SAR Positioning for Geodetic Applications

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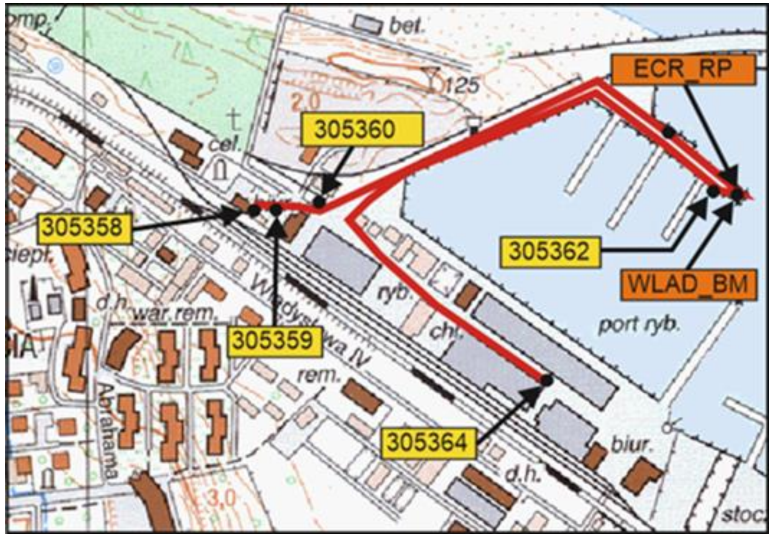
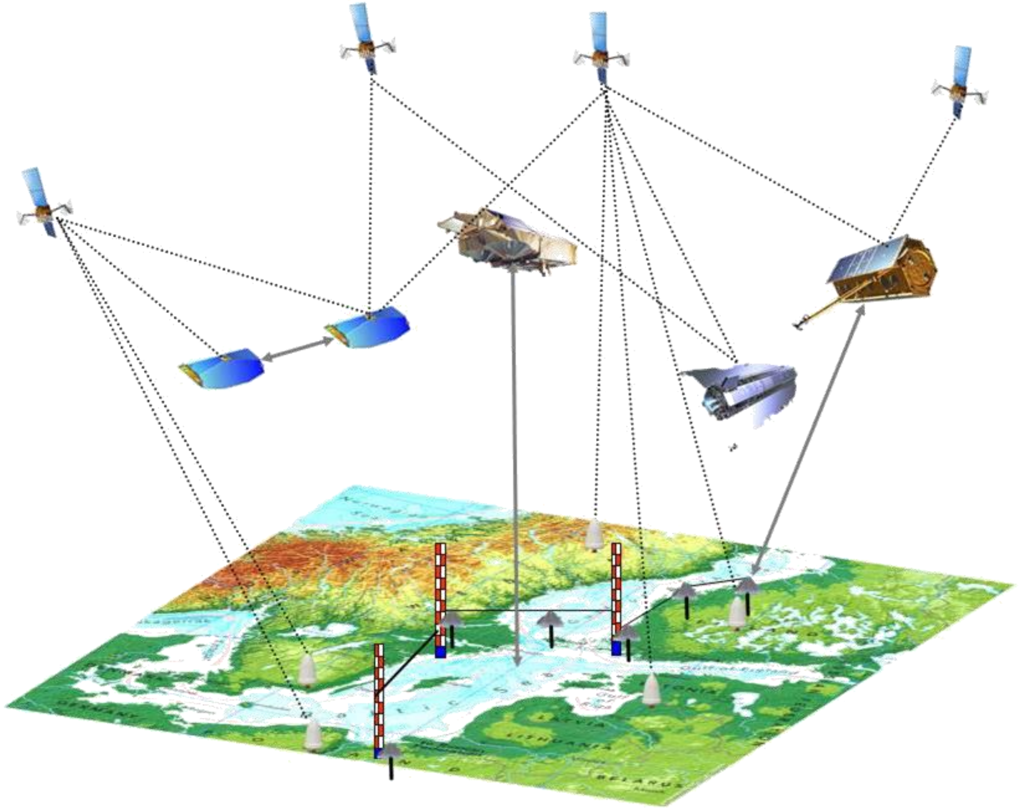
Geodetic Applications require an Integrated and Collocated Geodetic Ground and Space Segment



Władysławowo (Poland)

Vergi (Finland)

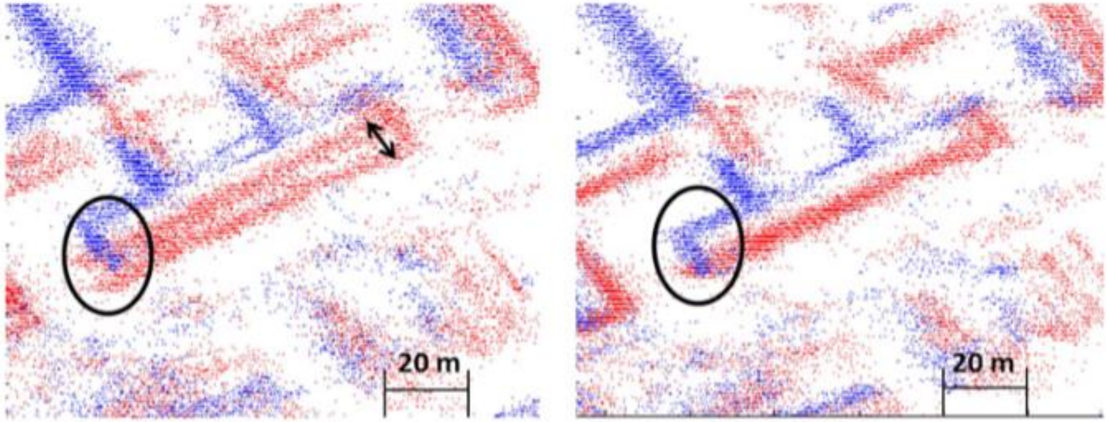


Workshop on the Geodetic Applications of Synthetic Aperture Radar, March 13 – 14, 2023. Aalto University, Espoo

General Research Questions – SAR for Geodesy

- Agreement on reference systems and methods for joint analysis of geodetic positioning observations.
- Well identifiable target points, simultaneously in radar image as well as in terrain.
- Ground control points for fusion and geo-localization of SAR tomography results to obtain absolute 3-D positions of a large amount of natural scatterers.
- Geodetic SAR Mission requirements: high-resolution, wide-swath, minimal time latency, homogeneous data, instantaneous precise positioning, electronic delays known.

Reference points (red dots) in the optical image of Berlin. All of the candidates are assumed base of lamp posts*



Fusion results before (left) and after (right) applying the reference point coordinate correction*

* from Zhu, Montazeri, Gisinger, Hanssen, Bamler: Geodetic SAR Tomography, IEEE Transactions on Geoscience and Remote Sensing, vol. 54, no. 1, pp. 18-35, Jan. 2016, doi: 10.1109/TGRS.2015.2448686

Geodetic Benchmarks - SAR Target Points

Requirements for Geodetic Benchmarks:

Long term stability and well identifiable on ground and in images (optical and radar)

Persistent Scatterers

from Zhu et al,
doi: 10.1109/TGRS.2015.2448686

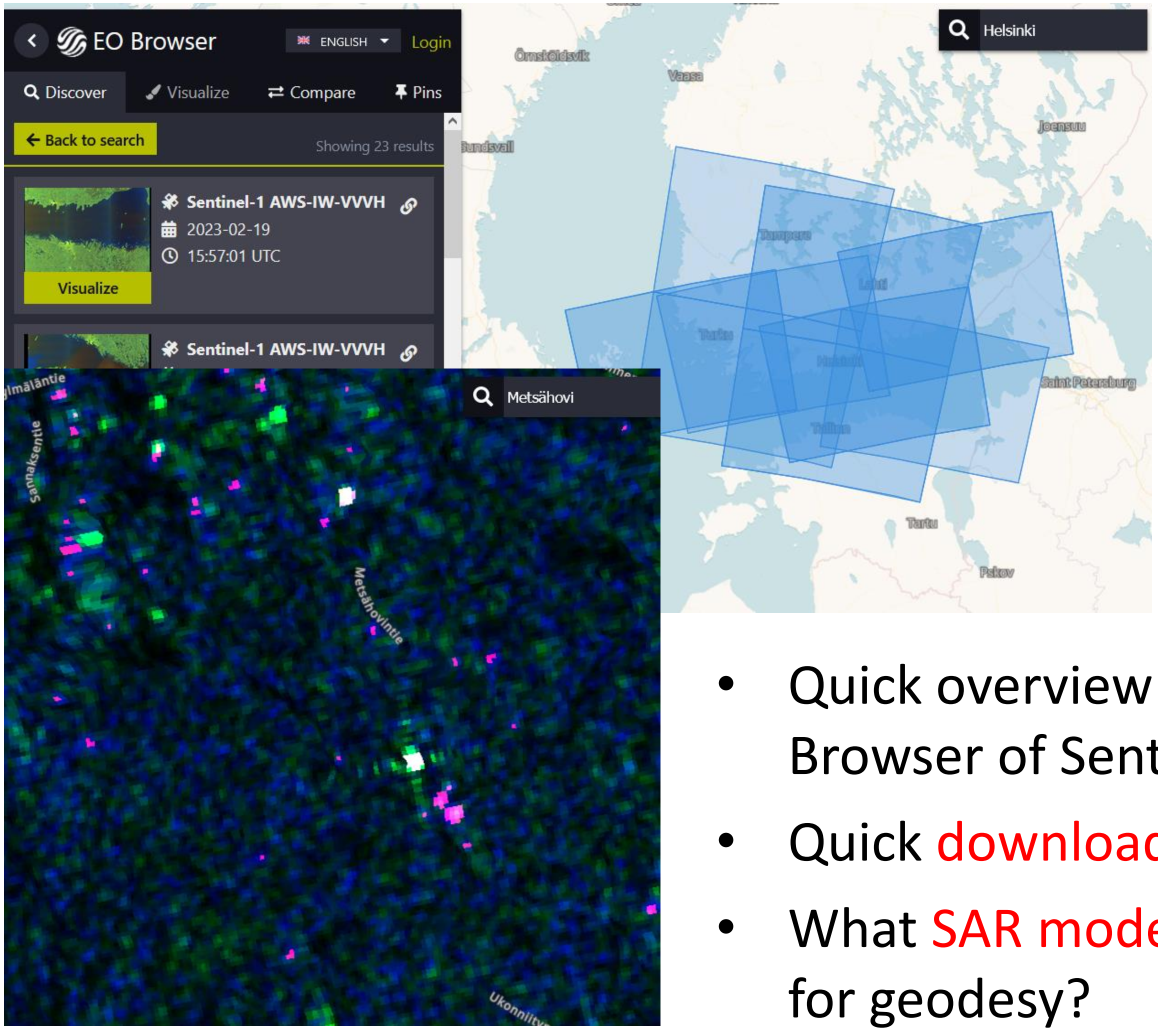
Not suitable as geodetic benchmark

Passive Geodetic Scatterers

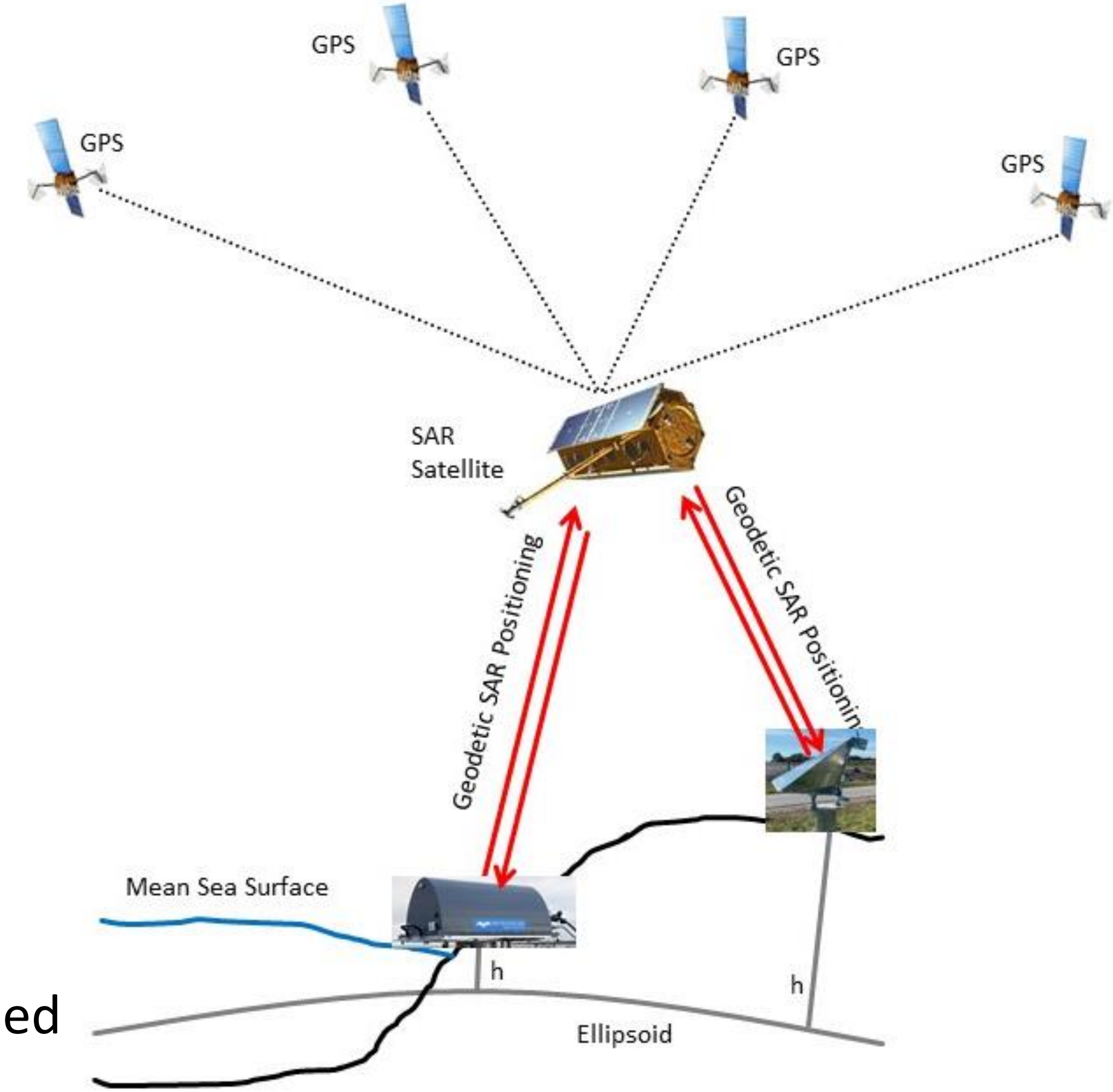
Active Geodetic Scatterers

3D Positioning with SAR – Research Questions

SAR Image Acquisition for Targets



- Quick overview with EO Browser of Sentinel Hub.
- Quick download required!
- What SAR modes are needed for geodesy?



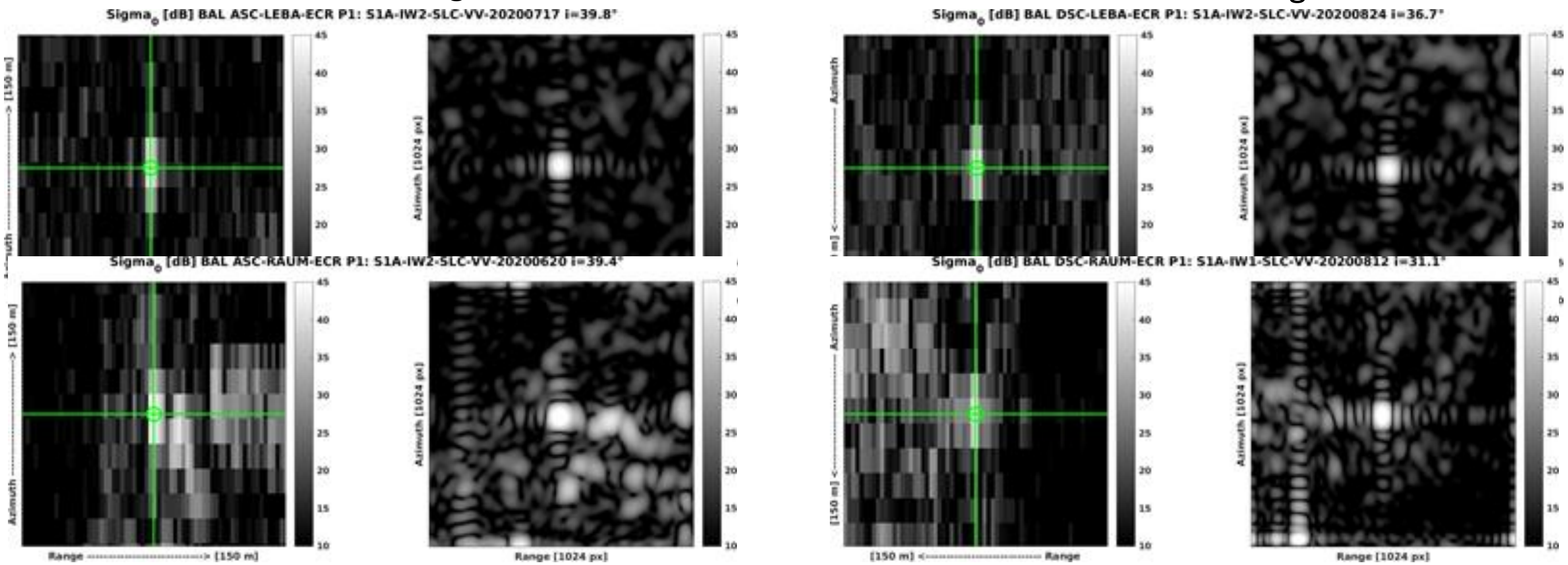
3D Positioning with SAR – Research Questions

Point Target Analysis: Range and Azimuth as primary Observables at Sub-Pixel Level

Ascending | Descending

ECR Łeba Poland

ECR Rauma, Finland



Left columns: Original Sentinel-1 SLC SAR image: area of 150m x 150m around ECR peak marked in green.

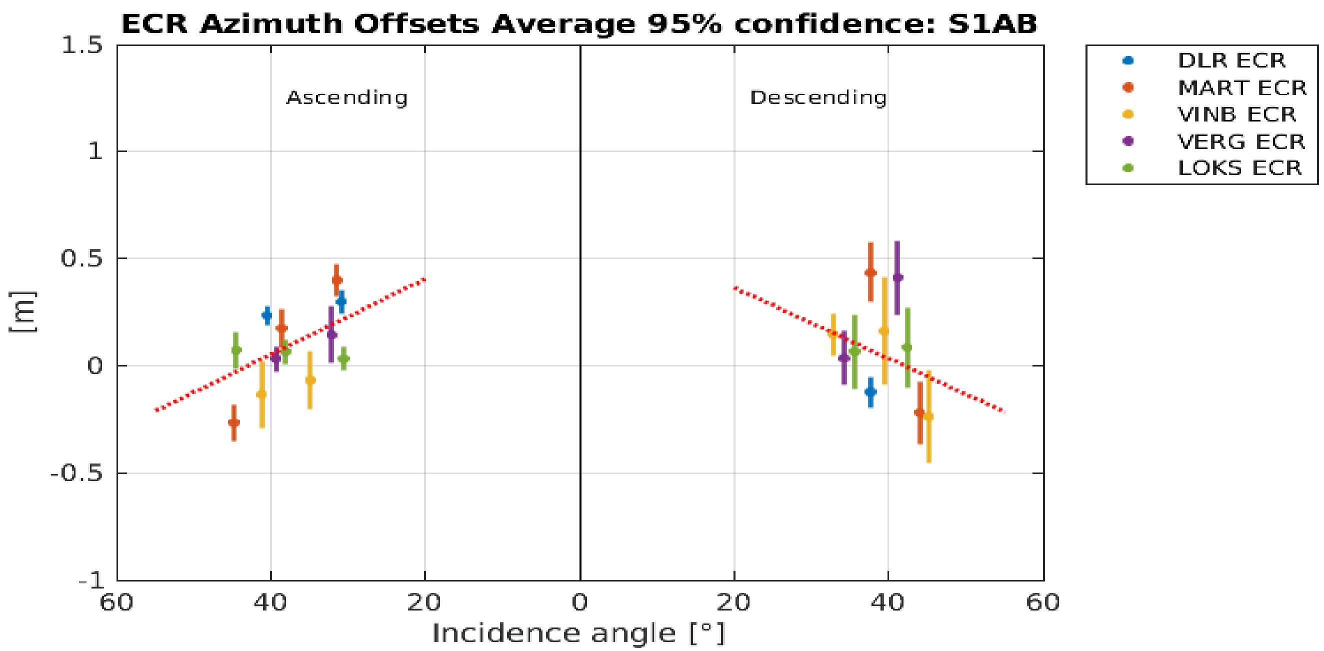
Right columns: Image areas of 32 x 32 pixels oversampled by a factor of 32 as generated by point target analysis to extract the ECR peak position

- Is there room for improvements in point target analysis?
- Targets for different SAR missions applicable (C-Band versus X-Band)?
- Targets for ascending and descending passes needed?

3D Positioning with SAR – Research Questions

Corrections for Atmospheric / Ionospheric Delays and Geodynamics

- Tropospheric corrections: What accuracy? From what sources (GNSS, Models, ETAD)? What about short term variations not represented in operation IFS ECMWF model?
- Ionospheric correction: What accuracy? From what sources (GNSS, Models)? ETAD is based on GNSS TEC product with 2.5x5 degree resolution. Is there a way to improve this with in-situ data?
- Geodynamic corrections: Is their quality sufficient for combination of SAR observations over longer time spans (definition of observation epoch)

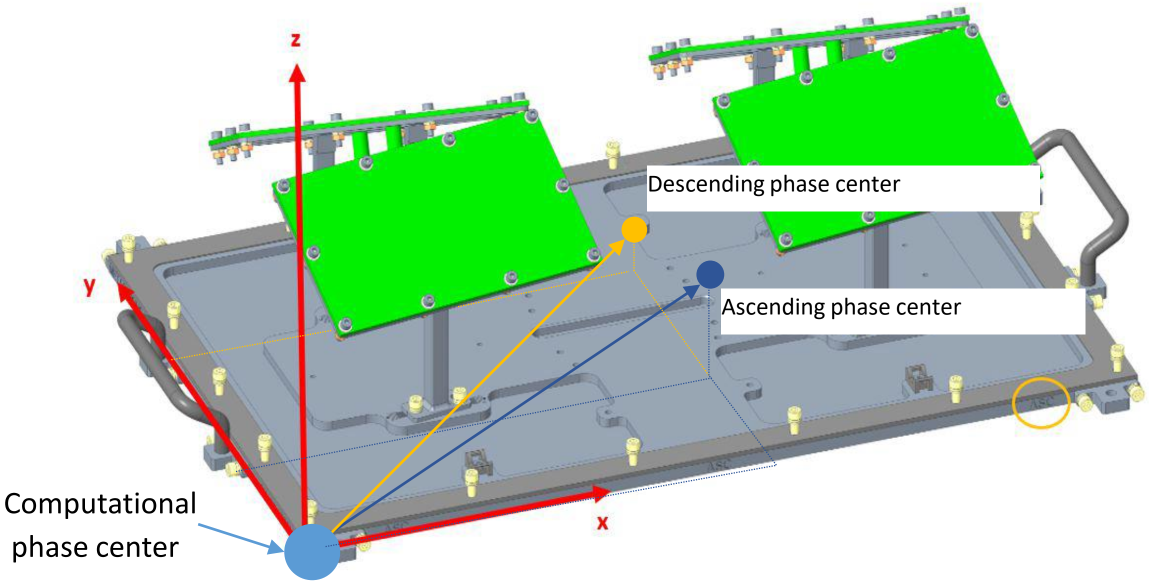


Linear model of the delay depending on incidence angle obtained by using few reference stations

3D Positioning with SAR – Research Questions

Space Sensor and Ground Targets System Calibration

- SAR sensor (satellite) calibration quality (oscillator drift, geometric calibration)? Sentinel-1A/B specific features to be considered. Is there a standard ESA product which corrects for all instrument and satellite related issues?
- Passive ground target calibration: Phase centers to be determined precisely for each CR type and viewing geometry?
- Active electronic ground target calibration (ECR): Definition of phase centers? Individual calibration needed per ECR? Impact of temperature on electronic delays (ECR)? Radiometric and phase stability (ECR)?

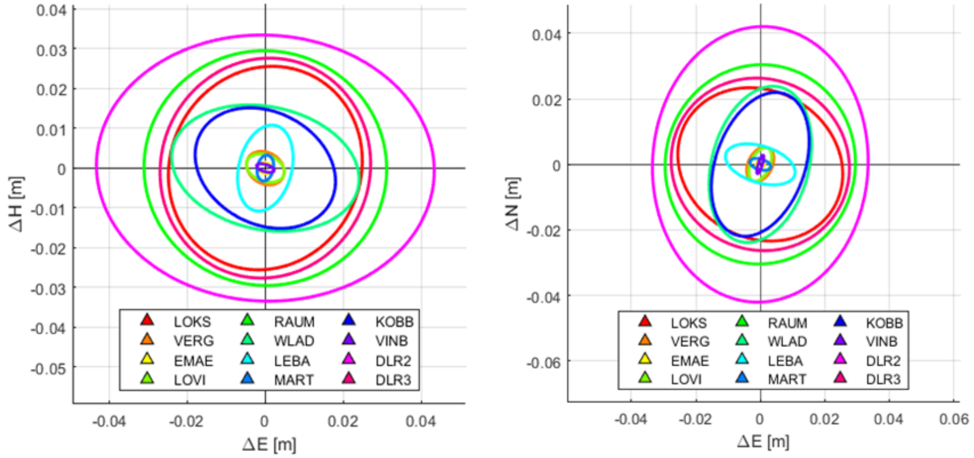


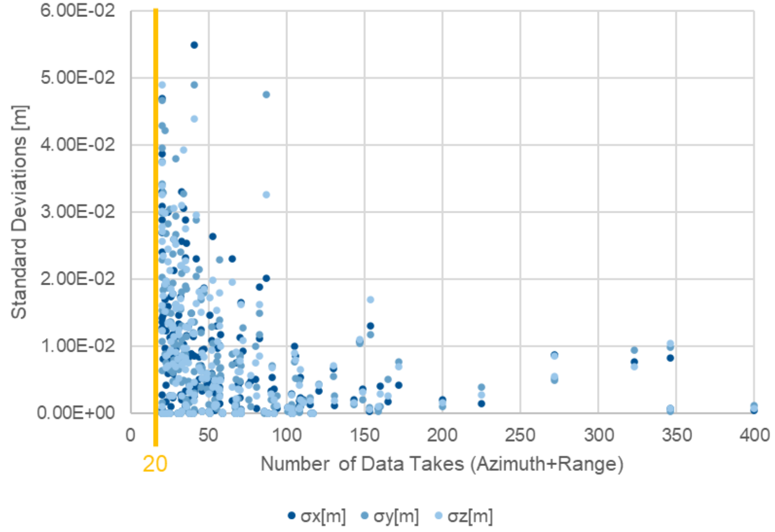
- Phase-center differs for ascending and descending geometry
- Offset in range and azimuth depends on incidence angle

3D Positioning with SAR – Research Questions

Coordinate Estimation by Solving Range-Doppler Equation

- Impact of viewing geometry (incidence angles)?
- Impact of orbit quality on positioning? What orbit quality is achievable?
- Requirements for targets for geodetic applications (form – CR vs multi-directional octahedrons, radar cross section, ascending/descending observations)?
- Contribution of range and azimuth image coordinates to positioning results?
- Number of observations needed for a positioning solution? Time variability possible?
- Differential positioning: How to? What errors might be eliminated? Over what distances?
- Other techniques for 3D positioning with SAR?

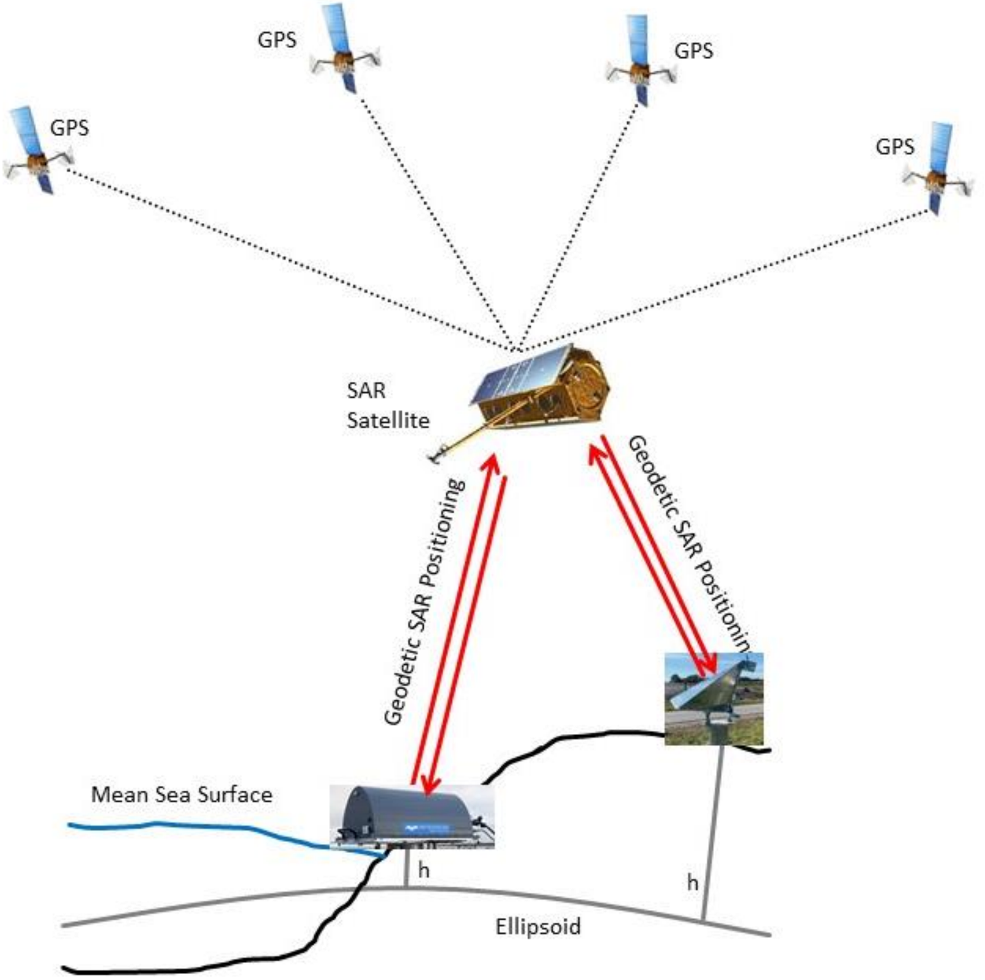




3D Positioning with SAR – Research Questions

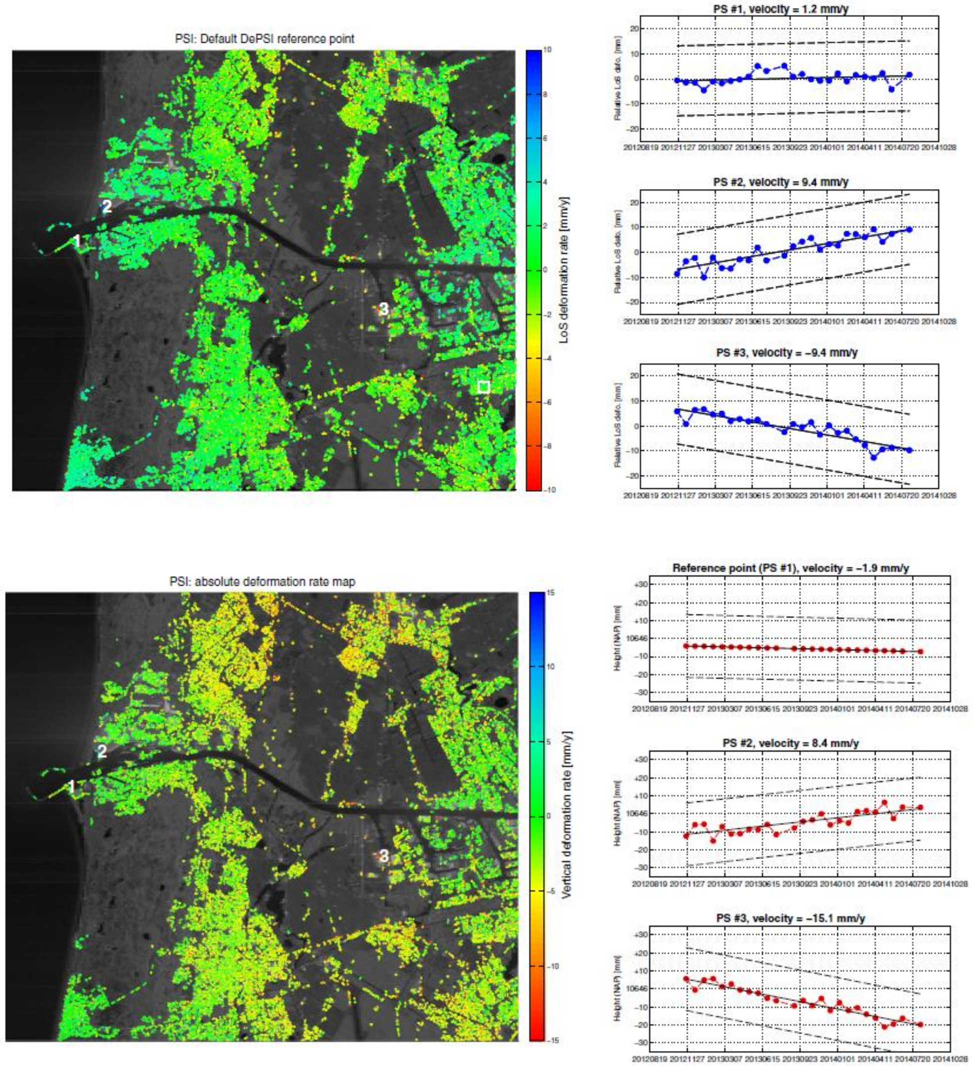
SAR for Satellite Geodesy & Space System Calibration

- SAR targets with known GPS determined coordinates as reference stations for satellite geodesy applications and system calibration?
- Geometric calibration of radar sensors with radar reflectors?
- Orbit validation by using SAR as an orbit tracking instrument? SAR range bias as a validation parameter?
- SAR ranges and azimuth as additional technique for precise orbit determination?



Combining 3D SAR / InSAR – Research Questions

- SAR 3D positions as absolute reference coordinates in order to fix the datum of SAR interferometry results?
- Network design for optimal InSAR deformation observations?
- Global integration of InSAR results in standard datums, such as the ITRF/ETRF?
- Requirements for absolute 3D coordinates for InSAR point cloud geolocalization?
- Investigation on absolute deformation estimates for large area, e.g., by cooperating GPS or 3D SAR positions?



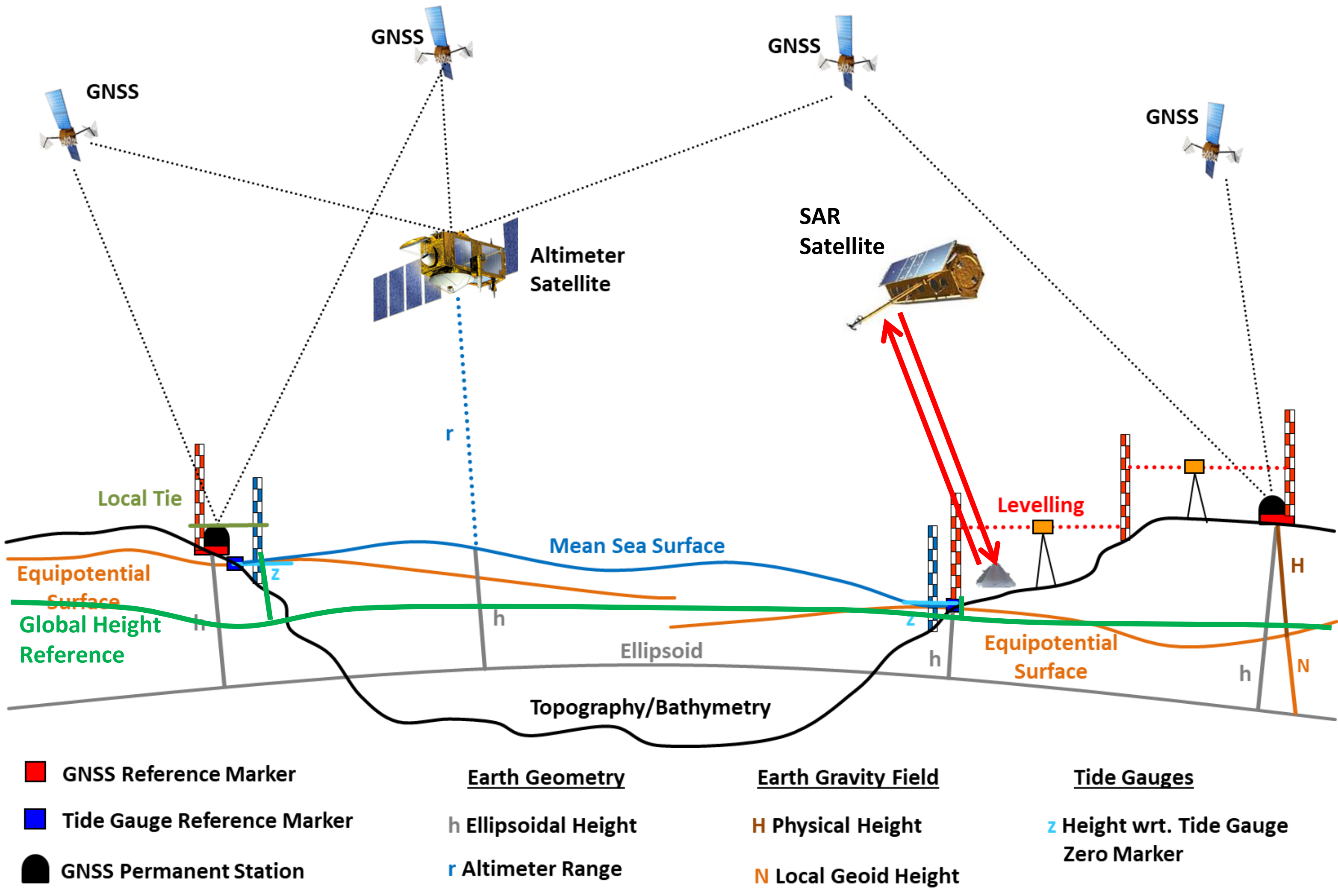
from Mahapatra et al, InSAR datum connection using GNSS-augmented radar transponders; J Geod (2018) 92:21–32; https://doi.org/10.1007/s00190-017-1041-y

Integration of Geodetic Observations and SAR

Objective 1
Connect tide gauge markers geometrically with GNSS network by geodetic SAR technique to determine vertical motion and to correct tide gauge readings.

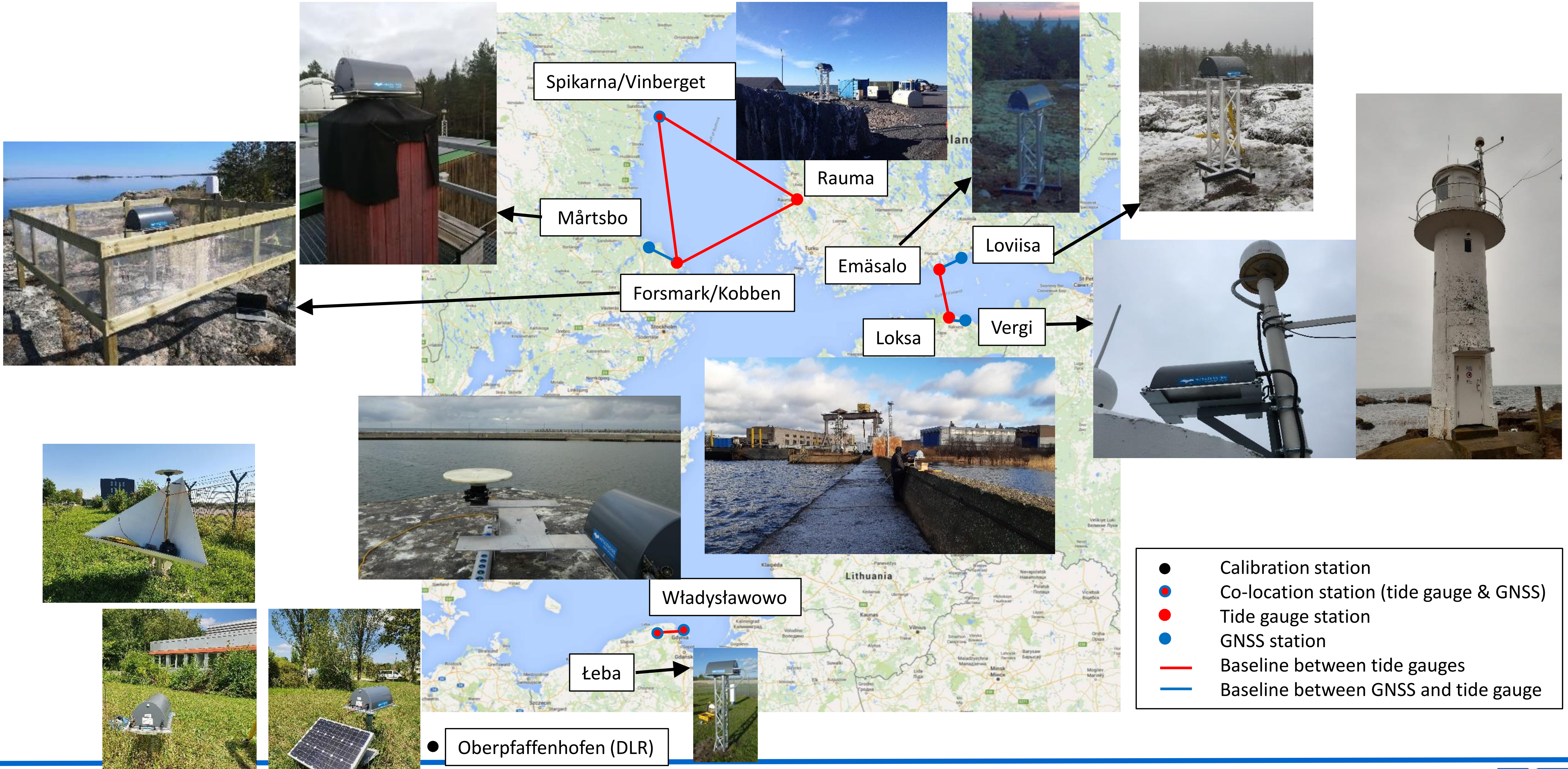
Objective 2
Unify height system at tide gauges to compute absolute physical heights with respect to a global reference. Local geoid modelling per tide gauge station.

Objective 3
Combination of geometric and physical heights in a common reference frame to determine absolute sea level heights and to connect height systems.



Reference: Gruber et al (2020), Remote Sens. 2020, 12, 3747; https://doi.org/10.3390/rs12223747

Integration of Geodetic Observations and SAR



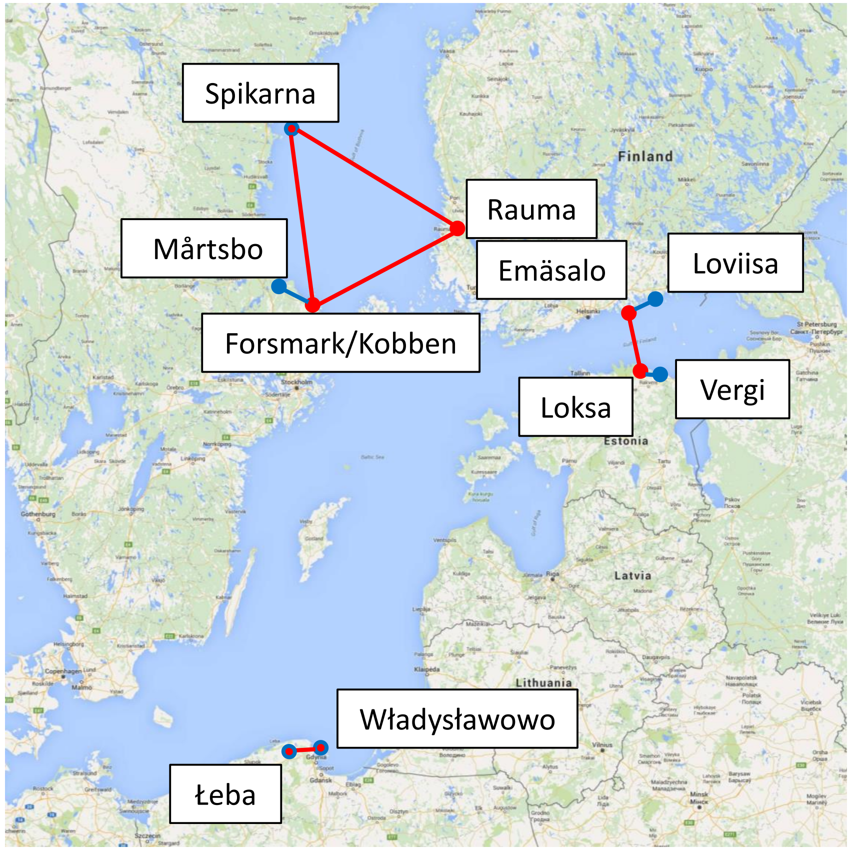
Integration of Geodetic Observations and SAR

Tide Gauge Baseline Sea Level Difference vs. ECR Tide Gauge Height Difference

Station	absolute performance		relative performance TG baseline $\Delta\Delta H^{TG}$ [m]						
	ECR vs. GNSS Δh [m]	ECR vs. TG H^{TG} [m]	LOKS	EMAE	RAUM	KOBB	WLAD*	LEBA*	VINB*
			Station B						
Loksa (LOKS)		0.616		0.648	0.637	0.299	0.497	0.063	-0.45
Emäsalo (EMAE)		-0.032	-0.648		-0.011	-0.349	-0.151	-0.585	-1.098
Rauma (RAUM)		-0.21	-0.637	0.011		-0.338	-0.14	-0.574	-1.087
Kobben (KOBB)		0.317	-0.299	0.349	0.338		0.198	-0.236	-0.749
Władysławowo (WLAD) *	-0.017	0.119	-0.497	0.151	0.14	-0.198		-0.434	-0.947
Łeba (LEBA) *	-0.435	0.553	-0.063	0.585	0.574	0.236	0.434		-0.513
Vinberget (VINB)*	-0.446	1.066	0.45	1.098	1.087	0.749	0.947	0.513	

Station A

5	**Stable** performance of the ECR with **high agreement** with GNSS or TG Measurements (≤ 0.15m)
3 (1)	**Stable** performance of the ECR with **low agreement** with GNSS or TG Measurements (≥ 0.15m)
1 (1)	**Unstable** performance of the ECR with **low agreement** with GNSS or TG Measurements (≥ 0.15m)



● Oberpfaffenhofen (DLR)

- Calibration station
- Co-location station (tide gauge & GNSS)
- Tide gauge station
- GNSS station
- Baseline between tide gauges
- Baseline between GNSS and tide gauge

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Summary

- Geodetic SAR positioning is similar to Precise Point Positioning with GNSS. Delay corrections and calibration is more challenging for SAR.
- Most accurate SAR positioning achieved with TerraSAR-X using improved orbit solutions. Accuracy by a factor of 2 to 3 worse than with GNSS depending on size of reflectors, number of passes and viewing geometries (*Gisinger)*
- At low latitudes azimuth observation accuracy is driving the North coordinate accuracy, while range observation accuracy is responsible for the East and Height coordinate accuracies. The latter are strongly influenced by multiple observation geometries *(Gisinger)*.
- For Sentinel-1, coordinate errors are significantly larger due to higher errors in azimuth and range observations (C-Band radar). The height component is less degraded due to observation geometry *(Gisinger)*
- For Sentinel-1 positioning accuracies can be improved by the number of repeated measurements (*Gisinger)*.
- Combination of multiple SAR missions with identical targets would provide best results *(Gisinger)*.

Outlook - SAR for Geodesy

- Geodetic SAR positioning less flexible than GNSS. Long-term position monitoring might be a possible application, but short term solutions are hardly achievable with SAR.
- Densification of permanent GNSS networks with SAR targets might be interesting as SAR doesn´t require sophisticated ground infrastructure (for passive reflectors).
- Relative positioning might reduce several kind of errors in SAR positioning?
- Passive targets need to be protected against rain and snow and shall be large enough to use them for different missions (radar bands).
- SAR as a satellite tracking technique for orbit validation or as observable to improve orbits. Compared to other techniques (like SLR) SAR is limited to single observations per path. Possible applications regarding the development of the ITRF can be considered (Gisinger).
- The accuracy of the orbit solution is the main driver for the measurement accuracy that can be obtained with the corrected and calibrated observations *(Gisinger)*.
- For geodetic applications calibration of sensors and targets is most critical. Also monitoring of the evolution of calibration parameters is required.