Geodetic SAR for Height System Unification & Sea Level Research Observation Concept and Results in the Baltic Sea

T. Gruber[1], J. Ågren[2], D. Angermann[3], A. Ellmann[4], C. Gisinger[5], J. Nastula[6], M. Poutanen[7], M. Schlaak[1], F. Nilfouroushan[2], S. Varbla[4], R. Zdunek[6], S. Marila[7], A. Engfeldt[2], T. Saari[7], A. Świątek[6]

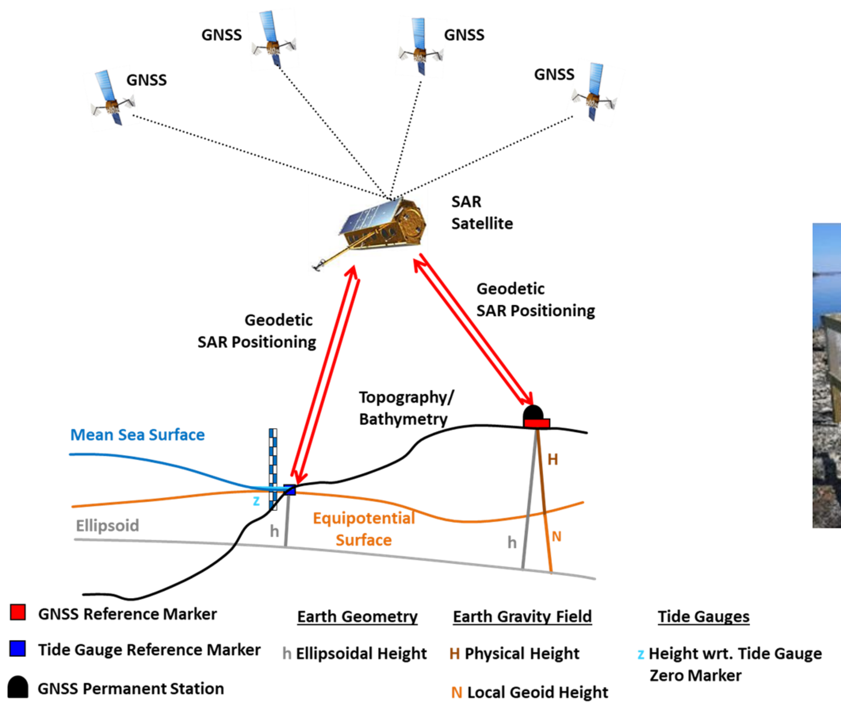
[1] Technical University of Munich, Institute of Astronomical and Physical Geodesy
[2] Lantmäteriet, Swedish Mapping, Cadastral and Land Registration Authority
[3] Technical University of Munich, Deutsches Geodätisches Forschungsinstitut
[4] Tallinn University of Technology, School of Engineering
[5] German Aerospace Center, Remote Sensing Technology
[6] Centrum Badań Kosmicznych, Polskiej Akademii Nauk
[7] Finnish Geospatial Research Institute

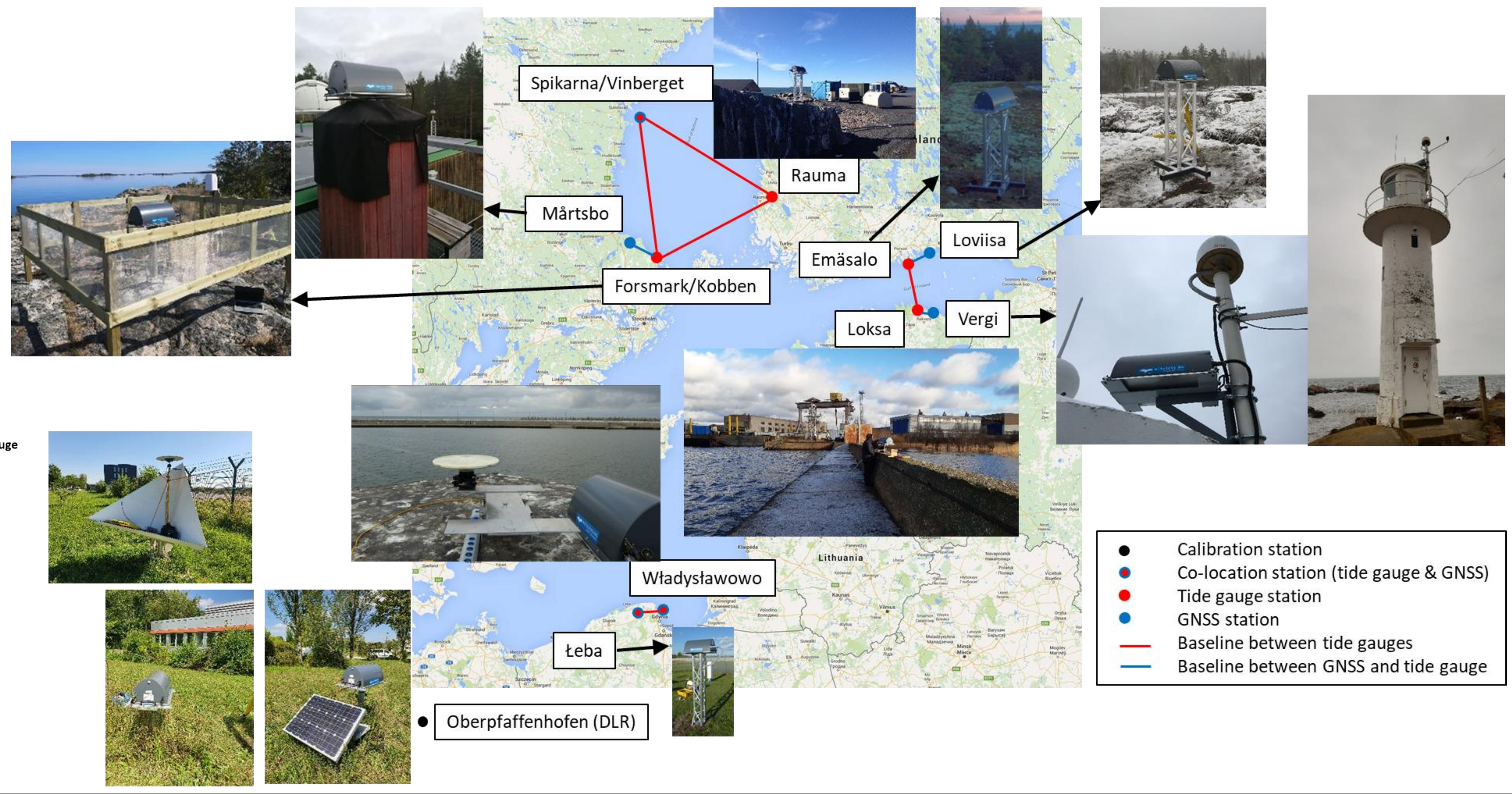
Introduction

Traditionally, **sea level** is observed at **tide gauge** stations, which usually also serve as **height reference stations** for national leveling networks. One of the main deficiencies to use tide gauge data for geodetic sea level research and height systems unification is that only a **few stations are connected to permanent GNSS** receivers next to the tide gauge in order to systematically **observe vertical land motion**. As a **new observation technique, absolute positioning by SAR** using active transponders on ground can fill this gap by systematically observing time series of geometric heights at tide gauge stations. By additionally knowing the tide gauge **geoid heights** in a global height reference frame, one can finally obtain **absolute sea level heights at each tide gauge**. With this information the impact of climate change on the sea level can be quantified in an absolute manner and height systems can be connected across the oceans.

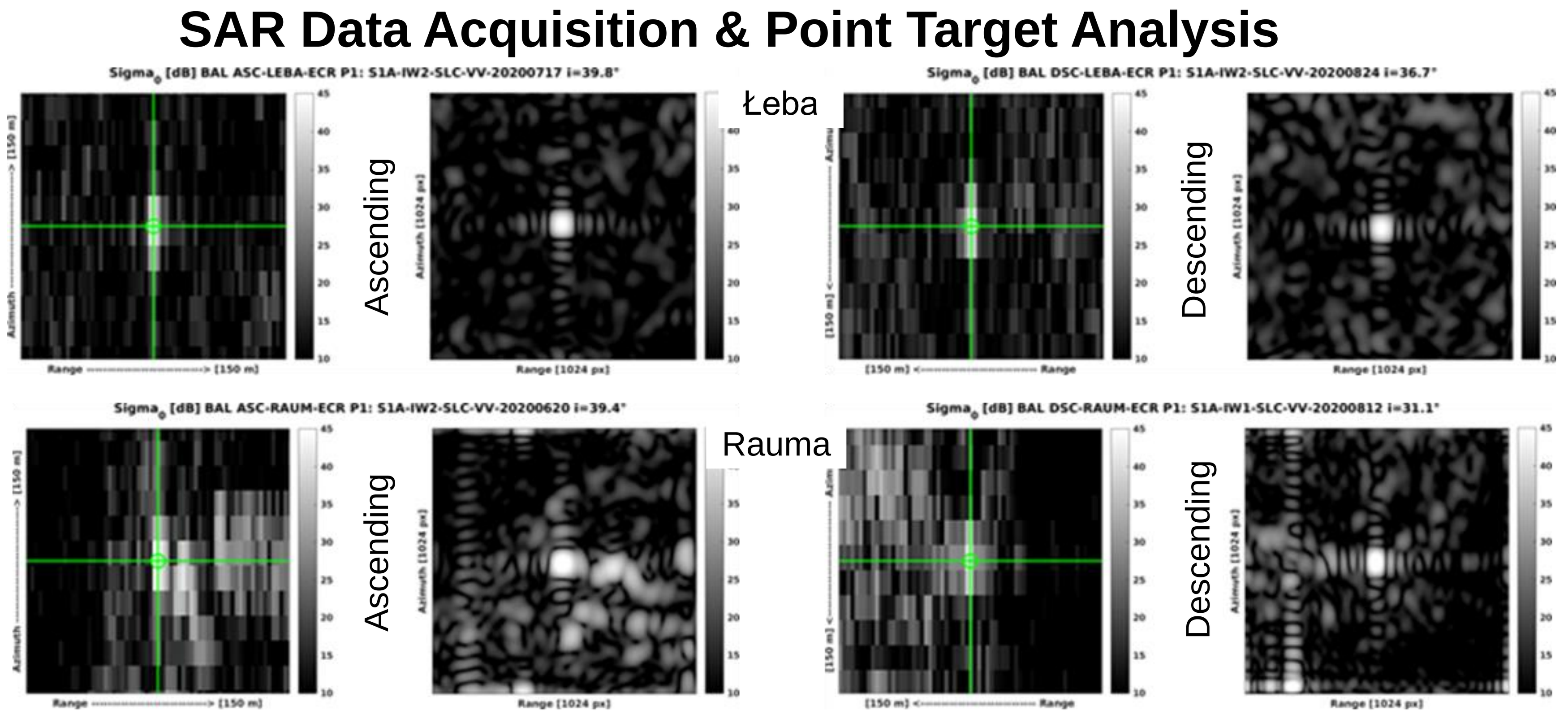
Baltic Sea Test Network

A **test network of electronic corner reflectors (ECR)** as targets for Sentinel-1 was realized in the Baltic Sea area. The ECR **locations were co-located with tide gauges and/or with permanent GNSS stations** in order to observe systematically the ellipsoidal heights of the tide gauges. Data for the year 2020 were collected at **10 stations** in Estonia, Finland, Poland and Sweden and jointly analyzed with GNSS data, tide gauge records and regional geoid height estimates.





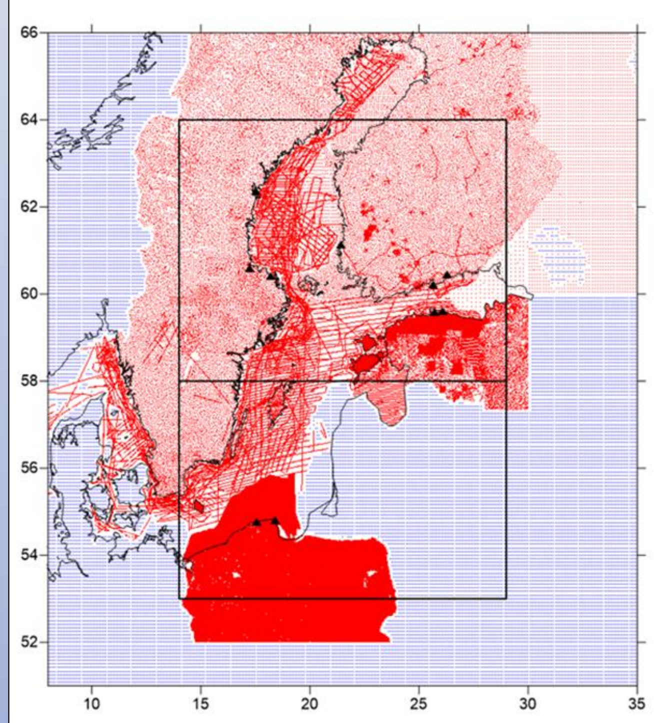
SAR Data Acquisition & Point Target Analysis

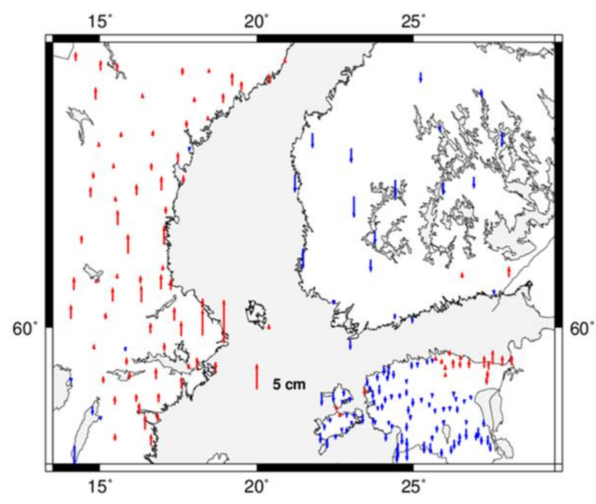


Left columns: Original Sentinel-1 SLC SAR image samples showing an area of 150 m x 150m around ECR peak marked in green. Right columns: Image areas of 32 x 32 pixels oversampled by a factor of 32 as generated by point target analysis to extract the ECR peak position.

Geoid

Least squares modification of Stokes' formula with additive corrections. **GOCO06S** as reference. Topographic RTM effects from **NKG2015 DEM**. Land uplift correction applied.

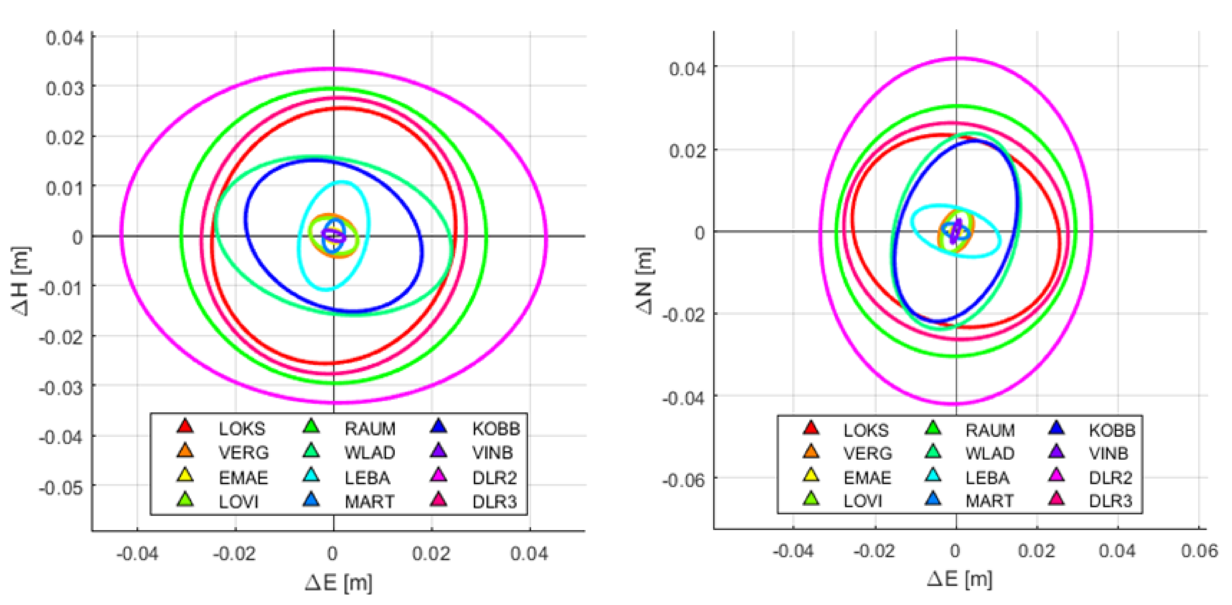




Left: Gravity data for gravimetric quasigeoid. NKG2015 data base plus other open datasets. Pseudo observations (5'x5') from EIGEN-6C4 (blue dots).

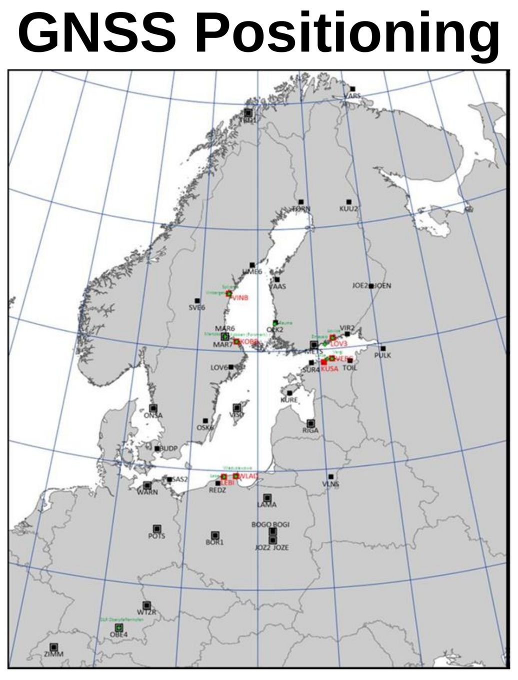
Right: GNSS/levelling residuals. Scale defined by the red arrow in the middle of the Baltic Sea.

SAR Positioning



Confidence ellipses for stations using all available observations in the year 2020. The confidence is shown in the local North, East (right image), and East, height (left image) coordinate frame.

GNSS Positioning



IGS: large square, EPN: small square , EUPOS: red square. RMS below 1 mm per axis.

Heights & Sea Level (Data Combination)

IERS2010 standards are applied to different observation types.

ECR Station @GNSS	Computed Ell. Height [m]	ECR Observed Ell. Height [m]	Difference [m]
Władysławowo	+34.623	+34.640	-0.017
Łeba	+33.954	+34.389	-0.435
Vergi	+29.073	+28.966	+0.107
Loviisa	+46.305	+46.840	-0.535
Mårtsbo	+75.526	+75.477	+0.049
Vinberget	+149.208	+149.654	-0.446

Left: SAR ellipsoidal heights at ECR stations versus co-located permanent GNSS station height using local tie.

Bottom: Physical height of tide gauge above common reference surface.

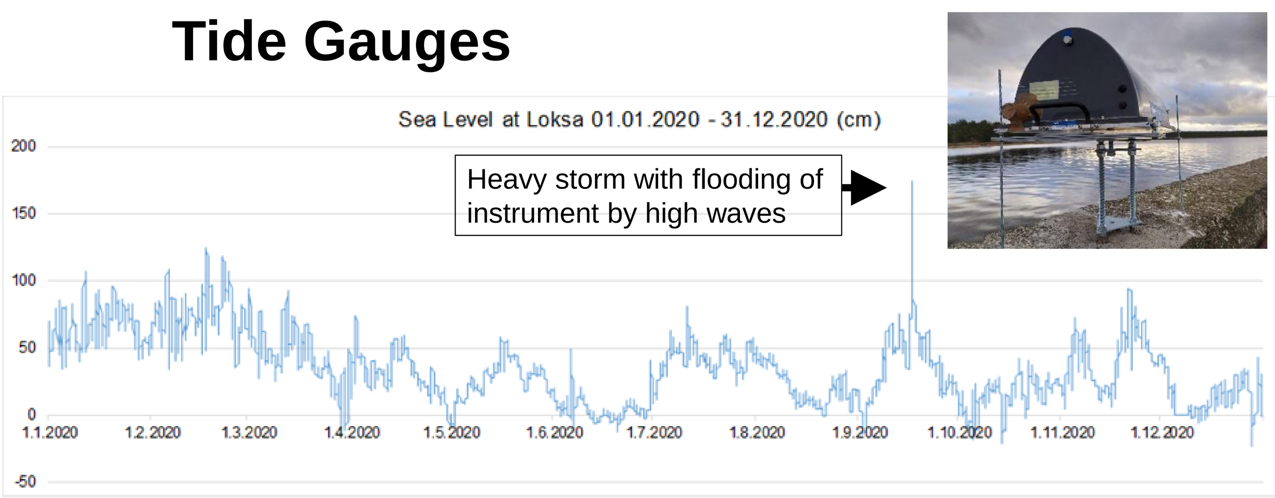
ECR Station @Tide Gauge	Physical Height Tide Gauge [m]
Władysławowo	+0.119
Łeba	+0.553
Loksa	+0.616
Emäsalo	-0.032
Rauma	-0.021
Kobben	+0.317
Vinberget	+1.066

Height differences between ECR & GNSS varying. 3 stations exhibit good agreement at dm level or better. **ECR derived heights cause differences.**

Tide gauges refer to EVRS. In **ideal case height shall be zero**. Deviations can be attributed to the performance of the SAR positioning.

Tide Gauges

Tide gauge readings for all stations in **EVRS**. Preprocessed tide gauge data for 2020 used for **annual mean sea level** in the common EVRS.



Conclusions

Results promising, but also exhibit problems related to the **ECR performance**. At co-located GNSS stations estimated heights agree between 2-50 cm. Most likely variable **electronic instrument delays** of ECRs are main reason. Each instrument needs to be **calibrated individually**. Valuable data set to develop the geodetic SAR positioning technique towards operability. All data and reports are available at: **https://www.asg.ed.tum.de/iapg/baltic/**

References: Gruber, T. et al. Geodetic SAR for Height System Unification and Sea Level Research - Observation Concept and Preliminary Results in the Baltic Sea. Remote Sens. 2020, 12, 3747. **https://doi.org/10.3390/rs12223747**
Gruber, T. et al. Geodetic SAR for Height System Unification and Sea Level Research - Results in the Baltic Sea Test Network; submitted to Remote Sens. 2022, under review.

Acknowledgement: The Project was funded by European Space Agency (ESA), Grant 4000126830/19/I-BG. Considerable Contributions were provided by the participating Institutes.