StereoSAR: level-1 performance analysis of TSCV measurements.

DOFS
Brest
11 October 2018

Maarten van den Oever European Space Agency (ESA)
Davide, Giudici, Advanced Remote Sensing Systems (Aresys),
Erik De Witte, European Space Agency (ESA),
Daniele, Mapelli, Advanced Remote Sensing Systems (Aresys),

StereoSAR Scope of the work

Aresys carried out the following tasks to arrive to an independent analysis of the StereoSAR mission concepts performance

- Analysis of the StereoSAR concept
- Define and implement a set of performance prediction models
- Carry out performance sensitivity analyses versus the key drivers:
  - Observation geometry (baseline & pointing strategy)
  - Instrument configuration (antenna)

StereoSAR: mission requirements

- StereoSAR mission goal: To retrieve mesoscale and sub-mesoscale wind and Total Surface Current Velocity (TSCV) maps in the global ocean, coastal areas and inland seas.
- Measurement concept: To simultaneously observe sigma0 and Doppler velocities along 3 lines of sight and in both polarisations, at high resolution.
- Accuracy requirements on TSCV parameters for StereoSAR mission

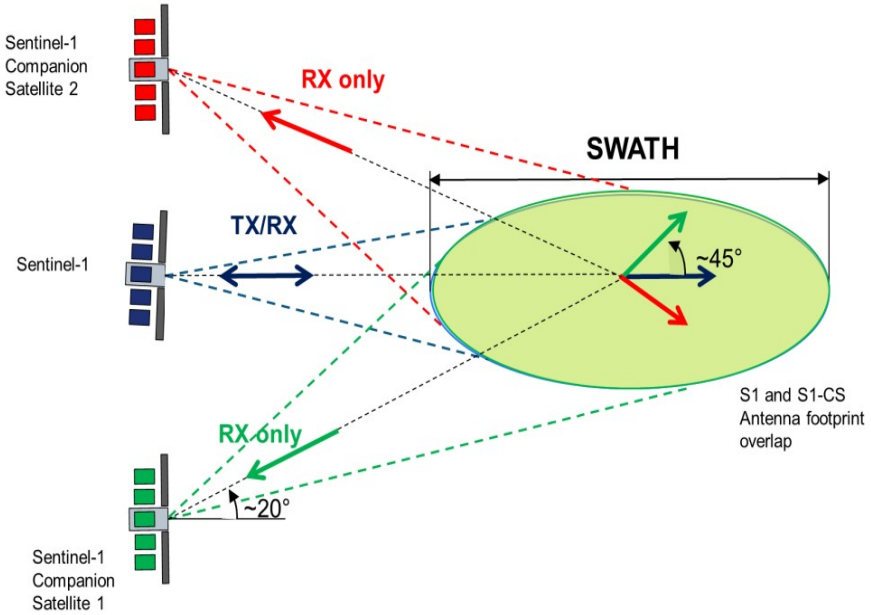
TSCV parameter	value
Modulus accuracy	≤ 0.2 m/s
Direction accuracy	≤ 40 °
Spatial horizontal resolution	≤ 5 km

User requirements derived from an **International User Consultation Meeting** in the frame of the ESA Global Current Project.

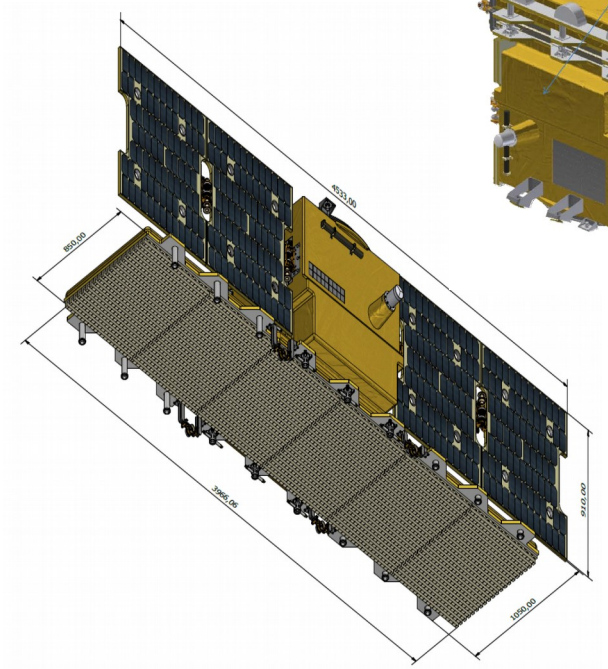
StereoSAR mission concept

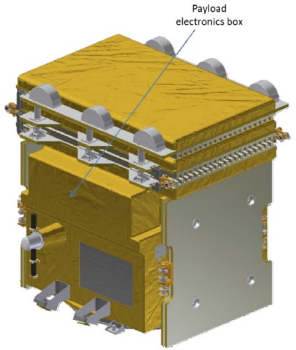
- **2 companion satellites**
- 1 flying ahead and 1 behind Sentinel-1
- they share the same orbit plane as Sentinel-1 (near-polar, sun-synchronous orbit with a 12-day repeat cycle);
- along-track distance ~275 km from Sentinel-1;

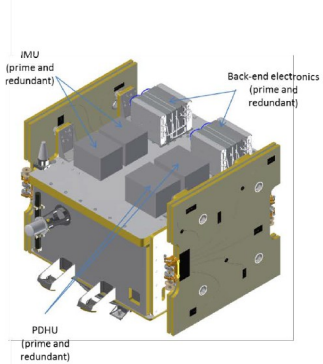
out-of-plane angle ~45° on the ocean surface (corresponding to an azimuth squint angle ~20°;

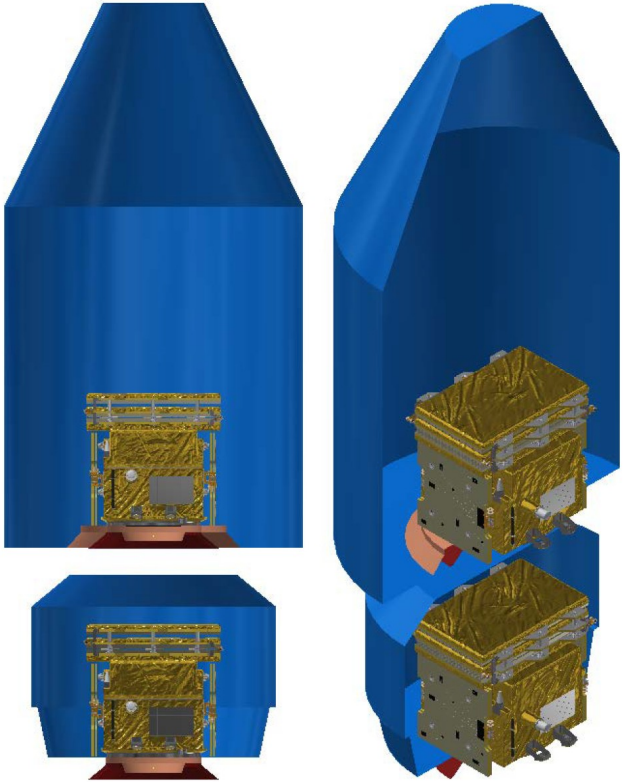


StereoSAR: spacecraft concept

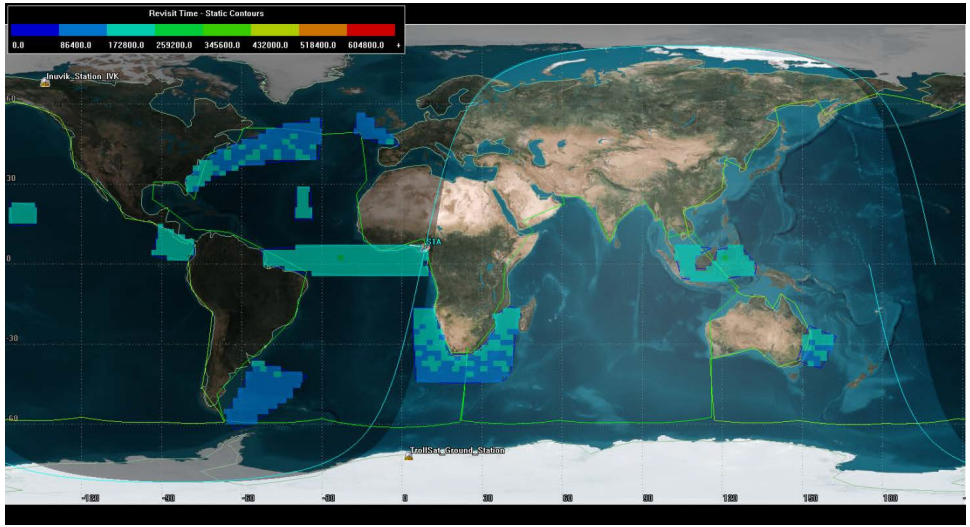








StereoSAR: Coverage Scenario’s



Observation Scenarios	Coverage Regions					
	S1 Synergy				Non Synergy	
	European Waters	Arctic	Antarctic	Global Sampling	Regional Areas	Coastal Areas
A	IW 2.08 mins					SM 2.91 mins
B		EW 12 mins			EW 7 mins	
C			EW 12 mins		EW 7 mins	
D					EW 0 mins	SM 4.48 mins
….					…	…
E					EW 6.95 mins	SM 2.85 mins
F				WV 8.44 mins	EW 0 mins	SM 2.62 mins
…				…	…	…
G				WV 8.44 mins	EW 7 mins	SM 0.98 mins
…				…	…	…
H				WV 8.44 mins	EW 9.8 mins	SM 0 mins

StereoSAR: Pointing bias

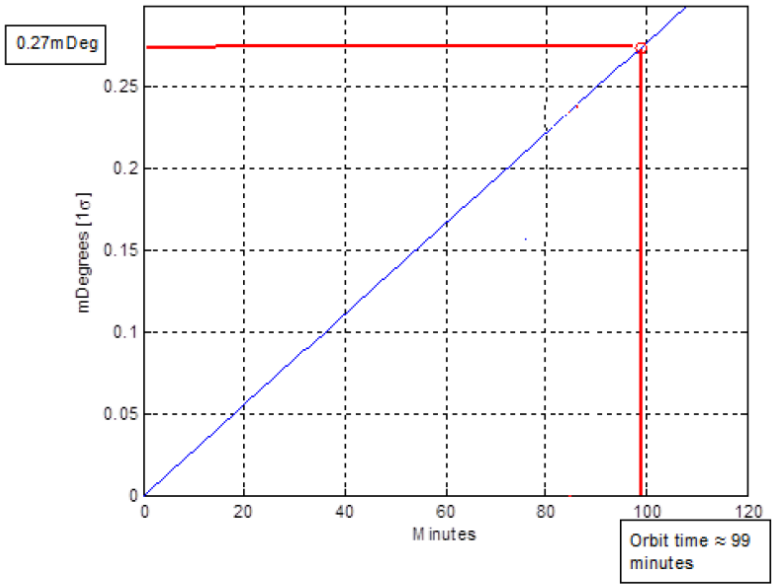


Figure 5-36: Variation of stability of an Astrix 200 IMU with time

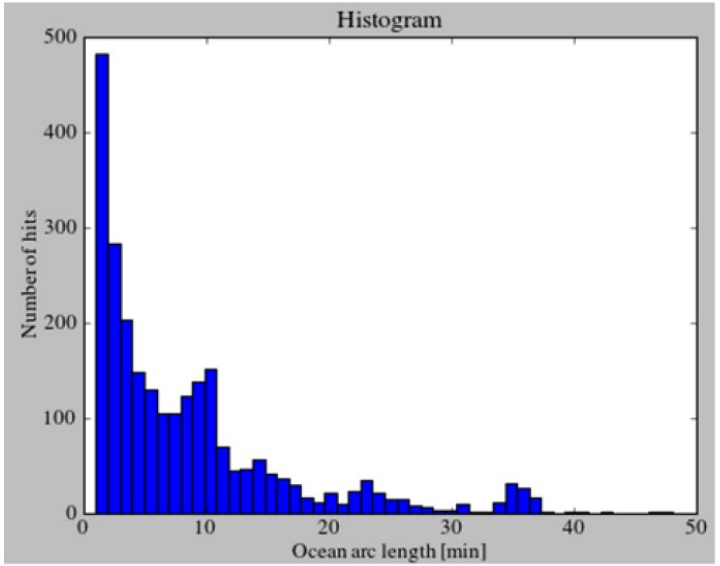


Figure 5-38: Histogram of the number of hits of specific ocean arc lengths over an orbit

StereoSAR: Performance Analysis

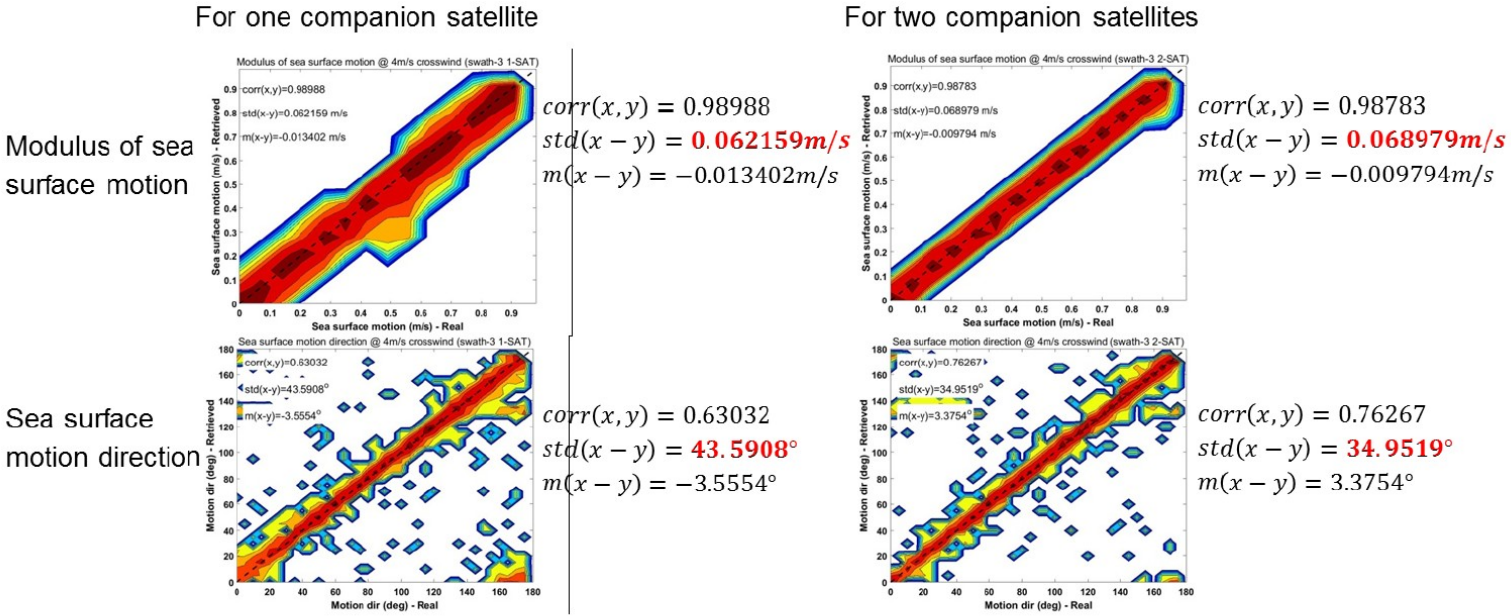
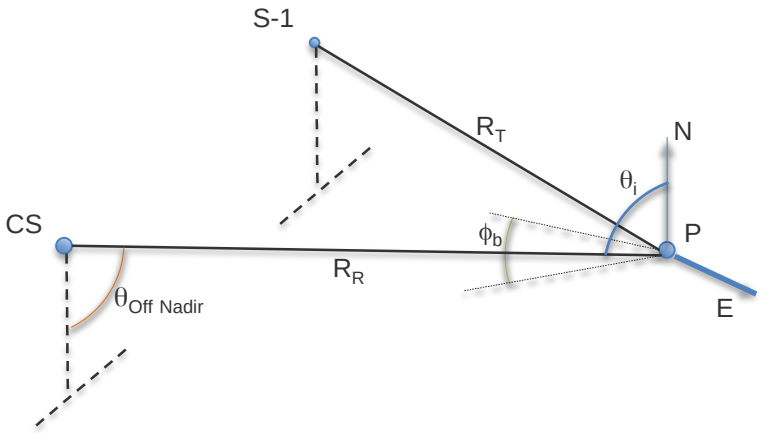


Figure 7-23: 2D velocity accuracy over 3 km x 3 km product

StereoSAR scattering model / geometry

- Well size 100 km x 100 km
- 4 m/s cross wind inside the well
- 25 m/s upwind outside the well
- Resolution 3 km x 3 km
- Ideal synchronization and focusing is assumed



StereoSAR mission concept

- S1-CS carry passive Synthetic Aperture Radar (SAR) receivers and use Sentinel-1 as a transmitter of opportunity

3 observations of the same area on the ground:
- ✓ 1 mono-static observation performed by Sentinel-1;
- ✓ 2 squinted bi-static observations performed by S1-CS.

- Sentinel-1's return Doppler signal from the ocean surface is measured by each SAR receiver;
- the **Doppler Centroid Anomaly (DCA) method** is applied to each acquisition in order to detect the TSCV vectors.

$$\omega_{dc} = \omega_{dc}^{phys} + \omega_{dc}^{geo} + \omega_{dc}^{elec} + \Delta\omega_{dc}$$

Geophysical term (DCA)

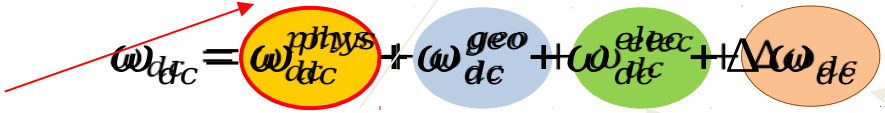
Geometric term

Antenna electronic miss pointing term

Residual error

StereoSAR: The Doppler Centroid Anomaly

The estimated Doppler frequency consists of several terms:



Geophysical term (DCA)

Geometric term

Antenna electronic miss pointing term

Residual error

ω_{dc}^{geo} is computed from the orbit/attitude data;

ω_{dc}^{elec} can be computed from the antenna model or estimated from SAR data acquired over stationary homogenous areas (e.g. rain forest);

$\Delta\omega_{dc}$ can be removed by setting Doppler equal to zero over land areas after first correcting for the deterministic terms.

The performance can be estimated by the STNR

StereoSAR CS system parameters

Parameter	Value
Antenna height	0.82 m
Antenna width	4 m
RX losses	1.75 dB
Noise figure	3.2 dB
Phase centres (az x el)	(6 x 10)
Element spacing elevation	0.70827 Lambda
Element spacing azimuth	0.70827 Lambda

StereoSAR analysis

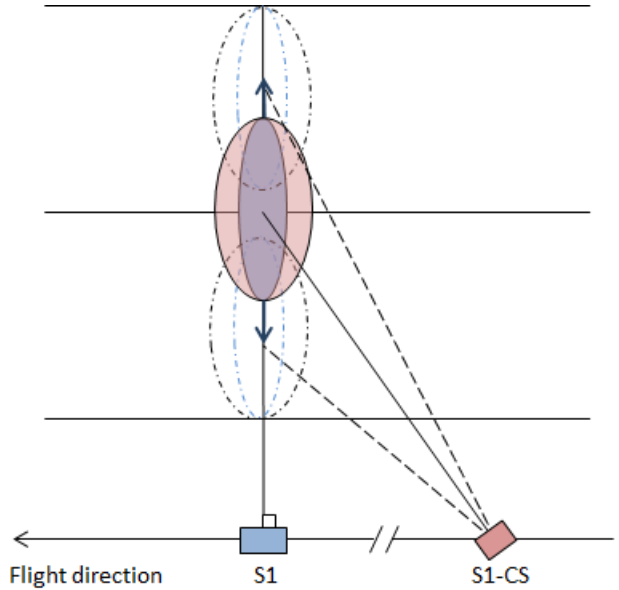
Pointing and geometry

The S1 and S1-CS beams should overlap by aligning the swaths; this is achieved by:

1) mechanically pointing the S1-CS's beam both in elevation and azimuth at the mid-swath position of Sentinel-1 (i.e. S1-CS's platform roll and pitch);

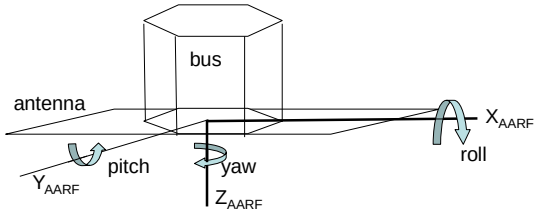
2) mechanically applying a rotation about the mechanical boresight of the S1-CS's antenna;

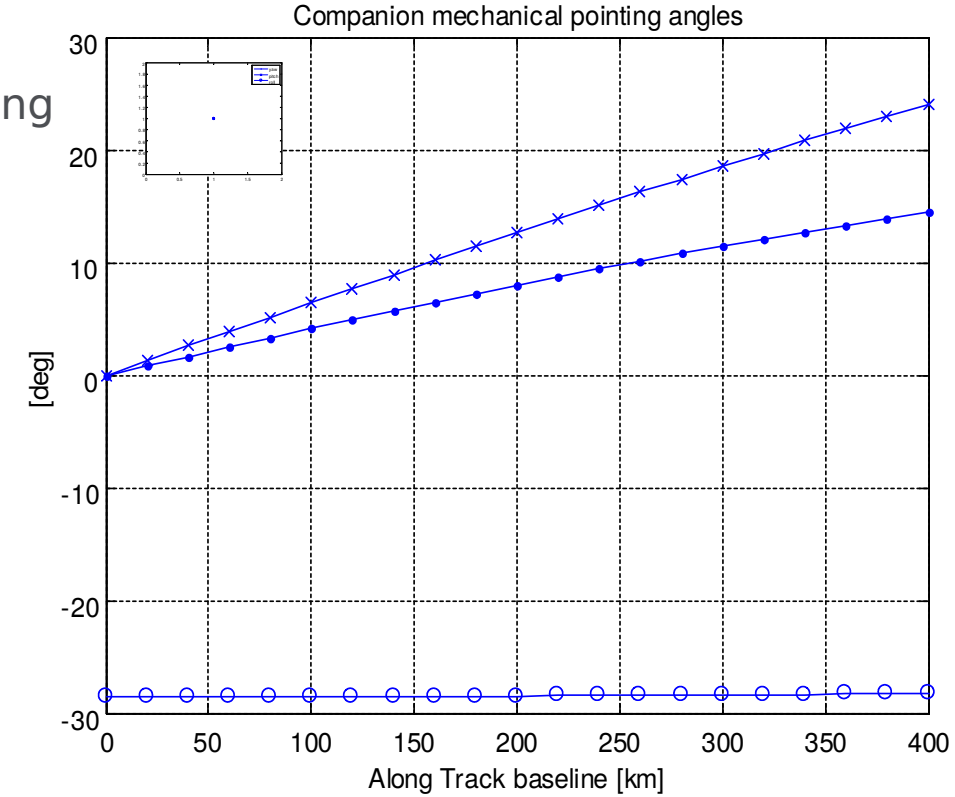
3) following the electric (TOPS) steering of S1



StereoSAR analysis

The roll pitch and yaw of the CS required to achieve mechanical pointing

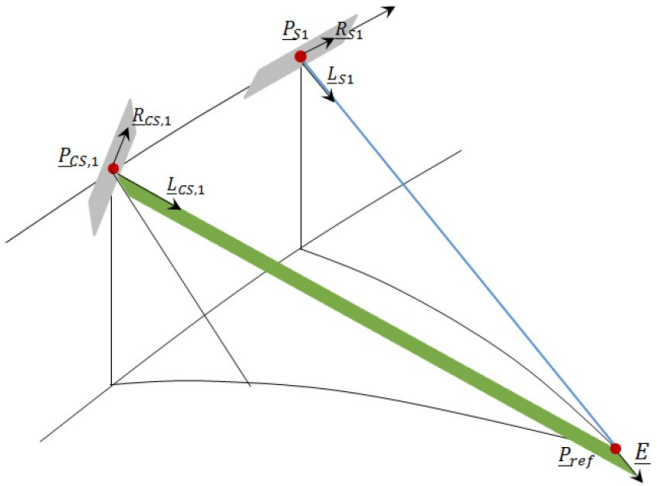


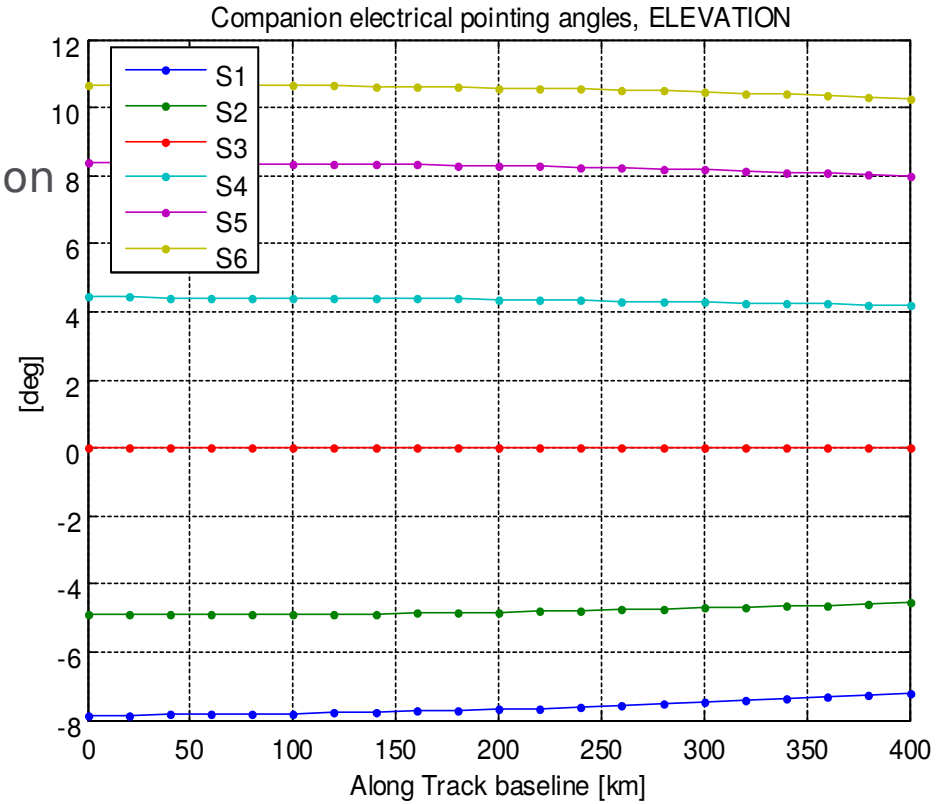


StereoSAR analysis

Mechanical alignment on the 3rd subswath of S1.

Other subswaths are aligned in elevation by electrical steering

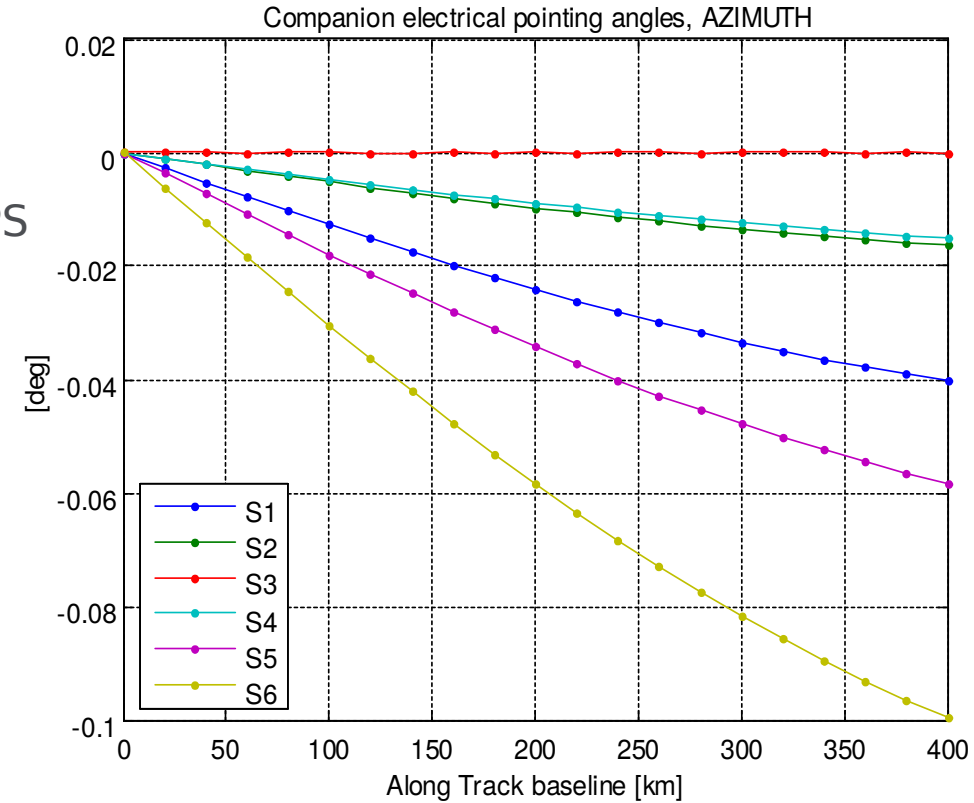




StereoSAR analysis

Electrical azimuth pointing for different subswaths.

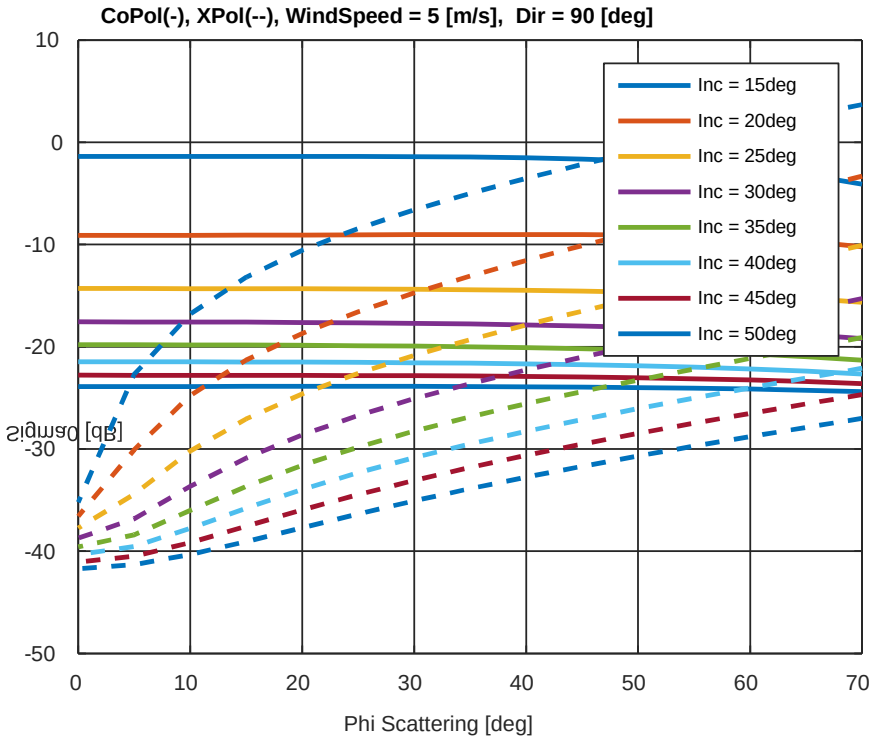
Required electrical pointing angles are relatively small compared to TOPS Steering range



StereoSAR scattering model

The scattering models used are the La Sapienza SSA2 models

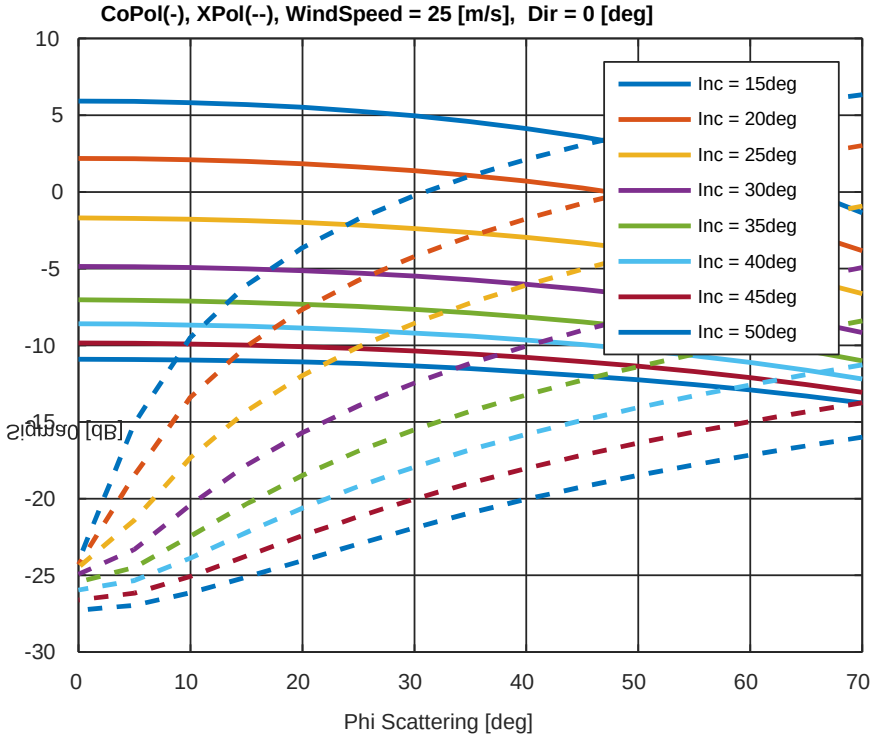
- 4 m/s cross-wind
- Solid line VV
- Dashed line VH
- Co-pol hardly affected
- Cross pol component increases with phi



StereoSAR scattering model

The scattering models used are the La Sapienza SSA2 models

- 25 m/s upwind
- Solid line VV
- Dashed line VH
- Cross pol component increases with phi



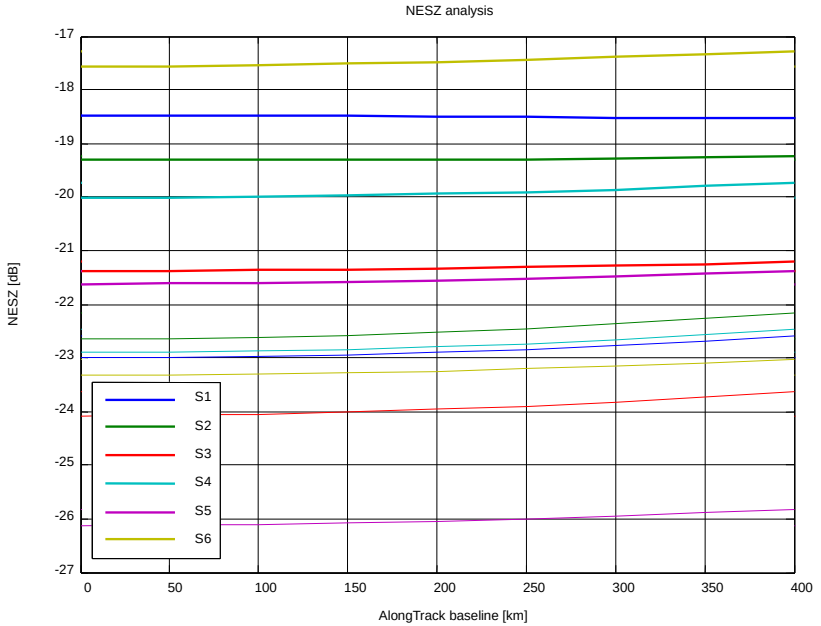
StereoSAR NESZ

Simulated NESZ in stripmap mode with

4 m/s wind speed

The dashed lines show the best values obtained in the swath.

The solid lines the worst case values



StereoSAR NESZ

Simulated SNR in stripmap mode with

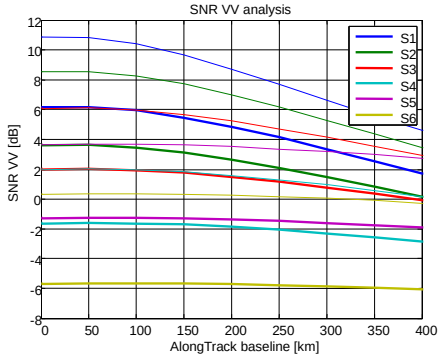
4 m/s wind speed.

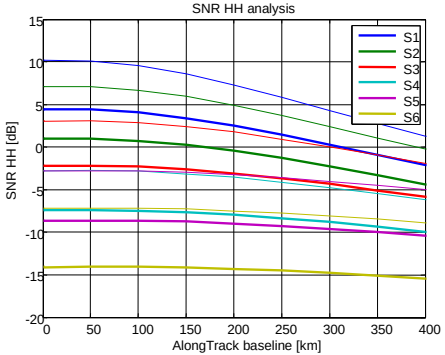
The cross-polarization SNR

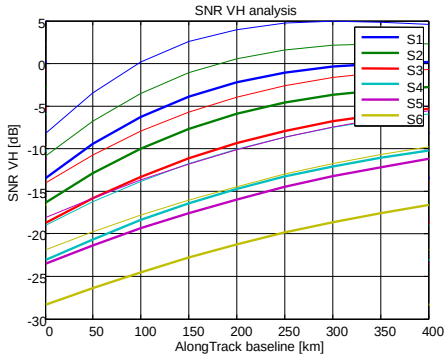
Increases with the baseline

The dashed lines show the best values obtained in the swath.

The solid lines the worst case values



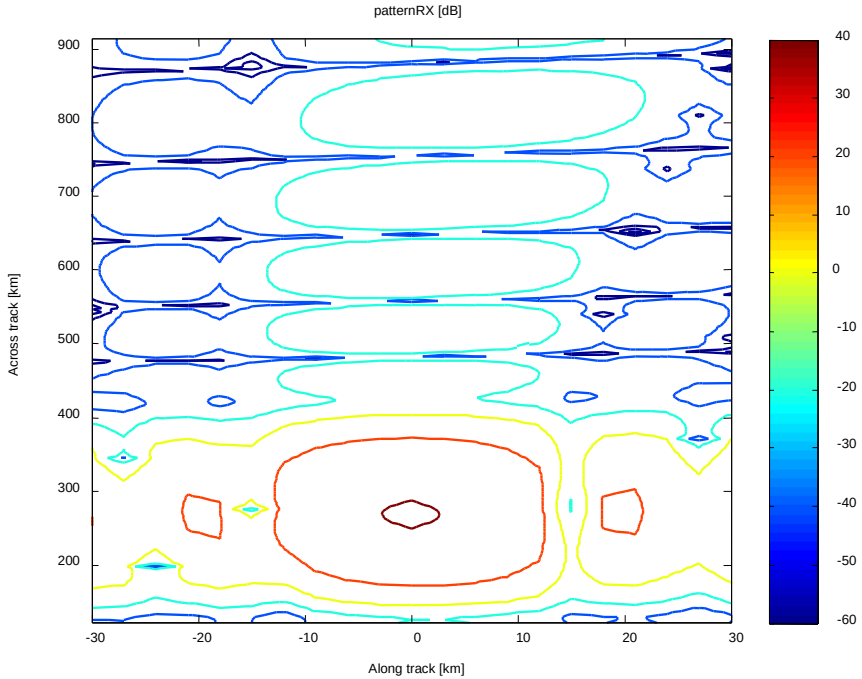




StereoSAR Antenna pattern

StereoSAR antenna pattern projected on ground.
Considering mechanical tilt

Parameter	Value
Antenna height	0.82 M
Antenna width	4 m
RX losses	1.75 dB
Noise figure	3.2 dB
Phase centres (az x el)	(6 x 10)
Element spacing elevation	0.70827 Lambda
Element spacing azimuth	0.70827 Lambda

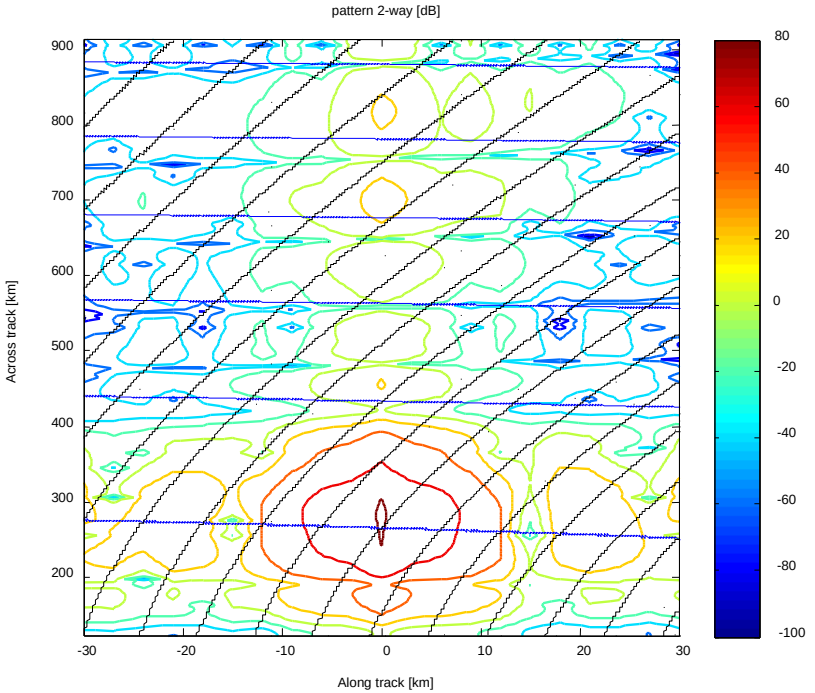


StereoSAR Antenna pattern

Computed 2 way pattern for S1 and S1-cs

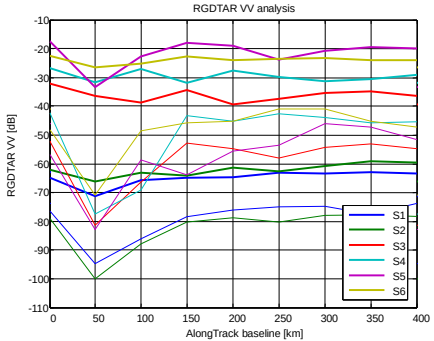
- 2 way pattern for 260 km baseline
- Iso-range in blue
- Iso-Doppler in black
- Intersections of these lines are dependent on the baseline

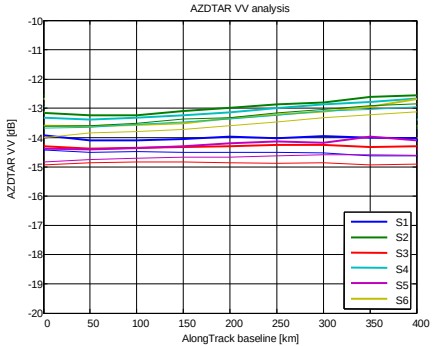
2 way pattern

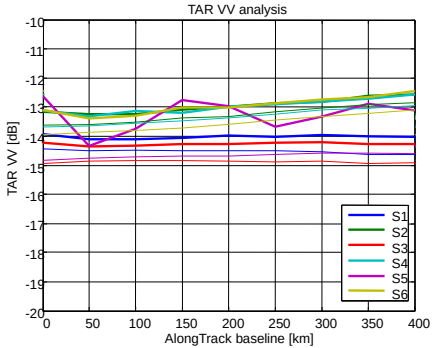


StereoSAR ambiguity ratios

- Range DTAR
- Azimuth DTAR
- TAR





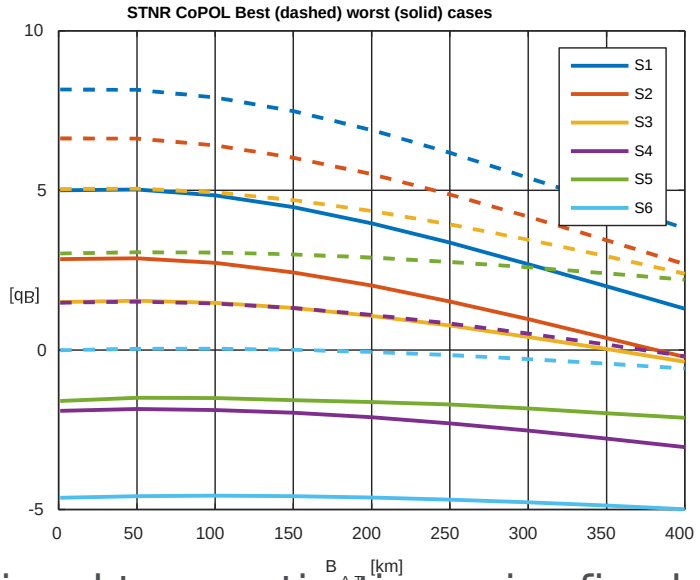


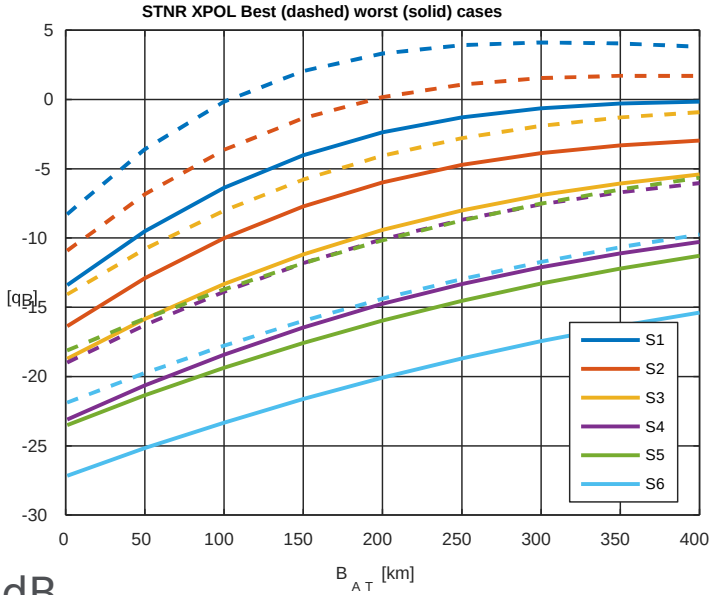
The dashed lines show the best values obtained in the swath.

The solid lines the worst case values

StereoSAR Total SNR ratios

Values of signal to total noise ratio(STNR) decrease with increasing baseline for CoPOL and increase for XPOL



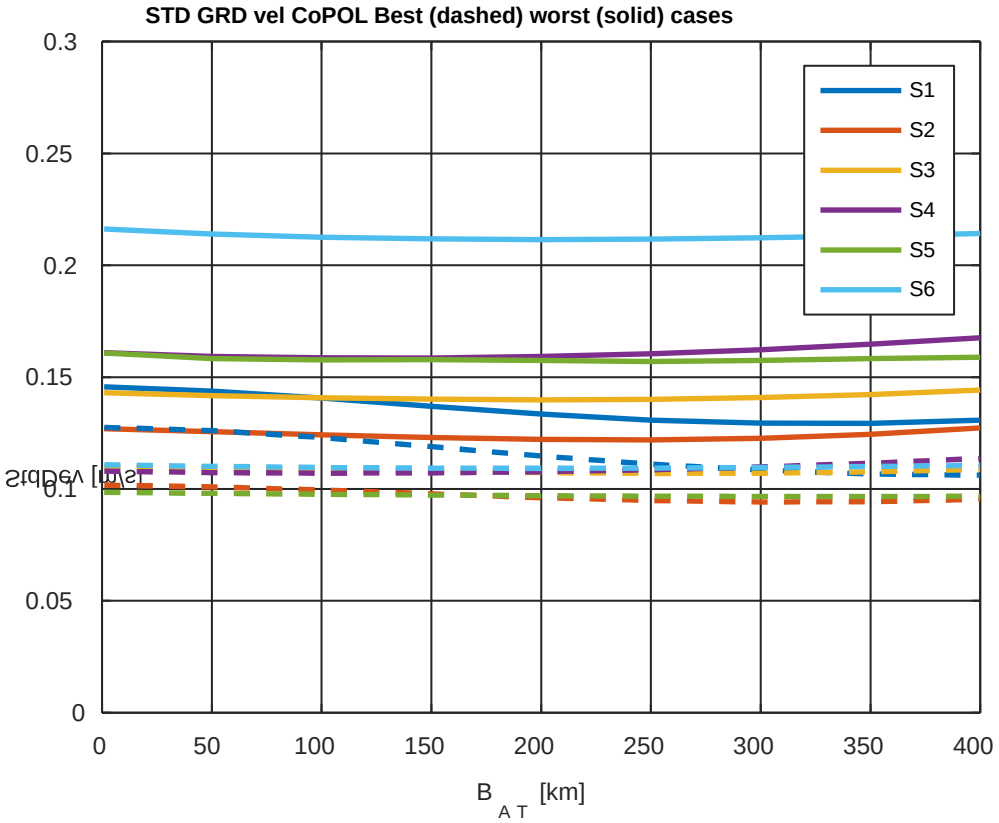


With signal to quantization noise fixed at 14.6dB

StereoSAR: LOS accuracy

Standard deviation on velocity in LOS direction shows little sensitivity to the increasing baseline in CoPOL.
It is below 0.2 m/s for most of the beams with a spatial resolution of 3 km x 3 km.

The XPOL component improves with a longer baseline



Conclusions

- An independent analysis of a concept with two companions to Sentinel-1 satellite as reported by Airbus has been carried out
- Similar performances of the StereoSAR concept have been reported by both studies
- The location of the ambiguities in the two way antenna pattern should be carefully evaluated in the mission design phase.
- Performance as a function of baseline length
    - Between 200 and 300 km seem optimal
    - Performance not very sensitive to baseline length
    - Concept should be optimized for overall retrieval of wind and current.