CyCLOPS: A Novel Strategic Research Infrastructure Unit for Continuous Integrated Spaced-based Monitoring of Geohazards

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ABSTRACT

Cyprus, being located on the Mediterranean fault zone, exhibits a unique geodynamic regime since its tectonic evolution is driven by the interaction of the Eurasian and the African plate. Besides its seismological interest, Cyprus exhibits many active landslides and slope instabilities in areas of steep topography that pose an imminent threat for entire settlements, critical infrastructure, and cultural and natural heritage landmarks. To address these challenges, a novel strategic research infrastructure unit, abbreviated CyCLOPS, is being developed and established by Cyprus University of Technology in cooperation with the German Aerospace Agency (DLR). CyCLOPS will utilize novel space technologies, including cutting-edge European space missions, such as Galileo, Copernicus Sentinel and TerraSAR-X along with state-of-the-art processing techniques to monitor the effects of geohazards, such as earthquakes and landslides, and assess their impact on the built environment and cultural heritage landmarks. The latter will be achieved by the robust and continuous estimation of ground deformation and its velocity gradients at a national and regional level. The determination of deformation will be carried out by means of novel integrated GPS/GNSS and SAR techniques, rendering Cyprus a dedicated calibration and validation site for European space missions.

I. INTRODUCTION

Cyprus is located within the Alpine-Himalayan seismic zone, which generates approximately 15% of the global number of earthquakes. Most of the earthquakes that occur in Cyprus are mainly attributed to the Cyprus Arc, the tectonic boundary between the African and Eurasian plates. Whilst the African plate moves to the north, it collides with the Eurasian plate, and hence it is subducted beneath the Anatolian microplate (Cyprus Geological Survey, 2012). During the past century, more than 500 earthquakes occurred within the wider geographic area of Cyprus. The most intense seismic activity is exhibited at the southwestern part of the Cypriot Arc (see Figure 1). Based on recent findings (Giardini et al., 2014), Cyprus is considered as one of the highest risk areas in Europe related to seismic risk. The European Seismic Hazard Map displays the ground shaking (i.e. Peak Horizontal Ground Acceleration, PGA) to be reached or exceeded with a 10% probability in 50 years. This reference value represents the shaking to be expected during the human lifetime in a standard building, corresponding to the average recurrence of such ground motions every 475 years, as prescribed by the national building codes in Europe. It's important to note that these values can be exceeded with 10% probability every 50 years.

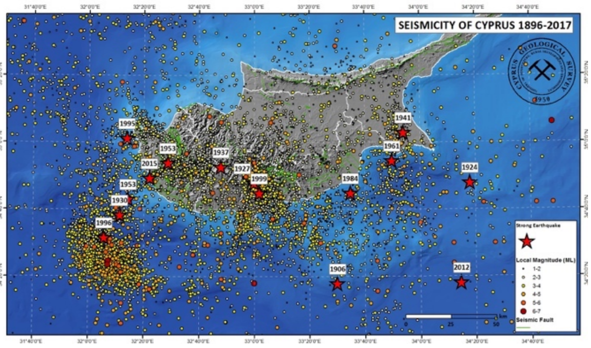

Figure 1. The seismicity of Cyprus (CGS, 2012)

Besides its unique geodynamic regime, Cyprus exhibits many active landslides and slope instabilities in areas of steep topography that affect the built environment by posing an imminent threat for entire settlements, critical infrastructure and cultural – natural heritage landmarks. The main natural causes of landslides can be attributed to the following (Cyprus Geological Survey, 2013): the geological conditions, the weather, the geomorphology, the hydrological regime and the regional seismicity. The geological formations of Cyprus, especially at the southwestern part, contain clay, marly layers, fractured and weak rocks. Furthermore, the winter rainfalls, often appearing as intense storm events are one of the most important landslide triggering factors. Moreover, Cyprus exhibits steep slopes generated by soil erosion, which, in turn, is caused by streams and rivers. Rapid changes in the concentration of the underground water from physical or man-made activities trigger not only landslides but also land subsidence phenomena. Finally, the huge residential development due to tourism and real estate investments introduces excessive load on the resistance of slopes resulting in landslides with severe impact.

To date, the combined result of landslides and earthquakes has already led to the abandonment of 8 villages mainly in the Paphos district (i.e. Choletria, Ayios Photios, Statos, Fasoula, Phinikas, Korfi, Kivides and Pentalia) and the resettlement of the population to safer areas. Furthermore, numerous properties and infrastructure (e.g. roads, pipelines, utility networks and agricultural facilities) are severely damaged or even destroyed because of on-going landslides or land subsidence phenomena. Finally, the case of Pissouri village (see Figure 2), which saw important development because of tourism, and a subsequent investment in real estate by foreign nationals, has sustained significant damage, posing a heavy burden on the shoulders of the local community and the government. Besides the direct costs inflicted by landslides (i.e. the restoration of damages), there are severe indirect costs that pose an imminent threat to Cypriot society and economy. Namely, reduced real estate values and, therefore, property tax revenues, permanent damage on cultural heritage landmarks, loss of industrial and agricultural productivity, loss of income and tourist revenue in affected areas, and finally loss of human and animal productivity due injuries or even deaths. Evidently, early and on-time identification of areas prone to landslides, or hotspots within an active phenomenon will lead to the required prevention actions that could save properties, cultural and natural heritage landmarks, infrastructure, restore public safety, and most importantly, save lives.

Figure 2. Landslide effects in Pissouri area

In Cyprus, current research infrastructure for monitoring and better understanding natural hazards is limited to traditional equipment (e.g. seismographs, inclinometers, drills etc.) and, hence, no thorough and systematic research has been carried out to determine ground deformation processes with high accuracy, dense spatial resolution and coverage (country-wide), in a most timely manner. The advent of space-based Earth Observation (EO) monitoring techniques brought a new era in the observation of natural hazards and provided an additional tool towards effective preparedness and emergency response upon the occurrence of such phenomena (Casagli et al., 2016).

Evidently, the formation of a state-of-the-art national geohazard monitoring research infrastructure, entails the augmentation of existing techniques with the most prominent EO technologies and satellite constellations to promote the observation, monitoring and understanding of geohazards in Cyprus and the Eastern Mediterranean region. This is the main objective of the 'Cyprus Continuously Operating Natural Hazard Monitoring and Prevention System', abbreviated CyCLOPS, a strategic research infrastructure unit project co-financed by the European Regional Development Fund and the Republic of Cyprus through the Research Promotion Foundation of Cyprus.

II. Space-based Natural Hazard Monitoring

The term ‘monitoring’ or ‘surveillance’ entails the systematic observation of variables or processes to produce time series. Indeed, the study of solid earth and atmospheric processes that change with time requires time series analysis based on continuous monitoring of the phenomena under investigation. Such phenomena are tectonic plate motion, land subsidence or submergence, or changes in sea level. Currently, continuous, state-of-the-art precise deformation monitoring is provided by GPS/GNSS receivers in the form of continuously operating reference or tracking stations (CORS). A CORS is a stationary GPS/GNSS receiver that collects data from visible (available) satellites on a 24-hour basis to produce 3D position information. Especially in the case of earthquakes, tracking stations not only do they provide accurate estimation of deformation, but they coop successfully with existing seismographic equipment. Seismometers are band limited, because of their form consisting of a spring and weight, especially for displacement waveforms due to rotational components of strong motion. Ergo, they exhibit a short-period magnitude saturation problem in cases of large earthquakes (Melgar et al., 2013a; Trifunac and Todorovska, 2001). On the contrary, GPS/GNSS receivers have no lower limit in bandwidth since the system is clearly larger that the target event. Another ‘advantage’ of GNSS compared to conventional equipment, beit geological or geotechnical, is the fact that it can provide absolute displacement information with respect to a global reference frame (e.g. ITRF2014) and not a ground inertial frame, as in the case of e.g. seismographs. Evidently, GNSS can generate on-time accurate deformation information that can be incorporated in early warning systems to promote public safety.

A. *GNSS CORS Networks*

Whilst a sole CORS measures ground displacement at a specific location, a network of CORS is required to account for a region. CORS networks vary in sizes and can be regional, national, continental or global, depending on the area of interest (Awange, 2012). CORS stations are installed on stable monuments (e.g. concrete or stainless-steel pillars) to achieve the maximum degree of accuracy in position determination. Ergo, CORS are differentiated in terms of tier status, i.e. the primary purpose for which the station has been established, and the expected stability of the monument (Intergovernmental Committee on Survey and Mapping (ICSM), 2014). Tier 1 CORS require monuments with high-degree of stability to enable geoscientific research and global reference frame definition. This sort of stations is installed to support continental or global high-accuracy networks, such as the International GNSS Service (IGS) network or the EUREF Permanent Network (EPN). The IGS stations are primarily used to determine the International Terrestrial Reference Frame (ITRF), which implements the global dynamic coordinate reference system (ITRS). Similarly, EPN stations are used in the determination of the European Terrestrial Reference Frame (ETRF), which defines the standard precise coordinate system used throughout Europe (ETRS) (Bruyninx et al., 2010). The determination of positions and velocities of CORS is carried out in the aforementioned coordinate reference systems, depending on the location of the area of interest. Tier 2 CORS require high-stability monumentation and are usually established by national geodetic agencies to realize and maintain national geodetic reference frames. Note that these CORS form the primary national GPS/GNSS network, and that Tier 1 CORS are usually a subset of Tier 2 stations to provide a tie between the national geodetic datum and the ITRF or ETRF. Tier 3 CORS require stable monuments (less stable than the previous categories) and are established by national, state, territory governments, and/or commercial agencies to densify the national infrastructure and to offer real-time positioning applications. It must be noted that Tier 3 stations usually operate within the national datum, rather than define it. In such cases, the interstation distance required to achieve centimeter level results (by means of real-time services) is around 70Km. On the other hand, CORS networks used in geodynamic/ geophysical monitoring usually have an interstation distance of 20Km – 30Km.

B. *Synthetic Aperture Radar (SAR)*

It is evident that to achieve denser spatial distribution and estimate deformation at a regional scale, CORS networks need either to be augmented by additional stations, which is cost inefficient and non-vital, or by employing other techniques of similar accuracy levels. Such a technique is the space-based Interferometric SAR (InSAR), which augmented by an array of specifically designed geodetic corner reflectors (CR) can yield very accurate results. InSAR is a technique that can determine ground displacements at the millimeter to centimeter level, with high spatial resolution. It can be employed to detect, measure and monitor crustal changes related to geophysical processes, such as earthquakes, volcanic eruptions and landslides. When combined with GPS/GNSS measurements, InSAR can infill the gaps within the CORS network, and capture anomalies of small spatial extent that would potentially be missed within a network of discrete point observations (Garthwaite et al., 2015). The principle of InSAR lies in the use of two or more radar images of the same area to identify ground deformation and its evolution through time.

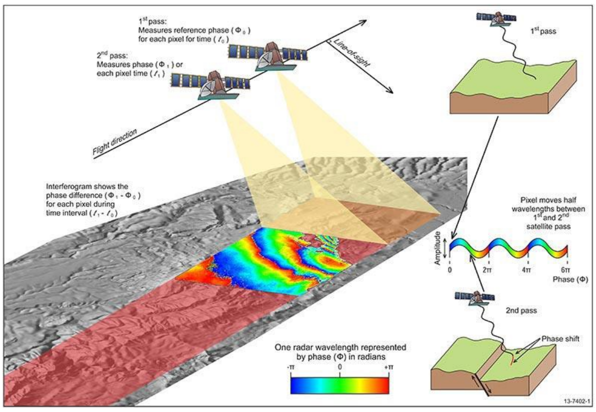

Figure 3. The principle of InSAR (Geoscience Australia,2014)

SAR satellites acquire images by transmitting microwave pulses to the surface of the Earth. SAR images contain two components: the intensity and phase of the backscattered microwave signal. The intensity provides information on the terrain slope and roughness, whilst the phase delivers the range between the satellite and the Earth's surface. The difference of the phase components of two SAR images of the same area acquired at different times, i.e. the phase shift referred as interferogram, indicates a change in the distance between the satellite and the ground. Consequently, displacements for the period of the SAR data coverage, can be computed by means of a least–square inversion on a network of numerous interferograms that originate from the available SAR image dataset. This technique is called Differential InSAR (DInSAR) and delivers two outputs; (a) velocity maps, which represent the displacement of each pixel averaged by the observation period, and (b) time-series maps, that depict the history of surface positions for pixels at each acquisition epoch. In a SAR image, the value of each pixel is the coherent sum of contributions from all scatterers within the corresponding ground resolution cell. Obviously, any relative movement of these scatterers or change in the view angle will cause their respective contribution to sum differently. This effect is called decorrelation (Hooper, 2008). DInSAR enables precise deformation monitoring and performs well in urban environments or rocky areas where noise effects on interferograms are low. In contrast, zones characterized by vegetation, agricultural fields, snow or water are affected significantly by temporal and spatial decorrelation (Lanari et al., 2007). An alternative SAR-based technique, increasingly popular in geodynamic/ geophysical monitoring research is the Persistent/ Permanent Scatterer InSAR (PSI). PSI uses surface scatterers with a strong and stable backscatter over long time periods and different view angles (persistent scatterer). In this way, the coherent sum is not biased by weaker signals within the resolution cell and the decorrelation effects are minimized. The distribution of persistent scatterers is more likely to be dense in urban environments. However, in rural areas the distribution is usually sparse, and hence problems may arise. These problems can be mitigated using corner reflectors (CRs).

Corner Reflectors

CRs are metallic structures designed to present a large Radar Cross Section (RCS) when viewed from a certain angle by a radar (see Figure 4). A radar signal impinging on a CR is strongly reflected back to the radar in a known way and so the received signal can be compared with the expected signal, thereby allowing characterization and calibration of the radar. For this reason, space agencies install and maintain CRs at sites for the densification of persistent scatterers and the calibration of space-borne SAR sensors. The high reflectance of CRs allows their position within a SAR image to be determined at a very high degree of precision. When combined with knowledge of the satellite orbit, the absolute range, or distance, between the sensor and the CR can be estimated. Surface deformations on the order of centimetres per year can be seen given a time series of such measurements, provided error sources such as atmospheric delay and geodynamical effects are properly accounted for. Such parameters can be estimated by GPS/GNSS. The German Aerospace Center (DLR) has conducted extensive research and came up with very promising results by achieving centimeter level accuracy using TerraSAR-X InSAR data and Corner Reflectors (Balss et al., 2014).

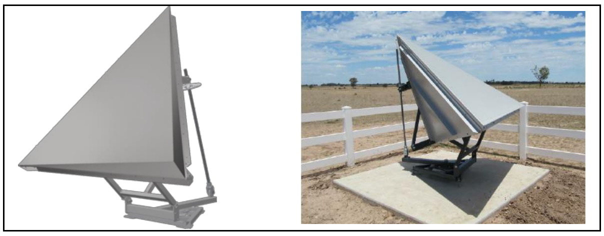

Figure 4. Examples of Corner Reflectors (Garthwaite et al., 2013)

Furthermore, the combination of ascending and descending passes enables separation of the up-down from east-west components and even, though with less precision, from the north-south component. In the absence of CRs, the technique can also be applied to strong ad-hoc scatterers such as Persistent Scatterers that occur, as stated above, at very high spatial densities in urban environments. This fact enables direct measurement of surface deformation at much higher spatial densities than possible with GPS/GNSS and bypasses the need for the complex and time-consuming techniques such as PSI (PS Interferometry) or SBAS (Small Baseline Subset). The field of geodetic SAR represents a paradigm shift in the exploitation of SAR imagery with great potential for surface deformation monitoring (Cong et al., 2016; Eineder et al., 2015). Evidently, the combined use of CORS network and geodetic SAR may yield spatial and temporal estimates of surface deformation with millimeter level precision and centimeter level accuracy.

III. Existing NH Monitoring Infrastructures

The deployment of combined CORS and CR arrays is recognized by large geospatial and geophysical institutions as been the most prominent way to research solid earth processes and natural hazards. Nevertheless, there are few agencies that have established a CORS/CR integrated array system. For the sake of conceptual clarity and completeness, two of the most advanced networks are described to highlight their strong points and novelty; GEONET and AUGS.

The most numerous and dense CORS network in the world used for geodynamic/ geophysical monitoring, and geodetic processes is in Japan. The GNSS Earth Observation Network System, abbreviated GEONET, is comprised of a permanent segment (see Figure 5) that numbers more than 1,300 CORS with an interstation distance of 20 – 30 Km (Tsuji et al., 2013; LaBrecque and Area, 2016). Seven stations are Tier 1 CORS and participate in the IGS global network. The system is further augmented by several mobile GNSS CORS positioned in areas of particular interest, such as volcanos. All stations are equipped with, at least, dual frequency receivers, compatible with all available GNSS and regional constellations (GPS, GLONASS, Galileo, BeiDou and QZSS) and collect data at a sampling rate of 1Hz. The TS are placed on top of 5m highly-stable pillars made of stainless steel. The network supports real-time communication to the control and data processing system using IP/VPN protocols. The data processing system is divided into 7 components; (a) the real-time communication operating unit, (b) the non-real-time communication operating unit, (c) the administration system, (d) the data storage server, (e) the static data analysis unit, (f) the real-time data analysis unit, and (g) the display (of results and analyses) units. The data processing system analyzes data in three different routine processing modes: quick, rapid and final (Miyahara et al., 2014). Quick analysis is carried out for all stations using 6-hour data 8 times per day. Rapid analysis takes place on a daily basis using 24-hour data. Final analysis is carried out using the final orbits of IGS (available at 12 days latency). It is noted that the aforementioned analyses are performed using the Astronomical Institute of Bern (AIOB) software Bernese 5.0. Scientists using a small subset of GEONET were able to demonstrate accurate earthquake magnitude and tsunami prediction within 5 minutes (Song, 2007; Ohta et al., 2012; Melgar et al., 2013b).

In 2017 the Geospatial Information Authority of Japan (GSI), which is responsible for the operation of GEONET, has announced the development of a real-time service based on GNSS observations to perform real-time positioning and automatic detection of co-seismic displacements (Kawamoto et al., 2017). The Real-time GEONET Analysis system for Rapid Deformation monitoring, abbreviated REGARD, enables rapid estimation of earthquake parameters, such as the magnitude and length, which is crucial information for tsunami early warning systems. REGARD is currently in experimental operation and is capable of processing data from 620 CORS.

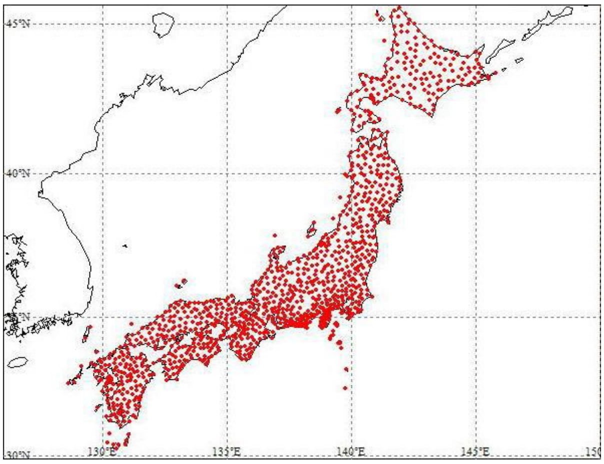

Figure 5. The distribution of CORS in Japan

The implementation of the Australian Geophysical Observing System (AGOS) infrastructure begun in 2010, after a total investment of 23mio AUD from the Australian Government via the Education Investment Fund. Geoscience Australia is the agency responsible for the implementation and the operation of the AGOS geospatial observatory, which features the following infrastructure [6]; (a) a network of geodetic marks, which includes co-located radar Corner Reflectors to perform precise determination of crustal deformation at a regional scale using combined InSAR and GPS/GNSS techniques; (b) Four high-precision CORS stations to densify the existing network of 101 CORS funded by the National Collaborative Research Infrastructure Strategy; (c) a Robotic GNSS antenna calibration facility (the only facility in the Southern Hemisphere); (d) a deployable pool of GNSS instrumentation for episodic campaign surveys; this includes 80 GPS/GNSS receivers, 10 ionospheric receivers, and 3 real-time kinematic kits; (e) an open-access repository of InSAR data from previous ERS satellites (operated by European Space Agency). The aforementioned infrastructure enables combination of high-precision geodetic techniques to yield the spatial and temporal estimates of multi-scale surface deformation achieving mm–level precision and cm–level accuracy. The research output of AGOS will also address crucial geodetic issues, such as the improvement of the temporal and spatial accuracy of the national Australian Datum. Note that the current Geocentric Datum of Australia 1994 (GDA94) is currently undergoing a modernization phase. The new datum named GDA2020 will be defined by taking into account the estimated displacement (currently at 1.6m since 1994) to provide modern, dynamic, and more precise positioning service than its predecessor (Geoscience Australia, 2016).

IV. The Case of Cyclops

To date, national infrastructure for investigating natural hazards in Cyprus is comprised by conventional equipment. From the local stakeholders' side, the Department of Geological Survey (DGS) maintains the local seismological network. However, crucial information on geodynamic processes, crustal deformation, the activity of existing faults, the occurrence of new and the study of existing landslides at the national level is limited and, in some cases, has yet to be determined due to the lack of the required resources. Furthermore, the Department of Land & Surveys (DLS) operates the national GPS/GNSS network abbreviated CYPOS, and the Electrical Authority of Cyprus (EAC) operates a similar network for its own needs, called ATLAS. Both networks are Tier-3 networks and their purpose are to facilitate mapping and standard surveying tasks. Concordantly, specifications, such as their monumentation and inter-station distance are not primarily intended for precise displacement and geohazard monitoring according to the required standards (Tier-1 or Tier-2). Moreover, the use of modern EO constellations, such as Sentinel-1, COSMO SkyMed and TerraSAR-X is limited and has yet to be fully exploited by means of products of national coverage, and in terms of the accuracy of the deformation output. Evidently, there is a lack of an integrated approach that will combine the best of each technology to provide a unified solution, which, in-turn, will upgrade monitoring, enhance preparedness and promote emergency procedures with respect to natural hazards.

The CyCLOPS project (RPF/INFRASTRUCTURES/ 1216/ 0050) aims to address this important challenge by establishing a novel integrated strategic infrastructure (SI) unit to monitor geohazards in Cyprus and the Eastern Mediterranean region. The unit will utilize cutting- edge Information & Communication Technologies (ICT), in the form of a unified system of interconnected hardware and software components to enable monitoring, and mitigate the impact of natural hazards, i.e. earthquakes, and landslides using state-of-the-art EO techniques.

Specifically, CyCLOPS will use two of the most prominent technologies that enable effective and accurate surveillance of solid earth activities; Global Navigation Satellite Systems (GNSS), and space-based Interferometric Synthetic Aperture Radar (InSAR) to provide early warning services, risk management, and mitigation of the impact of natural hazards on the built environment, such as critical infrastructure and cultural and natural heritage landmarks. Furthermore, the CyCLOPS SI unit will exploit the latest European space missions, i.e. Galileo and Copernicus programs. A co-located configuration of permanent GNSS CORS, weather stations, tiltmeters and corner reflectors will be established and installed in such way as to be compliant with (a) all current GNSS constellations (GPS, GLONASS, Galileo, BeiDou) and (b) the Copernicus Sentinel-1 and the TerraSAR-X EO SAR sensors. The design, installation and calibration of the system is carried out in close cooperation with the German Aerospace Agency (DLR).

A. *The Architecture of CyCLOPS*

CyCLOPS consists of two main components; a multi-parametric network (MPN) of heterogeneous sensors, and the Operations Centre (OC). The MPN, in-turn, is comprised of two segments; the permanent segment (PS) and the mobile segment (MS). The permanent segment includes 5 cutting-edge continuously operating high-rate GPS/GNSS reference stations, weather stations, and tilt meters, which will be installed at specific sites, on top of highly-stable monuments (e.g. concrete, or metallic pillars) to estimate ground displacements. Among the selected sites are nodes of the national seismological network to establish co-location of the space-related infrastructure with seismological equipment to enhance the estimation of earthquake parameters.

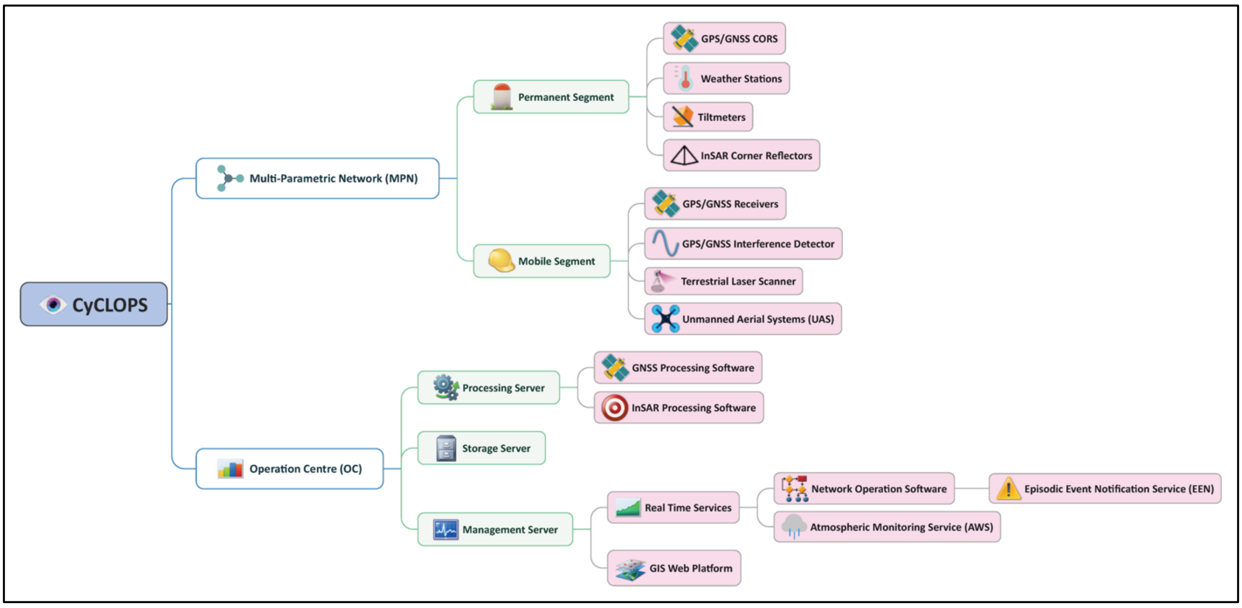

Figure 6. The main components of CyCLOPS

The sites where the infrastructure is installed need to fulfil several technical requirements to achieve maximum accuracy during measurements. Such requirements are provided by the International GNSS Service (IGS) and EUREF's Permanent Network (EPN), which mandate increased satellite availability, highly-stable monumentation, energy and communication redundancy, and avoidance of radio frequency interference (RFI) sources. Weather stations also co-locate with CORS to provide monitoring of atmospheric parameters, useful for modelling and mitigation of error sources, such as the ionospheric and tropospheric refraction imposed to the satellite signals due to traveling through the atmosphere. The weather stations also meet the guidelines set by IGS and EPN.

Note that although GNSS performs very accurate determination of ground displacements, it does this at a sparse spatial resolution. This is attributed to the fact that CORS measure position changes that refer to a single physical point on the surface of the Earth. Since the application area of CyCLOPS is the entire country, displacement information needs to be densified. To achieve denser spatial resolution, the PS is augmented by an array of novel, specifically designed SAR corner reflectors (CR), which will provide cm-level displacement monitoring at level and will complement the MPN by infilling gaps of deformation information that occur within the network.

To cover remote areas of interest and address situations of emergency, a set of deployable equipment is required. Therefore, five additional GPS/GNSS CORS are used to densify the PS, along with laser scanners and unmanned aerial systems (UAS). This set of infrastructure forms the Mobile Segment (MS). The MS is complemented by a portable Radio Frequency Interference (RFI) detector, which is used prior to CORS installation to enable unbiased observations by unwanted electromagnetic obstructions. In total, 10 permanent GNSS stations will complement the existing network of 14 CORS in Cyprus, reducing the inter-station distance at 20 – 30Km.

The management, storage and processing of the available information takes place at the Operations Centre (OC). The latter is comprised by three segments; (a) the processing server is the computational infrastructure where GPS/GNSS and geodetic InSAR processes are carried out; (b) the storage server handles the storage of the incoming sensor information, along with supplementary data required for processing, such as satellite ephemerides, clock files, atmospheric models etc. The storage server enables redundant backup via RAID, and external media, such as Network Attached Storage (NAS), cloud-based storage services and tape drives; (c) the management server, handles sensor configuration and control tasks, and hosts the real-time (RT) services.

B. *The Services of CyCLOPS*

By means of the aforementioned infrastructure, the SI unit will be able to develop a novel early warning system (EWS) to promote civil protection, protect the built environment via the development of novel applications and services, and stimulate collaborative research on natural hazards. To accomplish this objective, the EWS will provide the following services:

A real-time CORS displacement monitoring service. Registered users will be able to access the service on 24/7/365 basis via their personal computers or smart devices (e.g. smartphones and tablets) and have a visual image of the displacements occurring in the CORS positions.

The episodic event notification service (EEN) will enable system administrators and authorized end-users to receive real-time notifications on the occurrence of episodic events on their PCs and smartphones via email messages and SMS. Evidently, this feature will aid civil protection authorities and local stakeholders by accelerating processes related to public safety and enhance potential mitigation of impacts.

An atmospheric monitoring service (AMS) regarding ionospheric and tropospheric activity will be provided either as a web service or suitable app to the end-users. The AMS will provide useful data such as Integrated Precipitable Water Vapor (IPWV), tropospheric slant delay, total electron content (TEC), and ionospheric scintillation via analysis of weather station data and CORS observations. This information will enhance the detection of tectonic motions and will contribute towards atmospheric modelling required for GPS/GNSS and InSAR accurate processing.

The EES will provide a series of geospatial data and services by means of a robust web GIS platform. The platform will serve products derived by novel, high-accuracy, integrated GPS/GNSS and geodetic InSAR processing techniques. The results of the latter will be displacements and velocity information addressing the whole of Cyprus. This information will then be used to produce the following products:

Displacement maps. Displacement and velocity maps will be served on a twelve-month basis as the result of estimations of annual displacement and velocities. In case of more dynamic phenomena, displacement maps will be served more frequently (i.e. 6-month or earlier depending on the evolution of the process).

Susceptibility and Hazard maps. Using the above information and history records, susceptibility maps will be generated separately for earthquake and landslide phenomena. Consequently, hazard maps will be created to indicate sensitive areas in terms of population density, structural health, critical infrastructure and cultural landmarks.

Earthquake and Landslide history service. Information on past earthquakes and landslides will be catalogued in a specifically designed geospatial database (GDB).

End-users will be able to query the GDB and acquire valuable information on the history of a particular location with respect to earthquakes and landslides. Furthermore, the GDB will provide spatiotemporal services, such as the seismic and landslide activity of the country over the years, as well as information on the parameters of the aforementioned hazards.

Geospatial information on critical locations of the built environment. The Web GIS platform will be further augmented by a list of geospatial layers that will include the locations of critical elements of the built environment, such as cultural heritage landmarks, and critical infrastructure to enable effective online analysis of all the available information through a sophisticated web interface.

V. Conclusions

CyCLOPS, a novel research strategic infrastructure unit is presented in this paper. The SI will consist of a Permanent Segment of five state-of-the-art high-rate GPS/GNSS CORS, co-located with SAR Corner Reflectors, weather stations, tilt-meters and seismographs of the national DGS network. Furthermore, an additional number of five CORS of the same specifications with the permanent segment will form the Mobile Segment, which will address (monitor) situations of emergency. In this way, the SI will integrate the two most prominent space-based EO technologies (GNSS and SAR) to estimate deformation with dense spatial resolution at the cm- to mm-level using corner reflectors. This unique co-location of GNSS and CR will render Cyprus a dedicated calibration site for European EO constellations, such as Sentinel-1. By exploiting the estimated deformation, along with additional geological and geotechnical information the SI will also develop a novel early warning system to enhance preparedness. Evidently, CyCLOPS will liaise closely with the local stakeholders and provide valuable contribution to their mission, by promoting civil protection and public safety and by performing considerable knowledge transfer. This will be done within a framework aligned with the national and European priority axes, thereby promoting smart growth and environmental sustainability in Cyprus. CyCLOPS is anticipated to achieve full operational capability within the first quarter of 2020.

VI. Acknowledgements

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