Motion Detection Using TanDEM-X Along-Track Interferometry

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Outline

- Introduction
- Extraction of Motion Information from TanDEM-X ATI Data
- Examples
  - Land Applications
  - Marine Applications
- Conclusions

Introduction

- Space borne ATI has been shown with mono-static systems (TerraSAR-X, Radarsat-2) for traffic measurement, surface current mapping & ship detection

- Drawbacks of single-satellite ATI:
  - Short ATI baselines, i.e. low sensitivity to ground motions
  - Little flexibility in adaption to specific application
  - Aperture switching concepts reduce effective PRF / receiving channel

- Bi-static ATI with TanDEM-X:
  - Baseline is adjustable over a wide range
  - ATI *and* high effective PRF realizable (important for GMTI)
  - Multiple ATI baselines possible through alternating bi-static mode or through combination with dual-receive antenna (DRA) mode

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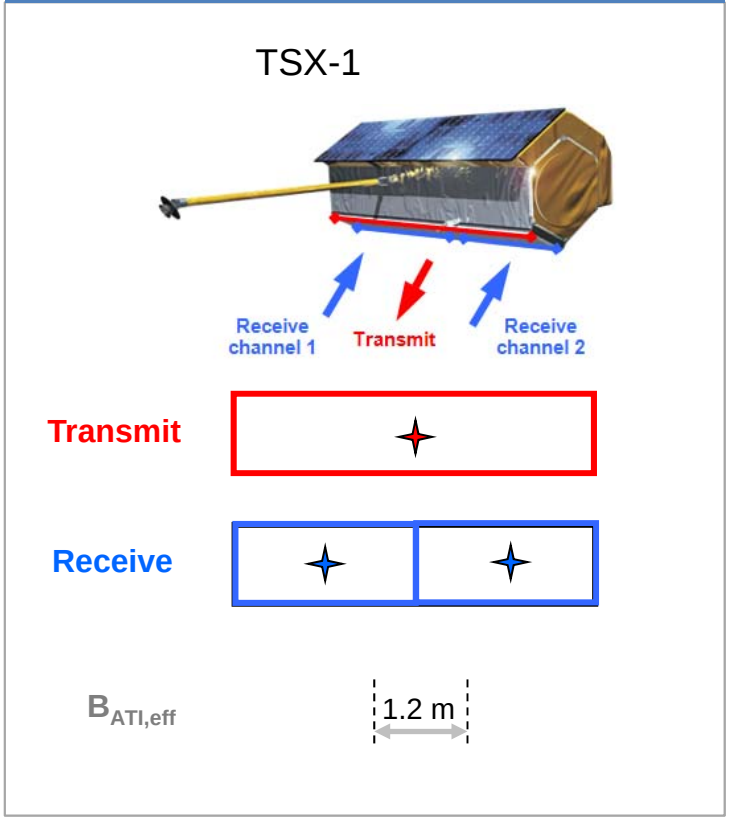
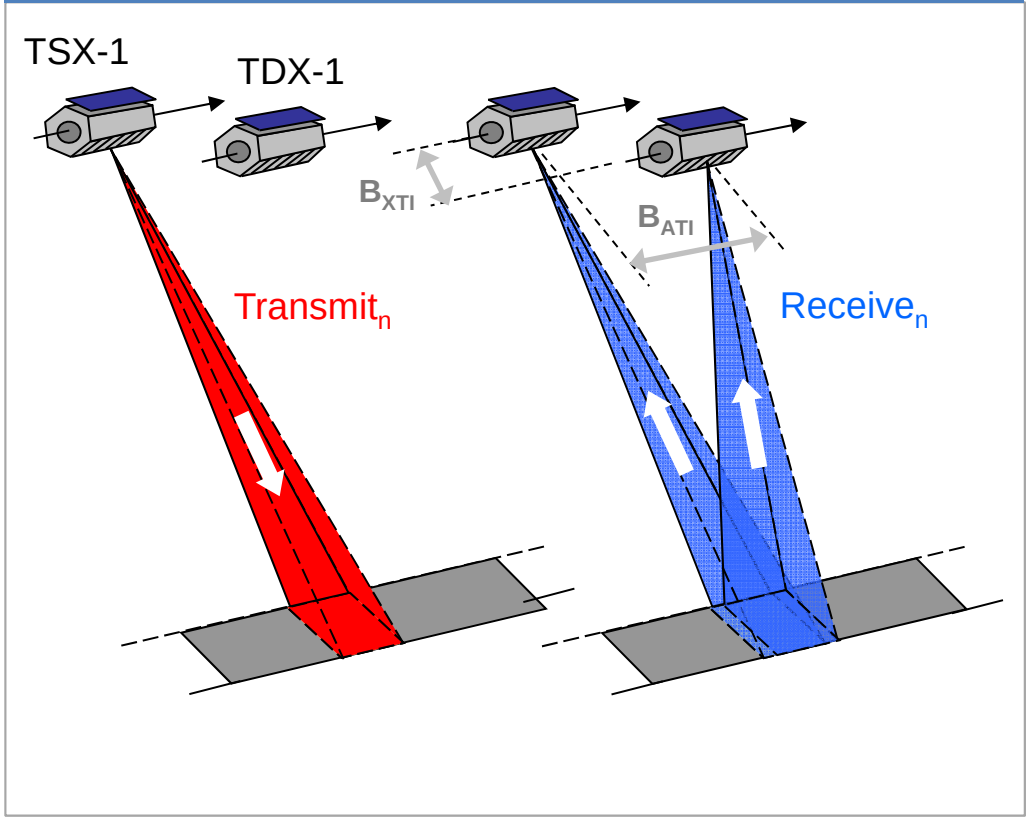
TerraSAR-X / TanDEM-X Along-Track Interferometry

TerraSAR-X: Mono-static



TanDEM-X: Bi-static, Transmitter/Receiver separated



- ATI baseline in the order of 1 m

- Large ATI baselines (e.g. 50 m) → highly sensitive even to motions that significantly deviate from line-of-sight
- Phase contributions from motion and topography

ATI phase: $\phi_{ATI} = \frac{4\pi \cdot B_{ATI,eff}}{\lambda \cdot v_s} v_g \cdot \sin\theta$

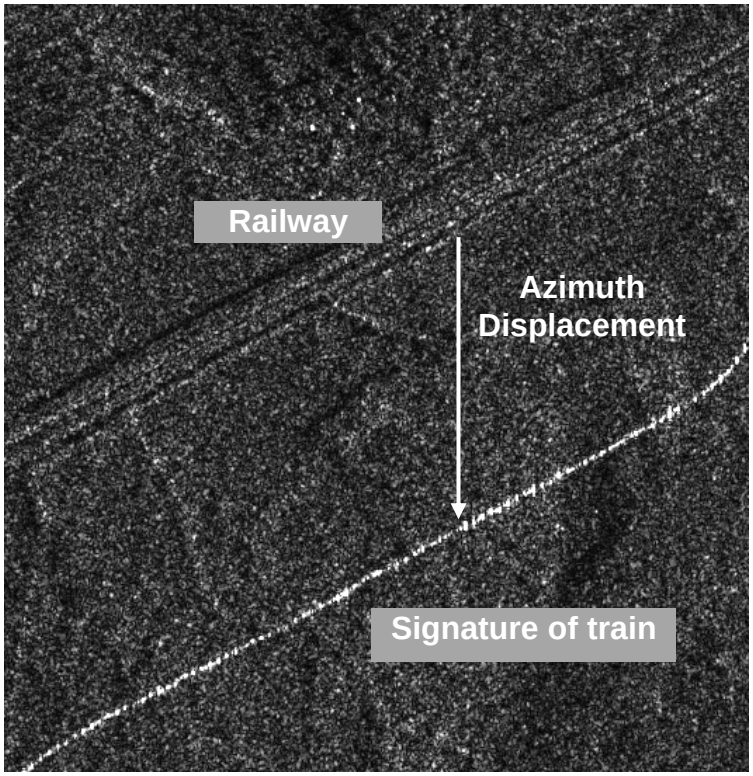
TanDEM-X: Interferometric Phase of Moving Objects (1)

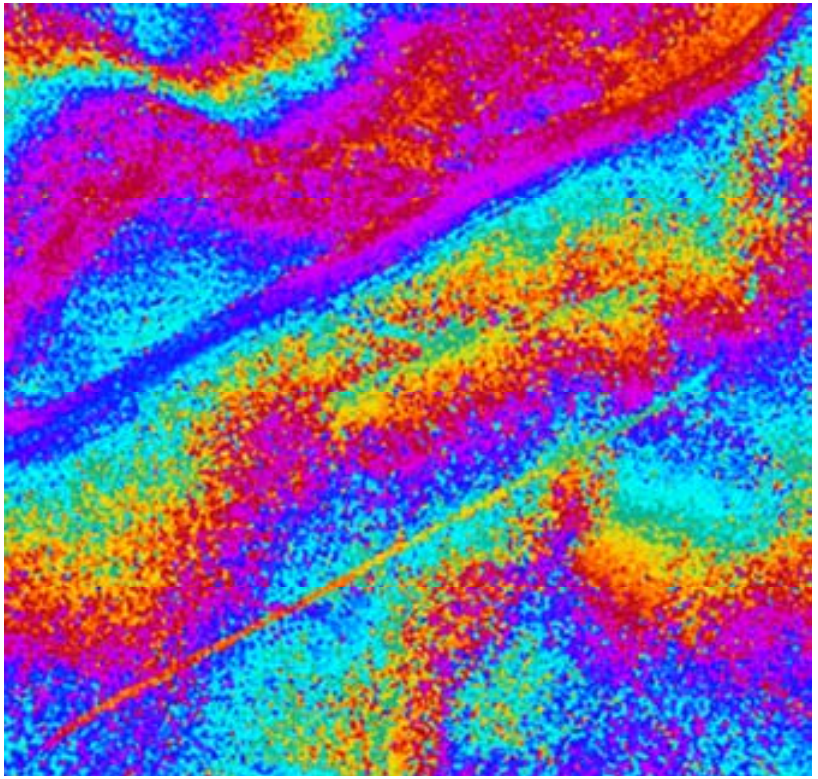
SAR Amplitude

Interferogram Phase

Flight direction

Look direction





TanDEM-X, 13.08.11, Siberia. B_{ATI}=136m, B_{XTI} = 133m

Phase at moving target position:

$$\phi_M = f\left(\phi_{ATI}, \phi_{XTI,displ}, \phi_{XTI,true}, SCR_{displ}\right)$$

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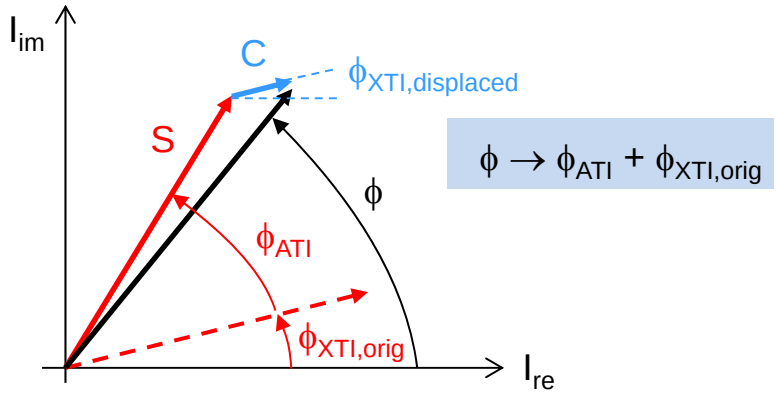
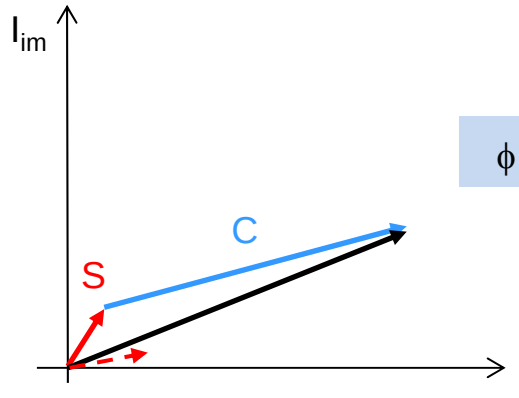
TanDEM-X Interferometric Phase of Moving Objects (2)

$\phi_{XTI,orig} \cong \phi_{XTI,displaced}$, SCR > 1



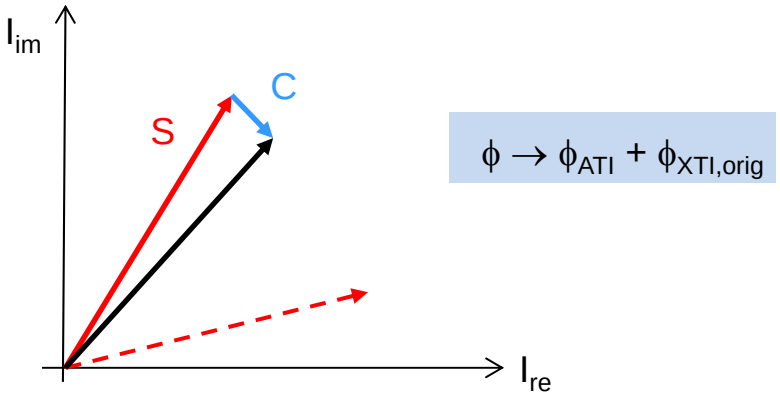
$\phi \rightarrow \phi_{ATI} + \phi_{XTI,orig}$

$\phi_{XTI,orig} \cong \phi_{XTI,displaced}$, SCR < 1



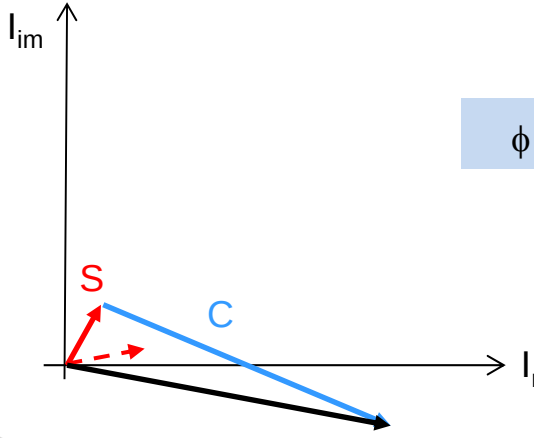
$\phi \rightarrow \phi_{XTI,displaced}$

$\phi_{XTI,orig} \neq \phi_{XTI,displaced}$, SCR > 1



$\phi \rightarrow \phi_{ATI} + \phi_{XTI,orig}$

$\phi_{XTI,orig} \neq \phi_{XTI,displaced}$, SCR < 1



$\phi \rightarrow \phi_{XTI,displaced}$

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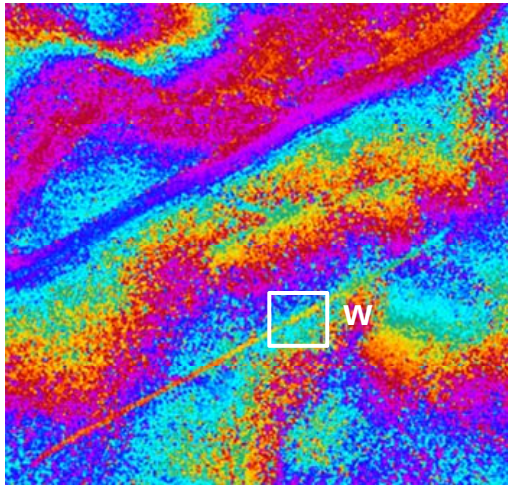
TanDEM-X Interferometric Phase of Moving Objects (3)

- ATI phase is recoverable for
  - Areas with constant elevation and/or
  - Small XT baselines

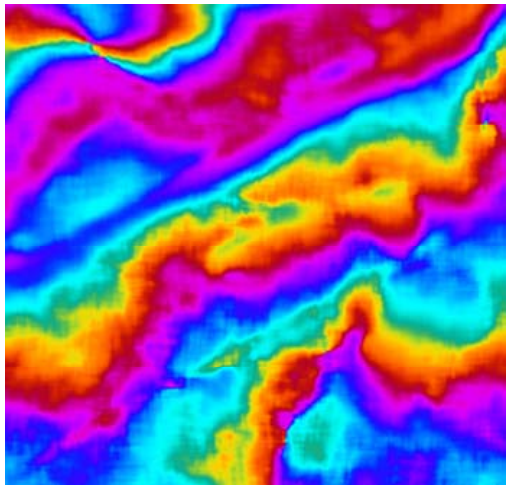
- A motion related phase, suitable for detection, can be extracted by
  - Local estimation & compensation of XTI phase
  - Subtraction of high-precision DEM

Extraction of Motion Phase by Sliding Window Operation

Original interferogram $\underline{I}$

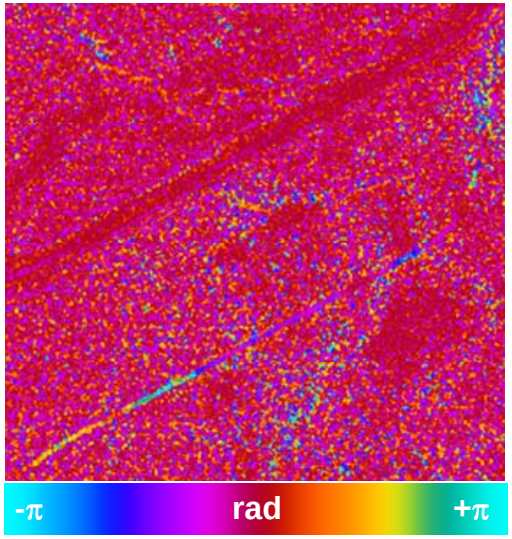


Estimated XTI phase



$$\hat{\phi}_{XTI,displaced}(m,n) = \frac{1}{w^2}\sum_{k=m-w/2}^{m+w/2}\sum_{l=n-w/2}^{n+w/2}\arg\{\underline{I}(k,l)\cdot e^{-j\phi_{flat}(k,l)}\} \quad | \; k \neq m, l \neq n$$

Motion phase



$$\hat{\phi}_{motion} = \arg\{\underline{I}\cdot e^{-j\hat{\phi}_{XTI,displaced}}\cdot e^{-j\phi_{flat}}\}$$

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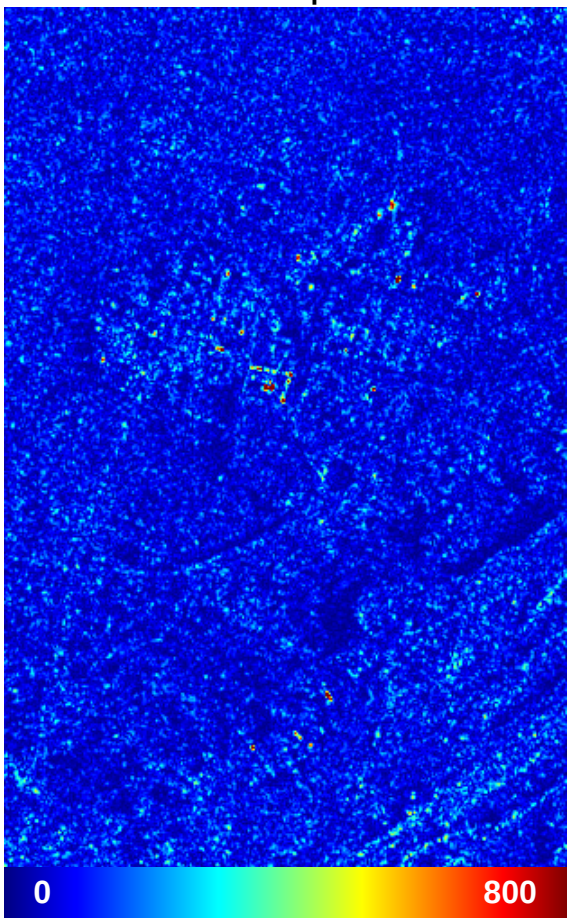
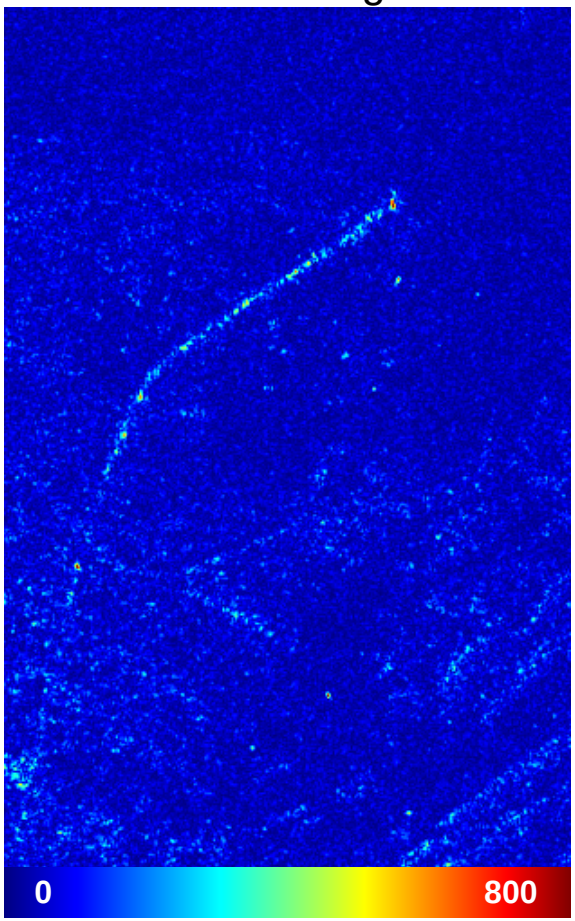
Clutter Suppression in TanDEM-X Data via DPCA

SAR amplitude



DPCA image



Coherence

$$D = \underline{S}_1 \cdot e^{-j\phi_{flat}} \cdot e^{-j\hat{\phi}_{XTI,displaced}} - \underline{S}_2$$

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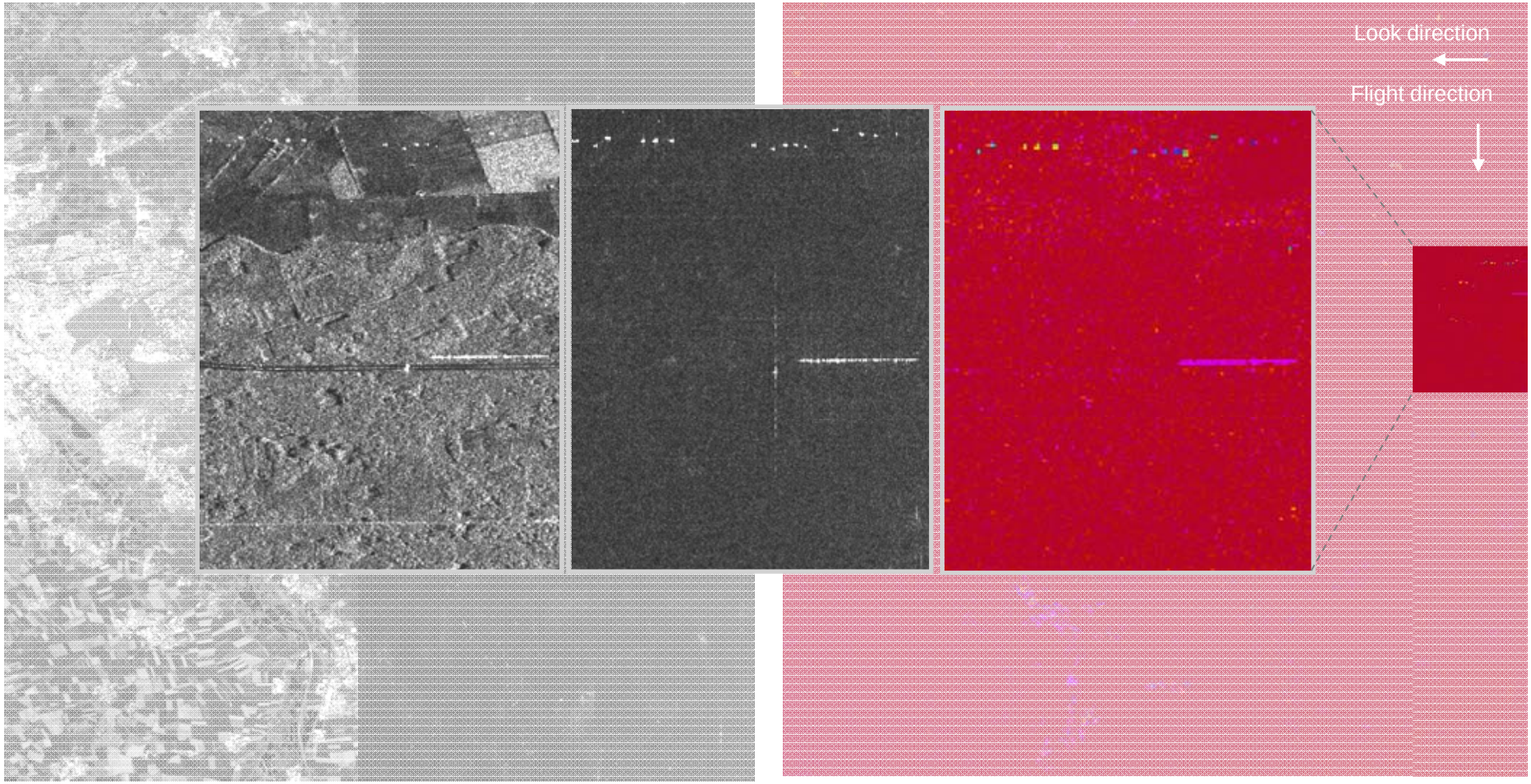
TanDEM-X ATI Data of Moving Vehicles, Hannover, Germany

Amplitude | Monostatic-Bistatic (DPCA) | Offset-corrected, hybrid interferometric phase



0 255

-180 deg +180

B_{XTI_eff} = 2.6 m, $h_{2\pi}$ = 11000 m, B_{ATI_eff} = 204 m, $v_{2\pi}$ = 0.58 m/s

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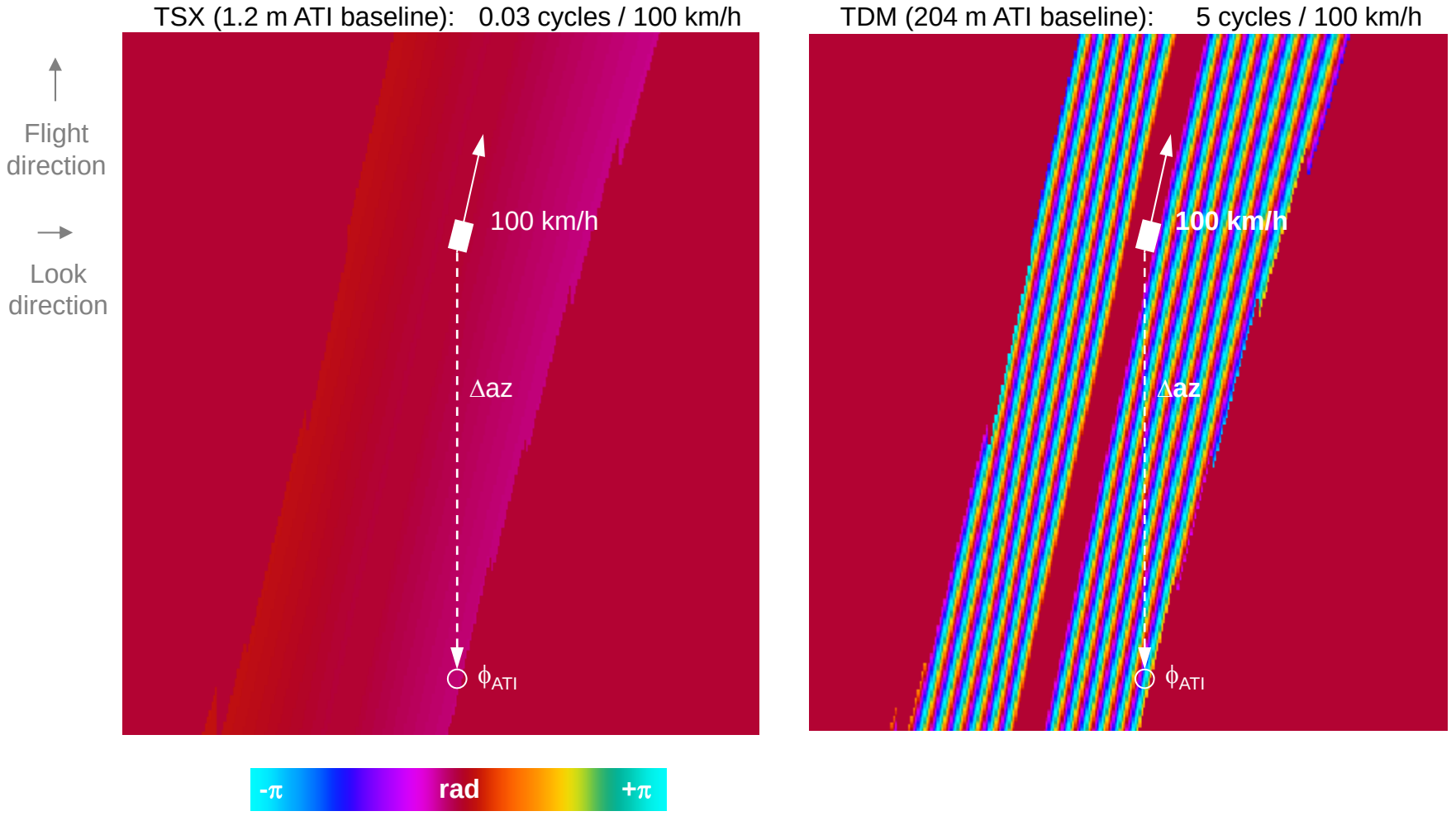
Near Along-Track Motion: ATI Phase Simulation



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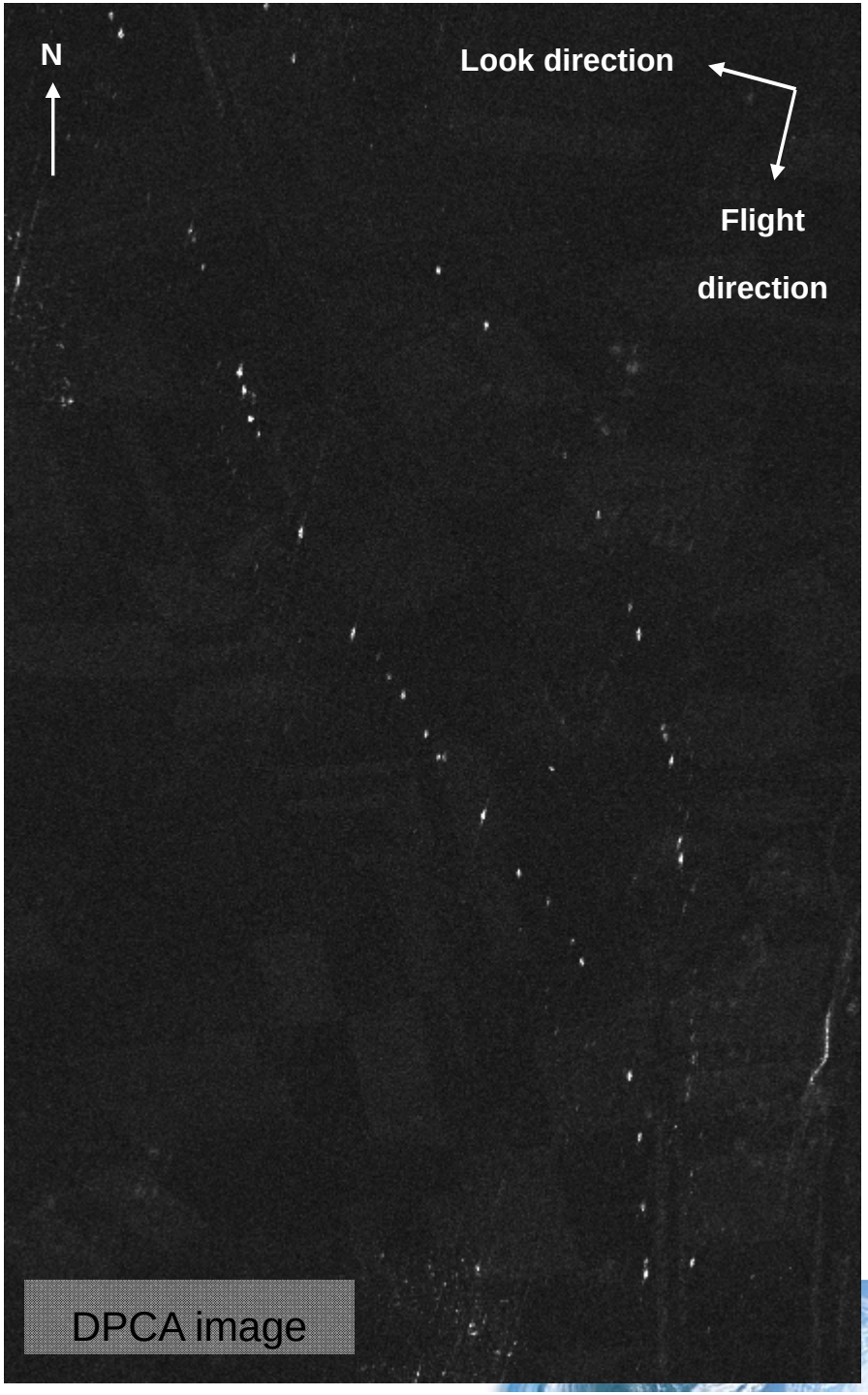
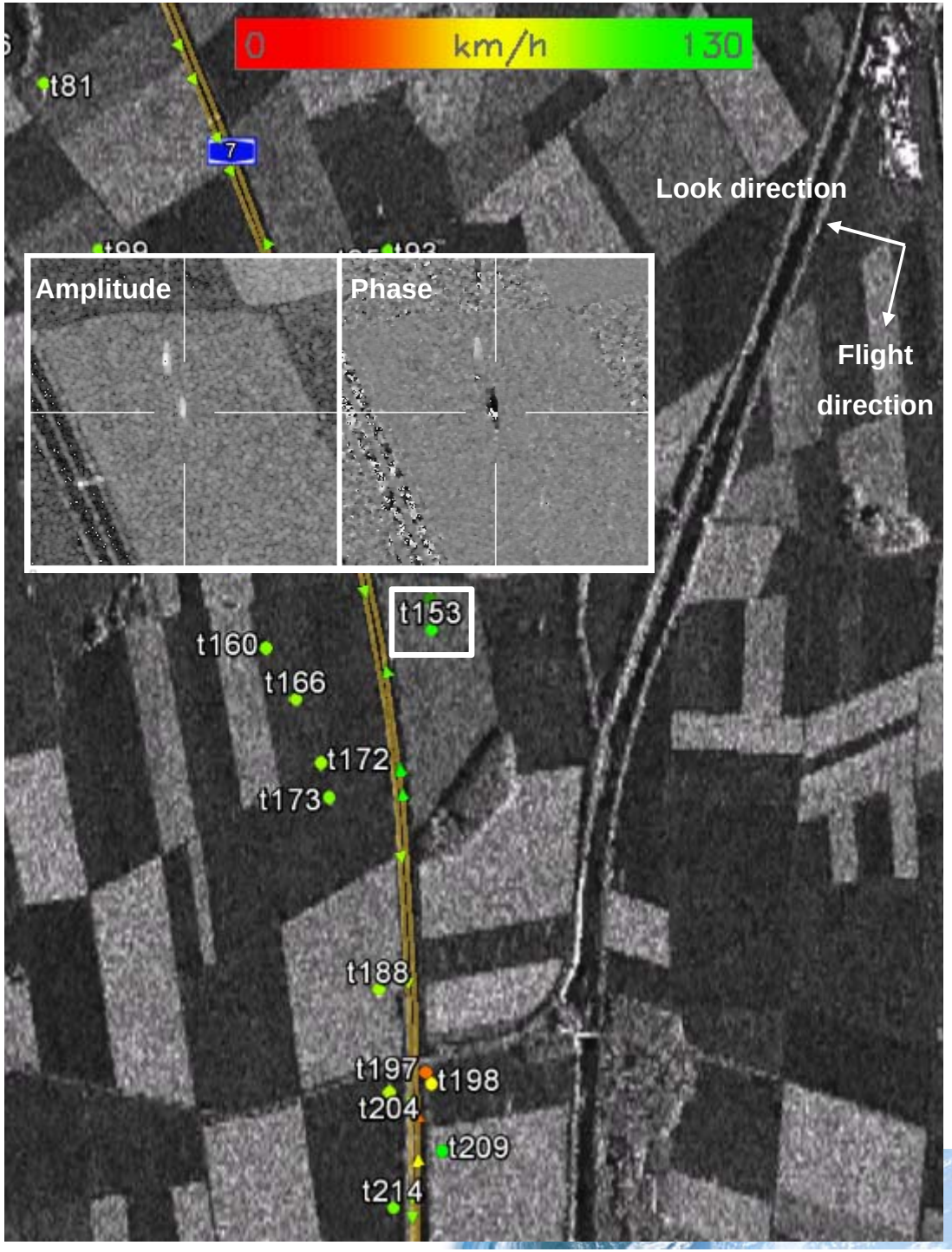


Example: Detection of Near Along-Track Motion by ATI / DPCA

Data: Hannover, Motorway A7, 22.6.2011

B_{XTI_eff} = 2.6 m, $h_{2\pi}$ = 11000 m,

B_{ATI_eff} = 204 m, $v_{2\pi}$ = 0.58 m/s



Automatic Detection of Near Along-Track Motion

- A large ATI baseline allows to **detect objects with very small LOS motion components** by means of multi-channel techniques (ATI, DPCA)
- Applications: **detection of traffic congestions** and **<u>near</u> along-track motion**
- ATI phase used for detection
- Velocity estimates can be obtained from FM rate, Doppler shift and azimuth displacement analysis of detected objects

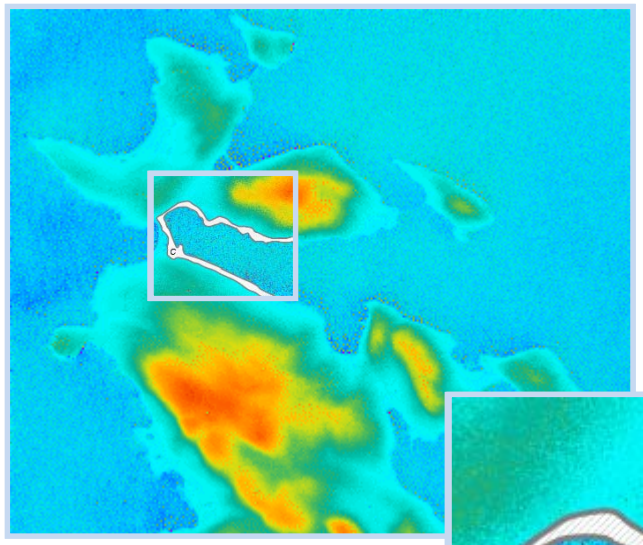
Data: Hannover, Motorway, A7, 22.6.2011

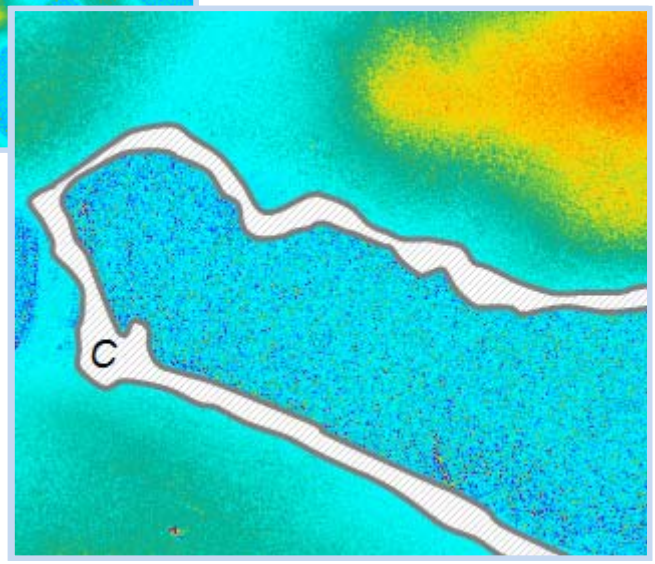
B_{XTI_eff} = 2.6 m, $h_{2\pi}$ = 11000 m,

B_{ATI_eff} = 204 m, $v_{2\pi}$ = 0.58 m/s

ATI Phase Extraction for Marine Applications

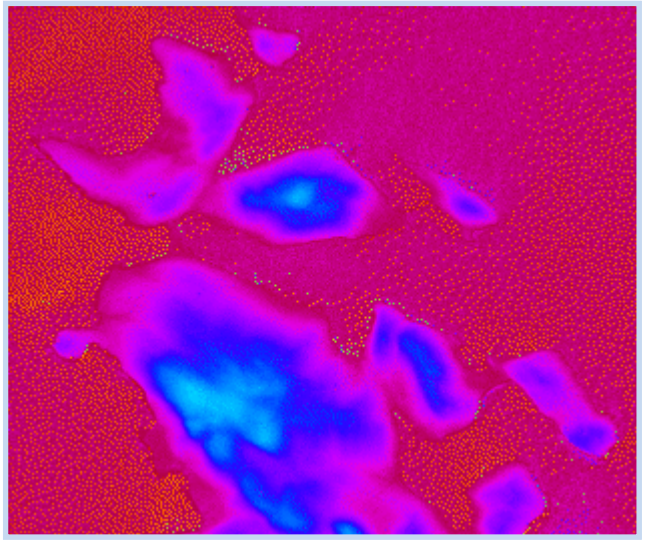
Hybrid interferometric phase





$$\hat{\phi}_m = \arg\{\underline{I} \cdot e^{-j\hat{\phi}_c} \cdot e^{-j\phi_{flat}}\}$$

Offset-corrected phase



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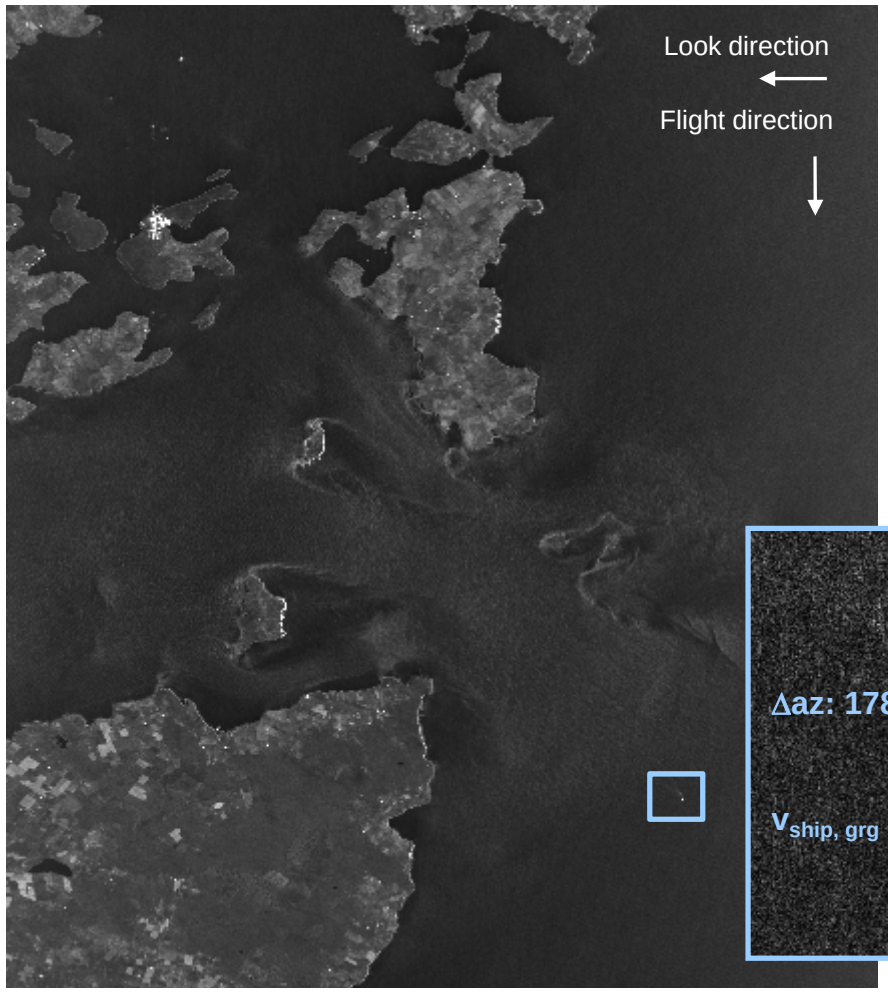
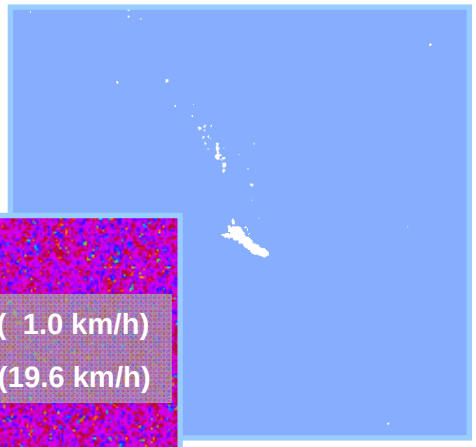
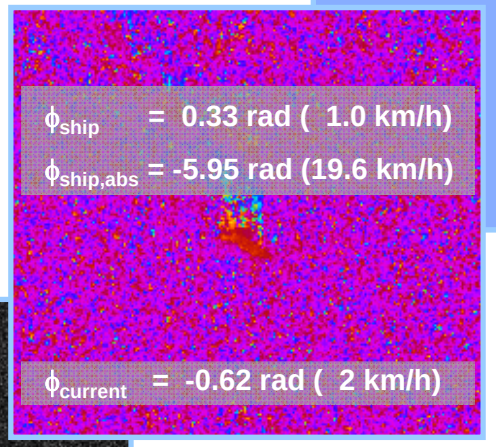
Example: Ship Detection & Measurement with TanDEM-X ATI



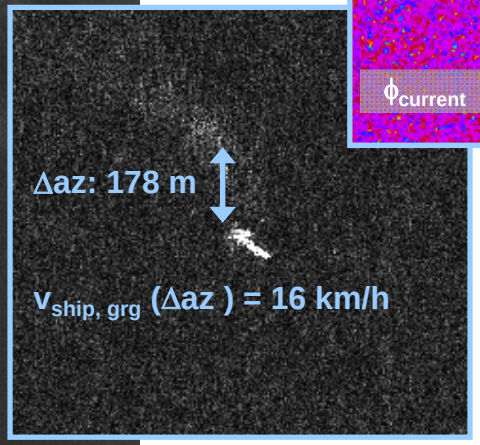
CFAR detection



Corrected phase



SLC



$v_{ship, grg}(\phi) = v_{ship,abs} - v_{current}$

$v_{ship, grg}(\phi) = 17.6$ km/h

Date: 19.03.12 $B_{ATI\_eff} = 41.1$ m $v_{2\pi} = 2.9$ m/s

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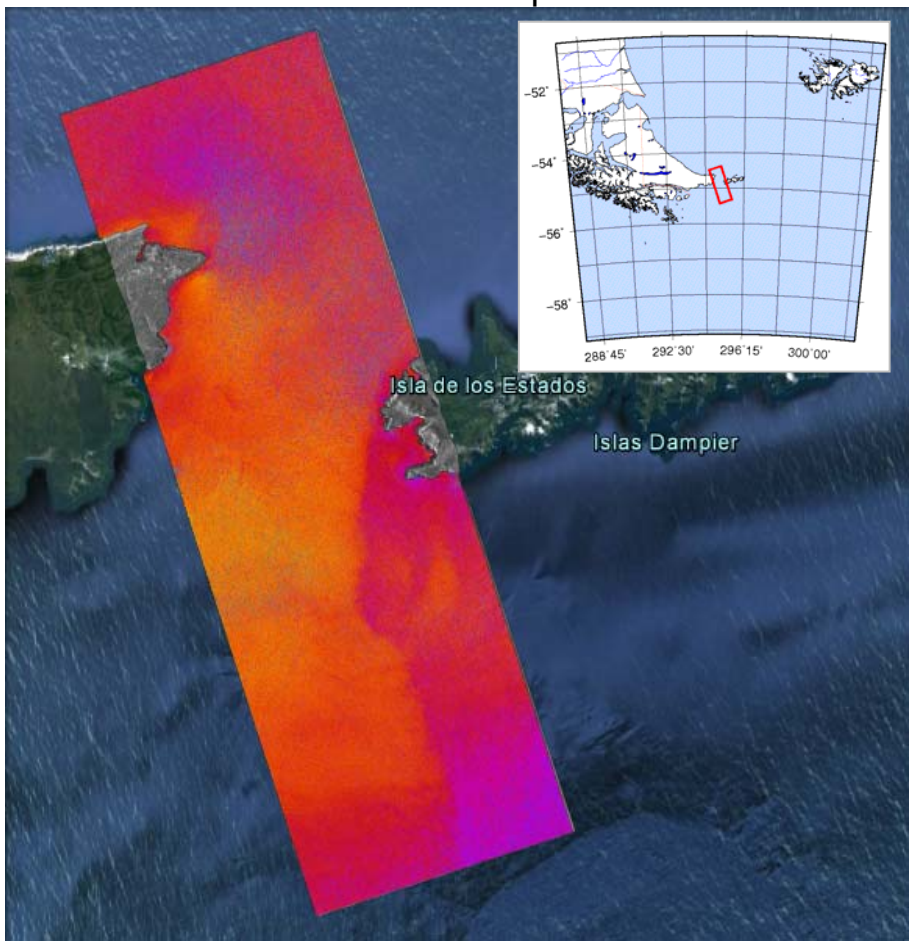
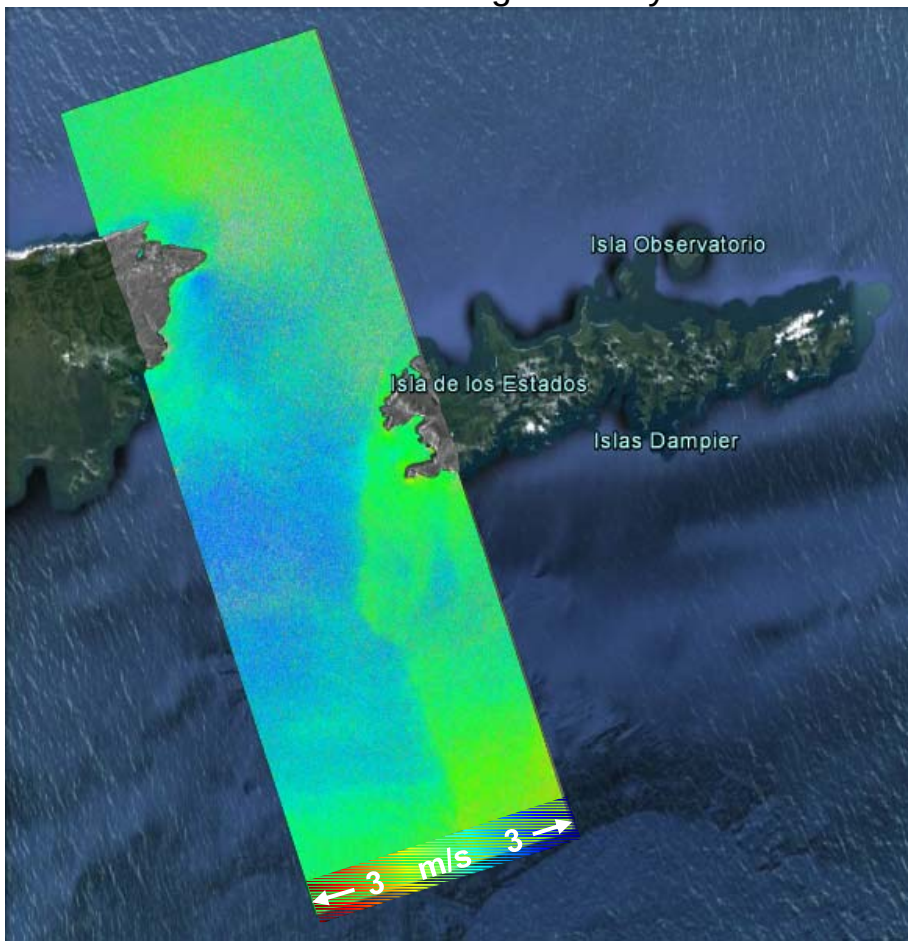
Tidal Current Mapping: Le Maire Strait, Argentina

Offset-corrected phase



-180 deg +180

Ground-range velocity



Date: 26.02.12 B_{ATI_eff} = 26.3 m $v_{2\pi}$ = 4.6 m/s

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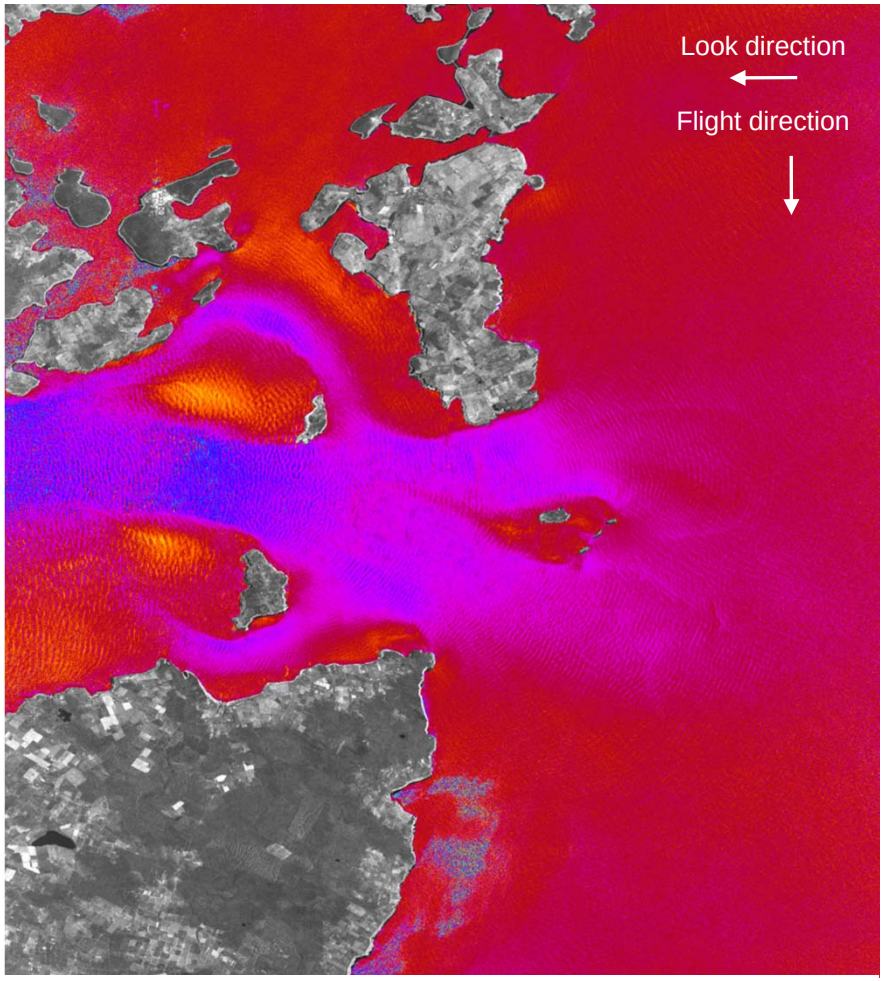
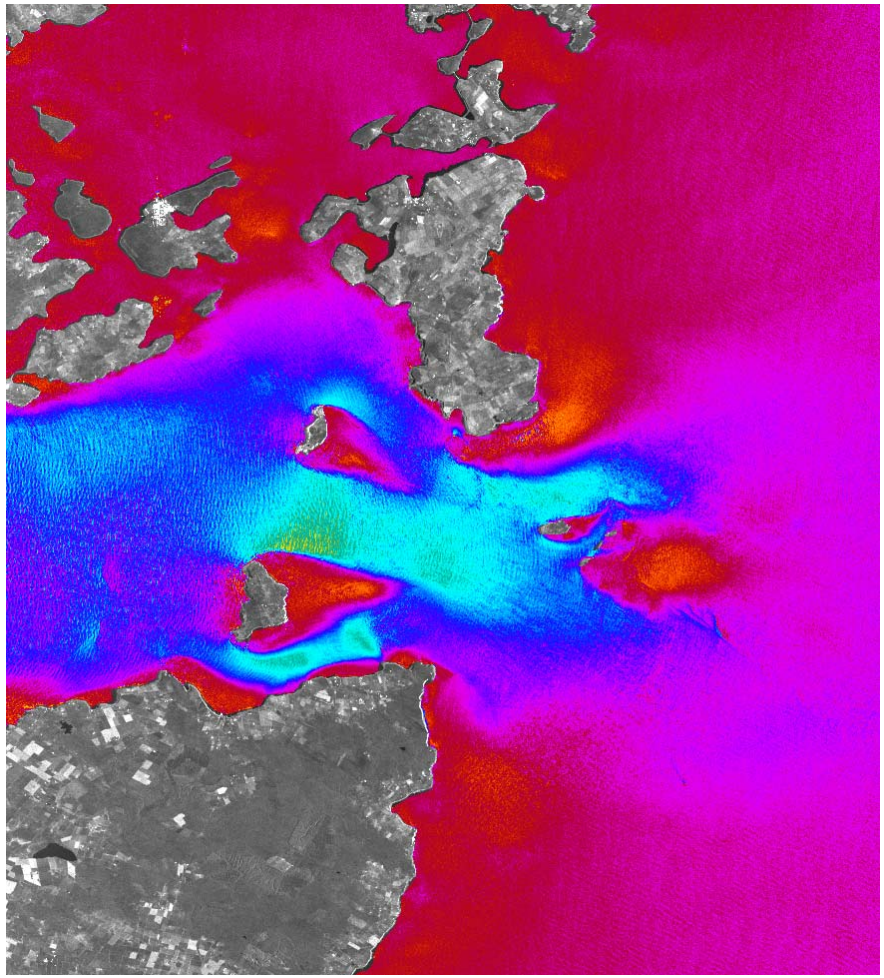
Tidal Current Mapping, Pentland Firth: Interferometric Phase



Date: 26.02.12 B_{ATI_eff} = 25.1 m $v_{2\pi}$ = -4.8 m/s



Date: 19.03.12 B_{ATI_eff} = 41.1 m $v_{2\pi}$ = 2.9 m/s

-180 deg +180

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Conclusions & Outlook

- The flexibility of the TanDEM-X interferometer and the high sensitivity to ground motions offer new possibilities for ground motion measurement by means of ATI techniques
- A large ATI baseline and high motion sensitivity enable the detection of even near-along-track motions. Applications like traffic measurement due benefit from this as the range of detectable motion directions is increased.
- Algorithms for ATI motion detection with TanDEM-X are currently integrated in the TerraSAR-X traffic processor (TTP)
- Ocean surface currents can be mapped with an unprecedented combination of wide coverage and high-resolution.

Thank you for your attention!

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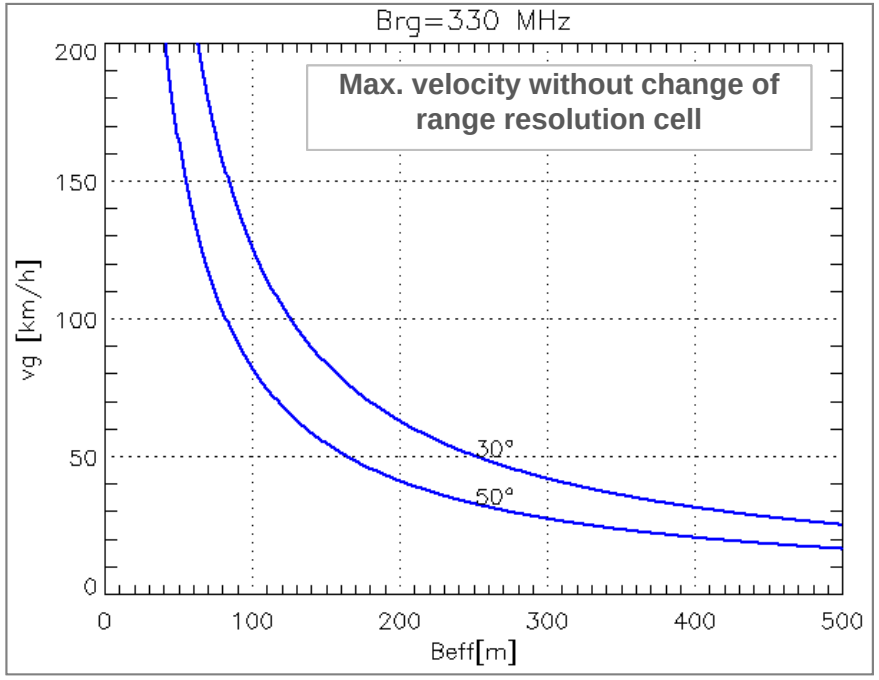
TanDEM-X ATI: Baseline Length and Maximum Velocity



Note: water surfaces & vegetation can de-correlate at significantly shorter ATI baselines (time lags)!

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