Establishment of a new geodetic infrastructure in Sweden using SAR Corner Reflectors (Progress report)

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LANTMÄTERIET

InSAR (Interferometric Synthetic Aperture Radar)

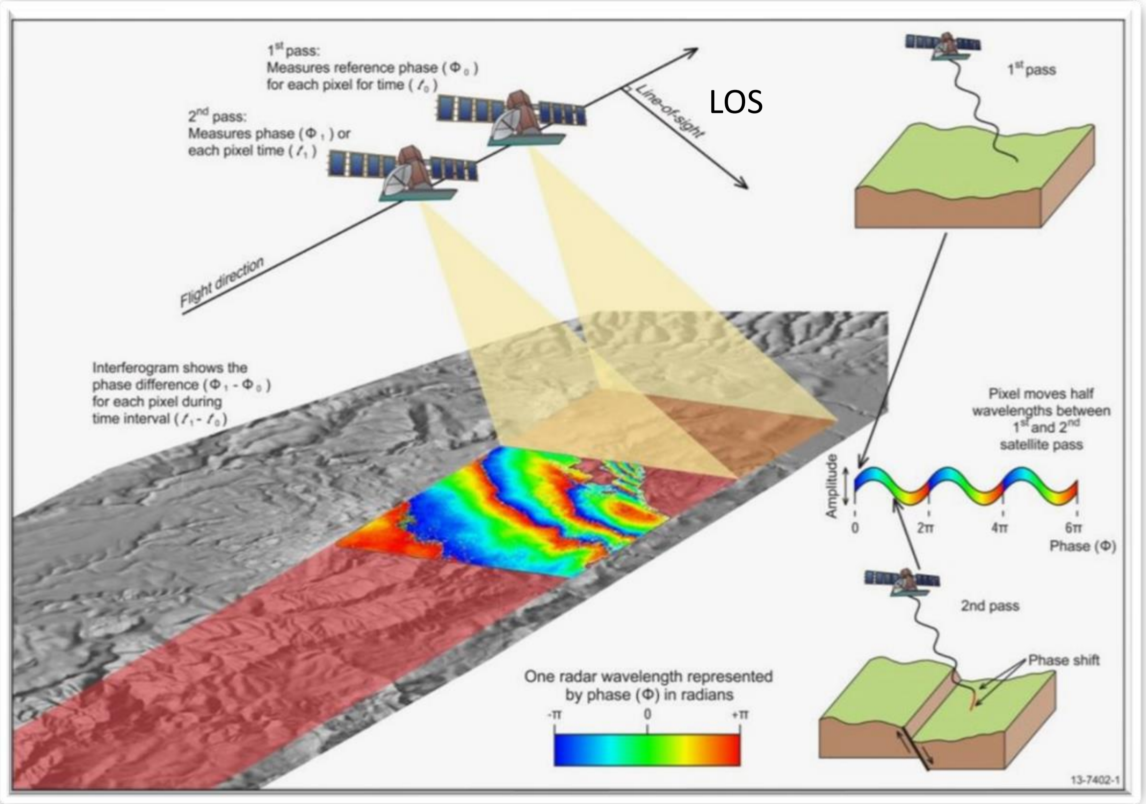
InSAR started in early **90s** with ERS1, 2,…,

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!



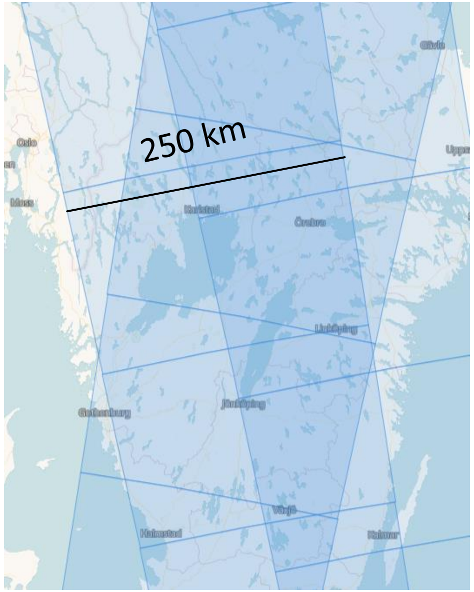
InSAR

Advantages

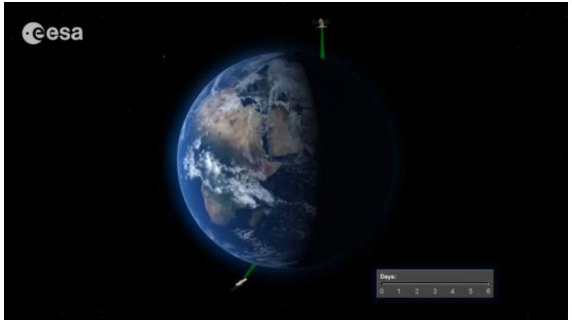
- Monitoring of large area with **Copernicus Sentinel 1** **(**spatial resolution 5X20 m)
- High acquisition frequency (for **S1A and B (not healthy!) every 6 days**)
- Higher spatial sampling (relative to GNSS)
- Generating time series (**spatio-temporal deformation**)
- Free of charge archived data (ERS1,2, …, Sentinel1)

Limitations:

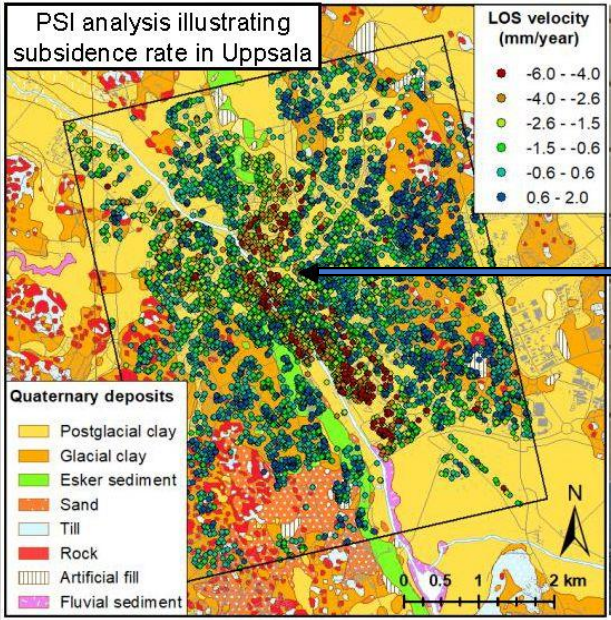
- Land cover limitations (vegetations, wetlands, …)
- Snow
- Less sensitive to N-S motion, **mainly vertical and E-W components**

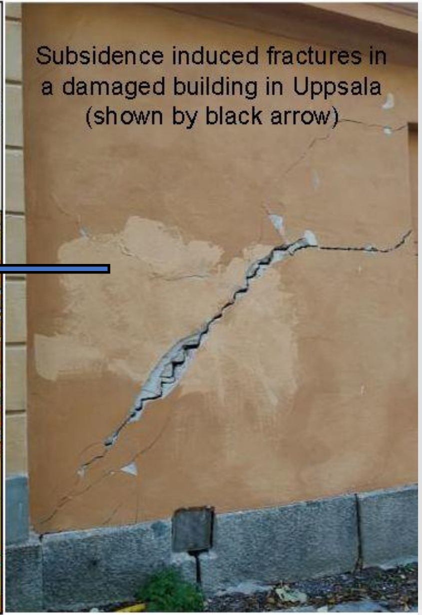


Large area coverage by Sentinel 1



InSAR applications: Land subsidence in Uppsala and Gävle Cities





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Article

Analysis of Clay-Induced Land Subsidence in Uppsala City Using Sentinel-1 SAR Data and Precise Leveling

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check for updates

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Article

Localized Subsidence Zones in Gävle City Detected by Sentinel-1 PSI and Leveling Data

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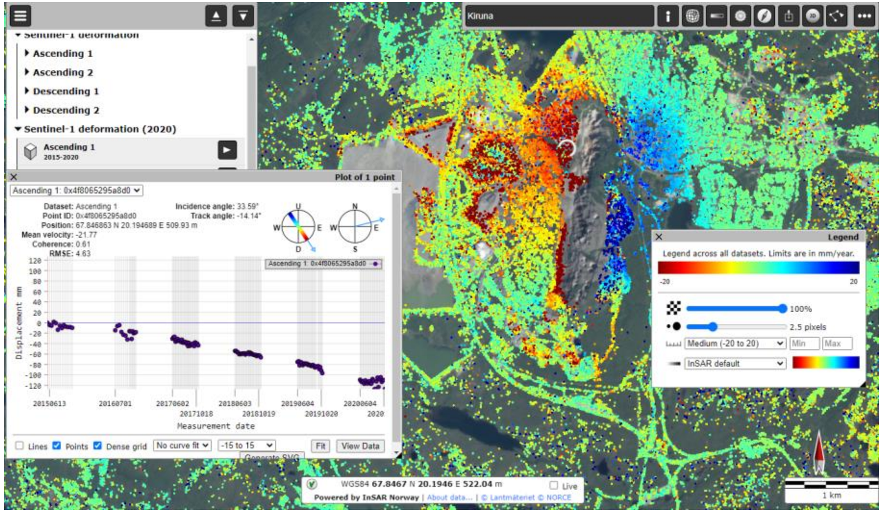
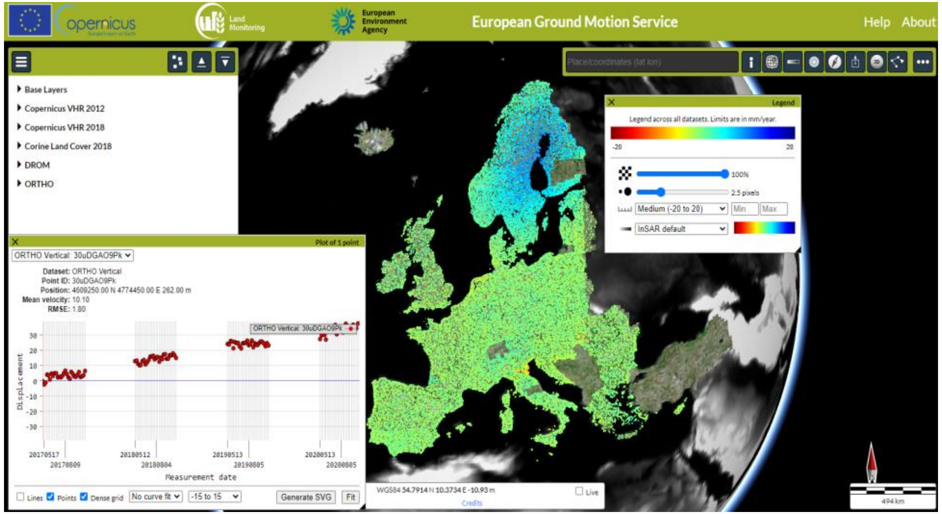
check for updates

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

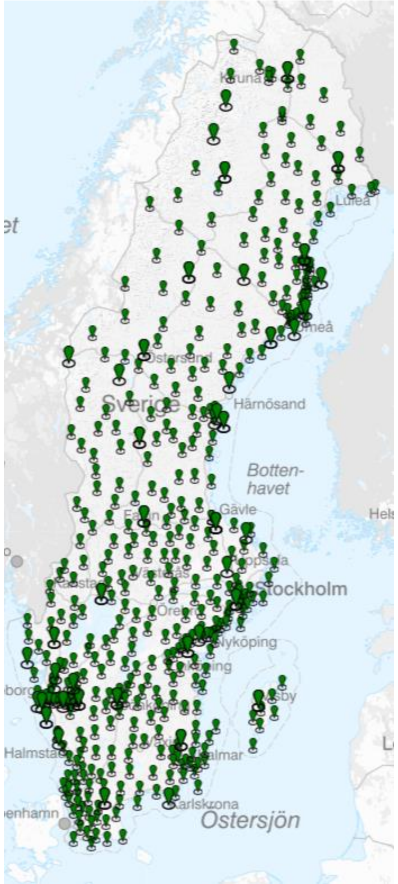
- InSAR can **measure** the ground movements accurately

- More efficient and less expensive stability control of the **geodetic infrastructure** (reference frames, tide gauges, GNSS permanent stations, leveling benchmarks, gravity points)

- Analysis of linear and non-linear movements

- 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 reference 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
- Linear and non-linear movements are identified

- **Natural coherent radar targets are abundant in urban areas but are very scarce in the vegetated and mountainous areas**

InSAR Corner reflectors, artificial reflectors (PS)!

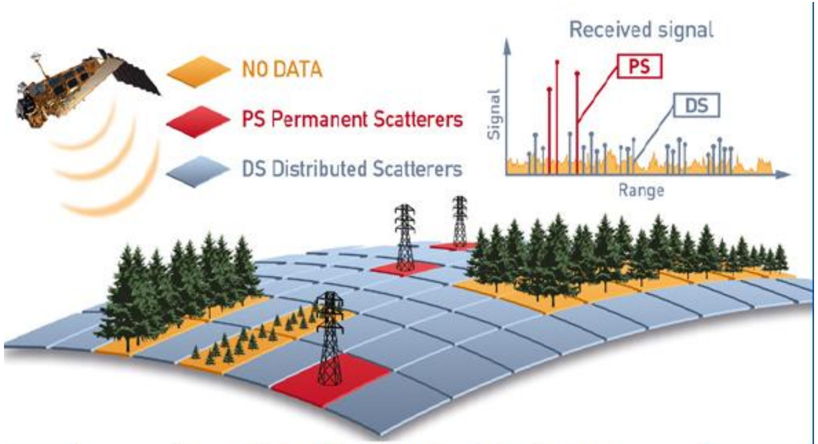
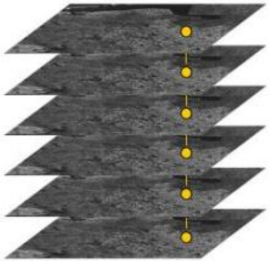


Image from TeleRilevamento Europa

PS: Natural: bare rocks, buildings, …
Artificial: corner reflectors, transponders
DS: cultivated field, debris, sparse vegetation areas, …



Why corner reflectors?

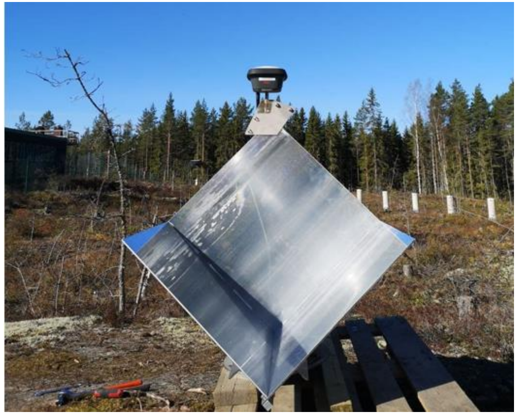
1. **To make a measurement point at desired location** to monitor the movements with InSAR technique accurately
2. **Improve spatial sampling** in areas where there are no natural persistent scatterers (e.g., grass field)

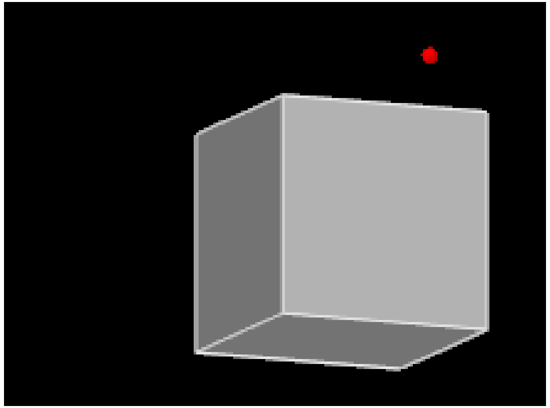
3. Link InSAR and other techniques

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

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

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





Animation showing the reflected rays in a corner of a cube (corner reflector principle) source: *https://en.wikipedia.org/wiki/Corner_reflector*

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

Corner reflectors applications

Different applications, for example Landslide monitoring

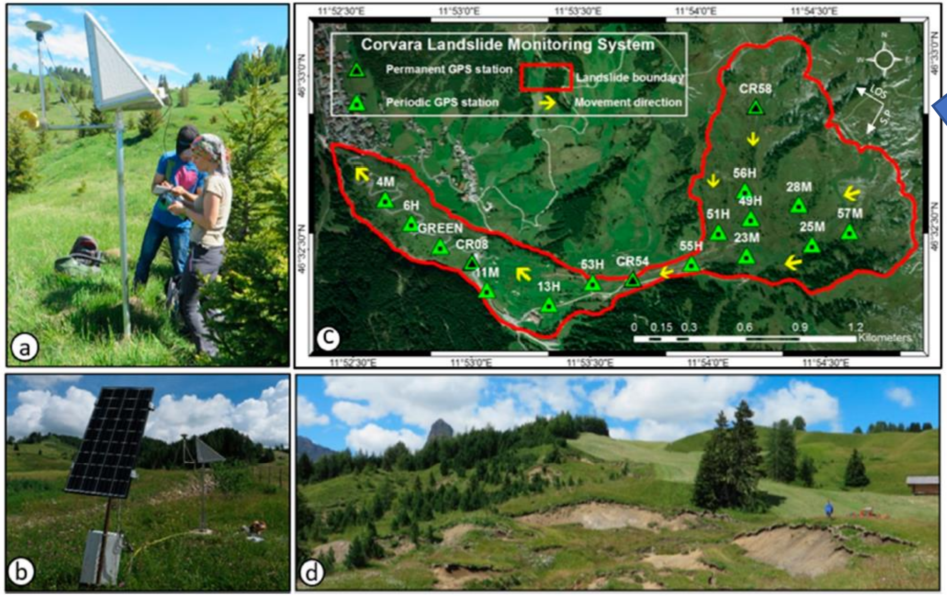
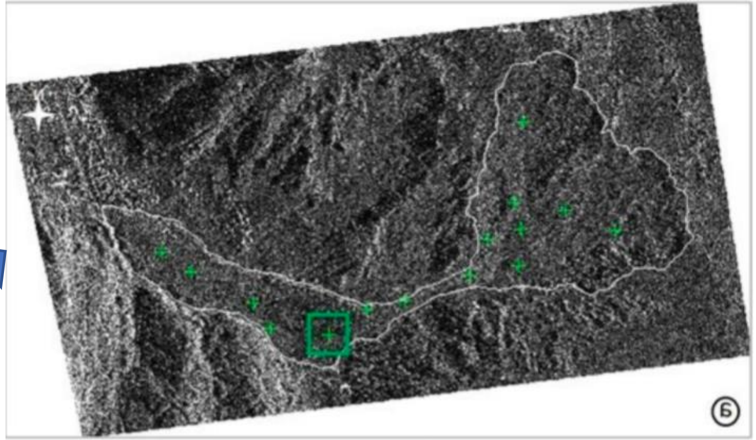
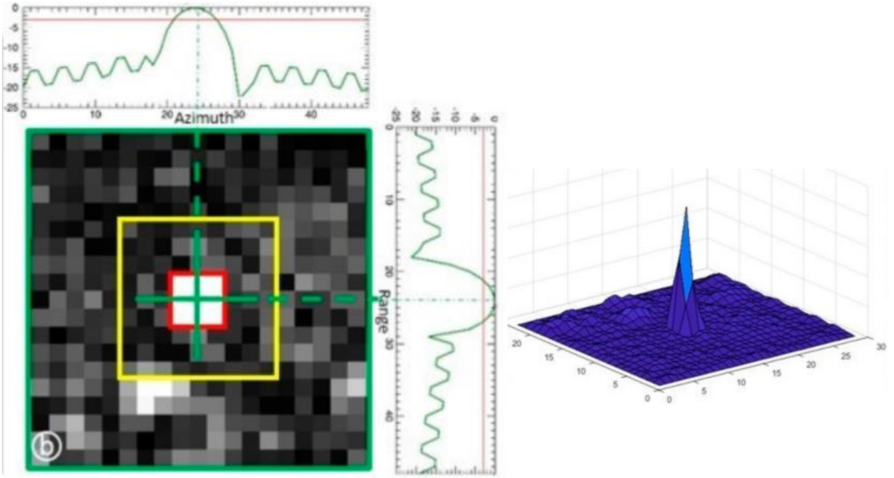


Figure 1. Corvara landslide monitoring system. (a) Periodic GPS measurements (monthly);

Corner reflectors in Alps (Darvishi et al. 2018)

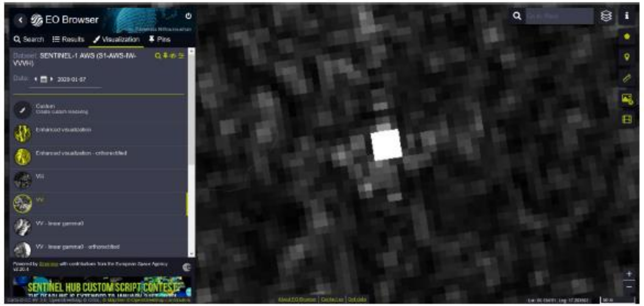




Active and Passive reflectors

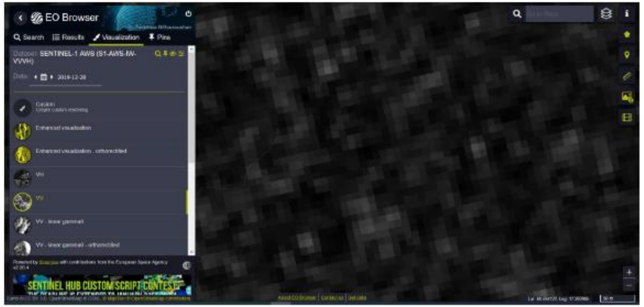
Passive Corner reflectors (no electronics)

Active or Electronic Corner **R**eflectors(**ECR**) or transponders, compact, but needs radio-frequency permission for installation



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

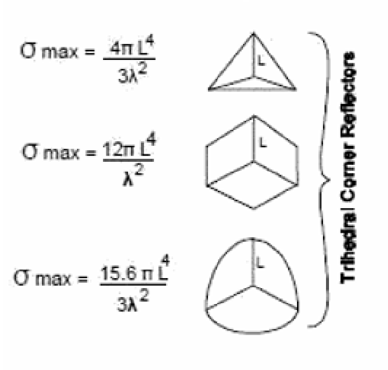
Backscattered images before and after ECR installation



Passive reflectors’ design and size

The radar response depends on target size, shape and radar frequency.

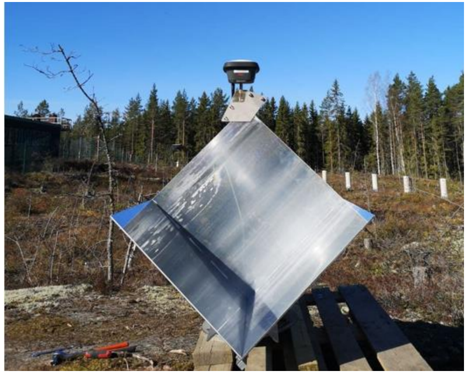
The **Radar Cross Section (RCS)** is the ratio of the energy reflected by the target to the SAR sensor and the transmitted energy.



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
35	1.25	0.90	0.72
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, the proper CR size and shape is selected



Ascending and descending tracks, Line of sight (LOS)

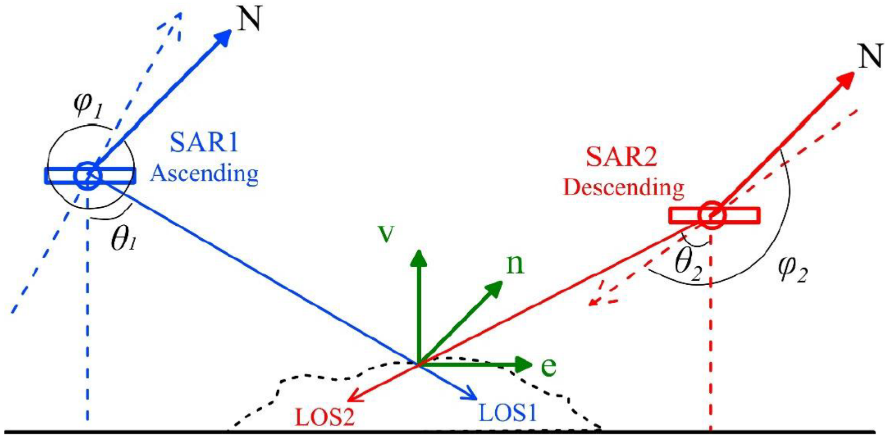
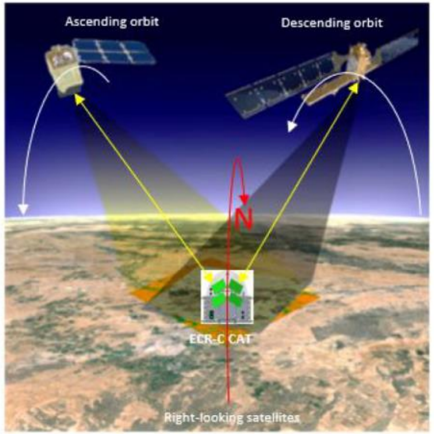


Figure 1. The satellite SAR imaging geometry along the ascending and descending orbits and the projection relation between the LOS displacement and the 3D motion components. The dashed arrows denote the flight directions of the ascending and descending orbits.

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



tud > citg > grs > dpga > **ecrActTimes**

TUDelft

ECR Activation Times

Enter station name and ECR position

Station name visb Latitude 57.394933 [deg] Longitude 17.259620 [deg] Height 48 [m]

Submit

```
Your request is being processed, please be patient, it could take up to 15-20 seconds...

Loaded TLE from tledata/resource-20-May-2022.tle
range:    15-May-2022 00:00:00 - 27-May-2022 00:00:00
stepsize: 00:00:05


Acquisitions visb (Lat/Lon/Hgt 57.3949 17.2596 deg, 48.0 m):

Acquisition time     Incidence  Azimuth  Orb  Satellite

2022-05-21 05:15:28    33.030   101.788  DSC  SENTINEL-1B
2022-05-21 16:28:40    34.071   258.434  ASC  SENTINEL-1B
2022-05-22 05:07:59    40.567   100.036  DSC  SENTINEL-1A
2022-05-26 16:36:51    41.441   260.175  ASC  SENTINEL-1B
2022-05-27 05:16:09    33.003   101.799  DSC  SENTINEL-1A
2022-05-27 16:29:22    34.092   258.445  ASC  SENTINEL-1A
2022-05-28 05:07:17    40.548   100.045  DSC  SENTINEL-1B
2022-06-01 16:37:32    41.460   260.184  ASC  SENTINEL-1A
```

Establishment of a CR network in Sweden

- There are **21** class A permanent GNSS stations with inter spacing around **250 km, suggested** for CR locations (some pre-analysis is needed in advance to check the background noise of the target area).

- Co-located stations; the **time serries and velocities** of GNSS and CRs can be corelated. In case of co-location with tide gauges, helps vertical land motion (VLM) and better sea level monitoring.

- Useful for **calibration of Swedish GMS and European GMS (EGMS)**

- Datum unification, possibility of linking Swedish CR network to the ones in the neighbor countries (Denmark, Finland, Norway, …), **making a regional network**

ECR locations in Sweden

1-**Mårtsbo**, installed January 7, 2020 (3 GNSS around)
2-**Kobben (Forsmark)** installed June 1, 2020 (GNSS + tide gauge)
3-**Vinberget (VINB)**, installed October 1, 2020 (GNSS + tide gauge)

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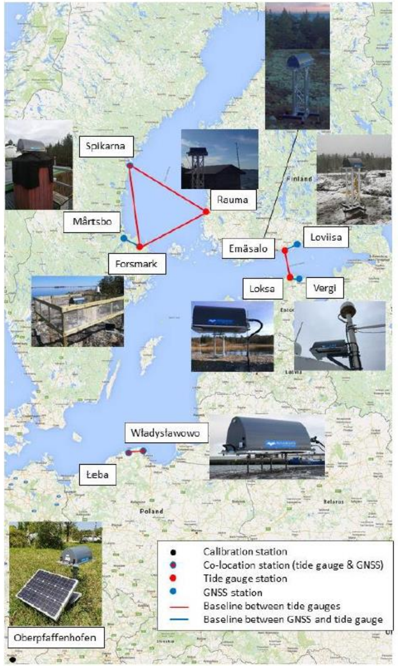
Article

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

Thomas Gruber [1,*], Jonas Ågren [2], Detlef Angermann [3], Artu Ellmann [4], Andreas Engfeldt [2], Christoph Gisinger [5], Leszek Jaworski [6], Simo Marila [7], Jolanta Nastula [6], Faramarz Nilfouroushan [2], Xanthi Oikonomidou [1], Markku Poutanen [7], Timo Saari [7], Marius Schlaak [1], Anna Świątek [6], Sander Varbla [4] and Ryszard Zdunek [6]

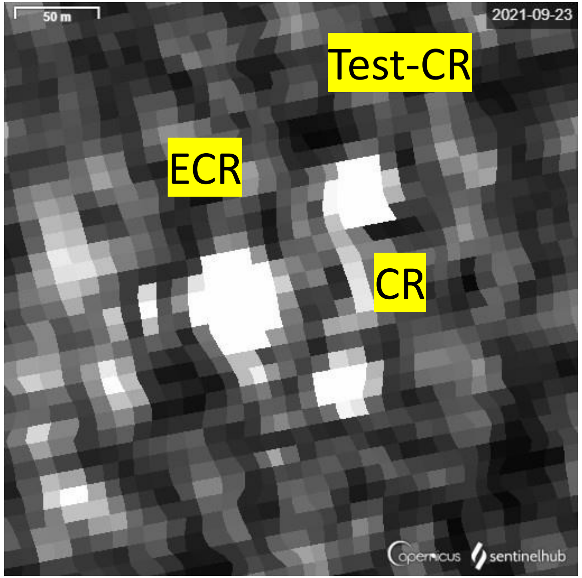


Mårtsbo

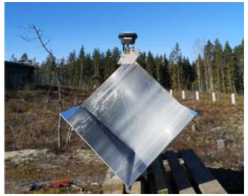
Kobben

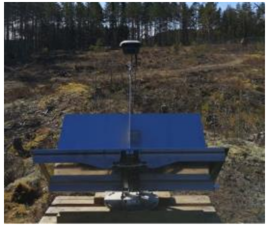
Vinberget

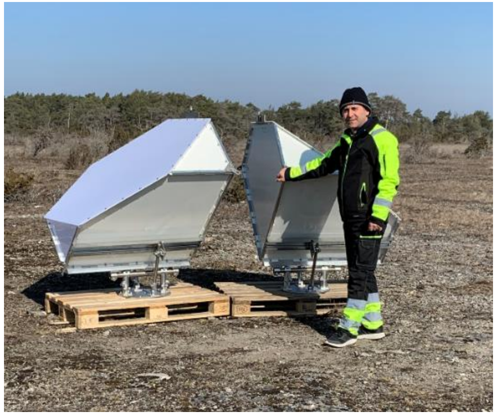
Experiments: temporary installations



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





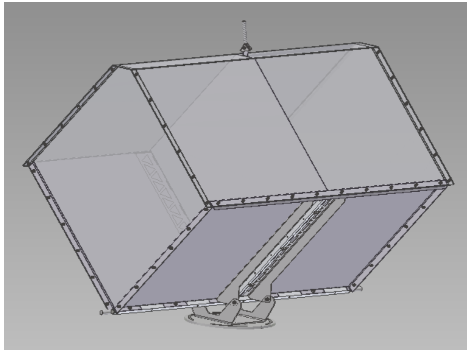


Field works with colleagues, Hans Åke, Nureldin Gido

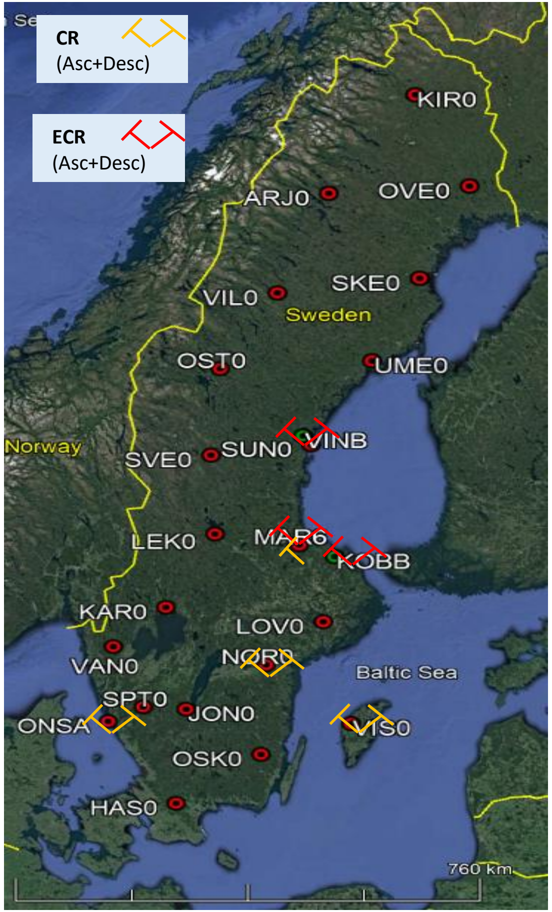
Installation of SAR reflectors ("permanent")

- **So far:** Active ECRs in 3 locations(installed during Geodetic SAR ESA project)
- Passive reflectors in 4 locations (1 at Mårtsbo, 1 at Norrköping, 2 at Onsala Space observatory, CRs provided by LM, installed by Chalmers team, 2 at Visby)
- Planned for **15** more passive reflectors for installation this year, office work and site visits are under progress

Image credit: Gunnar Elgered



Newly designed 15 CRs with snow cover



GNSS fundamental stations (red circles) and current CR/ECR installations

Installation of SAR Reflectors (continued)

- Installed on bedrocks
- Oriented with NRTK GNSS measurements

with colleagues Rickard Jäderberg, Nureldin Gido and Stefan Öberg

Image credit: Gunnar Elgered

Take home messages

- InSAR is a remote sensing/geodetic technique, based on analysis of **radar images taken in different time**
- InSAR has great potential to **detect and measure the ground surface motion** with mm accuracy
- The **geodetic infrastructure** of Sweden is being complemented using **corner reflectors**
- InSAR corner reflectors (or transponders) are co-located with GNSS stations or/and tide gauges to better **maintain the geodetic reference frames**

Thank you for your attention!

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

(Photo: F. Nilfouroushan)