Ship Detection and Motion Parameter Estimation with TanDEM-X in Large Along-Track Baseline Configuration

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TerraSAR-X-Add-on for Digital Elevation Measurements

TanDEM

→ Launched on 21st June 2010

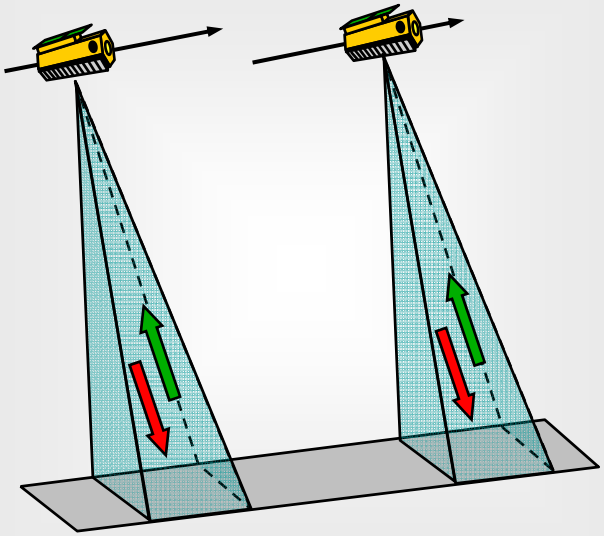
Mission Goals

- ❖ Global DEM → Level-3 standard
- ❖ Local DEMs → Level-4 like quality
- ❖ Demonstr. of innovative techniques applications
  (formation flying, bistatic acquisiton, Pol-InSAR, GMTI, ...)

DLR EADS ASTRIUM infoterra

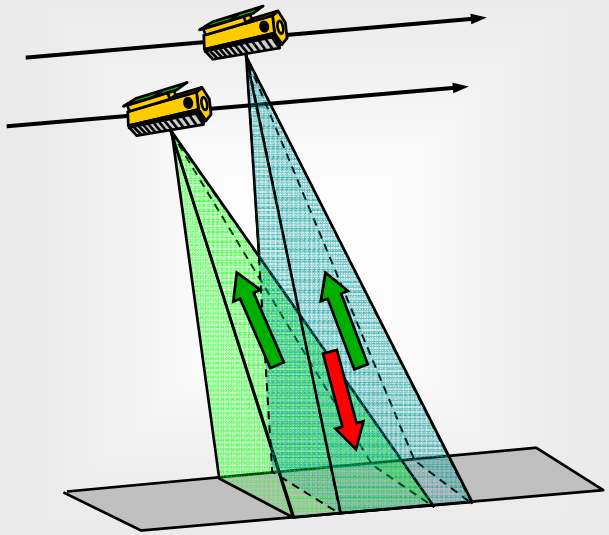
TanDEM-X Data Acquisition Modes

Pursuit Monostatic



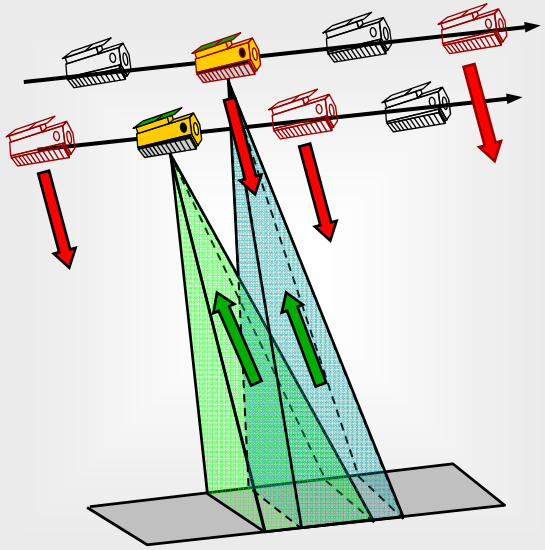
- both satellites **transmit and receive independently**
- **temporal decorrelation** & atmospheric disturbances
- **backup solution**

Bistatic



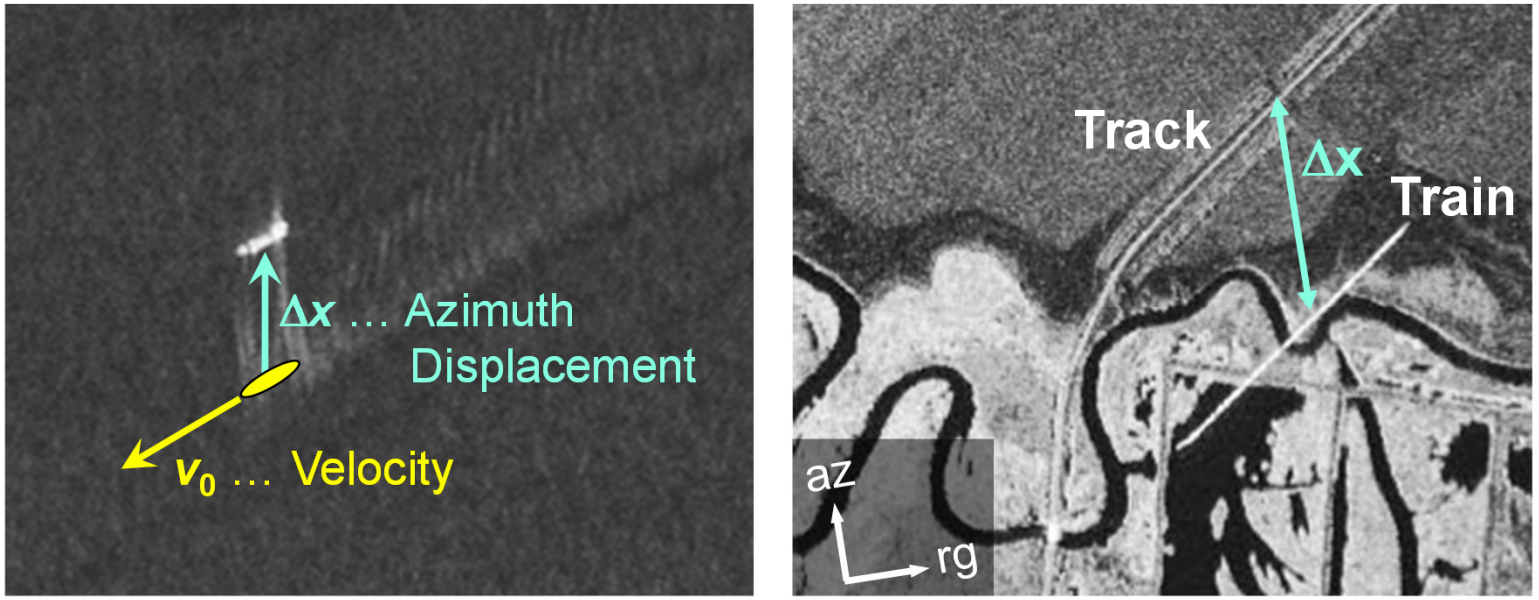
- one satellite transmits and both satellites **receive simultaneously**
- **dual use** of signal energy
- requires **synchronisation**

Alternating Bistatic



- **transmitter alternates** between PRF pulses
- provides **two baselines**
- enables synchronisation, **calibration** & verification

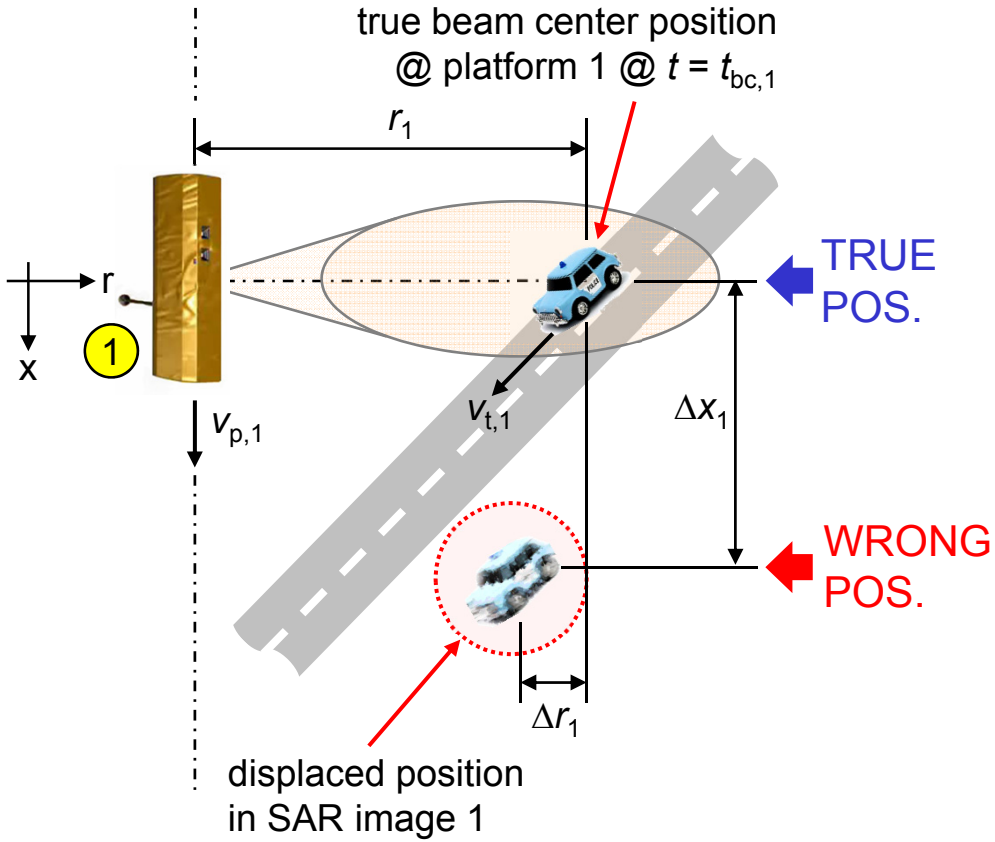
Synthetic Aperture Radar and Moving Targets



Single-channel TerraSAR-X images. Left: vessel in the Strait of Gibraltar; right: train near Wolgograd

- Moving targets in conventionally processed SAR images appear ...
  - Displaced from their true positions
    - Large azimuth displacement (slow ship → up to 600 m; fast car → up to 2 km and more)
    - Small range displacement (≤ 5 m for line-of-sight velocites ≤ 100 km/h)
    - Reason: Doppler shift due to across-track velocity
  - Blurred in azimuth direction
    - Reason: Along-track velocity and across-track acceleration

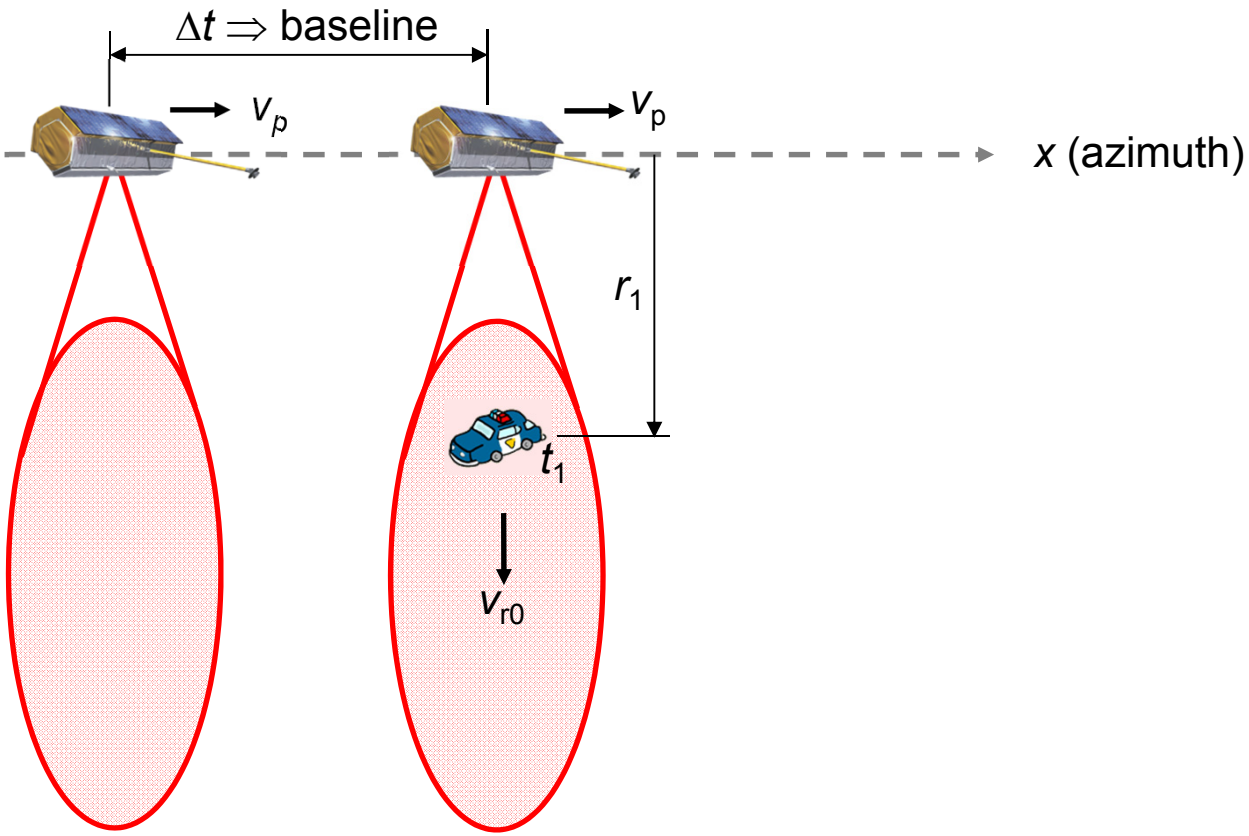
Ground Moving Target Indication (GMTI)



- Objectives of GMTI
  - Detection (at „wrong“ position!)
  - Parameter estimation
    - „true“ position
    - absolute velocity
    - moving direction

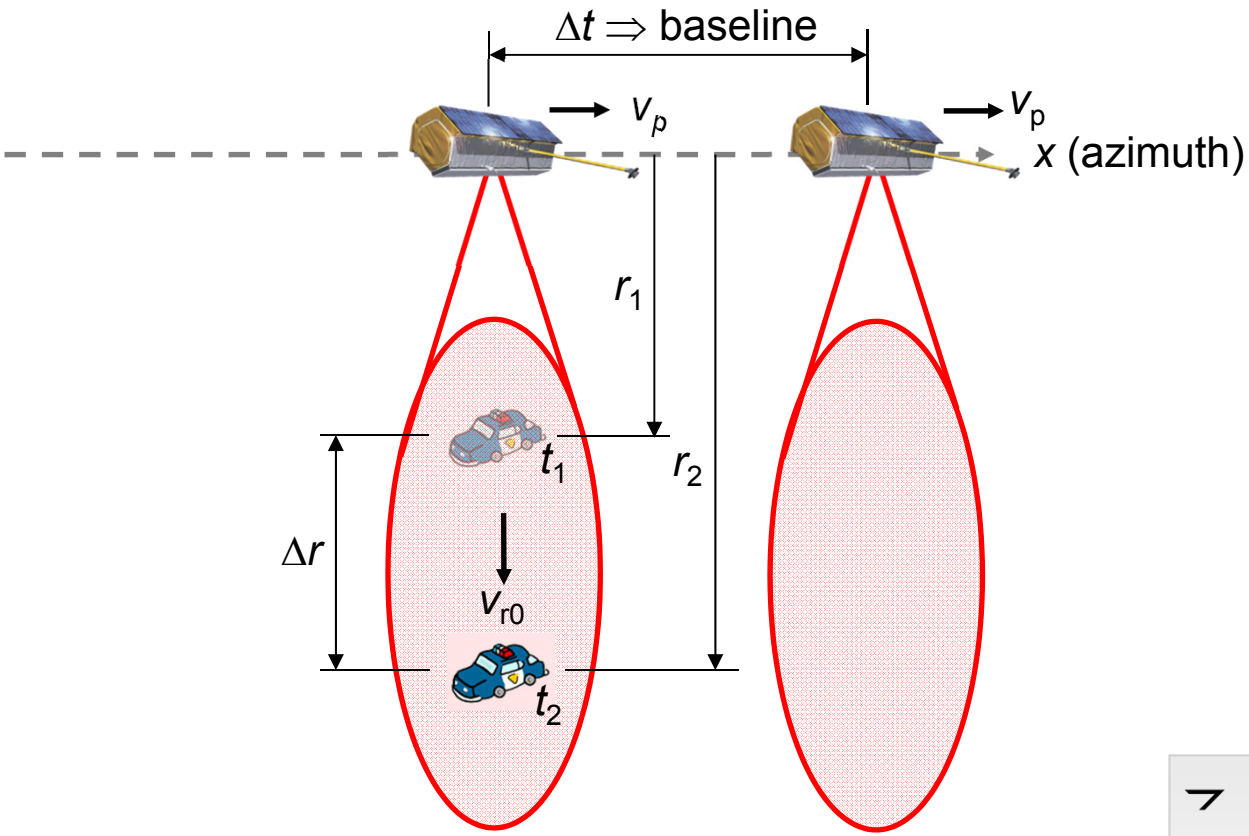
- Spaceborne GMTI so far ..
  - Single platform
  - Along-track interferometry
    (→ small baseline)
  - A priori knowledge-based GMTI
    (→ Road database)

Classical Along-Track Interferometry (ATI) Principle



The RX antennas are separated in flight or along-track (azimuth) direction, respectively.

Classical Along-Track Interferometry (ATI) Principle



Range Difference

$$\Delta r = r_1 - r_2 = v_{r0}\Delta t$$

Interferometric Phase

$$\Delta\phi = \frac{4\pi}{\lambda}\Delta r = \frac{4\pi}{\lambda} v_{r0}\Delta t$$

Azimuth displacement

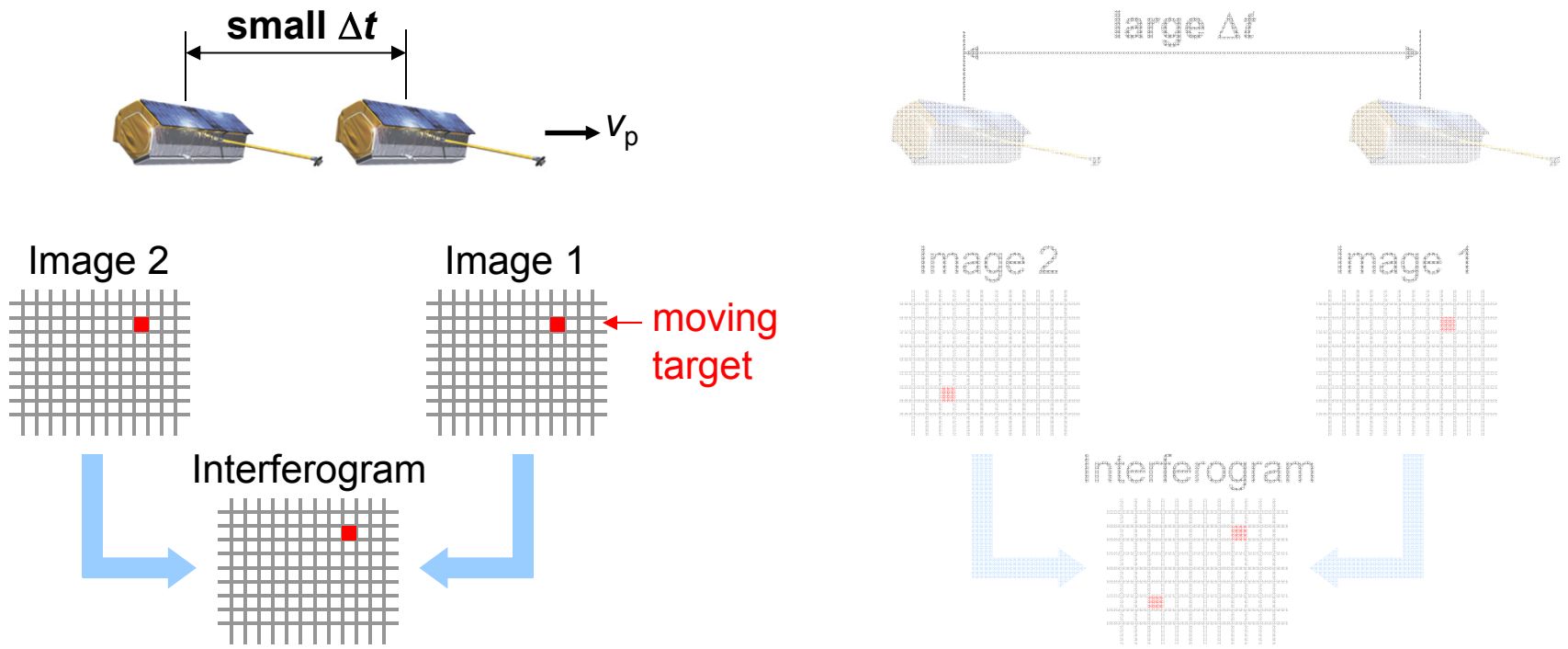
$$\Delta x \cong -r_0 \frac{v_{r0}}{v_p}$$

Δt … temporal baseline
v_{r0} … line-of-sight velocity

The RX antennas are separated in flight or along-track (azimuth) direction, respectively.

- ATI phase $\Delta\phi \rightarrow v_{r0} \rightarrow \Delta x$
- Problems: Noise + Clutter
- ⇒ Re-displacement errors (10s to 100s of meters)

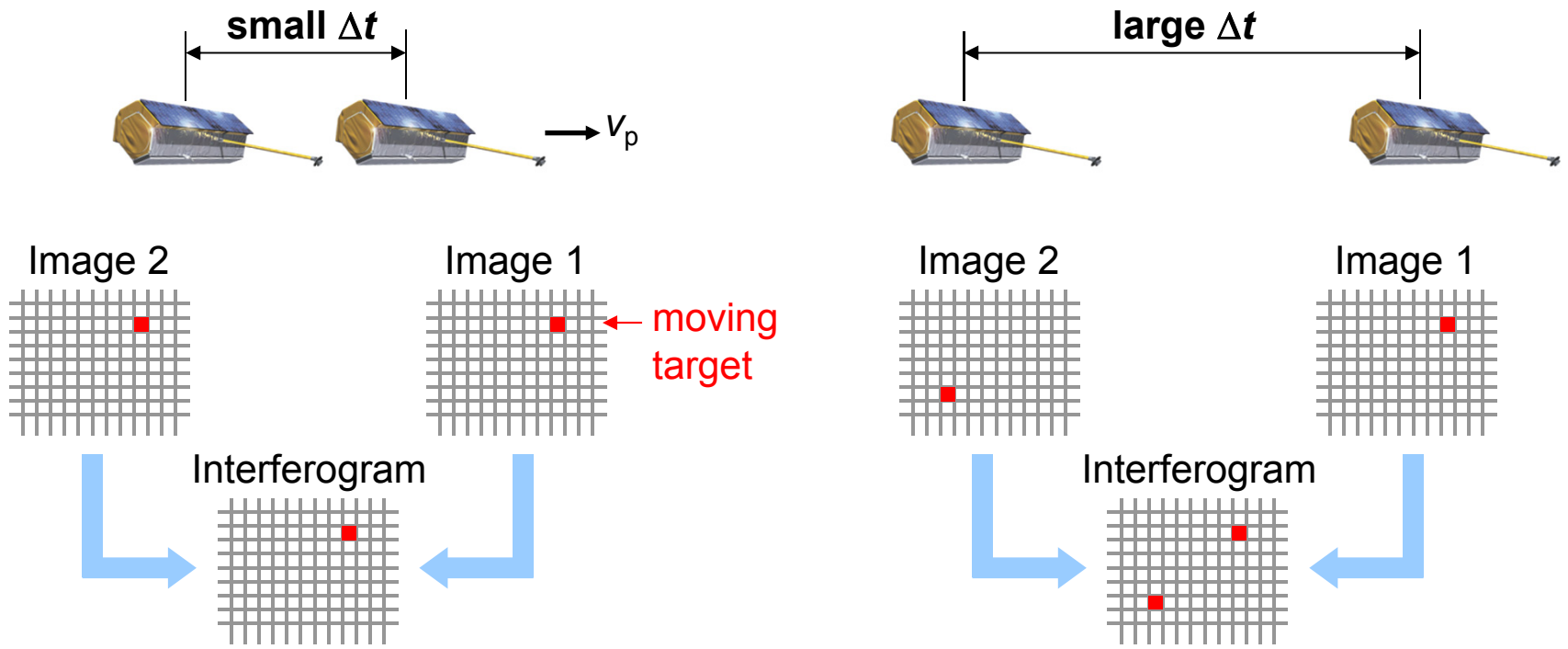
Along-Track Baseline



- Small baseline → Δt ≅ ms
  - Moving target keeps in res. cell
  - Only sensitve to v_{r0} (1D)
  - „Classical ATI“

- Large baseline → Δt ≅ s
  - Moving target leaves res. cell
  - 2D velocity estimation
  - Large-Along Track Baseline GMTI

Along-Track Baseline



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  - „Classical ATI“

- Large baseline → Δt ≅ s
  - Moving target leaves res. cell
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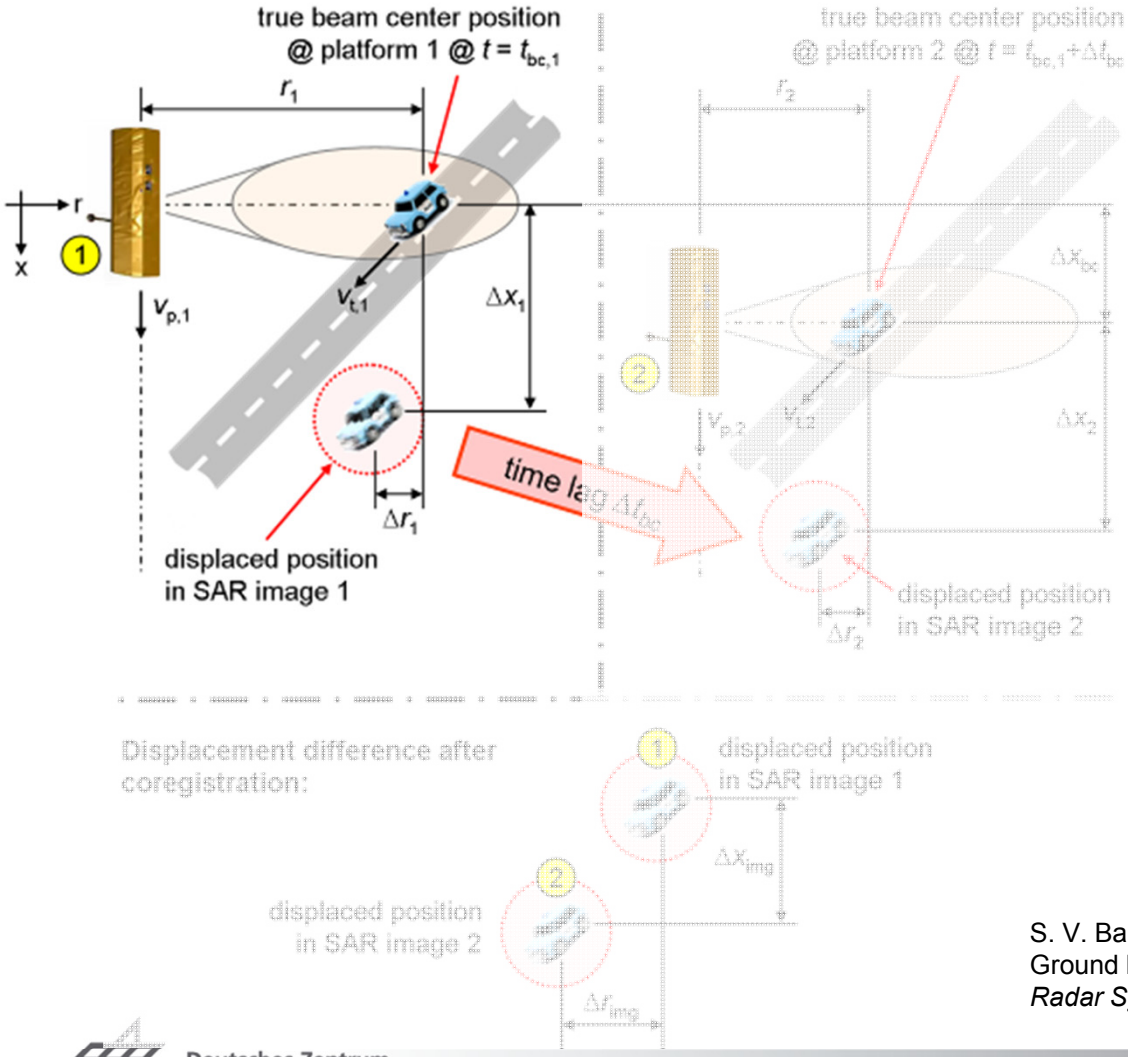
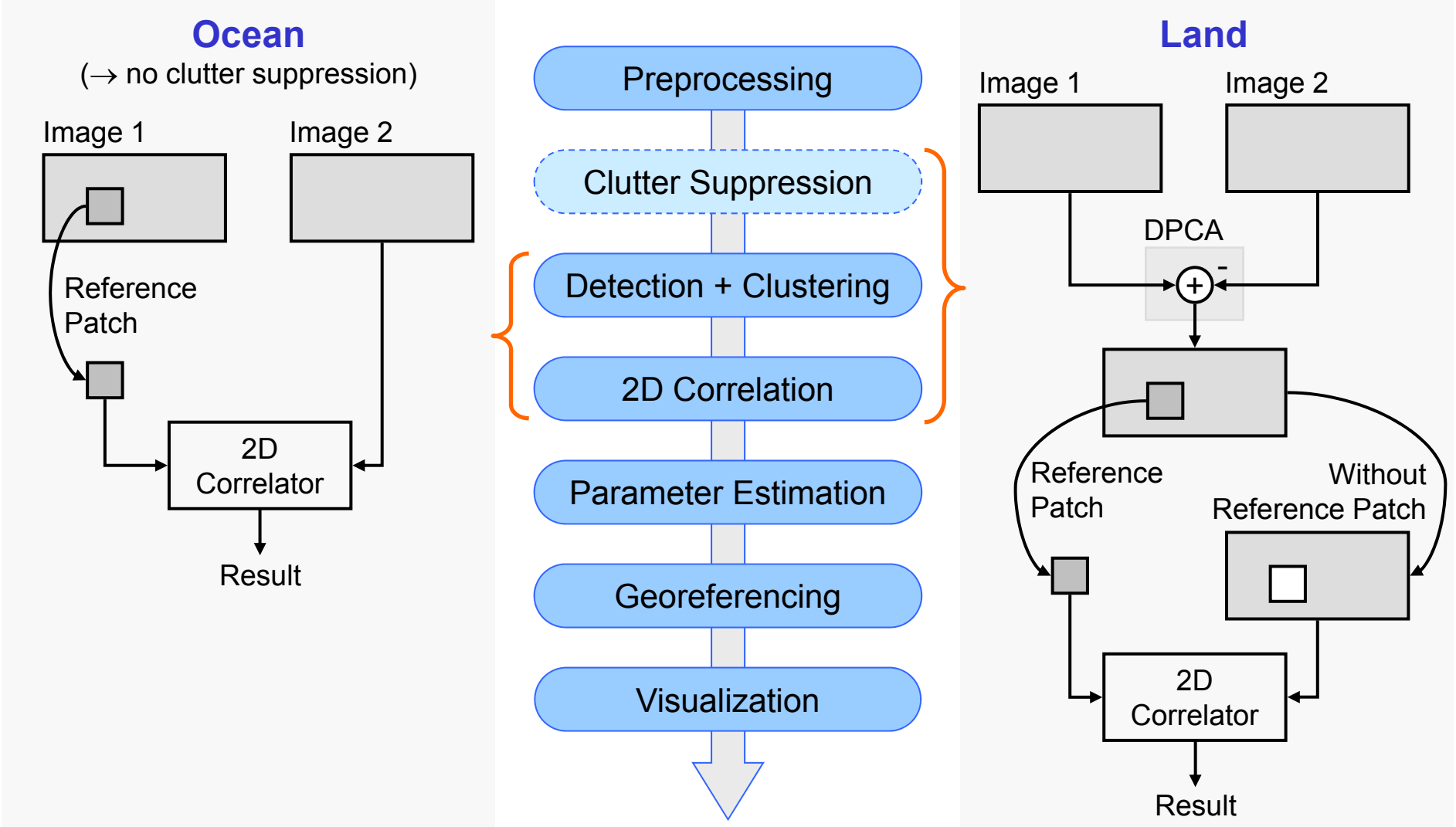
Large Along-Track Baseline GMTI → Principle



- Large along-track baseline ≅ 20 km ⇒ time lag ≅ 2.5 s
- Monostatic pursuit mode
- Moving target → displaced in both SAR images
- Displacement difference ⇒ true geographical position, velocity, heading (and acceleration)
- **No a priori knowledge required!**
- **Detection of vehicles moving on open land and open sea!**

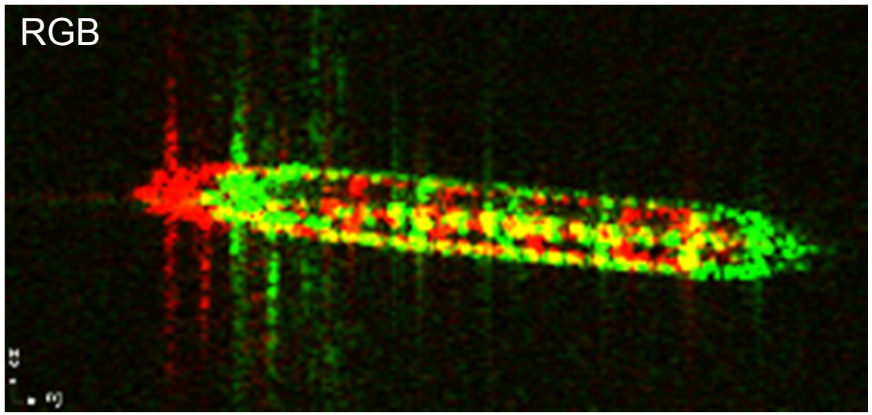
S. V. Baumgartner et al, "A Large Along-Track Baseline Approach for Ground Moving Target Indication Using TanDEM-X," in *International Radar Symposium (IRS)*, Cologne, Germany, September 2007.

Large Along-Track Baseline GMTI → Algorithm (II)



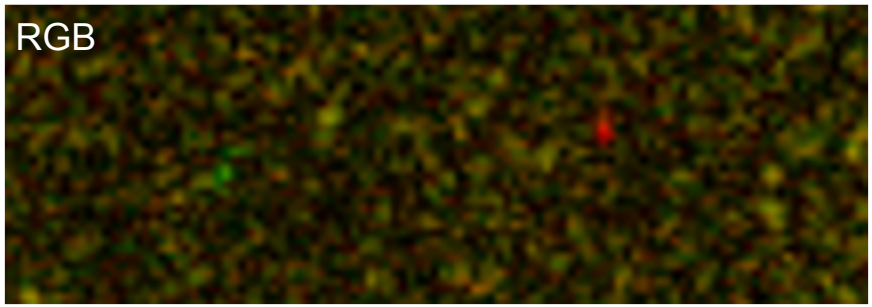
Large Along-Track Baseline GMTI → Algorithm

Ocean
(→ no clutter suppression)

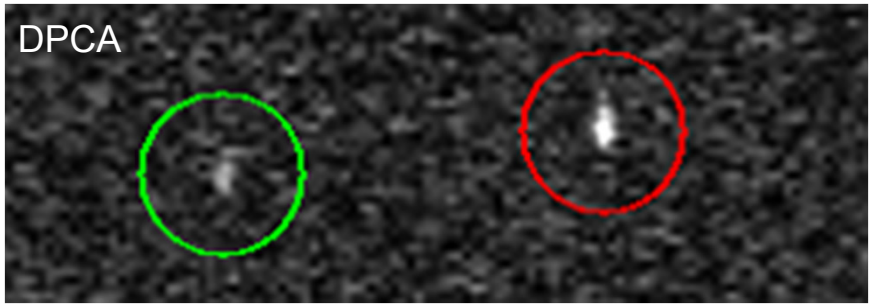


Superposition of single-channel images
red: TerraSAR-X image (fore)
green: TanDEM-X image (aft)

Land
(→ clutter suppression necessary)



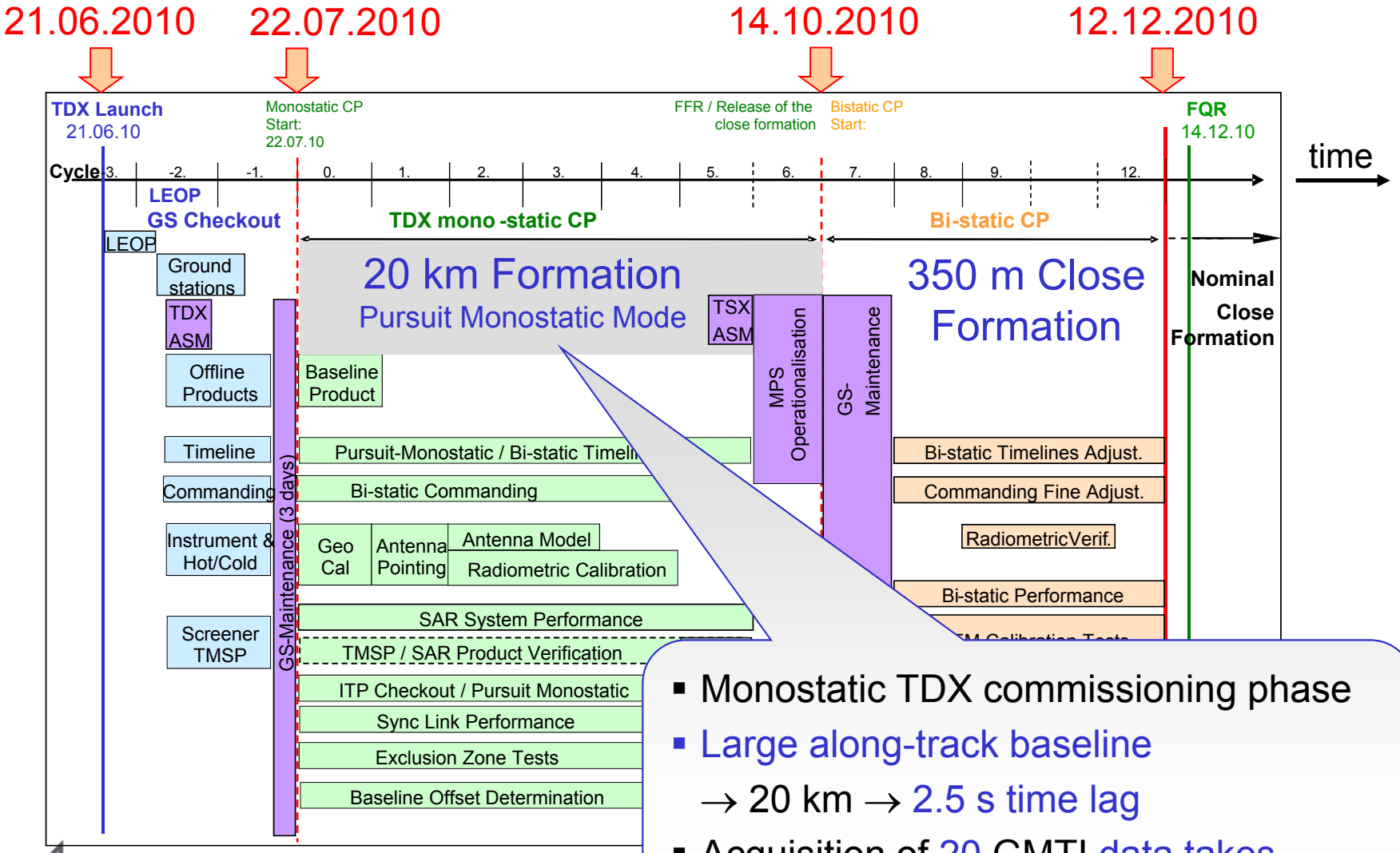
Superposition of single-channel images



Clutter-suppressed DPCA image

Experiments and First Results

Overview TanDEM-X Commissioning Phase



- Monostatic TDX commissioning phase
- Large along-track baseline
  → 20 km → 2.5 s time lag
- Acquisition of 20 GMTI data takes

Test Sites for Traffic Monitoring

Interstate 15
→ NE of Las Vegas
→ Monitoring of road vehicles
→ Low clutter contribution

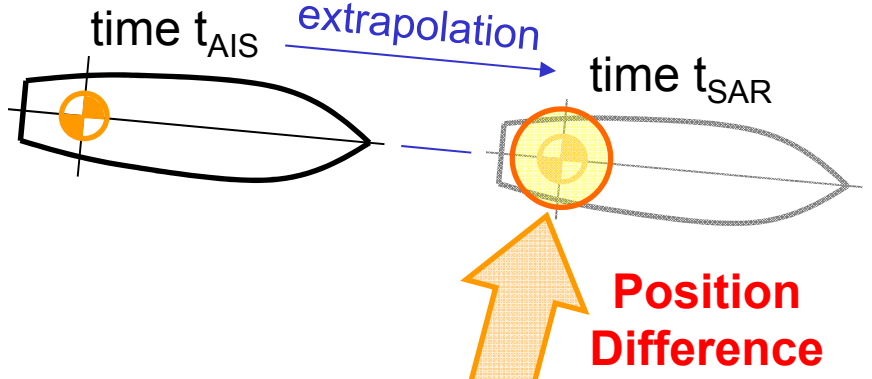
Strait of Gibraltar
→ Monitoring of ships
→ Always traffic
→ AIS data available

Verification Using AIS Data as Reference → Principle

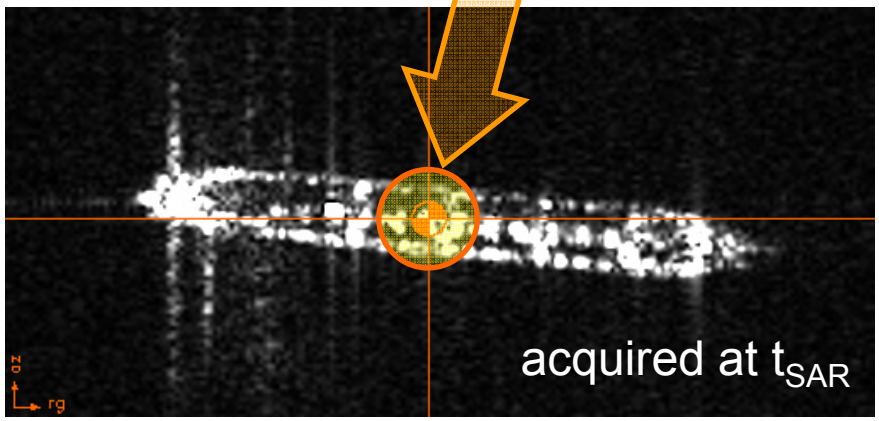
- Automatic Identification System
  - Standardized VHF transceiver
  - Ships with GT ≥ 300 tonns
  - ID, position, speed, moving dir., …
  - Available via internet (≅ real-time)

- Different acquisition times
  - $t_{AIS} \neq t_{SAR}$ (sec. → min)
  - Extrapolation of the AIS data
  - Const. velocity & head. assumed

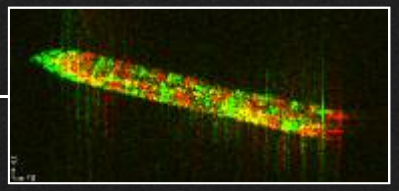
AIS: Position ⇒ GPS antenna / AIS



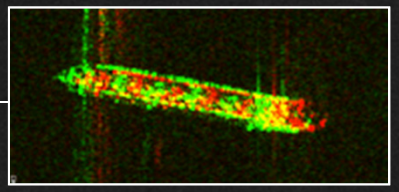
SAR: Area centroid ⇒ geocoded position



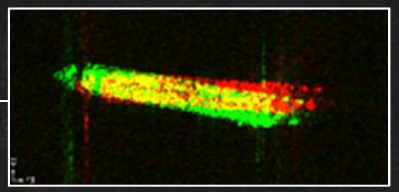
First Results: Vessel Monitoring in the Strait of Gibraltar



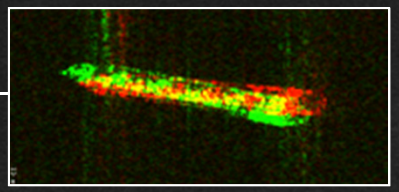
Coordinates:
35.949 N, -5.712 E
Velocity:
16.7 kn



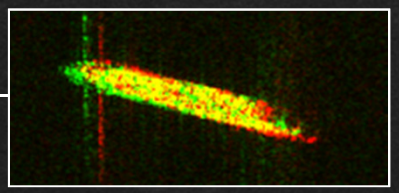
Coordinates:
35.953 N, -5.704 E
Velocity:
9.5 kn



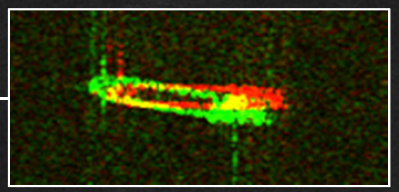
Coordinates:
35.960 N, -5.694 E
Velocity:
12.7 kn



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



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

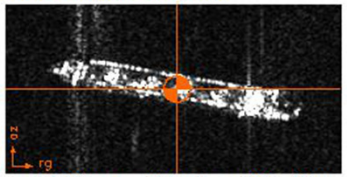


Coordinates:
35.963 N, -5.657 E
Velocity:
9.8 kn

Measured SAR-GMTI Data

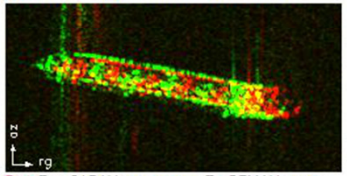
Target ID:	4
Latitude:	35.9530°
Longitude:	-5.7040°
Speed:	9.5 kn
Acceleration:	0.00 m/s²
Heading:	276.9°
Detected At:	2010-09-07T18:23:04.41Z

Detected Original Image



TerraSAR-X image, patch size (rg x az): 203 x 102 px.
The circle marks the pixel considered for geocoding.

Color Composite of Both Images



Red: TerraSAR-X image; green: TanDEM-X image.

Diff. to Closest AIS Reference Data

Absolute Position Difference:	55.8 m
Easting Position Difference:	-55.7 m
Northing Position Difference:	2.9 m
Speed Difference:	0.2 kn
Heading Difference:	4.9°
Observation Time Difference:	9.0 s

AIS Reference Data

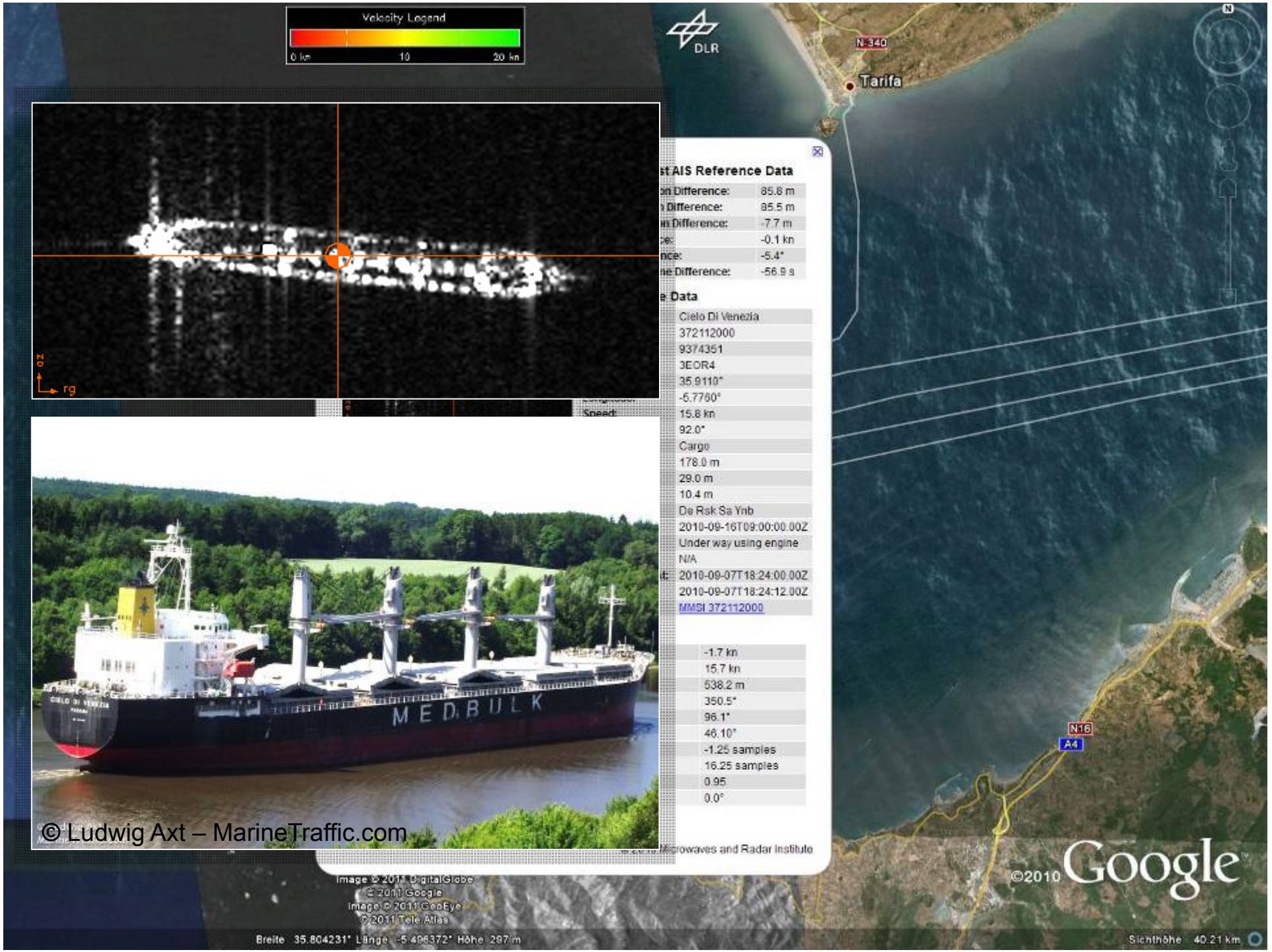
Name:	Alabama Belle
MMSI:	548752000
IMO Number:	8412144
Callsign:	DYPD
Latitude:	35.9530°
Longitude:	-5.7030°
Speed:	9.3 kn
Heading:	272.0°
Vessel Type:	Cargo
Length:	184.0 m
Beam:	30.0 m
Draught:	6.5 m
Destination:	Termisa Brazil
ETA:	2010-09-17T18:00:00.00Z
Status:	Under way using engine
Extra Info:	N/A
AIS Last Seen At:	2010-09-07T18:22:55.00Z
AIS Retrieved:	2010-09-07T18:23:02.00Z
Web Info:	MMSI 548752000

Additionaly Measured SAR-GMTI Data

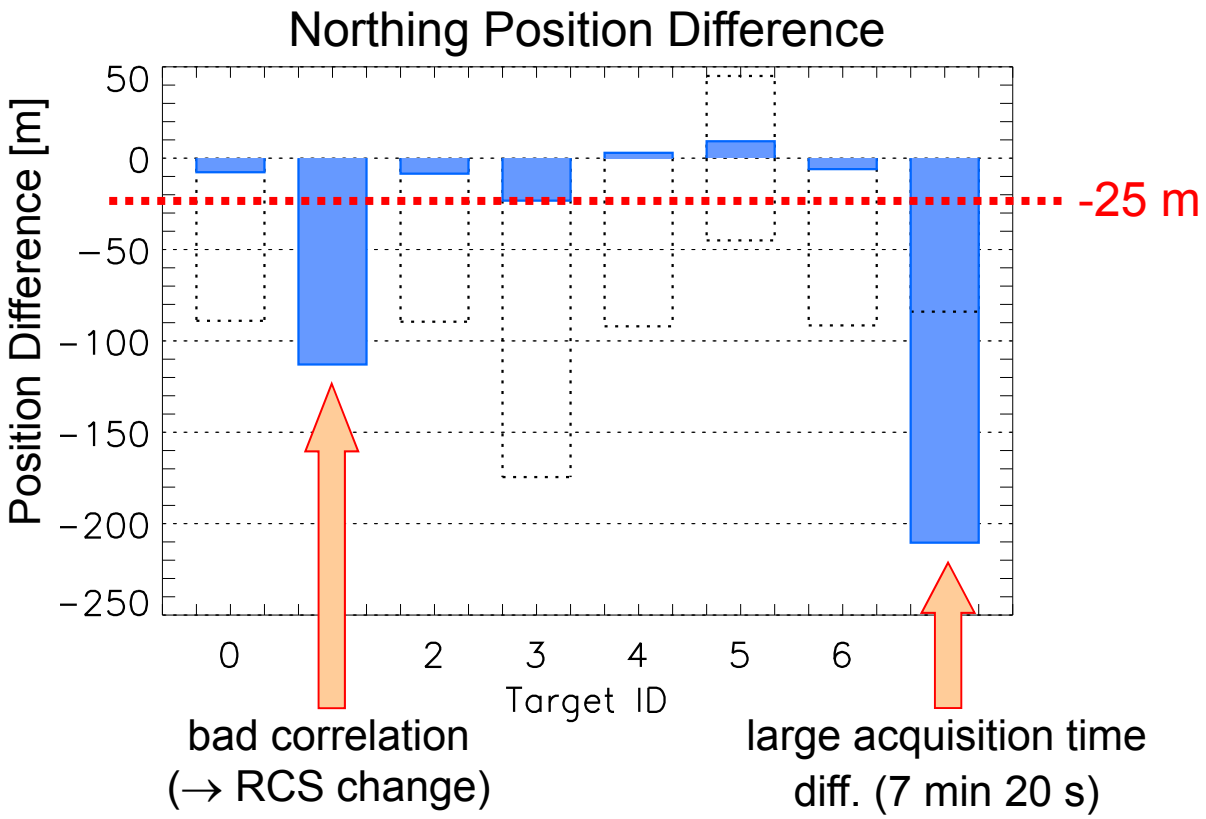
Along-Track Speed:	2.7 kn
Across-Track Speed:	-9.1 kn
Azimuth Displacement:	-317.1 m
Strip Heading:	350.5°
Target Heading With Respect to the Azimuth Direction:	-73.7°
Incidence Angle:	46.60°
Azimuth Displacement Difference:	2.00 samples
Range Displacement Difference:	-9.50 samples
Correlation Coefficient:	0.81
Rotation Angle:	0.0°

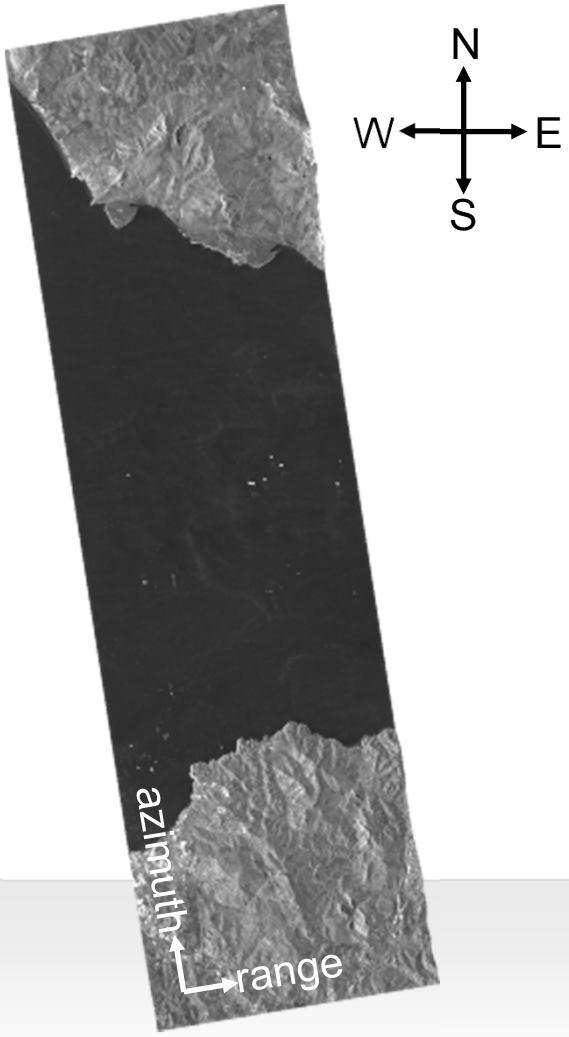
Deutsches Zentrum für Luft- und Raumfahrt
DLR

W
S
N
E


Velocity Legend
0 kn
10
20 kn
DLR
N 340
Tarifa
AIS Reference Data
Difference: 85.8 m
Difference: 85.5 m
Difference: -7.7 m
-0.1 kn
-5.4°
Difference: -56.9 s
Data
Cielo Di Venezia
372112000
9374351
3EOR4
35.9110°
-5.7760°
15.8 kn
92.0°
Cargo
178.0 m
29.0 m
10.4 m
De Rsk Sa Ynb
2010-09-16T09:00:00.00Z
Under way using engine
N/A
2010-09-07T18:24:00.00Z
2010-09-07T18:24:12.00Z
MMSI 372112000
-1.7 kn
15.7 kn
538.2 m
350.5°
96.1°
46.10°
-1.25 samples
16.25 samples
0.95
0.0°
az
rg
MEDBULK
© Ludwig Axt – MarineTraffic.com
N16
A4
©2010 Google
Breite 35.804231° Länge -5.496372° Höhe 297 m
Sichthöhe 40.21 km

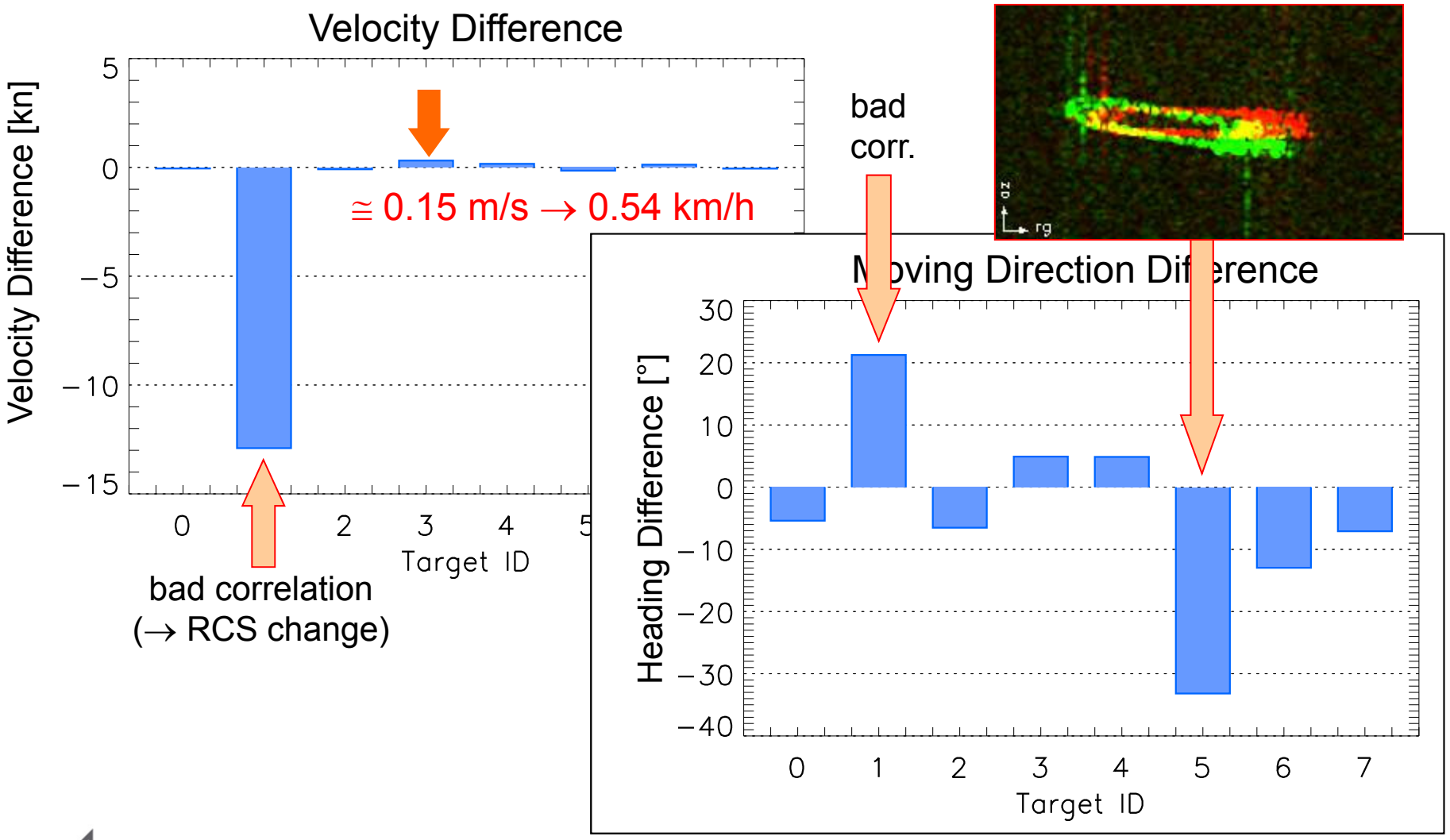
Verification Using AIS Data as Reference → First Results (I)



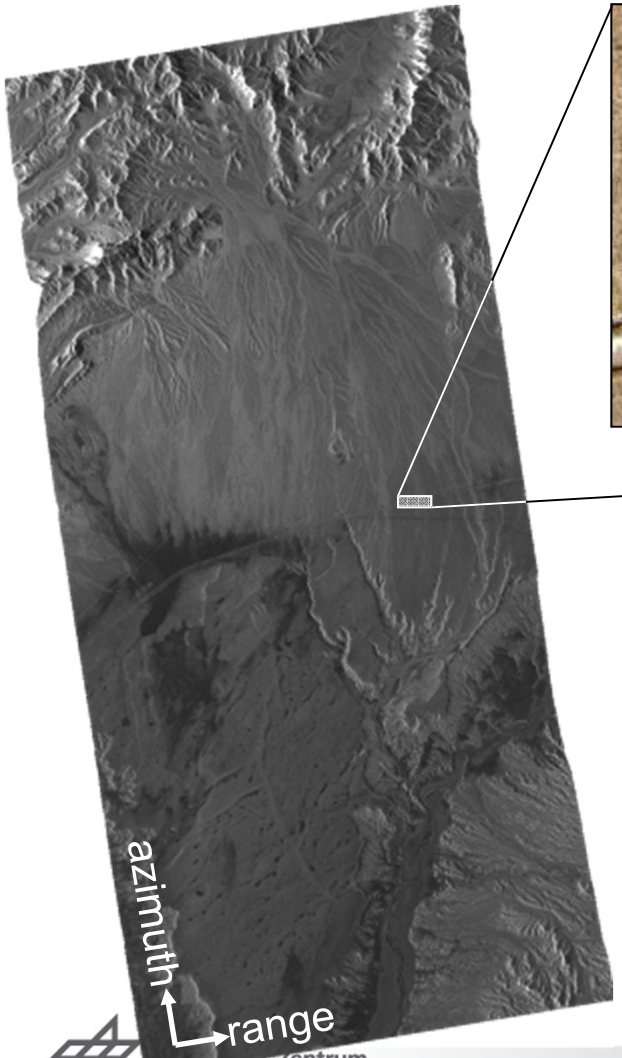


- Vessels have moved mainly in range direction
  - Northing pos. difference ~ azimuth re-positioning error
  - „True azimuth position is more difficult to estimate than range position!“

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

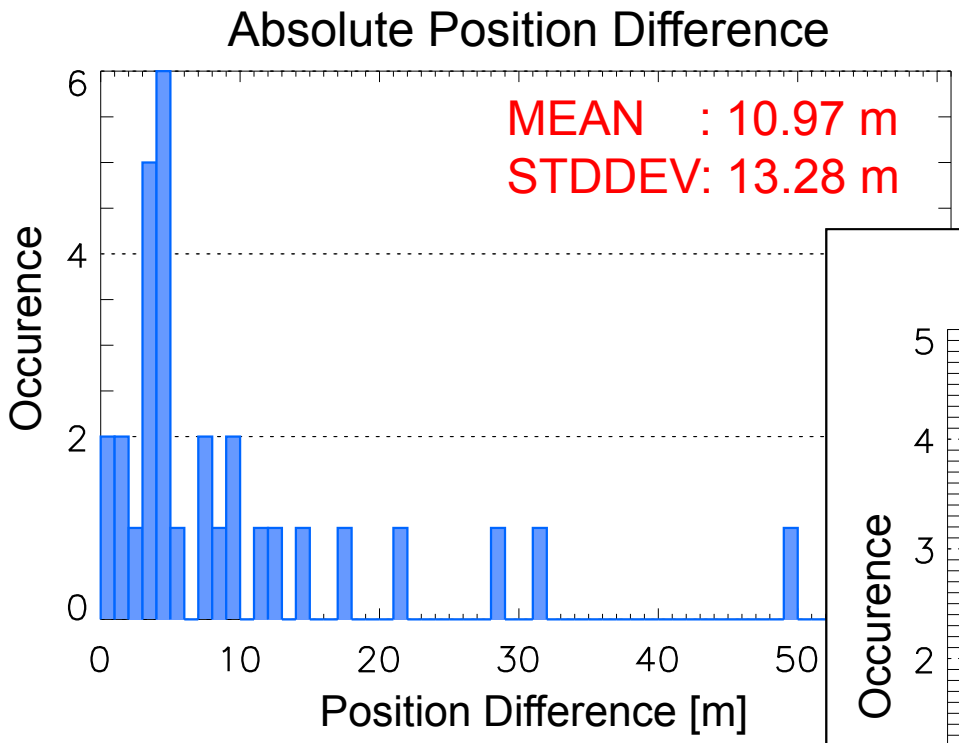


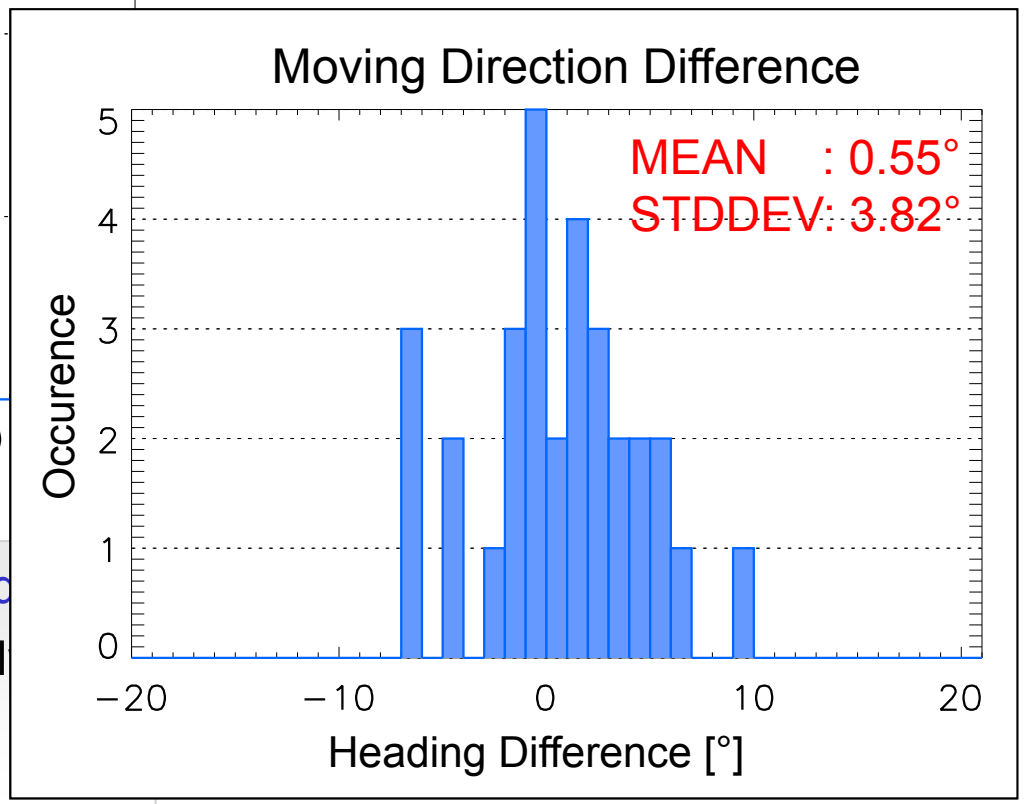
Verification Using Road Database as Reference → Principle



- Absolute Geographical Position „Error“
  - Estimated target position ↔ closest road point
- Target Moving Direction
  - Compared with known road direction
- Detection / False Alarm Rate
  - Unfortunately no ground truth available!

Verification Using Road Database as Reference → Results





- Simple detector → fixed threshold
- False detections skipped manually
  - 31 remaining „true“ targets (SCNR 10 to 24 dB)

Conclusions and Outlook

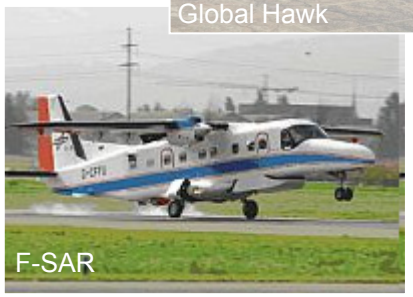
- Large Along-Track Baseline Algorithm
  - Proof of concept provided
  - Targets: point-like (small cars) ↔ extended (ships) ↔ „other“ movers / non-movers?
  - Excellent parameter estimation performance
  - You get both with one pass: High resolution SAR images + GMTI data

- Reference Data ↔ „Data Fusion“
  - „Traffic Monitoring“ → assignment to certain roads (automatically)
  - „Ship Monitoring“ → comparison / fusion with AIS data (automatically)

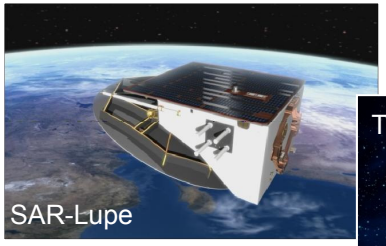
- Outlook
  - Not all acquired data takes evaluated so far; no robust (CFAR) detector implemented
  - Principally applicable for „future“ platforms ...

State-of-the-Art and Future?

Airborne

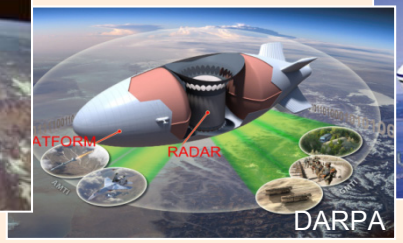


Spaceborne



Differences / selection criterions:

- Spatial / temporal coverage
- Endurance / range
- Applications



„High Altitude Airships (HAAs)“?