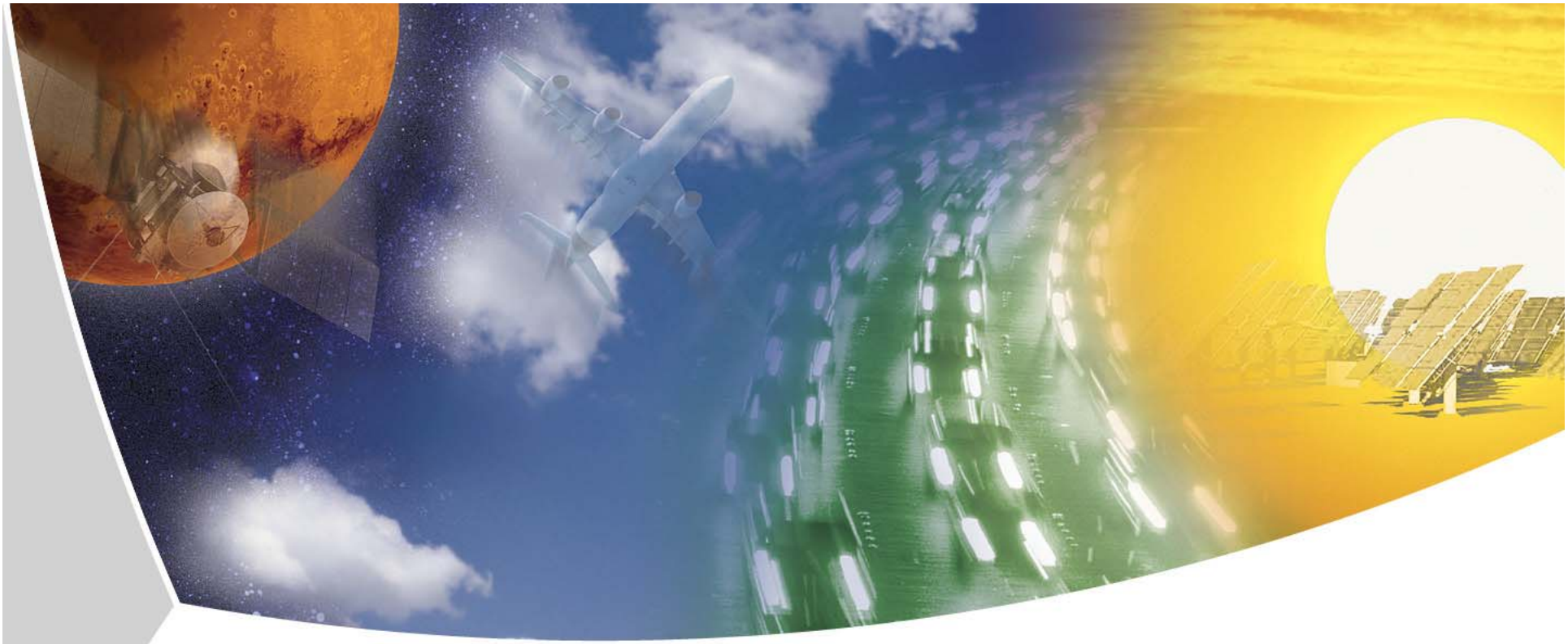


Experimental Radar Modes with TerraSAR-X and TanDEM-X

U. Steinbrecher[1], S. Baumgartner[1], S. Suchandt[2], S. Wollstadt[1], J. Mittermayer[1],

R. Scheiber[1], D. Schulze[1], H. Breit[2]

[1]German Aerospace Center (DLR), Microwaves and Radar Institute

[2]German Aerospace Center (DLR), Remote Sensing Technology Institute

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

20 Years GARS, 12.-15 November 2011, Punta Arenas / Chile

Outline

- Experimental Radar Modes of TerraSAR-X and TanDEM-X with potential Applications in Oceanography and Glaciology

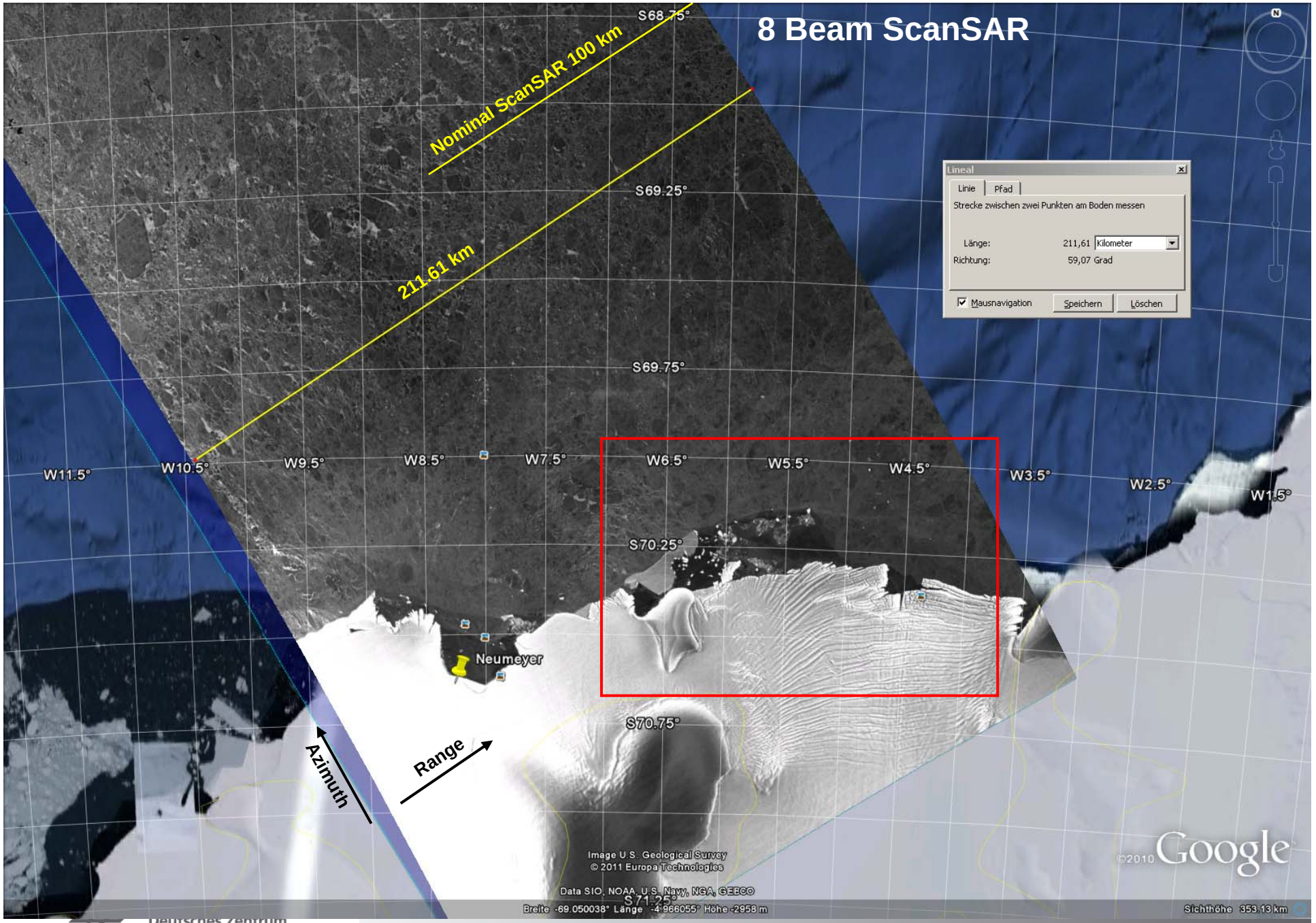
  - **Modes with higher coverage**
    - 8 Beam ScanSAR
    - 8 WideBeam ScanSAR

  - **Modes for Surface Movement Measurement**
    - ATIS **0.1 ms** time separation
    - Pursuit Monostatic **3 s** time separation
      - StripMap
      - ScanSAR
    - BiDiSAR **6 s** time separation
    - Crossing Orbits **1 d** or **5 d** or **6 days** time separation

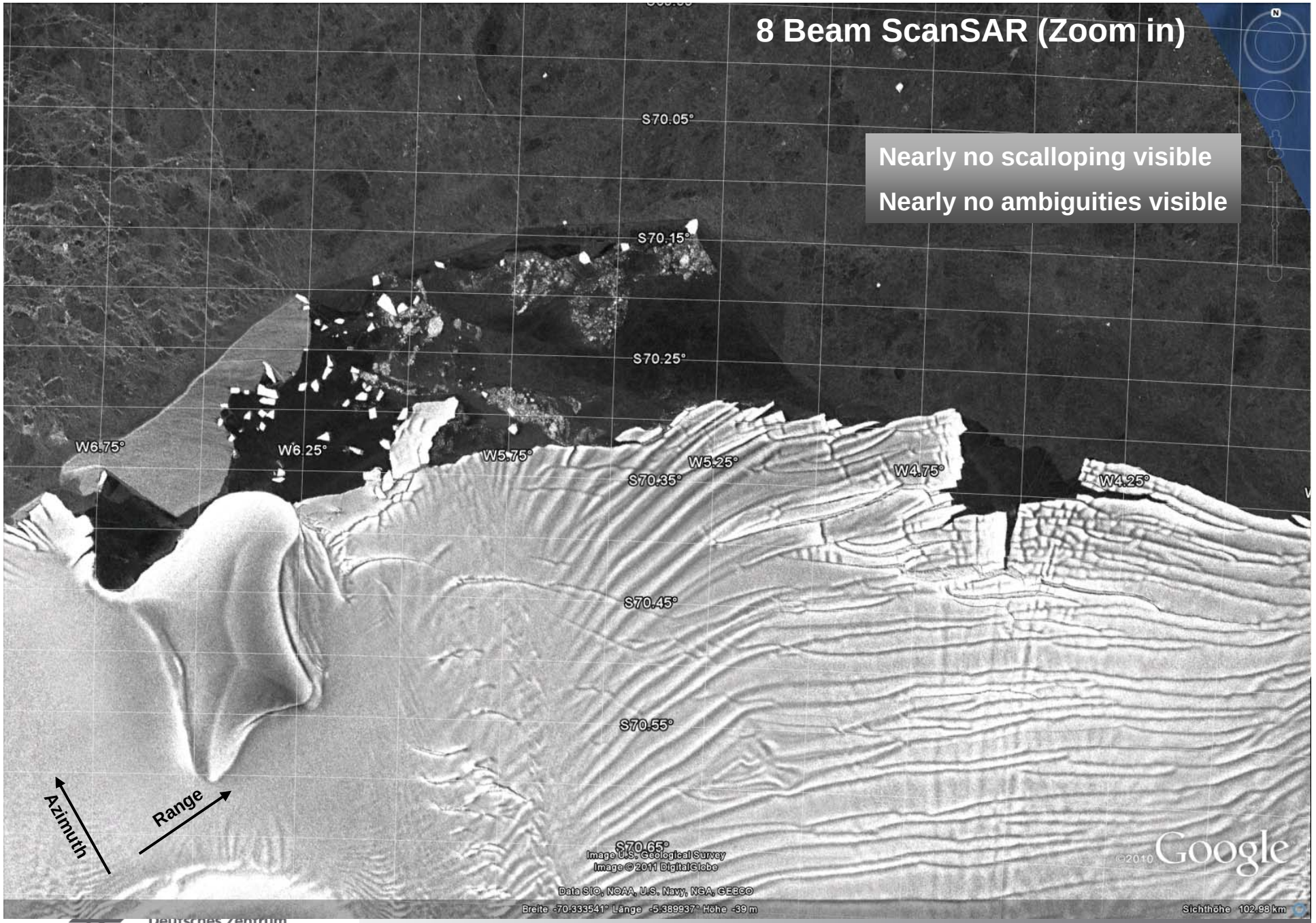
• Modes with higher Coverage I (200 km swath width)

- ScanSAR with 8 Beams i.e. 8 subswathes instead of standard 4 Beams
  - Swath width increases from 100 km to 200 km
  - Switching faster from subswath to subswath since cycle time remains
  - Burstlength per subswath is shorther
    - Resolution becomes worse, e.g. 40 m
  - Commanding
    - More complex
    - Higher onboard resource consumption (programming steps)
    - 32 Basic States are needed for a timing change (echo window)
    - Commanding will fail in case of large DataTake length and terrain variations, i.e. 255 Basic States are exceeded

8 Beam ScanSAR



8 Beam ScanSAR (Zoom in)



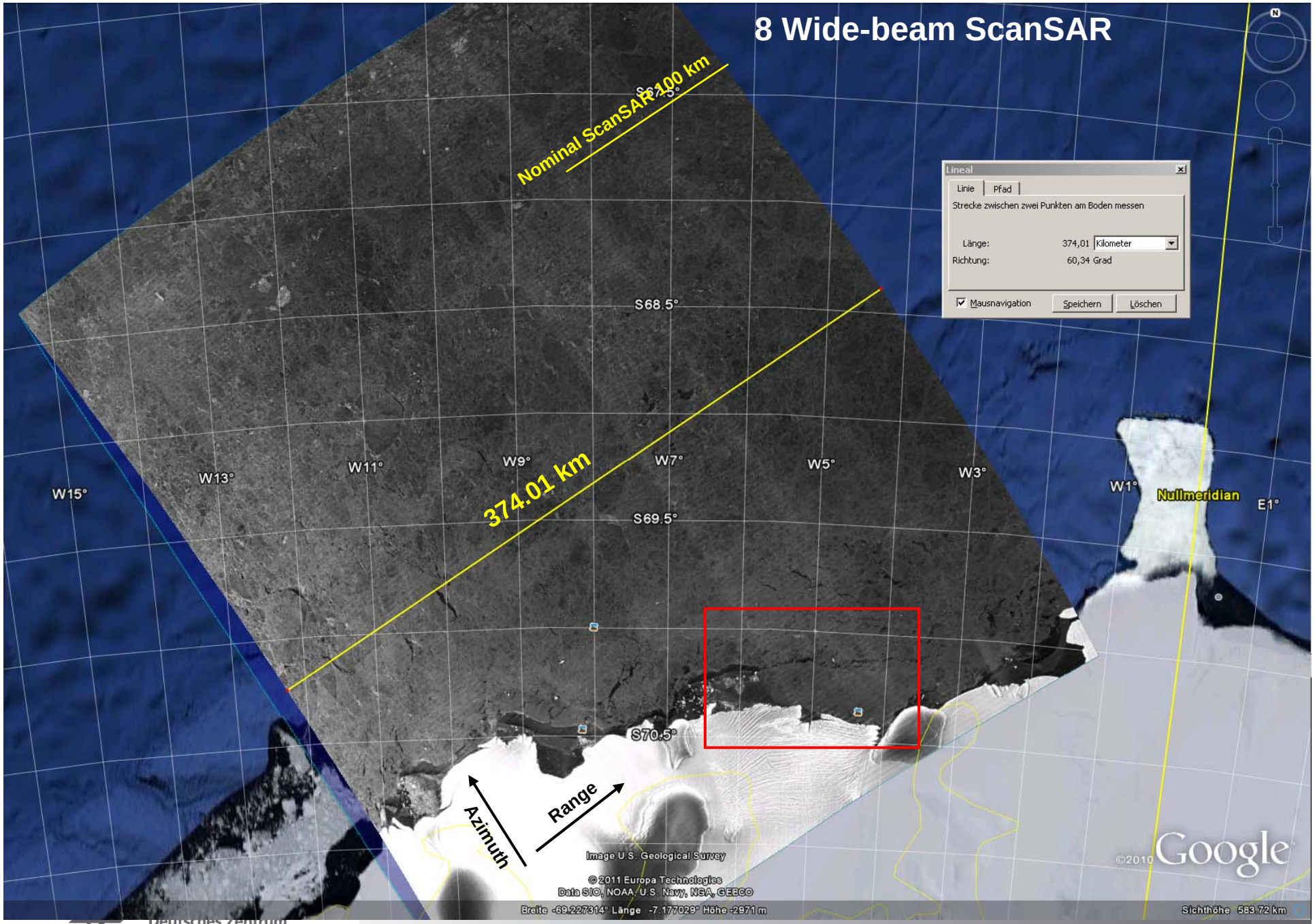
Nearly no scalloping visible

Nearly no ambiguities visible

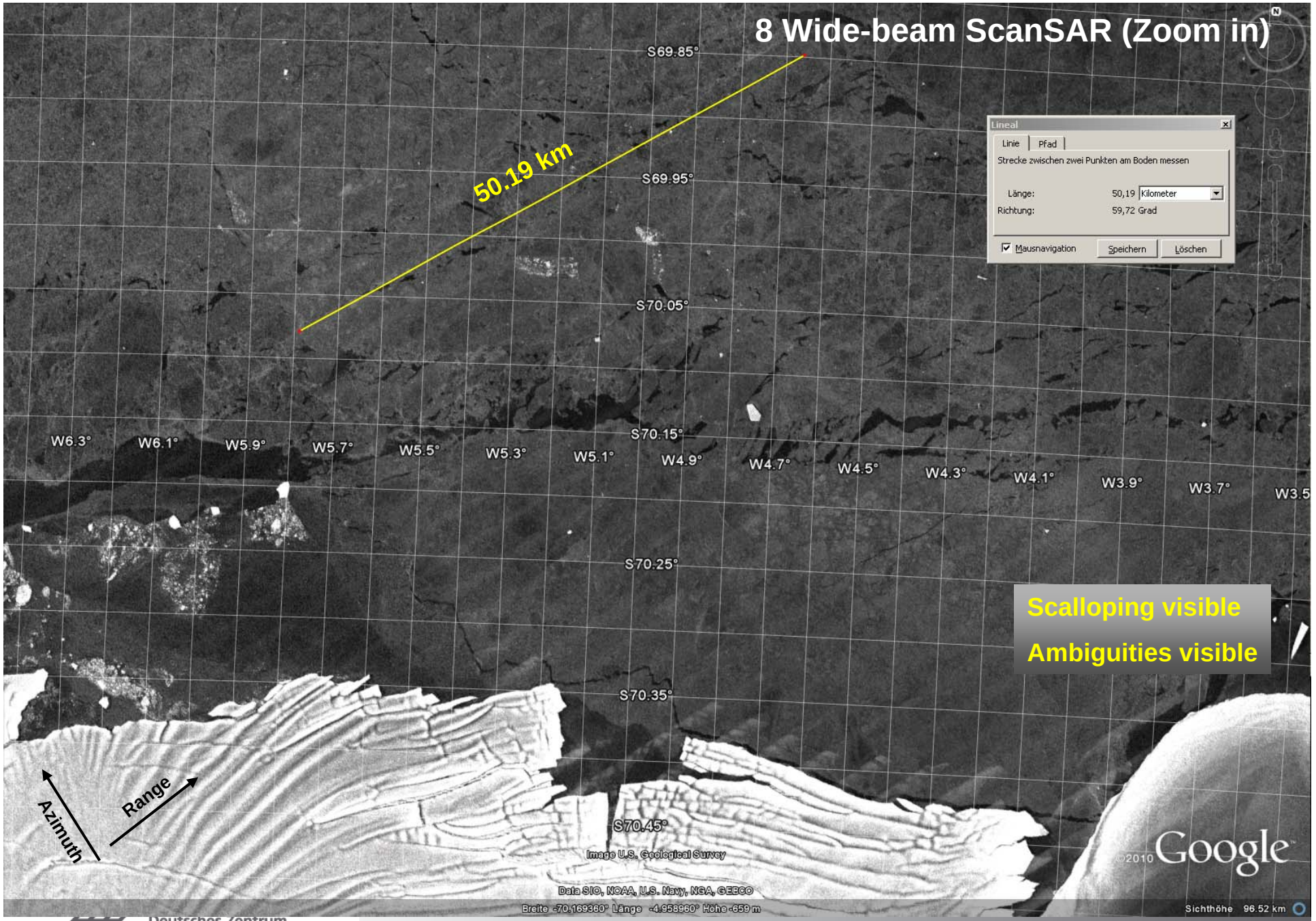
• Modes with higher Coverage II (370 km swath width)

- ScanSAR with 8 Wide Beams i.e. 45km subswathes instead of standard 30km subswathes
  - Expand footprint of each subswath by phase patterns
    - Less energy per area
    - Worse SNR
  - Decrease of TX pulse length to increase echo window length
    - Less transmitting energy
    - Worse SNR
  - Decrease PRF to increase echo window length
    - Higher azimuth ambiguities

8 Wide-beam ScanSAR



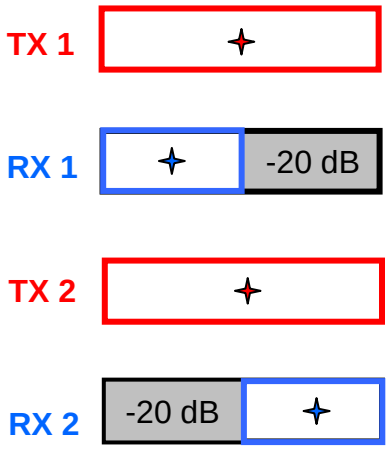
8 Wide-beam ScanSAR (Zoom in)

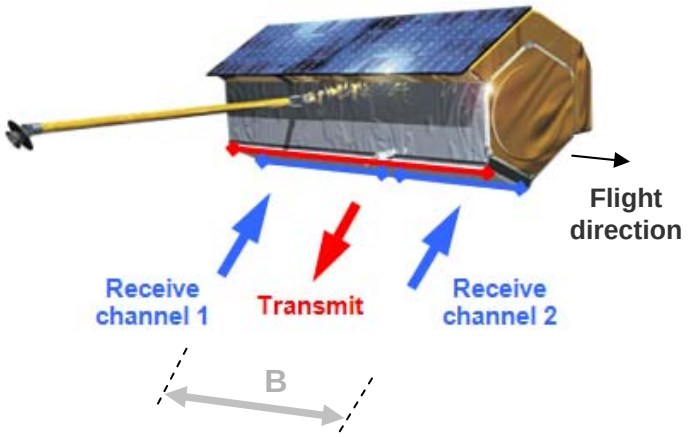


Modes for Surface Movement Estimation

by means of Interferometry or speckle tracking

- **ATIS (Along Track Interferometry by Aperture Switching) Single satellite**





Aperture Switching (AS)

- Switching between antenna parts on receive
- Constantly available (only nominal electronic used) in contrast to DRA (additional redundant electronic used)
- ATI baselines *B* (0.84 m – 1.43 m) ca. 0.1 ms time separation
- Many data takes of surface currents in oceans and rivers successfully acquired and processed

Data Acquisitions, Orkney Islands, 2009-2011

Sensor heading α: 196° from North

Imaging time: 6:41 UTC

AS Mode	
Az. sampling freq. *prf*	6680 Hz
Range bandwidth B_{rg}	300 MHz
Polarization	VV
Incidence angle ϑ	31.4°
ATI baseline B_{eff}	1.02 m
Swath width	5 km

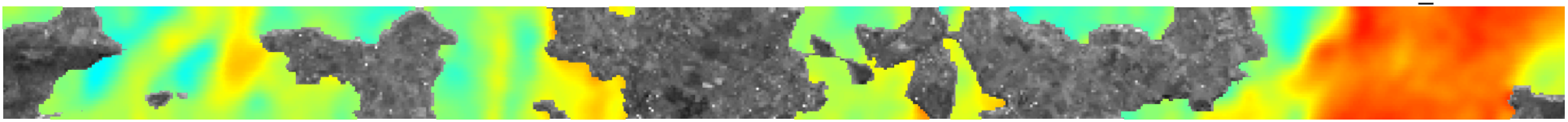
Data takes: 1 each 11 days 10/09-02/11 (with gaps)

DRA Mode	
Az. sampling freq. *prf*	3420 Hz
Range bandwidth B_{rg}	165 MHz
Polarization	HH
Incidence angle ϑ	31.2°
ATI baseline B_{eff}	1.15 m
Swath width	32 km

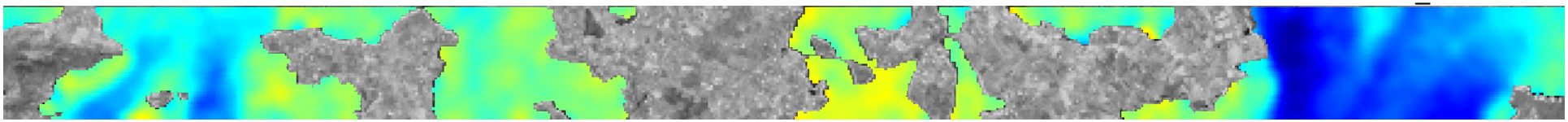
Data takes: 5 in 2010 (experimental campaign)

Surface Current Velocities from TerraSAR-X ATI (AS-Mode) Orkney Islands, 2009

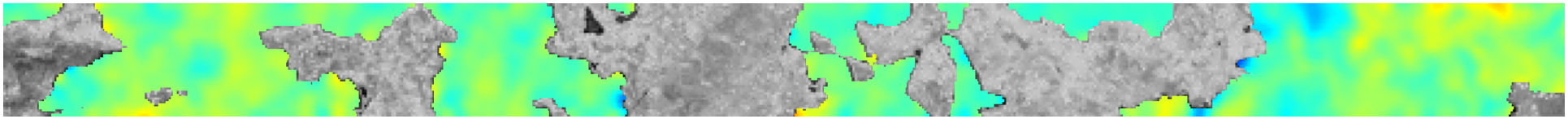
TSX_121109



TSX_231109



TSX_261209



Look direction

Flight direction

0 km 5

v_g

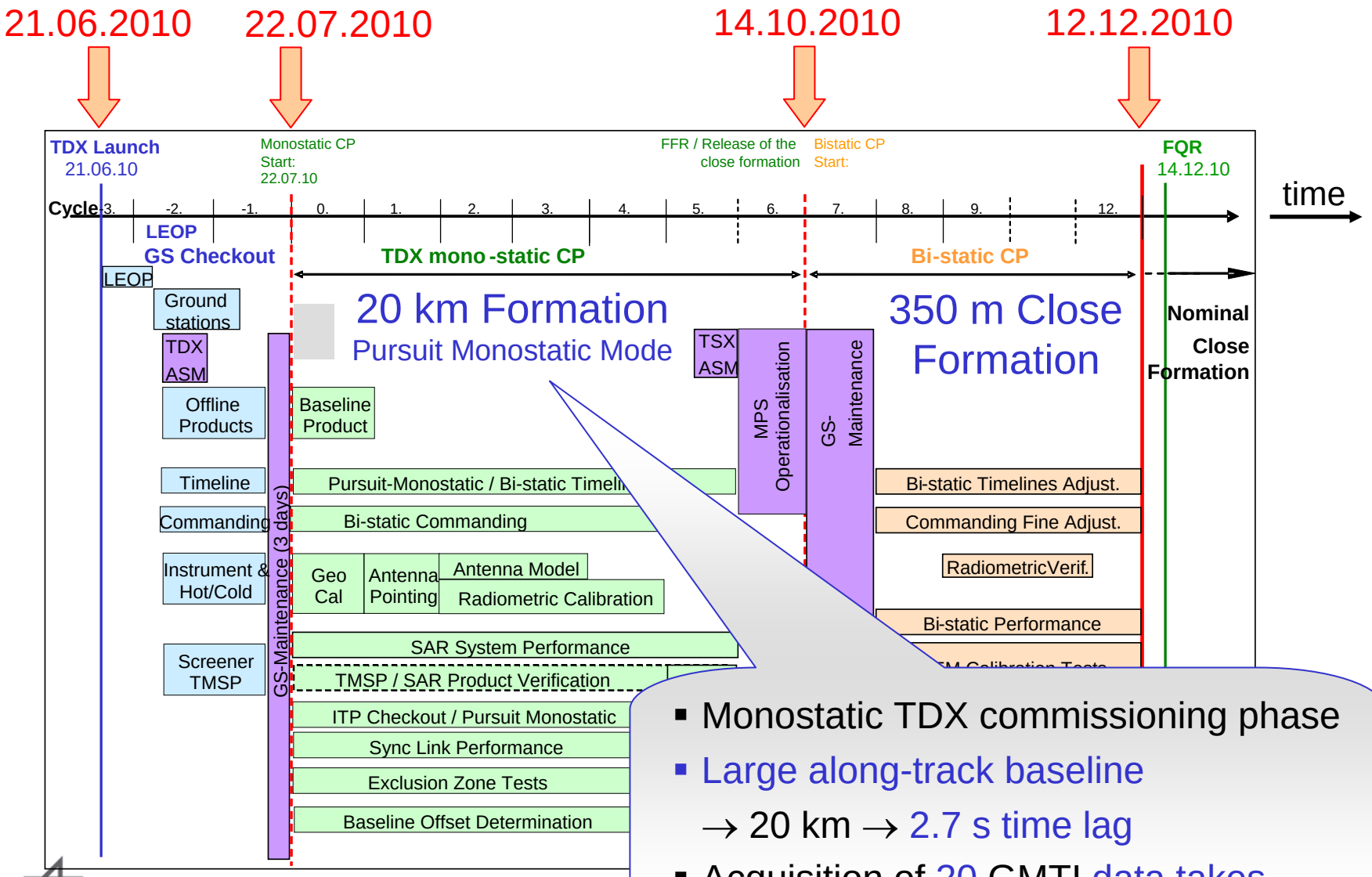
3 m/s towards Radar

Surface current velocity

3 m/s away from Radar

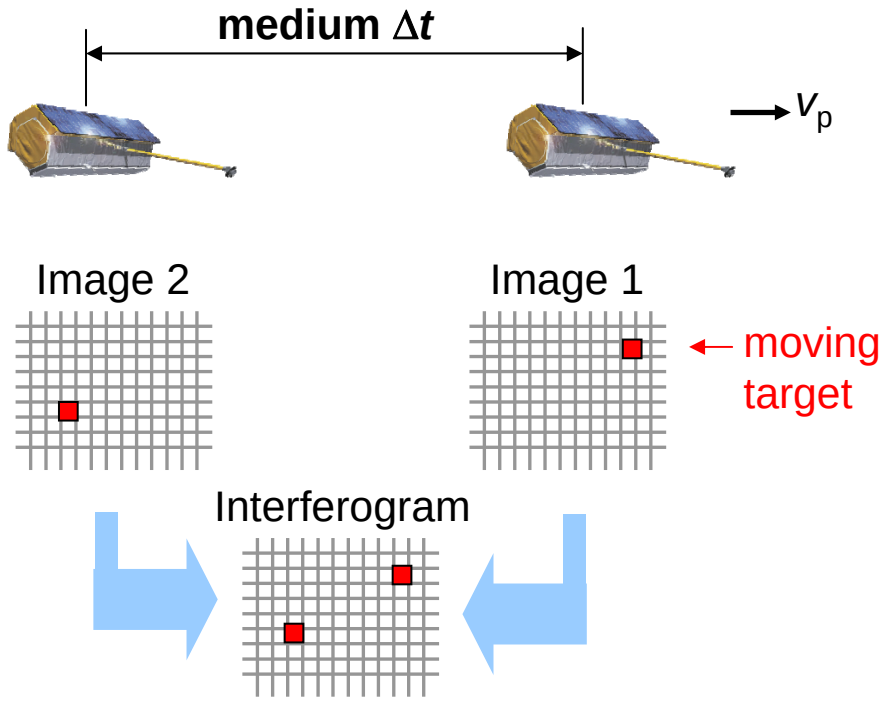
- Large-scale mapping of tidal surface currents with an operational space-borne SAR ATI sensor has been demonstrated
- Very promising results achieved even with single-satellite ATI modes i.e. with relatively small ATI baselines (sensitivities)

- **Pursuit Monostatic TSX-1 TDX-1 Phase (2.7 s), Dual satellite**



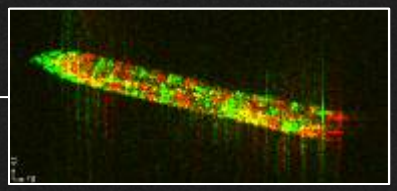
- Monostatic TDX commissioning phase
- Large along-track baseline
  → 20 km → 2.7 s time lag
- Acquisition of 20 GMTI data takes

- **Medium Along-Track Baseline**

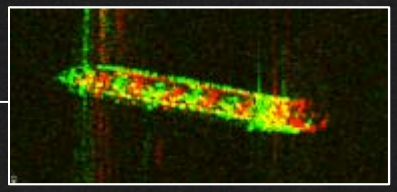


- Medium baseline → Δt ≅ s
  - Moving target leaves res. cell
  - 2D velocity estimation, by speckle tracking
  - Medium-Along Track Baseline GMTI

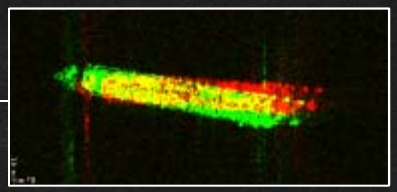
First Results: StripMap Vessel Monitoring in the Strait of Gibraltar



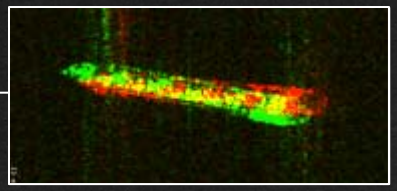
Coordinates:
35.949 N, -5.712 E
Velocity:
16.7 kn



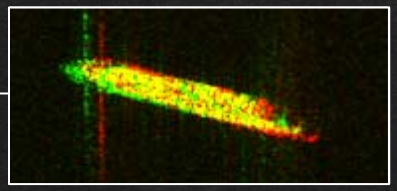
Coordinates:
35.953 N, -5.704 E
Velocity:
9.5 kn



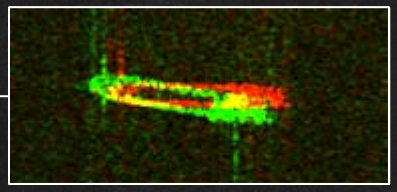
Coordinates:
35.960 N, -5.694 E
Velocity:
10.9 kn



Coordinates:
35.964 N, -5.700 E
Velocity:
8.7 kn



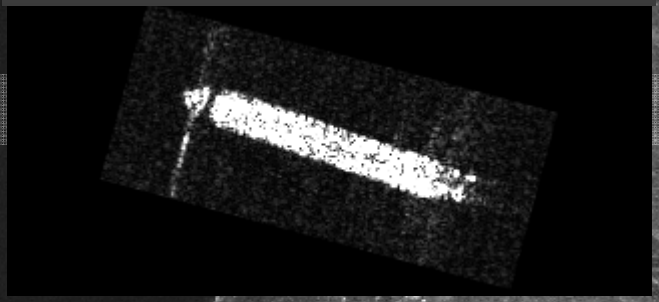
Coordinates:
35.951 N, -5.659 E
Velocity:
8.9 kn

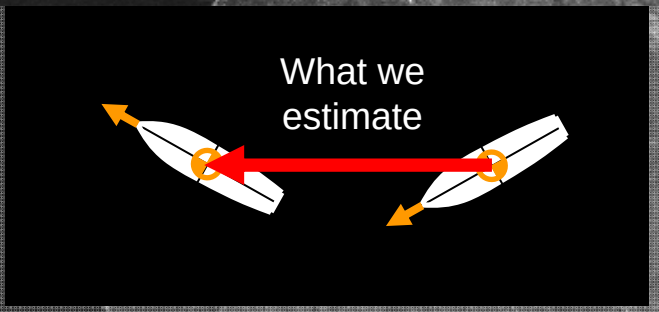


Coordinates:
35.963 N, -5.657 E
Velocity:
6.4 kn

Rotation has to be considered

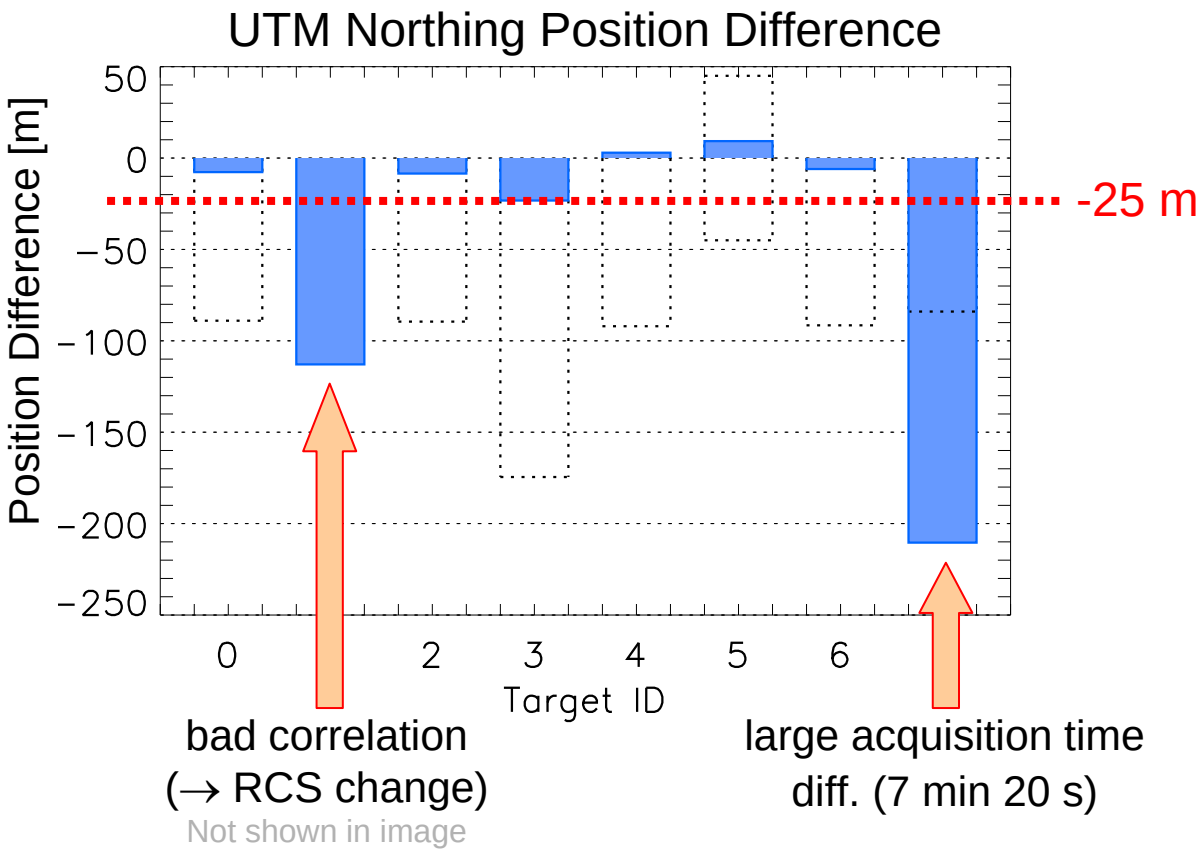
Movement correlation with all possible rotations

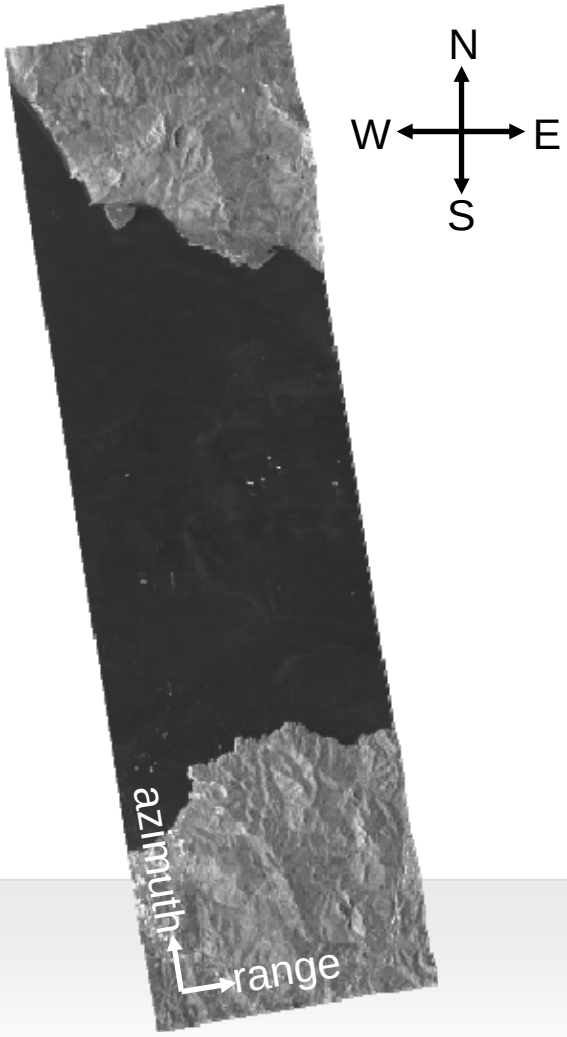




Verification Using AIS Data as Reference → First Results (I)

Position estimated with extrapolated AIS velocity

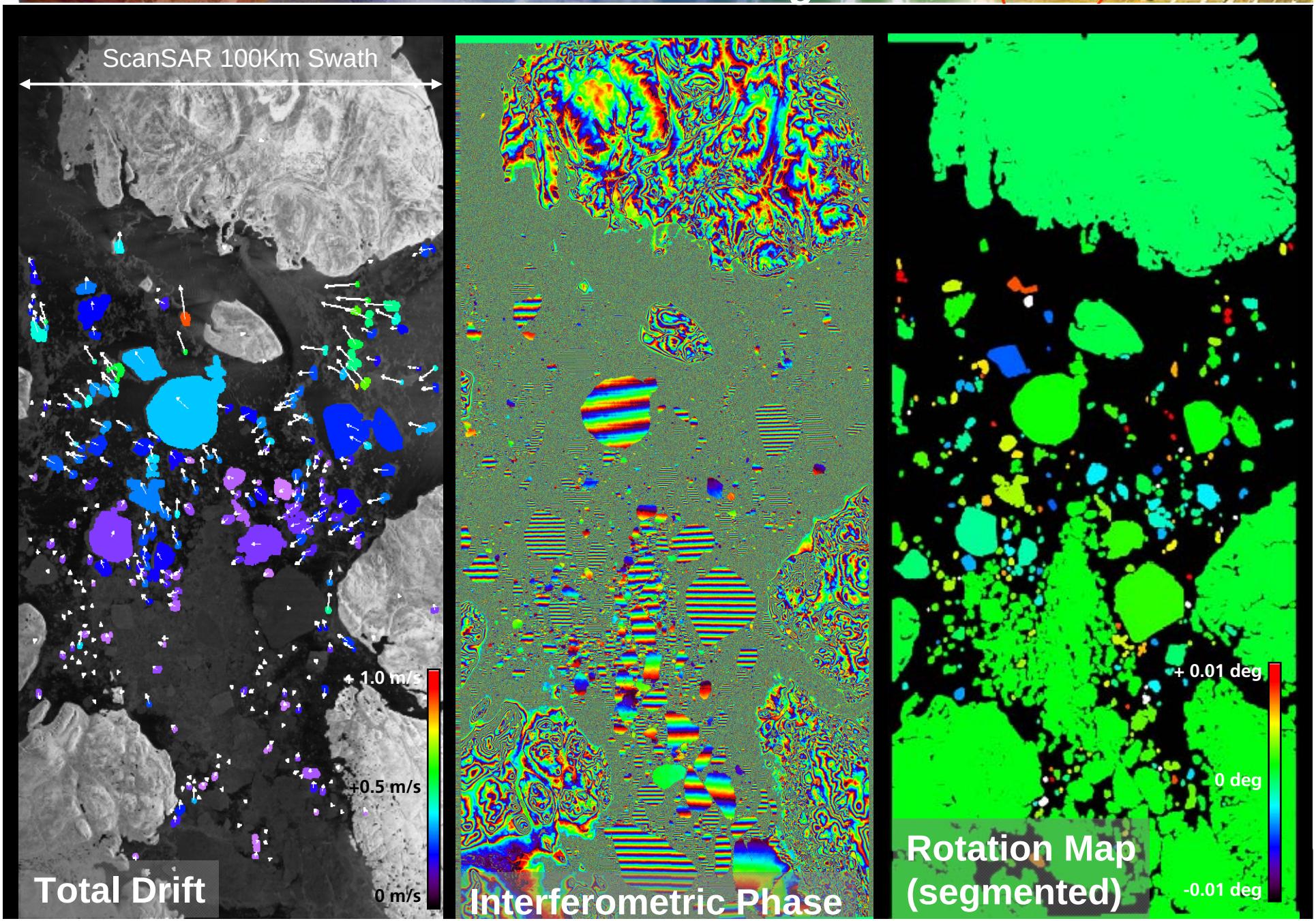




- Vessels have moved mainly in range direction
  - Northing pos. difference ~ azimuth re-positioning error
  - „True azimuth position is more difficult to estimate than range position!“

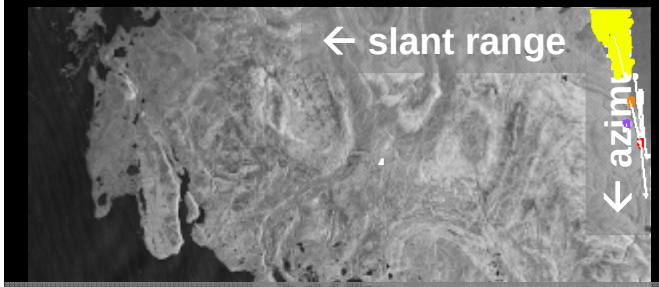
Cornwallis-Island: North-West Passage

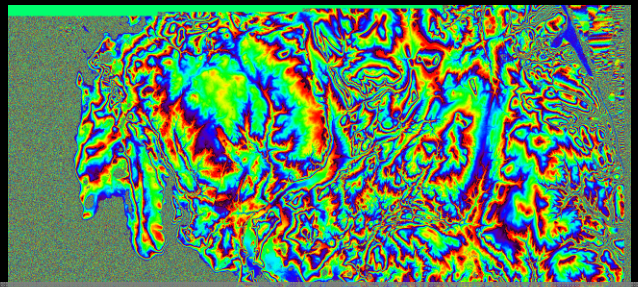
Aug 2, 2010, 13:13:37
(summer)



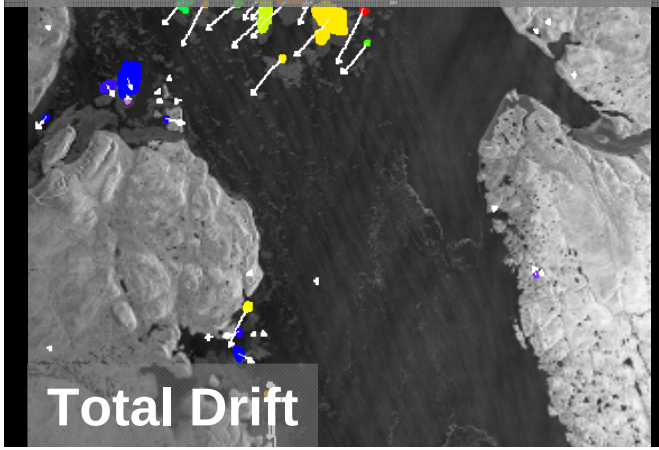
Cornwallis-Island: North-West Passage

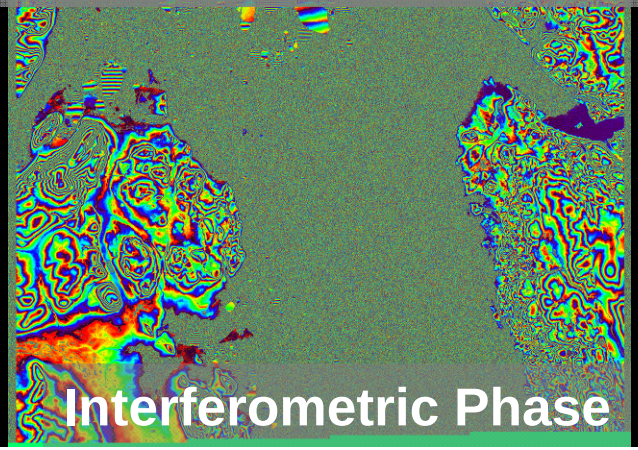
Aug 13, 2010, 13:13:37
(summer, 11 days later)

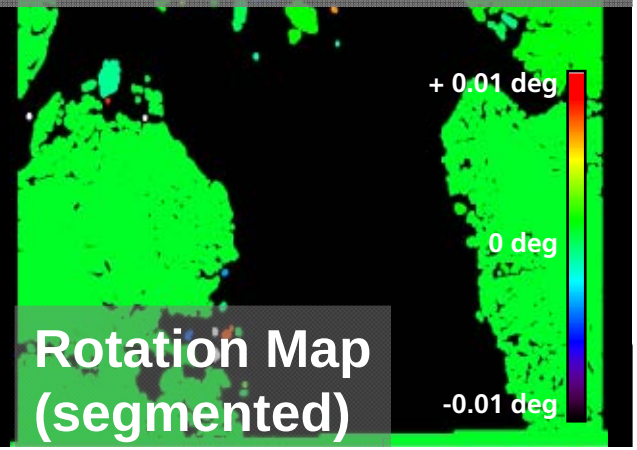




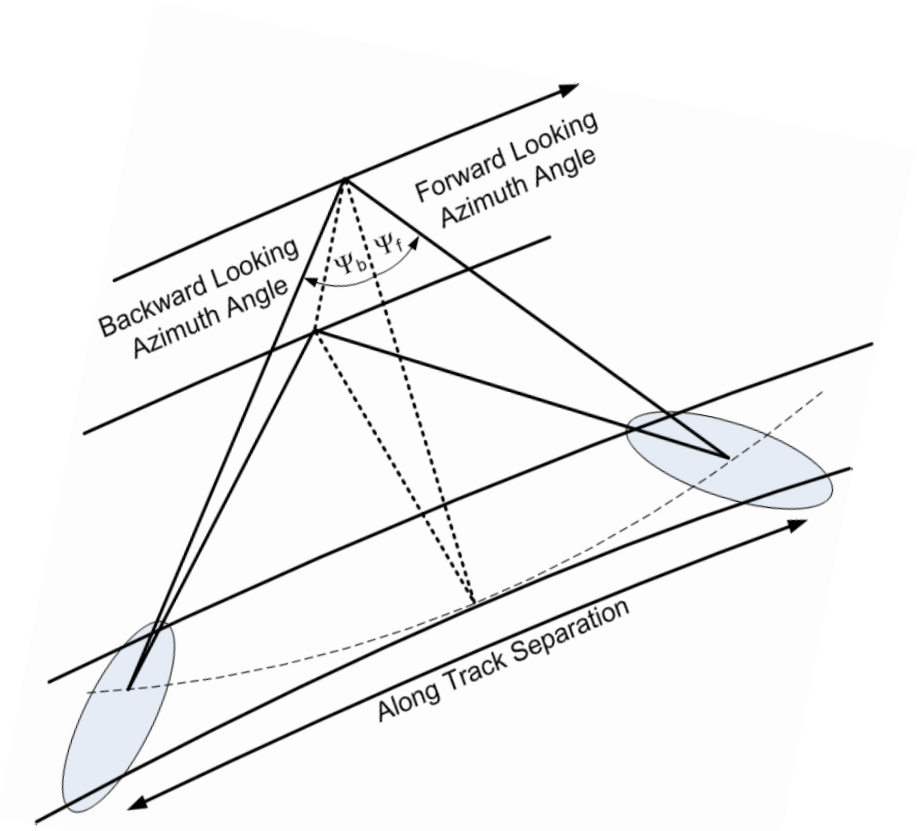
- First ever possibility for **instantaneous** sea ice drift measurements.
- Importance of **ice sheet rotation**, in addition to **ice drift** measurements.
- Possibility of **high resolution, short term ice drift predictions.**
- **ScanSAR** data acquisition is **feasible** and **essential** for large area coverage.
- **Next** possibility for **suitable TDX-TSX data** acquisition hopefully in **2013.**

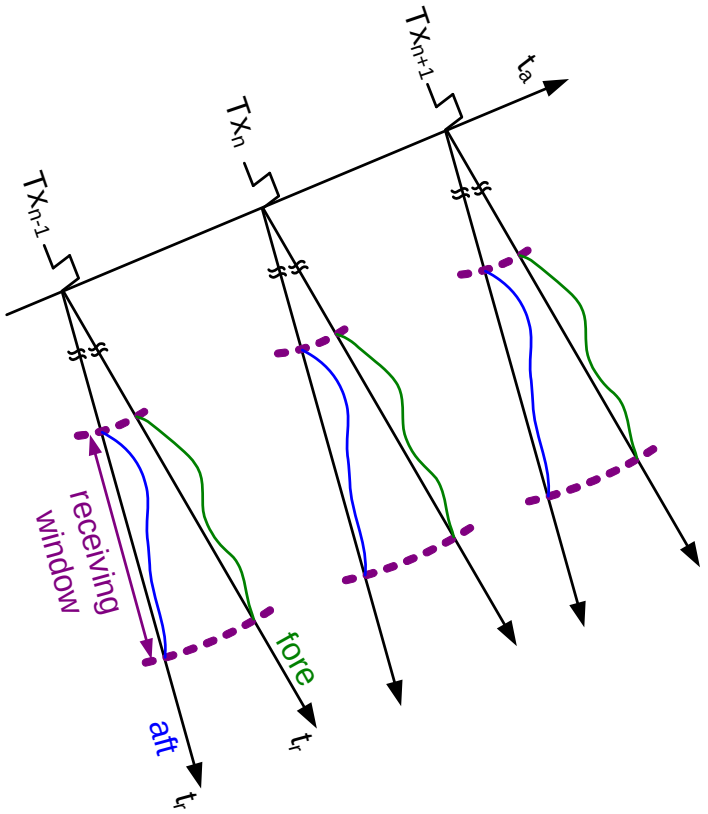






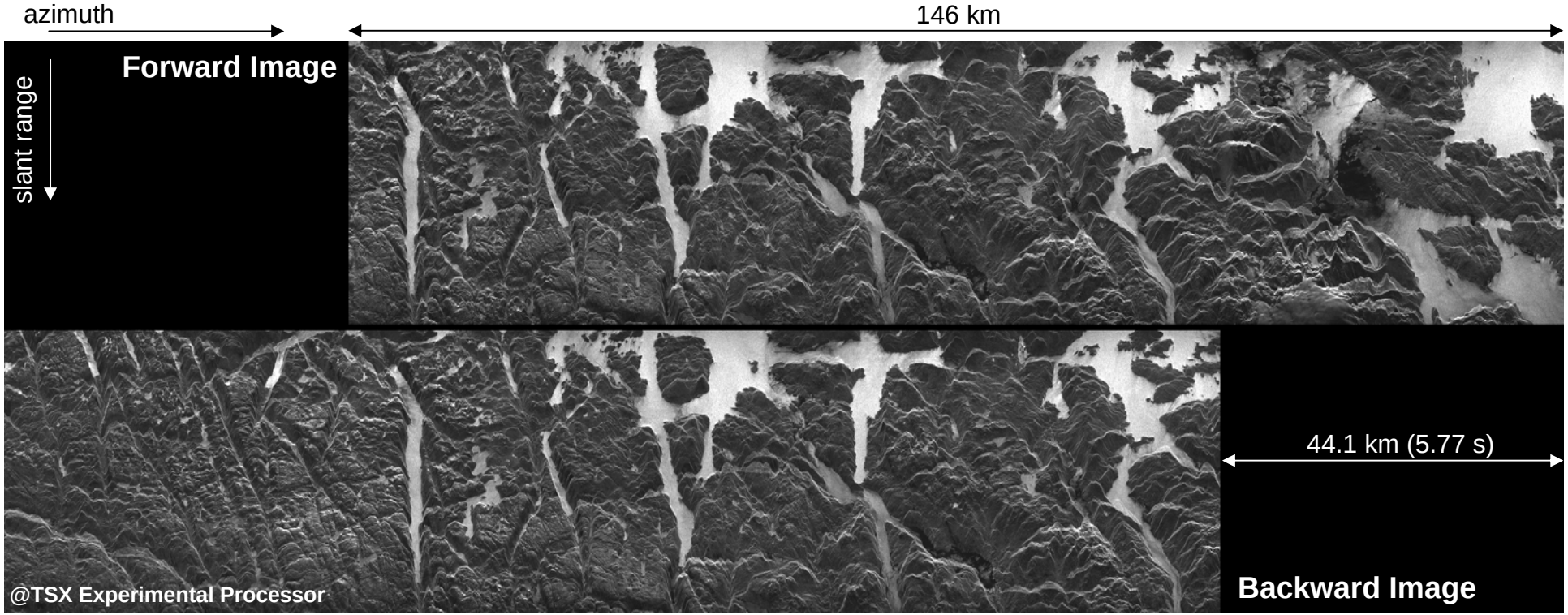
• Bi-directional SAR (BiDi), 6s time separation, Single Satellite





- azimuth beam shaping into two (or more) directions, e.g. forward and backward
- simultaneous reception of both images in time domain
- image separation in Doppler domain

Bi-directional SAR Experiment (July 2009)

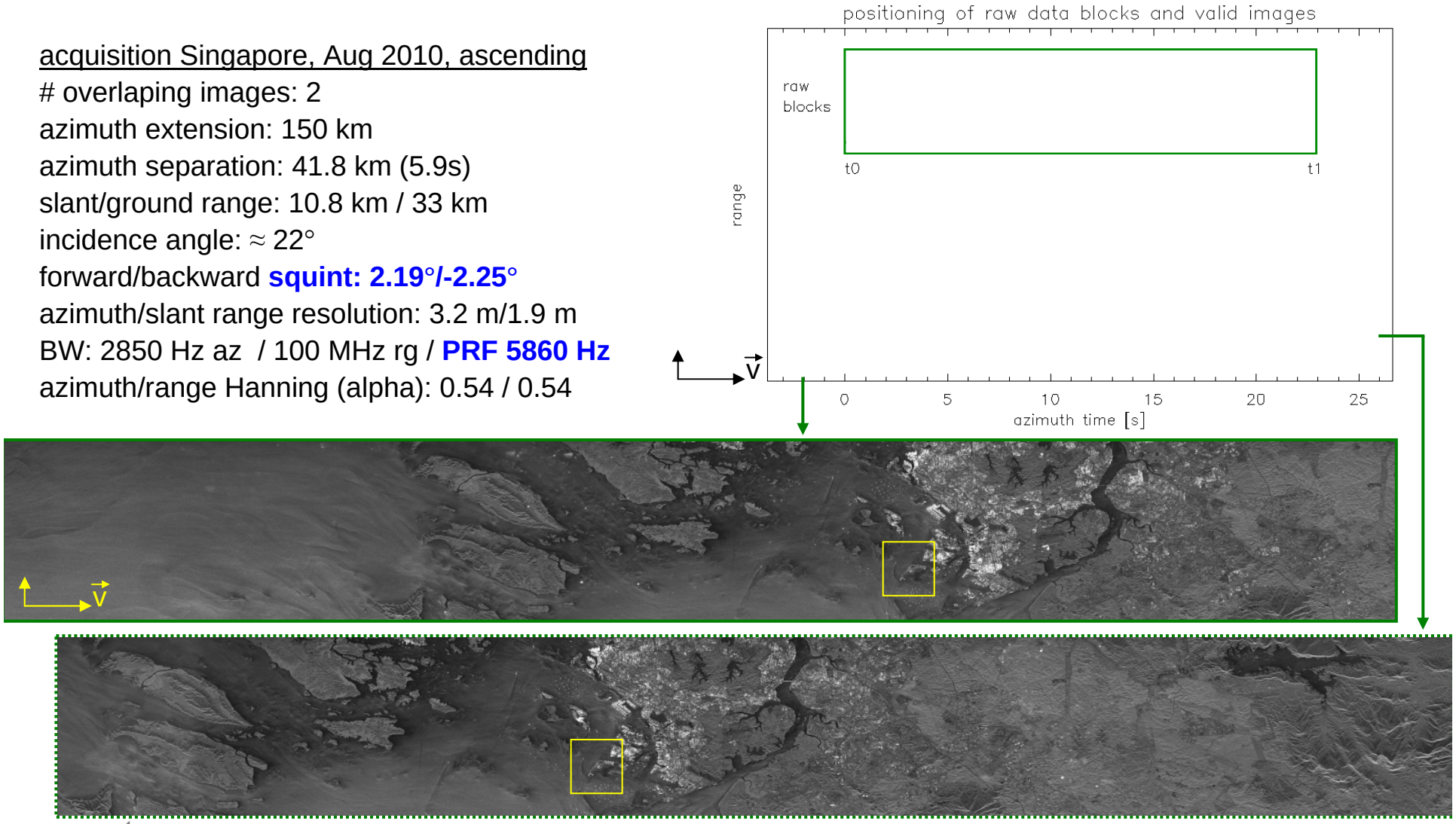


BiDi SAR provides repeated acquisitions with one satellite and one channel within seconds

Ref.: J. Mittermayer, S. Wollstadt, "Simultaneous Bi-directional SAR Acquisition with TerraSAR-X", Proc. of EUSAR 2010, Aachen, Germany.

BiDi SAR – Singapore Acquisition Example

<u>acquisition Singapore, Aug 2010, ascending</u>
overlaping images: 2
azimuth extension: 150 km
azimuth separation: 41.8 km (5.9s)
slant/ground range: 10.8 km / 33 km
incidence angle: ≈ 22°
forward/backward **squint: 2.19°/-2.25°**
azimuth/slant range resolution: 3.2 m/1.9 m
BW: 2850 Hz az / 100 MHz rg / **PRF 5860 Hz**
azimuth/range Hanning (alpha): 0.54 / 0.54

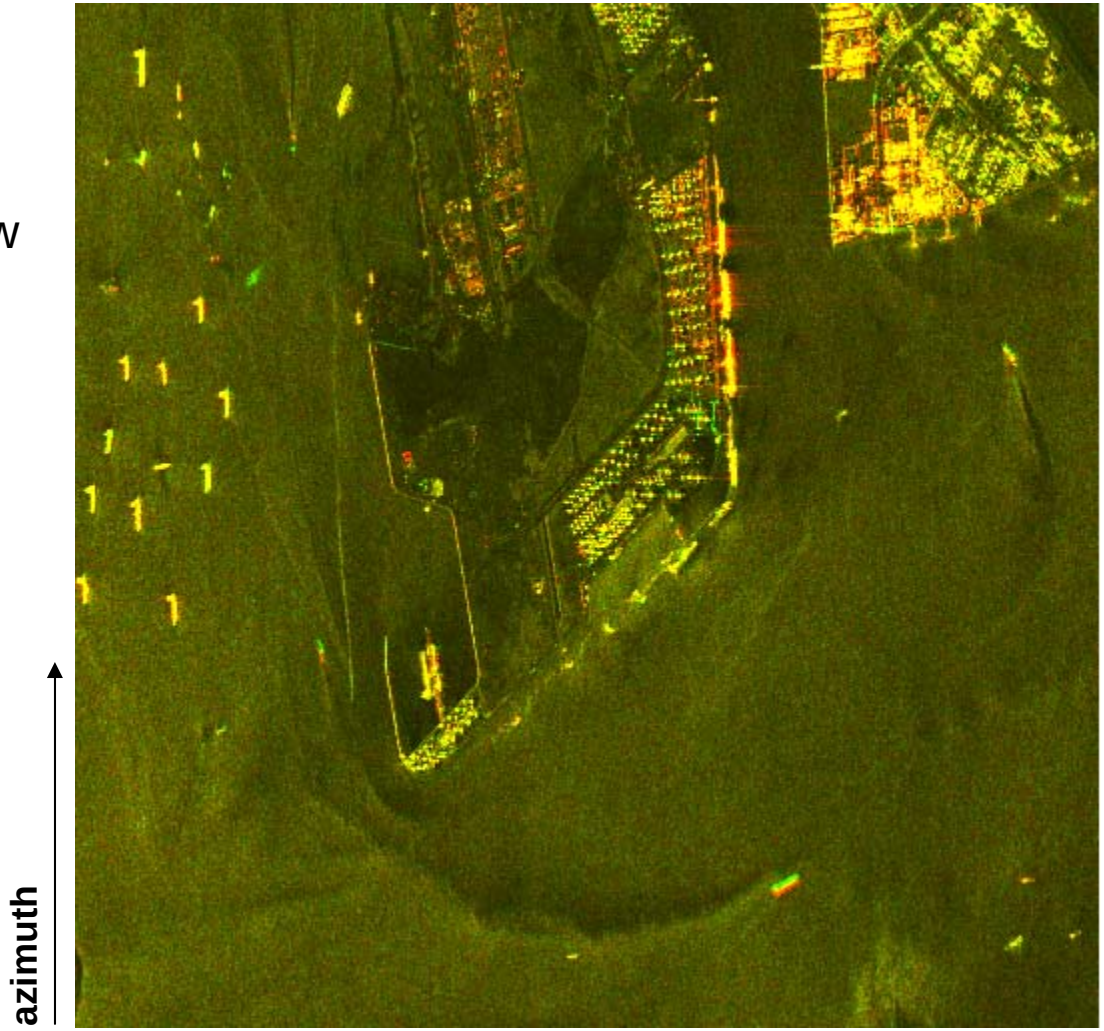


Fore and Aft Image Overlay

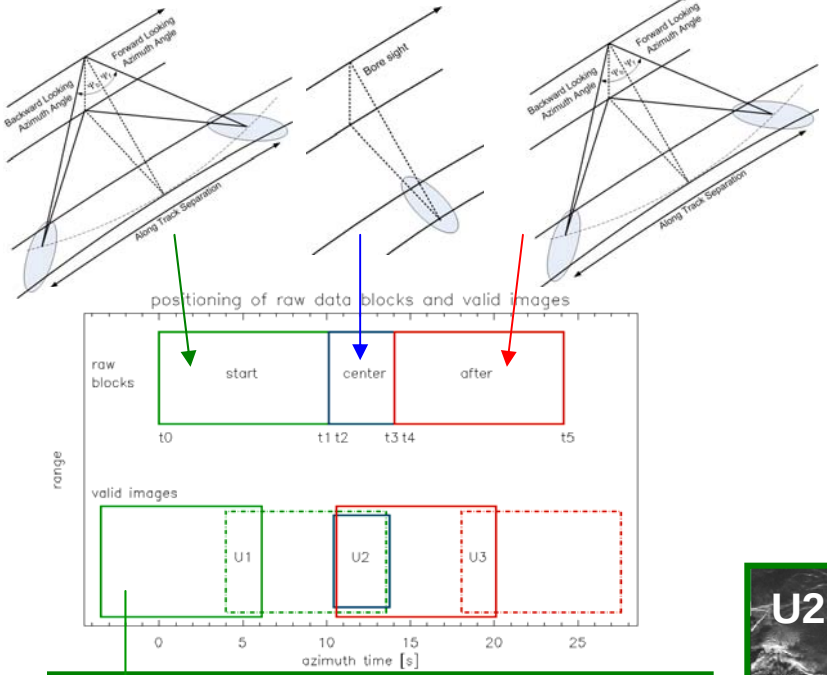
- colour composite of fore (red) and aft (green) image sections from single TerraSAR-X overflight
- equal backscatter combines yellow
- considerably differences in backscatter behaviour at 4.4° aspect angle difference
- motion of ships visible

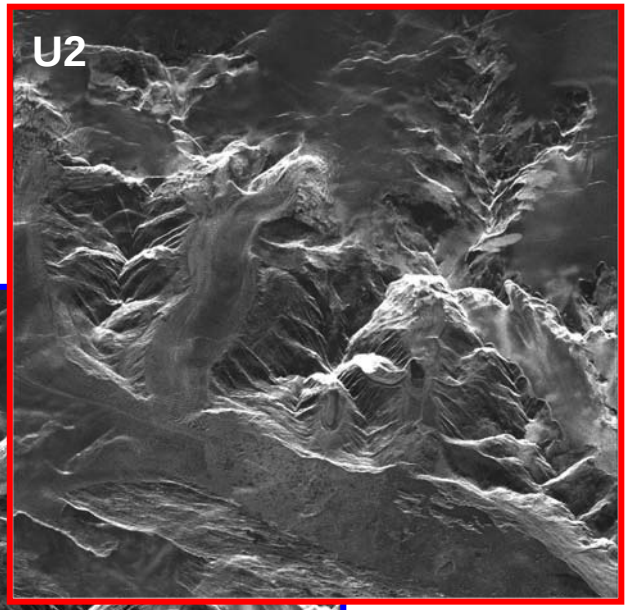
- 2D motion measurement is principally possible with one satellite, one pass, one channel

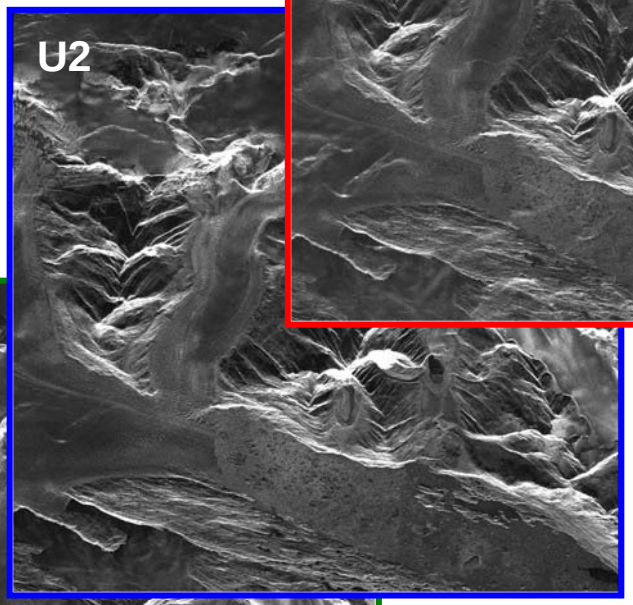
- Future: ScanSAR principally possible

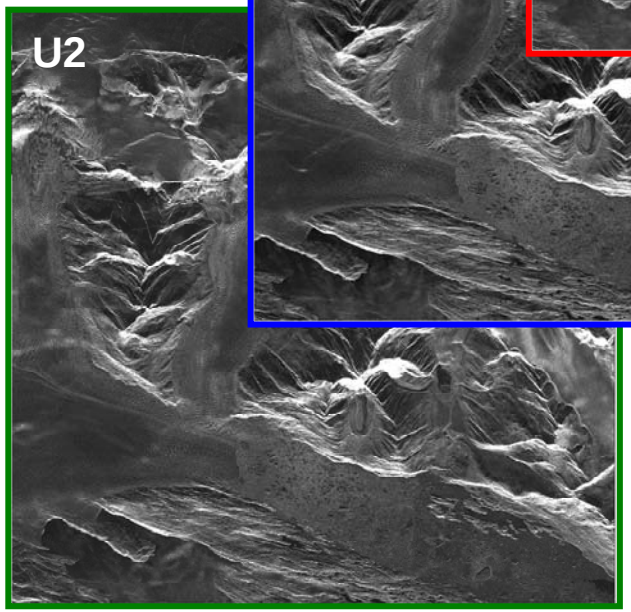


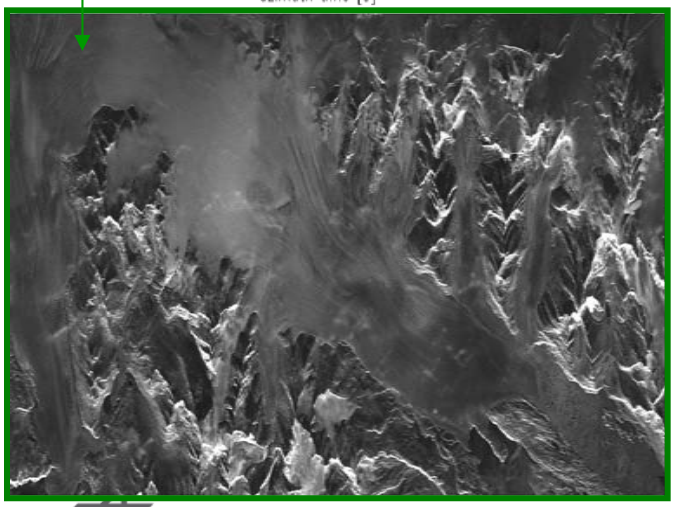
- **BiDiSAR TSX/TDX Short Time Series - Upsala Glacier – Dual satellite**







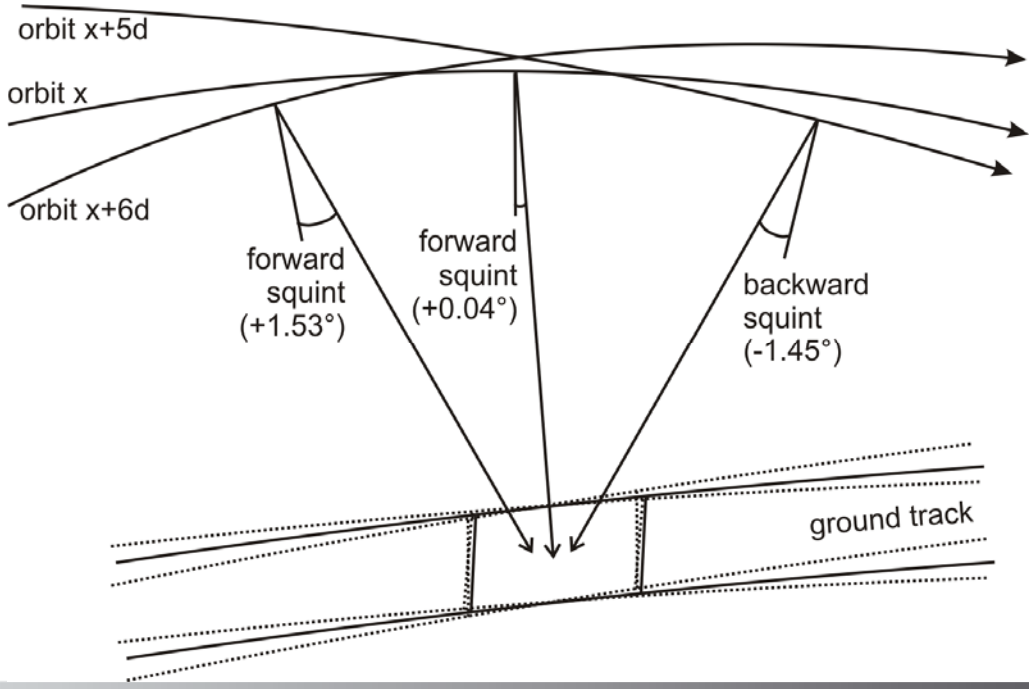


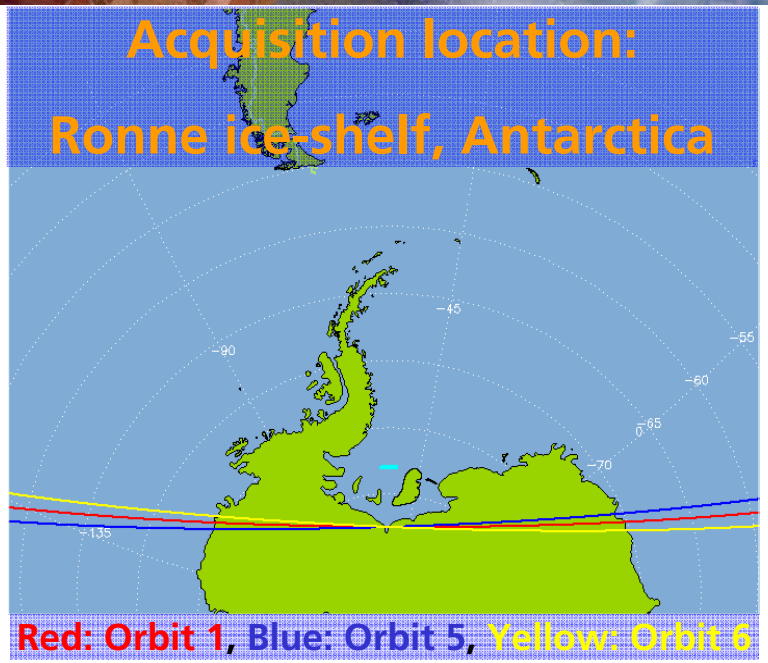


TSX Acquisition
42° inc.
PRF 5800 Hz
short time series
0s 3.6s 7.2s

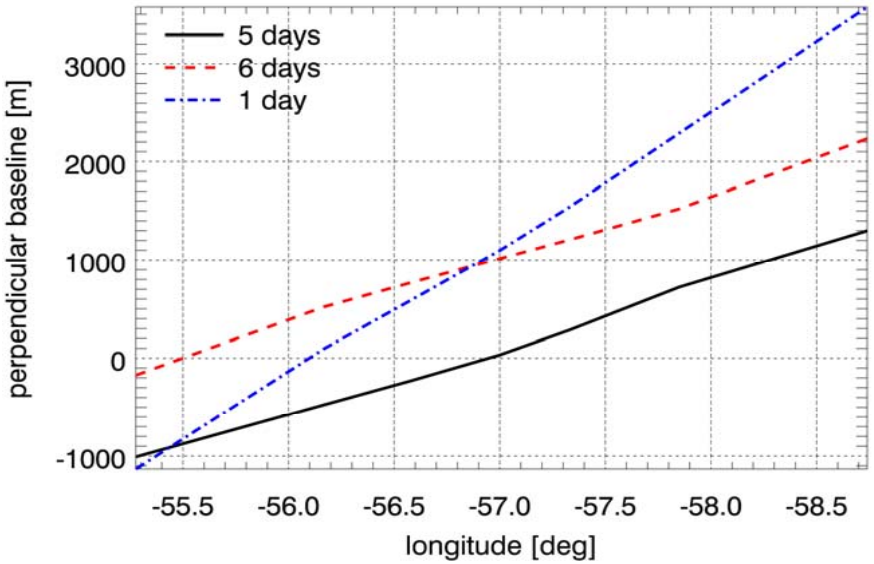
• Crossing Orbit Interferometry SAR, 1d or 5d or 6d time separation, Single Satellite

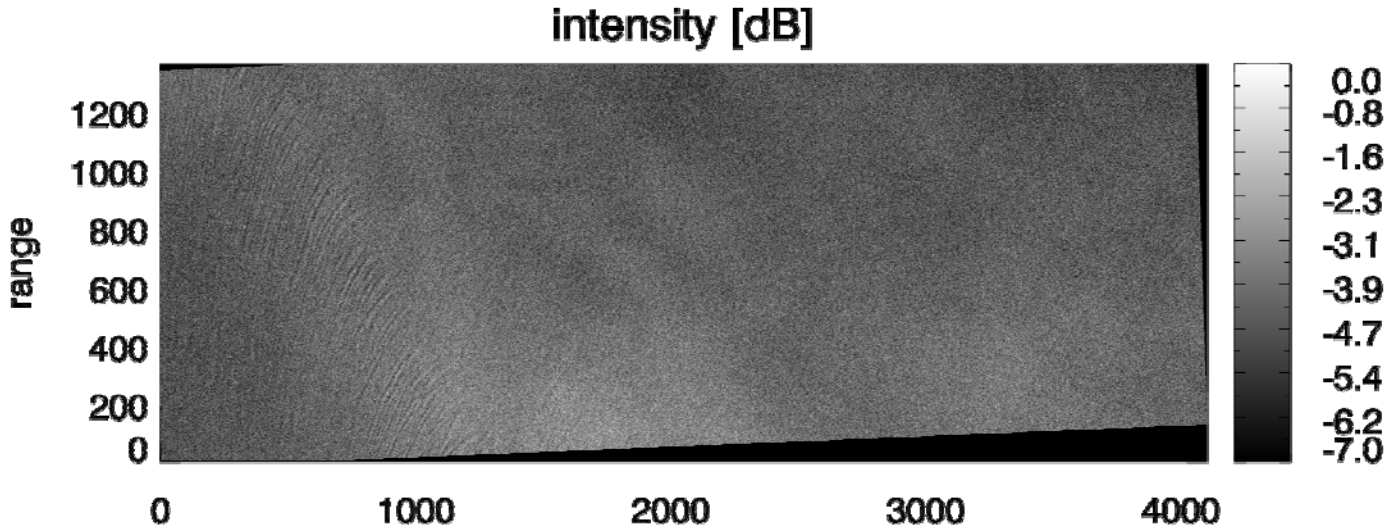
- Motivation
  - **Shorter revisit times than the repeat pass cycle of 11days**
- Method
  - **Utilize neighbored orbits for data acquisition, i.e. overlapping range spectra**
  - **Neighbored orbits appear after 5 and 6 days**
  - **Squinted azimuth beams are enabling the acquisition of scenes with of overlapping ground spectra**
- Crossing angles
  - **2.1° after 5d and 6d**
  - **4.2° after 1d (x+5d and x+6d)**
- Constraints
  - **Only possible at high latitudes**
  - **North: 84.5° to 88°**
  - **South: -75° to -80°**

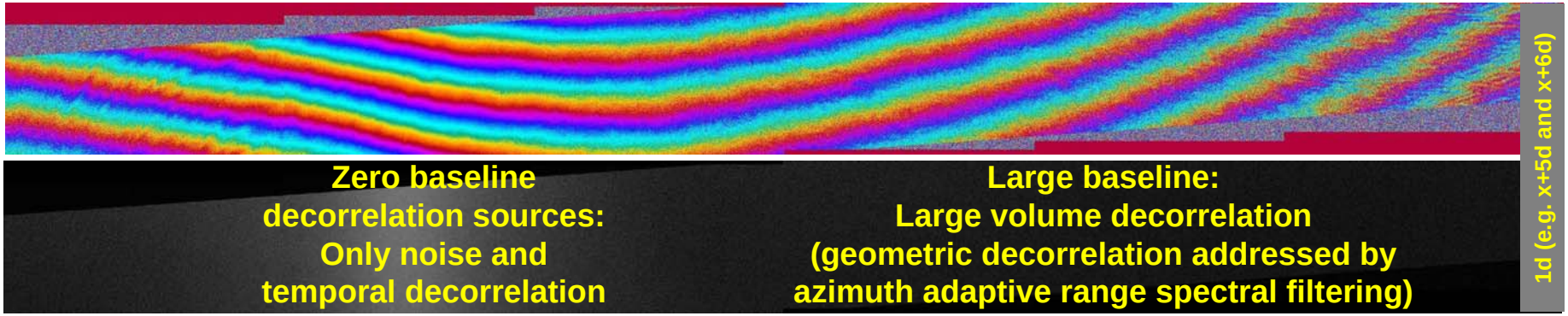


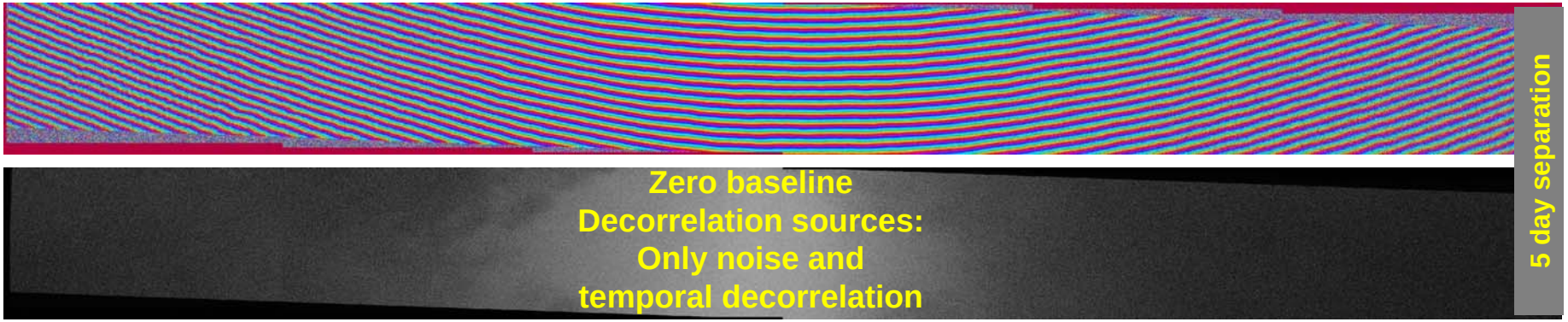


XTI with extreme baseline variation





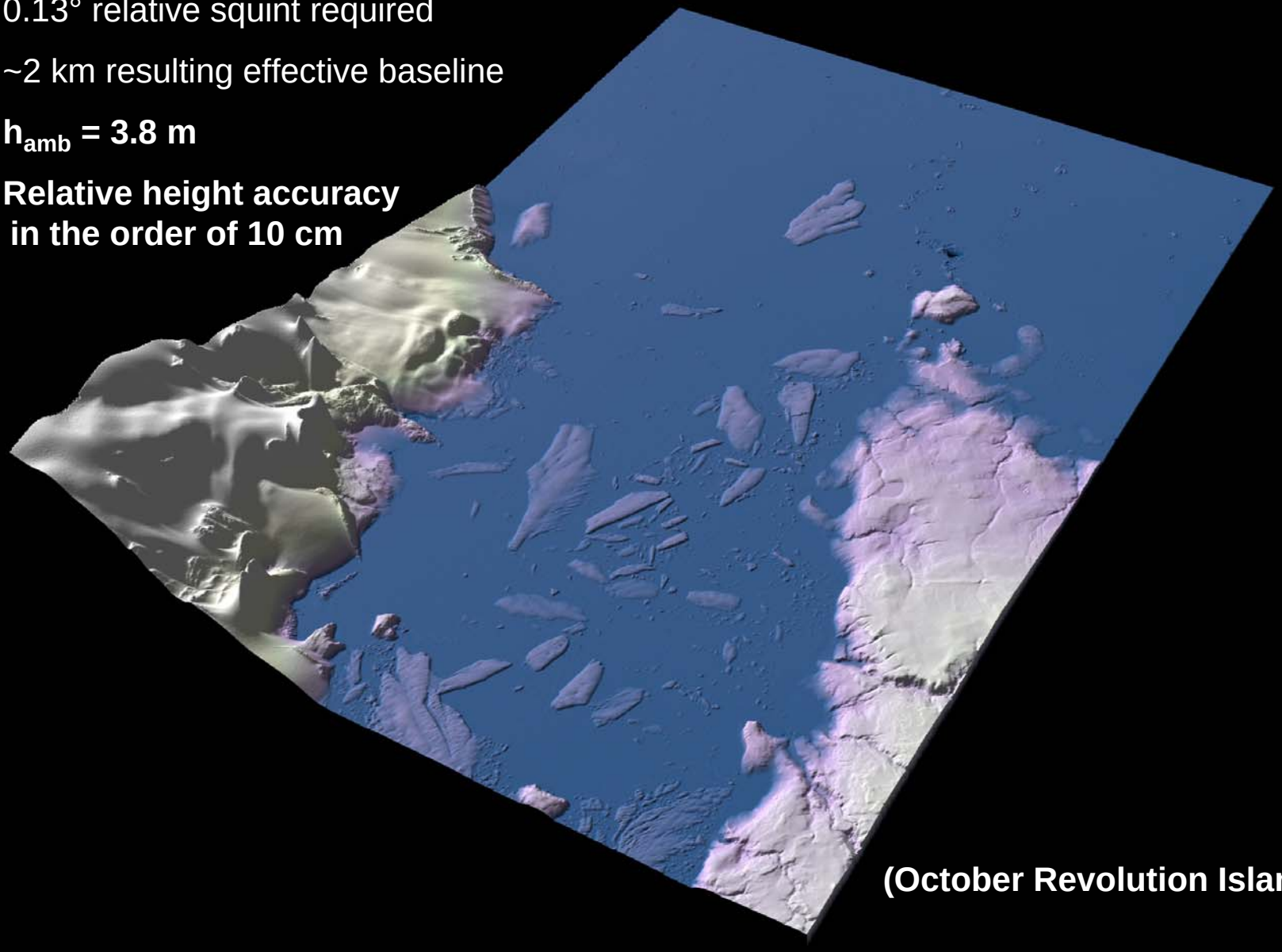




- Fringe rate is proportional to time-lag
  - Fringes indicate velocity gradients (velocity itself is ambiguous).
  - Velocity can be estimated from speckle tracking
- Coupling between height uncertainty and varying baseline introduces azimuth phase ramp

TanDEM-X first DEM was acquired with crossing orbit method

- Along track (~200 km, 28.5 s) separation results in crossing ground-tracks due to Earth Rotation
- 0.13° relative squint required
- ~2 km resulting effective baseline
- **h_{amb} = 3.8 m**
- **Relative height accuracy in the order of 10 cm**



(October Revolution Island)

Conclusions

- **Modes with higher coverage with single satellite**
  - 8 Beam ScanSAR
    - good performance
  - 8 WideBeam ScanSAR
    - not so good performance
- **Modes for Surface Movement Estimation**
  - ATIS **0.1 ms** time separation, **single satellite**
    - ocean current measurement
  - Pursuit Monostatic **3 s** time separation, **dual satellite, special formation**
    - StripMap; 2D Velocity and rotation measurements of small targets (ships)
    - ScanSAR; 2D Velocity and rotation measurements of areas (iceberg)
  - BiDiSAR **6 s** time separation; **Single and dual satellite**
    - Scattering of different aspect angles
    - 2D Velocity measurements
  - Crossing Orbits **1 d** or **5 d** or **6 days** time separation; **Single and dual satellite**
    - Along-track variable baselines

Experimental Radar Modes with TerraSAR-X and TanDEM-X: Contacts

- **Modes with higher coverage with single satellite**
  - 8 Beam ScanSAR and 8 WideBeam ScanSAR
    - Ulrich Steinbrecher
- **Modes for Movement Estimation**
  - ATIS **0.1 ms** time separation, ocean current measurement with **single satellite**
    - Steffen Suchandt
    - Helko Breit
  - Pursuit Monostatic **3 s** time separation, **dual satellite, special formation**
    - StripMap; 2D Velocity and rotation measurements of small scatters (ships)
      - Stefan Baumgartner
    - ScanSAR; 2D Velocity and rotation measurements of areas (iceberg)
      - Rolf Scheiber
  - BiDiSAR **6 s** time separation; **Single and dual satellite**
    - Scattering of different aspect angles
    - 2D Velocity measurements
      - Josef Mittermayer
  - Crossing Orbits **1 d** or **5 d** or **6 days** time separation; **Single and dual satellite**
    - Time variable baselines
      - Steffen Wollstadt
      - Francisco Lopez-Dekker