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Excellence Research Centre for Earth Surveillance & Space-Based Monitoring of the Environment

1st virtual EXCELSIOR International Technical Workshop

15 July 2020

CyCLOPS: A Strategic Research Infrastructure Unit for Monitoring Geohazards in Cyprus and the Southeastern Mediterranean Region

@excelsior2020eu

Dr. Chris Danezis

Cyprus University of Technology – ERATOSTHENES Centre of Excellence

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CONSORTIUM

Cyprus University of Technology · DLR · TROPOS Leibniz Institute for Tropospheric Research · DEC

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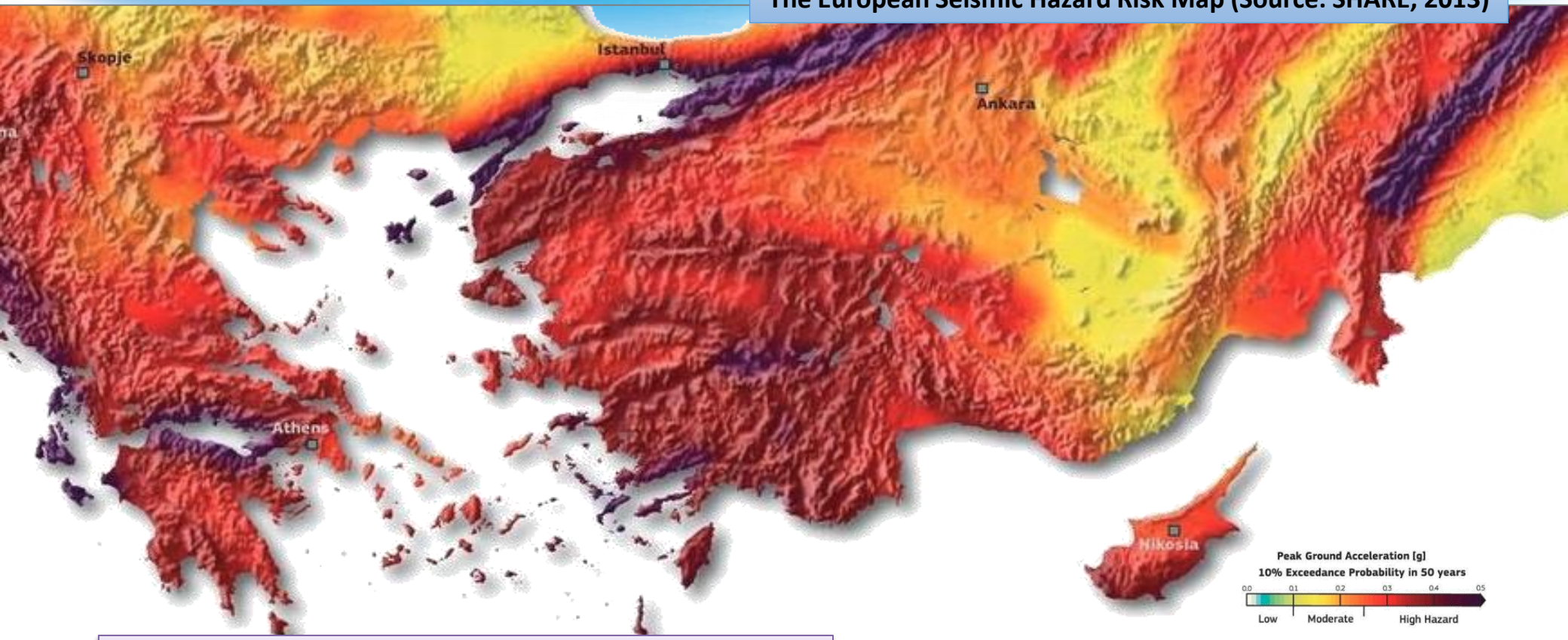
Natural Hazards in Cyprus – Earthquakes

Seismic Hazard in Cyprus

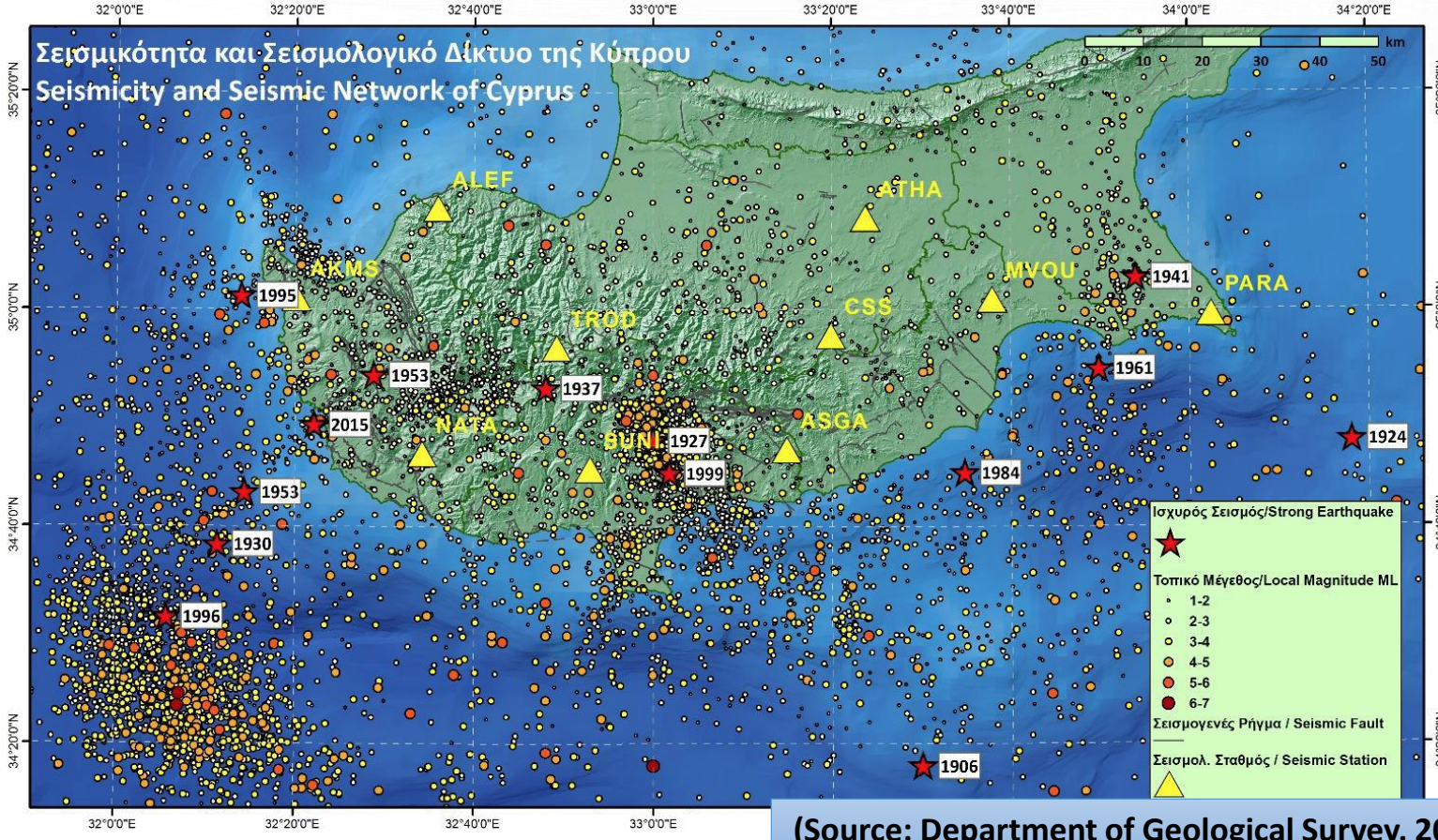
The European Seismic Hazard Risk Map (Source: SHARE, 2013)



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)

Natural Hazards in Cyprus – Earthquakes

The Seismicity of Cyprus up to 2018



(Source: Department of Geological Survey, 2018)

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Natural Hazards in Cyprus

Landslides in Cyprus

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Natural Hazards in Cyprus – Landslides

The case of Pissouri Village

Pissouri village

The image is not tilted!

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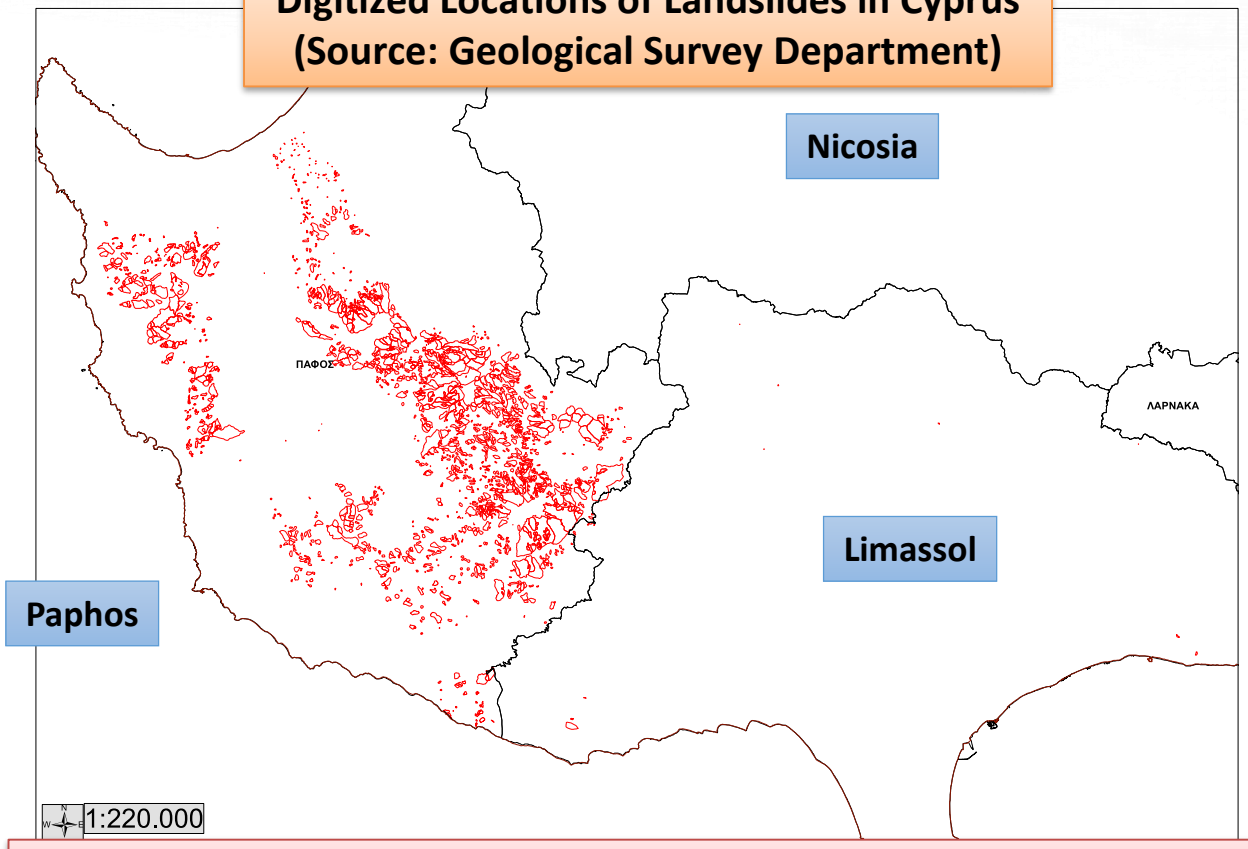
Natural Hazards in Cyprus – Landslides

Mapping of Landslide Location

Digitized Locations of Landslides in Cyprus (Source: Geological Survey Department)



The actual number is far more significant (limited data)

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The Effects of Natural Hazards in Cyprus

Social & Economic Impact

- The combined effect of Earthquakes and Landslides has an imminent impact on **public safety** and the **built environment**:

To date, 8 villages have been abandoned: Choletria, St. Photios, Statos, Fasoula, Finikas, Korfi, Kivides, and Pentalia.

Direct Costs and Threats

- **Population resettlement** costs;
- **Property damage**, **restoration** and **clean-up**;
- **Critical Infrastructure network restoration/ replacement** (e.g. road network, pipelines, utility networks etc.);
- **Permanent** damage of **Cultural Heritage landmarks**!

Indirect Costs

- Threat to **Construction Industry** and **Real Estate investments**;
  - **Devaluation of property → Reduction of Property Taxes**
- Loss of use of **critical infrastructure and utility networks**;
- Loss of income and **tourism revenue** in affected areas;
- Loss of **industrial** and **agricultural** productivity;

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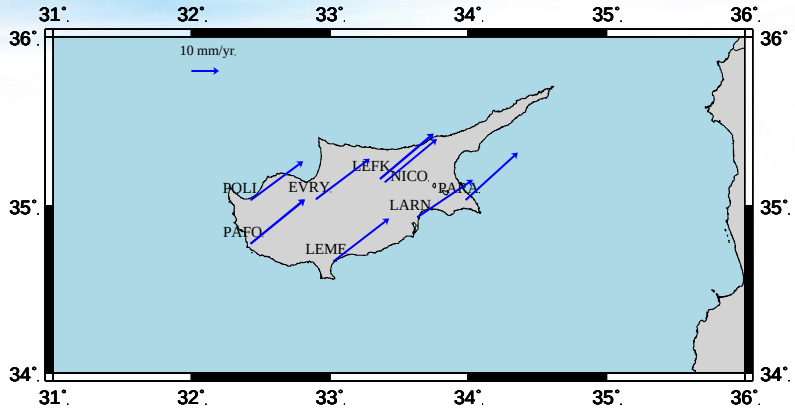
The Geodynamic Regime of Cyprus

Is Cyprus still or moving?

Station ID	Validity Period	X (t_o)	Y (t_o)	Z (t_o)
EVRY	A	4389846.035	2839909.319	3641645.008
LARN	A	4358623.310	2899369.048	3631599.949
LEFK	B	4360035.737	2870860.968	3652605.816
	C	4360035.736	2870860.987	3652605.816
LEME	A	4403058.471	2862122.638	3607630.266
NICO	A	4359415.715	2874117.069	3650777.829
PAFO	D	4427028.128	2812497.092	3617359.846
	E	4427028.124	2812497.091	3617359.841
PARA	A	4335378.631	2922300.281	3641064.127
POLI	A	4413130.062	2803627.159	3640911.041

Station Velocities [mm/year]

Station ID	Validity Period	Vnorth	Veast	Vup
EVRY	A	14.7	19.5	0.2
LARN	A	13.6	20.2	-4.9
LEFK	B	16.3	19.3	0.1
	C	16.4	19.3	0.2
LEME	A	15.6	20.3	0.3
NICO	A	15.7	18.9	-0.3
PAFO	D	16.1	19.6	1.7
	E	15.9	19.7	1.6
PARA	A	17.2	18.9	0.6
POLI	A	14.2	19.1	-0.4



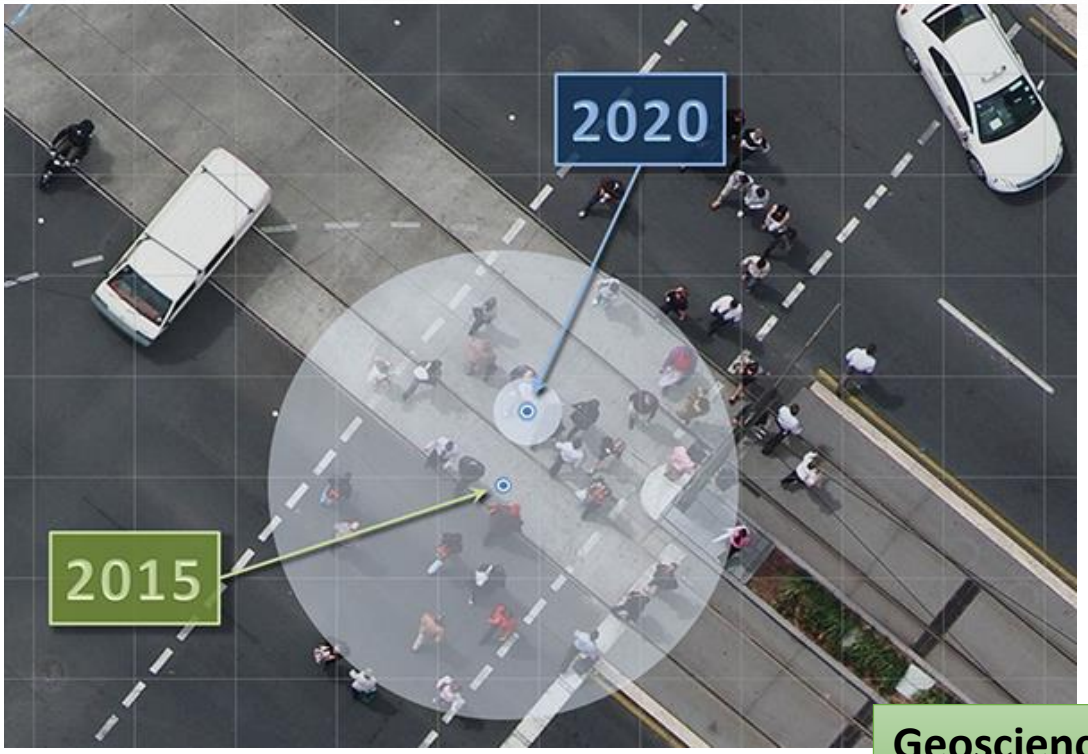
(Danezis et al, 2020)

Deformation and Mapping Infrastructure

The long-term unattended impact on maps and positioning activities

Accuracy

Integrity



Security

Geoscience Australia

'When people use GPS in their everyday lives, they are measuring their location today but using spatial data from 25 years ago (J. Dawson)'

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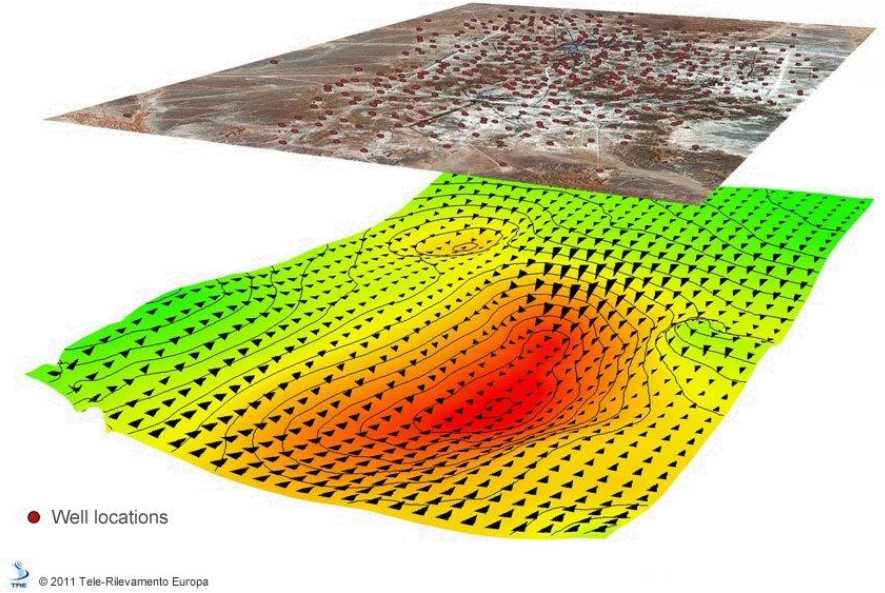
Earth Observation & Natural Hazards

State-of-the-Art Space-based ICT for Monitoring Natural Hazards

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)



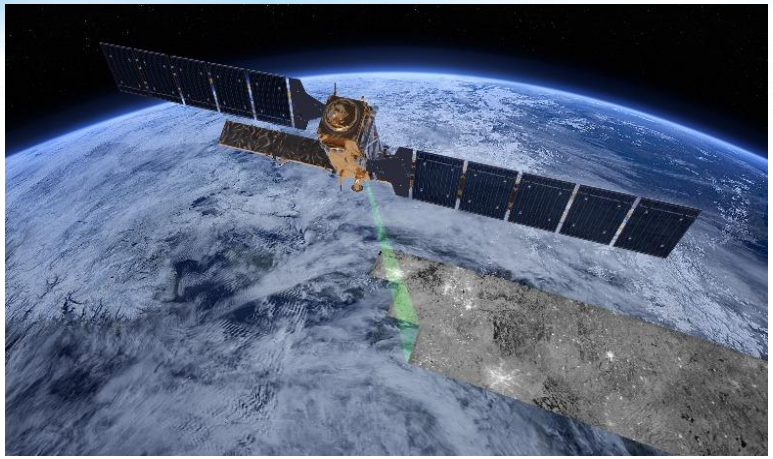
~cm- to mm-level <u>relative</u> displacement and velocity determination with <u>high resolution</u>

Earth Observation & Natural Hazards

GNSS and SAR Space Segments & Signals

<u>One-way</u> signal transmission from space constellation to ground receivers.

- Three (3) carrier frequencies for GPS:
  - L1: 1575.42 MHz
  - L2: 1227.60 MHz
  - L5: 1176.45 MHz

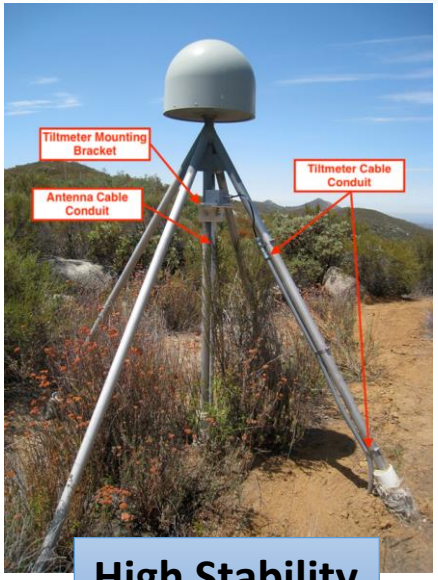


<u>Active</u> signal transmission from space and reception of backscatter from ground (radar imagery).

- Two (2) SAR missions will be used in CyCLOPS:
  - Sentinel-1 (C-band: 5.405 GHz)
  - TerraSAR-X (X-band: 9.6 GHz)

Earth Observation & Natural Hazards

GNSS Ground Segment – Tier 1 GPS/ GNSS Stations



High Stability

Medium - High Stability

Medium Stability

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

Ideally, the points under investigation must be located on and attached to solid bedrock.

Eventually, the study of daily position computations at each point unveils potential deformation (how fast and towards which direction the point is moving)

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Earth Observation & Natural Hazards

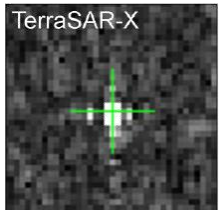
SAR Ground Segment

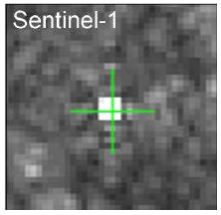



Corner Reflectors are artificial reflectors with zero radiation absorbance




They are used for enhancing signal reflectance back to the satellite and for calibration purposes.





The combination of Corner Reflectors with GNSS improves significantly SAR performance.

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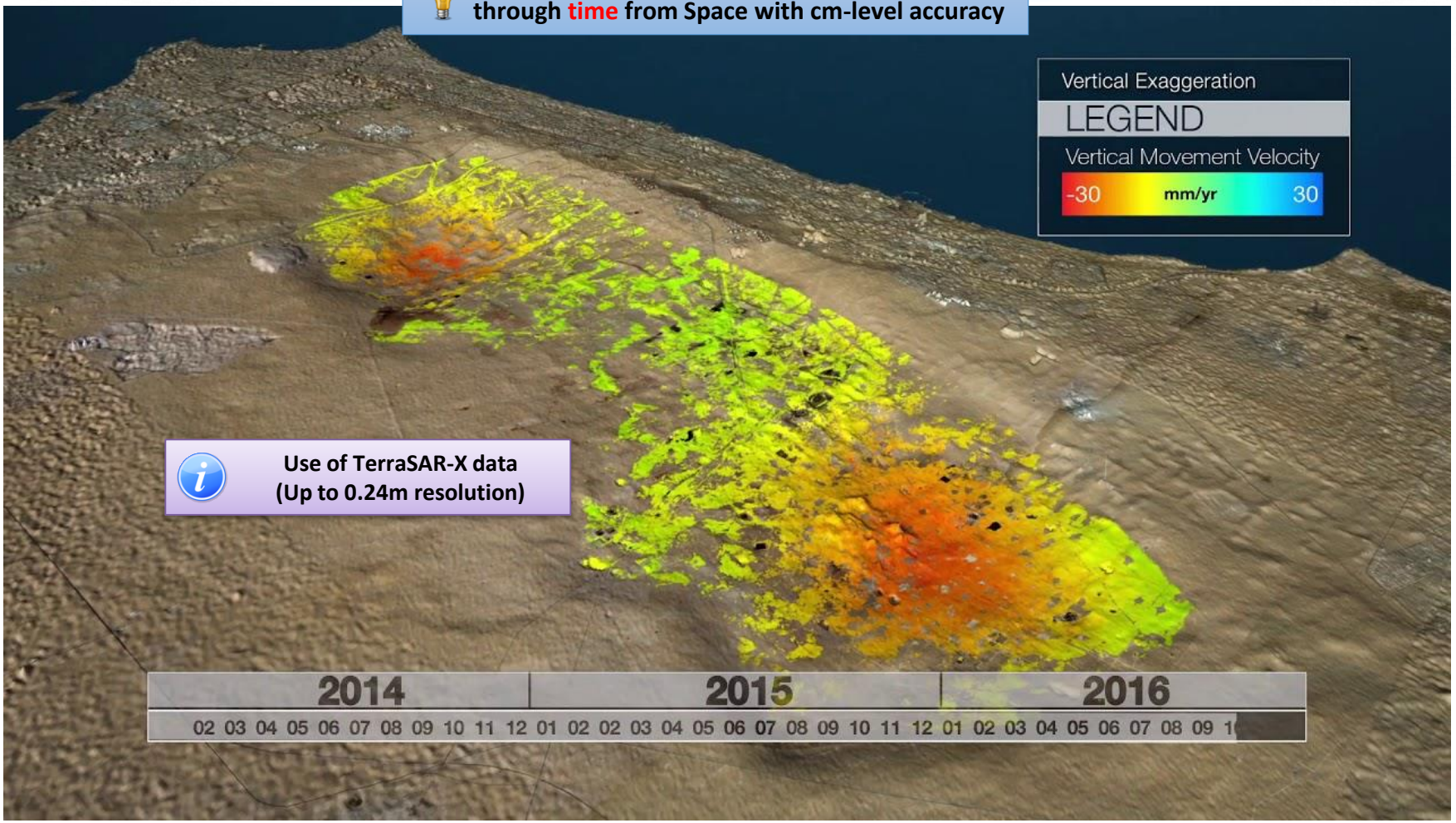
Earth Observation & Natural Hazards

Protecting Public Infrastructure, Natural & Cultural Landmarks

Determination of Ground Subsidence and Uplift through time from Space with cm-level accuracy



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Earth Observation & Natural Hazards

State-of-the-Art Technologies for Monitoring Natural Hazards

GPS

Galileo

GLONASS

BeiDou

Global Navigation Satellite Systems (GNSS)

Cyprus University of Technology

Geodetic SAR

Calibration

sentinel-1 Copernicus

TerraSAR X

Interferometric SAR (InSAR)

DLR

CyCLOPS

DLR a leader in Radar Remote Sensing will provide valuable knowledge in the field of SAR using cutting-edge processing techniques

- 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!

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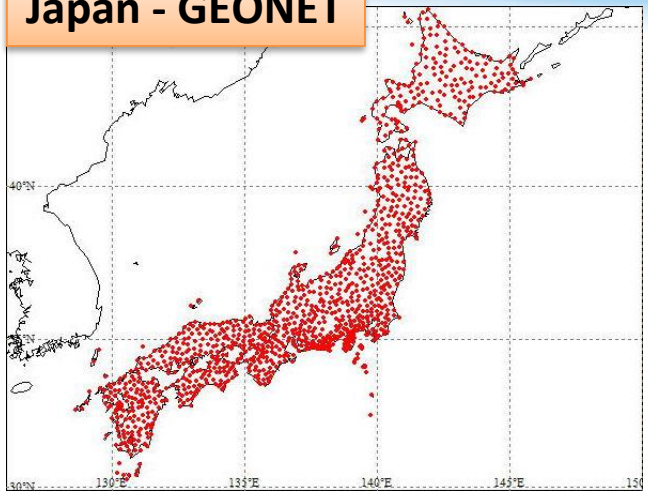
Earth Observation & Natural Hazards

Worldwide State-of-the-Art Infrastructures for Natural Hazards Monitoring

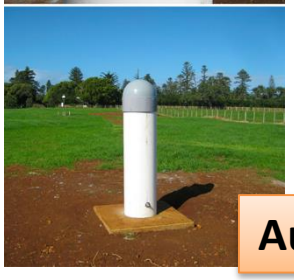
Japan - GEONET

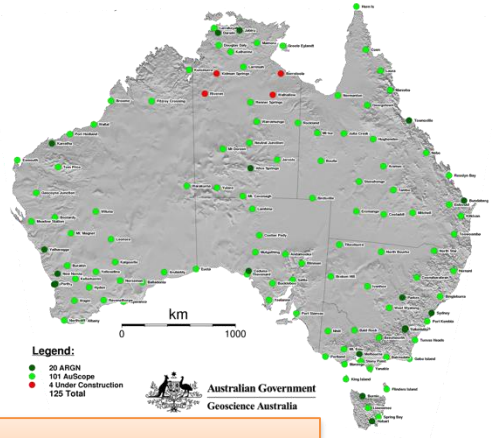


- Permanent segment of >1,300 GPS/GNSS CORS
- At least dual frequency GNSS receivers recording at 1Hz
- 5m stainless steel highly stable pillars
- 20 - 30km interstation distance
- 3 different processing modes: quick (every 6h), rapid (every 24h), final (every 12-18d).
- Earthquake magnitude and tsunami prediction within 5min using scientific software.

Australia – AuNET/ AGOS

- Permanent segment of 121 GPS/GNSS CORS.
- CORS mounted on top of concrete benchmarks.
- Network of Geodetic benchmarks (points) with Corner Reflectors.
- 80 deployable GPS/GNSS receivers.
- Robotic antenna calibration facility.
- Open-Access repository of previous ERS missions.





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The Idea behind CyCLOPS

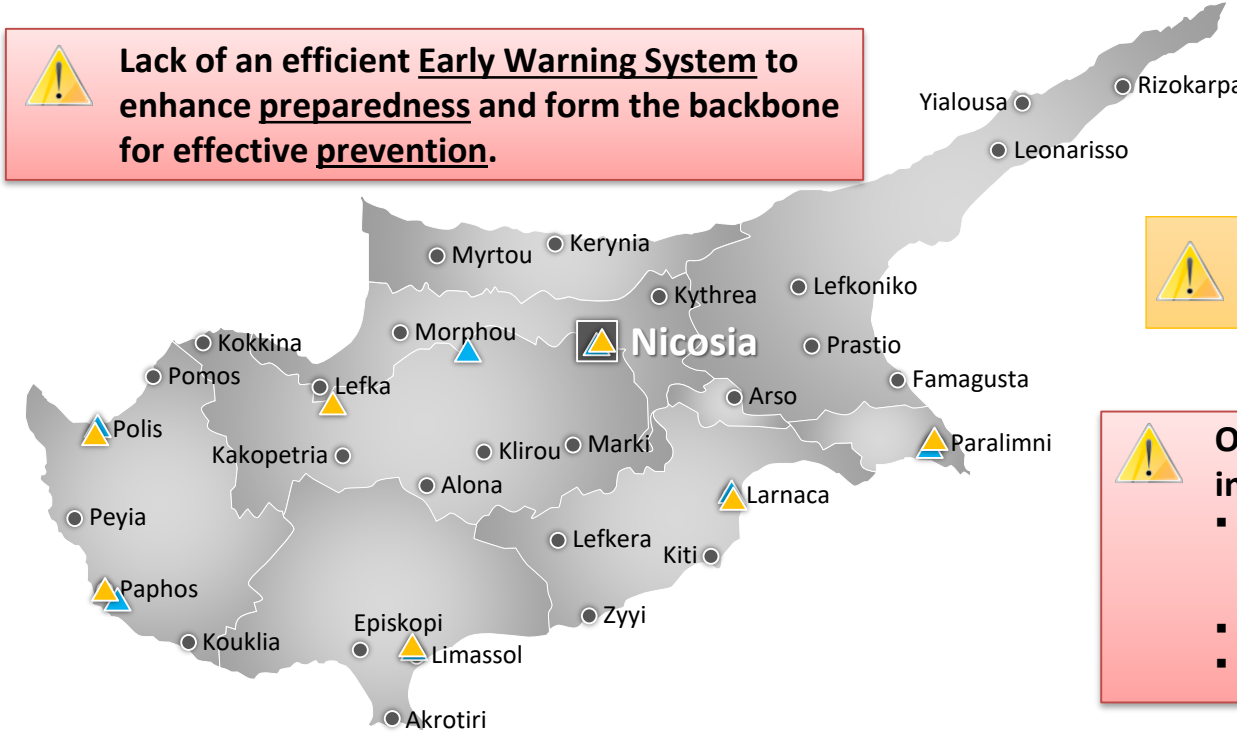
Existing Gaps

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

Seismographs, inclinometers, sparse drills conducted by the GSD.

2x GPS 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 prevention.



Outdated equipment

Insufficient Monumentation for Hazards Monitoring (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**

The Objectives of CyCLOPS

General Objectives of the Project

1	The Implementation of a Novel Integrated Strategic Infrastructure Unit to Monitor Natural Hazards in Cyprus and the Eastern Mediterranean Region
2	Address Critical Priority Pillars of the S^3Cy
3	Enable Close Cooperation with Local Stakeholders
4	Promote International Collaboration
5	Create Critical Mass of Researchers
6	Attract External Funds to become a Sustainable Research Unit

The SENDAI Seven Global Targets

The Sendai Framework for Disaster Risk Reduction

Project Innovation & Originality

So what's innovative in CyCLOPS?

- CyCLOPS will form the **backbone** for the **security-related** research **fully aligned** with important Global Initiatives on **Disaster Risk Reduction** (SENDAI Framework)
- Establishment of a **state-of-the-art integrated ICT SI** to monitor natural hazards.
- Development of a **novel Early Warning System** based on the **integrated** use of **Earth Observation ICT** technologies
- Establishment of a **novel sensor configuration/calibration and validation site** to further **promote** and **enhance** the use of **European Satellite Missions**
- CyCLOPS will be the basis for the definition of a **new**, **modernized National Geodetic Reference System** and will **augment National** & **International Frames**
- CyCLOPS will **augment** and **promote ESFRIs** on Geohazards such as the **European Plate Observing System (EPOS)**.

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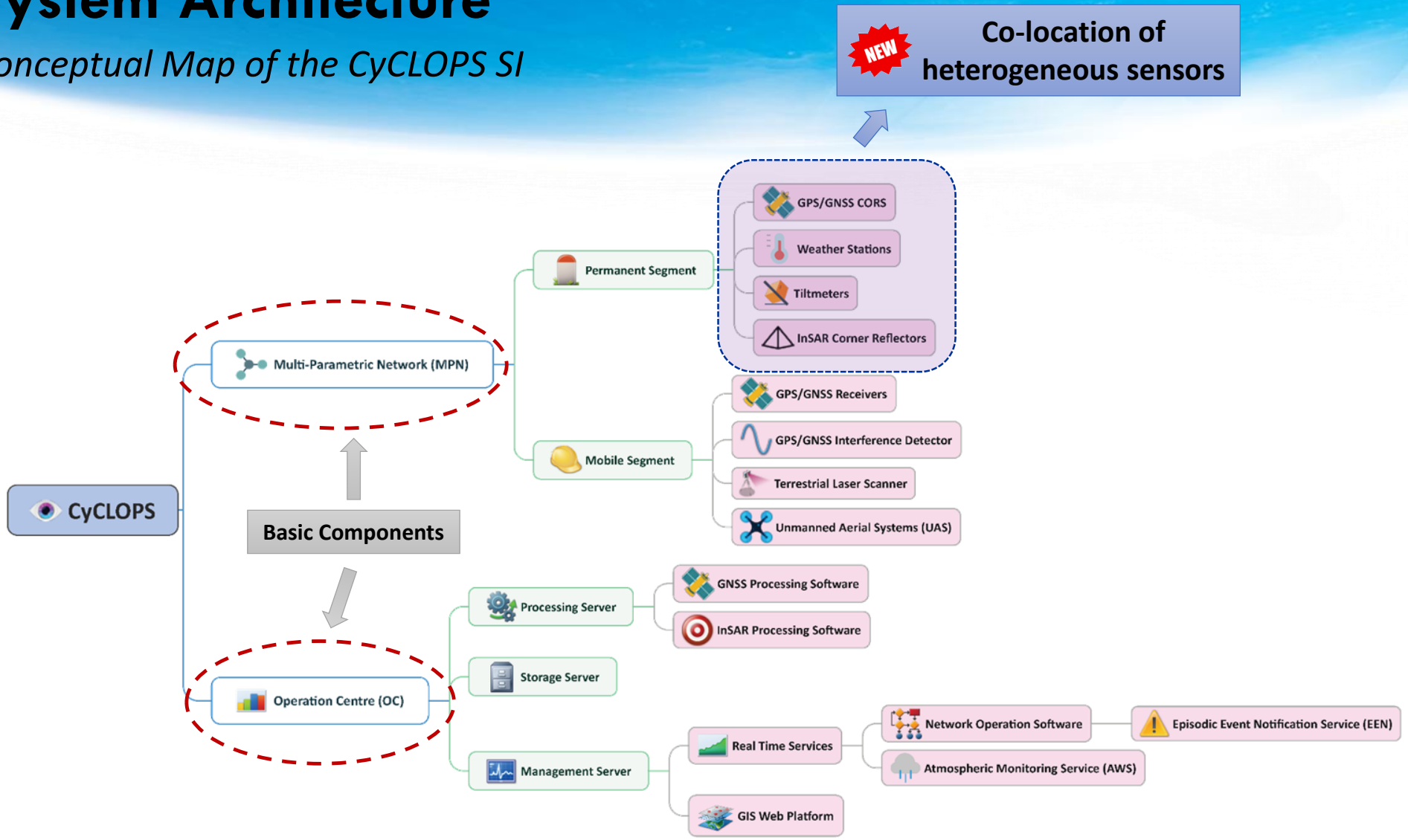
System Architecture

Conceptual Map of the CyCLOPS SI



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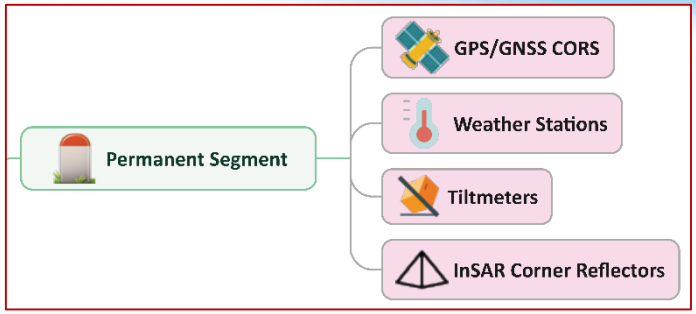
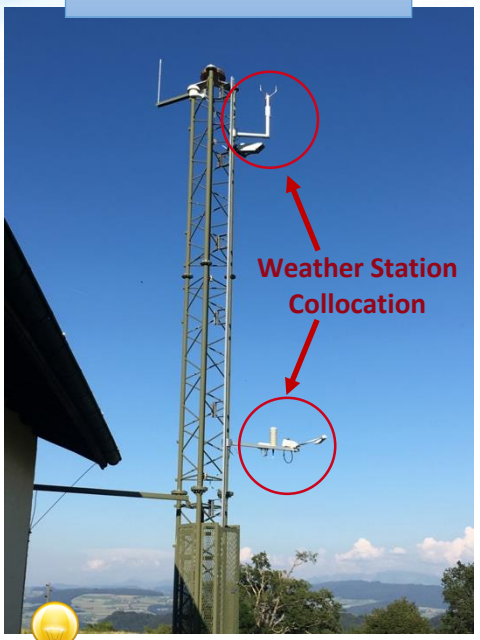
Permanent Segment

The Deployment of Permanent Segment



- A **minimum number** of **6x IGS-compliant CORS GNSS Stations** will be installed on **highly stable** monuments (Tier-1 stations).
  - Triple Frequency high-rate **Multi GNSS** (GPS, GLONASS, Galileo, Beidou) **receivers**.
  - Choke Ring or Equivalent Antennas for enhanced **multipath mitigation** and high **phase center stability**.
  - **Individually calibrated antennas** to support **Galileo use** in displacement determination.
- IGS-compliant **Weather Stations** and **Tiltmeters**.
- **Dual SAR Corner Reflector configuration (opposite facing)**.
- Detailed checks with respect to optimum **satellite availability** (line of sight), **multipath** and **unintentional jamming** using **multifrequency RF detector**.

Zimmerwald - CH



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.

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Permanent Segment

Locations for the Installation of Permanent Segment

Fundamental Point of Cyprus Geodetic Reference System

Locations suggested by the Department of Geological Survey

Locations are 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)**

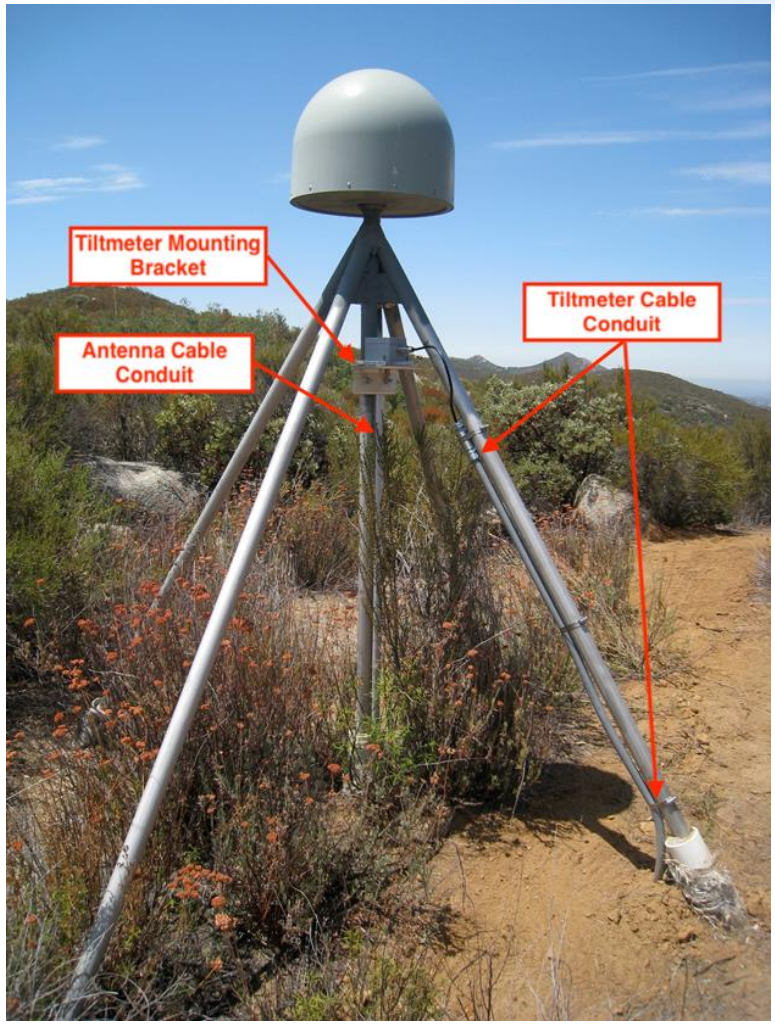
- **Cyprus Cities and Towns**
- **Locations of DLS CYPOS Stations (GPS & GLONASS)**
- **Locations of EAC ATLAS Stations (GPS)**
- **Potential Locations of CyCLOPS Stations (GPS, GLONASS, Galileo, Beidou)**

Permanent Segment

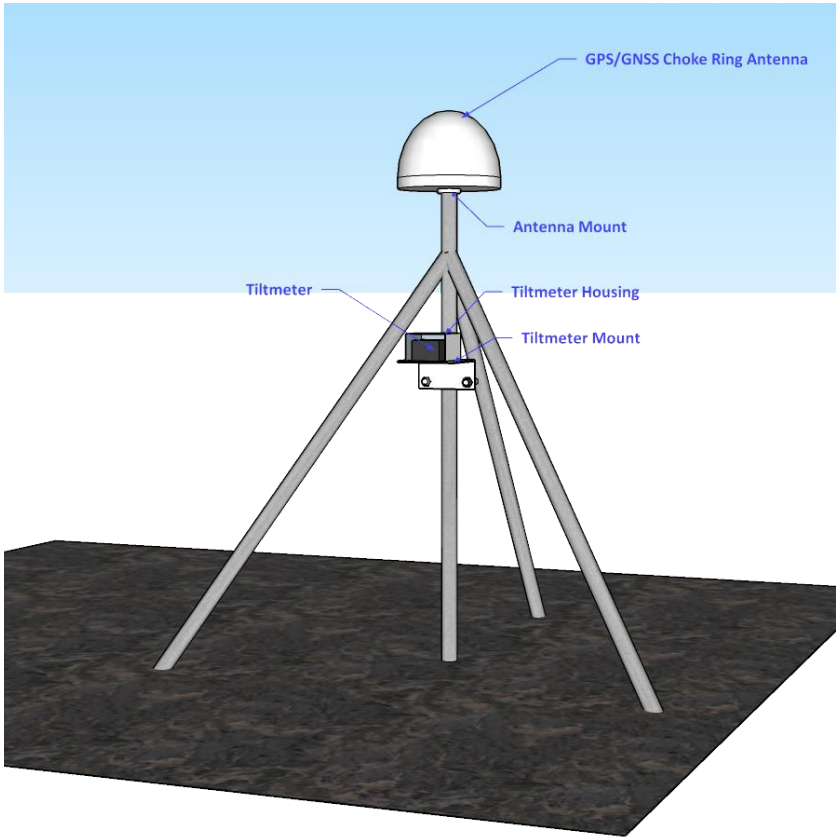
Locations for the Installation of the Permanent Segment

Permanent Segment – Troulloi Station (MVOU)

Permanent GNSS Station Layout

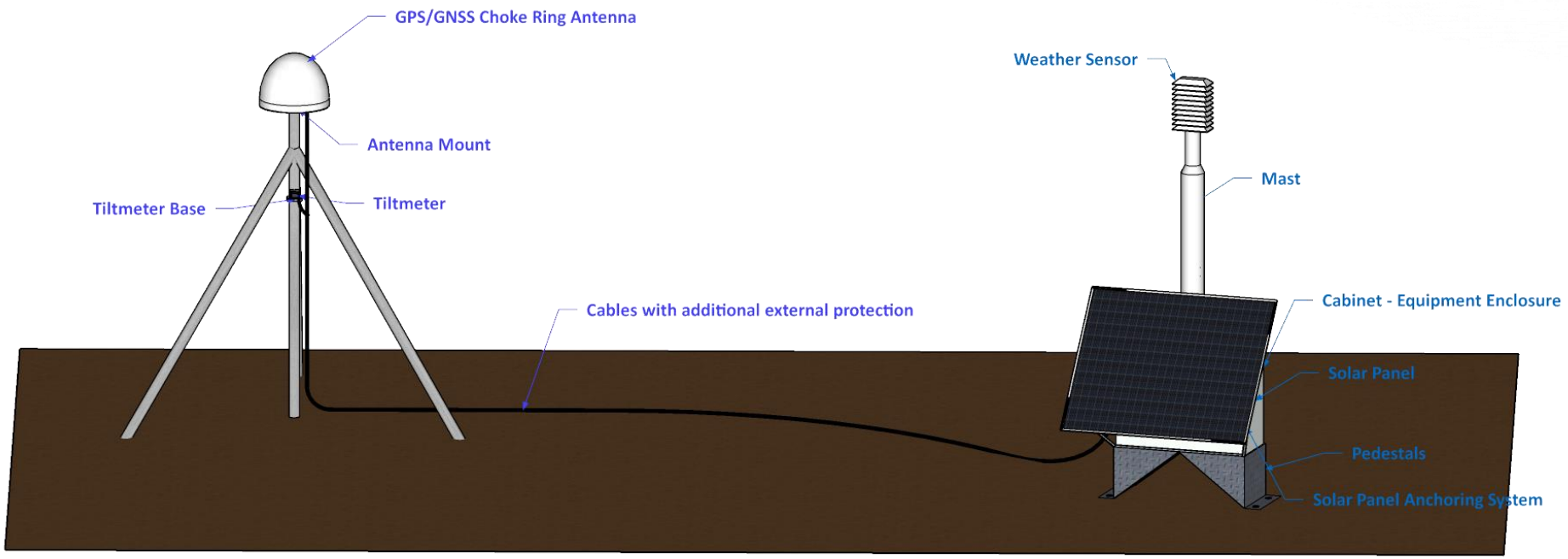


Custom Shallow Drilled Braced (Stainless Steel 304) Quadpod



Permanent Segment

Site Layout



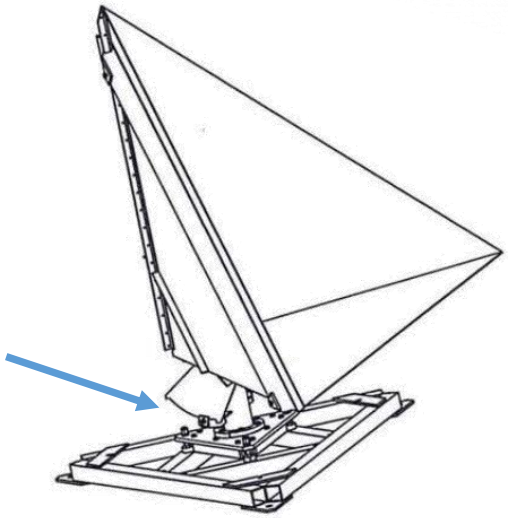
Permanent Segment

SAR Corner Reflectors

Azimuth Adjustment Range: -180° to +180°

Elevation Adjustment Range: -10° to +45°

Leveling Plate



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

Corner Reflectors Material: Aluminum AW-5754 H22 (White Coated)

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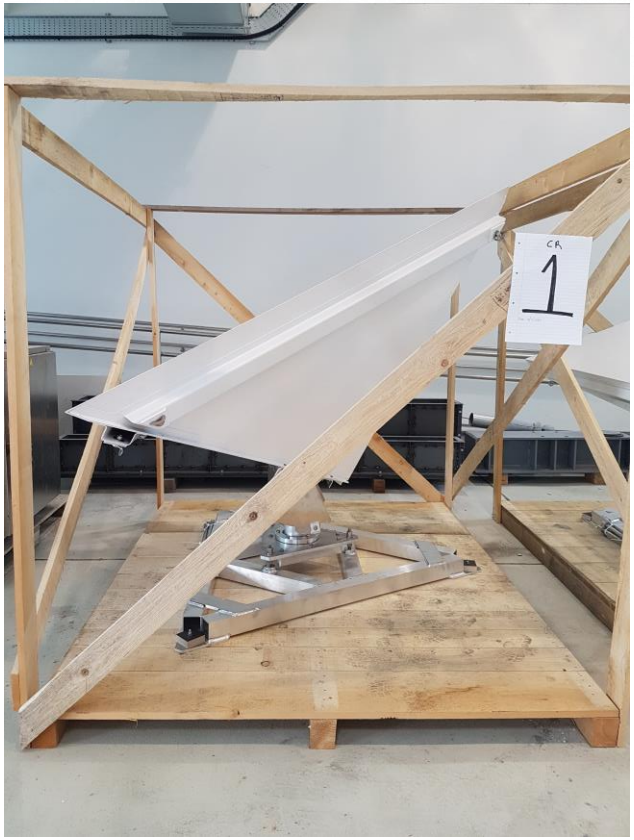
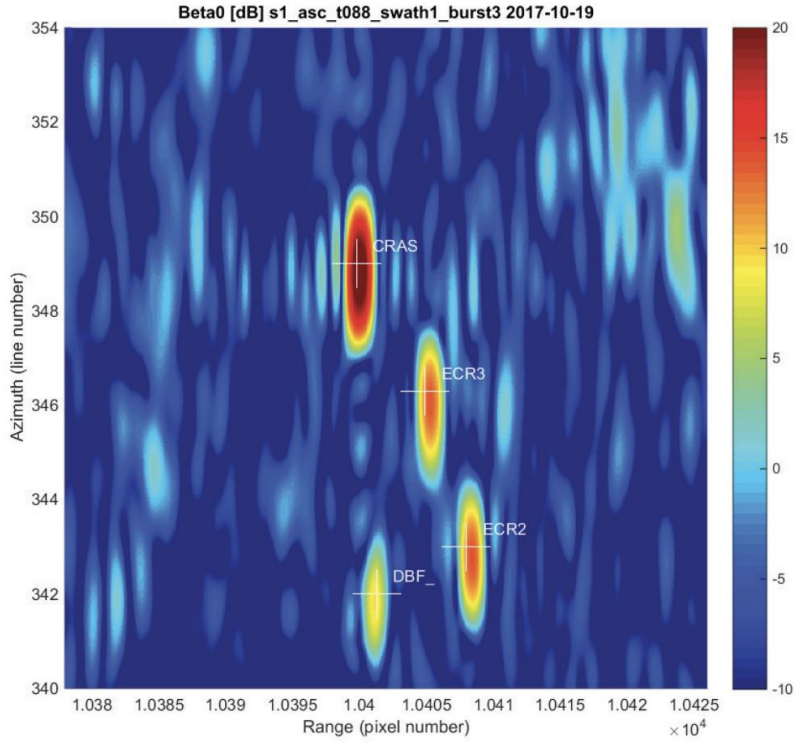
Permanent Segment

SAR Corner Reflectors



Permanent Segment

Electronic SAR Corner Reflectors (ECRs)



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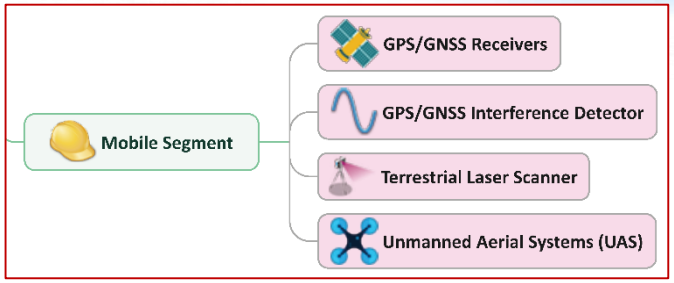
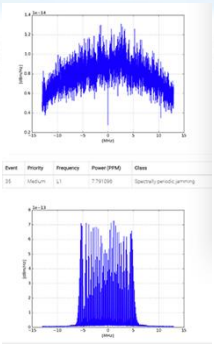
Mobile Segment

Terrestrial and Airborne Sensors



- Triple Frequency **Multi GNSS** (GPS, GLONASS, Galileo, Beidou) receivers.
- **Choke Ring or Equivalent Antennas** for enhanced **multipath mitigation** and **high phase center stability**.
- GNSS sensors will be positioned in specifically designed configurations with **redundant energy supply** (solar powered) and **bidirectional communication** (GSM/3G/4G) with the Operation Center.
- A **RF multi-frequency interference detector** will be used prior to site installation to investigate for **jamming sources**.
- A new Terrestrial Laser Scanner (TLS) will enable **imminent high-density geospatial data acquisition** (point clouds) for monitoring landslides or dynamic incidents and the **generation of DEM** which is **<u>needed</u>** in **SAR processing**.
- A UAS will **augment** the MS by providing information (**DEM generation**) in **hard-to-reach** and **larger scale** areas.



Example of a Mobile GPS/GNSS CORS Configuration

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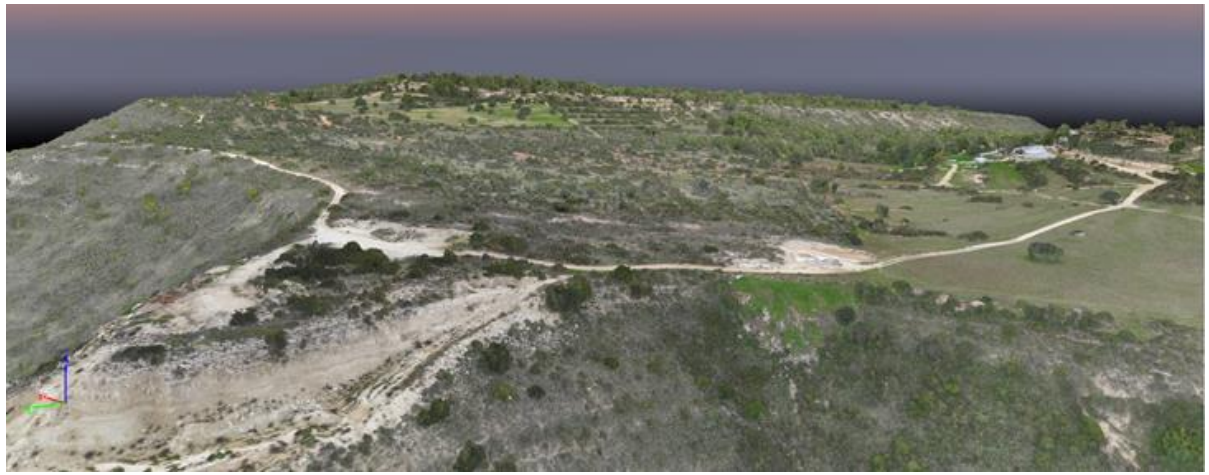
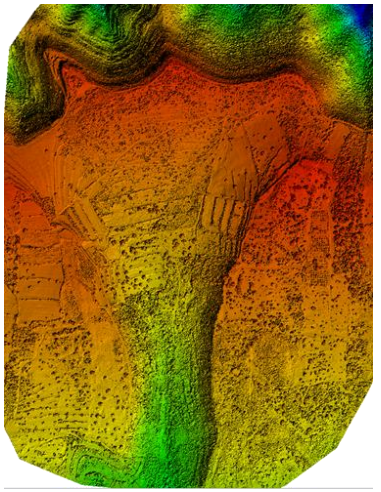
Mobile Segment

Latest Drone Acquisition – eBee X RTK

This model is used by the U.S. Army 101st Airborne Division

2D/ 3D Mapping and Terrain Modelling at the cm-level





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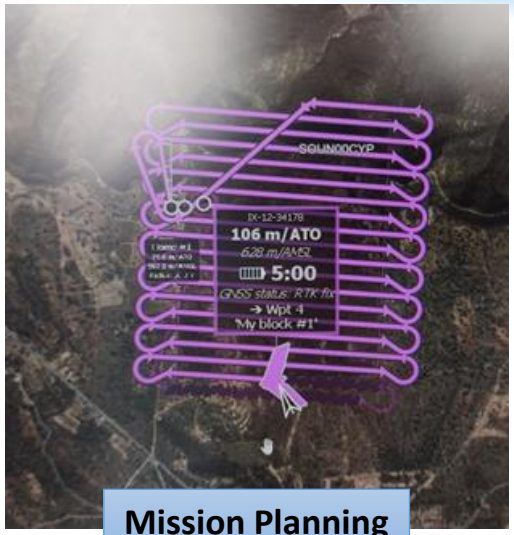
Mobile Segment

Precise 3D Terrain Modelling – Actual Case in Souni

Total Flight Time: < 1hr
Mapped Area: ~1km²
Product Accuracy: cm-level



Mission Planning

Data Acquisition

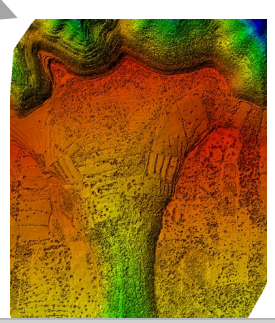
Position Corrections

4G/ UHF Links

Data Processing

Reality Capture

Orthophotos



Digital Terrain Models

EXCELSIOR

ERATOSTHENES: Excellence Research Centre for Earth Surveillance & Space-Based Monitoring of the Environment

The Operation Centre

IT Infrastructure & Components

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

OC Infrastructure will be installed at the CUT Main Datacenter

Processing Server

Management Server

Storage Server

- Hosting and Operation of the Scientific Software (Bernese GNSS 5.2, 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

Data Archiving

> 500GB/month

Cloud Storage

Tape Drives

05.06.2020

The Early Warning System

Connectivity and Communication with Users – Promoting Security

Establishment of Real Time Services:

Network Operation Software

Atmospheric Monitoring Service

Network Integrity Monitoring via Precise Positioning Techniques

Estimation of Atmospheric Refractions: (integrated precipitable water vapor, dry & wet components, Total Electron Content, Scintillation etc.)

Episodic Event Notification Service

Alerts sent to Stakeholders via email and SMS

Access to all RT services via smart devices

The Early Warning System

Ultra-Precise Positioning Methodologies

Development of the Processing Methodology:

- The remaining (**non-real-time**) services will be based on a **state-of-the-art processing methodology** that will **combine GNSS + SAR** techniques by means of **knowledge transfer** from **DLR (FRO)**.

Very precise GNSS station coordinates (along with ionospheric and tropospheric gradients) will be computed on frequent basis using cutting-edge customizable scientific GNSS processing software (e.g. Bernese GNSS)

Geodynamics/ Tectonics
mm-level accuracy
(*solutions in ITRF14 using stations from the IGS network*)

Landslides / Fault Detection
sub-mm level accuracy
(*local sensor cluster using shorter baselines*)

Position time-series of each station will be statistically checked on a frequent basis for discontinuities and potential outliers

Alert when a permanent offset (specified by DGS) above a certain threshold occurs

The Early Warning System

GNSS + InSAR Integrated Processing

Development of the Processing Methodology - InSAR:

Deformation monitoring will be carried out by means of a **combined GNSS + InSAR Technique**

Use of CRs as calibration/ reference points in the network of PSs

Estimate deformation map by means of PSI

Tie deformation map to the GNSS/CR co-located positions i.e. calibration to yield mm-level results

NEW This **unique** co-location of GNSS **permanent** stations and **CRs** will make **Cyprus** a **dedicated calibration site** for the Sentinel-1 constellation.

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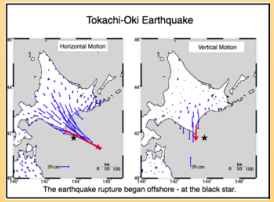
The Early Warning System

Development of an Integrated WebGIS Platform

Dedicated Deployment of ESRI ArcGIS Enterprise Server (+GeoProcessing, GeoEvent Manager, etc.)

Displacement Maps



Web GIS Platform

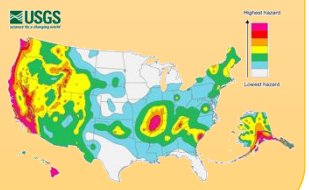
Rapid Crowdsourced Damage App

Data Repository

+ Weather Information
+ Geology Maps
+ Population Density
+ Structural Health Metrics
+ Utility, Transportation Networks
+ Cultural Heritage Landmarks
+ ...

By the People, For the People

Hazard & Risk Maps



Earthquake & Landslide History Service

Geospatial Information on critical locations

Episodic Event Notification Service

Creation of ShakeMaps in collaboration with GSD

Geohazards-related ML & AI-based Models

Development/Update of Structural Assessment Models

Atmospheric, Weather Models etc...

Applications – Case Studies

Case Studies: Monitoring Natural Hazards and the Built Environment

Determination of Station Velocities in Cyprus [DLS, EAC]

- Precise displacement and velocity determination for **both national networks (CYPOS + ATLAS)** using all available data (1Hz since 2012);
- **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

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

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CONSORTIUM

Cyprus University of Technology

DLR

TROPOS
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