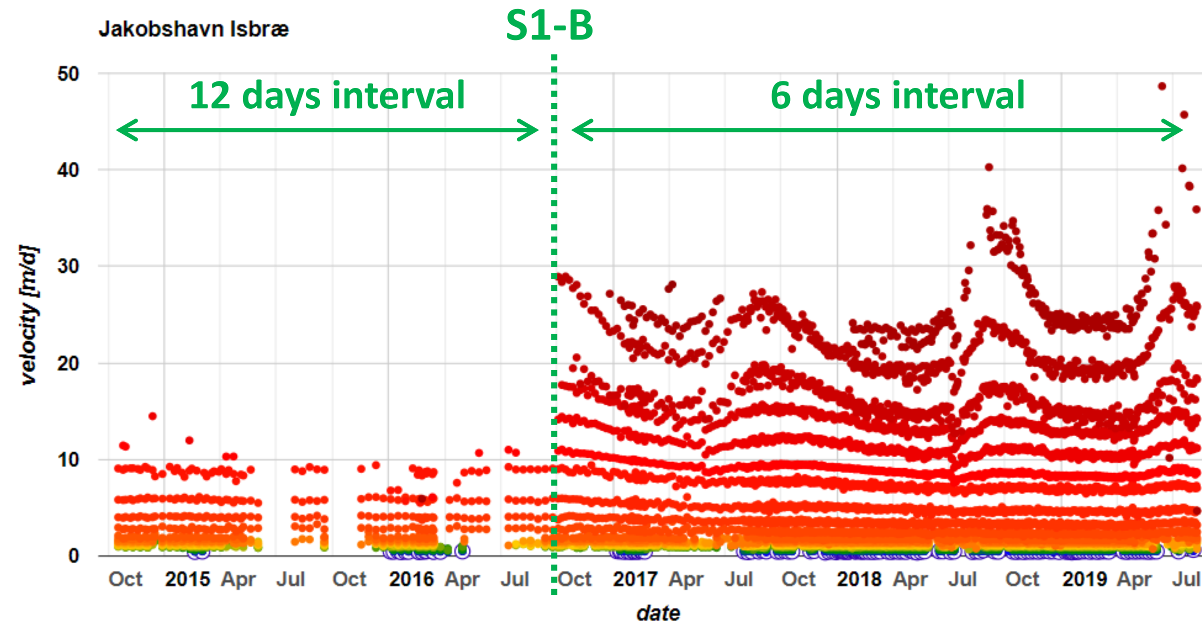
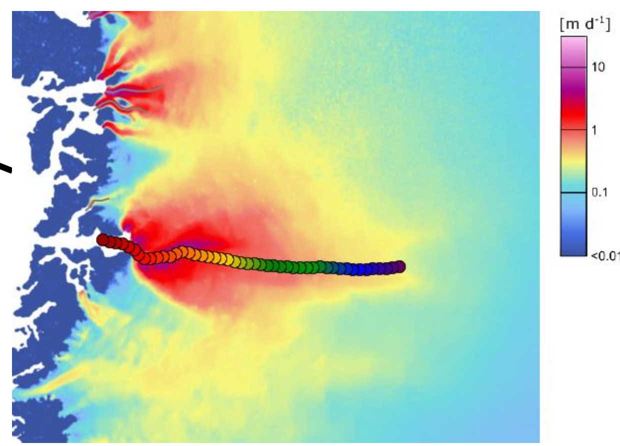
Monthly Ice Velocity Maps



Sentinel-1 Velocity Time series
Jakobshavn Isbrae – West Greenland

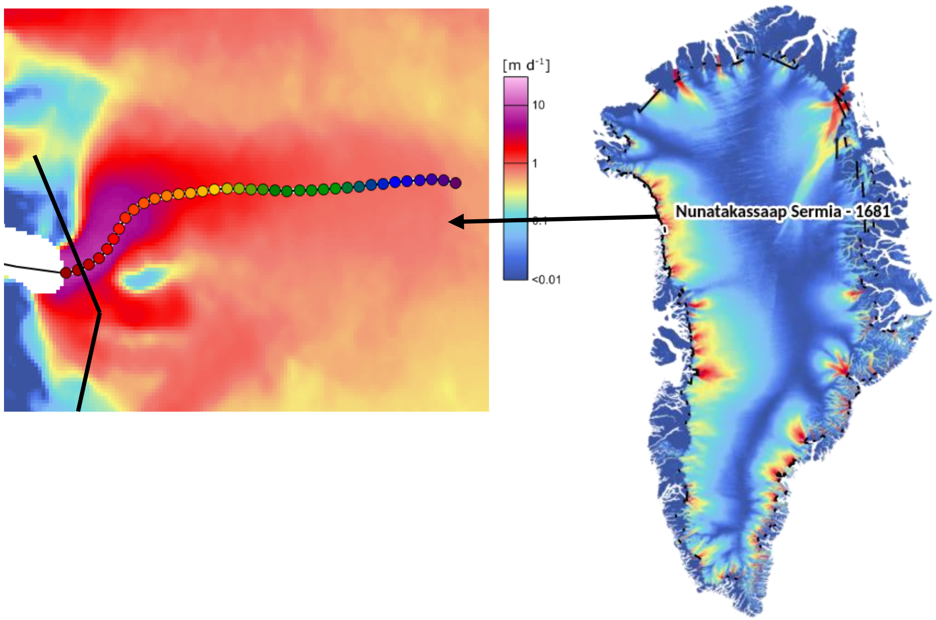


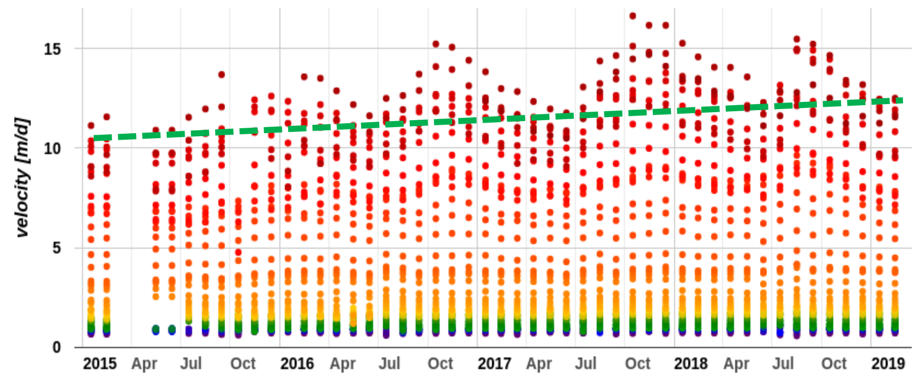


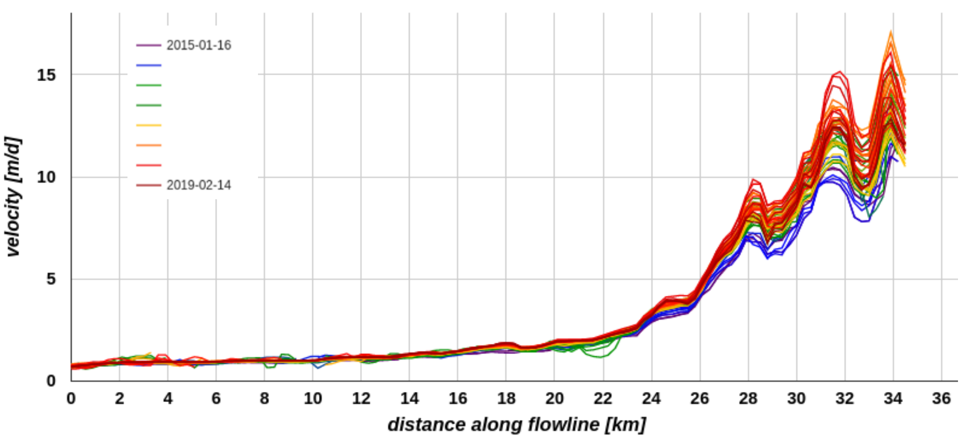


Terminus with fast velocity and seasonal variations

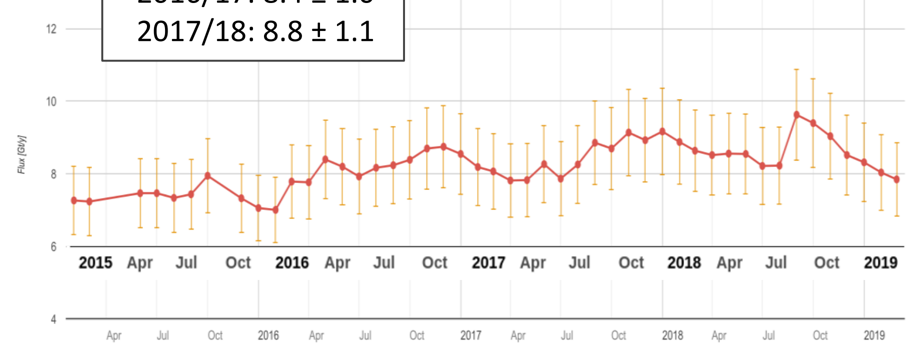
Sentinel-1 Velocity and Ice Flux Time Series
Nunatakassaap Sermia – West Greenland







Annual Flux [Gt/y]
2014/15: 7.3 ± 0.9
2015/16: 8.2 ± 1.0
2016/17: 8.4 ± 1.0
2017/18: 8.8 ± 1.1



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Ice velocity with InSAR

SAR interferometry measures **motion along the LOS**:

$$\boxed{\Delta\phi = \frac{4\pi}{\lambda}\Delta R}$$

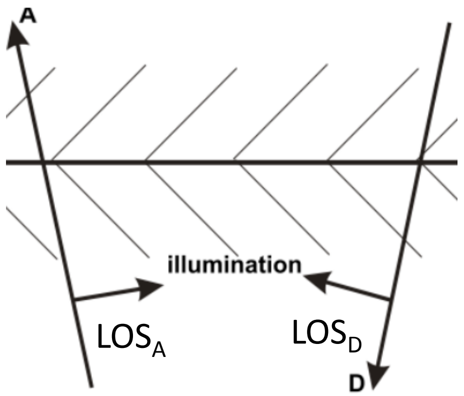
$\boxed{\text{3D velocity vector: } \mathbf{v} = \mathbf{v}_h + \mathbf{v}_z = v_E\,\mathbf{i}_E + v_N\,\mathbf{i}_N + v_z\,\mathbf{i}_z}$

Surface parallel flow assumption:

$$\mathbf{v} = \mathbf{v}_h + \mathrm{v}_z = \mathbf{v}_h + \boxed{\mathrm{v}_x \frac{\partial}{\partial x} S(x,y) + \mathrm{v}_y \frac{\partial}{\partial y} S(x,y)}$$

Vertical motion only due to slope

Combination of ascending, descending interferograms and projection on DEM for retrieving 3-D **surface** velocity



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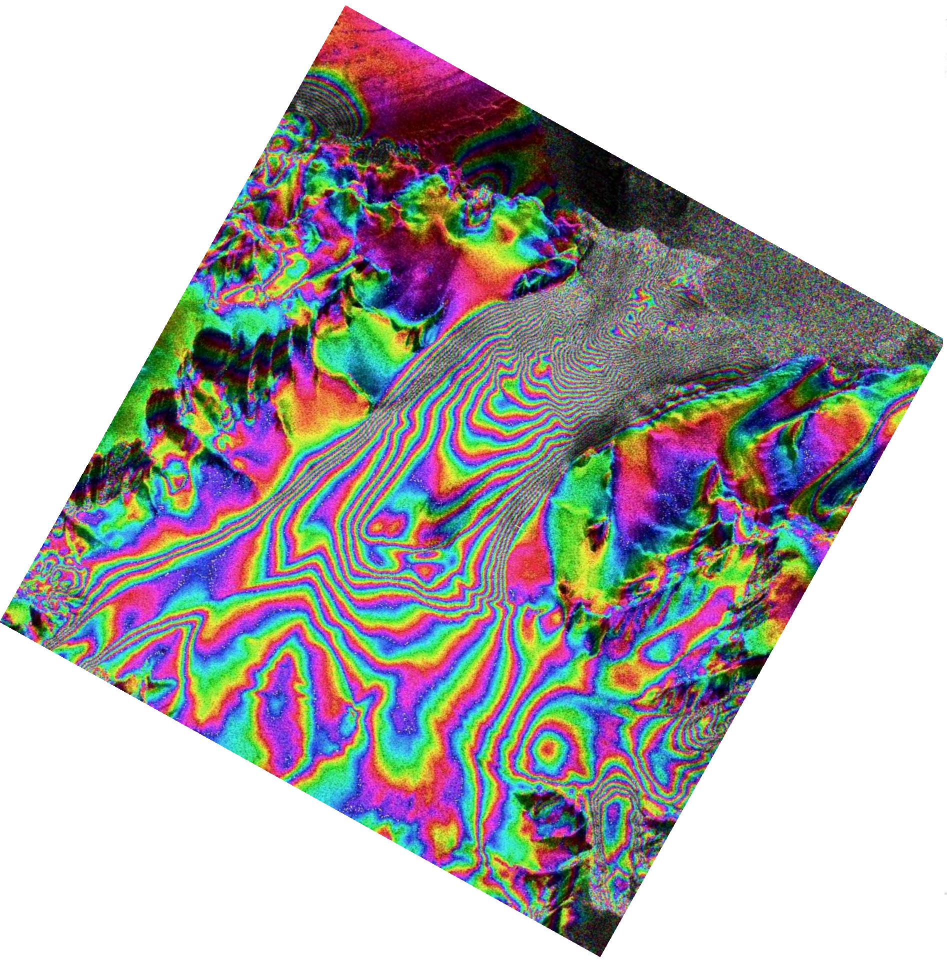
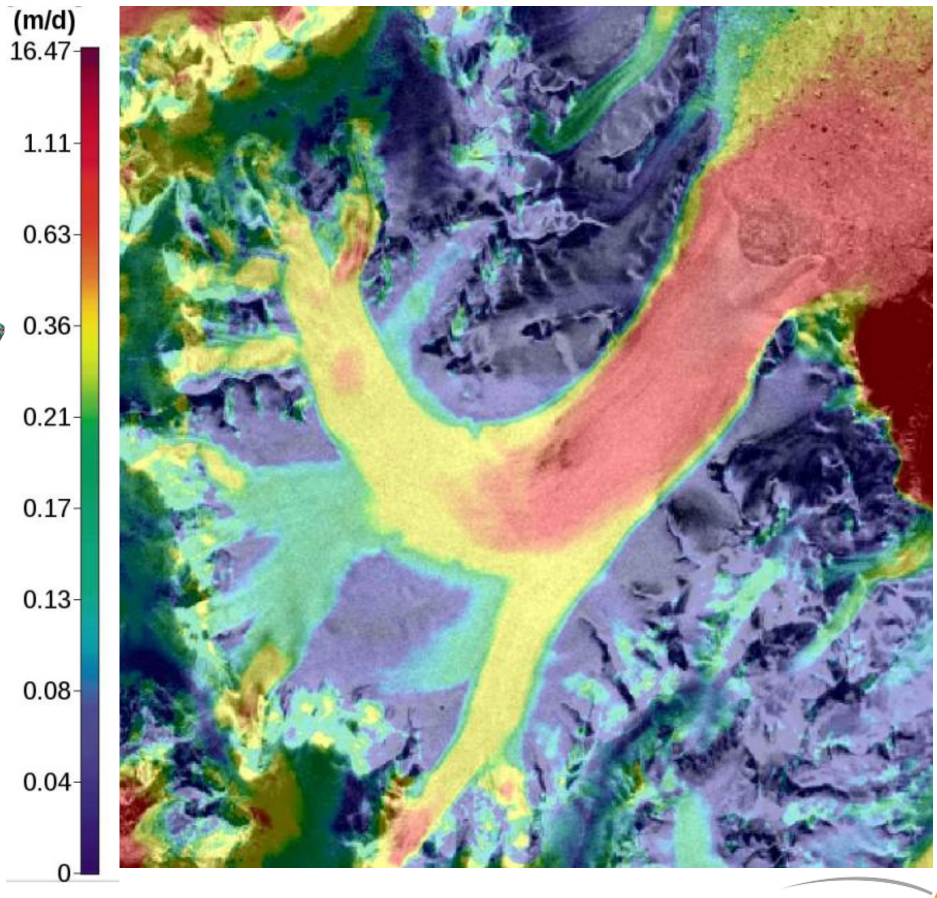
Ice velocity with InSAR

ERS-1/-2 Interferogram
1995-10-31/1995-11-01



Drygalski Glacier, Antarctic Peninsula

Velocity Map (magnitude) from InSAR data of crossing orbits



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3D Ice Motion with Offset Tracking

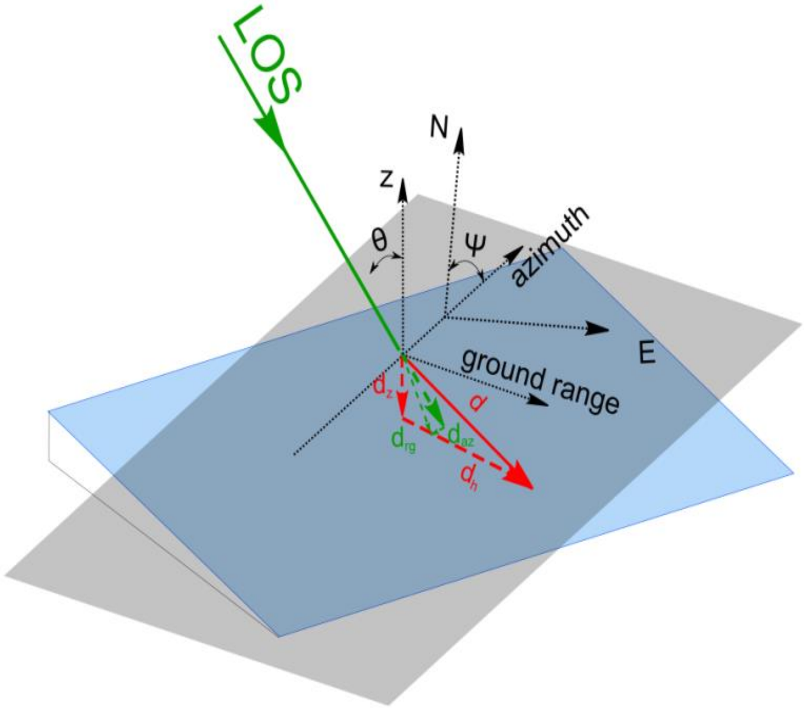
3D velocity vector: $\mathbf{v} = \mathbf{v}_h + \mathbf{v}_z = v_E \, \mathbf{i}_E + v_N \, \mathbf{i}_N + v_z \, \mathbf{i}_z$

Slant range and along-track components:

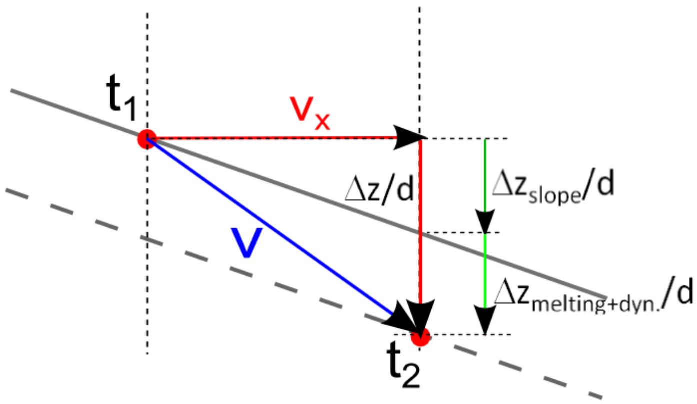
$$v_{sr} = v_x \cos\Psi \sin\theta - v_y \sin\Psi \cos\theta - v_z \cos\theta$$

$$v_{az} = v_x \sin\Psi + v_y \cos\Psi$$

θ - off-nadir angle (look angle) ψ - heading angle



v_z contributions



Crossing passes + stable conditions (same time interval)

For each geocoded pixel:

→ 4 velocity (displacement/Δtime) measurements: **$(v_{sr}, v_{az})_{asc}$** and **$(v_{sr}, v_{az})_{des}$**

→ SAR imaging geometry exactly known: ψ_{asc}, θ_{asc}, ψ_{des}, θ_{des}

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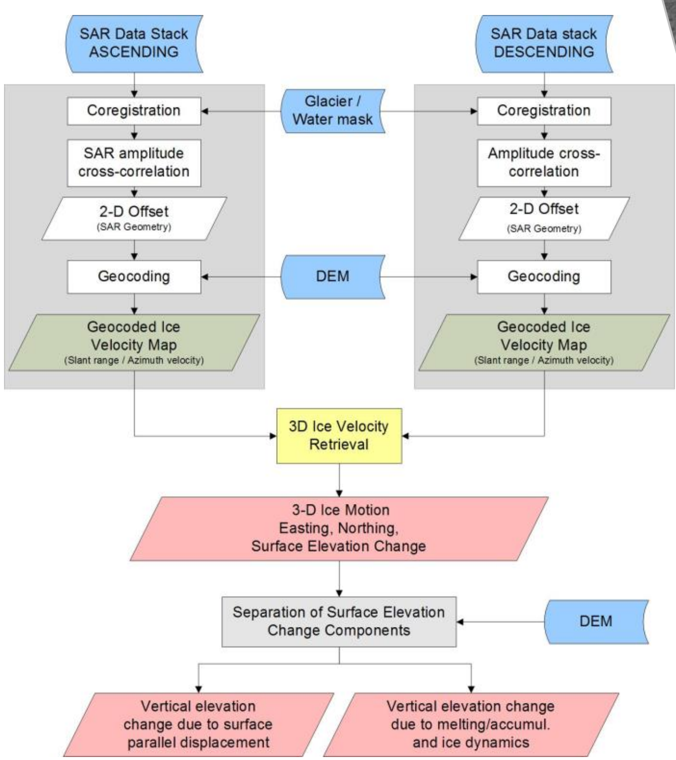
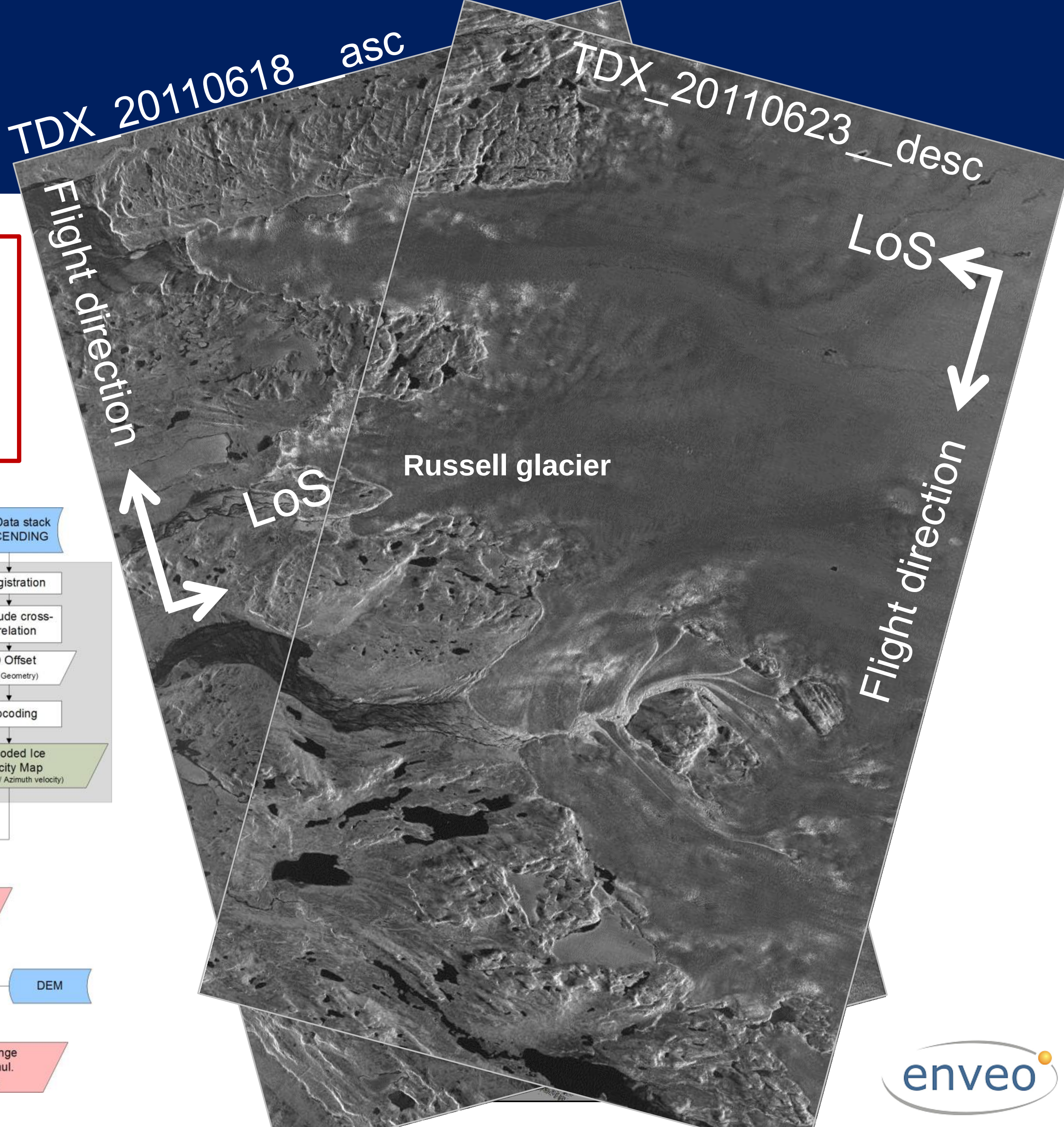
3D ice motion

TDX Stripmap mode:

- 3m resolution
- scene size (width x length) : 30 km x 50 km





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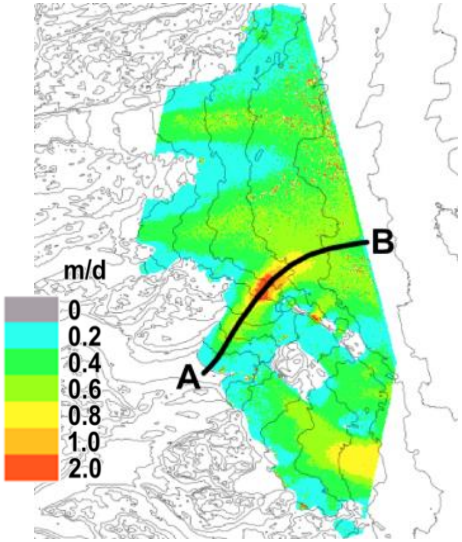
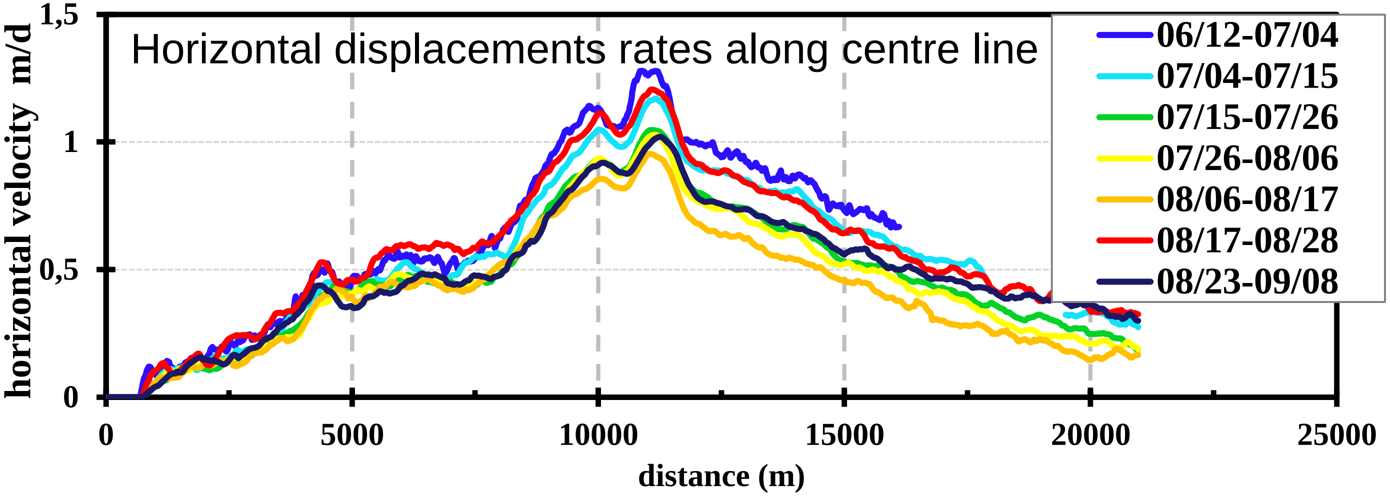
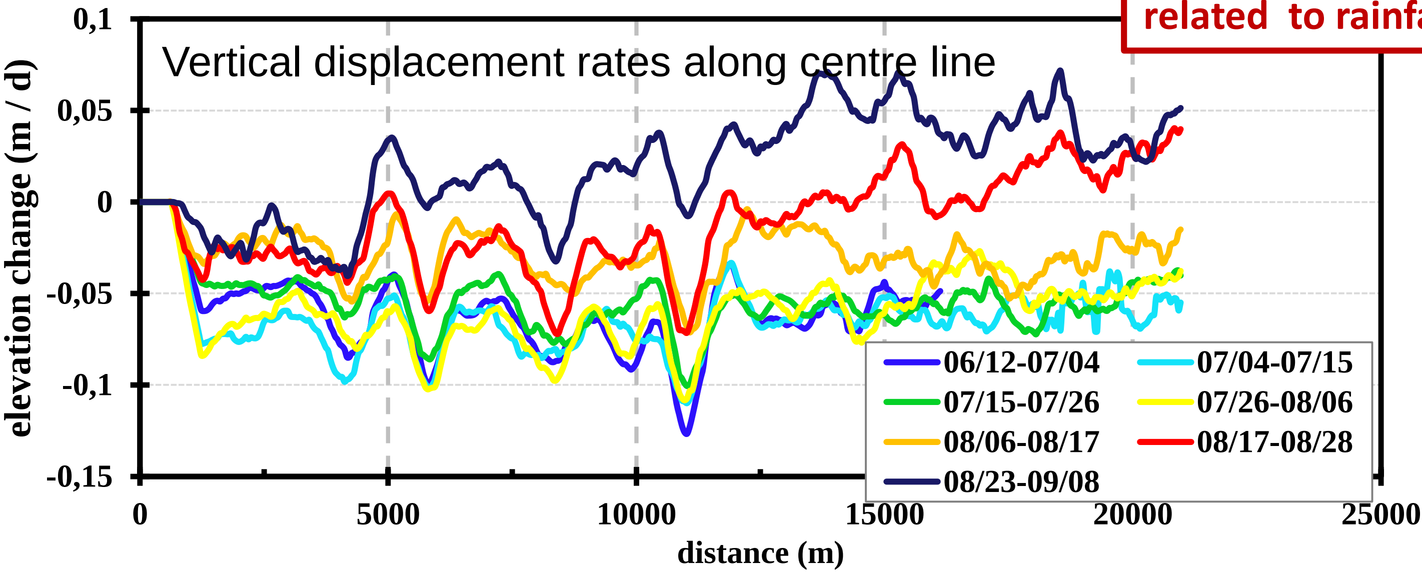
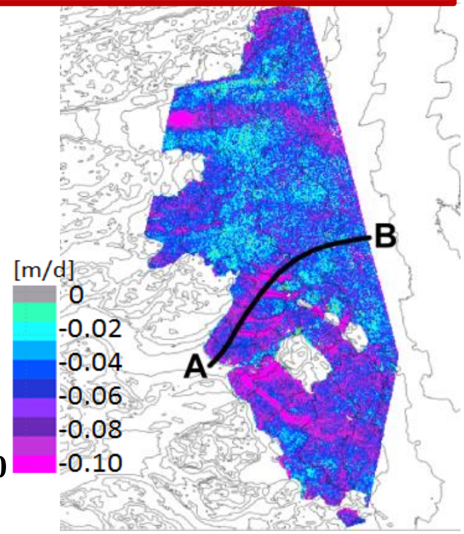
Horizontal and vertical displacement rates





Uplift and acceleration in late August related to rainfall

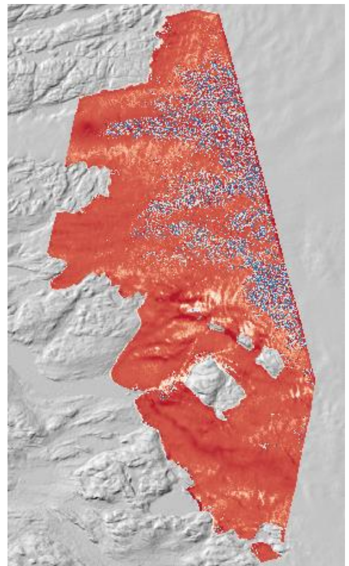




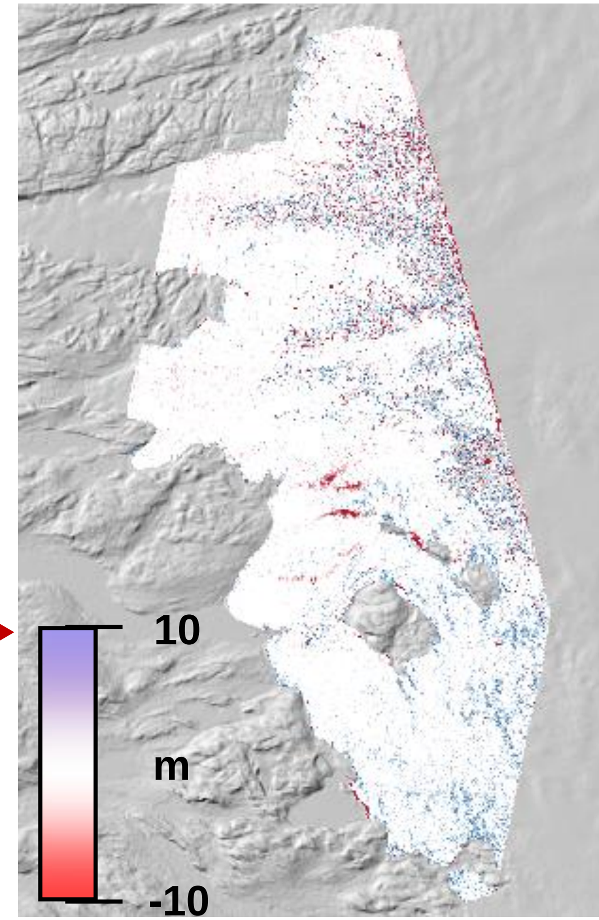
Intercomparison of Surface Elevation Changes

TDX DEM differences
12/06/2011
08/09/2011

Summed differences from
3D retrieval
12/06/2011
08/09/2011



Difference



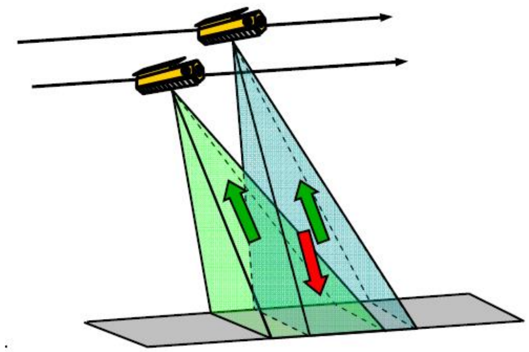
Mean difference of elevation changes between TDX and retrieved by 3D = 0.21 m (n = 1 687 644 pixels)

Total surface lowering for the period 12/06/2011 – 08/09/2011:

Δz from Sonic ranger	-3.24 m	(ablation)
Δz from SAR 3D velocity	-3.19 m	(ablation + emergence)

Geodetic mass balance from InSAR DEM differencing

Bistatic mode allows **elimination of temporal decorrelation** and atmospheric variations



- 1 (active) satellite is transmitting
- Both satellites receive simultaneously the radar echoes

Database for surface elevation change (SEC):

- TanDEM-X (TDM) bistatic InSAR time series (>3 years time steps)
- SRTM (where available)

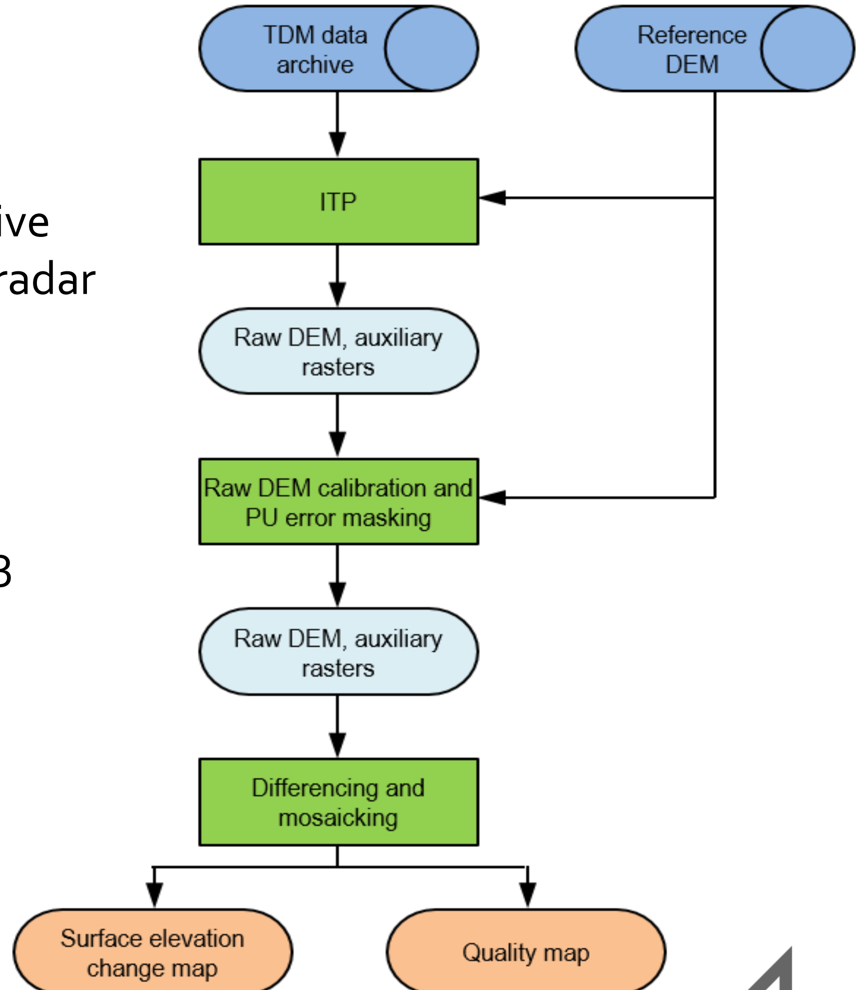
Total net glacier mass balance from SEC:

$$\dot{B} = \rho \int_A \frac{\Delta h}{\Delta t} \, dA$$

ρ – ice density

A - glacier basin area

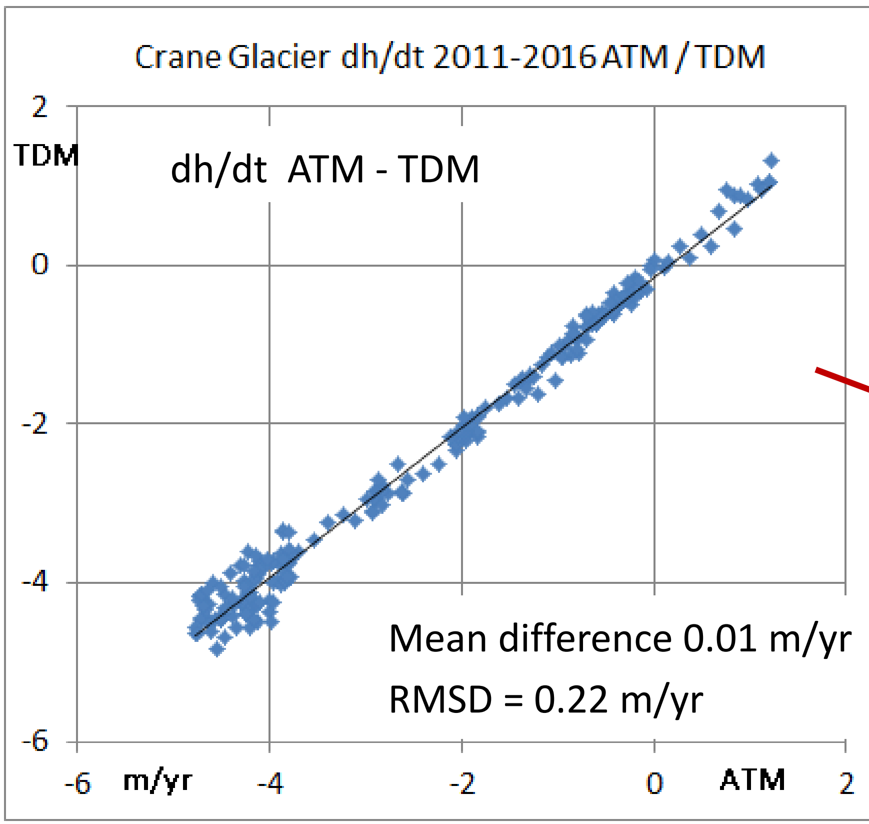
SEC processing line

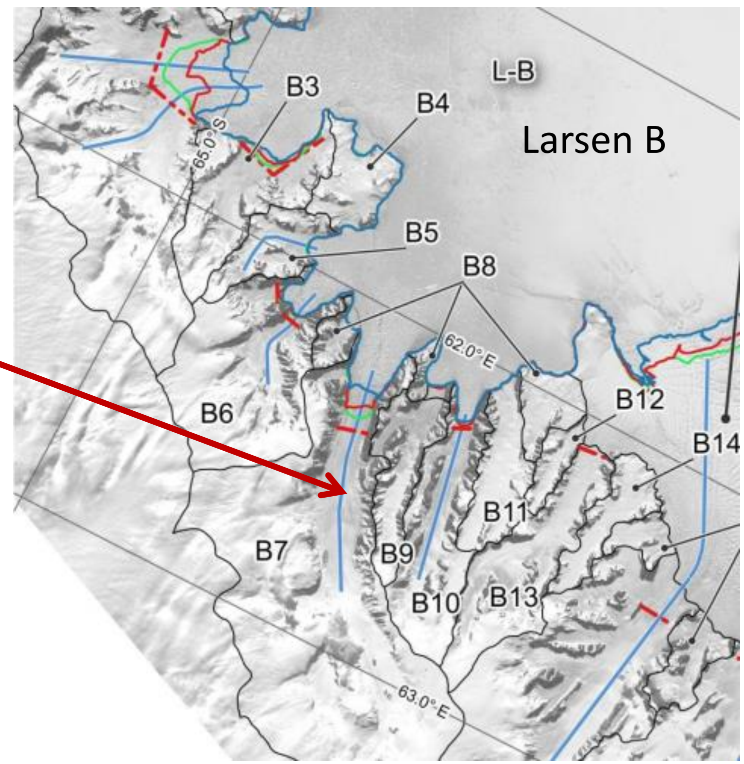


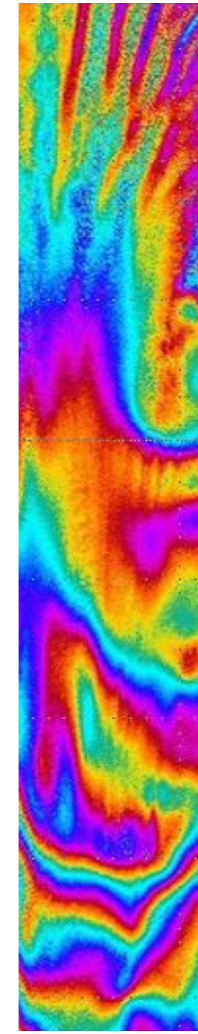
DEM differencing and glacier mass change Antarctic peninsula

Analysis of Surface Elevation Change (dh/dt) 2011 - 2016

- Use of TanDEM-X data acquired from same satellite track in winter (frozen snow/ice) → data sets with same σ° and same incidence angle
- Comparison TanDEM-X dh/dt with airborne lidar (ATM) data of NASA IceBridge, both data sets independently processed

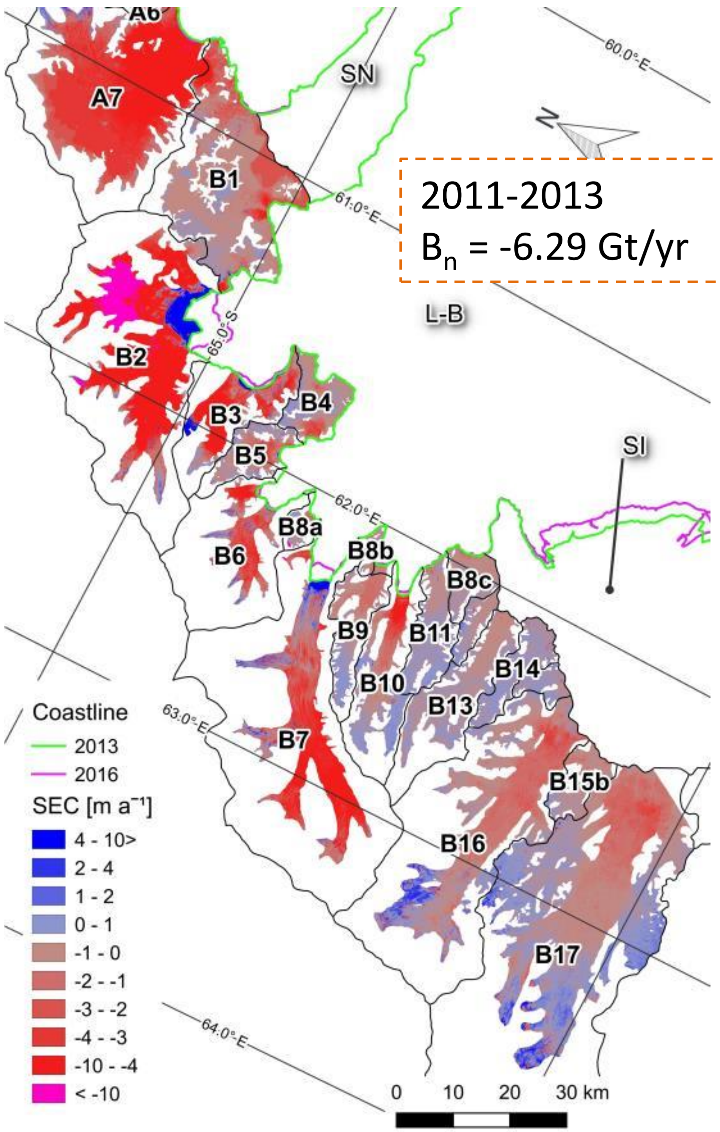


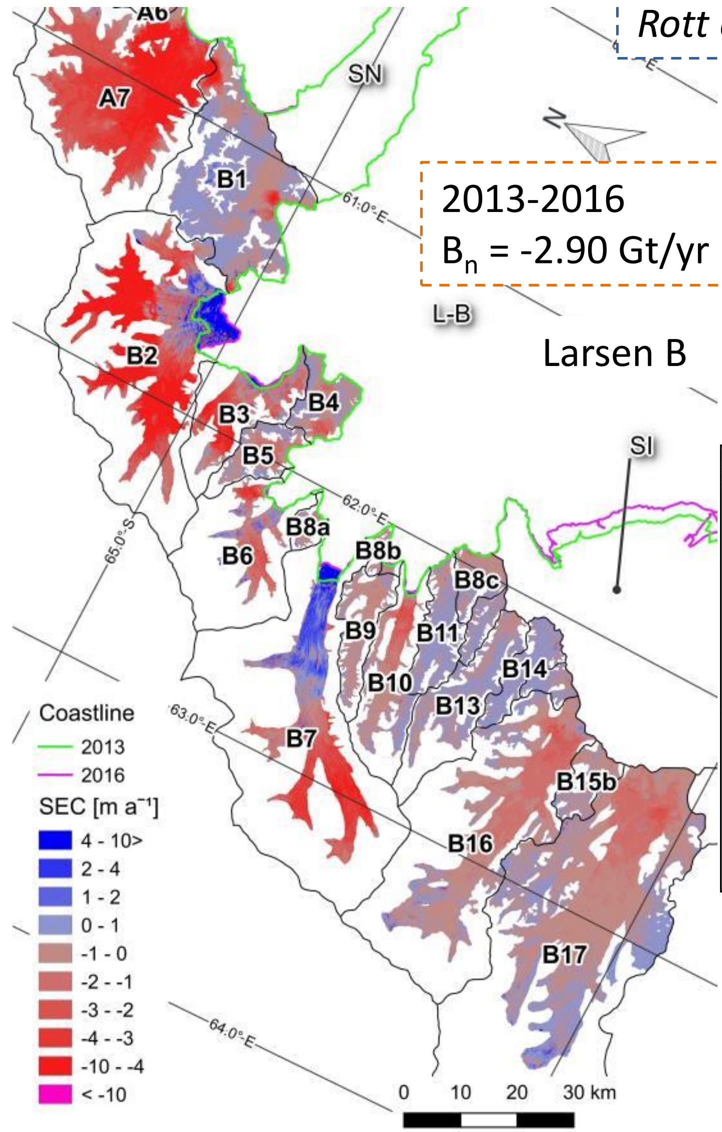


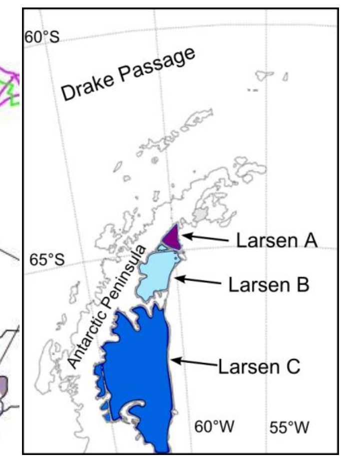


DEM differencing and glacier mass change Antarctic peninsula

Rott et al., 2018







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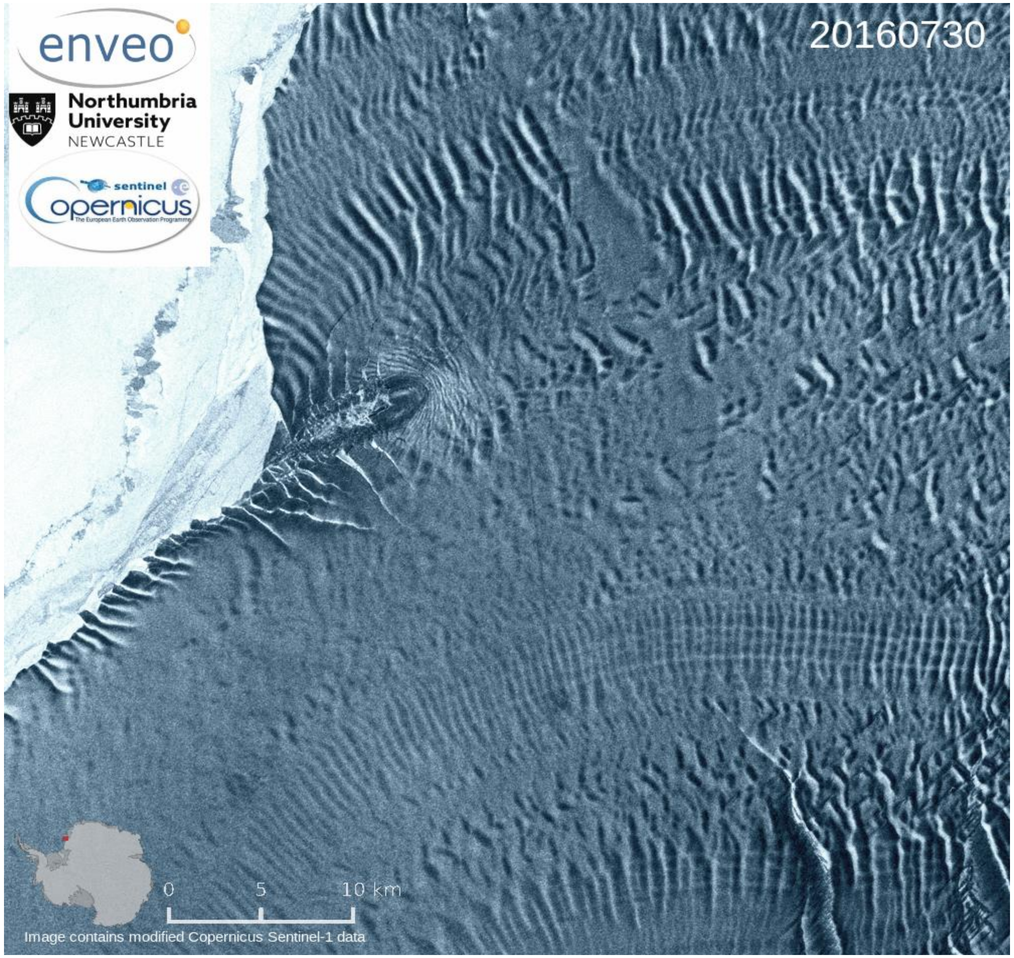
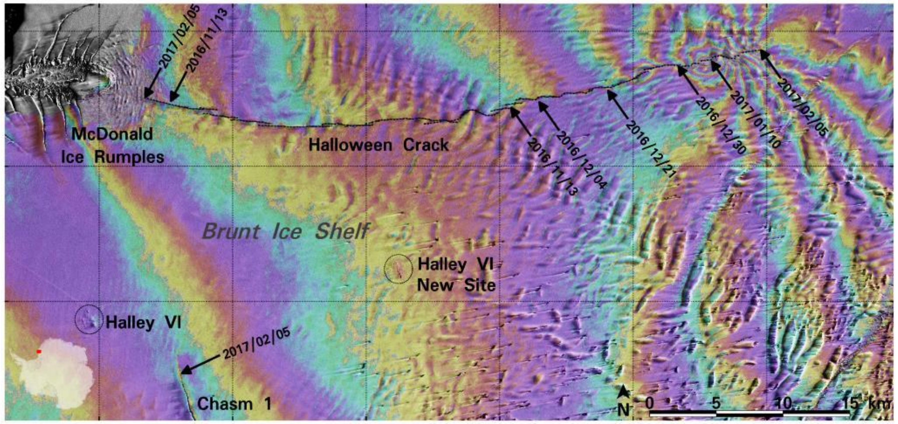
Sentinel-1 Brunt Ice Shelf Rift Monitoring





TCD, 2019, J. de Rydt et al.

Main limitations

Sentinel-1

DEM

Need for :

- Higher **temporal sampling**
- Diversity of **viewing geometries**

(e.g. simultaneous observations with different viewing angles)

- **Single-pass** data

Ionospheric disturbances

Ionospheric disturbances

Upcoming SAR missions

Copernicus mission:

ROSE-L (Sentinel Expansion)

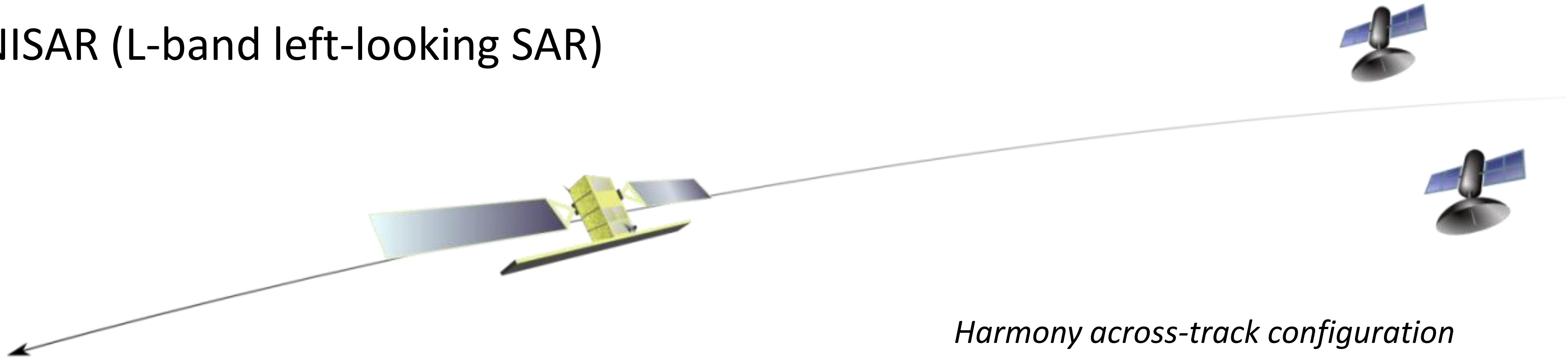
ESA EE10 Candidate missions:

Hydroterra (geostationnary C-band SAR)

HARMONY (SP-InSAR with S1)

NASA mission:

NISAR (L-band left-looking SAR)



Harmony across-track configuration

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snow, glaciers and ice sheets products and services

cryoportal .enveo.at

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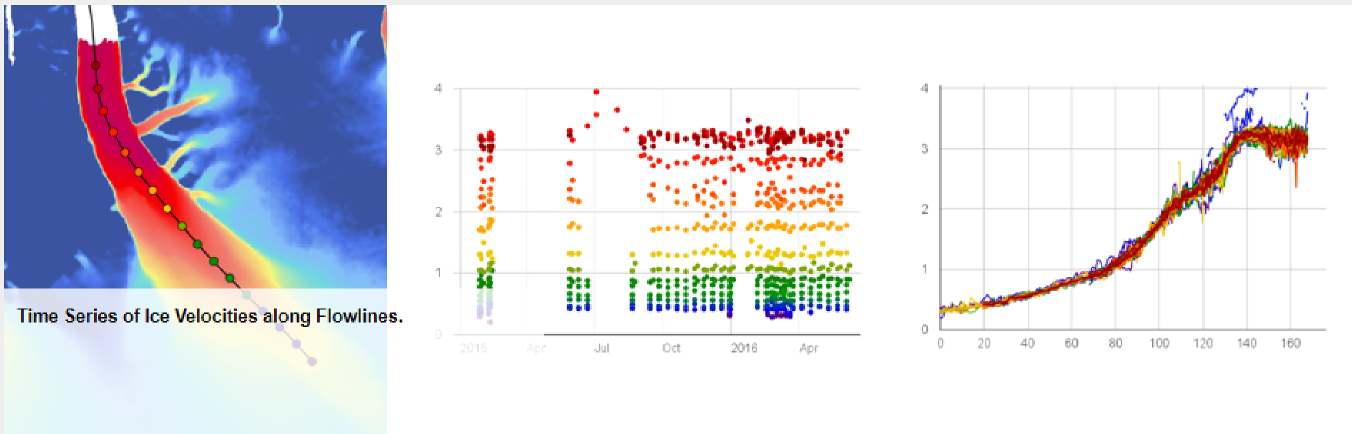
Example Products:



Time Series of Ice Velocities along Flowlines.

Access to data sets

Greenland | Antarctica | Glacier | Near Real Time Snow Services | Timeseries of Ice Flow and Calving

Contributing Organisations:

enveo, DLR, DTU, University of Zurich

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