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ABSTRACT

The "EXCELSIOR" H2020 Widespread Teaming Phase 2 Project: ERATOSTHENES: EXcellence Research Centre for Earth SurveiLlance and Space-Based MonIToring Of the EnviRonment is supported from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 857510 for a 7 year project period to establish a Centre of Excellence in Cyprus. As well, the Government of the Republic of Cyprus is providing additional resources to support the establishment of the ERATOSTHENES Centre of Excellence (ECoE) in Cyprus. The ECoE seeks to fill the gap by assisting in the spaceborne Earth Observation activities in the Eastern Mediterranean and become a regional key player in the Earth Observation (EO) sector. There are distinct needs and opportunities that motivate the establishment of an Earth Observation Centre of Excellence in Cyprus, which are primarily related to the geostrategic location of the European Union member state of Cyprus to examine complex scientific problems and address user needs in the Eastern Mediterranean, Middle East and Northern Africa (EMMENA), as well as South-East Europe. An important objective of the ECoE is to be a Digital Innovation Hub and a Research Excellence Centre for EO in the EMMENA region, which will establish an ecosystem where state-of-the-art sensing technology, cutting-edge research, targeted education services, and entrepreneurship come together. It is based on the paradigm of Open Innovation 2.0 (OI2.0), which is founded on the Quadruple Helix Model, where Government, Industry, Academia and Society work together to drive change by taking full advantage of the cross-fertilization of ideas. The ECoE as a Digital Innovation Hub (DIH) adopts a two-axis model, where the vertical axis consists of three Thematic Clusters for sustained excellence in research of the ECoE in the domains of Atmosphere and Climate, Resilient Societies and Big Earth Data Management, while the horizontal axis is

built around four functional areas, namely: Infrastructure, Research, Education, and Entrepreneurship. The ECoE will focus on five application areas, which include Climate Change Monitoring, Water Resource Management, Disaster Risk Reduction, Access to Energy and Big EO Data Analytics. This structure is expected to leverage the existing regional capacities and advance the excellence by creating new programs and research, thereby establishing the ECoE as a world-class centre capable of enabling innovation and research competence in Earth Observation, actively participating in Europe, the EMMENA region and the global Earth Observation arena. The partners of the EXCELSIOR consortium include the Cyprus University of Technology as the Coordinator, the German Aerospace Center (DLR), the Leibniz Institute for Tropospheric Research (TROPOS), the National Observatory of Athens (NOA) and the Department of Electronic Communications, Deputy Ministry of Research, Innovation and Digital Policy.

Keywords: Digital Innovation Hub, EMMENA, Earth observation, Cyprus

1. INTRODUCTION

The existing ERATOSTHENES Research Centre was established in 2007 at the Department of Civil Engineering and Geomatics, Faculty of Engineering and Technology of the Cyprus University of Technology in Cyprus. The "EXCELSIOR" H2020 Widespread Teaming Phase 2 Project will upgrade the existing Center into an autonomous and sustainable Centre of Excellence for Earth Surveillance and Space-Based Monitoring of the Environment (ECoE), which will provide the highest quality of EO services on National, Regional, European and International levels. The ECoE focuses on conducting basic and applied research and enabling innovation in the areas of remote sensing and space-based techniques for monitoring the environment. The integration of novel Earth Observation (EO), space and ground-based integrated technologies, will contribute to a more sustainable and systematic monitoring of the environment, the timely detection of societal risks/threats and the growth of vital economic sectors. The ECoE will contribute to the increased participation of the private sector in the development of EO applications and promote the creation of spinoff companies.

The establishment of an ECoE in Cyprus contributes in increasing R&D in the EO sector in Cyprus both on the public and private domain. It aims to elevate Cyprus within the European space sector by providing EO and geo-information services, which is growing significantly faster than other technical domains and are supported by European strategies and space programmes, such as Copernicus. As well as the European market, the ECoE will focus on the regional market, which includes the East Mediterranean, Middle East and North African (EMMENA) and Cyprus. Through the strategic partners DLR, NOA, TROPOS as well through international channels and networks such as the Group on Earth Observation (GEO), NASA and others, the ECoE will develop a significant role in the EO international arena.

The ECoE is greatly enhanced by its location in Cyprus due to several reasons. These include (a) unique geo-strategic position, as the most southern and most eastern EU member state, (b) Cyprus' prime location for siting a satellite EO data receiving station with a coverage footprint exceeding all other European stations, which includes the Middle East, Red Sea and Persian Gulf area; (c) Weather and climatic conditions providing 300 days of sunshine a year, favoring cloud-free satellite acquisitions and specific atmospheric research activities; (d) Opportunity of consolidating region-wide observatories such as for Solar Energy; (e) Supportive Cyprus Government regulations for operations and investment, especially in support of Digital Innovation Hubs; (f) Underdeveloped but emerging geo-information market in the EMMENA region due to public and governmental (environment and security) as well as private (e.g., oil and gas) needs in timely information and (g) Collaboration with European and International EO players and access to an active network of EO stakeholder in EMMENA.

The EXCELSIOR project vision as described in its business plan, is fully aligned with the Smart Specialization Strategy (S3Cy) for Cyprus [1,2,3] The S3Cy has been established by the Government of Cyprus [4], based on priority sectors that have been selected for future sustainable economic growth in Cyprus.

2. OPEN INNOVATION

Open Innovation is a key driver for the operations of the ECoE. Based on the European Commission, Open Innovation is an important component of the current European Innovation System, where all societal stakeholders are involved in innovation creation. Open Innovation 2.0 is an approach for innovation focused on solving key European challenges. 'Open Innovation 2.0 (OI2) [5] is considered as a new paradigm based on a Quadruple Helix Model where government,

industry, academia and civil participants work together to co-create the future, and drive structural changes far beyond the scope of what any one organization or person could do alone' [5]. Within the new Open Innovation process, there are five key elements [5]: (1) Networking; (2) Collaboration: involving partners, competitors, universities, and users; (3) Corporate Entrepreneurship by enhancing corporate venturing, start-ups and spin-offs; (4) Proactive Intellectual Property Management by creating new markets for technology and (5) Research and Development (R&D) which focuses on achieving competitive advantages in the market.

3. DIGITAL INNOVATION HUB: THEORETICAL CONCEPT

The concept of the Digital Innovation Hub (DIH) was formally launched by the European Commission (EC) in April 2016 in its Communication on “Digitizing European Industry” [6]. One of the more important pillars of the Digitized European Industry effort is the activity to develop a network of Digital Innovation Hubs (DIH). The use of DIH as an initiative that support digitalization and the development of the surrounding innovation ecosystem is vital in concrete territorial contexts⁷. DIHs are initiatives established to support digital transformation of existing industry across the European Union, and can be hosted by many types of organizations, such as cluster organizations. Extensive research has been conducted on the concept of DIH [6, 7-12].

The European Commission stated that the ‘Digital Innovation Hubs’ (DIH) can help ensure that every company, regardless of size or technological advance, can access digital opportunities. Building on and complementing the various national initiatives for digitizing industry, the European Commission can act to trigger further investments in the digitization of industry and support the creation of better framework conditions for the digital industrial revolution as announced in several EC portals and calls. With technical universities or research organizations at the core, DIHs act as one-stop-shops where companies, especially SMEs, startups and mid-caps can gain access to technology-testing, financing advice, market intelligence and networking opportunities.’

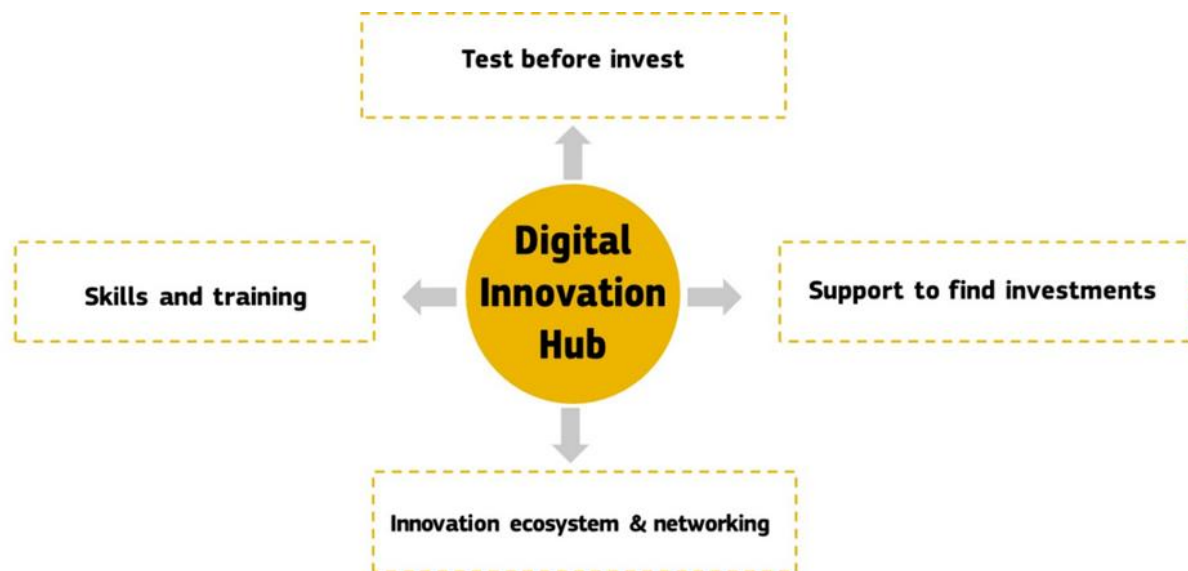


Figure 1. Concept of DIH (<https://ec.europa.eu/digital-single-market/en/digital-innovation-hubs>).

The Pan-European network of Digital Innovation Hubs (DIH) has been introduced as part of the European Smart Specialization Strategy to generate bottom-up digital innovations involving all industrial sectors. The DIH ecosystem mainly targets companies to become more competitive through technology infrastructure, knowledge and expertise in support to Open Innovation and Open Science practices. Therefore, the European Commission is investing €100 million per year from 2016 to 2020 to ensure the presence of a DIH in every region in Europe by 2020. Figure 2 provides an overview map of the concentration of DIHs in Europe in which the representation of DIHs in the Eastern Mediterranean is lacking. CYRIC is the only member in the DIH network from Cyprus and one of the strategic SMEs that provided a significant commitment for the EXCELSIOR H2020 teaming project.

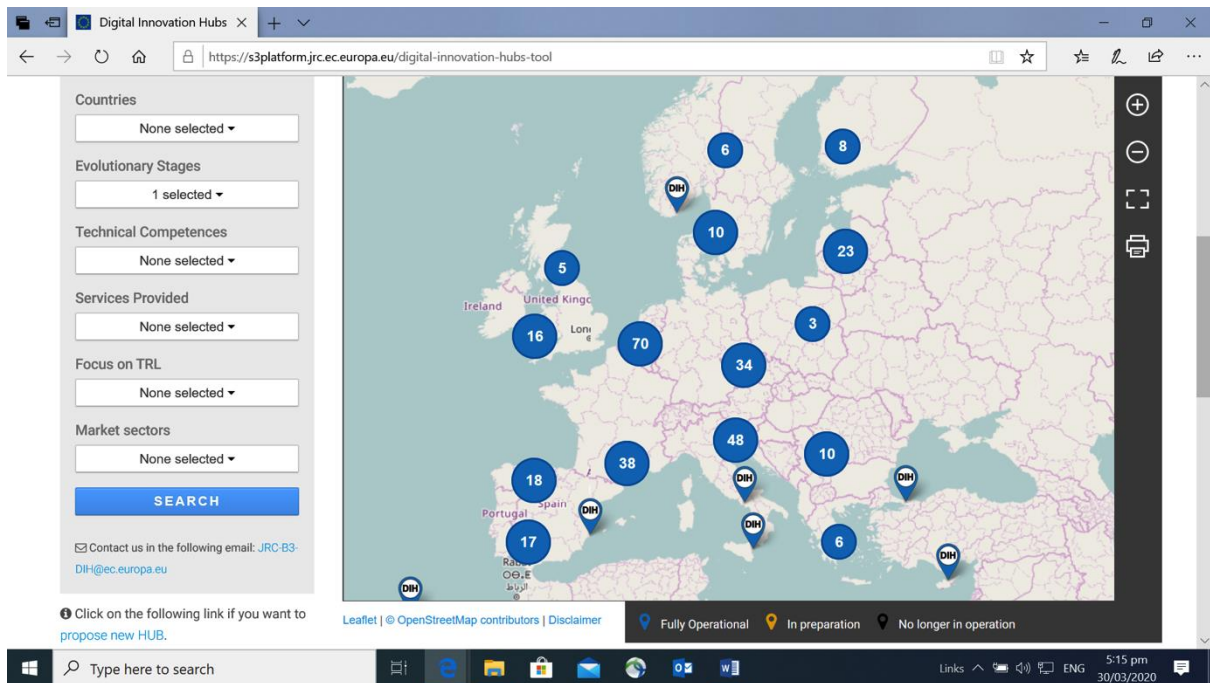


Figure 2. Geographic distribution of Digital Innovation Hubs in Europe [13].

DIHs can also support the development of the regional innovation ecosystem and business growth [14]. Moreover, in relation with S3Cy, some Hubs focus more on horizontal digitalization support, others are leading an S3Cy priority area or alternatively carry out a mixed portfolio of activities designed in interaction with stakeholder partners. Research indicates that DIHs in many regions must focus on increased transparency and clear communication to its potential beneficiaries.

4. DIGITAL INNOVATION HUB FOR EARTH OBSERVATION & BUSINESS MODEL FOR THE ERATOSTHENES CENTRE OF EXCELLENCE

One of the main concepts of the ECoE is to be a fully functional Digital Innovation Hub and a Research Excellence Centre for EO in the EMMENA region. It will create an ecosystem which combines state-of-the-art sensing and data management/processing technologies, cutting - edge research opportunities, targeted education services and promotion for entrepreneurship. In order to be a dynamic and innovative DIH, it will be based on two major infrastructures, which are a Satellite data direct receiving station and a Ground-based atmospheric remote sensing station as well as additional infrastructure.

The ECoE, in cooperation with DLR, will establish an EO Satellite Data Acquisition Station (DAS) to be able to directly receive data from EO satellite missions, which will allow Near Real Time (NRL) monitoring and thereby provide time-critical information for science and products within the receiving cone of the station, namely, over the EMMENA region. Cyprus comprises a unique location for this antenna, as it will be located in the farthest South-Eastern location within the European Union, thus providing an extended coverage compared to other European antenna locations, including a wide range of data from Eastern Europe, Northern Africa and the Middle East.

The ECoE, in cooperation with TROPOS, will establish a ground-based atmospheric remote sensing station (GBS) by consolidating all necessary infrastructure to set up a supersite for calibration/ validation, aerosol and cloud monitoring. The establishment of the GBS is a vital aspect of DIH, as the EMMENA region is a unique area where anthropogenic pollution, desert dust and clouds mix. To date, there have not been any integrated, cohesive studies regarding the atmospheric activities in the EMMENA region, whose results can be used to provide essential information to stakeholders and decision-makers.

The ERATOSTHENES Centre of Excellence (ECoE) adopts a two-axis model. The vertical axis consists of three Thematic Clusters and the horizontal axis consists of four Functional Areas as shown in Figure 3.

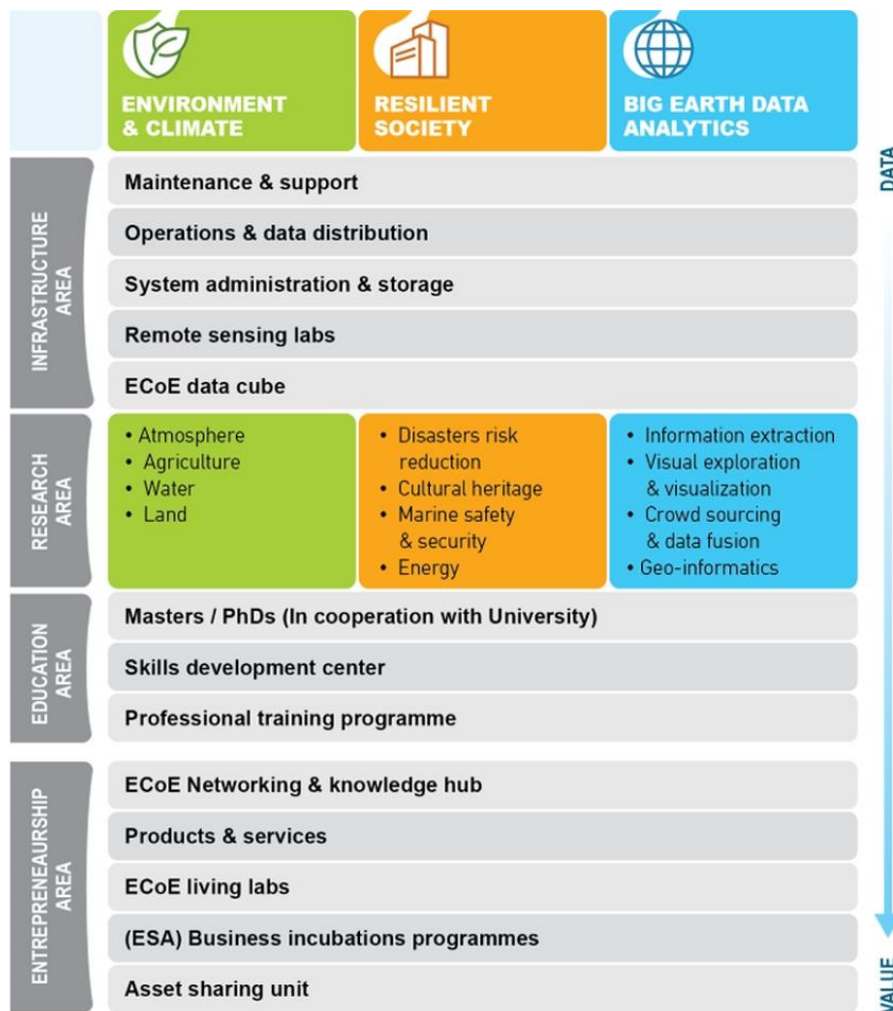


Figure 3. ECoE Digital Innovation Hub: two axis model.

In line with the ECoE Vision, the three Thematic Clusters are defined for sustained excellence in the areas of infrastructure, research, education and entrepreneurship in the thematic clusters of Environment and Climate, Resilient Societies and Big Earth Data Management.

The ECoE engages with the complete ecosystem of stakeholders in a Multi-Actor approach, linking actors segmented according to their geographic location (from central Europe, to South-Eastern Europe, to EMMENA region), their position in the EO value chain (from EO data providers, to science laboratories and research institutes, to SMEs and large industries) and their mandate (from Public Sector, to sectorial coordination organizations, to economic development banks, etc.).

- The ECoE will exploit the networks of which the EXCELSIOR partners are members to facilitate capacity building, knowledge transfer, research partnerships, etc.
- The Infrastructure Area will be responsible for the seamless use of the existing and future ECoE infrastructure, their proper operations and the available access to EO data by the ECoE staff and stakeholders.
- The Research Area will be responsible for the development of open-access science and research which will lead into the development of ECoE services.

- The Education Area will sustain the development and operation of the ECoE as a Regional Digital Innovation Hub. The specific activities of the Education area include the MSc & PhD-hosting programme, a Skills Development Centre and a Professional Training Programme.
- The Entrepreneurship Area will be responsible for ensuring the sustainability of the ECoE and stimulating national and regional growth, through the exploitation of the IPR, licensing of innovation and market uptake of new EO-based products, services and solutions generated by the ECoE and the Strategic Partners.

The sustainability of the ERATOSTHENES Centre of Excellence is based on the business model developed through the H2020 the Excelsior project. This business model has the following characteristics:

1. The Customer segments include National and European Research programs, Government departments, European and national agencies, companies, professional organizations, academia and end-users.
2. Customer relationship will be based on agreements and contracts for the development and operations of specialized EO applications, geo-information services and professional capacity building and academic education. Relations with the scientific community, start-up companies and various stakeholders in the domain will be established through collaborative projects, workshops and symposia. The dissemination channels include a dedicated website, social media, events, brochures, trainings, workshops, seminars, research publications and conferences.

The ECoE will provide added value both in Cyprus, in the EMMENA region and in Europe by contributing to the Smart Specialization Strategy for Cyprus (S3Cy) and fostering user-driven research and innovation in environmental science, natural resource management and civil security in the region. This will be based on satellite EO, other sources of data and state-of-the-art IT technologies.

5. APPLICATION AREAS

The ECoE advocates that the Centre will be a European focal point for cutting edge Earth Observation research in five main application domains. These application domains that were identified through a market and gap analysis for the EMMENA region are shown in Figure 4:



Figure 4. Five application domains of the ECoE.

5.1 Climate change monitoring

Cyprus provides the opportunity to perform state-of-the-art studies to shed light into the basic processes of precipitation formation. European networks of atmospheric research (EU ACTRIS initiative) require an observational supersite in EMMENA. The GBS will allow for climate change monitoring as well as monitoring climate, including aerosols, clouds, dust and pollution in the EMMENA region using the relevant expertise from TROPOS. The GBS will connect the ECoE with major European infrastructures for remote sensing, such as ACTRIS, EARLINET, Cloudnet, E-PROFILE, etc. Finally, the supersite data will support ESA and NASA in ground truth (calibration/validation) efforts of active and passive remote sensing and support companies that manufacture atmospheric instrumentation to assist users for pre-

processing of satellite images. The ERC has also participated in the past in the use of monitoring land cover and land use changes using Landsat TM/ETM+ and Sentinel for urban planning issues and for the investigation of Urban Heat events in Cyprus [15].

5.2 Water resource management

The ERC has a significant experience in the use of Earth Observation for monitoring irrigation demand [16,17]. The ERC has considerable experience in water quality monitoring in inland waters such as dams using field spectroscopy and satellite remote sensing [18, 19] and water leakages identification using optical and SAR images [20]. Currently, the ERC is participating in the ESA PEGS funded SWSOIP project. The SWSOIP project aims to develop validated algorithms and workflows to estimate the evapotranspiration values for specific crop types. An additional goal of the project is to develop a smart watering system which will provide the accurate water quantity to the plants without any human intervention. The project will pay attention to utilize all the available Sentinel data to gain useful information which can be used to support the estimation of Evapotranspiration through the development of an automated and autonomous irrigation system. The overall system will be developed and tested for the case study area located in the agricultural area of Mandria, in Paphos District area, in Cyprus.

5.3 Disaster Reduction

The European Union seeks to incorporate Disaster Risk Reduction (DRR) into its development cooperation activities, since climate change is expected to increase the frequency of natural disasters. Disasters have devastating effects on the development of a country and can negatively impact the achievements of long-standing initiatives. Countries in the EMMENA region are particularly vulnerable to disasters, since their mechanisms for disaster preparedness and mitigation are at high risk regarding the impact of climate change. Disaster Risk Reduction will be exploited, by transferring relevant expertise from NOA's BEYOND Centre of Excellence for EO-based monitoring of natural disasters. The ERC has produced a National Risk Assessment (NRA) study followed by the development of a Strategy for DRR in 2019, both funded by the EU, and is currently working on the establishment and appointment of a coordinating agency with responsibility and function to facilitate the inter-agency and multi-stakeholder cooperation process related to DRR. Also, the ERC has worked on several projects with countries in the EMMENA region regarding DRR. In 2018, ERC members participated as external advisors for the drafting of the NRA of Greece, which was prepared and submitted to DG ECHO by KEMEA and the Greece Civil Protection Mechanism.

In 2017, the ERC participated in a project regarding the use of a Geospatial early-warning Decision Support System (DSS) to prepare for disasters or planning for multiple hazards [21]. This system was successfully developed and tested in 2018 [22]. The DSS applied a holistic, integrated and synergistic approach to establish priorities using existing data, models and systems. During the same period, the ERC participated in the project "Preparedness for Appropriate accommodation in Emergency Shelters - PACES" funded by DG ECHO [23] aiming to produce a risk management planning process for seismic risk assessment. In 2019, ERC was involved in the United Nations Development Programme (UNDP) to provide professional services concerning the evaluation of the third phase of "Strengthening DRR management capacities in Lebanon" (LBN/CO/RFP/163/18). The ERC assessed the level of progress of DRR in Lebanon identified the best practices from the implementation of Disaster Risk Reduction Management (DRRM) in Lebanon, provided future concrete and actionable recommendations as well as developing a comprehensive Theory of Change to be used for the new phase of DRR of Lebanon.

The BEYOND Centre of Excellence operated by NOA, participated among others in several flagship and operational projects in the Disaster Risk Reduction area using innovative data exploitation methods and space assets e.g., Copernicus EMS Risk and Recovery, EFFIS, LinkER, SAFER, etc., which exploited the infrastructure and research developed in the BEYOND Center of Excellence and developed the pillars of FireHUB, GeoHub, FloodHUB, DustHUB [24-29]. The wide network of stakeholders maintained by the GEO-CRADLE coordination and support action lead by partner NOA provides evidence-based indications on how current space assets and EO data exploitation platforms offer optimum contribution to user organizations involved in DRR and Disaster Risk Management (DRM) which helps assess the necessary developments in terms of space solutions which are required to fill gaps and raise the level of society resilience to natural disasters.

Being the most south-eastern member state of the European Union, Cyprus is an excellent location for siting of ground-based satellite receiving stations, since satellites in low Earth orbit (such as most Earth Observation satellites) can be tracked and their data accessed in near-real-time, while observing areas in most of the EMMEA states. In particular, the visibility cone from a station in Cyprus covers the Eastern Mediterranean, and also the Black Sea, Caspian Sea, Red Sea

and the Persian Gulf (Figure 5). This unique location would enable Earth Observation-based maritime surveillance in NRT (less than 20 minutes after sensing), if a Data Acquisition Station (DAS) were established and operated in Cyprus. Hence, one objective of ECoE is to establish and operate a multi-band satellite data acquisition station, able to receive most of the current and planned Earth Observation satellite data streams. The station should include all necessary baseband electronics and data processing systems. DLR has extensive experience in the definition, establishment and operations of data acquisition stations and is operating multiple stations at its locations in Neustrelitz, Germany; O'Higgins, Antarctica and Inuvik, Canada and is supporting the ECoE in establishing such a station in Cyprus. Besides allowing third parties to use this unique station location, the strategic purpose of a DAS is also to perform science and to offer NRT products and value-added services derived from the EO data acquired at the station.



Figure 5. The visibility cone from a station in Cyprus.

These products and services specifically apply for the monitoring of the coastal areas, oceans and seas in the wider EMMENA region. Synthetic Aperture Radar (SAR) satellite data (such as Sentinel-1) deliver data, which allows the derivation of met-ocean parameters (e.g., wind and sea state) as well as to detect contaminant (oil) spills and objects on the sea surface (e.g., vessels, oil-platforms, the later possibly only apply in the Caspian Sea). The challenge therein is to process the data quickly, to apply automated information extraction algorithms (incl. machine learning), and to merge this with other ancillary information, such as data from the ship borne AIS (Automated Identification System), to generate the required information and maritime awareness charts quickly. Besides civil security critical maritime awareness, data from lower resolution satellite sensors (e.g., MODIS) deliver important information for monitoring environmental phenomena such as wildfires, droughts, vegetation state and water quality. The ECoE, supported by DLR, will develop an information hub enabling research and international cooperation in these near-real-time critical information categories and service delivery needs in the EMMENA region.

5.4 Access to Energy

Access to Energy research and services are developed by combining EO data, with physical modelling and machine learning to focus on energy nowcasting, projections, and short-term forecasting, using the relevant expertise from NOA (EMMENA Solar Energy Observatory) [24]. This builds upon the innovative research and EO-based solution developed in the GEO-CRADLE project (Solar Energy Nowcasting System (SENSE; www.solea.gr) [25]. It produces state-of-the-art solar energy assessments based on the synergy of Neural Networks (NN), Radiative Transfer (RT) simulations, real-time satellite observations (cloud movements), and Copernicus Atmosphere Monitoring Service (CAMS)-based retrievals (aerosol forecast). As a result, SENSE is capable of producing high-resolution maps (1nm, 0.05 x 0.05 degrees, 15 min), databases and time series of spectrally integrated irradiances of the order of 105 pixels (that represents a 10 x 10 degree region) within one minute. The SENSE system unites the multifarious local and regional solar energy needs and sustainable development policies. With the use of input data from CAMS for aerosols impact and from Spinning Enhanced Visible and InfraRed Imager (SEVIRI) onboard the MSG satellites for clouds impact, (and in a future version data from S-2, S-3 and S-4 missions), the system provides state-of-the-art EO in real time and climatology services,

products and databases, and is proven able to stimulate the interest of relevant stakeholders and decision makers like Ministries of Electricity and Renewable Energies, Electric Power Transmission Operators and Solar Energy investors from the private sector, in the EMMENA.

5.5 Big EO Data Analytics

Big Data Analytics is a top trend in science by academics and services by practitioners [30] and is directly aligned with EO industrial, educational and research activities. There is a necessity to move from traditional data-centric approaches to an efficient way of lowering the barriers caused by data volume, increased computing demands, and related complication in data management [31-33]. Using Cloud processing systems, it is now possible to move algorithms and tools to data repositories, making large volumes of EO data available to a wide range of users. It enables them to handle and visualize data they are interested in without having to download them. Cloud-computing allows avoiding large-volume data transfer issues that can impede the efficient and effective use of EO data [33]. Currently, vast EO data holdings, from a multitude of international satellite platform sensors are collected and available, though some of them not easily accessible. Recent studies have highlighted that more than 500 EO instruments and sensors are currently available (see Figure 6).

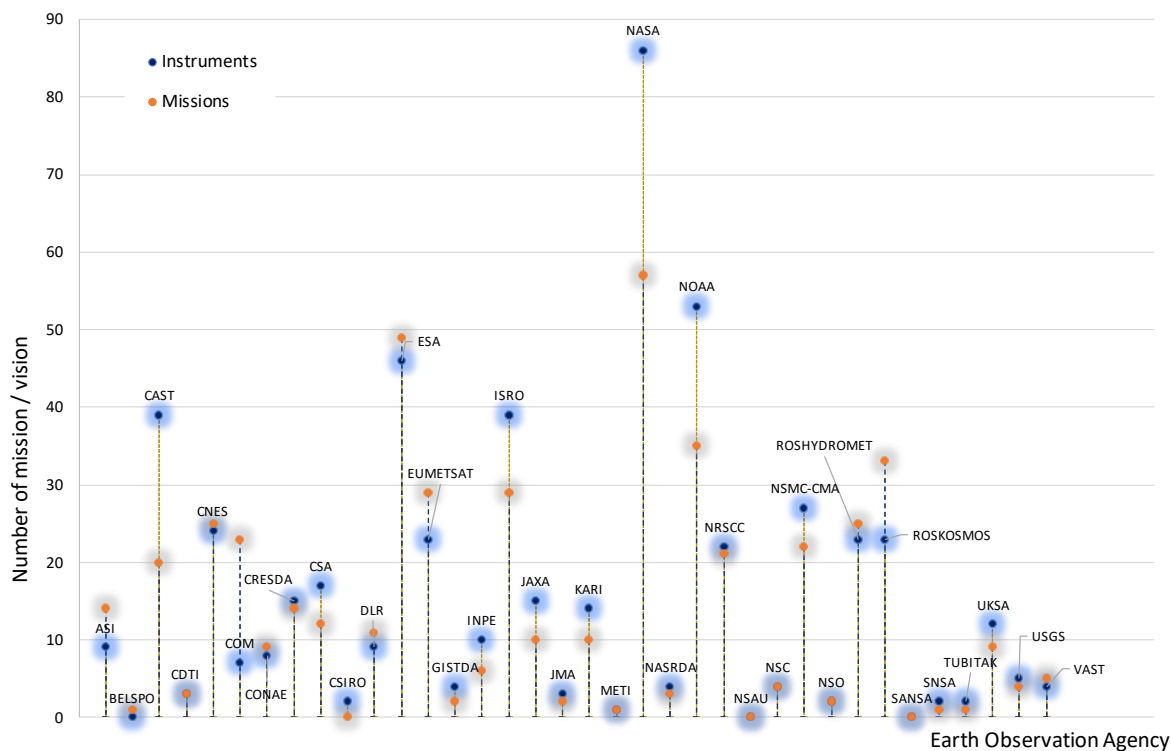


Figure 6. Earth Observation operated or approved missions and instruments per agency (data from CEOS Database) [28].

To bridge the gap between users’ expectations and current Big Data analytical capabilities, EO Data Cubes (EODC) have emerged as a new paradigm revolutionizing the way users can interact with EO data as well as providing a promising solution for the storage, organization, management, and analysis of Big EO data such as the Swiss Data Cube, the EarthServer, the E-sensing platform the Copernicus Data and Information Access Services (DIAS) or the Google Earth Engine [32]. Indeed, the above developments would not have been possible without Free and Open Data policies to facilitate access to data and Open Source code to efficiently develop software solutions [33].

In addition, new developments in EO sensors and the development of advanced image processing / modeling capabilities are fundamental changes that have occurred in recent years. Due to the variety of EO satellite sensors available from many space agencies, the CEOS has proposed a conceptual framework (virtual constellations) where these services could be shared for the benefit of the scientific community by providing harmonized data, filling observation gaps, and improving monitoring, etc. [34]. Such aspects will also be investigated during the life span of the ECOE project. Within

this context, actions for Big Earth Data management and analytics are foreseen for researching explorative algorithms to improve information retrieval from the petabytes of EO data. This effort will capitalize on the relevant science developed by NOAA and DLR partners and will build upon initiatives taken from the European Flagship Program Copernicus, as well as other initiatives developed by national and regional stakeholders. Moreover, the advancements provided by NOAA, will be fundamental for developing fully transferable and scalable EO-based solutions, and address the Big Data issues associated with large-scale environmental monitoring [35,36]. Exploiting HPC (High Performance Computing) and HPDA (High-Performance Data Analytics) distributed environments will enable the management and the processing of long time-series of Copernicus satellite data with advanced AI and ML techniques.

6. CONCLUSIONS

The establishment of the ECoE will provide new job opportunities and encourage future developments of EO products and services in Cyprus, the EMMENA region, and the European and global EO arena. The ECoE is expected to become a research and innovation hub as well as an investment attraction, since, according to the National Charter of European Research Area, it will contribute to the increased participation of the private sector in research and innovation activities and promote the creation of spinoff companies. The Open Innovation model in relation with the adoption of DIH is expected to facilitate collaborative activities with various stakeholders in order to enable progress in various aspects of EO research and development.

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