Status report on the installations of geodetic SAR corner reflectors in Sweden

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LANTMÄTERIET

InSAR (Interferometric Synthetic Aperture Radar)

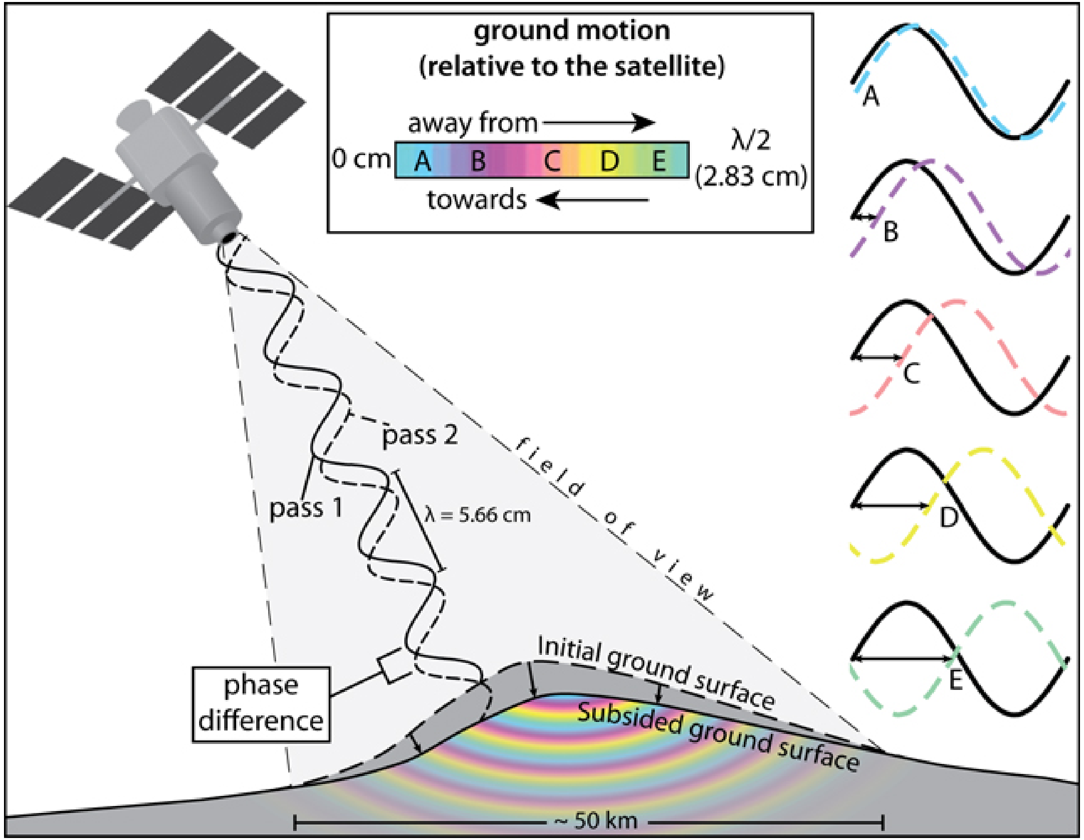
InSAR started in early **90s** with ERS1, 2,…,

SAR is an **active** radar system: the reflected signal is responsive **to surface characteristics like structure and moisture.**

No limitation with clouds;
24 hours system, day and night

-**InSAR** uses several radar images and correlate them for DEM generation and/or **ground motion measurements (DInSAR, PSI, …)**

Relative motion!



Source: volcano.si.edu

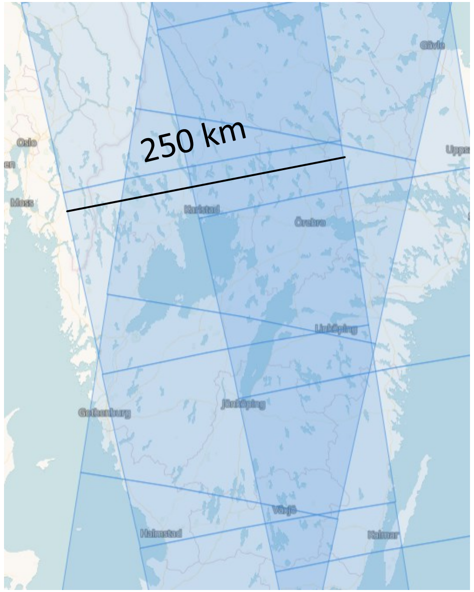
InSAR

Advantages

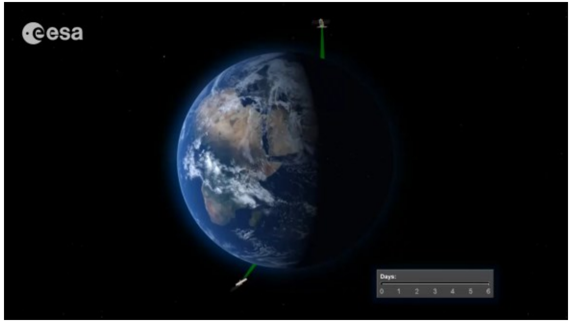
- Monitoring of large area with **Copernicus Sentinel 1** **(**spatial resolution 5X20 m)
- High acquisition frequency (12 days for **S1A**)
- Higher spatial sampling (relative to GNSS)
- Generating time series (**spatio-temporal deformation**)
- Available archived data (ERS1,2, …, Sentinel1 A,B)

Limitations:

- Land cover limitations (vegetations, wetlands, …)
- Snow
- Less sensitive to N-S motion, **mainly vertical and E-W components**

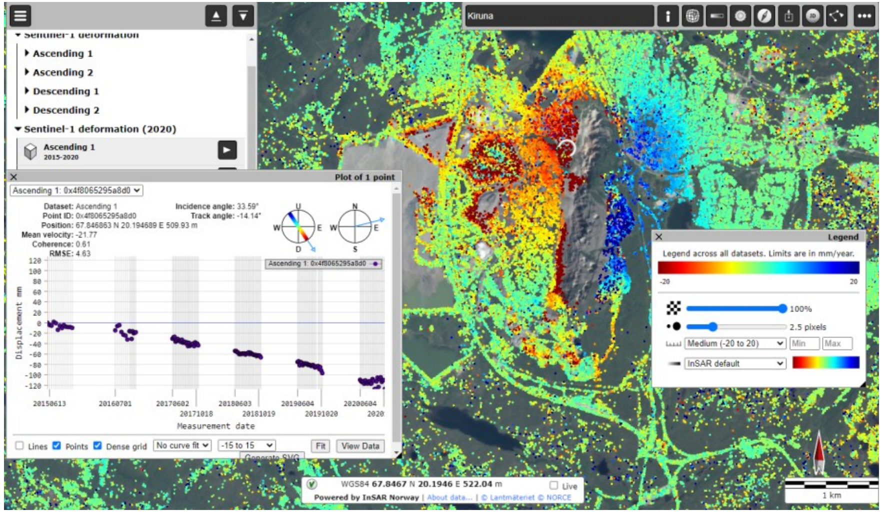


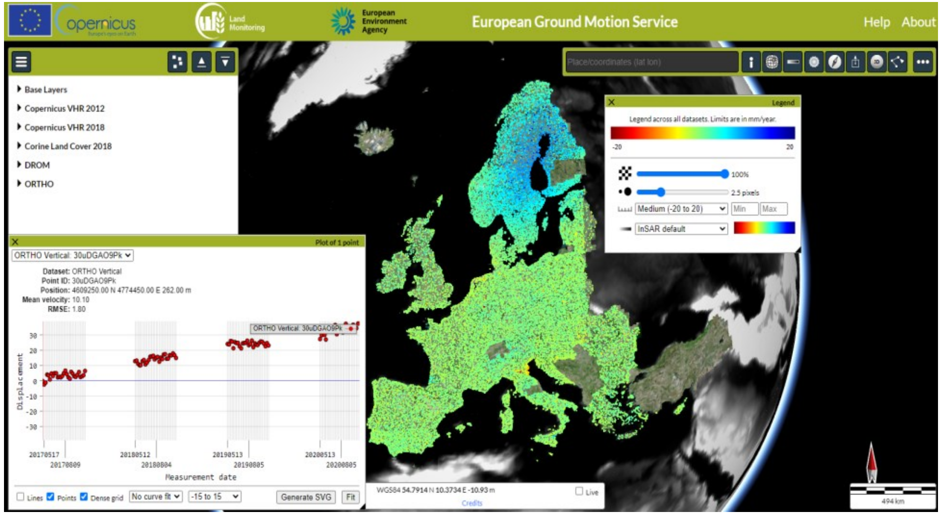
Large area coverage by Sentinel 1



InSAR applications: Ground Motion Services

Interactive ground motion maps and time serries





National Ground motion service of Sweden
https://insar.rymdstyrelsen.se/

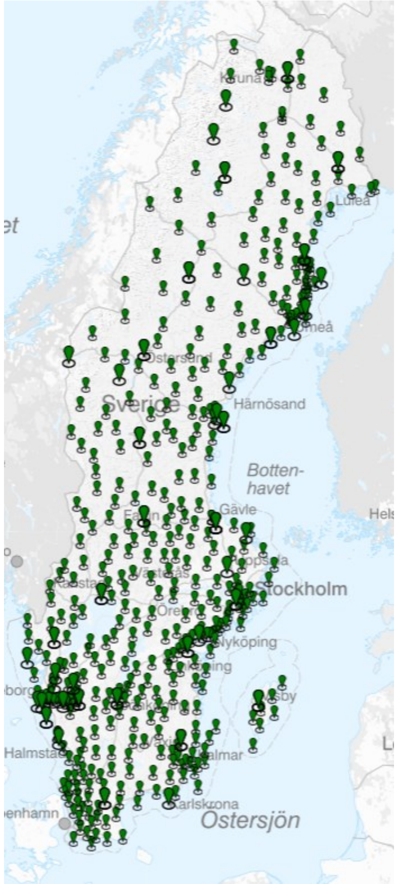
European Ground Motion Service (EGMS)
https://egms.land.copernicus.eu/

InSAR for Geodetic infrastructure

- InSAR can **measure** the ground movements accurately
- More efficient and less expensive stability control of the **geodetic infrastructure** (reference frames, tide gauges, GNSS permanent stations, leveling benchmarks, gravity points)
- Using InSAR time series → Analysis of linear and non-linear deformation
- Better understanding of ongoing processes:

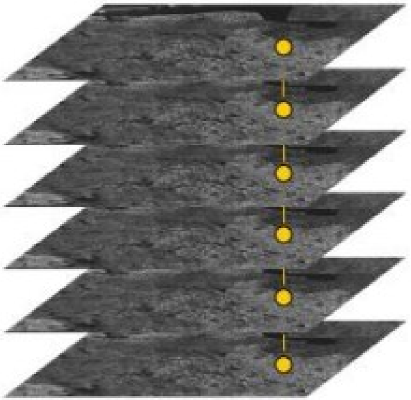
➢ Glacial isostatic adjustments (GIA modeling)
➢ Crustal deformations (plate tectonics,…)
➢ Hydrological loading signals

- Coastal erosion studies and better sea level predictions



Lantmäteriet SWEPOS GNSS stations

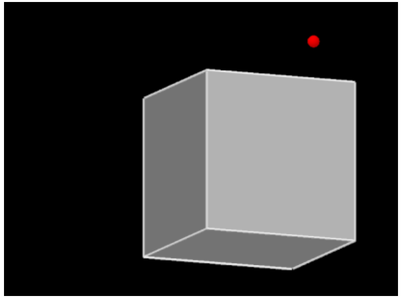
Natural and artificial persistent scatterers



- **Persistent scatterers** are **coherent radar targets** (**PS**) that can be clearly distinguished in all radar images and do not vary in their properties
- Sub-pixel radar reflections are analyzed
- **PS examples**: bare rocks, buildings, …

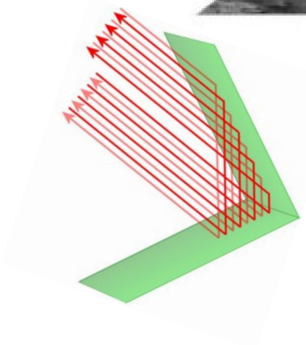
Artificial reflectors (artificial PS), InSAR Corner reflectors!

Useful for precise measurements due to its known Apex coordinates



Trihedral corner reflector

https://commons.wikimedia.org/w/index.php?curid=81552616



Why corner reflectors?

1. **To make a measurement point at desired location** to monitor the movements with InSAR technique accurately
2. **Improve spatial sampling** in areas where there are no natural persistent scatterers (e.g., grass field)

3. Link InSAR and other techniques

- Link and comparison between InSAR and other techniques (e.g., co-location of the CR with GNSS stations); make InSAR "absolute" (calibration)

- Link between different tracks of the same InSAR system, and/or, connection between different InSAR systems

4. Calibration of satellite imagery systems (e.g., NISAR)

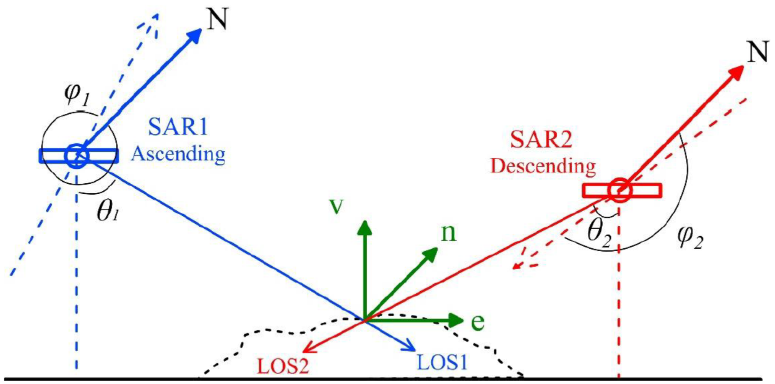


Figure 1. The satellite SAR imaging geometry along the ascending and descending orbits and the projection relation between the LOS displacement and the 3D motion components. The dashed arrows denote the flight directions of the ascending and descending orbits.

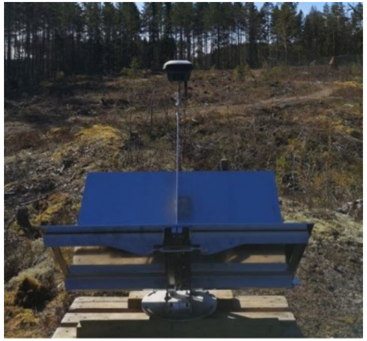
Remote Sensing **2015**, *7*, 9542-9562; doi:10.3390/rs70809542

Best to have both ascending and descending corner reflectors to better project LOS movements to EW and Up/down components

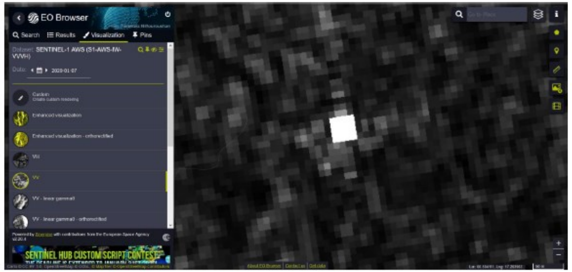
Modified after Hans van der Marel and Ramon Hanssen, EUREF 2018

Active and Passive reflectors

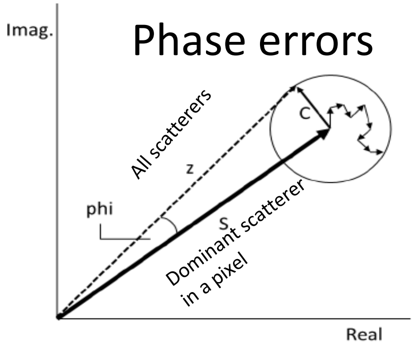
Passive Corner reflectors (no electronics)



Active or Electronic Corner **R**eflectors(**ECR**) or transponders, compact, but needs radio-frequency permission for installation, temperature issue, phase center….

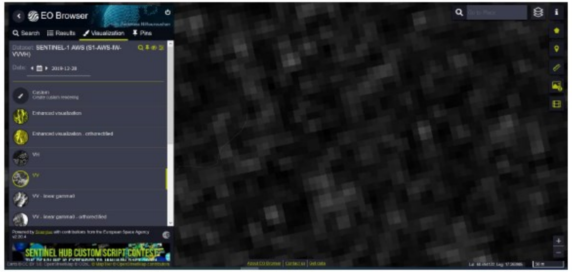


S1 image, January 7th, 2020, the first visit of S1 over the station.



Modified after Garthwaite et al., 2015

Note: “The reflector must be visible in the SAR image above the background signal level (the ‘**clutter**’). The typically used measure of target visibility in a SAR image is the **Signal-to-Clutter Ratio (SCR).** “

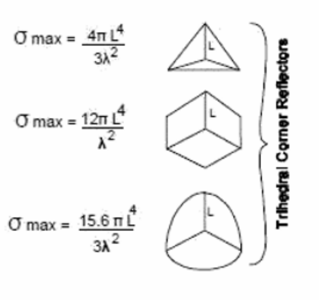


Backscattered images before and after ECR installation

Passive reflectors’ design and size

The radar response depends on target size, shape and radar frequency and other variable factors (clutter noise,…)

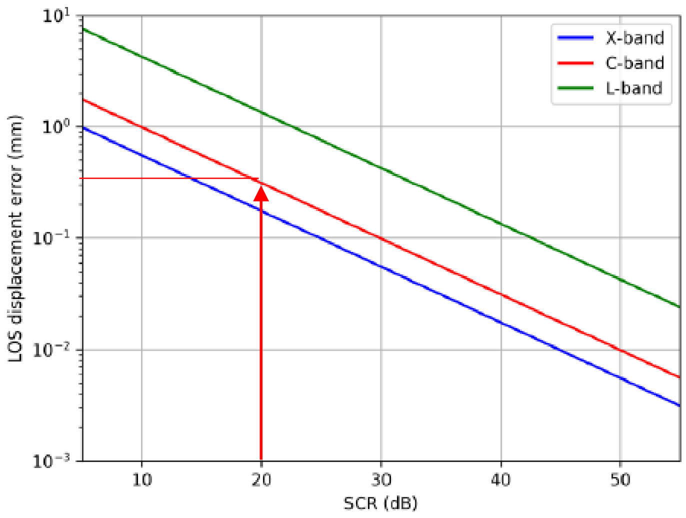
The **Radar Cross Section (RCS)** is the ratio of the energy reflected by the target to the SAR sensor and the transmitted energy.



RCS (dBm2)	a (triangular/m)	a (circular/m)	a (square/m)
25	0.70	0.50	0.40
30	0.93	0.67	0.54
	1.25	0.90	
40	1.66	1.19	0.96
45	2.22	1.59	1.28
50	2.96	2.12	1.71
55	3.94	2.83	2.28

Figure 1. Different type of trihedral corner reflectors and related peak RCS (Garthwaite et al., 2015b).

Based on required accuracy and application, background noise in the target area, the proper CR size and shape is selected.



LOS displacement error as a function of estimated **signal-to-clutter ratio (SCR)** (Garthwaite et al., 2015).

For Sentinel-1, C-band:

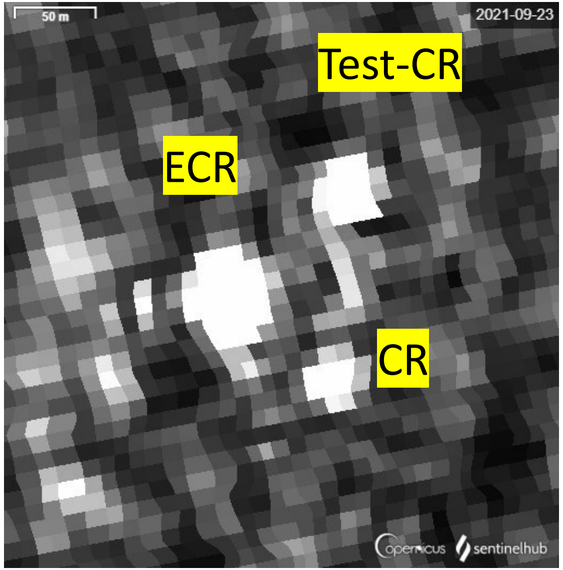
if SCR ~20 dB → LOS displacement error ~0.5 mm

Installation of the Corner reflectors in Sweden

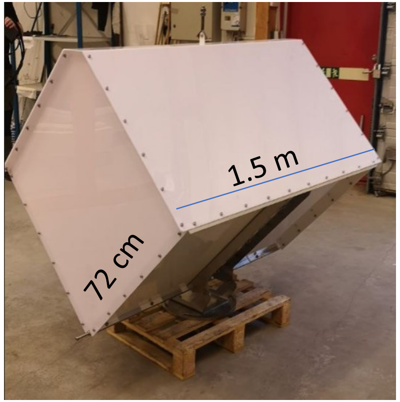
- There are **21** class A GNSS stations**, suggested** for CR locations (some pre-analysis is needed to check the clutter noise of the target location, permissions, road access, etc.).
- Co-located stations; the **time serries and velocities** of GNSS and CRs can be corelated. In case of co-location with GNSS and tide gauges, helps vertical land motion (VLM) and better sea level monitoring.
- Useful for future **calibration of Swedish GMS and European GMS (EGMS)**
- Datum unification, (see ESA Geodetic SAR project)
- **Partially founded by Swedish GMS project** (2021-2023, collaboration between NGU, SNSA, Trafikverket, Lantmäteriet, SGU, SGI, FOI, Chalmers Univ.)

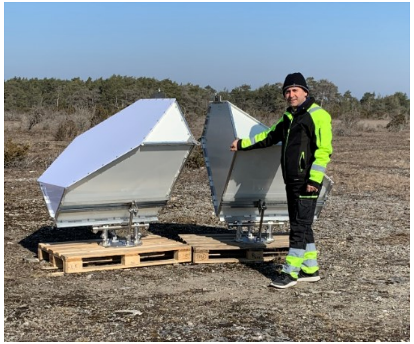
GNSS fundamental stations (red circles) and ECR installations (green)

Experiments: different shapes/size/orientation of passive CRs



VV-linear gamma orthorectified, backscattering time lapse, produced by EO Browser





Field works with colleagues, Hans Åke, Nureldin Gido

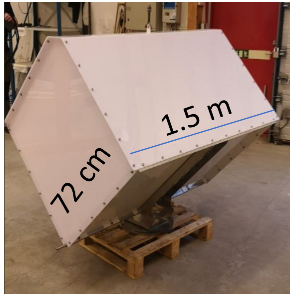
Installation of SAR reflectors (so far)

So far, 11 (active and passive) installed and planned for at least **13** more passive reflectors, office work and site investigations are under progress.

2022
- **01-Sep-22** **CR- Östersund (ASC+DSC)**
- **14-Jun-22** **CR - Sveg (ASC+DSC)**
- **11-May-22** **CR - Visby (ASC)**
- **11-May-22** **CR - Visby (DSC)**

2021
- **4-Nov-21** **CR- Norrkoping (ASC+DSC)**
- **14-Sep-21** **CR- Mårstbo (ASC)**
- **10-Sep-21** **CR- Onsala (DSC)**
- **01-Jun-21** **CR- Onsala (ASC)**

2020
- **01-Oct-20** **ECR - Vinberget (ASC+DSC)**
- **01-Jun-20** **ECR - Kobben (ASC+DSC)**
- **07-Jan-20** **ECR - Mårtsbo (ASC+DSC)**



Installed during ESA Geodetic SAR project

Installation of SAR passive reflectors

- Installed on bedrocks
- Apex position and orientation of the CR with NRTK GNSS measurements
- Co-located with GNSS stations (and for some stations with absolute gravity points)

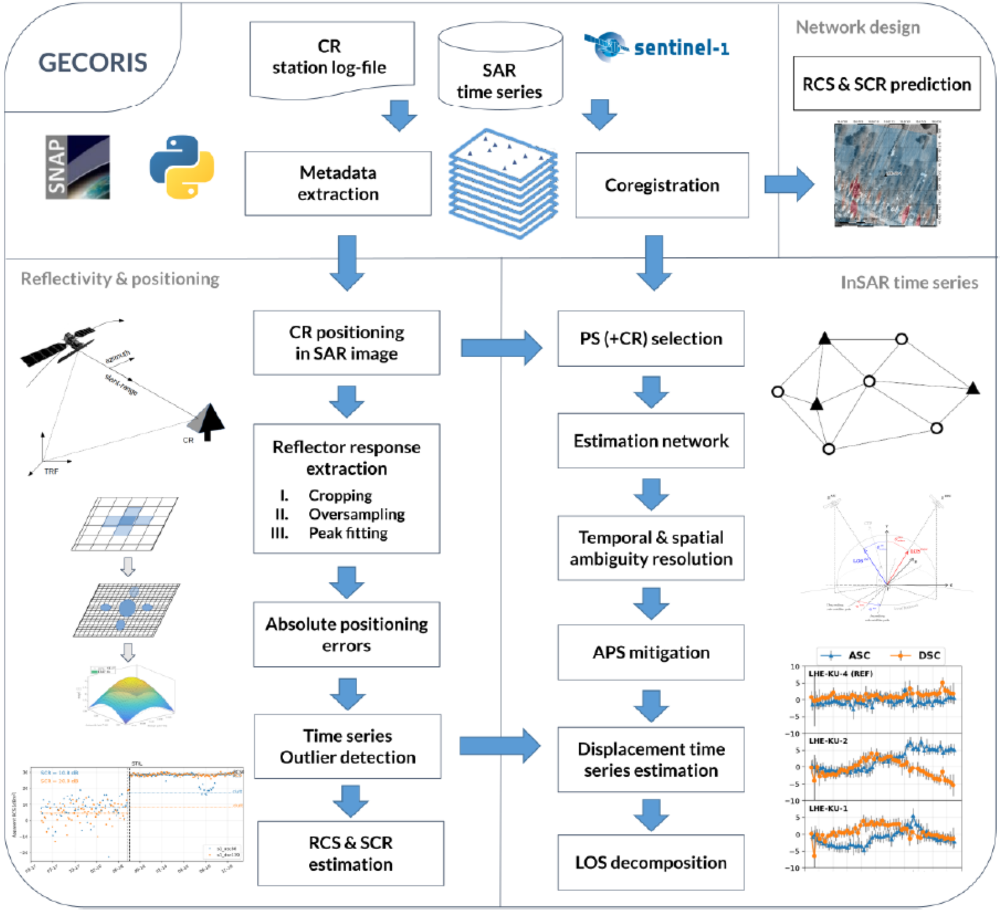
Image credit: Gunnar Elgered

Data analysis using (GECORIS) toolbox

(ESA SNAP + Python scripts)

https://gecoris.readthedocs.io/en/latest/index.html

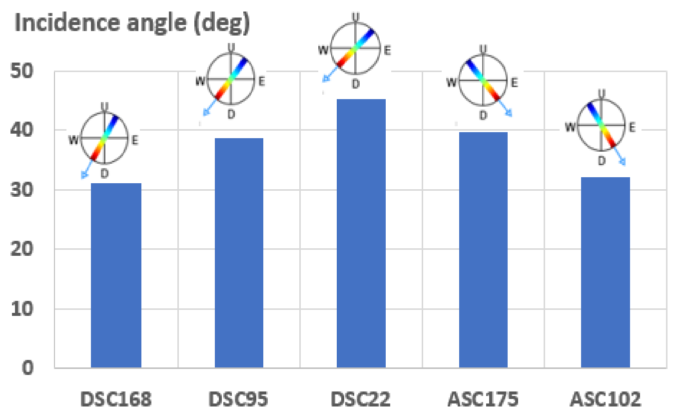
So far, we have done RCS and SCR prediction and estimation, not yet InSAR time series…



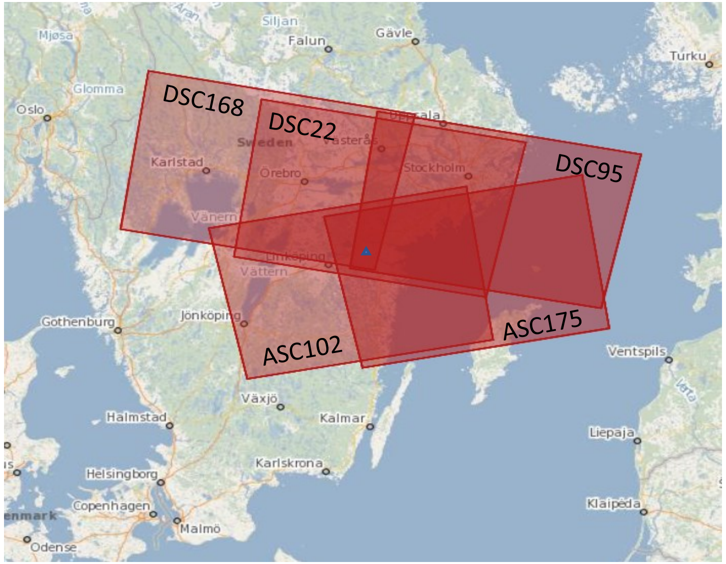
https://www.mdpi.com/2072-4292/13/5/926

SAR data analysis, Norrköping (1)

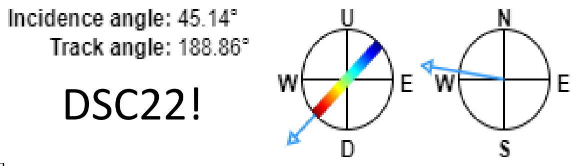
One year of Sentinel-1 SLC data for
2 Ascending and 3 descending tracks, before and after installations

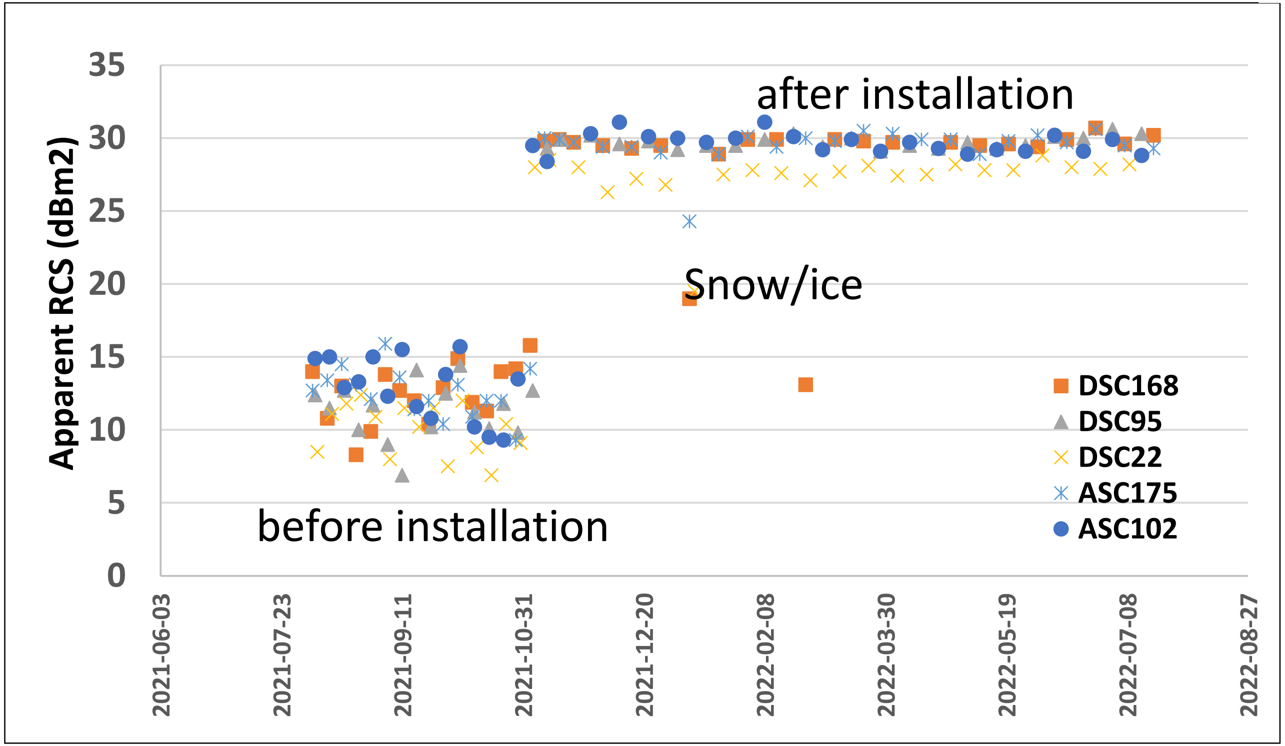


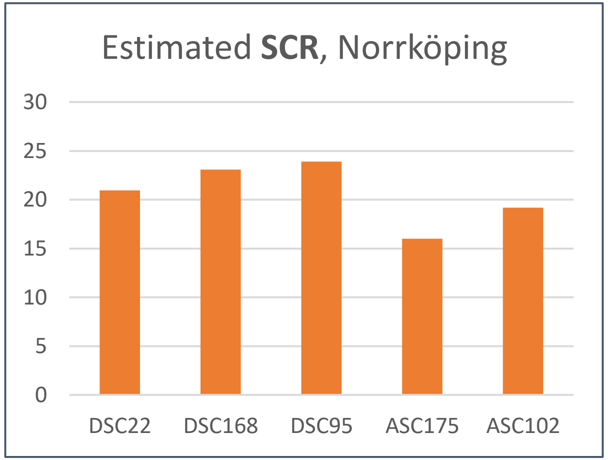
DBFT (60 cm inner leg, corner reflector in Norrköping, installed November 4th 2021



SAR data analysis, Norrköping (2)





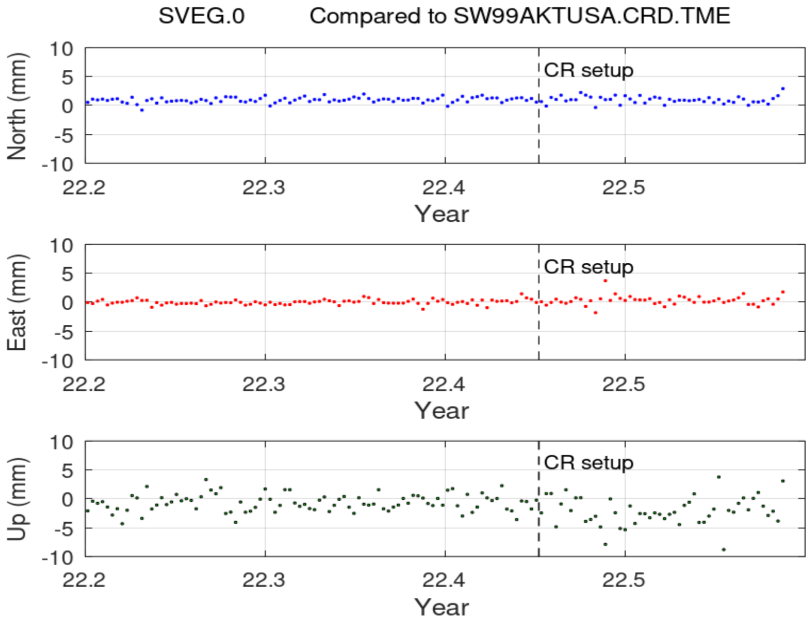


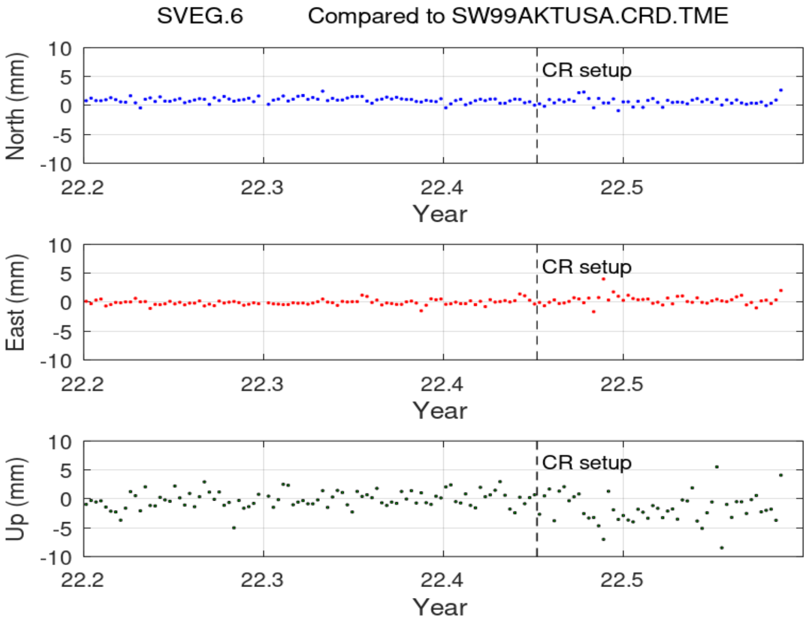
For Sentinel-1, C-band:

if SCR ~20 dB → LOS displacement error ~0.5 mm

Any multipath effect on SVEG.0 and SVEG.6 daily GNSS coordinates?

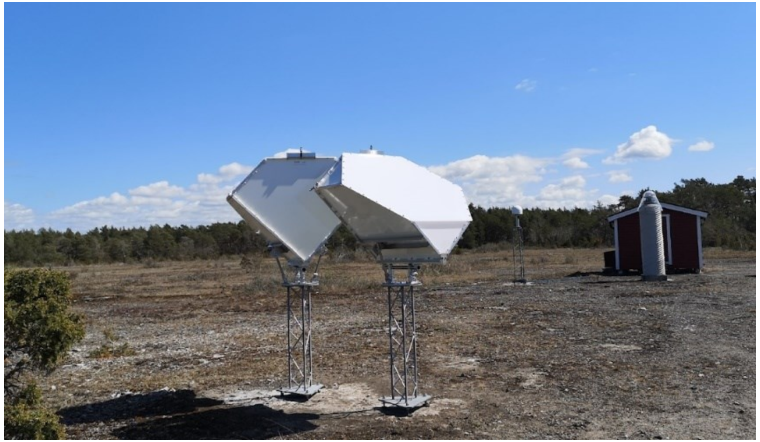
Coordinate time series of two GNSS stations before and after CR installation (different antenna, ~6 m away from corner reflector)

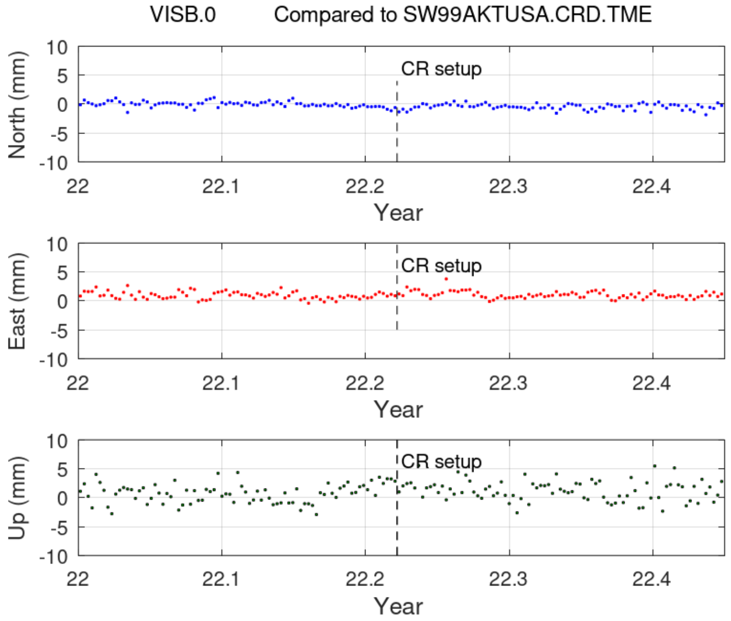


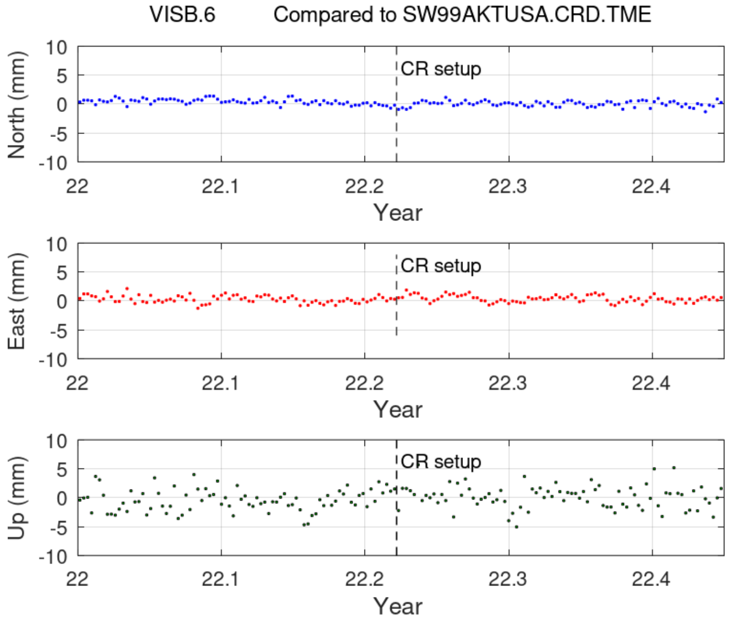


Any multipath effect on VISB.0 and VISB.6 daily GNSS coordinates?

Coordinate time series of two GNSS stations before and after CRs installation (different antenna!, ~20 m away from two corner reflectors)







Thank you for your attention!

Co-located corner reflectors and GNSS stations in Visby, May 11th, ,2022

(Photo: F. Nilfouroushan)