CEOS SAR WGCV 2023: Committee on Earth Observation Satellites Working Group on Calibration and Validation

CyCLOPS: The Establishment of an Integrated GNSS / SAR Geohazards Monitoring and Cal/Val Infrastructure in the Southeastern Mediterranean Region

Dr Chris Danezis

CUT Associate Professor

Head of CUT Laboratory of Geodesy

Coordinator of CyCLOPS Strategic Infrastructure

Oberpfaffenhofen, Tue Oct 17, 2023

The Objectives of CyCLOPS

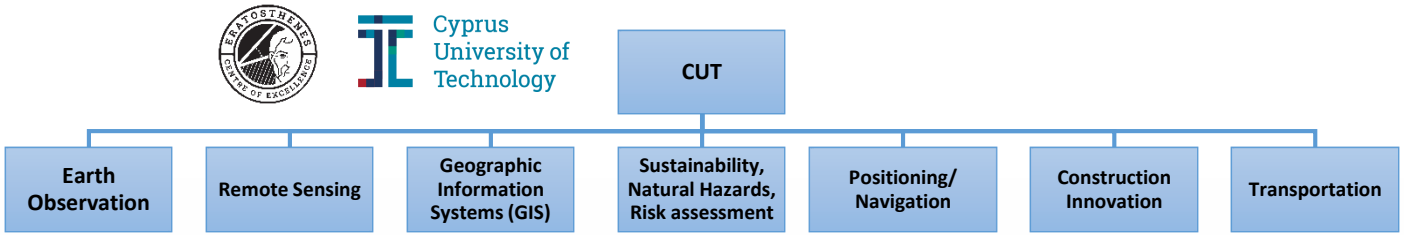
What is CyCLOPS and for what is it meant for?

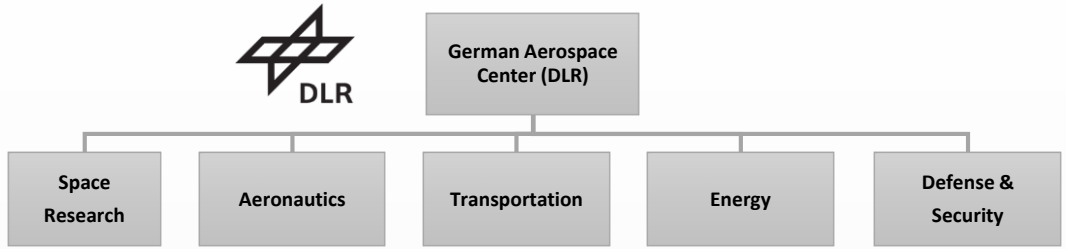
CyCLOPS is a Strategic Research Infrastructure co-funded by the European Union and the Republic of Cyprus to:

- **Promote** the study of **Solid Earth processes** and **Geohazards** in **Cyprus** and the **EMENA** region;
- **Establish** a novel **calibration** and **validation** site to further promote and enhance the use of **EO Satellite Missions**;
- **Augment** the existing **geodetic infrastructure**;
- **Form** the **basis** for a new **modernized National Geodetic Reference Frame** and **augment Regional** and **International Frames**;
- **Promote** critical **geodetic and geophysical initiatives** on monitoring **Natural Hazards**.

Consortium and Supporters

Who we are…





Supporters:

Department of Geological Survey

Department of Lands & Surveys

Cyprus Ministry of Defense

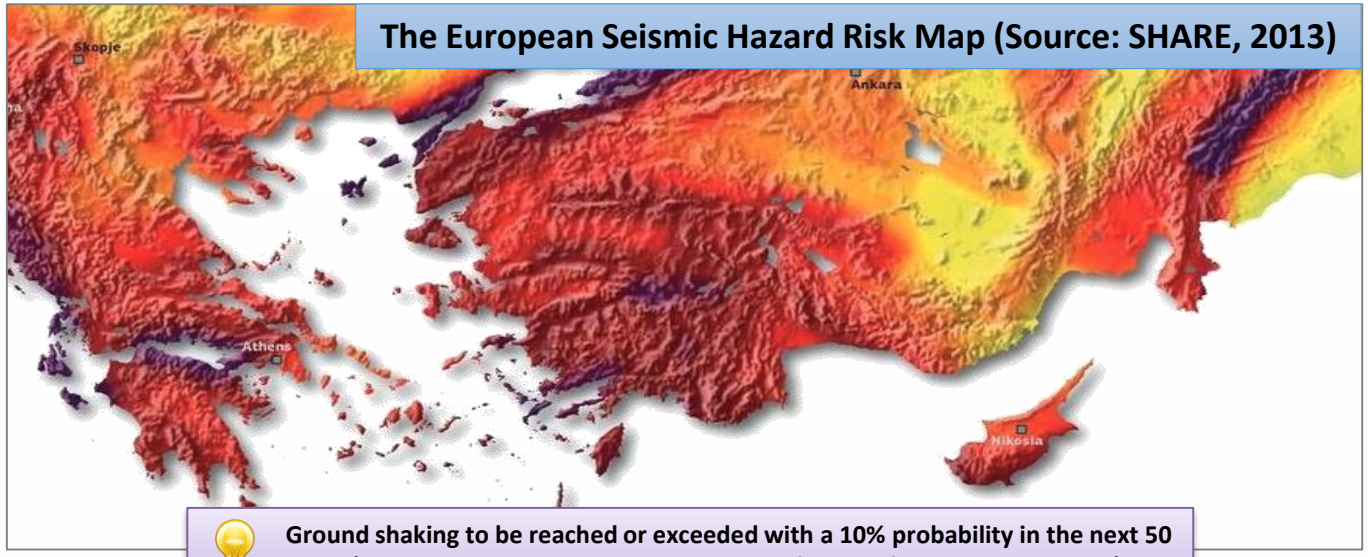
Cyprus Association of Rural & Surveying Engineers

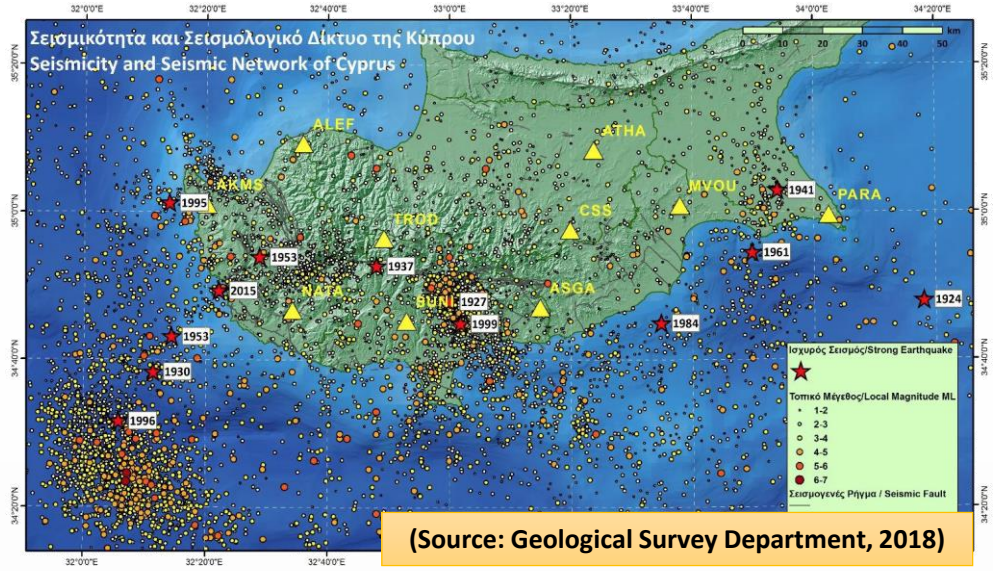
Cyprus Electricity Authority

European Plate Observing System

Natural Hazards in Cyprus

Earthquakes and Landslides





Natural Hazards in Cyprus

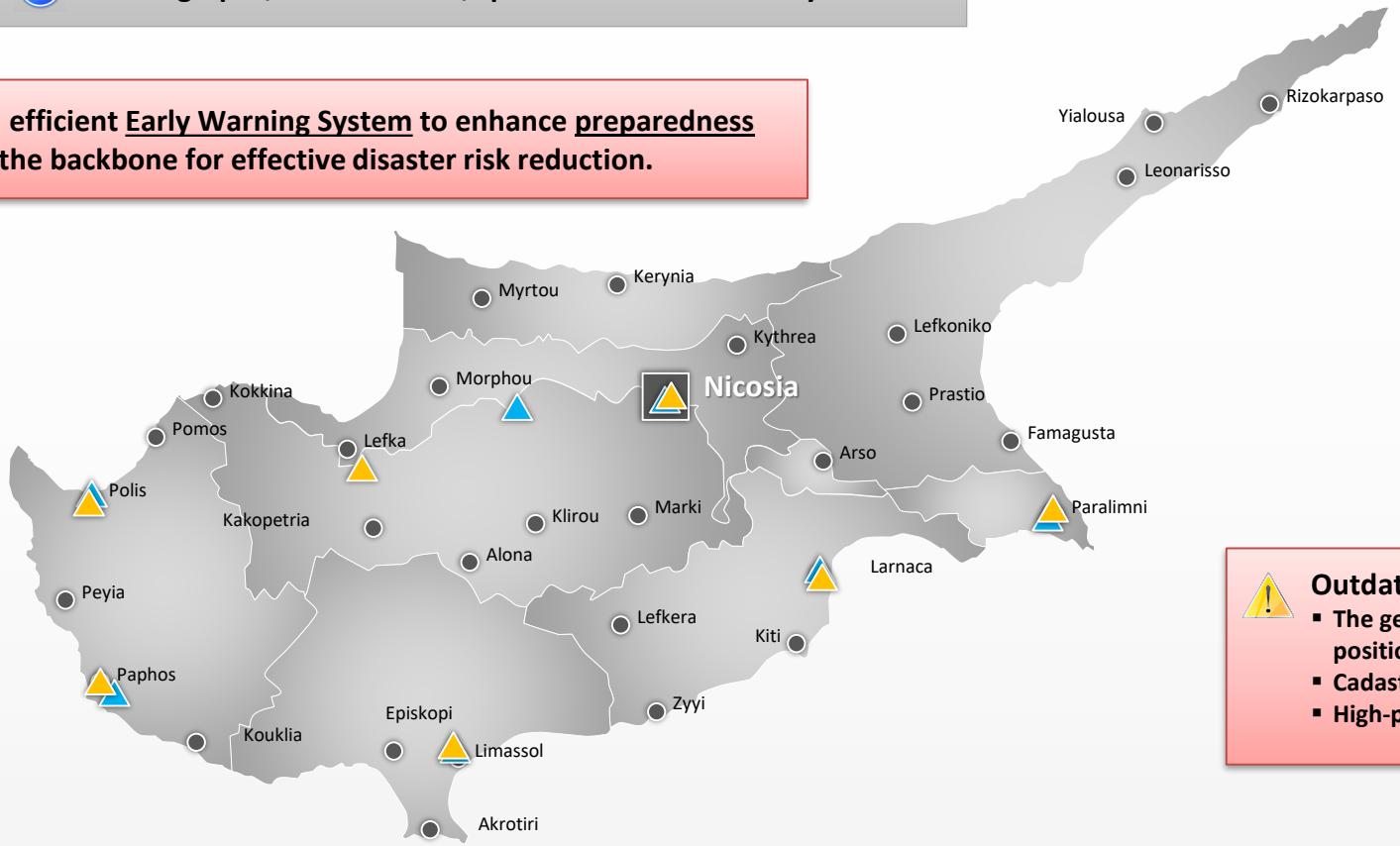
Current Infrastructure and Existing Gaps

Current infrastructure for monitoring and better understanding natural hazards is limited to conventional equipment.

Seismographs, inclinometers, sparse drills conducted by the GSD.

2x GNSS Networks of 7 stations each operated by DLS and EAC

Lack of an efficient Early Warning System to enhance preparedness and form the backbone for effective disaster risk reduction.



Outdated equipment

Insufficient Monumentation for Deformation Monitoring Applications (Tier-3)

Outdated geodetic and cartographic infrastructure (1993):

- **The geodynamic/ geotechnic regime has introduced shifts to the position of reference stations and datum benchmarks;**
- **Cadastral, mapping, hydrographic issues etc.**
- **High-precision LBS issues**

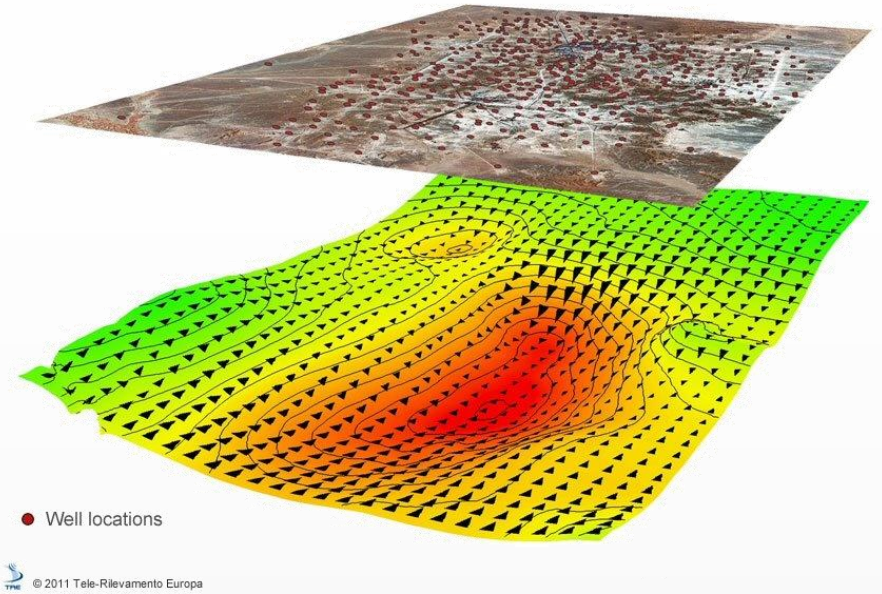
Earth Observation & Natural Hazards

Most Prominent EO Techniques for Monitoring Geohazards

Global Navigation Satellite Systems (GNSS)

mm-level <u>absolute</u> displacement and velocity determination for a <u>single</u> point on the Earth

Synthetic Aperture Radar (SAR, InSAR, PSI)



~cm- to mm-level <u>relative</u> displacement and velocity determination with <u>high resolution</u>

Earth Observation & Natural Hazards

Most Prominent EO Techniques for Monitoring Geohazards

GPS

Galileo

GLONASS

BeiDou

Cyprus University of Technology

Global Navigation Satellite Systems (GNSS)

Geodetic SAR

Calibration

Copernicus

TerraSAR X

Interferometric SAR (InSAR)

DLR

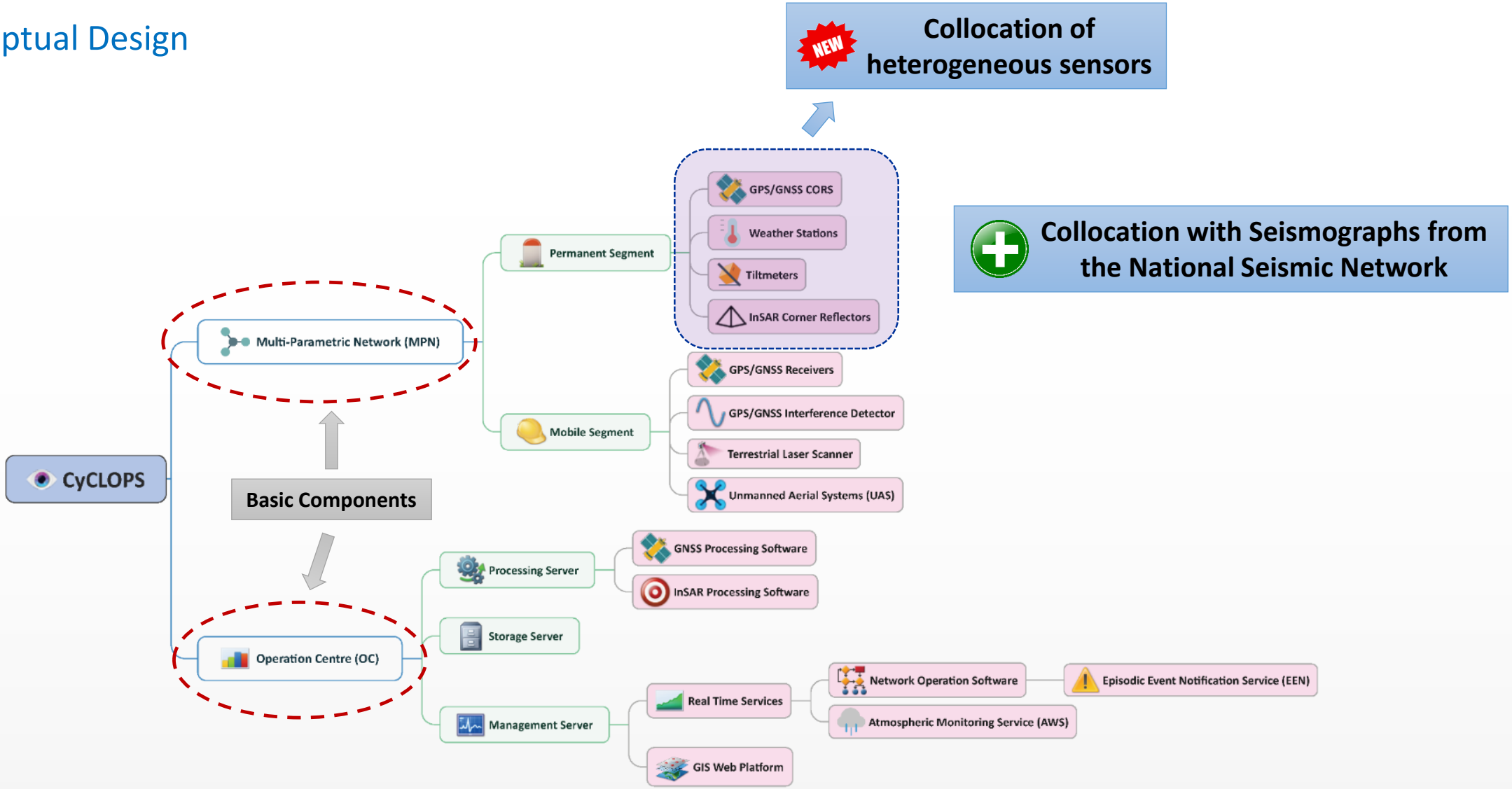
CyCLOPS

- GNSS provide atmospheric corrections and geodynamic-related information to correct SAR-derived ranges using Corner Reflectors.

The co-location of GNSS receivers + CRs may yield cm- to mm-level deformation products on a continuous basis!

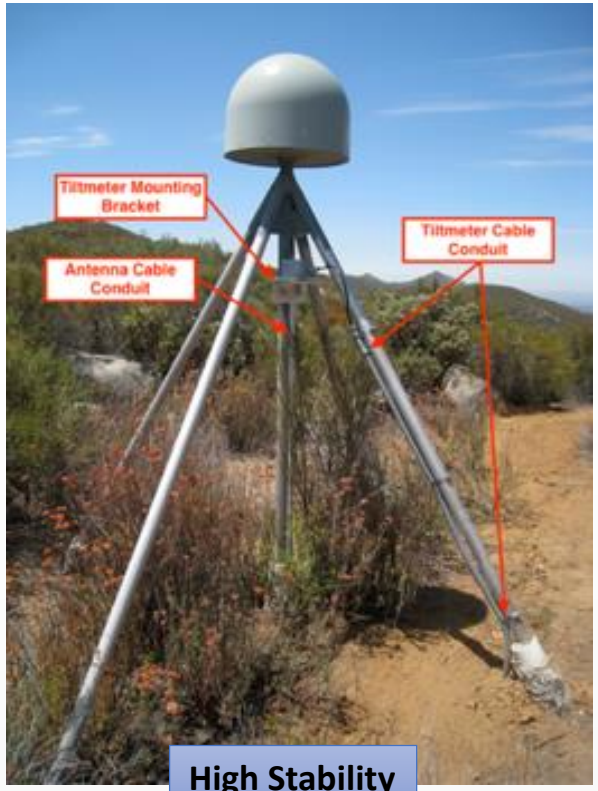
CyCLOPS Architecture

Conceptual Design



GNSS CORS Infrastructure

What kind of GNSS Equipment is used in High Precision GNSS Applications?



High Stability

Medium - High Stability

UNAVCO Taxonomy

Medium Stability

GPS/ GNSS Antennas are installed on top of very stable monuments at the points of interest.

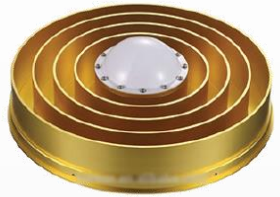
Ideally, reference points must be located on and attached to solid bedrock.

The Permanent Segment (PS)

Monumentation and Equipment Features

<u>Infrastructure Highlights</u>:

- 6x GPS/GNSS CORS are deployed throughout Cyprus on highly stable monuments:
  - Shallow-drilled braced quadpods (UNAVCO);
  - Vertical stainless-steel truss (sub-mm vibration at wind speeds of 140Km/h);
  - Choke Ring Antennas for enhanced multipath mitigation and high phase center stability;
  - SCIGN-compatible radome and **mount**;
  - Absolute antenna calibration files to support Galileo in displacement determination;
- IGS-compliant weather stations (Vaisala PTU307) and tilt-meters;
- Dual SAR Trihedral Corner Reflectors (two in each site) in opposite facing configuration.

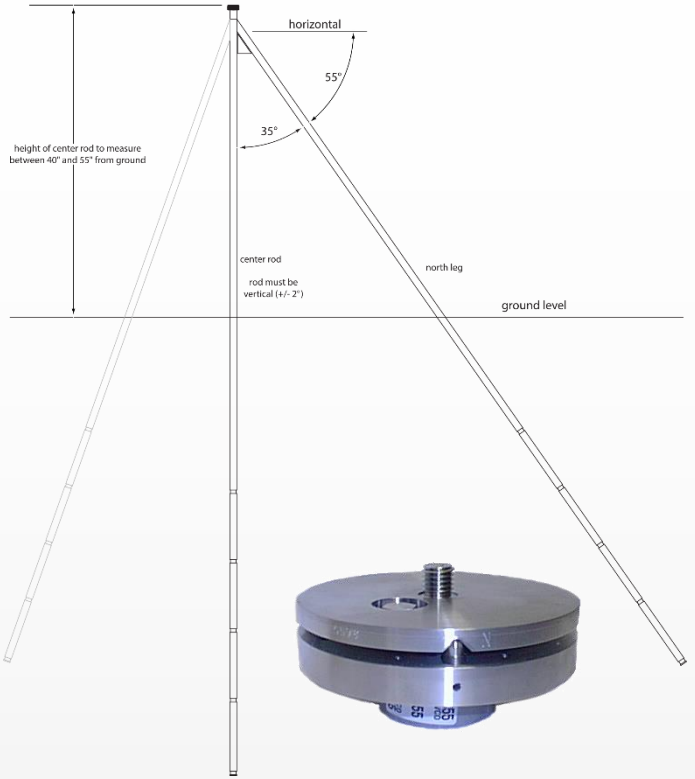


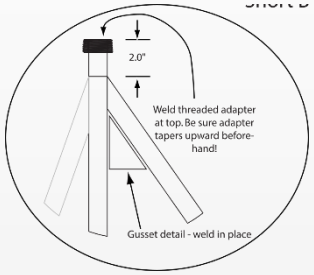
Two corner reflectors facing opposite directions to account for both ascending and descending passes of SAR satellites, yielding an increase of 50% in data availability for deformation monitoring.

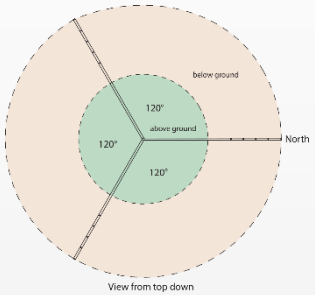
The Permanent Segment (PS)

Tier-1/2 GNSS CORS Monumentation Considerations

Shallow Drilled Braced Quadpod Monumentation







Compliance with UNAVCO Specs for High Stability Monumentation

The Permanent Segment (PS)

Installation of ASGA (Shallow Drilled Braced Quadpod)

The Permanent Segment (PS)

Installation of SOUN (Stainless Steel Truss)

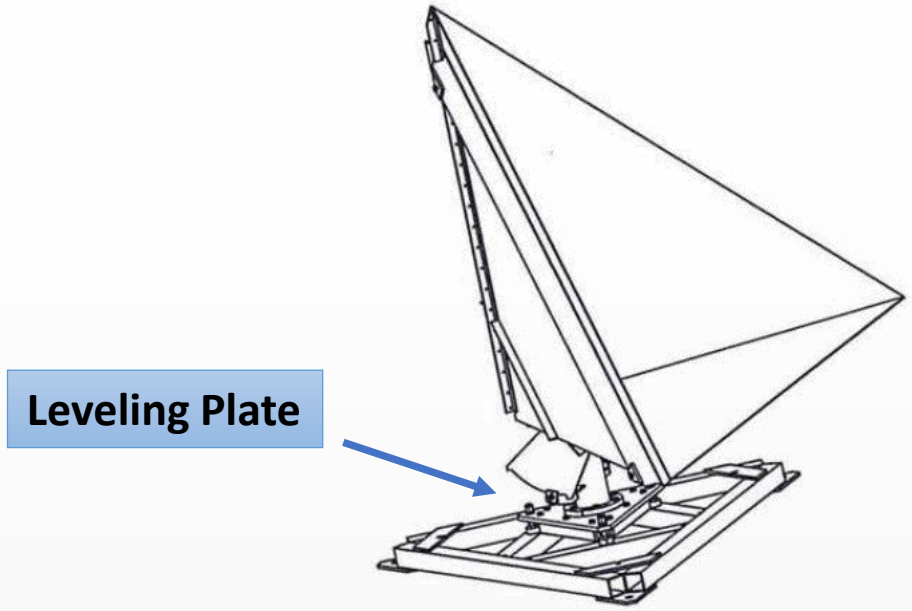
Permanent Segment (PS) – Implementation Phase

Triangular Trihedral Corner Reflectors (CR)

Cost: 6.3K EUR/unit

Azimuth Adjustment Range: -180° to +180°

Elevation Adjustment Range: -10° to +45°



Support for Sentinel-1, TerraSAR-X, COSMO-SkyMed etc (1.5m inner length)

Permanent Segment (PS) – Implementation Phase

Installation of CRs

- As in the case of GNSS monuments, the process begun by clearing the area, and excavating until revelation of bedrock;
- A thin layer of concrete was cast on top of exposed bedrock;
- The corner reflectors (CR) were then attached to bedrock, at a depth of 1m, by means of specifically designed anchors and very high-quality epoxy resin.
- The CRs were also fenced to avoid any disturbance by animals.

Smiling happy people!

The Permanent Segment (PS)

CR Installation at ALEV

The Permanent Segment (PS)

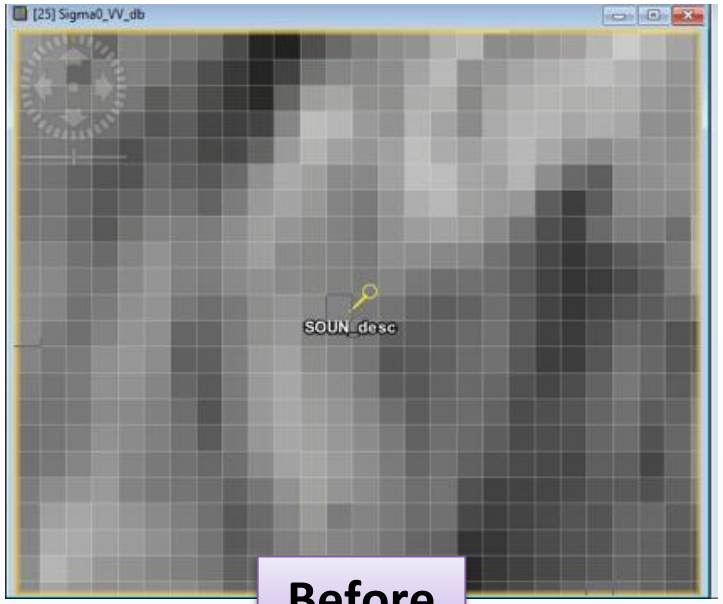
GNSS CORS + CR Collocation (ALEV)

GNSS CORS

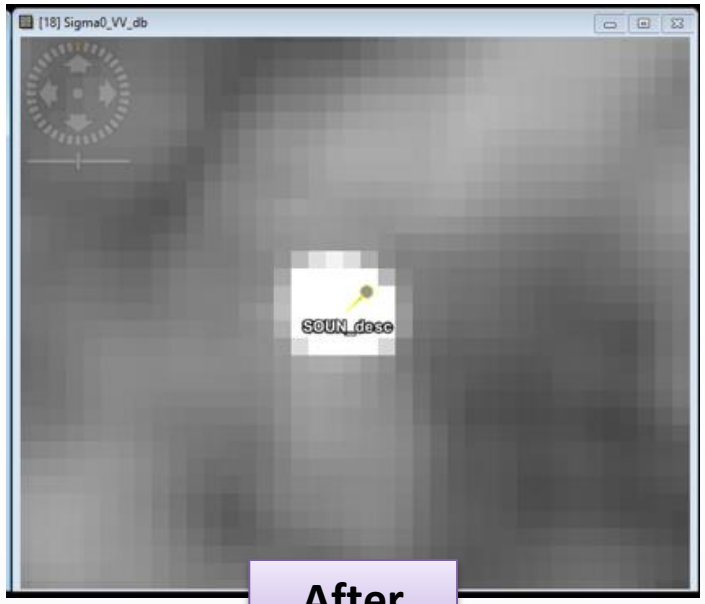
CR for Descending Pass

CR for Ascending Pass

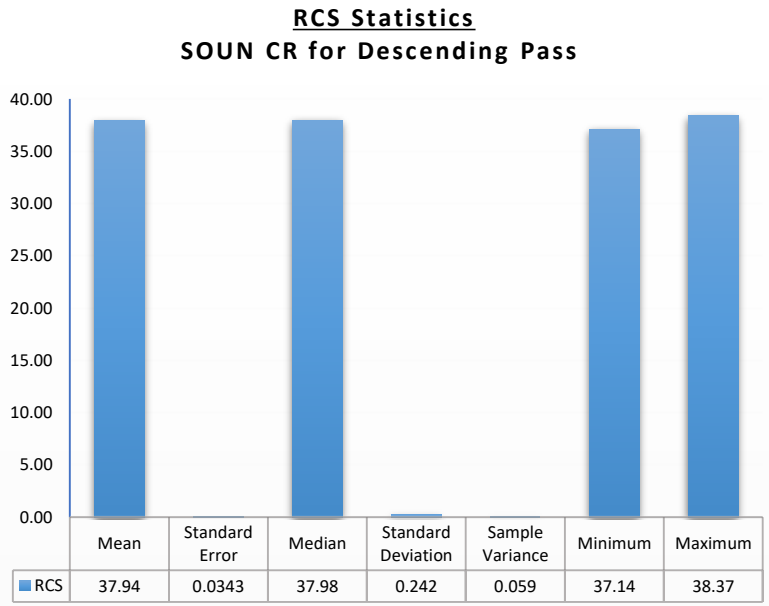
The Permanent Segment (PS)



Before



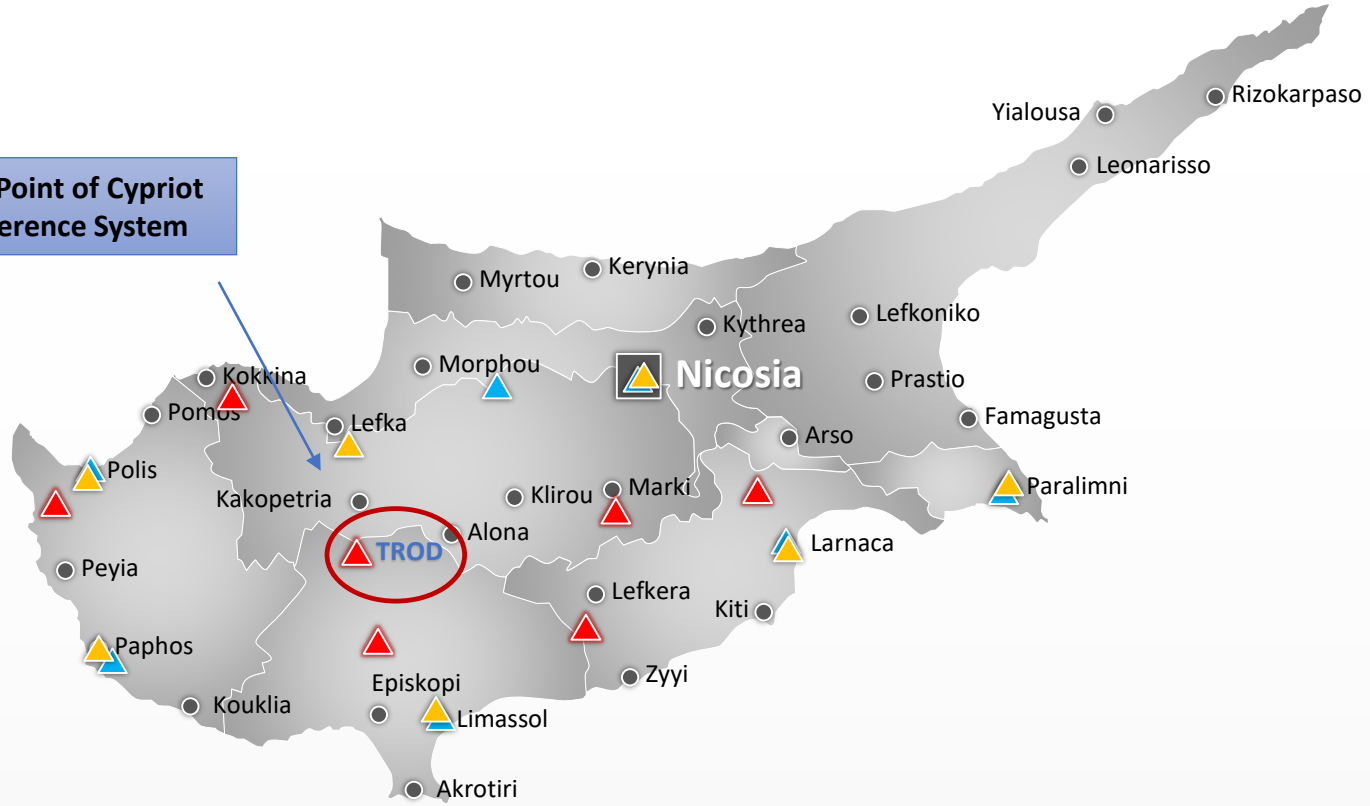
After



The impact of a CyCLOPS Corner Reflector on a radar acquisition (before and after installation)

The Permanent Segment (PS) – Site Locations

Fundamental Point of Cypriot Geodetic Reference System



- Cyprus Cities and Towns
- Locations of DLS CYPOS Stations (GPS & GLONASS)
- Locations of EAC ATLAS Stations (GPS)
- Potential Locations of CyCLOPS Stations (GPS, GLONASS, Galileo, Beidou)

Locations suggested by the Department of Geological Survey

Sites are located on top of solid bedrock.

Suggested Locations will enable further co-location with seismographs!

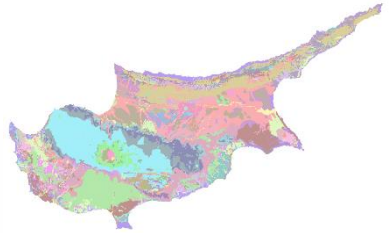
Co-location with the DGS network will aid in dealing with critical issues such as:

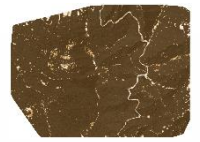
- **Energy Redundancy**
- **Communication Redundancy**
- **Restricted Access (Equipment safety)**

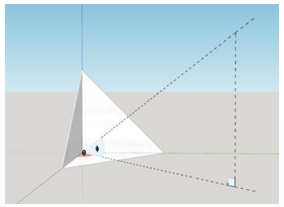
The Permanent Segment

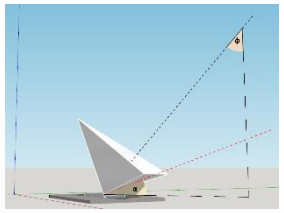
Determination of the most suitable sites for GNSS CORS/ InSAR CR collocation

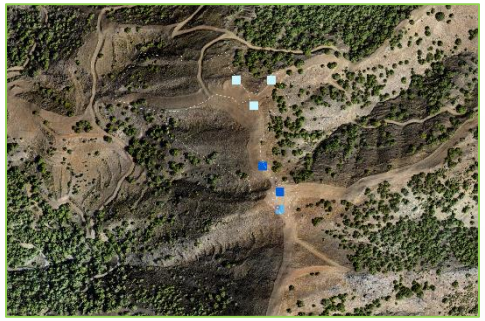
- A semi-automatic GIS-based multi-criteria methodology was developed according to current research literature considering a multitude of parameters:
  - Geological background,
  - Terrain slope and aspect,
  - Land ownership (state parcels),
  - Land cover and access,
  - Sigma Nought values,
  - Incidence Angle,
  - LoS and distance between GNSS CORS and TCRs
  - ….

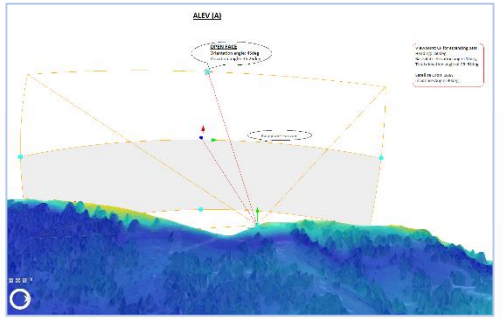


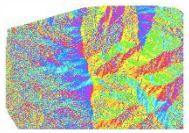


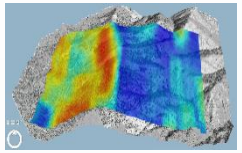


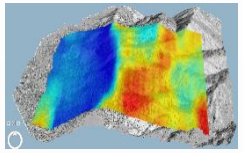


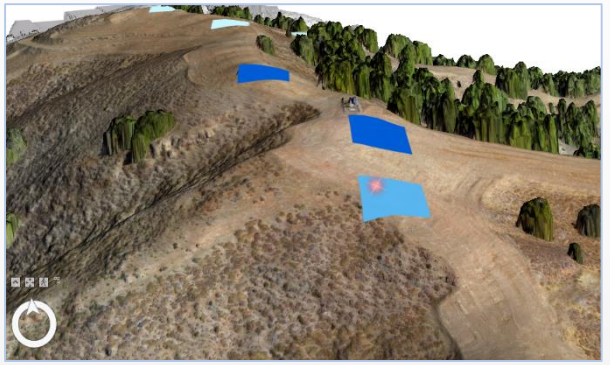


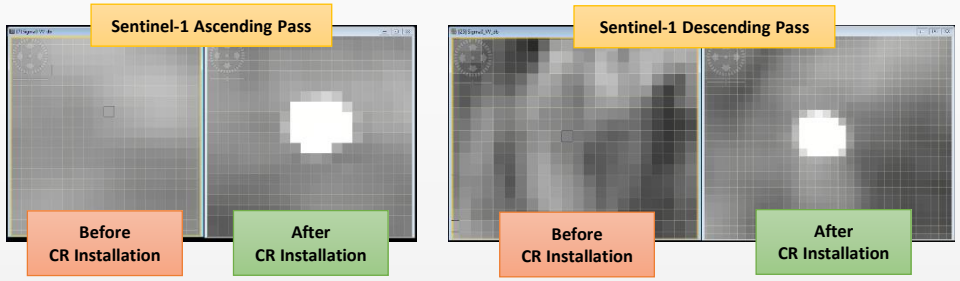






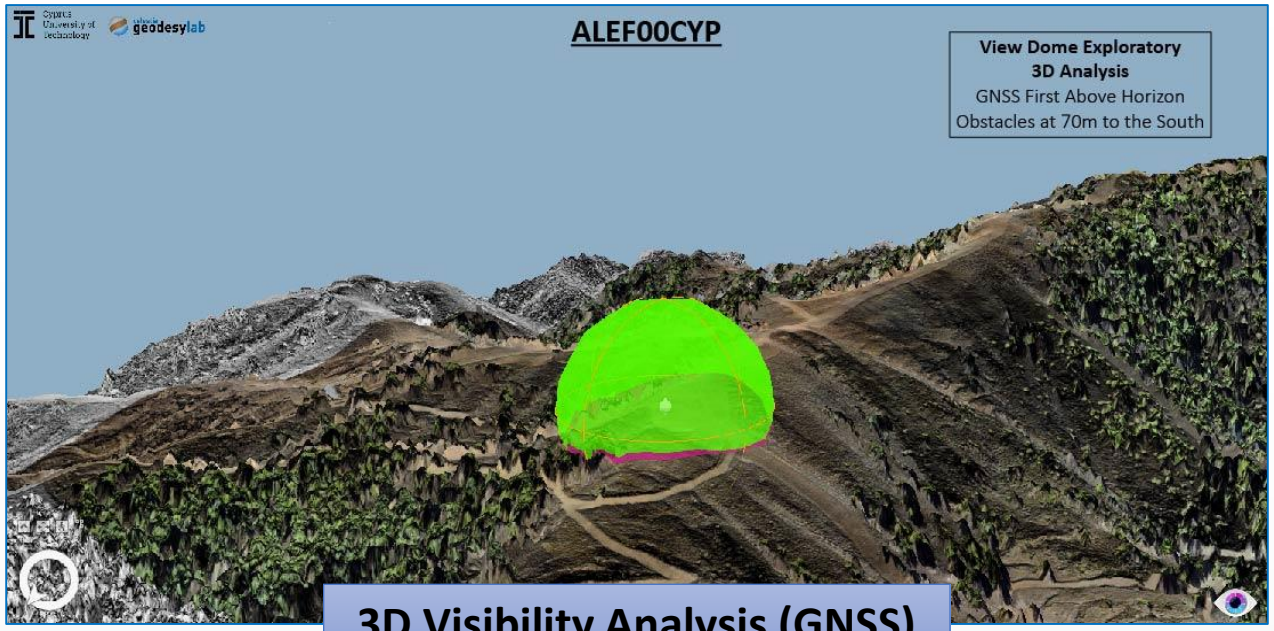




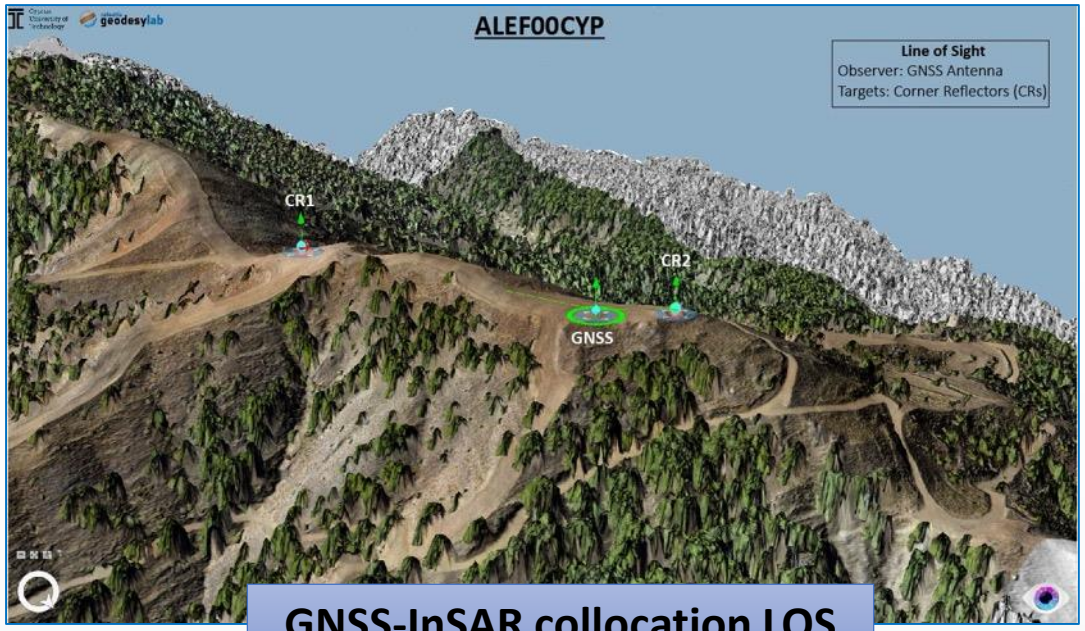


Permanent Segment (PS) – Determination of Site Locations

3D Visibility Analysis and Assessment



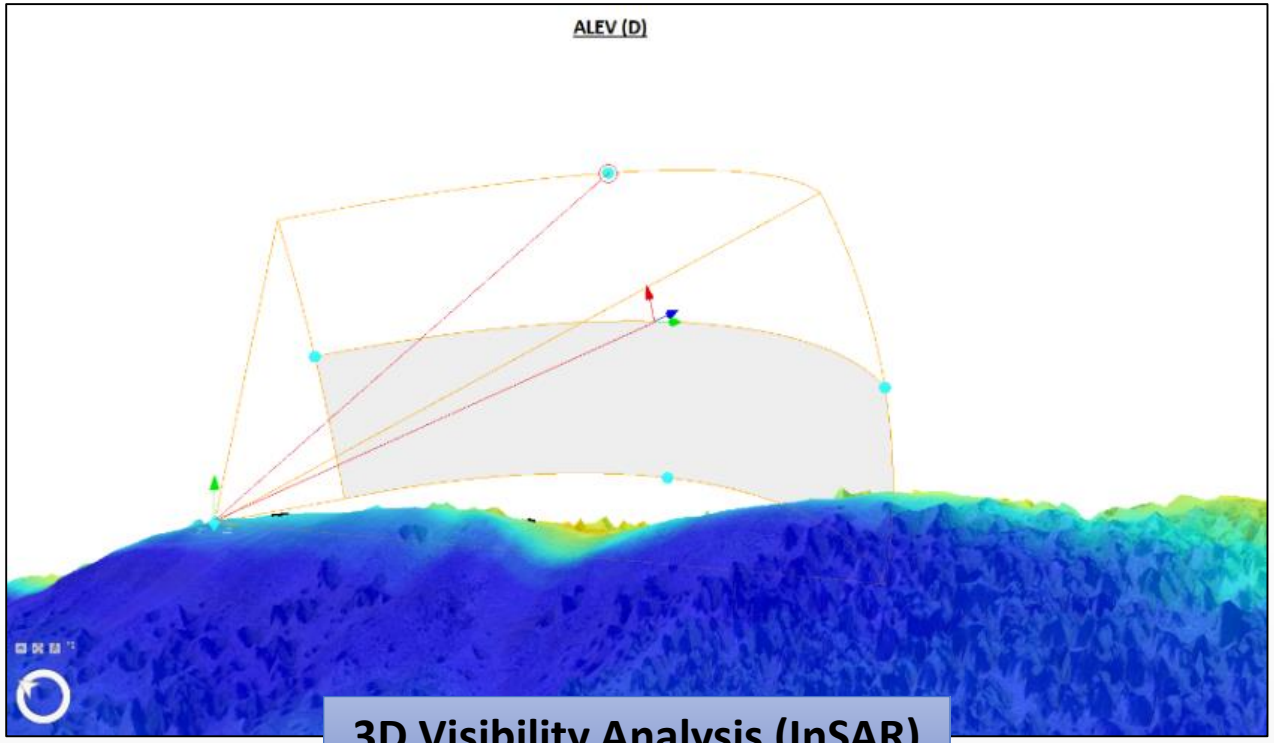
3D Visibility Analysis (GNSS)



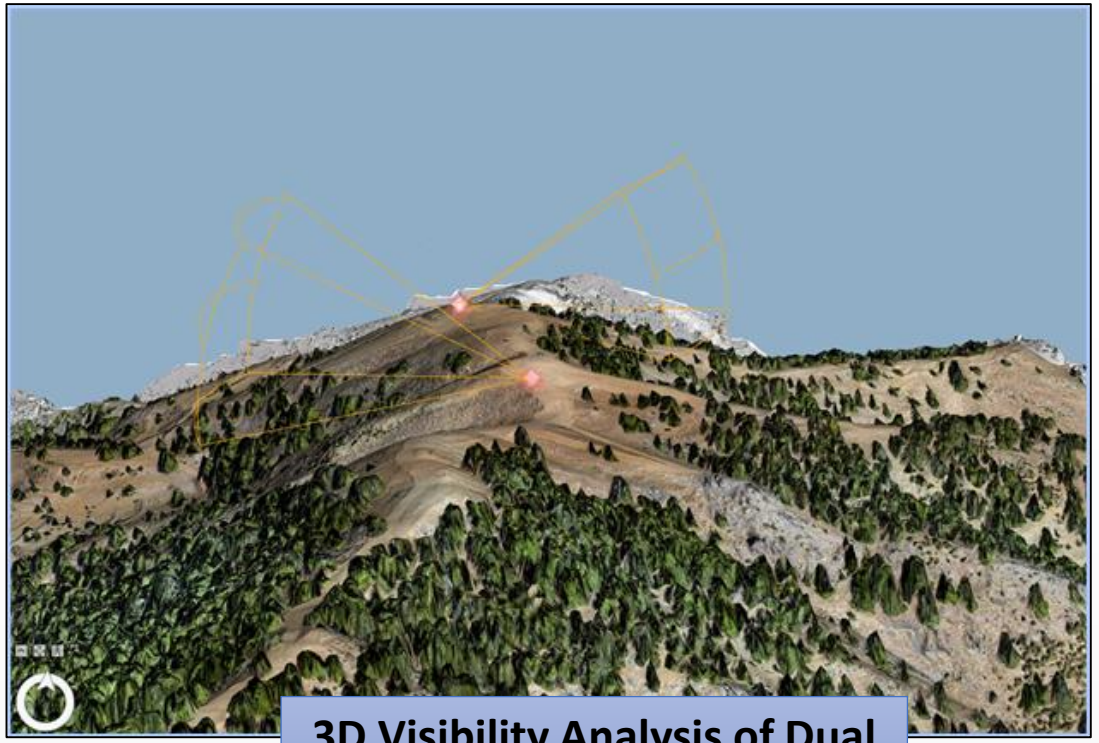
GNSS-InSAR collocation LOS

Permanent Segment (PS) – Determination of Site Locations

3D Visibility Analysis and Assessment



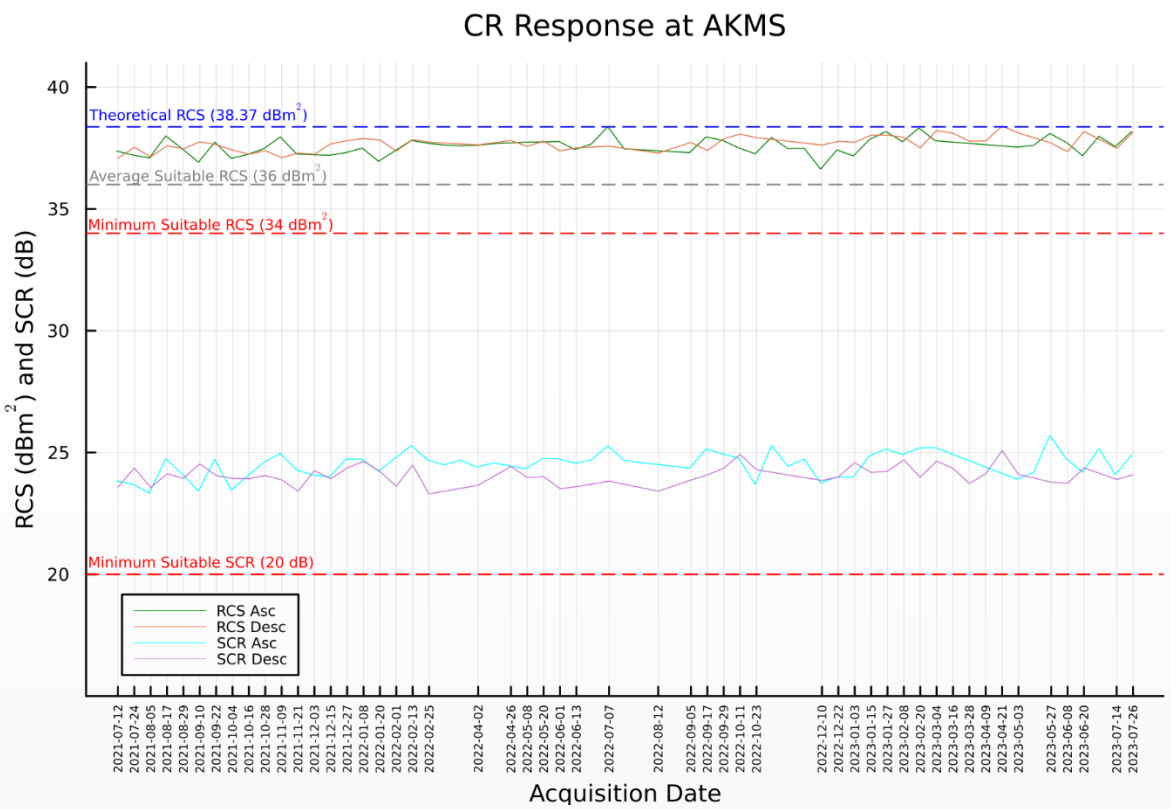
3D Visibility Analysis (InSAR)

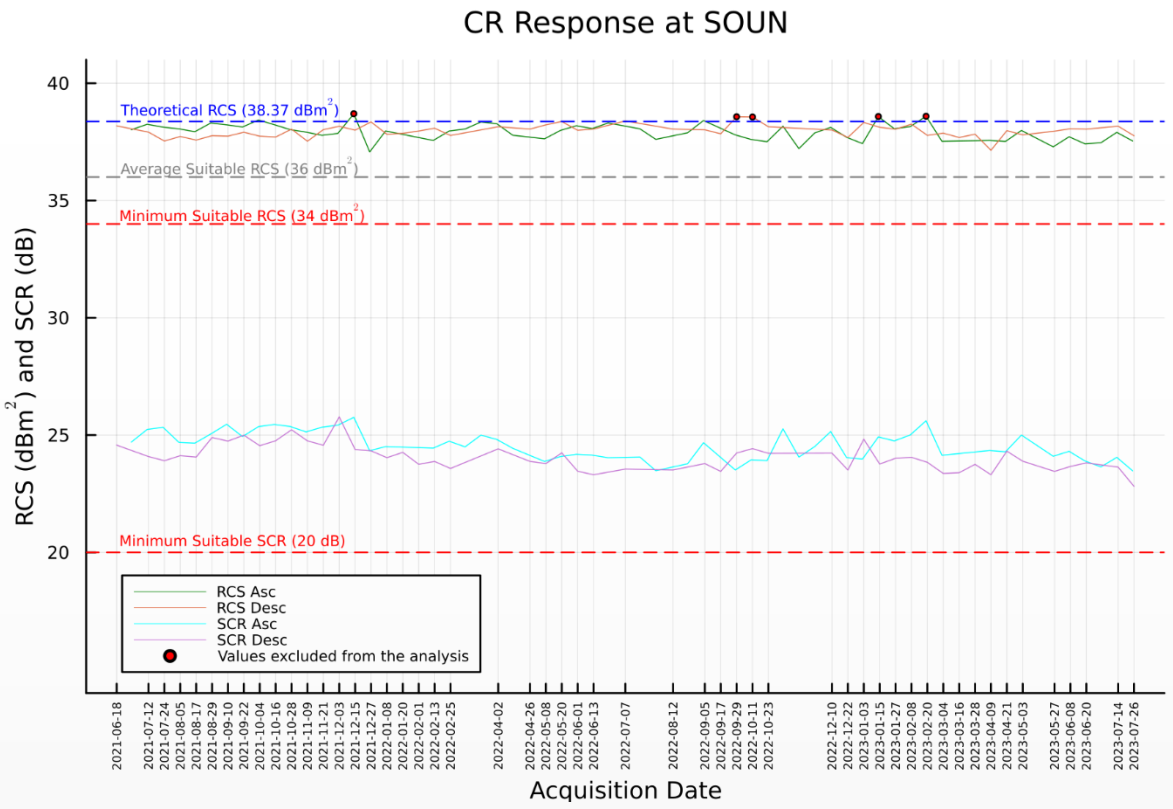


3D Visibility Analysis of Dual CR configuration (InSAR)

The Permanent Segment (PS) – CR Performance Assessment

RCS and SCR Estimation

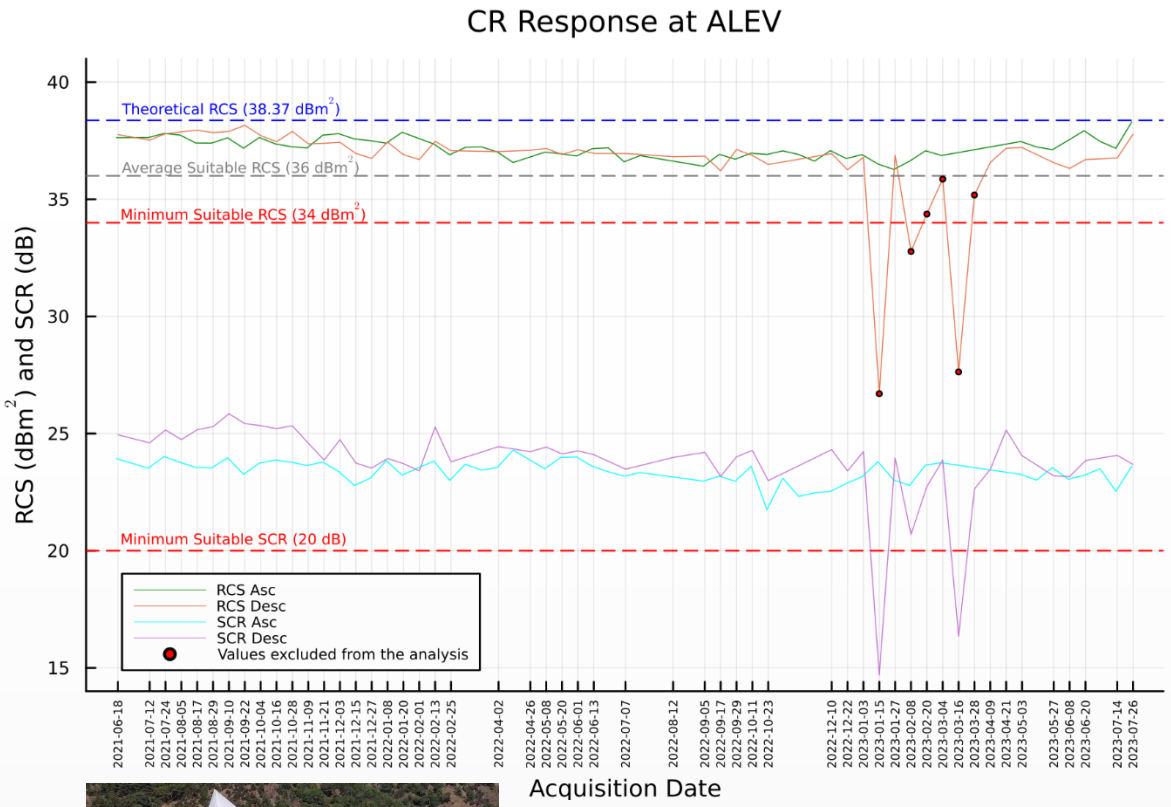


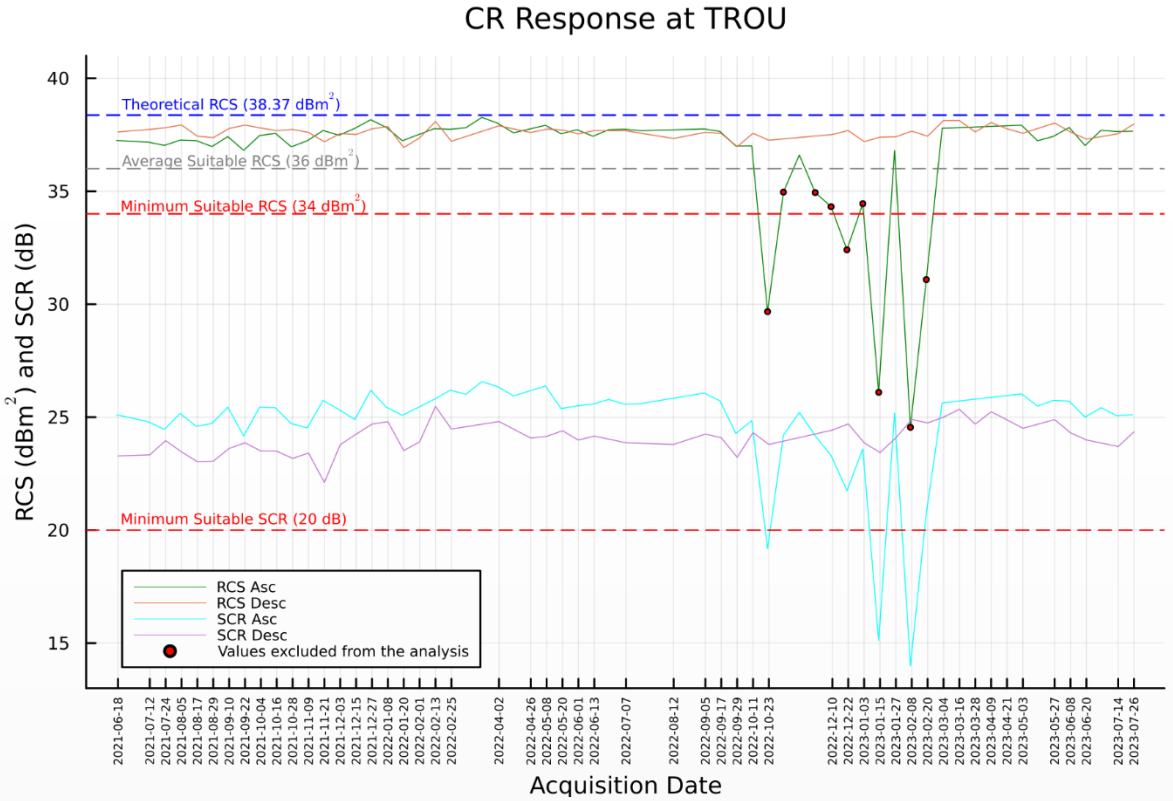


Some estimated RCS values for CRs (i.e., SOUN, MATS, ASGA) appear to exceed the theoretical RCS value. This discrepancy highlights imperfections in the calibration of Sentinel-1 imagery.

The Permanent Segment (PS) – CR Performance Assessment

RCS and SCR Estimation



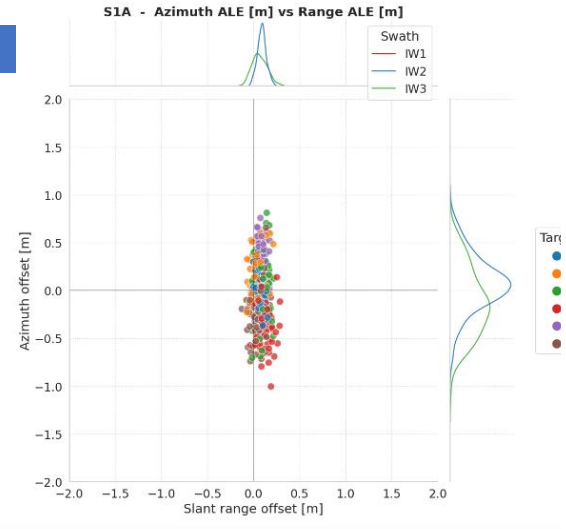


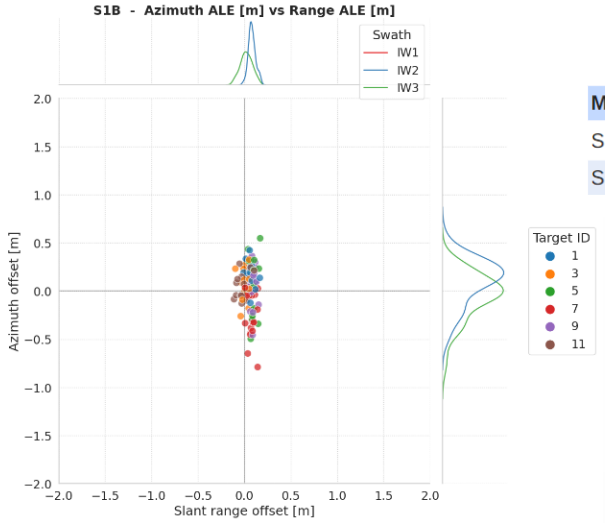
During a heavy rainfall period, a dramatic reduction of the backscattered signal was observed. The low CR response was attributed to poor water drainage from due significant soil & dust deposition.

The Permanent Segment (PS) – CR Performance Assessment

Geolocation Accuracy

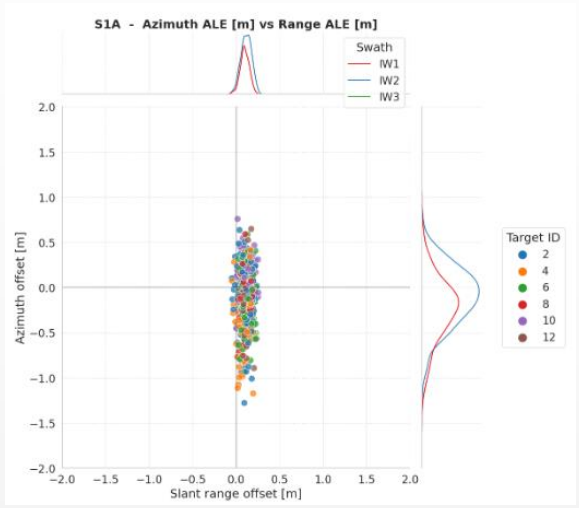
ASC

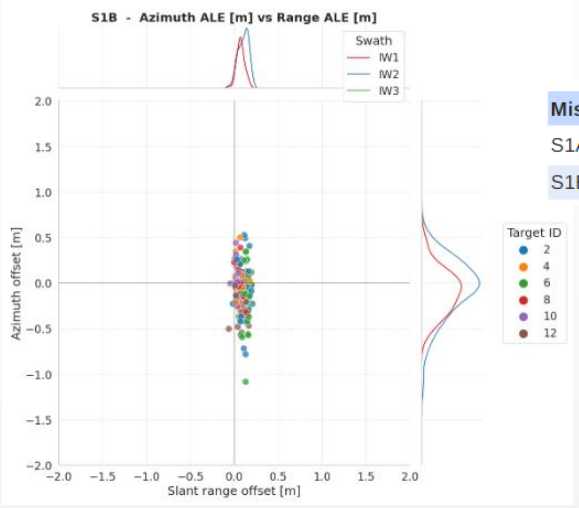




Mission	Num Obs	Range ALE [m]	Azimuth ALE [m]
S1A	352	0.081 ± 0.066	-0.020 ± 0.331
S1B	98	0.052 ± 0.060	0.018 ± 0.250

DESC



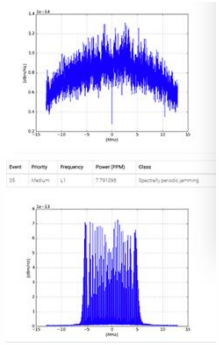


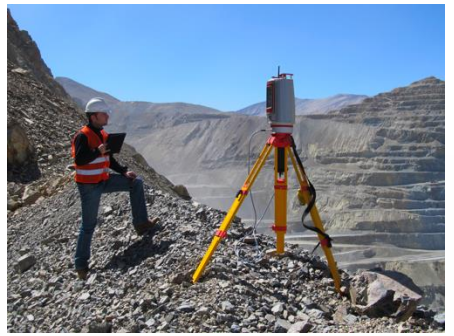
Mission	Num Obs	Range ALE [m]	Azimuth ALE [m]
S1A	474	0.111 ± 0.057	-0.155 ± 0.338
S1B	130	0.093 ± 0.056	-0.069 ± 0.279

The Mobile Segment (MS)

Mobile Segment Monumentation and Equipment Highlights

- 5x mobile GNSS CORS will be deployed to selected areas of interest (AoI).
  - Same receivers and antennas with the Permanent Segment;
  - GNSS equipment, weather station and tilt-meter will be mounted in specifically designed configurations (enclosures) with redundant energy supply (solar powered) and bidirectional communication (airFiber) with the Operation Center.
  - All receivers come with a Spectral Analyzer to identify unwanted interference prior to installation;
- 1x Terrestrial Laser Scanner will enable imminent high-density geospatial data acquisition for monitoring landslides and dynamic incidents;
- 1x Tactical-grade UAV, which offers high-resolution terrain mapping (~1hr of operation per battery) and supports large-scale data acquisition;
- **2x MetaSensing Electronic Corner Reflectors (ECRs) collocated with the GNSS CORS.**





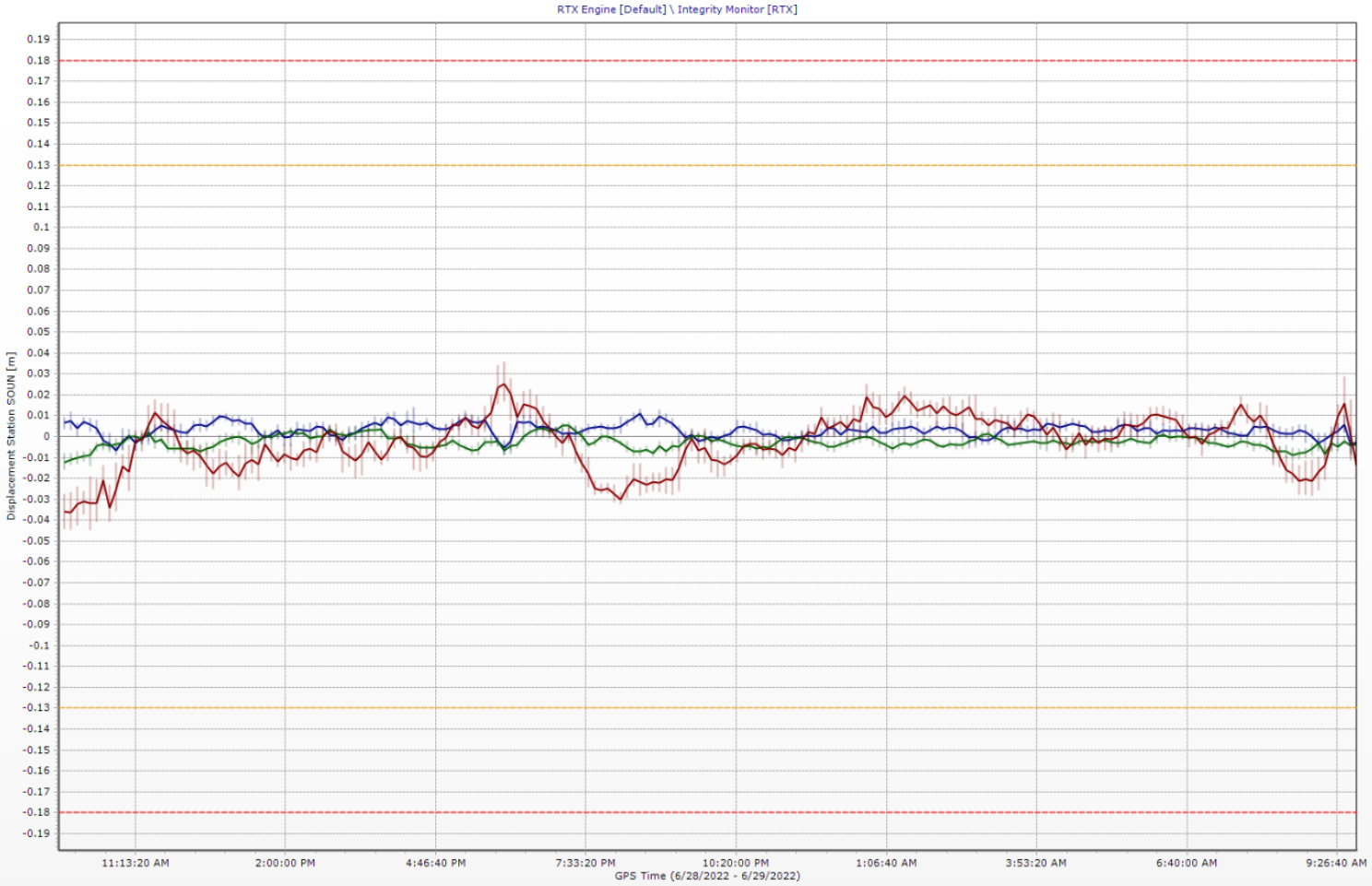
Example of a Mobile GPS/GNSS CORS Configuration

Mobile Segment (MS)

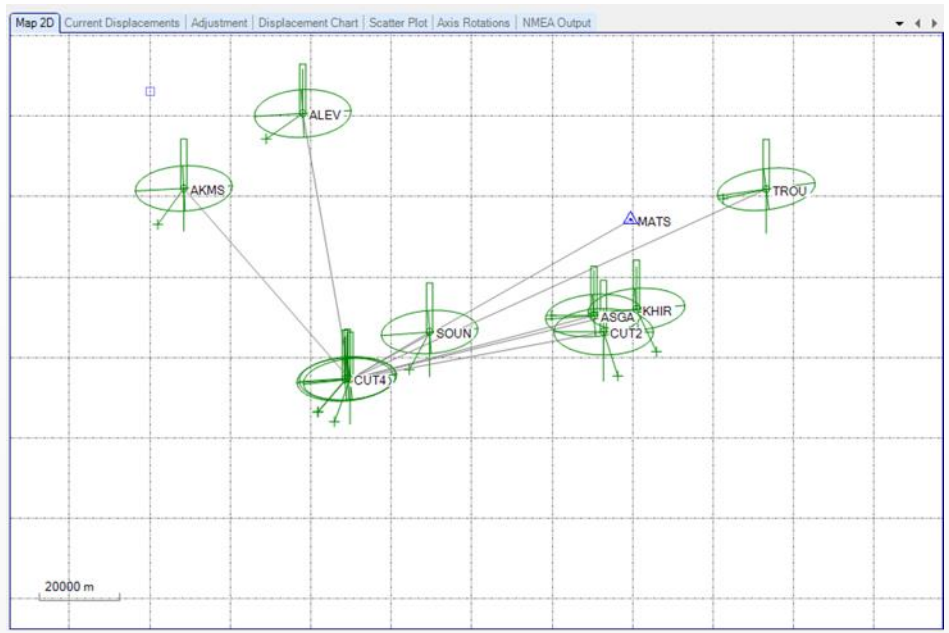
Mobile CORS & Electronic Corner Reflector Collocation

Real Time Services

Real Time Displacement Monitoring

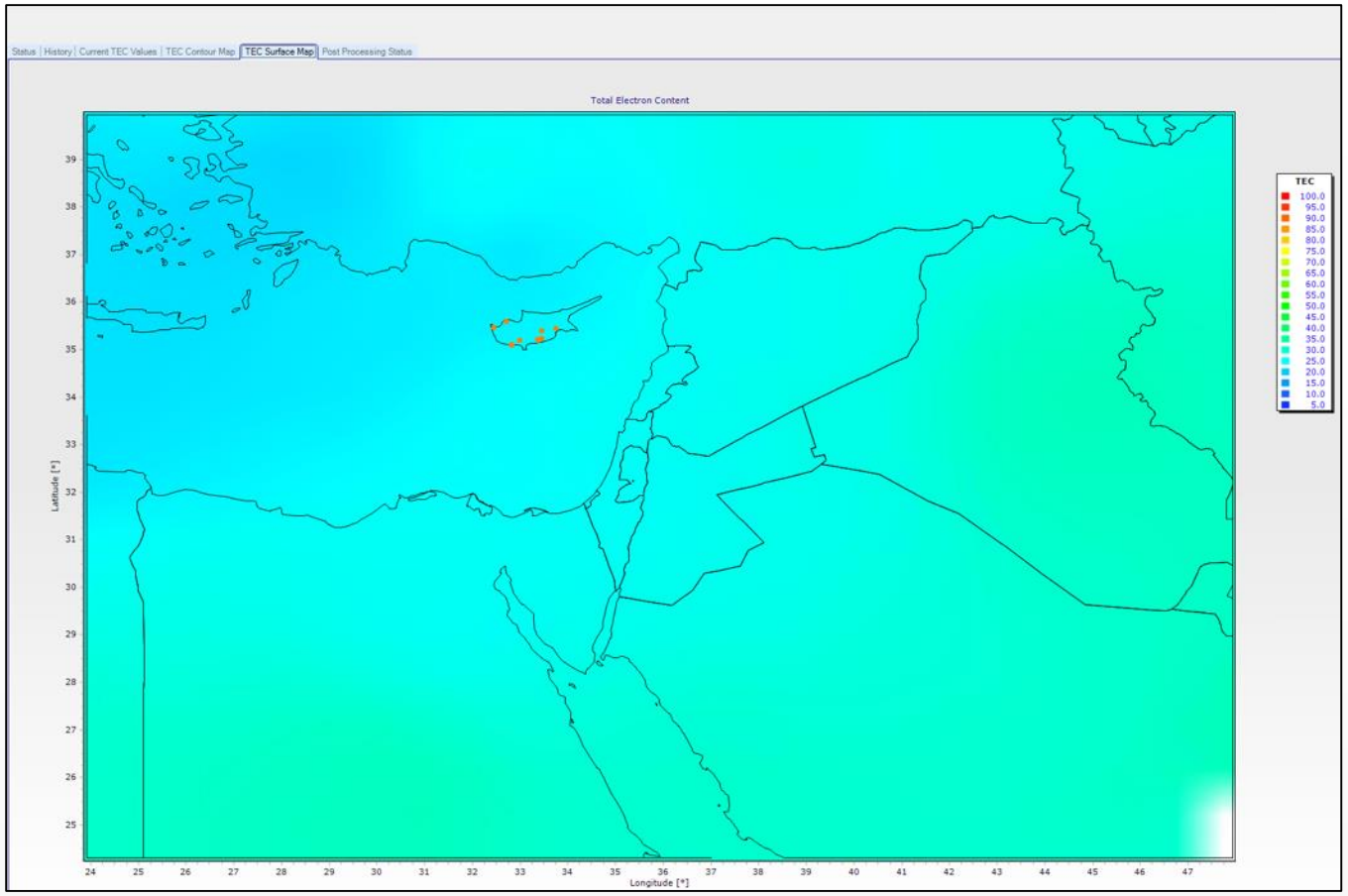


Status	Station Name	Station Code	Axis Rotation	Δ Northing [m]	Δ Easting [m]	Δ Height [m]	Δ 2D [m]	Δ 3D [m]	3-σ Δ Northing [m]	3-σ Δ Easting [m]	3-σ Δ Height [m]	3-σ Δ 2D [m]
	MATS	MATS		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	CUT3	CUT3		-0.003	-0.002	0.002	0.003	0.004	0.011	0.024	0.027	0.026
	TROU	TROU		-0.001	-0.004	-0.006	0.004	0.007	0.012	0.027	0.029	0.030
	AKMS	AKMS		-0.006	-0.004	-0.002	0.007	0.007	0.011	0.024	0.028	0.027
	CUT4	CUT4		-0.005	-0.004	0.005	0.006	0.008	0.011	0.024	0.027	0.026
	SOUN	SOUN		-0.002	-0.001	-0.009	0.003	0.009	0.011	0.024	0.027	0.026
	ALEV	ALEV		-0.004	-0.006	0.007	0.007	0.010	0.012	0.024	0.027	0.026
	ASGA	ASGA		0.000	-0.001	0.010	0.001	0.010	0.011	0.024	0.027	0.027
	CAVO	CAVO		-0.009	-0.003	-0.010	0.010	0.014	0.008	0.017	0.019	0.019
	KHIR	KHIR		-0.016	0.008	0.004	0.018	0.018	0.011	0.025	0.027	0.027
	CUT2	CUT2		-0.014	0.005	-0.028	0.015	0.032	0.014	0.030	0.037	0.033

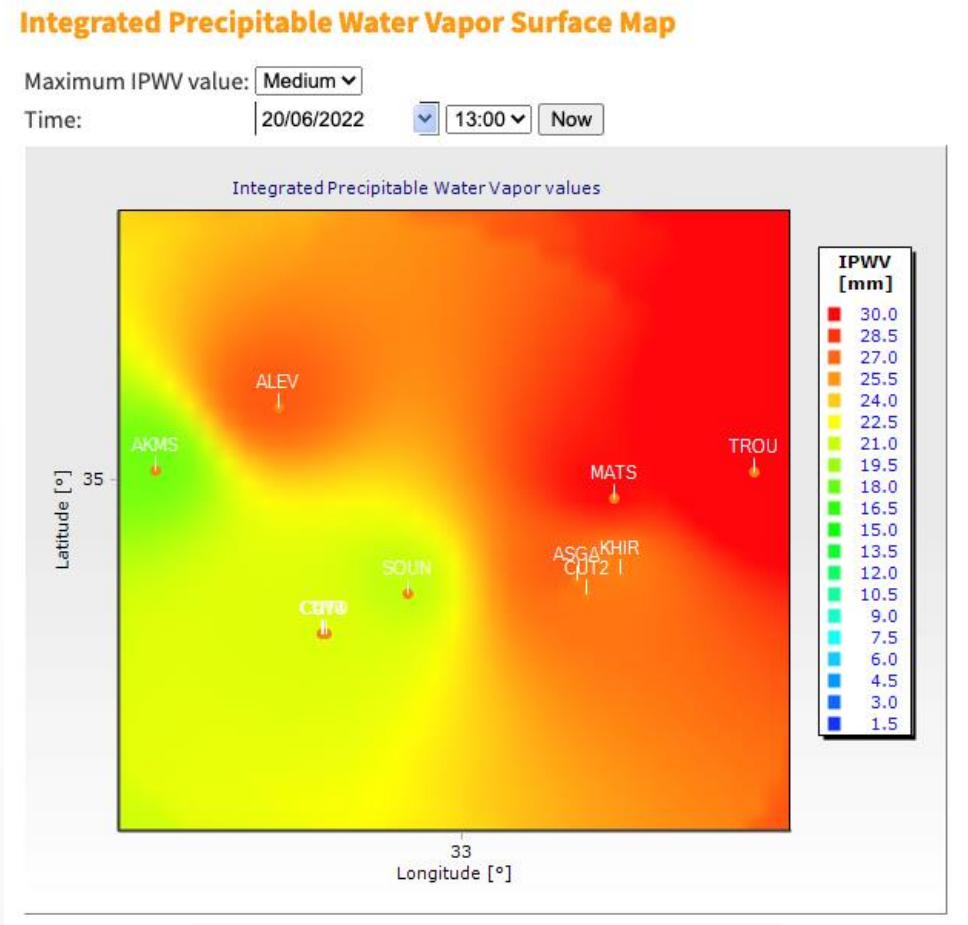


Real Time Services

Atmospheric Service



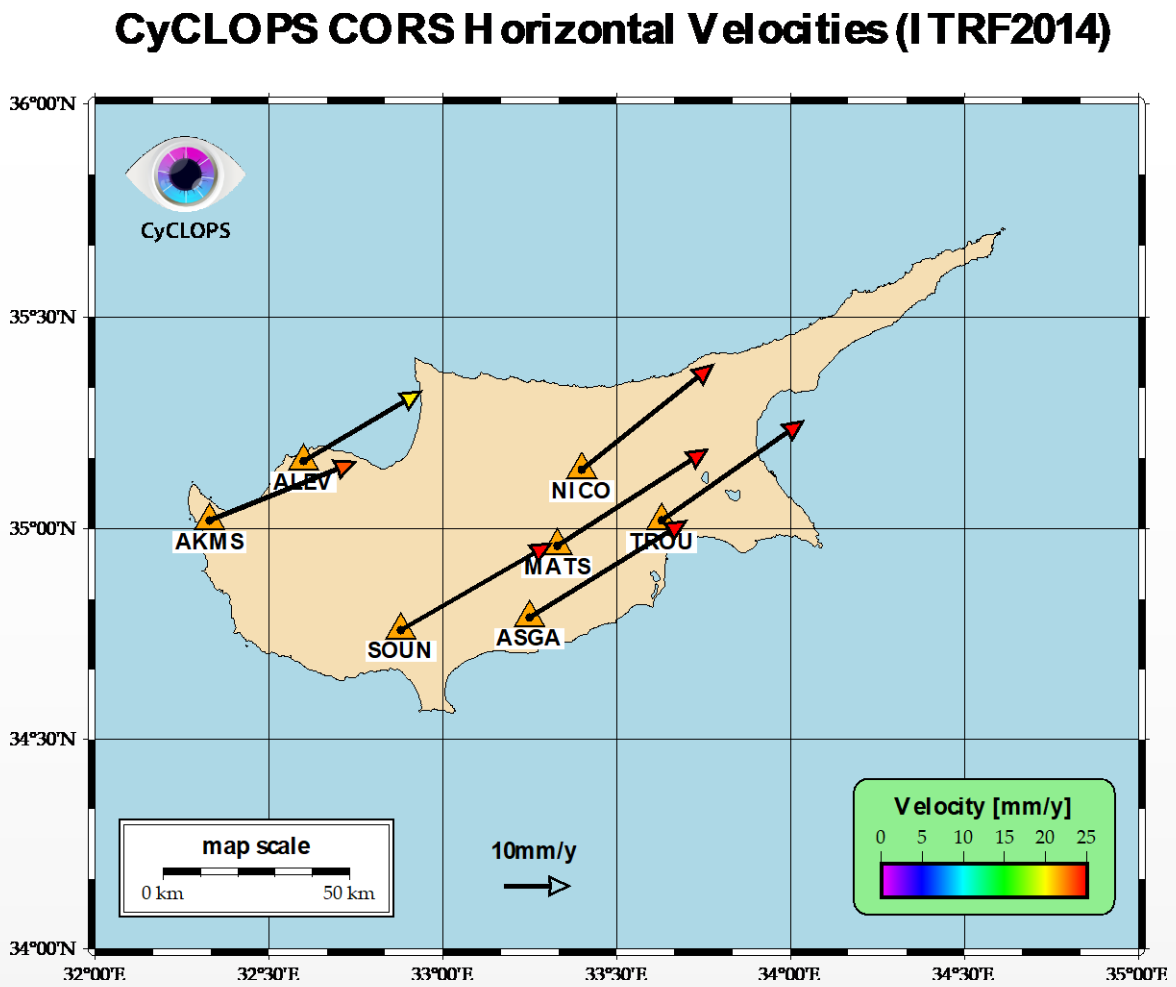
Ionospheric Activity

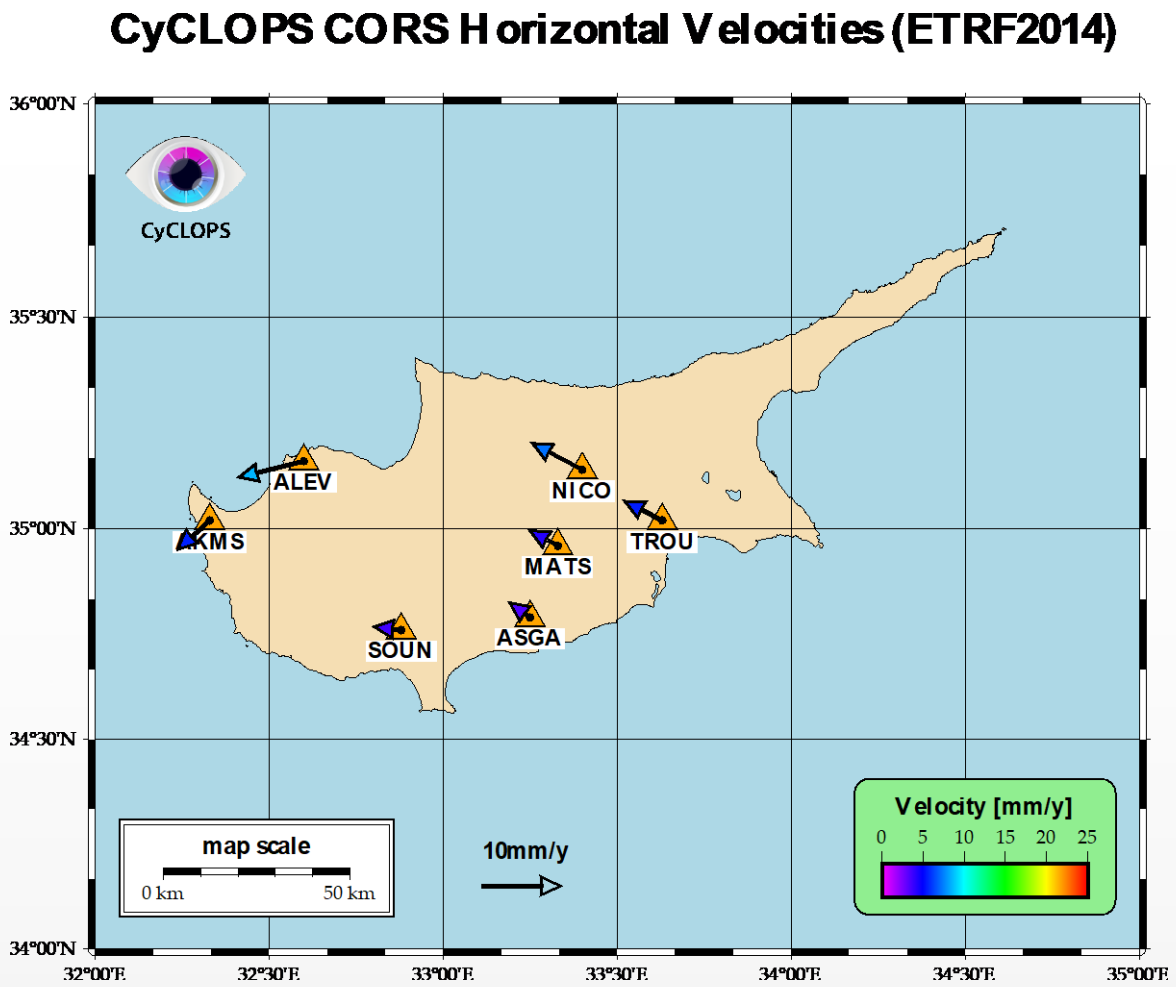


Tropospheric Activity

Preliminary Results

Towards a Cyprus Local Velocity Model





Processing Period: 08/2021 – 10/2022

CyCLOPS: A National Integrated GNSS/InSAR Strategic Research Infrastructure
for Monitoring Geohazards and Forming the Next Generation Datum of the Republic of Cyprus

Considerations and Multi-Criteria Decision Analysis for the Installation
of Collocated Permanent GNSS and SAR Infrastructures for Continuous Space-Based Monitoring of Natural Hazards

Thank you for your Attention!

Q+A Session

EUROPEAN UNION
European Regional Development Fund

Republic of Cyprus

Structural Funds
of the European Union in Cyprus

2016-2020 RESTART SEARCH
ΠΡΟΓΡΑΜΜΑΤΑ ΕΡΕΥΝΑΣ, ΤΕΧΝΟΛΟΓΙΚΗΣ ΑΝΑΠΤΥΞΗΣ ΚΑΙ ΚΑΙΝΟΤΟΜΙΑΣ

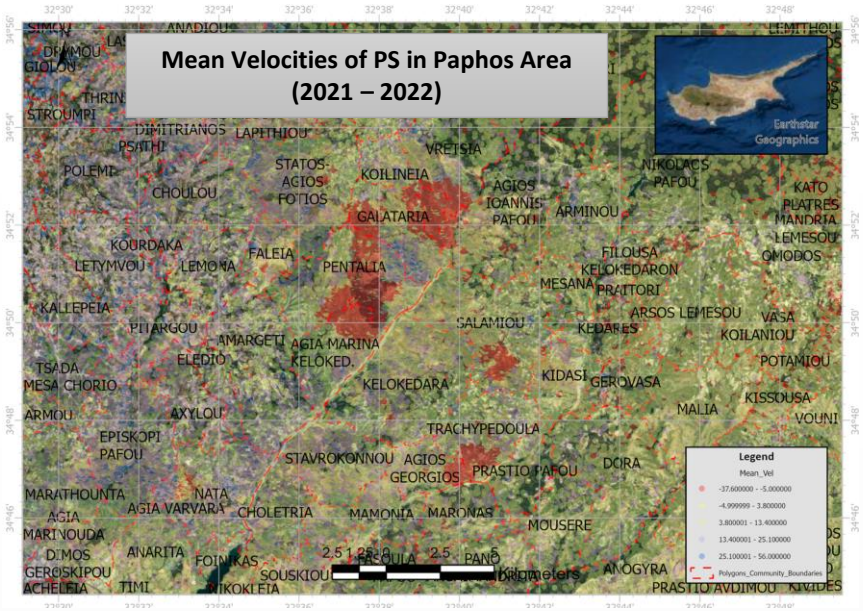
RESEARCH & INNOVATION FOUNDATION

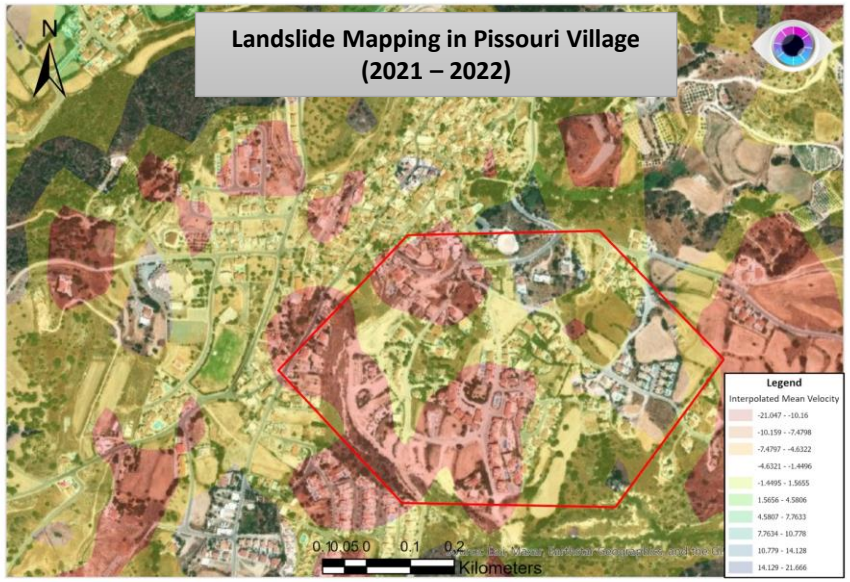
The project INFRASTRUCTURES/1216/0050 is co-financed by the European Union Regional Development Fund and the Republic of Cyprus through the Research and Innovation Foundation

CyCLOPS

Preliminary Results

GNSS + InSAR Processing

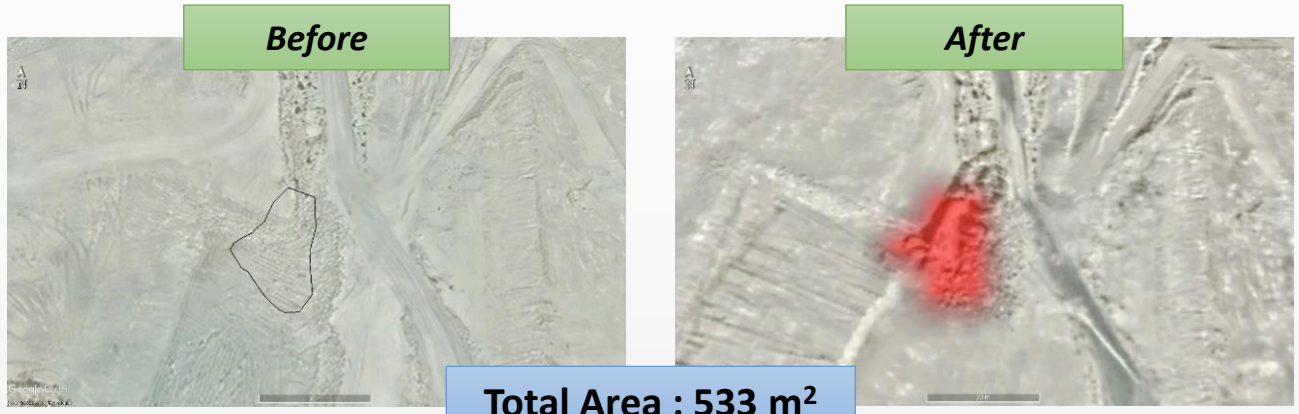




sentinel-1

Use of Electronic Corner Reflectors for the first time in Cyprus

Landslide Detection and Mapping at Vassilico Open-Pit Mine



Total Area : 533 m²