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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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**;

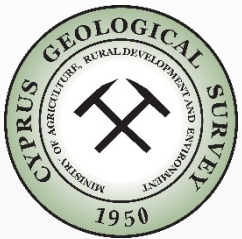- **Promote** critical **geodetic initiatives** on monitoring **Natural Hazards**.

Consortium and Supporters

Who we are…
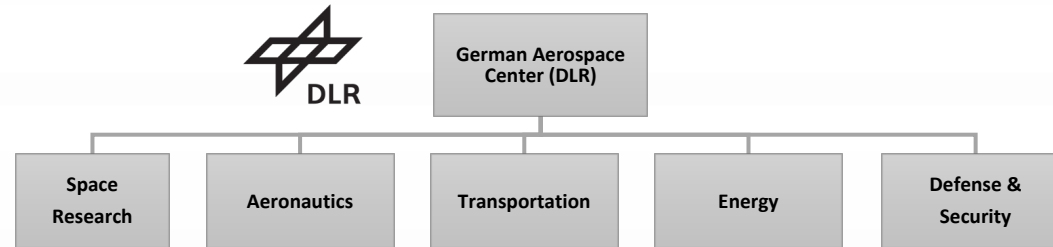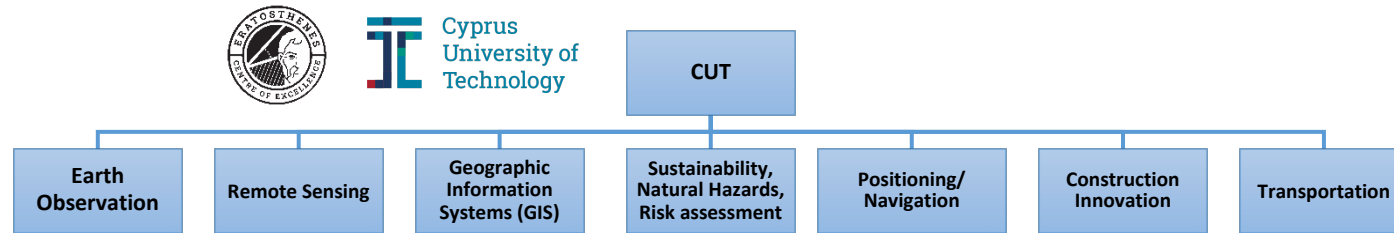
Supporters:

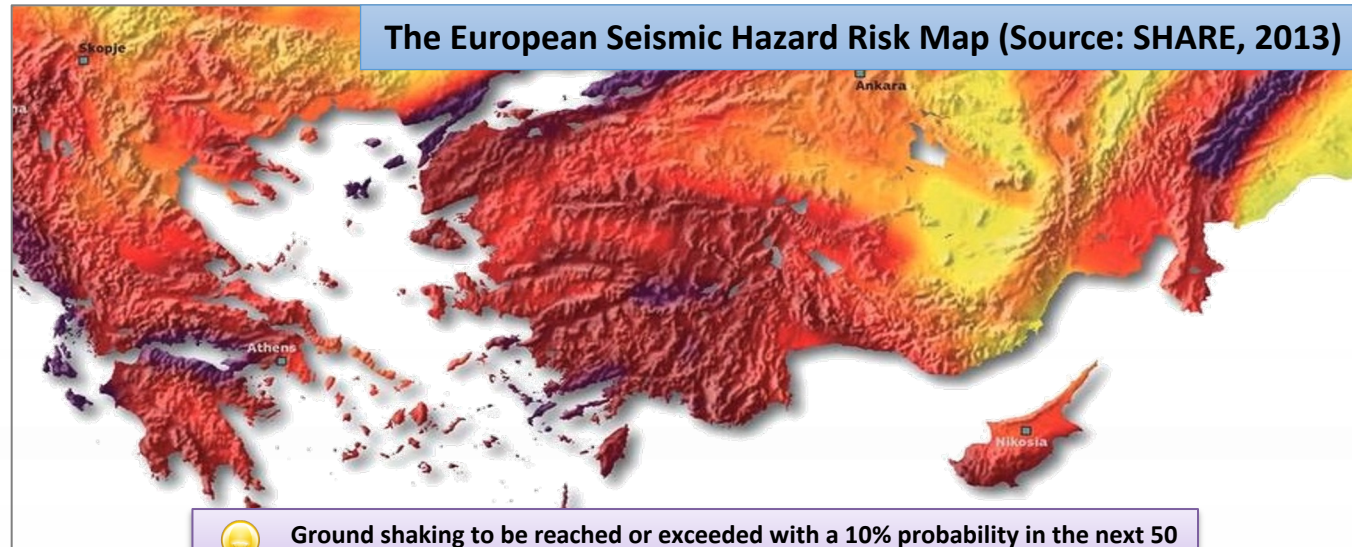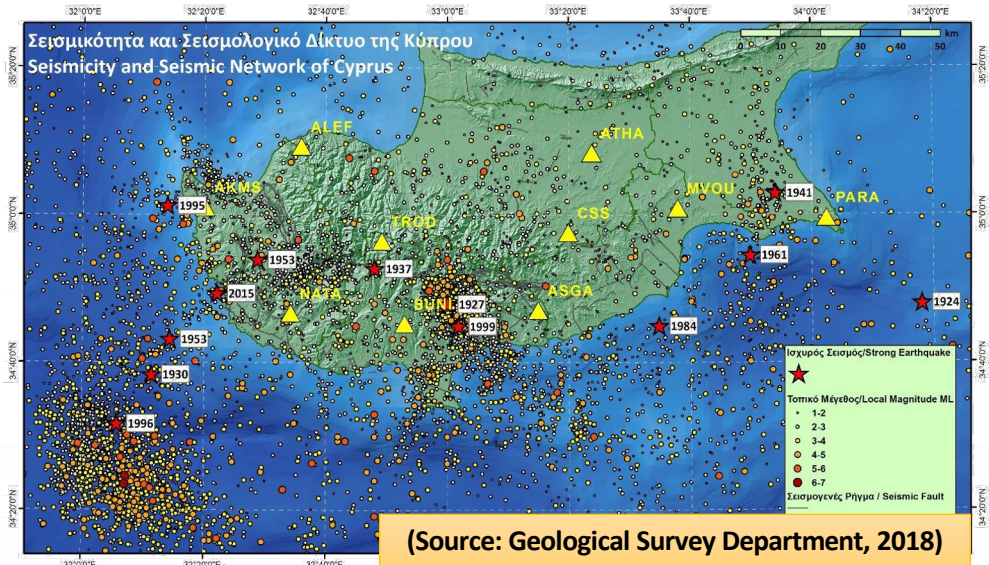| Department of Geological Survey | Department of Lands & Surveys | Cyprus Association of Rural & Surveying Engineers | Cyprus Electricity Authority | European Plate Observing System |

Natural Hazards in Cyprus

Earthquakes and Landslides

The European Seismic Hazard Risk Map (Source: SHARE, 2013)

💡 Ground shaking to be reached or exceeded with a 10% probability in the next 50 years (shaking to be expected on the human lifetime of a standard building)

Σεισμικότητα και Σεισμολογικό Δίκτυο της Κύπρου
Seismicity and Seismic Network of Cyprus

(Source: Geological Survey Department, 2018)

Natural Hazards in Cyprus
Current Infrastructure and Existing Gaps

(!) Current infrastructure for <u>monitoring</u> and better <u>understanding</u> natural hazards is limited to conventional equipment.
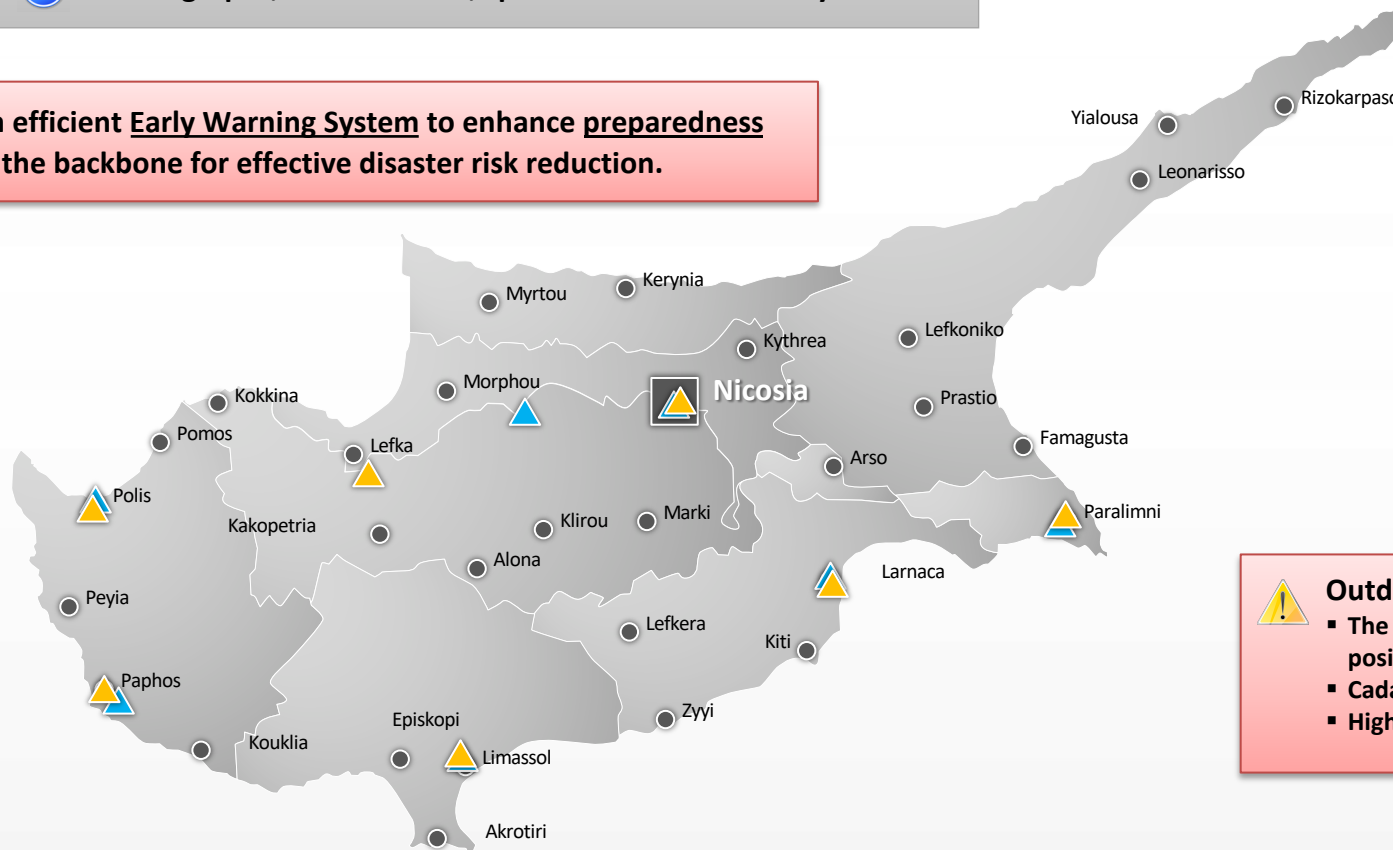
(i) **Seismographs, inclinometers, sparse drills conducted by the GSD.**

(i) **2x GNSS Networks of 7 stations each operated by DLS and EAC**

⚠ **Lack of an efficient <u>Early Warning System</u> to enhance <u>preparedness</u> 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**

Map labels: Yialousa, Rizokarpaso, Leonarisso, Kerynia, Myrtou, Lefkoniko, Kythrea, Morphou, Kokkina, Prastio, Nicosia, Pomos, Lefka, Famagusta, Arso, Polis, Kakopetria, Klirou, Marki, Paralimni, Alona, Larnaca, Peyia, Lefkera, Kiti, Paphos, Episkopi, Zyyi, Kouklia, Limassol, Akrotiri

Earth Observation & Natural Hazards

Most Prominent EO Techniques for Monitoring Geohazards

Global Navigation Satellite Systems
(GNSS)

Synthetic Aperture Radar
(SAR, InSAR, PSI)

mm-level <u>absolute</u> displacement and velocity determination for a <u>single</u> point on the Earth
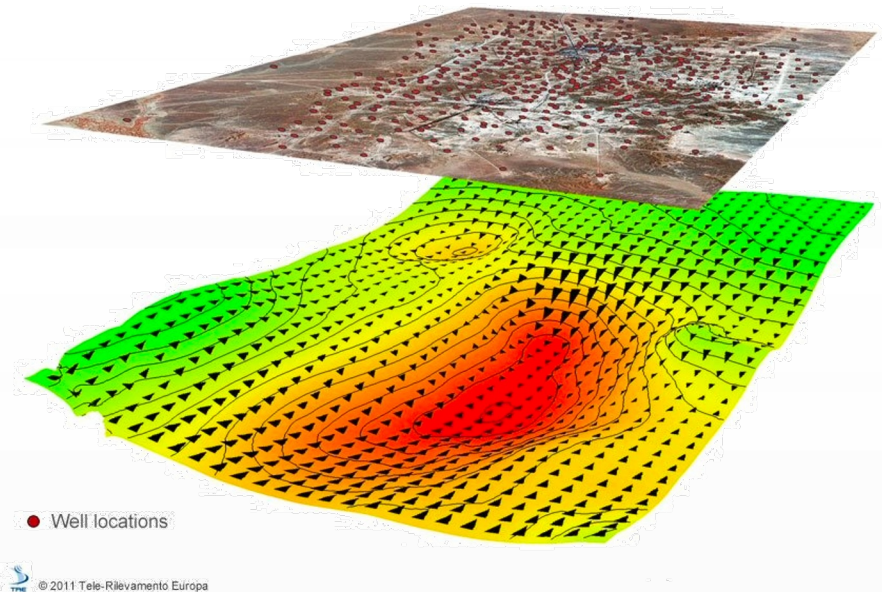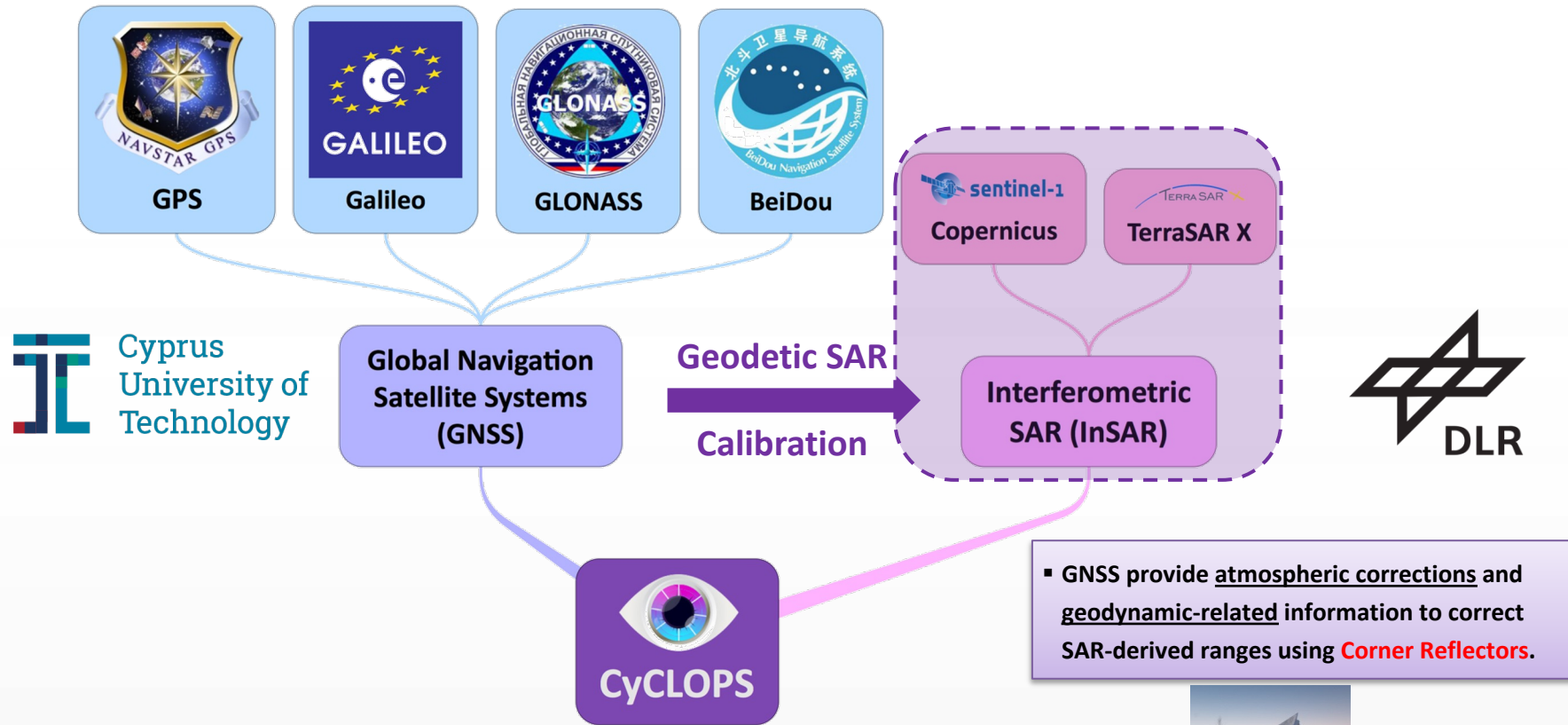
~cm- to mm-level <u>relative</u> displacement and velocity determination with <u>high resolution</u>

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 sentinel-1

TerraSAR X

Interferometric SAR (InSAR)

DLR

CyCLOPS

- GNSS provide <u>atmospheric corrections</u> and <u>geodynamic-related</u> 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 <u>continuous</u> basis!**

CyCLOPS Architecture

Conceptual Design

Collocation of heterogeneous sensors

Collocation with Seismographs from the National Seismic Network
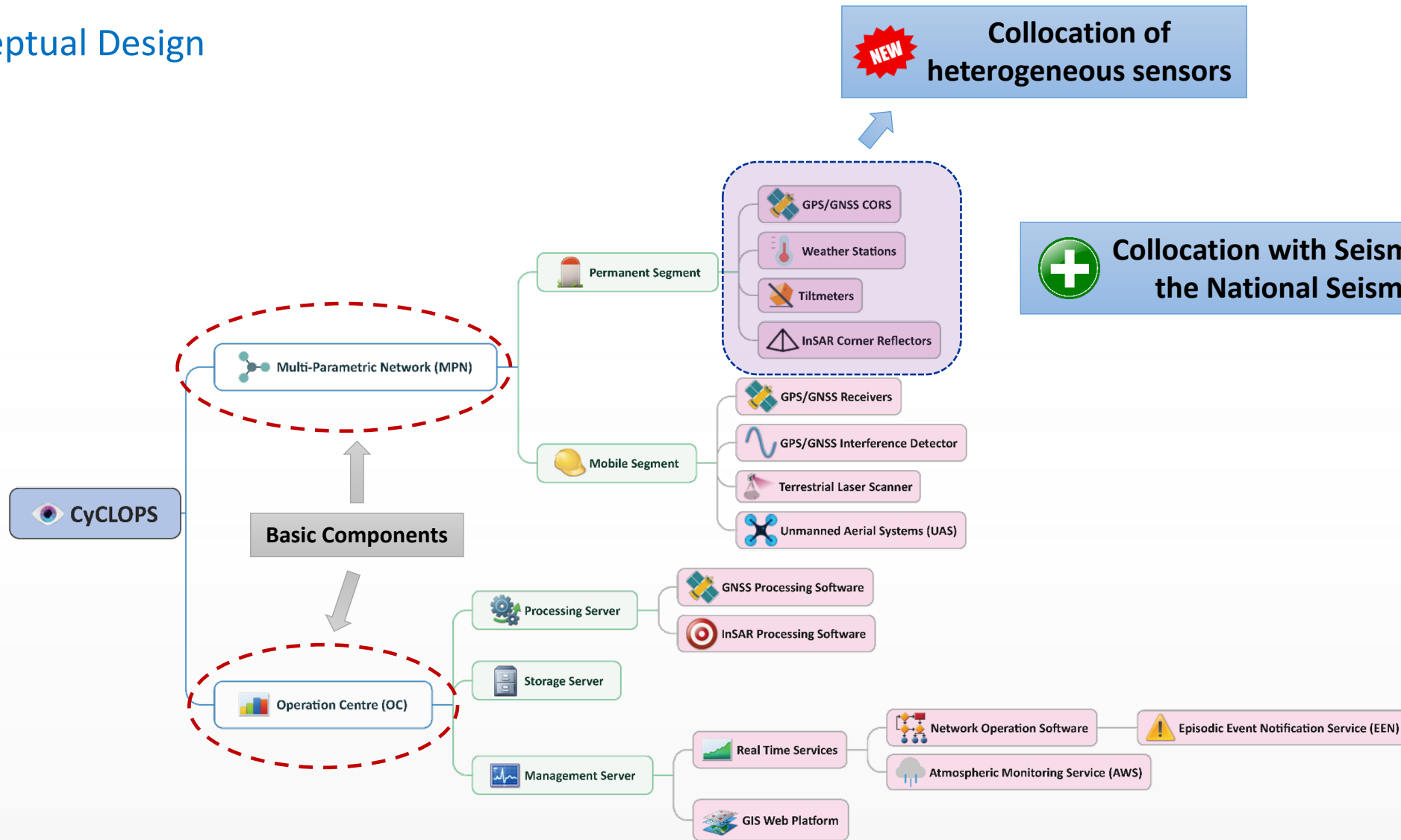
The Permanent Segment (PS)

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 and tilt-meters;

- Dual SAR Trihedral Corner Reflectors (two in each site) in opposite facing configuration.
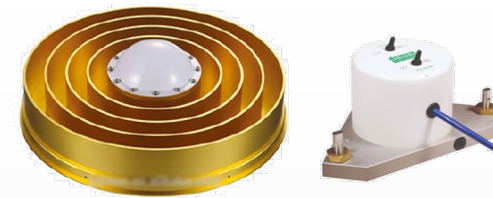
Two corner reflectors facing opposite directions to account for both ascending and descending passes of SAR satellites, yielding an **increase of 50% in data availability** for deformation monitoring.

The Permanent Segment (PS)

Tier-1/2 GNSS CORS Monumentation Considerations

Shallow Drilled Braced Quadpod Monumentation
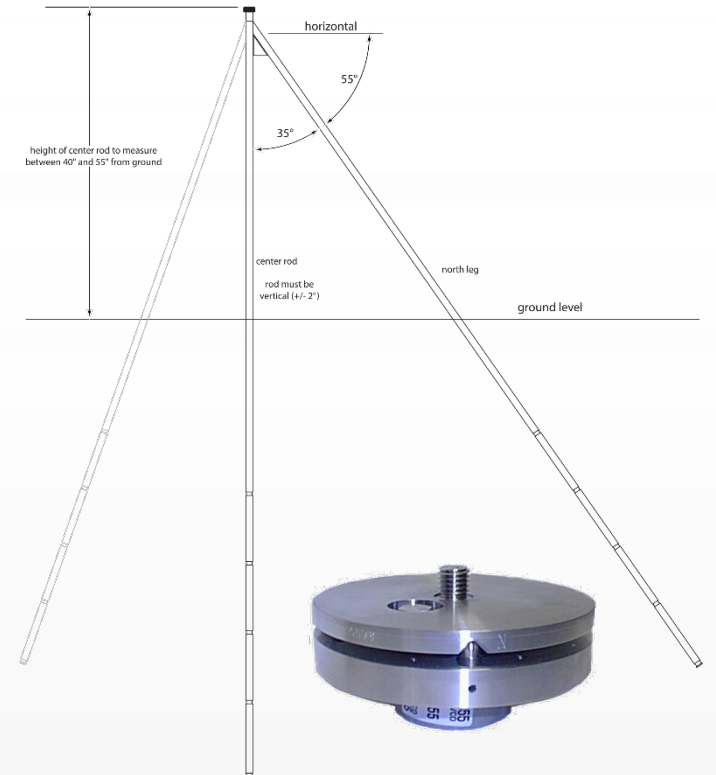
Compliance with UNAVCO Specs for High Stability Monumentation
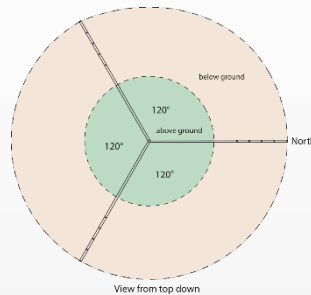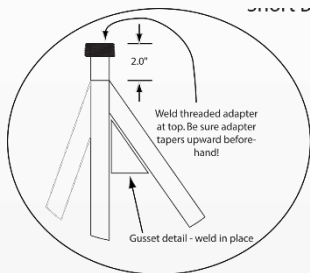
The Permanent Segment (PS)

Installation of ASGA (Shallow Drilled Braced Quadpod)

The Permanent Segment (PS)

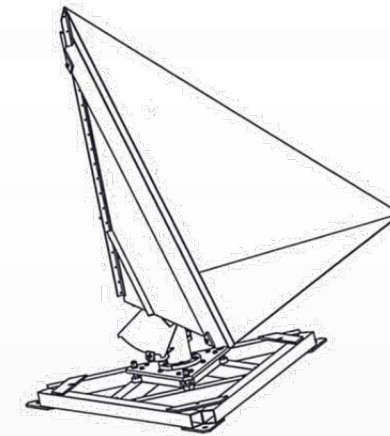Installation of SOUN (Stainless Steel Truss)

The Permanent Segment (PS)

Trihedral Corner Reflectors (TCRs)

Azimuth Adjustment Range: -180° to +180°

Elevation Adjustment Range: -10° to +45°

Permanent Monumentation Considerations (anchored in solid bedrock)

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

The Permanent Segment (PS)
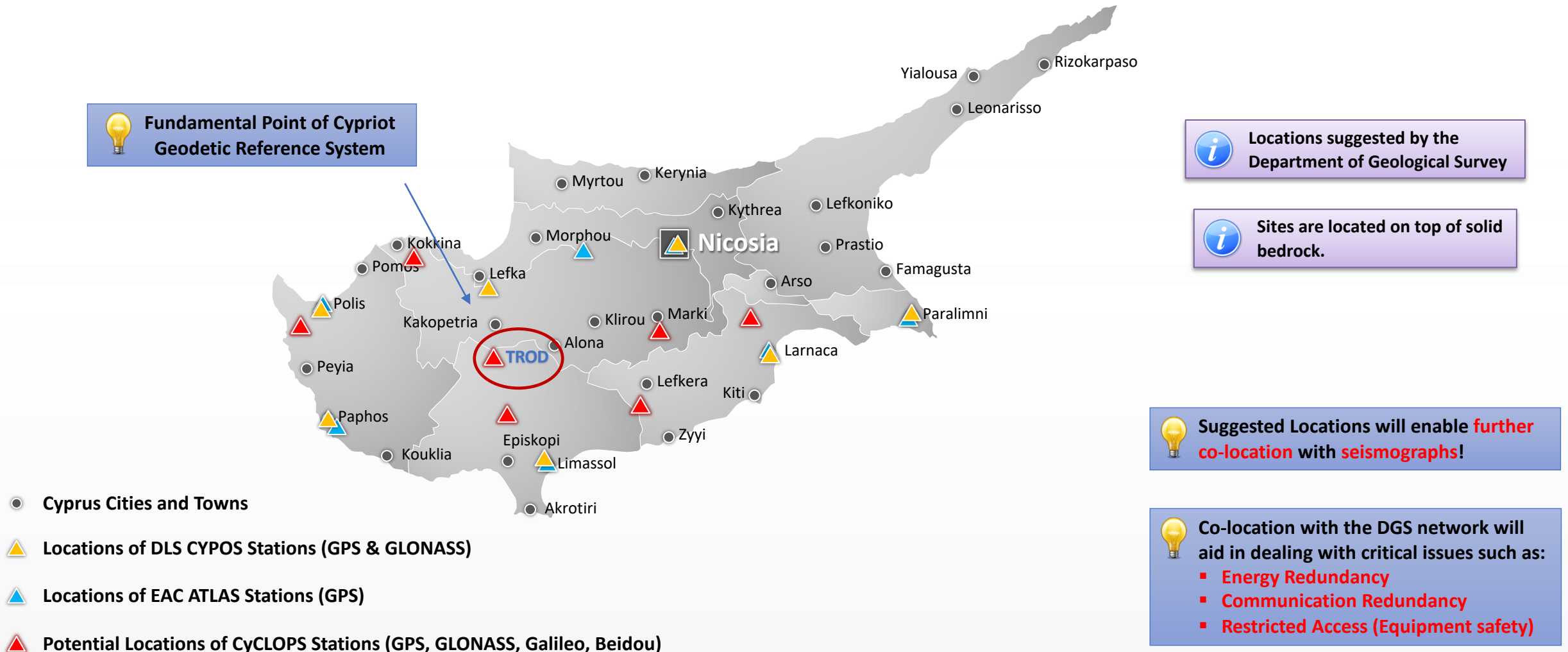
CR Installation at ALEV

The Permanent Segment (PS)
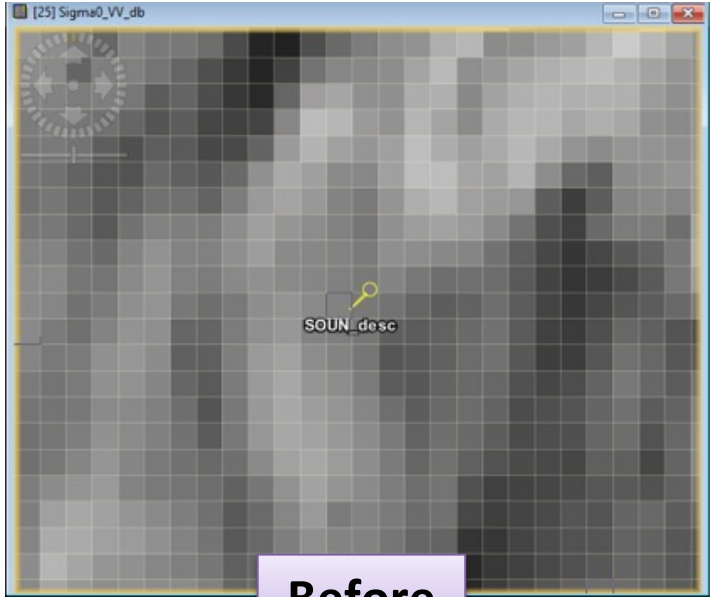
Before
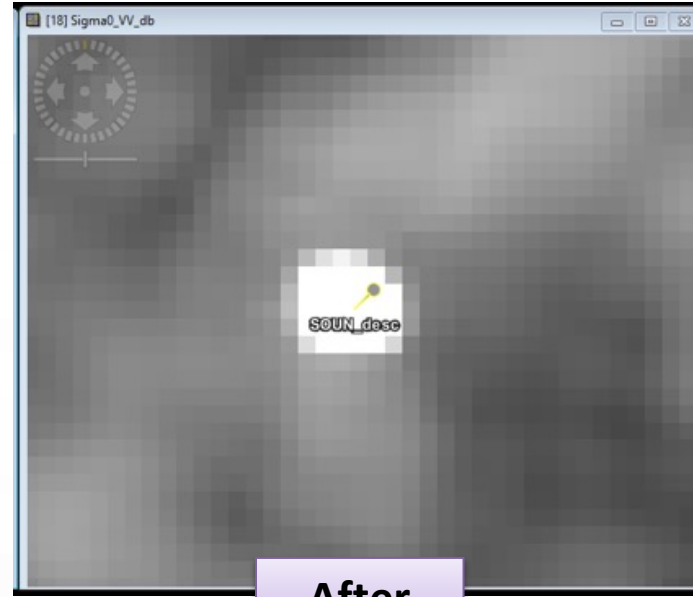
After

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

SOUN: Ascending Pass RCS Descriptive Statistics

	Mean	Standard Error	Median	Standard Deviation	Sample Variance	Minimum	Maximum
RCS	35.66	0.21	35.82	1.01	1.01	34.09	37.72

SOUN: Descending Pass RCS Descriptive Statistics

	Mean	Standard Error	Median	Standard Deviation	Sample Variance	Minimum	Maximum
RCS	35.62	0.22	35.68	1.05	1.10	33.78	37.47
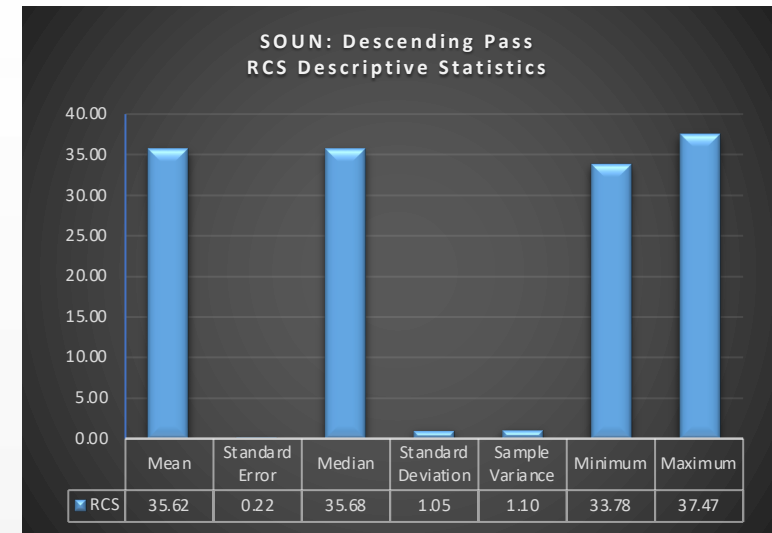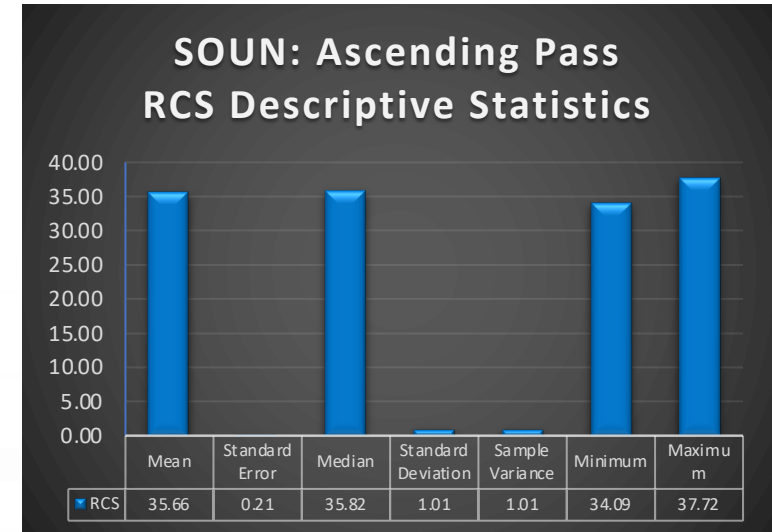
The Permanent Segment (PS) – Site Locations

Fundamental Point of Cypriot Geodetic Reference System

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)

Cyprus Cities and Towns

Locations of DLS CYPOS Stations (GPS & GLONASS)

Locations of EAC ATLAS Stations (GPS)

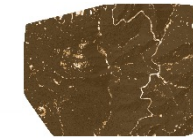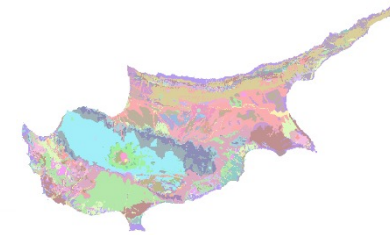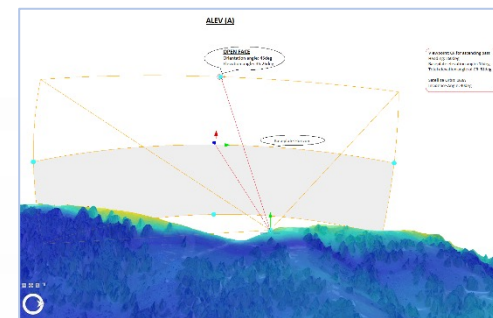Potential Locations of CyCLOPS Stations (GPS, GLONASS, Galileo, Beidou)

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

  - ....

Sentinel-1 Ascending Pass

Before CR Installation

After CR Installation

Sentinel-1 Descending Pass

Before CR Installation

After CR Installation

ALEV (A)
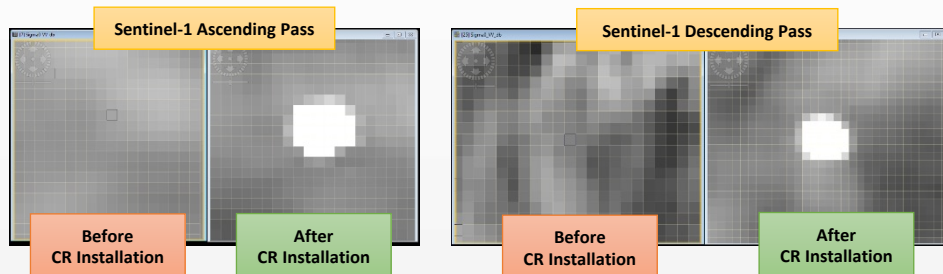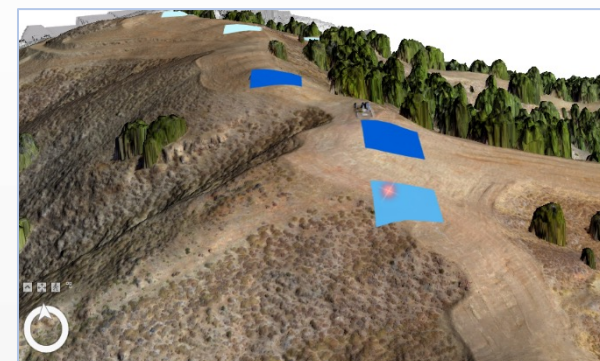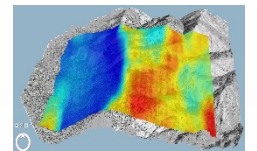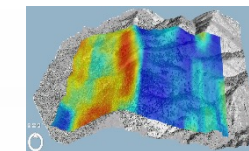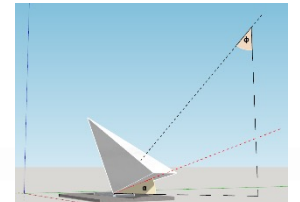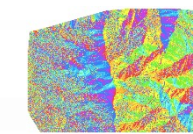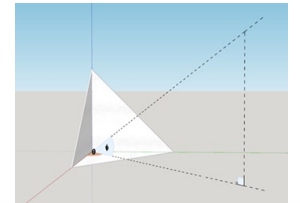
The Mobile Segment (MS)

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.
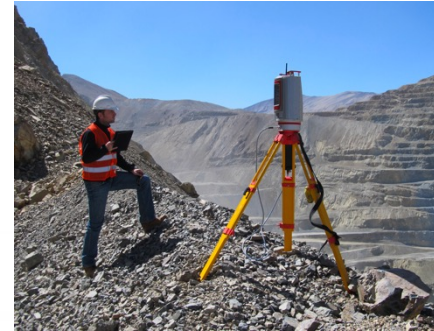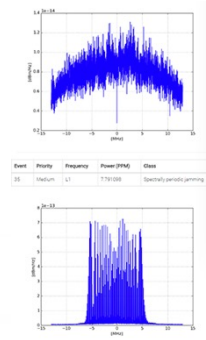
Example of a Mobile GPS/GNSS CORS Configuration

The Mobile Segment (MS)

Examples of Mobile Deployments at the Areas of Interest

Open-pit Mine

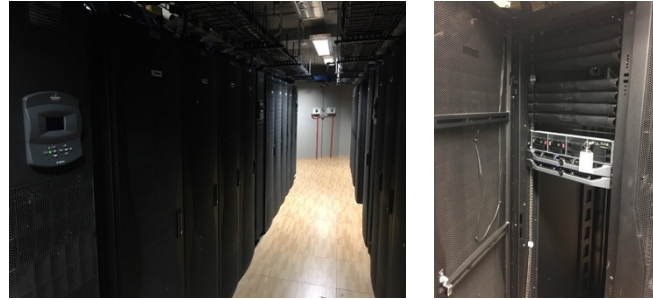**House Roof (Residential Area)**

Archaeological Site

The Operation Centre

Hardware and Software Infrastructure

- Hosting of the Sensor Network Operational Software
- Bidirectional Communication with MPN
- Hosting of Web GIS Portal & Services

Processing Server

Storage Server

Management Server

- Hosting and Operation of the Scientific Software (Bernese GNSS, MIT GAMIT/GLOBK, NASA JPL GipsyX, SNAP, MATLAB, ERDAS Imagine etc.)
- Computation of DD hourly/daily solutions for all reference station data hosted in the storage server;
- Time-series analysis of computed positions, and check for discontinuities;
- Computation of interferograms and time-series analysis of SAR Images.
- Estimation of displacement vectors and velocities.
- Susceptibility/Hazard/Risk Estimation Models

- CyCLOPS CORS stream/station ~ 200MB/day x 10 x 30 = 60GB/month
- 12GB/month from regional CORS Stations
- Additional storage from IGS stations
- IGS Precise Products (orbits, clock etc.)
- Weather Information/ Models (PS and Department of Meteorology)
- SAR Images: ~300GB/month
- High Resolution DEMs etc.
- Geospatial Databases (e.g. Microsoft SQL Server)
- Processing Results (Daily Solutions etc.)

Storage Redundancy

Cloud Storage

Data Archiving

> 500GB/month

SAN, NAS
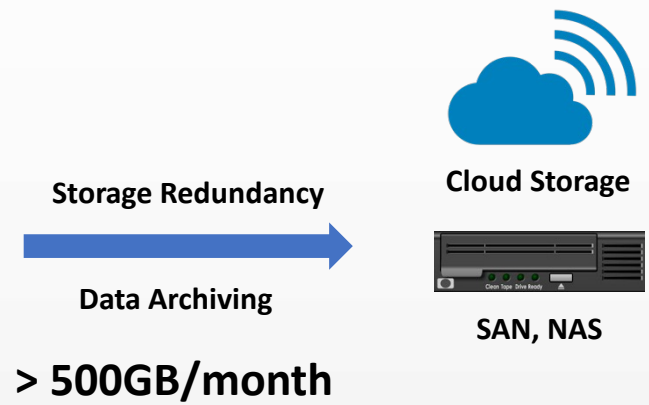
# The Operation Centre

Architecture
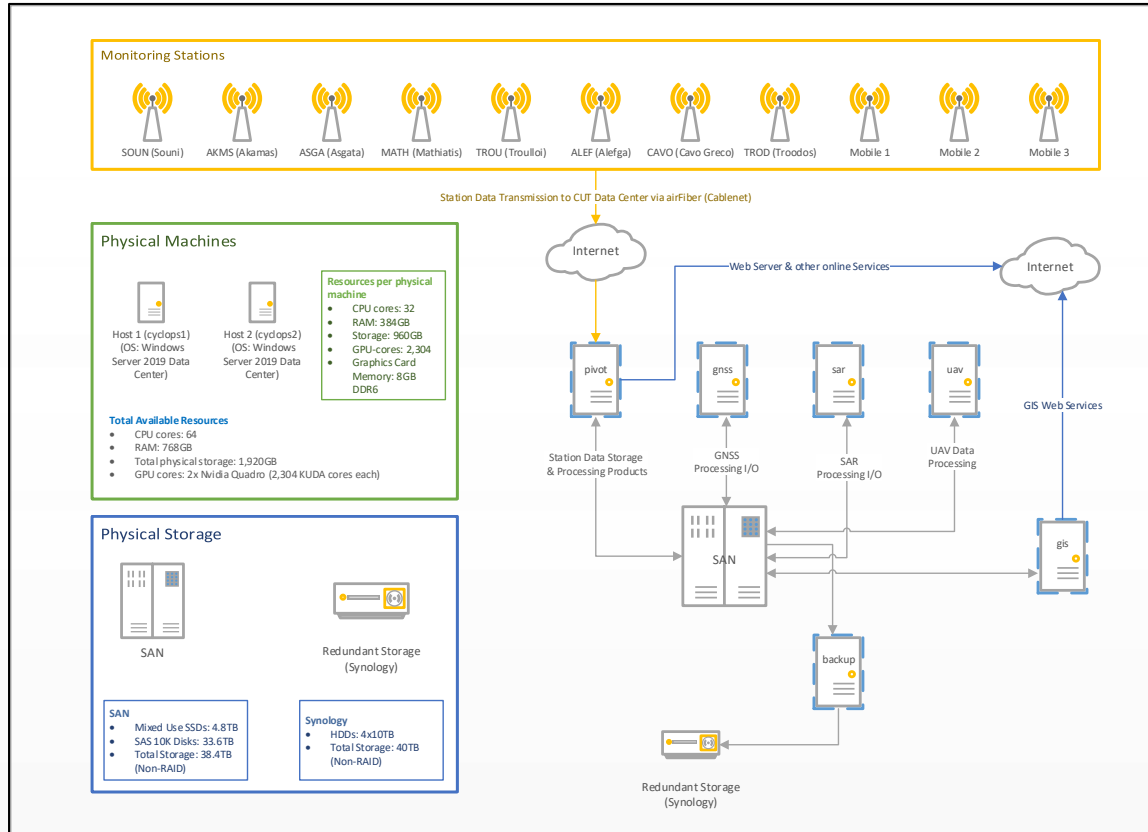
Dedicated expandable cluster with the following features:

- **CPU**: 64/128 Logical Cores/ Threads for processing,

- **RAM**: 768GB

- **Storage**: 40TB 12Gbps SSD/SAS Mixed Use HDs

- **Redundant storage**: 40TB (for backup)

- **Redundant operation in case of hardware failure**: It takes less than 2 minutes 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

Telecoms and Resource Monitoring
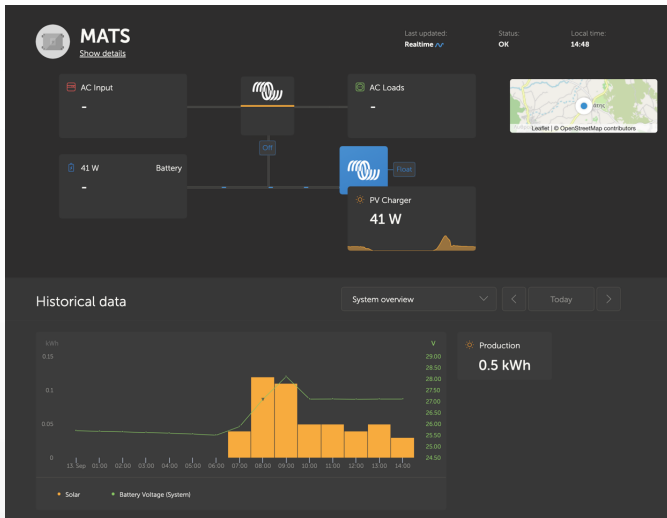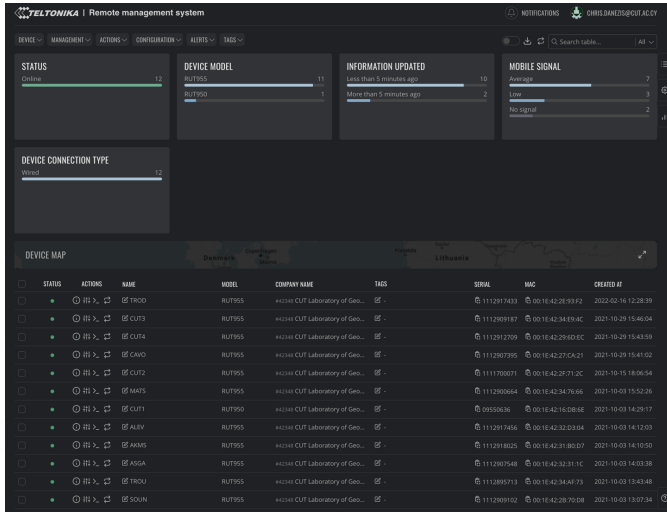
24/7/365 monitoring of telecommunications and solar output:

- 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
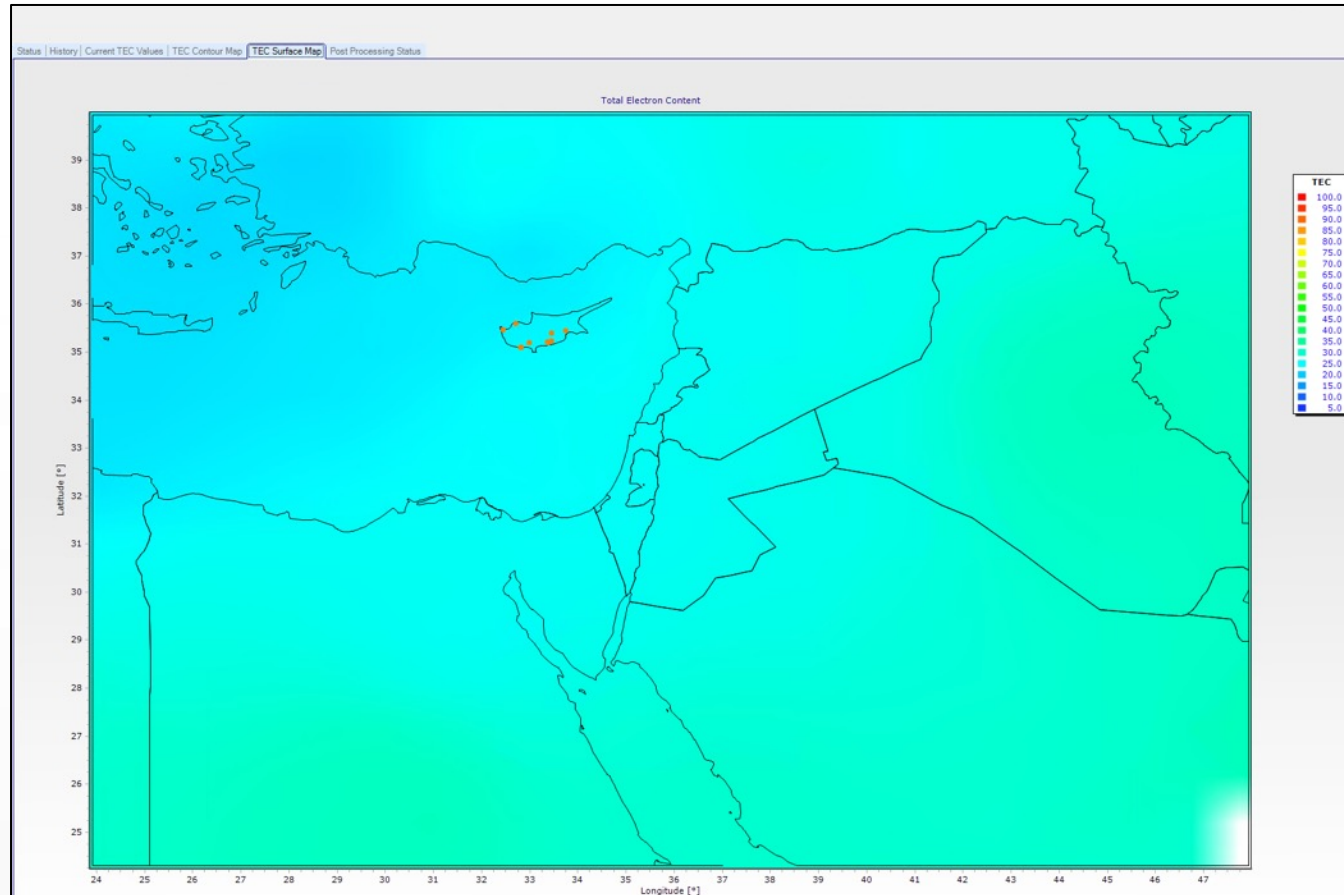
Real Time Services

Real Time Displacement Monitoring

Real Time Services

Atmospheric Service

Ionospheric Activity
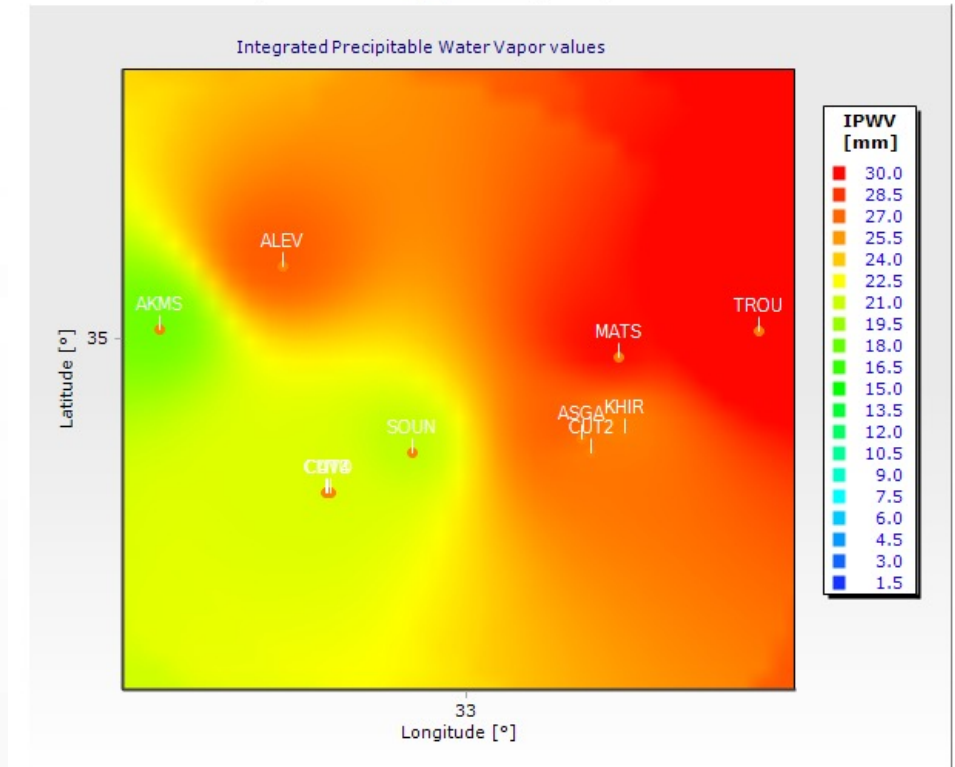
Tropospheric Activity

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.

Thank you for your Attention!

Q+A Session