



Satellite-based Services for Disaster Risk Management

CyCLOPS: Establishment of a Strategic Integrated Permanent GNSS and InSAR Array to Enhance Monitoring of Geohazards and Promote Infrastructure Resilience in Cyprus

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ECoE Infrastructure Coordinator

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The Objectives of CyCLOPS

What is CyCLOPS and for what is it meant for?

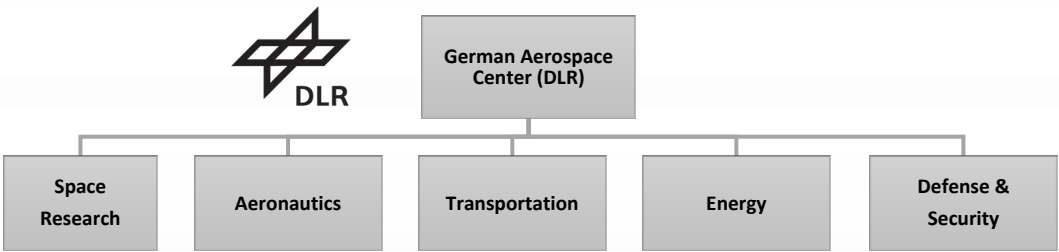
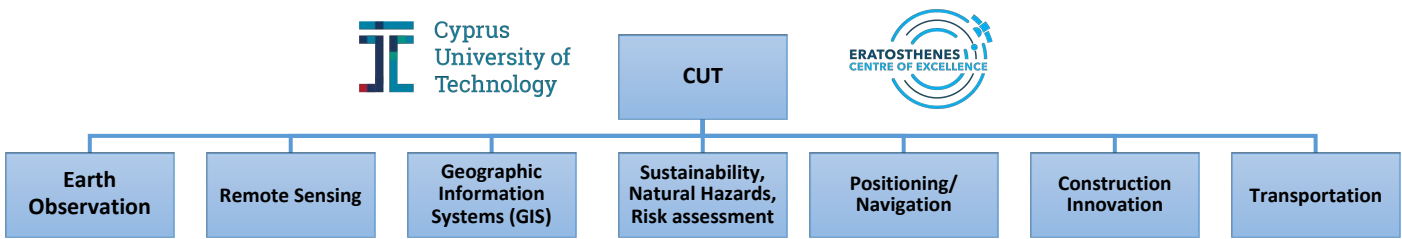
CyCLOPS is a Strategic Research Infrastructure co-funded by the European Union and the Republic of Cyprus to:

- **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** and **geophysical infrastructure**;
- **Form** the **basis** for a new **modernized National Geodetic Reference Frame** and **augment Regional and International Frames**;
- **Promote** critical **geodetic initiatives** on monitoring **Natural Hazards**.

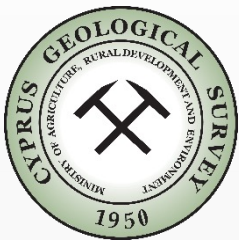


Consortium and Supporters

Who we are...



Supporters:



Department of Geological Survey



Department of Lands & Surveys



Ministry of Defence



Cyprus Association of Rural & Surveying Engineers



Cyprus Electricity Authority

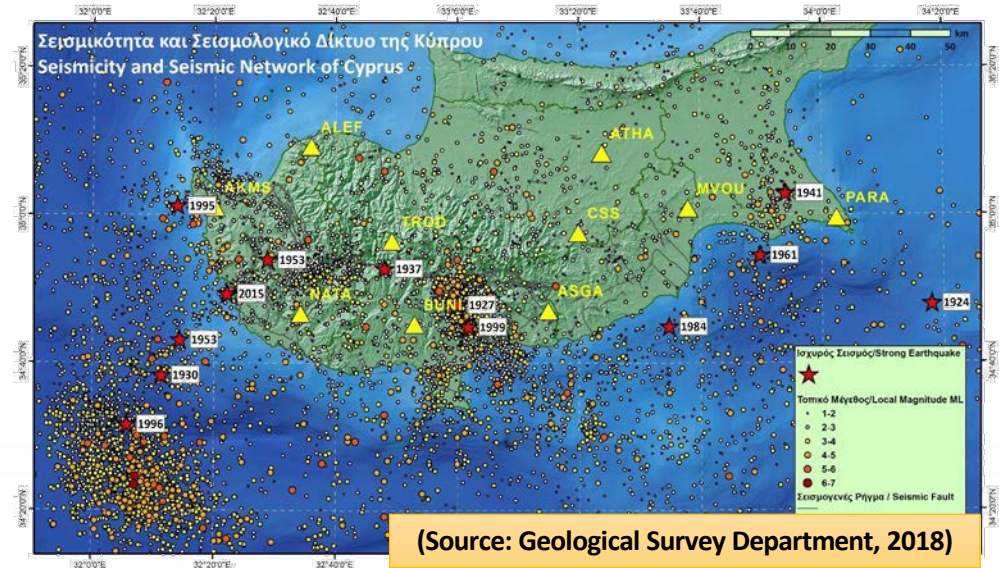
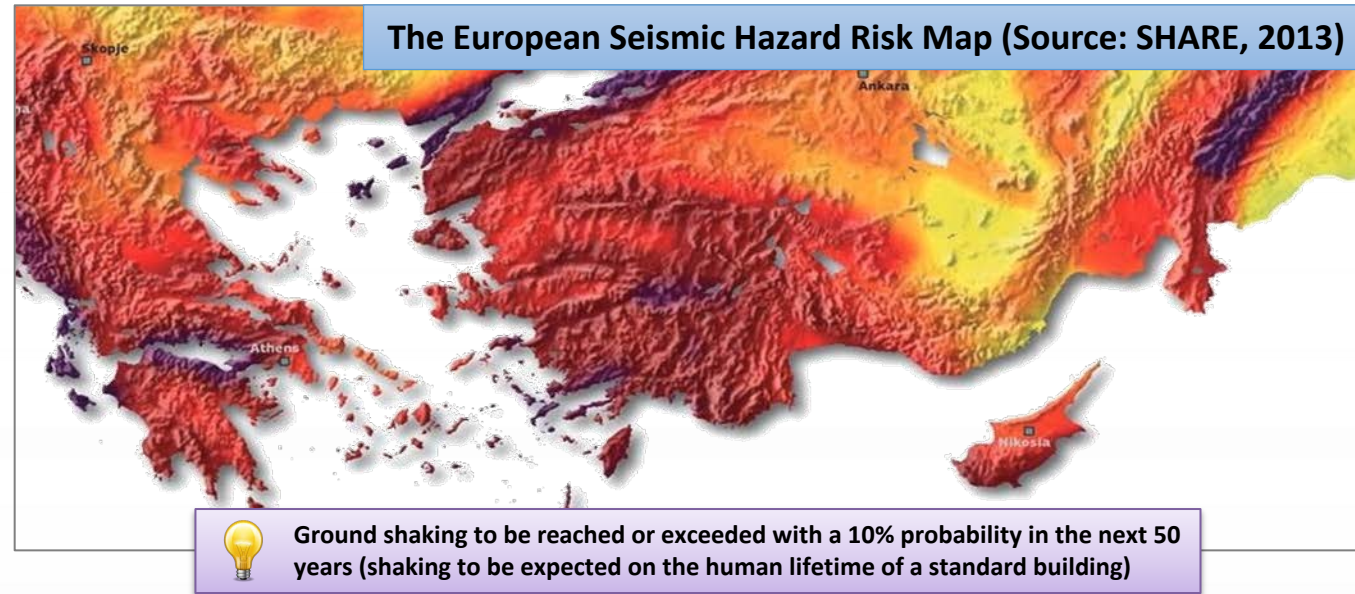


European Plate Observing System



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.

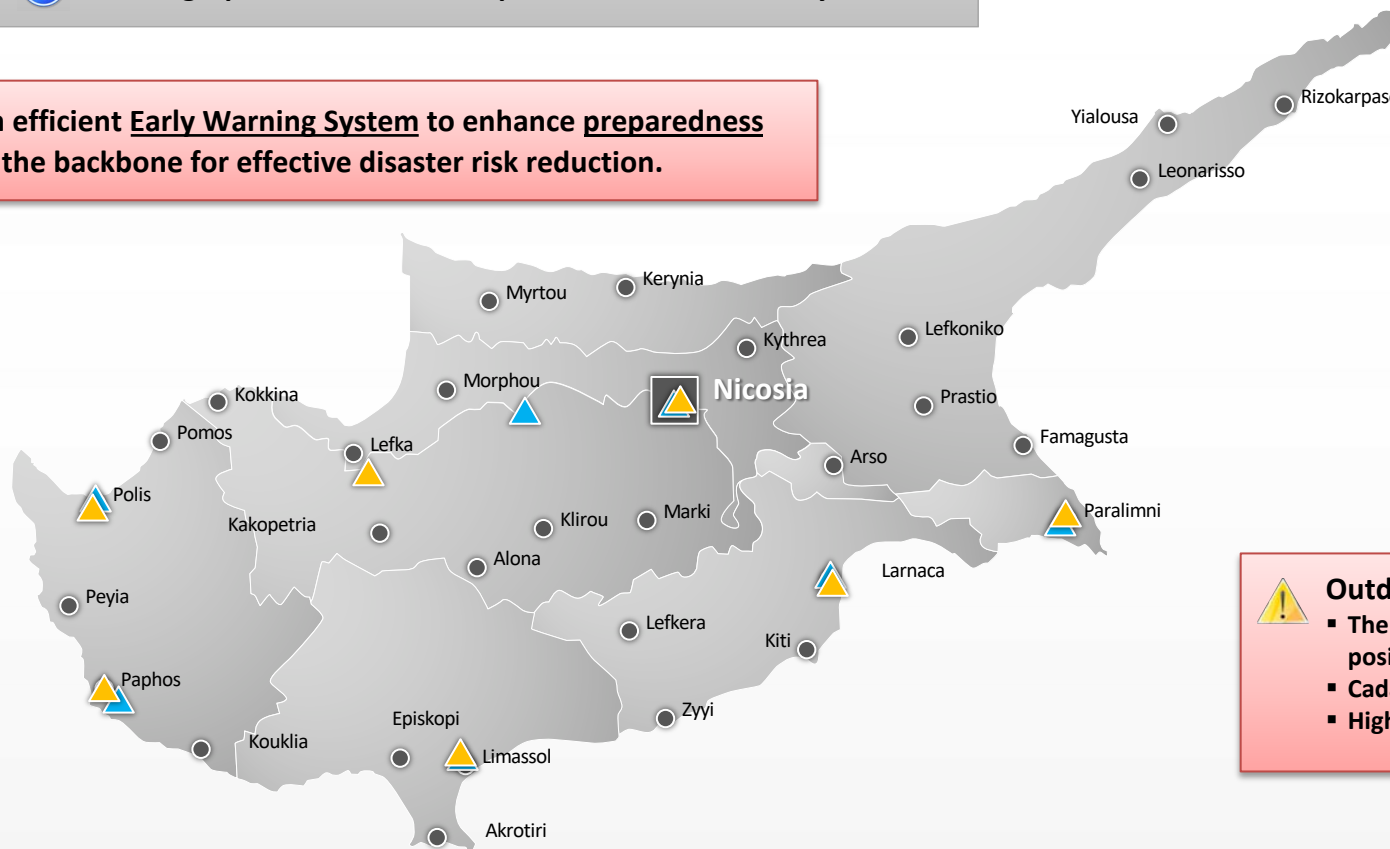
i Seismographs, inclinometers, sparse drills conducted by the GSD.

i 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/ geotecnic 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

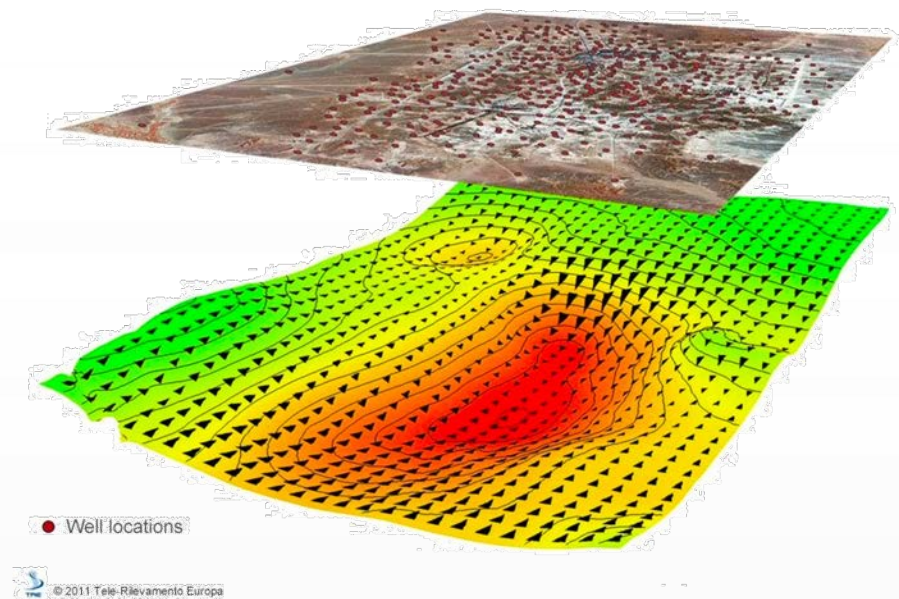


Global Navigation Satellite Systems (GNSS)



mm-level absolute displacement
and velocity determination for
a single point on the Earth

Synthetic Aperture Radar (SAR, InSAR, PSI)

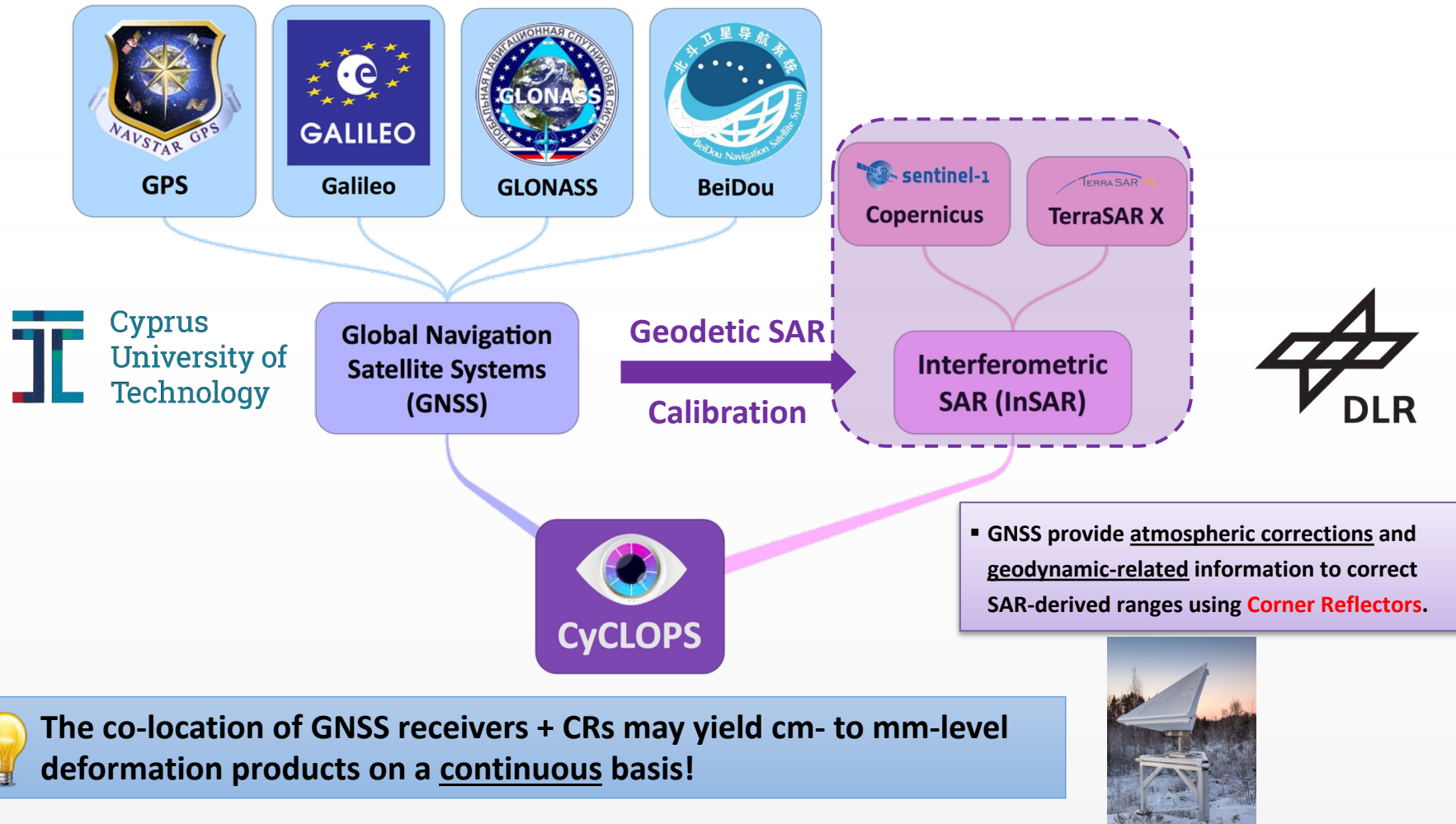


~cm- to mm-level relative displacement
and velocity determination with
high resolution



Earth Observation & Natural Hazards

Most Prominent EO Techniques for Monitoring Geohazards

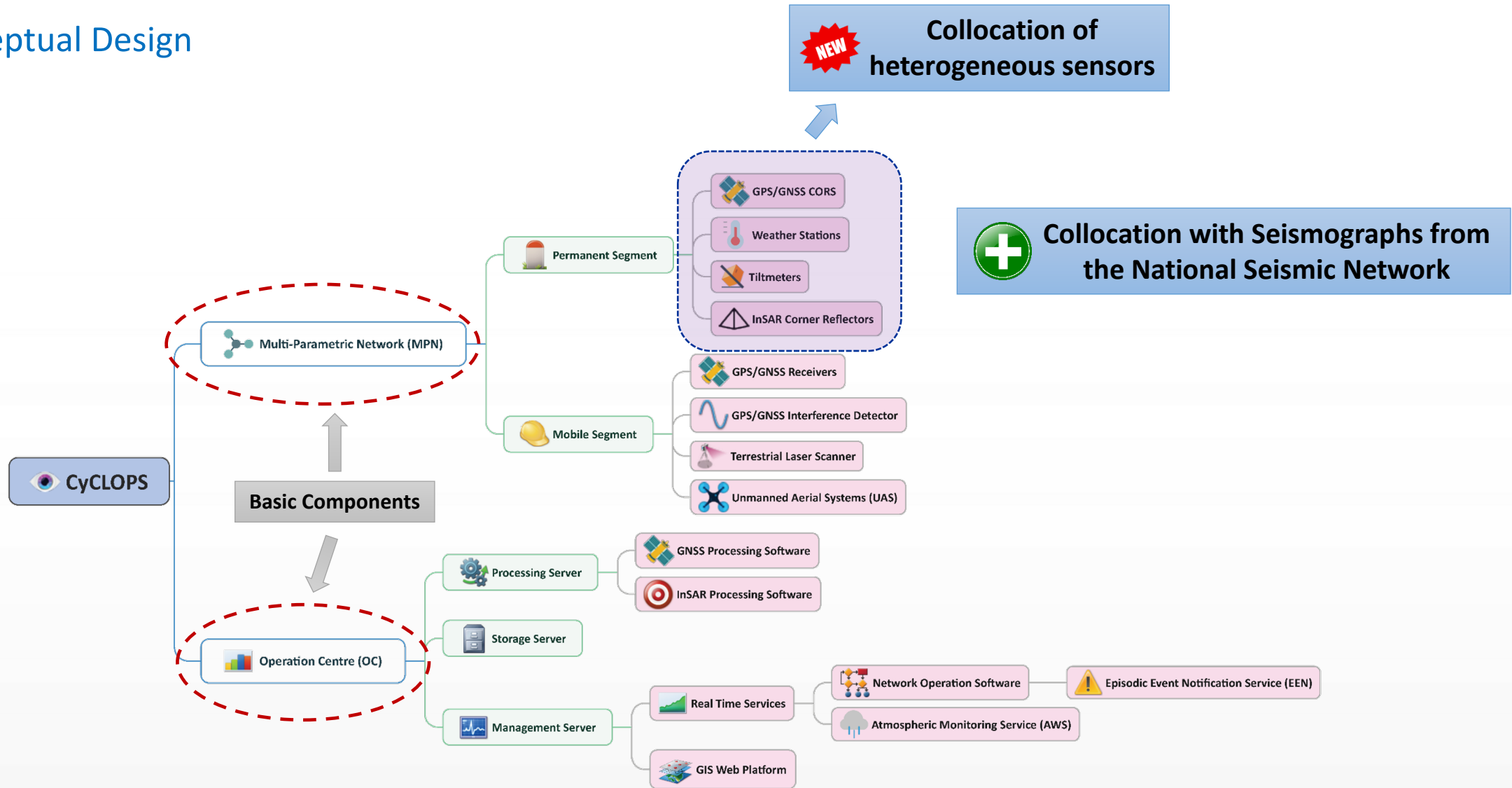


The co-location of GNSS receivers + CRs may yield cm- to mm-level deformation products on a continuous basis!



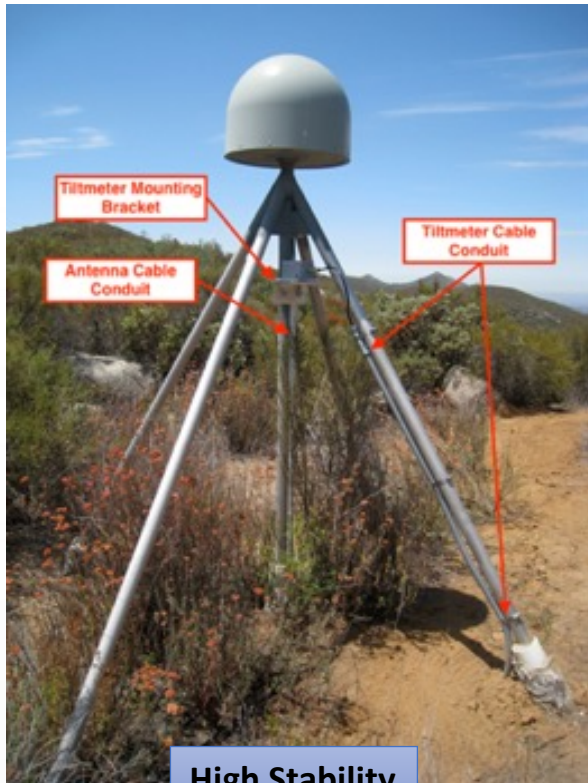
CyCLOPS Architecture

Conceptual Design



GNSS CORS Infrastructure

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



High Stability



Medium - High Stability



Medium Stability

 UNAVCO Taxonomy



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.

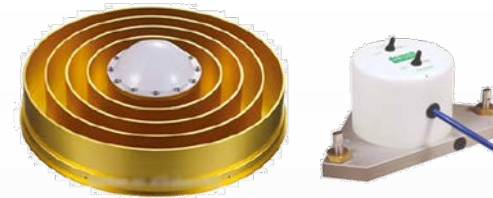


The Permanent Segment (PS)

Monumentation and Equipment Features

Infrastructure Highlights:

- 6x GPS/GNSS CORS will be 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.

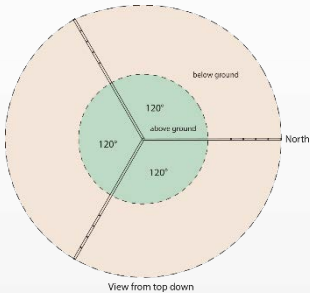
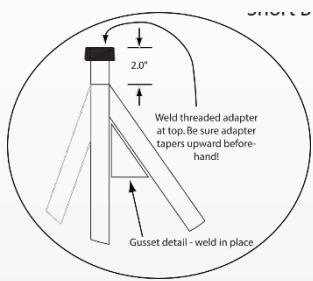
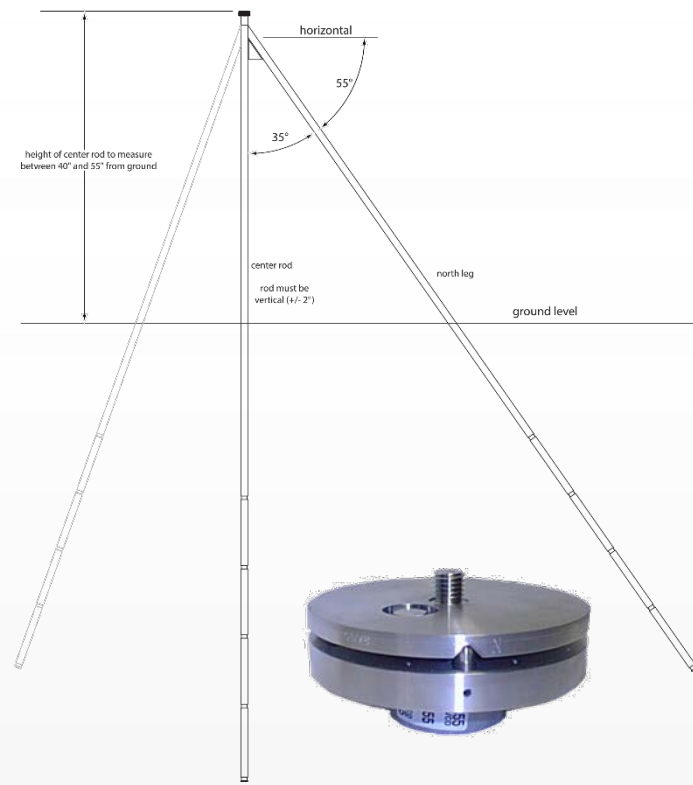


The Permanent Segment (PS)

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)



The Permanent Segment (PS)

Trihedral Corner Reflectors (TCRs)

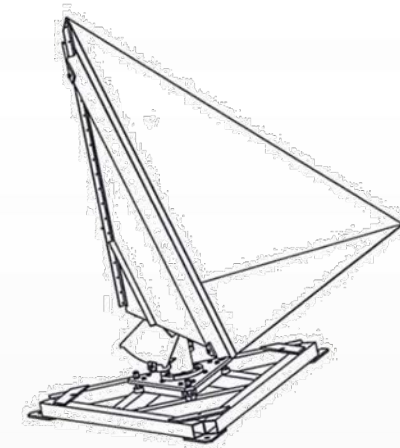


Calibration-grade Triangular Trihedral Corner Reflectors designed in collaboration with DLR

Azimuth Adjustment Range: -180° to $+180^\circ$

Elevation Adjustment Range: -10° to $+45^\circ$

**Permanent Monumentation Considerations
(anchored in solid bedrock)**



Support for Sentinel-1, TerraSAR-X, COSMO-SkyMed etc (2m corner length)

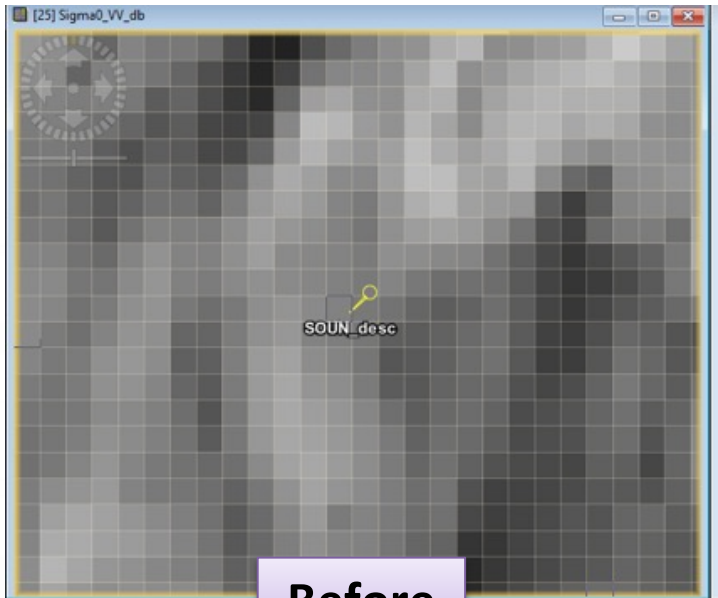


The Permanent Segment (PS)

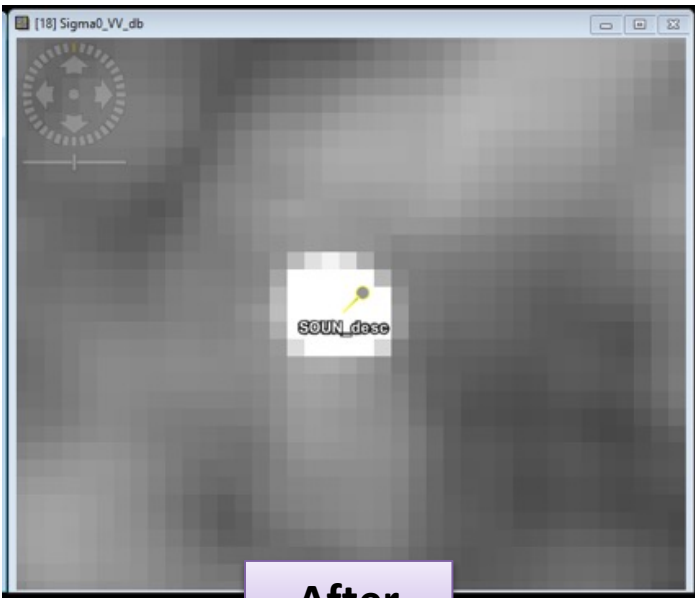
CR Installation at ALEV




The Permanent Segment (PS)

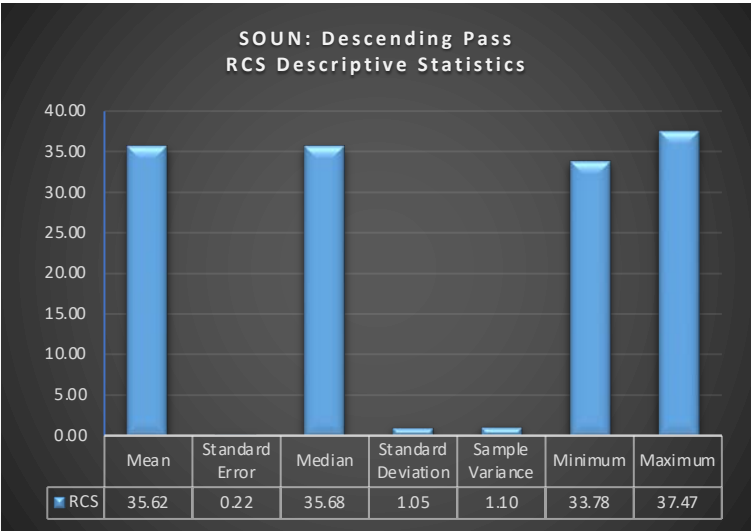
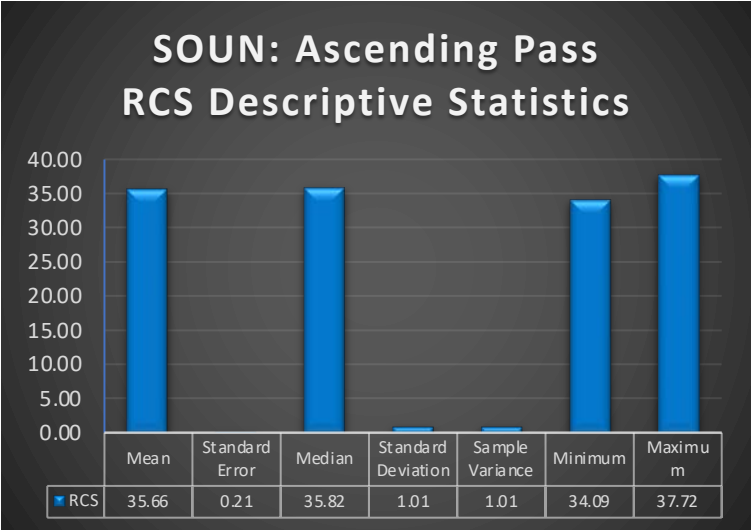


Before

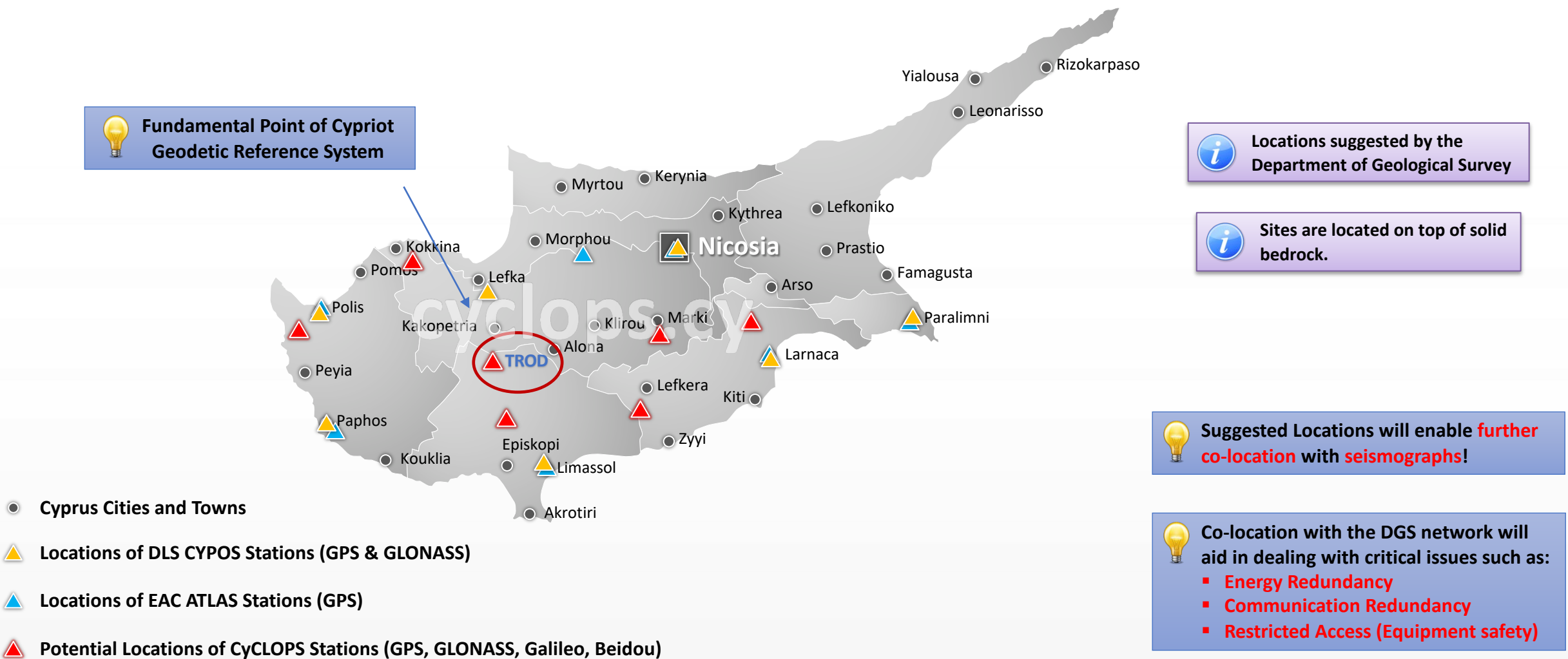


After

 The impact of a CyCLOPS Corner Reflector on a Sentinel-1 acquisition (before and after installation)



The Permanent Segment (PS) – Site Locations

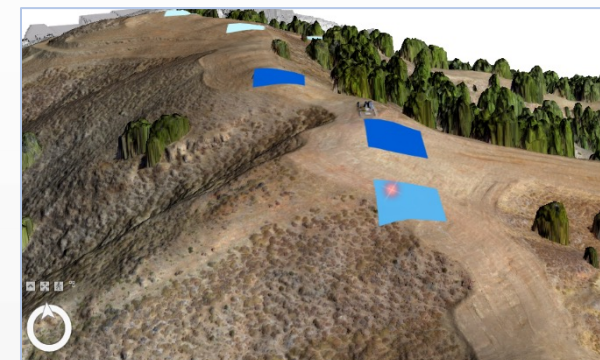
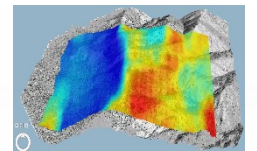
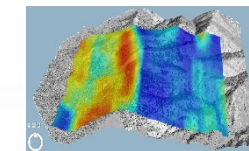
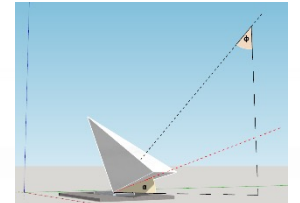
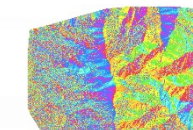
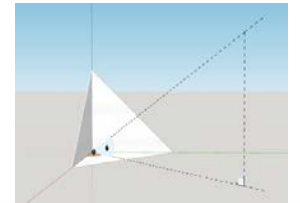
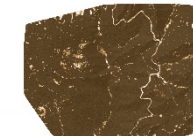
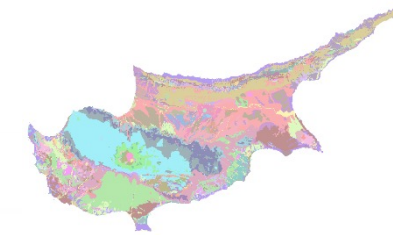
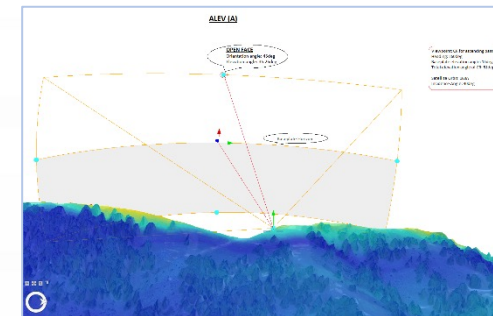
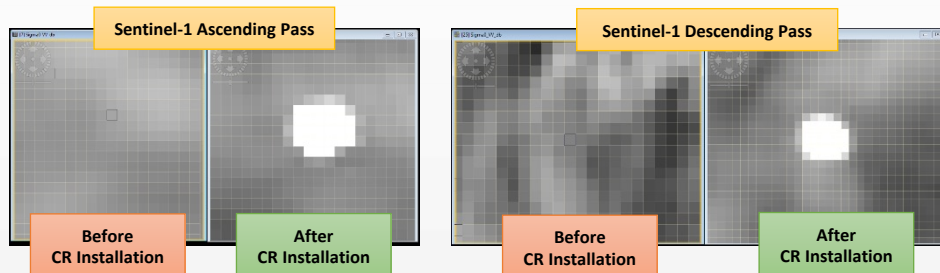


The Permanent Segment

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:

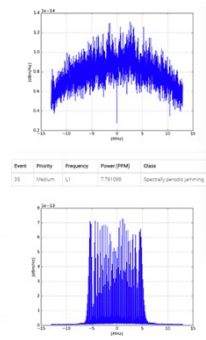
- Geological background,
- Terrain slope and aspect,
- Land ownership (state parcels),
- Land cover and access,
- Signal-to-Clutter Ratio (SCR),
- Incidence Angle,
- LoS and distance between GNSS CORS and TCRs
- ...



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



The Mobile Segment (MS)

Examples of Mobile Deployments at the Areas of Interest



Open-pit Mine



House Roof
(Residential Area)

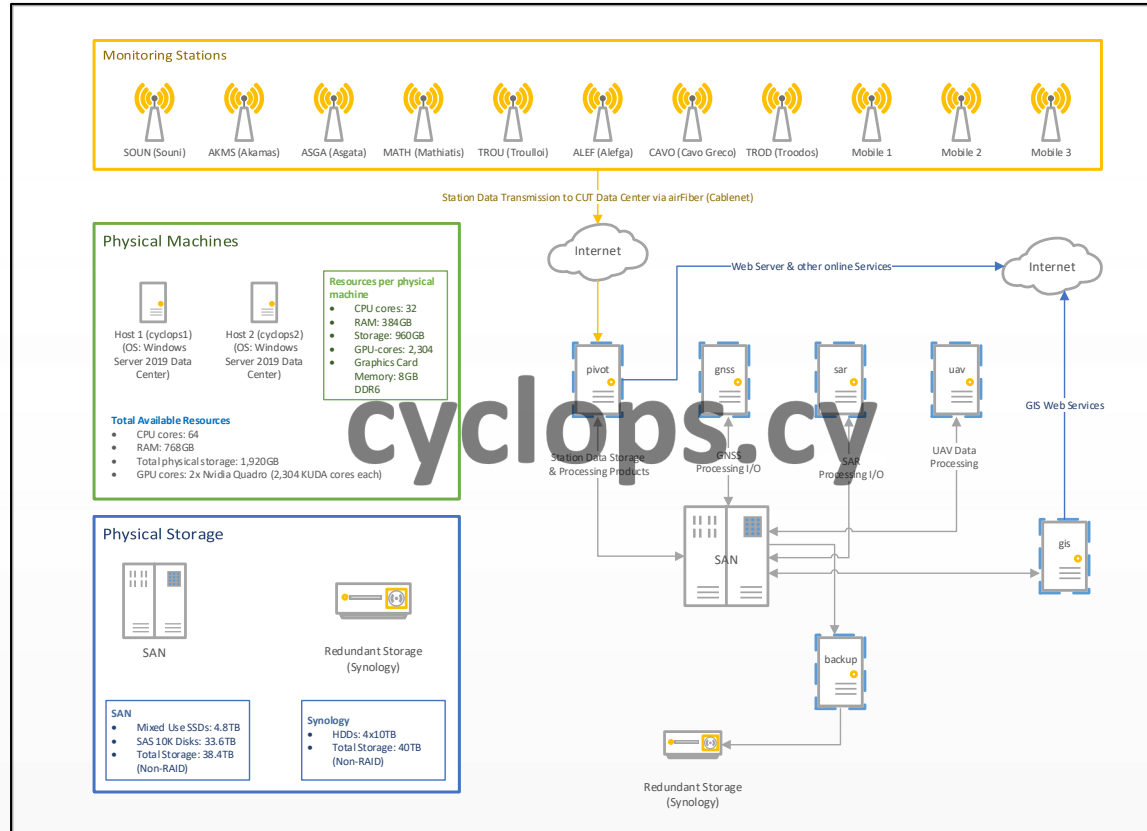


Archaeological Site



The Operation Centre (OC)

Architecture



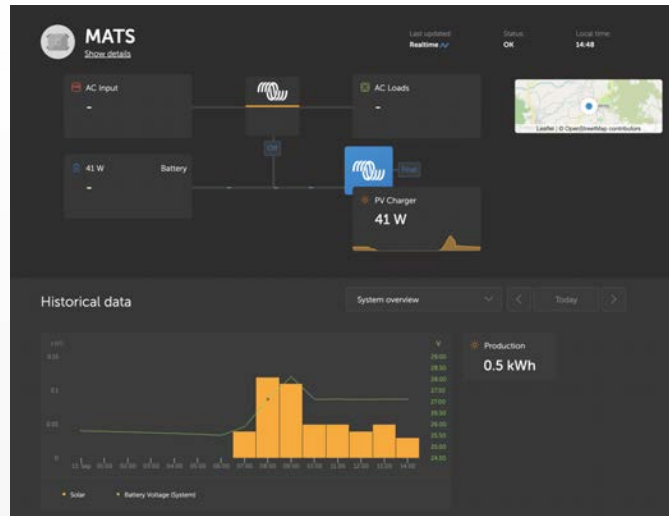
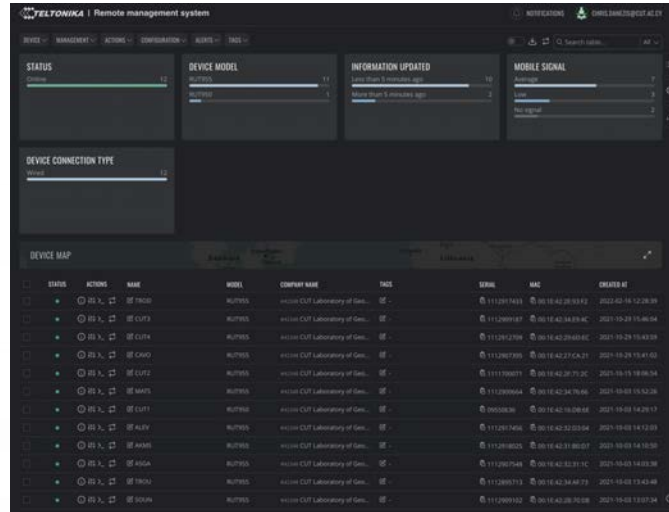
Dedicated expandable cluster with the following features:

- **CPU:** 64/128 Logical Cores/ Threads for processing,
- **RAM:** 768GB
- **Redundant operation in case of hardware failure:** It takes less than 1 minute to have the system up and running!
- Redundant **power supplies;**
- Both sensors and cluster components are protected against hackers, bots or unwanted malware.



The Operation Centre (OC)

Telecoms and Resource Monitoring



24/7/365 monitoring of telecommunications and solar output:

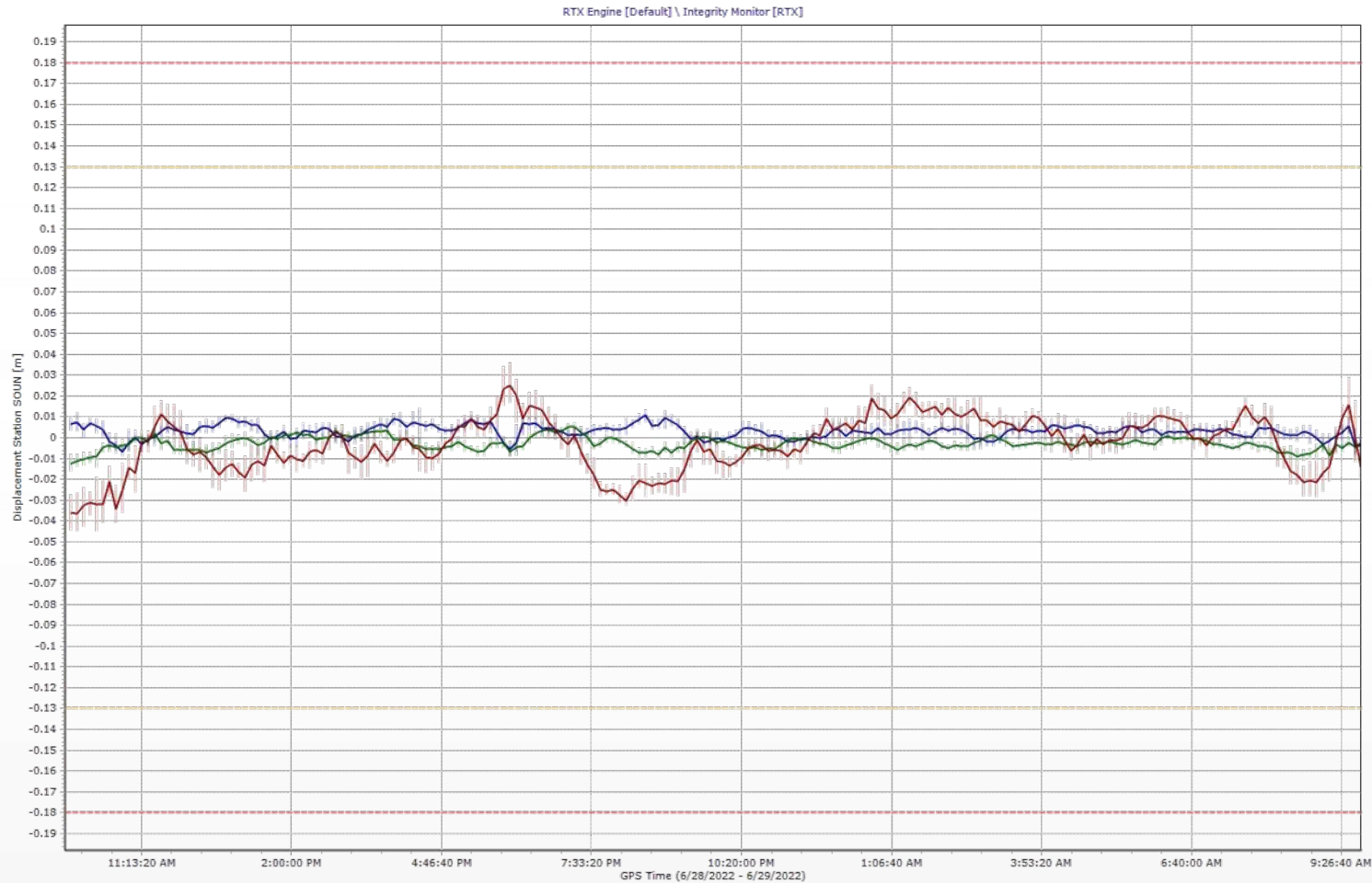
- Monitoring via desktop and smartphones;
- Alerts in case of telecommunication outage
- Alerts in case of a faulty energy component (battery or solar panel)

Prepared to replace batteries or solar panels in case of theft or malfunction within a time window of 5 days

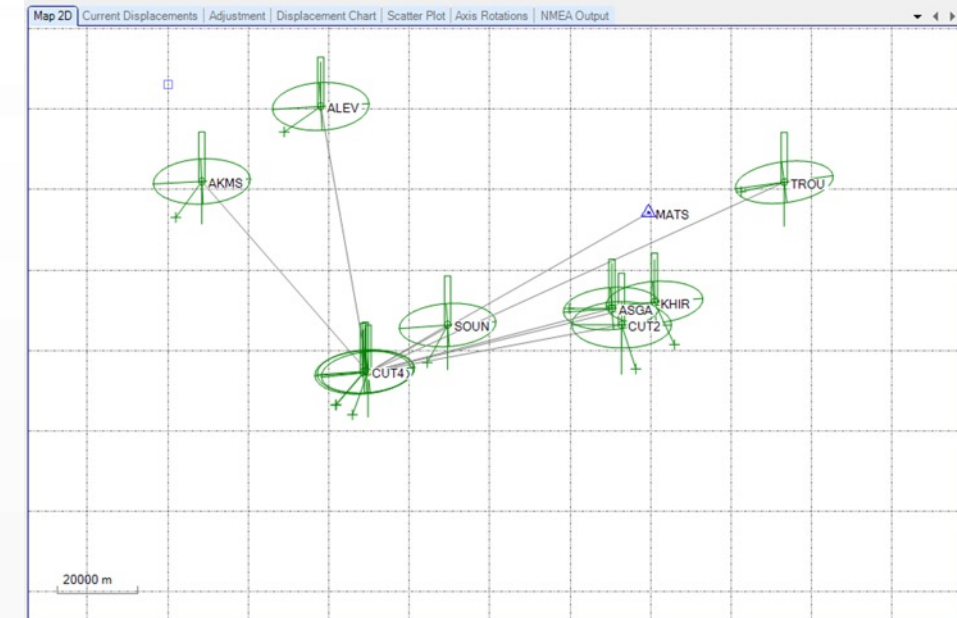


Real-Time Services (RT)

Real Time Displacement Monitoring

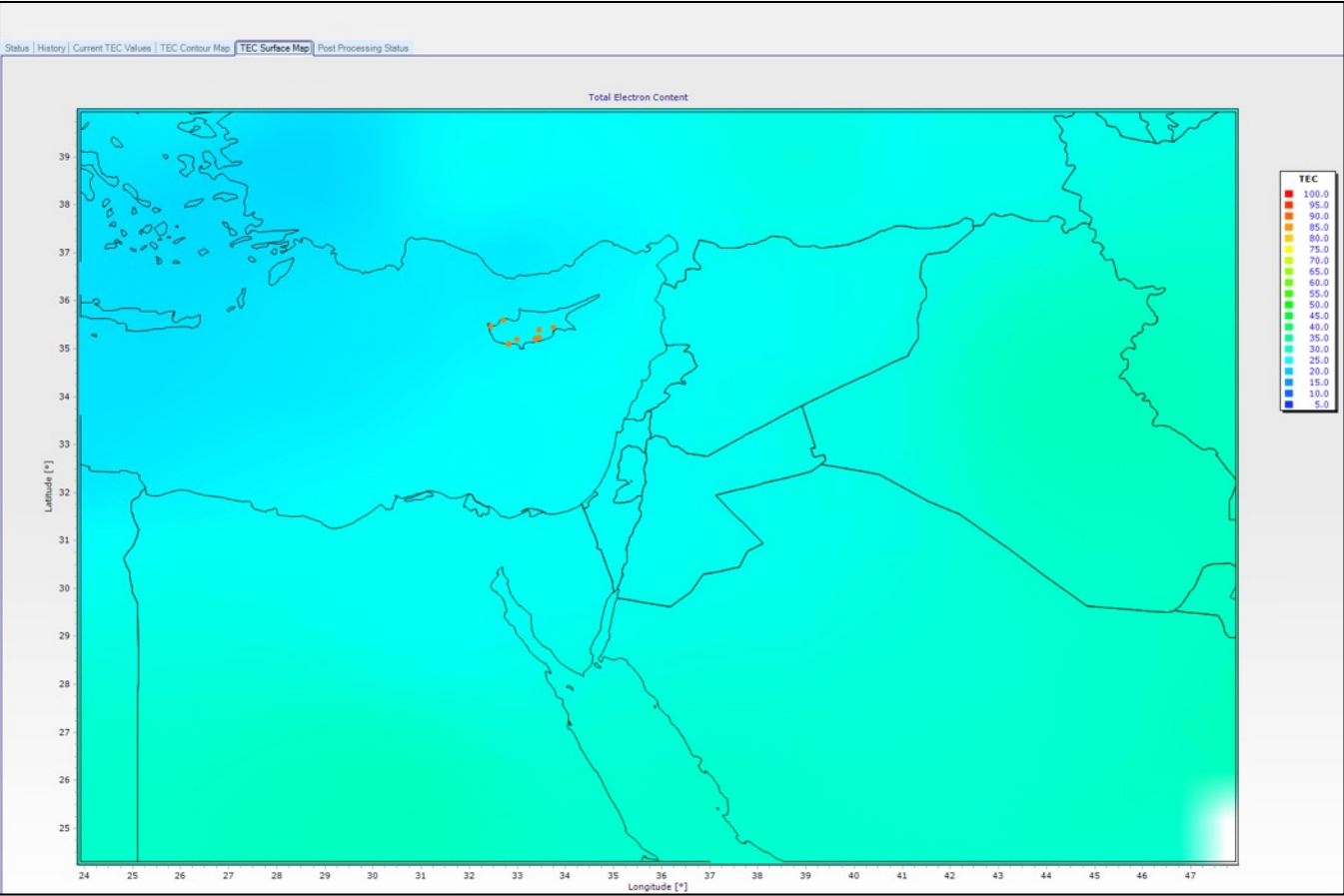


Status	Station Name	Station Code	Axis Rotation	Δ Northing [m]	Δ Easting [m]	Δ Height [m]	Δ 2D [m]	Δ 3D [m]	3- σ Δ Northing [m]	3- σ Δ Easting [m]	3- σ Δ Height [m]	3- σ Δ 2D [m]
▲	MAT5	MAT5		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
●	CUT3	CUT3	<input type="checkbox"/>	-0.003	-0.002	0.002	0.003	0.004	0.011	0.004	0.007	0.008
●	TROU	TROU	<input type="checkbox"/>	-0.001	-0.004	-0.006	0.004	0.007	0.012	0.007	0.009	0.010
●	AKMS	AKMS	<input type="checkbox"/>	-0.006	-0.004	-0.002	0.007	0.007	0.011	0.004	0.008	0.009
●	CUT4	CUT4	<input type="checkbox"/>	-0.005	-0.004	0.005	0.006	0.008	0.011	0.004	0.007	0.008
●	SOUN	SOUN	<input type="checkbox"/>	-0.002	-0.001	-0.009	0.003	0.009	0.011	0.004	0.007	0.008
●	ALEV	ALEV	<input type="checkbox"/>	-0.004	-0.006	0.007	0.007	0.010	0.012	0.004	0.007	0.008
●	ASSA	ASSA	<input type="checkbox"/>	0.000	-0.001	0.010	0.001	0.010	0.011	0.004	0.007	0.008
●	CAVO	CAVO	<input type="checkbox"/>	-0.009	-0.003	-0.010	0.010	0.014	0.008	0.017	0.019	0.019
●	KHIR	KHIR	<input type="checkbox"/>	-0.016	0.008	0.004	0.018	0.018	0.011	0.025	0.027	0.027
●	CUT2	CUT2	<input type="checkbox"/>	-0.014	0.005	-0.028	0.015	0.032	0.014	0.030	0.037	0.033



Real-Time Services (RT)

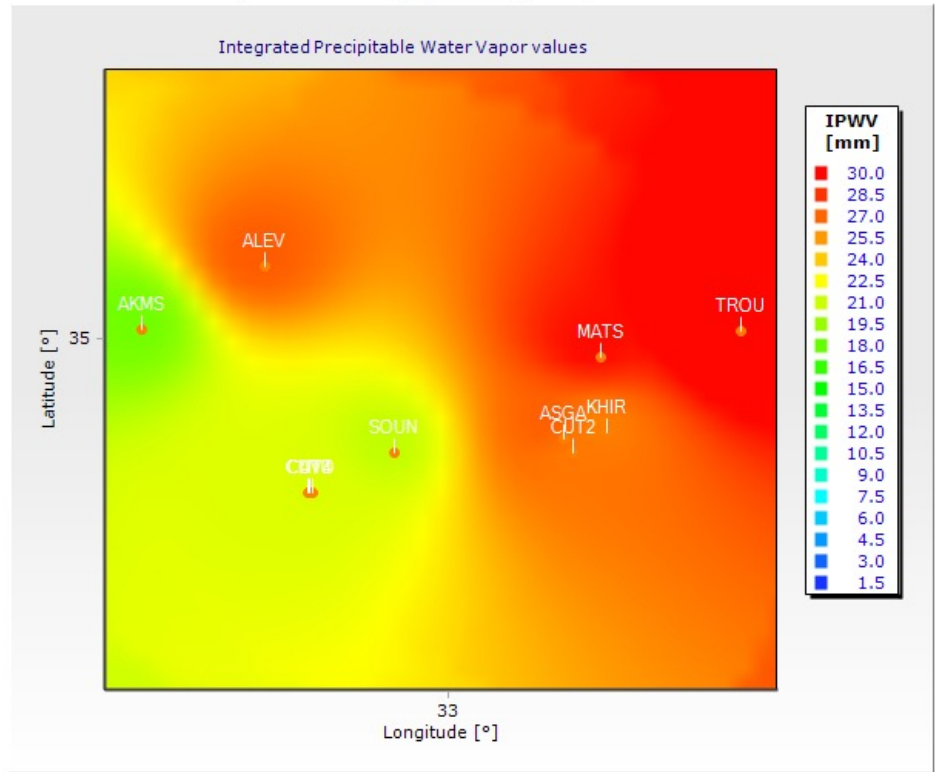
Atmospheric Service



Ionospheric Activity

Integrated Precipitable Water Vapor Surface Map

Maximum IPWV value:
Time:



Tropospheric Activity



Post Processing Services (PP)

GNSS + InSAR Processing

- **GNSS Post Processing** computation workflow using the Bernese GNSS 5.4 Processing Engine (BPE)
 - Daily station coordinates (Rapid + Final modes);
 - Tropospheric + Ionospheric products;
- Analysis for discontinuities or permanent deformation on both short-term and long-term basis.
- SAR Post Processing computation scenarios implemented using Open Source software (ESA SNAP, StaMPS etc.)
 - The SAR PP backend is currently automated and re-designed using in-house developed software;
 - The SAR PP core engine is migrated to GAMMA RS (ASF, NASA, ESA EGMS);
 - Calibration of SAR observations using GNSS PP input (geodynamic and atmospheric corrections) and CRs.



Case Studies

Monitoring Natural Hazards and Geodetic Infrastructure



■ Determination of Station Velocities in Cyprus [DLS, EAC]

- Precise displacement and velocity determination for **both national networks (CYPOS + PYTHEAS)** using all available data (1Hz since 2011);
- **Backbone** for the definition of a **new, dynamic CRS** for Cyprus.

• Landslide Monitoring in Chirokitia [DGS, DoA]

- Important Cultural Heritage landmark with landslide history.
- Suspicions on nearby **uncharted fault** by **DGS** and **geologists of DoA**.
- **Monitoring** and **determination** of **susceptible areas**.

• Landslide Monitoring in Pissouri Village [DGS]

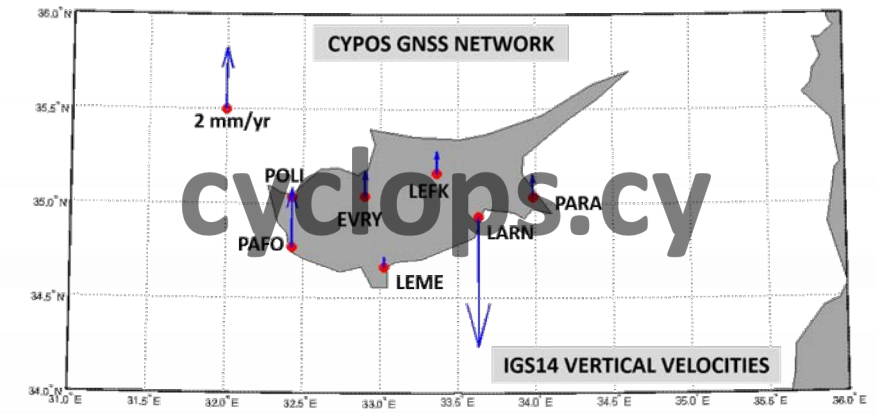
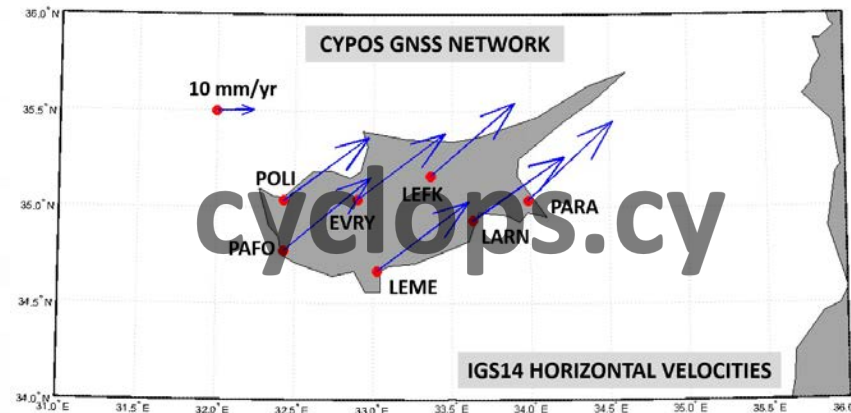
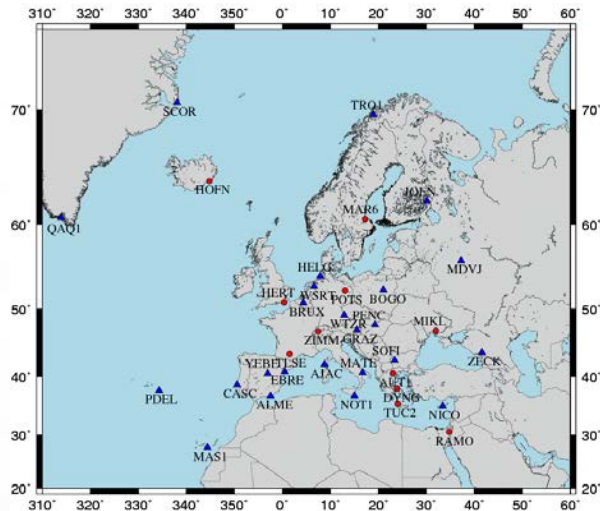
- Actual landslide case with **significant impact** on civilians and state.
- Concern for **potential landslides** occurring on other nearby locations.
- The whole village will be monitored using **GNSS + InSAR** techniques.



Preliminary Results

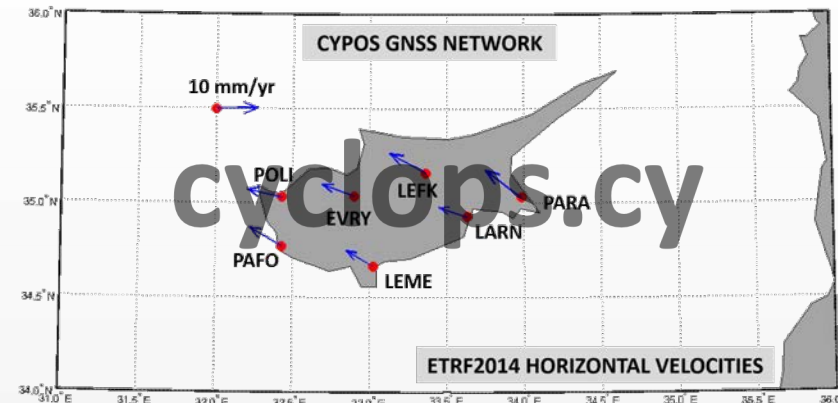
Cyprus Tectonic Motion – Estimation of CYPOS Station Precise Coordinates and Velocities (DLS)

- Estimation of Station Velocities in both ITRF2014(IGS14-IGSR3)/ETRF14



CYPOS: The national GNSS RTK services provider operated by the Department of Lands and Surveys

Data spanning an 11-year period were processed along with **34** Tier-1/2 (Class A) IGS+EPN stations to yield a multiyear stacking solution.

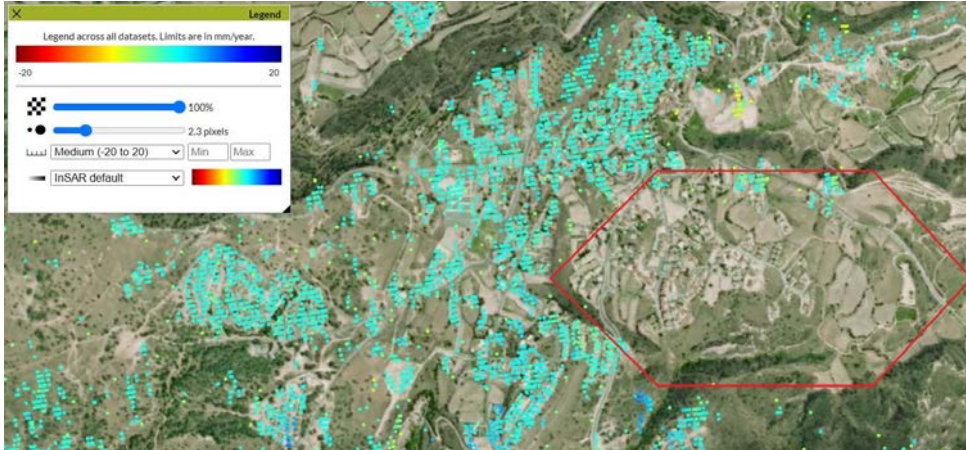


Velocities up to 2.5cm/year



Preliminary Results

Current Contribution to EU and International Space Organizations



EGMS: The area of interest is missing due to landslide's highly dynamic state.

CyCLOPS has the required infrastructure to contribute to and enhance the accuracy and reliability of EGMS in similar cases throughout Cyprus

CyCLOPS is already contributing a permanent GNSS reference station to EPOS

CyCLOPS contributes to CEOS SAR Cal/Val WG





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



RESEARCH
& INNOVATION
FOUNDATION

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