Chapter 20
Digital Earth in Europe

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Abstract In recent years, with the advancements in technology and research as well as changes in society, Digital Earth transformed. It evolved from its original concept of a 3D multilayer representation of our planet into a more practical system design to fulfil the demand for information sharing, which now embraces fields such as global climate change, food security and natural disaster prevention. In this novel scenario, Europe has become one of the major players at the global level; accordingly, the goal of this chapter is to provide a general overview of the major European contributions to the overall objectives of Digital Earth. These include the establishment of a European spatial data infrastructure through the Infrastructure for Spatial Information in Europe (INSPIRE) directive, the initiation of the Galileo and Copernicus programs that provide a wealth of big data from space, the launch of novel cloud-based platforms for data processing and integration and the emergence of citizen science. An outlook on major upcoming initiatives is also provided.

Keywords Information infrastructure · INSPIRE · Big data · Copernicus · Data access and information services - DIAS · Thematic exploitation platforms - TEPs · Citizen science · Digital europe · Horizon europe

20.1 Introduction

The original idea of Digital Earth (DE) first introduced by US Vice President Al Gore in 1998 envisioned a 3D multiresolution representation of our planet embedded with a variety of geo-referenced data to be transformed into understandable information (Gore 1999). Two decades ago, the major challenges in achieving such a vision were related to developing effective solutions for properly displaying, organizing and harmonizing data in space and time, as well as efficiently linking them to each other. Progress was necessary in the frameworks of Earth observation (EO), computational science, mass storage capacity and network speed, along with the definition of adequate metadata standards. At that time, the DE goal seemed difficult to achieve, if

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not impossible, but remarkable developments in data collection, hardware and software have led to several online web-mapping services (e.g., Google Maps, Microsoft Bing Maps) and desktop virtual globes (e.g., Google Earth, NASA's World Wind) that implement many of the features described by Gore in his speech just 10 years later, making DE real and accessible to millions of users (Annoni et al. 2011; Craglia et al. 2012). In this framework, the leading part was played by the United States, with key contributions from both the public and private sectors. However, with the advent of big data from space, the emergence of volunteered geographic information—VGI (e.g., citizen science, crowd-sourcing), the advancements in technology and research, as well as changes in society, the concept of DE also transformed (Goodchild et al. 2012). DE evolved into a more practical system design to fulfil the demand for information sharing and overcome the socioeconomic inequality in accessing and using the data (i.e., the digital divide) (Guo et al. 2016). Moreover, DE expanded its role in other fields related to global climate change, urban planning and management, agriculture and food security, and natural disaster prevention and response. This new vision will only become reality with effective integration of technologies from EO, global positioning and geo-information systems, sensor webs, virtual reality, and grid computing, as well as with proper gathering, harmonizing and sharing of data (also directly collected by nonexperts) through suitable information infrastructures. In this new paradigm, the role of Europe has gradually become more prominent, placing it at the forefront of DE implementation.

Notably, both research and commercial activities falling within the DE concept have been undertaken in the past 20 years at the single-country level in Europe; nevertheless, it is beyond the scope of this chapter to describe all these specific initiatives. Rather, our purpose is to provide a general overview of the major contributions to the overall objectives of DE from Europe as a whole. In this context, the first political initiatives embedding the DE concept date back to 2010 as part of the Europe 2020 strategy proposed by the European Commission (EC) (EC 2010), i.e., the executive branch of the European Union (EU), which, to date, is composed of 28 Member States. Europe 2020 aims to advance the economy in the EU, with a major focus on research and innovation. Among its 7 flagship initiatives, one has been specifically dedicated to the "Digital Agenda" (Annoni et al. 2011). In particular, this aims to improve the exploitation of information and communication technologies (ICTs) to foster innovation and develop a digital single market for generating smart, sustainable and inclusive growth in Europe.

In parallel, key European developments have provided major contributions to DE in the framework of information infrastructure, big data from space, geo-positioning and citizen science.

Effective data sharing is at the heart of DE and requires suitable and efficient dedicated information infrastructure, i.e., a framework of policies, standards and technologies that allow for finding, accessing, sharing and publishing information. The EC launched the spatial data infrastructure (SDI) initiative in 2001, which marked the beginning of SDI development in Europe. A few years later, this was followed by the "Infrastructure for Spatial Information in Europe" (INSPIRE) directive in 2007, a legal framework that requires EU Member States to share and properly document harmonized spatial and environmental data as well as establish a dedicated technical infrastructure. In particular, INSPIRE has become a model in the world; indeed, with respect to other SDIs solely supporting information discovery and access, it also addresses data harmonization, which allows them to be used seamlessly across national borders (EC 2018a).

Big data from space bring new opportunities in Earth Science and, in turn, to DE. These refer to the massive spatiotemporal Earth and space observation data collected by a variety of sensors ranging from ground-based to space-borne (EO satellites, navigation systems) and the synergetic use of data from other sources and communities (ESA 2019a). The first major European activity was the Envisat satellite mission started in 2002 and operated until 2012 by the European Space Agency (ESA) (ESA 2001). Envisat was the biggest and most complex satellite ever built and carried 9 EO instruments onboard, including imaging, atmospheric and temperature sensors (ESA 2019b). The mission (with an overall cost of ~2.3 billion euros) was the basis for the establishment of GMES, the Global Monitoring for Environment and Security initiative headed by the EC in partnership with ESA and the European Environment Agency (EEA). In particular, it first aimed to develop operational information services on a global scale using both space- and ground-based monitoring systems to support environment and security policy needs. GMES, officially endorsed in 2001, evolved over the next decade and, after the EU became directly involved in its financing and development, transformed into Copernicus in 2012. Specifically, Copernicus is the current EU's EO and monitoring program, which builds on existing national and European capacities; it includes both space and ground-based components and provides users with advanced data services (Copernicus 2019).

Concurrently, Europe has also been massively investing in the development and implementation of Galileo, its own civilian global navigation satellite system (GNSS). Galileo, whose conceptualization goes back to 1994, received major economic support from 2002 onwards. Two test satellites were successfully launched in 2005 and 2008, and the first satellite of the final constellation went into orbit in 2016. As of July 2018, 26 of the 30 planned active satellites have been launched and the system is expected to be completed by 2021. With respect to other existing GNSS, Galileo will provide higher precision positioning as well as a series of unique features aimed at improving people's security and safety in many fields.

Citizen science describes the nonprofessional involvement of citizens in a scientific process (Irwin (1995) and Bonney (1996)). Citizens can participate as observers or funders, by analyzing data or by providing data; moreover, they freely choose their degree of involvement based on personal interests, time or resources. After publishing a dedicated report in 2013 (Science Communication Unit; University of the West of England 2013), the EC officially began promoting and supporting citizen science due to its potential benefits for European researchers and society at large (EC 2017a). Since then, many projects have been funded that complement hundreds of dedicated citizen science activities in the different Member States.

In the following, major European contributions to DE are presented in detail. Section 20.2 is dedicated to an analysis of the information infrastructure in Europe, and Sect. 20.3 presents the many developments in the context of big data from space (including Copernicus and Galileo) and its exploitation. Section 20.4 provides an overview of the most relevant European citizen science projects; Sect. 20.5 introduces the two upcoming major programs supporting future digital innovation, Digital Europe and Horizon Europe. Finally, a brief conclusion is given in Sect. 20.6.

20.2 Information Infrastructure

A major element of the Europe 2020 Strategy—which set the objectives for smart, sustainable and inclusive growth of the EU by 2020—is the Digital Agenda. One of the seven pillars sustaining it is dedicated to the enhancement of interoperability and standards related to devices, applications, data repositories, services and networks (EC 2010). Therefore, efficient exploitation of spatial data infrastructures (SDIs) in combination with open data initiatives and portals have become a key component of Europe's efforts to assure more informed decision making as a basis for successful policy implementation.

The initial concepts related to the systematic realization—and later harmonization and linking—of SDIs emerged approximately two decades ago at the national level when governments began to initiate dedicated frameworks for enhanced utilization and sharing of data and information for applications in the public sector. These national spatial data infrastructures (NSDIs) primarily included technologies, standards, organizational and institutional structures, and Directives. The targeted applications were mostly aimed at sectors such as good governance, smart growth, or sustainable development (Nebert 2004). The NSDIs usually provide an institutionally sanctioned, automated means for remote search, access, use, and sharing of geospatial information by various providers and users (Pashova and Bandrova 2017). However, although the NDSIs in Europe often use similar technologies and standards, each country has many distinctive characteristics that result from specific national traditions, cultures and socioeconomic models.

To foster harmonization of the various national SDI developments at the European level, the EC started the first transnational SDI initiative in 2001 (EC 1995), which was succeeded in 2007 by the "Infrastructure for Spatial Information in Europe" (INSPIRE) directive (EC 2007, 2008). INSPIRE represents a legal framework implemented in a phased manner that defines a set of organizational rules and agreements for the establishment of an infrastructure for spatial information in the EU by the end of 2021. At the political level, the Directorate General Environment (DG Environment) is in charge of the overall coordination efforts, the Joint Research Centre (JRC) is responsible for the technical review, and EEA and Eurostat (the European Statistical Office) facilitate application and use case support.

According to the INSPIRE regulations, each Member State has to apply a minimum standard for open access to interoperable harmonized spatial and environmental data, along with related infrastructures, metadata and network services, which shall be completed with detailed documentation and reporting, as well as the establishment of a dedicated national coordination institution (EC 2018a). It is important to note that INSPIRE represents a transversal innovation that capitalizes on the manifold national and subnational SDIs that were already established and operated in the Member States across Europe. Hence, instead of creating any new centralized entity and data, INSPIRE focuses on making geoinformation seamlessly and easily searchable, accessible and interoperable across national borders through the harmonization and unification of standards, metadata and tools (EC 2015). A comprehensive overview of the INSPIRE initiative and contents is provided on the corresponding geoportal (http://inspire.ec.europa.eu/).

From the thematic point of view, INSPIRE covers 34 themes organized in three different annexes. These cover data and information related to the cadaster, land use and land cover, geology and soils, hydrology, agriculture, meteorology, transport and infrastructure, population, and environmental risks. In this context, one challenging factor is the requirement that all the data defined in the 34 themes of the three annexes can be utilized coherently and independently from the intended application. The key functionalities to fulfill this requirement and share the INSPIRE data and metadata are realized in the form of web-based services (Network Services) employing a service-oriented architecture (SOA) approach based on well-established standards such the Open Geospatial Consortium (OGC) (Döllner et al. 2019). Among others, the services include the catalogue service for web (CSW), web map service (WMS), web map tile service (WMTS), web feature service (WFS), web coverage service (WCS) and sensor observation service (SOS).

To control and evaluate the progress and extent of the INSPIRE implementation in the individual Member States, the directive provides two indicator-based mechanisms (Pashova and Bandrova 2017). Every three years, written reports must be submitted that address aspects such as coordination and organization structures, infrastructure management, monitoring of infrastructure and data use, data-sharing models and agreements, allocated budgets and arising costs, and gains and benefits at national and subnational levels. In addition, a dedicated set of performance indicators must be collected by the Member States on a yearly basis, describing the newly developed geo-information layers with all relevant metadata and related services. This reporting is administered by the INSPIRE committee, which is composed of representatives of all Member States, and the respective national contact points. According to the implementation plan, the Member States were obliged to transpose the directive into their national legislation by May 2009. Next, they had to provide their relevant national data collections "as-is" with the corresponding metadata through network services by December 2013, and all data listed in Annex I had to be accessible and interoperable by the end of 2017 (Döllner et al. 2019). Finally, the data covered by annexes II and III must be in place by end of 2021. In parallel to the Member State activities, stakeholder communities have been involved from the start of INSPIRE to actively help shape its implementation and critically review all technical developments.

The mid-term evaluation report published by the EEA in 2014 (EEA 2014) assessed an adequate progress of the implementation efforts and recommended some optimizations and improvements to close pending implementation gaps (often due to ineffective coordination at multiple levels) and foster exploitation of the profits through intensified integration of the private sector. Several alternative approaches were also applied to assess the progress in the development of SDI/NSDIs based on various political, institutional, organizational, conceptual, technical, and legal criteria (Pashova and Bandrova 2017). As a result, one of the outcomes was that Austria, Germany, Finland, France, Italy, the Netherlands, Poland, Portugal, and the UK are among the leading countries in SDI implementation.

Concerning the current challenges related to INSPIRE, the EU countries encountered many obstacles and shortcomings since the directive was put into effect almost 20 years ago. First, INSPIRE had to be initiated and established under complex conditions. Hundreds of national experts had to develop the technical specifications and standards for each specific thematic sector (including common and legally binding implementation rules), which had to be translated into more than 24 languages. Moreover, the various Member States showed a rather heterogeneous level of awareness and readiness in complying with the INSPIRE timelines, technical specifications and related recommendations. This effect was further amplified by the possibility given to each Member State to decide the most suitable strategy for implementing the INSPIRE framework based on specific individual needs. Consequently, the success of European-wide SDI realization strongly depends on the initiative, strategy and coherence of NSDI implementation at the national level.

However, the INSPIRE directive generally ensures that national and local governments provide high-quality and ready-to-use data and geoinformation to citizens, science and business across boundaries to support European environmental policies as well as initiatives such as e-Government and the EU interoperability framework. The INSPIRE datasets serve the European Water Framework Directive, the Habitats Directive, and the Clean Air Policy Package (EC 2015). INSPIRE makes quite valuable and direct contributions to the implementation of effective policies across Europe. The individual Member States also benefit from INSPIRE (Pashova and Bandrova 2017) due to the significantly enhanced access to geospatial information and the accelerated harmonization of their federal and municipal data inventories, improving the functionality and efficiency of public administration at all levels. This increased the effectiveness of several services that rely on geospatial data (e.g., disaster prevention and response, environmental impact analysis, risk assessment). In addition, the entry into force of INSPIRE could mitigate the drawbacks due to widespread national practices (and related business models) of selling geospatial data and incomplete and inconsistent policy frameworks.

As a means for offering easier access to spatial data in the EU, the Commission launched the new INSPIRE Geoportal on 18 September 2018 (http://inspire-geoportal.ec.europa.eu/). The redesigned portal is meant to become a "one-stop shop" for public authorities, businesses and citizens for discovering, accessing and using geospatial datasets relevant for specific application areas, particularly European environmental policy (EC 2018b). Moreover, the new Geoportal provides overviews of the availability of INSPIRE datasets by country and thematic area based on the metadata regularly harvested from the national data catalogs of different Member States. The Geoportal also allows for direct access to the so-called "priority datasets" (that were jointly selected by the Commission and the EEA) related to environmental reporting obligations in 6 different domains, "air and noise", "industry", "waste", “nature and biodiversity”, “water” and “marine”. The priority dataset list is a living inventory of environmental information needs and provides an instrument for i) monitoring progress on INSPIRE implementation; ii) incrementally building comparable INSPIRE maturity across Member States based on common settings; iii) planning tangible and usable INSPIRE deliverables for eReporting; and iv) promoting the reuse of the INSPIRE infrastructure for reporting purposes.

Of particular interest to the INSPIRE community are the novel funding opportunities offered to Member States by the Connecting European Facilities (CEF) instrument (EC 2018c); as an example, the recent 2018 CEF Telecom Public Open Data call (with an overall budget of approximately €18.5 million) key objectives include the generation of cross-border services providing access to harmonized thematic open datasets and the corresponding metadata.

For a comprehensive review of past and recent INSPIRE activities, the reader is referred to Cetl et al. (2019).

20.3 Big Data from Space

Given the key role of big data (including big data from space), in June 2015 the EC established the new “Space data for Societal Challenges and Growth” unit within the Directorate-General “Internal Market, Industry, Entrepreneurship and SMEs” (DG GROW). The unit is dedicated to implementing activities supporting the uptake of big data as a key economic asset to stimulate competitiveness and foster the growth of the European economy and employment (BDVA 2017). During the same period, its private counterpart was also established, namely, the Big Data Value Association (BDVA). The BDVA is an industry-driven international not-for-profit organization (counting 200 members all over Europe from large, small, and medium-sized industries and research and user organizations) that aims to develop the innovation ecosystem that will enable data and artificial-intelligence-driven digital transformation in Europe to deliver maximum economic and societal benefit. The importance of big data from space for the EC is further emphasized by the many dedicated calls for proposals included in the different Framework Programs for Research and Technological Development. Within Horizon 2020 (H2020—the current Framework Program), EO activities are recognized as a key element to accompany the remarkable EU investments in Copernicus (i.e., the European EO and monitoring program) and Galileo (i.e., the EU’s civilian global navigation satellite system—GNSS) (BDVA 2017). Since 2014, H2020 has funded two work programs (i.e., 2014–2015 and 2016–2017) and is now running the third for 2018–2020. The “Leadership in Enabling and Industrial Technologies” actions for Space (LEIT-Space) comprise specific calls dedicated to EO that target the evolution of Copernicus as well as the exploitation of existing European space infrastructure for the development of novel products and services based on remote sensing, geo-positioning and other types of satellite-enabled data. Other H2020 focus areas also support the uptake of big data from space and related technologies. These are of particular interest in the Societal Challenge framework in support of the “Climate action, environment, resource efficiency and raw materials” challenge, where one of the key actions is dedicated to strengthening the benefits for Europe of the Global Earth Observation System of Systems (GEOSS) (BDVA 2017). In addition to these calls, other European intergovernmental organizations strongly foster the exploitation of big data from space, among which ESA has a leading position.

In the following, the most relevant initiatives with a prominent role of big data from space in Europe are introduced. An overview of Copernicus is provided, including details on its three main components and the newly established data access and information services (DIAS). Next, the EuroGEOSS initiative is presented, followed by a description of ESA’s Thematic Exploitation Platforms (TEPs) and a brief review of Galileo and its major benefits.

20.3.1 Copernicus

The Copernicus program is a cornerstone of the EU’s efforts to monitor the Earth and its diverse ecosystems, and ensure that European citizens are prepared and protected in the face of natural or man-made disasters (EC 2016a). Copernicus is Europe’s eyes on Earth and a symbol of European strategic cooperation in space research and industrial development. It was established in 2012, building on the previous Global Monitoring for Environment and Security (GMES) program, and is coordinated and managed by the EC in partnership with ESA, the EU Member States and EU Agencies (Copernicus 2019). Copernicus aims to achieve a global, continuous, autonomous, high-quality, wide-range EO capacity by bringing together data collected in space, on the ground, in the sea and in the air to produce timely, reliable and easily accessible information. Moreover, it grants easy, autonomous and independent access to such information to support service providers, public authorities and other international organizations in improving the quality of life for European citizens. The program also drives economic growth, as it acts as a data source for several applications and services; recent estimates of the EC predict that its cumulative economic value will be on the order of 13.5 billion euros in 2008–2020 (EC 2016a). One of the major benefits of Copernicus relies on the policy for its data and products, which are released to all users and the public in general on a full, open and free-of-charge basis (EC 2014) (subject to appropriate conditions and limitations in specific cases), allowing for the development of several downstream services.

Copernicus comprises three different components: *Space*, In Situ and *Core Services*.

- The *Space* component includes the 5 families of dedicated Sentinel satellites as well as existing national and international missions (both commercial and public), known as the Copernicus Contributing Missions. The development of the *Space* component, including the launch and operation of the Sentinels and management of the ground segment, was delegated to ESA. The European Organization for the

Exploitation of Meteorological Satellites (EUMETSAT) coordinates the provision of space data and operational support for the climate change, marine environment and atmosphere monitoring services;

- The Copernicus In Situ component is responsible for gathering environmental measurements collected by data providers external to Copernicus, including ground-based, sea-borne or air-borne monitoring systems, as well as geospatial reference or ancillary data, collectively referred to as “in situ” data. It also identifies data access gaps or bottlenecks, supports the provision of cross-cutting data and manages partnerships with data providers to improve access and use conditions;
- The Copernicus *Core Services* produce value-added products available to the public that are generated based on the space and in situ data from the other two components. Products include six specific services: land monitoring, marine environment monitoring, atmosphere monitoring, emergency management, security, and climate change.

In the following, each component is presented in detail.

20.3.1.1 Space Component

The success of Copernicus is possible due to a well-engineered *Space* component for the provision of EO data to feed into a range of services to monitor the environment and support civil security activities. With more than 30 years of experience implementing missions to monitor Earth from space, ESA is responsible for developing and managing this core component of the program. The *Space* component includes ESA’s families of dedicated Sentinel satellites and missions from other space agencies, referred to as contributing missions. A unified ground segment through which the data are streamed and made freely available for the *Copernicus Services* completes the *Space* component. ESA is establishing a mechanism to integrate, harmonize and coordinate access to all the relevant data from the multitude of different satellite missions (ESA 2019c). This is being carried out in close cooperation with national space agencies, EUMETSAT and, where relevant, owners of non-European missions contributing to the Copernicus objectives.

The Sentinels carry a range of technologies such as radar and multispectral imaging instruments for land, ocean and atmospheric monitoring (ESA 2019c).

- Sentinel-1 provides all-weather, day and night radar imagery for land and ocean services. The twin satellites Sentinel-1A and Sentinel-1B were launched on 3rd April 2014 and 25th April 2016, respectively, and the mission currently delivers high-resolution data globally every 6 to 12 days at a rate of 2.5 TB per day. In January 2019, more than 3.5 million products were available for download, with a total volume of more than 5.5 PB of data;
- Sentinel-2 provides high-resolution optical imagery for land services. The twin satellites Sentinel-2A and Sentinel-2B were launched on 22nd June 2015 and 7th March 2017, respectively. After March 2018, the mission has a revisit frequency

of 5 days worldwide. In January 2019, approximately 8 million products were available for download, with a total volume of more than 4.2 PB of data;
- Sentinel-3 provides high-accuracy optical, radar and altimetry data for marine and land services. The twin satellites Sentinel-3A and Sentinel-3B were launched on 16th February 2016 and 25th April 2018, respectively. The mission will reach a revisit time shorter than 2 days globally with an expected rate of 0.3 TB of data per day;
- Sentinel-4 and Sentinel-5 (whose launches are planned for 2021 and 2020, respectively) will provide data for atmospheric composition monitoring from geostationary and polar orbits, respectively;
- Sentinel-5 Precursor was launched on 13th October 2017 and bridges the gap between Envisat (which delivered data from 2002 to 2012) and Sentinel-5; and
- Sentinel-6 (whose launch is planned for 2020) will provide radar altimetry data to measure global sea-surface height, primarily for operational oceanography and climate studies.

The contributing missions include 30 past, existing and planned missions from ESA, the Member States, EUMETSAT and other European and international third-party mission operators that share part of their data with Copernicus (ESA 2019c). They are grouped in 5 different categories:

- Synthetic aperture radar (SAR) sensors, for all weather day/night observations of land, ocean and ice surfaces (e.g., TerraSAR-X, TanDEM-X, RADARSAT-2, ALOS/PALSAR, Kompsat-5);
- Very high resolution (VHR) optical sensors for targeting specific sites, mostly in urban areas and for security applications (e.g., WorldView-1/2/3/4, Kompsat-2/3, DEIMOS-2, SPOT-5/6/7);
- High-resolution and medium-resolution optical sensors for supporting regional/national land monitoring activities (e.g., Landsat-5/7/8, Proba, DEIMOS-1);
- Medium-low-resolution optical sensors for gathering information on land cover as well as for monitoring oceans, coastal dynamics and ecosystems (e.g., Proba-V, Oceansat-2);
- High-accuracy radar altimeter systems for sea level measurements and climate applications (e.g., Envisat RA-2);
- Radiometers to monitor land and ocean temperature (e.g., ODIN); and
- Spectrometer measurements for air quality and atmospheric composition monitoring (e.g., GOSAT).

Notably, the free and open access policy of Copernicus has triggered unprecedented opportunities for both academia and industry. The main challenges are the growing volume of data from the *Space* component and its heterogeneity (in terms of formats, semantics, measurements, resolutions, and modalities) due to the diversity of sensors employed. Accordingly, volume, variety, velocity and veracity apply to this type of datasets, which cannot be handled by traditional databases and processing methodologies; rather, they require advanced preprocessing, data harmonization, analytics, and uncertainty propagation analyses and the deployment of suitable knowledge models (BDVA 2017).

20.3.1.2 In Situ Component

The Copernicus In Situ component comprises a number of environmental local measurements collected from ground-based, sea-borne or air-borne monitoring systems. These are used to calibrate, assess and supplement the information provided by satellites, which is essential to deliver consistent and reliable data over time (EC 2015). The In Situ component includes data collected from sensors mounted onboard airplanes or weather balloons, positioned on riverbanks or high towers, drifting in the ocean on buoys or pulled through the sea by ships. Background topographic information (e.g., digital elevation models, administrative boundaries, transportation network maps) also falls under the In Situ umbrella, along with information collected by citizen scientists or volunteer contributors (e.g., OpenStreetMap) as well as data gathered by unmanned aerial vehicles—UAVs (i.e., drones) (EC 2015).

The In Situ component mostly includes contributions from the Copernicus Member States, since a consistent part of the data and monitoring infrastructure is owned and operated by single national governments. However, it also benefits from international efforts to collect and share information, in many cases from international research infrastructures. To guarantee reliable and sustainable provision of data for its services, Copernicus has to effectively coordinate with a variety of providers, from local conservation groups to global meteorological bodies. The goal of the In Situ component is to comprehensively explore the complex and manifold landscape of local data, identify gaps by comparing requirements against available information, support the provision of cross-cutting data, and establish and manage partnerships with data providers to improve the conditions of access and use (EC 2015). Timely implementation of the INSPIRE directive is expected to improve access to local datasets and considerably facilitate data discovery and access operations. INSPIRE will also improve the timeliness and quality of the Copernicus services.

All Copernicus service operators are granted direct access to data from the In Situ component as an integrated part of their workflows and according to their day-to-day operational needs (provided that they set up and manage the technical interfaces themselves). Since December 2014, under a delegation agreement with the EC, EEA has been appointed coordinator of this component (EC 2015).

20.3.1.3 Core Services

The Copernicus *Core Services* provide standardized multipurpose information common to a broad range of application areas relevant to EU policies in six different domains, namely, ocean (CMEMS 2019), land (CLMS 2019) and atmosphere (CAMS 2019) monitoring, emergency response (CEMS 2019), security (Copernicus Security Service 2019), and climate change (C3S 2019). The effective use of big data (from the *Space* and In Situ components) and advanced data mining techniques are two key elements to their success. The development of the preoperational version of the services was undertaken a few years ago through a series of projects launched by the EC and partly funded through the EU's 7th Framework Program (FP7). These projects were: MyOcean (ocean), Geoland2 (land), MACC and its successor MACC II (atmosphere), SAFER (emergency response) and G-MOSAIC (security). Most of them also contributed to the monitoring of climate change. In each of the target thematic areas, the range of products developed in response to users' needs is growing, along with the number of users. In addition, projects designed to explore the scope for downstream services supporting specialized topics have been launched, widening the range of available products. These will directly support national, regional or local activities as well as niche European and global markets. Below, additional details are provided for each of the existing *Core Services*.

Copernicus Atmosphere Monitoring Service (CAMS): CAMS is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the EC. It has been fully operational since 2014 and provides businesses, policy makers and scientists with consistent and quality-controlled information on the atmosphere anywhere in the world; it also allows for assessing the past (based on the analysis of historical data records) and generating predictions for the next few days. The service monitors and forecasts parameters related to air pollution and health, solar energy, greenhouse gases and climate forcing. CAMS also compiles emissions inventories to support modeling and estimation of the CO_2 and CH_4 fluxes at the Earth's surface. The main application domains benefiting from use of this service include renewable energies, meteorology, climatology, environmental monitoring and health.

Copernicus Marine Environment Monitoring Service (CMEMS): CMEMS has been operational since 2015 and provides regular and systematic core reference information on the state of the physical oceans and regional seas. It delivers data and products that support major applications in the marine area such as maritime operations (e.g., search and rescue, transport and ship routing, marine safety), marine resources (e.g., fishery, aquaculture), coastal and marine environment (e.g., coastal erosion, sea temperature monitoring, water quality monitoring, pollution control). It also provides key information for weather, climate and seasonal forecasting (e.g., temperature, salinity, currents, wind, sea ice). By jointly exploiting satellite data and in situ observations, the service provides state-of-the-art analyses and forecasts on a daily basis, which offer an unprecedented capability to observe, understand and anticipate marine environment events.

Copernicus Land Monitoring Service (CLMS): CLMS has been operational since 2012 and comprises 4 main components: i) a *global* component providing a series of qualified biogeophysical global products on the status and evolution of the land surface (e.g., albedo, land surface temperature, top-of-canopy reflectance) at mid to low spatial resolution, which are used to monitor the vegetation, water cycle, energy budget and terrestrial cryosphere; ii) a *Pan-European* component aimed at generating land-use/land-cover maps (i.e., CORINE) and high-resolution layers (HRSLs) describing the 5 major land cover types, i.e., artificial surfaces, forest areas, agricultural areas (permanent grasslands), wetlands, and water bodies; iii) a *local* component providing specific and more detailed information that is complementary to the *Pan-European* component and is focused on identified hotspots (i.e., major EU city areas, riparian zones, grassland rich sites) prone to different environmental challenges; and

iv) an *imagery and reference data* component gathering satellite images and in situ data, forming the input for the creation of many information products and services (e.g., the Land Use and Coverage Area frame Survey—LUCAS database).

Copernicus Climate Change Service (C3S): C3S has been operational since 2018 and addresses the environmental and societal challenges related to the climate changes associated with human activities. C3S supports the adaptation and mitigation policies of the EU by providing consistent and authoritative information about the past, present and future climate, as well as tools to enable climate change mitigation and adaptation strategies by policy makers and businesses. The service complements the established range of meteorological and environmental services that each European country has in place and provides access to several climate indicators (e.g., temperature increase, sea level rise, ice sheet melting, ocean warming) and climate indices (e.g., based on records of temperature, precipitation, and drought events). C3S is implemented by ECMWF and relies on climate research carried out within the World Climate Research Program (WCRP) responding to user requirements defined by the Global Climate Observing System (GCOS).

Copernicus Emergency Management Service (EMS): EMS produces timely and reliable geo-spatial information derived from satellite and in situ data supporting the management of geophysical, meteorological and man-made hazards, as well as emergency situations and humanitarian crises. The service comprises 2 different components: i) an *on-demand mapping* component that provides maps for rapid emergency response as well as risk and recovery maps, bolstering the decision-making process in all the phases of the emergency cycle (i.e., preparedness, prevention, disaster risk reduction, emergency response and recovery); and ii) an *early warning* component including the European Forest Fire Information System—EFFIS (aimed at monitoring forest fires and forest fire regimes in the European, Middle Eastern and North African regions) and the European Flood Awareness System—EFAS (aimed at providing flood forecasts to support flood risk management).

Copernicus Security Service: This service tackles Europe's security challenges by providing key information to support crisis prevention, preparedness and response improvement in three application areas: (i) *border surveillance*—to increase the internal security of the European Union using near real-time data over land and sea, as well as fight cross-border crime and reduce the death toll of illegal immigrants at sea; (ii) *maritime surveillance*—to increase maritime security in the framework of navigation, fisheries control, marine pollution, and law enforcement by jointly exploiting Sentinel-1 and other sources of maritime information; and (iii) *support to EU External Action*—to assist third-world countries in crisis situations and prevent global and trans-regional threats with potential destabilizing effects using available geo-information for remote areas experiencing critical security issues.

20.3.2 Data Access and Information Services

To improve access to big data from space and maximize the benefit to different user communities (on an equal basis to all Member States and countries participating in the program), the EC recently funded the development of 5 competitive cloud-based platforms known as data and information access services (DIAS) (CREODIAS 2019; MUNDI 2019; ONDA 2019; SOBLOO 2019; WEKEO 2019). The DIAS allow for centralized access to Copernicus data and products and offer advanced computing resources and tools (open source and/or on a pay-per-use basis) for online processing and analysis (Copernicus 2019). This will create the possibility to easily build new applications and offer added-value services. Each platform also provides access to additional commercial satellite or nonspace datasets, and premium offers in terms of priority or support. By providing a single access point for all Copernicus data and information, the DIAS allow for users to develop and host their own applications in the cloud (ensuring protection of intellectual property rights), without the need to download bulky files from multiple access points and process them locally. This will enable simpler and more user friendly exploitation and data combination, and thus promote innovation. Furthermore, competition between the DIAS will ensure that the best service is delivered to the users and avoid customer lock-in on a specific platform among the 5 (Copernicus 2019). A DIAS functionally consists of 3 types of services:

- **Back office services** that provide access to Copernicus data and information (unlimited, free and complete), as well as to any other data offered by the DIAS provider, in a scalable computing environment where users can build and operate their own services;
- **Interface services** encompassing tools that facilitate users in the development of applications. This environment is developed and managed by the DIAS service providers (according to their specific business models) and offers scalable computing and storage resources to the users at competitive commercial conditions;
- **Front office services** that are provided by third parties (e.g., EU Projects, ESA, EUMETSAT, developers and companies) and are based on exploitation of the Copernicus data and products available through the back office services.

The success of DIAS strongly depends on the strong relationship between the different Copernicus actors as well as on the involvement of Member States and participating countries, information and communication technology (ICT), the EO industry and third parties interested in using Copernicus data and information. The support to and integration of the DIAS into the workflows of ESA and EUMETSAT is expected to further enrich the environment offered by the platforms. Moreover, the integration of DIAS and DIAS-based services into the European Open Science Cloud (EOSC) will make it possible to connect the EO domain to other fields of science at a European level, facilitating the transition from research to commercialization (BDVA 2017).

20.3.3 Thematic Exploitation Platforms

ESA is Europe's gateway to space and its main mission is to shape the development of Europe's space capability and ensure that investments in space continue to deliver benefits to the citizens of Europe and the world. For more than 20 years, EO satellites developed or operated by ESA have provided a wealth of data, which is increasing like never before, especially due to the Sentinel missions. This expanding operational capability of global monitoring from space and data from long-term EO archives, models and in situ networks allow for unprecedented insight into the interconnections of the Earth system between oceans, ice, land and atmosphere. However, while the amount of big data from space represents a key opportunity for academia and industry, it also poses major challenges to achieving comprehensive exploitation of the data. Several initiatives are currently supported by ESA through different programs, among which the development and implementation of the Thematic Exploitation Platforms (TEPs) started in 2014 has a prominent role (ESA 2019d). The TEPs supply a collaborative virtual work environment that provides—through one coherent interface—access to the following:

- relevant big data from space;
- computing resources and hosted processing;
- a platform environment that allows for users to integrate, test, run, and manage applications without the need to build and maintain their own infrastructure;
- standard platform services and functions including collaborative tools, data mining and visualization applications, development tools (e.g., Python, IDL), communication tools (e.g., social networks), as well as documentation, accounting and reporting tools; and
- repositories of advanced processing applications (including those developed by other users).

Moreover, the user community is present (and visible), directly involved in the governance of the platforms and enabled to share and collaborate (ESA 2019d).

Seven different TEPs have been developed, each addressing a specific area of environmental research, namely, geohazards (GEP 2019), forestry (F-TEP 2019), hydrology (H-TEP 2019), food security (Food Security TEP 2019), as well as costal (C-TEP 2019), polar (Polar TEP 2019) and urban areas (U-TEP 2019). In the following, additional details are provided for each TEP.

Geohazards TEP (GEP): The GEP aims to support the exploitation of satellite EO information for geohazards and is based on the Supersites Exploitation Platform (SSEP), originally initiated in the context of the Geohazard Supersites & Natural Laboratories (GSNL) initiative (SSEP 2016). The core user communities for the GEP are the groups of practitioners working on the Seismic Hazards Pilot (CEOS 2019a) and the Volcano Pilot (CEOS 2019b) of the Committee on Earth Observation Satellites (CEOS). The former is a three-year demonstration project intended to showcase the benefits of EO satellite data in the context of seismic hazard research, whose major goals are to (i) support the generation of globally self-consistent strain rate estimates and mapping of active faults at the global scale; (ii) support and continuation of the GSNL for seismic hazards and volcanoes; and (iii) develop and demonstrate advanced science products for rapid earthquake response. The main objectives of the Volcano Pilot through the GEP are to (i) demonstrate the feasibility of integrated, systematic and sustained monitoring of Holocene (i.e., the current geological epoch) volcanoes using space-based EO; (ii) demonstrate the applicability and improved timeliness of space-based EO products for reducing the impact and risk of eruptions; and (iii) build the capacity for exploiting EO data in volcanic observatories in Latin America to showcase global capacity development opportunities.

Coastal TEP (C-TEP): Sustainable coastal development requires accurate and easily accessible knowledge about the dynamic processes shaping coastal zones as well as suitable long-term analysis and automatic trend detection tools. The C-TEP provides a dedicated service for observation and monitoring of the coastal environment. The integration of satellite and near real time (NRT) EO data, in situ data and model predictions in the virtual platform provide an effective means to characterize and understand the many linked coastal processes across a wide range of space and time scales. Key applications include coastal bathymetry, coastal change monitoring, and early warning for pollution discharges, harmful algal blooms and storm surges.

Forestry TEP (F-TEP): The F-TEP vision is to be a one-stop shop for forestry remote sensing applications. The platform offers online processing services and tools (e.g., versatile satellite image analysis, GIS software) for generating value-added forest information products by means of simple and easy-to-use push-button functionalities. It also supports the generation of forest and land cover maps, change maps, and the estimation of continuous forest variables (e.g., growing stock volume). The F-TEP serves users with expertise in forestry rather than EO as well as remote sensing professionals and service providers. These include UN REDD (i.e., the United Nations program on Reducing Emissions from Deforestation and Forest Degradation) and other international programs, national forest inventories, universities and research centers, forest managers, land use planning and nature conservation agencies, as well as value-adding industry and sustainable development NGOs. The platform is closely coordinated with the Food and Agriculture Organization of the United Nations (FAO), the JRC and the Global Forest Observation Initiative (GFOI).

Hydrology TEP (Hydro-TEP): As water affects all societal and environmental domains, there is a major need for integrated, open water information services offering efficient access to cross-regional and multidisciplinary water information. This is even more critical in the developing world, where data are generally sparse. The Hydro-TEP aims to facilitate exploitation, processing and visualization of different types of data (EO, in situ, socioeconomic or meteorological) to better comprehend water-related challenges by combining a holistic understanding of the water cycle with evidence-based governance and increased public awareness. The main services supported by the platform are water quality monitoring, floods and drought risk, climate change forecasts and hydropower and aquaculture assessment. Current users of the Hydro-TEP comprise water authorities, regional mandated authorities, river basin organizations, and universities and research centers.

Polar TEP: The polar regions are remote and hostile environments where collecting data is strongly hindered by the extreme weather conditions, lack of infrastructure and long periods of darkness during the winters. As a consequence, satellites are the only source of consistent, repeatable, year-round and wide-area coverage information. Polar TEP enables users to access and exploit this information to support their operations and science as efficiently as possible. The main current applications include iceberg risk assessment, derivation of ice sheet and ice stream surface velocities, and ice concentration and thickness estimation. An initial pilot project was carried out to demonstrate the potential of the platform to investigate the current and future iceberg risk in Baffin Bay. Different datasets, processors and models have been deployed and integrated to allow for investigating linkages between iceberg populations, observed and modeled changes in ice sheet movement and calving rates, ocean circulation and iceberg trajectories. Current user communities of the Polar TEP include scientific researchers, industry, local indigenous populations, and regional and national governments.

Urban TEP (U-TEP): From the beginning of the 2000s, more than half of the global human population is living in urban environments, and the dynamic trend of urbanization is growing at an unprecedented speed. The U-TEP aims to open up new opportunities to facilitate effective and efficient urban management and safeguard livable cities by systematically exploring the unique EO capabilities in Europe in combination with the big data perspective arising from the constantly growing sources of geo-data. The platform is envisaged to initiate a step change in the use of EO data and geospatial analytics by enabling any interested user to easily exploit and generate thematic information on the status and development of the built environment based on multisource data collections (e.g., EO imagery, statistics, surveying, and volunteered geographic information). The capabilities of participation and sharing of knowledge by using new media and ways of communication will help boost interdisciplinary applications with an urban background. The U-TEP provides a unique portfolio of thematic products and services and, by the end of 2018, was successfully used to process more than 3 PB of EO data and activate a community of more than 300 institutions from all around the world (including the UN, the World Bank, the Organization for Economic Co-operation and Development—OECD, the World Food Program and the Bill and Melinda Gates Foundation).

Food Security TEP: The challenge of increasing the food supply to feed a growing global population makes the sustainability of agriculture and aquaculture as critical as ensuring food security. Food production systems need to optimize the use of water, energy and fertilizers, reduce pollution and soil degradation, and maximizing high-quality agricultural yields and fish harvest under increasingly unstable environmental conditions. To support future sustainable and efficient farming and aquaculture, the Food Security TEP (i) offers direct access to key satellite products and derived data; (ii) allows for on-the-fly computation, visualization and manipulation of basic key indices; and (iii) provides high-accuracy, quality-checked biophysical parameters that are suitable for use in operational scenarios. The Food Security TEP builds on a large and heterogeneous user community that includes small-scale farmers and agricultural industry, public science and the finance and insurance sectors, local and national administrations and international agencies. A forum of experts from this community (i.e., the Partnership for Growth and Sustainability) supported ESA in defining the project requirements, and enables the team to continually develop the platform in accordance with their needs.

20.3.4 EuroGEOSS

The Group on Earth Observations (GEO) is a partnership of more than 100 national governments, 100 participating organizations and the EC. It envisions a future where decisions and measures for the benefit of humankind are informed by coordinated, comprehensive and sustained EO. A central part of the GEO's Mission is to build GEOSS, i.e., a set of coordinated, independent EO information and processing systems that interact and provide access to diverse information for a broad range of users in the private and public sectors (GEO 2019). EuroGEOSS is the European component of GEOSS and complements the other three ongoing GEO initiatives, namely, AfriGEOSS in Africa (initiated in 2013), AmeriGEOSS in the Americas (initiated in 2014), and AOGEOSS in Asia and Oceania (initiated in 2015). EuroGEOSS will be a gateway for European EO programs and projects to GEOSS, with Copernicus as a major element (GEO 2019). Its added value will comprise the following (EC 2017b):

- the user-driven systematic coordination, integration and scaling up of existing services (based on a wide range of data sources) to address sustainable development goals—SDGs, GEO societal benefit areas—SBA (e.g., biodiversity and ecosystem sustainability, food security and sustainable agriculture, sustainable urban development, energy and mineral resources management) and other GEO priorities in the European context;
- the leveraging of global datasets through the GEOSS common infrastructure (GCI) and their exploitation within a European context; and
- additional support to Copernicus to address new communities within GEO and act as an incubator for possible new Copernicus services and applications supporting European priorities.

It is not the objective of EuroGEOSS to establish new data platforms in Europe. Rather, it builds on the GCI and DIAS to take advantage of multiple, existing or upcoming capacities in Europe, including the INSPIRE database, the Copernicus *Space* component, Copernicus *Core Services* products, output products from services offered by the TEPs, citizen observations, and additional data/products from agencies and organizations (e.g., ESA, EUMETSAT, ECMWF) (EC 2017b).

The exploitation of EO data and products, including Copernicus, and the subsequent market creation will be boosted by global cooperation approaches regarding data collection, processing and codesign of information products within the GEOSS context. A more coherent European action towards GEO would complement existing national and supra-national strategies, leverage EO European investments including those from the commercial sector and reduce fragmentation within Europe.

The initial phase of EuroGEOSS was supported through H2020. The EuroGEOSS roadmap 2017–2019 foresaw an initial phase to establish EuroGEOSS during the fourth quarter of 2017, a consolidation phase to start addressing EuroGEOSS pilot applications in 2018 and a third phase in 2019 to showcase the EuroGEOSS added value (EC 2017b).

At the heart of the EuroGEOSS is the ambition to foster the European user dimension in the process of scaling up existing multidisciplinary pilot applications. Emphasis is placed on the "last mile" of the innovation process, enabling preoperational services that could extend/reinforce other GEO initiatives and flagships. For this purpose, reviews of European user needs will be conducted on a regular basis to consider all possible European user communities involved in ongoing GEO tasks as well as other communities in Europe identified by EuroGEOSS members (EC 2017b). The initiative will take full advantage of the many user platforms and consultation processes that are conducted at continental, national and local levels by the members of the European GEO Caucus. EuroGEOSS will aggregate user demand at regional levels from both GEO-aware and GEO-unaware European users. This process will ensure pilot applications driven by structured, consolidated user needs of regional significance.

20.3.5 Galileo

The original idea for Galileo—Europe's own global navigation satellite system (GNSS)—dates back several decades. Galileo was agreed upon in 1994 and, after many delays and setbacks, became available in December 2016 and is foreseen to reach full operational capability by 2021 (Reillon 2017). The system is operated by the European GNSS Agency (GSA) and ESA, with the program oversight by the EC and the political oversight by the European Council and the European Parliament.

Galileo allows for users to determine their location and the location of other people or objects at any given moment, and the ability to determine their velocity and the current system time. It is interoperable with GPS and GLONASS, (i.e., the US and Russian GNSS, respectively), and by relying on a large constellation of satellites and exploiting multiple frequencies, it will provide better service to the users, with real-time positioning accuracy in the meter range (Hecker et al. 2018c). At full deployment, Galileo will comprise 30 satellites (24 operational, plus 6 in-orbit spares) 26 of which have been launched as of July 2018. This large number, together with the optimized constellation design and the availability of three active spare satellites per orbital plane, ensure that the loss of one should not have a discernible effect on the users. Moreover, contrary to all other GNSS, Galileo will provide good coverage even at latitudes higher than 75°N (i.e., corresponding to the most northerly tip of Europe) (Hecker et al. 2018c).

Galileo has several other unique technical features. The two most relevant are the Search and Rescue (SAR) return data link for user notification and the signal authentication for civil users. Both represent important technologies that are expected to provide high added value to EU citizens and worldwide users.

To support the SAR function, satellites are equipped with a transponder, which is able to transfer the distress signals from a user's transmitter to regional rescue coordination centers, which then initiate rescue operations. The system sends a response signal to the users, informing them that the situation has been detected and help is on the way. This latter feature is new and is considered a major upgrade to the existing systems, which do not provide user feedback (Hecker et al. 2018c). The Galileo SAR service represents Europe's contribution to the worldwide satellite-based distress signal detection and localization system COSPAS-SARSAT (where COSPAS is an acronym for the Russian "Cosmicheskaya Sistema Poiska Avariynyh Sudov", which translates to "Space System for the Search of Vessels in Distress" and SARSAT is an acronym for search and rescue satellite-aided tracking). Currently supported by 44 countries, COSPAS-SARSAT was established by Canada, France, the former Soviet Union and the United States in 1979 and provides help to people in danger in the context of aviation, vessels, worldwide expeditions, and people equipped with personal locator beacons (COSPAS-SARSAT 2019). Galileo complements COSPAS-SARSAT with additional satellites and sensibly improves the coverage and accuracy of the located emergency position. Moreover, several research projects supported by the GSA under Horizon 2020 are creating end-to-end solutions based on the Galileo SAR service and leveraging its return link.

Galileo is the only GNSS envisaged to provide open and free signal authentication (Galileo GNSS 2017), i.e., a technical mechanism that allows for verifying if the received navigation signals truly originate from the stated source. Galileo is expected to start transmitting the "Open Service Navigation Message Authentication" in mid-2019 (EGSA 2019a). This feature will help effectively mitigate deliberate signal manipulation and strongly increase the security for Galileo-based timing and positioning applications (especially in critical and safety-relevant fields).

Since all other GNSS constellations are operated by organizations with a military background, there has been concern that navigation signals might be degraded or rejected for civil use (even in specific regions only). Dedicated techniques have been developed similar to the GPS' "Selective Availability", which intentionally reduced the quality of its open signal until the year 2000 (Hecker et al. 2018c). Although these tactics were rarely used in the past, their employment cannot be completely precluded, with potentially dangerous consequences as GNSS are increasingly used in safety critical applications and highly relevant infrastructure. Operated under civil control, Galileo ensures Europe's strategic autonomy with respect to satellite positioning under all circumstances, thus avoiding the abovementioned dependencies and risks. This will also strengthen the EU's position, which can actively influence the GNSS strategy and pave the way for long-term investments and technologies.

The range of applications that Galileo is expected to support is vast and spans different market segments in both the private and public sectors (EGSA 2019b). The most relevant comprise the following:

Emergency, security and humanitarian services: Galileo's SAR service will help save lives, e.g., in the event of an airplane or boat crash. The system will also be an invaluable asset for border control authorities and coastguards (e.g., ensuring faster rescue operations) and to support security-related applications (e.g., helping locate missing persons, stolen property or lost pets).

Environment and weather: Galileo will support geology, geodesy and meteorology research in mapping and measuring of oceans, tides and sea levels, and tracking icebergs, pollutants and dangerous goods. Moreover, it will allow for improving the quality of atmospheric measurements (especially the level of water vapor, which is particularly important in the context of weather forecasting), to advance the study of the ionosphere and space weather, and to better monitor (and hence comprehend) the movements of animal populations.

Agriculture: Galileo will become an asset for the agriculture community. Through the joint exploitation of in situ information, it will allow for improved parcel yield due to customized treatments, improved monitoring of the distribution and dilution of chemicals, and more efficient property management.

Fisheries: Galileo will provide fishermen with improved navigational aids and allow for more accurate and effective exchange of information between vessels and stations. The SAR service will be particularly important to the fishery industry.

Energy: Galileo's high-quality time synchronization will result in better services for the transportation and distribution of energy; modern energy networks strongly rely on accurate location systems (e.g., in case of failure, power grids monitoring instruments will be synchronized with maximum accuracy). Furthermore, by exploiting Galileo's services, marine drilling activities will become safer in the gas and oil fields (where precise time measurements are fundamental when employing seismic streamer or gun arrays).

Once fully operational, Galileo will offer 4 different high-performance services worldwide (EGSA 2019c):

- *Open Service (OS)*: open and free of charge positioning and timing services;
- *Commercial Service (CS)*: complements the OS by providing an additional navigation signal and added-value services in a different frequency band (the CS signal can be encrypted to control access to the service);
- *Public Regulated Service (PRS)*: restricted to government-authorized users to support sensitive applications requiring high-level service continuity; and
- *Search and Rescue Service (SAR)*: in support of COSPAS-SARSAT.

Although Galileo is running behind its original schedule, many application domains are already profiting from its entry into operation and many more will do so in the near future. This is also due to the system interoperability with other GNSS, which results in more satellites in view and thus more measurements and improved accuracies (Hecker et al. 2018c).

Furthermore, it is foreseen that Galileo and the European Geostationary Navigation Overlay Service—EGNOS (a system based on a network of ground stations and 3 geostationary satellites that combines GPS and Galileo signals to improve the accuracy and robustness of navigation in Europe), will provide consistent economic benefits to the European space industry, as well as for a variety of downstream GNSS-based services and applications. These are estimated to be on the order of ~ 130 billion euros for 2014–2034 (against the total Galileo costs of ~ 16 billion euros from the early 1990s until 2020) (Hecker et al. 2018c).

20.4 Citizen Science

The term citizen science (CS)—coined by Irwin (1995) and Bonney (1996) in the mid-1990s—describes the nonprofessional involvement of citizens in a scientific process. The concept of CS has been rapidly adopted in the international and European policy landscape as well as by the scientific research community and has received considerable attention in recent years. However, CS is not a new phenomenon. Depending on the definition, the concept of the participation of citizens in scientific processes can be traced back to the eighteenth century (Mahr et al. 2018). The field of CS is diverse, and there is no universally accepted definition. According to SiS.net (2017), CS can be described as a method to practice scientific research at larger scales, as a movement that democratizes scientific research processes or as a social capacity to produce knowledge. Various approaches of determining a definition for the term CS are discussed by Eitzel et al. (2017). The EC has used various definitions for CS in its policy documents. In EC (2016b), the definition of the Oxford English Dictionary (OED 2014) is applied: CS is *"scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions"*. Instead, in the H2020 work program 2018–2020 (EC 2018d) the definition *"Citizen Science* [...] *covers a range of different levels of participation: from raising public knowledge about science, encouraging citizens to participate in the scientific process by observing, gathering and processing data, right up to setting scientific agenda and co-designing and implementing science-related policies"* is used. In this context, the European Citizen Science Association (ECSA) developed ten principles of CS, which complement the above-mentioned definitions (ECSA 2015; Robinson et al. 2018). For a general overview of the most relevant CS activities in addition to those discussed in this chapter related to the European framework, refer to Chap. 18.

20.4.1 Citizen Science in the European Policy Landscape

The EC emphasizes the opportunities of CS in its Open Science Policy by stating "Citizen Science can contribute to the Commission's goal of Responsible Research and Innovation, as it reinforces public engagement and can redirect research agendas towards issues of concerns to citizens" (EC 2016b). CS is recognized by the EC as an important pillar of the Open Science (OS) concept and, together with Open Access, is at the forefront of new frameworks for research and innovation. The assignment of CS to OS, which is implied by this statement, is controversial. Science Europe (2018), an association of European research funding organizations (RFOs) and research performing organizations (RPOs), argues that CS is increasingly considered an independent discipline whereas DITOs (2018) and Hecker et al. (2018a) see them as equal disciplines that enrich and partly depend on each other.

In 2013, the EC dedicated an entire report to environmental CS, which highlighted the role of new and emerging mobile technologies for CS and the perception of the quality of research by CS and discussed the influence of CS on European environmental policymaking (UWE 2013). Together with the outcomes of a green paper on CS by socientize (EC 2013) and the resulting white paper on CS for Europe in 2015 (Sanz et al. 2015), the results of the report prepared the ground for the aforementioned statements on CS in the EU Open Science Policy "*Open Innovation, Open Science, Open to the World—a Vision for Europe*" (EC 2016b) and were streamlined into the *EC Action Plan for Environmental Reporting (Action 8)* (EC 2017c) and the *Horizon 2020—Work Program 2018–2020* (EC 2018d). The level of consideration of CS in the upcoming Horizon Europe Program is still under discussion.

For the practical implementation of CS, JRC is the EU organization with the highest activity level (Science Europe 2018). The JRC is collaborating with several other EU institutions (including EEA) in the Environmental Knowledge Community (EKC), which investigates the creation and exchange of knowledge in environmental policy making processes and the role of CS in environmental policy making (Schade et al. 2017). The EKC operates a Knowledge and Innovation Project (KIP) on CS, with a focus on how CS data could be used qualitatively to complement European environmental monitoring and reporting processes. Another activity of the JRC that directly addresses European policy making is the development of a CS platform (EC 2019a). The platform will support CS projects and foster the consideration of their needs in the European policy making process.

The EC observes the development of CS projects with the Open Science Monitor (EC 2019b), which currently utilizes the repositories of SciStarter (https://scistarter.com/) and Zooniverse (https://www.zooniverse.org/). In 2016, a detailed EU-wide survey on CS was conducted (see Fig. 20.1). It showed that the majority of CS projects were initiated in Central and Western Europe and that the primary subject of most projects was in life sciences. In 2018, JRC published an inventory of environmental CS projects based on a study of a consortium of the EC (DG Environment, DG JRC), Bio Innovation Service (FR), Fundacion Ibercivis (ES) and The Natural History Museum (UK) (Bio Innovation Service 2018). It identified 503 projects (444 with participating actors from European countries, 12 European initiatives, 29 global initiatives and 18 from other regions; see Fig. 20.2). Even though both studies have a different focus and might not cover all activities, they show that the CS engagement of Eastern European countries has increased.

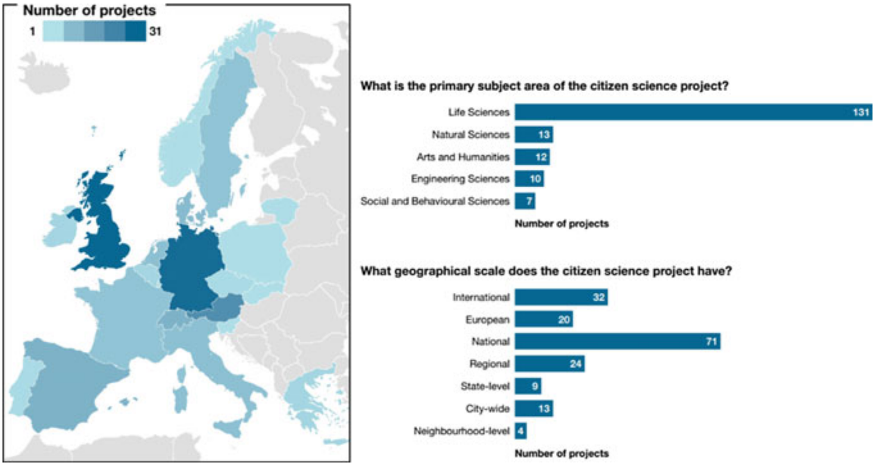

Fig. 20.1 Map of CS activities taking place across Europe; field of study of the project; and geographical scale of the project based on an EU-wide survey of CS conducted in 2016. *Source* European Commission (2016b) as cited in Science Europe (2018)

20.4.2 FP7 and H2020 Citizen Science Projects

With its Research and Innovation programs, the EU is an active funder of CS initiatives. The Seventh Framework program (FP7) was the EU funding program from 2007 to 2013, its successor H2020 is the framework program for 2014 to 2020, which will be followed by Horizon Europe. Some of the projects aim to enable CS participation and raise the general awareness of environmental and societal challenges; other projects focus on the involvement of citizens to engage in specific research questions. The following summary provides an incomplete overview of funding sections with instances of CS-related projects:

CAPS (Collective Awareness Platforms for Sustainability and Social Innovation): The CAPS seek new models to create awareness of emerging sustainability challenges. They aim to offer collaborative solutions based on modern information and communication technologies. A range of CAPS have been funded and are listed at https://capssi.eu. Among them, two of the most interesting are:

- *MakingSense*, which offers a toolkit of open source software and hardware, digital maker practices and open design that enables citizens and local communities to engage in pressing environmental questions (www.making-sense.eu); and
- *SOCRATIC*: whose main objective is to provide citizens and organizations with collaborative space and allow for them identify innovative solutions to achieve the United Nations Sustainable Development Goals (SDGs) (www.socratic.eu).

SwafS (Science with and for Society): The SwafS program objective is to build effective cooperation between science and society. The "Responsible Research and Innovation" program supports the design and implementation of innovative ways to

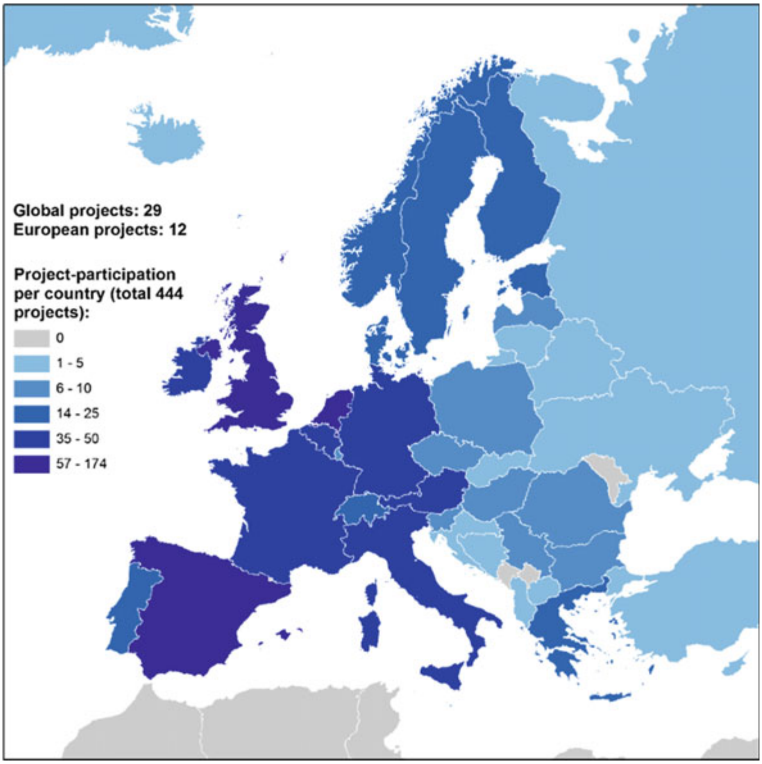

Fig. 20.2 Map of the environmental CS activities taking place across Europe based on the "Study on an inventory of CS activities for environmental policies". Twelve projects were listed as being on the European scale, and 26 were on a global scale. In addition, 444 projects had participants from European countries (multiple countries can be assigned to one project). *Source* own illustration based on EC (2018e)

connect science and society more broadly (http://ec.europa.eu/research/swafs/). In this framework, two representative activities are:

- *DITOs (Doing It Together Science)*, which connects research institutions, museums, science galleries and art institutions to engage people with CS in Europe (http://togetherscience.eu/); and
- *SPARKS*, which is an awareness-raising project dedicated to familiarizing and engaging European citizens with the concept and practice of Responsible Research and Innovation (RRI) (http://www.sparksproject.eu/).

Citizen Observatories: Citizen observatories commonly exploit the capabilities offered by the citizens' own devices (EC 2018e). Under the FP7 Environment Theme, 5 CS observatories were funded: COBWEB (biosphere monitoring), CITI-SENSE (air pollution monitoring), WeSenseIt (flood and drought monitoring) OMNISCIENTISTS (odor monitoring) and Citclops (coastal and water quality monitoring). Four others have been established through the H2020 Societal Challenge 5 (climate action, environment, resource efficiency and raw materials), namely, SCENT, Ground Truth 2.0, the GROW Observatory and Landsense (which contributes to EO analyses in the framework of land use and land cover monitoring (https://landsense.eu/)). Projects have also been undertaken to improve the coordination between CS observatories in Europe and support the integration of their outcomes in European policy (Gold 2018) (e.g., WeObserve www.weobserve.eu).

COST (European cooperation in science and technology): COST aims to connect research initiatives across Europe with initiatives outside Europe to enable researchers and innovators to develop ideas in any field of science and technology in cooperation with their peers. This includes the fostering of citizen participation in research activities (www.cost.eu). Interesting activities include:

- *Citizen Science COST Action CA15212*, which aims to investigate and extend the impact of the educational, policy, scientific and civic results and achievements of CS to use it for social innovation and socioecological transition (http://cs-eu.net/); and
- *Networking Lake Observatories in Europe (NETLAKE) COST Action ES1201*, which was funded from 2012 to 2016 and aimed to monitor 25 European lakes with the support of CS methods (NETLAKE 2017).

Notably, the FP7 *socientize* project aimed to promote the usage of science infrastructures and considered society itself as infrastructure for e-science by utilizing technology, innovation and creativity. *Socientize* compiled the aforementioned green and white papers on CS for Europe (Sanz et al. 2015) (www.socientize.eu).

20.4.3 Initiatives and Platforms in EU Member States and Public Organizations

In addition to CS projects and actions that are mainly based on funding by EU programs, many initiatives developed in Europe with national funding or through private and institutional engagement. A prominent role is played by the ECSA, a nonprofit association aimed at encouraging the growth of CS in Europe. It was launched in 2013 and consists of European and international individual and organizational members (Science Europe 2018). To foster policy advances and initiate and strengthen CS in Europe, the ECSA published 'Citizen Science as part of EU Policy Delivery-EU Directives' (ECSA 2016) and developed ten principles of CS (ECSA 2015; Robinson et al. 2018) for use in discussions with the EC. Several governments of EU Member States and public organizations actively support CS, particularly environmental protection agencies. One example is the Scottish Environment Protection Agency (SEPA), which fosters CS initiatives with a large support infrastructure, including best-practice guidance to support public authorities (Pocock et al. 2014). CS platforms and capacity-building initiatives increase the visibility of projects and help cultivate networks in the CS community (Hecker et al. 2018b). They produce training materials, distribute new developments and establish contacts to policy makers, scientists and stakeholders (Bonn et al. 2016, Richter et al. 2018). Examples of such platforms are *Bürger schaffen Wissen* (www.buergerschaffenwissen.de, Germany), *Österreich forscht* (www.citizen-science.at, Austria), *Schweiz forscht* (www.schweiz-forscht.ch, Switzerland), *Observatorio de la Ciencia Ciudadana en España* (http://ciencia-ciudadana.es, Spain) and the *Scottish Citizen Science Portal* (https://envscot-csportal.org.uk/, Scotland). A consortium of the nonprofit research associations Helmholtz and Leibniz, together with university partners, leads the *Bürger schaffen Wissen* (GEWISS) program in Germany. It published the green paper Citizen Science Strategy for 2020 (Bonn et al. 2016), which describes the understanding, requirements and processes of CS in Germany. For an extensive overview of European CS projects, we refer the reader to the *Inventory of citizen science activities for environmental policies* (EC 2018e) and the accompanying report (Bio Innovation Service 2018).

20.5 Digital Europe and Horizon Europe

To support future digital innovation (a fundamental prerequisite for effective implementation of DE in the coming years) in the framework of the next long-term EU budget for 2021–2027, the Commission is proposing two major programs: Digital Europe and Horizon Europe (EC 2018f, 2019c).

Digital Europe builds on the Digital Single Market strategy launched in May 2015 with the main objectives of increasing the EU's international competitiveness and shaping Europe's digital transformation for the benefit of citizens and businesses. The program will promote the large-scale deployment of digital technologies across economic sectors and will support the digital transformation of public services and businesses (EC 2019c). With a budget of €9.2 billion, Digital Europe will boost frontline investments in key relevant contexts:

- *high-performance computing*: €2.7 billion will be invested in projects aimed at strengthening supercomputing and data processing in Europe, with a goal of deploying a world-class supercomputer and data infrastructure with exascale capabilities (i.e., billion calculations per second) by 2022–2023 and post-exascale facilities by 2026–2027;
- *artificial intelligence (AI)*: €2.5 billion will be allocated to activities supporting the uptake of AI across the European economy and society, taking into account all the correlated socioeconomic changes and ensuring an appropriate legal and ethical framework. The idea is to create open 'European libraries' of algorithms to support both the public and private sectors to identify the most suitable solutions for their needs. The establishment of digital innovation hubs across the EU will also make it possible for small business and local innovators to access testing facilities;

- *cybersecurity*: €2 billion will be dedicated to boosting cyber defense and the EU's cybersecurity industry. This will be carried out by financing state-of-the-art cybersecurity equipment and infrastructure as well as by supporting the development of the necessary knowledge and skills;
- *advanced digital skills*: €700 million will be invested to form the current and future workforce through training courses and traineeships aimed at providing the necessary advanced skills to access supercomputing, artificial intelligence and cybersecurity; and
- *ensuring wide use of digital technologies*: €1.3 billion will support the digital transformation of public administration and related services, as well as their interoperability within the EU. Digital innovation hubs will become "one-stop shops" for both public administrations and small/medium-sized enterprises by providing access to technological expertise and experimentation facilities.

In addition to Digital Europe, financing for research and innovation in next-generation digital technologies will continue and be reinforced under the upcoming Horizon Europe program. Horizon Europe is the successor of H2020 and will be the biggest research and innovation funding program ever, with an overall budget of approximately €100 billion (EC 2018f). The new program will reinforce the Union's scientific and technological bases to help address major global challenges and contribute to achieving the United Nations SDGs; moreover, at the same time, it will boost the Union's competitiveness, including that of its industries. Horizon Europe will help deliver on the Union's strategic priorities and support the development and implementation of its policies. The program is designed around three main pillars: (i) the *Open Science* pillar, which supports researchers through fellowships, exchanges, and funding to projects defined and driven by researchers; (ii) the *Global Challenges* pillar, which directly supports research addressing societal challenges; and (iii) the *Open Innovation* pillar, which aims to make Europe a front runner in market-creating innovation.

Horizon Europe is expected to generate the following:

- new (and more) knowledge and technologies, promoting scientific excellence and impact. It will continue facilitating cross-border collaborations between innovators and top scientists, as well as allow for trans-national and cross-sector coordination between public and private investment in research and innovation;
- positive effects on growth, trade and investment flows as well as on quality jobs and international mobility for researchers in the European Research Area. The program is expected to increase the GDP by an average of 0.08–0.19% over 25 years (which corresponds to a potential return of up to €11 for each euro invested over the same period); and
- significant social and environmental impacts created by translating scientific results into new products, services and processes, which will help successfully deliver on political objectives, as well as social and eco-innovation.

The Digital Europe and Horizon Europe programs will work hand-in-hand: Horizon Europe provides key investments in research and innovation, and Digital Europe builds on these results to create the necessary infrastructure and support deployment and capacity building, which will provide input for future research in AI, robotics, high-performance computing and big data.

AI is foreseen to become the main driver of economic and productivity growth and will contribute to the sustainability and viability of the industrial base in Europe. Accordingly, the Union aims to develop trusted AI based on ethical and societal values, building on its Charter of Fundamental Rights; people should trust AI and benefit from its use for their personal and professional lives. Thus, the Communication "Artificial Intelligence for Europe" of 25 April 2018 proposed a dedicated strategy that supports the ambition for Europe to become the world-leading region in developing and deploying cutting-edge, ethical and secure AI (EC 2018g). Furthermore, in the related coordinated Action Plan of 7 December 2018, the Commission explicitly proposed the development and deployment of dedicated AI capacities, taking direct advantage of Copernicus data and infrastructure to foster geo-location-based services to support agriculture, air quality, climate, emissions, the marine environment, water management, security and migration monitoring, and citizen science (EC 2018h). These will be accompanied by initiatives supporting AI-based exploitation of EO data and information in both the public and private sectors.

20.6 Conclusions

Most of the visionary features of the original DE view formulated by Al Gore in 1998 were implemented in practice only 10 years later in several web-mapping platforms and desktop virtual globes. This led to an evolution of the DE concept, in light of the concurrent advancements in technology and research, as well as changes in society. DE expanded its role in other fields (e.g., related to global climate change, natural disaster prevention and response) and transformed into a more practical system design to fulfil the demand for information sharing and overcome the socioeconomic inequality in accessing and using the data. In a few years, Europe became one of the key players in DE at the global level. Through the INSPIRE Directive, it created a legal framework for the establishment of a European SDI relying on single NDSIs. By jointly supporting data discovery, access and harmonization, INSPIRE has become a model in the world and its complete entry into force in 2021 will become a milestone for the implementation of transnational services. Furthermore, the EO mass data collected within the Galileo and Copernicus programs place Europe at the forefront of the big data from space paradigm. Galileo will enable higher precision positioning, with consequent key improvements in a variety of applications (especially once full operation begins in 2021). Moreover, its SAR and signal authentication features will improve people's security and safety in many fields. Copernicus provides continuous monitoring of our planet through a comprehensive set of sensors mounted onboard the Sentinel satellites (whose families will grow in the next decade) as well as a number of environmental local measurements. From such a wealth of data, the ultimate goal of the program is to generate key information for the users; this is directly carried out by the different core services and made possible through novel cloud-based platforms such as the DIAS and the TEPs. The last 5 years saw the increasing emergence of CS in Europe, which proved to be an effective tool to support researchers and society at large, with hundreds of projects and initiatives funded throughout the different EU Member States. The implementation of dedicated platforms facilitated the uptake of CS in different fields and raised awareness of environmental and societal challenges. Further advancement is expected in the near feature, e.g., by giving citizens the possibility of collecting and contributing real-world data through novel (and connected) sensors directly immersed in their environments. Europe has clear plans for the future and is creating a basis to establish an overall framework in which DE will gain even more importance. This will be possible by means of the Horizon Europe and Digital Europe programs. The former will support research and innovation by strengthening the scientific and technological bases of the Union and fostering its global competitiveness and innovation capacity; the latter will procure high-tech resources and skills for use by European businesses and the public sector. In both cases, the effective integration of cutting-edge AI will be one of the main challenges in the next years.

In conclusion, the European experience illustrates that big data from satellites are a fundamental aspect for the future of DE, as they will allow for analyses that were unimaginable just few years ago. To maximize their benefit, the implementation of processing platforms that enable advanced processing are essential (the integration of novel AI-based methodologies is one of the priorities), as well as the establishment of effective SDIs to share derived products and guarantee access to them beyond national borders. In this framework, the role of citizens can become a key asset through their involvement in directly collecting and sharing data and actively providing feedback.

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