Initial Validation Results from the Integrated Use of Permanent GNSS Stations and SAR Corner Reflectors in Cyprus by means of the CyCLOPS Strategic Infrastructure

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Introduction — A

The Cyprus Continuously Operating Natural Hazards Monitoring and Prevention System, abbreviated **CyCLOPS**, is a national strategic research infrastructure unit, with main objective the systematic study of geohazards in Cyprus and the broader EMMENA region[1]. CyCLOPS achieved full operational capacity in June 2021. Since then, it continuously monitors the geodynamic regime of the southeastern Mediterranean area along with several active landslides occurring at the western part of the island. Consequently, **the objective of this research is to deliver a brief presentation of the infrastructure, the first experience after 1.5 years of system operation, and outline results from the analysis of SAR products using our Corner Reflectors.** The latter can be carried out, for instance, by means of the SAR Calibration Tool (SCT), developed by Aresys Srl [2], to estimate accurate geometric and radiometric calibration for Sentinel-1 products over Cyprus.

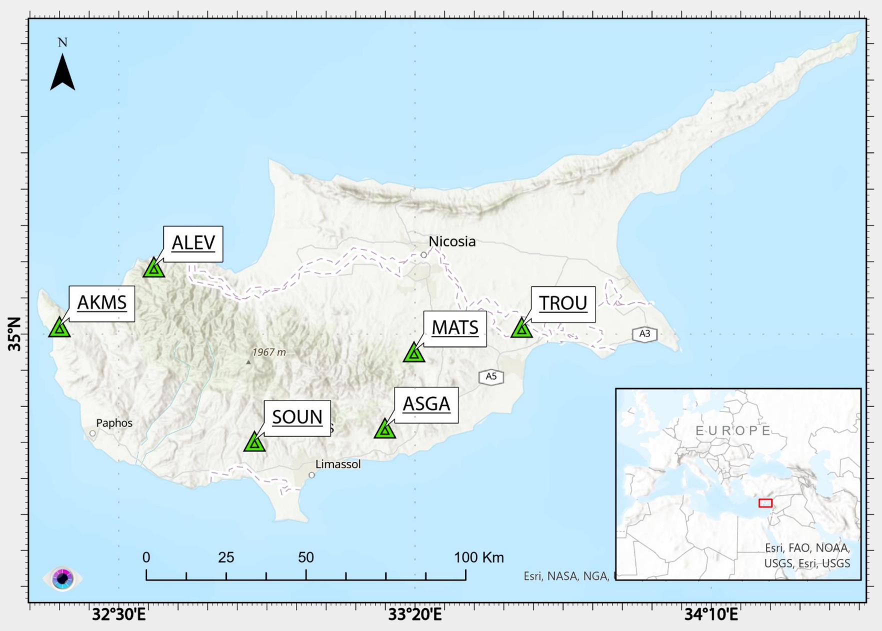

Figure 1: Site Locations of the CYCLOPS Permanent Segment.

CyCLOPS Multi-Parametric Network — B

CyCLOPS is comprised of two main components; (a) a multi-parametric network of sensors (MPN) established throughout the government-controlled areas of Cyprus and (b) an Operation Centre (OC). The MPN is comprised of a permanent and a mobile segment, which is deployed in areas of interest. The permanent segment as illustrated in **Figure 1** includes six permanent sites, each of which contains a Tier-1 GNSS reference station co-located with two calibration-grade triangular trihedral corner reflectors (CRs) of 1.5m inner length to account for both the ascending and descending tracks of SAR satellite missions, such as ESA's Sentinel-1. A representative example of the collocation can be seen in **Figure 2(a)**, **(b)**, **(c)**, and **(d)**. Furthermore, the GNSS equipment is collocated with precise weather stations and tiltmeters. The monumentation mounting considerations for the permanent segment are aligned with the most stringent specifications, as outlined by UNAVCO, IGS and EPN. Two types were adopted for the monumentation of GNSS CORS; the shallow drilled braced monument type (SDBM) and a specifically designed 3m-tall metallic truss, as illustrated in **Figure 2(a)** and **Figure 3**, respectively. Therefore, besides its zero-order geodetic nature, the unit aims to become a calibration and validation (Cal/Val) infrastructure for current and future SAR satellites constellations. The mobile segment is comprised of the same grade of GNSS equipment, hosted on a specifically designed mobile configuration, which enables flexibility in the deployment of the stations, even in harsh environments, to monitor dynamic phenomena, such as landslides. Furthermore, the mobile segment includes electronic corner reflectors (ECRs), which are, again, co-located with the GNSS sensors, weather stations and tiltmeters (as illustrated in **Figure 4(a)**, **(b)**, and **(c)**. Although the main purpose of CyCLOPS is the geohazards' monitoring, the infrastructure is designed to support radiometric calibration and geometric validation of C and X-band Synthetic Aperture Radar (SAR) imagery.

Figure 2(a): ALEV00CYP: GNSS CORS monumented with the SDBM type.

Figure 2(b): ALEV02CYP: CR for Descending Pass.

Figure 2(c): The ALEV site's collocation.

Figure 2(d): ALEV01CYP: CR for Ascending Pass.

Figure 4(c): The collocation of ECR and GNSS Mobile Station

Figure 4(b): ECR configuration, powered by a solar panel.

Figure 3: The Stainless-Steel Truss Monument of the SOUN00CYP GNSS CORS.

Figure 4(a): The GNSS Mobile Station

Methodology — C

Radiometric Calibration

The **radiometric calibration** process involves comparing the backscattered radar reflectivity signal from CR, with known Radar Cross-Section (RCS) values present in the generated SAR images. By employing the integral method [3-5], the absolute calibration factor is derived from the intensity of these reference targets. To assess radiometric calibration, a Point-Target-Analysis (PTA) was performed, analyzing the CRs' response on the Single Look Complex (SLCs) data. This analysis estimates key parameters, including peak signal power, **clutter power**, **RCS,** and Signal to Clutter Ratio (**SCR**) following the methodologies outlined in [6]. The two-year-long dataset was studied thoroughly to verify the temporal stability of the network and identify potential accuracy fluctuations caused by precipitation collection in the CRs.

Geolocation Accuracy

Furthermore, the **geolocation accuracy** represents the remote sensing platform's capacity to precisely assign accurate geographic positions to surface features captured in SAR imagery. The primary objective is to estimate the azimuth and slant/ground range image pixel position of specific CRs visible in SAR image products with the utmost accuracy.

For each CR, a fixed reference point (RP) below the CR apex (phase centre) was surveyed using GNSS static measurements and accounted for the height offsets between the RP and the apex (see **Figure 5**). Their 3D coordinate positions were corrected with respect to the coordinates of the co-located CyCLOPS GNSS/CORS at each site.

Evaluating SAR **Absolute Location Error** (ALE) involves a comparison of the range and azimuth coordinates of extracted point targets from the images with the expected values derived from the range-Doppler model and known target coordinates [7]. This assessment of geolocation accuracy will account for various factors that influence the CRs' position, initially determined through precise surveying. Factors, such as the effects of SAR signal propagation delay through the troposphere and ionosphere, as well as geodynamical effects like the coordinate reference frame, plate tectonics, and solid Earth tides (SET) [8,9], were carefully considered during the evaluation process.

Figure 5: Static Measurements at ALEV02CYP

Results — D

The **Point Target Analysis** shows overall consistent values from the CR installation dates. In case of TROU01CYP and ALEV02CYP, a decrease of the signal is observed at some dates during a rainy period. The poor signal quality is attributed to slow drainage from the CR due to soil deposition. The measured RCS values are similar to the theoretical RCS (38.30 dB). The lower mean RCS is measured at ALEV site, where the highest clutter values are observed.

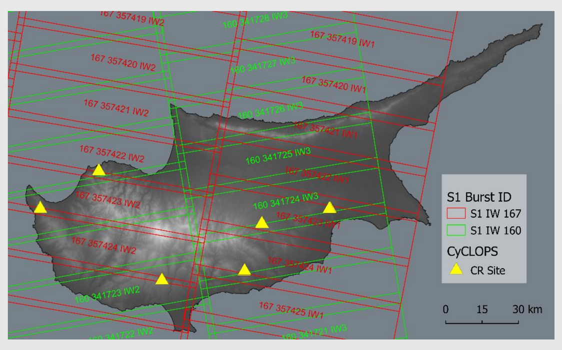

Figure 6: S1 Burst footprint over Cyprus

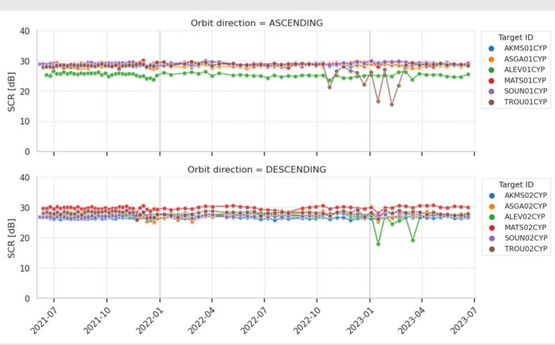

Figure 7: SCR measurements along the 2-year long dataset

Target ID	Num Obs	SCR [dB]	Clutter [dB]	Peak P [dB]	RCS [dB]
AKMS01	75	28.59 ± 0.39	-9.14 ± 0.35	19.46 ± 0.22	38.10 ± 0.24
ASGA01	73	28.25 ± 0.46	-9.35 ± 0.42	18.91 ± 0.26	38.24 ± 0.28
ALEV01	76	25.30 ± 0.64	-7.17 ± 0.60	18.13 ± 0.33	35.52 ± 0.75
MATS01	77	28.85 ± 0.59	-10.18 ± 0.59	18.67 ± 0.21	37.87 ± 0.29
SOUN01	77	29.05 ± 0.39	-9.54 ± 0.44	19.51 ± 0.25	38.27 ± 0.29
TROU01	72	28.48 ± 0.68	-10.13 ± 0.41	18.35 ± 0.70	37.57 ± 0.74
Total|Mean	450	28.09 ± 0.52	-9.25 ± 0.47	18.84 ± 0.33	37.59 ± 0.43

Target ID	Num Obs	SCR [dB]	Clutter [dB]	Peak P [dB]	RCS [dB]
AKMS02	150	26.44 ± 0.41	-7.45 ± 0.33	18.99 ± 0.25	37.51 ± 0.36
ASGA02	74	27.51 ± 0.81	-7.43 ± 0.69	20.08 ± 0.35	37.43 ± 0.55
ALEV02	148	27.36 ± 0.64	-9.43 ± 0.45	17.93 ± 0.71	36.63 ± 0.70
MATS02	77	29.79 ± 0.53	-10.13 ± 0.45	19.67 ± 0.41	37.55 ± 0.43
SOUN02	78	27.27 ± 0.49	-7.63 ± 0.44	19.64 ± 0.25	38.22 ± 0.30
TROU02	77	28.05 ± 0.68	-8.22 ± 0.63	19.84 ± 0.17	37.68 ± 0.27
Total|Mean	604	27.74 ± 0.59	-8.38 ± 0.50	19.36 ± 0.36	37.50 ± 0.44

Table 1,2 : PTA parameters; mean and standard deviation values.

The **Absolute Location Error** shows low standard deviation values in azimuth and range. In both Ascending and Descending orbits, the bias between S1A and S1B observations has been corrected by applying the updated Instrument Timing Calibration (ITC) constant [10].

Mission	Num Obs	Range ALE [m]	Azimuth ALE [m]
S1A	352	0.026 ± 0.065	0.026 ± 0.331
S1B	98	-0.001 ± 0.060	0.064 ± 0.250

Mission	Num Obs	Range ALE [m]	Azimuth ALE [m]
S1A	474	0.149 ± 0.058	-0.176 ± 0.338
S1B	130	0.130 ± 0.058	-0.090 ± 0.279

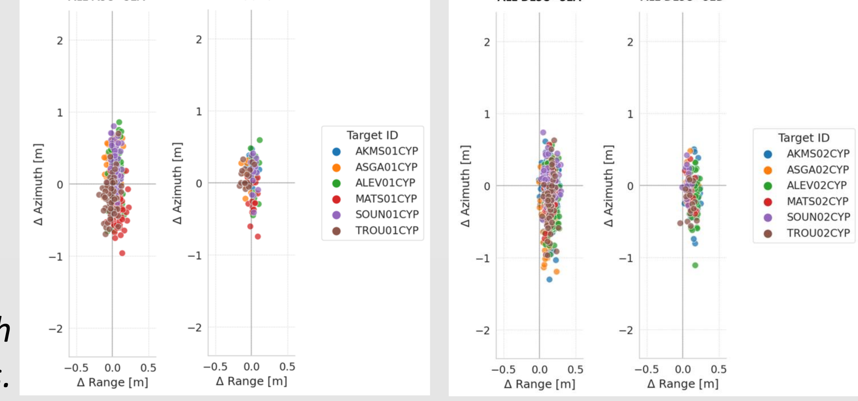

Figure 8: Range and Azimuth ALE for both Ascending (Left) and Descending (Right) orbits.

Conclusions — E

The initial validation results, from a preliminary survey, indicates performance as expected from a properly installed high-quality CR network. The radiometric parameters show overall constant values during the period of study, and the geolocation measurements indicate high precision in both range and azimuth ALE. A continuous monitoring is foreseen to ensure the correct operation of the CR network.

References — F

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