Sentinel-1 Extra Wide Swath Mode for InSAR applications within the terrestrial cryosphere

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Part 1: Introducing Extra Wide swath for InSAR

Extra Wide swath

Aimed use:

- sea ice
- maritime oil spill monitoring
- maritime security services

Distributed mainly in **raw** and GRD, no SLC*

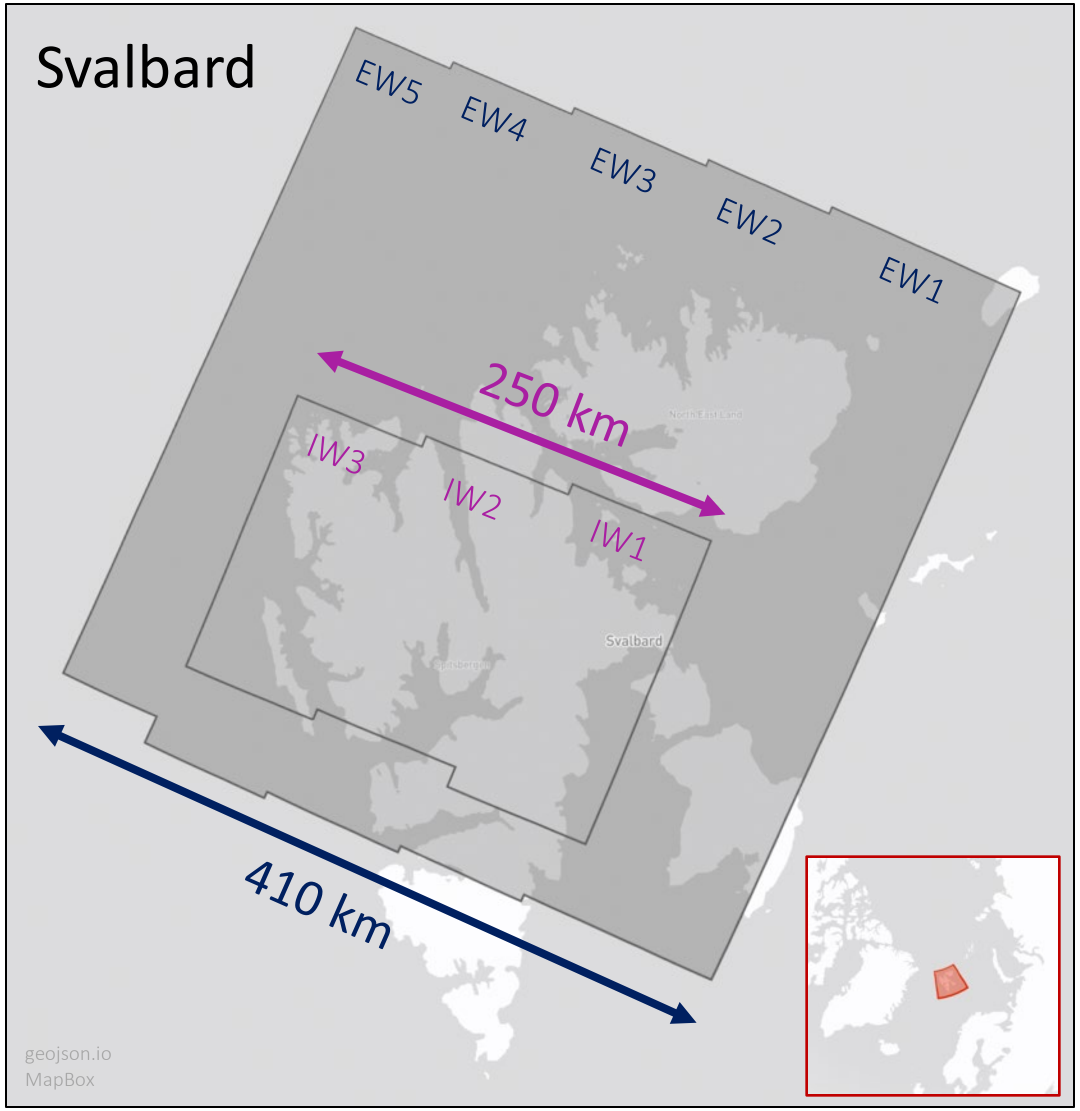
* Limited availability over certain regions

Same characteristics as IW:

- burst synchronisation
- baseline
- Doppler stability

} **suitable for InSAR**

Different **swath width** and **resolution**



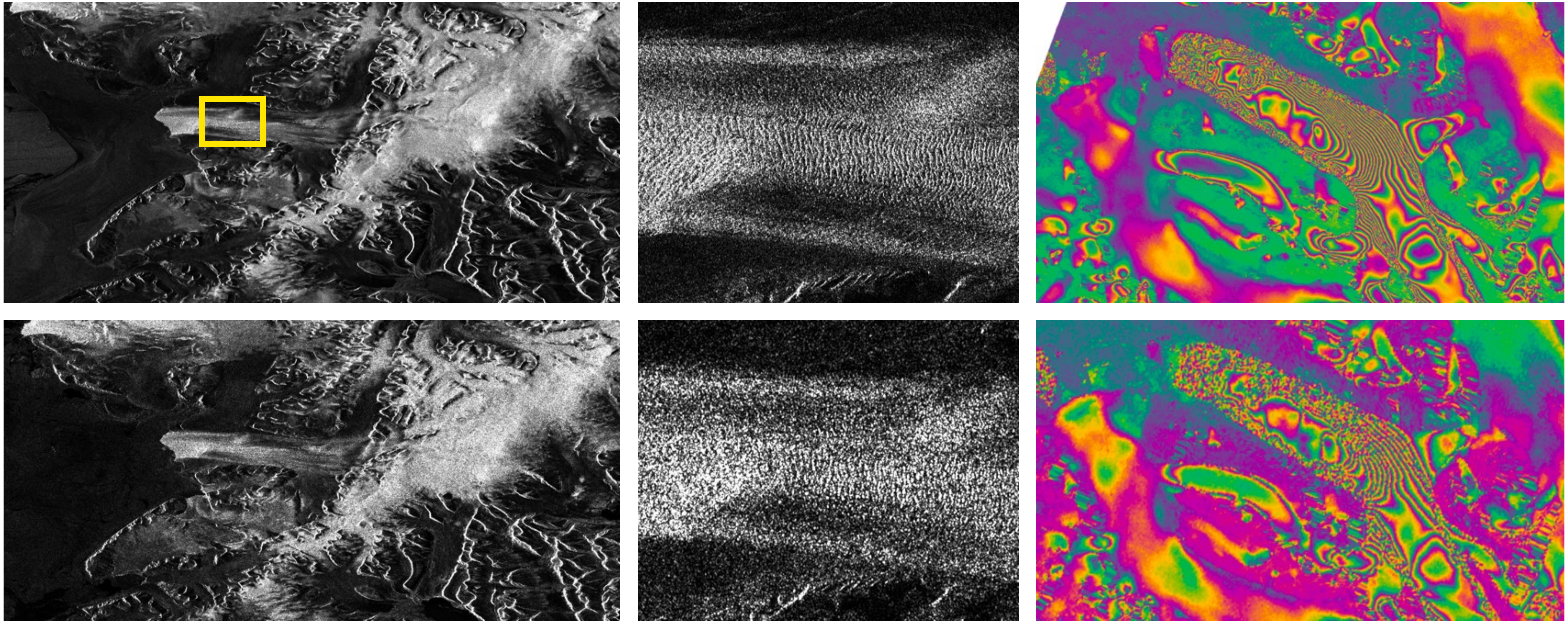
Resolution an issue?

IW SLC (ra x az) 2.7-3.5 x 22 m.

EW SLC **7.9-15 x 43 m.** ← roughly 4 times worse

IW

EW

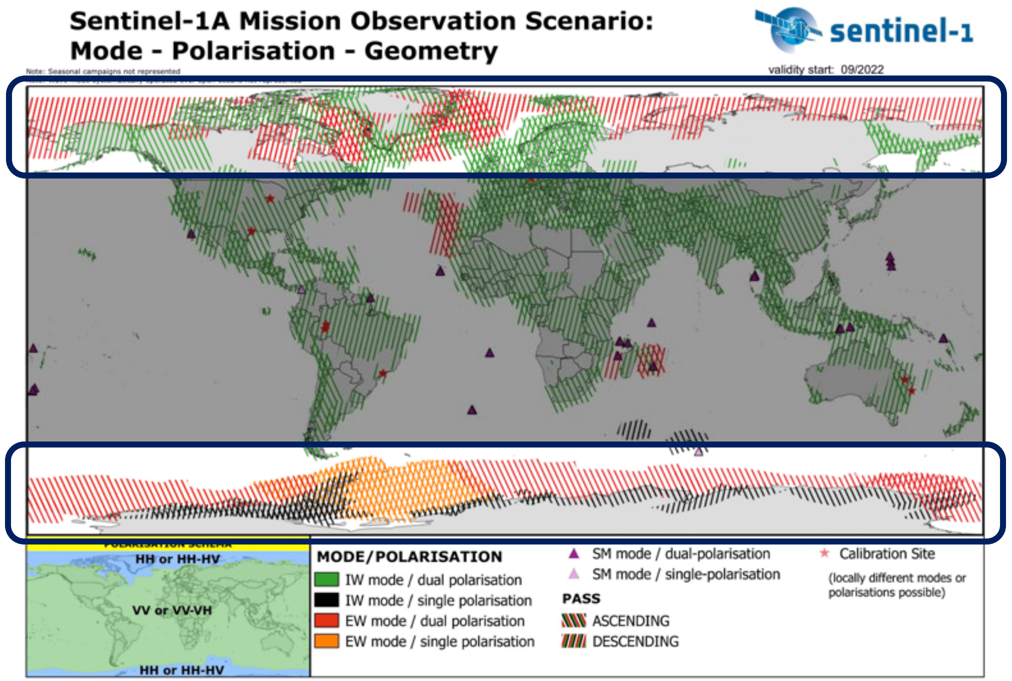


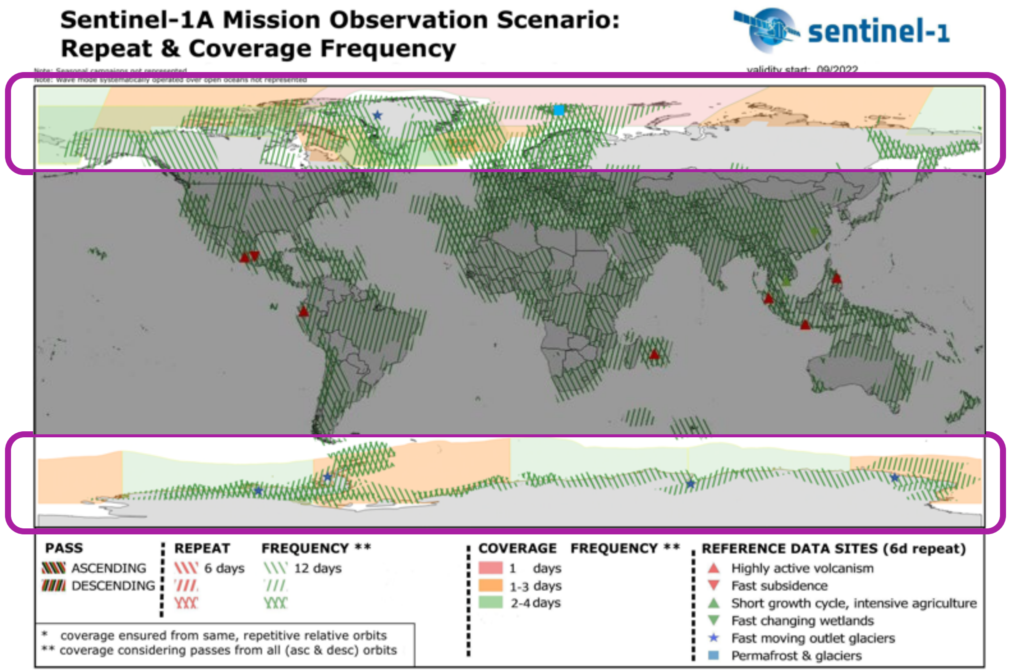
EW availability

Aimed use:

- sea ice
- maritime oil spill monitoring
- maritime security services

- Acquisitions primarily in **polar regions**
- **Densely overlapping** orbits (up to daily with S1B)
- Other applications
  - → permafrost
  - → glaciology





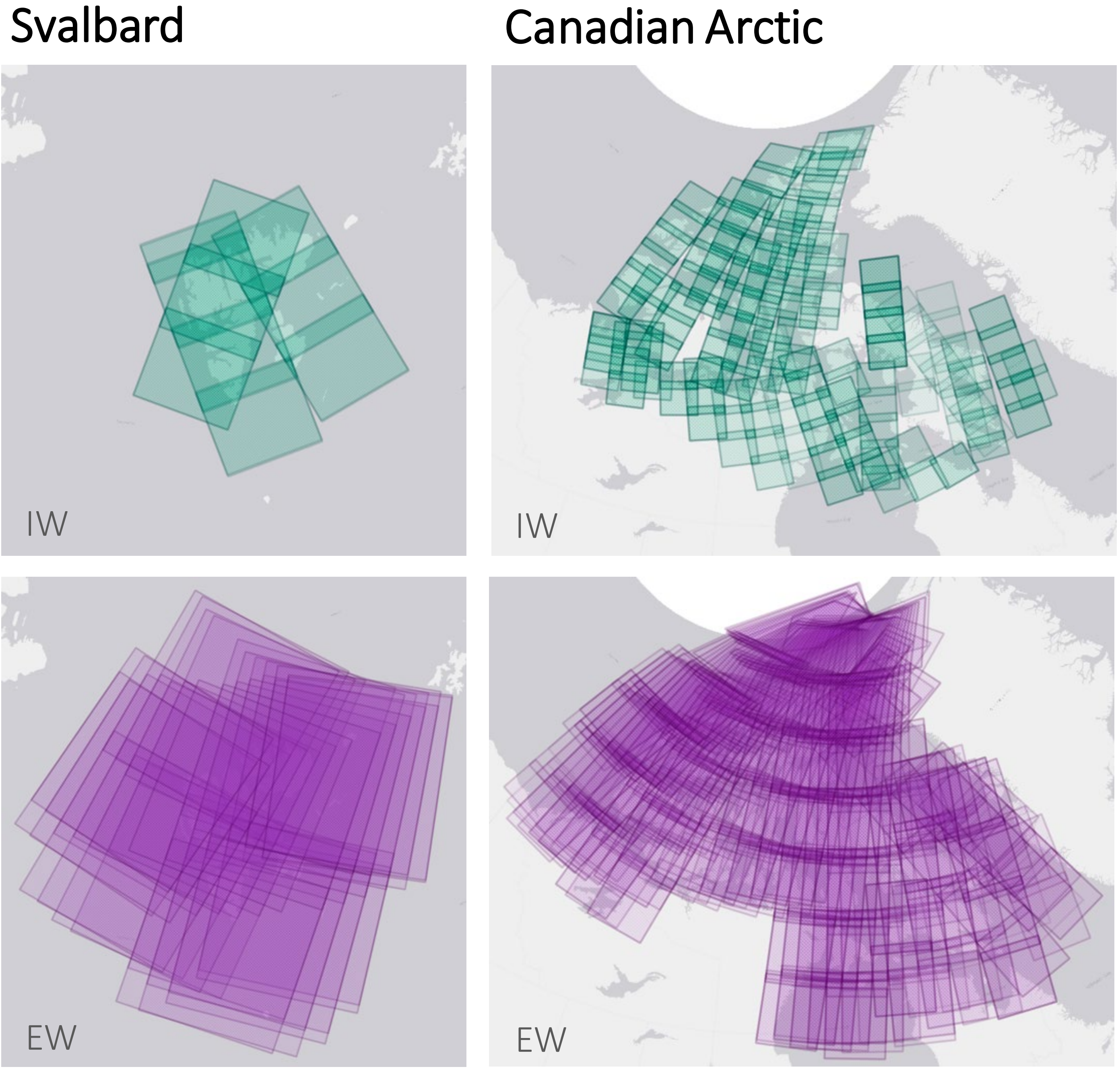
Availability examples Permafrost

S1 archive (raw data):

Svalbard IW	3.445
Svalbard EW*	14.058
Can. Arctic IW	39.860
Can. Arctic EW*	64.837

* Mostly descending orbits

- Up to daily sampling
- Many 6-day repeat stacks
- More complete coverage with EW

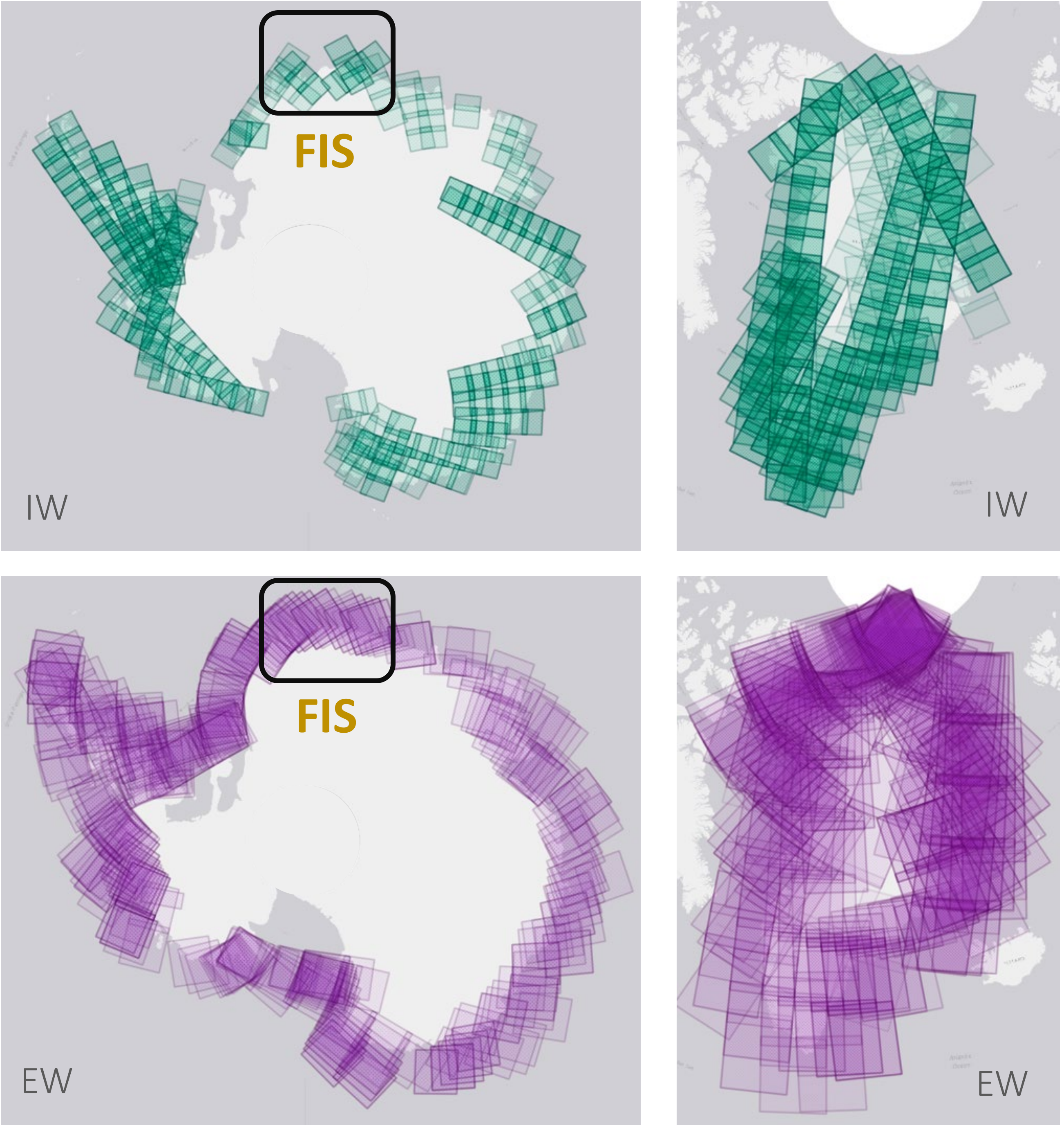


Availability examples
Ice sheets

S1 archive (raw data):

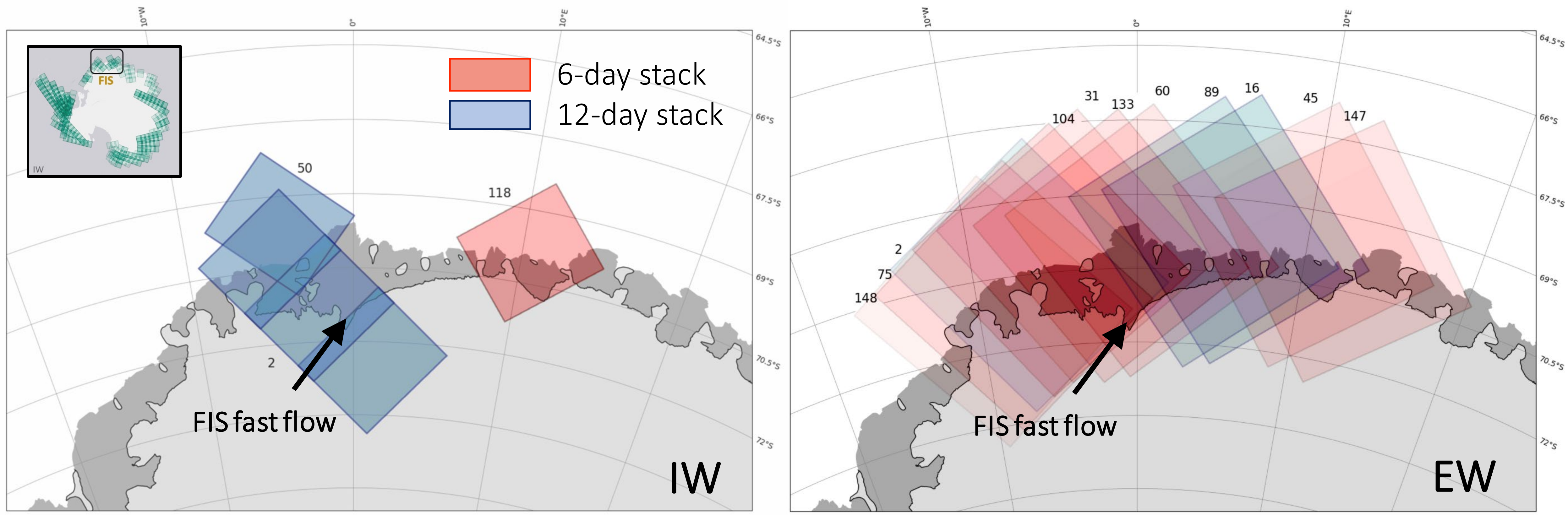
Antarctica IW	75.369
Antarctica EW	62.041
Greenland IW	44.431
Greenland EW	62.490

- Large overlaps between adjacent EW scenes
  → high sample rate
- Different ascending and descending geometries between IW and EW



Availability example
Fimbul Ice Shelf, East Antarctica

→ 6-day repeat necessary because of fast flow

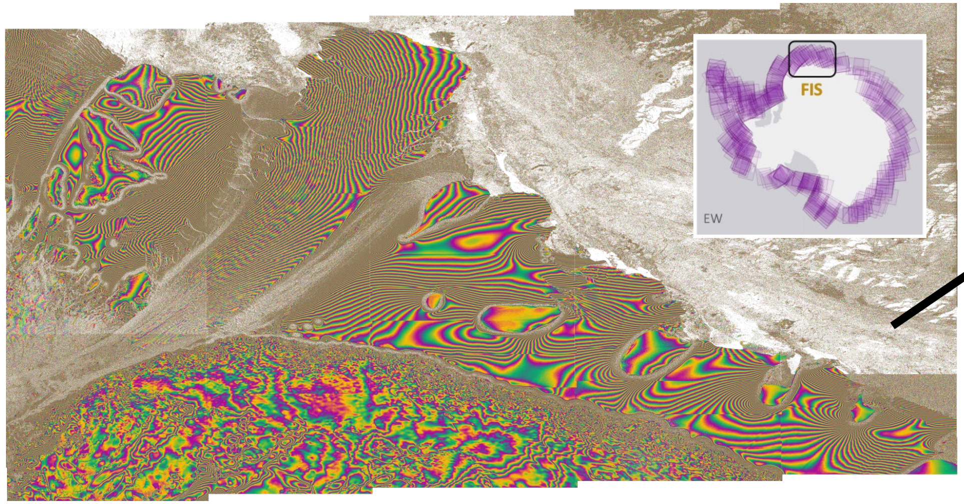


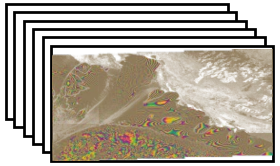
no (IW) vs. eight (EW) 6-day repeat stacks

Part 2:
EW InSAR Glaciology

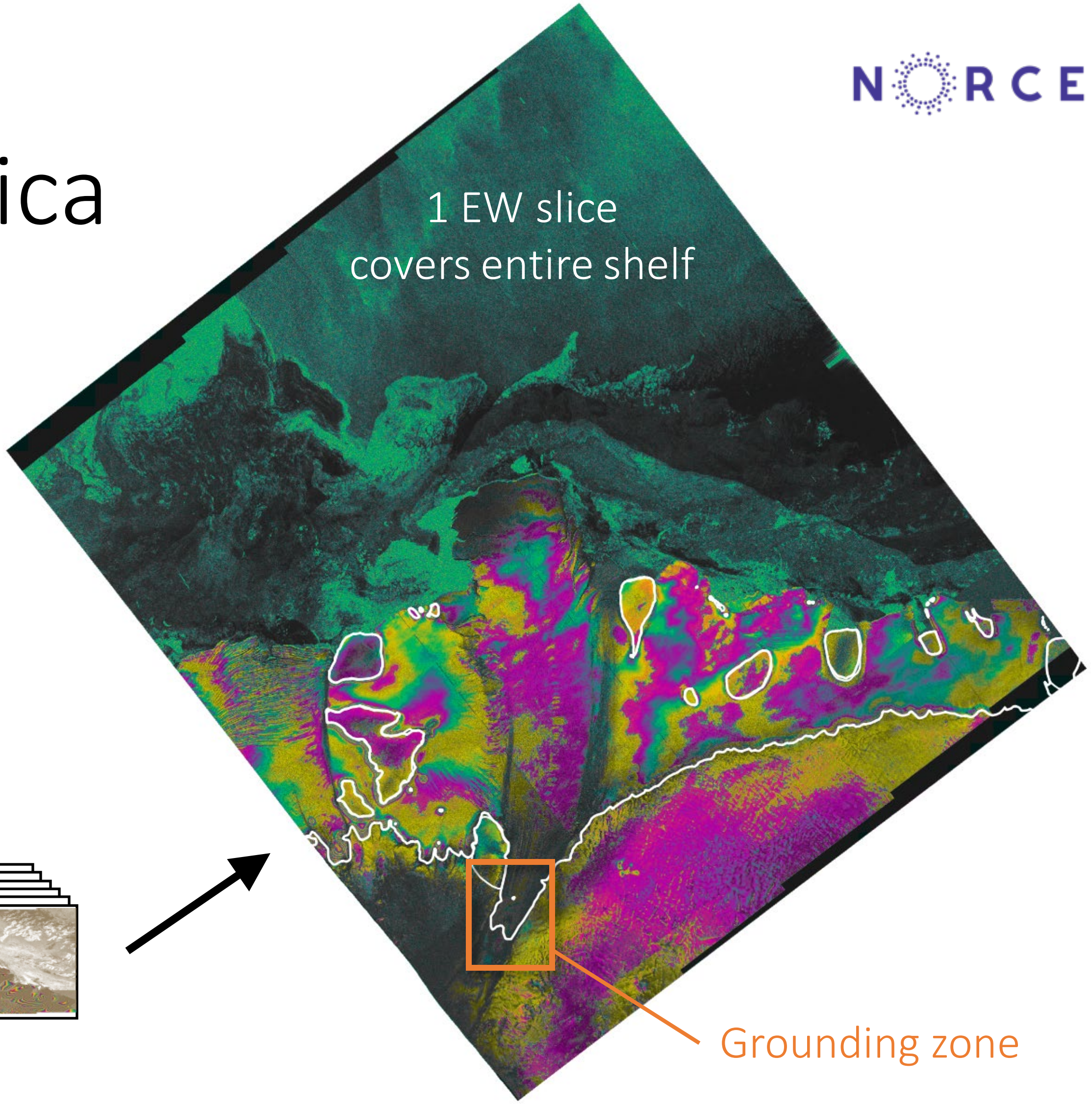
EW-based InSAR results
Fimbul Ice Shelf, East Antarctica

- Large ice shelf in Queen Maud Land
  → drains approx. 124.000 m^2
- Flow speeds up to **750 ± 20 ma^{-1}**
- Last 'known' grounding line is from ERS (1994)

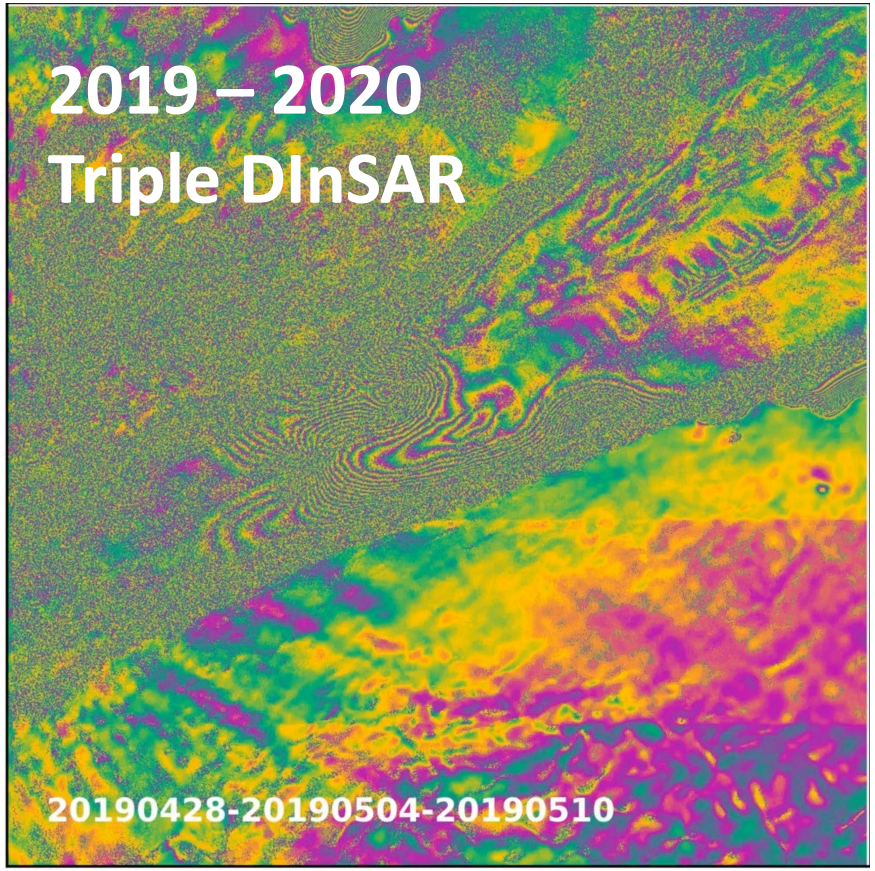




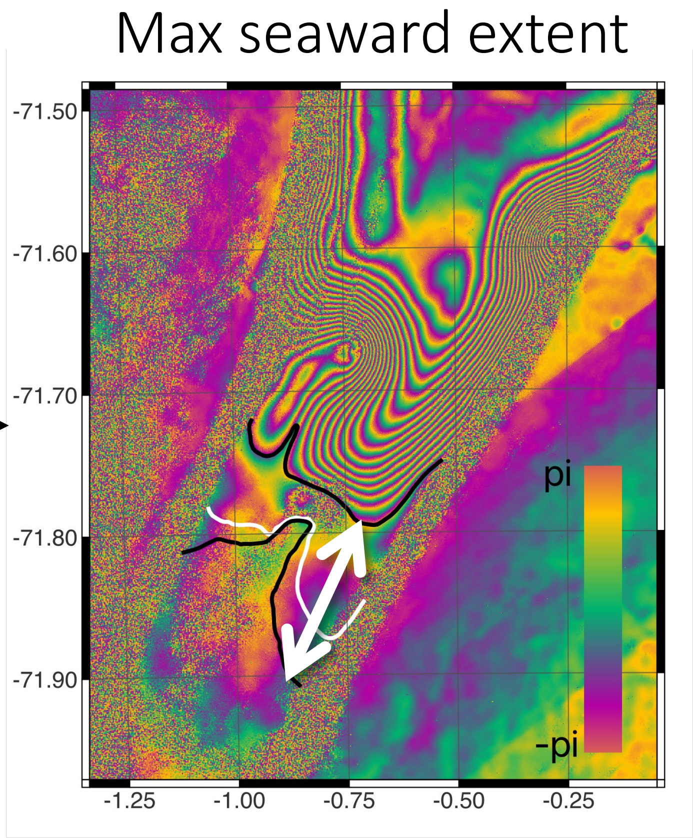
340 scenes
All 6- and 12-day pairs daisy-chained InSAR
3- and **4-pass double differential InSAR**



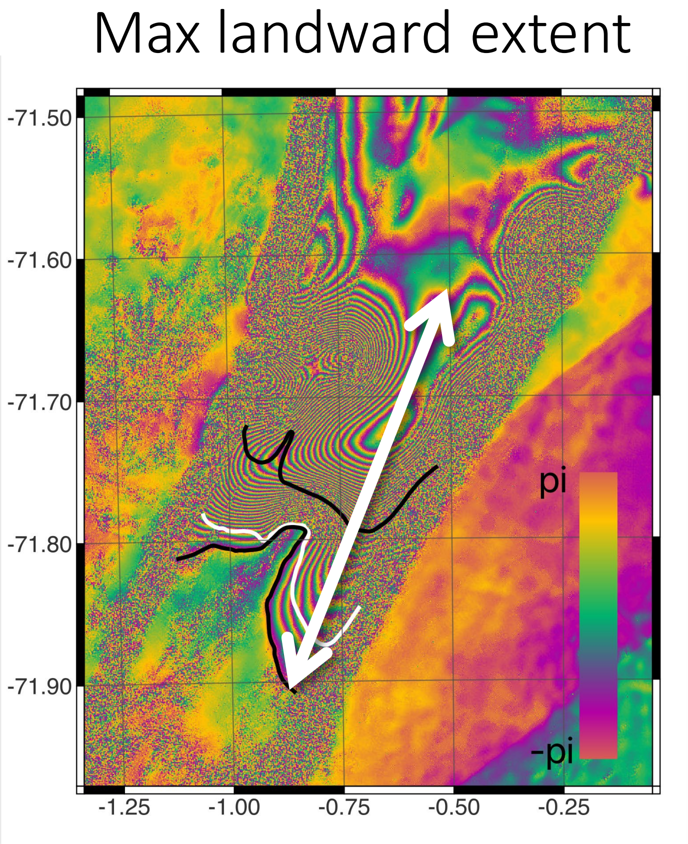
Short-term grounding line variation



Triple DInSAR: $(\Phi_{t3}-\Phi_{t2}) - (\Phi_{t2}-\Phi_{t1})$



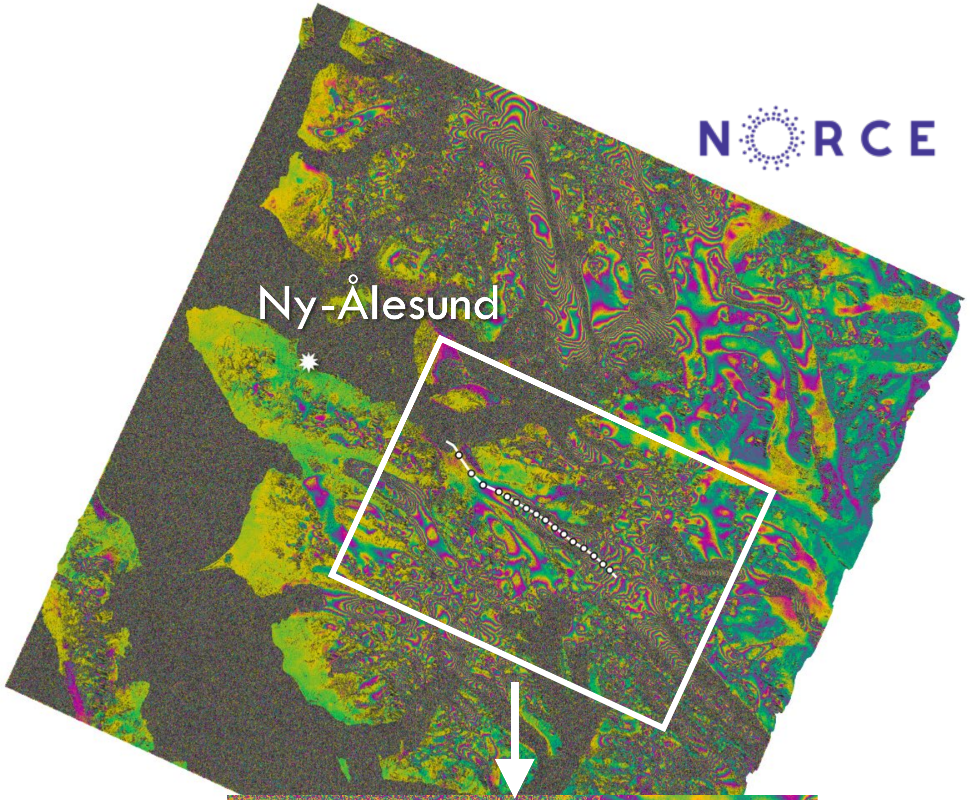
13 ± 1 km
grounding zone width

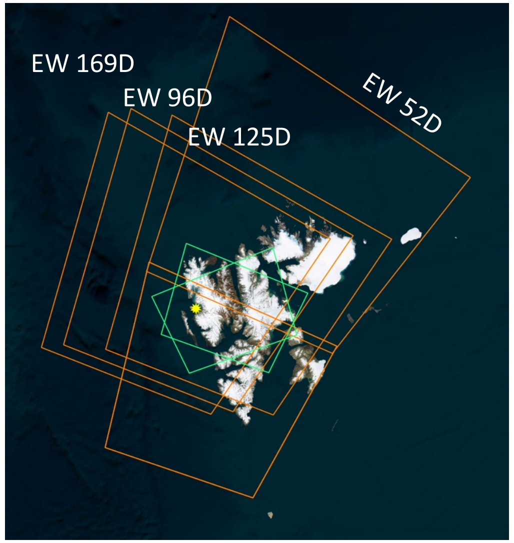


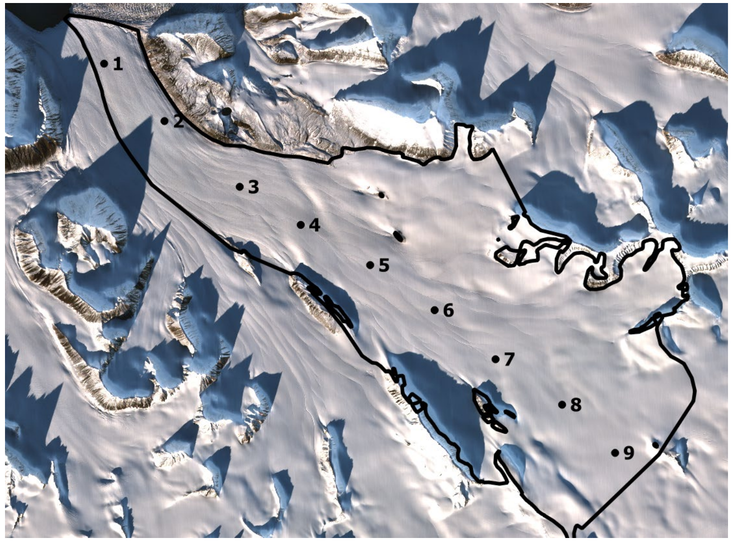
> 34 km
flexure zone width

InSAR LOS velocties timeseries

- 4 EW swaths - all descending orbits
- Both 6 day- and 12 day interferograms
- Time series length dependent on the orbit, but cover 2016 – 2023
- No coherence in July/August due to melt/rain

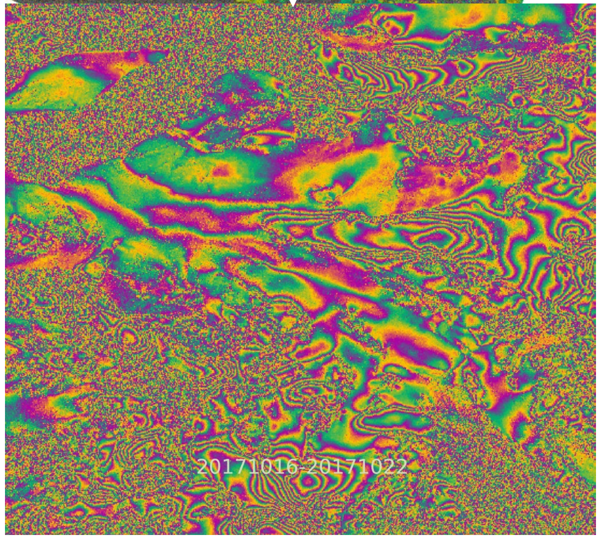






GPS stake network

Jack Kohler, NPI

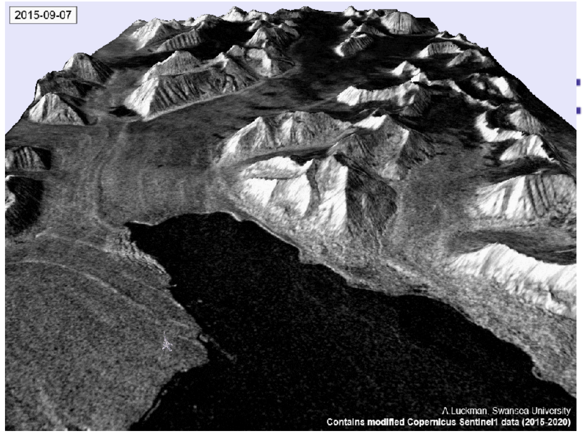


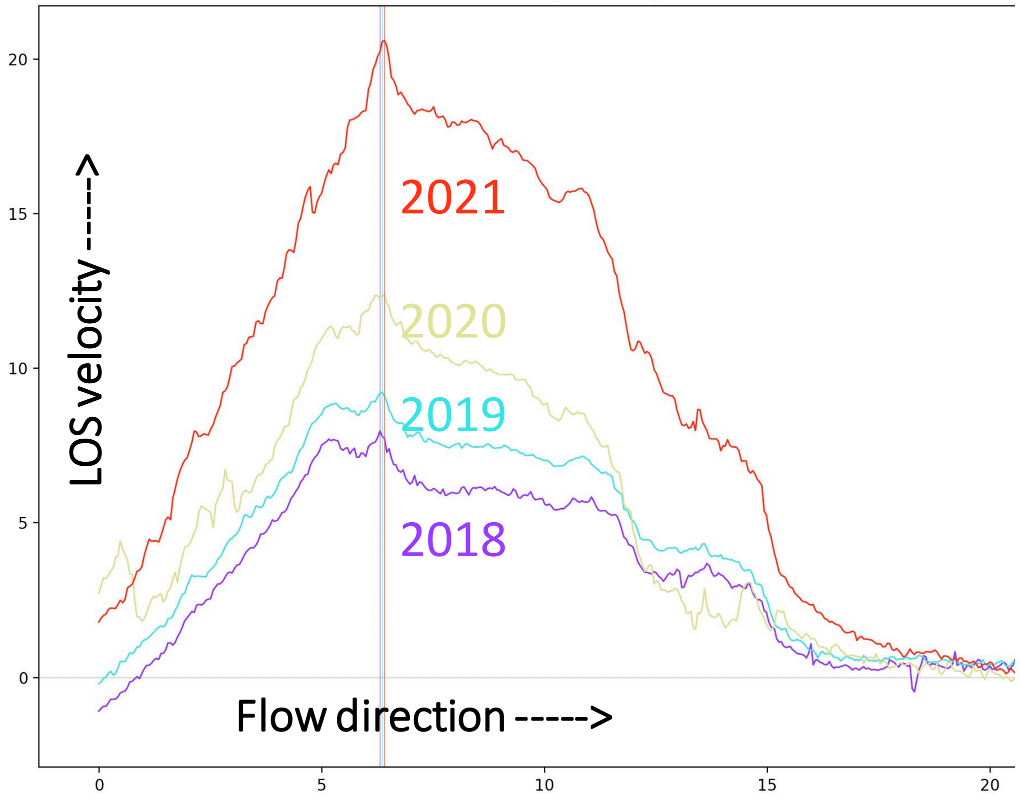
6-day ifgms

adrianluckman.wordpress.com

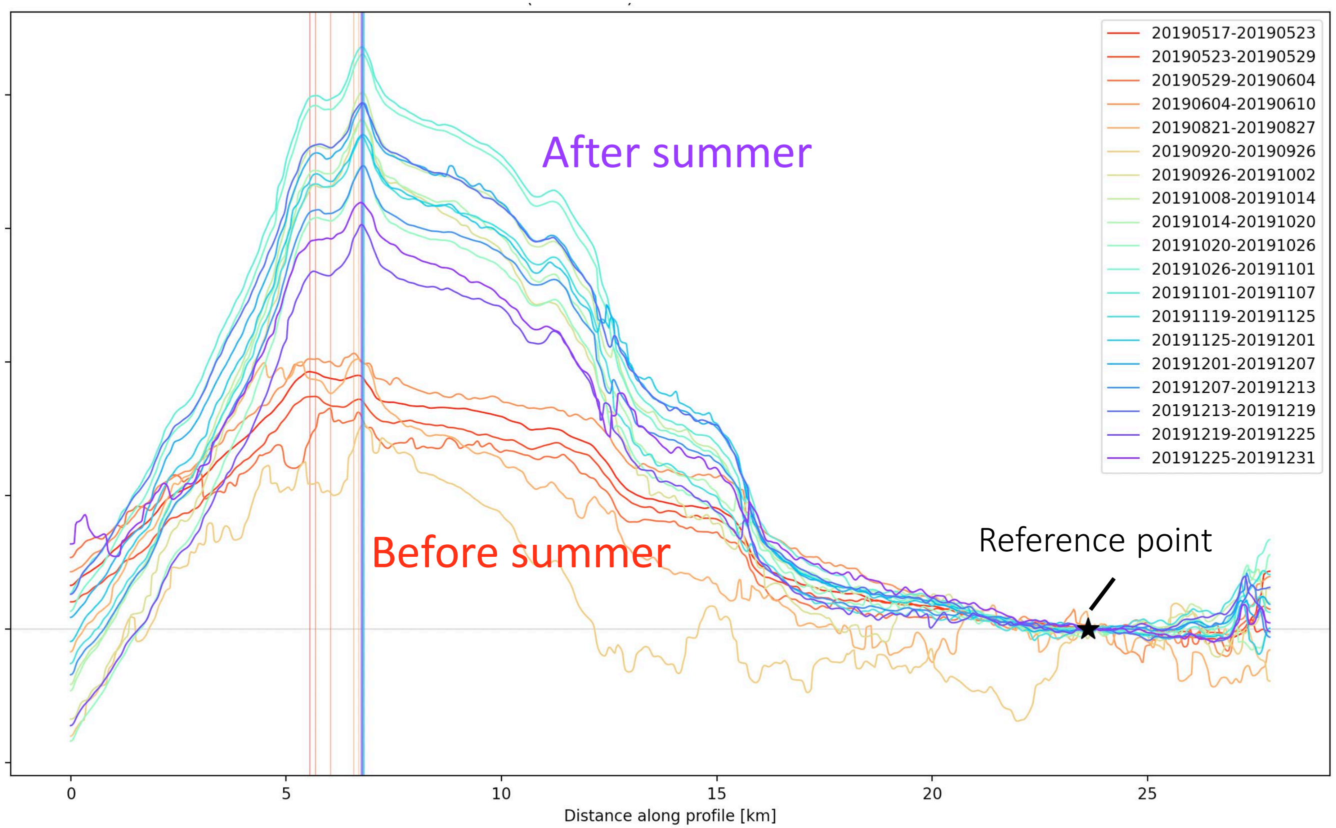
Surge onset monitoring (InSAR based velocities)

Surge: periodically increase in glacial velocity and advance →





1: annual means



2: individual observations

Conclusions
EW InSAR for glaciology

1. Time series of ice shelf **grounding lines** from different orbits
   → Quantified large short-term grounding zone variability
   → Comparing ERS snapshots to S1 timeseries is not trivial

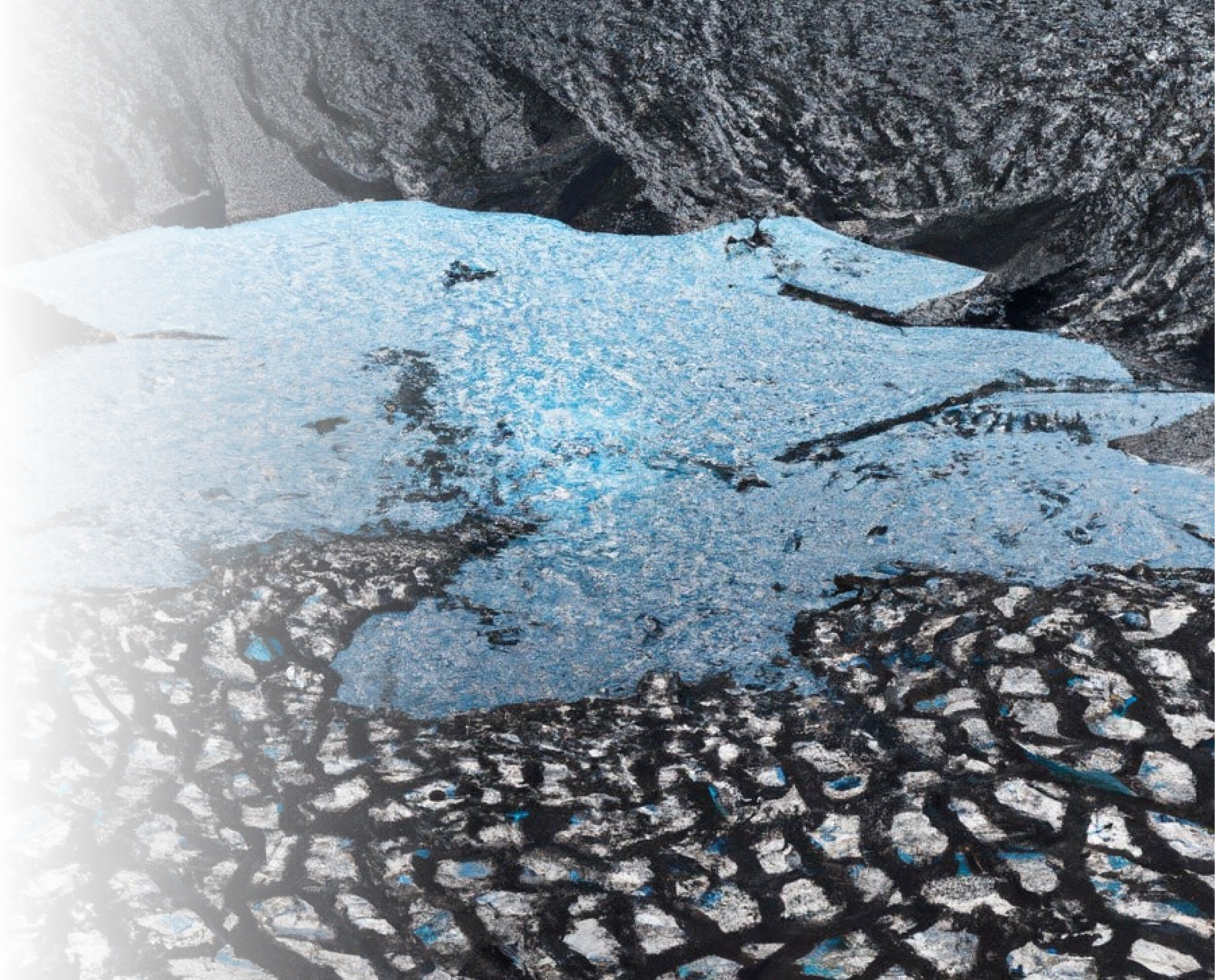
only possible with EW!

2. Capturing **glacial surge onset** in Svalbard
   → Dense data coverage can be very helpful in understanding underlying processes
   → Minimize multilooking to overcome low resolution

Many other potential applications of EW data:

→ Crack identification and monitoring with InSAR
→ Capturing sub-/englacial lake drainage events
→ Offset tracking time series

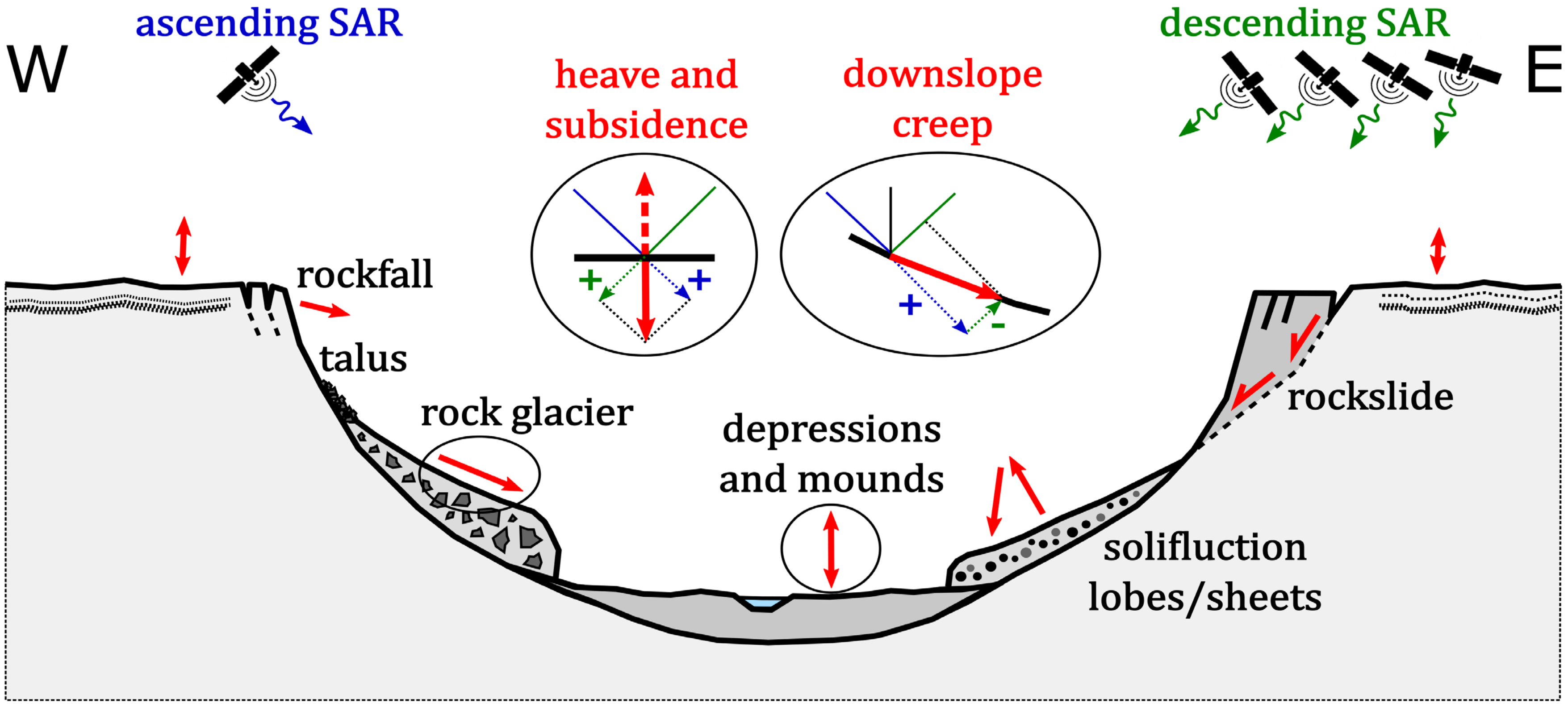
Part 3:
EW InSAR
Permafrost



EW InSAR for permafrost applications

Study area: Svalbard (long experience using IW)

Application: Thaw subsidence and frost heave from ice formation & melting in the ground and creeping permafrost landforms on slopes.



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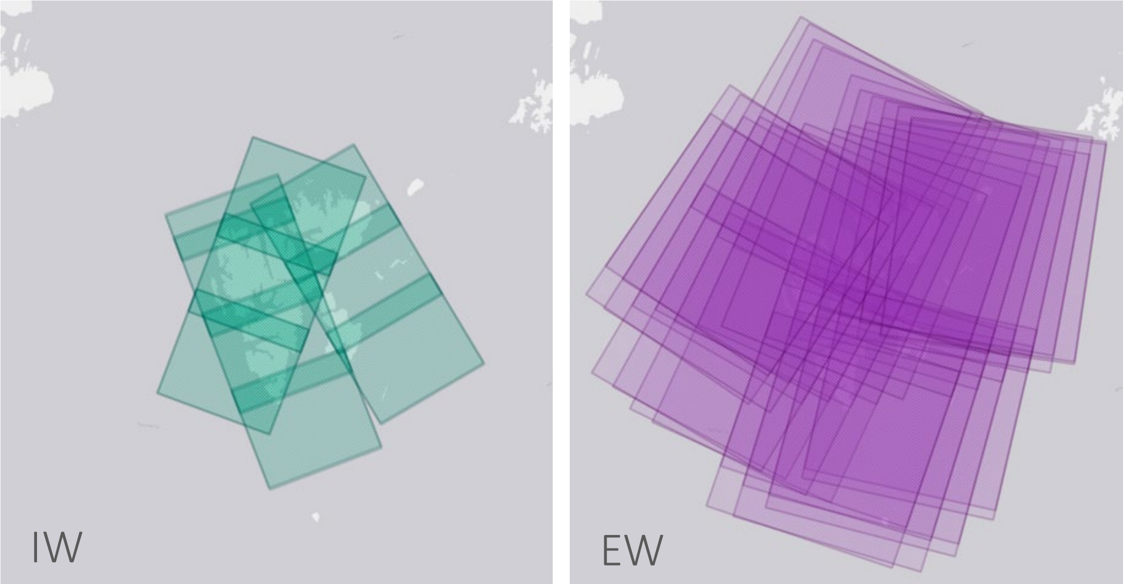
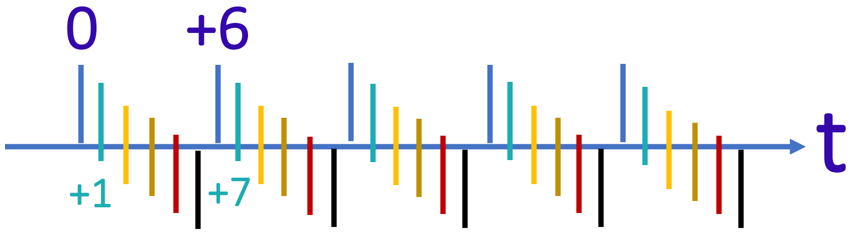
Why combining IW and EW for permafrost applications in Svalbard?

- **To scale up the investigation of large permafrost areas:** From regional analysis to InSAR over the whole archipelago.
- **To integrate complementary viewing angles:** From LoS to 2-3D displacements.
- **To increase the temporal resolution:** From 6 days to daily time series.

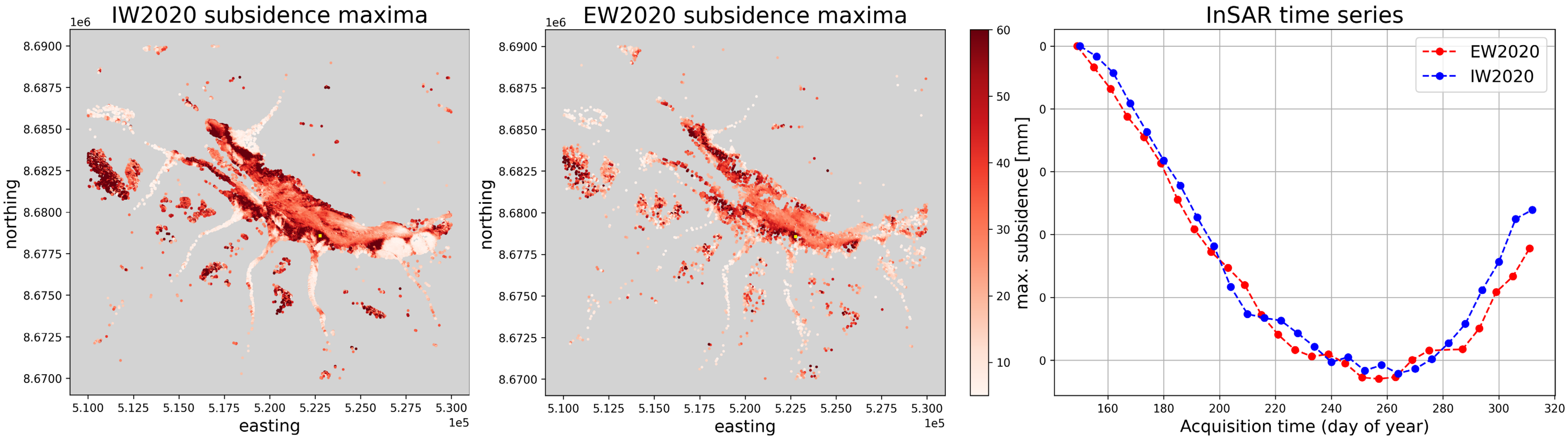




EW InSAR for permafrost applications: First IW-EW comparison

NORCE

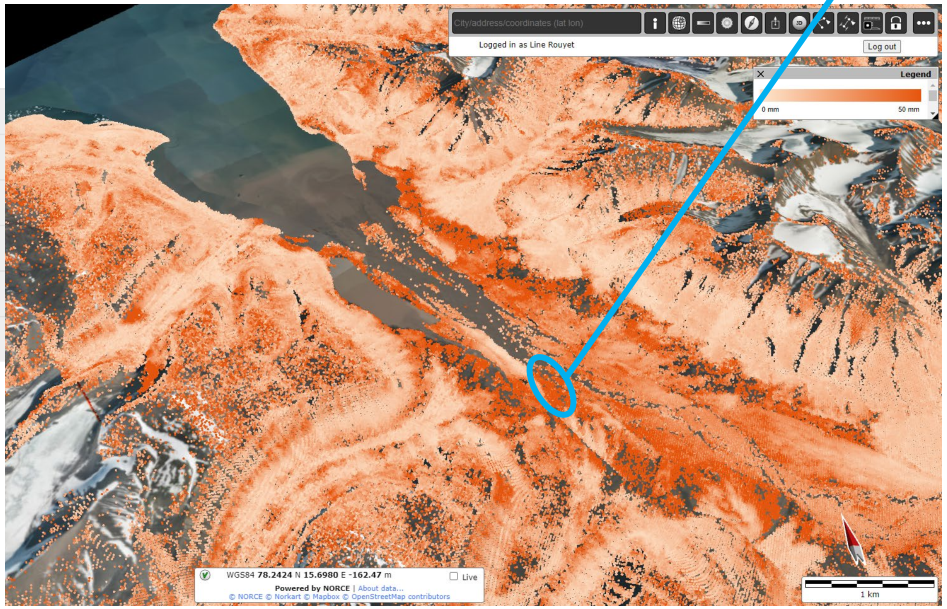
- Focus on flat lowlands with expected vertical seasonal subsidence-heave patterns.
- Similar SBAS processing with IW and EW modes.
- Good spatio-temporal consistency despite the different resolutions of the products.

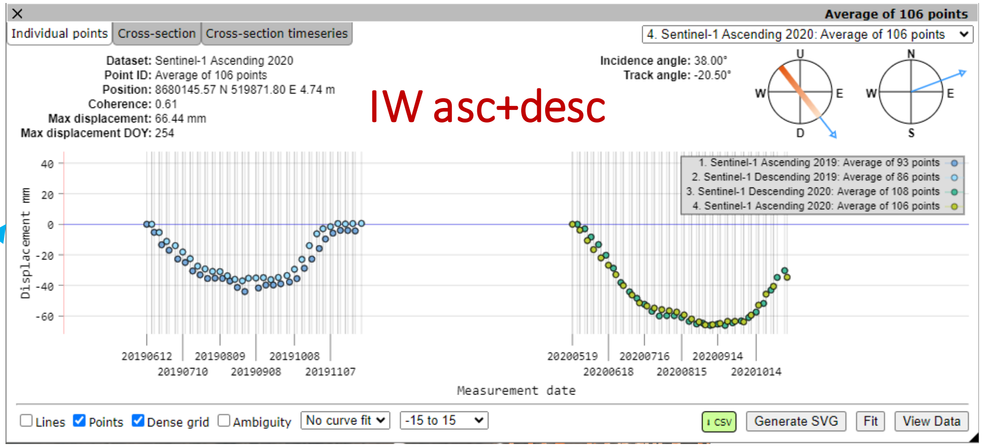


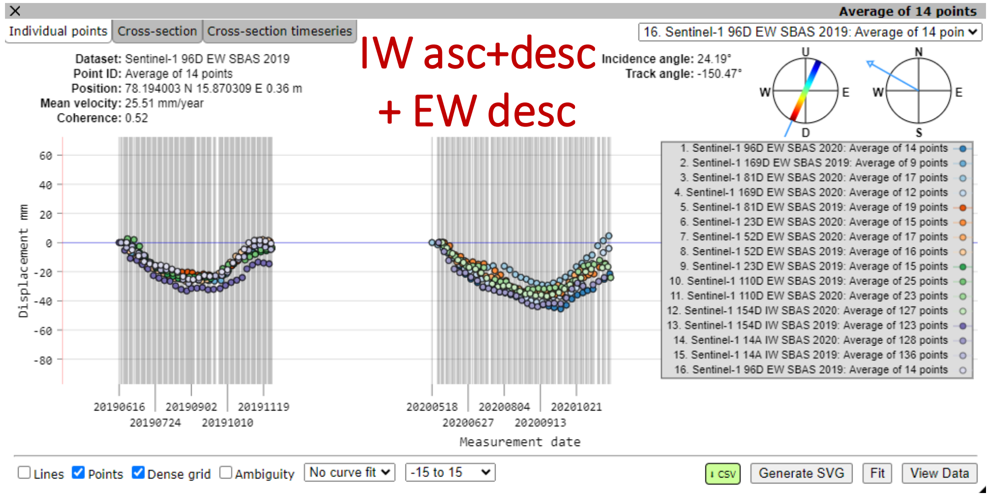
EW InSAR for permafrost applications: Ongoing work and next steps

- Process and combine all available IW/EW tracks to increase the temporal resolution.
- Note: preliminary results with no correction for time reference, incidence angle, resolution difference, etc.
- Next step: Correct each series to compare the results. Synergetic integration of multiple tracks in SBAS chain.

- EW-Explore
  - Longyearbyen
    - Sentinel-1 110D EW
      - Sentinel-1 110D EW SBAS 2017 — Contains modified Copernicus Sentinel data
      - Sentinel-1 110D EW SBAS 2018 — Contains modified Copernicus Sentinel data
      - Sentinel-1 110D EW SBAS 2019 — Contains modified Copernicus Sentinel data
      - Sentinel-1 110D EW SBAS 2020 — Contains modified Copernicus Sentinel data
      - Sentinel-1 110D EW SBAS 2021 — Contains modified Copernicus Sentinel data
      - Sentinel-1 110D EW SBAS 2022 — Contains modified Copernicus Sentinel data
    - Sentinel-1 14A IW
    - Sentinel-1 154D IW
    - Sentinel-1 169D EW
    - Sentinel-1 23D EW
    - Sentinel-1 52D EW
    - Sentinel-1 81D EW
    - Sentinel-1 8D EW
    - Sentinel-1 96D EW







Summing up

- **EW InSAR for terrestrial applications is possible.**
- Most of the EW archive is unexploited.
- EW can cover holes for IW. In polar areas: especially important now that S1B is missing.
- EW availability in time and in space enables up to daily sampling.
- Spatial resolution can be an issue to consider depending on the application.

→ Can be applied in other regions, for example:
Ice velocity in Greenland or permafrost regions in the North America

→ Combination with IW archive will more than double the coverage and increase the temporal resolution of the time series.

→ However, EW not always available in SLC (f.ex Antarctica). To consider in the future?

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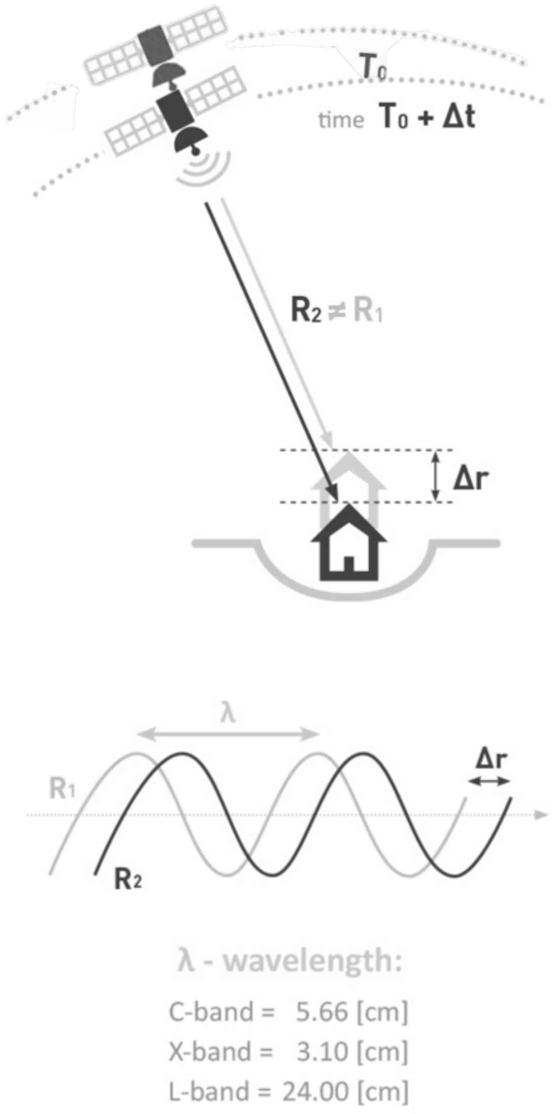
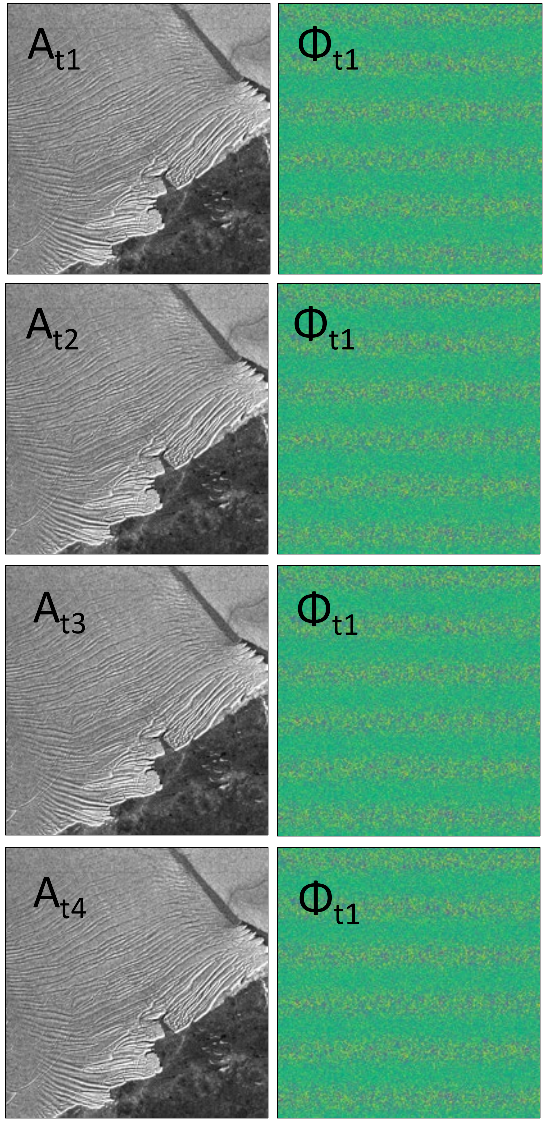
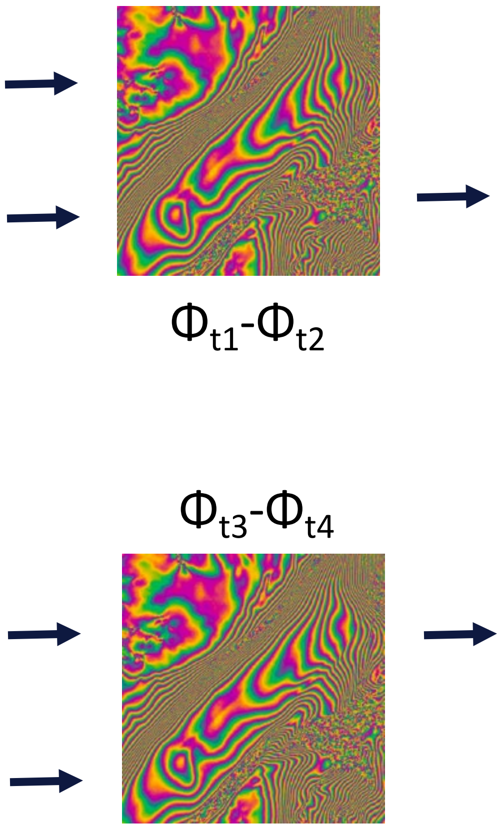
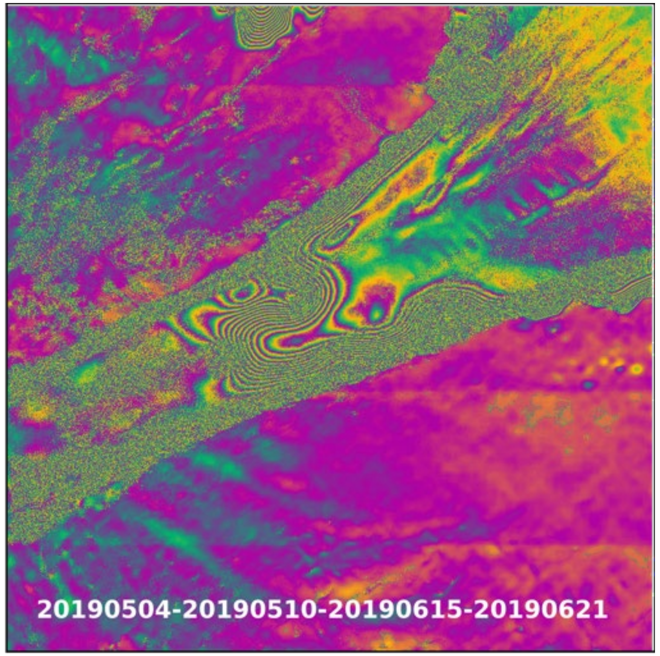
Backup slides

Double Differential Interferometric Synthetic Aperture Radar
TDInSAR / QDInSAR







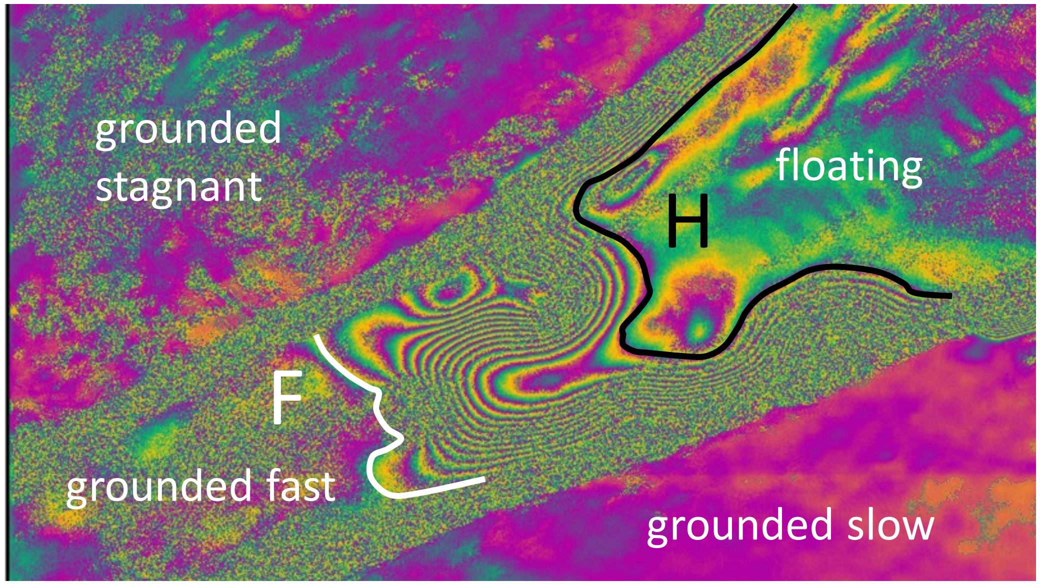


Triple: $(\Phi_{t1}-\Phi_{t2}) - (\Phi_{t2}-\Phi_{t3})$

Quadruple: $(\Phi_{t1}-\Phi_{t2}) - (\Phi_{t3}-\Phi_{t4})$

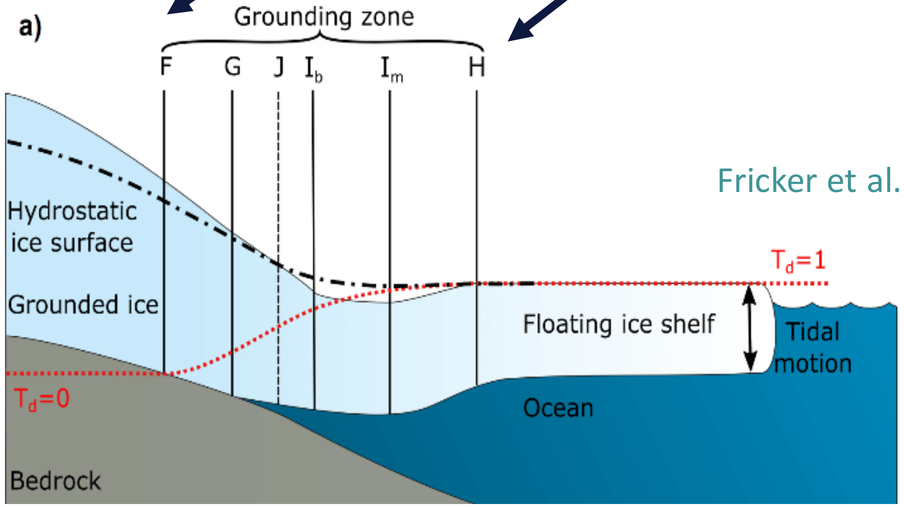
InSAR-based GL detection

- Tidal and atmospheric pressure variation ice shelf heights η visible as interferometric fringes
- Traditionally, detection is done by manual annotation



F landward flexure limit

Hydrostatic line



Fricker et al.